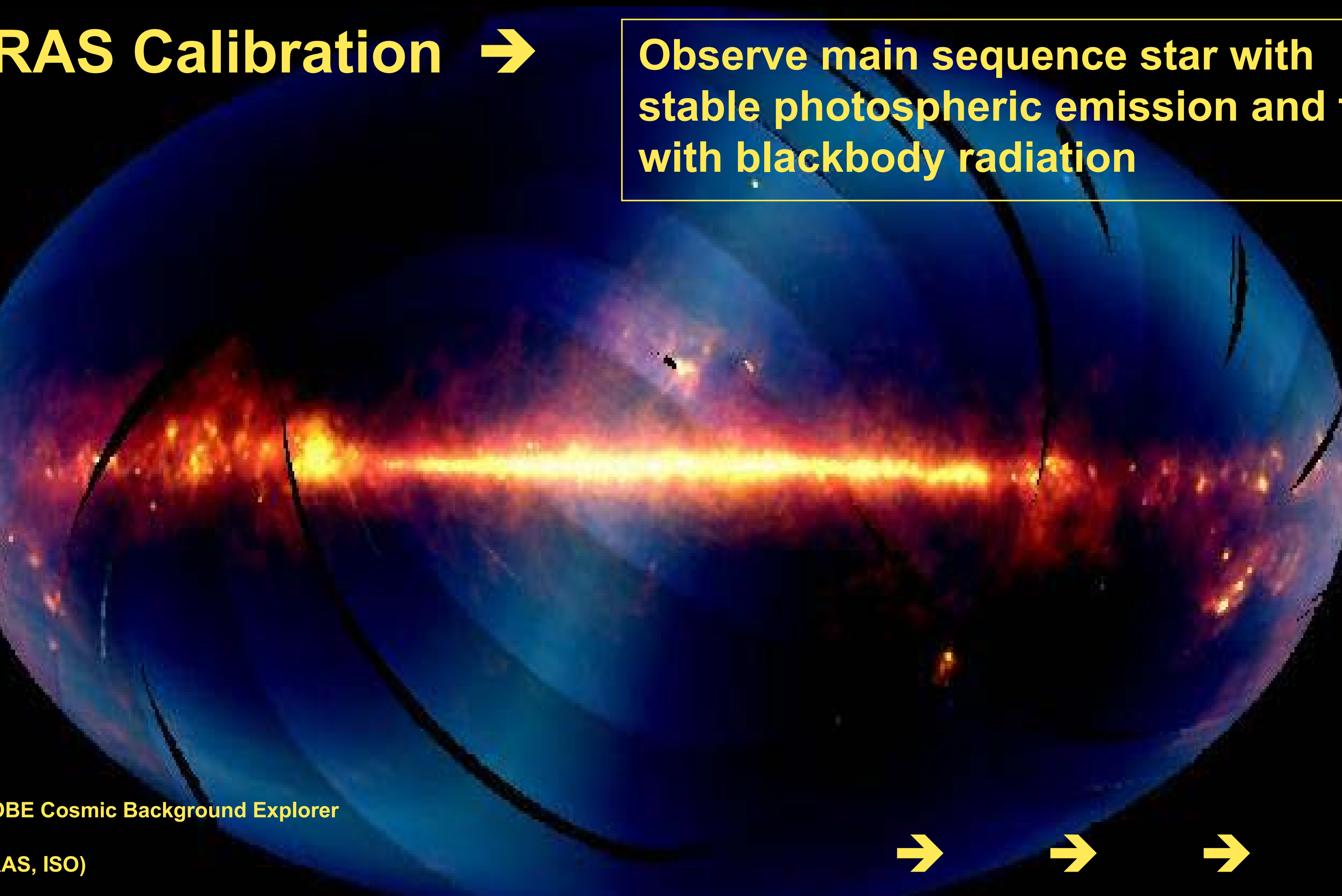
Dust Detection in
Extra-solar Planetary Systems

RAS Calibration →

Observe main sequence star with stable photospheric emission and fit with blackbody radiation



OBE Cosmic Background Explorer

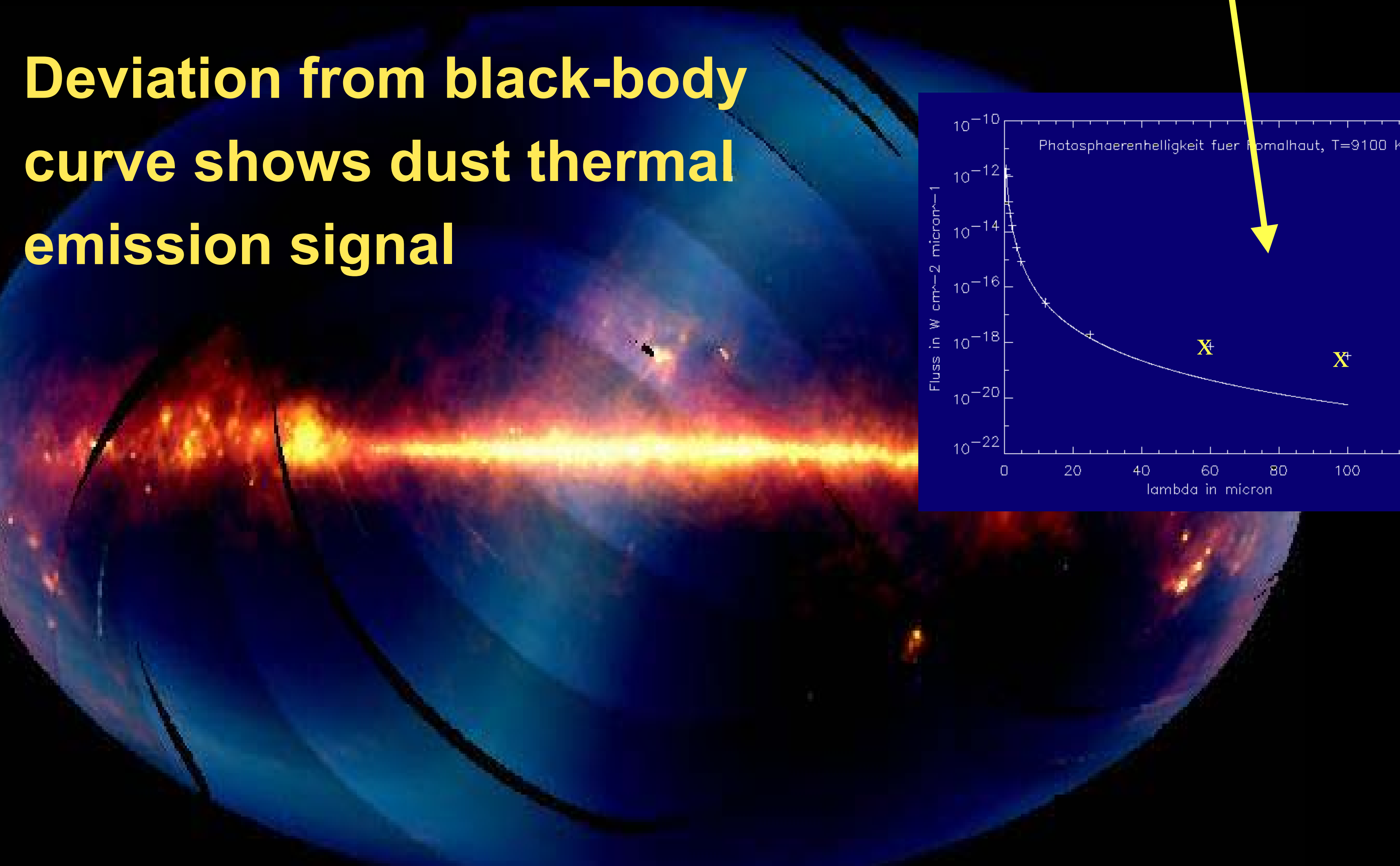
AS, ISO)

→ → → →

Vega Phenomenon:

IR - Excess

Deviation from black-body curve shows dust thermal emission signal



Vega Phenomenon:

Dust at r > 40 AU

Keplerian orbits

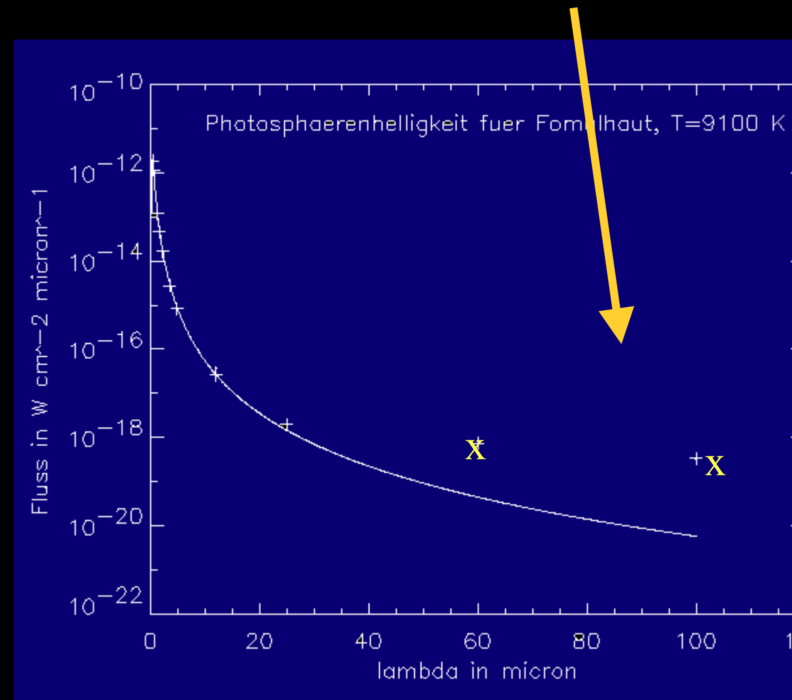
Poynting-Robterson effect and collisions limit lifetime

