Abstract Book

IAUS336

Abstract Book

IAU Symposium 336

Astrophysical Masers

unlocking the mysteries of the universe

dedicated to the memory of
Malcolm Walmsley
(1941-2017)

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Cagliari, Italy

IAUS336

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Oral Presentations

Session 1 - Theory of masers and maser sources

Mark J. CLAUSSEN - National Radio Astronomy Observatory - USA

Isotopic SiO Maser Emission from the BAaDE Survey

The Bulge Asymmetries and Dynamical Evolution (BAaDE) project aims to map the positions and velocities of up to $\sim$ 20,000 late-type stars with SiO maser emission along the full Galactic plane, with a large concentration in the Galactic Bulge and inner Galaxy. Both J=1->0 and J=2->1 transitions using the Very Large Array (VLA) and the Atacama Large Millimeter Array (ALMA) are being observed. In the VLA observing setup, in addition to the ^{28}SiO, v=1 and v=2 J=1->0 maser transitions, the bandwidth was wide enough to include the J=1->0 transitions of the rare isotopologues of the SiO molecule in both the ground and vibrationally excited states: ^{29}SiO, v=0, ^{30}SiO, v=0, ^{29}SiO, v=1, and ^{29}SiO, v=2. Approximately 10% of the initial $\sim$3500 targets of the project show maser emission from at least one of these lines. Some of these stars (with isotopic maser emission) show high radial velocities which implies that they are indeed in the Galactic Bulge or inner Galaxy (i.e. not foreground objects). We will present line profiles, line ratios, refined detection statistics, and the implications of the detection of the isotopic maser emission on pumping schemes that have been previously presented.

Malcolm GRAY - Jodrell Bank Centre for Astrophysics - UK **(invited)**

Maser Theory – Old Problems and New Insights

Maser theory encompasses a vast range of treatments from the most simplified analytic mathematical solutions to complex computational models that employ thousands of pieces of molecular data. I shall attempt to consider a range of these topics from recent advances in the analysis of polarization on methanol masers, through 3-D finite element modelling of maser clouds to a renewed interest in the coherence properties of maser objects. This last interest results from the discovery of maser cores smaller than 1 million km in diameter and the detection of significant temporal coherence from cross-correlation spectrometry.

Sergey KALENSKIY - Lebedev Physical Institute RAS - Russia

Class I methanol masers in low-mass star formation regions

We present the review of the results on Class I methanol masers detected in low-mass star forming regions (LMSFRs). These masers, called further LMMIs, are associated with postshock gas in the lobes of chemically active outflows in LMSFRs NGC1333, NGC2023, HH25, and L1157. LMMI luminosities at 44 GHz match the relation "maser luminosity–protostar luminosity", established earlier for high- and intermediate-mass protostars. No variability of LMMIs have been found in 2004–2011. VLA observations of NGC1333I4A, HH25MMS, and L1157 at 44 GHz demonstrate that the maser images consist of compact spots, unresolved or barely resolved with a spatial resolution of 0.2 arcsec. The brightness temperatures of the strongest spots are hundreds of thousands Kelvins. Many spots consist of two spatial components and exhibit double spectral lines. Some spots demonstrate broad (3-5 km/s) spectral lines with the brightness temperatures about 1000 K. Thus, in spite of large linewidths, these objects could be weak masers. We believe that turbulence plays an important role in forming the image and the spectrum of maser emission. However, LMMI properties cannot be explained within the frames of already published models of methanol masers in turbulent medium. Therefore some additional factors are required in order to explain the observed LMMI properties.

Boy LANKHAAR - Chalmers University of Technology - Sweden

Quantum-chemical calculations revealing the effects of magnetic fields on methanol

Maser observations of both linear and circular emission have provided unique information on the magnetic field in the densest regions of star forming regions, where non-maser magnetic field tracers are scarce. While linear polarization observations provide morphological constraints, the magnetic field strength determination is done by measuring

Zeeman splitting in the circularly polarized emission. In particular, methanol is of special interest as it is the most abundant maser species and its different transitions probe unique areas around the protostar. However, its exact Zeeman-parameters are unknown. Experimental efforts to determine the Zeeman-parameters have failed. Here we present quantum-chemical calculations to the Zeeman-parameters of methanol, along with theoretical calculations to the hyperfine structure, which are also necessary to interpret the Zeeman effect in methanol (and some other astrophysical methanol studies). We find that the Zeeman-effect in methanol is non-linear and comment on its applicability in astronomical magnetic field studies. We discuss different mechanisms for hyperfine-preferred pumping in the maser-action. We give an outlook on rigorously treating non-linear Zeeman-effects in radiative transfer modelling of maser-species interacting with a magnetic field.

Silvia LEURINI - INAF OACagliari - Italy **(invited)**

Physical properties of Class I methanol masers

As first realised in the late '80s, methanol masers come in two varieties, termed Class I and II by Menten (1991). While Class II masers had been intensively studied in the past, until recently relatively little attention was paid to Class I methanol masers. In this review, I will focus on the recent progress in our understanding of Class I methanol masers both from an observational and from a theoretical point of view.

Karl M. MENTEN - MPIfR - Germany **(review)**

Fifty Years of Maser Research

Cosmic masers have now been studied for more than half a century. While the most prominent and most widespread maser lines from the OH, H_2O, CH_3OH and SiO molecules have frequencies in the centimeter range, (sub)millimeter studies have led to the detection of a large number of shorter wavelength maser transitions from these and many other molecules, even in the THz regime. The resulting multi-line datasets allow radiative transfer/excitation modeling, which delivers constraints on the (often extreme) physical conditions in the regions from which the maser lines are emitted. Masers serve as important signposts of interesting sources or phenomena. This has become particularly apparent by the recently found correlation of extreme bursts of maser intensity and large changes in the emitting star forming regions' total luminosity. The development of spectral line interferometry, in particular VLBI, has been inextricably interwoven with maser research. High angular resolution allows pinpointing centers of activity and the high precision astrometry afforded by VLBI has made masers unique probes of Galactic structure and supermassive black holes. I shall give a broad overview of astronomical maser science illustrated by examples that highlight the above mentioned aspects.

Ruby VAN ROOYEN - North West University - South Africa

MASERS: A Python package for statistical equilibrium calculations applied to masers

Astrophysical masers are useful tools for studying the various environments in which they occur. Interpretation of maser emission is, unfortunately, not as straightforward as that of thermal line emission. Understanding maser emission requires some knowledge of the physical conditions under which a population inversion can occur which is usually determined from solving the statistical rate equations assuming steady state. A number of codes are available to solve for the steady state level populations. However, some of these codes were developed only to be used for thermal line emission and not for masers. Experimentation with some of these codes to search for conditions under which a population inversion occur have shown that they may become unstable, making the results unreliable. For this reason the MASERS Python package was developed which is stable for both thermal line and maser emission. I will describe the methods used in solving for the level populations and present some results applied to hydroxyl and formaldehyde masers.

Bringfried STECKLUM - Thueringer Landessternwarte Tautenburg - Germany

R variability, maser activity & protostellar accretion

Methanol and water masers are signposts of young, luminous stars. Quite a number of objects exhibit maser flare activity, and about a dozen of them have already been revealed to vary periodically. While several mechanisms were proposed to explain this behavior, the lack of concurrent IR data makes it difficult to identify the cause. Only recently, 6.7 GHz methanol maser flares were observed to be triggered by accretion bursts of high-mass young stellar objects (HMYSOs). This evidence has confirmed the IR-pumping of the class II methanol masers. It suggests that regular changes of the IR flux might lead to maser periodicity. Thus we scrutinized space-based IR imaging of YSOs associated with periodic methanol masers. For G107.298+5.639, an intermediate-mass protostar hosting methanol and water masers, we succeeded to extract the IR light curve from archival WISE data. Thus, for the first time a relationship between the maser periodicity and the IR variability could be established. While the IR light curve shows the same period of ∼34.6 days as the masers its shape is distinct from that of the maser flares. Possible reasons for the IR variability are being discussed.

Koichiro SUGIYAMA - National Astronomical Observatory of Japan - Japan

Long-term and highly frequent monitor of 6.7 GHz methanol masers to statistically research periodic flux variations around high-mass protostars using Hitachi 32-m

We initiated a long-term and highly frequent monitoring project toward 442 methanol masers at 6.7 GHz (Dec > -30 deg) using Hitachi 32-m radio telescope in Dec 2012. The observations have been carried out daily, monitoring a spectrum of each source with intervals of 9-10 days. In Sep 2015, the number of the target sources and intervals were redesigned into 143 and 4-5 days. This monitoring provides us complete information how many sources show periodic flux variations in high-mass star-forming regions, which have been detected in 20 sources with periods of 30-670 days so far (e.g., Goedhart et al. 2004). The periodic flux variations with short timescale must be a unique tool to investigate high-mass protostars themselves and their circumstellar structure on a very tiny spatial scale of 0.1 au. In particular, the periodic variations showing continuous pattern can be caused by pulsation of high-mass protostars with kappa mechanism (Inayoshi et al. 2013), and these sources are unique probes to understand physical parameters, such as a mass, radius, and an accretion rate on the stellar surface, through a period-luminosity (P-L) relation. We aim to verify the P-L relation by combining complete samples of periodic flux variations and the theoretical pulsation model. We have already obtained new detections of periodic flux variations from 30 methanol sources with periods of 20-410 days. Here, we will present progress of our monitoring project as well as the latest P-L relation.

Gabriele SURCIS - INAF OACagliari - Italy **(invited)**

Maser Polarization

Through the observation and analysis of maser polarization is possible to measure the magnetic field in several astrophysical environments (e.g., star-forming regions, evolved stars). In particular from the linearly and circularly polarized emissions we can determine the orientation and the strength of the magnetic field, respectively. In my talk I will show the implications, on observed data, of the new estimation of the Landé g-factors for the methanol maser. Furthermore, I will briefly review the results achieved in observing the polarized maser emission from several maser species after the last Maser Symposium held in 2012 in South Africa.

Marian SZYMCZAK - Torun Center for Astronomy - Poland

On the origin of methanol maser variability: Clues from long-term monitoring

High-mass young stellar objects (HMYSO) displaying methanol maser flux variability probably trace a variety of phenomena such as accretion events, magnetospheric activity, stellar flares and stellar wind interactions in binary systems. Here we review the results of the ongoing monitoring programme of the 6.7 GHz methanol line in a large sample of HMYSOs with the Torun 32m radio telescope. The aims are to study possible origins for the variability and to identify plausible objects for detailed studies of the gas environment of HMYSOs. Our new findings include:

(i) detection of rapid and high amplitude flares of individual features in several sources, (ii) detection of new cyclic sources, (iii) presence of strong anti-correlation between intensity and line-width for flaring features that is expected for unsaturated amplification, (iv) a weak anti-correlation between the maser feature luminosity and variability measure, i.e. the maser features of low luminosity tend to be more variable than those of high luminosity. Statistical analysis of basic properties of powering objects and the derived variability measures supports an idea that burst activity of methanol masers is driven mainly by changes in the infrared pumping rate.

Taylor TOBIN - University of Illinois Urbana-Champaign - USA

Constraining Theories of SiO Maser Polarization: Analysis of a $\pi/2$ EVPA Change

The full theory of polarized SiO maser emission from the near-circumstellar environment of Asymptotic Giant Branch stars has been the subject of debate, with theories ranging from classical Zeeman origins in the presence of a magnetic field (eg. Goldreich, Keeley, & Kwan 1973; hereafter GKK) to predominantly anisotropic propagation effects (eg. Asensio Ramos et al. 2005). Features with an internal electric vector position angle (EVPA) rotation of $\sim \pi/2$ offer unique constraints on theoretical models. In this work, results are presented for one such feature that persisted across five epochs of SiO ν=1, J=1-0 VLBA observations of TX Cam. We examine the fit to the predicted dependence of linear polarization and EVPA on angle (θ) between the line of sight and the magnetic field against the GKK and other models. We also present results on the dependence of m_c on θ and their theoretical implications. Finally, we discuss the applicability of our data to other theories, potential causes of the observed differences, and upcoming work.

Session 2 - Galaxies and Supermassive Black Holes

Megan ARGO - University of Central Lancashire - United Kingdom

Over-resolving the masers in M82?

VLA observations probing OH absorption in the nearby starburst galaxy M82 serendipitously discovered several previously-undetected main line masers. All of the maser spots were significantly brighter than typical Galactic masers, an effect likely due to the superposition of several masing clouds along a particular line of sight. This conclusion was supported by later VLA observations at higher velocity resolution, showing significant velocity structure in several of the maser spots. In order to investigate this population further we obtained EVN observations at high spatial and velocity resolution, which showed that several of the maser spots are indeed resolved into multiple spatial components on scales of a few milliarcseconds, with one spot splitting into a spectacular 3.5-parsec ring at these resolutions. The story was still incomplete, however. The total flux recovered in the EVN observations is much less than that observed in the VLA observations at the same velocity resolution. To test whether this flux reduction is due to variability, or to a diffuse component to which the EVN is not sensitive, we obtained a second epoch of EVN data, as well as intermediate spatial scale e-MERLIN observations at matched velocity resolution. I will present the results of this new study, and what the maser population is teaching us about the ISM in this nearby starburst galaxy.

Jim BRAATZ - NRAO - USA **(invited)**

The Megamaser Cosmology Project

The Megamaser Cosmology Project (MCP) aims to measure the Hubble Constant by determining geometric distances to circumnuclear 22 GHz H_2O megamasers in galaxies well into the Hubble flow. In combination with the recent, exquisite observations of the Cosmic Microwave Background by WMAP and Planck, these measurements provide a direct test of the standard cosmological model and constrain the equation of state of dark energy. The MCP is a multi-year project that has recently completed observations and is currently working on final analysis. When complete, we expect to achieve about a 4% measurement. Given the tension between the Planck prediction of H_0 in the context of the standard cosmological model and astrophysical measurements based on standard candles, the MCP

provides a critical and independent measurement that does not rely on external calibrations or distance ladders. The second goal of the MCP is to measure "gold standard" masses of supermassive black holes (SMBH) by tracing the Keplerian rotation curves of megamaser disks only tenths of a pc from the nuclei and well within the SMBH "sphere of influence." To date we have measured 20 SMBH masses, many with <10% uncertainties. These masses deviate from the M-sigma relation at the low-mass end, implying that any feedback that controls the apparent co-evolution of SMBHs and their elliptical host galaxies has not yet taken hold in later-type galaxies as traced by megamasers.

Paola CASTANGIA - INAF OACagliari - Italy

A new jet/outflow maser in the nucleus of the Compton-thick AGN IRAS15480-0344

A relationship between the 22 GHz water maser detection rate and large nuclear column densities in AGN has often been cited in the literature. We have entertained a search for maser emission in a well-defined sample of Compton-thick AGN aimed at investigating, on firm statistical bases, the aforementioned relationship. Here we report the results of the survey, which yielded a surprisingly high maser detection rate, with a particular focus on the newly discovered luminous water maser in the lenticular (field) S0 galaxy IRAS15480-0344. The maser spectrum shows two main features: a broad weak blueshifted (w.r.t. the systemic velocity of the galaxy) component and an extremely bright narrow line feature at the systemic velocity of the galaxy. Recently, VLBI observations have been obtained to image the line and continuum emission in the nucleus of this galaxy. The radio continuum emission at the VLBI scales is resolved into two compact components that are interpreted as jet knots. In this talk, I will discuss the possible nature of the maser emission as associated with a nuclear jet/outflow. This scenario is consistent with the hypothesis of the presence of strong nuclear winds recently invoked to explain the main characteristics of field S0 galaxies.

Xi CHEN - Guangzhou University - China **(invited)**

Extragalactic class I methanol maser: A new probe for starbursts and feedbacks of active galaxies

With regard to the rich detections of the methanol maser phenomena in our Galaxy, to date, extragalactic methanol maser emission were detected towards star formation regions in nearby galaxies, the Large Magellanic Cloud (LMC) and M31. Recently we preformed the first search for the 36.2 GHz class I methanol masers towards a sample of nearby active galaxies using the Australia Telescope Compact Array (ATCA). The ATCA observations produced the first extragalactic detection of this transition which has now been observed towards a number of sources, including the nearby starburst galaxy NGC 253 and the major merger system Arp 220. And furthermore single dish survey with the NRAO Greenbank Telescope (GBT) for 36.2 GHz class I methanol masers towards active galaxies has also made a few possible detections of emission from this transition. In this talk, a research progress for the extragalactic methanol masers at this transition including the published works and the new observing data with higher angular resolution using the ATCA and Jansky Very Large Array (JVLA) will be present. These observations reveal that extragalactic class I masers are located at the inner end of the galactic bar, are likely due to large-scale cloud-cloud collisions.

Simon ELLINGSEN - University of Tasmania - Australia

The Maser-Starburst connection in NGC253

NGC253 is one of the closest galaxies with a nuclear starburst and has been widely studied across the electromagnetic spectrum. It shows strong molecular emission from a wide range of species, including water masers close to the centre. Recently we have reported the detection of the extragalactic class I methanol masers at 36.2 and 44.1 GHz and the first extragalactic cyanoacetylene masers towards NGC253. In both cases the masers lie at the edge of the central molecular zone and appear to trace the region where the galactic bar is transporting cold molecular gas towards the centre of the galaxy. We discuss the properties of the methanol and cyanoacetylene masers in NGC253 and their differences from those seen in Galactic star formation regions. We also compare the distribution of the masers with that of molecules and atomic gas within NGC253 and discuss the implications for further searches for these new extragalactic maser transitions.

Jenny Emma GREENE - Princeton University- USA **(invited)**

Using Megamaser Disks to Probe Black Hole Accretion

Megamaser disk galaxies provide a unique window in black hole-bulge scaling relations, by yielding exquisite black hole mass measurements regardless of the stellar distribution, star formation properties, etc, of the host galaxy. Furthermore, the masers trace the outer accretion disk, allowing us the opportunity to study fueling mechanisms on pc scales in these galaxies. We discuss the view of black hole-bulge scaling relations afforded by megamaser disk galaxies, as well as our ongoing work to understand what fuels active galaxies.

Christian HENKEL - MPIfR - Germany **(review)**

Extragalactic Maser Surveys

In this review talk, extragalactic ammonia, methanol, and hydroxyl maser observations will be briefly summarized. Nevertheless, the main focus is on water vapor, and here (1) on progress of the Megamaser Cosmology Project (MCP) which is getting close to its completion, (2) to H2O maser emission from ULIRGs, and (3) to thoughts about potential follow-ups after the MCP has been completed.

