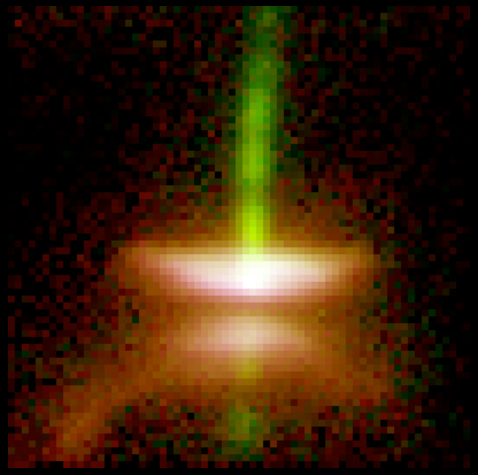
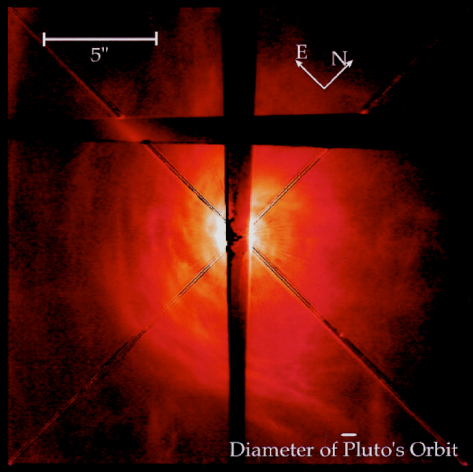
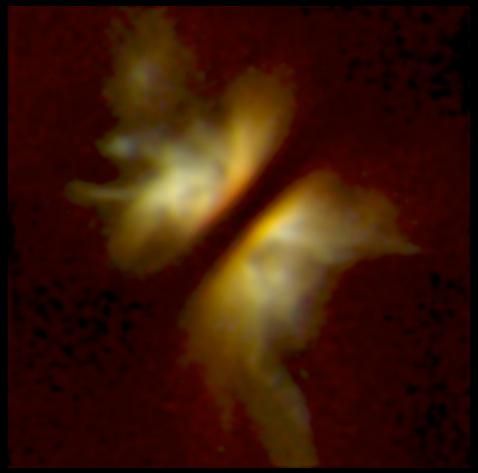
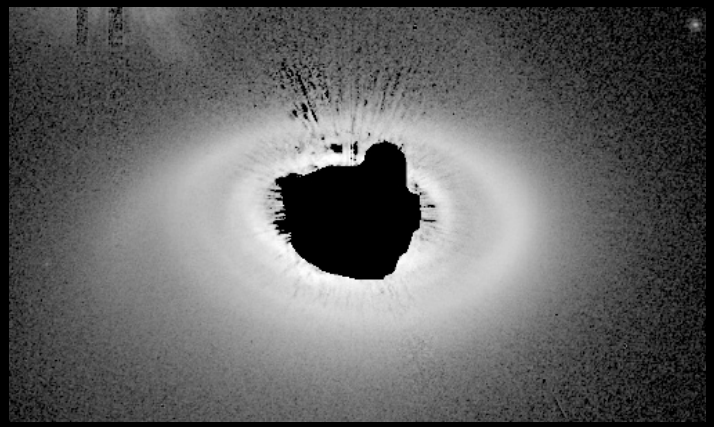
Gas in Protoplanetary Disks

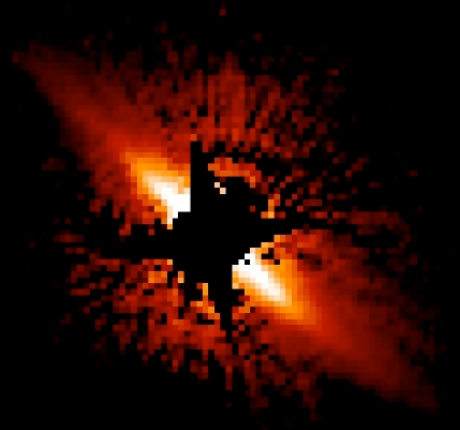
Aki Roberge (NASA GSFC)











Theoretical & Observational Timelines

Theory

Gas giant planets form

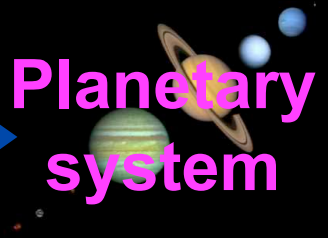
Terrestrial planets form

Disk clearing

Star formation

Time (millions of years)