“2nd Generation” dust
Dust debris shell

System contains planetesimals

(Early review by Backman&Paresce in Protostars & PlanetsIII 1992,Arizona,Press)

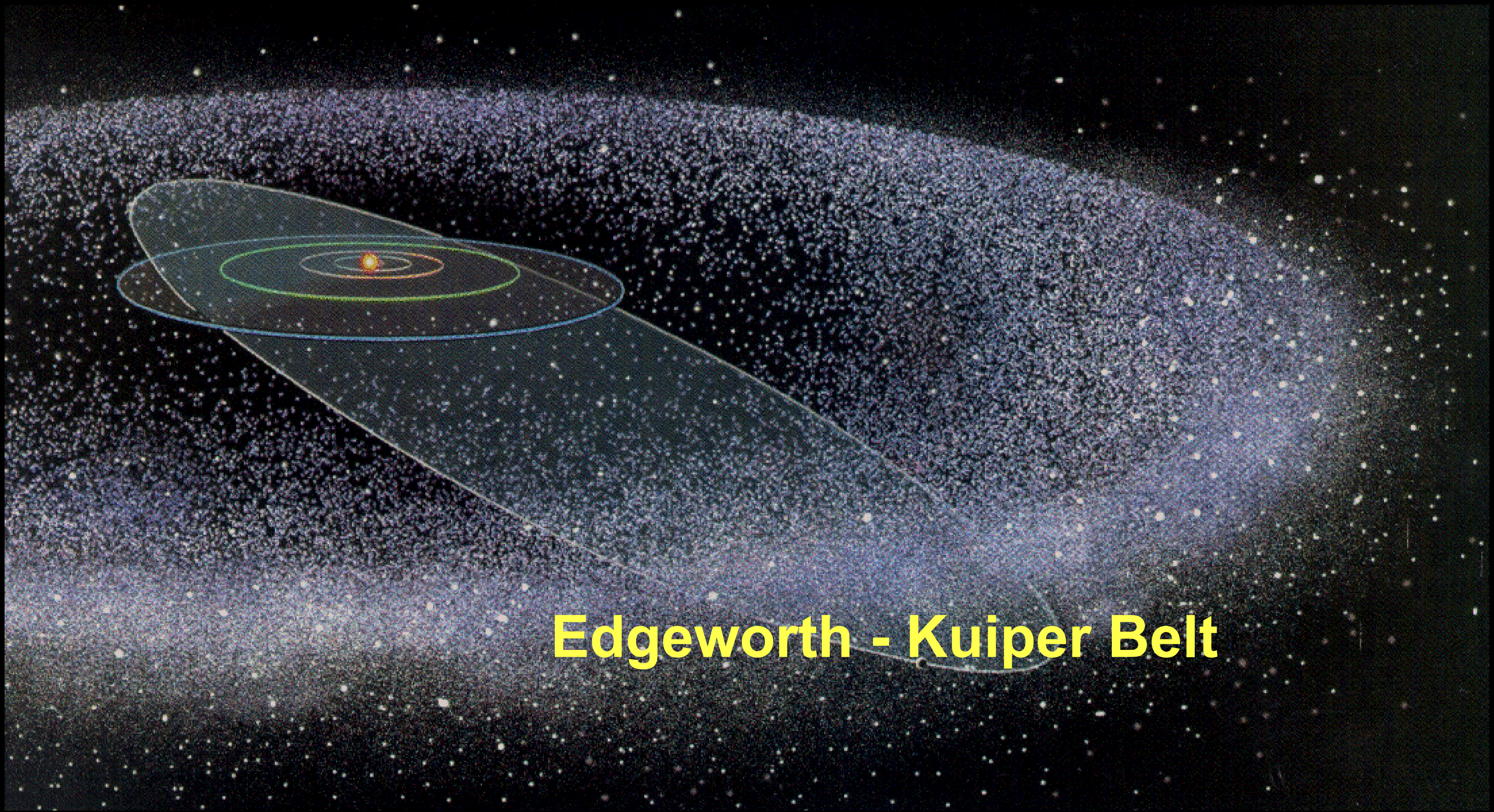
Dust at r > 40 AU

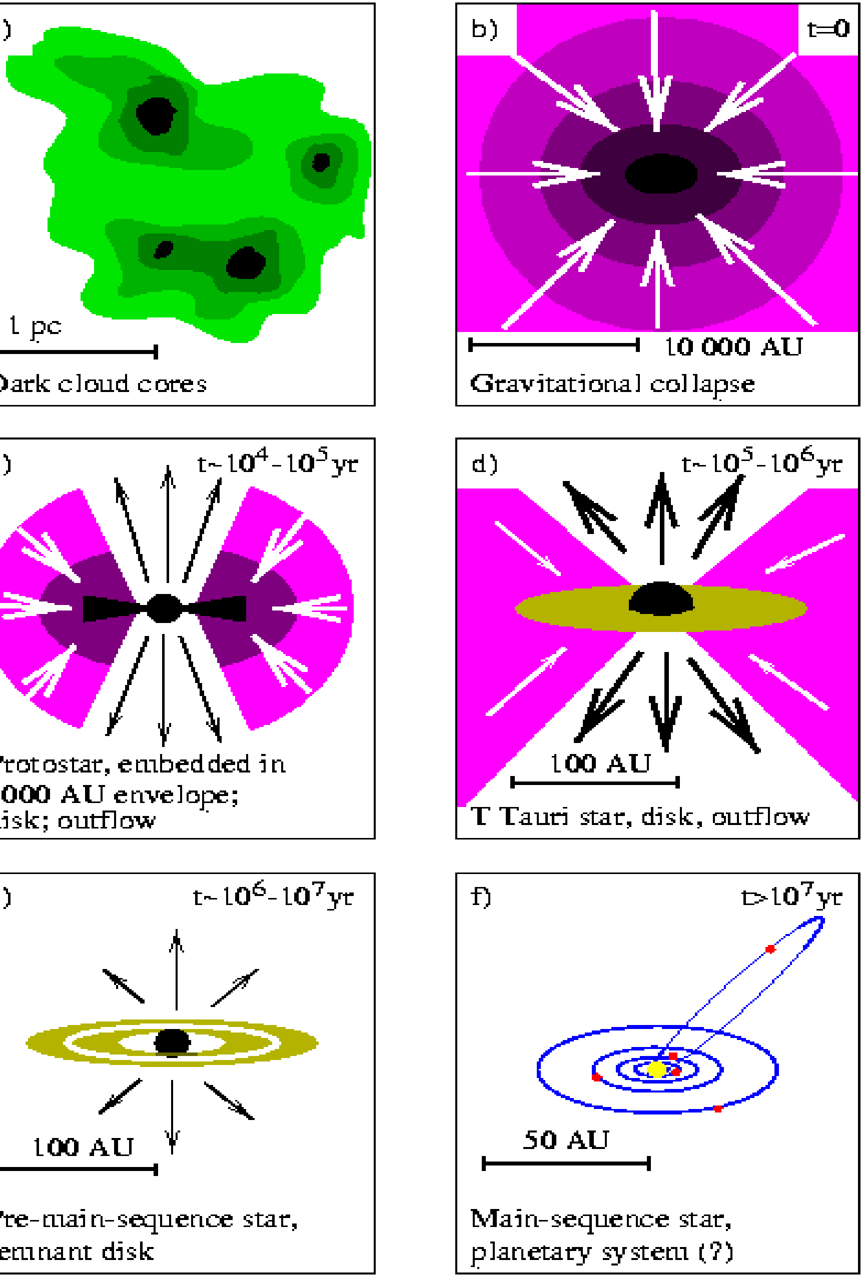


*) 1 AU = avarege distanceEarth - Sun

Majority of debris shells observed as point source

Compare to solar system beyond 40 AU:





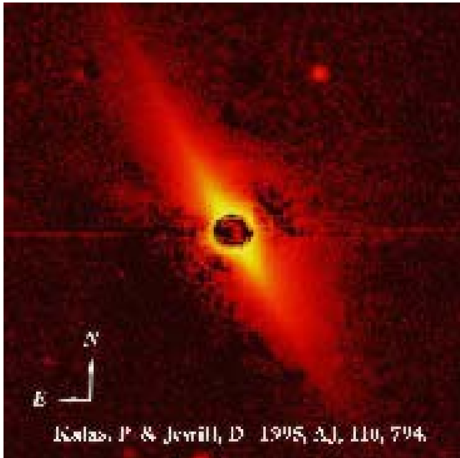
Hogerheijde 1998, after Shu et al. 1987

Formation of Star and Planetary system

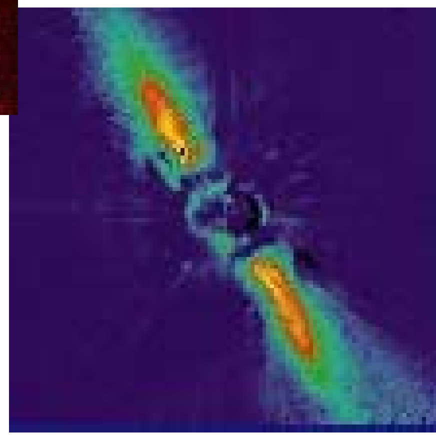
(observation in brackets)

