Prospective(s) of imaging with VEGA

Florentin Millour
And the VEGA team

Prospective(s) of imaging with VEGA

Florentin Millour
And the VEGA team

Prospective(s) of imaging with VEGA

Florentin Millour
And the VEGA team

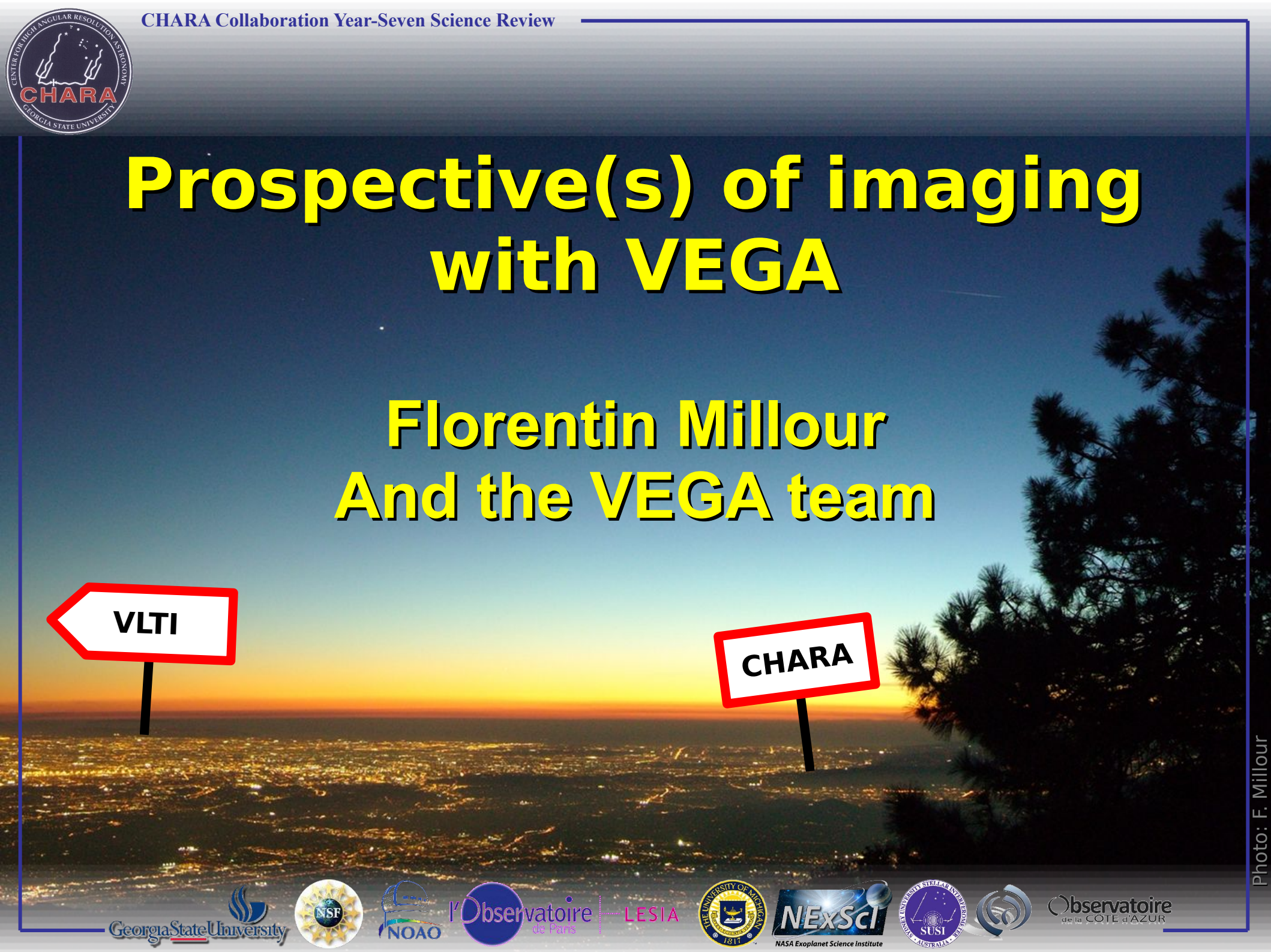
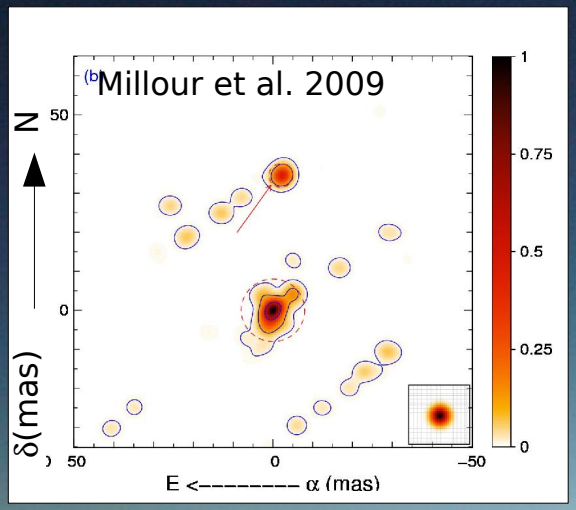
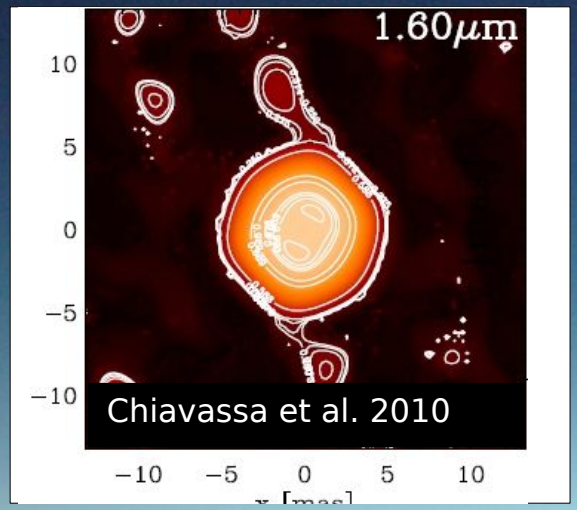


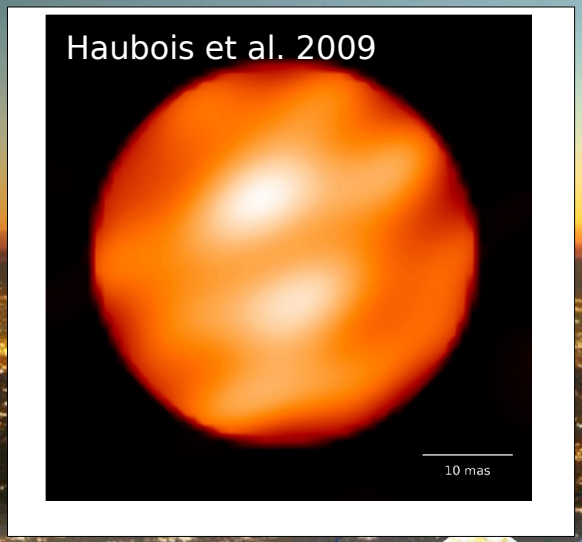
Photo: F. Millour

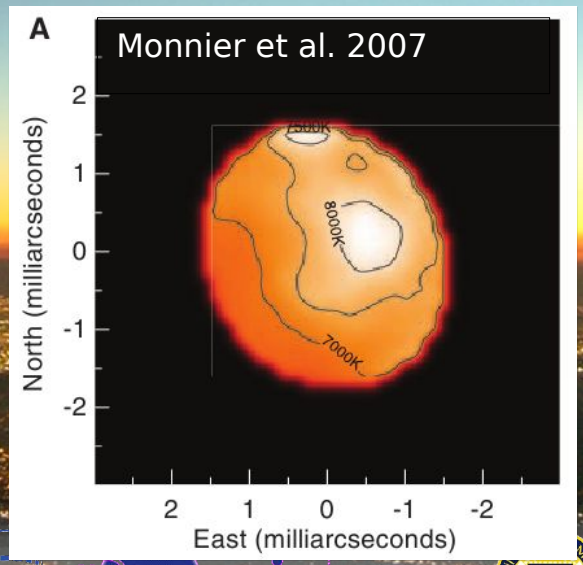
Imaging with interferometry

- **Squared visibility (V^2)**







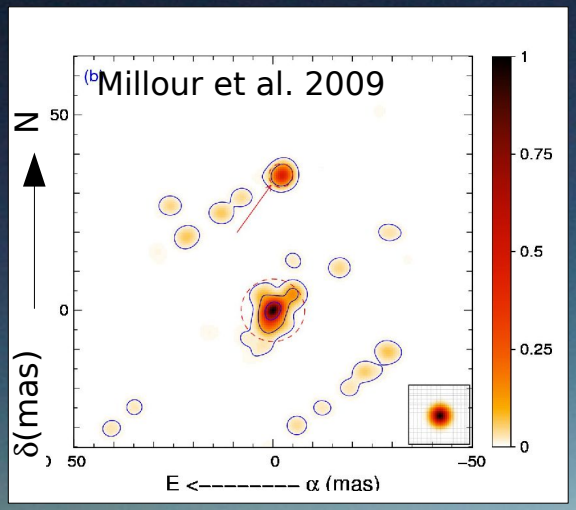


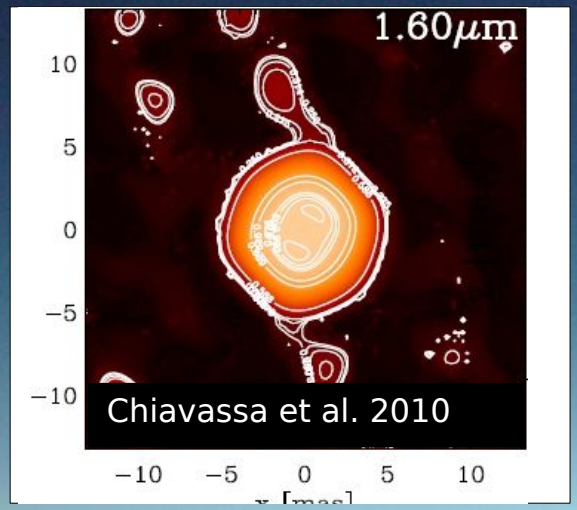
- **If $N_{tel} > 2$**
  Closure phase
- **If spectrograph**
  Spectra,
  Differential phases,
  Differential visibility
- **If well-sampled UV plane**
  Image synthesis

