IMPLICATIONS FROM THE CENSUS OF NEIGHBORING REGIONS

IN SITU DUST FORMATION IN B[E] STARS

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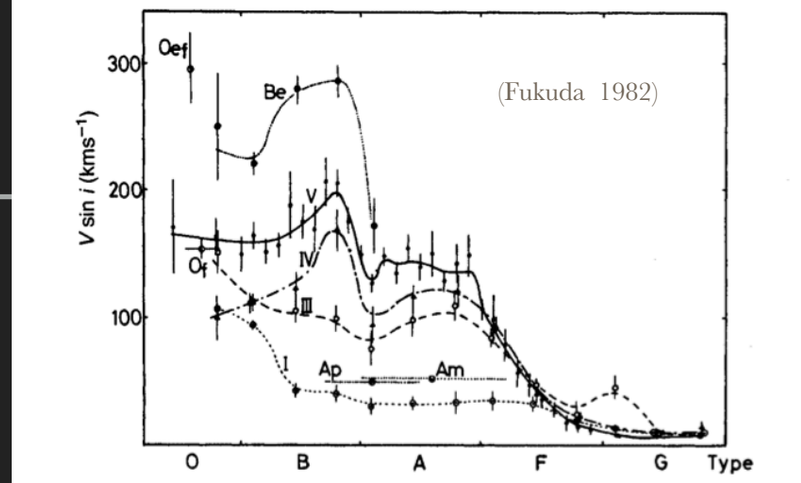
OUTLINES

- B[e]-type stars
- Selection of dusty Be stars
- Featureless cold dust emission
- Neighboring Census
- Near-IR excess and Balmer line emission
- Dust formation scenario & model of B[e] stars

B[E]-TYPE STARS



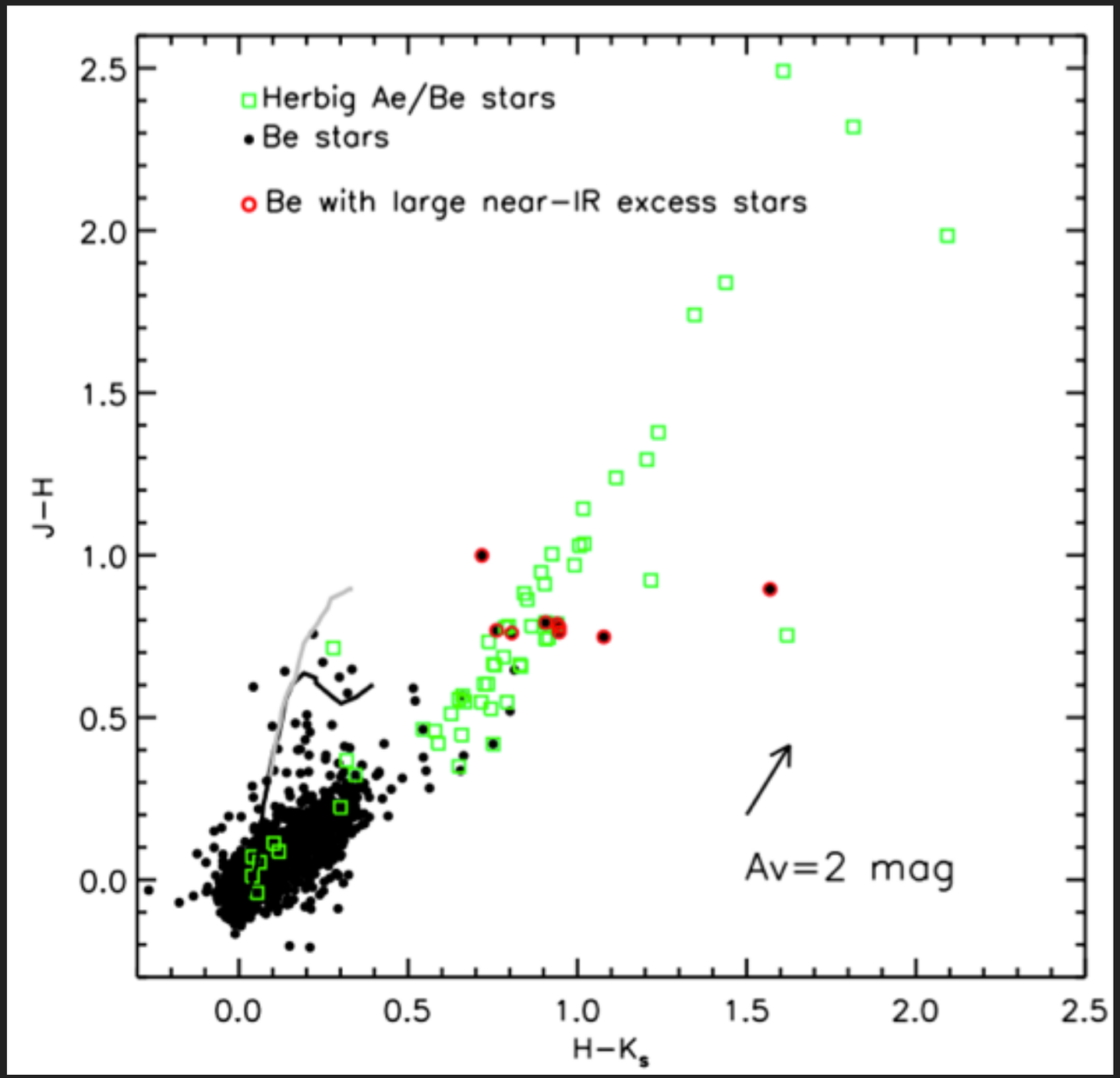
(Fukuda 1982)

Figure 2.18: Average rotational velocities of stars ⟨$V \sin i$⟩. Stars are designated by ● Main sequence stars (V), ▲ Subdwarfs (VI), ○ Giants (III), ◎ Supergiants (I) ⊕ Be stars, ◐ Of stars, ◑ Oef stars, ◒ Am stars, and ◓ Ap stars. (From Fukuda 1982)

- B-type star: rapidest rotators
  - Also aging rapidly from pre-MS (0 - 10 Myr), MS (10 - 1000 Myr) to post-MS phase, with the widely ranged stellar parameters
    - M ~ 2 - 20 $M_\odot$, T ~10000 - 30000 K, R ~ 2 - 5 $R_\odot$, L ~ 4×10^4 - 1×10^2 $L_\odot$
- B[e]-type stars = hot stars with forbidden emitters
  - Enigmatic features: Strong IR excess & strong Hα emission
  - Heterogeneous phase: from pre-MS to PN and binary
  - Unclassified B[e] stars or FS CMa stars (binary origin):
    - Lack of cold dust and isolated form SFR

DUSTY TARGETS SELECTION

- A very robust existence of circumstellar dust –> H–K > 0.7 mag (Allen 1973).
- Gas free-free emission is not responsible for this extent



SELECTED STARS

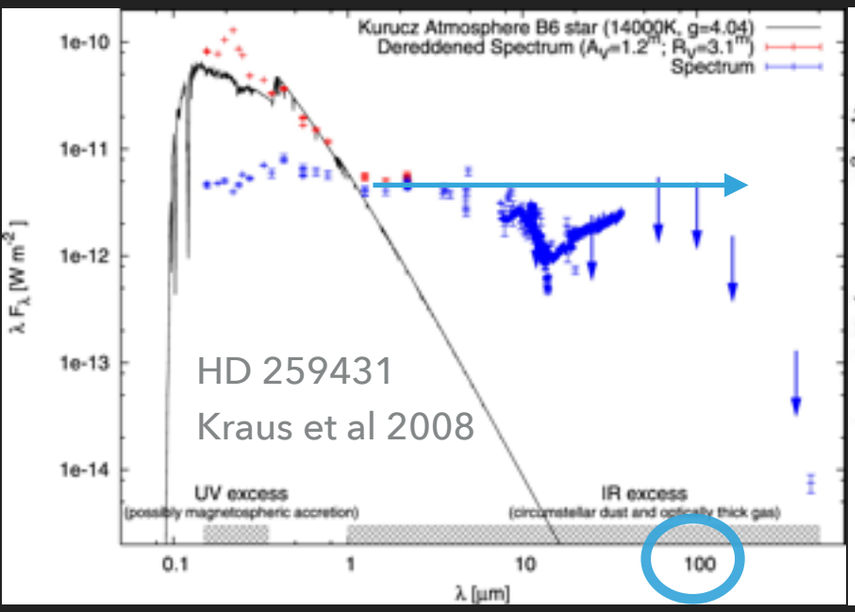
- *HD 45677, HD 50138, CD-24 5721 and CD-49 3441, MWC 623, HD 85567, HD 98922, HD 259431* and HD 181615.
  - All show forbidden line(s)
- Most of these them were not only considered as FS CMa stars (Miroshnichenko 2007).
- But also in the list of Herbig star (Thé et al. 1994).
- Binarity
  - With known Spectral types: MWC 623 and HD 181615
  - Spectro-astrometric binary: HD 45677, HD 50138, HD 85567, HD 98922, HD 259431

