IR2022: An Infrared Bright Future for Ground-based IR Observatories in the Era of JWST

Abstract Booklet
(Sorted by Presentation Order)

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Day 1 - Live Talks

High Resolution Infrared Spectroscopy in the JWST Era

Matt Richter
University of California Davis

As we enter the JWST era, and on the threshold of the ELT era, high spectral resolution observations in the thermal infrared will continue to be important and may increase in importance. Even with the sensitivity of JWST, the limited spectral resolution means line profiles will often be unresolved and weak features may be hidden by a strong continuum or nearby features. To fully understand the objects we study with JWST, we will need the information provided by high-resolution spectroscopy. The ELTs, along with new instrumentation, will be important tools in this process. Perhaps someday we will be able to use a cold, space telescope equipped with a high-resolution spectrograph.

Unraveling planet formation using thermo-chemical disk models

Inga Kamp
Kapteyn Astronomical Institute, University of Groningen

We have entered an era where we have multi-wavelengths (multi instrument) data for representative samples of planet forming disks. Each instrument probes specific regions in the disk and if used alone leaves us sometimes with degeneracies in the interpretation. I will show the power of combining data (across instruments/missions) to enhance the scientific understanding of the data and to characterise the environments in which planets are forming.

Probing the terrestrial planet-forming zone: utilizing high spectral resolution, spatial resolution, and sensitivity

Sierra Grant
Max Planck Institute for extraterrestrial Physics (MPE)

In order to characterize the innermost regions of planet-forming disks, we require instrumentation with high spectral resolution, high spatial resolution, and high sensitivity. Today's state-of-the-art instruments (e.g., CRIRES+, GRAVITY, JWST-MIRI) now/will offer these capabilities, but the real opportunity lies in combining instruments with different strengths. In this talk, I will focus on what we have learned about protoplanetary disks from such instruments in the past, provide an example of current work, and discuss the future opportunities that can come from combining CRIRES+, GRAVITY(+), and JWST-MIRI observations. Together, these instruments can shed light on the dust and gas structure and the chemical abundances in the terrestrial planet-forming regions in a way that would be very difficult or impossible using only one instrument or method.

The Missing Link: Connecting Exoplanets and Galactic Chemical Evolution via Stellar Abundances: Isotopic Carbon and Oxygen Abundances in Solar Twin Stars

David Coria

University of Kansas

I present the first isotopic abundances of ^{13}CO and C^{18}O in solar twin stars and test the results against several galactic chemical evolution (GCE) models with different nucleosynthesis prescriptions. First, I compare the observed spectra to synthetic spectra generated from custom solar atmosphere models derived from the PHOENIX atmosphere code. Next, I compare the calculated abundances to GCE models that consider isotopic yields from massive stars, asymptotic giant branch (AGB) stars and novae. The ^{12}C / ^{13}C and ^{16}O / ^{18}O ratios determined for this sample of solar twins are consistent with predictions from the selected GCE models. This project constitutes the first in a stellar chemical abundance series seeking to: (1) support the James Webb Space Telescope (JWST) as it characterizes exoplanet atmospheres, interiors, and biosignatures by providing host star abundances (2) identify how unexplored stellar abundances reveal the process of galactic chemical evolution and correlate with star formation, interior, age, metallicity, and activity; and (3) provide improved stellar ages using stellar abundance measurements. Our measurements will provide a baseline for JWST exoplanet atmospheric abundance measurements, help identify the "missing link" between current GCE models and inconsistent observations and may provide a new means of determining stellar ages. By measuring elemental and isotopic abundances in a variety of stars, we not only supply refined host star parameters, but also provide the necessary foundations for complementary exoplanet characterization studies and ultimately contribute to the exploration of galactic, stellar, and planetary origins and evolution.

MATISSE-VLTI at the time of JWST and ELT era

Bruno Lopez

Laboratoire J.-L. Lagrange, Observatoire d ela Côte d'Azur

MATISSE is the VLTI mid-infrared imaging spectro-interferometer . In this presentation, we will give an overview of the instrument concept, signal, observing modes and performance limits, as well as the physical motivation behind its concept. MATISSE can operate as a stand alone instrument or in combination with the GRAVITY fringe tracker. The latter mode, called GRA4MAT, allows to reach better performance, which will be presented as well. GRA4MAT is based on the GRAVITY fringe tracker and adapted by ESO and our team to be used for MATISSE. MATISSE has been opened to the community since mid-2019 and we will illustrate the powerful multi band imaging capability, yielding thermal and dust composition maps, with a selection of frontline science results on AGNs, disks around young stars and stellar physics. The commissioning of the instrument will be finalized in 2022 in all its modes. MATISSE is thus still being optimized, in particular the GRA4MAT mode to reach the maximum sensitivity in the high spectral resolution modes with UTs. Finally, we will present the technical improvements foreseen in the coming years, such as the MATISSE-Wide off-axis fringe tracking considered in the context of the GRAVITY+ project and the related VLTI upgrades. GRAVITY+ will improve the AO sensitivity, will add the possibility of wide-field off-axis fringe tracking, and will thus contribute to a significant gain to the fringe tracking sensitivity on the UTs. Moreover, our team members are working on a second generation fringe tracking which will enlarge at least two key science avenues in the mid-IR recently opened by MATISSE: mid-infrared imaging of a large number of AGN dust tori and related dust structures and high contrast imaging of time-variable structures in protoplanetary disks around solar mass young stars. This expansion from the observations of a few typical targets to a much larger sample of sources of a same family will lead to two classes of breakthroughs: (1) Imaging of many targets will reveal the variety of geometries beyond the archetypes, leading to an understanding of the interplay of the underlying physical processes. (2) Access to statistical analysis of the relations between the physical parameters describing the sample of sources.

Full-VLTI, high-spatial resolution, infrared observations of circumbinary discs around evolved binaries: are they protoplanetary discs?

Akke Corporaal

KU Leuven

High-spatial resolution observations has been improving our understanding of circumstellar discs tremendously. In this talk, I'll focus on a class of evolved objects that show stable, dusty circumbinary discs, namely post-asymptotic giant branch (post-AGB) binary systems. Surprisingly, these surrounding circumbinary discs share a lot of common properties with protoplanetary discs around young stars. Using infrared interferometric techniques to spatially resolve the emission from the very inner regions of these discs, we gain insight into both the dynamical disc-binary interaction and the physical conditions in the disc inner regions. In this talk, I will present the results of our thorough observing campaign using all the current VLTI instruments, PIONIER, GRAVITY, and MATISSE, to reveal the circumbinary disc around one such post-AGB binary system. I will show models that reproduce the visibility data of all bands, providing strong implications on the inner disc properties and disc-binary interactions and discuss the importance of high-spatial resolution observations to further constrain the morphology of circumstellar discs.

The first interferometric survey in K-band of massive YSOs

Evgenia Koumpia

European Southern Observatory (ESO)

Circumstellar discs are essential for high-mass star formation. Also, binarity appears to be an inevitable outcome. Indeed, the vast majority of massive stars are found in binaries (up to 100%). Our understanding of the geometry and physical properties of the innermost regions of discs around massive stars and their associated binarity is sparse due to a lack of observational guidance. In this talk, I will present the first systematic study towards a sample of Massive Young Stellar Objects (MYSOs) as observed with long-baseline near-infrared K-band interferometry on VLTI (GRAVITY, AMBER). Geometrical models are employed to derive the characteristic size of the 2μm continuum and ionised gas emission towards this sample of MYSOs and investigate binarity. MYSOs are placed in a luminosity-size diagram for the first time, and their location is directly compared to their low and intermediate-mass counterparts. In addition, the investigation on the origin of the ionised gas emission (Brgamma) points towards a disc-wind interaction. Finally, I will present the first statistics on young high-mass binarity tracing 2-300 au separations and directly compare them to their pre-main and main sequence equivalents, reporting an increasing fraction with evolution.

Using mid-IR instrumentation to investigate disc evolution in massive YSOs

Abigail Frost
KU Leuven

Massive stars (M>8$M_{\odot}$) hold huge influence in the cosmos, affecting scales from their own stellar environment and to whole galaxies. Despite their importance, the formation of massive stars is poorly understood as they are deeply embedded, distant and rare, which introduces more observational challenges compared to low-mass star formation. Protostellar discs play key roles in the accretion process and formation of planetesimals for low-mass young stellar objects (YSOs), and form various substructures as different physical processes occur within them. In this talk I will present my recent work which has sought to probe the elusive discs of massive young stellar objects (MYSOs). By probing a sample of MYSOs using mid-IR interferometry and imaging, RT modelling and combining this with results from NIR spectra, I have been able to attribute the features of these discs to an evolutionary sequence. I will present these results and discuss our next steps in understanding massive protostellar disc evolution including how low-mass disc studies can help us understand MYSO disc evolution and how future mid-IR instrumentation and the use of high-spatial resolution techniques will be crucial to probing their processes.

