Peering into the most massive star in the Galaxy with near-infrared interferometry

Image credits: Montage (J. Groh), VLTI (ESO), Eta Car (N. Smith + NASA)

Jose Groh (Geneva Observatory, Switzerland)

Collaborators

O. Absil (Liege), JP Berger (ESO), M. de Becker (Liege), JB Le Bouquin (Grenoble), J. Hillier (Pittsburgh), T. Madura (NASA/GSFC), S. Owocki (Delaware), H. Sana (STScI), G. Weigelt (Bonn)

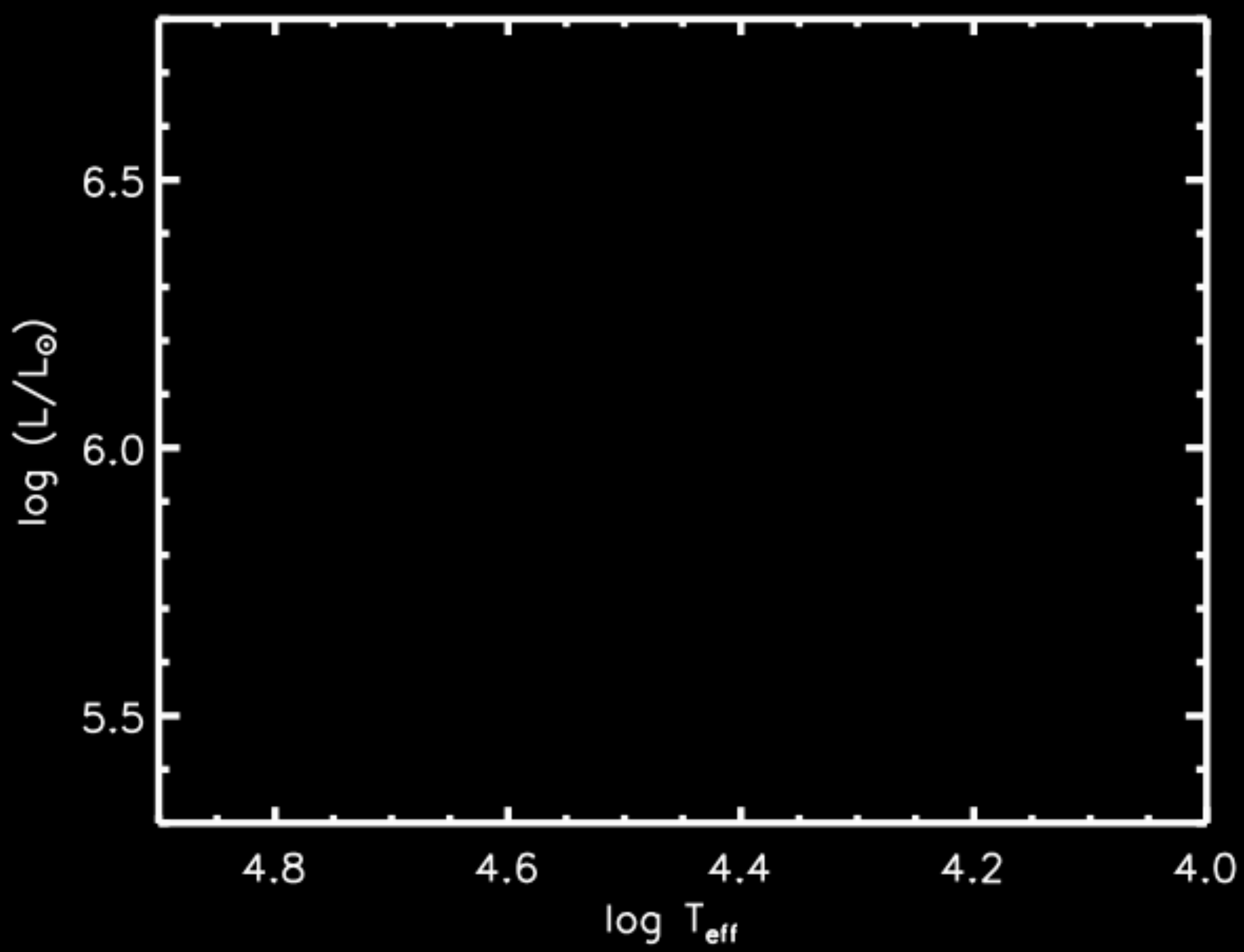
Observatoire de Genève, fondé en 1772

FNS SNF
Fonds national suisse
Schweizerischer Nationalfonds
Fondo nazionale svizzero
Swiss National Science Foundation

Massive stars bridge many fields of (astro)Physics

- Star formation
- Chemical evolution
- Supernova, Black Holes, Neutron Stars
- Distant Universe (first stars, reionization, cosmology)
- Intergalactic, interstellar, circumstellar media
- High-energy physics, particle physics, ...
- Stellar evolution

Stellar evolution above 30 $M_\odot$ at solar Z



(after evolutionary tracks in Groh+ 14)

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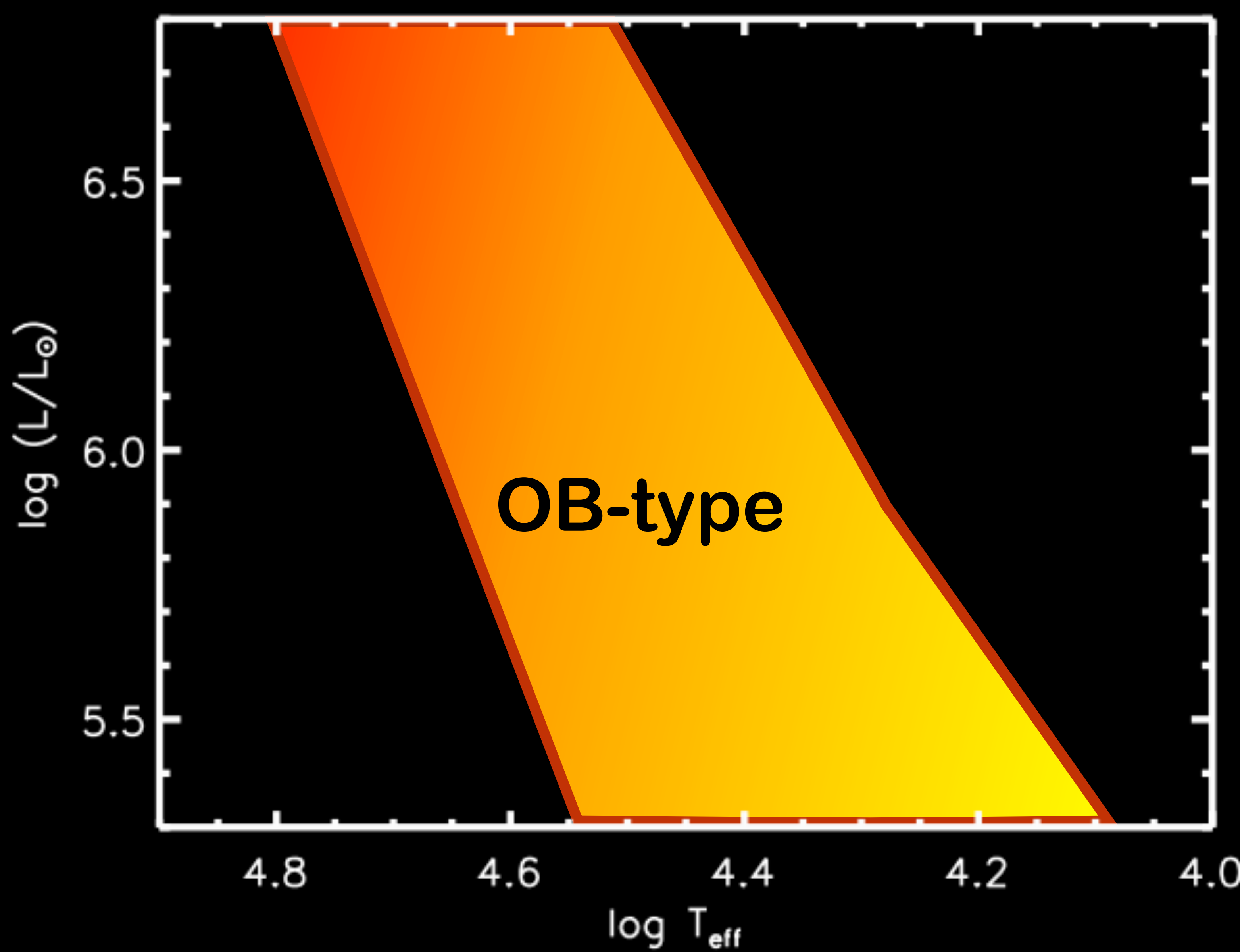

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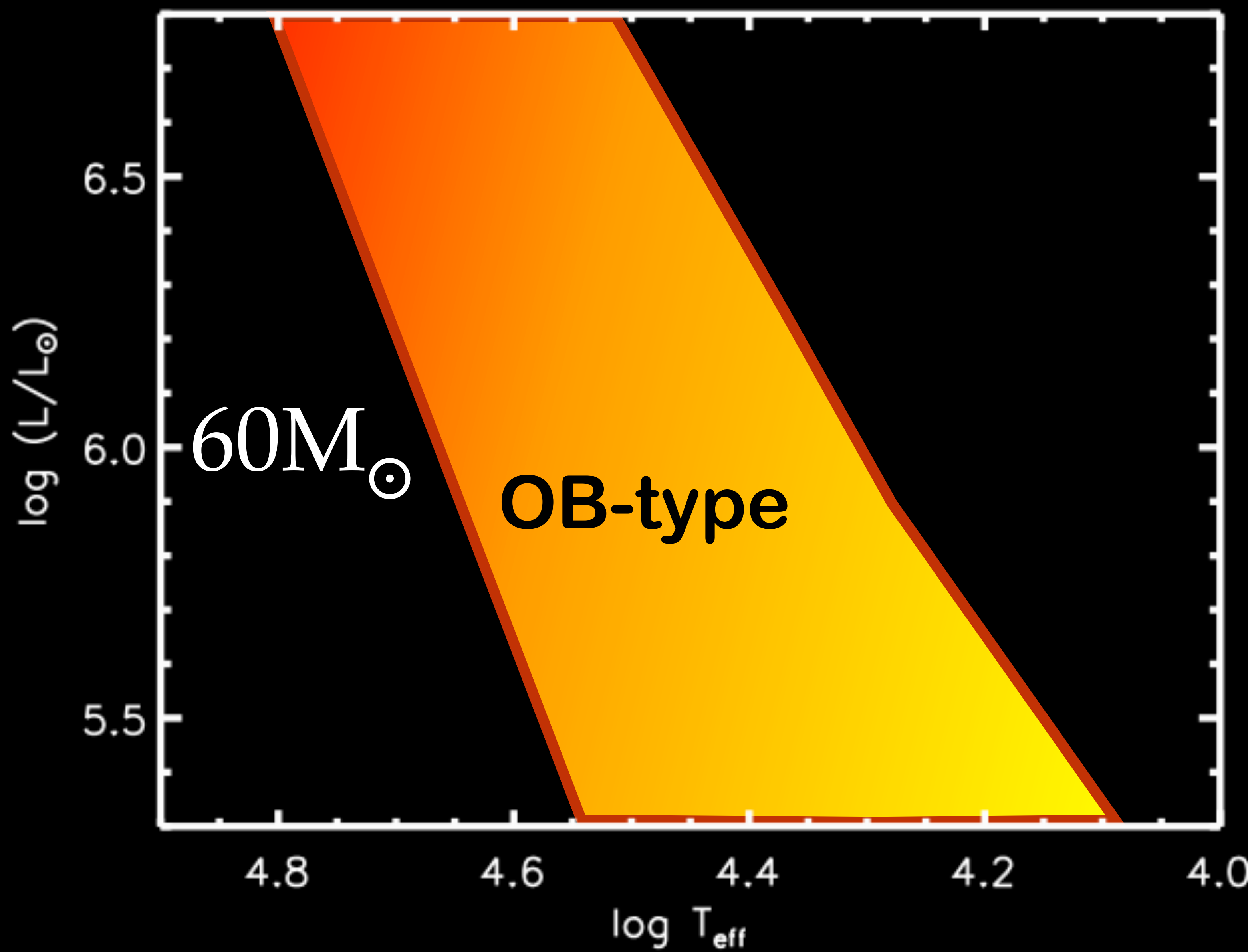

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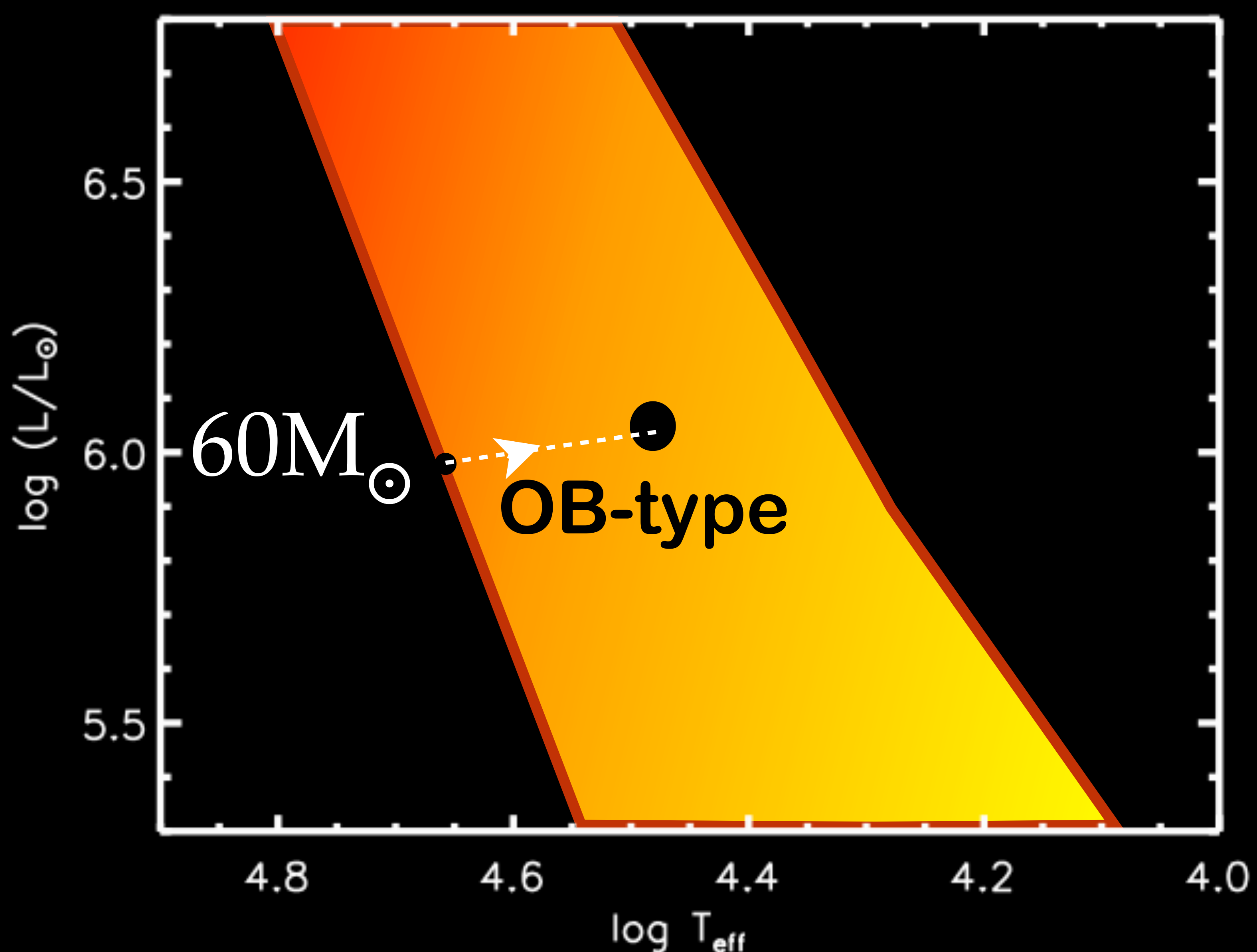

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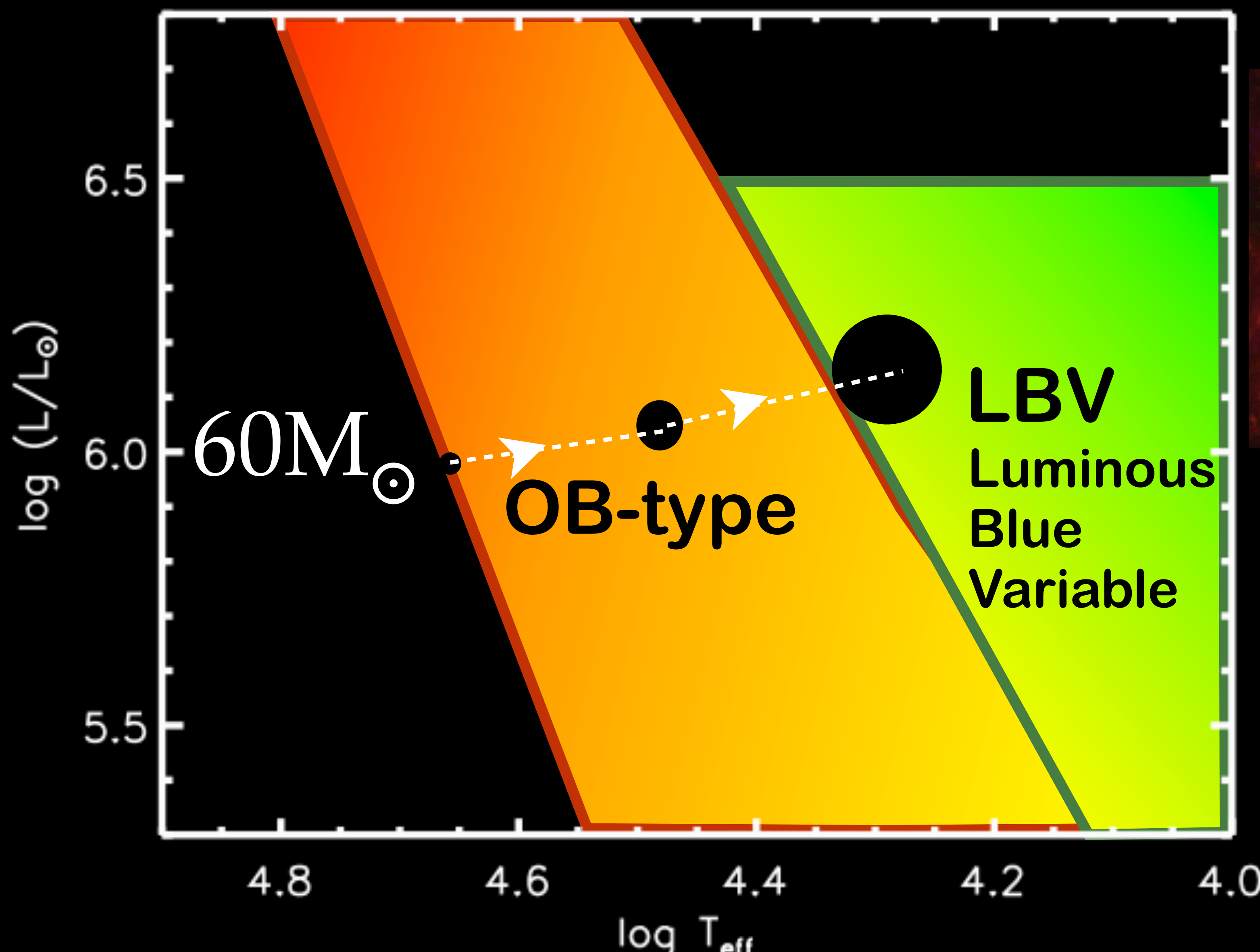