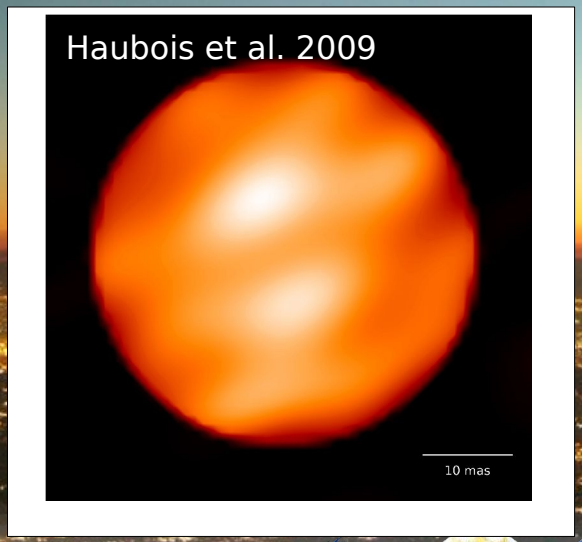
Photo: F. Millour

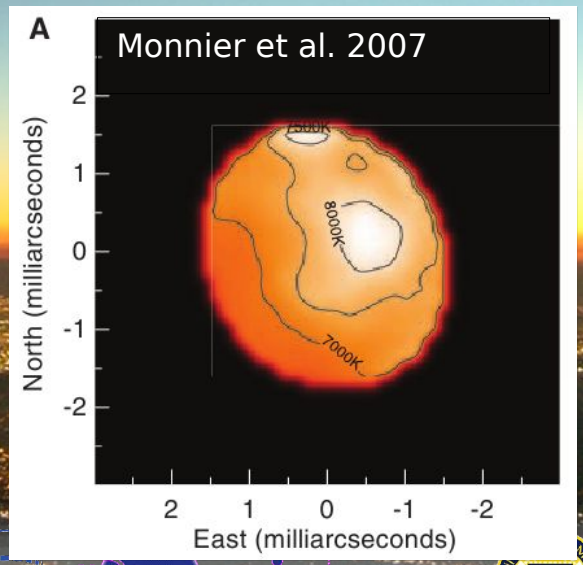
Imaging with interferometry

- **Squared visibility (V^2)**





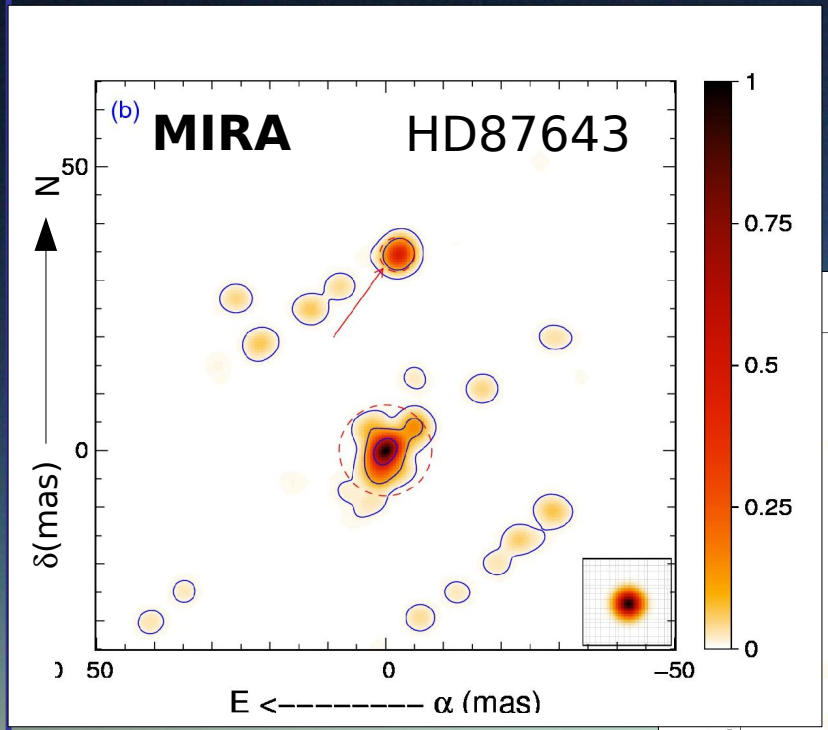


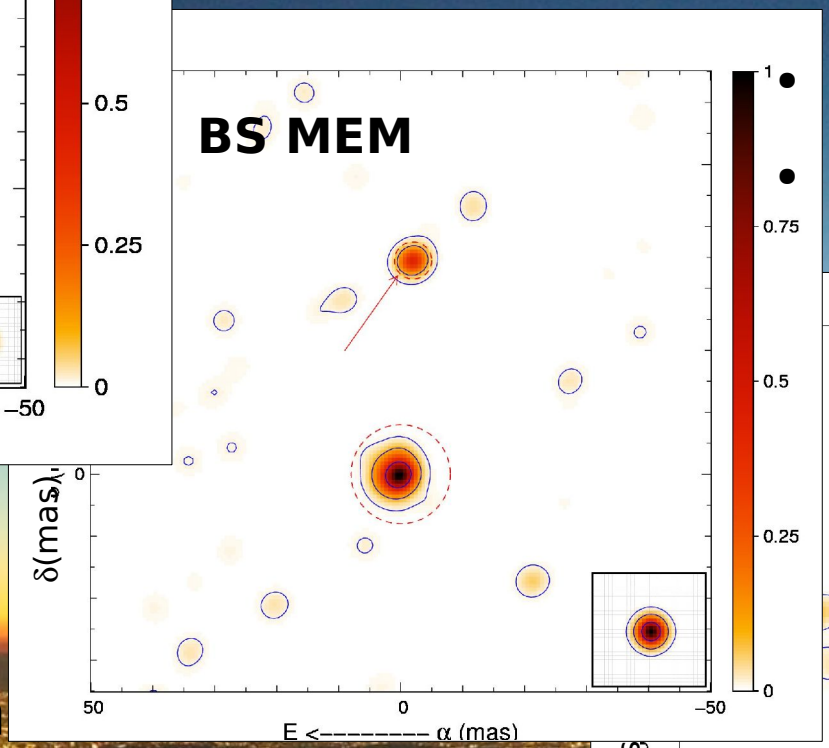


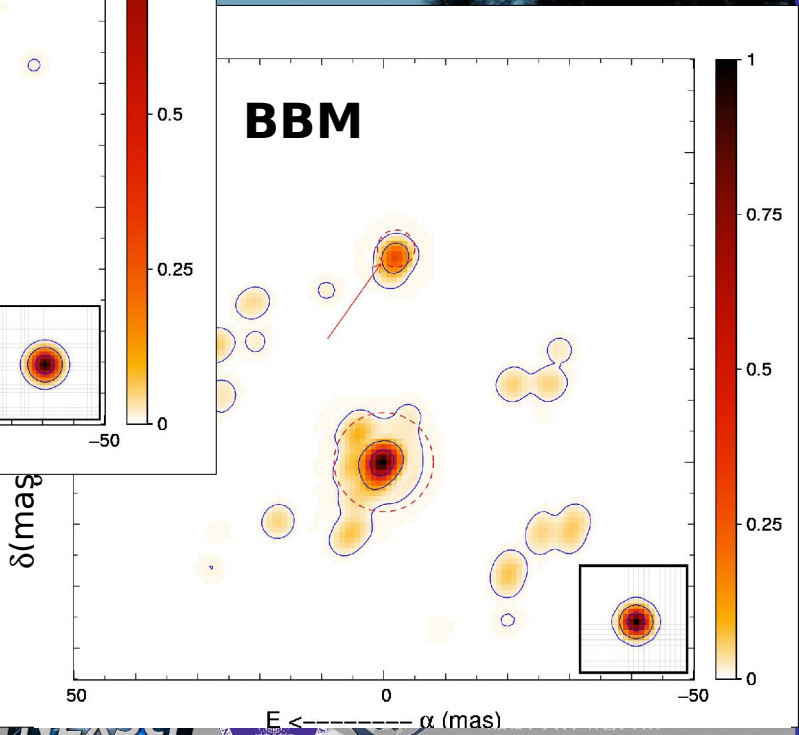
- **If $N_{tel} > 2$**
  Closure phase
- **If spectrograph**
  Spectra,
  Differential phases,
  Differential visibility
- **If well-sampled UV plane**
  Image synthesis

Photo: F. Millour

Image-reconstruction software







- Many free parameters:
  - Super-parameter,
  - prior,
  - Initial image
  - Convergence?

Millour et al. 2009

$N_{parameters} >> N_{obs}$

=> regularization prior

Photo: F. Millour

Image-reconstruction limits

Problems

- $N_{pixels} >> N_{observations}$
- Weak phases (1/3 information 3T)
- Bad UV sampling
- Convergence

Workarounds

- Regularization
- Prior
- Field-of-view
- Symmetries
- Spectral coverage
- Phase referencing