- **a) Molecular cloud(gas)**
- **b) Gravitational collaps**
- **c) Protostar**
  (IR Emission from dust)
- **d) T - Tauri Star**
  (dust & gas emission)
- **e) Pre-mainsequence star**
  (dust & stellar spectrum)
- **f) Main sequence star**
  (stellar spektrum)
  (small...IR Exzess, Gas)

Observation of ß - Pic dust disk from visual to submm



0.5 µm

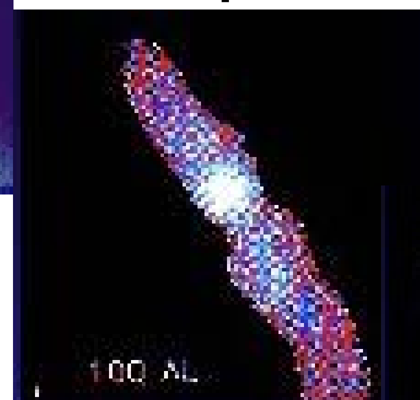


1 - 2 µm

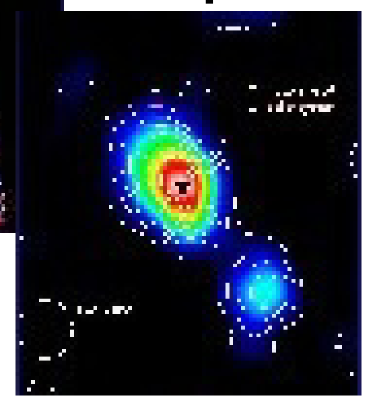
Scattered light

Thermal Emission

20 µm

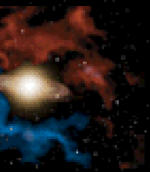


850 µm



Detect asymmetries & structures
--> models of dust cloud formation from planets and planetesimals

toplanets and Protoplanetary Disks



Note: Click on a column heading to re-sort list.

Star	Object	Mass	Average Distance	Object Type	Updated
BD +31 643	BD +31° 643 Protoplanet Disk	--	2300 AUs	Protoplanetary Disk	
beta Pictoris	b Pic Inner Protoplanet Disk	--	24 AUs	Protoplanetary Disk	
	b Pic Outer Protoplanet Disk	--	380 AUs	Protoplanetary Disk	
Fomalhaut	Fomalhaut Protoplanetary Disk	--	5 AUs	Protoplanetary Disk	
G339.88-1.26	G339.88-1.26 Protoplanet Disk	--	0.1 AUs	Protoplanetary Disk	
GM Aurigae	GM Aurigae Protoplanetary Disk	0.047	--	Protoplanetary Disk	16 Jul 2003
Great Orion Nebula	Orion Nebula Proplyd Disks	--	--	Protoplanetary Disk	
HD 141569	HD 141569 Inner Protoplanet Disk	--	86 AUs	Protoplanetary Disk	
	The HD 141569 Protoplanet	--	225 AUs	Protoplanet	

Comparison

Solar System:

Planets < 50 AU
Kuiper objects 50-100 AU
Oort cloud > 10 000 AU
Zodiacal dust < 3 AU
Dust in Kuiper belt likely

circum-stellar systems:

dust at 50 - 1000 AU
Planetesimals ≈ 100 km
dust < 50 AU ejected by
"invisible planet"?

one (few) systems with
planet AND dust shell

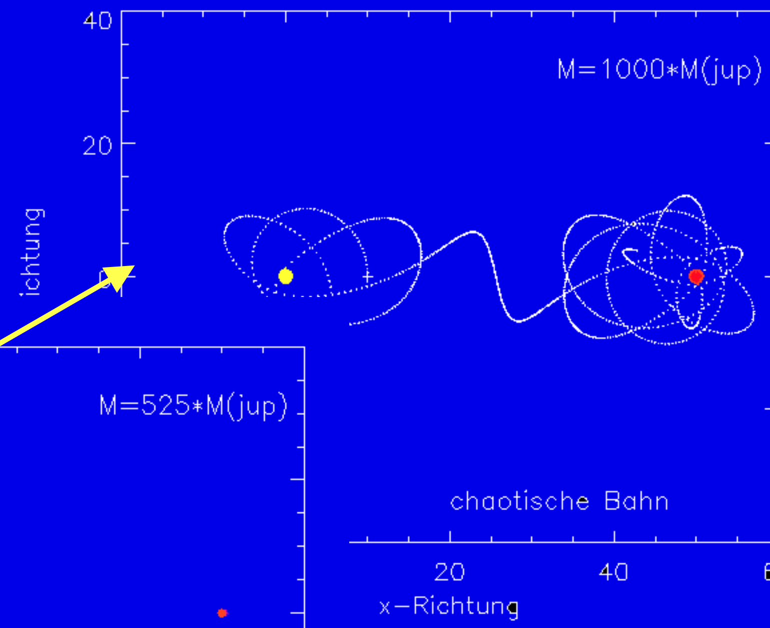
Gas and dust are observed in systems
with planetesimals and / or "small" planets

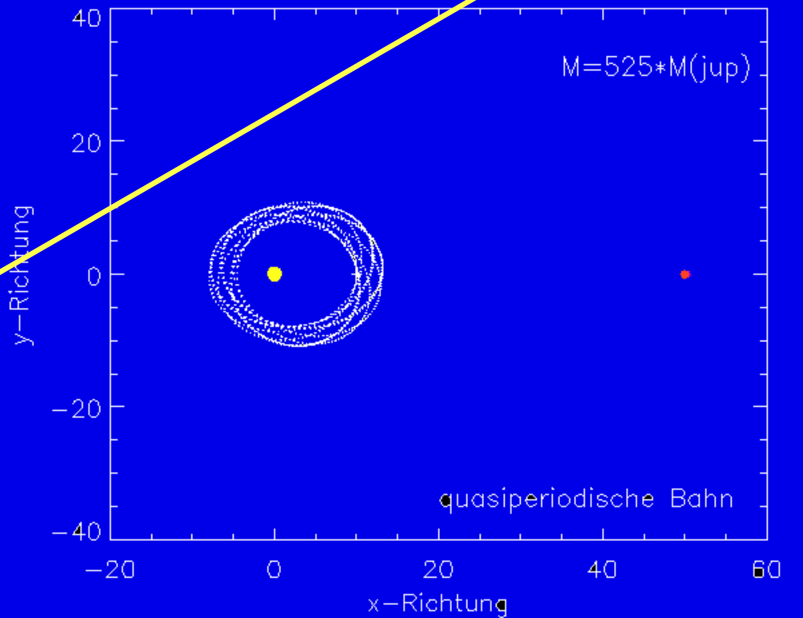
sources?

