DEBRIS DISKS

2mm excess

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and NIKA2 collaborators : N. Ponthieu, J.F. Macias-Perez, L. Perotto, F. Mayet, F. Ruppin, X-F Désert, B. Ladjelate, A. Ritacco and everyone who made NIKA2 possible.

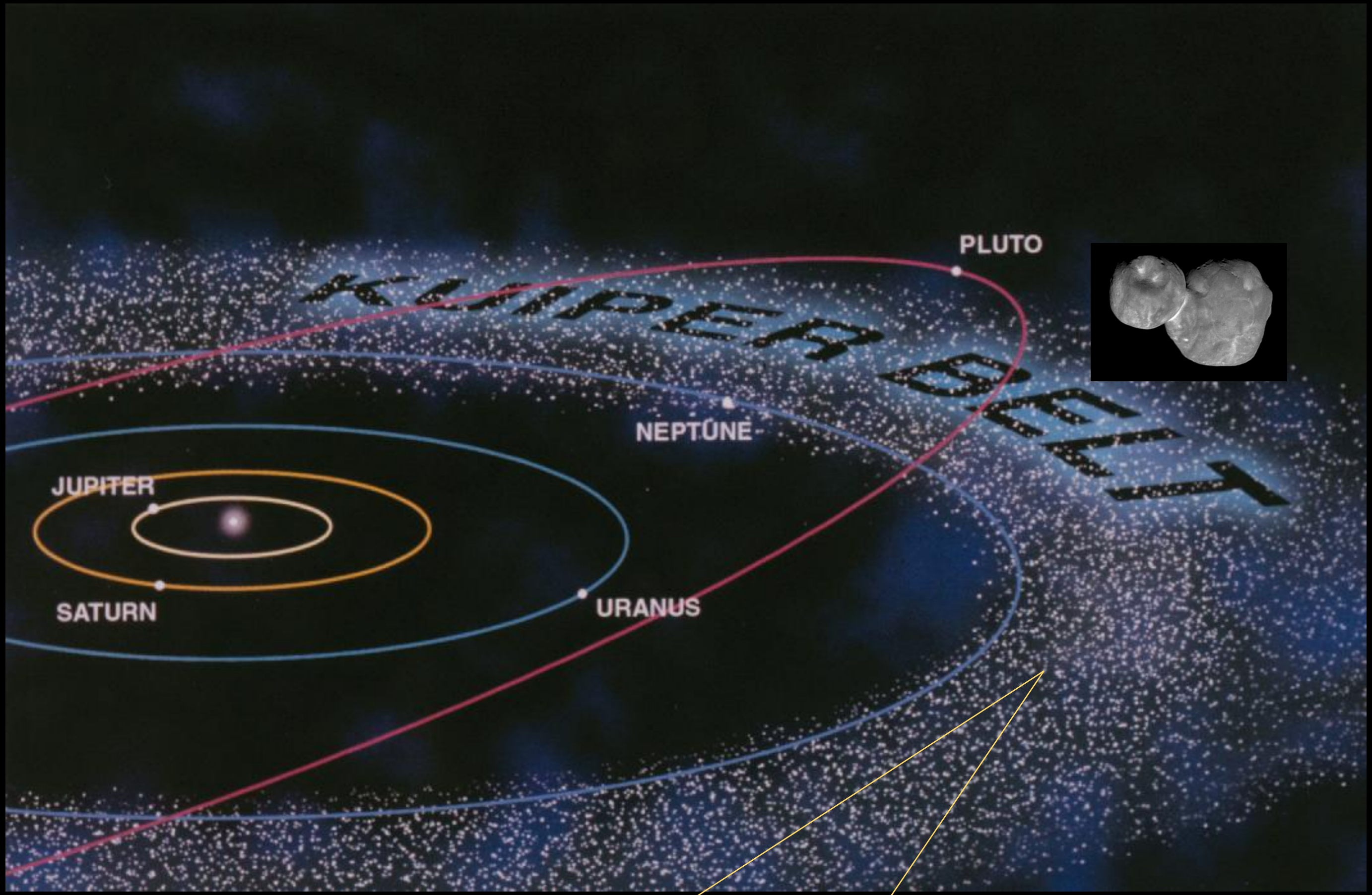
and

J-C Augereau (IPAG), M. Booth (Jena), W. Holland (UK ATC)

Outline :

- Background on debris disks
- Millimeter-λ domain, key for determination of the total mass of debris disks
- NIKA2 photometry of slightly extended sources : three debris disks
- Modelisation of SED of these 3 debris disks in the millimeter-λ domain.
- Perspectives

HISTORY



- Kenneth Edgeworth (1943) : in the outer region of S.S., there must be primordial material in form of small bodies but are too scattered to condensate into planets.

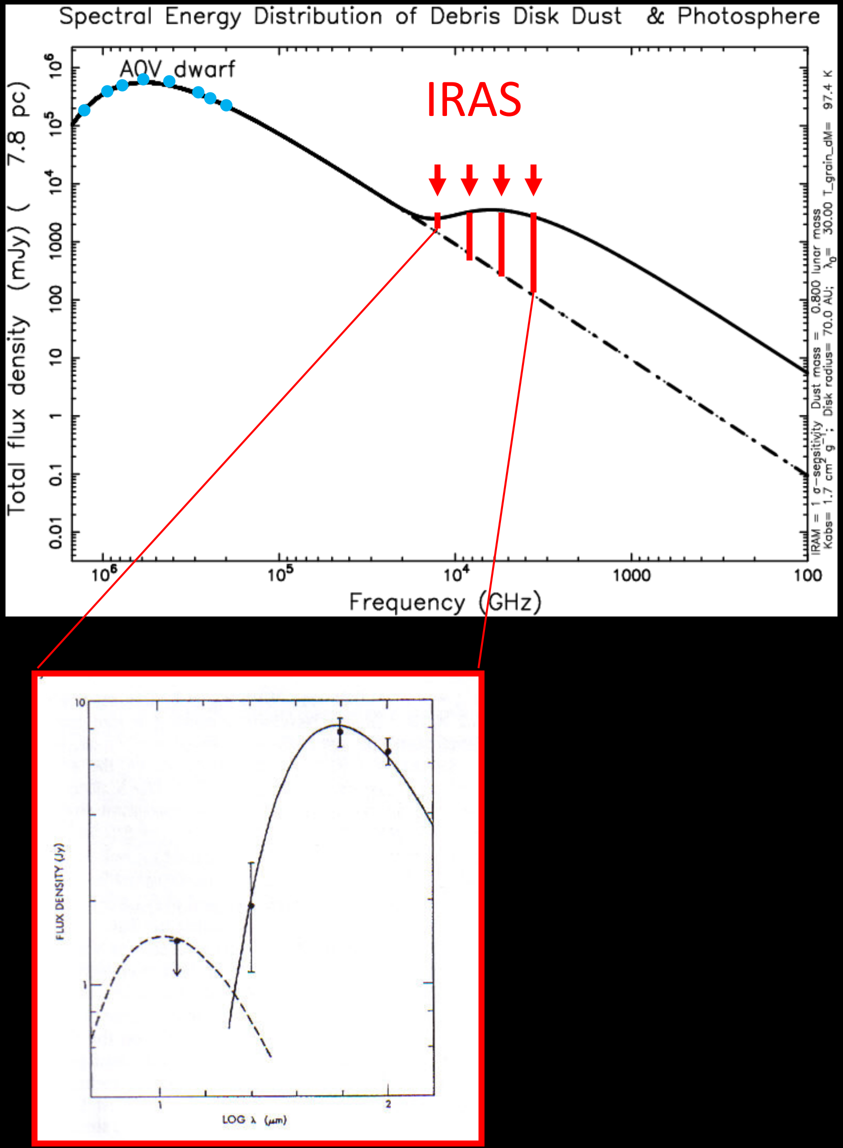
- Gerard Kuiper (1951) : disk of small bodies in the outskirt of the S.S. has existed in the early phase of the system but has been dispersed by Pluton far away in the Oort cloud (One Earth mass at the time).

- D. Jewitt and J. Luu (1993) : first small object detected beyond Neptune, in the K-E belt.

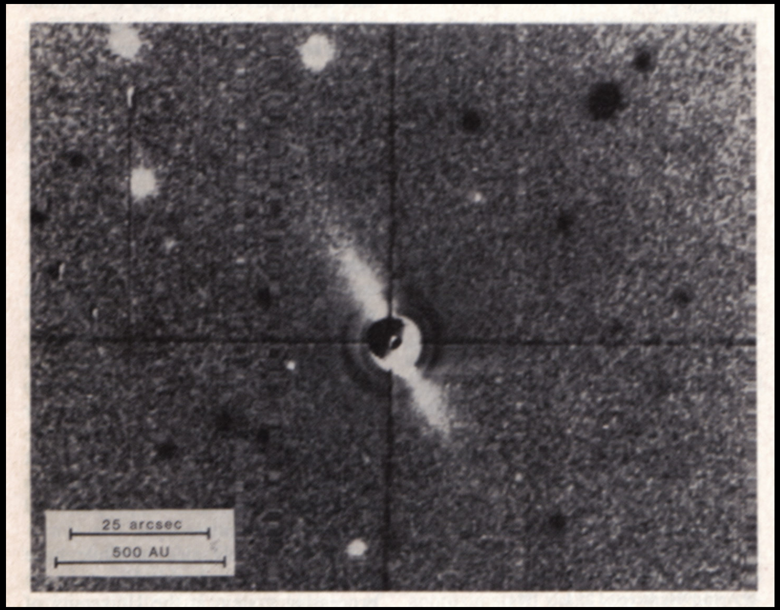
- Satellite IRAS launched in 1983 : mid & far IR excesses detected around Vega, Aumann et al (1984).

- Mayor & Queloz (1995) at Observatoire Saint Michel Haut de Provence : First extra solar planet detected.

History



Aumann et al (1984) :
the first debris disk was discovered serendipously as excesses above photospheric level by IRAS for the A0V star Vega.



Smith & Terrile (1984) :

First image of a debris disk (edge on) in scattered light around the A5V star Beta Pic at Las Campanas Observatory, Chile.

