Searching for accretion among low-mass members in the Orion Nebula Cluster

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COMPETE 2020
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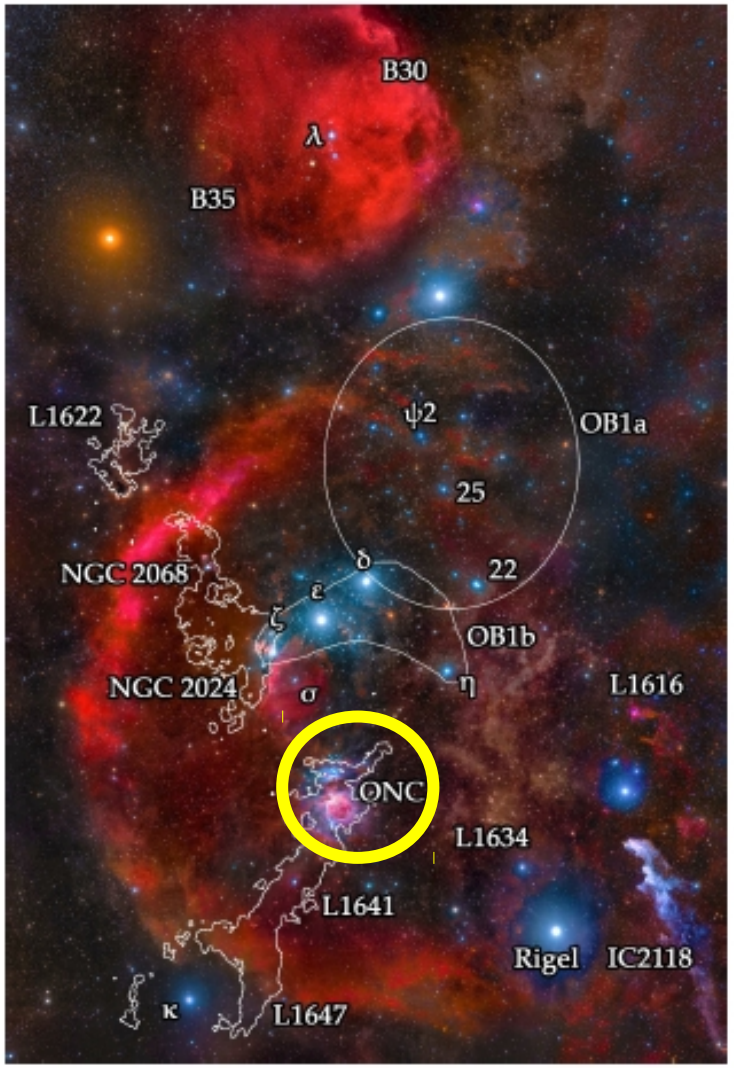
ONC → Orion Nebula Cluster (M42 / NGC 1976)

- One of the nearest and massive star forming clusters
- Radius ~ 3 pc
  Hillenbrand (1997); Hillenbrand+(2013)
- Age ~ 2.2 Myr
  Reggiani+(2011)
- Distance: 388 ± 5 pc
  Kounkel+(2017)



Kounkel+(2018)

Motivation: Is there on-going accretion among low-mass members of the ONC?

- **Previously in Biazzo+(2009):**
  - Characterized 91 low-mass ONC members (FLAMES/GIRAFFE);
  - None of them are accreting according to White & Basri (2003) accretion criterion;
  - **Nevertheless**, few stars show 10%-width larger than the median of the sample plus a slow rotation rate;
  - Stars show Li I (6708Å) in absorption and IR excess;

There is evidence that these stars should have on-going accretion!

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X-shooter proposal
PI: S. Alencar

Were observed 4 of the *possible accretors* from Biazzo+(2009) + JW847 between January and March 2015

- X-shooter spectrograph @ VLT
  Vernet+(2011)
- **UVB** + **VIS** + **NIR**
  300-2500 nm
- Resolution UVB / VIS / NIR
  4000 / 6700 / 3900
- Reduction with
  v2.7.1 X-shooter pipeline + IRAF
  Modigliani+(2010)

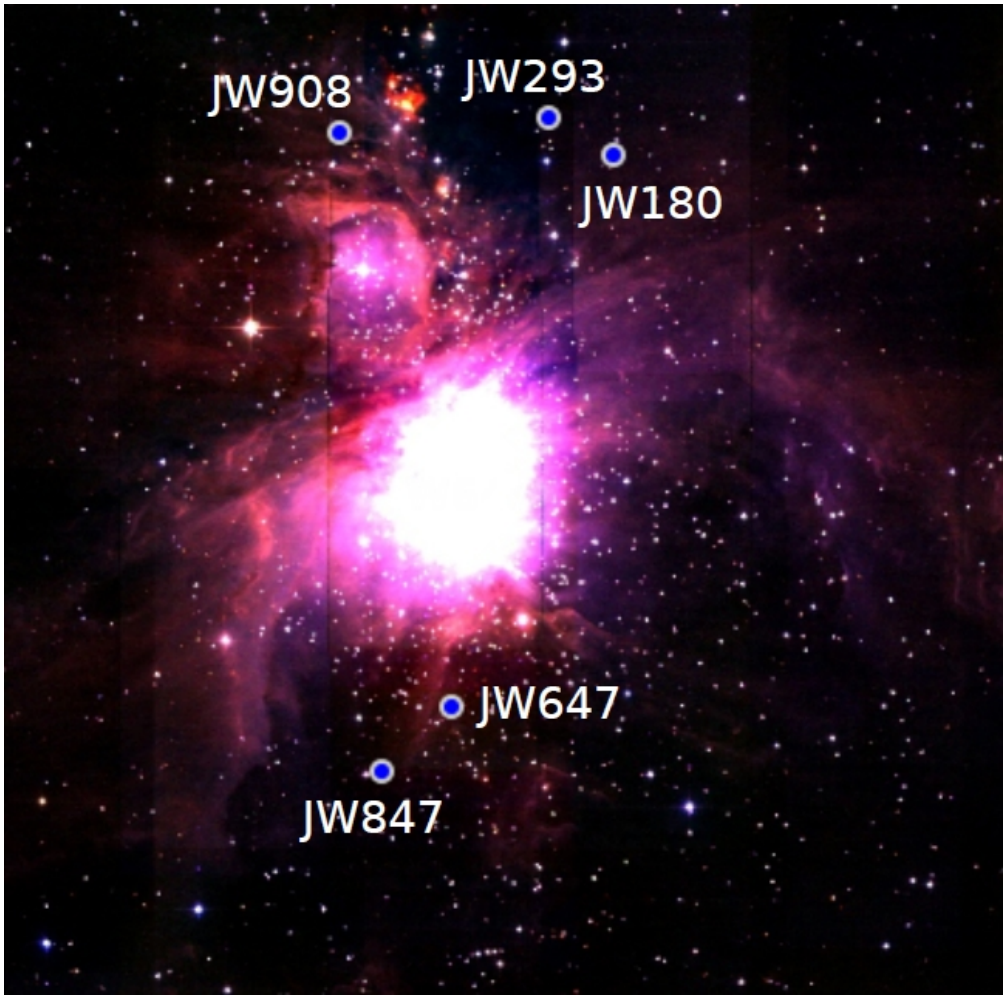

Figure made with Aladin Lite interactive sky maps (Bonnarel+2000; Boch & Fernique 2014)

