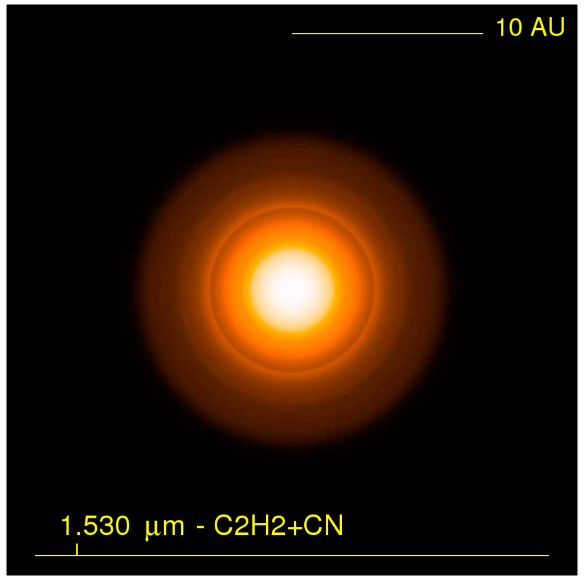
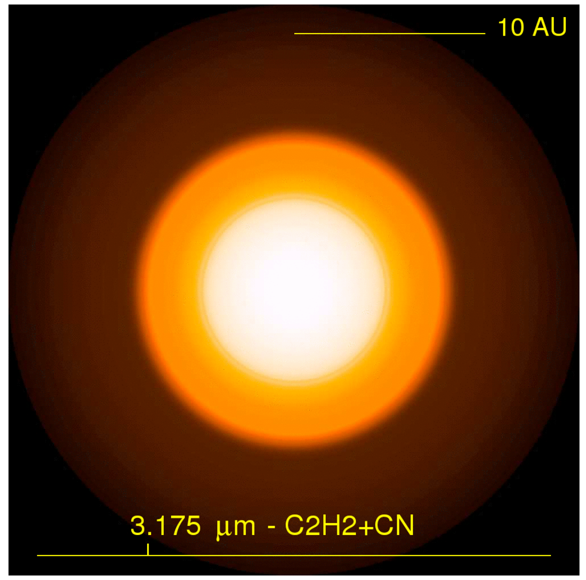
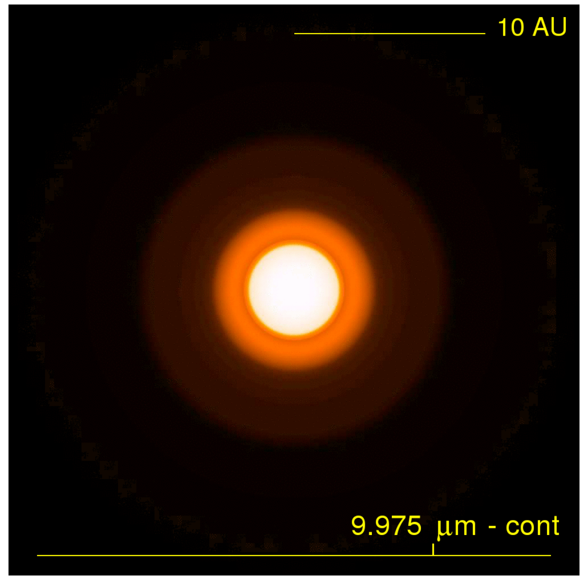
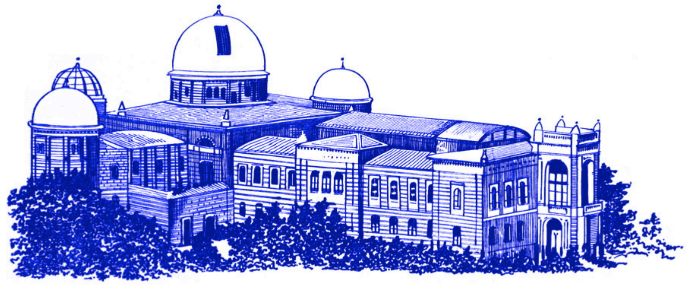




C-rich stars:



Atmospheric models vs spectro-interferometric observations



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FWF Der Wissenschaftsfonds.

