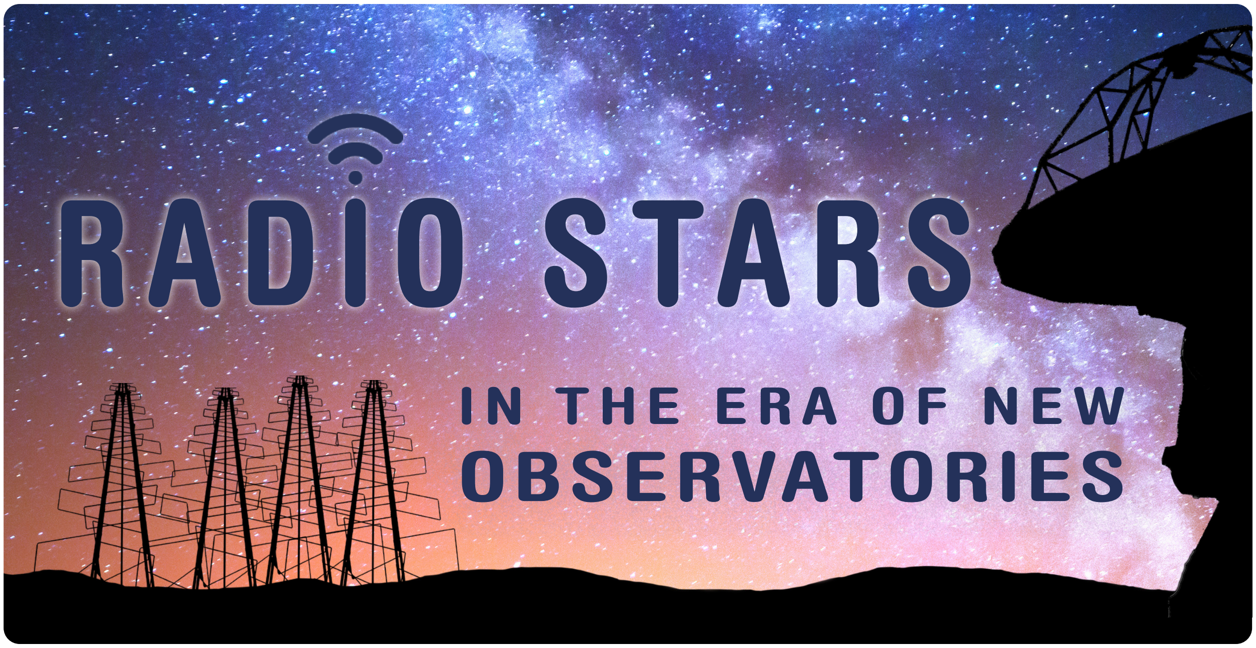

ABSTRACT AND PROGRAM BOOKLET

APRIL 17–19, 2024

MIT HAYSTACK OBSERVATORY
WESTFORD, MASSACHUSETTS, USA

Conference Location:
Massachusetts Institute of Technology Haystack Observatory
99 Millstone Road
Westford, Massachusetts, USA 01886
Main phone number: 1-617-715-5400
Meeting web site: `https://www.haystack.mit.edu/radio-stars-2024`

Scientific Organizing Committee:
Richard Ignace (East Tennessee State University, USA)
Lynn Matthews (MIT Haystack Observatory, USA, Chair)
Michael Rupen (National Research Council, Canada)
Loránt Sjouwerman (National Radio Astronomy Observatory, USA)
Stephen White (Air Force Research Laboratory, USA)

Local Organizing Committee:
Heidi Johnson (MIT Haystack Observatory)
Nancy Wolfe Kotary (MIT Haystack Observatory)
Lynn Matthews (MIT Haystack Observatory)
Dianne Tonnelli (MIT Haystack Observatory)
John Tsai (MIT Haystack Observatory)

Acknowledgments:
The Organizers gratefully acknowledge financial support for the Radio Stars workshop through a grant from the National Science Foundation.

Local Information

Welcome to MIT Haystack Observatory. Here is some information that you may find useful during your visit.

Site Access Information: The gates at the entrance to Haystack Observatory are open from 7:00am through 5:15pm Monday through Friday. At all other times, a key card or access code is required. If for some reason you require access to the Observatory outside of normal hours, you may contact the Lincoln Laboratory guard using the phone available at the gate (extension 5612).

Internet Service: Wireless internet is available throughout the Observatory. Visitors may sign in either via "eduroam" or the "MIT GUEST" network. For "MIT GUEST", an initial registration step is required, during which an access code will be sent to the user's cell phone. Visitors without cellular service may instead generate a sponsored access request by entering the email of IT staff member John Tsai (johntsai@mit.edu).

Health Precautions: Masking during the meeting is encouraged but not required. A supply of high-quality masks will be available at the front desk and in the main entranceway to the Observatory.

Emergency Numbers: The Haystack front desk may be reached between 8:00am and 5:00pm at 617-715-5400. For urgent questions outside normal business hours, LOC chair Lynn Matthews may be reached by phone or text at 617-715-5594. *In case of a serious emergency, dial 911 from any phone.*

Code of Conduct: MIT Haystack Observatory is committed to maintaining a respectful, welcoming community and an environment that is free from harassment. All meeting participants agree to follow MIT's policies regarding responsible and ethical conduct, including the guidelines for personal conduct as described here: `http://conduct.mit.edu/relations-and-responsibilities`. Meeting participants with any concerns about harassment or violations of MIT's Code of Conduct may contact a member of the LOC in person or via email (radiostars3-loc@mit.edu), or else may contact one of the MIT resources list here: `https://idhr.mit.edu/submitincidentreport`.

Hiking Trails: The 1300 acre Haystack campus contains several miles of wooded hiking trails. Trail guides are available at the front desk. However, we urge anyone going into the woods to take along a cell phone. After being in the woods or grassy areas, it is also important to carefully check skin and clothing for deer ticks. Deer ticks (which can be less than one mm across) are capable of transmitting Lyme disease, a potentially serious bacterial illness (`http://www.cdc.gov/lyme/index.html`). Symptoms may include chills, fever, muscle aches, and/or a characteristic "bulls-eye" rash. Prompt removal of ticks in most cases prevents transmission of Lyme-causing bacteria. The risk of Lyme disease remains present in Massachusetts year-round.

Registered Participants

Carlos Ayala (Caltech, USA)
cayala@caltech.edu

Paul Barrett (The George Washington University, USA)
pebarrett@gwu.edu

Anna Bartkiewicz (Torun Institute of Astronomy, Poland)
annan@astro.umk.pl

Tony Beasley (National Radio Astronomy Observatory, USA)
tbeasley@nrao.edu

Rajorshi Bhattacharya (University of New Mexico, USA)
rbhattacharya1995@unm.edu

Emily Biermann (University of Pittsburgh, USA)
emily.biermann@pitt.edu

Sanne Bloot (ASTRON, The Netherlands)
bloot@astron.nl

Behzad Bojnordiarbab (Chalmers University of Technology, Sweden)
bojnordi@chalmers.se

Paul Boven (JIVE, The Netherlands)
boven@jive.eu

Andrew Burkhardt (Worcester State University, USA)
aburkhardt@worcester.edu

Joseph Callingham (ASTRON/Leiden University, The Netherlands)
callingham@astron.nl

Laura Chomiuk (Michigan State University, USA)
chomiukl@msu.edu

Juan Bautista Climent (Universitat de Valencia, Spain)
cliojuan@uv.es

Cristina-Maria Cordun (ASTRON, The Netherlands)
cordun@astron.nl

Barnali Das (CSIRO Space and Astronomy, Australia)
Barnali.Das@csiro.au

Ivey Davis (Caltech, USA)
idavis@caltech.edu

Dillon Dong (National Radio Astronomy Observatory, USA)
ddong@nrao.edu

Laura Driessen (University of Sydney, Australia)
laura.driessen@sydney.edu.au

Jan Forbrich (University of Hertfordshire, United Kingdom)
j.forbrich@herts.ac.uk

Walter Golay (Center for Astrophysics | Harvard & Smithsonian, USA)
wgolay@cfa.harvard.edu

Carl Gottlieb (Center for Astrophysics | Harvard & Smithsonian, USA)
cgottlieb@cfa.harvard.edu

Alex Griswold (Alex Griswold Productions, USA)
grisbiz@gmail.com

Jose Carlos Guirado (Universidad de Valencia, Spain)
guirado@uv.es

Richard Ignace (East Tennessee State University, USA)
ignace@etsu.edu

Devojyoti Kansabanik (National Centre for Radio Astrophysics, Tata Institute of Fundamental Research, India)
devojyoti96@gmail.com

Melodie Kao (Lowell Observatory, USA)
mkao@lowell.edu

Robert Kavanagh (ASTRON, The Netherlands)
kavanagh@astron.nl

Mary Knapp (MIT Haystack Observatory, USA
mknapp@mit.edu

David Konijn (ASTRON, The Netherlands)
konijn@astron.nl

Nancy Kotary (MIT Haystack Observatory)
nwk@mit.edu

Megan Lewis (Leiden Observatory, The Netherlands)
meollewis@gmail.com

Justin Linford (National Radio Astronomy Observatory, USA)
jlinford@nrao.edu

Jing-Ze Ma (Max Planck Institute for Astrophysics, Germany)
jingze@mpa-garching.mpg.de

Lynn Matthews (MIT Haystack Observatory, USA)
lmatthew@mit.edu

Brett McGuire (MIT, USA)
brettmc@mit.edu

Shazrene Mohamed (University of Virginia, USA)
shazrene@virginia.edu

Isabella Molina (Michigan State University, USA)
molinai1@msu.edu

Surajit Mondal (New Jersey Institute of Technology, USA)
surajit.mondal@njit.edu

Arielle Moullet (National Radio Astronomy Observatory, USA)
amoullet@nrao.edu

Tara Murphy (University of Sydney, Australia)
tara.murphy@sydney.edu.au

Robert Mutel (University of Iowa, USA)
robert-mutel@uiowa.edu

Divya Oberoi (National Centre for Radio Astrophysics, India)
div@ncra.tifr.res.in

Jazmín Ordóñez-Toro (Instituto de Radioastronomía y Astrofísica, UNAM, Mexico)
n.ordonez@irya.unam.mx

Kevin Ortiz Ceballos (Center for Astrophysics | Harvard & Smithsonian, USA)
kortizceballos@cfa.harvard.edu

Gisela Ortiz-Léon (Instituto Nacional de Astrofísica, Optica y Electronica. Mexico)
gortiz@inaoep.mx

Eli Pattie (Texas Tech University, USA)
eli.pattie@ttu.edu

Sonu Tabitha Paulson (Tata Institute of Fundamental Research, India)
sonu.tabitha@gmail.com

Ylva Pihlström (University of New Mexico, USA)
ylva@unm.edu

Emil Polisensky (Naval Research Laboratory, USA)
emil.polisensky@nrl.navy.mil

Anita M. S. Richards (JBCA, University of Manchester, United Kingdom)
a.m.s.richards@manchester.ac.uk

Kovi Rose (University of Sydney, Australia)
kovi.rose@sydney.edu.au

Michael Rupen (NRC, Canada)
Michael.Rupen@nrc-cnrc.gc.ca

Loránt Sjouwerman (National Radio Astronomy Observatory, USA)
lsjouwer@nrao.edu

Chris Tandoi (University of Illinois Urbana-Champaign, USA)
ctandoi2@illinois.edu

