A New Search for Galactic Objects with the B[e] Phenomenon

Anatoly Miroshnichenko

Univ. of North Carolina – Greensboro, USA

Pulkovo Observatory, Saint-Petersburg, Russia

Fesenkov Astrophysical Institute, Almaty, Kazakhstan

Nazgul Alimgazinova, Aisha Naurzbayeva, Aizhan Kuratova

Al-Farabi Kazakh National University, Almaty, Kazakhstan

Sergei Zharikov, UNAM, Ensenada, Mexico

Nadine Manset, CFHT Corp., Kamuela, Hawaii, USA

Ashish Raj, Univ. of Delhi & Inst. of Astrophysics, Bangalore, India

Richard J. Rudy, Aerospace Corp. (retired)

OBA Stars: Variability and Magnetic Fields

April 26 – 30, 2021, Saint-Petersburg, Russia

The B[e] Phenomenon

Discovery – Allen & Swings(1976, A&A, 47, 293)

- 65 B–type stars (out of 700) with forbidden line emission ([Fe II], [O I], [O III]) and IR excess at λ=2 μm
- 5 groups of B[e] stars: **supergiant B[e], pre-main-sequence B[e], compact Planetary Nebulae B[e], symbiotic B[e], and unclassified B[e] –** Lamers et al. (1998, A&A, 340, 117)
- 32 unclassified B[e] – no reliable distances OR mixture of features from different groups.
- Most unclassified B[e] stars became FS CMa objects

FS CMa objects (Miroshnichenko 2007, ApJ, 667, 497) has NOT replaced the "Unclassified B[e]" group but rather rejected some explanations about the objects' nature.

Only B[e]sg and FS CMa objects seem to create dust due to binary interaction, the other groups have dust created earlier

FS CMa = HD 45677

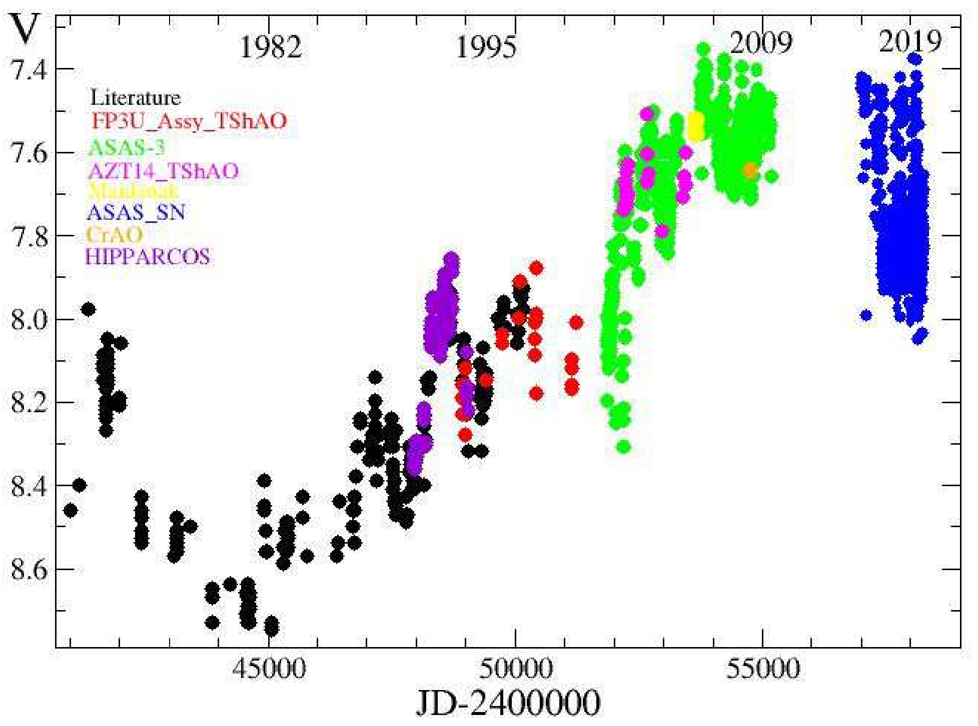
Emission-line spectrum discovered in 1898.

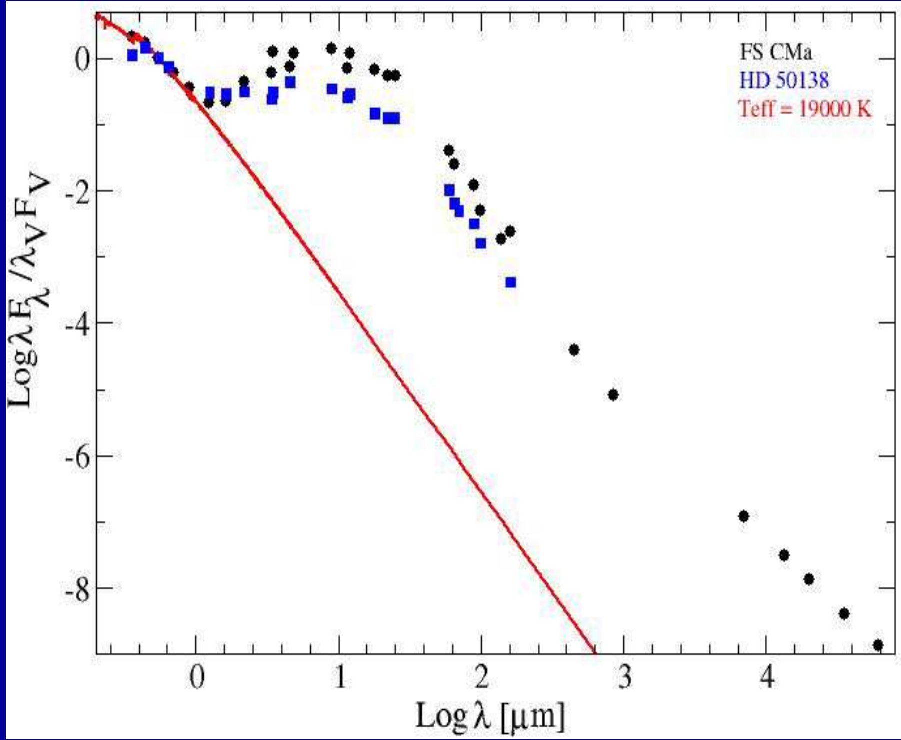
One of the first hot stars with discovered IR excess (1970).

V-band data: two cyclic components 296.5 and 1600 days (1990's).

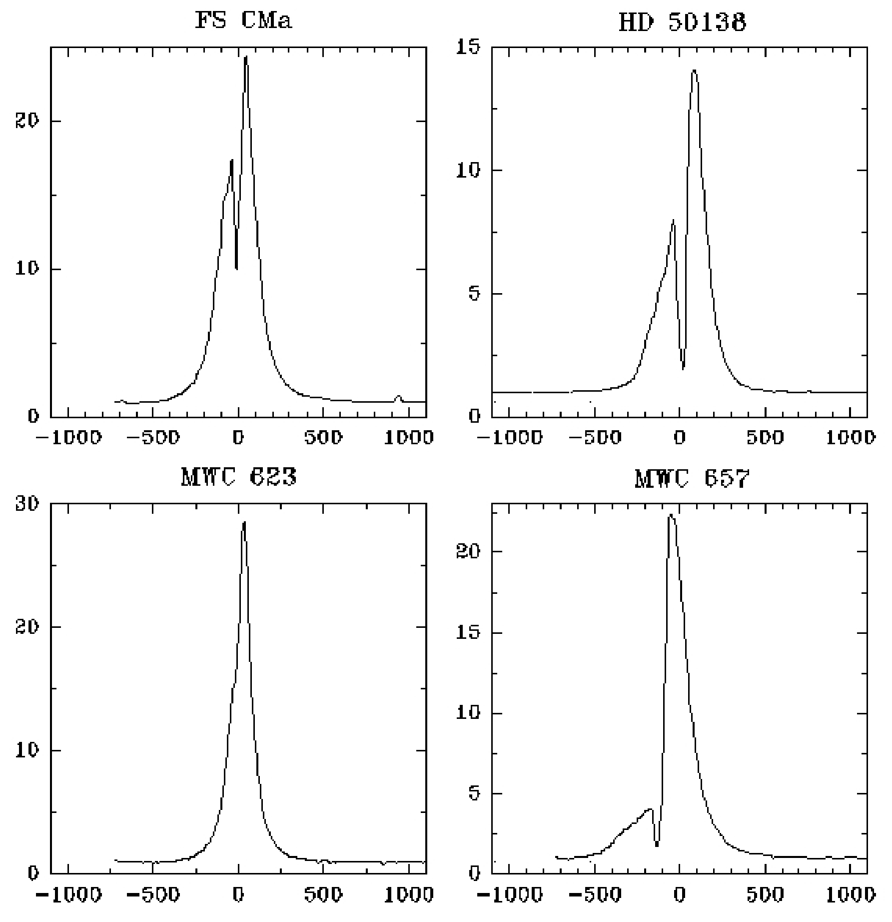
G. Herbig did not consider it a pre-main-sequence object (1994).

