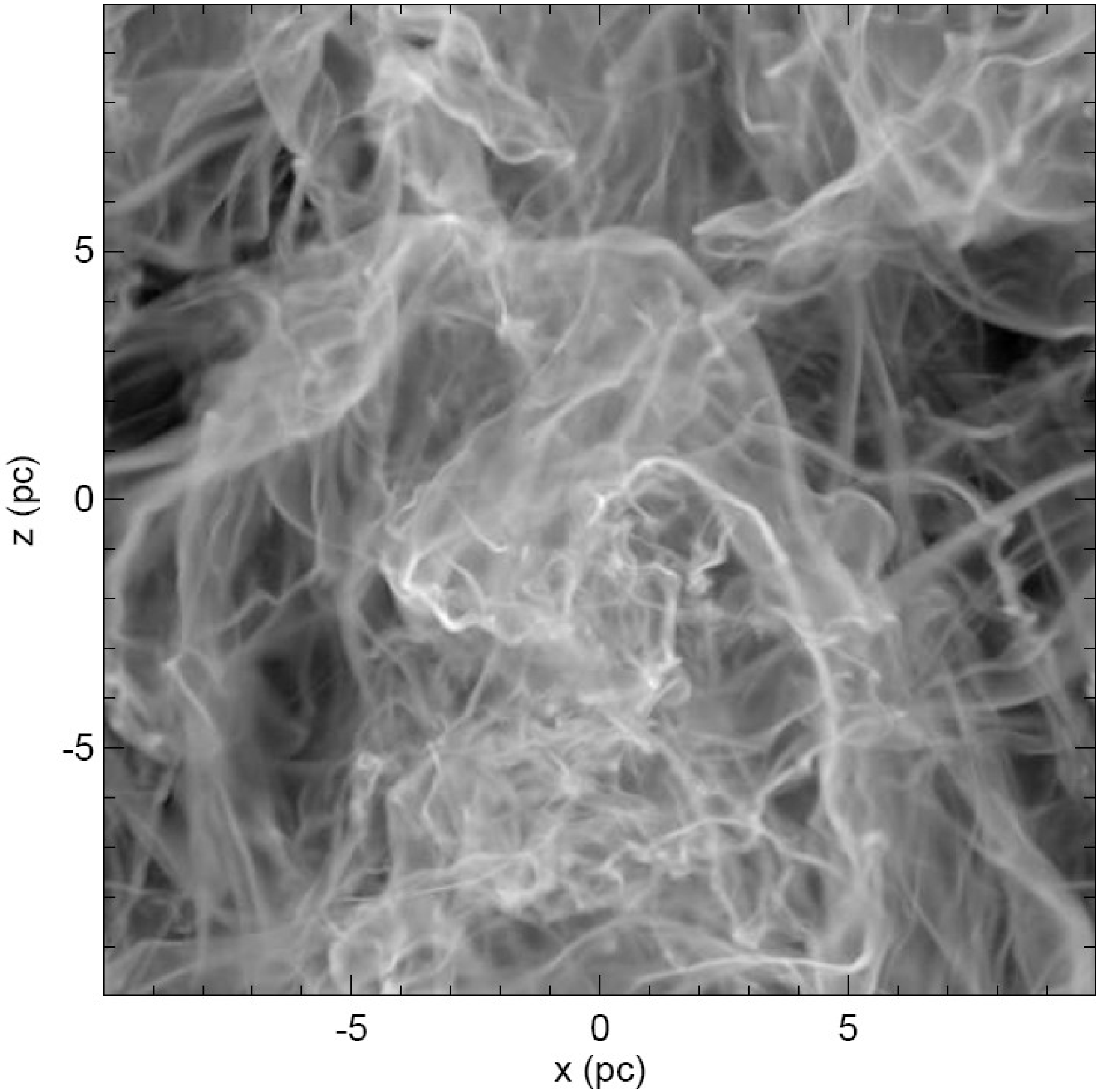
How Stars Are Born

Molecular Clouds

- Molecular clouds are not too regular – they are called clouds for a reason!
- They form behind the shock wave of a spiral arm, so the gas inside is highly ***turbulent***.
- Properties:
  - Mass: 10^3 - 10^6 $M_\odot$
  - Lifetime: < 20 Myr
  - Sizes: 10 – 30 pc

Turbulence in Molecular Clouds



Computer model

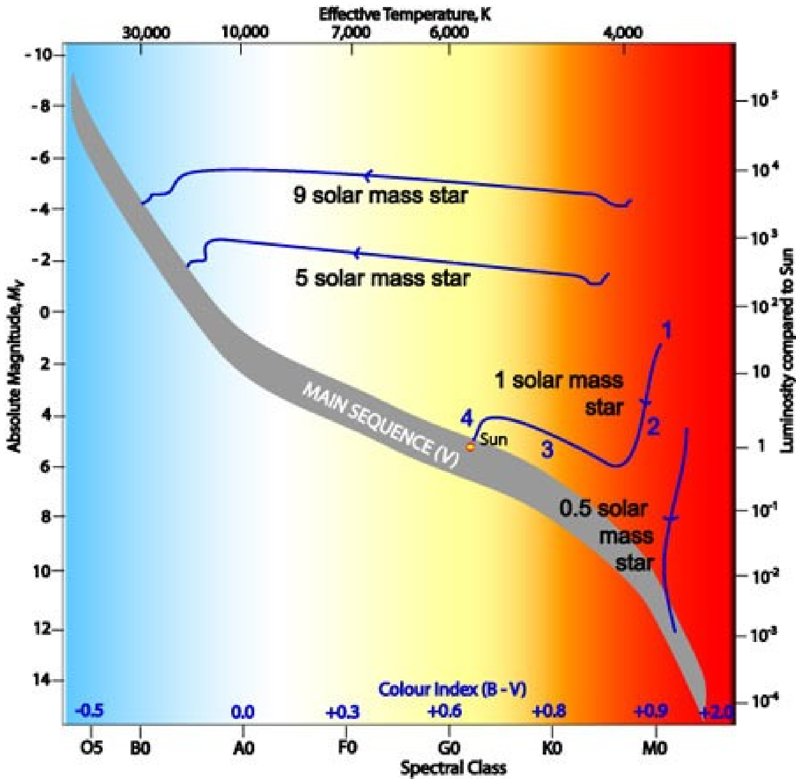
Interstellar Chemistry

- Molecular clouds contain:
  - Molecular hydrogen (H_2)
  - Cosmic dust
  - Lot's of other molecules, including familiar ones: NaCl, N_2, O_2, CO, FeO, H_2O, NH_3, CH_4, CO_2, C_2H_5OH, $(CH_3)_2CO$, C_6H_6 …
  - Many other organic molecules (~ 160) – a good start for life!

