- Nighttime observing has 4 more nights. Check the webpage.

- **1st exam is October 10th– Friday!**

- Justin will have an extra office hour Thursday (10/9) before exam– 4:00 to 5:00pm.

- I will have an extra office hour Wednesday (10/8) before exam– 10:30 to 11:30am.

Exam #1

- **Date:** Friday, Oct. 10th
- **Place and Time**: In class, at the normal 12:00-12:50pm time.
- **Format**: 40 multiple choice problems and 2 bonus questions (extra credit).
- **Bring:**
  - Yourself, well-rested and well-studied
  - A #2 pencil
  - On the test you will be given numbers or equations (if any) that you will need. You may **not** use your book or your class notes.

Exam #1

- **Topics included**: All material through Extra-solar planets. Lecture and reading material are both included. My goal is to test for understanding of the concepts we have discussed, and how they fit together.
- **Study tips.** We have covered a lot of material in a short time, so here are some tips on how to approach your studies for the exam.
  - Topics covered in lectures should be stressed.
  - Homework questions have good examples of questions that may show up on the exam. An excellent way to begin studying is to review the homework problems, particularly those you missed (or got right but were not so sure about). Be sure you understand what the right answer is, and more importantly, **why** it is right.
  - You will need to understand and be able to use any equations that have been introduced in class. Calculations using these equations will be kept simple--it is possible to do the exam without a calculator, but you can bring one if you wish.

Exam #1

- **In-Class Q and A:** On Wed., Oct. 8th, some time will be allotted in class to ask questions about material on the exam. For example, if there are homework answers you do not understand, this would be an excellent time to ask. To get the most out of this time, you are strongly encouraged to begin studying prior to this class.
- **Out of Class Q and A:** On Wednesday, Oct. 8th, I have office hours from 10:30 to 11:30am. On Thursday, Oct. 9th, Justin has TA office hours of 4:00 to 5:00pm. You should bring questions.

Outline

- What are the facts about the Solar System?
- What can sort of theory of Solar System Formation can we imagine?
- Interlude for angular momentum
- A circumstellar Disk
- Planetesimals
- Does this work for other systems?
- Extrasolar planets

What is the origin of the Solar System?

- Explain present-day Solar System data.
- Predict results of new Solar System data.
- Should explain and predict data from other stars!

What are clues to solar system origins?

Some Facts of the Solar System

- Mass of solar system: mostly in the sun, but outer planets more massive than inner.
- Most of the motions in the Solar System are counter clockwise (problems with Venus, Uranus, or Pluto) in a flat system (pancake-like).
- The inner planets are rocky and the outer planets are gaseous.

Data: Planet's Dance

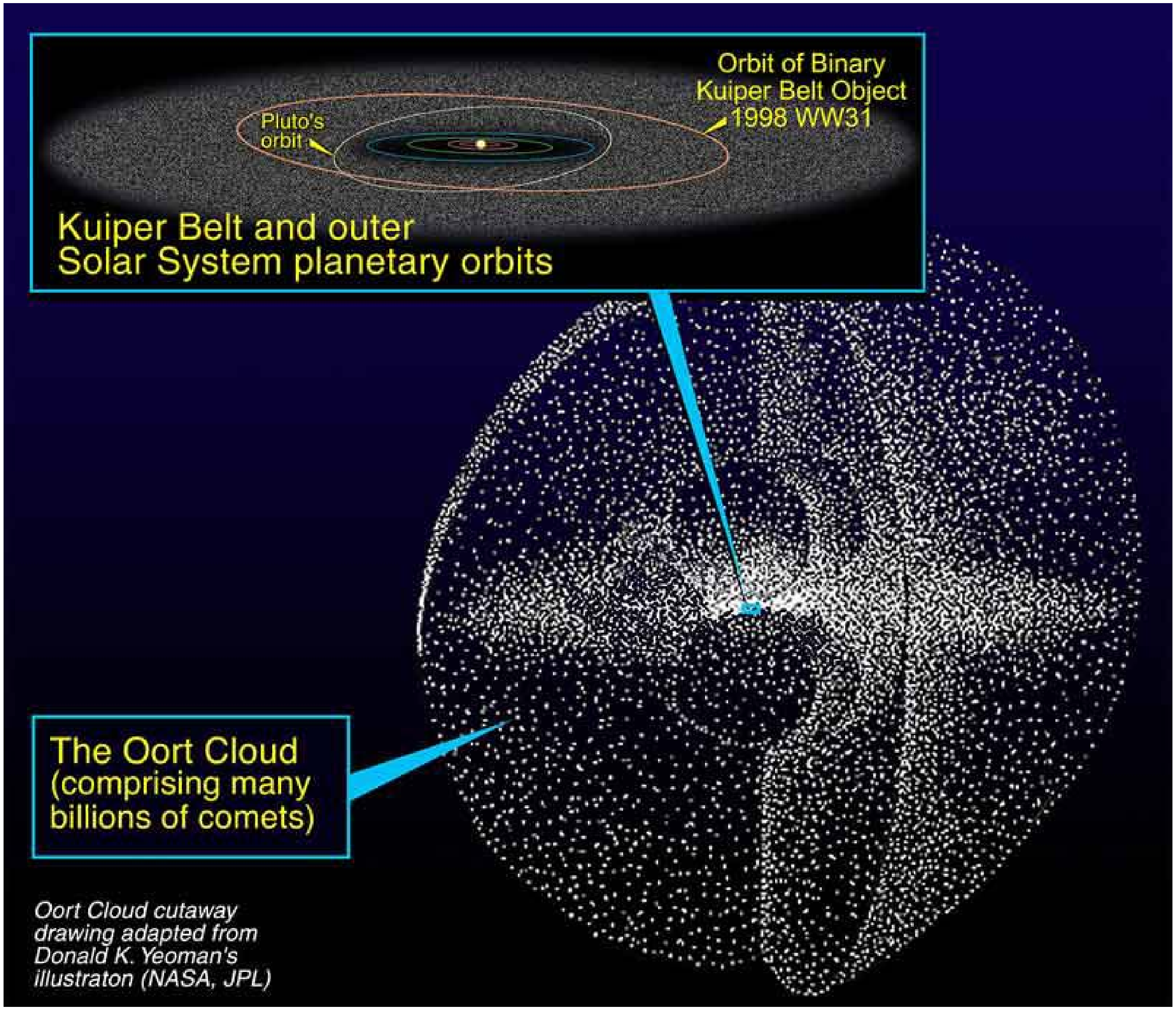
http://janus.astro.umd.edu/javadir/orbits/ssv.html

Data:
The Structure of the Solar System

- What are the furthermost solar system objects from the sun and what is their distribution?
  - icy objects/comets

Furthermost objects form the Oort cloud!
So…Spherical Geometry.

Data: Kuiper Belt



Data:
What is the age of the Solar System?

- Earth: oldest rocks are 4.4 billion yrs
- Moon: oldest rocks are 4.5 billion yrs
- Mars: oldest rocks are 4.5 billion yrs
- Meteorites: oldest are 4.6 billion yrs
- Sun: models estimate an age of 4.5 billion yrs

Age of Solar System is probably around 4.6 billion years old

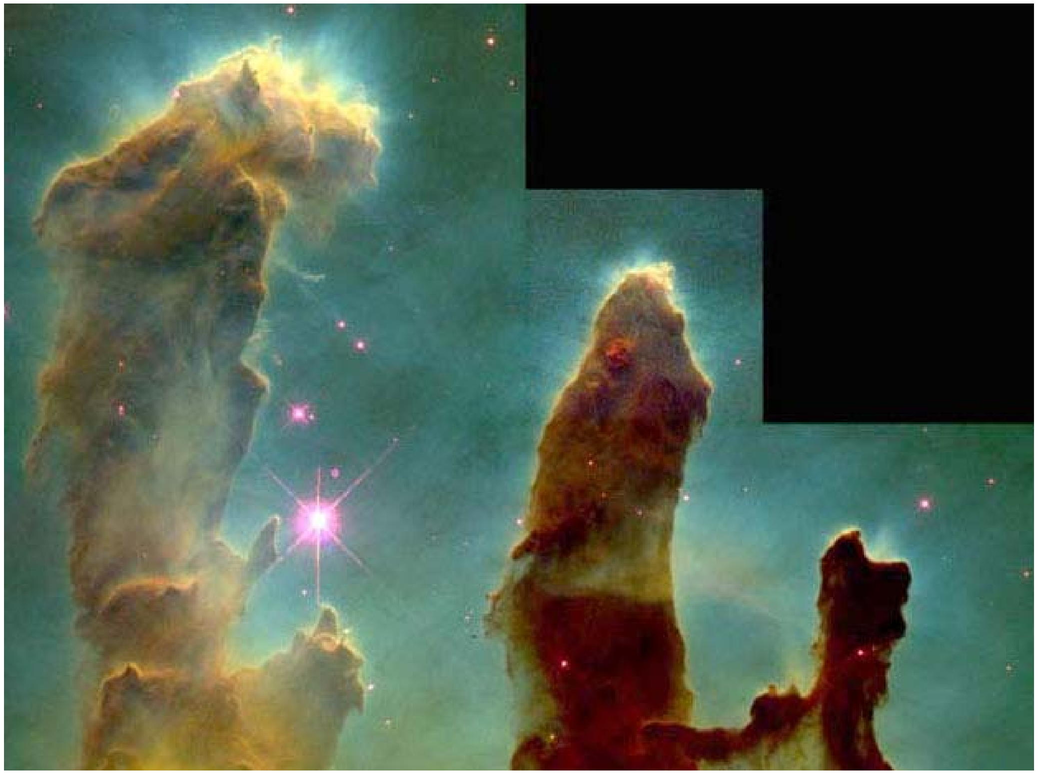
Origin of Solar System:
Solar Nebula Theory