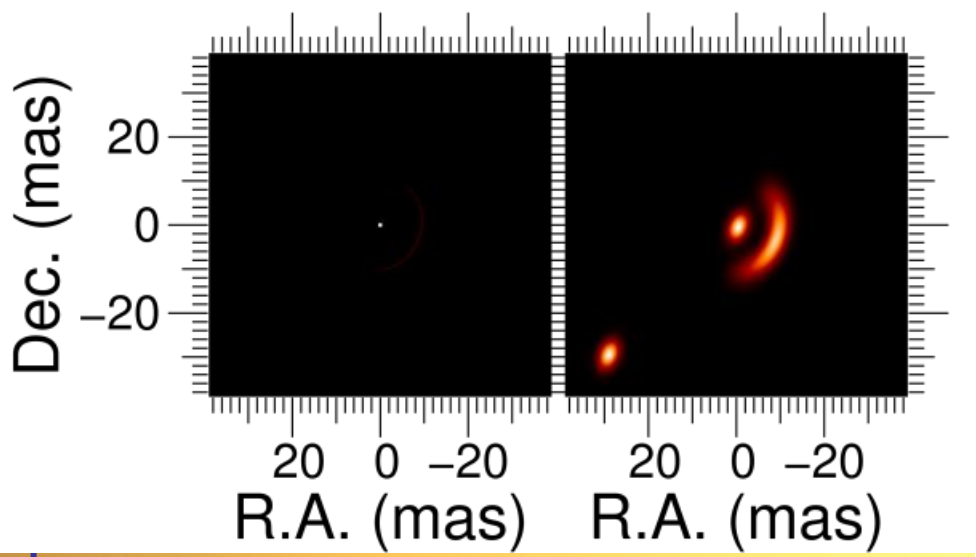
Photo: F. Millour

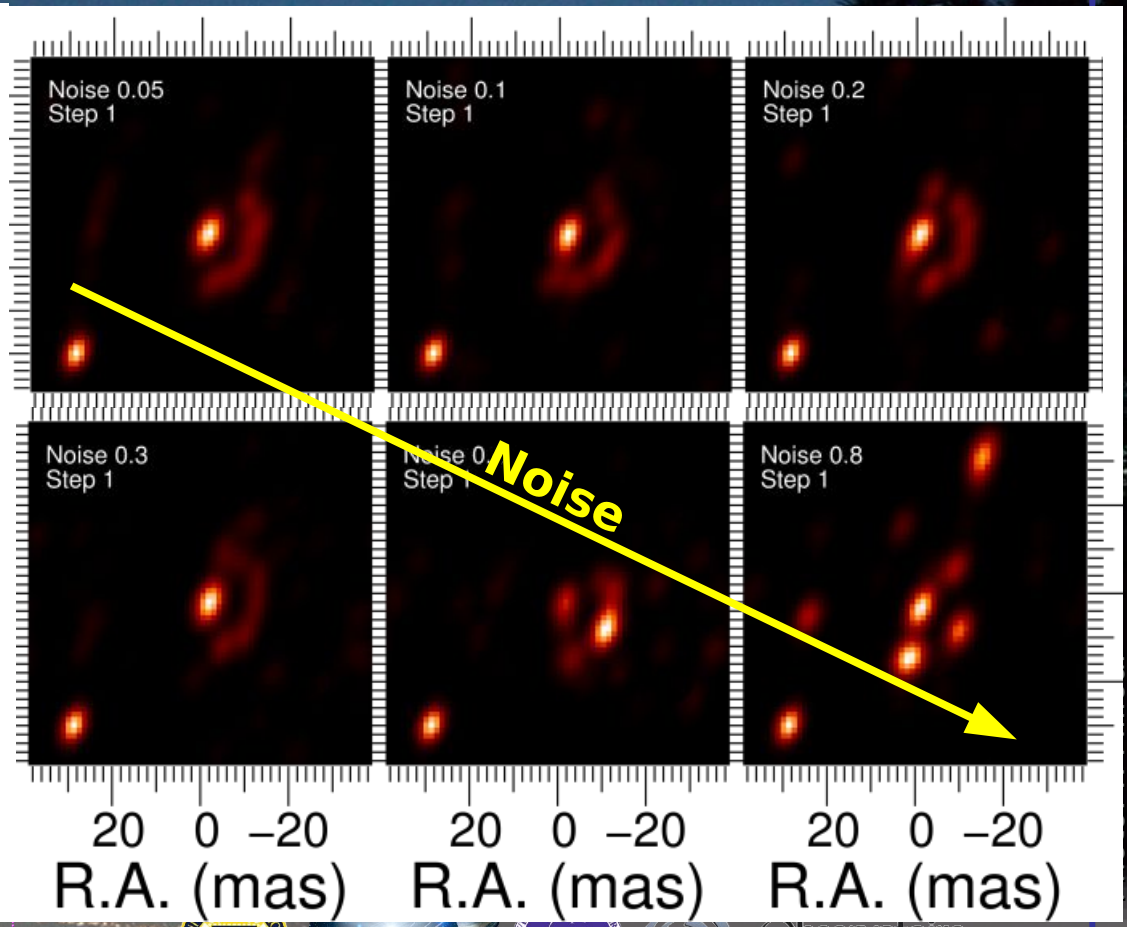
Limits: noise

- Example : disk simulation « observed » with VLTI/AMBER

Model

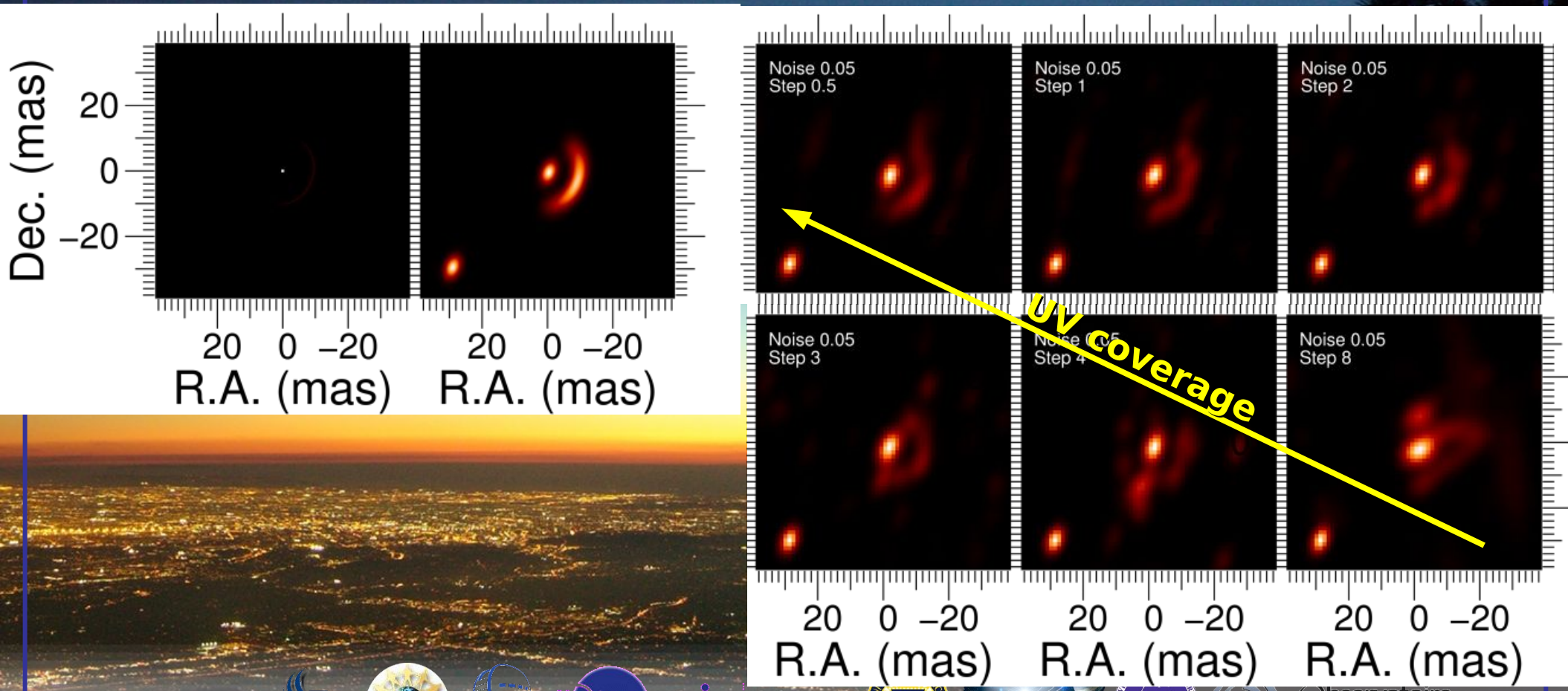
Simulations AMBER
Reconstruction MIRA





Limits: UV plane

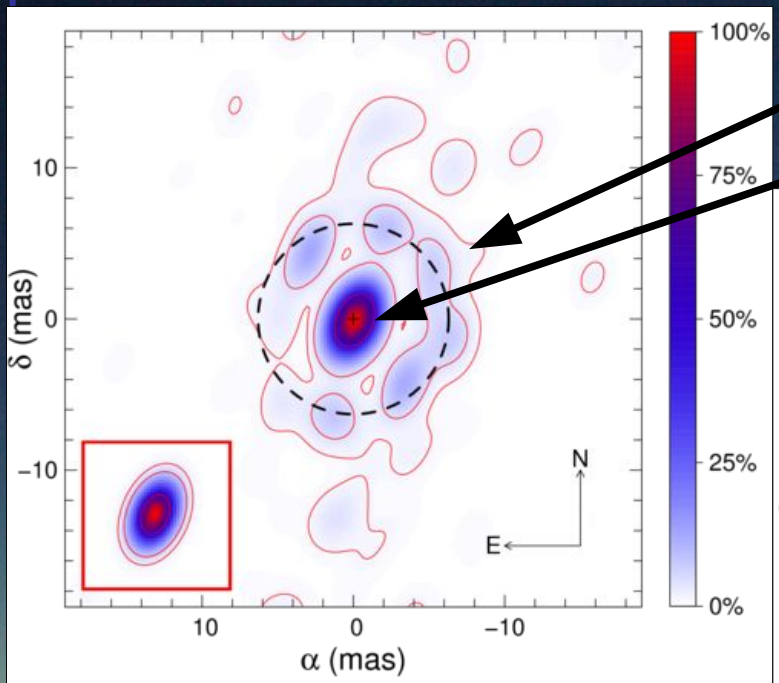
- Example : disk simulation « observed » with VLTI/AMBER



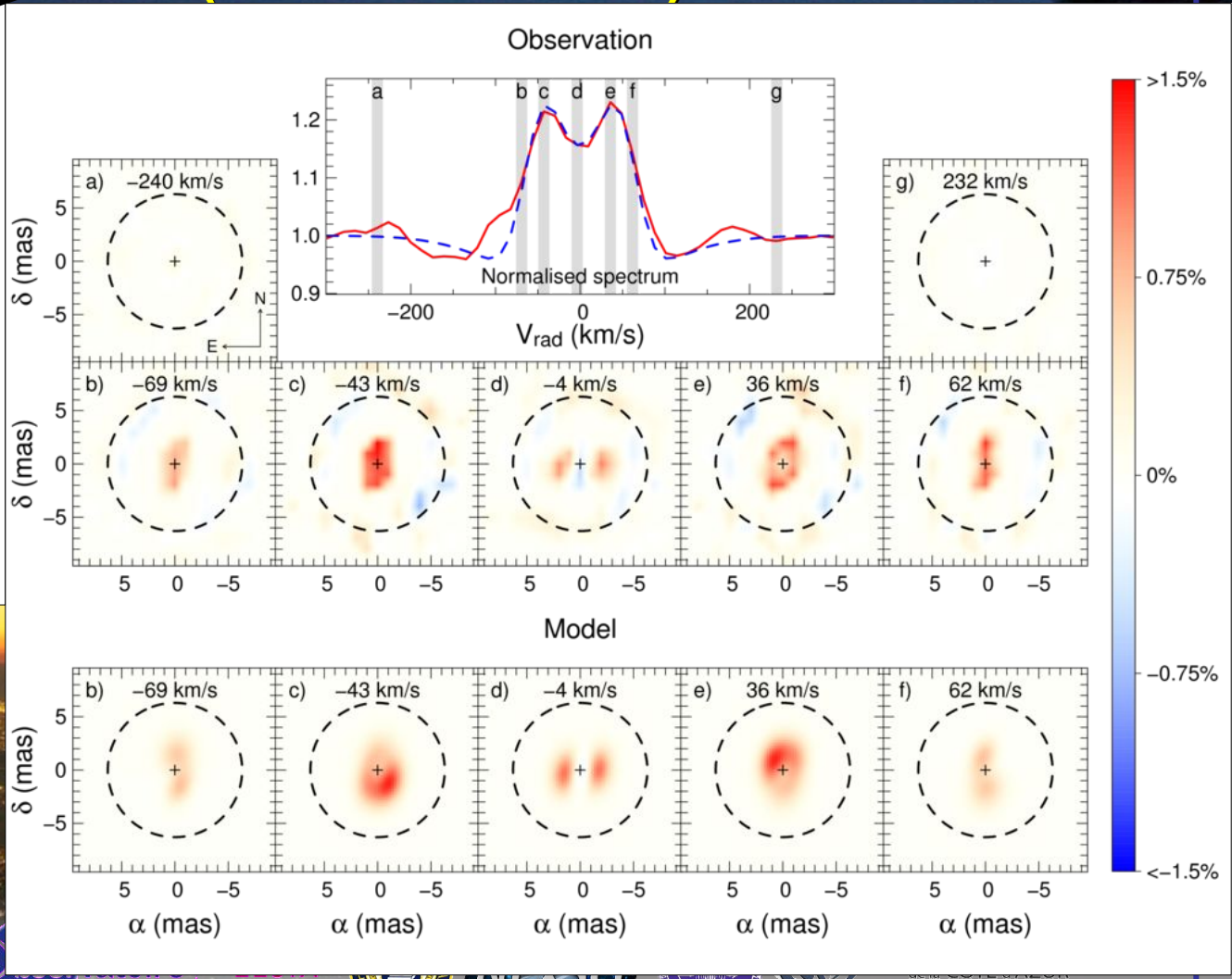
Hyperspectral imaging

3 Pup : supergiant A[e] star

- Dust (Inner sublimation rim)
- Gas (circumstellar disk)