These ONC members have been characterized in several large surveys

Table 1: Stellar parameters available in the literature for the ONC targets.

JW	2MASS	$d^{(1)}$ (pc)	SpT$^{(2)}$	RV$^{(3)}$ (km s^{-1})	$v \sin i^{(4)}$ (km s^{-1})
180	J05345819-0511536	323	M5	20.0 ± 1.4	44.1 ± 1.0
293	J05350682-0510385	386	M5	27.9 ± 1.7	46.8 ± 3.0
647	J05352029-0530395	412	M5e	26.4 ± 0.3	15.0 ± 0.7
847	J05352983-0532534	386	K3/G8	27.8 ± 0.2	44.5 ± 0.7
908	J05353534-0511114	395	M4.5	29.4 ± 0.6	16.3 ± 0.6

References:
(1) Gaia Collaboration+(2016,2018); Luri+(2018); **(2)** Hillenbrand(1997); **(3)** Cottaar+(2015); **(4)** Da Rio+(2016)

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Reclassified as a M0.5
Hillenbrand+(2013)

We used spectral indices to infer about SpT

- **Spectral type**

  1) Narrow-band spectral indices (ratios of average fluxes)

  - M-type: Riddick+(2007)
  - K and early M-type: Herczeg & Hillenbrand (2014)
  - K5 and later: Jeffries+(2007)

  Average of spectral types

  2) Target spectra vs templates

  Non-accreting class III YSOs
  Manara+(2013,2017)

- **Effective temperature**

  1) M-type: Luhman+(2003)

  2) Earlier type: Kenyon & Hartmann (1995)

  Temperature scales

JW647 and JW847 deviate more from H97 classification

Table 2: Spectral type and $T_{\rm eff}$ derived for the ONC targets.

JW	SpT lit	SpT derived in this work				$T_{\rm eff}$(K)
	H97[1]	RRL07[2]	J07[3]	HH14[4]	Adopted	
180	M5	M5.0	M5.1	M5.0	M5	3125
293	M5	M4.8	M4.8	M4.8	M4.5	3197
647	M5e	M3.2	M0.6	M2.1	M1	3705
847	K3/G8	...	K6.6	K1.2	K6	4205
908	M4.5	M4.5	M4.5	M4.4	M4.5	3197

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Gaia DR2 distances were used to derive L* and R*

- **Luminosity**
  - Stellar flux is integrated for the entire spectrum
  - Flux → Luminosity: $L_* = 4\pi d^2 F_*$

- **Stellar radius**

$$R_* = \left(\frac{F_* d_*^2}{\sigma T_{\rm eff}^4} \right)^{1/2}$$

Table 3: Luminosity and stellar radius derived for the ONC targets.

JW	$\log L_*(L_\odot)$	$R_*(R_\odot)$
180	-0.97	1.12
293	-0.89	1.17
647	-0.35	1.62
847	0.28	2.62
908	-0.86	1.21

We used the evolutionary tracks and isochrones of Siess+(2000) to plot the HR diagram

- This work
- ▲ JW647 after veiling correction (r_{610nm} = 0.5)
- ■ Hillenbrand (1997) rescaled to Gaia DR2 distances