Collisional fragmentation cascade (Dohnanyi 1969)

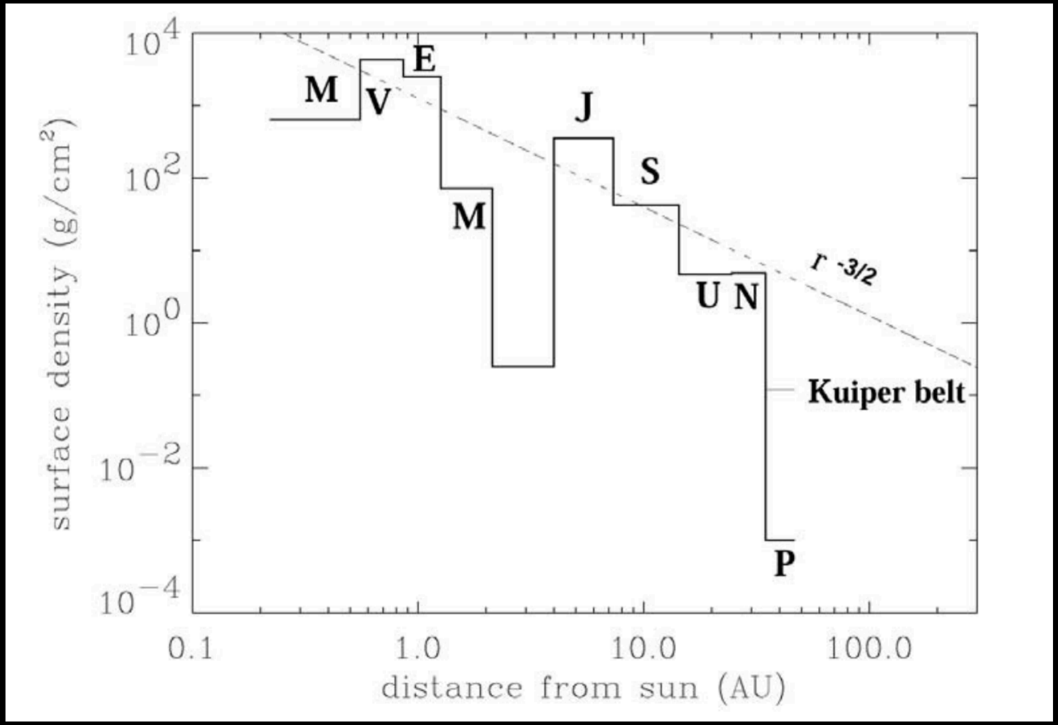
- Fragment size distribution : $n(a) \propto a^{2-3qd}$ from grain size $a_{min} \sim a_{blow\ out}$ (micronic) to size $a_{max} \sim 100$ km.

- Self-similar collisional cascade (material strength independant of planetesimal size) : q_d=11/6 makes $n(a) \propto a^{-3.5}$

- Total emitting/reflecting surface is dominated by small grains ($S \propto 1/\sqrt{a_{min}}$) while total mass is dominated by large bodies ($M \propto \sqrt{a_{max}}$)

The Kuiper Belt and its Primordial Sculpting

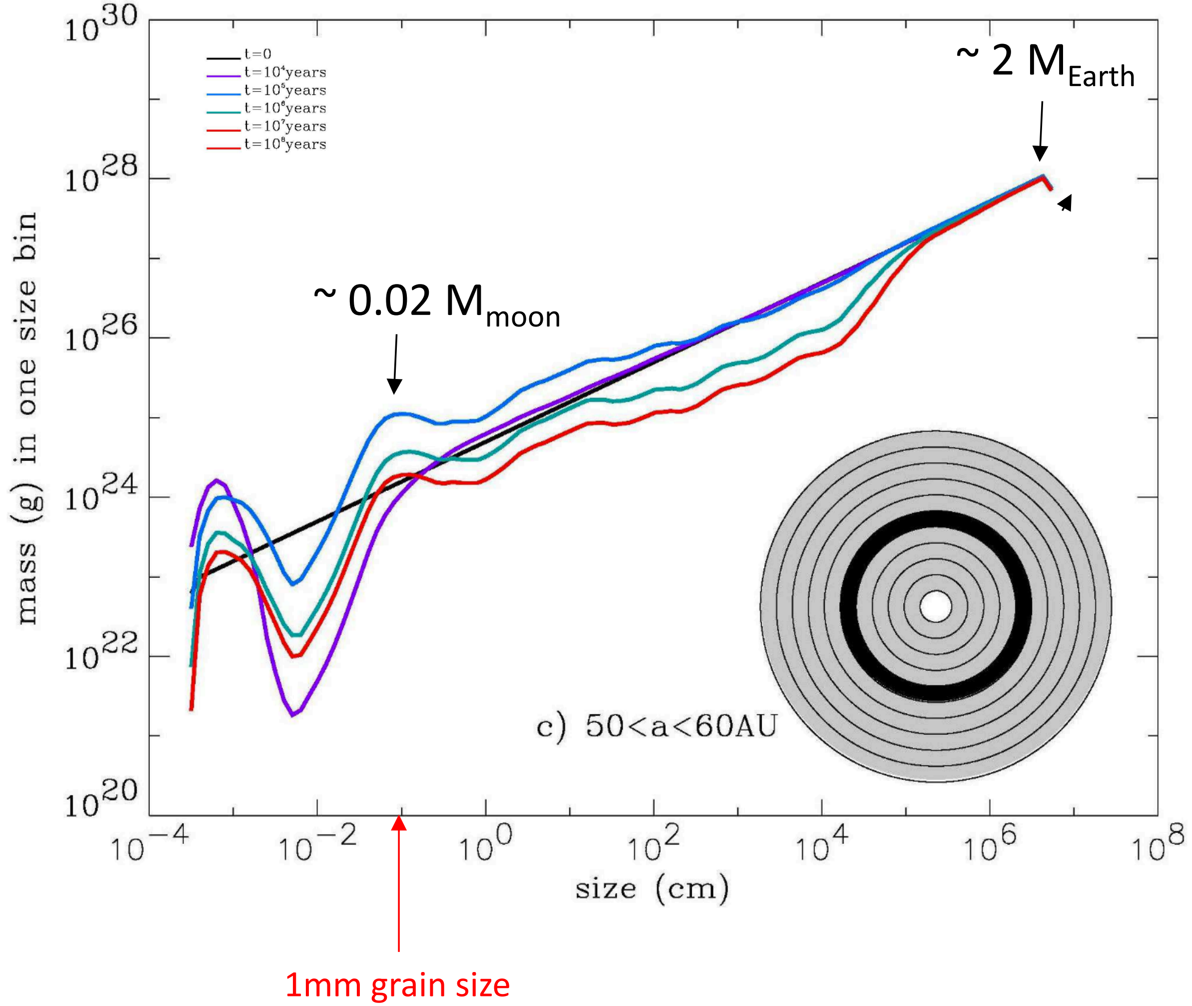
Minimum Mass Solar Nebula



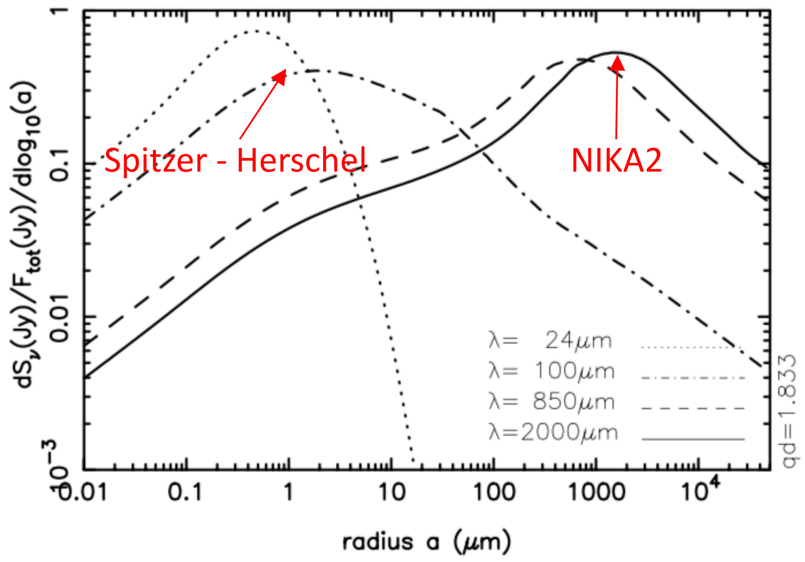
Morbidelli, Brown, Levison 2003

From dust mass to total mass of the debris disk

Mass distribution in a collisional cascade
(Thébault & Augereau 2007)



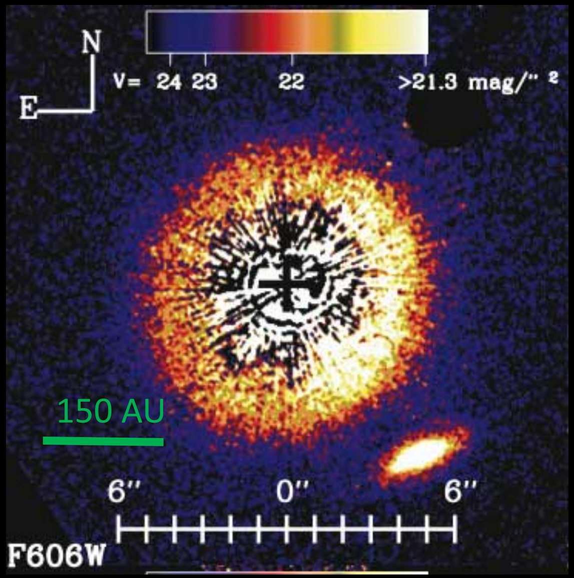
dS_ν / dlog(a) : Contribution to the total flux density of dust emission in each grain size bin for the dust size distribution n(a) $\propto$ a $^{-3.5}$



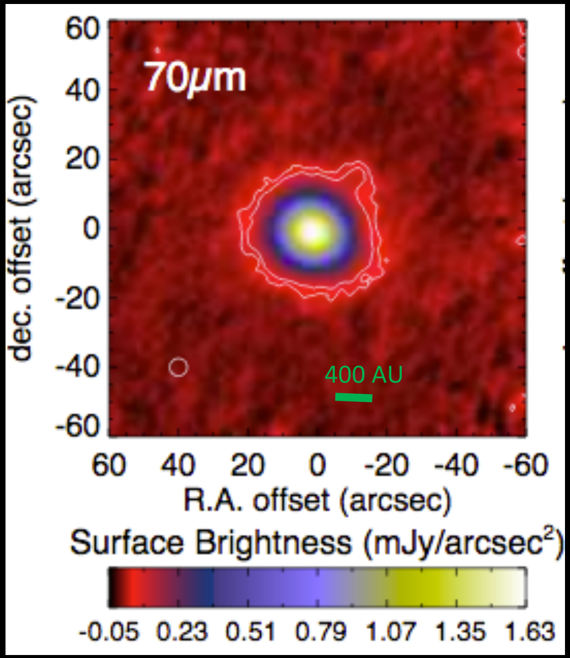
NIKA2 senses emission from the right grain size (a ~ 1mm) to extrapolate to km sized planetsimals via collisional cascade and derive the total mass of the disk.

