

Image reconstruction in the visible

F. Millour

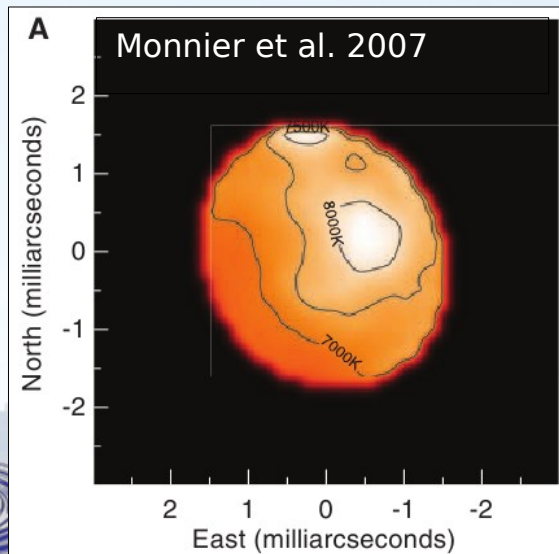
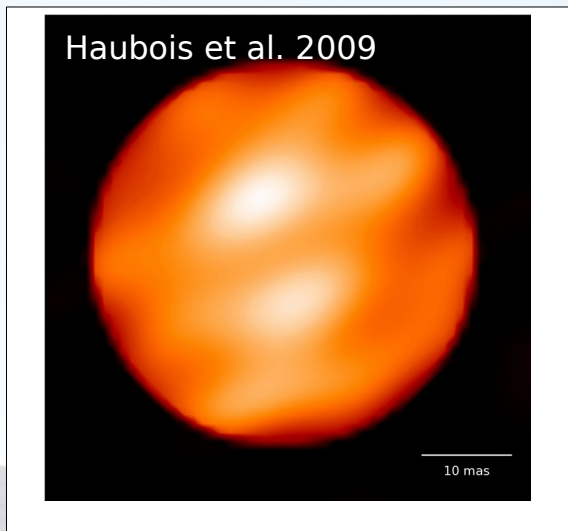
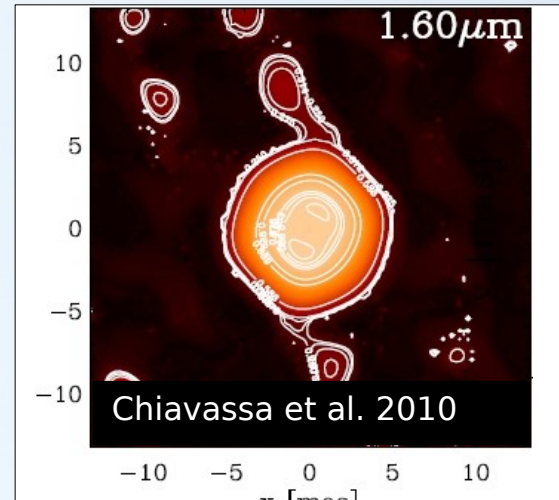
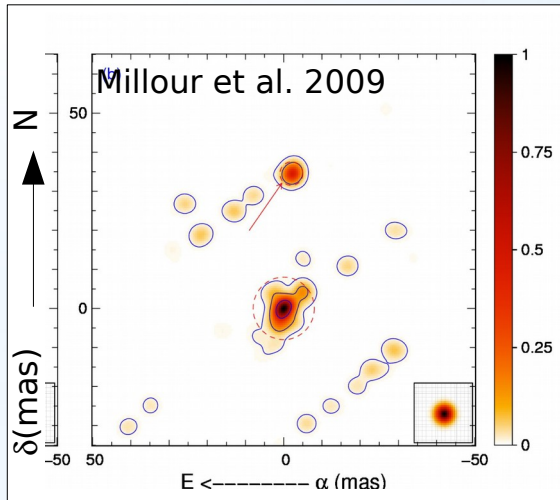
**with contributions from A. Labeyrie, D. Mourard,
J. Schneider, F. Soulez, M. Tallon, I. Tallon-Bosc,
T. ten Brummelaar, E. Thiébaud**



Observatoire
de la CÔTE d'AZUR

Imaging with interferometry

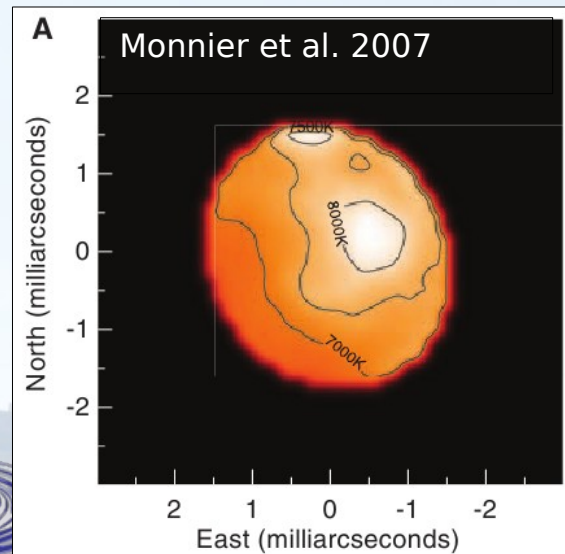
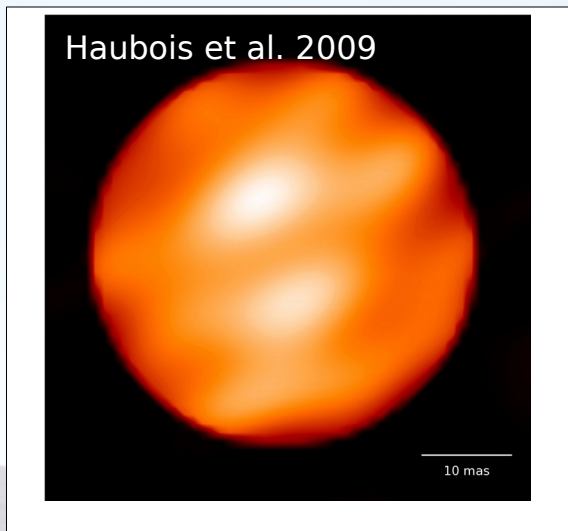
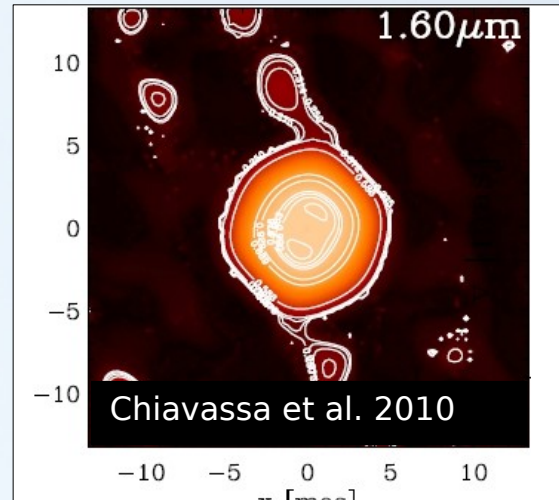
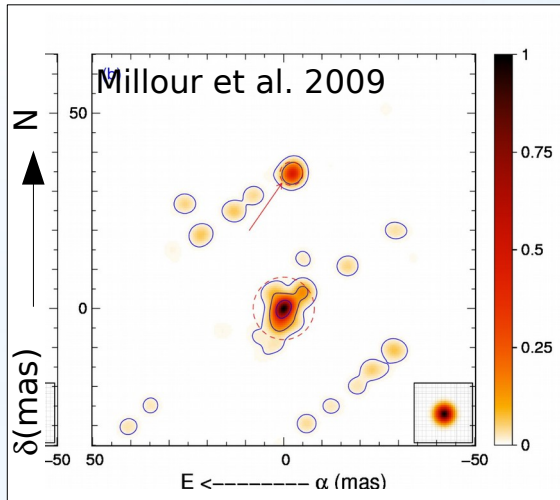
- Squared visibility (V^2)



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

Imaging with interferometry

- Squared visibility (V^2)