"*nebula*" = cloud

Gravitational Collapse

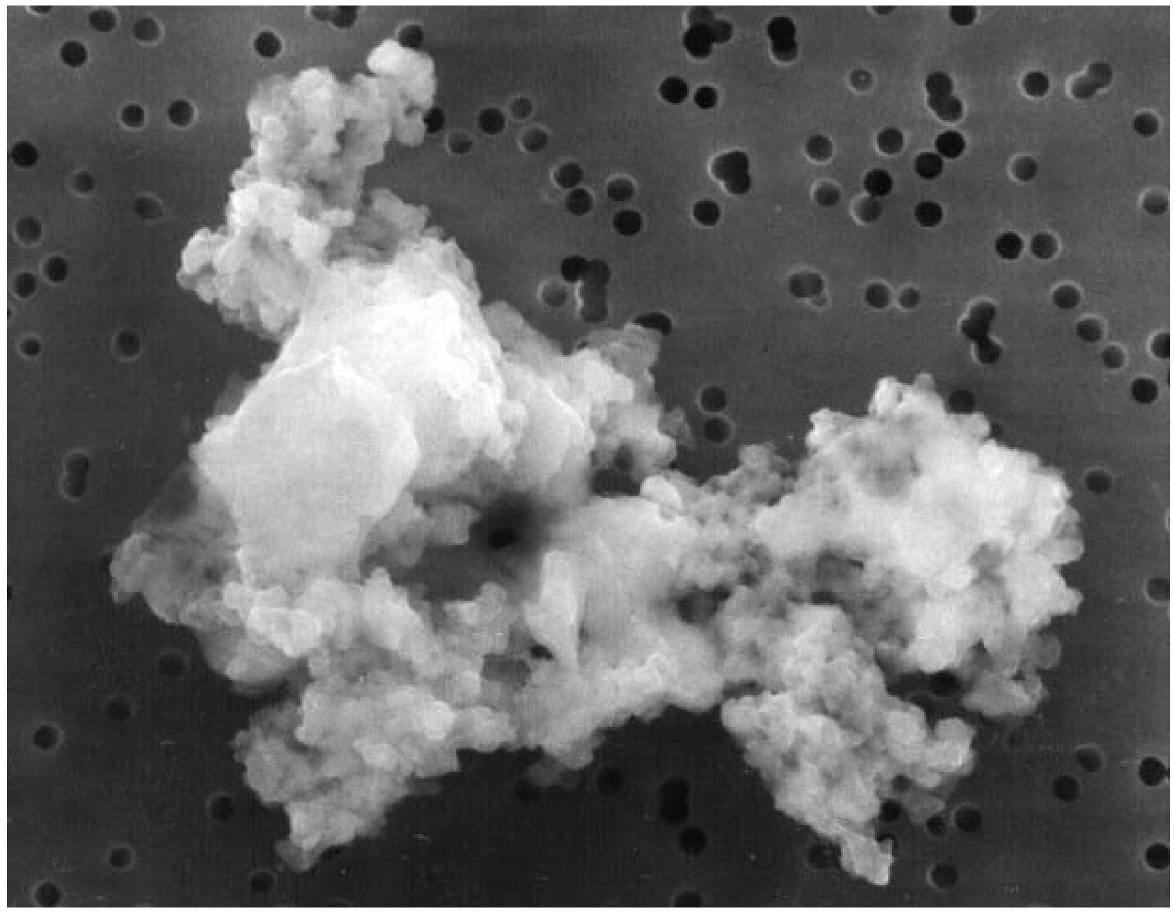
The basic idea was put forth by Immanuel Kant (the philosopher)– Solar System came from a Gas Nebula:

4.5 billion years ago: a slowly spinning ball of gas, dust, and ice with a composition of mostly hydrogen and helium formed the early Solar System.



Interplanetary Dust

- Caught by U2 plane
- 10 microns (100 microns is width of a hair)
- The particle is composed of glass, carbon, and a conglomeration of silicate mineral grains.



http://antwrp.gsfc.nasa.gov/apod/ap010813

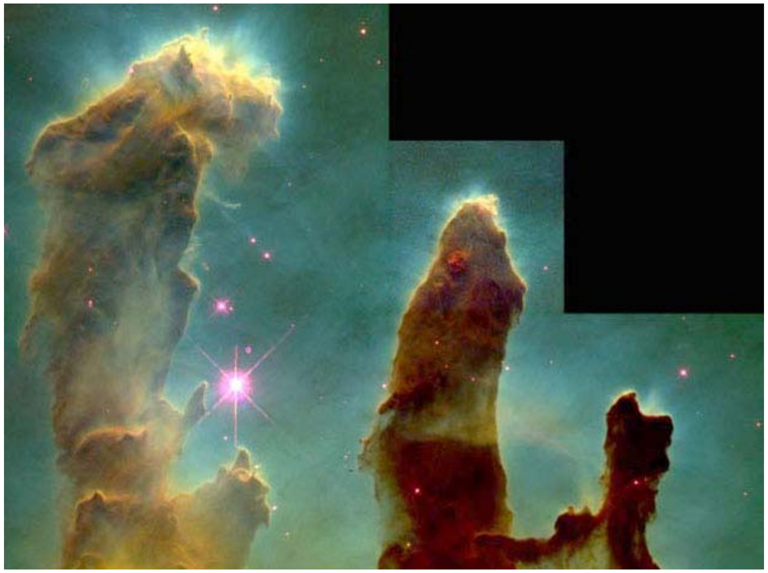
Interstellar Clouds

http://www.seds.org/messier/more/oricloud.html

Origin of Solar System: *Solar Nebula Theory*

In these clouds are small clumps that become gravitational unstable. The gas and dust has mass (thus gravity).

Gravity is inverse square law, so closer = stronger. Once it falls in a little, gets pulled in more. RUNAWAY GRAVITY!



And gravity pulls it toward the center– contract!

Question: What do you think happens?

But..

- Not all mass falls in directly. Why?

- All gas has a small spin that preferentially causes the formation of a flattened structure – time for an interlude.

Interlude: Angular Momentum

for spinning or orbiting objects:

$$\text{angular momentum} = (\text{mass}) \times (\text{velocity}) \times \left(\begin{array}{c}\text{distance to} \\ \text{spin/orbit} \\ \text{axis}\end{array}\right)$$

in closed system
Angular momentum is a single, *constant* number: =*conserved*!

keep same dist. to axis → vel. same
move closer to axis → speed up!

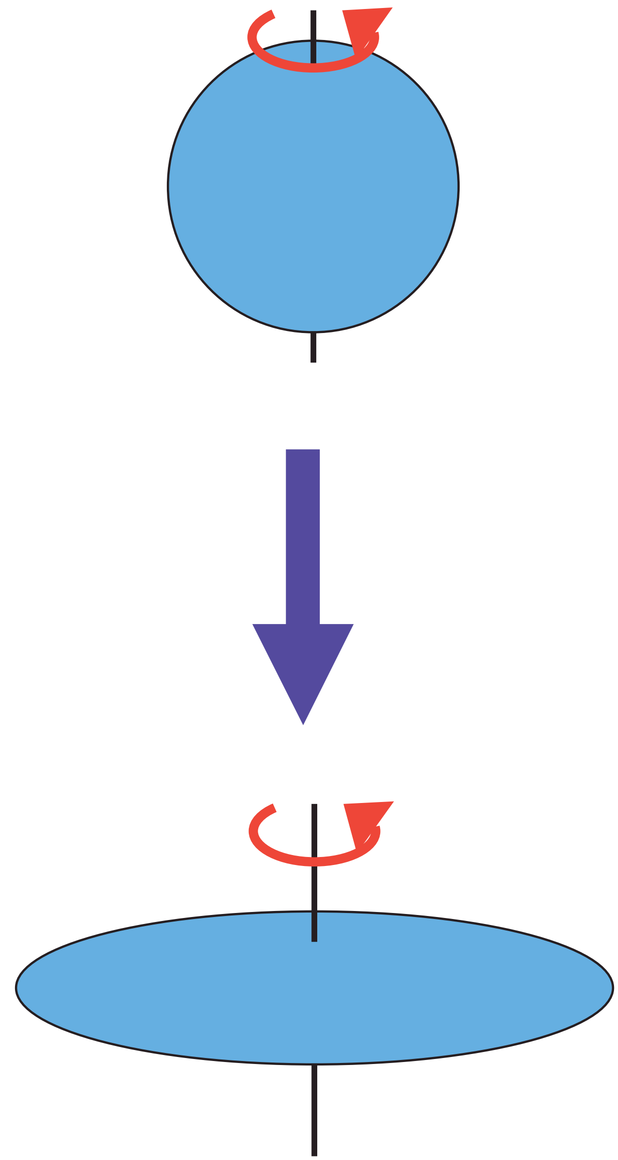
recall Kepler 2nd law – really due to angular momentum!

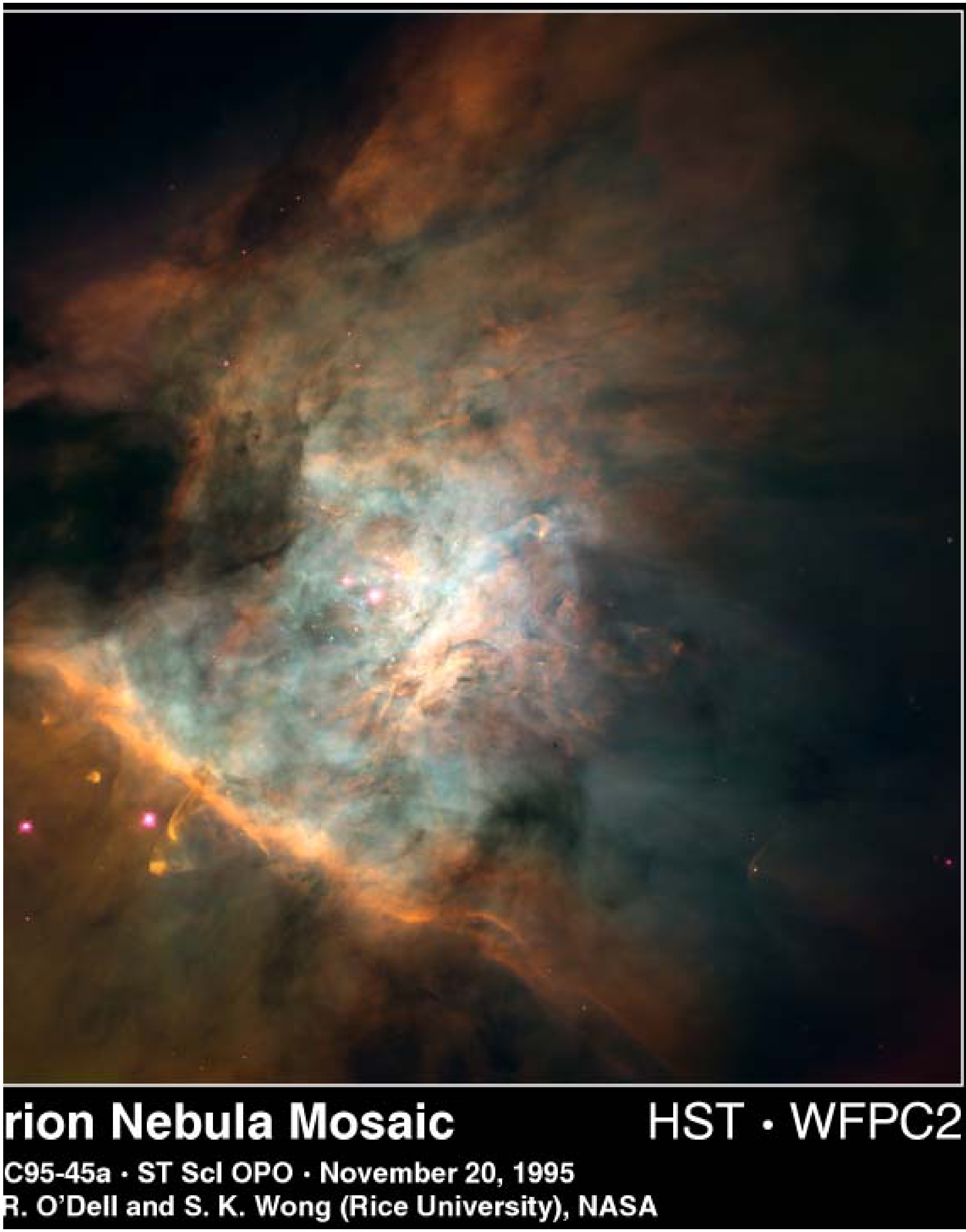
Origin of Solar System:
Solar Nebula Theory