THE THREE DEBRIS DISKS STUDIED UNDER THE AUSPICES OF NIKA2 OPEN TIME

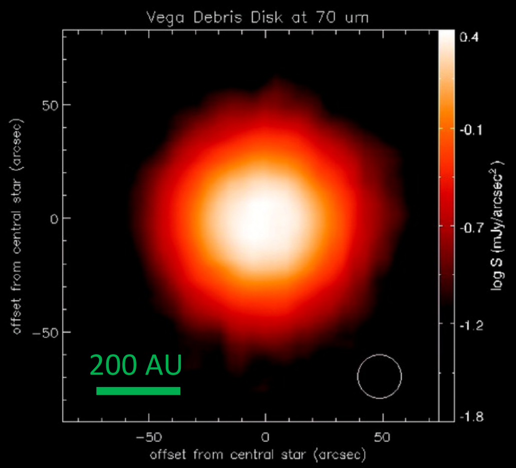
Star	Dist (pc)	Spectral type	Age (Myr)	Mass (M_sol)	Lum. (L_sol)	Planets
Vega	7.76	A0V (9600K)	400-600	2.11	37	No known
HR8799	39.0	A5V (7400K)	20-50	1.47	4.9	4
HD107146	28.5	G2V (5850K)	80 - 200	1.09	1.1	No known
Sun	-	G2V (5778K)	4600	1.0	1.0	8



HD107146 : Ardila et al 2004 (HST, scattered light)



HR8799 : Matthews et al, 2018 Herschel

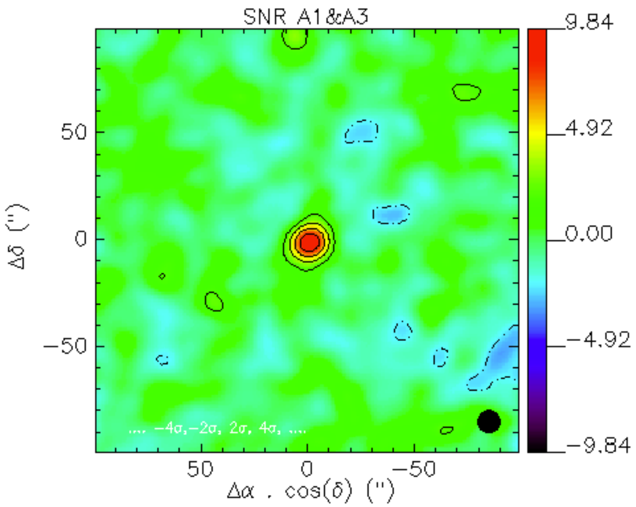


Vega : Su et al 2005, Spitzer, 70 micron

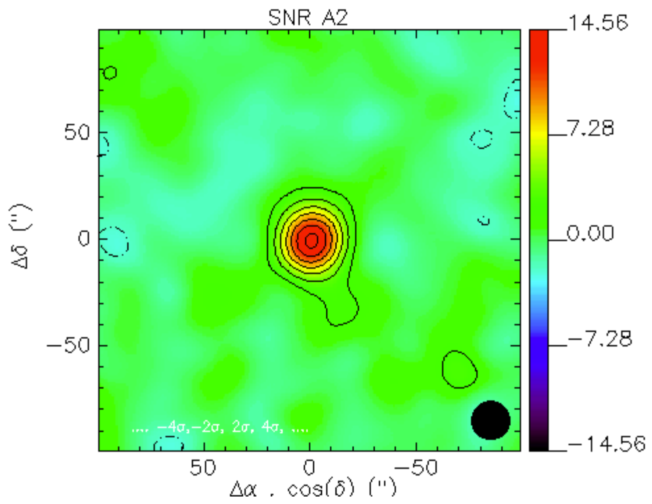
HD107146

Star	Dist (pc)	Spectral type	Age (Myr)	Mass (M_sol)	Lum. (L_sol)	Planets
HD107146	28.5	G2V (5850K)	80 - 200	1.09	1.1	No known

NIKA2 SNR map at 1mm



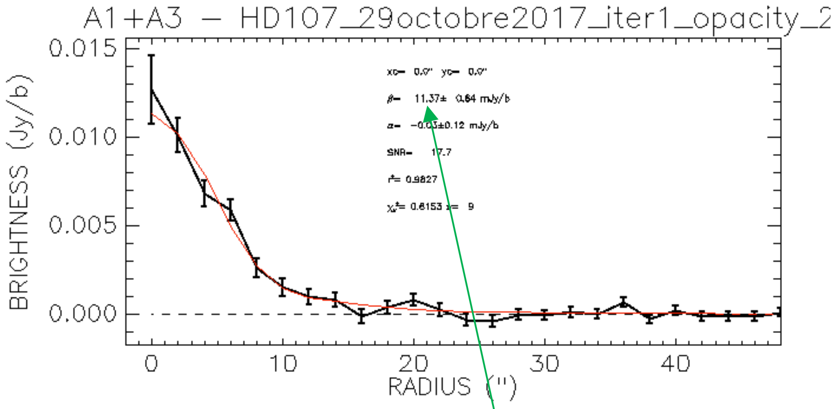
NIKA2 SNR map at 2mm



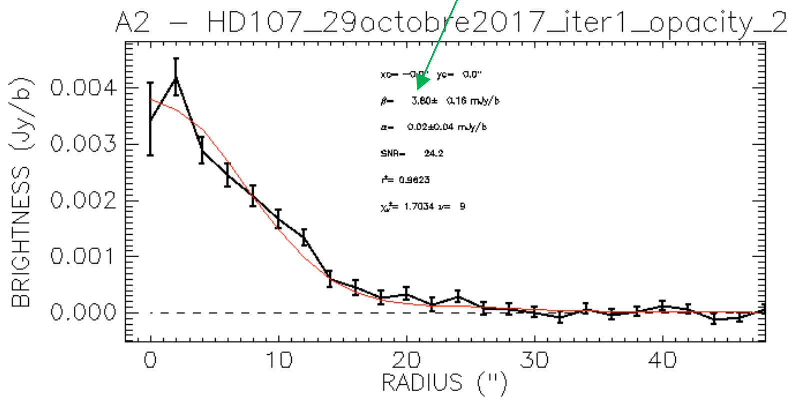
Conditions : tau_{225} ~ 0.2 ; elev ~ 50deg ; T_{int} = 1 hour

Unresolved debris disk around the star HD107146

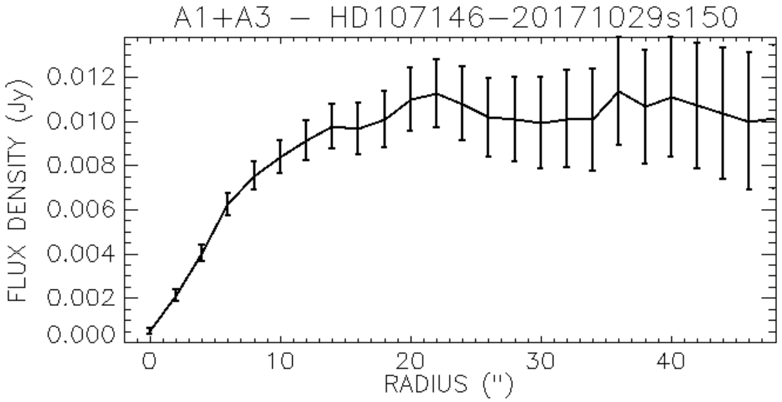
Fit of template to radial profile



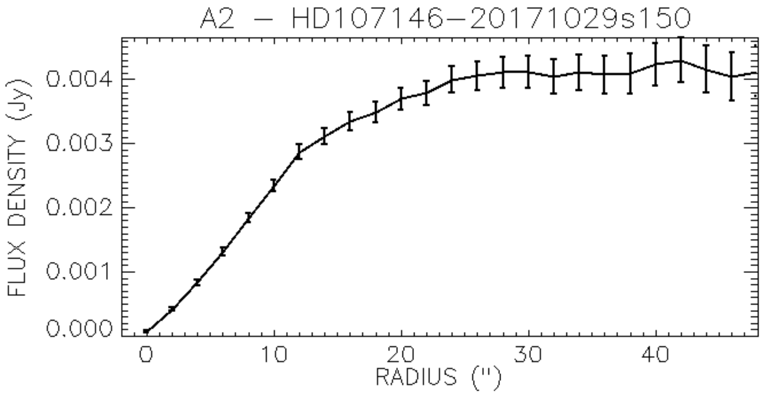
Peak flux density



Aperture photometry



Integrated flux density = 11 ±2 mJy



Integrated flux density = 4 ±0.4 mJy

2D Gaussian fit

Array	S_ν $\pm\sigma_{SS}$ (mJy)	Fwhm (”)	chi_ν^2
A1/1mm	11.89 ±0.25	11.5	0.952
A3/1mm	13.47 ±0.20	11.5	0.958
A1&A3 1mm	12.25 ±0.16	11.5	0.960
A2/2mm	4.06 ±0.04	18.0	1.024

Map area used for 2D gaussian fit : $(fwhm x1.5)^2$
Opacity option =2

Debris disk around HD107146

Method	S_ν $\pm\sigma_{SS}$ at 1mm (1153 microns) (mJy)	S_ν $\pm\sigma_{SS}$ at 2mm (mJy)
Radial profile fit	11.37 ±0.84	3.80 ±0.15
Aperture photometry	11 ±2	4 ±0.4
2D Gaussian fit	12.25 ±0.16	4.05 ±0.03

