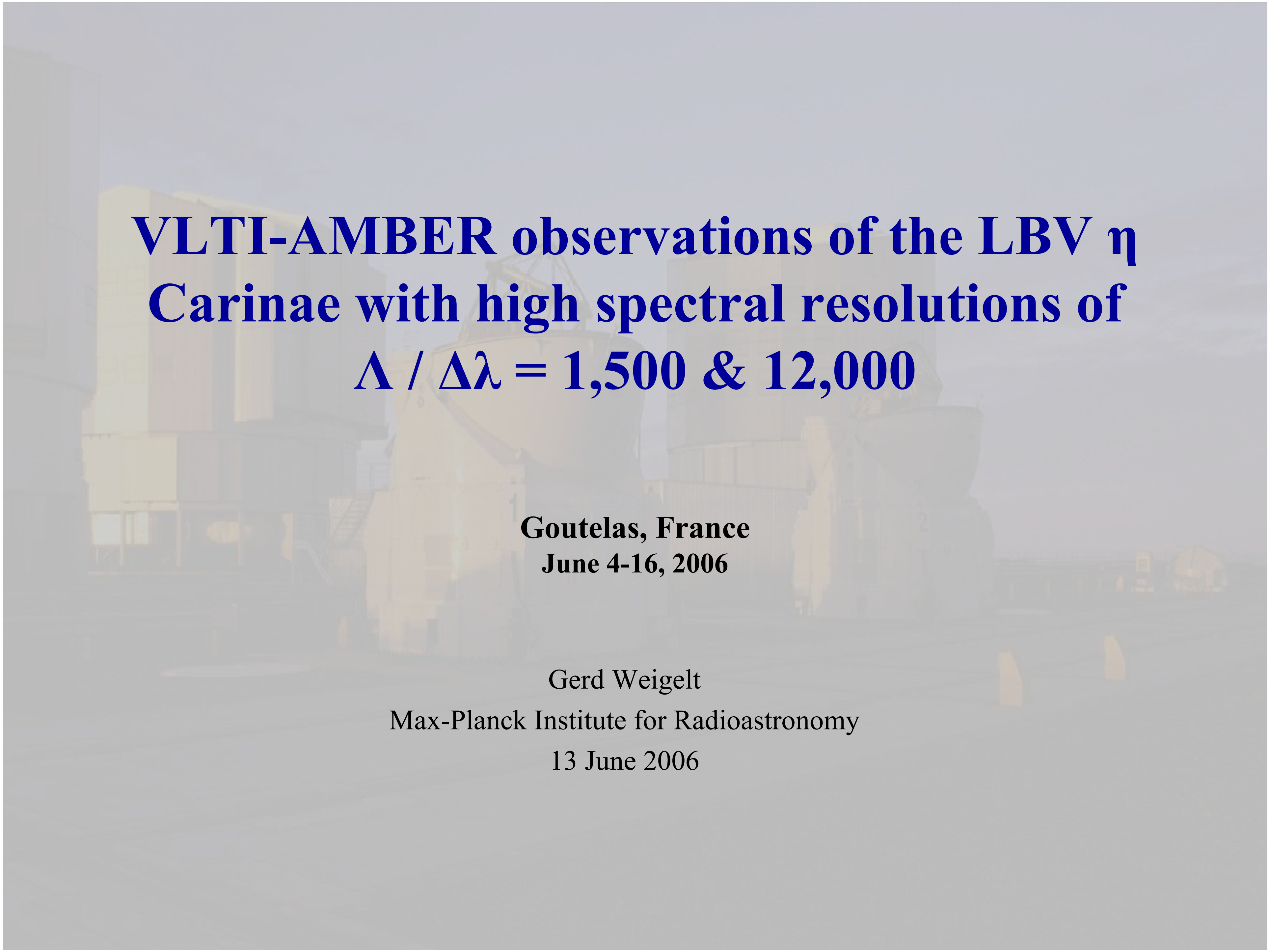


VLTI-AMBER observations of the LBV η Carinae with high spectral resolutions of $\Lambda / \Delta\lambda$ = 1,500 & 12,000

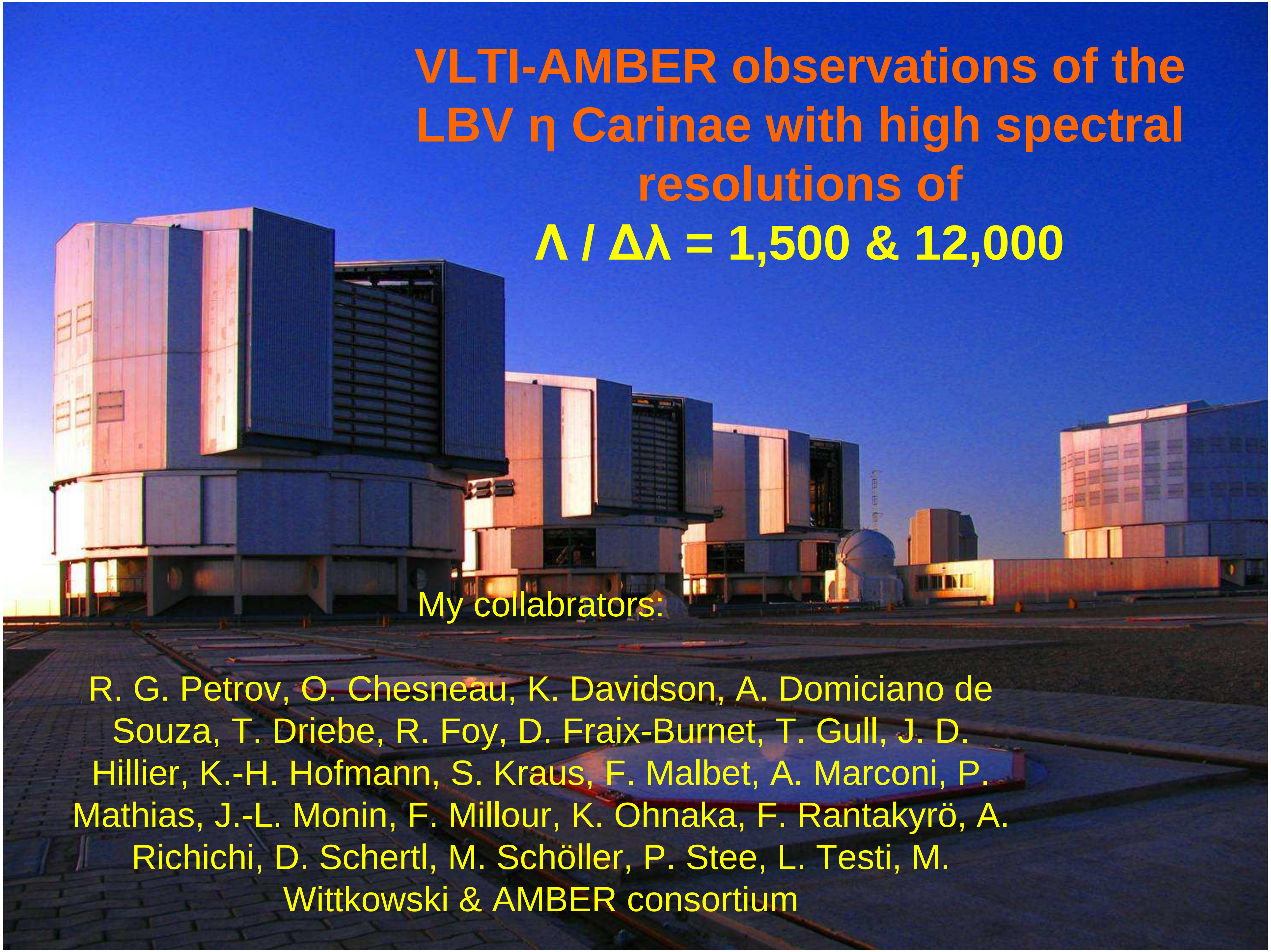
Goutelas, France

June 4-16, 2006

Gerd Weigelt

Max-Planck Institute for Radioastronomy

13 June 2006


VLTI-AMBER observations of the LBV η Carinae with high spectral resolutions of
$\Lambda / \Delta\lambda$ = 1,500 & 12,000
My collabrators:
R. G. Petrov, O. Chesneau, K. Davidson, A. Domiciano de Souza, T. Driebe, R. Foy, D. Fraix-Burnet, T. Gull, J. D. Hillier, K.-H. Hofmann, S. Kraus, F. Malbet, A. Marconi, P. Mathias, J.-L. Monin, F. Millour, K. Ohnaka, F. Rantakyrö, A. Richichi, D. Schertl, M. Schöller, P. Stee, L. Testi, M. Wittkowski & AMBER consortium

