

# Infrared study of Transitional Disks in Ophiuchus with Herschel

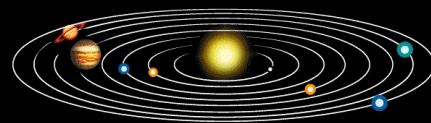
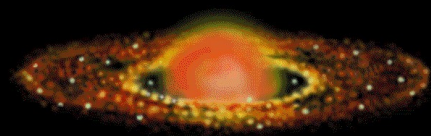
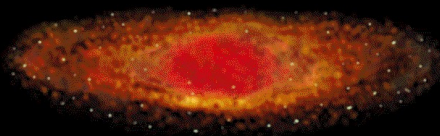
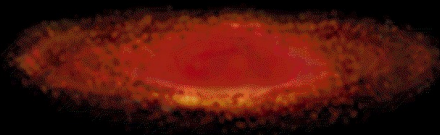
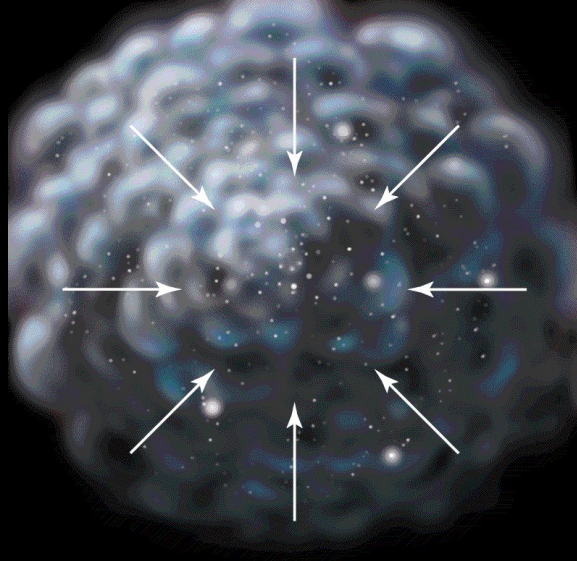
Rebollido et al. (2015), A&A, 581, A30



Isabel Rebollido – ESAC  
Bruno Merín – ESAC  
Álvaro Ribas – ESAC, CAB  
Hervé Bouy – CAB  
Ignacio Bustamante – ESAC, CAB  
Pablo Riviere-Marichalar – ESAC

Timo Prusti – ESA/ESTEC, Göran L. Pilbratt – ESA/ESTEC  
Philippe André – CEA, Péter Ábrahám – Konkoly Observatory

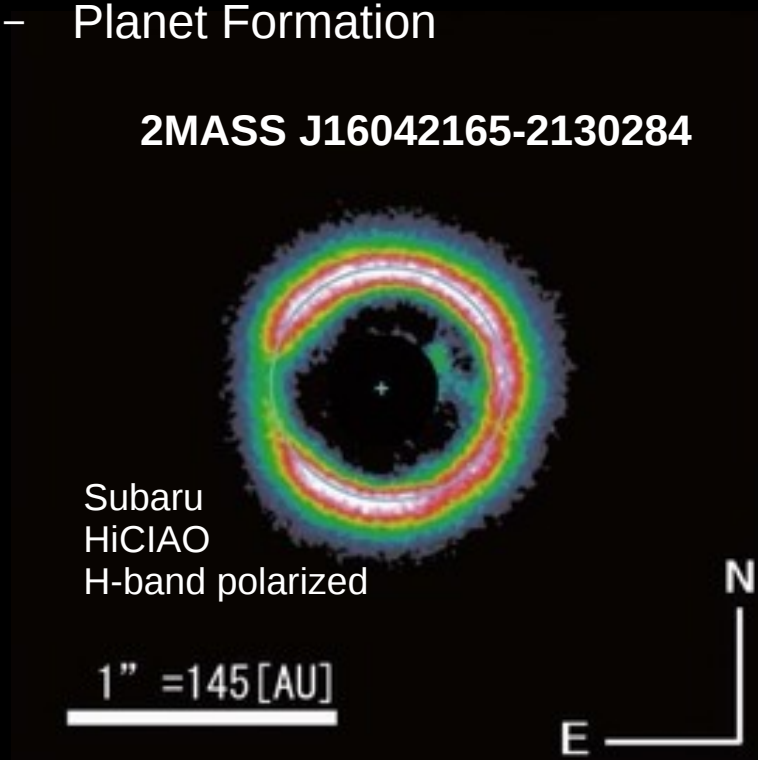
Credit: ESO/L. Calçada.



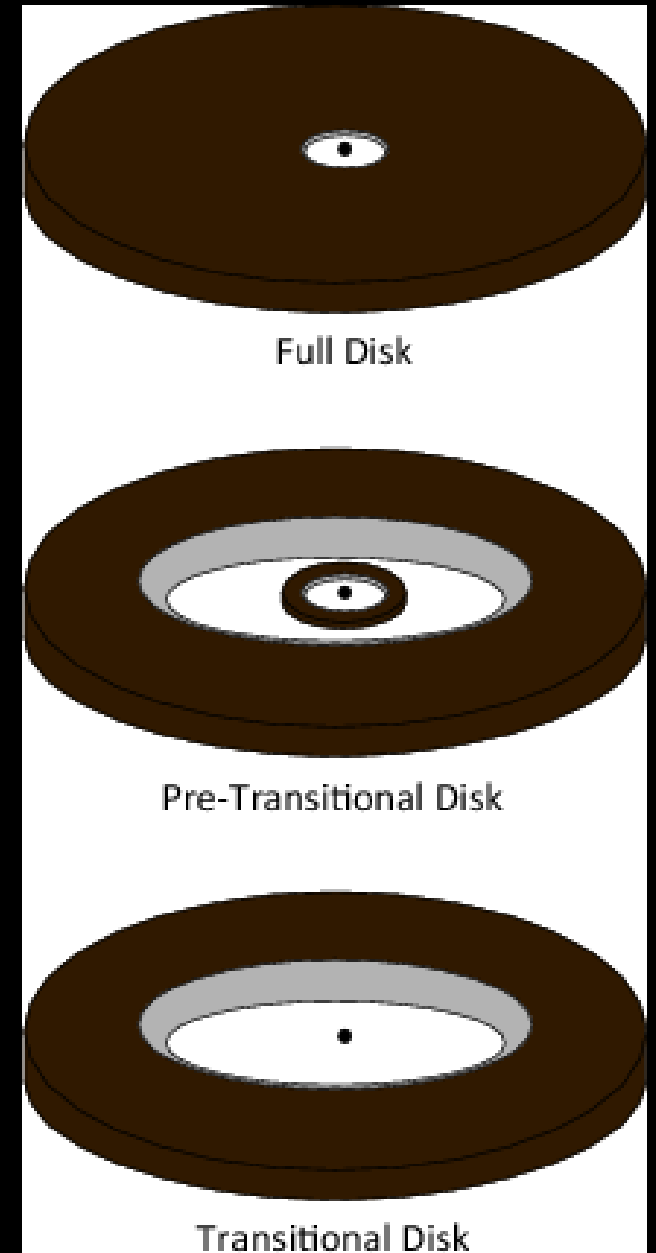
## Transitional Disks

Protoplanetary disks around young stars which have inner gaps, probably due to:

- Photoevaporation
- Grain growth
- Planet Formation

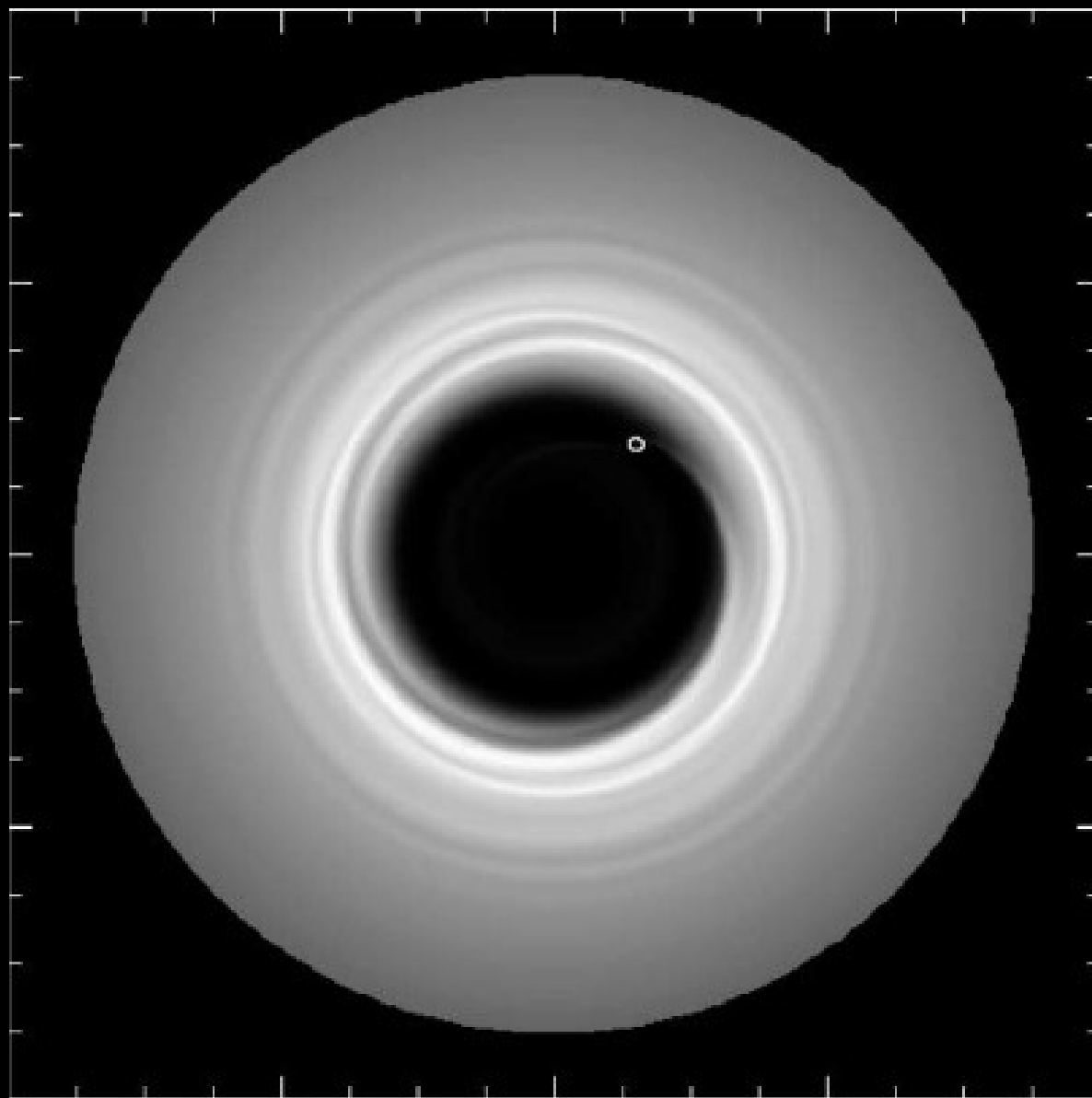


Mayama et al. (2012)