Proto-stars

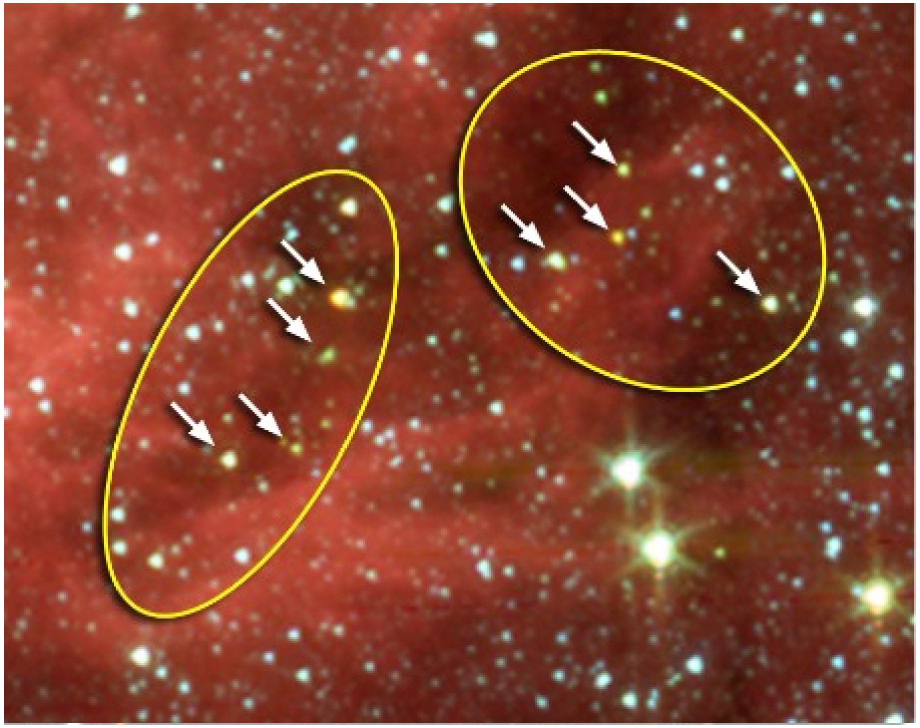
- Densest parts of molecular clouds are called ***cores***. When cores begin to collapse, they very fast (in 100,000 yrs) reach pressure equilibrium.
- At this point they are called ***proto-stars***. They are round, but do not burn hydrogen yet (too cold at the center).
- On a CMD they follow a ***Hayashi track***.

Theoretical Hayashi Tracks of Protostars



Proto-stars

- Proto-stars are highly embedded in the surrounding molecular gas, they are only visible in the infrared.



Optical view vs IR with Spitzer Space Telescope

Destruction of Molecular Clouds

- Molecular clouds are destroyed by UV radiation from young stars and by supernova explosions.
- We do not know which of the two is the most important, both processes appear to work well.
- Supernovae fell out of fashion in the last year or two.

Radiation Pressure Blowing Tarantula nebula Apart

- In huge star forming regions, like Tarantula Nebula, radiation pressure does the job.

Pillars of Creati

Star-Birth Clouds · M16 HST · WFPC2

PRC95-44b · ST ScI OPO · November 2, 1995
J. Hester and P. Scowen (AZ State Univ.), NASA

Orion Nebula (M42)

A recipe for a mess (a beautiful one too):
Molecular gas + Turbulence + Star formation.

Formation of Massive Stars

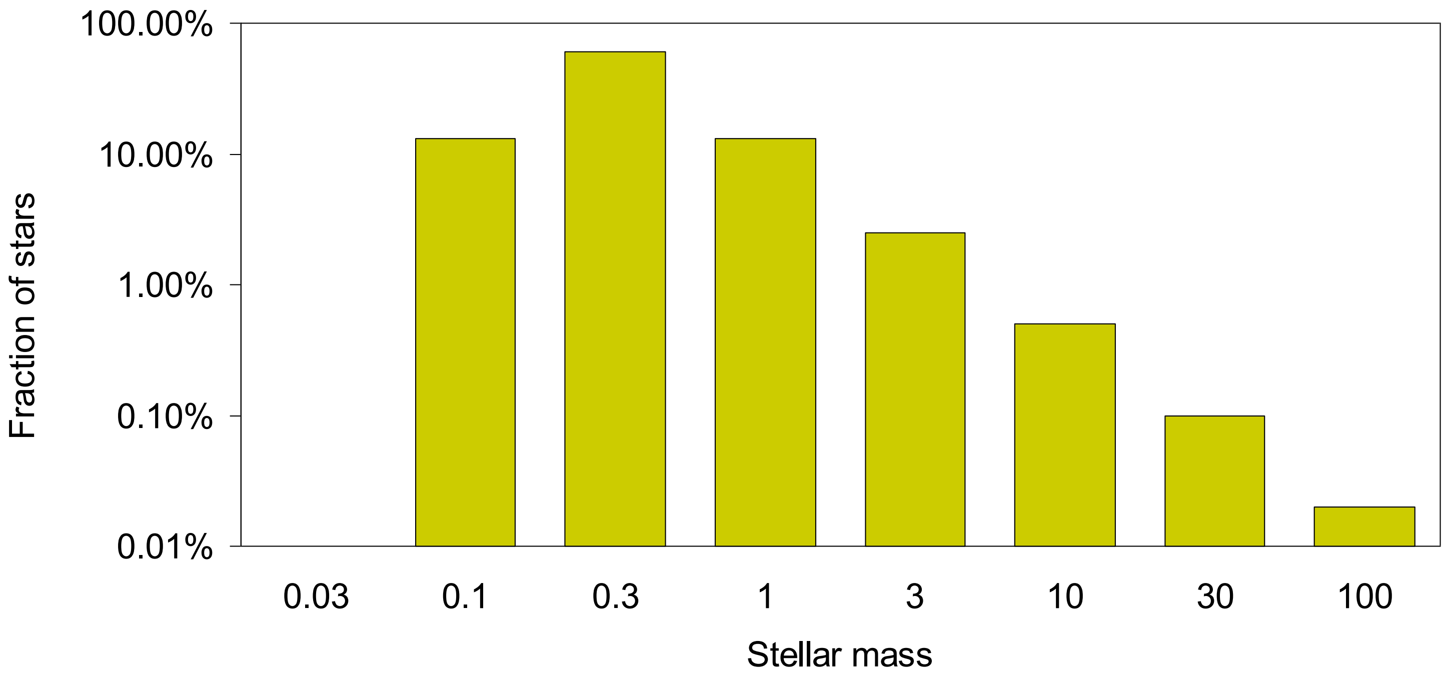
- Formation of massive stars (more than 10 $M_\odot$) is not well understood:
  - They boil their own environment way too fast.
  - Their radiation pressure is so high, it prevents enough gas from accreting.
- One hypothesis proposes that massive stars form by merging of smaller ones inside dense stellar clusters.
- That makes sense – most of massive stars form in clusters and groups.