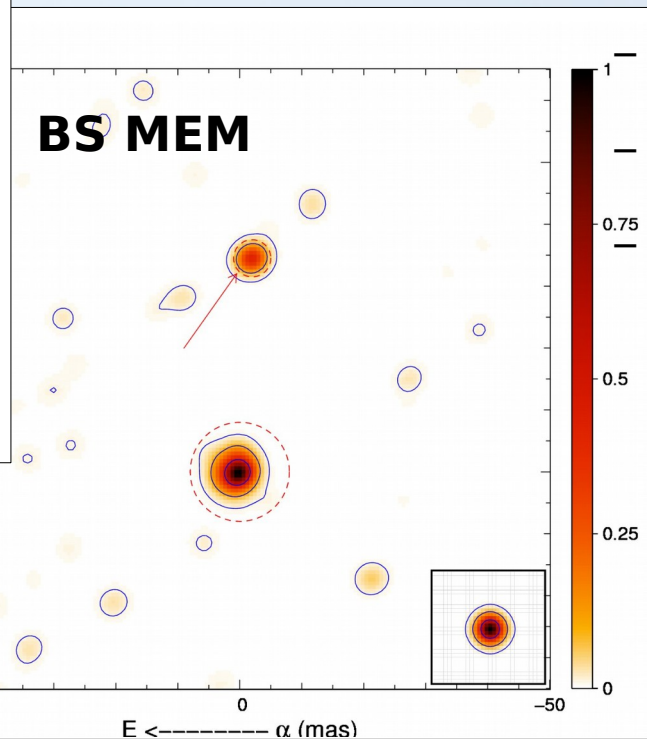
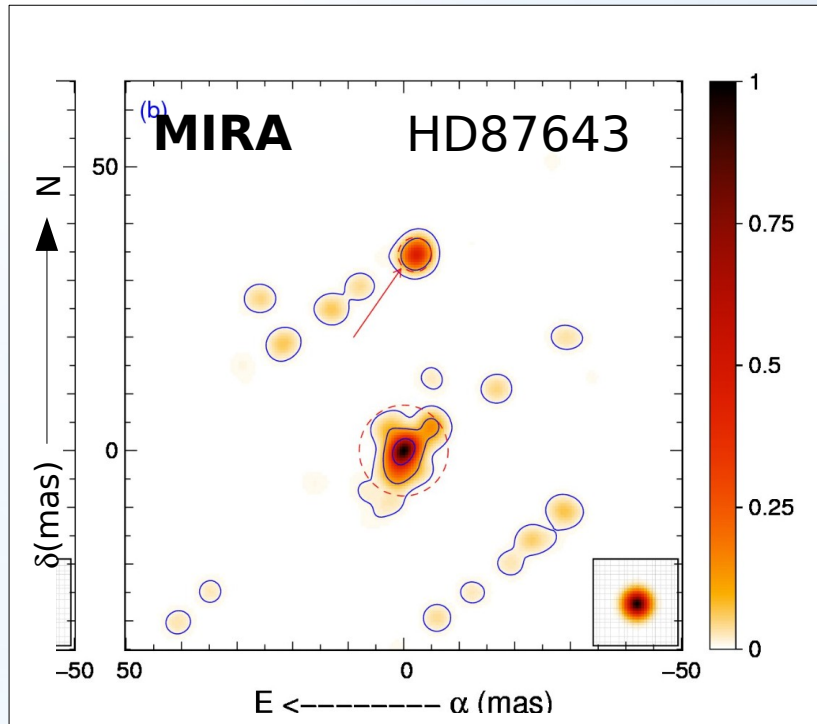


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Closure phase

- If spectrograph
Spectra,
Differential phases,
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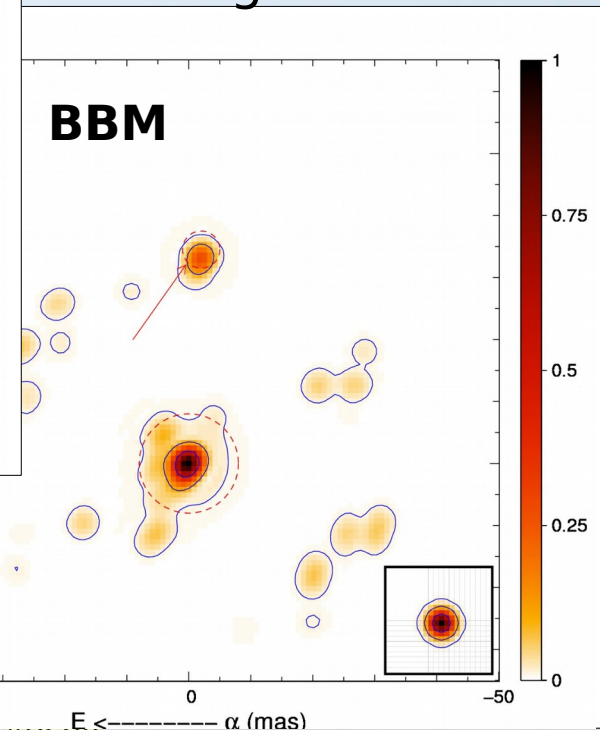
- If well-sampled UV
plane
Image synthesis

Image-reconstruction software



- **Many free parameters:**

- Super-parameter,
- prior,
- Initial image
- Convergence?



Millour et al. 2009

$N_{\text{parameters}} \gg N_{\text{obs}}$
 \Rightarrow regularization prior



Image-reconstruction limits

Problems

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

Workarounds

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



Facilities

- VLT
 - South hemisphere / 4T/4T or 8T(?)
 - Good UV coverage (reconfiguration)
 - Future NAOMI adaptive optics / current MACAO **dichroic issue**
 - Observation strategy / use IR WFS of GRAVITY ?
- CHARA
 - North hemisphere / 6T
 - Limited field of view (**not enough short baselines**)
 - Adaptive optics
- SUSI (?)
- PFI (?)
- MROI (?)

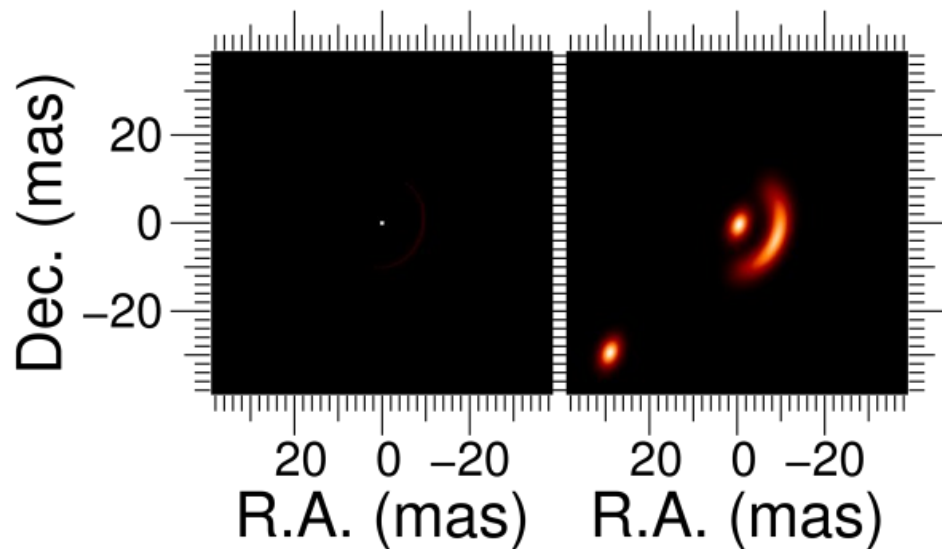


Observatoire
de la COTE d'AZUR

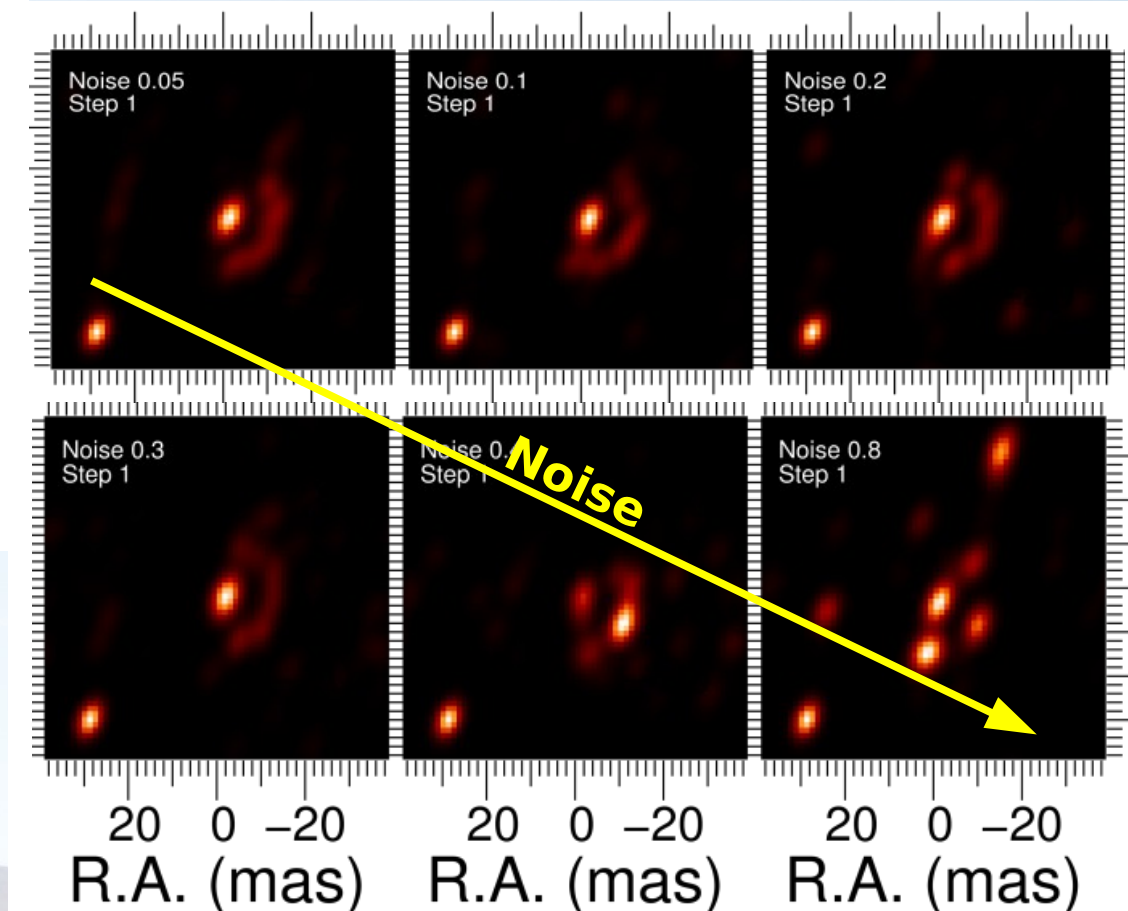
Limits: noise

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

Model



**Simulations AMBER
Reconstruction MIRA**



Specific noises/biases to the visible ?