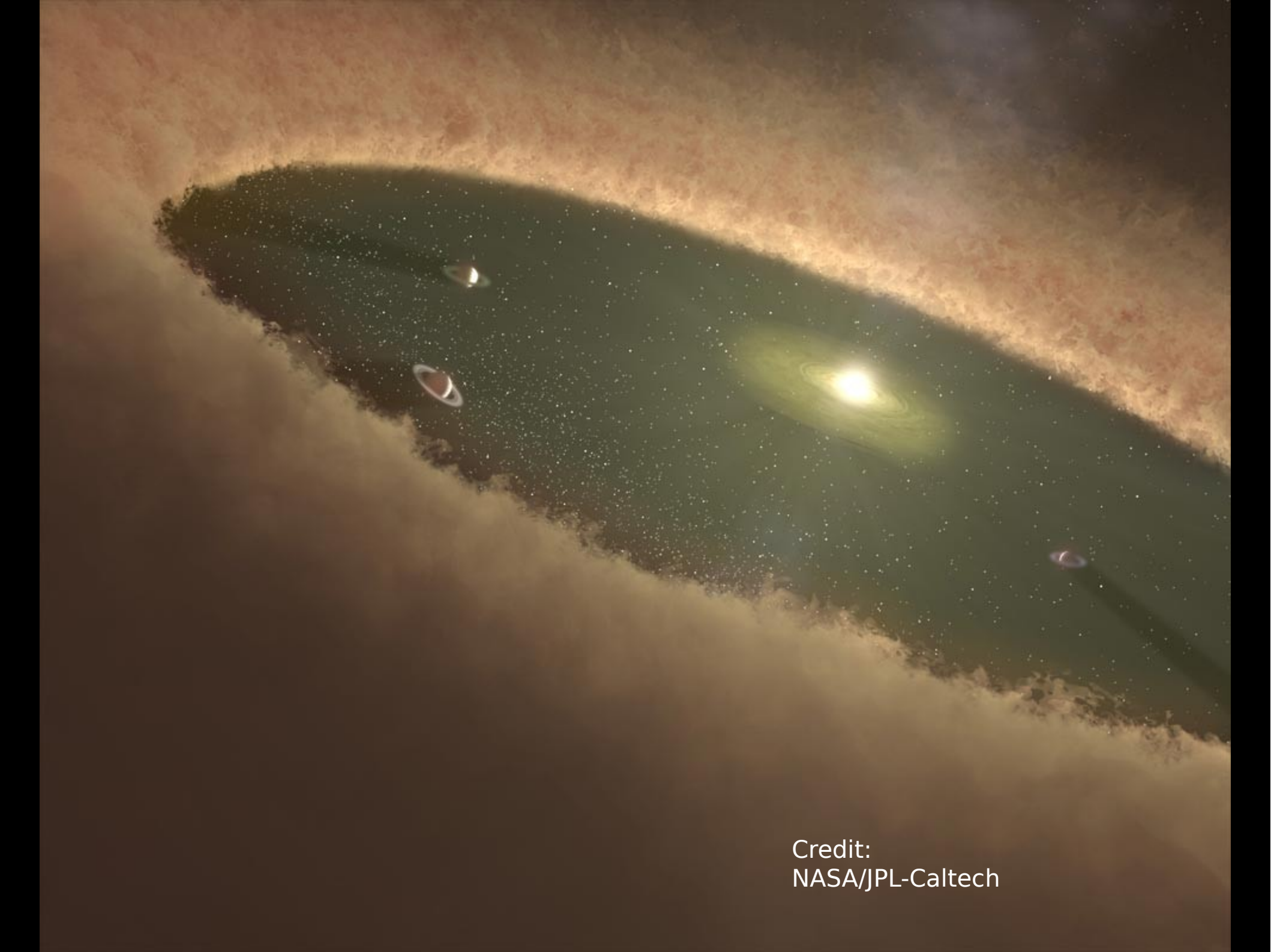
Espaillet et al. (2014) 3

# Hydrodynamical simulation of a planet forming transitional disk



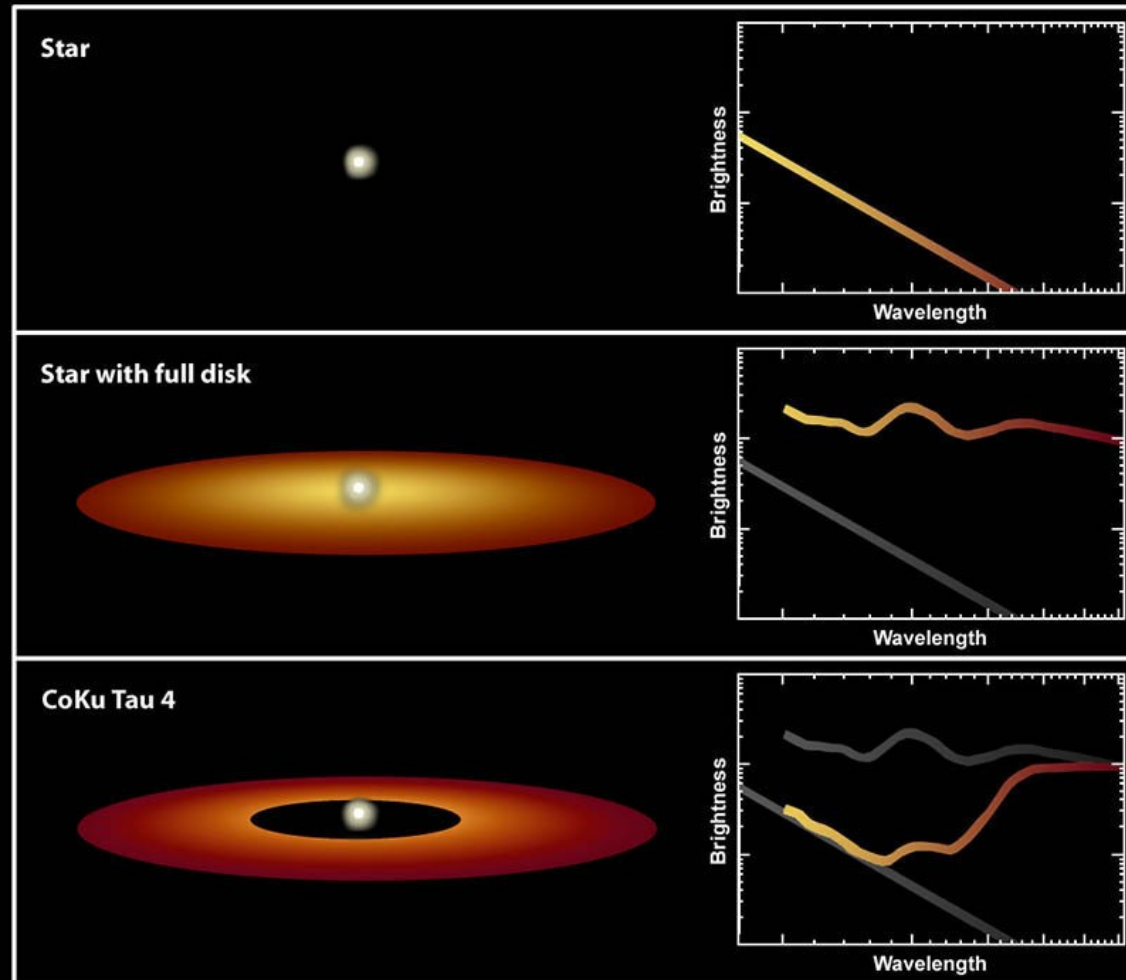
Quillen et al. (2004)





Credit:  
NASA/JPL-Caltech

# Spectral Energy Distribution



Inner Gap in Circumstellar Disk    Spitzer Space Telescope • IRS

NASA / JPL-Caltech / D. Watson (University of Rochester)

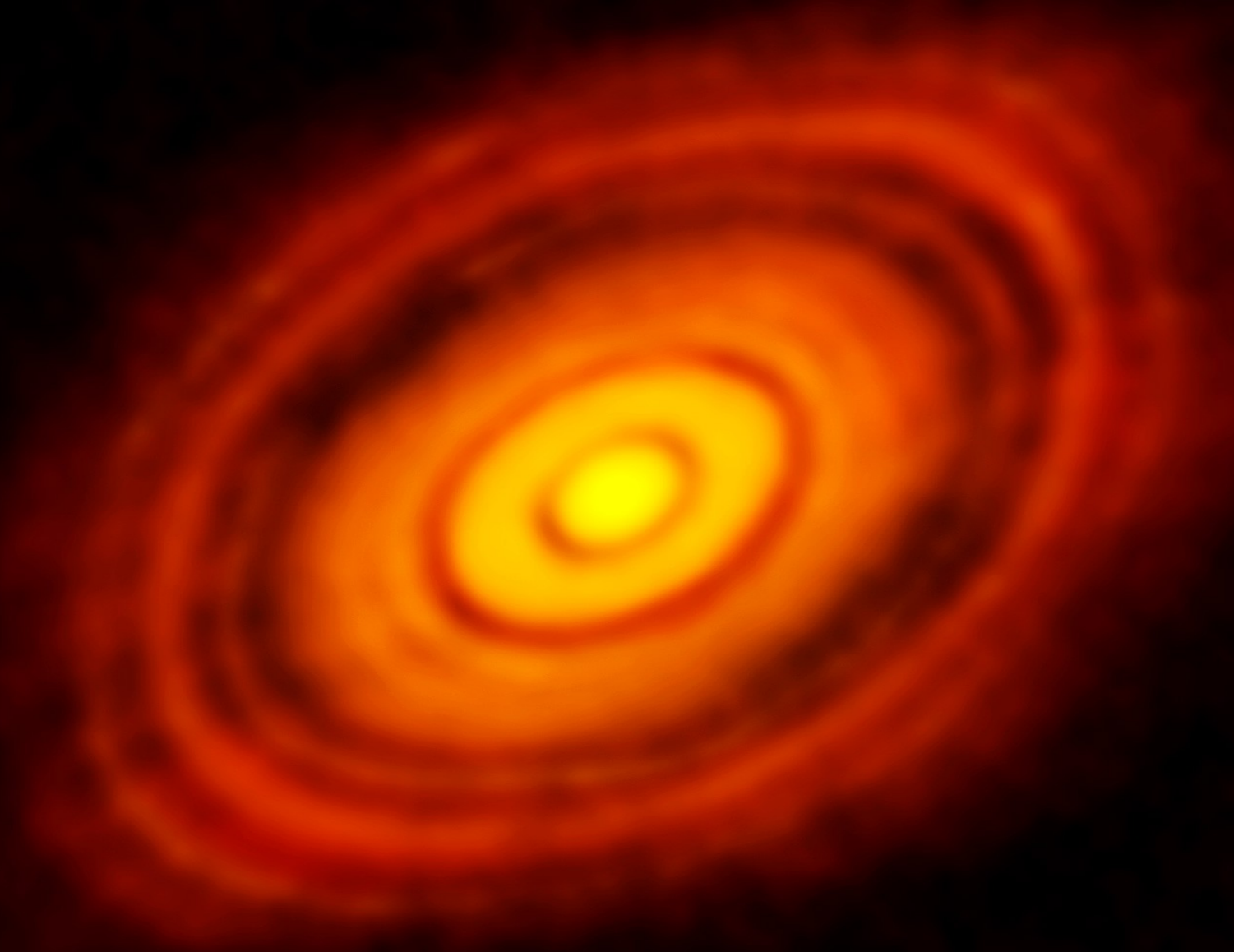
ssc2004-08c

**HL TAU**

ALMA  
850  $\mu\text{m}$

90 AU

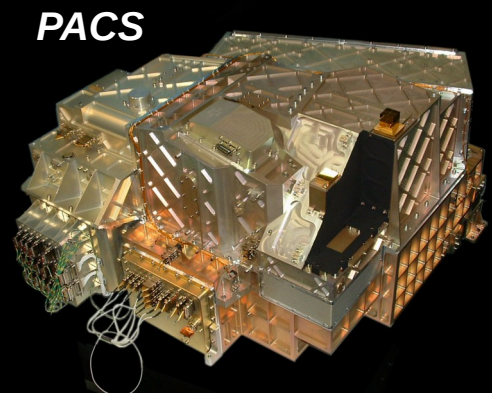
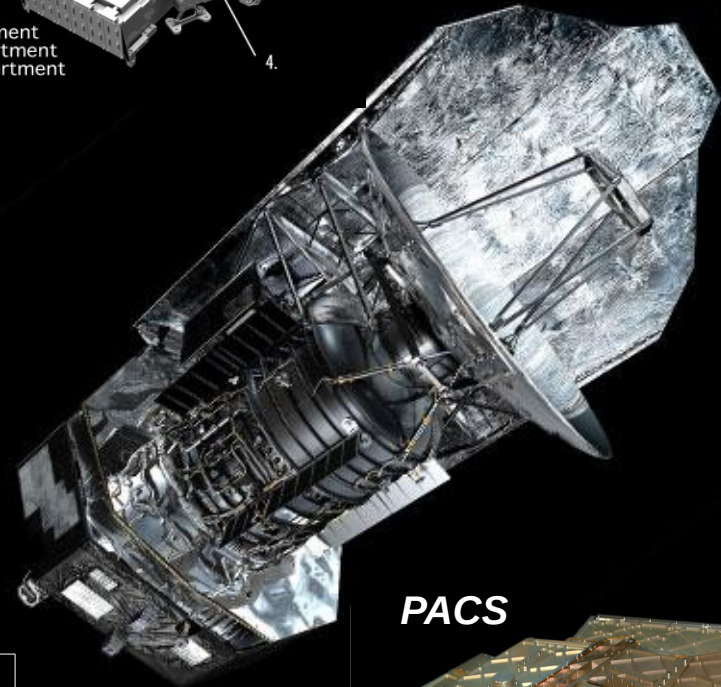
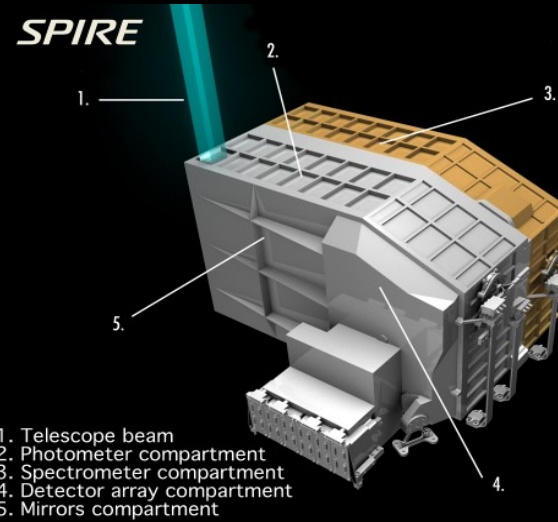
---



Credit:  
ALMA(NRAO/ESO/NAOJ);  
C. Brogan, B. Saxton (NRAO/AUI/NSF)

# Herschel Space Observatory

- 3,5 m mirror
- Covered from 55  $\mu\text{m}$  to 670  $\mu\text{m}$
- Instruments:
  - HIFI
  - PACS
  - SPIRE



Imaging Instruments	PACS	SPIRE
Wavelengths ( $\mu\text{m}$ )	70, 100, 160	250, 350, 500



Optical  
RGB

$\rho$ -Ophiuchi

125 pc

2-5 Myr

>250 YSO's

Credit:  
Robert Gendler, Jim  
Misti, and Steve Mazlin

R: 24  $\mu\text{m}$   
G: 8  $\mu\text{m}$   
B: 4,5  $\mu\text{m}$



## $\rho$ -Ophiuchi

125 pc  
2-5 Myr  
>250 YSO's



R: 160  $\mu\text{m}$   
G: 100  $\mu\text{m}$   
B: 70  $\mu\text{m}$

## $\rho$ -Ophiuchi

125 pc  
2-5 Myr  
>250 YSO's



**$\rho$ -Ophiuchi**  
**1.38°x1.38°**  
**PACS – 70  $\mu$ m**

**Herschel Gould's Belt Survey (PI: Ph. André)**  
**& OT2\_pabraham\_3 (PI: P. Ábrahám)**



## HIPE (Herschel Interactive Processing Environment)

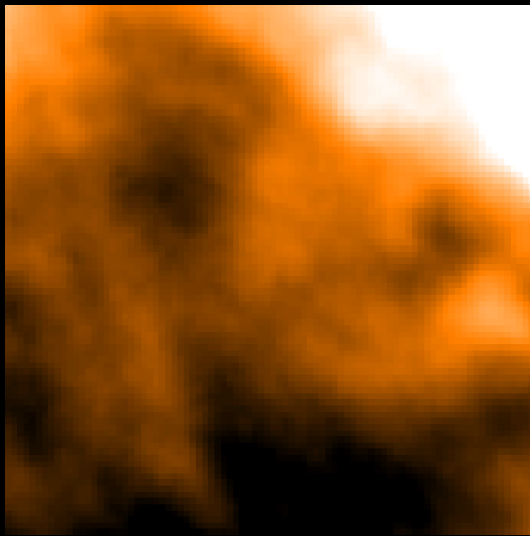
Python-based analysis software specifically designed for Herschel data analysis

