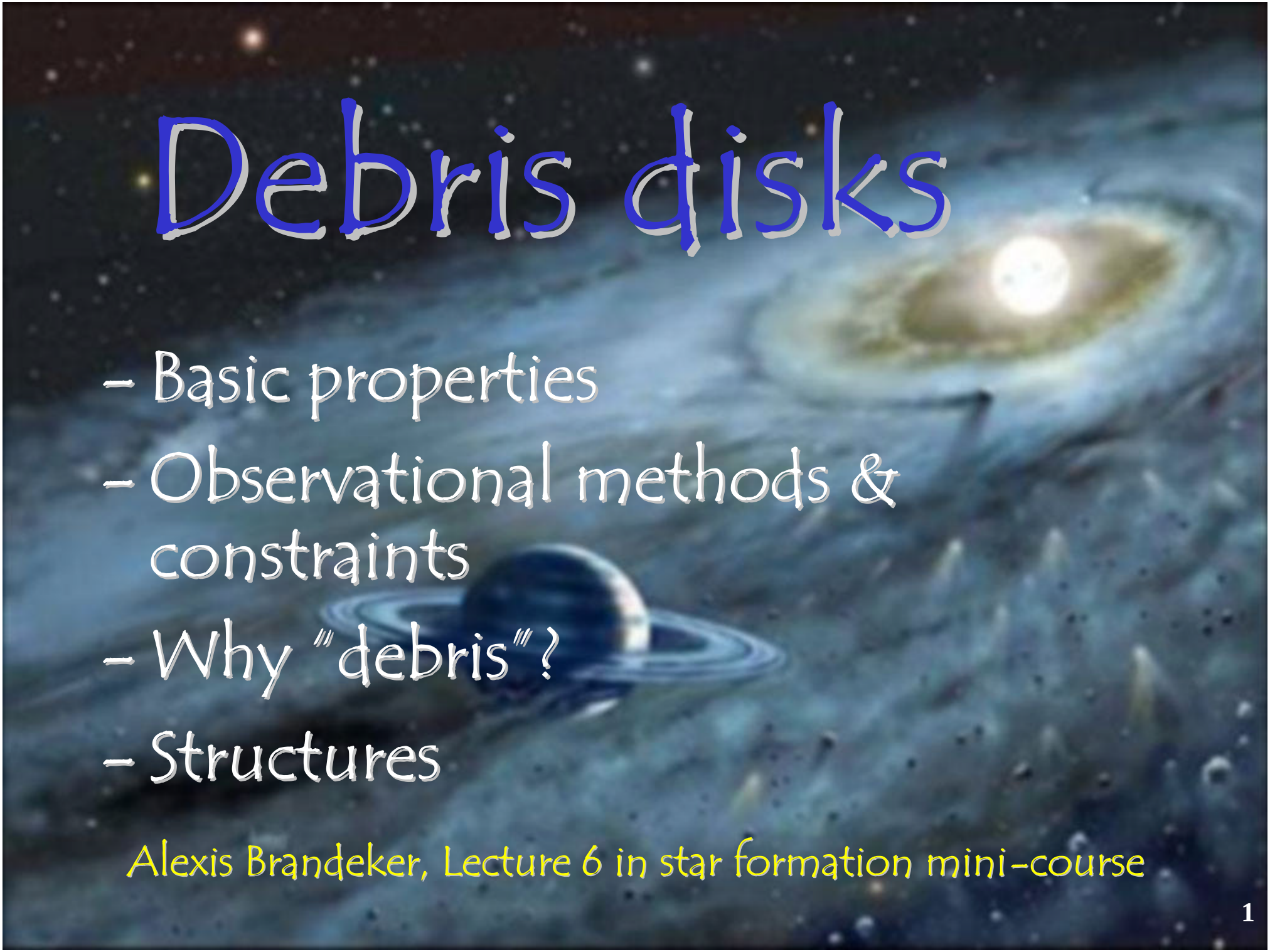
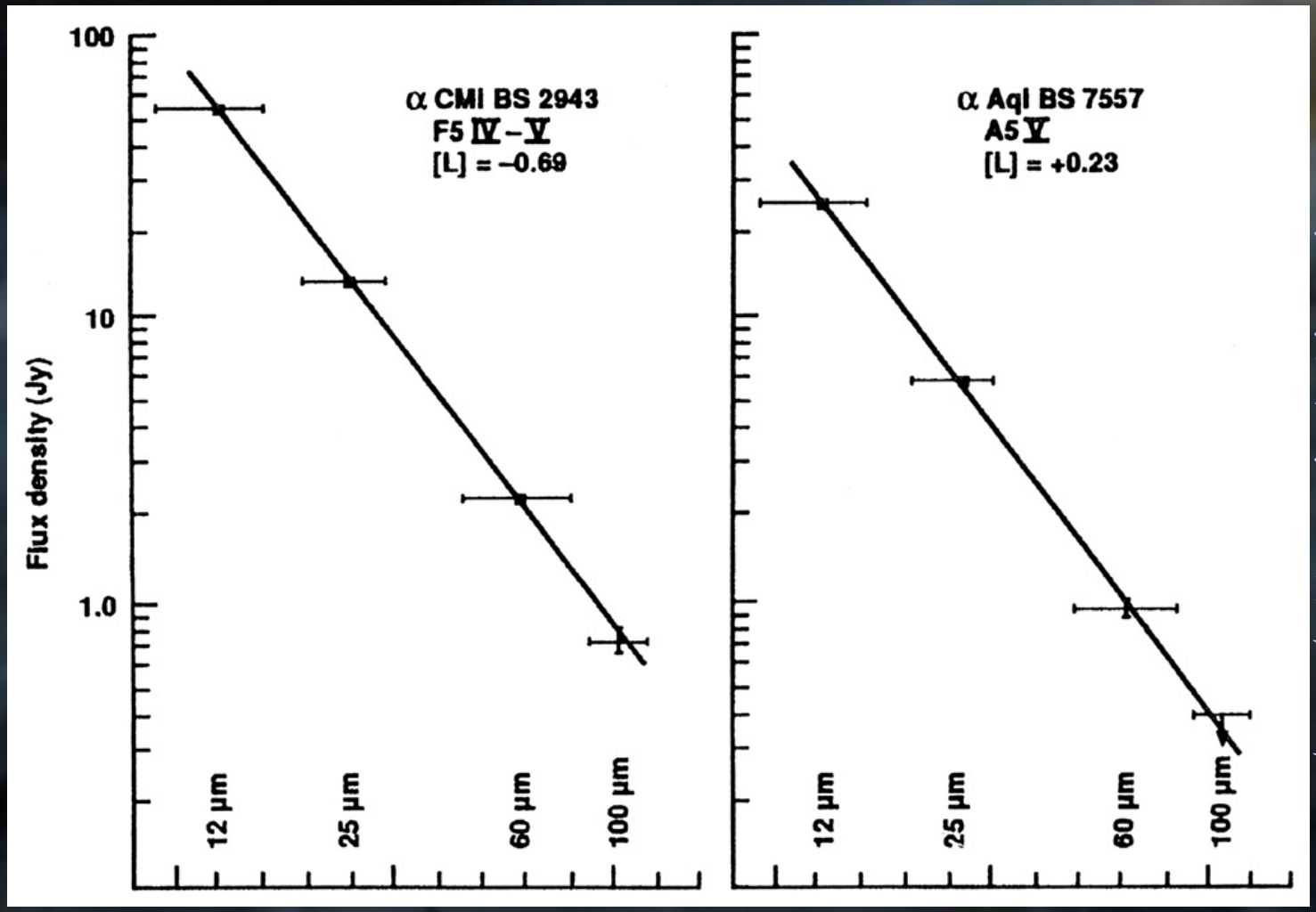


# Debris disks

- Basic properties
- Observational methods & constraints
- Why "debris"?
- Structures

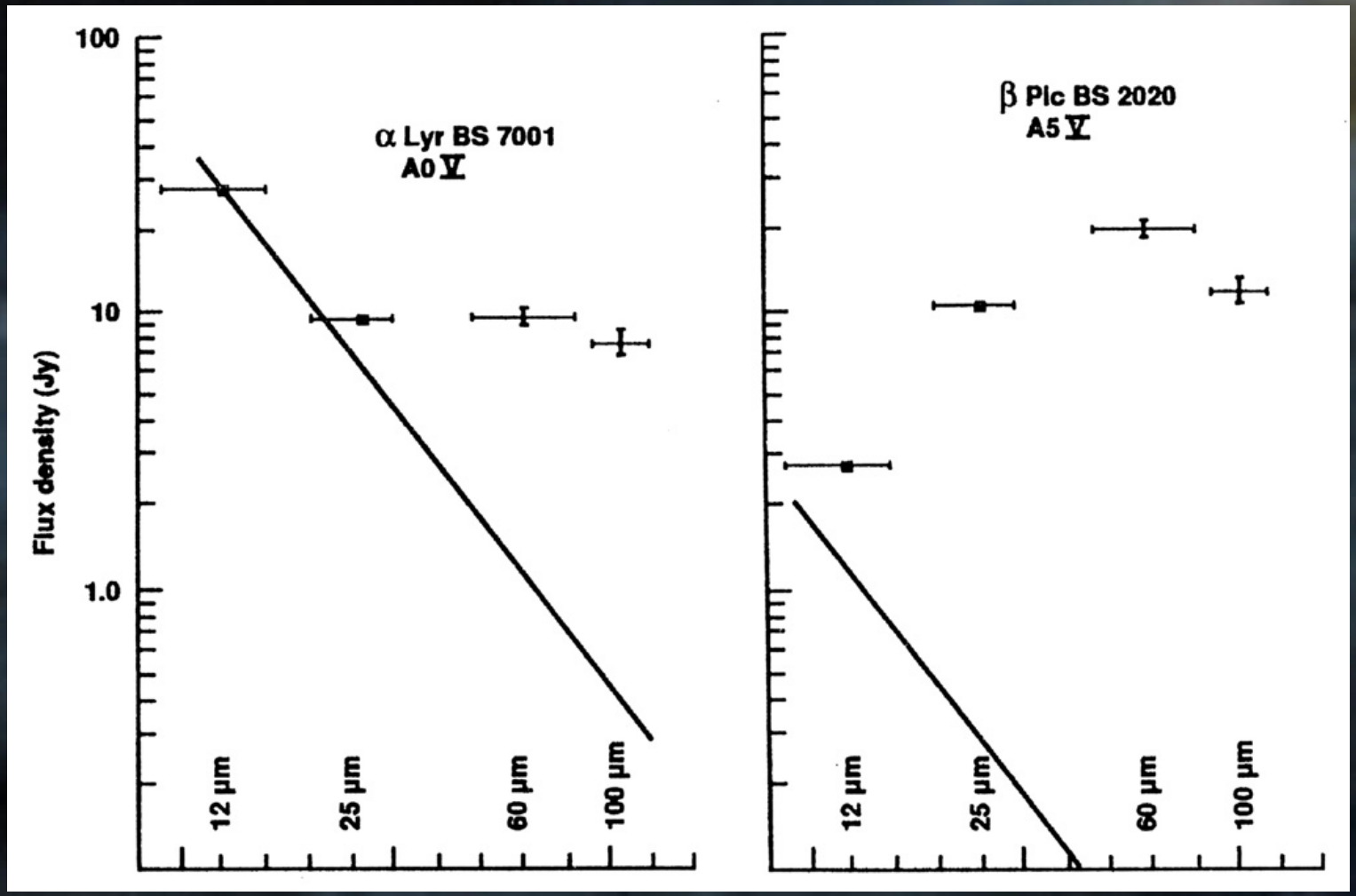
Alexis Brandeker, Lecture 6 in star formation mini-course