Day 2 - Live Talks

The Promise of the Mid-IR for Detecting and Characterising Exoplanets with Direct Imaging

Beth Biller
University of Edinburgh

Direct imaging, and direct spectroscopy in particular, have great potential for advancing our understanding of extrasolar planets. In combinations with other methods of planet detection, direct imaging and spectroscopy will allow us to eventually: 1) fully map out the architecture of typical planetary systems and 2) study the atmospheric properties of exoplanets (colors, temperatures, etc.) in depth. To date, $\sim$ 20 young, giant exoplanets have been directly imaged, although future instruments will enable direct imaging of lower mass as well as older exoplanets. While the focus remains on young planets this field will be dominated by IR observations; young planets are self-luminous in the IR and thus have more favourable star-planet contrasts, amenable to imaging using high-contrast coronagraphic imagers along with adaptive optics. The majority of direct imaging to date has been in the near-IR (1-2.5 μm), but the advent of JWST as well as future ground-based high-contrast instruments will push further into the IR, producing high-fidelity data at wavelengths longer than 3 um. This opens up a multitude of new and unexplored spectral features, providing tests especially for the presence of silicate clouds and non-equilibrium chemistry in the atmospheres of these planets. I will detail our current state of knowledge regarding characterisation of these atmospheres and prospects with upcoming / future instruments. Additionally, the mid-IR likely can open up new detection space as well, with sensitivity to somewhat older planets compared to the near-IR.

The LBTI - Instrument overview, future developments, and sunergies with JWST, future space missions and ELTs.

Steve Ertel
University of Arizona

The Large Binocular Telescope Interferometer (LBTI) is a NASA-funded PI instrument on the Large Binocular Telescope (LBT). It is designed for exceptional resolution and sensitivity at thermal-infrared wavelengths for both direct adaptive optics imaging and interferometry. With its adaptive secondary mirrors and distributed adaptive optics (AO) system, faint limiting magnitude for natural AO reference stars, cryogenically cooled beam combiner, angular resolution up to the equivalent of a 23m telescope for snapshot imaging, and cutting-edge infrared technology, the LBT/LBTI features many of the characteristics of future extremely large telescopes (ELTs). It thus serves as an ELT pathfinder both technologically and scientifically. LBTI's higher resolution, smaller inner working angle, and ability to observe brighter targets, but overlapping wavelength range and capabilities also create important synergies with JWST. At the same time, the LBTI has successfully struck a balance between an actively developed instrumentation experiment and a productive science instrument available to the broad LBT user community.

In this talk, we will present an overview of the LBTI's design and capabilities. Key points will be illustrated using exemplary science results. We will also discuss future instrumentation and science plans developed by our instrument team and possibilities for other researchers to get involved in order to best exploit the LBTI as an instrumentation platform.

Mid-Infrared Imaging of Habitable-Zone Exoplanets with LBTI

Kevin Wagner

University of Arizona

In the next decades, ground-based direct imaging capabilities at mid-infrared wavelengths will be needed alongside JWST in order to image planets close to their stars – including most nearby habitable-zone planets. The ESO/Breakthrough-sponsored New Earths in the Alpha Centauri Region (NEAR) program on the VLT recently completed the first ultra-deep imaging campaign in the mid-IR and demonstrated the first sensitivity to habitable-zone sub-Neptune-sized planets. In this talk, I will describe our on-going efforts to upgrade the mid-infrared capabilities of the LBT based on the lessons from NEAR, which will enable coordinated deep explorations for low-mass habitable-zone planets in both the Northern and Southern skies. I will also discuss our key observational program: LESSONS: The LBT Exploratory Survey for Super-Earths/Sub-Neptunes Orbiting Nearby Stars. Finally, I will discuss the potential scientific and societal benefits of imaging nearby habitable-zone exoplanets.

Direct characterization of and search for gas giant exoplanets with near-infrared long-baseline interferometry

Jens Kammerer

Space Telescope Science Institute

Understanding the formation of gas giant planets is a major goal of contemporary exoplanet science since these planets are believed to dominate the architecture and evolution of planetary systems. A detailed characterization of an extrasolar planet requires the combination of multiple techniques exposing its physical and orbital parameters, its atmospheric composition, and its dynamical interaction with the circumstellar environment. Near-infrared long-baseline interferometry with VLTI/GRAVITY has proven its ability to directly image already known gas giant exoplanets and contribute micro-arcsecond astrometry and medium-resolution K-band spectra toward the comprehensive characterization of these objects. Furthermore, GRAVITY demonstrated the first direct detection of exoplanets whose existence was predicted from radial velocity and Gaia measurements, heralding a new era for direct imaging of exoplanets where planet searches are no longer blind, but target systems with radial velocity or astrometric trends to maximize the survey efficiency. We present our study of the HD 206893 debris disk system, a clone of the archetypical beta Pictoris system, hosting the reddest known sub-stellar companion HD 206893 B. Using GRAVITY spectra and astrometry, we derive a super-solar C/O ratio and a mass close to the boundary between exoplanets and brown dwarfs. By combining our data with spectra from the literature, we find that its unusually red color is likely caused by a layer of sub-micron sized dust particles in its upper atmosphere, and future JWST observations (PI Kammerer) are required to constrain the size distribution of these particles. Finally, we illustrate our search for an additional planet in the HD 206893 system whose existence has been predicted from indirect techniques and highlight how GRAVITY observations of multi-planet systems can yield unprecedented constraints on planet masses, ages, and therefore formation scenarios.

Preparing for the future of direct imaging exoplanets

Emily Rickman

European Space Agency/Space Telescope Science Institute (ESA/STScI)

Very little is known about giant planets and brown dwarfs at an orbital separation great than 5 AU. And yet, these are important puzzle pieces needed for constraining the uncertainties that exist in giant planet formation and evolutionary models that are plagued by a lack of observational constraints. In order to observationally probe this mass-separation parameter space, direct imaging is necessary but faces the difficulty of low detection efficiency.

To utilize the power of direct imaging, pre-selecting companion candidates with long-period radial velocities, coupled with proper anomalies from Hipparcos and Gaia, provide a powerful tool to hunt for the most promising candidates for direct imaging. Not only does this increase the detection efficiency, but this wealth of information removes the degeneracy of unknown orbital parameters, like the inclination, leading to derived dynamical masses which can serve as benchmark objects to test models of formation and evolution.

With upcoming missions like JWST and Roman, as well as ground-based facilities like the ELT, observing time is valuable and the strategy of direct imaging needs to be re-defined to pre-select targets. Looking further ahead, perfecting these strategies will be necessary as we look toward a large IR/O/UV mission, as recommended by the Astro 2020 decadal survey report, to pinpoint the location of terrestrial planets amenable to direct imaging.

I present the ongoing work towards creating a tool to use this information to select candidates for direct imaging with upcoming and future instruments. Ultimately this will lead us to a catalogue of benchmark objects that can be used to test models of planet formation and evolution.

High Contrast Imaging with JWST

Laurent Pueyo

STScI

I will discuss how JWST High Contrast imaging modes fit within the current state of the art of exoplanetary science. Webb's exquisite sensitivity will allow us to imagine giant planets that are much colder than the ones directly detected using existing facilities. I will discuss how this will significantly advance our understanding of exoplanetary atmospheres and architectures. I will focus on a couple key science questions regarding the formation and evolution of giant planets, and highlight cycle 1 programs that will address them. I will also discuss synergies with existing and upcoming ground-based observing facilities. Finally I will place these discussions in the context of projected performances, updated using data from observatory cryo-vacuum tests.

The LBTI/HOSTS survey for habitable-zone dust around nearby stars

Virginie Faramaz

University of Arizona - Steward Observatory

Habitable-zone dust around nearby stars, dubbed exozodiacal dust, critically constrains the sensitivity of future exo-Earth imaging space missions. Moreover, the origin and properties of the dust provide important constraints on the presence and dynamics of minor bodies in the inner system, and of giant planets in and around the habitable zone. This crucially affects whether rocky, habitable-zone planets exist in the system, as well as their likelihood to be genuinely habitable.

The LBTI has recently completed the HOSTS survey for exozodiacal dust in the N band using nulling interferometry on the Large Binocular Telescope. Our sensitivity is an order of magnitude better than previous observations. Scaling the Solar system's dust distribution, it is now the most sensitive instrument to detect such dusty analogues in mature planetary systems— even more sensitive than Herschel, ALMA, or JWST for our most suitable targets! The HOSTS survey has already critically informed all major US and European exo-Earth imaging mission studies and have been prominently featured in the Astro2020 decadal survey.