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- S. Sacuto

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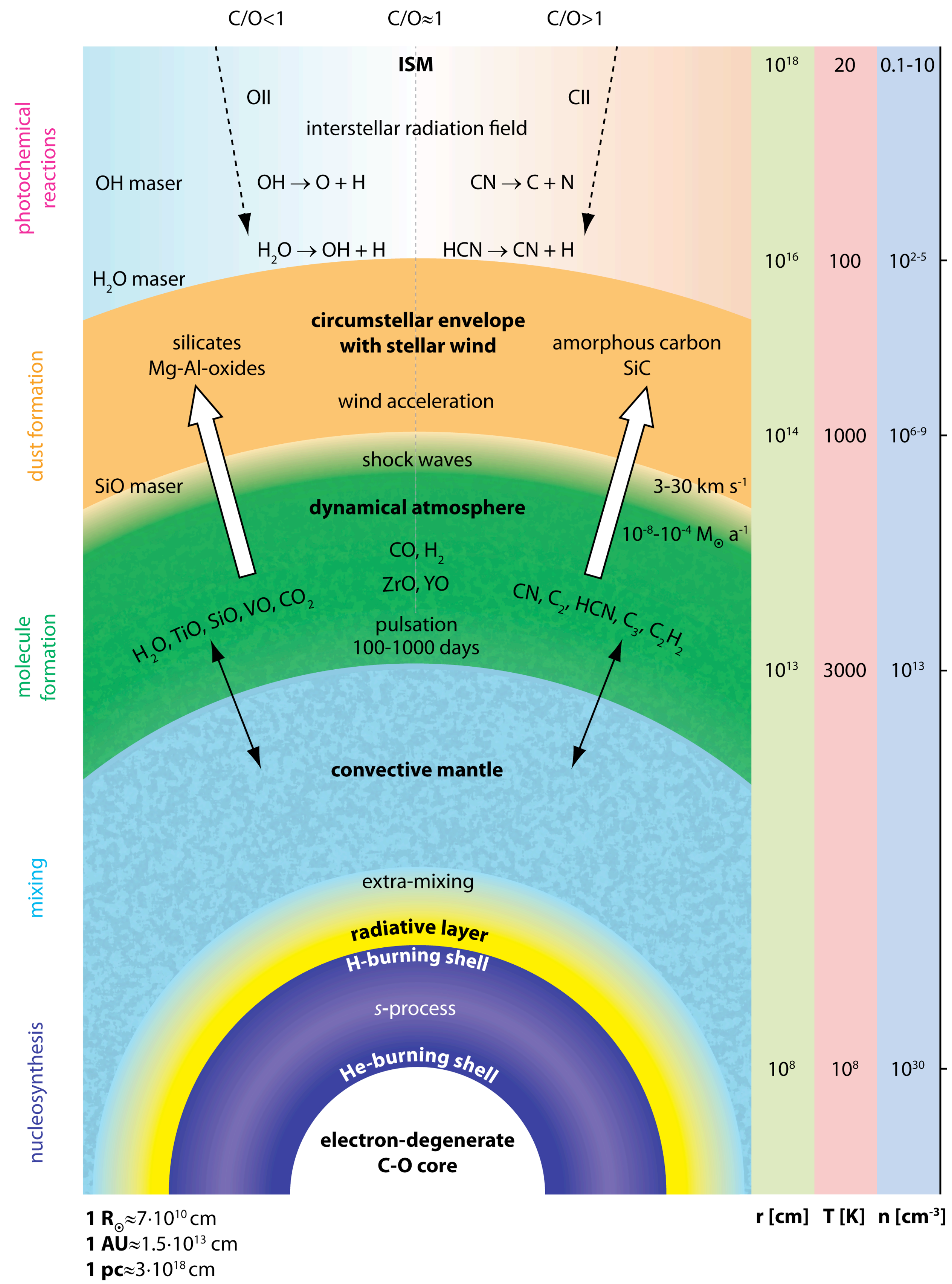
ESO

AGB C-stars

- $1 < M < 4\ M_\odot$
- C-O core and He/H burning shell, a convective envelope
- $[C/O] > 1$
- Presence of CO, C_2, C_2H_2, C_3, CN, HCN
- SiC dust, amorphous carbon



Schematic view of an AGB star (adapted by J. Hron & M. Lederer) after an idea from T. Le Bertre.

Why C-stars?

Important for stellar and galactic evolution:

- mass-loss responsible for enrichment of ISM
- understand the complicate interaction of pulsation and the stellar atmosphere
- gain inside dynamical processes of dust formation and mass-loss

Scientific Background

Spectroscopy and interferometry complementary tools for determining main parameters of the star & testing theoretical model atmosphere

- Wittkowski et al. (2004; 2006) compared observations VLTI/VINCI of cool O-rich giants with PHOENIX & ATLAS (plane parallel)
- Neilson et al., 2008 investigated same stars with new spherically symmetric ATLAS models

Which parameters can we constrain for C-stars by using Spectroscopy and Interferometry?

Why is so important to have good stellar parameters estimation ?

Stellar Evolution

Most of the empirical formulae to determine mass-loss depends on stellar parameters (Temperature, Mass, C/O ratio, metallicity…)

What is the advantage of using model atmospheres?

Possibility to have a self consistent prediction of the different observables.

Hydrostatic model atmospheres

Recent new grid of COMARCS models (Aringer et al. 2009) based on MARCS code (Gustafsson et al., 1975; 2008) used in Jørgensen et al. (1992), Aringer et al. (1997):

- 1-D models (spherically symmetric models)
- hydrostatic equilibrium, LTE & chemical equilibrium
- treatment of molecular absorption with OS technique

- COMA (Copenhagen Opacities for Model Atmosphere; Aringer et al. 2000)
- opacities of main species for a given temperature-density structure (ionization equilibrium & molecule formation)

Spectral Synthesis

- assume chemical equilibrium to calculate molecular abundances
- line list + OS data (Lederer et al., 2009) for computing opacities (LTE)
- spherical radiative transfer code (spectrum + spatial intensity)

Targets and Observations

Selection criteria:

- bright objects (K < 3)
- low variability Δ V < 2
- (very) low mass-loss values from literature

