New insights into Eta Carinae with PIONIER

Collaborators
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Ejected mass: $\sim 10$ to $20 \, M_\odot$
from high-res MIR imaging (Smith+ 03)
Eta Carinae and the Homunculus nebula

Central Source:
- $L \approx 5 \times 10^6 \, L_\odot$
- $M > 100 \, M_\odot$
- $\dot{M} \approx 8 \times 10^{-4} \, M_\odot/\text{yr}$
- $v_{\infty} \approx 420 \, \text{km/s}$

(Hillier+ 01, Groh+ 12)

Needs interferometry to probe the inner 20 mas:
- mass loss
- rotation
- binarity
Mass loss and extension of the photosphere

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

\[ r_{\text{hydr}} = r_{\text{phot}} \]
Mass loss and extension of the photosphere

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

Sun

r_{hydr} = r_{phot}

Atmosphere

Eta Car

r_{phot} (set by free-free emission)

Atmosphere

r_{hydr}

Stellar Wind

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Mass loss and extension of the photosphere

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

$\dot{M}(\Omega/2)$

$\mathcal{r}_{\text{hydr}} = \mathcal{r}_{\text{phot}}$

Eta Car

$\mathcal{r}_{\text{phot}}$ (set by free-free emission)

Sun

Atmosphere

Stellar Wind
Mass loss and extension of the photosphere

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

$\dot{r}$

Eta Car (M/2)

$r_{\text{phot}}$ (set by free-free emission)

Sun

$\dot{r_{\text{hydr}}} = r_{\text{phot}}$

Atmosphere
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
Etau Carinae mass loss
(van Boekel+03; Weigelt+07; Kervella 07; Groh+10, 12)

Mass-loss rate in 2002-2005: \(~ 8.4 \times 10^{-4} \) Msun/yr

Groh+12
Variability in Eta Carinae mass loss?
(Mehner+10, 12, Corcoran+10, Gull+11, Groh+12, Teodoro+12, Madura+13)

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

Mehner+12
Eta Car PIONIER data

Data taken by O. Absil on 2012 Mar and 2013 Feb
7 spectral channels across the H band
Probing changes in mass loss with PIONIER

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

NLTE 1D model
$M_{\text{dot}} = 8.4 \times 10^{-4} \, \text{M}_{\odot}/\text{yr}$
Probing changes in mass loss with PIONIER

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

NLTE 1D model
\[ M_{\text{dot}} = 4.2 \times 10^{-4} \ \text{Msun/yr} \]

NLTE 1D model
\[ M_{\text{dot}} = 8.4 \times 10^{-4} \ \text{Msun/yr} \]

PIONIER 2012-2013 data do NOT support a noticeable change in Eta Car’s mass-loss rate.
Rotation: elongation of the K-band photosphere
(van Boekel+ 03; Kervella 07; Weigelt+07; Groh+10)
Rotation: elongation of the K-band photosphere
(van Boekel+ 03; Kervella 07; Weigelt+07; Groh+10)

**Homunculus**
- $i=41^\circ$; $PA=131^\circ$

**Geometric model**
- $PA\sim134^\circ$; $b/a=1.25$

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

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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

Rad. Transf. VINCI+AMBER

$v_{\text{rot}}/v_{\text{crit}}=0.77$ to $0.92$

i=60° to 90°  
PA=108° to 142°

Eta Car A

rapid rotator: rotation axis misaligned with the Homunculus

Groh+10
Binarity of Eta Carinae: effects are time dependent

Orbit: $i=139^\circ$, $\omega=243^\circ$, PA=$312^\circ$, $e=0.9$, $P=5.54$ years
(Damineli 96; Madura 12)
Binarity of Eta Carinae: effects are time dependent

Orbit: \( i=139^\circ, \omega=243^\circ, PA=312^\circ, e=0.9, P=5.54 \) years

(Damineli 96; Madura 12)
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(Damineli 96; Madura 12)

Around periastron

Eta Car A

Eta Car B

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Binarity of Eta Carinae: effects are time dependent

Orbit: $i=139^\circ$, $\omega=243^\circ$, PA=$312^\circ$, $e=0.9$, $P=5.54$ years

(Damineli 96; Madura 12)

Around periastron

wind-wind collision zone

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Effects due to the companion star around periastron

‘bore hole’ and free-free emission from the wind-wind collision

3-D isodensity surface
Effects due to the companion star around periastron

‘bore hole’ and free-free emission from the wind-wind collision

3-D isodensity surface

carving of the wind, exposing the hotter, inner parts (‘bore hole’ effect, Madura & Owocki 2010)
Effects due to the companion star around periastron

‘bore hole’ and free-free emission from the wind-wind collision

3-D isodensity surface

carving of the wind, exposing the hotter, inner parts (‘bore hole’ effect, Madura & Owocki 2010)

free-free emission from the dense post-shocked primary wind compressed along the shock cone walls
Effects due to the companion star around periastron

‘bore hole’ and free-free emission from the wind-wind collision

3-D isodensity surface

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Groh+10,12
Effects due to the companion star around periastron

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3-D isodensity surface

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Fit to the visibilities

VinCI data

2D model

(Groh et al. 2010a)

Groh+10,12
Both rotation and binary effects explain the previous data

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

Binary model fits data as well as single, rapid-rotating star

Rapid rotator

Wind-wind collision model

Fit to the visibilities

(Groh et al. 2010a)
Rotation as seen by PIONIER

Data taken by O. Absil on 2012 Mar (close to apastron) at 1.875 micron

Variation of visibility as a function of PA
Rotation as seen by PIONIER

Data taken by O. Absil on 2012 Mar (close to apastron) at 1.875 micron

Variation of visibility as a function of PA

![Graph showing variation of visibility as a function of position angle (PA) with spatial frequency. The graph includes a color scale and a inset image labeled 'rapid rotator model'.]
PIONIER data reveals a rapid rotator

Data taken by O. Absil on 2012 Mar -- only spectral channel 6 (1.875 micron)

Variation of visibility as a function of PA

![Graph showing variation of visibility as a function of PA](image)

- **Visiblity squared**
- **Spatial frequency (m/micron)**

**Rapid rotator model**

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Binary effects not enough to fit PIONIER data

Data taken by O. Absil on 2012 Mar (close to apastron) at 1.875 micron

Variation of visibility as a function of PA

Visibility squared

Spatial frequency (m/micron)

PA

wind-wind collision model

PA 130
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Preliminary image reconstruction: all data
by JB Le Bouquin
Preliminary image reconstruction: all data

by JB Le Bouquin
Preliminary image reconstruction: short+inter

by JB Le Bouquin

beam nearly circular
Preliminary image reconstruction: short+inter
by JB Le Bouquin

beam nearly circular
Preliminary image reconstruction

Wind-wind collision model

Image reconstruction

Rotation model

RA offset (mas)

DEC offset (mas)

$I/I_{\text{max}}$

0.0 0.2 0.4 0.6 0.8 1.0

José Groh - New insights into η Car with PIONIER
- no changes in Mdot over last 15 years;
- rapidly-rotating primary star (~80% critical speed) seem at i~70-90deg (misaligned with Homunculus);
- no strong binary effects (WWC) around apastron.
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AND SPECTROPOLARIMETRY

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