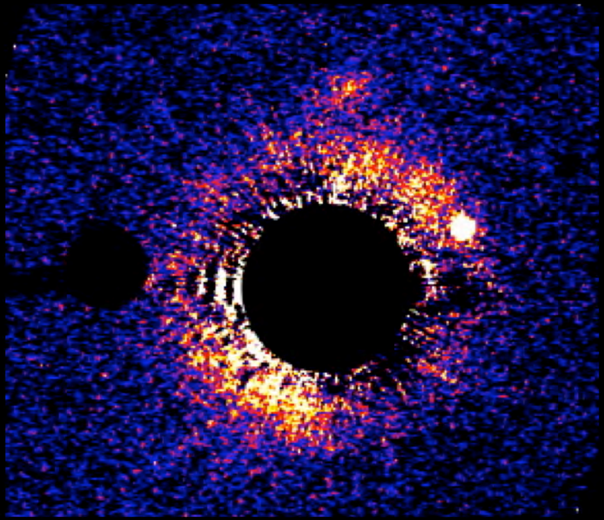
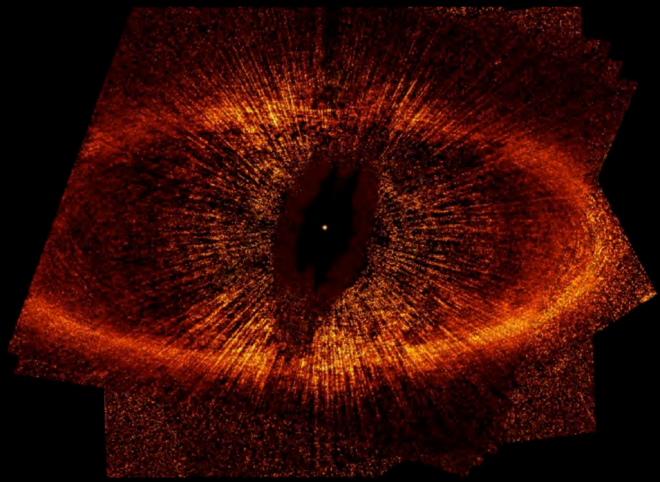
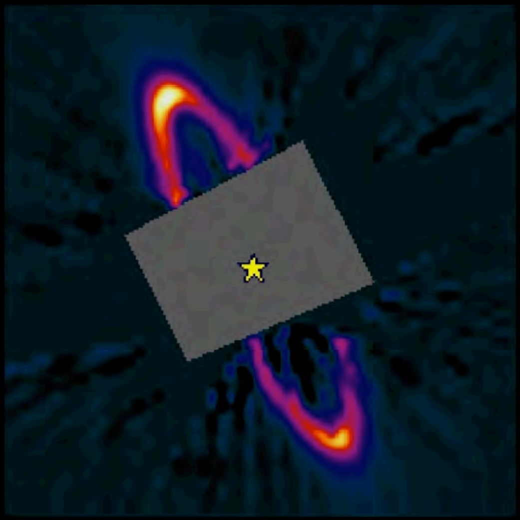
Studies of Debris Disks with the New HST

Aki Roberge (NASA GSFC)

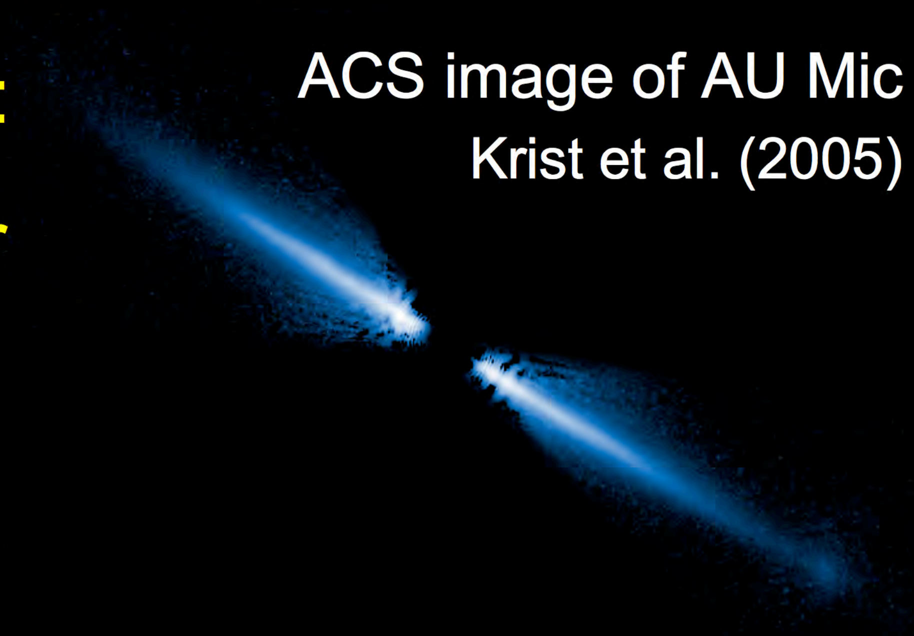




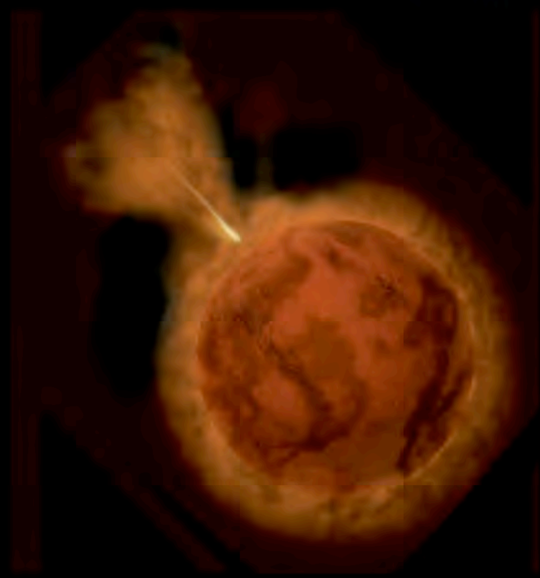


Debris Disks

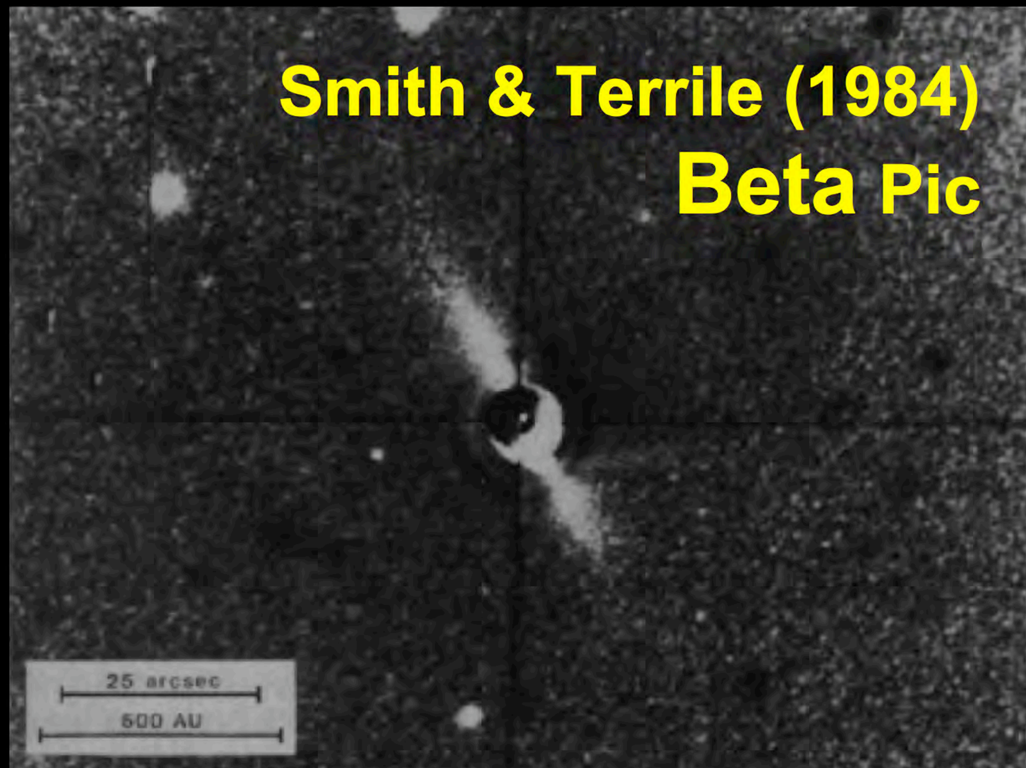
- Wide range of ages :
  ~ 10 Myr to ~ 1 Gyr
- Optically thin disks
  - Short dust lifetimes
- Secondary material
- Delivery of volatiles to terrestrial planet surfaces
  (e.g. Morbidelli et al. 2000)



