Oral Abstracts for

Exoplanets, the Solar System and the Origins of Stars, Planets and Life

Parallel Session

Exoplanets, the Solar System and the Origins of Stars, Planets and Life

Tuesday, June 26, 2018

Start	End	Session	Speaker
8:00 AM	9:00 AM	Registration - Grand Ballroom Foyer	
8:45 AM	9:00 AM	Welcome - Grand I	
9:00 AM	10:00 AM	**Plenary: The Formation of Planets in the Terrestrial Zone and Conditions of Habitability**	**Andrea Isella** (B. Matthews, Chair)
10:00 AM	10:20 AM	Poster Flashes - Exoplanets	
10:20 AM	11:00 AM	Break and Posters	
11:00 AM	12:00 PM	**Plenary: The Cosmic Harmony of Galaxies and their Black Holes**	**Alex Pope** (Jackie Hodge, Chair)
12:00 PM	12:20 PM	Poster Flashes - Galaxy Evolution	
12:20 PM	2:00 PM	Lunch	
Exoplanets, the Solar System and the Origins of Stars, Planets and Life - David Wilner, Chair			
2:00 PM	2:30 PM	**Star Formation in the Galaxy**	**Yancy Shirley**
2:30 PM	2:50 PM	Constraints on the Structure of Embedded Disks with ALMA/the VLA: Setting the Stage for the ngVLA	Patrick Sheehan
2:50 PM	3:20 PM	**Molecular Inheritance and Processing in Protoplanetary Disks**	**Fred Ciesla**
3:20 PM	4:00 PM	Break & Posters	
Exoplanets, the Solar System and the Origins of Stars, Planets and Life - Brett McGuire, Chair			
4:00 PM	4:30 PM	**High Resolution Imaging of Protoplanetary Disks**	**Laura Perez**
4:30 PM	4:50 PM	What Drives Accretion in Protoplanetary Disks?	Jake Simon
4:50 PM	5:10 PM	The Circumstellar Disk and Asymmetric Outflow of the EX Lup Outburst System	Antonio Hales
5:10 PM	5:30 PM	The First Kinematical Detection of Embedded Planets in Protoplanetary Disks	Richard Teague
5:30 PM	6:00 PM	**M Dwarfs: the Treasure Trove of Planets**	**Courtney Dressing**
6:00 PM	7:00 PM	Poster Reception	

Bold = Invited Speaker

Italics = ngVLA Community Studies Talk

Andrea Isella (Rice University)

Topic: Exoplanets, the Solar System and the origins of Stars, Planets and Life

The Formation of Planets in the Terrestrial Zone and Conditions of Habitability

Astronomical observations have revealed thousands of exo-planets including the first exo-planets located in the habitable zone of their host star. Furthermore, observations of young stellar systems at unprecedented angular resolution have delivered images of newborn planetary systems that unveil the physical processes involved in the assembly of planets. Key challenges for the next decade are to characterize the population of planets in the habitable zone, investigate their formation mechanism, understand how they might acquire the key ingredients for life, and assess their capability to sustain life. Addressing these questions requires a multi-disciplinary approach and a substantial advance in the astronomical instrumentation. In my talk, I will present a review of the study of planets in the terrestrial zone and discuss some of the technical capabilities required to unveil the their formation and the conditions of habitability.

Alexandra Pope (University of Massachusetts Amherst)

Topic: Galaxy Evolution Mechanisms

The Cosmic Harmony of Galaxies and their Black Holes

In this talk, I discuss our picture of how galaxies and their supermassive black holes coevolve over cosmic time, especially during the peak, heavily dust-obscured, epoch of galaxy evolution from z~1-4. The past decade has revealed fundamental relationships that govern how galaxies grow through star formation, and become passive. Observations of active black holes in distant galaxies have increased thanks to a multi-wavelength approach, but our precise understanding of how they coevolve with stars over cosmic time remains limited. Future infrared space telescopes such as JWST and, eventually Origins Space Telescope, will concurrently measure the star formation and black hole accretion rates in typical galaxies out to the highest redshifts.

Yancy Shirley (University of Arizona)

Topic: Exoplanets, the Solar System and the origins of Stars, Planets and Life

Star Formation in the Galaxy

Star formation occurs in molecular clouds with hierarchical structure that observers have organized into filaments, clumps, and cores. Recent surveys of the Galactic plane and the nearby Gould Belt clouds at far-infrared through millimeter wavelengths have identified large, statically significant samples of clumps and cores that allow us to study how their physical properties vary in different evolutionary stages. Despite this recent progress, much work still remains to be done, especially at high angular resolution. I shall first review the topology of molecular clouds with an emphasis on the physical properties of filaments, clumps, and cores. I shall also highlight how future proposed radio telescope facilities (i.e. ngVLA and AtLAST) can directly answer some of the fundamental questions in star formation.

Patrick Sheehan (University of Oklahoma)

Josh Eisner (University of Arizona)
John Tobin (University of Oklahoma)

Topic: Exoplanets, the Solar System and the origins of Stars, Planets and Life

Constraints on the Structure of Embedded Disks with ALMA/the VLA: Setting the Stage for the ngVLA

Class 0 & I protostars are thought to represent early stages in the star formation process. Protostellar disks form during these early stages, when both disk and protostar are still embedded in their natal envelope. As such, they provide an opportunity to study the initial conditions of protostellar disks, before any significant disk evolution or planet formation has occurred. We have conducted a survey of Class 0 & I protostars with ALMA and the VLA to study the structure of their disks. Our sample includes 9 Class I protostars in Ophiuchus as well as all 330 Class 0 & I protostars from the Herschel Orion Protostar Survey that were observed with ALMA and the VLA as part of the VANDAM Survey. We fit detailed radiative transfer models to our sample and find that Class I disks have similar structure to Class II disks, including several Class I disks with gaps, cavities, and other interesting features. Our measurements show that Class I disks are, on average, more massive than the older Class II disks. As such, Class I disks may be a better representation of the initial mass reservoir available for planet formation. However, the sensitivity and resolution of current facilities, as well as the optical depth of shorter wavelength observations, limit our ability to study the structure of these disks. As such, the ngVLA will be crucial for furthering these works. We will finish by discussing how the ngVLA will advance studies of embedded disks in the future, including resolving the structures of large samples of embedded disks out to 1.5kpc.

