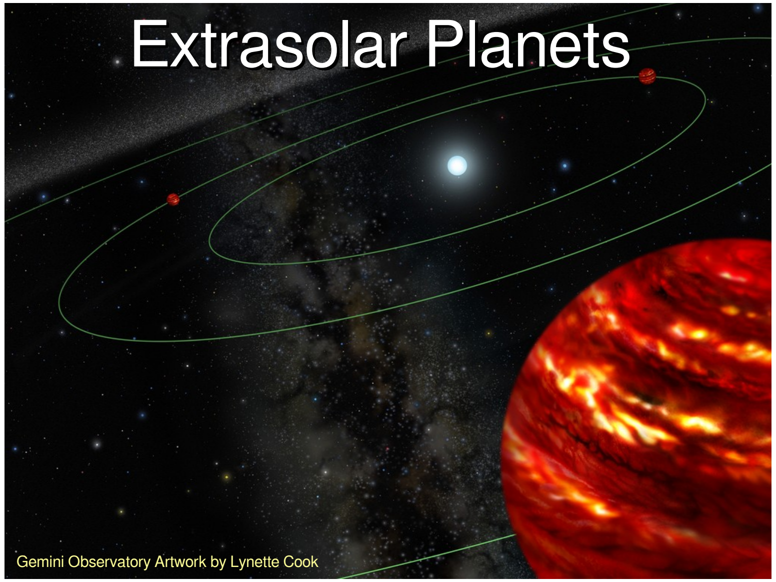
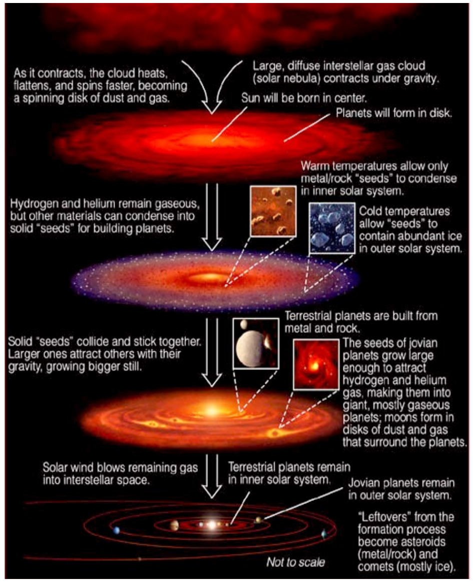




Open issues

have to form planets in ~ few Myrs

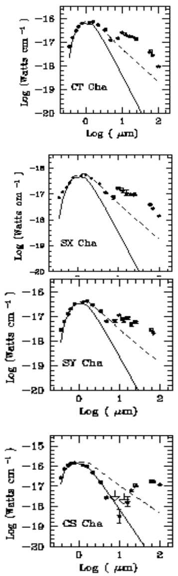
1) how did the gas disk disperse?
2) how are planetesimals made? Are dust grains sufficiently sticky?
3) what makes chrondrules?
4) How do planetesimals survive collisions?
5) What is Jupiter's role in the fate of other planets?
6) Do giant planets only form outside frost lines? If so, how to explain the extra-solar hot Jupiters?
7)....

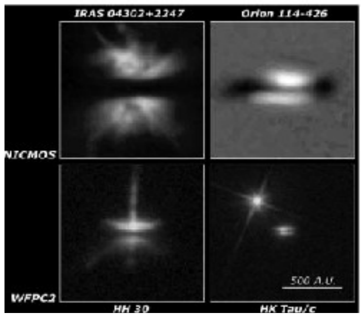
Build-up: Protoplanetary disks

Of the stars near the Sun, ~5% have Jupiter-mass planets. (Fraction will increase with longer time span.)

Proto-planetary Disks
observed around > 50% young stars (< 10 Myrs)

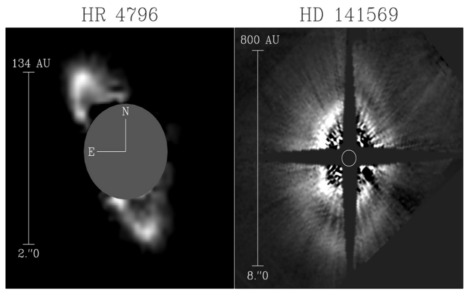
mostly detected through infrared emission in excess of the expected near-black-body from the star.





some are directly imaged in scattered light (HST)

Left-overs: debris disks



The inner Solar system is filled with zodiacal dusts
(ground-down asteroids & comets)

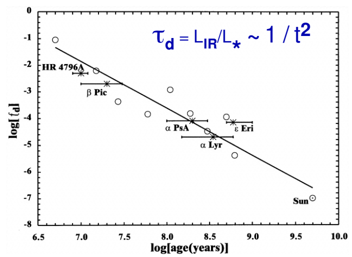
Would not be observable for other stars.

