Forbidden Ca lines as disc tracers

Spectroscopic survey of emission-line stars. I. B[e] stars

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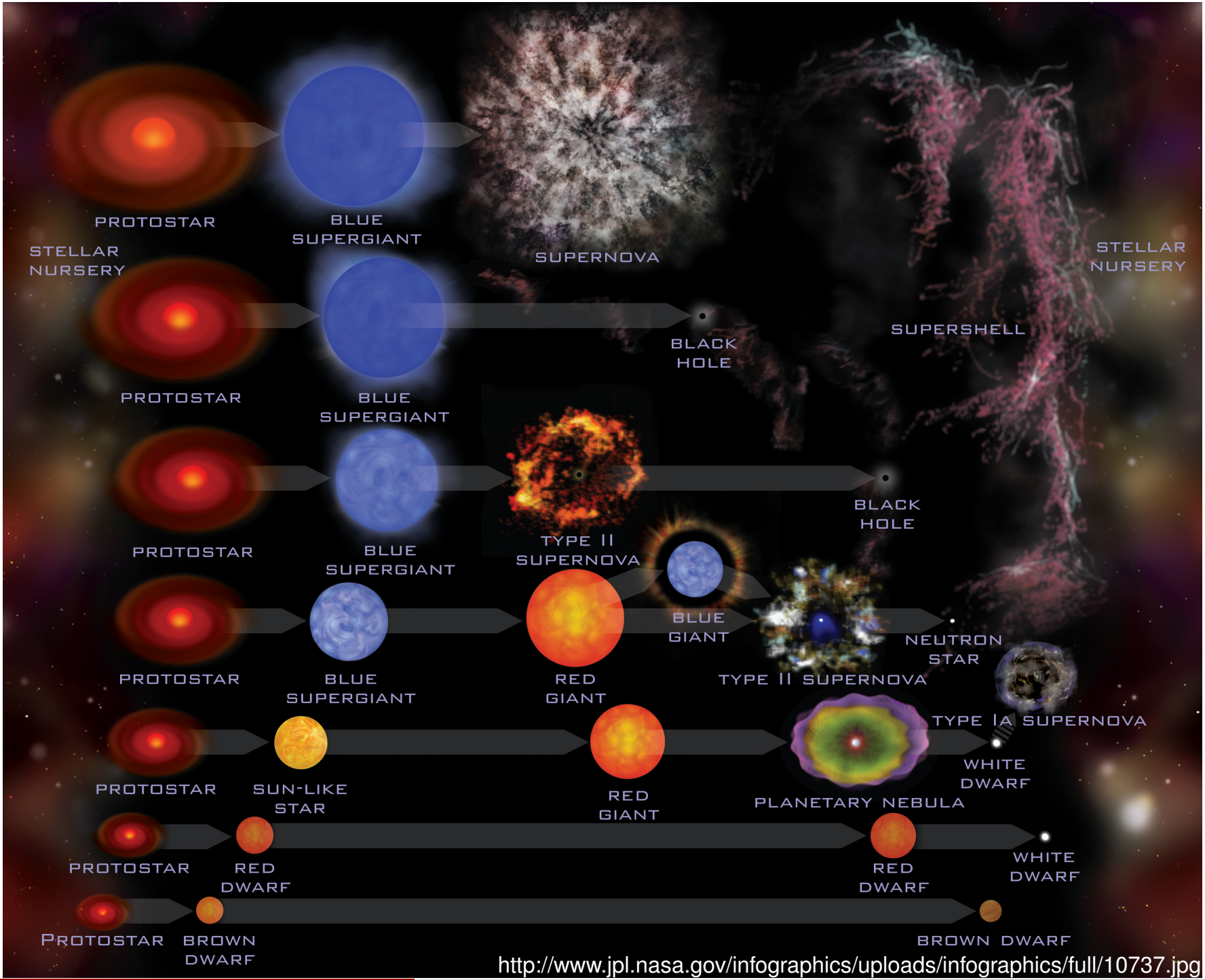
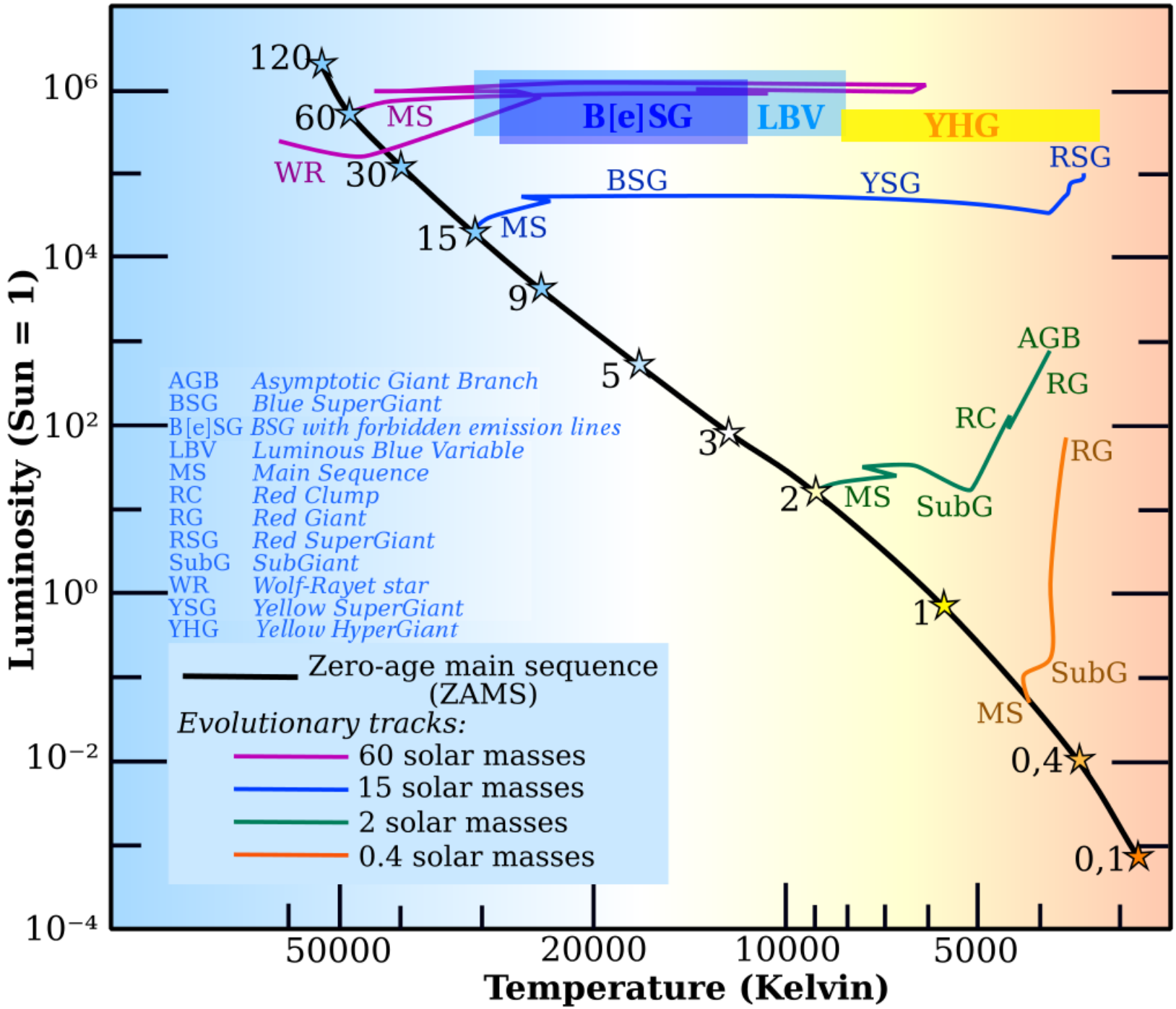
A Science Vision for European Astronomy in the Next 20 Years