HK Lyr, DR Ser, Z Psc, RV Mon, CR Gem

UKIRT/UIST spectra (*IJHKL* bands) R = 400-2400

PTI *K* broad band visibility and IOTA (for Z Psc) *K* broad band

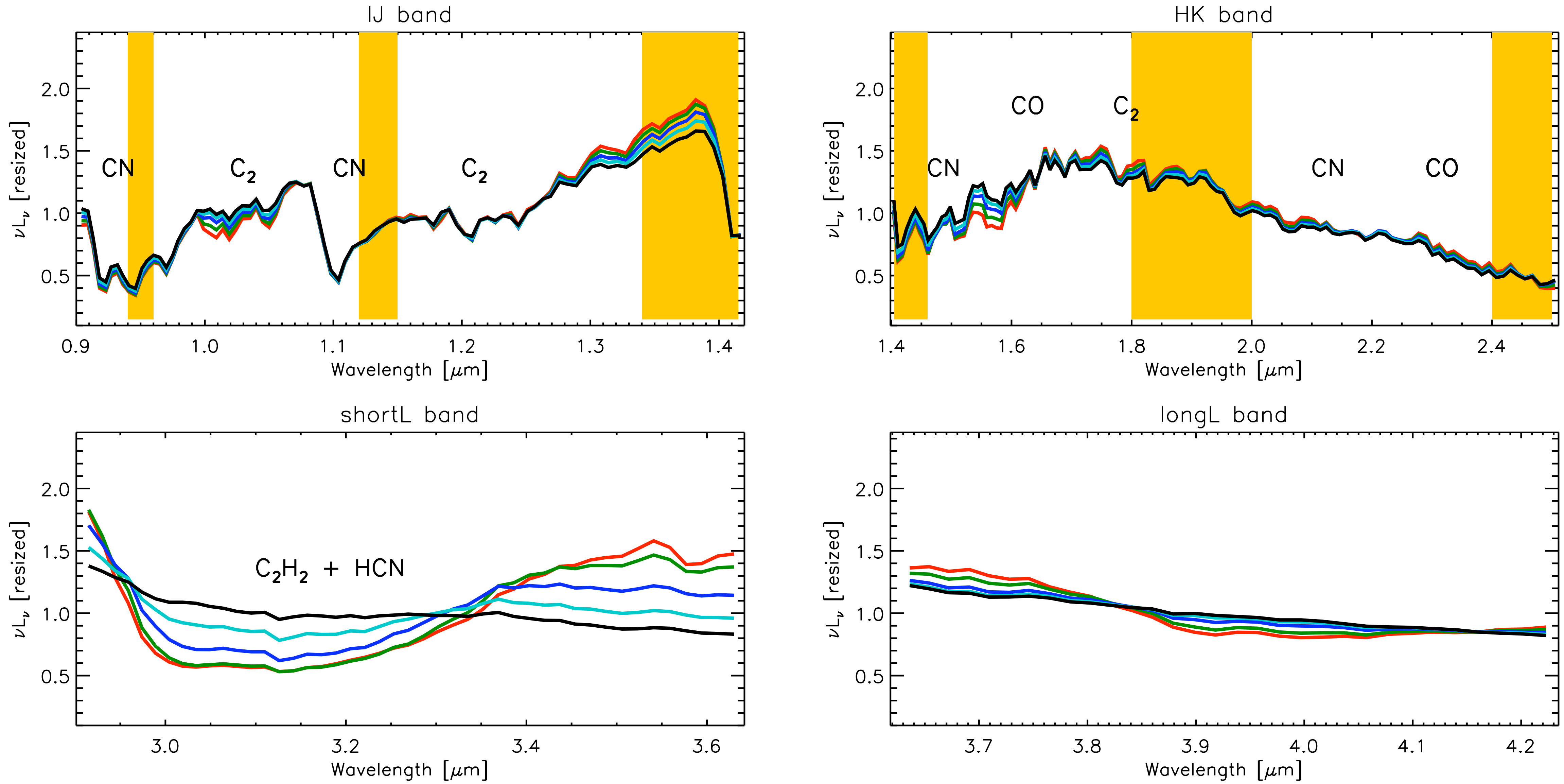
H broad band and *K* narrow band data available from PTI, not used in this presentation

How we proceed

Spectroscopy:

1) χ^2 to compare the full UKIRT spectra to constrain model temperature (quite good approximation especially using 3.1 microns feature C_2H_2+HCN)
2) χ^2 examine single spectral features : C_2 (1.02, 1.20 microns); CO(2.29 microns); C_2H_2+HCN (3.1 microns) features constrain C/O ratio

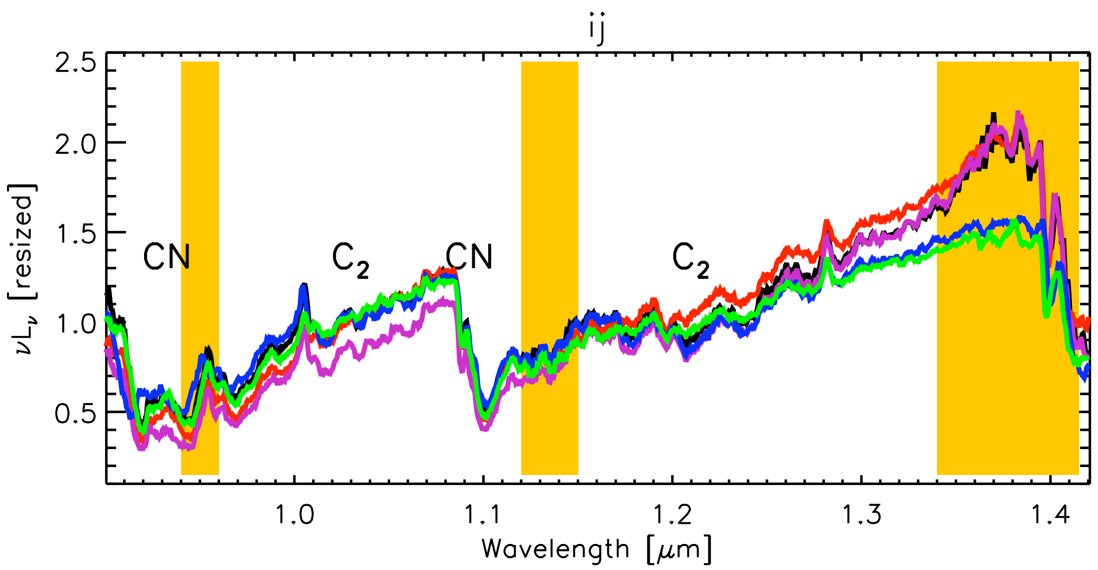
Temperature dependence (models)