Gas and dust disks detected

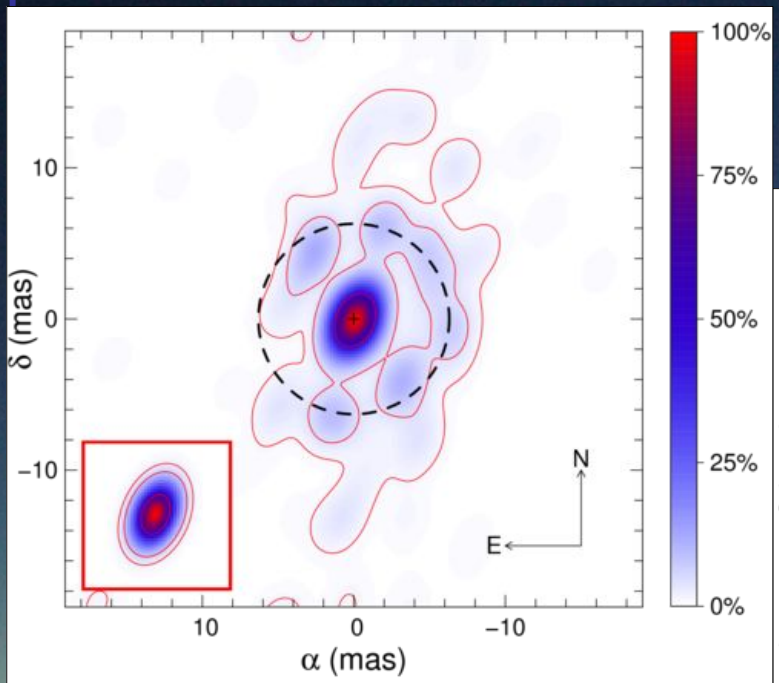


Millour et al. 2011

Hyperspectral imaging

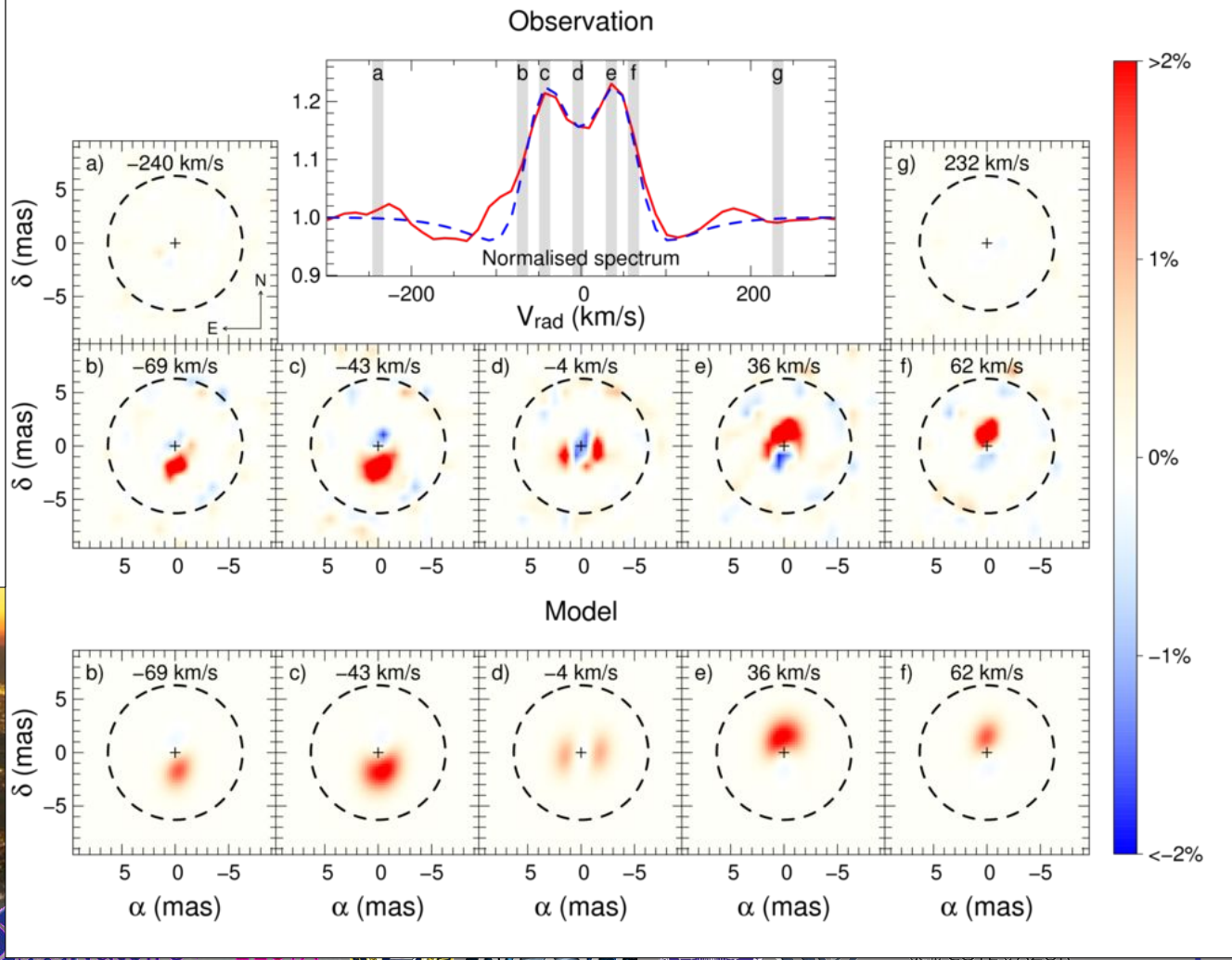
3 Pup : supergiant A[e] star

self-calibration : differential phases in the image-reconstruction process!

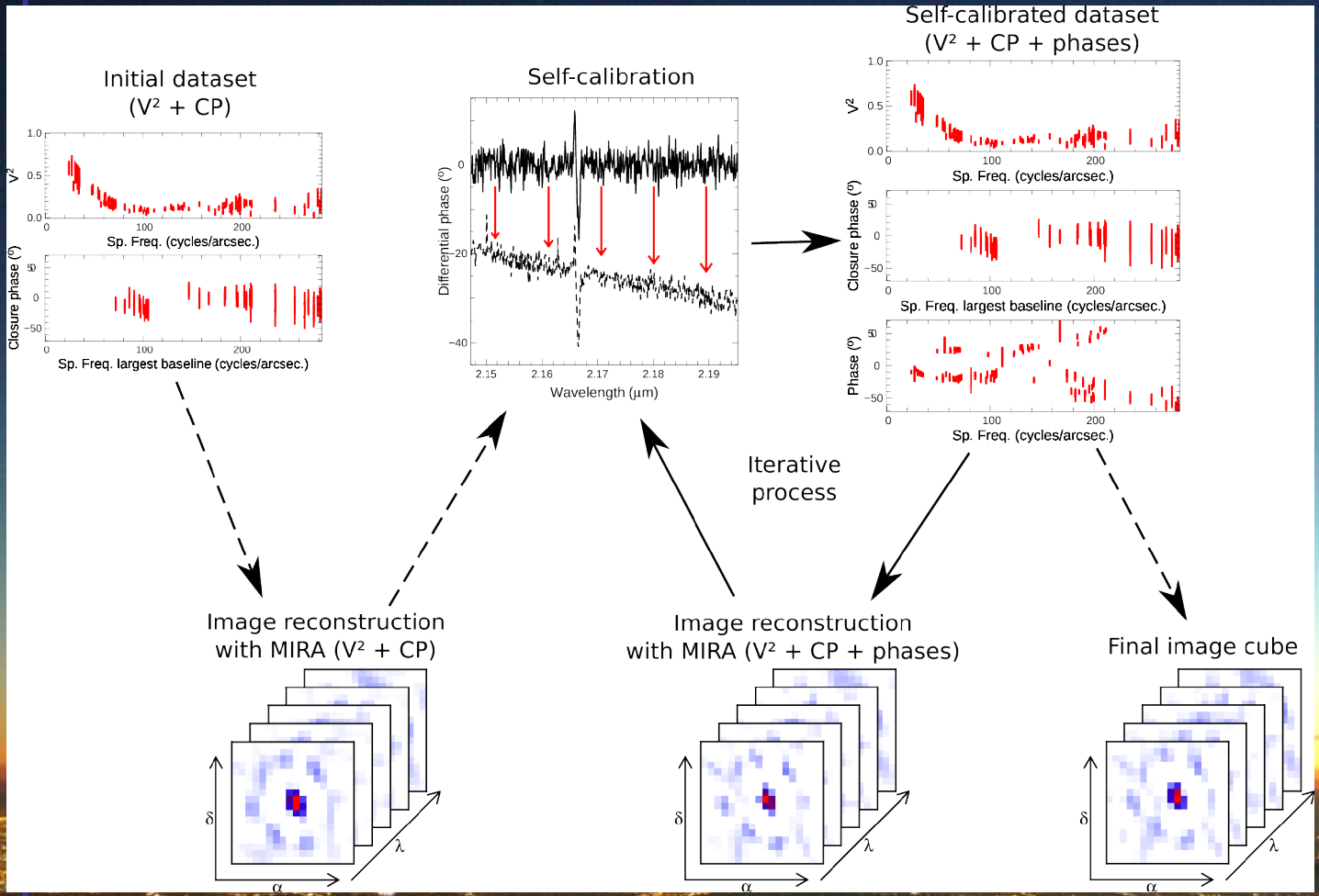


Gas and dust disks characterized

Millour et al. 2011



How does it work?



Millour et al. 2011

To be refined:

- Performances,
- Error estimates,
- Initial guess,
- Convergence,

Photo: F. Millour

Imaging with VEGA ?

- VEGA can produce images (3/4T)
- 1st step: imaging tests on theta ori C
- 2nd step: propose dedicated imaging programs
  - Imaging the disk of a Be star
  - Imaging spotty stellar surfaces
  - Not yet feasible: Imaging a « Pinwheel » nebula in the visible
  - Other ideas?

Photo: F. Millour

Resolving the magnetically confined wind-shock region of theta^1 *Orionis C*

Stefan Kraus[1]
Florentin Millour[2]
Denis Mourard[2]
Philippe Stee[2]
Olivier Chesneau[2]
Philippe Berio[2]
Omar Delaa[2]
Alain Spang[2]
VEGA team
CHARA team

Unique characteristics:

- **Periodicity of 15.422±0.002 d (Stahl et al. 2003)**
- **Zeeman-Signatures (1.1±0.1 kG, Donati et al. 2002) in phase with spectroscopic periodicity (one of only two O-stars with detected magnetic field)**
- **X-ray variability in phase with the magnetic field**
- **M1 + M2 = 47±4 M_{sun}**

d = 410±20 pc (Kraus et al. 2009)

