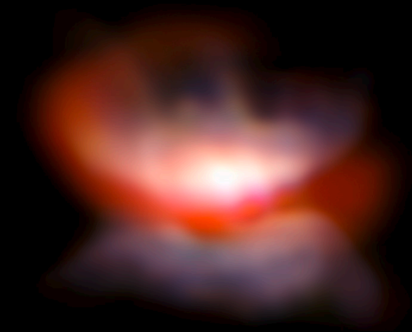
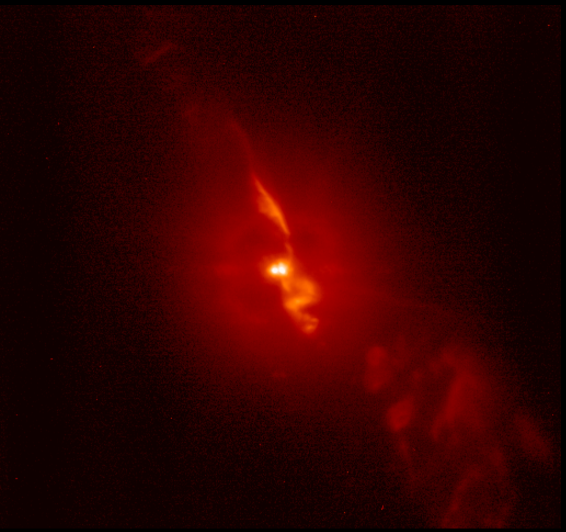
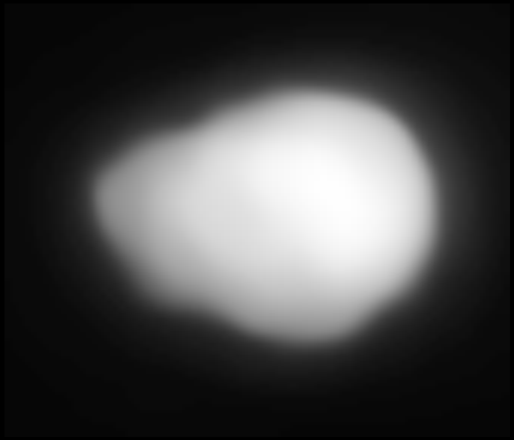
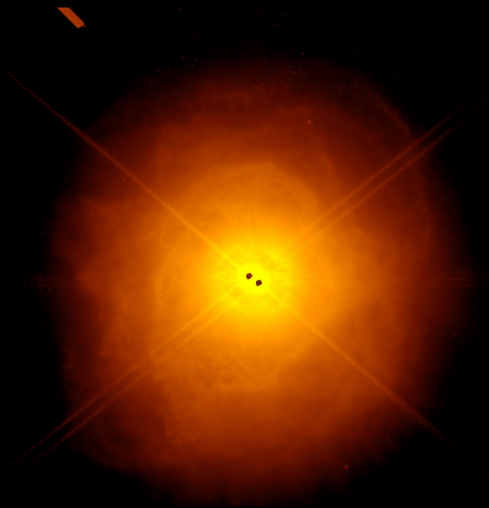


“Other Science” GTO with SPHERE

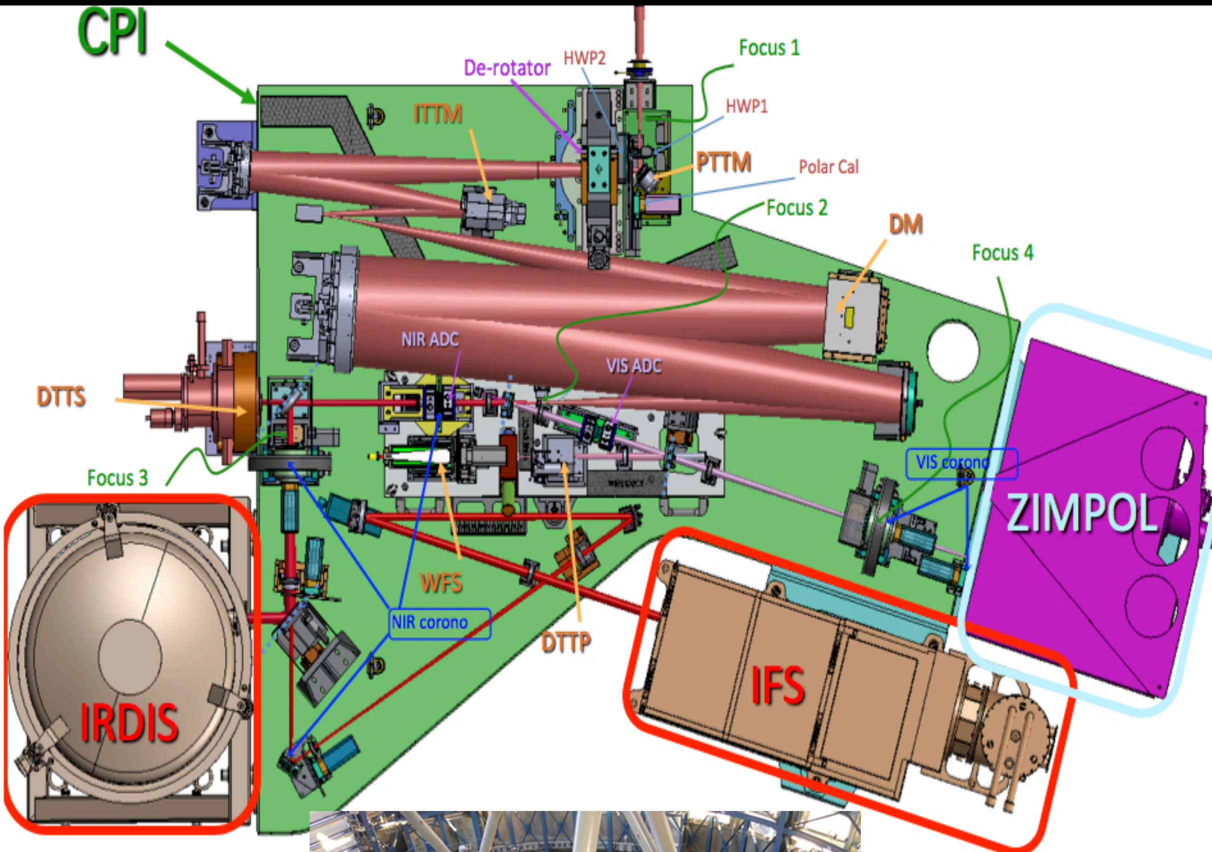


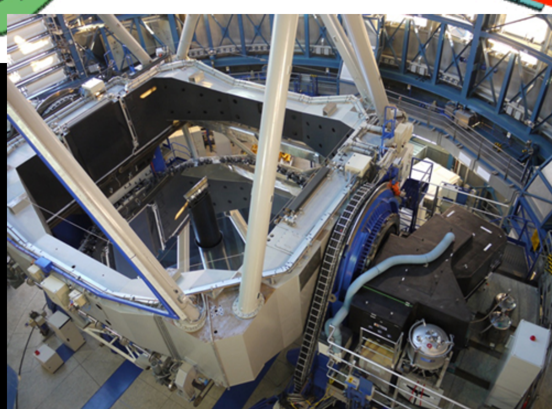




Eric Lagadec
Laboratoire Lagrange
Observatoire de la Côte d’Azur

SPHERE: The VLT planet finder





- New generation extreme adaptive optics on the VLT
- First light in 2014
- Visible and NIR imaging, polarimetry, IFU
- Consortium: IPAG, LAM, LESIA, Lagrange, Amsterdam, Heidelberg, Zurich, Geneva
- 250 nights of GTO!

Planets direct imaging

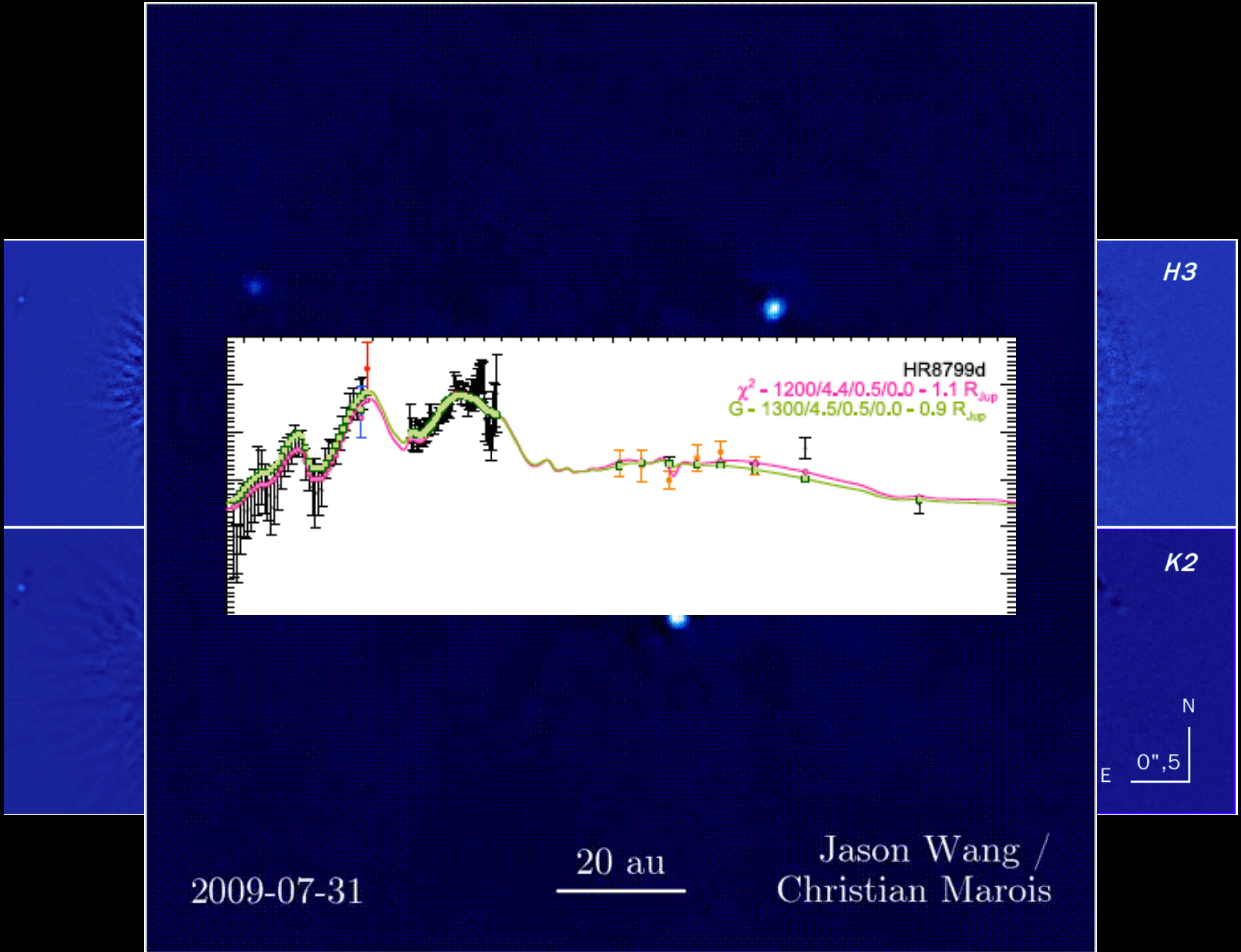
Planets direct imaging

Stars are 1 billion times brighter than planet.
Like a glow worm next to a lighthouse...

