Diversity of Debris Disk Structures

Combining Resolved Imaging and SED Models

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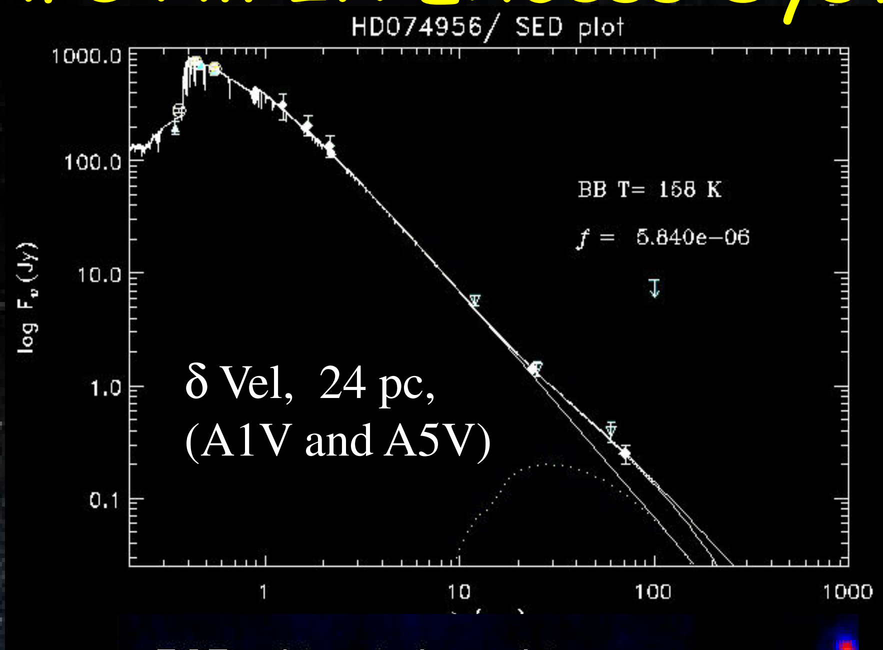
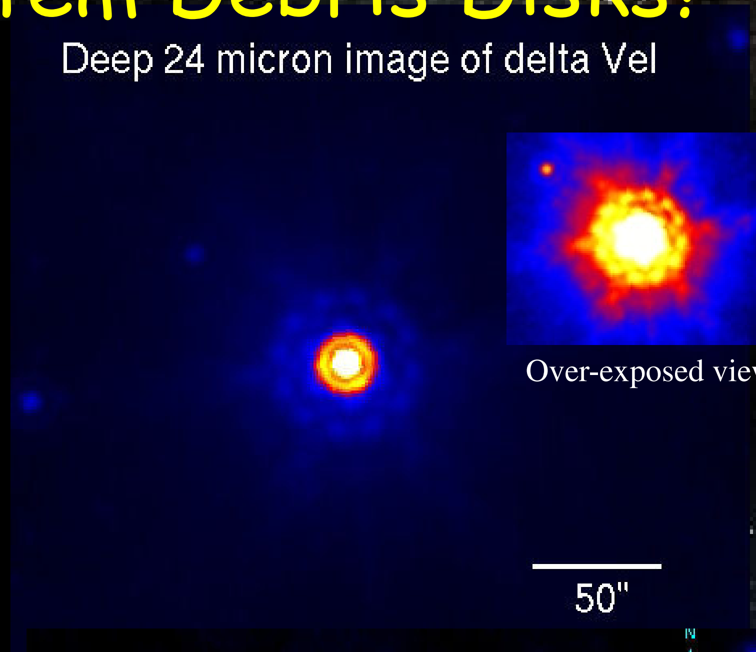
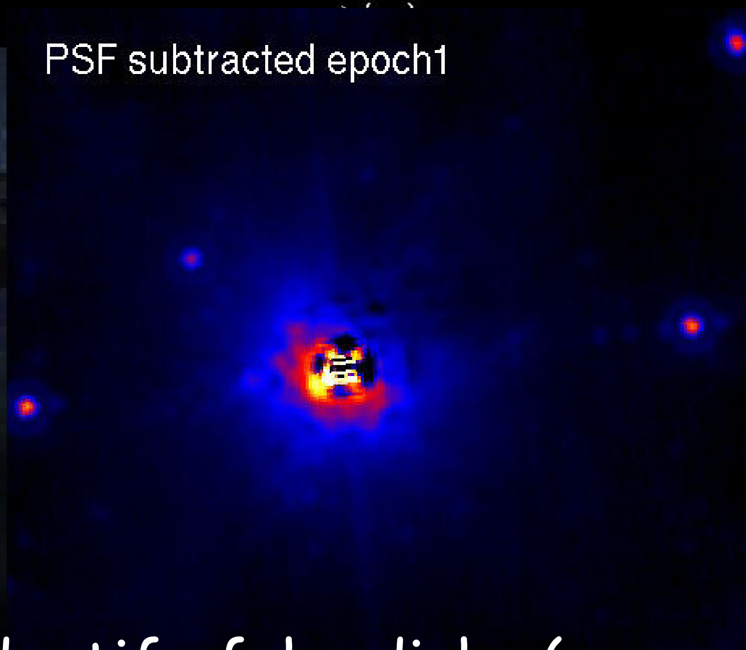
Take Away Points

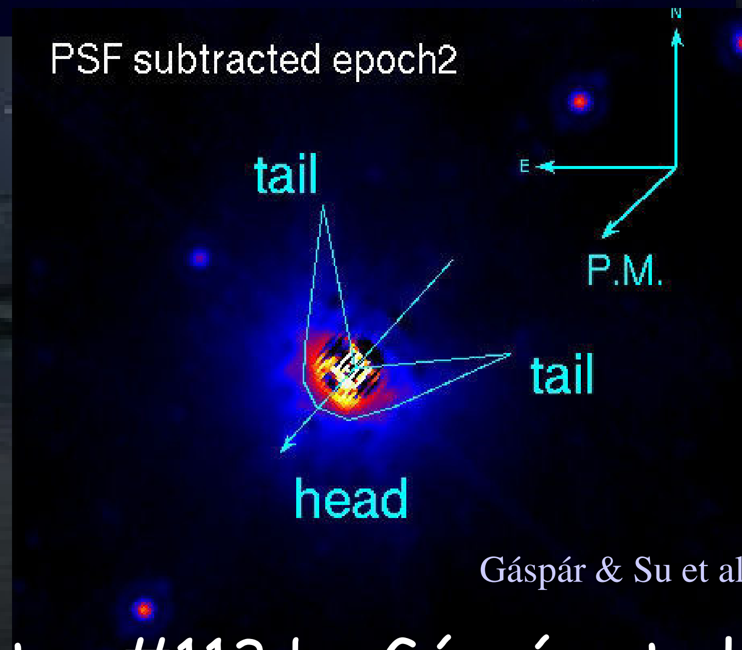
- Spitzer has been great to identify systems with infrared excess (review by Carpenter).
- Resolved images + detailed observed spectral energy distributions (SEDs) have prompted a major shift on how people think about debris disks.
- Debris disk structure is not as simple (narrow rings and blackbodies) as we thought before:
    1. an order of magnitude range in disk size around similar stars (e.g., β Leo & γ Oph).
    2. complex sub-structures hinting at dynamical processes in the planetary systems (e.g., ε Eri).