Brown Dwarfs

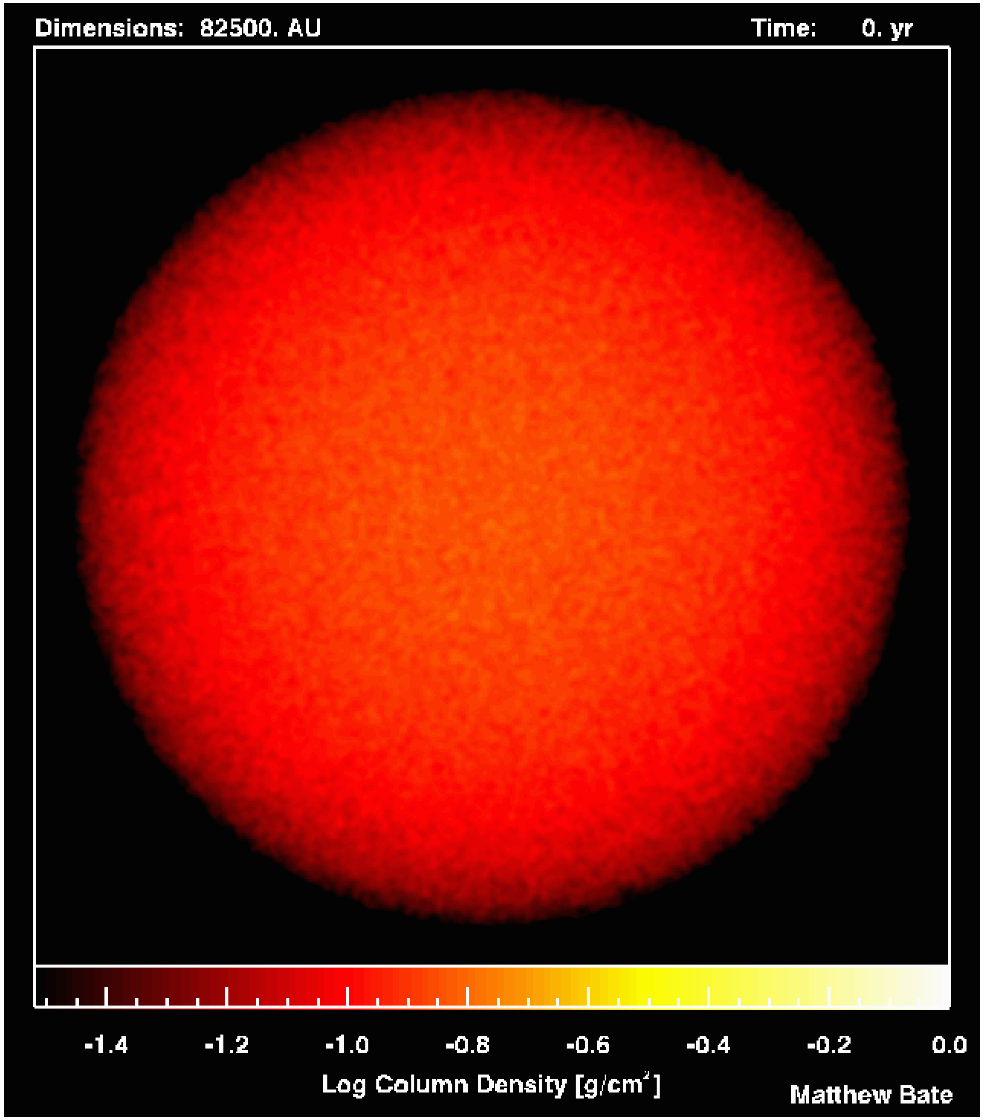
- Very low mass proto-stars (less than 0.08 $M_{\odot}$) never get hot enough for hydrogen burning to begin.
- They never become stars – instead, we call them ***brown dwarfs***. They also used to be called "planetars" and "substars".
- They will slowly cool and compress for tens of Gyr. Then hydrogen in the core will become solid, and they will remain in that state forever, as hydrogen black dwarfs.

Initial Mass Function

- Measures fractions of stars of given mass.
- Surprisingly universal – the same in all star forming regions and in all galaxies.