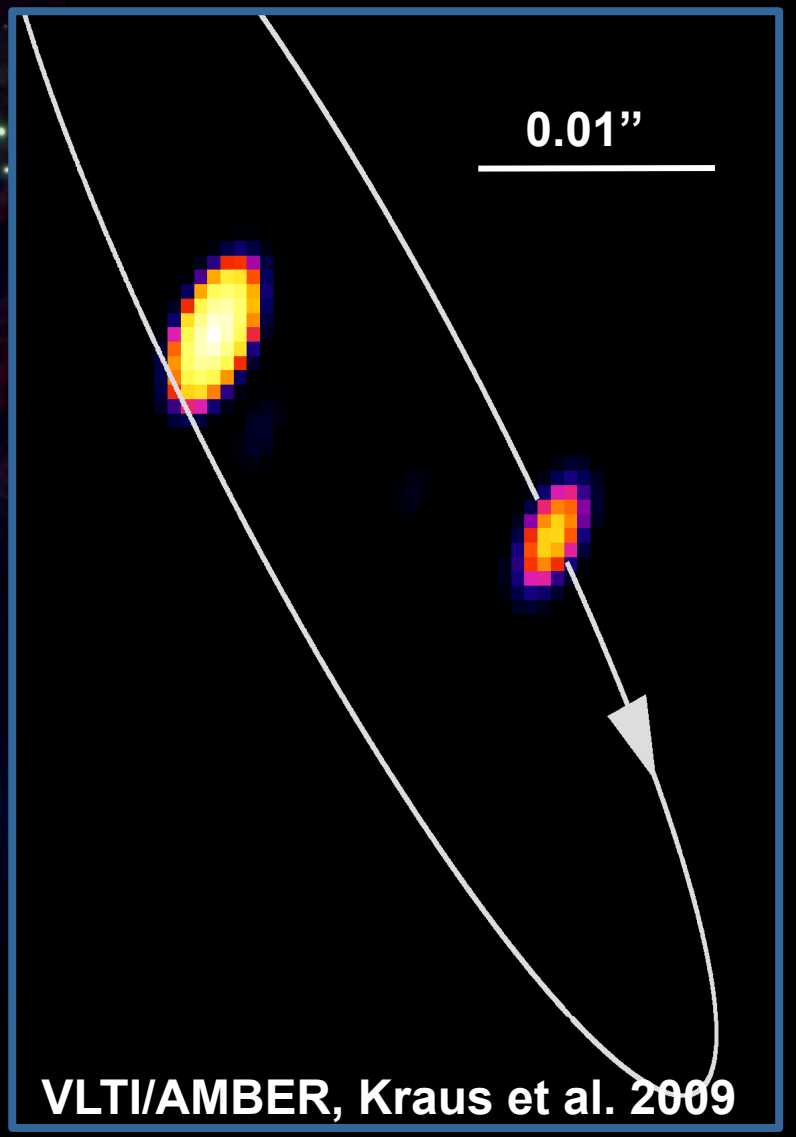
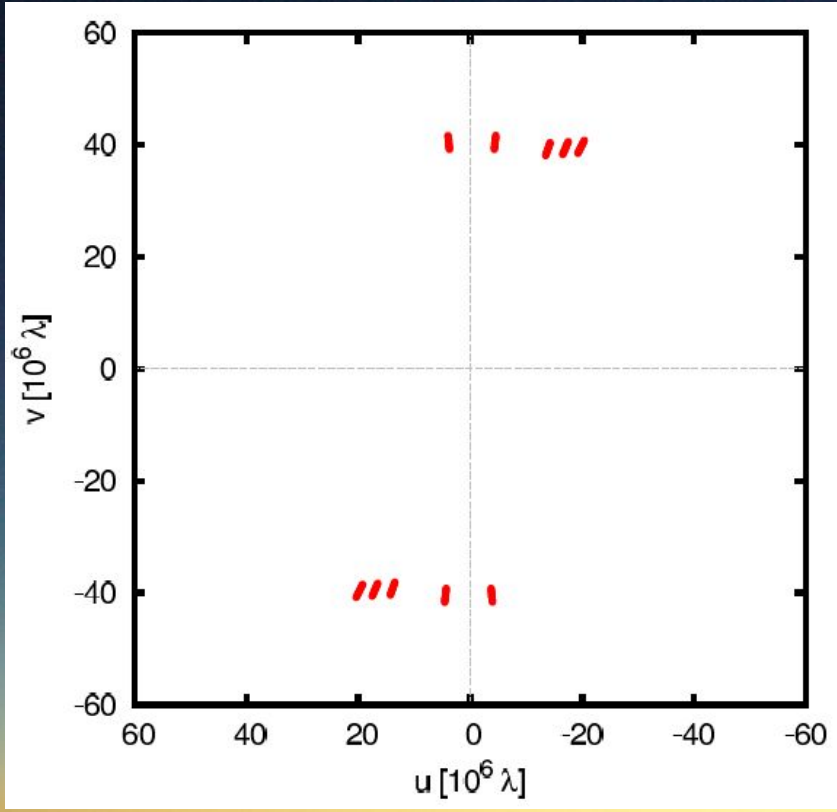


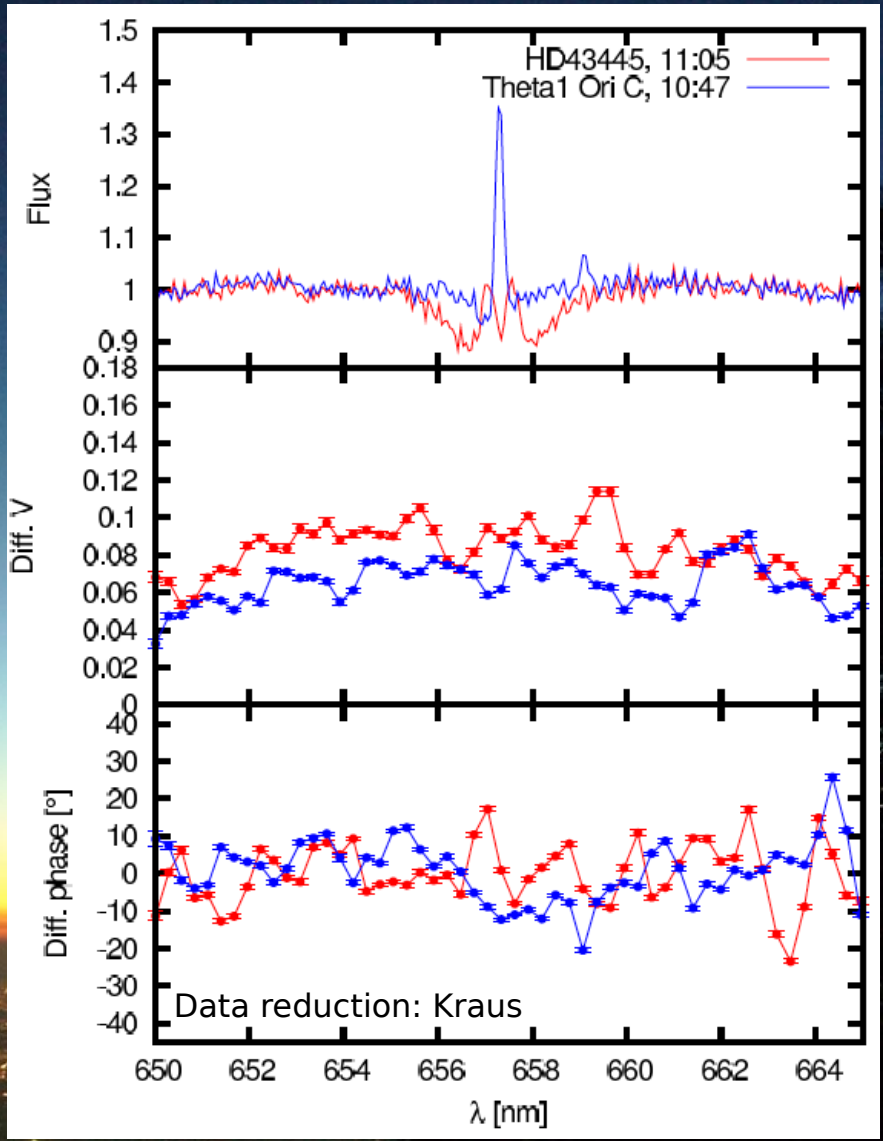
Image credits: ESO/McCaughrean

1 University of Michigan, Ann Arbor
2 Laboratoire Fizeau, Nice

Transparent courtesy: S. Kraus

VEGA 2008 observations





=> UV coverage not enough to get relevant astrometry

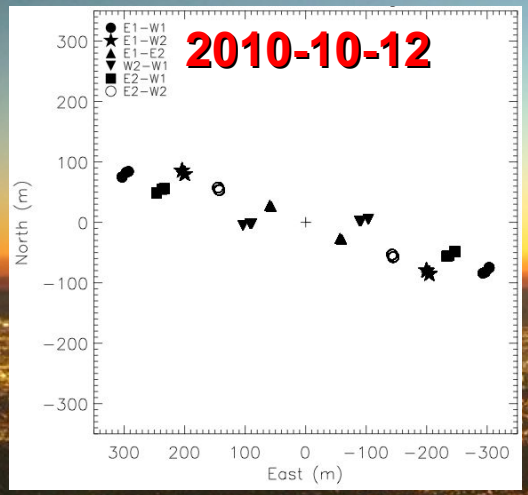
=> SNR not enough to get relevant spectral variations

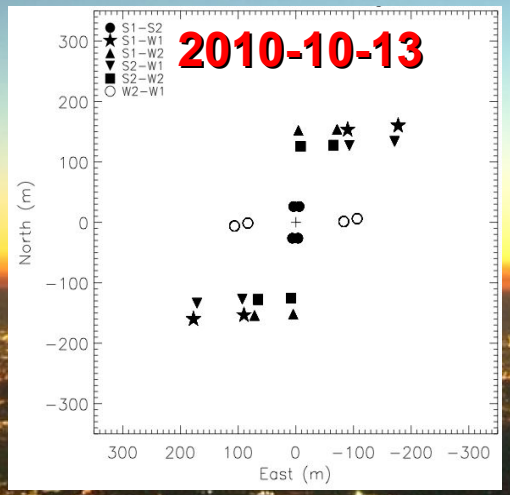
Photo: F. Millour

Imaging Theta Ori C

Programme	Objet	Date	Base	Nbr Obs	PI-DRS	Qualité (0-5)	Etat
V23	Theta1 OriC	2010-10-12	E1E2W2	1	Stefan		+MIRC
V23	Theta1 OriC	2010-10-12	E2W2W1	1	Stefan		+MIRC
V23	Theta1 OriC	2010-10-13	S1S2W2	1	Stefan		+MIRC
V23	Theta1 OriC	2010-10-13	S2W2W1	1	Stefan		+MIRC
V23	Theta1 OriC	2010-10-14	S1S2W2	2	Stefan		+MIRC
V23	Theta1 OriC	2010-10-14	S2W2W1	2	Stefan		+MIRC
V28	Theta Ori	2008-11-23	S1S2	3	Stefan		
V28	Theta Ori	2008-11-24	S1S2	3	Stefan	4	fini
V28	Theta Ori	2009-11-18	S1S2	2	Stefan		
V28	Theta Ori	2009-11-20	W1W2	2	Stefan		

MIRC + VEGA UV coverage





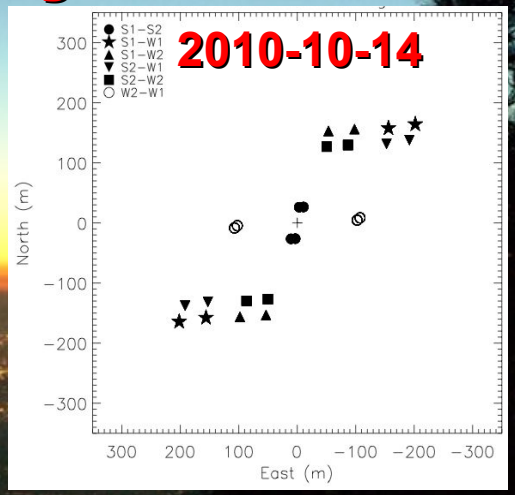


Photo: F. Millour

Imaging Theta Ori C with VEGA

See S. Kraus 8th year CHARA review in 2012

Photo: F. Millour

Imaging with VEGA ?