In this talk, we will present the main survey results and discuss future prospects of exozodiacal dust studies with the LBTI and future instrumentation. We have detected dust around ∼25% of our survey targets and have obtained new NASA funding for follow-up characterization of those systems. There is a clear correlation with the presence of massive, cold debris disks, and we can take advantage of this to harvest more exozodiacal dust detections for future characterization. A detailed sensitivity study has provided clear paths forward for further improving LBTI's sensitivity to exozodiacal dust by a factor of a few, possibly up to an order of magnitude. This will enable us to detect and study true Solar system analogs in the near future. The parallel development of a mid-infrared nuller for the VLTI will enable similar observations in the southern hemisphere and allow for connecting the habitable zone dust to hot dust closer to the star for a complete picture of the architectures and dynamics of the inner regions of mature planetary systems.

Influence of water vapor on ELT/METIS high contrast imaging performance

Olivier Absil

University of Liège

The variability of the water vapor column density is a significant contributor to the image quality of ground-based diffraction-limited mid-infrared instruments. In this talk, I will show how interferometry measurements from the GRAVITY and MATISSE interferometers at the VLTI can be used to estimate the actual amount of wavefront error that an instrument like METIS will face on the ELT. I will show that the METIS high-contrast imaging performance at N band will be driven by water vapor seeing, which dominates wavefront errors over adaptive optics residuals in the mid-infrared. I will then describe the strategy that we are planning to use in METIS to partly mitigate the effect of water vapor seeing, and I will discuss how future interferometric observations could help in the preparation of future METIS operations.

MIRAC-5 in 2022: An Overview and the Possibility of Mid-IR Ammonia Detection in Gas Giants

Rory Bowens
The University of Michigan (UM)

Advances in adaptive optics (AO) systems and mid-infrared detectors are enabling ground-based mid-infrared systems to complement space-based missions on several fronts. Proper utilization of both these approaches, particularly ahead of the completion of thirty meter class telescopes, is crucial for mid-infrared astronomy. We describe the MIRAC-5 cryostat which will use a new Geosnap mid-infrared detector as part of the Mid-InfraRed Adaptive-optics(AO)-assisted Instrument Development (MIRAID) Project. Due to the success of space-based infrared platforms, and the assumption that adaptive optics are not needed in the mid-infrared, there are very few ground-based mid-infrared detectors that take advantage of AO systems. Yet the angular resolution and contrasts achievable with ground-based mid-IR AO systems open up unique scientific opportunities. As one of the only 3-13 micron cameras used in tandem with AO, MIRAC-5 will be complementary to the James Webb Space Telescope and capable of: 1) characterizing warm gas giant planets discovered through direct imaging surveys with AO at shorter wavelengths; 2) imaging forming protoplanets (and characterizing their circumplanetary disks); and 3) directly detecting cold mature planets discovered through radial velocity surveys. MIRAC-5 will be commissioned on the MMT utilizing the new MAPS AO system in later-2022 with plans to move to Magellan with the MagAO system in 2023. We will review MIRAC-5's design and expected capabilities, as well as explore its ability to detect the 10.2-10.8 micron NH3 in the atmosphere of warm planetary mass companions such as GJ 504b (Teff $\sim$550 K).

Day 2 - Related Pre-Recorded Talks

VISIR at VLT - status and recent results

Valentin Ivanov
ESO

VISIR is 8-20 micron camera and spectrograph at the VLT. We describe the status of the instrument, the recent improvements in the data reduction system, and summarize the latest scientific results from VISIR.

Day 3 - Live Talks

Challenging the difficulties in ground-based MIR observations: The case of TAO/MIMIZUKU

Takafumi Kamizuka

The University of Tokyo

In the JWST era, investigations of faint objects will greatly progress thanks to the unprecedented high sensitivity and spatial resolution of the JWST. The role of ground-based observations in such an era will be survey observations of bright sources and monitoring observations of time-varying phenomena. The mid-infrared instrument TAO/MIMIZUKU, which we are currently developing, aims to play such a role.

The TAO (the University of Tokyo Atacama Observatory) is an observatory that the University of Tokyo is constructing at the summit of Co. Chajnantor (5640-m altitude) in the Atacama Desert, Chile. The high altitude and dry climate suppress precipitable water vapor, allowing for stable observations in the MIR and extending the atmospheric window to 38 microns. The TAO will be equipped with a 6.5-meter telescope, and the MIMIZUKU will be the first-generation MIR instrument mounted there. The MIMIZUKU will enable imaging and low-resolution (R=60-600) spectroscopy in 2-38 microns. We aim to use this capability to study the formation, growth, and destruction of dust around young and evolved stars by monitoring the associated temporal changes.

There are some difficulties in ground-based MIR observations. One is the strong thermal background radiation from the atmosphere and the telescope. Since the background radiation is much brighter than astronomical sources and is highly variable, it is important to remove it. The simplest way to do this is to switch observing positions before the background level changes, take data at each position, and subtract them. This technique is called "chopping," and the MIMIZUKU will have a chopping system (beam switcher) in its cold optics. We are developing such a system that enables beam switching with a chop throw of > 30 arcsec, a frequency of > 2 Hz, and a power consumption of < 100 mW.

Another difficulty is the variable atmospheric absorption. In order to measure the brightness and spectrum of an object, it is necessary to observe a reference object with known brightness and spectrum, and compare them to correct for the atmospheric absorption. The best way to accurately correct for the time-varying atmospheric absorption is to observe the two sources simultaneously. Such observations are difficult due to the small number of objects observable from the ground, but they are very important for monitoring that requires accurate atmospheric correction. To overcome this problem, we have developed a system called Field Stacker (FS) and installed it on the MIMIZUKU. This system makes it possible to pick up arbitrary two objects in the telescope field-of-view (FoV) and observe them simultaneously. We confirmed in test observations at Subaru that this kind of observation actually improves the accuracy and reliability of photometric and spectroscopic data. In this talk, I will talk about these efforts to overcome the difficulties of ground-based MIR observations and future prospects of observations with TAO/MIMIZUKU.

Enhanced Signal-to-Noise Ratio, FWHM, and Strehl Ratio improvements through Mid-Infrared Drift Scanning

Amílcar Torres-Quijano
University of Texas at San Antonio

Astronomical observations performed from ground-based mid-infrared (MIR) instrumentation requires the removal of the fast time variable components of array background and sky/background variation. "Chopping" has been typically employed, which involves oscillating the telescope's secondary mirror a few times a second. Yet, this creates various detrimental effects which include: (a) reducing on-object photon collection time, (b) "nodding" of the telescope to remove the radiative offset created by the chopping, (c) places strict demand on the secondary mirror, (d) depends on a frequently fixed chop-frequency regardless of sky conditions. Once we move into the thirty-meter telescope era, chopping the secondary mirror will be unfeasible. To address these issues drift scanning can be employed to remove the necessity of chopping if the sky and background are sufficiently stable. We report the drift scanning results obtained while utilizing the MIR instrument CanariCam on the 10.4m Gran Telescopio Canarias (GTC). We also note the potential applications to other instruments such as TAO/MIMIZUKU and 30m class instruments.

Mission-target asteroids: thermal-IR characterization from ground

Thomas Müller
Max-Planck-Institut für extraterrestrische Physik (MPE)

Interplanetary missions to asteroids, like the Hayabusa, Hayabusa2, OSIRIS-REx, DESTINY+ or DART/Hera project, depend a good knowledge of the target object prior to the critical mission phases. Ground-based IR observations (at different times, observing geometries, wavelengths) play a very important role in this context: Via radiometric studies, in combination with auxiliary observations in the visible or near-IR, it is possible to derive the object's size, shape, spin properties, albedo, and thermal properties. The ground-based IR measurements are often absolutely critical, even in cases where detections from IR space surveys or IR space observatories are available. The ground-based data, mainly in N-band, partially also in M and/or Q-band, are well suited to monitor rotational properties (on hour or day scale), phase or aspect angle studies (over weeks/months) and to obtain well-calibrated fluxes over several orders of magnitude (from mJy almost up to kJy) needed for the determination of high-quality thermophysical properties. In comparison with space-based observations, the ground-based observations are less restricted in accessible solar elongation range and non-sidereal tracking speeds, both aspects are very relevant for near-Earth object mission targets. The ground-based IR measurements also play an important role for connecting and interpreting the results from in-situ findings on small scale (available only for very few objects which are considered fundamental for the understanding of the formation and evolution of planetary systems) with global, disk-integrated measurements (available for most of the small bodies). The ground-based IR characterization of these objects is therefore an important contribution to the understanding of our Solar System. We will present examples of past, ongoing and planned ground-based IR measurements of interplanetary mission targets, the role of these measurements for the characterization of the objects, and their importance for Solar System research.