Planets direct imaging

Planets direct imaging

And very far!
A glow worm in New York.



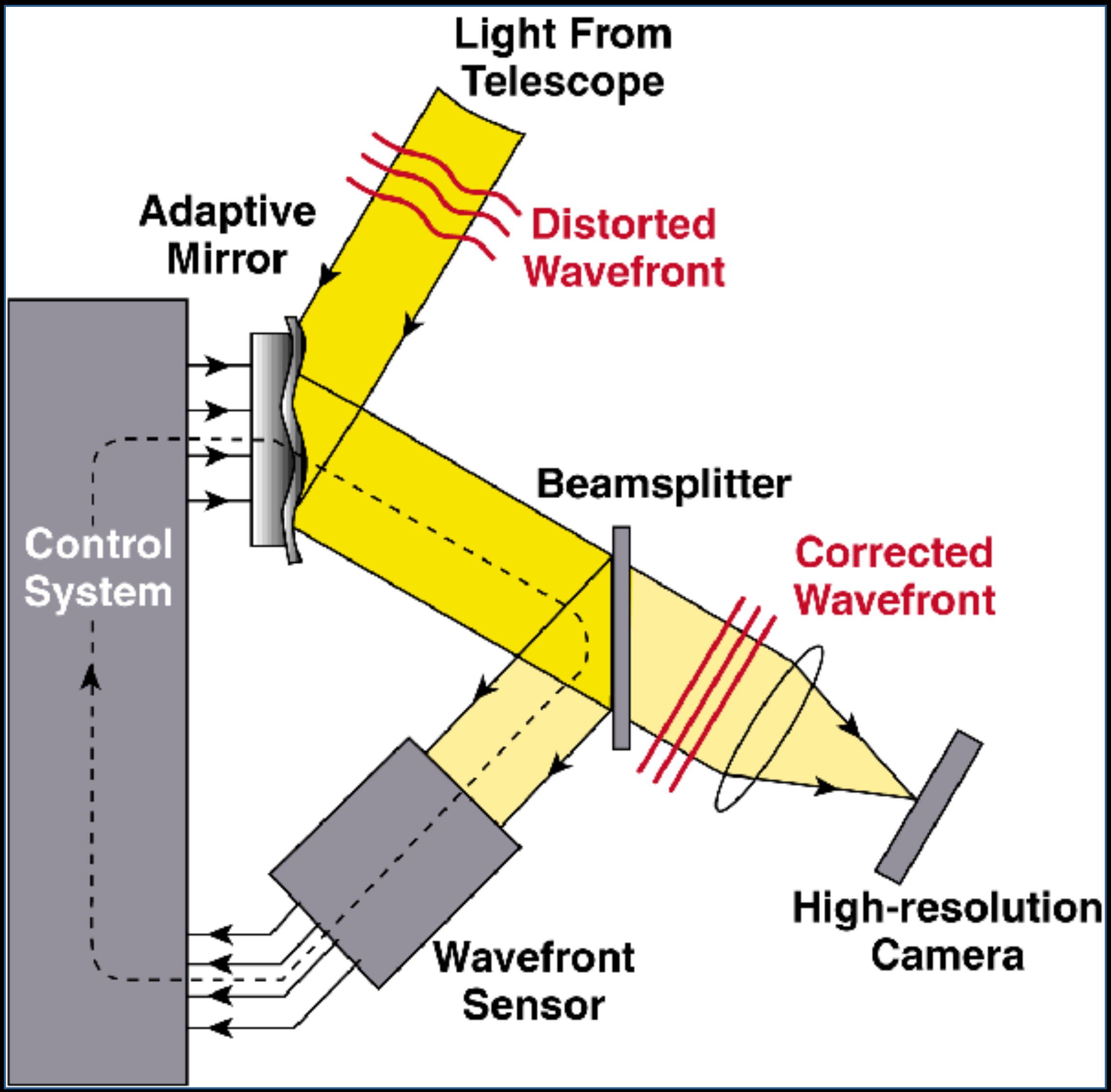
HR8799d
χ² - 1200/4.4/0.5/0.0 - 1.1 R_Jup
G - 1300/4.5/0.5/0.0 - 0.9 R_Jup
H3
K2
N
E
0",5
20 au
2009-07-31
Jason Wang /
Christian Marois

3 instruments in one

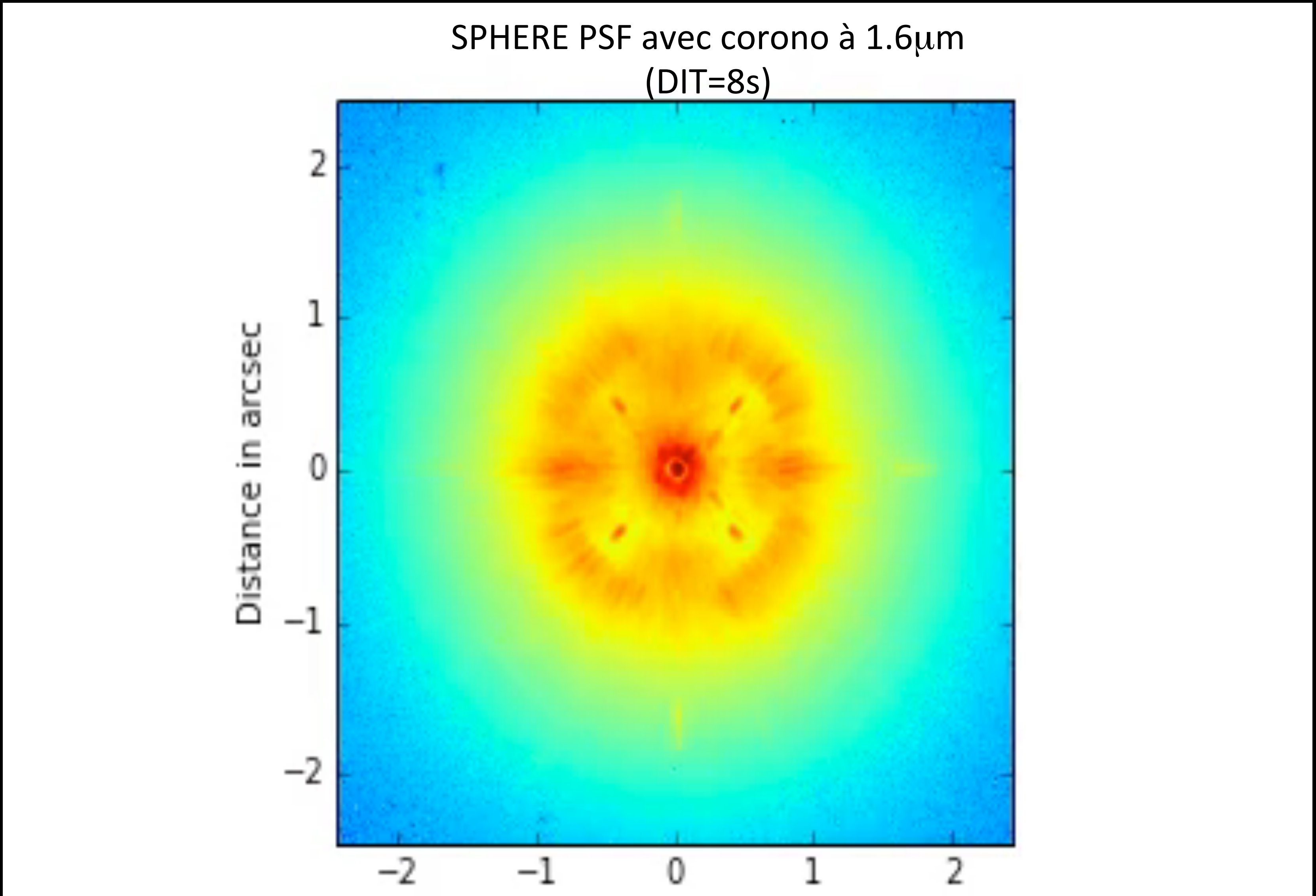
- Extreme adaptive optics (~1400 actuators)
- Many coronographs
- IRDIS: NIR differential imaging + polarimetry + spectroscopy(13.5”*13.5”)
- ZIMPOL: optical imaging + polarimetry (3.5”*3.5”)
- IFS: NIR Integral Field Spectroscopy (1.75”* 1.75”)

Deformable mirror

Feedback loop: next cycle corrects the (small) errors of the last cycle

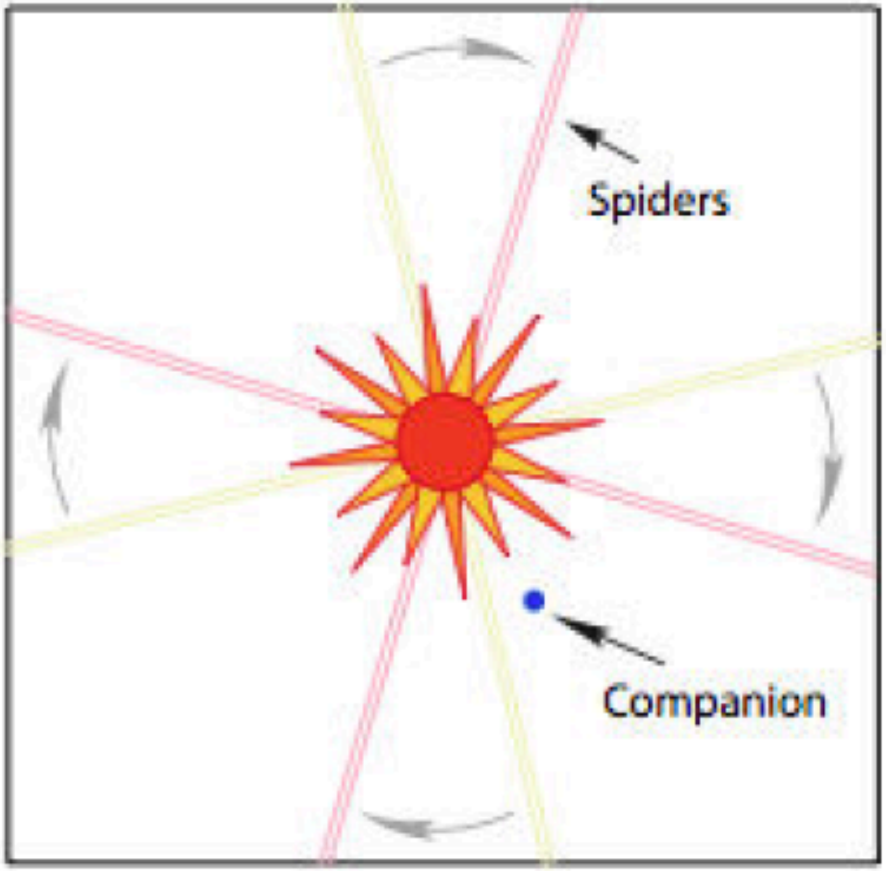


SPHERE: fairly stable !