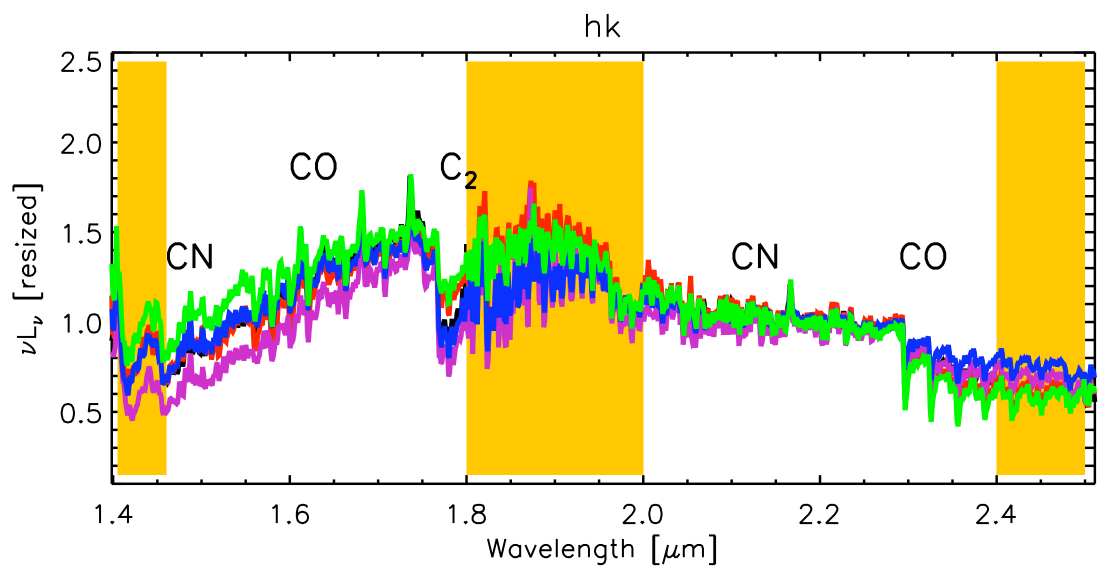


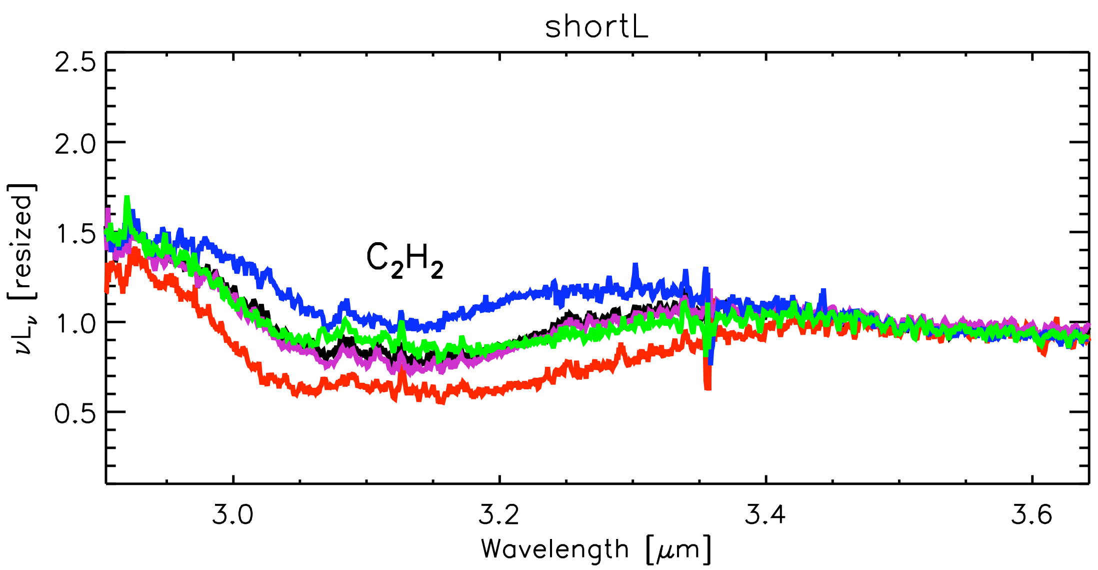
T_{eff} = 2800 K
T_{eff} = 2900 K
T_{eff} = 3000 K
T_{eff} = 3100 K
T_{eff} = 3200 K

