Young Brown Dwarfs & Giant Planets: Recent Observations and Model Updates

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Paper details

- Young Jupiters are Faint: New Models of the Early Evolution of Giant Planets

  Authors: J.J. Fortney, M.S. Marley, O. Hubickyj, P. Bodenheimer, and J.J. Lissauer

  - Astronomische Nachrichten, Vol. 326, Issue 10, p. 925-929

Overview

- Introduction to Sub-Stellar Objects
- Brown Dwarf Models
- Recent Independent Mass Estimates
  - Calibrate the Mass-Luminosity-Age Relationship
- Recent revision to the models

Brown Dwarf (BD) and Giant Planets (GP) definitions

Brown Dwarfs and Giant Plants fall into the category of sub-stellar objects.

- Brown Dwarf – sub-stellar objects that do not fuse H into He
  1. $13\ M_J < M_{BD} < 90\ M_J$
  2. Sub-stellar objects that form through to gravitational instabilities.
- Giant Planet
  1. Sub-stellar objects that do not burn deuterium ($M_{GP} < 13\ M_J$)
  2. Sub-stellar objects that formed in a circumstellar disk, under a specific formation mechanism.

Other arguments based on mass, formation, and location. Planetmos (planetary-mass objects, ie. sub-brown dwarfs) & Planetars (planet-stars)

Sub-stellar objects

$M_{SS} < 90\ M_J$
$R_{SS} \sim R_J$
$T_{effSS} < 3000$ K

Short History:

1963 – Kumar studies degenerate cores in low mass stars

1980-1990s – Searches for brown dwarfs in star forming regions and around nearby stars.

1988 – Becklin & Zuckerman discover the first L dwarf (GD 165-B), a likely brown dwarf

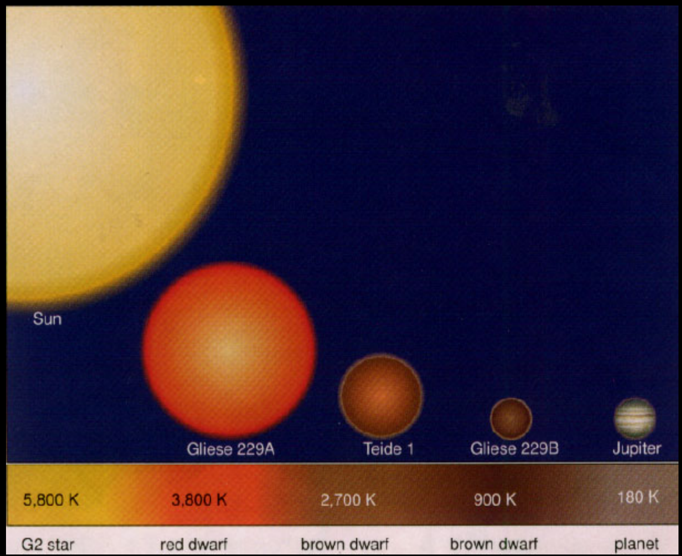
1990 – First brown dwarf confirmed (Teide 1, SpT M8, Pleiades cluster)

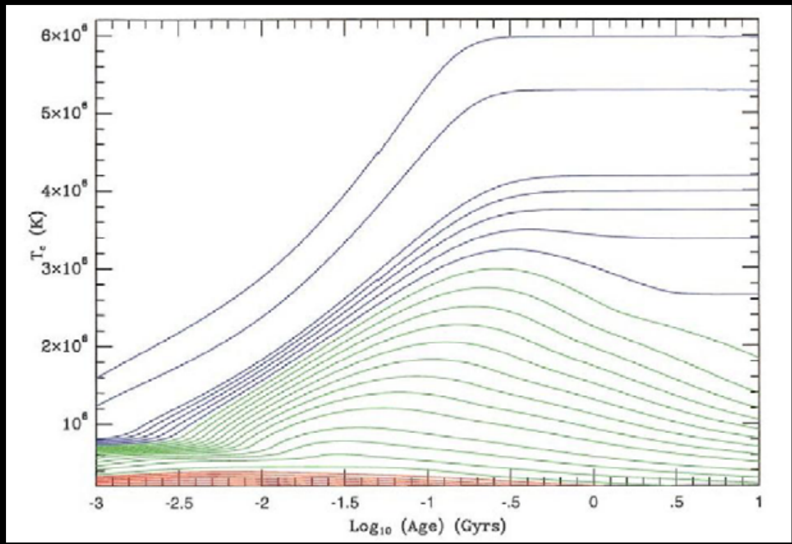
1993 – Wolszczan discovers a planet around a pulsar (PSR 1257+12)