Solar nebula competition:
gravity vs angular momentum

- If fall perpendicular to spin axis
  speed up → resistance
  centrifugal force

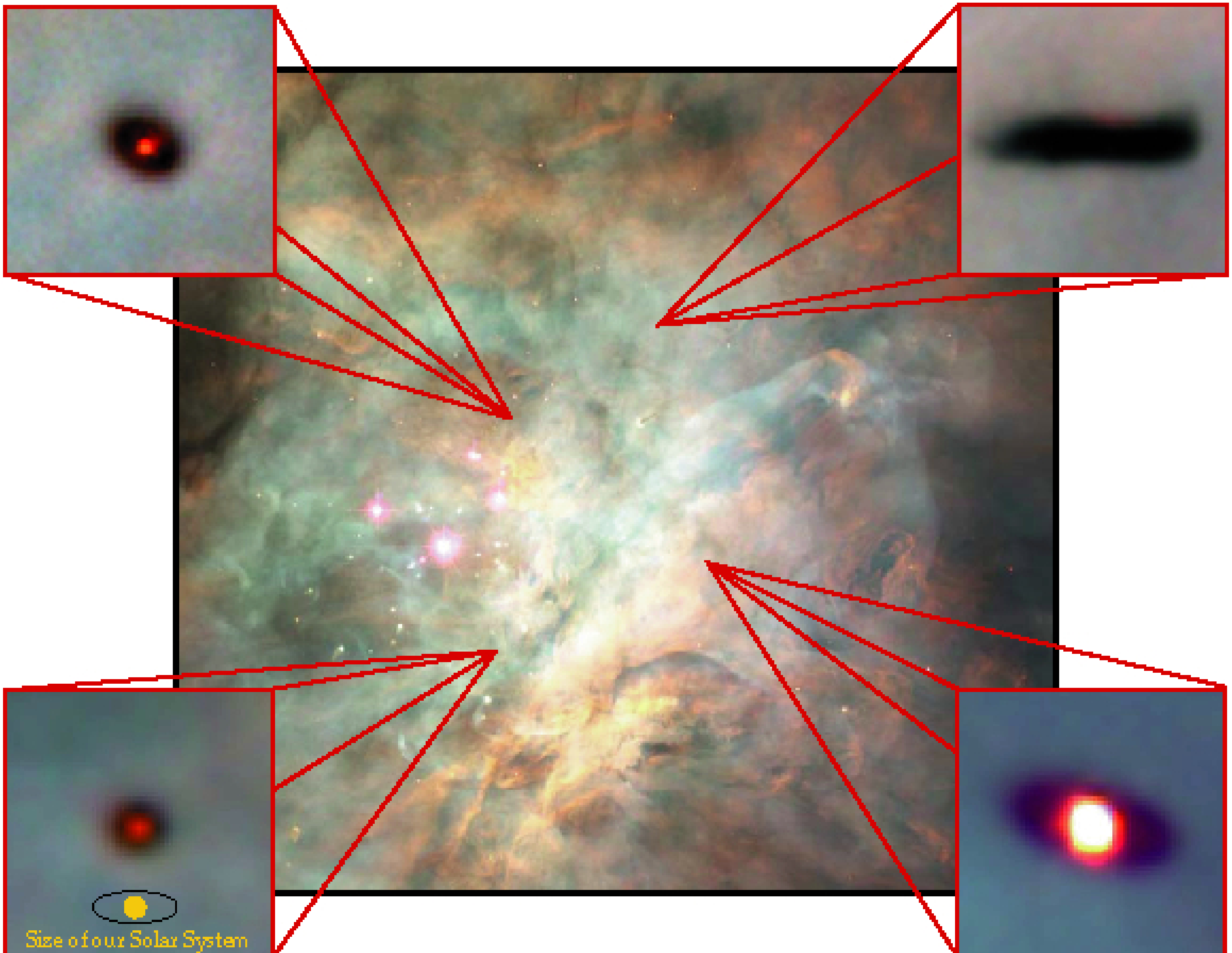
- If fall parallel to spin axis
  same speed, so no resistance
  → form ***protoplanetary disk***
  – Origin of ecliptic!
  – Organizes orbits in same direction
  – Organizes spins along initial spin axis



