The structure of Herbig Ae/Be disks

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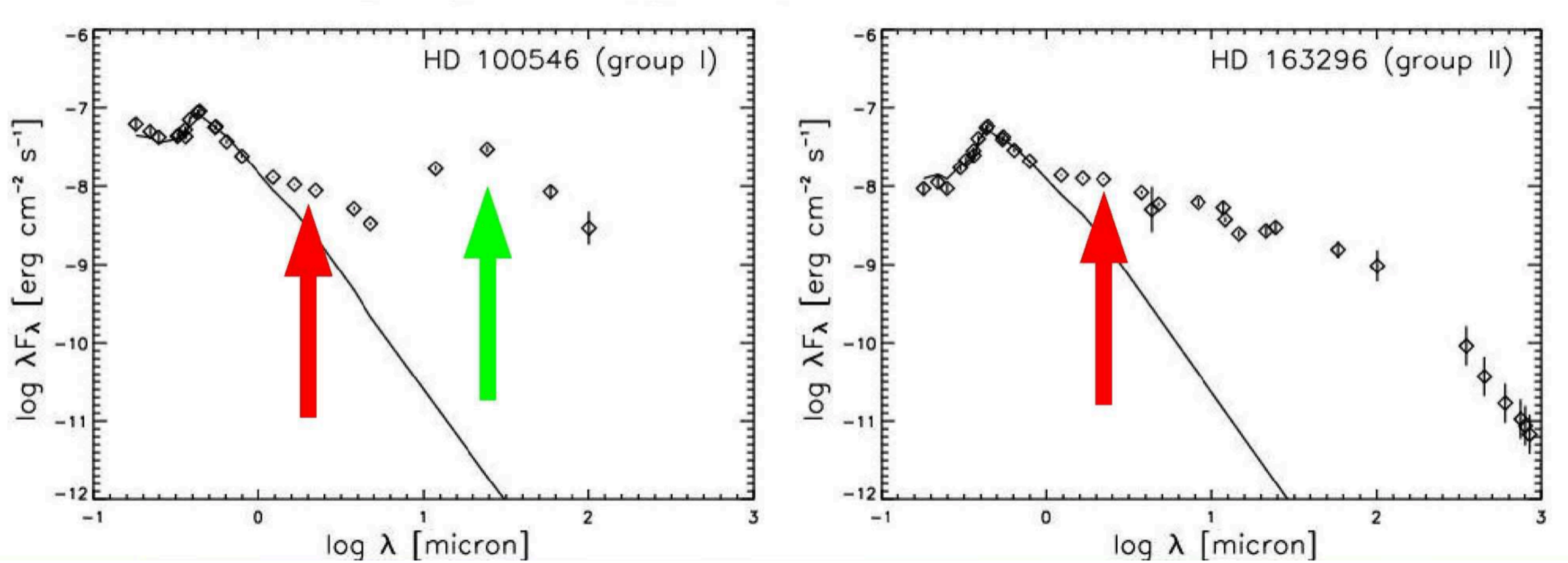
Herbig Ae/Be stars

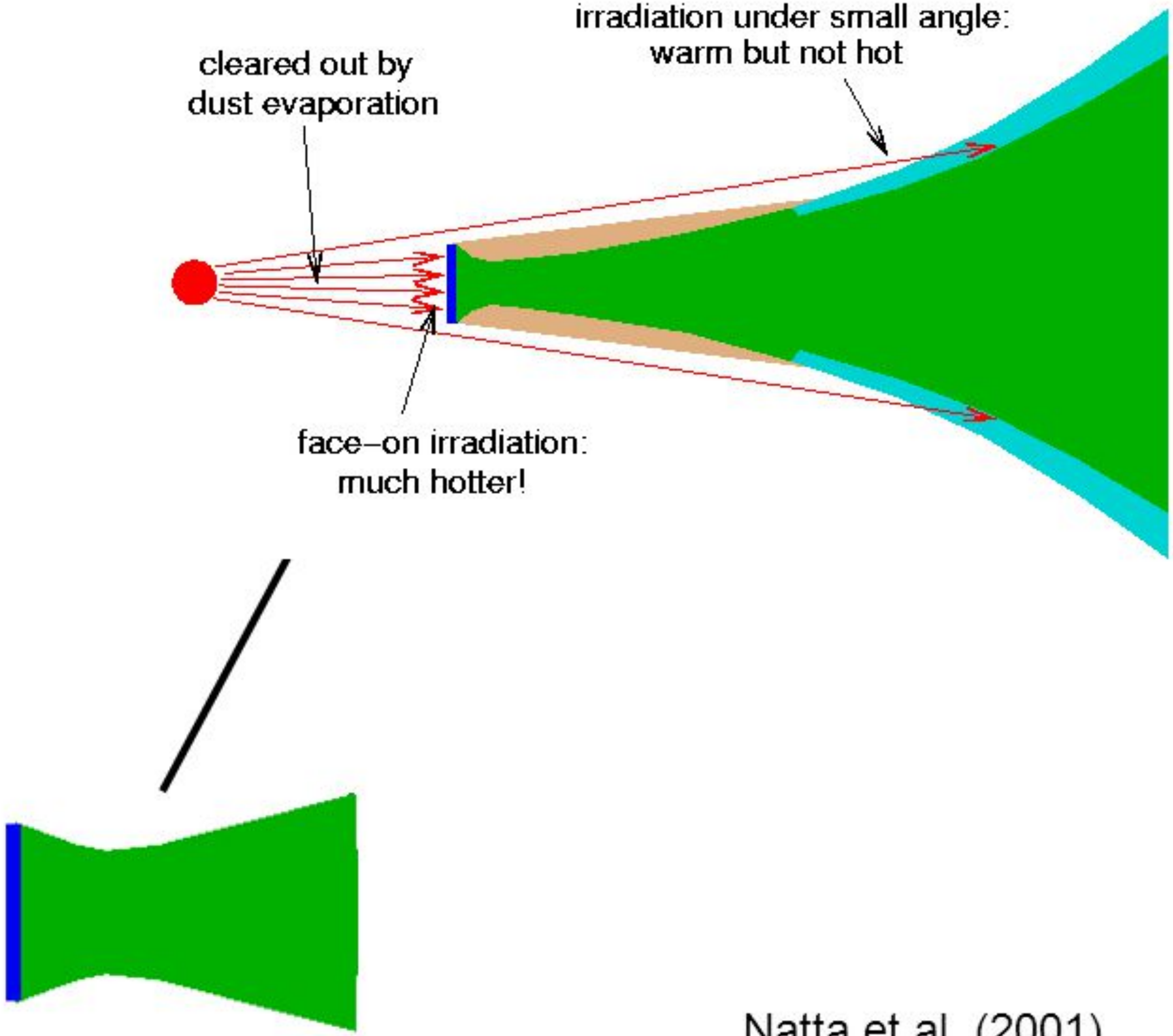
- Young stars, intermediate mass (2-8 M_{sun})
- B, A and early F spectral type
- Excess emission in infrared (circumstellar disk)
- Accretion rate: 10^{-6} – 10^{-7} M_{Sun} /yr (Mendigutía et al. 2012)

Disks around Herbig Ae/Be stars



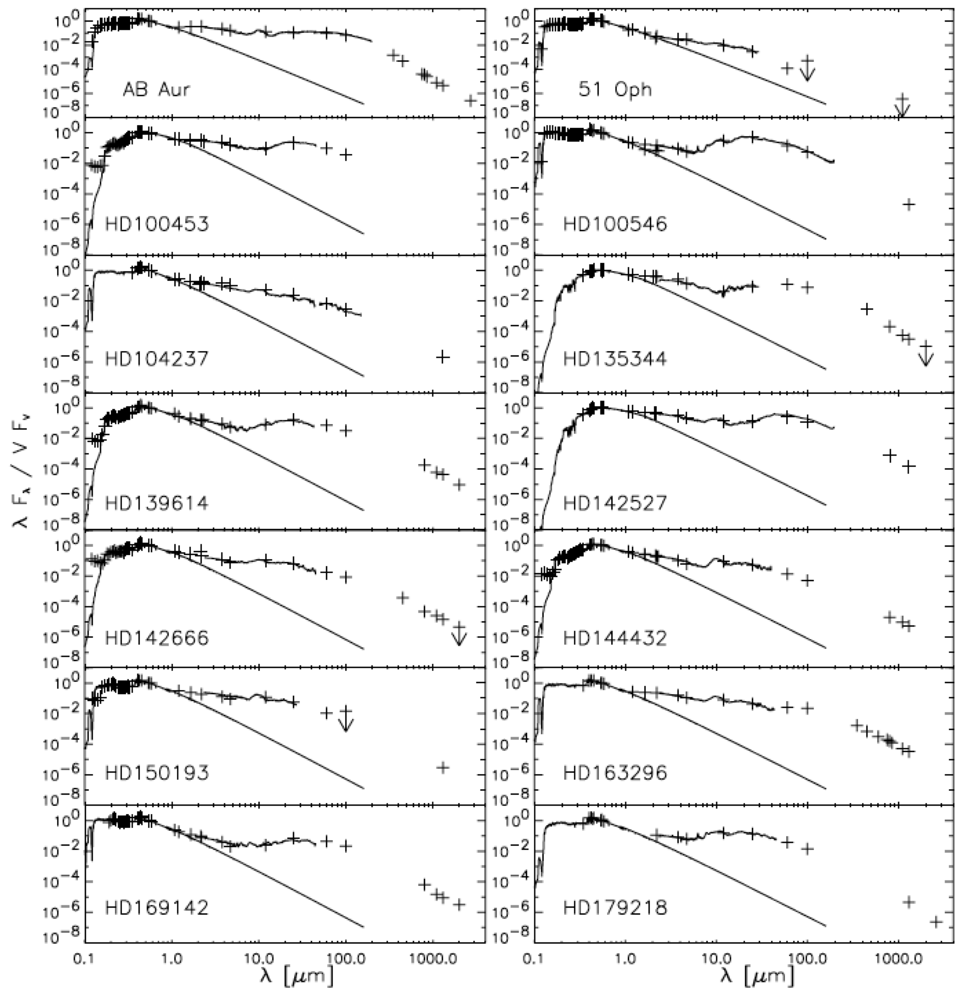
Meeus et al (2001, A&A, 365, 476)

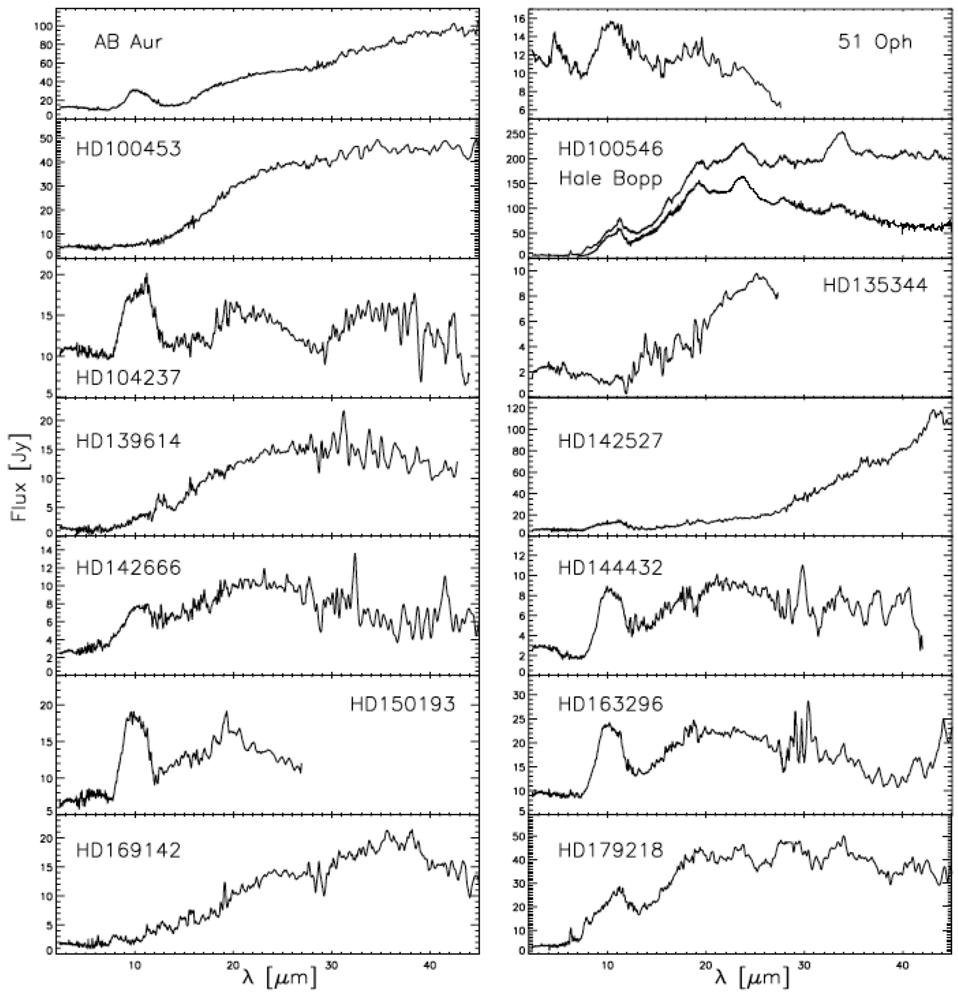
Dust evaporation and disk inner rim



Natta et al. (2001)
Dullemond, Dominik & Natta (2001)

Meeus classification of Herbig Ae/Be stars

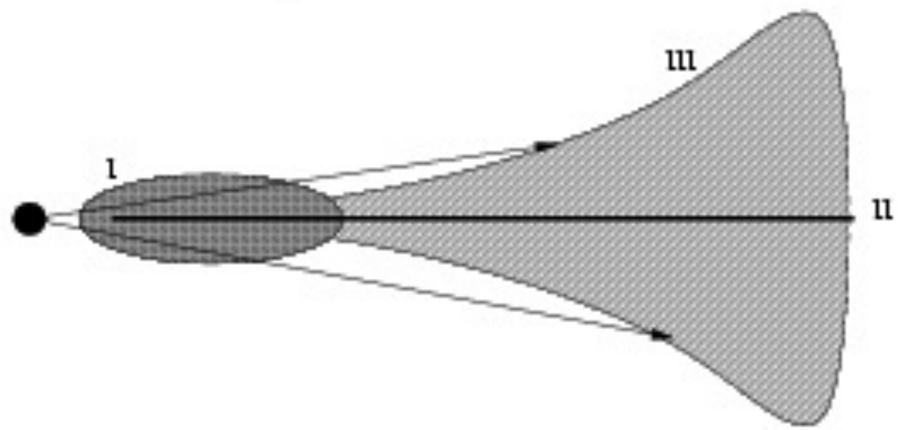




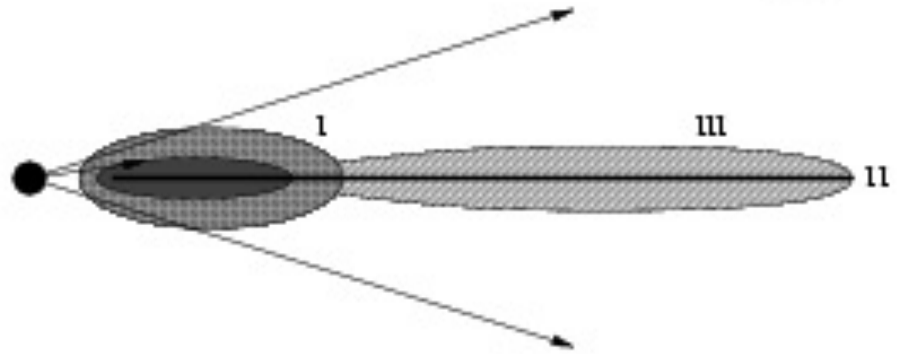
Meeus et al (2001, A&A, 365, 476)

Meeus classification of Herbig Ae/Be stars

Group Ia (with silicate)
Group Ib (without silicate)



Group IIa (with silicate)



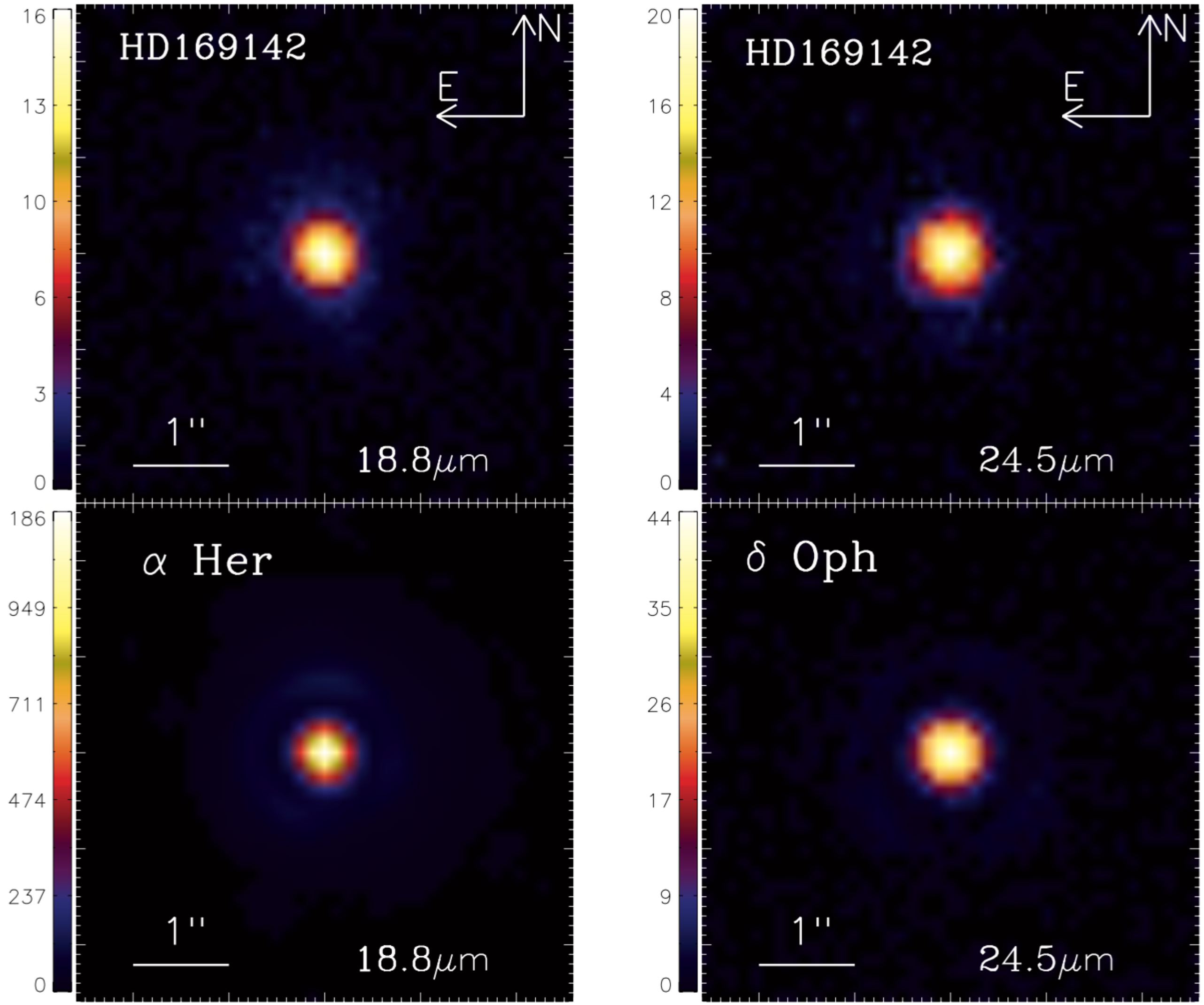
Evolution from Group I to Group II (?)