Jake Turner (Cornell University, USA)
jaketurner@cornell.edu

Grazia Umana (INAF Osservatorio Astrofisico di Catania, Italy)
grazia.umana@inaf.it

Jakob van den Eijnden (University of Warwick, United Kingdom)
jakob.van-den-eijnden@warwick.ac.uk

Harish Vedantham (Netherlands Institute for Radio Astronomy, The Netherlands)
vedantham@astron.nl

Rachel Weller (The University of New Mexico, USA)
rweller1@unm.edu

Stephen White (Air Force Research Lab, USA)
smwhitemd@gmail.com

Montana Williams (New Mexico Tech, USA)
mnwilliams27@gmail.com

Timothy Wing Hei Yiu (ASTRON, The Netherlands)
yiu@astron.nl

Vanessa Yanza Lopez (Universidad Nacional Autonoma de Mexico, Mexico)
v.yanza@irya.unam.mx

Radio Stars in the Era of New Observatories

Final Program

Wednesday, April 17

8:30-9:00 Coffee/Tea and Registration

I. Setting the Stage
Chair: Robert Mutel

9:00-9:05 Welcome
Phil Erickson, MIT Haystack Director

9:05-9:20 Logistics/Objectives of the Workshop
Lynn Matthews

9:20-10:05 Prospects for Stellar Astronomy with Future Radio/(Sub)millimeter Facilities *(Invited)*
Grazia Umana

Poster Highlights (Part 1)
Chair: Richard Ignace

10:05-10:25 Poster Flash Presentations
Poster authors, Group 1

10:25-10:55 COFFEE/POSTERS

II. Circumstellar Chemistry
Chair: Anita Richards

10:55-11:35 Astrochemistry of Circumstellar Environments *(Invited)*
Brett McGuire

11:35-11:55 ATOMIUM: ALMA Tracing the origins of molecules in dust forming oxygen rich M-type stars
Carl Gottlieb

11:55-12:15 Stellar Studies with ALMA's Wideband Sensitivity Upgrade
Arielle Moullet

12:15-1:15 LUNCH

12:55-1:10 (Optional) Tour of the Haystack 37-m Antenna

led by Jens Kauffmann

III. Stellar Interactions and Environments

Chair: Dillon Dong

1:15-1:45 Hydrodynamic Simulations as a Tool for Understanding Circumstellar Environments and Stellar Interaction *(Invited)*

Shazrene Mohamed

1:45-2:05 Unveiling runaway massive star bow shocks with current and future radio observatories

Jakob van den Eijnden

2:05-2:25 The bow shock at the center of NGC 6334A with deep VLA observations. Is It a colliding wind region or a bow shock of a runaway star?

Vanessa Yanza Lopez

IV. Evolved Star Atmospheres

Chair: Ylva Pihlström

2:25-2:45 When is a photosphere not a photosphere? Radio continuum and maser case studies of O-rich AGB/RSG

Anita Richards

2:45-3:05 Synthetic ALMA observations of large-scale convection in 3D simulations of Red Supergiants

Jing-Ze Ma

Poster Highlights (Part 2)

Chair: Richard Ignace

3:05-3:25 Poster Flash Presentations

Poster authors, Group 2

3:25-3:55 COFFEE/POSTERS

V. Stellar Masers as Tools for Galactic Science and Stellar Astrophysics

Chair: Loránt Sjouwerman

3:55-4:25 Studying Stellar Evolution and Mass Loss with Masers *(Invited)*

Anna Bartkiewicz

4:25-4:45 SiO masers in Galactic Miras: the intersection of BAaDE and OGLE

Megan Lewis

4:45-5:05 Exploring SiO Maser Dynamics in Thin-Shelled Mira Stars: VLBI Follow-up and Calibration Strategies

Ylva Pihlström

END OF DAY 1

Thursday, April 18

8:30-9:00 Coffee/Tea

VI. Radio Stars with the Highest Angular Resolutions

Chair: Justin Linford

9:00-9:30 VLBI Astrometry as a Tool for Stellar Astrophysics *(Invited)*
Gisela Ortiz-León

9:30-9:50 Timelapse VLBI imaging of the Close Active Binary HR 1099
Walter Golay

9:50-10:10 Pushing for higher precision VLBI astrometry of radio stars
Paul Boven

10:10-10:30 Exploring the radio emission of Ultracool Dwarfs with VLBI
Juan Bautista Climent Oliver

10:30-11:00 COFFEE/POSTERS

VII. The Sun as a Radio Star

Chair: Stephen White

11:00-11:40 Of Ripples and Roars : Progress and Promise in Low Frequency Radio Solar Physics *(Invited)*
Divya Oberoi

11:40-12:00 Robust Detection of Linearly Polarized Emission from Meterwave Solar Emission: Questioning the Conventional Assumptions
Devojyoti Kansabanik

12:00-12:20 Using radio observations to constrain magnetic fields in the CME plasma
Surajit Mondal

12:20-1:30 LUNCH

VIII. Space and Space Weather

Chair: Melodie Kao

1:30-2:00 Solar and Stellar Radio Emission from Space *(Invited)*
Mary Knapp

2:00-2:20 Space Weather Around Young Suns (SWAYS): A dedicated system for radio and optical monitoring of the space weather of solar-type stars
Ivey Davis

2:20-2:40 Adventures of Young Radio Stars: intense radio outbursts, X-ray megaflares, and a novel VLBI search for ensuing coronal mass ejections

Jan Forbrich

2:40-3:00 Radio search for extrasolar coronal mass ejections and energetic particle events

David Konijn

3:00-3:30 COFFEE/POSTERS

IX. Ultracool Dwarfs

Chair: Jose Carlos Guirado

3:30-4:00 Radio Emission as Tool for Studies of Ultracool Dwarfs and Star-Planet Interactions *(Invited)*

Melodie Kao

4:00-4:20 Stellar mass loss through a low-frequency lens

Sanne Bloot

4:20-4:40 Search for a spectral cut-off and periodic signal from a radio brown dwarf binary

Timothy Wing Hei Yiu

4:40-5:00 Investigating exoplanet magnetospheres through radio transit observations

Jake Turner

5:00-5:15 Discussion/Announcements

5:15-6:00 Wine/Beer Reception (Haystack Observatory Lobby)

6:00-7:30 Workshop Banquet (New England Clam Bake at Haystack Observatory)

END OF DAY 2

Friday, April 19

8:30-9:00 Coffee/Tea

X. Radio Emission from Hot Stars

Chair: Harish Vedantham

9:00-9:30 Radio Emission from Magnetic Massive Stars *(Invited)*

Barnali Das

9:30-9:50 Unveiling Elusive Radio Flares in Hot Magnetic OBA Stars with the VLITE Commensal Sky Survey

Emil Polisensky

9:50-10:10 Modeling Long-Wavelength Thermal Emissions from Non-Spherical Circumstellar Media: Applications to structured envelopes of hot massive stars

Richard Ignace

XI. Radio Star Surveys

Chair: Joe Callingham

10:10-10:50 The wide diversity of radio supernovae *(Invited)*

Dillon Dong

10:50-11:15 COFFEE/POSTERS

XI. Radio Star Surveys (cont.)

Chair: Joe Callingham

11:15-11:35 Millimeter-wave Flaring Stars from the South Pole Telescope

Chris Tandoi

11:35-11:55 Understanding the radio stars population with ASKAP, on the path to the SKA

Tara Murphy

11:55-12:15 The Sydney Radio Star Catalogue: a new catalogue of radio stars

Laura Driessen

12:15-1:00 LUNCH

XII. Stellar Explosions

Chair: Michael Rupen

1:00-1:40 Physical Drivers and Radio Signatures of the Diversity of Nova Eruptions *(Invited)*

Laura Chomiuk

1:40-2:00 The Symbiotic Recurrent Nova V745 Sco at Radio Wavelengths

Isabella Molina

2:00-2:20 VLBA Images of the Fastest Nova V1674 Her

Montana Williams

XIII. Looking Back and Looking Ahead

Chair: Michael Rupen

2:20-3:00 Summary and Perspectives *(Invited)*

Robert Mutel

END OF WORKSHOP

Radio Stars in the Era of New Observatories

An MIT Haystack Observatory Conference

April 17–19, 2024

Program Abstracts

Poster Presentations

(in alphabetical order by first author)

Carlos Ayala*
Caltech

Stellar Radio Transients in the VLA Sky Survey

We present results from the largest non-targeted search for radio-emitting stars to date, spanning two epochs of the 33,885 deg^2 Very Large Array Sky Survey (VLASS) to a depth of ∼0.9 mJy. Our search uses the fact that stars tend to exhibit much faster and strong variability than AGN in the radio to separate stars from background sources. The 80 sources in our sample are selected as Galactic *transients*: radio point sources detected in VLASS Epoch 2, not detected in VLASS Epoch 1, and spatially associated with objects of significant parallax in *Gaia* Data Release 3. These Galactic transients have 3 GHz luminosities in the range 10^{14} - 10^{19} erg s^{-1} Hz^{-1} and are primarily emitted by 3 classes of stars: tight binaries ($n = 43$), pre-main sequence (PMS) stars ($n = 23$), and M dwarfs ($n = 6$). The remaining transients are from 5 unclassified stars, 1 magnetic chemically peculiar star, 1 low-mass X-ray binary, and 1 recurrent nova. Using TESS lightcurves and archival ROSAT observations, we find that the vast majority of the stars, regardless of classification, are rapidly rotating and X-ray luminous, suggesting that 3 GHz stellar radio transients are primarily due to magnetic activity from strong fields amplified by rapid rotation. Based on our sample, we infer a luminosity function and duty cycle for each of the 3 classes. Our results suggest that variability will be an efficient means of identifying large samples of radio stars in upcoming radio surveys.

* *Co-authors:* Dillon Dong, Gregg Hallinan, Casey Law, Yuping Huang, and Ivey Davis

Paul Barrett*
The George Washington University

Submillimeter observations of the magnetic cataclysmic variable AR Sco

AR Sco, the so called white dwarf pulsar, contains a rapidly rotating magnetic white dwarf ($P_{\rm spin}$ = 117.0564 s) accreting from a cool, red dwarf companion in a 3.56 hour orbit. It is a strong radio source ($\sim$ tens mJy) with an inverted spectral index between $1 - 1000$ GHz that is indicative of synchrotron emission. This paper presents the first submillimeter observations of AR Sco using the Submillimeter Array (SMA), helping to fill a critical gap in the spectral energy distribution between 10 and 600 GHz. The average flux densities at 220 and 354 GHz are 114 and 86 mJy, respectively. The lower than expected flux density at 354 GHz suggests a break in the synchrotron emission at about 200 GHz. A periodogram analysis of the 220 GHz observations shows a modulation with an amplitude of $\approx 6\%$ at a period of 58.5595 s or about twice the spin frequency of the white dwarf. This implies that the synchrotron emission arises from interactions of the accreted matter with the WD's magnetic dipole and not from the photosphere of the donor star, which would be modulated at twice the beat frequency. We model the radio emission using an assemble of slow-cooling synchrotron models and find that the observations constrain the WD to have a moderate magnetic moment ($\sim 10^{33}$ G cm^3), challenging the assertion of a strong magnetic moment ($\sim 10^{35}$ G cm^3) based on its spin-down power. A weak magnetic moment avoids the problem of how the WD spun-up to such a rapid rotation rate and then acquired a very strong magnetic field. We conclude that AR Sco is a *magnetic propeller* like AE Aqr.

