Planet Formation

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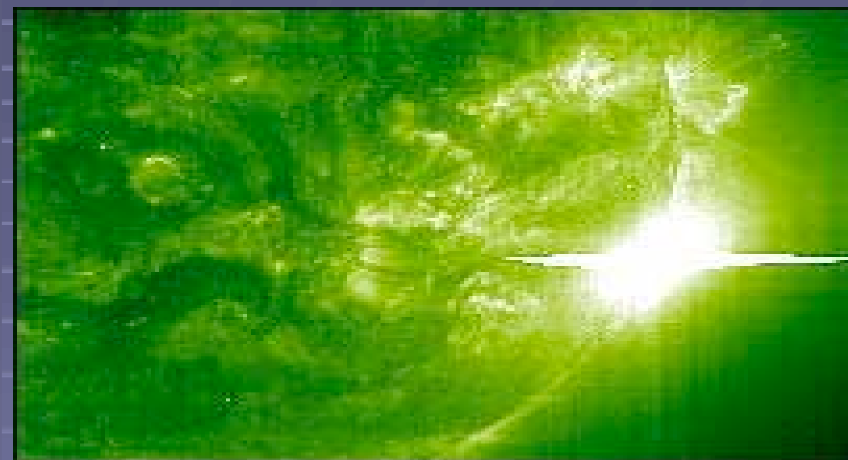
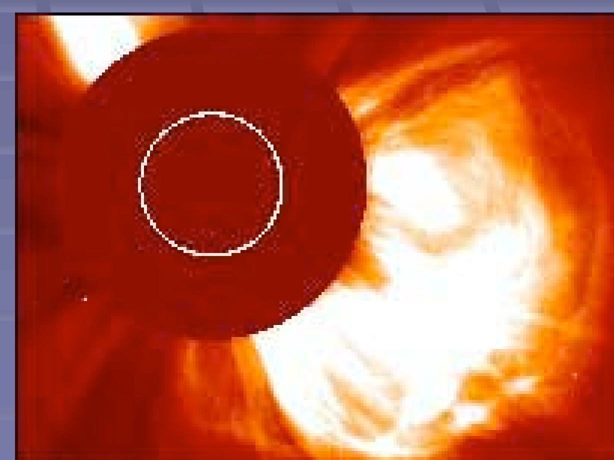
AST 205

Astronomy News Flash

- Biggest solar flare ever recorded went off today
- Sun is in the midst of a period of very intense solar activity
- Coronal mass ejection is not aimed at Earth (unlike last week's much weak flare)





Basic Paradigm

- Laplace introduced in the 1700's: the key elements of the theory
  - A slowly spinning cloud collapses and cool to form the Sun and a rotating disk. This rotating disk fragments to form the planets
  - Key element: Angular momentum conservation

Laplace(1749-1827)

Key Solar System Observational Facts I

- Solar system planets are all nearly coplanar and orbit the Sun in a prograde direction.
- Planets occupy most of the stable orbits
- Small planets, composed mainly of rocky material lie closest to the Sun. Mercury has the highest density
- Gas planets (Jupiter has 90% H and HE, Saturn ~80%; Neptune and Uranus contain 5-20% H and He)
- Asteroids occupy region between Mars and Jupiter. Collisionally evolved population