# Discovery of debris disks



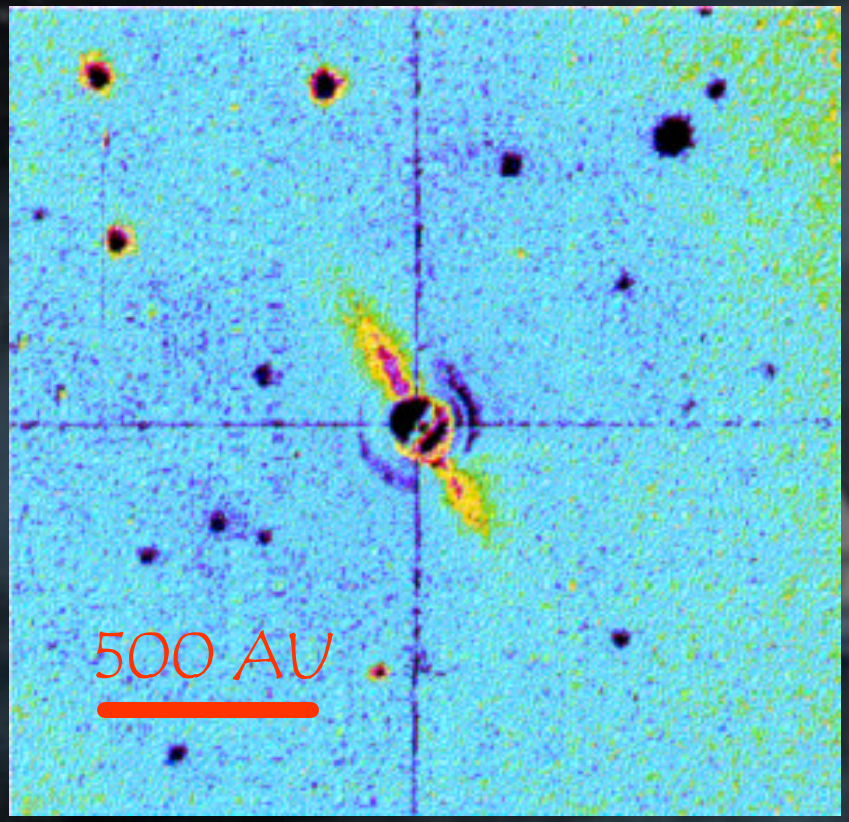

From Backman & Parece 1993, PPIII, 1253

# Discovery of debris disks




From Backman & Parece 1993, PPIII, 1253

# First disk spatially resolved: β Pictoris

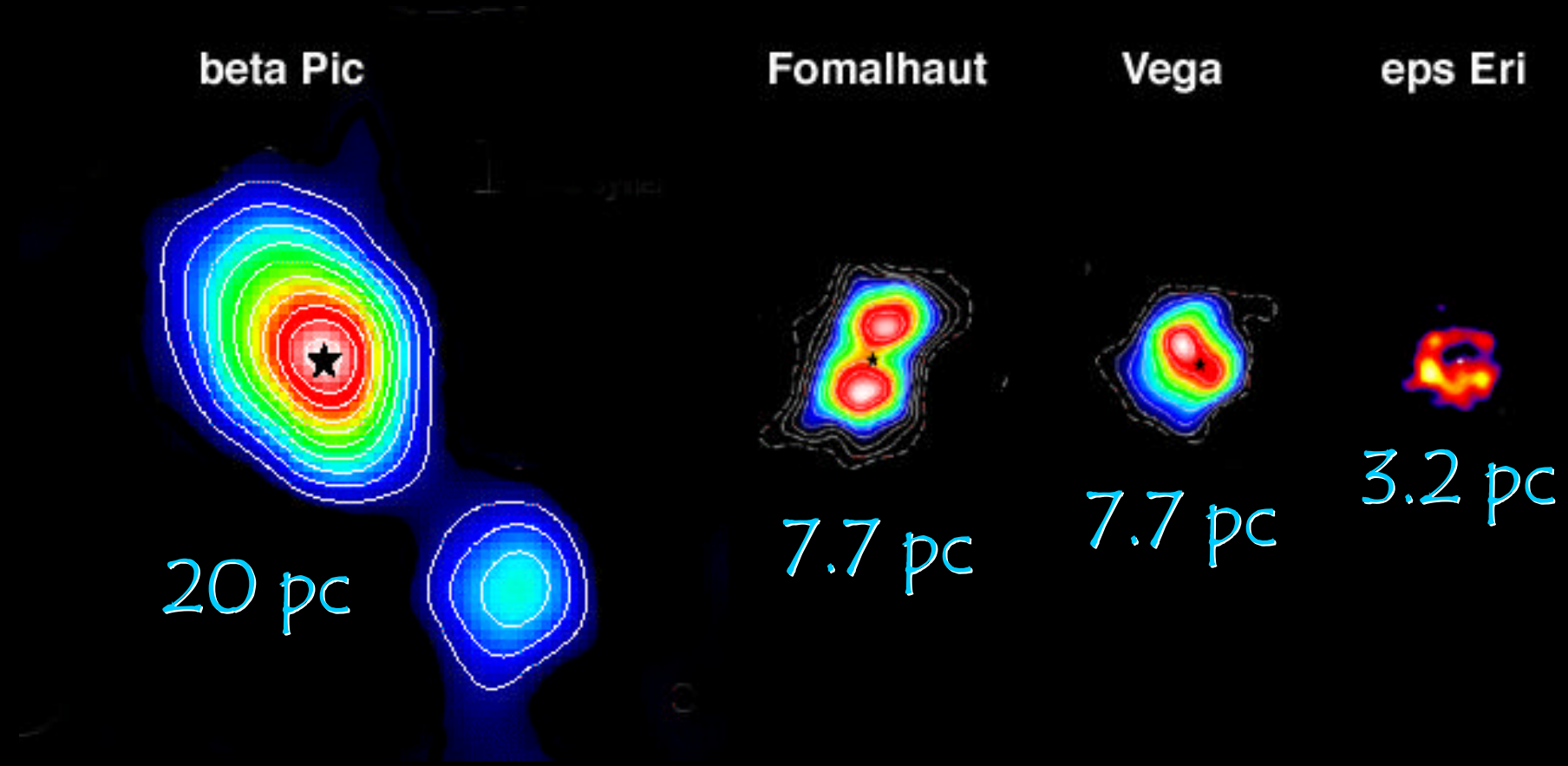


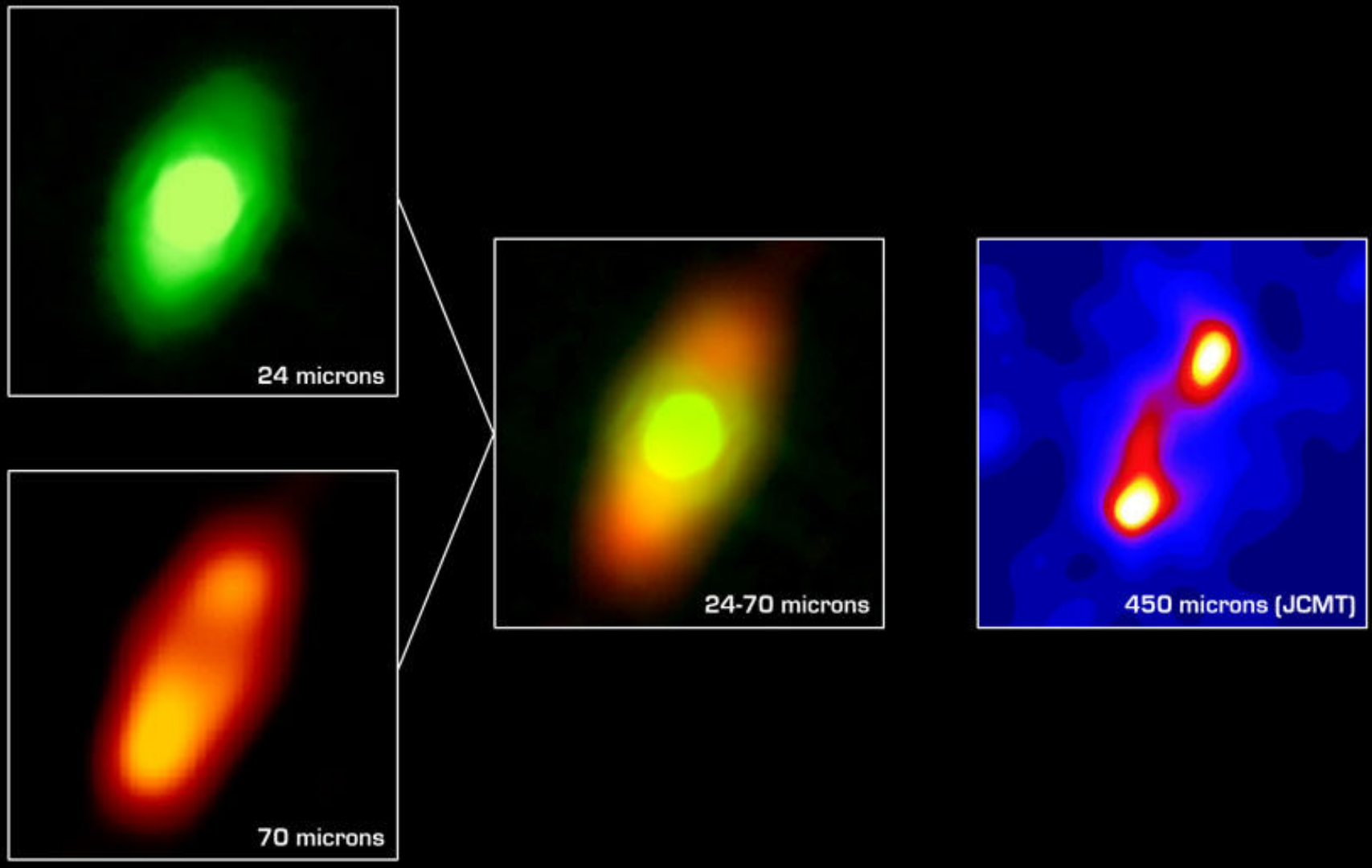

Discovery image by Smith & Terrile 1984 (Sci. 226, 1421)

# Properties

- Large (up to 1000 AU) dusty disks found around young main-sequence stars ~ 10 Myr – 1 Gyr
- Dust disk mass M ~ $10^{-3}$ to a few $M_{Earth}$.
- Essentially free of gas
- Cold; typically 30 – 300 K
- Dominating dust emission from μm to mm sized grains

# "The fabulous four" at 850m





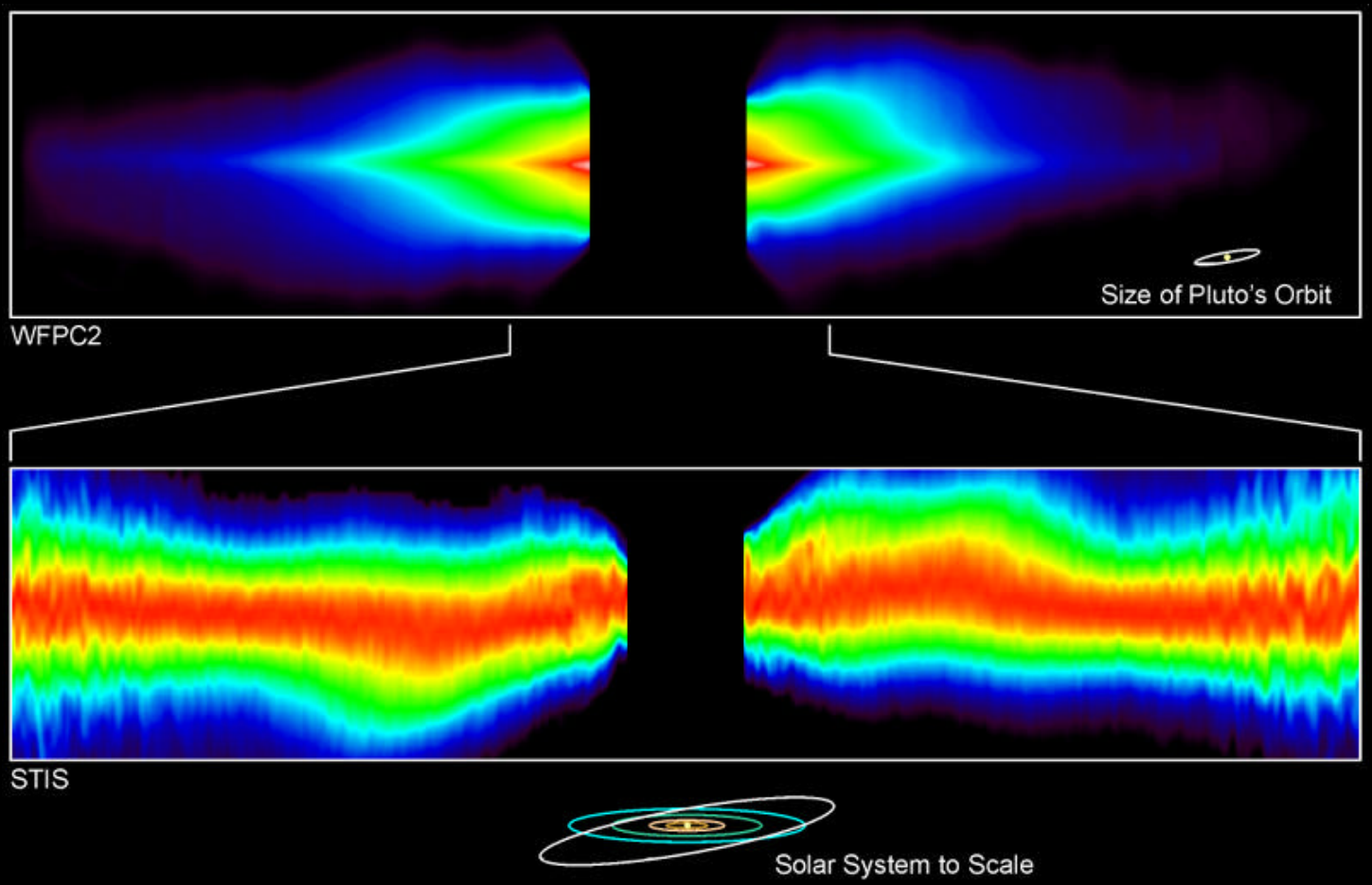

## Fomalhaut Circumstellar Disk

## Spitzer Space Telescope • MIPS

NASA / JPL-Caltech / K. Stapelfeldt (JPL)