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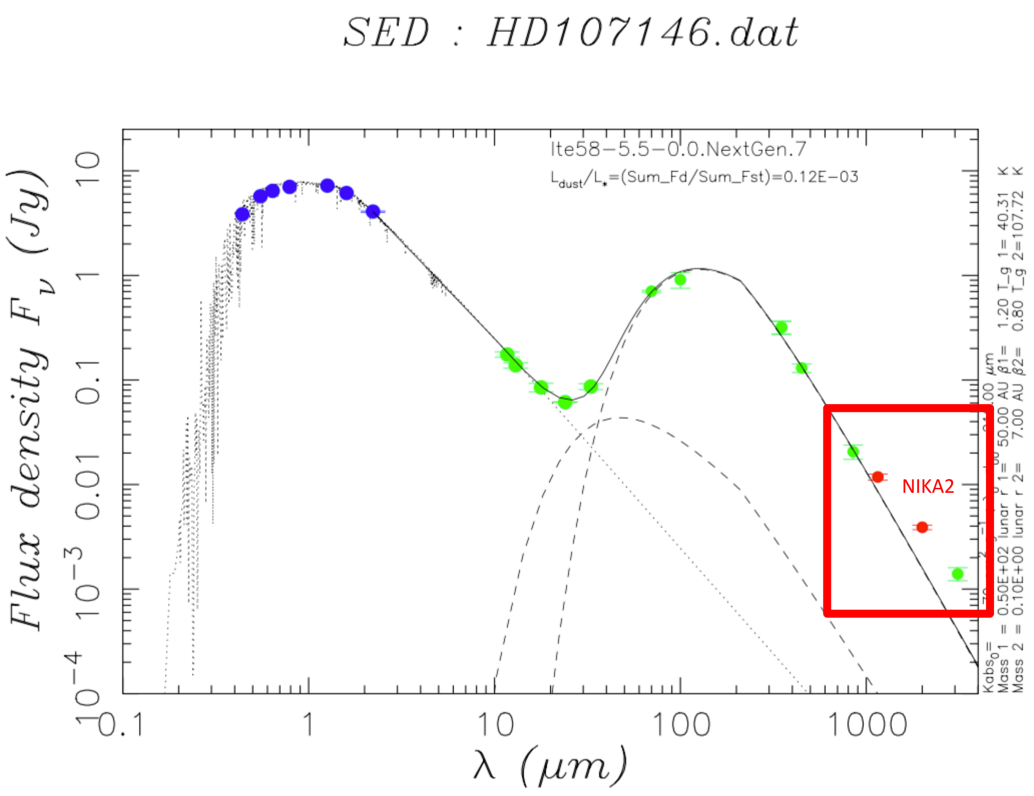
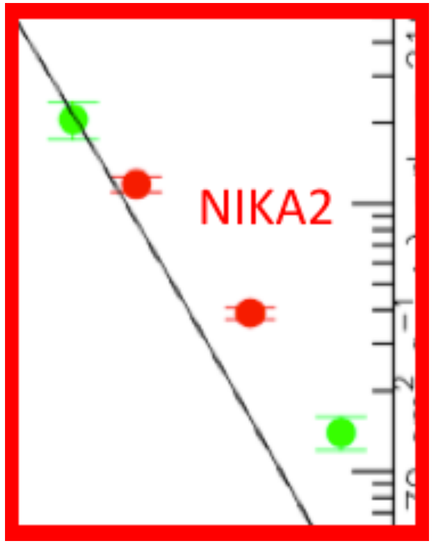
Emissivity :

$\epsilon = \epsilon_0 \quad \text{if} \quad \lambda < \lambda_0$

$\epsilon = \epsilon_0 (\lambda/\lambda_0)^{-\beta} \quad \text{if} \quad \lambda > \lambda_0$

$\epsilon_0 \sim 210 \mu m$





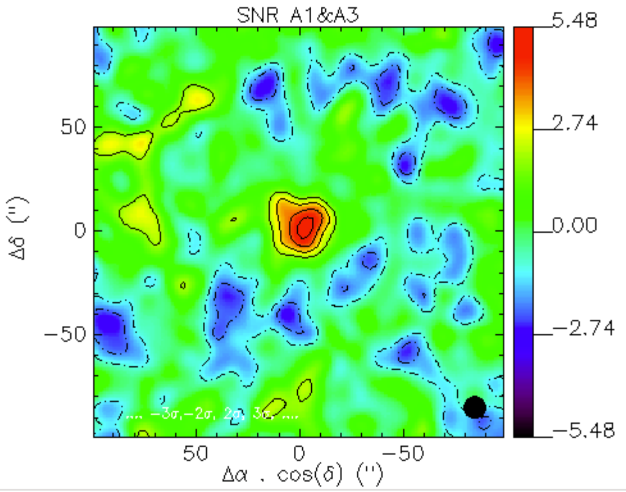
Spectral index α = 2+β = log(11.37mJy/3.80mJy)/log(260.GHz/150.GHz) = 1.99 ±0.15

That is β ~ 0 ; NIKA2 observations sense mostly black body pebbles (not small, grey body dust)

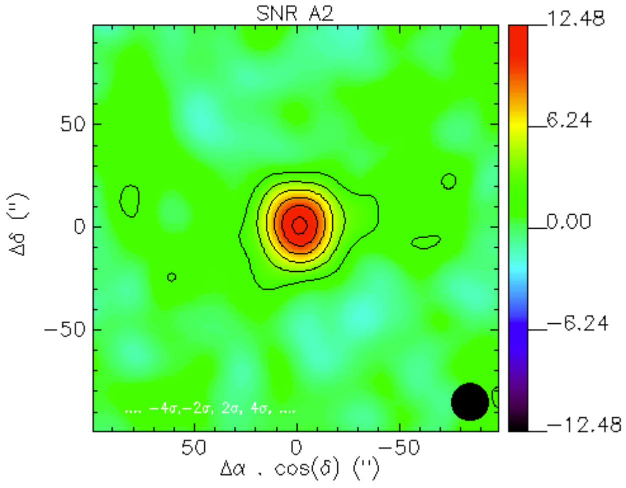
Debris disk around VEGA

Star	Dist (pc)	Spectral type	Age (Myr)	Mass (M_sol)	Lum. (L_sol)	Planets
Vega	7.76	A0V (9600K)	400-600	2.11	37	No known

NIKA2 SNR map at 1mm

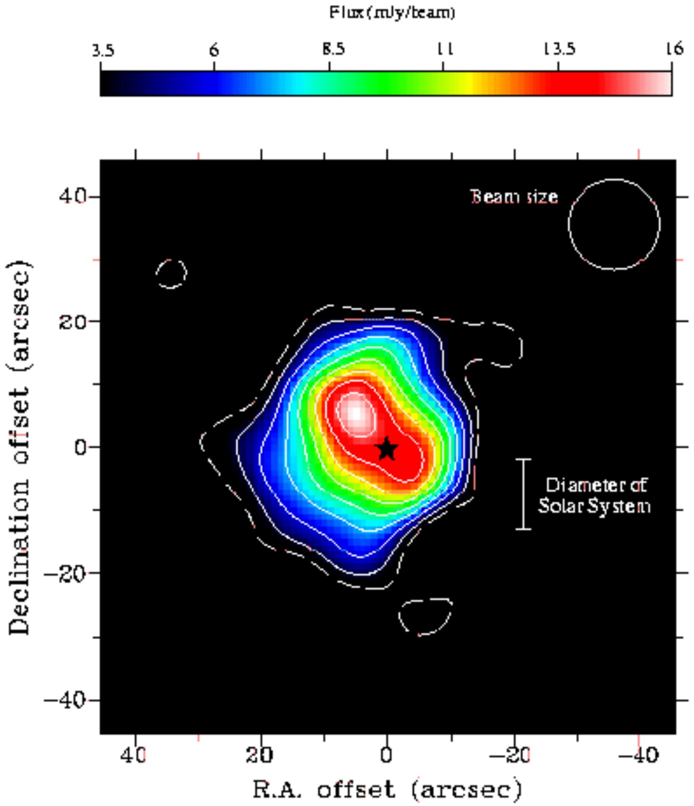


NIKA2 SNR map at 2mm

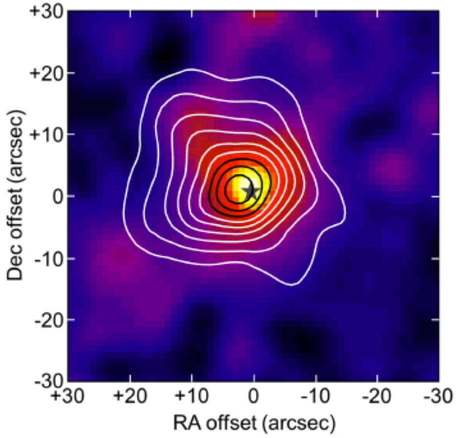


Conditions : $\mathrm{tau}_{225} \sim 0.2 - 0.3$; elev ~ 60deg ; $T_{int} = 3$ hours

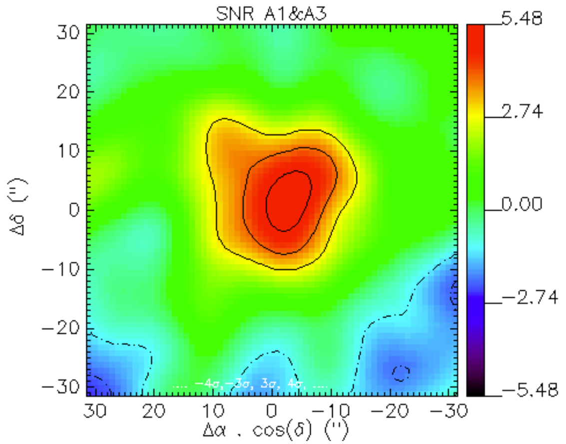
Vega



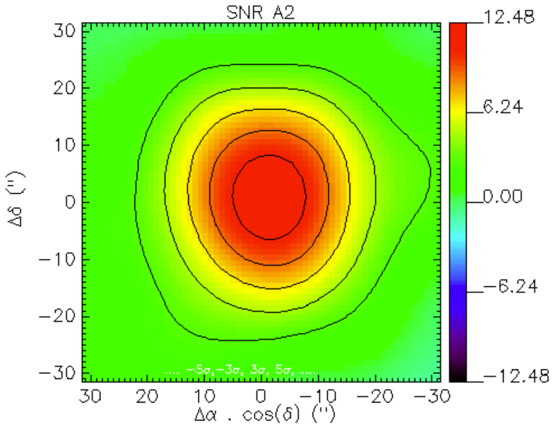
SCUBA (850 microns)
Holland et al (1998)



SCUBA2 (850 microns)
Holland et al (2017),
Level : +3σ, ….