1 5 10 ~ 1 Gyr



Planetary system

Primordial disk

Transitional disk

Debris disk

Observation

Disk Evolution

10 – 100 $M_{Jupiter}$	few M_{Lunar} (dust)
Total Mass	
10 – 100 $M_{Jupiter}$	?
Gas Mass	

Time (millions of years)

1 5 10 ~ 1 Gyr

Primordial disk

Transitional disk

Debris disk

Observation

Giant Planet Formation & Migration

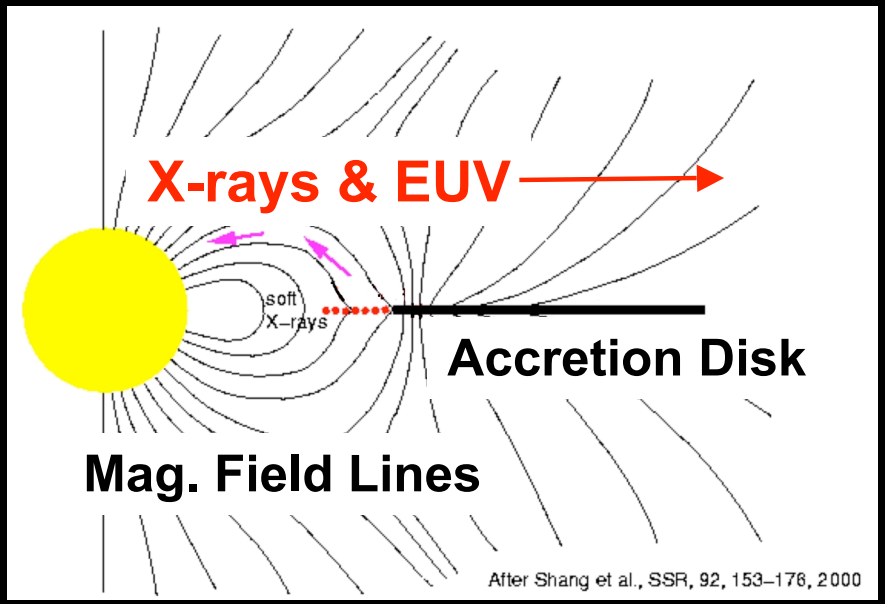
- Gas lifetime limits timescale for giant planet formation
- Causes migration (leading to hot Jupiters)

Measuring Gas Masses

- Two ways of estimating gas mass :
  1) Dust mass × interstellar gas:dust ratio (100:1)
  2) CO mass × interstellar H_2:CO ratio
- But disk gas:dust ≠ interstellar gas:dust
  - Disk gas:dust ratio : 100 (primordial) → ~ 0 (debris)
- Problems with CO technique :
  1) Sub-mm ^{12}CO emission lines often saturate
  2) H_2:CO ratio sensitive to UV, freeze-out of CO

Mid-IR Gas Emission

- Few mid-IR H_2 detections
  - Probably due to low line-continuum contrast
  - Only hot (T > 500 K) gas lines
- Ne II emission @ 12.8 μm
  - 20% of CTTS w/ spectra from c2d Legacy program (Lahuis et al. 2007)



Upcoming Primordial Gas Studies

- Large dispersion in estimates of gas lifetimes
  - Between ~ 10 Myr and < 1 Myr (Hillenbrand 2005)
- Herschel Space Observatory
  - Far-IR to sub-mm imaging and spectroscopy

http://herschel.esac.esa.int/

Herschel Open Time Key Project

- "Gas in Protoplanetary Systems" (GASPS)

  PI: W. Dent (UKATC)