1) Sample construction: **261 YSO's** (from Ribas et al. 2014 + Cieza et al. 2010)

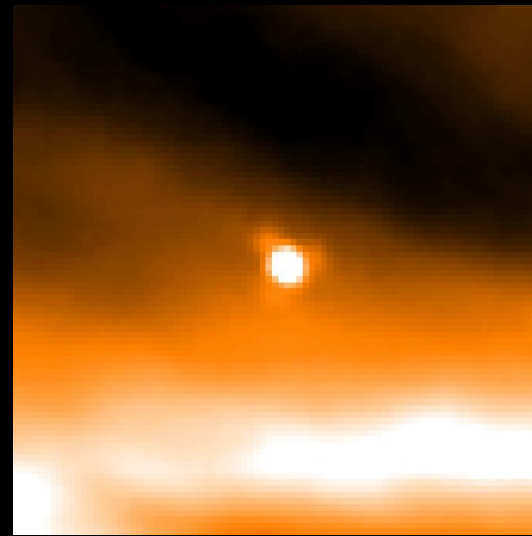
2) Source Extraction & Aperture Photometry



3) Visual Inspection

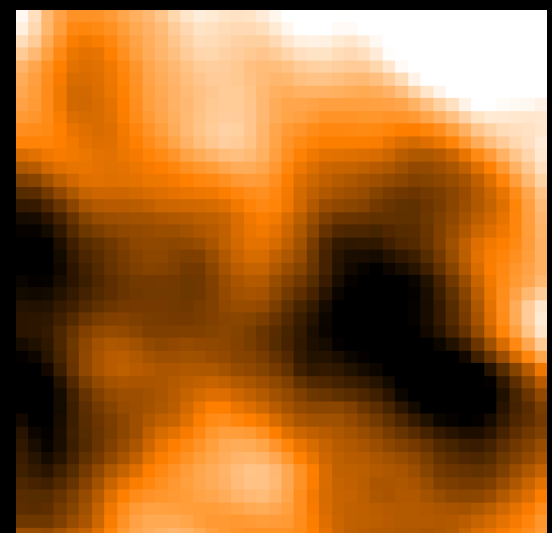
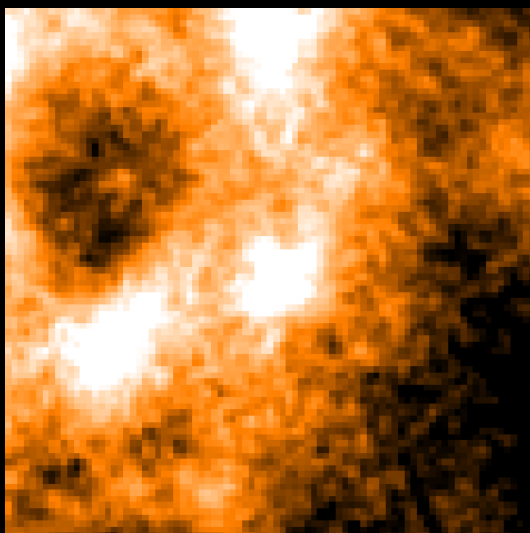
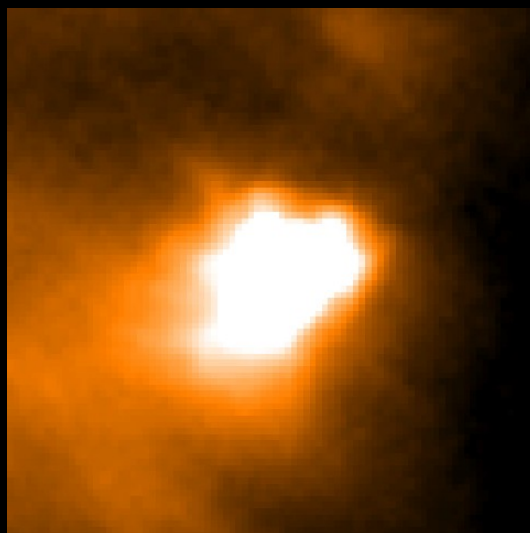
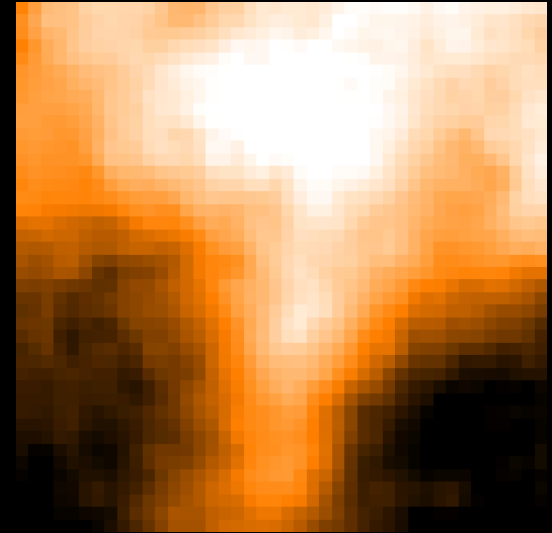
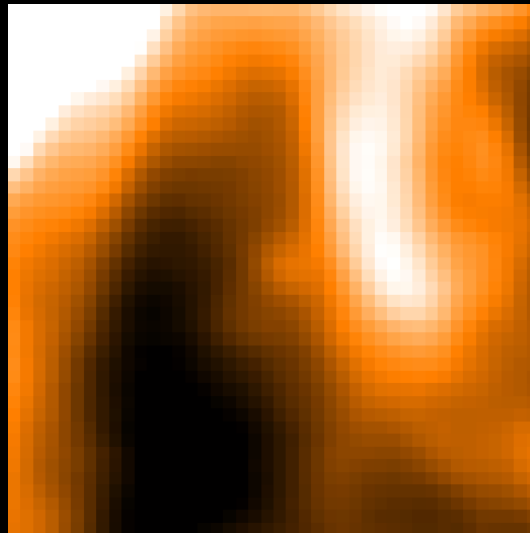
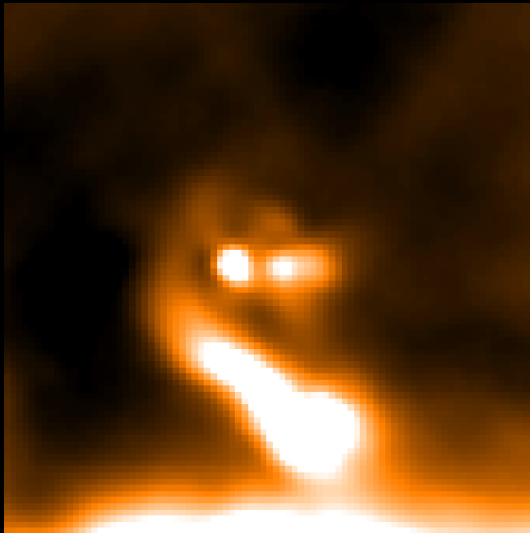