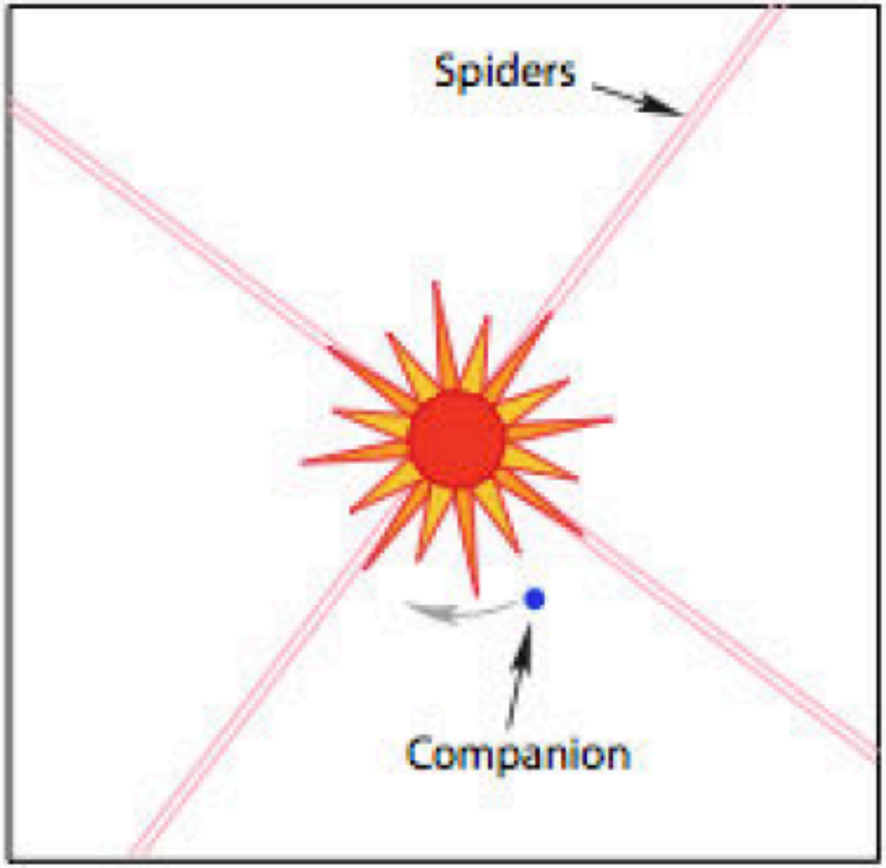


SPHERE: the lord of the rings

Angular differential imaging



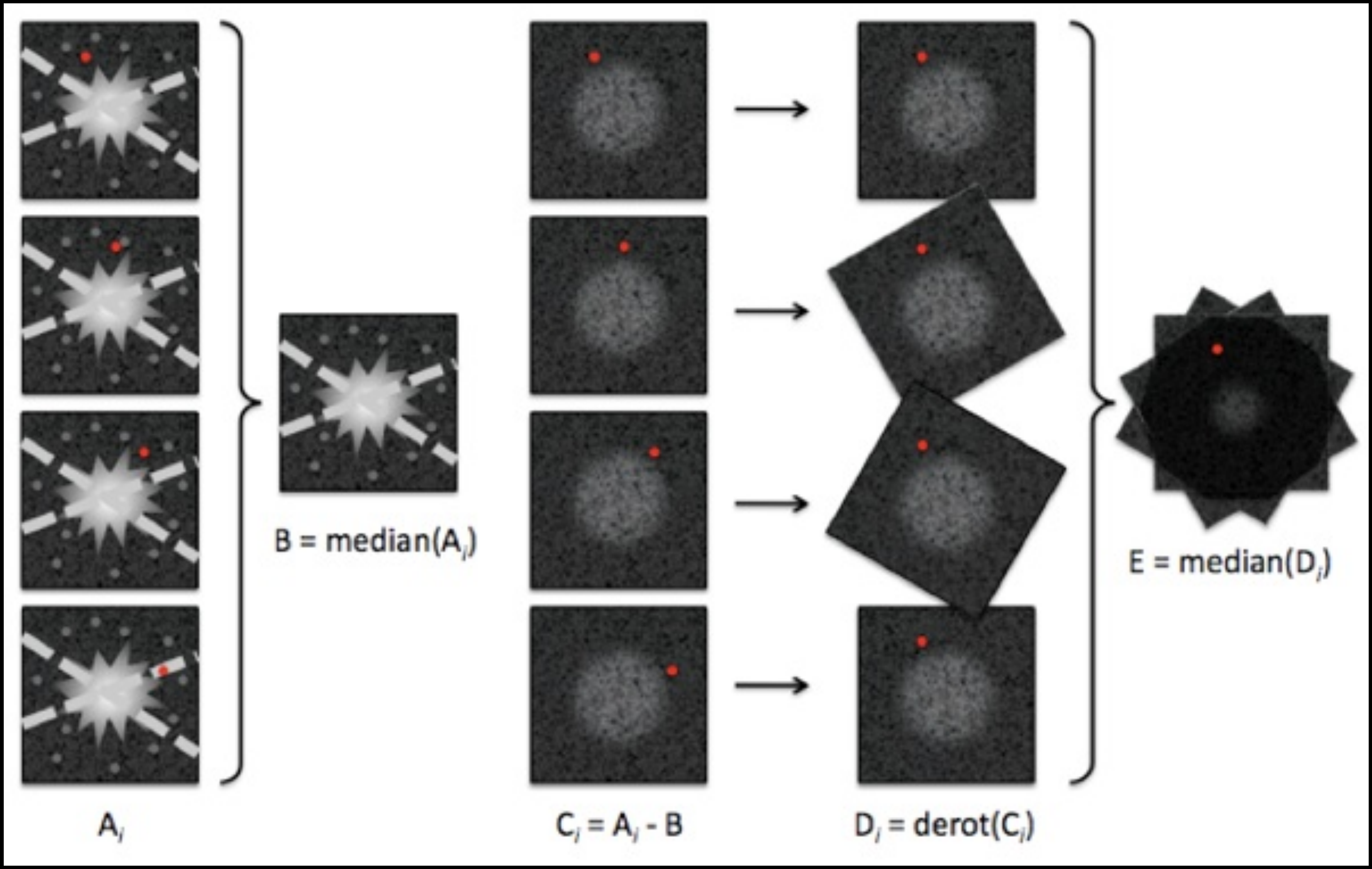
Field tracking



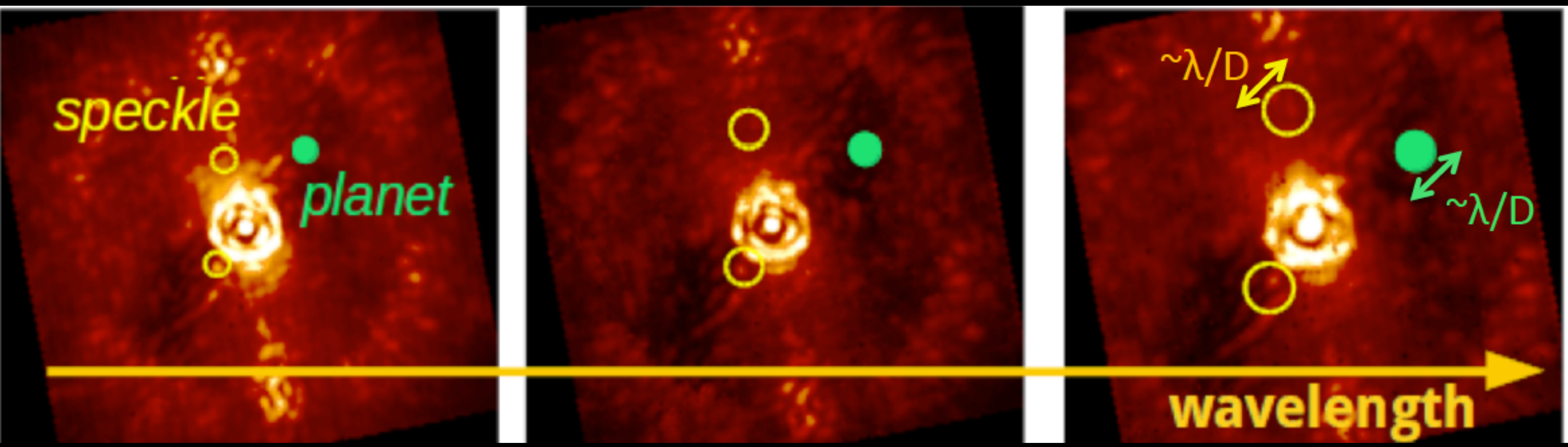
Pupil tracking

We use the rotation of the field to enhance the contrast!

