AMBER obs of RS Cap: CO and water vapor in the atmosphere

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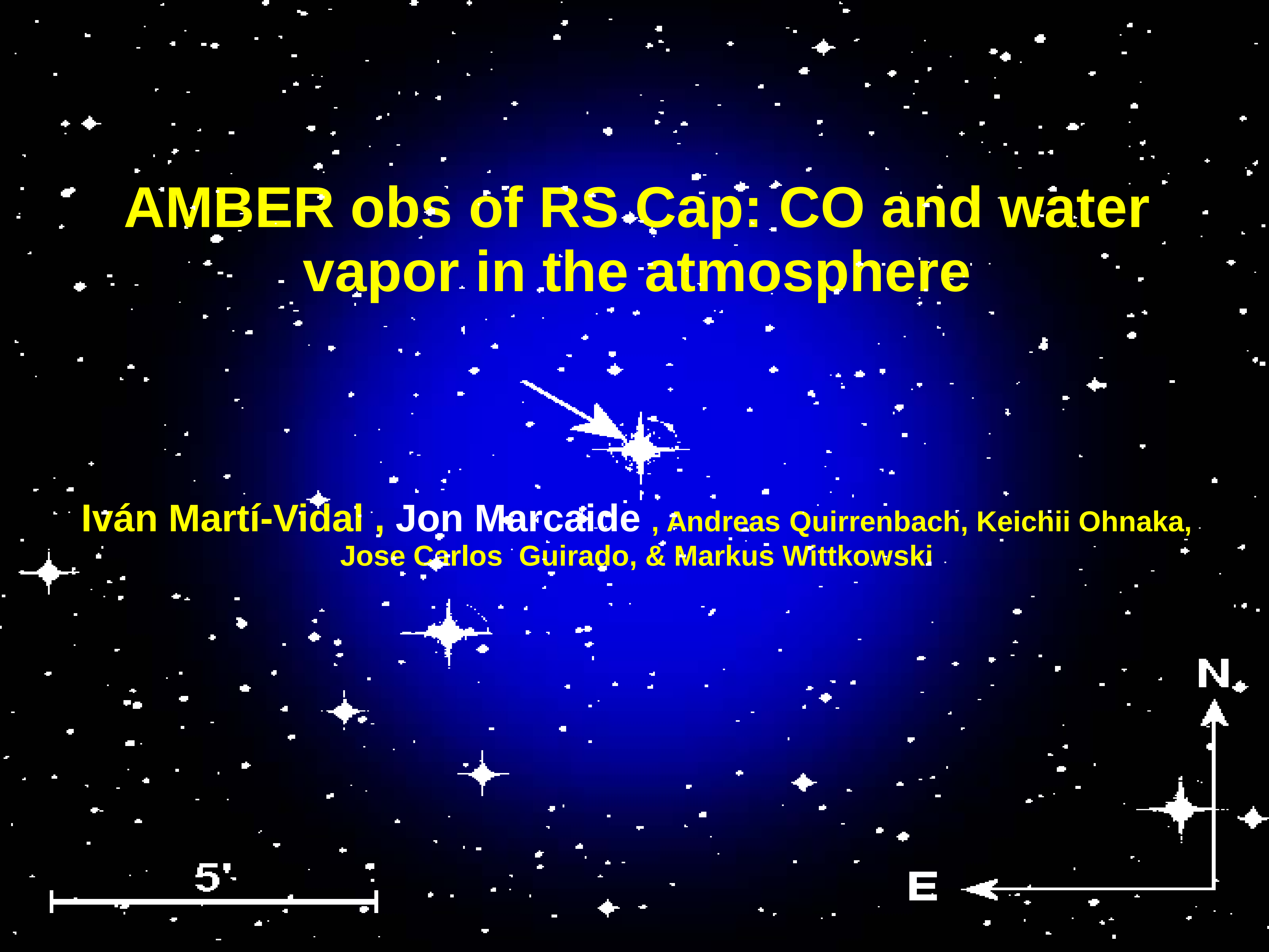


Three of us are beginners in this game...

We are radioastronomers with a VLBI background in radiosupernovae, radiostars, AGN, precision differential astrometry, etc...

