Gas in debris disks

Alexis Brandeker
Stockholm Observatory

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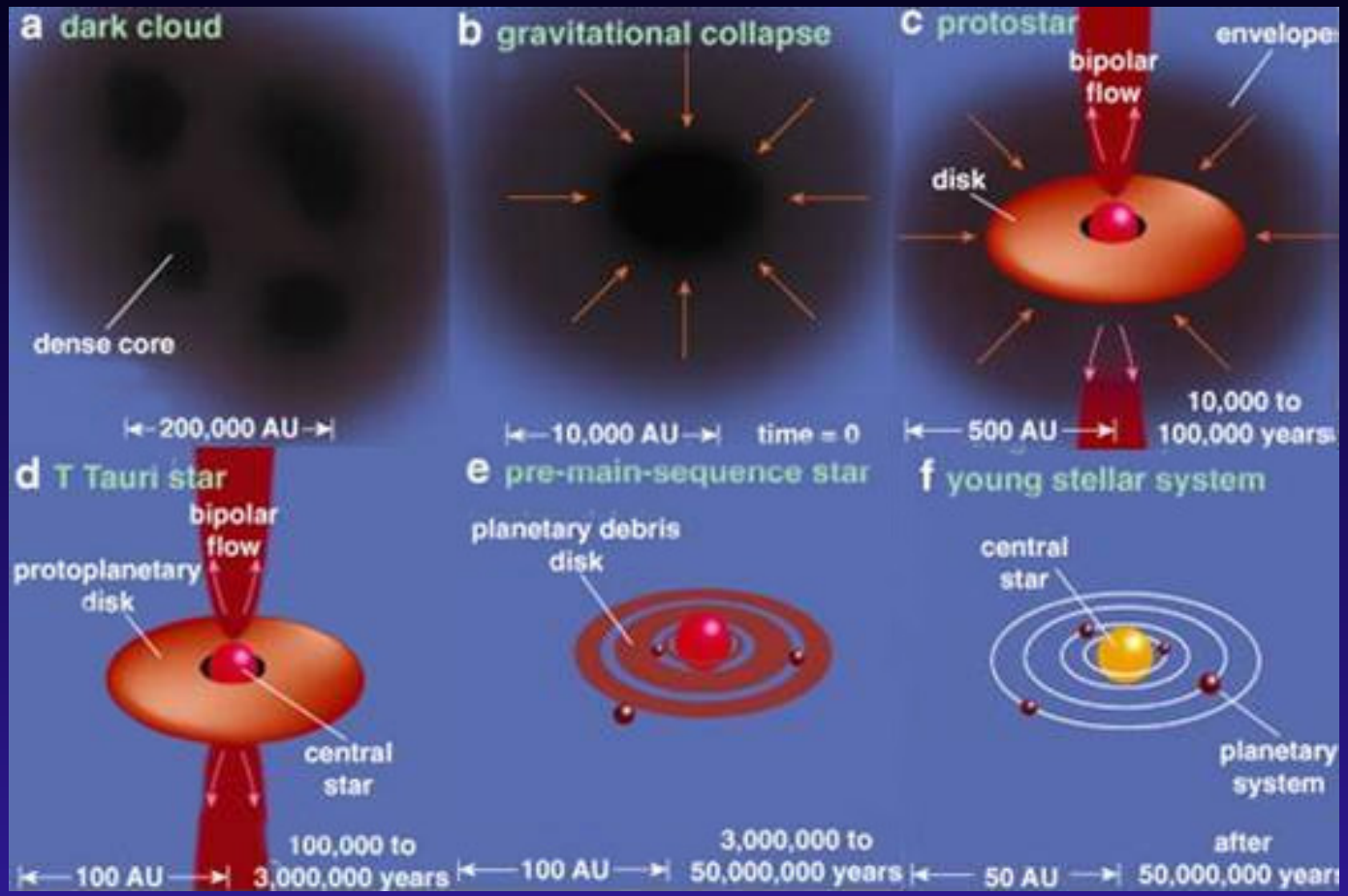
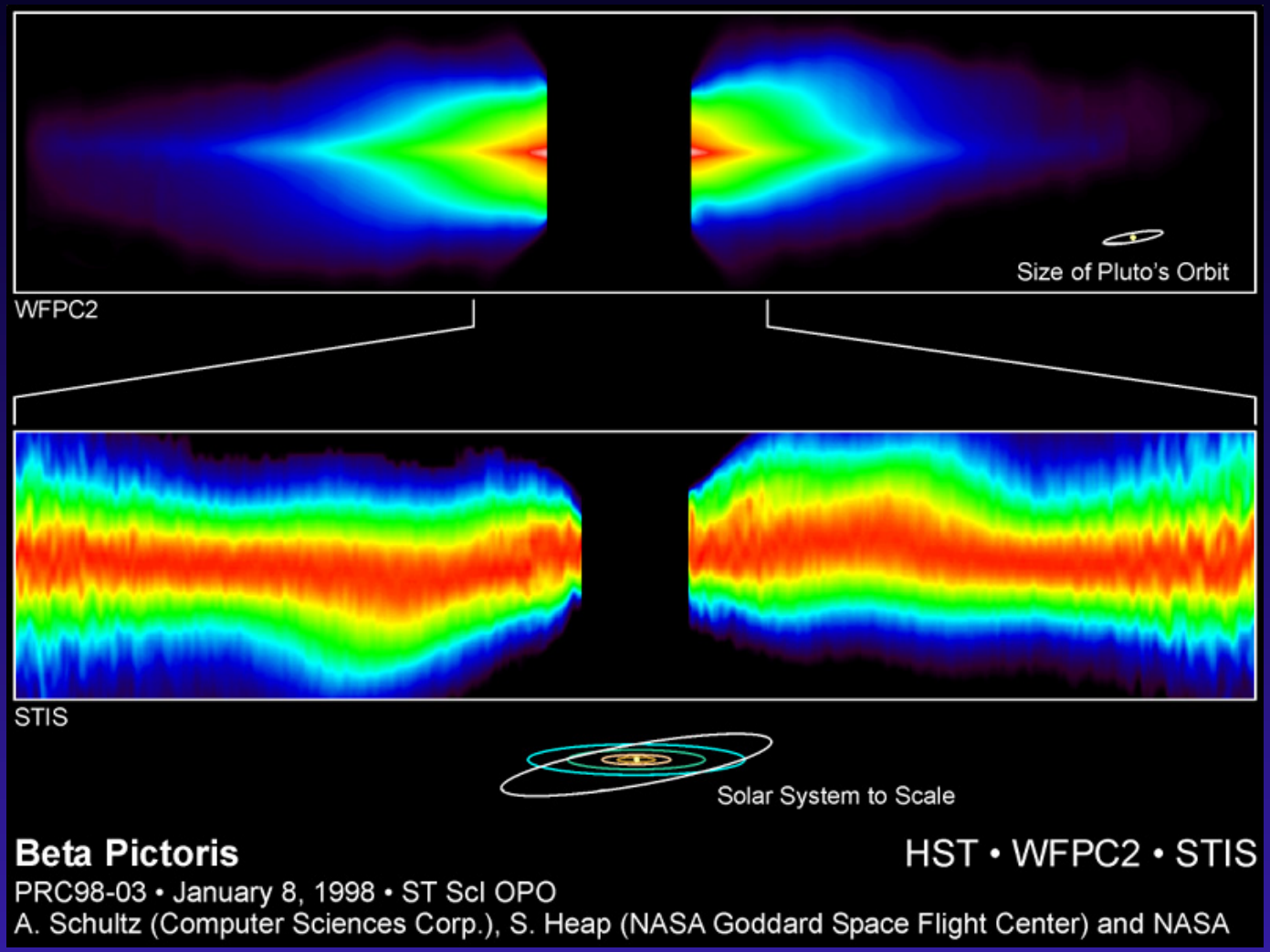
Contents