Infrared ground-based observations of small solar system bodies in the JWST era

Takafumi Ootsubo

National Astronomical Observatory of Japan

Observations of comet C/1999 O1 (Hale-Bopp) with the Infrared Space Observatory (ISO) and ground-based observatories provided us with many precious data. Since then, the synergy between infrared satellites and ground-based telescopes has made great contributions to the progress of our knowledge of small solar system bodies. Spitzer Space telescope and mid-infrared instruments on the 8-m class telescope, including Subaru/COMICS, have revealed that the ubiquitous presence of crystalline silicates together with icy grains in cometary dust. Herschel Space Observatory and ground-based infrared observations have determined the size and surface properties of many Trans-Neptunian Objects and distant objects in the outer edge of the solar system. The many properties of water, organic molecules, and dust must be revealed with the infrared observations with JWST in the near future.

We need, however, much more flexible observations on time and place for the small solar system bodies, like comets and near-earth objects. In addition to objects in the solar system, we also have two interlopers from the interstellar space, interstellar objects 1I/2017U1 ('Oumuamua) and 2I/Borisov, until now. Since 2I/Borisov was discovered on 2019 August 29 UT, more than three months before the perihelion passage, many observations were carried out, and molecules, such as C_2, CN, and NH_2, have been detected. However, we have never obtained mid-infrared data of interstellar objects, and the dust properties are almost not known. In this talk, we will summarize the major topics of the ice and dust in the small solar system bodies with near- to far-infrared observations and introduce the future plan of the infrared observations with near- and mid-infrared ground-based observations (VLT/VISIR, TAO/MIMIZUKU, etc.) in the JWST era.

Red transients and their dusty remnants

Tomasz Kamiński

Nicolaus Copernicus Astronomical Center

I am going to present a new group of visual and infrared transients, known as luminous red novae, that are thought to erupt due to stellar collisions. Their remnants are very rich in molecular gas and freshly-formed dust, producing rather exotic spectral signatures that are best explored in the infrared. I am going to discuss how ground-based infrared observations have helped us to understand these systems and how they further our understanding of stellar mergers and evolution of close binaries.

Daily monitoring of Betelgeuse with the Himawari-8 meteorological satellite

Daisuke Taniguchi
The University of Tokyo

High-cadence monitoring observation is an important complement to observations with large-aperture telescopes. However, time-series observations are generally limited to ground-based ones, which can only be carried out within atmospheric windows and are affected by the Sun for several months. Here we introduce a brand-new concept: using meteorological satellites as "space telescope". As a demonstration of this concept, we present almost daily 16-band photometry of Betelgeuse in 0.45–13.5 micron using the Himawari-8 geostationary meteorological satellite from January 2017 to today. Analyzing these light curves, we show that an enhanced dust extinction may have contributed in part to the Great Dimming occurred in early 2020, an unusual fall and rise in the optical brightness of Betelgeuse by $\sim$1.2 mag. We also discuss the future ability of meteorological satellites for the time-domain investigation of other evolved stars.

Energetic nuclear transients in luminous infrared galaxies

Seppo Mattila
University of Turku

There have been a number of observations of infrared (IR) echoes associated with tidal disruption events (TDEs). These arise as a result of re-radiation of the TDE's UV/optical photons by dust in the nuclear environment. Furthermore, there have been multiple fortuitous discoveries of IR echoes in the nuclei of luminous infrared galaxies (LIRGs) over the last few years, which have been identified as TDE candidates. LIRGs are dusty systems often resulting from galaxy mergers and hosting both a powerful starburst and an active galactic nucleus (AGN). TDE candidates in the dusty nuclei of LIRGs are challenging to identify and can often be out of the reach of optical or X-ray observations due to the large column densities of gas and dust obscuring them. Therefore, IR observations are required to characterise them, and can provide important information on the population of TDEs and their rates in these dust obscured nuclear environments. Additionally, IR echoes can be used to probe the total radiated energies from TDEs in cases where a significant fraction of the radiated energy was re-processed by dust to IR wavelengths.

Here we present our search for nuclear transients within local LIRGs using mid-IR observations performed by the WISE satellite, which are almost unaffected by dust extinction. In this search we found multiple new TDE candidates through detection of luminous and slowly evolving mid-IR outbursts. We characterise the nature of these objects through modelling of the spectral energy distributions of their host galaxies and measurements of their luminosities and resulting energetics as well as by comparison of these properties with those of previously published TDEs and TDE candidates. Combining previous discoveries with the new transients detected as part of this search, we set a new lower limit for the rate of dust obscured TDEs occurring within LIRGs. We discuss the potential of ground-bases IR observations for such studies using the current and future facilities.

HIgh-energy neutrino sources in the IR

Robert Stein
Caltech

Astrophysical neutrino sources were first discovered by IceCube in 2013, and there has since been an ongoing search to find the origin of these neutrinos. Neutrino detections are now published in real-time in the form of public alerts, enabling electromagnetic follow-up. In recent years, neutrino follow-up campaigns by the Zwicky Transient Facility (ZTF) at optical wavelengths have identified two Tidal Disruption Events (TDEs) as likely neutrino sources. These TDEs both exhibited dramatic dust echoes, as seen in observations at NIR and MIR wavelengths. Searching for similar dust echoes revealed a third TDE-like flare as another likely neutrino source. I will discuss how IR can be used to identify further neutrino sources, and the prospects for a planned IR neutrino follow-up program with the upcoming WINTER telescope.

Time Domain Astronomy with JWST

Mansi Kasliwal
Caltech

Many astronomical events shine the brightest in the infrared due to atomic opacity, self enshrouding, dust extinction, or low temperature. For example, when we saw the first electromagnetic counterpart to gravitational waves from a binary neutron star merger, it was the rapid reddening due to bound-bound opacity and infrared spectral features that confirmed the synthesis of heavy elements by the r-process. Systematically unveiling our dynamic infrared sky requires the combination of a new generation of wide-field infrared surveyors as well as spectroscopic follow-up with JWST. In this talk, I will review various time-domain science opportunities with JWST.

Day 3 - Related Poster

The Small Body Infrared Database

Róbert Szakáts
Konkoly Observatory, Research Centre for Astronomy and Earth Sciences, ELKH

One of the objectives of the Small Bodies: Near and Far (SBNAF) Horizon 2020 project was to create an easy-to-use database for ground-based, airborne, and space thermal infrared observations of small bodies. We collected published thermal IR measurements for our selected samples of Solar system targets including data from large missions (e.g. catalogues based on Akari, IRAS and WISE observations) and also data from smaller scale and individual reductions (e.g. the Herschel Space Observatory measurements of near-Earth and main belt asteroids). The main goal of this database is to help scientists working in the field of small body thermal emission modeling. The database has the option to include additional data of Solar System small bodies observed at thermal IR wavelengths either from space or with ground-based instruments. The database is online (http://ird.konkoly.hu) and accessible since March 2019 (see Szakáts et al., 2020). Recently our database was used, e.g. to help determine the shape and spin properties of (208) Lacrimosa asteroid in the Koronis family, (Vokrouhlický et al., 2021), to model the thermophysical state of two Hilda asteroids (1162) Larissa and (1911) Schubart, (Chavez et al., 2021) and to model the thermal emission of large main belt asteroids (Ali-Lagoa et al., 2020). In a recent update we added 324 new flux densities for 23 resonant trans-Neptunian and scattered disk objects to the database from Farkas-Takács et al. 2020, and in total we have now 170461 records (see the Release Note of February 2, 2021). In an upcoming update we are planning to extend the database with WISE W2 data, Uranus and Neptune satellite data, with flux densities from Herschel serendipitous asteroid observations, and disk-integrated thermal data of the Moon (Müller et al., 2021). The WISE W2 data will bring shorter wavelength flux densities to the database for selected asteroids. During the processing special attention will be given to those small bodies, mainly NEAs, for which the reflected light can cause discrepancies when calculating the colour correction factor. We will also include a large number of Herschel serendipitous asteroid observations (Szakáts et al., 2021).

Right now the database consists of space-based observations, but it was not exclusively created for that type of data. We plan to expand the records with ground-based and airborne, photometric and spectroscopic data, too. In the era of JWST and with the upcoming new telescopes there is not only an opportunity to broaden our database, but there is also need from the scientific community to have a tool that can help both observation planning and the interpretation of new thermal emission data. The Small Body Infared Database can serve all these needs.