False Positive

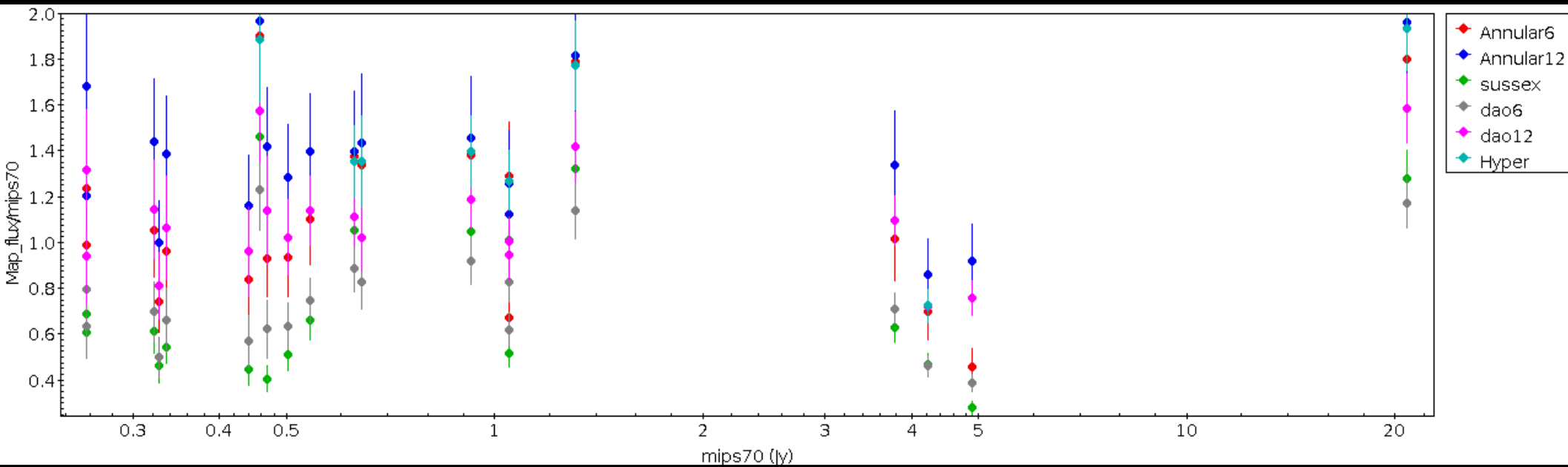


Good Detection

### 3) Visual Inspection

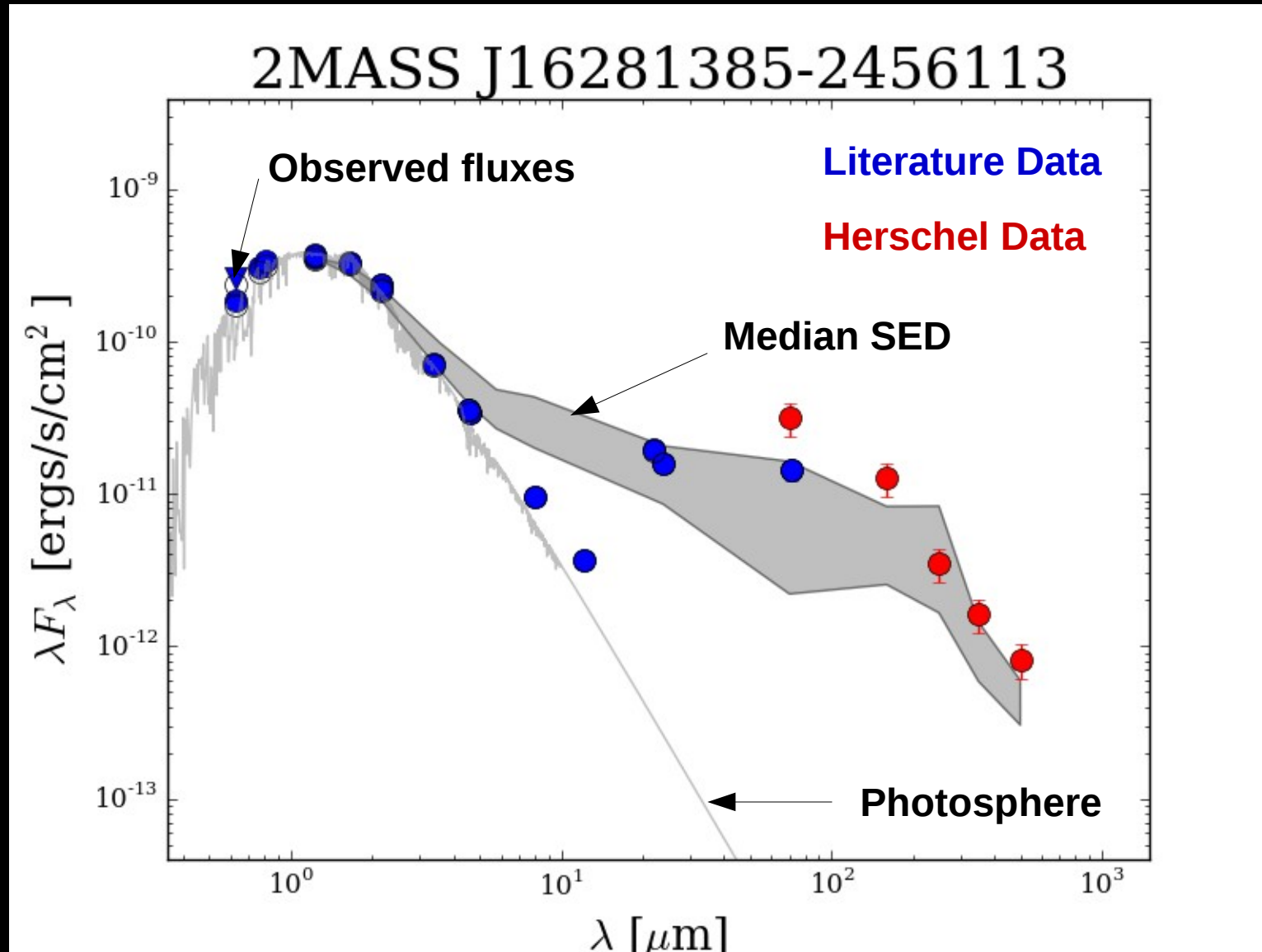


## 4) Photometry study



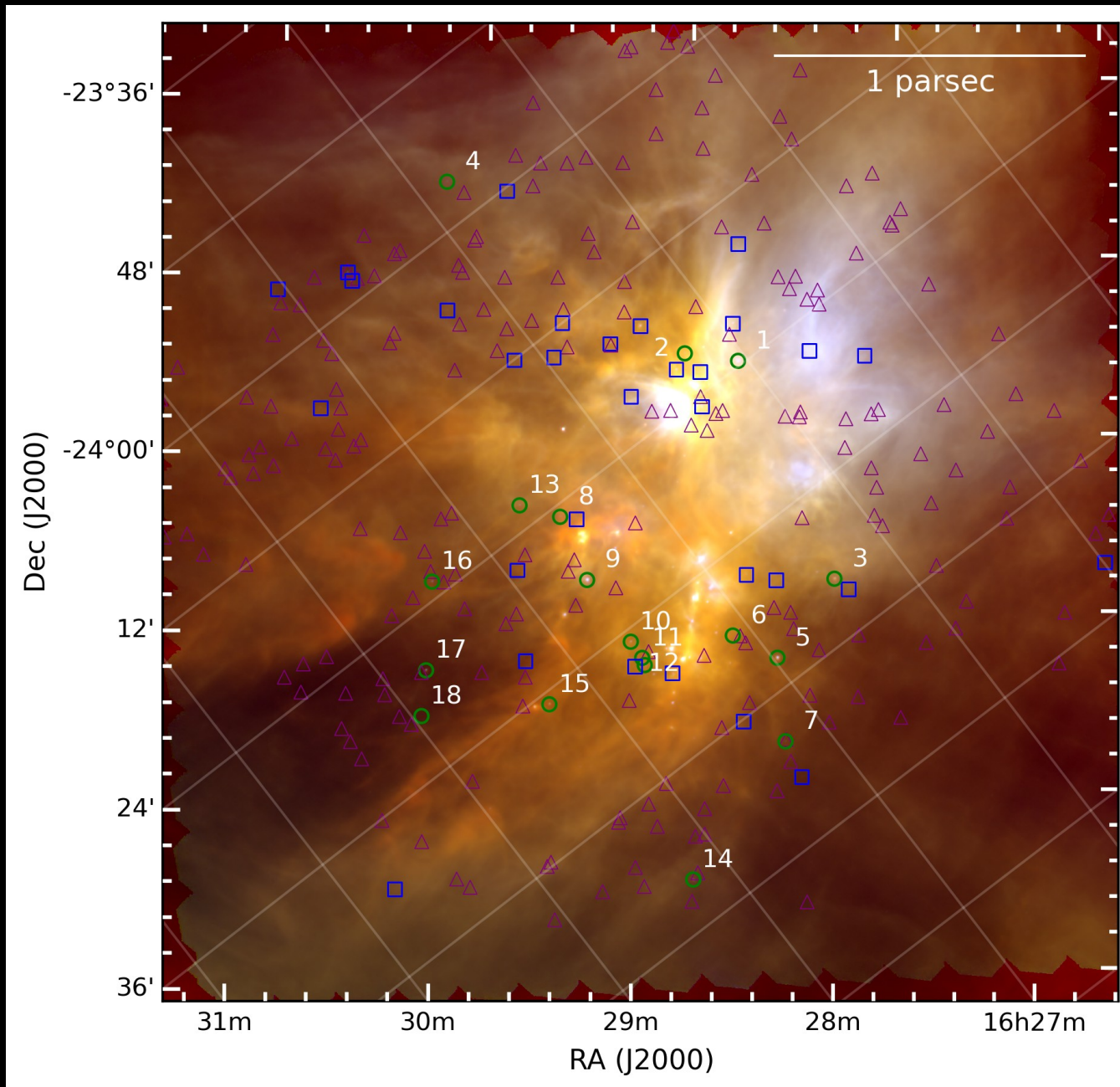
We estimated an uncertainty of 25% for the measured fluxes

## 5) SED construction

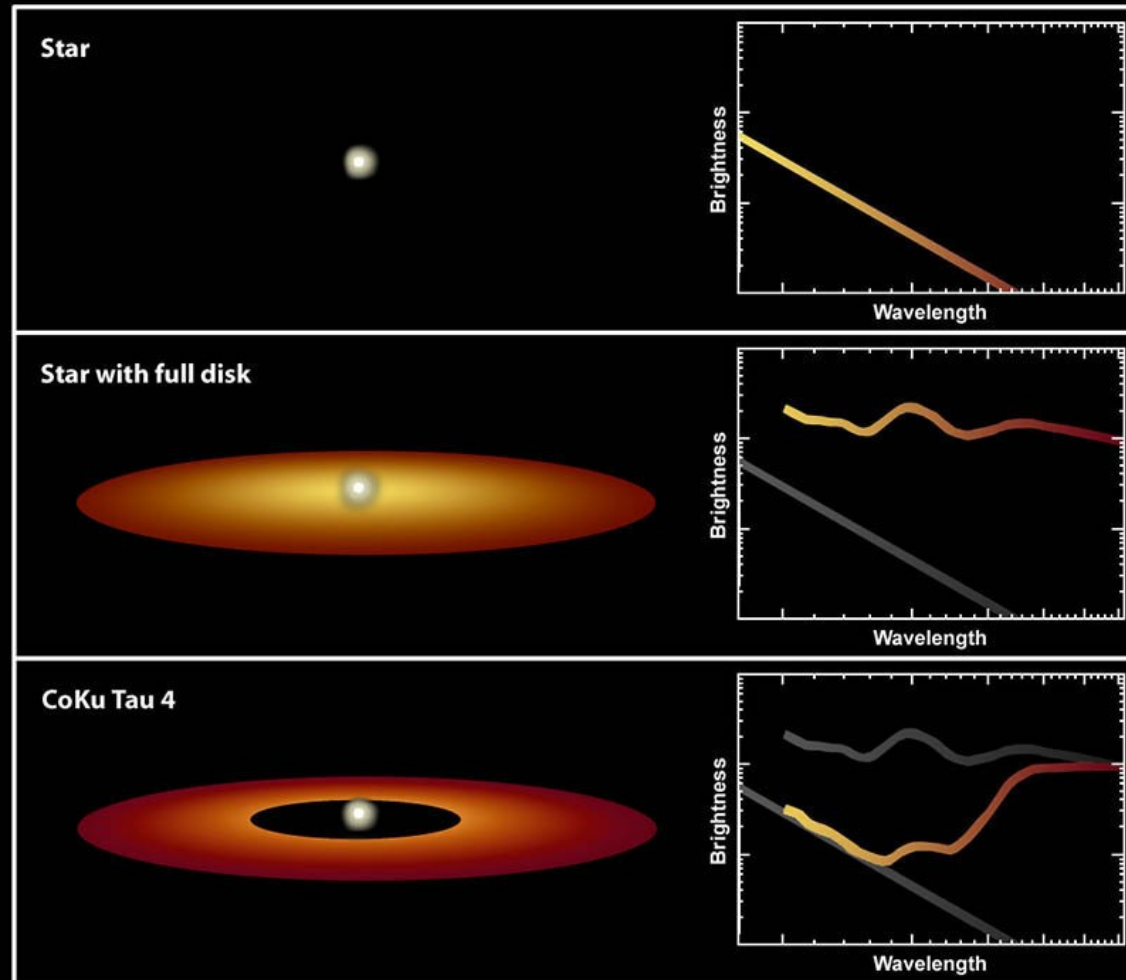




49 objects detected from a sample of 261



# Spectral Energy Distribution

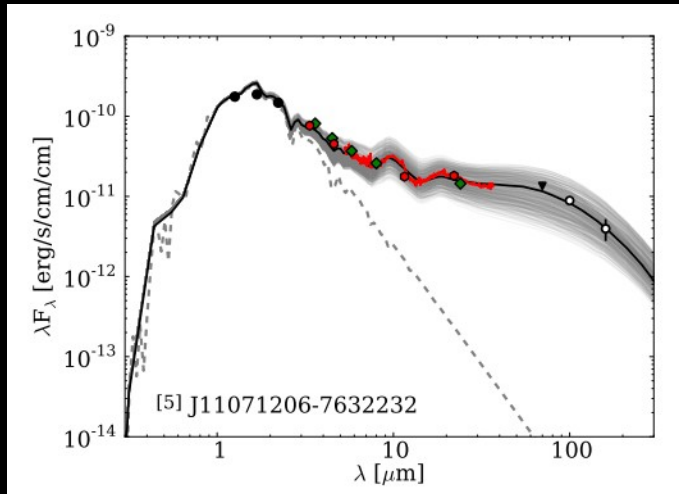


Inner Gap in Circumstellar Disk      Spitzer Space Telescope • IRS

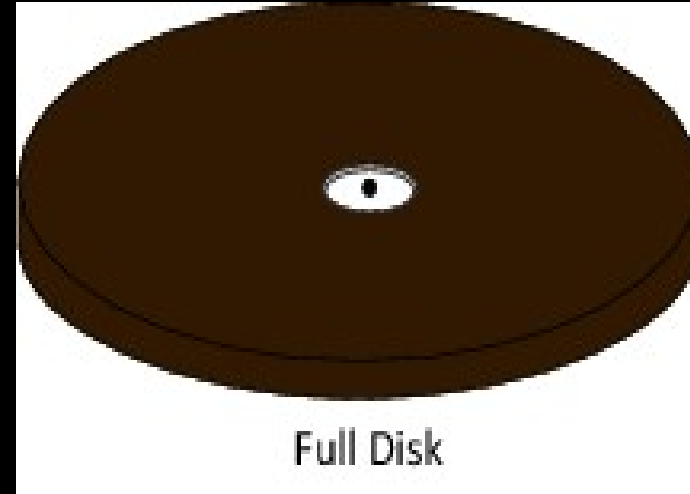
NASA / JPL-Caltech / D. Watson (University of Rochester)

ssc2004-08c

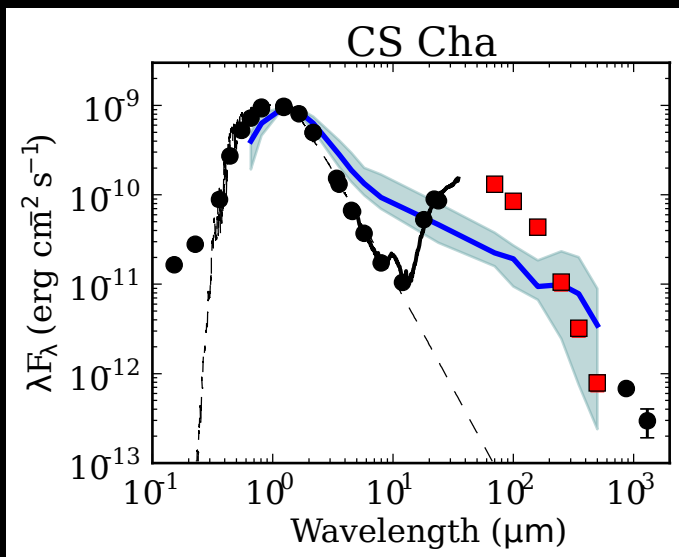
# Spectral Energy Distribution



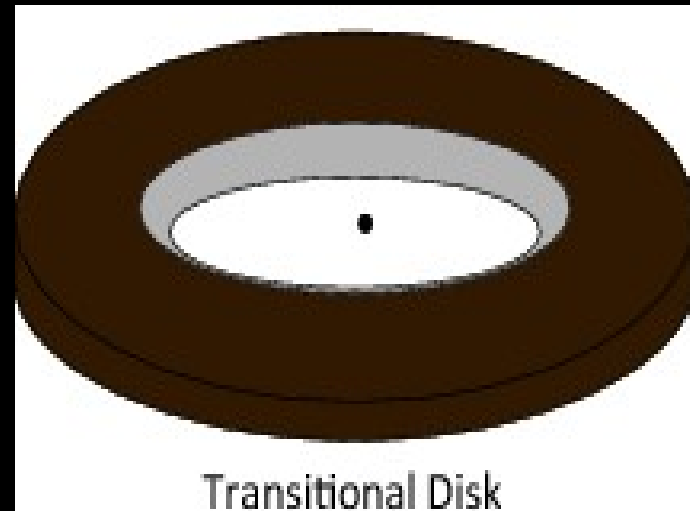
Olofsson et al. (2013)



Full Disk

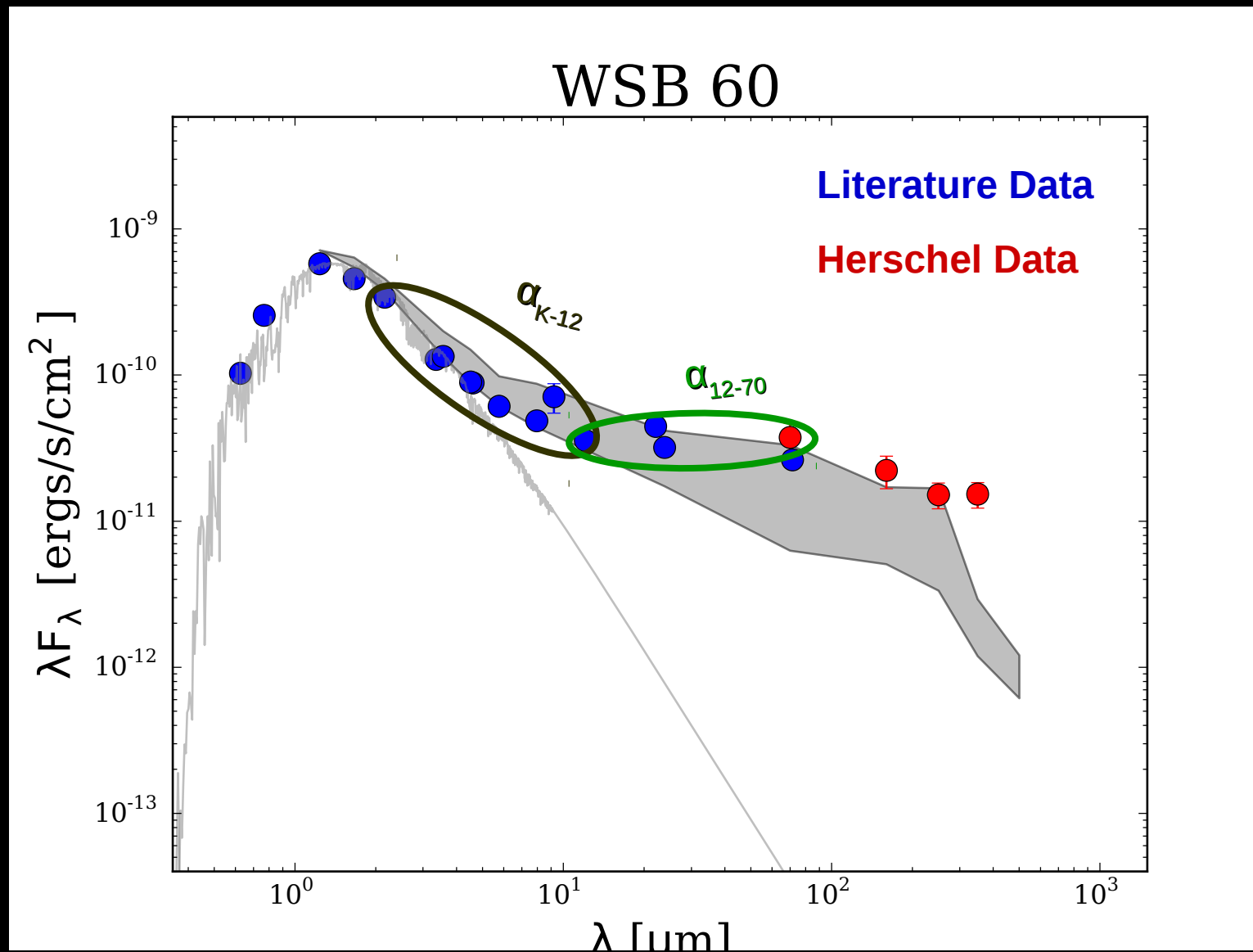


Ribas et al. (2013)