Are All IR Excess System Debris Disks?









Gáspár & Su et al. 2008

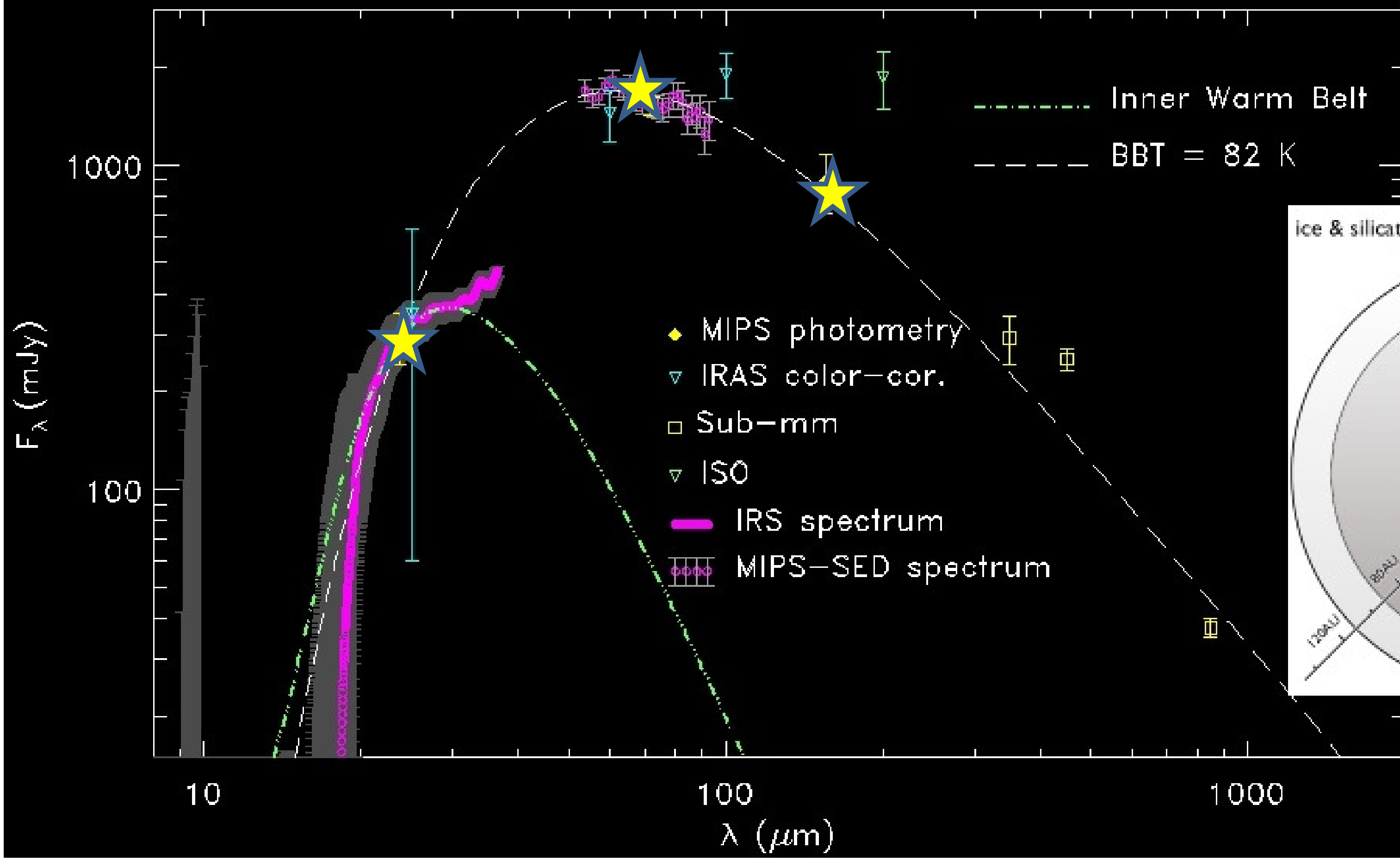
- identify fake disks (see poster #113 by Gáspár et al.)

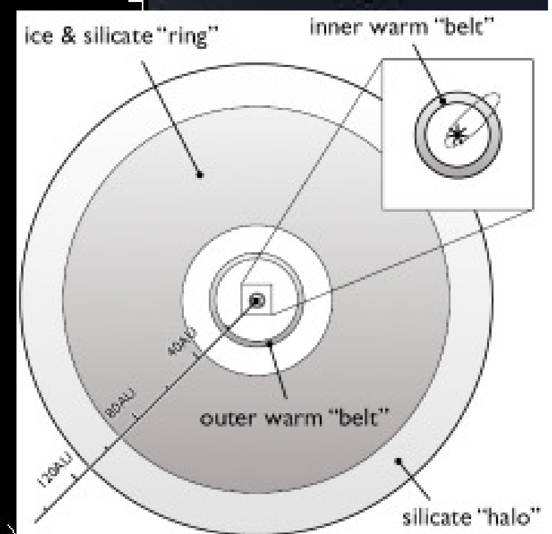
Power of SEDs + Resolved Images

case: ε Eri (K2V, 1 Gyr, 3.22 pc), a face-on disk

Details see Poster #107 by Marengo et al., Review by Stapelfeldt

Blackbody of 82 K fits well for broadband photometry, BUT……

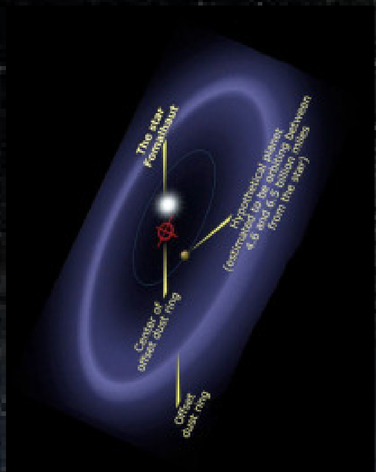




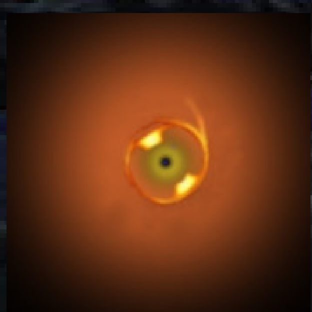
Backman et al. , ApJ, in press.