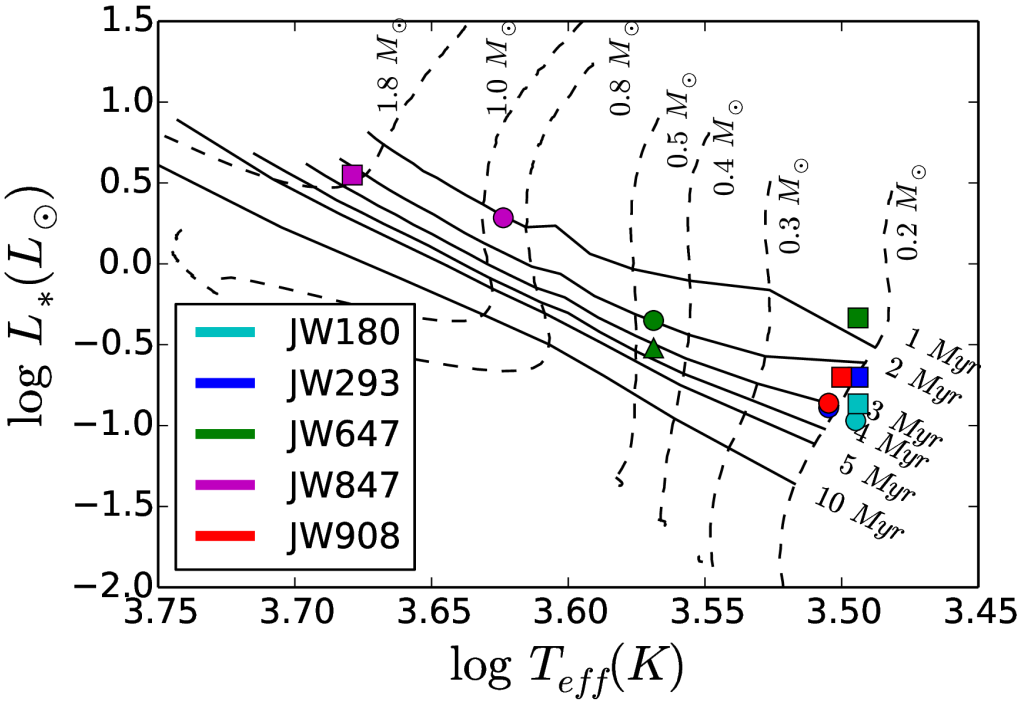
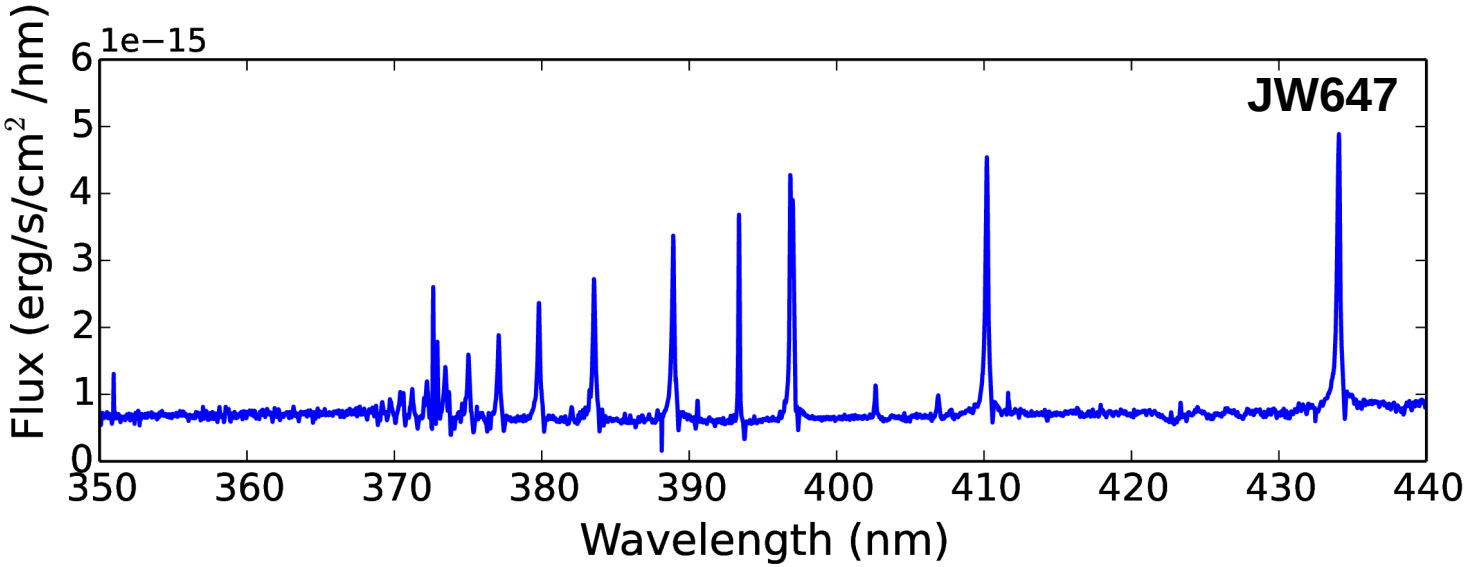


Table 4: Mass and age interpolated with Siess on-line tool for the ONC targets.

JW	$M_*(M_\odot)$	Age (Myr)
180	0.17	3.53
293	0.21	3.14
647	0.47	1.96
847	0.90	1.03
908	0.21	2.99

JW647 shows the strongest Balmer Jump in the sample



- Balmer jump ~370 nm;
- BJ_{obs} = F(360 nm) / F(400 nm)
  Herczeg & Hillenbrand (2008)
- Accretor if BJ_{obs} > 0.5 for any mid-M-type dwarf

Table 5: Observed Balmer jump measurements.

JW	SpT (This work)	BJ_{obs}
180	M5	0.53
293	M4.5	0.46
647	M1	1.08
847	K6	0.61
908	M4.5	0.50

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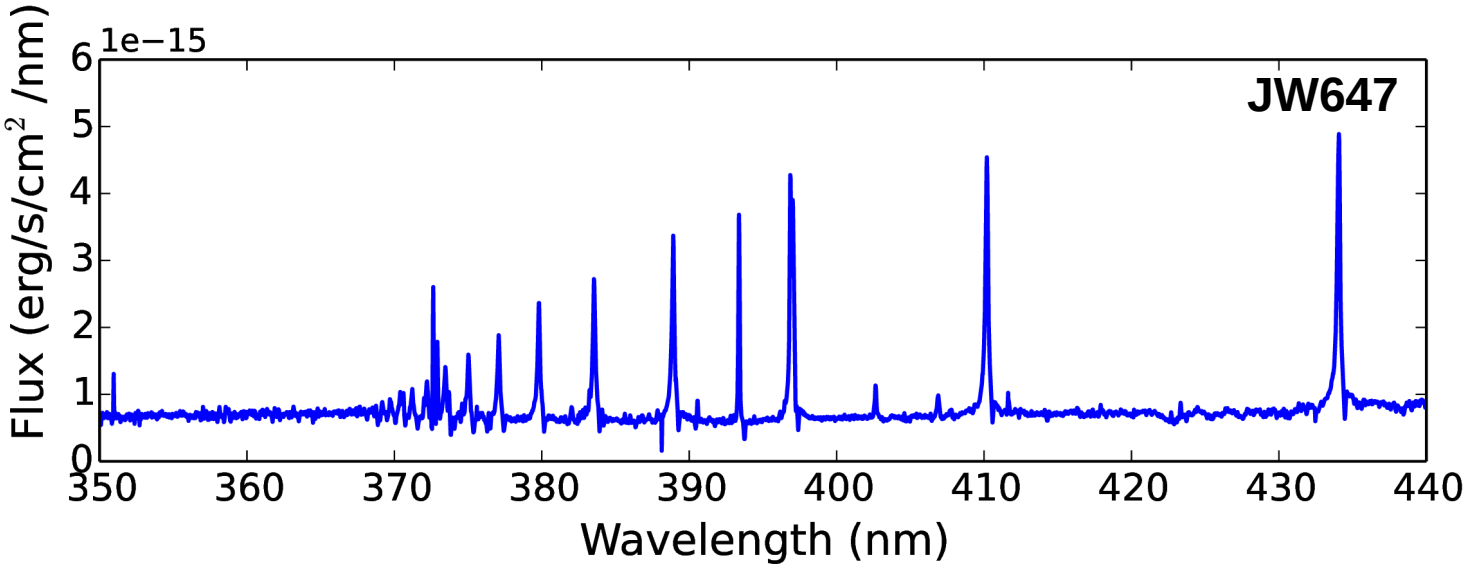