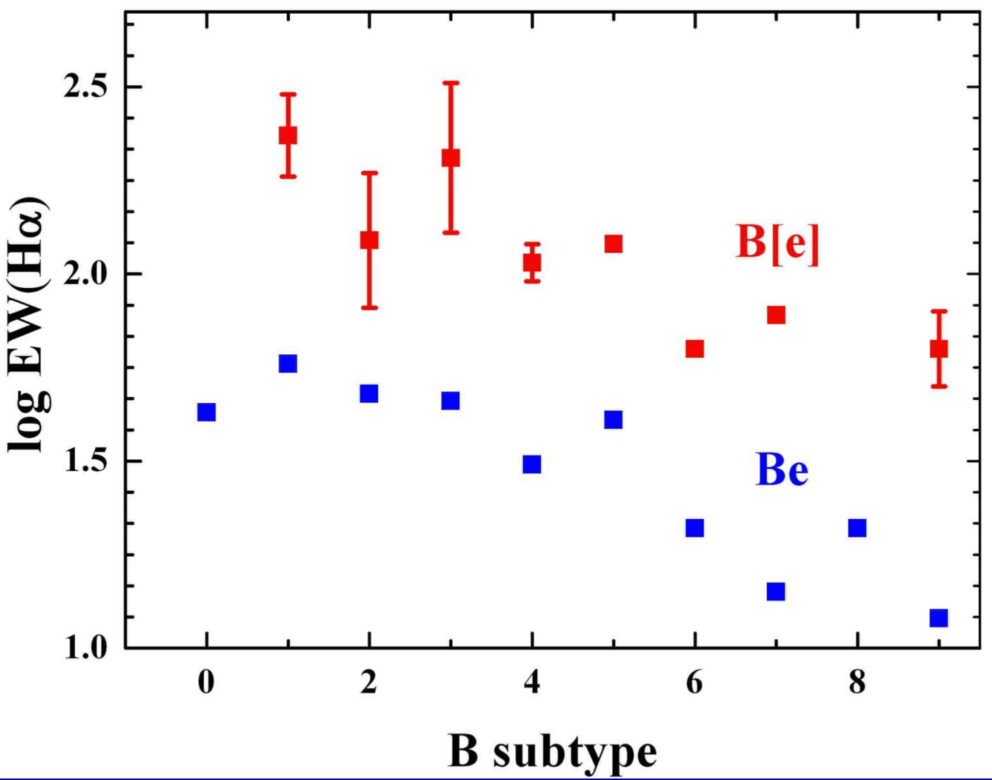
J.-P. Swings suggested it to be a prototype B[e] star (2006).





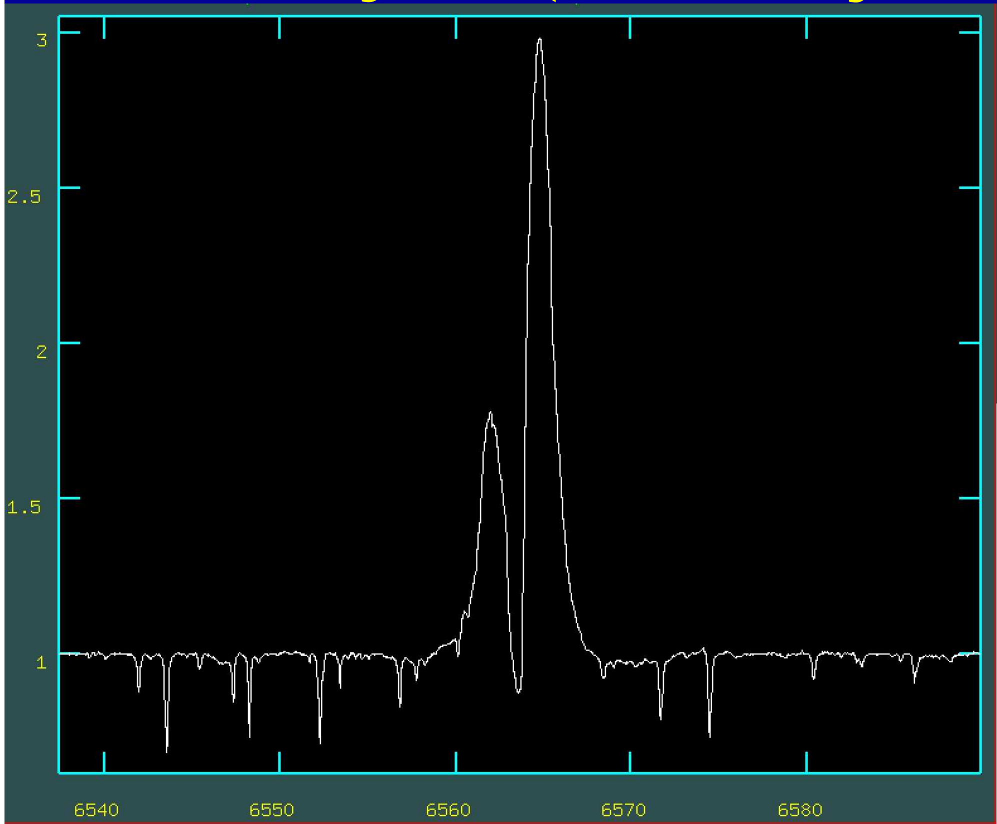
Emission-Line Strength





Miroshnichenko (2008, Astron. Soc. of the Pacific Conf. Ser, 388, 205)

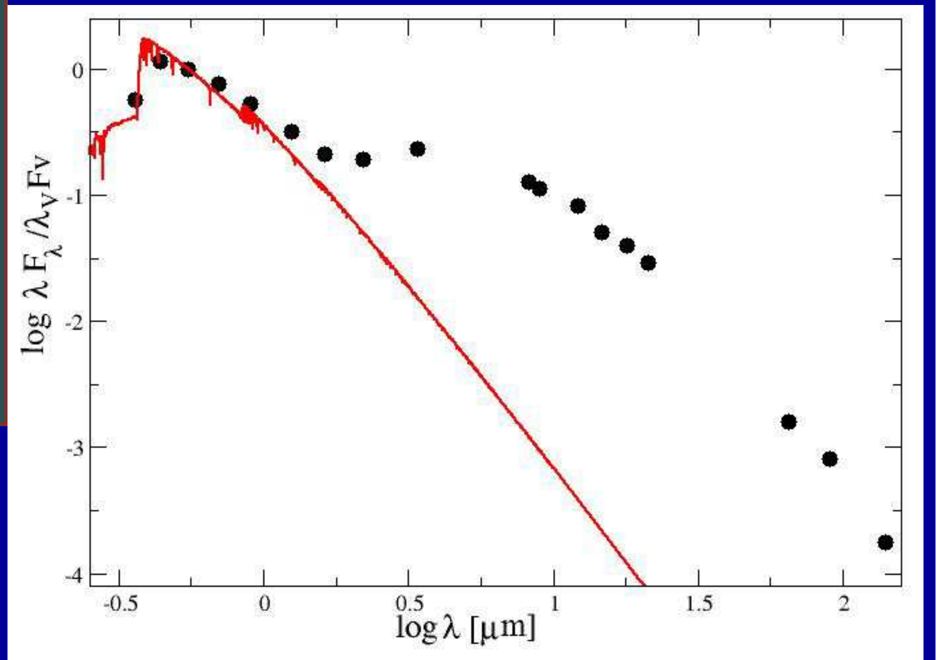
3 Pup – the brightest and coolest FS CMa object (formerly a B[e] supergiant)