Mid-IR imaging of the disk of HD169142:

Measuring the size of the gap

Honda et al. (ApJ 752, 143, 2012)

Subaru/COMICS
18.8um, 24.5um

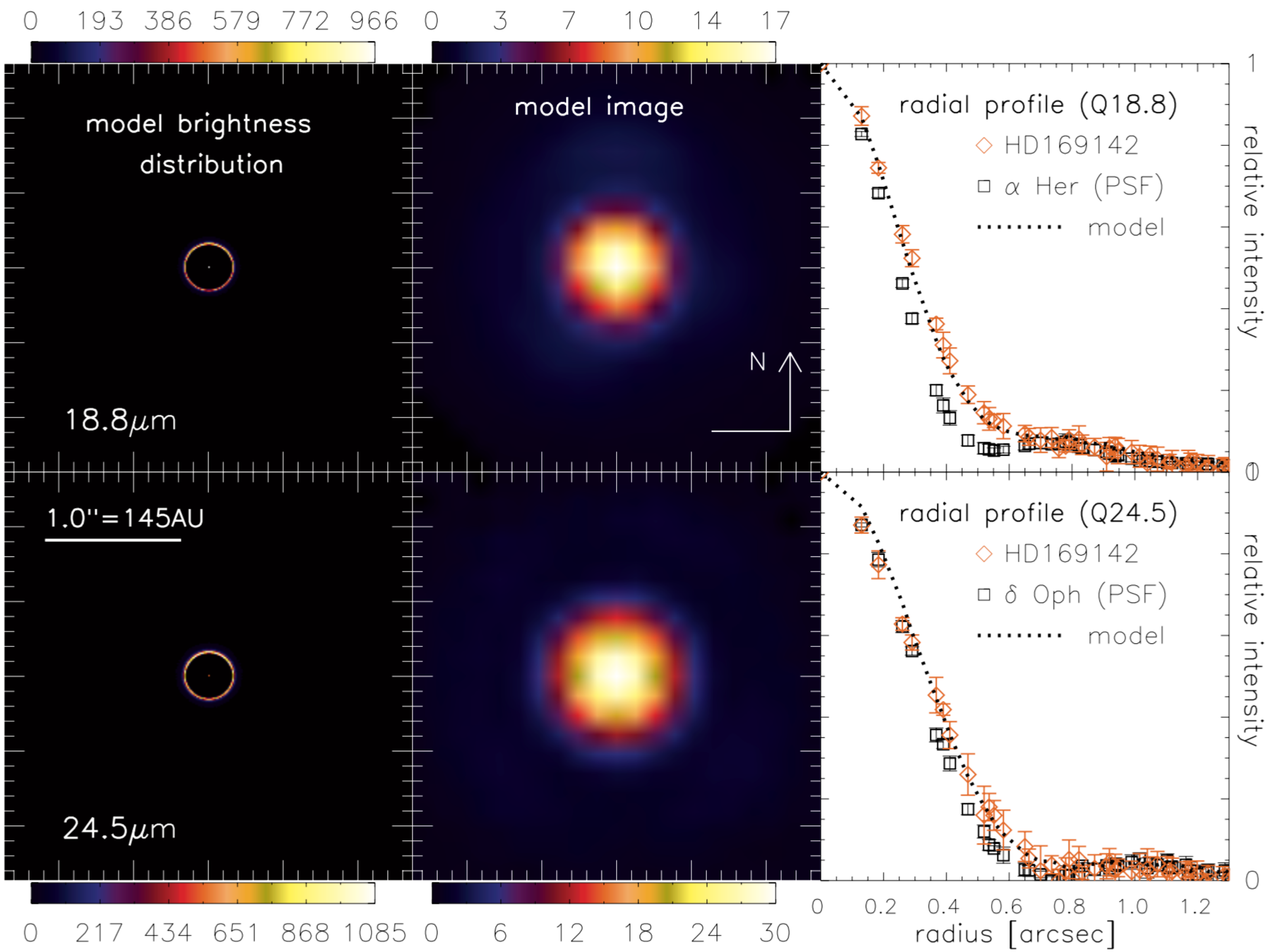


Mid-IR imaging of the disk of HD169142: Measuring the size of the gap

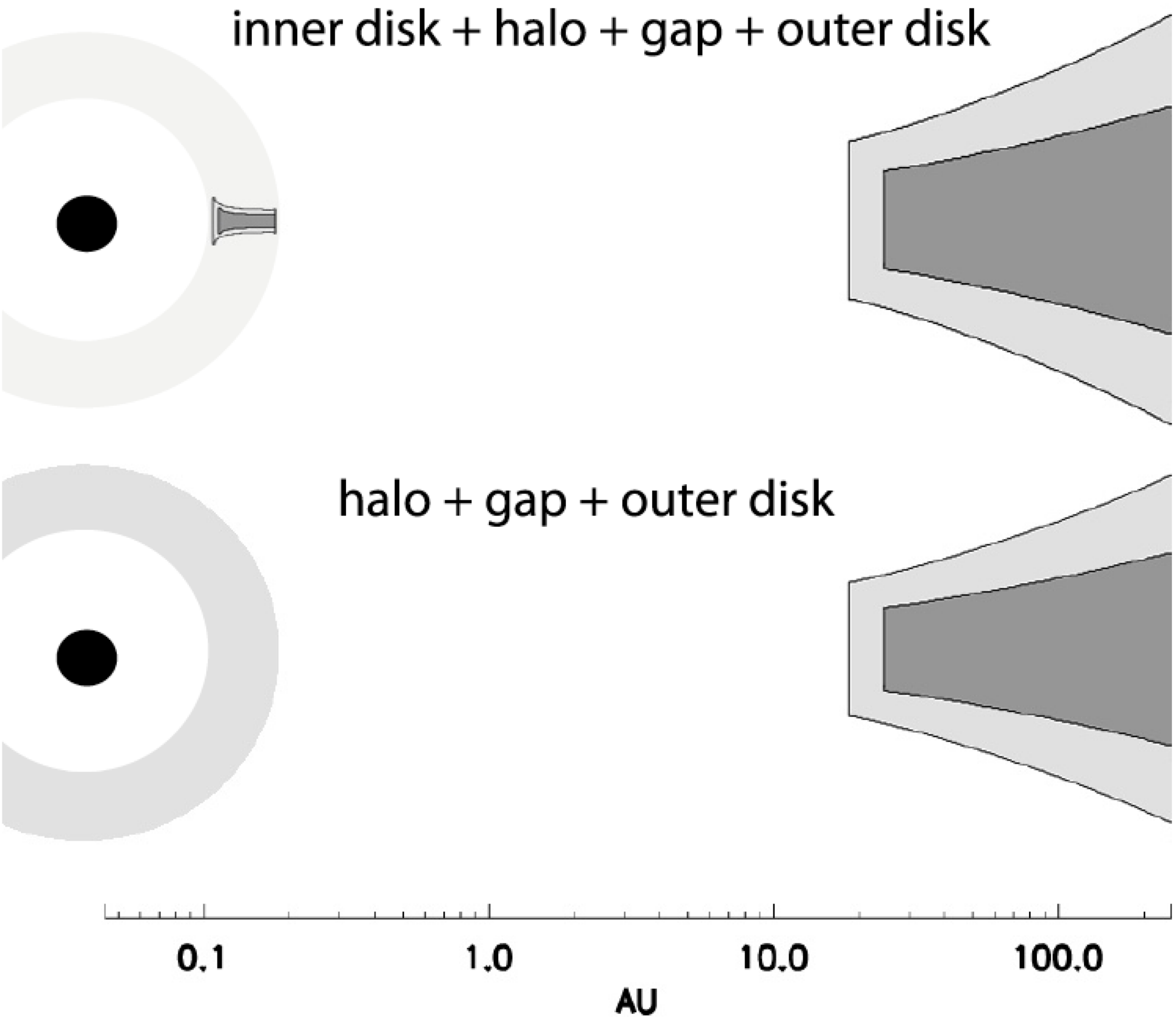
@18.8um:
0.604”+/-0.017”

@24.5um:
0.680”+/-0.034”

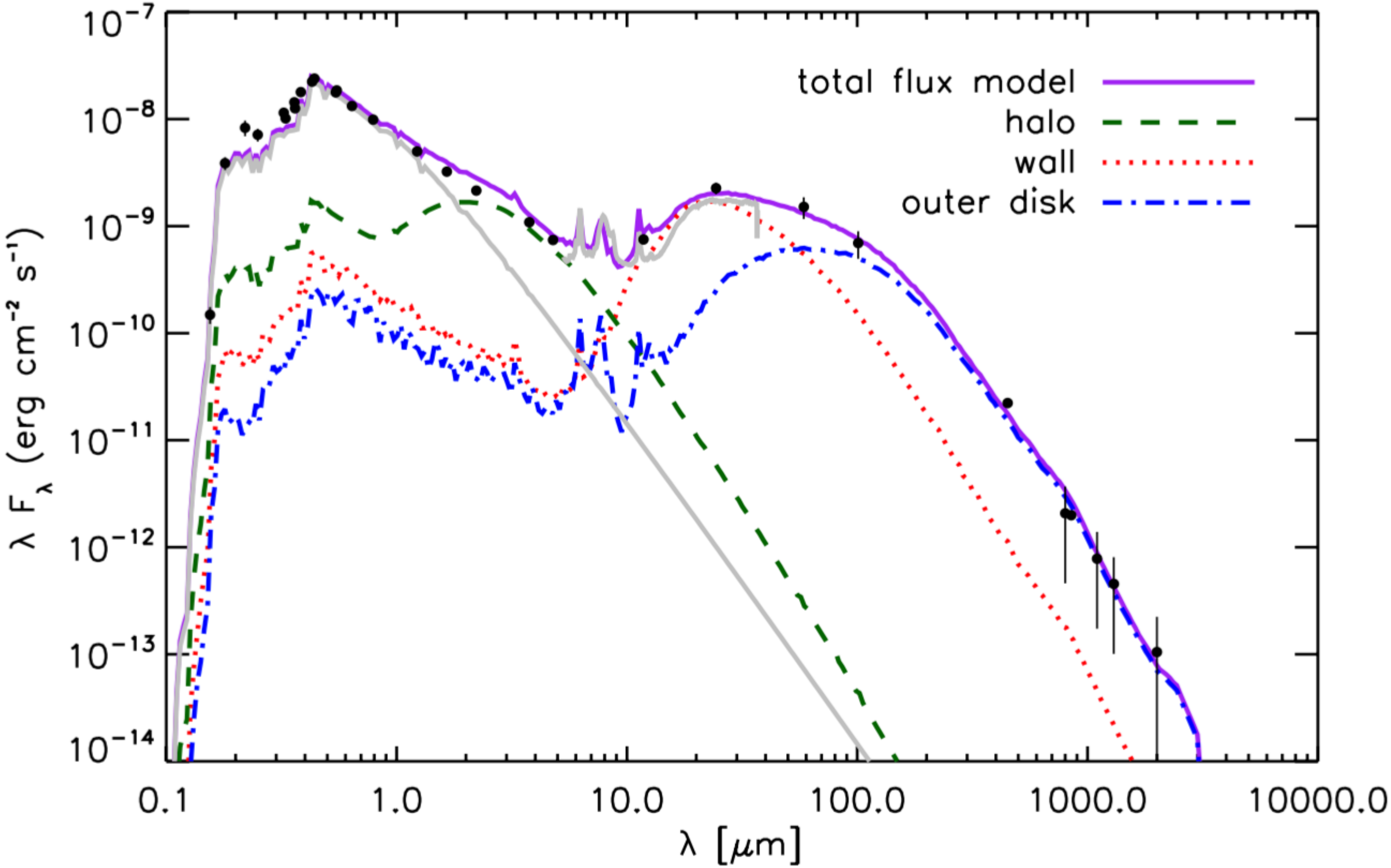
Size is similar, which is not consistent with a continuous flaring disk model!



Disk geometry



SED fitting



total flux model
halo
wall
outer disk
λ F_λ (erg cm⁻² s⁻¹)
λ [μm]
0.1
1.0
10.0
100.0
1000.0
10000.0

SED fitting

Parameters of HD 169142 System Used in our Best-fit Model

Parameter	Value	Remarks
Spectral type	A5Ve	Dunkin et al. (1997)
Extinction A_V	0.46 ± 0.05	van den Ancker (1999)
log g	4.22	van den Ancker (1999)
Temperature	8200 K	Dunkin et al. (1997)
Distance	145 ± 15 pc	de Zeeuw et al. (1999)
Age	6^{+6}_{-3} Myr	Grady et al. (2007)
Stellar luminosity	$15.33 \pm 2.17\ L_\odot$	van den Ancker (1999)
Stellar mass	$2.28 \pm 0.23\ M_\odot$	van den Ancker (1999)
Stellar radius	$1.94 \pm 0.14\ R_\odot$	van den Ancker (1999)
Gas disk mass	$(0.16\text{–}3.0) \times 10^{-2}\ M_\odot$	Panić et al. (2008)
Dust disk mass	$4 \times 10^{-4}\ M_\odot$	Fit to the submillimeter photometry
Inclination	13°	Raman et al. (2006); Dent et al. (2005)
Accretion rate	$\leqslant 10^{-9}\ M_\odot\ \mathrm{yr}^{-1}$	Grady et al. (2007)
R_{halo}	0.1–0.2 AU	Geometrically high, optically thin component to fit the NIR
R_{in}	23^{+3}_{-5} AU	Fit to RBP of Subaru/COMICS data
R_{out}	235 AU	Panić et al. (2008)
Surface density exponent	-1.0	Hydrostatic equilibrium
Particle size	$a = \{0.03\ \mu\mathrm{m}, 1\ \mathrm{cm}\}$	Power-law distribution of -3.5
Silicates	70%	Similar to Mulders et al. (2011)
Amorphous carbon	30%	Zubko et al. (1996)
M_{PAH}	$0.45 \times 10^{-7}\ M_\odot$	Uniform PAH distribution
M_{halo}	$0.28 \times 10^{-10}\ M_\odot$	Only carbon
M_{disk}	$0.3 \times 10^{-3}\ M_\odot$	Mass of grains $a = \{0.03\ \mu\mathrm{m}, 1\ \mathrm{cm}\}$ in the disk

A study of dust properties in the inner sub-au region of the Herbig Ae star HD 169142 with VLTI/PIONIER ⋆

L. Chen[1], Á. Kóspál[1,2], P. Ábrahám[1], A. Kreplin[3], A. Matter[4], and G. Weigelt[5]

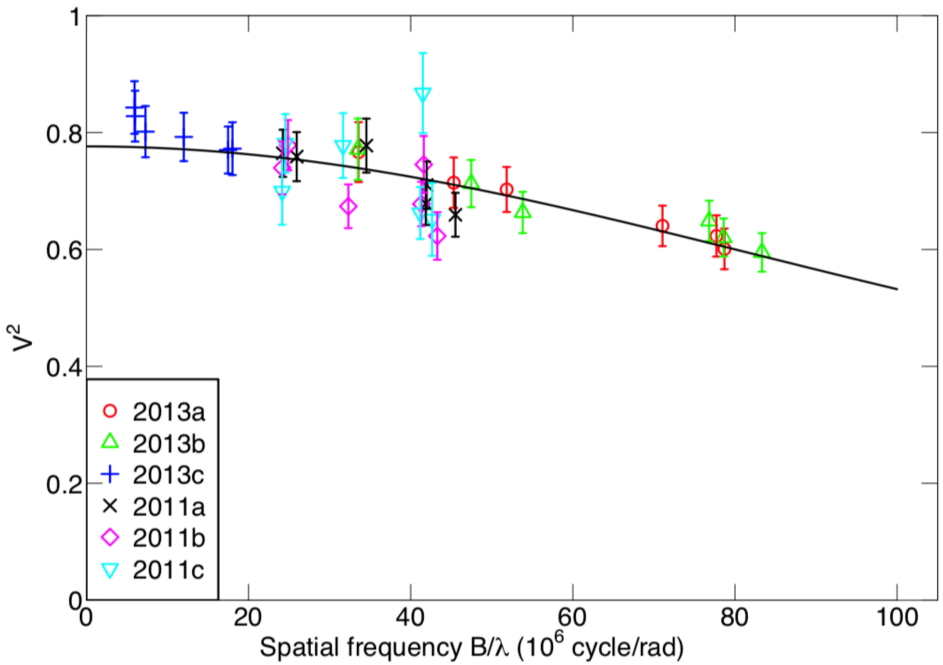
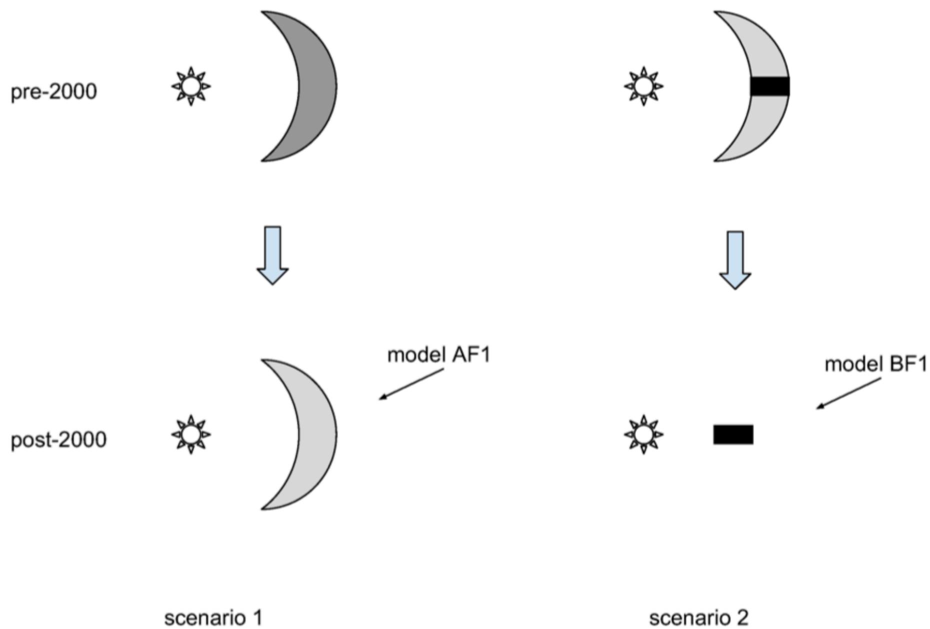


Fig. 2. Visibilities from the PIONIER observations of HD 169142, and our star-ring-halo model fitting.



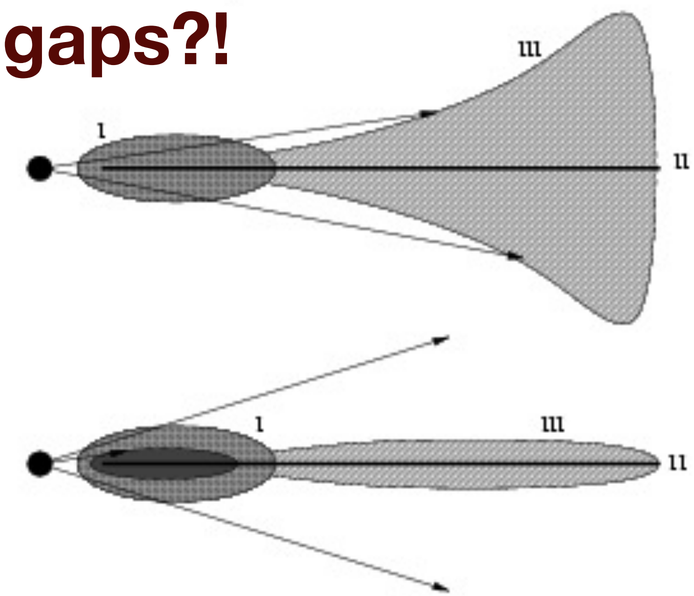
Chen et al (2007, in press)

Meeus classification of Herbig Ae/Be stars

HD169142 is a Meeus Ib disk, and it has a gap

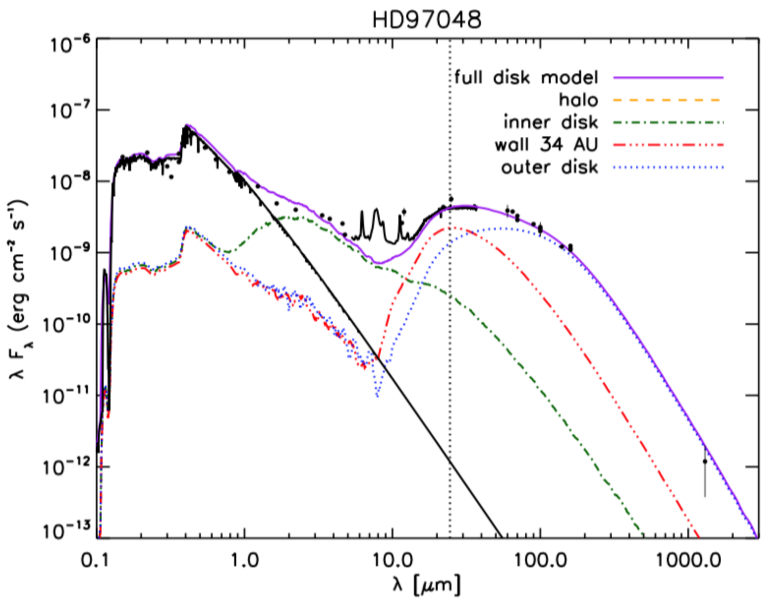
Other Group I sources also have gaps: AB Aur (Honda et al., 2010), HD 142527 (Fukagawa et al., 2006, Fujiwara et al., 2006, Verhoeff et al., 2011), HD 135344 (Brown et al., 2009), HD 36112 (Isella et al., 2010), HD100546 (Bouwman et al., 2003, Benisty et al., 2010, Mulders et al., 2011)

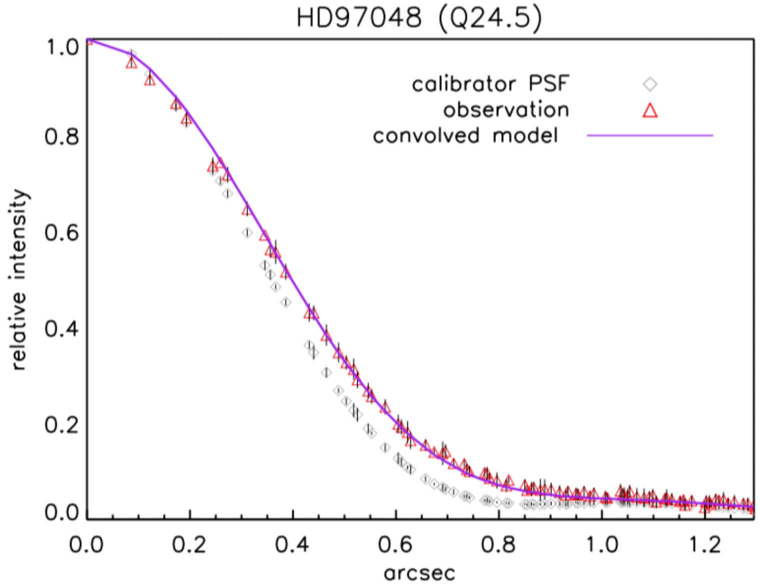
Maybe all Group I sources have gaps?!