Tiege Patrick McCARTHY - University of Tasmania - Australia

Class I Methanol Maser Emission in NGC4945

Megamasers from the water and hydroxyl species have been observed in hundreds of extragalactic sources. These megamasers are proven tools for high-resolution study of accretion disks, jets and also investigation of the properties of their host galaxies. Despite several searches of nearby galaxies, extragalactic methanol is far less commonly observed than these other masing species. Class II methanol masers in nearby galaxies are simply star-formation maser sites. However, unlike the class II emission, recent observations of class I masers show them tracing larger scale features of the host. The few examples we have of extragalactic class I maser emission indicates that these masers may provide an insight into star-formation rates in starburst galaxies. I will present a recent detection of 36.1-GHz class I emission in NGC4945. NGC4945 is a barred spiral, classified as a Seyfert2 and Starburst type galaxy with a strong water megamaser associated with a circumnuclear accretion disk. I will discuss this detection along with follow-up observations, how this source fits in with the other extragalactic examples of this transition and its implication in further searches for extragalactic class I emission.

Francesca PANESSA - INAF-IAPS Roma - Italy

Water maser emission in hard X-ray selected AGN

Water megamaser emission is powerful in tracing the inner region of active nuclei, by mapping accretion disks and providing important clues on their absorption properties. From the X-ray spectra of AGN, it is possible to estimate the intrinsic power of the central engine and the obscuring column density. The synergy between X-ray and water maser studies allows to tackle the AGN inner physics from different perspectives. For a complete sample of AGN selected in the 20-40 keV energy range, we have investigated the presence of water maser emission and its connection to the X-ray emission, absorption and accretion rate. The hard X-ray selection of the sample results in a water maser detection rate much higher than those obtained from optically-selected samples.

Dominic PESCE - University of Virginia - USA

AGN accretion disk physics using water megamasers

The accretion disks surrounding supermassive black holes in nearby AGN are observed to host 22 GHz water maser activity. The masers arising in disks with particularly favorable geometry and kinematics are useful probes of the environment in the immediate vicinity of the black holes. We have analyzed single-dish 22 GHz spectra taken with the GBT to identify 32 such "Keplerian disk systems", which we used to investigate possible maser excitation mechanisms, place limits on the magnetic field strengths in the accretion disks, and in certain cases explore interstellar scintillation. Our results do not support a spiral shock model for population inversion in these disks, and we find

that any reverberating signal propagating radially outwards from the AGN must constitute <10% of the total maser variability observed in these sources. Additionally, we have used ALMA to begin exploring the variety of sub-mm water megamasers that are also predicted – and, in the case of the 321 GHz transition, found – to be present in these accretion disks. By observing multiple masing transitions within a single system, we can constrain the physical conditions (e.g., gas temperature and density) in the accretion disk.

Ylva PIHLSTROM - University of New Mexico - USA

Methanol masers in the Andromeda galaxy

Is M31 going to collide with the Milky Way, or spiral around it? We don't know - yet! Determining the gravitational potential in the Local Group has been a challenge since it requires 3D space velocities and orbits of the members, and most objects have only had line-of-sight velocities measured. Compared to the less massive group members, the transverse velocity of M31 is of great interest, as after the Milky Way, M31 is the most dominant constituent and dynamic force in the Local Group. Proper motion studies of M31 are preferentially done using masers, as continuum sources are much weaker, and are enabled through the high angular resolution provided by VLBI in the radio regime. The challenges of achieving high astrometric accuracy at high VLBI frequencies (>20 GHz) makes observations at lower frequencies attractive, as long as sufficient angular resolution is obtained. In particular, we have discovered 6.7 GHz methanol masers in M31 using the VLA, and in this talk we will address their feasibility as VLBI proper motion targets using a set of global VLBI observations.

Tim ROBISHAW - Dominion Radio Astrophysical Observatory - Canada

Zeeman Splitting of OH Megamasers as a Probe of Magnetic Fields in Starburst Galaxies

In 2008, the first extragalactic detection of Zeeman splitting in hydroxyl (OH) megamaser emission was made towards five starburst galaxies using the 305-m Arecibo telescope. Subsequently, a large-scale Zeeman survey of every OH megamaser in the Arecibo sky has been conducted. We will provide an overview of this census of magnetic fields in starburst galaxies and also present the first VLBI map of Zeeman splitting in an external galaxy. Further opportunities to observe these amazing magnetic probes using the FAST, SKA, and ngVLA telescopes will be discussed.

Till SAWALA - University of Helsinki - Finland **(review)**

The Local Group mass and its connection to outstanding cosmic puzzles

The dwarf galaxies of the Local Group represent some of the most discriminating tests of structure formation on small scales, and of the Lambda-CDM cosmological model or its alternatives. Based on results from recent cosmological hydrodynamic simulations of the Local Group, I will discuss how the impact of baryonic physics affects the relation between the observed galaxies and the underlying dark matter structures. While many of the apparent small-scale failures of Lambda-CDM may be resolved when processes including supernova feedback and reionisation are taken into account, a precise determination of the Local Group velocity vector and the inferred total mass become important discriminants between different dark matter models.

Sherry SUYU - MPA - Germany **(invited)**

Progress toward an accurate Hubble Constant

The Hubble constant is a key cosmological parameter that sets the present-day expansion rate as well as the age, size, and critical density of the Universe. Intriguingly, there is currently a tension in the measurements of its value in the standard flat Lambda-CDM model-observations of the Cosmic Microwave Background with the Planck satellite lead to a value of the Hubble constant that is lower than the measurements from the local Cepheids-supernovae distance ladder and strong gravitational lensing. Precise and accurate Hubble constant measurements from independent probes, including water masers, are necessary to assess the significance of this tension and the possible need of new physics beyond the current standard cosmological model. In this talk I will present the progress toward an accurate Hubble constant determination.

Andrea TARCHI - INAF OACagliari - Italy

SRT observations of Local Group dwarf galaxies

The dwarf galaxies in the Local Group (LG) reveal a surprising amount of spatial structuring. In particular, almost all non-satellite dwarfs belong to one of two planes that show a very pronounced symmetry. In order to determine if these structures in the LG are dynamically stable or, alternatively, if they only represent transient alignments, proper motions measurements of these galaxies are required. A viable method to derive proper motions is offered by VLBI studies of 22-GHz water (and 6.7-GHz methanol) maser lines in star-forming regions. In 2016, in the framework of the Early Science Program of the Sardinia Radio telescope (SRT), we have conducted an extensive observational campaign to map the entire optical body of all the LG dwarf galaxies that belong to the two planes, at C and K band, in a search for methanol and water maser emission. In this talk, I will outline the project and present its first results on three targets. While no luminous maser emission has been detected in these galaxies, a number of interesting weaker detections has been obtained, associated with particularly active star forming regions. In addition, we have produced deep radio continuum maps for these galaxies, aimed at investigating their star forming activity and providing an improved assessment of star formation rates. Our results will be discussed in the scheme of the relation between expected (water) maser detections and star formation rates in nearby galaxies.

Jiang-Shui ZHANG - Guangzhou University - China

A systematic observational study of radio properties of H2O megamaser hosts: Guide for H_2O megamaser survey

H_2O megamaser Seyfert 2s tend to have higher nuclear radio luminosities than non-masing Seyfert 2s from analyzing archival data from different telescopes (Zhang et al. 2012). This has been confirmed by our follow-up study on multi-band (11, 6, 3.6, 2, 1.3 cm) radio properties of maser host Seyfert 2s, through systematic Effelsberg observations (Liu et al. 2017). The nuclear radio luminosity was supposed to be a suitable indicator to guide future AGN maser searches. Thus we performed a pilot survey by the Effelsberg-100 m telescope on H_2O maser emission toward a small sample of radio-bright Seyfert 2 galaxies with relative higher redshift (>0.04). Our pilot survey led to one new megamaser source and one additional possible detection, which reflects our success in selecting H_2O megamaser candidates compared to previous observations. Our successful selection technique may provide good guiding for future H_2O megamaser surveys, i.e., Seyfert 2s with radiobright nuclei. More H_2O detections at a large distance ($z>0.04$) can be expected from a large systematic survey of such radio-bright Seyfert 2 galaxies. These have the great potential to increase our knowledge on the central highly obscured but still very enigmatic regions of active Seyfert galaxies (Zhang et al. 2017).

Session 3 - The Structure of the Milky Way

Ortwin GERHARD - MPIfEA - Germany **(review)**

Perspectives on Galactic Structure

The Milky Way is currently the subject of great observational effort. This includes both ESA's unique Gaia mission, as well as a multitude of ground-based surveys. Several of these are already returning data of unprecedented depth and quality for large numbers of Milky Way stars. These new data are likely to lead to a quantum step in our understanding of Milky Way structure and evolution. In this talk I will give an overview of the stellar components and the dark matter distribution in our barred Galaxy, discuss recent advances in the structure of the Milky Way as well as uncertainties, and outline areas where the new data are likely to lead to major progress.

Mareki HONMA - NAOJ - Japan **(invited)**

Maser Astrometry and Galactic structure studies with VLBI

Galactic maser sources, such as star-forming regions and late-type stars, are excellent targets for high-accuracy radio astrometry. So far accurate parallaxes and proper motions have been measured for more than one hundred maser sources located at a distance of up to ∼10 kpc. In this talk, I would like to introduce basics of astrometry with VLBI and also present recent results of astrometry of Galactic maser sources. First I will quickly review the basics of accurate position measurements with VLBI, which is common to astrometry with VLBA/BeSSeL, VERA and other VLBI arrays. Then I will present the recent results of maser astrometry, mainly focusing on those from VERA (VLBI Exploration of Radio Astrometry), covering topics such as the Galactic parameter determinations, studies of the rotation curve and spiral arms, calibrations of period-luminosity relation of Mira variables, and so on.

Lucas Jordan HYLAND - University of Tasmania - Australia

The Structure of the Milky Way: View from the Southern Hemisphere

S.P.I.R.A.L - Southern Parallaxes with Interferometric Radio Astrometry Large survey. The exclusive association of Class II methanol masers with high mass star formation regions and in turn spiral arms, makes them ideal tracers of spiral structure. The bright and compact nature of masers also makes them good sources for Very Long Baseline Interferometry, with their fluxes visible on some of the longest terrestrial baselines. The success of the BeSSeL (Bar and Spiral Structure Legacy) project has demonstrated the use of masers in large-scale high-precision trigonometric parallax surveys. This survey was then able to precisely map the spiral arms visible from the Northern Hemisphere and recalculate the fundamental Milky Way parameters R_0 and θ_0. The majority of the Milky Way is visible from the Southern Hemisphere and at the present time the Australian LBA (Long Baseline Array) is the only Southern Hemisphere array capable of taking high-precision trigonometric parallax data. We present the progress-to-date of the Southern Hemisphere experiment, including a new parallax towards G287.367+0.6. We will also unveil a new broadband Southern Hemisphere array, capable of much faster parallax turnaround and atmospheric calibration, and a discussion of preliminary results.

Katharina IMMER - Joint Institute for VLBI ERIC - The Netherlands

How maser observations unravel the gas motions in the Galactic Center

The Central Molecular Zone (CMZ), the inner 450 pc of our Galaxy, is an exceptional place with high densities, high gas temperatures and large velocity dispersions. It has been suggested that the formation of stars and clusters in this area is related to the orbital dynamics of the gas. The complex kinematic structure of the molecular gas was revealed by spectral line observations. However, these results are limited to the line-of-sight-velocities. To fully understand the motions of the gas within the CMZ, we have to know its location in 6D space (3D location + 3D motion). We conducted a mini-survey of three water and three methanols masers in the CMZ with the VLBA to determine their parallaxes and proper motions, the only method to develop a reliable 6D picture of the CMZ, in combination with the maser positions and line-of-sight velocities. The observations were completed in the summer of 2017. I will present first results and compare them to recent models that have tried to explain the inflow of gas towards and its kinematics within this region.

Jingjing LI - Purple Mountain Observatory, CAS - China

Trigonometric Parallaxes of Star Forming Regions in the Scutum Arm

The BeSSeL Survey measured accurate parallaxes and proper motions of up to 90 high mass star forming regions in the Milky Way between 2012 and 2015. Here we report measurements of trigonometric parallaxes for 12 high-mass star-forming regions in the Scutum spiral arm of the Milky Way as part of the BeSSeL Survey. Combining our new measurements with previous measurements, we will map the structure and the kinematics of the Scutum Arm between the Galactic longitude 5 degree and 35 degree.

François MIGNARD - Observatoire de la Côte d'Azur - France **(invited)**

Gaia explores the Milky Way

On the 14th September 2016 the European Space Agency and the European consortium DPAC have jointly released the first results of Gaia, precisely 1000 days after the launch. With one billions stars catalogued with accurate positions, the Gaia scientists have produced the best ever map of the sky. In addition a smaller astrometric catalogue with 2 million stars included also their distances and annual motion on the plane of the sky. A small set of variable stars with light-curves and a reference system based on the extragalactic sources of the ICRF positioned for the first time in the visible were parts of this release. In this review I will recall the main scientific objectives of the mission and the technical means implemented to achieve the goals and get a the mission completion positions, distances and proper motions of more than one billion sources. The main results of the Gaia DR1 will be presented and evaluated and I will describe the current status of the program and finally detail the content of the second release scheduled in Spring 2018 that will include parallaxes for most of the stars.

Jürgen OTT - National Radio Astronomy Observatory - USA

SWAG Water Masers in the Galactic Center: Tracing and Timing Stages of Star Formation in Molecular Gas Streamers

The Galactic Center is an extreme environment that contains large amounts of molecular and ionized gas as well as a plethora of energetic objects such as evolving stars and a supermassive black hole, Sgr A*. Water masers are an extinction-insensitive probe for star formation and thus ideal for studies of star formation stages in this highly obscured region. With the Australia Telescope Compact Array, we observed the entire Central Molecular Zone (CMZ; the inner ∼500pc) with about 1pc resolution over ∼42 spectral lines and deep continuum (1-2cm wavelength) in the large, ∼600 hour/6500 pointing SWAG survey: "Survey of Water and Ammonia in the Galactic Center". We detect hundreds of 22GHz water masers that can be assigned to star formation sites (molecular outflows of protostars) and AGB stars. The star formation masers are mainly located on gas streamers that surround the CMZ and theoretical models predict the existence of a star formation sequence, triggered by the gas passage near the pericenter defined by Sgr A*. Our ammonia data shows that gas is heated near pericenter passages. The water maser data identifies individual stages of star formation events as a function of pericenter distance and via the streamer models as a function of time since star formation was initially triggered. This allows us to derive a detailed evolutionary scenario of star formation in the GC and to tighten up a possible star formation sequence.

Mark REID - Harvard-Smithsonian CfA - USA **(invited)**

Structure and Kinematics of the Milky Way

While we now know distances to galaxies at the edge of the Universe, we have only just begun to measure distances accurately throughout the Milky Way. Maser astrometry is now provided parallaxes with accuracies of ±10 microarcseconds, which corresponds to 10% accuracy at a distance of 10 kpc! The Japanese VERA project and the VLBA's BeSSeL Survey have now provided 200 parallaxes for masers associated with young, high-mass stars. Since these stars are found in spiral arms, we now are directly mapping the spiral structure of the Milky Way. Combining parallaxes, proper motions, and Doppler velocities we have complete 6-dimensional phase-space information. Modeling these data yields the distance to the Galactic Center, the rotation speed of the Galaxy at the Sun, and the nature of the rotation curve.

Nobuyuki SAKAI - National Astronomical Observatory of Japan - Japan

Eight new astrometry results of 6.7 GHz CH_3OH and 22 GHz H_2O masers in the Perseus arm

Spiral arm is a prominent structure in a disk galaxy. Nevertheless, several dynamical models have showed different results and the nature is not understood well. We aim to discriminate the dynamical models observationally for revealing the role of the spiral arm on galactic dynamics (evolution). We conducted astrometry observations toward seven 6.7 GHz and one 22 GHz masers in the Perseus arm with VLBA and VERA, respectively. We obtained the

eight new astrometry results in the Perseus arm. By combining those with previous astrometry results (Choi et al. 2014), we determined an arm width of 0.41 kpc and a pitch angle of 8.2±2.5 deg for the Perseus arm. By using a large sample of the Perseus arm (> 30 sources), we divide the sample into "13 trailing near sources", "14 leading far sources", and "4 unknown sources" to examine kinematic feature (i.e., non-circular motion) at each side separately. Interestingly, we found the near sources show a large inward motion (U = 14±1 km/s) and far sources do not show an inward motion (U = 0 ±1 km/s) or show an outward motion (-4±2 km/s) at the most far side. The tendency might be regarded as the "damping phase of the spiral arm" presented in the non-steady spiral model (Baba et al. 2013). Also, the small pitch angle of the Perseus arm (< 10 deg) supports the damping phase based on "pitch angle vs. arm amplitude" relation shown in Grosbol et al. (2004).

Lorant SJOUWEMAN - National Radio Astronomy Observatory - USA

Thousands of Stellar SiO masers in the Galaxy: The Bulge Asymmetries and Dynamic Evolution (BAaDE) survey

Circumstellar SiO masers can be observed in red giant evolved stars throughout the Galaxy. Since stellar masers are not affected by non-gravitational forces, they serve as point-mass probes of the gravitational potential and form an excellent sample for studies of the Galactic structure and dynamics. Compared to optical studies, the non-obscured masers are in particular valuable when observed close to the highly obscured Galactic Bulge and Plane. Their line-of-sight velocities can easily be obtained with high accuracy, proper motions can be measured and distances can be estimated. Furthermore, when different mass and metallicity effects can be accounted for, such a large sample will highlight asymmetries and evolutionary traces in the sample. In our Bulge Asymmetries and Dynamic Evolution (BAaDE) survey we have searched 20,000 infrared selected evolved stars for 43 GHz SiO masers with the VLA in the northern Bulge and Plane and are in the process of observing another 10,000 stars for 86 GHz SiO masers with ALMA in the southern Bulge. Our instantaneous detection rate in the bulge is close to 70%, both at 43 and 86 GHz, with occasionally up to 7 simultaneous SiO transitions observed in a single star. In this talk we will outline the BAaDE survey, its first results and some of the peculiar maser features we have collected. Furthermore we will discuss the prospects for obtaining proper motions and parallaxes for individual maser stars to reconstruct individual stellar orbits.

