Star and Planet Formation
Star and Planet Formation in the IR

- $t < 0.03$ Myr: Class I
  - Black body
  - Infrared excess

- $t \approx 0.2$ Myr: Class II
  - Disk
  - Protoplanetary disk?

- $t \approx 1$ Myr: Class III
  - Stellar black body

- $t \approx 10$ Myr: Debris + planets?
Star and Planet Formation with IRTF

http://irtfweb.ifa.hawaii.edu/research/biblio/dissertations.html

1999
David Trilling
Lisa Prato

2000
Richard Webb
Elisha Polomski
Jenny Patience
Karl Haisch Jr.

2001
Bernadette Rogers
Robert Fisher
Tracy Beck

2003
Jeff Bary
Dawn Peterson
Caer-Eve McCabe

2004

2005
Sean Brittain
Scott Dahm
Qingfeng Zhu
Claudia Knez
Katelyn Allers

2007
Michael Connelley

2008
William Carpenter
Marc Berthoud

2009
Hao Yang
Nicholas Moskovitz
Carl Melis
Catherine Espaillat

2011
Joshua Schlieder
Dagny Looper
Kevin Flaherty
Casey Deem
Christopher Crockett

2012
Kari Wojtkowski
Philip Castro

2013
Christine Trombley
Kyoung Kim
Brendan Bowler

2014
Melissa McClure
Paul Dawson

2016
Kimberly Aller

Instrumentation Development

2011
Michael Lundquist
Jonathan Gagne
Disks are Common

Most disks are studied through their IR continuum emission.
The Timescale for Planet Building


However, this metric is inexact: what about the gas?

Wyatt (2008)
Hernandez et al. (2007)
Verifying They Really Are Disks

Carr & Tokunaga 1992, Carr 1995

WL 16

IRAS 04302+2247
Orion 114-426

NICMOS
WFPC2

HH 30
HK Tau/c

500 A.U.
High Binary Fraction in Taurus

e.g. Simon et al. 1995
Characterizing Protostars

Testing Magnetospheric Accretion

Hartmann et al. (2016, ARAA)
Measuring Fields with Zeeman Effect

\[ \Delta \lambda = \frac{e}{4\pi mc^2} \lambda^2 g_{\text{eff}} B \]

\( \varepsilon \) Eri (K2 V)
\( B = 1.44 \text{ kG}, f = 9\% \)
\( \lambda = 1.56485 \mu\text{m} \)
\( g_{\text{eff}} = 3.0 \)

Residual Intensity

\[ \text{Residual Intensity} = 1.0 \]

\[ \Delta \lambda \text{ (Å)} \]

\[ -1.0 \text{ to } 1.0 \]
Caveats:
- Theory assumes dipole
- We measure mean field
- Uncertainty on x-axis difficult to quantify

Additionally: no correlation with rotation rate, Rossby number, etc.

Also Yang et al. (2008), Yang & Johns-Krull (2011)
Comparison with Equipartition Fields

- $3.0 < \log g < 3.5$
- $3.5 < \log g < 3.75$
- $3.75 < \log g < 4.0$
- $4.0 < \log g$

Data from Johns-Krull (2007) & Yang et al. (2008)
Forming Planets (& Brown Dwarfs)

Core Accretion: Dust collides and sticks together, building up larger bodies. May take about 10 Myr to build Jupiter.

Gravitational Instability: Disk instability leads to rapid planet formation.
Radial Velocity Searches
Very Large Spots

2000/04/25 05:34 UT

V410 Tau:

Hatzes (1995)
Spots and Reflex Motion

- what happens to a stellar spectrum in the presence of a spot?
- example: one line in young star spectrum
- large spot rotates around star in ~few day period
Infrared Spectroscopy

- spot / photosphere contrast less in IR
- therefore spot induced RV amplitude is less
- but planet induced RV amplitude should be the same
CI Tau RV Variations

Johns-Krull et al. (2016)

K7 CTTS

$P_{\text{rot}} = 7.1 \, \text{d}$

$M = 0.8 \, M_\odot$

$\dot{M} = 1.5 \times 10^8 \, M_\odot/\text{yr}$

$Disk \, i = 45^\circ.7 \pm 1^\circ.7$

Mahmud et al. (2011)
Orbital Properties

Table 4. CI Tau Orbital Properties and Inferred Mass of CI Tau b

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Using IR RVs</th>
<th>Using IR &amp; Optical RVs</th>
</tr>
</thead>
<tbody>
<tr>
<td>P (days)</td>
<td>8.9975 ± 0.0395</td>
<td>8.9941 ± 0.0175</td>
</tr>
<tr>
<td>K (km s⁻¹)</td>
<td>1.046 ± 0.213</td>
<td>0.936 ± 0.199</td>
</tr>
<tr>
<td>e</td>
<td>0.42 ± 0.16</td>
<td>0.25 ± 0.18</td>
</tr>
<tr>
<td>Mₚ sin i (Mₖ)</td>
<td>8.42 ± 1.48</td>
<td>8.05 ± 1.59</td>
</tr>
</tbody>
</table>

\[ a_p = 0.084 \text{ AU} = 12.1 \text{ R}_* \]

Johns-Krull et al. (2016)
Next Steps
Planet Formation at Earlier Stages

Brittain et al. (2014)
Other Recent Young Planets

Donati et al. (2016)

V830 Tau

[Graphs and diagrams related to the topic of young planets, including RV data, residual RVs, and Planck functions for two temperatures.]
Polarimetry and Magnetic Characterization

\[ \Delta \lambda = \frac{e}{4 \pi m c^2} \lambda^2 g_{\text{eff}} B \]

\( \varepsilon \) Eri (K2 V)

\( B = 1.44 \text{ kG}, f = 9\% \)

\( \lambda = 1.56485 \mu \text{m} \)

\( g_{\text{eff}} = 3.0 \)
Characterizing Protostars

e.g. Doppmann et al. 2005
Future: Gas Disk Lifetimes

Wyatt (2008)
Hernandez et al. (2007)

\[ \tau_{\text{acc}} = 2.3 \text{ Myr} \]
\[ \tau_{\text{dust}} = 3.0 \text{ Myr} \]
Future: Gas Disk Lifetimes

GM Aur

Accreting stars vs IRAC excess [%]

\[ \tau_{\text{acc}} = 2.3 \text{ Myr} \]

\[ \tau_{\text{dust}} = 3.0 \text{ Myr} \]
Future: Gas Disk Lifetimes
Thank You