**Co-Author:* Mark Gurwell (Center for Astrophysics | Harvard & Smithsonian)

Rajorshi Bhattacharya*
University of New Mexico

Evolved Stars: Distance estimates using infrared data and Supervised Machine Learning

The Bulge Asymmetries and Dynamical Evolution (BAaDE) radio-wavelength survey aims to present a comprehensive study of the inner regions of the Galaxy to improve our understanding of Galactic structure and dynamics, with a focus on the bulge stellar population distribution and age. The BAaDE survey consists of 28,062 infrared color-selected red giant stars, the majority of which are of Mira-type and lie on the Asymptotic Giant Branch (AGB). To date, approximately 10,000 of these stars have measured line-of-sight velocities determined from SiO maser lines. To optimize how these velocities are incorporated into dynamical models, and to allow any existing spatial separation between populations to be distinguished, 3D positions are desirable. Due to the sizeable AGB sample in our survey, we explore methods which can be consistently be applied to any AGB star within the full sample. We will first discuss an approach using distance-calibrated infrared (IR) Spectral Energy Distribution (SED) templates. We will then extend the discussion into how by applying Supervised Machine Learning on large astronomical datasets, we can successfully regress/classify different parameters, for example, distances. To test the accuracy of our machine learning models we also show results from their application on the BAaDE survey.

* *Co-authors:* Ylva Pihlström, Loránt Sjouwerman

Emily Biermann*
University of Pittsburgh

CMB Surveys as Transient Detectors

Due to their large sky area and high sensitivity, cosmic microwave surveys (CMB) are uniquely positioned to perform blind transient searches of the millimeter sky. Recent analyses of these data reveal that CMB surveys are excellent stellar flare detectors. In this talk, I will outline the current state of millimeter transient astronomy with a focus on millimeter flares discovered in my work building a blind transient search pipeline for the Atacama Cosmology Telescope. I will present our preliminary detections of stellar flares and how they relate to the broader millimeter and radio stellar flare landscape. I will also discuss the applications of this pipeline for the Simons Observatory Large Aperture Telescope, a future CMB survey being built in the Atacama Desert, and make predictions on the number and nature of stellar flares we expect to see.

* *Co-authors:* Yaqiong Li, Sigurd Naess, ACT Collaboration

Behzad Bojnordiarbab*
Chalmers University of Technology

Unveiling the structure of evolved stars' extended atmospheres: Capabilities of SKA and ngVLA

The heavy mass-loss experienced by evolved asymptotic giant branch (AGB) stars provides metals and dust to the interstellar medium (ISM) from which new stars and planets will form. In our current understanding, mass loss occurs through dust-driven winds originating from the extended atmospheres of these stars. However, our understanding of the extended atmospheres of AGB stars is still incomplete. State-of-the-art simulations show that large convective cells play an important role, but recent observations at milliarcsecond resolution with ALMA have shown that the conditions in the extended atmospheres might be different than predicted by the models. Low-frequency observations of evolved stars with SKA and ngVLA will make it possible to study the critical outer regions of the extended atmospheres where dust forms and is accelerated in a novel way. With the high resolution and sensitivity of SKA and ngVLA, we can use the continuum emission to constrain atmospheric density and temperature structures at larger distances from the star. Also, simultaneous observations of SKA, ngVLA, and ALMA will produce wide-range multi-wavelength data for various radii of the extended atmosphere, enabling us to test and constrain theoretical models in a way that was not possible before. With the large field of view of ngVLA and SKA, we can study the temporal evolution of evolved star atmospheres and dust-forming regions. In this presentation, I will share our recent results obtained from studying evolved star models, highlighting their practical significance and usefulness for observational studies. Furthermore, I will discuss the substantial potential for the SKA and ngVLA to revolutionize detailed observations in this field.

* *Co-authors:* Wouter Vlemmings (Chalmers), Theo Khouri (Chalmers), Suzanne Höfner (Uppsala University)

Andrew Burkhardt*
Worcester State University

A Rigorous K-Band Hunt for Aromatic Molecules (ARKHAM): How aromaticity varies across the earliest stages of star formation

Since the initial detection of benzonitrile (C_6H_7CN), TMC-1 has proven to be an incredibly rich source for aromatic molecular detections. From the first results of the ARKHAM (A Rigorous K-Band Hunt for Aromatic Molecules) survey with the Green Bank Telescope, it was shown that simple rings are quite ubiquitous in similar objects, being detected in an additional 4 sources in Taurus and Serpens. Here, we present the next major release of this survey, substantially increasing the number of sources with benzonitrile detections. We will also present a cross-cloud comparison to test whether aromatic chemistry is dependent on its parent cloud. This will in turn provide key insights into the top-down vs bottom-up debate for the origins of aromatic molecules in the earliest stages of star formation.

* *Co-authors:* Brayden Wilcomb, Brett McGuire

Cristina-Maria Cordun*
ASTRON

Hide and seek: Hunting for hot Jupiters at decameter wavelengths

Gaseous exoplanets generate low-frequency radio emission (<40 MHz) associated with aurorae via circularly polarized cyclotron maser mechanism. Measuring the electron density and the magnetic field of giant exoplanets, which is only possible at radio frequencies, is necessary to understand the impact of space weather on exoplanets. Until today, direct imaging of radio exoplanets has not been successful, with only a handful of tentative detections. The Low-Frequency Array (LOFAR) is ideally suited to detect giant exoplanets because it can observe at frequencies below 40 MHz and has high sensitivity. However, imaging at such low frequencies is challenging due to high interference levels and rapidly varying ionospheric conditions. To overcome the technical challenges of imaging below 40 MHz, I will present a new pipeline that corrects for all the known instrumental and ionospheric effects. Then, I will show the deepest images down to 15 MHz of a radio exoplanet candidate and use them to constrain the scaling laws that predict the radio luminosity of exoplanets. A clear detection of Tau Bootes b would be the first in the field of radio exoplanets and a step forward for imaging at low frequencies. I will end with a brief overview of the learned lessons and introduce an ongoing major LOFAR upgrade that will facilitate deeper imaging down to 15 MHz.

* *Co-authors:* Harish Vedantham, Joe Callingham, Michiel Brentjens

William R. F. Dent*
ALMA JAO

Betelgeuse: extraordinary events

Betelgeuse's Great Dimming in 2020 almost certainly involved a mass ejection leading to dust formation. This may have partially blocked the light in our direction, but could also have involved intrinsic stellar dimming and the formation of cool surface spots. In 2022, it was recognised that Betelguese had subsequently undergone a change in periodicity. By April this year, it had also reached an historically high optical brightness (∼0.0 magn). Thus it may be undergoing an increase in pulsation amplitude generally, possibly pressaging an increase in mass loss rate or a symptom of an internal upheaval.

Betelgeuse was observed in 2015 and 2023 at 230–450 GHz using ALMA long baselines, showing details as fine as 8 mas. The continuum from the well-resolved radio atmosphere, together with lines of SiO and CO in the molecular shell are compared before and after the Great Dimming. VLA observations at 5–22 GHz over decades have provided long-term insights. Betelguese has also been resolved by e-MERLIN at 5 GHz at 6 epochs since 2012, the most recent just a few days before the once-in-a-lifetime occultation by Solar system asteroid 319 Leona on 12 December 2023. About a hundred amateur astronomers observed and recorded the event. The ALMA, VLA and e-MERLIN observations were also invaluable in providing astrometric solutions to allow the position of Betelguese to be determined to better accuracy than the 44-mas stellar diameter, helping the reconstruction of its convective photosphere in the visible domain in unprecedented detail from the eclipse light curve (analysis is ongoing at present).

* *Co-authors:* Miguel Montargès, Pierre Kervella, Anita Richards†, Eamon O'Gorman, Lynn Matthews, Yoshi Asaki, Luke Maud, Graham Harper

† Presenting author

Roberta Humphreys*
University of Minnesota

High Mass Loss in Hidden Clumps and the SW Clump in ALMA Observations of the Red Hypergiant VY CMa

New ALMA CO maps and continuum images of VY CMa allow us measure the proper motions and line of sight velocities of a cluster of four clumps near the star, not visible in the optical and infrared images. We estimate their masses and time since ejection. All four were ejected during VY CMa's very active period in the early 20th century. Together with two additional knots observed with *HST*, VY CMa experienced at least six outflows in 30 years with a total mass lost $> 0.07 M_{\odot}$. Combined with optical and infrared maps, the ALMA CO maps also permit a multi-wavelength survey of the IR-bright "SW Clump". The SW Clump is not a single feature but several separate knots. Is it an expanding bubble or separate events apparently along the same direction of a major outflow?

* *Co-authors:* Anita Richards†, Kris Davidson, Ambesh Singh, Leen Decin, Lucy Zuirys
†Presenting author

Devojyoti Kansabanik*
National Centre for Radio Astrophysics, Tata Institute of Fundamental Research, Pune, India/CPAESS-UCAR, Boulder, CO, USA

Measuring Magnetic Fields of Coronal Mass Ejection in Corona and Inner Heliosphere using Wide Field of View Spectro-polarimetric Radio Imaging

Coronal mass ejections (CMEs) are the strongest drivers of space weather. Measurements of the plasma parameters of CMEs, particularly magnetic fields entrained in the CME plasma, are crucial to understanding their propagation, evolution, and geo-effectiveness. Spectral modeling of gyrosynchrotron (GS) emission from CME plasma has long been regarded as one of the most promising remote observation techniques for estimating spatially resolved CME plasma parameters. However, imaging the very low flux density CME GS emission in close proximity to the Sun with orders of magnitude higher flux density has proven to be rather challenging. This challenge has only recently been met using the combination of data from the Murchison Widefield Array (MWA) and the recently developed spectropolarimetric snapshot imaging pipeline optimized for this data (P-AIRCARS). This has now brought routine detection of GS within reach, and the next challenge to be overcome is that of constraining the large number of free parameters in GS models. A few of these parameters are degenerate and need to be constrained using the limited number of spectral measurements typically available. We present studies of spectropolarimetric modeling of GS emissions from two different CMEs, which establish that these degeneracies can be broken using polarimetric imaging.

However, this methodology is only useful to measure CME magnetic fields up to $\sim 10\ R_{\odot}$. At higher coronal heights and inner heliosphere, CME magnetic fields can be estimated by measuring the Faraday rotation of linearly polarized galactic/extragalactic radio sources. This method has been used using small field of view (FoV) instruments at high frequency (e.g., VLA) to measure magnetic fields along a single line of sight (LoS). We have recently started exploring the FR measurements due to CME using the MWA. The advantage of using the MWA is its wide FoV and lower observing frequency. Lower observing frequency provides sensitivity to smaller magnetic fields. At the same time, wide FoV will provide simultaneous measurements along multiple LoSs and enable the estimation of vector magnetic fields by constraining empirical flux-rope models of CMEs. We present the challenges that need to be overcome to achieve these goals and some initial results.

