Solar System Formation

AAS Long Beach 2013
Background

• Our solar system formed 4 terrestrial planets close to the Sun and 4 Jovian (gas) planets farther away.
• Jupiter, the largest planet, takes almost 12 years to orbit the Sun.
• Our solar system was thought to be ‘normal’ until exoplanets found and confirmed.
• Now our solar system appears to be unique.
From Dust to Planetesimals: Criteria for Gravitational Instability of Small Particles in Gas

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AAS221@LongBeach 01/07/2013

Collaborator: Eugene Chiang

• How high must the dust density $\rho_d$ be to trigger direct gravitational collapse?
• Equivalently, how small must $H_d$ be?
Testing the Circumstellar Disk Hypothesis of Methanol Maser Rings with High Spatial Resolution Infrared Data

James M. De Buizer

SOFIA-USRA

221st AAS – Long Beach, CA – January 8, 2013 – Presentation 205.02
MASER

• Microwave Amplification by Stimulated Emission of Radiation

• Maser emission is associated with both the early and late stages in the life of a star.
New VLBI survey has found 15% of 6.7 GHz methanol maser sources (9 sources) can be fit by ellipses.

Since methanol maser emission only is found around very young high mass stars:
Are these methanol maser rings tracing circumstellar disks around massive young stellar objects (MYSOs)?
Using the IR to test disk scenario for maser rings

Typical maser ring radii are 0.3” (300 mas)

High Resolution Near Infrared Imaging

- Used Gemini North NIRI/Altair AO instrument
  - Up to 70mas resolution at 2\textmu m
  - Astrometry triangulated from 2MASS/Hipparcos stars on field for $1\sigma \approx 110\text{mas}$ abs. positional errors

High Resolution Mid-Infrared Imaging

- Used Gemini South and T-ReCS
  - Natural resolution of 0.30” at 8\textmu m
  - Deconvolutions yield 150mas resolution at 8\textmu m
  - Special Gemini MIR pointing scenario employed yields $1\sigma = 60\text{mas}$ absolute positional errors
Are methanol maser rings tracing disks?

- IR emission from deeply embedded high mass young stellar objects comes from the outflow cavities.
- Our NIR and MIR continuum imaging results for four sources are problematic for the disk scenario.
- Combined with the SED modeling, it can be said that none of our 4 sources yield convincing evidence that the maser rings are tracing disks.
- The next step is performing proper motion studies of the maser spots.

The Submillimeter and Radio View of Disks in Multiple Systems

Robert J. Harris
Harvard University
Jan. 8, 2013

Advisor: Sean M. Andrews
Collaborators: David Wilner, Adam Kraus, Claire Chandler, Katherine Rosenfeld, Luca Ricci, Laura Perez
+ rest of Disks@EVLA Group.
These systems lead to the planets seen in these systems. How? Does this differ from isolated formation?

**Circum-component disks**

![Image of HK Tau A and HK Tau B](image1.png)

Harris et al. 2012

**Circumbinary disks**

![Image of Kepler 16b](image2.png)

Pietu et al., 2012

**Circumcomponent planet: α Cen Bb**

**Circumbinary planet Kepler 16b**

![Graph showing transits](image3.png)

Doyle et al., 2012
Grain physics

Dust coagulation

Brownian motion

Differential settling/drift & turbulent stirring

(a miracle happens)

Sweep-up

Runaway growth

Oligarchic growth (N-body gravity)

1μm 1mm 1m 1km 10^3 km

C. Dullemond
Conclusions

- Stellar multiples as planetary nurseries.
- Millimeter photometry consistent with tidal truncation
- Detailed (i.e. quantitative) models fail.
- Location of material matches planetary demographics
- Grain properties in multiples
- Radial drift seems to restrict growth in UZ Tau E disk (cf. AS 209)
- Many more systems to do, stay tuned.
From Classical Disks to Transition Disks: An Increasing Dust-to-Gas Ratio?