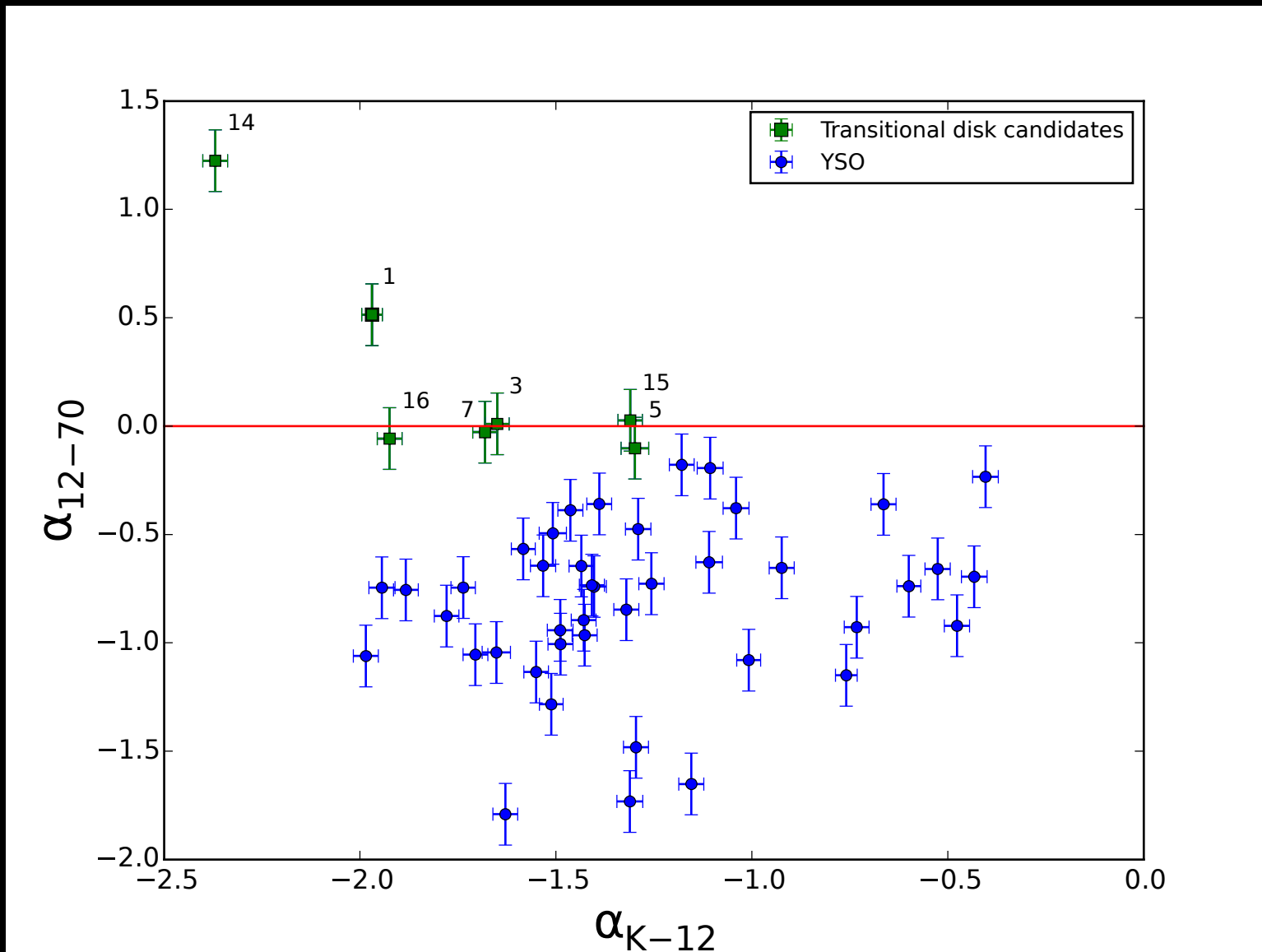
Transitional Disk

# Identification of Transitional Disks

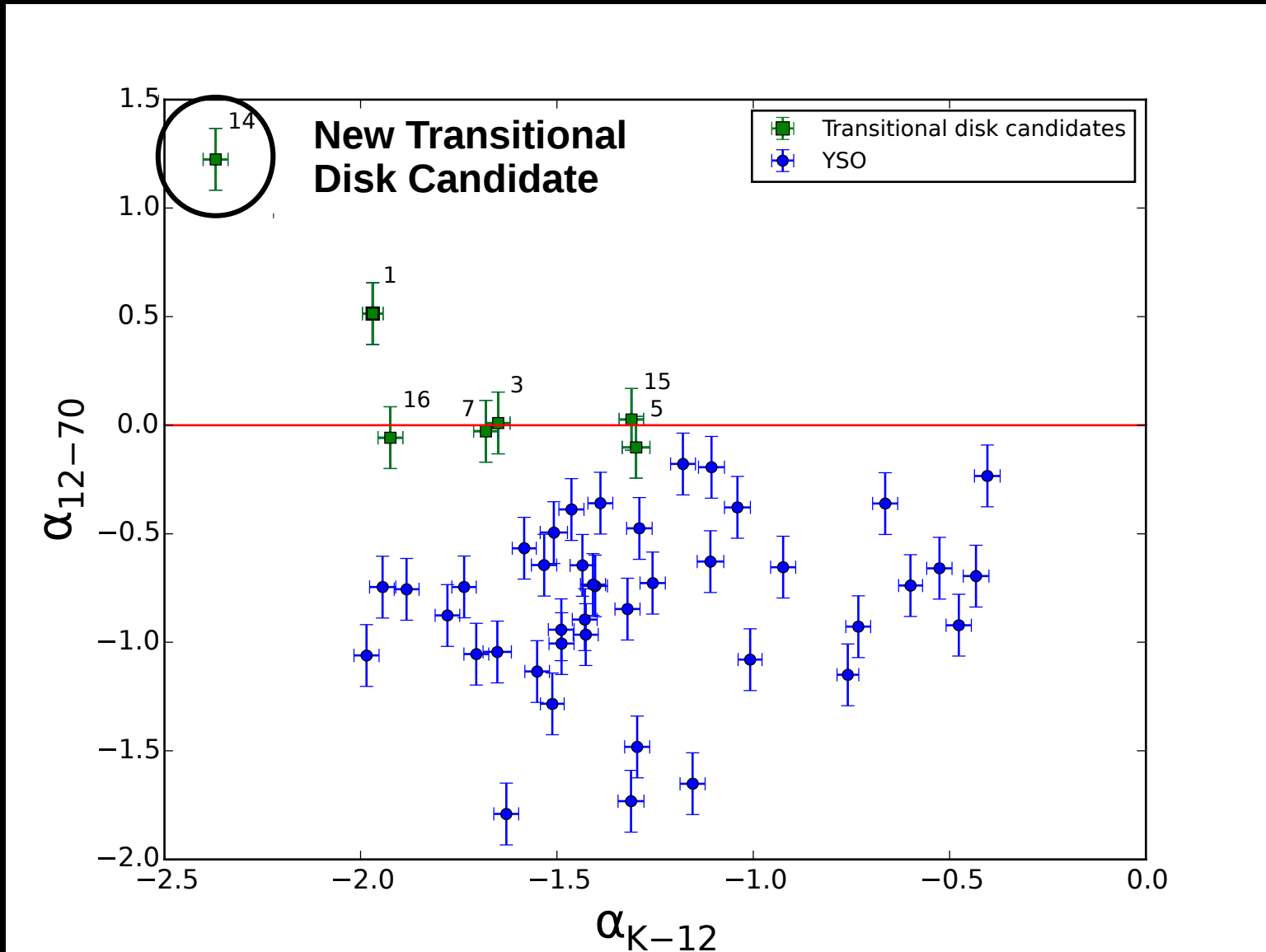




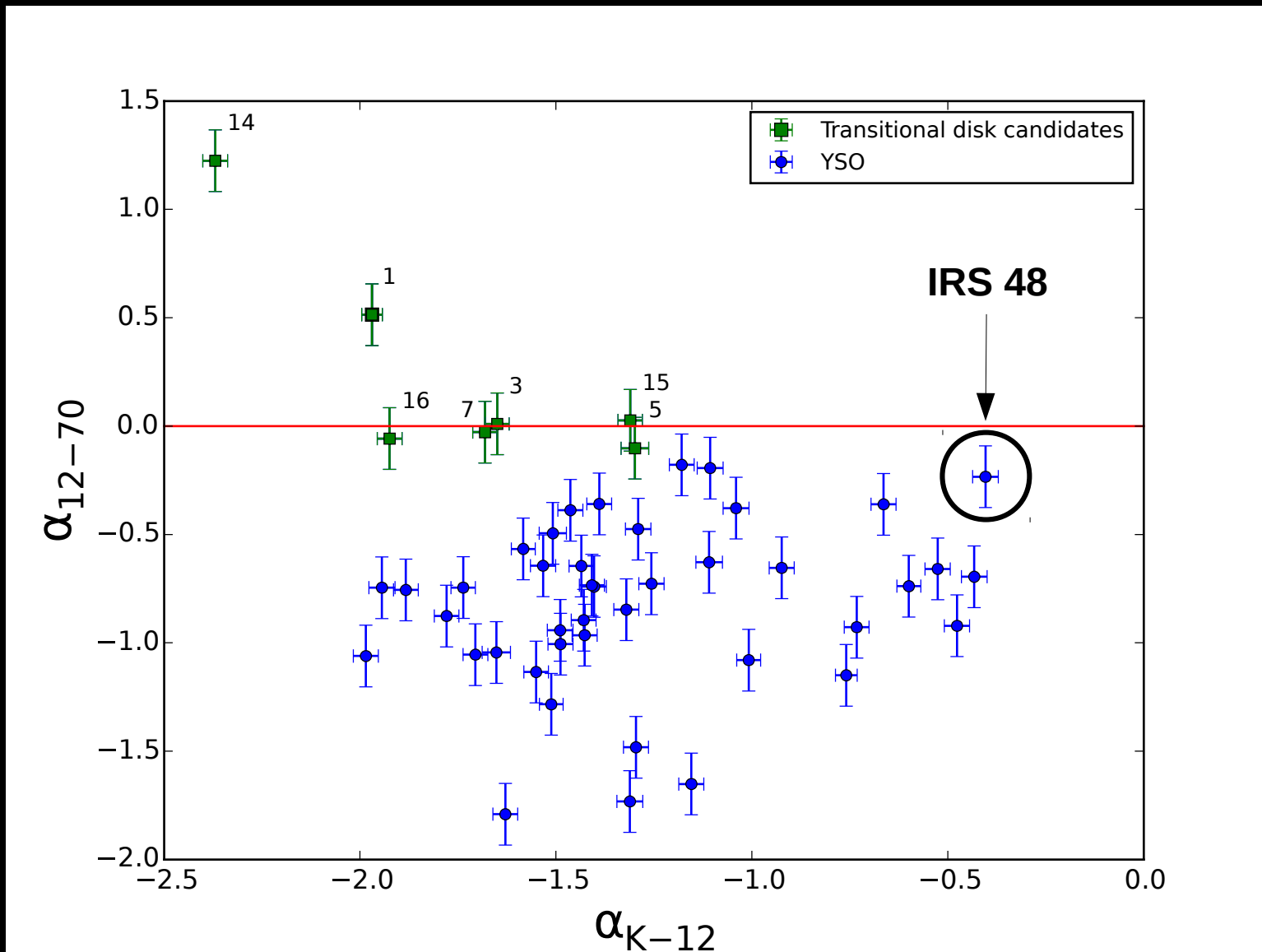
# Identification of Transitional Disks



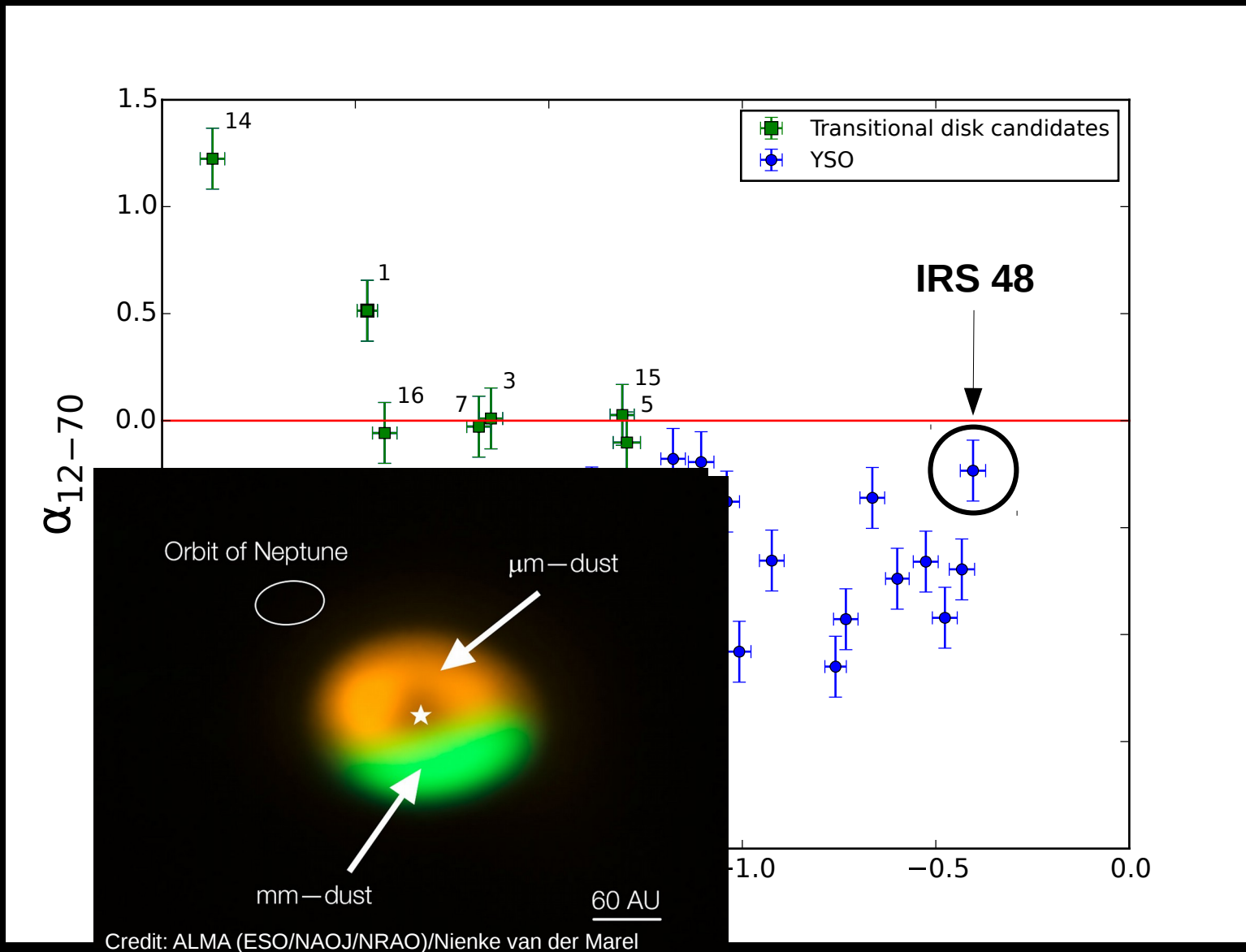
# Identification of Transitional Disks



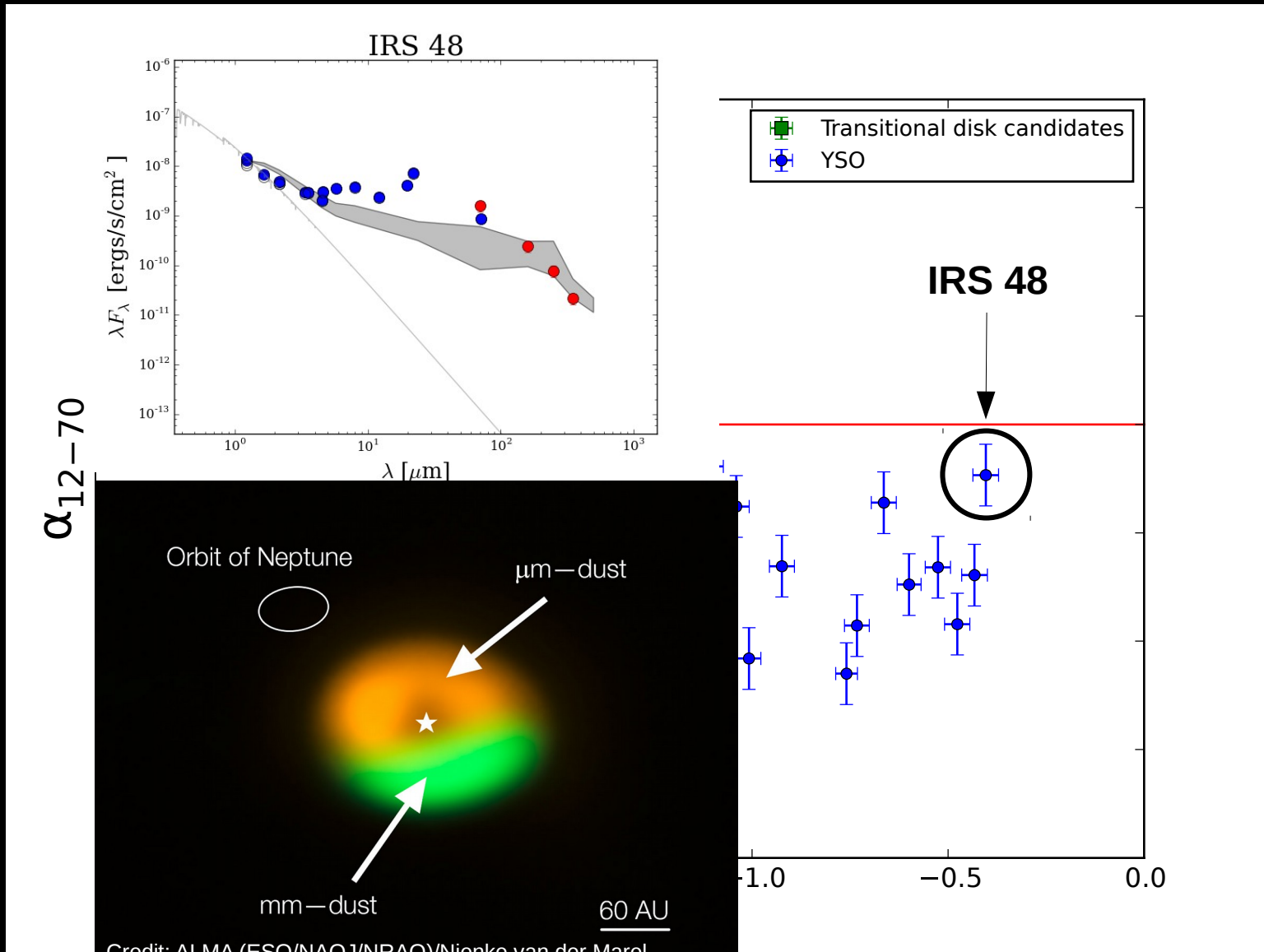
# Identification of Transitional Disks



# Identification of Transitional Disks

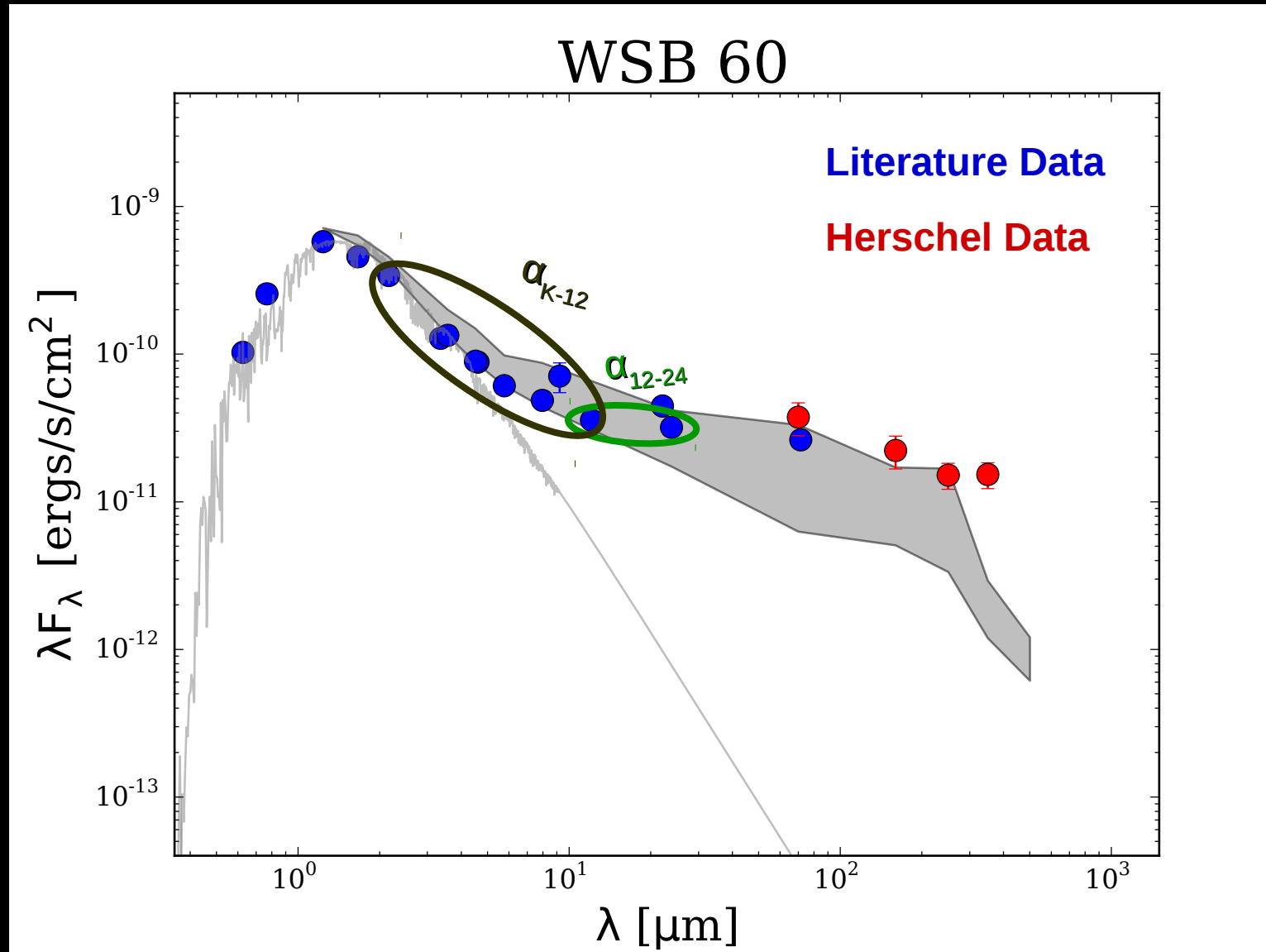


# Identification of Transitional Disks

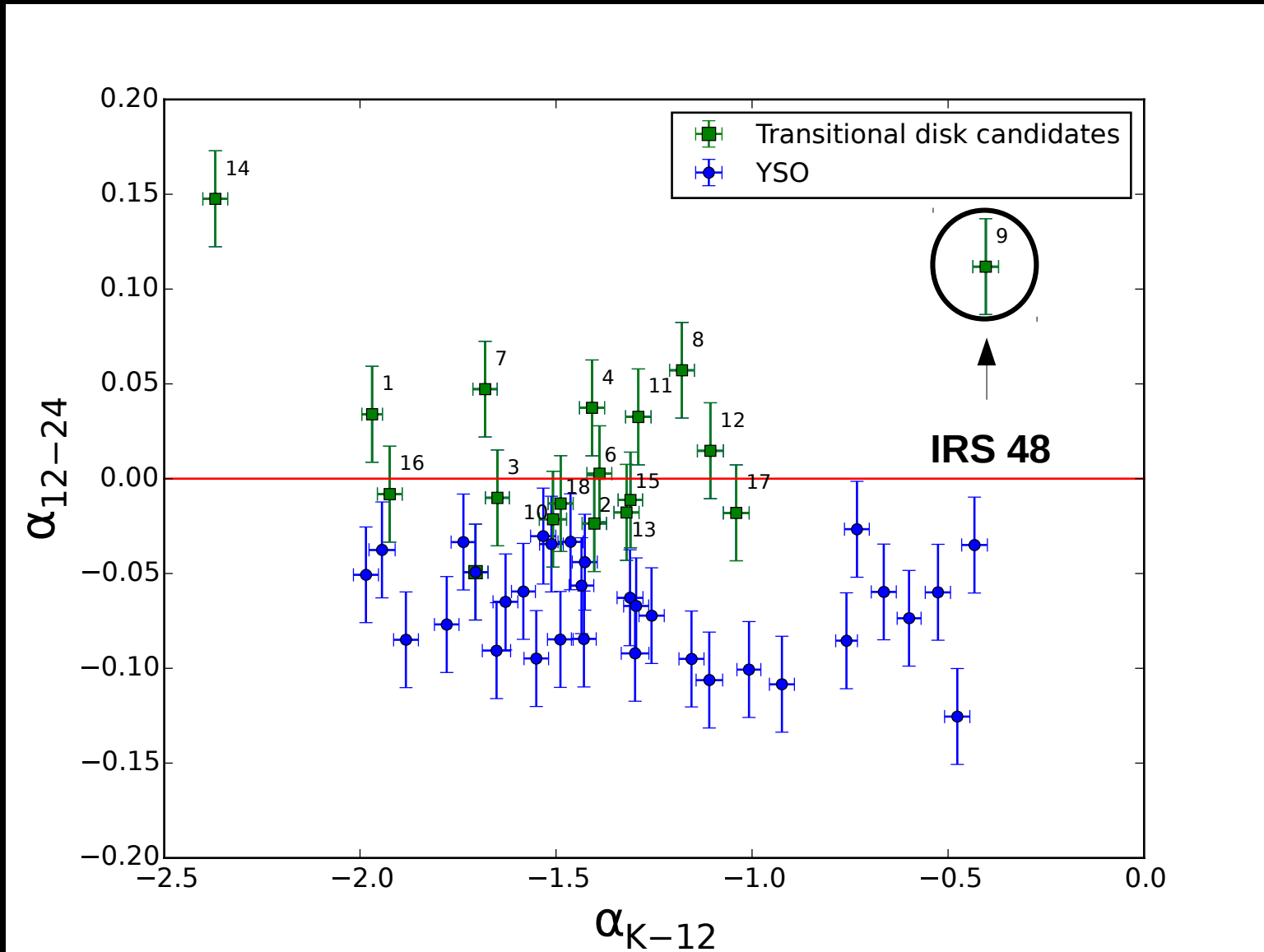




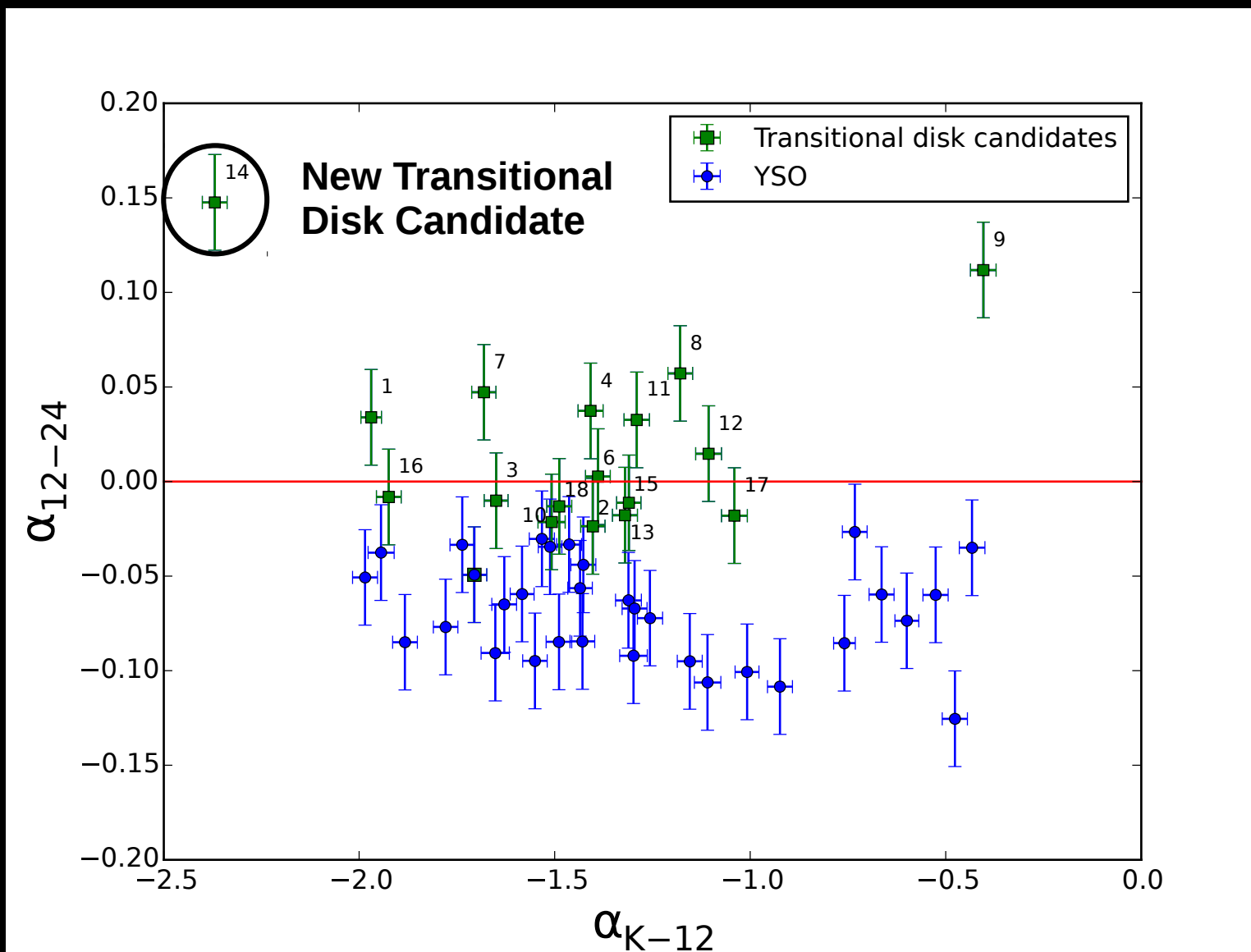