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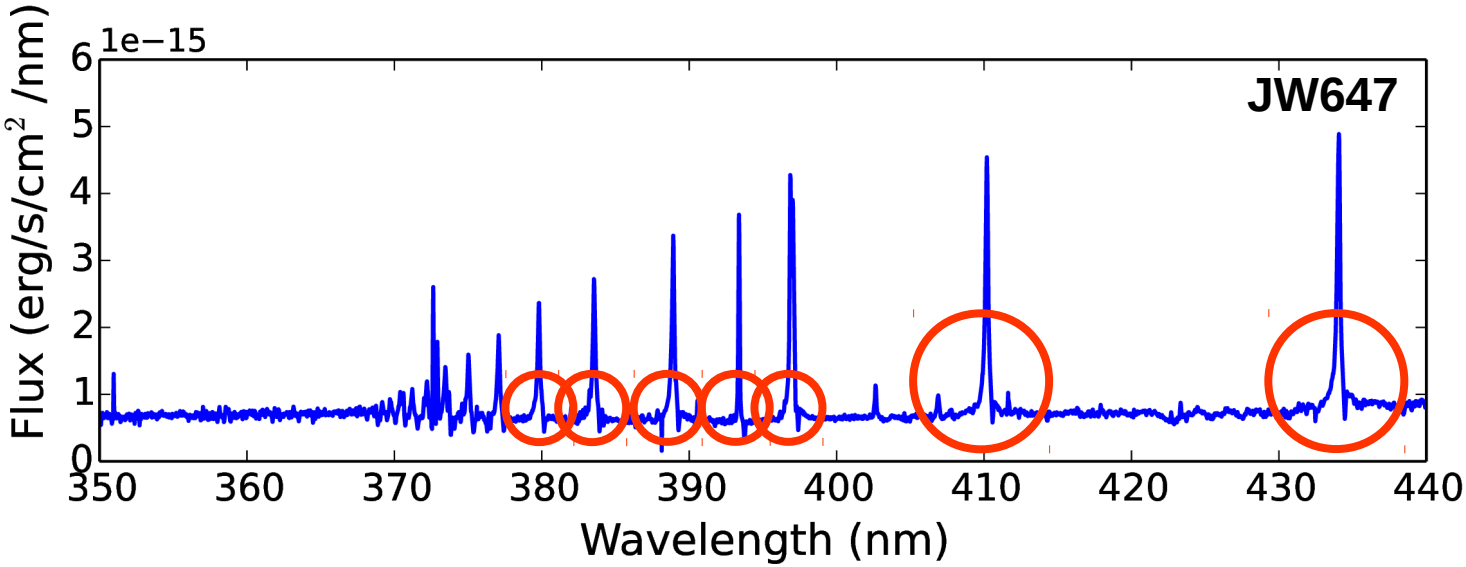

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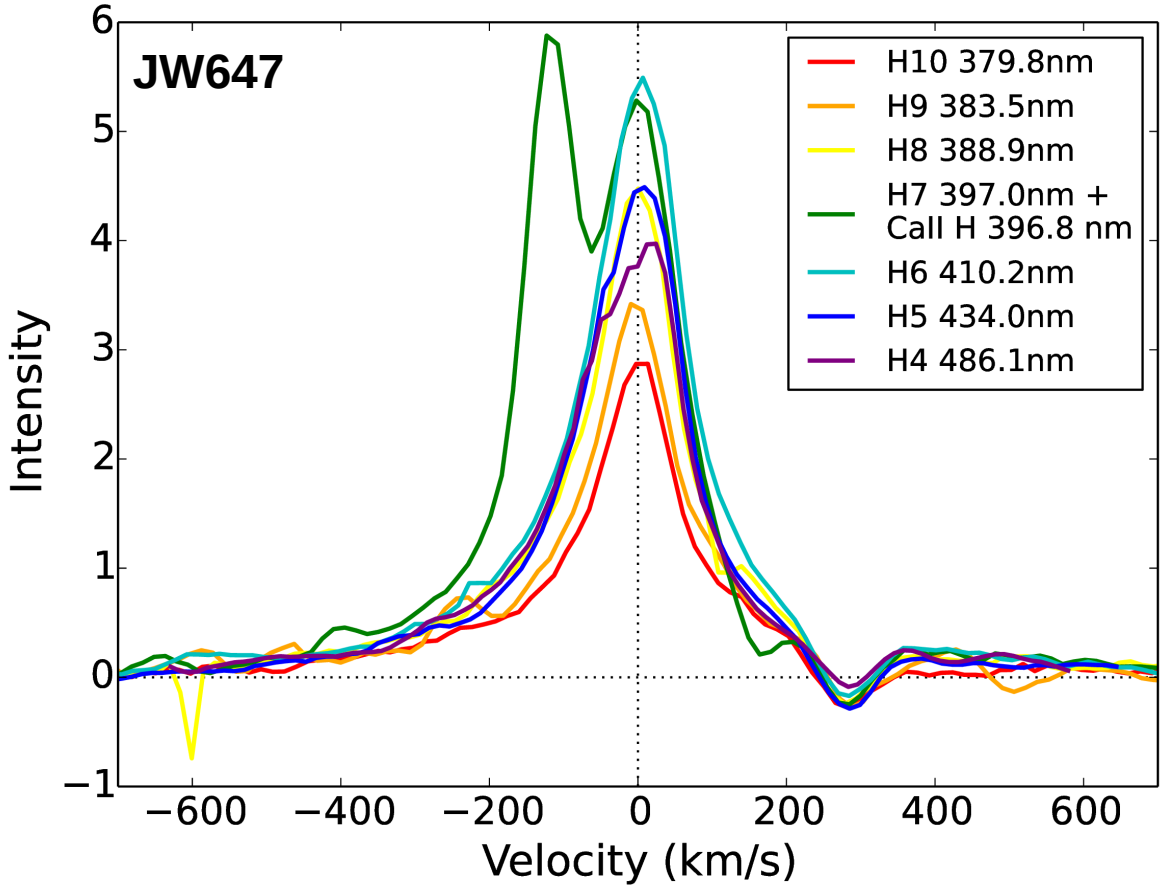
Several Balmer lines show Inverse P Cygni (IPC) profiles for JW647

- H7 or Hε (397.0 nm) is partially blended with Ca II H (396.8 nm);
- The redshifted absorption extends until few hundreds of km/s;
- The IPC overlaps in all the Balmer lines presented.

JW647 should be accreting!