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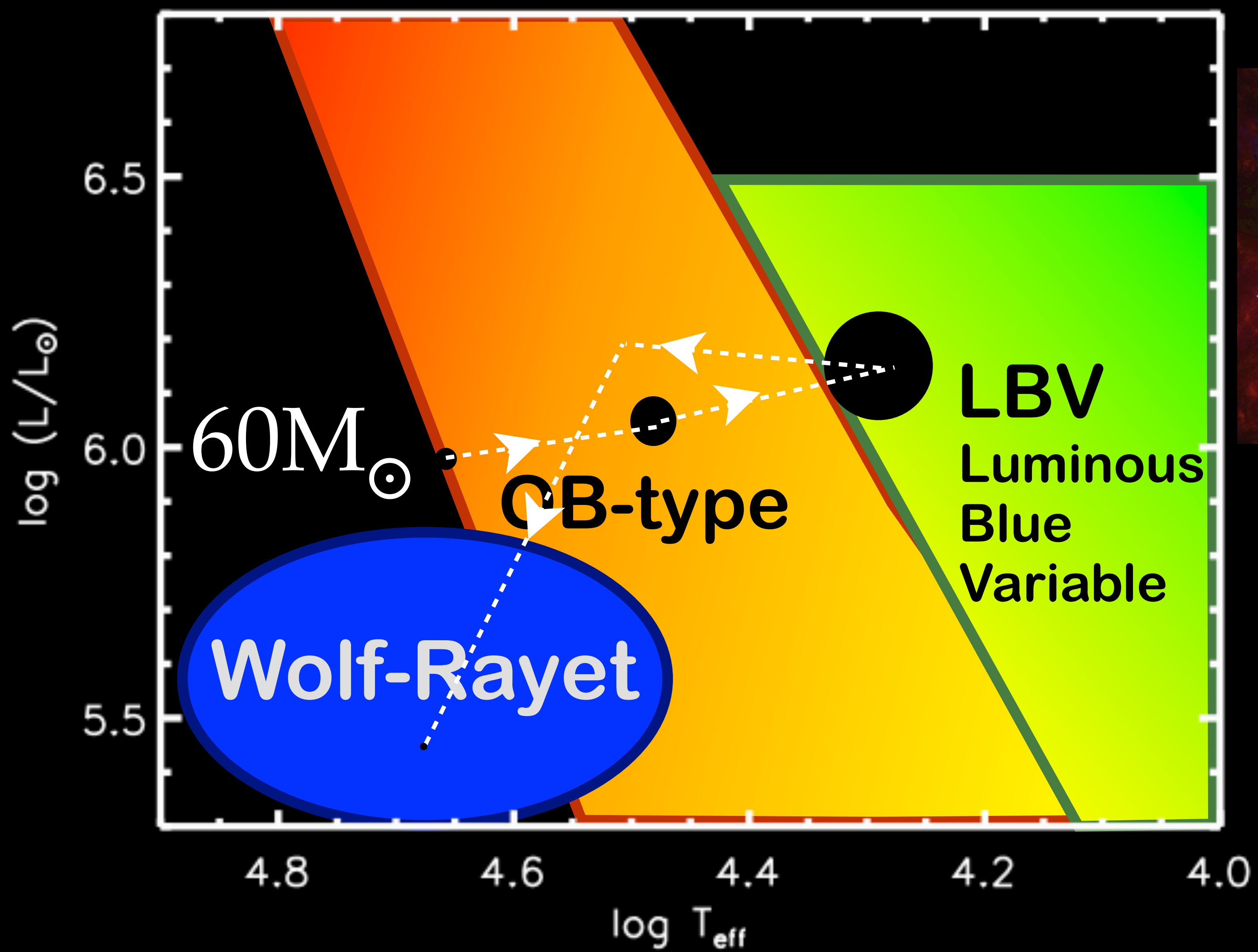

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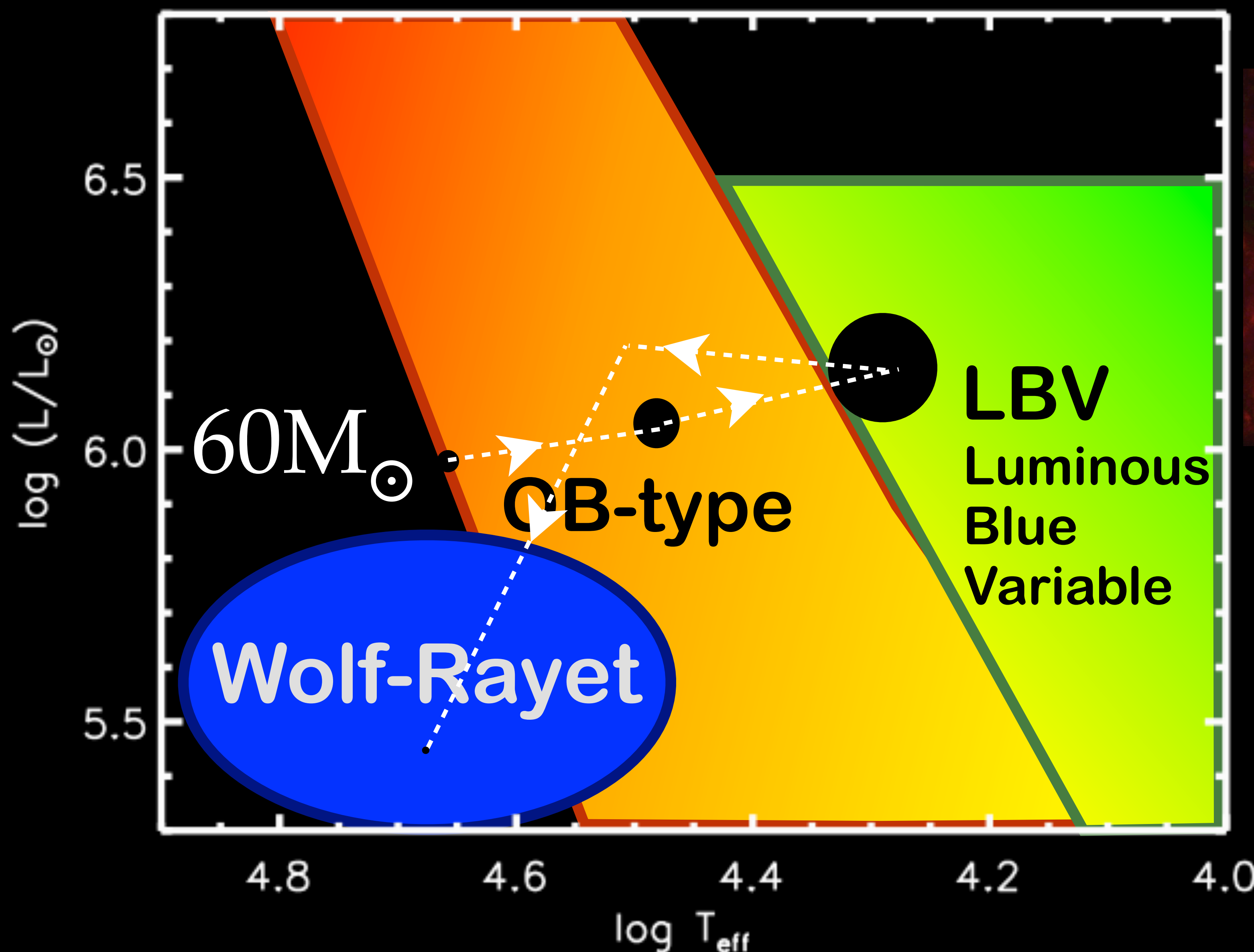
Stellar evolution above 30 $M_\odot$ at solar Z

OB-type → LBV → WR → SN Ibc



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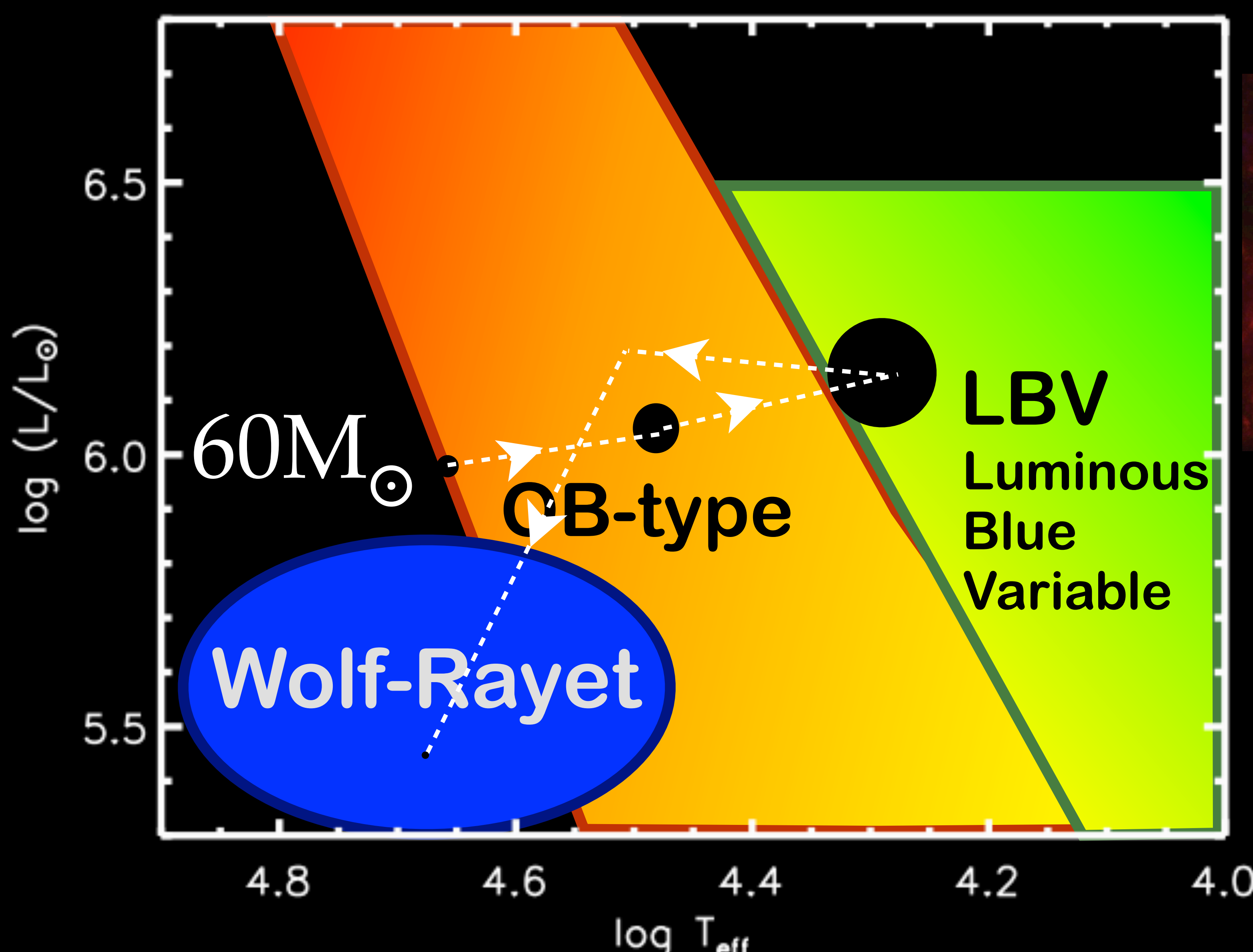

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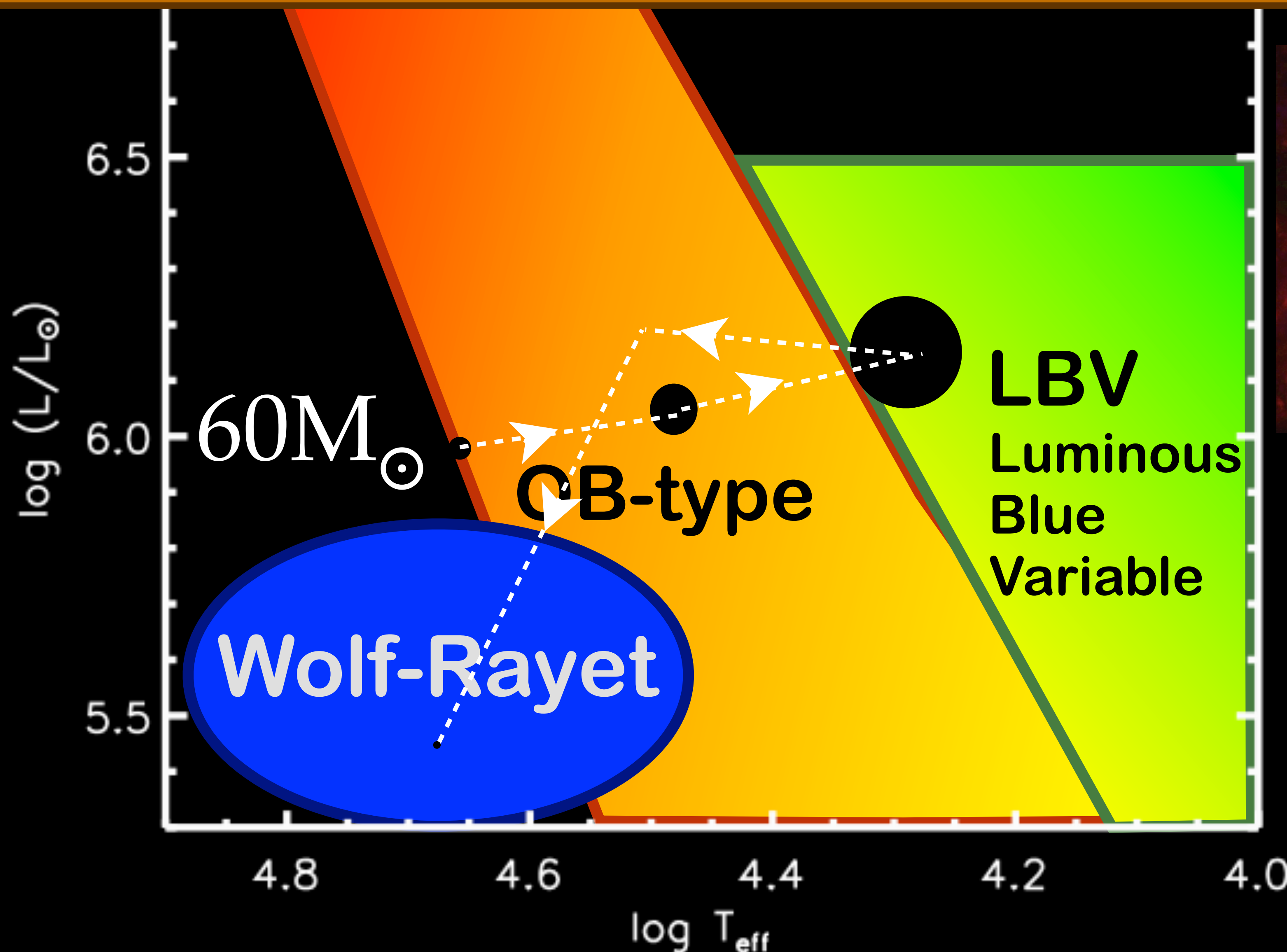

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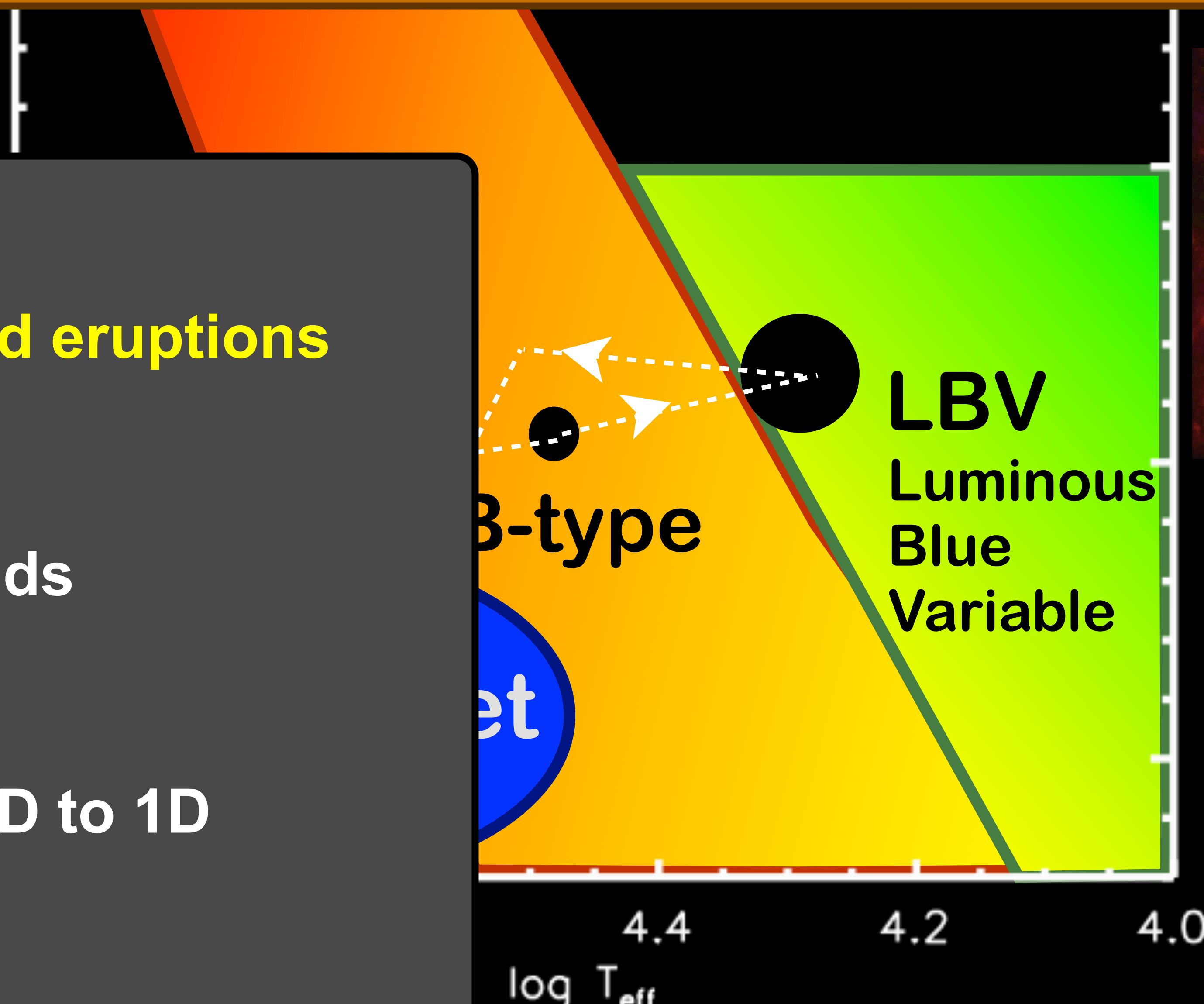


- Binarity
- Mass loss and eruptions
- Rotation
- Magnetic Fields
- Convection
- Going from 3D to 1D
- Metallicity
- Explosion properties, ...