Resolving Disks around A Stars

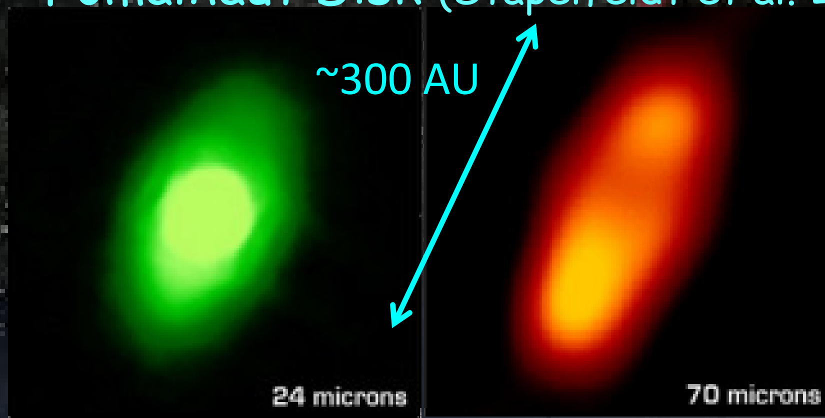
- break degeneracy in spectral energy distribution modeling

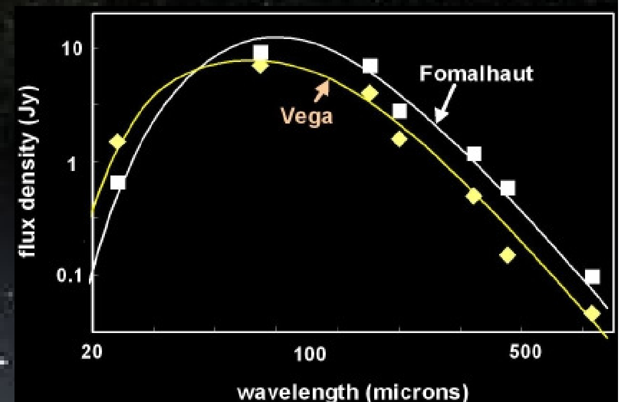


illustration

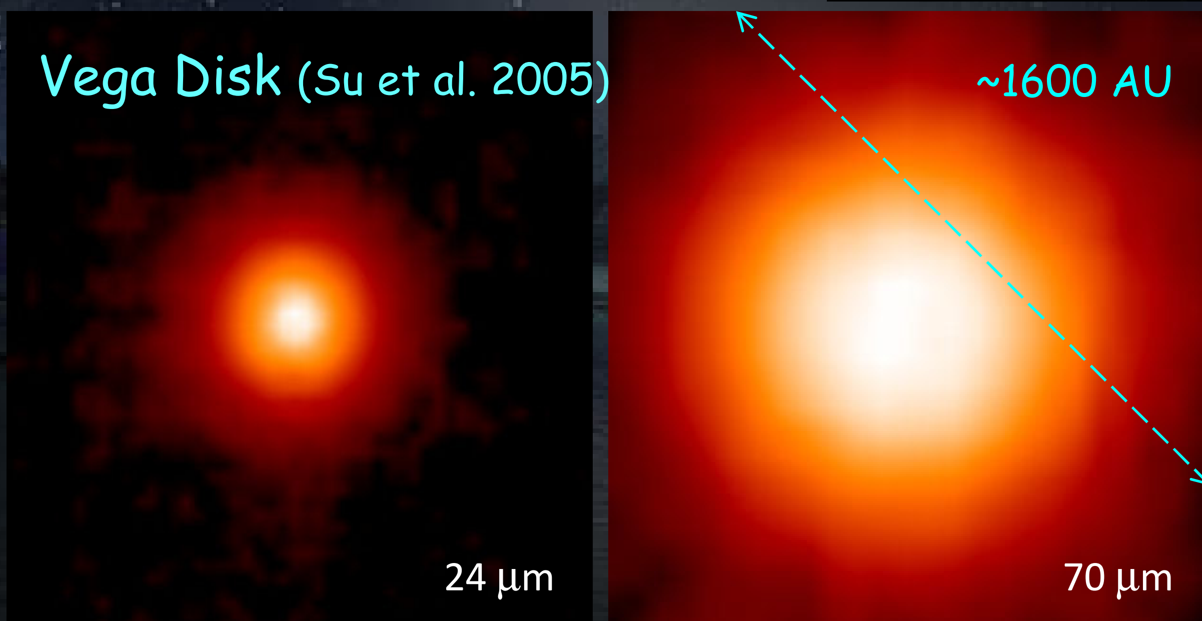


Fomalhaut Disk (Stapelfeldt et al. 2004)





Vega Disk (Su et al. 2005)



Debris Disk Model

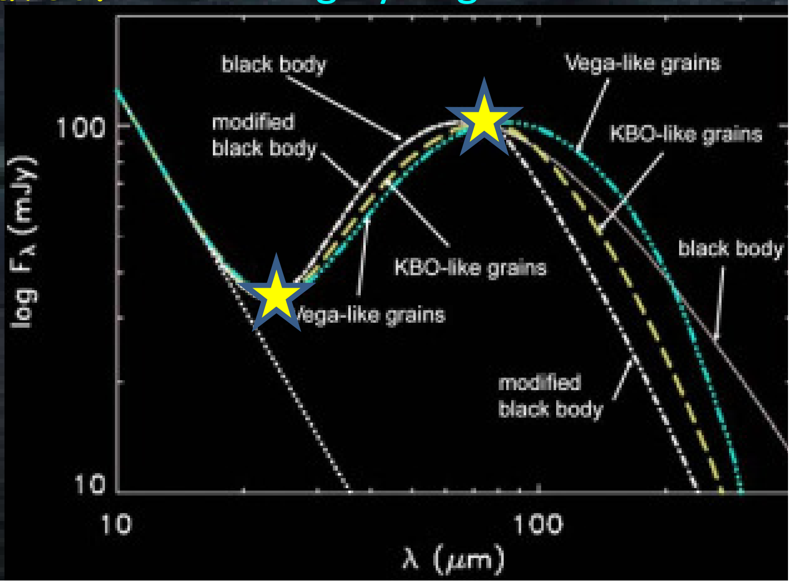
	Simple	Complex
Density	axially symmetric, geometrically thin	density enhancement due to MMRs, offset multiple rings,
Grain size distribution	collisional equilibrium, uniform distribution at all radii	wavy size distributions, various distribution at different zones
Dust properties	compact grains	fluffy, multiple compositions

- axially symmetric, geometrically thin disk
- surface number density : $\Sigma(r) = \Sigma_0(r/r_{in})^{-p}$, from r_{in} to r_{out}
- grain size distribution : $n(a) = n_0 a^{-q}$, from a_{min} to a_{max}
- given a grain properties (Q_{abs}), $T_d(a,r)$ is computed.

highly degenerate!

Various Cases:

- p = 0: P-R drag dominated disk
- p = 1: outflow disk
- q = 3.5: grains in theoretical collisional equilibrium
- $a_{min} \approx a_{bl} = 0.46\ (L_*/L_{sun})(M_{sun}/M_*)$
- $a_{max} \approx 1000\ \mu m$.



Deep 24 μm Imaging

- FWHM of 6" resolution @ 24 μm (vs. 18" @70 μm)
- deep imaging to aim for 1-σ of 0.01% of the background
- observed at two epochs for different roll angles
- 12 A-type debris disks within 40 pc

HD	Name	Sp.	Age (Myr)	Dist. (pc)	fd	Td (K)	Resolved? 24 um	Resolved? 70 um
102647	β Leo	A3V	50-300	11.1	2.0E-05	123	Yes. P.A.~118	No.
161868	γ Oph	A0V	200	29.1	7.5E-05	81	Yes. P.A.~56	Yes.
139006	α CrB	A0V	350	22.9	1.4E-05	129	Yes. P.A.~164	Yes.
95418	β UMa	A1V	300	24.4	1.3E-05	116	Yes. P.A.~106	No.
14055	γ Tri	A1V	300	36.1	6.7E-05	75	Yes. P.A.~166	Yes.
110411	ρ Vir	A0V	10?	36.9	3.7E-05	84	Yes. P.A.~90	No.
38678	ζ Lep	A2V	300	21.5	9.8E-05	193	No.	No.
115892	ι Cen	A2V	350	18.0	1.1E-05	228	No.	No.
106591	δ UMa	A3V	300	25.0	5.0E-06	250	No.	No.
87696	21 Lmi	A7V	390	28.0	1.5E-05	164	No.	No.
135379	β Cir	A3V	600	29.6	2.0E-05	130	No.	No.
71155	30 Mon	A0V	300	38.3	2.5E-05	105	No.	No.

challenges: stable but complex PSF structure, bright sources with majority flux from photospheres , enhanced jailbars, accumulated dark latents, many background sources...