* *Co-Authors:* Angelos Vourlidas, Surajit Mondal, Divya Oberoi

Devojyoti Kansabanik*
National Centre for Radio Astrophysics, Tata Institute of Fundamental Research, Pune, India/CPAESS-UCAR, Boulder, CO, USA

Toward Commissioning Solar Observations with MeerKAT: Opening a New Frontier in Solar Radio Physics

Solar radio emissions provide several unique diagnostics to estimate different physical parameters of the solar corona, which are hard to access with observations at other wavelengths. However, imaging the very dynamic solar coronal emissions spanning a large range of angular scales (a few arcseconds to a few solar radii) at radio wavelengths is extremely challenging. At GHz frequencies, MeerKAT radio telescope provides extremely good spectroscopic snapshot sampling in the Fourier plane (*uv*-plane) due to its large numbers of antennas (currently 64). This makes MeerKAT possibly globally the best-suited instrument at the present time for providing high-fidelity spectroscopic snapshot solar images. At GHz frequencies the Sun has much higher flux density than any other astronomical sources in the sky. Hence, observing the Sun with sensitive radio telescopes like MeerKAT requires one to attenuate the solar signal suitably and maintain an optimum level of operation of the instrument. We embarked on our voyage of observing the Sun with MeerKAT by observing the Sun in the sidelobes of the primary beam. The images obtained show extremely good morphological similarities with the EUV images as well as the simulated radio images at MeerKAT frequencies demonstrating the high-fidelity of these images. Although this approach was successful, it is naturally better to observe the Sun in the main lobe of the primary beam. This requires introducing suitable attenuation in the signal chain to keep the system in the linear regime. One also needs to figure out a strategy for absolute flux density calibration while using additional attenuation in the signal chain. We have been working towards this and will present the current status of our efforts toward commissionsing solar observations with the MeerKAT. Once commissioned, this will enable a host of novel studies, open the door to a large unexplored phase space with significant discovery potential, and also pave the way for solar science with the upcoming Square Kilometre Array-Mid telescope, for which MeerKAT is a precursor.

**Co-authors:* Marcel Gouws (SARAO, South Africa), Divya Oberoi (NCRA-TIFR, India), Sarah Buchner (SARAO, South Africa), Surajit Mondal (NJIT, USA)

Robert Kavanagh
ASTRON

Unraveling (sub)-stellar magnetospheres

Magnetic fields are ubiquitous in low-mass stars. They strongly influence many key physical processes over the course of the star's life, such as the outflows of material from the star via quiescent stellar winds and eruptive coronal mass ejections. These processes can have major consequences for orbiting exoplanets, which may be stripped of their atmospheres due to impact of these outflows. However, if the planet possesses its own magnetic field, it may be shielded from such effects. To date, our knowledge of stellar magnetism is primarily thanks to measurements of the Zeeman effect in spectral lines. For sub-stellar objects however, these magnetically-sensitive lines disappear, rendering the Zeeman effect useless in measuring their magnetic fields. That being said, radio observations can provide an alternative pathway to measure the magnetic fields of both stars and sub-stellar objects. Inside their magnetospheres, bright coherent radio emission can be generated via auroral processes. These occur at the local cyclotron frequency, which allows for magnetic field strengths to be measured directly. In this talk, I will discuss our recent progress on inferring magnetospheric structure on both stars and brown dwarfs via radio observations. This methodology will become very useful with the advent of sensitive very low-frequency radio observations, which will allow us to directly probe the magnetospheres of exoplanets for the first time.

Justin Linford*
National Radio Astronomy Observatory

Upcoming Improvements to the VLBA

The Very Long Baseline Array (VLBA) celebrated 30 years of full science operations in 2023. The next few years will see several improvements to the VLBA. Novel techniques to improve the performance of the instrument are already being employed. New synthesizers are being deployed that will offer more tuning options than currently available. The aging ROACH Digital Back-ends (RDBEs) will be replaced as part of the VLBA New Digital Architecture (VNDA) project, which will bring many new features to the instrument. A new ultra-wideband receiver is also a real possibility, which could finally allow Ka-band observations on the VLBA.

* *Co-authors:* Walter Brisken, Lucas Hunt, Steven Tremblay, Jay Blanchard

Lynn D. Matthews*
MIT Haystack Observatory

Spatially Resolved Observations of the Atmosphere of Betelgeuse with the VLA and ALMA

The red supergiant Betelgeuse underwent a historic optical dimming in 2019–2020. Multi-wavelength observations and modeling have suggested this event resulted from a surface mass ejection and accompanying dust formation, instigated by the confluence of a shock wave with the pulsation phase. Spatially resolved observations of the extended atmosphere of Betelgeuse at cm and mm wavelengths provide valuable diagnostics of such phenomena by tracing global changes in the structure and temperature profile of the atmosphere. Resolved observations with the Karl G. Jansky Very Large Array (VLA) in 2019 August, just prior to the onset of its historic "Great Dimming" event, revealed evidence that changes had occurred in the temperature and density structure of the atmosphere between $r \sim 2 - 3R_\star$ in the months preceding the dimming, consistent with the passage of a strong shock wave. We have obtained additional epochs of spatially resolved measurements between 2021–2023 using the VLA and the Atacama Large Millimeter/submillimeter Array (ALMA). We will describe the implications of these recent measurements for understanding both recent and long-term evolution of the atmosphere of Betelgeuse. We also preview prospects for future imaging studies of Betelgeuse with the ngVLA.

$*$*Co-Authors:* K. Akiyama (MIT Haystack Observatory), A. K. Dupree (Center for Astrophysics | Harvard & Smithsonian)

Jazmín Ordóñez-Toro*
Instituto de Radioastronomía y Astrofísica, UNAM

Determination of Dynamic Masses in the Young Multiple Stellar System EC 95 Located in the Serpens Main Core

In this study, we present dynamical mass measurements for the young multiple stellar system EC 95, situated in the core of the Serpens star-forming region. This system is a triple hierarchical structure, comprising EC 95A categorized as a Herbig AeBe protostar, EC 95B previously designated as a T Tauri star, and the third component, EC 95C. We have precisely measured the masses of the components in the close binary EC 95A and EC 95B using multi-epoch observations employing Very Long Baseline Interferometry (VLBI) techniques. Our dataset includes both previous and the most recent observations obtained as part of the "Dynamical Masses of Young Stellar Multiple Systems with the VLBA" project (DYNAMO–VLBA), totaling 32 epochs covering 12 years of observation. The observations span a significant fraction of their orbit, with an estimated period of 21.6 ± 0.1 years. Our results reveal masses of 2.17 ± 0.10 $M_\odot$ for the primary component and 2.04 ± 0.12 $M_\odot$ for the secondary. These updated mass values contribute to enhancing the understanding of the stellar dynamics in this system. Additionally, our observations include the detection of the third component, EC 95C, providing valuable insights into the triple nature of the system.

* *Co-authors:* Sergio A. Dzib, Laurent Loinard

Kevin Ortiz Ceballos*
Center for Astrophysics | Harvard & Smithsonian

A Volume-Limited Radio Search for Magnetic Activity in 140 Exoplanets with the Very Large Array

We present the results of a search for radio emission in 77 stellar systems, hosting 140 exoplanets, predominantly within a distance of 17.5 pc using the Very Large Array (VLA) in the frequency range of $4-8$ GHz. This is the largest search to date for radio emission due to magnetic activity in exoplanetary systems at this frequency range. We obtained new observations of 58 systems, and analyzed archival observations of an additional 19 systems. Our choice of frequency and volume limit are motivated by radio detections of ultracool dwarfs (UCDs), including T dwarfs with masses down to the exoplanet threshold of 13 M_J. Our surveyed exoplanets span a mass range of $\approx 10^{-3} - 10$ M_J and semi-major axes of $\approx 10^{-2} - 10$ AU. We detect radio emission from a single target, although we find that its radio luminosity agrees with its known X-ray luminosity and the G"udel-Benz relation for stellar activity, indicating a likely stellar origin for the emission. For the remaining sources our 3σ upper limits are generally $L_\nu \lesssim 10^{12.5}$ erg s^{-1} Hz^{-1}, comparable to the lowest radio luminosities in radio-detected UCDs. Our results are consistent with previous targeted searches of a few individual systems at GHz frequencies while greatly expanding the sample of observed systems. Our survey sensitivity is comparable to the predicted fluxes from a few systems considered as potential candidates for detectable star-planet interaction. We conclude that observations with future instruments such as the Square Kilometer Array and the Next Generation Very Large Array will be necessary to further constrain radio emission mechanisms from exoplanet systems at these frequencies.

**Co-Authors:* Yvette Cendes[1], Edo Berger[1], Peter K. G. Williams[1]
[1]Center for Astrophysics | Harvard & Smithsonian

Eli Pattie*
Texas Tech University

Rapid radio variability in black hole and neutron star X-ray binary jets

X-ray binaries are systems where a black hole or neutron star accretes material from a companion. These systems host accretion disks which emit in X-ray, and jets which emit nonthermal radio. There are many open questions pertaining to jets in particular, as they are difficult to study in detail: their collimation and launching mechanisms via magnetic fields, speeds, opening angles, and structure. Here I present an ongoing project: a collection of archival and new high sensitivity radio data for a number of black hole and neutron star X-ray binaries, for which I have produced radio power spectra to quantify the level of rapid variability present (seconds-hours). Radio variability is related to physical jet parameters such as speed and opening angle, thus providing an overall sense of their structures. Specifically, we compare black hole to neutron star systems, and high accretion rate to low accretion rate for similarities or differences among X-ray binary jet behaviors.

* *Co-Authors:* Tom Maccarone, Alex Tetarenko

Sonu Tabitha Paulson*
Tata Institute of Fundemental Research, Mumbai

Unveiling the Cosmic Cradle: clustering and massive star formation in the enigmatic Galactic bubble N59

We present an investigation focused on a segment of the emphSpitzer mid-infrared bubble N59, specifically referred to as R1 within our study. Situated in the inner Galactic plane, this region stands out for its hosting of five 6.7 GHz methanol masers, as well as numerous compact H II regions, massive clumps, filaments, and prominent bright rims. As 6.7 GHz masers are closely linked to the initial phases of high-mass star formation, exploring regions that exhibit a high abundance of these maser detections provides an opportunity to investigate relatively young massive star-forming sites. To characterize the R1 region comprehensively, we utilize multi-wavelength (archival) data from optical to radio wavelengths, together with ^{13}CO and C^{18}O data. By combining near-infrared (NIR) and mid-infrared (MIR) data, we identify 12 Class I and 8 Class II sources within R1. Furthermore, spectral energy distribution (SED) analysis of selected sources reveals the presence of four embedded high-mass sources with masses ranging from 8.70-14.20 M_{odot}. We also identified several O and B-type stars from radio continuum analysis. Our molecular study uncovers two distinct molecular clouds in the region, which, although spatially close, occupy different regions in velocity space. We also find indications of a potential hub-filament system fostering star formation within the confines of R1. Finally, we propose that the feedback from the H II regions has led to the formation of prominent Bright Rimmed Clouds (BRC) within our region of interest.

* *Co-authors:* K. K. Mallick and D. K. Ojha

Kovi Rose*
University of Sydney

The detection of radio emission from the latest-type ultracool dwarf in a circular polarisation search

I present the coolest dwarf detected in radio and describe a method for identifying radio emission from ultracool dwarfs (UCDs) in all sky MHz to GHz surveys.