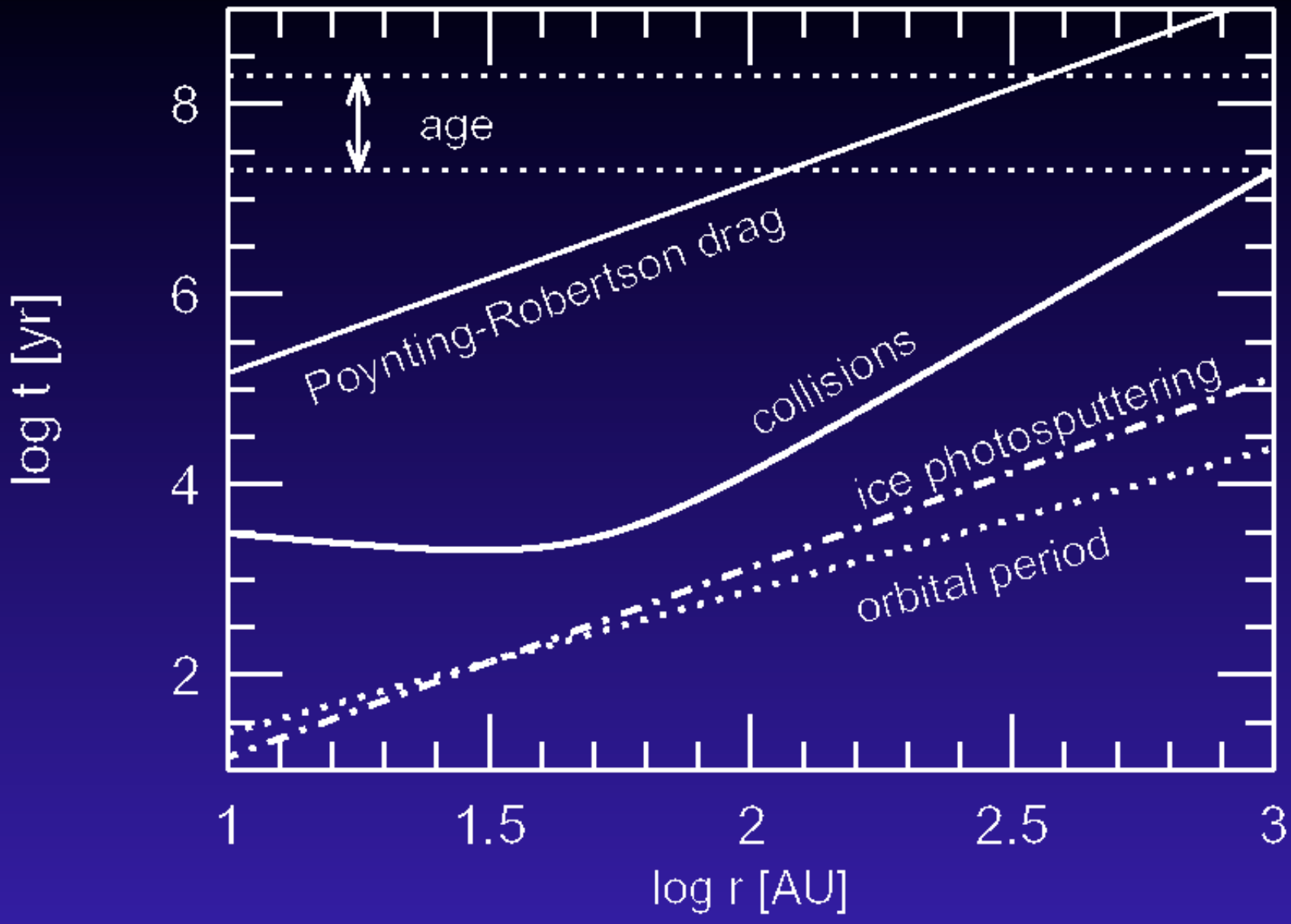
- What is a debris disk?
- Observations of gas in debris disks
- Gas production in debris disks
- Keeping the gas from escaping
- The composition of dust/gas



http://ssc.spitzer.caltech.edu/documents/compendium/galsci/

β Pictoris in scattered light
(20 pc, 15 Myr, A5V)