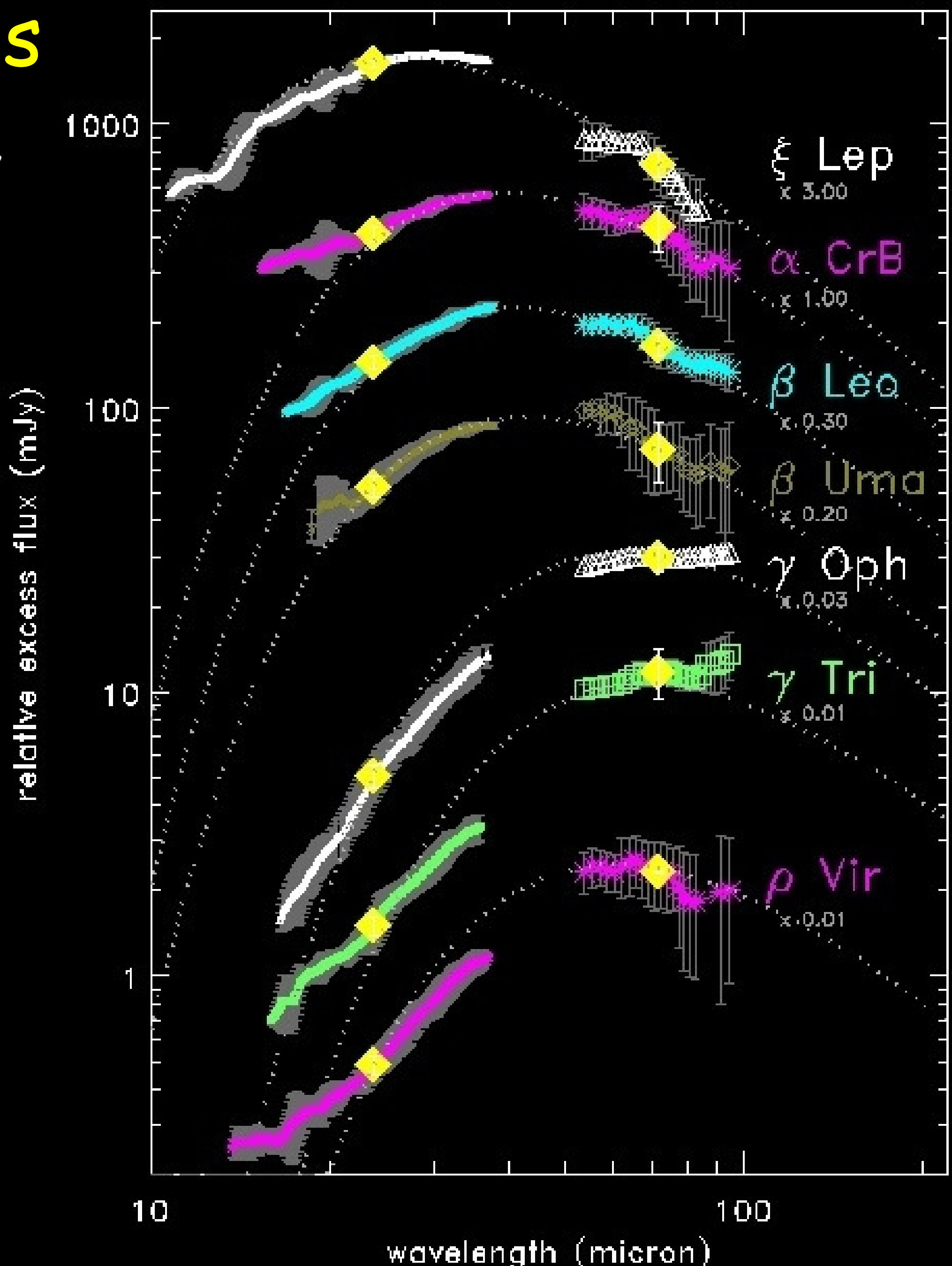
Detailed Excess SEDs

- MIPS 24 and 70 μm photometry
- IRS low-res. (R~120) spectrum (5-35 μm) (Chen et al. 2006)
- MIPS-SED mode (R~20) data (55-95 μm)
- Others (IRAS, ISO, submm...)

Td ≥ 100 K
→ B.B.-like for λ >20 μm (some showing warm comp. also see poster #114 by Morales et al.)

