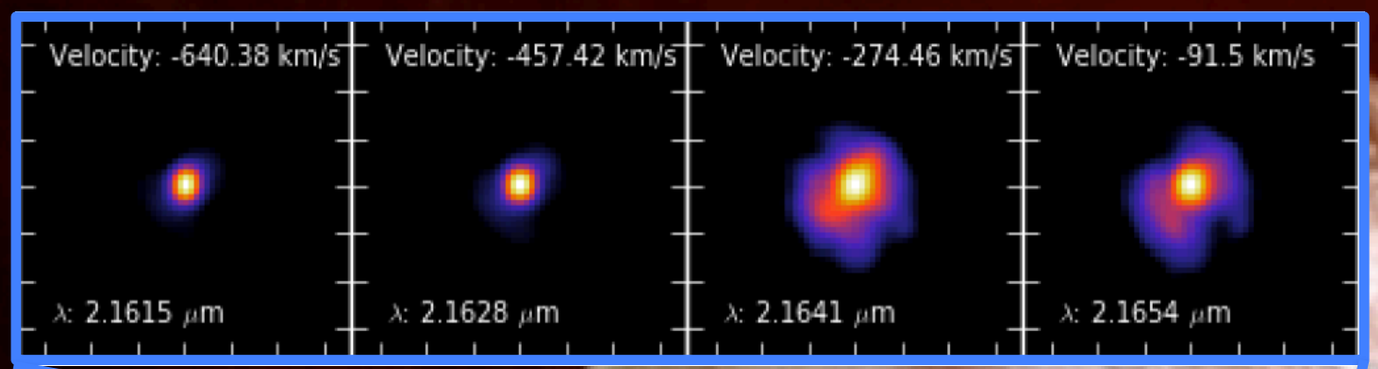
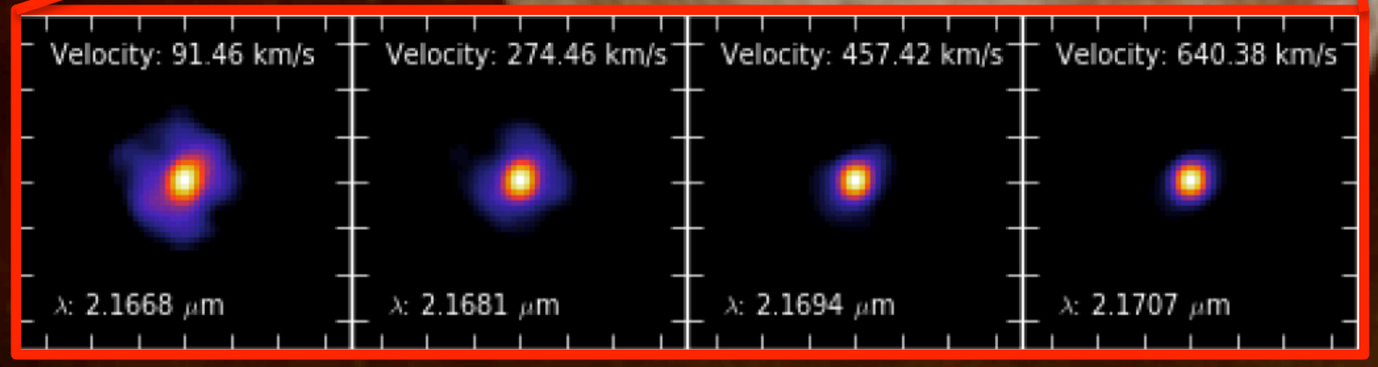
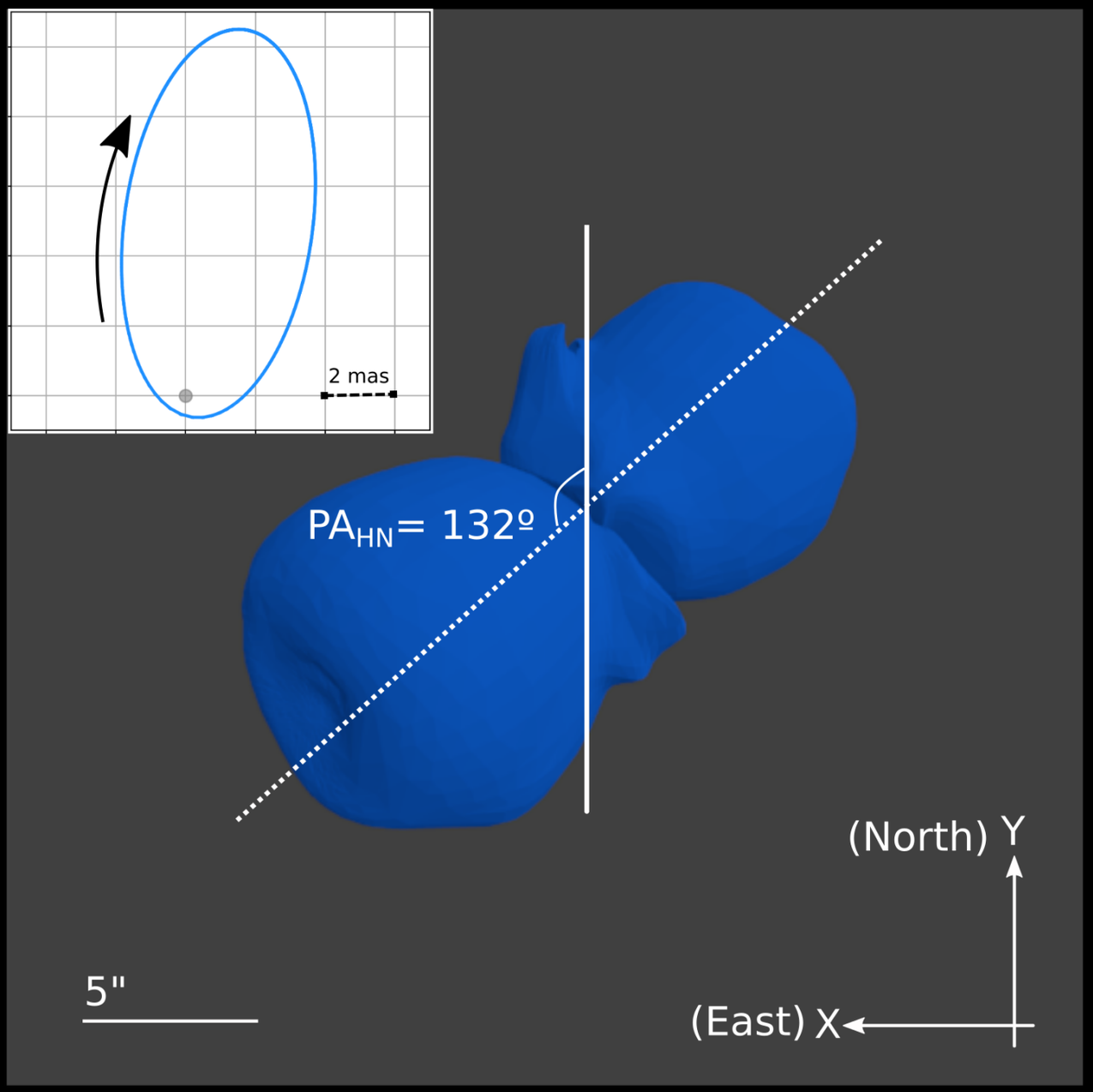
GRAVITY/VLTI chromatic image reconstruction of the Eta Car wind-wind collision region

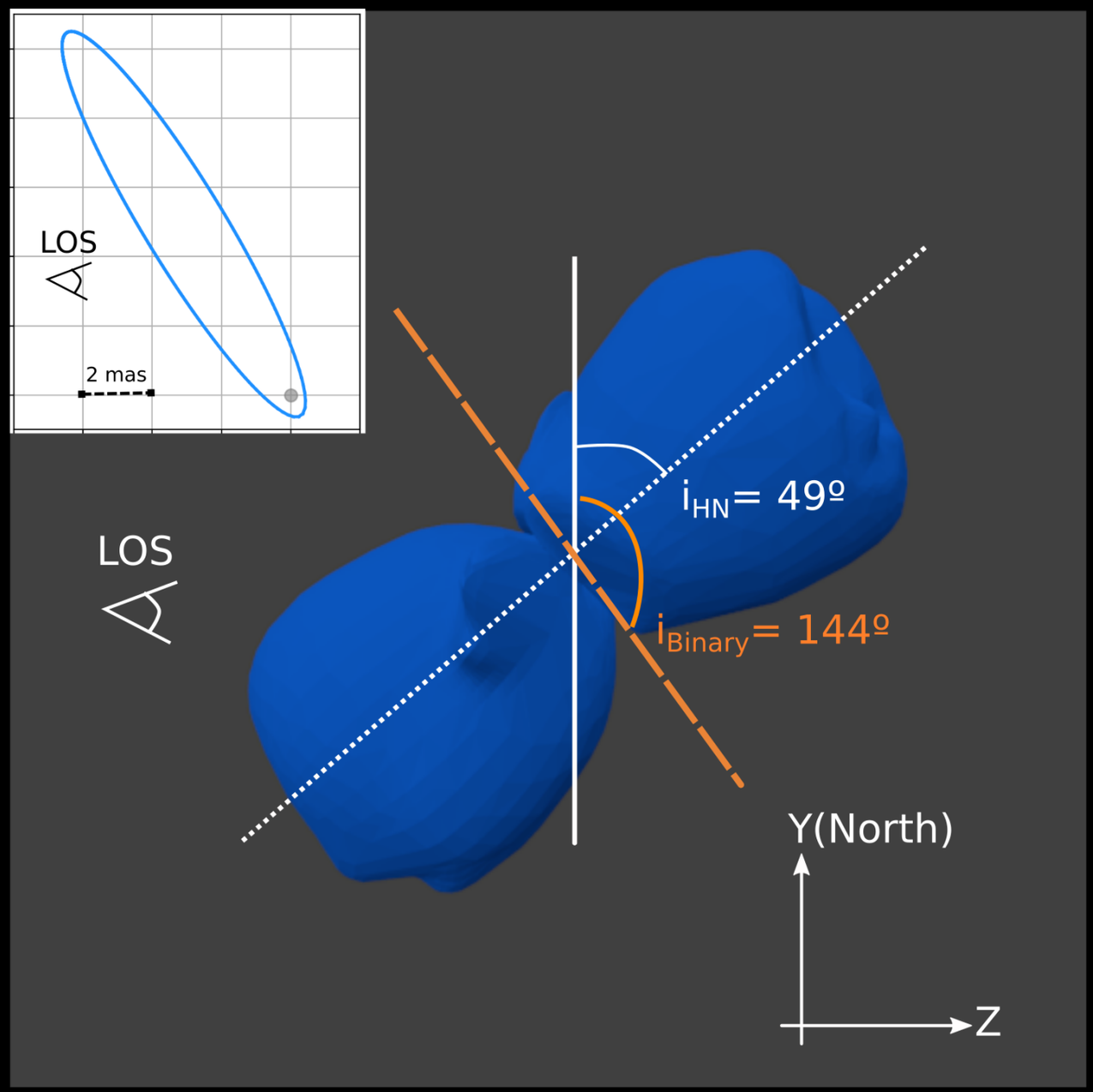




Joel Sanchez-Bermudez (MPIA)
(On behalf of the GRAVITY-VLTI team)

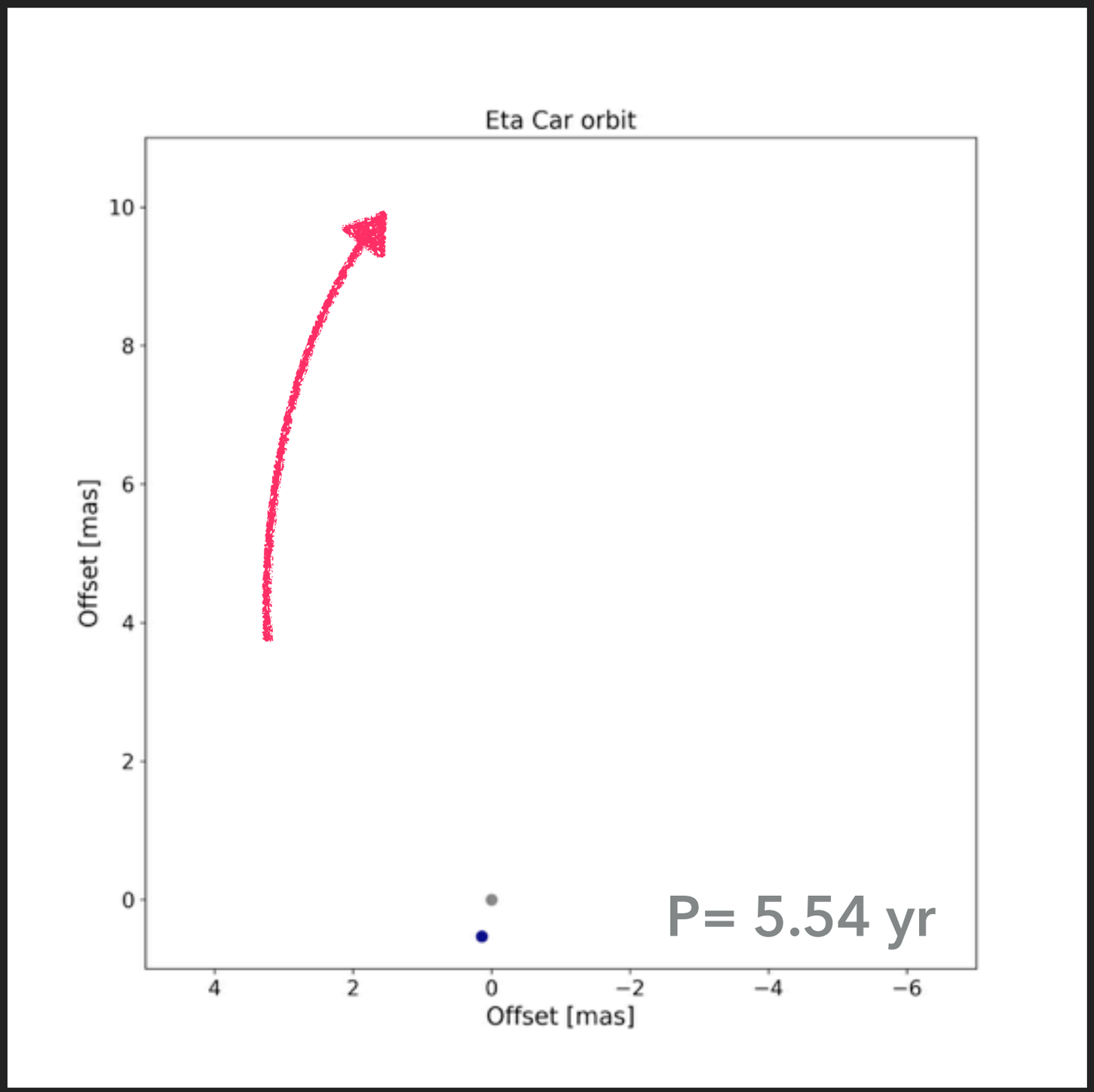
ETA CAR: IMAGING THE CORE





Damineli et al. 1997; Hillier et al. 2001; Damineli et al. 2008b,a; Corcoran et al. 2010

ETA CAR: IMAGING THE CORE



PROPERTIES η_A:

- M > 100 M⊙
- $\dot{M}$ ~8.5x10^{-4} M⊙/yr
- v_{wind} ~ 420 km/s

PROPERTIES η_B:

- $\dot{M}$ ~1x10^{-5} M⊙/yr
- V_{wind} ~ 3000 km/s

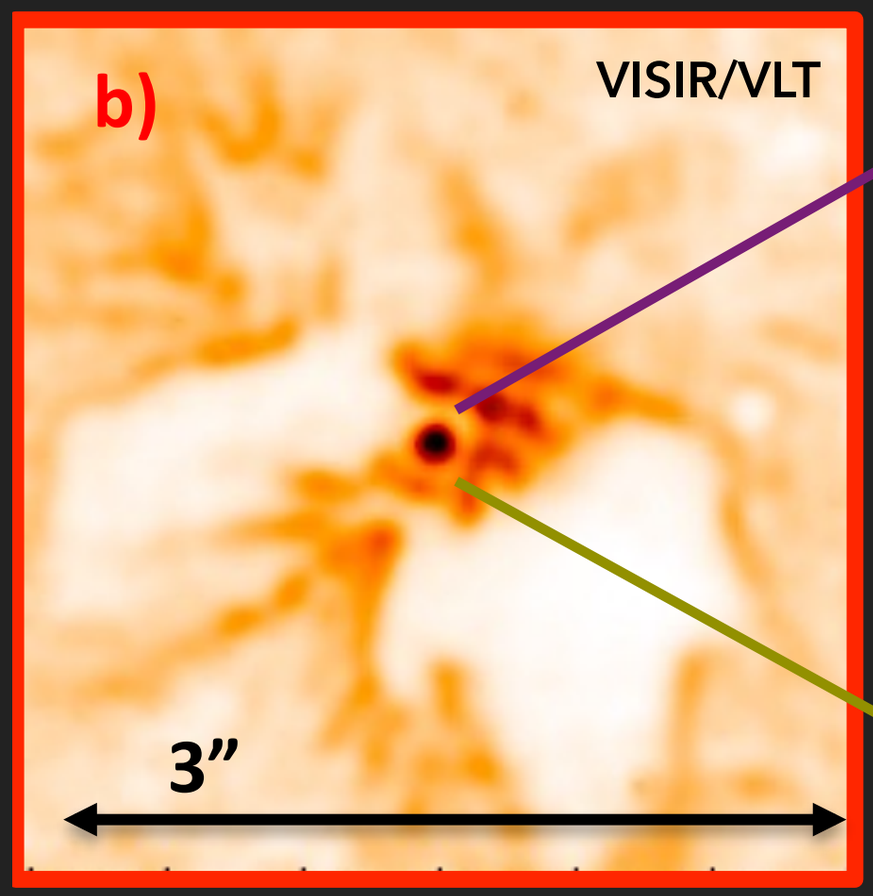
Orbital solution:

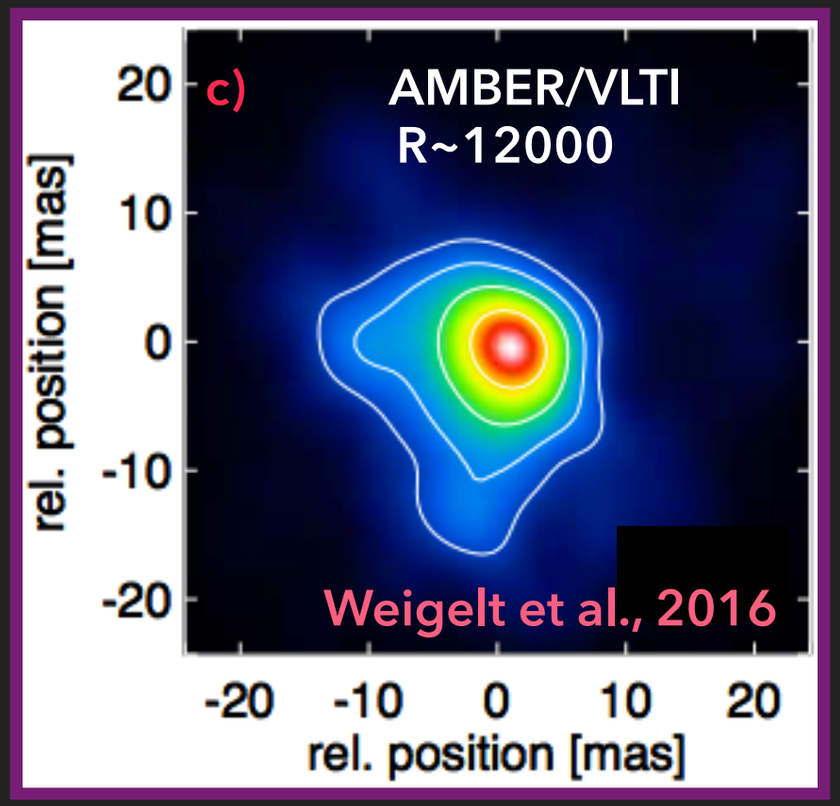
- e = 0.9
- i = 144°
- Ω = 47°
- ω = 243°

e.g., Damineli 96; Davidson & Humphreys 97; Davidson et al. 01; Hillier et al. 01, 06; Pittard & Corcoran 2002; Groh et al. 12b

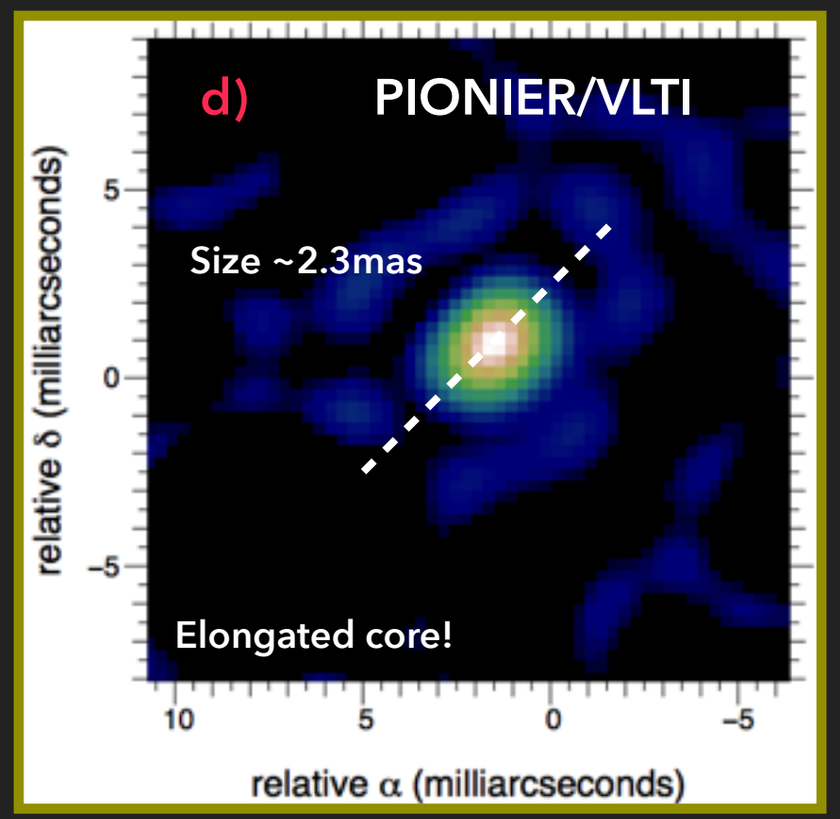
ETA CAR: IMAGING THE CORE

N-band (8.0 µm)





K-band (2.2 µm)

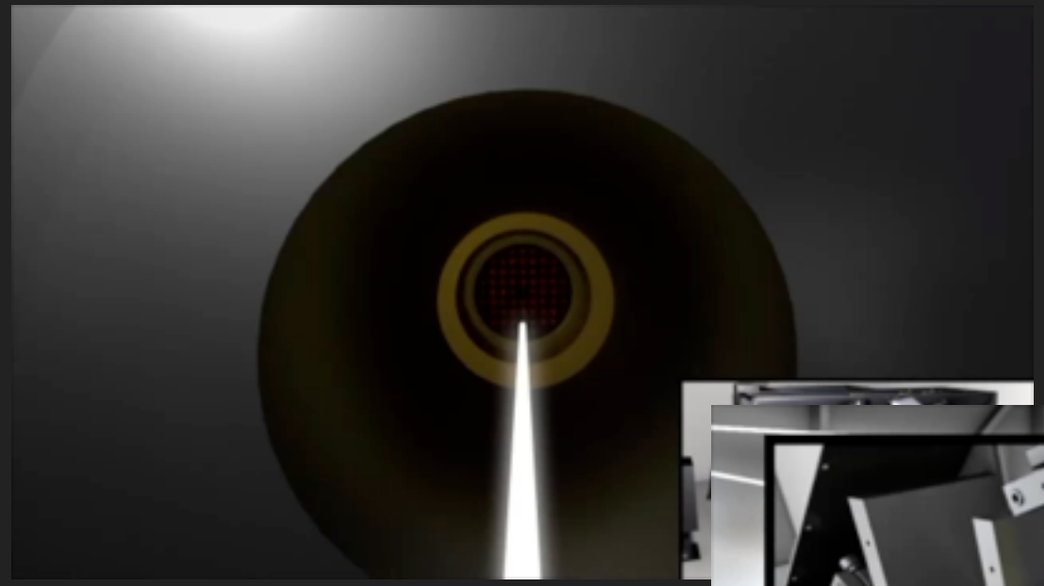


H-band (1.7 µm)

See the poster No. 93!

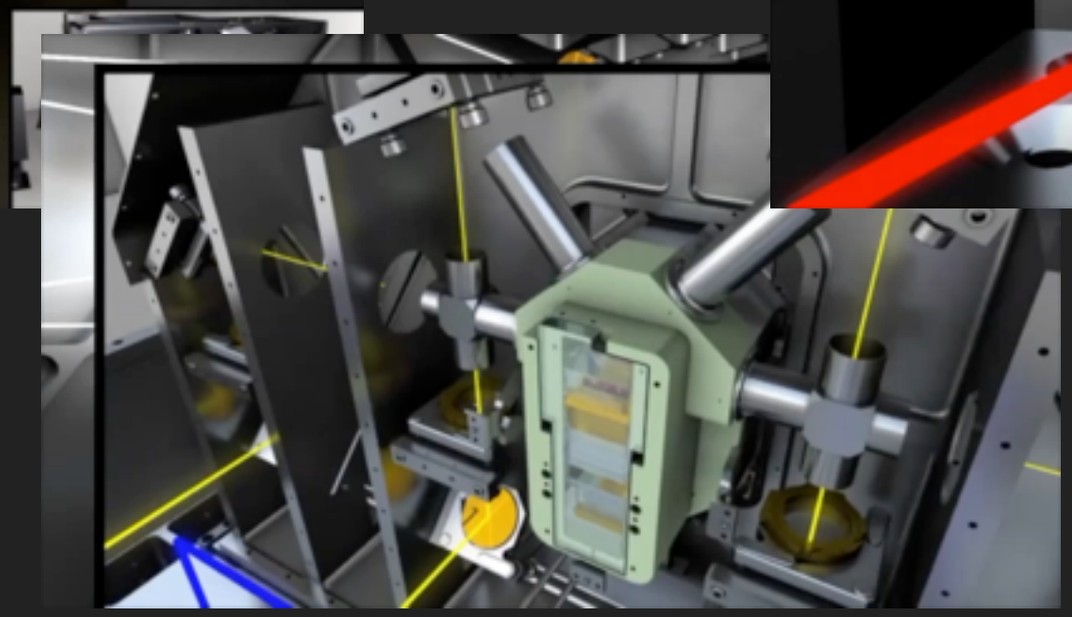
- K-band (~**1.9-2.5 μm**)
- Angular Resolution: ~**2 mas**
- Phase referenced visibilities
- Narrow-angle astrometry: **10μas**
- Simultaneous interferometric obs. of two objects (**DUAL mode**)
- Spectral resolution: **50, 500, 4000**
- Limiting K_{mag}: **16.5** (objective: 18)

GRAVITY collaboration et al., 2017

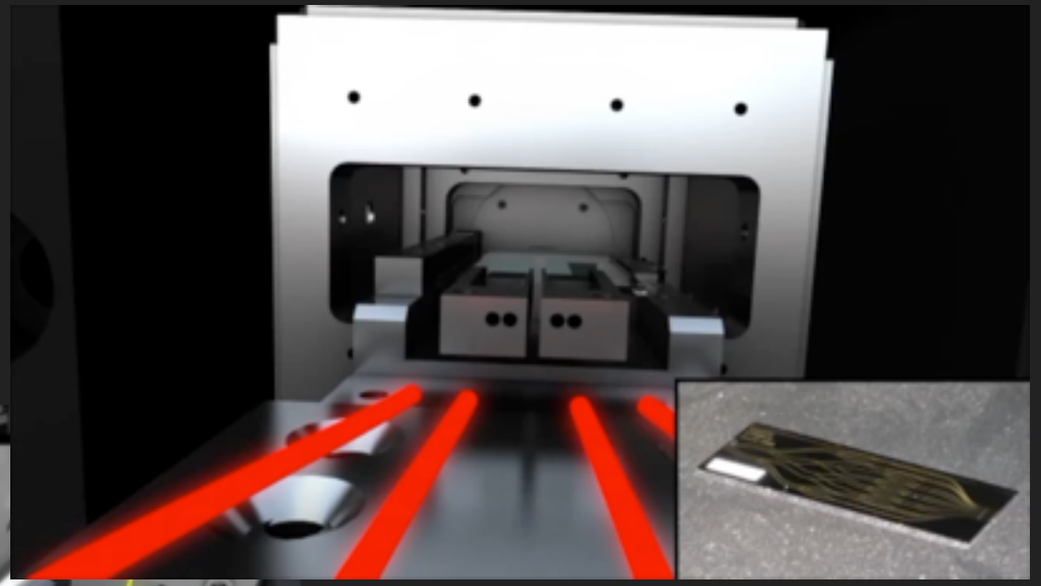


Infrared Wavefront Sensor

CIAO units!