Orbital evolution

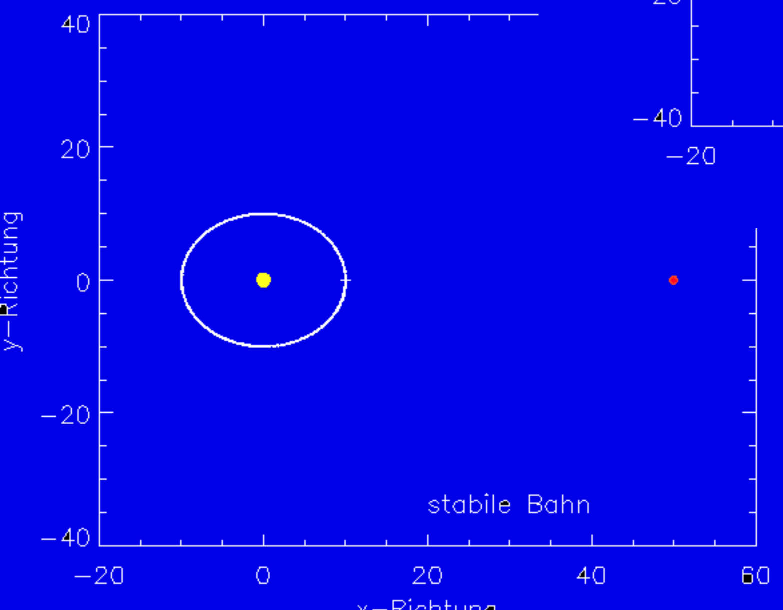
Three Body Problem

Particle in gravity field of sun & Planet





Increase mass of planet



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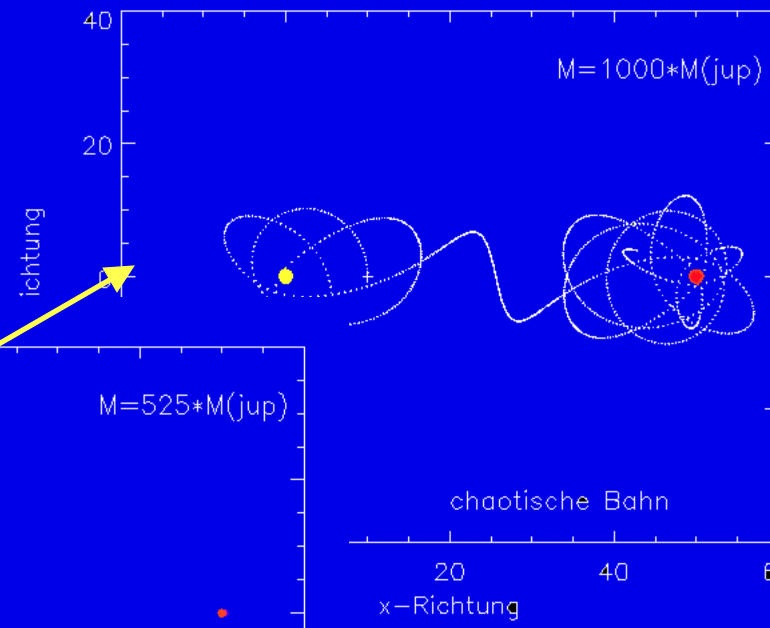
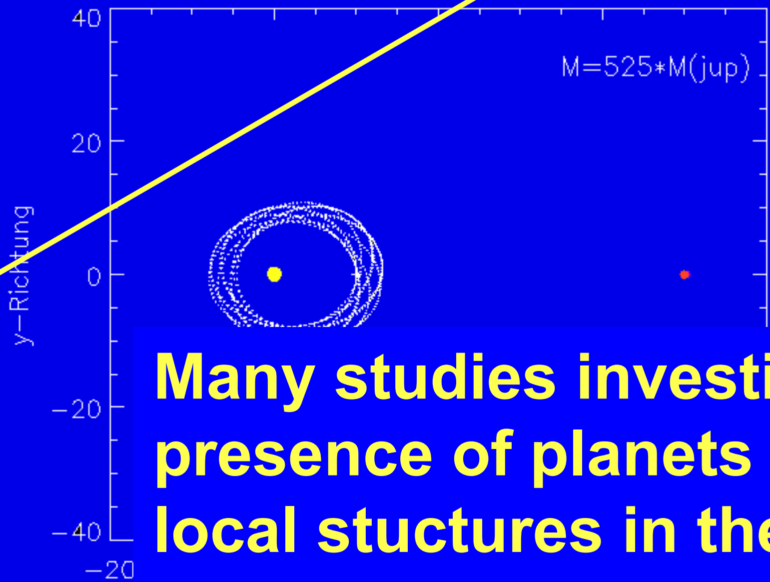
Local structures

Ejection of particles

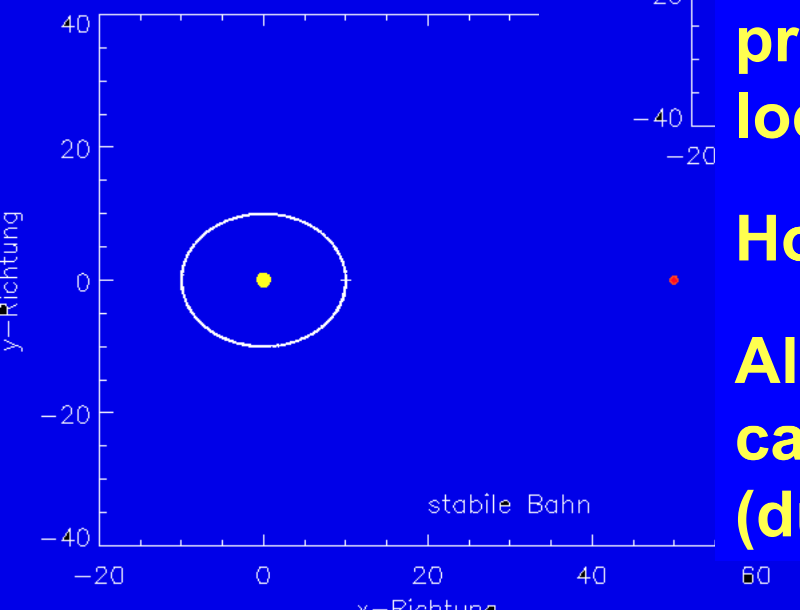
Three Body Problem

Particle in gravity field of sun & Planet





Increase mass of planet



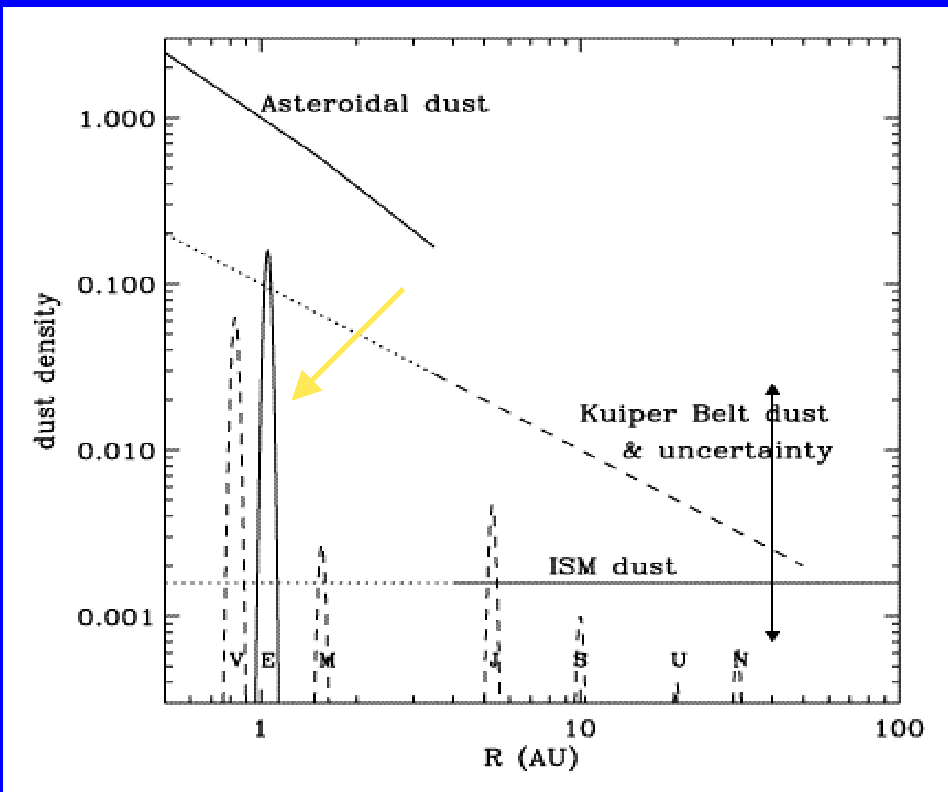
Many studies investigate how the presence of planets generates local stuctures in the dust shells

However:

Also dust production by collsions can generate local structures (dust trail of comets..)

Dust Distribution in Solar System

Radial number density profile (model):



From NASA Interstellar Probe Web

Shown are the expected local structures in the dust density along the orbits of the solar system planets

Only observed near Earth (Reach et al. Nature 1994) in COBE data

Competing effects?
Collisions, Lorentz force

Variation of particle size and structures lets the density enhancements disappear ?

observed ring systems have very narrow size distribution!