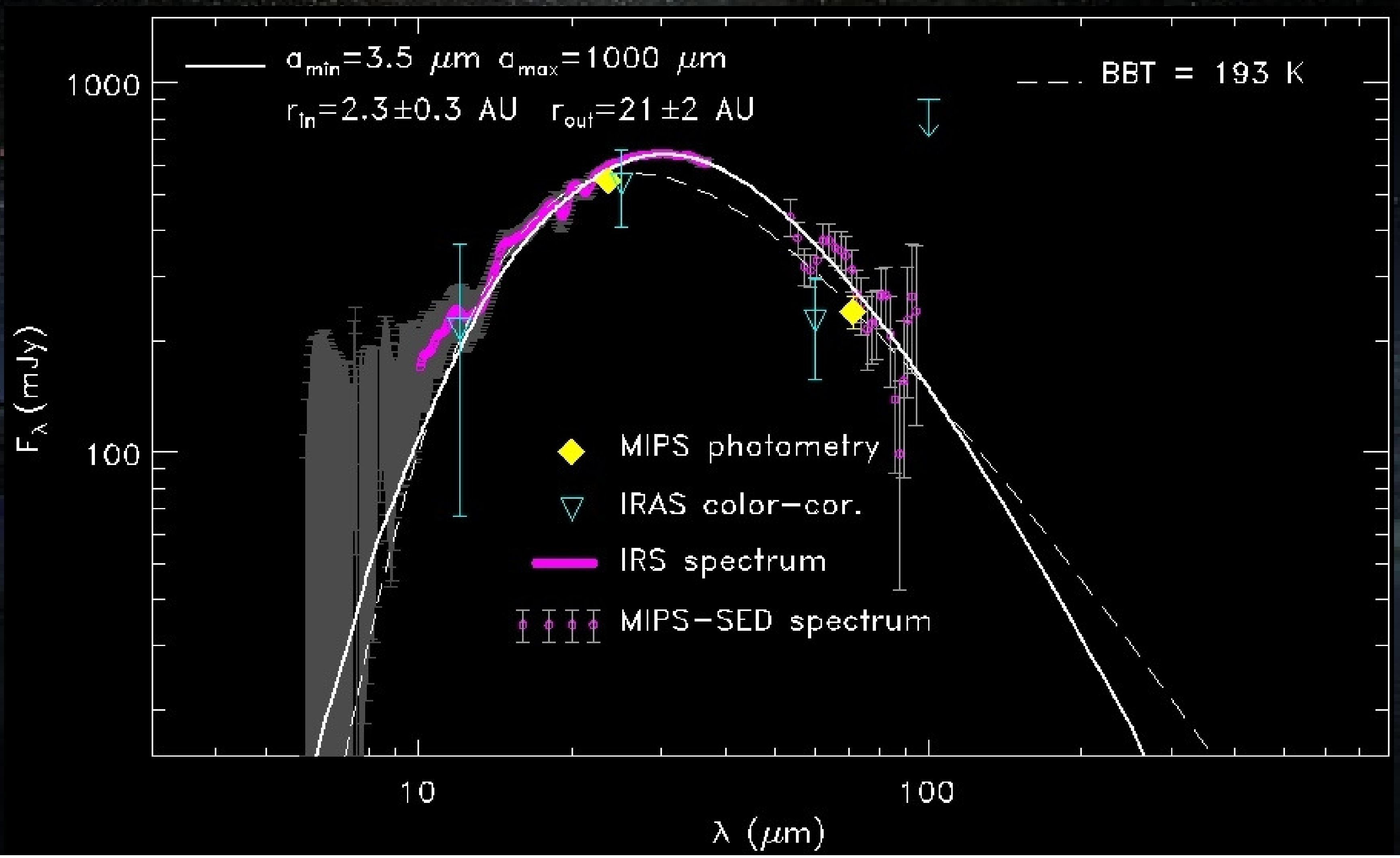
Td < 100 K
→not B.B.-like at all

Disks come in a broad variety!

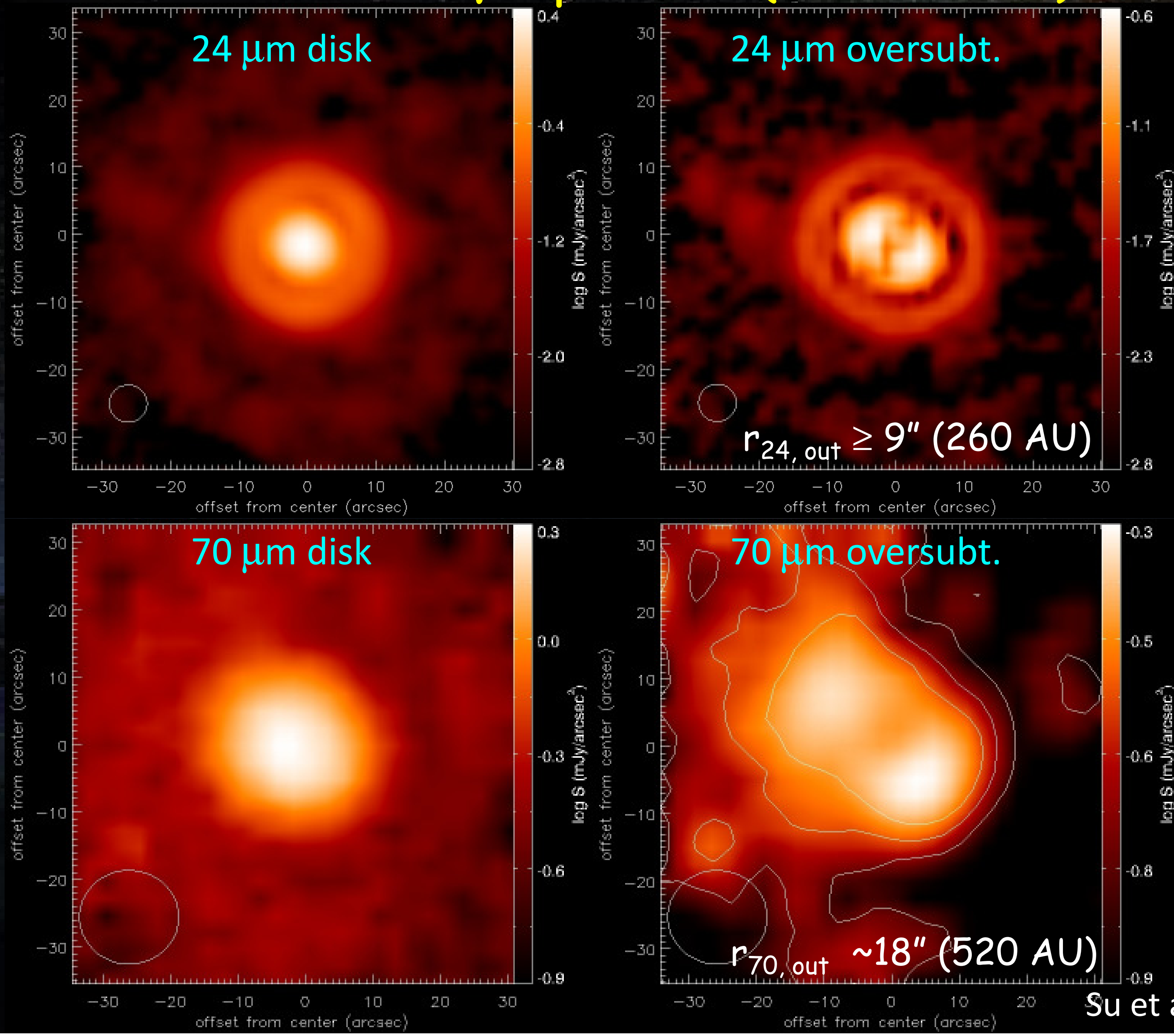


Unresolved Disk around ζ Lep (HD 38678)

- A2V, ~300 Myr, 21.5 pc
- point source, FWHM@24 μm is: 5.61″x5.55″ (after subt.)
- Gemini images suggests a very compact disk (Moerchen et al. 2007)