Maxim VORONKOV - CSIRO - Australia

Interferometry of class I methanol masers, statistics and the distance scale

The Australia Telescope Compact Array (ATCA) participated in a number of survey programs, both targeted and blind, to search for and image common class I methanol masers with high angular resolution. This resulted in a largest sample (to date) of these masers studied at arcsecond resolution, and provided us the basis for statistical analysis. In particular, apart from a small number of high-velocity features, class I methanol masers seem to trace the systemic velocity better than the middle of the velocity range of the associated 6.7-GHz masers (which is often used to estimate kinematic distances). There is also a small, but significant systematic offset of 0.57±0.07 km/s between velocities of these masers. In addition, the large statistics provided by more than 1400 emission components reveal an accurate empirical relationship: the number of maser regions falls off exponentially with the linear distance from the associated young stellar object traced by the 6.7-GHz maser, and the scale of this distribution is 263±15 mpc. Although this relationship still needs to be understood in the context of the broader field, it can be utilised to estimate the distance using methanol masers only. This new technique has been analysed to understand its limitations and future potential. It turned out, it can be very successful to resolve the ambiguity in kinematic distances, but, in the current form, is much less accurate if used on its own. The limiting factors are discussed.

Session 4 - Star Formation

Zulema ABRAHAM - IAG - Universidade de São Paulo - Brazil

Maser Effects in Recombination Lines: the case of Eta Carinae

Population of high quantum number states can depart from their LTE values at high densities (Ne $\sim 10^6 - 10^8$ cm^{-3}) and temperatures of the order of 10000 K. In this case, the intensity of recombination lines can be strongly amplified. The departure of LTE depends on density and temperature, and it is different for different quantum numbers, allowing the determination of the physical and kinematic conditions of the emitting region through the observation of recombination lines of different quantum numbers. This was the case of the massive binary system Eta Carinae. This system was observed with ALMA in the recombination lines H21 α, H28 α, H30 α, H40 α and H42 α and the continuum at the frequencies of the corresponding lines. The continuum spectrum was characteristic of a compact HII region, becoming optically thin at around 300 GHz. From the intensity and width of the recombination lines we concluded that the not-resolved emission region, assumed spherically symmetric, is a shell of 40 AU radius and 4 AU width, expanding at velocities between 20 and 60 km/s, with density 10^7 cm^{-3} and temperature of 17000 K.

Anna BARTKIEWICZ - Nicolaus Copernicus University - Poland

Expansion of methanol maser rings

Ring like sources at the 6.7 GHz methanol maser line were discovered a decade ago with the European VLBI Network. In the past years, we have been incessantly working to address the nature of these rings. Interestingly, methanol rings do not coincide with HII regions, nor they show 22 GHz water maser emission typically, and also the infrared emission is located off the centres of the rings. I will present a proper motion study over several years for six methanol maser rings. Our findings suggest that such rings originate from outflows and/or expanding radial shocks tracing velocities of a few km/s.

Maite BELTRÁN - INAF OAArcetri - Italy **(review)**

Perspectives on Star Formation: the formation of high-mass stars

The formation process of high-mass stars has puzzled the astrophysical community for decades from both a theoretical and an observational point of view. In this talk, I will present an overview of the current theories and status of the observational research on this field, outlining the progress achieved in recent years on our knowledge of the initial phases of massive star formation, the fragmentation of cold, infrared-dark clouds, and the evidence for circumstellar accretion disks around OB stars. The role of masers in helping us to understand the mechanism leading to the formation of a high-mass star will also be discussed.

Shari BREEN - University of Sydney - Australia **(invited)**

A Golden Age for Maser Surveys

Masers are becoming increasingly important probes of high-mass star formation, revealing details about the kinematics and physical conditions at the elusive, early stages of formation. Over the last decade significant investment has been made in a number of large-scale, sensitive maser surveys targeting transitions found in the vicinity of young, high-mass stars. Individually, these searches have led to valuable insights into maser populations, their associated star formation regions, and often revealed further details such as Galactic structure. In combination, they become even more powerful, especially when considered together with complementary multi-wavelength data. Another consequence of large maser surveys has been the identification of a number of especially interesting sources that have been the subject of subsequent detailed studies. I will summarize the recent plethora of maser surveys, their results, and how they are contributing to our understanding of star formation. I will also talk about the bright future of maser surveys in the decade to come.

Crystal BROGAN - National Radio Astronomy Observatory - USA

The extraordinary outburst in the massive protostellar system NGC6334I-MM1: dimming of the hypercompact HII region and destruction of water masers

I will present results from our 2016 JVLA DDT observations of the massive protostellar outburst in NGC6334I-MM1 (see accompanying contribution by Todd Hunter). The JVLA continuum data at 5 and 1.4 cm reveal that the free-free emission powered by the central protostar, modeled as a hypercompact HII region from our 2011 JVLA data, has dropped by a factor of 4 since 2011, and is likely due to the outburst observed in the millimeter continuum that began in 2015. Additionally, the water maser emission toward MM1, which had previously been strong (500 Jy) has dramatically reduced. In contrast, the water masers in other locations in the protocluster have flared, with the strongest spots associated with CM2, a non-thermal radio source that appears to mark a shock in a jet emanating 2" (2600 au) northward from MM1. Additional evidence for the jet appears in our ALMA observations as a collimated high velocity feature in dense molecular gas tracers. The pre-outburst luminosity and HCHII region are consistent with a deeply-embedded central object having a spectral type of B4 (ZAMS). The observed quenching of the HCHII region suggests a reduction in uv photon production due either to an elevated disk-mediated accretion rate that is ongoing, or the rapid accretion of a substantial mass (0.1 M_{sun}) which has caused the protostellar photosphere to expand and radiate at a much larger luminosity, but with a lower effective temperature.

Ross Alexander BURNS - Joint Institute for VLBI ERIC - The Netherlands

Water masers in bowshocks: Addressing the radiation pressure problem of massive star formation

In this contribution we present new VLBI observations of 22 GHz H_2O masers tracing bowshocks at the tips of collimated jets - a sign of fresh ejections in a sample of well known massive young stellar objects. The history of ejections, gleaned from the literature, suggests that these massive stars form by episodic accretion as inferred from the accretion-ejection connection. We discuss episodic accretion as a potential route to solving the "radiation pressure problem" in forming massive stars - with maser observations providing an essential observational tool.

James Okwe CHIBUEZE - Square Kilometre Array - South Africa

Sharpless-76E: Astrometry and Bipolar Outflows

Using VLBI Exploration of Radio Astrometry, we have conducted multi-epoch observations of the H_2O masers associated with Sharpless 76E. The measured annual parallax is 0.521±0.024 mas corresponding to the distance of 1.92±0.09 kpc. From the parallax measurement, we obtained the peculiar motion of Sh2-76EMM1 (UMM1, VMM1, WMM1) to be (-9±3, 10±4, 6±4) km s^{-1} and Sh2-76EMM2 (UMM2, VMM2, WMM2) to be (-5±12, 3±14, -21±22) km s^{-1}, where U, V and W are directed towards the Galactic Centre, in the direction of Galactic rotation and towards the Galactic north pole, respectively. The internal motion of the H_2O masers trace two separate bipolar outflows, one associated with Sh2-76EMM1 and the other with Sh2-76EMM2. The spectral energy distribution (SED) of Sh2-76EMM1 suggests it to be a class I YSO. We have only limited data points for the SED fit of Sh2-76EMM2, therefore can only speculate it to be probably a class II based on its comparative K-band and H-band magnitudes.

Ciriaco GODDI - Radboud University/Leiden Observatory - The Netherlands

Measuring Magnetic Fields from Water Masers in the Synchrotron Protostellar Jet in W3(H_2O)

We report full polarimetric VLBA observations of water masers towards the TW Object in the W3(OH) high-mass star forming complex. This object drives a synchrotron jet, which is quite exceptional for a high-mass protostar, and is associated with a strongly polarized water maser source, W3(H_2O), making it an optimal target to investigate the role of magnetic fields on the innermost scales of protostellar disk-jet systems. The linearly polarized emission from water masers provides clues on the orientation of the local magnetic field, while the measurement of the Zeeman splitting from circular polarization provides its strength. The water masers trace a bipolar, biconical outflow at the center of the synchrotron jet. Although on scales of a few thousand AU the magnetic field inferred from the masers is on average orientated along the flow axis, on smaller scales (10s to 100s of AU), we have revealed a misalignment

between the magnetic field and the velocity vectors, which arises from the compression of the field component along the shock front. Our measurements support a scenario where the magnetic field would evolve from having a dominant component parallel to the outflow velocity in the pre-shock gas, with field strengths of a few tens of mG (at densities of 10^7 cm^{-3}), to being mainly dominated by the perpendicular component of a few hundred of mG in the post-shock gas where water masers are excited (at densities of 10^9 cm^{-3}).

Sharmila GOEDHART - SKA SA - South Africa **(invited)**

Periodic Masers in Star Forming Regions

The first periodic Class II methanol maser was reported on in 2003. Since that time, a number of different monitoring programmes have found periodic masers, as well as other modes of variability. In a few cases, periodicity has been found in other maser species such as formaldehyde and water. Several distinct characteristics of light curves have been noted, possibly pointing to different underlying mechanisms for periodicity if one assumes a linear response to incoming radiation. I will give a brief overview of the known periodic sources, discuss current theories, and present new results obtained from monitoring mainline hydroxyl masers using the seven-element Karoo Array Telescope (KAT-7) during its science verification phase.

Tomoya HIROTA - National Astronomical Observatory of Japan - Japan

ALMA observations of submillimeter H_2O and SiO lines in Orion Source I

We present observational results of the H_2O and SiO lines toward the Orion Source I, the nearest high-mass protostar candidate at the distance of 418 pc, by using ALMA at resolutions of 0.1"-0.4". The ALMA observations were carried out in cycles 0, 1, and 2 at the frequencies of band 6 (232 GHz), 7 (321-336 GHz), 8 (428-498 GHz), and 9 (658 GHz). The spatial structures of the high excitation lines at lower-state energies of >2000 K tend to show compact structures consistent with the circumstellar disk and/or base of the northeast-southwest bipolar outflow with the 100 au scale. The highest excitation transition, the SiO (v=4) line at band 8, has the most compact structure which is unresolved at 0.1" resolution. On the other hand, lower-excitation transitions are more extended than 200 au tracing the outflow lobes. Almost all the line maps show common velocity gradients perpendicular to the northeast-southwest outflow axis suggesting rotation motions of both the circumstellar disk and outflow. The bright H_2O lines at 321 GHz, 474 GHz, and 658 GHz show clear signatures of maser emissions, while some of the detected lines including vibrationally excited H_2O and SiO (v=1) lines are consistent with thermal emissions characterized by spatially extended structures and broad linewidths. We will discuss dynamical structures of rotating disk/outflow system associated with Source I and possible excitation mechanism of the multiple H_2O and SiO lines.

Todd HUNTER - National Radio Astronomy Observatory - USA

The extraordinary outburst in the massive protostellar system NGC6334I-MM1: the rise of dust and emergence of Class II 6.7 GHz methanol maser emission

Our 2015 and 2016 ALMA 1.3 to 0.87 mm observations (resolution ∼200 au) of the massive Galactic protocluster NGC6334I revealed that an extraordinary outburst (luminosity increase of approximately 70x) had occurred in the dominant millimeter dust core MM1 when compared with our 2008 epoch SMA data. In this presentation, I will describe the evidence for the outburst, as well as new results from our recent JVLA DDT observations of the 6.7 GHz Class II masers in this region. These masers had not previously been detected toward MM1 in any published interferometric observations recorded over the past 30 years that targeted the bright masers toward other members of the protocluster (MM2 and MM3=NGC6334F). CH_3OH masers now appear both toward and adjacent to MM1 with the strongest spots located about 1 arcsec (1300 au) north of the MM1B hypercompact HII region. These data provide direct observational evidence of episodic accretion in a deeply-embedded high mass protostar and affords a unique opportunity to assess the ongoing impact of this event on the surrounding cluster, including its effect on the masers in the neighboring protocluster members.

Jihyun KANG - Korea Astronomy & Space Science Institute - Republic of Korea

Linear Polarization of Class I Methanol Masers in Massive Star Forming Regions

Class I methanol masers have known as good tracers of collisions of outflows from central protostellar objects to their surrounding mediums, however, the observations of their polarized emission have been very rare, especially at 44 and 95 GHz. We present the results of the linear polarisation observations of methanol masers at 44 and 95 GHz towards 39 massive star forming regions. These two lines are observed simulateously with the 21-m Korean VLBI Network (KVN) telescope in single dish mode. About 60% of the observed showed fractional polarisation of a few percents at least at one of the two transition lines. We note that the linear polarization of the 44 GHz methanol maser is first detected in this study including single dish and interferometer observations. We find the polarization properties of these two lines are similar as expected, since they trace similar regions. As a follow-up study, we have carried out the VLBI polarization observations toward a few 44 GHz maser targets using the KVN telescope. We present preliminary VLBI polarization results of G10.34-0.14 as well.

Kee-Tae KIM - Korea Astronomy & Space Science Institute - Republic of Korea

Understanding high-mass star formation through KaVA observations of water and methanol masers

We have started a systematic observational study of the 22 GHz water and 44 GHz class I methanol masers in high-mass star-forming regions as a four-year KaVA (KVN and VERA Array) large program since 2016. The primary science goal is to understand the dynamical evolution and circumstellar structures of high-mass young stellar objects (HM-YSOs) by measuring spatial distributions and 3D velocity fields of water and methanol maser features. Our sample consists of 87 HM-YSOs in various evolutionary phases, many of which are associated with multiple maser species. In the first year, we carried out snap-shot imaging survey of 25 water masers and 19 methanol masers to check detectability and variability of maser features. In particular, all the 44 GHz methanol masers but one have been first observed with VLBI. Based on these results along with the archive data of VERA and KVN, we will select suitable target sources and start multi-epoch monitoring observations to measure the proper motions of maser features from the second year. By combining follow-up observations with VERA (astrometry), JVN/EAVN (6.7 GHz class II methanol masers), ALMA (thermal molecular lines and continuum), and single-dish spectral line data, we will reveal the physical properties and 3D dynamical structures of disk, jet/outflow, and infalling envelope, and their relationship between the evolutionary phases of HM-YSOs. In this talk, we will present brief summary of our large program and show the initial results.

James MORAN - Harvard-Smithsonian CfA - USA

The Structure of the Maser Emission in MWC349

The SMA has been used to image the emission from radio recombination lines of hydrogen at subarcsecond angular resolution from the young high mass star MWC349A in the H26, H30 and H31 alpha transitions at 353, 232 and 211 GHz, respectively. Emission was seen over a range of 80 km/s in velocity and 50 mas (corresponding to 60 AU for a distance of 1200 pc). The emission at each frequency has two distinct components (see Martin-Pintado, et al., A&A, 530, L15, 2011 and Zhang, et al., ApJ, 837, 53, 2017), one from gas in a nearly edge-on annular disk structure in Keplerian motion, and another from gas lifted off the disk at distances of up to about 25 AU from the star. The slopes of the position velocity curves for the disk emission show a monotonic progression of the emission radius with frequency with relative radii of 0.85±0.04, 1 and 1.02±0.01 for the H26, H30 and H31 transitions, respectively. This trend is consistent with theoretical excitation models of maser emission from a region where the density decreases with radius and the lower transitions are preferentially excited at higher densities. The mass estimate is constrained to be 10-15 solar masses, much lower that reported in early measurements. The distribution of the wind emission among the transitions is surprisingly different, which reflects its sensitivity to excitation conditions. The wind probably extracts significant angular momentum from the system.

Luca MOSCADELLI - INAF OAArcetri - Italy **(invited)**

Masers as probes of the gas properties close to forming stars

This talk concisely reviews the main contribution of VLBI maser observations to investigate high-mass star formation (SF). VLBI of the intense 6.7 GHz methanol and 22 GHz water masers are unique tools to infer the 3-D gas kinematics in proximity to (at distances of hundreds AU from) the high-mass young stellar objects (YSO), tracing rotation, expansion and infall, and also revealing the detailed structure of the outflows. Maser polarization measurements allow us to determine the magnetic field configuration in the region of jet acceleration and collimation, where the maser observations can be usefully compared with the model predictions of magnetocentrifugally driven jets. In sinergy with recently upgraded interferometers (JVLA, e-MERLIN), as well as with ALMA at higher frequencies, maser VLBI can play a fundamental role to address the many, still open problems of high-mass SF.

Kazuhito MOTOGI - Yamaguchi University - Japan

A Face-on Accretion System in High Mass Star-Formation: Possible Dusty Infall Streams within 100 Astronomical Unit

We report on interferometric observations of a face-on accretion system around a high mass young stellar object, G353.273+0.641. The innermost accretion system of 100-au radius was resolved in 7-mm continuum image taken by J-VLA. A low brightness temperature (∼235 K) and a spectral index steeper than 2 indicate a grey-body emission from warm dust. 6.7 GHz CH_3OH masers associated with the same system were also observed by ATCA. The masers showed a spiral-like, non-axisymmetric distribution with a systematic velocity gradient. The line-of-sight velocity field was consistently explained by an infall motion along a parabolic streamline that falls onto the equatorial plane of a face-on system. Our infall model expects that the streamline is quasi-radial and reaches the equatorial plane at 16 au in radius. This is clearly smaller than that of typical accretion disks in high mass star formation, indicating that initial angular momentum was very small, or the CH_3OH masers selectively trace accreting materials that have small angular momentum. The super-resolution image suggests that the continuum emission also stems from the dusty infall stream. Otherwise, it independently traces an accretion disk of 100-au radius on the equatorial plane. In the former case, the initial specific angular momentum was smaller than $\sim 6 \times 10^{20}$ cm^{-2} s^{-1}, or a significant fraction of initial angular momentum could be removed outside than 100 au.

Carolina B. RODRÍGEZ-GARZA - UNAM Instituto de Radioastronomía y Astrofísica - Mexico

Interferometric and single-dish observations of 44, 84 and 95 GHz Class I methanol masers

We present a Very Large Array survey of 56 massive star-forming regions in the 44 GHz methanol maser transition; 24 of the 56 fields showed maser emission. The data allow us to demonstrate associations, at arcsecond precision, of the Class I maser emission with outflows, HII regions and shocks traced by 4.5 micron emission. We find a total of 81 maser components with linewidths ranging from 0.17 to 3.3 km/s with a nearly flat distribution and a median value of 1.1 km/s. The relative velocities of the masers with respect to the systemic velocity of the host clouds range from -2.5 to 3.1 km/s with a distribution peaking near zero and a small redshifted asymmetry. Spitzer images together with VLA centimeter continuum emission reveal multiple sources in each field; the masers seem to favor the younger sources in the fields. We report a possible instance of a 44 GHz maser associated with a low-mass protostar. If confirmed, this would be the second such association known. Thirty-nine of these sources were also observed with the Large Millimeter Telescope to search for Class I (84 and 95 GHz) and Class II (107 and 108 GHz) methanol transitions. We used a wide-band receiver (73-111 GHz) which revealed many other spectral lines that are common in star-forming regions. We find a 74%, 55%, 3% and a 45% detection rate for the transitions at 84 GHz, 95 GHz, 107 GHz and 108 GHz, respectively. Confirmation of the maser nature of this emission will require interferometric observations.