1995+ - Many RV discoveries of extrasolar planets.

1995 – Nakajima & others discover the first methane dwarf (GL 229B).

Since sub-stellar objects never reach the main sequence, their evolution is significantly different than stellar evolution.





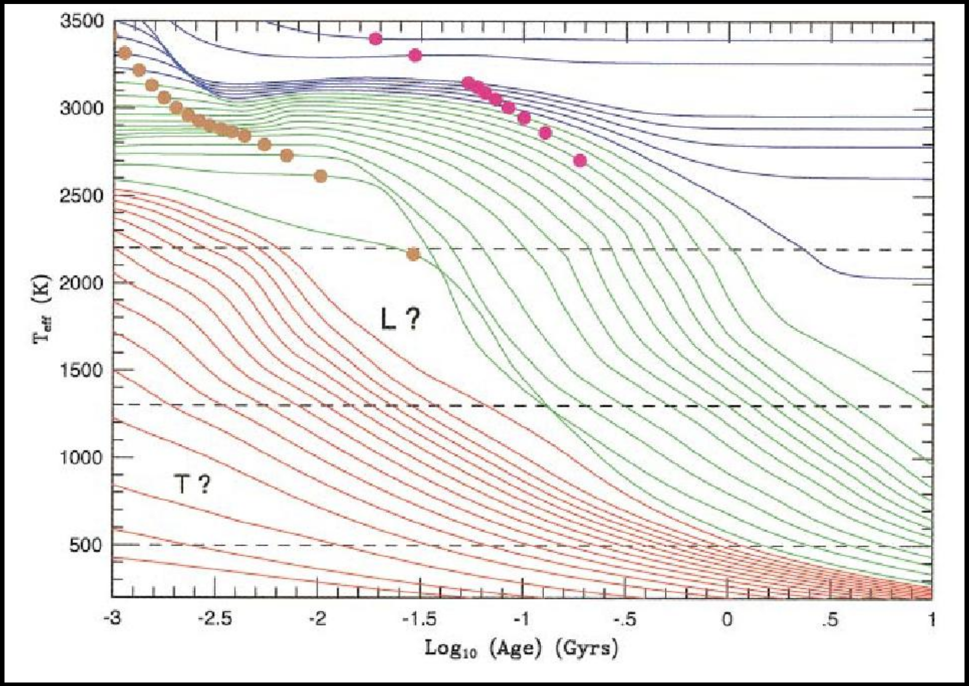
Burrows et al. 2001

Evolution of Sub-Stellar Objects

- Brown dwarfs evolve across spectral types M, L, and T.
- An L dwarf can be either a star or a brown dwarf, depending on its age.

20 M_J object
@ 1 Myr old
SpT ~ M8, T ~ 2700K
@ 1 Gyr old
SpT > T6, T ~ 1000K

T_{eff} vs. Log (Age)



Burrows et al. 2001

Motivation for Studying Young Sub-Stellar Objects

- Sub-stellar objects are more numerous than stars. They occur both in the field (single or binary), and in star forming regions.
- Formation mechanisms are not well understood, but recent studies have helped constrain models.
  - Possible overlap between stellar and planetary mass object formation mechanisms.
  - Ejection?
  - Fragmentation?
- The study of young sub-stellar object in clusters constrains the bottom of the IMF, and aids in the determination of cluster size and age.
- Low-mass objects are more luminous when they're young.
  - Young sub-stellar objects are the best candidates for the direct detection of extrasolar planets!