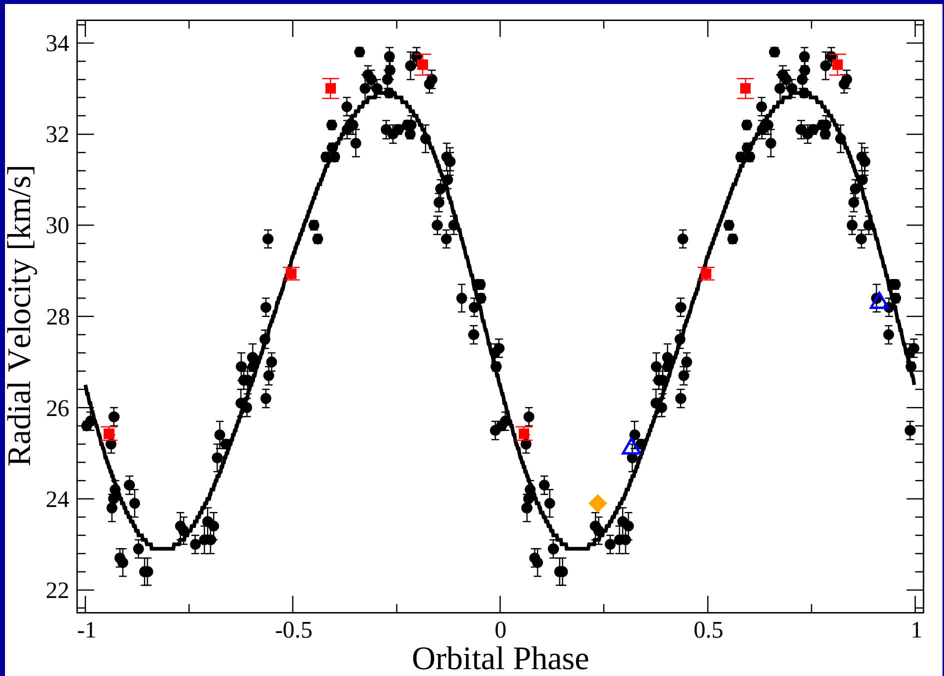
V = 3.96 mag, A3 Ib

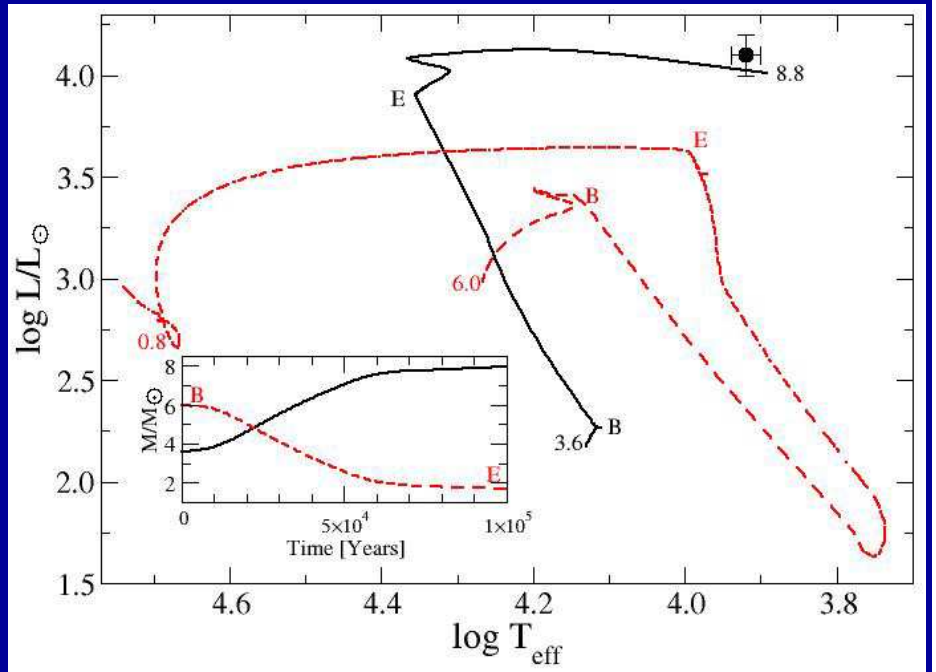
Teff = 8500 K

D = 650 pc (GAIA)



3 Pup – Binary System





Orbital period: 137.3±0.1 days, K_1 = 5.0±0.8 km/s,

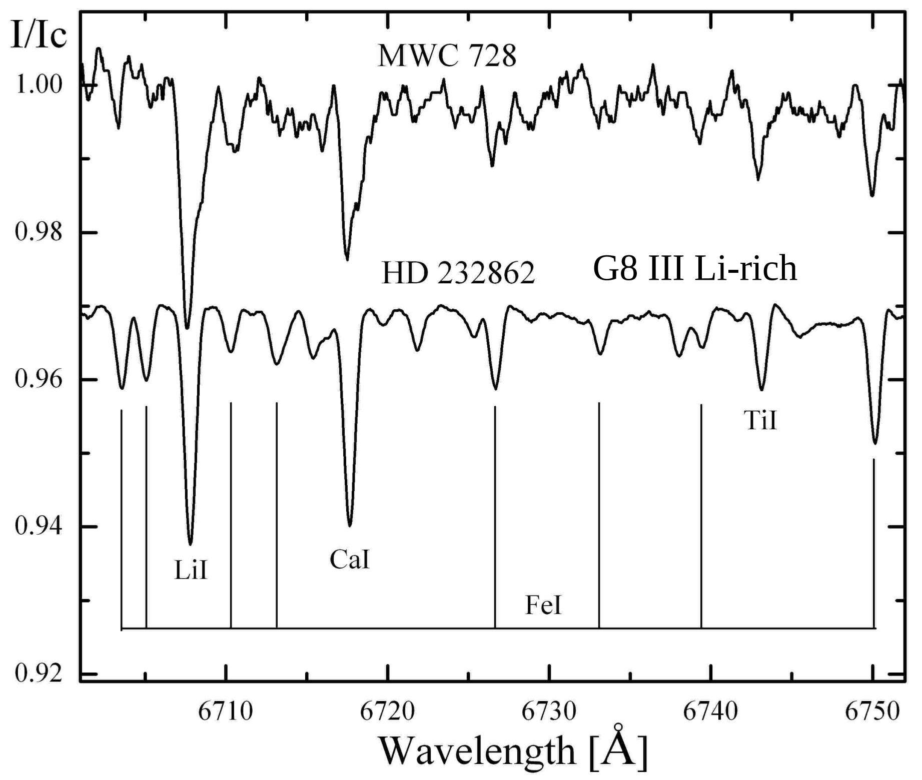
e = 0.05±0.05, $f(M_2) = 1.8\ 10^{-3}\ M_\odot$

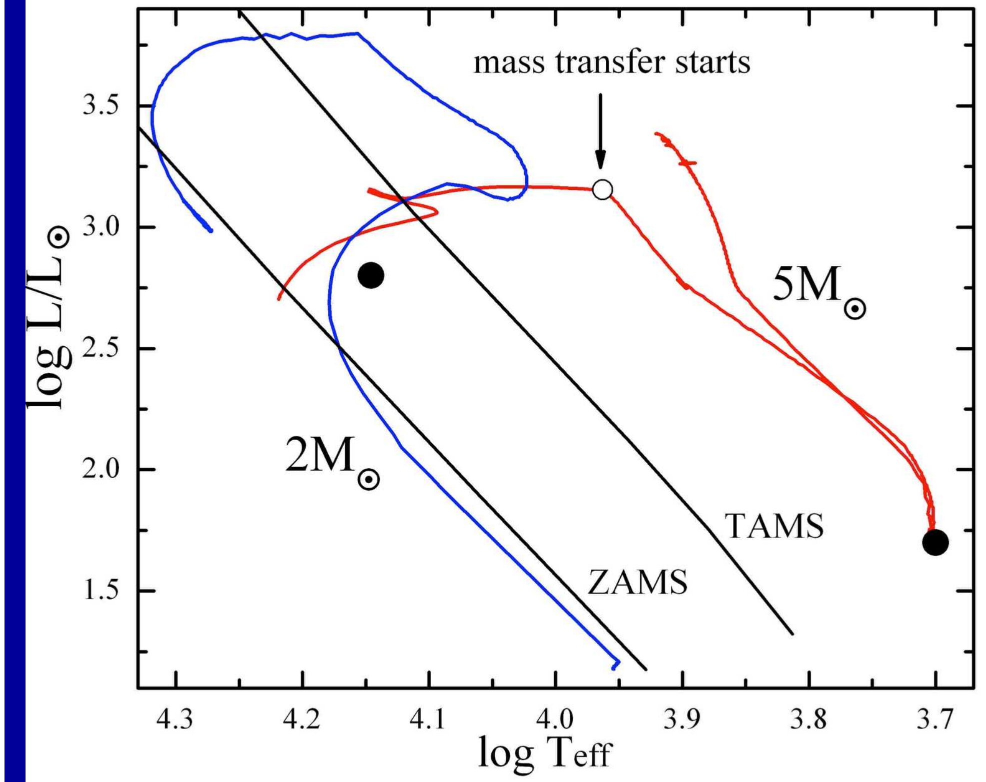
Initial masses: $M_1 = 3.6\ M_\odot$, $M_2 = 6.0\ M_\odot$

Current masses: $M_1 = 8.8\ M_\odot$, $M_2 = 0.8\ M_\odot$

Miroshnichenko et al. (2020, ApJ, 897, id. 48)

MWC 728 (B5Ve + G8 III)





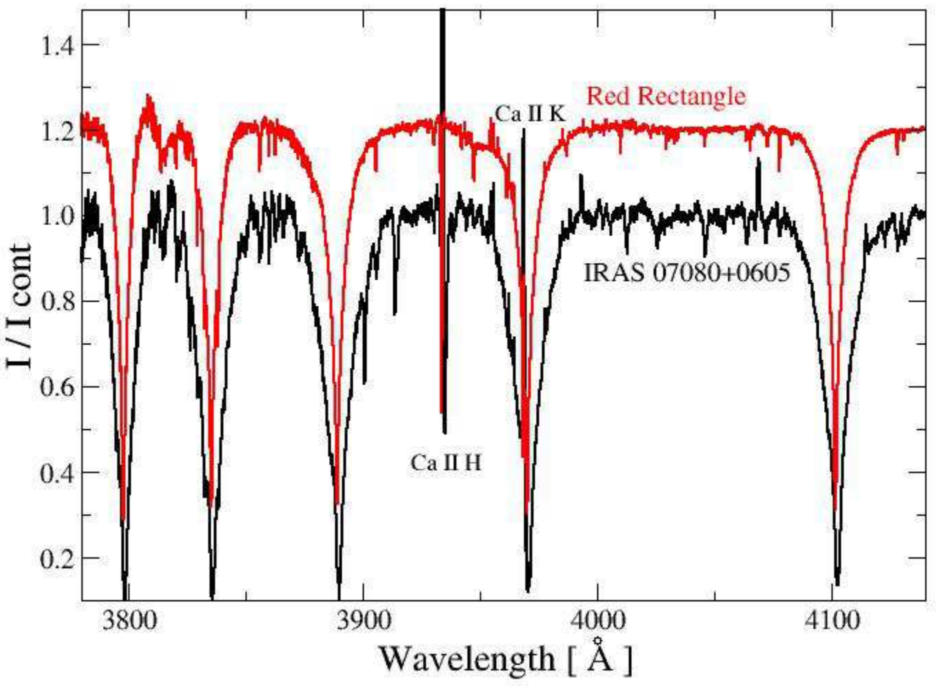
MWC 728: V = 9.8 mag, Orbital period: 27.5 days