Angular differential imaging

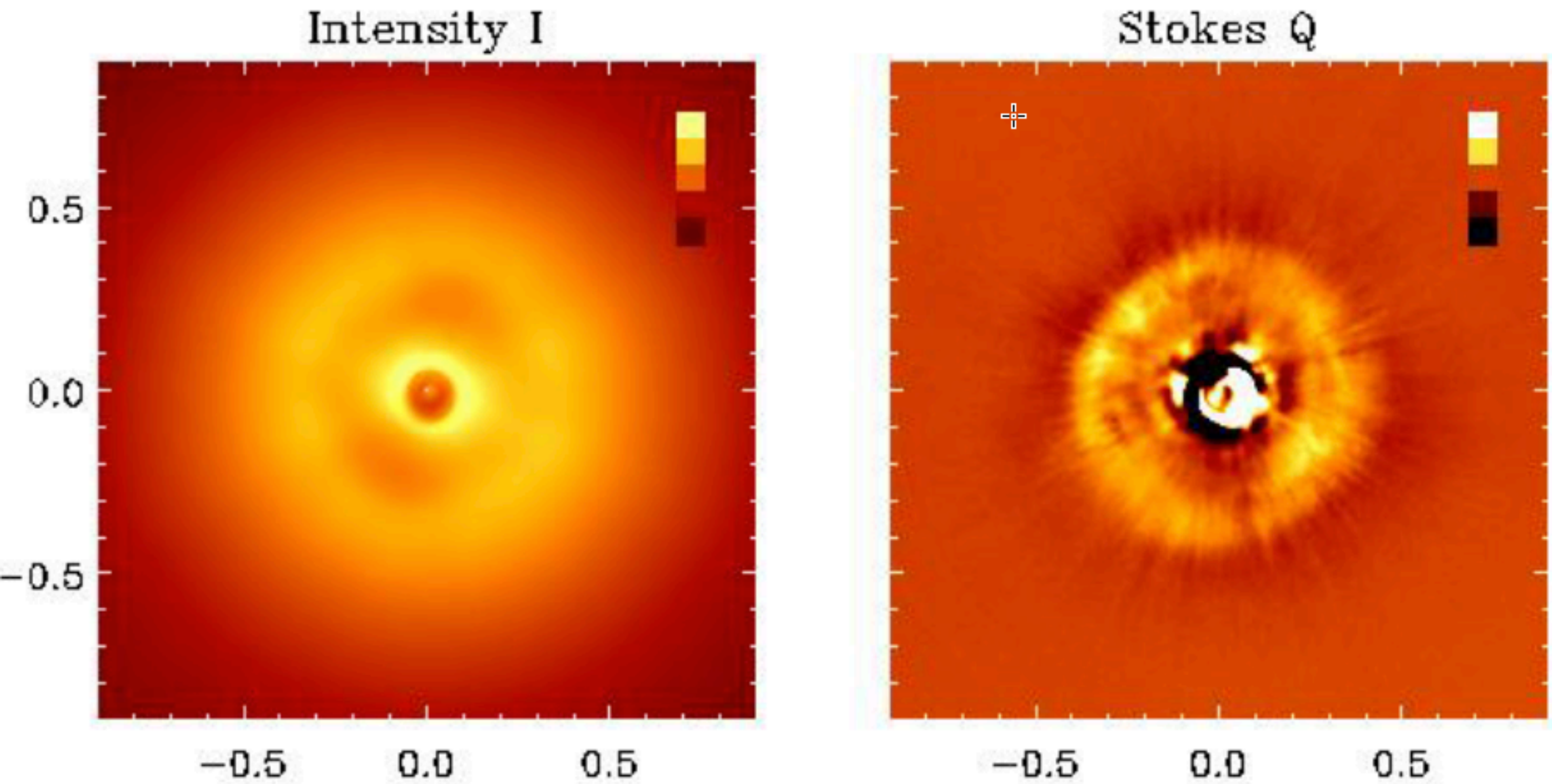


Spectral differential imaging



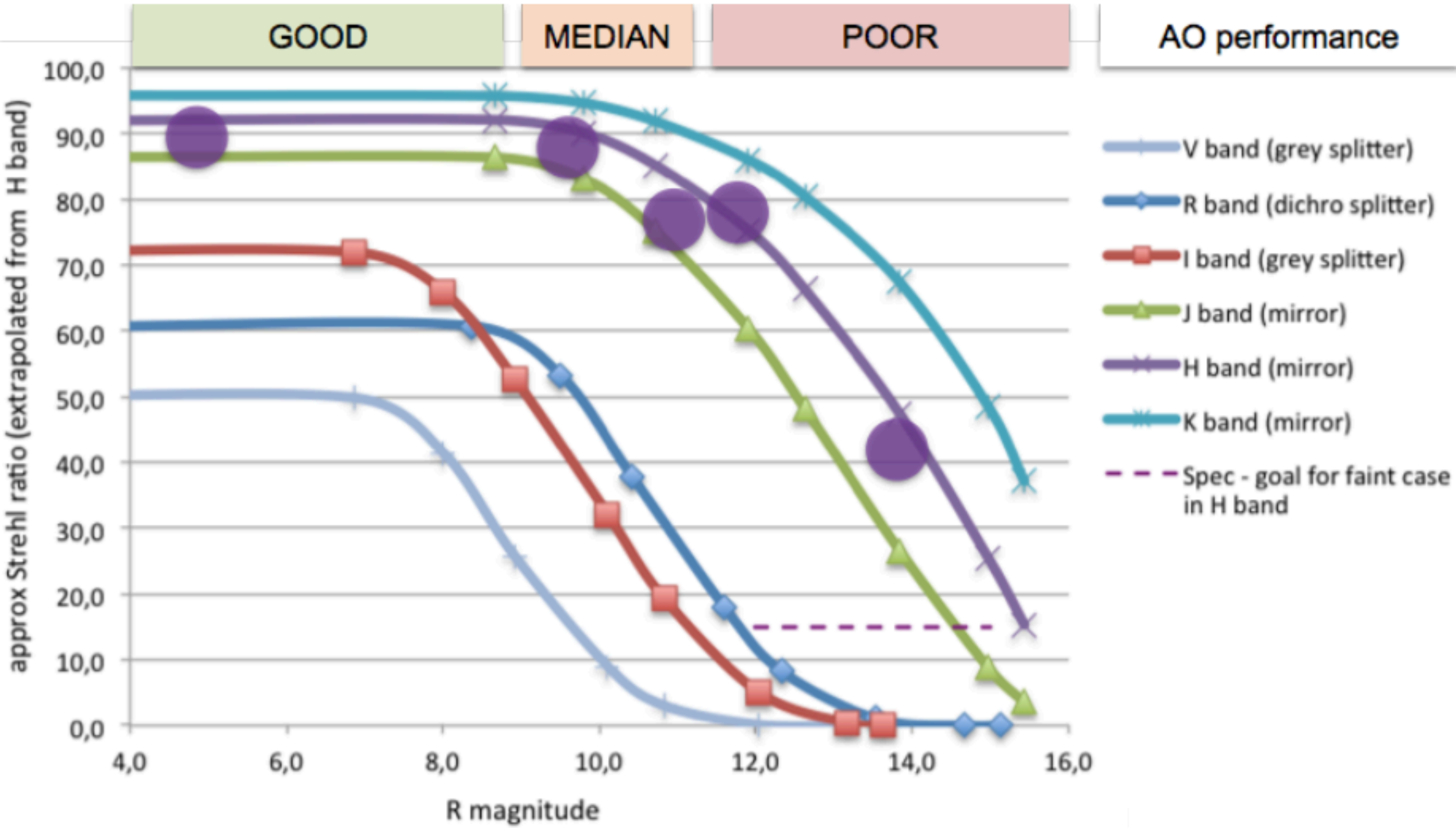
Speckles move with wavelenght, planets do not!

Polarisation differential imaging

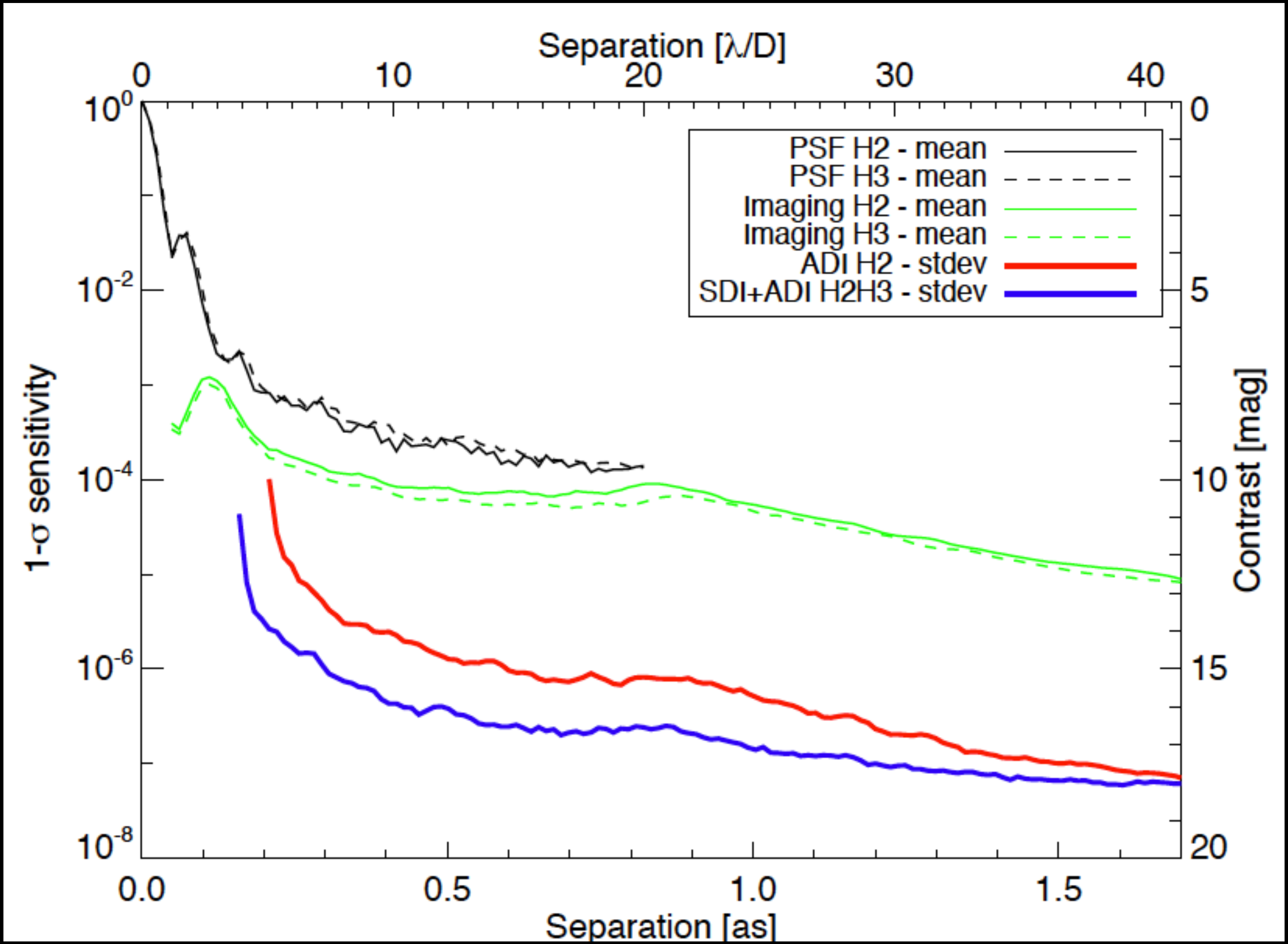


Light from the star (usually) not polarized, discs/planets polarized

SPHERE performances



SPHERE performances



SPHERE and Lagrange

Technical contributions:

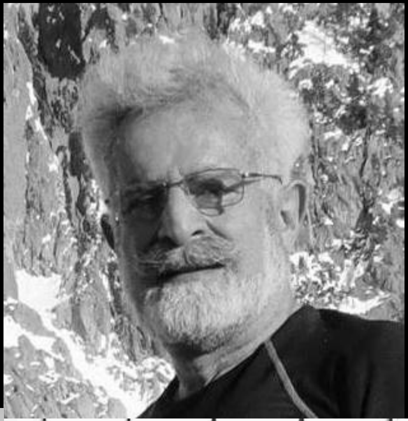
- Apodising coronographs
- Opto-mecanics
- High contrast laboratory tests