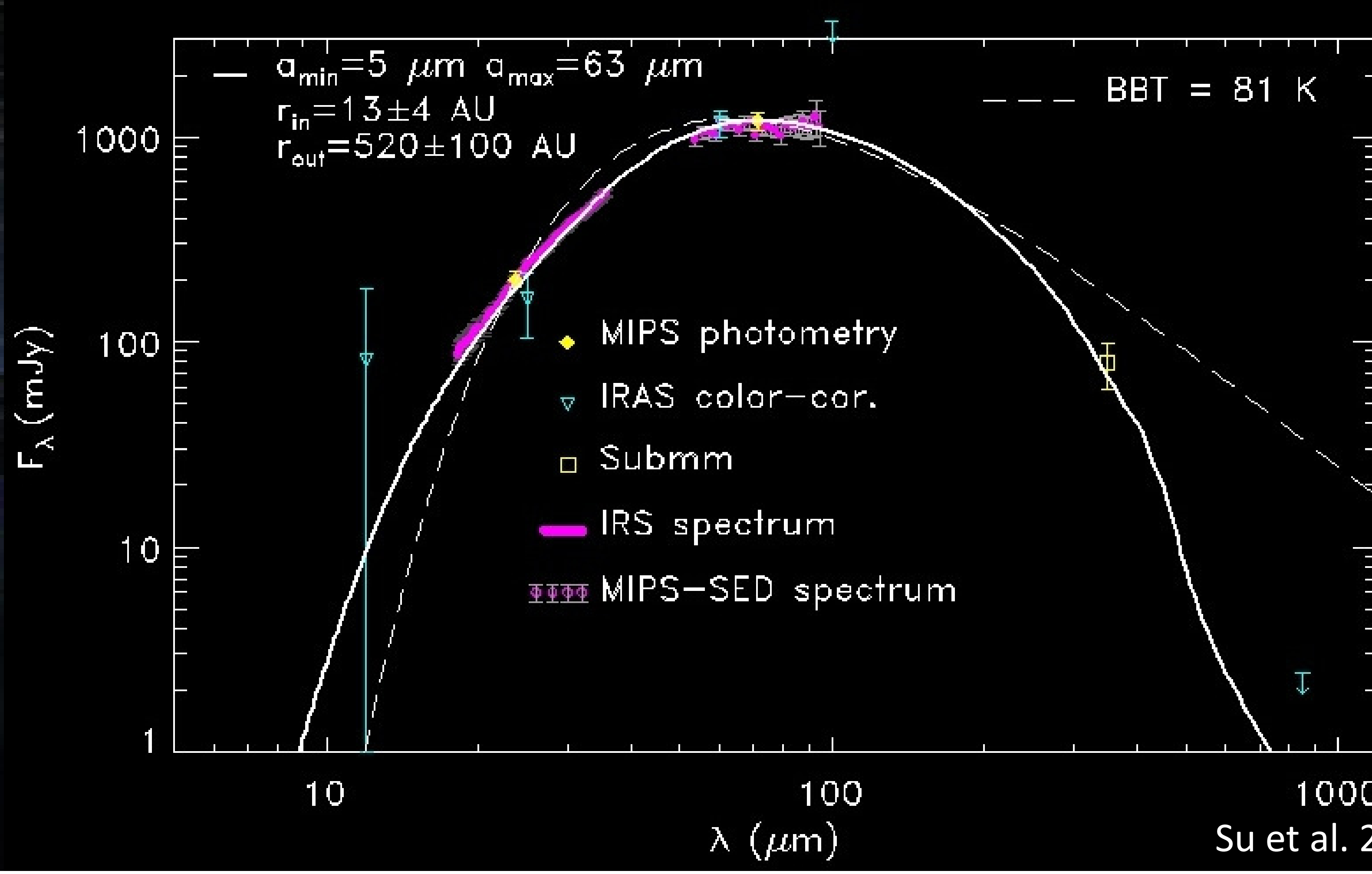
Resolved Disk around γ Ophiuchi (HD161868)



Su et al. 2008

Resolved Disk around γ Ophiuchi (HD161868)

- A0V, ~200 Myr, 29.1 pc
- $r_{24,\,out} \geq 9''$ (260 AU), $r_{70,\,out}$ ~18″ (520 AU), P.A.~55°
- i ~ 50°± 5° , consistent with *v*sin*i* of 210 km/s
- a huge disk! (~ 4 times of Fomalhaut disk)



Su et al. 2008

Resolved Disk around β Leonis (HD102647)

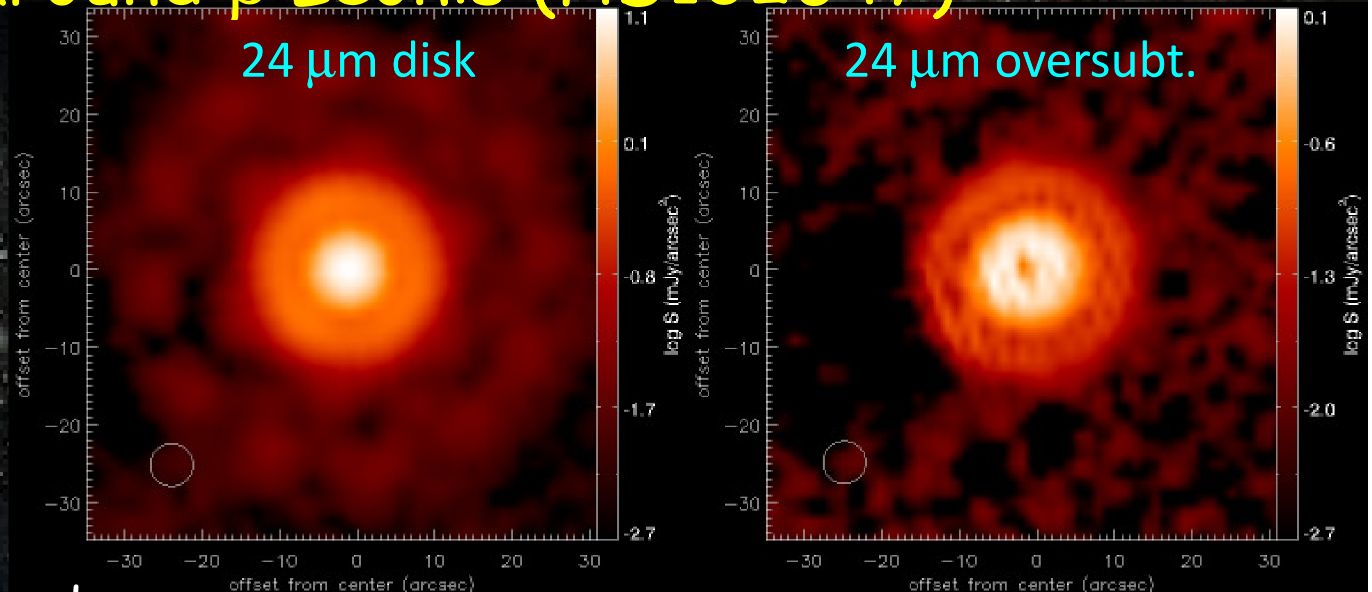
- A3V, 11.1 pc
- resolved at 24 but not at 70 μm