Groh talk @ SP13
(17:30 tomorrow)

(after evolutionary tracks in Groh+ 14)

Eta Carinae and the Homunculus nebula

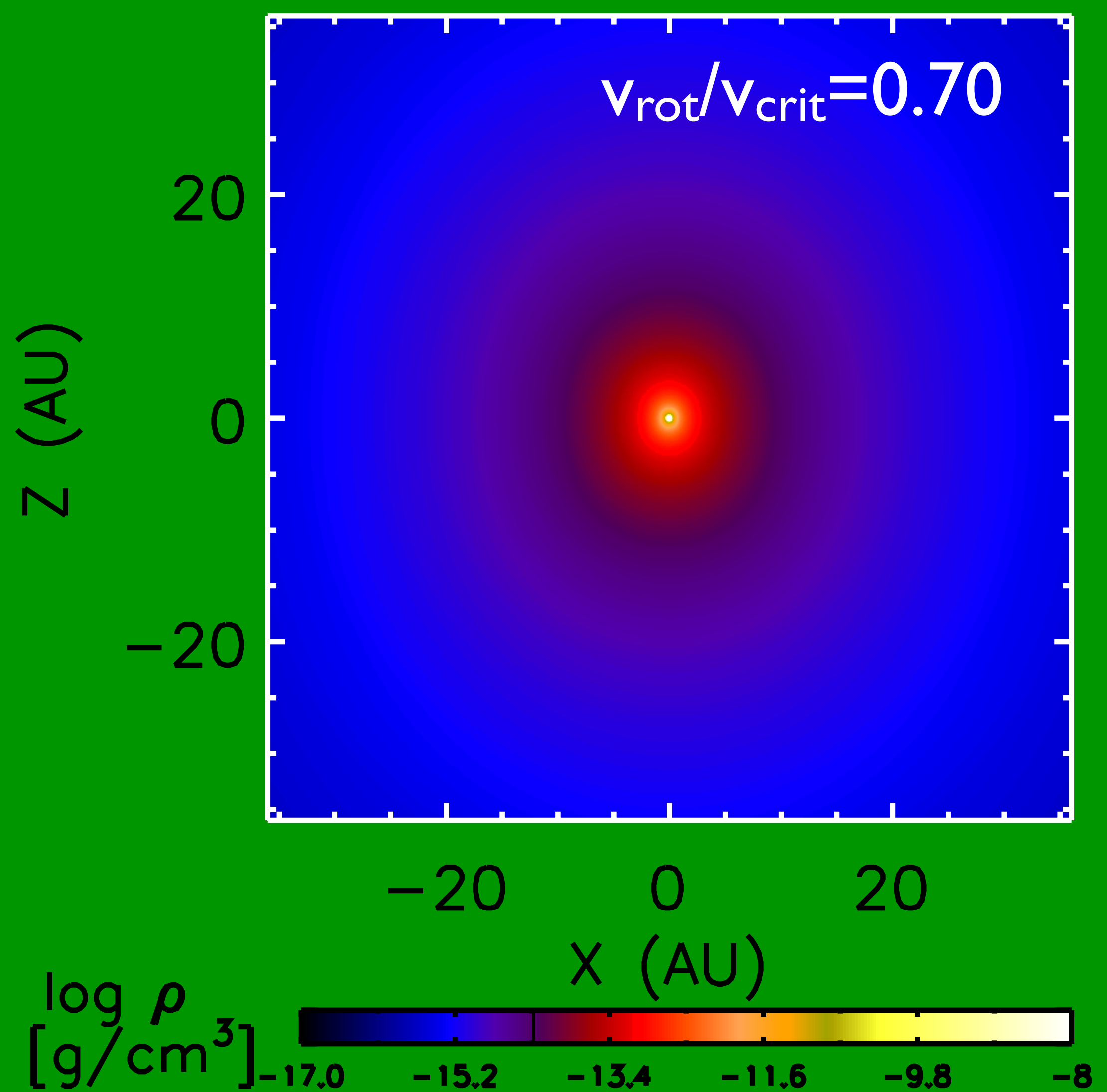
Needs interferometry to probe the inner 10 mas:

- rotation
- mass loss
- binarity

Effects of rapid rotation on a stellar wind

Deviation from spherical symmetry depends on $W = v_{rot}/v_{crit}$ (Owocki et al. 1998):

$$\text{prolate}: \quad \frac{\rho(\theta)}{\rho_0} \propto \sqrt{1 - W^2 \sin^2\theta}$$



Groh+ 10

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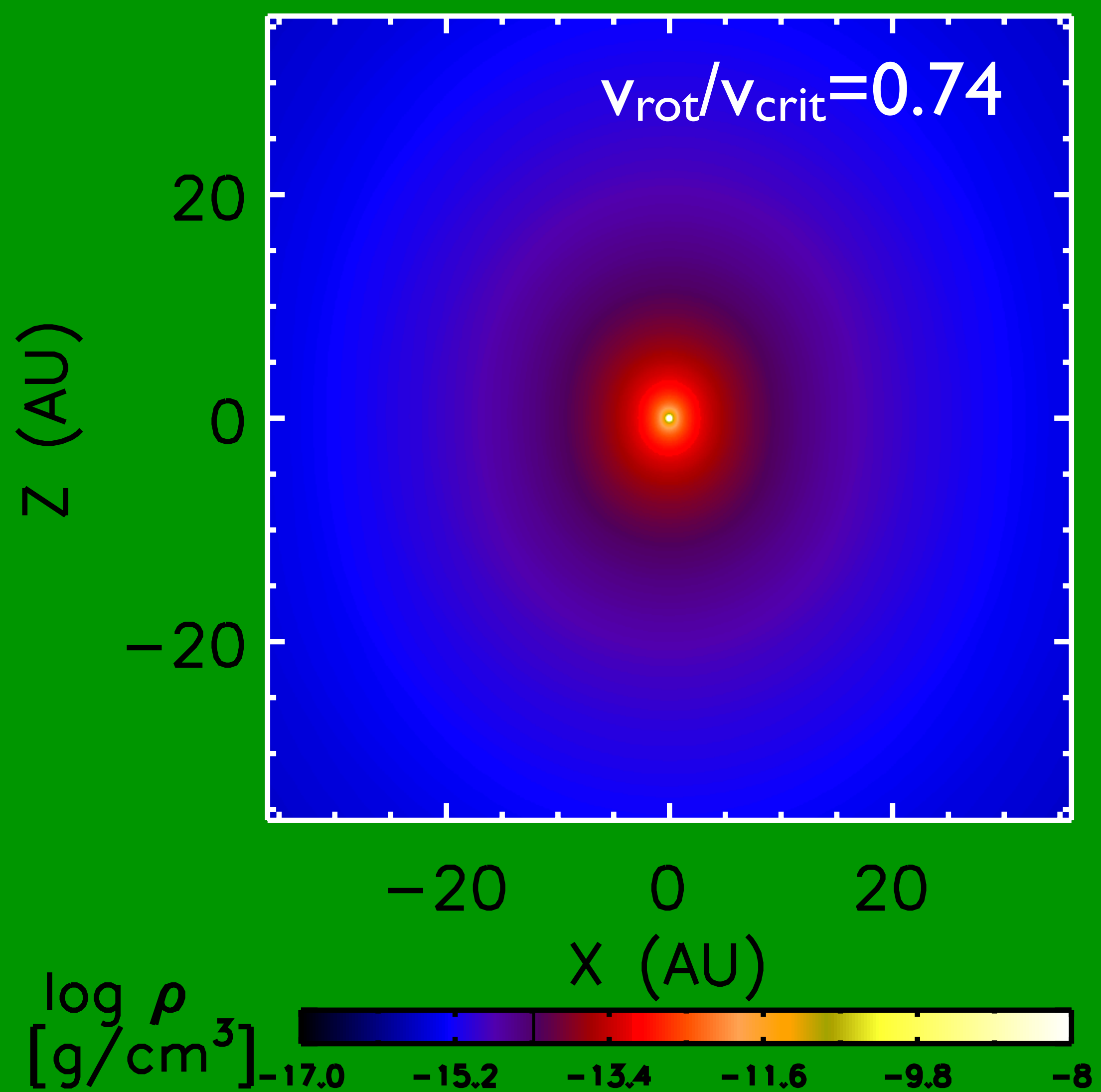

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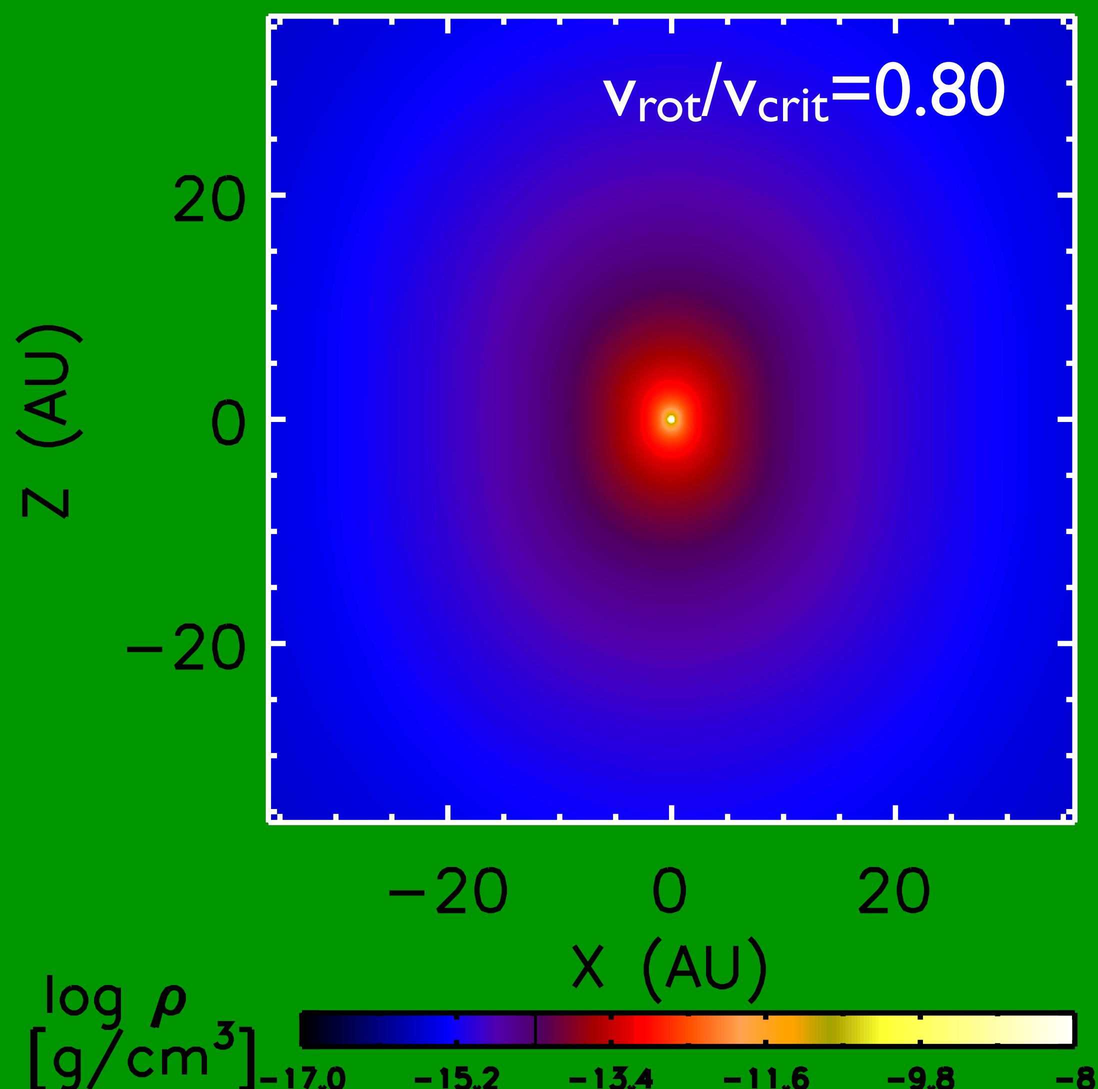

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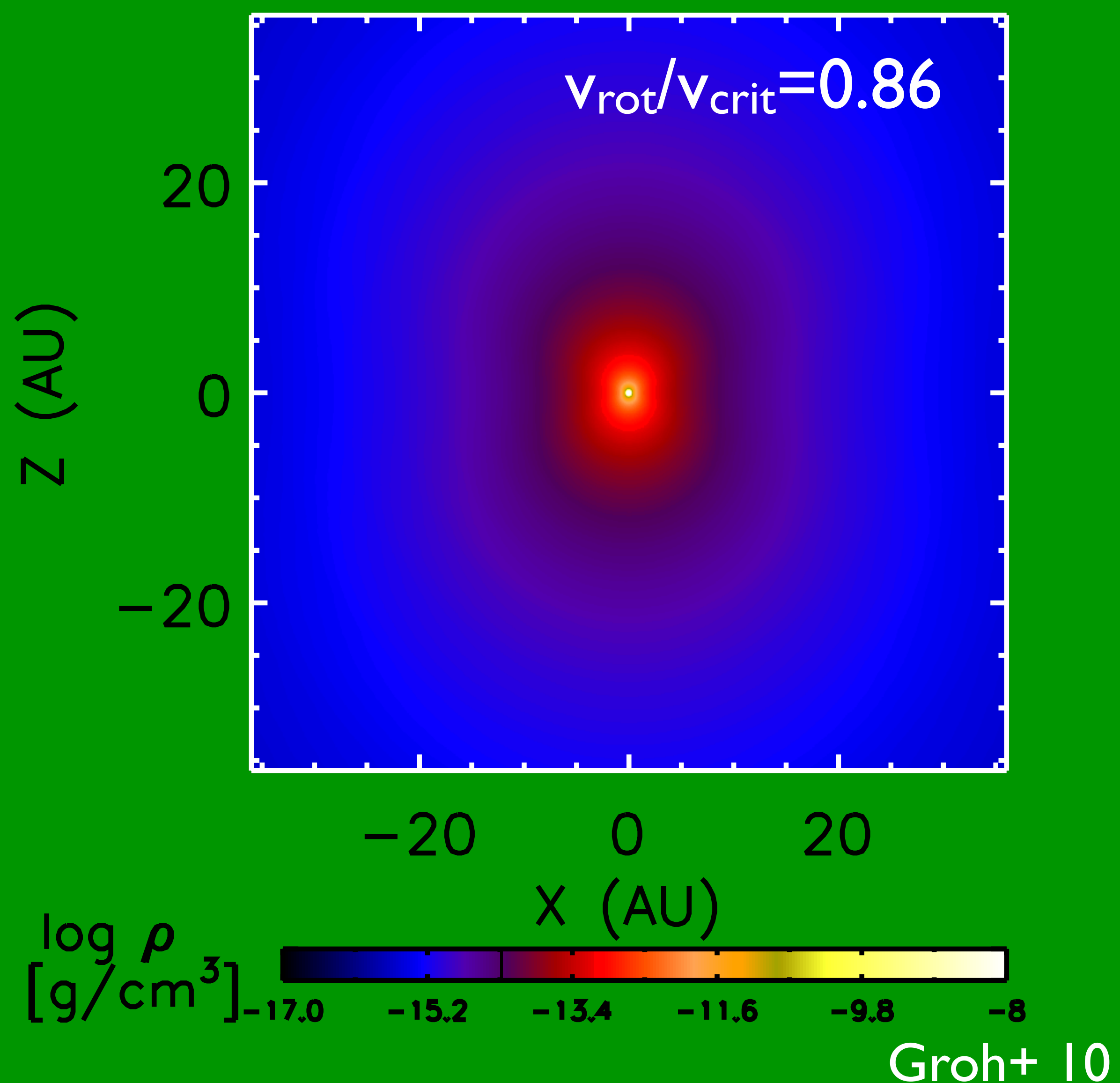

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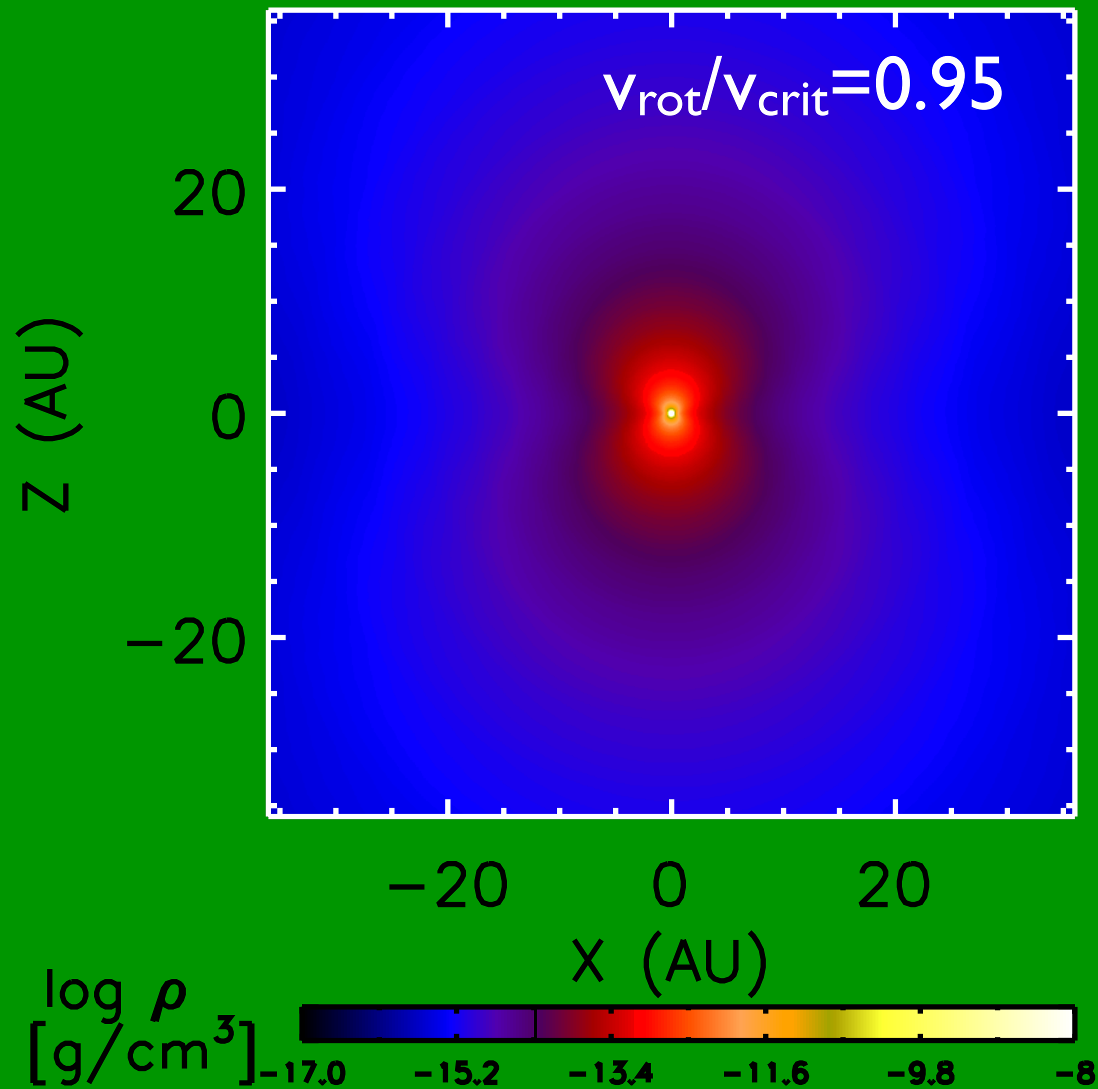