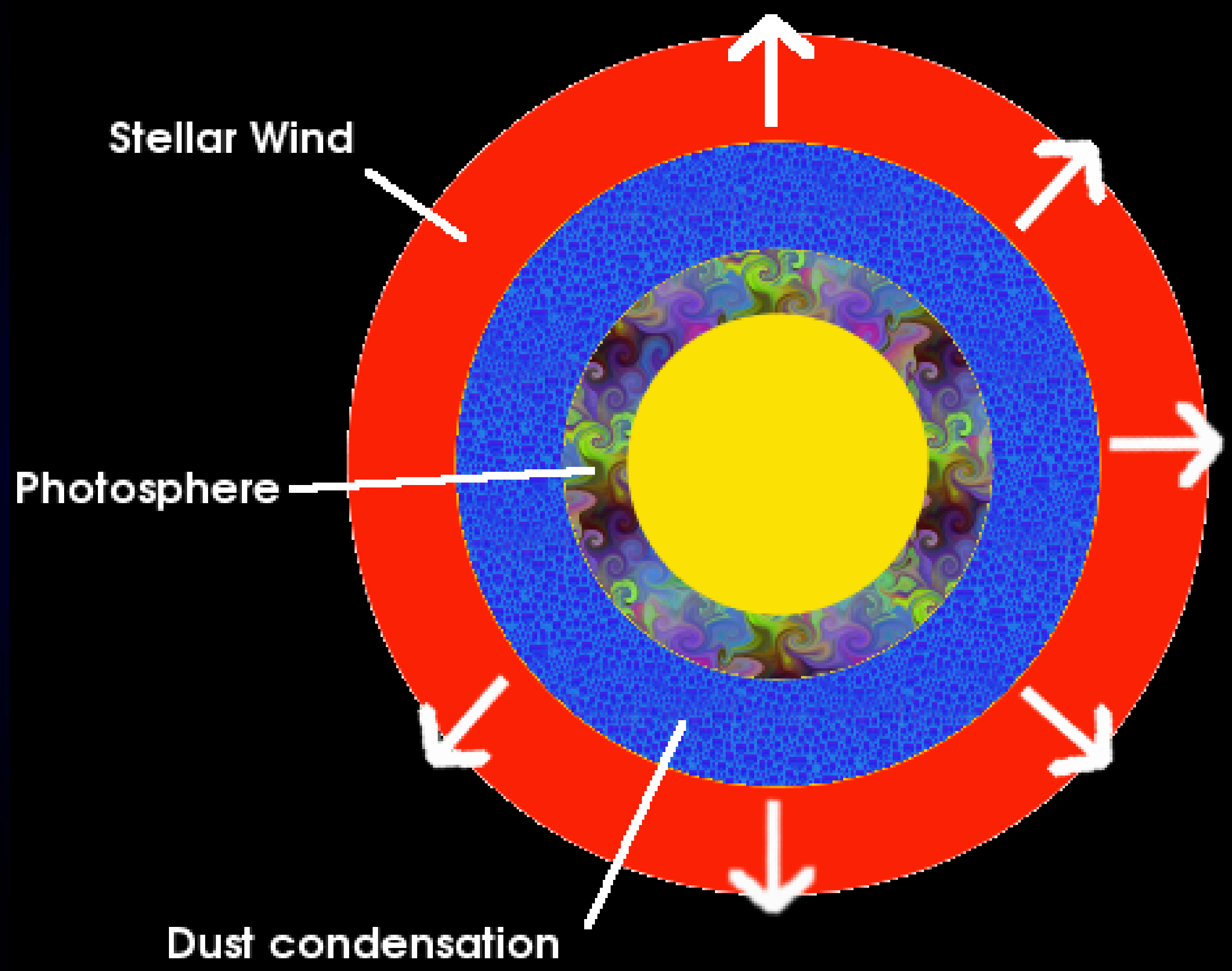
SCIENTIFIC CASE

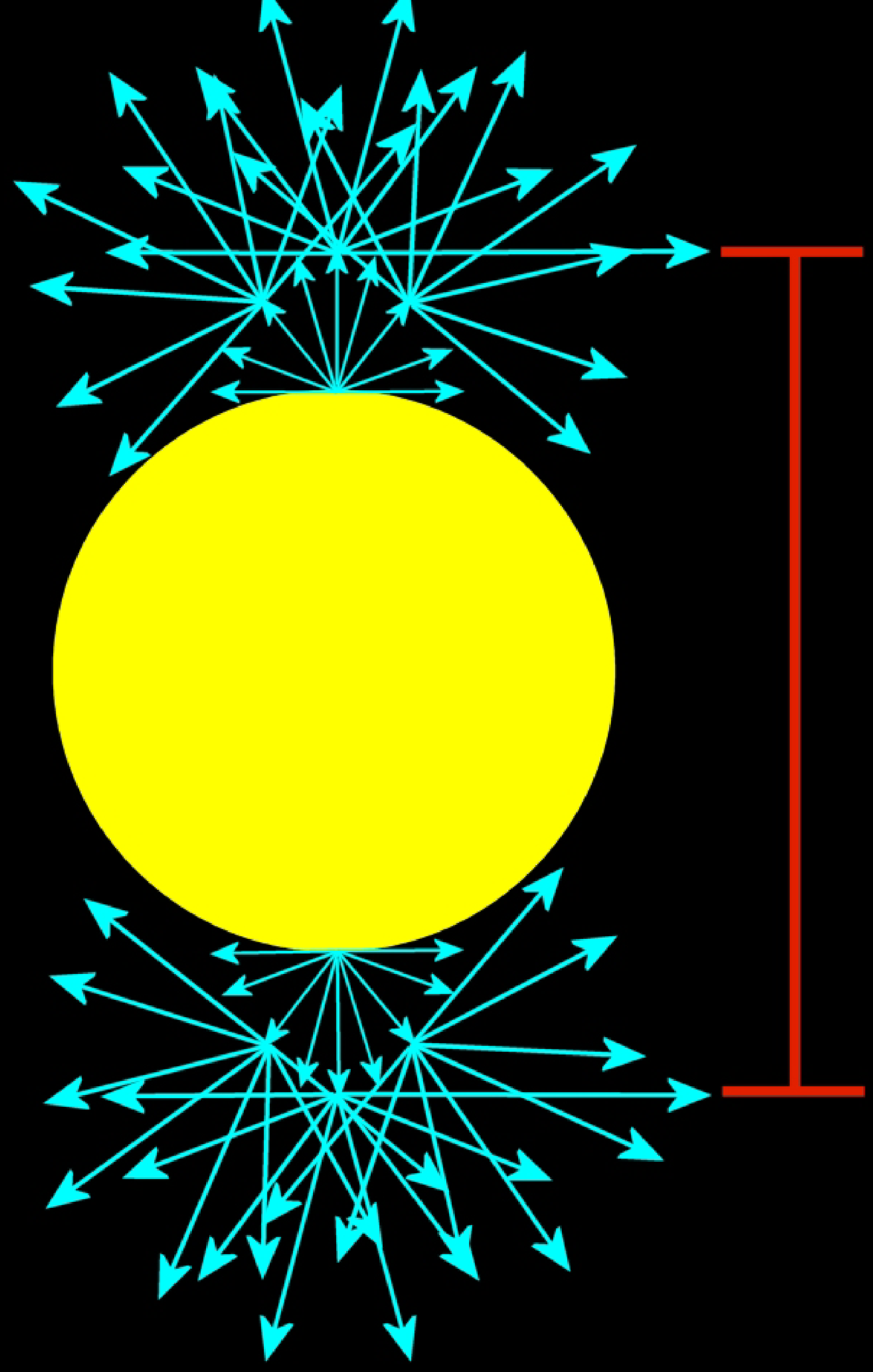
- RS Cap is an AGB star

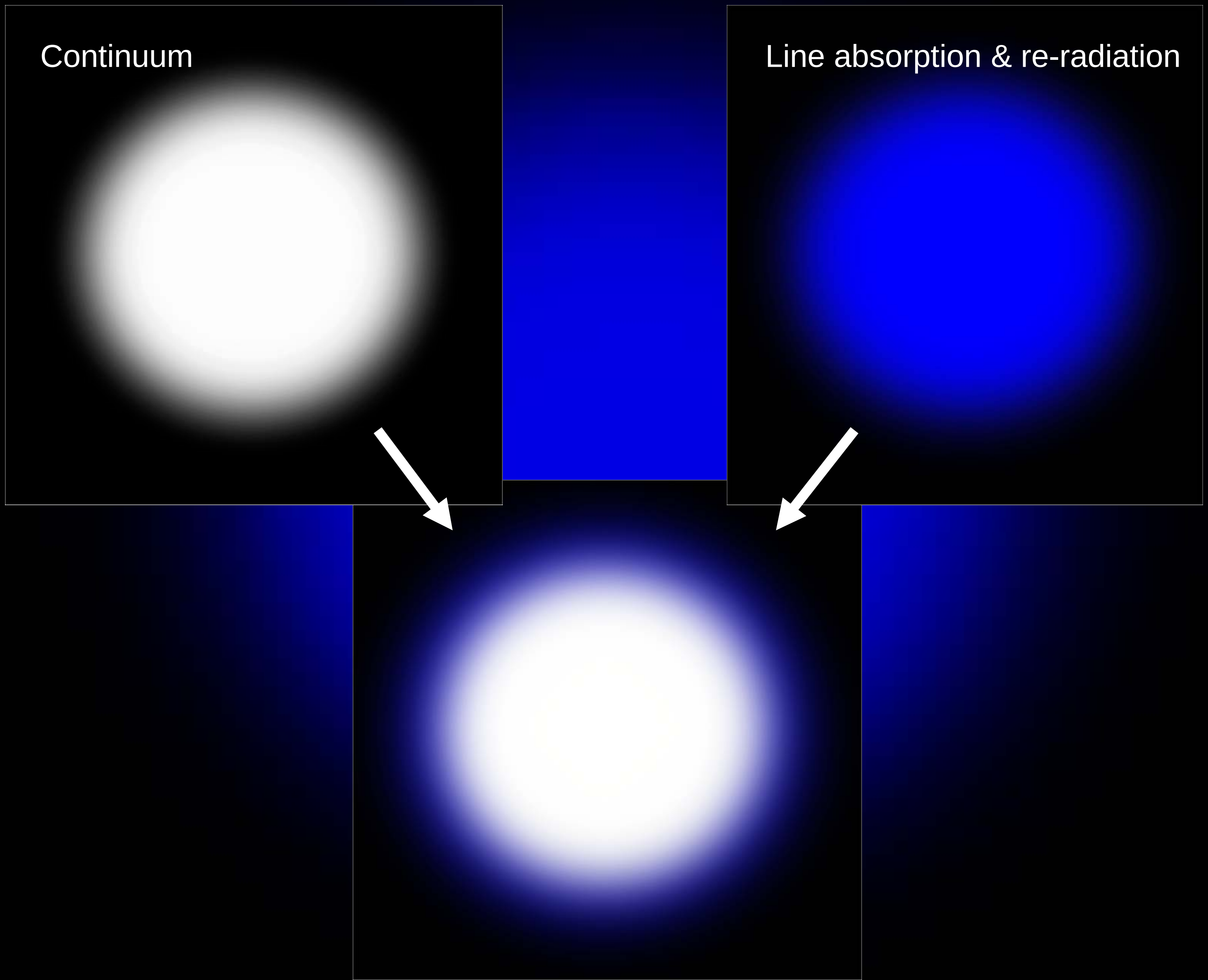
-AGBs are characterized by extended atmospheres and dense stellar winds (~10^{-7} – 10^{-5} Msun/yr) which decisively influence the stellar evolution and the composition of the ISM.

- The stellar wind mechanism in AGBs is not well known (radiative pressure, pulsations,…?) and specially so in irregular pulsators (SRa, SRb, or L).

- Near-IR interferometric observations allow us to study the inner region of the stellar atmosphere of large molecular gas content. (Thermodynamics and hydrodynamics of this region are not well characterized either.)


Stellar Wind
Photosphere
Dust condensation




Continuum
Line absorption & re-radiation

Precedents

-**Quirrenbach et al. (2001)**
AGB star diameters measured in TiO (712nm) and continuum (754nm).
More extended atmospheres in TiO than predicted by models.

-Perrin et al. (2004)
Diameters of Mira stars in narrow bands around 2 µm.
CO y H_20 molecular shells at about twice the photospheric radius

-**Mennesson et al. (2002)**
Comparison between 11 y 2 µm.
Systematically larger sizes at 11 µm in Mira stars y SR.

-**Ragland et al. (2008), Pluzhnik et al. (2009)**
H_20 (1.5 & 1.8µm) lines en Mira stars.
Inhomogeneous distribution of water vapor in the internal part of the atmosphere

-**Ohnaka et al. (2009).**
Betelgeuse with AMBER a 2.3 µm (R~12000).
Inhomogeneous dynamics of the CO.

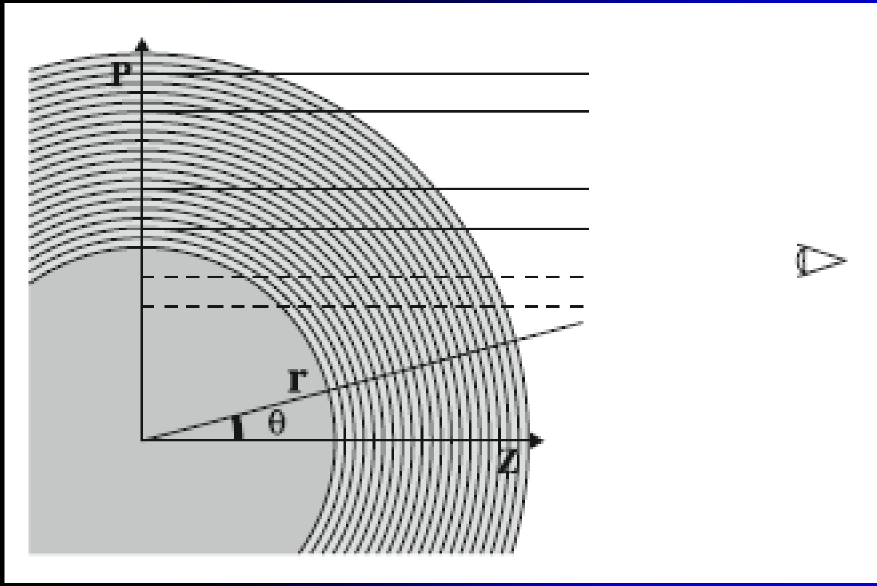
-Woodruf et al. (2009)
Large size increases longward of 2.29 µm in Mira stars
Interpreted as water vapor

With AMBER we sample the visibility function on the UV-plane, and ultimately determine the stellar radius R ($\tau \sim 1$) for a range of wavelengths.