Plan

- Eta Carinae: mass 70 to 100 solar masses, 1843 outburst caused the Homunculus nebula; **optically thick, aspheric stellar wind** (4 mas diameter of this gas region or ~ 9 AU), binary?, WR companion, wind-wind interaction zone

- movie: binary and wind-wind interaction zone

- Observations: visibilities, differential phases, closure phases

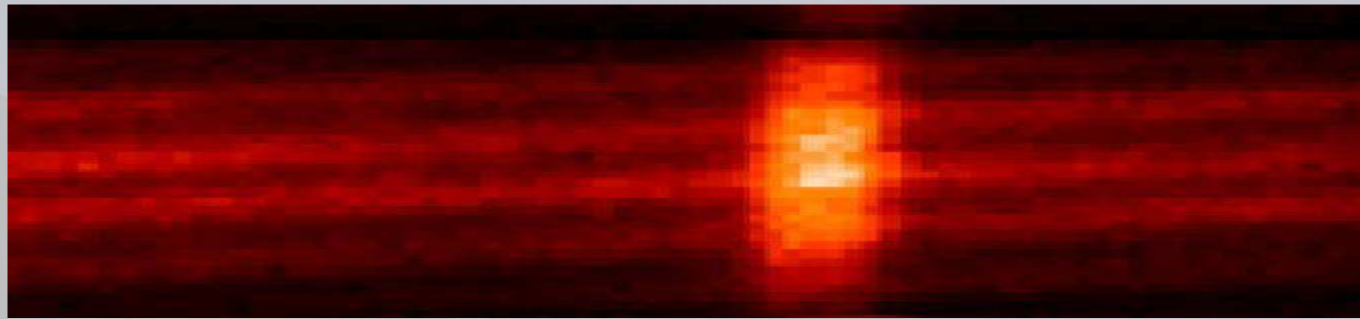
- Comparision of the observations with model predictions (Hillier et al. 2001)

- Results & interpretetation

(Reference: “Weigelt et al., Near-Infrared interferometry of Eta Carinae with high spatial and spectral resolution using the VLTI and the AMBER instrument”, A&A Submitted)

Eta Car observations: visibilities, differential phases, closure phases

$\lambda / \Delta \lambda = 1{,}500$

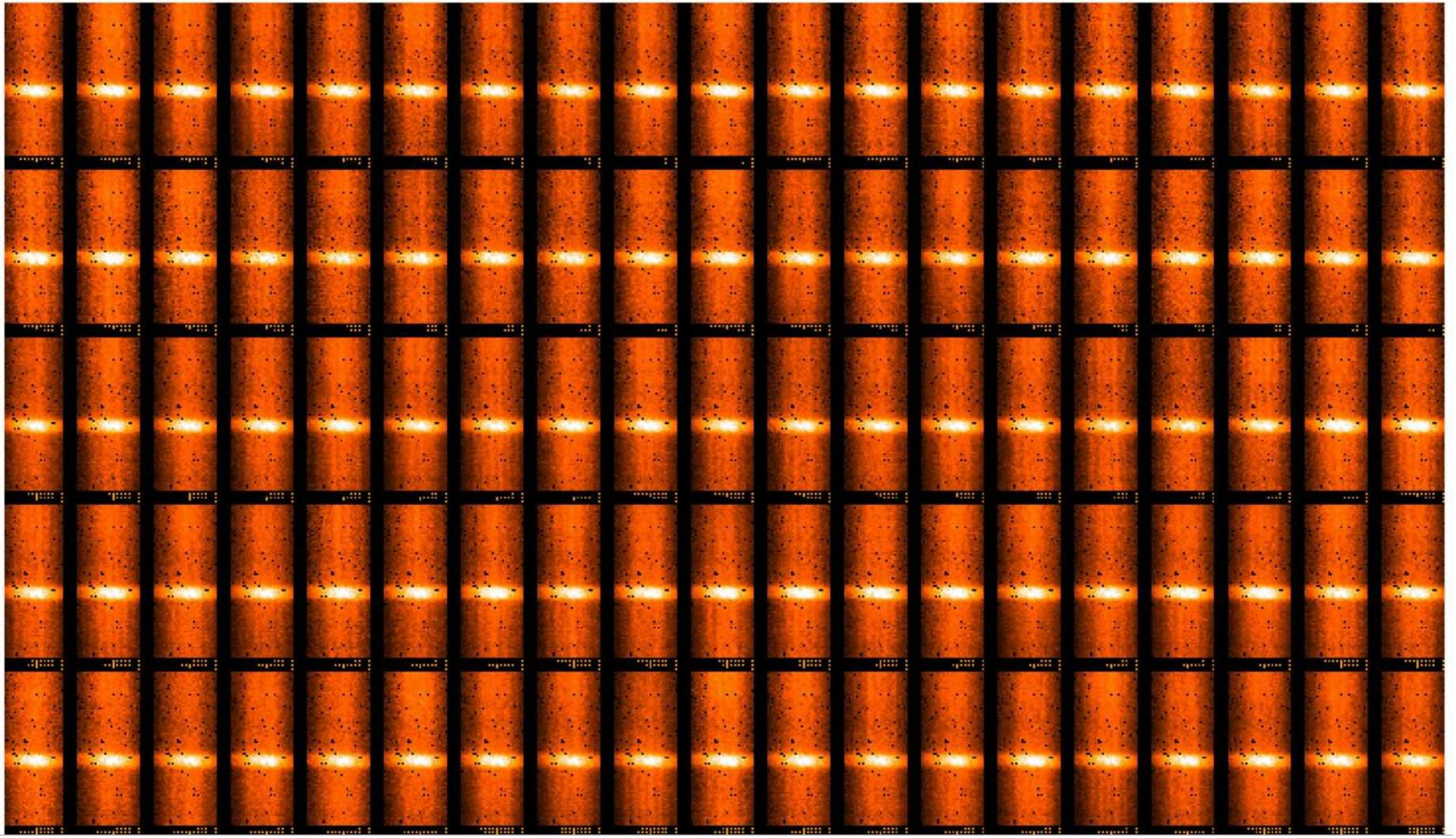


→ λ

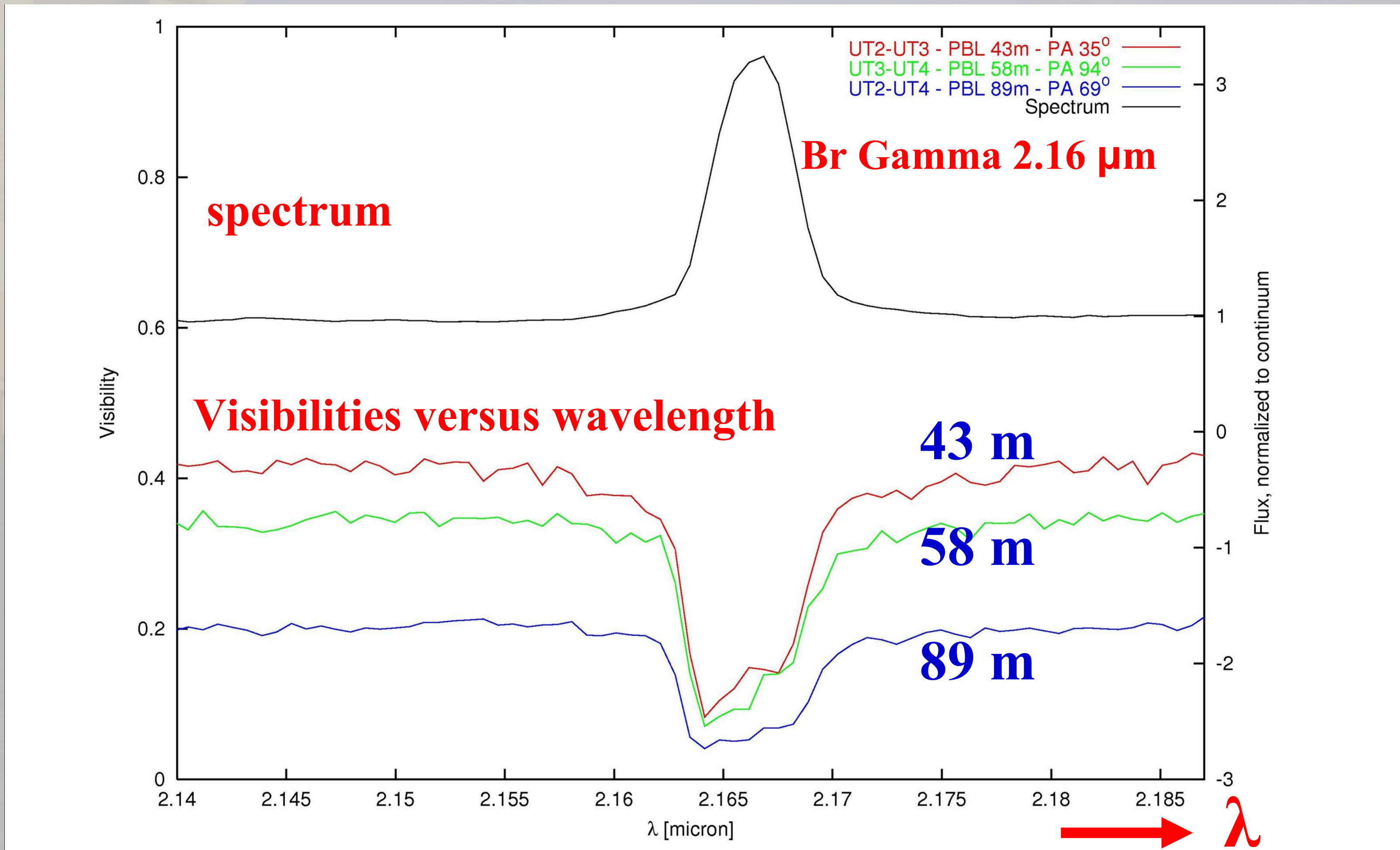
- First spectro-interferometry of η Car
- Measurements were carried out in Dec. 2004 (orbital phase 0.268) and Feb. 2005 (phase 0.299) with three 8 m UTs of the VLTI
- **Spectral resolutions $\lambda/\Delta\lambda$ =1,500 and 12,000**
- Observations around the He I 2.059 µm & the Br γ 2.166 µm emission lines
- Visibilities, differential & closure phase
- Goal of the studies: wavelength dependence of the optically thick, aspheric wind region; test of model predictions; binary?