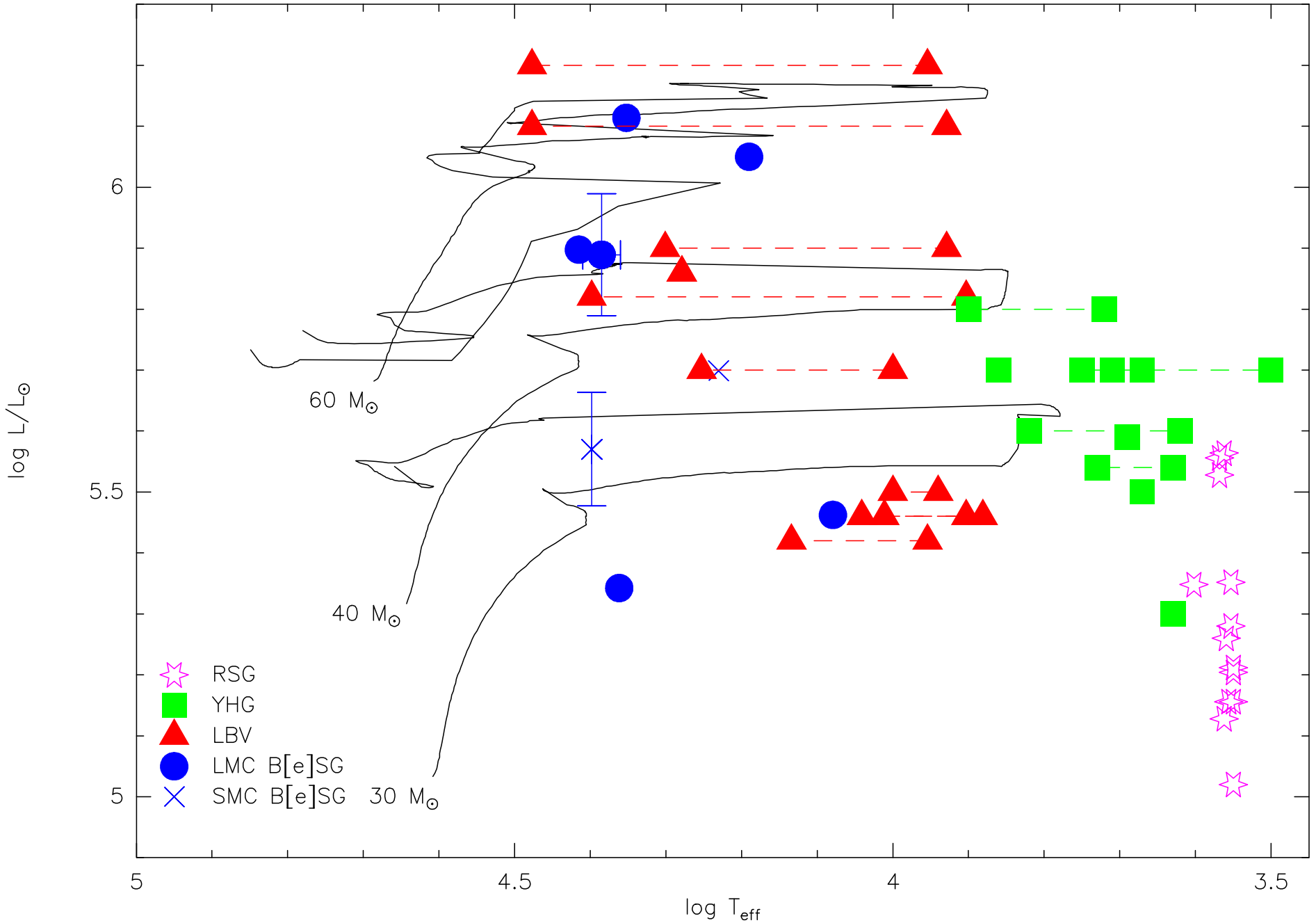
- **What is the origin and evolution of stars and planets?**
  - How do stars form?
  - Do we understand stellar structure and evolution?
  - What is the life-cycle of the interstellar medium and stars?
  - How do planetary systems form and evolve?
  - What is the diversity of planetary systems in the Galaxy?
  - Is there evidence for life on exoplanets?
- How do galaxies form and evolve?
- Do we understand the extremes of the Universe?
- How we fit in?