MARCS model atmospheres

http://marcs.astro.uu.se/index.php

Gustaffson et al. 2008, A&A, 486, 951



- Hydrostatic atmosphere

-Spherical symmetry

- Radiative transfer including spectral lines

-Model defined by T_{eff} , log(g), M, chemical composition, and speed of micro-turbulence

From monochromatic instensity profiles obtained from MARCS, the model visibilities can be estimated (Henkel Transform) and compared to observed ones.

VLTI/AMBER observations OF RS Cap

RS Cap:

SRb (ΔV=0.5, Hipparcos; ΔB=2, Kukarkin et al. 1969)

K= -0.5 ; (RS Cap/18 Cap in H: 0.25/0.42
->use of FINITO fringe tracker possible)

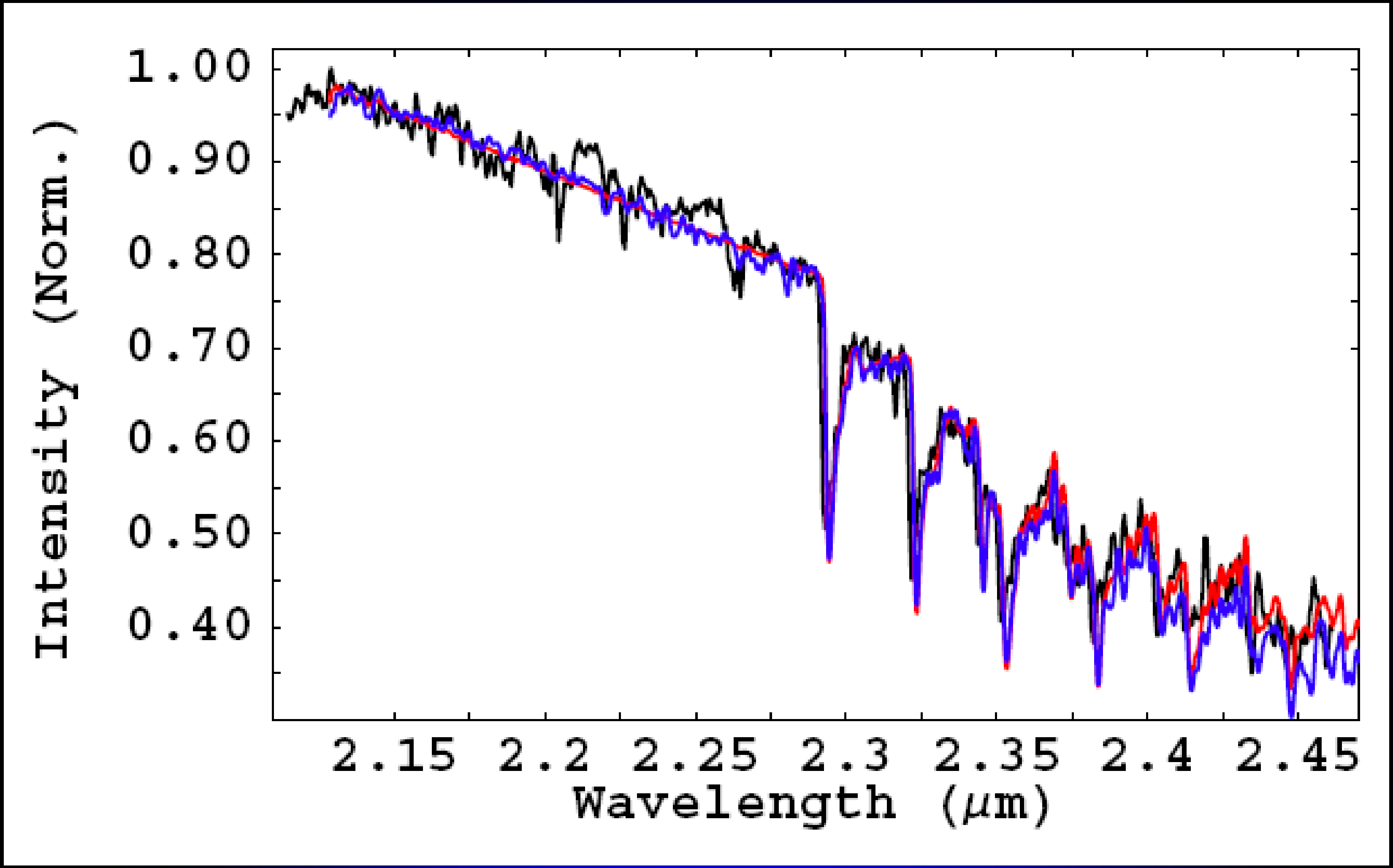
AMBER:

AMBER K-band obs (2.13-2.47 μm, R~1500).

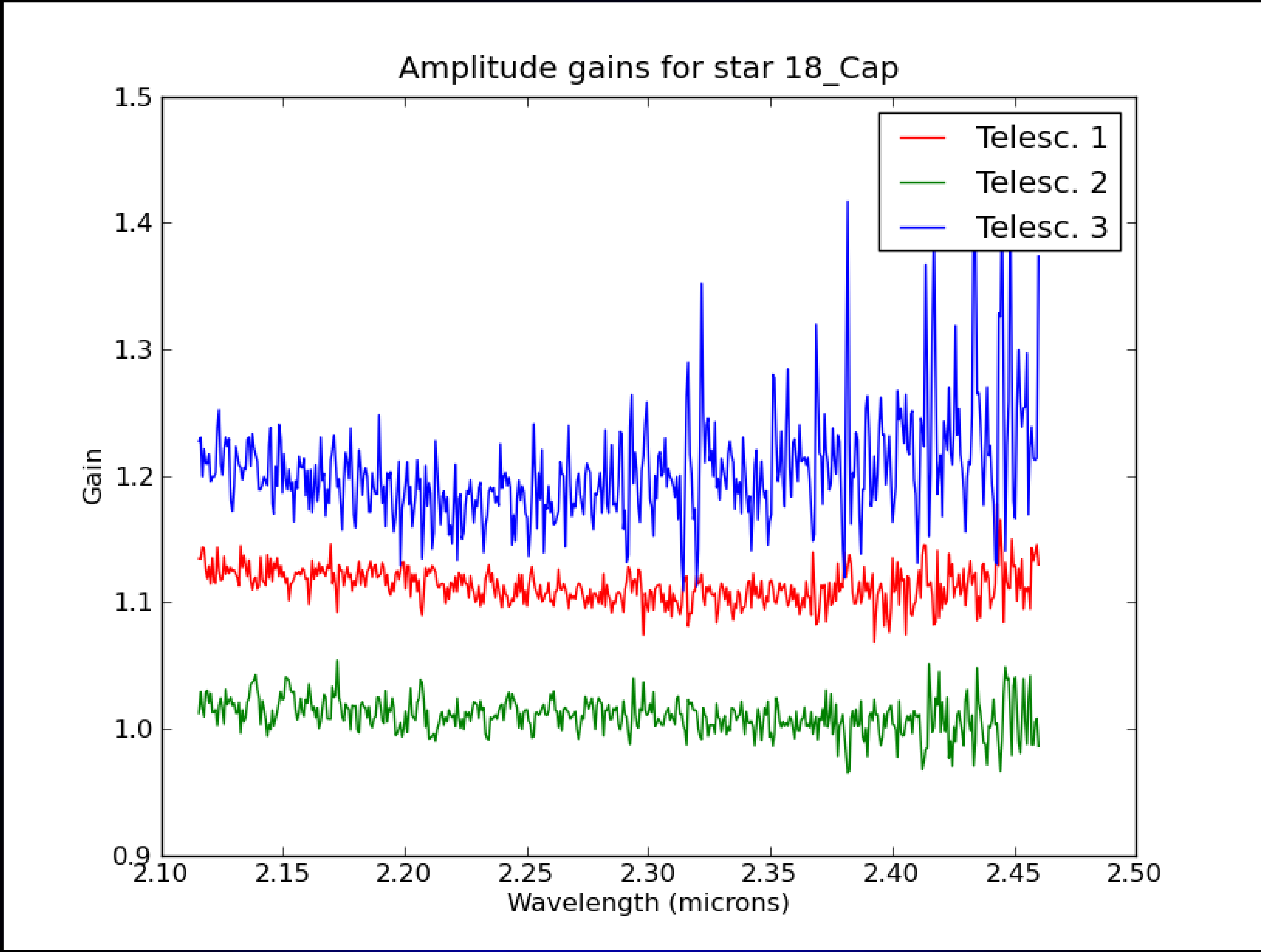
Continuum emission + ^{12}CO (2-0), (3-1), (4-2) +^{13}CO (2-0)

Positions of AT-telescopes: E0, G0, and H0
Angular resolution ~8 mas.