  – 400 hours for about 200 late B to M stars,

  ages = 1 – 30 Myr

- [C II], [O I], H_2O
- Disk gas lifetimes, total disk masses

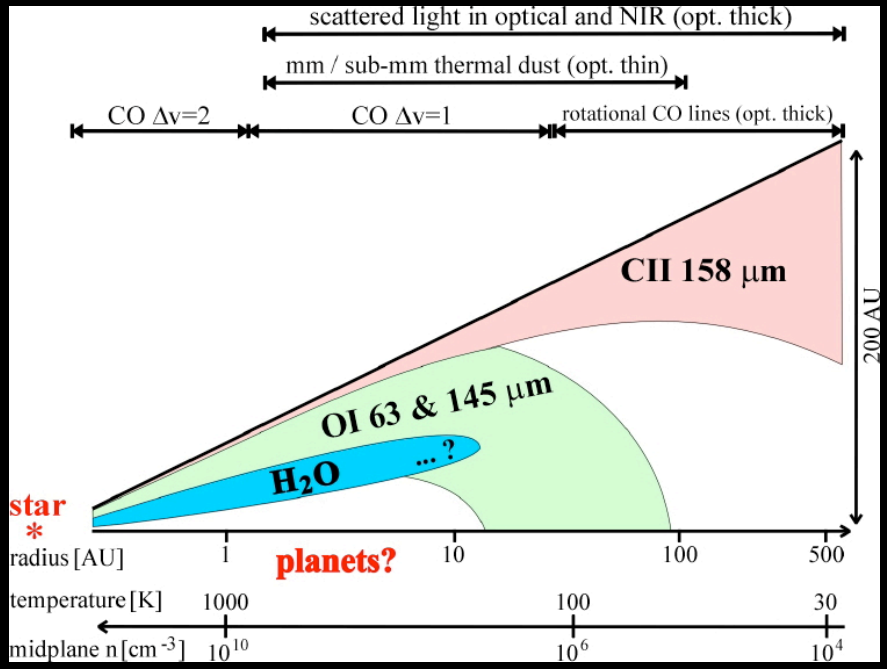
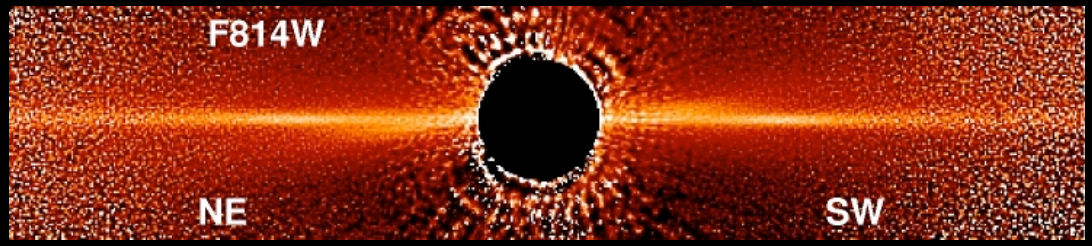


Image credit : I. Kamp

Secondary Gas in Debris Disks

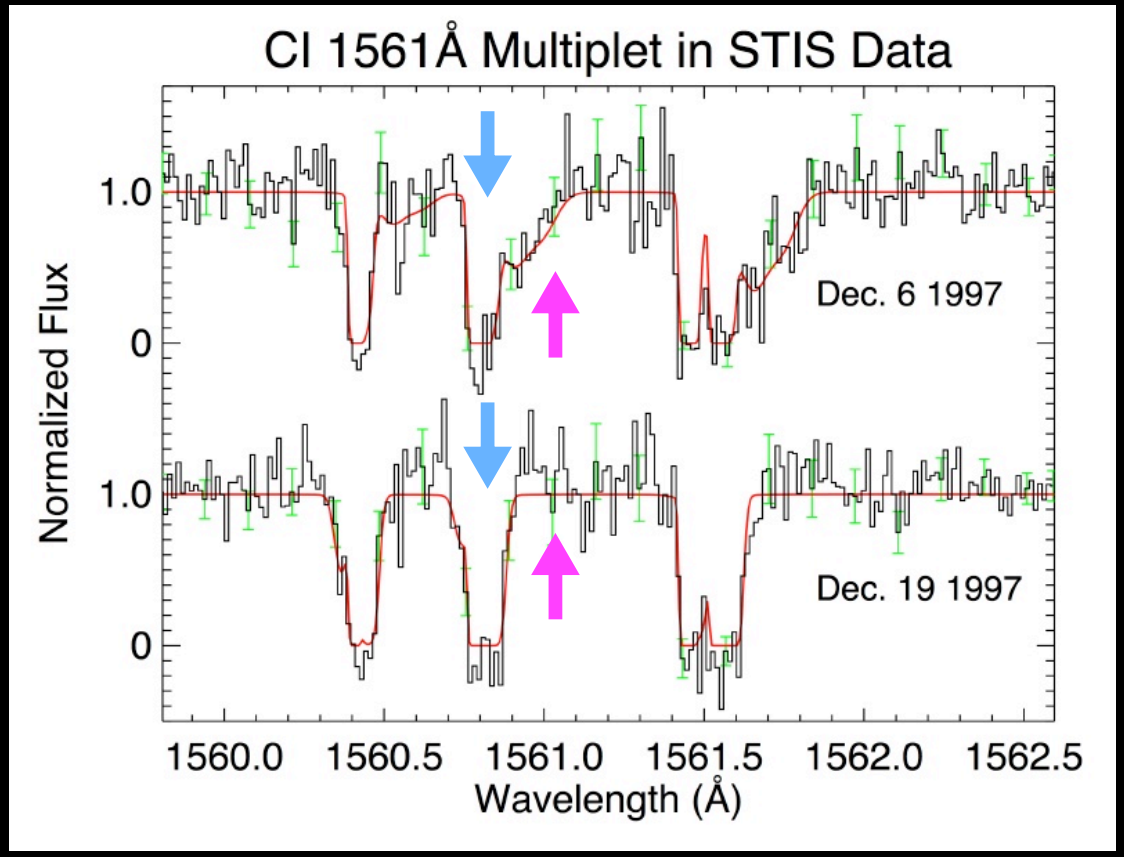
- Debris gas from planetesimals
  - Low gas:dust ratios
  - Mostly atomic gas