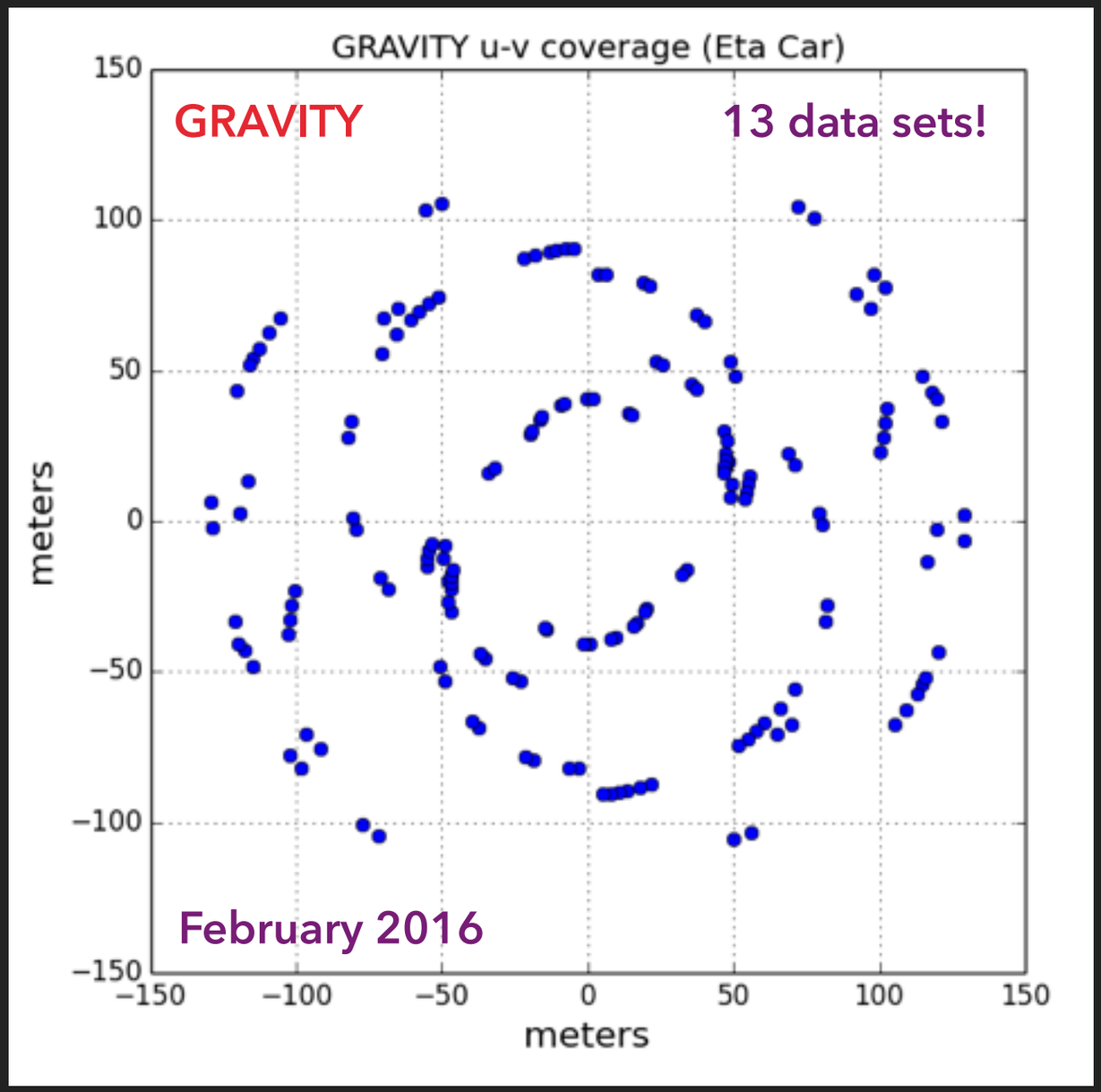
Star Separator



IC Beam Combiner

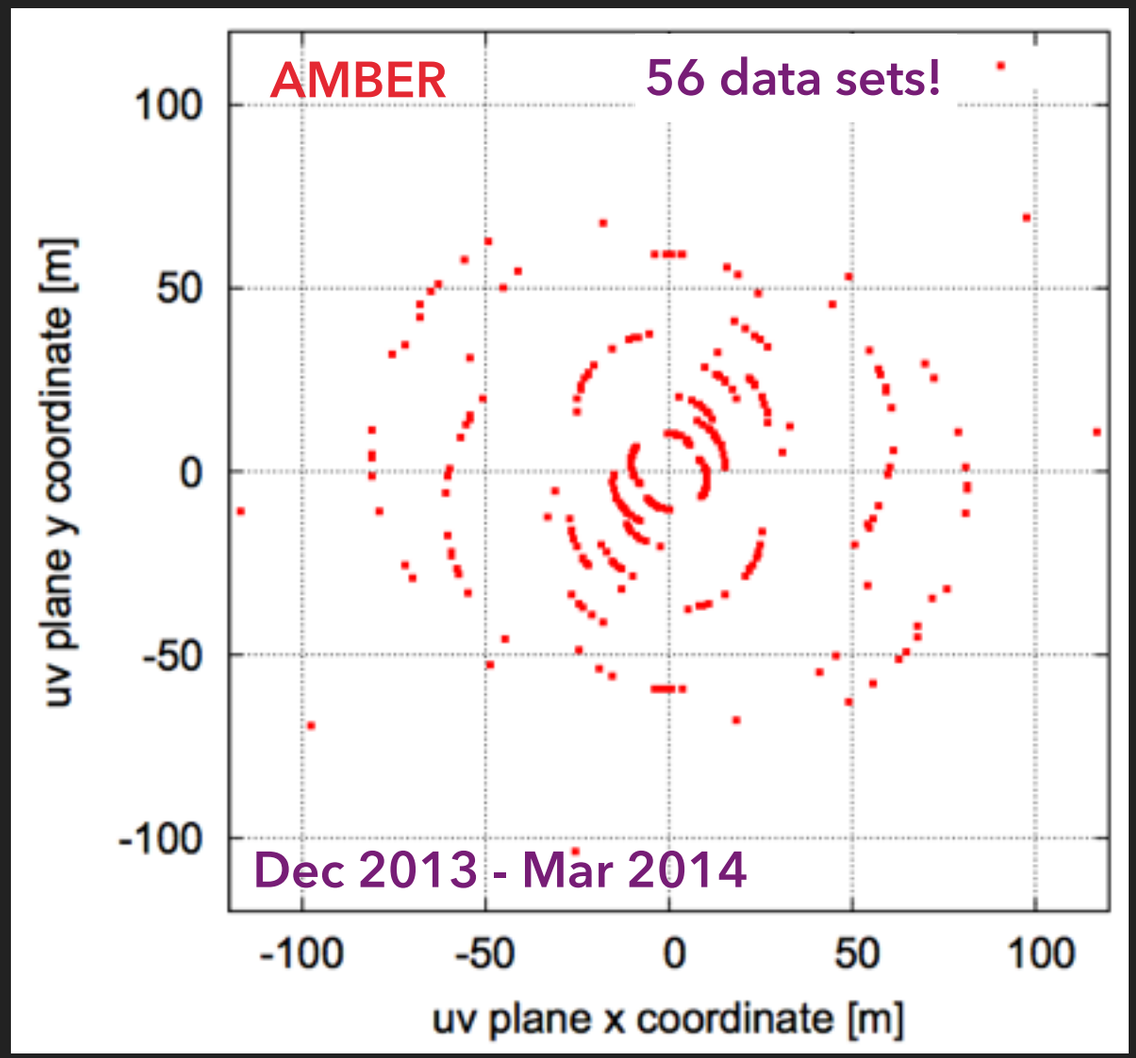
ETA CAR: IMAGING THE CORE

u-v coverage



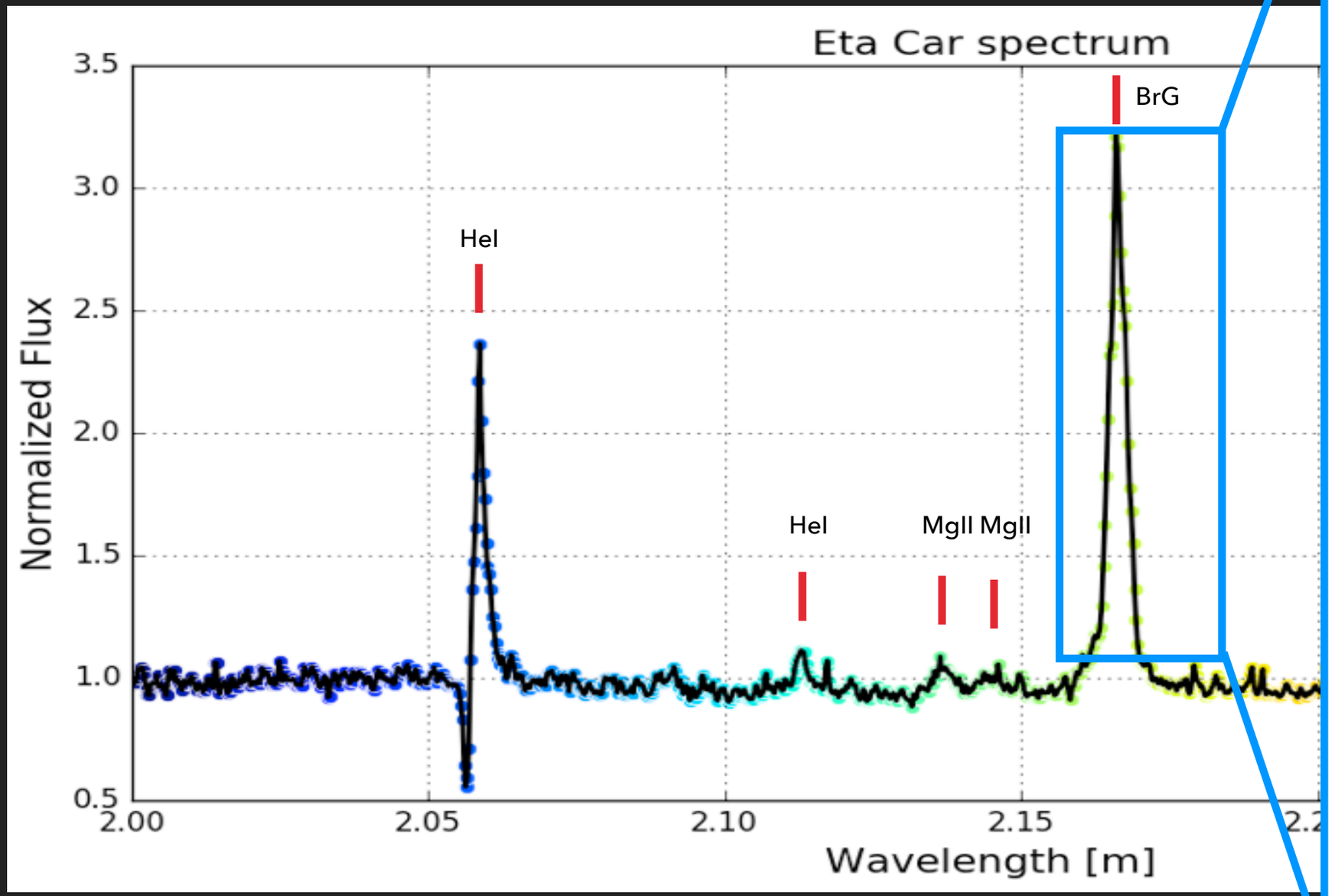
GRAVITY —> θ~3.49 mas (λ/D)
AMBER —> θ~6.00 mas

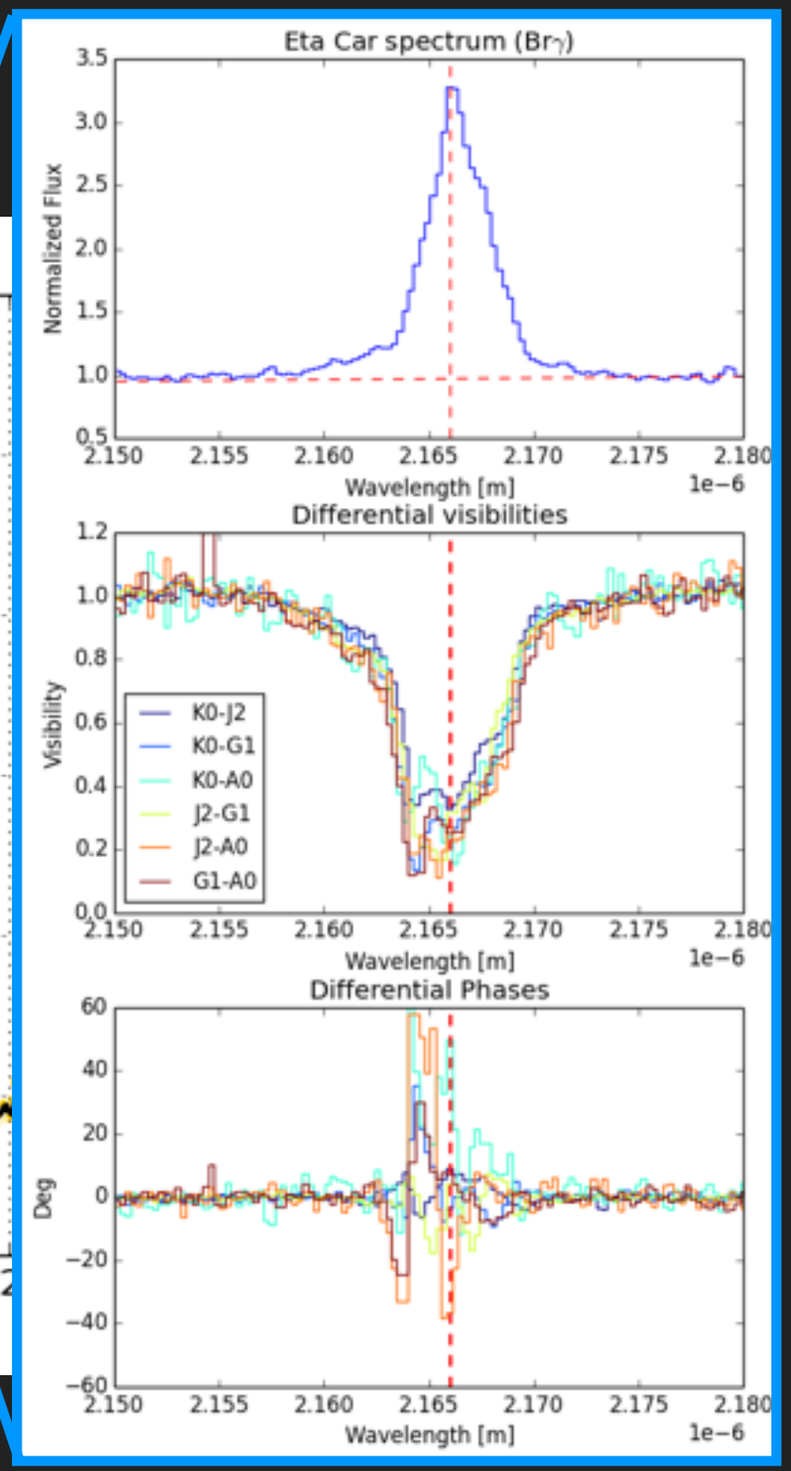
- High-Res observations (R~4000)
- 13 data sets (February 2016)
- B_{max} ~130 m, B_{min} ~40 m



ETA CAR: IMAGING THE CORE

GRAVITY Science Beam Combiner: Calibrated Spectrum





ETA CAR: IMAGING THE CORE

Image reconstruction in optical interferometry

$$\boldsymbol{x}_{ML} = \underset{\boldsymbol{x}}{\operatorname{argmin}}[1/2\chi^2(\boldsymbol{x}) + \mu R(\boldsymbol{x})]$$

Likelihood

Hyperparameter

Regularizer

- **SQUEEZE (Monte Carlo)**
  F. Baron

- **BSMEM, MiRA, PAINTER, IRBis (Gradient Descent)**
  J. Young, E. Thibaut, A. Schutz, K.-H. Hofmann

Regularizers
L0-norm
L2-norm
Entropy
Total Variation

Sanchez-Bermudez et al., **Imaging capabilities of the VLTI/MATISSE spectro-interferometric instrument**
Proc. SPIE 9907, Optical and Infrared Interferometry and Imaging V, 99070B, 2016

ETA CAR: IMAGING THE CORE

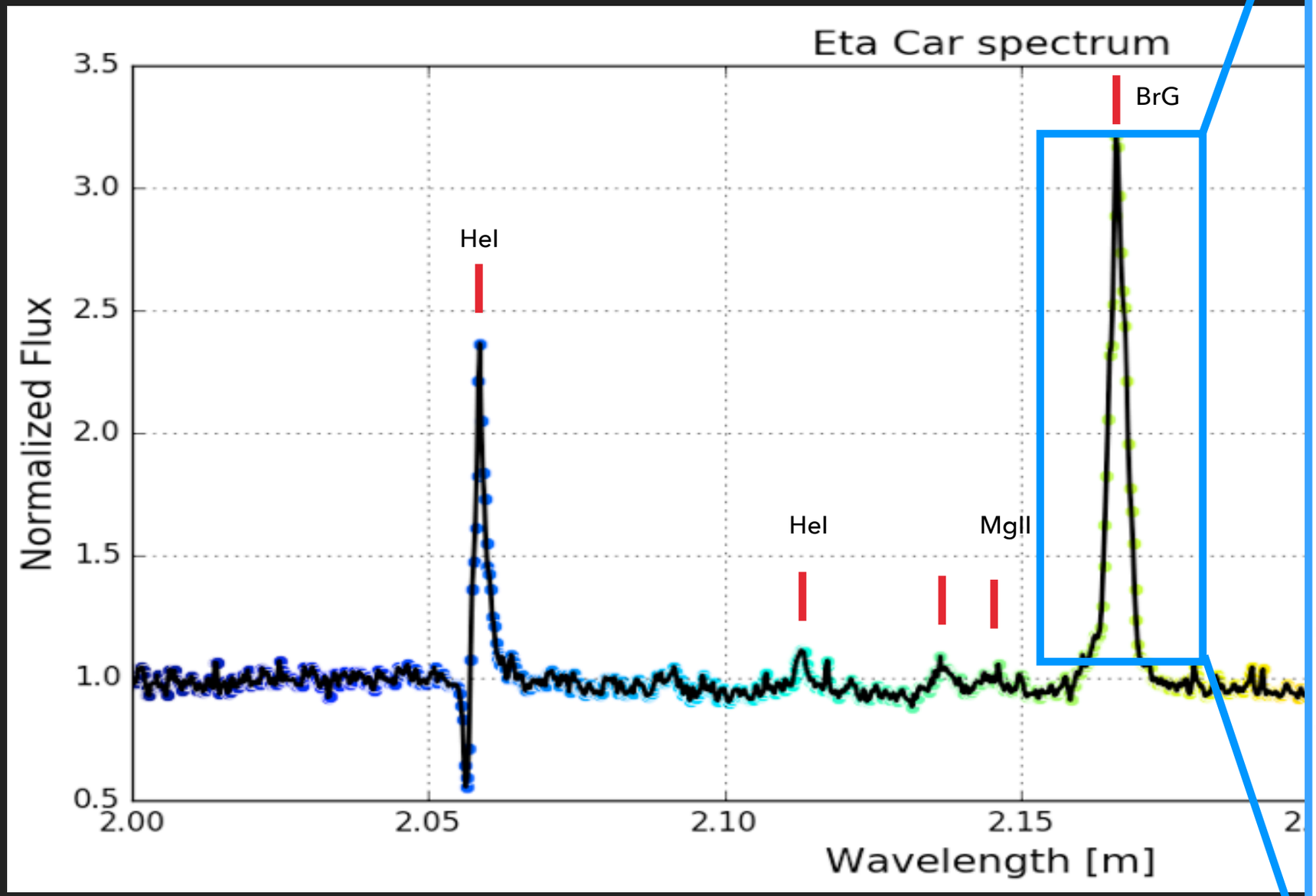
Image reconstruction parameters

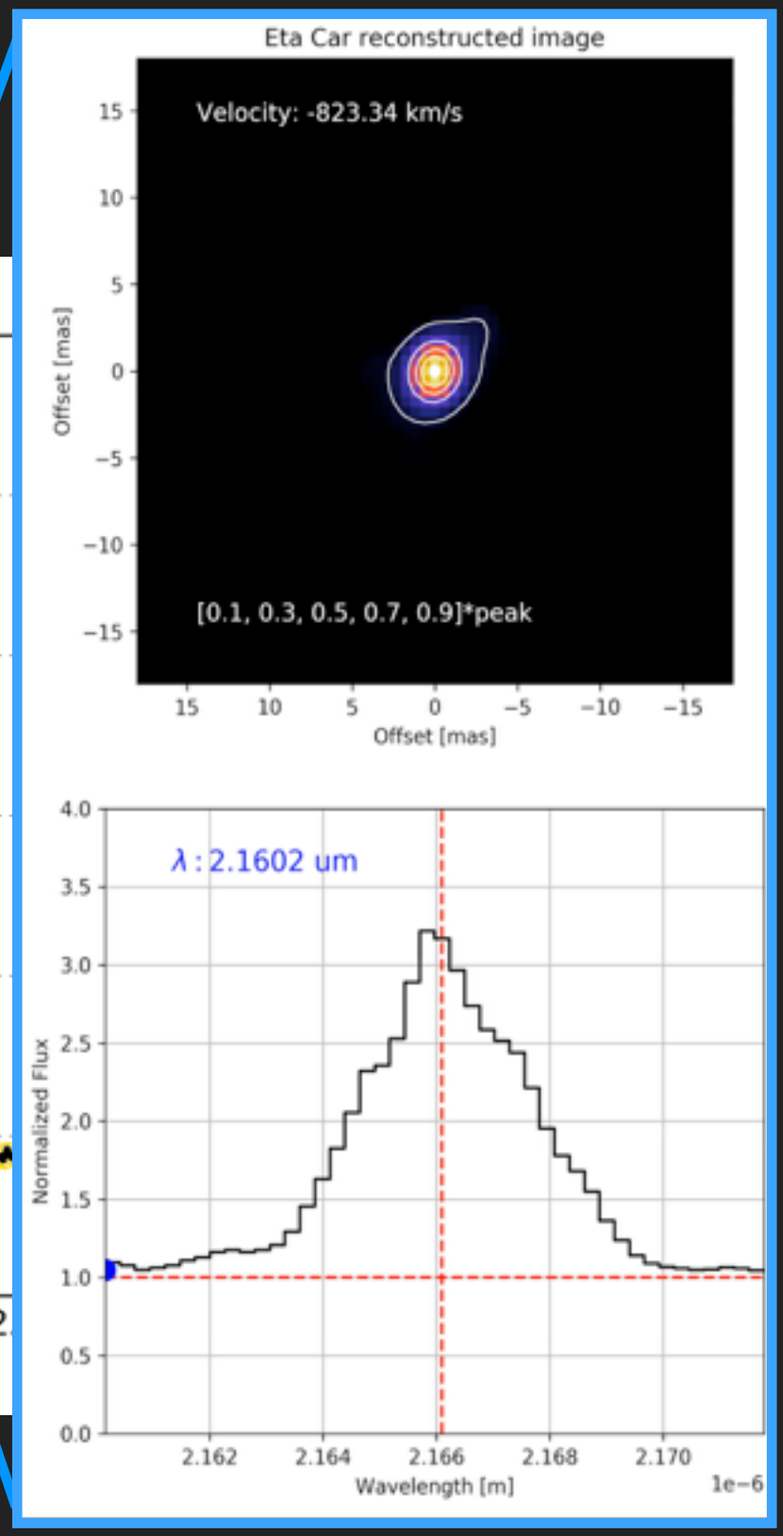
SQUEEZE; Baron+2010b

Band	Brγ (2.160 - 2.172 μm)
Pixel Grid	167x167 (100 mas)
Pixel Scale	0.6 mas/pixel
Chains	50
Iterations	250
Initial Image	Gaussian with 50% of the total flux
Observables	V^2 + CPs + Differential Phases
Regularizers	L0-norm (avoid point-like sources), Laplacian (favours extended sources), Transpectral reg. (L2-norm across the spec.)