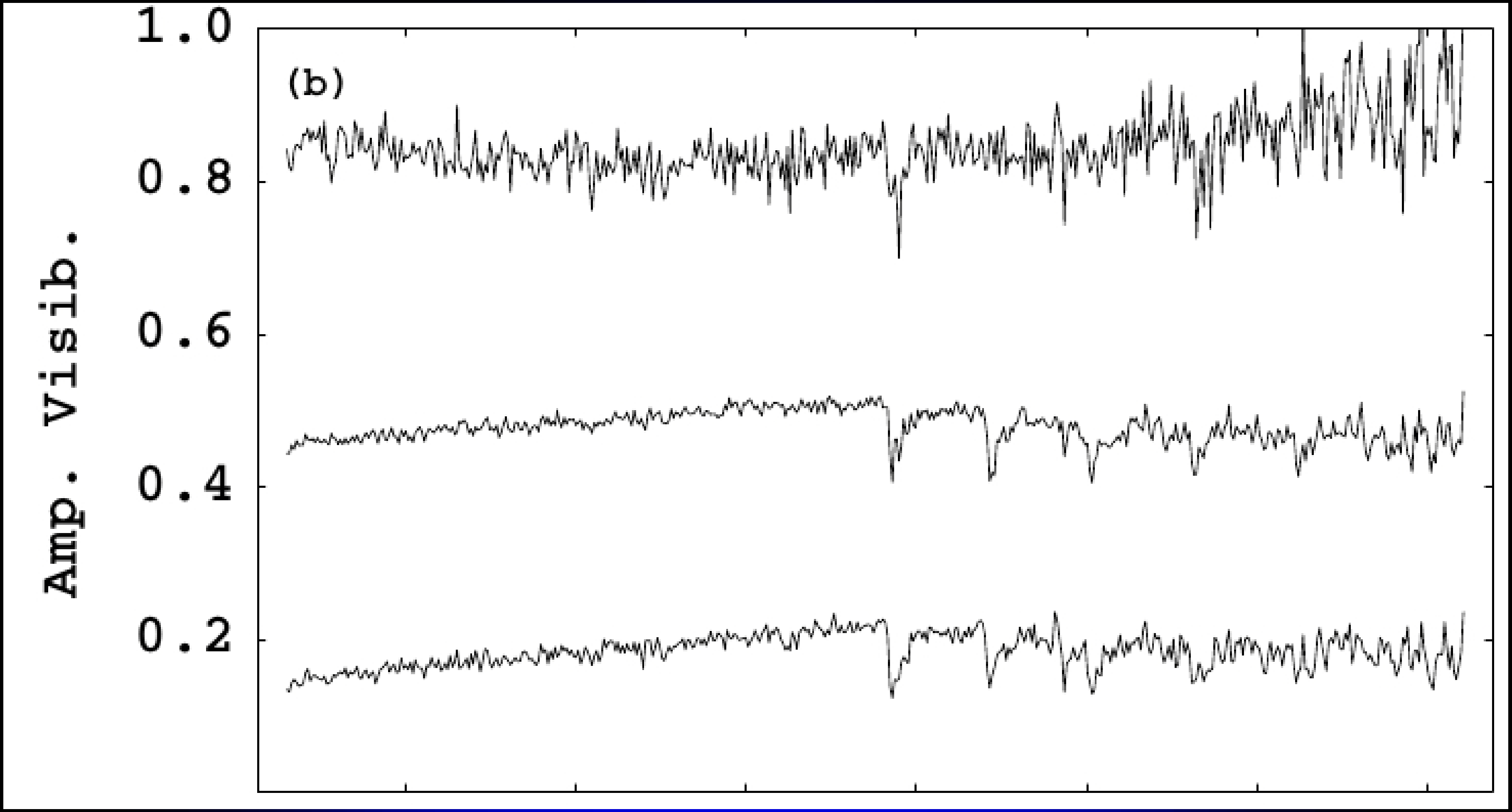
Data reduction: amdlib 2.2



Calibrated (average) spectrum (black)



Amplitude gains obtained from 18_Cap assuming a UD diameter of 5.02mas



RS Cap visibility amplitudes accross the spectrum
(for all 3 baselines)

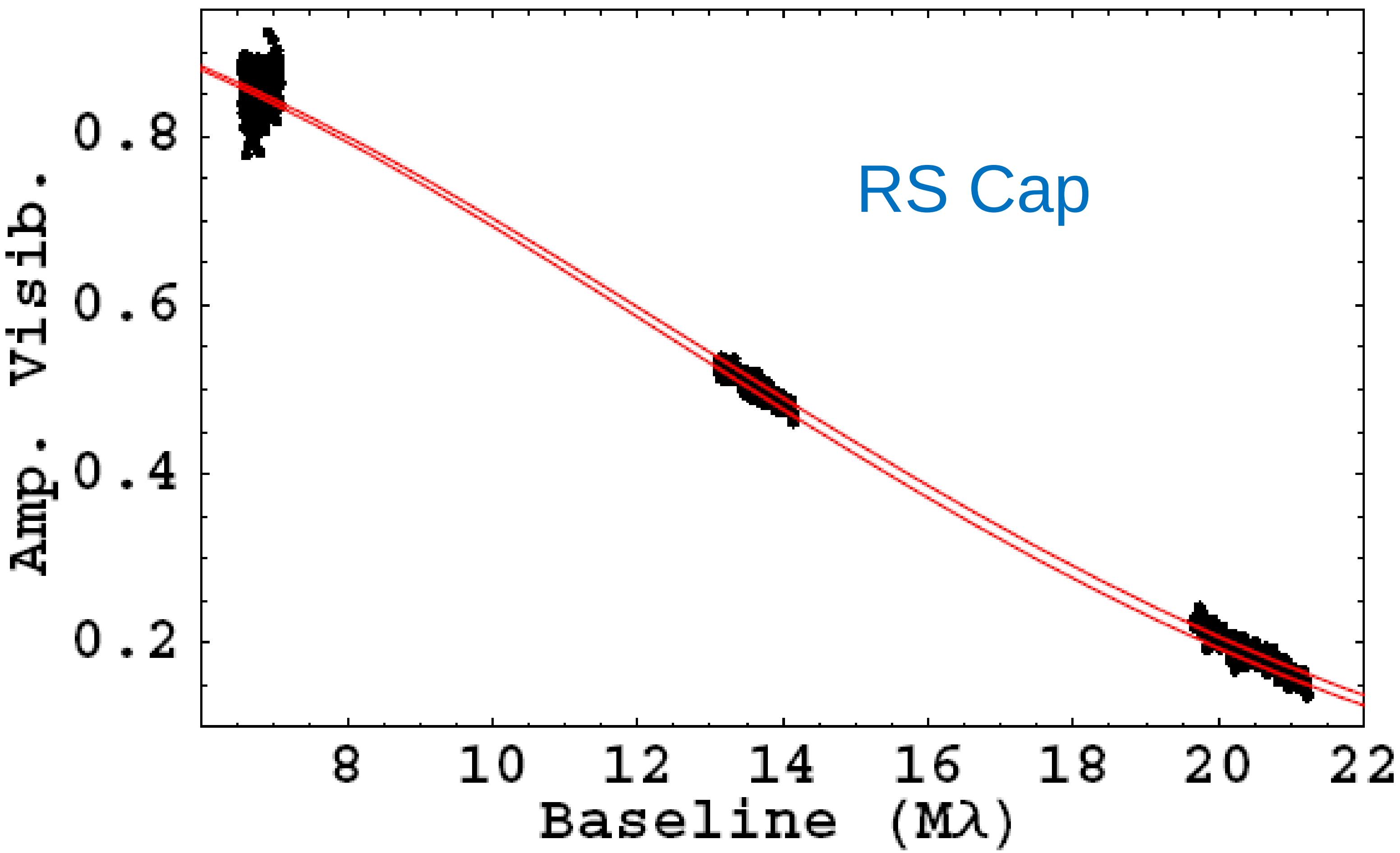
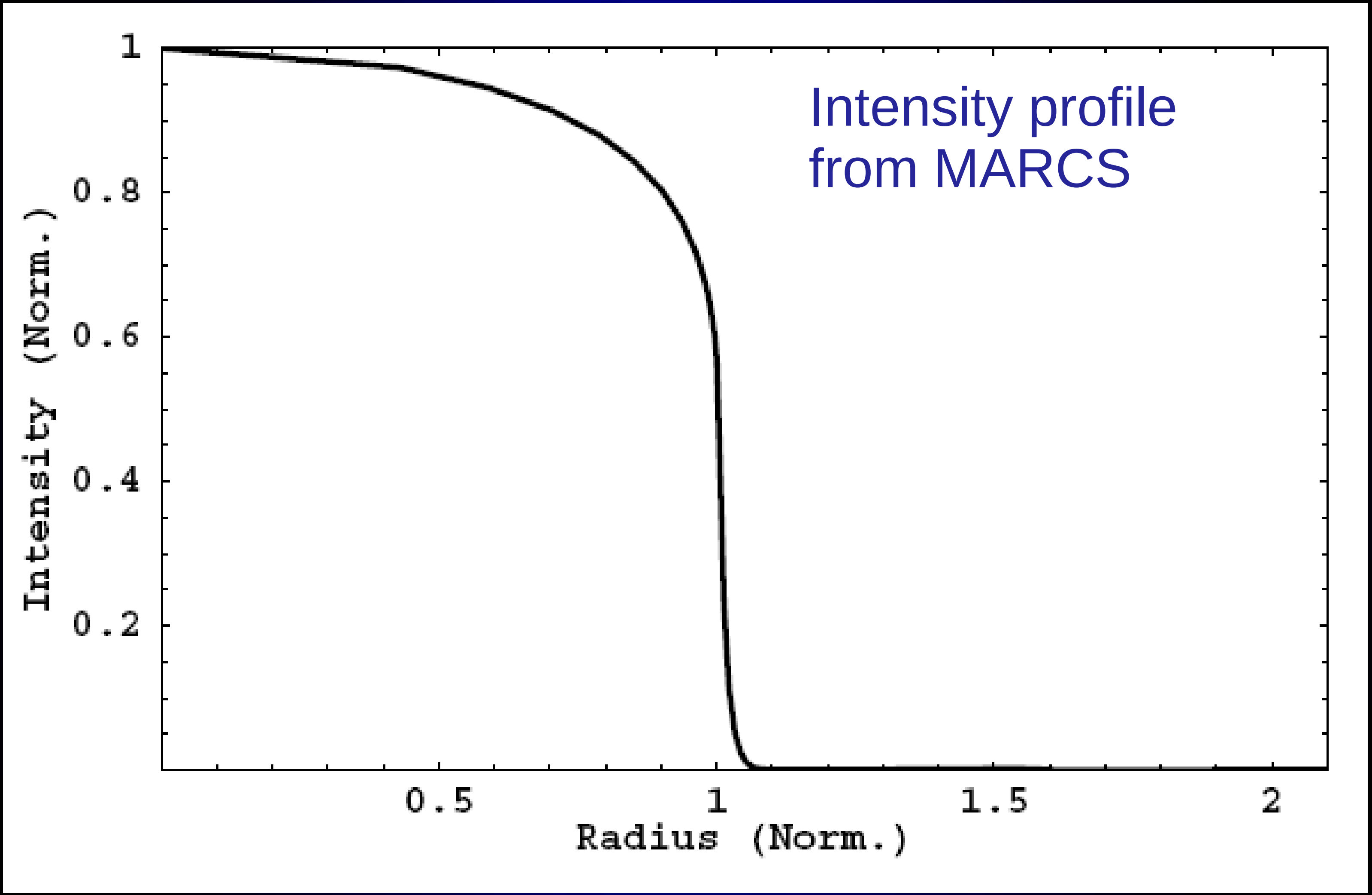