ACS image of AU Mic
Krist et al. (2005)



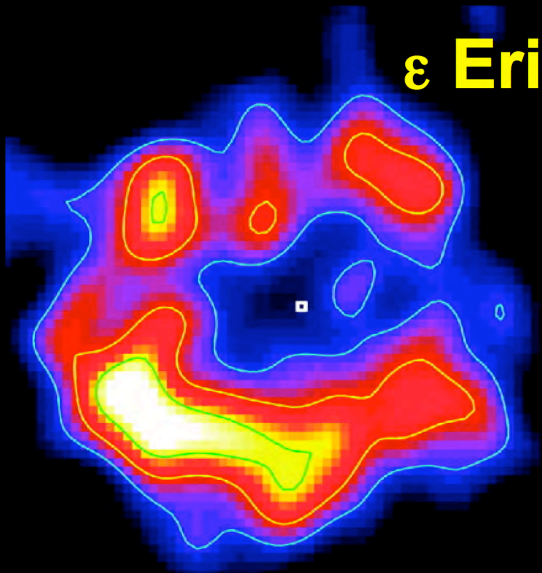
High-Contrast Imaging



- 20 imaged debris disks (P. Kalas disk gallery)
  - First with HST: ~ 65%
  - Only with ACS: ~ 45%

Dust Structures

Clumps
ε Eridani @ 850 μm



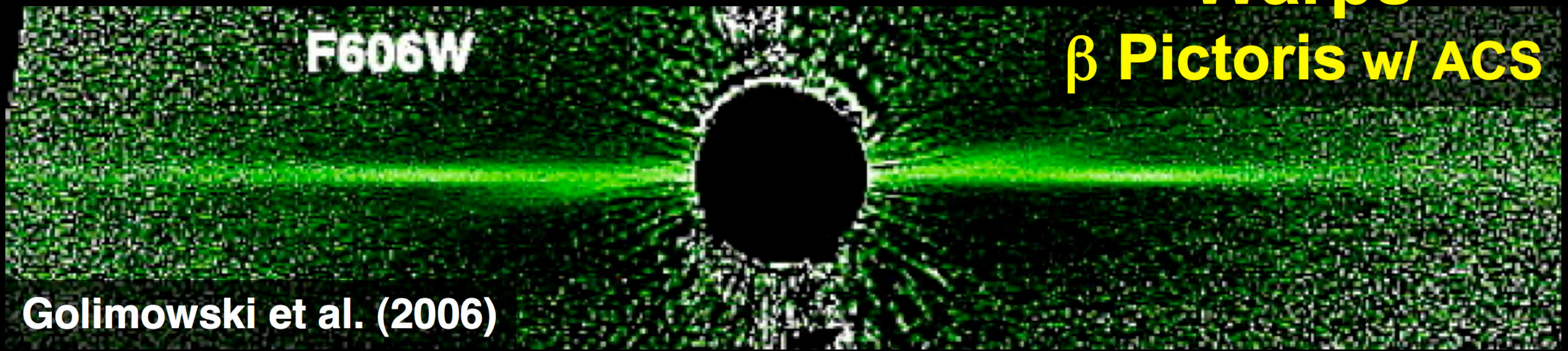
Greaves et al. (2005)

Caused by unseen planets ?

Rings
HR 4796 w/ NICMOS

Schneider et al. (1999)

Warps
β Pictoris w/ ACS



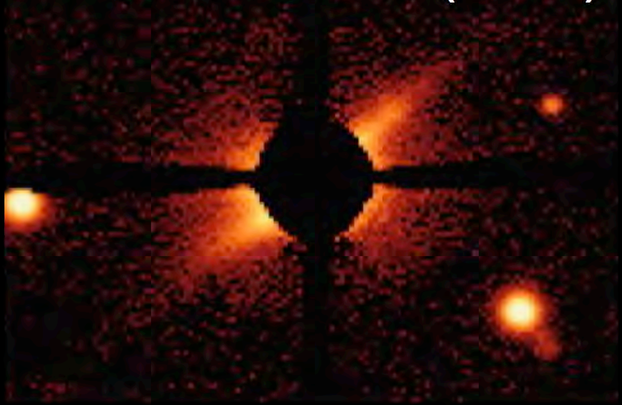
Golimowski et al. (2006)

Future Disk Imaging

- HST best for debris disk imaging
  - Coronagraphy w/ ACS, STIS, NICMOS
  - ACS is most sensitive
- New disks from Spitzer & Herschel
- Need ACS High-Resolution Channel (HRC)

AU Mic – Ground

Kalas et al. (2004)



ACS

Krist et al. (2005)

Gas in Debris Disks

- Low gas-to-dust ratios
  - – Only one with cold CO emission

    49 Ceti (e.g. Dent et al. 2005)

- Atomic gas in a few debris disks

Beta Pictoris (e.g. Lagrange et al. 1998)

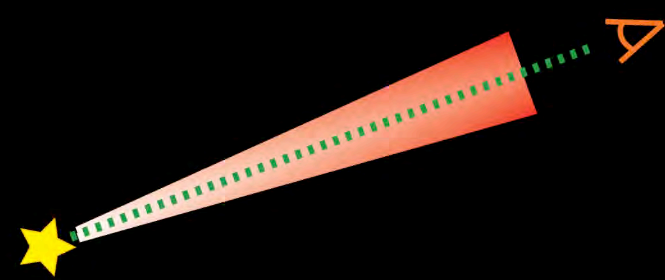
51 Ophiuchi (e.g. Roberge et al. 2002)

Sigma Herculis (Chen & Jura 2003)

HD 32297 (Redfield 2007)

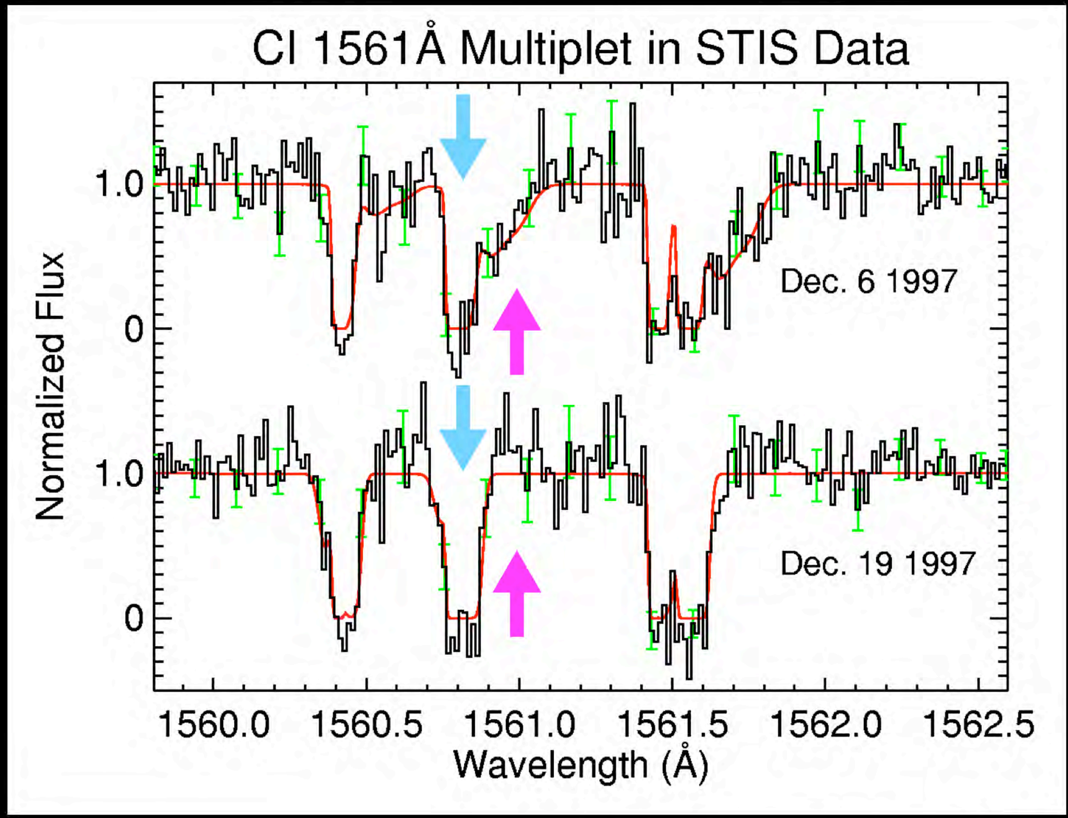
HD 158352, HD 118232, HD 21620, HD 142926