ETA CAR: IMAGING THE CORE

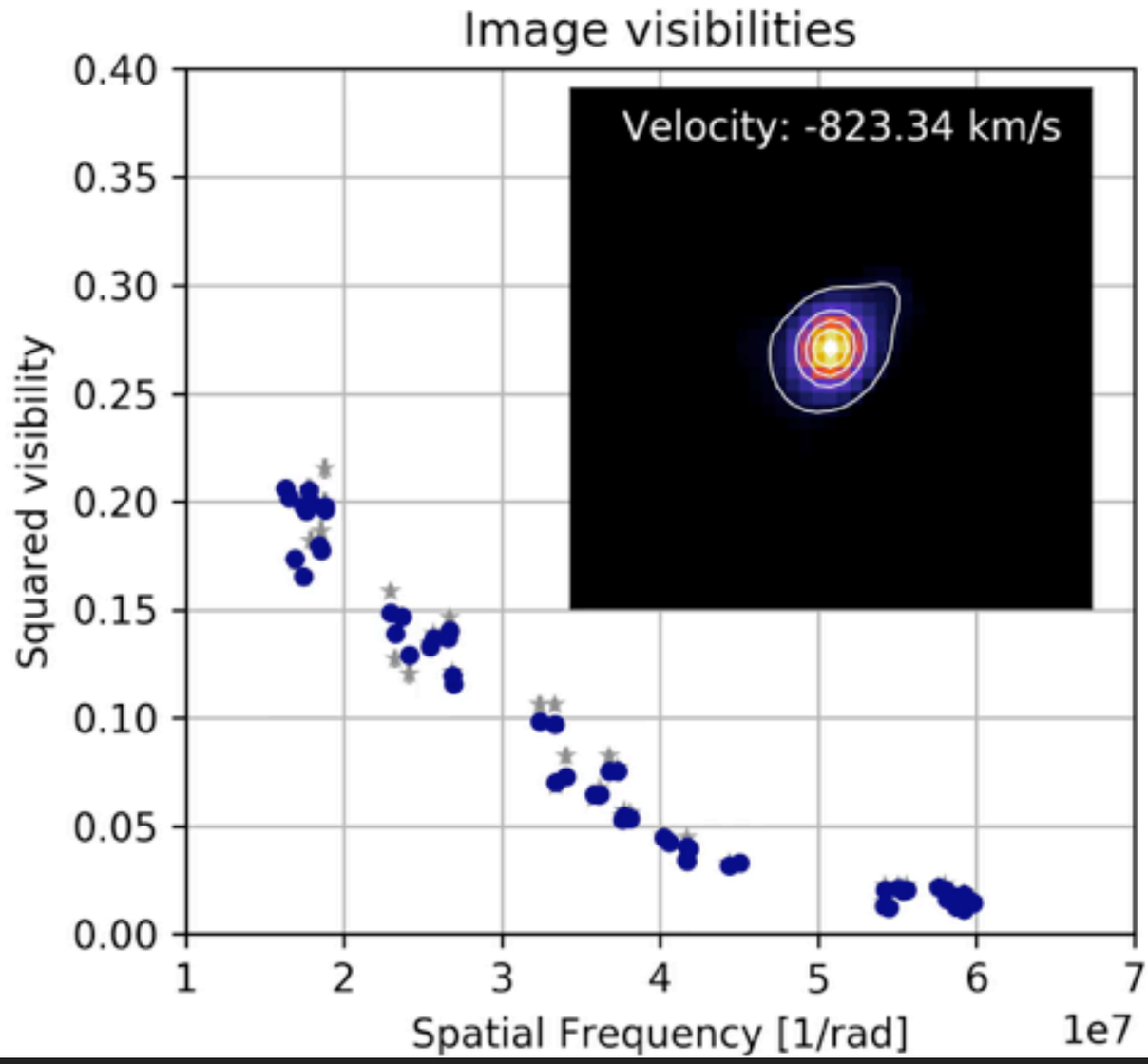
GRAVITY Science Beam Combiner: Calibrated spectrum