Fig. 4. Visibility amplitudes between 2.13 and 2.29 μm as a function of baseline length. Black, observations; red, model predictions with a uniform-disk diameter of 7.75 + 0.07 mas (lower line) and 7.75 − 0.07 mas (upper line).



$V(q) = HT\,[\,I\,(r/R_{Ross})]$ (HT Hankel Transform)

Fitting the continuum part of the observed visibility amplitudes to synthetic visibilities obtained from profiles of MARCS with:

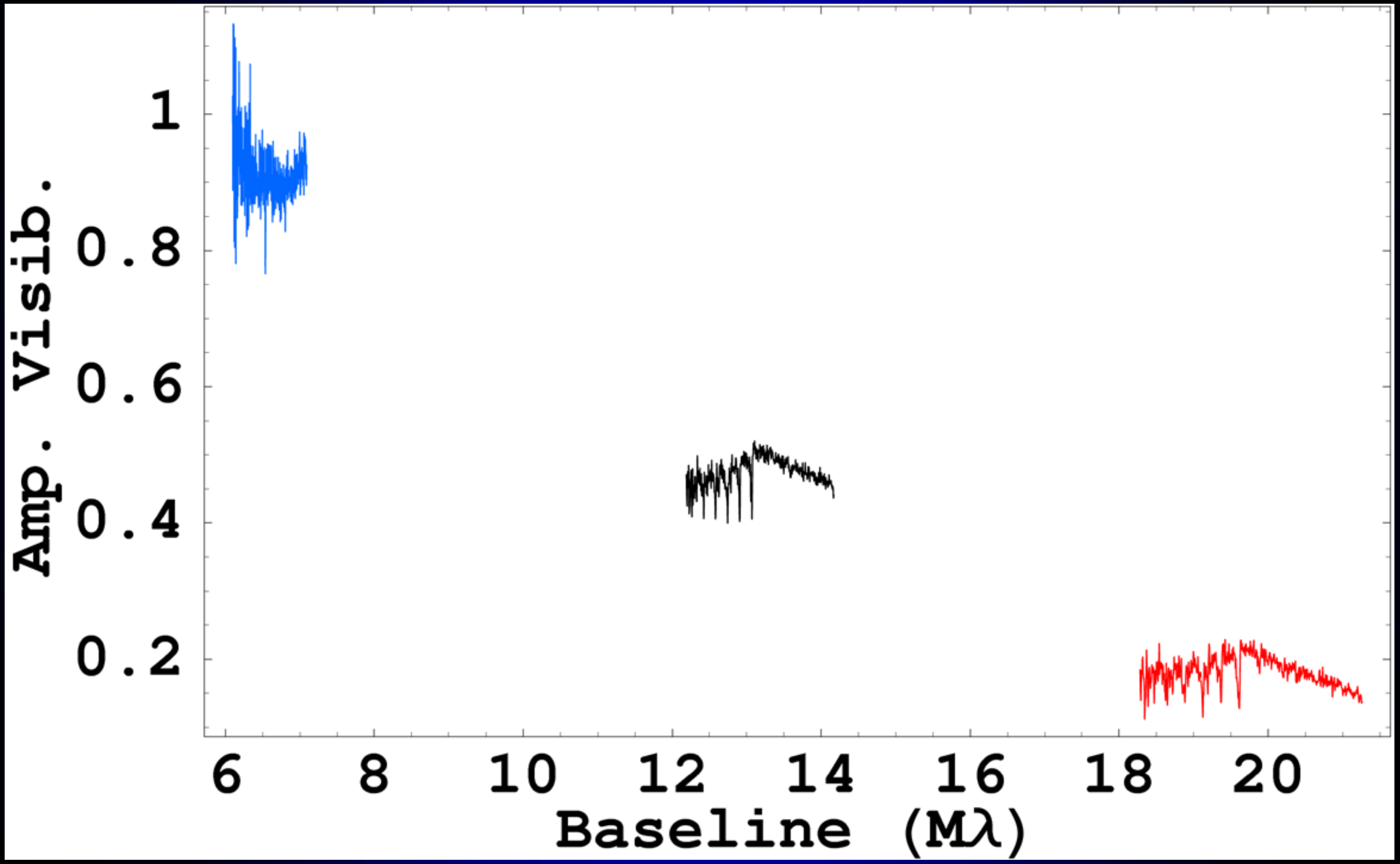
M= 2 Msun
Log g =0.0
C/N= 1.5, 12C/13C = 20<, [Fe/H]=0.0
Microturbulence speed: 10km/s

results in an estimate of the

Rosseland angular diameter of 7.95 (0.07) mas

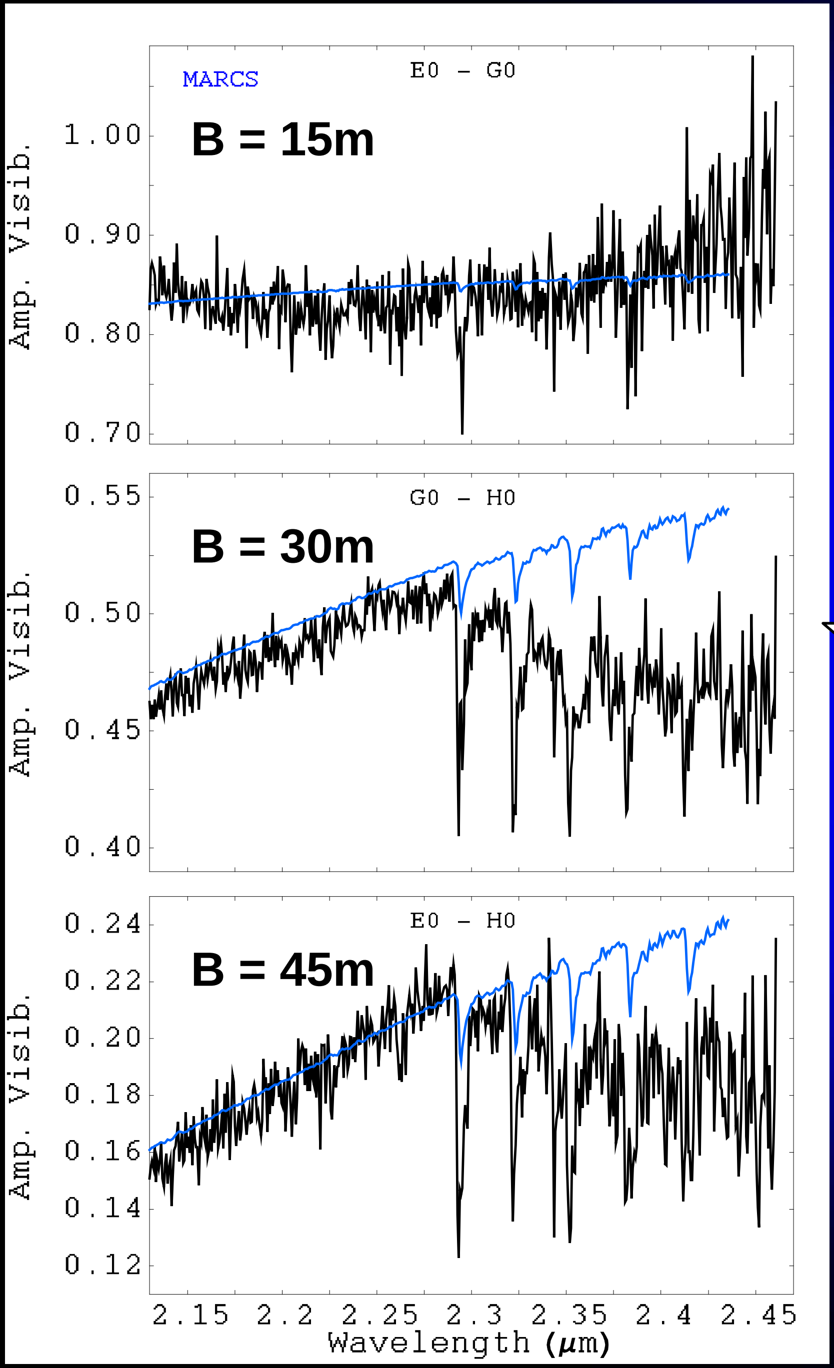
(bolometric flux from Richichi at al (1992) : 2.01 (0.2) E-6 erg/cm^2 s)