Fred Ciesla (University of Chicago)

Sebastiaan Krijt (University of Chicago)

Topic: Exoplanets, the Solar System and the origins of Stars, Planets and Life

Molecular Inheritance and Processing in Protoplanetary Disks

The building blocks of planets originate within molecular clouds, with planet formation beginning once those clouds begin to collapse, giving way to a young star surrounded by a protoplanetary disk. During the formation and early evolution of disk, a period lasting millions of years, the solids and gas originally present in the cloud will be processed in a variety of ways, depending on their location and dynamical evolution through the disk. Close to the star, this processing may include complete vaporization and destruction of minerals and compounds, resulting in the formation of new solids or molecules. Further out in the disk, where temperatures are expected to be <50 K, the processing may be relatively minor, allowing the initial inventory of the molecular cloud to be preserved. The extent, variation, and duration of processing in these various environments is critical to understand as it will set the compositions of the materials from which planets and their atmospheres will form.

Despite recent advances, observations aimed at understanding this processing and the impact it has on planetary materials have proven to be a challenge. Changes in gas composition of infalling and disk material have been observed around the centrifugal barrier of some disks (Sakai et al. 2014), however these distances (~100 AU) are generally well outside the region where planet formation is expected to occur. Observations of regions near where planets form are limited by spatial resolution and the fact that planets form in the optically thick midplane.

Within our Solar System, meteorites provide a record of the processes that occurred within our own protoplanetary disk, the solar nebula. These meteorites contain a mix of materials that record a variety of disk environments and processing histories: from the Calcium, Aluminum-rich Inclusions which appear to have condensed from a gas at temperatures in excess of 1500 K, to pre-solar silicates, SiC, and organics which are preserved dust from the atmospheres of dying stars, which survived incorporation into the solar nebula and avoided any environments which exceed a few hundred Kelvin, otherwise they would have been destroyed (e.g. Krot et al. 2009). The fact that these materials are found together in the same meteorite points to a dynamic disk, where planetesimals form from materials that were mixed and transported across many different environments, being exposed to different pressures, temperatures, and radiation environments along the way. It is this dynamic setting that will set the levels of processing that occurs in these disks and the compositions of planetary building blocks.

I will review the constraints from meteorites on the abundances and distribution of materials which appear to have been inherited from the interstellar medium and discuss how these constraints can be understood in the context of protoplanetary disk models. I will then highlight recent work that allows us to understand the detailed processing that primitive materials experience and how they are altered and transformed within a dynamic protoplanetary disk. Further, I will discuss how we can apply our models for disk evolution and planet formation to connect disk observations to the processes we believe are taking place in the hidden, interiors where planets are forming and what future work is needed to achieve these goals.

Refs: Krot, A. (2009) *Geochimica et Cosmochimica Acta* 73, 4963-4997. Sakai, N. et al. (2014) *Nature* 507, 78-80.

Laura Pérez (Universidad de Chile)

Topic: Exoplanets, the Solar System and the origins of Stars, Planets and Life

High Resolution Imaging of Protoplanetary Disks

The process of disk evolution and planet formation will leave an imprint on the distribution of solid particles at different locations in a protoplanetary disk, resulting in a variety of substructure (gaps, rings, spirals, vortices, clumps, etc.) over large and small scales. The role of these small-scale features is fundamental: theory predicts that without substructure large solids would be lost due to radial drift, impeding planetesimal and planet formation. In this talk, I will highlight recent observations of protoplanetary disks at high spatial resolution, from scattered light to the radio-wave regime, that show some form of substructure, and I will discuss how the different features that we observe may be connected to protoplanetary disk evolution and planet formation.

Jacob Simon (University of Colorado)

Xue-Ning Bai
Kevin Flaherty (Wesleyan University)
Meredith Hughes

Topic: Exoplanets, the Solar System and the origins of Stars, Planets and Life

What Drives Accretion in Protoplanetary Disks?

It is still uncertain what exactly is responsible for driving angular momentum transport in protoplanetary disks, thus setting the environment in which planets are born. This transport may find its origin in turbulence driven by the magnetorotational instability (MRI), magnetically driven winds that remove angular momentum vertically, or some combination of both. Recently, using ALMA, our group has made substantial progress in constraining the strength of turbulence in the outer regions of protoplanetary disks. Surprisingly, these observational constraints stand in stark disagreement with predicted signatures of turbulence from numerical simulations, bringing into question the turbulent origin of angular momentum transport. These results might suggest that accretion is driven (at least in the outer disk) primarily by a magnetically launched wind. However, here, I will present recent numerical simulations showing that even in a wind-dominated accretion flow, significant turbulence is induced by highly localized regions of active MRI superimposed on an otherwise laminar flow within the disk. I will then show that in the outer disk, both weak magnetic fields and very low ionization levels are necessary in order to be consistent with the low turbulence values inferred from observations. In light of these results, I will present a new model for protoplanetary disks, in which a large-scale vertical magnetic field confined to the inner disk blocks ionizing radiation from reaching the outer disk, while allowing the inner disk to continually accrete. I will finish the talk by describing several powerful predictions made by this new model that will be testable with future ALMA observations.

Antonio Hales (NRAO/ALMA)

S. Perez (U. Chile)
M. Saito (NAOJ)
C. Pinte (U. Grenoble)
L. Knee (NRC Herzberg Astronomy and Astrophysics Research Centre)
I. de Gregorio-Monsalvo (ESO/ALMA)
B. Dent (ESO/ALMA)
C. Lopez (ALMA)
A. Plunkett (ESO)
P. Cortes (NRAO/ALMA)
S. Corder (NRAO/ALMA)
L. Cieza (U. Diego Portales)

Topic: Exoplanets, the Solar System and the origins of Stars, Planets and Life

The Circumstellar Disk and Asymmetric Outflow of the EX Lup Outburst System

We present Atacama Large Millimeter/submillimeter Array (ALMA) observations at 0.3”-resolution of EX Lup, the prototype of the EXor class of outbursting pre-main sequence stars. The circumstellar disk of EX Lup is resolved for the first time in 1.3mm continuum emission and in the J=2-1 spectral line of three isotopologues of CO. At the spatial resolution and sensitivity achieved, the compact dust continuum disk shows no indications of clumps, fragments, or asymmetries above 5-sigma level. Radiative transfer modeling constrains the characteristic radius of the dust disk to 23au and a total dust mass of $1.0x10^{-4}$MSun (33 Mearth), similar to other EXor sources. The ^{13}CO and $C^{18}O$ line emission trace the disk rotation and are used to constrain the disk geometry, kinematics, and to estimate a total gas disk mass of $5.10x10^{-4}$MSun. The ^{12}CO emission extends out to a radius of 200au and is asymmetric, with one side deviating from pure Keplerian rotation. We detect blue-shifted, ^{12}CO arc-like emission located 0.8” to the north-west, and spatially disconnected from the disk emission. We interpret this extended structure as the limb-brightened walls of a cavity excavated by an outflow, which are more commonly seen in FUor sources. Such outflows have also been seen in the borderline FU/EXor object V1647 Ori, but they have not been found in EXor objects. Our detection provides evidence that the outflow phenomenon persists into the EXor phase, suggesting that FUor and EXor objects are a continuous population in which outflow activity declines with age, with transitional objects such as EX Lup and V1647 Ori.