NIKA2 (1mm)
Level : +2σ, …

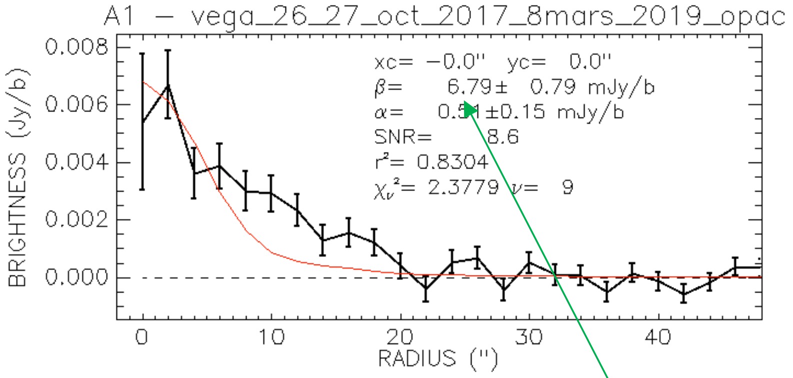


NIKA2 (2mm)
Level : +2σ, …

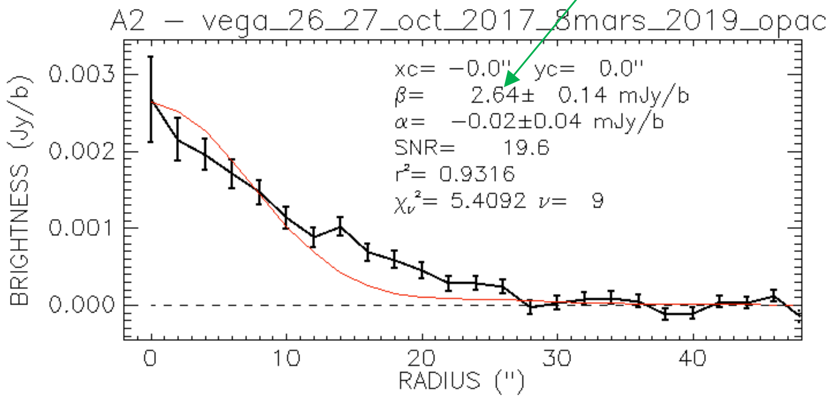
Vega extended theta('') * 7.7pc = .. AU → Aperture photometry

VEGA

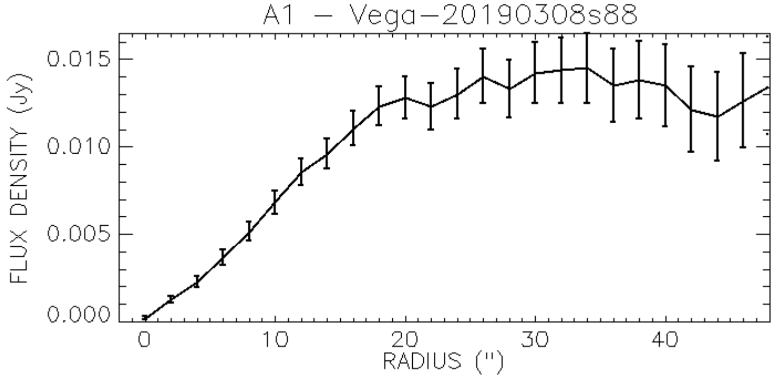
Fit of template to radial profile



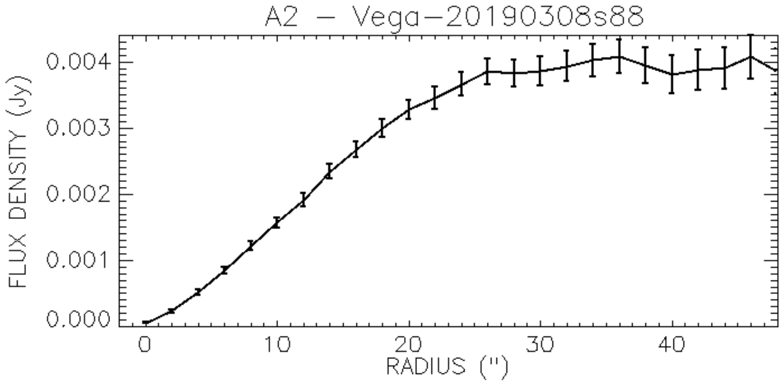
Peak flux density



Aperture photometry



Integrated flux density =13.5 ±2mJy

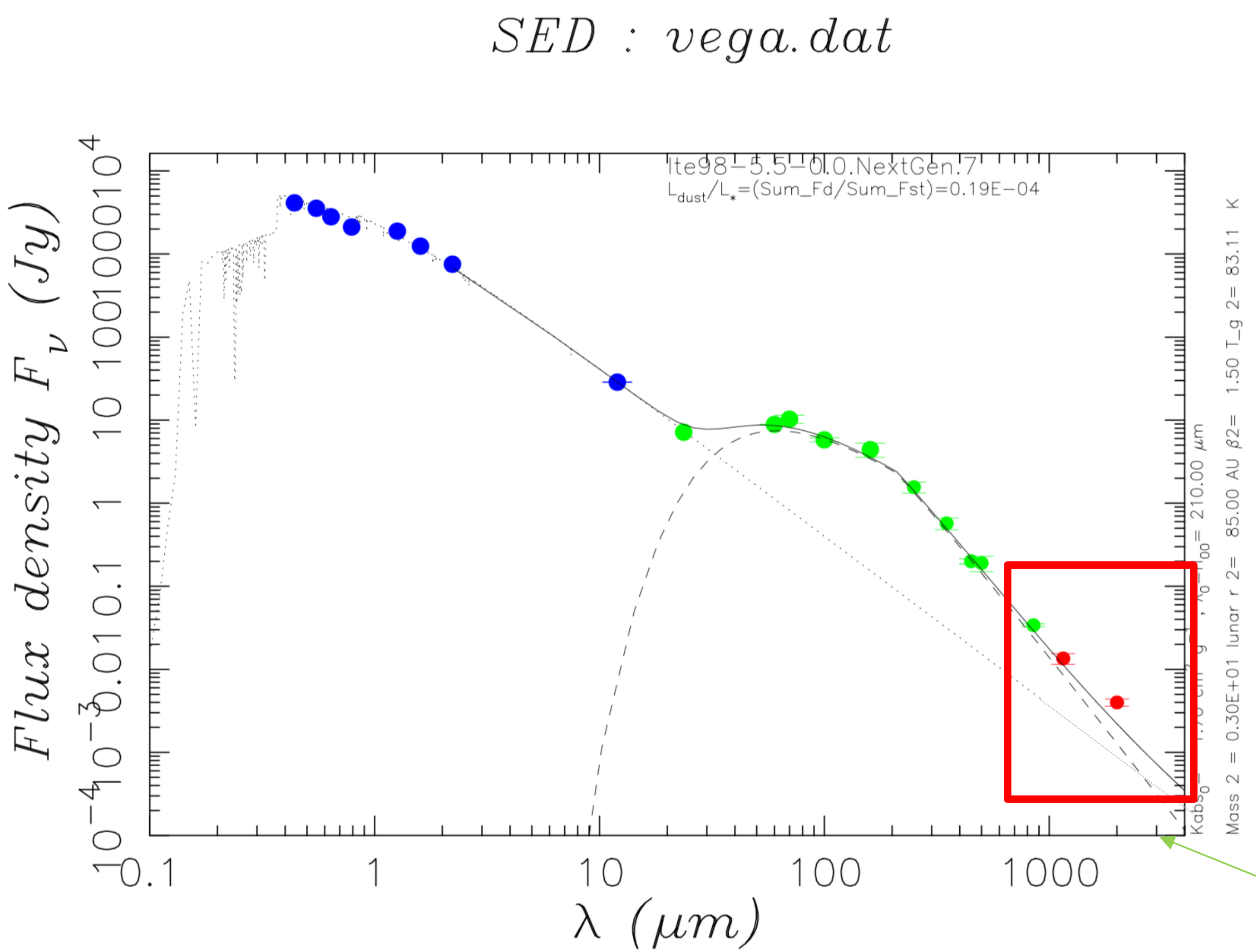


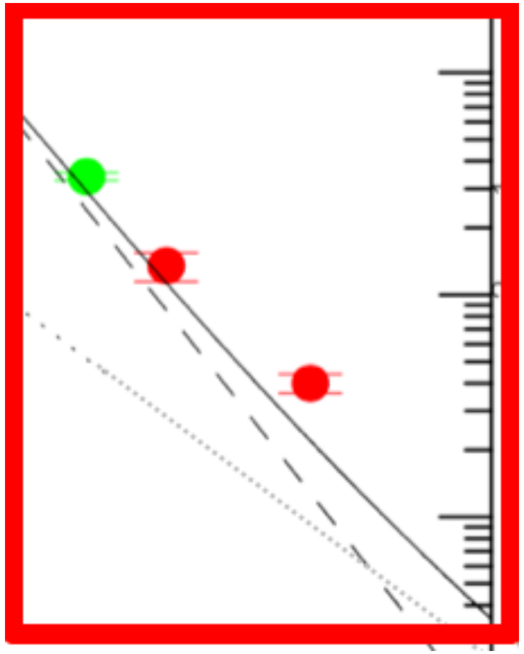
Integrated flux density = 4. ±0.4 mJy

2D Gaussian fit

Array	S_ν $\pm\sigma_{SS}$ (mJy)	Fwhm (″)	chi_ν^2
A1/1mm	6.57±0.39	19.	0.883
A2/2mm	2.57±0.04	20.0	1.045

Array A3/1mm 26&27oct2017 dead during Vega scans





3mm NIKA3 !

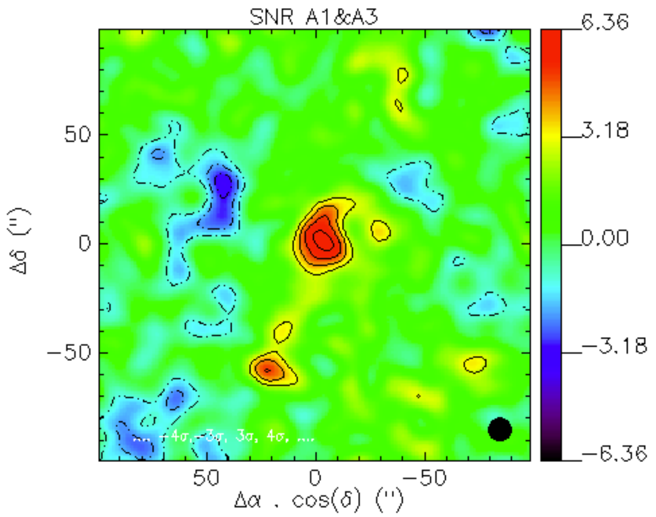
Spectral index α = 2+β = log(13.5mJy/4.0mJy)/log(260.GHz/150.GHz) = 2.21 ±0.32

That is β ~ 0 ; NIKA2 millimeter-wave observations sense mostly black body pebbles (not grey body dust)