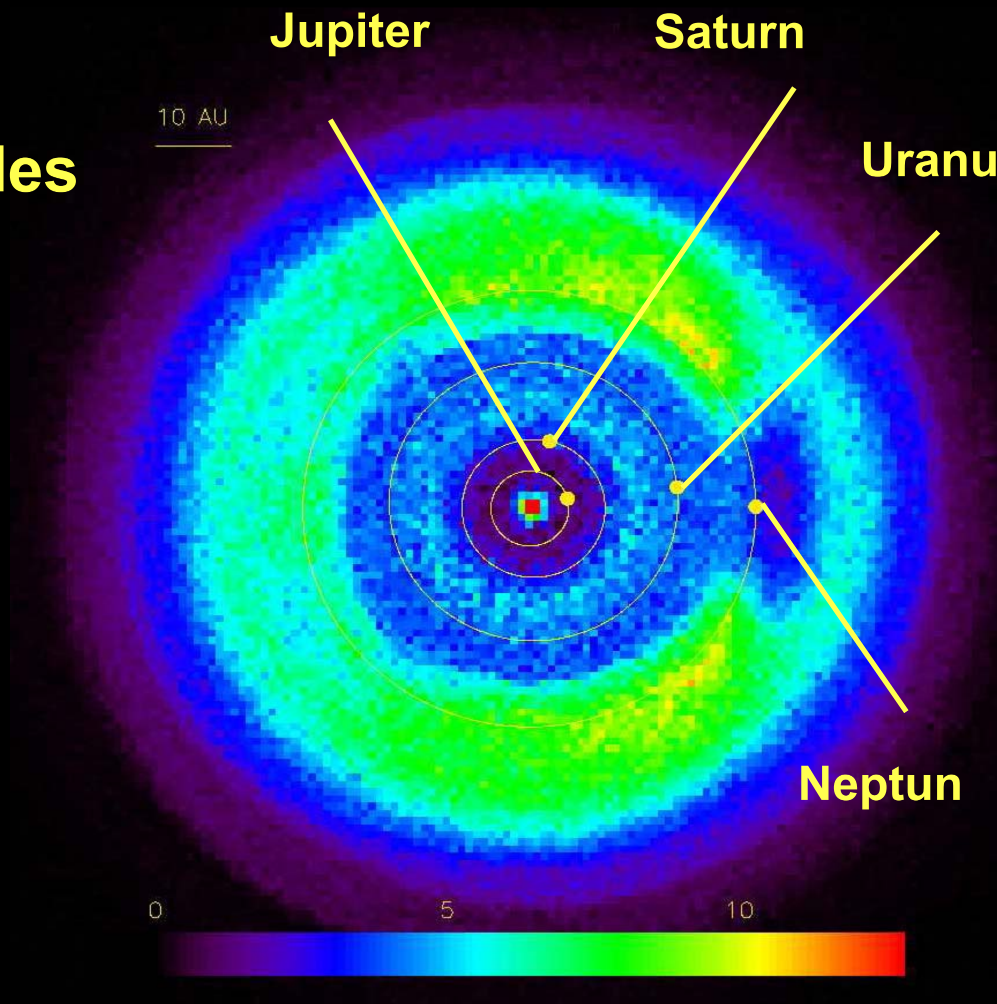
Dust in Kuiper Belt

Calculation for 10 μm particles

Resonance with Neptun

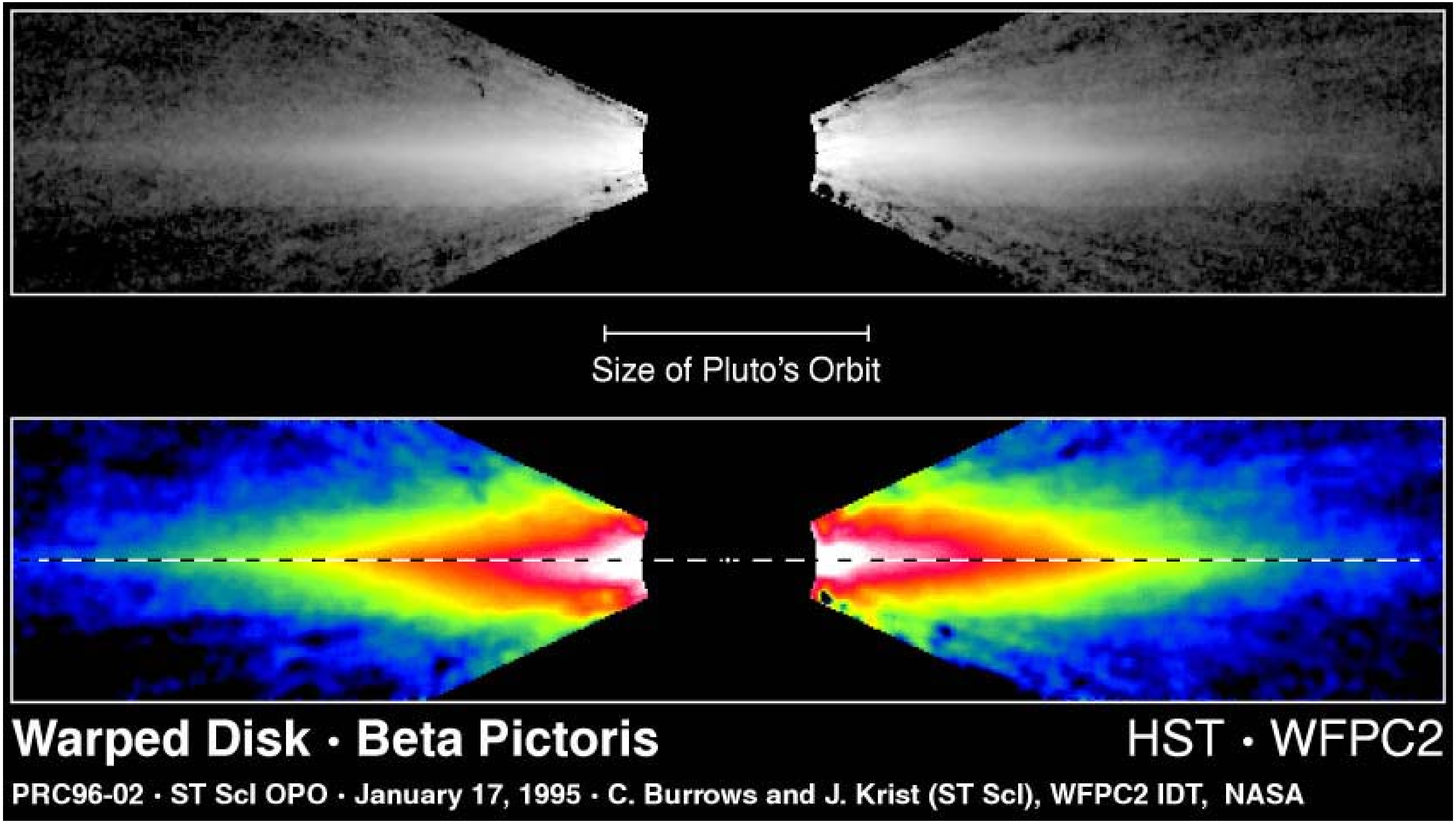
> 50% ejected from System

Liou & Zook 1999)



(Liou & Zook 199

Asymmetries - not clear whether generated by planet (Kalas &Jewitt 1998)



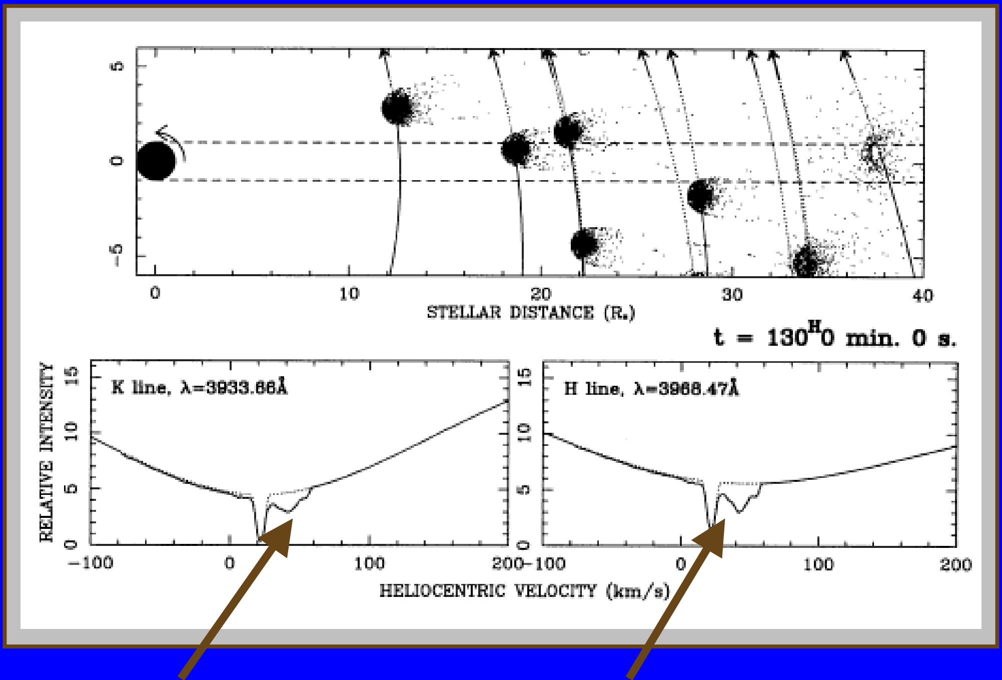
Im Spatial resolved observation of dust disk around beta- pictoris

≈ 10 systems „near Earth" (at distance less than 50 parsec) observed with spatial resolution

‘Circum stellar comets’

➔ *“Fast Evaporating Bodies”*

Model:
Absorption of stellar light by circumstellar gas



(Grady et al. 2000)

Observation:
Variation & Asymmetry of stellar photospheric lines *“redshift”*

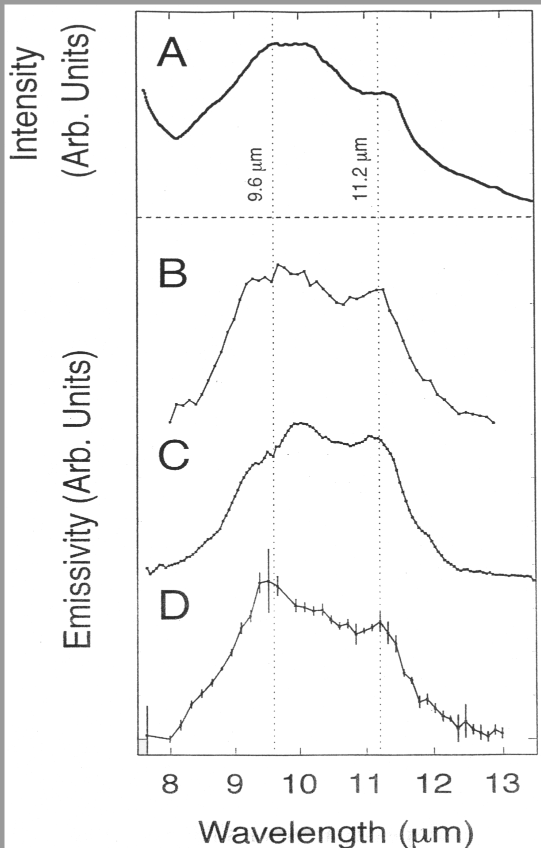
Δv = 200 - 400 km/s
detection H, He, C, N, O, S, Zn, Na, Mn,Si, Mg, Cr, Fe, Al, Ca

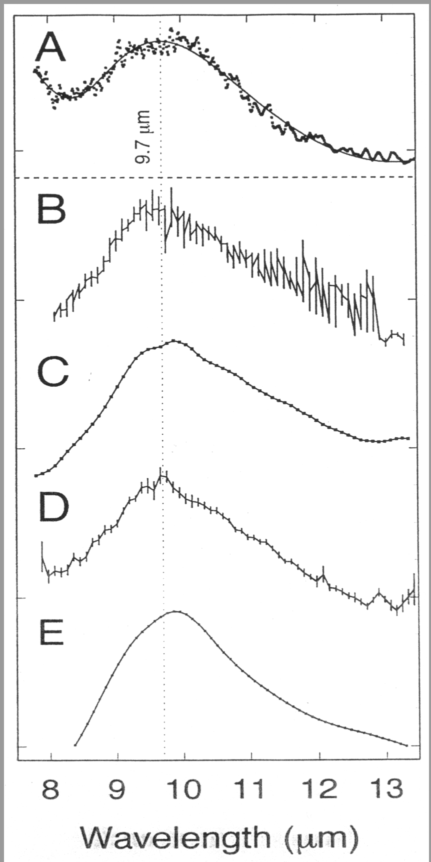
Lagrange et at. Review in Protostars & Planets IV)