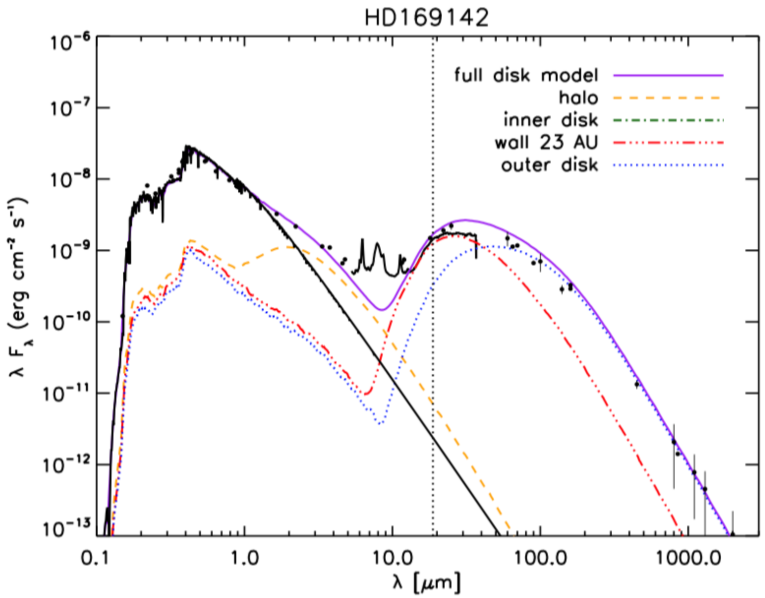


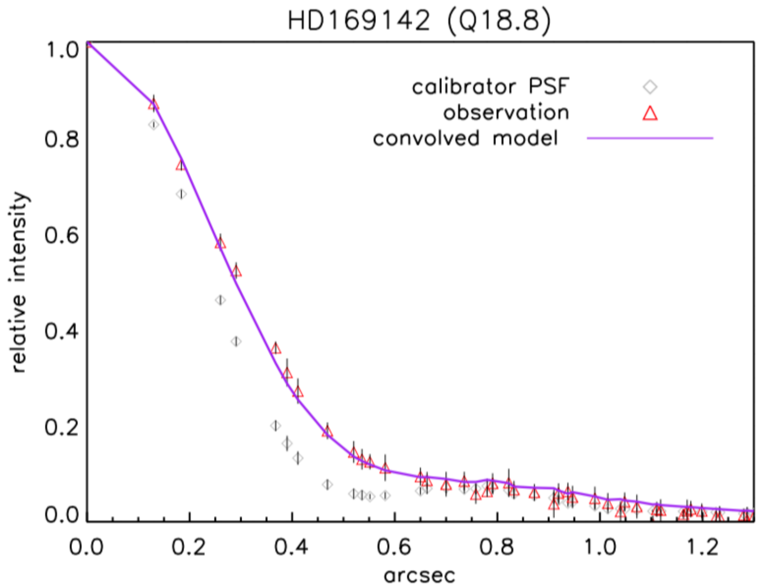
Observations of other Herbig stars

Maaskant et al. 2013, A&A 555, A64

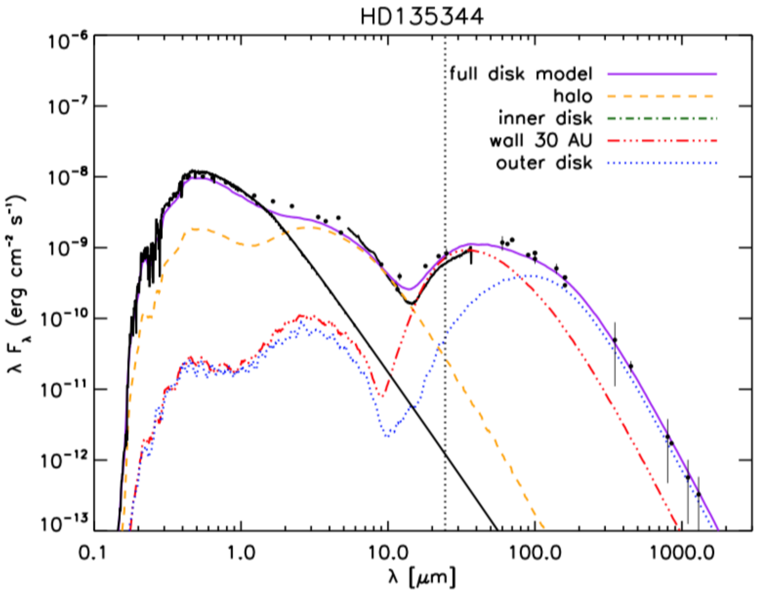


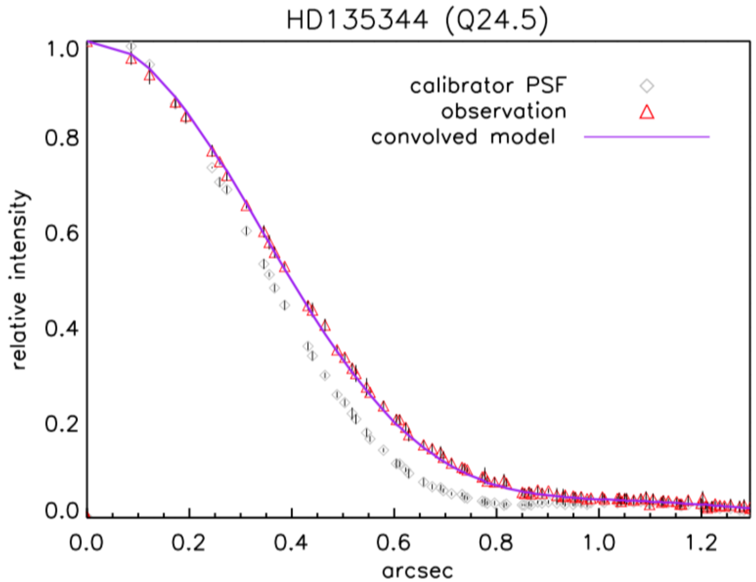


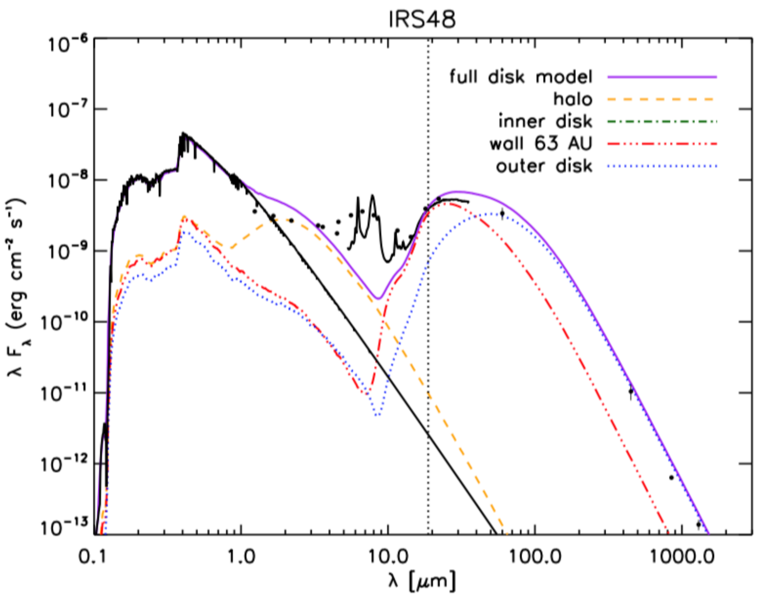


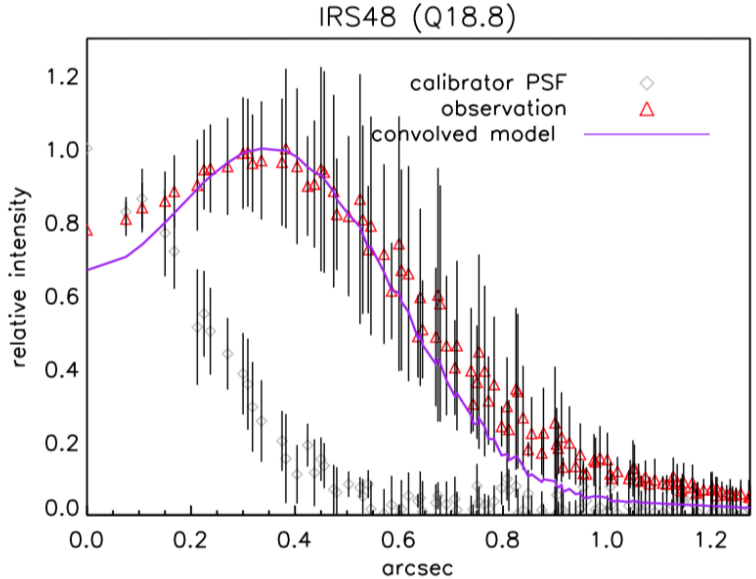


Observations of other Herbig stars





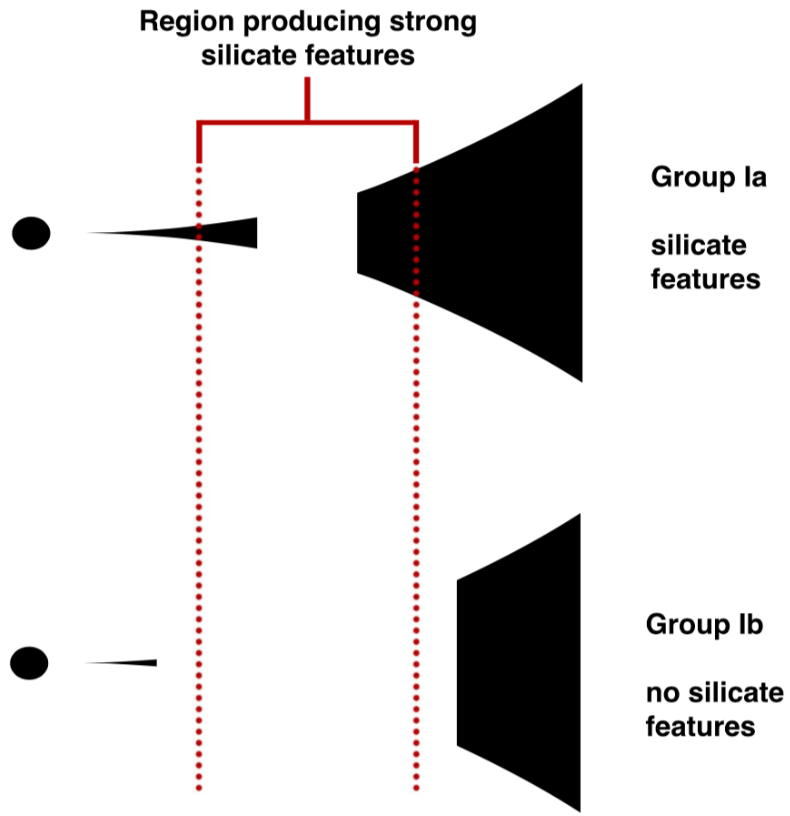




Gaps in Group I sources

Object	M_{dust} $[M_\odot]$	M_{halo} $[M_\odot]$	$R_{innerdisk/halo}$ [AU]	R_{wall} [AU]	R_{out} [AU]	a $[a_{min}, a_{max}]$	p
HD 97048	6.0×10^{-4}	...	0.3–2.5	34^{+4}_{-4}	500	{0.5 μm, 1mm}	–3.5
HD 169142	0.8×10^{-4}	0.31×10^{-12}	0.1–0.2	23^{+4}_{-4}	235	{0.5 μm, 1mm}	–3.5
HD 135344 B	1.0×10^{-4}	0.47×10^{-12}	0.1–0.3	30^{+4}_{-3}	200	{1.0 μm, 1mm}	–4.0
Oph IRS 48	3.0×10^{-5}	0.50×10^{-12}	0.1–0.3	63^{+4}_{-4}	235	{0.1 μm, 1mm}	–4.0

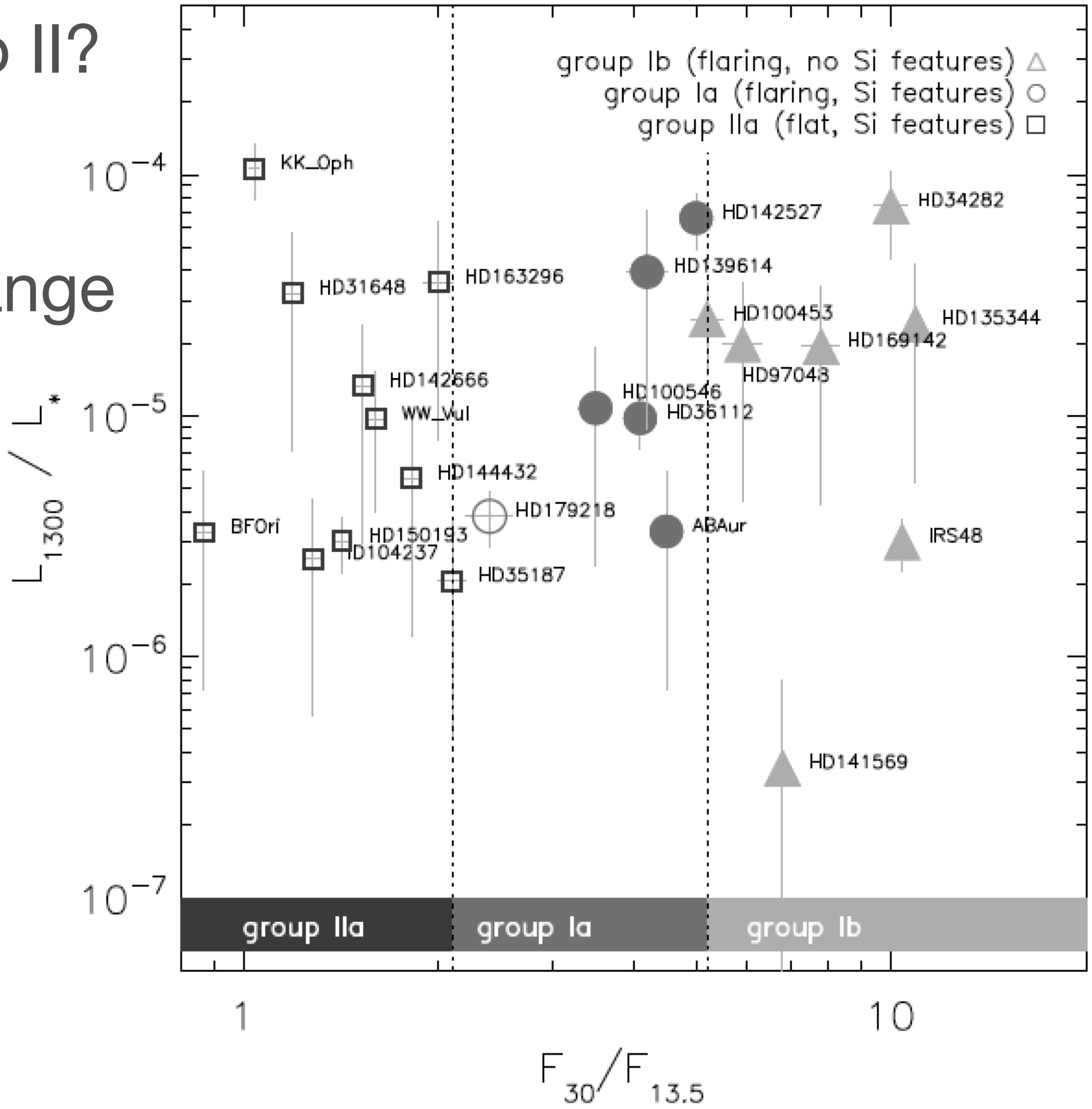
Explanation for the Group I a/b difference (yes/no silicate feature):



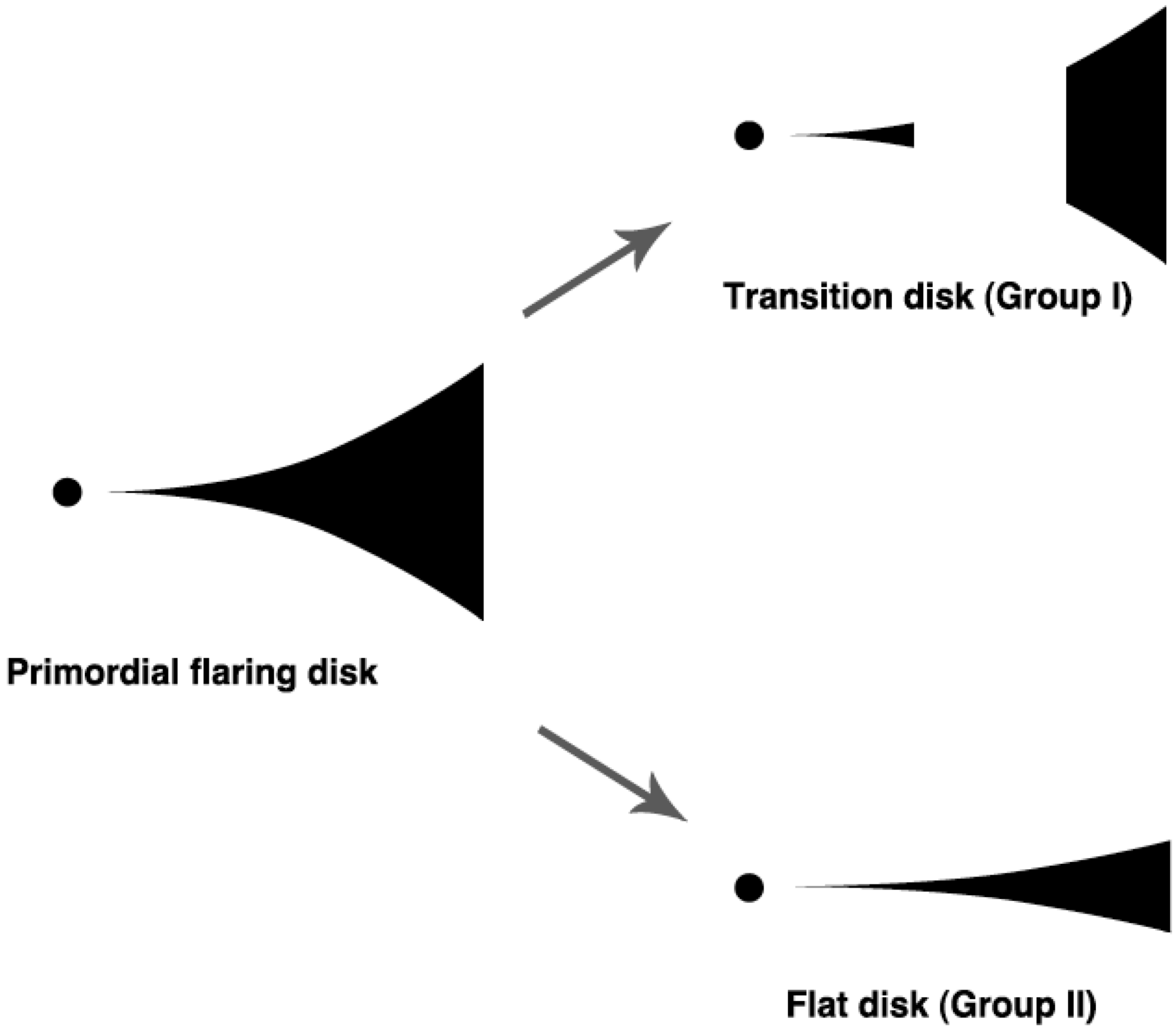
Gaps in Herbig disks

Evolution from Group I to II?
Not obvious…

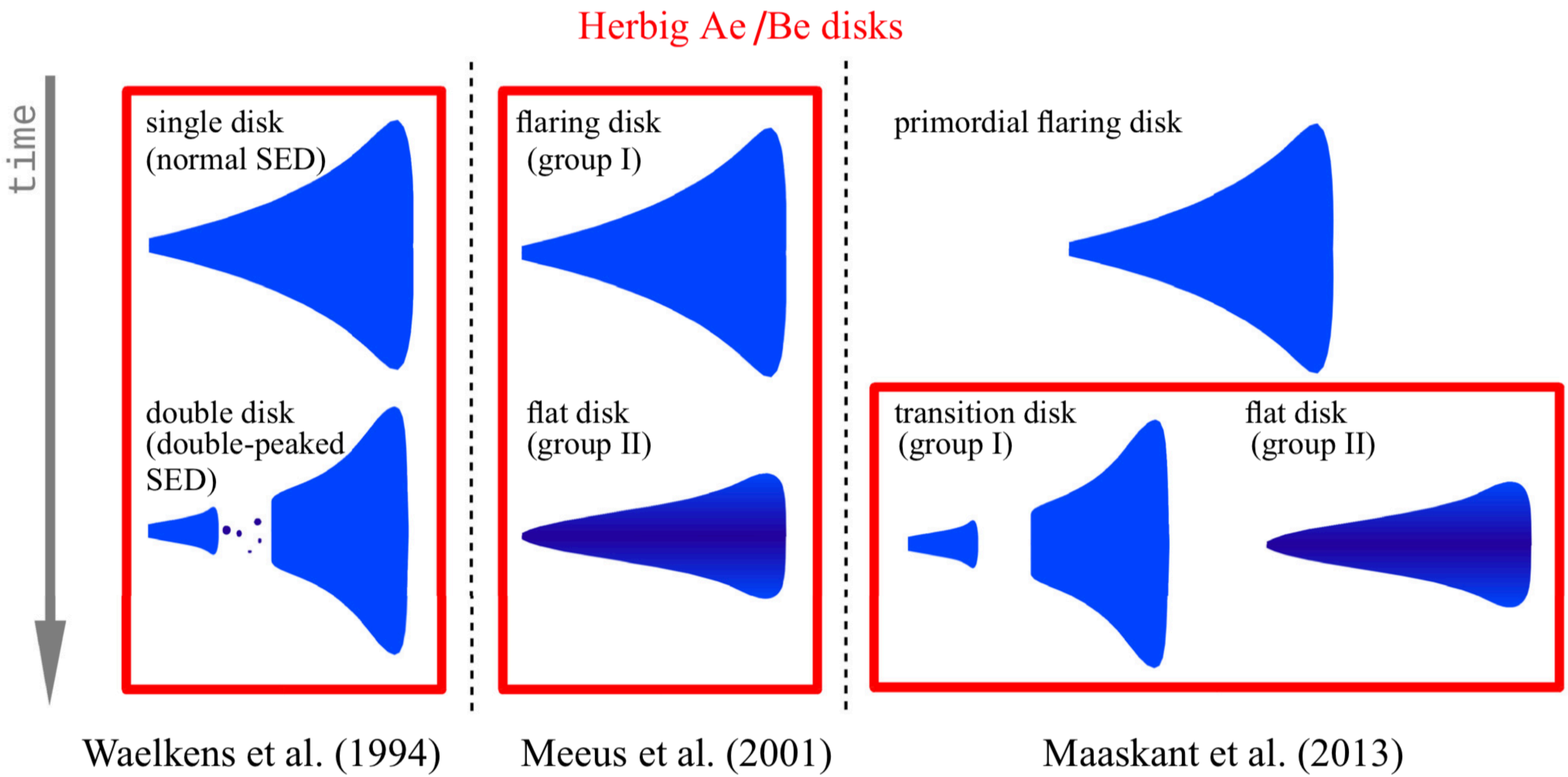
Group Ia -> Ib -> IIa strange



Disk evolution in Herbig stars?