http://www.jpl.nasa.gov/infographics/uploads/infographics/full/10737.jpg



https://commons.wikimedia.org/wiki/File:Stellar_evolutionary_tracks-en-with-text.svg

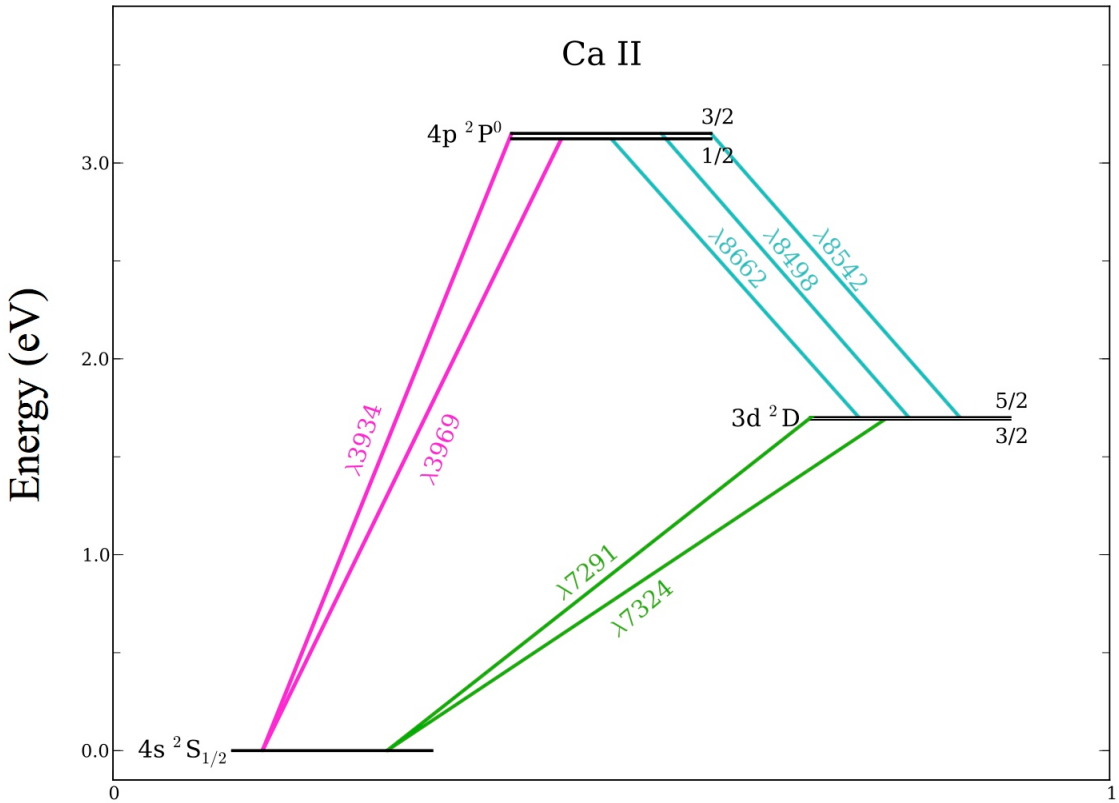


Aret et al. 2012, MNRAS 423, 284

Disc tracers

Tracers for structure and kinematics of circumstellar matter:

- Dust: imaging, interferometry
- Molecules: CO, SiO ...
- H neutral regions: [O I], [Ca II],
- H ionized regions: H recombination lines



