Planet Formation Across the Stellar Mass Spectrum

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Why Stellar Mass?

- Things change:
  - Luminosity/Temperature
  - Orbital period
  - Disk mass and lifetime
  - These all impact on planet formation
  - e.g. giant planet frequency
Outline

- Background
- Snow Line (ApJL 06)
- Giant Planet Frequency (ApJ 08)
- Disk Dispersal (ApJ to be resubmitted)
Background
Star-Disk-Planet Timeline

- Star
- Disk
- Planet

- Mass

- PMS
- main sequence
- evolved
- debris disks
- LHB
- exoplanets
- found

10^5 10^6 10^7 10^8 10^9

Time (years)

-accretes ↔ disperses

-star + disk

-~mm ~km

-giants & migration

earths
T Tauri star + disk

Hubble

Not Hubble
Snow Line

- Distance where disk becomes cold enough to water to be in ice phase
- Extra (icy) material to make planets
- Temperature determined by stellar luminosity, disk accretion, or both.
Grain growth
Planetesimals

Kokubo & Ida 1998
Viscous Evolution

- spreads disk
- accretion
- depletion
- declines over time
- heats disk
PMS evolution

Isochrones at: $1\times 10^6$ $3\times 10^6$ $1\times 10^7$ years

searched on: si

Siess et al 2000
Isolation

- all mass in an annulus put into one protoplanet
Gas Giants

Pollack et al. 1996
Photoevaporation

- critical radius
- wind
- accretion
Main Sequence
Debris disks

Kalas et al. 2005
stars with detectable planets

\[
\begin{array}{|c|c|c|}
\hline
N_{\text{HOSTS}} & N_{\text{STARS}} \\
\hline
3 & 169 \\
34 & 803 \\
9 & 101 \\
\hline
\end{array}
\]
Snow Line
Snow Line Moves

- Snow line moves inward as star contracts
- Sets where “super-Earth” planets can form
Gas Giant Frequency
Motivation

- Better model of snow line
  - Ida & Lin use $L_{\text{star}}^2$ proportionality
  - Too far for intermediate-mass stars
- Look at formation regions
- Predict/Explain frequency with stellar mass
Snow Line and Isolation

disk lifetime

isolation masses

snow line
Regions where giants form

\[ t_{\text{core}} = 1.0 \times 10^6 \text{yr} \]
\[ M_{\text{core}} = 10 M_\oplus \]
\[ \delta = 1.5 \]
Disk mass range

no of stars

low-mass stars

disk mass scales with stellar mass

higher-mass stars

disk mass
Fraction of stars with gas giants
Summary

- Giant planet frequency increases with stellar mass
- Lower metallicity of intermediate mass planet hosts is due to more massive disks
Hot Super-Earths
Motivation

- Searches for low-mass planets
  - CoRoT/Kepler - transits - short periods
- Structural planet models
  - Derive bulk properties from density
- Look at signatures of two mechanisms
  - Inward migration or scattering
Super-Earth Origins

enough to make super Earths
Scattering

formation on circular orbits

inner planet gets close periastron

circularised?
jupiters: maybe
earthss: unlikely
Scattering Results

Scattering to small periaestra possible

Low mass stars with close snow line

Circularisation unlikely  \textit{(Raymond et al 2008)}

Summary

Possible around low mass stars

Hard to detect (long periods)
Migration

planets stop at inner disk edge
bigger planet = faster migration

disk gone
1-10 Myr
Migration model

Stellar mass (M\text{sun})

Planet mass (M\text{Earth})

Hot super-Earths

No hot super-Earths
Summary

Snow line important in both models

scattering: eccentric planets, hard to find

migration: possible, observational signatures
Disk Dispersal
Motivation

✦ Many clusters show mass dependence
✦ Expected from a simple dispersal model
✦ Planet orbits change with stellar mass
✦ Attempt to verify/quantify for use in models
Study

- Get IR and HαEW data for 1-10 Myr clusters
- Derive disk fractions, overall and in mass bins
- Look for stellar mass dependence, quantify
- Compare with model
- Effects on planet formation?
Disk Signatures

Inner Gap in Circumstellar Disk  Spitzer Space Telescope • IRS
NASA / JPL-Caltech / D. Watson (University of Rochester)  ssc2004-08c
Cluster HR diagrams

1. Taurus
2. Cha I
3. IC 348
4. Tr 37
5. NGC 2362
6. OB1bc
7. Upper Sco
8. OB1a/250ri
9. NGC 7160

log $L$ (L/L$_{\odot}$) vs log $T_{\text{eff}}$ (K)
Disk Fraction Decay

The graph shows the relationship between disk fraction and age (in Myr). Each point represents a different galaxy, labeled with numbers 1 to 9. The x-axis represents age in Myr, and the y-axis represents disk fraction.
Binned disk fractions

Solar mass bin fraction

super Solar mass bin fraction
Photoevaporative model

disk fraction

higher mass 1 Myr 10 Myr

lower mass

time

higher mass
Model Comparison

Solar mass bin fraction

super Solar mass bin fraction

Solar mass bin fraction
How many stars for $3\sigma$?
Consequences?

Real?
Possible explanation

- Intermediate mass stars lose disks too early for planets to migrate
- Gap a direct result of faster disk dispersal
Summary & Future

- Some evidence of stellar mass dependent disk dispersal
- May cause observed exoplanet distributions
- More stars and clusters
- Get both IR and Hα for objects
- High resolution spectra (also binaries)
Summary
Snow line moves and sets where large planets form

Giant planet frequency changes with stellar mass

Also trends for super-Earth mass planets, testable by Kepler

Disk dispersal varies with stellar mass and has consequences for planet formation
Disk dispersal (outside-in)

Small Star with Evaporating Disk

Hot Massive Star

Tail

0.5 Light Year

Balog et al. 2006
Photoevaporation

- Critical radius
- Surface density
- Wind

Graph showing the spreading and photoevaporation of a T Tauri disk over time (0.5 Myr, 3 Myr, 6 Myr, 6.01 Myr, 6.02 Myr, 6.03 Myr, 6.06 Myr, 6.12 Myr).

Alexander et al. 2006
Range of Stellar Masses

t_{\text{core}} = 1.0 \times 10^6 \text{yr}

M_{\text{core}} = 10 M_{\odot}

\delta = 1.5

more mass in disk
Fig. 1. Metal distribution for planet-hosting (P-H) giants (full line), P-H dwarfs with periods larger than 180 days (dashed line) and all P-H dwarfs (dotted). The giants show a distribution shifted to lower metallicity by about 0.2–0.3 dex with respect to the dwarfs.
more conjunctions and start closer

filled: survivors
grey: ejected
blank: collisions

closest periastron

start farther and fewer conjunctions

snow line
Binned disk fractions
Model Comparison

The diagram shows a comparison of MB4 and MB3 fractions over log time (yr). The inset highlights specific data points with markers.