Disk evolution in Herbig stars?

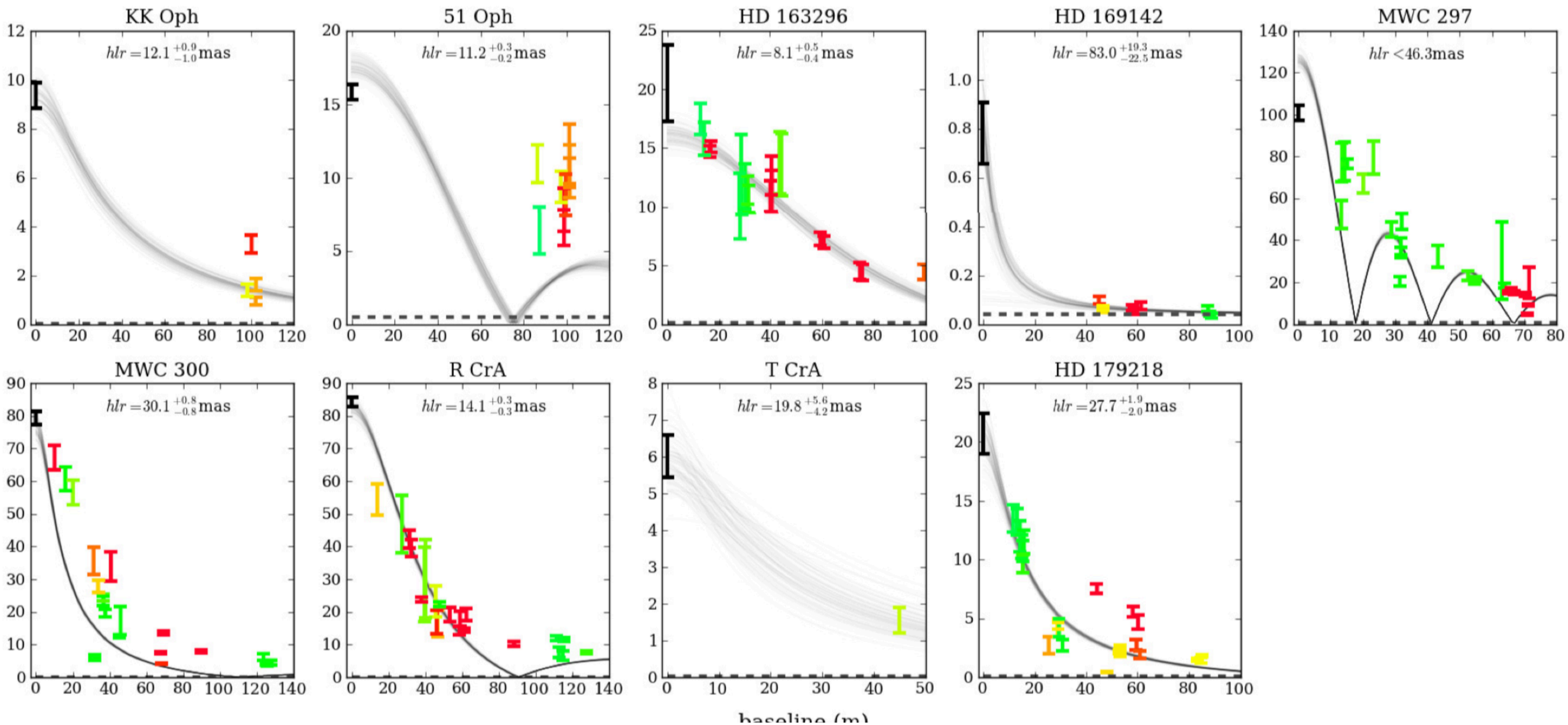


Menu et al (2015, A&A 581, A107)

The structure of disks around intermediate-mass young stars from mid-infrared interferometry

Evidence for a population of group II disks with gaps★

J. Menu[1,2,★★], R. van Boekel[2], Th. Henning[2], Ch. Leinert[2], C. Waelkens[1], and L. B. F. M. Waters[3,4]



Menu et al (2015, A&A 581, A107)

MIDI observations of disk structure

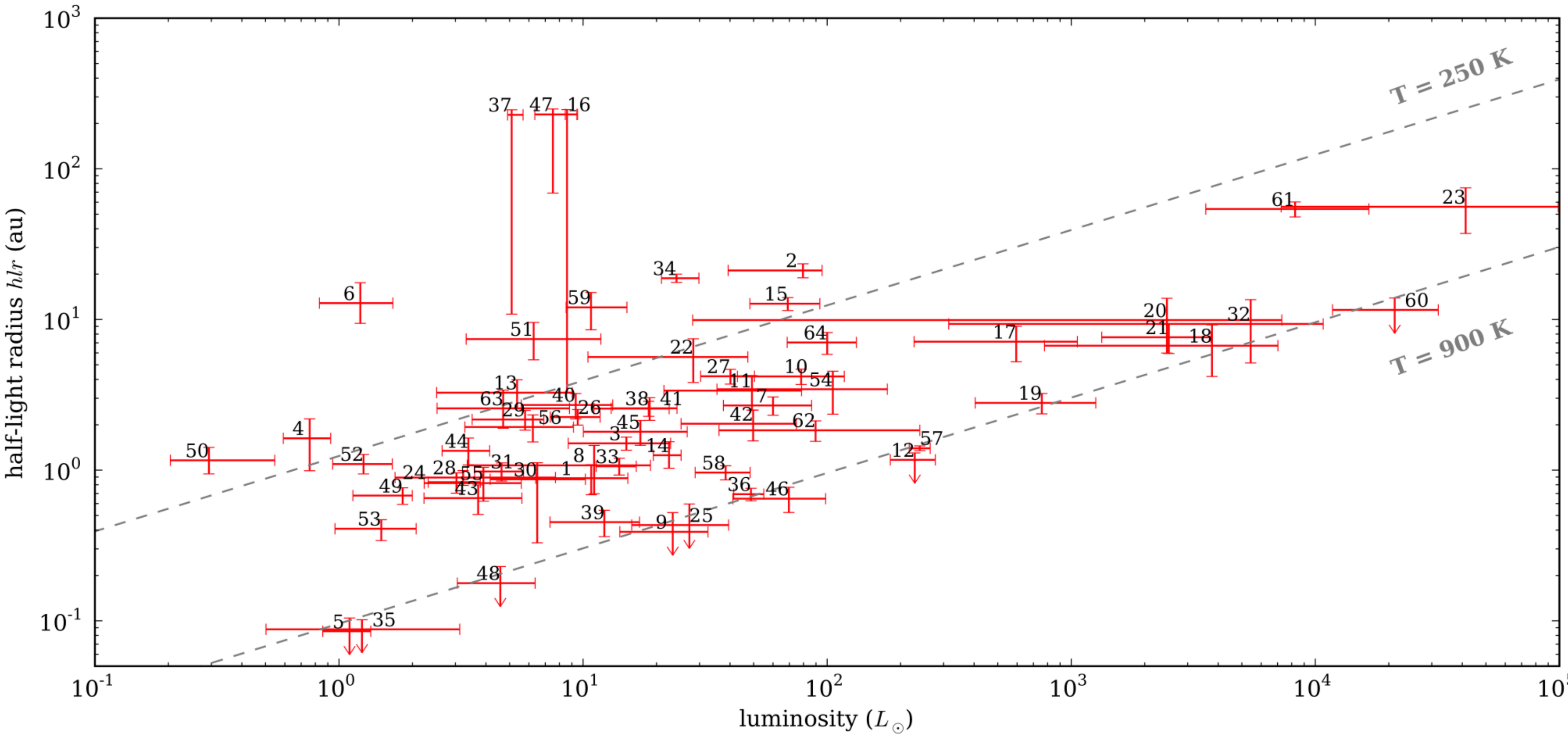
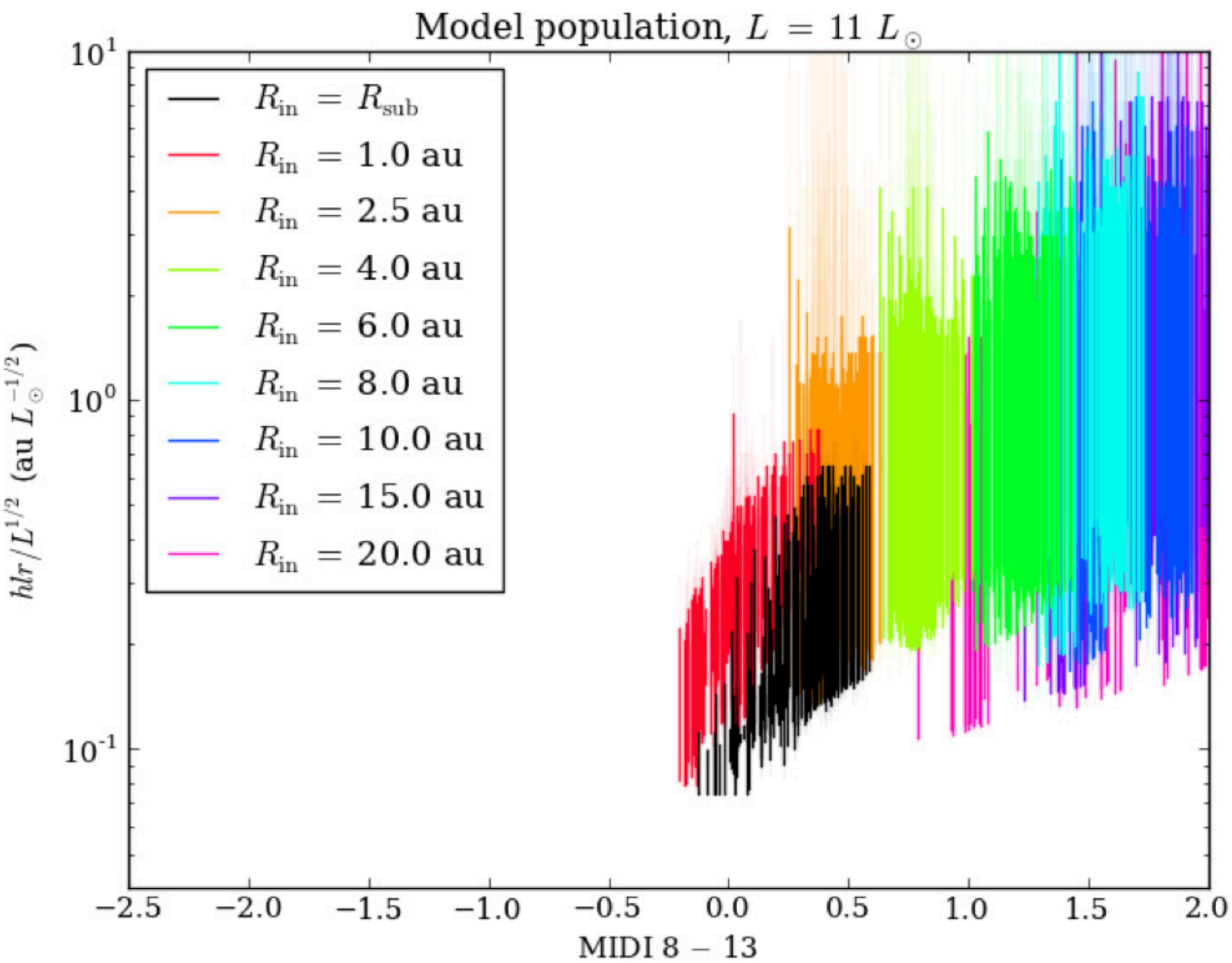


Fig. 3. MIDI size-luminosity diagram for protoplanetary disks: plot of the half-light radii of the disks at 10.7 μm vs. the stellar luminosity of the sample targets. The gray dashed lines indicate the expected distance at which gray, optically thin dust at the indicated temperature would be located (cf. Monnier et al. 2009).

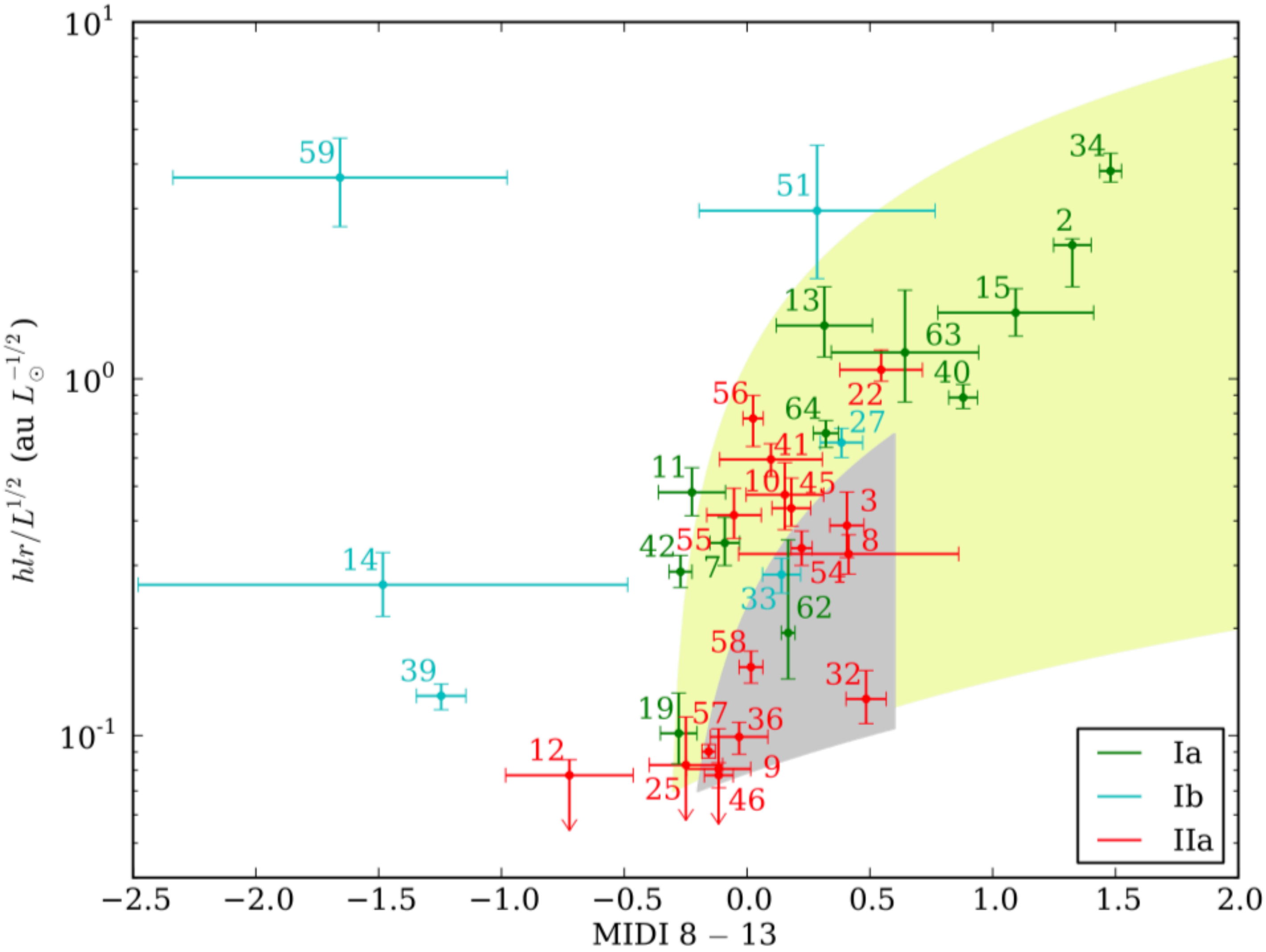
Menu et al (2015, A&A 581, A107)

MIDI observations of disk structure



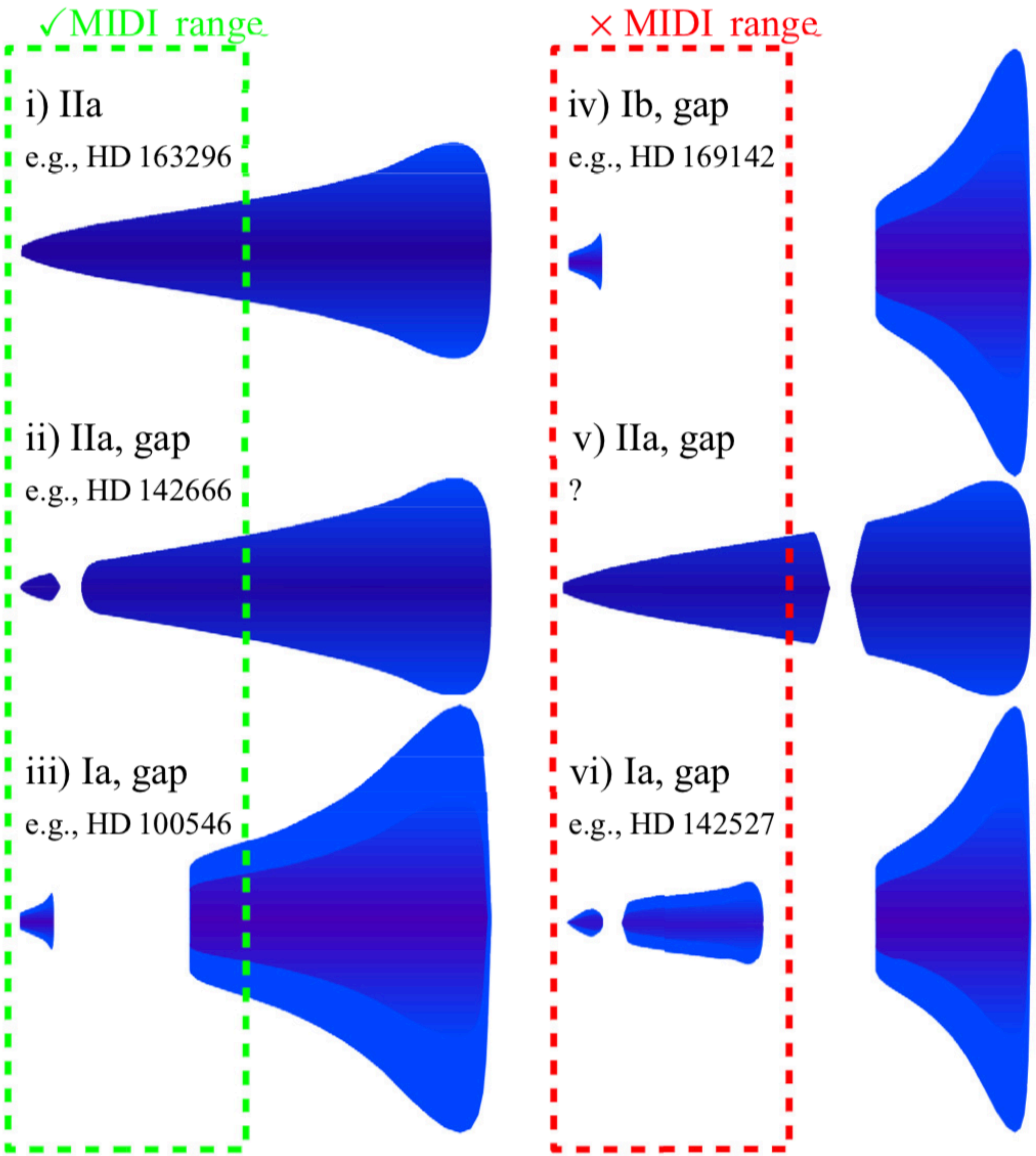
Menu et al (2015, A&A 581, A107)