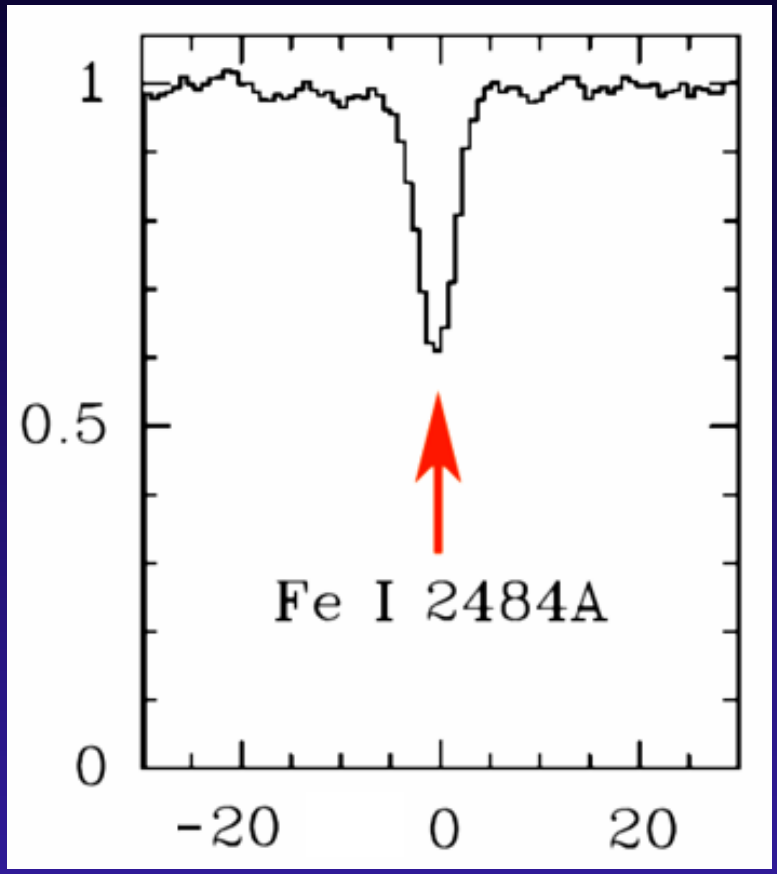




From Artymowicz 1997, AR 25:175

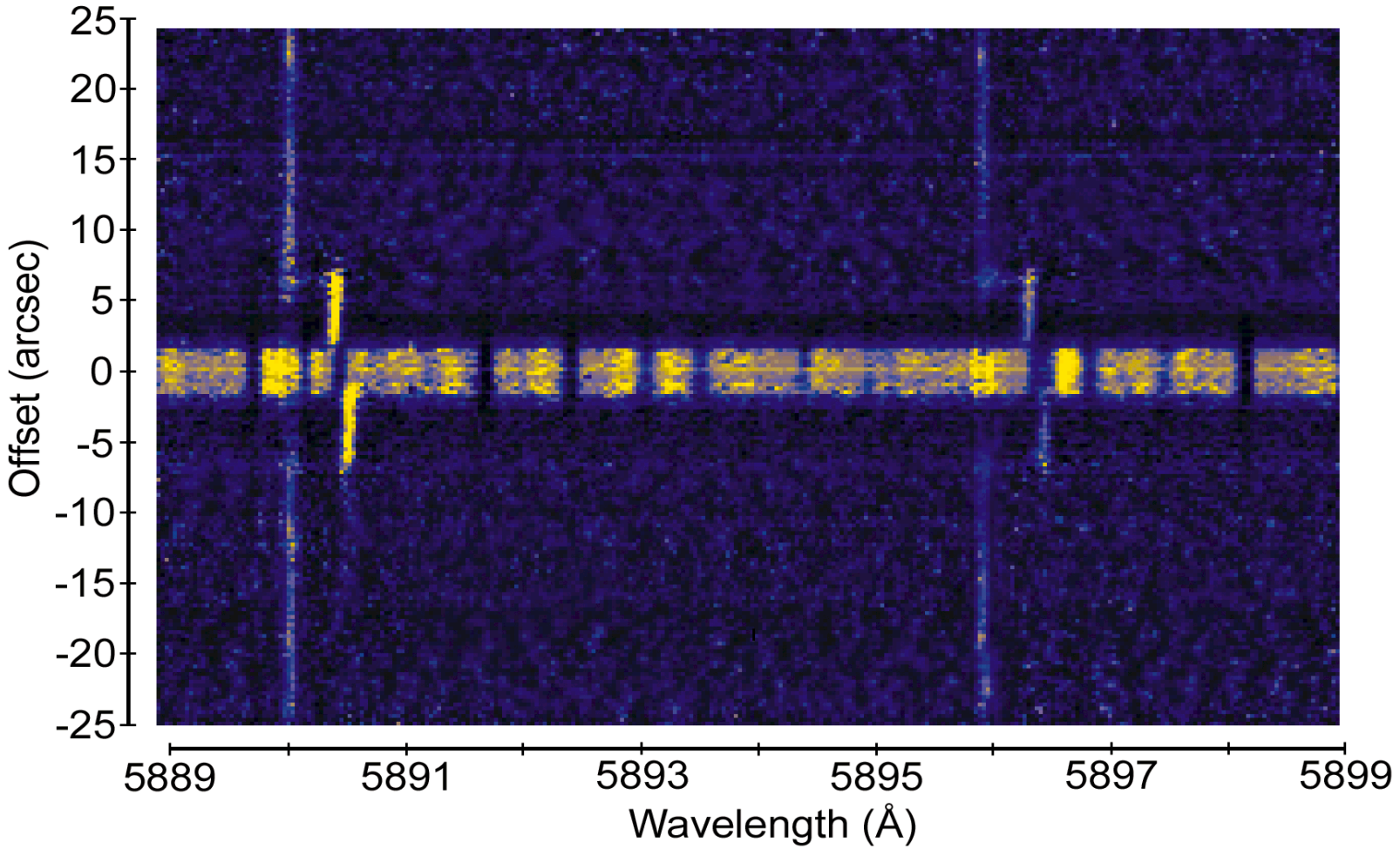
β Pictoris gas

- β Pictoris found to be "shell" star by Slettebak (1975, ApJ, 197:137)

