# ATMOSPHERES OF C-RICH AGB STARS OBSERVATIONS AND MODELS

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"Blowing in the Wind", 8 August 2016

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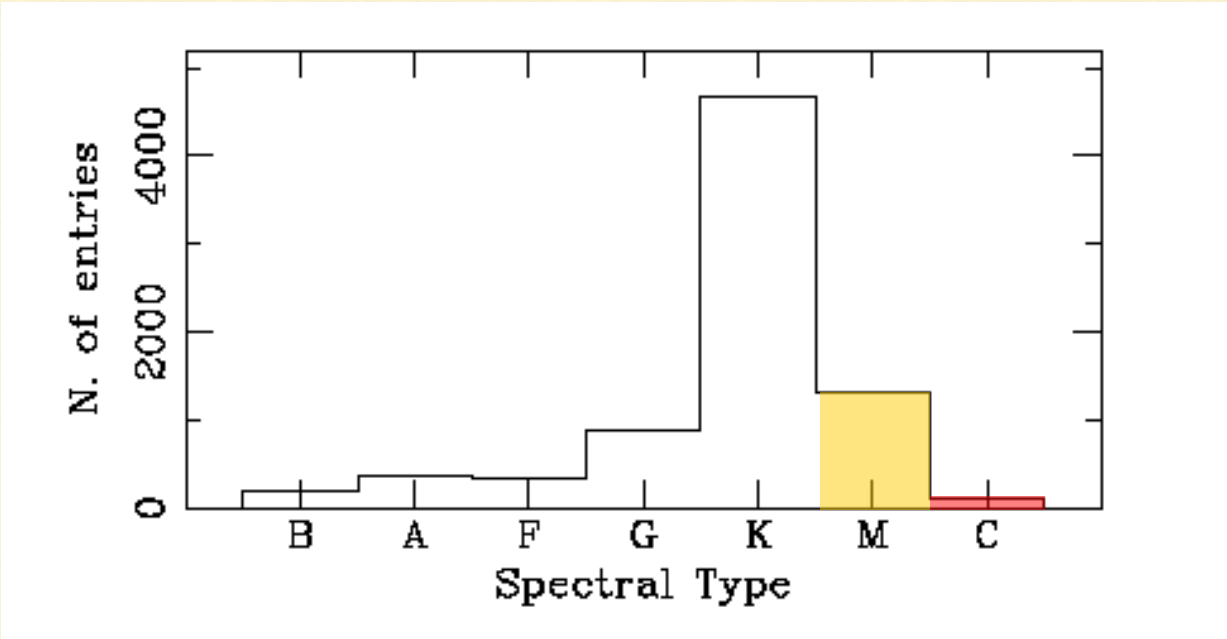
# CARBON STARS

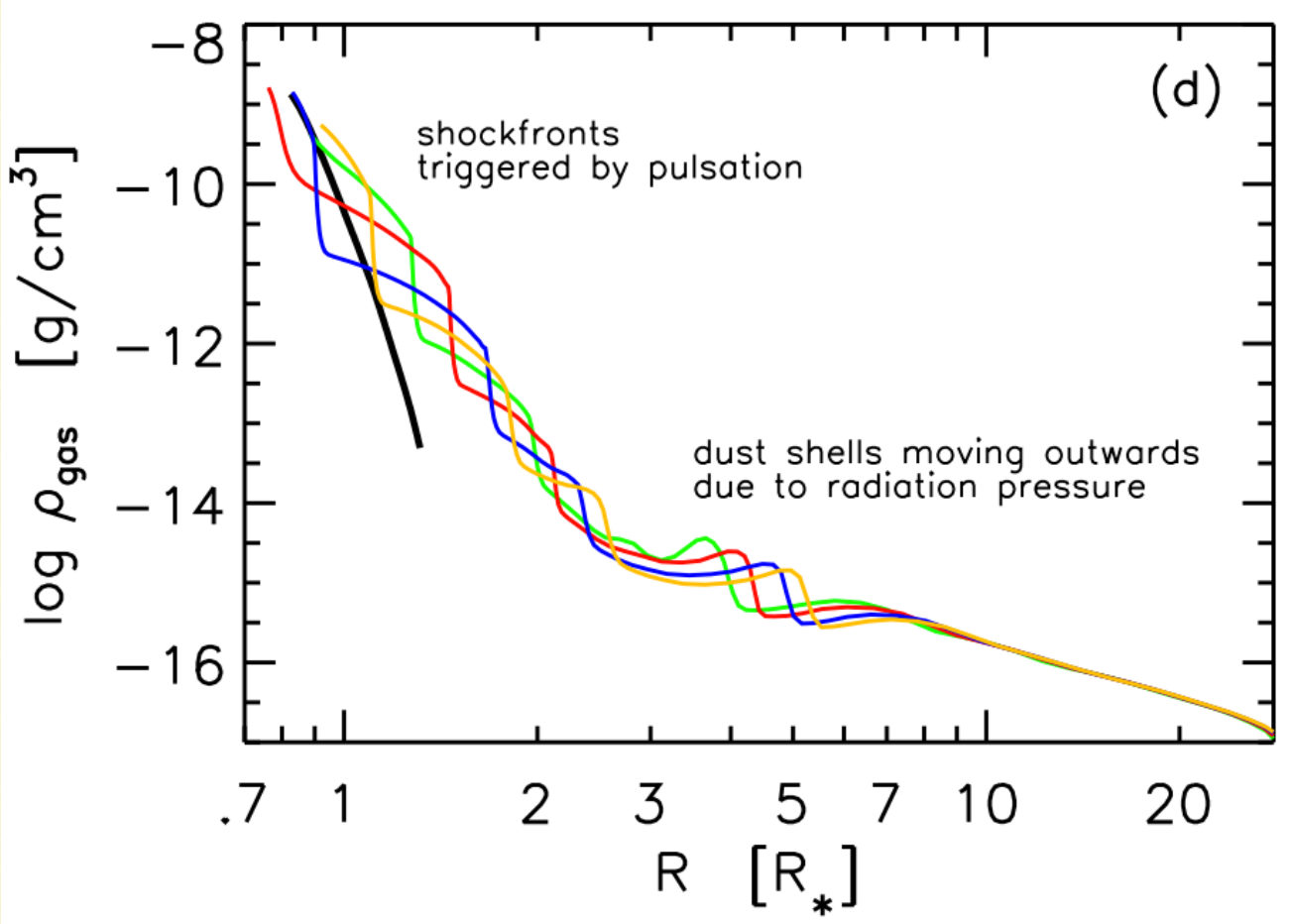
- Prominent members of stellar populations → important for stellar and galactic evolution
- Dust-formation process rather well understood → advantage for atmospheric models
- Few data from interferometry