MIDI observations of disk structure



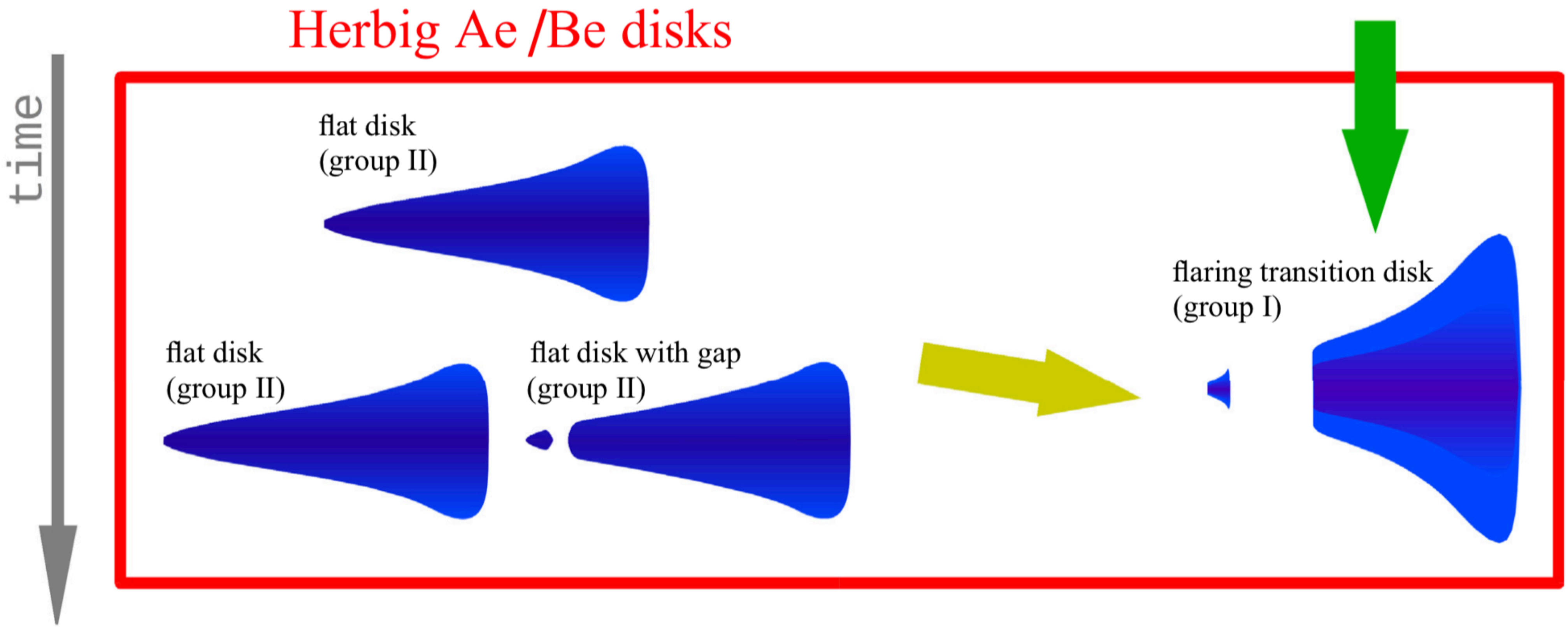
Menu et al (2015, A&A 581, A107)

MIDI observations of disk structure



Menu et al (2015, A&A 581, A107)

MIDI observations of disk structure



Menu et al (2015, A&A 581, A107)

ALMA unveils rings and gaps in the protoplanetary system HD 169142: signatures of two giant protoplanets

D. Fedele[1], M. Carney[2], M. R. Hogerheijde[2], C. Walsh[2,3], A. Miotello[2], P. Klaassen[4], S. Bruderer[5], Th. Henning[6], and E. F. van Dishoeck[2,5]

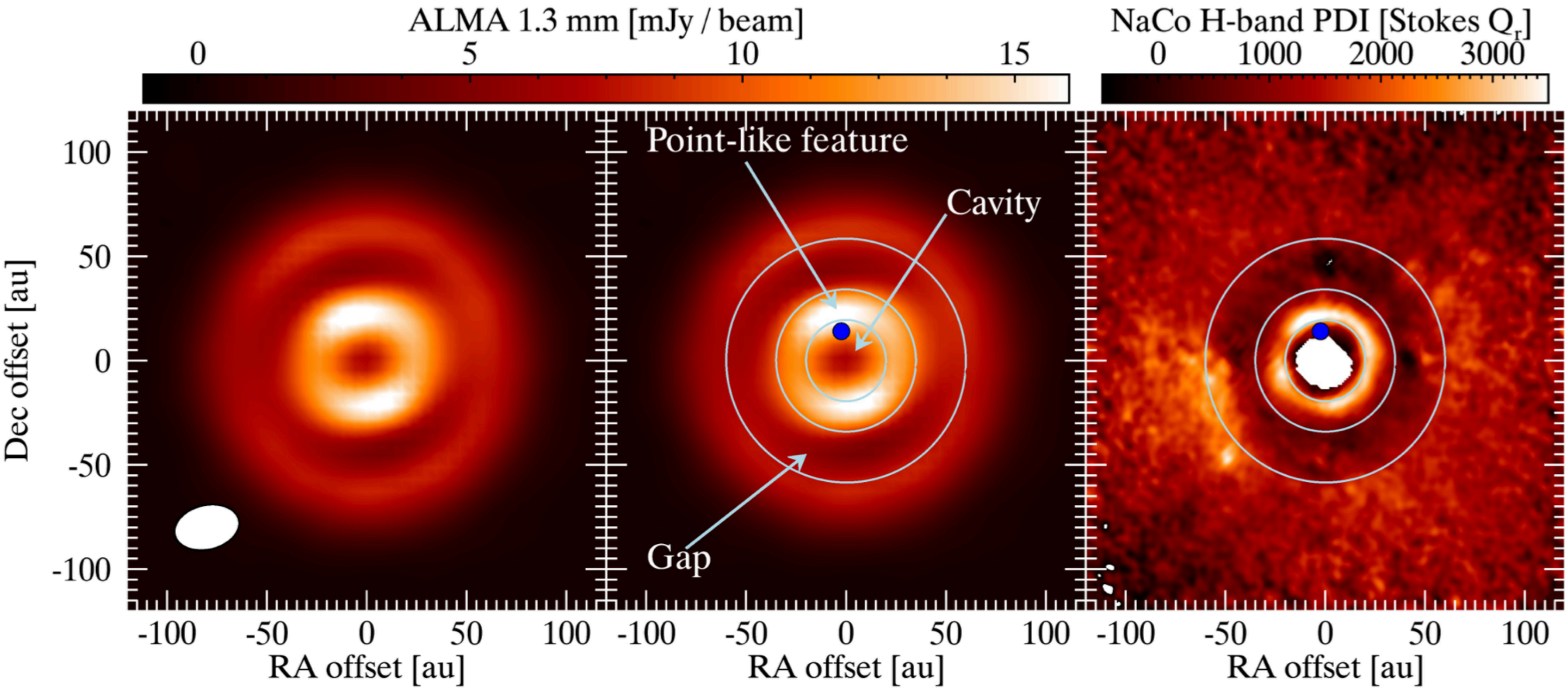


Fig. 1. (*Left*) ALMA 1.3 mm continuum map with Briggs weighting, robust = 0.5. (*Center*) Overlaid with the position and size of the inner dust cavity and gap, and the position of the L'-band point-like feature. (*Right*) NaCo H-band polarimetric differential image (Quanz et al. 2013).

Fedele et al (2017, A&A 600, A72)

Cavity and other radial substructures in the disk around HD 97048

G. van der Plas[1,2], C. M. Wright[3], F. Ménard[4,5], S. Casassus[1,2], H. Canovas[6], C. Pinte[4,5], S. T. Maddison[7], K. Maaskant[8], H. Avenhaus[1,2], L. Cieza[2,9], S. Perez[1,2], and C. Ubach[10]

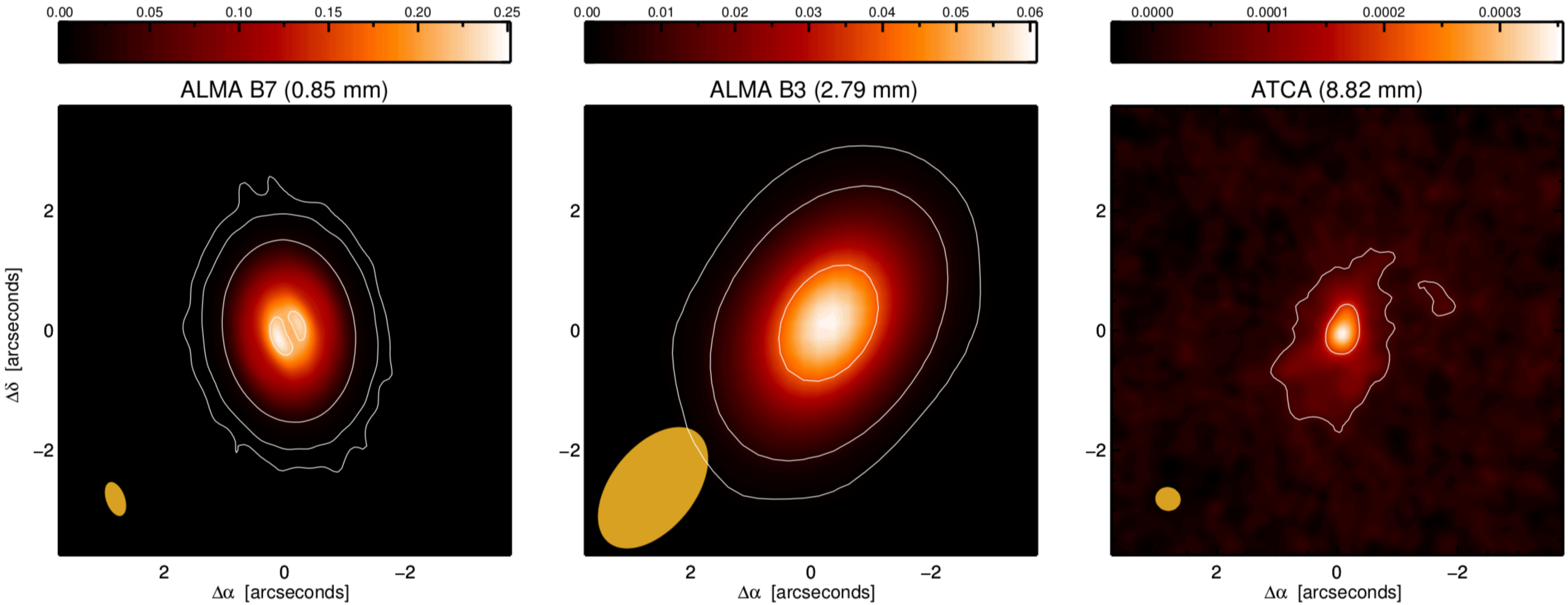
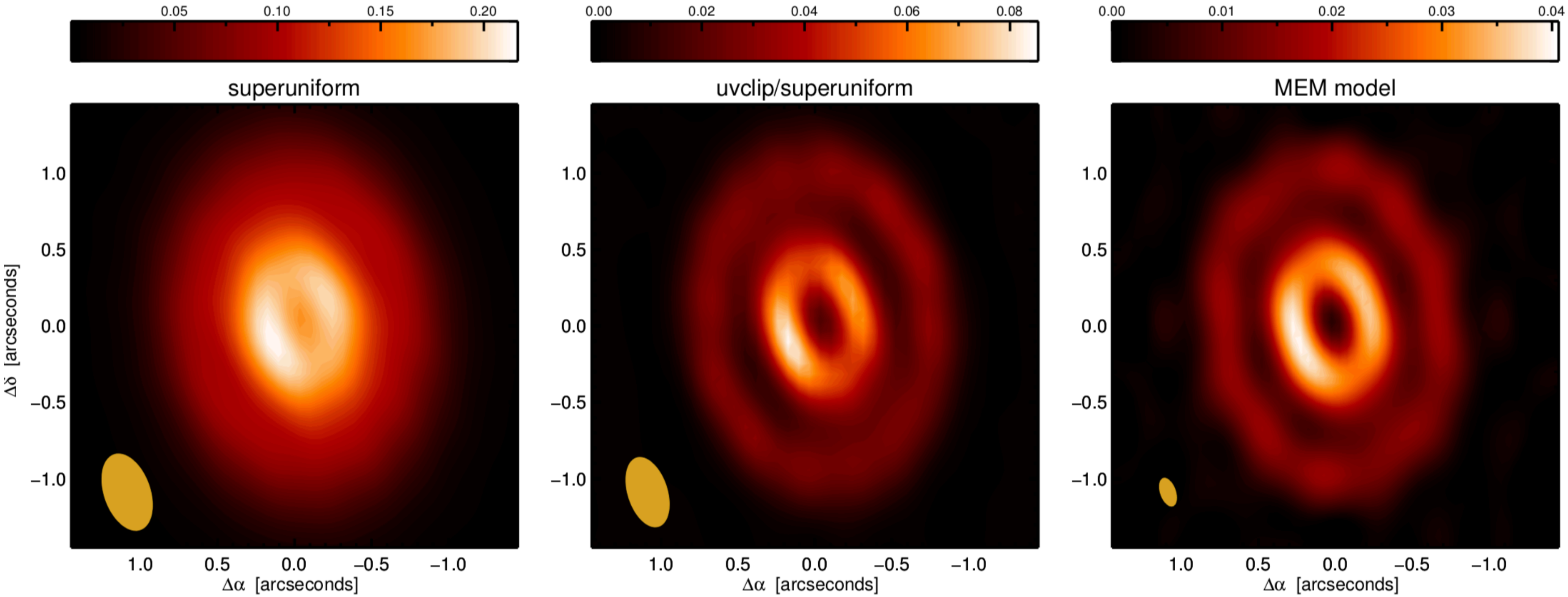


Fig. 1. Images of HD 97048 for the ALMA band 7 (*left panel*) and band 3 (*central panel*) and the combined ATCA 33+35 GHz (*right panel*) observations, reconstructed using uniform (ALMA) and natural (ATCA) weighting. The intensity scale for all images is in units of Jy/beam. Overplotted in each panel are contours with 3, 15, 100, and 1100 times the rms value of 0.20, 0.18 and 0.010 mJy beam^{-1}, respectively. The beam is shown in orange in the bottom left corner of each panel.

(van der Plas et al., A&A 597, A32 (2017)

Cavity and other radial substructures in the disk around HD 97048

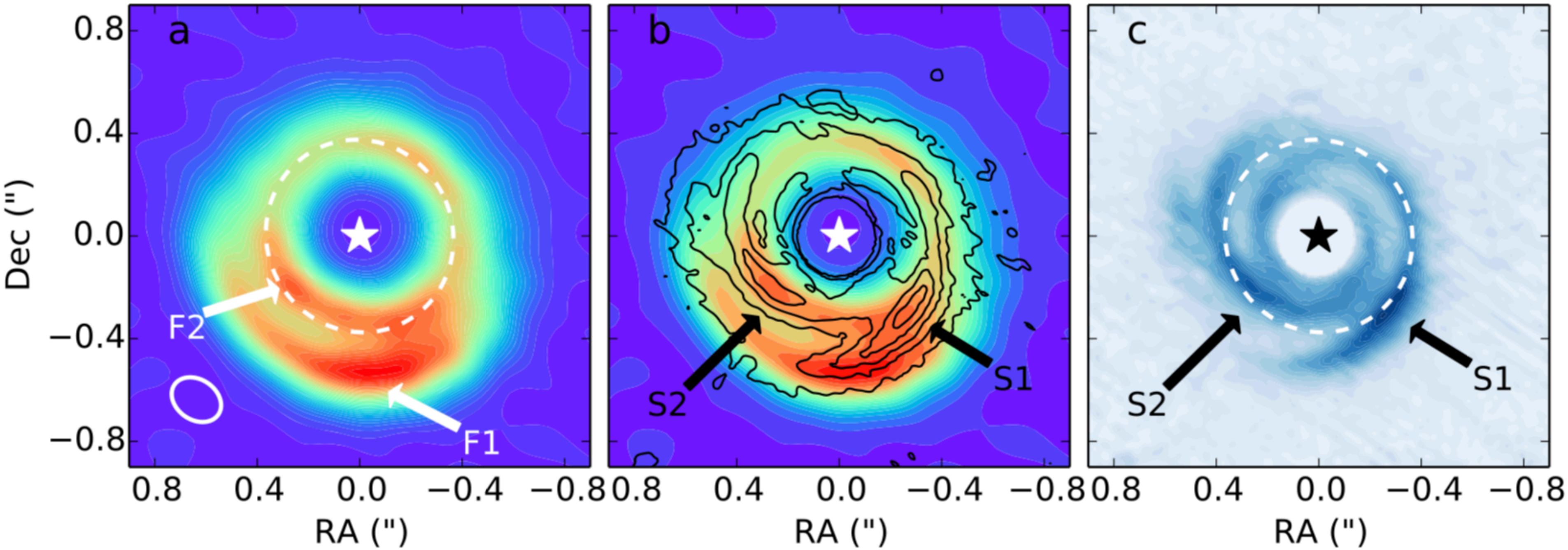
G. van der Plas[1,2], C. M. Wright[3], F. Ménard[4,5], S. Casassus[1,2], H. Canovas[6], C. Pinte[4,5], S. T. Maddison[7], K. Maaskant[8], H. Avenhaus[1,2], L. Cieza[2,9], S. Perez[1,2], and C. Ubach[10]



(van der Plas et al., A&A 597, A32 (2017))

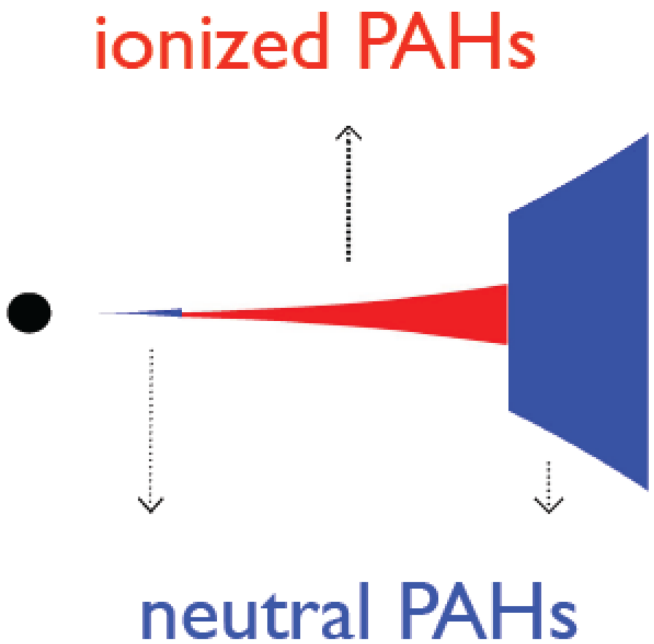
VORTICES AND SPIRALS IN THE HD 135344B TRANSITION DISK

N. VAN DER MAREL[1], P. CAZZOLETTI[2], P. PINILLA[3], AND A. GARUFI[4,5]



(van der Marel et al., ApJ 832, id. 178, 2017)

PAH ionization as a tracer of gas flows through disk gaps

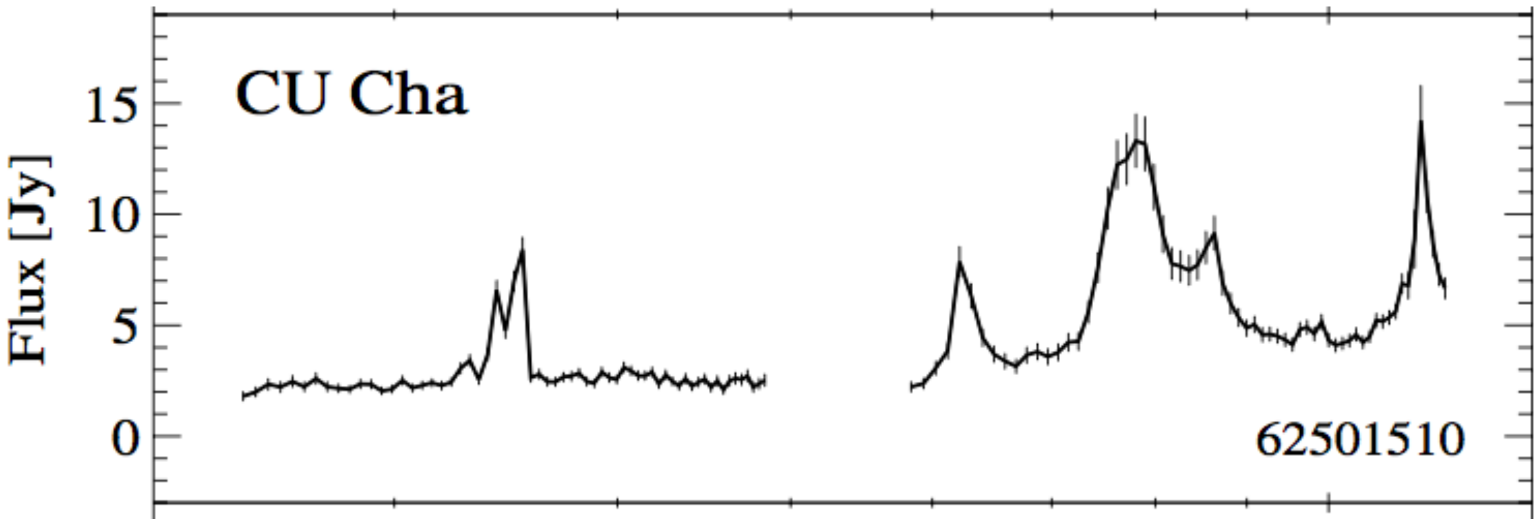


Koen Maaskant
(PhD student Leiden Observatory)