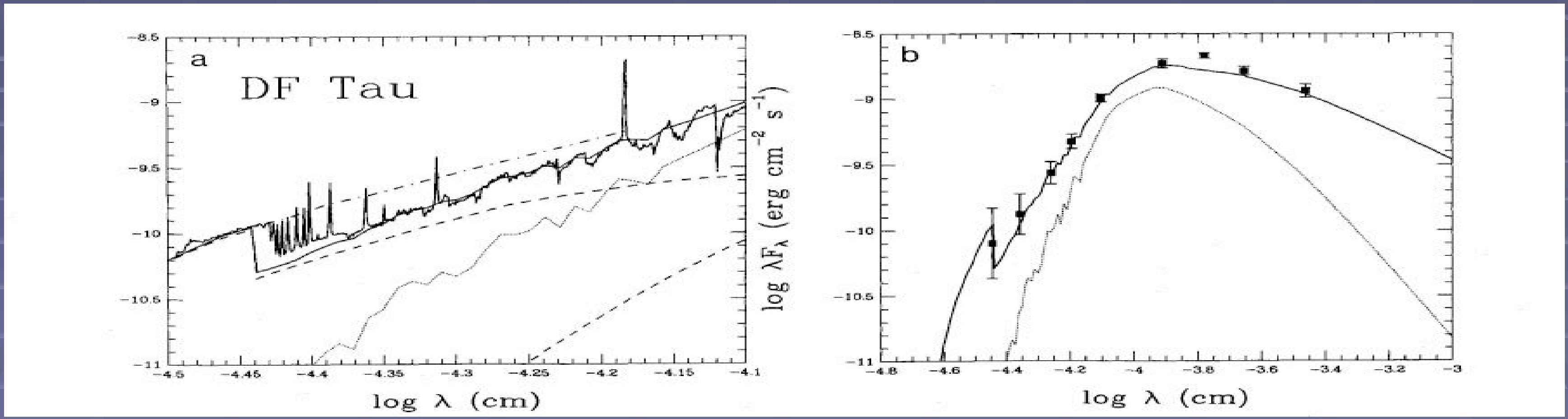
Key Solar System Observational Facts II

- Comets: swarms of ice-rich solid bodies (10^{12}-10^{13} 1 km size objects isotropically distributed at ~10^4 AU)
- Satellite systems: mini-solar systems around Jupiter and Saturn
- Uniform isotopic composition
- Differentiating and melting: all the major planets, moons and many asteroids
- Impact craters seen on most satellites. Current impact rates can not explain number of craters.
- Angular Momentum Distribution

Star Formation

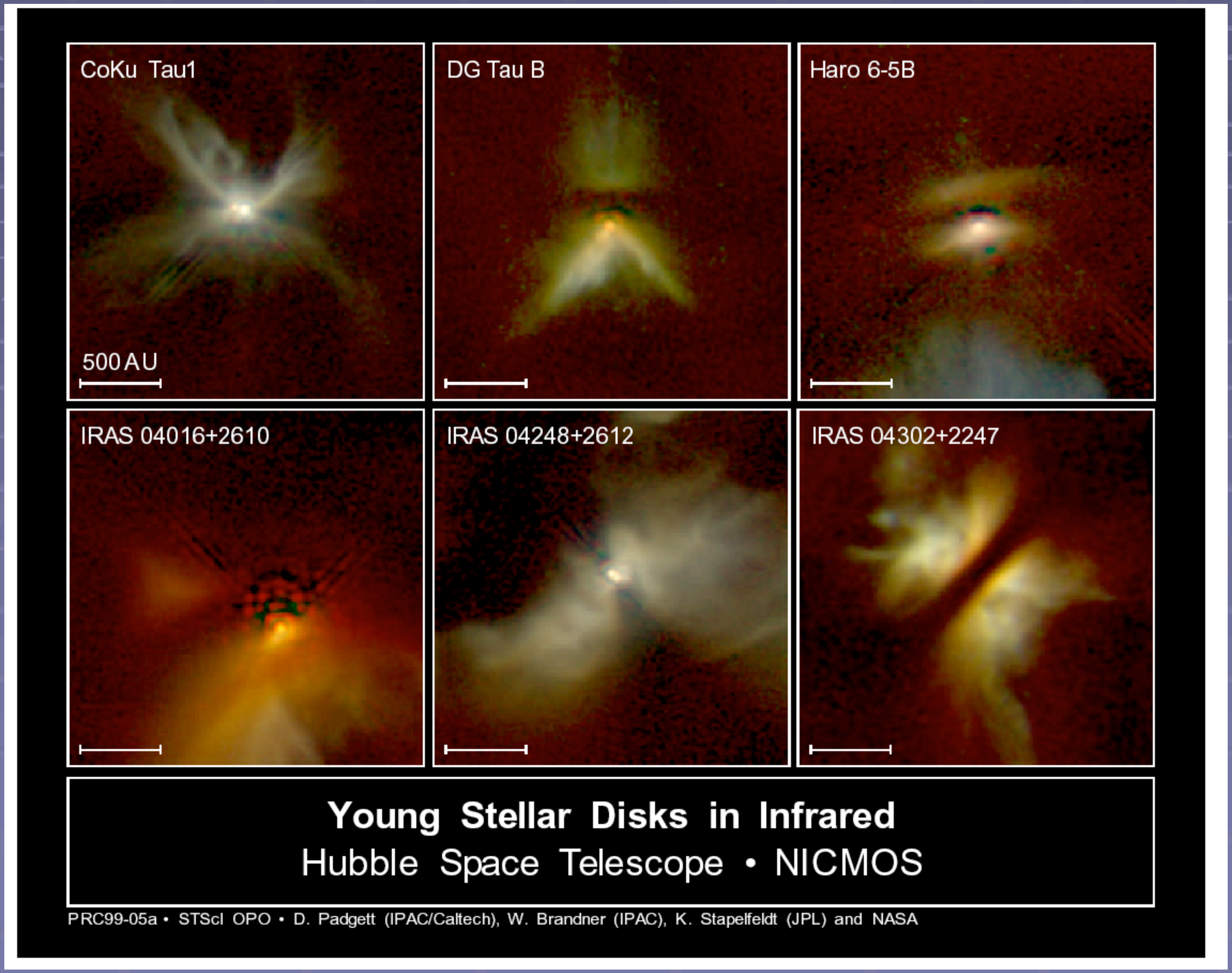
- Molecular clouds: sites of star formation
  - Clouds compressed by spiral arms or by shocks from supernova
  - Cloud cores collapse
    - Initially cores can cool but eventually become too dense to cool
    - Angular momentum conservation limits collapse
      - Fragmentation into binaries (most stars in binaries)
    - Central core reaches temperatures greater than million degrees and begin to burn Deuterium
    - Wind from young star may end collapse phase