Planet detection algorithms:

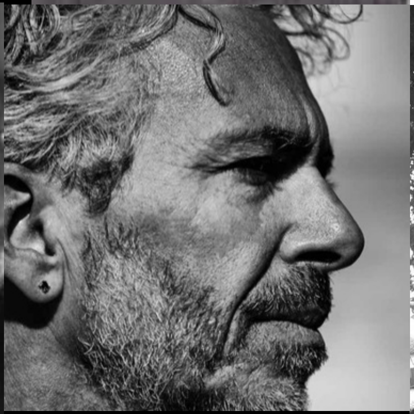
- Integration to the SPHERE pipeline

End to end numerical simulations

- CAOS/SPHERE






SPHERE Data Center

- Reduction of calibrations (every 24h)
- GTO data reduction within 24h
- Reduction for all data after ~2 years
- PI data reduction on demand
- Development of pipelines

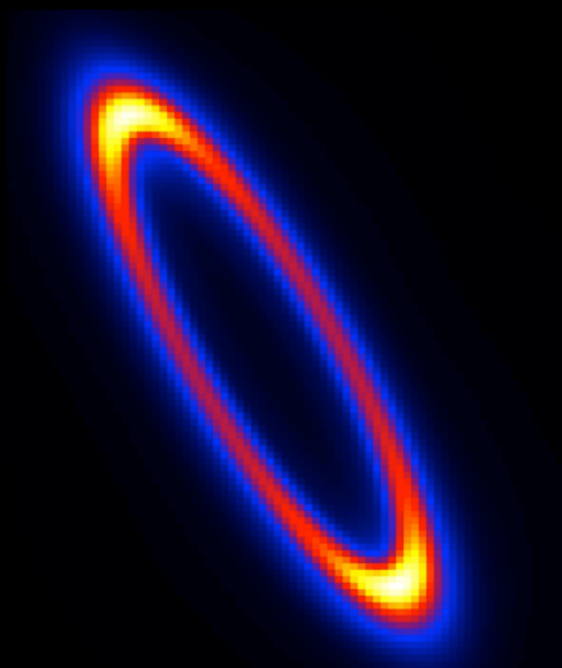
OSUG
Observatoire des Sciences de l'Univers de Grenoble

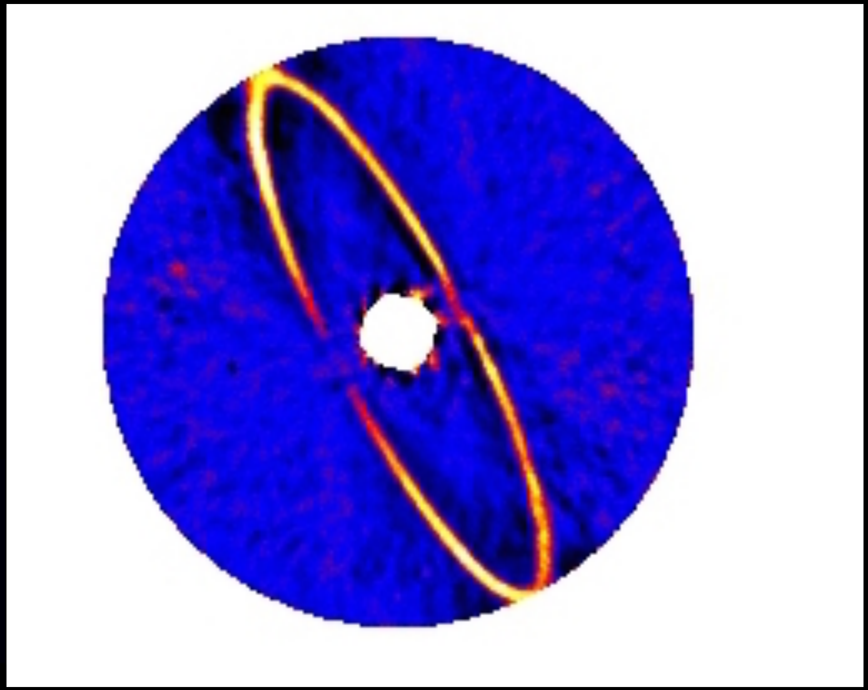
Observatoire de la CÔTE d'AZUR

l'Observatoire de Paris

Institut Pythéas
Observatoire des Sciences de l'Univers
Aix*Marseille Université

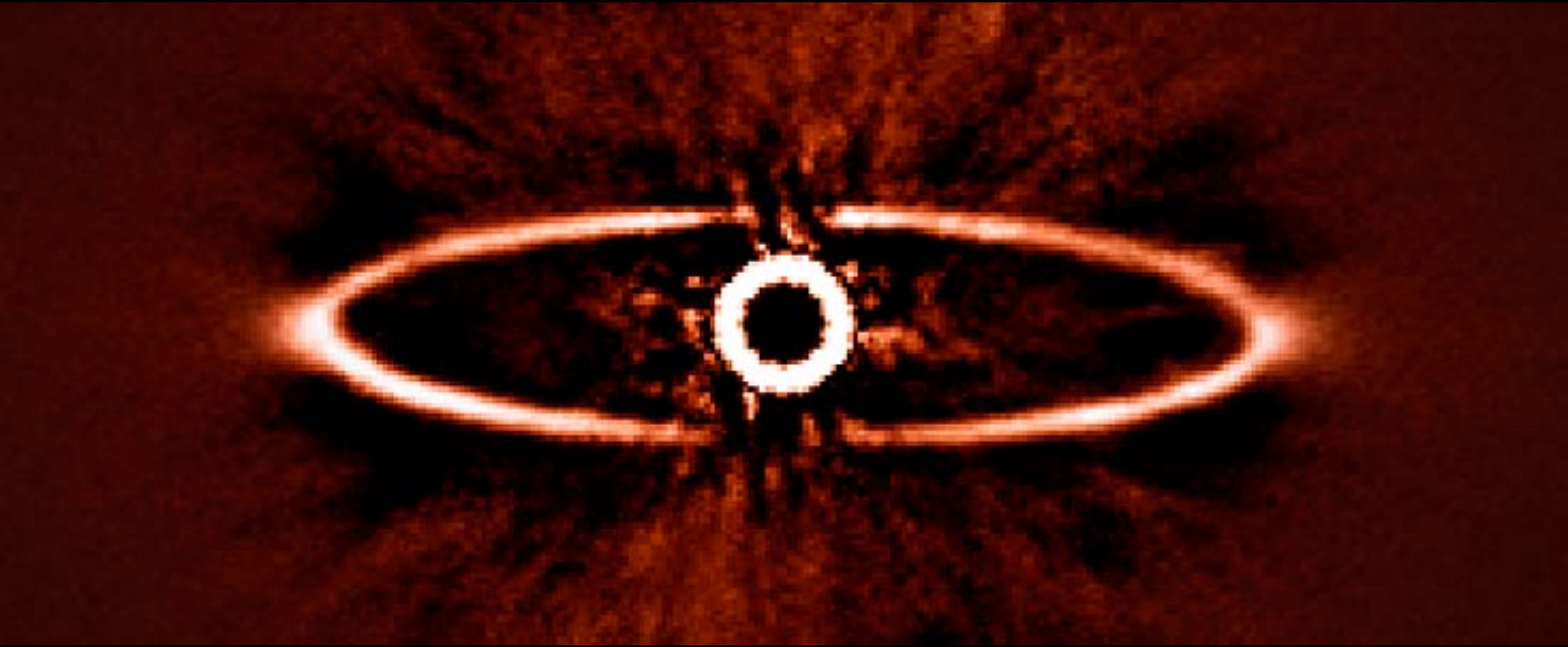
Discs!!



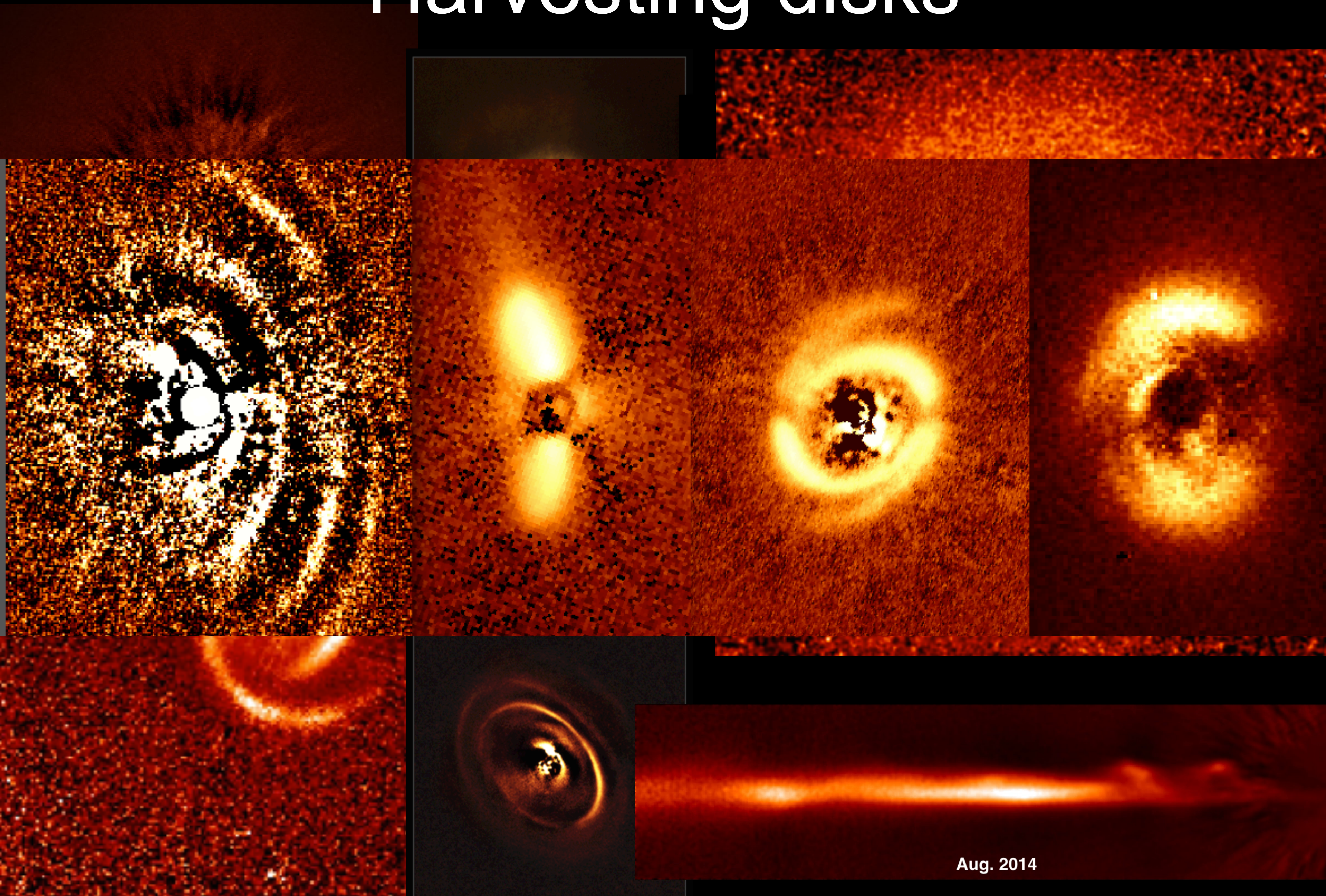


Ceci n’est pas un modèle!