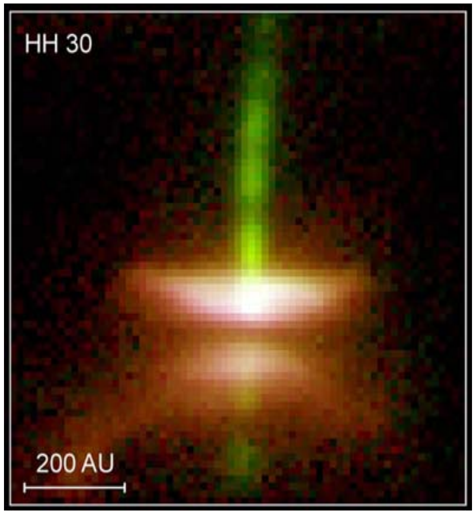


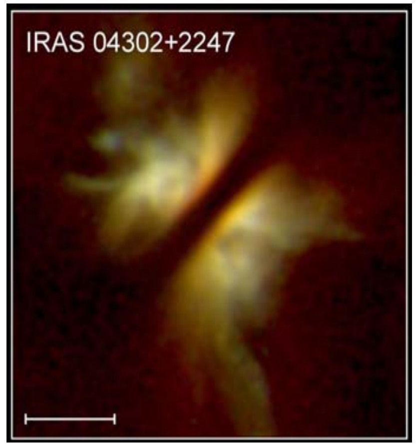
The Orion Nebula

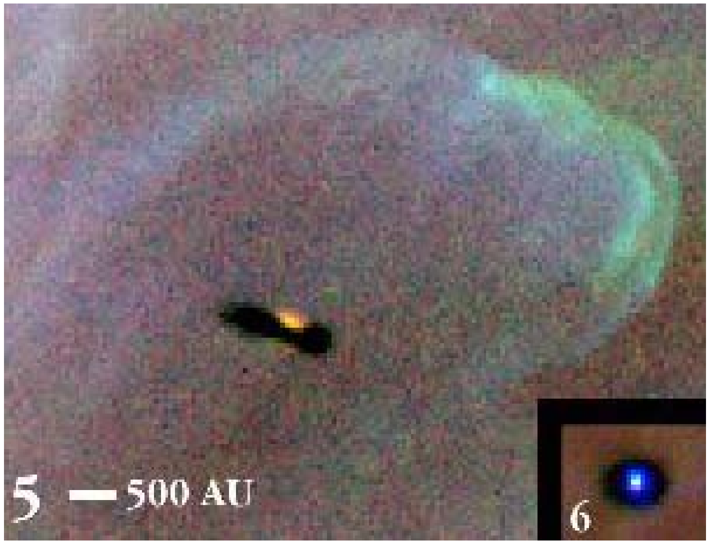
And Disks around Young Stars are Common

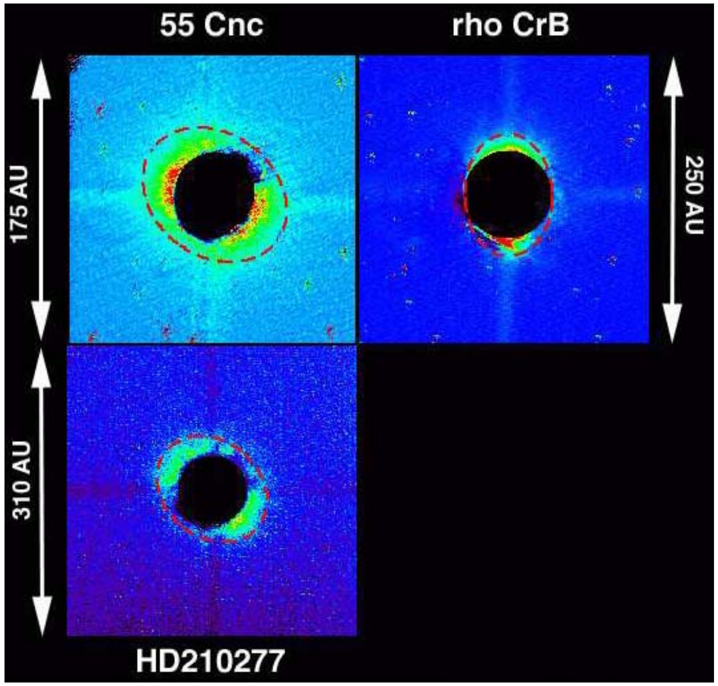


And Disks around Young Stars are Common



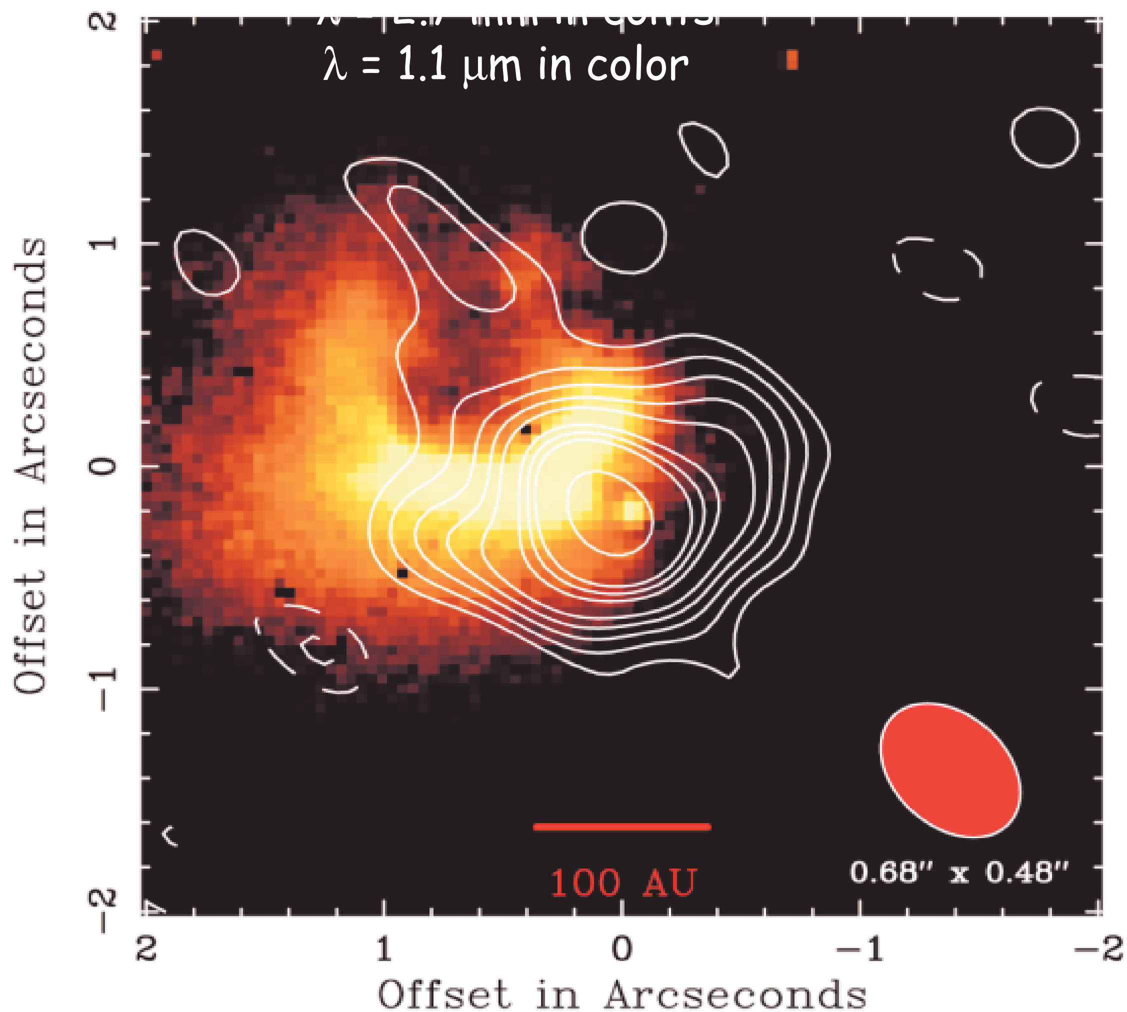






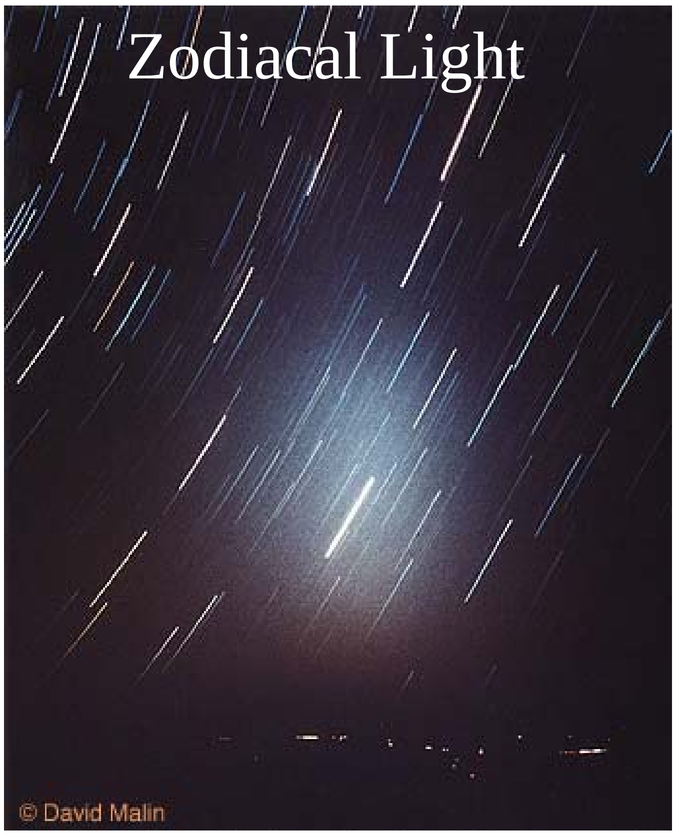
http://www.ifa.hawaii.edu/users/tokunaga/SSET/SSET.htm

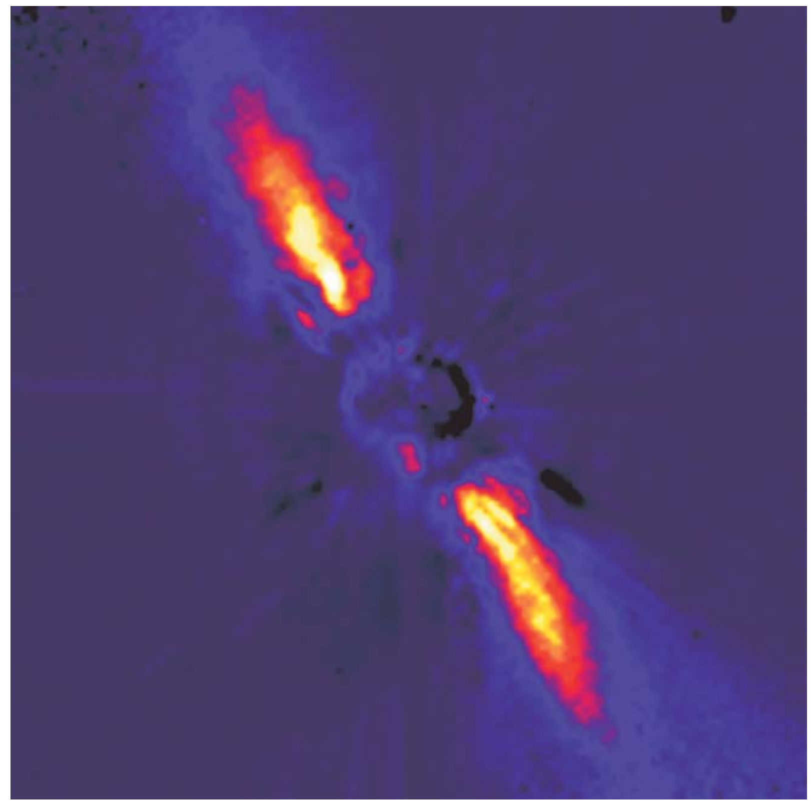
The Circumstellar Disk of HL Tauri



Do Fossil Disks Exist around other Stars?

- We see old disks around other stars (e.g. Vega and Beta Pictoris) as well as our own.



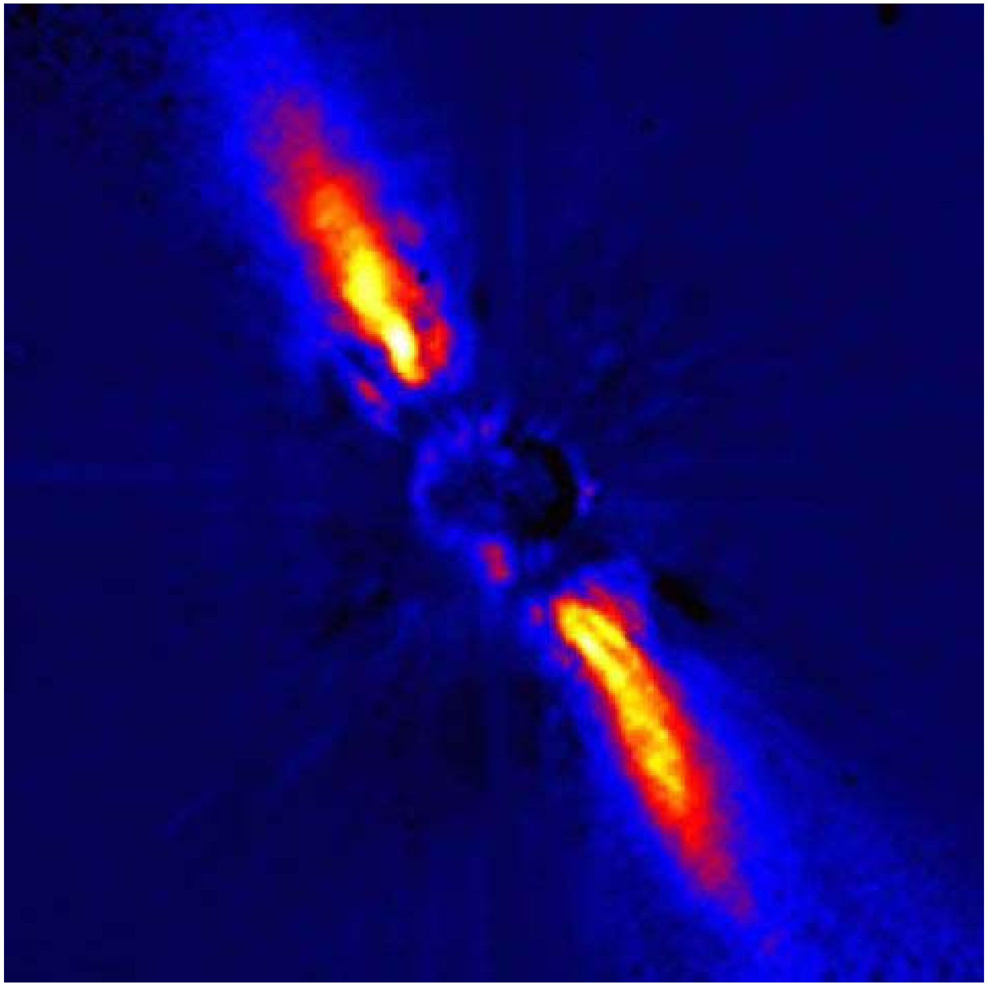


http://www.eso.org/outreach/press-rel/pr-1997/phot-16-97.html

http://antwrp.gsfc.nasa.gov/apod/ap970826.html

Disks Around Young Stars

- many (> 50%) of newborn stars surrounded by a disk of material!
- disks thick, blocks light
  - enough material to make planets
  - agrees with Solar Nebula theory!