The Conventional SS Models
Arizona & Lyon

- Burrows et al. (1997) & Baraffe et al. (2003) assume an "initially hot start."
- Assumptions
  1. Fully convective
  2. Pick a radius
  3. Adiabatic at all stages of evolution
- For young ages (< 1 Gyr), these initial assumptions are very important and affect predicted observables.

You should be careful when you derive a sub-stellar object's mass at young ages.

Recent Observations of Young, Sub-Stellar Objects 1

- Mohanty, Jayawardhana, Basri
- Observe mid to late-M sub-stellar objects in Upper Scorpius (3-5 Myr) and Taurus (1 Myr) (HIRES at Keck)
  1. Take spectrum. Compare spectrum to synthetic spectra, and derive surface gravity and temperature.
  2. Obtain photometry. Use known cluster distance and photometry to determine the surface flux, and then use this info to derive a radius.
  3. Get mass from radius and gravity.
  4. Compare to theoretical models!

$g=GM/R^2$

- Conclusion: High mass (> 30 M_J) T_{eff} < T_{eff} predicted

  Low mass (< 30 M_J) T_{eff} > T_{eff} predicted

  M_{min} ~ 13 M_J

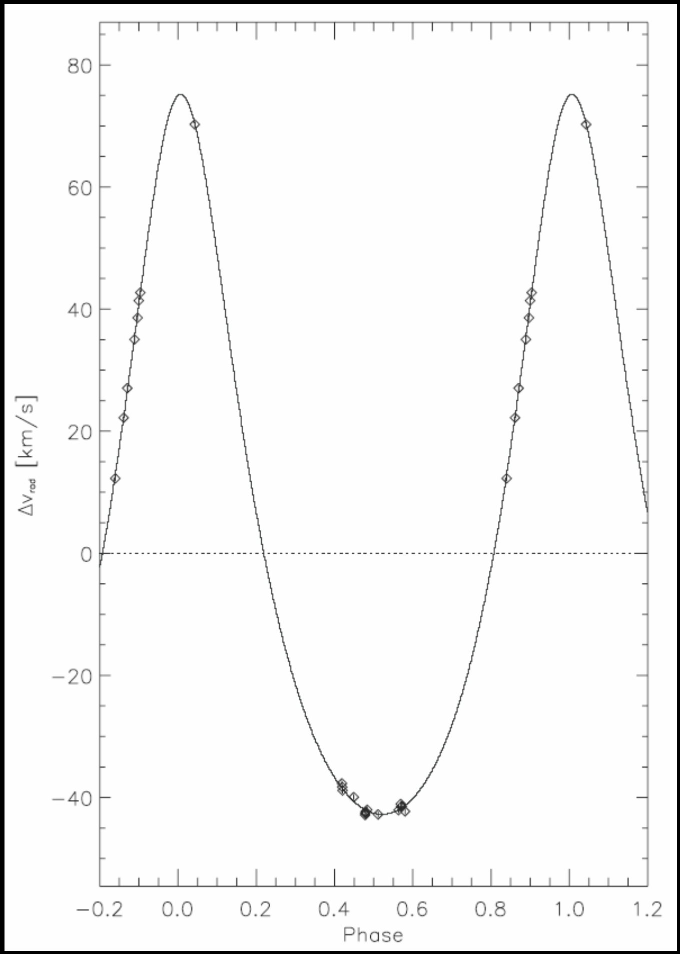
Observations are inconsistent with the existing models!