Sauron's eye

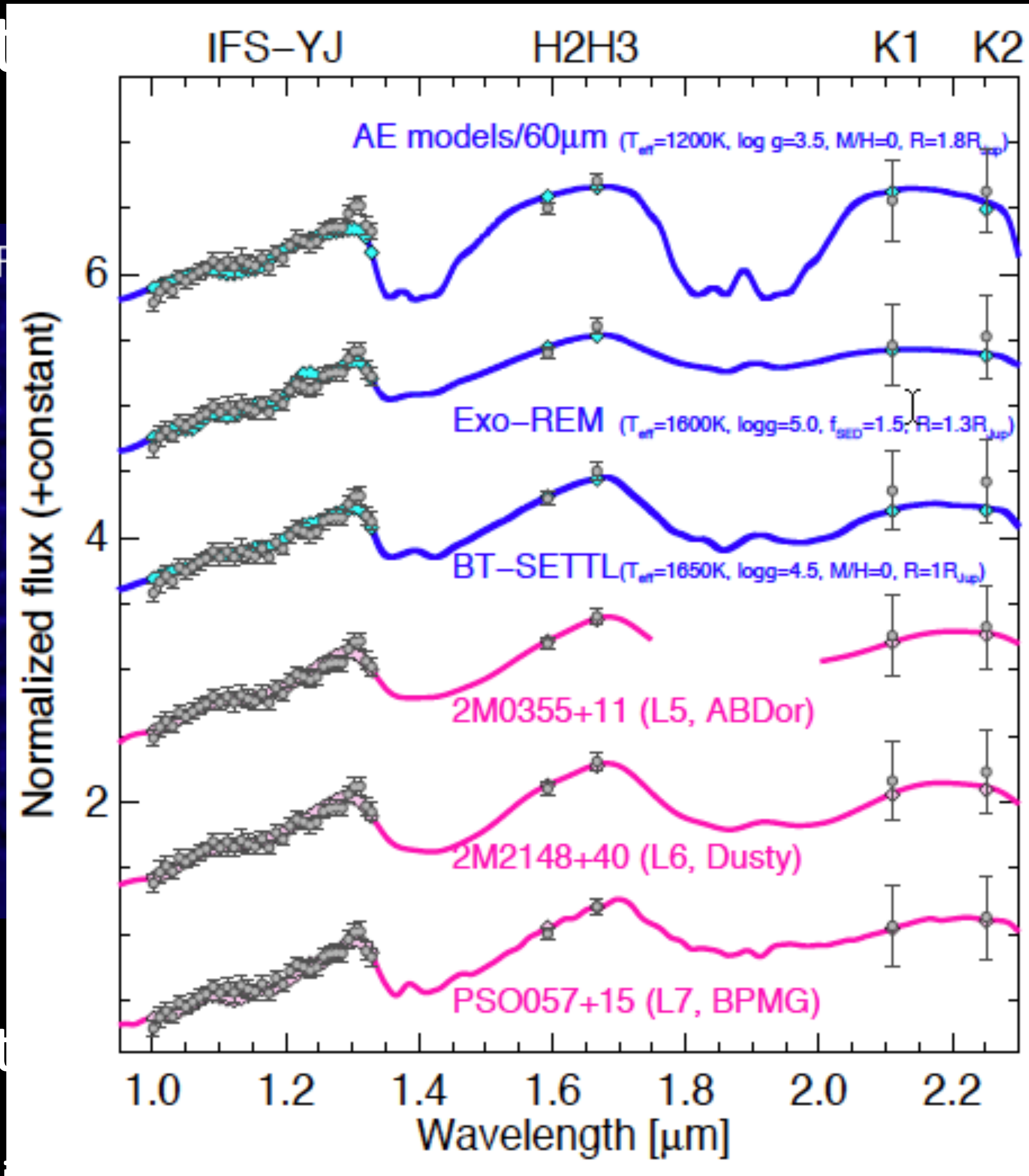


Harvesting disks



First 5426

IFS-YJ (F
017)
0.2''