- Photon-counting \Rightarrow No closure phase !
- « Trou du centreur »
- Other specific bias source?

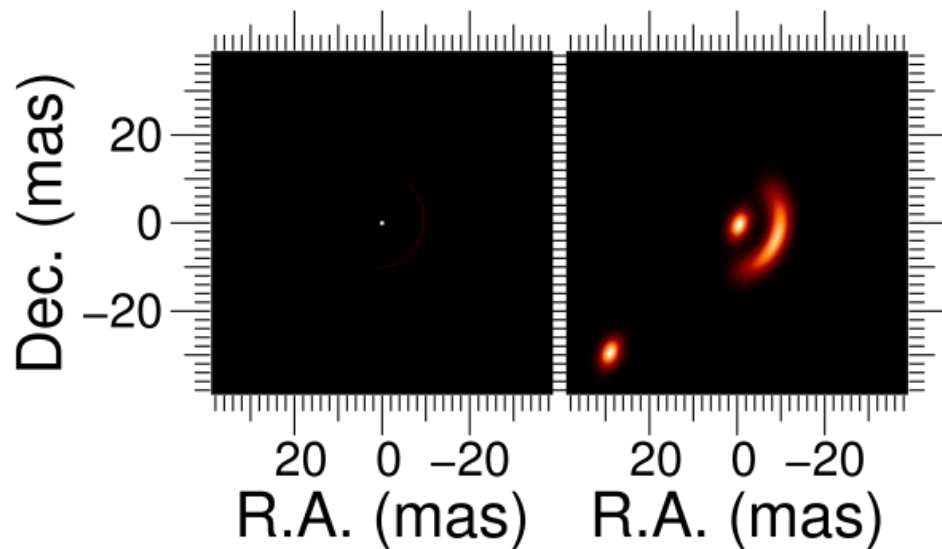


Limits: UV plane

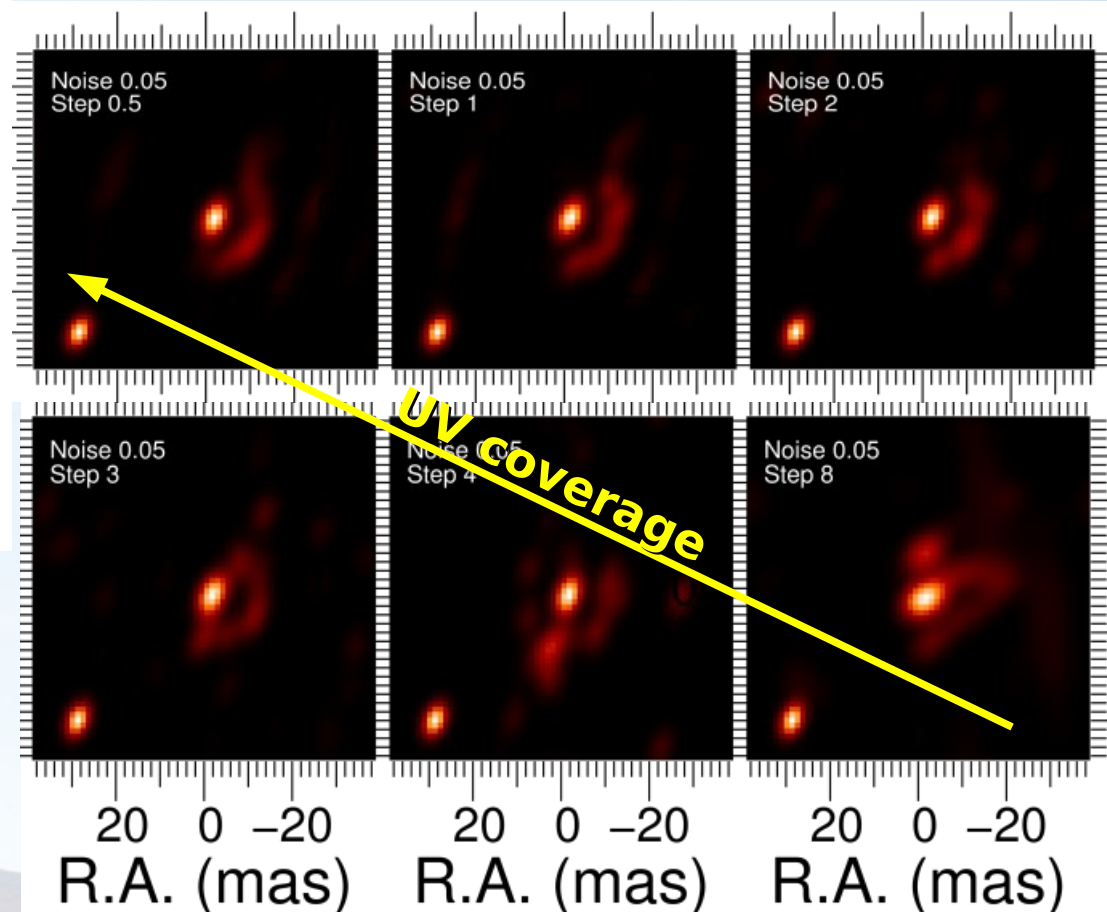
CHARA report : Tuthill et al. [Http://www.chara.gsu.edu/CHARA/Reports/tr86.pdf](http://www.chara.gsu.edu/CHARA/Reports/tr86.pdf)

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**Simulations AMBER
Reconstruction MIRA**



How many telescopes for imaging ?

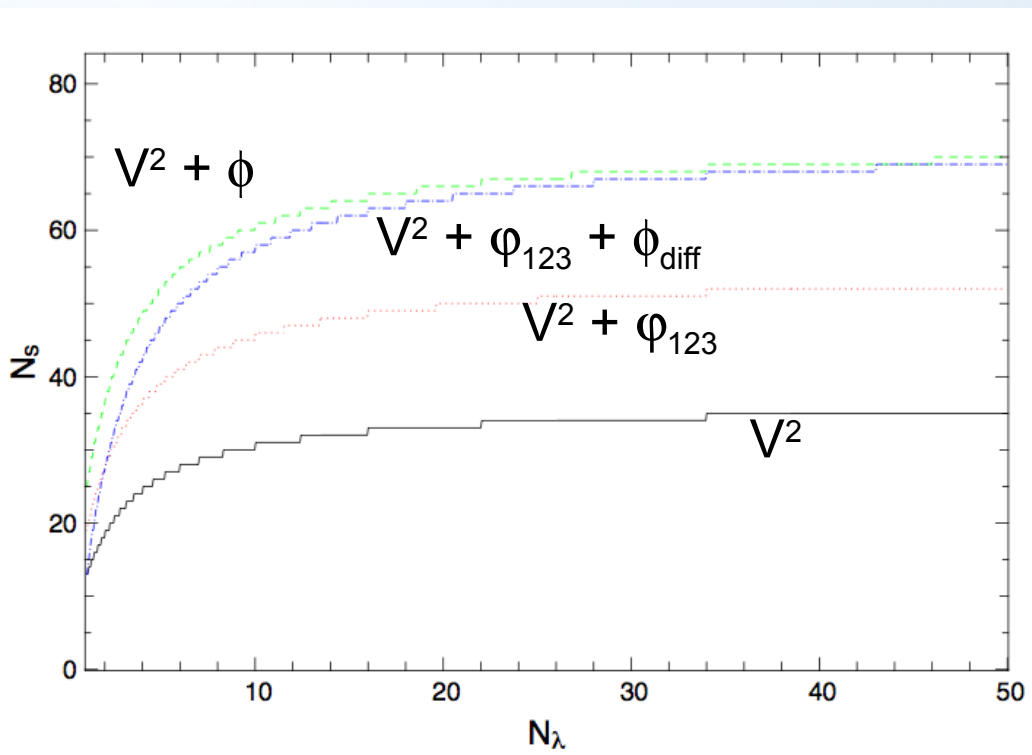
- CHARA report : Tuthill et al.
[Http://www.chara.gsu.edu/CHARA/Reports/tr86.pdf](http://www.chara.gsu.edu/CHARA/Reports/tr86.pdf)
- 4 strict minimum with supersynthesis & configurations
- CHARA experience : 6 minimum for snapshot imaging

- How many programs need snapshot imaging (« 4D » image reconstruction) ?
- What about speckle data ?