Planet Formation in the Disk

Heavy elements clump

1. Dust grains collide, stick
   form “planetesimals" (about 10^{12} of them!)
   (like asteroids!)
2. Gravity: big planetesimals attract small
   fewer & larger objects (100's)
   Collisions build up inner planets, outer planet cores.
3. Collisions can also account for odd motions of Venus (backwards), Uranus (rotates on its side), and Pluto (high inclination of orbit). Proof of period of high collision evident on moon

What it might have looked like.

http://eeyore.astro.uiuc.edu/~lwl/classes/astro100/fall03/Lectures/solarsystemform.mov

Why are the Planets so different then?

Temperature is key factor

- Inner Solar System: **Hot**
  - Light gas (H, He), ice evaporated, blown away
  - Only heavy elements left
- Outer Solar System: **Cool**
  - H, He remain
  - Fall onto rocky planet core “seeds“

Using Jupiter as an example:

- probably had its own disk
- 4 inner moons are rock
- 4 Galilean moons mock those in Solar System
  - More dense moons are close, less dense further out

Fate of planetesimals

- those nearest planets collided with planets
- those between Mars and Jupiter remain as asteroids
- those near Jupiter & Saturn gravitationally ejected from solar system
- those near Uranus and Neptune ejected to Oort cloud
- those beyond Neptune remain in Kuiper belt.

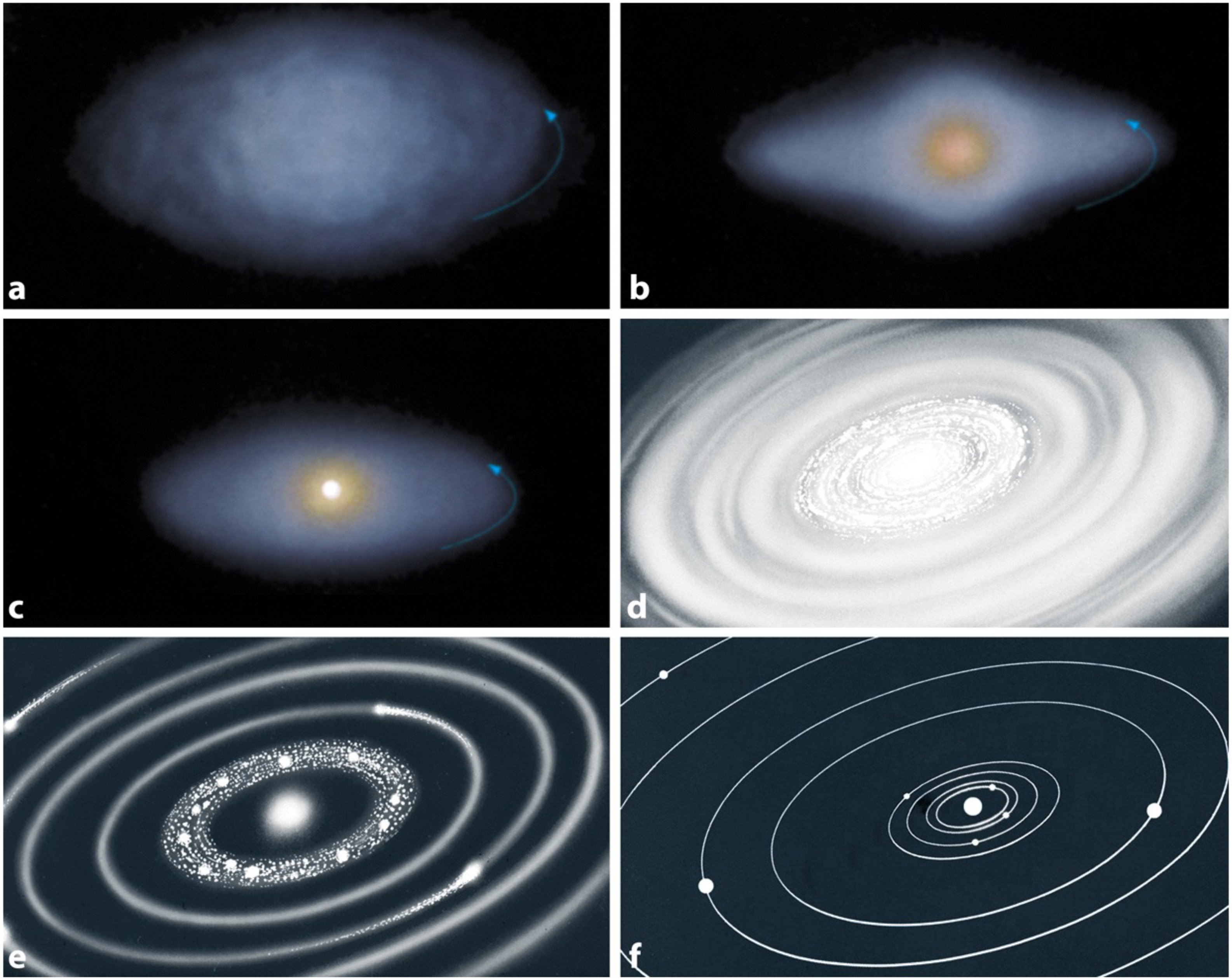
http://www.usm.uni-muenchen.de/people/gehren/vorlesung/4.1_Himmelsmechanik/kosmogonie/dia_15.html

Results

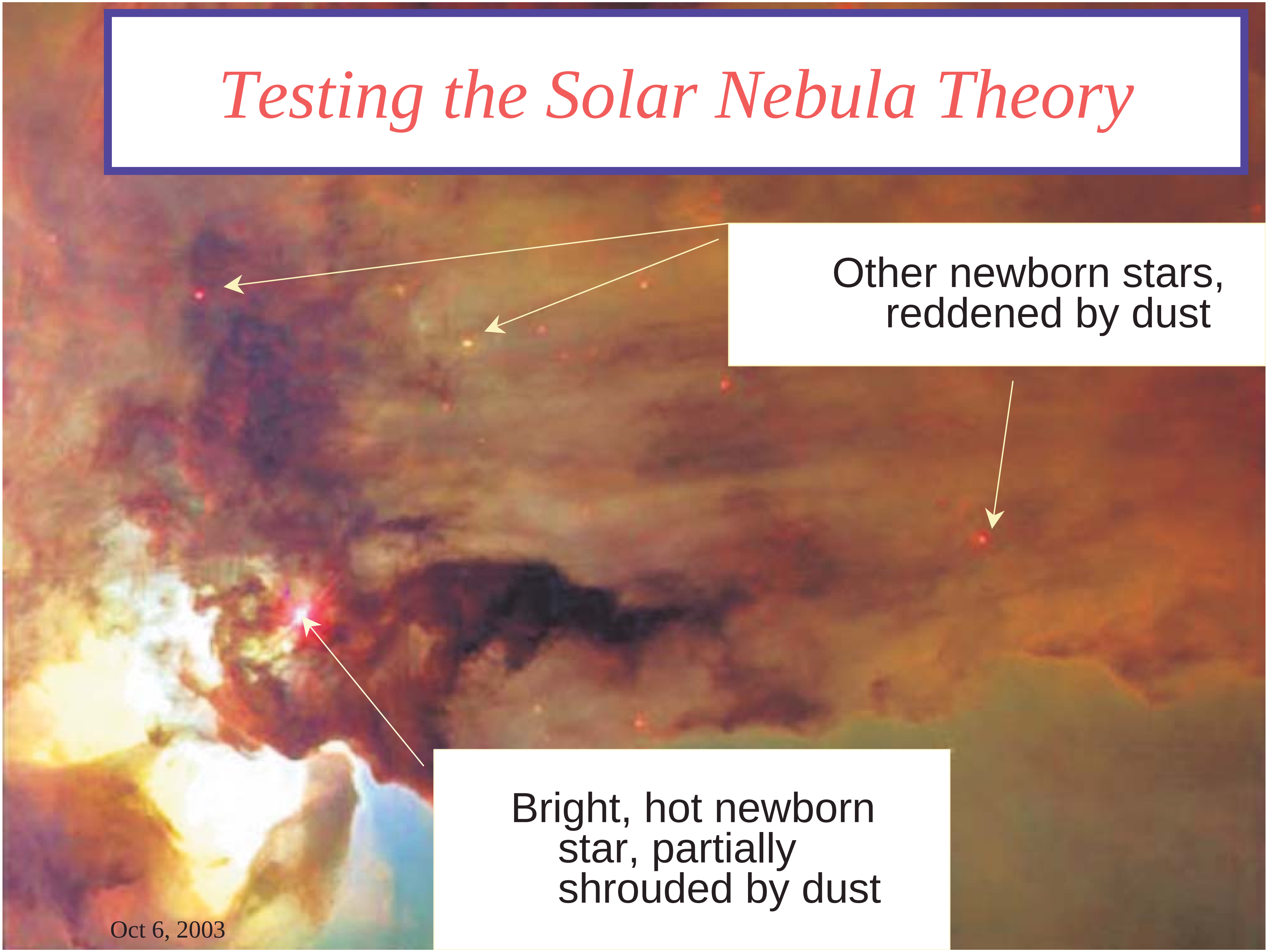
So: most disk matter goes into planets

- except stable zones where existing planet gravity prevents clumping
- Between Mars and Jupiter, beyond Neptune:
- Asteroids and comets are leftover planetesimals! “Fossils” of solar system birth!

Formation of the Solar System
4.6 billion years ago



Testing the Solar Nebula Theory



Oct 6, 2003

What Are We Looking For?

General Predictions of Solar Nebula Theory

- ☺ Are interstellar dust clouds common? ***Yes!***
- ☺ Do young stars have disks? ***Yes!***
- ? Are the smaller planets near the star?
- ? Are massive planets farther away?

Test Of Exoplanets

Planets around other stars
= extrasolar planets = *"exoplanets"*

Hard to find!

Cannot just look at star

- planet lost in glare

Can use Newton's laws

- Newton 3rd Law: star pulls on planet,
- but planet pulls on star with equal & opposite force
- planet lighter, moves faster
- but star must move too!