ssc2003-06i

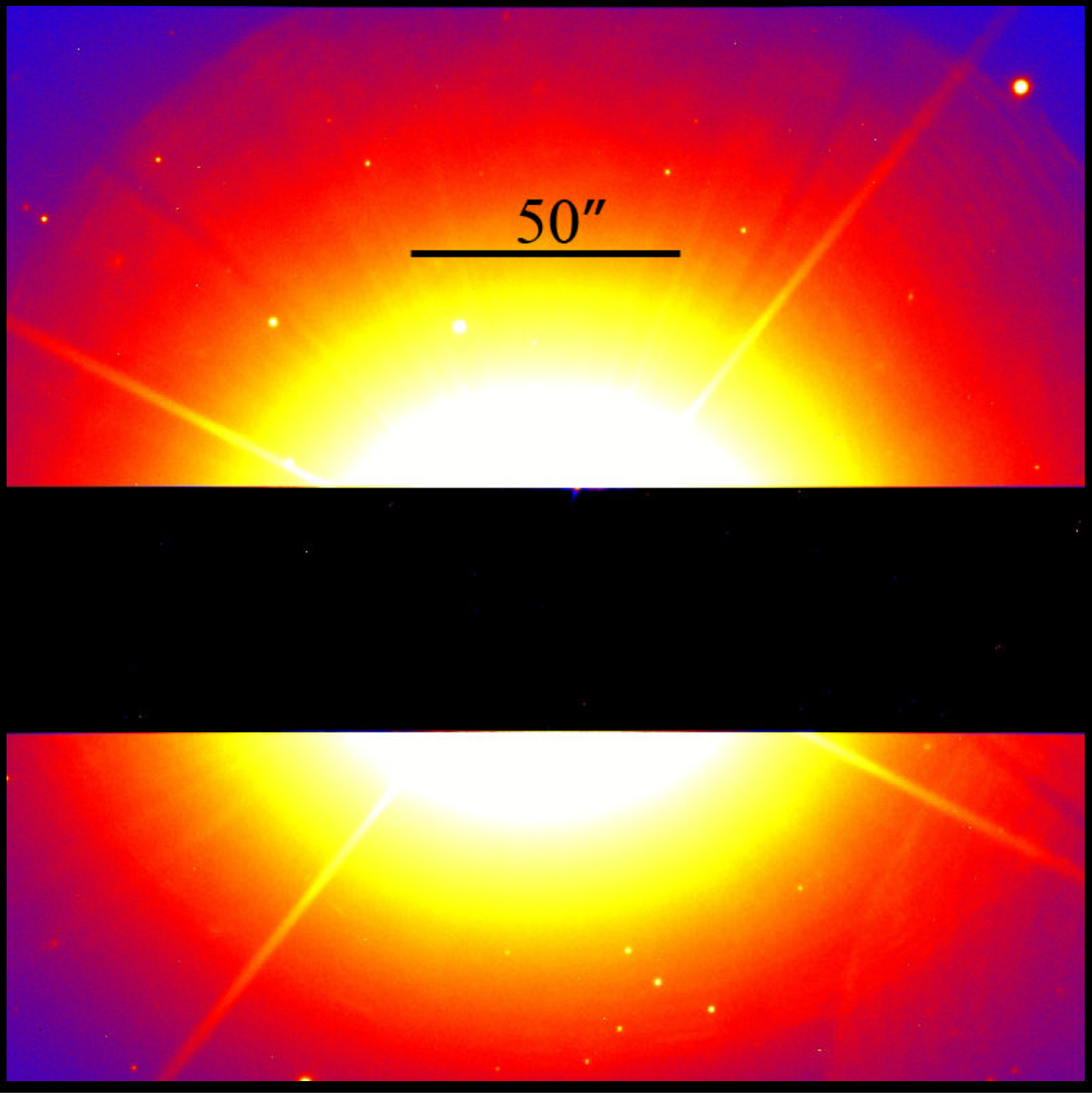
# β Pictoris in scattered light

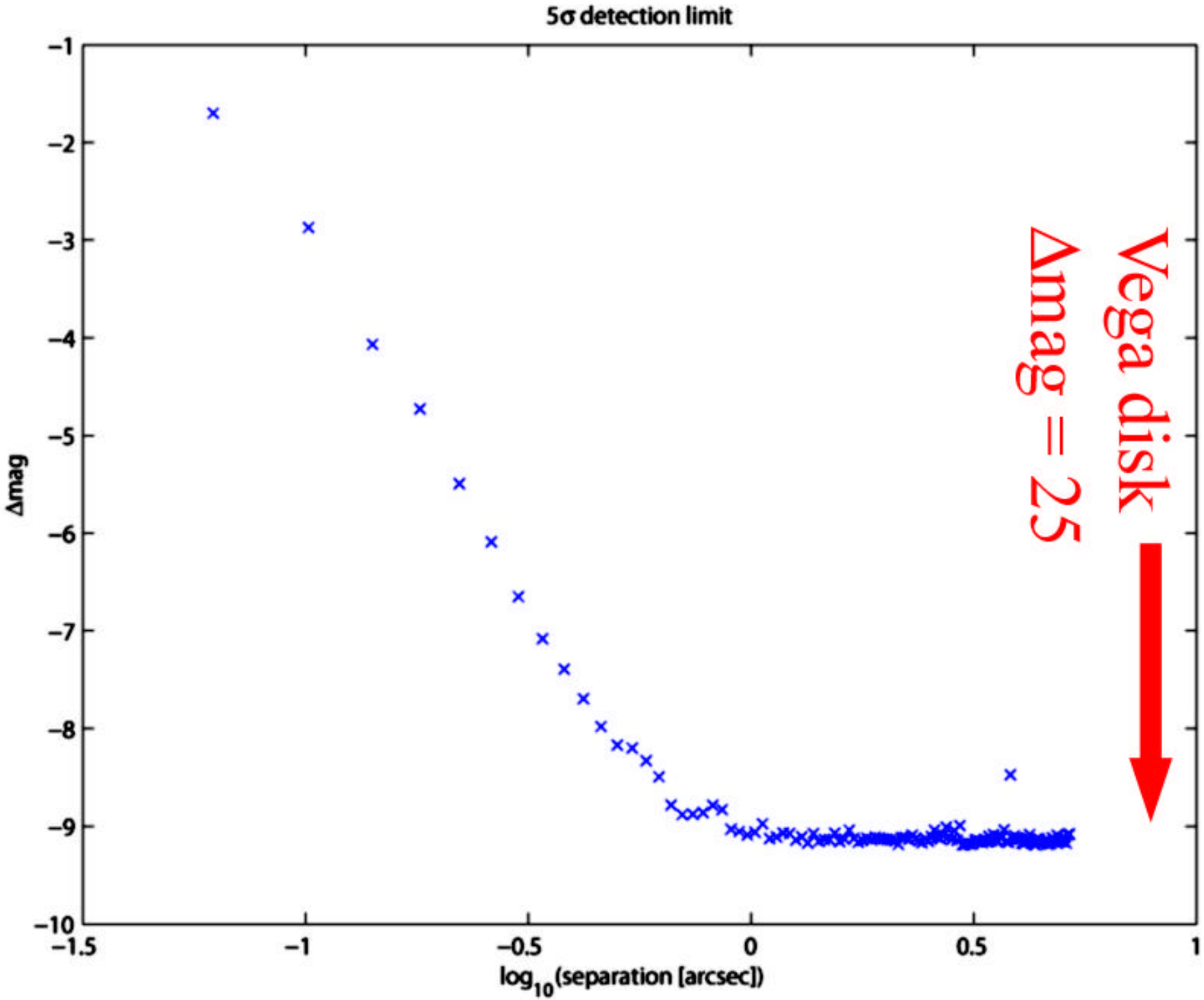


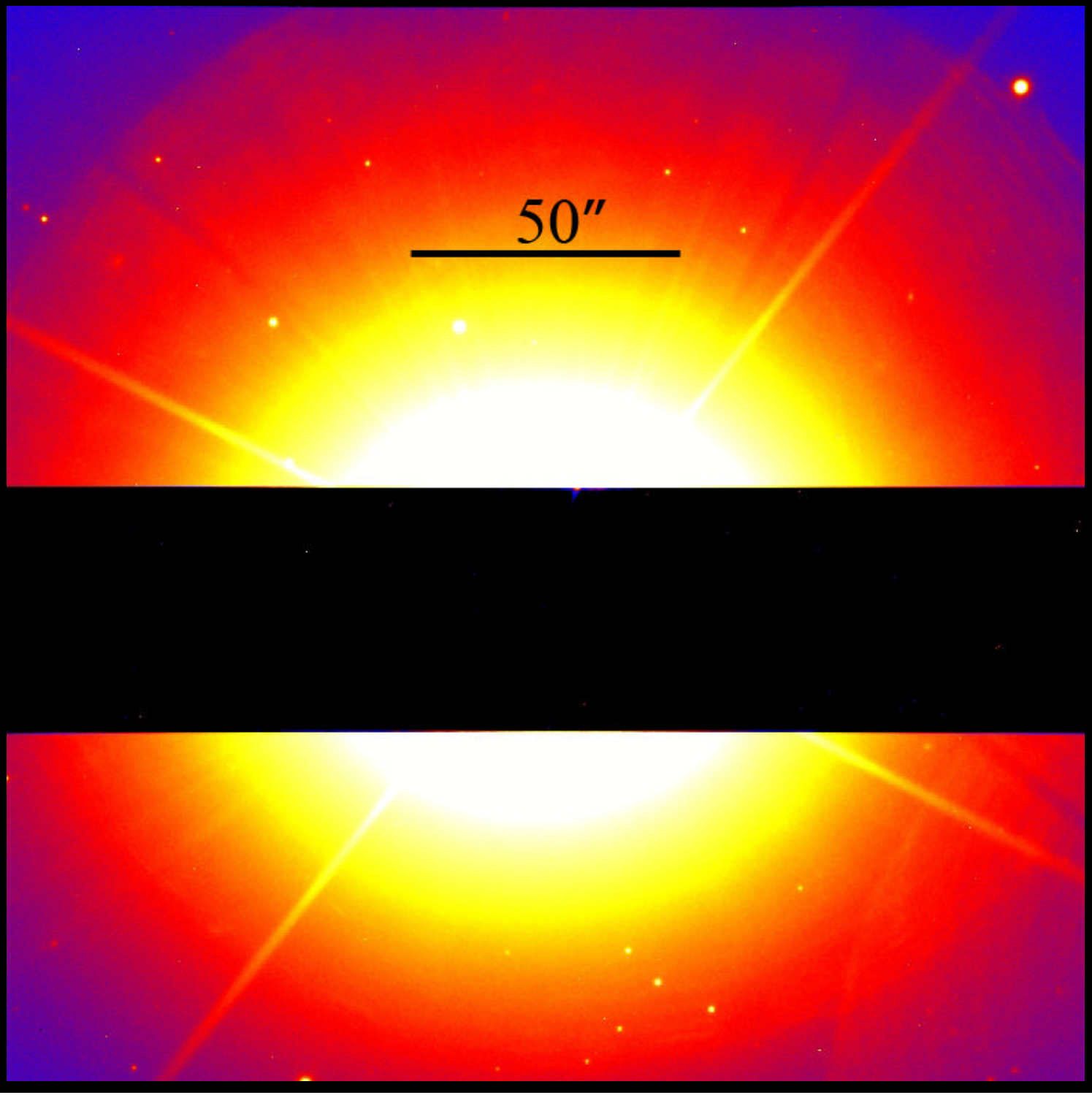

**Beta Pictoris** HST • WFPC2 • STIS

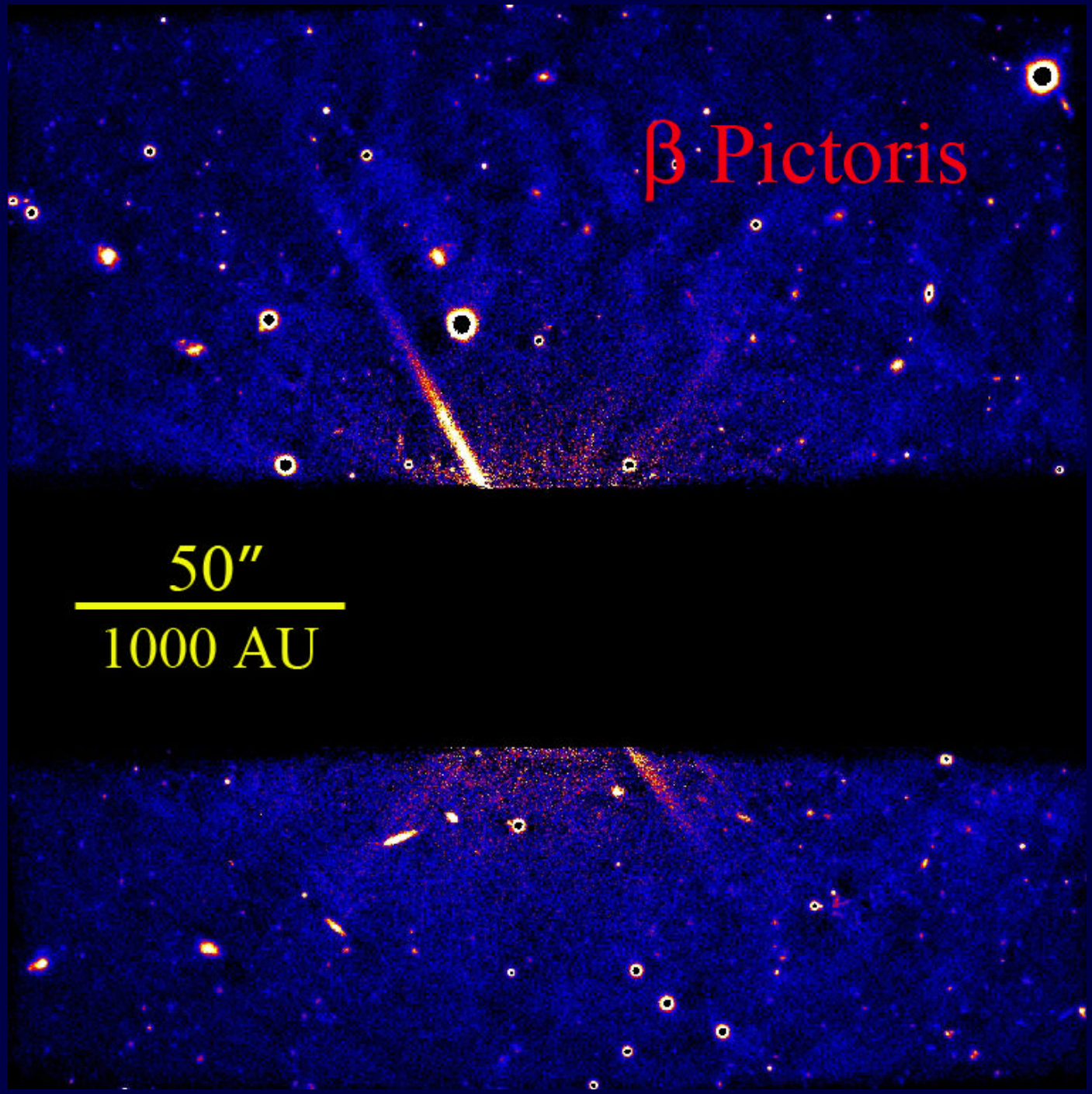
PRC98-03 • January 8, 1998 • ST ScI OPO

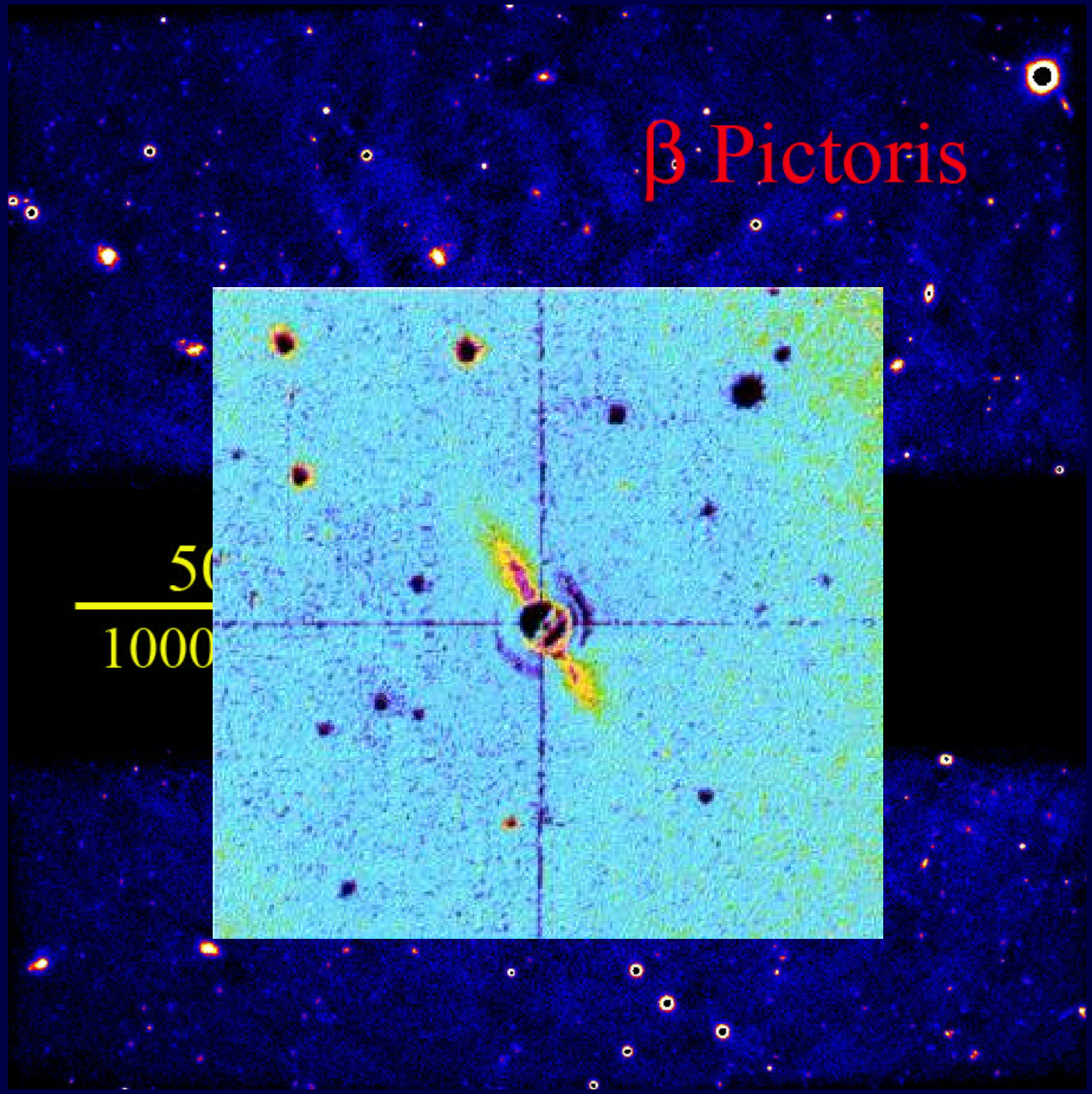
A. Schultz (Computer Sciences Corp.), S. Heap (NASA Goddard Space Flight Center) and NASA

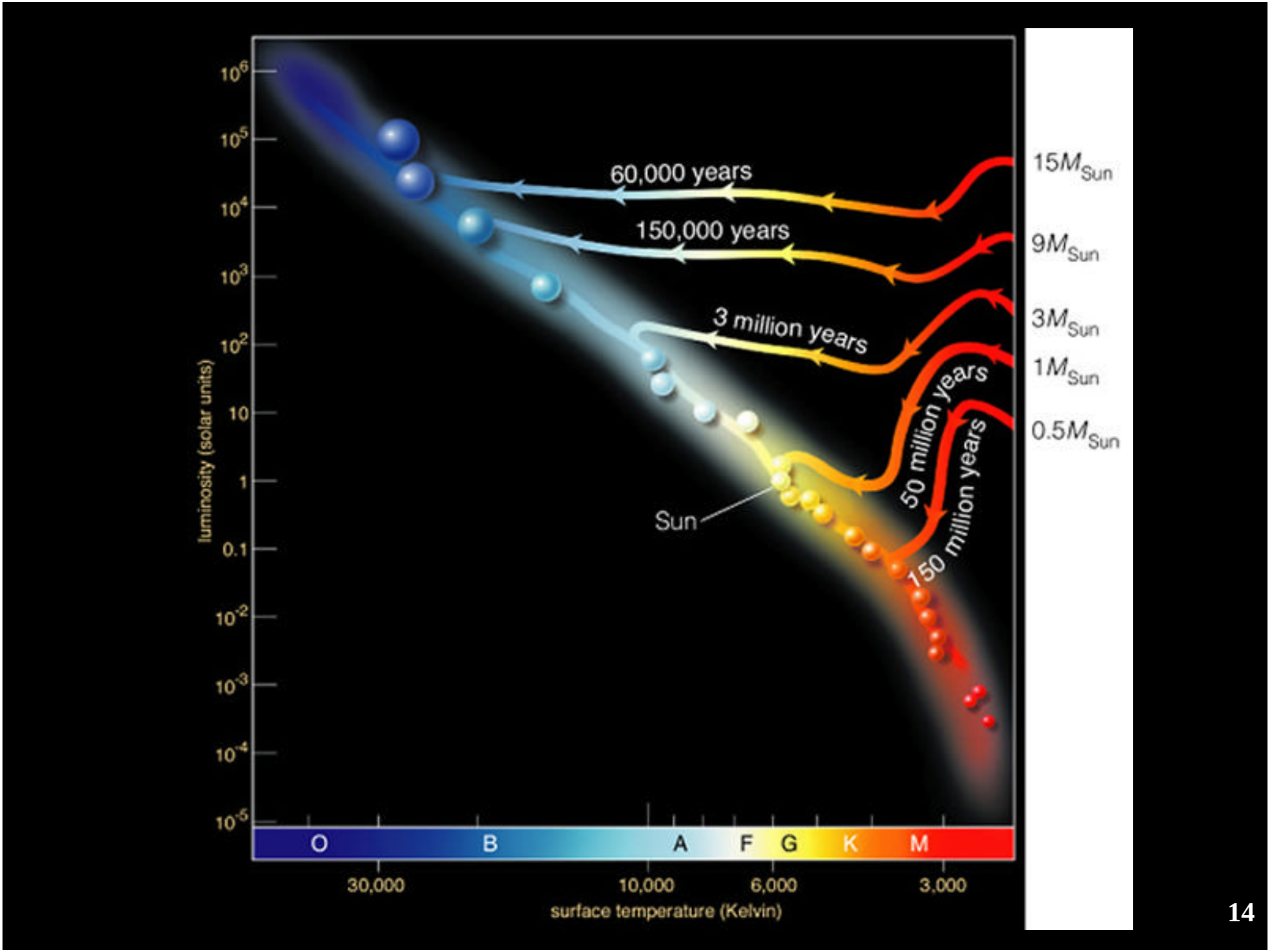

50″

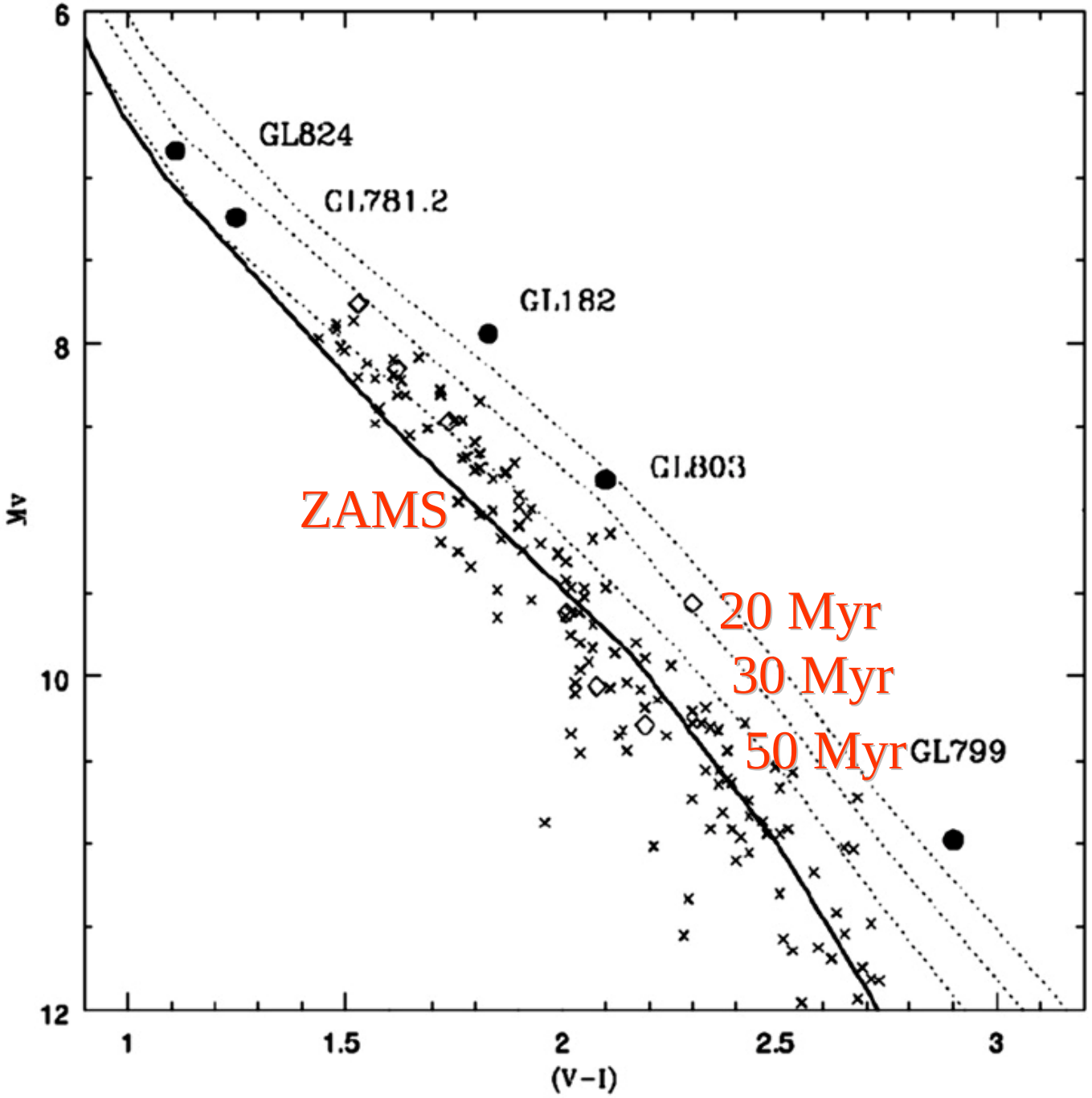

5σ detection limit
Δmag
log10(separation [arcsec])
−1
−2
−3
−4
−5
−6
−7
−8
−9
−10
−1.5
−1
−0.5
0
0.5
1
Vega disk
Δmag = 25