log g = -0.40; M = 2M_{sun}; Z = Z_{sun}; [C/O] = 1.05

Determination of temperature

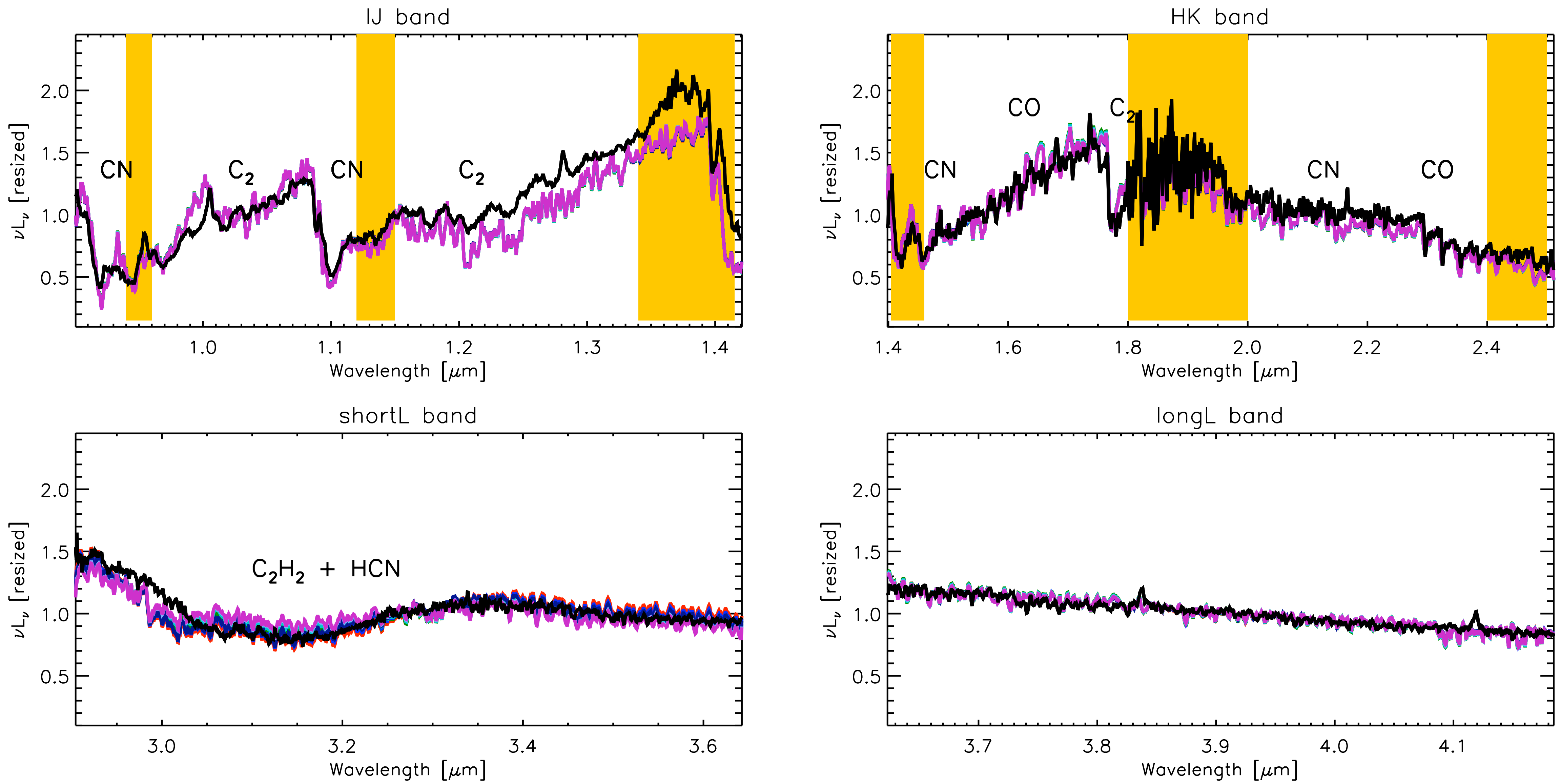






ID	Temperature [K]
HK Lyr	3100 ± 50
CR Gem	3070 ± 50
Z Psc	3130 ±60
RV Mon	3180 ± 50
DR Ser	3070 ± 40

Example of comparison models-observations after spectroscopic fit



black line = HK Lyr spectrum

colored lines = models

T_{eff} = 3100 K; Z = Z_{sun}; [C/O] = 1.4; M = 1, 2 M_{sun}; log g = 0.,-0.2, -0.4,-0.5

Log *g* and Mass are not constrained!!!!