CHARM catalog
(Richichi et al. 2005)

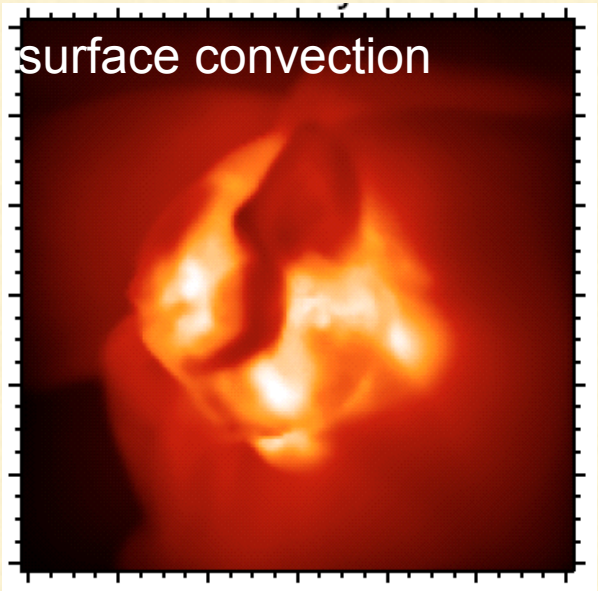
# COMPLEX ATMOSPHERES OF C-RICH AGB STARS

- Time-dependent complex radial structure of atmospheric and wind region
- Constraints for Dynamic Model Atmospheres (DMAs) by comparing with observations
- Investigate the stratification of the atmosphere —> interferometry!




Nowotny et al. (2011)

Freytag & Höfner ( 2008)

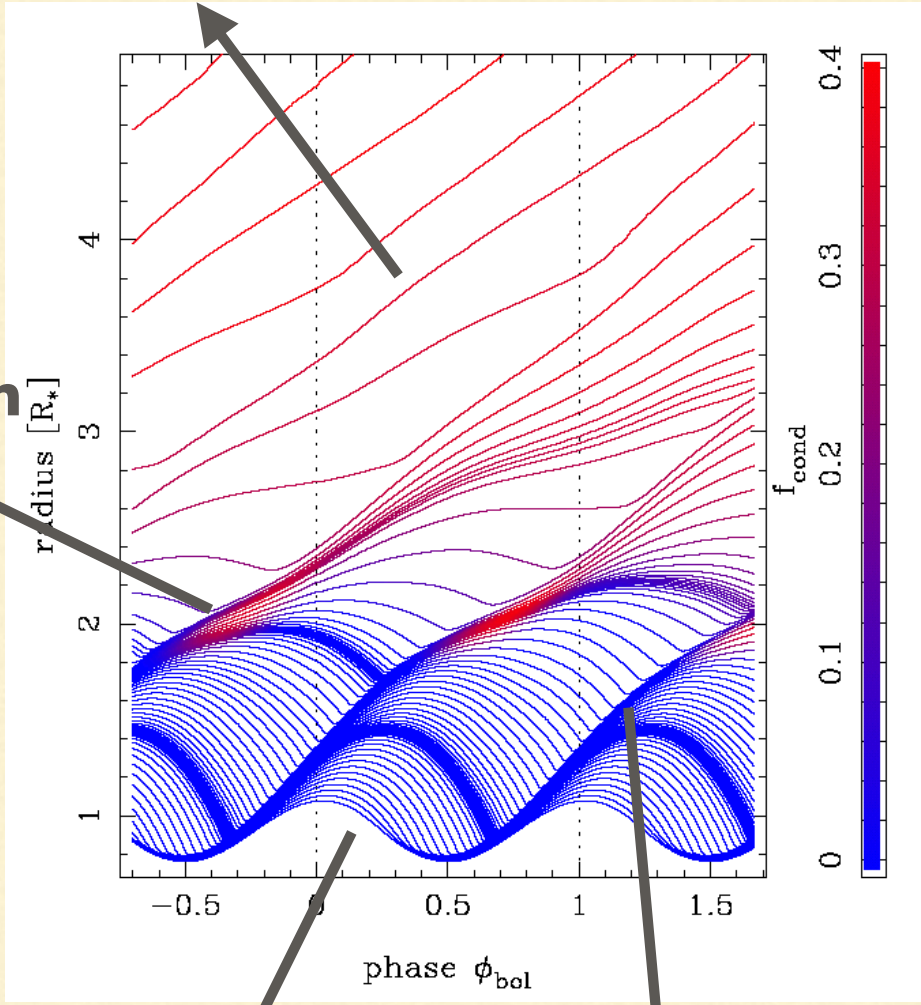



Pulsating stellar atmosphere with complex large-scale structures

**Stellar wind**

e.g. Höfner et al. ( 2003)

**Dust formation**




**Pulsation**

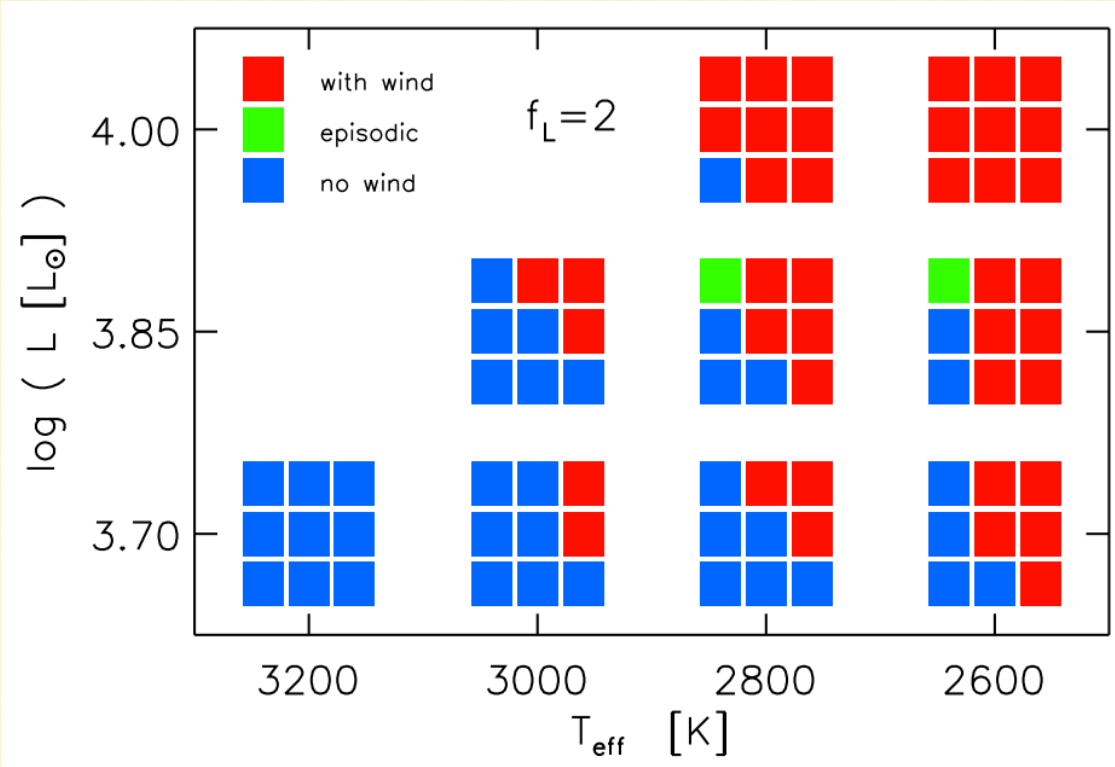
**Shock fronts**

Spatial & temporal fluctuations: temperature, density, abundance, intensity distribution, morphology of the spectrum