(Roberge & Weinberger 2008)



Atomic Gas in Beta Pic

- Narrow unvarying features at $v = v_\star$: stable gas
- Variable shifted features: vaporization of star-grazing planetesimals (FEBs) (e.g. Beust et al. 1990)



Roberge et al. (2000)

Species	Column Density (cm^{-2})	Reference
H I	$\lesssim$ few $\times 10^{19}$	Freudling et al. (1995)
H_2	$\leq 3 \times 10^{18}$	Lecavelier des Etangs et al. (2001)
C I	$(2-4) \times 10^{16}$	Roberge et al. (2000)
C II	$2.0^{+2.1}_{-0.4} \times 10^{16}$	this work, §4.3
O I	$(3-8) \times 10^{15}$	this work, §4.9
O II	$(3-8) \times 10^{11}$	inferred, §6.4
OH	$\leq 2 \times 10^{13}$	Vidal-Madjar et al. (1994)
CO	$(6.7 \pm 0.5) \times 10^{14}$	Roberge et al. (2000)
Na I	$(3.4 \pm 0.4) \times 10^{10}$	Brandeker et al. (2004)
Na II	$\geq 3 \times 10^{13}$	inferred, §6.4
Mg I	2.5×10^{11}	Vidal-Madjar et al. (1994)
Mg II	$\geq 2 \times 10^{13}$	Lagrange et al. (1998)
Al I	$\leq 4 \times 10^{10}$	Lagrange et al. (1998)
Al II	4.5×10^{12}	Lagrange et al. (1998)
Si I	$\leq 1 \times 10^{13}$	Lagrange et al. (1998)
Si II	1×10^{14}	Lagrange et al. (1998)
P I	$\leq 7.0 \times 10^{11}$	this work, §5.5
P II	$\leq 9.2 \times 10^{13}$	this work, §5.6
S I	5.4×10^{12}	Lagrange et al. (1998)
S II	5×10^{12}	inferred, §6.4
Ca I	$\leq 2 \times 10^{9}$	Vidal-Madjar et al. (1986)
Ca II	$1.26^{+3.75}_{-0.63} \times 10^{13}$	Crawford et al. (1994)
Ca III	$1.3^{+3.8}_{-0.6} \times 10^{13}$	inferred, §6.4
Cr I	3.5×10^{9}	inferred, §6.4
Cr II	3.5×10^{12}	Lagrange et al. (1998)
Mn I	$\leq 3 \times 10^{10}$	Lagrange et al. (1998)
Mn II	3×10^{12}	Lagrange et al. (1998)
Fe I	1×10^{12}	Lagrange et al. (1998)
Fe II	$(3.7 \pm 0.5) \times 10^{14}$	J. Debes (1999), personal communication
Ni I	$\leq 7.6 \times 10^{10}$	this work, §5.4
Ni II	1.5×10^{13}	Lagrange et al. (1998)
Zn I	$\leq 7 \times 10^{10}$	Lagrange et al. (1998)
Zn II	2×10^{11}	Lagrange et al. (1998)
Total Upper Limit :	$\lesssim$ few $\times 10^{19}$	
Total Measured :	$5.7^{+2.3}_{-1.1} \times 10^{16}$	not including inferred values, upper limits

HST-STIS

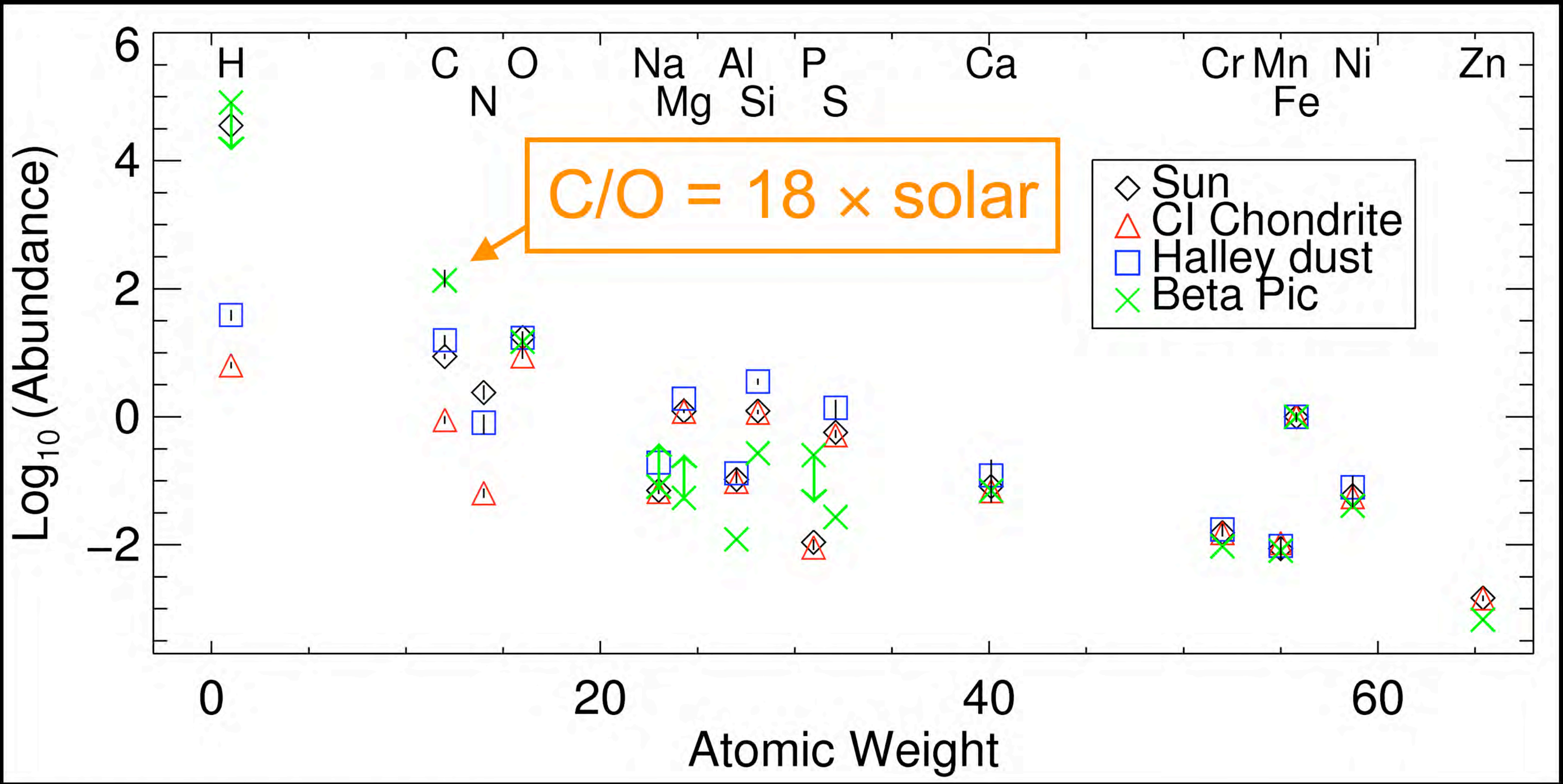
HST-GHRS

FUSE

Ground

Roberge et al. (2006)