Recent Observations of Young, Sub-Stellar Objects 2

- UScoCTIO 5
- SpT M4, q ~ 1, Age 3-5 Myr
- Keck HIRES, determined this is a spectroscopic binary.
- Observations from Keck, CTIO, and Magellan to determine orbit (36 days).

$$T^2 = \frac{4\pi^2}{G(M+m)} \cdot a^3$$

- $M_{pri} > 0.32\ M_s$
- $M_{predicted} \sim 0.23\ M_s$



Reiners, Basri, & Mohanty 2005

Recent Observations of Young, Sub-Stellar Objects 3

- AB Dor C,(AB Dor K1)

AB Dor moving group (Age ~ 50 Myr)

SpT M8, T_{eff} ~ 2,600K

ρ = 0.156”, 2.3 AU

VLBI measured an astrometric companion, got orbital info.

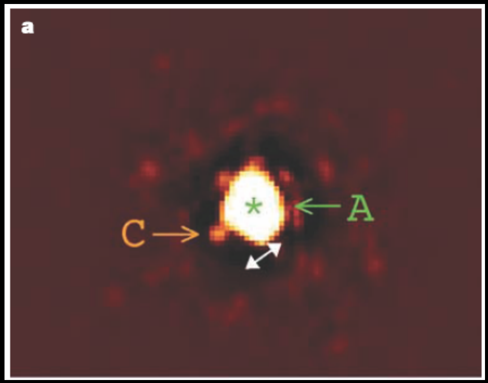
M_C = 0.090 ± 0.005 M_S

Models predict M_c = 0.070 M_s and 0.038 M_s

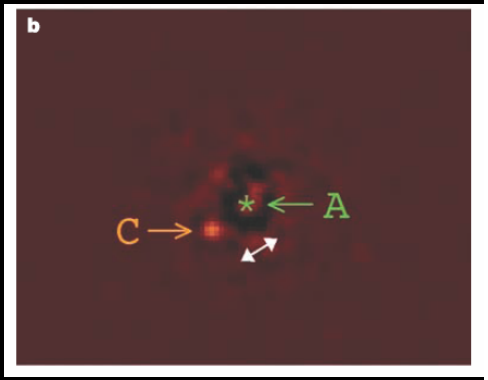
Close et al.

Discovery images

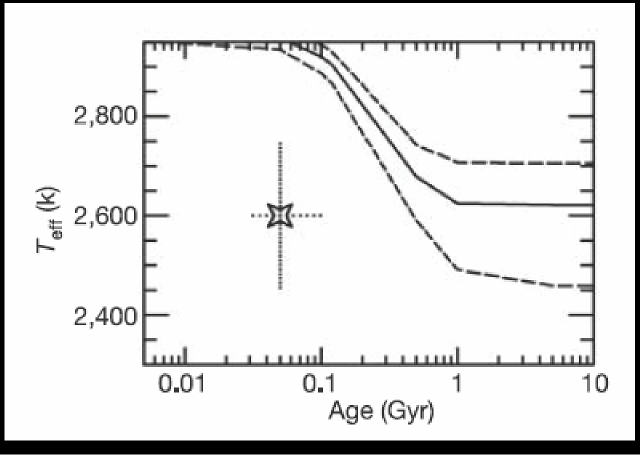
Without SDI



With SDI



Lyon Models Teff v. Age



Modes of Giant Planet Formation: Core-Accretion Gas Capture

1. Dust particles form planetesimals through accretion.
2. Gas accretion rate increases, solid accretion decreases, and eventually the gas and solid mass become equal.
3. Runaway gas accretion. Prior evolution is referred to as the Nebular Stage.
4. Gas accretion reaches a limiting value, where the gas begins to accrete hydrodynamically.
5. Accretion stops.
6. Planet contracts and cools.