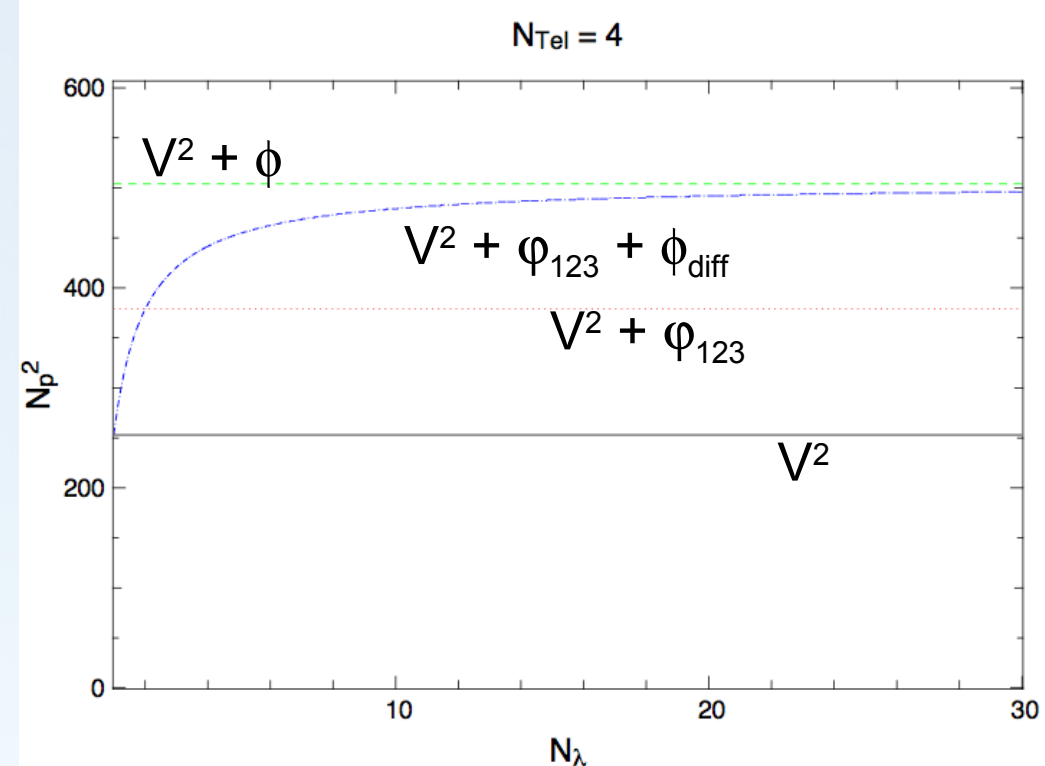


Que se passe-t-il lorsque l'on ajoute des longueurs d'ondes en interférométrie?

CLEAN-like



Reconstruction d'images



Multiwavelength imaging / model-fitting

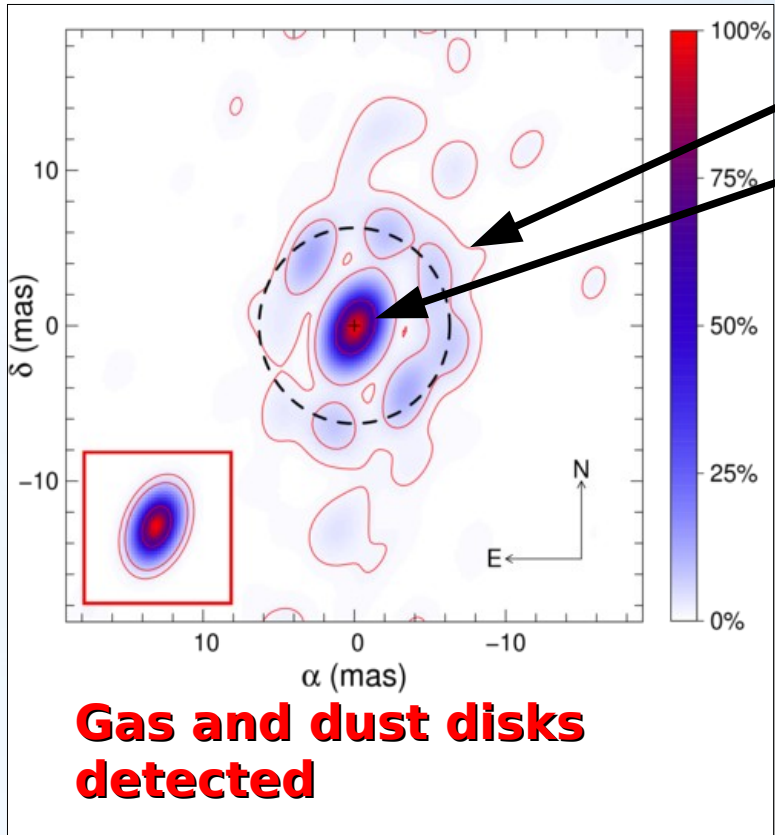
- Self-calibration algorithm
Millour et al. 2011
- ANR POLCA will provide chromatic algorithms
 - Understand noises
Schutz et al. 2013
 - Develop new algorithms
 - PAINTER
Schutz et al. 2014
 - MIRA3D
work in progress Thiebaut
- Chromatic LITpro
Tallon et al. 2014 SPIE
- FitOmatic prototype tool
Millour et al. 2009 A&A
- SPIDAST
Cruzalèbes et al. 2013 MNRAS