Collaborators: *Xander Tielens, Rens Waters, Michiel Min, Carsten Dominik*

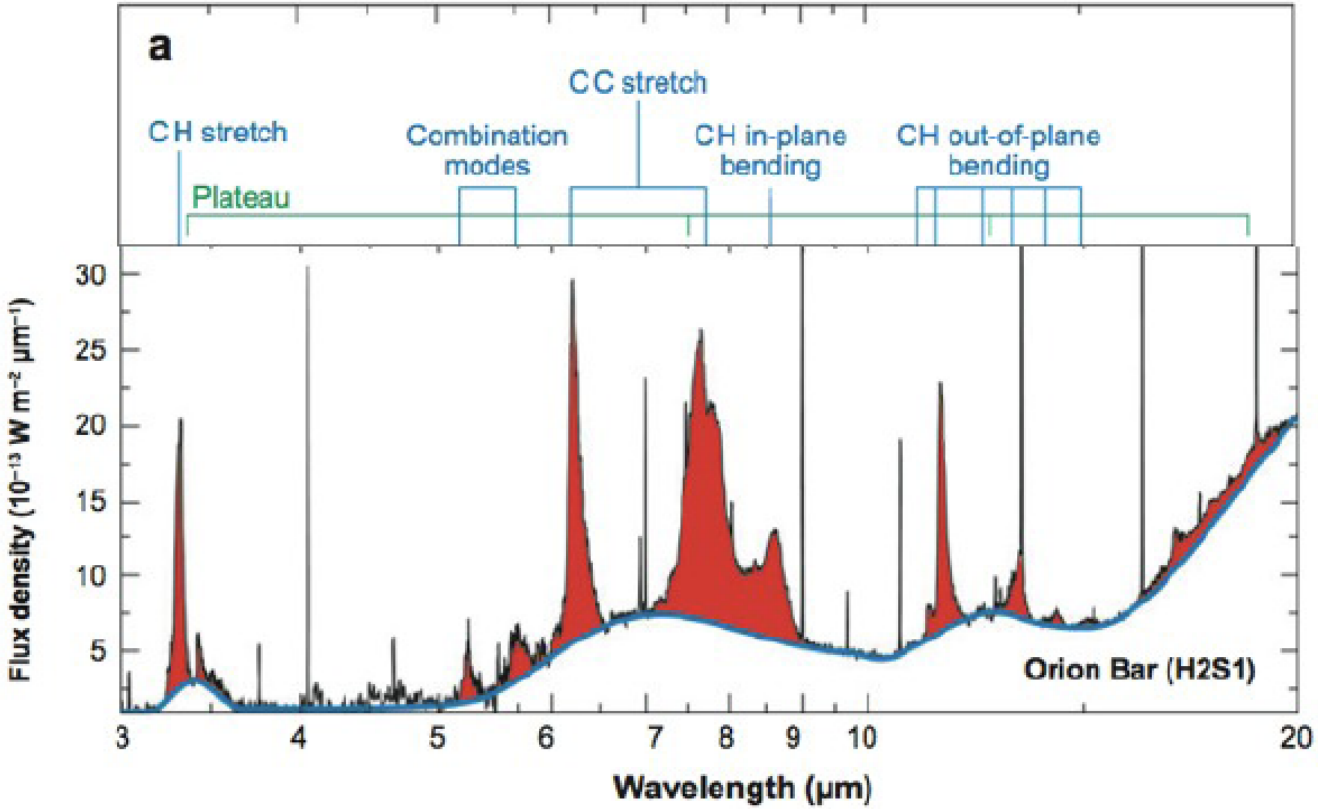
Introduction to PAHs

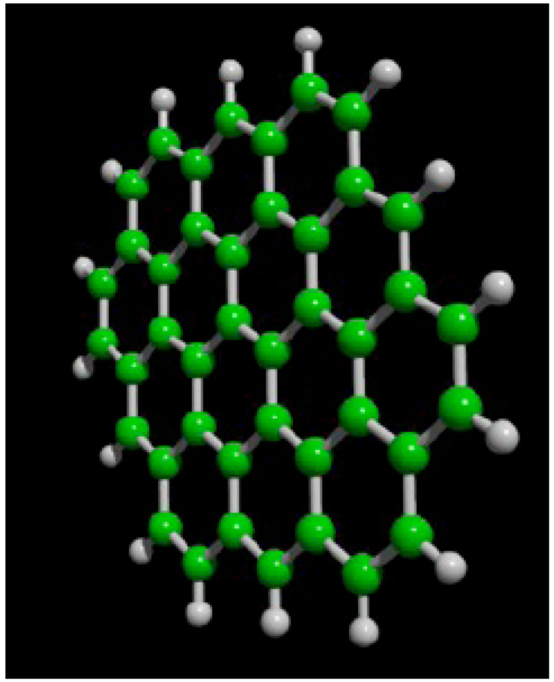
Polycyclic aromatic hydrocarbons (PAHs) can be observed in the infrared spectra of protoplanetary disks of Herbig Ae/Be stars, and - with a lower frequency - T Tauri stars The strength of the features decreases with stellar effective temperature. They can be used as tracers of the outer disk



Kóspál et al. (2012)

PAHs probe the physical conditions of a region (density, temperature, radiation field)
(e.g.: Hudgins & Allamandola 1999, Allamandola et al. 1999, Galliano 2008, Tielens 2008, Bauschlicher et al 2009, Ricca et al 2012).

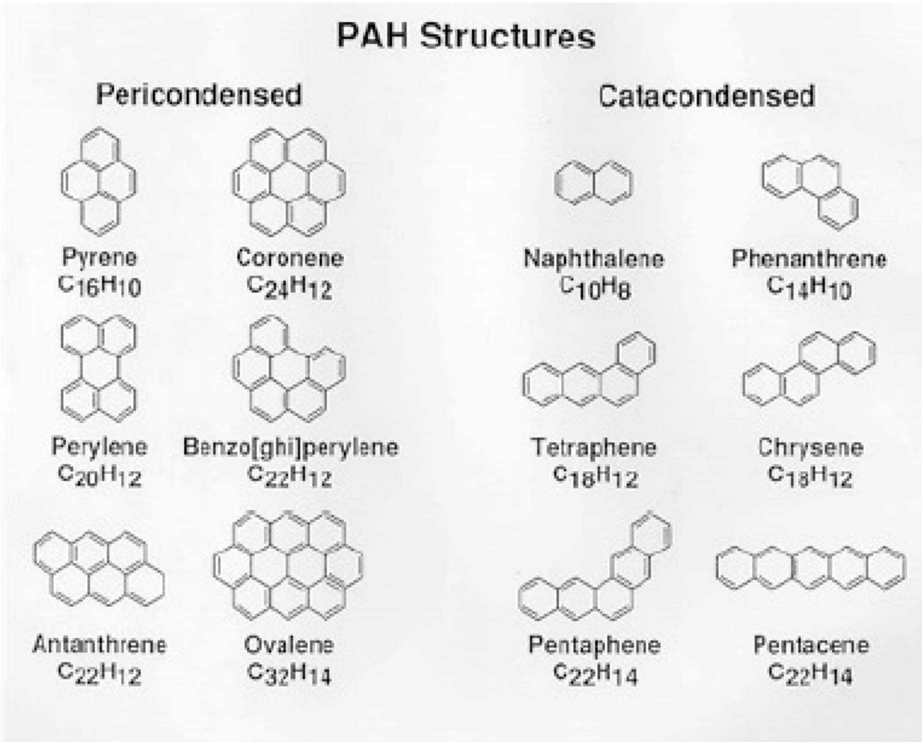


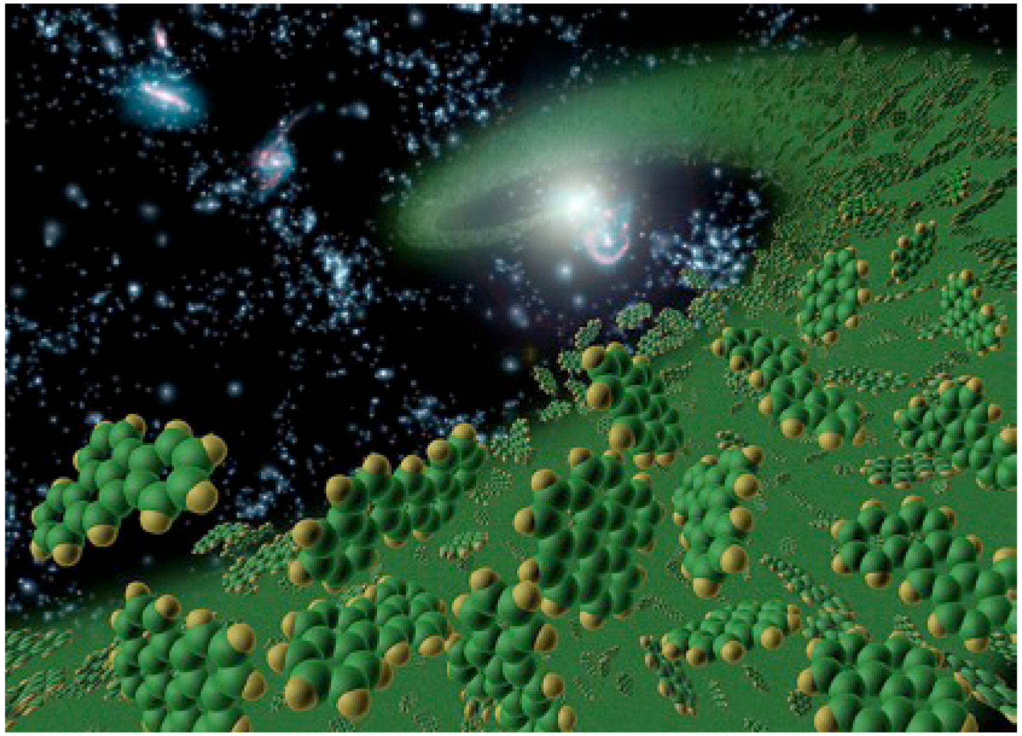


Peeters et al. 2002

PAHs

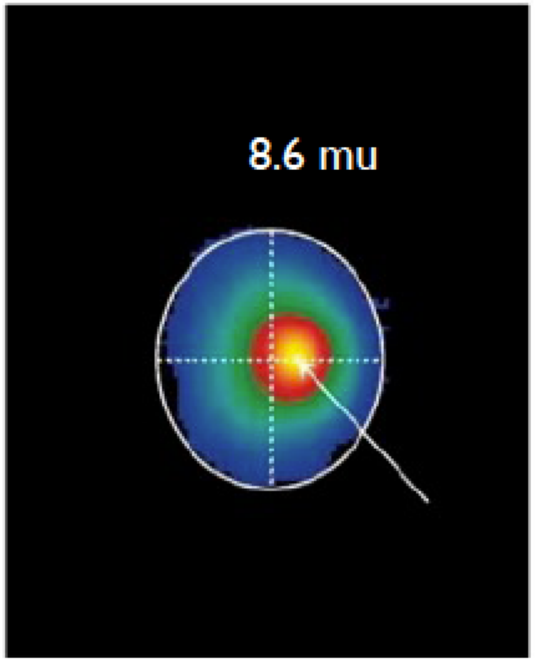
Electronically excited by UV photons (quantum heating)
Cooling by CH- and CC- stretching and bending modes

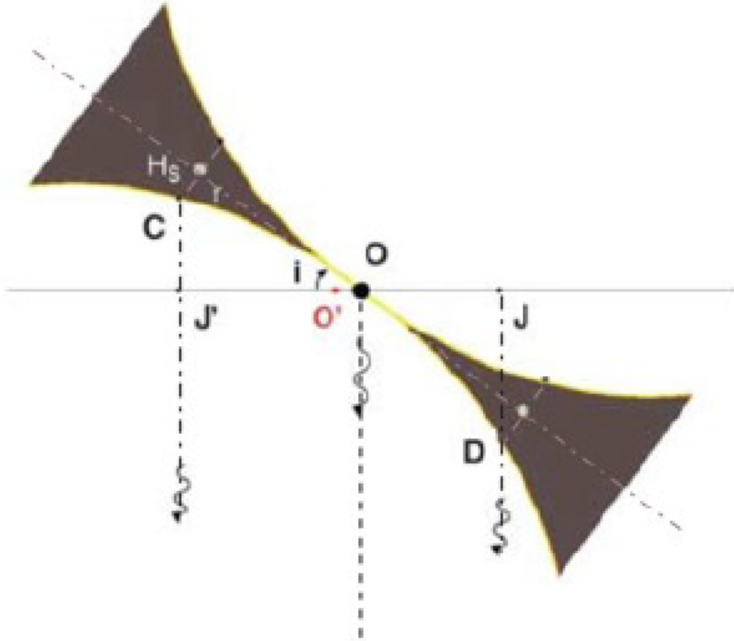




PAHs and the disk structure

Tracing the flaring disk structure

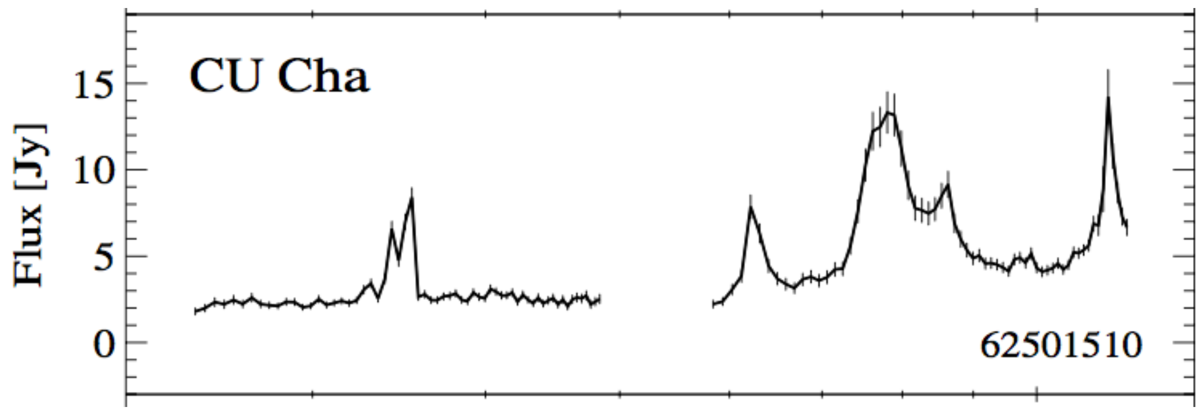




HD97048, Lagage et al 2006, Doucet et al 2006

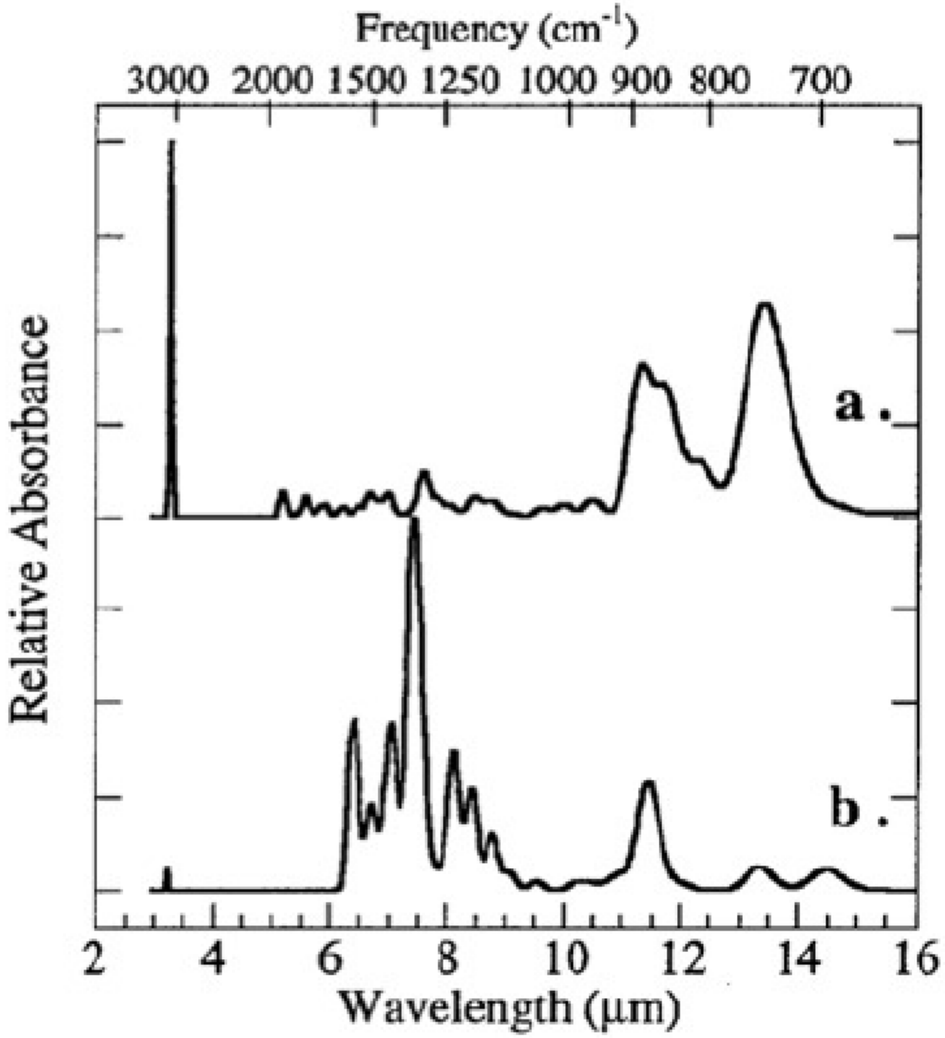
PAHs

An important parameter that influences the relative feature strength of the CH and CC modes is the effect of ionization CC modes being carried predominantly by ions and CH modes by neutrals
6.2/11.2 ratio measures ionization



- can we use the ionization balance of PAHs as a tracer of processes in protoplanetary disks?

neutral and ionized PAH spectra:

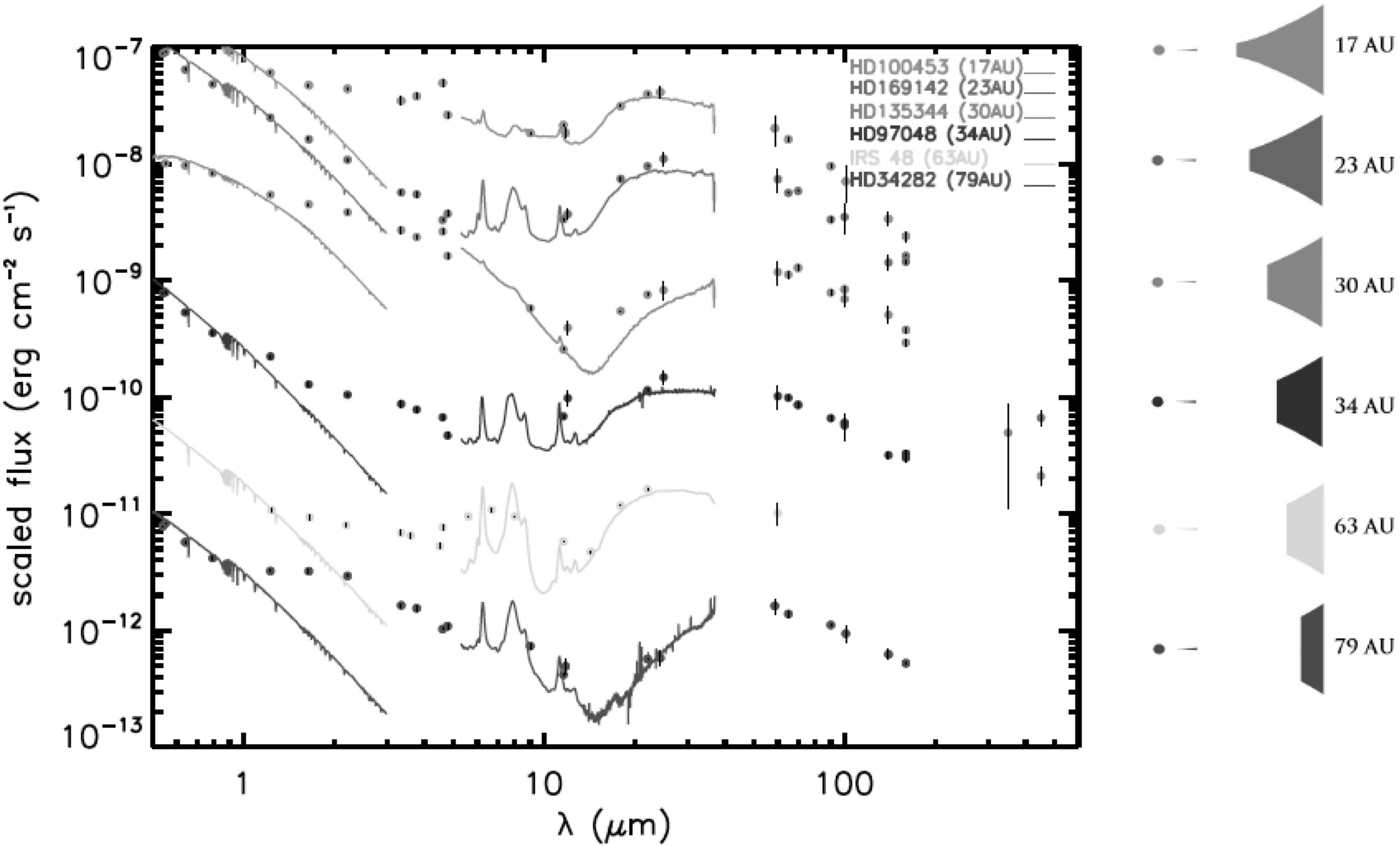


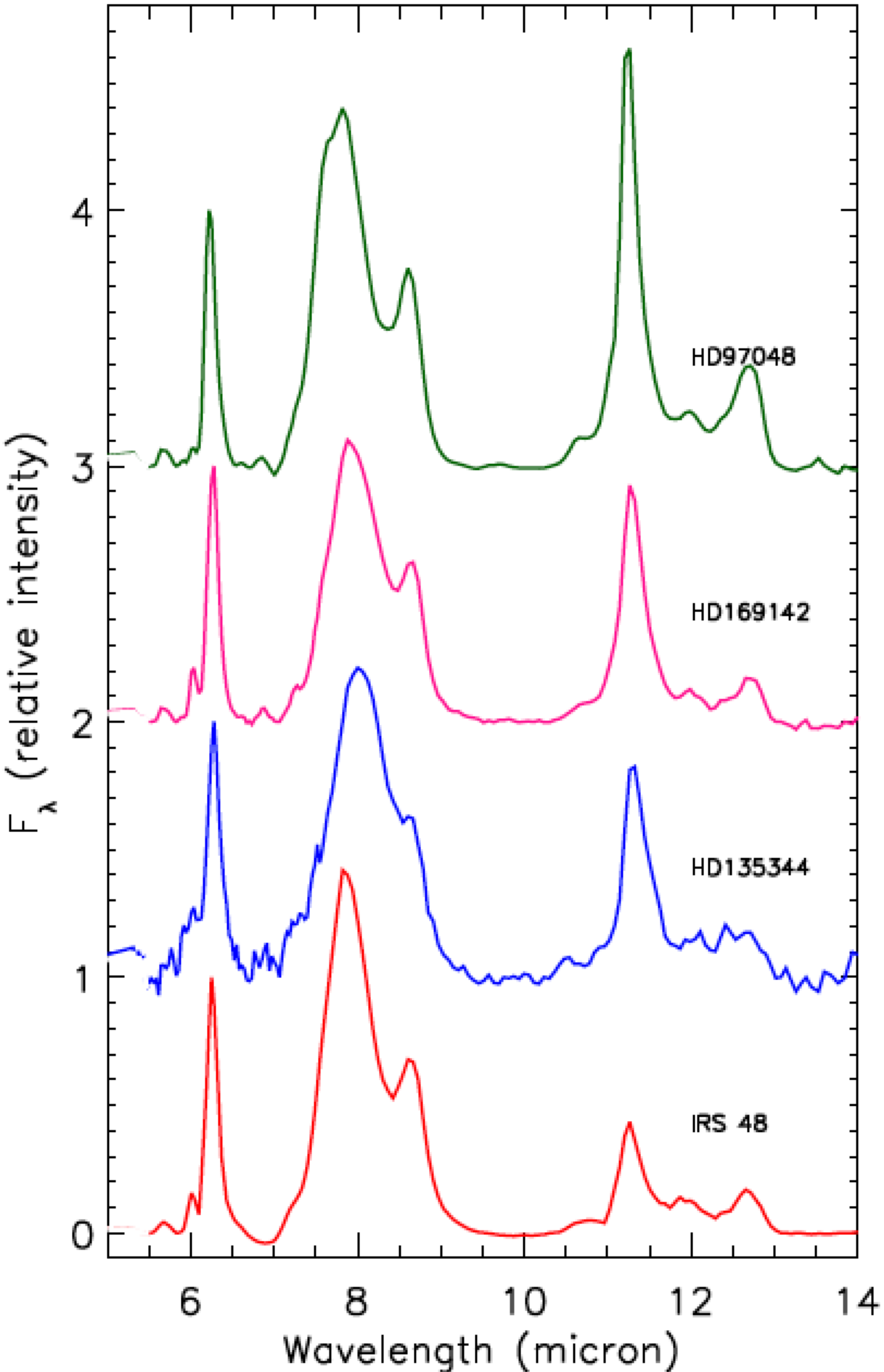
Neutral

ionized

Allamandola et al 1999

Our sample with gaps





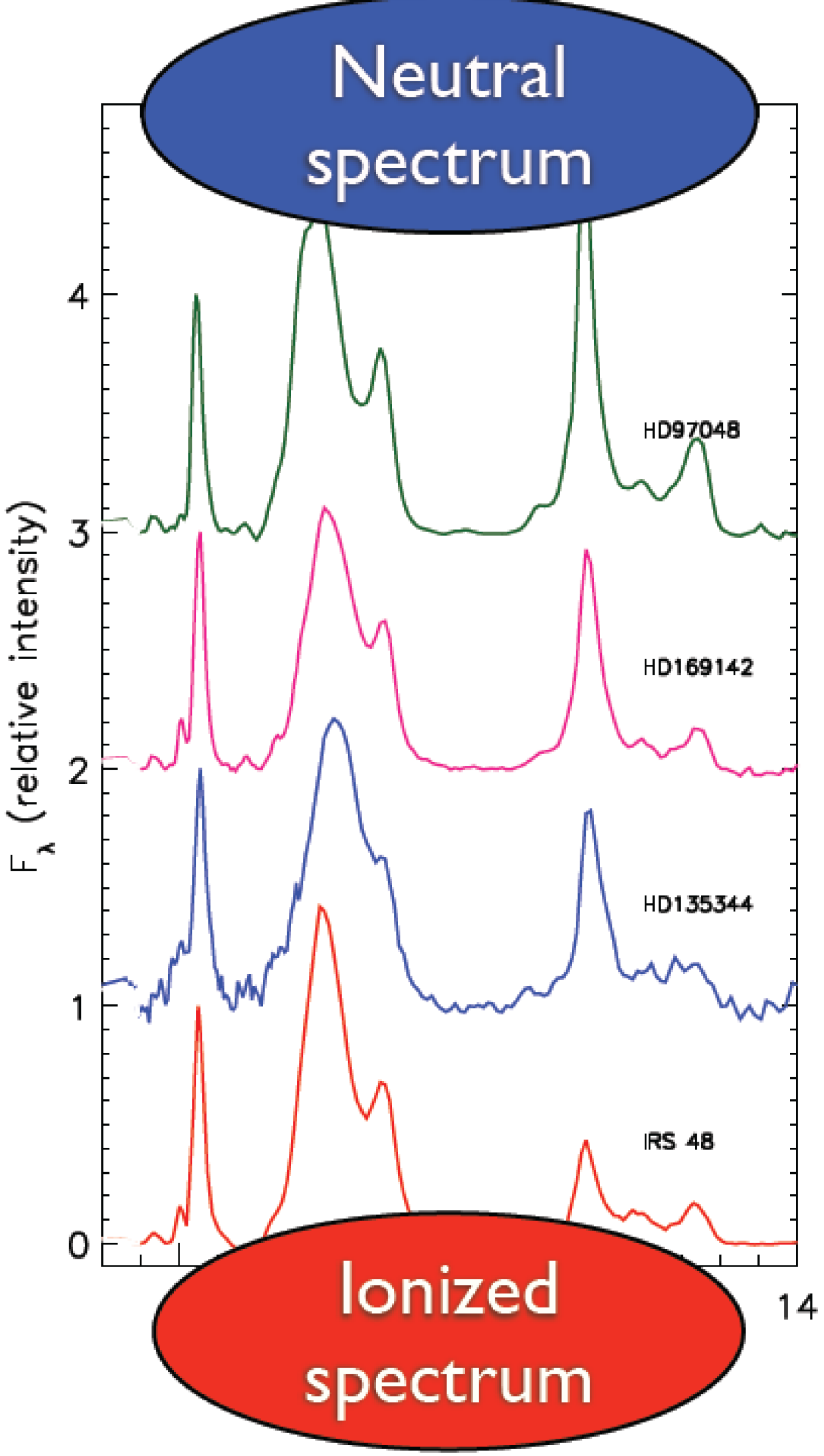
HD97048

HD169142

HD135344B

Oph IRS 48

Maaskant et al 2013, 2014

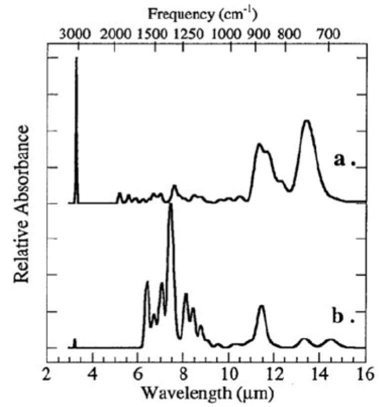


HD97048

HD169142

HD135344B

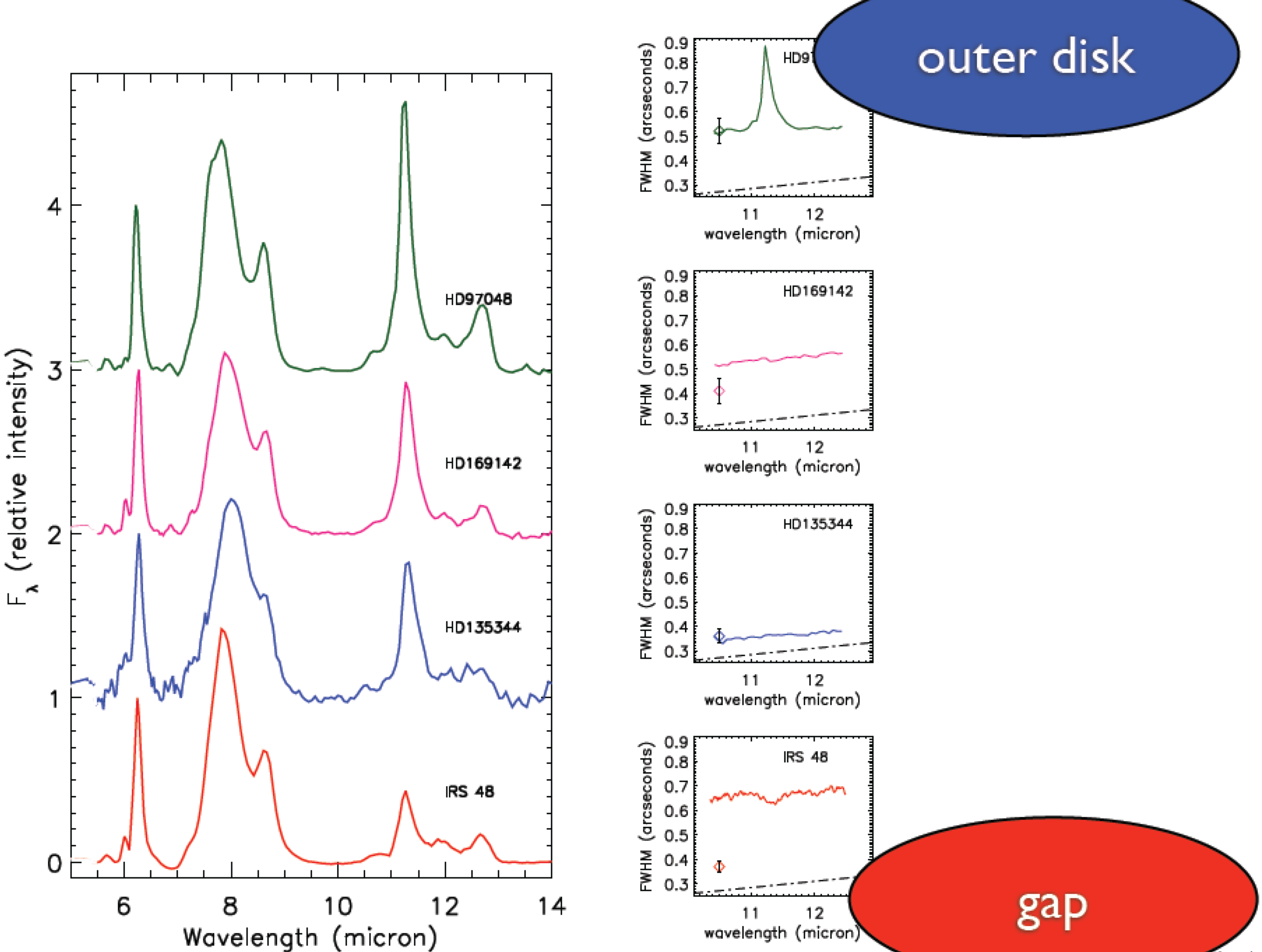
Oph IRS 48



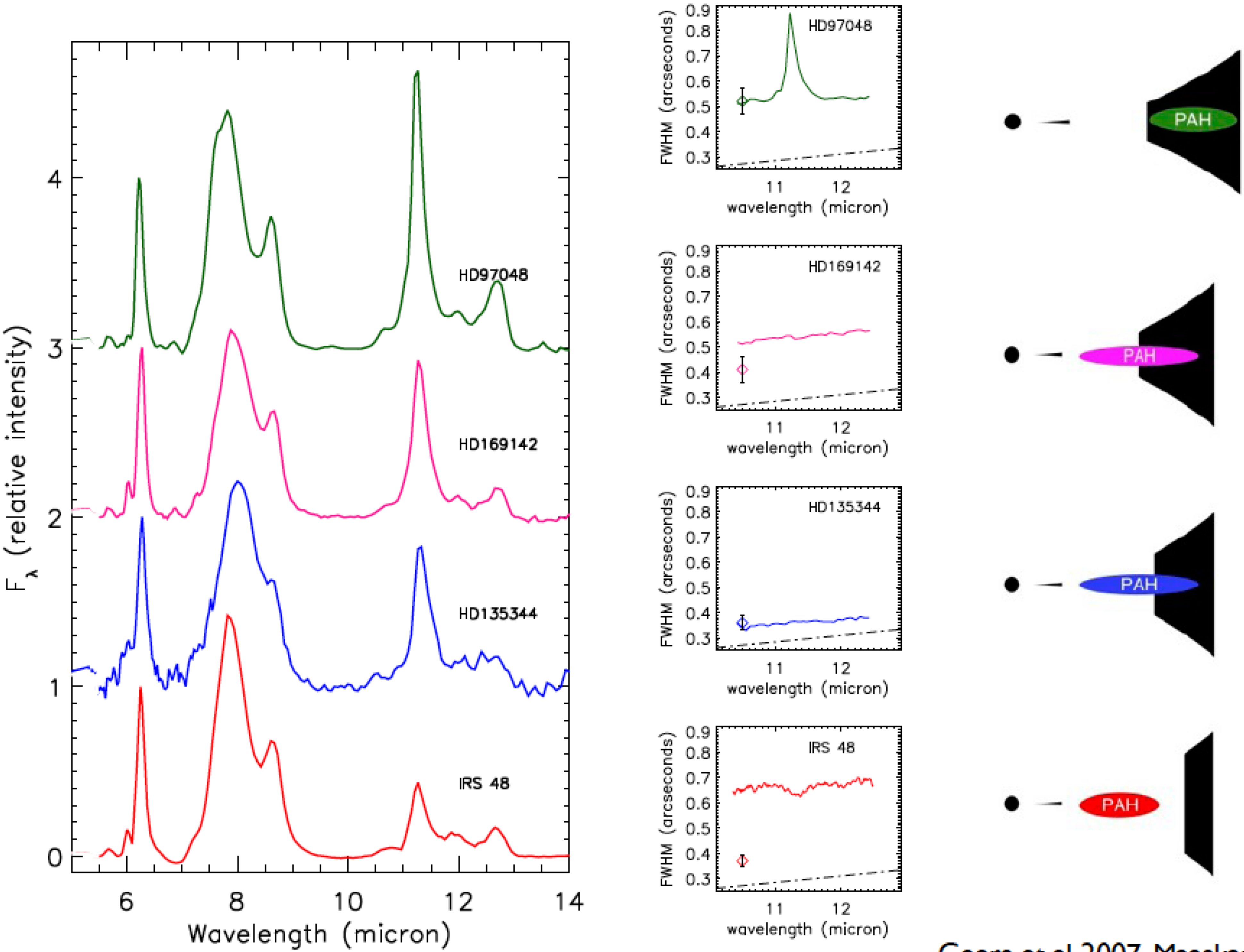
Neutral

ionized

Maaskant et al 2013, 2014

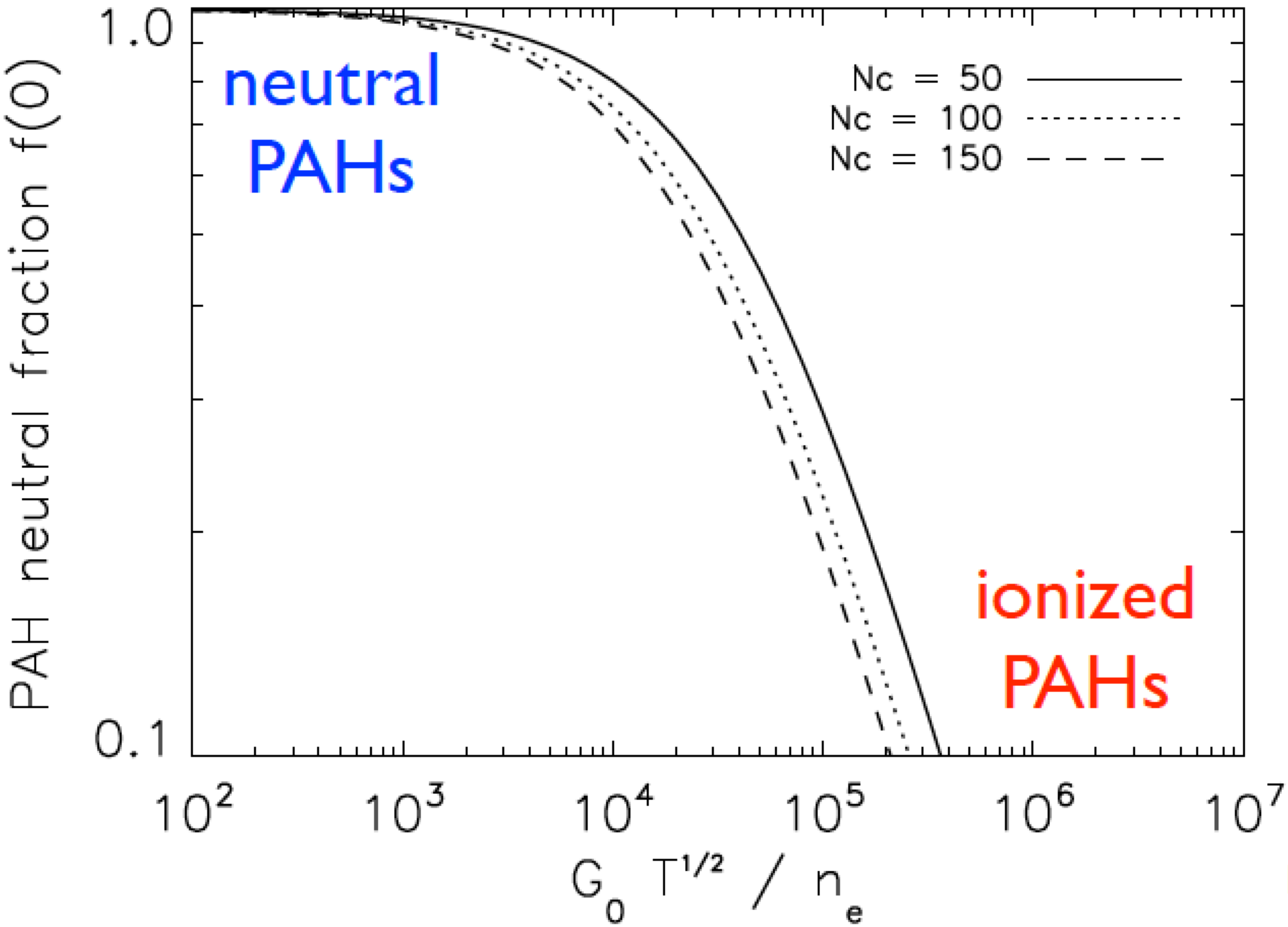


kant et
al 2013, 2014



Geers et al 2007, Maaskant et al 2013, 2014

PAH model in RT code MCMax (Min et al 2009)