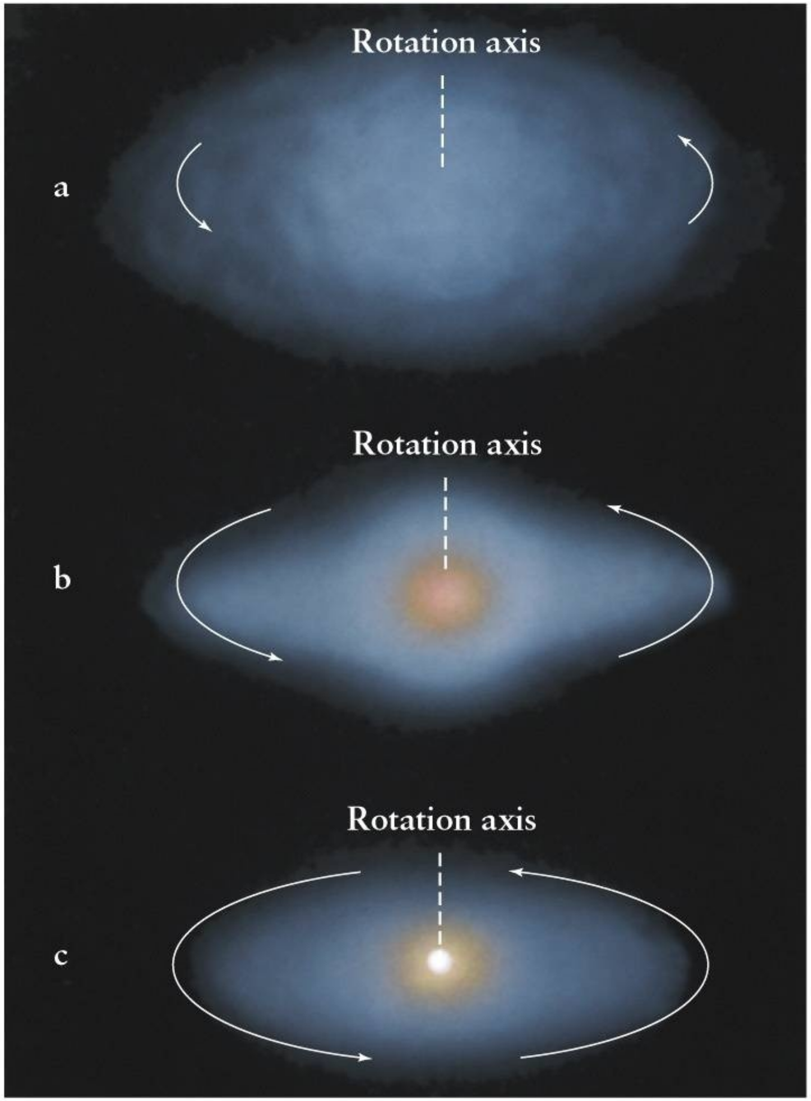


Computer Models



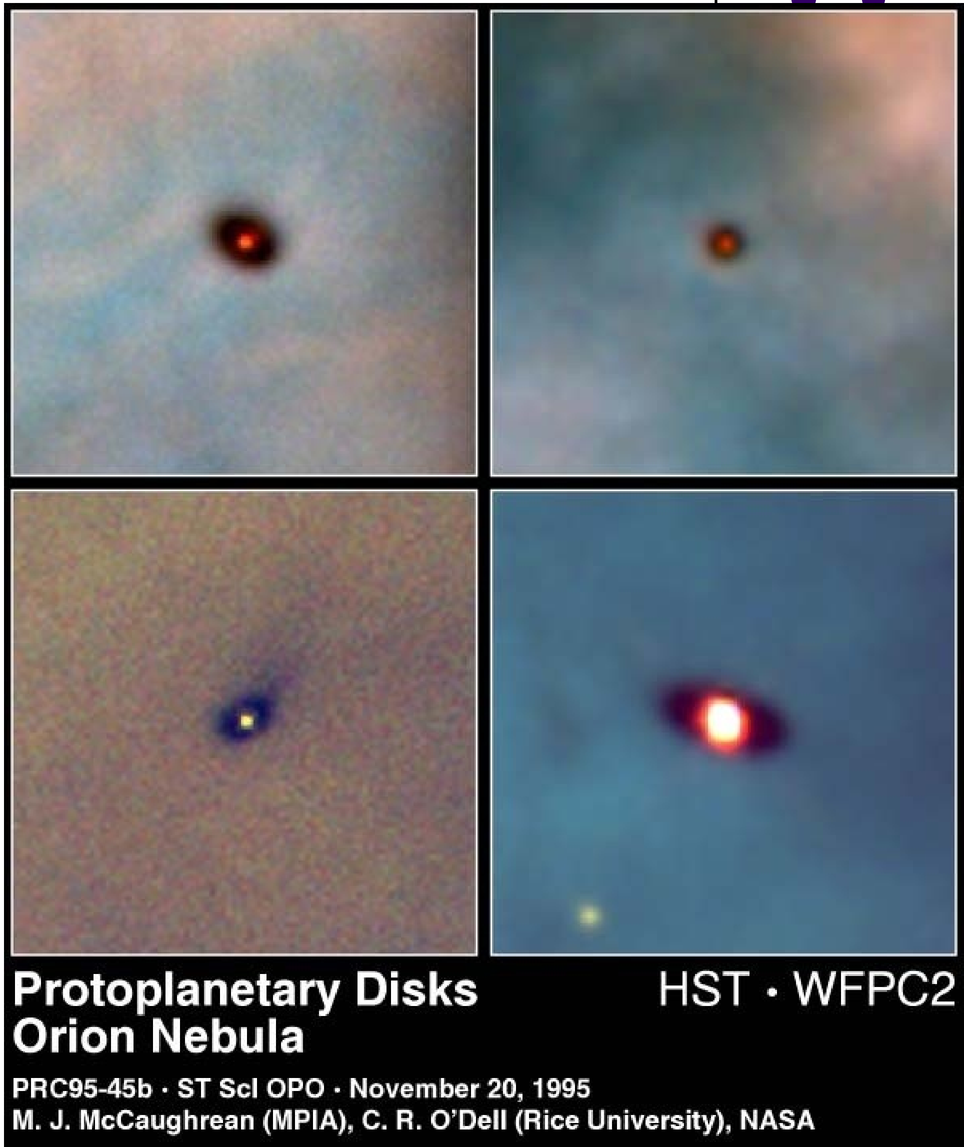
Proto-stars and proto-planetary disks

- Since molecular clouds are turbulent, gas there has all kinds of motions.
- As a proto-star forms, some gas in the collapsing core rotates too fast to form a sphere – it remains in as a ***proto-planetary disk***.