Richard Teague (University of Michigan)

Jaehan Bae (Carnegie DTM)
Edwin Bergin (University of Michigan)
Tilman Birnstiel (University Observatory, Ludwig-Maximilians-Universitaet Munich) Dan Foreman-Mackey (Center for Computational Astrophysics, Flatiron Institute)

Topic: Exoplanets, the Solar System and the origins of Stars, Planets and Life

The First Kinematical Detection of Embedded Planets in Protoplanetary Disks

I will present the first kinematical detection of proto-planets embedded in their parental disk. These unique observations open up an entirely new avenue for exploring planetary origins at the time of volatile delivery and across the full radius of the gaseous disk.

We have developed a new method to measure exceptionally precise rotation velocity curves from molecular line emission, achieving a precision of ~2m/s. Deviations observed in the gas rotation from a Keplerian profile allow for a direct probe of the radial pressure gradient in the gas, thus providing us with a *direct probe of the gas distribution in a protoplanetary disk*.

We detect these characteristic perturbations in rotation velocity in 12CO, 13CO and C18O emission. By directly measuring the height above the midplane where the emission arises from we are able to isolate perturbations due to the pressure gradient as a function of height and radius in the disk. This allows for unparalleled constraints on the gas surface density profile and thus the presence and mass of embedded planets.

Comparisons with hydrodynamic simulations allow us to constrain the planetary masses to a precision of 50%. As this method is sensitive to the pressure gradient, rather than a flux (a relative value vs. an absolute value), our results are robust against uncertainties in the bulk properties of the disk, such as the total gas mass. Furthermore, this method is *entirely independent of the radial emission profile and thus the constraints do not require any assumptions on gas-to-dust ratios, grain evolution or chemical abundances,* unlike traditional methods.

These results will change how we analyze observations of molecular line emission from not only protoplanetary disks but any astrophysical accretion disk.

Courtney Dressing (University of California, Berkeley)

Topic: Exoplanets, the Solar System and the origins of Stars, Planets and Life

M dwarfs: the Treasure Trove of Planets

Despite their diminutive stature, M dwarfs are ideal targets for exoplanet searches. Seventy-five percent of stars in the galaxy are M dwarfs and the Kepler mission revealed that planetary systems orbiting small stars are enticingly common: the typical early M dwarf hosts 2.5 planets smaller than Neptune with periods shorter than 200 days and one in four early M dwarfs harbors a potentially habitable planet. More recently, the discoveries of several potentially habitable planets orbiting late M dwarfs may indicate that the smallest stars host habitable planets at an even higher frequency than larger M dwarfs. In addition to their prevalence and their high rate of planet occurrence, M dwarfs are attractive targets for exoplanet studies because planets orbiting small stars are more detectable: for a planet with a fixed size and insolation flux, transits will be deeper, more frequent, and more likely to occur if the planet orbits a smaller star. Similarly, a planet with a fixed mass induces a larger radial velocity signal when orbiting a low-mass star. Despite the small physical size of the habitable zones of M dwarfs, many of these stars are close enough that planets within their habitable zones could be directly imaged by the next generation of extremely large telescopes. Recognizing this “M Dwarf Advantage,” a slew of ground-based facilities specifically designed to detect planets orbiting M dwarfs have already begun operations and many more are preparing to start searching for planets orbiting the nearest stars. I will review past discoveries about the treasure trove of planets orbiting M dwarfs and discuss upcoming plans to detect even more planets orbiting these red gems. In particular, I will highlight the NASA TESS mission and the prospects for detecting hundreds of transiting planets orbiting the brightest and nearest M dwarfs. These planets will be extremely attractive targets for radial velocity mass measurement with red spectrographs and atmospheric characterization with *Spitzer*, *HST* and *JWST*.

Exoplanets, the Solar System and the Origins of Stars, Planets and Life

Wednesday, June 27, 2018

Start	End	Session	Speaker
9:00 AM	10:00 AM	**Plenary: Stellar Mass and Supermassive Black Holes in Era of Multi-Messenger Astronomy**	**Sebastian Heinz** (Joe Lazio, Chair)
10:00 AM	10:20 AM	Poster Flashes - Black Holes	
10:20 AM	11:00 AM	Break and Posters	
11:00 AM	12:00 PM	**Plenary: The Evolution of Astrochemistry from Planet Formation Through to Exoplanets**	**Ilse Cleeves** (Laura Fissel, Chair)
12:00 PM	12:20 PM	Poster Flashes - Galaxy Evolution	
12:20 PM	12:30 PM	Conference Photo	
12:30 PM	2:00 PM	Lunch	
Exoplanets, the Solar System and the Origins of Stars, Planets and Life – Antonio Hales, Chair			
2:00 PM	2:30 PM	**The Evolution of Protoplanetary Disks and the Timescale for Planet Formation**	**Jonathan Williams**
2:30 PM	2:50 PM	Rings, Gaps, Cavities: The Connection Between Large and Transitional Disks	Nienke van der Marel
2:50 PM	3:20 PM	**Rapidly Evolving Debris Disks and Their Connection to Giant Impacts and Planet Formation**	**Alan Jackson**
3:20 PM	4:00 PM	Break & Posters	
Exoplanets, the Solar System and the Origins of Stars, Planets and Life – Jacob Simon, Chair			
4:00 PM	4:30 PM	**Giant Planets in the Solar System**	**Imke de Pater**
4:30 PM	4:50 PM	*Mapping Circulation and Chemistry in Uranus's Deep Atmosphere with Radio Observations*	*Ned Molter*
4:50 PM	5:10 PM	*Witnessing Planetary Systems in the Making with the Next Generation Very Large Array*	*Luca Ricci*
5:10 PM	5:30 PM	One Planet, Many Gaps and Rings	Robin Dong
5:30 PM	6:00 PM	**Characterization of Exoplanet Atmospheres**	**Jonathan Fortney**
6:30 PM	9:30 PM	Conference Dinner at Punch Bowl Social	