- VEGA can produce images (3/4T)
- 1st step: imaging tests on theta ori C
- 2nd step: propose dedicated imaging programs
  - Imaging the disk of a Be star

Request for Observing Time at the CHARA Array
For the Period
April 1 – August 30, 2011
Type only within boxed areas immediately after hyphens

A. P.I. Name – Florentin Millour
B. Co-P.I. Names – Philippe Stee, Anthony Meilland, Omar Delaa
C. Observing Participants – Potentially all proposers
D. Proposal Title – Imaging the possibly warped disk of the Be star Kappa Draconis

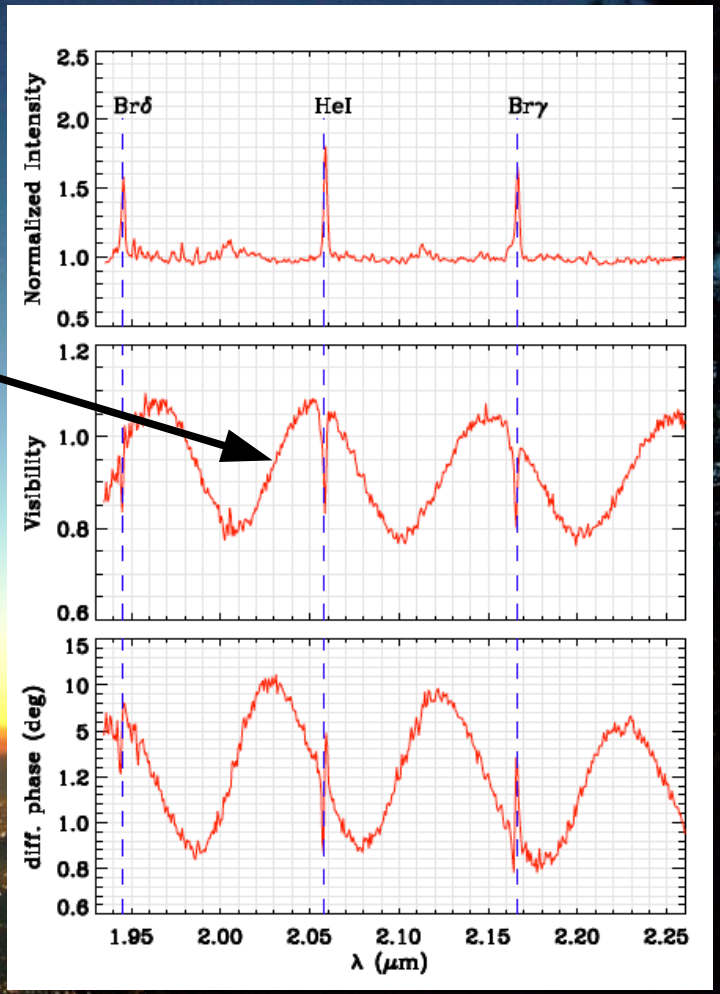
in

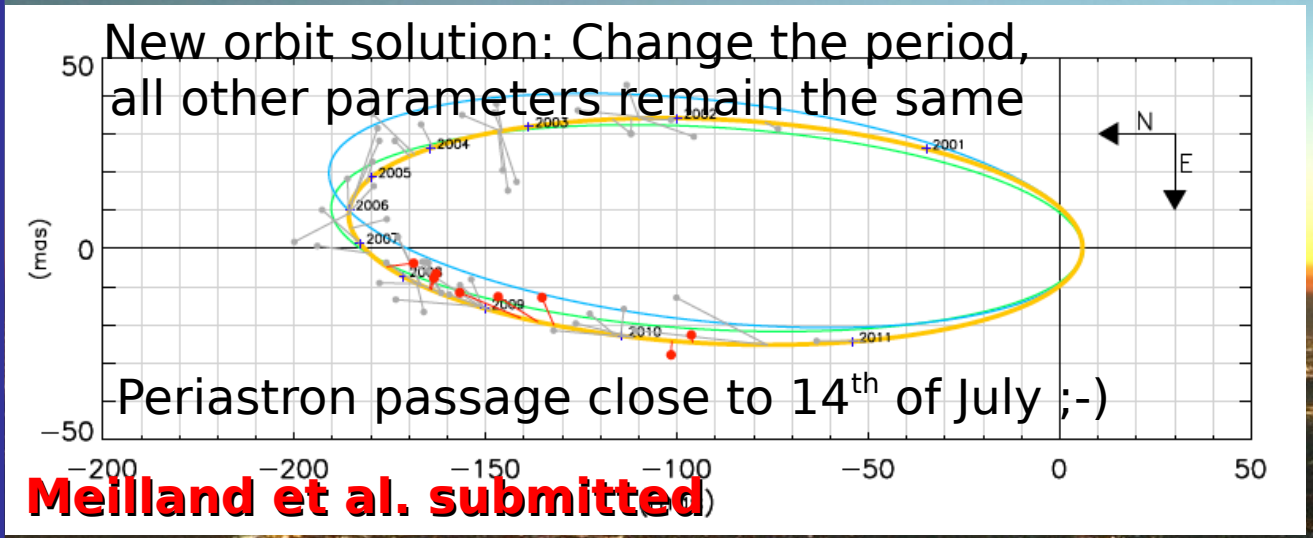
Photo: F. Millour

Be stars studies with VEGA

- Delaa et al. Various Be stars (PhD thesis)
- Meilland et al. Delta Sco combined AMBER + VEGA

AMBER resolves both the binary and the line emission!



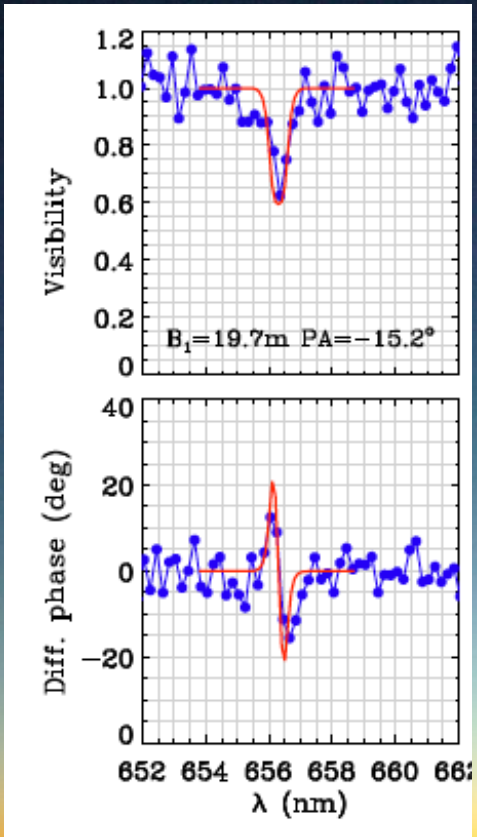


Meilland et al. submitted

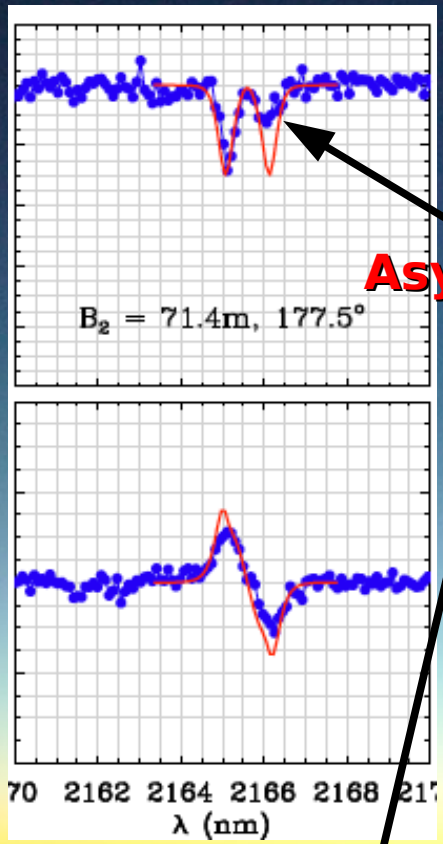
Photo: F. Millour

Delta Sco disk

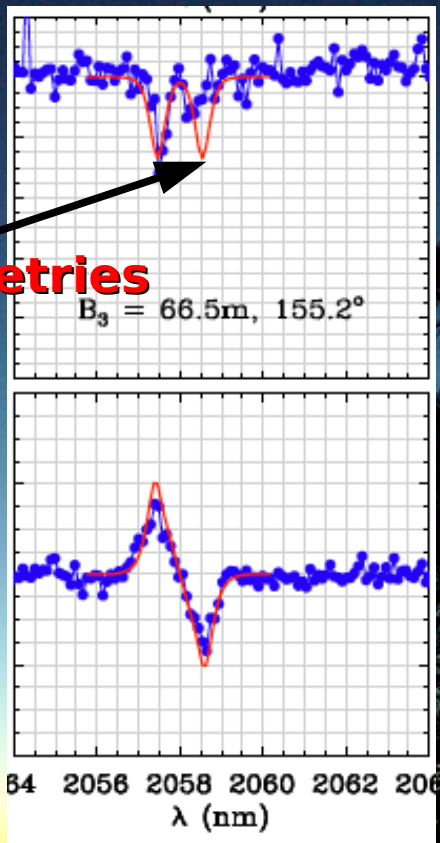
H α



Br γ

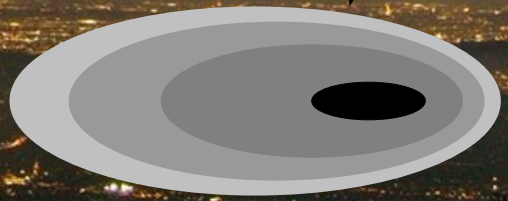


He I



Asymmetries

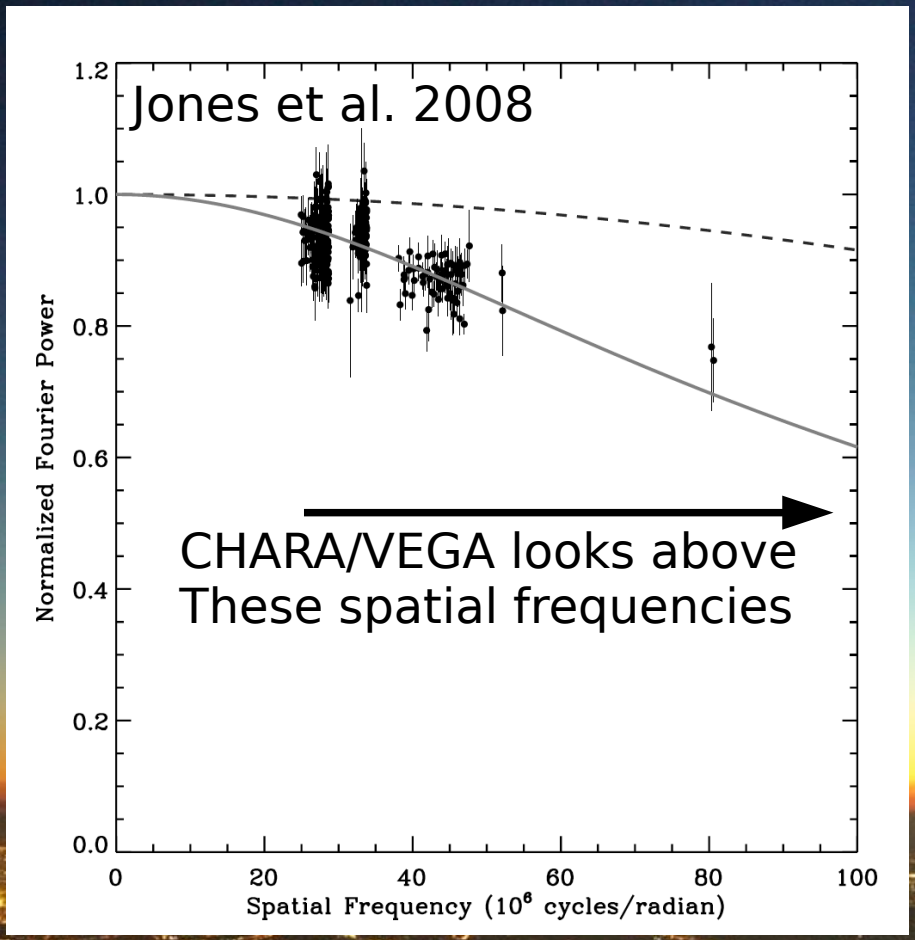
- Keplerian rotation
- Size H α > Br γ > He I
- Tidal effects?
  Induced disk oscillations?