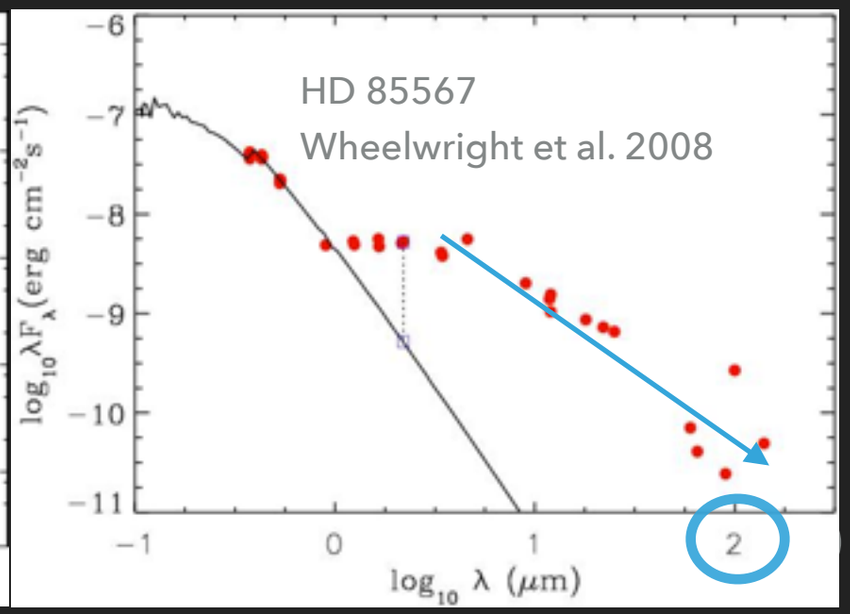
POSSIBLE INDICATIONS OF AGE

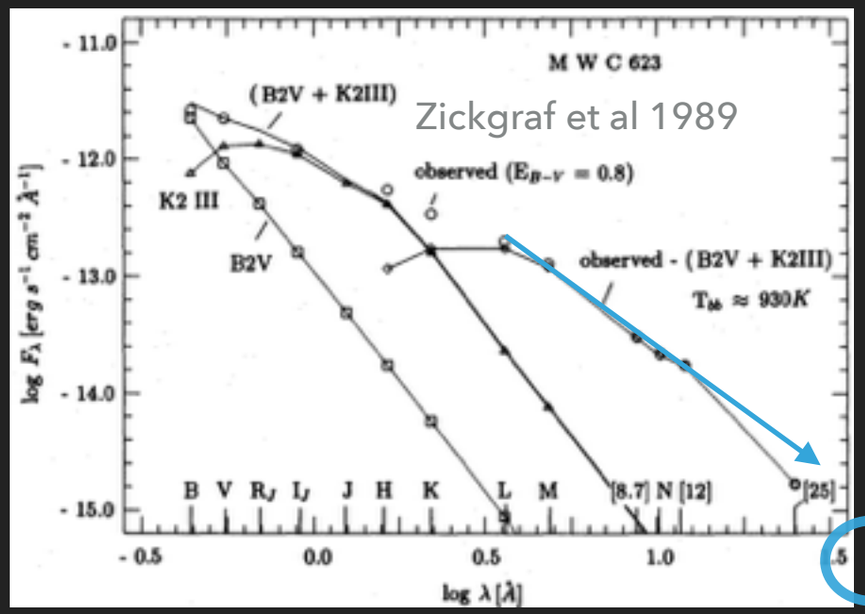
- Open clusters, de la Fuente et al. (2015)
  - FS CMa candidates found Young clusters (Mercer 20, 70).
- ^{13}CO emission in K-band spectra (Kraus 2009) –> Evolved stars
  - Heavy elements from stellar interior –> the surface
  - Mass loss –> Disk region –> condense to molecules.
  - FS CMa stars found with ^{13}CO emission.
    - MWC 137, HD 327083 and GG Car, Hen 3-298
- Our targets: None of our targets have these indications
  - –> Neighbor Census is necessarily (1) cold dust (2) nearby SFRs

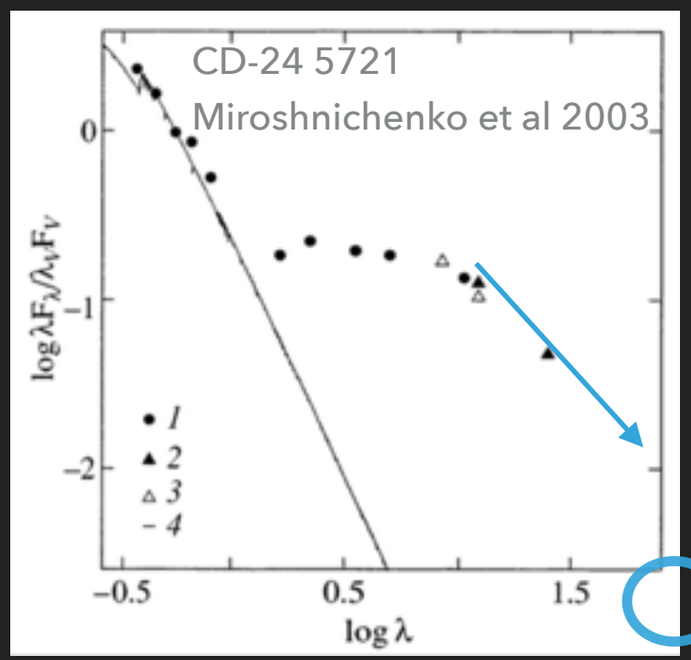
COLD FEATURELESS DUST EMISSION

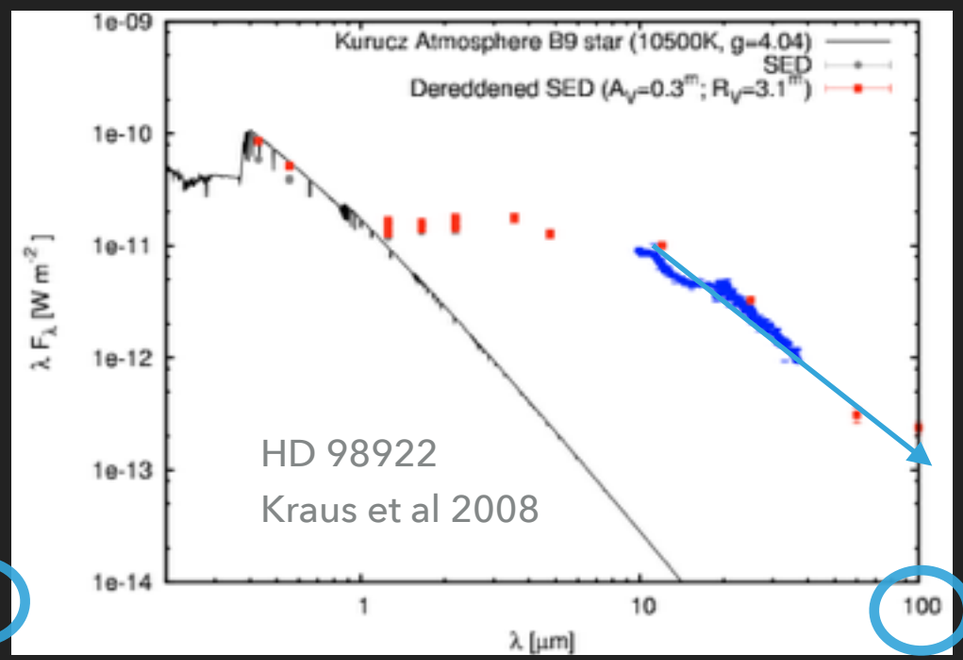
- Except HD 259431, a steep decrease in mid- and far-IR flux