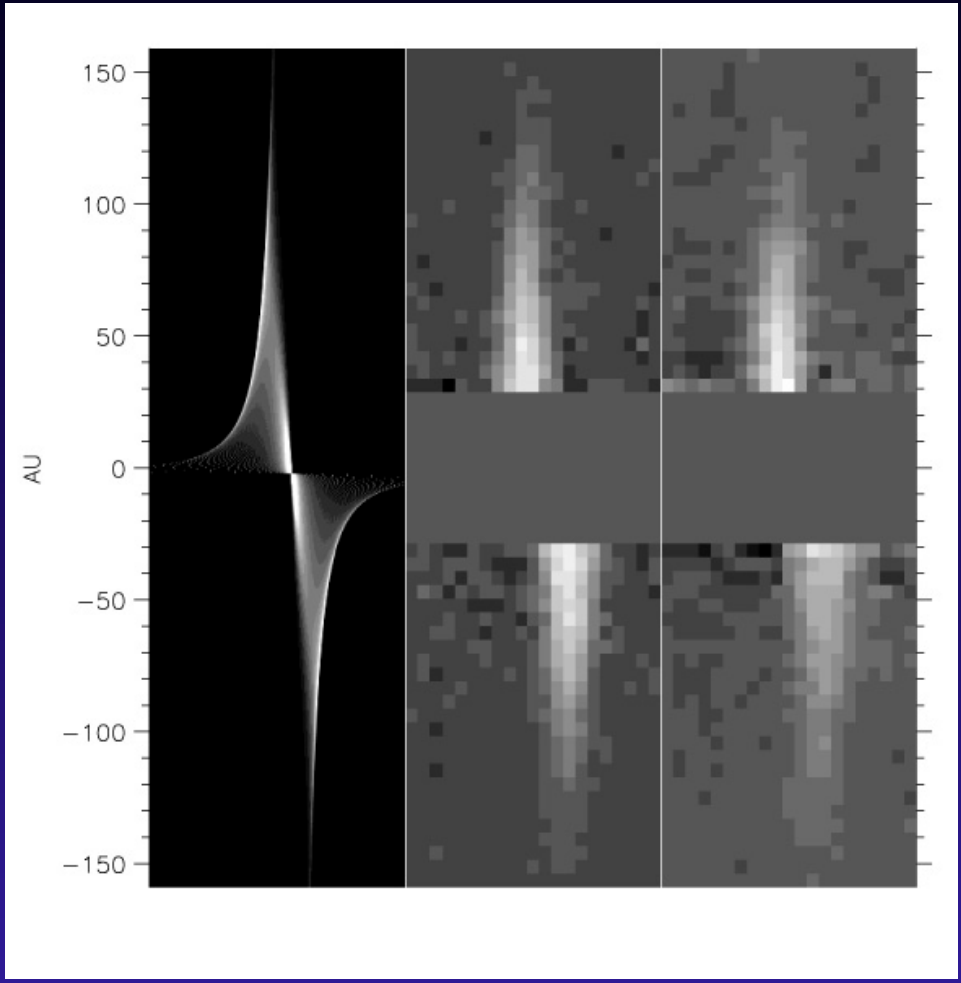


Lagrange et al. 1998, A&A 330:1091

Extended gas

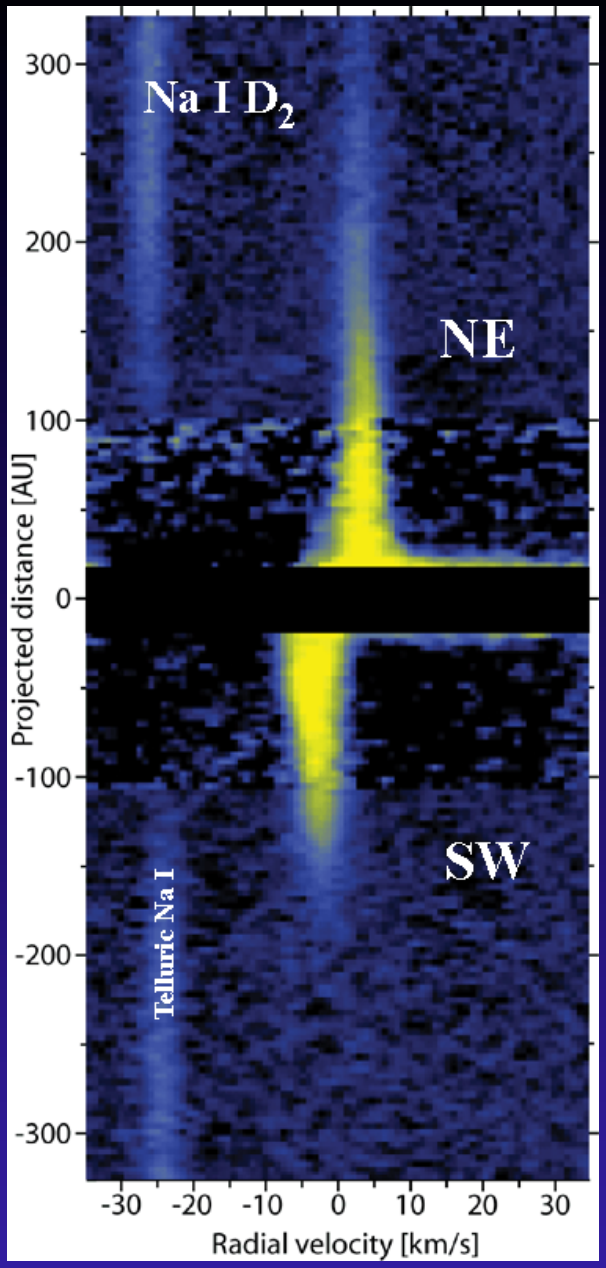


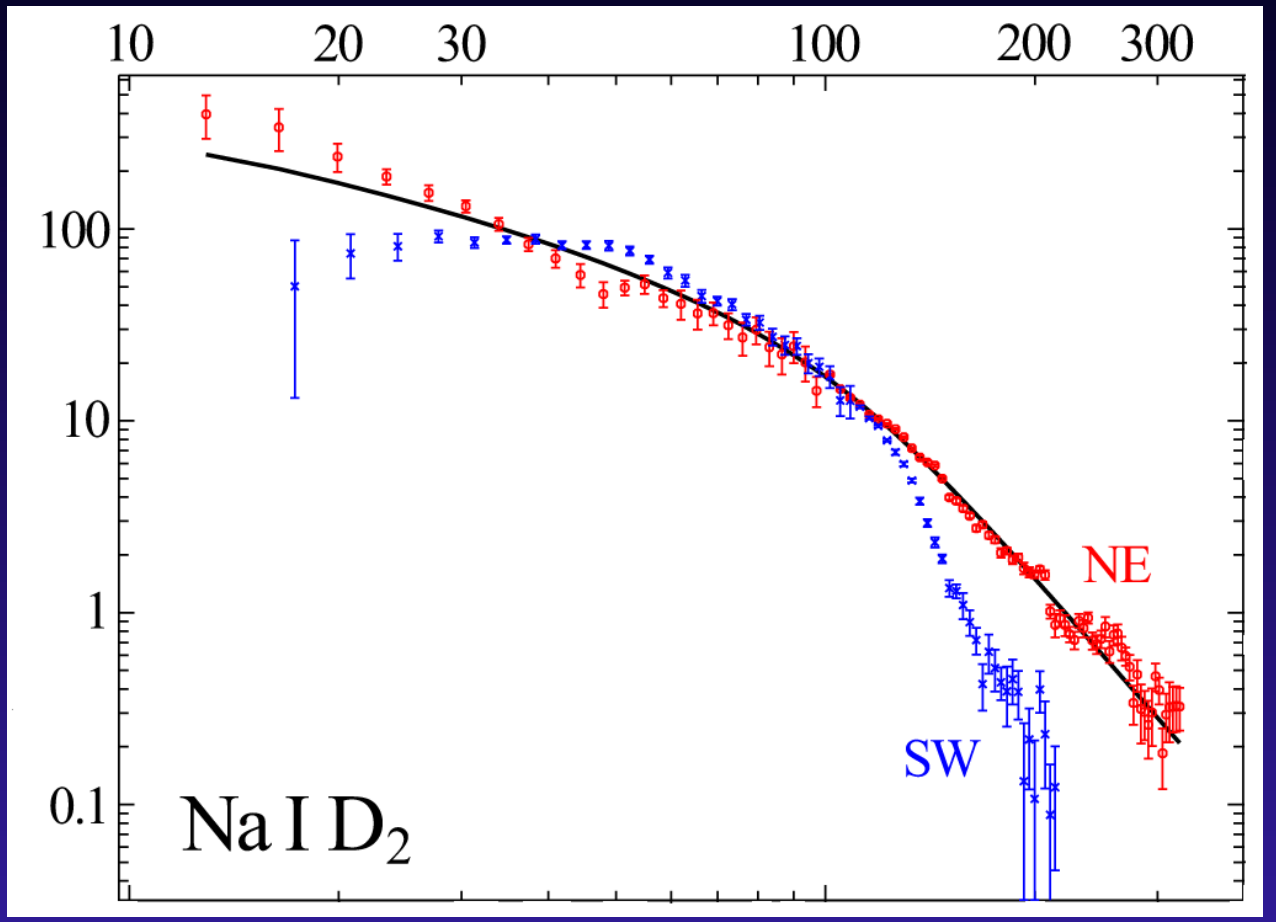
NTT/EMMI Olofsson et al. 2001, ApJ 563:L77