Meilland et al. submitted

Photo: F. Millour

Imaging the disk of Be stars
a self-cal-friendly imaging program



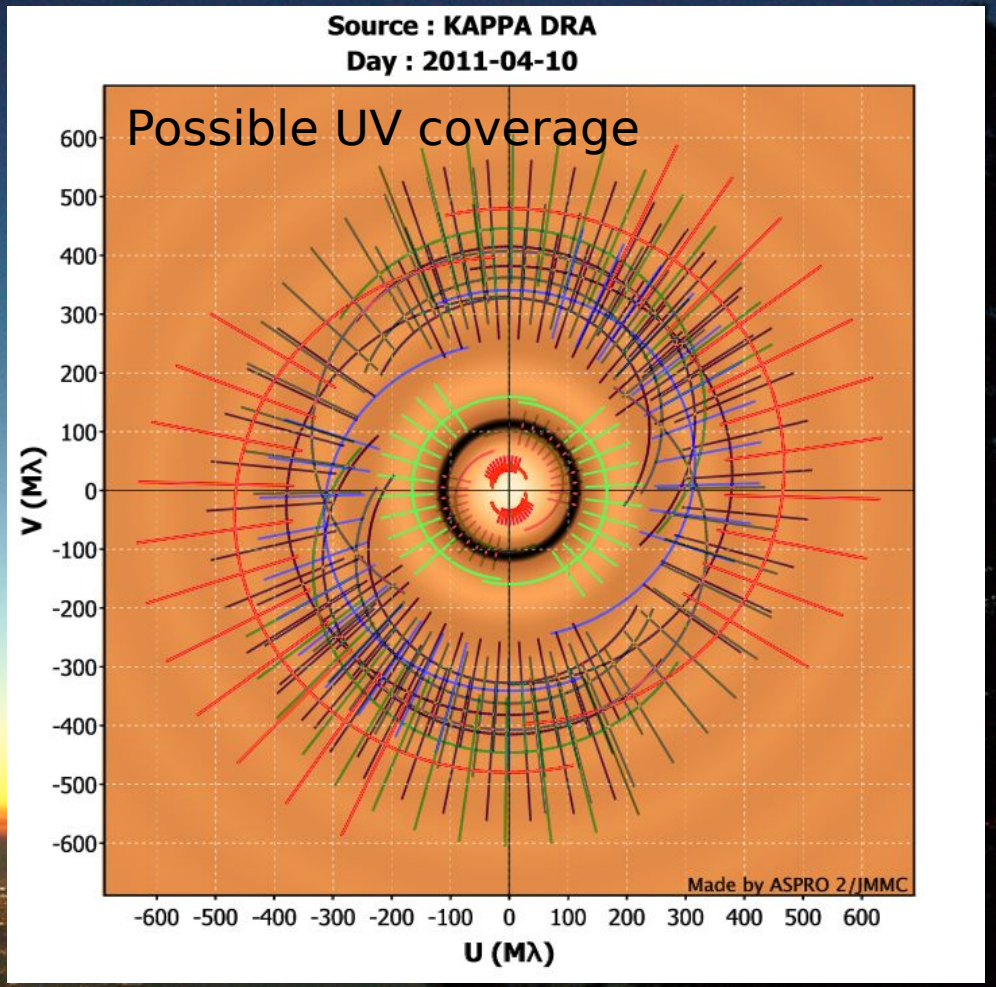
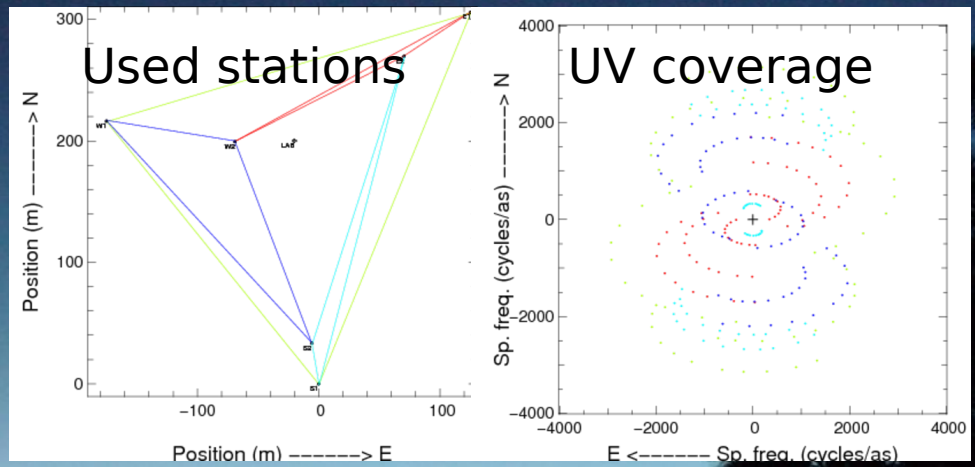


Photo: F. Millour

Imaging the disk of Be stars

- CHARA/VEGA
  - V2 noise 0.05
  - CP noise 0.01
- 1 point every hour
- Good knowledge of errors



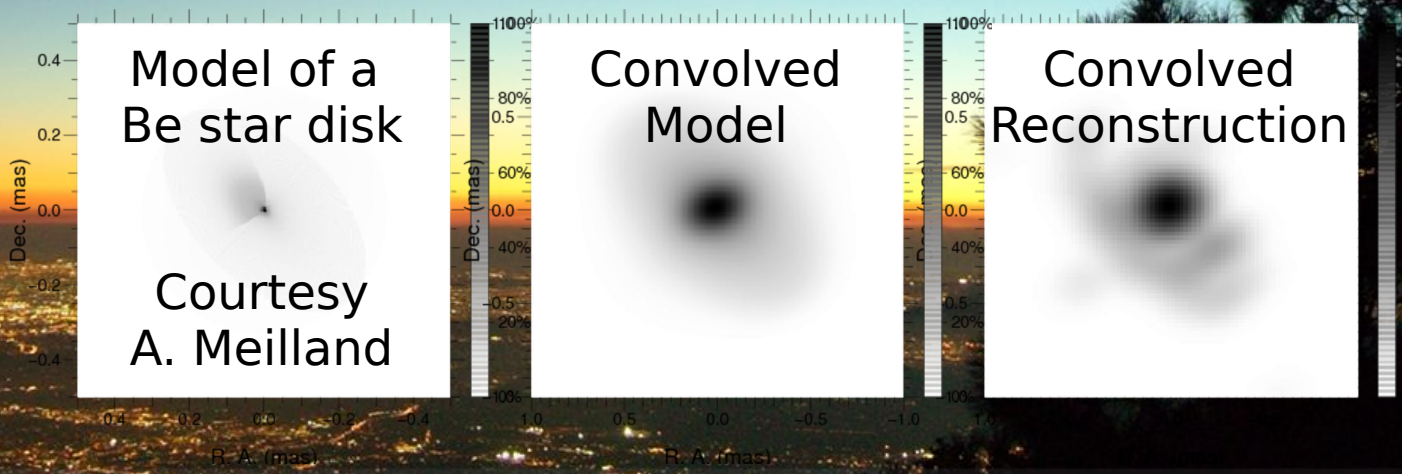
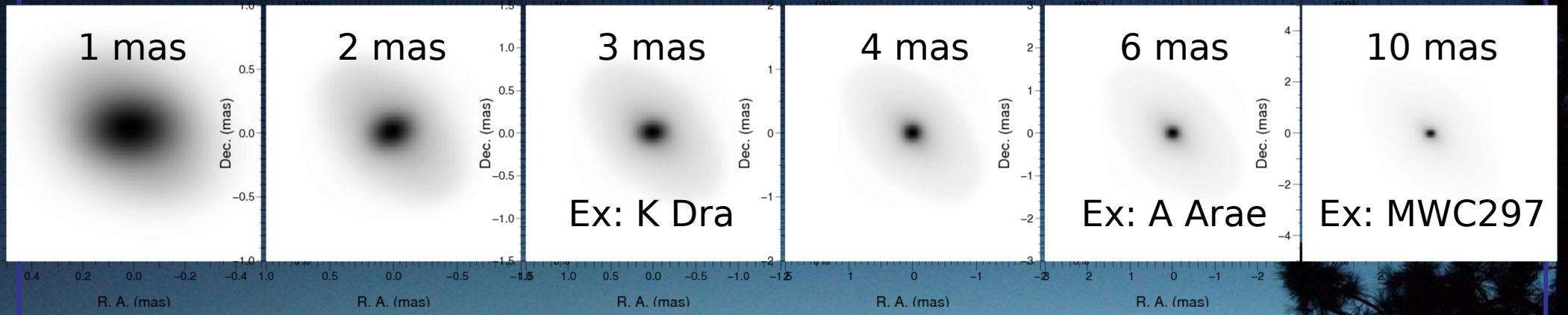