Teff = 3160 (160) K



Amp. Visib.
1
0.8
0.6
0.4
0.2
6
8
10
12
14
16
18
20
Baseline (Mλ)

RS Cap vs. *MARCS*



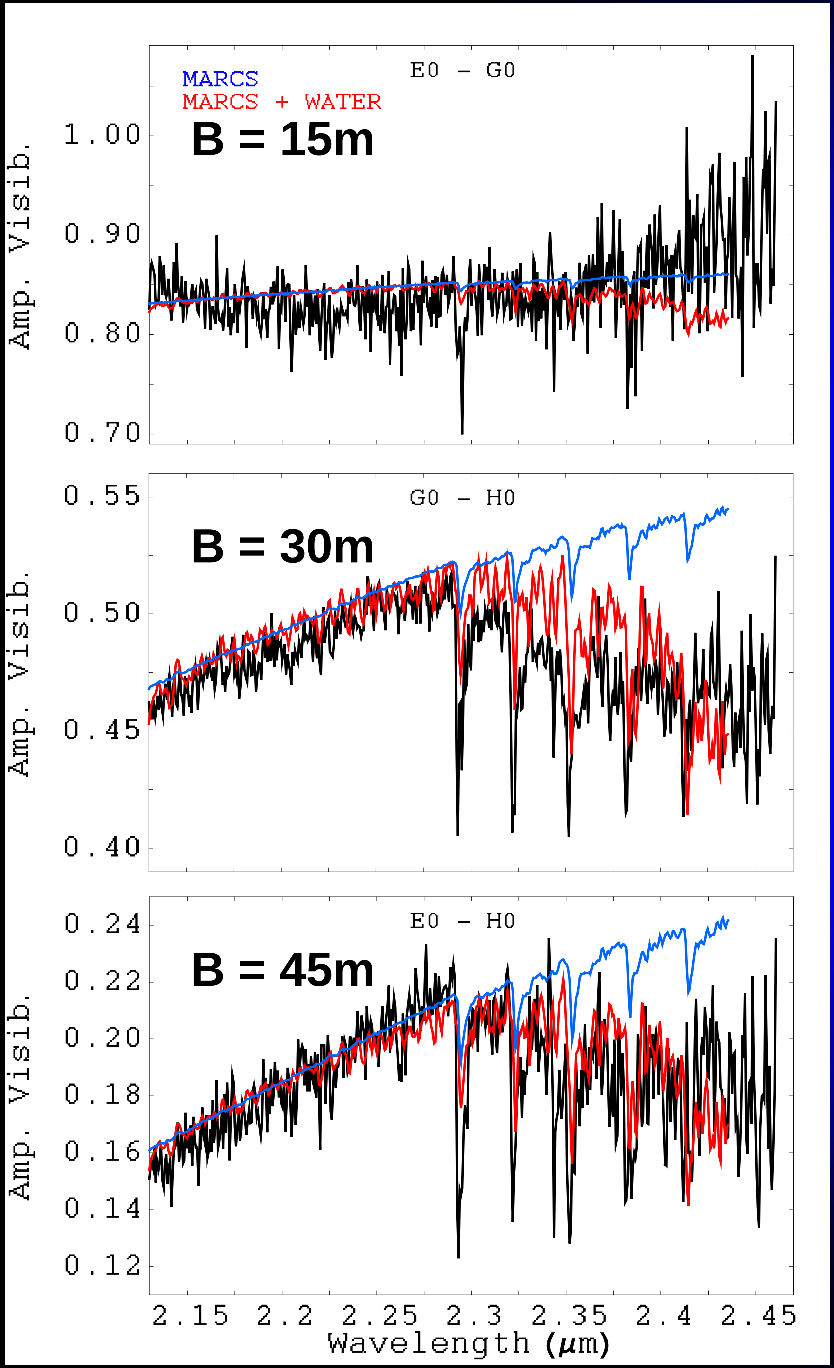
- The CO absorbing region is much more extended then indicated by the modeling with *MARCS*.

- An additional extended absorbing region is needed for λ > 2.3 μm.

☆ The pseudo-continuum observed by Mennesson et al. (2001) can be explained adding an extended water vapor region (Tsuji 1988; Ohnaka 2004).

The water vapor has a broad absorption band centered at 2.7 μm.

RS CAP vs. *MARCS*



- A narrow (tenth of star radius) water vapor region at 1500K placed at about twice the star radius (column density 1E21/cm^2) helps reproduce the visibilities when added to the MARCS model.

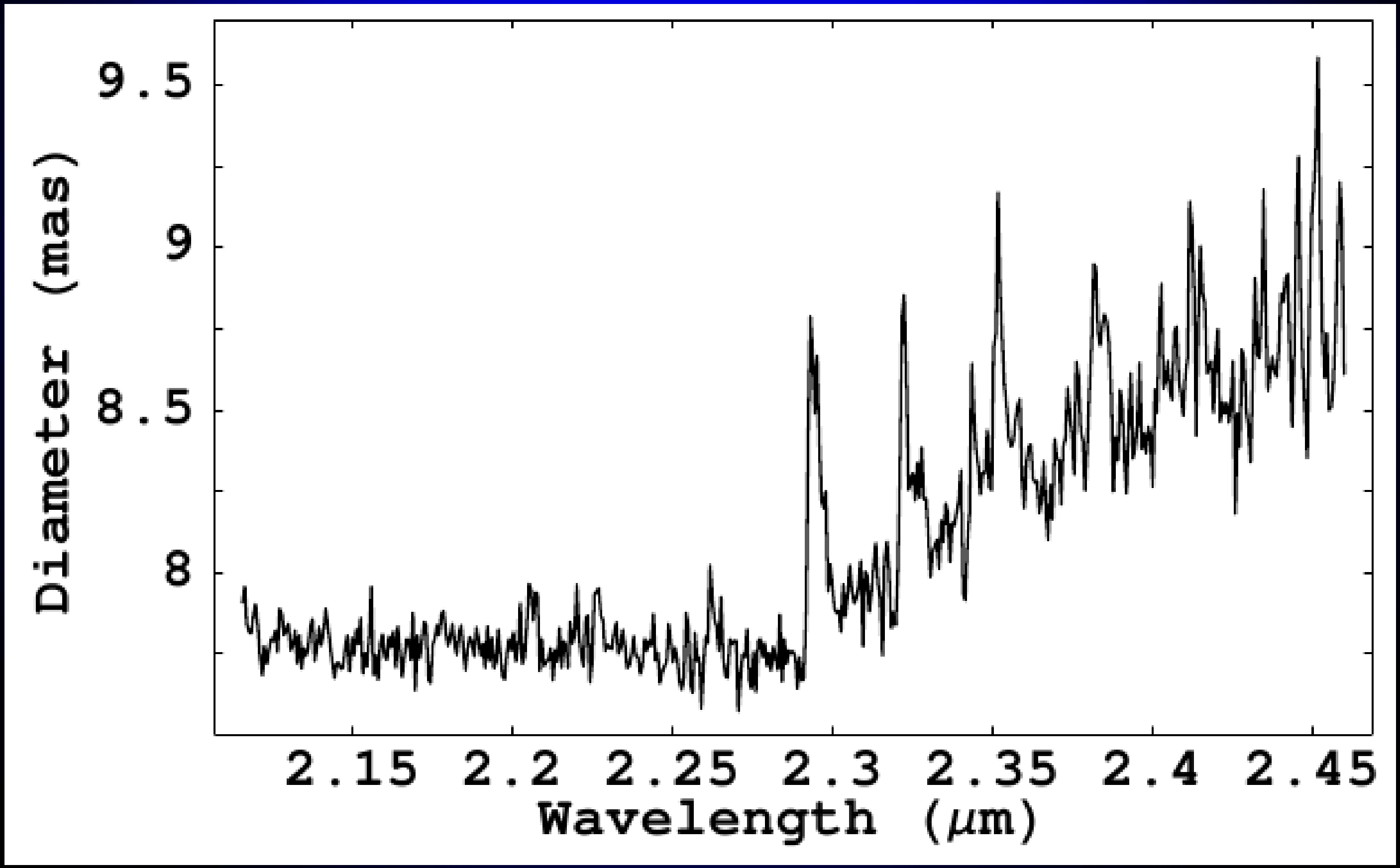
-The CO-bandhead diameters are still larger than predicted by the MARCS model by a factor of about 2.

The fit improves for smaller star masses but even with M ~ 0.5 Msun the fit is not fully satisfactory

Tantalizing evidence of a very extended CO region (based on data from short baseline E0-G0). Possible transition region at the base of the stellar wind.

RS Cap

1. CO opacity alters size by ~10-12%
2. Sistematic size increase for λ > 2.28 μm due to water vapor



T_{eff} from continuum: 3160 (160)K

CONCLUSIONS

- We have observed RS Cap spectro-interferometrically at K-band with VLTI/AMBER with the goal of studying the distribution of the atmospheric tracer molecule CO.

- The MARCS (stellar structure) models are incapable of fully reproducing the observed CO structure and of constraining the star mass.