NTT/EMMI Olofsson et al. 2001, ApJ 563:L77

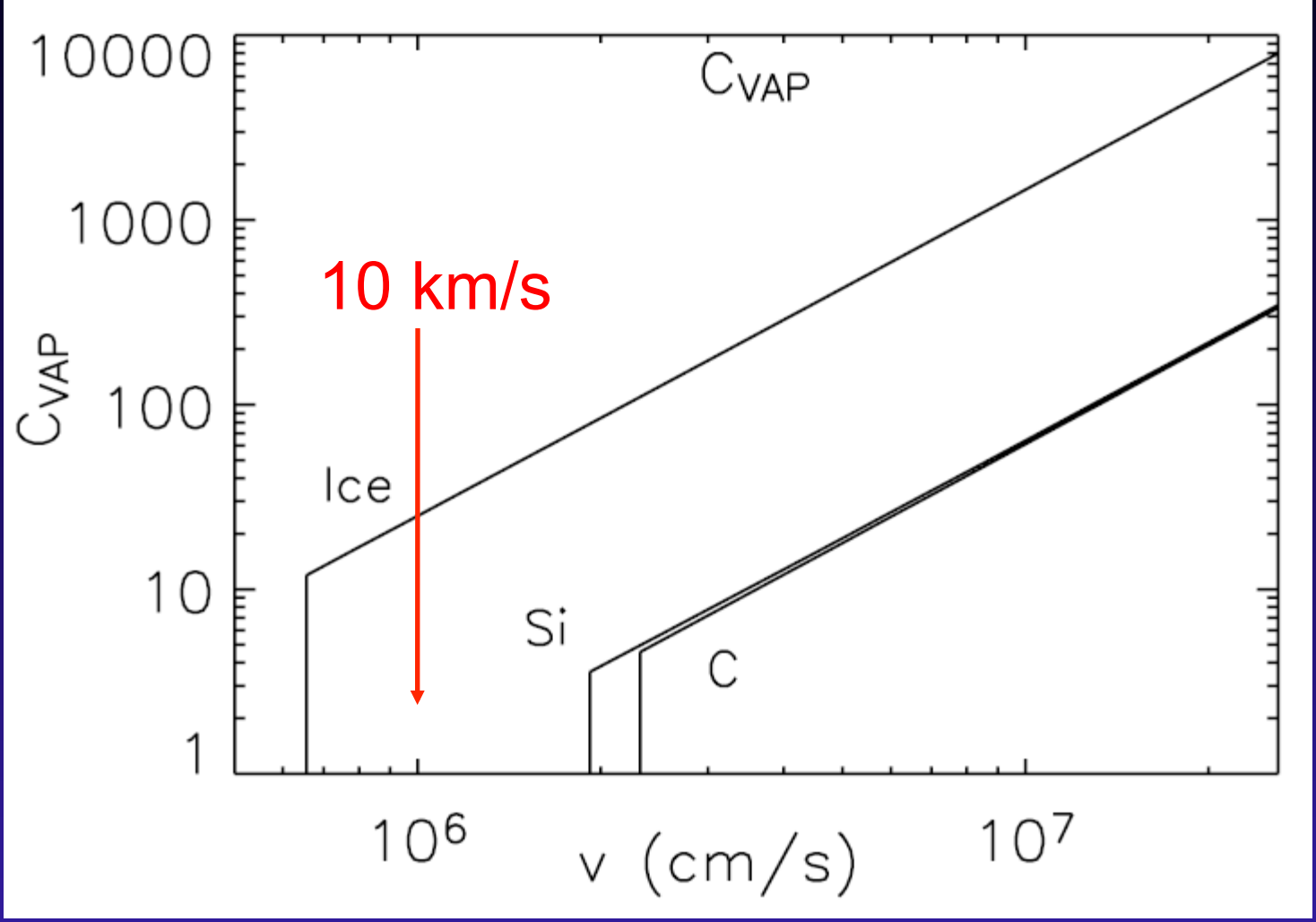
Asymmetris in the gas disk





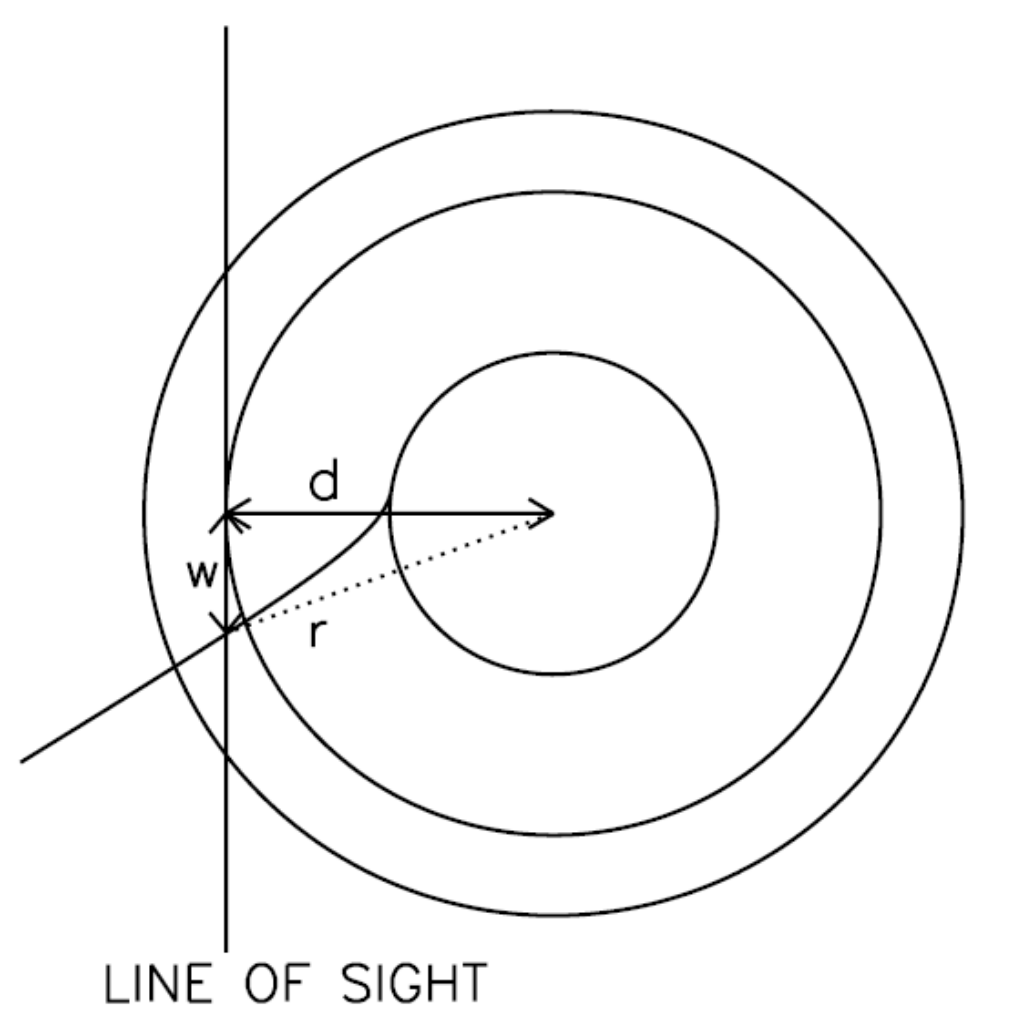
VLT/UVES Brandeker et al. 2004

Grain-grain collisions



Czechowski & Mann 2007, ApJ 660:1541

β-meteoroids!



Czechowski & Mann 2007, ApJ 660:1541

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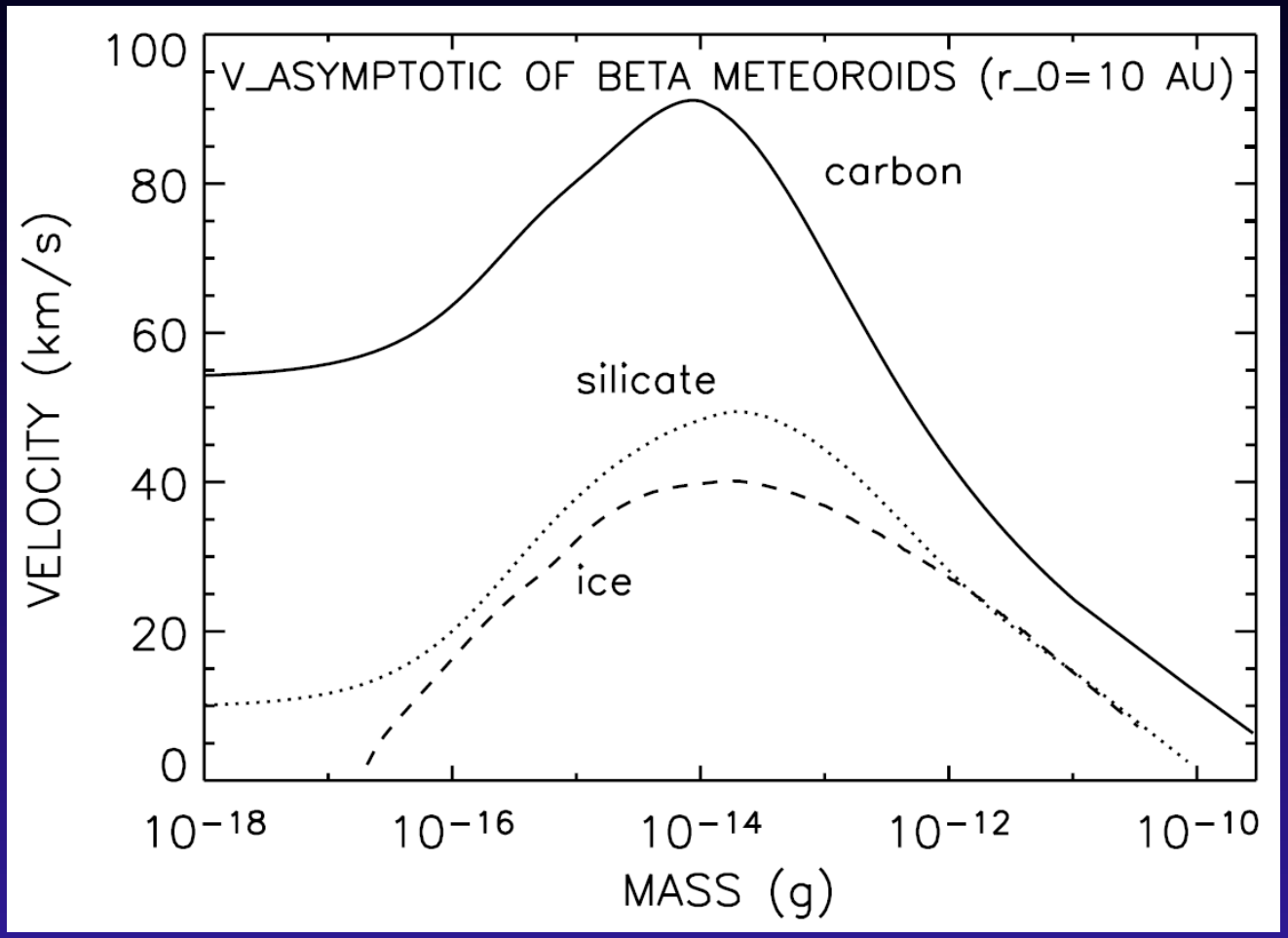
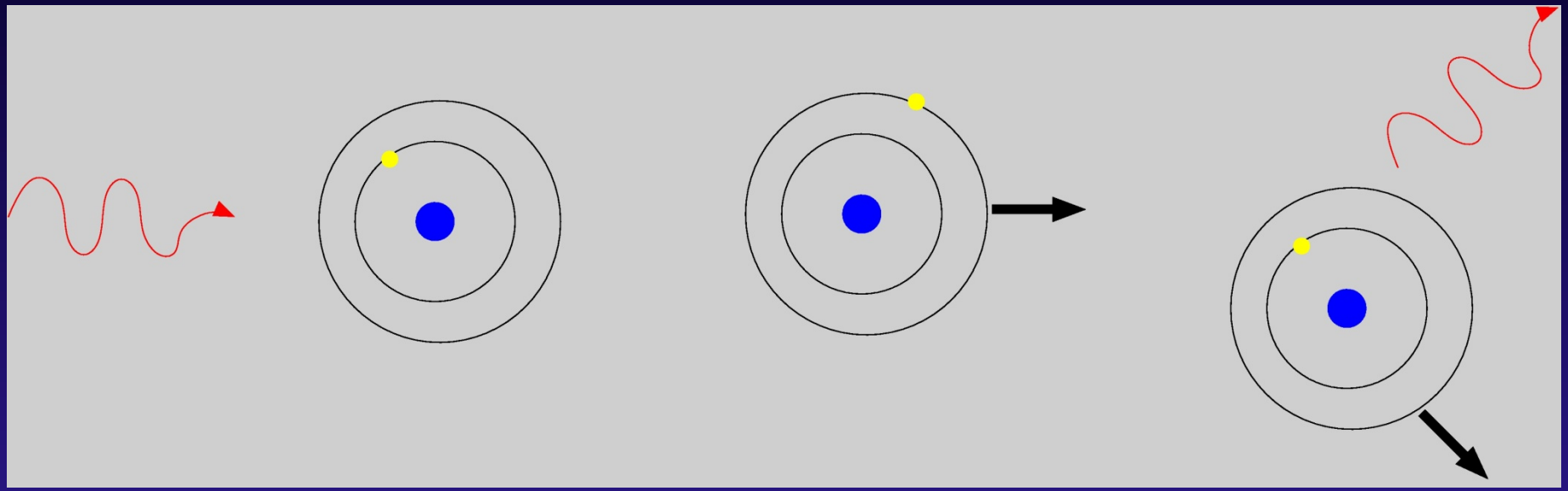