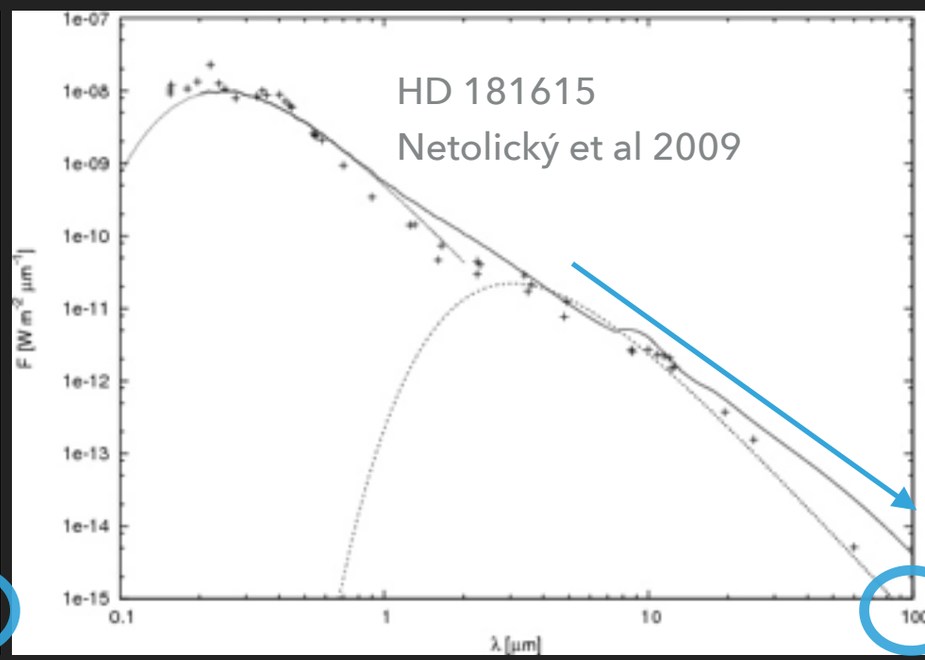






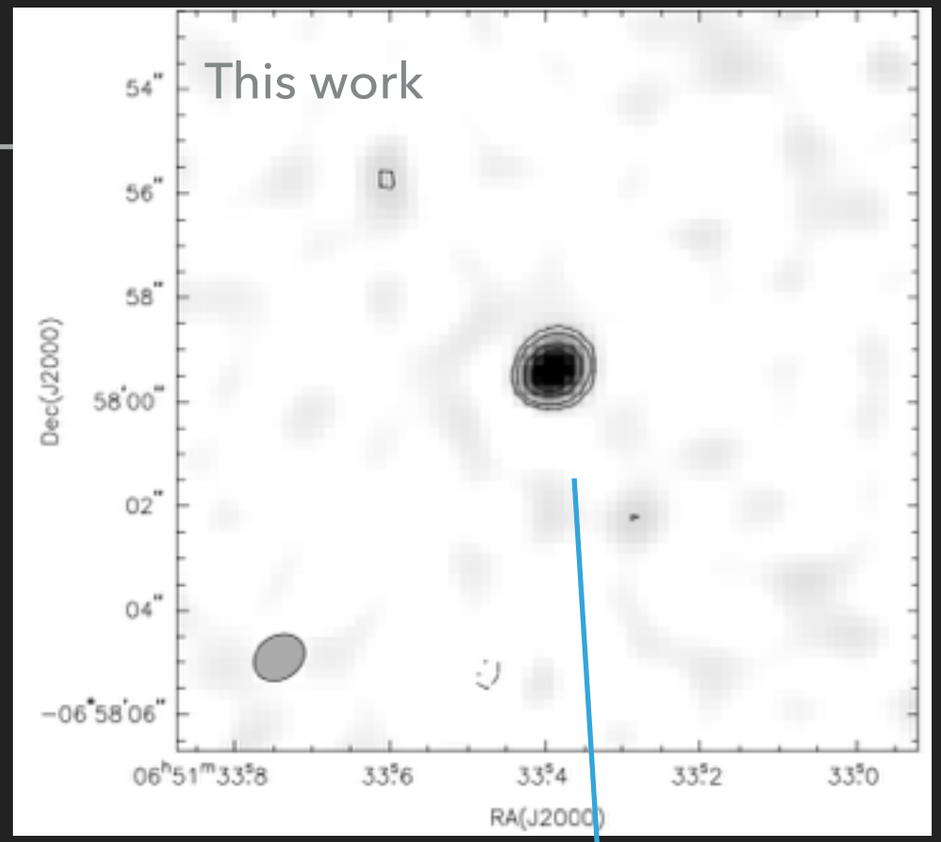


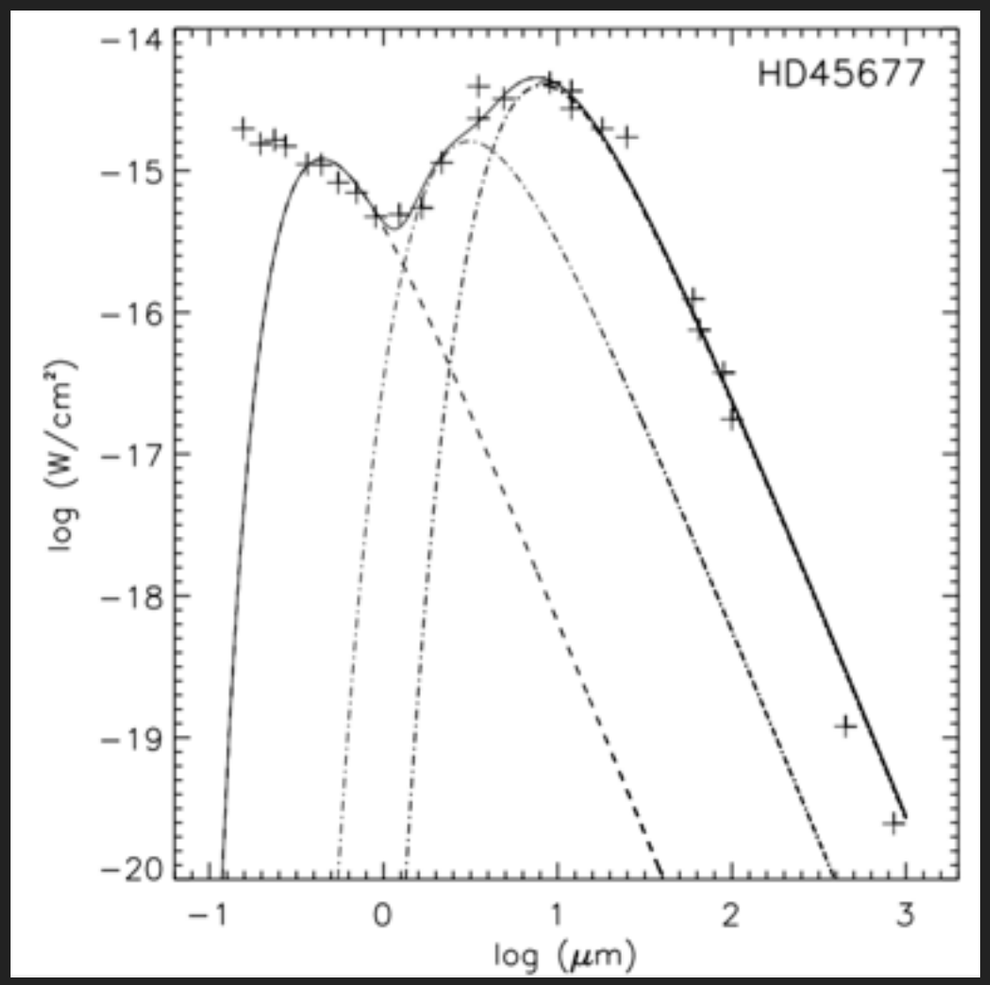


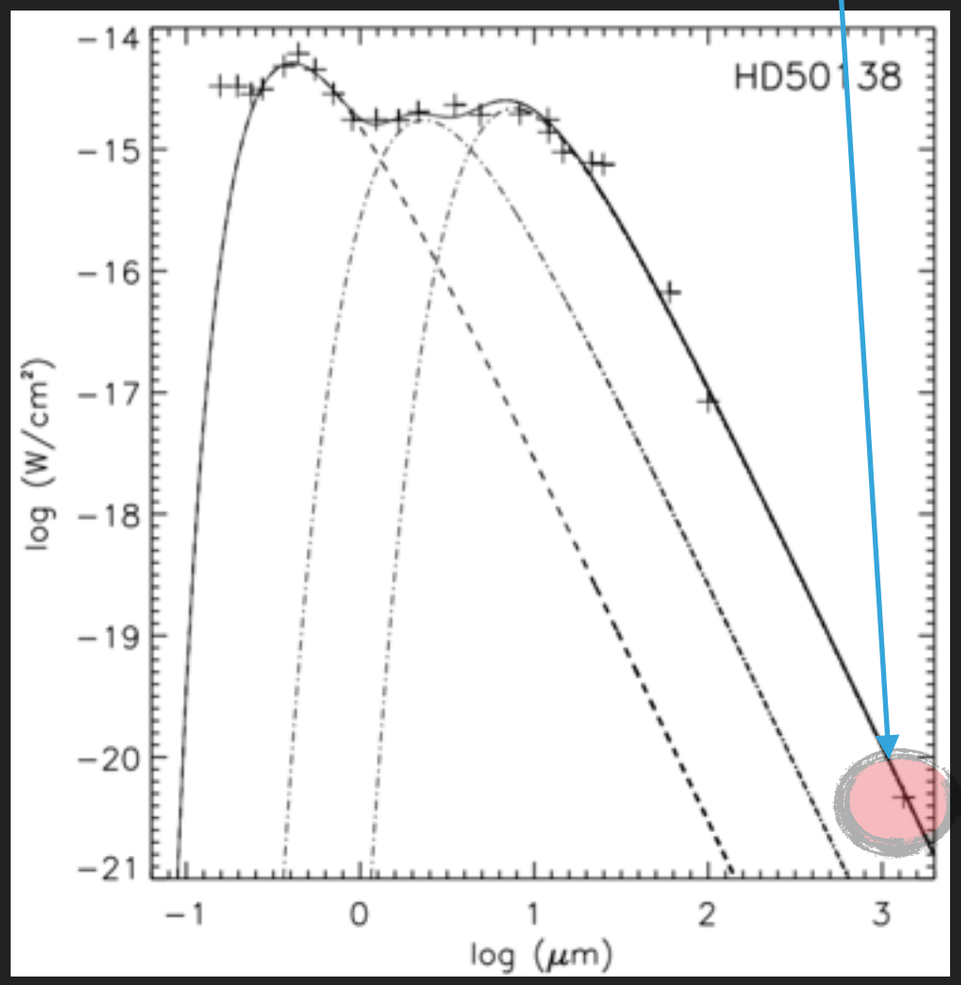


ANY COLDEST LEFTOVER?