Day 4 - Live Talks

From the ground to space: an infrared view of active galactic nuclei

Cristina Ramos Almeida
Instituto de Astrofísica de Canarias

In the past 10-15 years our view of the circumnuclear material of active galactic nuclei (AGN) has completely changed thanks to the combination of new observations and models. In particular, infrared and sub-mm high angular resolution observations from ground-based observatories have been crucial to peer into the innermost regions of AGN and study the geometry and composition of the nuclear obscurer, and how it is connected with the central engine (feeding) and the host galaxy (feedback). In this talk I will summarize recent observational results in the infrared and sub-mm ranges showing that the circumnuclear material of AGN is complex and highly dynamic, varying with the periods of nuclear activity, AGN luminosity and Eddington ratio. I will also discuss future prospects in the field based on the upcoming JWST data that will greatly contribute to our knowledge of the immediate surroundings of AGN.

Resolving the dusty heart of NGC 1068 with MATISSE

Violeta Gamez Rosas
Leiden Observatory

Interferometry in the mid infrared is a powerful observing technique to study the emission of the dust in the central regions of AGNs. The spectro-interferometer MATISSE at the VLTI offers both, a high angular resolution of up to 3 mas, and a wide spectral range by including the L, M and N bands in three different spectral resolution modes. This allows for a more complete analysis of the properties of the dust and its spatial distribution. In this talk I will present the first image reconstructions of the dusty heart of NGC 1068 and the thermal map derived through Gaussian modelling (Gamez Rosas et al., Nature in press). I will discuss details on the composition of the dust and how the cross-identification of the MATISSE map with ALMA and VLBA maps together with the water masers further reveal the position of the hidden black hole.

The Dusty Heart of Circinus: First Imaging of the Circumnuclear Dust

Jacob Isbell

Max Planck Institute for Astronomy

Active galactic nuclei play a key role in the evolution of galaxies, but their immediate environments are poorly understood due to a lack of angular resolution. Infrared interferometry makes it possible to resolve the circumnuclear dust in the nearest Seyfert 2, the Circinus Galaxy. Previous observations have revealed complex structures and polar dust emission but interpretation was limited to Gaussian modeling. MATISSE makes it possible to image these structures for the first time. We aim to precisely map the morphology and temperature of the dust surrounding this active nucleus through interferometric imaging. We observed the Circinus Galaxy with VLTI/MATISSE, producing 150 correlated flux spectra and 100 closure phase spectra. The novel inclusion of closure phases makes interferometric imaging possible for the first time. We use IRBis to reconstruct images in the N-band at $\sim$10mas resolution. We fit blackbody functions with dust extinction to several aperture-extracted fluxes from the images to produce a temperature distribution of central dusty structures. We find significant substructure in the circumnuclear dust: around 0.5 Jy of central unresolved flux, a thin disk with diameter 1.9 pc oriented along $\sim$ 45 deg, and $\sim$ 4pc $\times$ 1.5 pc polar emission extending orthogonal to the disk. The polar emission exhibits patchiness, which we attribute to clumps of dust. Flux enhancements to the East and West of the disk are seen for the first time. We distinguish the temperature profiles of the disk and the polar emission: the disk shows a steep temperature gradient indicative of denser material; the polar profile is flatter, indicating clumpiness and/or lower dust density. The unresolved flux shows a high temperature, $\approx$370 K. The polar dust remains warm ($\sim$200 K) out to 1.5 pc from the disk. We attribute approximately 60% of the 12 μm flux to the polar dust, 10% to the disk, and 6% is unresolved; the remaining flux is resolved out. The recovered morphology and temperature distribution resembles modeling of accretion disks with radiation-driven winds at large scales, but we place new constraints on the sub-parsec dust. The subparsec features imaged here place new, spatially resolved constraints on physical modeling of circumnuclear dust in active galaxies; we show strong evidence that the polar emission consists of dust clumps. The dynamics of the structures and their role in the Unified Model remain to be explored.

The inner parsec of NGC 1068

Pierre Vermot

Astronomical Institute - Czech Academyof Sciences

I present a description of the inner parsec of NGC 1068, a famous nearby AGN.

The presentation will mainly discuss a GRAVITY/VLTI observation, and how it was used to constrain a 3D radiative model of the hot dust in the inner region of the torus at unprecedented spatial resolution. This region is complex, and the NIR emission alone is not sufficient to draw a complete description of it. Hence, other observations at very high angular resolution will be presented in an attempt to fill the gaps and understand the mechanisms operating in this central parsec region.

ELT/METIS and the AGN torus

Leo Burtscher
Leiden Observatory

The Mid-infrared E-ELT Thermal Infrared imager and Spectrograph (METIS) is one of the three first-light instruments selected for the European Extremely Large Telescope (ELT) and will cover the thermal infrared wavelength range, from ca. 3-13 microns. It will be a versatile instrument featuring diffraction-limited imaging and long-slit spectroscopy in the L/M and N bands as well as high spectral resolution (R$\sim$100,000) integral field spectroscopy in the L and M bands.

Its spatial resolution of 25 (70) mas in the L (N) band corresponds to a linear scale of 1 (3) parsec in nearby (10 Mpc) galaxies. For nearby AGNs, METIS forms the missing link between JWST and ground-based interferometry in both resolution and sensitivity. METIS will primarily observe continuum emission from dust at 100-800 K, but it will also be sensitive to the emission lines in this wavelength range, e.g. Brackett alpha, coronal lines like [Si IX] and [Ar VI] and [Al VI], molecular lines of CO and H2O, and broad silicate emission and absorption lines.

As such it is well matched to tackle several of the outstanding questions in current AGN research including "What triggers AGN activity?" and "How do AGN outflows connect to the host galaxy?". In this talk, I review METIS' instrumental capabilities with a particular focus on the prospects for AGN research.

Modeling and resolving AGN IR nuclear emission in the era of 30-m class telescopes

Robert Nikutta
NOIRLab

All resolved parsec-scale emission from AGNs to date is thanks to interferometers in the Near (NIR) to Mid-Infrared (MIR), and in the sub-millimeter to millimeter regimes. In the case of MIR, the interferometric combination of just a few telescope beams does resolve the emission but can not reconstruct an image directly, without resorting to modeling the sampled brightness distribution in the sky. A future generation of extremely large telescopes with apertures up to 40 meters is currently being planned or built. They will not only resolve the nuclear IR emission in nearby AGNs, but will also be able to deliver images that will allow us to characterize the emission morphology directly. This will help in understanding the origin of observed morphologies, which, somewhat in tension with classical AGN unification, in a sizable fraction of nearby AGNs shows a clear elongation in the polar direction of the system, not necessarily where the IR-emitting dust is believed to reside around AGNs.

To understand the makeup and geometry of the dusty obscurer in AGNs, empirical comparison of modeled 2d emission morphologies with observations will no longer be sufficient. Instead, models must now deliver the emergent 2d brightness distribution as the result of radiative transfer calculations through a 3d distribution of dusty matter. We introduce with HYPERCAT a large hypercube of 2d model images, across many wavelengths, computed for a large volume of parameter space with the 3d CLUMPY model of dusty AGN tori. We also deliver a Python software suite designed to interpolate a realistic image at any intermediate wavelength or parameter value. HYPERCAT can then simulate observations (e.g., single-dish, interferometry, IFU), can compute the PSFs of TMT, GMT, ELT, Keck, and JWST telescopes, and can take camera pixelization and detector noise into account. Finally, HYPERCAT is not limited to AGN models, but can indeed be supplied with any other hypercube of images as long as images close in parameter space are also close in the appearance of their images.

Using HYPERCAT, we demonstrate how ELTs will resolve the nuclear AGN emission at NIR and MIR wavelengths, and we explore the parameter ranges that produce images with polar elongation. We find that on scales of several parsecs "classical" clumpy AGN torus models can deliver the observed polar elongations (y/x extension about 1.5-2). On larger scales of tens of parsecs other components, likely non-torus, may be required to explain current IR observations. We also fit recently published images of NGC 1068 obtained with VLTI/GRAVITY in the K band, and derive compatible 3d dust distributions.

Molecular and ionized gas kinematics in nearby active galaxies: a view from Near-IR observations

Marina Bianchin

Federal University of Santa Maria (UFSM)

We study the gas distribution and kinematics of the ($43.43 \leq \log \text{Lbol} \leq 44.83$) nearby ($0.004 \leq z \leq 0.014$) Seyfert galaxies observed with the Near-infrared Integral Field Spectrograph (NIFS) in the J(1.25μm) and K(2.2μm) bands. We analyse the most intense emission lines detected on these spectral wavebands: [Fe II] 1.2570 μm and Paβ and H_2 2.1218 μm, that traces the hot ($\sim$2000 K) molecular gas. The dominant kinematic component is rotation in the disc of the galaxies, except for the ionised gas in NGC 5899 which shows only weak signatures of a disc component. We find ionised gas outflow in four galaxies, while signatures of H_2 outflows are seen in three galaxies. The ionised gas outflows display velocities of a few hundred km/s, and their mass-outflow rates are in the range 0.005-12.49 $M_\odot$/yr. Their kinetic powers correspond to 0.005-0.7 per cent of the AGN bolometric luminosities. Besides rotation and outflows signatures in some cases, the H_2 kinematics reveals also inflows in three galaxies. The inflow velocities are 50-80 km/s and the mass inflow rates are in the range $1\text{-}9 \times 10^{-4}$ $M_\odot$/yr for hot molecular gas. These inflows might be only the hot skin of the total inflowing gas, which is expected to be dominated by colder gas. The mass inflow rates are lower than the current accretion rates to the AGN, and the ionised outflows are apparently disturbing the gas in the inner kpc.