Czechowski & Mann 2007, ApJ 660:1541

Radiation force



(Rodrigo Fernández)

On average, atoms move in direction of incident radiation

Fernández et al. 2006, ApJ 643:509

TABLE 1

RADIATION FORCE COEFFICIENTS

Ion	$\beta^{a,b}$	Ion	β^{b}	Ion	$\beta^{a,b}$	Ion	$\beta^{a,b}$
H I	$(1.6\pm0.1)10^{-3}$	F III	$(5.0\pm1.0)10^{-9}$	S II	$(9.0\pm1.0)10^{-5}$	V I	72 ± 4
Ne III	$(9.0\pm2.0)10^{-4}$					V II	4.4 ± 0.2
Na I	360 ± 20					V III	0
Na II	0					Cr I	93 ± 5
Na III	0					Cr II	$(6.0\pm3.0)10^{-7}$
Mg I	74 ± 8					Cr III	...
						Mn I	28 ± 3
						Mn II	7 ± 1
						Mn III	...
						Fe I	27 ± 2
						Fe II	5.0 ± 0.3
C III	$(8.5\pm0.9)10^{-6}$	Al II	0.36 ± 0.05	Ca I	330 ± 40	Fe III	$(3.0\pm0.6)10^{-7}$
N I	$(2.1\pm0.1)10^{-4}$	Al III	12 ± 1	Ca II	50 ± 10	Co I	16 ± 1
N II	$(7.5\pm0.5)10^{-6}$	Si I	6.0 ± 0.6	Ca III	...	Co II	0
N III	$(7.0\pm1.0)10^{-6}$	Si II	9 ± 9	Sc I	220 ± 20	Co III	$(4.0\pm2)10^{-7}$
O I	$(3.3\pm0.2)10^{-4}$	Si III	$(5.8\pm0.6)10^{-4}$	Sc II	$(1.3\pm0.4)10^{3}$	Ni I	26 ± 2
O II	$(3.1\pm0.7)10^{-9}$	P I	3.4 ± 0.6	Sc III	$(9.0\pm3.0)10^{-2}$	Ni II	$(7.0\pm2.0)10^{-2}$
O III	$(6.5\pm0.6)10^{-7}$	P II	$(2.2\pm0.3)10^{-3}$	Ti I	97 ± 5	Ni III	$(3.0\pm2.0)10^{-7}$
F I	0	P III	$(5.0\pm2.0)10^{-4}$	Ti II	28 ± 2	p[c]	4.4×10^{-11}
F II	$(3.5\pm0.9)10^{-6}$	S I	0.56 ± 0.09	Ti III	$(5.0\pm0.1)10^{-4}$	e[c]	0.27

[a] $\beta = 0$ means that no ground state transitions are known in the range $1000\text{Å} < \lambda < 50000\text{Å}$

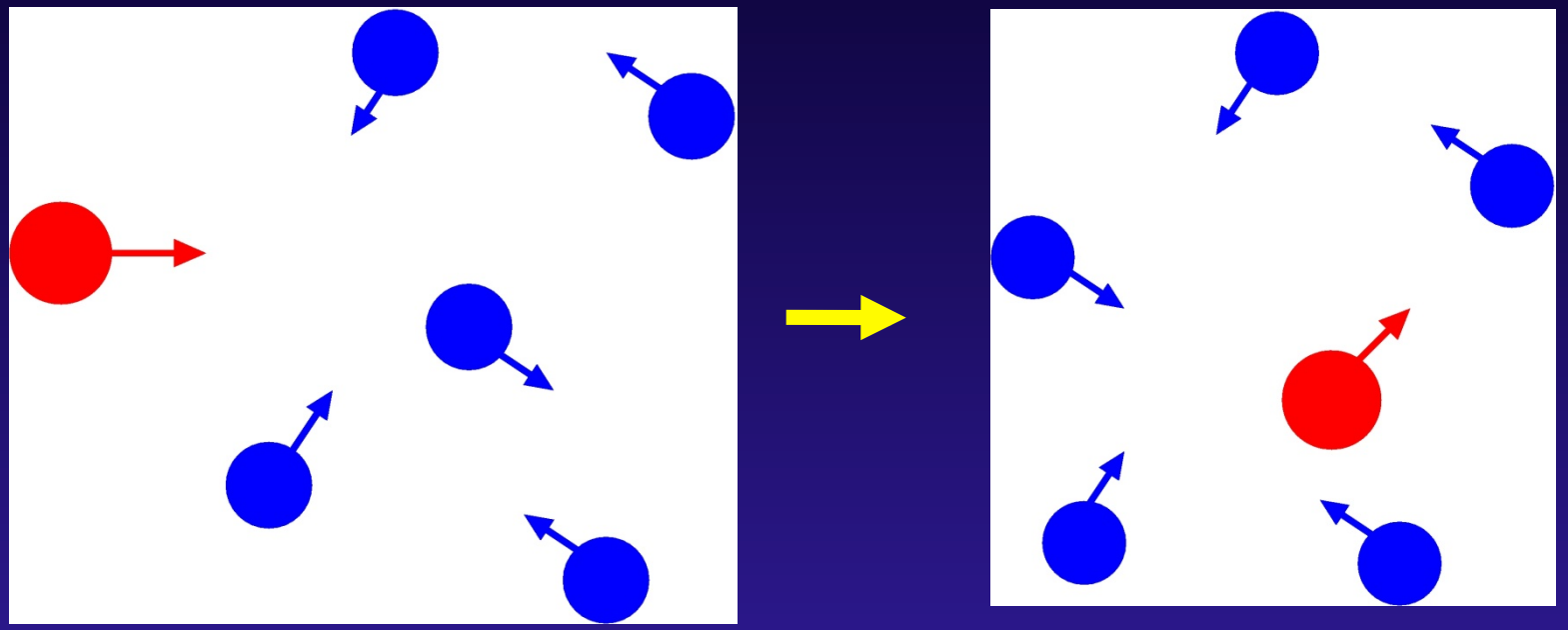
[b] Empty entries mean that no atomic data was available

[c] Proton and electron value calculated using Thomson cross section

Collisional braking: principle

before

after



(Rodrigo Fernández)