Sungrazer 1882 II (Great September Comet) Painted by Ichigoro Ogawa (1882)

SOHO/LASCO image ESA SOHO Webpage

Infrarot Spectra:





Thermal emission of small grains ≠ black body

Emission features are characteristic for material „silicate feature“

Allows comparions of properties

Observations for only one debris shell

A: GEMS-rich IDP
B: Comet Halley
C: Comet Hale-Bopp
D: star with silicate-rich disk

A: GEMS
B,C: Molecular Clouds
E: T Tauri star
D: M-type Supergiant

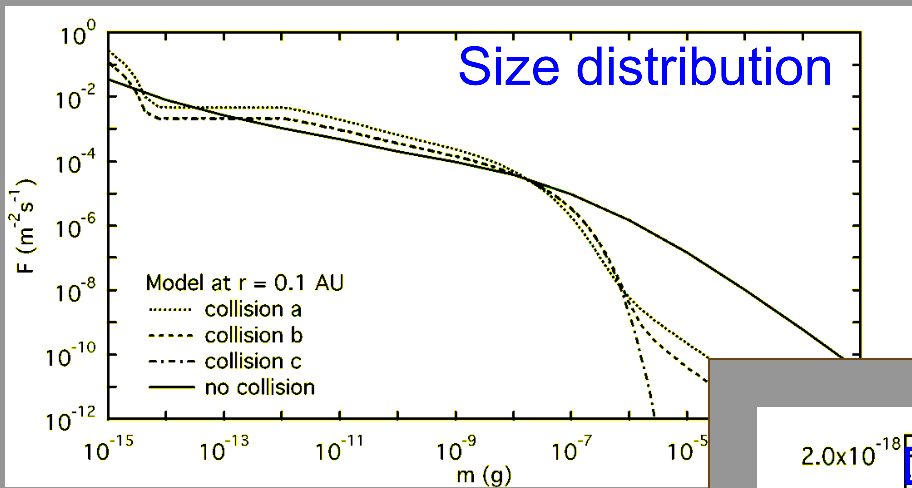
J. P. Bradley *et al.*, 1999

Collision Evolution

Collisions

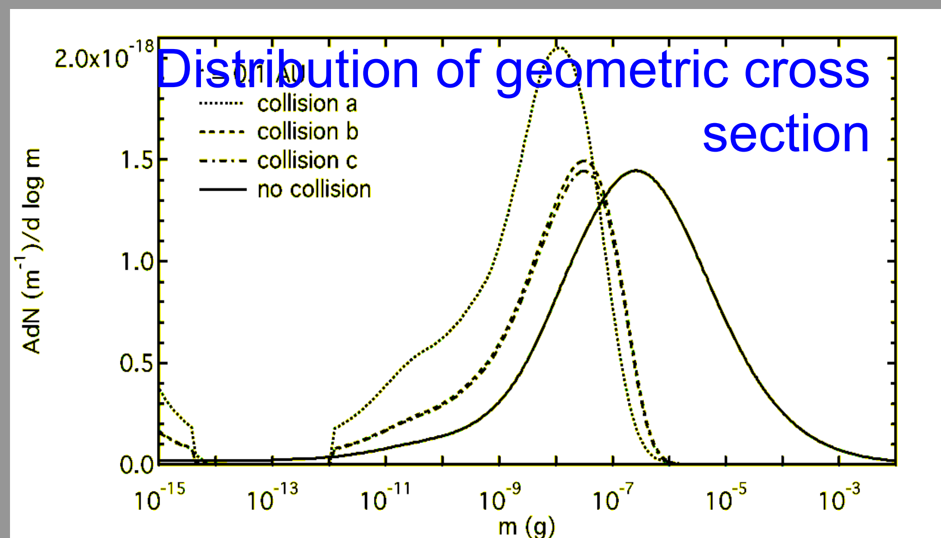
- relativ velocities 1 - 100 km/s
- dust destruction
- production of fragments
- partial sublimation

Collisions in Solar System < 1 AU



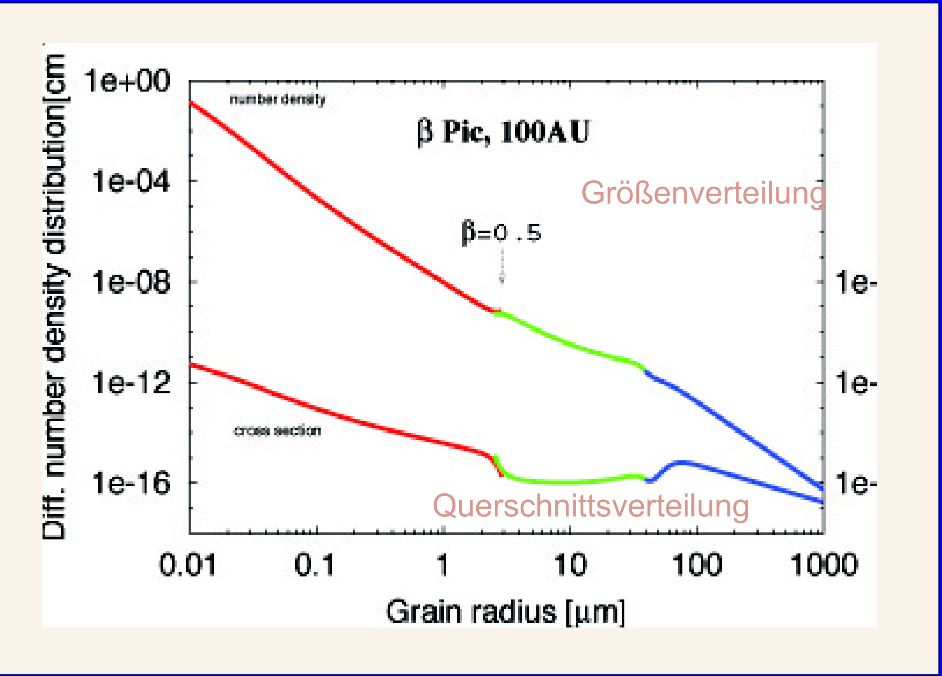
Ishimoto & Mann 1998

Collisions shift the size distribution



Observe „different particles“ near the sun

Model Calculation collisions and size distribution around ß - Pictoris



Size distribution varies

Dust-free zone at r < 40 AU can be caused b collisions

Krivov & Mann 2000, Mann & Levasseur-Regourd 2002

Comparison to Solar System:

→ → →

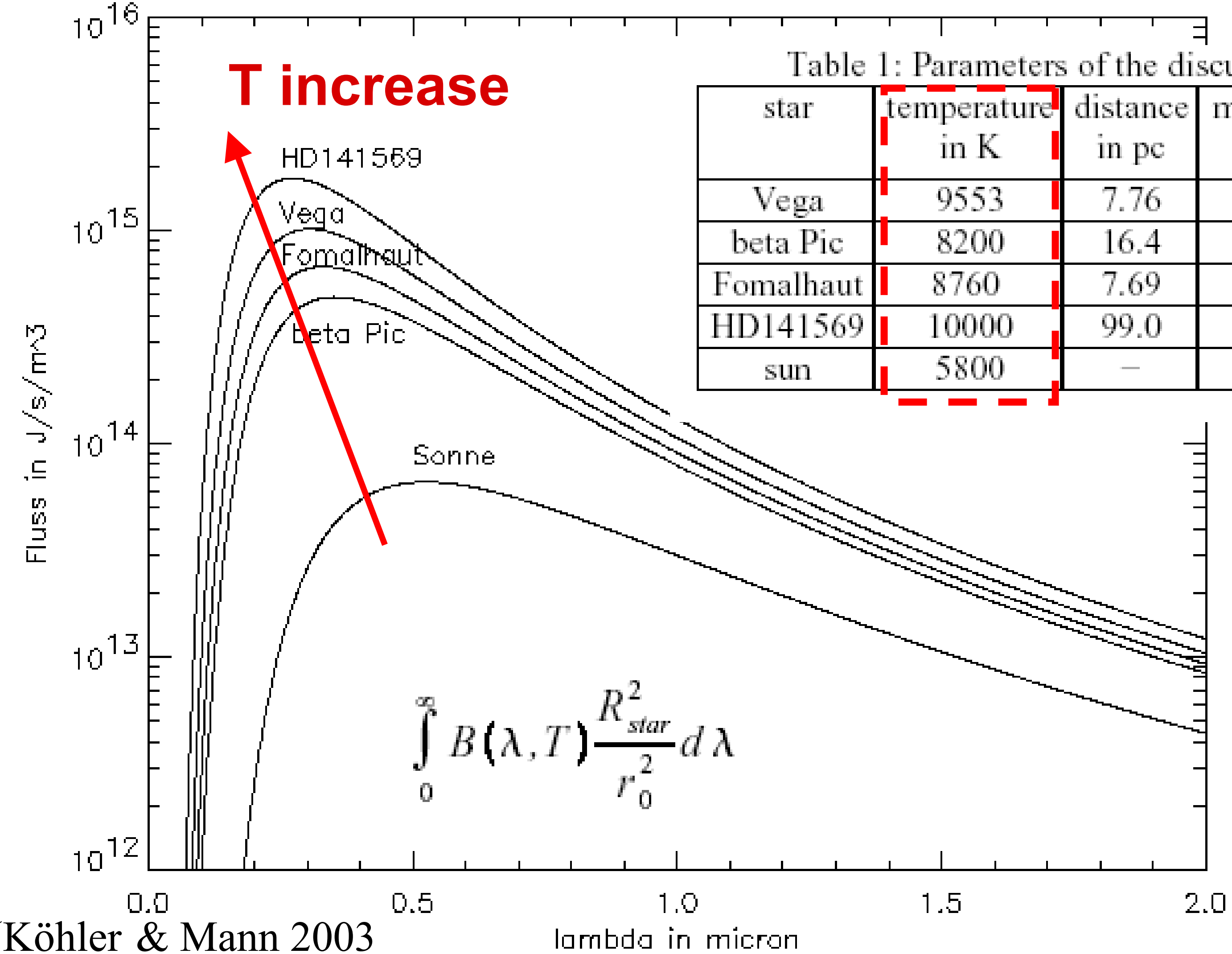
Existence of <u>Comets observed</u>

Existence of <u>Planetesimals infered</u>

Existence of <u>Planets unclear</u>

What about acting forces ?