Yet, ~10% of stars observed to have dusty debris disks.

Older stars have less dust, so likely a transient phenomenon.

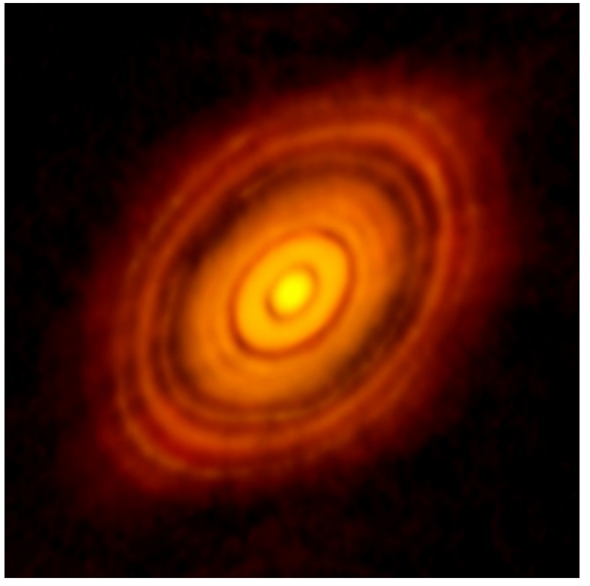
Also, the dust seen in scattered and reprocessed light will be blown away quickly, so it must be replenished for some time.

Some debris disks show "rings" or "edges," suggesting dynamical imprints of planets and/or nearby stars?

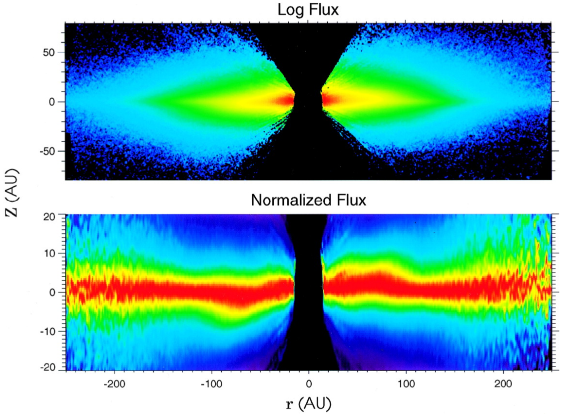


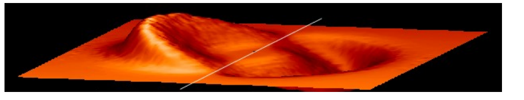
Planet formation in action?

HL Tau with ALMA

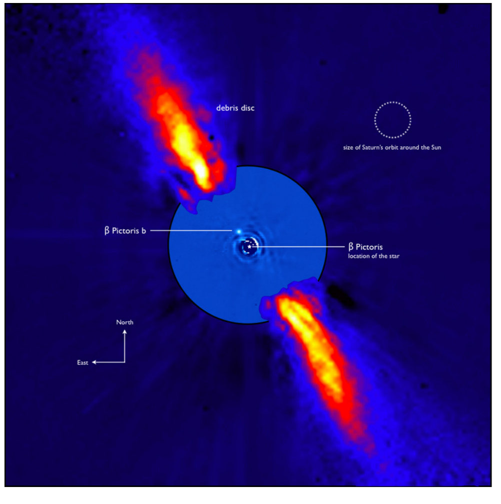


The dusty disk of β Pictoris -- *warps, "comets" striking, evaporated metals*





The dusty disk of β Pictoris -- *warps, "comets" striking, evaporated metals*



ESO press release 42/08

Properties of exoplanets:

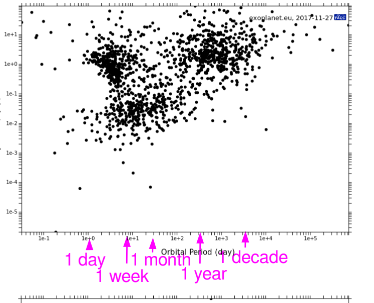
RV studies show
Unexpected variation!

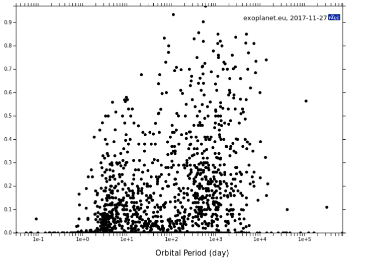
1) Large range of masses
low masses: limited by sensitivity;
high masses: real cut-off at ~10 M_J.