50″

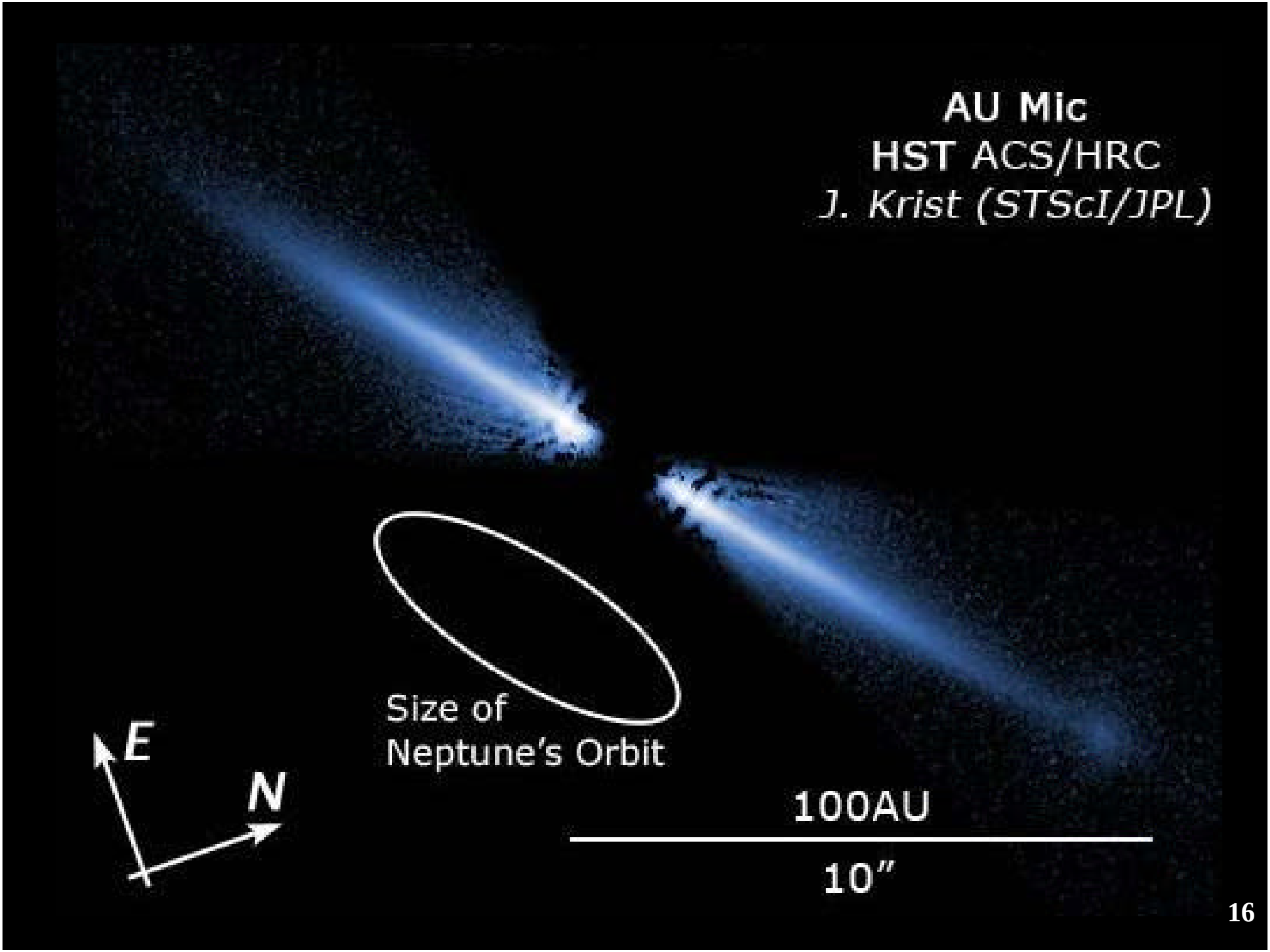

β Pictoris
50″
1000 AU


β Pictoris
5(
1000

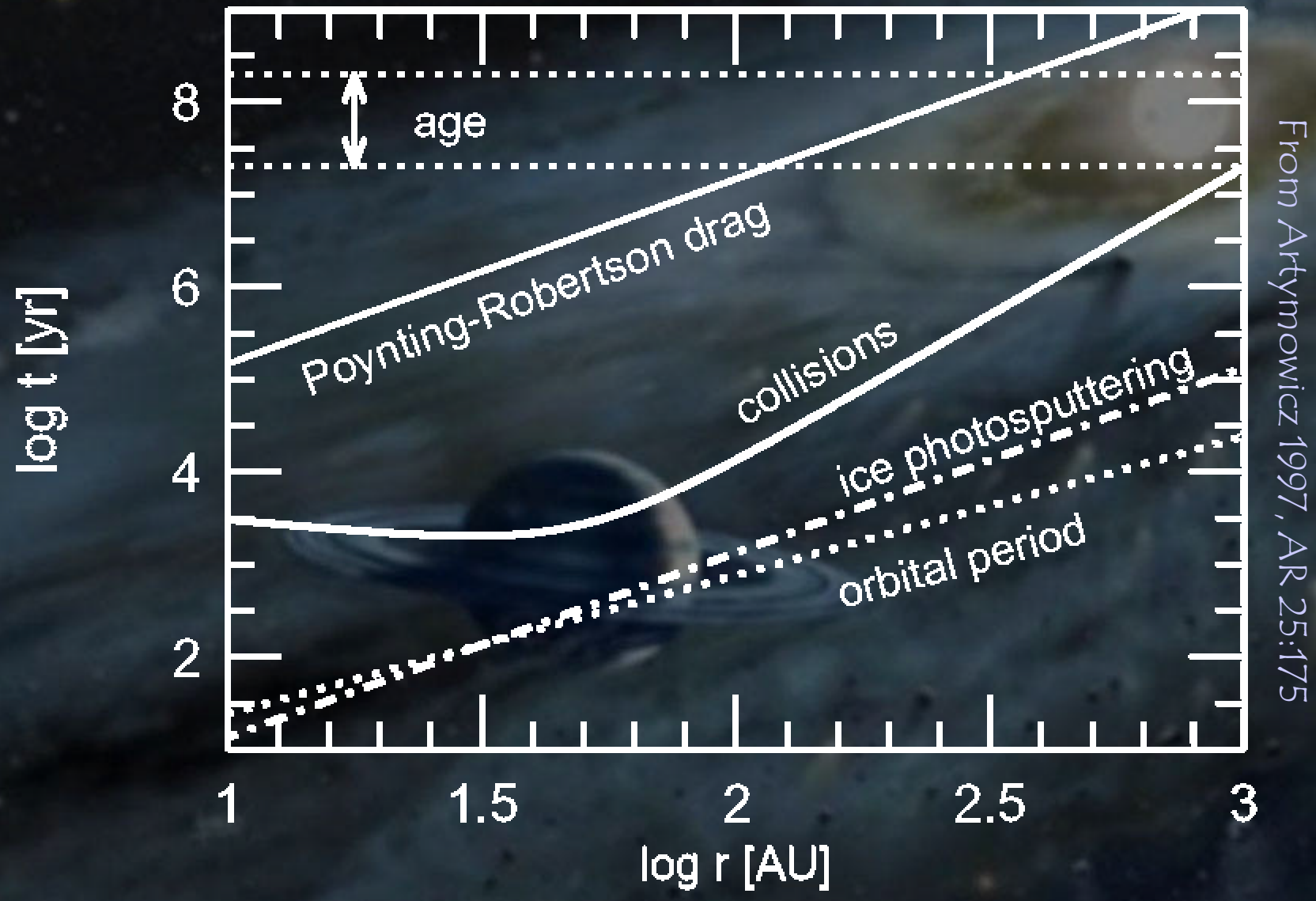

luminosity (solar units)
$10^6$
$10^5$
$10^4$
$10^3$
$10^2$
10
1
0.1
$10^{-2}$
$10^{-3}$
$10^{-4}$
$10^{-5}$
60,000 years
150,000 years
3 million years
50 million years
150 million years
Sun
$15M_{Sun}$
$9M_{Sun}$
$3M_{Sun}$
$1M_{Sun}$
$0.5M_{Sun}$
O
B
A
F
G
K
M
30,000
10,000
6,000
3,000
surface temperature (Kelvin)