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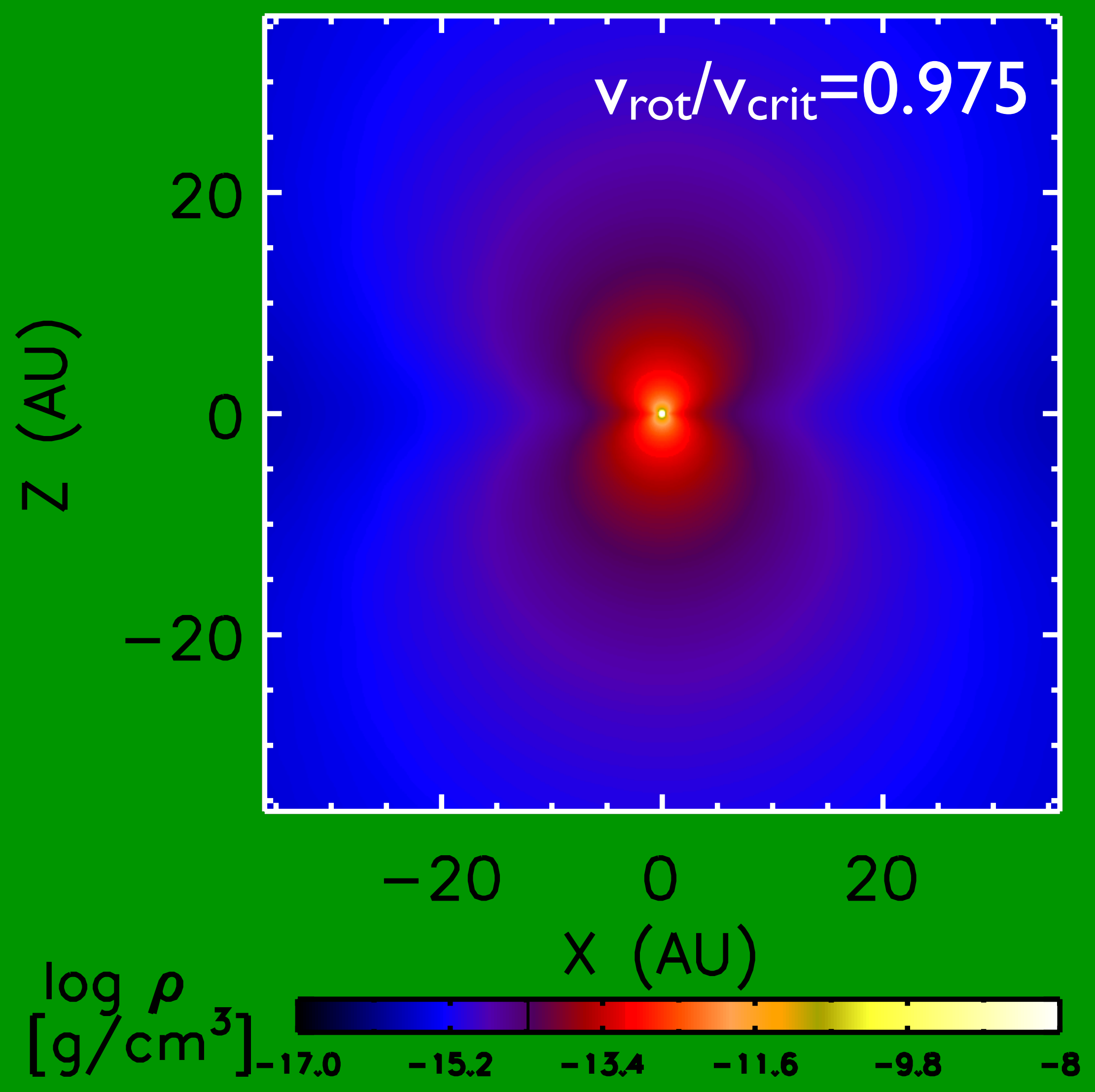

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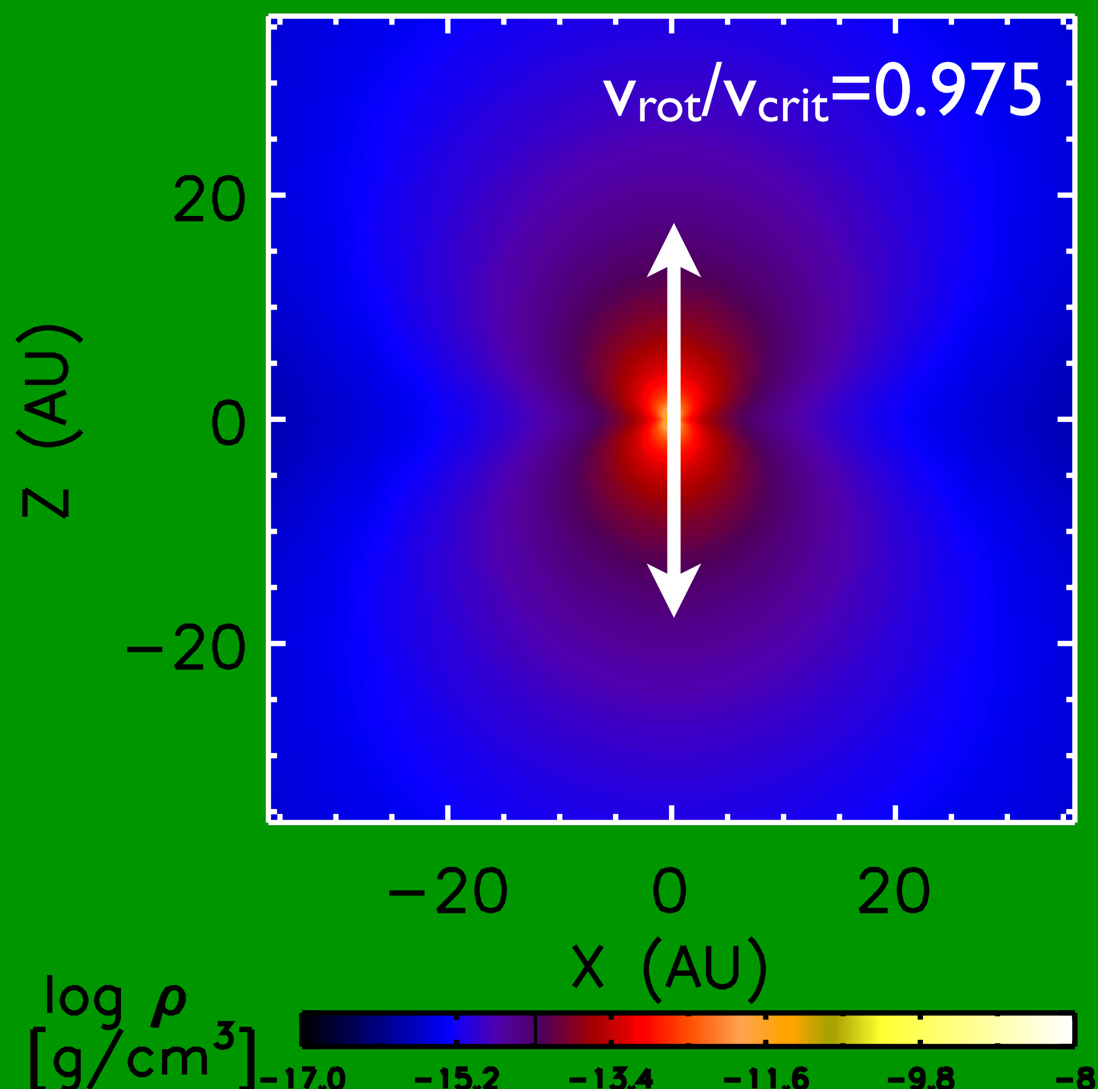

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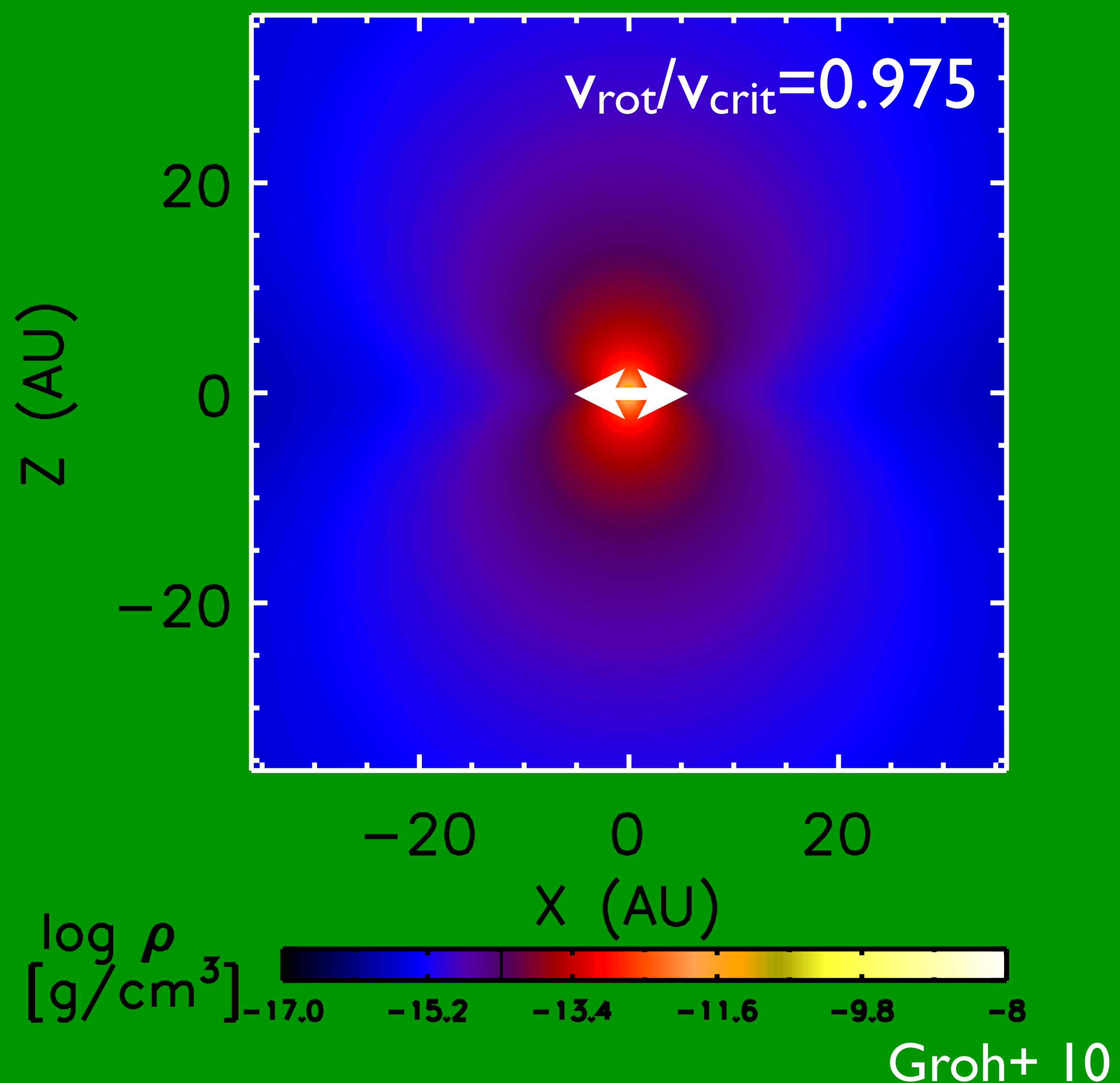


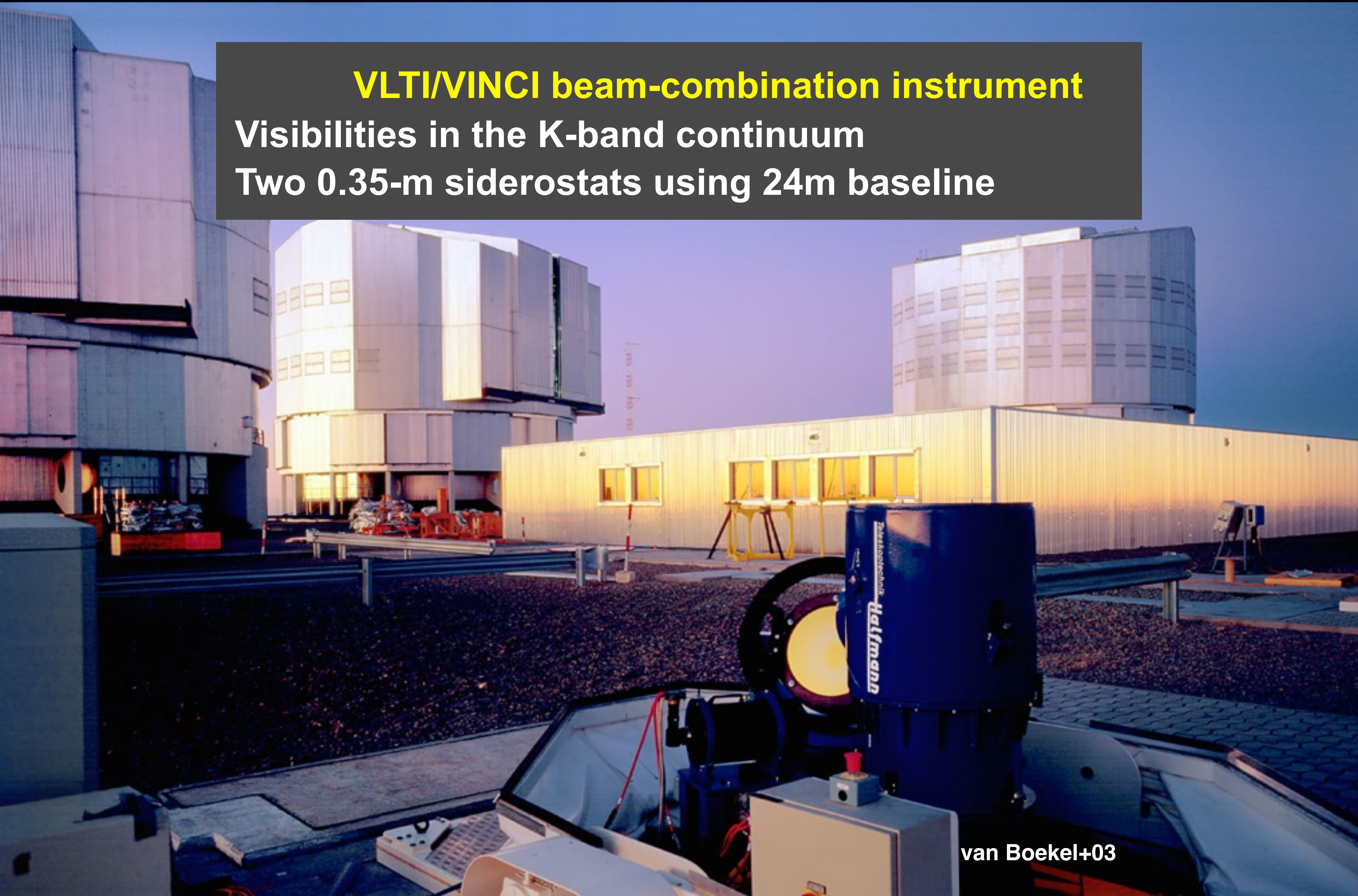
Rotation: elongation of the K-band photosphere

(van Boekel+ 03; Kervella 07; Weigelt+07; Groh+10)

VLTI/VINCI beam-combination instrument

Visibilities in the K-band continuum

Two 0.35-m siderostats using 24m baseline



van Boekel+03

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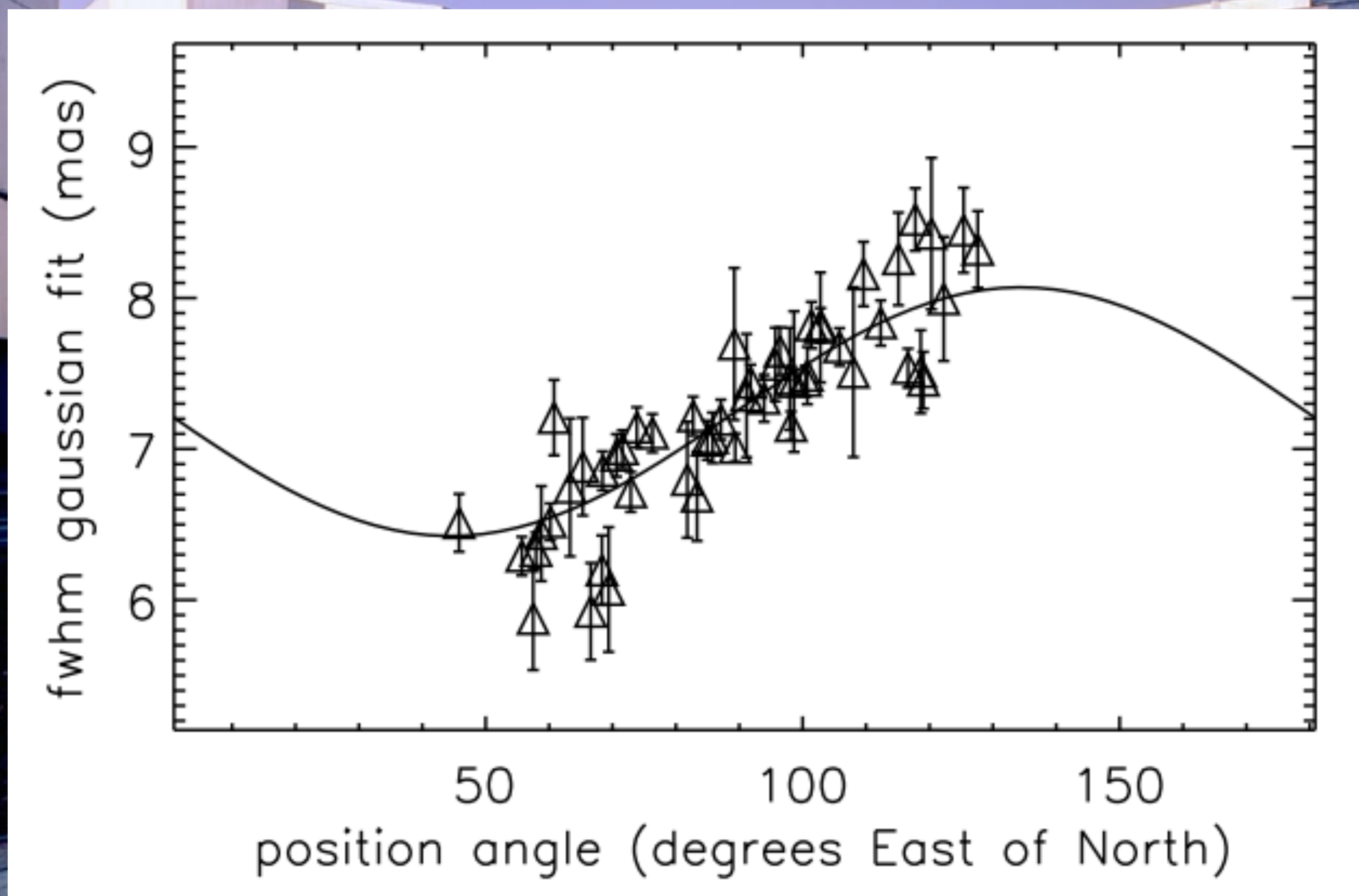