Star Wobble

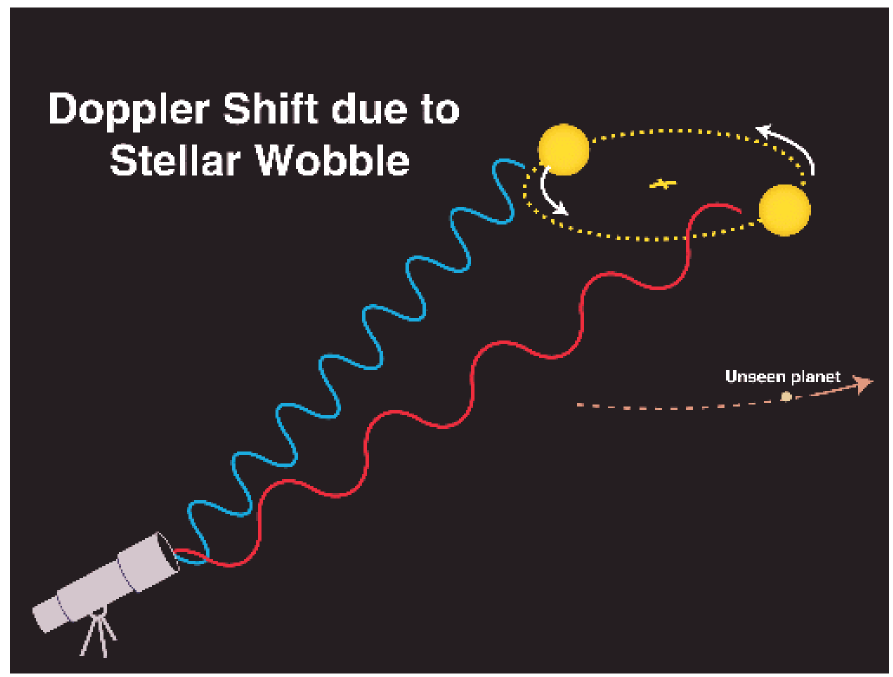
Newton's 3rd Law:

- *both* planet *and star* move
- both orbit fixed "center of gravity"

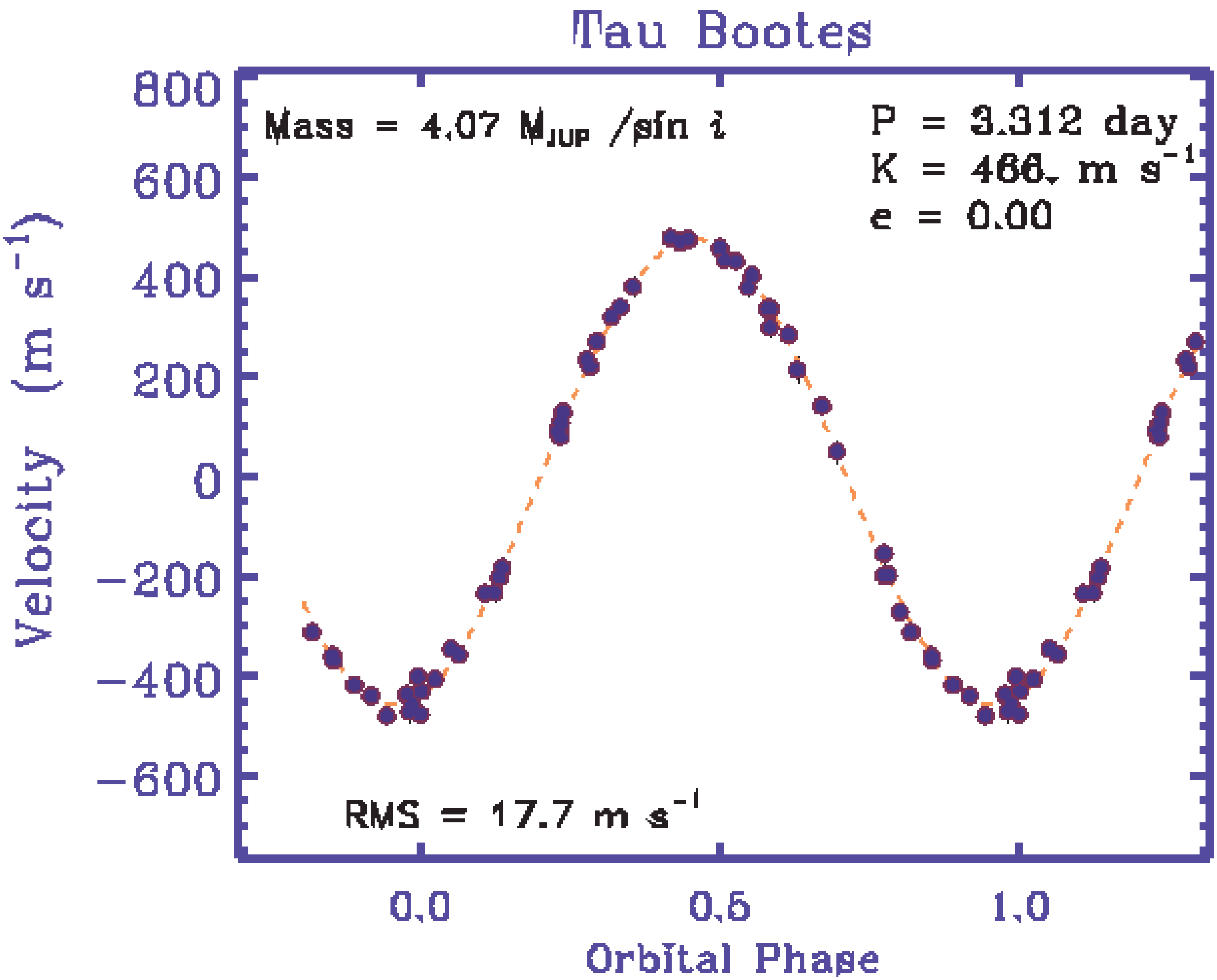
http://www.howstuffworks.com/planet-hunting2.htm

- Star's period? Place your bets…
  same as planet

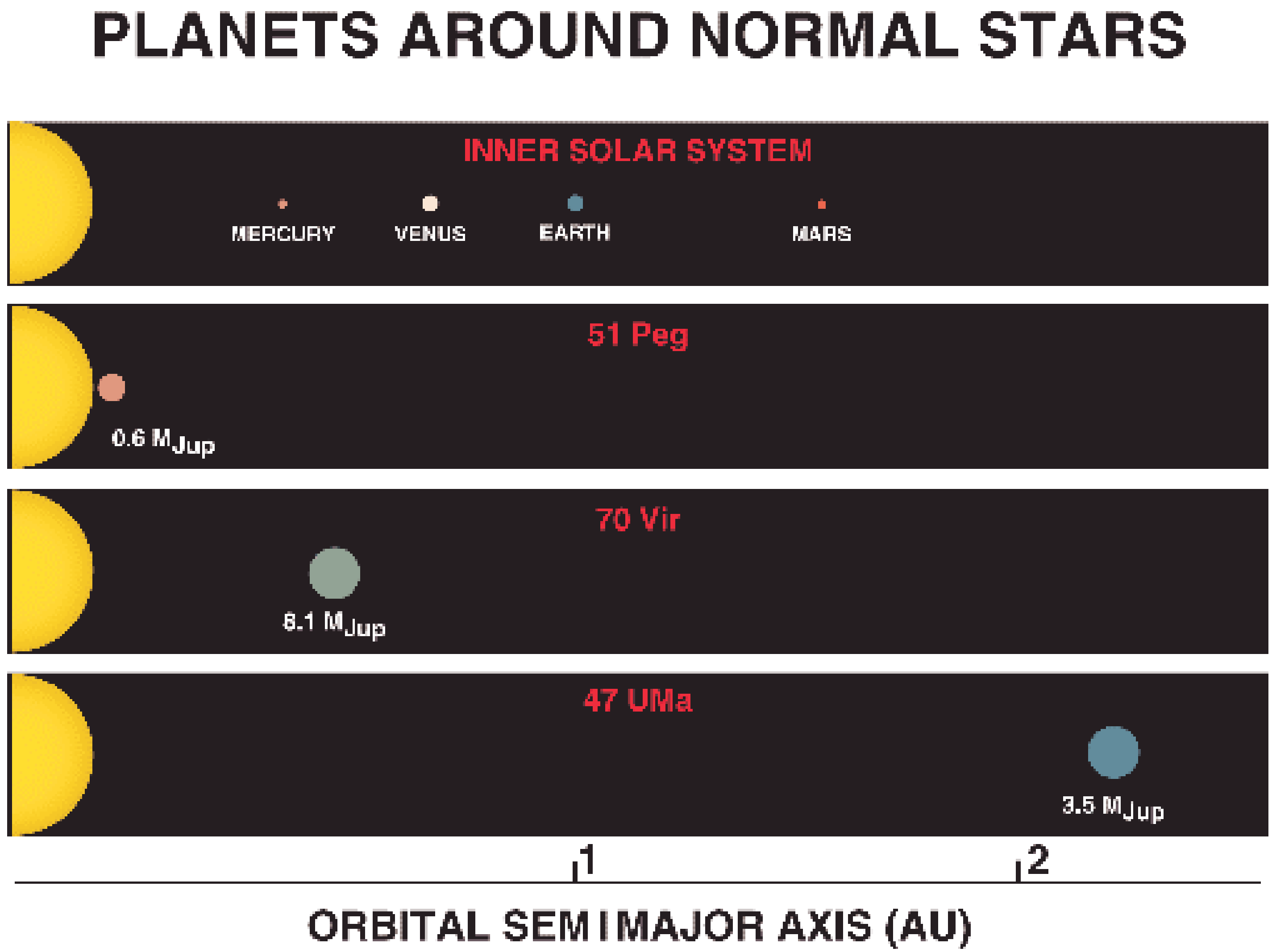
- star movement too small to see
  - moves in small, tight circle
  - but "wobble" in star speed detected!