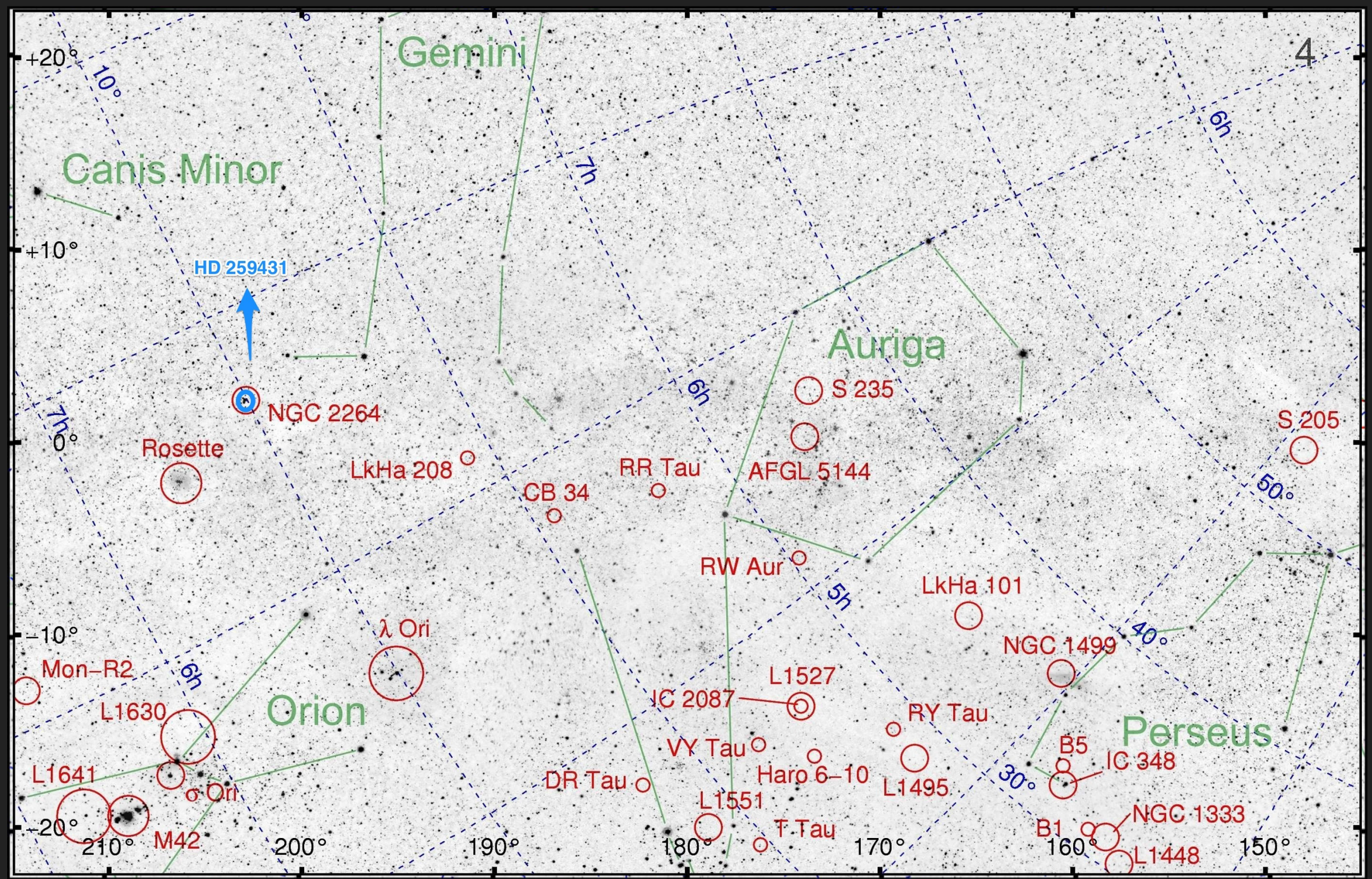
- Two targets with sub/mm data
- The steep decreases extend to sub/mm –> rule out the existence of coldest SFR leftover
- Are there any nearby SFR ?