# DYNAMIC MODEL ATMOSPHERES (DMA)

(Mattsson et al., 2010, Eriksson et al., 2014)

- Grid of 540 Models with 140 000 time-steps (different phases of the stellar pulsation)
- Main parameters that characterize the DMA:
  L, $T_{eff}$, M, log(g), C/O, Δu
- Independent fit of SED and interferometry (computational reasons)

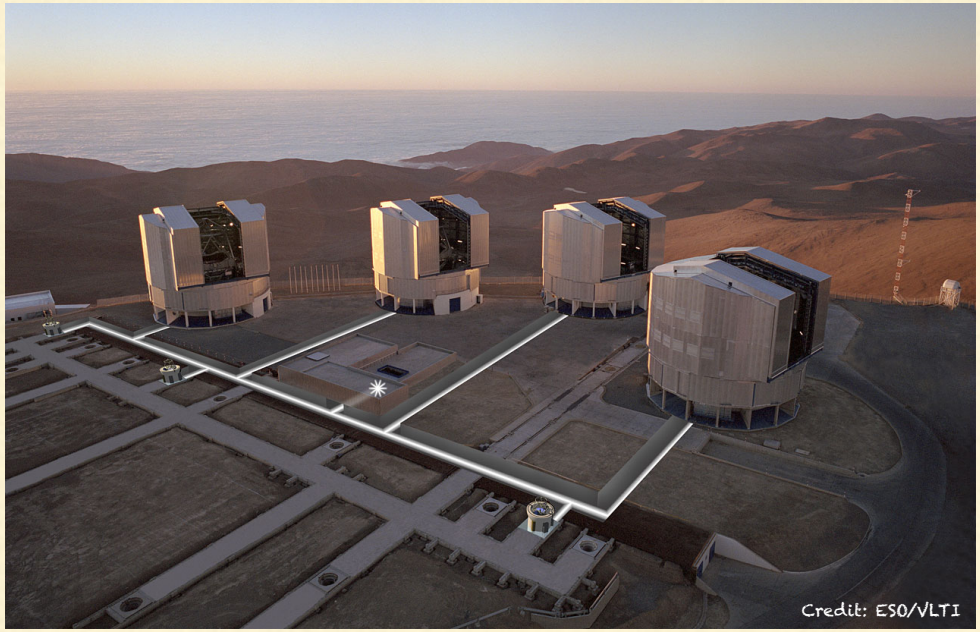


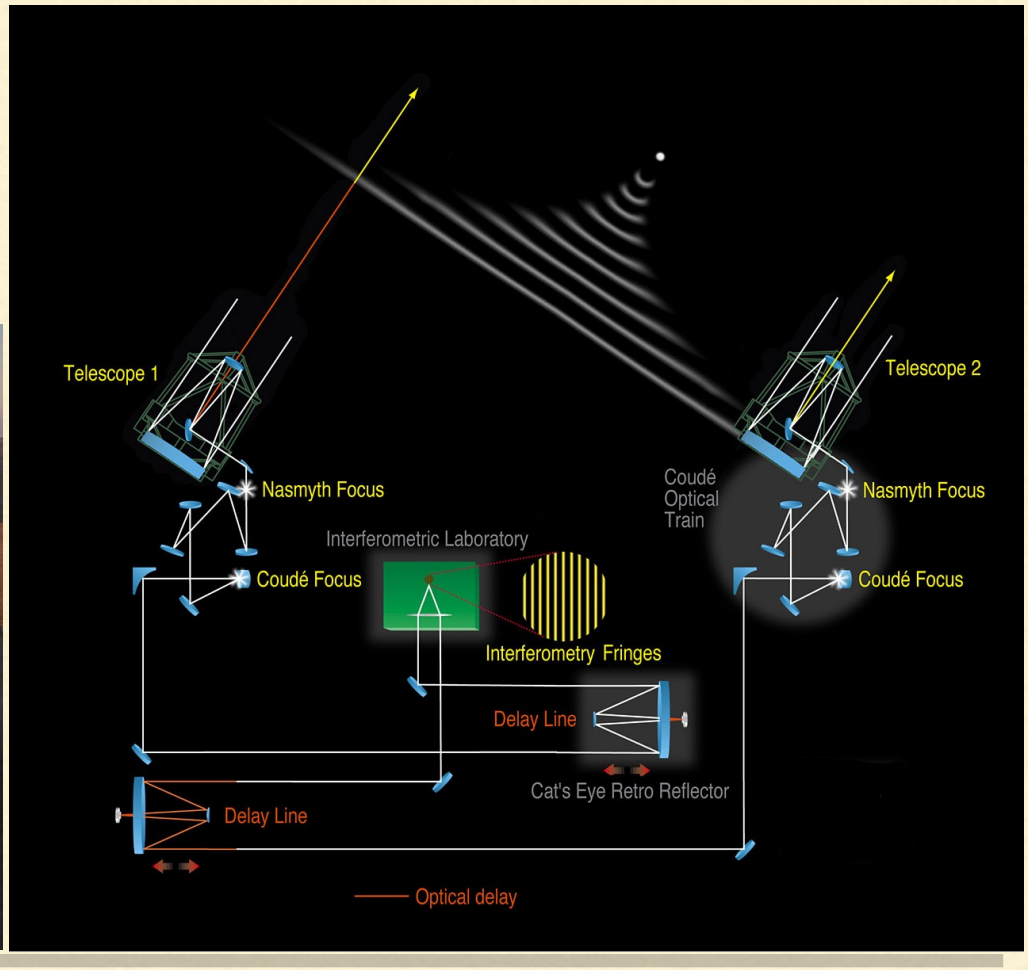

Eriksson et al. (2014)

# INTERFEROMETRY

- Light combined from different apertures
- VLTI/MIDI: MID-infrared Interferometric Instrument
- 2 telescopes
- N-band
- Observables: visibility, differential phase, spectrum