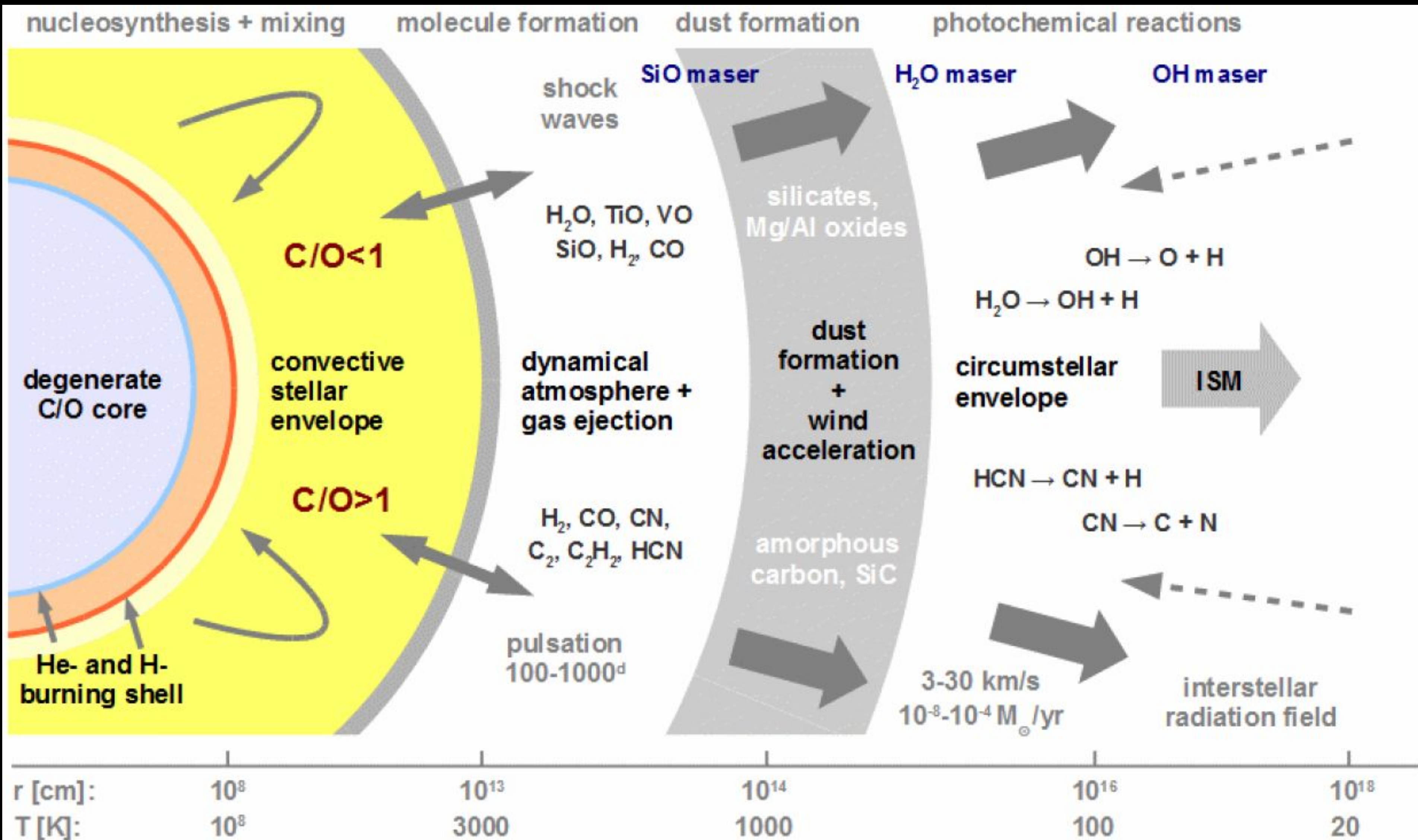
- Separat
- 6-12 M

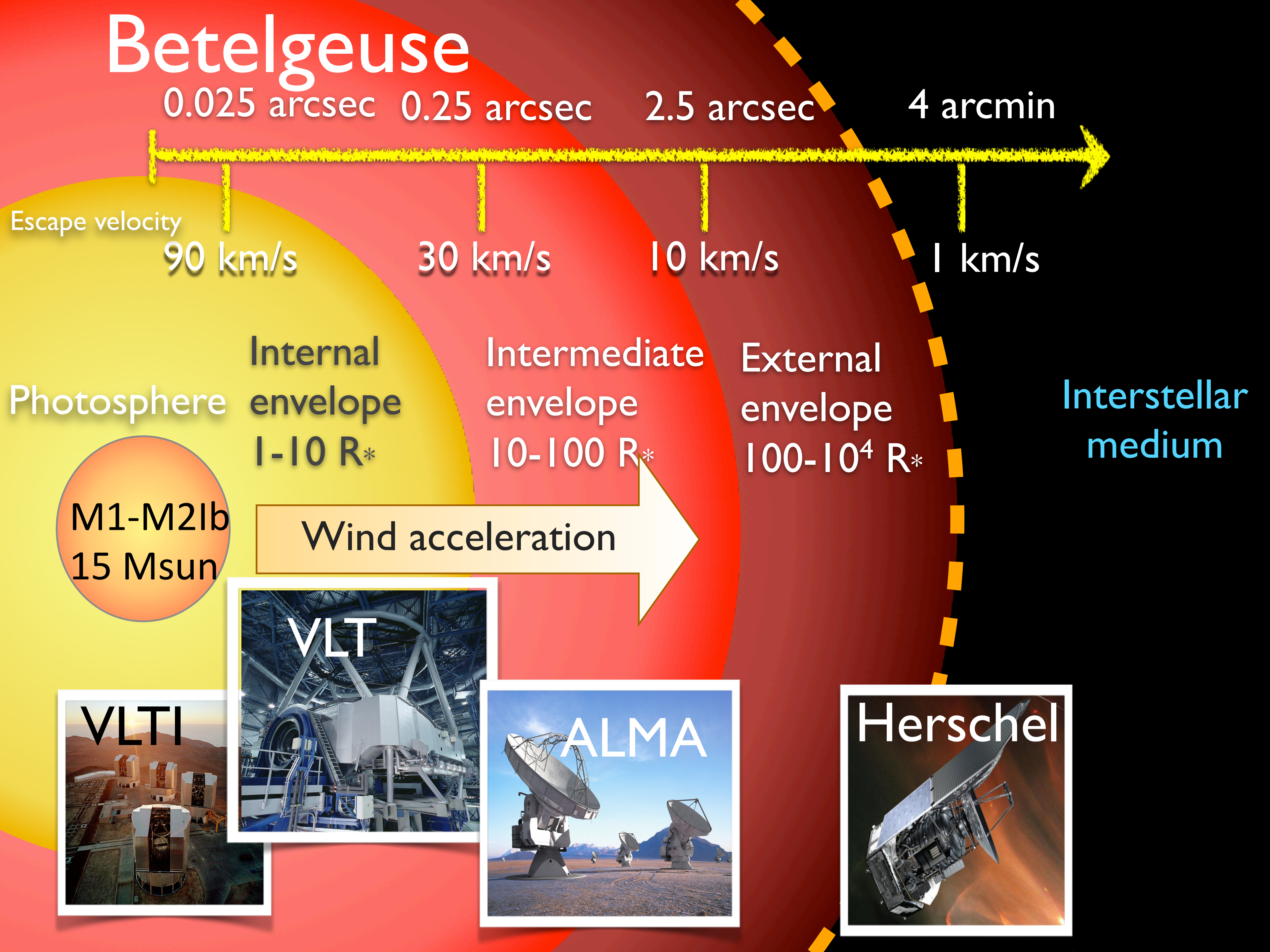
auvin et al., 2017

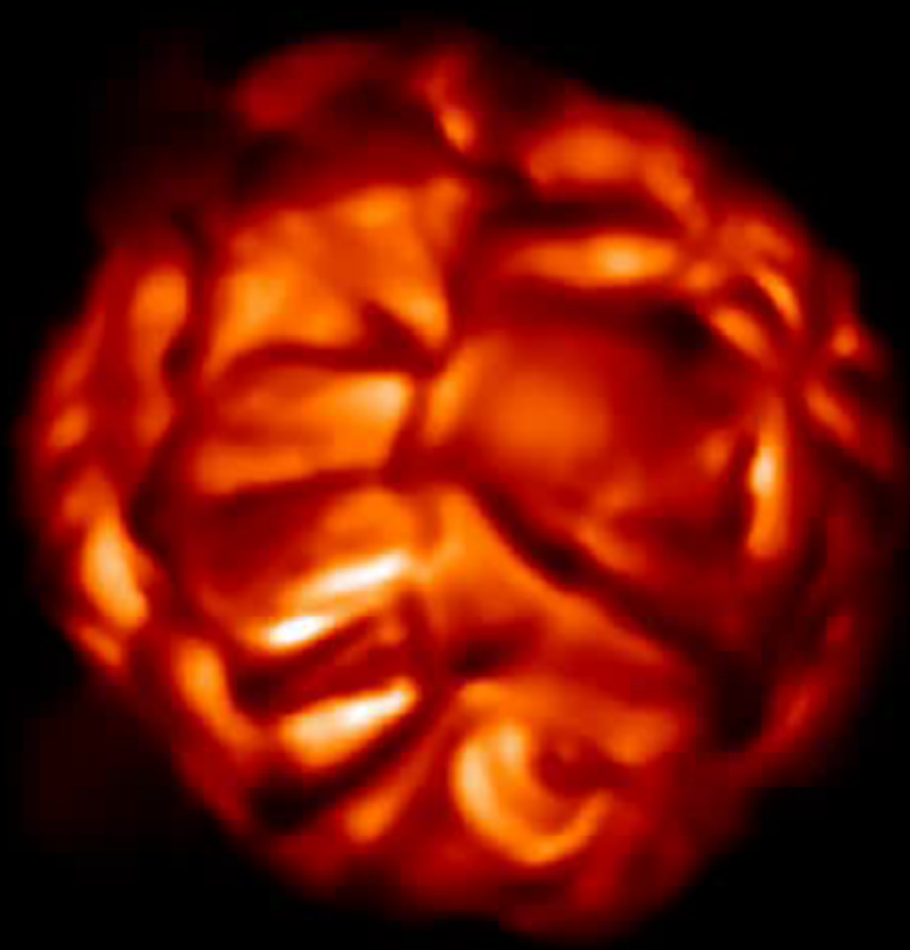
Goals of “Other Science”

- Science cases non related to planets/disks
- Show the community that SPHERE is versatile
- A few temporal monitoring programs
- Short program that should then lead to successful open time proposals
- Evolved stars, solar system, jets, AGNs etc…

AGBs and RSGs: physics at all spatial scales



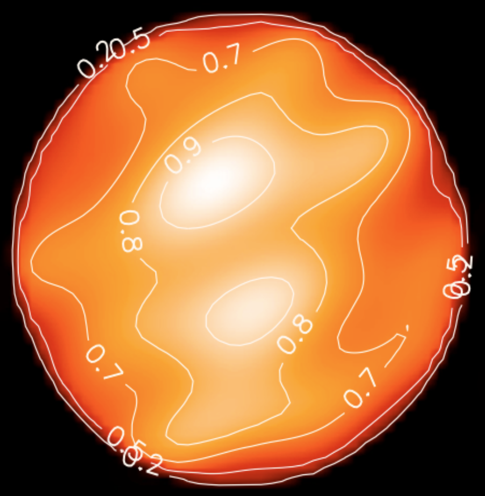

Betelgeuse
0.025 arcsec
0.25 arcsec
2.5 arcsec
4 arcmin
Escape velocity
90 km/s
30 km/s
10 km/s
1 km/s
Photosphere
Internal envelope 1-10 R*
Intermediate envelope 10-100 R*
External envelope 100-10^4 R*
Interstellar medium
M1-M2Ib
15 Msun
Wind acceleration
VLTI
VLT
ALMA
Herschel

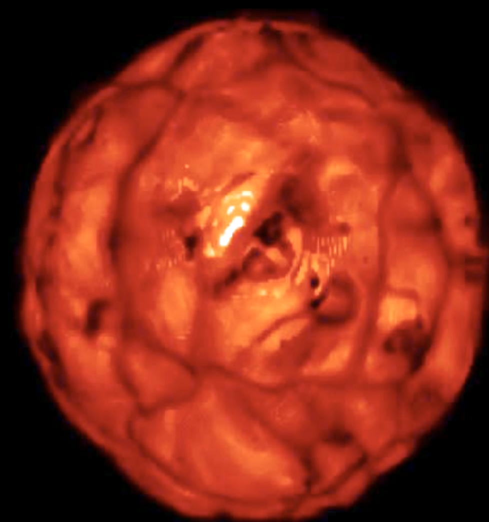


Simulation by B. Freytag

http://www.astro.uu.se/~bf/

Photosphere





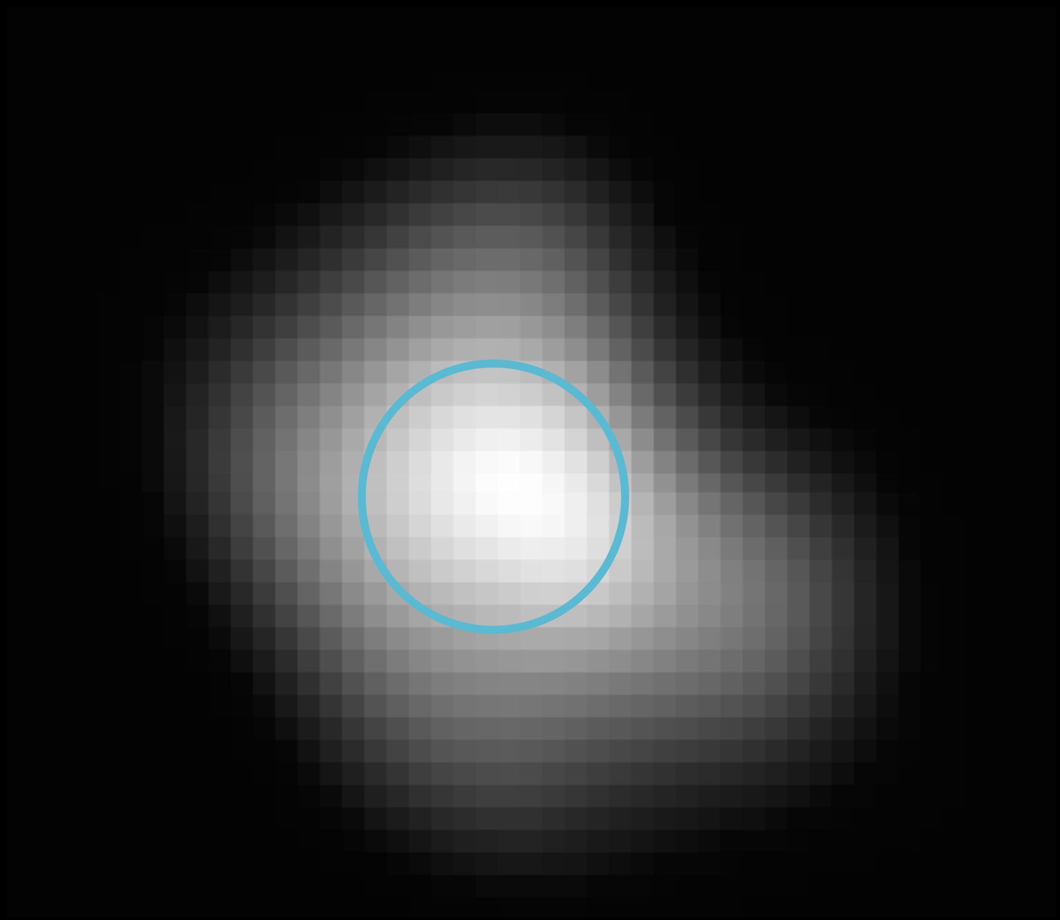
Interferometry
(1.64µm, Haubois et al. 2009)

Model
(1.64µm, Chiavassa et al. 2010)