Marziani et al. arXiv:1311.1529

Survey

1. Goal
   Study physical conditions traced by [CaII] lines and to investigate how common they are.
2. Objects
   Emission-line stars surrounded by dense circumstellar material:
   evolved stars: Be and B[e], Yellow Hypergiants (YHG), post-AGB etc.
   young stars: Herbig Ae/Be, T-Tauri, FU Orionis stars, etc.
3. Instruments
   - Coudé spectrograph @ Ondřejov 2 m telescope, Czech Republic[1]
   - FEROS @ ESO 2.2 m telescope, Chile[2]
   - FIES @ NOT 2.5 m, Spain
   - NES @ BTA 6 m, Russia

[1] A. Aret, M. Kraus, M. Šlechta, Spectroscopic survey of emission-line stars - I. B[e] stars, 2016, MNRAS, 456, 1424
[2] A. Aret, M. Kraus, M.F. Muratore, M. Borges Fernandes, Observational tracers for high-density disc-like structures around B[e] supergiants, 2012, MNRAS, 423, 284

Sample

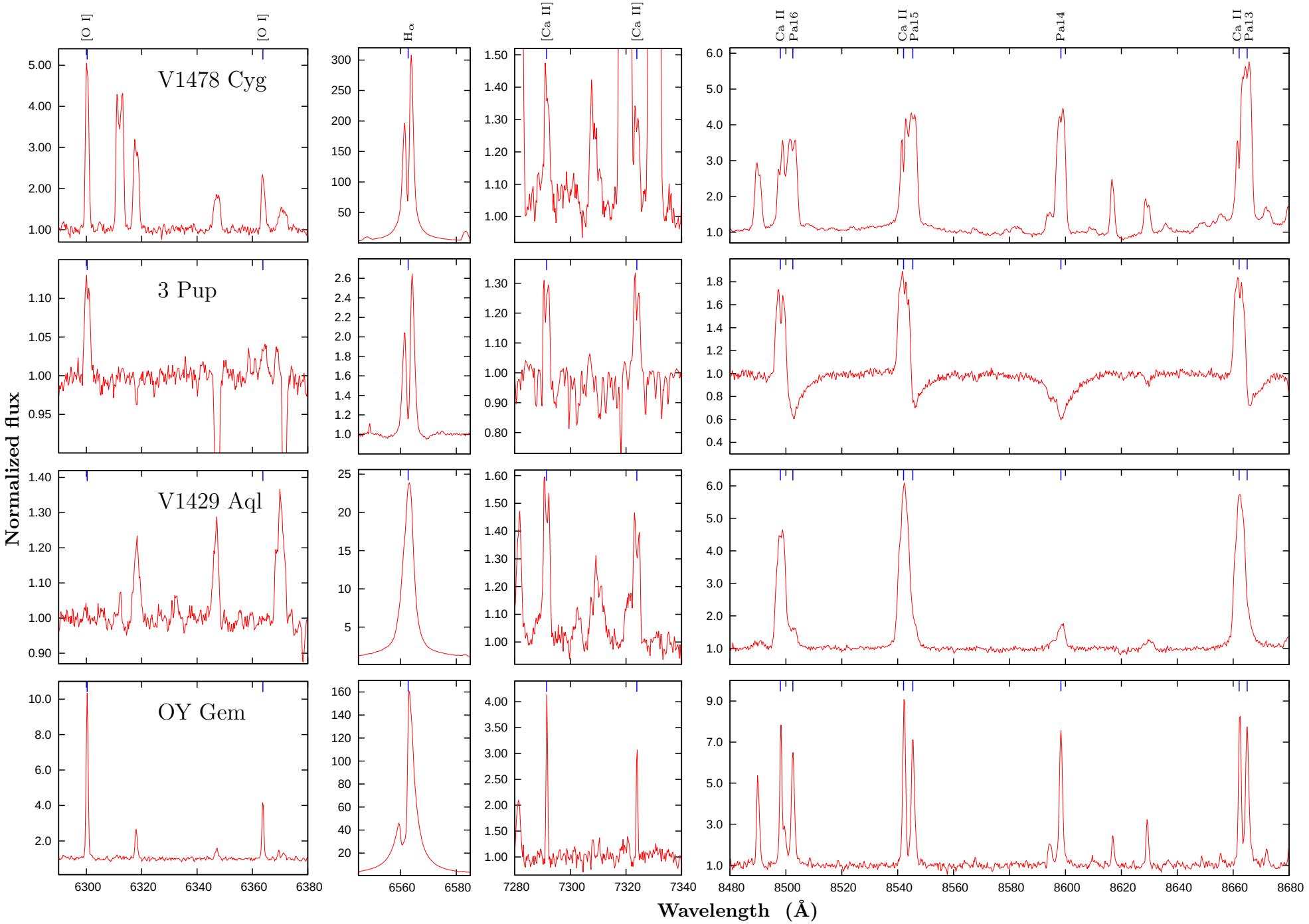
9 B[e] stars, 4 YHGs, 1 post-AGB star, 2 peculiar objects with dense disks,
30 Be stars and 3 emission-line stars of O–B types,
9 pre-main-sequence stars.