2) Large range of periods
short end: hot Jupiters! (but note bias)
long end: limited by sens./time coverage

3) Large range of eccentricities
Circular at short periods → tides;
no preference for circular at long P
(though less eccentric than binaries)

$$T_p = T_s \sqrt{\frac{R_s}{2a}}\ (1-A)^{1/4}$$
$$\approx\ 1100\,K \left(\frac{0.1\,AU}{a}\right)^{1/2}$$
$$(\textit{Jupiter: } T_p \sim 120\,K)$$



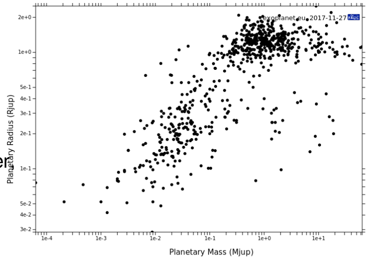


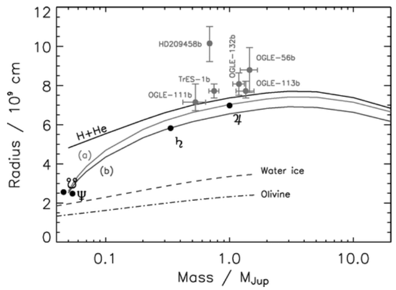
Properties of exoplanets:

Transit studies show
Unexpected variation!

Large range of radii
Some planets have sizes similar to Jupiter but others are significantly bigger.
(Many small ones in graph have only upper limits to mass.)

- Bloated? But hard to "inflate" a giant planet!
- Never shrunk? But how to get a planet close to the star sufficiently fast?
- Why the variety?



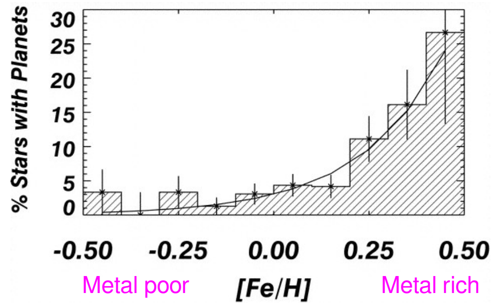


Properties of exoplanets:

Planet occurrence depends on
Host star properties.

More metal-rich stars are much more likely to have planets.

One property that can be understood...



Puzzle 1:
"Hot Jupiters"

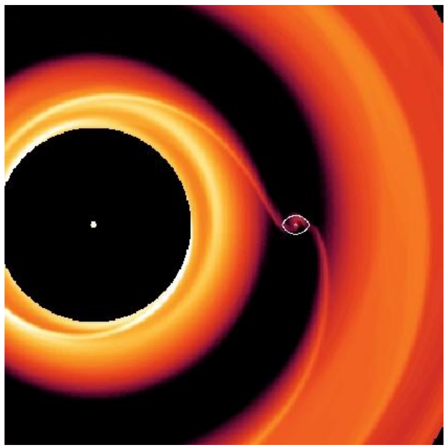
Possible solutions for the close-in orbits:

1) Migration (favoured);
   due to interaction with
   a) disk (but how to stop?)
   b) other planets
   c) stellar companions
2) Close-in formation

Possible solutions for the big sizes:

1) Fast migration
2) Tidal/wind heating

But why the range?



Puzzle 2:
Eccentric orbits

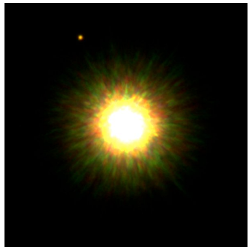
Possible solution:

Interaction with
   a) disk (but why only some?)
   b) other planets
   c) stellar companions

b+c can be due to "Kozai" mechanism: if highly inclined, a third body can induce eccentricity in inner orbit (combined with tidal friction, this could also cause migration).

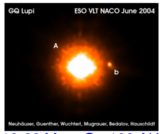
b may also be due to multiple planets in orbits bordering on instability.

Puzzle 3 (possibly):
Far out (and rogue?) planets

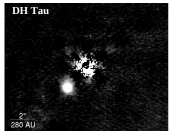


Possible solution:

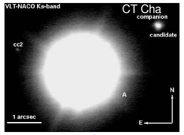
a) Formed like star?
b) Migrate outward?
   interaction with disk, planets?



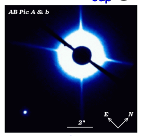
10-20 M_{Jup} @ ~100 AU



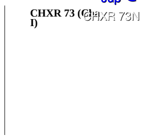
~12 M_{Jup} @ ~330 AU



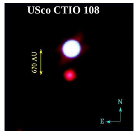
12-20 M_{Jup} @ ~440 AU



~12 M_{Jup} @ ~260 AU



~12 M_{Jup} @ ~230 AU



~14 M_{Jup} @ ~670 AU

~8 M_{Jup} @ ~55 AU
(brown dwarf primary)