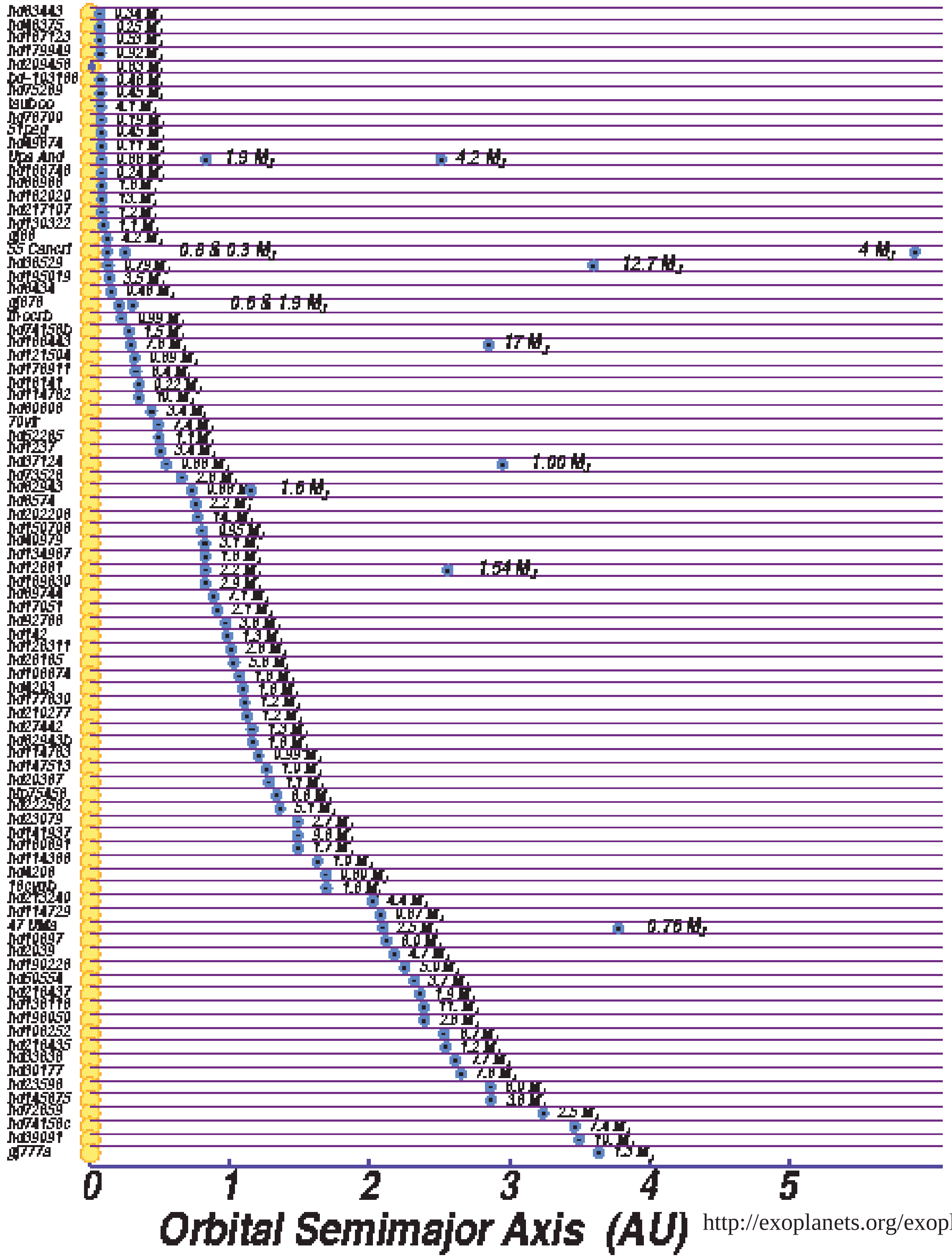
Planets around other Stars?



Early Discovery-- 1996



As of this month, there are at least 110 Planets around other nearby Stars.



http://exoplanets.org/exoplanets_pub.html

Oct 6, 2003

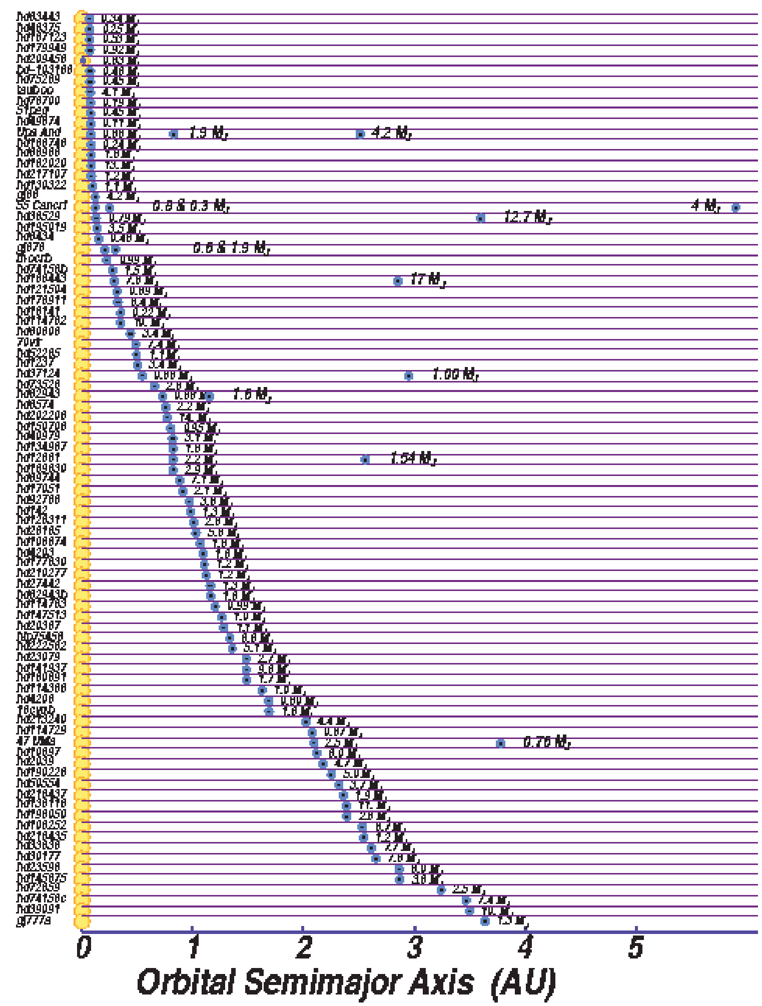
Exoplanets: *Results to Date*

- Over 110 planets detected so far
  - More than 10 times the number in our Solar System!

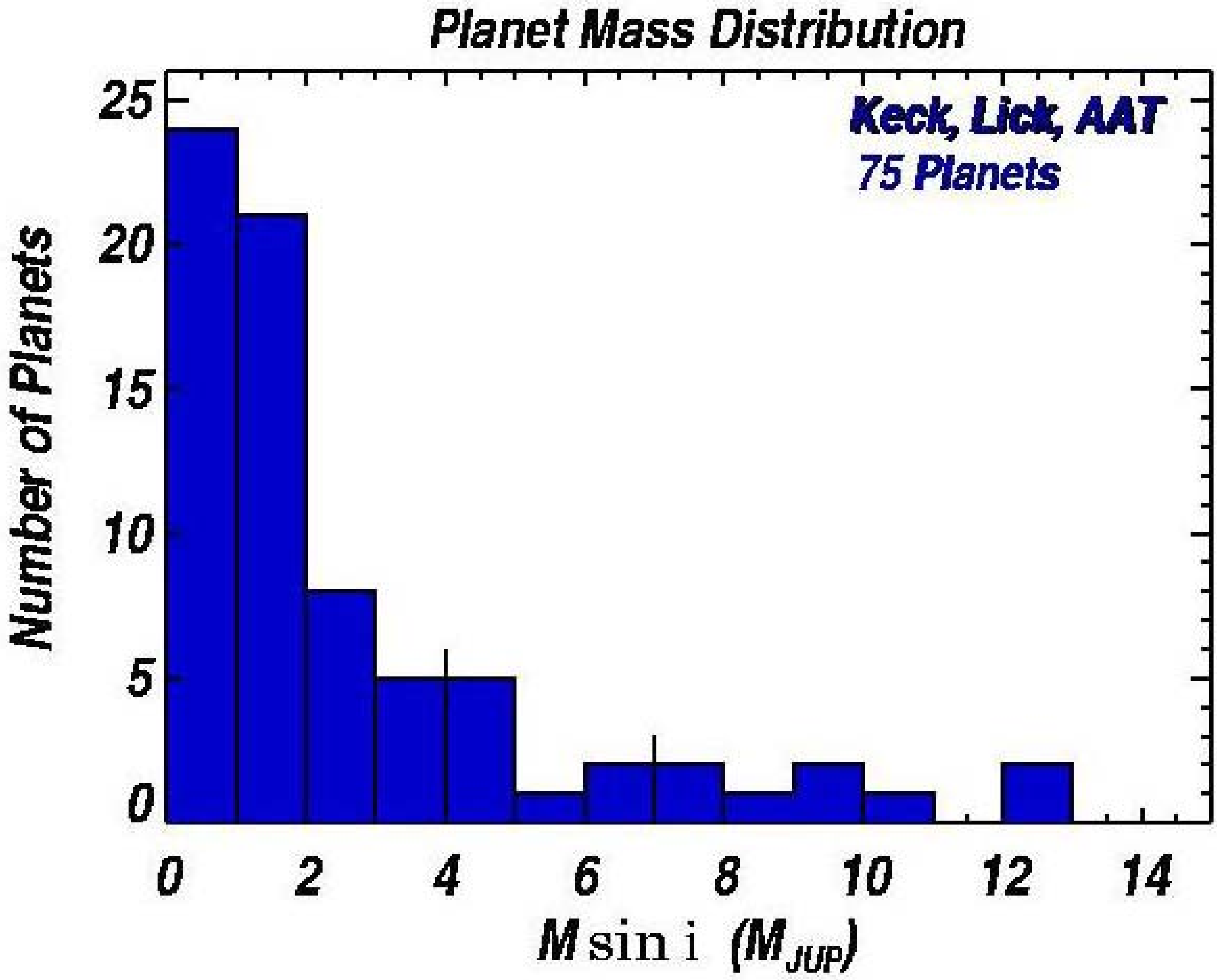
- measure $P_{star} = P_{planet}$

  Kepler, Newton:
  - planet distance $P^2 = a^3$
  - Note: get distance w/o directly measuring it!