Collision frequency – Braking inertia

Fernández et al. 2006, ApJ 643:509

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H I	$(1.6\pm0.1)10^{-3}$	F III	$(5.0\pm1.0)10^{-9}$	S II	$(9.0\pm1.0)10^{-5}$	V I	72 ± 4
He I	0	Ne I	0	S III	$(2.0\pm1.0)10^{-4}$	V II	4.4 ± 0.2
He II	···	Ne II	0	Cl I	$(2.3\pm0.4)10^{-3}$	V III	0
Li I	900 ± 40	Ne III	$(9.0\pm2.0)10^{-8}$	Cl II	$(3.7\pm0.4)10^{-7}$	Cr I	93 ± 5
Li II	0	Na I	360 ± 20	Cl III	$(3.0\pm2.0)10^{-6}$	Cr II	$(6.0\pm3.0)10^{-7}$
C I	$(3.3\pm0.1)10^{-2}$			Ar I	$(1.7\pm0.3)10^{-6}$	Cr III	···
C II	$(2.3\pm0.2)10^{-3}$			Ar II	0	Mn I	28 ± 3
C III	$(8.5\pm0.9)10^{-6}$			Ar III	$(1.5\pm0.2)10^{-7}$	Mn II	7 ± 1
				K I	200 ± 20	Mn III	···
				K II	···	Fe I	27 ± 2
				K III	$(4.4\pm0.2)10^{-4}$	Fe II	5.0 ± 0.3
C III	$(8.5\pm0.9)10^{-6}$	Al II	0.36 ± 0.05	Ca I	330 ± 40	Fe III	$(3.0\pm0.6)10^{-7}$
N I	$(2.1\pm0.1)10^{-4}$	Al III	12 ± 1	Ca II	50 ± 10	Co I	16 ± 1
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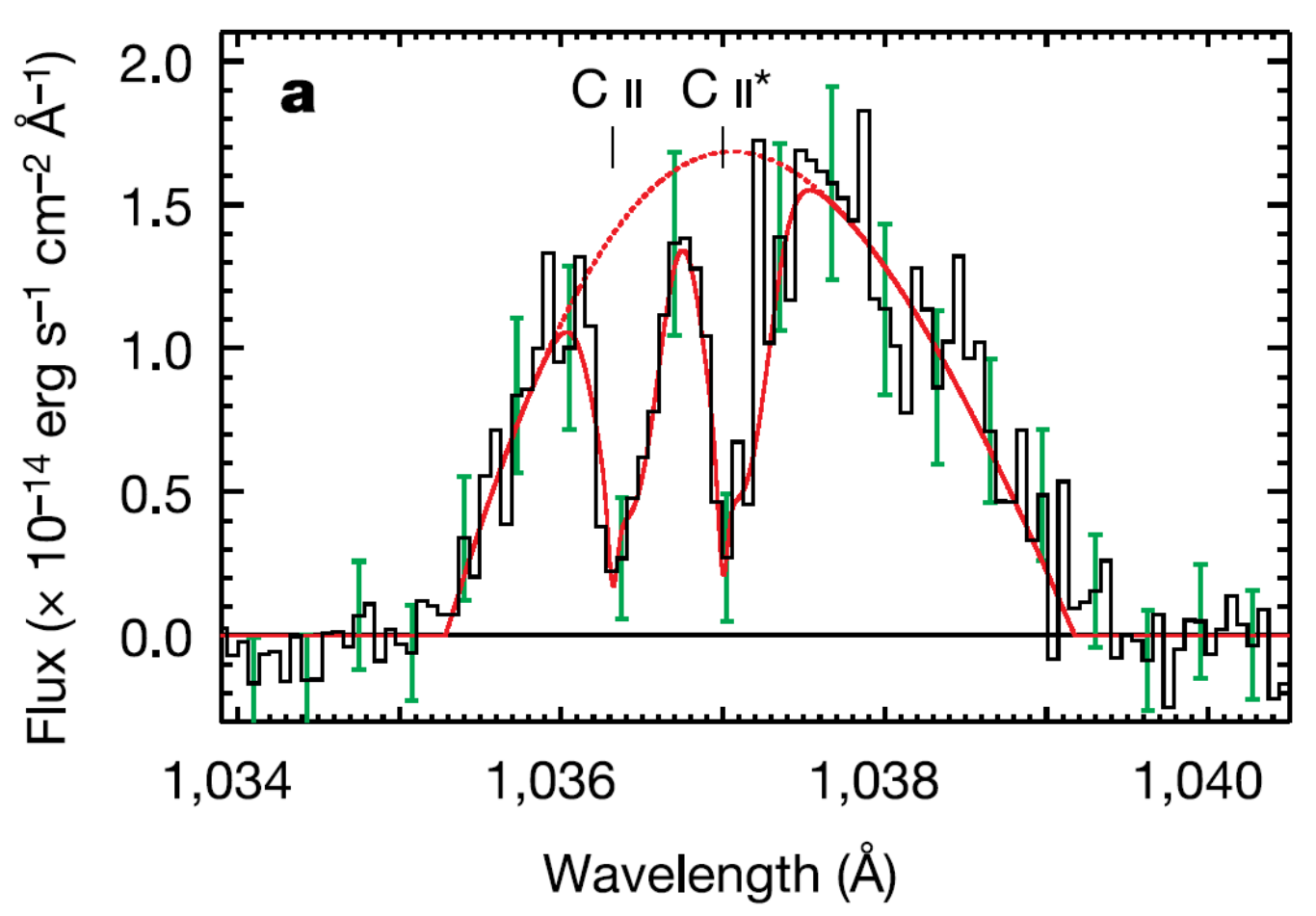
[b] Empty entries mean that no atomic data was available

[c] Proton and electron value calculated using Thomson cross section

Element	v_{ion} [b] (km s^{-1})	n_I/n_{II+} [c]
Li I	0.11	4.4×10^{-6}
Be I	58	4.4×10^{-2}
B I	0.41	6.1×10^{-4}
Na I	3.3	3.2×10^{-4}
Mg I	1.1	6.4×10^{-4}
Al I	5.0×10^{-4}	8.5×10^{-7}
Si I	0.02	1.3×10^{-4}
P I	8.7	1.5×10^{-1}
K I	0.5	1.5×10^{-4}
Ca I	0.03	3.5×10^{-6}
Sc I	3.5	7.0×10^{-4}
Ti I	0.6	3.0×10^{-4}
V I	0.2	1.2×10^{-4}
Cr I	0.9	4.8×10^{-4}
Mn I	0.4	7.6×10^{-4}
Fe I	0.5	9.0×10^{-4}
Co I	0.8	2.9×10^{-3}
Ni I	0.3	4.8×10^{-4}