**With interferometry we can study the stratification of the stars atmospheres**

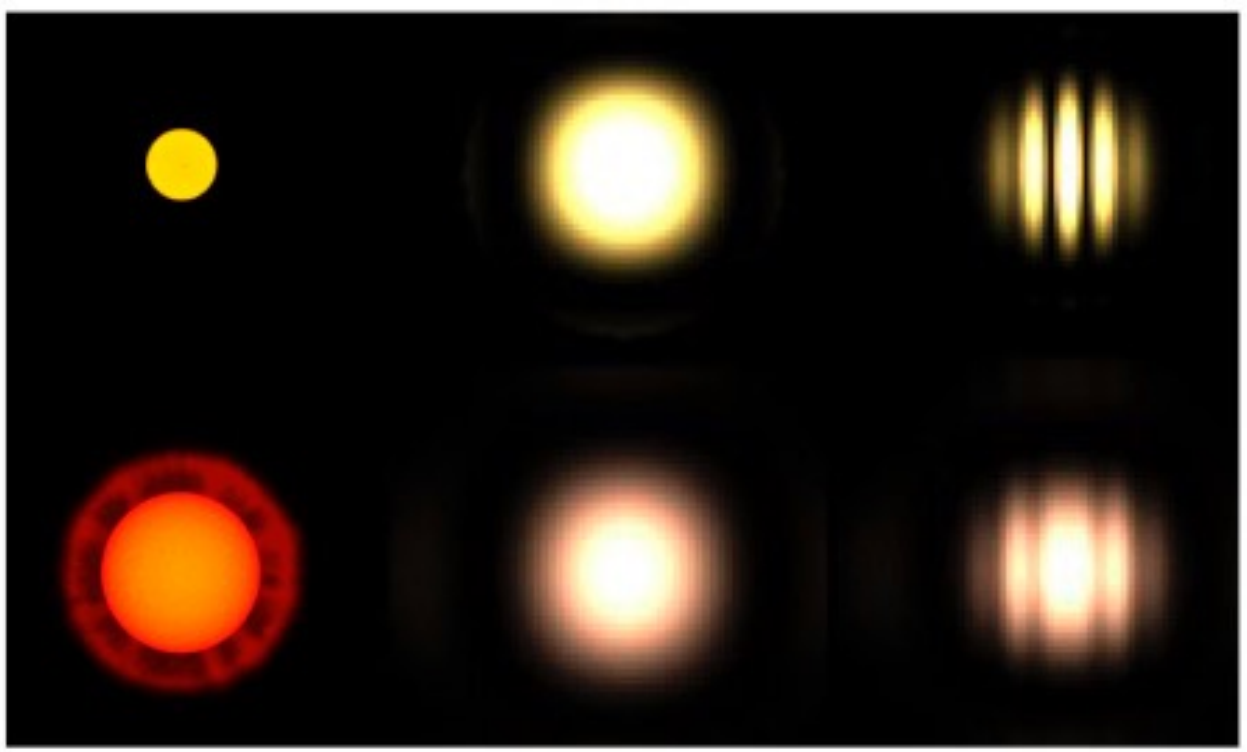


# WHAT DO WE MEASURE?

- We observe—> FRINGES
- We measure a complex quantity—> VISIBILITY

- **Fringe visibility = contrast between fringes—> angular dimension of the object**
- **Fringe phase related to the location of the fringes—>symmetry of the object**

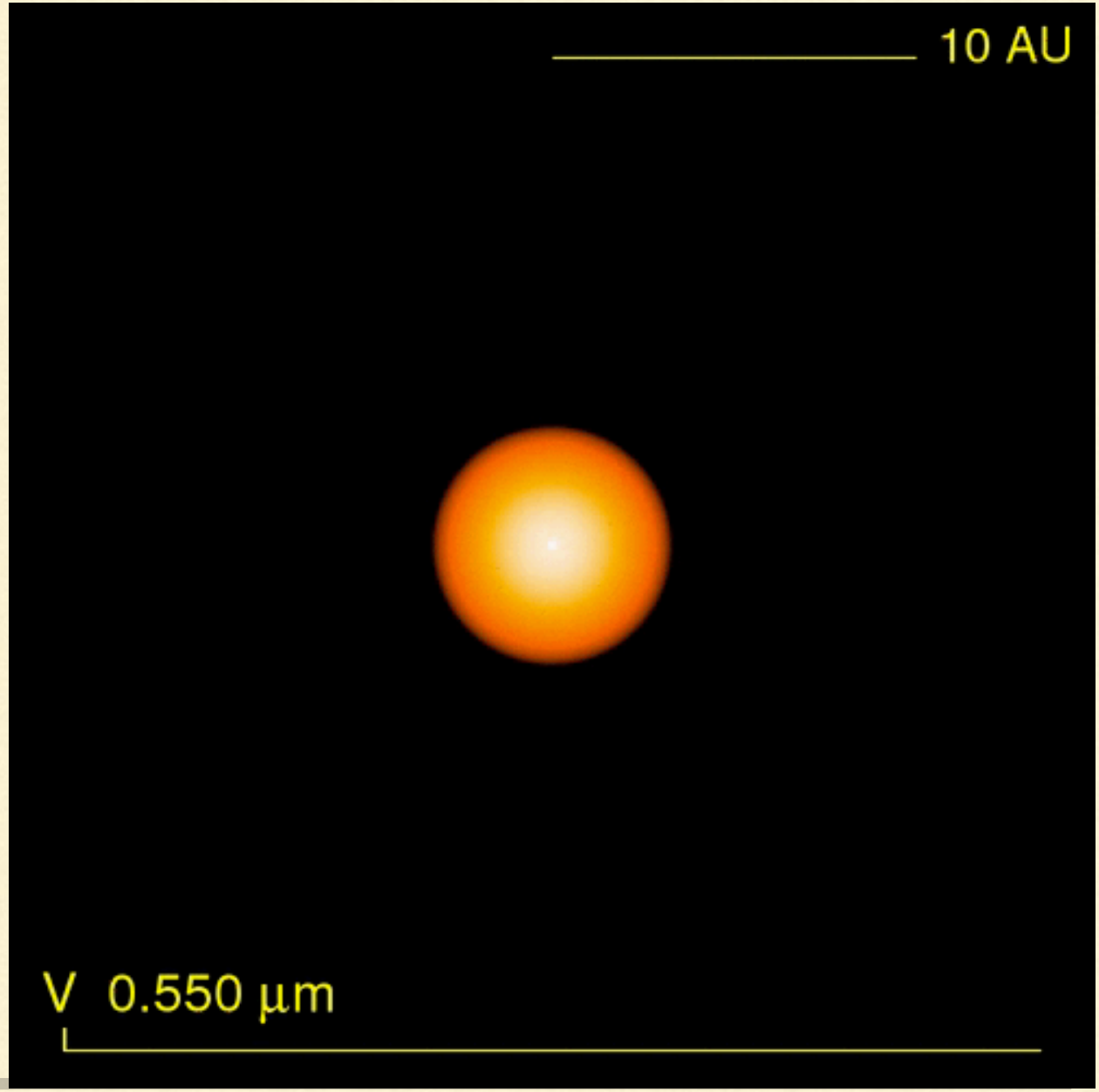


Interferometric Fringes from Star with Different Angular Diameters
(Simulation)