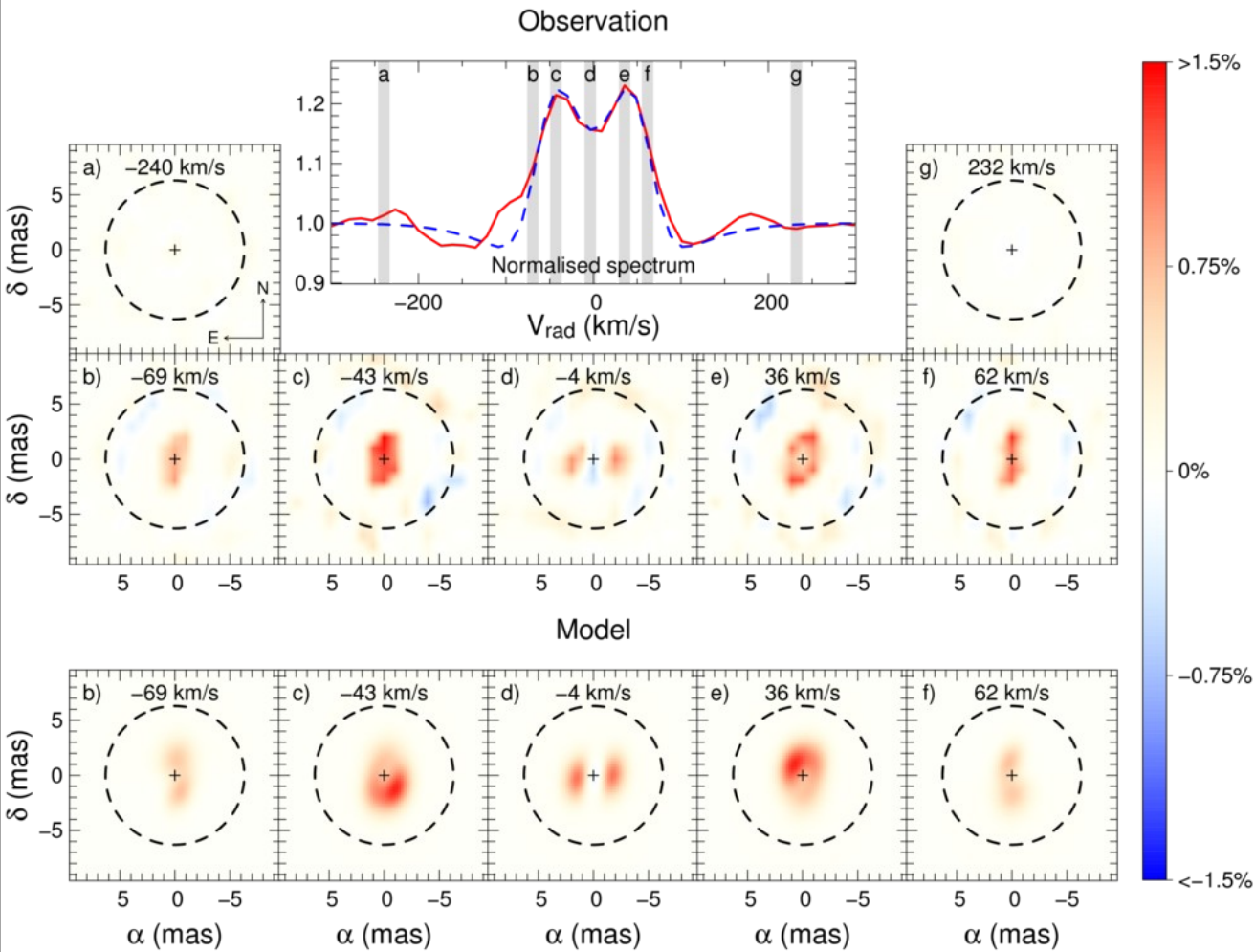
Multiwavelength imaging

3 Pup : supergiant A[e] star

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



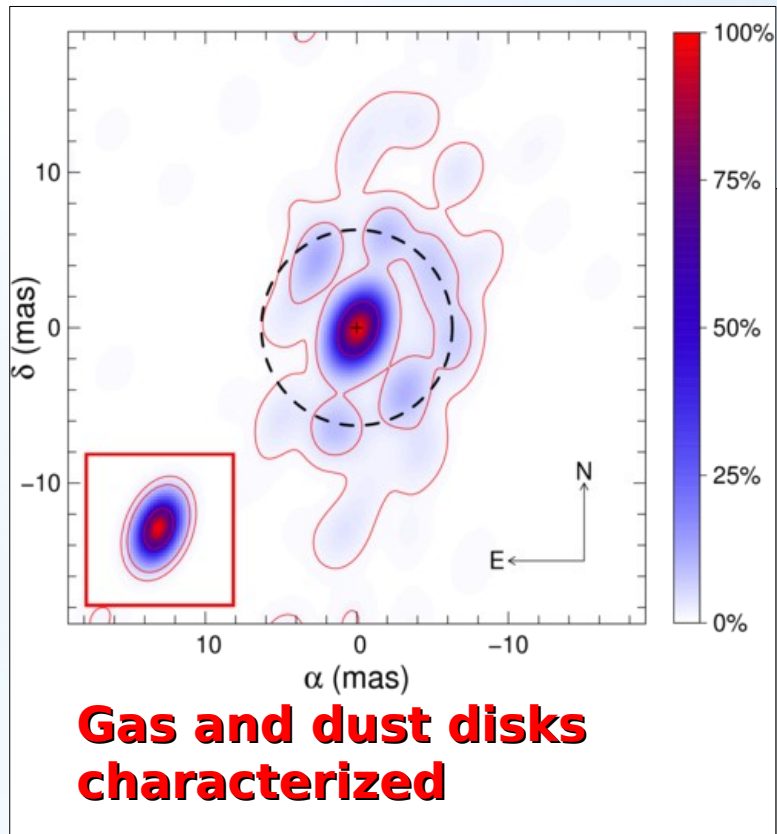
Millour et al. 2011



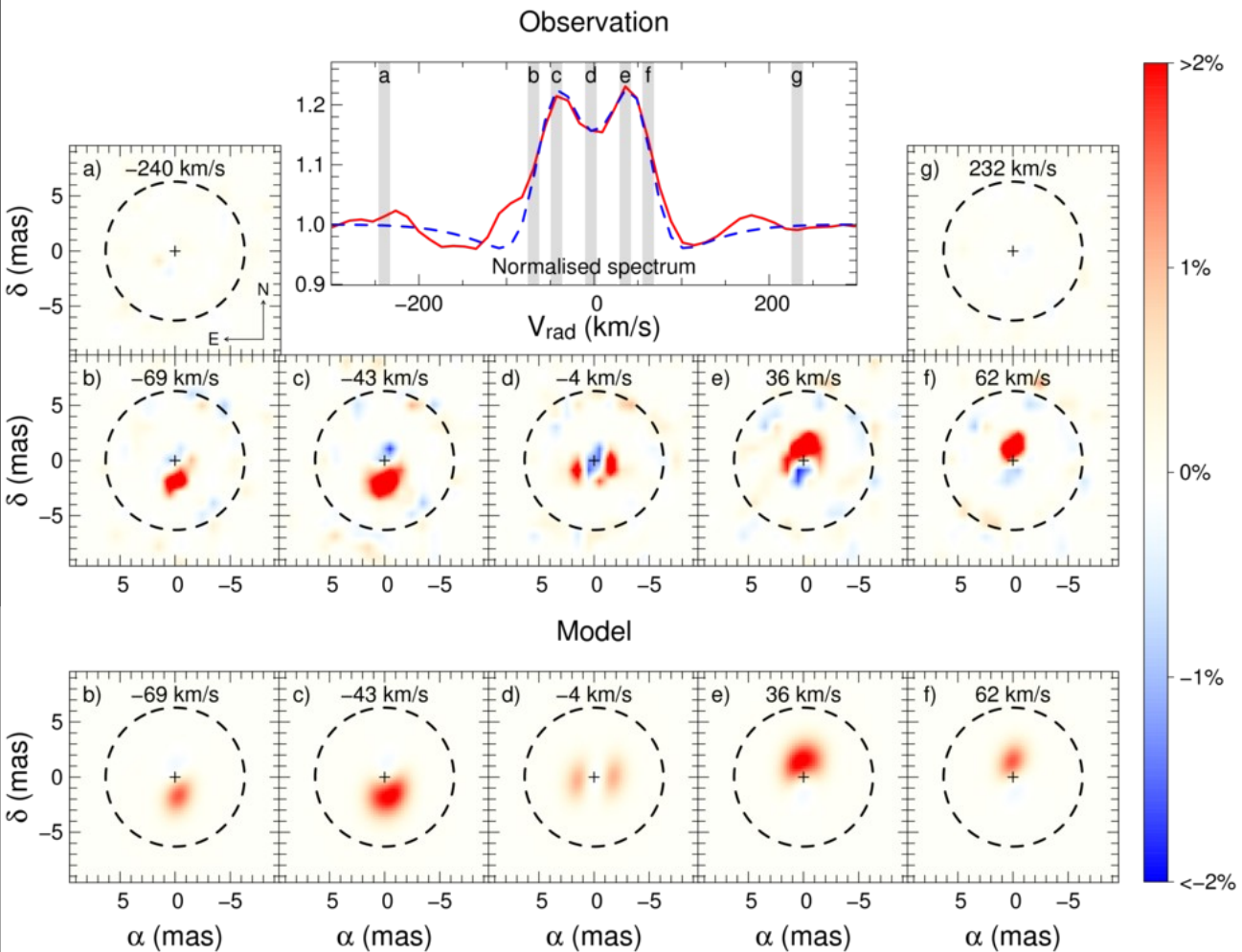
Multiwavelength imaging

3 Pup : supergiant A[e] star

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



Millour et al. 2011



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?



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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

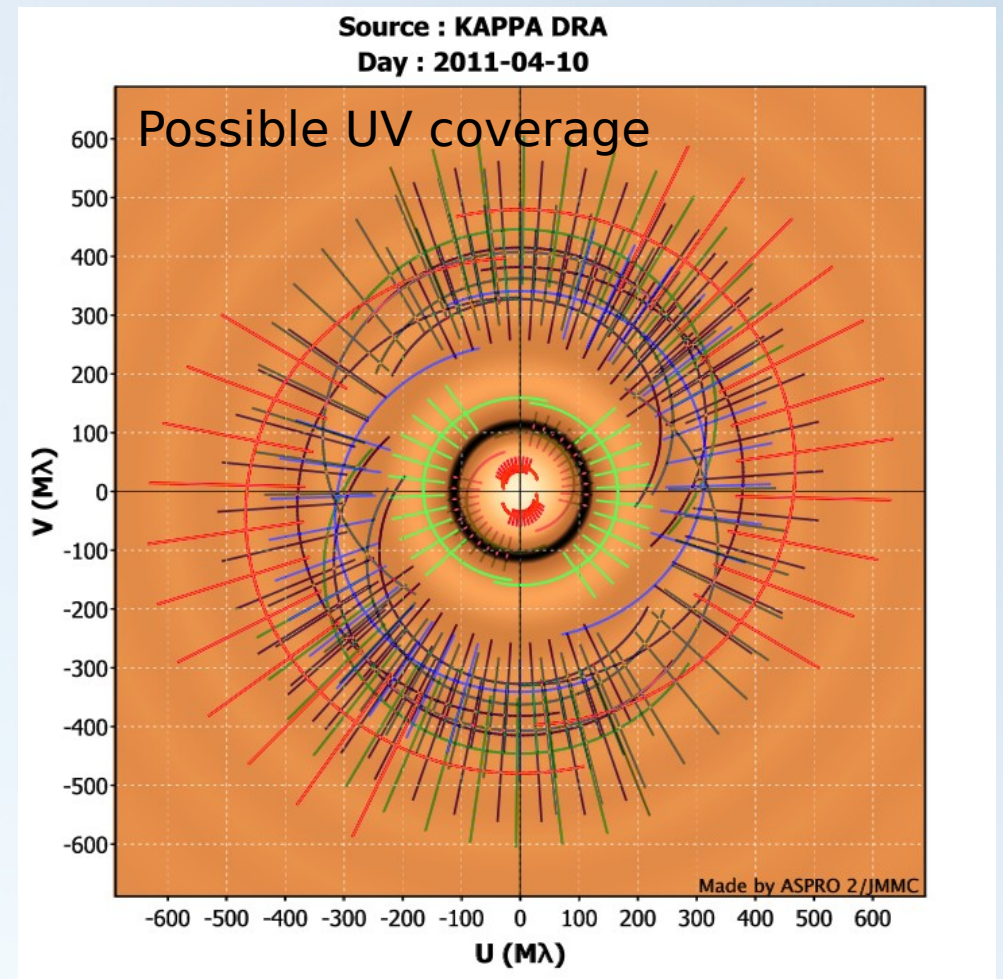
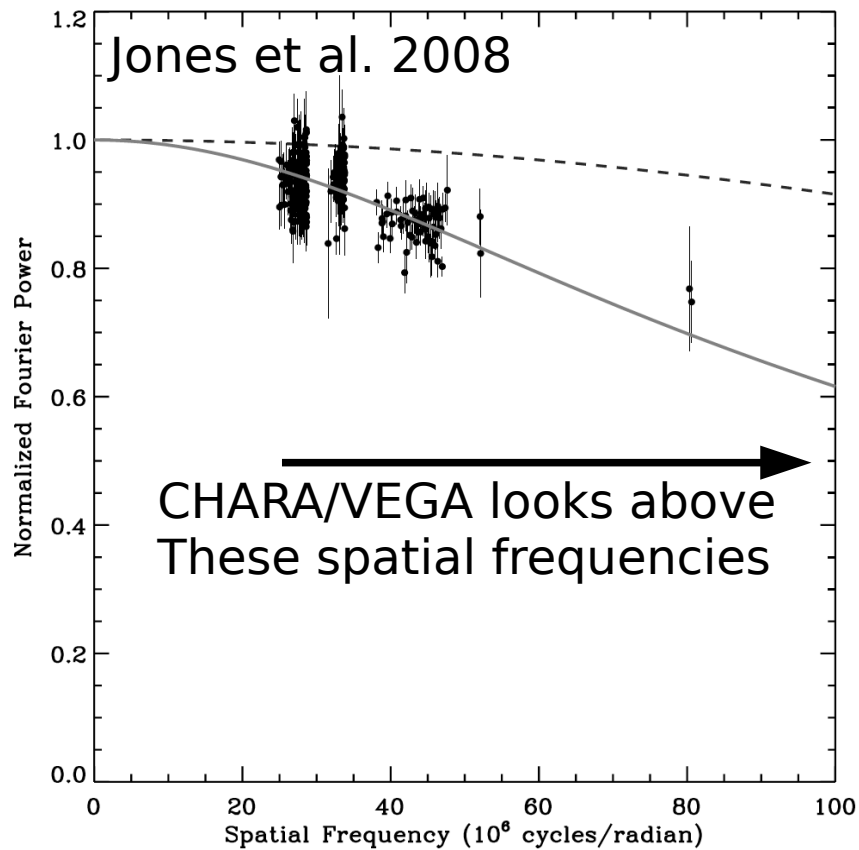
C. Observing Participants – Potentially all proposers