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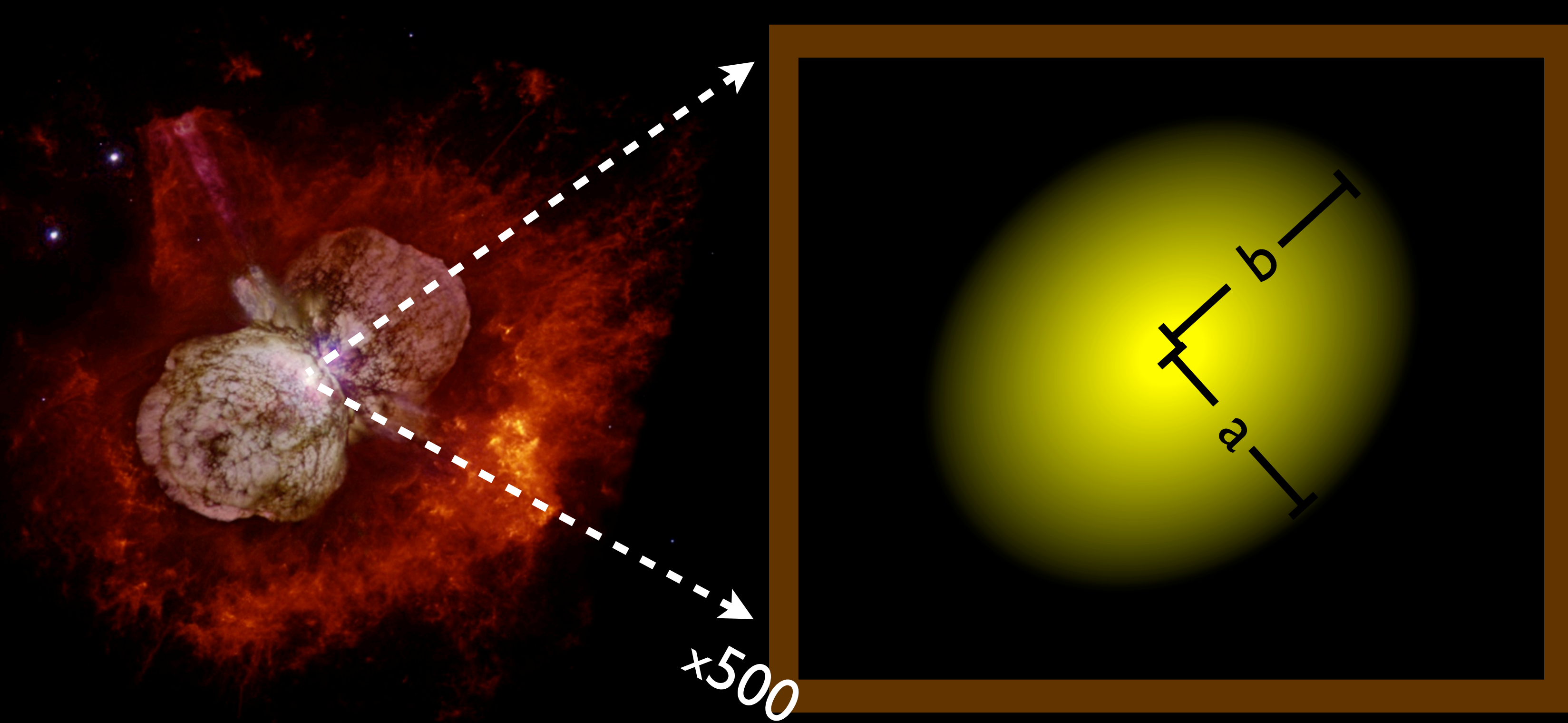
Homunculus
i=41° ; PA=131°

Geometric model
PA~134° ; b/a=1.25



Eta Car A
rapid rotator: rot. axis aligned with the Homunculus polar axis

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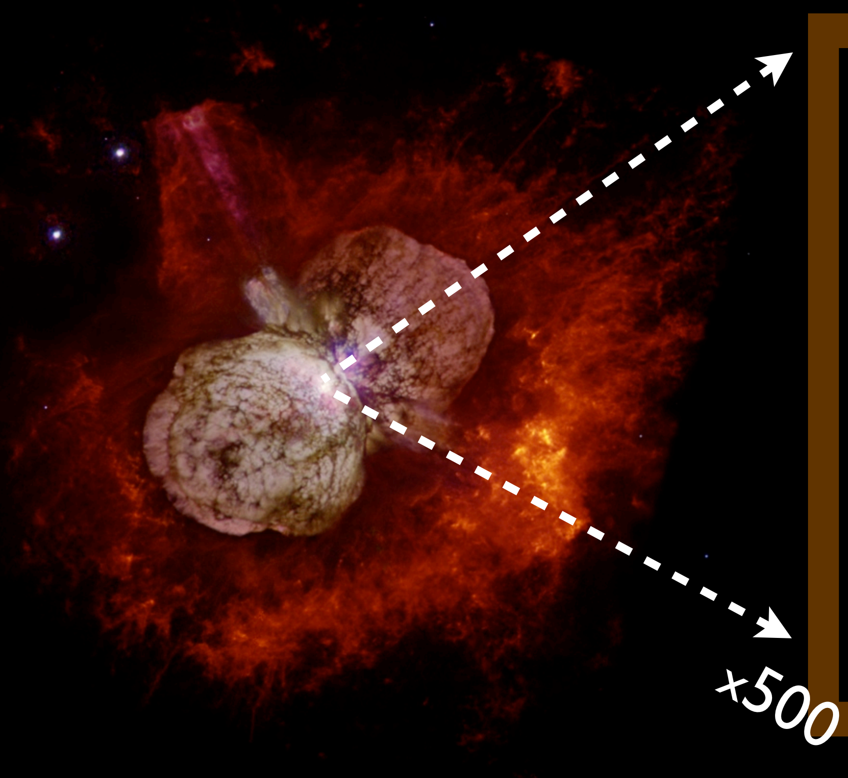

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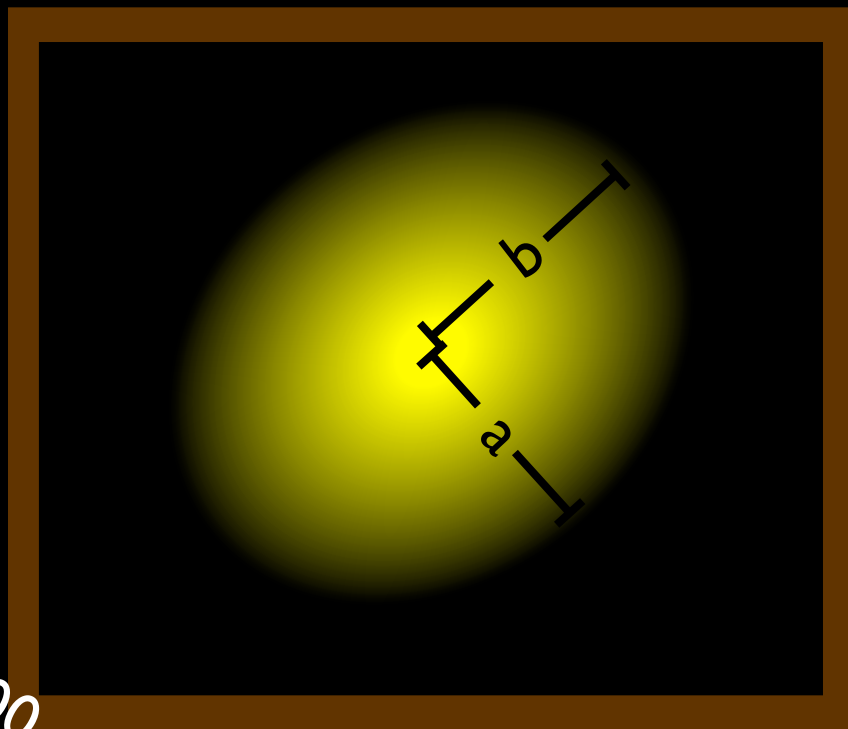
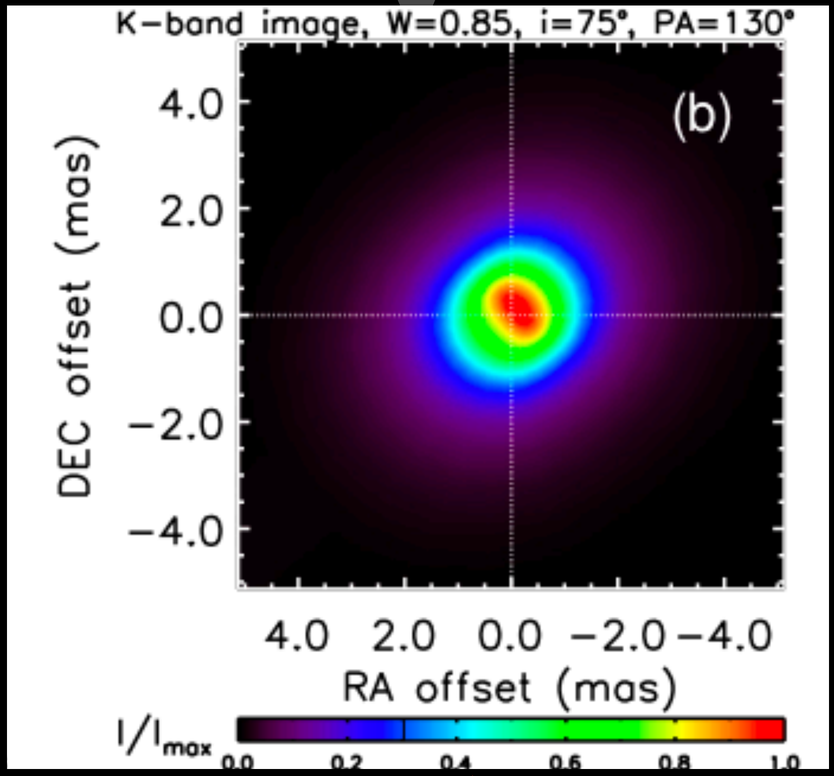


Eta Car A
rapid rotator: rot. axis aligned with the Homunculus polar axis

Rad. Transf. VINCI+AMBER
v_{rot}/v_{crit}=0.77 to 0.92
i=60° to 90°
PA=108° to 142°

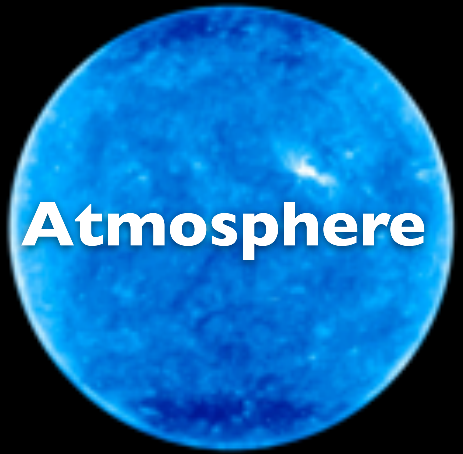


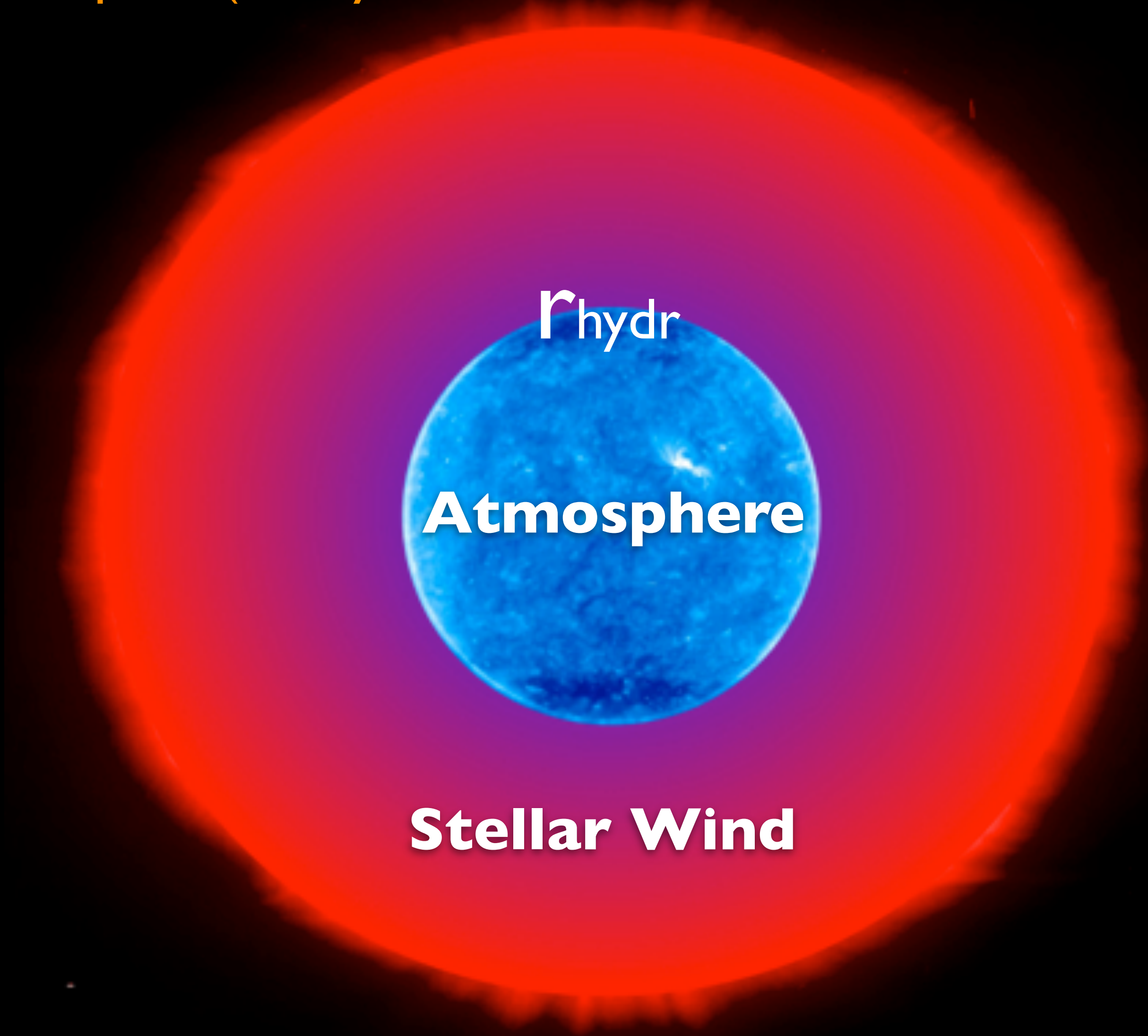
Eta Car A
rapid rotator: rotation axis **misaligned** with the Homunculus

Groh+10

Mass loss and extension of the photosphere

Strong stellar wind causes the photosphere to be formed in the wind





Mass loss and extension of the photosphere

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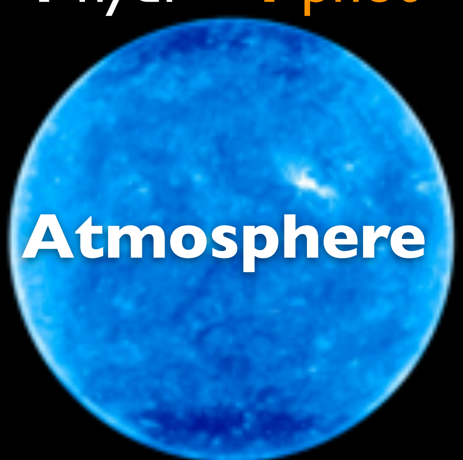
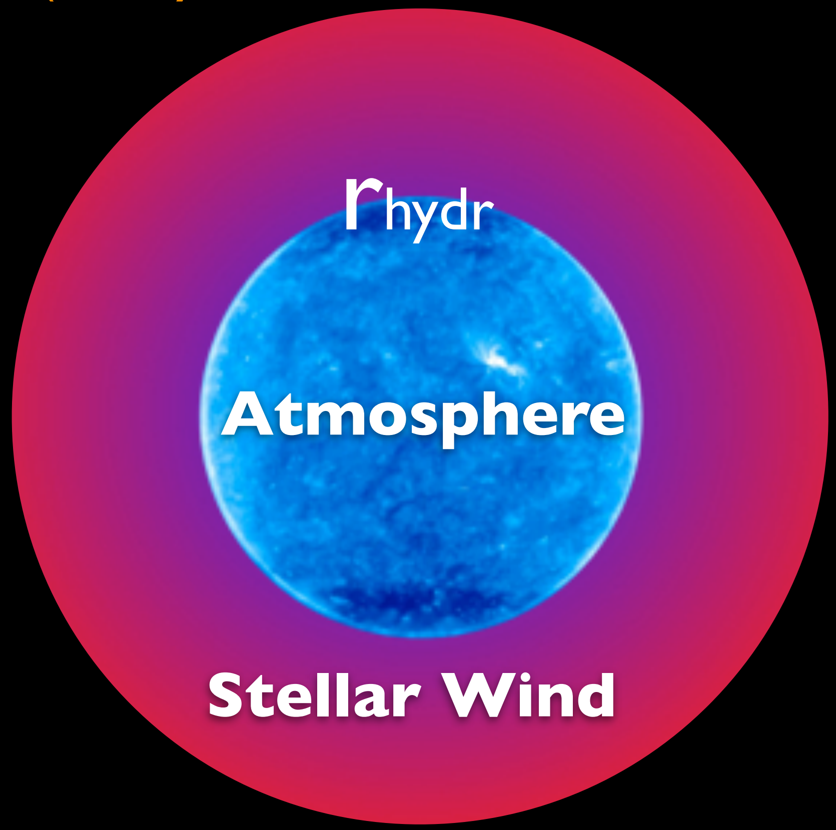
Sun

$r_{hydr} = r_{phot}$



Eta Car ($\dot{M}$/2)

r_{phot} (set by free-free emission in the K-band)



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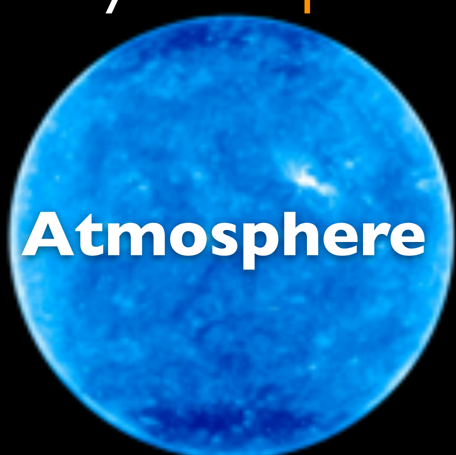