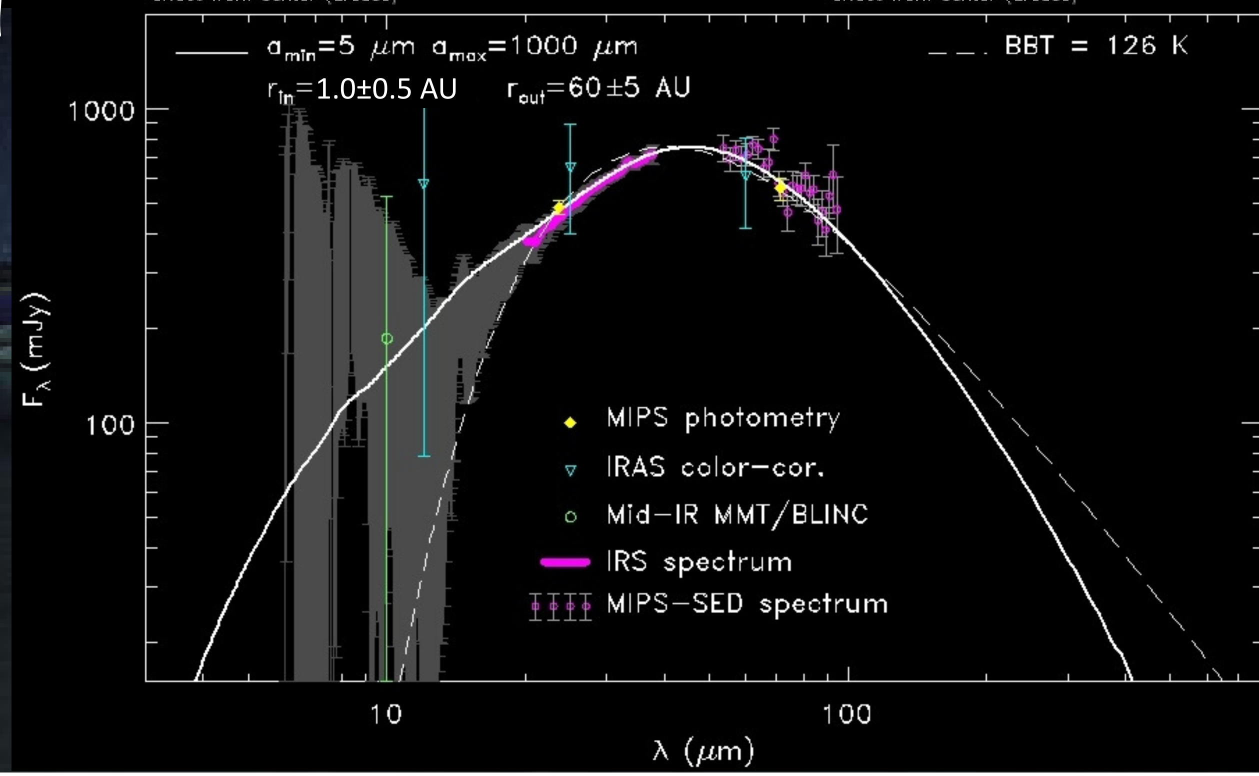
→ r_{out} ~55 AU based on deconvolved 24 μm image

→ r_{out} < 80 AU based on unresolved 70 μm

→ ~3% excess seen at 10 μm (see poster #115 by Wilson et al.)

→ a compact disk! (~ ⅓ of Fomalhaut)





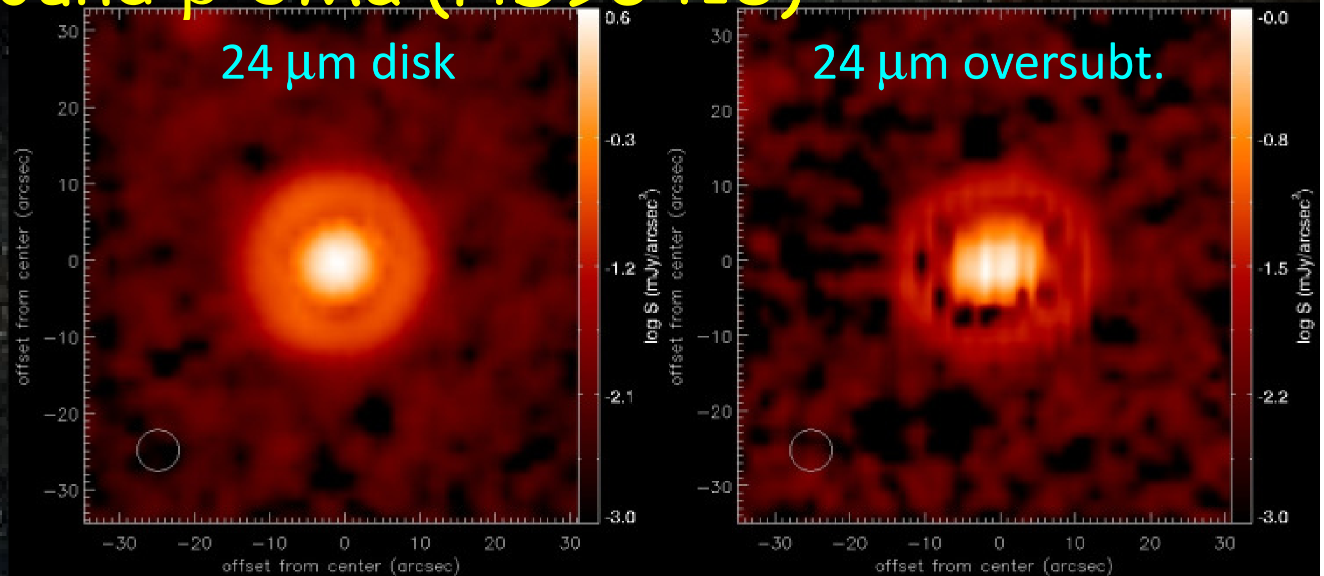
Resolved Disk around β UMa (HD95418)

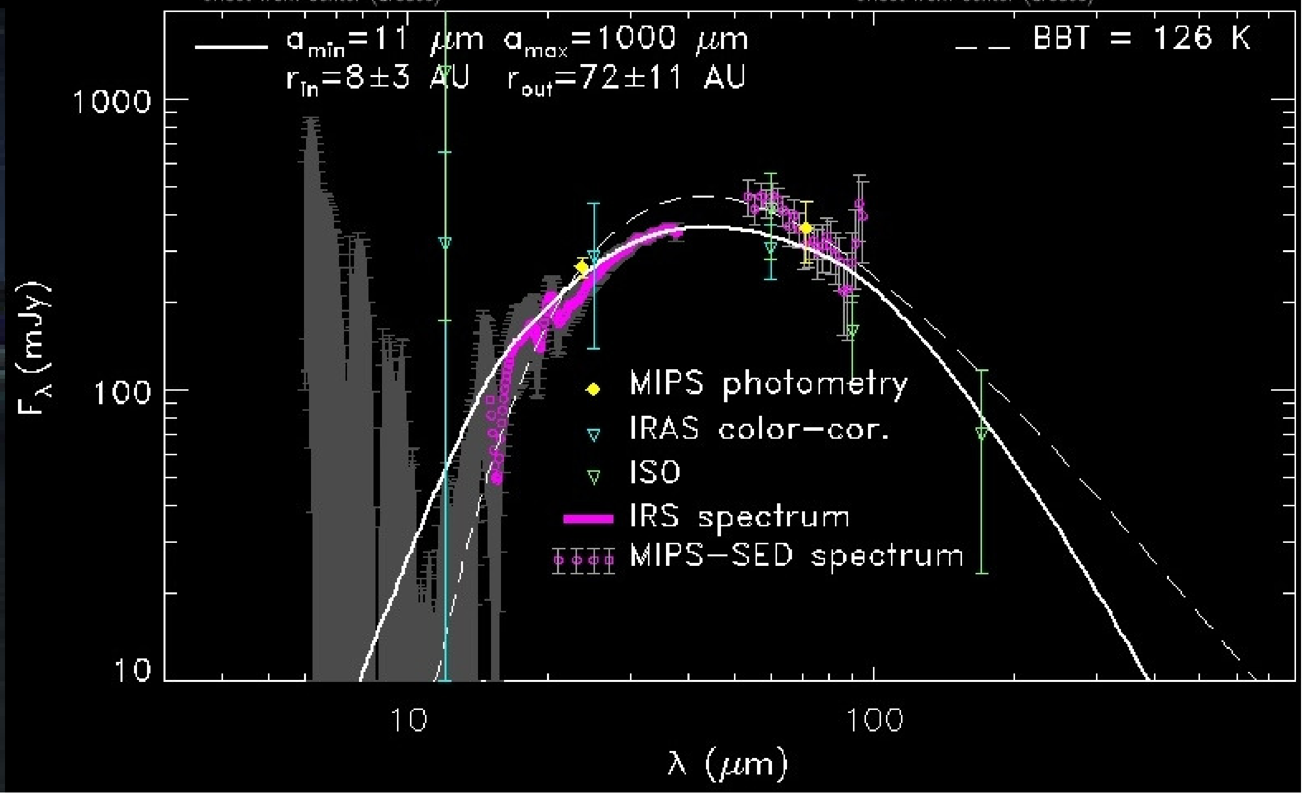
- A1V, 24.4 pc
- resolved at 24 but not at 70 μm