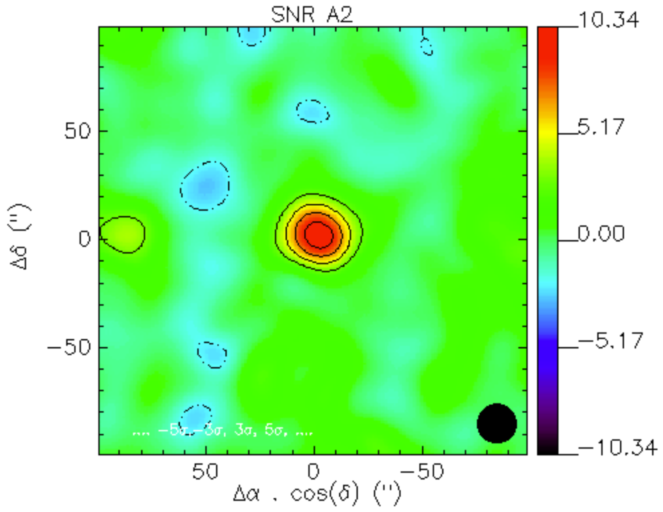
HR8799

Star	Dist (pc)	Spectral type	Age (Myr)	Mass (M_sol)	Lum. (L_sol)	Planets
HR8799	39.0	A5V (7400K)	20-50	1.47	4.9	4

NIKA2 SNR map at 1mm

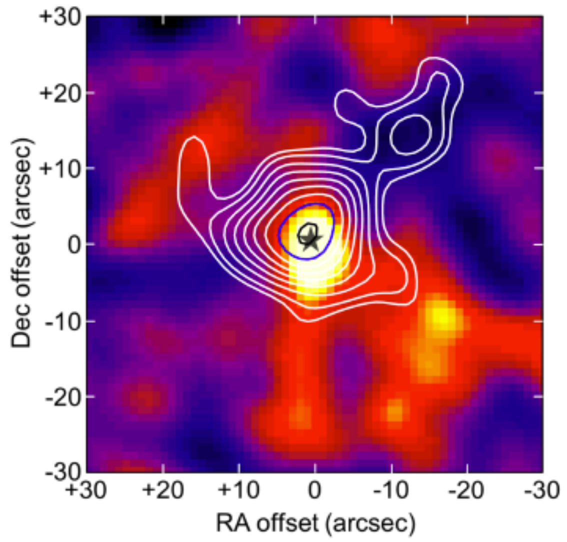


NIKA2 SNR map at 1mm

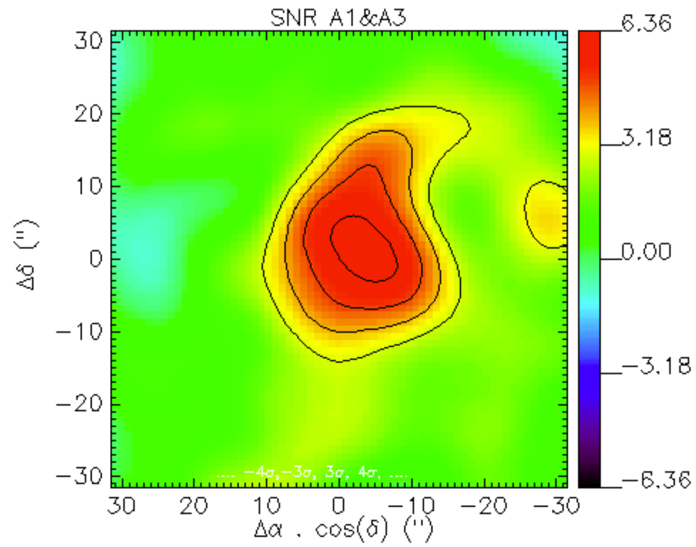


Conditions : $tau_{225} \sim 0.2 - 0.3$; elev ~ 50deg ; $T_{int} = 4$ hours

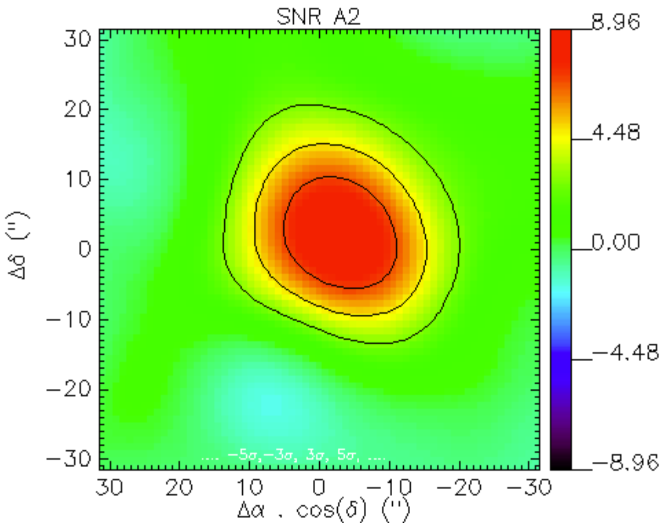
Debris disk around HR8799



SCUBA2 (850 microns)
Holland et al 2017
Level : +3σ, ….

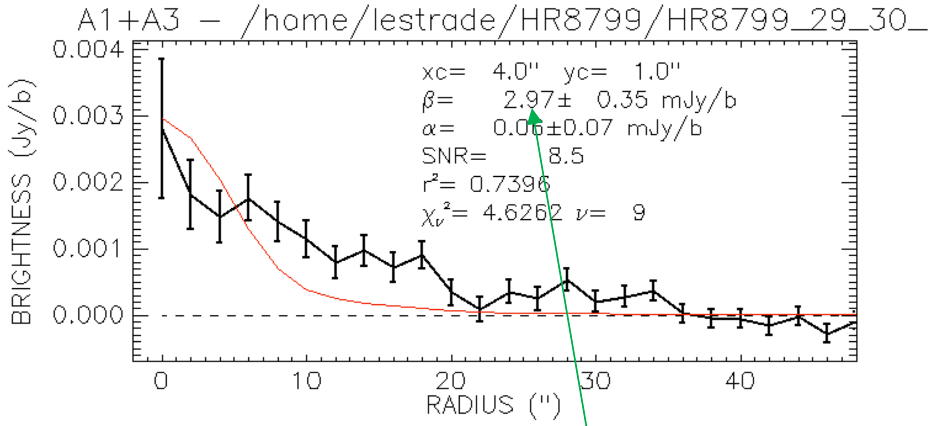


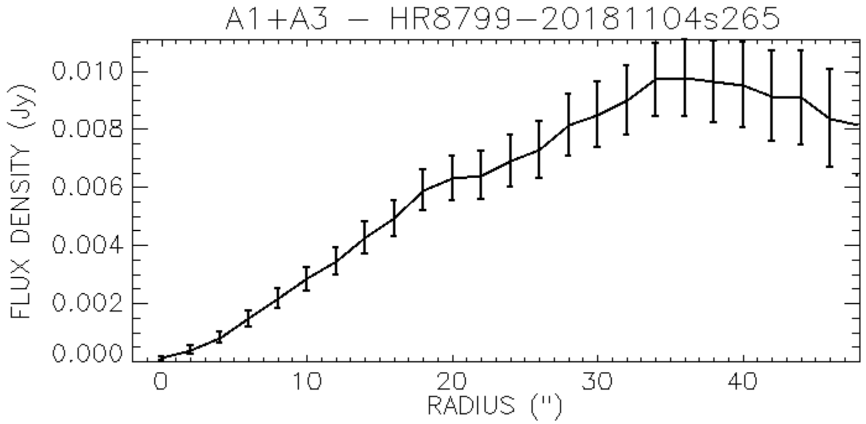
NIKA2 1mm
Level : +2σ, ….



NIKA2 2mm
Level : +2σ, ….