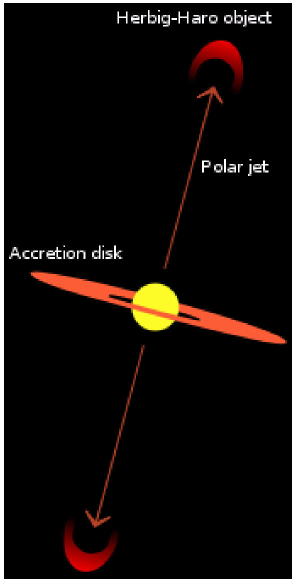
Proto-planetary disks

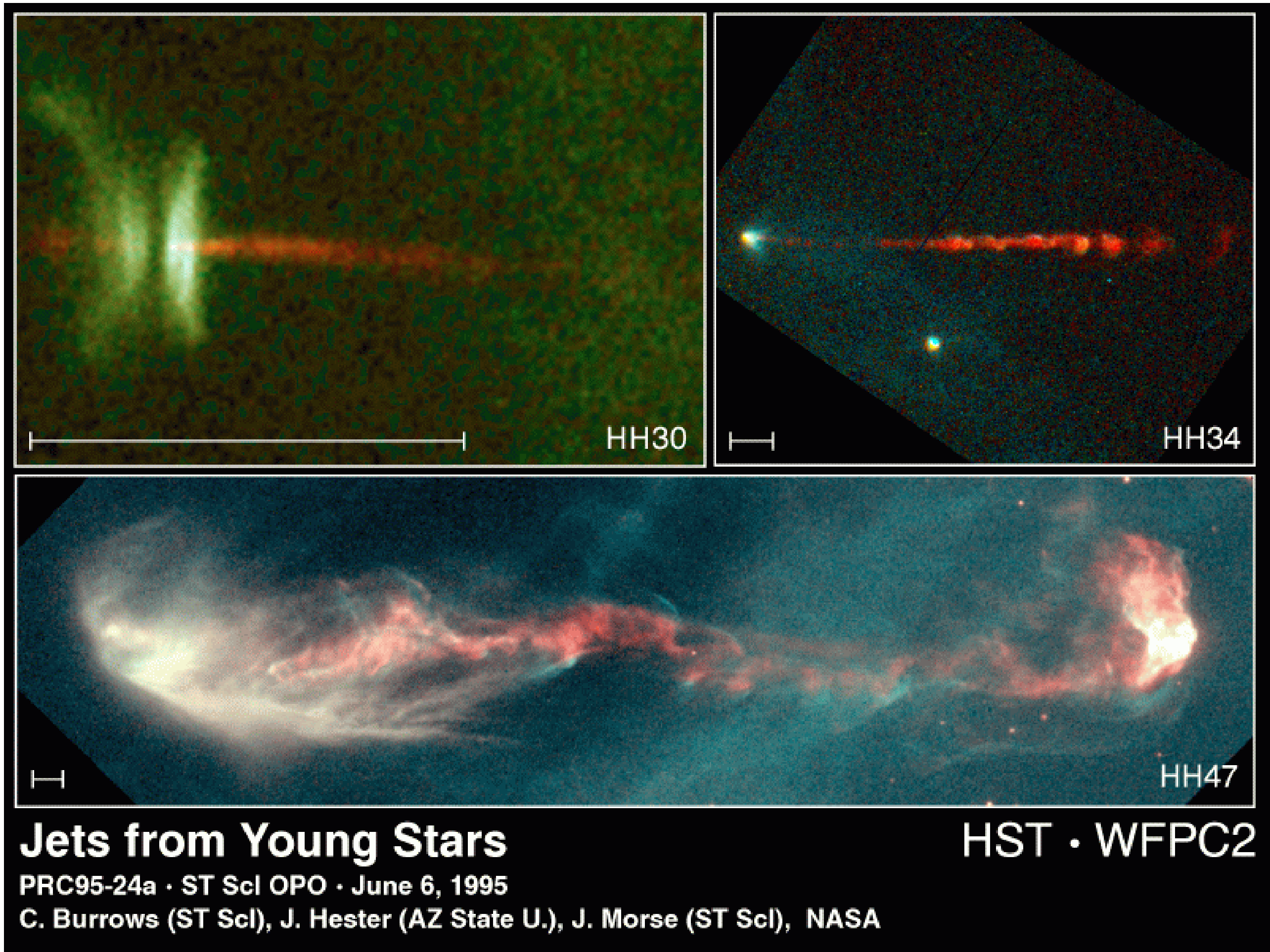
- In Orion Nebula (the nearest star forming region) proto-planetary disks can be distinguished with the Hubble Space Telescope.
- They are often shortened to ***proplyds***.



Proto-stellar Jets

- Some young stars have ***proto-stellar jets***.
- We do not know what causes them…





A Race to Become Planets

- Dust grains in proto-planetary disks can stick together, or ***coagulate***. As they grow, when they reach a size of about 1 km, they become ***planetesimals***.
- At the same time nearby massive stars keep boiling the proplyd away. It is a race – if planetesimals form too slow, the disk will be destroyed, and no planets would form.

Planetesimals and Planets

- Planetesimals keep bumping into each other and growing.
- When they reach sizes of about 100 km, they become too rare to bump into each other often.
- But some miracle happens, and they keep growing until they form ***rocky planets*** – like terrestrial planets in the Solar System.
- Some rocky planets may grown really big – 10 times the Earth mass. Then they rapidly accrete surrounding gas, to become gas giants.