Alberto SANNA - Max-Planck Institut für Radioastronomie - Germany

The CepHeus-A Star formation and proper Motions (CHASM) Survey – Where is the mass reservoir of massive young stars? –

The CHASM survey is a large astrometric project of the VLBA which makes use of both CH_3OH and H_2O masers, in the vicinity of Cepheus-A HW2, in order to measure the proper motions of T-Tauri stars with respect to HW2. The CHASM survey combines the expertise we have gained with the BeSSeL and Gould's Belt surveys, with the aim to measure the Bondy-Hoyle accretion radius of a young massive star for the first time. As a first result of the survey, I will discuss the distribution of the low-mass young stars population around HW2. I will also present the results of the pilot study we have conducted on the CH_3OH masers around Cepheus-A HW2 with the EVN. With the aim to complement the large-scale star and gas kinematics (from CHASM) with that near HW2, we have recently shown that the CH_3OH gas within 900au from HW2 undergoes planar infall (Sanna et al. 2017).

Session 5 - Evolved Stars

Se-Hyung CHO - KASI - Republic of Korea **(invited)**

A Study of Evolved Stars by Simultaneous Observations of H_2O and SiO Masers Using KVN

A large number of oxygen-rich evolved stars exhibit SiO maser emission together with H_2O maser. Their intensity variations show a good correlation with the stellar pulsation. In addition, their spatial distributions and kinematics complement each other because SiO masers arise from infall and outflow regions inside the dust formation layer, while 22 GHz H_2O maser arises from radially accelerated regions above the dust layer. Therefore, it is important to perform simultaneous observations of both SiO and H_2O masers. However, many observers have performed these maser observations separately due to lack of system which can be operated in both maser bands together. In particular, VLBI observations of 86 GHz SiO maser were very limited and those of 129 GHz SiO maser none yet. However, the Korean VLBI Network (KVN) can be operated at the H_2O 22 GHz and SiO 43/86/129 GHz maser bands simultaneously, which lead us to perform the combined studies of H_2O and SiO masers including SiO J=2-1 and J=3-2 masers. Here we report these results using KVN mainly based on KVN Key Science Project (KSP) of evolved stars. We aim at investigating spatial structure and dynamical effect from 43/86/129 GHz SiO to 22 GHz H_2O maser regions associated with a stellar pulsation and development of asymmetry in circumstellar envelopes. We also investigate a mutual association and difference among these masers. At the first stage of our KSP through every one or two-month VLBI and single dish monitoring observations, we obtained the astrometrically registered maps of SiO and H_2O masers toward nine evolved stars using the source frequency phase referencing method (Dodson et al. 2014). In particular, the 86/129 GHz SiO (v=1, J=2-1 and J=3-2) masers were clearly imaged toward several objects for the first time. The SiO v=1, J=3-2 maser shows different distributions compared to those of SiO v=1, 2, J=1-0 and v=1, J=2-1 masers implying a different physical condition.

Richard DODSON - ICRAR/UWA - Australia

KVN astrometric observations of H2O and SiO masers in Calabash Nebula

We have performed successful astrometric observations of the iconic PPNe, the Calabash Nebula (OH231.8+4.2) using the KVN and Source/Frequency Phase Referencing. This, for the first time, robustly confirms the alignment of the SiO masers close to the AGB star which drives the bi-lobe structure with the water masers in out-flow. We are able to trace the bulk motions for the H_2O masers over the last few decades and model the SiO structure in the circumstellar material. These results confirm the power of the KVN/SFPR to tackle the very hardest challenges in astrometry.

Sandra ETOKA - University of Hamburg/JBCA - Germany/United Kingdom

Distances of Stars by mean of the Phase-lag Method

OH/IR stars are red giants and red supergiants with an optically thick circumstellar envelope that emit strong OH 1612 MHz emission. They are commonly observed throughout the Galaxy but also in the LMC and SMC. Hence, the precise inference of the distances of these stars will ultimately result in better constraints on their mass range in different metallicity environment. The extent of their circumstellar envelopes, as seen in 1612-MHz OH-maser emission, can be as large as 10000 AU (corresponding to 1.25 arcsec at 8 kpc and 0.2 arcsec at 50 kpc). With such an extent, the so-called "phase-lag method", consisting in measuring the linear diameter of the circumstellar envelope obtained from the time-delay measurement of the 1612-MHz OH-maser variability curves of the back and front sides of the shell, provides a powerful technique to retrieve the distance of such stars as far as the SMC. Through a multi-year long-term monitoring program at the Nancay Radio telescope (NRT) and a complementary high-sensitivity mapping campaign at the eMERLIN and JVLA to measure precisely the angular diameter of the envelopes, we have been re-exploring this method for a sample of stars, in order to refine the poorly-constrained distances of some and infer the currently unknown distances of others. We present here an update of this project.

Jose-Francisco GÓMEZ - Istituto de Astrofisica de Andalucia - Spain

Water masers as signposts of extremely young PNe

It was previously thought that water masers could not be present in planetary nebulae (PNe), due to the short expected lifetimes of this emission after the end of the AGB. However, there are now five PNe known to harbor water masers. These are probably very young PNe, and thus, important objects to study the onset and early development of the photoionization that characterize PNe. Maser emission in PNe seems to preferentially trace circumstellar toroids, although it may trace collimated jets during short periods of time. I will present some of our results on the search for new water-maser-emitting PNe, and on the (short-time) evolution of these objects. I will highlight the case of IRAS 15103-5754 whose maser distribution and radio continuum spectrum has dramatically changed during the past few years, probably as the result of the early development of a photoionized region.

Liz HUMPHREYS - European Southern Observatory - Germany

SiO Masers With ALMA Long Baselines

SiO masers and thermal emission have been observed towards the Mira AB system using ALMA 15 km baselines. The data have revealed a wealth of information on the physical conditions of the inner circumstellar envelope (CSE) of Mira A. On larger scales, they trace the binary wind interaction between Mira A and B. Here, we describe how we have used the data to search for signs of rotation in the inner CSE, important for understanding magnetic field generation in the stars. We also establish which of the eight SiO transitions observed show unambiguous signs of maser emission, as well as discussing the origin of absorption observed over the stellar disk. Finally, we compare the observational results with hydrodynamical maser radiative transfer + stellar atmosphere simulations.

Hiroshi IMAI - Kagoshima University - Japan **(invited)**

Towards decadal continuous viewing of circumstellar maser sources

The twinkles of maser features have always been fascinating us with new findings in interstellar and circumstellar physics, in particular the final evolution of envelopes of oxygen-rich, intermediate-mass stars. They host "classical" species of maser emission such as that from silicon-monoxide, water, and hydroxyl molecules, whose variety of combination may provide unique probes into different stages of the rapid evolution of circumstellar envelopes. At the same time, these masers can sometimes cause big uncertainty in our interpretation of their spatio-kinematics and origins as well as the excitation mechanisms. One of such examples is a series of proposed spatio-kinematical models of water masers associated with high-velocity bipolar outflows from AGB and post-AGB stars hosting water masers, so called "water fountains". Another is the models of silicon-monoxide masers, which may be affected by a combination of stellar radiation and shock propagation in the circumstellar envelopes. In order to unambiguously understand these issues

observationally, one needs to consider continuous monitoring of the individual maser gas clumps through a few cycles of the activity of or episodic events of gas ejection from the central pulsating dying stars. In the talk, our previous efforts on long-term monitoring observations will be summarized, especially for one of the water fountain sources W43A. Then, our current efforts on the large programs of decadal, intensive monitoring observations of circumstellar maser sources are introduced. The uniqueness of the programs highlighted lies in that the water and silicon monoxide maser lines will be simultaneously mapped at high cadence (2-8 weeks) of VLBI observations. This monitoring program will be conducted from 2018 using the East Asia VLBI Network for 10 and more stellar sources. A large fraction of the targets will be selected from 80 stars in the sample of our present snap-shot observation program, the Expanded Study on Stellar Masers (ESTEMA).

Akiharu NAKAGAWA - Kagoshima University - Japan

Astrometric VLBI observation of the Galactic LPVs; Miras and OH/IR stars

We show two studies about the Galactic LPVs based on the technique of astrometric VLBI. We use a VLBI array 'VERA' to measure their parallaxes, and the following two studies are built up on these measurements. First one is a calibration of K-band period luminosity relation (PLR) of the Galactic Miras. Since the PLR offers a distance indicator, its calibration is crucial to reveal their distribution in the MWG. Parallax of 14 LPVs, including Miras, will be presented together with 10 parallaxes from VLBA. Current results of the Galactic PLR is solve to be Mk=-3.52logP+1.09 (Nakagawa et al. 2016). Consideration of interstellar and circumstellar extinction is needed for more accurate calibration. Next study has just started. Extension of the PLR to longer period range (>1000 d) will be discussed. In this period range, mass loss ratio is high, stars are obscured and they are recognized as OH/IR stars. We estimated mid-infrared absolute magnitudes of dozen of OH/IR stars and found that they show a loose concentration around -14 mag at λ of 11.6 μm. This indicates an existence of PLR for OH/IR stars. To confirm this prediction, we will start astrometric VLBI observation of two OH/IR stars NSV25875 and OH127.8+0.0 at 43 GHz with VERA. Astrometry of OH/IR stars will also help us to confirm a non-steady spiral arms proposed from the latest simulation study of the galactic dynamics. Mid-infrared monitoring toward candidates of pulsating OH/IR stars is also discussed with TAO project.

Gábor OROSZ - Kagoshima University - Japan

Water Fountains and the Formation of Planetary Nebulae

Planetary nebulae often express beautiful, multipolar, point symmetric shapes - while their progenitors are characterised as having spherical layered structures. As stars exhaust their nuclear fuel and depart from the asymptotic giant branch, they launch powerful jets that are believed to be responsible for creating the diverse shapes of PNe. Spectacular examples of collimated jets are those traced by water masers, in objects named "water fountains" (with jet speeds and sizes on the order of 100 km/s and 1000 AU respectively). Water fountains are very rare due to their short timescales (on the order of 100 years) and as such the launching mechanism of their collimated jets remains an unresolved puzzle. In our talk, we introduce the VLBI maser astrometric analysis of IRAS 18113-2503 and IRAS 18043-2116, two remarkable and unique water fountains with spectacular bipolar bow shocks in their high-speed collimated outflows. Using our results from the VLBA and VERA arrays, we unveil the spatiokinematic structures and trigonometric distances (>10 kpc) of the bipolar bow shocks. Seen for the first time in water fountains, the measured 3D maser velocities (>200 km/s) clearly show that the jets are formed in very short-lived, episodic outbursts, which are intrinsically linked to the driving source and driving mechanism. We discuss possible interpretations, such as episodic accretion due to a binary system or magnetorotational instability, and their implications on stellar evolution.

Andrés Felipe PÉREZ-SÁNCHEZ - European Southern Observatory - Chile

Deep into the Water fountains: A detailed study toward IRAS 15445-5449

Water fountain nebulae are Galactic sources where observational studies of H_2O and OH maser emission could provide important information about the interaction between fast and slow winds propagating throughout their circumstellar

envelopes (CSEs). In this talk I will present the results of a detailed observational study of the spatial distribution of the 22 GHz H_2O maser emission, and both satellite and main line OH maser emission detected toward the WF IRAS 15445-5449. The observing program was carried out using the Austral Telescope Compact Array (ATCA). Our results suggest that the 22 GHz H_2O maser emission traces not only the jet-like structure, but also a dark equatorial structure in the midplane between the bipolar lobes. Moreover, the spatial distribution of the OH maser lines is also consistent with a large-scale midplane structure, although both OH and H_2O might be tracing different spatial scales within that equatorial region.

Guy PERRIN - LESIA - France **(review)**

Perspectives on Evolved Stars

Evolved stars are well known as key players for the enrichment of the Universe in atoms and molecules. The global picture is quite well known: the gas envelope reaches a distance from the star where dust can condense, making the effect of radiation pressure on the grains efficient enough that the dust shell drags the gas envelope away to the interstellar medium. Parts of the details of the mechanism are still elusive though. How and where dust condense in pulsating AGB stars, how can material be lifted up in the atmosphere of red supergiants are examples of questions to be solved. A lot of progress has been achieved in the past two decades with both imaging and spectroscopic techniques. A continuum of angular resolutions gives access to a continuum of spatial scales from fractions of the stellar disk up to a few stellar radii. This has been made possible by the advent of adaptive optics and long baseline interferometry in the optical and infrared domains. It has helped to establish connections between large and smaller spatial scales, including the masers. At sub-millimetric and millimetric wavelengths, ALMA has produced extraordinary images of mass loss. Spectro-polarimetry has led to measurements of magnetic fields so far undetected. I will review some of the results and how they connect to the big picture. I will give perspectives in the context of future instrumentation in the era of large facilities and of future space missions.

Anita RICHARDS - JBCA, University of Manchester - United Kingdom

Hot and cold running water: understanding evolved star winds

There are still many question-marks concerning mass-loss from evolved stars, such as how the wind is initially accelerated or what determines the clumping scale. Masers have been used to map the kinematics and spatial structure of winds for decades, but, hitherto, reconstructing physical conditions has been highly uncertain due to the exponential nature of maser amplification. Now, thanks to ALMA and e-MERLIN, we have image cubes for at least five water maser transitions around VY CMa, at spatial resolutions comparable to the size of individual clouds or better. These lines cover excitation states from 204 to 2360 K. We analyse their locations and how they are overlapping or segregated, using the model of Gray et al. 2016, to constrain variations of number density, temperature and other physical properties, on scales of a few au. This is more than an order of magnitude finer than is possible with thermal lines, comparable to individual cloud sizes or locally almost homogenous regions. Our results are compared with the models of Decin et al. 2006 and Matsuura et al. 2013 for the general properties of the VY CMa CSE.

Daniel TAFOYA - Chalmers University of Technology - Sweden

Sub-millimeter maser emission from warm water-fountain nebulae

Collimated outflows and jets are a ubiquitous phenomenon found in several astrophysical contexts. While they have been broadly studied in star forming regions and in compact objects, their presence in low-mass evolved stars was not recognized until recently. It is now widely accepted that jets are responsible for sculpting bi(multi)polar cavities in the expanding circumstellar envelope (CSE) of low-mass evolved stars. These cavities are seen as spectacular asymmetric pre- and planetary nebulae. The details of the launching and collimation of the jet and its interaction with the CSE remain unknown. So far, the best tool to study them is provided by a small sub-group of post-AGB stars that exhibit high-velocity collimated water masers, which are assumed to arise in the interaction region of the jet and the CSE. These objects are known as to water-fountain nebulae (WFN). The physical properties of the jet and the interaction

region with the CSE are assumed based on the conditions necessary to produce the water maser line at 22 GHz, which is the only transition used to identify these sources. Recently we carried out a search for sub-mm water masers in a group of WFN and detected for the first time 321 GHz masers toward three sources. In this talk I will present the results of the first detection of sub-mm water masers toward WFN and propose a new scenario for the interaction of the jet and the CSE to explain the coexistence of the 22 and 321 GHz water masers in these sources.

Dong-Hwan YOON - Korea Astronomy & Space Science Institute - Republic of Korea

Simultaneous VLBI observations of H_2O and SiO masers toward VX-Sgr

We performed simultaneous VLBI observations of H_2O 616-523 (22.2 GHz) and SiO v=1, 2, J=1-0 (43.1, 42.8 GHz) and v=1, J=2-1, J=3-2 (86.2, 129.3 GHz) masers toward VX Sagittarius using the Korean VLBI Network (KVN). The astrometrically registered maps of the 22.2 GHz H_2O and 43.1, 42.8, 86.2 GHz SiO masers were successfully obtained at two epochs of 2016 February 27 and 2016 March 27 by adopting the Source Frequency Phase Referencing (SFPR) method. These results make it possible to determine the accurate position of central star as a dynamical center of 22.2 GHz H_2O maser and relative locations of 43.1, 42.8, 86.2 GHz SiO masers. We confirmed the correlation of position between 86.2 GHz and 43.1, 42.8 GHz maser which was known as simulation. Detecting to the outermost 129 GHz ring structure has presented a new challenge to the controversial SiO pumping mechanism. In addition, it is possible to investigate the morphological and kinematic variations of clumpy structures from SiO maser to H_2O maser regions together with the development of asymmetric structure of H_2O maser region.

Session 6 - New facilities

Willem BAAN - ASTRON - The Netherlands

H_2O MegaMasers at High Resolution

Two powerful MegaMasers, NGC3079 and NGC4258, have been detected on ground to space baselines with the RadioAstron Observatory (RAO), the RAO K-band survey consists of fringe detections at increasing baselines for all strong sources that are observable with RadioAstron, which also includes the Circinus galaxy, the MM NGC4945, and the star-formation regions LMC-N113 and M33-IC133. The H_2O MM emission in NGC3079 has been detected only at a 1.9 Earth diameter (ED) baseline and not beyond, while NGC4258 has been detected eleven times between at 1ED and 26.9ED. The two detected sources indicate strong differences in their masering environments. The data at increasing baselines show that up to 90% of the line emission of NGC4258 disappears at highest resolution, while the features of the more distant NGC3079 already disappear beyond 2ED. Unresolved features with higher apparent gain remain in the spectrum at longer baselines, while more diffuse emission components are being resolved. Therefore the bulk of the observed emissions consists of unsaturated emission from an environment that is consistent with an extended distribution of clouds with varying amplifying gains that is superposed on the spatial structure of a background continuum. At very high resolution the isolated spectral features also provide more accurate estimates of the magnetic field.

Anna BONALDI - SKA Organization Jodrell Bank - United Kingdom **(invited)**

The SKA

I will give an update on the status of the SKA project and a review of the capabilities of SKA, with a focus on the technical and scientific aspects more relevant for Masers.

Francisco COLOMER - JIVE/OAN-IGN - The Netherlands/Spain **(invited)**

Masers! What can VLBI do for you?

Maser processes are common in the Universe. These can be found in star formation regions, in circumstellar envelopes (CSEs) around evolved stars (mainly around AGB and post-AGB stars), in our and other galaxies.

