SPF2
star and planet formation in the southwest
12-16 March 2018, Biosphere 2, Oracle AZ

Welcome!
Joan Najita (NOAO)
Thanks!

- For attending
- Paola + Kaitlin + SOC for organizing
- Our sponsors
THE GOLDEN AGE

of Star & Planet Formation
Figure 1.1 Figure 7 of Shu et al. (1987) illustrating the four stages of star formation.

Observations of the end results of these processes, i.e., resultant young stellar groups, however, are more readily made using traditional optical and near-infrared observing techniques. In particular, from observations of mass, age and spatial distributions of different regions at different stages of evolution, we can begin to piece together the picture of how stars within those regions formed and what role birth environment may have played in this process.

The first issue that must be addressed in this matter is to understand that not all stellar groups are the same. They come in many different flavors, the most common of which (and those that will be discussed in this work) are described below.

- **Young stellar clusters.** In its most general definition, a star cluster is a group of stars that is gravitationally bound. This fact implies that young clusters either have densities $\rho^* \geq 1 M_\odot pc^{-3}$ and thus remain stable against galactic tidal forces (Bok, 1934) and interactions with giant molecular clouds (Spitzer, 1958), or are still deeply embedded in primordial molecular gas and dust that binds them together.

The fried egg model of disks (no planets)

- Do disks exist?
- Are there planets around other stars?
- What determines the masses of stars?
Amazing Wealth

- Tools for observing (HST, Spitzer, Kepler, ALMA, …), computing
- Theoretical ideas
- Observational discoveries….
TGFTM

Amazing wealth of resources and advances
• Makes our job easy (never labor over what to do next!)
• And hard (impossible to keep up with literature)

Meetings like this are so valuable
• Catch up on what’s been done
• Interact, reflect on what’s important to do next!

Highlights from the schedule: hot topics, open questions
Star and Planet Formation

Cloud Cores, embedded YSOs

Planets + debris

Revealed star + disk
Exoplanet Populations

Clues to nature of planet formation and underlying processes!
Exoplanet Populations

Review by Scott Gaudi
Talk by G. Mulders

What other messages?
Disks in Star and Planet Formation

1. Dense cores, precursors to stars, form within clumps.

2. Cores condense into young stars surrounded by dusty disks.

3. Planets form from the disks, and new solar system is born.

Important for buildup of stellar masses
Birthplaces of planets
Disk Accretion

May be episodic (talks)

Driven by gravitational instability in Class I phase…

Magnetorotational Instability in T Tauri phase?

L. Hartmann
Disk Accretion

May be episodic (talks)

Driven by gravitational instability in Class I phase...

Magnetorotational Instability in T Tauri phase?

L. Hartmann
Disk Accretion...It’s Embarrassing

MRI in trouble
Can disk winds save the day?
What evidence for the right kind of winds?

Talks by K. Flaherty, I. Cleeves, D. Gole

Tues Discussion session: Disk Turbulence
(M. Hughes, J. Simon)

MRI in trouble
Can disk winds save the day?
What evidence for the right kind of winds?

Disk dust masses measured from mm continuum imply $M_d/M_* \sim 0.01$

How much more mass in large solids and gas?

Andrews et al. 2013
Disk Masses

Disk dust masses measured from mm continuum imply $M_d/M_* \sim 0.01$

How much more mass in large solids and gas? 10% 0.1%

Andrews et al. 2013

Review by I. Pascucci
Talks by M. Ansdell, J. Huang, M. Tazzari
Tues Discussion session: All About Disks (J. Williams, R. Martin)
Dust: Problematic Tracer of $M_d$

Images of disks

Meteoritic record

- CAIs
- Iron meteorite parent bodies
- Chondrules
- Angrites
- 4 Vesta / HED
- Mars differentiation
- Earth
- Moon

Results of modelling
- Planetary growth
- Oligarchic growth

Inner disk chemistry

Organics/water within snowline

This is not a primordial disk

Planetesimals form within 1 Myr

Non-migrating (> km) icy bodies beyond snowline

Righter & O’Brien 2011

$\log (M_{\text{disk}} / M_{\text{Sun}})$

$F_{\text{HCN}} / F_{\text{H}_2\text{O}}$

Time after $T_0$ (million years)