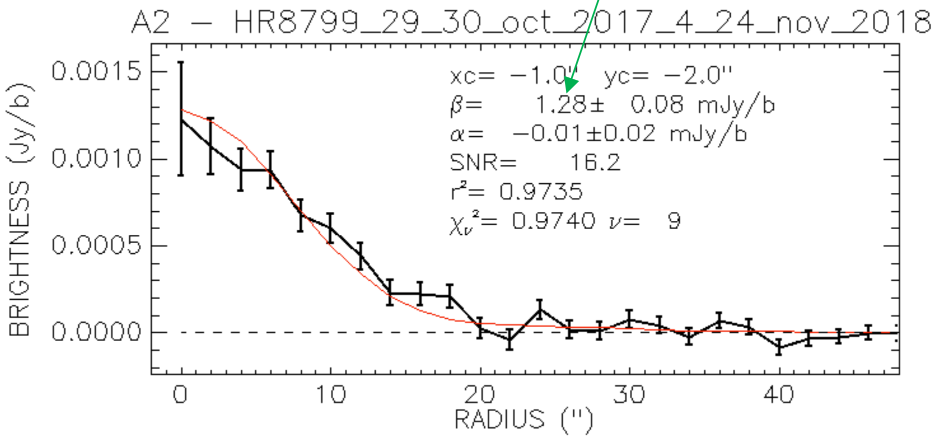
HR8799

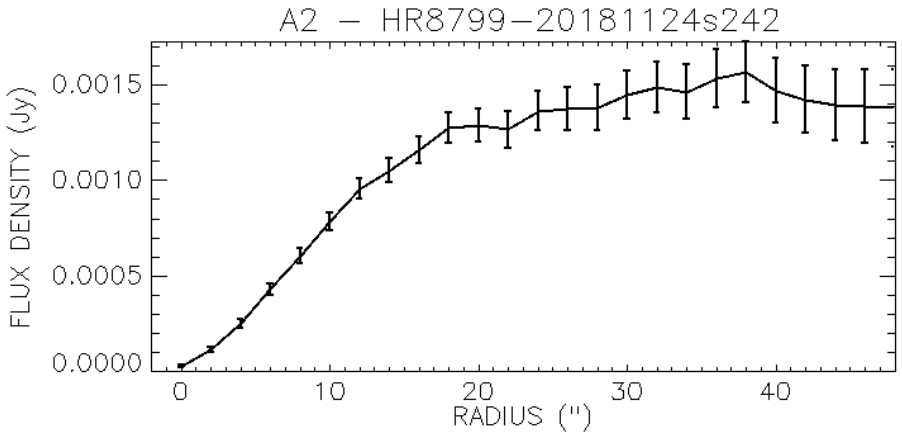




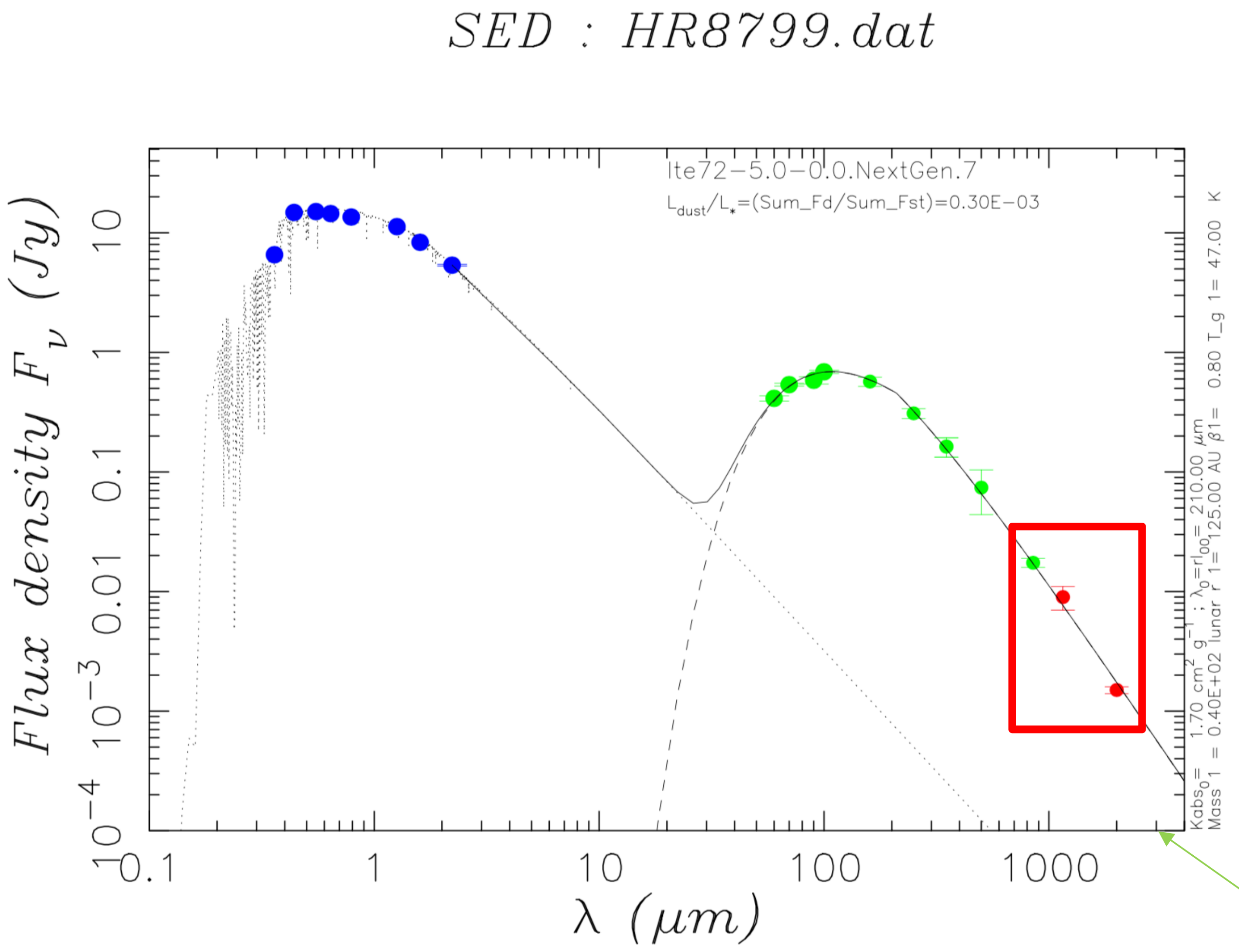
Peak flux density

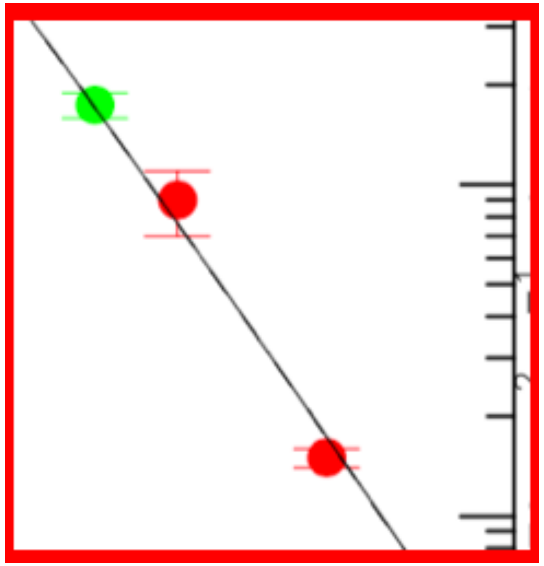
Integrated flux density = 9 ±2 mJy





Integrated flux density = 1.5 ±0.15 mJy



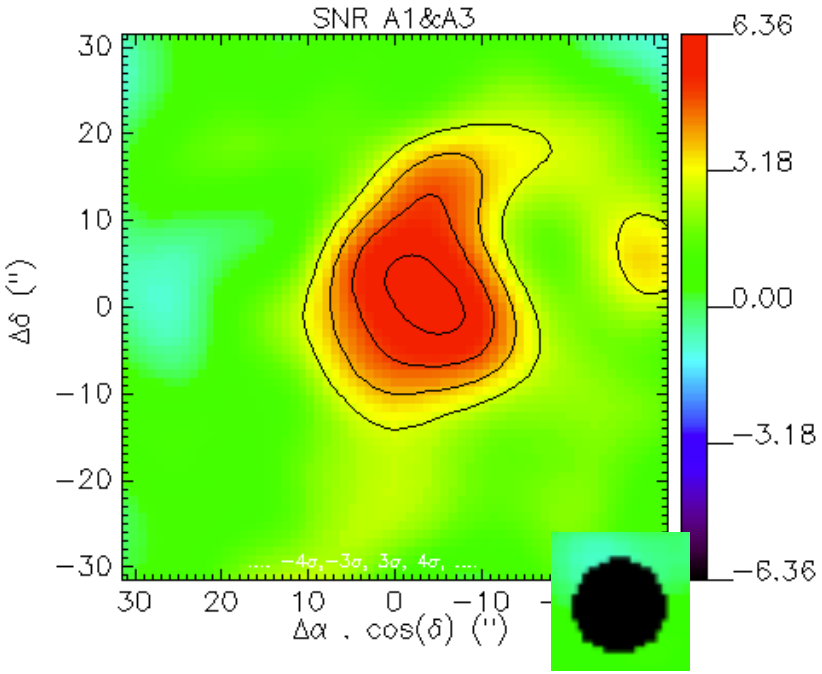


3mm NIKA3 !

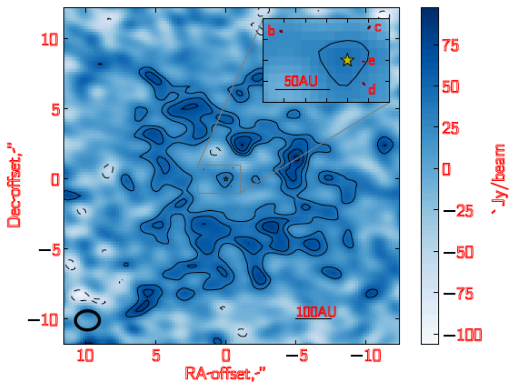
Spectral index α = 2+β = log(9.0mJy/1.5mJy)/log(260.GHz/150.GHz) = 3.38 ±0.45

That is β=1.38 +/- 0.45 ; NIKA2 millimeter-wave observations sense mostly small, grey body dust)

HR8799



NIKA2 1153 microns
Level : +2σ, ….



ALMA 1300 microns
Level : +2σ, ….

Iram 30m :

S_ν = 9.0 ±2 mJy

Deconvolved radius ~ 320 AU

ALMA :

S_ν = 2.8 ±0.5 mJy at λ=1300 microns
i.e. 4.1mJy at NIKA2 λ=1153 microns

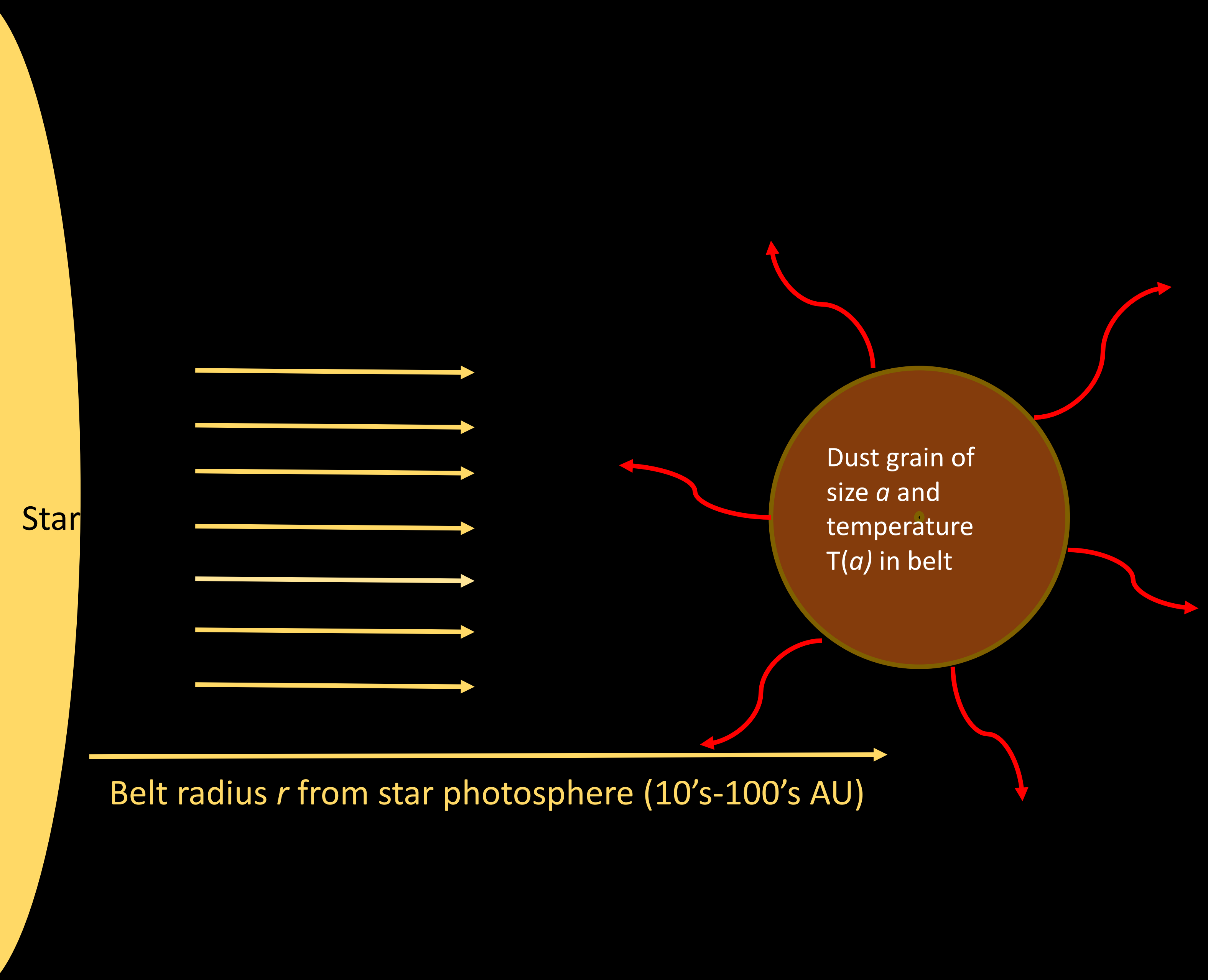
Belt : radius ~ 270 AU ; inclination ~ 40 deg