M_{acc} was quantified through line flux measurements

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$$f_{line} \rightarrow L_{\rm line} = 4\pi d^2 f_{\rm line}$$

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$$f_{line} \rightarrow L_{\rm line} \rightarrow \log(L_{\rm acc}/L) = a \log(L_{\rm line}/L) + b$$

Alcalá+ (2014)

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$$f_{line} \rightarrow L_{\rm line} \rightarrow L_{\rm acc} \rightarrow \dot{M}_{\rm acc} = \left(1 - \frac{R_*}{R_{\rm in}}\right)^{-1} \frac{L_{\rm acc} R_*}{G M_*} \approx 1.25 \frac{L_{\rm acc} R*}{G M_*}$$

Gullbring+ (1998)

$$\downarrow$$

$$R_{\rm in} = 5 R_*$$

M_{acc} was quantified through line flux measurements

- We found several accretion tracers for:
  - **JW180** (-10.1)
  - **JW293** (-10.0)
  - **JW647** (-8.5)
  - **JW908** (-9.8)

  } $\log \dot{M}_{\rm acc}\,(M_{\odot} yr^{-1})$

- **JW847** has only few accretion tracers in emission.

Line	λ (nm)
H10	379.8
H9	383.5
H8	388.9
Ca II (K)	393.4
Ca II (H)	396.8
H7 (Hϵ)	397.0
He I	402.6
H6 (Hδ)	410.2
H5 (Hγ)	434.0
He I	447.1
H4 (Hβ)	486.1
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Br7 (Brγ)	2166.1

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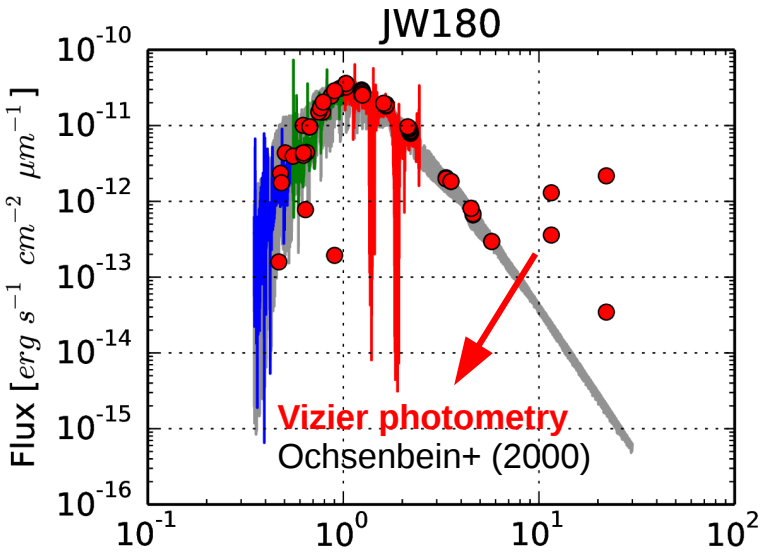
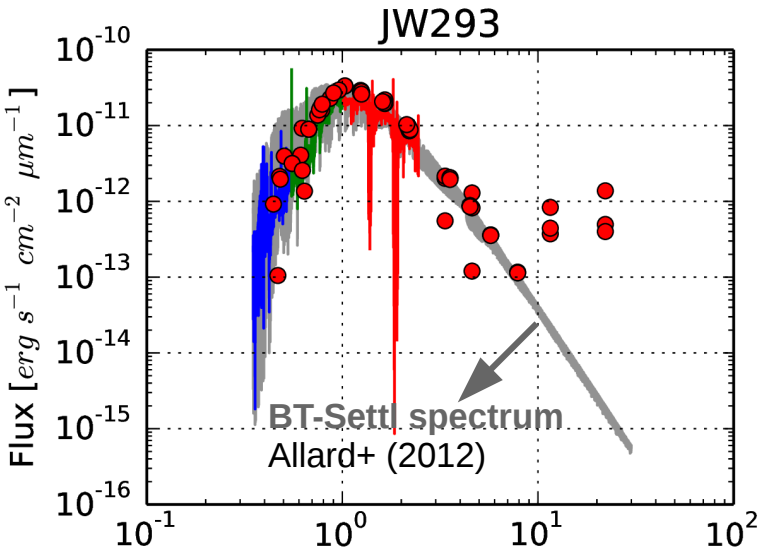
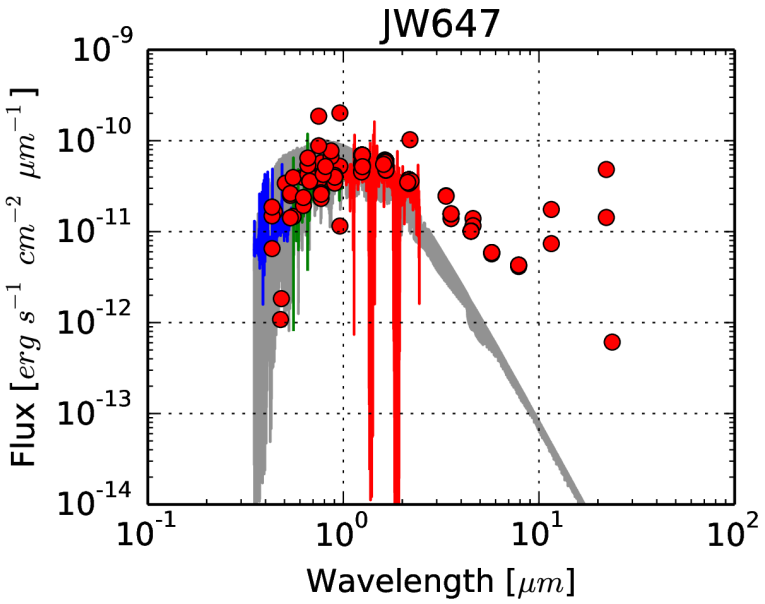
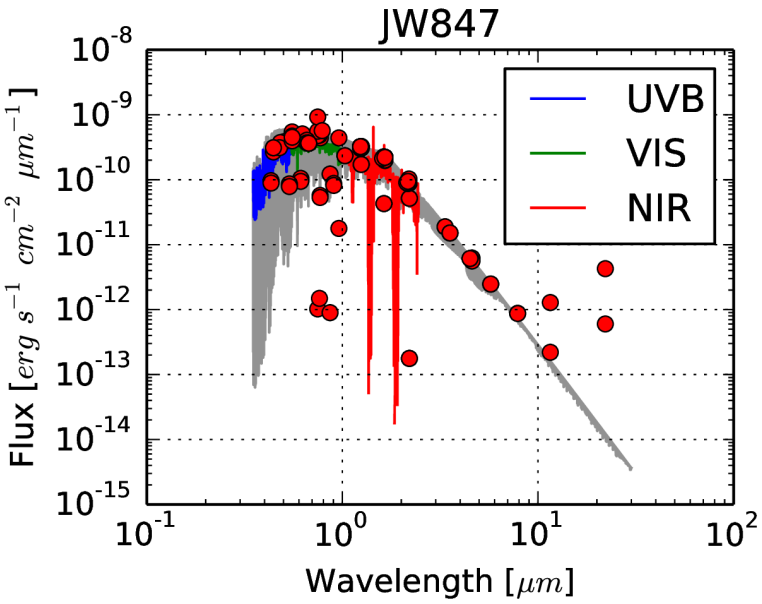
IR excess → Circumstellar disk