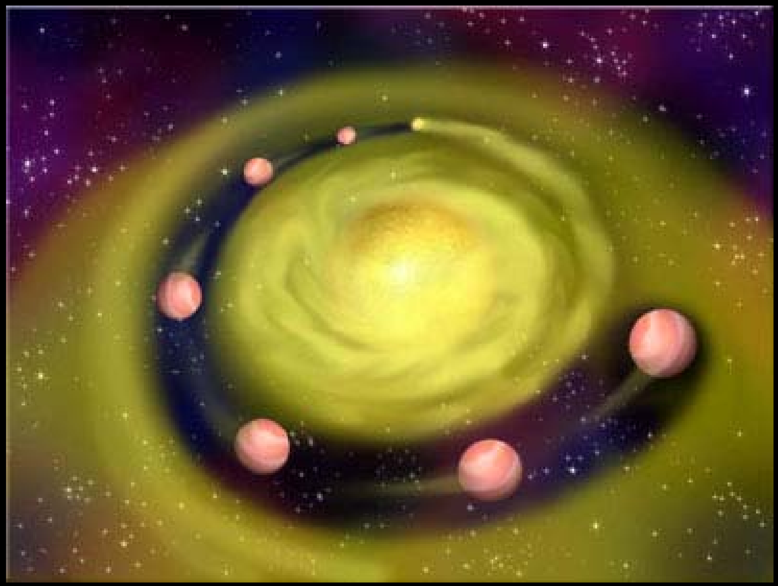


Image Credit, Meg Stalcup

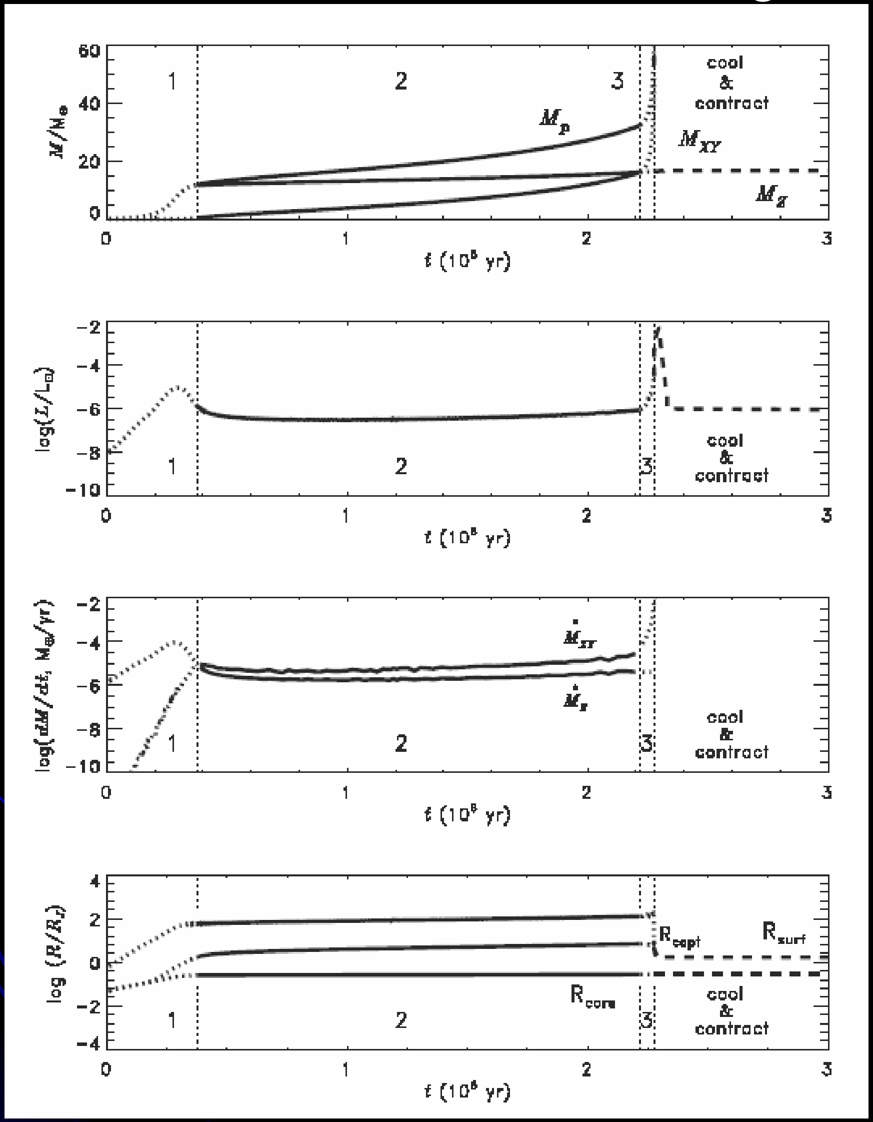
Core-Accretion Model Revisions to Evolution Models: $1M_J$ example