## Additional criterion



# Additional criterion

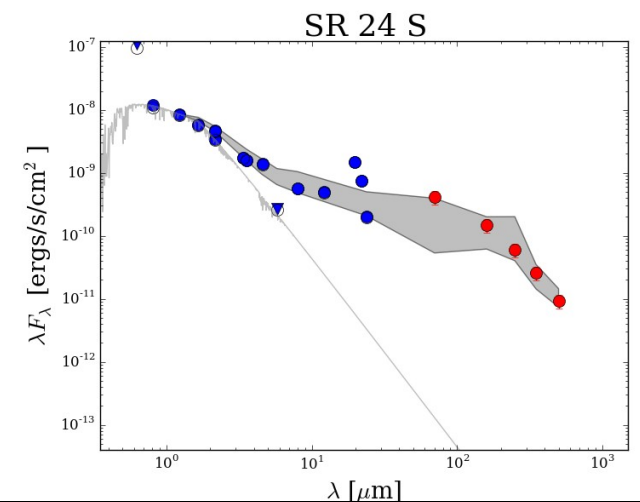
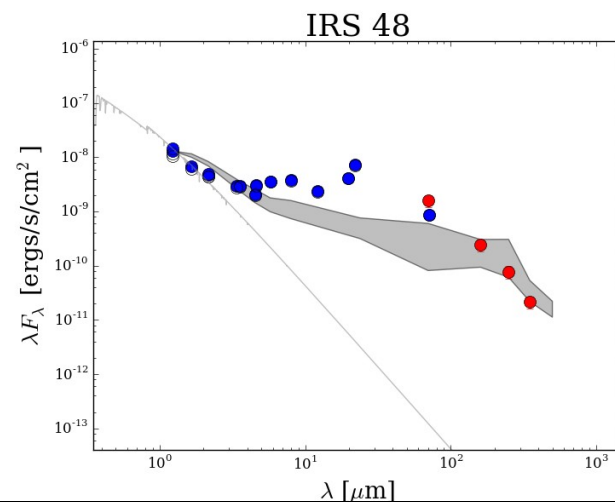
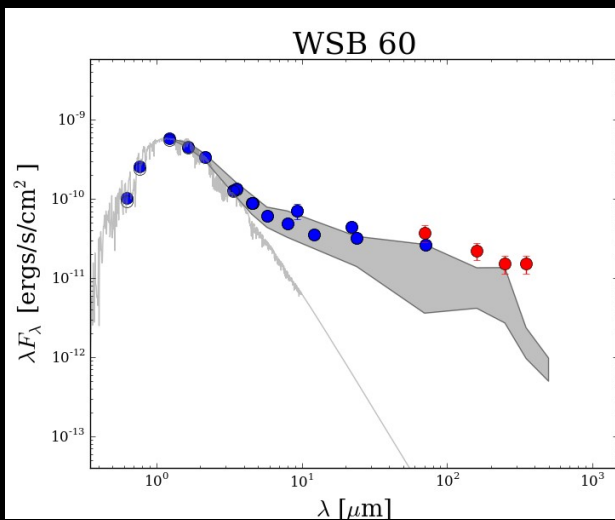
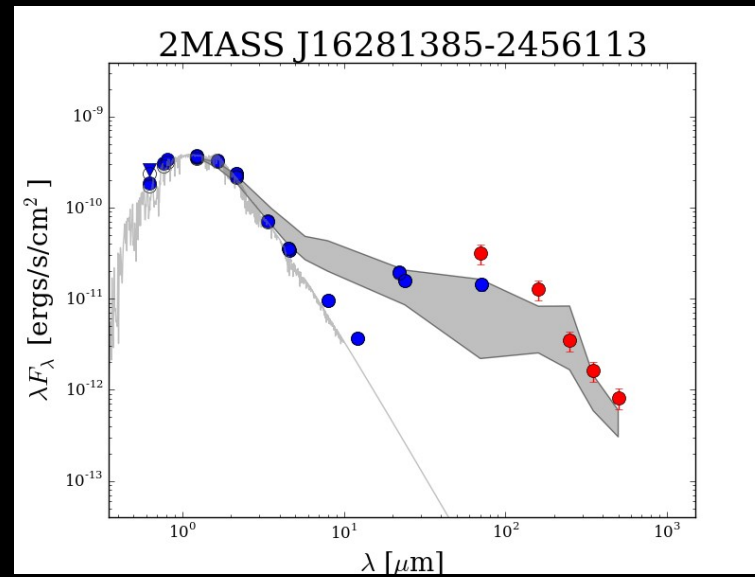


## Additional criterion



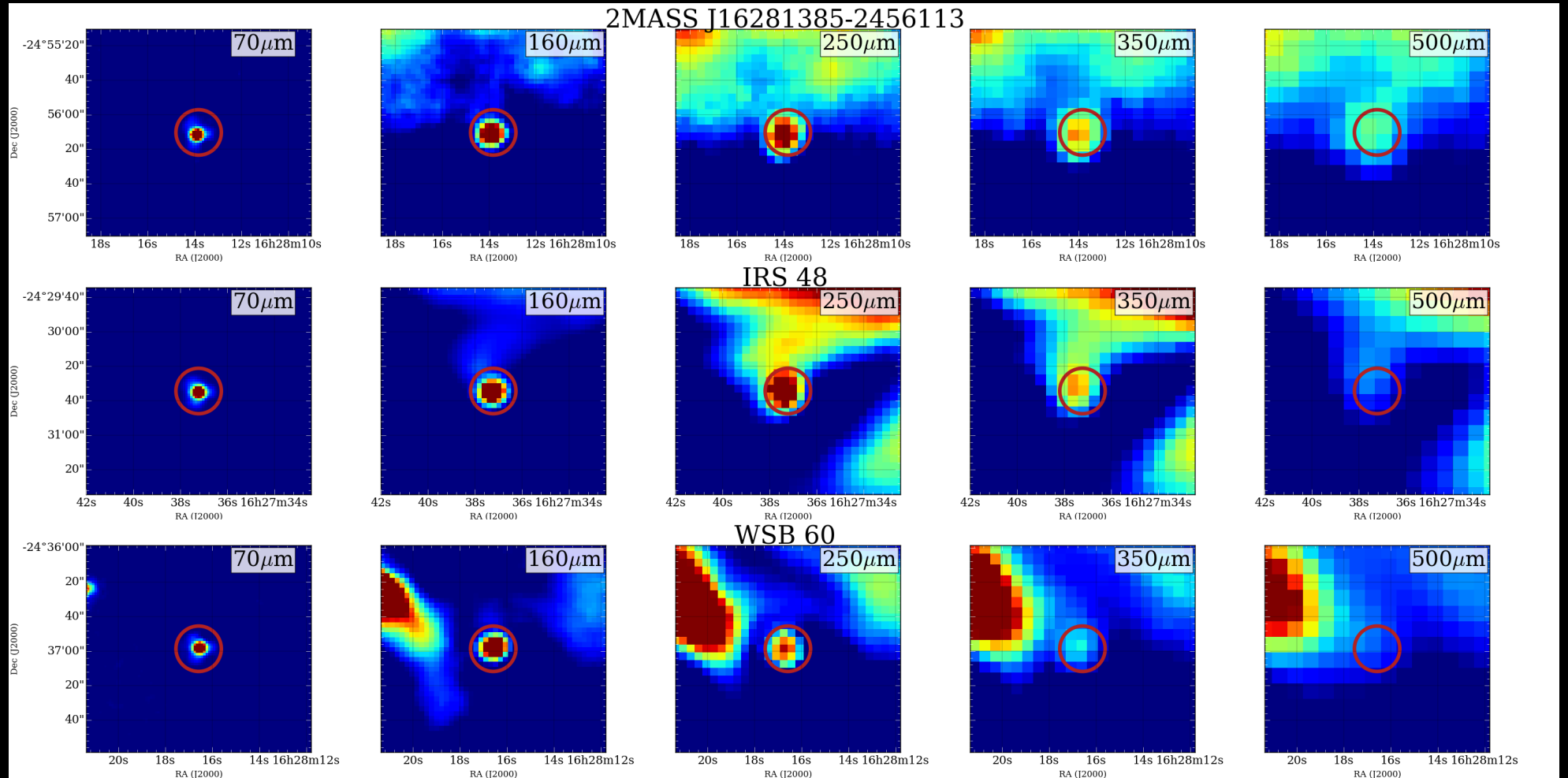
# Analysis Results

## Transitional disks candidates



# Analysis Results

## Transitional disks candidates





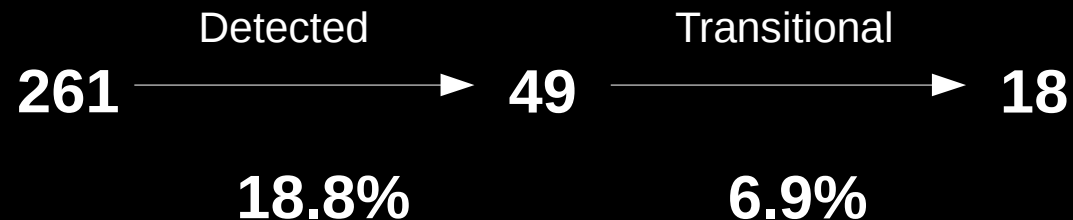
## Analysis Results

I.D.	Name	Id. Criterion
1	Haro1-6	12-70
2	DoAr24	12-24
3	DoAr25	12-70
4	WSB40	12-24
5	SR24S	<b>12-70</b>
6	2MASS J16270659-2441488	12-24
7	WSB46	12-70
8	2MASS J16273084-2424560	12-24
9	IRS48	12-24
10	IRS49	12-24
11	2MASS J16273863-2438391	12-24
12	WSB52	12-24
13	SR9	12-24
14	2MASS J16281385-2456113	12-70
15	WSB60	12-70
16	SR20W	12-70
17	SR13	12-24
18	2MASS J16285694-2431096	12-24

## Analysis Results

Number of detected sources per band				
70 $\mu\text{m}$	160 $\mu\text{m}$	250 $\mu\text{m}$	350 $\mu\text{m}$	500 $\mu\text{m}$
49	25	19	15	8
18.8%	9.7%	7.3%	5.8%	3.1%

From a list of **261 initial YSO's** we detected **49 objects** in at least one Herschel band, and from those, **7 are considered as transitional disks candidates, according to the 12-70 criterion**, and other 11 according to the complementary criterion .