- Evidence of water vapor in a narrow extended region.

Astronomy & Astrophysics manuscript no. Marti-Vidal-RSCap
February 3, 2011

AMBER observations of the AGB star RS Cap: extended atmosphere and comparison with stellar models★

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Accepted for publication in A&A

arXiv:1101.5749

ABSTRACT

We report on K-band VLTI/AMBER observations at medium spectral resolution (~1500) of RS Capricorni, an M6/M7III semi-regular AGB star. From the spectrally-dispersed visibilities, we measure the star diameter as a function of observing wavelength from 2.13 to 2.47 microns. We derive a Rosseland angular diameter of 7.95 ± 0.07 mas, which corresponds to an effective temperature of 3160 ± 160 K. We detect size variations of around 10% in the CO band heads, indicating strong opacity effects of CO in the stellar photosphere. We also detect a linear increase of the size as a function of wavelength, beginning at 2.29 microns. Models of the stellar atmosphere, based on the mass of the star as estimated from stellar-evolution models, predict CO-size effects about half of those observed, and cannot reproduce the linear size increase with wavelength, redward of 2.29 microns. We are able to model this linear size increase with the addition of an extended water-vapor envelope around the star. However, we are not able to fit the data in the CO bandheads. Either the mass of the star is overestimated by the stellar-evolution models and/or there is an additional extended CO envelope in the outer part of the atmosphere. In any case, neither the water-vapor envelope, nor the CO envelope, can be explained using the current models.

Key words. techniques : interferometric – stars : atmospheres – stars : late type – stars : invididual : RS Cap

Further comments

-Data from other AGBs are being analyzed (by Belen Arroyo).

-CO and water vapor seem to be rather ubiquitous… some times even in sources observed (and tagged) as calibrators.

Fortunately(?), we have also observed (thought to be) AGB stars without those molecules in the spectrum!!

AMBER/VLTI: The size of ABDor A as an age indicator

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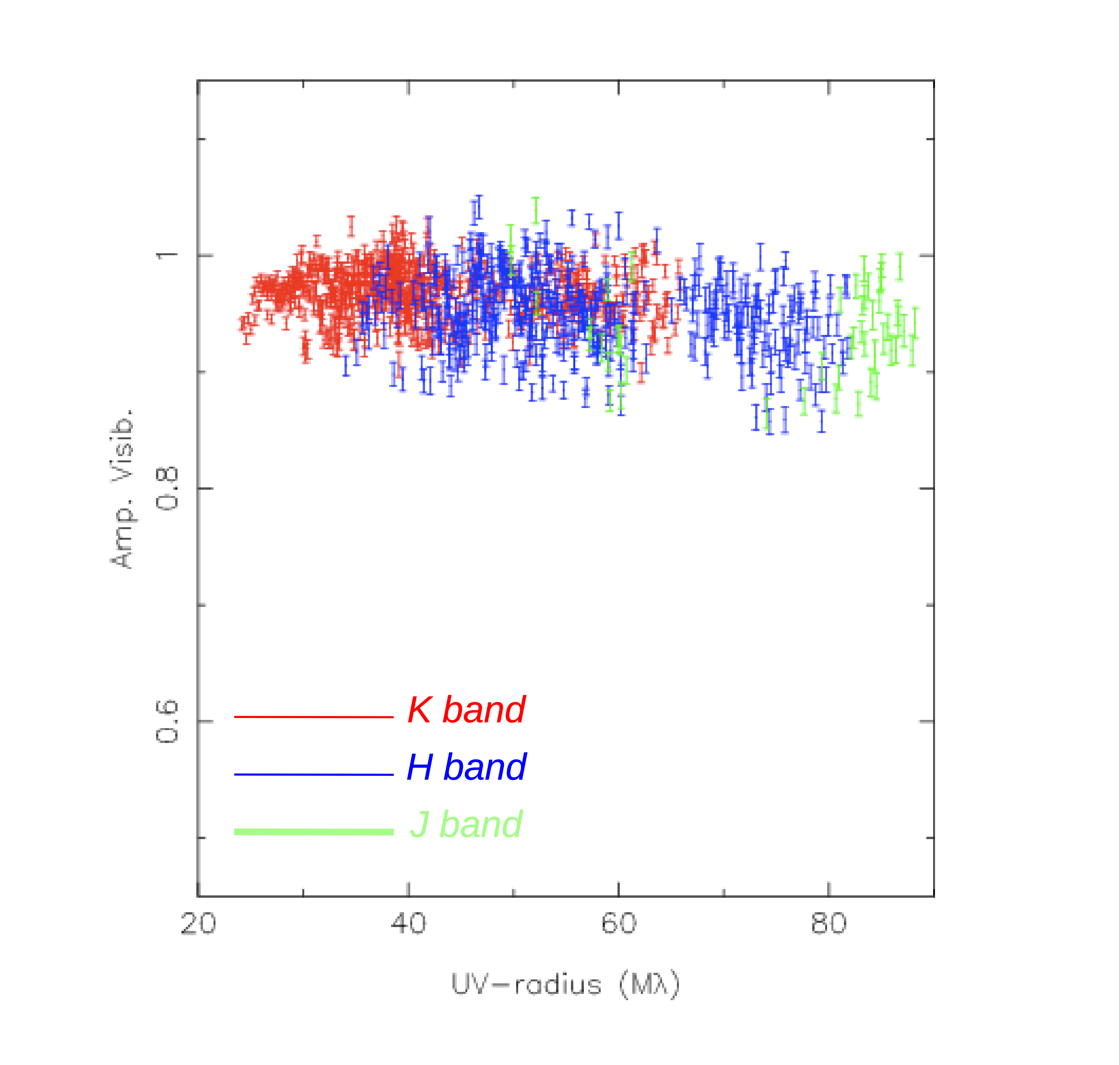
J.-B. LeBouquin