ESO PR Photo 10d/01 (18 March 2001 )

# SYNTHETIC INTENSITY PROFILES

- Based on dynamic models for C-stars by Höfner et al. 2003 (1-D, frequency-dependent radiative transfer, piston for pulsation, time-dep. formation of amorphous carbon)
- Profiles and visibilities calculated for narrow and broad band filters
- Visibility is the Fourier transform of the intensity profile



# THE SAMPLE OF C-RICH STARS

- RU Vir → Rau et al. (2015)
- R Lep
- R Vol
- R For

} Mira

- Y Pav
- U Hya
- AQ Sgr
- X TrA

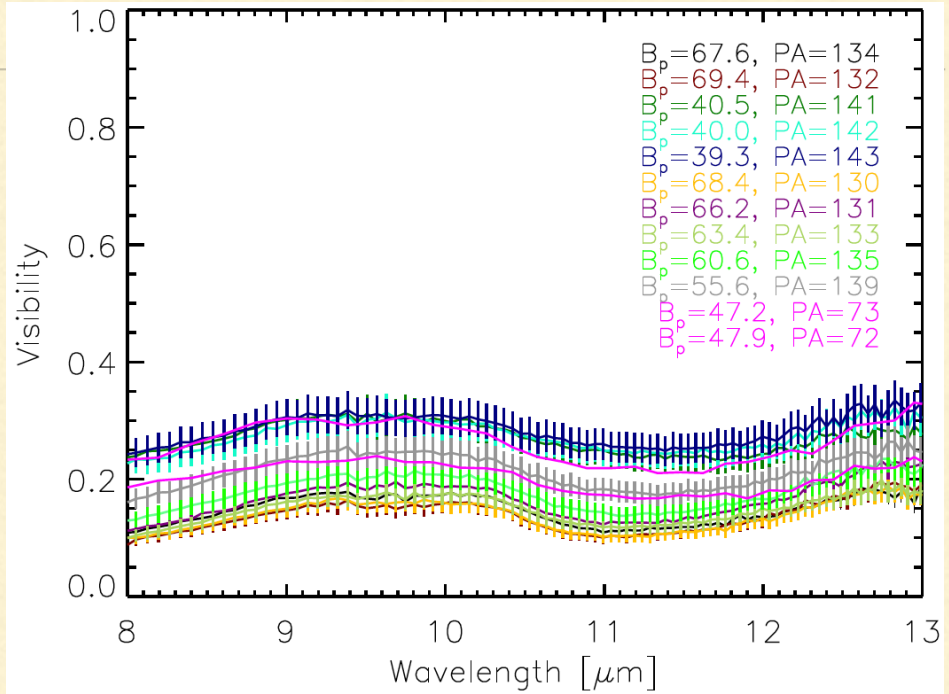
} Semiregular & Irregular

} Rau et al. (subm.) + PhD thesis

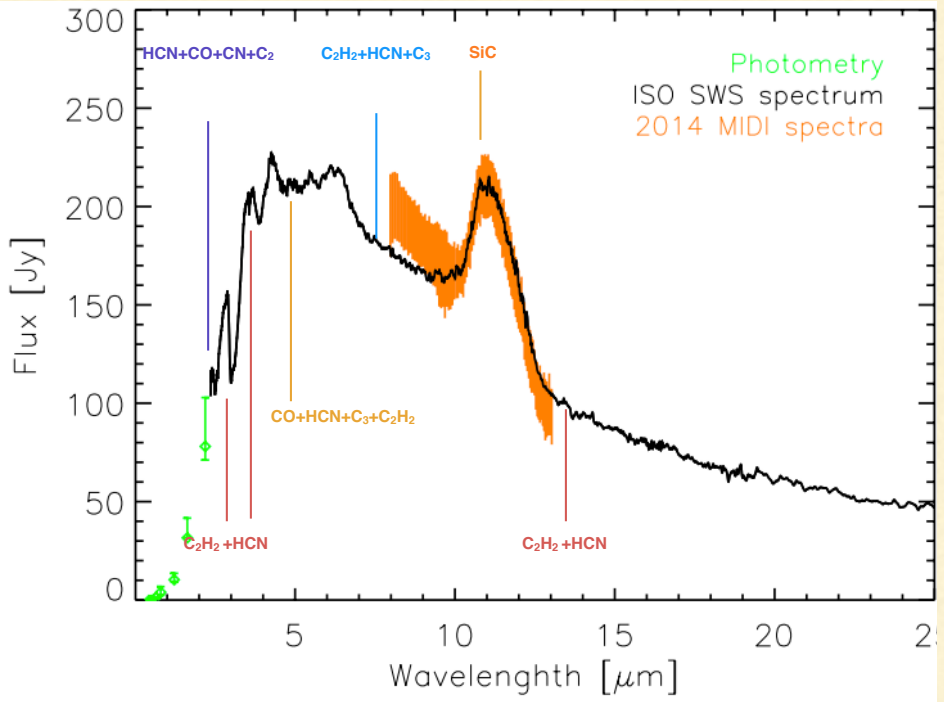
# DATA

- **Photometry**
  SAAO, ESO, ASAS, AAVSO, …
- **Spectroscopy**
  ISO SWS/IRAS/IRTF spectra
- **Interferometry**
  VLTI/MIDI