Beta Pic Gas Composition



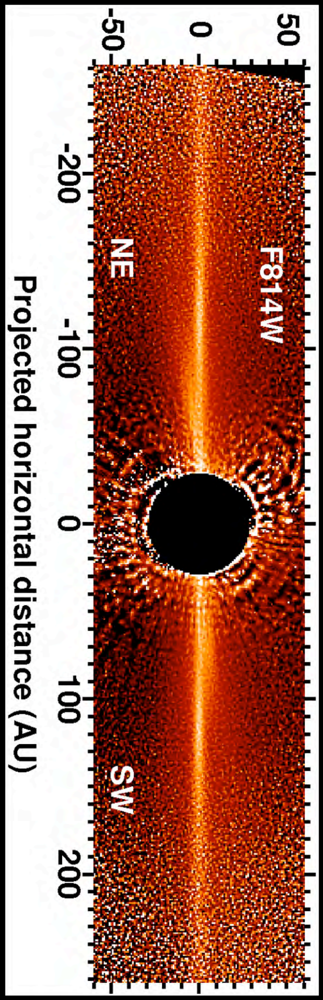
Roberge et al. (2006)

C-rich AGB stars: C/O < 1.2

(Mattsson et al. 2007)

Dynamics of the Gas

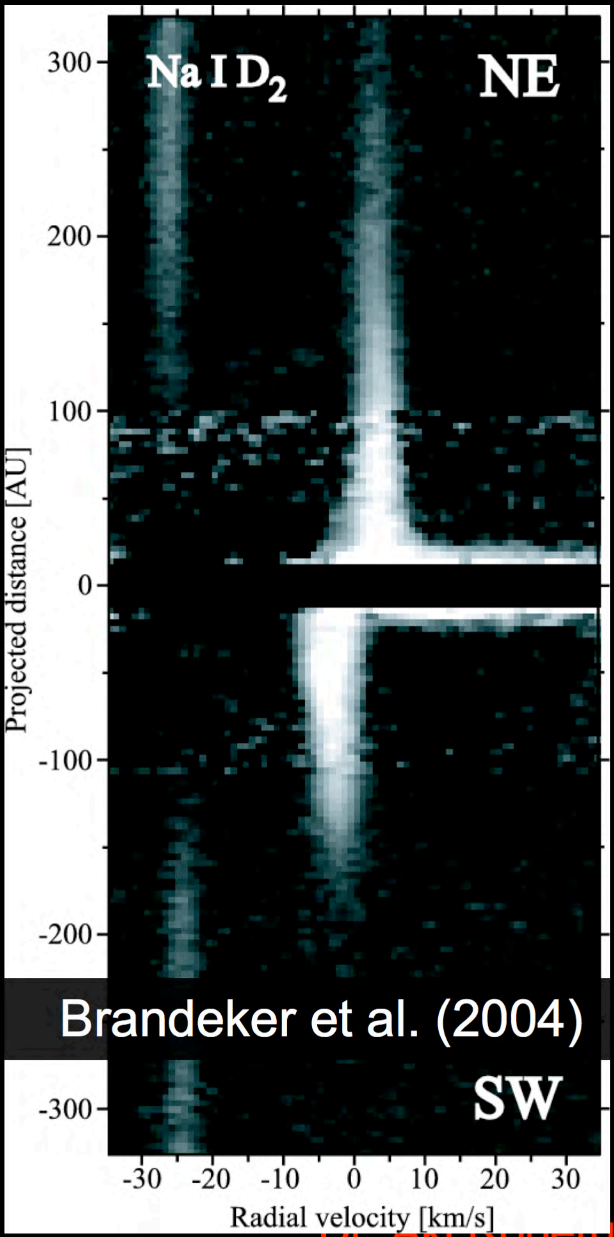
- Radiation pressure ➔ blow away stable gas (e.g. Lagrange et al. 1998)
- Need unseen braking gas



Golimowski et al. (2006)

Dynamics of the Gas

- Radiation pressure → blow away stable gas (e.g. Lagrange et al. 1998)
- Need unseen braking gas
- Image in resonantly scattered Na I emission (Olofsson, Brandeker, & Liseau 2001)



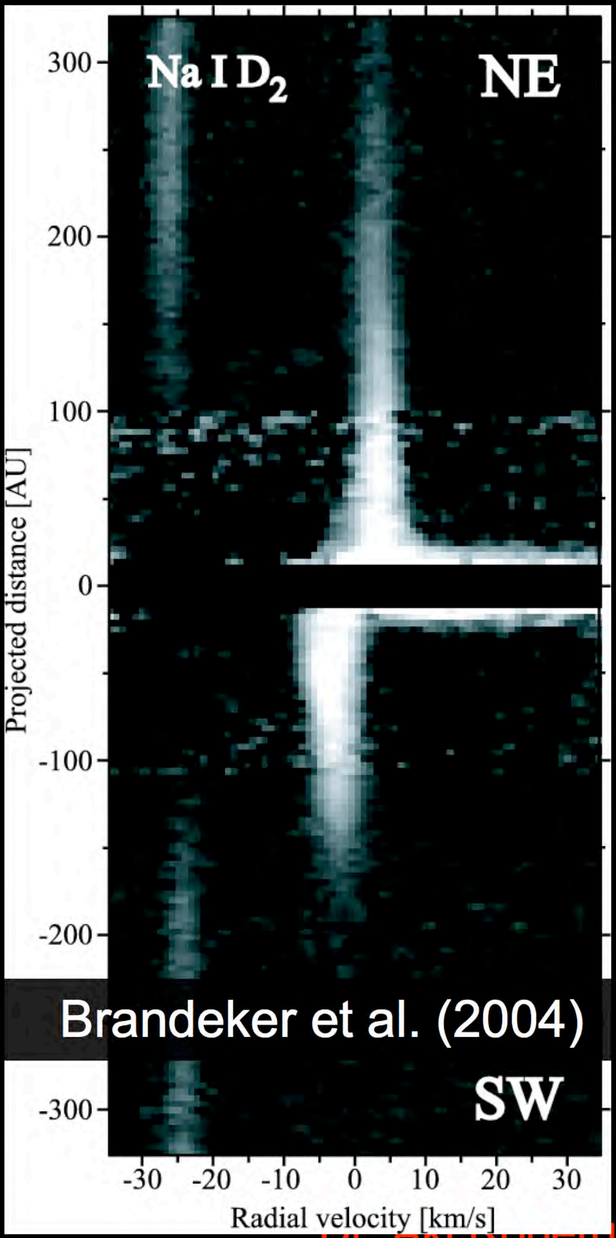
Brandeker et al. (2004)