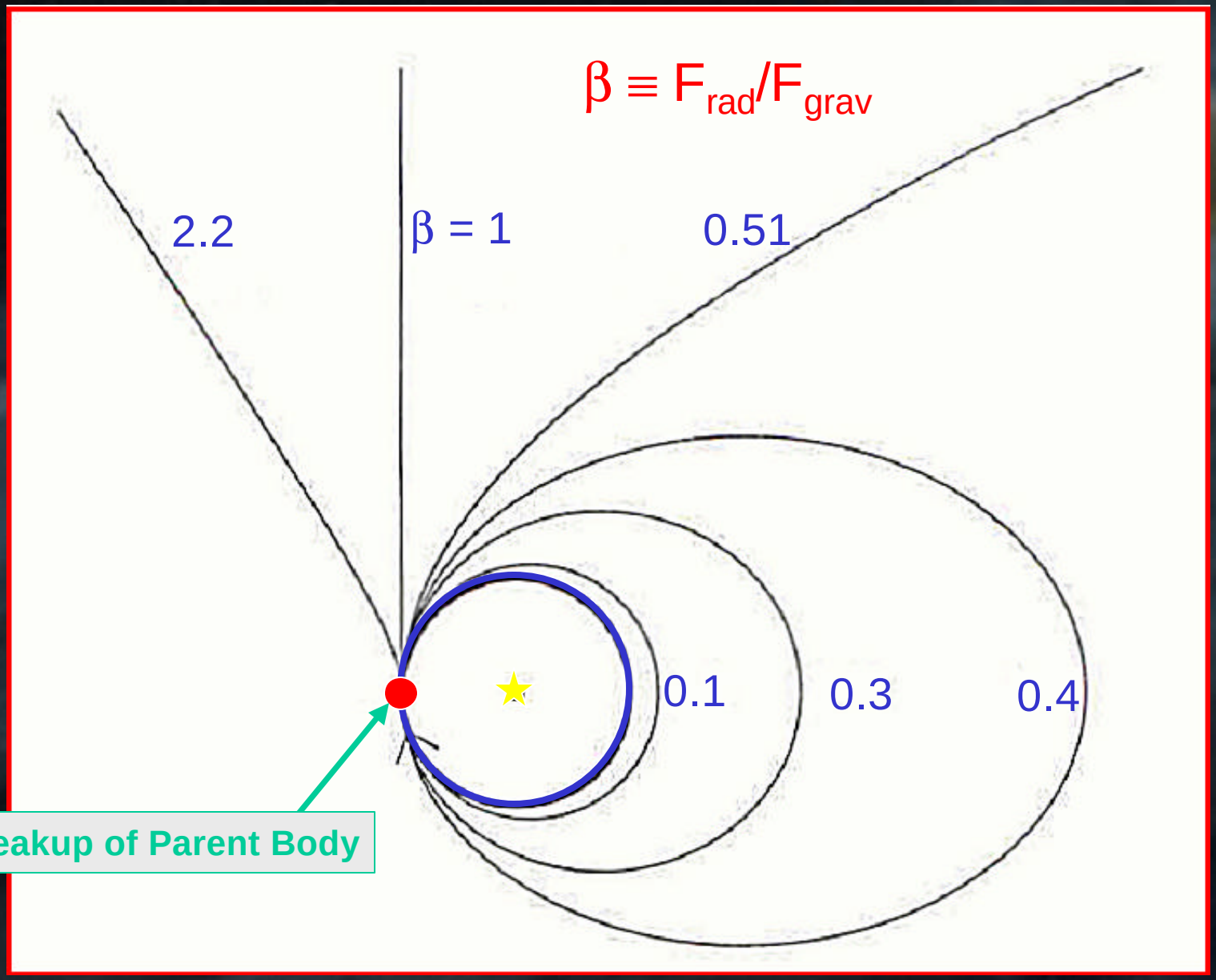

Barrado y Navascués 1999

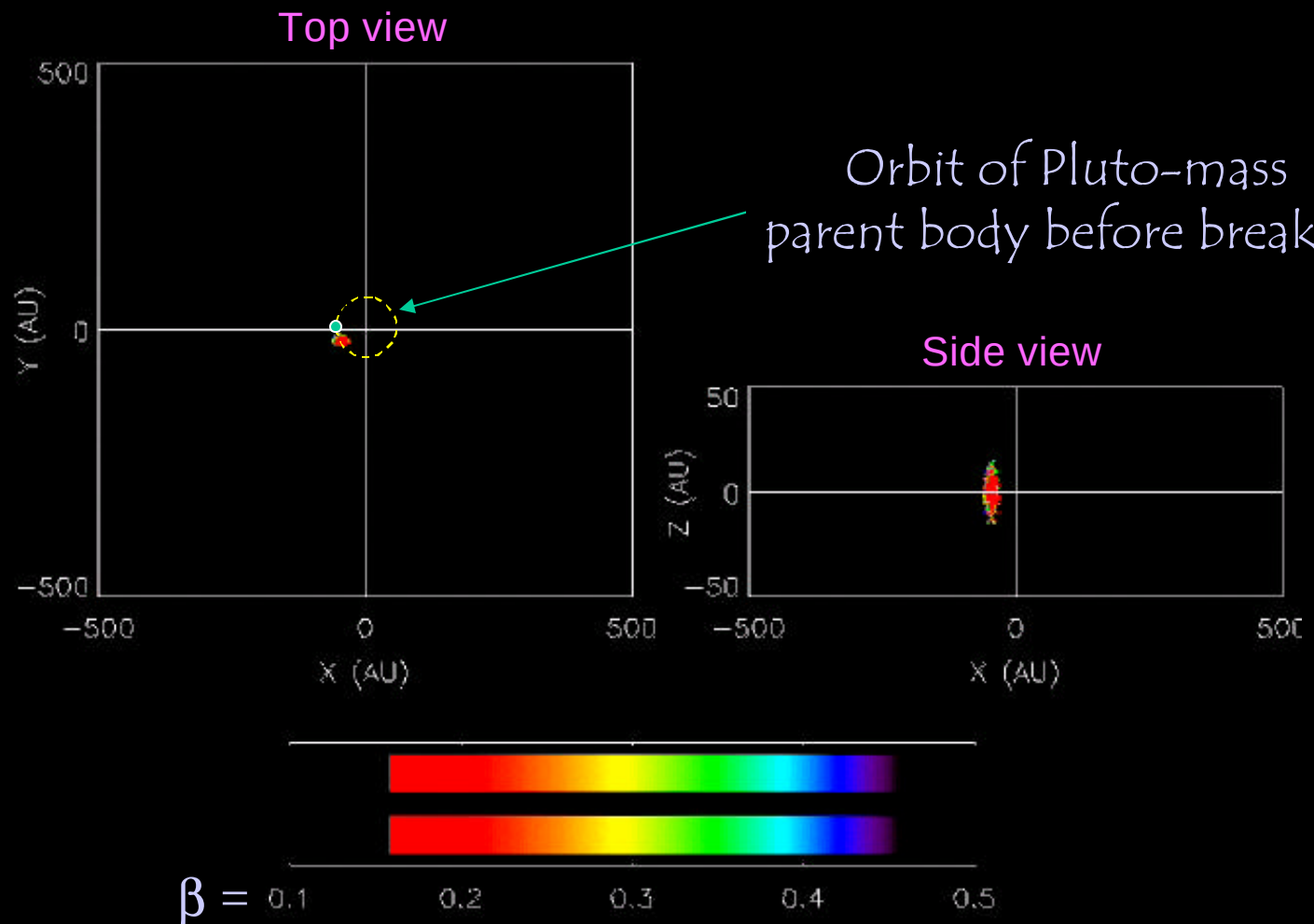

AU Mic
HST ACS/HRC
J. Krist (STScI/JPL)
Size of
Neptune's Orbit
E
N
100AU
10″

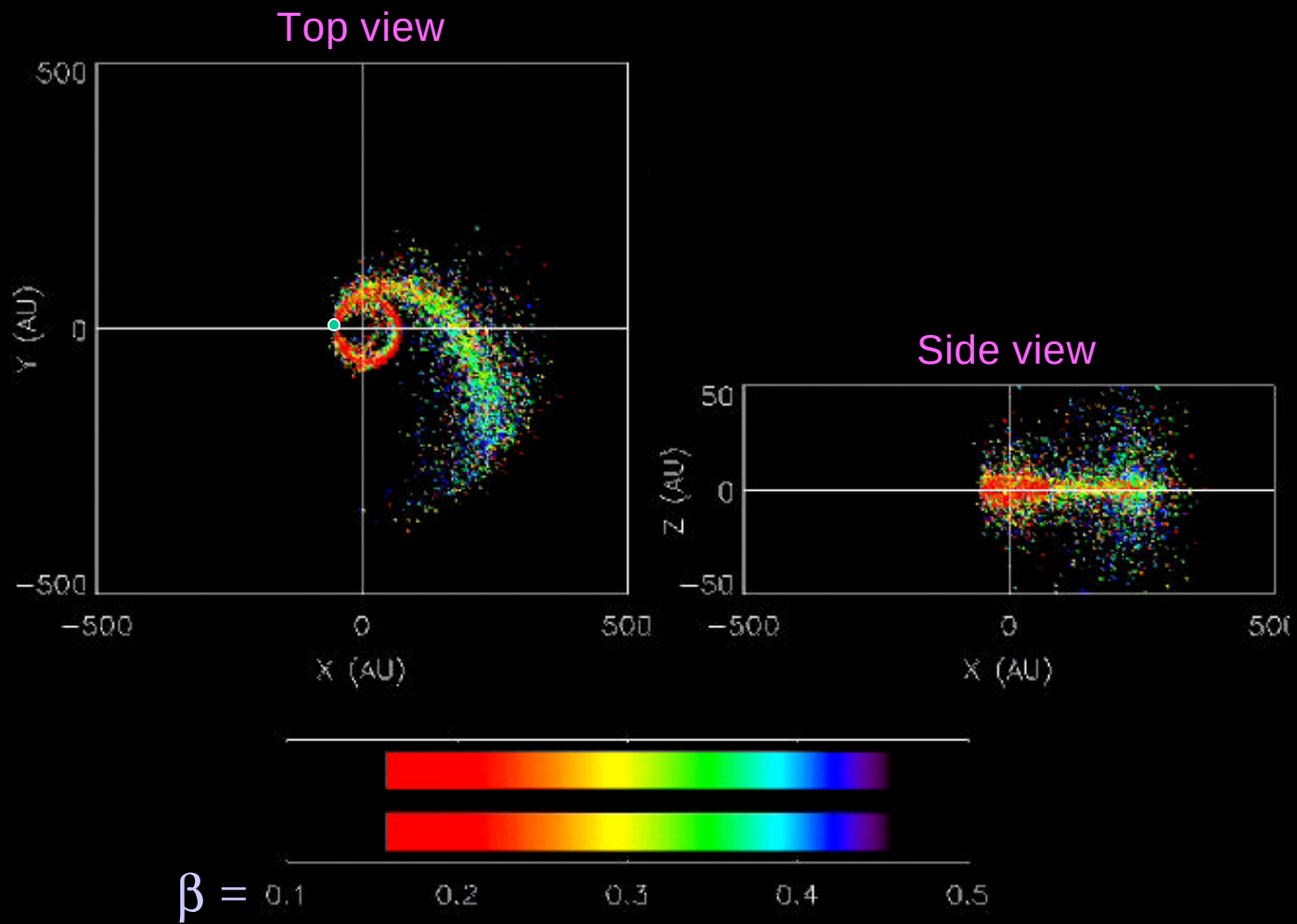
# Why "debris"?




From Artymowicz 1997, AR 25:175


β ≡ F_rad/F_grav
2.2
β = 1
0.51
0.1
0.3
0.4
Breakup of Parent Body


Top view
500
0
−500
Y (AU)
−500
0
500
X (AU)
Orbit of Pluto-mass
parent body before breakup
Side view
50
0
−50
Z (AU)
−500
0
500
X (AU)
β = 0.1 0.2 0.3 0.4 0.5
Elapsed time: 21 years


Top view
500
0
−500
Y (AU)
−500
0
500
X (AU)
Side view
50
0
−50
Z (AU)
−500
0
X (AU)
β =
0.1
0.2
0.3
0.4
0.5
Elapsed time: 569 years

# Subaru/COMICS

(Y.Okamoto et al. 2004)

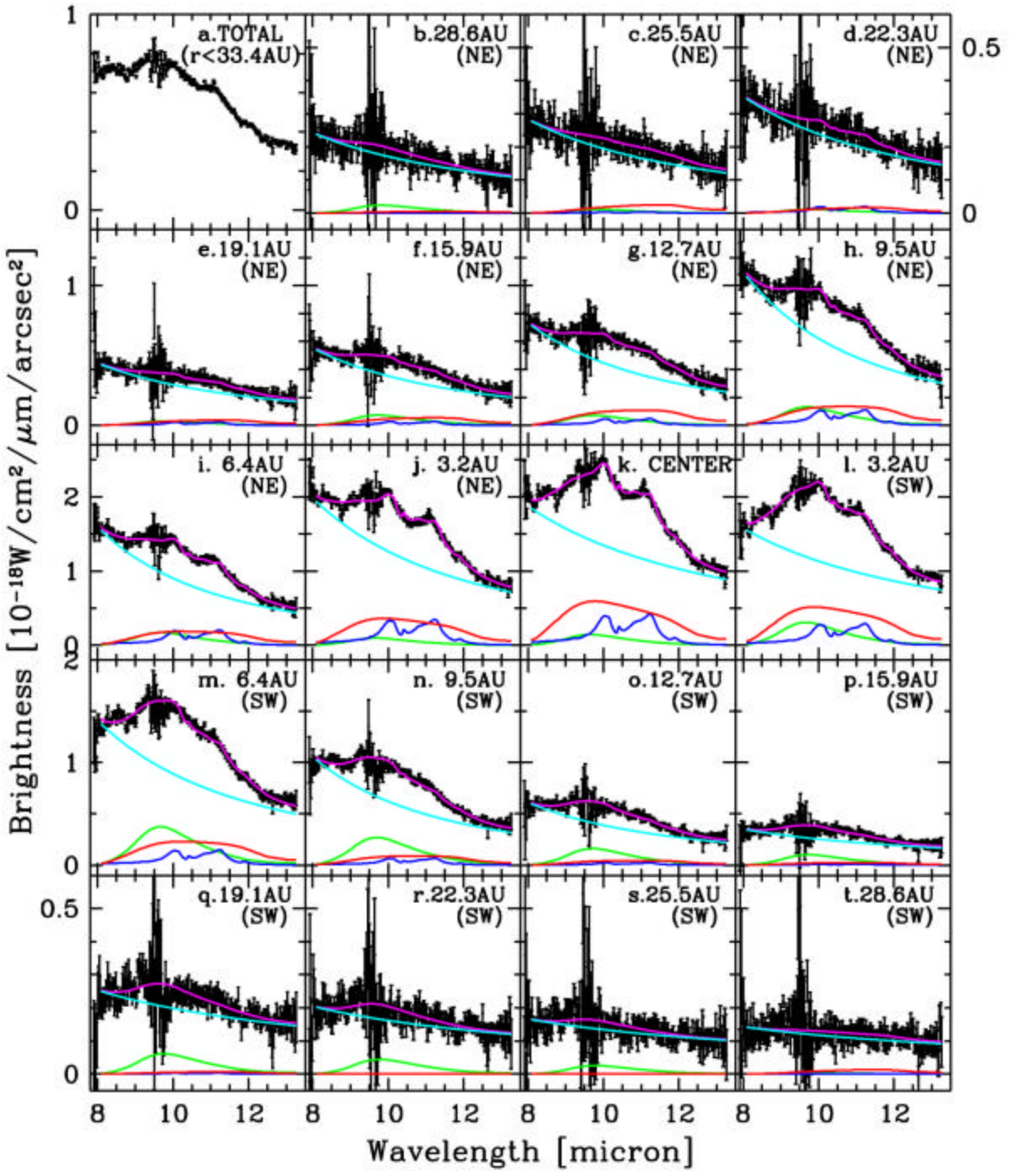
Total (magenta)

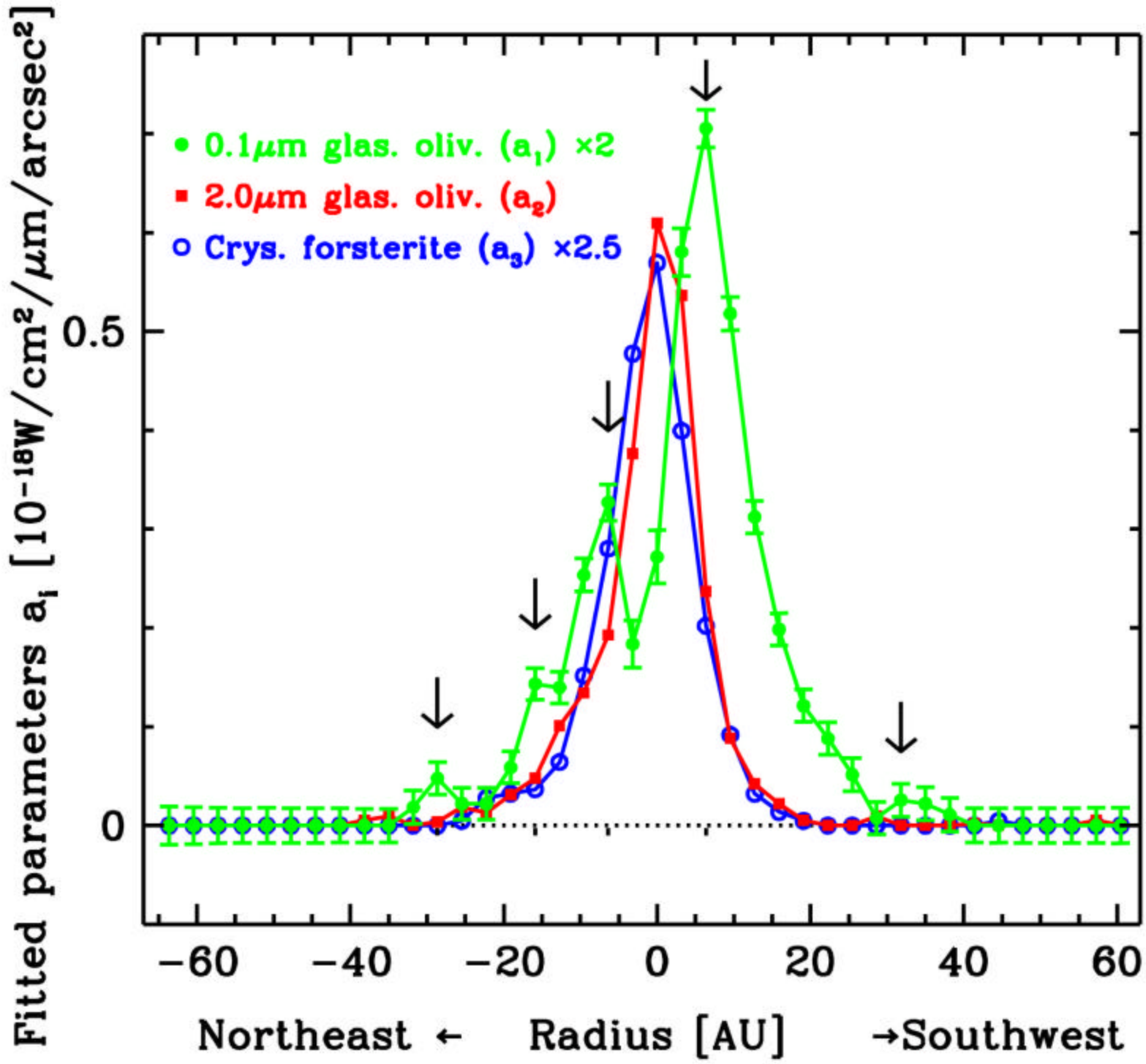
0.1mm amorphous olivine (green)

2mm amorphous olivine (red)

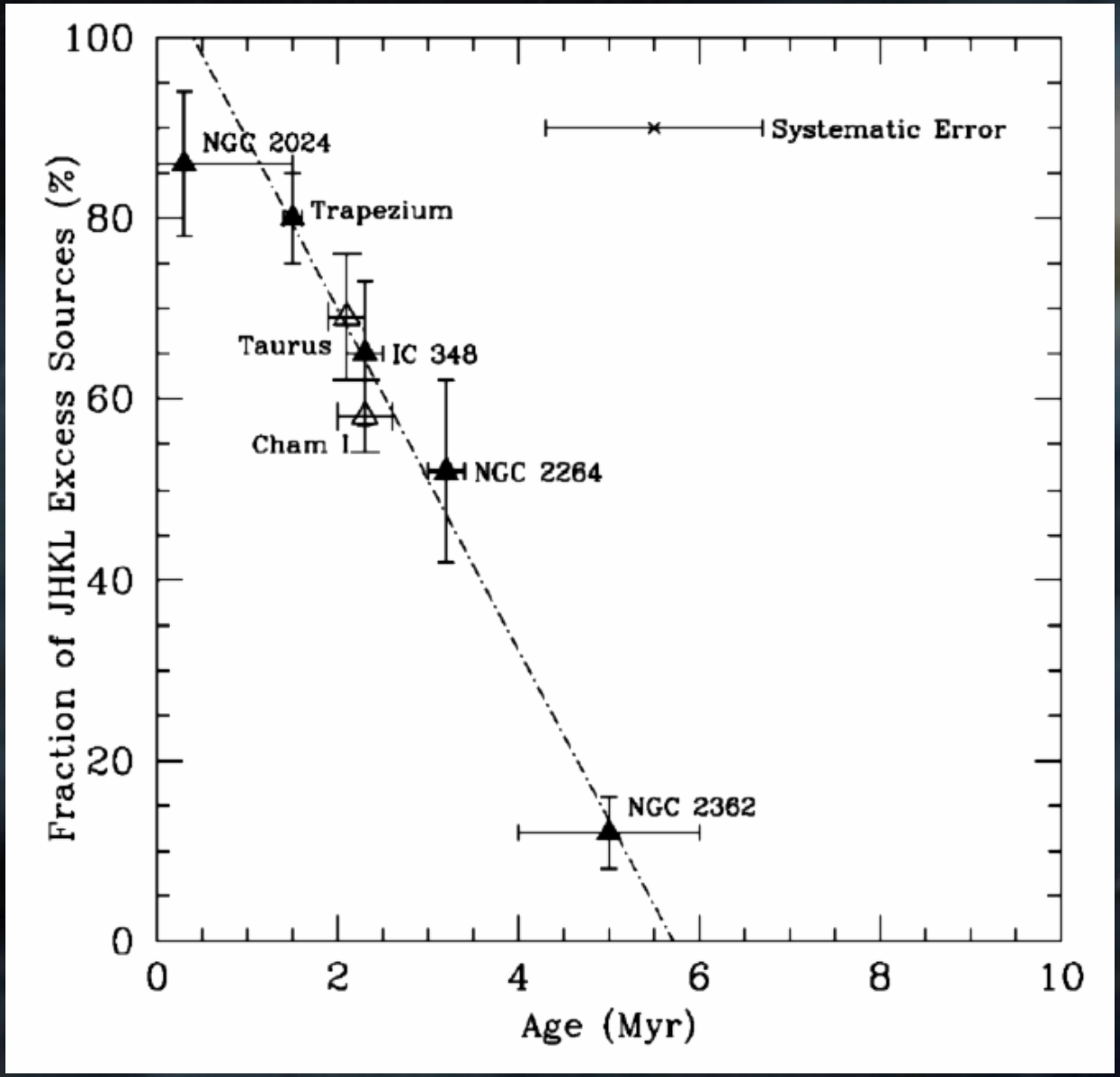
Crystalline forsterite (blue)

Power-law continuum (cyan)