Since the maser emission is bright and compact, high resolution VLBI observations are a basic tool to provide useful information, by studying their distribution and other characteristics. The advent of recent technological developments and instruments make now possible to study cosmic masers not only in a more efficient way, but also opens new scenarios for the study of these emissions, which we will review.

Eric MURPHY - NRAO - USA **(invited)**

The Next Generation Very Large Array (ngVLA)

Inspired by dramatic discoveries from the Jansky VLA and ALMA, a plan to pursue a large collecting area radio interferometer that will open new discovery space from proto-planetary disks to distant galaxies is being developed by NRAO and the science community. Building on the superb cm observing conditions and existing infrastructure of the VLA site, the current vision of the ngVLA will be an interferometric array with more than 10 times the effective collecting area and spatial resolution of the current VLA and the Atacama Large Millimeter Array (ALMA), operating at frequencies spanning ∼1.2 - 116 GHz. The ngVLA will open a new window on the universe through ultra-sensitive imaging of thermal line and continuum emission down to milliarcecond resolution, as well as deliver unprecedented broad band continuum polarimetric imaging of non-thermal processes. In addition, the ngVLA will be optimized for observations at wavelengths between the exquisite performance of ALMA at submm wavelengths, and the future SKA-1 at decimeter to meter wavelengths, thus lending itself to be highly complementary with these facilities.
Additionally included in current ngVLA planning is an option to greatly expand current U.S. VLBI capabilities by both replacing existing VLBI antennas/infrastructure with ngVLA technology and adding additional stations on 1000 km baselines to bridge the gap between ngVLA and existing VLBA baselines.

Alison PECK - Gemini Observatory - USA **(invited)**

Masers and ALMA

Masers have been well-known phenomena for decades, but water masers at 183, 321, 325 and 658 GHz have only been detected since the 1990s. Early detections came from single-dish telescopes with follow-up observations from the PdBI and the Submillimeter Array. Detecting them at these short wavelengths has been very difficult due to water in our atmosphere, meaning that even in very good weather, one can only detect very bright masers, such as those in stellar atmospheres. In the last 7 years, a new window on submillimeter water masers, both Galactic and now extragalactic, has opened. The ALMA site is ideal for the detection of water because there is so little of it to absorb the celestial signal. Located at high altitude, above a large fraction of the Earth's atmosphere, ALMA sits on the edge of the driest desert on the planet, meaning that the air that does remain above the telescope is frequently extremely low in water vapor content. Combine this with sensitive, stable receivers covering a number of masing transitions from 183-658 GHz and you have an excellent machine for detecting and characterizing submillimeter water masers. In addition, other molecules also exhibit maser emission in the ALMA observing bands, such as SiO and HCN.In this talk, we present a review of just a few of the exciting results that have been obtained with ALMA, along with some insights into the technology that has made these observations possible.

Maria RIOJA - ICRAR/UWA - Australia

"MultiView" Calibration for Precise Astrometry at Low Frequencies

Astrometric measurements play a fundamental role in a wide variety of research fields, with VLBI holding the record for the highest precision measurements in astronomy. In the last decade there have been huge strides in achieving the full astrometric potential, arising from advanced calibration strategies that accurately compensate the dominant tropospheric propagation residual effects that have led to micro-arcsecond precision measurements, most notably at 22 GHz. The arrival of the Square Kilometer Array, which will focus on the lower frequencies in Radio Astronomy (3 to 0.1 GHz) will revitalise all aspects of astronomy at these wavebands. Significant new developments will be required to extend the above mentioned level of astrometric precision to the low frequency regime, which are dominated by ionospheric effects that pose a rather different set of challenges. This presentation reports on "MultiView", a calibra-

tion scheme which relies on observations of multiple calibrators surrounding the target field of interest to correct for the direction dependent residual effects. I will present a demonstration of the MultiView technique and a comparison with other existing astrometric methods. MultiView is ideal for the innovative multibeam capabilities planned for the SKA and the pathfinders.

Andrej M. SOBOLEV - Ural Federal University - Russia **(invited)**

RadioAstron space-VLBI project: studies of masers in star forming regions of our Galaxy and mega-masers in external galaxies.

Observations of the masers in the RadioAstron (RA) mission yielded detections of fringes for a number of sources in both H2O and OH maser transitions. Several sources display numerous ultra-compact details. This proves that implementation of the space VLBI technique for maser studies is possible technically and is not always prevented by the interstellar scattering, maser beaming and other effects related to formation, transfer and detection of the cosmic maser emission. RA observations provided absolute record of the angular resolution in astronomy. Fringes from the NGC 4258 megamaser were detected on baseline ∼26.7 Earth Diameters (∼340,000 km). This corresponds to the angular resolution ∼8 μas sufficient to measure parallax of the maser source in the nearby galaxy LMC. The sharpest "direct" linear resolution $< 4 \cdot 10^{11}$ cm was achieved in observations of the maser in Orion. RA also detected the smallest structures ever observed in a Galactic maser. Analysis of the data on Cep A water maser indicates that the source contains features with the sizes about the diameter of the Sun. The space-Earth cross power spectrum shows two unresolved components smaller than 15 μas ($\sim 1.6 \cdot 10^{11}$ cm) separated by $\sim 160 \pm 35$ μas which differ in velocity by 0.5 km/s. The brightness temperatures are $> 2 \cdot 10^{14}$ K, and the line widths are 0.5 km/s. Most of the flux density (∼90 per cent) is contained in a halo of diameter 1 mas. We discuss possible interpretations for the compact structure.

Poster Presentations

POSTER 1 - ***Exploring why the detection efficiency of disk megamasers in local Seyfert 2 AGN is so***
Alberto MASINI - INAF-OABO -Italy
The low detection efficiency of disk megamasers in Seyfert 2 (Sy2) galaxies is well known, and prevents researchers in building a statistically relevant sample of AGN with these peculiar properties. Starting from the result of the Megamaser Cosmology Project (MCP) group, who finds that the detection efficiency of disk megamasers in Sy2 AGN is $< 1\%$ (Gao et al. 2017; Braatz et al. in prep), we investigate the possible reasons for this. We show that, unless the maser beaming angle is very small (± 5 degrees from the edge-on line of sight, while from the literature a ± 10 degrees is found), the only geometry argument is not able to explain the low detection efficiency is Sy2, which should be $\sim 3\%$ for a reasonable average covering factor. We then investigate the possible role of pseudobulges in shaping the presence of sub-pc Keplerian disks, calculating the megamaser hosts' stellar masses and carefully looking into the fraction of pseudobulges in late-type galaxies at the typical masses considered. Finally, we consider also the role of the radio continuum luminosity at 22 GHz as a crucial parameter which could lower the 3% detection efficiency, based on geometry argument alone, to the observed $< 1\%$ value.

POSTER 2 - ***Using hydrogen radio-recombination maser lines to reveal the kinematics and origin of ionized winds***
Alejandro BÁEZ RUBIO - Universidad Nacional Autónoma de México - Mexico
Since the detection of hydrogen radio-recombination maser lines (RRLs) toward MWC349A in the year 1989, it is clear that these lines are excellent tools to constrain the kinematics of very dense and inner ionized layers. In fact, the detection of new maser sources in the last six years has revealed that these lines could be detected toward a higher number of ultracompact HII regions than previously thought. In this poster, I will review about what information we basically derive from these lines, and the recent advances provided by their modelling with the MORELI code, a 3D non-LTE radiative transfer Model for Recombination Lines. In particular, I will show how the launching point of the ionized wind around MWC349A has been constrained by modelling the Herschel RRLs with this code, supporting that its wind is originated at a distance of about 24 au, which is also consistent with disk-wind models as recently claimed by other authors with the analysis of SMA observations. In addition, I will also discuss the most recent detected sources showing maser RRLs such as MWC922, a B[e] star which strongly resembles MWC349A. Finally, I will explain the prospects of using these maser RRLs to study objects with different evolutionary stages and masses.

POSTER 3 - ***Pumping regimes of Class I methanol masers***
Andrej M. SOBOLEV - Ural Federal University - Russia
Sobolev et al. (2005,2007) provided observational examples and theoretical analysis that Class I methanol maser (MMI) pumping has at least 4 regimes defined by the series of the brightest maser line. Extensive surveys confirm this conclusion: Survey of 36 and 44 GHz lines (belong to J(-1)-(J-1)(0)E and J(0)-(J-1)(1)A+ series) by Voronkov et al. (2014) shows that these masers are widespread but only 23 per cent of maser features is detected in both transitions. These lines define 1st and 2nd regimes of MMI pumping. Survey of 25 GHz line from the J(2)-J(1)E series by Voronkov et al. (2007) shows that these masers are widespread but mostly weak. Bright example of OMC-1 clearly shows existence of the 3rd regime. Survey of the 9 GHz line from the J(-2)-(J-1)(-1)E series by Voronkov et al. (2010) shows that these masers are rare but clear examples of the 4th regime exist. Recent paper by Leurini et al. (2016) presented most extensive analysis of the MMI models. The study distinguished only 3 of 4 mentioned regimes. This can be explained that the authors did not take into account considerable beaming effects: clear example of more refined model matching observational data is published in Voronkov et al. (2006). In the current paper we present more extensive and refined analysis which shows that the beaming leads to considerable changes in the model line ratios and brightness estimates. This eliminates discrepancy between observations and models of Class I methanol masers.

POSTER 4 - ***Excited OH Masers in Late Type Stellar Objects***

Angelica Erica STRACK - Western Illinois University - USA

The final stages of low-mass stellar evolution are characterized by significant mass loss due to stellar pulsations during the AGB phase, which lead to the development of planetary nebulae. Molecular masers of H_2O, SiO, and ground state OH transitions are commonly detected in oxygen-rich late type stars (OH/IR objects). In contrast, excited OH maser transitions are rare. We review the field of excited OH masers in late type stellar objects. We discuss in particular our study of the carbon-rich pre-planetary nebula CRL 618 (a prototypical post-AGB star). Observations conducted in May 2008 with the 305m Arecibo Telescope resulted in the first detection of a 4765 MHz OH maser line in a late type stellar object, and the detection was confirmed in follow up observations the same year. Subsequent observations in 2015 and 2017 resulted in non-detection of the 4765 MHz OH line. In addition, in 2008 and 2015 we searched for all other OH transitions within 1 to 9 GHz with the Arecibo Telescope, and detected no other lines. Our observations indicate that the 4765 MHz OH maser in CRL 618 is highly variable, possibly tracing a short-lived phenomenon during the development of a pre-planetary nebula. Based on the velocity of the line relative to systemic, the maser was likely tracing outflowing gas from the bipolar nebula. We acknowledge support from F. Rodeffer and M. & C. Wong RISE scholarships.

POSTER 5 - ***Long term methanol maser monitoring program***

Artis ABERFELD - VIRAC - Latvia

A sample of 41 6.7-GHz methanol masers observable from the northern hemisphere are monitored starting with summer 2016. We employ the 32-m and 16-m telescopes of the Ventspils International Radio Astronomy Center, located in Irbene. The observations were performed at 3-5 day intervals. When the intensity of a source was seen to be varying rapidly, the intervals were reduced to a day or a few hours. It was found that most the sources display a significant level of variability with time, ranging from a few days, up to several months and, perhaps, years. Several types of maser behavior were observed, including: non-varying, monotonic increases or decreases, un-periodical, quasi-periodic and periodic variations. It is too early to estimate periods for most of the observed periodical masers, although 4 shortest periods are likely little more than 200-days long. The Irbene observatory will pursue methanol maser monitoring program in the coming years with the aim to obtain insight of the evolution in the long term variability of methanol masers.

POSTER 6 - ***Pinning Down the Aquila Spur***

Bo HU - Nanjing University - China

Sub-structures like branches and spurs are commonly found in extra spiral galaxies, regardless of the number or configure of the spiral arms. Milky Way has been long investigated in its spiral structure, and the evidence of spurs between revealed by Galactic plan HI and molecular surveys. Using VLBI parallax measurements of Class II methanol masers, we have located a galactic sub spiral structure, the Aquila spur, for the first time. The Aquila spur emerges from the Scutum arm, showing typical larger pitch angle. Larger average peculiar motions of the spur indicate it may be less stable than the major arms.

POSTER 7 - ***Verifying Gaia parallaxes of Long Period Variables via VLBI Maser Astrometry***

Bo ZHANG - Shanghai Astronomical Observatory, CAS - China

Long Period Variables including Miras and Semi-regulars show well defined Period Luminosity Relation (PLR) in infrared, they are important distance indicators. However, as for other types of variables, the zero-point for the PLR of LPVs is not well established. The most straightforward method to calibrate the zero-point is to measure distances of Galactic LPVs by trigonometric parallax. Gaia, the successor to Hipparcos should in principle enable major advances for distances of LPVs. However, LPVs present some challenges to Gaia. Firstly, LPVs have large ranges in visual magnitude. Thus, some variables may be either too bright or too faint for accurate observations by Gaia at some phases. Secondly, the size of a LPV is $\approx$2 AU, which means that its angular size exceeds its parallax. Thirdly, LPVs can have large variations in brightness across their stellar disks, and bright patches may move around in their

photospheres in complex manners. All these effects may limit the accuracy of Gaia astrometry of LPVs. Fortunately, they would have no influences on parallaxes for circumstellar OH, H_2O and SiO masers from VLBI measurements, which promise to provide accurate distances to significant numbers of LPVs. Therefore, VLBI can provide a critical check on Gaia parallaxes of LPVs.

POSTER 8 - ***Variability of Water Masers in W49N: Results from Effelsberg Long-term Monitoring***
Busaba HUTAWARAKORN KRAMER - MPIfR / NARIT - Germany / Thailand
We present the results from an ongoing long-term monitoring of the 22-GHz water maser in W49N with the 100-m Effelsberg radio telescope from February 2014 to July 2017. The unique Effelsberg's spectral line observation capability provides a broad velocity range coverage from -500 to +500 km/s with a spectral resolution better than 0.1 km/s. Following the strong major outburst in W49N in late 2013, we have started a long-term monitoring programme at Effelsberg. The major outburst feature (up to 80,000 Jy) at high velocity (∼98 km/s) has faded away in 2014. However, we found that the site still active with several high velocity blue-shifted outbursts. Some features appear at extremely high velocities (up to ±300 km/s) and show rapid flux variations within a 1-2 month period. This sub-year scale variability implies that the water masers could be excited by episodic shock propagation caused by a high-velocity protostellar jet. We also detected periodical variability in several features which lead to further detailed follow-up studies with VLBI observations.

POSTER 9 - ***Ubiquitous millimeter-wavelength Class I methanol masers associated with massive (proto)stellar outflows: ALMA and SMA results***
Claudia CYGANOWSKI - University of St. Andrews - United Kingdom
We report the discovery of widespread millimeter-wavelength Class I methanol maser emission associated with protostellar molecular outflows in the massive (proto)cluster G11.92-0.61. Our ∼0.5"-resolution SMA and ALMA observations of the 229 GHz and 278 GHz Class I transitions reveal seven and twelve candidate masers, respectively: all 229 GHz masers have 278 GHz counterparts, and five are also coincident with 44 GHz Class I masers previously detected with the VLA. For paired masers, the peak intensities at 229 GHz and 278 GHz are correlated. We also find tentative evidence for a correlation between the strength of millimeter-wavelength Class I maser emission and the energy of the associated molecular outflow. We also show initial results from an SMA survey of ∼20 GLIMPSE Extended Green Objects (EGOs) that includes the 229 GHz Class I transition (at ∼3" resolution). In this sample, candidate 229 GHz maser emission (identified based on line ratios) is ubiquitous towards massive molecular outflows, suggesting that higher-resolution ALMA observations will continue to uncover copious millimeter methanol maser emission in massive star-forming regions.

POSTER 10 - ***VLBI astrometry of a water maser source in the Sgr B2 complex with VERA***
Daisuke SAKAI - University of Tokyo - Japan
We have conducted astrometric observations toward a 22 GHz water maser source associated with Sgr B2 complex in the Galactic center region with VERA (VLBI exploration of Radio Astrometry). We measured a trigonometric parallax and absolute proper motion of the Sgr B2 complex with respect to an extra-galactic source by observing the water maser source at 9 epochs from 2014 to 2016. The measured distance was 7.52(+3.01/-1.67) kpc for Sgr B2M region. We also succeeded to measure internal motions of maser spots in Sgr B2M, N, and S region. The number of spots which we could measure the internal motions are about 400. The distribution of the maser spots shows that the maser spots are associated with envelopes of HII regions seen in radio continuum image obtained with VLA and ALMA. We discuss relative motions between Sgr B2M, N, and S by using the internal motions and line-of-sight velocities.

POSTER 11 - ***Methanol masers revealing the large scale magnetic field of the high mass protostar IRAS18089-1732***

Daria DALL'OLIO - Chalmers University of Technology - Sweden

The importance of the magnetic field in high mass star formation (HMSF) is not yet fully clear and there are still many open questions concerning its role in the accretion processes and generation of jets and outflows. In the past few years, masers have been successfully used to study the magnetic field at few AU scales around massive protostars.Thanks to their narrow and strong spectral lines and through their polarized emissions, it is possible to reconstruct the morphology and the strength along the line of sight of the magnetic field, by measuring linear polarization angles and Zeeman splitting. I will present IRAS18089-1732, a well studied HMSF region, showing a hot core chemistry and a disk-outflow system. Previous observations of polarized dust made with SMA revealed an ordered magnetic field oriented around the disk. Our MERLIN observations show that the magnetic field in the 6.7 GHz methanol maser region is consistent with the magnetic field constrained by the SMA observations. This confirms that methanol masers trace the large scale field, and that the large scale field component, even at the AU scale of the masers, dominates over any small scale field fluctuations. Moreover I will present a tentative detection of circularly polarized line emission, from which we derive a field strength that is consistent with previous estimates. I will also present an outlook on the methanol polarization observations that are part of our eMERLIN 'Feedback during MSF' legacy project.

POSTER 12 - ***Missing flux of SiO maser at 7mm in IRC+10011***

Jean-François DESMURS - Observatorio Astronómico Nacional - Spain

VLBI observations of SiO masers recover at most 40-50% of the total flux obtained by single dish observations at any spectral channel. Some previous studies seems to indicate that, at least, part of the lost flux is divided up in many weak components rather than in a large resolved emission area. Taking benefit of the high sensitivity and resolution of the HSA, we investigate the problem of the missing flux of SiO maser emission at 7 mm in the AGB stars and obtained a high dynamic range map of IRC+10011 to check if part of the missing flux is contained in many very weak maser components.