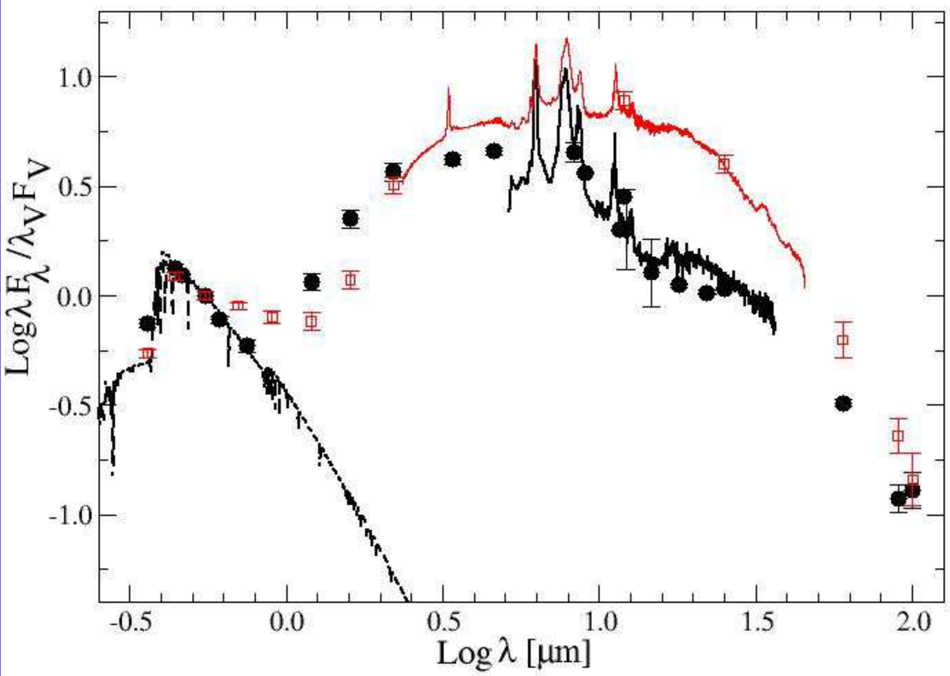
V-band flux fraction: hot star 60%, cool star 10%, disk 30%

Distance: 1.0 kpc (our study), 0.31±0.02 kpc (GAIA EDR3)

Miroshnichenko et al. (2015, ApJ, 809, 129)

IRAS07080+0605





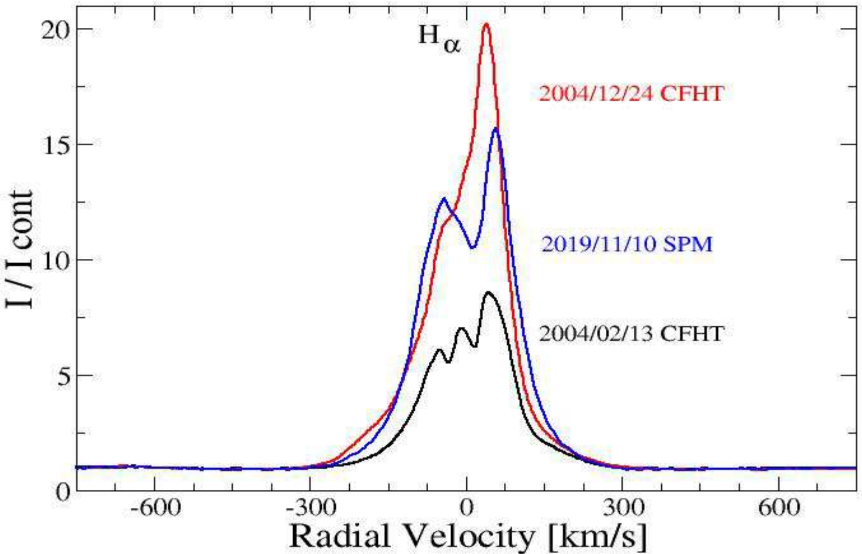
V = 12.0 mag, Teff ~8700 K,

D = 542±9 pc (GAIA EDR3)

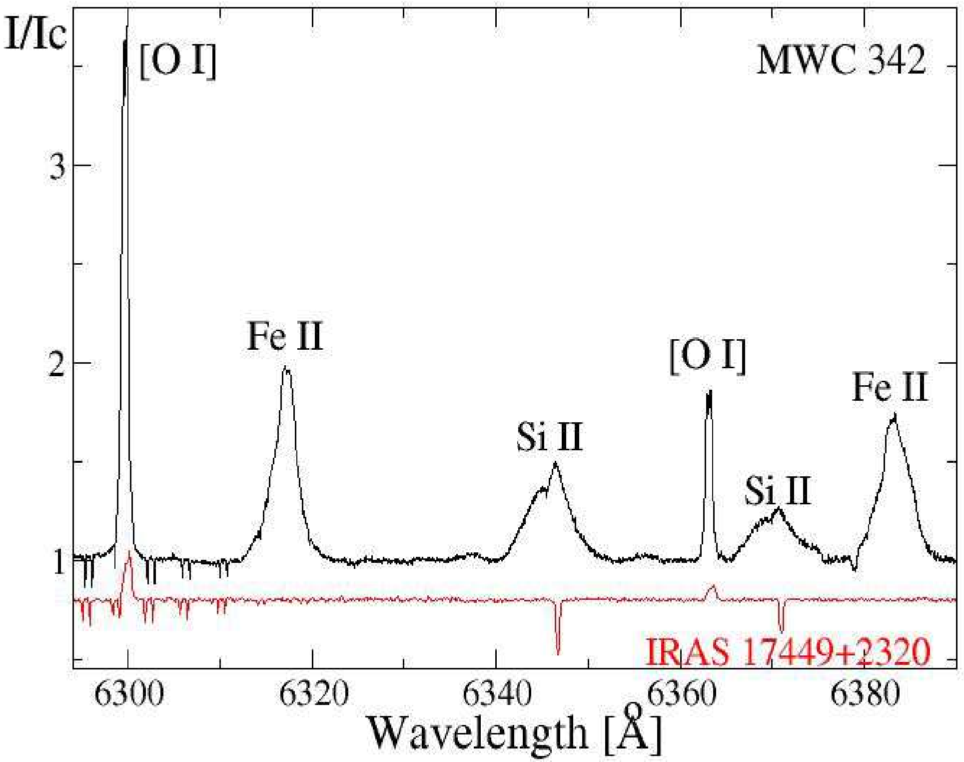
Grey circumstellar extinction –

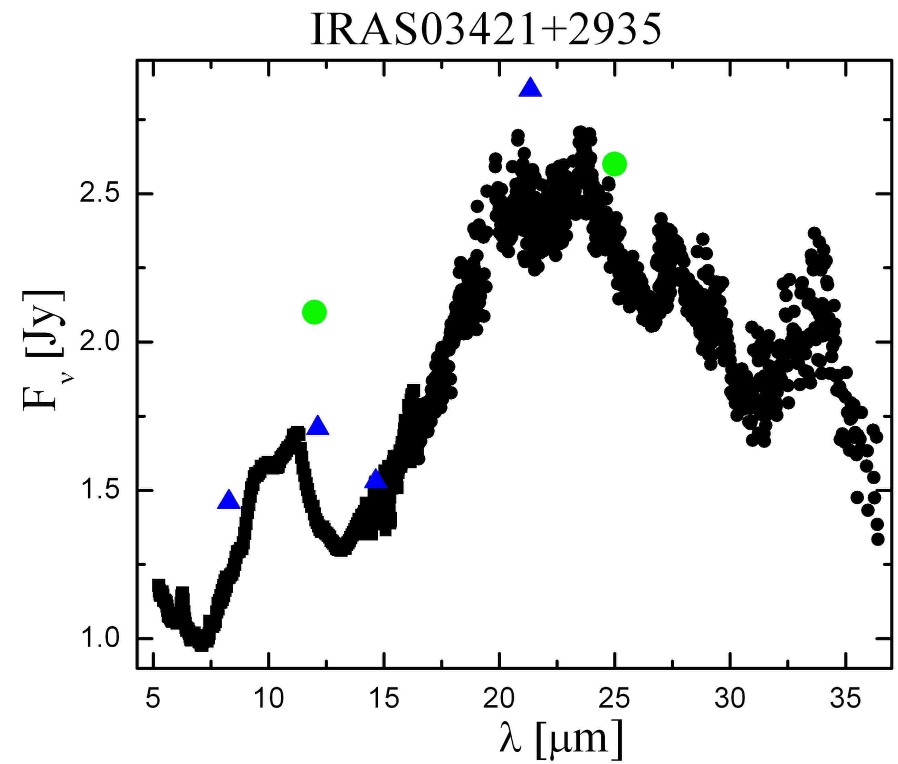
Visual attenuation ~30 times

Khokhlov et al. (2020, Odessa Astron. Publ., 33, 141)