$F_{\text{HCN}} / F_{\text{H}_2\text{O}}$ vs. $\log (M_{\text{disk}} / M_{\text{Sun}})$

Log (M_{disk} / M_{Sun})
Solids in Protoplanetary Disks vs. Exoplanets & Debris Disks

- **Class I disks**
- **Class II disks (s)**

Andrews et al. 2013

Najita & Kenyon 2014

No 5-30 $M_E$ microlensing planets

Class II disks are not primordial disks!
Planet Formation: an Efficient Process

If Class I sources are “primordial”...

- Planet formation efficiency > 30%
  
  Losses (migration, scattering) increase required mass
  
  May predict undiscovered planet populations

- Planets form with stars (protostellar = protoplanetary)

How efficient are planet formation theories?
Building Planetesimals and Protoplanets

Migrating icy bodies within snowline dump H$_2$O vapor (not seen)
Planetesimals and Protoplanets

Condensation at Snowlines
Streaming Instability, other concentration processes

Pebble accretion

Simon et al 2016

What are some observational tests of these pictures / processes?
What are some observational tests of these pictures / processes?
Holes, Lobes, Arms, Warps, Rings & Gaps

Are these fingerprints of planets or something else? How can we tell? If it’s planets, what masses, how many, located where?
Holes, Lobes, Arms, Warps, Rings & Gaps

Are these fingerprints of planets or something else? How can we tell? If it’s planets, what masses, how many, located where?

Reviews by M. Benisty, Z. Zhu
Talks by Hammer, Nealon, Huang, Bae, Dipierro, Cazzoletti, Schoonenberg, Matra, Facchini, Keppler
Thurs Discussion session (R. Dong, P. Pinilla)
Rings and Gaps are Common

- TW Hya
- V883 Ori
- HD163296
- HL Tau
- Elias 2-27
- HD142527

Rings -- Common?
Spiral arms -- Rare?
What Causes Gaps – Planets?

One $10 \, M_\oplus$ planet could create many rings and gaps
See talks by Huang, Bae, Dipierro
What Creates Gaps – Snowlines?

Condensation at snow lines spurs growth to > 10 cm, reduces continuum opacity?

Talks by Schoonenberg, Matra
Origin of Rings and Gaps

Zhang et al:
**Snowlines** accelerate growth > cm size
- Disks become optically thin
- 10 cm or larger objects form

Dong et al:
A 10 $M_e$ planet can do it.

How to tell the difference? Study distribution of gas, particles of different sizes (i.e., wavelengths)
Origin of Rings and Gaps

Organics/water within snowline

Inner disk chemistry says most disks have formed non-migrating icy planetesimals

Log \( \frac{M_{\text{disk}}}{M_{\text{sun}}} \)

\( \frac{F_{\text{HCN}}}{F_{\text{H}_2\text{O}}} \)

Najita et al. 2013

Jet

Unusual MIR colors
Holes, Lobes, Arms, Warps, Rings & Gaps

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Star and Planet Formation

Cloud Cores, embedded YSOs

Revealed star + disk

Very evolved – not “protoplanetary”!

Planets + debris
EvoluIonary Stages of Star Formation

What is a primordial disk?
When does planet formation begin?

Build the star

Embedded object:
Star assembling its mass; has a disk, outflow, envelope.

Classical T Tauri star:
Star essentially formed; has a disk.

Build the planet

Weak T Tauri star:
Little/no accretion, gas, and dust
Possible planetesimals for later debris production
Evolutionary Stages of Star Formation

What is a primordial disk?
When does planet formation begin?

Start building the planet

Embedded object:
Star assembling its mass; has a disk, outflow, envelope.

Classical T Tauri star:
Star essentially formed; has a disk.

Finish building the planet

Weak T Tauri star:
Little/no accretion, gas, and dust
Possible planetesimals for later debris production
Star and Planet Formation

Reviews by M. Bate, J. Tobin
Talks by Fischer, Karnath, Hsieh, Rosen

What are disks like in the star-building phase?