POSTER 13 - ***OH masers as probes: How does the variability fade away during the AGB - post-AGB transition?***

Dieter ENGELS - Hamburger Sternwarte - Universität Hamburg - Germany

We perform a monitoring program of several dozen OH/IR stars of the 1612 MHz OH maser emission with the Nancay Radio Telescope. These stars in the galactic disk are complemented by several OH/IR stars in the galactic bulge, which were monitored with the Hartebeesthok Radio telescope. The transition of stars with masses ∼2-8 M_{sun} from the Asymptotic Giant Branch (AGB) to the post-AGB stage takes place while the stars are undergoing strong mass-loss and are surrounded by an optically thick circumstellar shell. We use the maser emission as a proxy for the underlying stellar variability. As early monitoring programs already have shown, some stars are large amplitude variables with periods up to 7 years, others show small or even no amplitude variations. This dichotomy in the variability behaviour is assumed to mark the border between the AGB and the post-AGB stages. The absence of stars known to be currently in transition, indicate a rather fast transition time (<10000 yrs). With the current program, we wish to find objects in transition and to describe their variability properties. Furthermore constraints on the transition time will be searched for.

POSTER 14 - ***Searching for warped disk AGN candidates***

Elena FEDOROVA - National Taras Shevchenko University of Kyiv - Ukraine

Mapping the maser emission of subnuclear regions of active galactic nuclei enable us to determine some interesting details of the geometry of the accretion disks under the condition that it they have a "maser skin". Additional information about disk warp in the innermost zone near the central blachk hole can be disclosed by means of modeling the shape of the relativistically broadened iron emission lines in the energy range 6-7 keV. Here we analyze the influence

of the accretion disk geometry (warp) on the shape of the set of relativistically broadened emission lines, as well as consider some examples of AGNs identified by maser mapping techinque as warped, and having the complex shape of iron lines near 6.4 keV.

POSTER 15 - ***A survey for OH masers in H_2O maser galaxies with Effelsberg and Green Bank radiotelescopes***

Elisabetta LADU - Università degli Studi di Cagliari - Italy

We present a search for OH maser emission in two samples of galaxies hosting H_2O masers with the 100-m Effelsberg radiotelescope and the Green Bank Telescope. This survey is aimed at providing new clues to the debated apparent rarity, or even possible mutual exclusion of the simultaneous presence of megamaser emission from OH and H_2O in the same galaxy. A possible explanation invokes the extreme and different physical conditions for OH and H_2O maser emission to take place. However, this hypothesis needs to be verified by extending the samples where maser emission from both molecular species are searched for and by detailed observations of individual dual-maser targets. Our study establishes new upper limits on the OH maser luminosity for 34 galaxies, out of which 28 had no OH measurements reported. Our work duplicates the number of H_2O maser searched for OH emission. No new maser detections have been found confirming the paucity of 'double-maser' sources. OH absorption, both in the 1667 and 1665 MHz transitions, is instead detected for two galaxies in the sample, providing promising targets for follow-up interferometric measurements useful to investigate the molecular gas in the (likely) nuclear regions of the hosts.

POSTER 16 - ***Measurement Beam Polarization Pattern of KVN and Polarization Error of Maser Source***

Eodam HWANG - Korea Astronomy & Space Science Institute - Republic of Korea

Star formation is important study in astronomy, which is fundamental in all fields. In this star forming region, magnetic fields are thought to play an important role. but we still don't know about the magnetic fields. Maser is an important tool for obtaining magnetic field information. And in star forming region, maser can be distributed in a large area and can be observed as multiple spots within beam angle. In this case, if it is polarization observation, there is an additional error due to position offset apart from observation equipment error in center. It can be determined by observing a celestial object without polarization. So, we measured this additional error of KVN (Korean VLBI Network) in non-center and displayed by 2D beam pattern image. Then we applied it to maser source.

POSTER 17 - ***Long-term photometric observations in field of the star formation region NGC7129***

Evgeni SEMKOV - Institute of Astronomy and NAO - Bulgaria

The region of NGC 7129 is a part of a larger structure, called Cepheus Bubble, and its represents a region with active star formation. The presence of a large number of Herbig-Haro objects, collimated jets, Herbig's Ae/Be and T Tauri stars, water masers, molecular outflow and other young objects have been reported in previous studies in the region. Using recent data from photometric monitoring and data from the photographic plate archives we aim to study, the long-term photometric behavior of pre-main sequence objects in the field. Our optical photometric observations were performed with the 2-m RCC and 50/70-cm Schmidt telescopes of the National Astronomical Observatory Rozhen (Bulgaria) and the 1.3-m RC telescope of the Skinakas Observatory (Crete, Greece). Most suitable for long-term photometric study are the plate archives of the big Schmidt telescopes that have a large field of view, as the 105/150 cm Schmidt telescope at Kiso Observatory, the 67/92-cm Schmidt telescope at Asiago Observatory, the Palomar Schmidt telescope and others. So far we have published our results for the light curves of V350 Cep and V391 Cep. Now we present these curves supplemented with new data that describe more accurate the photometric behavior of the objects. For the first we present the results from a photometric monitoring of four newly discovered young variable stars. Our photometric monitoring is complemented by spectral observations of some of the stars in this area.

POSTER 18 - ***Tracing the innermost regions of massive protostars by complementing high-resolution radio continuum and maser observations, and Near-Infrared imaging***

Fabrizio MASSI - INAF-OAArcetri - Italy

To probe the jet-disk connection in massive ($M > 7\ M_{sun}$) protostars, we have started a pilot programme that consists in very deep observations of a subsample of high-mass YSOs, with $d < 4$ kpc, through the H2 narrow-band filter centred at 2.12 μm by exploiting both LUCI cameras at LBT. H2 line emission at 2.12 μm has been routinely used to trace collimated gas outflows from YSOs. Our goal is trying and detect jets as near as possible to the driving YSOs so that we can connect it to innermost, high-resolution radio tracers. The selected targets are part of a larger sample of high-mass YSOs exhibiting jet signatures. The molecular and ionized components of the flow had already been mapped with unprecedented angular resolution and sensitivity, by complementing multi-epoch VLBI observations of water masers, with high-angular resolution, multi-frequency (6, 13, and 22 GHz), deep imaging (rms noise 10 μJy) of radio continuum emission with the JVLA in the framework of the BeSSeL (Bar and Spiral Structure Legacy) survey. While the radio/maser observations have allowed us to constrain the geometrical and physical properties of the flows at distances of a few 0.1 arcsec (i. e., $<$ a few 400 AU), our NIR imaging yield information on angular scales of $\sim$10 arcsec. As yet, 4 targets have been observed, namely G111.25-0.77, G092.69+3.08, G075.76+0.34, G074.04-1.71. We will show what is the picture resulting by combining, radio, maser, and NIR observations of the 4 massive protostars.

POSTER 19 - ***Radio continuum of galaxies with H_2O megamaser disks***

Fateme KAMALI - Max-Planck Institut für Radioastronomie - Germany

H_2O-disk-maser galaxies are active galaxies where 22 GHz H_2O maser emission is detected in their accretion disks. They are a unique sample of targets, with the circumnuclear disk being viewed edge-on and with the rotation axis oriented parallel to the plane of the sky. We studied the radio continuum of 24 H_2O-disk-maser galaxies with the VLA at 33 GHz with 200 - 500 mas resolution. The aim of our studies was to investigate the nuclear environment of the H_2O-disk-maser galaxies and to relate the maser and host galaxy properties to those of its radio continuum emission. Out of 24 galaxies in our sample, 21 show radio emission at levels of 4.5-240 sigma. From the detected sources, five sources show extended emission, including one source with three main components and one with two main components. The remaining 16 exhibit compact cores. In NGC4388, we find a jet-like 33 GHz continuum feature that appears to be oriented perpendicular to the H_2O-megamaser disk. Our spectral index analysis prefers a jet to radio core as the source of observed radio emission (index of 0.7 - 1.0 using the negative sign convention). A correlation analysis shows that the 33 GHz luminosities anti-correlates with the maximum rotation velocity of the galaxy. The hard X-ray and radio luminosities show stronger correlations with the maser disk's inner radii than with the maser disk's outer radii.

POSTER 20 - ***VLBA masers studies in a 10^5 $L_\odot$ star forming region IRAS 18360-0537***

Gang WU - Xinjiang Astronomical Observatory, CAS - China

Whether high-mass stars form mediated by disk/outflow system, in a similar way as low-mass stars form, remains a hot topic in the studies of high-mass star formation. We have observed a 10^5 $L_\odot$ high-mass young stellar object, IRAS 18360-0537, with VLA and SMA. These observations revealed a self-consistent bipolar outflow and potential accretion disk system. Because of extremely high resolution and easily penetrate to the high extinction region, VLBI observations are of great help in studies of high mass star forming regions and less contaminated by the envelope. For a better understanding of IRAS 18360-0537, we carried out VLBA obserrvations of OH, CH_3OH, and H_2O masers in IRAS 18360-0537 to investigate the immediate vicinity of the central protostar.

POSTER 21 - ***Exciting Discoveries in the HartRAO Maser Long-term Monitoring Programme***

Gordon MacLEOD - Hartebeesthoek Radio Astronomy Observatory - South Africa

We present the results of two sources, NGC 6334F and G351.78-0.54, from our long-term multi-transition maser monitoring programme. NGC 6334 F is a massive star-forming region in the Cat's Paw Nebula. We report a major flaring

event in 10 transitions in hydroxyl, water and methanol and are able to set its birthday on 1 January 2015 give or take 10 days. From variability, polarization, and pumping mechanism studies we suggest these masers are from a different area than the previously reported methanol maser positions. Analysis of historical data further suggests earlier flares occurred. G351.78-0.54 is another massive star-forming region in which we have 25 years of monitoring data. We present systemic blue and red-shifted velocities in various transitions suggestive of an expanding region. We propose upgrading our observing capabilities and collaborative observation programmes with other observatories to increase the number of maser sources studied.

POSTER 22 - ***Accurate OH maser positions in SPLASH***

Hai-Hua QIAO - Curtin University - Australia

Masers are important astrophysical objects which can be used to understand the chemical and physical environment of the interstellar medium (ISM). The hydroxyl radical (OH) was the first molecule discovered in the ISM and can produce strong stimulated spectral line emission (OH masers). Our research will measure accurate positions of OH masers based on the results from the Southern Parkes Large-Area Survey in Hydroxyl (SPLASH). SPLASH observed OH in four ground-state transitions across the inner Galactic plane (332 degrees $<$ l $<$ 10 degrees, |b| $<$ 2 degrees; 358 degrees $<$ l $<$ 4 degrees, 2 degrees $<$ b $<$ 6 degrees; in total 176 square degrees). The transitions show thermal emission, absorption or maser emission. We used the Australia Telescope Compact Array to accurately determine the positions of these OH masers. We then compare these positions with the Methanol Multibeam (MMB) survey, H2O Southern Galactic Plane Survey (HOPS), Red MSX Source, SIMBAD and the Galactic Legacy Infrared Mid-Plane Survey Extraordinaire maps to identify which kind of astrophysical object they are associated with. Comparing our results with surveys of other masers, e.g. the MMB survey for 6.7-GHz methanol masers and HOPS for 22-GHz water masers, we will construct a maser evolutionary sequence in star forming regions.

POSTER 23 - ***Cloud-Cloud Collision in the HII region RCW 36: Evidence for a high-mass star cluster formation***

Hidetoshi SANO - Nagoya University - Japan

Collision between two molecular clouds is one promising mechanism to form the high-mass stars. We present new CO observations toward the HII region RCW 36, containing a young stellar cluster with two O-type stars and an H_2O maser. We have revealed two molecular clouds lying at the velocities of $\sim$5.5 and $\sim$9 km/s. Both clouds are very likely to be physically associated with the stellar cluster, as verified by the good spatial correspondence among the two molecular clouds and the infrared filaments. This also supported by a high intensity ratio of CO J = 3-2 / 1-0 $>$ 0.6, indicating that the gas temperature is increased due to heating by the O-type stars. We propose that RCW 36 and its stellar cluster were formed by a collision between the two molecular clouds, with a velocity separation of 5 km/s. The velocity separation and complementary spatial distributions of the two clouds are in good agreement with observational signatures expected for high-mass star formation triggered by a cloud-cloud collision (e.g., Fukui et al. 2017 and the references therein). We also noted a displacement between the complementary spatial distributions of the two clouds, which we calculate to be 0.85 pc. We estimate the collisional timescale to be $\sim$0.2 Myr, which is roughly consistent with the stellar cluster age derived from the HR diagram, assuming a distance of 1.9 kpc.

POSTER 24 - ***Magnetic field generated by the extreme red supergiant VY CMa***

Hiroko SHINNAGA -Kagoshima University - Japan

Evolved stars experience high mass-loss rates forming thick circumstellar envelopes (CSEs). Since asymmetric geometries of CSEs are common, and with very complex structures for some cases, radiative pressure from the stars can explain only a small portion of the mass-loss processes; thus the essential driving mechanism is still unknown, particularly for high-mass stars. We report on magnetic field measurements associated with the well-known extreme red supergiant, VY Canis Majoris (VY CMa). We measured the linear and circular polarization of the SiO v = 0, J = 1-0 transition, using a sensitive radio interferometer. The measured magnetic field strengths turned out to be

very high, indicating that the magnetic field is a key element in understanding the stellar evolution of VY CMa as well as the dynamical and chemical evolution of the complex CSE of the star.

POSTER 25 - ***Peculiarities of maser data correlation / postcorrelation in Radioastron Mission***

Ivan LITOVCHENKO - Astro Space Center, Lebedev Physical Institute - Russia

In this poster we describe the main features of space-ground VLBI data processing of maser experiments in Radioastron project mission using ASC correlator. The new ASCFX software correlator has been developed in the Astro Space Center of Lebedev Physical Institute (Moscow, Russia). It has all the necessary functions to correlate all the data of the Radioastron Mission. On 01.07.2017, using the ASCFX correlator we correlated all 148 masers sessions that were observed by the Radioastron. Correlation on the space-ground bases was found in 41 sessions. Data Processing Center of the Astro Space Center has the unique data archive which stores all raw data that has being observed by the Radioastron Mission. Currently, it's about 2500 TB. This archive allows us to re-correlate any experiment of the project, if we have updated information about it. For maser experiments such information can be, for example, an improved orbit of Radioastron or different coordinates of bright maser spots. We discussed the main features and difficulties of calibration and postprocessing the masers experiments of Radioastron Mission on the example of two sources W3OH and OH043. Finally, preliminary results for the 6 observing sessions of these two sources are presented.

POSTER 26 - ***First galactic maser observations on Ventspils radio telescopes - instrumentation and data reduction***

Ivar SHMELD - VIRAC - Latvia

Ventspils International Radio Astronomy Centre (VIRAC) has two fully steerable Cassegren System 32 and 16 m radio telescopes (RT-32 and RT-16 respectively). After great renovation and modernization program during the years 2013 - 2016 the Galactic masers, particularly CH3OH research and monitoring program became one of the most important realized on these telescopes. Both telescopes are equipped with broadband cryogenic receivers covering 4.5-8.8 GHz frequency band. Digital backend consist form DBBC-2 (Digital Base Band Convertor developed by HAT-LAB, Italy) and FLEXBUFF (data storage system based on commercially available server system) are used for data digitalization and registration. A special program complex for spectral line data reduction and correction was developed and implemented. Developed automated observation system for both telescopes allows scheduling extensive maser monitoring programs in the parallel with other observations. First results of VIRAC Galactic maser observations are highlighted.

POSTER 27 - ***Time-dependent numerical modelling of hydroxyl masers***

Jabulani Paul MASWANGANYE - North-West University - South Africa

In 2003, Goedhart et al. reported the periodic variability in the methanol masers at 6.7- and 12.2-GHz, with a 246 day period. The periodic variability in methanol masers were further confirmed by 16 sources, to take the current total to 17. The origin of periodicity in methanol masers is yet to be confirmed. However, there are several hypotheses which try to explain the origin of the periodicity in the maser. These hypotheses argue that the periodicity in masers arises from the changes in either the dust temperature (Parfenov et al., 2014, Sobolev et al., 2007, Araya et al., 2010, Inayoshi et al., 2013) or seed photon flux (van der Walt, 2011, van der Walt et al., 2009, Maswanganye et al., 2015). To date, none of these hypotheses had been confirmed by observations. Also, some of the hypotheses do not explicitly predict the expected maser light curves. Thus, it can be asked if the time-dependent numerical modelling of masers can give an insight into what is likely to be the origin of periodicity in these masers? Although, hydroxyl masers are different species to methanol maser, but they are both radiatively pumped. Also, Goedhart et al., (Prep) found that hydroxyl masers show correlated variations with methanol masers in G9.62+0.19E. Therefore, in this investigation, the time-dependent numerically modelling of hydroxyl masers is conducted. We investigate different dust temperature variation profiles how they induce the maser brightness variability.

POSTER 28 - ***Interim Results of Simultaneous Time Monitoring of SiO and H_2O Masers in post-AGB star OH231.8+4.2 (= QX Pup)***

Jaeheon KIM - Shanghai Astronomical Observatory, CAS - China

We present the results from simultaneous monitoring observations of H_2O (22 GHz) and SiO J=1-0, 2-1, 3-2 maser lines (43, 86, 129 GHz) in post-AGB star OH231.8+4.2 (= QX Pup). This study has been carried out with 21-m radio telescopes of the Korean VLBI Network from 2009 to 2015. Depending on the transitions, 9-24 epochs of data were obtained. For total 13 transitions which observed, we focus mainly on 22 GHz H_2O and 43 GHz SiO v=1,2, J=1-0 maser lines. For SiO v=1, J=1-0, only 7 epochs out of 23 epochs were detected during our monitoring, showing averagely 0.13 Jy of peak flux. SiO v=2, J=1-0, however, were relatively common detected in 18 epochs, showing averagely 0.18 Jy of peak flux. H_2O maser was always detected in all epochs, showing 16 times stronger peak flux than SiO v=2, J=1-0 maser. The detected H_2O masers show mainly double-peaked line profiles with local small line structures nearby redshifted peaks. From the monitoring results, we found that the variations in the flux of SiO and H_2O masers correlate well with the optical light curve of the central star, QX Pup. The phase delay between the peak flux variations of SiO and H_2O masers and the light curve is 0.0-0.2 periods. We analyzed the properties of detected maser lines, and investigated its evolutionary state utilizing the full widths at zero power (FWZP). We also investigated the infrared properties, utilizing the 1.2-160 μm spectral energy distribution (SED) and IRAS LRS spectra.