- wobble speed gives planet mass

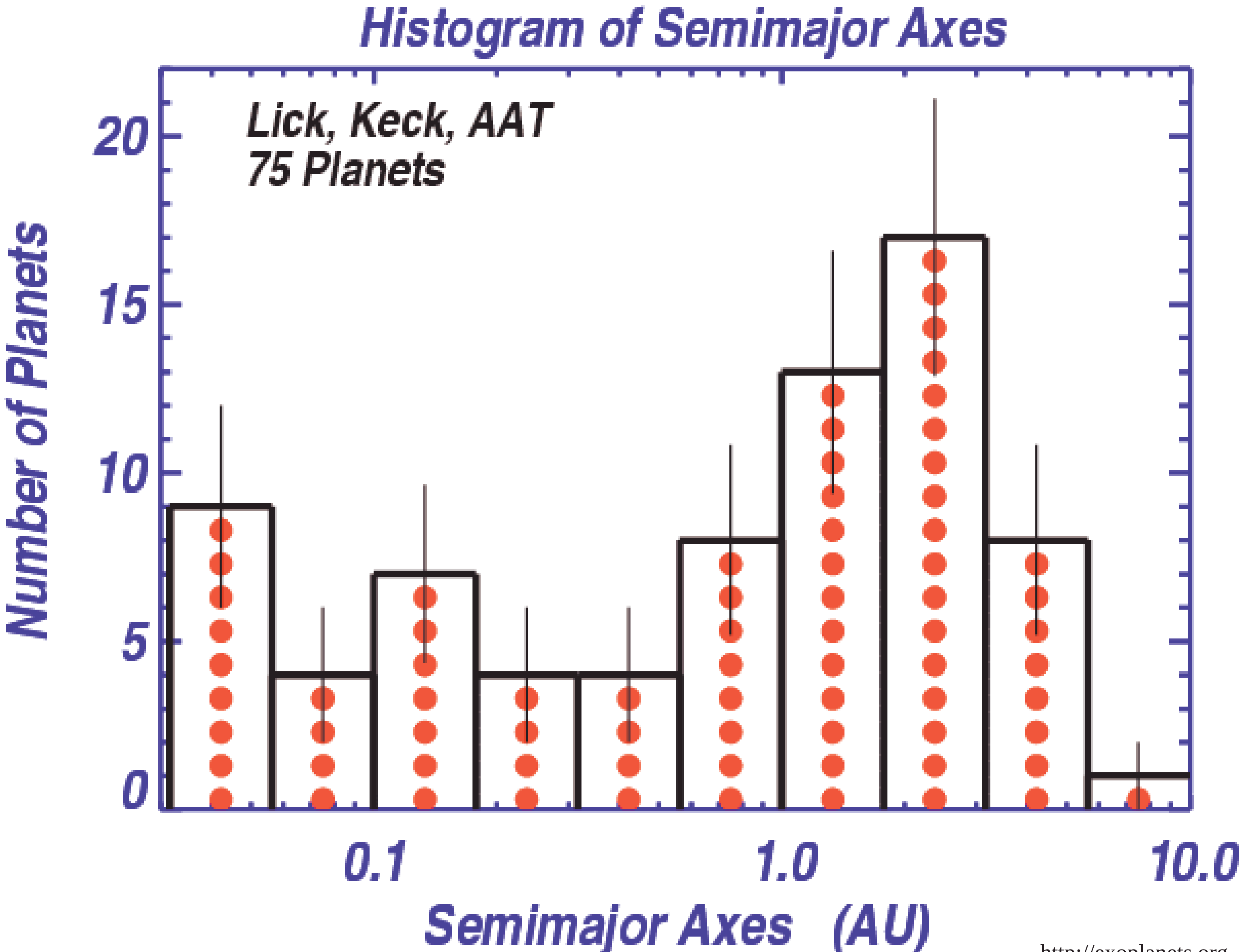


Masses



http://exoplanets.org

Semi-Major Axes



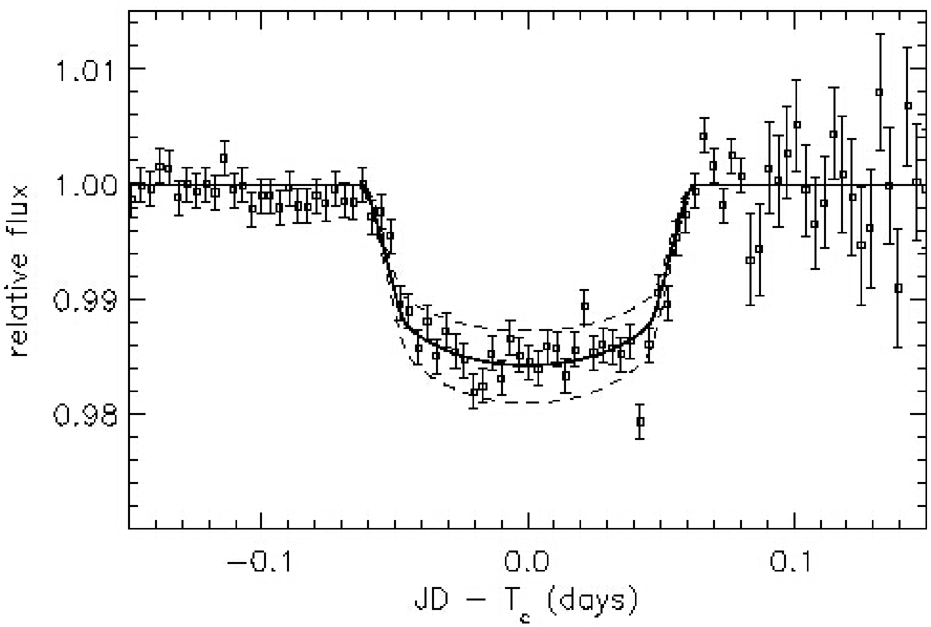
http://exoplanets.org

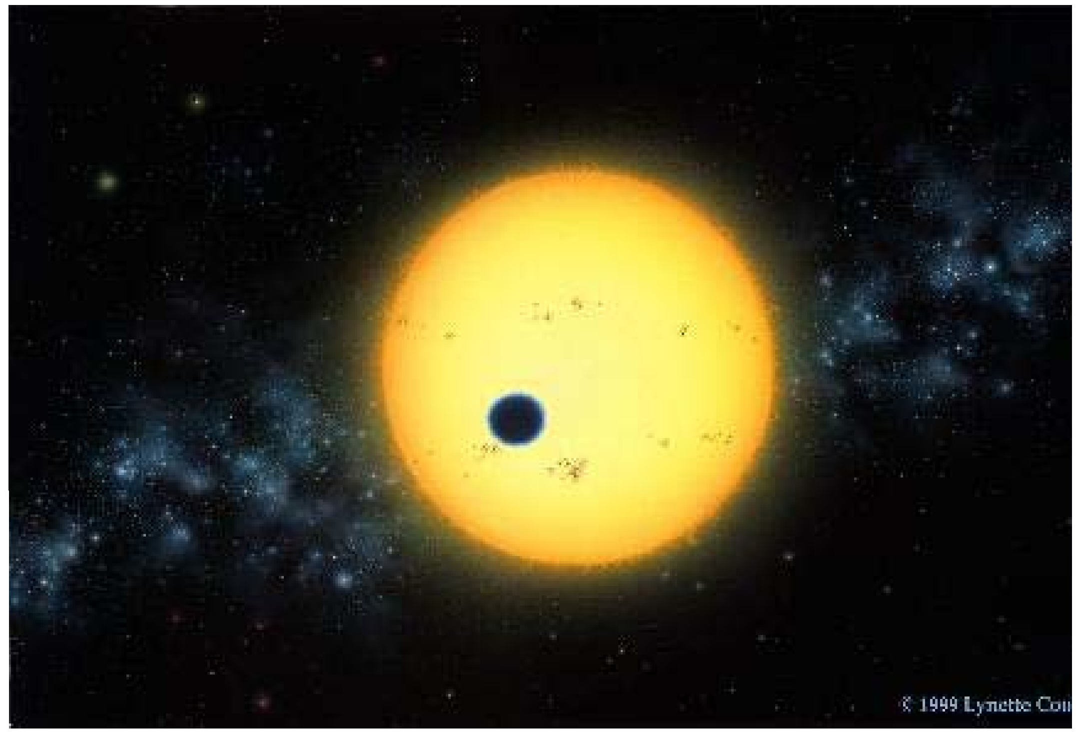
List

http://exoplanets.org/planet_table.shtml

And Transits of Some

- What if the detected planet transits the star?
- http://www.howstuffworks.com/planet-hunting2.htm
- A few solid detections.





http://www.hao.ucar.edu/public/research/stare/stare.html

Other Planets, Other Stars

47 Ursae Majoris System– 51 light years away (near the Big Dipper). 13 years of data has shown 2 planets– 1 Jupiter like and 1 Saturn like.

Wow!

Exoplanets: *Results to Date*

No Surprise:

- ✓ New planets are massive
- ✓ Why? needed to get big wobble
- ✓ If not massive, we could not have found them

Big Surprise:

- ? Period of few days--whip around stars
- ? Most planets are very near stars!
- ? Example: tau Boo is 3.6 x Jupiter mass,
  but closer than Mercury's orbit!

What Are We Looking For?

General Predictions of Solar Nebula Theory

- ☺ Are interstellar dust clouds common? ***Yes!***
- ☺ Do young stars have disks? ***Yes!***
- ? Are the smaller planets near the star?

  Not the ones found so far!
- ? Are massive planets farther away?

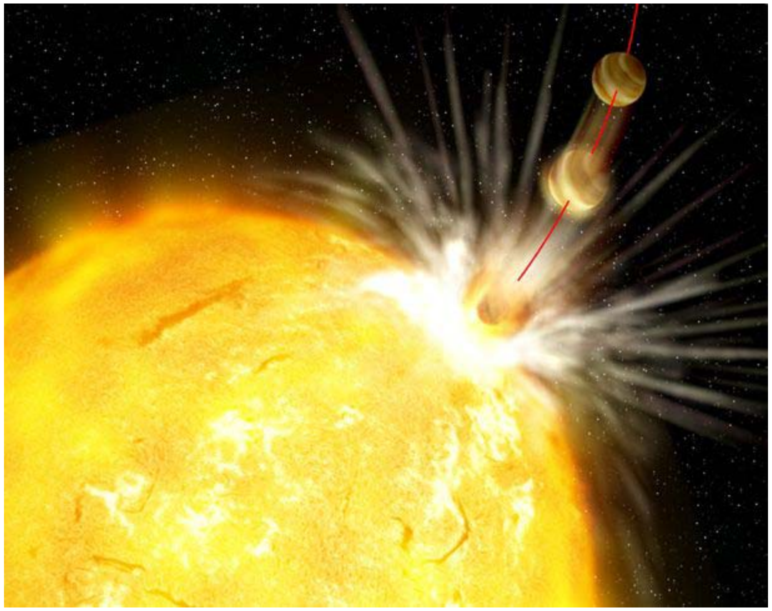
  Not most of the ones found so far!

Exoplanets: Implications

Solar Nebula **Theory**:
- giant planets born far from star

Exoplanet Data:
- Giant planets found very close

Theory is *incomplete/wrong*!



New questions:
? Who is normal: them or us?
? Are giant planets born close in?
? Are some giant planets born far out, move in?
"planet swallowing"!?!

Anyway: planets common.
✓ good news in search for life elsewhere...