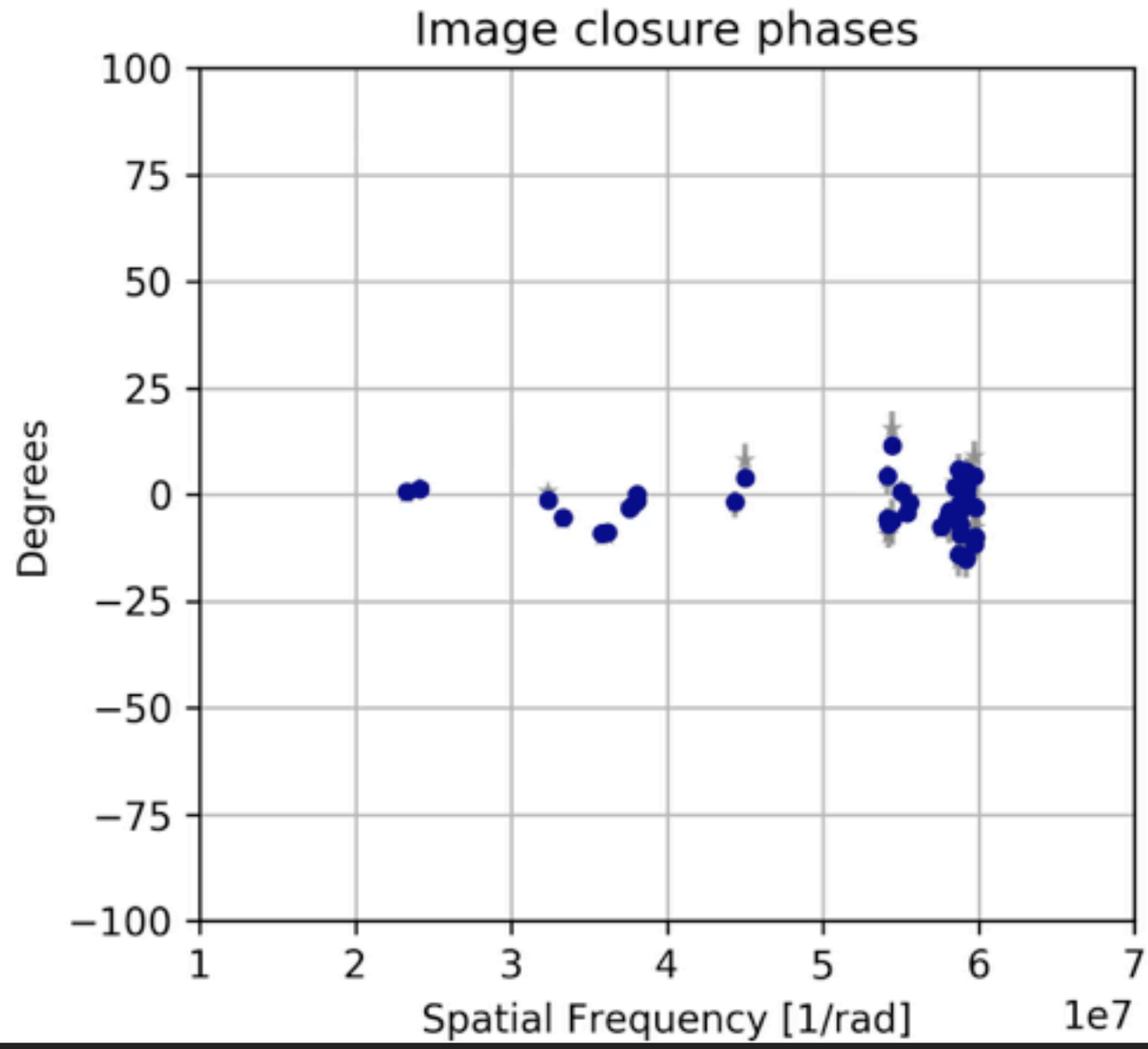


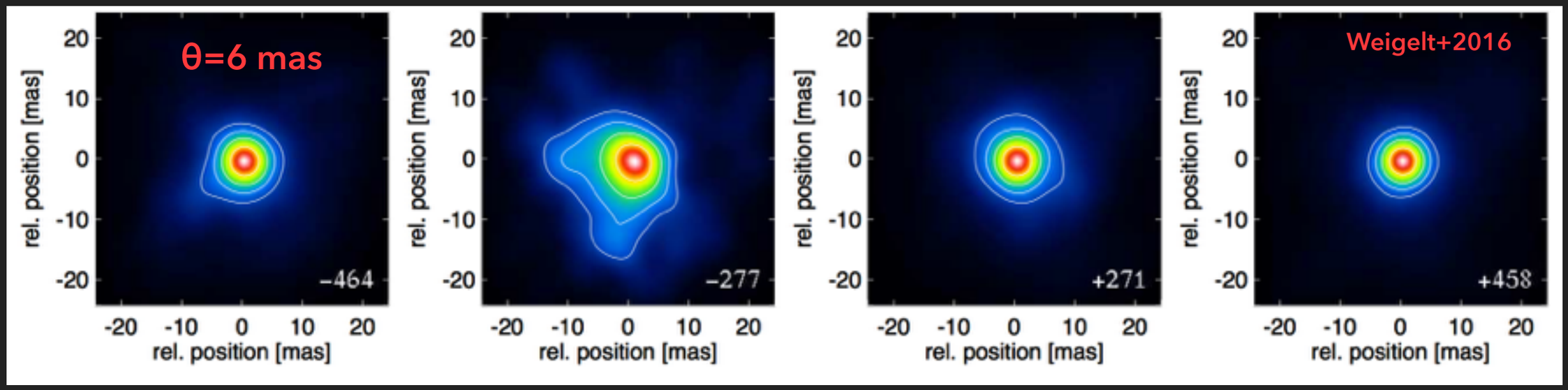


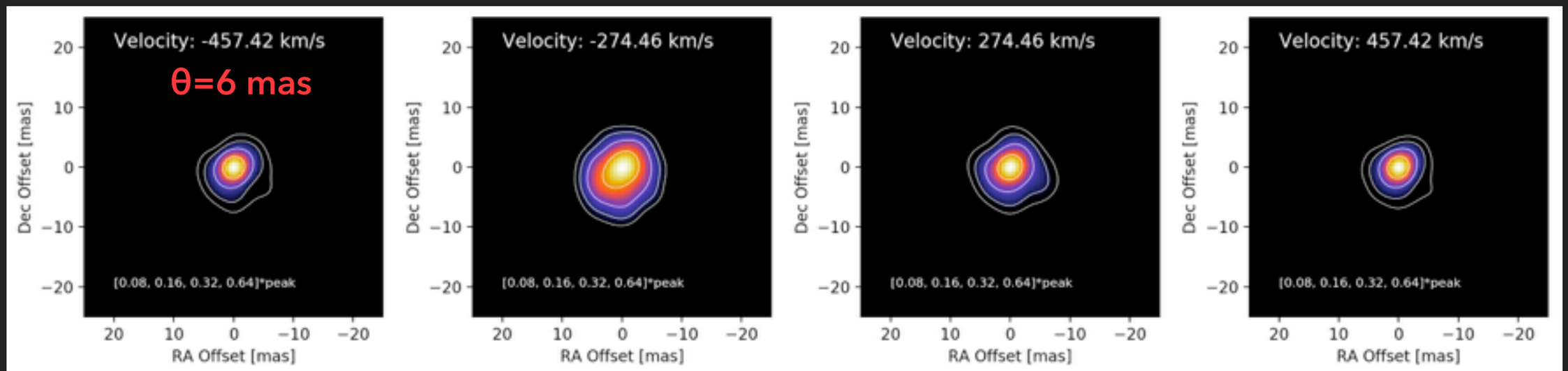
ETA CAR: IMAGING THE CORE

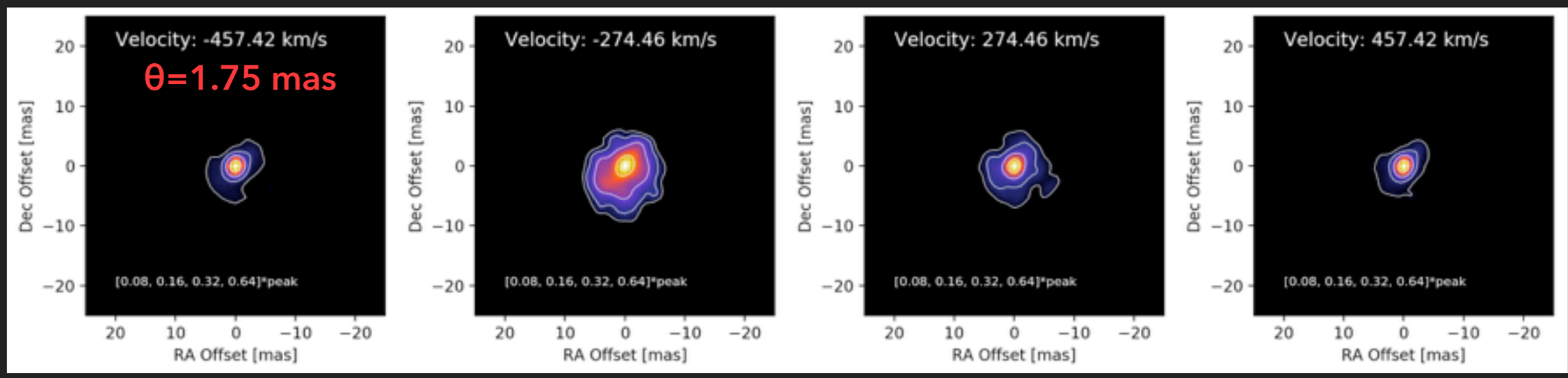
Image fitting to V2 and closure phases



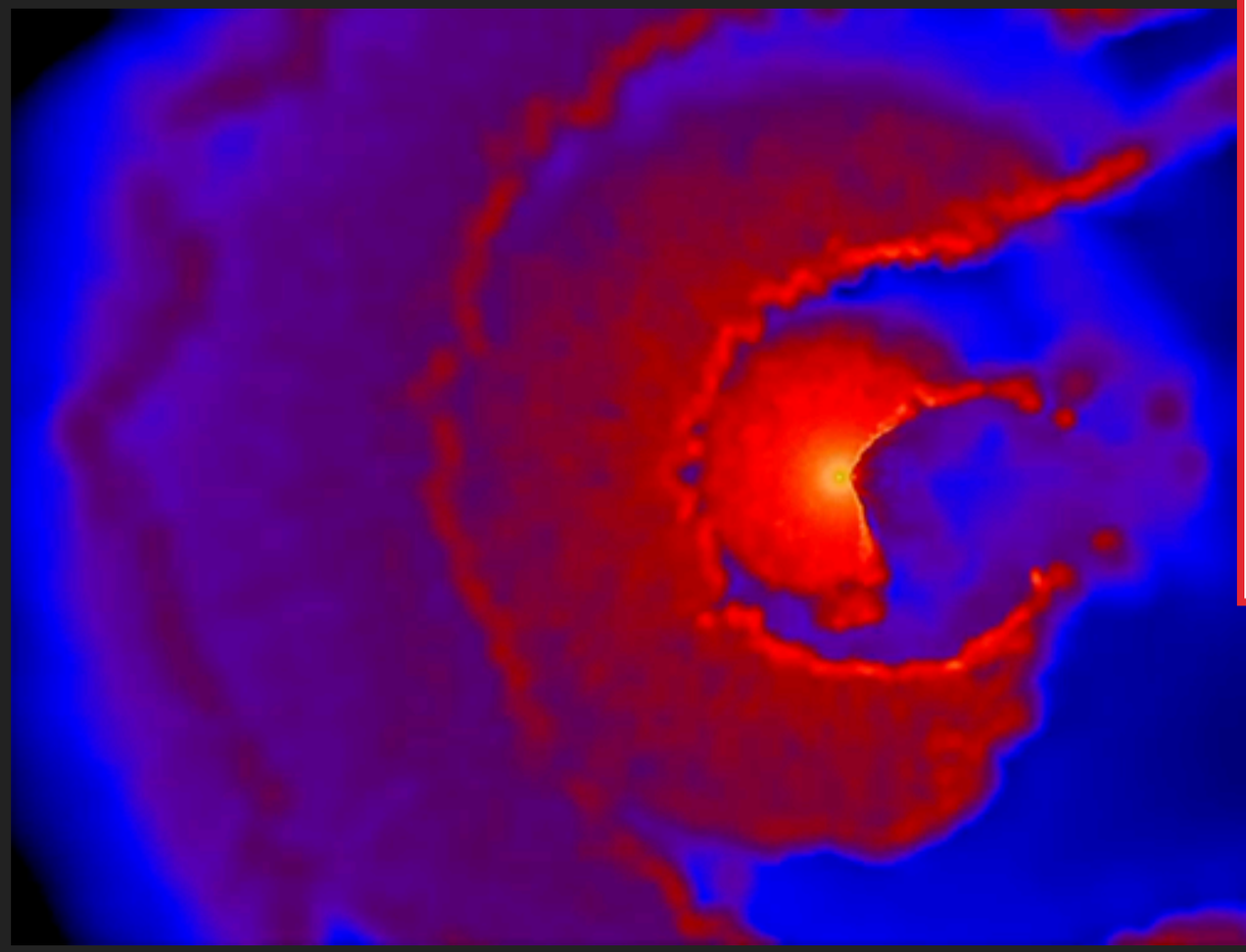


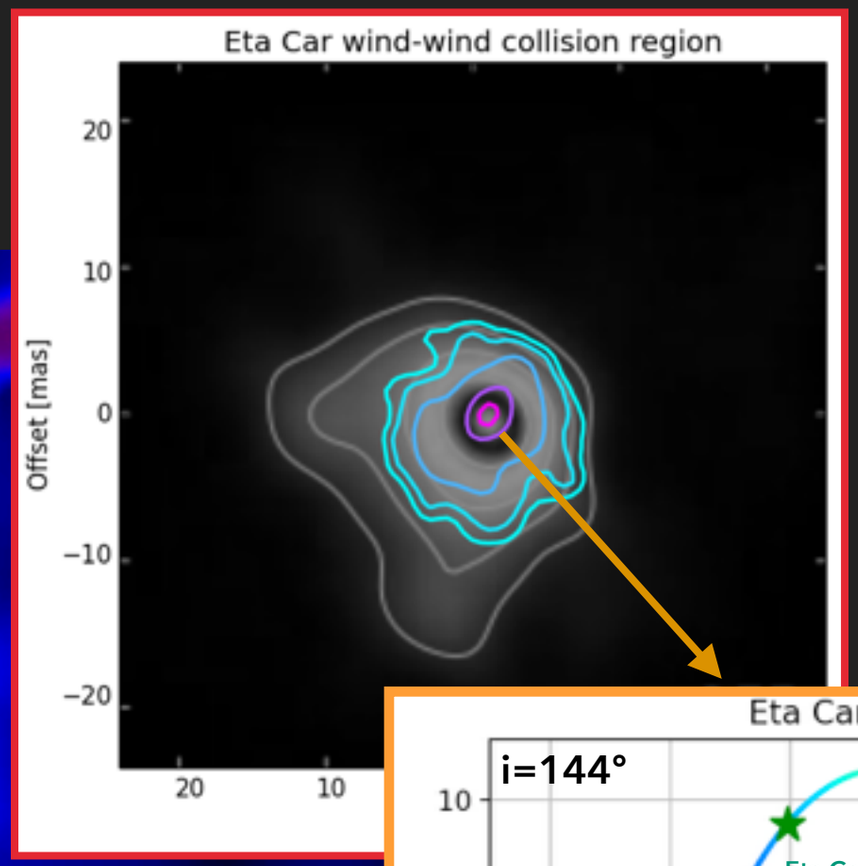

θ=6 mas
−464
−277
+271
Weigelt+2016
+458
rel. position [mas]
rel. position [mas]

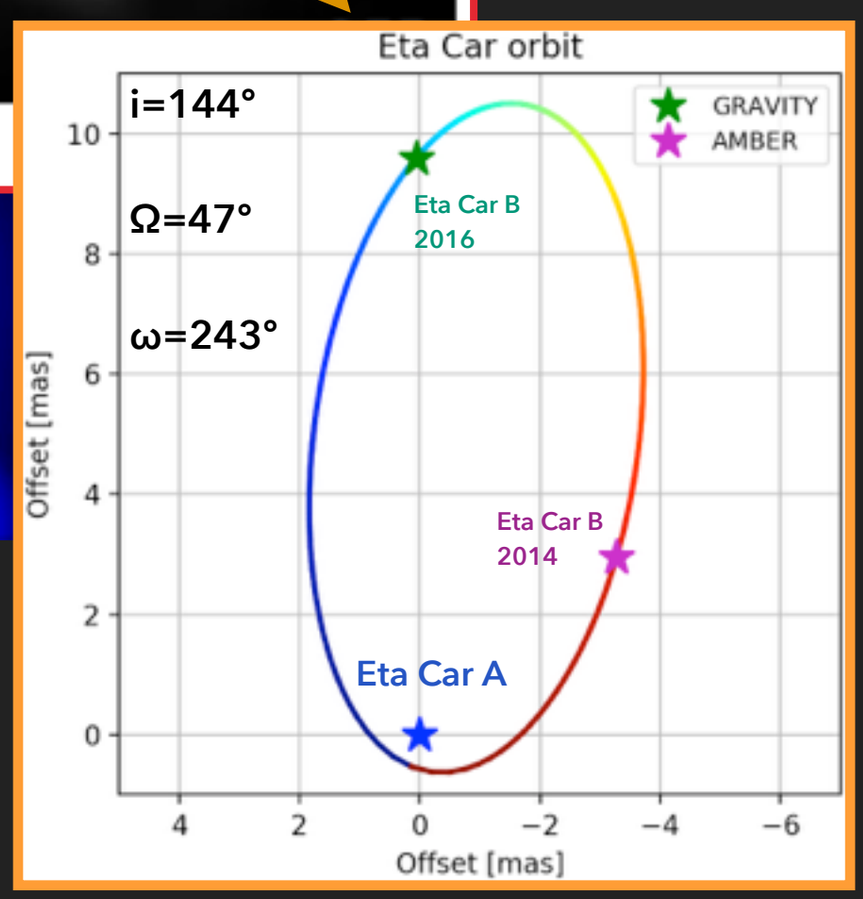

Velocity: -457.42 km/s
θ=6 mas
Velocity: -274.46 km/s
Velocity: 274.46 km/s
Velocity: 457.42 km/s
[0.08, 0.16, 0.32, 0.64]*peak
Dec Offset [mas]
RA Offset [mas]


Velocity: -457.42 km/s
θ=1.75 mas
Velocity: -274.46 km/s
Velocity: 274.46 km/s
Velocity: 457.42 km/s
[0.08, 0.16, 0.32, 0.64]*peak
Dec Offset [mas]
RA Offset [mas]