Pre-Main Sequence Stars



- Stars that are still collapsing
- After ~million years, PMS enter T Tauri phase
  - Broad spectral energy distribution (disk?)
  - X-ray emission; large sunspots; rapid rotation
- Strong bipolar outflows seen in many PMS

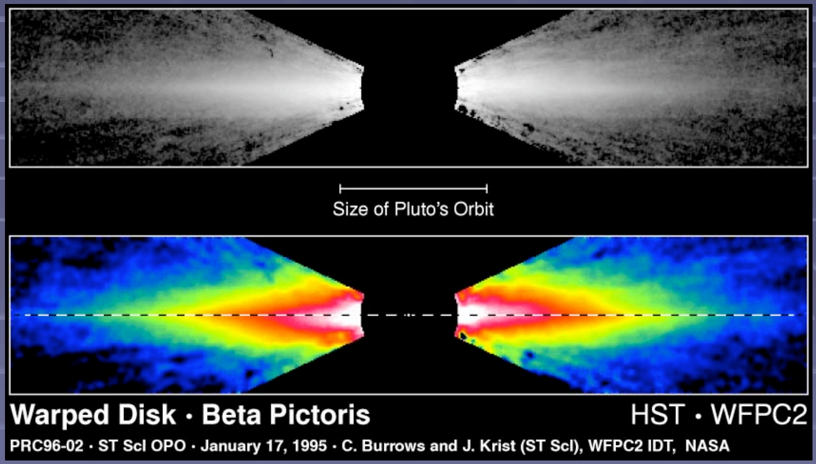
Proto-stellar disks



Primitive Solar Nebula

- Based on converting observed solar system into gas disk (0.02 solar mass disk)
- Infall stage
- Disk stage
  - Evolution governed by angular momentum transport
    - Role of magnetic fields
    - Gravitational torques
  - Dust grains condense in cooling disk
  - After 10^6 -10^7 years, T Tauri winds clear gas

Dust Disks



- Dust disks seen in infrared: excess above stellar blackbody
- Coronagraphs have detected dust disks around nearby stars.
- Some stars have much more dust than our Sun
- Variations in dust properties

Formation of Solid Bodies

- Grain condensation and growth
  - Grains slowly separate from gas in disk
- Growth from 1 cm - 1 km is not understood
  - Drag problem: 1 m size objects spiral inwards within 100 yr
  - Agglomeration growth: grains collide and stick
  - Alternative approach: quiescent disk: dust cools and coagulates to form planet
- Planetesimals to Planet Embryos
  - Gravitational focusing is now important
  - Evolution sensitive to velocities of planetesimals in disk
  - Runaway growth starts once gravitational focusing is important. Embryo growth stops when the planet has accumulated nearly all of the nearby mass. Needs new material scattered into its accretion zone (other embryos? Drag?)