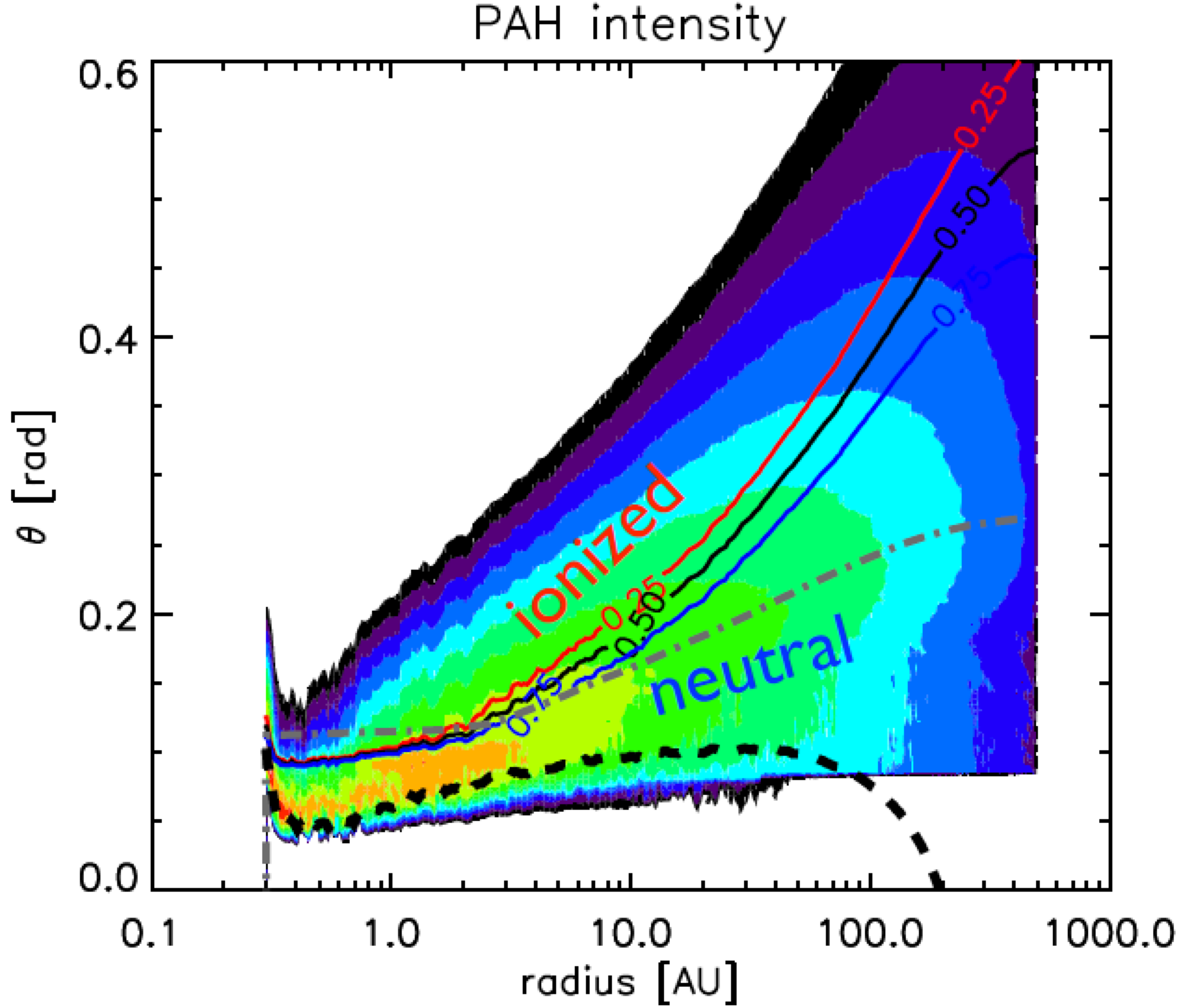


ionization parameter

Bakes & Tielens 1994
Tielens 2005
Galliano 2008

Benchmark model

~90 %
neutral
at all radii



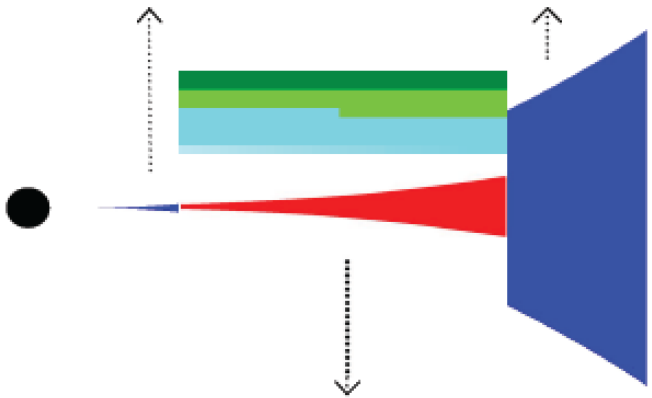
How to get ionized PAHs in disks?

↓

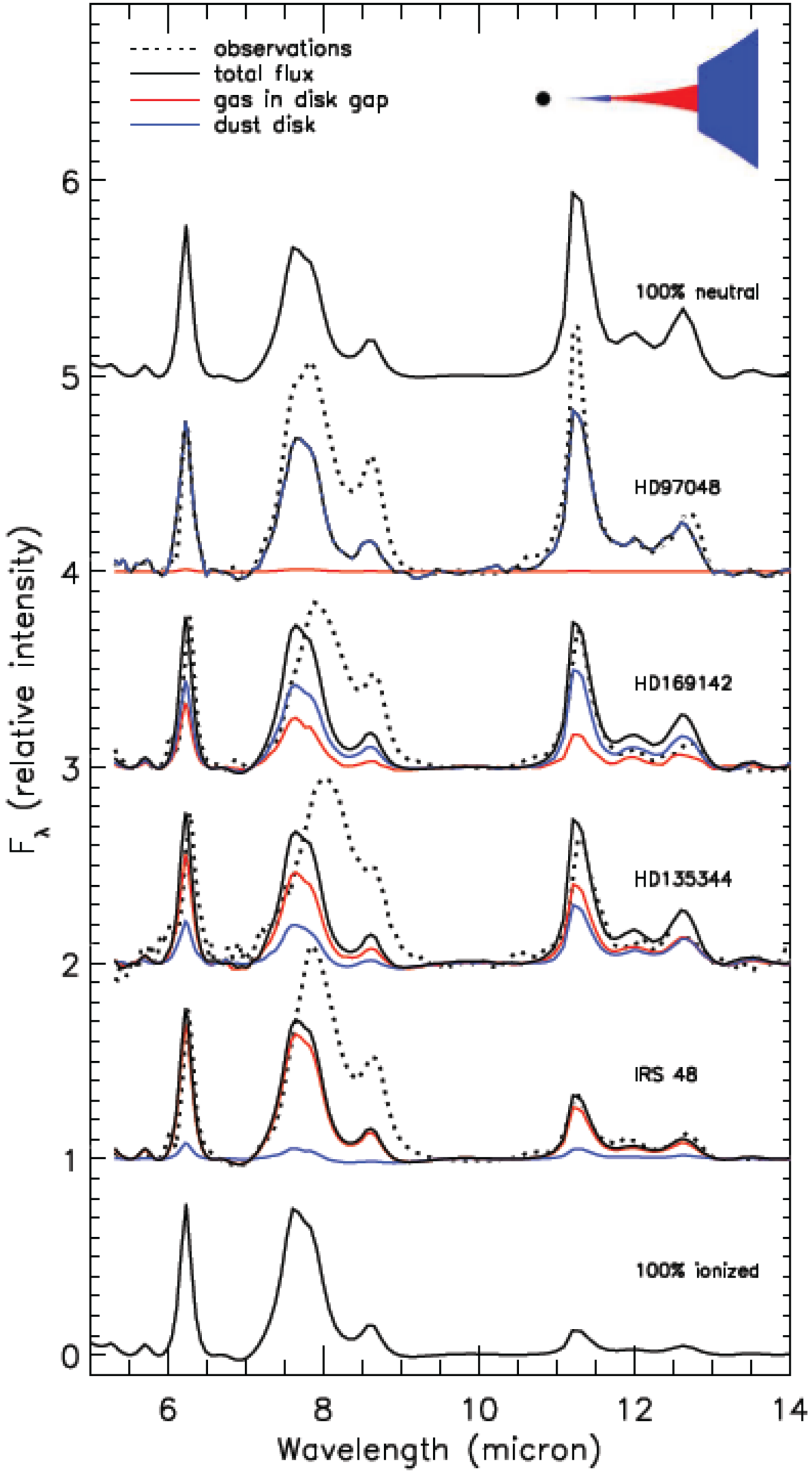
Optically thin gaps!

Demonstration: RT models of four transitional disks

neutral PAHs

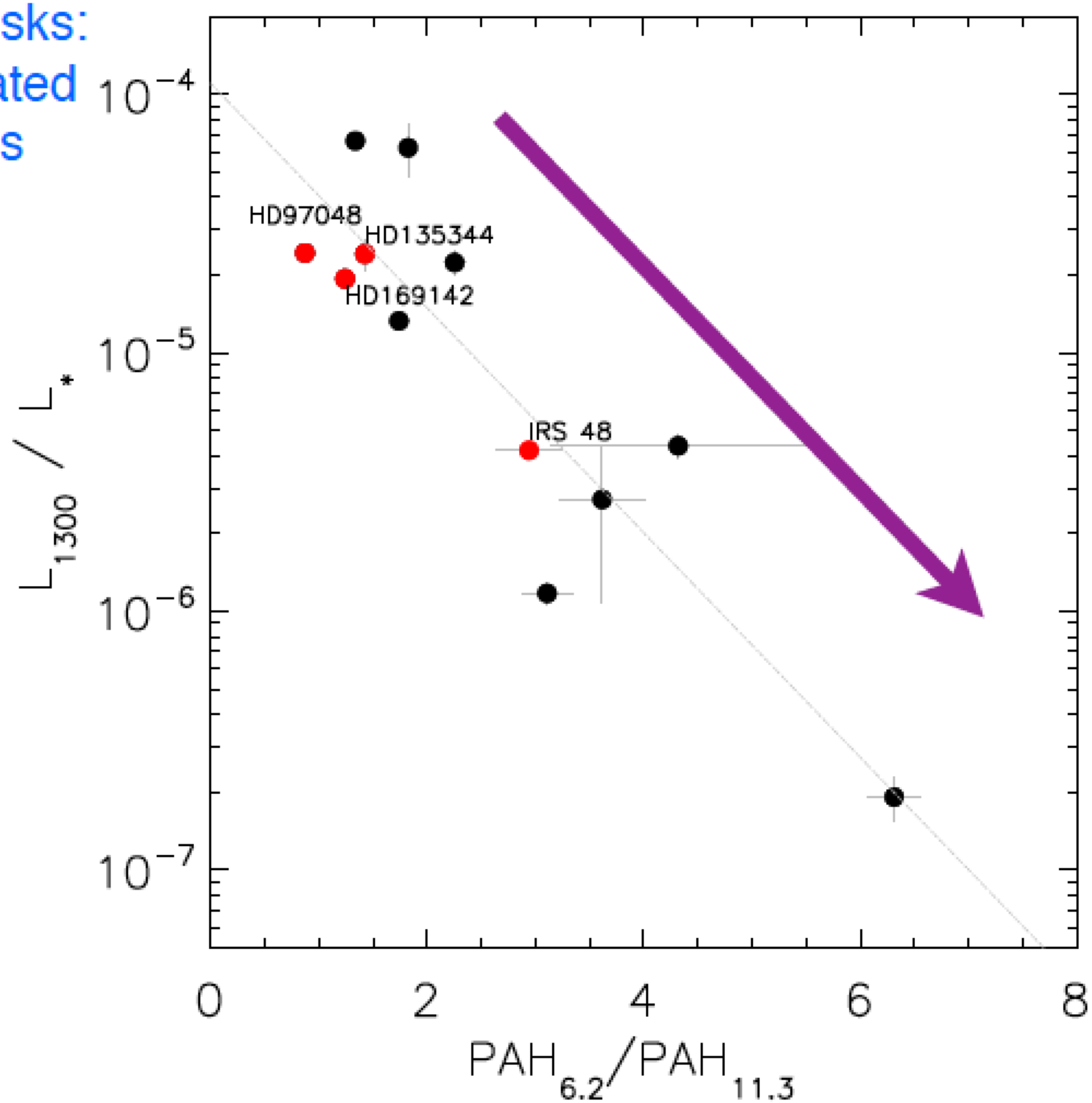


ionized PAHs



Trend:
mm luminosity (disk mass) vs PAH ionization

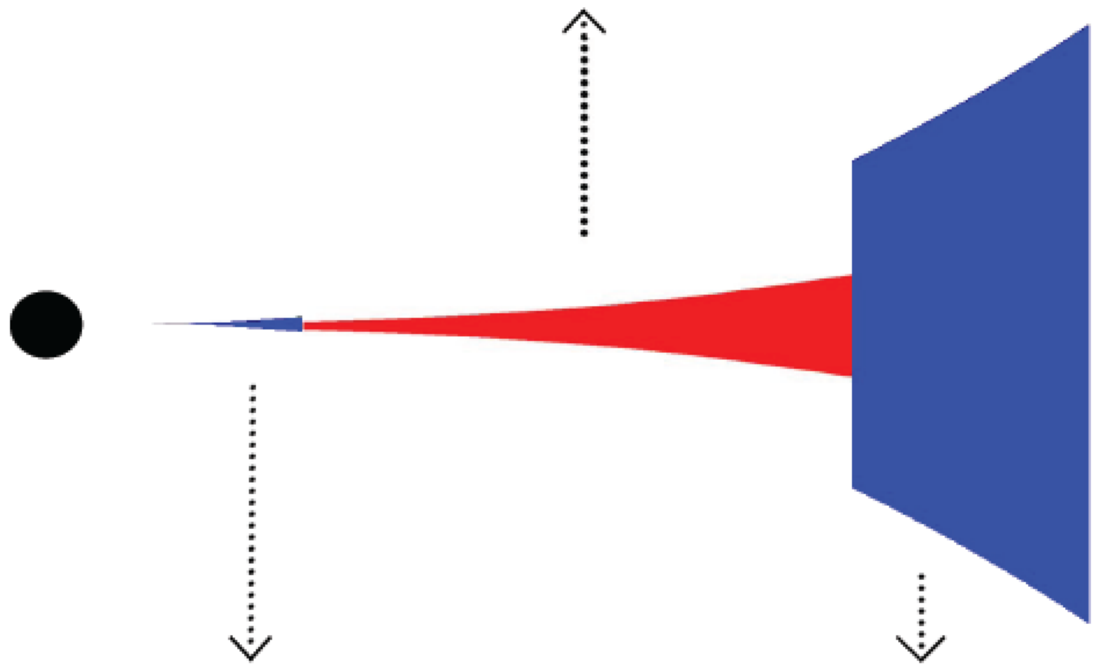
Higher mass disks: spectra dominated by neutral PAHs



Lower mass disks: spectra dominated by ionized PAHs in gaps

Conclusion

Ionized PAHs in low density, optically thin gas flows through the gap (high UV field, low electron density)



Neutral PAHs in optically thick disk (low UV field, high electron density)

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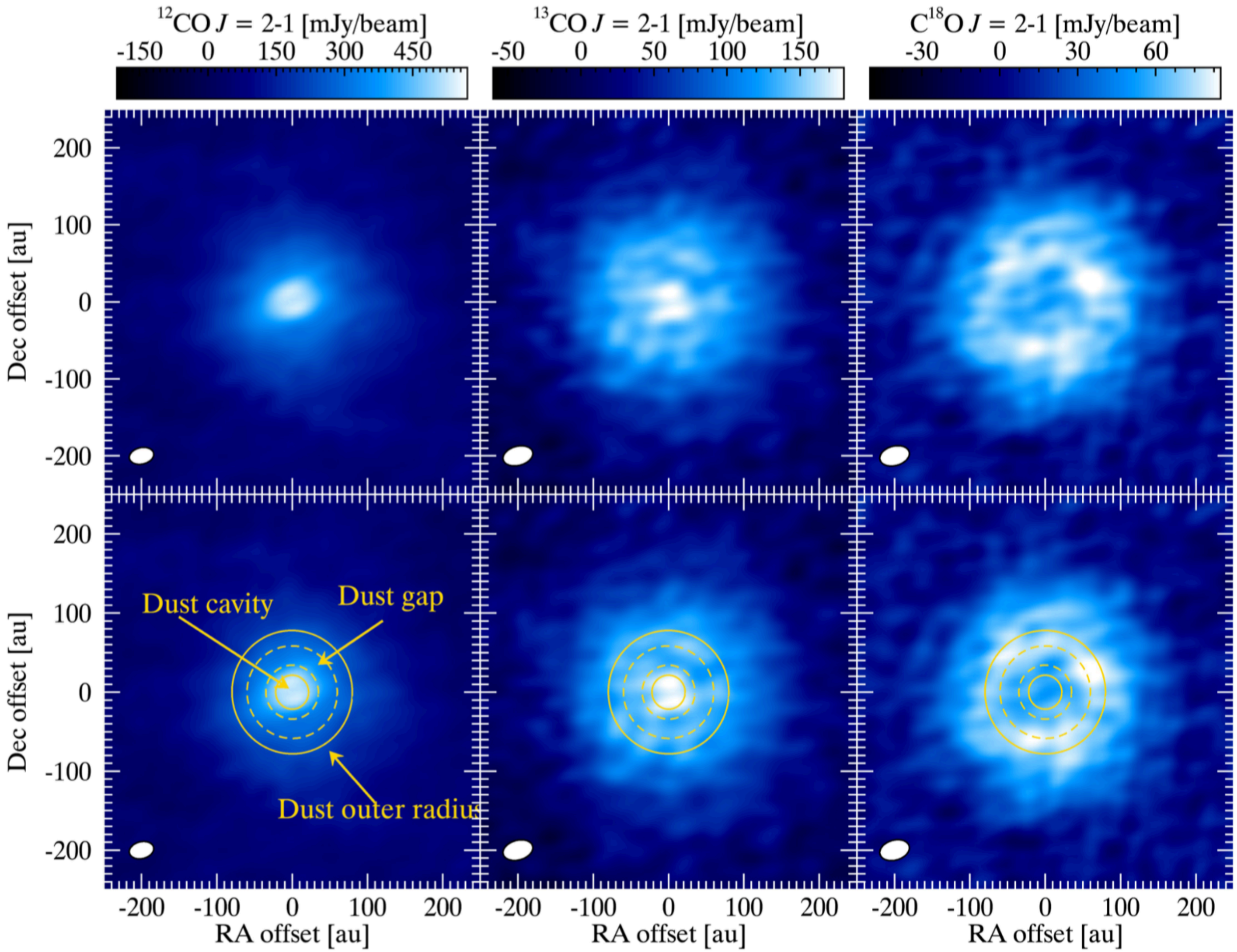

Fedele et al (2017, A&A 600, A72)

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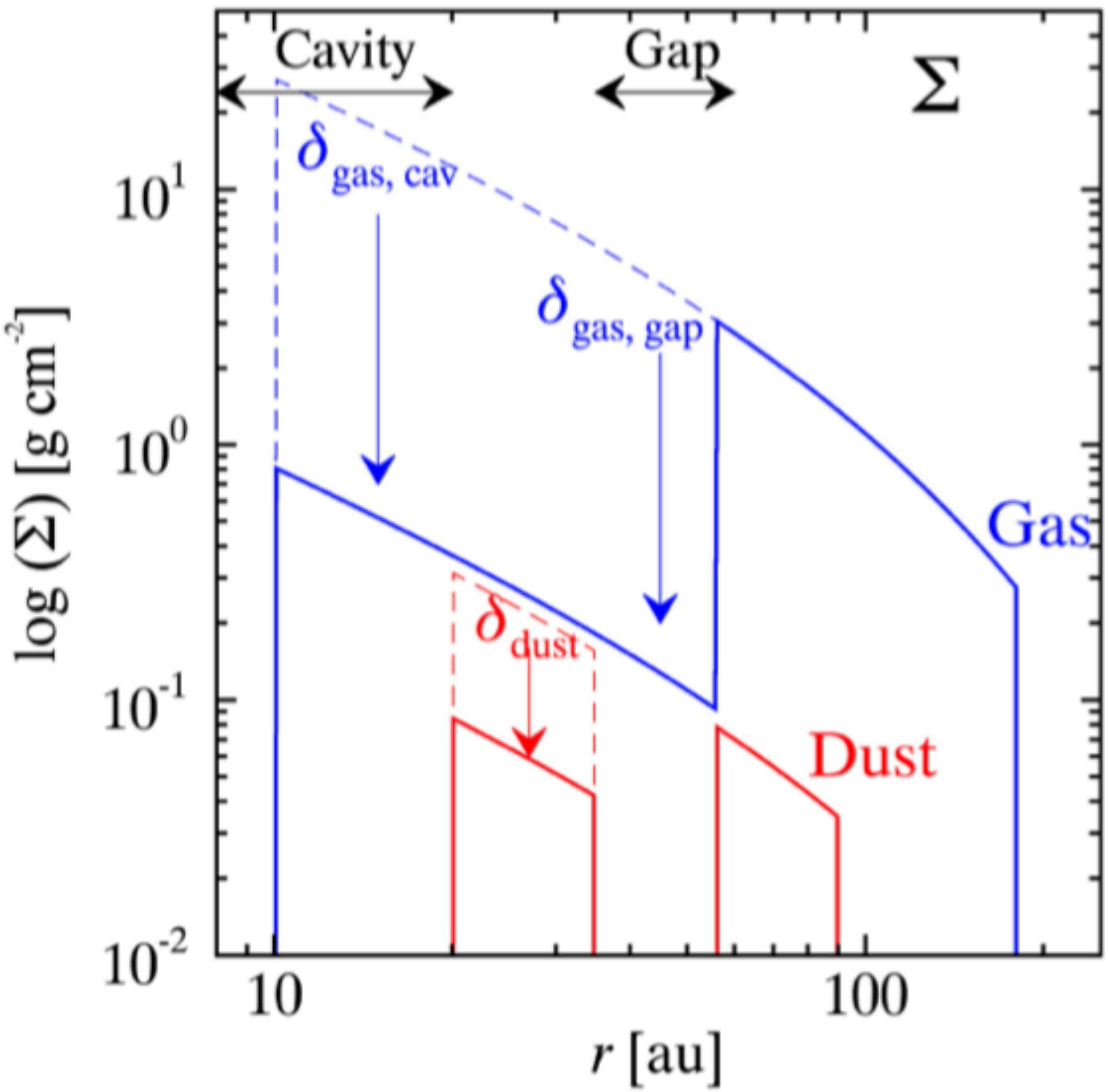

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