Bold = Invited Speaker

Italics = ngVLA Community Studies Talk

Sebastian Heinz (UW-Madison)

Topic: Black Holes & Transient Phenomena

Stellar Mass and Supermassive Black Holes in Era of Multi-Messenger Astronomy

I will discuss the future of multi-wavelength studies of the growth history of black holes at all mass scales over the coming decades. Just as numerical modeling of accretion and ejection phenomena approach an ab-initio understanding of the innermost regions of black hole atmospheres, the next generation of radio and X-ray telescopes will allow an unprecedented view of non-thermal phenomena that holds the keys to understanding some of the mysteries of black hole growth that have plagued black hole studies for that past five decades. My discussion will be motivated by a modern 3D MHD numerical view into black hole atmospheres.

Ilse Cleeves (Harvard-Smithsonian CfA)

Topic: Exoplanets, the Solar System and the origins of Stars, Planets and Life

The Evolution of Astrochemistry from Planet Formation Through to Exoplanets

Protoplanetary disks are the birthplaces of planetary systems. Studying their physical conditions and compositions provides constraints on how planets form and with what chemical make up: whether they are rocky or gas-rich, whether their atmospheres are carbon or oxygen rich, and so forth. In recent years the unprecedented sensitivity of ALMA has demonstrated a rich diversity in observed molecular emission strength and emitting geometries, hinting at an active disk chemistry during planet formation even for simple molecules. Going forward, we need to understand what the main evolutionary drivers are of this active chemistry (for example, the coupling of ice coated grains and grain growth), and if what we learn for well-studied bright/massive/nearby objects holds for the broader population of disks. Together these explorations will compliment and motivate our understanding of the march toward chemical complexity in disks, where the future highly sensitive ngVLA will shed light on the richer, and potentially prebiotic, organic chemistry of disks.

Jonathan Williams (University of Hawaii)

Topic: Exoplanets, the Solar System and the origins of Stars, Planets and Life

The Evolution of Protoplanetary Disks and the Timescale for Planet Formation

Stars form surrounded by dusty disks. Through accretion and outflows, these disks dissipate over a few million years and, apparently far more often than not, they leave behind an exoplanetary system. I will discuss the revolution in our understanding of disk evolution and planet formation through ALMA observations in the last 5 years, its potential for the next decade, and the promise of the ngVLA as we look at larger particles, smaller radii, and time-variable phenomena.

Nienke van der Marel (NRC Herzberg Astronomy and Astrophysics)

Topic: Exoplanets, the Solar System and the origins of Stars, Planets and Life

Rings, Gaps, Cavities: The Connection Between Large and Transitional Disks

Protoplanetary disks of gas and dust around young stars are the birth cradles of planets. Of particular interest are the so-called transition disks with large inner dust cavities. ALMA has played a revolutionary role in resolving structures in these disks, showing a large range of cavities, asymmetries and clumps in the dust, and evidence for companions in the gas structure. However, ALMA has also revealed that large primordial disks usually consist of multiple rings rather than a smooth distribution: an indication that clearing happens early-on and disks evolve rapidly. Now that the number of disks resolved at high resolution is getting significant, it is possible to compare morphologies of disks statistically. Current disk observations show evidence for an evolutionary link between large multi-ring disks and transitional disks with large dust cavities, providing new hints for their origin. New facilities such as the NGVLA will resolve these disks to even more detail at longer wavelengths, disclosing the distribution of the larger dust pebbles, the building blocks of planets.

Alan Jackson (University of Toronto)

Topic: Exoplanets, the Solar system and the origins of stars, planets and life

Rapidly Evolving Debris Disks and Their Connection to Giant Impacts and Planet Formation

Traditionally debris disks have been associated with the slow, quasi-steady state grind down of remnant planetesimals akin to those that populate our own Asteroid and Kuiper belts. In recent years however an increasing number of bright, warm debris disks have been found to display variability on timescales of days to months, challenging this traditional notion. At the same time resolved observations of cold debris disks are revealing complex, asymmetric morphologies that similarly do not fit within this traditional framework.

The final phases of planet formation are chaotic, involving stochastic collisions between planetary embryos. As well as building larger planets these collisions also release large quantities of debris. I will discuss how these stochastic debris releases can lead both to short term variability similar to that observed in some warm debris systems, and to longer term asymmetries like those seen in some resolved cold debris disks.

Imke de Pater (UC Berkeley)

Topic: Exoplanets, the Solar System and the origins of Stars, Planets and Life

Giant Planets in the Solar System

Understanding the coupling of gas abundances, temperature, and dynamics of the deep atmospheres of the giant planets is vital to our understanding of these planets as a whole, and to our understanding of extrasolar giant planets. Optical and near-infrared observations typically probe no deeper than the upper cloud layer (around 1-2 bar), so it is not known where the base of such cloud layers or storms are; the base is important since the temperature/pressure at the bottom of the cloud layers is tied to the composition of the cloud.

Observations at ngVLA wavelengths will probe to tens of bars, and provide information on the 3D structure of the main sources of opacity in these atmospheres, which in turn can be used to determine where clouds form (the main sources of opacity --NH3, H2S, H2O—are all condensable gases), and to infer the overall dynamics in the atmospheres.

The stratosphere can be probed via emission lines of e.g., CO, HCN, and H2O. The distribution and line profiles of these species will help distinguish between species (or fractions thereof) brought up from the deep atmospheres versus those brought in from the outside.

In this talk we will show the latest results from VLA observations, and discuss what we can learn from ngVLA observations.