β Pic gas disk in Keplerian rotation out to 100s of AU

Dynamics of the Gas cont'd

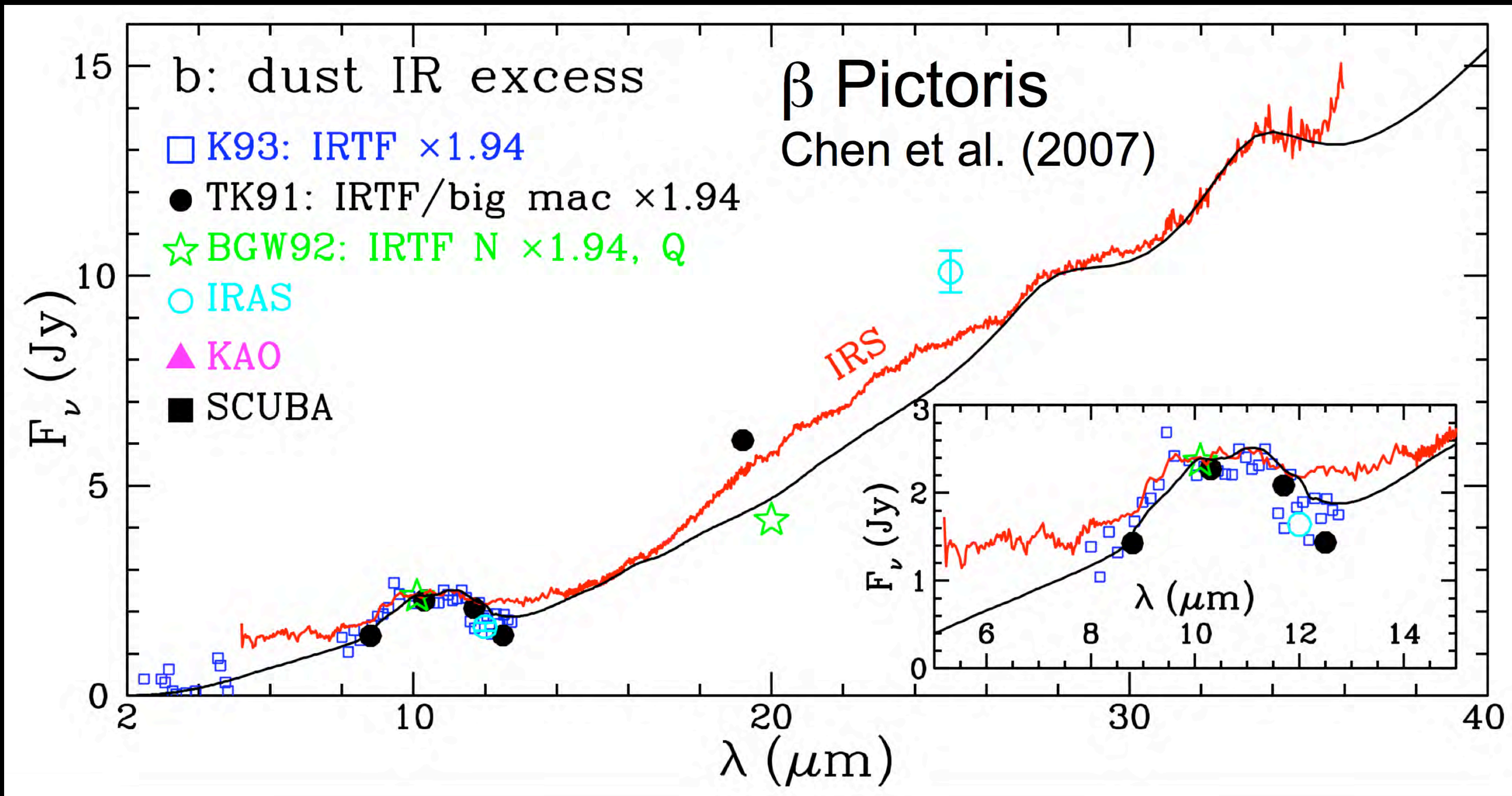
- Modeling of Coulomb forces (Fernandez, Brandeker, & Wu 2006)
  - Ions couple into single fluid with effective β-value
  - If solar abundance, still need unseen braking gas
- C is important in ionic fluid

If C ≥ 10 × solar,
gas will self-brake



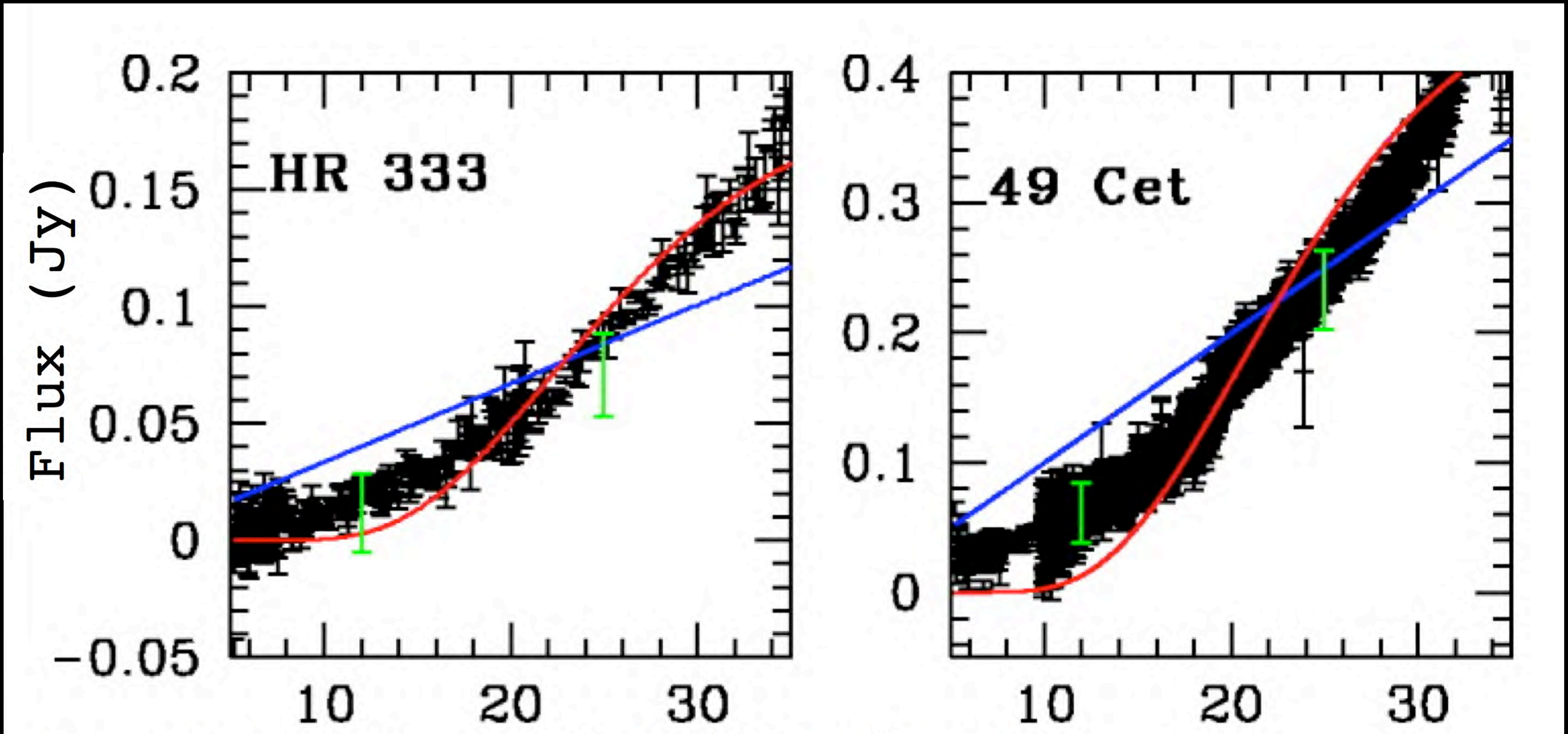
Brandeker et al. (2004)