James T. Keane
University of Arizona, Lunar and Planetary Laboratory

Ilaria Pascucci (UA), Sean Andrews (CfA), Bill Dent (ESO), Catherine Espaillat (CfA), Gwendolyn Meeus (UAM), Wing-Fai Thi (UJF), Peter Woitke (ROE).
Transition Disks

Transition disks are a rare (~10%) subclass of protoplanetary disks, in the process of dispersing their inner dust disk. SED models and interferometric imaging indicate the presence of an inner gap, out to ~few AU. The method by which these gaps form is still uncertain.
DDX: the Debris Disk Explorer

Lewis C. Roberts Jr.
Geoffrey Bryden, Wesley Traub, Stephen Unwin,
John Trauger, John Krist, J. Kent Wallace
Jet Propulsion Laboratory, California Institute of Technology
Karl Stapelfeldt
Goddard Space Flight Center
Mark Wyatt
University of Cambridge
Three Science Objectives

Place the Solar System in context

Reveal the presence of perturbing planets

Characterize the size and composition of disk dust

HR 8799

Fomalhaut

AU Mic
Balloons offer near space-like conditions at a fraction of the cost

Science payload:
• 0.75m off-axis telescope
• Visible Coronagraph - 10^{-8} contrast
• V&I-band images of disks.

Gondola System:
• Will use the flight proven WASP pointing system. A key enabling technology

Balloon launches:
• Test Flight, Ft. Sumner NM, September 2016
• Science Flight - 30 nights, New Zealand, June 2017
DDX will observe disks that no other current instrument can.
How will things change at the end of the DDX mission?

- Will be the first flight of a visible coronagraph, a key technology demonstration for future space coronagraphs.
- Will image or provide upper limits to >60 disks.
- Will have a more comprehensive understanding of the myriad types of debris disks.
Hot on the Trail of Warm Planets Around Cool Stars

John A. Johnson
California Institute of Technology

Alfred P. Sloan Fellow
David & Lucile Packard Fellow
Kavli Fellow

http://exolab.caltech.edu
Exoplanetary Science
Goal: Understanding Our Origins

- Molecular Cloud Collapses to form disk
- Planets form within disk
- Gravitational interactions among planets
- Planets detected today

- $10^5$ years
- $10^6$ years
- $10^7$ years
- $10^8$ years
- $10^9$ years
- $10^{10}$ years

Currently Unobserved → Observable
Exoplanetary Science
Goal: Provide a Galactic Context

Mercury
Venus
Earth
Mars
Jupiter
Saturn
Uranus
Neptune

Rocky planets in close
Gas giants far away
Exoplanetary Science
Goal: Discover Life Elsewhere in the Galaxy

Of all of the topics of study in astronomy, exoplanets hold a special place in the imagination. More than stars, nebulae, or galaxies, they are places.

- Jason Wright’s thesis
The Bigger Story

- We have strong evidence that the Kepler-32 planets formed in < 10 Myr and migrated inward through gaseous disk
  - Inner planet too close to form there
  - Middle planets’ 3:2:1 commensurability demands a gentle migration mechanism
- The Kepler-32 planets are representative of all of Kepler’s M dwarf planets, and therefore M dwarfs throughout the Galaxy
- These are powerful constraints on the timescale and nature of the mechanisms that form some of the most numerous planetary systems in the Galaxy!
- The Solar System is rare.
  - Most stars are M dwarfs
  - Most planets formed around M dwarfs
The Occurrence Rate of Small Planets Around Small Stars

Dressing & Charbonneau (submitted to ApJ)

• The occurrence rate of Earth-size planets in the habitable zone is 0.06 planets per small star.

• With 95% confidence, there is a transiting Earth-size planet in the habitable zone of a small star within 31 pc.
- We have characterized all of the Cool KOI host stars, and we’re gearing up to do more
  - Stellar astrophysics is the key to understanding Kepler’s planet candidates
- We have validated and characterized some of the smallest planets in the *Kepler* sample by focusing on the M dwarfs
  - Even the false positives have turned out to be interesting!
- We have uncovered clues about the dominant mode of planet formation throughout the Galaxy
  - The Solar System is starting to look weird from a Galactic perspective
The Fingerprints of Stars

• [http://www.youtube.com/watch?v=uG4xe9cNpP0](http://www.youtube.com/watch?v=uG4xe9cNpP0)