Other Features of FS CMa Objects





MWC 342 – B1 [e]

IRAS 17449+2320 – B9[e]

Spectra from ESPaDOnS at CFHT (R ~ 65,000)

MWC 728 – B5 V[e] + G8 III

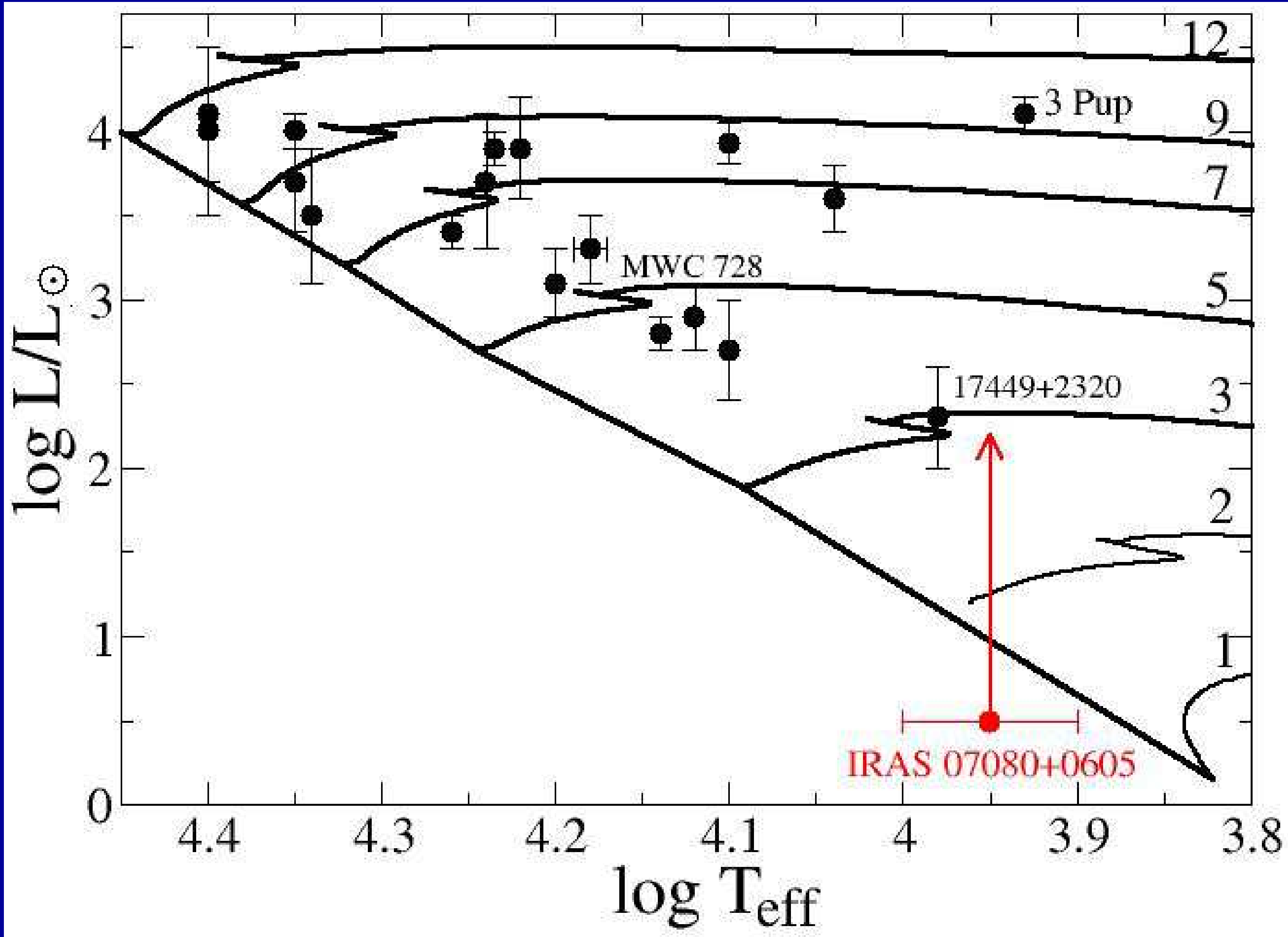
Spitzer Space Observatory

Miroshnichenko et al. (2011, IAU Symp. 272, 412)

Basic Parameters of FS CMa Objects

- ✓Primary Companion: B0–A0 + emission lines
- ✓Secondary Companion : G–K, sdO, or degenerate typically much fainter than the primary
- ✓Location outside of star-forming regions
- ✓Luminosity: $\leq 500\ L_\odot$ – $\sim 3\ 10^4\ L_\odot$
- ✓Strong IR excess peaks at $\lambda \sim 10$–$30\ \mu m$ and steeply decreases towards longer wavelengths
- Circumstellar Gas distribution: disk-like
- Circumstellar Dust distribution: (probably circumbinary disk)

HRD for FS CMa Objects



FS CMa Type Binary Sketch

Search Sources and Strategies

- Before 2007 : catalogs of emission-line stars (e.g., Kohoutek & Wehmeyer 1999, A&AS, 134, 255) and IRAS.
- After 2007: NOMAD catalog (USNO─B1.0 + 2MASS) and later UCAC4 - easier searchers due to good astrometric accuracy (< 1”).
- Analysis of IR properties of known FS CMa objects resulted in establishing photometric criteria to search for hot stars with circumstellar dust, avoiding classical Be stars and objects with cold dust only (e.g., Planetary Nebulae).

J─H > 0.7 mag

J─K > 1.4 mag

$m_B - m_V < 1$ mag

$m_V - K > 2$ mag

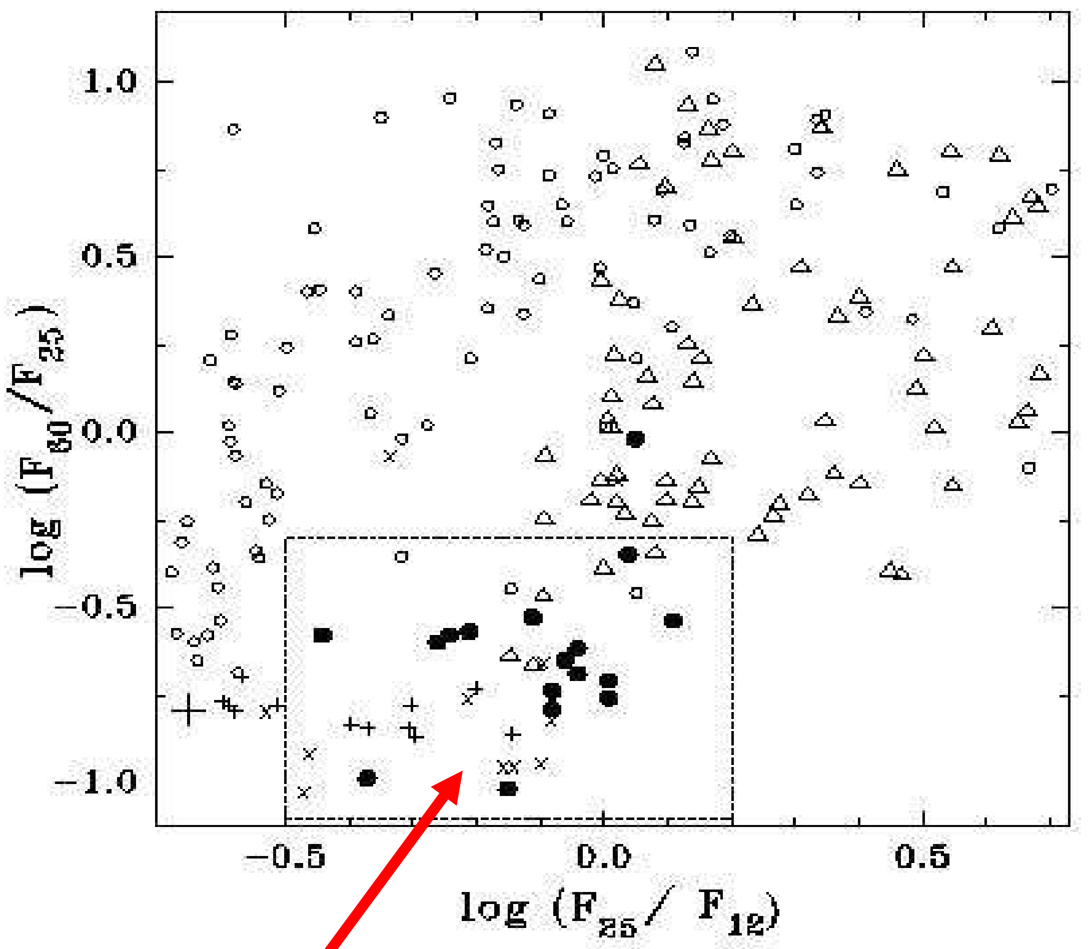
K – [12] > 3 mag

NOMAD & UCAC4

(I/297 & I/322A in Vizier)