POSTER 29 - ***Variability of water masers in evolved stars on the timescale of decades***

Jan BRAND - INAF - IRA - Italy

We present the results of 25 years of monitoring water masers in Mira variables and Red Supergiants with the Medicina 32-m and Effelsberg 100-m antennas. Malcolm Walmsley was one of the initiators of the collaboration that carried out this project. We show the power of a long monitoring period especially when complemented with occasional interferometric observations. As an example we present UHer, for which we have derived the 3-D distribution of the maser spots, and their lifetimes, from multi-epoch VLA-observations. The 'single-dish-only' observations provide evidence for variations on timescales of decades, which likely are connected to structural changes in the maser shells. Such variations include strong intensity flares lasting several months and systematic velocity gradients of maser components developing over years, as well as other secular variations which are superimposed on periodic variations following the stellar light variations.

POSTER 30 - ***New water maser source near HW3d in the massive star-forming region Cepheus A***

Jeoung-Sook KIM - National Astronomical Observatory of Japan - Japan

The VLBI observations of the water masers at 22 GHz can provide the proper motion of warm astrophysical gas near young stellar objects. Cepheus A is the second nearest high mass star-forming region after Orion. It is characterized by the presence of several phenomena such as a complex molecular outflow, multiple radio continuum sources, known as HW sources. The radio continuum and water maser emission have been detected toward HW2, HW3b and HW3d regions, and all of them are considered harboring young stellar objects. In particular, HW3b turned out that be a star-forming region by the 22 GHz water maser observations with VERA in 2007 (Chibuez et al 2012). In VLBI observations in 2014 with KaVA (combined array of Korean KVN and Japanese VERA facilities), we found an unexpected new maser feature that seems to be related to HW3d. The new maser feature in its peak was the brightest in Cepheus A and, furthermore, the proper motion of $\sim$5.3 mas/yr was faster than other regions. We would discuss about what makes the new maser feature, apart $\sim$700 mas from in HW3d.

POSTER 31 - ***Filamentary Flows and Clump-fed High-Mass Star Formation in a G22***

Jinghua YUAN - National Astronomical Observatories, CAS - China

The G22 cloud is a hub-filament system composed of four supercritical filaments. We have detected gradients along three filaments. A total mass infall rate of about 700 M_{sun} Myr^{-1} would double the hub mass in about three free-fall times. This suggest that most, if not all, of the masses of the central clumps C1 and C2 would have been accumulated

via large-scale filamentary flows. The most massive and densest clump C1 would be in global collapse with an infall velocity of 0.26 km/s and a mass infall rate of $5{\cdot}10^{-4}$ M_{sun} yr^{-1}, which is supported by the prevalent HCO+ (3-2) and ^{13}CO (3-2) blue profiles. A hot molecular core (SMA1) was revealed in clump C1 based on the SMA observations. At the center of SMA1, there is a massive protosta (MIR1) driving multipolar outflows which are associated with clusters of class I methanol masers. With a mass about 11-15 Msun, the protostar MIR1 may be still growing with an accretion rate of about $7{\cdot}10^{-5}$ M_{sun} yr^{-1}. Filamentary flows, clump-scale collapse, core-scale accretion coexist in G22, suggesting that pre-assembled mass reservoirs (i.e., high-mass starless cores) may not be prerequisite to form high-mass stars. In the high-mass star formation process, the central protostar, the core, and the clump can grow in mass simultaneously via core-fed/disk accretion, clump-fed accretion, and filamentary/cloud collapse.

POSTER 32 - ***SMA CO observations of two periodic methanol maser sources***

Johan VAN DER WALT - North West University - South Africa

We present ^{12}CO(2-1), ^{13}CO(2-1) and C^{18}O(2-1) maps obtained with the SMA of two periodic methanol maser sources, viz. G22.357+0.066 and G25.411+0.105. The light curve of the first of these two sources has the same flaring behaviour as the 12.2 GHz masers in G9.62+0.20E. For the second source the light curve of the periodic maser is similar to an |sin(x)| function. The aim of the observations is to investigate whether there are any obvious differences between the two high mass star forming regions that host periodic methanol masers with different light curves.

POSTER 33 - ***The Extensive Database of Astrophysical Maser Sources (eDAMS): the First Release on Circumstellar Maser Sources***

Jun-ichi NAKASHIMA - Ural Federal University - Russia

We introduce the Ural Federal University database of circumstellar maser sources (the UrFU database). The number of published catalogs of circumstellar maser sources so far has been relatively limited. In particular, the compilation work comprehensively including the three major maser species in evolved stars (i.e., SiO, H_2O, OH) has been practically limited only to the Benson's catalog, which was published more than a quarter of a century ago. For OH masers alone, there exists the University of Hamburg (UH) database, but there is no updated compilation work for H_2O and SiO masers. In order to utilize the information of masers in actual studies, it is highly desirable to have a database containing all the three main masers. We are currently constructing such a database in collaboration with UH. The information about the basic transition lines of the three major maser species has already been released on the Internet. At the moment of submission of this abstract, the information of 8134, 10011 and 8616 observations (4421, 5170 and 6198 objects) respectively on SiO, H_2O and OH masers have been collected. And the database includes the data newly released to public. In this presentation, we briefly summarize, (1) outline of the data collected, (2) overview of the user interface of the database web system, (3) possible applications utilizing the UrFU database, and (4) future development plans. The URL of the UrFU database: http://maserdb.ins.urfu.ru/.

POSTER 34 - ***Dynamics of jet/outflow driven by high-mass young stellar object revealed by KaVA 22 GHz water maser observations***

Jungha KIM - National Astronomical Observatory of Japan - Japan

We have started 22 GHz water maser observations as a part of four-year KaVA (KVN and VERA array) large program since 2016 to understand dynamical evolution of high mass young stellar objects (HM-YSOs). The general summary of our KaVA large program and the statistical results at 44 GHz will be presented by Kee-Tae, Kim and Koichiro, Sugiyama, respectively. Eventually, we are going to investigate the dynamics of jets/outflows from HM-YSOs by analyzing 3D velocity structure of maser features. In the first year, snap-shot imaging survey toward 25 HM-YSOs at 22 GHz has been carried out to check detectability and variability of maser features. Calibrated data toward 19 sources has been delivered so far. Water maser features were detected toward 16 sources among 19 with the detection rate of ∼84%. Spatial distributions of maser features for individual sources have been mapped. Based on the results from the first year project, we are going to select the targets for further monitoring observations. I will present statistical results at 22 GHz from the first year project of our KaVA large program.

POSTER 35 - ***Rapid burst of 6.7 GHz methanol maser in high mass star region G33.64-0.21***
Kārlis BĒRZIŅŠ - VIRAC - Latvia

We report another 6.7 GHz methanol maser burst in high mass star region G33.64-0.21 of its second component at v_{LSR}= 59.6 km s^{-1} in August 2016 as observed by VIRAC radio telescope RT-32 in Irbene, Latvia. Since its discovery already several bursts of the second spatial component of G33.64-0.21 have been reported previously (Szymczak et al. 2000; Fujisawa et al 2011; Fujisawa et al 2014). The maximum peak flux density of the source this time was measured to reach 343 Jy that is 13 times increase comparing to the lower level of 26 Jy of this component. This time observations of increasing phase of the burst were missed however the decay phase, lasting approximately 20 days, was intensively observed with one day intervals showing that the flux density was not dropping smoothly as expected in one time excitation model. The significant oscillations were discovered during decay phase indicating more complex burst mechanism that cannot be explained by a simple heating of the region. The spatial structure of the G33.64-0.21 is now thought to be well understood from its VLBI observations (Fujisawa et al 2011; Szymczak et al. 2017). In this poster we analyze available data trying to understand and put some limits on physical mechanisms causing this kind of rapid methanol maser flux density fluctuations on timescales of less than 24 hours. Now the source G33.64-0.21 has been included in list of regularly monitored objects by VIRAC RT-32 and/or RT-16.

POSTER 36 - ***6.7 GHz Methanol Masers Observation with Phased Hitachi and Takahagi***
Kazuhiro TAKEFUJI - NICT - Japan

For the sake of high-sensitivity 6.7 GHz methanol maser observations, we developed a new technology for coherently combining the two signals from the Hitachi 32 m radio telescope and the Takahagi 32 m radio telescope of the Japanese VLBI Network. Furthermore, we compared the SNRs of the 6.7 GHz maser spectra for two methods. One is a VLBI method and the other is the newly developed digital position switching, which is a similar technology to that used in noise-cancelling headphones. We report the progress of the development and the observation.

POSTER 37 - ***VERA single-dish observations***
Kazuyoshi SUNADA - National Astronomical Observatory of Japan - Japan

We will report the activities of the VERA single-dish observations. We are carrying out the single-dish observations with two purposes. First purpose is the monitoring observations of known H_2O maser sources. Because water maser emission shows time variability, it's important to monitor its intensity to progress the VERA observations effectively. Observations have been started since December 2015 at intervals of two months. Present monitoring list consists of 300 H_2O maser sources, which is composed of the sources proceeding with the VERA observations and the sources waiting the VERA observations. More than 100 sources were replaced by the others, because the H2O maser emissions of these sources were not detected for more than one year. The second purpose is the survey for new water maser sources. Since there are many H_2O maser sources which we could not detect their maser emission for a long time, it's also important to search new maser sources to increase VERA observation candidates. We used various catalogs, such as the AKARI-FIS Bright Source Catalogue, for our source selection. We are carrying out the survey observations at an interval between VLBI observations. We are successfully finding several new H_2O maser sources per a year. These new sources are added to the monitoring list and are continuing the monitoring observations.

POSTER 38 - ***Full polarization analysis of OH masers at 18-cm toward the W49 A star-forming region***
Kitiyanee ASANOK - NARIT - Thailand

W49 A is a star-forming region (SFR) found in the constellation of Aquila. It contains 3 active regions: W49 North (W49 N), W49 South West (W49 SW) and W49 South (W49 S). We present an analysis of these regions based on 2 epochs of 1.6-GHz OH masers (e)MERLIN observations obtained in full-polarization. The first epoch of observations was obtained in 2005 with MERLIN while the second epoch was obtained in 2013 with the e-MERLIN upgraded system. The magnetic field strengths deduced from Zeeman pairs splitting are found to be dynamically significant. The physical and polarimetric properties inferred from the 4 ground-state OH maser lines will be discussed.

POSTER 39 - ***Manifestations of the cyclotron maser effect in near-Earth space***

Liudmyla KOZAK - National Taras Shevchenko University of Kyiv - Ukraine

Maser effects are observed not only in the atmospheres of stars and laboratory equipment. We encounter them in the near-Earth space. The cyclotron maser effect determines the level of low-frequency electromagnetic radiation and regulates the number of charged high-energy particles in the given region. The propagation velocity of magnetohydrodynamic perturbations in the magnetosphere varies widely from hundreds to thousands of kilometers per second. This leads to the locking of magnetohydrodynamic waves in the system, the realization of normal or resonant modes, and the possibility of resonant pumping of energy into these modes. Ultralow-frequency (ULF) perturbations are hydromagnetic oscillations of a plasma with spatial scales comparable to the dimensions of the magnetosphere, and their parameters depend on the topology of the magnetic field of the system. Note that, the maser mechanism generates the ULF radiation in the radiation belt and it is obtained that the various dynamic emission spectra are the consequence of different modes of wave generation in this maser. Within the framework of the research, we obtain that the model of a radially inhomogeneous plasma cylinder adequately describes the ULF perturbations in the Earth's magnetosphere and the appearance of a fast magnetosonic wave in the magnetospheric plasma leads to the generation of AlfvÃ©n waves with a discrete spectrum. The work is done in the frame of the grant Az. 90 312 from the Volkswagen Foundation.

POSTER 40 - ***X-Ray Characteristics of Water Megamaser Galaxies***

Katharina LEITER - University of Würzburg - Germany

Water maser galaxies are a rare subclass of Active Galactic Nuclei (AGN). They play a key role in modern cosmology, providing a unique way to measure geometrical distances to galaxies within the Hubble flow. Modern megamaser observational programs have the goal to measure the Hubble parameter with an accuracy of 3% and to provide a constraint on the equation of state of dark energy. An increasing number of independent measurements of suitable water masers is providing the statistics necessary to decrease the uncertainties of such measurements. Studies at X-ray energies have the potential to yield important constraints on target-selection criteria for future maser surveys, increasing their detection rate. We have compiled the X-ray characteristic properties for a unique and homogeneous sample of Type 2 AGN with water megamaser activity observed by XMM-Newton and for a control sample of non-maser galaxies, both analyzed in a uniform way. A comparison of the luminosity distributions confirm previous results (from smaller and/or less systematic studies) that water maser galaxies appear more luminous than non-maser sources. In addition, the maser phenomenon goes along with more complex X-ray spectra, higher column densities and higher equivalent widths of the Fe Kα line. Both a sufficiently luminous X-ray source and a high absorbing column density in the line of sight towards that source are necessary prerequisites to favor the appearance of the water megamaser phenomenon in AGN.

POSTER 41 - ***VLA observations of a sample of low-brightness 6.7 GHz methanol masers***

Luca OLMI - INAF - OAArcetri - Italy

Olmi et al. (2014) conducted a survey for 6.7 GHz methanol masers with the Arecibo Telescope toward far infrared sources selected from the Hi-GAL catalog of massive cores. They reported a number of sources with weak 6.7 GHz methanol masers, possibly indicating regions in early stages of star formation. Here we describe the results of follow-up observations that were conducted with the Very Large Array (VLA) in New Mexico to characterize this new population of "weak" 6.7 GHz methanol masers.

POSTER 42 - ***Magnetic fields and radio emission processes in maser-emitting planetary nebulae***

Lucero USCANGA - University of Guanajuato - Mexico

We present polarimetric observations of the four ground-state transitions of OH, toward a sample of maser-emitting planetary nebulae (PNe) using the Australia Telescope Compact Array. This sample includes five confirmed OH-emitting PNe, two confirmed and one candidate H_2O-maser-emitting PNe. Polarimetric observations are important since may provide information of the magnetic field related to these sources. Maser-emitting PNe are extremely young

PNe and magnetic fields may be a key ingredient to understand the early evolution and shaping process of PNe. We also intend to study the physics of the ionized gas in several of these sources by analyzing their spectral energy distribution at radio frequencies.

POSTER 43 - ***Astrometric comparisons between maser emission and GAIA***

Luis Henry QUIROGA NUÑEZ - Leiden University / JIVE - The Netherlands

Radio astrometric measurements using Very Long Baseline Interferometry (VLBI) have provided distances and proper motions for maser-bearing young massive stars (Bar and Spiral Legacy survey -BeSSeL-: Reid et al. 2009,2014). The ongoing BAaDE (Bulge Asymmetries and Dynamical Evolution - BAaDE-: Sjouwerman et al. 2015) survey plans to obtain astrometric information of SiO masers stars located in the inner Galaxy and bulge. These stars are associated with evolved, mass-loosing stars. By overlapping optical (GAIA) and radio (BAaDE) surveys, we expect to obtain important clues on the intrinsic properties and population distribution of evolved stars. Moreover, a fundamental comparison of Galactic parameters obtained with Gaia and VLBI can be done using radio observations on different targets: young massive stars (BeSSeL) and AGB stars (BAaDE).

POSTER 44 - ***Monitoring and search for periodic methanol masers***

Mateusz OLECH - Nicolaus Copernicus University - Poland

A small group of 6.7 GHz methanol masers showing periodic variability has been identified in recent years. Several scenarios have been proposed to explain this phenomenon but none of them is satisfactory. An overview of the possible mechanisms of periodic variations will be presented in the context of results obtained during the monitoring and search for new periodic sources using the Torun 32 m radio telescope and EVN.

POSTER 45 - ***Simultaneity and Flux Bias between 43 and 86 GHz SiO Masers***

Michael STROH - University of New Mexico - USA

The Bulge Asymmetries and Dynamical Evolution (BAaDE) project aims to derive dynamics of the inner Galactic Bulge using line-of-sight velocities derived from over 20,000 red giants harboring SiO maser emission. We make use of both the VLA and ALMA in order to complete our ambitious survey throughout the galactic plane. Due to the different receivers available, we observe the 43 and 86 GHz SiO maser transitions with VLA and ALMA respectively. Therefore, our program assumes that sources with J=1-0 SiO masers will also harbor J=2-1 SiO masers, and vice versa. While this is supported by a previous study (Sjouwerman et al. 2003), some models using RADEX (Van der Tak et al. 2007) indicate that there may be ranges of density and temperatures where the J=1-0 transitions exhibit maser emission while the J=2-1 transitions will not. To test the robustness of our assumption, we used ATCA to observe nearly 100 of our brightest Galactic Bulge maser sources near simultaneously in both the 43 and 86 GHz SiO transitions. We present our observational results detailing the relative maser strengths from J=2-1 and J=1-0 SiO transitions. Since our original VLA and ALMA observations were observed to the same flux level, we can investigate whether effects like Malmquist biases exists between the two samples.

POSTER 46 - ***A Circumstellar Disk in IRAS 23151+5912?***

Miguel Angel TRINIDAD - University of Guanajuato - Mexico

We present radio continuum and water maser observations toward the high-mass star-forming region IRAS 23151+5912 from the VLA archive. We detected a continuum source, which seems to be a hypercompact HII region. In addition, we detecteted a water maser group about 4" south from the continuum source. We also present results of the analysis of six observations epochs of the water masers, which are tracing a like-arc structure. However, its kinematics is quite complex, since while one section of the structure seems to be moving away from one center, another section seems to be approaching.

POSTER 47 - ***Estimates of brightness temperatures for galactic maser sources observed by space interferometer "RadioAstron"***

Nadezhda N. SHAKHVOROSTOVA - ASC, Lebedev Physical Institute - Russia

Maser sources represent one of the main targets of RadioAstron science program. Ultra-high angular and high spectral resolutions provided by RadioAstron provide tight limits on the sizes of the most compact maser spots and estimates of their brightness temperatures. Current results of the survey data obtained in the RadioAstron maser observations are presented. Brightness temperatures and angular sizes for the spots in a number of maser sources are estimated. Very compact features with angular sizes of 20 to 60 angular microseconds are observed in star-forming regions. Corresponding linear sizes are about 5-10 million km. Estimates of brightness temperatures range from a few 10^{14} to several 10^{16} K.