WIND-WIND COLISSION REGION

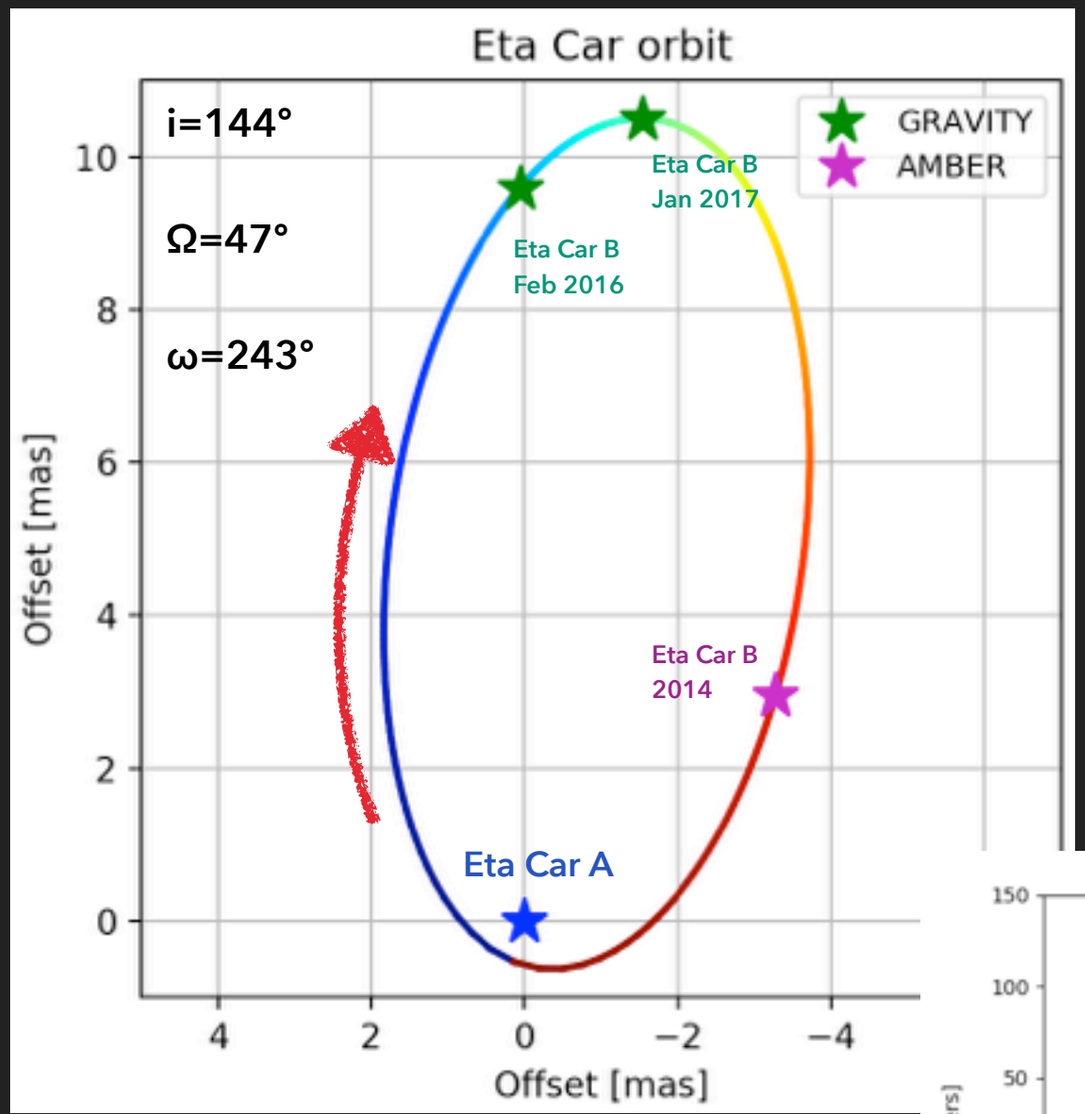


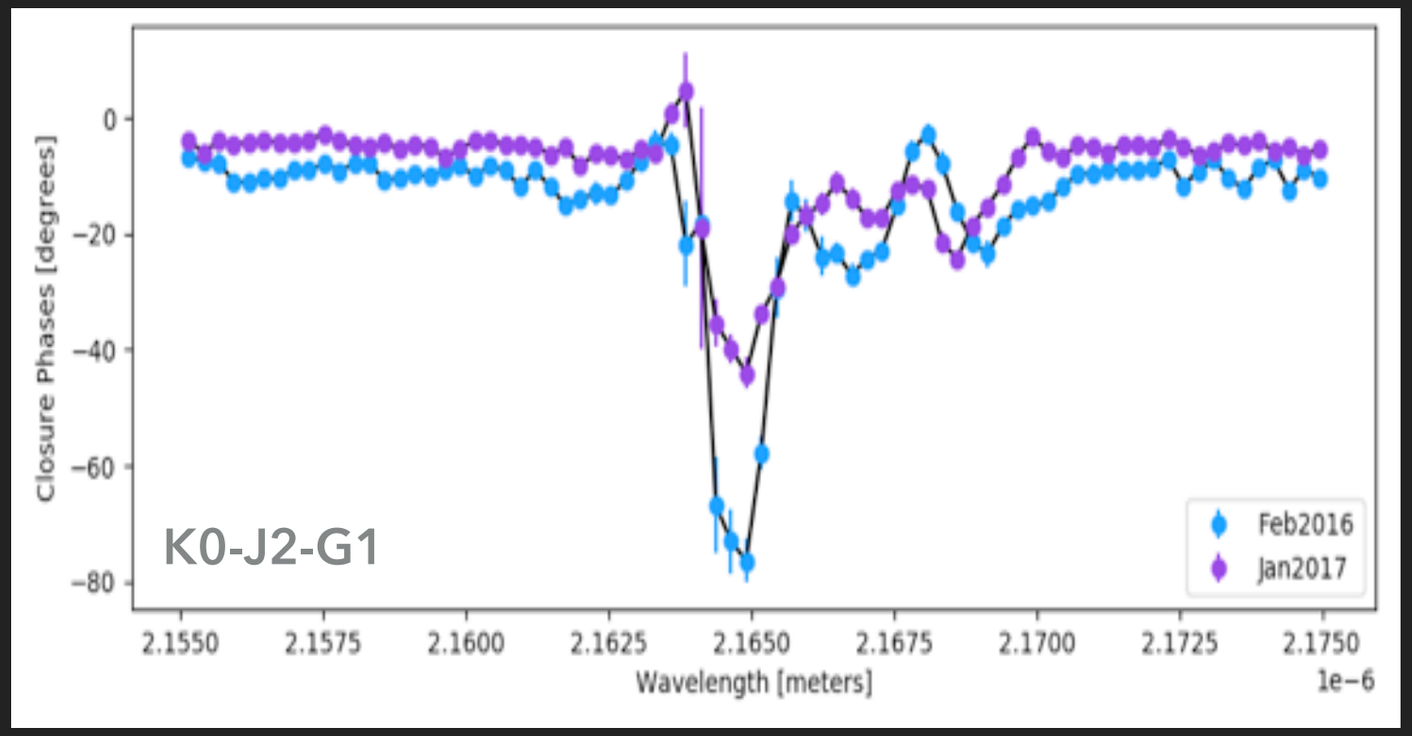


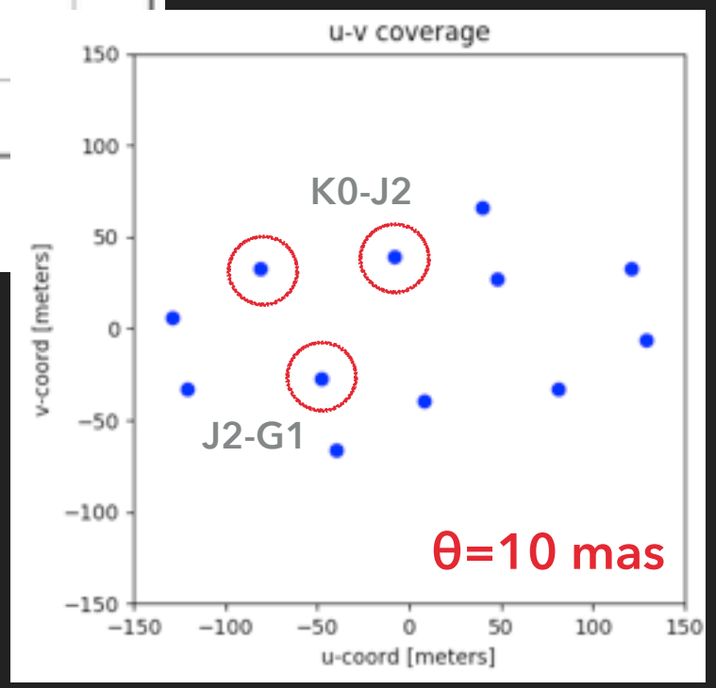


Hydrodynamical Simulations: Madura+2012; Madura +2013; Clementel+2015b

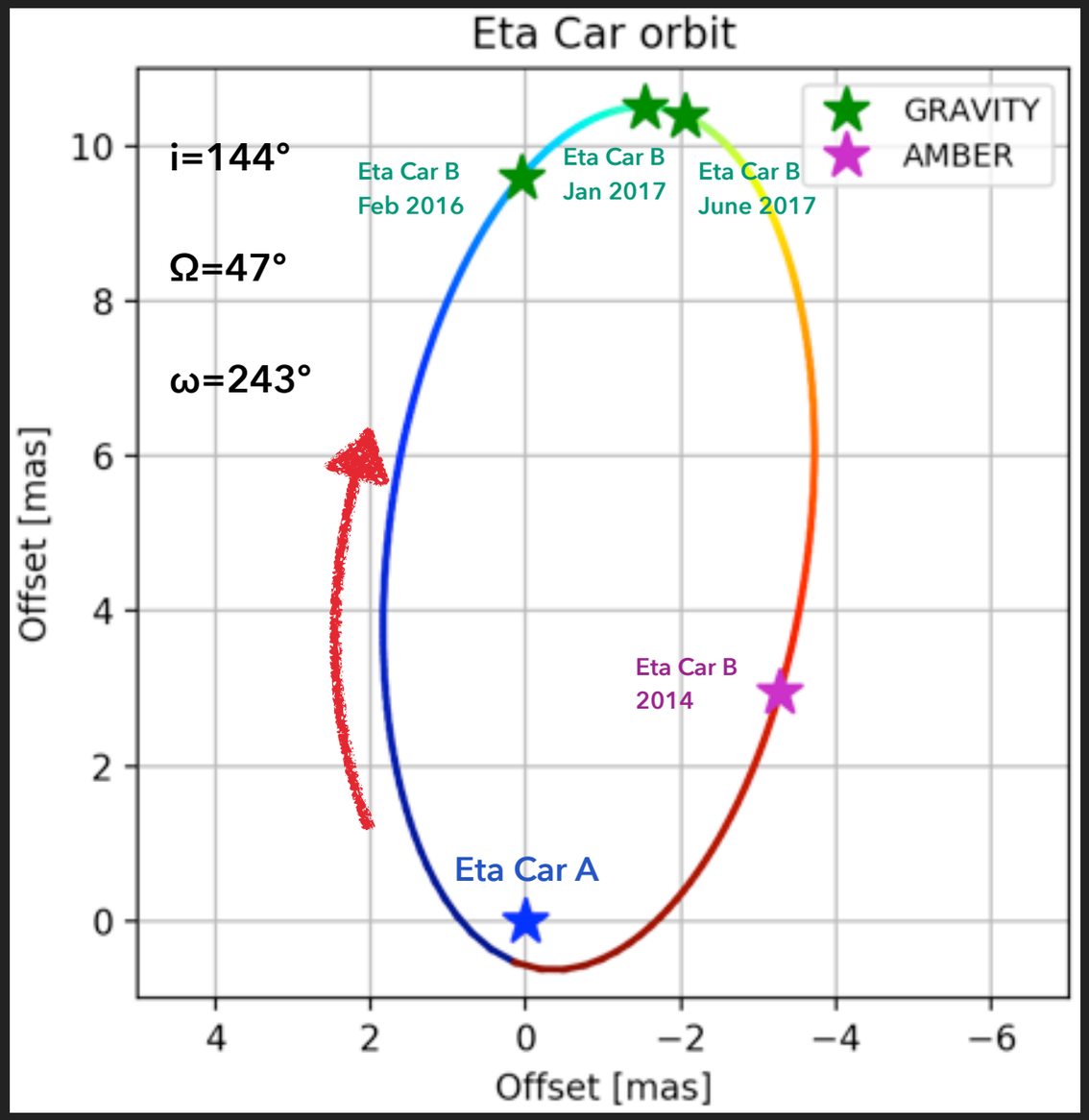
WIND-WIND COLISSION REGION

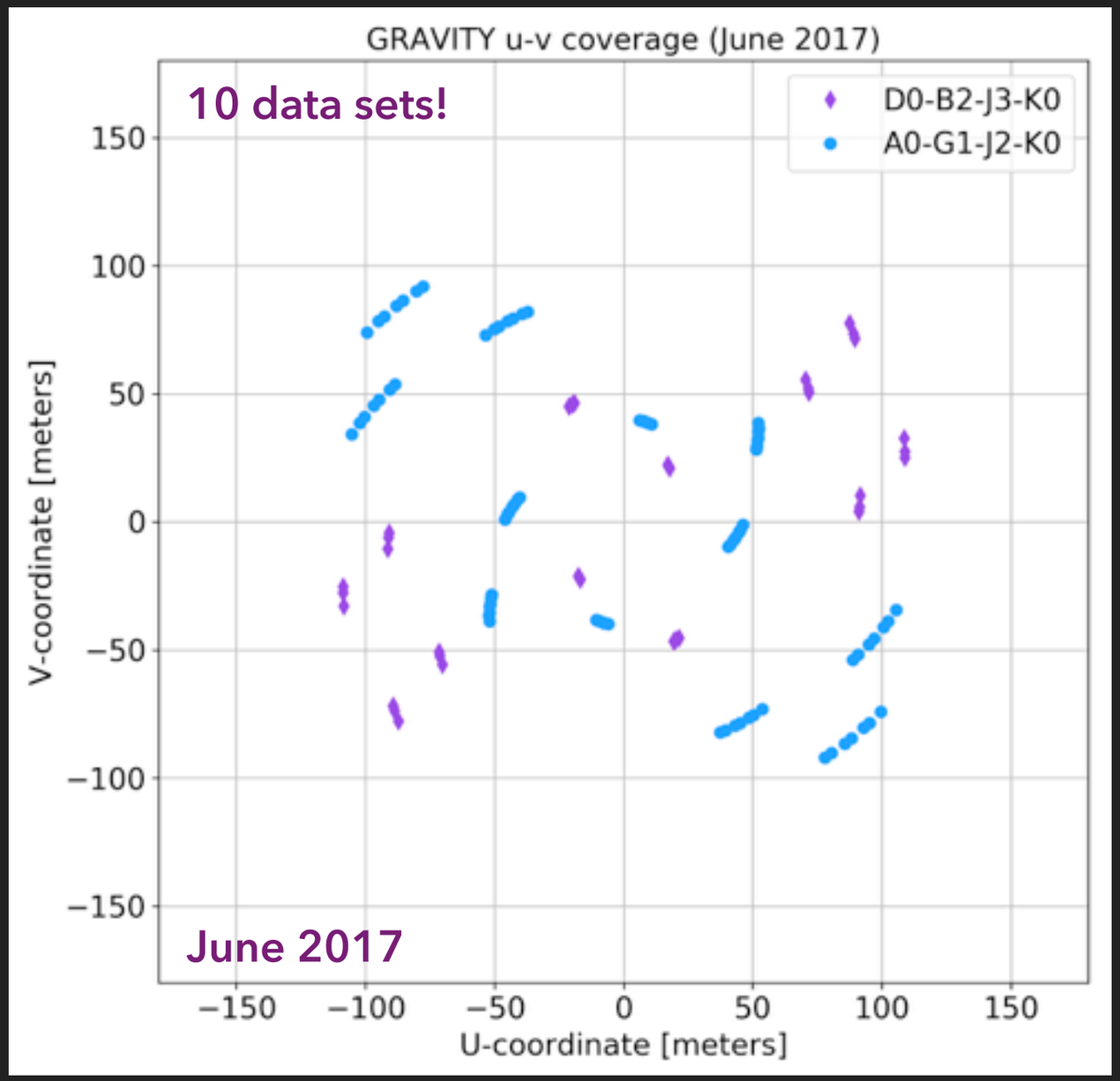






WIND-WIND COLISSION REGION

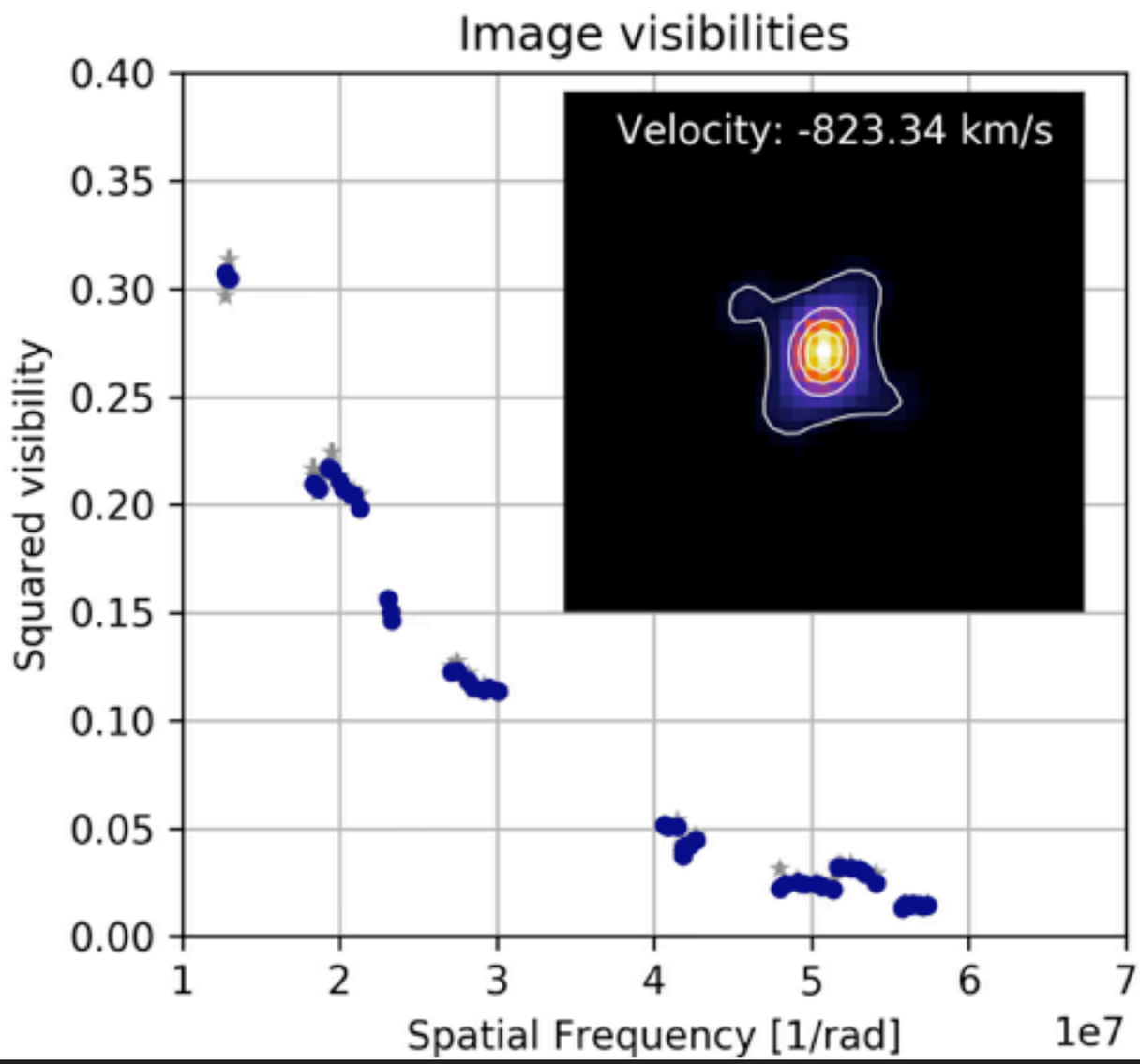


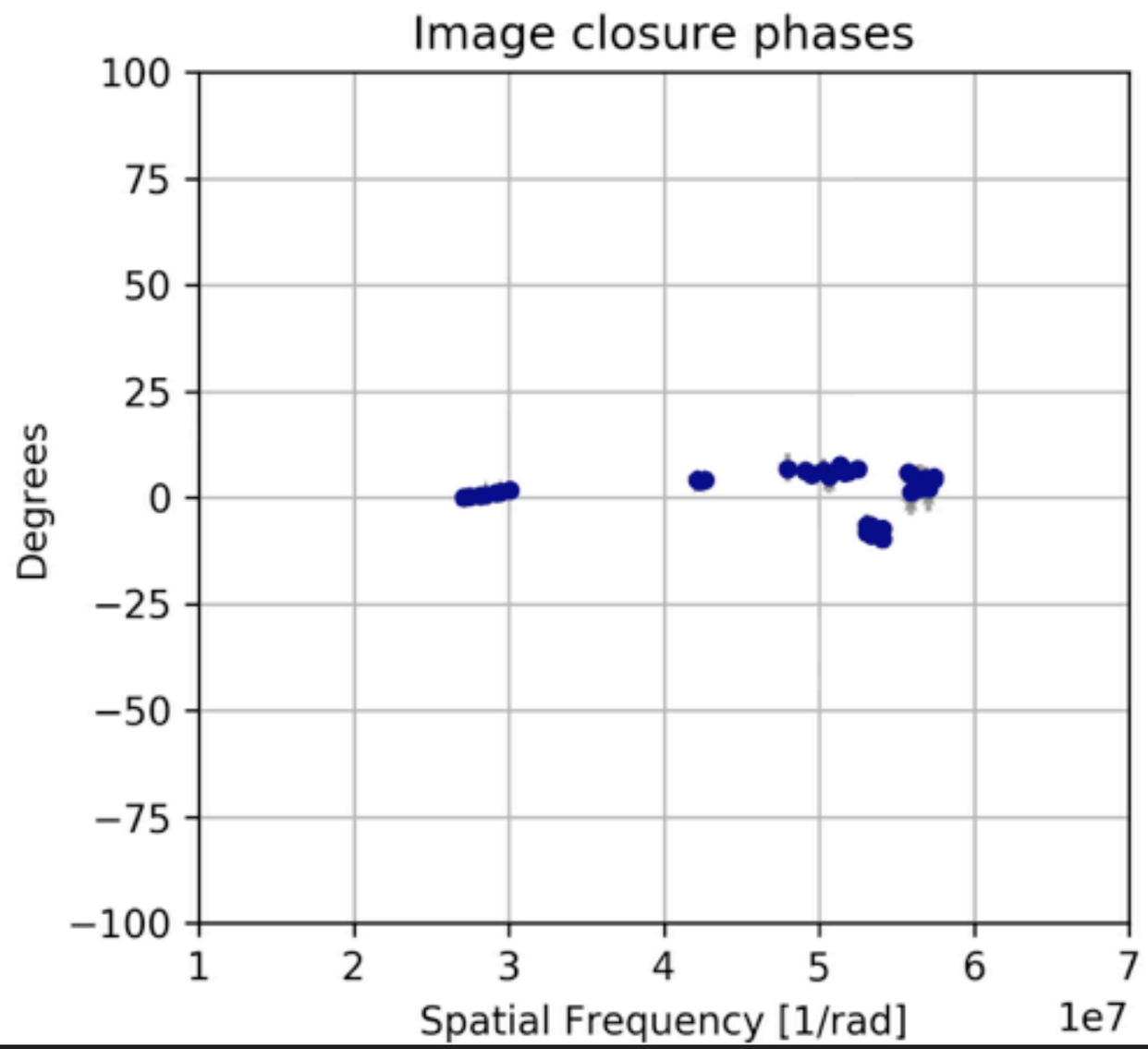


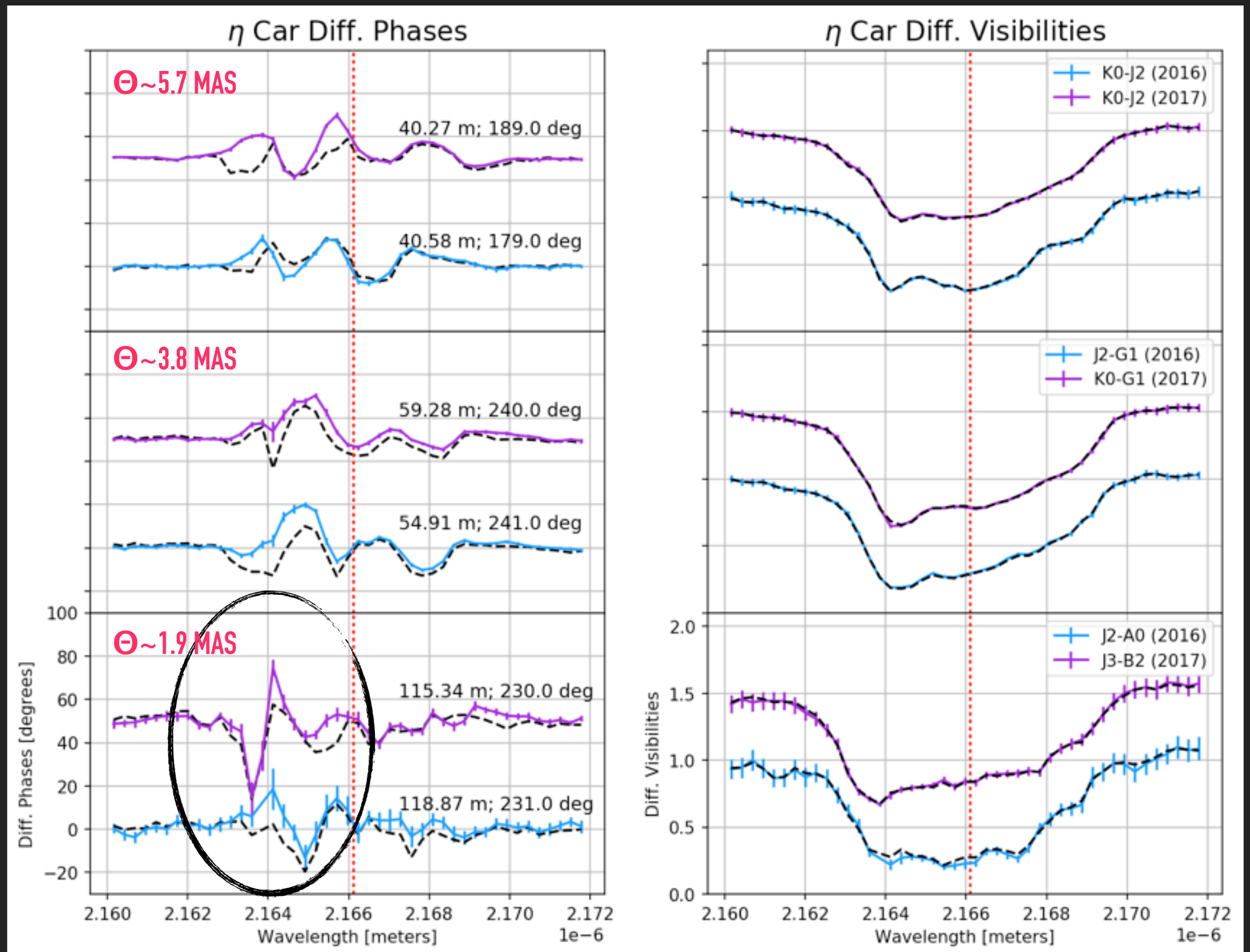
Second imaging epoch of GRAVITY data!