Stars and pulsars are the only known sources of significant circularly polarised emission. Coherent emission from UCDs tends to be highly circularly polarised and is tied to UCD magnetospheric dynamics. This emission is often rotationally modulated and can be used to measure UCD rotational periods. Auroral currents driving UCD emission are generated by co-rotational breakdown between the magnetosphere and circumstellar plasma, or as the result of magnetospheric interaction with a companion. Radio studies of UCDs can thus be used to probe magnetic fields and to identify binaries or exoplanets.

We used the ASKAP RACS-mid survey to identify circularly polarised sources, most of which had not been previously detected in radio. We conducted ATCA and MeerKAT observations of an unknown source later identified as a T8 dwarf. We measured periodic, rotationally modulated coherent emission from this object – the coolest dwarf detected in radio.

We measured the T8 dwarf's rotation period and placed a lower limit on its magnetic field strength. Our method can be used with future all sky surveys to detect and study UCDs and their companions.

* *Co-authors:* Tara Murphy, Laura Driessen

Loránt Sjouwerman
National Radio Astronomy Observatory

The Bulge Asymmetries and Dynamical Evolution (BAaDE) Survey

The Bulge Asymmetries and Dynamic Evolution (BAaDE) project aims to significantly improve models of the structure and dynamics of the inner Galaxy. The goal is to probe into regions not reachable with optical and nIR sampling of the Galactic Bulge and Plane by performing an SiO maser survey in evolved AGB stars. These CSE masers reveal the stellar line-of-sight kinematics and can be used as point-mass particles in dynamical modeling representing the older stellar populations. The survey will be complementary to many other surveys, either because of very limited overlap (e.g., sampling different types of objects) or by providing additional information (e.g., providing velocities). The project also includes novel studies to obtain relatively accurate stellar distances in order to derive general stellar properties like bolometric and maser luminosities. The BAaDE survey, by itself or in combination with approximate distances, will yield a wealth of data allowing many different studies and statistical analysis on AGB stars, CSEs and SiO maser modeling and occurrence. Here we will showcase our data and highlight some of the early results.

Rachel Weller*
The University of New Mexico

Dynamics at the Crossroads of the Galactic Bar and Disk With Red Supergiant SiO Masers

There is much to be learned from the mapping of the structure and dynamics of the Milky Way. Many large-scale surveys exist to model this, yet there is a gap in our knowledge due to interstellar extinction and stellar density restricting the optical and near-IR. We can fill this gap with radio wavelengths, where work has been done with surveys such as BAaDe and BeSSel. Despite this, many details of the structure are yet to be determined. I will present a survey of circumstellar SiO maser emission in Red Supergiants (RSGs) that we are using to construct models of the bar and disk in otherwise compromised or unsampled regions. We have observed 653 sources at 43 GHz with the VLA believed to be RSGs and are currently analyzing the data to determine distances to, line-of-sight velocities, and positions of RSGs at regions of kinematic interest. I will provide an overview of the preliminary work and potential results of this survey, as well as the future work and modeling to be done. I will discuss how this work can also be used to constrain the pumping mechanisms of SiO maser emission, and the process in which we will model masing conditions.

* *Co-authors:* Ylva Pihlström, Michael Stroh, Loránt Sjouwerman

Oral Presentations: Day 1

Grazia Umana
INAF

Prospects for Stellar Astronomy with Future Radio/(Sub)millimeter Facilities (Invited)

Radio astronomy is experiencing a new momentum with the design and construction of next-generation radio infrastructures that will achieve unprecedented sensitivity, frequency coverage and spatial resolution. Even before these facilities become operational, along with major upgrades to the existing one, a series of telescopes and demonstration systems, known as pathfinders and precursors, are already operational and producing data of the highest quality, paving the way for new science. After a brief illustration of the new "landscape" and its progress, I will present some scientific highlights of precursors and pathfinders, with particular a ttention to ASKAP, MeerKAT and LOFAR. Some examples in various areas of stellar astrophysics, where we expect the new structures to have the greatest impact, will be also provided.

Brett McGuire
MIT

Astrochemistry of Circumstellar Environments (Invited)

Circumstellar environments are unique chemical laboratories where some of the most exotic and fascinating extrasolar molecules are made and detected. Indeed, around 25% of molecular discoveries outside our solar system have been made in the immediate surroundings of IRC+10216 and VY Canis Majoris. Particularly notable among these are a wealth of metal-bearing species (like, actual metals, not just astronomer metals!). Observations of these molecules not only give us insight into the chemistry of these environments, but also provide probes of the physical structure and evolution of the sources themselves. In this talk, I'll provide a high-level whirlwind tour of some of the most exciting astrochemical discoveries in these environments.

Carl Gottlieb*,†
Harvard-Smithsonian Center for Astrophysics

ATOMIUM: ALMA Tracing the origins of molecules in dust forming oxygen rich M-type stars

Seventeen oxygen rich, AGB and, RSG stars—spanning a range in (circum)stellar parameters and evolutionary phases— were observed between 214 and 269 GHz in Band 6 with the ALMA 12 m array at an angular resolution of $\sim 0.025''$ to $\sim 1''$, a sensitivity of 1.5–5 mJy beam^{-1}, and a spectral resolution of $\sim$1.3 km s^{-1} in the ATOMIUM Large Program. One of the primary goals of the ATOMIUM program is to gain a quantitative understanding of the physicochemical processes which occur during the phase transition in which gaseous diatomic and triatomic molecules (e.g., AlO, AlOH, TiO, and OH) are converted to small dust grains in the inner wind of oxygen rich AGB stars, and the subsequent increase in size of the dust grains in the intermediate wind. In the talk today I will present a brief overview of the 24 molecules that were identified in the survey, and will discuss in some detail how the molecules inform us about the inner wind and the AGB outflow. The resulting maps of the distributions of the 24 molecules and of the associated continuum will serve as a benchmark in the development of quantitatively accurate chemical kinetic calculations of the inner and intermediate winds, and as a guide in the current development of hydrodynamic simulations of binary systems.

[*] *Co-author:* Leen Decin
† On behalf of the ATOMIUM consortium

Arielle Moullet*
NRAO

Stellar studies with ALMA's Wideband Sensitivity Upgrade

High-sensitivity access to the sub-millimeter wavelength range has proved central to the study of stellar environments at both ends of the stellar evolutionary cycle. Through velocity-resolved rotational and maser transitions, sub-millimeter spectra unveil the gas composition and kinematic structure of circumstellar and protostars' envelopes, constraining mass-loss, accretion and chemical enrichment processes. We present in this talk how the ALMA's wideband sensitivity upgrade (WSU), which is currently ongoing and is expected to be completed for all ALMA bands in the mid 2030s, can impact this field.

WSU's improved line and continuum sensitivity across all bands will increase the efficiency for all types of observations, extend the use of submm spectroscopy to farther sources and allowing for the exploration of faint molecular (CO, SO) and dust structures indicative of the presence of companions. But the dramatic increase of the instantaneously correlated spectral bandwidth, achieved through an expansion of the receivers' spectral grasp and the computing capabilities of the new correlator, will be mor specifically a game changer for high-velocity resolution spectral surveys. In practice, at the resolution necessary to chemically characterize stellar environments (0.2–0.5 $\mathrm{km\,s^{-1}}$), the WSU will make such surveys much more efficient (by a factor 4–50, depending on the spectral band), enabling unprecedented comprehensive chemical inventories. Finally, the WSU will also offer the possibility to achieve ultra-high velocity resolution, down to 1–15 m $\mathrm{s^{-1}}$ in narrow windows, allowing for a new level of characterization of infall structures in the cold envelopes of protostars.

* *Co-Authors:* A. Wootten (NRAO), S. Mohamed (University of Virginia)

Shazrene Mohamed
University of Virginia

Modelling the Circumstellar Environments of Interacting Stars (Invited)

The circumstellar environments of evolved stars are highly structured and complex, often featuring equatorial and bipolar outflows, and frequently punctuated with cavities, clumps, arcs, shells and spirals. In this talk I will review the detailed simulations combined with high-resolution, multi-wavelength observations that are giving us new insights into the formation of these structures, and in doing so, advancing our understanding of the underlying physical processes that drive and shape stellar winds, outbursts and explosions. In particular, I will discuss recent progress and remaining challenges for studies of three key processes: stellar wind interactions with nearby (sub-)stellar companions, wind-wind interactions, and interactions with the interstellar medium. I will highlight the implications of these interactions for systems ranging from symbiotic and colliding-wind binaries, to bow shocks around runaway stars, and nova and interacting supernova explosions.

Jakob van den Eijnden
University of Warwick

Unveiling runaway massive star bow shocks with current and future radio observatories

Massive stars, when travelling supersonically with respect to their surroundings, create bow shocks when their stellar winds collide with the ISM. Hundreds of such structures are known in the Milky Way, discovered predominantly through their thermal dust emission in the IR band. These bow shocks, however, can also emit non-thermally due to the acceleration of particles at the shock front. Such emission is expected to show up in the radio band, through direct synchrotron emission, or (very-)high energy bands, through inverse Compton processes. These non-thermal signatures for particle acceleration have, until recently, been challenging to find, with only a single radio bow shock known before 2022. In the past two years, the advent of MeerKAT and ASKAP have spurred a step-change in the search and study of bow shock radio counterparts and the underlying particle acceleration. MeerKAT's and ASKAP's combination of field of view, sensitivity, and ability to detect low-surface brightness extended radio sources has driven this development; a combination that will only be improved upon with future radio interferometers. In this talk, I will briefly review these recent developments before turning to the promise of LOFAR2.0, MeerKAT+, SKA and ngVLA for this topic. Specifically, I will discuss their impacts on our understanding of massive-star-driven particle acceleration and physical inferences of the stellar wind.

Vanessa Yanza Lopez*
National Autonomous University of Mexico

The bow shock at the center of NGC 6334A with deep VLA observations. Is It a colliding wind region or a bow shock of a runaway star?

Evidence of compact radio sources in the center of compact and ultra compact H II regions have emerged from high angular resolution. It was first suggested that these compact radio sources are tracing the ionized winds of the massive star that ionizes the corresponding H II region. NGC 6334 is a large complex of several massive star forming regions located at 1.34 kpc. It is known that NGC 6334A has a compact source at its center with non-thermal emission of unclear nature. The first authors suggested that it could be a colliding wind region. Here, we study the possible nature for this central source through deep VLA observations taken with the A configuration and X (10 GHz), K (22 GHz) and Ka (33 GHz) bands. These data show the arc-shaped structure of the compact source, and the spectral index analysis returns a negative value ($\alpha = -0.53 \pm 0.13$), confirming the non-thermal nature. Explaining the morphology and the spectral index of the source, two scenarios are explored: a colliding wind region of a binary system of two massive stars and the runaway star that was ejected to high velocity for the interaction between two or more bodies.

* *Co-Authors:* Sergio Dzib, Luis Felipe Rodriguez, Aina Palau, Josep Maria Masque

Anita M. S. Richards*
JBCA, University of Manchester

When is a photosphere not a photosphere? Radio continuum and maser case studies of O-rich AGB/RSG

New ALMA, e-MERLIN and VLA results explore the innermost few stellar radii of cool, evolved AGB and RSG. At radio wavelengths, free-free emission dominates the stellar atmosphere (plus some chromospheric contribution). The temperature, and thus the peak frequency of emission, decreases with distance from the star. This means that the apparent radius of the radio atmosphere – where it becomes optically thick – is larger at lower frequencies. Measurements of angular size and brightness temperature as a function of cm to mm wavelength, available for a few stars, can be fitted by first- or second-order curves.

