Understanding the origins and diversity of planets

Dr. Emma Marcucci (STScI)
Dr. Farisa Morales (JPL)
Dr. Hilke E. Schlichting (UCLA)

Facilitator: Dr. Emma Marcucci (STScI)
Additional Resources

http://nasawavelength.org/list/2240

Resources:
- Citizen Science: Disk Detective
- Citizen Science: Exoplanet Explorer¹
- Active Accretion Learning Game²
- Exoplanet Travel Bureau
- Eyes on Exoplanets (including tutorial video)
- Exploring Solar Systems Across the Universe

Highlighting the 15th Anniversary of the Spitzer Space Telescope:
- CoolCosmos - Exoplanets
- TRAPPIST-1 Products
- Additional Spitzer resources (images, videos, news releases): http://www.spitzer.caltech.edu/

Press Releases (selected examples)
- Chandra May Have First Evidence of a Young Star Devouring a Planet
- First Confirmed Image of Newborn Planet Caught with ESO’s VLT
- Hubble Gets Best View of a Circumstellar Debris Disk Distorted by a Planet
- Hubble Directly Observes Planet Orbiting Fomalhaut
- Spitzer Finds Organics and Water Where New Planets May Grow
Outline of this Science Briefing

1. Resources – Greatest Hits

2. Dr. Farisa Morales (JPL) – Exploring Planetary Debris Systems

3. Dr. Hilke Schlichting (UCLA) – Origin and Diversity of Exoplanets

4. Discussion / Questions
Resources on Planetary Formation

Disk Detective – Citizen Science

Exoplanet Explorers – Citizen Science

Eyes on Exoplanets – Interactive, self-guided exploration

Emma Marcucci
Space Telescope Science Institute
Disk Detective – Citizen Science
originally presented September 2017 by Dr. Marc Kuchner (NASA GSFC)

We need your help to discover the birthplace of planets in never-before seen data!

What is WISE looking for?
WISE is a NASA mission surveying the whole sky in infrared. This project is looking at stars to find dusty debris disks, similar to our asteroid field. These disks suggest that these stars are in the early stages of forming planetary systems. Learning more about these stars can tell us how our Solar System formed.
Disk Detective

Step 1 – Watch the images

Step 2 – Select descriptor(s)

Step 3 – Finish
Exoplanet Explorers

Step 1 – Examine Light Curve

Step 2 – Does it look like the example?

Step 3 – Done
Eyes on Exoplanets
originally presented March 2017 by Carolyn Slivinski (STScI)

https://eyes.nasa.gov
Eyes on Exoplanets

Learning through comparison

Different views

Latest Discoveries

View from Earth

Weird Planets

Search

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Exoplanet missions

Home

About the Star

Name: TRAPPIST-1
Distance from Earth: 39 light-years
Visible to the naked eye: no
Constellation: Sextans
Planets: 7

Star type: M
Magnitude (brightness): 18.6
Mass: 0.08 Suns

PLANETARY SYSTEM VIEW

HOW LONG TO TRAVEL HERE?

COMPARE WITH OUR SOLAR SYSTEM

HABITABLE ZONE
EXPLORING PLANETARY DEBRIS SYSTEMS

Dr. Farisa Morales

Image Credit: NASA/JPL-Caltech
Stars Form with Proto-Planetary Disks
Building Planetesimals


Image Credit: NASA/JPL-Caltech
Planet Perturbations Induce Dust Production

Formation of Rubble Bands

http://www.spitzer.caltech.edu/video-audio/724-ssc2004-17v2-Swirling-Rings-of-Dust
Exoplanetary Systems

Exoplanet Observations

Debris Disk Observations

Image Credit: NASA/JPL-Caltech
What factors inform us of their architecture?

Ultimately, we want to know how they compare to the solar system.
SED Modeling – Two Belts

(SED = Spectral Energy Distribution)

Figure 1
Morales et al. (2011)
Dust production is clearly favored at the same characteristic $T_{\text{dust}}$ horizon across the large stellar spectral range (B8-K0) — slightly above the ice evaporation temp. for inner belts!

Note the relative void in $T_{\text{dust}} \sim 100$ K.
How does *Herschel* help clear the picture?

By providing the spatial distribution, we can learn about grain properties.
Herschel Resolved Outer/Cold Rings!

(PSF subtracted Mosaic)

~2” – 5” \rightarrow ~30 – 270 AU

Figure 1
Morales et al. (2016)
SED Modeling Using Inhomogeneous Particles

Are the dust grains rocky or icy?
Grain Structures & Composition

- There exists a degeneracy: **grain properties** vs. **radial position**
  - Breach degeneracy by considering resolved locations (grain’s position) & and realistic particle properties (homogeneous rocky & inhomogeneous icy)

- Why Icy Particles?
  - Protostellar sources (Preibisch et al., 1993)
  - Cometary dust (Kimura et al., 2009)
  - Kuiper belt objects (KBOs) *have distinctly high albedos* → reflective water-ice particles (Stansberry *et al.*, 2005, Brucker *et al.*, 2009)

A presolar (stardust) grain of silicon carbide, SiC. The grain is only 3 μm across. Photo by Rhonda Stroud, Naval Research Lab., and displayed in Nittler (2003).