Eta Car raw data
3 UTs, medium spectral resolution, Br Gamma region

AMBER.2004-12-26T07:52:26.114.fits - HD-93308 (1) - λ_{eff} 2100.205 nm - 0.0400000 s - GMR

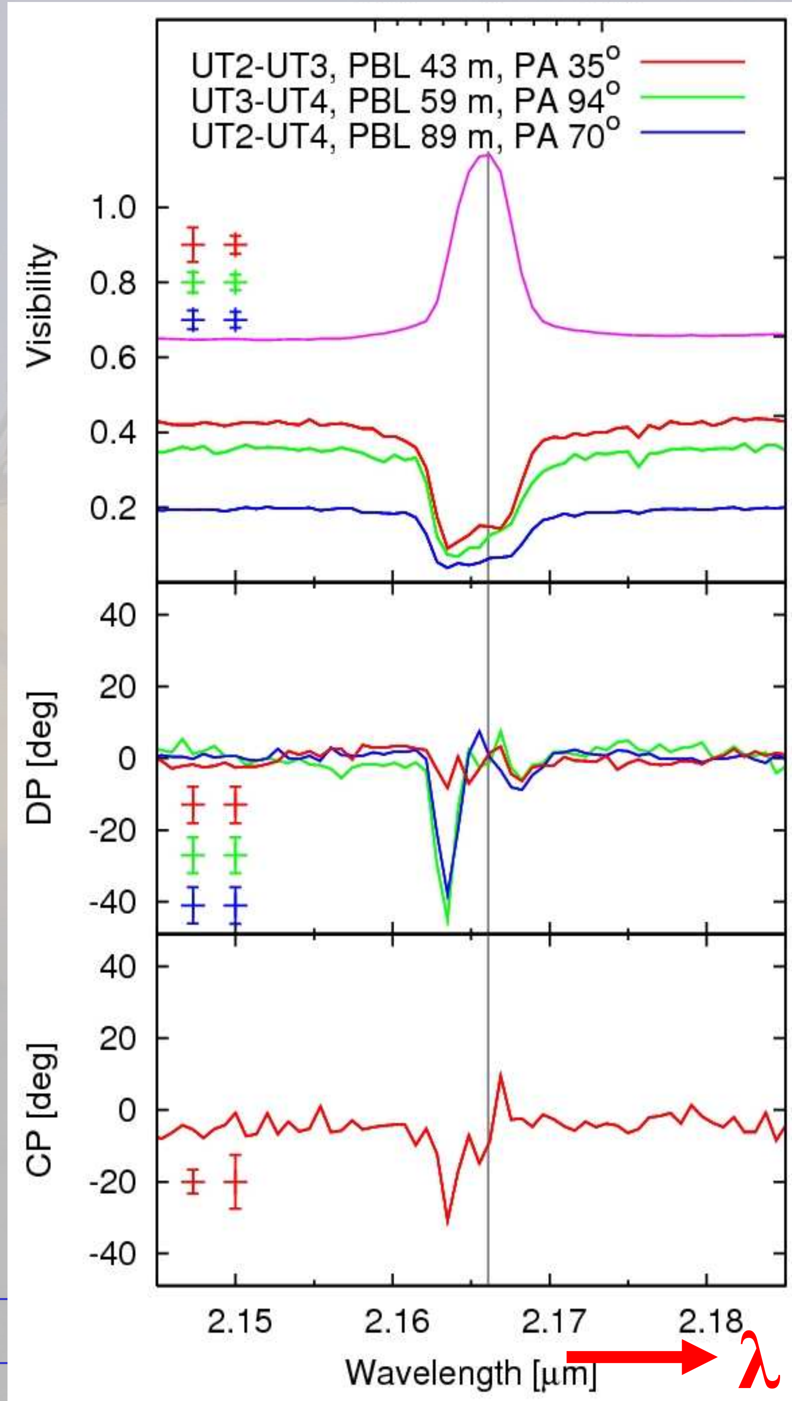


Observations near the Br Gamma line: Visibilities at baseline lengths 43, 59, and 89 m; medium spectral resolution λ/Δλ =1,500



VLTI-AMBER observations of η Car with high spectral resolutions of **λ/Δλ =1,500**:

Wavelength dependence of visibilities, differential phase, closure phase



Spectrum

Visibilities:

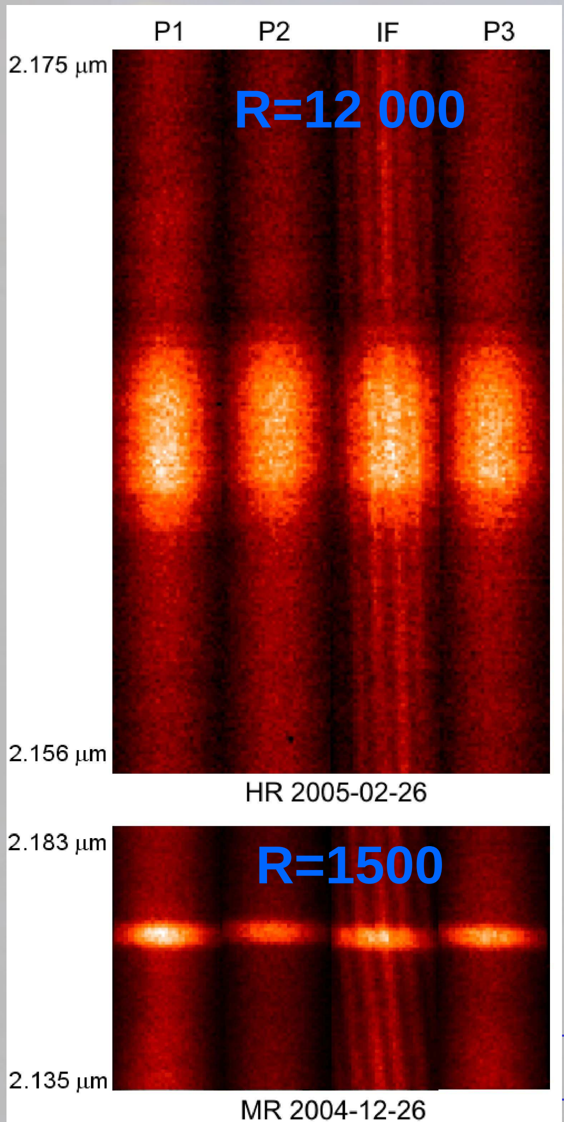
43, 58, & 89 m

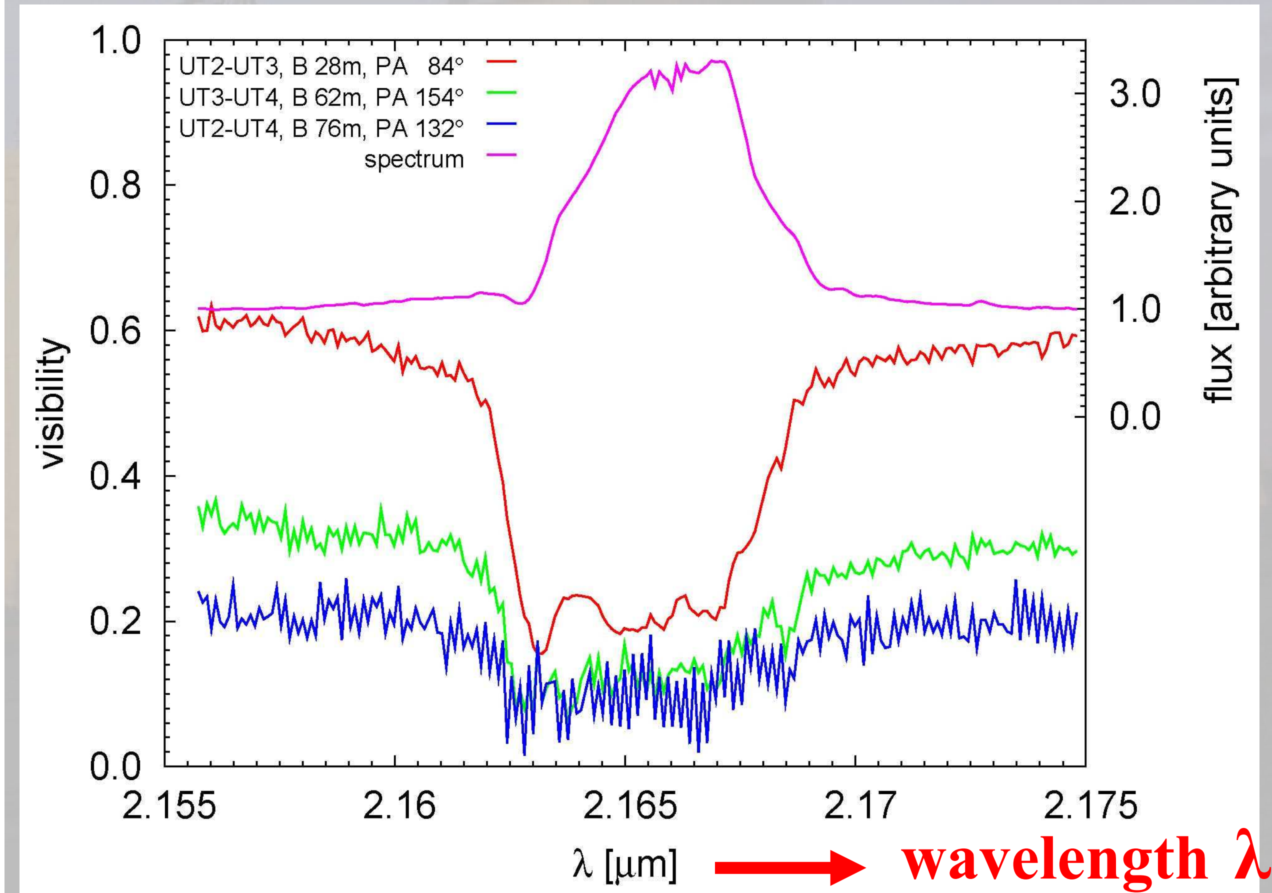
Differential phase:

43, 58, & 89 m

Closure phase

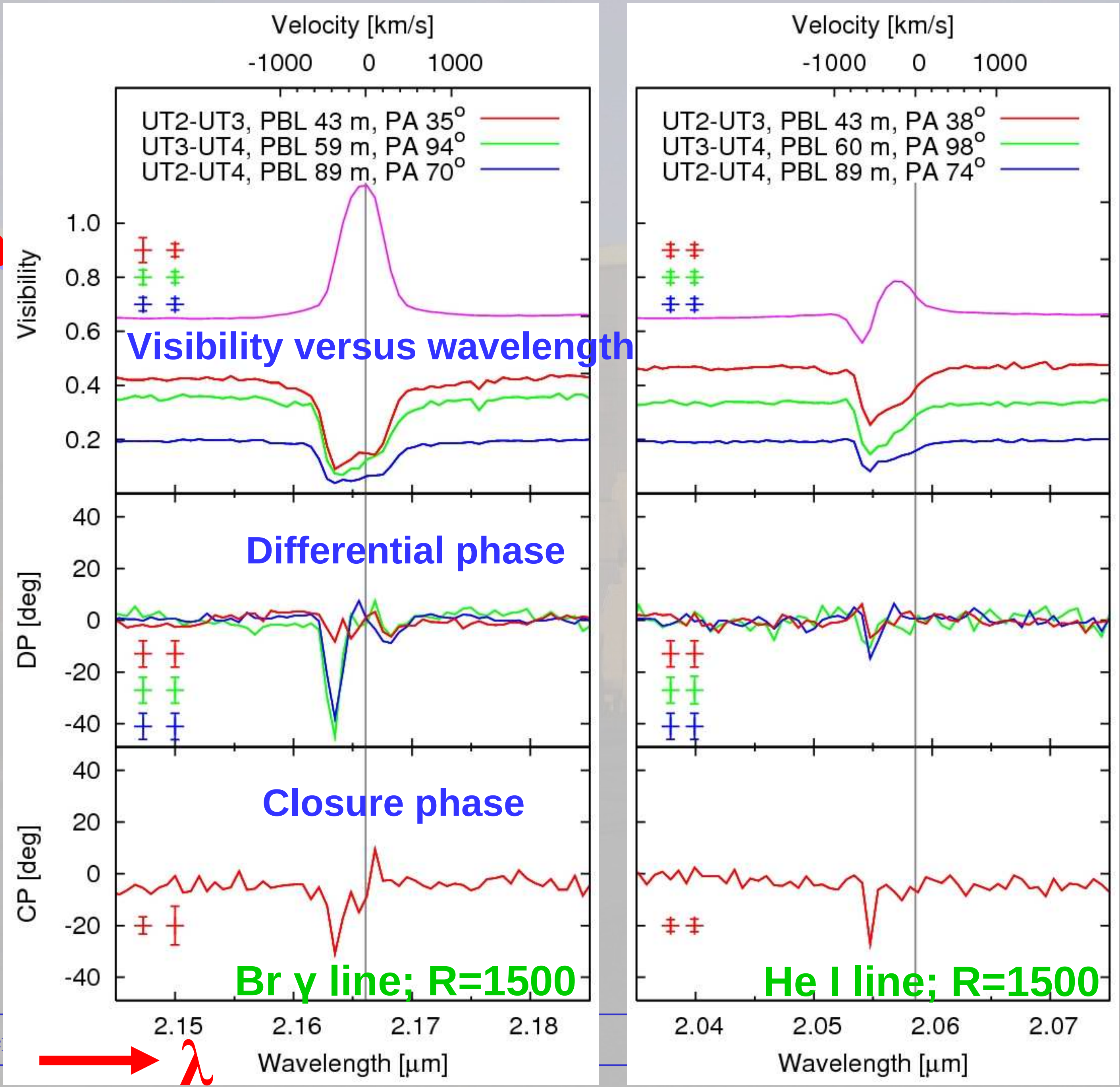
Observations: Visibilities: baseline lengths 28, 62, 76 m; UT2-UT3-UT4; spectral resolution **12,000**