Golimowski et al. (2006)

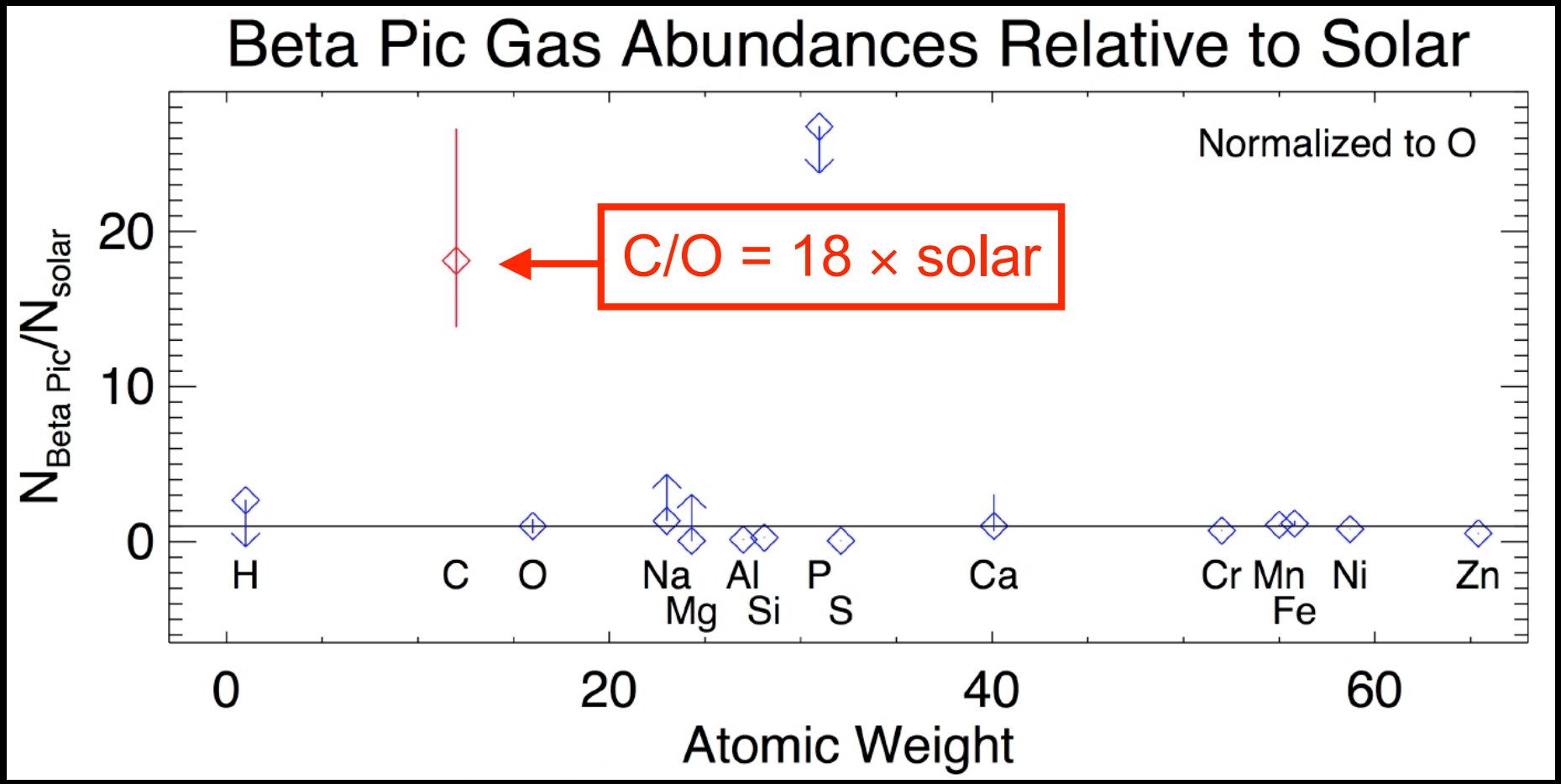
Secondary Gas in Debris Disks

- Debris gas from planetesimals
  - Low gas:dust ratios
  - Mostly atomic gas
- Narrow unvarying features at $v = v_{\star}$: stable gas
- Variable redshifted features : star-grazing planetesimals (FEBs)