Mid-IR and Optical Emission Line Diagnostics for Simultaneous IMBH and Stellar Excitation in Dwarf Galaxies

Chris Richardson

Elon University

Intermediate mass black holes (IMBHs) in $10^3 - 10^4$ $M_\odot$ range remain scandalously undetected. Dwarf galaxies show promise in revealing active IMBHs intermingled with persistent star formation. We developed photoionization simulations to address the uncertainties associated with mixing IMBH and starlight excitation, complex gas cloud geometries, and differing AGN SED shapes. We find that AGN emission line diagnostics in optical and mid-IR AGN diagnostics are often degenerate with respect to these uncertainties. However, we are able to show, in contrast to recent work, that [O III]/Hβ typically remains bright for dwarf AGN powered by IMBHs down to 10^3 $M_\odot$. Corroborating recent work, we also find that dwarf AGN can be classified as star forming and/or AGN depending on the optical diagnostic being used. In the mid-IR, [O IV] 25.9μm and [Ar II] 6.98μm are far more robust indicators of AGN activity

than optical diagnostics. We provide several diagnostic diagrams based on these lines, valid over a wide range of AGN fractions, metallicities, and ionization parameters, to find active IMBHs in dwarf galaxies in the era of JWST.

Local analogs to high-redshift galaxies

Skarleth Motino Flores

USRA/SOFIA

Understanding the physical processes driving galaxy formation and evolution is one of the most important goals of observational cosmology. It is also one of the most difficult problems to address due to the large distances and time scales involved. When observing the most distant universe, also known as the high-redshift (high-z) universe, we are observing the young universe, the first galaxies that were formed.

The faintness and small sizes of galaxies in the early universe make detailed observations extremely challenging with current telescopes. An alternative and complementary approach is to identify nearby galaxies that are analogs to the distant galaxies, where the physical processes can be studied in greater details than what is possible in high-z galaxies.

I have therefore selected a sample of nearby star-forming galaxies that are potential local analogs to high-z galaxies. These local galaxies are young, star-forming, have low metallicities and are likely to have star formation histories (SFH) similar to the high-z galaxies. In order to characterize these galaxies, I use observations with the SOFIA telescope together with ancillary data, to study their dust properties and how it is related to the star formation activity. I also use FIR fine structure lines to identify the neutral and ionized gas components in the galaxies.

My overall aim is to produce a detailed characterization of the properties of the local galaxies and determine their SFH and analyze their connexion with photometric and spectroscopic results for high-z galaxies obtained with Herschel and ALMA.

In this talk, I will present the dust emission characterization through a two-component black-body, derived using infrared observations with SOFIA/HAWC+ instrument and ancillary data from Spitzer, Herschel, among others. Then I present the Spectral Energy Distribution (SED) from ultraviolet to far-infrared wavelengths for the local analogs to high-z galaxies, which is derived using the fitting procedure LIGHTNING. Also, the ionized gas is characterized by the [C II]-158 microns and [O III]-88 microns fine-structure lines using the SOFIA/FIFI-LS integral field unit (IFU). These lines are accessible with ALMA for high-z objects and my results for the local analogs can be used to infer the interstellar medium properties of the high-z galaxies.

Resolving the magnetized accreting flow toward active galactic nuclei: an infrared polarimetric approach with ELTs

Enrique Lopez Rodriguez
KIPAC/Stanford

To explain the transfer of energy surrounding black holes, most of the theoretical models (BZ; Blandford & Znajek 1977, Beckwith et al. 2009, Begelman & Silk 2016), if not all, must incorporate magnetic fields (B-fields). As matter rotates and gets closer to the black hole, the outgoing radiation results in an extraction of energy from the black hole. The BZ process states that matter rotating around the black hole must have a B-field. This is the main physical mechanism for powering the core of galaxies that contain active super massive black holes (SMBHs), known as active galaxies. Although these processes can explain the dynamics of matter close to the black hole, and all host galaxies contains kpc-scale B-fields, there is still no clear scientific interpretation of how the matter from the host galaxy at scales of 10-100 pc-scales feeds SMBHs.

Future infrared (IR) polarimetric capabilities in 30-m class telescopes will allow us to obtain a complete picture of the link between extragalactic B-fields and black hole growth from a magnetohydrodynamical framework. The combination of high-spatial resolution ($\sim$few pc-scales for galaxies $\leq$ 40 Mpc), high-sensitivity (several microJy), and bi-hemispheric observations will provide a statistically significant sample of nearby active galaxies to perform IR polarimetric observations of their resolved polarized thermal emission at 1-100 pc-scales.

In this talk, I present the role of B-fields in the unification scenario of active galaxies and how we can detect the signature of B-fields in the well-defined dusty structure in the core of active galaxies. I will present a review of what we have learnt from IR polarimetric observations of active galaxies and the prospects of this analysis using future extremely large telescopes.

Day 4 - Related Posters and Pre-recorded Talks

Torus and polar dust emission in GATOS Seyfert galaxies

Almudena Alonso Herrero

Centro de Astrobiología

I will present high (0.3″) angular resolution mid-IR observations of nearby Seyfert galaxies selected from the Galaxy Activity, Torus, and Outflow Survey (GATOS) and compare them with ALMA far-IR continuum and CO(3-2) observations. We detected extended mid-IR emission (typically in the polar direction) in more than half the sample although the unresolved component contributes more than 60% of the emission in this sample. The Eddington ratios and nuclear hydrogen column densities (NH) of half the sample are favorable to launching polar and/or equatorial dusty winds, according to numerical simulations. We generated new radiative transfer CAT3D-WIND disk+wind models and model images at 8, 12, and 700micron. We tailored these models to the properties of the GATOS Seyferts in this work. At low wind-to-disk cloud ratios, the far-IR model images have disk- and ring-like morphologies. The characteristic "X"-shape associated with dusty winds is seen better in the far-IR at intermediate-high inclinations for the extended-wind configurations. In most of the explored models, the mid-IR emission mainly comes from the inner part of the disk and cone. Extended biconical and one-sided polar mid-IR emission is seen in extended-wind configurations and high wind-to-disk cloud ratios. When convolved to the typical angular resolution of our observations (obtained with 8-10m class telescopes), the CAT3D-WIND model images reproduce qualitative aspects of the observed mid- and far-IR morphologies. However, low to intermediate values of the wind-to-disk ratio are required to account for the observed large fractions of unresolved mid-IR emission in our sample. I will also present predictions for observed torus-wind morphologies with the METIS instrument on the ELT based on these CAT3D-WIND models. The results in this work provide observational support for the torus+wind scenario. The wind component is more relevant at high Eddington ratios and/or active galactic nucleus luminosities, and polar dust emission is predicted at nuclear column densities of up to 10^{24} cm^{-2}. The torus or disk component, on the other hand, prevails at low luminosities and/or Eddington ratios.

Diffuse Ionized Gas in Edge-On Galaxies

Janayna de Souza Mendes

UFSC

Galaxies are large objects present in the universe, mainly composed of gas, dust and stars, which can be classified in different ways. So when we have a spiral galaxy that, when observed, you can only see its edge, we call it an edge-on galaxy. Thus, to understand the sources of extraplanar diffuse gas ionization (DIG), our sample is composed of 8 edge-on galaxies with integrated field spectroscopic data observed with MUSE at the VLT, located in Chile. Thus, optical emission lines were measured to analyze their changes as a function of distance to the galactic plane and then compare the results obtained with theoretical models of photoionization to try to find the main sources of ionization in extraplanar DIG. In the preliminary results presented for the galaxy IC1553, it is possible to observe that the DIG extends outside the galactic disk, and that the ratio of emission lines [N II]/Halpha increases as it moves away from the plane of the galaxy.