In the optical and IR, emission from AGB and RSG can be reasonably-well approximated by a modified black body law, but the radio-regime slope tends to be shallower than the Rayleigh-Jeans tail, and does not always converge to the optical curve. The stellar diameter-wavelength relationship similarly hits Terra Incognita between tens of micron and mm wavelengths. Thanks to the ATOMIUM large project and other ALMA observations, we now have some of the first sub-mm measurements of stellar properties (at high enough resolution to avoid dust contamination) which explore the unknown relationships between angular size and temperature in this spectral region. Even higher resolution of the kinematics is possible using mm-wave SiO and water masers, which appear to trace as close as $2R_\star$. We present example results including for R Aql and VY CMa. Such observations also allow accurate proper motion measurements for these spotty stars, whose diameters can exceed their parallax.

* *Co-authors:* Asaki, Baudry, Brand, Danilovich, Decin, Dent, Etoka, Gottlieb, Gray, Harper, Humphreys, Montargès, Pimpanuwat, Sahai, Singh, Wong, Yates, Ziurys

Jing-Ze Ma*
Max Planck Institute for Astrophysics

Synthetic ALMA observations of large-scale convection in 3D simulations of Red Supergiants

Evolved cool stars have convective motions on the surface, which could span a large fraction of stellar radius for (super)giants. I will present 3D CO5BOLD simulations of red supergiants post-processed to predict synthetic ALMA images and SiO spectra, and compare them with the actual ALMA observations. Taking Betelgeuse as an example, I will demonstrate the significance of the synthetic radial velocity maps as bridges between theories and observations. I will further discuss how the advances in 3D simulations, together with upgrades in ALMA, can help us understand the complex interplay between rotation, convection, and mass loss of evolved cool stars.

* *Co-authors:* Andrea Chiavassa, Selma de Mink, Ruggero Valli, Stephen Justham, Bernd Freytag

Anna Bartkiewicz
Torun Institute of Astronomy, Nicolaus Copernicus University

Studying Stellar Evolution and Mass Loss with Masers (Invited)

Cosmic masers play an important role as a tool in stellar studies. They are broadly used for deriving kinematics, physical conditions of different regions, hidden in the dense environment very close to the young and also evolved stars and associated with large-scale outflows. I will summarize the use of masers in studies of mass loss at diverse stellar evolution stages like a magnetohydrodynamic disk wind traced by water masers in high-mass star-forming regions, the wind motions in asymptotic giant branch stars and red supergiants, water fountains in evolved stars. Finally, I will present recent discoveries of episodic accretion that is uniquely related to the outbursting methanol transition at 6.7 GHz.

Megan Lewis
Leiden Observatory

SiO masers in Galactic Miras: the intersection of BAaDE and OGLE

The BAaDE survey has observed SiO masers in over 10 thousand asymptotic giant branch (AGB) stars in the Galactic plane, yielding line-of-sight velocities, maser fluxes, and maser line ratios for these sources. However, the variable nature of AGB stars adds an extra layer of complexity to the interpretation of these data. Independently, the OGLE survey has released a catalog of period data and light curves for over 60 thousand Mira variables in the Milky Way, with more than 2000 of these corresponding to the SiO maser sources we surveyed with BAaDE. With both variability and maser information, we explore maser detection rates as a function of stellar period and phase as well as period-luminosity relations for maser-bearing Miras. We find SiO maser detection rate increases with period with very high rates (80–90%) for Miras with periods over 500 days, and that the detection rate of the SiO v=3 maser transition is strongly affected by stellar phase. This provides more evidence that the v=3 transition may be more efficiently pumped in denser environments. Finally, we have compiled a sample of over 300 sources most likely to be in the Galactic Center. This sample is used to derive period-luminosity relations which are specific to maser-bearing Miras. These more tailored relations may be necessary in order to derive accurate distances for maser stars because of the infrared effects of circumstellar envelopes.

Ylva Pihlström*
University of New Mexico

Exploring SiO Maser Dynamics in Thin-Shelled Mira Stars: VLBI Follow-up and Calibration Strategies

The main BAaDE survey of SiO masers in thin-shelled Mira stars throughout the galaxy has been completed, and the results are reported in other contributions in this conference. One of our follow-up projects has been to investigate the possibility of conducting VLBI observations on a select subset of targets. Our primary scientific objective is to determine the positions, proper motions, and parallaxes (thus obtaining distances and 3D velocities). Secondary objectives include determining the 3D orbit family of the objects (circular, radial/very elongated, x2) and investigating the variability of the SiO maser features over a timescale of a year. In this presentation, we will discuss the first VLBA tests and progress in determining alternative calibration methods when high-frequency calibrators are sparse in the sky.

* *Co-Authors:* Loránt Sjouwerman, Huib van Langevelde

Oral Presentations: Day 2

Gisela Ortiz-Léon
Instituto Nacional de Astrofisica, Optica y Electronica

VLBI astrometry of stellar and planetary systems (Invited)

Stellar non-thermal radio emission is a suitable target for astrometric studies with Very Long Baseline Interferometry (VLBI). Examples of objects that produce continuum non-thermal radiation are young stars, M-dwarfs and ultracool dwarfs. VLBI observations of these objects can resolve close binary systems and reveal the presence of hidden substellar companions. VLBI can also measure dynamical masses of binary systems and the 3D orbital architecture of planetary systems. On the other hand, non-thermal emission from maser lines could arise in low- and high-mass young stars. VLBI astrometry of masers is a valuable tool for tracing the gas kinematics around these objects. In this talk, I will present our latest work on VLBI astrometry of young stars and on astrometric searches for substellar objects in nearby low-mass stars. To conclude, I will discuss how astrometric studies with next-generation instruments could provide valuable insights into planet formation and evolution and into the dynamical effects of stellar companions.

Walter Golay*
Center for Astrophysics | Harvard & Smithsonian, University of Iowa

Timelapse VLBI imaging of the Close Active Binary HR 1099

We report multi-epoch astrometric VLBI observations of the chromospherically active binary HR 1099 (V711 Tau, HD 22468) at six epochs over 63 days using the Very Long Baseline Array at 22.2 GHz. We determined hourly radio centroid positions at each epoch with a positional uncertainty significantly smaller than the component separation. The aggregate radio positions at all epochs define an ellipse in the co-moving reference frame with an inclination $i = 39.5^{+3.6}_{-3.5}$ degr and longitude of ascending node $\Omega = 212 \pm 22$ degr. The ellipse center is offset from the Third Gaia Celestial Reference Frame position by $\Delta\alpha = -0.81^{+0.25}_{-0.37}$ mas, $\Delta\delta = 0.45^{+0.23}_{-0.25}$ mas. All radio centroids are well-displaced from the binary center of mass at all epochs, ruling out emission from the inter-binary region. We examined the motion of the radio centroids within each epoch by comparing hourly positions over several hours. The measured speeds were not statistically significant for five of the six epochs, with 2σ upper limits in the range 200–1000 km sec^{-1}. However, for one flaring epoch, there was a $\sim 3\sigma$ detection $v_{\rm perp} = 228 \pm 85$ km sec^{-1}. This speed is comparable to the mean speed of observed coronal mass ejections on the Sun.

* *Co-authors:* Robert L. Mutel, Evan E. Abbuhl

Paul Boven*
Leiden University / JIVE

Pushing for higher precision VLBI astrometry of radio stars

M dwarfs are the most ubiquitous stars in our galaxy, and nearly half of them will be part of a multiple system. Due to their magnetic activity, they often exhibit radio emission above their thermal emission at radio frequencies, allowing us to study their emission and orbits with very high accuracy. Possible findings include the reflex motion due to companions or exoplanets around these cool stars, or spatially resolving their emission structure.

Achieving sufficient accuracy in the calibration of such VLBI observations can be challenging. We report on the results of our astrometic VLBI observations of the M dwarf binary GJ 3789 (DG CVn). We employ MultiView calibration, and determine the orbits using a Markov Chain Monte Carlo solver, resulting in an accurate 5D orbital determination, with all orbital and astrometric parameters determined to at least 4 significant digits.

VLBI with next generation instruments such as the ng-VLA and SKA1-Mid will be better suited to these astrometric observations. Due to their smaller dish sizes, it is more likely to have the target and phase reference sources within the same primary beam. They will also offer sub-arraying to get simultaneous beams on calibrators and target. The higher sensitivity of these future instruments will allow us to study a larger volume of these interesting systems.

* *Co-Authors:* G. Bower, H. Vedantham, H. J. van Langevelde

Juan Bautista Climent Oliver
Universidad de Valencia

Exploring the radio emission of Ultracool Dwarfs with VLBI

The field of compact radio emission in objects with spectral type later than M7 (ultracool dwarfs; UCDs) is vastly unexplored, with only a few successful detections. However, VLBI observations can provide unique insights in UCDs' magnetospheres, star-planet interactions, unveil the presence of companions via astrometric measurements of the reflex motion, test evolutionary models via dynamical mass determination in binary systems, and much more. In this talk, we will present the latest results on VLBI efforts of UCDs, which have revealed magnetic structures in these objects akin to the Van Allen belts. We will also take a sneak peek into novel VLBI detections showcasing distinctive radio-emitting behaviors in various UCDs.

Divya Oberoi*
National Centre for Radio Astrophysics - Tata Institute of Fundamental Research

Of Ripples and Roars : Progress and Promise in Low Frequency Radio Solar Physics (Invited)

Low radio frequencies (<300 MHz) have long been known to provide diagnostics of the solar corona which are complementary to those available from other wavebands. High dynamic range and high fidelity imaging of the radio Sun, required to access much of this science, is however extremely challenging. Only comparatively recently the instrumental capabilities and imaging algorithms have caught up with these exacting demands. This talk will present a review of the progress made in the areas of instrumentation and algorithms in the past few years, and new science results enabled from this work, with a focus on the work done with the Murchison Widefield Array (MWA). They span a large range – from tantalising evidence for nanoflare based coronal heating to estimating magnetic fields entrained in coronal mass ejections, and discovering previously unknown characteristics of solar radio bursts known since 1950s. Not only does this work represent remarkable progress towards realising the potential of solar radio observations in areas like coronal magnetography and space weather, it is also uncovering unanticipated new features in solar emissions, sometimes forcing a rethink of the conventional wisdom. I will place this work in context of the Square Kilometre Array Observatory, currently under construction and expected to become available by 2028. I will also share our plans for the near term.