→ r_{out} ~70 AU based on deconvolved 24 μm image

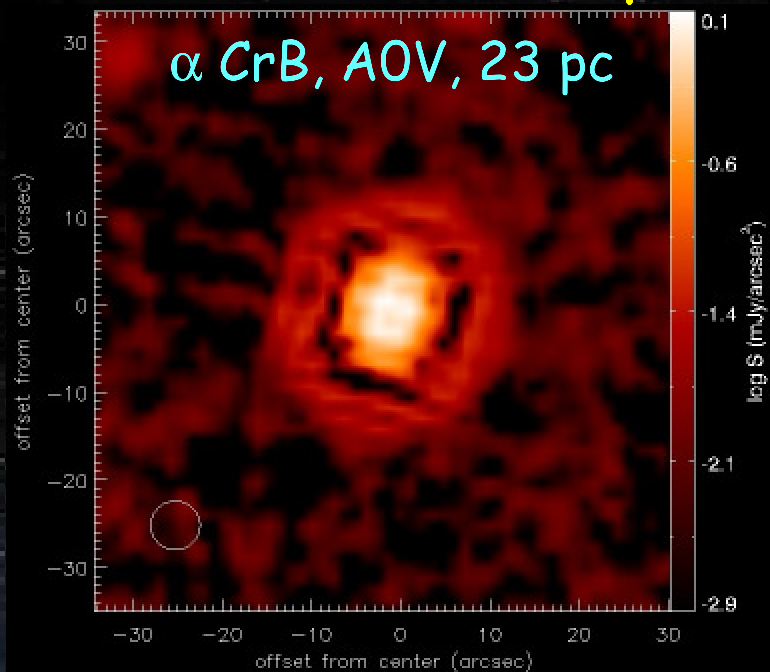
→ r_{out} < 125 AU based on unresolved 70 μm

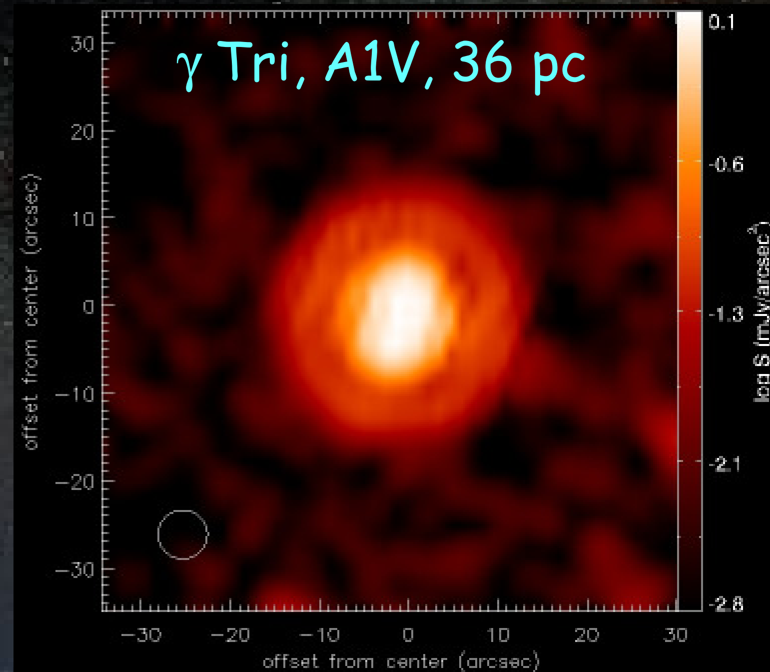
→ a compact disk! (~ ½ of Fomalhaut)

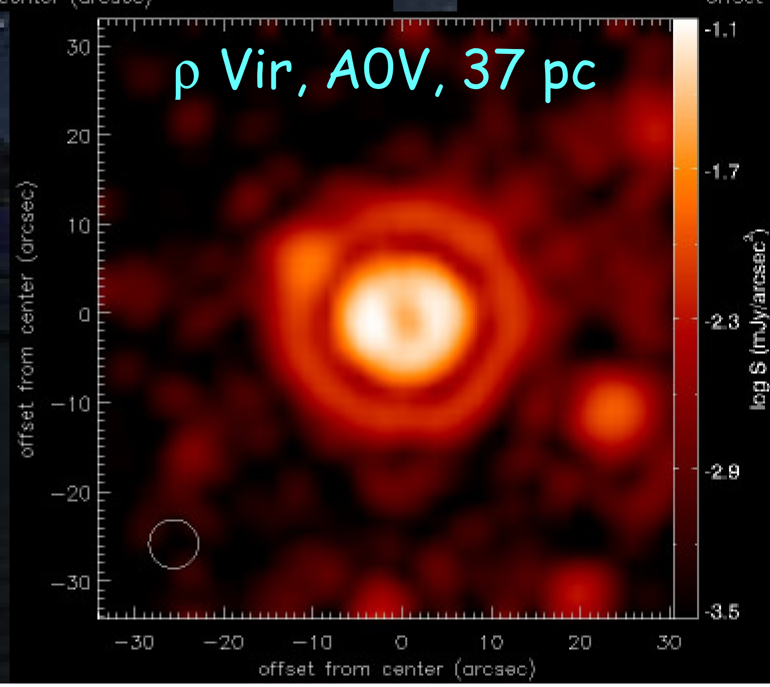




Other Resolved 24 μm Disks







After PSF over-subtraction

Summary

- A sample (14) of nearby A-type debris disks within 40 pc
  ~60% resolved at 24 μm and ~35% at 70 μm.

Name	Sp. Type	Age (Myr)	f_d	$T_{[24-70]}$ (K)	r_{out} (AU)	$M_d(M_\oplus)$	Multiple belts?
Vega	A0V	200	2.3E-005	81	~150/~800	8E-003	Yes.
Fomalhaut	A3V	200	6.6E-005	70	~150	1E-002	Yes.
ζ Lep	A2V	300	9.8E-005	206	~20	1E-004	Yes. (talk by Akeson)
β Leo	A3V	50-300	2.0E-005	123	~60	2E-004	Yes. (talk by Akeson)
β Uma	A1V	350	1.3E-005	116	~80	4E-004	?
γ Oph	A0V	250	7.5E-005	81	~520	1E-002	Maybe?

-The outer radius of the disks varies over a factor of 40, from 20 AU to 800 AU for a group of stars with similar spectral type and age.

- The structure of debris disks can be complex as revealed by multi-wavelength observations. SED modeling is a necessary tool to extract the correct interpretation of debris disk characteristics; parameters can be constrained by combining optical scattered light and thermal infrared images.