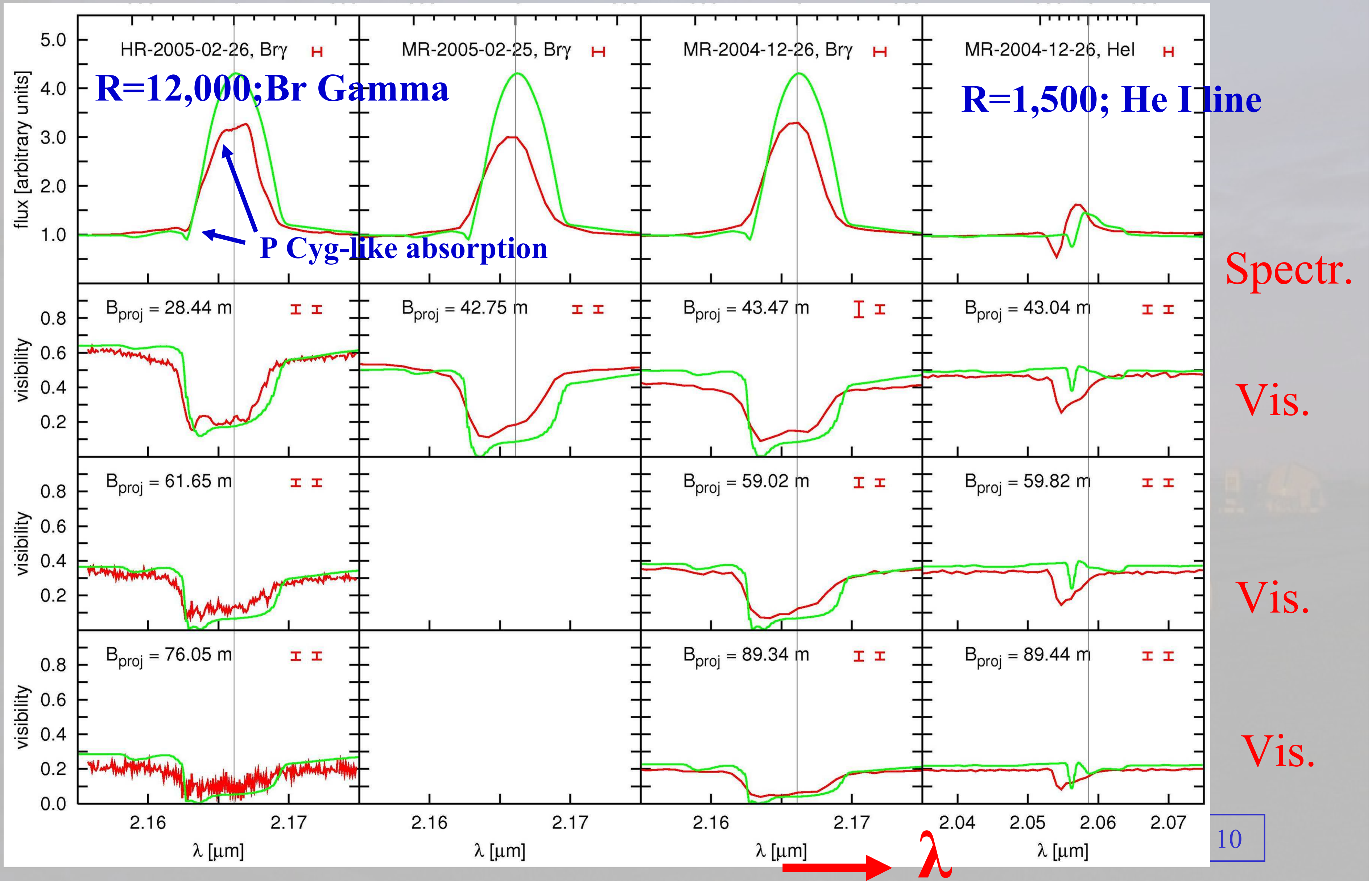


Br Gamma & He I line:

spectral resolution 1500



Comparison of observations with Hillier et al. 2001models



Comparison of the measured visibilities with the predictions of the Hillier et al. 2001 model (red lines)

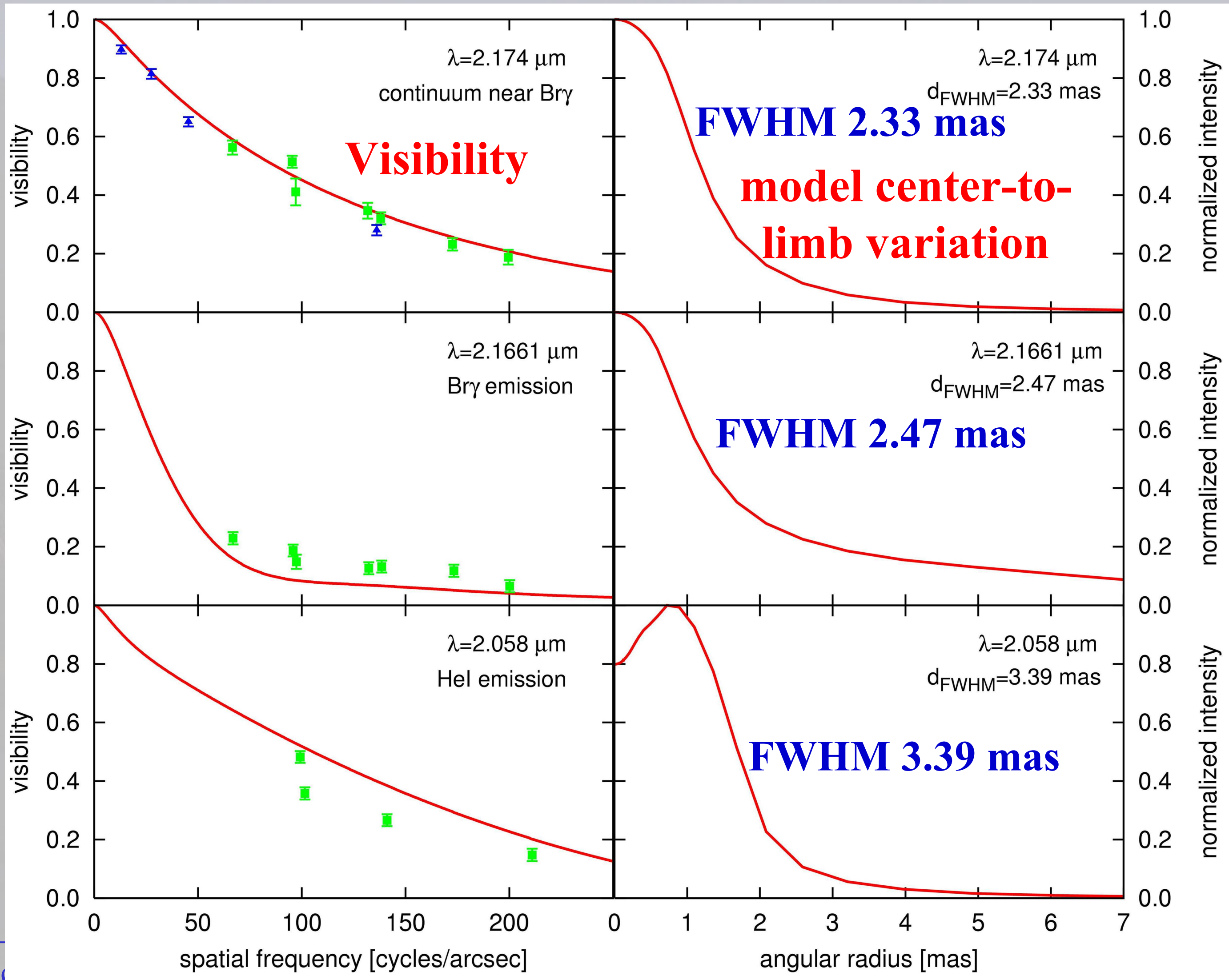
Visibility versus spatial frequency or baseline:

2.174 µm contin.:
Green sq.: AMBER
Blue triangles: VINCI (van Boekel et al. 2003)
Lines: Hillier model

2.1661 µm Br γ:

2.058 µm He I emission l.:

Gauss? FWHM ?



Spatial frequency (or baseline length)

Results (1): Comparison of the measured visibilities with the predictions of the Hillier et al. 2001 model

When comparing the AMBER **continuum** visibilities with the NLTE radiative transfer model from Hillier et al. 2001, we found a good agreement between the model and observations.