Roberge et al. (2000)

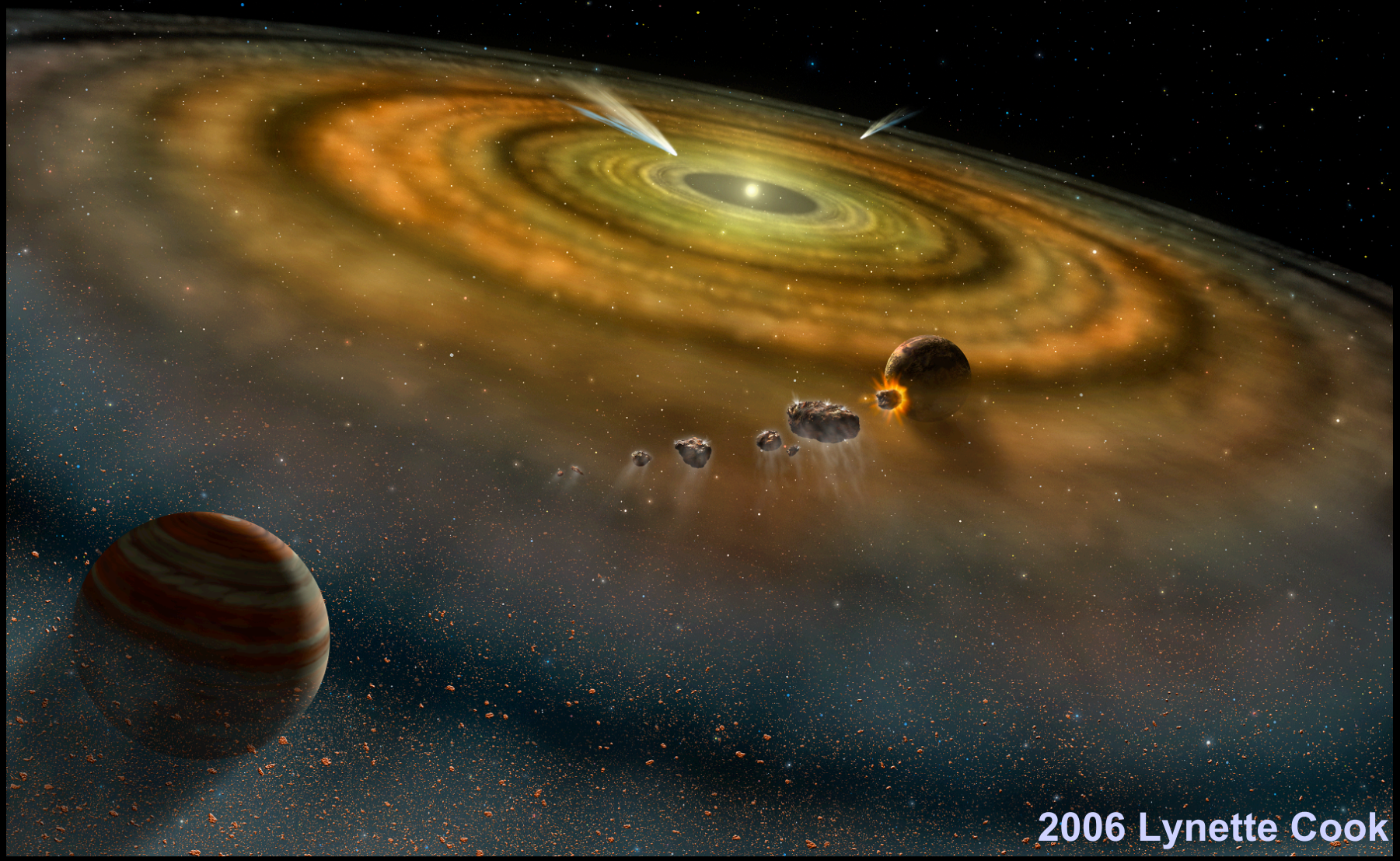
Beta Pic Gas Composition



Roberge et al. (2006)

C-rich AGB stars: C/O < 1.2

(Mattsson et al. 2007)


2006 Lynette Cook