Dust Composition from Mid-IR Spectra



Small, warm amorphous & crystalline silicates

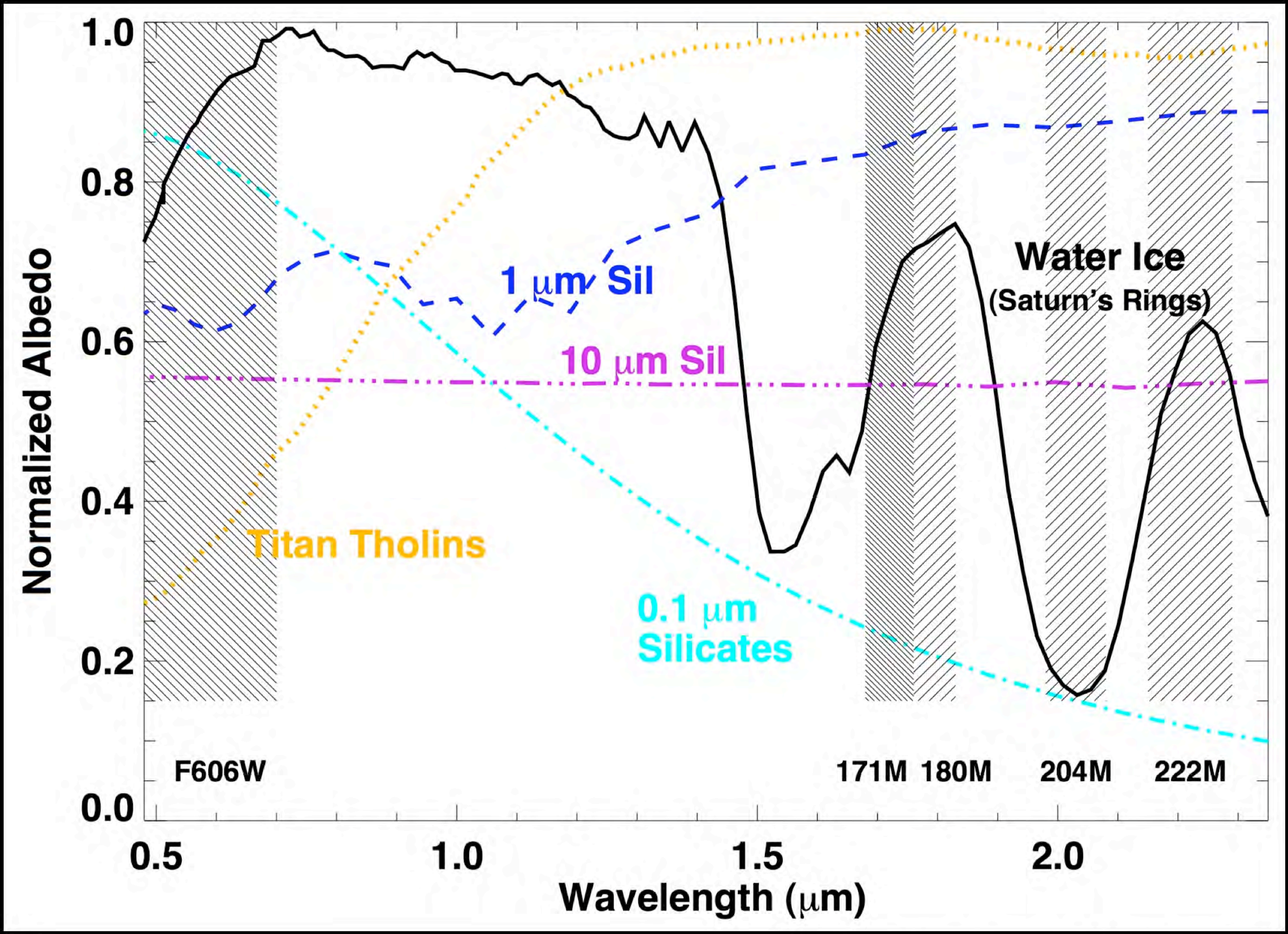
Dust Composition from Mid-IR Spectra



Chen et al. (2006)

Cold grains, large grains → no composition info.

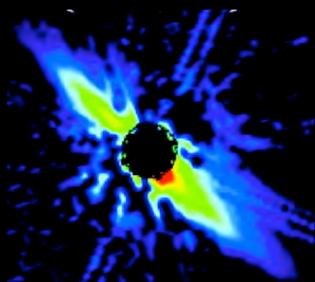
Albedos of Grains



From A. Weinberger

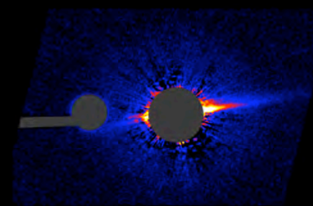
Scattered Light Colors

HD 32297
Blue
Schneider et al. (2005)



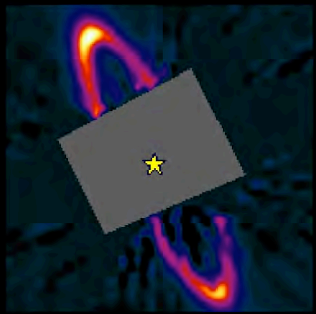
AU Mic
Blue
Krist et al. (2005)

HD 15115
Blue
Kalas et al. (2007)

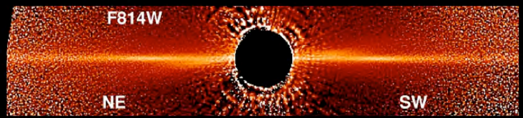


HD 92945
Neutral
Golimowski et al., in prep.

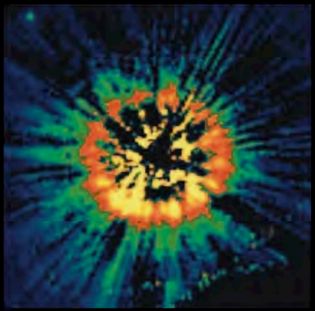
HR 4796A
Red
Schneider et al., in prep.



Beta Pic
Red
Golimowski et al. (2006)



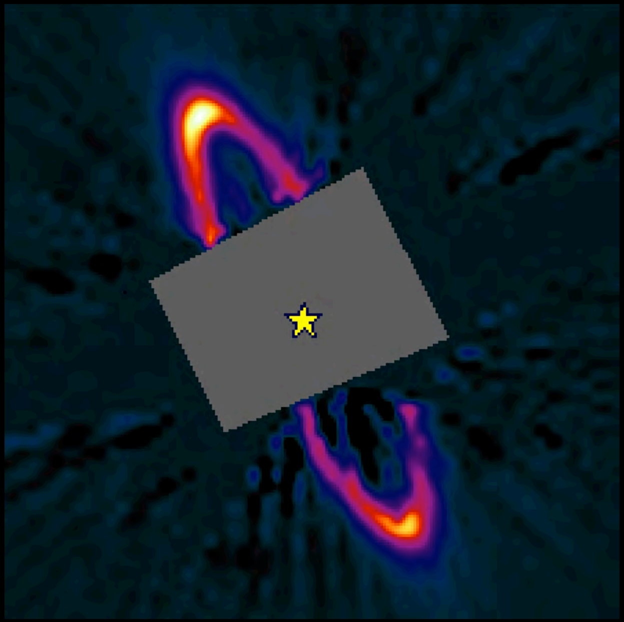
HD 181327
Red
Schneider et al. (2006)



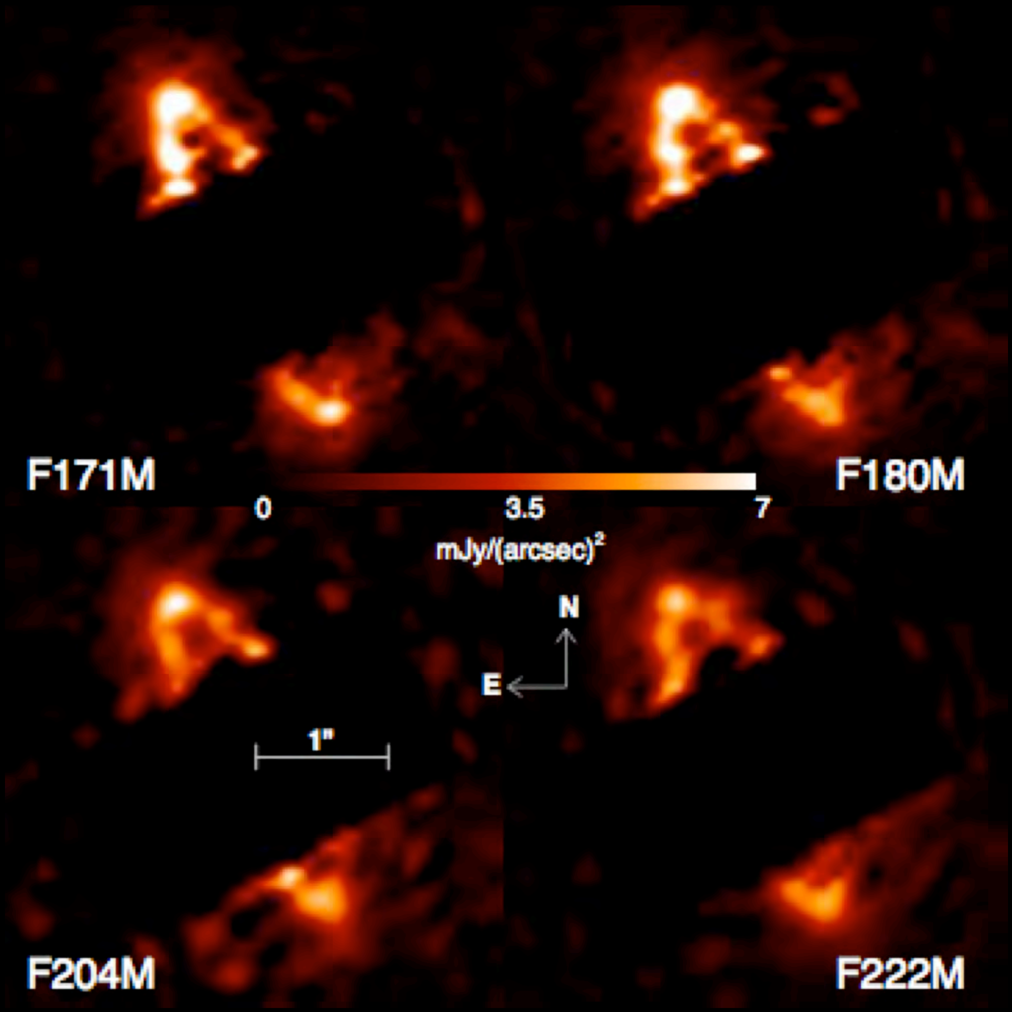
HD 107146
Red
Ardila et al. (2004)