The best fit was obtained with a slightly rescaled version of the original Hillier et al. model (rescaling by 1-2%), corresponding to **FWHM continuum diameters of 2.27 mas at λ =2.040 µm and 2.38 mas at λ = 2.174 µm.** FWHM problematic …

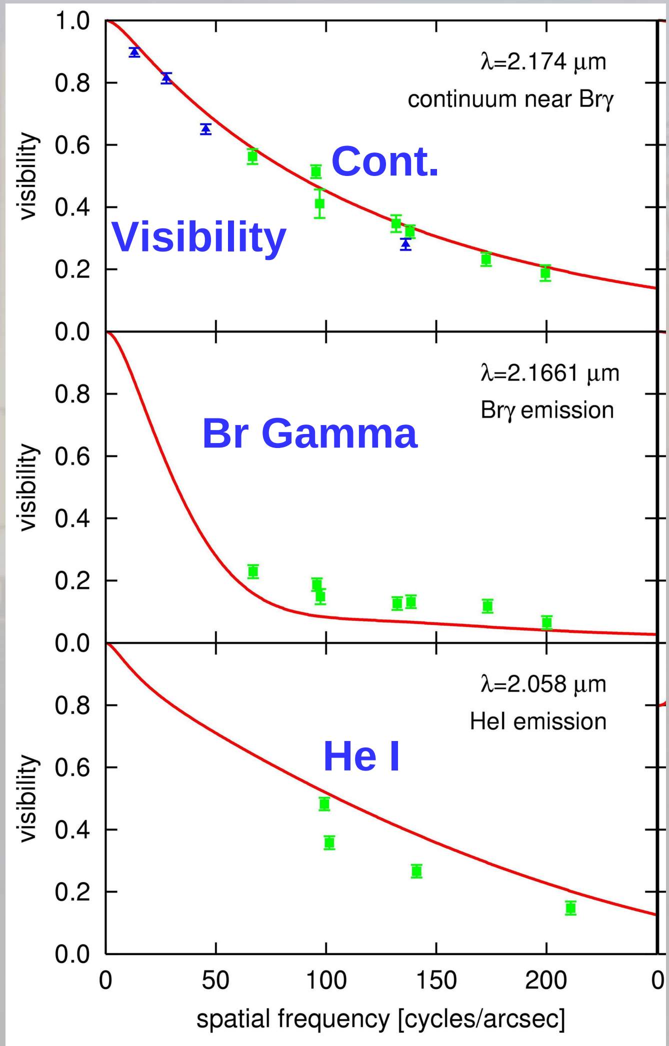
If we fit Hillier et al. 2001 model visibility shapes to the observed AMBER visibilities, we obtain, for example, **50% encircled-energy diameters of 4.3, 6.5 and 9.6 mas** in the **2.17 µm continuum, the He I, and the Br Gamma emission lines**, respectively.

FWHM Gaussian diameter

In the K-band continuum, we resolved Eta Car's optically thick wind. From a Gaussian fit of the K-band continuum visibilities in the projected baseline range from 28-89 m, we obtained a FWHM diameter of **4.0 ± 0.2 mas**. Gaussian fit problematic …

Taking the different field-of-views into account, we found good agreement between the AMBER measurements and previous VLTI/VINCI observations of Eta Car presented by van Boekel et al. 2003.

Results (1): Resolution of η Car' s optically thick wind region in the continuum & within Br γ & He I.



If we fit Hillier et al. (2001) model visibilities to the observed AMBER emission line visibilities, we obtain the following 50% encircled-energy diameters:

K continuum: 4.3 mas
Br Gamma: 9.6 mas
He I 2.06: 6.5 mas.

Comparison of the measured visibilities with the predictions of the Hillier et al. 2001 model (red lines)

2.040 µm Cont.

2.040 µm Cont.