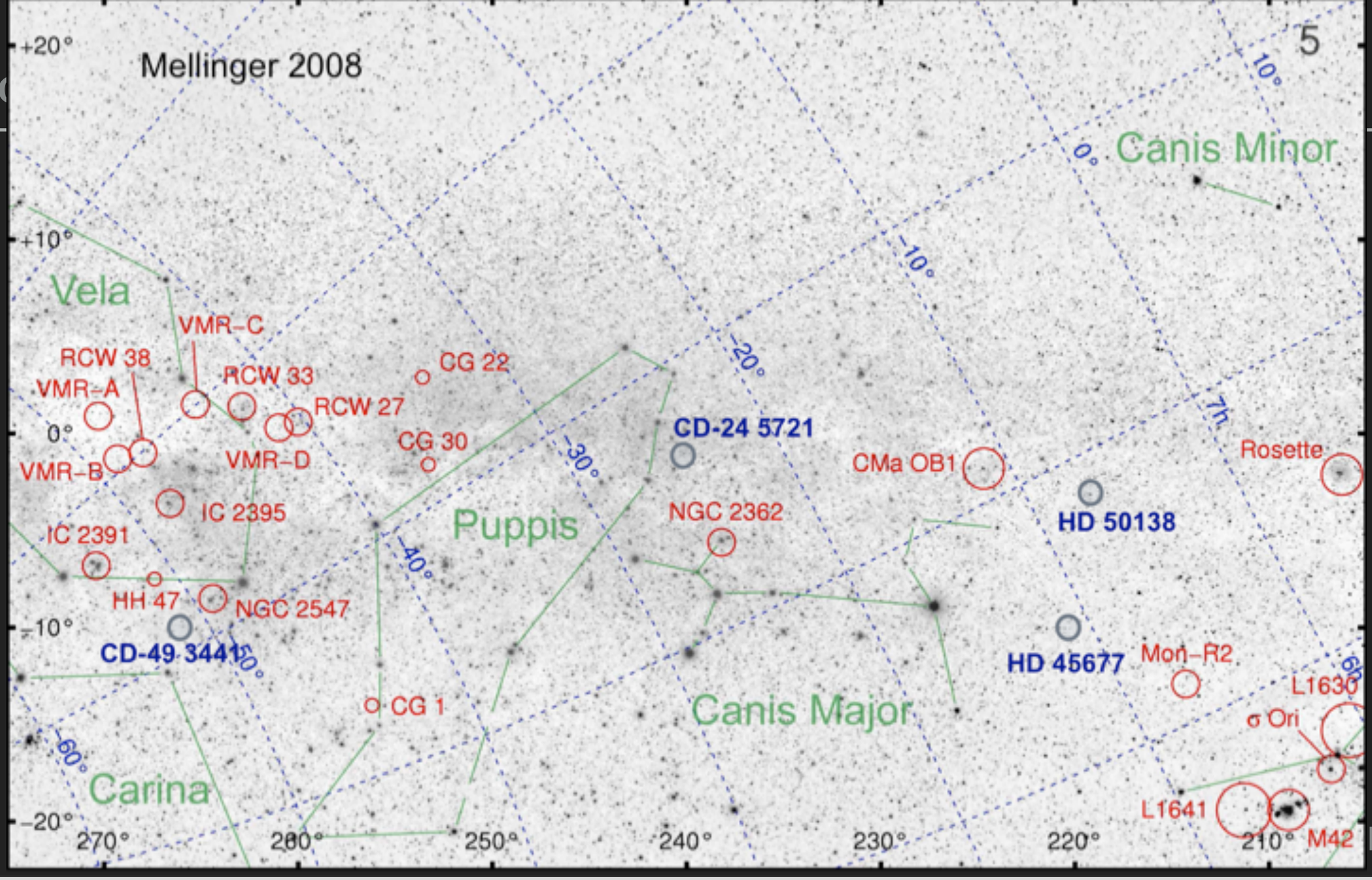






NEIGHBORING CENSUS —> ISOLATED NON-PRE-MS





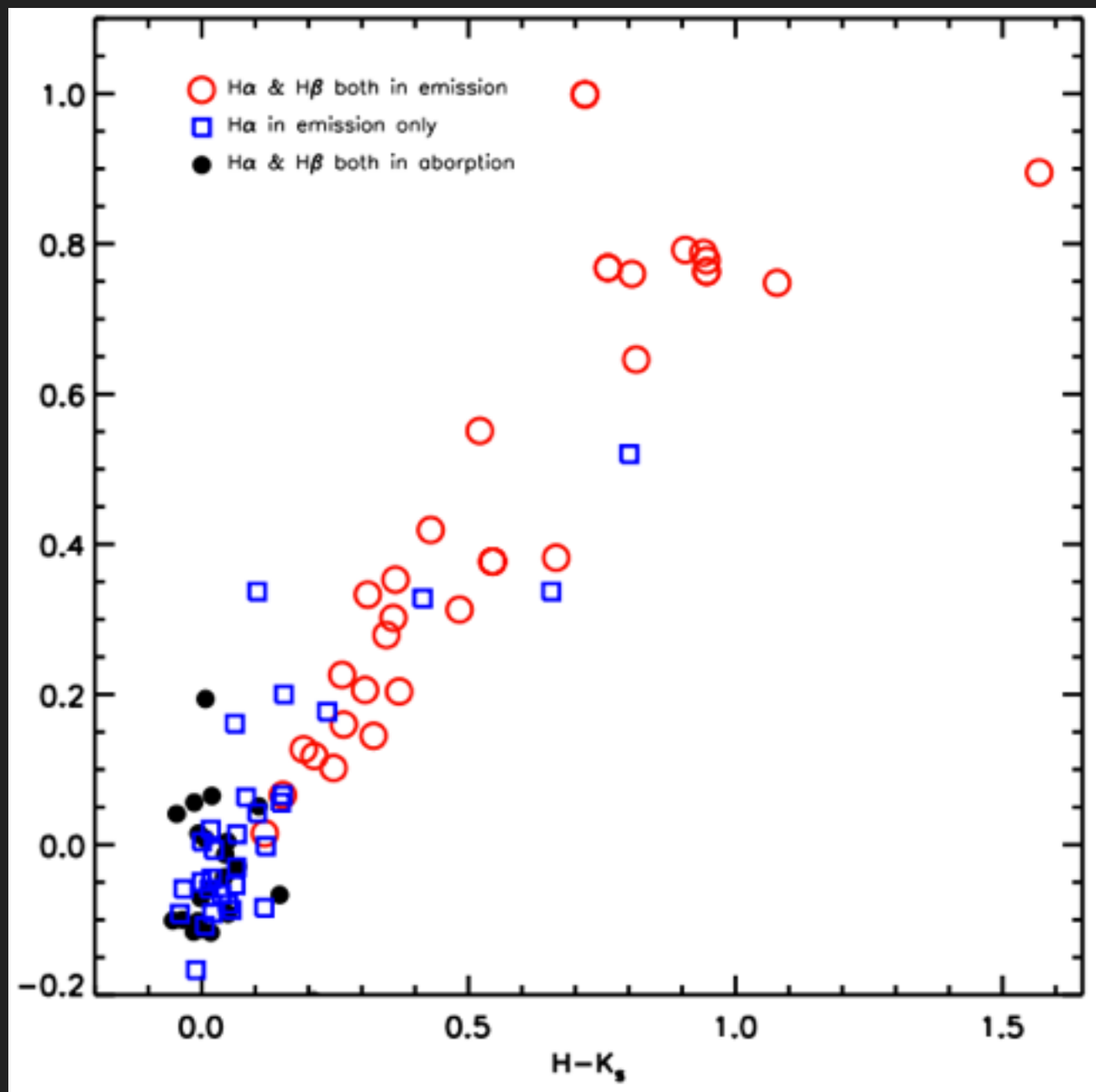
Evans 1979

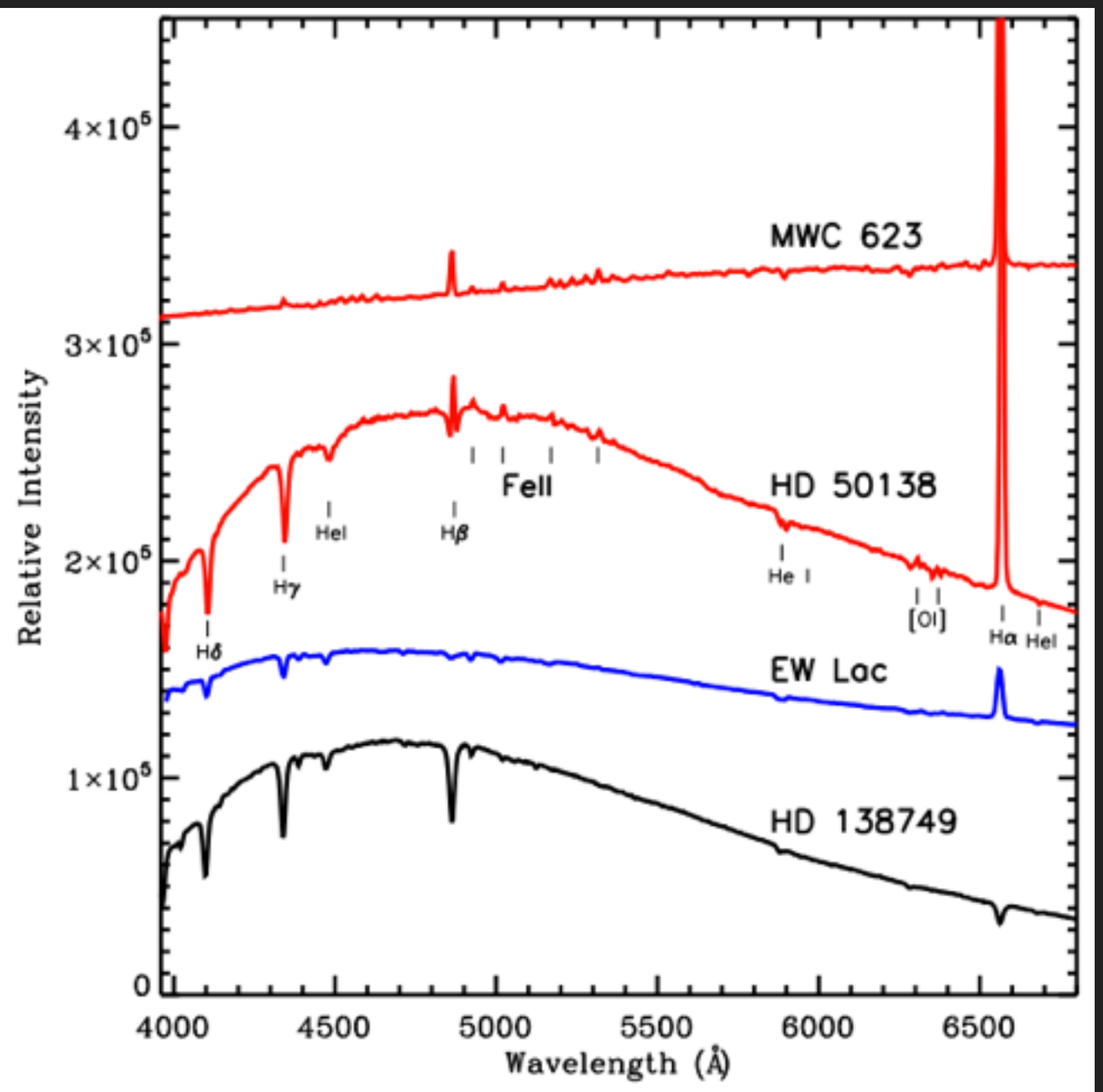
B[e] stars	Nearby SFR	Projected dist.	SFR dist.	Object dist.	Object *μ (mas)*	Object V_r
HD 45677	Mon-R2	8 degree	800 pc	279 pc	(2.0, 0.3)	21.6 km/s
HD 50138	GN 06.47.6.01	50 arcmin	1 kpc	392 pc	(-3.3, 4.1)	34.2 km/s

Van Leeuwen 2007 Wilson 1953

BALMER EMISSIONS AND NEAR-IR EXCESS

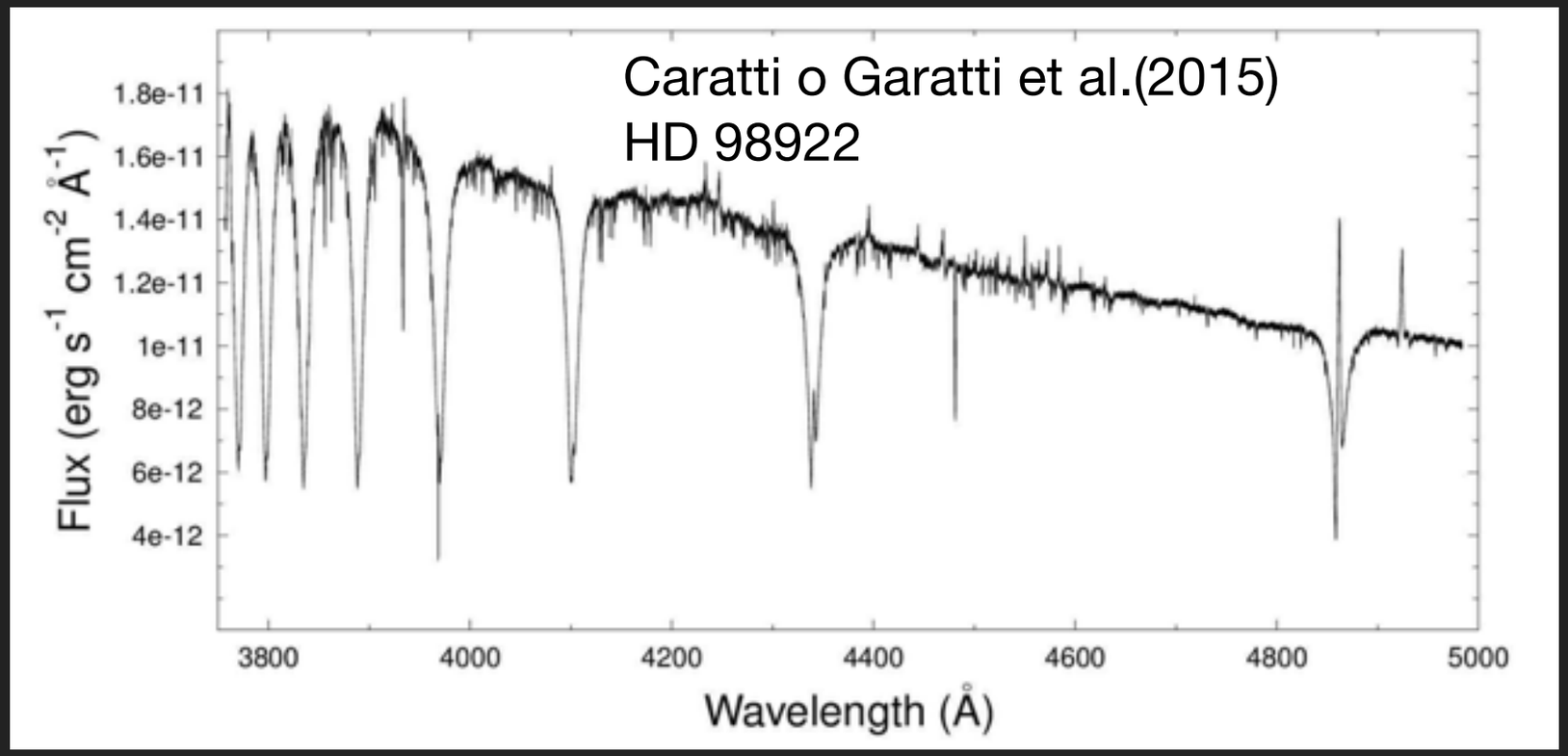
- The Balmer emission is related to the level of NIR excess
- Also seen in Herbig stars and T Tau stars (e.g., Manoj et al 2006, Cabrit et al 1990)