Organic Material in HR 4796A

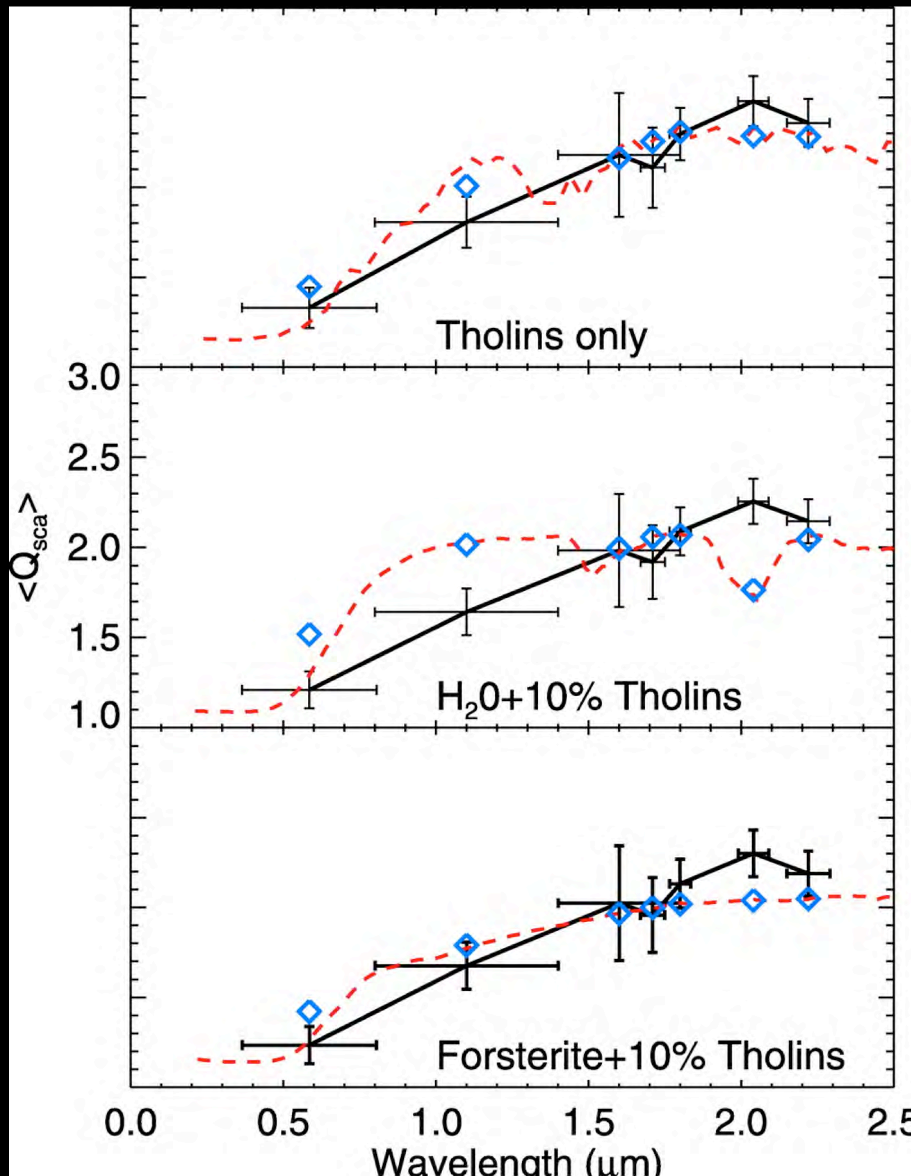
STIS Image
Schneider et al., in prep.



NICMOS Images
Debes, Weinberger, & Schneider (2008)



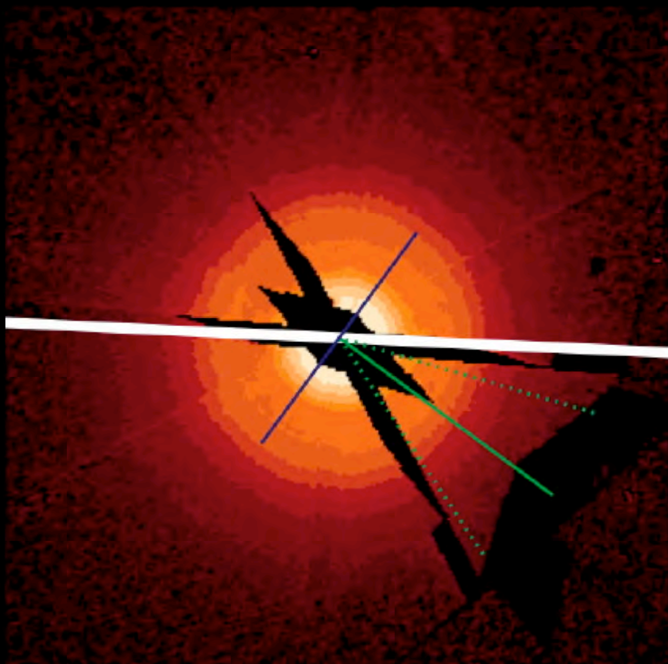
Organic Material in HR 4796A

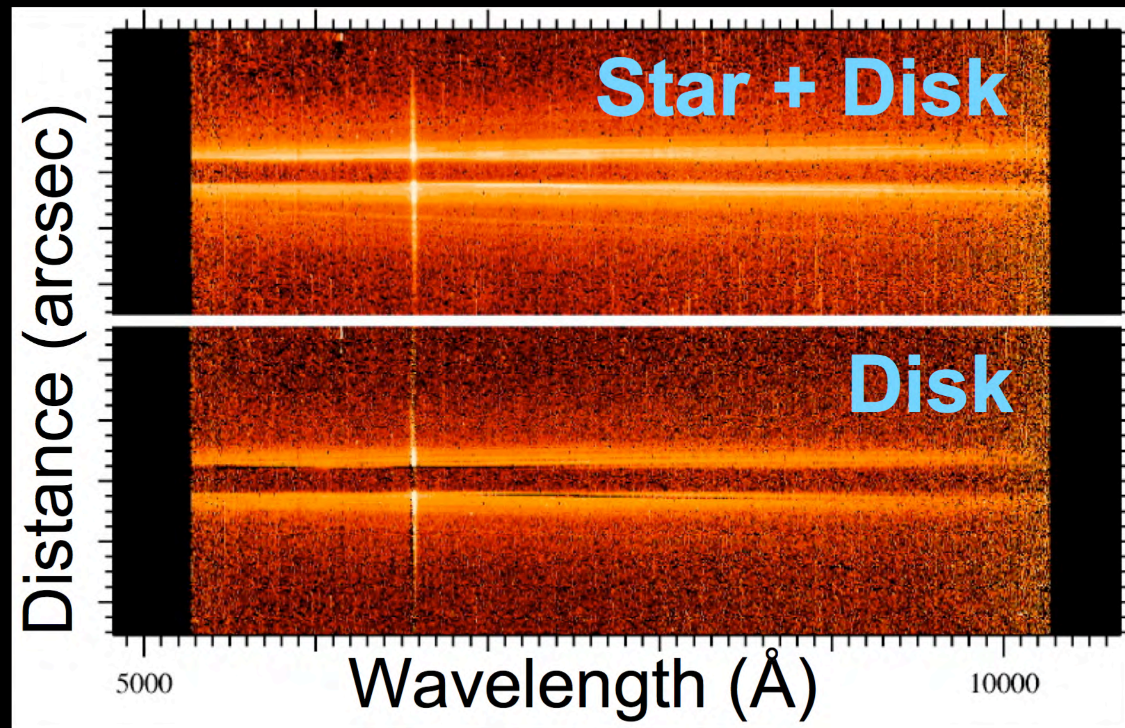


Debes, Weinberger, & Schneider (2008)