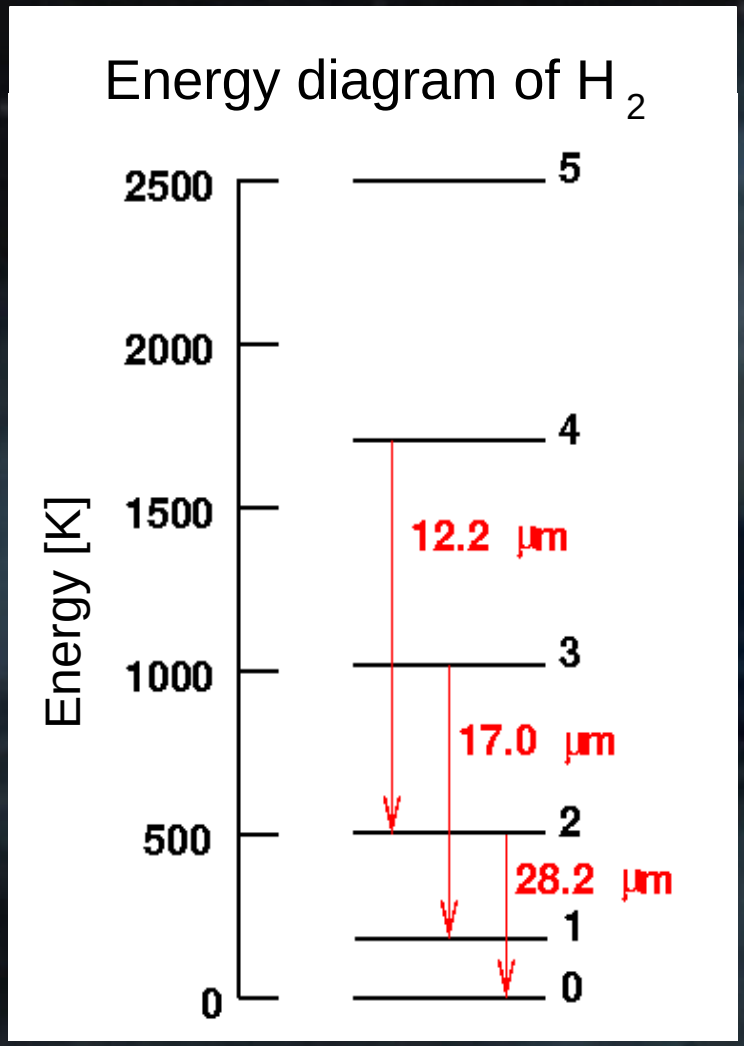

0.1μm glas. oliv. (a1) ×2
2.0μm glas. oliv. (a2)
Crys. forsterite (a3) ×2.5
Fitted parameters ai [10-18W/cm2/μm/arcsec2]
0.5
0
−60
−40
−20
0
20
40
60
Northeast ←
Radius [AU]
→Southwest

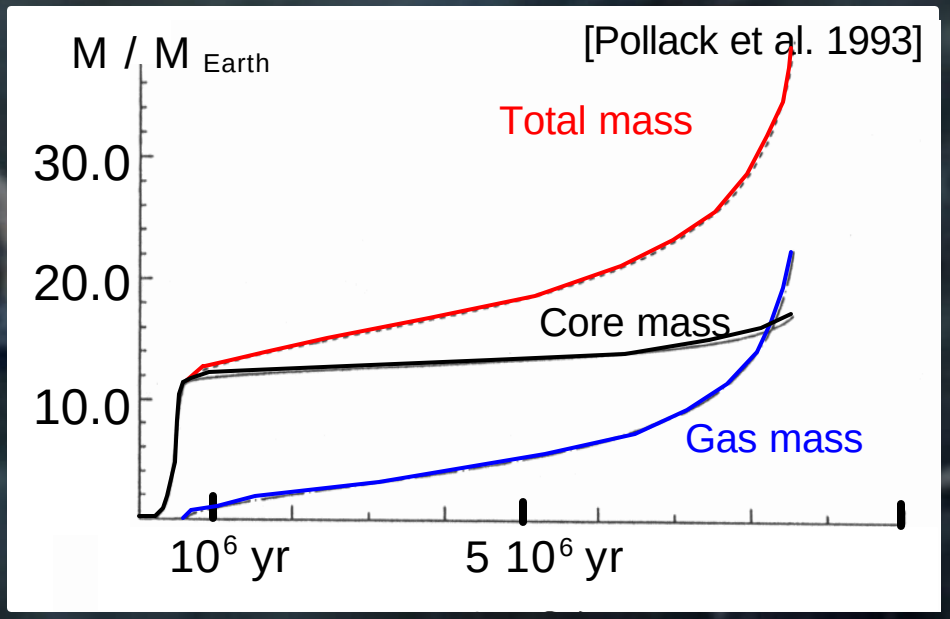
# Dust disk lifetimes



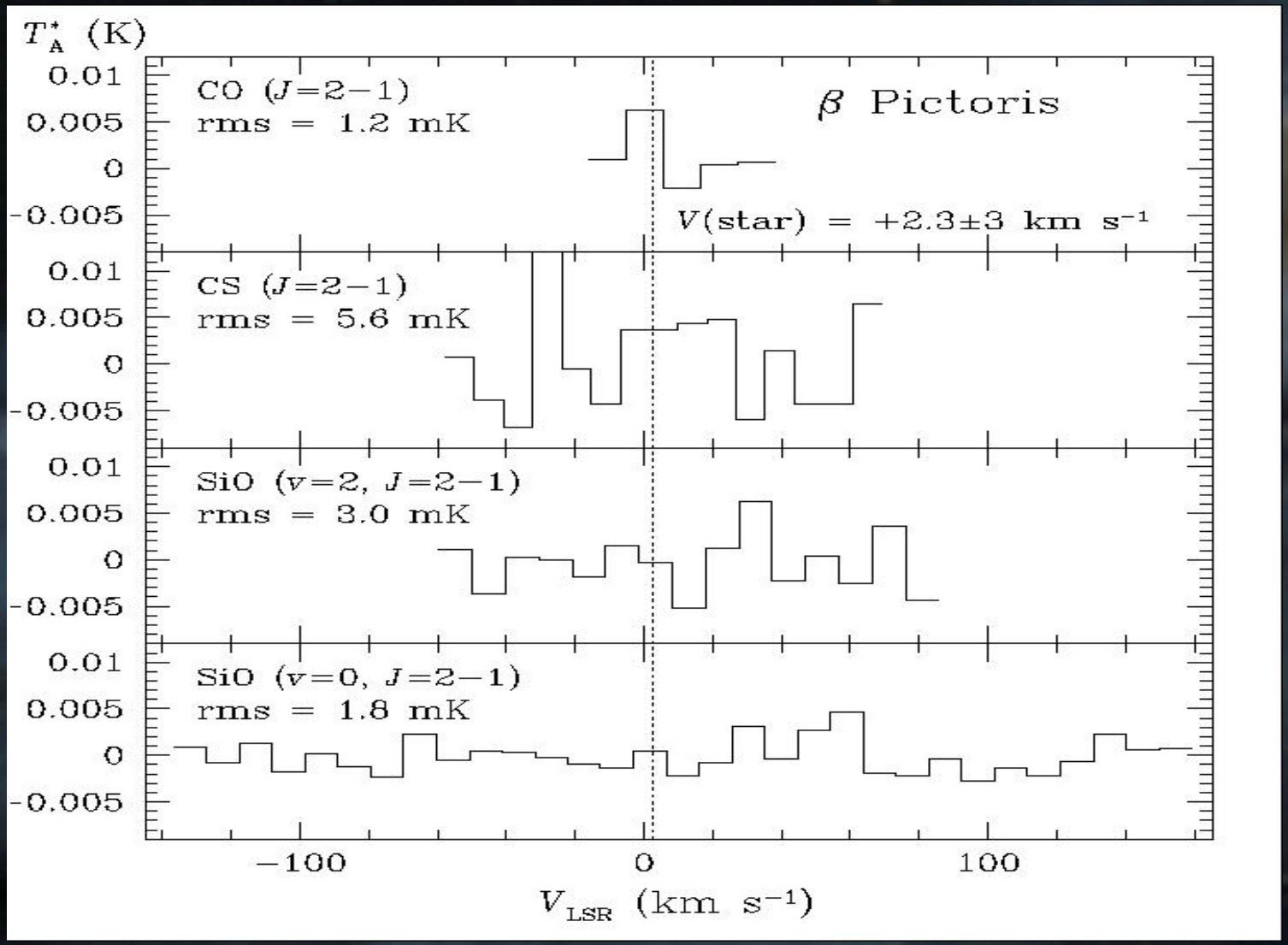

From Haisch, Lada & Lada 2001, ApJ, 553, 153

# What about gas?



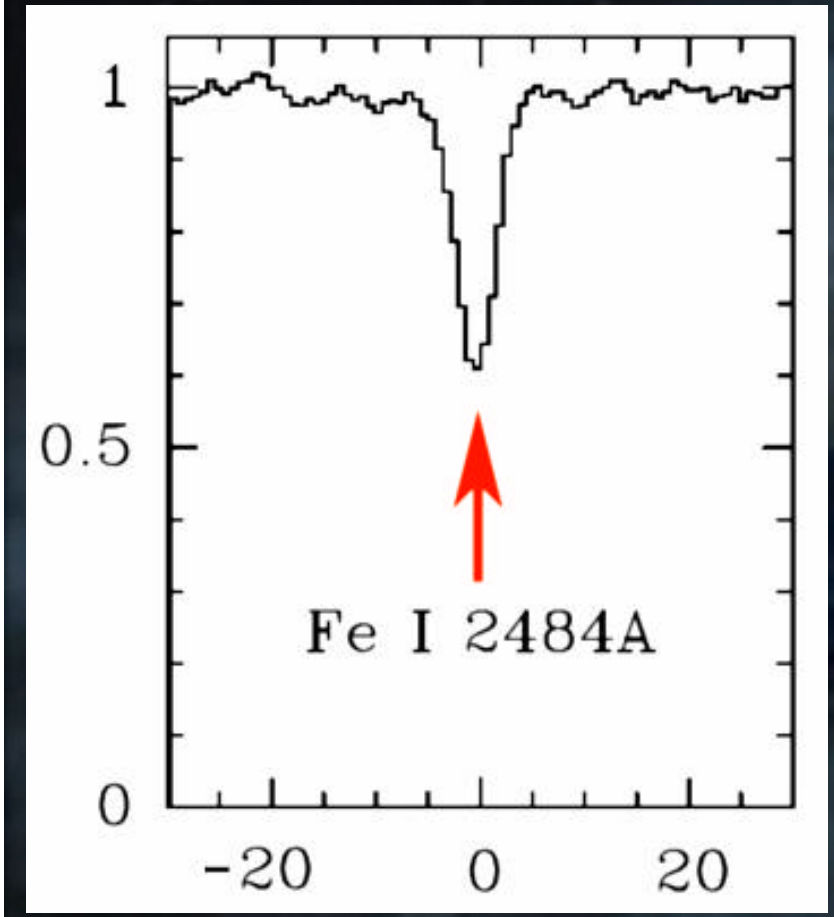



# mm/submm observations



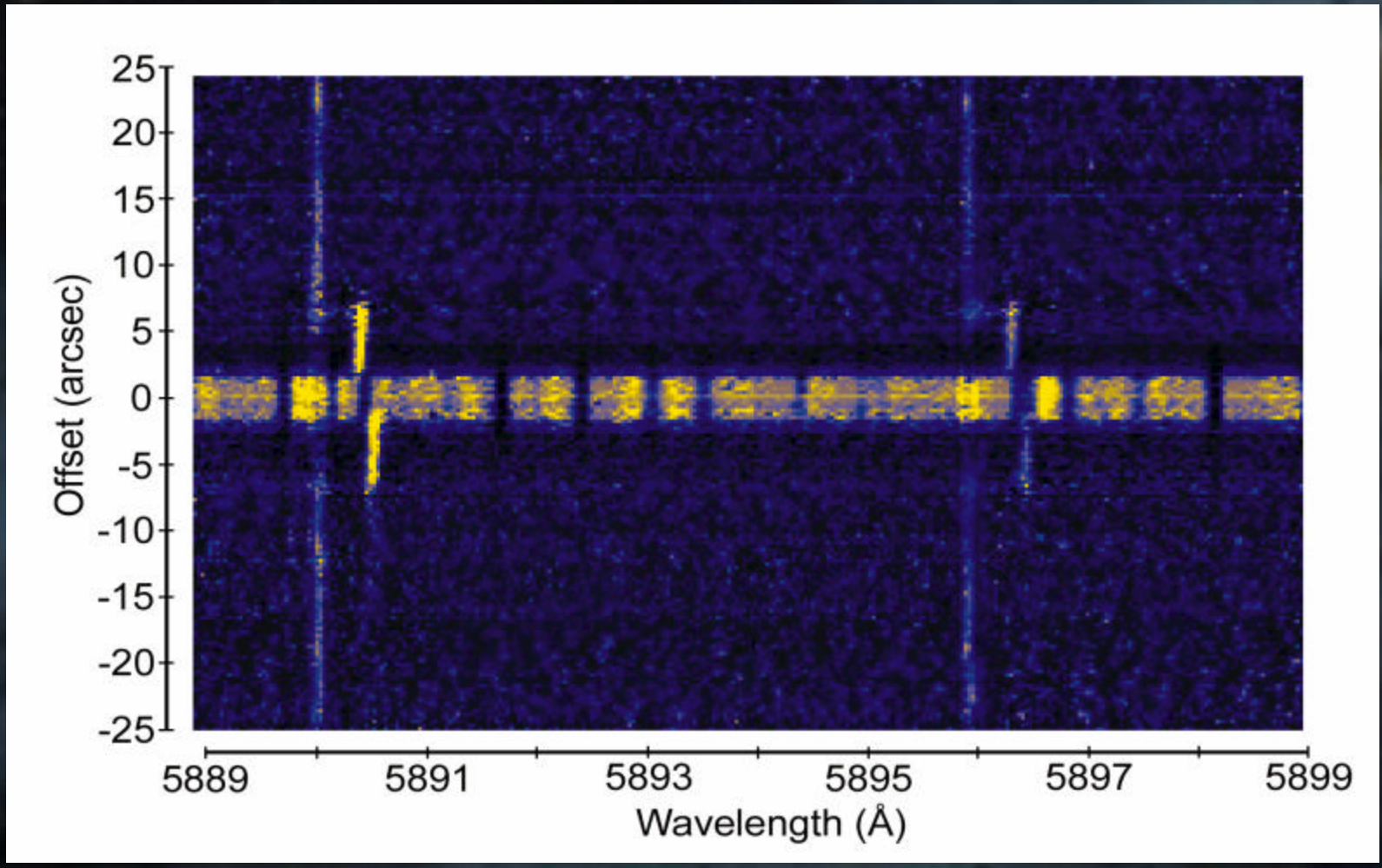

Liseau & Artymowicz 1998, A&A 335, 935

# Edge-on Þ absorption!




| Ion | $\Delta v$ km s$^{-1}$ | $\sigma_{\Delta v}$ km s$^{-1}$ |
|---|---|---|
| Fe I | −0.0 | 0.3 |
| Na I | −1.2 | 0.3 |
| Ca II | −0.3 | 2.1 |
| Ti II | 0.2 | 0.8 |
| Ni I | 0.4 | 0.4 |
| Ni II | 2.8 | 3 |
| Cr II | 2.2 | 3 |