Criterion to search in other IR catalogs (e.g., MSX, WISE, AKARI)

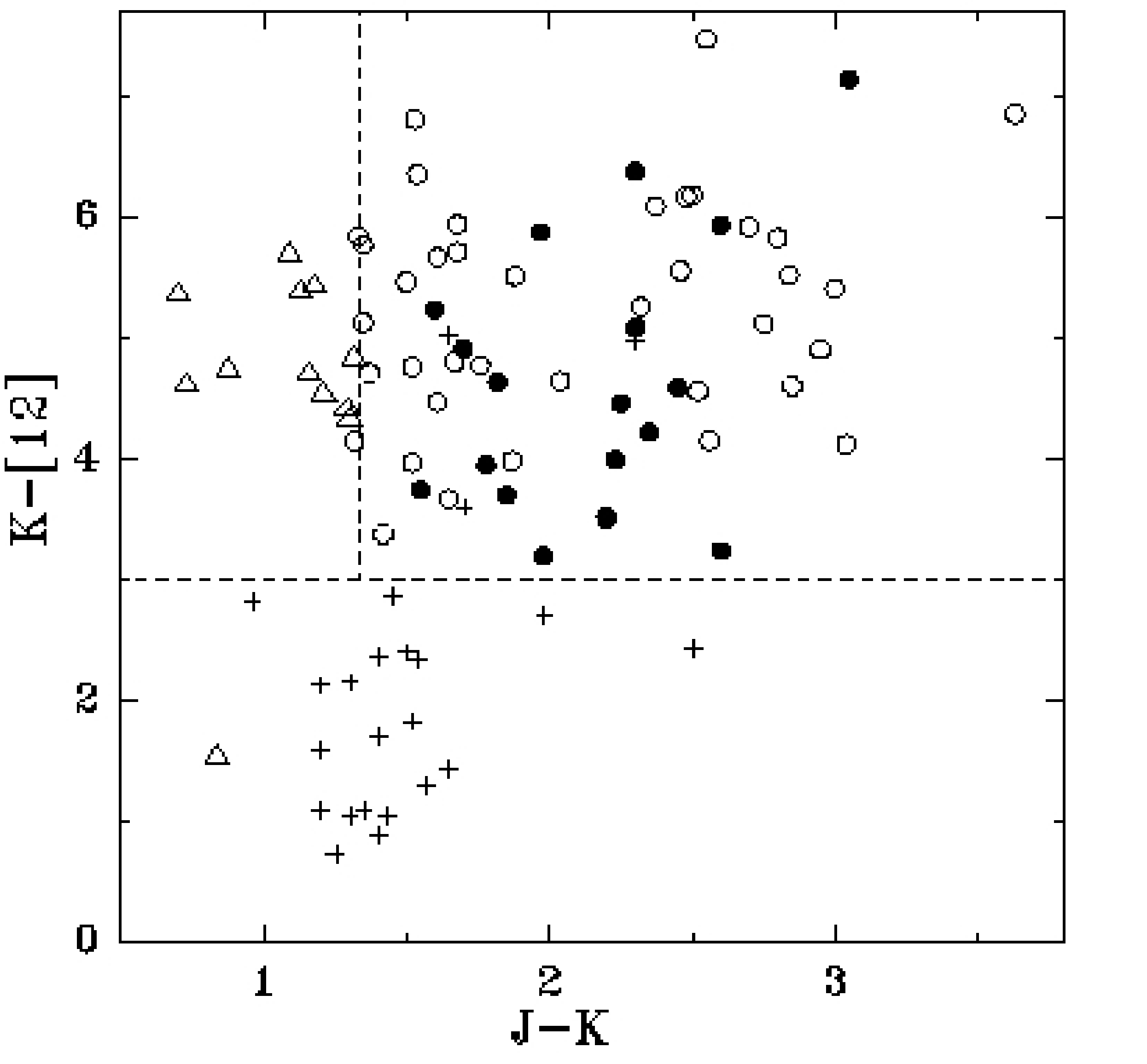
IRAS color-color diagram



- • – FS CMa stars
- Δ – Herbig Ae/Be
- o – Vega-type
- × – symbiotic stars
- + – VV Cep binaries

Dusty envelopes of FS CMa stars are compact

Near-IR and IRAS fluxes



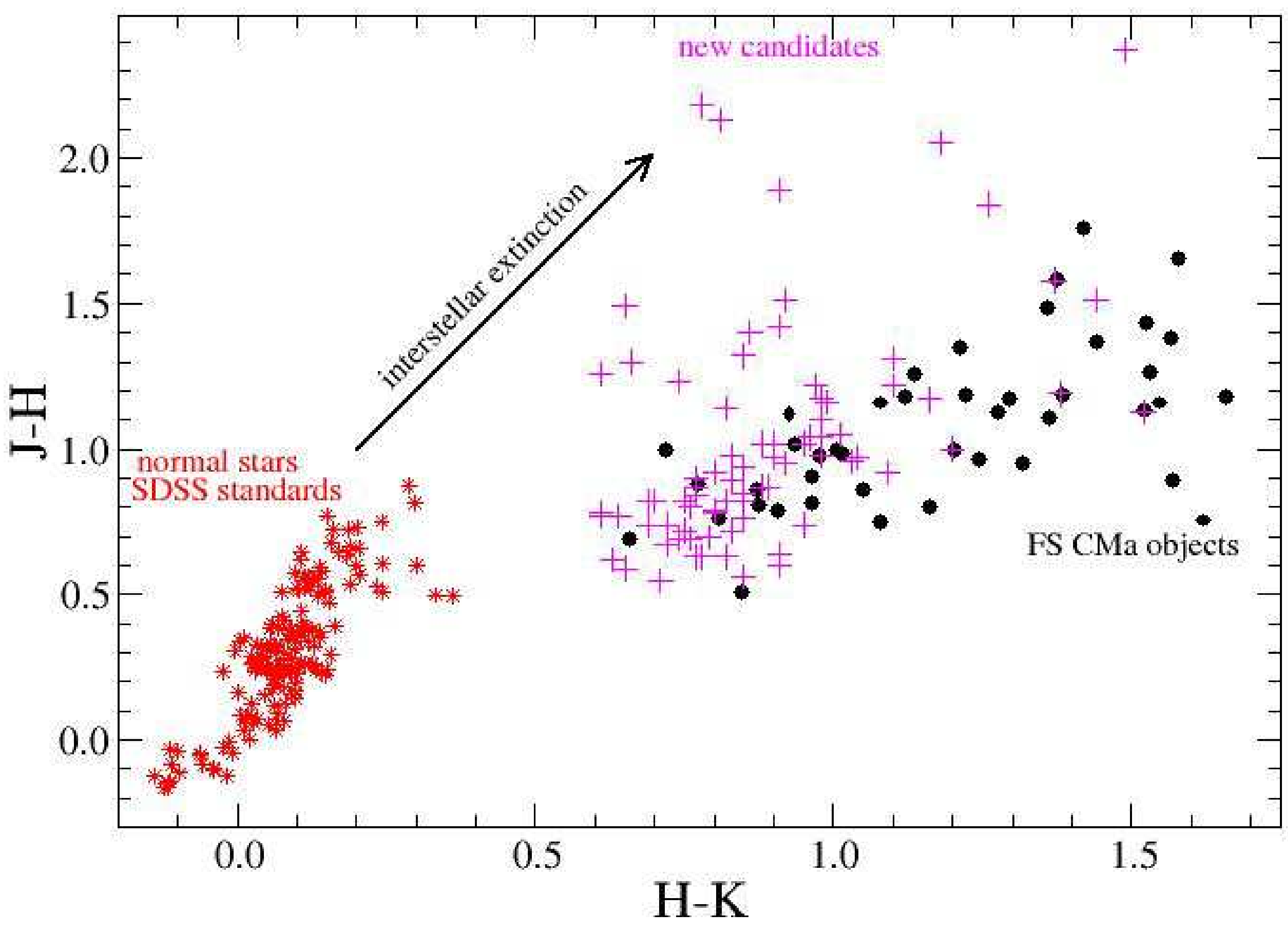
Cross-correlation of the 2MASS and USNO catalogs with IRAS 12-μ m fluxes