Stellar Radiation



(Köhler & Mann 2003

Table 1: Parameters of the discussed stars

star	temperature in K	distance in pc	mass in M_{sun}	radius in R_{sun}
Vega	9553	7.76	2.5	2.0
beta Pic	8200	16.4	1.5	1.4
Fomalhaut	8760	7.69	2.3	1.7
HD141569	10000	99.0	2.3	2.7
sun	5800	–	1.0	1.0

Total Stellar Flux

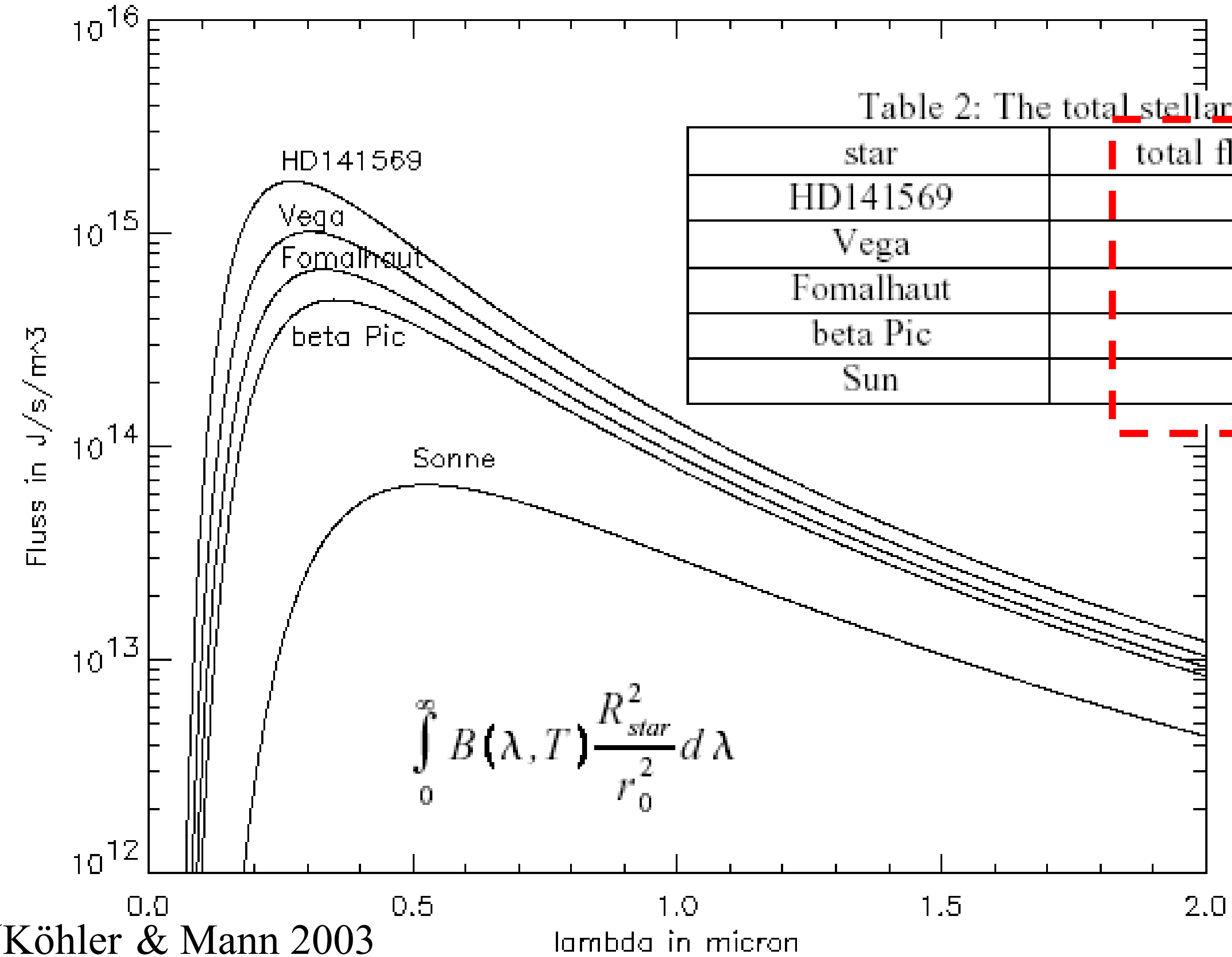


Table 2: The total stellar fluxes

star	total flux in kW/m²
HD141569	90.39
Vega	41.31
Fomalhaut	21.05
beta Pic	11.00
Sun	1.40

$$\int_0^\infty B(\lambda, T) \frac{R_{star}^2}{r_0^2} d\lambda$$

(Köhler & Mann 2003

Comparison to Solar System:

Radiation pressure force force increases as a result of higher stellar photospheric temperatures

Small particles are ejected!

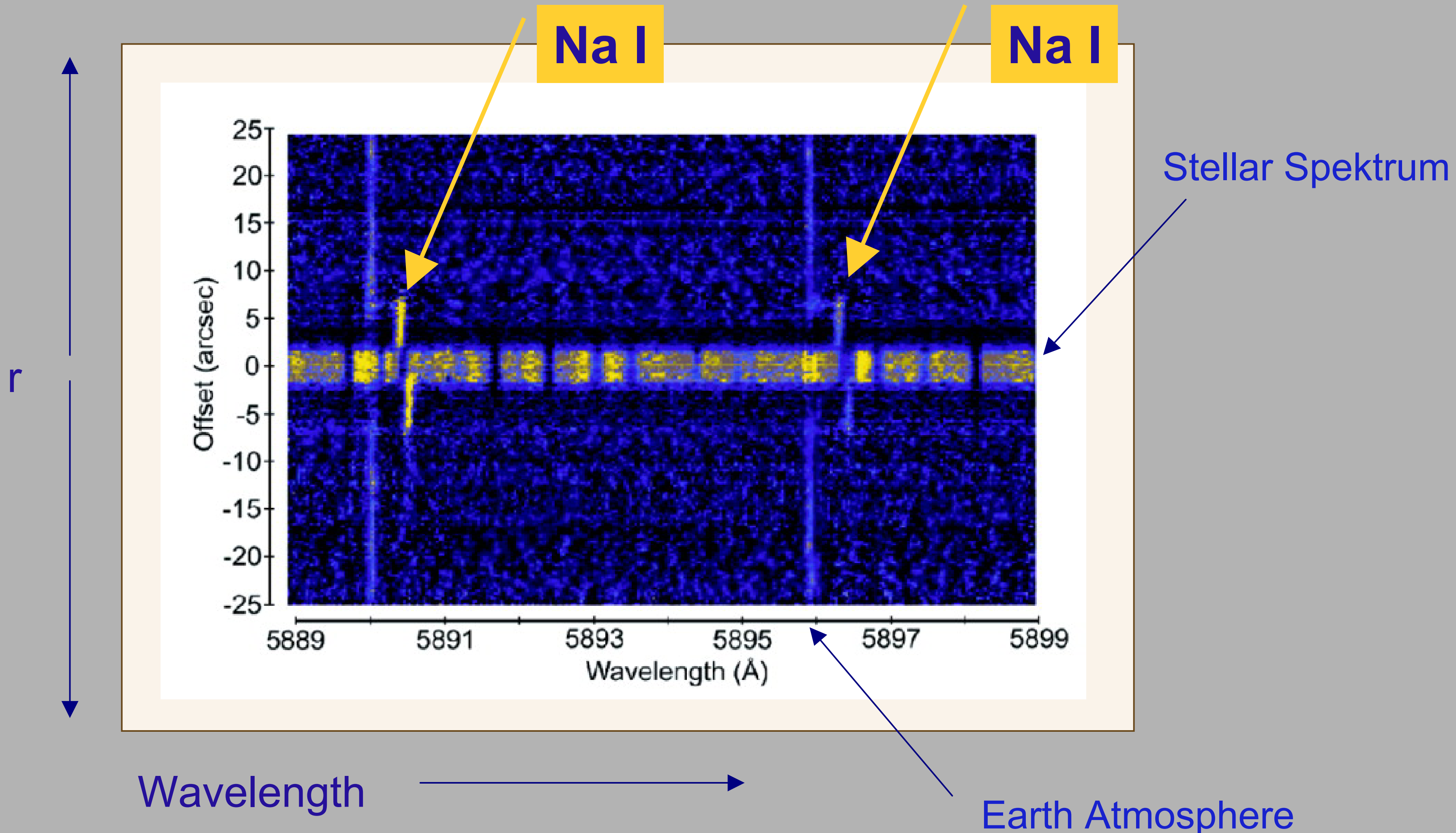
Particles have shorter Poynting-Robertson lifetime

Collisional destruction increases as a result of higher dust number densities

Lifetime often limited by collisions !