Size of ABDorA



Size of ABDorA

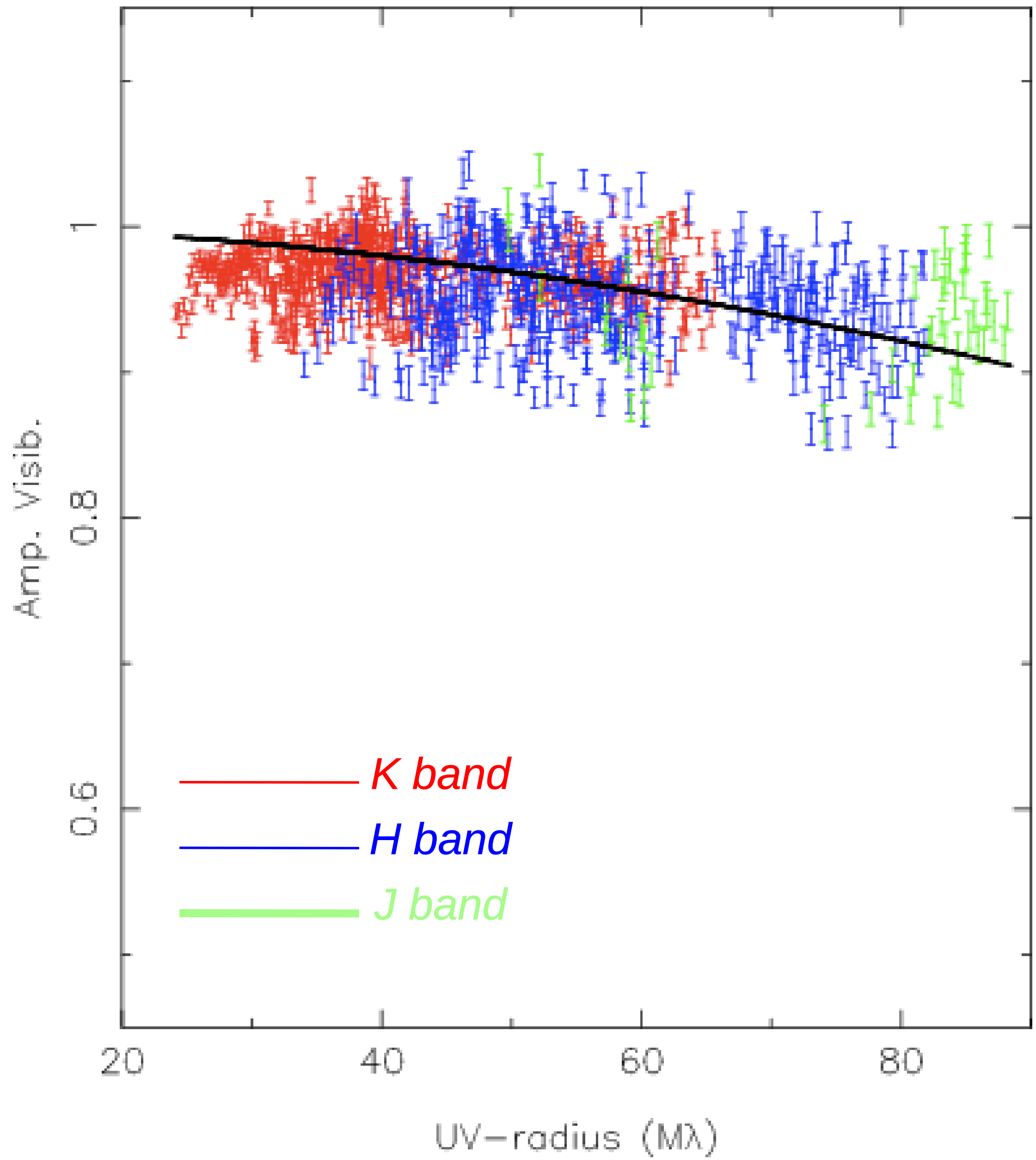
ABDorA

UD-diameter= 0.62±0.04 mas

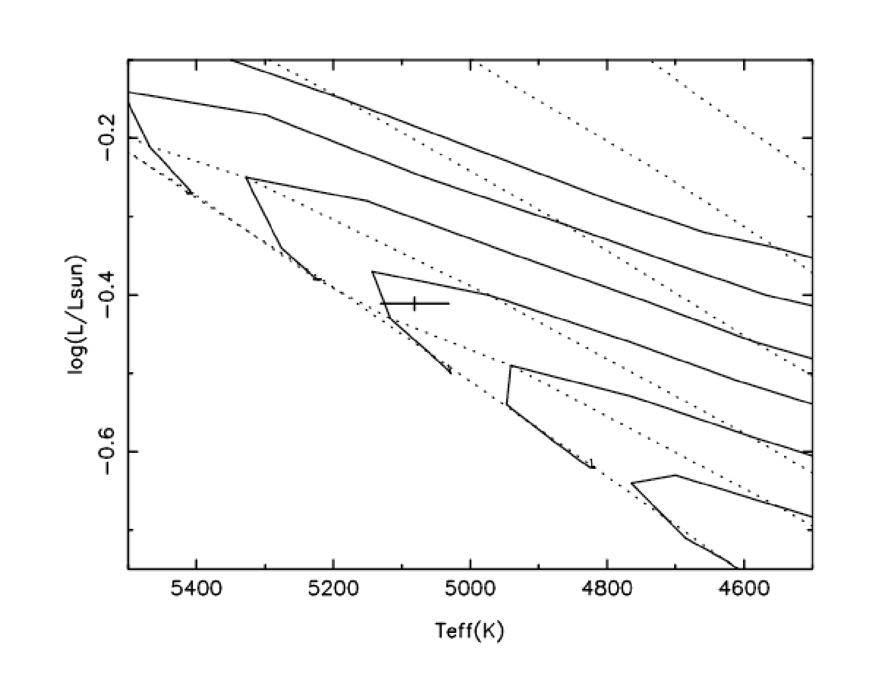
LD-diameter = 0.60±0.04 mas

Using the distance
(11.9 ± 0.1 pc)

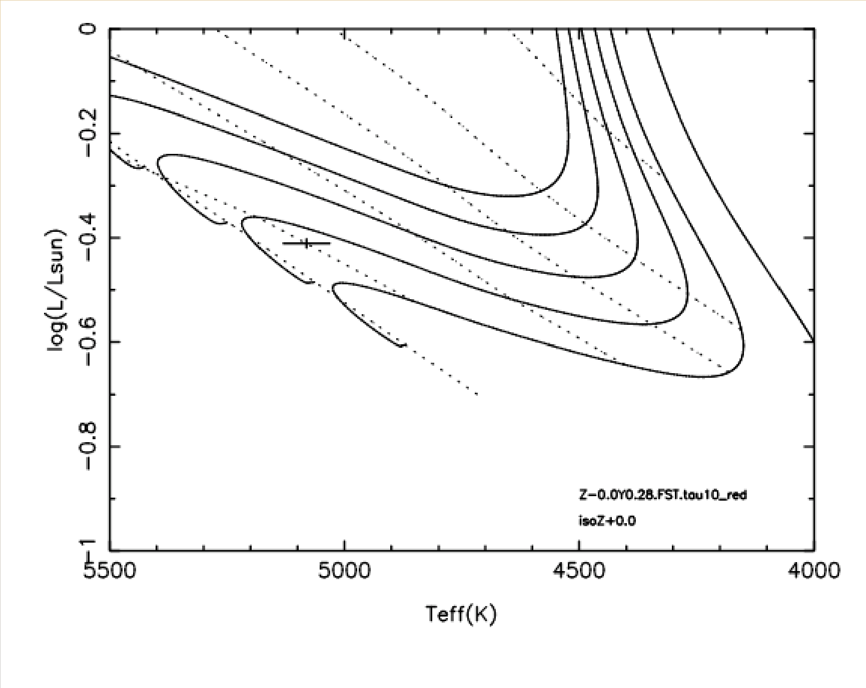
R = 0.96±0.06 R☉



Comparison with PMS models

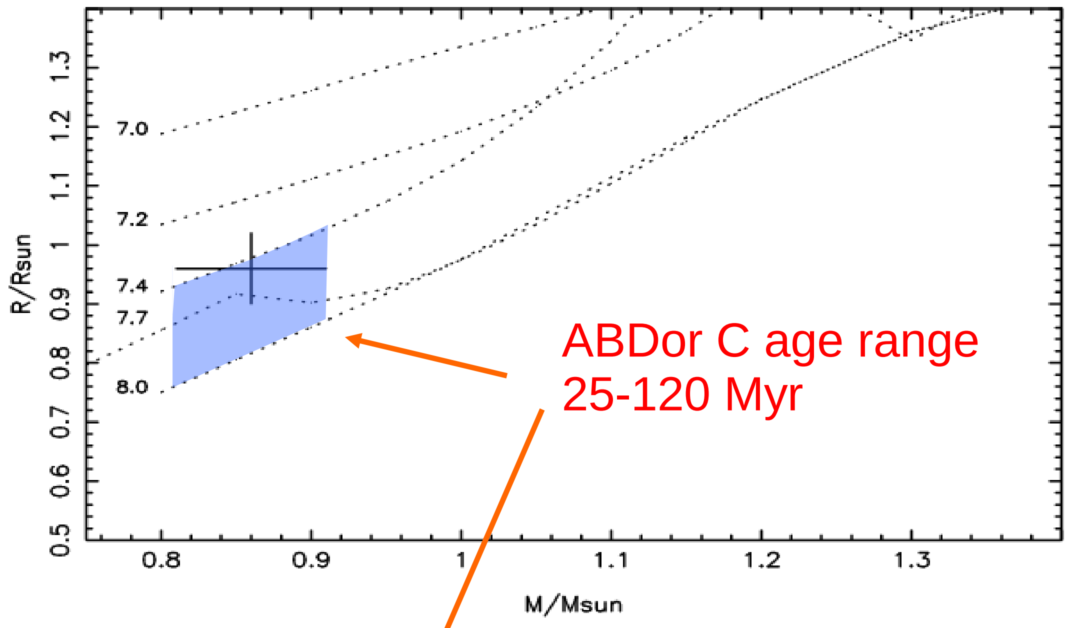


Barrafe et al. 1998

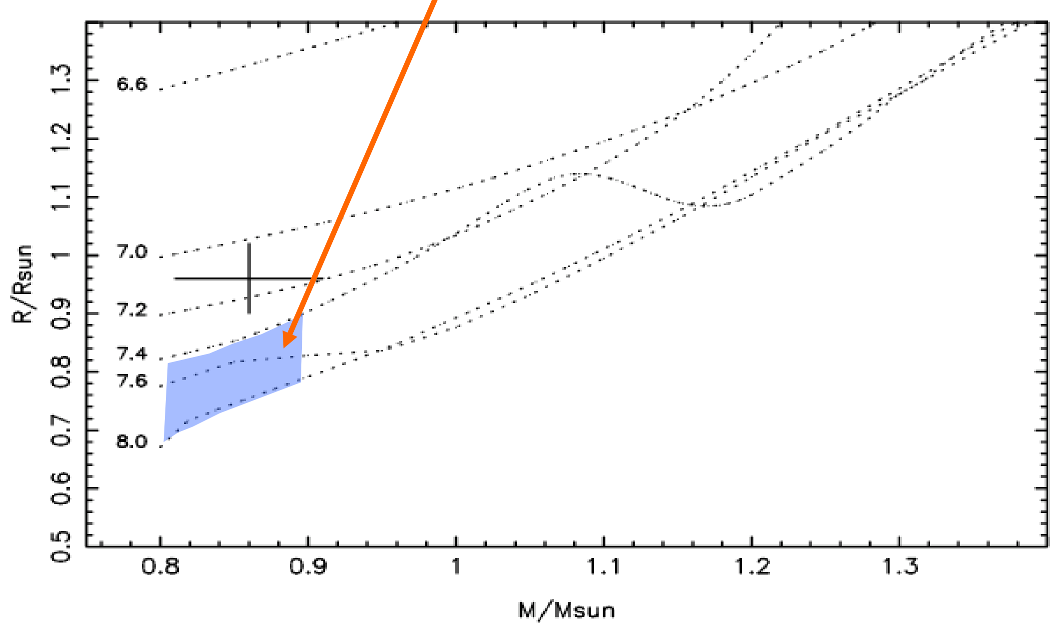


Montalban+D'Antona 2006

Comparison with PMS models



Barrafe et al. 1998



Montalban+D'Antona 2006

Comments on the size

HR diagram and M-R plane do not give the same age for the same object.

Geometric models used for ABDor A shape are simple (UD, LD).

- Ellipticity important (fast rotator)?
- Role of the intense magnetic field in ABDor A in its shape?

For the UD/LD model tested:

- For ABDor A, comparison of theoretical and measured values in the M-R plane (and HR diagram) seems to favor the younger side of the range 25 – 120Myr (range estimated for ABDor C), being perhaps 40 Myr, appropriate if a star activity correction factor of about 15% of size (Torres et al. 2006) is assumed.