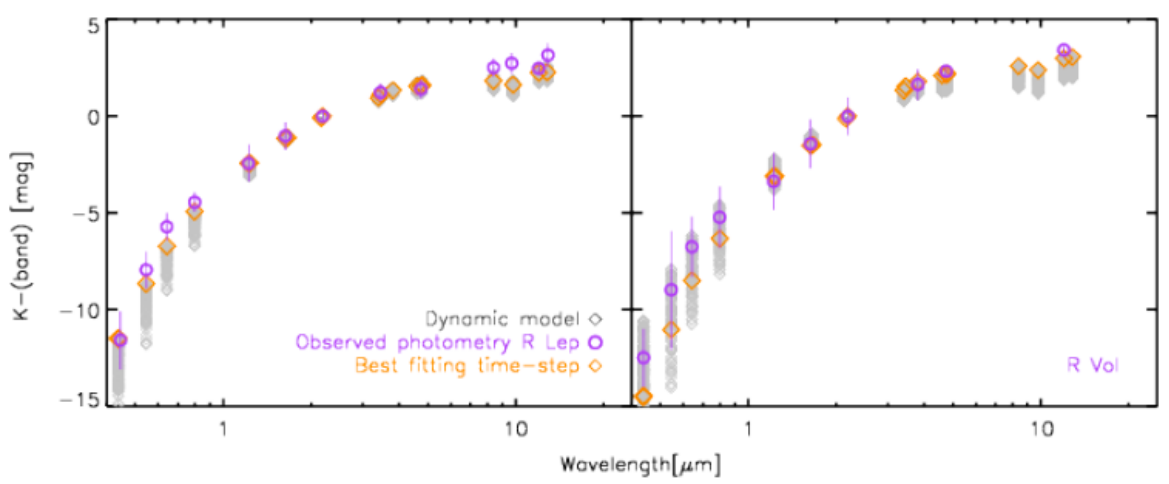
NOTE: data not taken at same phase or cycle!