Spectra are obtained with Coudé spectrograph @ Ondřejov 2-m telescope:

- [O I] $\lambda\lambda$6300, 6364 – $R \simeq$13 000 ($\sim 23\,\mathrm{km\,s^{-1}}$)
- [Ca II] $\lambda\lambda$7291, 7324 – $R \simeq$15 000 ($\sim 20\,\mathrm{km\,s^{-1}}$)
- Ca II IR triplet $\lambda\lambda$8498, 8542, 8662 – $R \simeq$18 000 ($\sim 17\,\mathrm{km\,s^{-1}}$)

Star	Class	[Ca II]	[O I]	Ca II IR	$M_*/\mathrm{M}_\odot$	Disc, incl.
V1478 Cyg	B[e]SG	D	S	D	38	yes, 82°
3 Pup	B[e]SG	D	D	D	15-20	yes, 38°
CI Cam	B[e]SG cand	–	–	D	$>$12	uncertain
V1972 Cyg	B[e]SG cand	–	S	emiss.	–	uncertain
V1429 Aql	B[e]SG cand	D	emiss.	S	66	yes, 73°
OY Gem	B[e] cPNe	S	S	S	0.62	uncertain
V743 Mon	B[e] uncl	–	S	emiss.	5	yes, 56°
BD+23 3183	B[e] uncl	–	S	–	$<$4	uncertain
HD 281192	B[e] uncl	–	S	–	4	uncertain

S – single peaked emission line; D – double peaked emission line


[O I]
[O I]
Hα
[Ca II]
[Ca II]
Ca II Pa16
Ca II Pa15
Pa14
Ca II Pa13
V1478 Cyg
3 Pup
V1429 Aql
OY Gem
Normalized flux
Wavelength (Å)