* With past and present members of the MWA solar and heliospheric science collaboration

Devojyoti Kansabanik*
National Centre for Radio Astrophysics, Tata Institute of Fundamental Research

Robust Detection of Linearly Polarized Emission from Meterwave Solar Emission: Questioning the Conventional Assumptions

Polarization of solar radio emissions provides some unique diagnostic tools to understand emission mechanisms and probe coronal magnetic fields along with other plasma parameters. In principle, these emissions can be elliptically polarized, having both circularly and linearly polarized components. However, observations of solar radio emissions have primarily been focused on circular polarization. Although there have been some reports of the detection of linear polarization in the 1960s, doubts were expressed about the reliability of these detections due to limitations of instrumental calibration. From conventional wisdom, no linear polarization is expected from solar radio emission (e.g. Grognard & McLean, 1973). This is due to the high differential Faraday rotation which should wash out any trace of linear polarization as the emission propagates through the coronal plasma. Soon after the work by Grognard & McLean (1973), this was widely accepted and any detection of linear polarization was assumed to be of instrumental origin. This view is so well established that this assumption is routinely used for calibrating solar spectropolarimetric observations, even for recent studies (Morosan et al. 2022). The state-of-the-art polarimetric calibration algorithm for spectropolarimetric solar imaging, P-AIRCARS (Kansabanik et al., 2022, 2023), does not rely on any such assumptions and provides high-fidelity and high-dynamic-range spectropolarimetric snapshot solar images using new generation instruments like the Murchison Widefield Array (MWA). Spectropolarimetric snapshot images provided by P-AIRCARS using MWA observations have led to robust imaging detection of linearly polarized emission from multiple different types of meter wavelength active solar emissions. This detection of linearly polarized emission has also been confirmed by simultaneous observation with the MWA and the upgraded Giant Metrewave Radio Telescope (uGMRT) at overlapping spectral bands. We present multiple examples of robust imaging detection of linearly polarized metric solar emissions along with one simultaneous MWA-uGMRT observation, which challenge the conventional wisdom. We will also present some possibilities for the origin of this linearly polarized solar emission.

**Co-authors:* Surajit Mondal (NJIT, USA), Soham Dey (NCRA-TIFR, India), Divya Oberoi (NCRA-TIFR, India)

Surajit Mondal*
New Jersey Institute of Technology

Using radio observations to constrain magnetic fields in the CME plasma

Coronal Mass Ejections (CMEs) play a very important role in space weather. Out of all the properties that determine the geo-effectiveness of CMEs, the magnetic field is perhaps the least constrained one. Radio observations can play a significant role in providing this crucial information. Detection and modeling of the CME gyrosynchrotron emission can be used to constrain the CME magnetic field. Observations with the Nançay Radioheliograph, Murchison Widefield Array, and the newly commissioned Owens Valley Long Wavelength Array (OVRO-LWA) with a solar-dedicated backend show that it is possible to detect the radio emission from CMEs. Here we present some preliminary results using data from the OVRO-LWA, which demonstrate that it might indeed be possible to detect the CME radio emission rather routinely. We will also present the first possible detection of thermal gyroresonance emission from a CME. This opens up the exciting possibility of not only measuring the spatially resolved magnetic field in radio-emitting CMEs, but also tracking its evolution in the so-called "middle corona".

**Co-Authors:* Bin Chen, Dale Gary, Gregg Hallinan and the OVRO-LWA team

Mary Knapp
MIT Haystack Observatory

Solar and Stellar Radio Emission from Space (Invited)

Radio astronomy has traditionally been an Earth-bound science, but there are exciting opportunities to expand on ground-based work and open entirely new fields of inquiry through space-based radio telescopes. Space-based radio astronomy opens new resolution space with the addition of VLBI baselines longer than the Earth's diameter and new frequency domains by escaping the effects of the Earth's neutral and ionized atmosphere. Low frequency (<10 MHz) is a particularly exciting domain since it cannot be accessed from the Earth's surface. In this talk, I will give an overview of science cases enabled by space-based radio instruments across a range of frequencies, with particular focus on solar/stellar/exoplanet applications. I will review past and current radio instrumentation in space and preview near-term radio observatories set to launch in the next 5 years as well as ambitious concepts on longer timescales. Finally, I will touch on the key technologies that will enable advances in space-based radio astronomy in the next decades.

Ivey Davis*
California Institute of Technology

Space Weather Around Young Suns (SWAYS): A dedicated system for radio and optical monitoring of the space weather of solar-type stars

On the Sun, Type II and III bursts are examples of plasma emission prominent below 100 MHz and are possible tracers for coronal mass ejections (CMEs) and solar energetic particle (SEP) events. Because of the association of these bursts with particle motion, stellar equivalents of Type II and III bursts have been targets of low-frequency space weather studies in the hopes of having unambiguous evidence of bulk particle motion from stars. As-of-yet, however, there has been no published detection of such emission. The difficulty in such detections is driven in part by the sensitivity required to support the time-frequency resolution needed to identify the unique spectrogram structure of the emission. It has been exacerbated by a lack of coordinated observations with other parts of the electromagnetic spectrum in order to associate the emission with flaring activity, as well as there having been a focus on late-type M-dwarfs, which may have magnetic fields that suppress such emission at frequencies observable from the Earth. To address this, we have begun the study of Space Weather Around Young Suns (SWAYS) observing program. This is a dedicated, coordinated, multi-wavelength effort to monitor space weather from nearby, solar-type stars in addition to M dwarfs and currently includes the Owens Valley Radio Observatory Long Wavelength Array (OVRO-LWA) operating between 13–86 MHz and the small optical instrument Flarescope. The two instruments have been conducting nightly observations to identify flaring emission and possible associated plasma emission in the radio. Here, we present the status of the observing campaign, which includes ~100 hours per instrument dedicated to the K-dwarf ϵ Eridani.

* *Co-authors:* Gregg Hallinan, Navtej Saini

Jan Forbrich*
University of Hertfordshire

Adventures of Young Radio Stars: intense radio outbursts, X-ray megaflares, and a novel VLBI search for ensuing coronal mass ejections

The sensitivity upgrades of both the NRAO Very Large Array (VLA) and the Very Long Baseline Array (VLBA) have begun to provide us with a much improved perspective on stellar centimeter radio emission, particularly concerning young stellar objects (YSOs), in ideal preparation for ngVLA and SKA science. For the first time we now have systematic access to the cm-radio time domain on short timescales and the possibility to disentangle thermal and nonthermal emission. I will mainly present an update on the Orion Radio All-Stars, an ongoing project targeting the star-forming Orion Nebula Cluster (ONC) with the VLA, VLBA, and ALMA. I will first present the increasingly well-characterized ONC radio sample, including first constraints on YSO radio flares and their relation with X-ray flares, as well as on the resulting high-energy irradiation of their surroundings. I will then focus on a VLBA non-thermal variability survey of all identified VLA targets in Orion in the largest such survey of YSO emission to date, enabled by software correlation—currently in a coordinated joint VLBA-Chandra large program to look for radio emission from coronal mass ejections following X-ray megaflares. Other than providing a nonthermal census, I will additionally discuss the use of the VLBA for precision stellar astrometry in the Gaia era. I will conclude with a complementary look at variable YSO millimeter continuum emission in the ONC, targeting synchrotron flares in this new window on high-energy processes in YSOs, using ALMA.

* *Co-Authors:* Sergio Dzib, Jaime Vargas-Gonzalez, Eoin O'Kelly, Kosta Getman

David Konijn
ASTRON & Kapteyn Institute

Radio search for extrasolar coronal mass ejections and energetic particle events

Coronal mass ejections (CMEs) are a dominant contributor to space weather in the solar system, with the potential to catastrophically erode planetary atmospheres. Traditional stellar activity probes, such as flares, cannot indicate if a CME is present. A characteristic radio burst (called type-II burst) is an unambiguous CME signature but there have been no such bursts detected due to a lack of sensitivity and time on sky. I will show that by using the solar flare-CME relationship, we should be able to find >100 type-II bursts within the Low-Frequency Array Two-Metre Sky Survey. I will present a progress report of our ambitious project to search over 12 petabytes of data to identify extrasolar CMEs. In particular, I will present our discovery of the first extrasolar type II burst, which contains the first unambiguous CME signatures, detected by the Low-Frequency Array. I will end by presenting plans for a more ambitious search to discover extrasolar (so-called) type-III bursts that trace energetic particle events.

Melodie Kao
Lowell Observatory

Radio Emission as Tool for Studies of Ultracool Dwarfs and Star-Planet Interactions (Invited)

As ultracool dwarf stars (M7 and later spectral type), including brown dwarfs, approach planetary masses and temperatures, their stellar-like flare activity gives way to planet-like auroral and radiation belt activity. These overlapping magnetic activity regimes position brown dwarfs as unique, powerful, and accessible laboratories that probe star-planet interaction and exoplanet magnetospheric physics. Maturing low frequency radio arrays and a highly anticipated ngVLA will provide new means for detecting and characterizing substellar magnetospheres. Now is a critical time to prepare for an upcoming era of star-planet interaction and comparative magnetospheric science by harnessing detailed studies of ultracool and brown dwarf magnetic activity. I will synthesize the state of the art for brown dwarf magnetospheric studies; discuss implications for exoplanet magnetism, star-planet interactions, and extrasolar moons and volcanism; and highlight opportunities for the next generation of ground- and space-based radio facilities.

Sanne Bloot
ASTRON, Kapteyn Astronomical Institute

Stellar mass loss through a low-frequency lens

Stellar winds govern the lives of stellar systems, from dictating the evolution of the star itself to eroding the atmospheres of exoplanets. The impact of the wind on a stellar system is largely determined by the mass-loss rate – which is notoriously difficult to measure on dwarf stars since the wind is so tenuous. Currently, mass-loss rates of cool stars have to be modelled or inferred indirectly, for example from astrospheric Ly*alpha* absorption. In this talk, I will present a more direct method to constrain the mass-loss rate of a star using detections of low-frequency coherent radio emission, exploiting the lack of free-free absorption to place upper limits on the stellar mass-loss rate. When we apply this method to M dwarfs detected with LOFAR at 120 MHz, we find upper limits on the order of 4 times the solar mass-loss rate, independent of distance. While these limits are already competitive with other methods, we expect to reach upper limits of 0.5 times the solar mass-loss rate or lower in the near future.

Timothy Wing Hei Yiu
ASTRON, the Netherlands Institute for Radio Astronomy

Search for a spectral cut-off and periodic signal from a radio brown dwarf binary

Brown dwarfs display Jupiter-like auroral phenomena such as coherent radio emission, which is a probe of magnetospheric acceleration mechanisms and allows us to directly measure the emitter's magnetic field strength. Radio observations of the coldest brown dwarf are particularly interesting since their magnetospheric phenomena may be very similar to those in gas-giant exoplanets. Here we study J1019, a radio-bright brown dwarf binary (T5.5+T7). The fact that J1019 is in a binary implies that we can constraint its mass, which allows us to (a) test dynamo scaling theories which predict the B-field strength of brown dwarfs/gas-giant exoplanet, and (b) study magnetospheric interactions which may be powering J1019's radio emission. In this talk, I will present our latest radio observations of J1019 from 3 different telescopes (LOFAR, VLA, and GMRT). I will show that J1019 exhibits pulsed coherent emission that repeats on hour-timescale and present our latest efforts to find a cut-off in J1019's radio spectrum to directly measure its B-field strength.

Jake Turner
Cornell University

Investigating exoplanet magnetospheres through radio transit observations

One of the most important properties of exoplanets has not yet been directly detected despite decades of searching: the presence of a magnetic field. Observations of an exoplanet's magnetic field would yield constraints on its planetary properties that are difficult to study, such as its interior structure, atmospheric dynamics and escape, habitability, and any star-planet interactions. Many different complementary techniques have been proposed to study exoplanet magnetic fields.