STIS Coronagrapic Spectroscopy

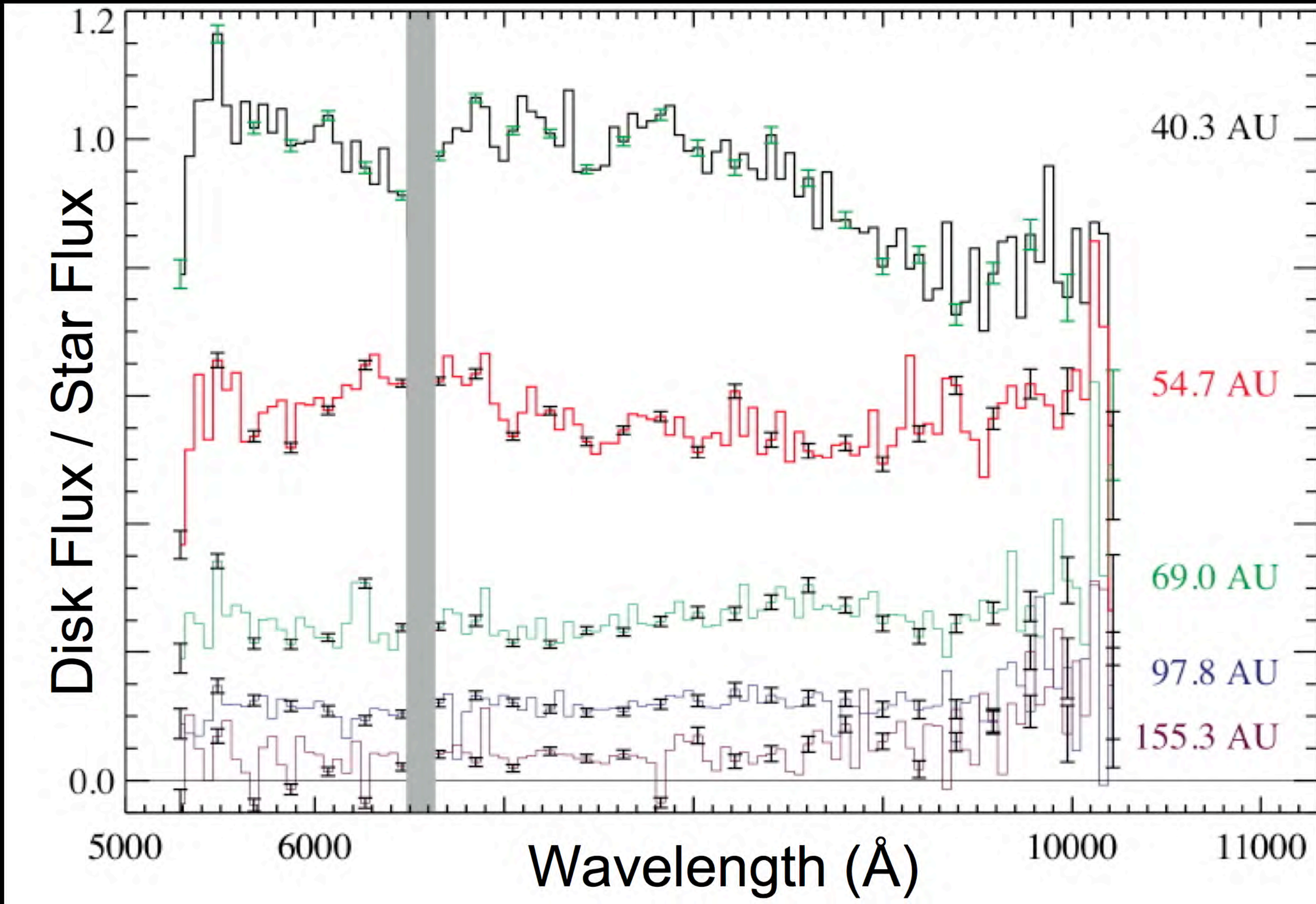
TW Hydrae





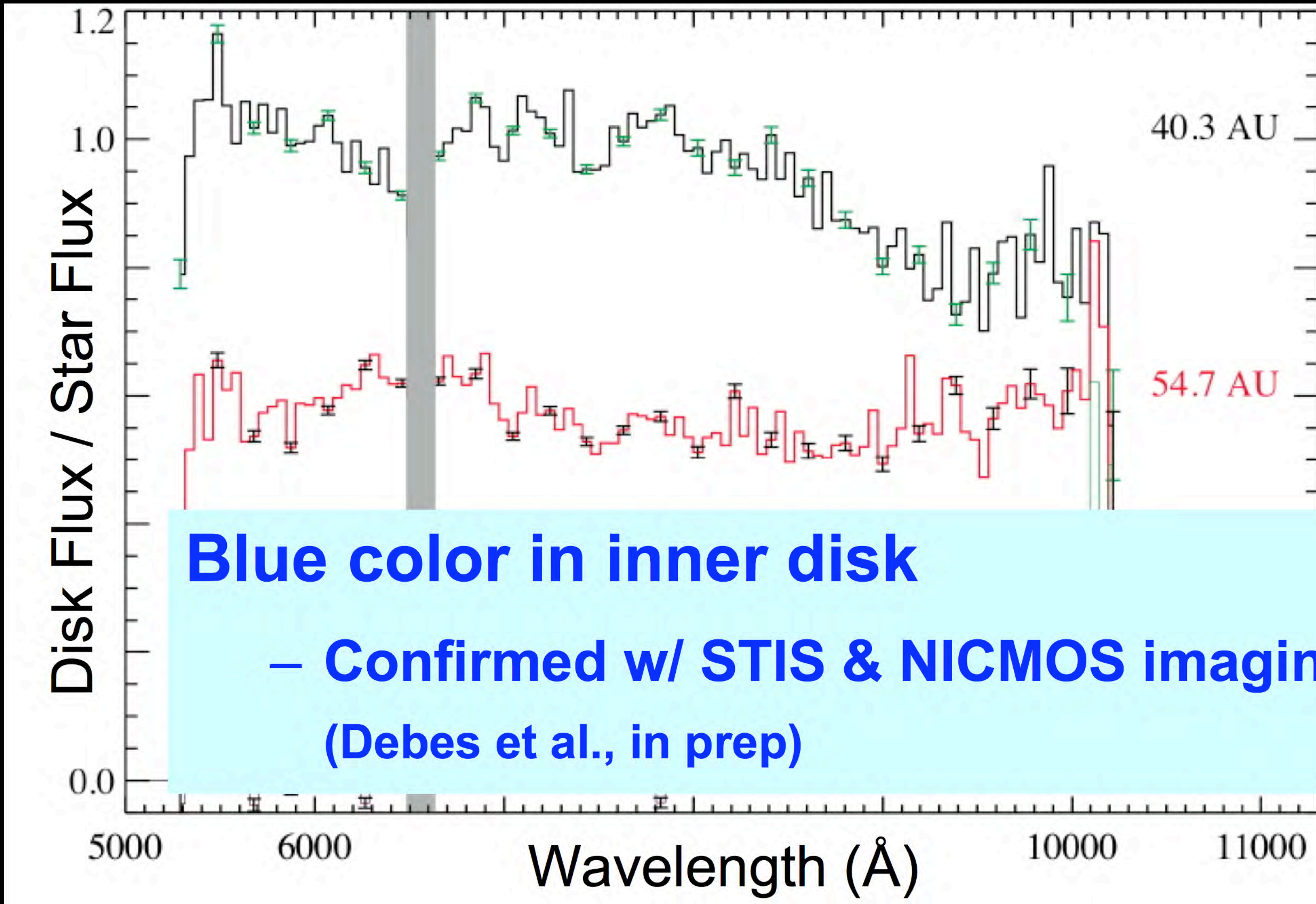
Roberge, Weinberger, & Malumuth (2005)

Spectra of TW Hya Dust Disk



Roberge, Weinberger, & Malumuth (2005)

Spectra of TW Hya Dust Disk



Blue color in inner disk

- **Confirmed w/ STIS & NICMOS imaging**
  (Debes et al., in prep)

Roberge, Weinberger, & Malumuth (2005)

Summary

1) High-contrast imaging

STIS, NICMOS, & ACS

2) UV spectra of debris gas

GHRS & STIS

3) Disk colors from coronagraphy

STIS & NICMOS

4) Coronagraphic spectroscopy

STIS

Summary