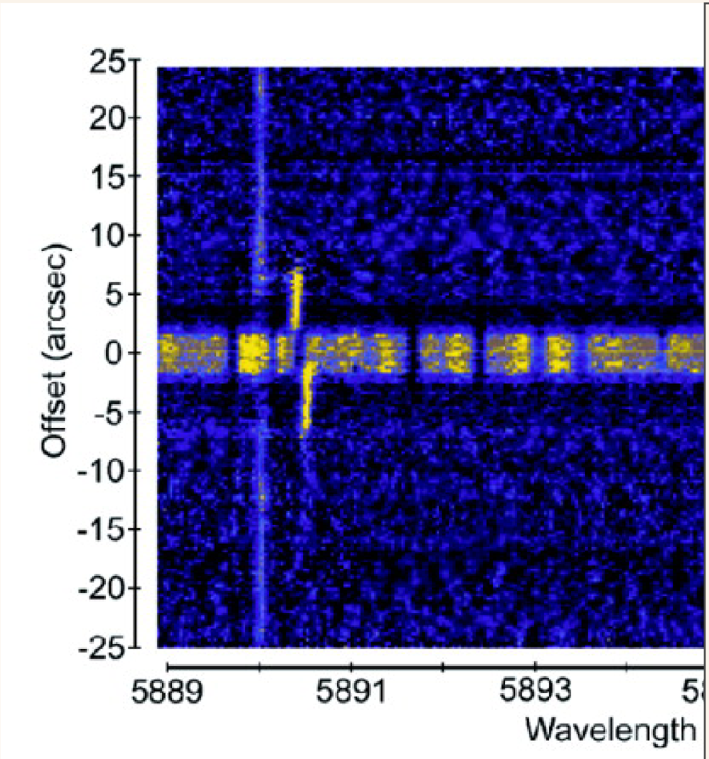
(see works by Artymowicz, Lecavalier about Beta-Pic collision evoltion

Stable Gas Component around ß - Pic



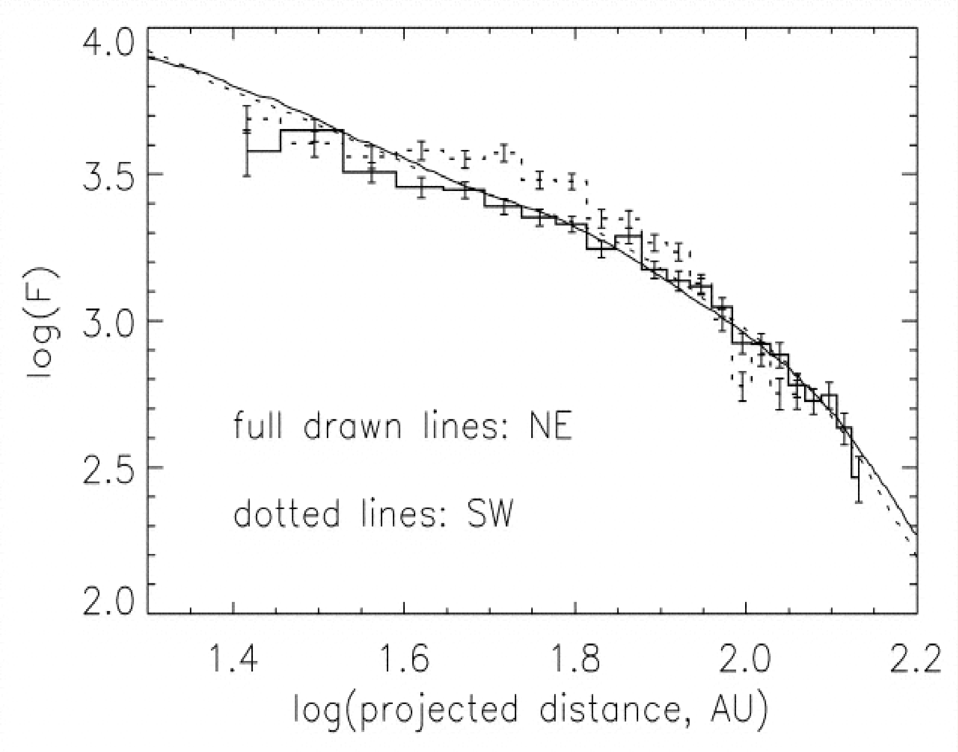
Detection of Na I Resonance Line (5990Å & 5996Å) at 30 - 140 AU

Stable Gas Component around ß - Pic



Ölofson, Liseau & Brandeker 2001

Radial Density Profiles for Gas & Dust:

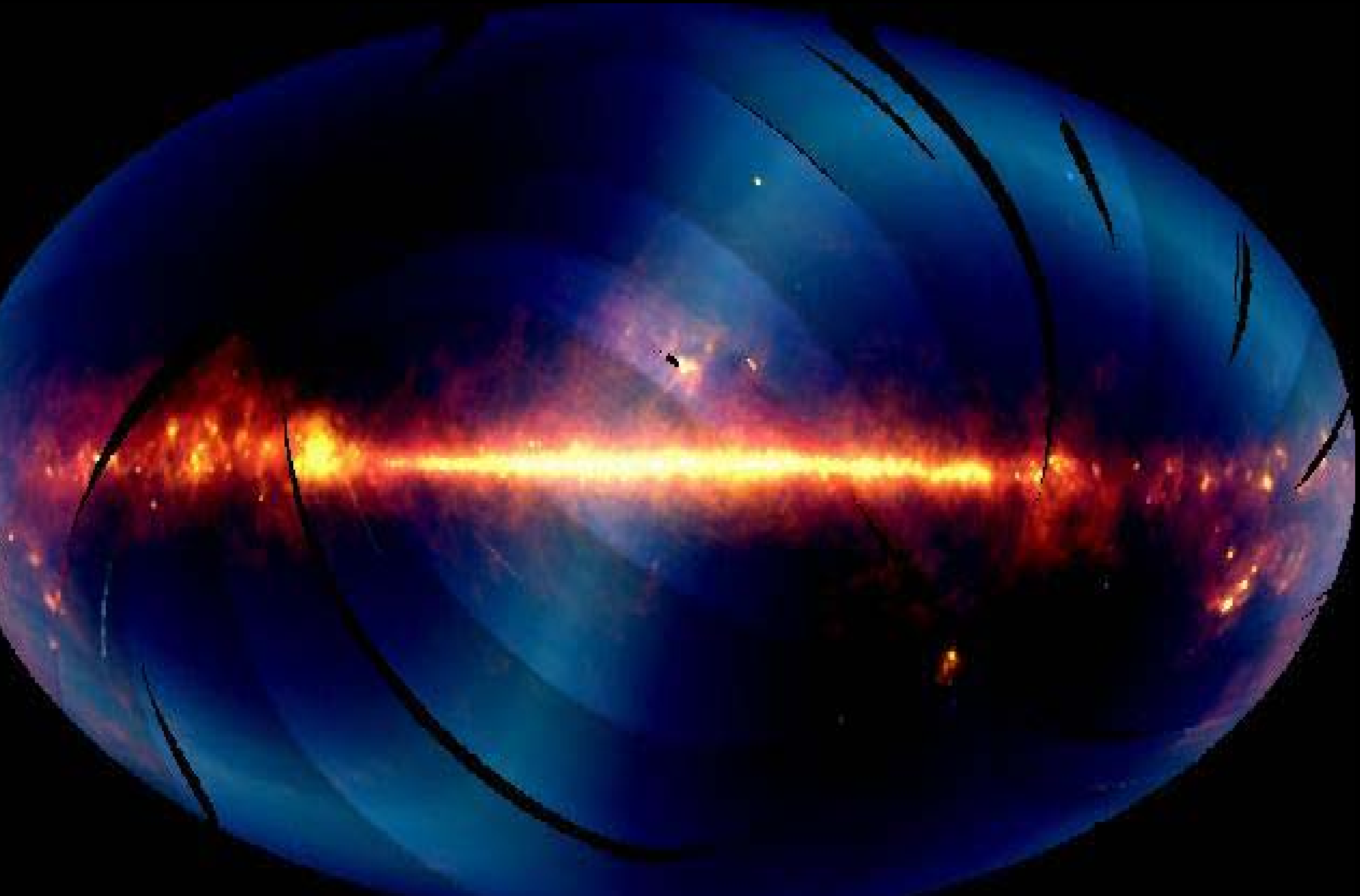


➔➔ **Gas component in Keplerian orbits follows dust motion**

Summary

- Circumstellar Debris Disks are the circum-stellar systems that are most similar to our solar system
- Observations provide information about size distribution & spatial distribution
- Some observations of IR spectra, more spectral data expected in future - allow a better comparison of material properties

Please ask Questions!



Gravitational force F_{grav} and radiation pressure force F_{rad}

The major forces acting on a dust particle with the mass m in a distance r from the star are the gravitational force F_{grav} and the radiation pressure force $F_{pr.}$ Both forces are proportional to $1/r^2$ and it is useful to calculate their ratio: as

$$\beta = \frac{F_{rp}}{F_{grav}} \qquad (2)$$

$$\beta = \frac{\pi \cdot R_{star}^2}{\gamma \cdot M_{star} \cdot c} \frac{G}{m} \int_0^\infty B(\lambda, T) Q_{pr}(s, \lambda) d\lambda \qquad (3)$$

where G is the effective geometric cross section, B the Planck function, R_{star} the radius of the star, c the velocity of light, Q_{pr} is the efficiency factor for radiation pressure, γ is the gravitational constant and s the particle size [12]. This equation is valid for particles at distance r >> $R_{star.}$

(Köhler & Mann 2003