Edward Molter (University of California Berkeley)

Imke de Pater (University of California Berkeley)
Joshua Tollefson (University of California Berkeley)
Statia Luszcz-Cook (American Museum of Natural History)
Bryan Butler (National Radio Astronomy Observatory)
Robert Sault (National Radio Astronomy Observatory)
Chris Moeckel (University of California Berkeley)
David Deboer (University of California Berkeley)

Topic: Exoplanets, the Solar System and the origins of Stars, Planets and Life

Mapping Circulation and Chemistry in Uranus's Deep Atmosphere with Radio Observations

The revolutionary exoplanet census carried out by the *Kepler* spacecraft has revealed Uranus and Neptune-sized "ice giants" to be the most common class of planet in our Galaxy. Studies of exoplanetary surfaces and atmospheres are in their nascence, and interpretation of results relies heavily on observations of our own solar system. Yet, many aspects of our giant planets, particularly the ice giants, remain mysteries. We present new preliminary *VLA* and *ALMA* maps of Uranus that combine the high spatial resolution and broad wavelength coverage of both telescopes to probe the circulation pattern of Uranus's troposphere in three dimensions in detail. Brightness temperature variations across the planet reveal areas of humid (rich in methane and hydrogen sulfide) upwelling as dark regions and areas of dry subsidence as bright regions. The observations span a broad wavelength range from 20 cm to 1 mm, resolving the atmosphere in layers spanning a pressure range from 1-100 bars. We discuss the implications of these maps for circulation models of the Uranian atmosphere, and speculate on further advances in studies of planetary atmospheres made feasible by the *ngVLA*.

Luca Ricci (California State University, Northridge)

Topic: Exoplanets, the Solar System and the origins of Stars, Planets and Life

Witnessing Planetary Systems in the Making with the Next Generation Very Large Array

The discovery of thousands of exoplanets over the last couple of decades has shown that the birth of planets is a very efficient process in nature. Theories invoke a multitude of mechanisms to describe the assembly of planets in the disks around pre-main-sequence stars, but observational constraints have been sparse on account of insufficient sensitivity and resolution. Understanding how planets form and interact with their parental disk is crucial also to illuminate the main characteristics of a large portion of the full population of planets that is inaccessible to current and near-future observations. In this talk I will described the critical contribution expected in this field by the Next Generation Very Large Array.

Ruobing Dong (University of Arizona)

Topic: Exoplanets, the Solar System and the origins of Stars, Planets and Life

One Planet, Many Gaps and Rings

We investigate the observational signatures of super-Earths (i.e., planets with Earth-to-Neptune mass), which are the most common type of exoplanet discovered to date, in their natal disks of gas and dust. Combining two-fluid global hydrodynamics simulations with a radiative transfer code, we calculate the distributions of gas and of submillimeter-sized dust in a disk perturbed by a super-Earth, synthesizing images in near-infrared scattered light and the millimeter-wave thermal continuum for direct comparison with observations. In low-viscosity gas (alpha <= 1e-4), a super-Earth opens two annular gaps to either side of its orbit by the action of Lindblad torques. This double gap and its associated gas pressure gradients cause dust particles to be dragged by gas into three rings: one ring sandwiched between the two gaps, and two rings located at the gap edges farthest from the planet. Depending on the system parameters, additional rings may manifest for a single planet. A double gap located at tens of au from a host star in Taurus can be detected in the dust continuum by the Atacama Large Millimeter Array (ALMA) at an angular resolution of ~0.03 arcsec after two hours of integration. Ring and gap features persist in a variety of background disk profiles, last for thousands of orbits, and change their relative positions and dimensions depending on the speed and direction of planet migration. Candidate double gaps have been observed by ALMA in systems such as HL Tau (D5 and D6) and TW Hya (at 37 and 43 au); we submit that each double gap is carved by one super-Earth in nearly inviscid gas.

Jonathan Fortney (UC Santa Cruz)

Topic: Exoplanets, the Solar System and the origins of Stars, Planets and Life

Characterization of Exoplanet Atmospheres

I will discuss recent advances in observations and modeling of exoplanetary atmospheres, with a particular focus on transiting planets. For giant planets, a planet mass-atmospheric metallicity relation predicted by core-accretion planet formation theory is just beginning to be unveiled. Also our phase space for planetary atmospheres has recently expanded, with some of these ultra hot atmospheres having more in common with M stars and planets we've so far known. Steps forward for the atmospheres of smaller planets are of course more tentative, and often ""cloudy,"" but I will review what we currently know from Hubble data, and our prospects for JWST and 2030's space telescopes.

Exoplanets, the Solar System and the Origins of Stars, Planets and Life

Thursday, June 28, 2018

Start	End	Session	Speaker
9:00 AM	12:20 PM	Working Groups/Free Time	
12:20 PM	2:00 PM	Lunch	
2:00 PM	3:00 PM	**Plenary: Pulsars in the Galactic Center as Fundamental Tests of Gravity**	**Dimitrios Psaltis** (Walter Brisken, Chair)
3:00 PM	3:20 PM	Poster Flashes - Black Holes	
3:20 PM	4:00 PM	Break and Posters	
Exoplanets, the Solar System and the Origins of Stars, Planets and Life - Nienke van der Marel, Chair			
4:00 PM	4:30 PM	**The Critical Role of the ngVLA in Revealing Complex Molecular Evolution and Its Role in Planet Formation and the Origins of Life**	**Brett McGuire**
4:30 PM	4:50 PM	*Protonated Carbon Dioxide Emission as a Diagnostic of Planet-Forming Regions of Disks*	*Liton Majumdar*
4:50 PM	5:10 PM	Misaligned Protoplanetary Disks - Evidence for Planet-Disk Interaction?	Ryan Loomis
5:10 PM	5:30 PM	Final Results from SPOTS: The Search for Planets Orbiting Two Stars	Ruben Asensio Torres
5:30 PM	6:00 PM	**Extrasolar Space Weather and its Impact on Planetary Habitability**	**Gregg Hallinan**

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Italics = ngVLA Community Studies Talk

Dimitrios Psaltis (University of Arizona)

Topic: Black Holes and Transient Phenomena

Testing General Relativity with the Event Horizon Telescope, Pulsars, and Stars around Sgr A*

The Event Horizon Telescope is a mm VLBI array that commenced its full array operations in April 2017. Its primary goal is to generate the first images of black holes with horizon-scale resolution for the two primary targets, Sgr A* in the center of the Milky Way and the black hole in the center of M87. Measuring the shape and size of the shadows cast by the black holes allows for testing the no-hair theorem of General Relativity and for searching for large-scale quantum fluctuations of the black-hole metrics. In the case of Sgr A*, tests with the Event Horizon Telescope can be combined with monitoring of orbits of stars and pulsars in its vicinity to provide consistency checks and further constraints on any deviations from General Relativity.