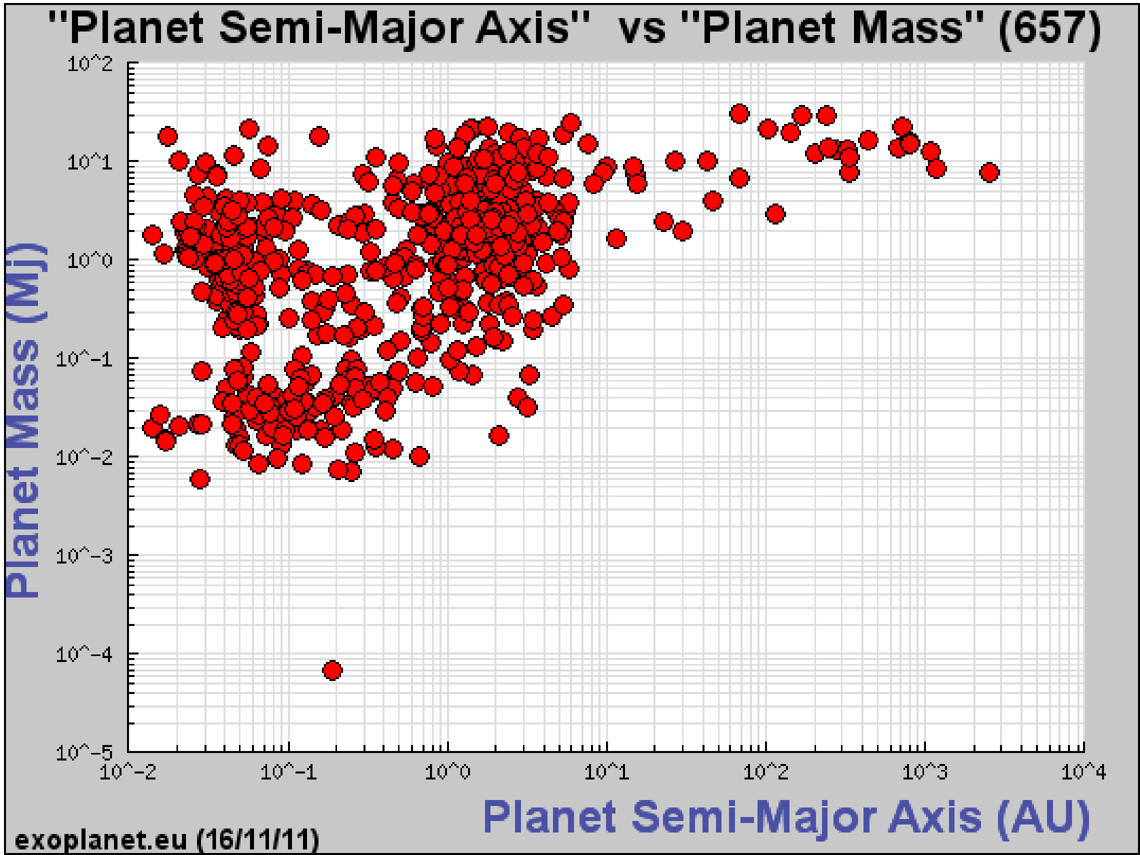
Extrasolar Planets

- So far, 704 (as of 11/16/11) have been detected.
- Most are detected by measuring wobbling of the parent star.
- What planets are best detected by this method?
  - **A**: terrestrial planets close to the star.
  - **B**: terrestrial planets far away from the star.
  - **C**: gaseous giants close to the star.
  - **D**: gaseous giants far away from the star.
- Some planets are discovered by their ***transit*** of a parent star.

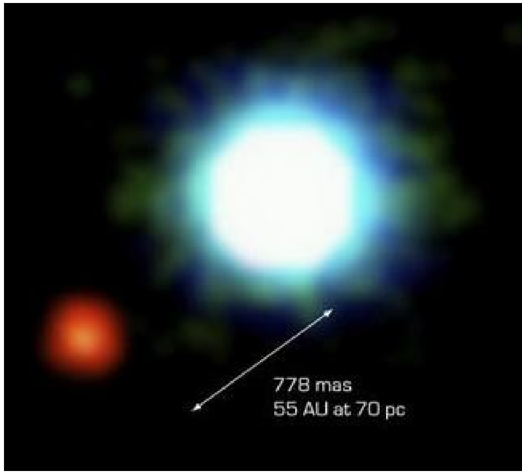
Properties of Extrasolar Planets

http://exoplanet.eu

- The sample of planets discovered so far is heavily ***biased***: it is much easier to discover massive planets close to the star.
- There is only one planet smaller than the Earth known, but it orbits a politically incorrect star (a neutron star).