Determination of mass, log g, distance

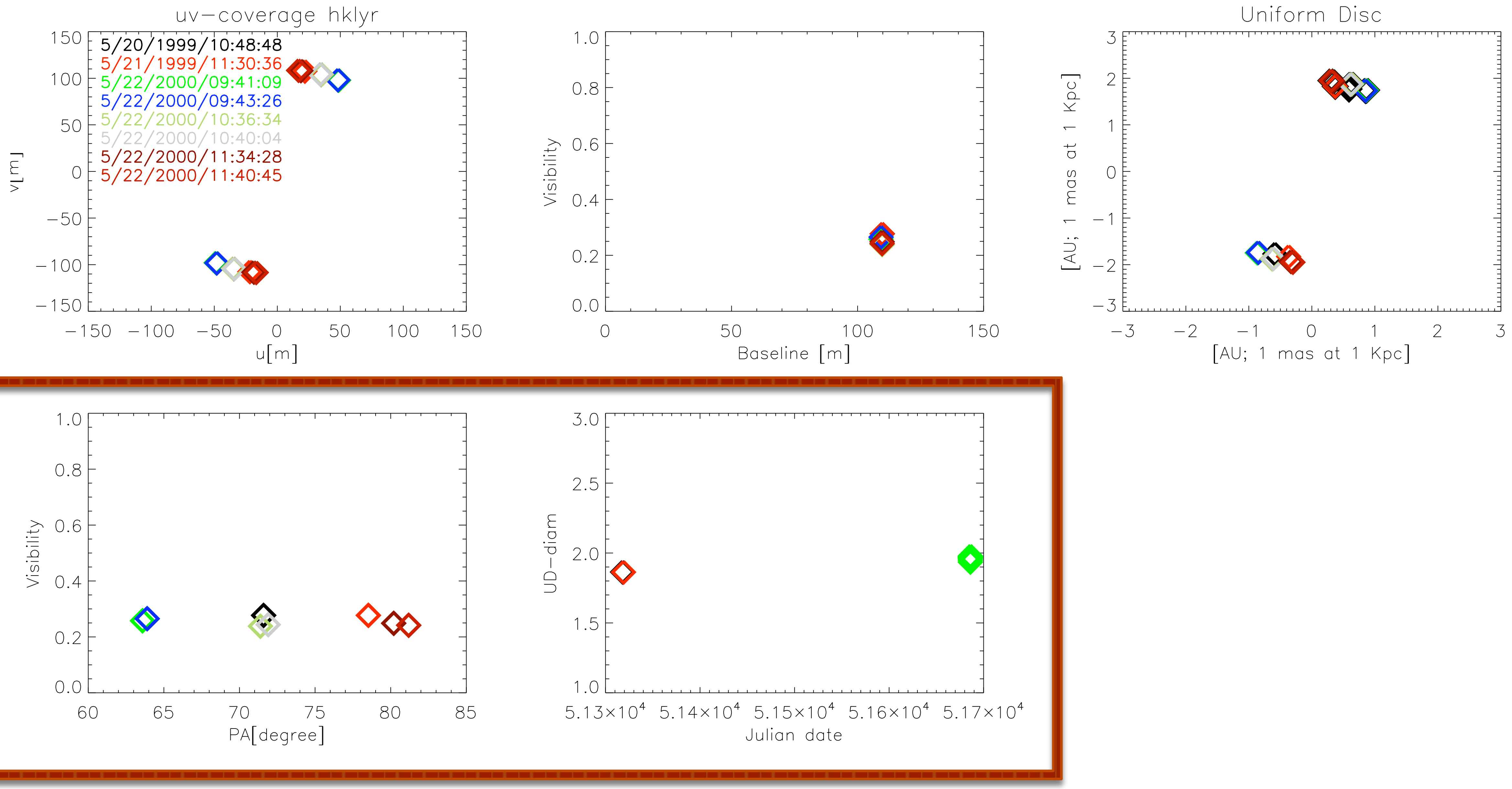
Degenerate problem! ☹

→ **Interferometry**

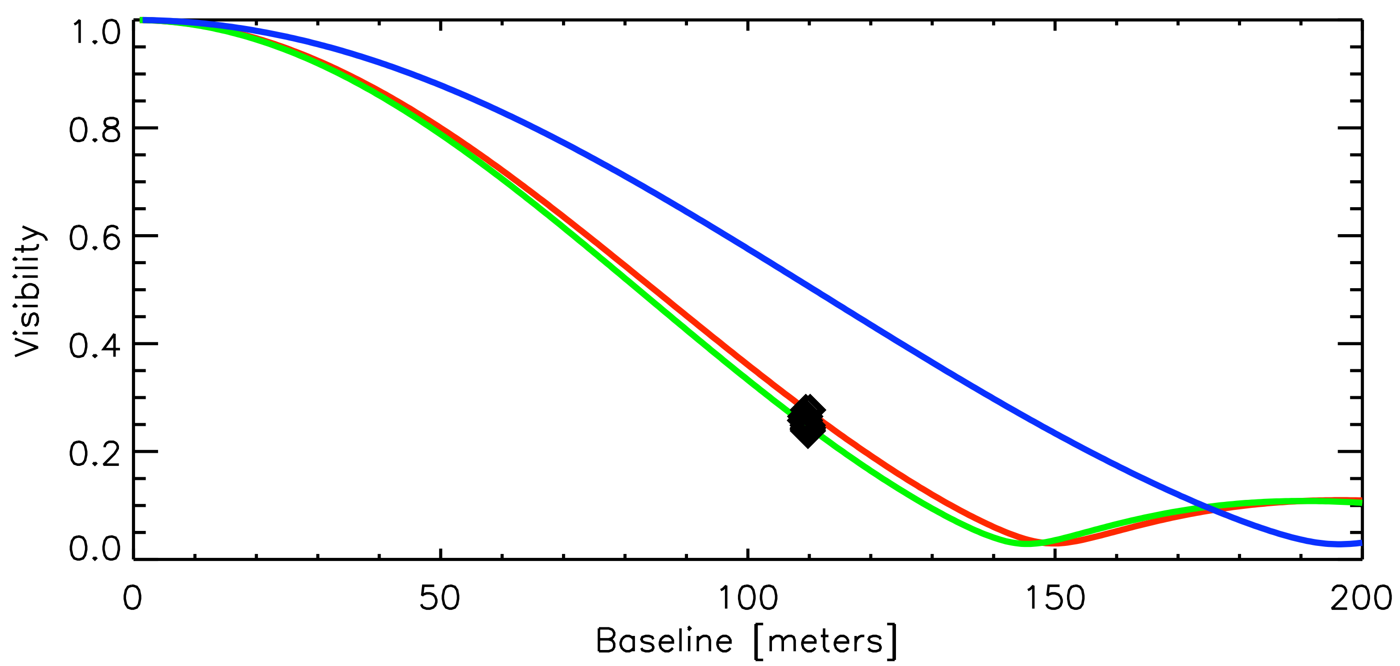
1. check of variability or eventual asymmetries
2. <u>adopt 3 different distances estimates</u>

   (Hipparcos; Bergeat et al., 2004; Claussen et al. ,1986)
3. χ^2 to fit PTI data points
4. best fitting model constrain log *g* and mass for a given distance
5. discussion on best fitting parameters/check stellar evolution theory

Plot example of the check variability and asymmetries (HK Lyr)