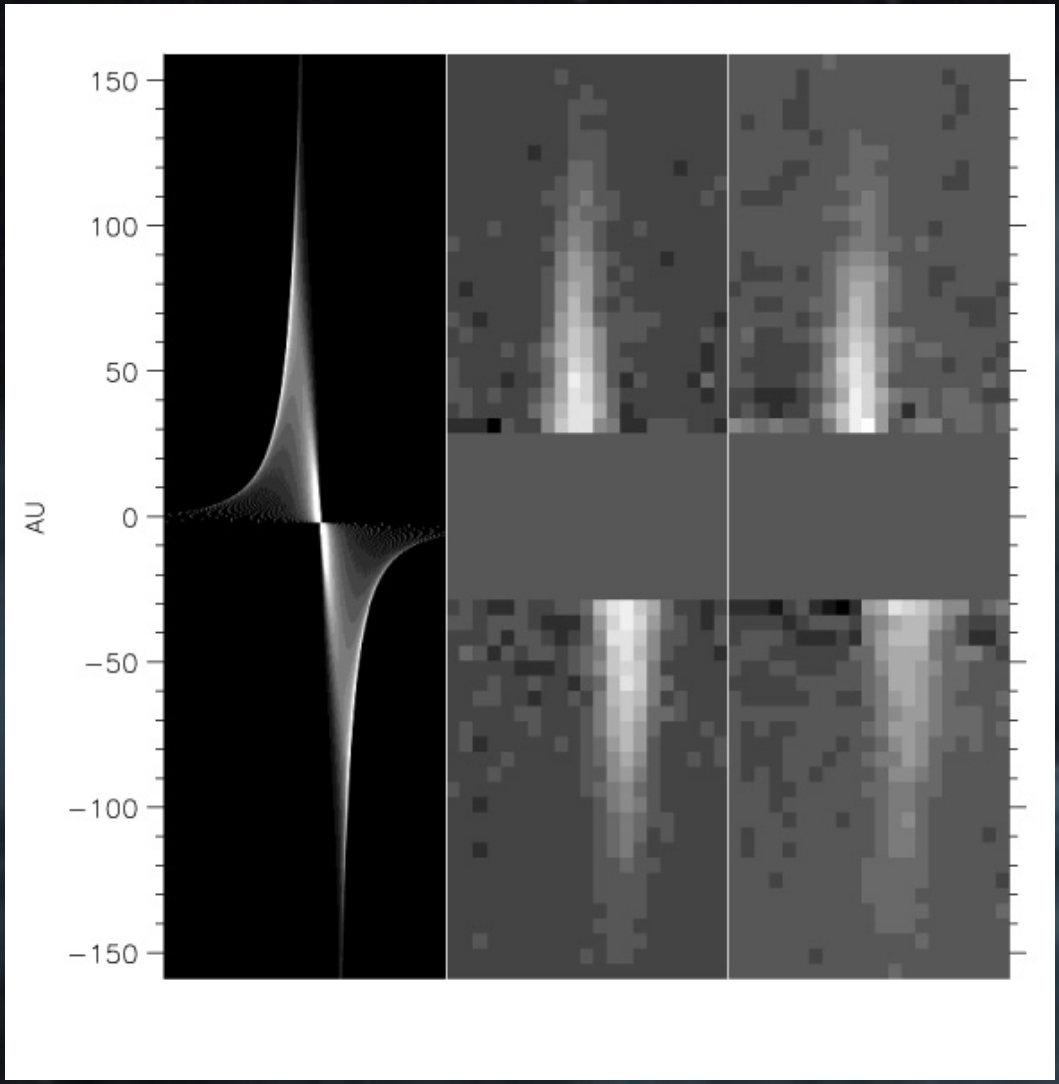
# Gas in emission




Olofsson, Liseau & Brandeker 2001, ApJL 563

Sodium D1/2 lines toward **b** Pictoris

# Dynamical studies...



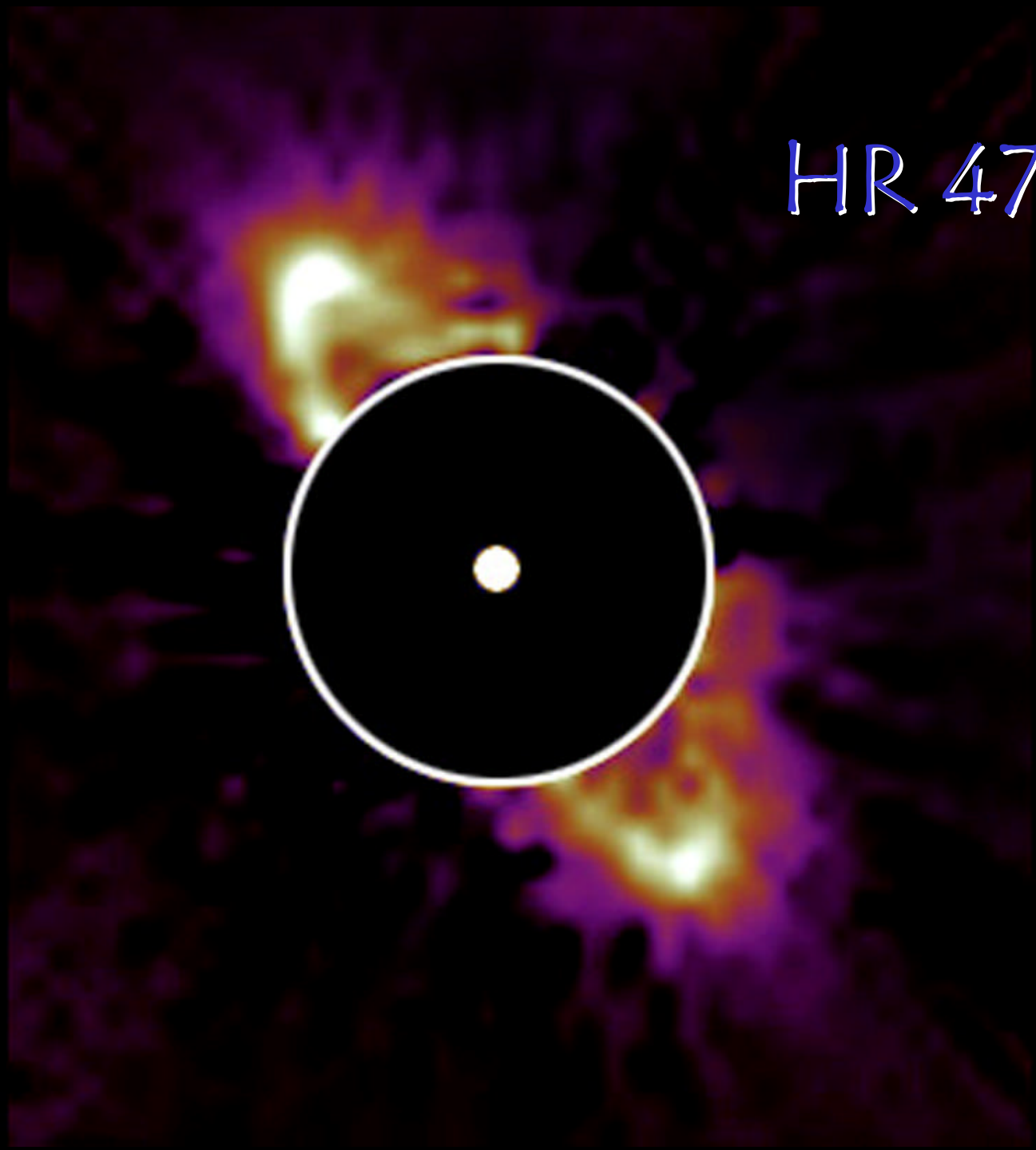

Stellar structure:

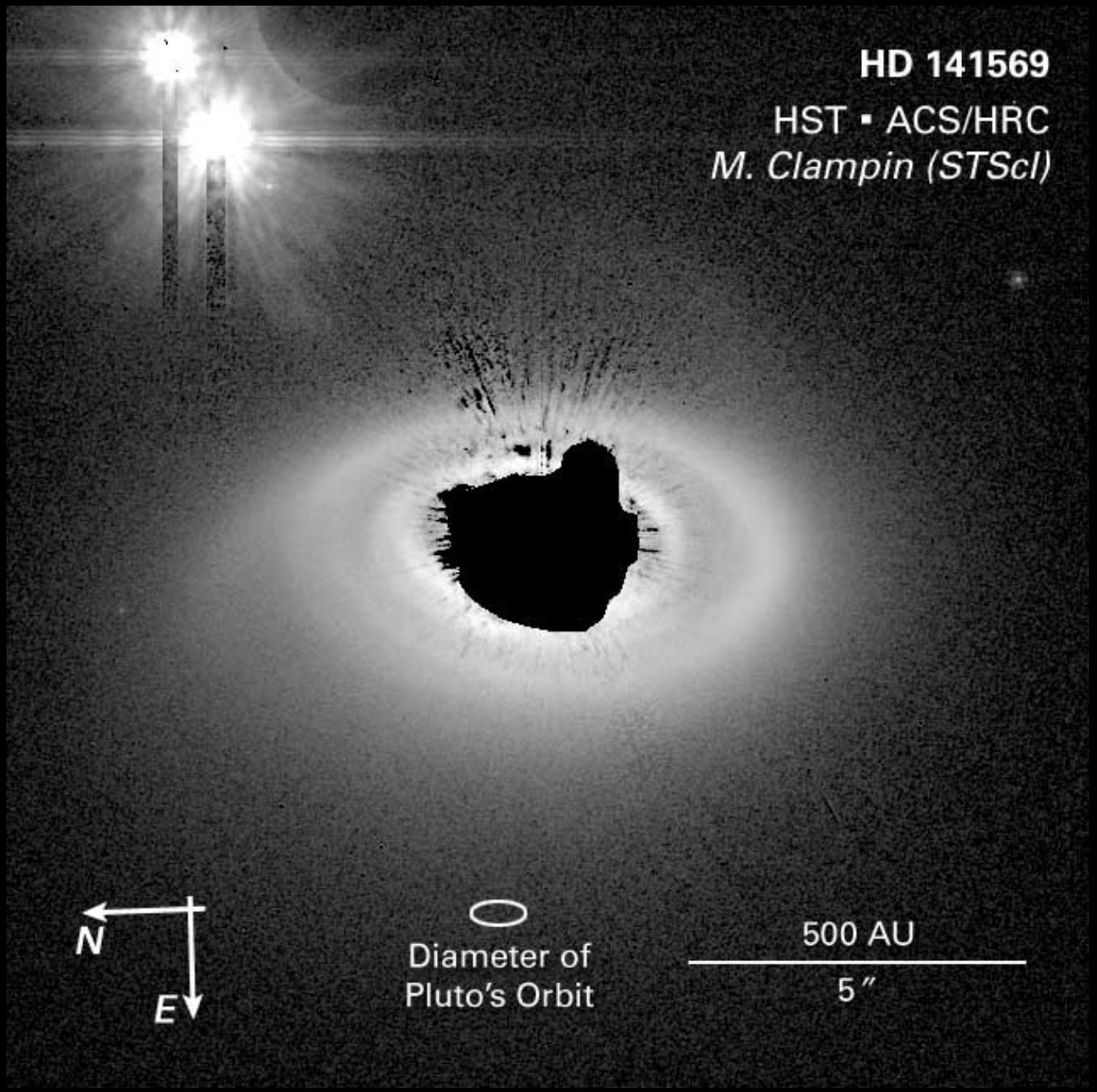
$M_* = (1.75 \pm 0.1) M_\odot$

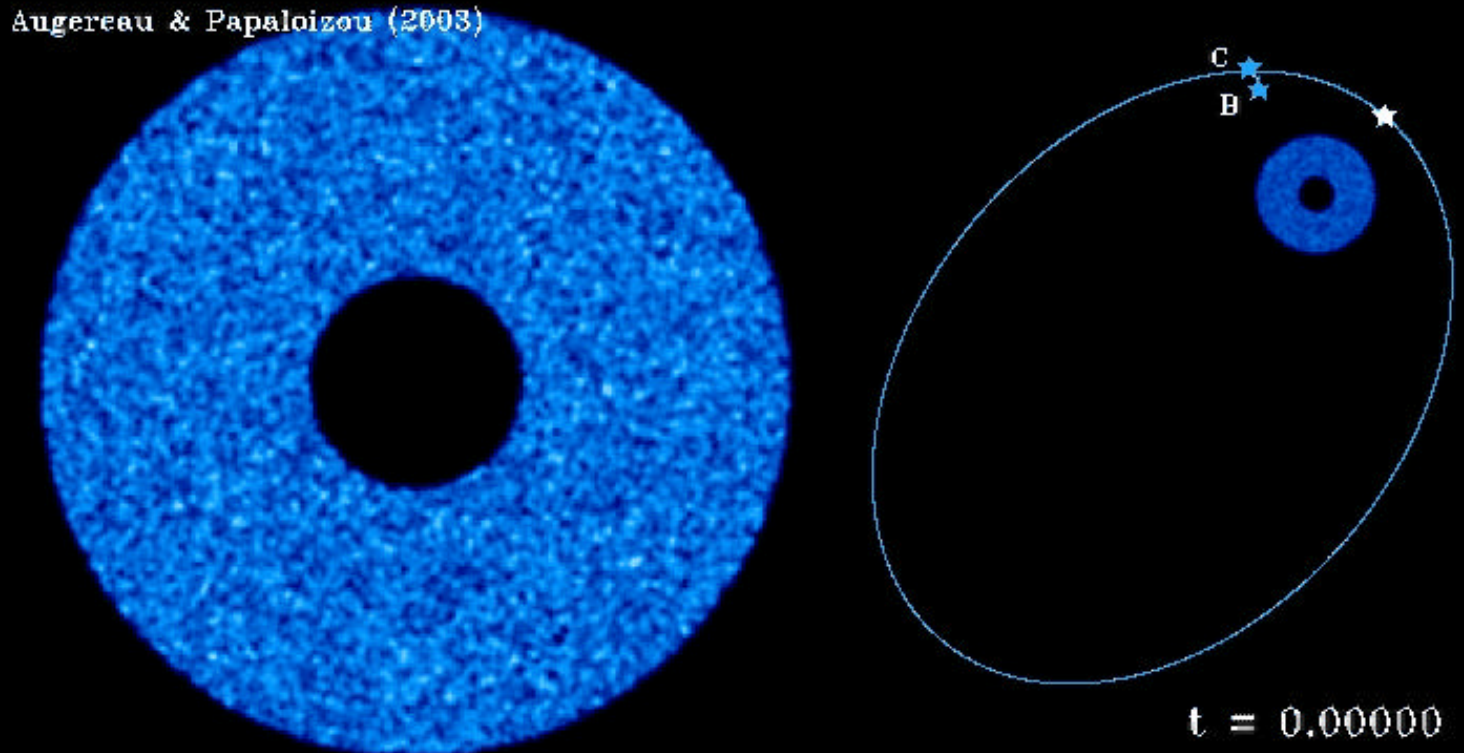
Gas dynamics:

$M_{dyn} = (1.40 \pm 0.05) M_\odot$

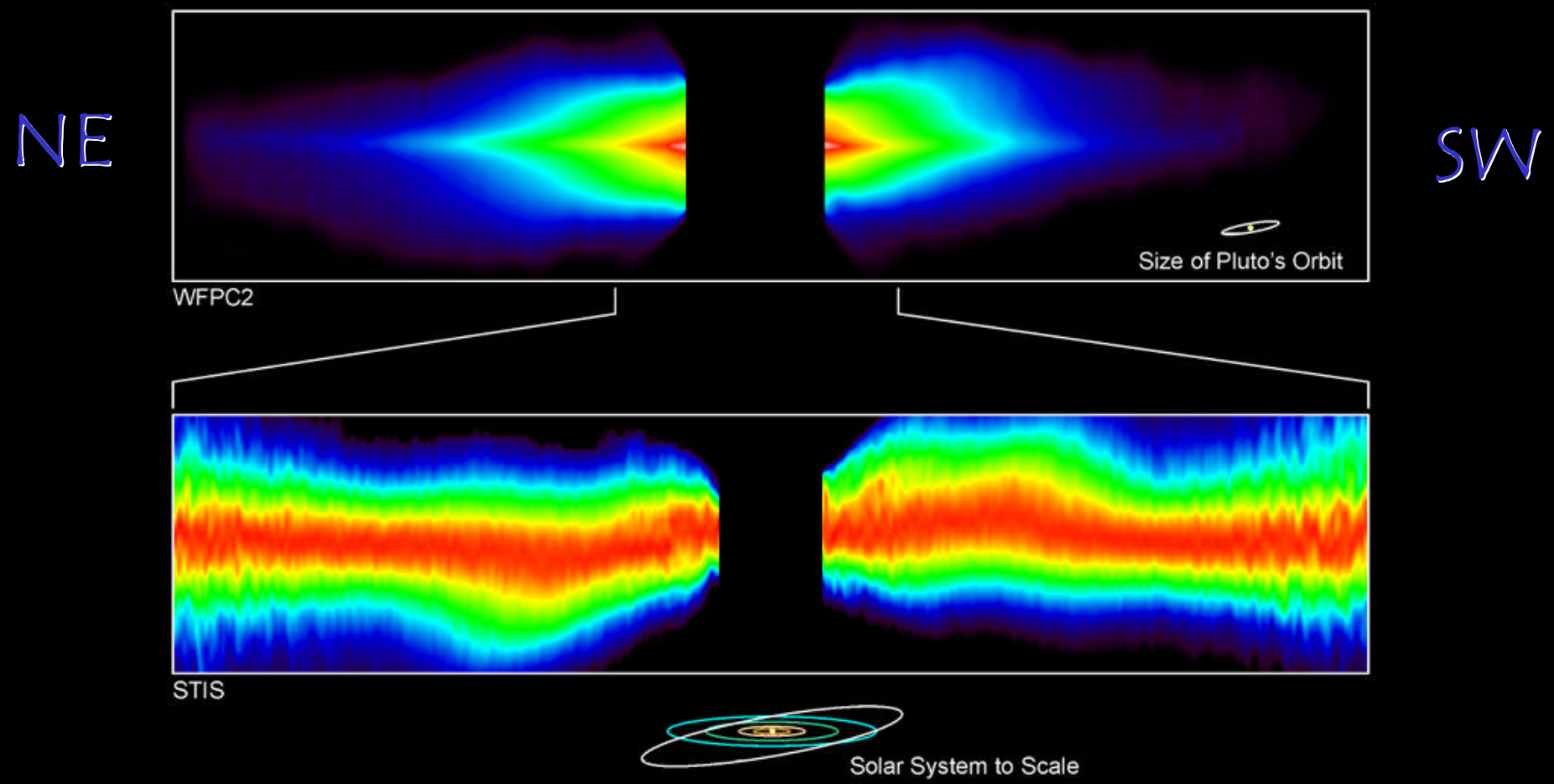
Discrepancy probably due to radiation pressure!