Modelling

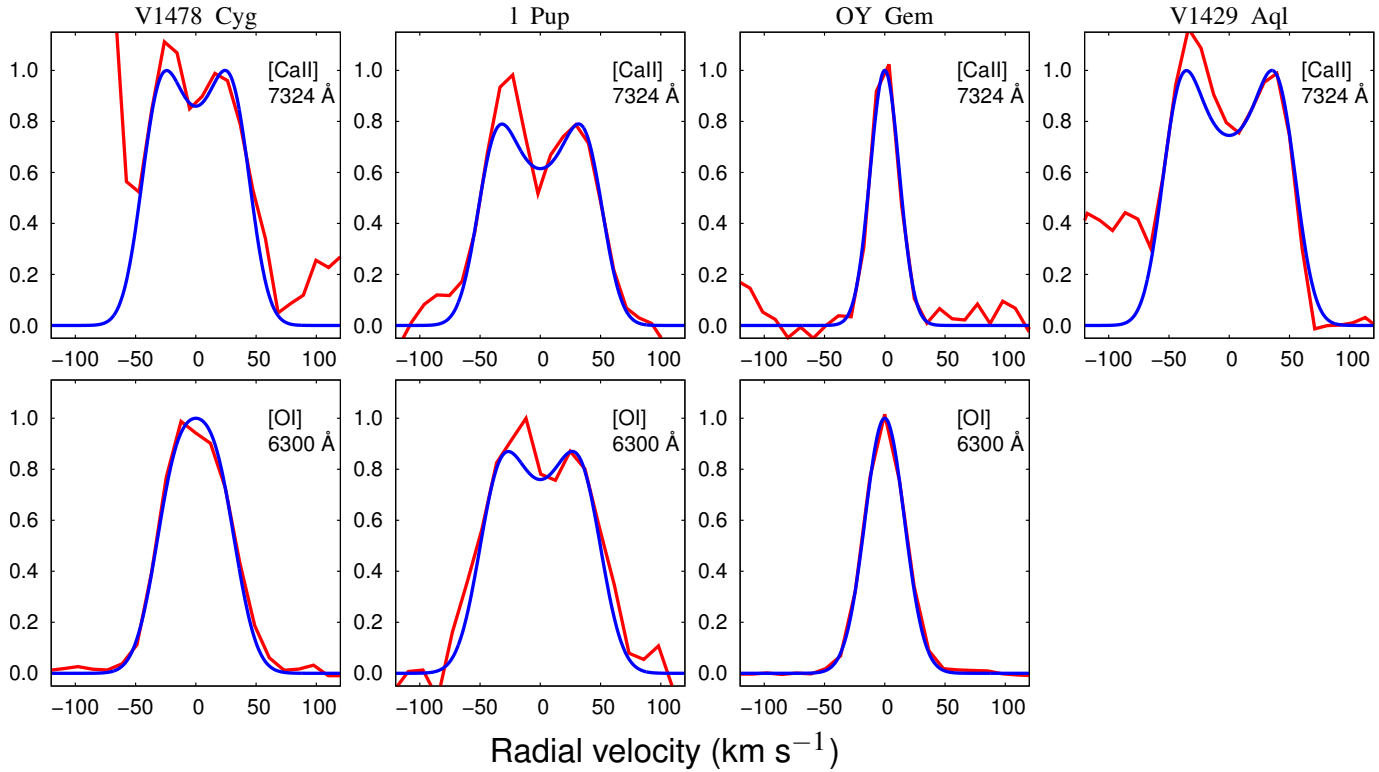
Purely kinematic model

- **Assumption**
  Emission originates from a narrow (i.e. constant velocity) rotating ring.

- **Parameters**
  - ▷ free: rotation velocity
  - ▷ fixed: inclination angle
  - ▷ fixed: resolution of the spectrograph

- **Keplerian rotation**
  $\frac{V^2}{R} = \frac{GM}{R^2} \implies R = \frac{GM}{V^2}$

Disc kinematics



		[Ca II]		[O I]	
Star	M_*[M$_\odot$]	$V_{\rm rot}$[km s^{-1}]	R [AU]	$V_{\rm rot}$[km s^{-1}]	R [AU]
V1478 Cyg	38	38±1	24.6±1.3	25±1	55.7±5.9
3 Pup	15-20	72±1	3.0±0.4	68±1	3.4±0.5
	9-10.5		1.67±0.13		1.87±0.14
V1429 Aql	66±9	50±1	23.4±4.0	–	–
OY Gem	0.62	0		0	

Conclusions

- For the B[e] supergiants V1478 Cyg and l Pup the kinematics obtained from the [O I] and [Ca II] line profiles agrees with a Keplerian rotating disc scenario.
- The LBV candidate V1429 Aql shows no [O I] lines, but the profile of its [Ca II] lines suggests that the emission originates in the hot, ionized circumbinary disc.
- Forbidden lines in the spectra of a compact planetary nebula OY Gem display no kinematical broadening beyond spectral resolution.
- Appearance of [Ca II] lines requires environments of high density and large emitting volume:
  - ▷ None of the low-mass B[e] stars displays [Ca II] line emission.
  - ▷ None of the classical Be stars displays [Ca II] line emission.