Photo: F. Millour

Imaging the disk of Be stars

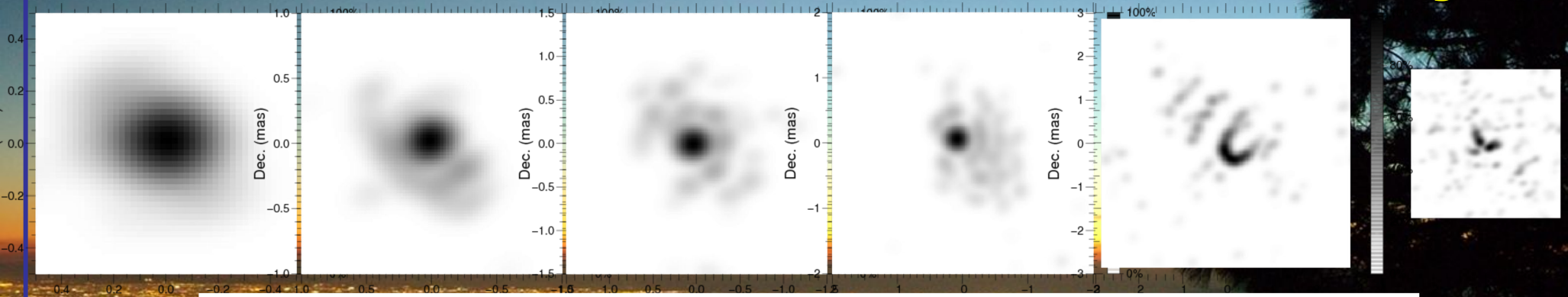
Convolved model



Under-resolution

Convolved reconstructed image

Aliasing

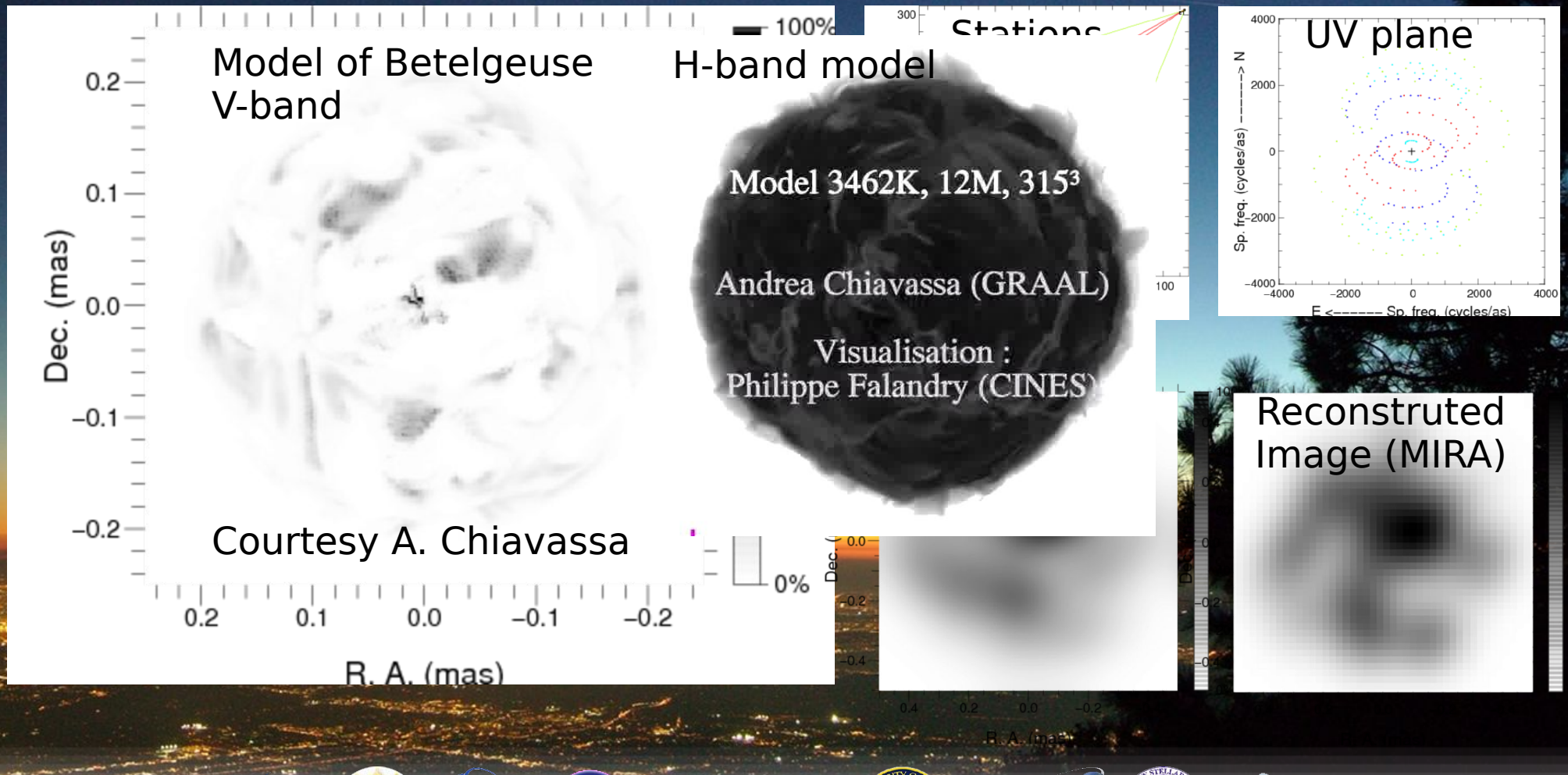


=> range of feasibility with CHARA/VEGA:
from 1 to 4 mas disk size... OK for Kappa Dra!
BUT lots of asymmetries induced by
large noise on closure phase (to be verified)
How self-cal improves the situation has to be checked

Photo: F. Millour

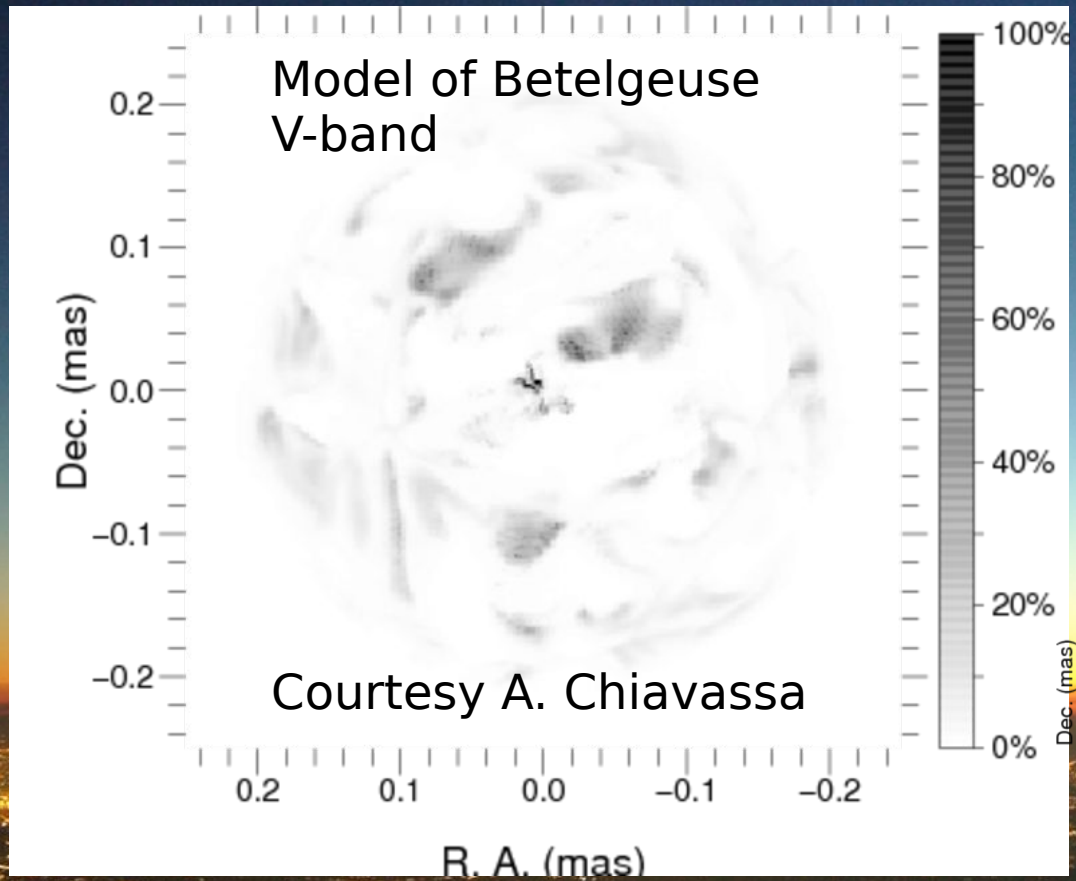
Imaging the spotty surface of [supergiant] stars

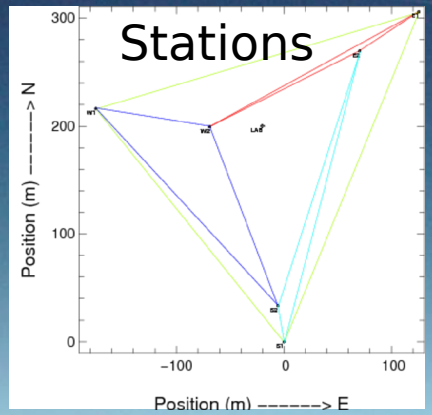
- Case-study proposed by A. Chiavassa, O. Delaa

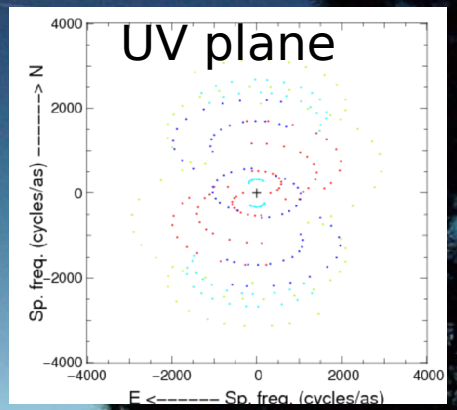


Imaging the spotty surface of [supergiant] stars

- Case-study proposed by A. Chiavassa, O. Delaa







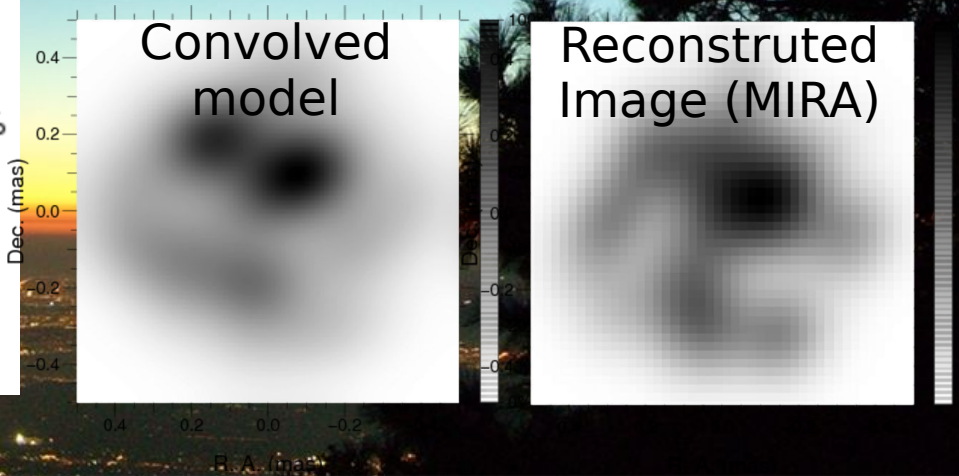
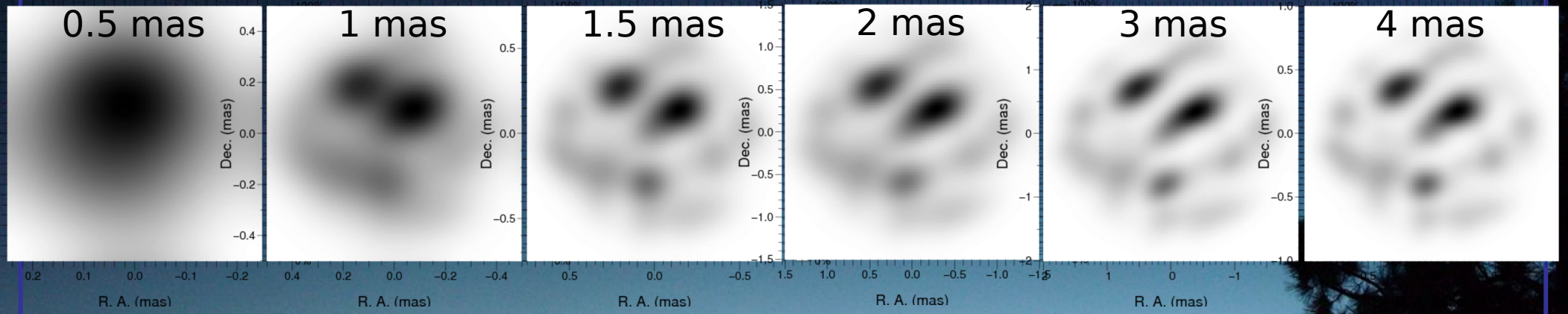


Photo: F. Millour

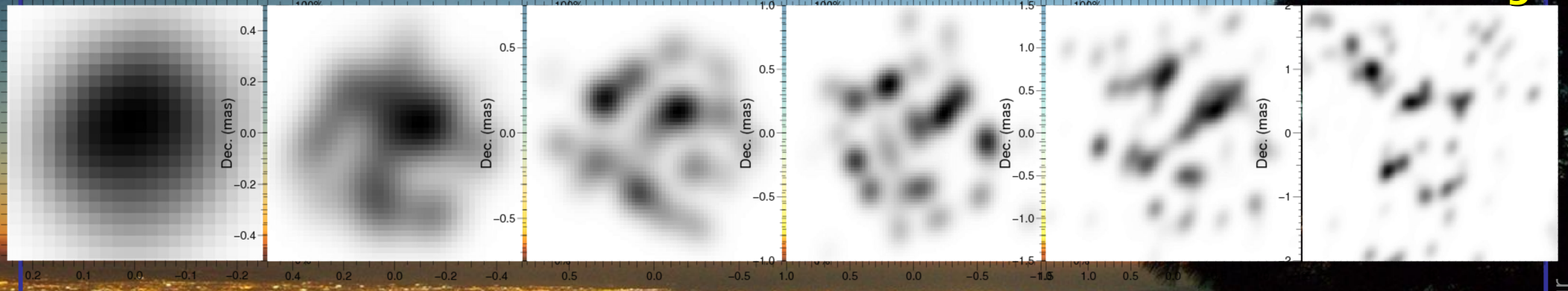
Influence of the star size

Convolved model



Convolved reconstructed image

Under-resolution — **Aliasing**



=> range of feasibility of stellar surfaces imaging with CHARA/VEGA: from 1 to 3 mas, but then magnitude limit problem

Photo: F. Millour

Conclusions

- VEGA is able to produce images of stellar objects
  - typically 1 mas < size < 3 mas
    => need for shorter(!) baselines
    (i.e. Theta Ori C will be difficult)
- Challenges to tackle:
  - Measure low-contrasts => use NIR coherencing
  - Good estimates of errors

Photo: F. Millour