Brett A. McGuire (NRAO)

Topic: Exoplanets, the Solar System and the origins of Stars, Planets and Life

The Critical Role of the ngVLA in Revealing Complex Molecular Evolution and Its Role in Planet Formation and the Origins of Life

As molecules grow in size and complexity, their rotational spectra both shift lower in frequency and become increasingly crowded. In single-dish spectra, sources containing these lines are unresolved, and the resulting line survey data are line-confusion limited, preventing the detection of weak, underlying features of truly complex species. Extant interferometric facilities like the VLA can resolve this source structure, narrowing the spectral lines and reducing confusion, but at a high cost in surface-brightness sensitivity that again prevents the detection of these lines. Here, I will discuss these challenges to detectability in the context of existing facilities, and the limits of complexity these facilities can likely probe. I will also overview the utility of the ngVLA to resolve individual populations of complex molecules with the sensitivity required for detecting these weak signals, the role of these observations in calibrating models of chemical evolution, and the powerful applications of these constrained models on our understanding of the role of chemistry in regulating the composition of exoplanets and their atmospheres.

Liton Majumdar (NASA Jet Propulsion Laboratory)

Topic: Exoplanets, the Solar System and the origins of Stars, Planets and Life

Protonated Carbon Dioxide Emission as a Diagnostic of Planet-Forming Regions of Disks: A ngVLA Community Studies Round 2 Approved Program

Carbon dioxide cannot be observed in the gas phase through rotational transitions in the far-infrared or submillimeter range due to its lack of permanent dipole moment. It has to be observed through its vibrational transitions at near- and mid-infrared wavelengths. The protonated form of CO2, HOCO+, is an interesting alternative to track the gas phase CO2 in the millimeter/submillimeter regime. The ngVLA gives the unique opportunity to detect the four strongest transitions of HOCO+ at 21.38 GHz (1-0), 42.76 GHz (2-1), 85.53 GHz (4-3) and 106.91 GHz (5-4) in protoplanetary disks simultaneuosly. The detection of HOCO+ in a protoplanetary disk would be a great achievement and would pave the way for better understanding of the overall disk temperature structure, ionization structure, H2O and CO2 snow lines, overall C/O ratio and linking them with future observations of CO2 atmospheres in exoplanets. Observation of CO2 in exoplanet atmospheres is also one of the major science themes for James Webb Telescope (JWST). This link can also complement ngVLA and JWST each other.

Ryan Loomis (Harvard-Smithsonian Center for Astrophysics)

Topic: Exoplanets, the Solar System and the origins of Stars, Planets and Life

Misaligned Protoplanetary Disks - Evidence for Planet-Disk Interaction?

Recent high resolution observations of protoplanetary disks in both (sub)-mm continuum emission and optical/near-IR scattered light have unveiled a wide range of complex sub-structures in the outer regions of disks (> 5 AU), including rings, gaps, spirals, and vortices. Simultaneously, photometry from exoplanet surveys has found that young stars with quasi-periodic dimming events due to inner disk occultations, the so-called dipper systems, are common. All generally accepted mechanisms for this behavior require edge-on viewing geometries, but recent ALMA observations of the outer disks of these systems have found a wide range of inclinations. This tension can be resolved if the inner and outer disks of these systems are misaligned, and such a geometry has the potential to explain trends such as the Kepler dichotomy in more evolved exoplanetary systems. In this talk we show how asymmetries in dust continuum observations can be used to constrain disk misalignments, highlighting new ALMA observations of the dipper systems AA Tau and J1604-2130. We additionally discuss how these observations are synergistic with GPI and SPHERE scattered light imaging. Major observational and theoretical challenges remain, however, in explaining the origins of the misalignments and their relationship with concurrent planet formation. No mechanism for exciting misalignments has yet to be observationally confirmed, and we discuss what capabilities will be needed to distinguish between different scenarios. In particular, we show how the ngVLA and 30-m class optical/near-IR telescopes will be well-suited to observing these systems, with sufficient resolution to directly probe inner disk regions and high enough sensitivity.

Ruben Asensio-Torres (Stockholm University)

Markus Janson (Stockholm University)

Topic: Exoplanets, the Solar System and the origins of Stars, Planets and Life

Final Results from SPOTS: The Search for Planets Orbiting Two Stars

A large number of direct imaging surveys for exoplanets have been performed in recent years, which have yielded the first directly imaged planets and provided constraints on the prevalence and distribution of wide planetary systems. However, these surveys generally focus on single stars, hence binaries and higher-order multiples have not been studied to the same level of scrutiny. This motivated the initiation of the SPOTS survey, which is a direct imaging study encompassing 62 close and bright binaries, performed first with VLT/NACO and now with VLT/SPHERE. The study is the first to systematically study the distribution of wide planets in multiple systems. Here, we will describe the layout of the survey, the result of the follow-up of planetary candidates in the sample, and the detection of novel features in a newly resolved circumbinary disk which may indicate the presence of one or two unseen planetary companions. We will also discuss our statistical analysis on circumbinary planets and its implications on planet formation.

Gregg Hallinan (Caltech)

Topic: Exoplanets, the Solar System and the origins of Stars, Planets and Life

Extrasolar Space Weather and its Impact on Planetary Habitability

It is becoming increasingly apparent from studies of young solar analogs that the enhanced magnetic activity of the young zero-age main sequence Sun, powered by its rapid rotation, was a major factor in defining the atmospheric properties of the solar system planets. The enhanced radiative output at higher energies leads to strong expansion of planetary atmospheres while, simultaneously, the stellar wind of a young star is much denser and faster, compressing the magnetosphere, particularly during coronal mass ejections (CMEs), which are also presumed to be much more frequent. The long-term impact of such activity was recently established in dramatic fashion by the MAVEN mission to Mars, which confirmed that ion loss due to solar coronal mass ejections (CMEs) early in Mars history likely severely depleted its atmosphere. The impact will be more severe for most of the candidate habitable exoplanets to be discovered in the coming decade, due to the overwhelming preponderance of terrestrial planets orbiting M dwarfs. Studies of the likely impact of stellar flares and CMEs on planets in the habitable zone around such stars suggest that these events severely erode planetary atmospheres. I will discuss how next-generation radio facilities, including the ngVLA, can be used to directly constrain the presence of a stellar wind, particularly during a CME, and diagnose the presence of high-energy particle populations produced during flares. One of the most exciting prospects is the direct detection of planetary magnetospheres, which may be a crucial ingredient for retaining a planetary atmosphere and biosphere.