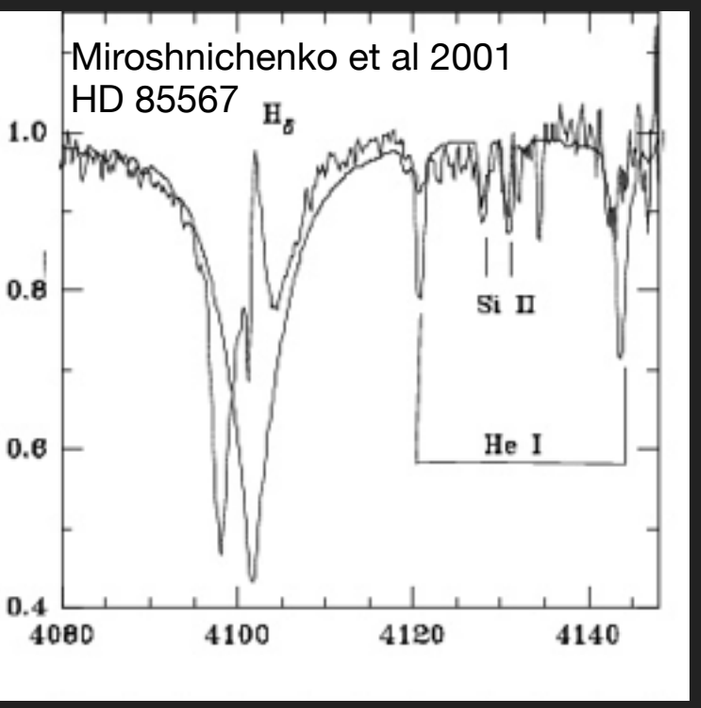


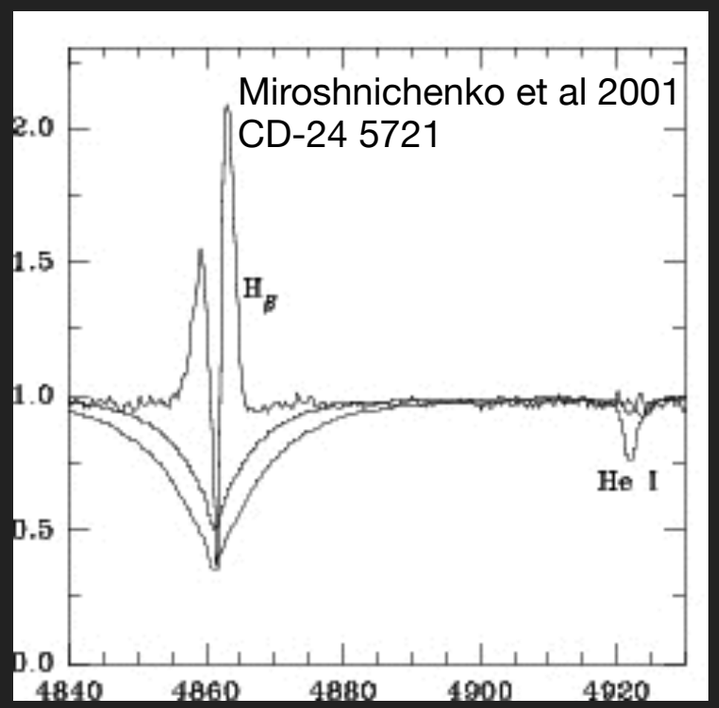


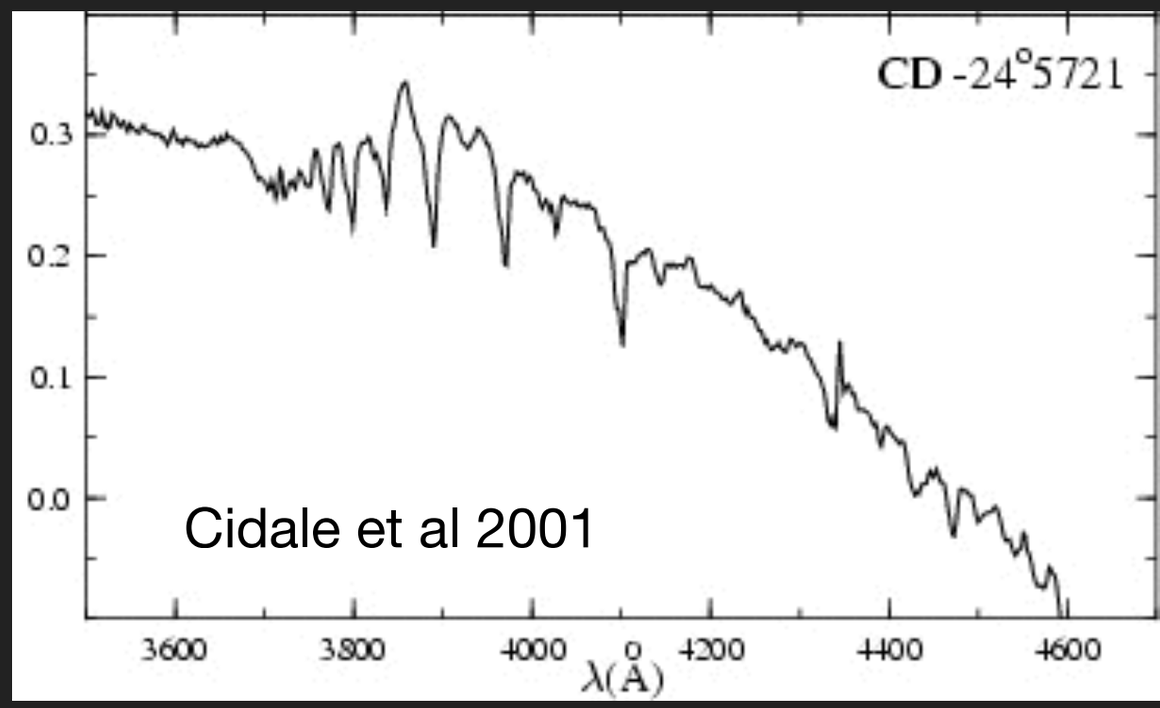
DUSTY TARGETS —> HBETA EMISSION AT LEAST