HR 4796A


HD 141569
HST ▪ ACS/HRC
M. Clampin (STScI)
N
E
Diameter of
Pluto's Orbit
500 AU
5″


Augereau & Papaloizou (2003)
C
B
t = 0.00000

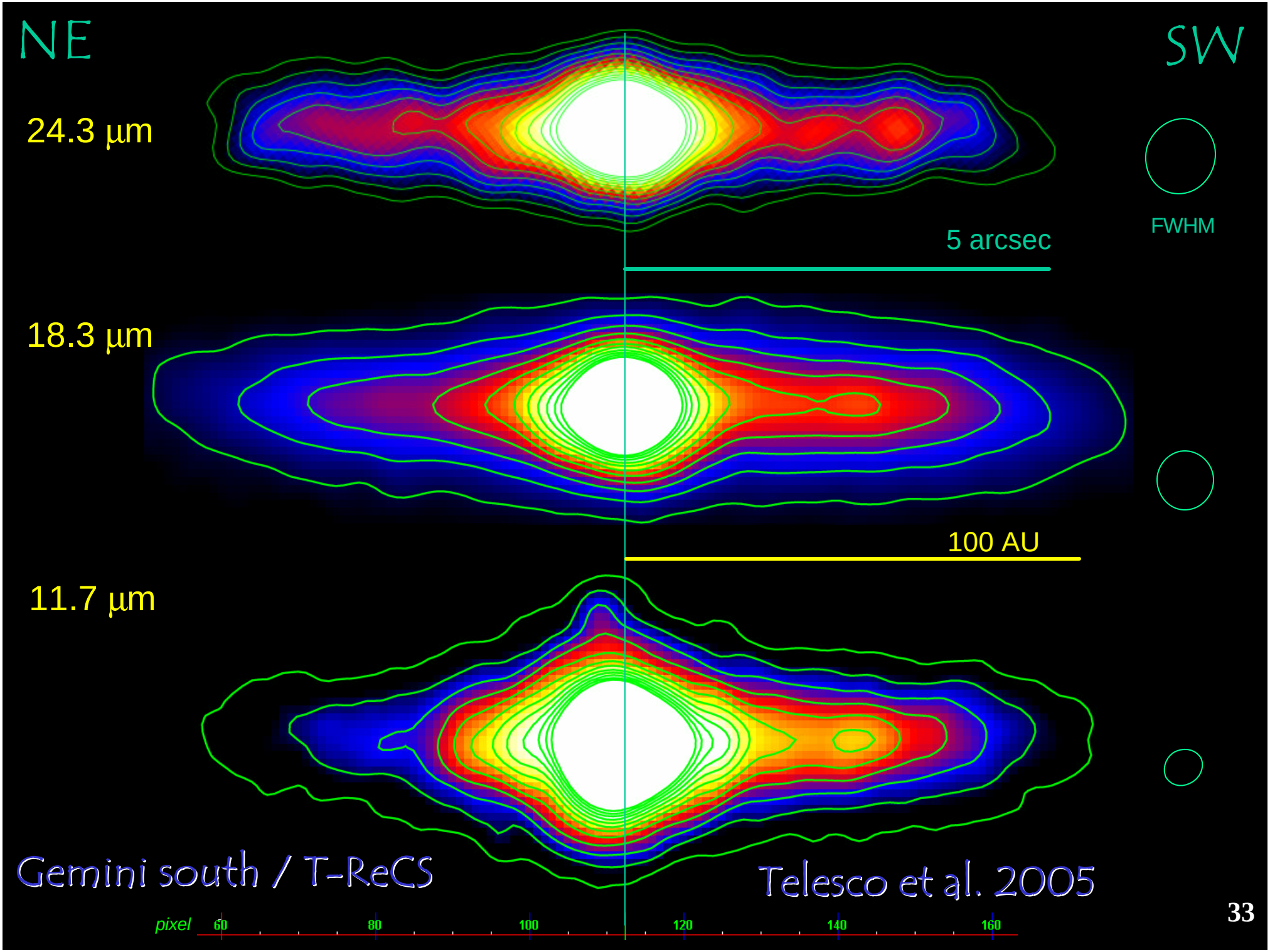
# β Pictoris in scattered light



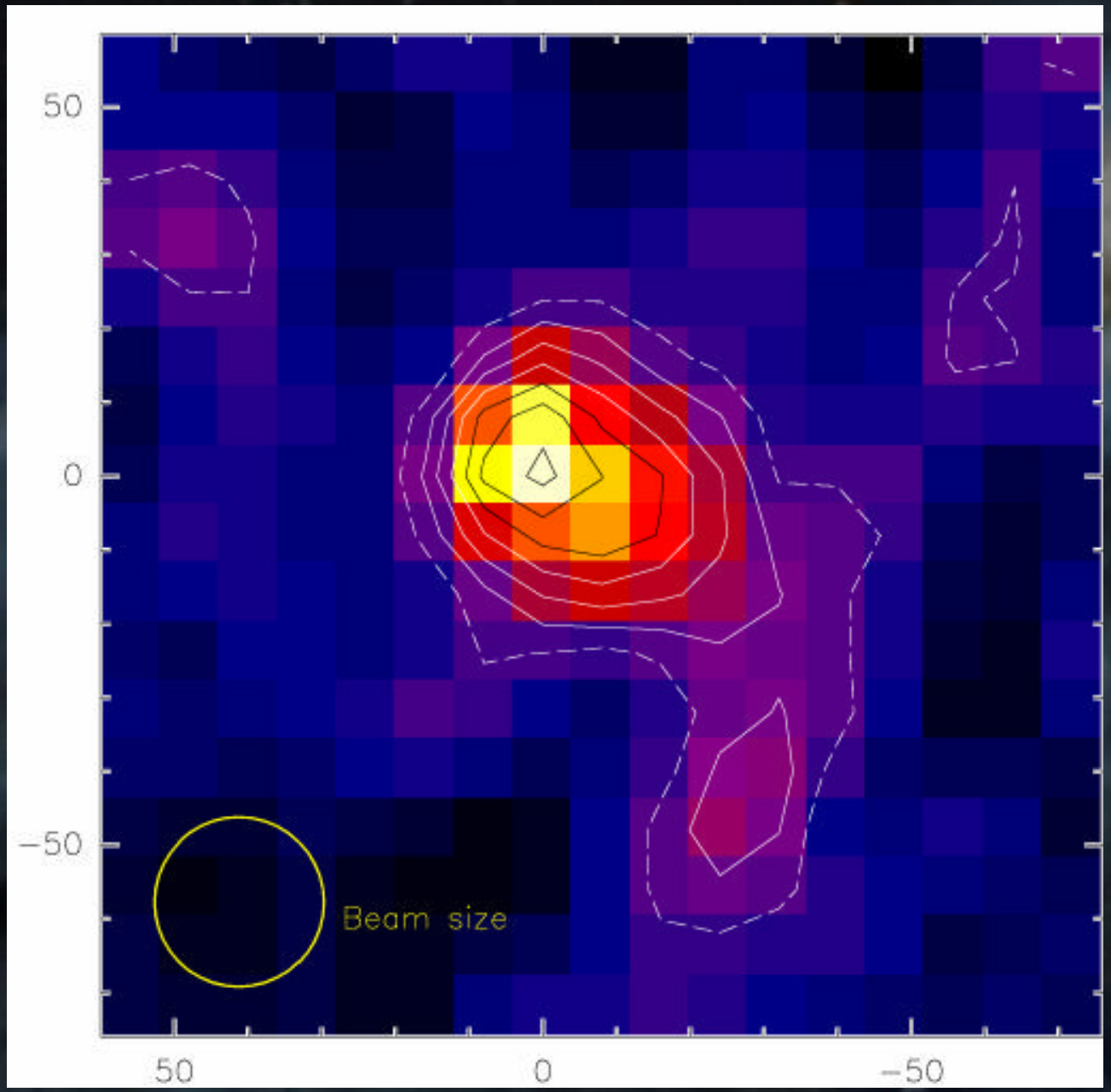

**Beta Pictoris** HST • WFPC2 • STIS

PRC98-03 • January 8, 1998 • ST ScI OPO

A. Schultz (Computer Sciences Corp.), S. Heap (NASA Goddard Space Flight Center) and NASA

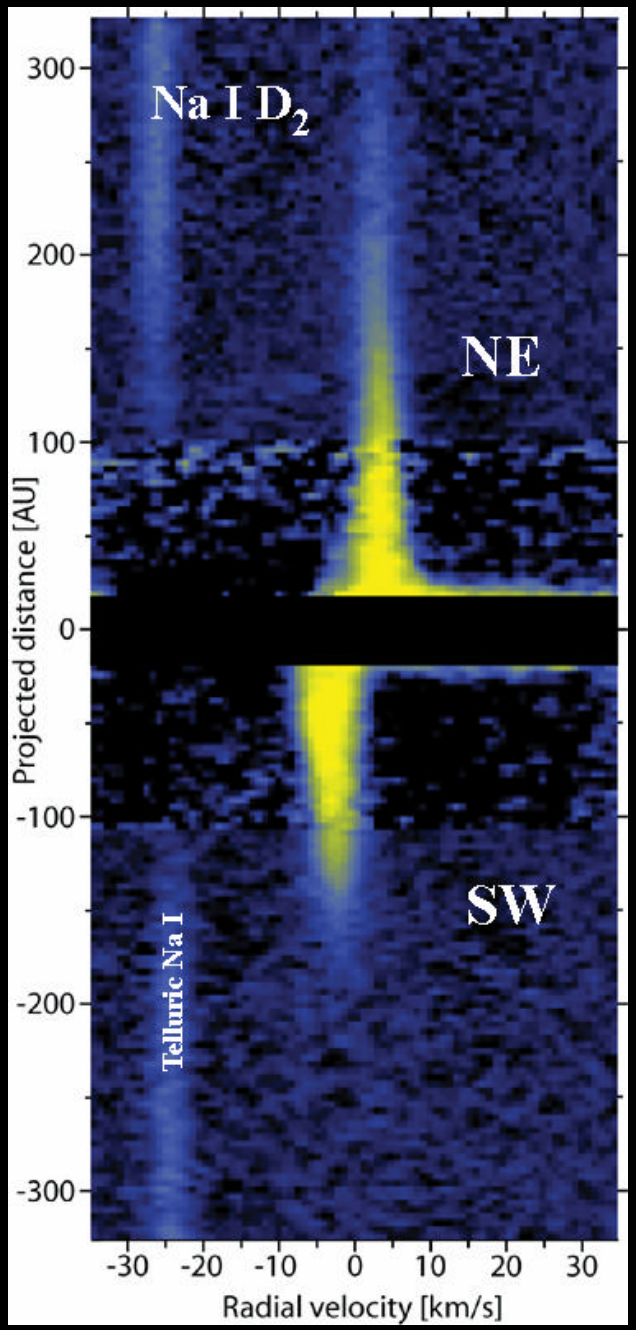

NE
SW
24.3 µm
FWHM
5 arcsec
18.3 µm
100 AU
11.7 µm
Gemini south / T-ReCS
Telesco et al. 2005
pixel
60
80
100
120
140
160

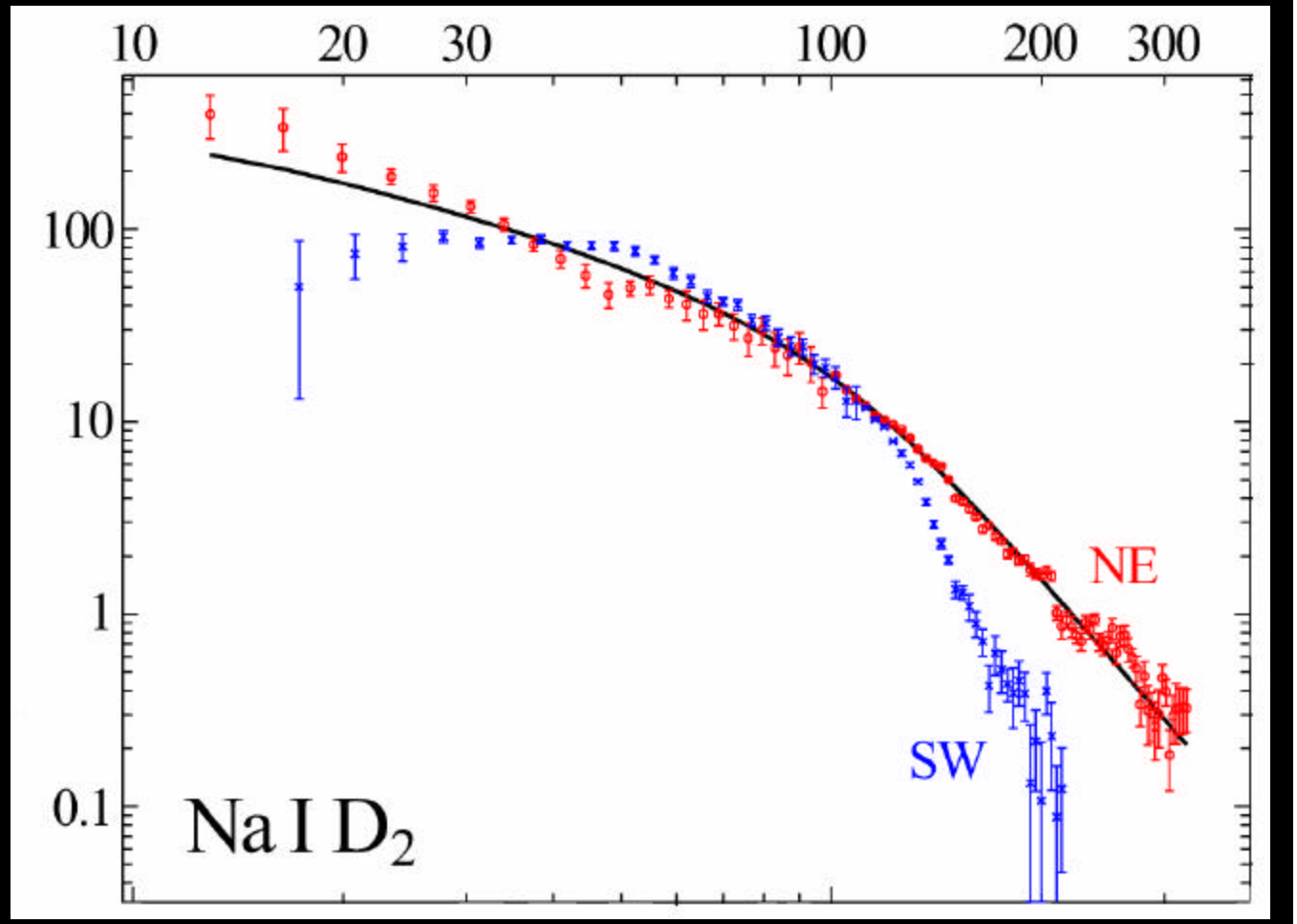
# 1.2 mm (SEST/SIMBA)




Liseau et al. 2003

# Asymmetris in gas disk

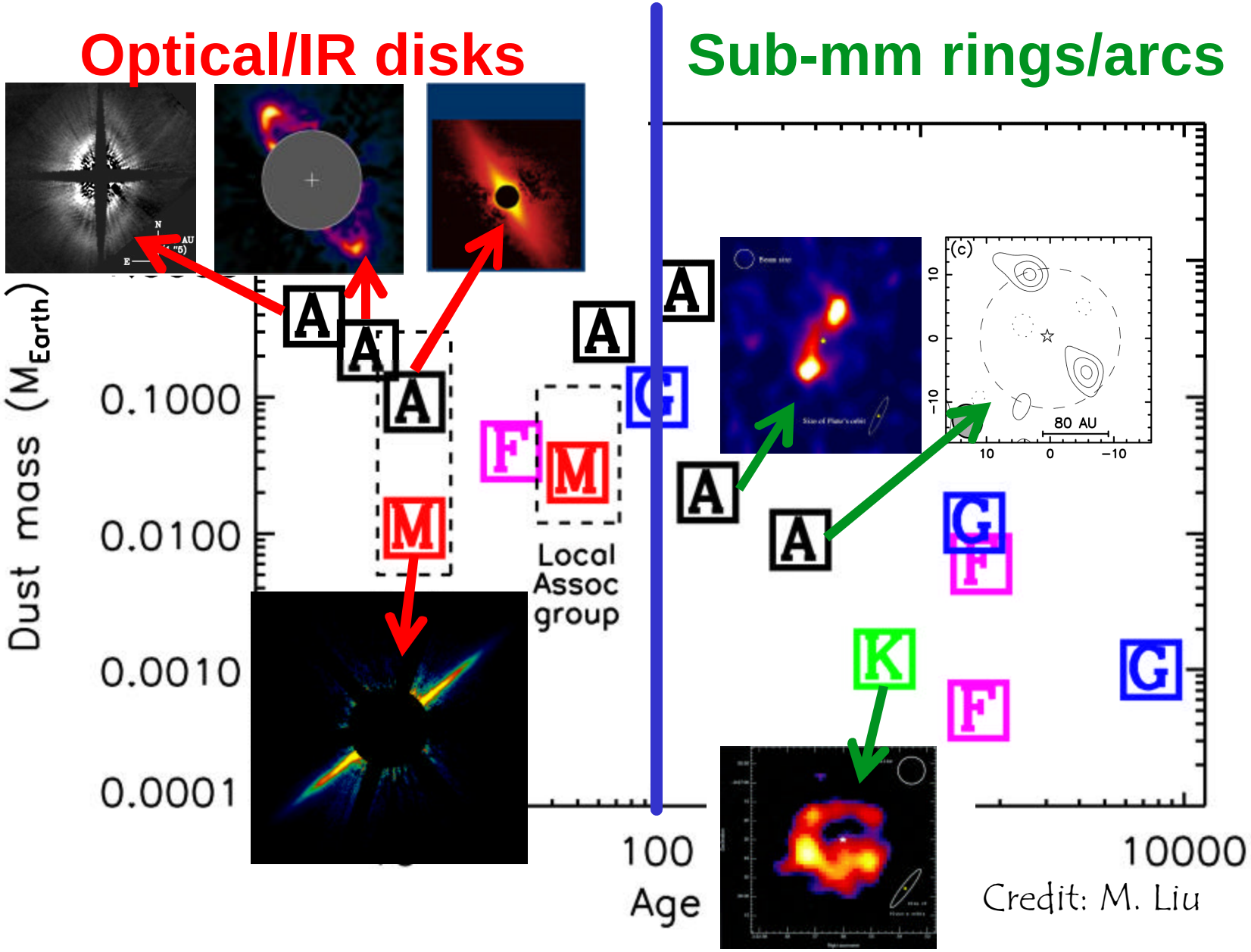



VLT / UVES

(Brandeker et al. 2004)

# Evolution: young vs. old debris



# StarStrider