Formation of Terrestial Planets

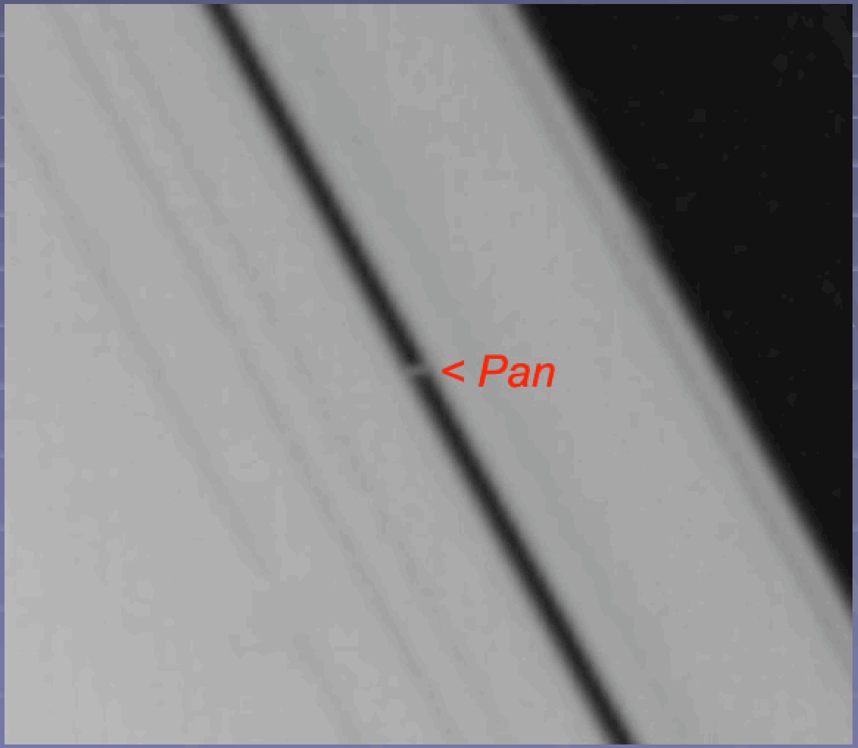
- Self-limiting nature of growth may lead to regularly spaced embryos
- Bombardment phase and planetary differentiation
- Accumulation and loss of volatiles

Formation of Jovian Planets

- Large amounts of H and He suggest that Jupiter and Saturn formed within 10^7 yr
- Gas Instability hypothesis
  - Massive disks are unstable to clumping
  - Problems: Uranus and Neptune; Differentiation seen in outer planets; asteroids, etc
- Core Instability hypothesis
  - First accrete planetesimals
  - Planetesimal accrete an atmosphere from the surrounding gas nebula. Accretion rate is rapid once mass exceeds 10-20 Earth Masses
- Theory predicts gas giants should only form in outer regions of solar system.

Planetary Migration

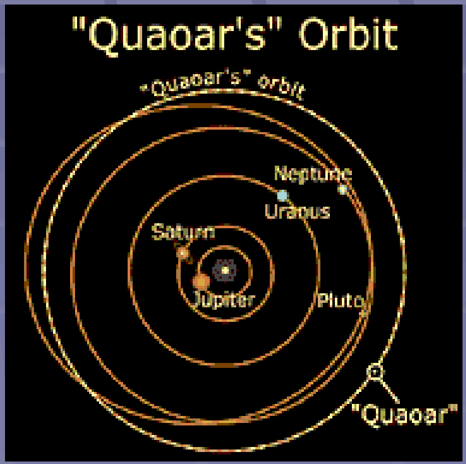
- Planets interact with accretion disk. They excite waves in the disk and transfer energy and angular momentum to the disk
- This drag force pulls planet inwards. Rapid process: Earth in a gaseous disk is dragged inwards in 10^5 years
- Does this process destroy all planets? Multiple generations of planets?



Pan in Saturn's ring

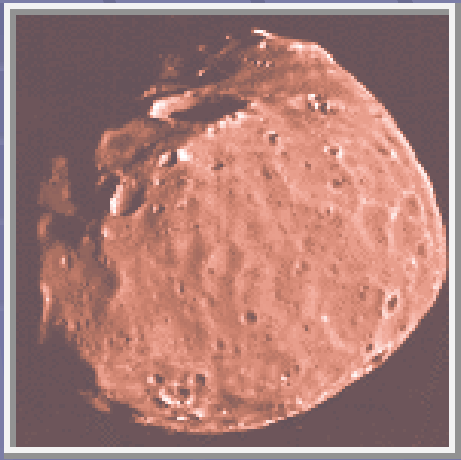
Small Bodies

- Fossils from solar system formation
- Asteroid belt: Jupiter strong gravitational pull prevented the formation of a planet. Heated up orbits so collisions are too violent
- Comets: Formed among outer planets gravitationally ejected outward
  - Kuiper Belt
  - Oort Cloud



Origin of Planetary Satellites

- Jovian moons
- Martian moons (captured planetesimals)
- Earth/Moon system: giant impact model
  - Mars size object collides with Earth after it has differentiated
  - Ring of material around Earth coagulates to form Moon
  - Explains similarities between Earth's crust and moon



Are Earths Common?

- We don’t know how to form planets so hard to tell.
- How important is migration? Where there several generations of Jupiters?
- Did the Sun form in an unusual environment? Al^{26} suggests the presence of nearby dying star.