- HD 98922 –> Hη
- HD 85567 –> Hδ
- CD-24 5721 –> Hβ
- CD-49 3441 –> Hβ



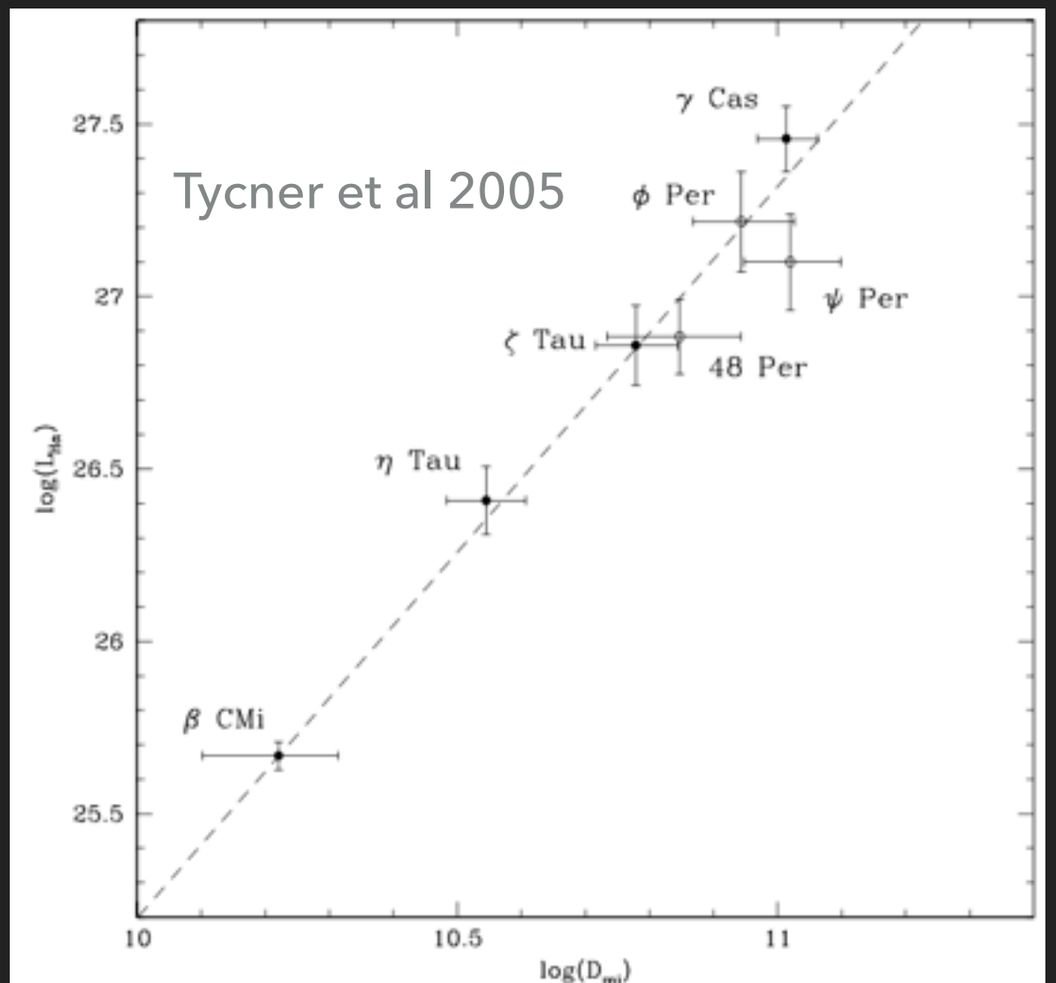






DUST CONDENSATION SCENARIO

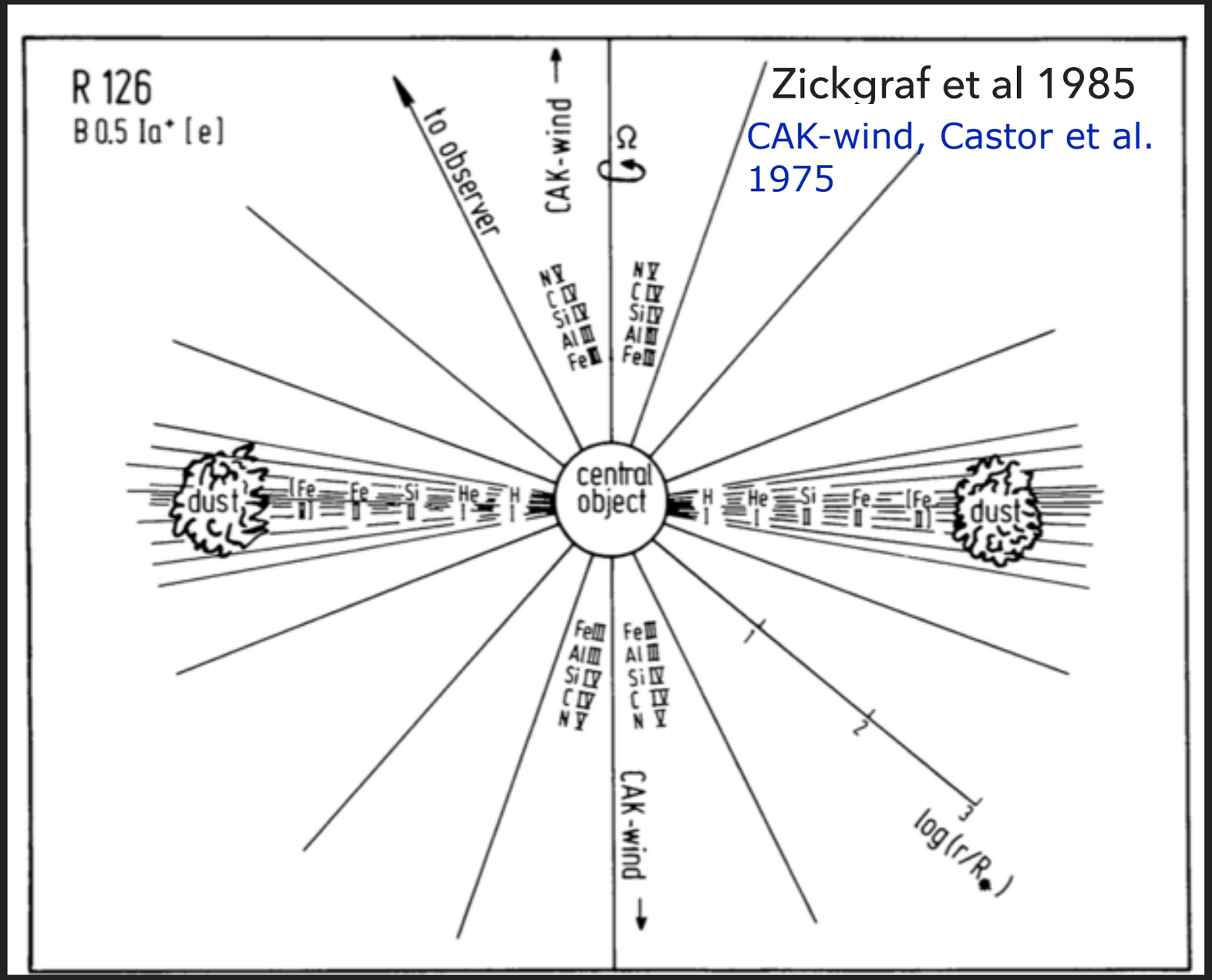
- Positive Relations in Be stars
  - Balmer emission & NIRE (This work)
  - Ha luminosity & disk size (Tycner)
  - Indication of the disk size: Our targets > Classical Be stars



- Dust condensation scenario
  - The copious hot plasma produces the prominent Ha emission lines
  - The forbidden lines form in the tenuous envelope
  - The expanding gas cools off and condenses to form dust grains.
  - Support Zickgraf et al (1985) model

B[E] MODEL: TWO-COMPONENT WINDS

- Two component winds
  - Hot polar wind –> high excited features
  - Expanding cool and dense equatorial wind –> low excited
  - High res line profilies (Zickgraf 2003)
- Dust condense in outer rim –> IR excess



CONCLUSIONS

- Nine dusty B[e] stars are selected by the color limits of free-free emission.
- Eight targets are not pre-MS objects
  - The cold dust emissions are absent up to the millimeter wavelength, indicating the lack of coldest SFR leftover.
  - Their isolation from star-forming activity or young stellar populations.
- Disk dust grains therefore should be produced in situ at the outer rim of a large disk

GAS & DUST POLARIZATION

- Hydrogen b-f absorptive opacity
- Thomson scattering

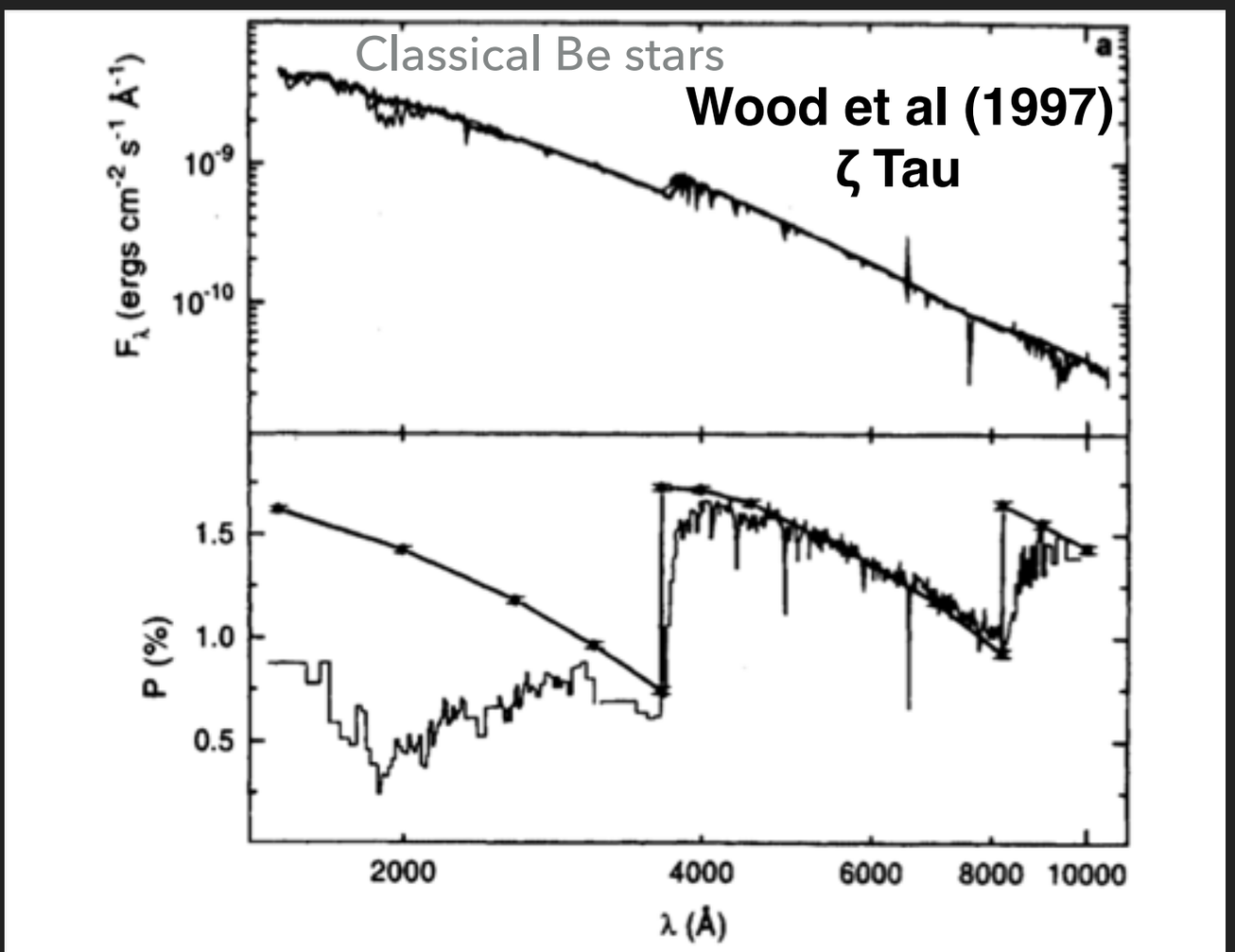
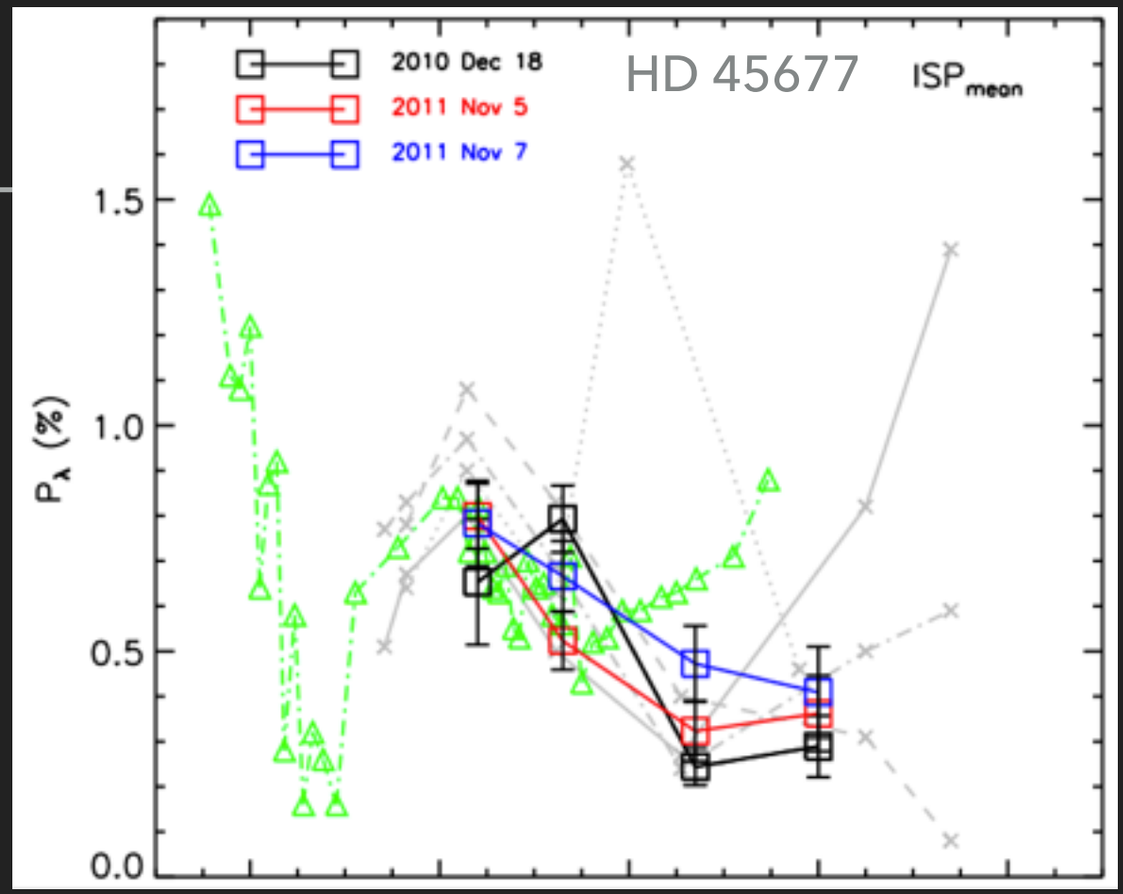
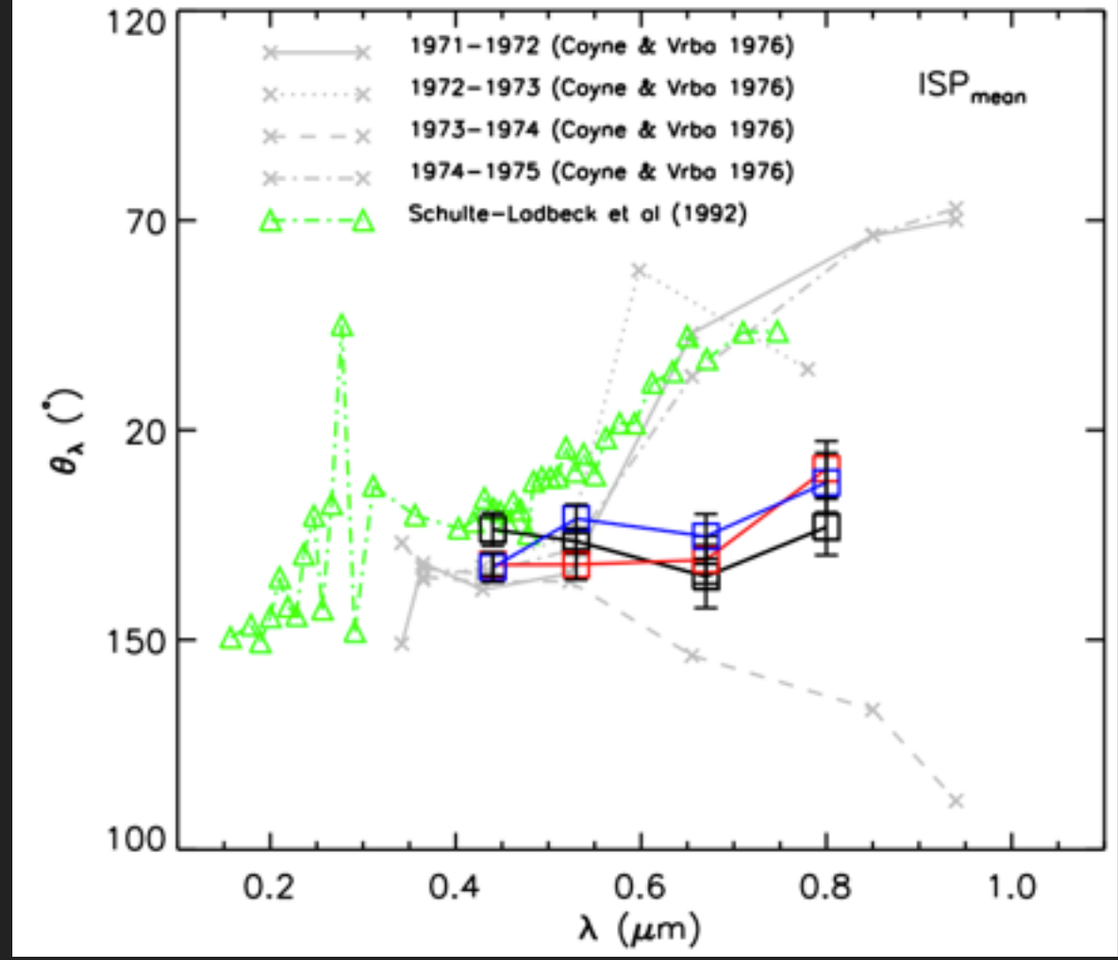