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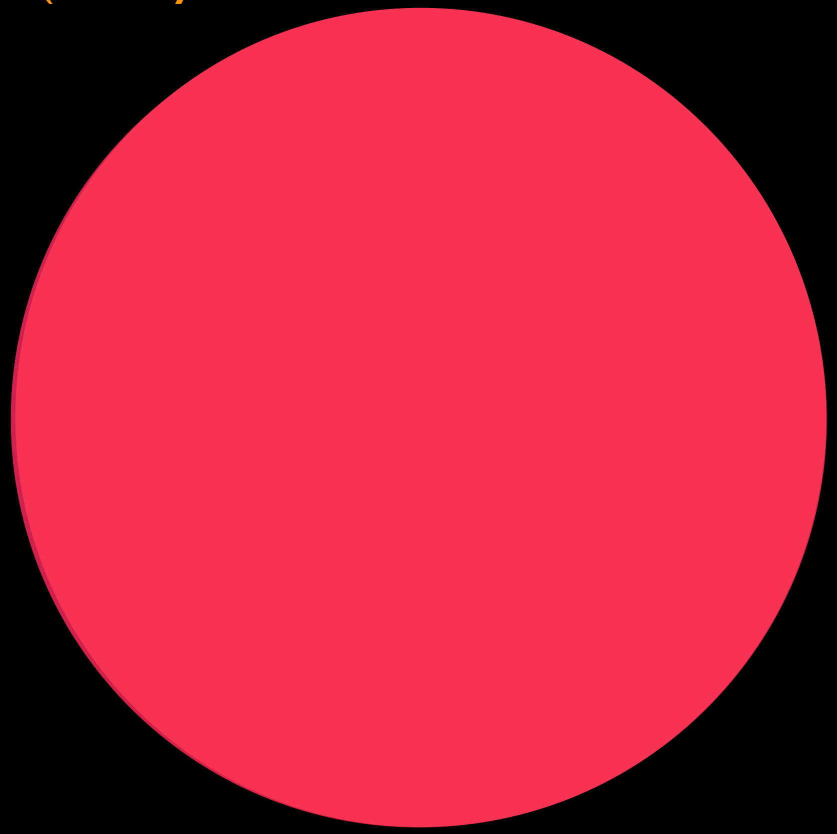
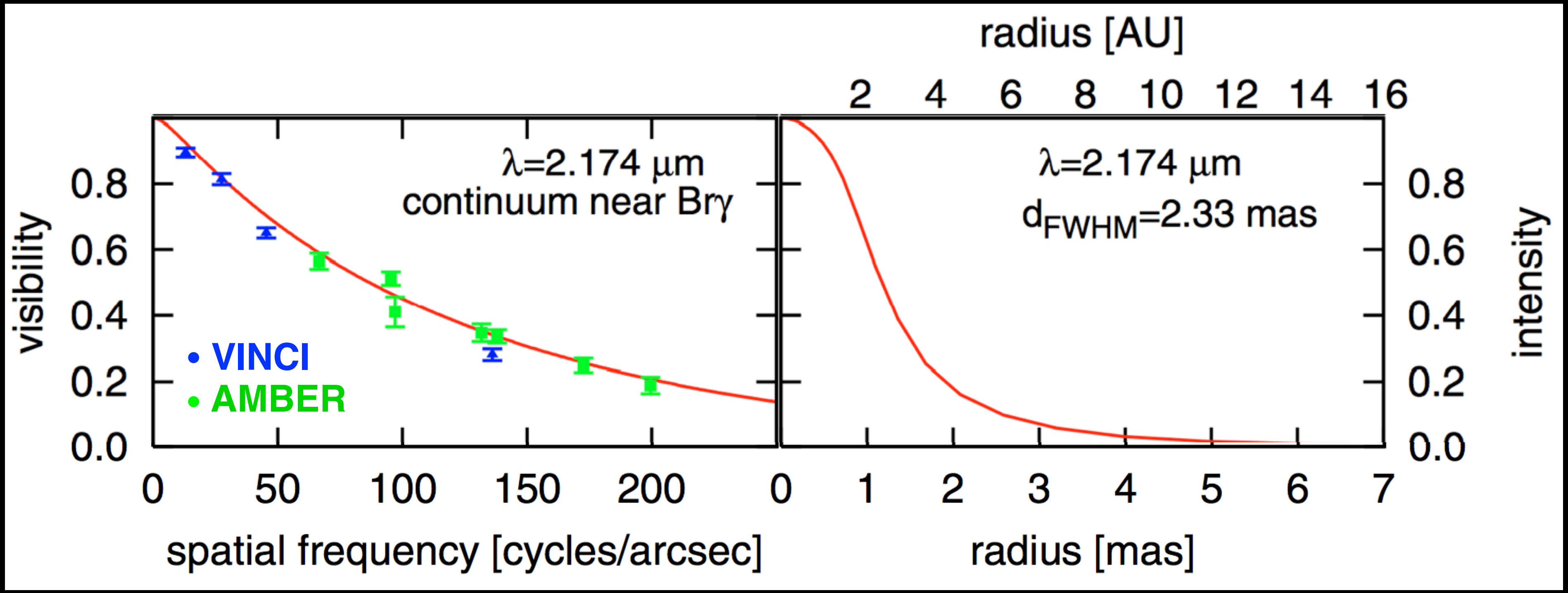
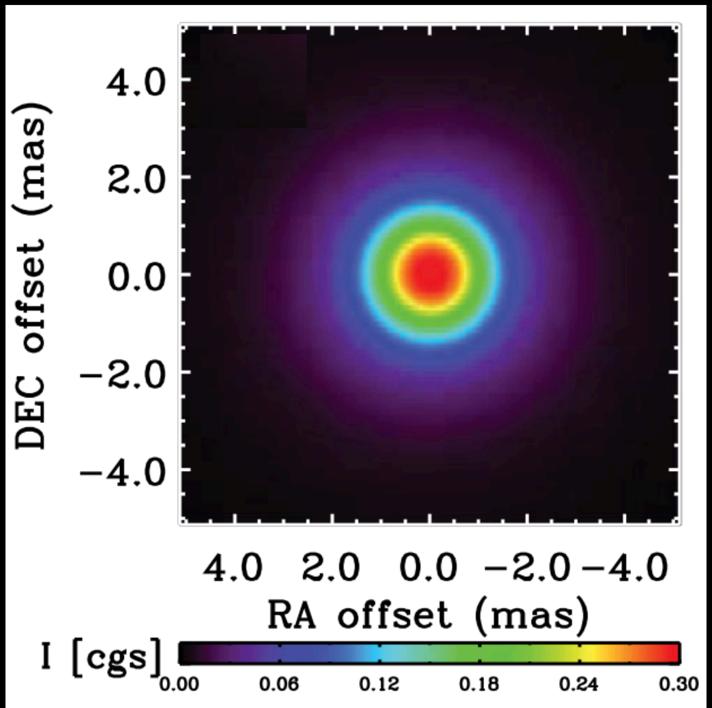


Eta Carinae mass loss

(van Boekel+03; Weigelt+07; Kervella 07; Groh+10, 12)

Observations | NLTE 1D model | NLTE 1D model image





Weigelt+07

Groh+12

Eta Carinae mass loss

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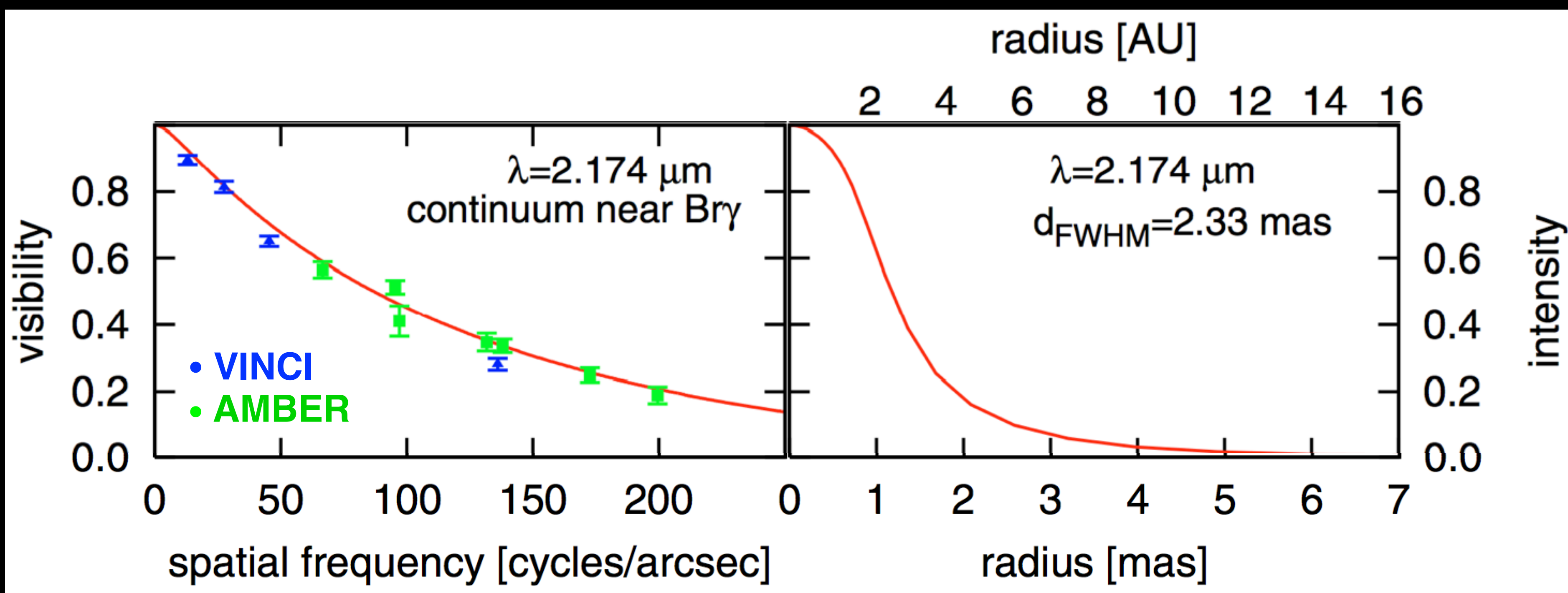
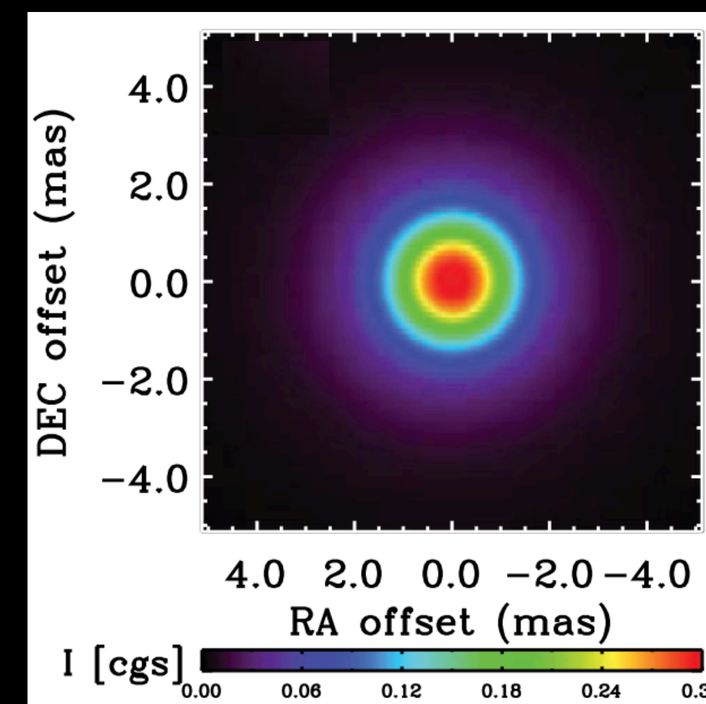
Observations **NLTE 1D model** **NLTE 1D model image**



Weigelt+07



Groh+12

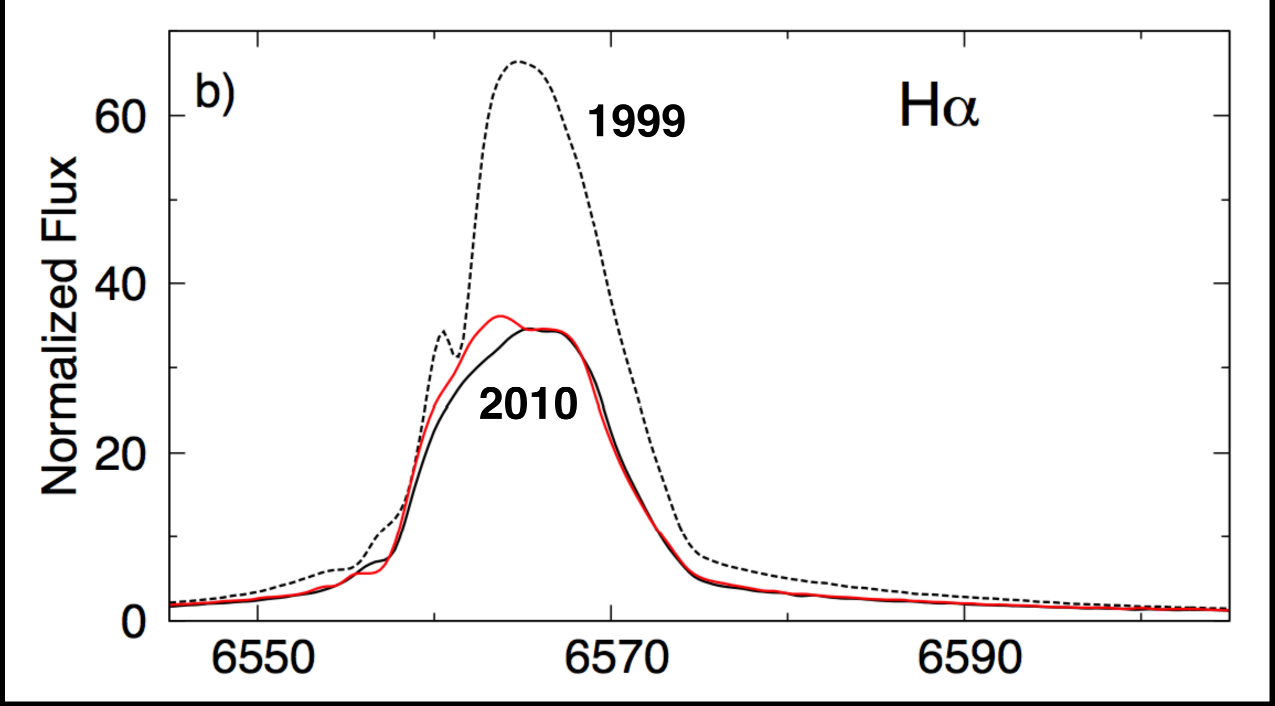
Mass-loss rate in 2002-2005: ~ 8.4 x 10^{-4} Msun/yr

Groh+12

Variability in Eta Carinae mass loss?

(Mehner+10, 12, 14 Corcoran+10, Gull+11, Groh+12a,b, Teodoro+12, Madura+13)

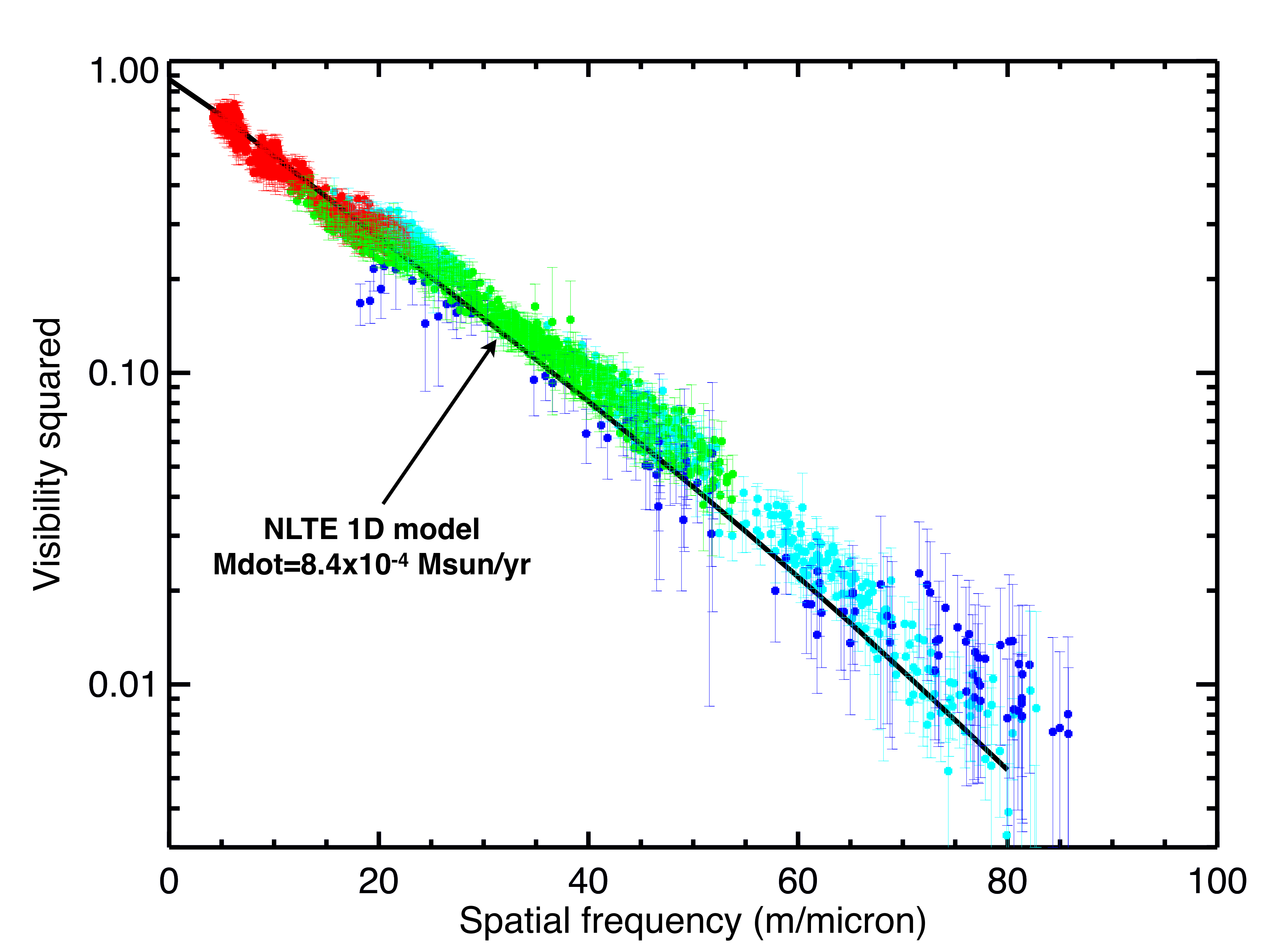
Mass-loss rate reduction by a factor of 2 in the last 10 yr?