In this talk, I will present a new technique to study the magnetic fields of exoplanets using radio transits. When an exoplanet transits its host star, stellar emission is expected to be absorbed by the planetary atmosphere and magnetosphere. The magnetospheres of close-in planets, which are abundant with free electrons at high densities and temperatures, can be investigated in the mm as the radio transit depths are affected by free-free absorption. AU Mic is currently the only system where this new technique can be tested since the star is the only known transiting host star to exhibit quiescent emission between 1.5–15 GHz. I will discuss the theoretical predictions and the prospect of observing a transit of AU Mic b, the innermost planet, with current radio facilities. In the future, this technique will become more fruitful for studying the magnetic fields of a diverse set of planets when more exoplanet host stars are detected with the SKA and ngVLA.

Oral Presentations: Day 3

Barnali Das
CSIRO Space & Astronomy

Radio Emission from Magnetic Massive Stars (Invited)

Magnetic massive stars emit radio emission by a variety of mechanisms. In this talk, I will present an overview of different emission mechanisms (thermal, non-thermal, incoherent and coherent) as well as the different drivers of radio emission (wind-magnetospheric interactions, binarity etc.) from these stars. I will go into more details on the stars emitting rare exotic coherent radio emission, i.e. electron cyclotron maser emission. I will describe the latest developments in this particular aspect. I will also describe how one can probe the host stars using their radio emission, and how these information complement those obtained at other wavebands. Finally, I will touch upon the open questions and problems with the current ideas, and how one might be able to resolve those in the future.

Emil Polisensky*
Naval Research Laboratory

Unveiling Elusive Radio Flares in Hot Magnetic OBA Stars with the VLITE Commensal Sky Survey

Hot magnetic stars generally possess stable, kiloGauss surface magnetic fields with simple topologies. However, a subset of these stars experiences elusive small-scale explosive events triggered by centrifugal breakout mechanisms. Conventional magnetospheric diagnostics often fail to capture these faint flares, as they rarely produce distinguishable transient signatures. Recently, a particularly energetic radio flare was observed in the hot magnetic star CU Virginis, suggesting that certain extreme cases might be detectable. Inspired by this discovery, we conducted a targeted search for transient radio sources in the initial two epochs of the VLITE Commensal Sky Survey (VCSS), centered on 761 hot magnetic stars. Our search revealed three detections, confirmed through a false-association analysis (yielding probabilities $<1\%$) against potential imaging artifacts. Using the available stellar parameters, we conclude that all three stars are suitable for harboring centrifugal magnetospheres where centrifugal breakout can occur. Although our current data do not allow us to make a definitive association of the detections with the stars, our findings align with the hypothesis that the flares originated within the stellar magnetospheres. Additional detections in the ongoing VCSS epoch 3 may further illuminate the nature of these cryptic events and advance our comprehension of dynamic magnetospheres in hot magnetic stars.

* *Co-authors:* B. Das, W. Peters, M. E. Shultz, E. Semenko, T. E. Clarke

Richard Ignace
East Tennessee State University

Modeling Long-Wavelength Thermal Emissions from Non-Spherical Circumstellar Media: Applications to structured envelopes of hot massive stars

Hot massive stars have ionized stellar winds that at long-wavelengths can produce IR/radio excesses. However, for bound-free and free-free opacities, observability of excesses are limited to relatively high densities, such as high mass-loss winds (e.g., Wolf-Rayet stars or OB supergiants), or situations involving circumstellar disks such as those of Be stars, magnetically channeled winds, or interacting binaries. Interpreting data where steady-state and spherical symmetry do not apply can be challenging, but also offers diagnostic opportunities for testing various scenarios through parametric modeling. As examples, I describe how spectral energy distributions (SEDs) and time variability can be used to probe circumstellar media of hot massive stars using the examples of porous winds, co-rotating interaction regions (CIRs), and strongly magnetically channelled winds (based on the rigidly rotating magnetosphere, or RRM).

Dillon Dong
NRAO

The Wide Diversity of Radio Supernovae (Invited)

Over the past few years, wide-field surveys and sensitive follow-up observations have revealed that radio supernovae span over 3 orders of magnitude in evolutionary timescale and 10 orders of magnitude in peak luminosity. Each part of this parameter space maps to different outcomes of stellar evolution. Very high radio luminosities can indicate relativistic jets and a compact object at the center of the explosion, and/or dense (likely aspherical) gas ejected by extreme mass loss in star's final ∼centuries of life. Very low radio luminosities can be due to under-energetic explosions, and/or very weak winds from the exploded star and its companion(s). In this talk, I will highlight examples of supernovae that inhabit vastly different parts of this parameter space, discussing the reasons why they are so (over/under)luminous. I will also discuss the bigger picture of how such explosions currently found, what types of explosions we could be missing, and how probing new parts of observational parameter spaces with next-generation radio facilities could help us refine our physical picture of the most energetic outbursts in stellar evolution.

Chris Tandoi
University of Illinois Urbana-Champaign

Millimeter-wave Flaring Stars from the South Pole Telescope

We have conducted a short-duration transient search of four years of data from the South Pole Telescope (SPT). Using the SPT-3G camera, a 1500 square degree region of the southern sky has been observed on a nearly daily cadence in frequency bands centered at 95, 150, and 220 GHz. We present a new flare star catalog which includes 111 flaring events detected from 66 unique stars, greatly increasing the number of known mm-wave flaring stars. This large sample of flaring stars and events can help us to understand the physics behind the initial particle acceleration phase of stellar flares, and are important for planning the next generation mm-wave transient surveys such as CMB-S4 and the Simons Observatory (SO).

Tara Murphy[*]
University of Sydney

Understanding the radio stars population with ASKAP, on the path to the SKA

Until recently, the population of radio-loud stars has been studied primarily through targeted observations of a small number of stars with previously identified indicators of magnetic activity; such as strong radio activity, flaring or variability in other wavebands, or the presence of chromospheric emission or absorption lines.

Previous widefield radio surveys have typically consisted of only a few epochs (or a single epoch), which has limited our ability to distinguish stellar emission from background AGN. As a result it has been difficult to constrain population statistics such as the surface density and fraction of the population producing radio emission in a particular variable or spectral class.

The Australian SKA pathfinder (ASKAP) telescope is transforming our understanding of radio star populations. For the first time we are able to monitor hundreds (and potentially 1000s) of stars at gigahertz radio frequencies. We can investigate timescales as short as seconds, with monitoring periods over months to years.

In this talk I will present some of our results, including recently published work in which we monitor a sample of radio stars detected in circular polarisation searches of the multi-epoch ASKAP Variables and Slow Transients survey. Based on this work we anticipate detecting several hundred new radio stars for each year of our ASKAP survey, and tens of thousands in next generation all-sky surveys with the Square Kilometre Array.

I will also discuss the prospects for current and future radio stars studies with ASKAP and the SKA.

[*]*Co-authors:* Joshua Pritchard, George Heald

Laura Driessen
University of Sydney

The Sydney Radio Star Catalogue: a new catalogue of radio stars

I will present a new catalogue of ∼850 radio stars detected below 2 GHz: the Sydney Radio Star Catalogue (SRSC). Over 800 of these stars were identified using ASKAP, and up to ∼650 of these stars have not been detected in the radio prior to their ASKAP detection. The ASKAP stars in the SRSC were found using a range of techniques: circular polarisation searches, proper-motion searches, variability searches and multiwavelength cross-matching. We have also included published radio stars from e.g. MeerKAT and V-LoTSS in the SRSC. The catalogue contains stars from across the Hertzsprung-Russell diagram, from ultra-cool dwarfs to blue supergiants to Wolf Rayets. The previous best-known radio star catalogue, the Wendker catalogue, contained approximately 200 radio stars detected below 2 GHz. All but 40 of the stars in the SRSC were found using ASKAP, and of those ASKAP detected stars 110 are in the Wendker catalogue and another 6 are classified as radio stars in Simbad. This means that up to ∼600 of the stars in the catalogue have not been detected in the radio prior to their ASKAP detection. Hence the SRSC is a big leap forward in our understanding of the population and characteristics of radio stars. I will present an overview of the SRSC catalogue, including the properties and types of stars, an exploration of the binarity of the sample, the X-ray-radio characteristics using eROSITA_DE observations, and the circular polarisation properties. I will also highlight some individual objects of particular interest.

Laura Chomiuk
Michigan State University

Physical Drivers and Radio Signatures of the Diversity of Nova Eruptions (Invited)

Nova eruptions—thermonuclear transients that occur on the surfaces of accreting white dwarfs—are strikingly diverse in their properties, showing a wide range of ejecta masses, velocities, and optical light curves. I will discuss the properties of the underlying binary that drive this diversity, including white dwarf mass, accretion rate, and binary orbital period. I will then demonstrate how the diversity of nova eruptions manifests at radio wavelengths, highlighting both thermal and synchrotron emission mechanisms.

Isabella Molina*
Michigan State University

The Symbiotic Recurrent Nova V745 Sco at Radio Wavelengths

V745 Sco is a Galactic symbiotic recurrent nova which experienced eruptions in 1989 and 2014. Recurrent novae are intriguing candidate progenitors of Type Ia supernovae (SNe Ia). Radio observations of novae can give us information on the physical characteristics of the white dwarf and the process that the binary undergoes during the nova outburst. In this talk, I will discuss new observations of the recurrent novae V745 Sco and the implications for its status as a potential Type Ia supernova progenitor. I will present radio light curves (1-37 GHz) of the 1989 and 2014 eruptions and explain why we think the light curve is synchrotron dominated. I also present optical spectroscopy covering the first ∼100 days of eruption, in order to constrain the evolution of the nova ejecta sweeping up circumstellar material and decelerating. We attempt to model V745 Sco's radio emission to learn more about the ejecta morphology and the circumstellar environment. Surprisingly, compared to expectations for synchrotron emission (from e.g. radio supernovae), light curves spanning 5–37 GHz all peak around the same time (∼18-26 days after eruption) and with similar flux densities (5–9 mJy). Simple spherically symmetric models can not explain either the rapid deceleration of the blast wave or the distinct radio light curve.

* *Co-authors:* Laura Chomiuk, Elias Aydi, Justin Linford, Montana Williams, Kirill Sokolovskii, Jeno Sokoloski, Amy Mioduszewski, Koji Mukai

Montana Williams*
NMT

VLBA Images of the Fastest Nova V1674 Her

The classical nova V1674 Her erupted in June 2021. V1674 Her is considered to be the fastest evolving classical nova to date. The eruption faded from peak optical brightness by two magnitudes in ∼1.2 days. The host system contains a white dwarf and dwarf companion with an orbital period of ∼3.67 hours. V1674 Her was detected by NuStar, Swift, Fermi-LAT, e-EVN, and VLA. We present observations from the VLBA at 20, 24, and 35 days after eruption. We analyzed the resolved images to trace the evolution of the non-thermal components and derive physical properties of the ejecta. We compare the non-thermal emission to the thermal emission observed by the VLA. Additionally, we put the radio synchrotron morphology in context with the optical counterparts from the Gaia catalog.

* *Co-Authors:* Justin Linford, Kirill Sokolovsky, Laura Chomiuk, Elias Aydi, Jennifer Sokoloski, Koji Mukai, Adam Kawash, Amy Mioduszewsk, Michael Rupen

Robert Mutel
University of Iowa

Summary and Perspectives (Invited)