POSTER 48 - ***Exploring the Nature of MMB Sources: A search for class I masers and their associated outflows***

Nichol CUNNINGHAM - National Radio Astronomy Observatory - USA

We will present the results from a class I 44 GHz methanol maser follow-up survey, observed with the MOPRA telescope, towards 272 sources from the Methanol Multi beam survey (MMB). We detect over half (57%) of the 6.7 GHz class II MMB maser sources have an associated class I 44 GHz methanol maser at a greater than 6 sigma detection level. It has been previously suggested that the collisionally excited class I maser emission is tracing the jet/outflow in massive star forming regions and may potentially trace an earlier evolutionary stage compared with emission from the radiatively pumped class II methanol maser that is likely being excited much closer to the central massive star. As part of the MOPRA follow-up observations, we simultaneously observed SiO emission which is a known tracer of shocks and outflows in massive star forming regions. Furthermore, we explore the evolutionary nature of these sources using data from the Herschel Hi-Gal and Glimpse surveys. We will show how the association of class I 44 GHz methanol maser emission is related to the presence of outflows and the evolutionary nature of the region towards a large sample of MMB sources.

POSTER 49 - ***Analysis of bipolar outflow parameters, magnetic fields and maser activity relationship in EGO sources***

Olga BAYANDINA - Astro Space Center, Lebedev Physical Institute - Russia

We explore a possible common pumping mechanism for class I methanol masers (cIMM) and the OH(1720) maser, for those cases where both masers are found near molecular outflows that might shock the interstellar gas and provide for collisional pumping of both molecular masers. The observations were carried out in 2013 toward 20 cIMM positions in EGOs, which are MYSO and outflows identified from the GLIMPSE survey by association with extended 4.5 μm emission. The JVLA was used in C configuration (synthesized beam 12") in the L frequency band in four OH lines. OH maser emission was detected in 10 sources; all in main OH lines. OH(1720) emission was detected in only one EGO G45.47+0.07, the strongest at 4.5 μm. In it, the separation between peak OH(1720) and OH(1665) maser features is 0.6"; between OH(1720) and cIMM is 6" (0.02 and 0.17 pc, respectively). The magnetic field strength is identified from Zeeman pairs in which the RCP and LCP components are coincident on the maps of maser spots and varies from about 0.6 to tens of mG for different objects. To check larger region around every EGO we re-observed these 10 using NRT (France) with a beam 3.5'x19'. The result for emission lines is the same, but half of the sources also show absorption at 1720 MHz. Constraints on the parameters of the bipolar outflows and physical conditions in the masering medium as well as on the type of interstellar shocks producing cIMM pumping but not OH(1720) in EGOs are discussed.

POSTER 50 - ***Remarkable global outburst of methanol maser in G24.33+0.14***

Pawel WOLAK - Torun Centre for Astronomy - Poland

A strong outburst of 6.7GHz methanol maser occurred in high-mass young stellar object G24.33+0.14 between November 2010 and January 2013. The target was observed with the Torun 32m radio telescope, as a part of long-term

monitoring programme. Almost all twelve spectral features ranging from 108 to 120 km s^{-1} varied synchronously with time delays of the minimum and maximum flux densities of about two weeks which indicates that the variability is caused by global changes in the pump rate. However, the maxima of two features with the highest relative amplitude of 40-60 are delayed by about 2.5 months and the features undergo essential transformation with a velocity drift of 0.23 km s^{-1} yr^{-1}. This suggests that the variability may be caused by changes in the maser path length due to large-scale gas motions. VLA data obtained shortly after the outburst suggest an outflow morphology of 6.7 GHz methanol maser emission that is consistent with the outflow shape observed in the SiO lines.

POSTER 51 - ***Statistical analysis of the physical properties of the 6.7 GHz methanol maser features based on VLBI data***

Rafał SARNIAK - Nicolaus Copernicus University - Poland

High mass stars play important role in Galactic evolution, and methanol masers are well known tracers of their formation. We present a study of the milliarcsecond structures of the 6.7 GHz methanol masers. Statistical analysis of features from a sample of 60 objects observed by EVN allows us to consider the possible interrelationships between the individual properties. We studied in detail the properties of the maser clouds and calculated the mean and median values of the projected size, velocity gradients, brightness temperature and power. Dependence between these values and total luminosity of pumping source is also considered.

POSTER 52 - ***Probing Early Phases of High Mass Stars with 6.7 GHz Methanol Masers***

Sonu Tabitha PAULSON - Indian Institute of Space Science and Techn. - India

Methanol masers at 6.7 GHz are the brightest of class II methanol masers and have been found exclusively towards massive star forming regions. These masers can thus be used as a unique tool to probe the early phases of massive star formation. Modelling spectral energy distributions (SEDs) of masers is one of the most effective methods to study the nature of massive star formation sites. We present here the SED studies of around 500 methanol masers chosen from the MMB catalogue, which falls in the Hi-GAL range ($|l|\leq 60°$, $|b|\leq 1°$). The masers are studied using the ATLASGAL, MIPSGAL and Hi-GAL data at wavelengths ranging from 24 - 870 micrometers. A single grey body component fit was used to model the cold dust emission whereas the emission from the warm dust is modelled by a black body. The clump properties such as isothermal mass, FIR luminosity and MIR luminosity were obtained using the best fit parameters of the SED fits. The clump masses range from few ten to 1000 $M_{\odot}$. The FIR luminosities of the sources associated with 6.7 GHz maser emission falls in the range 500-8920 $L_{\odot}$. We discuss the physical properties of the sources and explore the evolutionary stages of the sources having 6.7 GHz maser emission in the timeline of high mass star formation.

POSTER 53 - ***Transition of outflow from wind-like to collimated morphology in the massive star-forming region W75N***

Soon-Wook KIM - Korea Astronomy & Space Science Institute - Republic of Korea

W75N(B) is a massive star-forming region contains three maser sources of VLA1, VLA2 and VLA3 associated with massive young stellar objects at different evolutionary phases. We have performed a few VLBI observations of the 22 GHz water masers for last few years, and found several interesting features, which may provide important clues to understand the evolution of the massive young stellar objects. In 2007, we first found that the water maser distribution in VLA2 has been evolved from a wind-like to a more elongated, collimated morphology for eight years since 1999 (Kim et al. 2013). In 2012, the water maser distribution in VLA2 is still expanding along the direction parallel to the radio jet of VLA1. The magnetic field around VLA2 has been changed its orientation to the new direction of the major-axis of the wind-like structure, and is aligned with the magnetic field in VLA1 (Surcis et al. 2014). In 2014, the VLA observations support our previous VLBI observations. The radio continuum observations of VLA2 show that it is a thermal, collimated ionized wind and that it has evolved from a compact to an elongated one (Carrasco-Gonzalez et al. 2015). Recent VLBI observations would be introduced and discussed.

POSTER 54 - ***Periodic methanol masers and colliding wind binaries***

Stefanus P. VAN DEN HEEVER - Hartebeeshoek Radio Astronomy Observatory - South Africa

In the last few decades it has been firmly established that class II methanol masers are exclusively associated with high-mass star formation. Thus, they provide a valuable tool by which small scale structures in high-mass star formation can be studied. To date ∼1000 methanol maser sources have been observed. More recently, a long-term monitoring program discovered that some of these methanol masers show periodic/regular flaring behaviour. Several hypotheses have been proposed in the past to explain this behaviour. The hypothesis we consider is that of a colliding wind binary (CWB) system, in which the additional ionizing photons produced from the shocked gas of the colliding winds, causes an influence of the position of the ionization front (of the HII region). This influence at the ionization front in turn causes an increase in the electron density, and thus an increase in the radio free-free emission from that part of the ionization front which the maser "sees" and amplifies. A quasi-time-dependent model was constructed to include all of these aspects and it seems to describe the flare profile remarkably well.

POSTER 55 - ***LBA high resolution observations of the OH masers towards the massive star-forming region G351.417+0.645***

Thanapol CHANAPOTE - Khon Kaen University - Thailand

We present the results from the Australian Long Baseline Array (LBA) observation of the ground and excited state OH masers at high resolutions towards the massive star-forming region G351.417+0.645 in 2012. We obtain the most accurate spatial gradient magnetic fields at ground state transitions and can verify the reliability of magnetic field strengths measured from previous lower resolution observations. In comparison with previous LBA observations in 2001 at 6.0 GHz, we identified several matched Zeeman pairs. We found that the OH maser features have no significant change of magnetic field strengths and directions with small internal proper motions, implying quite stable physical conditions. Besides, we found that 1665- and 6035-MHz OH maser features reveal the same trend of reversal magnetic fields. Moreover, we also analyzed the physical conditions at different locations from the coincidence of different OH maser transitions based on current OH maser models.

POSTER 56 - ***Chemical differentiation in the inner envelope of a young high-mass protostar associated with Class II methanol maser emission***

Timea CSENGERI - Max-Planck Institut für Radioastronomie - Germany

The origin of the highest mass stars is still an enigma in modern astrophysics. Only massive clumps, at the onset of star formation, can reveal the initial conditions and shed light on the necessary physical processes leading to their formation. From the 870 micron ATLASGAL survey of the inner Galaxy, we identified the complete sample of infrared quiet massive clumps located closer than 5 kpc. We targeted this sample in the frame of the SPARKS project with ALMA, reaching the physical scales of individual collapsing envelopes of ∼1000 au. Our sample uncovers a significant sample of the so far known highest mass Class 0 like protostars. Here I will present ALMA observations of the immediate vicinity of a ∼15 solar mass protostar in its main accretion phase, associated with bright class II methanol maser emission, and discuss the chemical diversity of its massive envelope.

POSTER 57 - ***First simultaneous mapping of four 7 mm SiO maser lines using the new broad band VLBI System (OCTAVE-system)***

Tomoaki OYAMA - National Astronomical Observatory of Japan - Japan

We report simultaneous very long baseline interferometry (VLBI) mapping of 28 SiO v=1, 2, 3 and 29 SiO v=0 J=1-0 maser lines at the 7 mm band toward the semi-regular variable star, W Hydrae , using the new broad band VLBI system (OCTAVE system) newly equipped in the VLBI Exploration of Radio Astrometry (VERA) and in the 45 m telescope of the Nobeyama Radio Observatory. Although these masers were spatially resolved out, fortunately their compact maser spots were detected in 1000 km baselines of VERA. We found the locations of the v=3 maser emission which are unexpected from the currently proposed maser pumping models. Mapping of the 29 SiO maser line in W

Hydrae is the third result after those in WX Psc and R Leo. This paper shows the OCTAVE system (OCTAVE-Data Acquisition System and Software Correlator system) and scientific implication of simultaneous VLBI observations of multiple SiO maser lines as realized using the OCTAVE System.

POSTER 58 - ***Australian Long Baseline Array Observations of masers in G339.884-1.259***

Vasaant KRISHNAN - INAF - OAArcetri - Italy

G339.884-1.259 is a prominent source in the study of high-mass star formation. It is relatively nearby at a distance of 2.1 kpc, shows intense emission at 6.7 GHz of ∼1500 Jy - ranking amongst the strongest at this transition - and strong water maser emission of 39.2 Jy at 22 GHz. Interestingly, many rare methanol transitions (e.g. at 19.9, 37.7, 107.0 and 156.6 GHz) have been found to be coincident with G339.884-1.259, suggesting that it has an exceptional environment or might be going through a special or short-lived evolutionary phase. These factors contribute to distinguishing it in understanding high-mass star formation. My collaborators and I have been making multi-epoch VLBI observations of the methanol and water masers in G339.884-1.259 using the Australian Long Baseline Array (LBA). Over the course of several years, our sub-milliarcsecond precision measurements allow us to trace the proper motions of individual maser features in the plane of the sky. When combined with the direct line-of-sight radial velocity, these trace the 3D gas kinematics of the associated high-mass star formation region. I will be presenting the first results from our analysis. The proper motions of the methanol 6.7 GHz methanol masers in G339.884-1.259 will be overlayed with 8 GHz continuum emission and recent 22 GHz water maser observations. We are using these measurements to dissect the dynamical accretion and outflow processes associated with massive star formation in this source..

POSTER 59 - ***Star formation in the extreme outer Galaxy***

Yan SUN - Purple Mountain Observatory, CAS - China

The Extreme Outer Galaxy(EOG) cloud not only delineates the spiral structure and warping of our Galaxy, but it also serves as an excellent target for studying the star-formation process that is very different from that of the solar neighborhood. So far, more than 200 EOG clouds were newly detected by Sun et al. (2015, 2017). Although EOG clouds may have low-density, star formation did occur in the extreme environment. Using Effelsberg 100-m, we have carried out water maser survey towards the EOG clouds, which resulted in 4 maser detections, three of them are new detections(02/2016). Using IRAM 30-m, we have achieved J=2-1 CO/^{13}CO/C^{18}O maps for the EOG clouds(03/2017). We also did pointing observation toward six clouds, more than four dense gas tracers were detected in each clouds.

POSTER 60 - ***Triggered formation of O stars and excitation of masers in colliding gas flows in two starbursts NGC6334 and R136***

Yasao FUKUI - Nagoya University - Japan

NGC6334 and R136 are two outstanding starbursts in the Local Group, where numerous O/early B stars are forming. We found evidence for colliding gas flows with relative velocity of more than 12 - 50 km s^{-1} in the two regions (Fukui et al. 2017a PASJ,69,51; 2017b, arXiv170605771). It is likely that the starbursts were triggered by colliding supersonic gas flows with timescale of 0.1-1 Myrs. It is shown by MHD simulations of colliding flows that such supersonic collisions very efficiently compress gas into high density and create physical conditions which favor high-mass star formation (Inoue and Fukui 2013 ApJ,774,31). Very young stars in these starbursts are known to harbor H_2O and OH maser spots. Comparisons between the maser spots and the colliding flows revealed a tight kinematical relationship between masers and colliding flows, suggesting that the proposed collision compressed gas to form maser spots. In this contribution, we also present comparison of H_2O/OH/methanol masers with colliding flows in other ∼30 O star forming regions possibly triggered by cloud-cloud collision, and discuss a role of colliding flows in exciting maser emission.

POSTER 61 - ***Mapping the local Milky Way***

Ye XU - Purple Mountain Observatory, CAS - China

The nature of the spiral structure of the Milky Way has long been debated. Only in the last decade have astronomers

been able to accurately measure distances to a substantial number of high mass star forming regions, the classic tracers of spiral structure in galaxies. We will talk about the recent parallax results around the local area, which shows the Local arm is larger than previously thought, and both its pitch angle and star formation rate are comparable to those of the Galaxy's major spiral arms such as Sagittarius and Perseus.

POSTER 62 - ***Intermittent Mass Blowout of the Red Supergiant S Per***

Yoshiharu ASAKI - National Astronomical Observatory of Japan - Japan

We report high spatial resolution images of single epoch three SiO maser transitions and one water maser transitions of the single epoch VLBI observation for S Per. Simultaneous observation of the masers claim that the SiO masers are spatially distributed in the central 100 AU region surrounded by the 400 AU water maser distribution. The SiO masers forms a torus structure with the diameter whose shape resembles to a spatial distribution of much larger long-lived water masers with the life times of longer than 10 years. From the long period visual light curve, S Per has repeated active and quenched pulsation phases by turn for several decades. It is considered that S Per has had intermittent mass blowout repeatedly when the pulsation is active for several years. Because the star has experienced the time interval of several years between the active pulsation phases, S Per's ejected circumstellar envelops does not collide to the previously ejected gas, so that the gas physical condition to radiate the water maser can be kept for much longer than the lower mass counterparts.

POSTER 63 - ***KVN imaging results for the H_2O and SiO masers of the evolved stars***

Youngjoo YUN - Korea Astronomy & Space science Institute - Republic of Korea

We present the results of the simultaneous observations for the H_2O and SiO masers emitted from the circumstellar envelopes (CSEs) of the evolved stars. Korean VLBI Network (KVN) has observed the stellar masers at four frequency-bands (K, Q, W and D bands) simultaneously since August 2014. In order to find out the spatial distributions of the H_2O and SiO masers around the evolved stars, we use the source frequency phase referencing (SFPR) method which can give us the astrometric informations of the maser sources. The relative spatial distributions between the H_2O and SiO masers are precisely determined from the SFPR method, which are crucial to investigate the physical links between the inner and outer parts of the CSEs of the evolved stars. The temporal variabilities of not only the spatial distribution but also the intensity of the maser spots are also obtained from our multi-epoch observations, which enable us to trace the physical characteristics of the CSEs along the stellar phase. From our results, the multi-frequency observation of KVN is proved to be powerful to investigate the characteristics of the evolutionary process of the evolved stars relating to the maser pumping mechanism.

POSTER 64 - ***The bursting variability of 6.7 GHz methanol maser of G33.641-0.228***

Yuta KOJIMA - Yamaguchi University - Japan

The 6.7 GHz methanol maser of G33.641-0.228 was first reported by Szymczak et al. (2000). It is reported by Fujisawa et al. (2012, 2014) that the spectral component at V_{lsr}= 59.6 km/s exhibits fast variability. A daily monitoring observation shows that this spectral component increases several times per day for the observations in 2009, and decaying on a slightly longer timescale after a sharp increase. The timescale of the burst is the shortest among the variability of the all masers known so far. In order to investigate the fine structure of the burst, we conducted a total of 469 days observations from 2014 to 2015. When burst occurred, observations were made several times a day so that to investigate the short-term variabilities. As a result, we found eleven bursts, and observed that flux density reaches more than seven times per day in the largest burst. Moreover, at the decay phase of the largest burst, the flux density repeatedly increased and decreased rapidly, and its time scale was as short as e-folding time of 0.24 d. Since these characteristics of the burst similar to the solar radio burst, we propose a burst model as follows; energy accumulated by the magnetic field on the surface of the young stellar object is released in a short time, and the radiation generated from this energy release is maser-amplified. According to this model, the maser emission might be circularly polarized, so we are analyzing the variability focusing on the circular polarization.

POSTER 65 - ***H_2O maser observation using 26-meter Nanshan Radio Telescope of XAO***

Yuxin HE - Xinjiang Astronomical Observatory, CAS - China

Interstellar H_2O masers are very abundant in the Milky Way, and they are reliable tracers of high-mass star formation regions within the Milky Way. Their strong intensity and small apparent size make H_2O masers as a good probe of the dynamics and physical conditions within star formation regions. In the past few years, we have performed a 22 GHz H_2O maser survey towards BGPS sources using the 25-meter NanShan Radio Telescope (NSRT) of Xinjiang Astronomical Observatory (XAO), and detected more than one hundred masers. Our aim is to study star formation activities associated with these sources, as well as search for any correlations that may exist between 22 GHz H_2O masers and the evolutionary stage of high-mass star formation regions (Xi et al. 2015, 2016). The NSRT has been upgraded and with the effective diameter of 26 meter now. Next month, we are planning to do H_2O maser survey in single-point mode towards 481 molecular clouds identified by Du et al. (2016), of which 457 probably belong to the Outer arm. Next, molecular clouds with H_2O maser will be used to delineate the Outer arm through VLBI observation using the trigonometric parallax method.