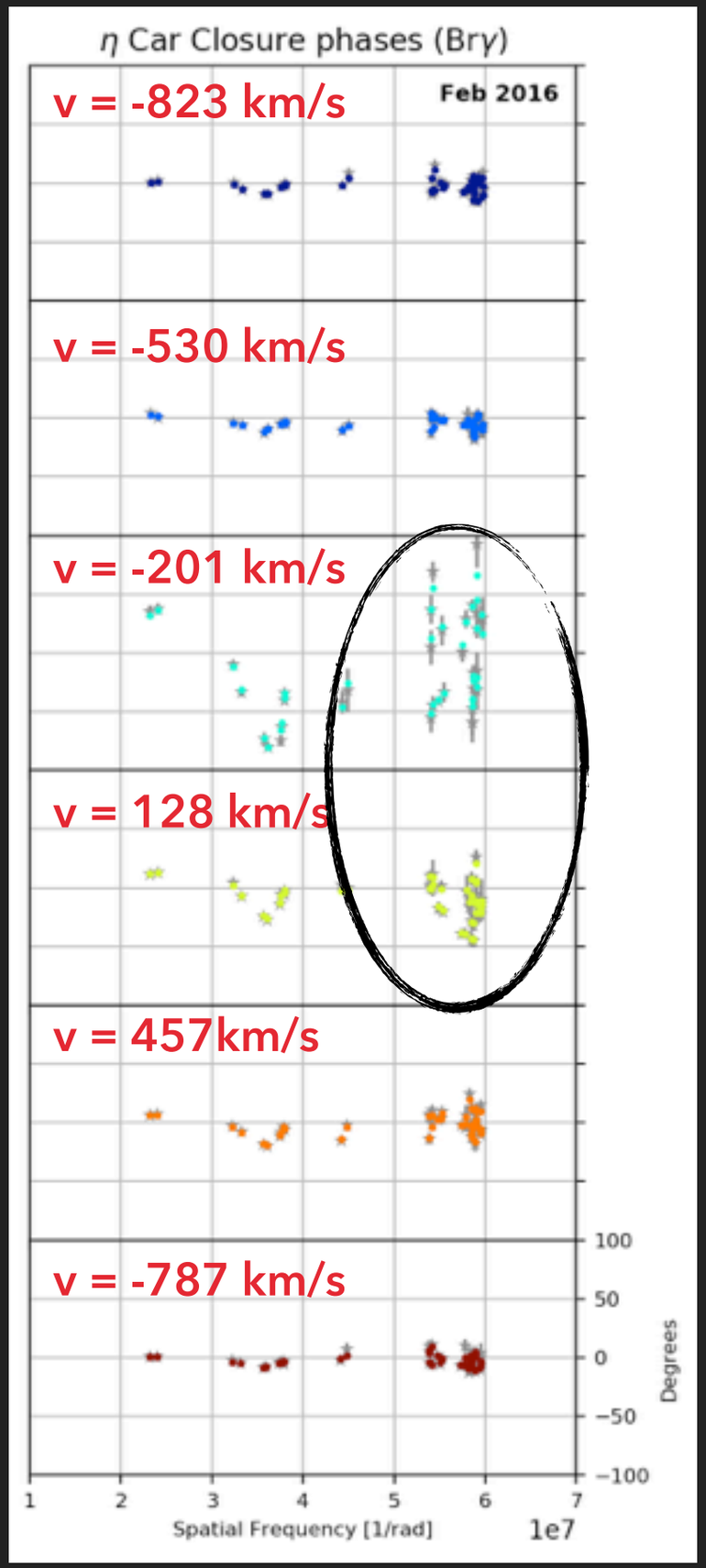
WIND-WIND COLISSION REGION

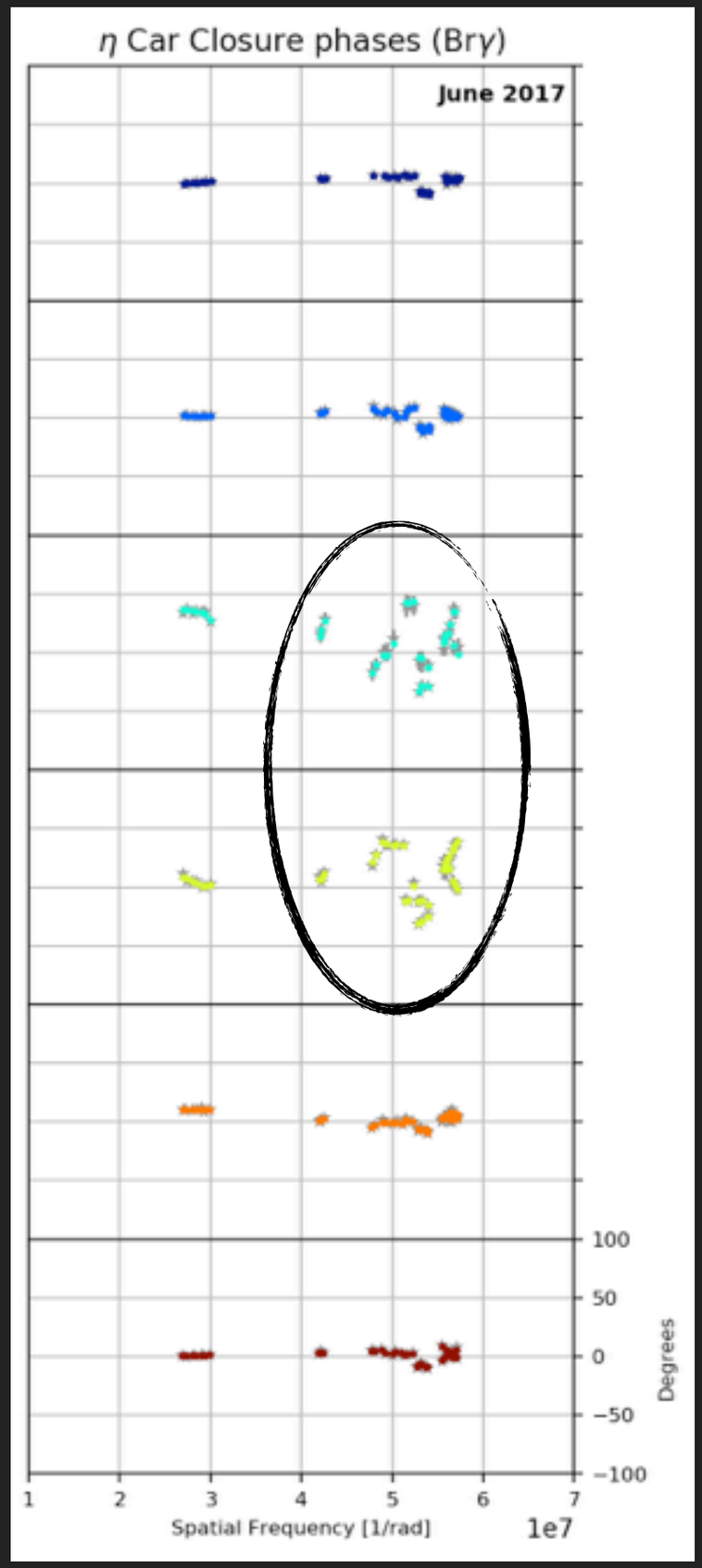
Model fitting to V2 and closure phases






η Car Diff. Phases
Θ~5.7 MAS
40.27 m; 189.0 deg
40.58 m; 179.0 deg
Θ~3.8 MAS
59.28 m; 240.0 deg
54.91 m; 241.0 deg
Θ~1.9 MAS
115.34 m; 230.0 deg
118.87 m; 231.0 deg
Diff. Phases [degrees]
Wavelength [meters]
1e−6
η Car Diff. Visibilities
K0-J2 (2016)
K0-J2 (2017)
J2-G1 (2016)
K0-G1 (2017)
J2-A0 (2016)
J3-B2 (2017)
Diff. Visibilities
Wavelength [meters]
1e−6


η Car Closure phases (Brγ)
Feb 2016
v = -823 km/s
v = -530 km/s
v = -201 km/s
v = 128 km/s
v = 457km/s
v = -787 km/s
100
50
0
−50
−100
Degrees
1
2
3
4
5
6
7
Spatial Frequency [1/rad]
1e7


η Car Closure phases (Brγ)
June 2017
100
50
0
−50
−100
Degrees
1
2
3
4
5
6
7
Spatial Frequency [1/rad]
1e7

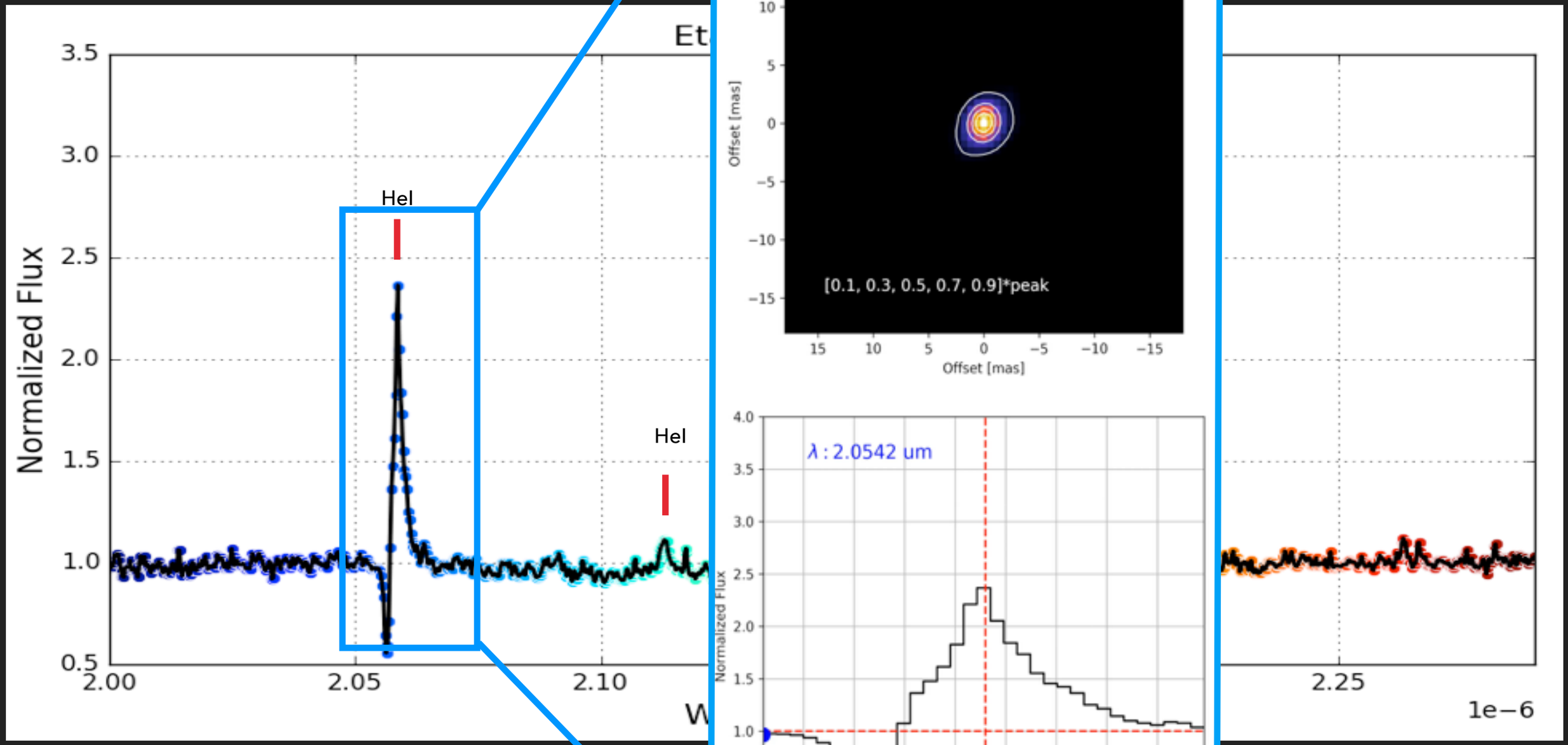
ETA CAR: IMAGING THE CORE

GRAVITY Science Beam Combiner: The HeI line

Band	HeI (2.054 - 2.063 μm)
Pixel Grid	167x167 (100 mas)
Pixel Scale	0.6 mas/pixel
Chains	50
Iterations	250
Initial Image	Gaussian with 50% of the total flux
Observables	V^2 + CPs + Differential Phases
Regularizers	L0-norm (avoid point-like sources), Laplacian (favours extended sources), Transpectral reg. (L2-norm across the spec.)

ETA CAR: IMAGING THE CORE

GRAVITY Science Beam Combiner



SUMMARY

1. **Continuum elongated core consistent with previos NIR Interferometric observations.**

2. **The extended structure in the images is consistent with the wind-wind collision scenario.**

3. **The most extended emission is observed at blue-shifted velocities (WWCZ in the LOS).**

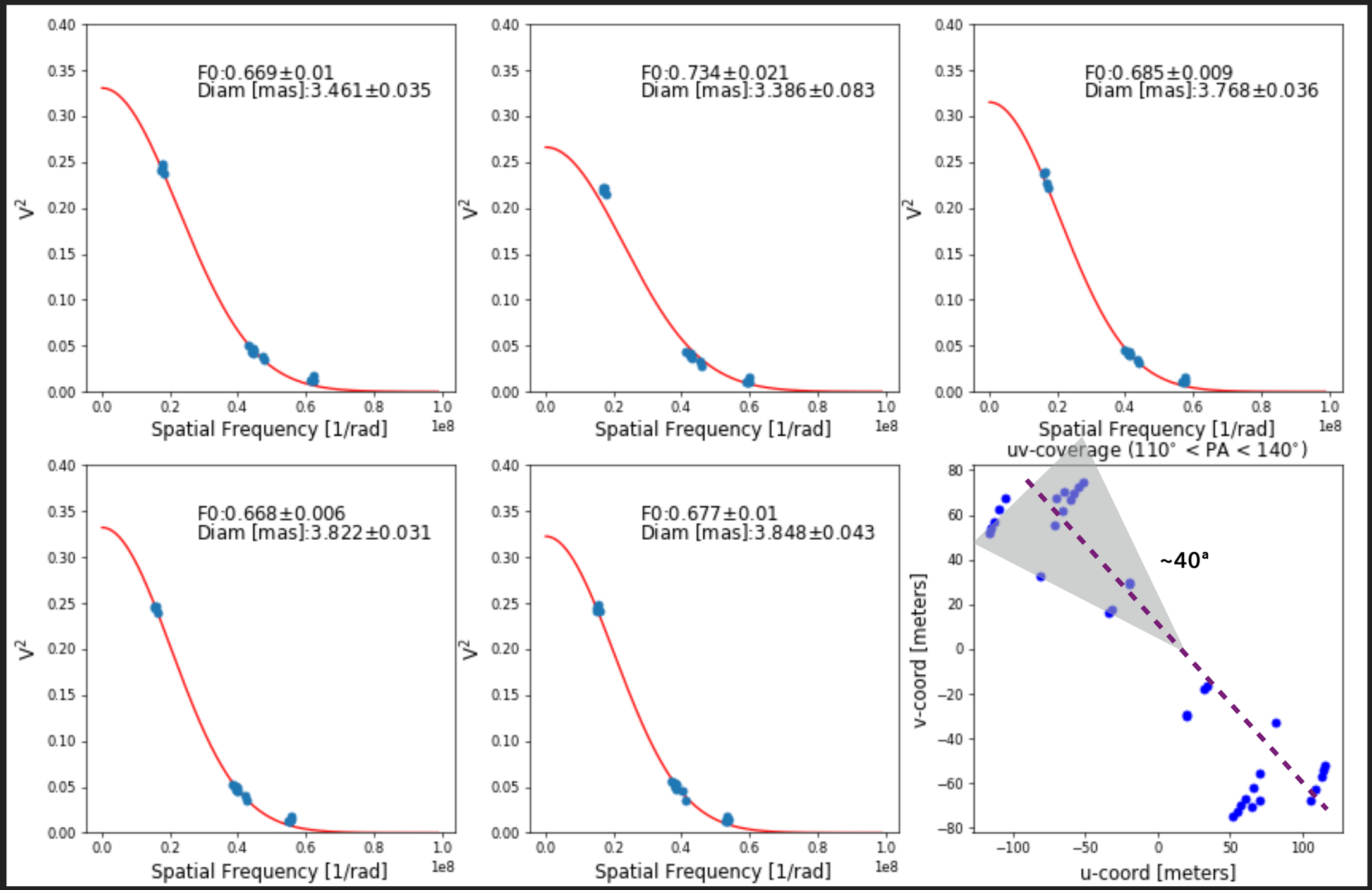
4. **Time-dependent changes in the observables at all spatial scales (particularly for compact structures)**