Mehner+12

Probing changes in mass loss with VLTI/PIONIER

Data taken by O. Absil on 2012 Mar and 2013 Feb



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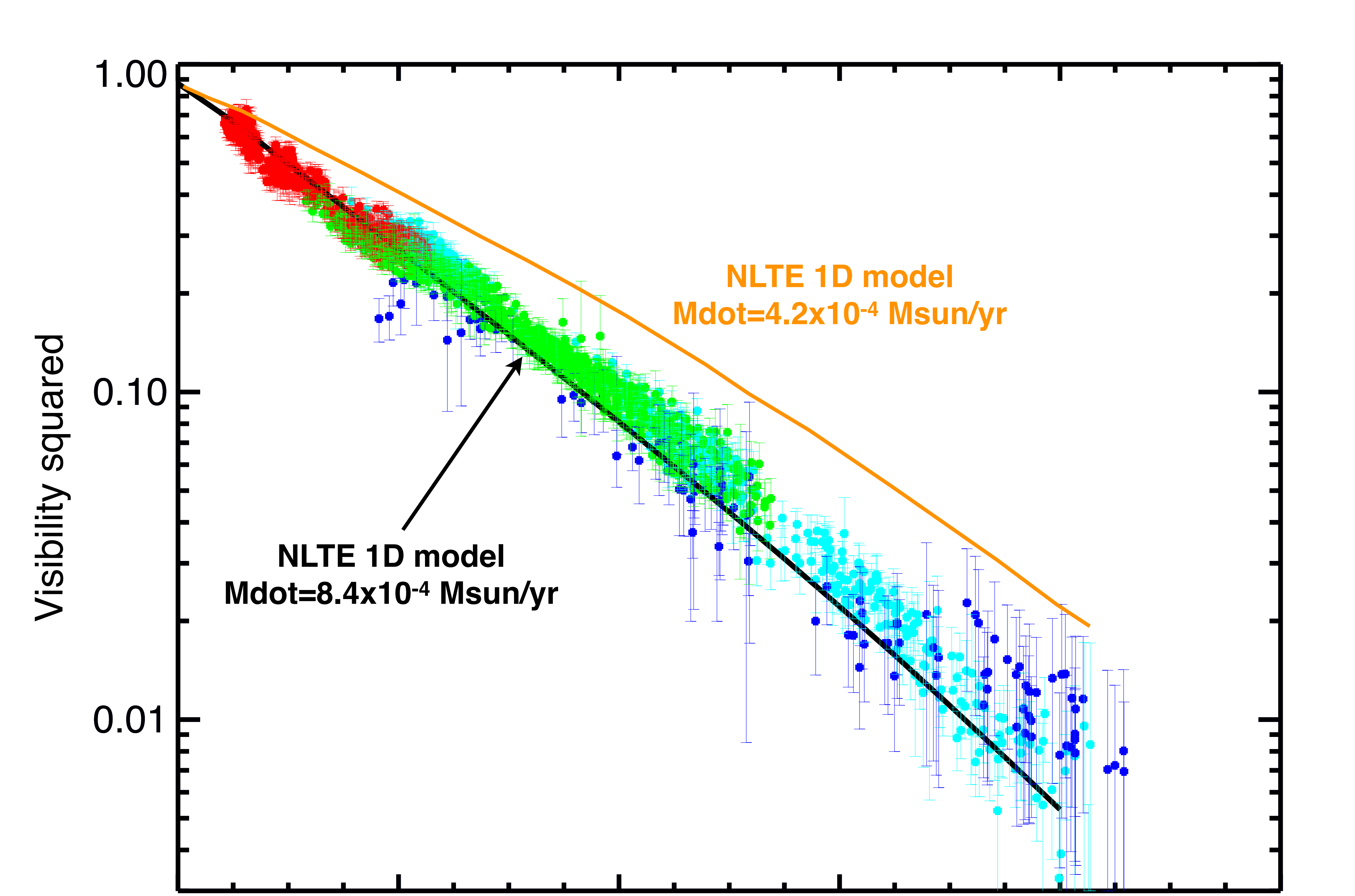
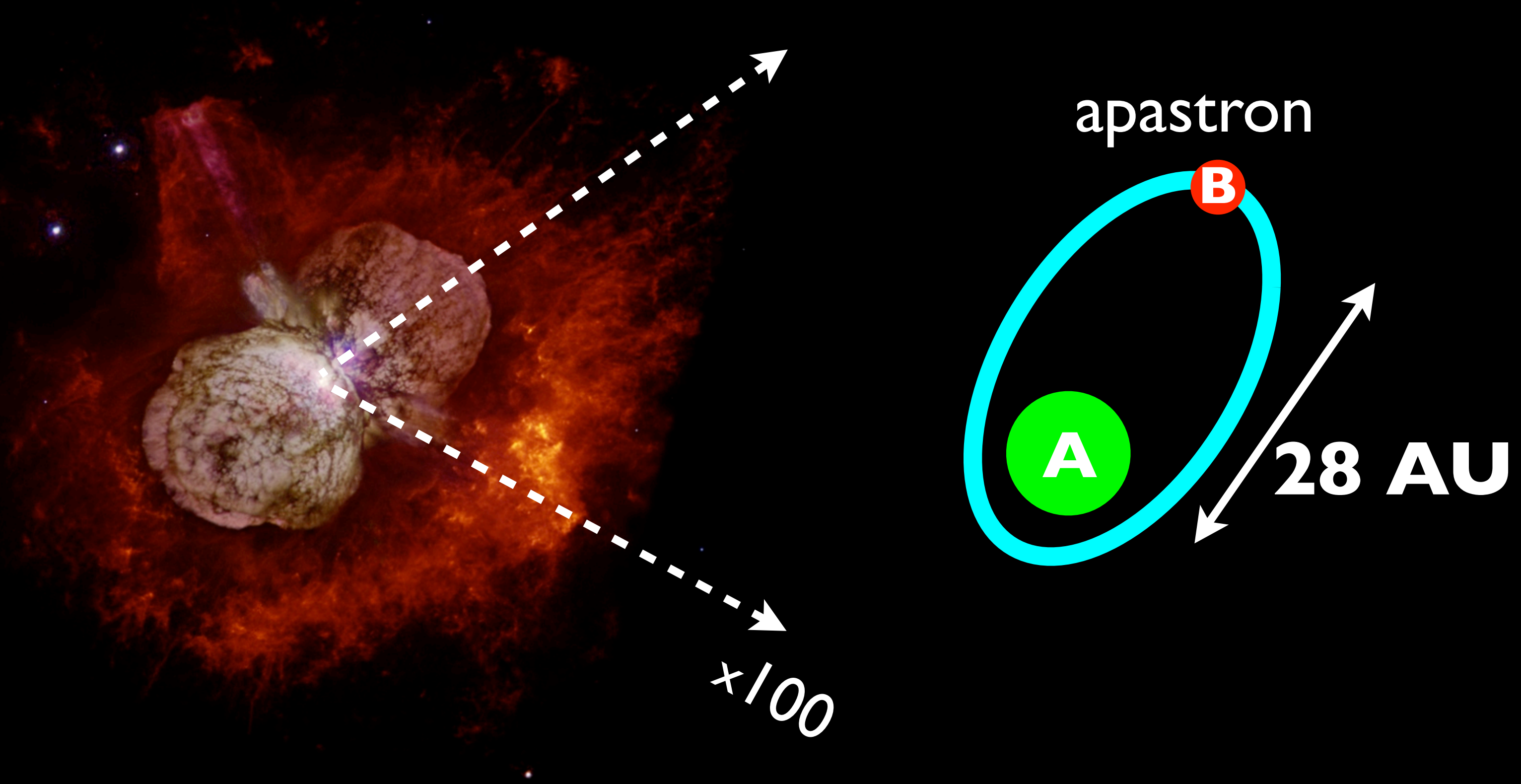


PIONIER 2012-2013 data do NOT support a noticeable change in Eta Car's mass-loss rate.

Binarity of Eta Carinae: effects are time dependent

Orbit: i=139°, ω=243°, PA=312°, e=0.9, P=5.54 years
(Damineli 96; Madura+ 12)



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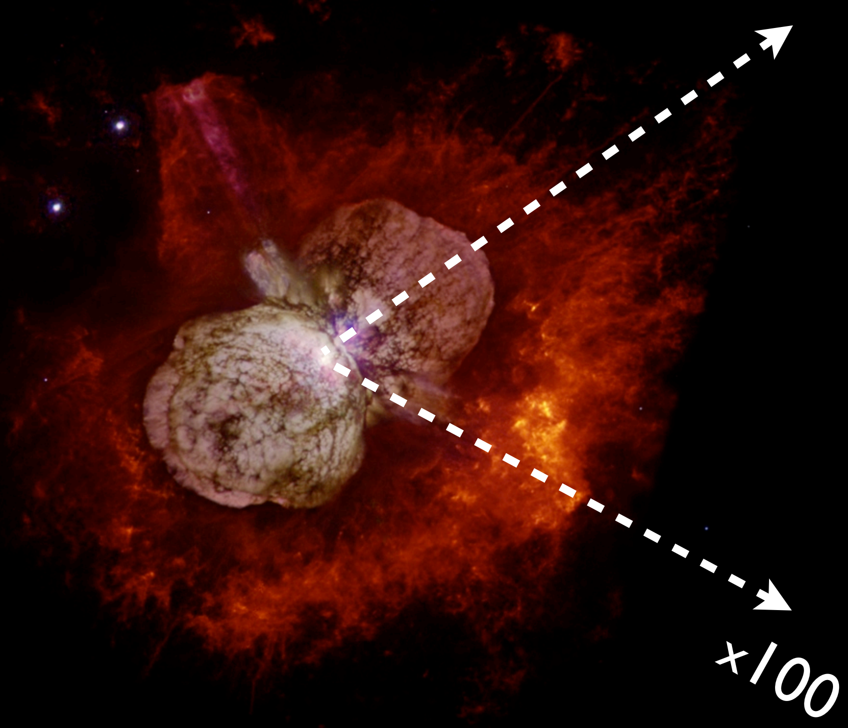

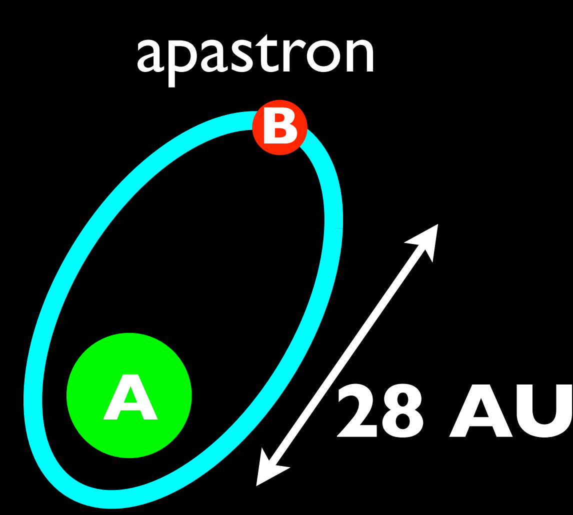

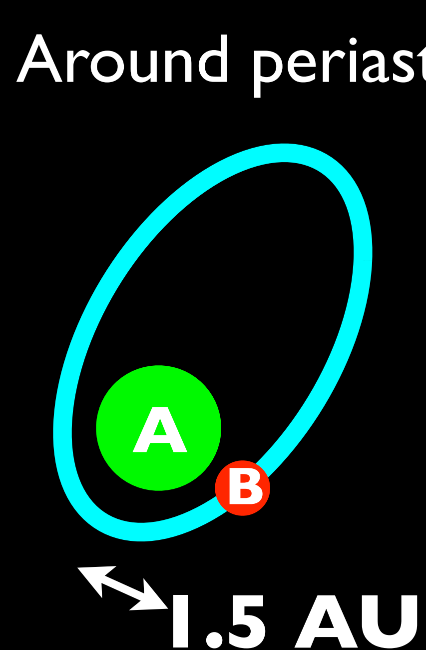

Effects of binarity in Eta Car

Changes in the density structure of the primary wind

Density cuts from 3D hydrodynamical SPH simulations of the Eta Car binary system (Madura +13): orbital period P=5.54 yr, eccentricity e=0.9.

Eta Car B

Eta Car A

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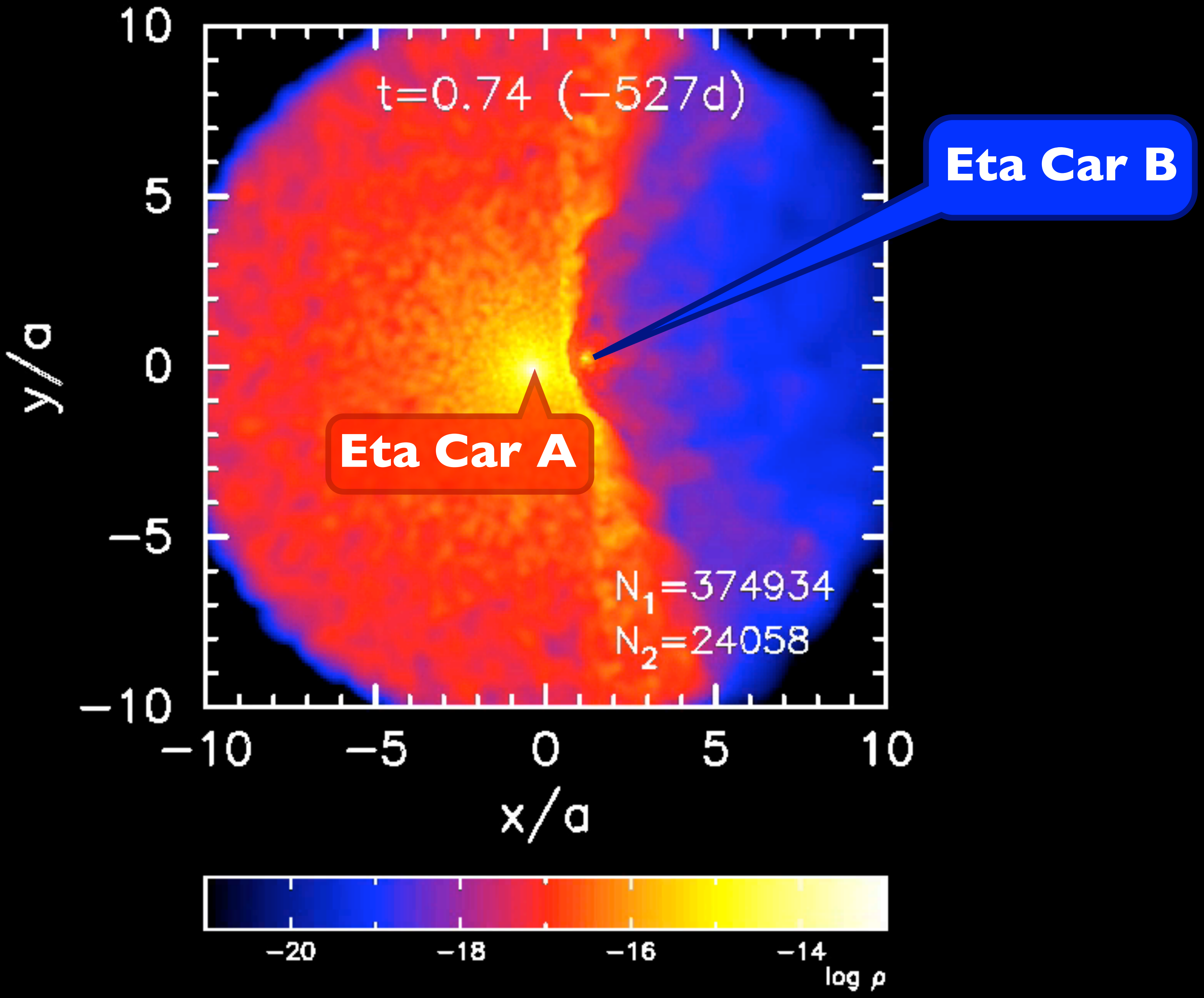

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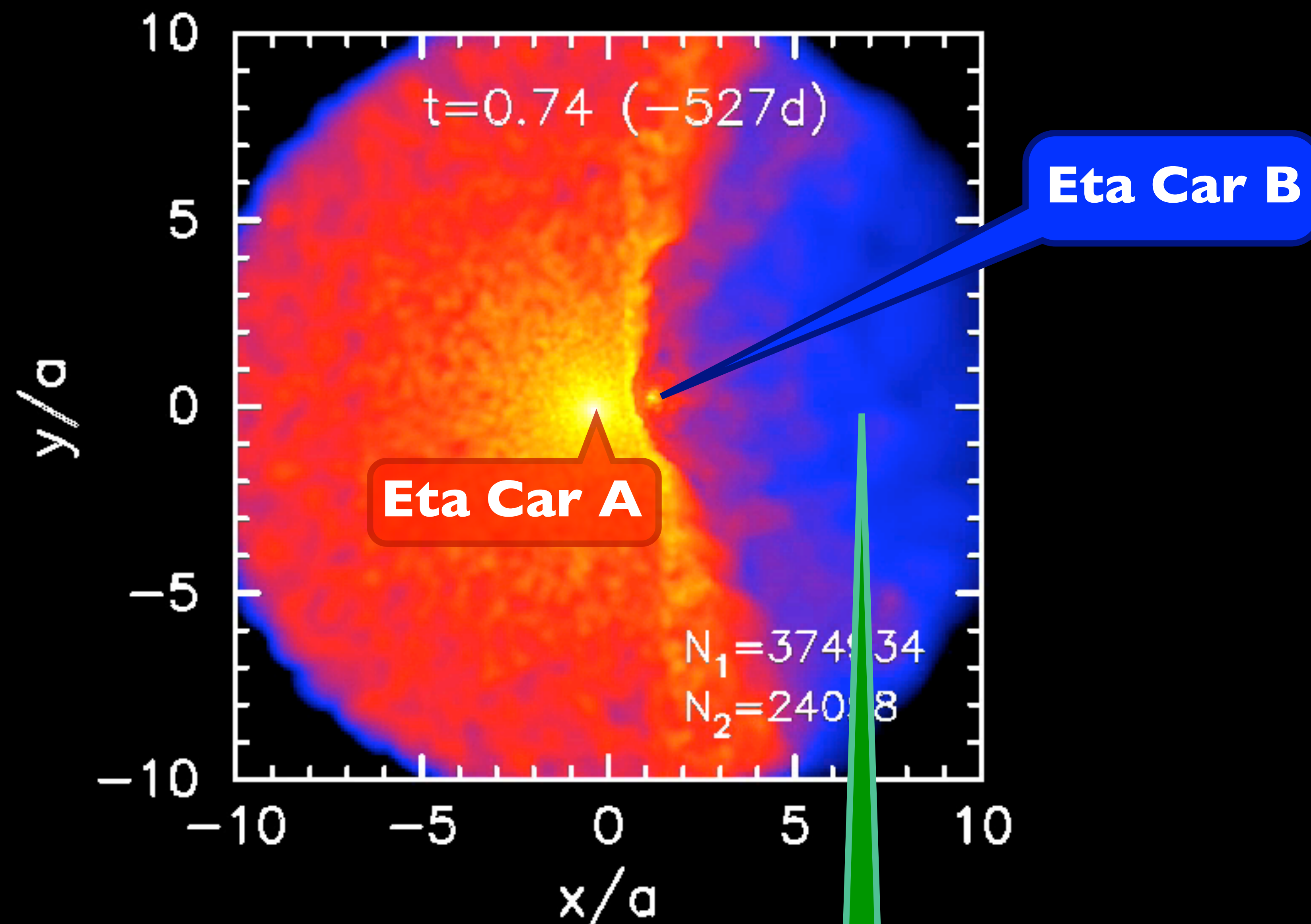

Fast wind of the companion produces a **cavity** in the dense wind of the primary star

(Pittard & Corcoran 2002, Okazaki+ 08, Parkin+ 09, 11; Madura+ 12, 13).