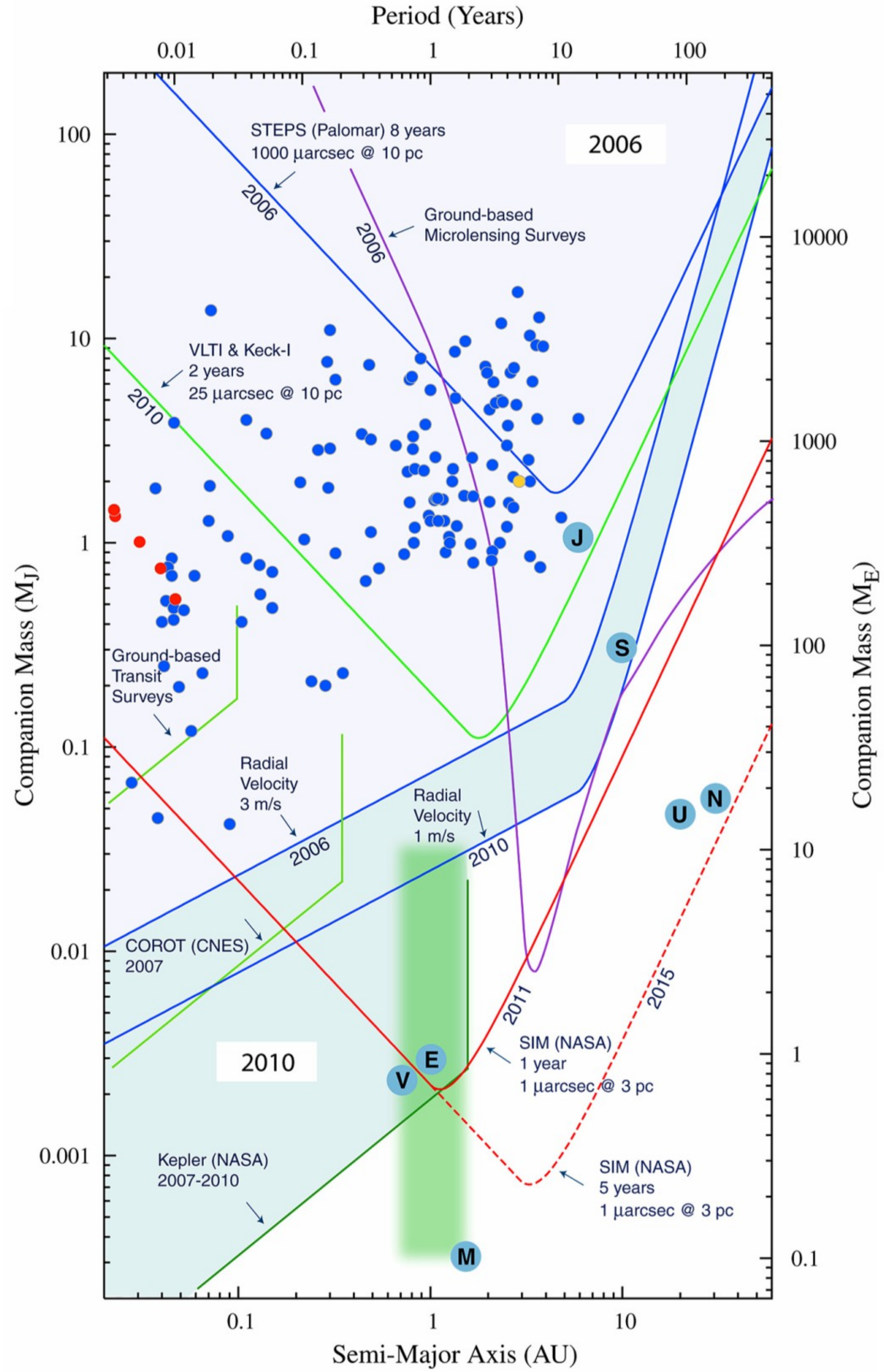
Mysteries



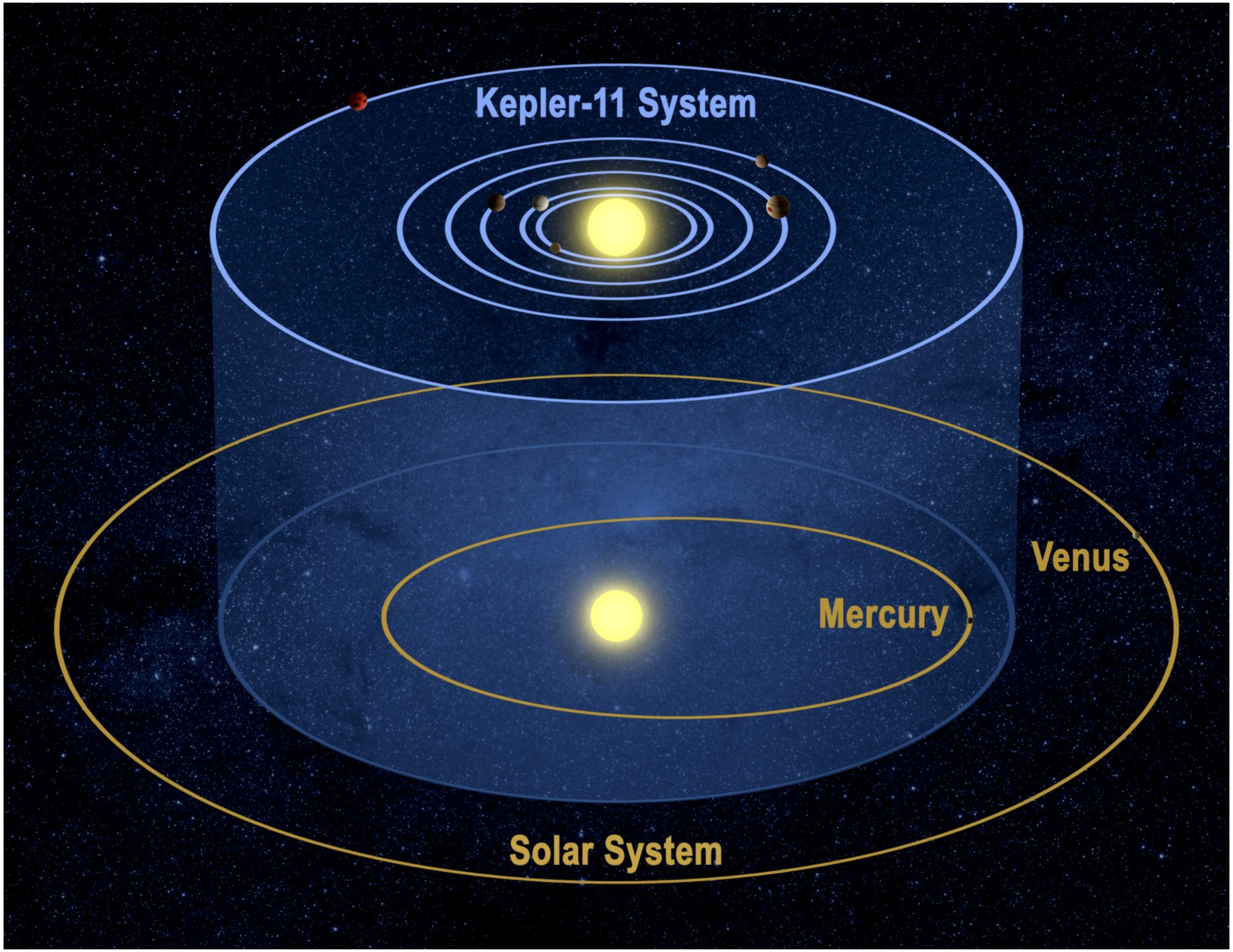
- Many planetary systems have jupiters close to the star – no terrestrial planets would survive there.
- Many planets have very elongated orbits.
- Some of ***exoplanets*** have no water.
- None of the known planetary systems resembles the Solar system – bad news for sci-fi writers!

Kepler

- Search for exoplanets is the main goal for NASA – they sacrificed most of other astronomy for it.
- Kepler mission was launched in Mar 2009. So far Kepler discovered 25 new planets and has over 1,200 candidates.
- Five are both near Earth-size and orbit in the habitable zone of their stars.