![Presolar grain of SiC](Photo by Rhonda Stroud, Naval Research Lab.)
The SED Model

We model each ring as **optically thin** thermal emission from a series of **annuli** around the parent star.
SEDs with *Herschel* – HD 159492

- The shape of the SED and the fixed radial location suggests that the composition of grains in the outer belt is **icy** (not rocky)!!

- HD 159492
  - A5IV-V,
  - ~170 Myr
  - 42.2 pc
  - $f_{\text{MB}} = a_{\text{min}}/a_{\text{BOS}} \approx \frac{1}{3} - \frac{1}{4}$
  - $M_{\text{cold}} \approx 0.08 \, M_{\text{Moon}}$

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*Figure 5*  
Morales et al. (2016)
SEDs with *Herschel* – HD 70313

- **Icy** grains best fit the shape of the outer dust emission and radial location

- HD 70313
  - A3V, $V \approx 300$ Myr
  - 51.4 pc
  - $f_{MB} = a_{min}/a_{BOS} \approx 1$
  - $M_{cold} \approx 0.23 M_{moon}$

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Dr. Morales  
Summer 2018
SEDs with *Herschel* – HD 166

- HD 166
  - K0V
  - ~456 Myr
  - 13.7 pc
  - $f_{MB} = a_{min}/a_{BOS} \approx 1$
  - $L_{\text{cold}} \approx 7.5 \times 10^{-5}$
  - $M_{\text{cold}} \approx 0.009 \, M_{\text{Moon}}$
1. **Spitzer** sees both warm and cold excess emission of debris around A- and solar-type main sequence stars.

2. **Spitzer** IRS well-characterized the warm—Asteroidal dust emission.

3. **Herschel** PACS confirmed the presence of the cold-Kuiper belt like dust, and helps constrain the modeling of dust at longer $\lambda$.

4. Some PACS images are spatially **RESOLVED** at 100 and/or 160 $\mu$m.

5. **Radial location** plus dust flux help **break the degeneracy** in SED modeling; i.e. grain properties, size distribution and composition vs. radial location.$\Rightarrow$ **Reveals Water Ice**

6. **GAPS** are evident $\Rightarrow$ What’s in between? Planets?
Planet Hunting—an ongoing effort

Do they look like us?
Planet Hunting
NASA-Keck II Observatory
(2012 – present)
Planet Hunting
NASA-Keck II Observatory (2012 – present)
Adaptive optics -- Gemini Observatory

https://www.youtube.com/watch?v=CyGRLr9H1x4
DISCOVERY OF A LOW-MASS COMPANION AROUND HR 3549

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ABSTRACT

We report the discovery of a low-mass companion to HR 3549, an A0V star surrounded by a debris disk with a warm excess detected by WISE at 22 μm (10σ significance). We imaged HR 3549B in the L band with NAOS-CONICA, confirmed its position angle of ≈157°, corresponding to another radio source, and measured its mass ratios. The mass ratios. The mass ratios.
The TRENDS High-Contrast Imaging Survey. VII. 
Discovery of a Nearby Sirius-like White Dwarf System

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ABSTRACT
Monitoring the long-term radial velocity (RV) and acceleration of nearby stars has proven an effective method for directly detecting binary and substellar companions. Some fraction of nearby RV trend systems are expected to be comprised of compact objects that libration induce a
Thank You!
Origin and diversity of Exoplanets

Prof. Hilke Schlichting (UCLA)
Kepler Planets

4496 Planetary Candidates

1218 Planets in Multi-Planet Systems
Kepler Planets

- 4496 Planetary Candidates
- 1218 Planets in Multi-Planet Systems
Kepler Planets

4496 Planetary Candidates

1218 Planets in Multi-Planet Systems
For comparison, the Earth’s atmosphere contains less than $10^{-6}$ of its mass and has an atmospheric scale height that is only $\sim 0.1\%$ of its radius.
Exoplanet Densities

Giant Impacts can strip the atmosphere of exoplanets leading to a diversity in compositions

Inamdar & Schlichting 2016

Data from Weiss & Marcy 2014, Juntof-Hutter et al. 2015, Barros et al. 2015
Exoplanet Densities

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Take Home Points

1) Super-Earths & Mini-Neptunes are the most abundant planets known to date in our galaxy.

2) About 50% of stars have a close-in Exoplanet larger than Earth in size.

3) About 10% of stars have a ‘Jupiter’.

4) Small number of Giant Impacts can give rise to a large diversity in exoplanet densities. Explanation for diverse bulk densities observed in multiple planet systems: e.g. Kepler-11, Kepler-20, Kepler-36, Kepler-48, and Kepler-68.
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