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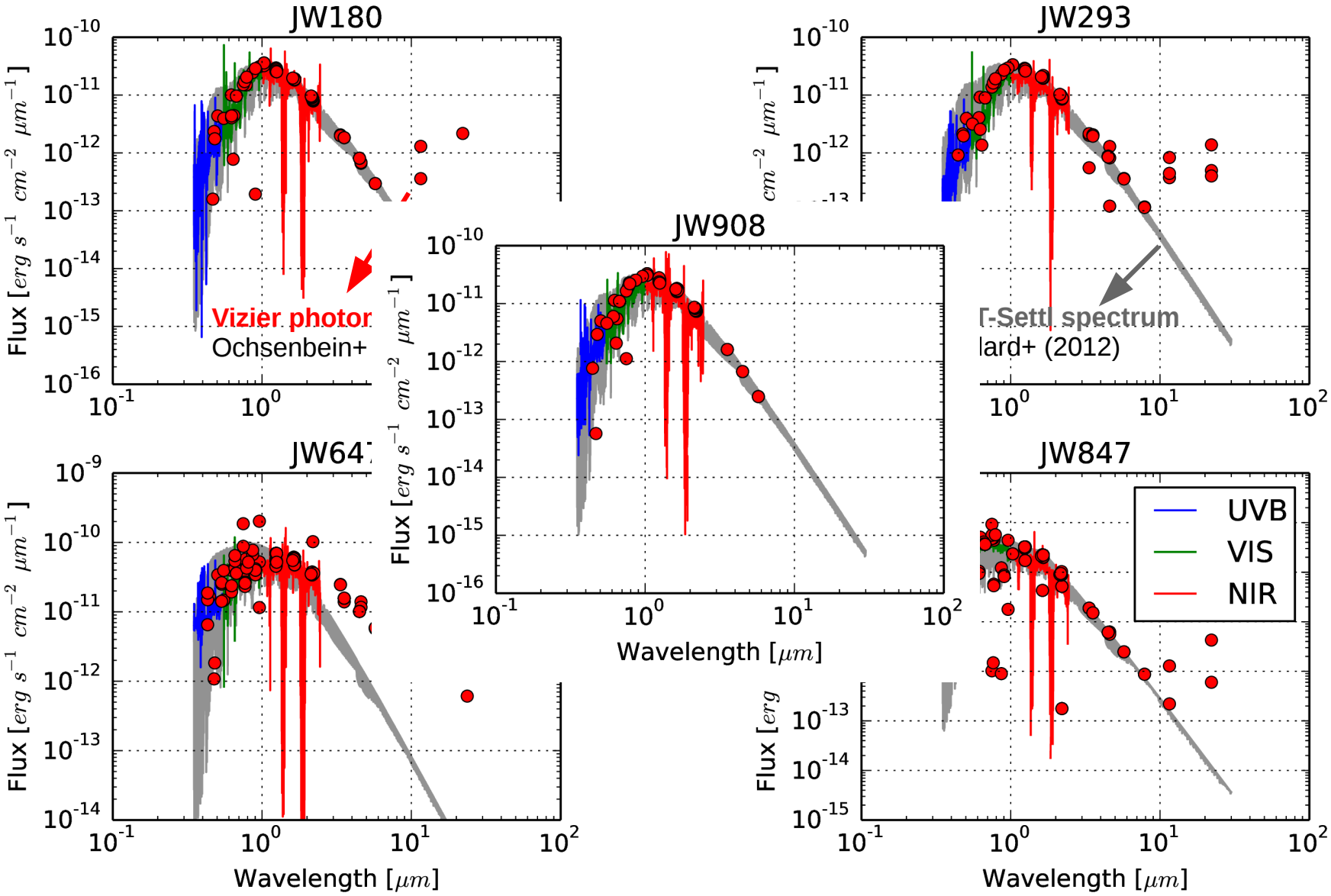
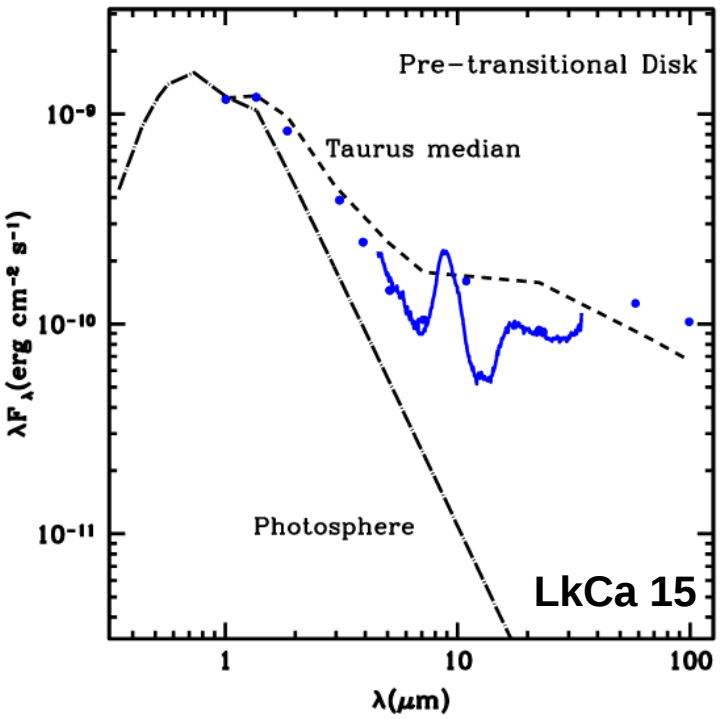
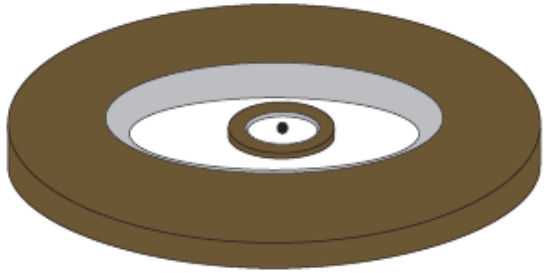


We suspect that we have transitional and pre-transitional disks in our sample

- **Pre-transitional disk:**
  Has a gap that separates an inner dust ring from an outer one. Shows significant NIR (1-5 μm) and MIR (5-20 μm) excess.