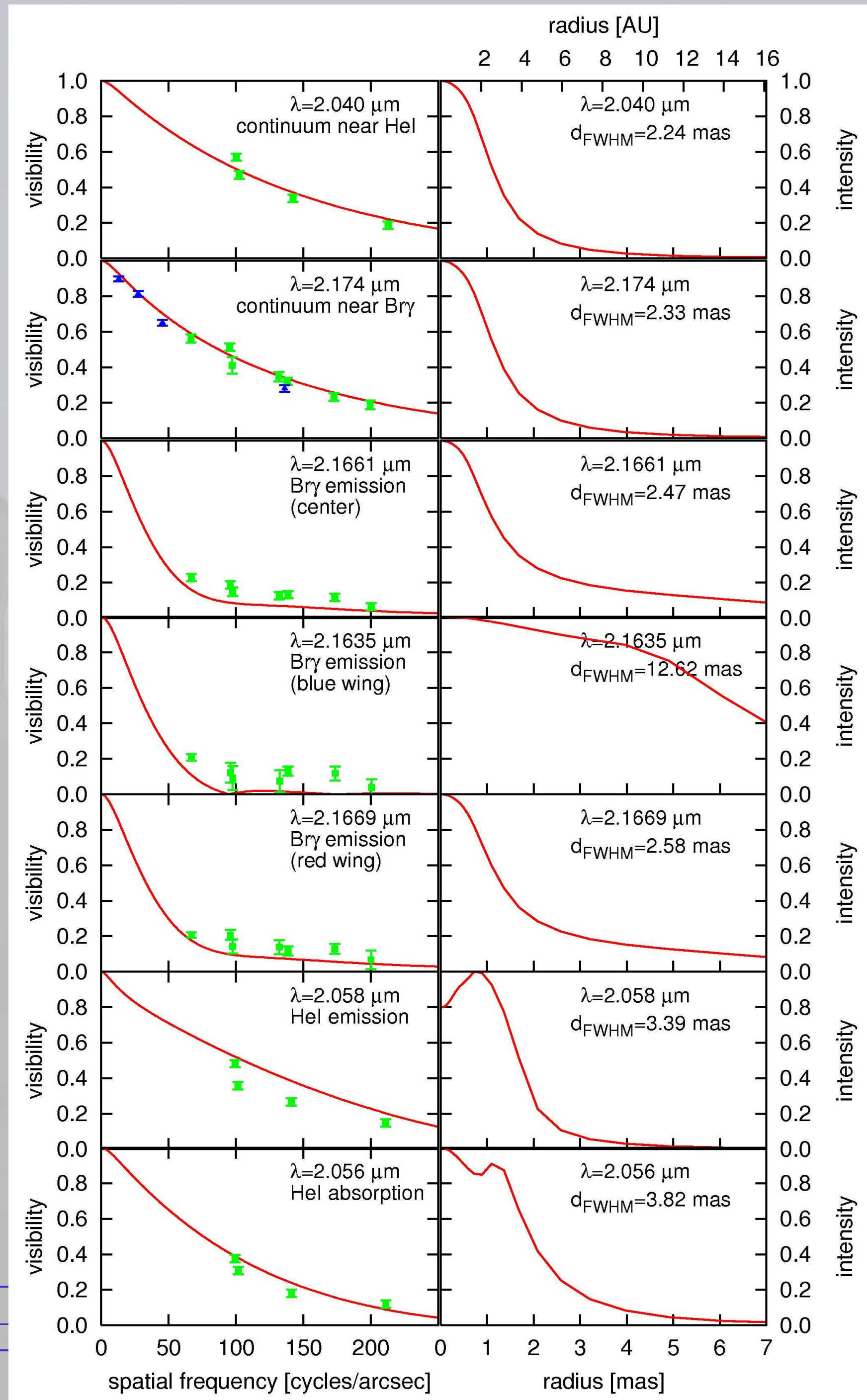
2.1661 µm

2.1635 µm

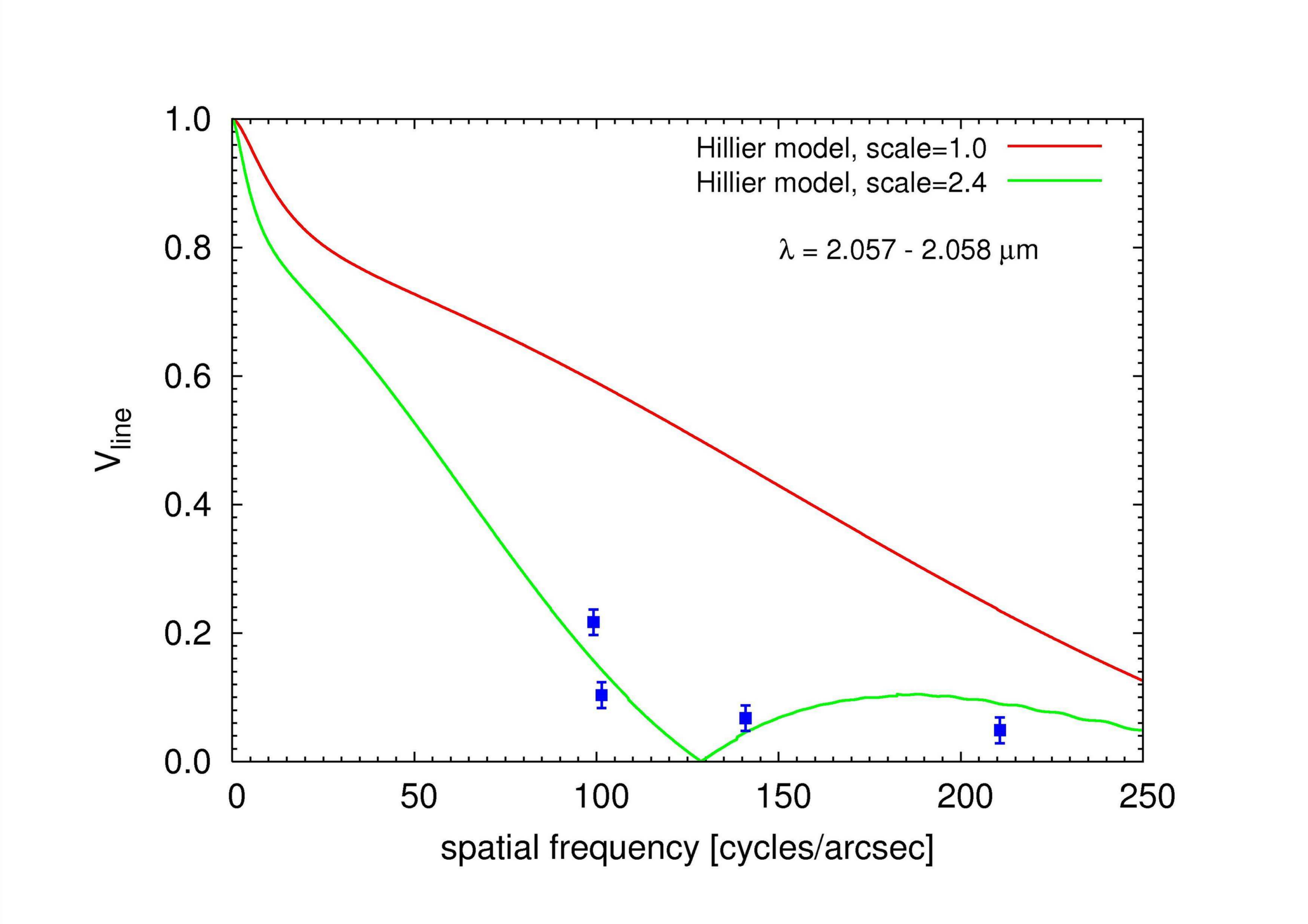
2.1669 µm

2.0580 µm

2.0560 µm



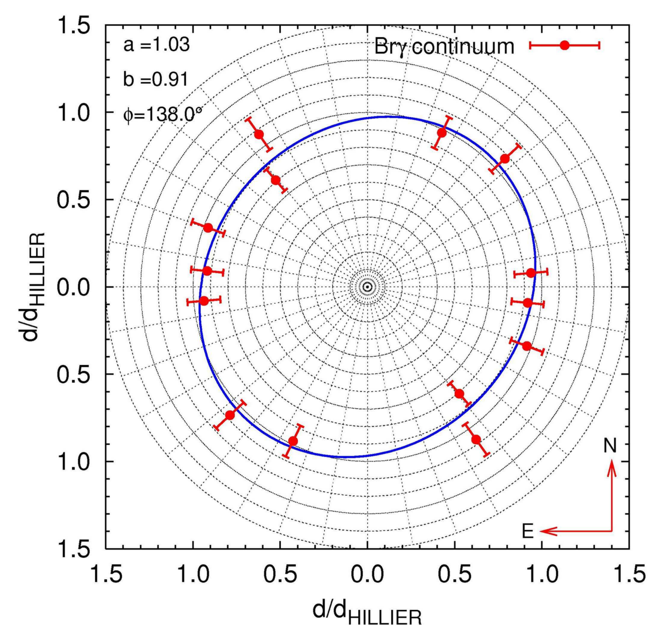
Continuum-corrected He I visibility: wind-wind interaction zone?



Sizes of the line-emitting regions (continuum-subtracted diameters)

For the Br Gamma and He I line-emitting regions, we obtain FWHM diameters of approx. 15.4 and 8.2 mas, respectively, if we fit continuum-corrected Hillier et al. model model visibility profiles to the observed continuum-corrected visibilities.

Results (2) - Elongated K-band shape:
PA=128 ± 15° & projected axis ratio of 1.21 ± 0.08



In the continuum around the Br Gamma line, we found an **asymmetry towards position angle 128±15° with a projected axis ratio of 1.21±0.08**.

This result confirms the earlier finding of van Boekel et al. 2003 using VLTI/VINCI and **supports theoretical studies which predict an enhanced mass loss in polar direction for massive stars rotating close to their critical rotation rate** (Owocki et al. 1996, Dwarkadas & Owocki 2002, von Zeipel 1924).

These models predict a higher wind speed & density along the polar axis than in the equatorial plane.

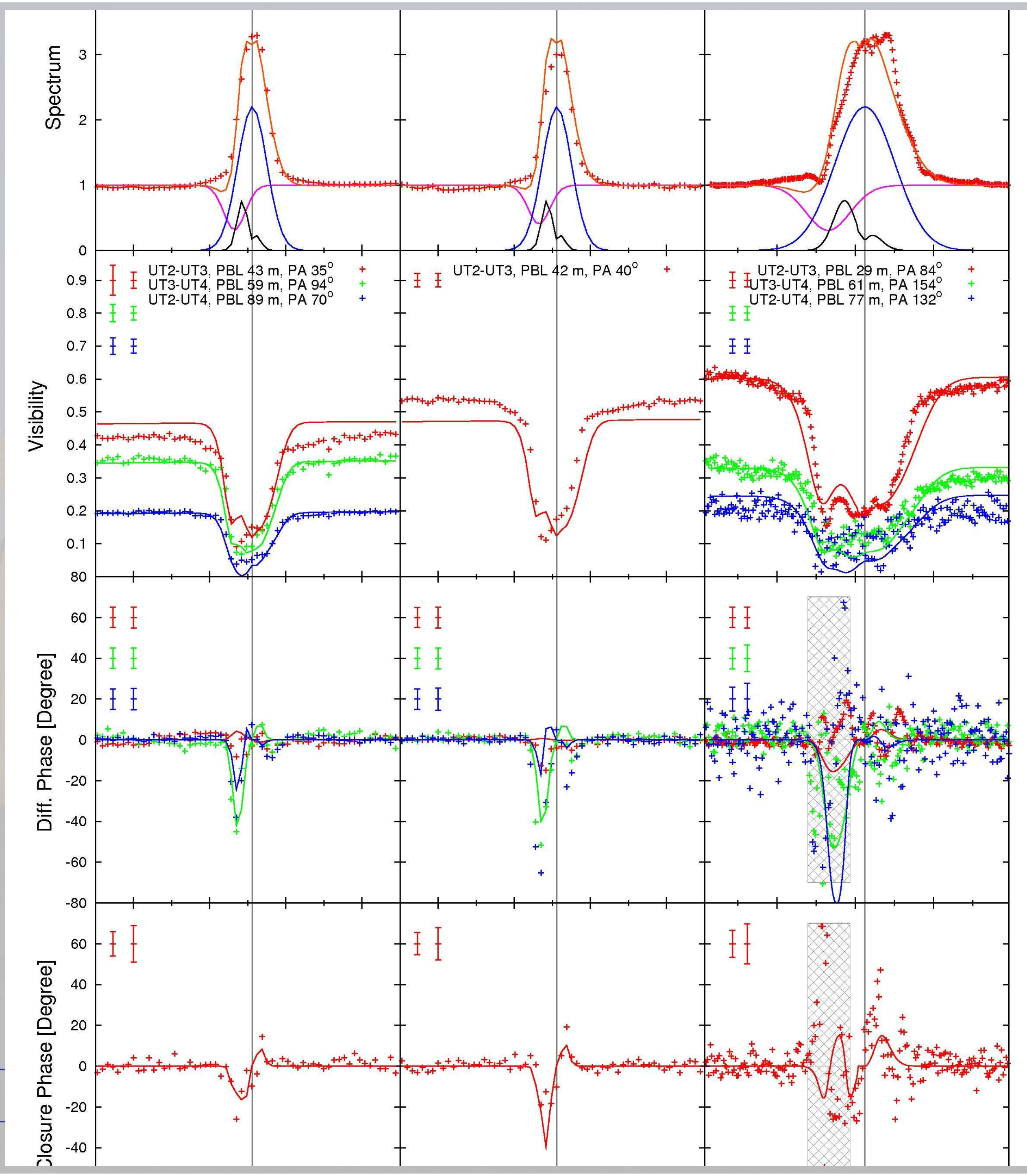
Results (3): Modelling of all observations

For both the Br Gamma and the He I emission lines, we measured non-zero differential phases and non-zero closure phases within the emission lines, indicating a complex, asymmetric object structure.