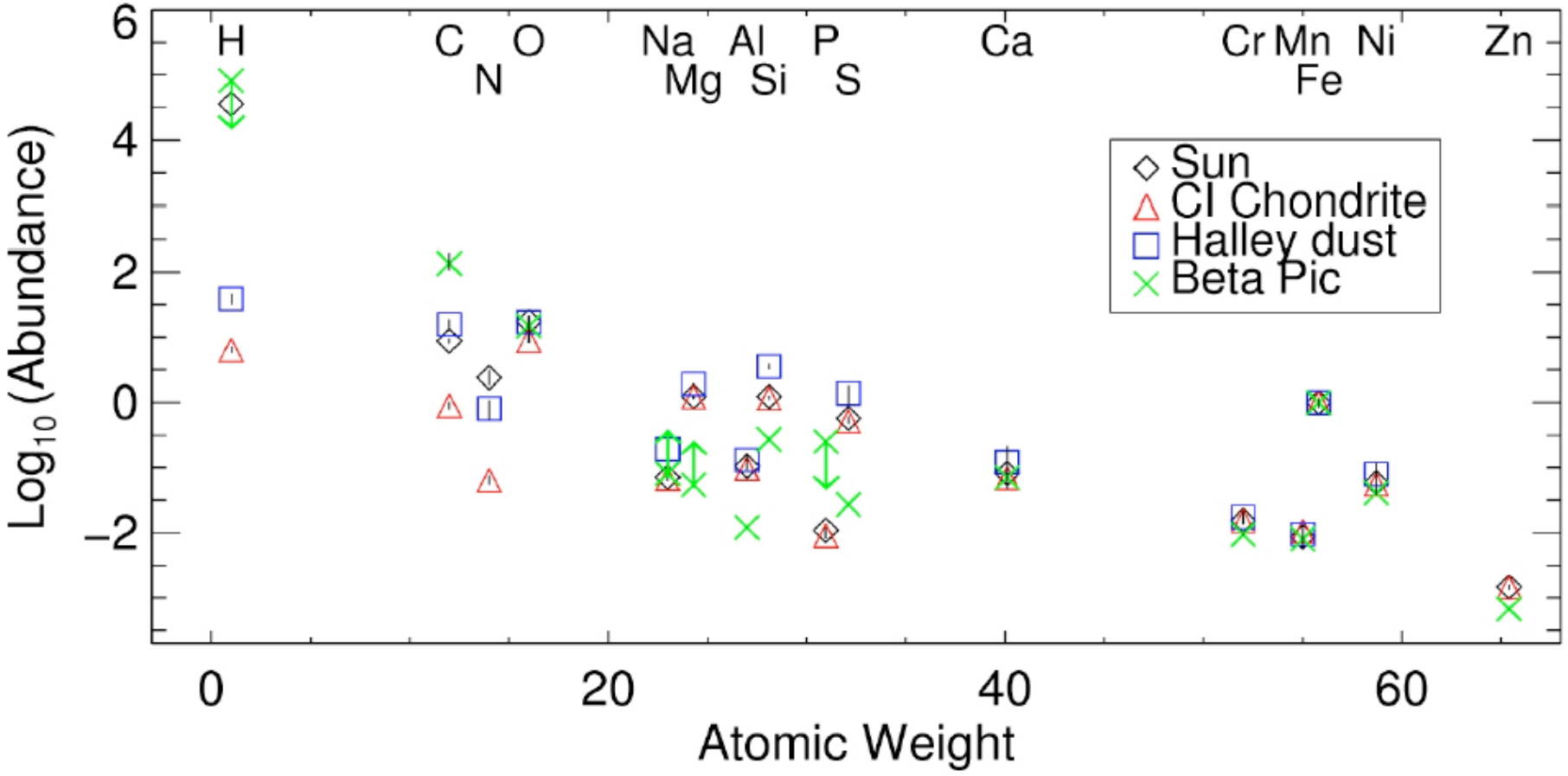
Velocity at ionisation

FUSE: Carbon absorption



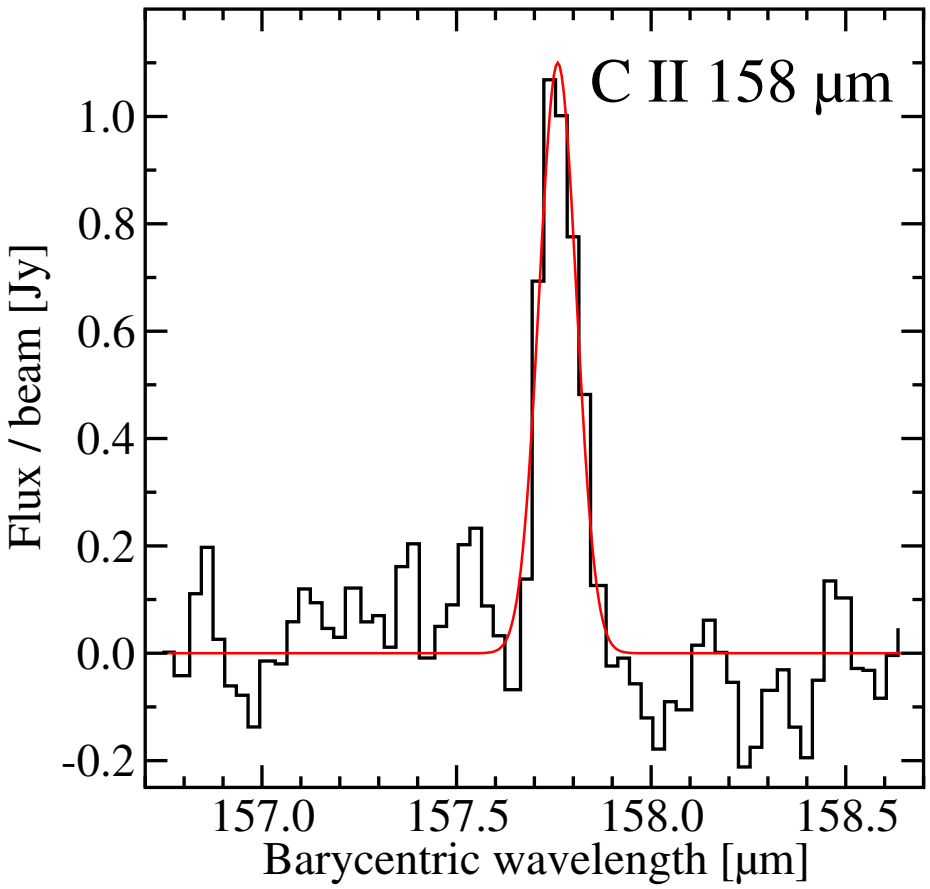
Roberge et al. 2006, Nature 441:724

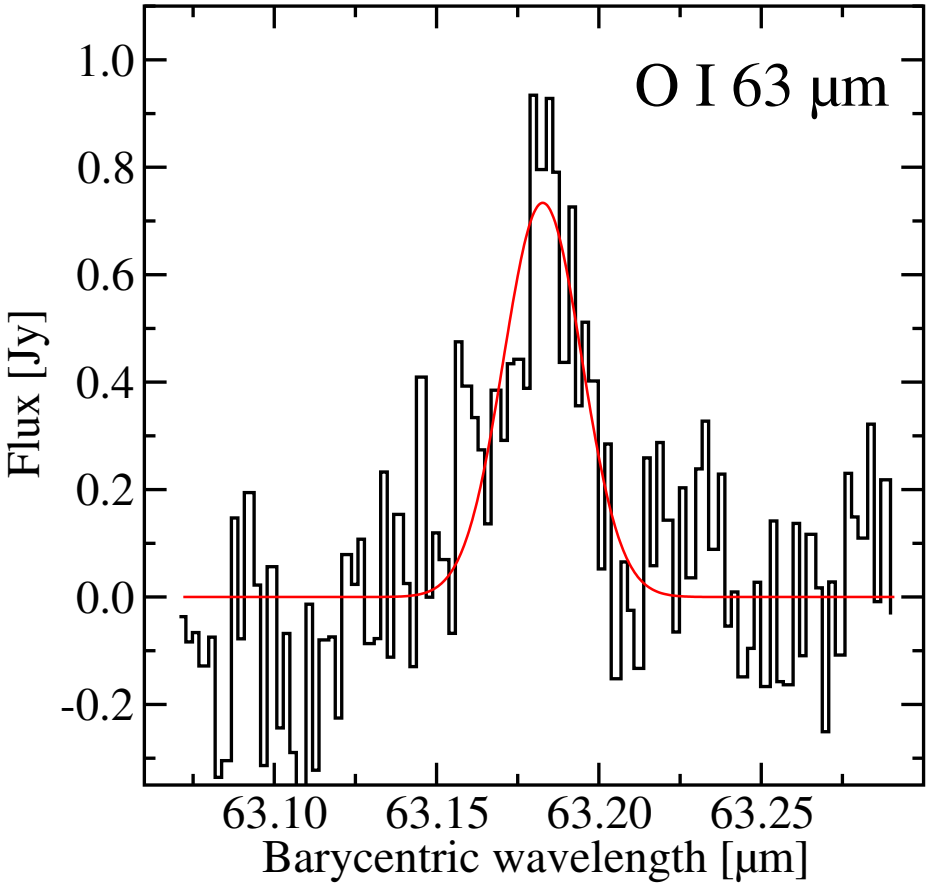
β Pictoris gas disk composition



Roberge et al. 2006, Nature 441:724

Herschel/PACS





Summary

- Gas is *currently* produced in the debris disk of β Pictoris
- C/O ~ 0.5 (solar) while both are ~400x more abundant than heavier elements
- Estimated current gas mass ~ 0.01 M_{Earth},
  dust mass (up to 1 cm) ~ 0.3 M_{earth}
  ➔ gas/dust ~ 1/30

ISIMA project

- Quantify gas removal mechanisms, in particular through:
  - radiation pressure
  - accretion
  - evaporation
- Goal: understand current gas abundances in detail and relate to abundances at production time, i.e. the elemental composition of planetesimals, building blocks of planets