Espaillat+(2014)





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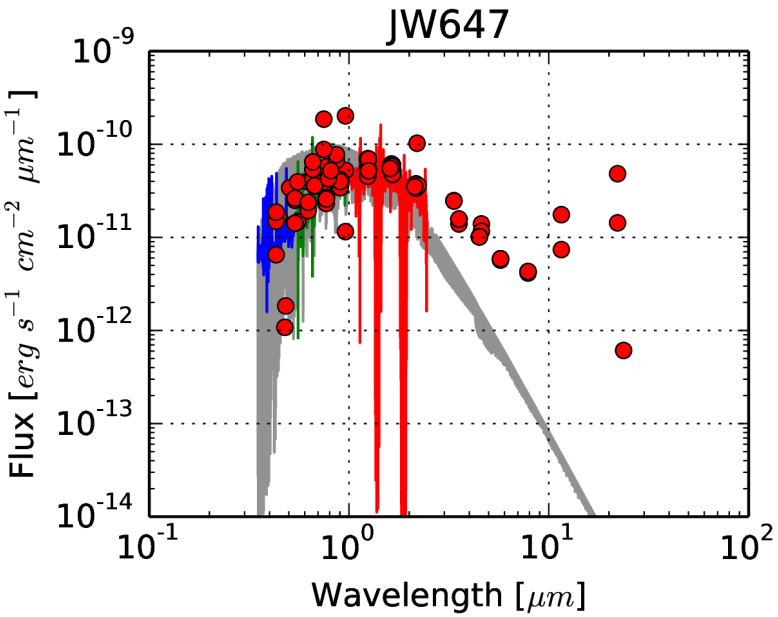

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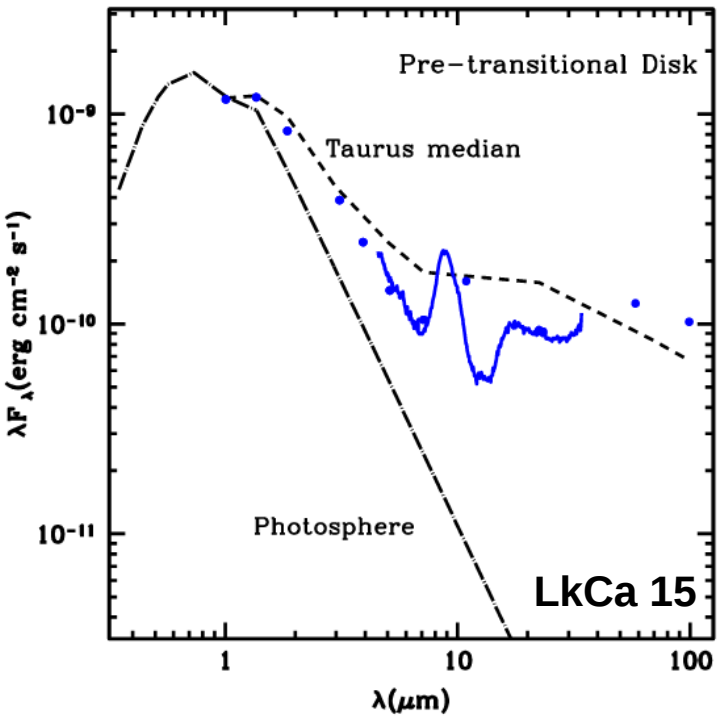

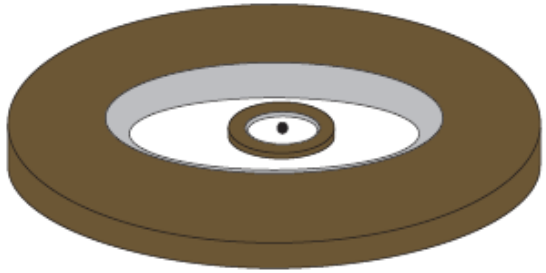

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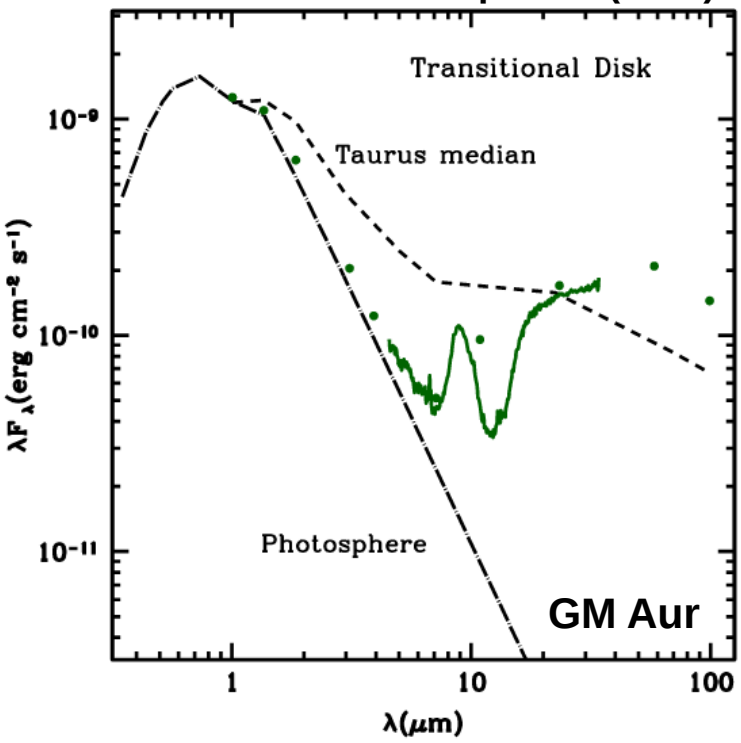
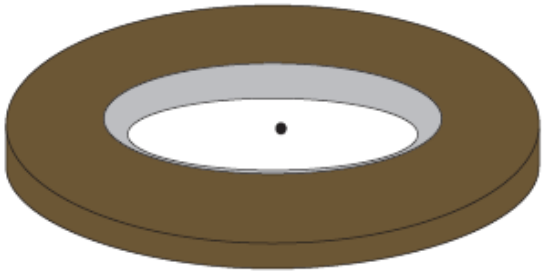
- **Transitional disk:**
  Has an inner disk hole. Shows small NIR excess and strong MIR excess.