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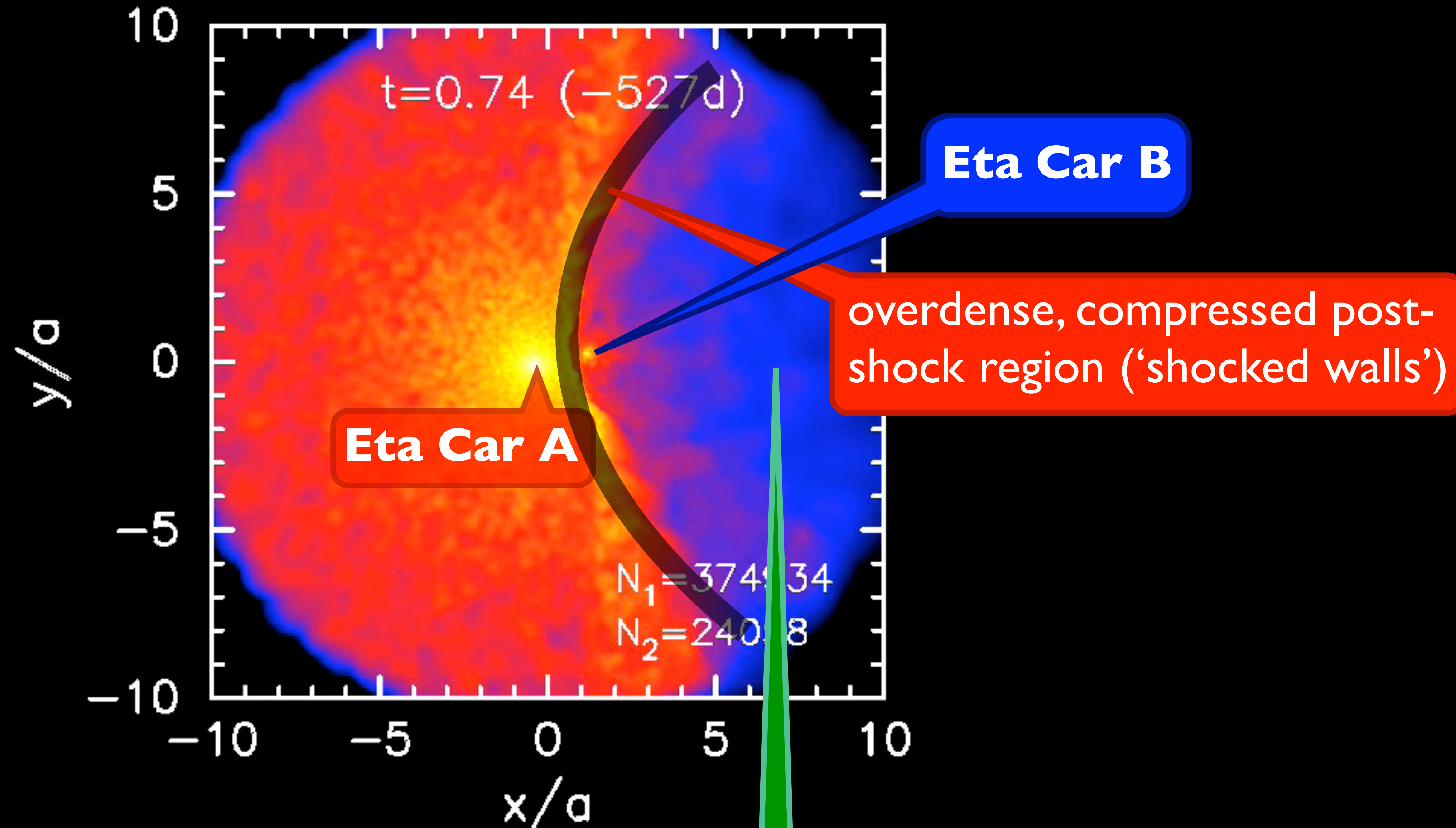

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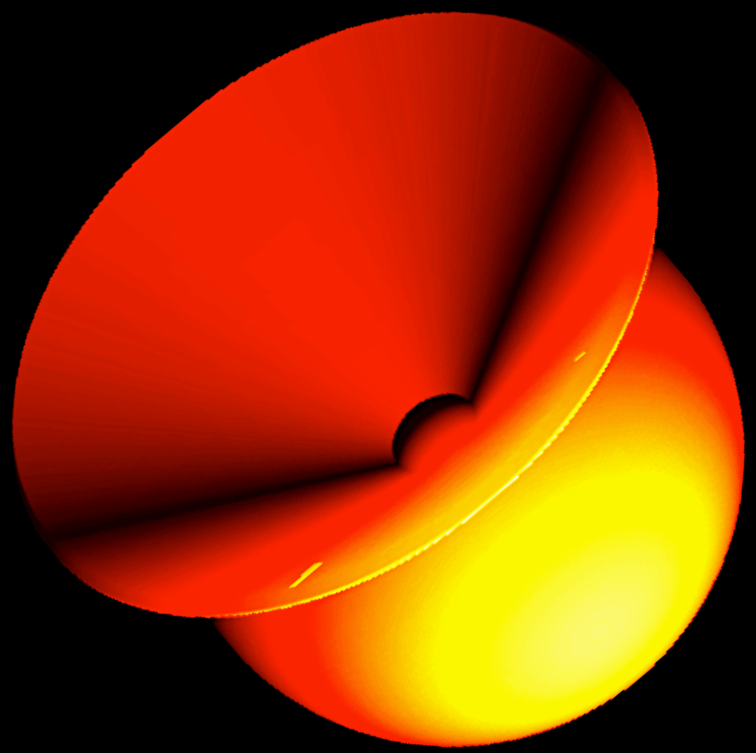
Effects of the companion star on Eta Car

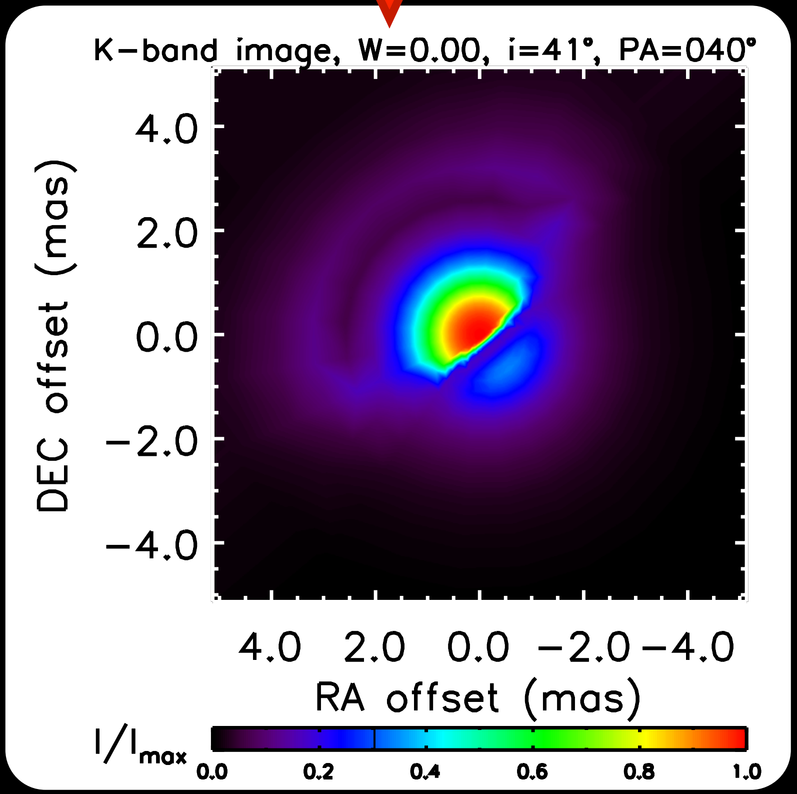
Near-infrared: geometry of the K-band continuum emitting region

A 2D model with i=41° (139°) and longitude of periastron of ω=243° provides a reasonably good fit to the VINCI observations at orbital phase ϕ=0.93.

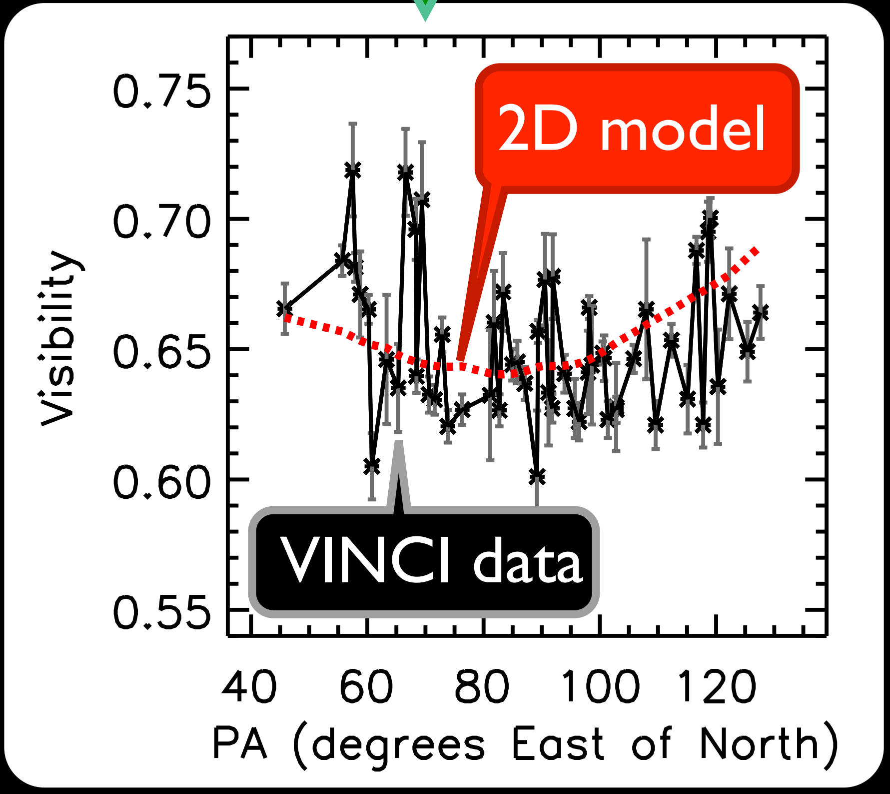
3-D isodensity surface



K-band continuum image



Fit to the visibilities



(Groh et al. 2010a)

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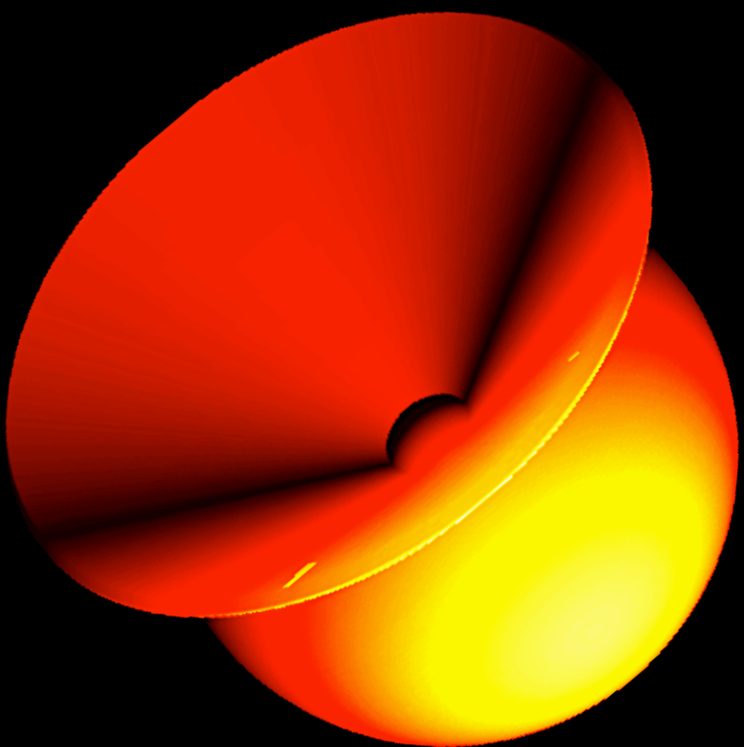
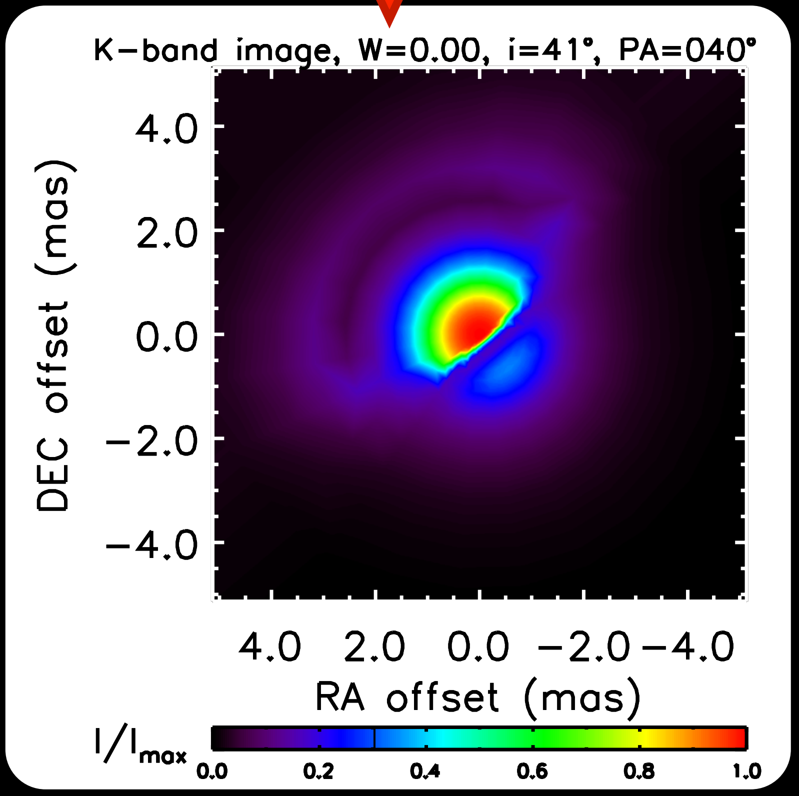
A 2D model with i=41° (139°) and longitude of periastron of ω=243° provides a reasonably good fit to the VINCI observations at orbital phase ϕ=0.93.

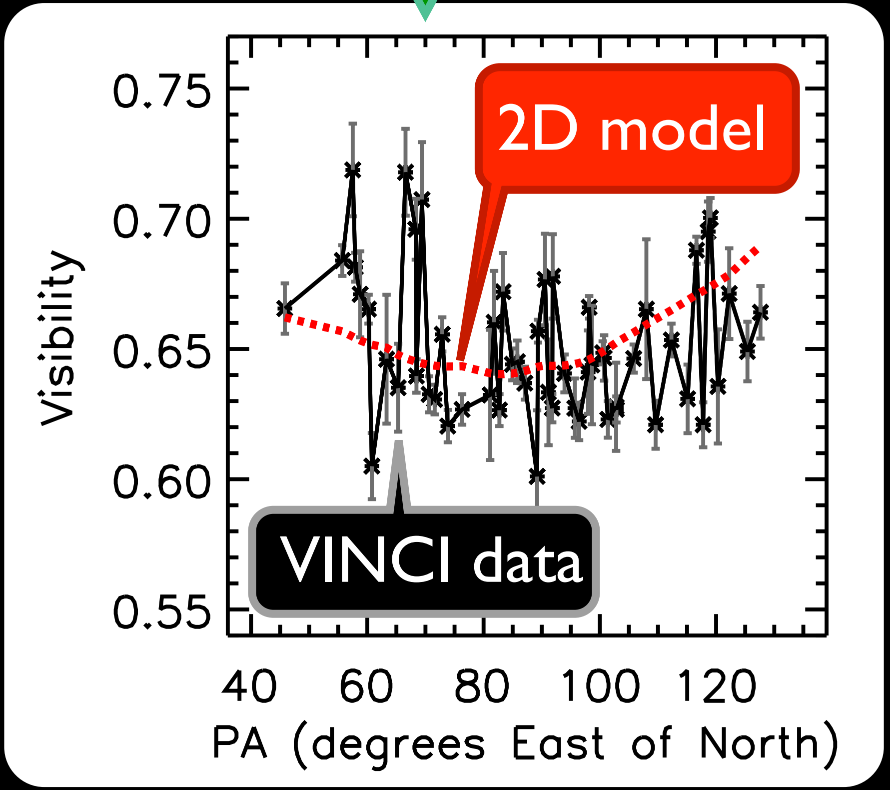
3-D isodensity surface



K-band continuum image



Fit to the visibilities



(Groh et al. 2010a)

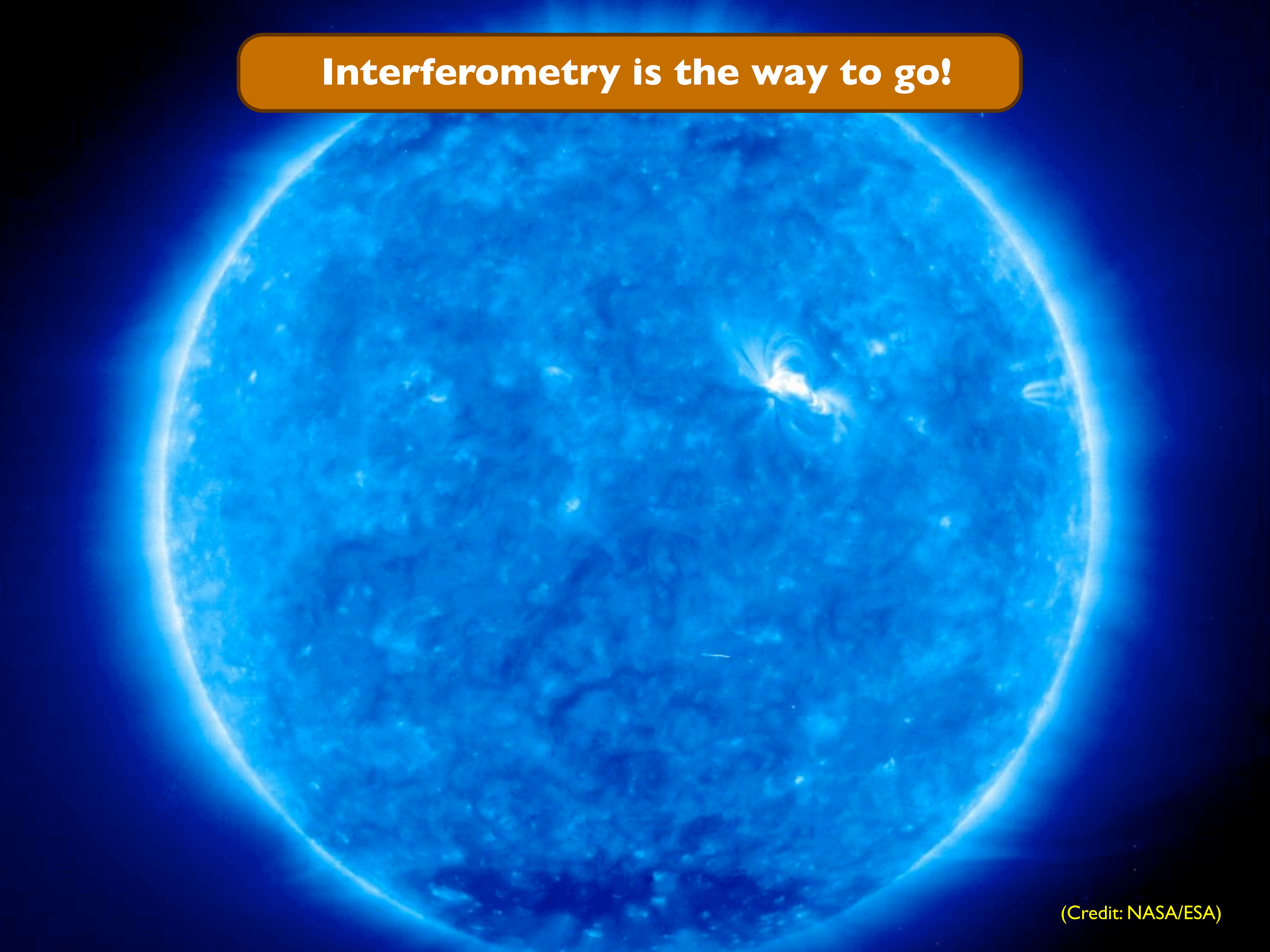
Binary model fits data taken at periastron

Take way messages

- Interferometry is key to probe rotation, mass loss, and binary effects in massive stars
- Eta Carinae is key for understanding how O stars become WR stars and how LBVs explode as SNe

Eta Carinae seen by interferometry:
- no changes in Mdot over last 15 years;
- rapidly-rotating primary star (~80% critical speed) seem at i~60-90deg (misaligned with Homunculus);
- strong binary effects (WWC) around periastron.

Interferometry is the way to go!



(Credit: NASA/ESA)