Mass v. Time

Luminosity v. Time

Accretion v. Time

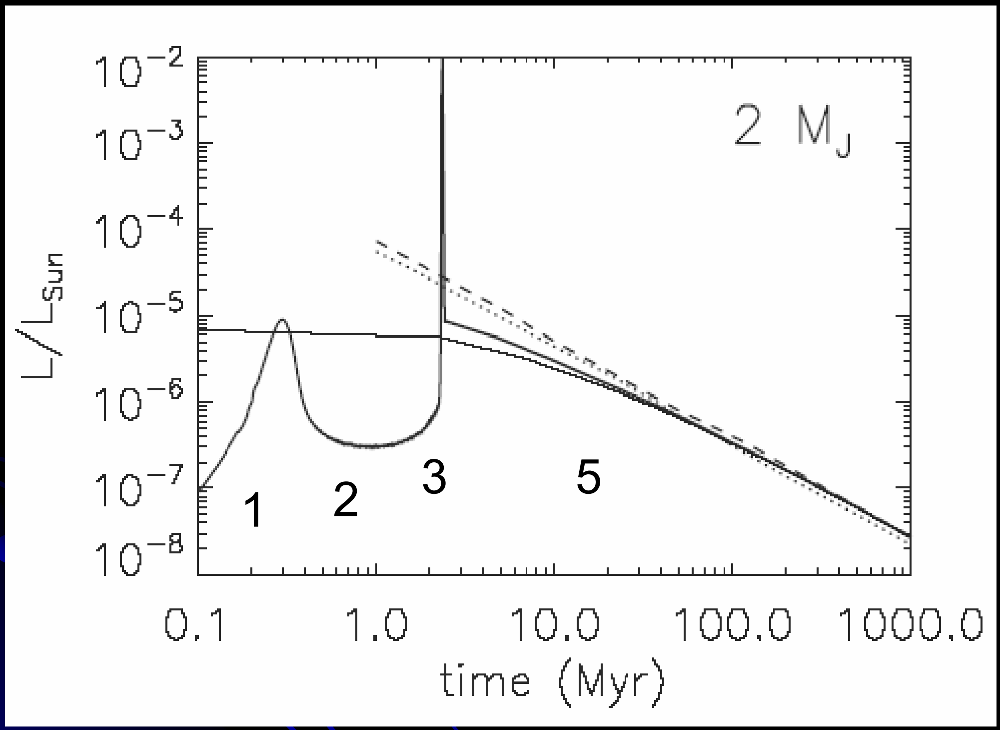
Radii v. Time



1. Solid planetesimal accretion
2. Solid core influences gas envelope
3. Runaway gas accretion

Hubickyj et al. 2005

Core-Accretion Model Revisions to Evolution Models 2: 2 M_J example



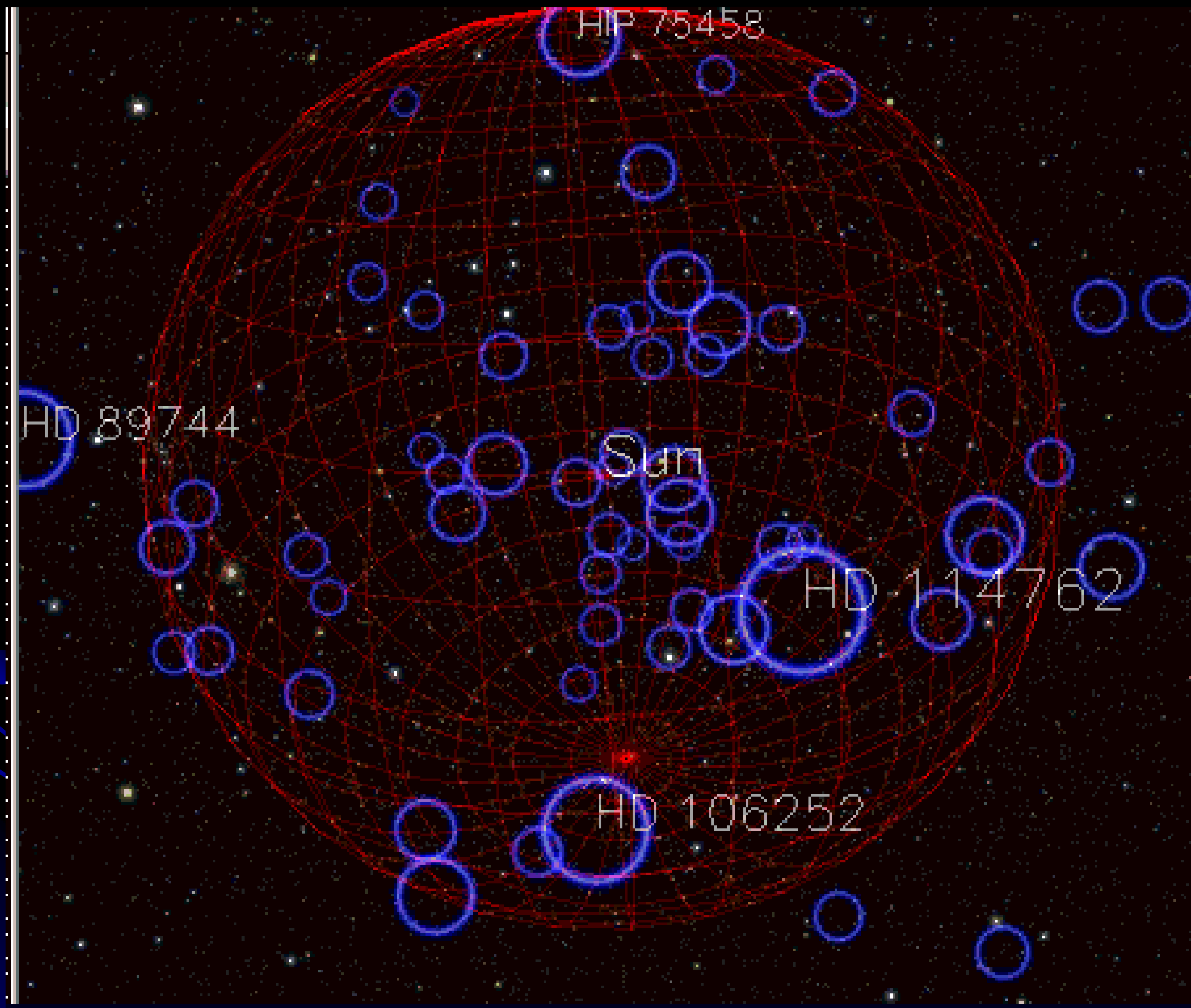
1. Solid planetesimal accretion
2. Solid core influences gas envelope
3. Runaway gas accretion

Model luminosity at 2.5 Myr is only 1/3 that predicted by the current models.

These differences exist for tens of millions of years (models still ~50% overluminous at an age of 20 Myr)

Thick solid line – Fortney et al. 2005 (this paper)
Dotted lines – Burrows et al. 1997
Dashed line – Baraffe et al. 2003

According to this model, the other models *underestimate* the true masses of the planets!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HD 89744
Sun
HD 114762
HD 106252