Exoplanets, the Solar System and the Origins of Stars, Planets and Life

Friday, June 29, 2018

Start	End	Session	Speaker
9:00 AM	10:00 AM	**Plenary: Connecting Interstellar Gas and Star Formation in Nearby Galaxies**	**Karin Sandstrom** (Aaron Evans, Chair)
10:00 AM	10:40 AM	Break and Posters	
Exoplanets, the Solar System and the Origins of Stars, Planets and Life – Stefanie Milam, Chair			
10:40 AM	11:10 AM	**A Statistical Comparison of Exoplanet and Protoplanetary Disk Properties**	**Gijs Mulders**
11:10 AM	11:40 AM	**Determining the Process of Planet Formation in the Outer Solar System via the Measuring Structure of the Trans-Neptune Belt**	**JJ Kavelaars**
11:40 AM	12:00 PM	`Scopes on Ropes: Balloon Astronomy as Tool for Studying Star and Planet Formation over Next Decade	Laura Fissel
12:00 PM	1:40 PM	Lunch	
Exoplanets, the Solar System and the Origins of Stars, Planets and Life – James Di Francesco, Chair			
1:40 PM	2:10 PM	**The Breakthrough Listen Initiative: Determining the Prevalence of Technologically-Capable Life**	**Andrew Siemion**
2:10 PM	2:30 PM	Exoplanets Found by Gravitational Microlensing Challenge the Core Accretion Theory	David Bennett
2:30 PM	2:50 PM	The Direct Imaging Search for Earth 2.0: Blue Dot or Red Herring?	Claire Guimond
2:50 PM	3:20 PM	**Key Questions in Planet Formation for the Coming Decade**	**Fred Adams**
3:20 PM	4:00 PM	Break & Posters	
4:00 PM	5:00 PM	Summary and Final Remarks	

Bold = Invited Speaker

Italics = ngVLA Community Studies Talk

Karin Sandstrom (University of California, San Diego)

Topic: Galaxy Evolution Mechanisms

Connecting Interstellar Gas and Star Formation in Nearby Galaxies

Star formation on galactic scales is governed by the need to collect interstellar gas into successively denser and colder phases, beginning with the accretion of low density gas from the circumgalactic medium all the way through the collapse of dense protostellar cores in molecular clouds. How effectively gas can proceed through these changes in its chemical and physical state depends on the local environment and therefore can vary within and between galaxies. Nearby galaxies are our best laboratory for studying these processes, providing an external, galaxy-wide perspective on the structure and properties of ISM gas. I will discuss our current observational constraints on the key phase transitions that govern the state of gas in nearby galaxies. In particular, I will discuss the properties of the cold neutral gas, the balance between neutral and molecular gas phases, and the density structure of molecular clouds and its relation to star formation. Key aspects of the physics of ISM gas in nearby galaxies remain out of the reach of current observational facilities and I will outline how future observations with the ngVLA, the SKA, and the Origins Space Telescope will revolutionize our understanding of the physics of ISM gas and star formation in nearby galaxies.

Gijs Mulders (University of Arizona)

Topic: Exoplanets, the Solar System and the origins of Stars, Planets and Life

A Statistical Comparison of Exoplanet and Protoplanetary Disk Properties

The Kepler survey has shown that exoplanets smaller than Neptune are extremely common and can be found around a wide variety of stars. Combined with large surveys of star forming regions, it becomes possible to connect the population of exoplanets to the protoplanetary disks in which they form.

In this talk, I will explore the relations between exoplanets and their host stars, in particular how planet occurrence rates depend on stellar mass and metallicity. Most surprising, planets occur more frequently around low-mass M dwarfs than around sun-like stars, in contrast to the lower protoplanetary disk masses observed with ALMA for low-mass stars. These results indicate that inward migration of planetary building blocks plays a crucial role during planet formation, and that planets in protoplanetary disks form early and efficiently.
I will highlight the areas where the census of disks and exoplanets is incomplete and where current and future surveys can map this terra incognita.

JJ Kavelaars (National Research Council of Canada)

Topic: Exoplanets, the Solar System and the origins of Stars, Planets and Life

Determining the Process of Planet Formation in the Outer Solar System via the Measuring Structure of the Trans-Neptune Belt.

The discovery, tracking and characterization of the members of the Kuiper belt over the last two and half decades has revealed a complex orbital history for giant planets of the solar system and challenged our understanding of the processes of planetesimal accretion. Indeed, the structure trans-Neptune region is extended, comprised of distinct physical and orbital classes and, the member objects appear to have formed over a range of location across the outer solar system. Very little about the trans-Neptune region looks like the structure that Kuiper likely envisioned and ensemble of material is better referred to as the ‘trans-Neptune region’. The orbital distribution within this region of the solar system is of particular interest to those attempting to determine the dominant processes of planetary system formation.

I will review the current knowledge of the orbital and size distributions of material in the Kuiper, focusing in particular on results determined from the Outer Solar System Origin Survey and its precursors. I will then highlight some of the puzzles that continue to evade understanding and how those puzzles connect to attempts to understand the processes of planet formation, where new insights might come from in the near term and on some longer time horizons.

Laura Fissel (National Radio Astronomy Observatory)

Topic: Exoplanets, the Solar System and the origins of Stars, Planets and Life

`Scopes on Ropes: Balloon Astronomy as Tool for Studying Star and Planet Formation over the Next Decade

Stratospheric balloons can lift up to 3,000 kg science payloads as high as 40 km above the Earth's surface (above 99.5% of the atmosphere), offering a near-space platform for a small fraction of the cost of an equivalent satellite. Balloon telescopes therefore offer a cost-effective option for wide-frequency deep mapping experiments as well as access to regions of the electromagnetic spectrum that cannot be observed from the ground, and have led to important advances in star formation, galaxy evolution, cosmology, and high energy astrophysics. In this presentation I will discuss prospects for the coming decade in balloon astronomy, highlighting upcoming telescopes that will study star and planet formation. I will overview some design considerations and limitations in building balloon-borne telescopes, with particular reference to the Balloon-borne Large Aperture Sub-mm Telescope for Polarimetry (BLASTPol) and its successor BLAST-TNG, a highly sensitive polarimeter that will make detailed magnetic field maps of dozens of molecular clouds, placing important constraints on the role of magnetic fields in star and planet formation. Finally, I will discuss how with improving ballooning technology, such as NASA's new Super-Pressure Balloon program, we will soon have the capability for mid-latitude science flights of several months (rather than days) duration. These advances will allow the construction of balloon-borne "observatories" targeting polarimetry, large area mapping, and variability studies, providing complementary data to high-resolution observations from ground-based telescopes.