We developed a physically motivated **model**, which shows that the **asymmetries (DPs and CPs) measured within the wings of the Br Gamma line are consistent with the geometry expected for an aspherical, latitude-dependent stellar wind.**

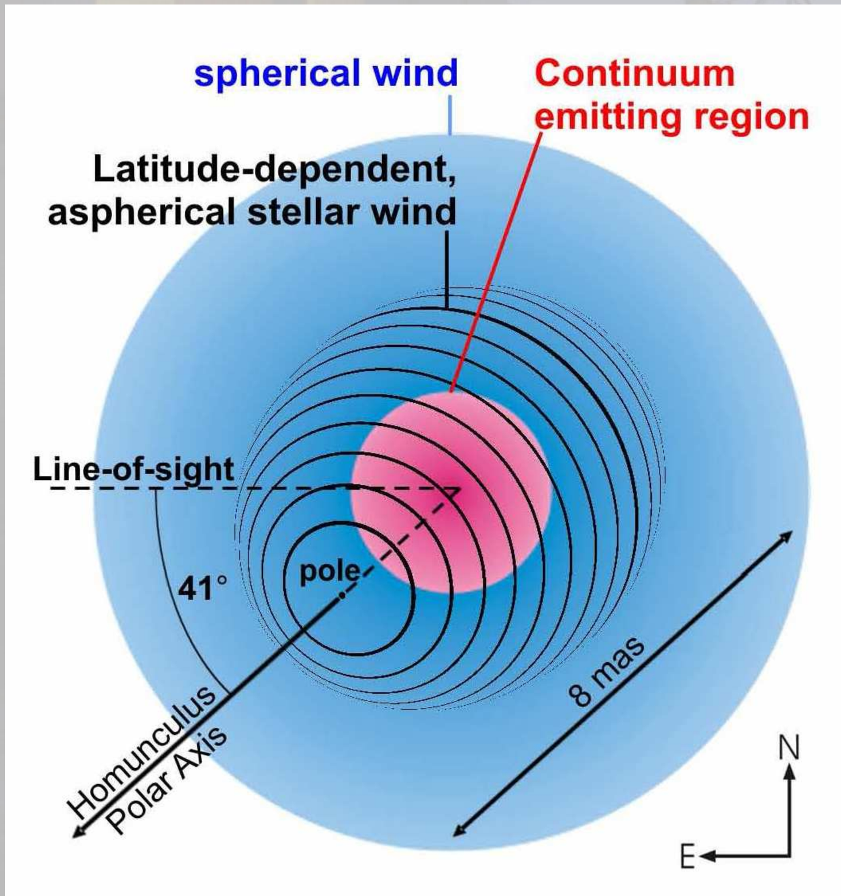
Additional VLTI/AMBER measurements and radiative transfer modeling will be required to determine the precise parameters of such an inclined aspherical wind.

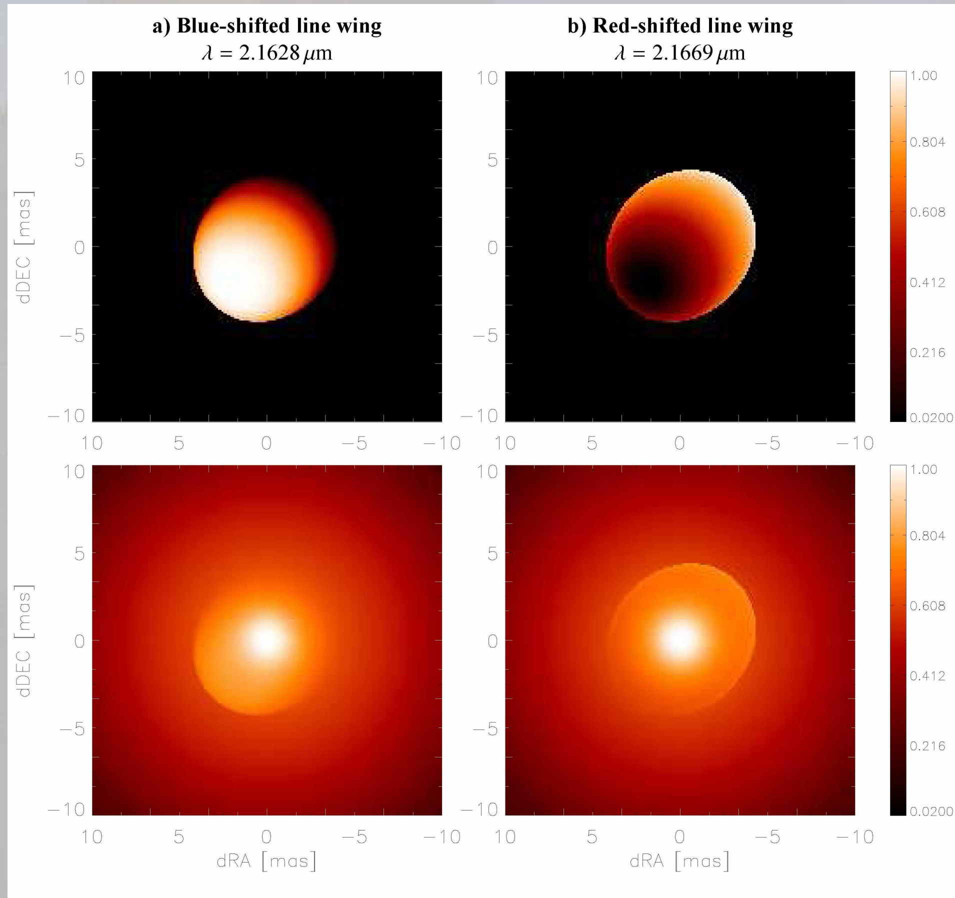
Results (4): Aspherical Eta Car model



Results (4): Modelling of all observations

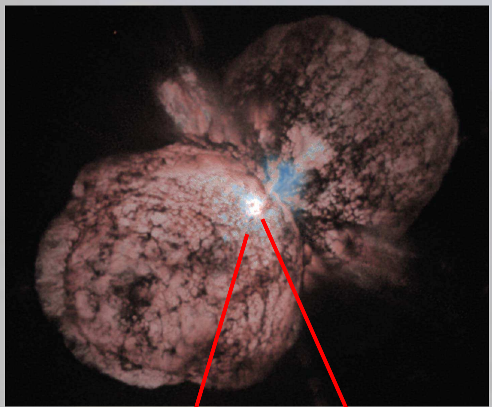
Blue-shifted wing: 2.163 µm **red wing: 2.167 µm**





Summary :

(1) Resolution of η Car's optically thick, aspheric wind region in the continuum & within Br γ & He I

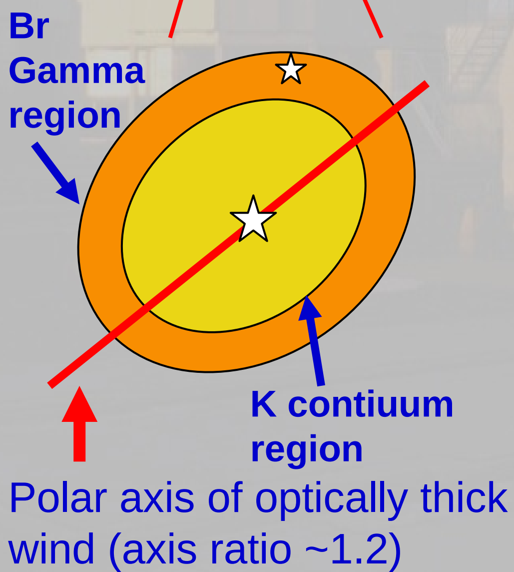


(2) 50% encircled-energy diameters (fit of Hillier et al. model CLV shapes):

K cont.: 4.3 mas

Br Gamma: 9.6 mas **He I 2.06: 6.5 mas**

(3) K-band elongation: **PA=128 ± 15° & projected axis ratio of 1.21 ± 0.08** (confirms van Boekel et al. 2003). **This aspheric wind can be explained by models for line-driven winds from luminous hot stars rotating near their critical speed** (e.g., Owocki et al. 1996). The models predict a higher wind speed and density along the polar axis than in the equatorial plane.



(4) We developed a simple aspherical stellar wind model which can explain the spectra, visibilities, differential & closure phases. Companion?