Espaillat+(2014)





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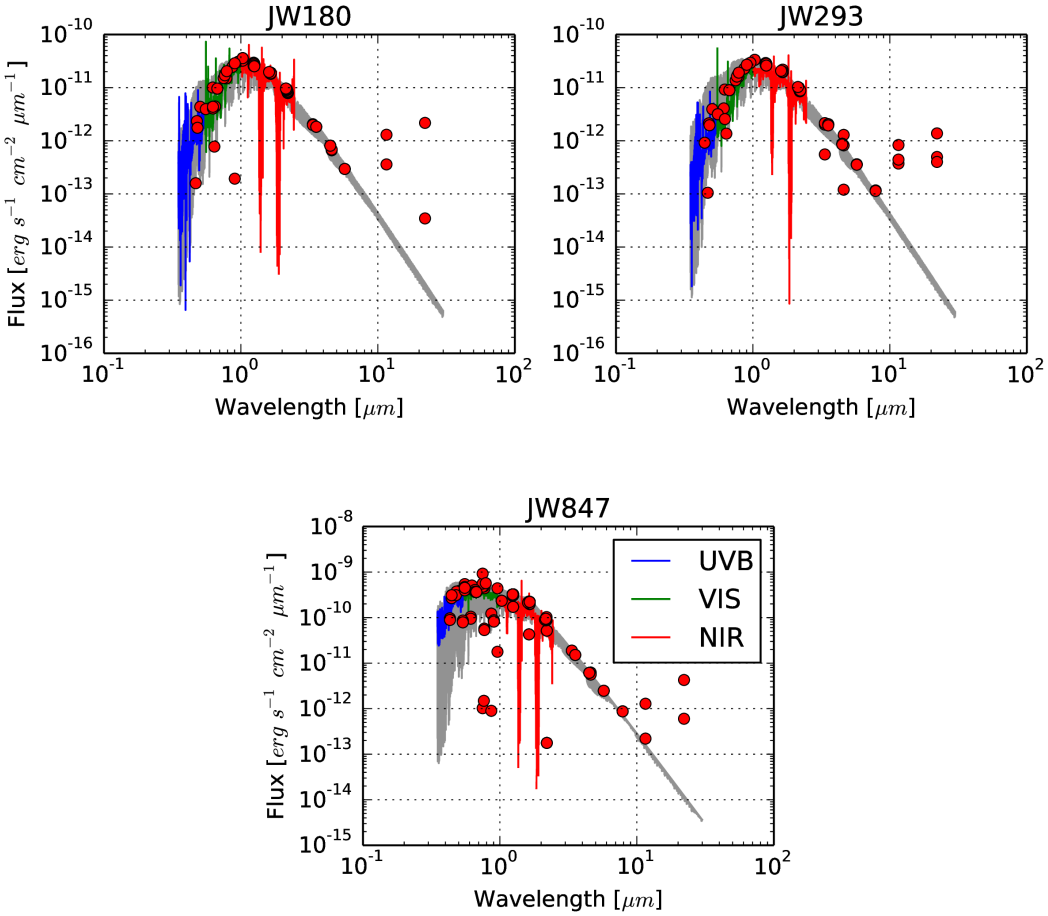

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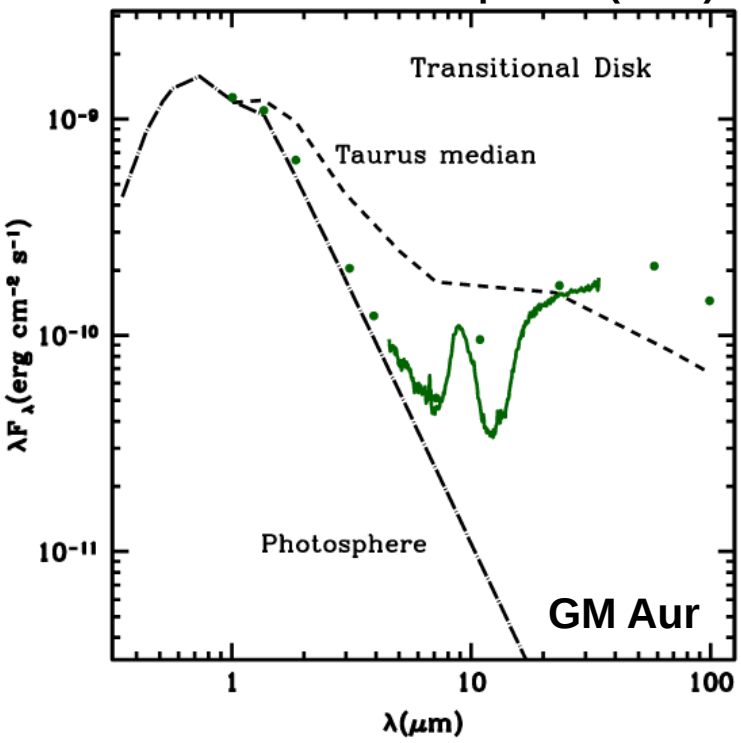

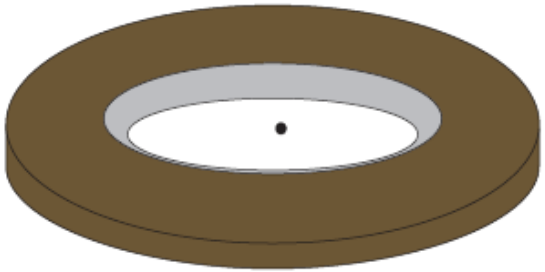

Transitional Disk

Conclusions

- **JW847 has no significant accretion tracers** in emission;
- **JW647 has clearly on-going accretion** supported by:
  - IPC profiles among Balmer emission lines
  - Typical accretion rate for a CTTS: $\dot{M}_{\rm acc} = 10^{-8.5}\, M_{\odot}/yr^{-1}$
- **JW180, JW293 and JW847:**
  Small NIR + strong MIR excesses → **transitional disks**;
- **JW647:**
  Significant NIR + MIR excesses → **pre-transitional disk**;
- **JW908** shows no NIR excess, but we do not have MIR photometry. Has accretion tracers in emission.

Thank you!

Questions?

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