Andrew P. V. Siemion (University of California, Berkeley | Radboud University, Nijmegen, Netherlands | SETI Institute, Mountain View, California | Institute of Space Sciences & Astronomy - University of Malta)

On Behalf of the Breakthrough Listen Team

Topic: Exoplanets, the Solar System and the origins of Stars, Planets and Life

The Breakthrough Listen Initiative: Determining the Prevalence of Technologically-Capable Life

A revolution in our knowledge of the exoplanet population has brought with it the incredible realization that our galaxy is awash in oases for life. Coarsely speaking, it is now clear that all of the necessary precursors and preconditions for life to arise exist in abundance throughout the cosmos. Knowledge of these facts has sharpened our scientific curiosity about whether or not life has indeed arisen elsewhere in the universe, and if so, whether any of that life evolved the same capacity to probe and contemplate the universe as human beings. The search for extraterrestrial intelligence (SETI) seeks to answer this question by conducting searches for direct or indirect effects of extraterrestrial technologies, so-called "technosignatures." At the forefront of these experiments is the Breakthrough Listen Initiative, a 10-year research program that is conducting the most comprehensive, intensive and sensitive search for extraterrestrial technologies in history. Breakthrough Listen employs radio and optical telescopes around the world and is developing sophisticated algorithms to sift through massive amounts of observational data. Here we will review the current status of the Breakthrough Listen program, including both existing facilities and nascent engagements with new telescopes and datasets just coming online. We will also present some highlights from the ancillary science made possible by Breakthrough Listen instrumentation and analysis methodology, especially in the area of fast radio bursts.

David P. Bennett (NASA Goddard Space Flight Center)

Daisuke Suzuki (Institute of Space and Astronautical Science, JAXA), Shigeru Ida (Tokyo Tech), Christoph Mordasini (Universität Bern) and the MOA Collaboration

Topic: Exoplanets, the Solar System and the origins of Stars, Planets and Life

Exoplanets Found by Gravitational Microlensing Challenge the Core Accretion Theory

The MOA Collaboration has measured the mass ratio function of exoplanets beyond the snow line and found a break and likely peak in the mass ratio function at a mass ratio of $q \sim 10^{-4}$, using a sample of 30 exoplanets found by gravitational microlensing. We now compare this cold planet mass ratio function to exoplanet population synthesis models from two different groups. These comparisons favor models with minimal migration of gas and ice giant planets. We also find that these population synthesis models cannot account for the smooth rise in the mass ratio function from super-Jupiter mass ratios of $q \sim 0.02$ down to q $\sim 10^{-4}$. Instead, the models predict a deficit of planets at $q \sim 2 \times 10^{-4}$, because planets at this mass ratio are thought to be rapidly accreting gas in the runaway accretion phase of gas giant planet formation. It is thought to require unusual circumstances to have planets end up at this mass ratio beyond the snow line, but the microlensing results indicate that planets of this mass ratio are more common than Jupiter-mass gas giants. This suggests that the core accretion theory may have to revised. Alternatively, it may be that this feature is somehow smoothed out when combining results for stars of different host masses. We discuss how this possibility will be tested with mass measurements of exoplanet microlens systems and how we will obtain a complete picture of the planet population orbiting at ≥ 1 AU with masses as low as that of Mars with the exoplanet microlensing survey of the WFIRST mission.

Claire Guimond (McGill University)

Nicolas Cowan (McGill University)

Topic: Exoplanets, the Solar System and the origins of Stars, Planets and Life

The Direct Imaging Search for Earth 2.0: Blue Dot or Red Herring?

Direct imaging is likely the best way to characterize the atmospheres of Earth-sized exoplanets in the habitable zone of Sun-like stars. Previously, Stark et al. (2014, 2015, 2016) estimated the Earth twin yield of future direct imaging missions, such as LUVOIR and HabEx. We take an important next step by extending this analysis to other types of planets, which will act as false positives for Earth twins. We define an Earth twin as any exoplanet within half an e-folding of 1 AU in semi-major axis and 1 RE in planetary radius, orbiting a G dwarf. Using Monte Carlo analyses, we quantify the biases and planetary false positive rates of Earth searches. That is, given a pale dot at the correct projected separation and brightness to be a candidate Earth, what are the odds that it is, in fact, an Earth twin?Our notional telescope has a diameter of 10 m, an inner working angle of 3?/D (62 mas at 1.0 ? m), and an outer working angle of 10?/D (206 mas). With no precursor knowledge and one visit per star, we detect many more un-Earths-77% of detected candidate Earths have an un-Earthlike radius and/or semi-major axis, and their mean radius is 2.3 R_E, a sub-Neptune. The odds improve if we image every planet at its optimal orbital phase, helped either by precursor knowledge or multi-epoch direct imaging. 47% of detected Earth twin candidates are false positives in this targeted scenario, with a mean radius of 1.7 R_E. The false positive rate is robust to stellar spectral type and the assumption of circular orbits. The majority of false positives will be ""big and dark"" planets with large radii and low apparent albedos. Indeed, the radius-albedo degeneracy is the ultimate challenge in reflected light direct imaging. The false positive rate is ?50\% unless all planets have the same albedo and we know that value a priori. We might reduce the degeneracy via a mass-radius relation, if we know planetary mass from radial velocity or astrometry.

Fred C. Adams (University of Michigan)

Topic: Exoplanets, the Solar System and the origins of Stars, Planets and Life

Key Questions in Planet Formation for the Coming Decade

The past two decades have witnessed an explosion of observational data concerning extra-solar planetary systems. Planets are known to be common and sample a wide range of masses, including a large population in the mass interval between Earth and Neptune. Planetary systems display a diversity of architectures and are subject to a host of interesting dynamical phenomena. Parallel developments in theory have solidified our understanding of many important issues that play a role in planet formation. The challenge for the coming decade is to develop a comprehensive and predictive theory that ties together the multitude of physical processes that influence the properties of both the planets themselves and the dynamical systems where they reside.