Conclusion observations for the small sample :

HD107 : β= 0 ±0.15. (age 80-200 Myr)
Vega : β= 0 ±0.32. (age 400-600 Myr)
HR8799 : β= 1.38 ±0.45 (age 20-50 Myr)

$$S_\nu(\lambda, r) = \int_{a_{min}}^{a_{max}} Q_{abs}(a,\lambda) \times B_\nu(T(a,r),\lambda) \times \pi a^2/d_*^2 \times dN$$

$$dN \;\propto\; M_{dust}\; a^{-3.5}\; da$$



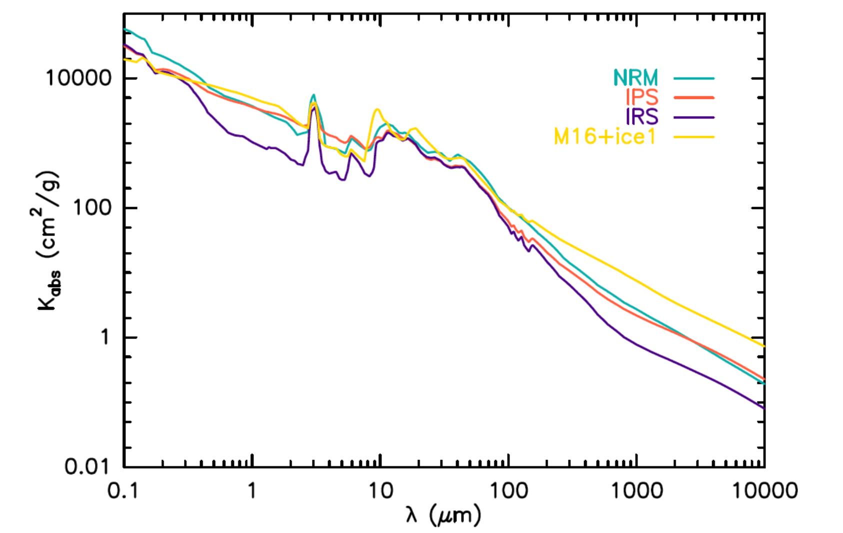
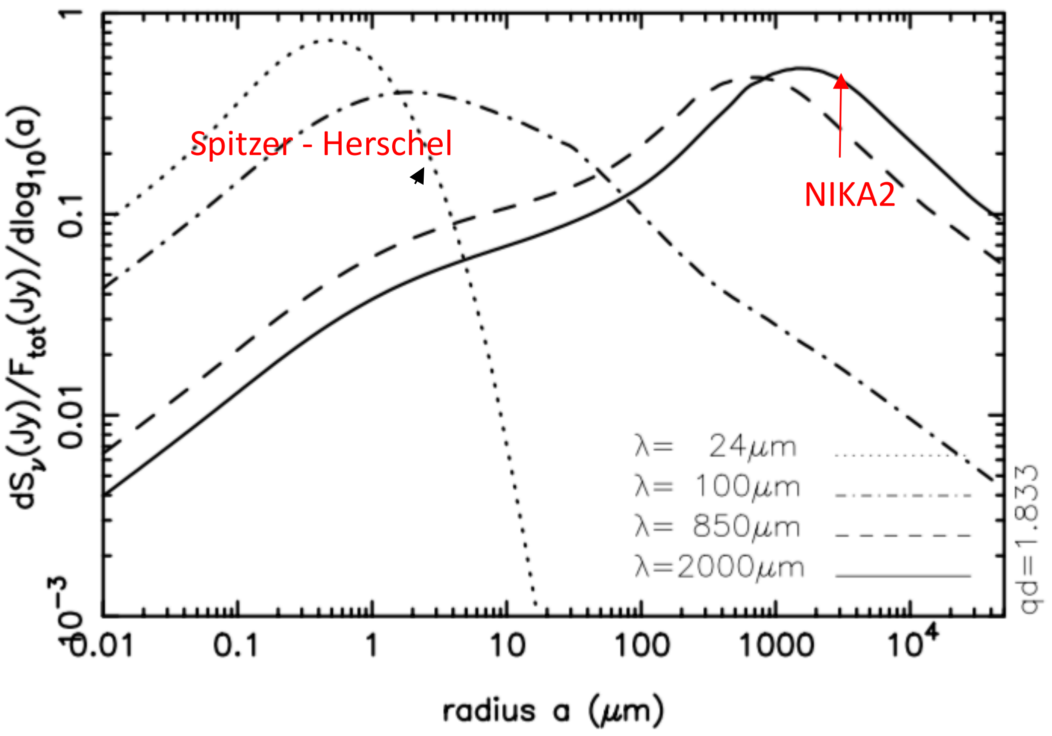


Figure 1. Dust properties when including iron rich (IRS), iron poor (IPS) and normal silicates (NRM) in the dust mixture (see

Code SIGMA (Lefevre et al 2019)

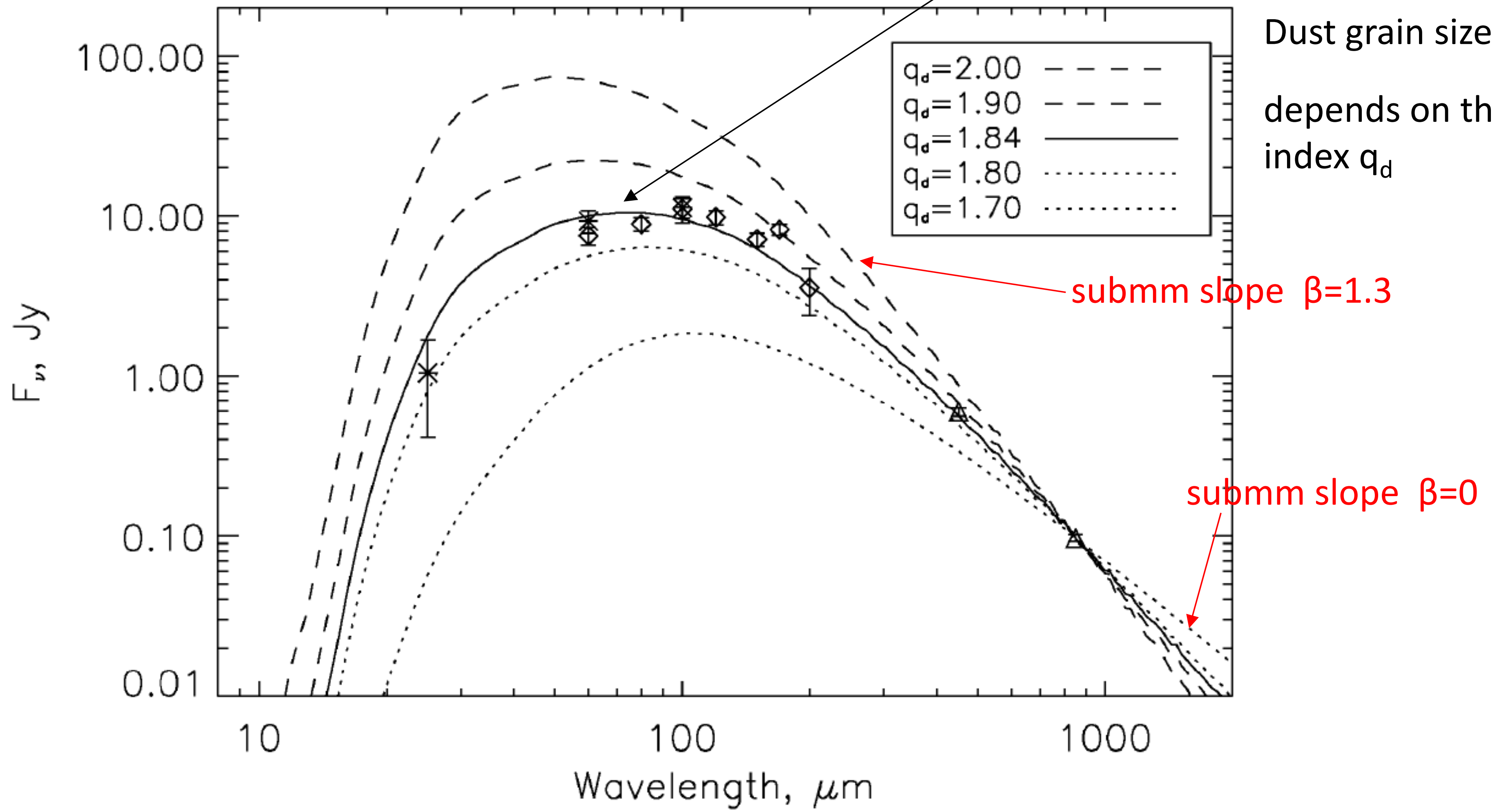
dS_ν / dlog(a) : Contribution to the total flux density of dust emission in each grain size bin for the dust size distribution n(a) $\propto$ a $^{-3.5}$



Self-similar collisional cascade : q_d=11/6 ~ 1.833

Dust grain size distribution : $n(a) \propto a^{2-3qd}$

depends on the planetesimals strength index q_d



SED for « standard » dust composition (1/3 amorphous sllicate and 2/3 organic refractory material) for the debris disk around Fomalhaut (Wyatt & Dent 2002)

Concluding remarks

- Consistency of NIKA2 photometry for mJy sources using three methods : 10% (likely precision not accuracy though).
- In our small sample : spectral index becomes Rayleigh-Jeans in the millemeter-λ domain for the two disks with age > 100 Myr.
- Observation of a larger sample of disks and a grid of model to explore composition versus particle size distribution power law will improve determination of total mass of debris disk.
- 3mm band would be a great addition to sense millimeter sized pebbles at the bottom of the collisional cascade in debris disks.