D. Proposal Title – Imaging the possibly warped disk of the Be star Kappa Draconis

E. Abstract (Clearly and briefly state your scientific goals and indicate if this is a PhD thesis project) –

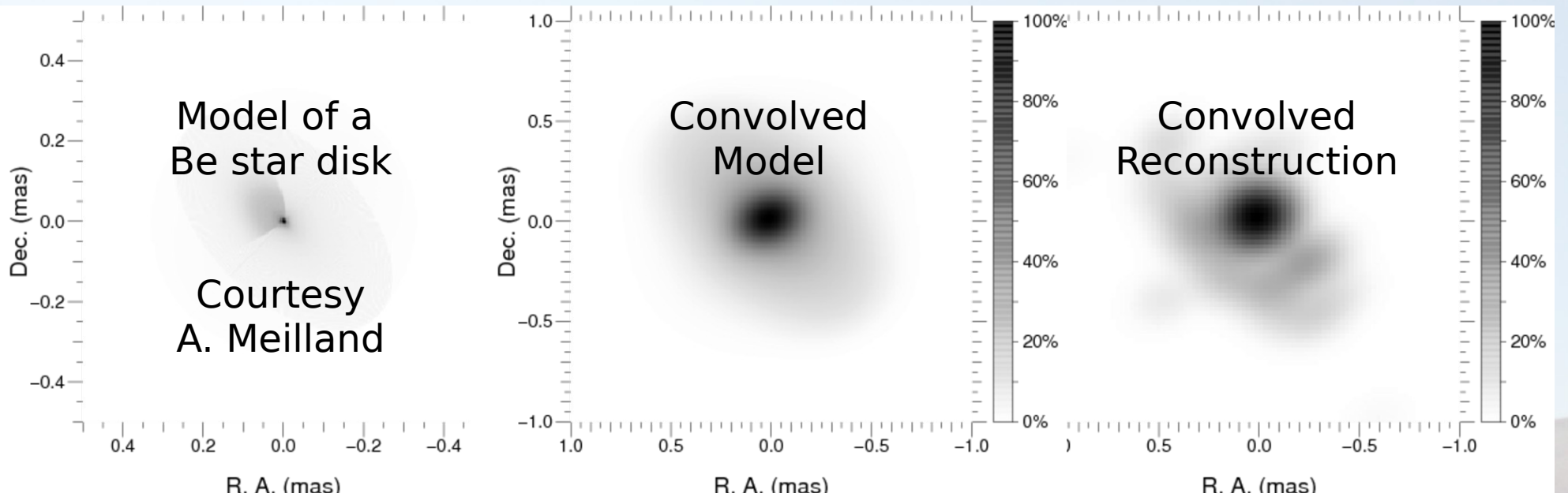
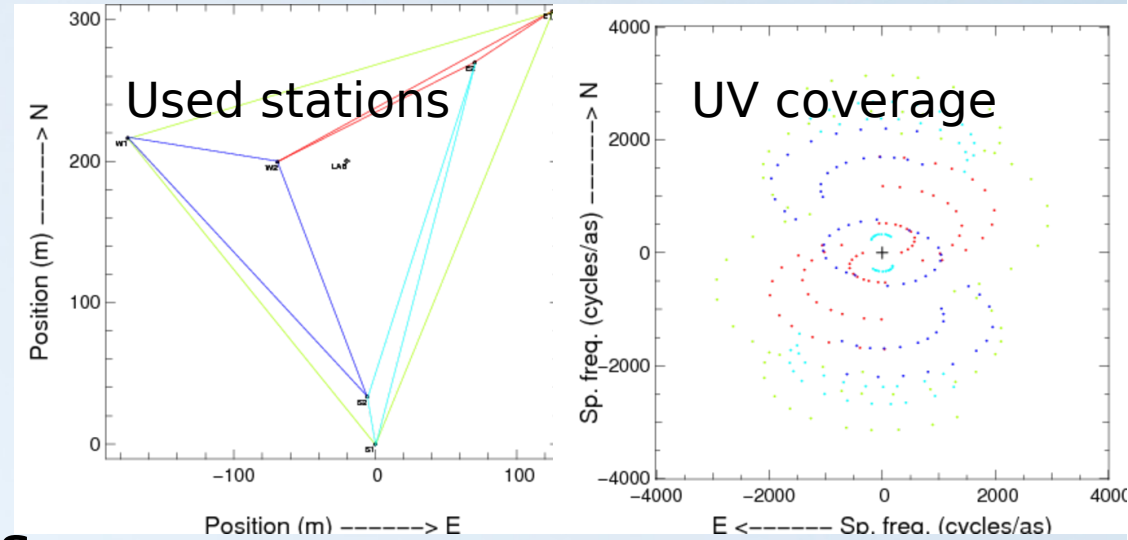
ula