Surprisingly Strong K-band Emission Found in Low Luminosity Active Galactic Nuclei

Antoine Dumont

University of Utah

Infrared (IR) integral field spectroscopy (IFU) spectroscopy has demonstrated to be a powerful tool in the study of the ‘dusty’ torus, which plays a significant role in the AGNs unified theory. The observed scaling relations between IR emission and nuclear X-ray for bright AGN are in good agreement with this model. However, it is unclear if this relation holds for less-luminous AGN. In this work, we present the detection of near-infrared (NIR) emission from low-luminosity AGNs (LLAGNs). Our galaxy sample includes 15 objects with detected (2-10) keV Xray emission, dynamical black hole mass estimates from the literature, and available Gemini/NIFS IFU data. We decompose the spectral data cubes into a stellar and continuum component, assuming the continuum component comes from thermal emission from hot dust (as seen in higher luminosity AGN). We detect nuclear thermal emission in 14 out of 15 objects. This emission causes weaker CO absorption lines and redder continuum (2.05-2.28 microns) in our K-band data, as expected from hot dust around an AGN. The NIR emission is correlated with the (2-10) keV X-ray flux, providing further evidence of an AGN origin. We examine the dependence of NIR and (2-10) keV X-ray luminosity as a function of the black hole accretion rate, and find an excess of NIR emission at the lowest Eddington ratios. The nature of this emission remains unclear, with one possibility being an increased contribution from jet emission at these low luminosities. These observations suggest JWST will be a useful tool for detecting the lowest luminosity AGN.

Resolving Polar Dust in AGN with JWST: Going Beyond the PSF

Mason Leist
The University of Texas at San Antonio (UTSA)

The launch of the James Webb Space Telescope (JWST) promises to revolutionize infrared astronomy and our understanding of outflows in active galactic nuclei (AGN). Our approved Cycle 1 program (GO 2064), will use JWST's exquisite low surface brightness sensitivity in the mid-infrared (MIR) to observe the diffuse polar dust emission found in AGN with unprecedented sensitivity. Relying on JWST's stable PSF, we will use deconvolution techniques to establish the structure of this diffuse emission below the resolution of the telescope. To explore these techniques, we have used MIRISim to simulate JWST's complex PSF applied on a model of an AGN consisting of a resolved biconical structure and an unresolved AGN point source. Here we report on our assessment of the optimum deconvolution strategy, based on comparisons of the flux, FWHM, and Strehl ratios of the deconvolved images with the input model. Our work aims to connect the observations of high-resolution MIR imagers on large ground-based telescopes with the much higher sensitivity JWST observation.

Resolving the extended emission of H2 on M58

Ivan E. Lopez
UNIBO-INAF

We developed a spectral fitting tool that allows the modeling of physical emission processes. We applied this tool to the SINGs sample, looking for low luminosity AGN with molecular hydrogen emission. Our results show evidence of extended H2 emission surrounding the nuclear region of M58 up to distances of 1 kpc. H2 emission is likely excited by shocks triggered by the interaction between the radio jet and the interstellar medium. The regions of shocked gas are also characterized by a low PAH ratio PAH7.7/PAH11.3, which might be accounting for low-rate star formation or destruction of dust grains. We also obtained better spatial resolution images in NIR with Gemini observations, which shows a correspondence between the H2 extended emission and dust lanes observed with HST.

The Ionization and Destruction of PAHs in AGNs

Yanxia Xie
The Kavli Institute for Astronomy and Astrophysics at Peking University (KIAA-PKU)

Polycyclic aromatic hydrocarbon (PAH) emission serves as a valuable tracer of star formation rate (SFR) and the physical conditions of the interstellar medium in galaxies. PAH emission is also detected in galaxies containing active galactic nuclei (AGNs), both in the integrated mid-infrared (IR) spectra and from spatially resolved spectra of nearby galaxies. However, their applicability to the host galaxies of AGNs as an SFR indicator is controversial given the ability of PAH molecules to survive the harsh radiation field of an active nucleus. Many works have shown that AGNs present distinctive PAH band ratios and mass content from the star-forming galaxies. In this talk, I will present our recent studies on PAH emissions of a lower-redshift quasar sample. We find that PAHs increasingly underestimate the SFR (by $\sim$0.5 dex) for quasars with bolometric luminosity $> 10^{46}$ ergs/s. Furthermore, the PAH ratios indicate that powerful AGNs preferentially destroy small grains and enhance the PAH ionization fraction in their host galaxies. In the end, I will discuss how the next-generation observations from space and ground-based telescopes will advance our understanding in this field.

Day 5 - Live Talks

Polycyclic Aromatic Hydrocarbons (PAHs) and dust in HII regions and Photodissociation regions.

Els Peeters
University of Western Ontario

The IR sky is aglow with emission from HII regions and Photodissociation regions. Their IR signature is extremely rich revealing strong HI recombination lines, atomic fine-structure lines, molecular hydrogen lines, Polycyclic Aromatic Hydrocarbon (PAH) emission and dust continuum emission. As such, these regions are a prime target for ground- and space-based IR facilities. In this talk, I will discuss how synergies between ground-based facilities and JWST can advance our understanding of HII regions and Photodissociation regions, in particular with regards to PAHs and dust which dominate the IR emission of these regions. I will highlight present and future ground-based observations that will complement the JWST Early Release Science Program "Radiative feedback from massive stars" which will observe the Orion Bar.

A UIR band feature detected in the N-band low-resolution spectrum of WR 125 with Subaru/COMICS

Izumi Endo
The University of Tokyo

Given their carbon-rich nature, dusty WC binaries could exhibit the unidentified infrared (UIR) bands. Additionally, they can be possible source of the carries of the UIR bands in the early universe due to the shorter timescale for massive stars to evolve to WR stars.
In this talk, I will present the detection of a broad 8 μm feature in newly formed dust around the carbon-rich Wolf-Rayet (WC) binary WR 125 from N-band low-resolution spectroscopy and N-band and Q-band imaging with Subaru/COMICS in 2019 October. WR 125 is a colliding wind binary (WC7+O9) that exhibited renewed dust formation starting in 2018, ~28 years after its first dust formation episode had been observed. Archival infrared spectra of five dusty WC stars, WR 48a, WR 98a, WR 104, WR 112 and WR 118 obtained with ISO/SWS are reanalyzed and compared with the WR 125 spectrum to search for a similar feature. I analyze the dusty WC spectra using two different extinction curves to investigate the impact of interstellar extinction correction on the presence and/or properties of the 8 μm feature. All of the dusty WC spectra dereddened with the two different extinction curves show a broad (FWHM=1-2 μm) feature around 8 μm. I suggest that these 8 μm features seen in the dusty WC spectra may be related to the Class C unidentified infrared (UIR) bands. In order to better understand the nature of the UIR bands of WR stars, which can possibly be a significant contributor of the band carries in the early universe, further infrared observations of other dusty WC stars and multi-epoch observations of episodic/periodic dust forming WC stars are needed. These can be directly addressed with the mid-IR instrumentation on upcoming platforms such as the Tokyo Atacama Observatory, the James Webb Space Telescope, and 30-m class telescopes.

High Resolution Temperature Map of the Central half-parsec of the Galaxy

Cuc Dinh

Univeristy of California, Los Angeles

The proximity of the center of our Galaxy offers a unique opportunity to observe the environment of a supermassive black hole with a resolution inaccessible in any other galaxy. The Galactic supermassive black hole is not very bright but there is a large reservoir of material – the Circumnuclear Disk – presently orbiting outside a distance of ∼pc. Some gas is flowing inward orbiting along spiral trajectories that collide near the central region. There are also a large number of small-scale structures that trace local phenomena. One example is the population of G-objects – dust enshrouded objects believed to be the product of binary mergers. In order to characterize all these features we created a high-resolution dust temperature map of the central half parsec by comparing Lp (3.8 microns) and PAH1 (8.6 microns) band data obtained respectively with the NIRC2 imager at Keck Observatory and the VISIR camera on the VLT. With our color temperature map we were able to identify several previously unidentified compact sources. Some might belong to the G-objects population. We also characterize the temperature of several known features, both resolved and unresolved, in the region.

Current and future for infrared observations of supernovae and evolved stars

Mikako Matsuura

Cardiff University

It has been considered that dying stars play important roles for chemical evolutions of galaxies, by providing newly formed elements and by forming and destroying dust grains. High mass stars end their lives at explosive events, supernovae (SNe). I will present existing infrared observations of SN 1987A, using SOFIA, and VLT, as well as ALMA, and prospects of JWST. These observations demonstrate dust and elements ejected by SN, as well as the process of dust grains being destroyed by SN shocks. Low- and intermediate-mass stars evolve into the asymptotic giant branch (AGB) phase, shedding their mass. The material lost by the AGB stars are ionised and brighten up as a planetary nebula (PN), when the central star reaches to the white dwarf phase. I will present prospect of JWST observations of dust in the PN, NGC 6302, an excellent site of mineralogy, and demonstrate importance of incoming high-angular and high-spectral infrared spectrometry.