Figure 5.28: Model fitting for the Be star ζ Tau. Upper panel: thin disk model (thick line) and observed (thin line) spectra. Lower panel: linear polarization for the respective





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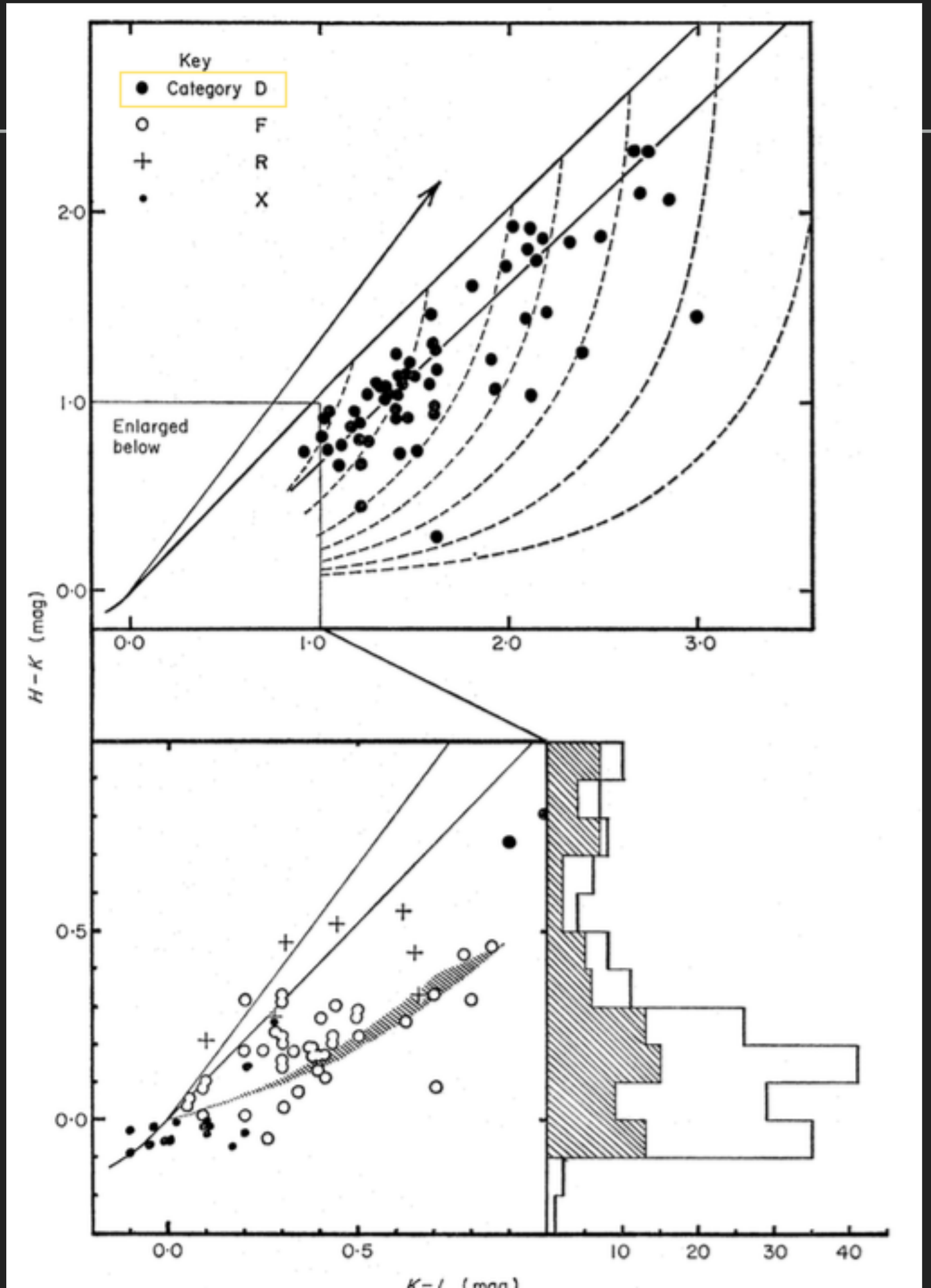
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Emissaries in HR Diagram

- From ionized gas above the photosphere radiation.
- Any stage during stellar evolution
  - Pre-Main Sequences: T Tauri and HABe stars
  - Evolved stars: Wolf-Rayet stars, giants and supergiants.
- The Be stars are the only bright emissaries lie on (or slightly above) the MS (Gehrz et al 1974).
  - They show small amount **near-IR excess** due to plasma emission.