5. **New reconstruction of images of the HeI (2.054) line**

6. **Future RT and Hydro simulations will help to constrain the physical parameters of the observed structures.**

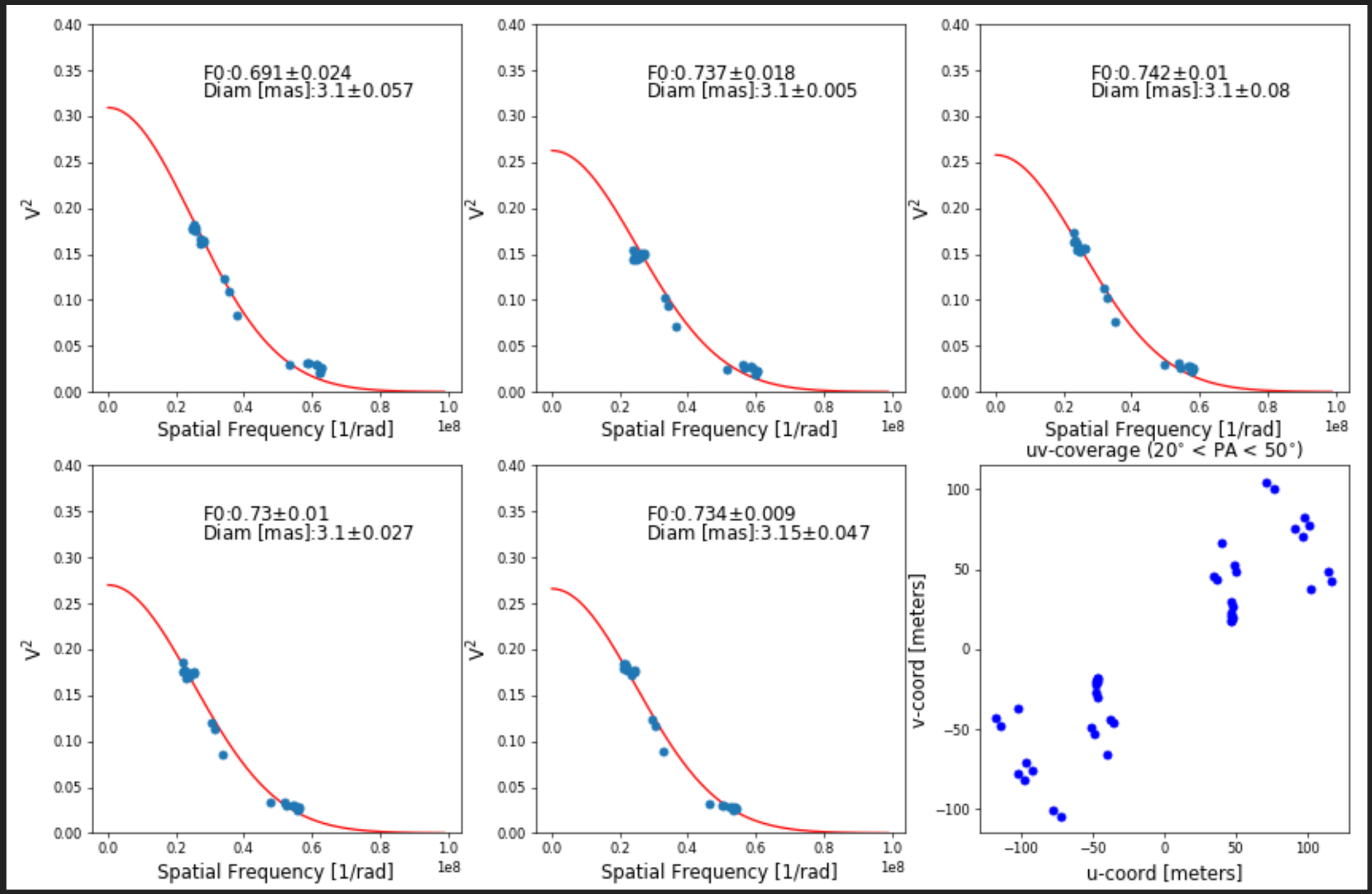
ETA CAR: IMAGING THE CORE

GRAVITY Fringe tracker: Estimating the size of the core



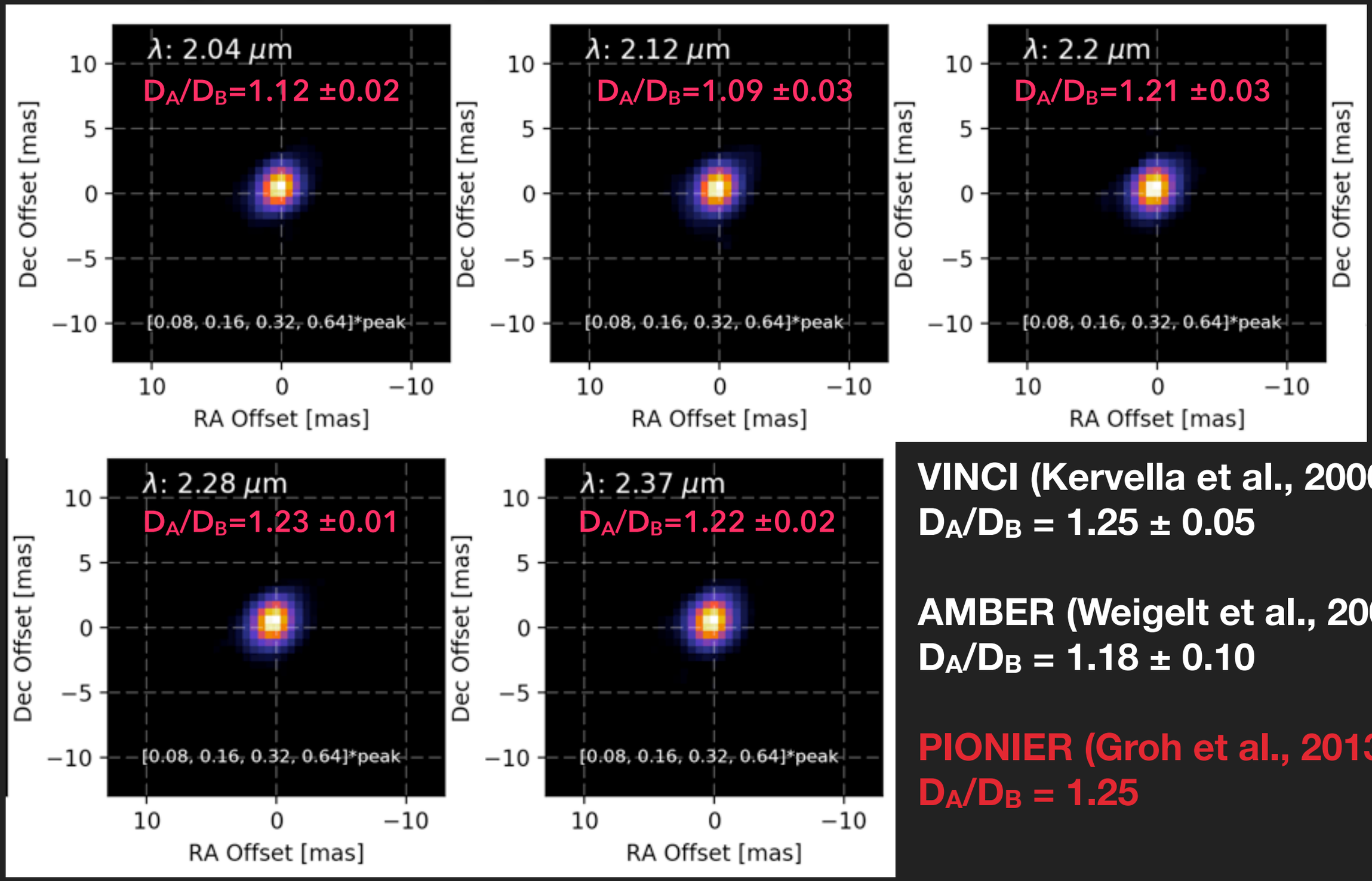
ETA CAR: IMAGING THE CORE

GRAVITY Fringe tracker: Estimating the size of the core



ETA CAR: IMAGING THE CORE

GRAVITY Fringe tracker: Estimating the size of the core



VINCI (Kervella et al., 2000):
D_A/D_B = 1.25 ± 0.05

AMBER (Weigelt et al., 2007):
D_A/D_B = 1.18 ± 0.10

PIONIER (Groh et al., 2013):
D_A/D_B = 1.25

CMFGEN

Groh+2012: HST spectrum (Visible)

Ṁ=8.5e-4 M⊙/yr

v∞=420 km/s

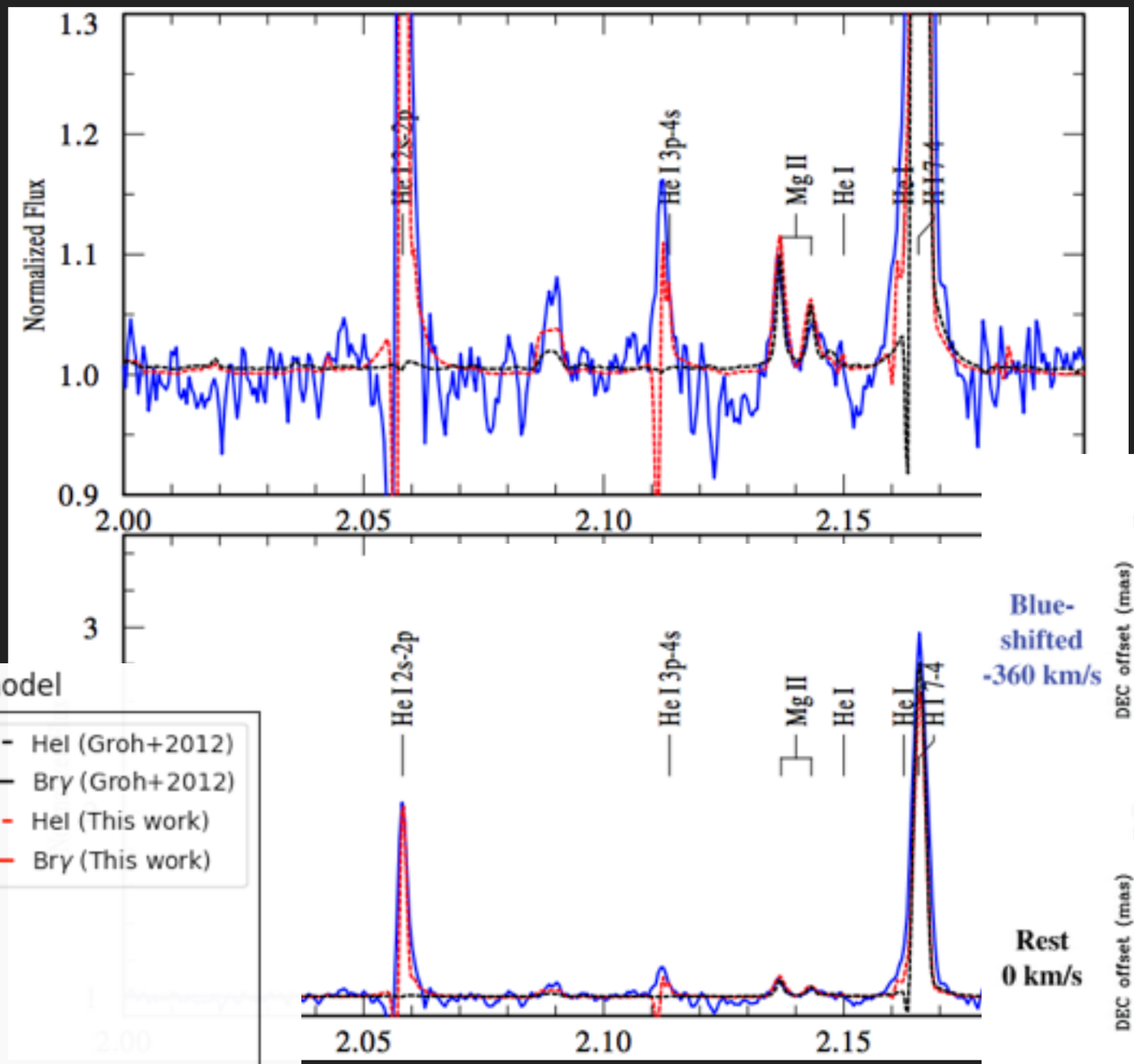
Teff= 9400 K

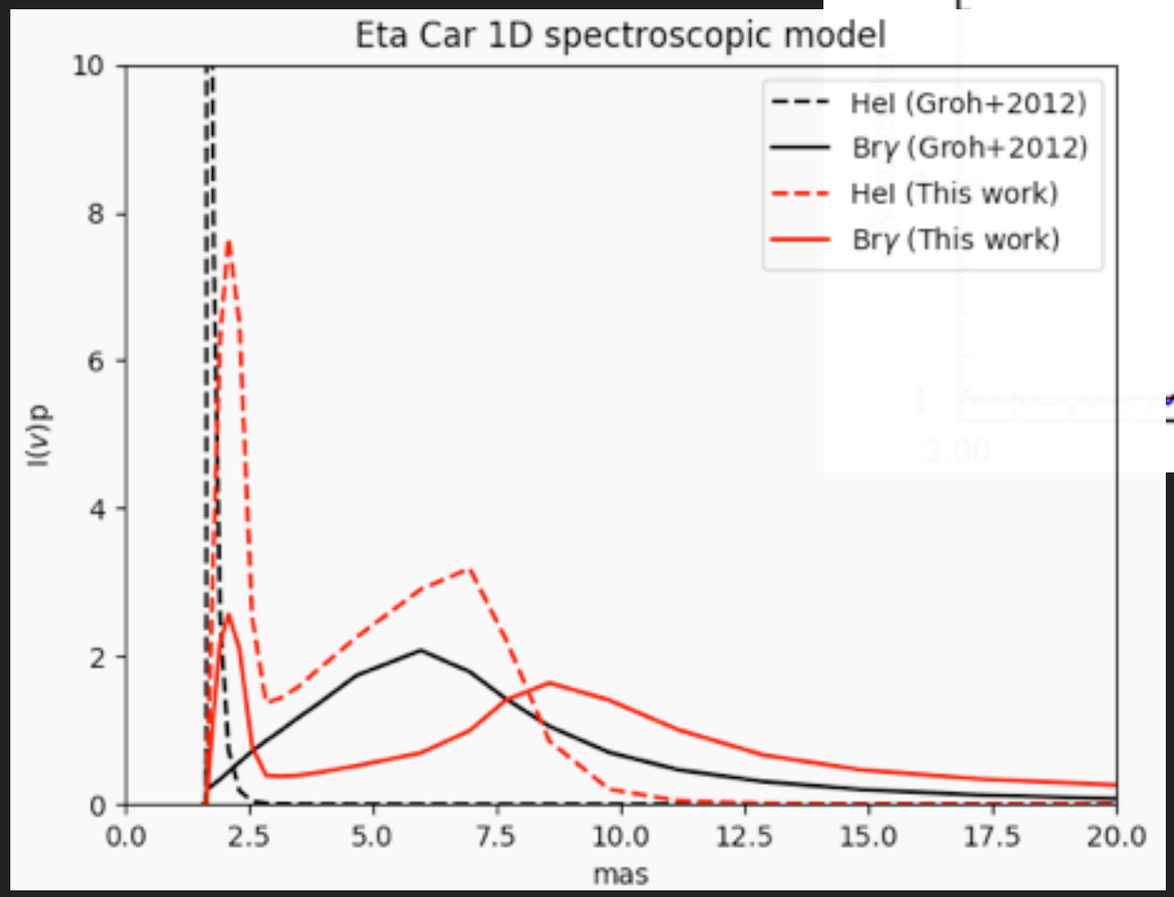
This work:

Ṁ=1.7e-4 M⊙/yr

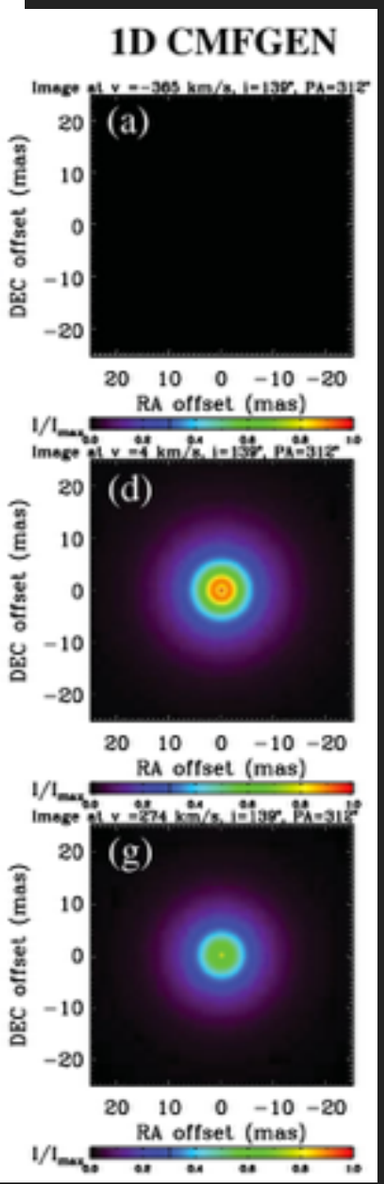
v∞=420 km/s

Teff= 13000 K





Model by: J. Bestenlehner



THANK YOU!