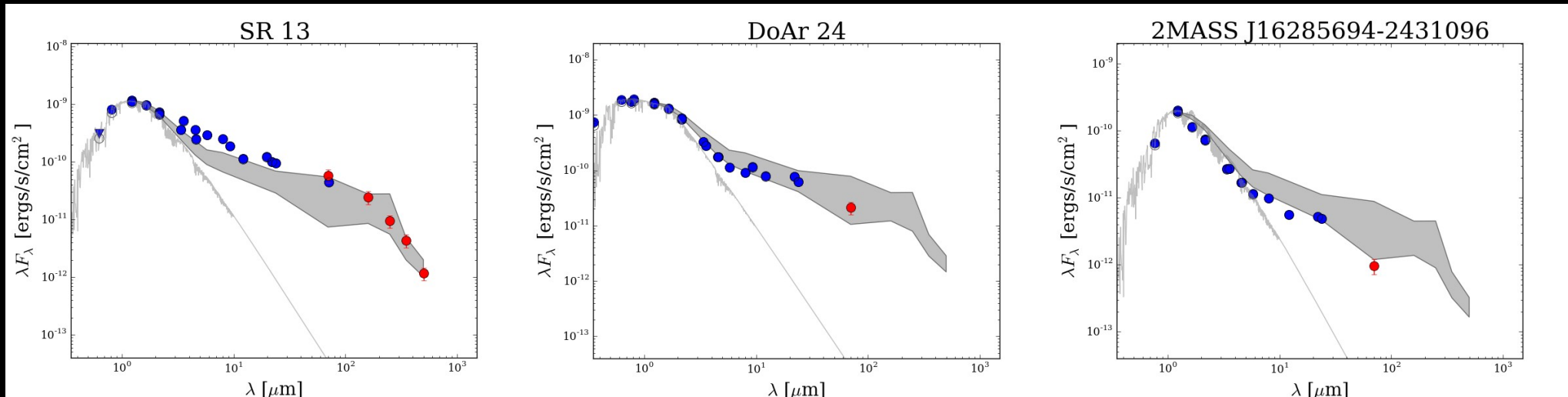


**Fraction of Transitional Disk Candidates**

**37%**

## Analysis Results

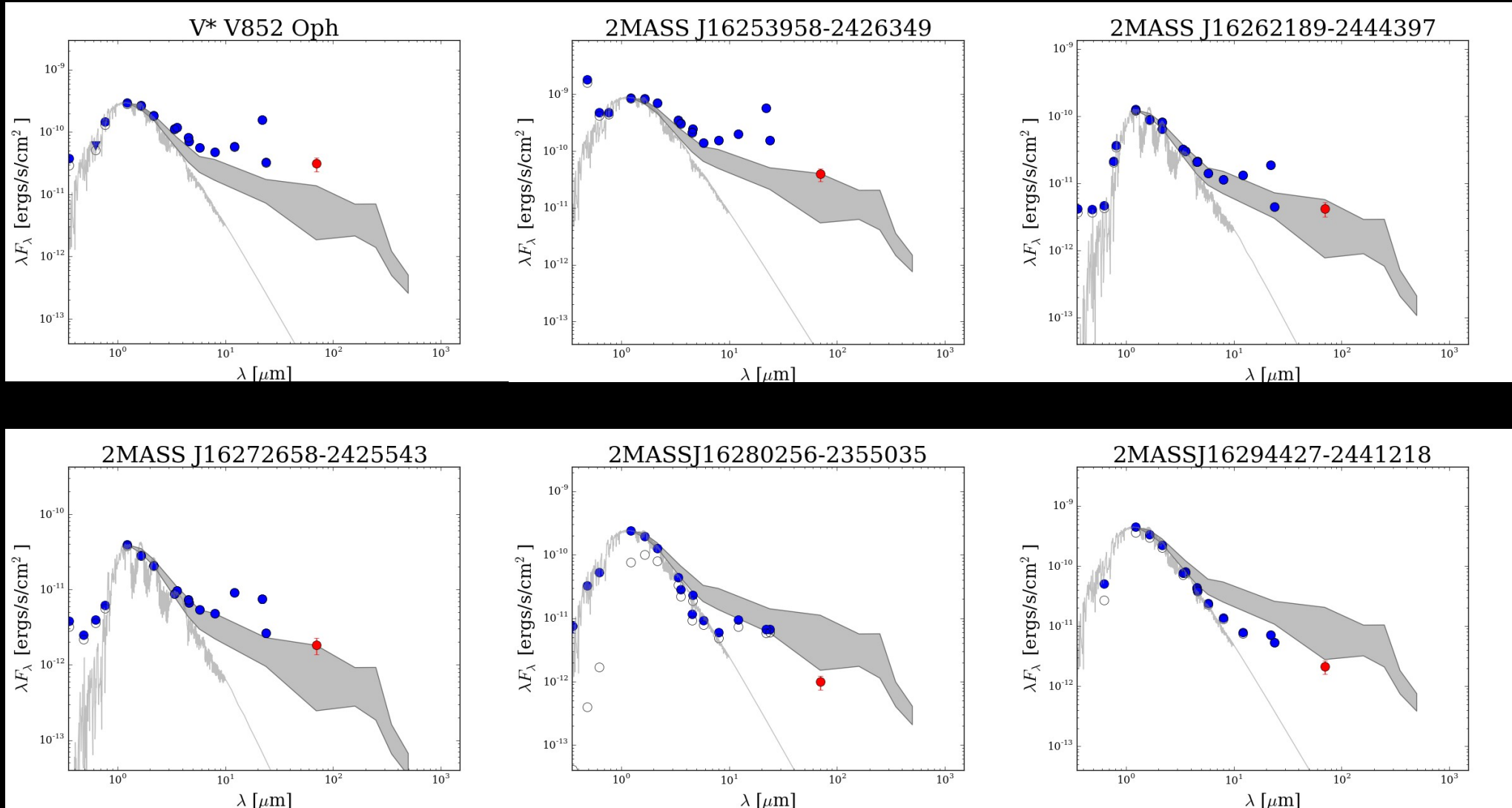
Likely, some of the candidates are not transitional. They show very flat slopes, and fulfil the criterion due to the uncertainties.



The sample requires a deeper study.

# Analysis Results

## Additional interesting objects

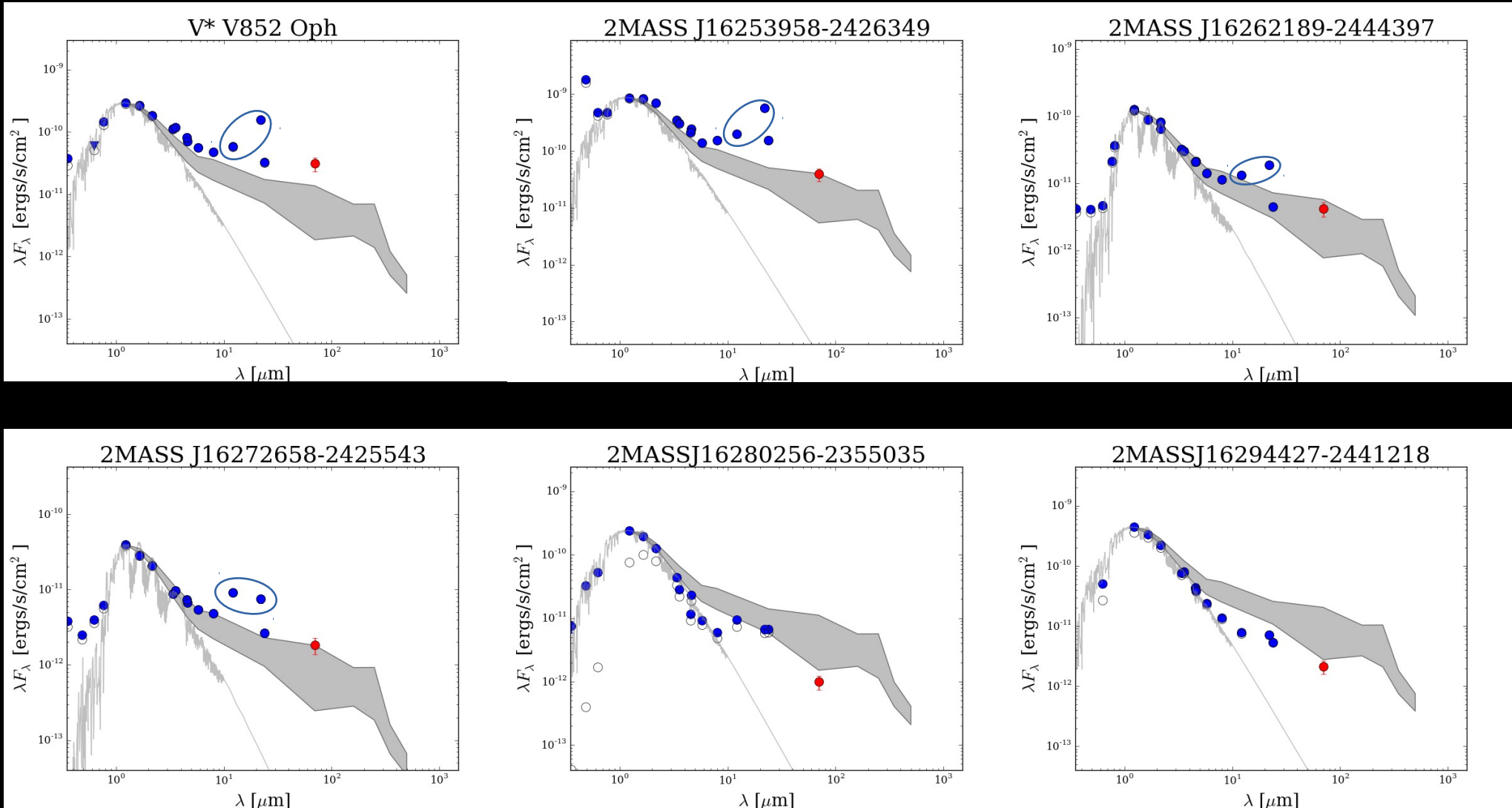




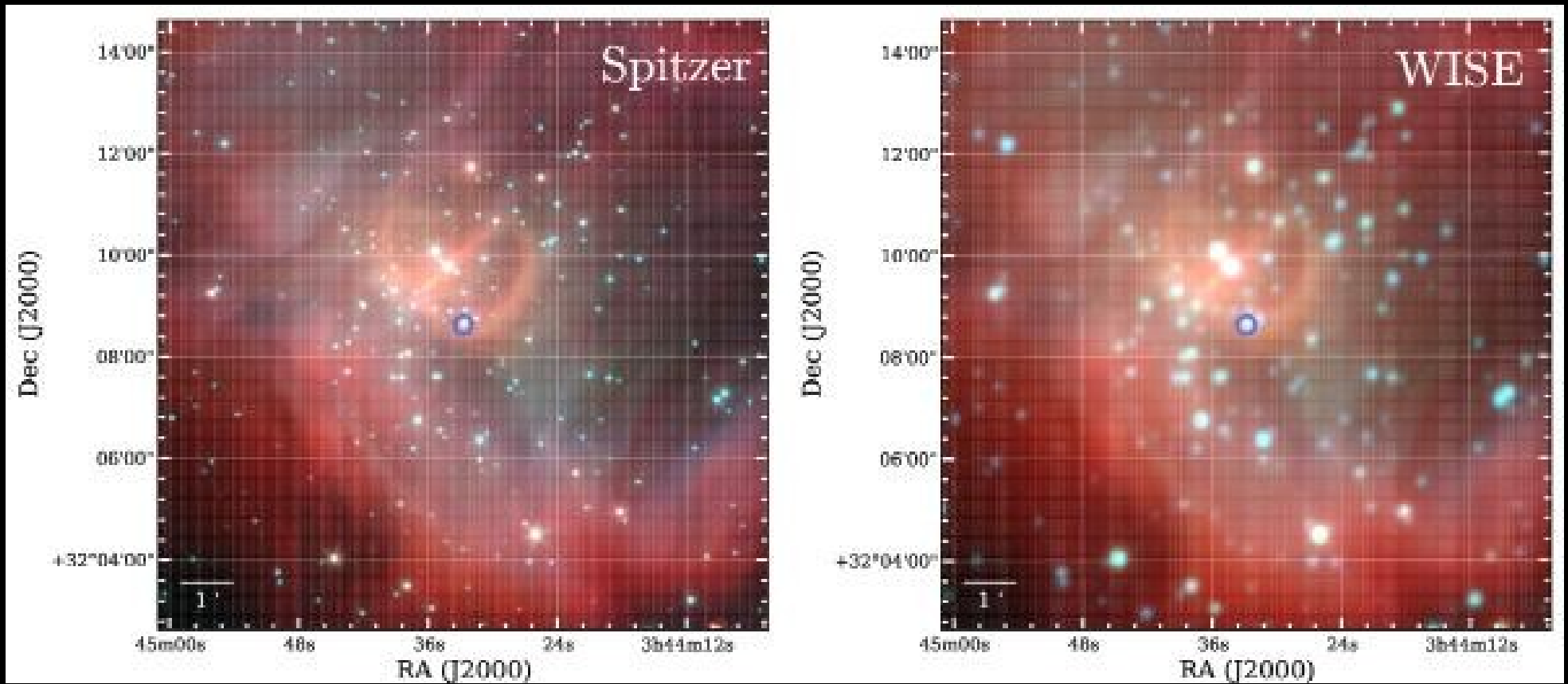
# Analysis Results

Additional interesting objects

WISE points



# Analysis Results



Ribas et al. (2014)

## Summarizing

- We have detected and provided IR fluxes for **49 disks** from an initial list of 261 YSO's in the region of  $\rho$  – Ophiuchi in at least one band with Herschel data.
- 18 of them fulfill the criteria to be considered transitional disks, and 6 more are considered interesting objects for follow up.
- Herschel data has been proven to be very useful to detect new transitional disks candidates.
- We have found an extremely interesting candidate (2MASS J16281385-2456113), new to the literature.