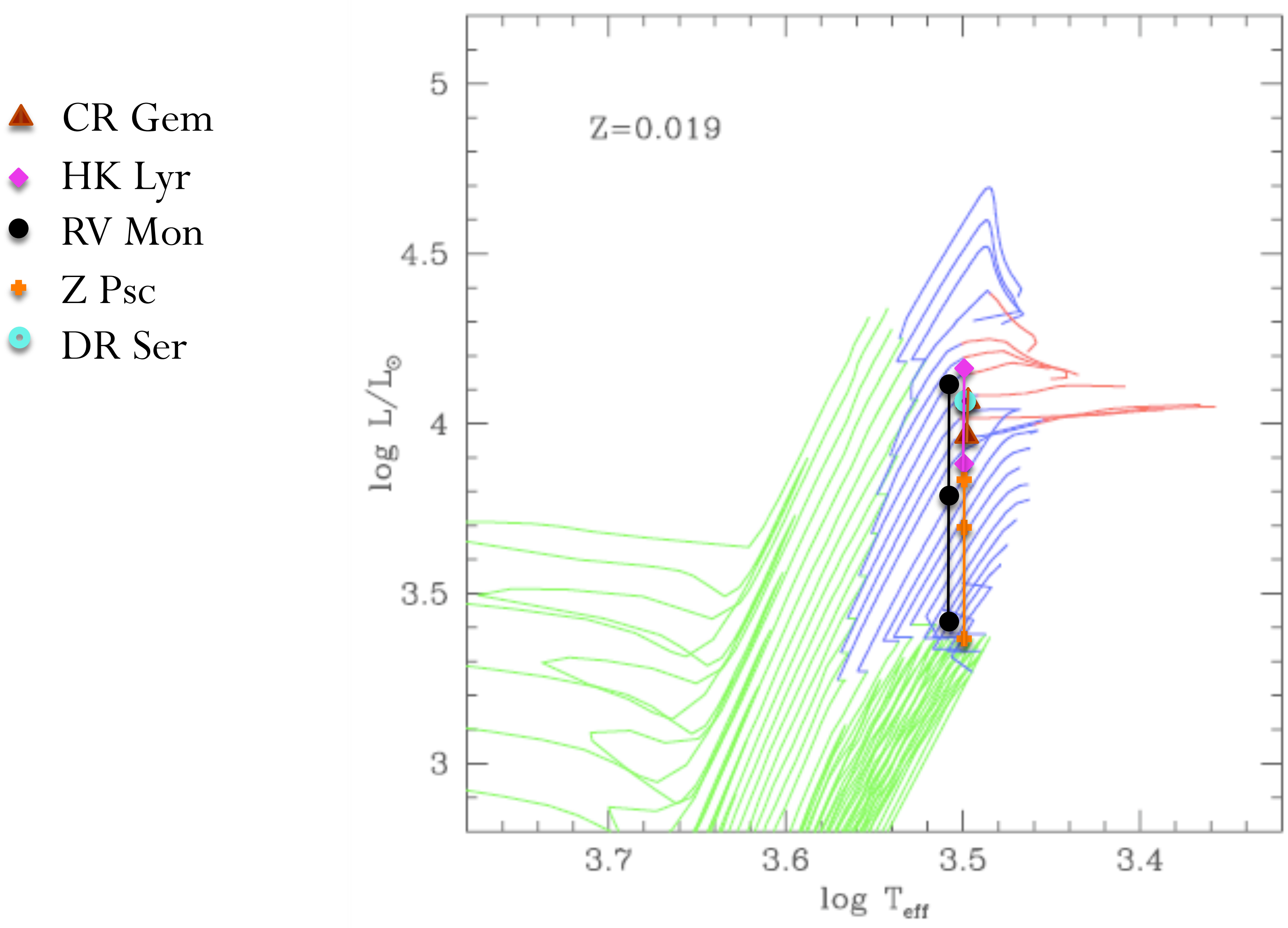
HK Lyr:
when one of the distances does not fit



d_{hipp} = 1369 pc
d_{Berg} = 730 pc
d_{Claus} = 900 pc
◆ = PTI measurements

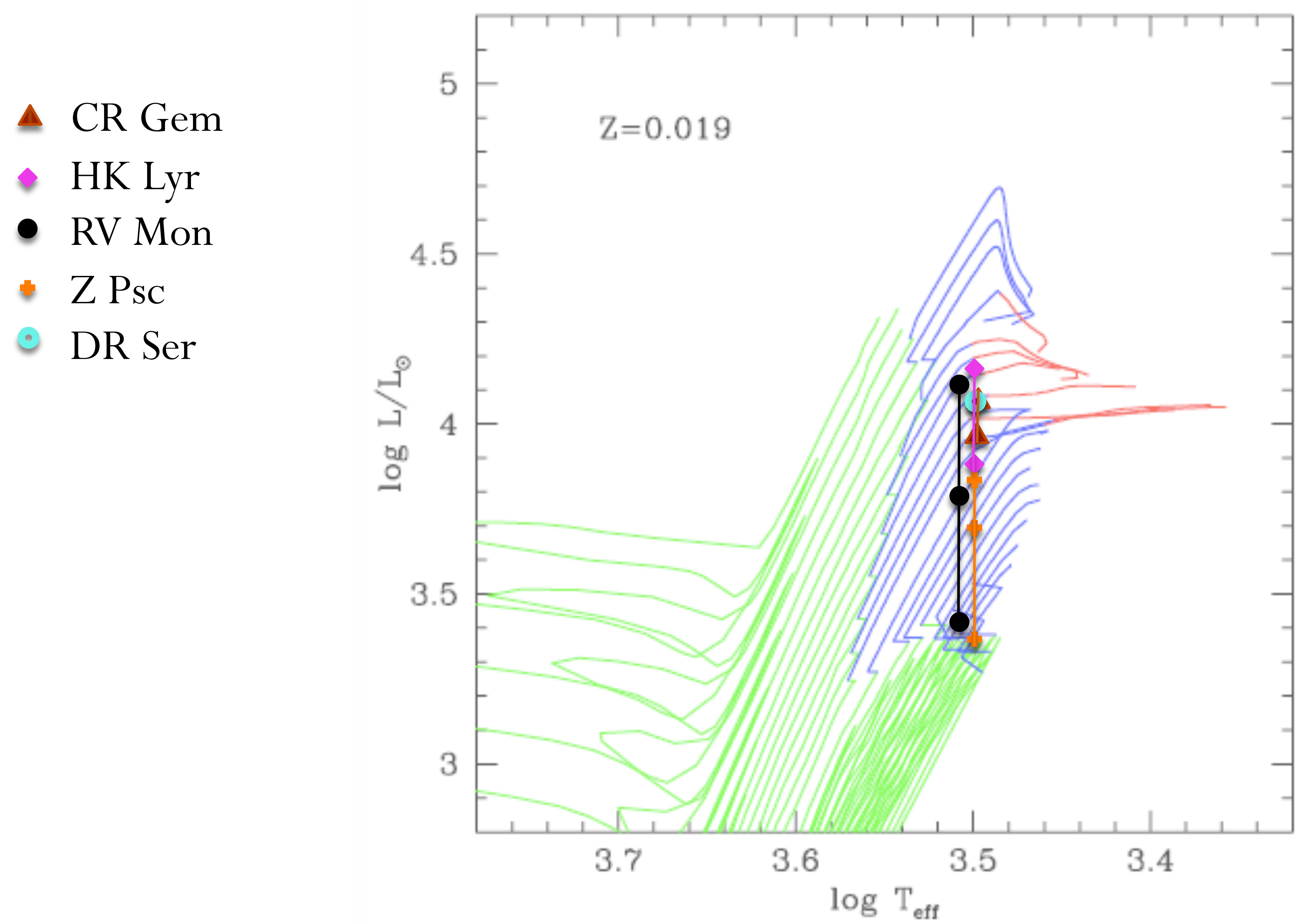
- No profile at d_{Hipp} can fit the PTI interferometric observations!
- d_{Berg} profiles can be well fitted with M = 2 M_{sun} and log g =-0.2
- d_{Claus} profiles can be well fitted with M = 2 M_{sun} and log g =-0.4