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



Imaging the disk of Be stars

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



Model of a
Be star disk

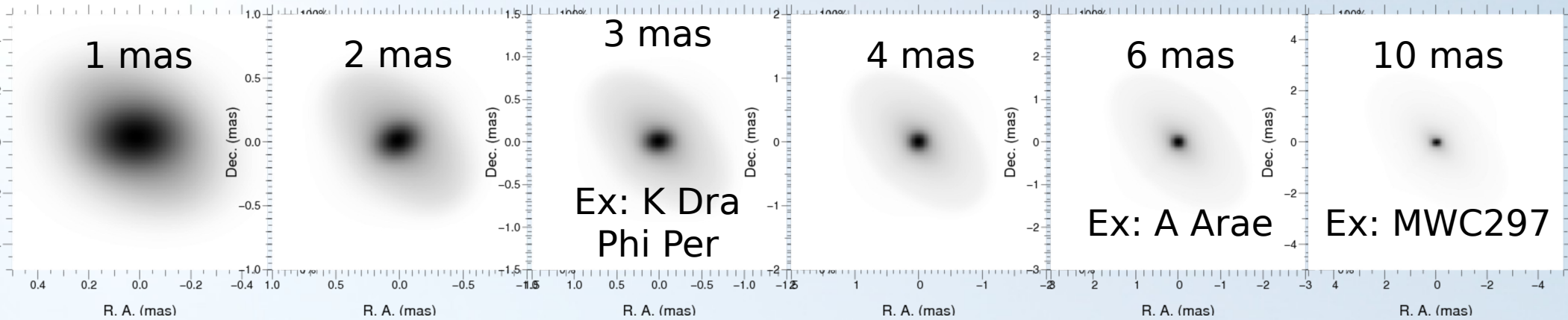
Courtesy
A. Meilland

Convolved
Model

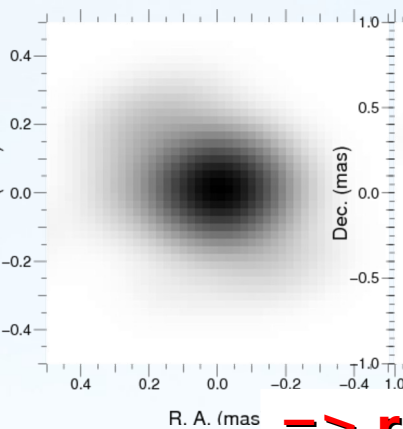
Convolved
Reconstruction

Imaging the disk of Be stars

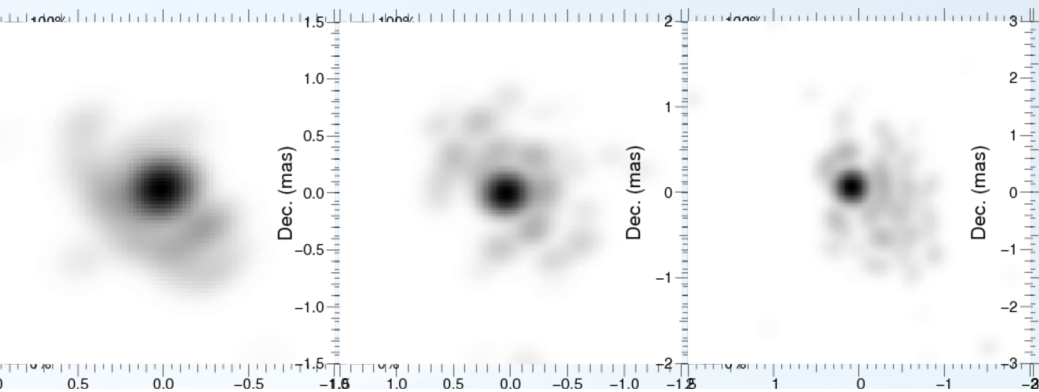
Convolved model



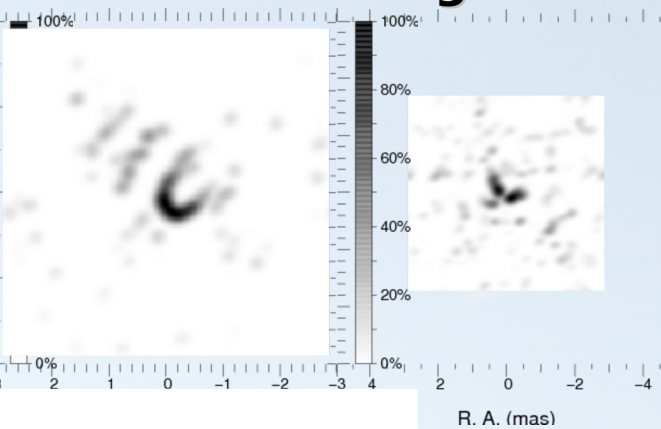
Under-resolution



Convolved reconstructed image



Aliasing

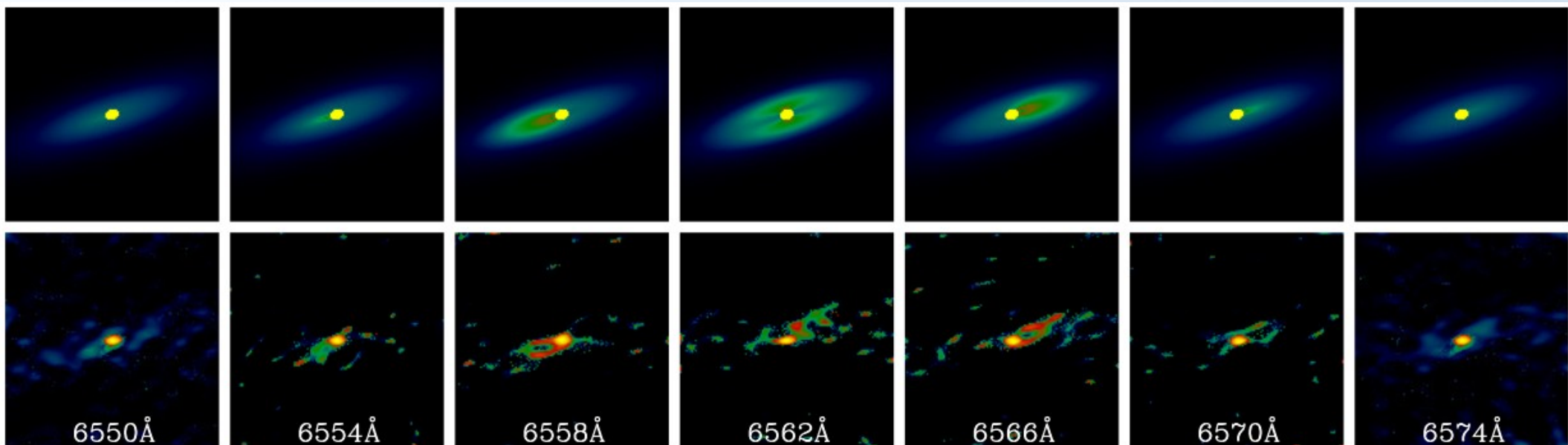


**=> range of feasibility with CHARA/VEGA:
from 1 to 4 mas disk size... OK for Kappa Dra!
BUT lots of asymmetries induced by
large noise on closure phase (to be verified)
How self-cal improves the situation has to be checked**

Actual VEGA images !