J – 1.2 microns

K – 2.2 microns

○ FS CMa objects, Δ - RV Tau; + - cool stars

Near-IR Colors: FS CMa Objects & New Candidates



Data from the 2MASS catalog

The Galactic FS CMa Group

23 are most likely not supergiants, HAeB[e], or symbiotics

7 – not enough data (recently classified: MWC 922 – PN, MWC 137 – sgB[e])

9 – Miroshnichenko (2007, ApJ, 667, 497) IRAS

10 – Miroshnichenko et al. (2007, ApJ, 671, 828) IRAS

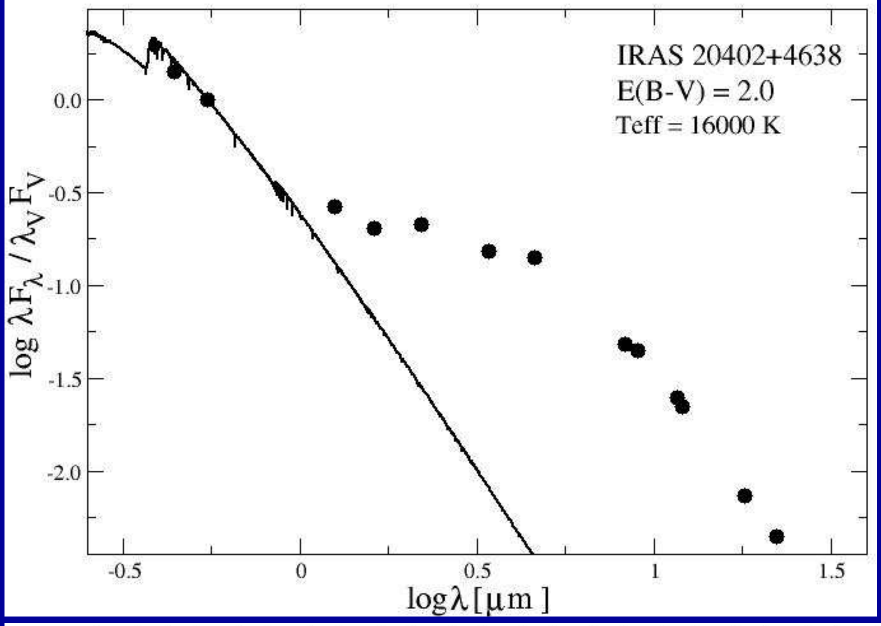
20 – Miroshnichenko et al. (2011, Proc. IAU Symp., 272, 260) from an emission-line star survey (Kohoutek & Wehmeyer 1999, A&AS, 134, 255)

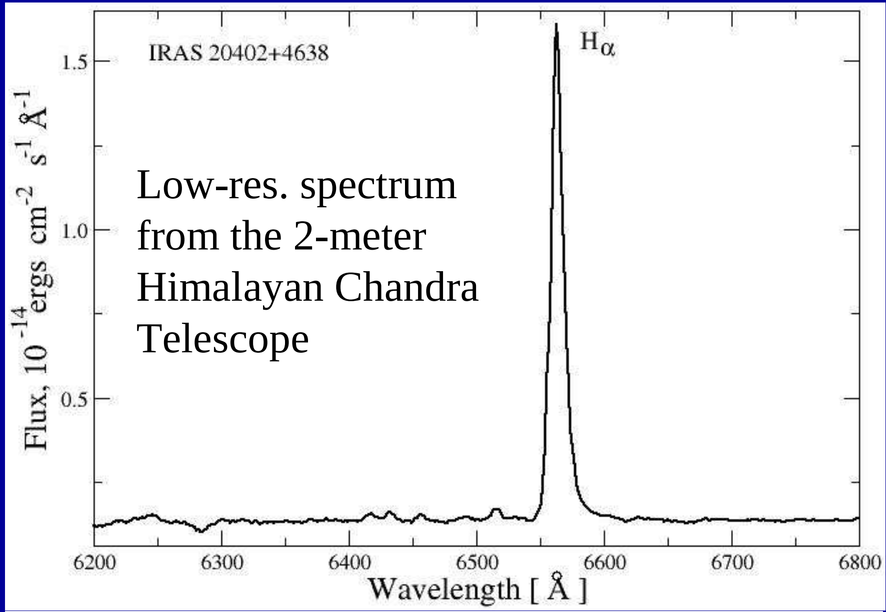
10 – Kuratova et al. (2017, ASP Conf. Ser, 508, 229) NOMAD

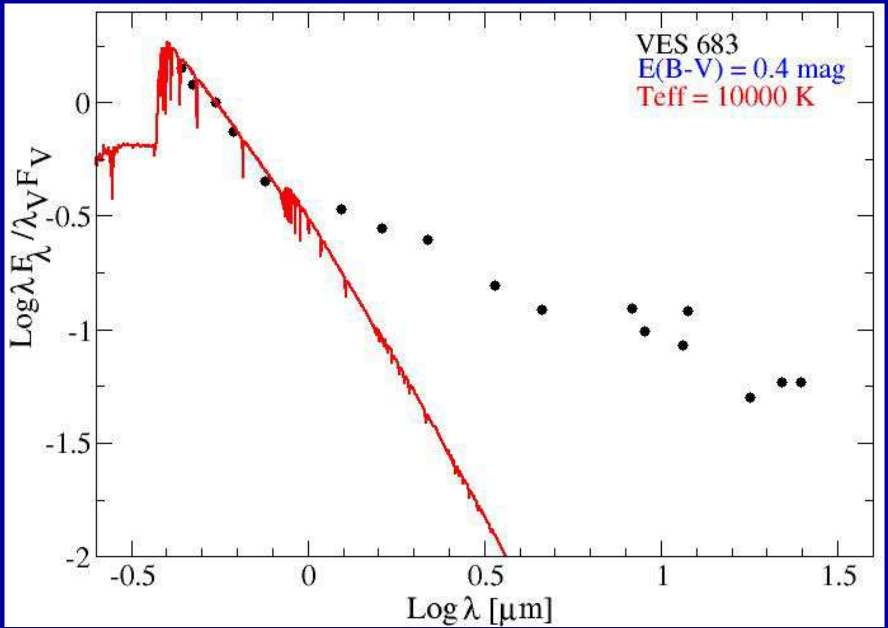
23 new based on UCAC4 and 2MASS (45 observed out of 80 candidates)

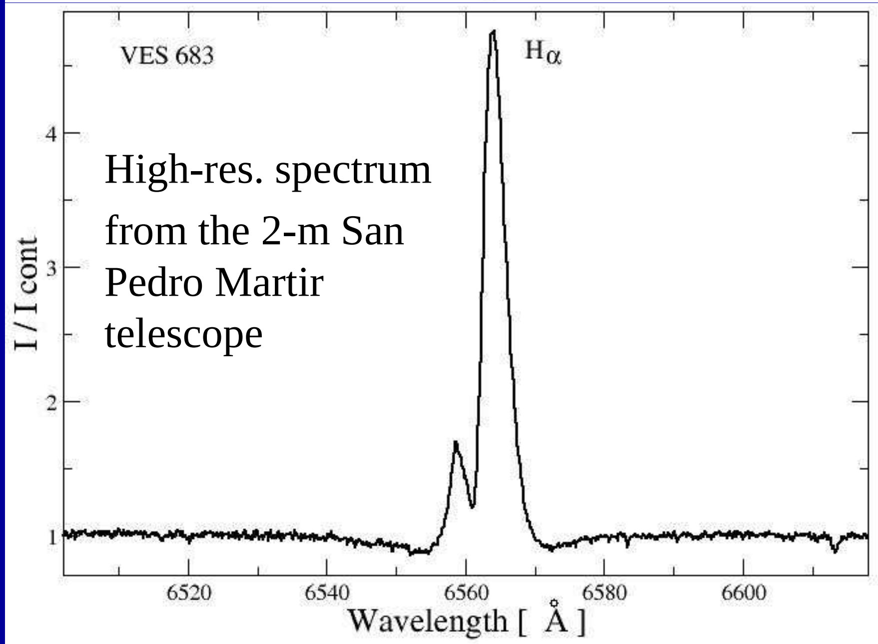
Total: over 100 members and candidates (keeps growing)