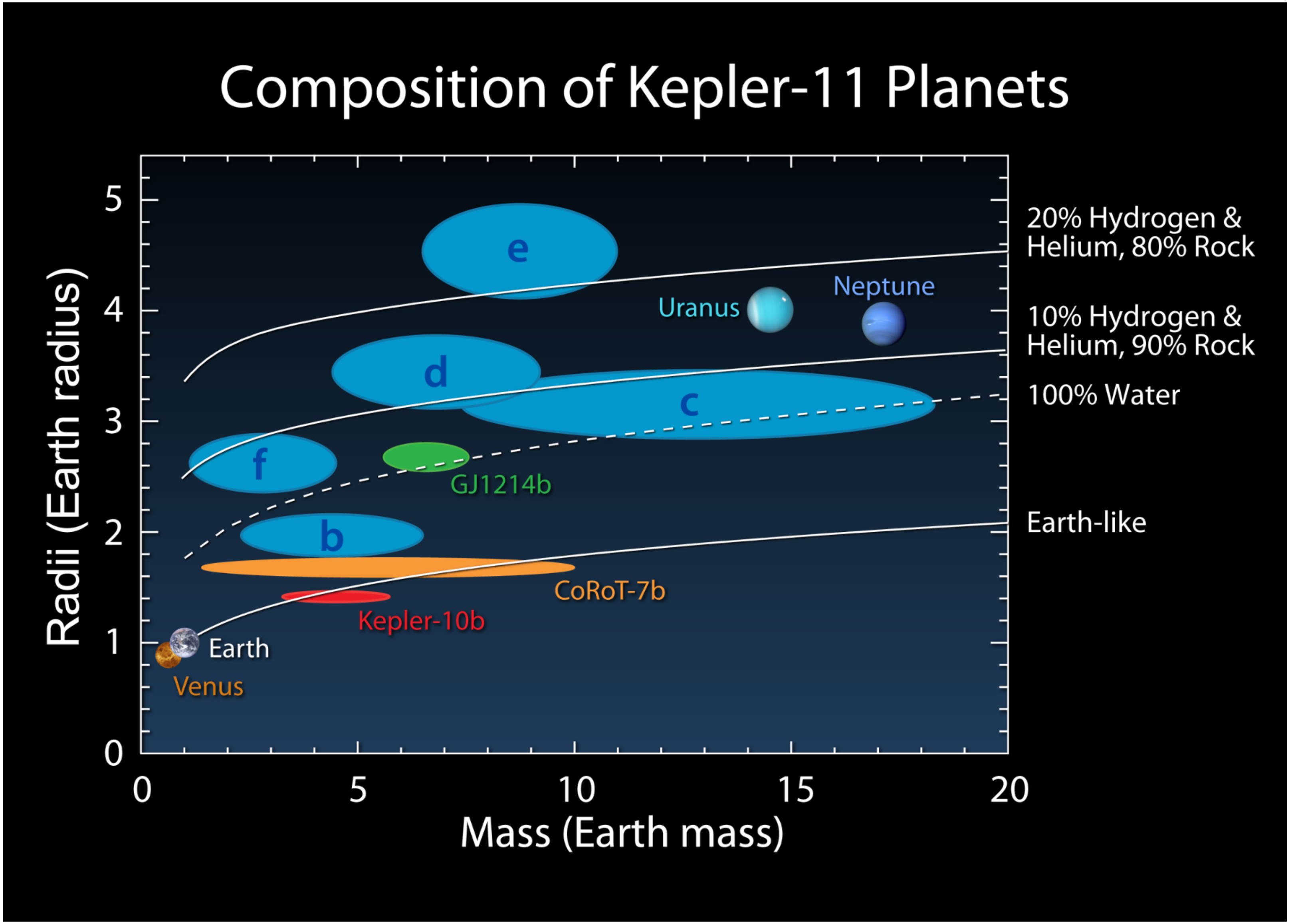


Kepler-11



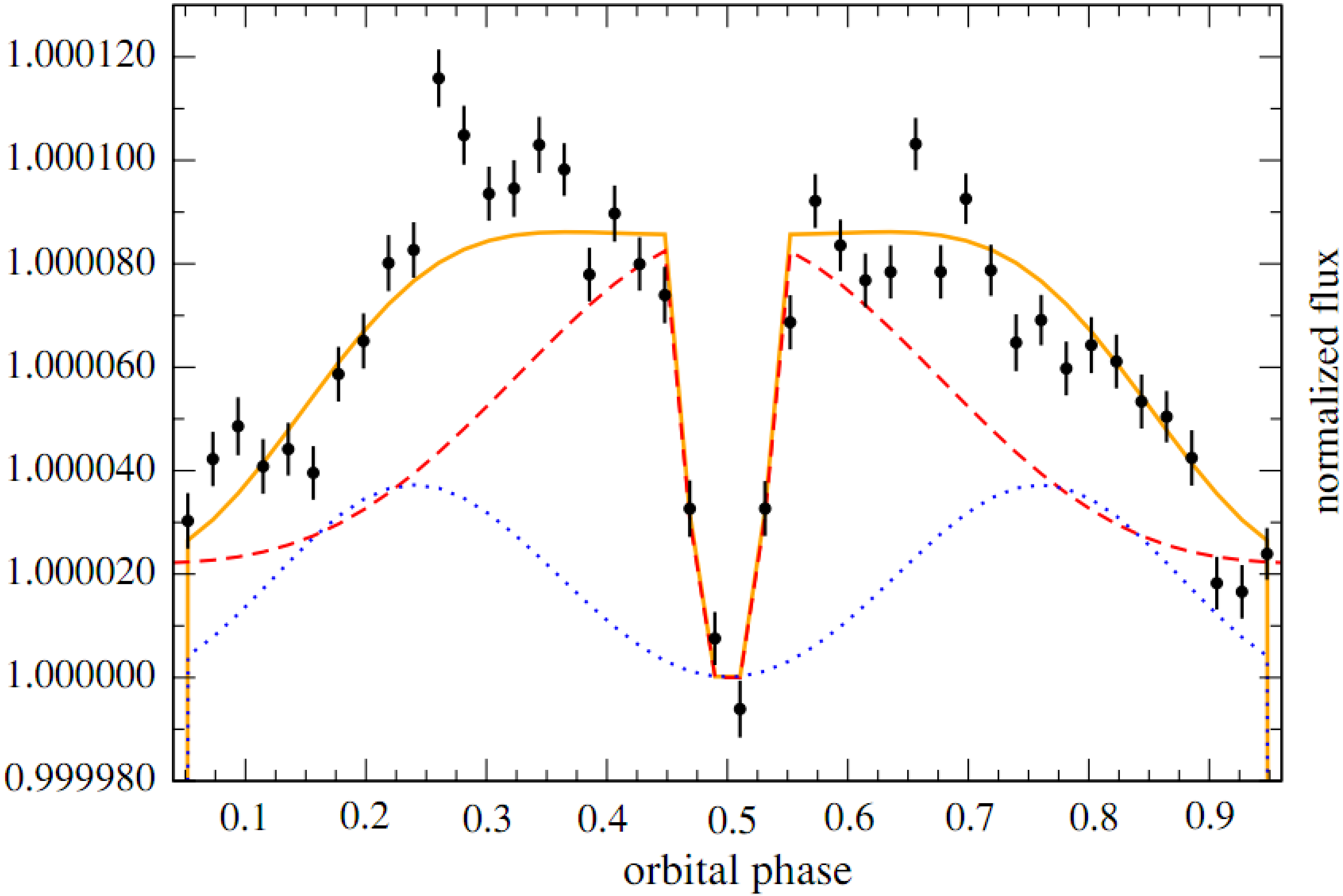
- 6 planets around 1 star, all very close to the star

Kepler-11



Composition of Kepler-11 Planets
Radii (Earth radius)
Mass (Earth mass)
0
1
2
3
4
5
0
5
10
15
20
e
d
c
f
b
GJ1214b
CoRoT-7b
Kepler-10b
Earth
Venus
Uranus
Neptune
20% Hydrogen &
Helium, 80% Rock
10% Hydrogen &
Helium, 90% Rock
100% Water
Earth-like

Kepler-12B



1.000120
1.000100
1.000080
1.000060
1.000040
1.000020
1.000000
0.999980
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
orbital phase
normalized flux