Comparison with Isochrones



Marigo et al. 2008

Completely wrong distances?!

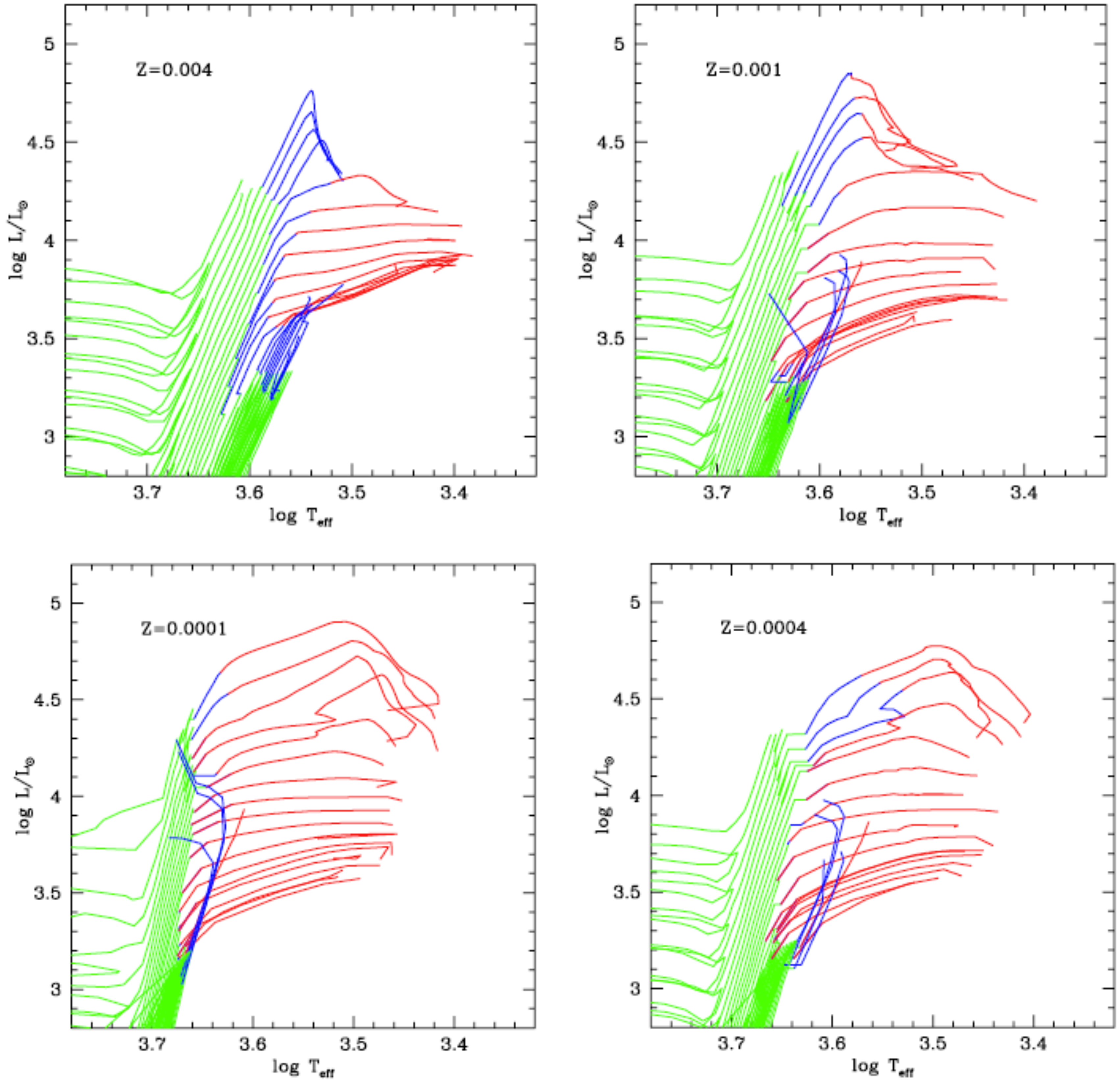


Marigo et al. 2008

Conclusions

- For the first time we are able to fit spectra of C-stars in the range between 0.9 and 4 microns
- Spectroscopy and Interferometric observations can be fitted at the same time in consistent way by hydrostatic models
- confirmation of 3 micron feature as good estimator for the temperature of the carbon stars
- spectroscopic observations are not sensible to log g and mass of the object
- interferometry can help to constrain log g and mass for carbon stars, but some considerations on the distance are needed!

Metallicity a possible solution?



Marigo et al. 2008