Newly Found Candidates





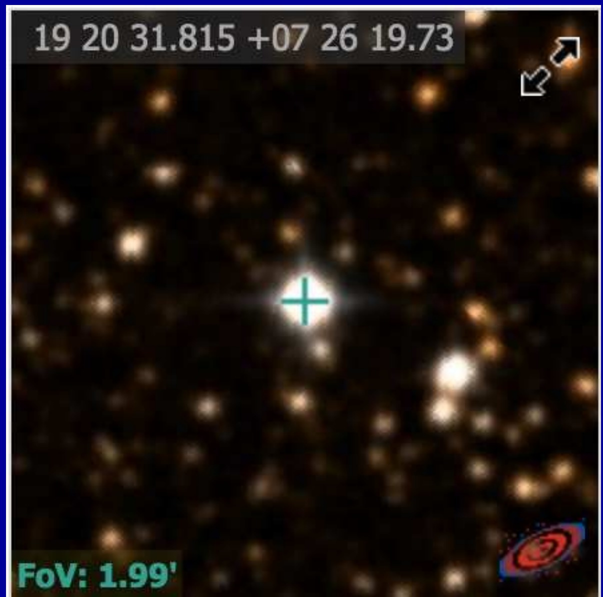


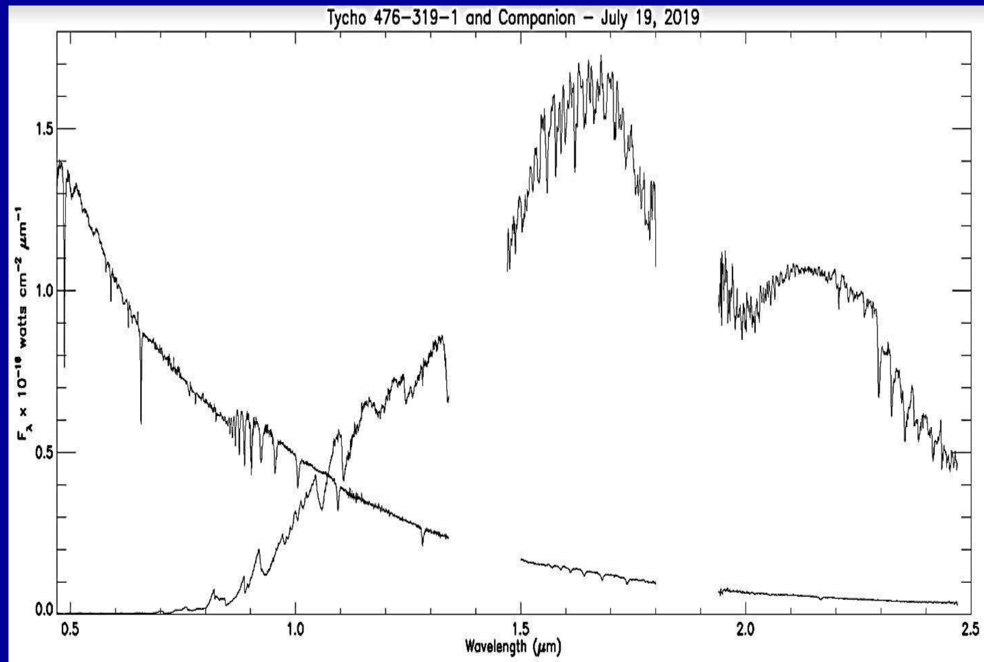


Impostors

Similar photometric properties may have:

- Carbon stars (3 objects)
- Visual hot + cool star pairs (4 objects)
- Distant hot stars affected by strong interstellar reddening





Low-res. Spectra of the components of a close pair TYC 476-319-1

3-m Lick Obs. telescope + spectrometer NIRIS (Rudy et al.,AJ,118,666 1999)

Conclusions

- FS CMa objects is a large, still growing group of hot stars with circumstellar dust (**>70 objects in the Galaxy and 8 in the LMC**)
- Can be important for the Galactic dust budget

Nature:

- Binary systems: check calculations of interacting binaries evolution + adding circumstellar matter evolution to this modeling
- Single stars with unusually strong winds or mergers

- Further studies: regular high-resolution & high S/N observations, search for precursors and descendants

Observing Campaign Announcement
δ Sco – Next Periastron

Very bright binary: V = 1.6 - 2.3 mag, Dec. $-22^{\circ}\ 37'$

Orbital period : 10.8092 ± 0.0005 years = 3948.0 ± 1.8 days

Next periastron: 2022 April 22 – 26 (JD 2459693.9 ± 1.8)

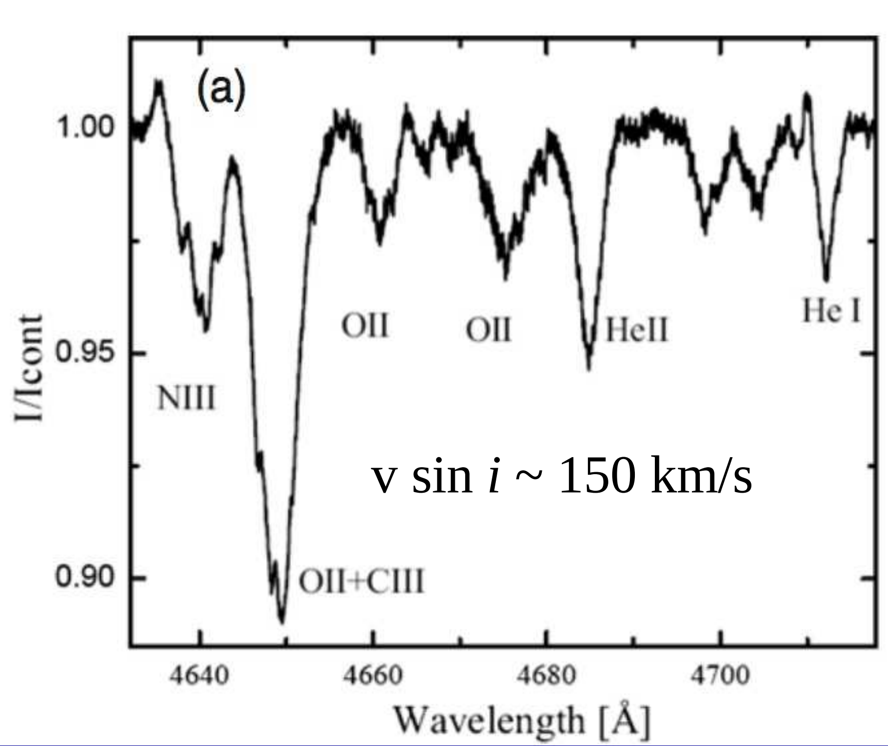
Can be observed between late January and late September

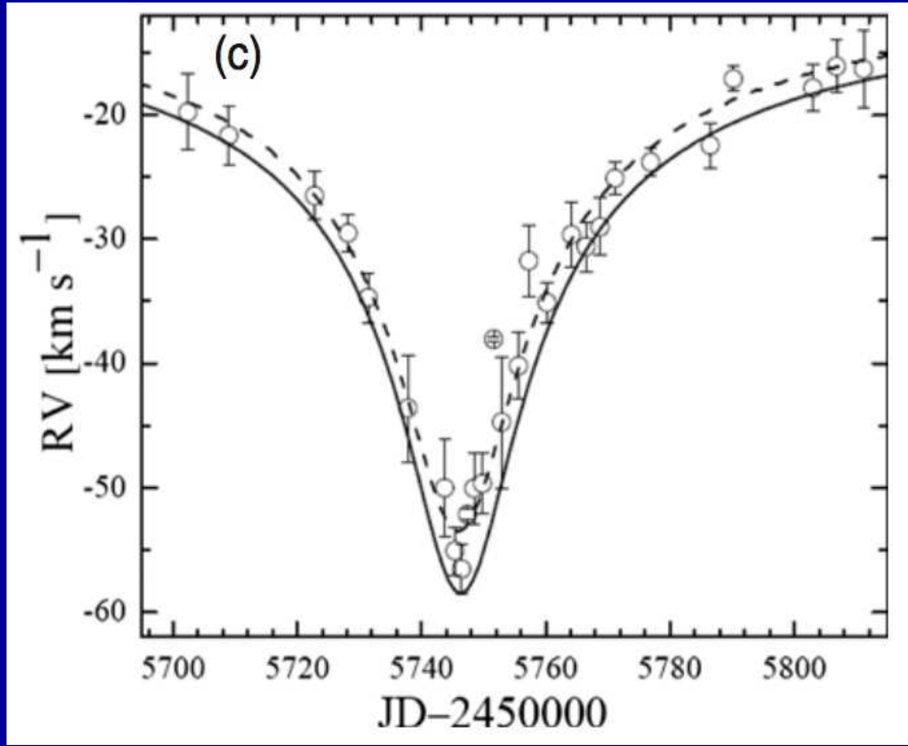
Campaign time frame: Spring 2021 to Fall 2022

Goals (at least):

- Monitor spectral line variations in profiles and radial velocity (most important – Hα and He II 4686 Å)
- Further orbit refinement
- Study secondary's impact on the primary's disk
- Search for signatures of the secondary

δ Sco at periastron 2011





Spectrum taken at the 3.6-meter Canada-France-Hawaii Telescope (R ~ 65,000)

Radial velocity curve for the He II 4686 Å line near periastron time.
Solid line – orbit 2000

Dashed line – orbit 2011

From Miroshnichenko et al. (2013, ApJ, 766, 119)

Pro-Am campaign including 10 clear night at a 0.8-m telescope on Tenerife

Conference announcement

“Hot Stars: Life with Circumstellar Matter”

Almaty, Kazakhstan, July 2022

Main focus on hot stars with circumstellar material, which shows up as spectral line emission, excess radiation in the visual and infrared regions, stellar spectrum veiling, nebulocities, brightness and spectrum variations.

Types of object: pre-main-sequence Herbig Ae/Be stars, Be stars, objects with the B[e] phenomenon, hot supergiants, Wolf-Rayet stars, Luminous Blue Variables, and planetary nebulae.

Email: al.stars2020@gmail.com

Website: https://almaty-stars2020.org