Multiple mass loss events on timescales of hundreds of years of the post-Red Supergiant the Fried Egg

René Oudmaijer

University of Leeds

The fate of a massive star during the latest stages of its evolution is highly dependent on its mass-loss rate and geometry. The geometry of the mass-loss process can be inferred from the shape of the circumstellar material, having a significant influence on the evolution of massive stars (25 and 40 Msun), i.e., type II SN progenitors. In this context, yellow hypergiants (YHGs) offer an excellent opportunity to study mass-loss events. I will present the analysis of a large set of near- and mid-infrared data in spectroscopic, photometric, and interferometric (GRAVITY/VLTI) modes, towards the IRAS 17163-3907 and its associated Fried Egg Nebula. This talk will cover the first reconstructed images of IRAS 17163-3907 around the 2-micron emission tracing milli-arcsecond scales, but also how our 2D radiative transfer modelling of VISIR data led to the discovery of a third hot inner shell with a maximum dynamical age of only 30 yr. We find three observed distinct mass-loss episodes which are characterised by different mass-loss rates and can inform theories of mass-loss mechanisms, which is a topic still under debate both in theory and observations. These will be discussed in the context of photospheric pulsations and wind bi-stability mechanisms.

Revisiting and Resolving Carbon-rich Wolf-Rayet Dust Factories

Ryan Lau

Institute of Space and Astronautical Science (ISAS)

For decades, a subset of carbon-rich WR (WC) stars have been known to actively form dust despite their extreme environments. Although these systems can produce copious amounts of dust, they have been commonly overlooked as significant sources of dust in the ISM of galaxies in the local and early Universe due to the persisting mysteries on their dust formation and the influence of binary companions. In this talk, I will highlight our major results that combine a dust SED analysis of Galactic dust-forming WC stars with Binary Population and Spectral Synthesis (BPASS) models and show that WC binaries can be early and significant sources of dust at LMC-like and solar metallicities in constant star-forming environments. I will also discuss the results our research program that combines archival and new infrared (IR) imaging observations to investigate the properties of dusty WC outflows. Our future plans for studying dusty WC outflows notably include approved Early Release Science observations with the James Webb Space Telescope (JWST) in Cycle 1.

Analysis of RSGs in YMC in the central region of the MW

Randa Asad

American University of Sharjah

Recent surveys uncovered new Young Massive Clusters (YMCs) that host dozens of Red Supergiants (RSGs) in the inner Milky Way. These clusters are ideal for studying the most recent and violent star formation events in the inner Galaxy. However, due to the high extinction that affects the Galactic plane, they need to be studied through infrared (IR) spectroscopy. IR spectra of RSGs have proven to be powerful tools for obtaining chemical abundances. I will present the results obtained for our RSGs spectra observed with VLT/Xshooter.

Stars lensed by the Supermassive Black Hole in the center of the Milky Way: predictions for future high-resolution instruments

Michał Michałowski

Astronomical Observatory Institute, Adam Mickiewicz University

Gravitational lensing is an important prediction of general relativity, providing both its test and a tool to detect faint but amplified sources and to measure masses of lenses. For some applications, (e.g., testing the theory), a point source lensed by a point-like lens would be more advantageous. However, until now only one gravitationally lensed star has been resolved. Future telescopes will resolve very small lensing signatures for stars orbiting the supermassive black hole (SMBH) in the center of the Milky Way. The lensing signatures, however, should be easier to detect for background stars. I will show the prediction that the Extremely Large Telescope (ELT), Thirty Meter Telescope (TMT), and Giant Magellan Telescope (GMT) will resolve the lensed images of around 100 stars in the background of the SMBH. The James Webb Space Telescope (JWST) will likely be limited by the confusion caused by stars near the Galactic center. I will also describe what observational characteristics are needed to achieve this (resolution and depth). Finally, I will discuss other observational signatures of lensed stars, which could be searched for with high-resolution instruments.

Day 5 - Related Posters and Pre-recorded Talks

PAHs Near and Far: Ground and Airborne 3-5 micron observations of PAHs in Planetary Nebulae and Star Forming Regions in the Era of JWST

Erin Smith
National Aeronautics and Space Administration (NASA) Goddard Space Flight Center (GSFC)

Polycyclic Aromatic Hydrocarbons (PAHs) exhibit bright, broad emission features throughout the infrared with main features at 3.3, 6.2, 7.7, 8.6, 11.3 and 12.7 μm. These bands arise from the UV excitation of PAHs and relaxation through the vibration, bending and/or stretching of the C–H and C–C bonds. This emission has been observed in multiple astronomical phenomena, including planetary nebulae, where they are believed to be formed, and star-forming regions, which has led to their use as a marker for estimating star formation rates in distant galaxies. Many of these bands are accessible from ground-based observatories, including 3.3 micron PAH feature and its associated aliphatic features at 3.4-3.6 microns. We used ground-based (Lick/FLITECAM and Keck/NIRSPEC) observations of the ~3-5 micron spectra of young planetary nebulae and nearby star-forming regions, to investigate the spatial distribution and spectral variation of PAH emission, and stratospheric (SOFIA/FLITECAM) observations to constrain the theoretical contribution of the 4.4-4.8 micron deuterated-PAH features and the weak 5.25 PAH emission feature. Studying young PNs and nearby star-forming regions with ground-based telescopes gives a unique opportunity for fully understanding PAH emission, processing and variation that can be used in interpreting the extra-galactic PAH spectra JWST will study.

Investigating Star Formation at the Galactic Center with SOFIA/FORCAST

Matthew Hankins
Arkansas Tech University

The Galactic Center (GC) contains some of the most extreme conditions for star formation in our galaxy, yet the predicted star formation rate (SFR) overestimates the observed SFR by an order of magnitude. Mid-infrared observations trace warm (~100 K) dust emission, which are ideal for probing recent star formation and provide an important piece of this puzzle. The GC is well known for its bright and complex emission in the infrared, which have presented issues with confusion and/or saturation. Recent observations with SOFIA/FORCAST have overcome much of these issues to provide maps of the brightest portions of the inner ~200 pc of our galaxy, and we will present continuing work to study relatively isolated sources in the region which is part of an ongoing SOFIA cycle 9 program.

Using MiraFitter to Identify Circumstellar Dust Around Optically-Thin Oxygen-Rich Mira Variables

Lisa Shepard
University of Texas at San Antonio (UTSA)

Both ground-based and space-based observatories are capable of measuring infrared spectra of dust in space. There are various studies of dusty environments that focus on the shape and strength of silicate features near 10μm and 18μm. The study I present may impact how people interpret silicate dust in their observations. Radiative Transfer (RT) modeling has often been used to analyze spectra and obtain a match to the overall spectral energy distribution with certain parameters. While RT modeling should allow us to build a spectrum that includes all contributions to the observed spectra, we are hampered by a lack of detailed or appropriate laboratory data for such modeling. This limits the application of RT modeling if we want to determine the detailed mineralogy of the dust.

In some cases (usually very optically-thin scenarios), we can simply eliminate a continuous contribution to the observed spectrum to isolate any observed features and measure their basic spectral parameters. I created a program called MiraFitter to investigate several methods of continuum elimination using spectroscopy data for the archetypal dusty AGB star, Mira. I have investigated the $\sim$10μm and $\sim$18μm spectral features in the continuum-eliminated spectrum including peak position, barycenter, and full width half maxima (FWHM). The positions and widths of observed spectral features were compared with those seen in laboratory spectra. The results show that the method of continuum elimination matters for correct identification of dust minerals, while varying the temperature and precise continuum shapes do not have a major effect on the positions of spectral features.

Exploring the Largest and Brightest Massive Star-Forming Regions of the Milky Way

James De Buizer
Stratospheric Observatory For Infrared Astronomy (SOFIA) - Universities Space Research Association (USRA)

Far less is known about high-mass star formation compared to low mass star formation. Furthermore, most stars form in clusters, but most of the research focusses on the processes and environmental impacts of isolated star formation rather than star formation in clustered environments. The most massive young OB clusters are formed within giant HII (GHII) regions, making them ideal laboratories for studying the environments of both massive and clustered star formation, simultaneously.

In this talk, I will discuss the results from our ongoing mid-infrared observations of GHII regions in the Milky Way with the Stratospheric Observatory For Infrared Astronomy (SOFIA) aimed at understanding the physical and kinematic properties of clustered star forming regions. By combining the SOFIA data with Spitzer-IRAC data and Herschel data, as well as radio continuum and line data, we have a rich, multi-wavelength dataset that allows for detailed analyses of each GHII region. By the time of this meeting, we will have published in-depth studies of 7 of the 43 GHII regions in our Galaxy, with more studies yet to come.

GHII regions are too bright to be observed by JWST. However, emission from GHII regions are believed to dominate the overall emission of typical galaxies like our Milky Way. Therefore, in-depth studies of the nature of Milky Way GHII regions will help to decipher the emission of distant galaxies that JWST will be studying.