Mourard et al. Submitted
Be star Phi Persei

Model



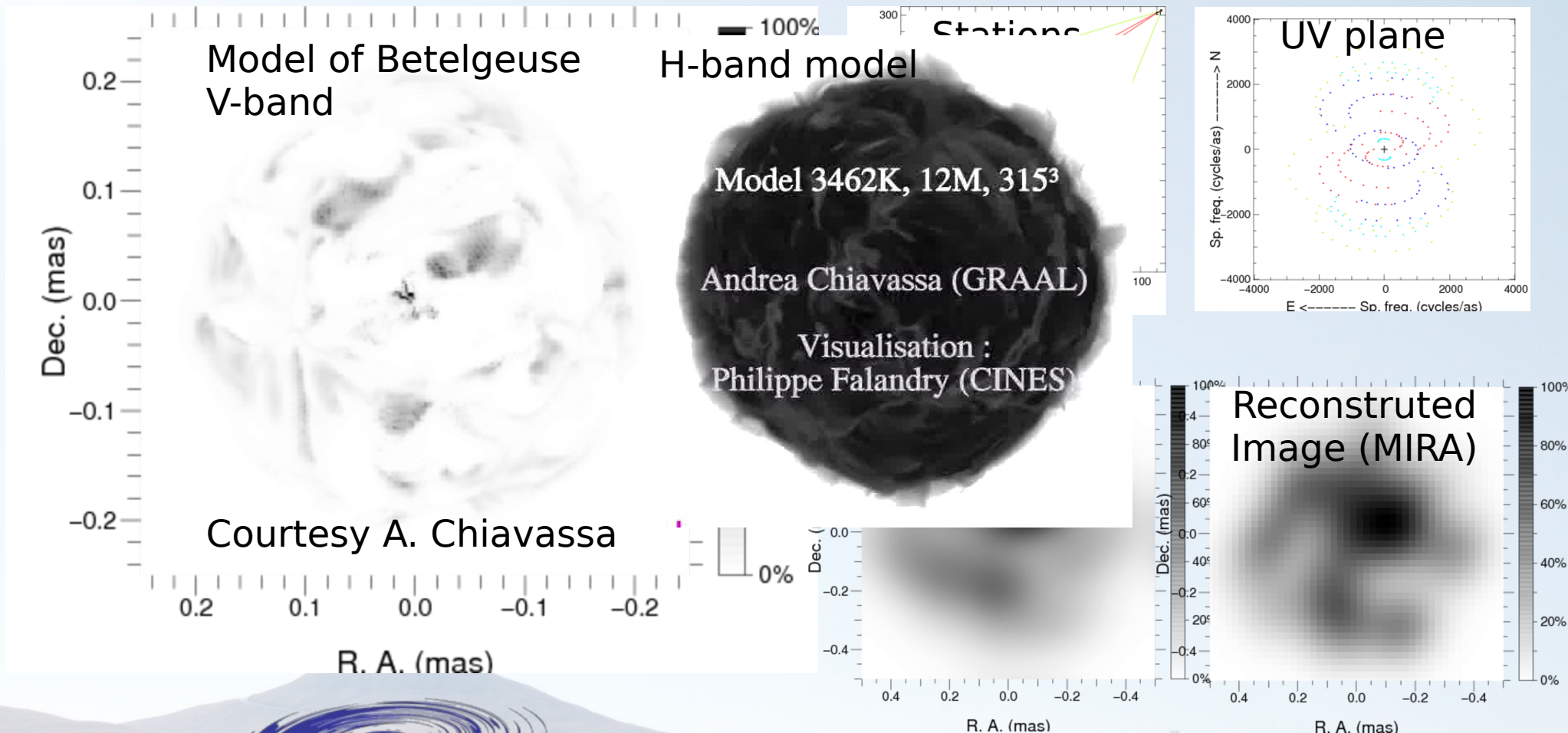
Image



Wavelength

Imaging the spotty surface of [supergiant] stars

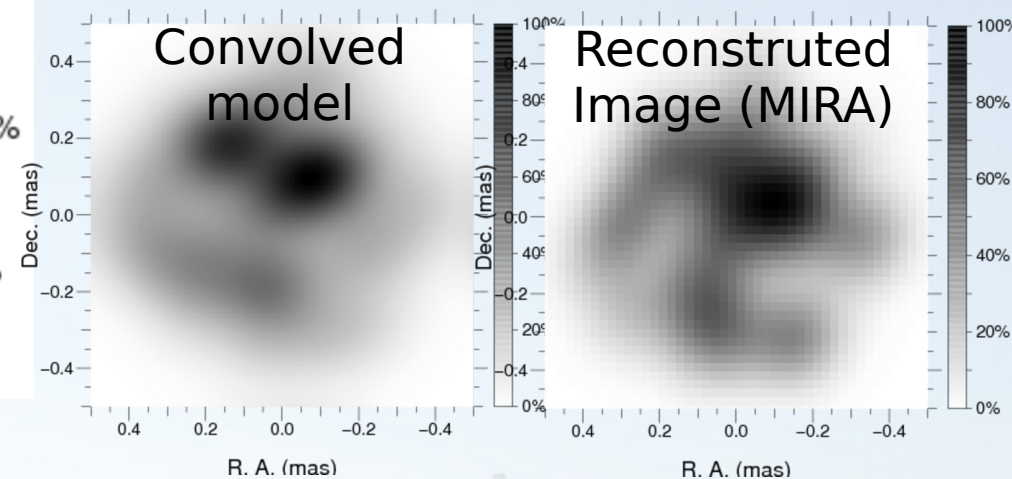
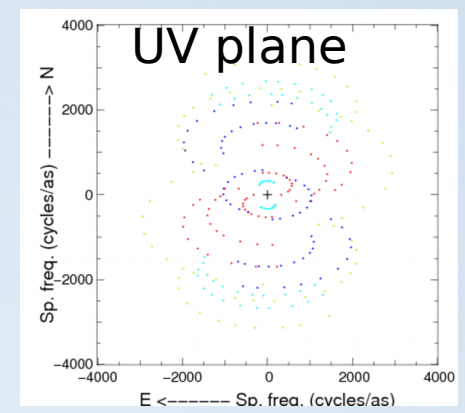
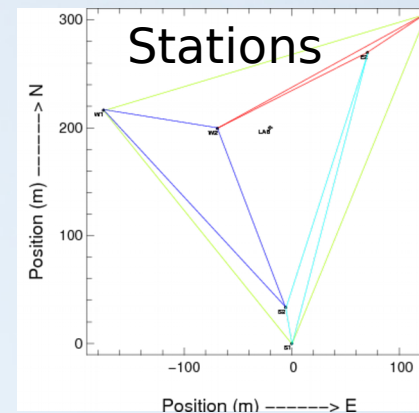
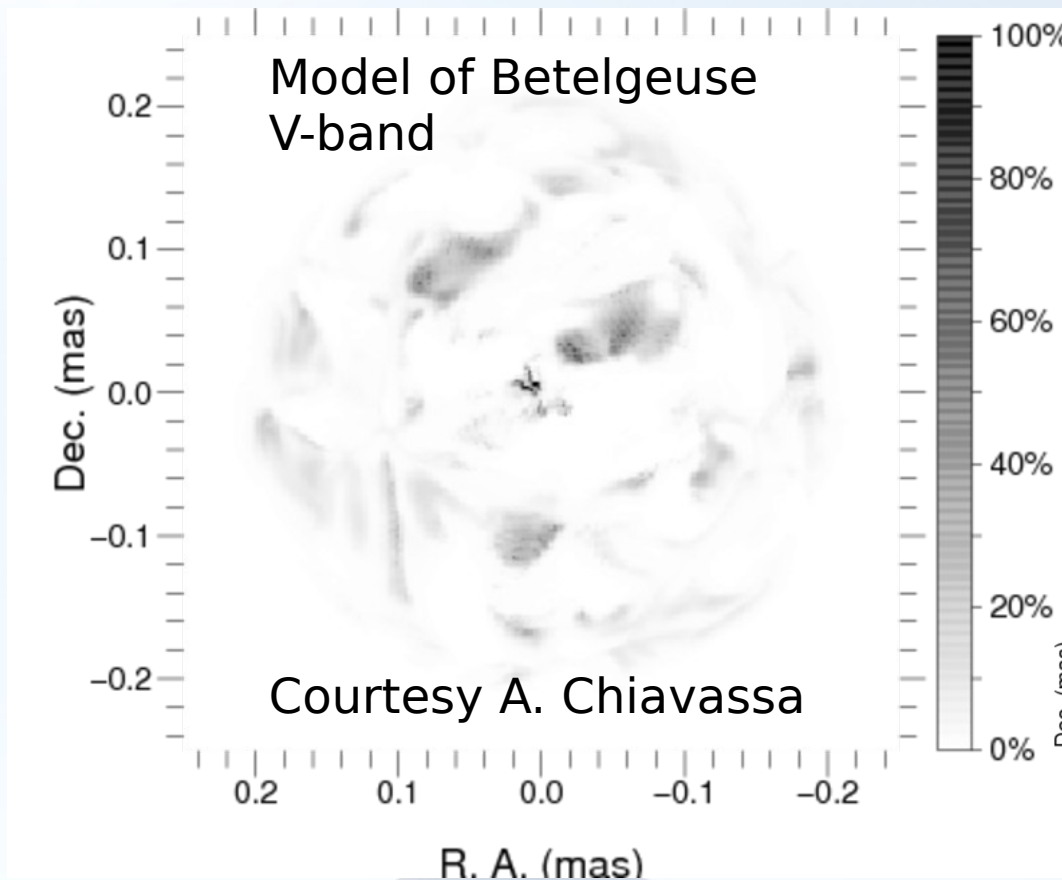
- Case-study proposed by A. Chiavassa, O. Delaia



Courtesy A. Chiavassa

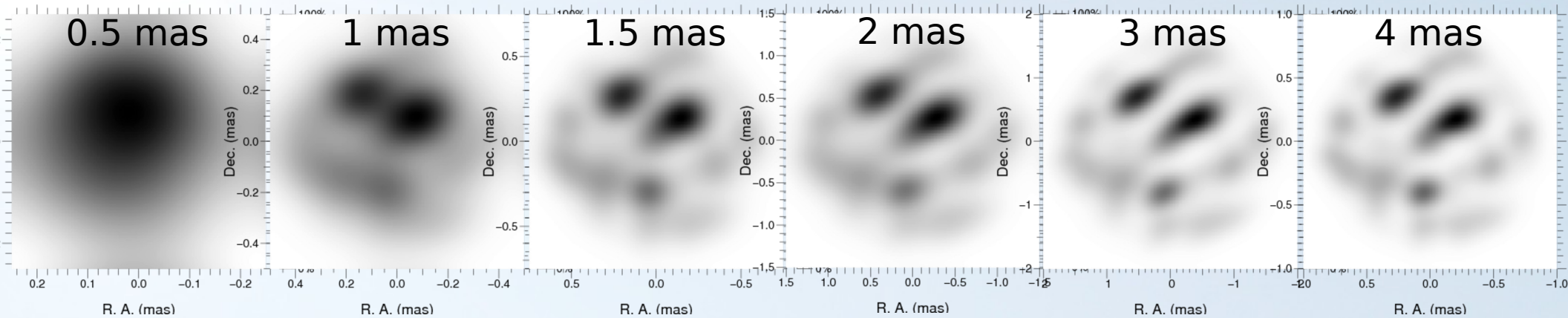
Imaging the spotty surface of [supergiant] stars

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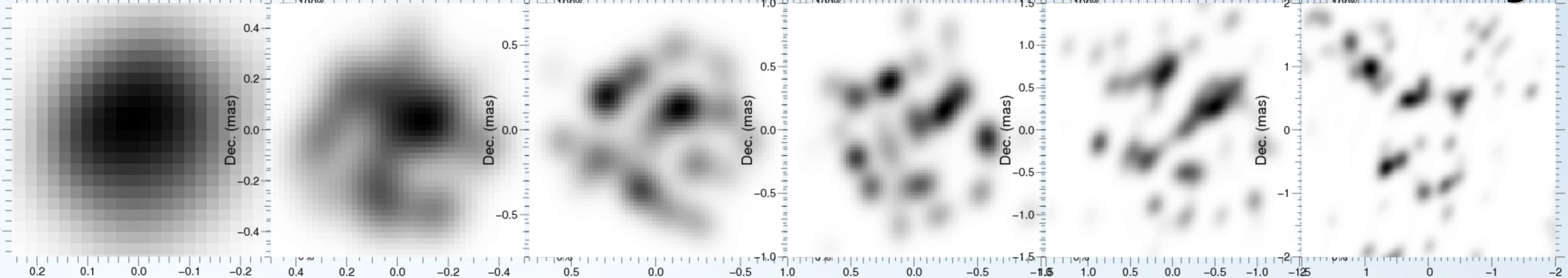
Influence of the star size

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

Summary

- UV coverage
 - long AND short baselines
 - Ntel : 4 minimum, 6 better
- Facilities
 - CHARA **or** VLT ?
 - CHARA **and** VLT ?
- Spectro-interferometry highly recommended
 - Software do exist now : self-cal, PAINTER, fitOmatic, LITpro
 - Imaging with no or few closure phases is possible
- Low visibilities !
 - Baseline bootstrapping ?