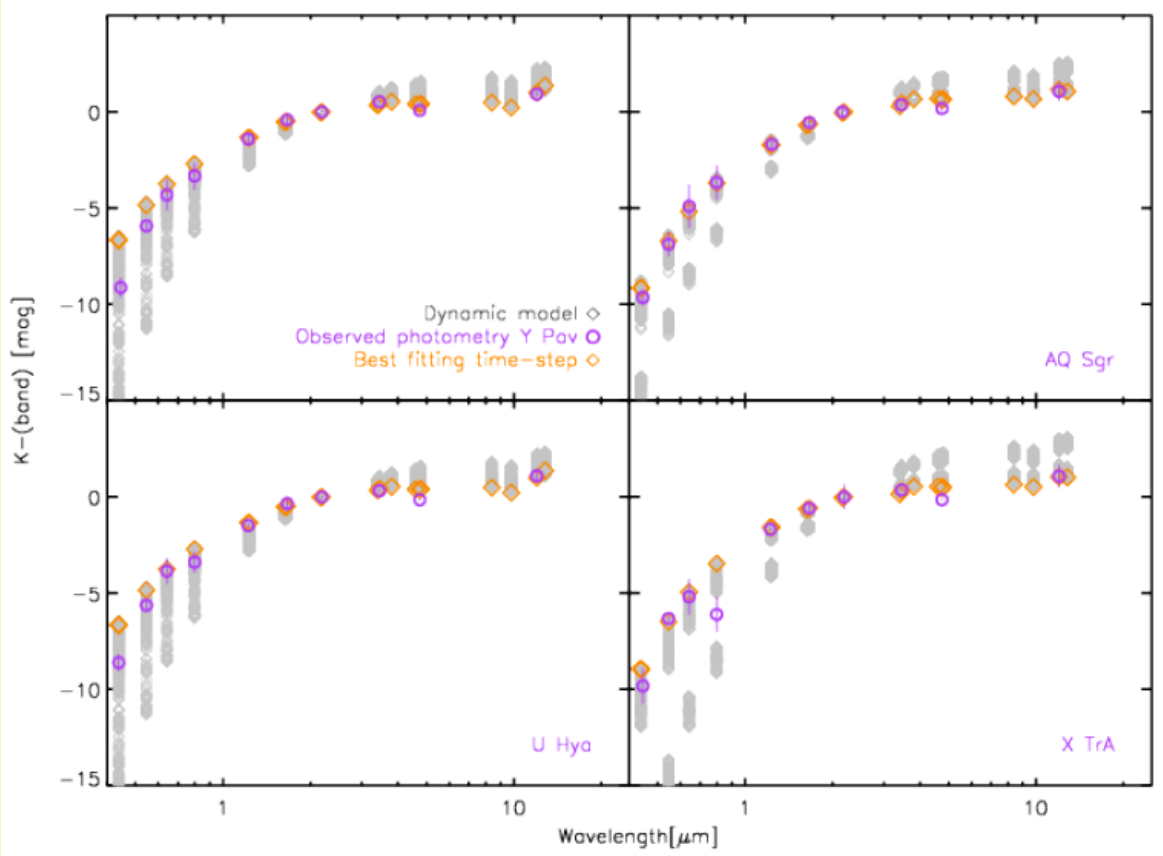

**Rau et al. (2015)**



# OTHER STARS RESULTS — SED

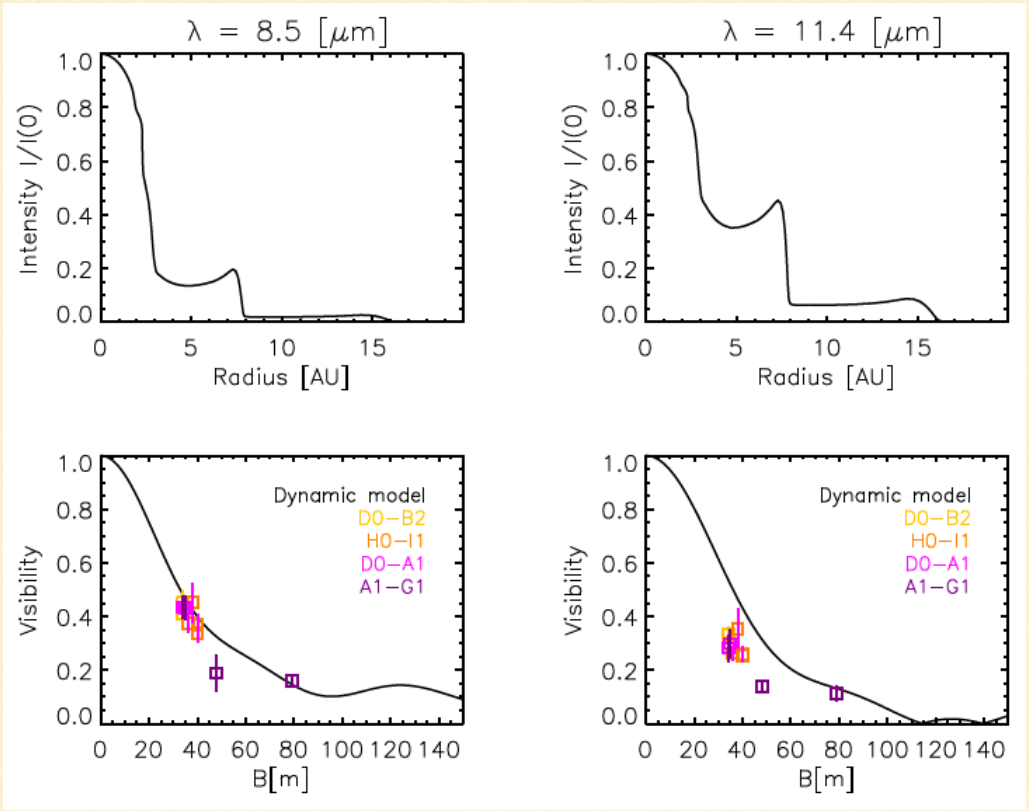



Mira stars

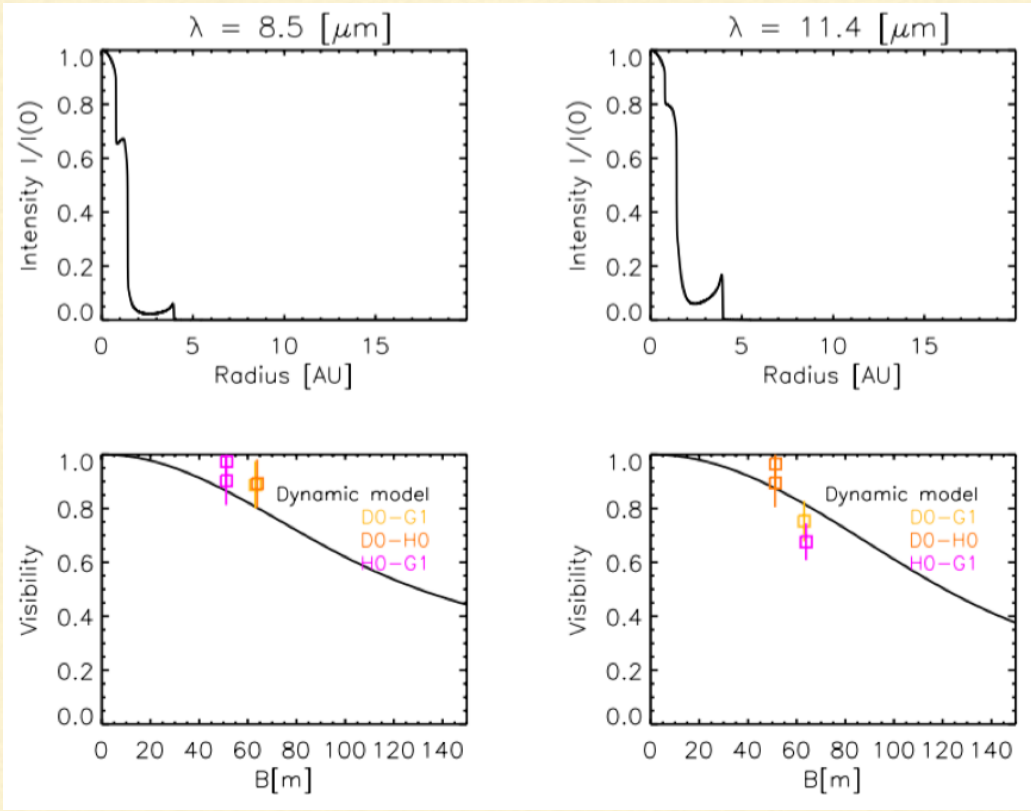



Semiregular &
Irregular stars

# RESULTS — INTERFEROMETRY I

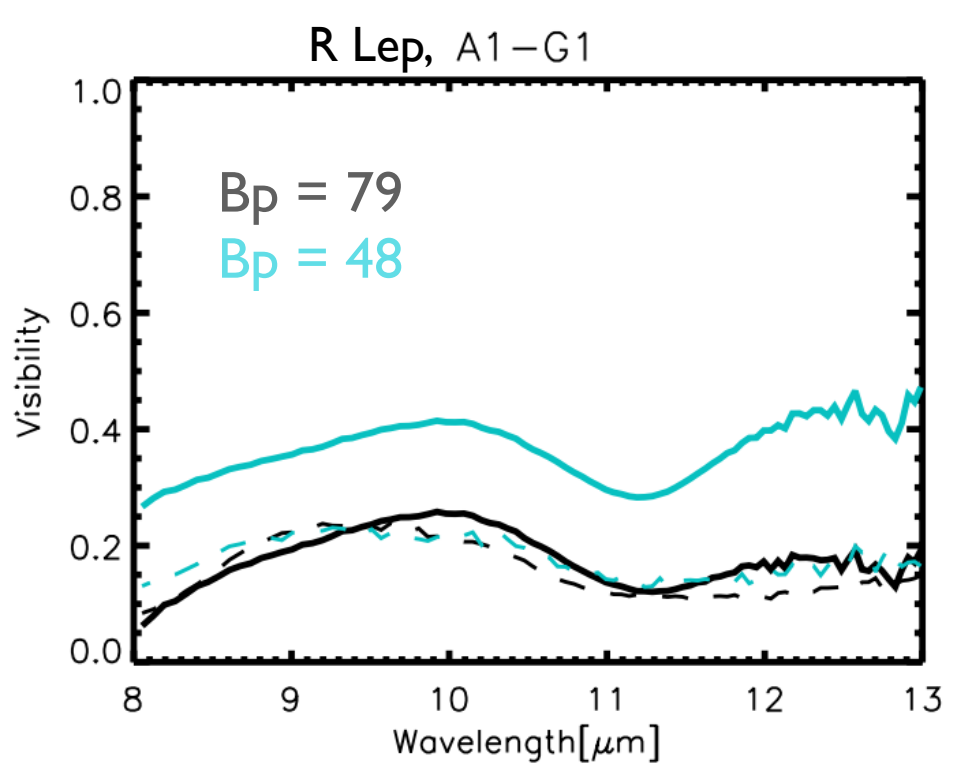


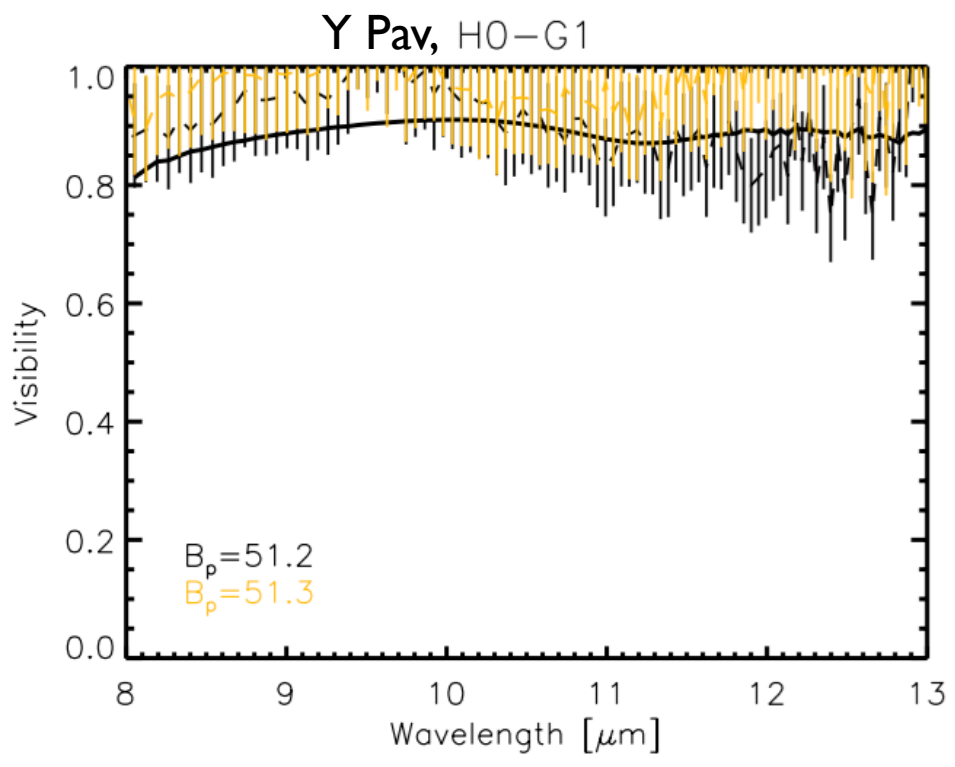

R Lep




Y Pav

# RESULTS — INTERFEROMETRY 2



# DERIVING STELLAR PARAMETERS

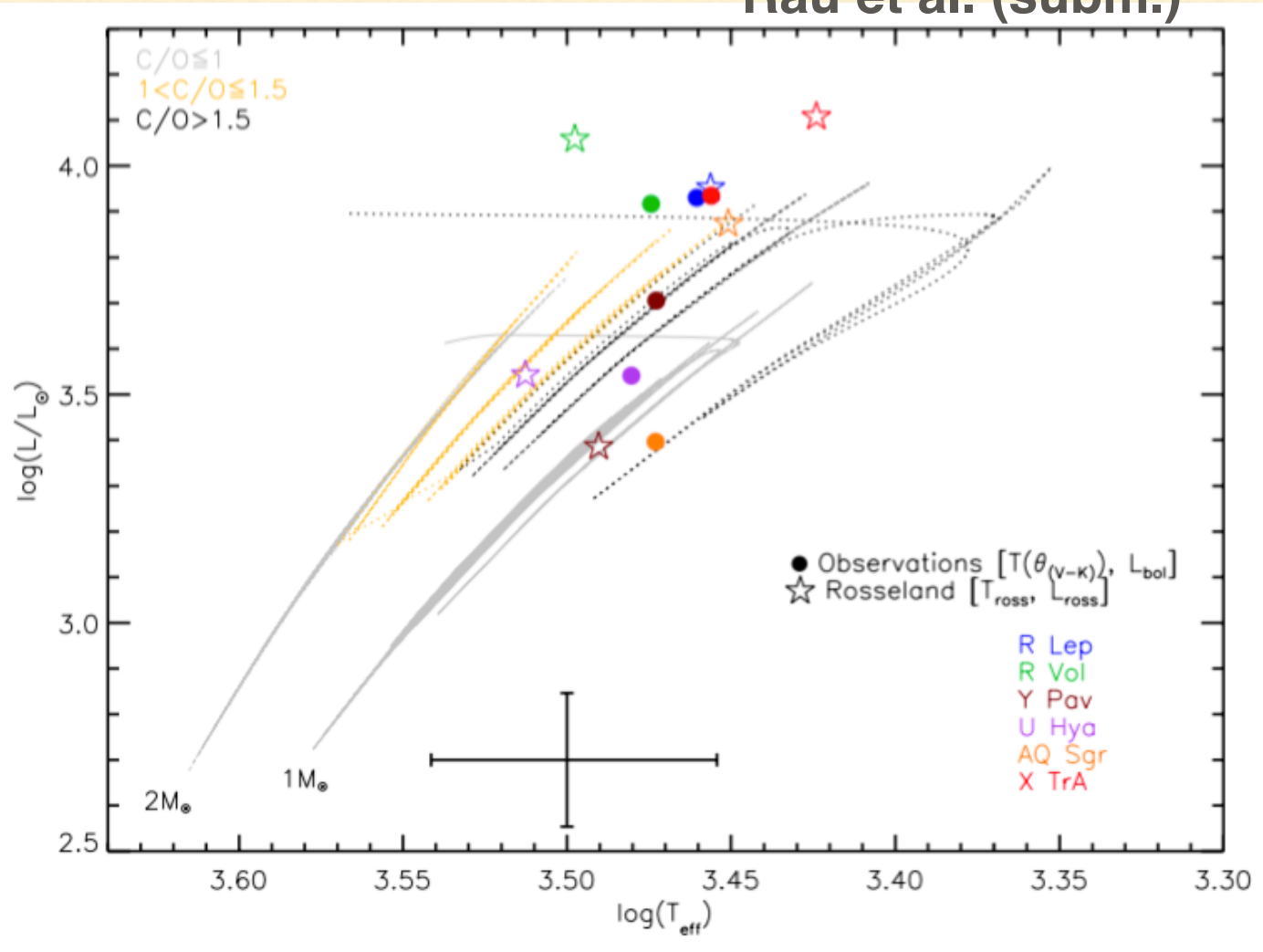
- From the fitting →
  fundamental parameter of the models: L, $T_{eff}$, M, log(g), C/O, Δu, $R_{Ross}$, $\theta_{Ross}$
- From the photometric observations →
  $\theta_{(V-K)}$ (Van Belle et al. 2013), $L_{bol}$
- From the interferometric observations →
  10μm UD diam

# COMPARISON WITH EVOLUTIONARY TRACKS

- $T_{DMA}$, $L_{DMA}$ ≈ $T_{OBS}$, $L_{OBS}$ (but AQ Sgr, Y Pav)
- Good agreement with the C/ O ratio & Mass of the DMA

Tracks from Marigo et al. (2013)

**Rau et al. (subm.)**



# CONCLUSIONS

- Atmospheres are extended with indications for shell-like stratification, larger in the Miras
- Stellar parameters are in agreement with the location of the stars in the evolutionary tracks
- Differences at wavelength shorter than 1μm (probably data-related)

**The adventure of carbon stars ⋆**

**Observations and modelling of a set of C-rich AGB stars**

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# FUTURE PERSPECTIVES…

- Models without SPL assumptions, **Rau et al. (in prep.)** → the condensation degrees are lower which probably implies less dust extinction in the visual region which can improve the fit in the visual

- ALMA proposal on RU Vir (finger crossed…!)

- MATISSE from 2019