50 mas

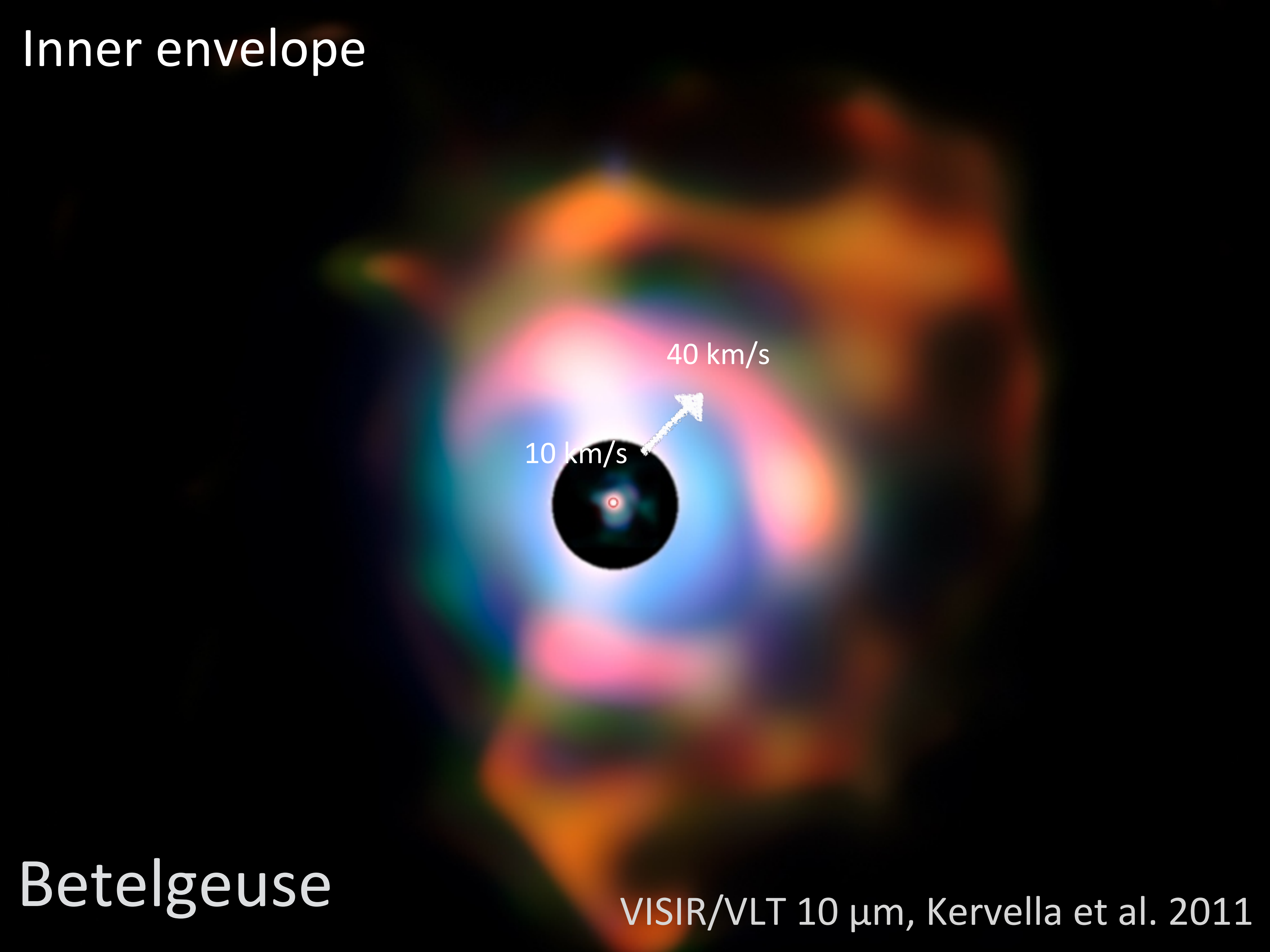
IOTA, NIR, Haubois et al., 2016

Photosphere

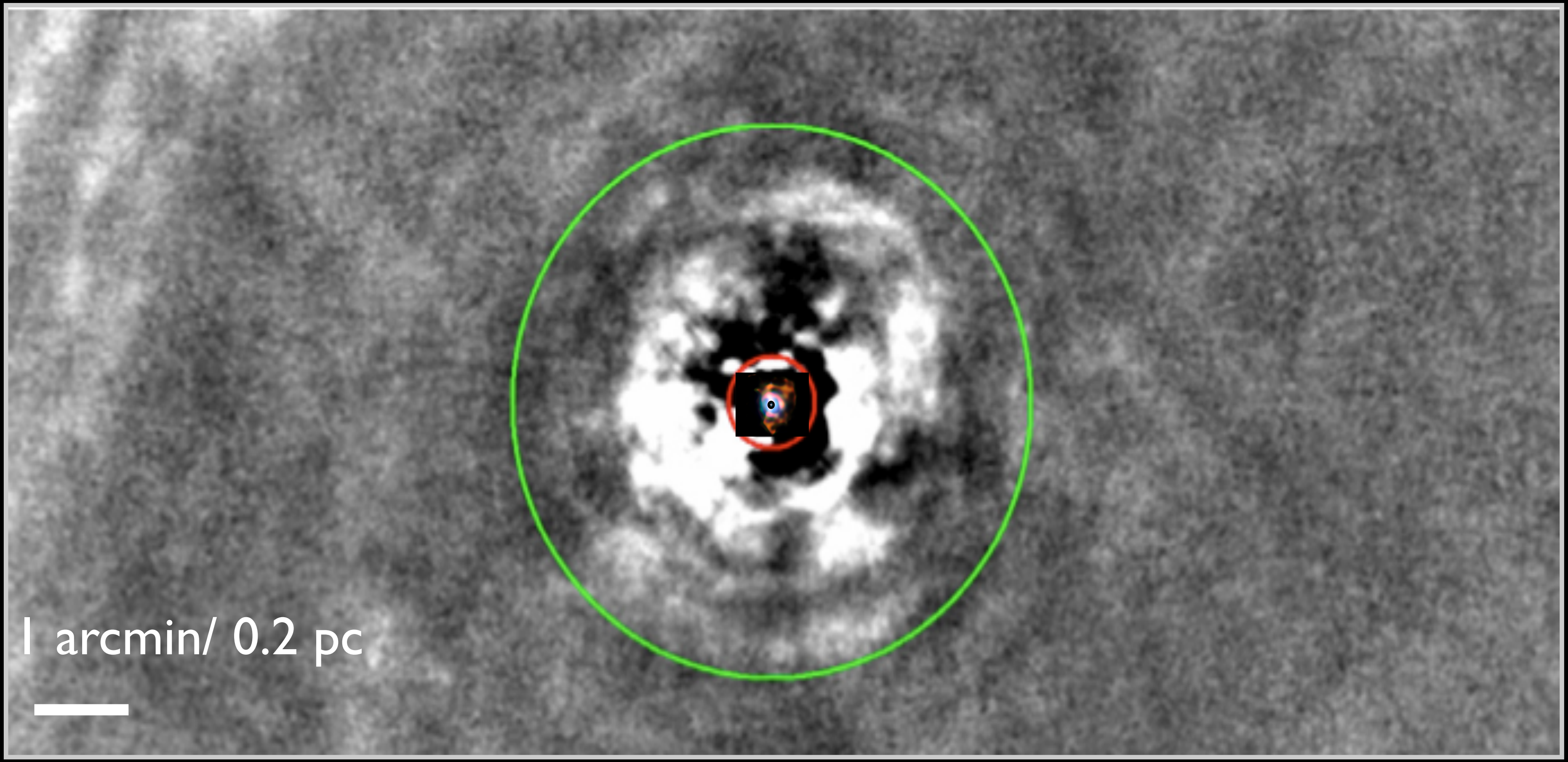


Betelgeuse

SPHERE/VLT, optical, Kervella et al., 2016


Inner envelope
40 km/s
10 km/s
Betelgeuse
VISIR/VLT 10 µm, Kervella et al. 2011

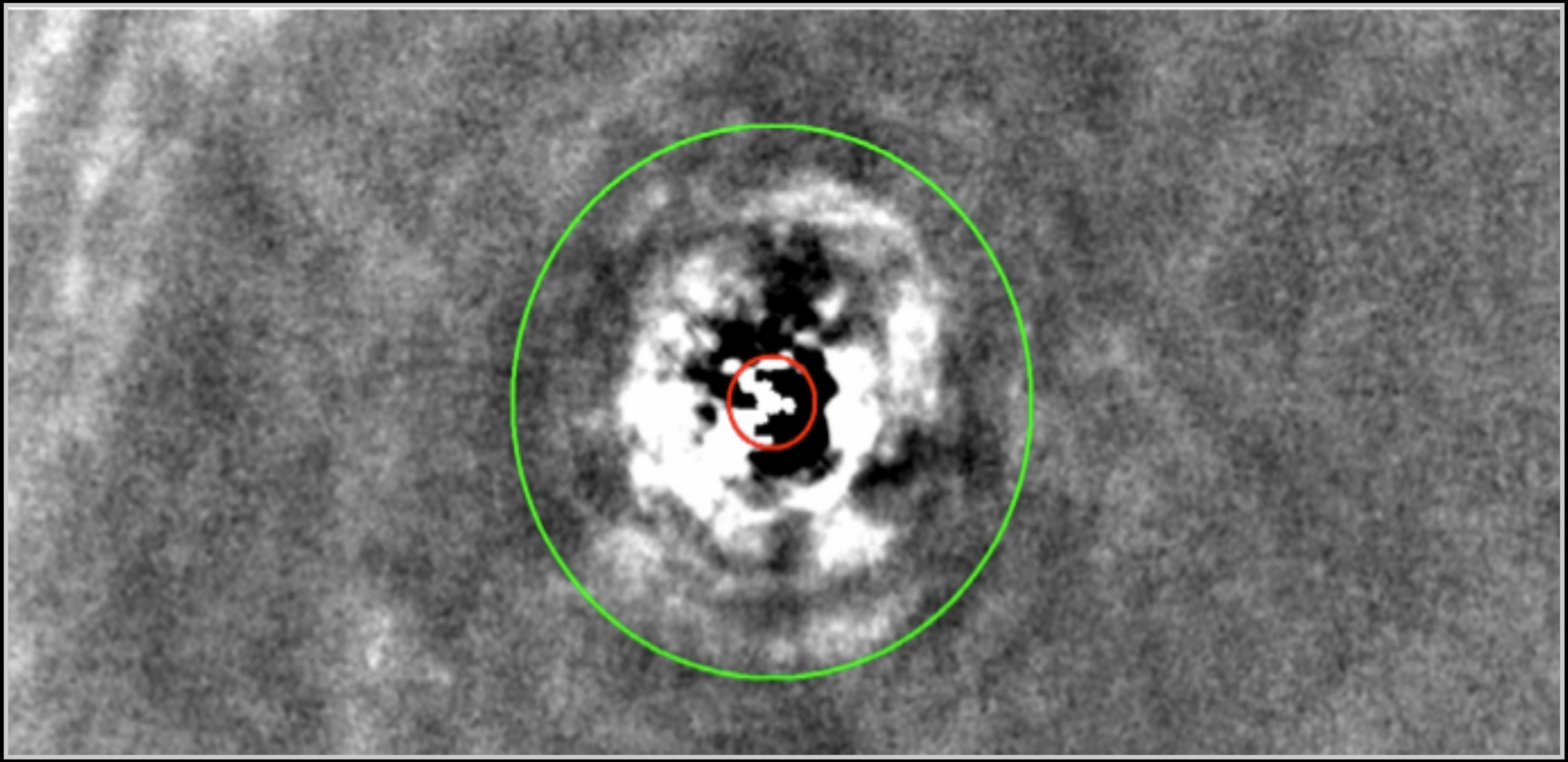
Intermediate envelope



Betelgeuse

Herschel 70-250 μm, Decin et al. 2012

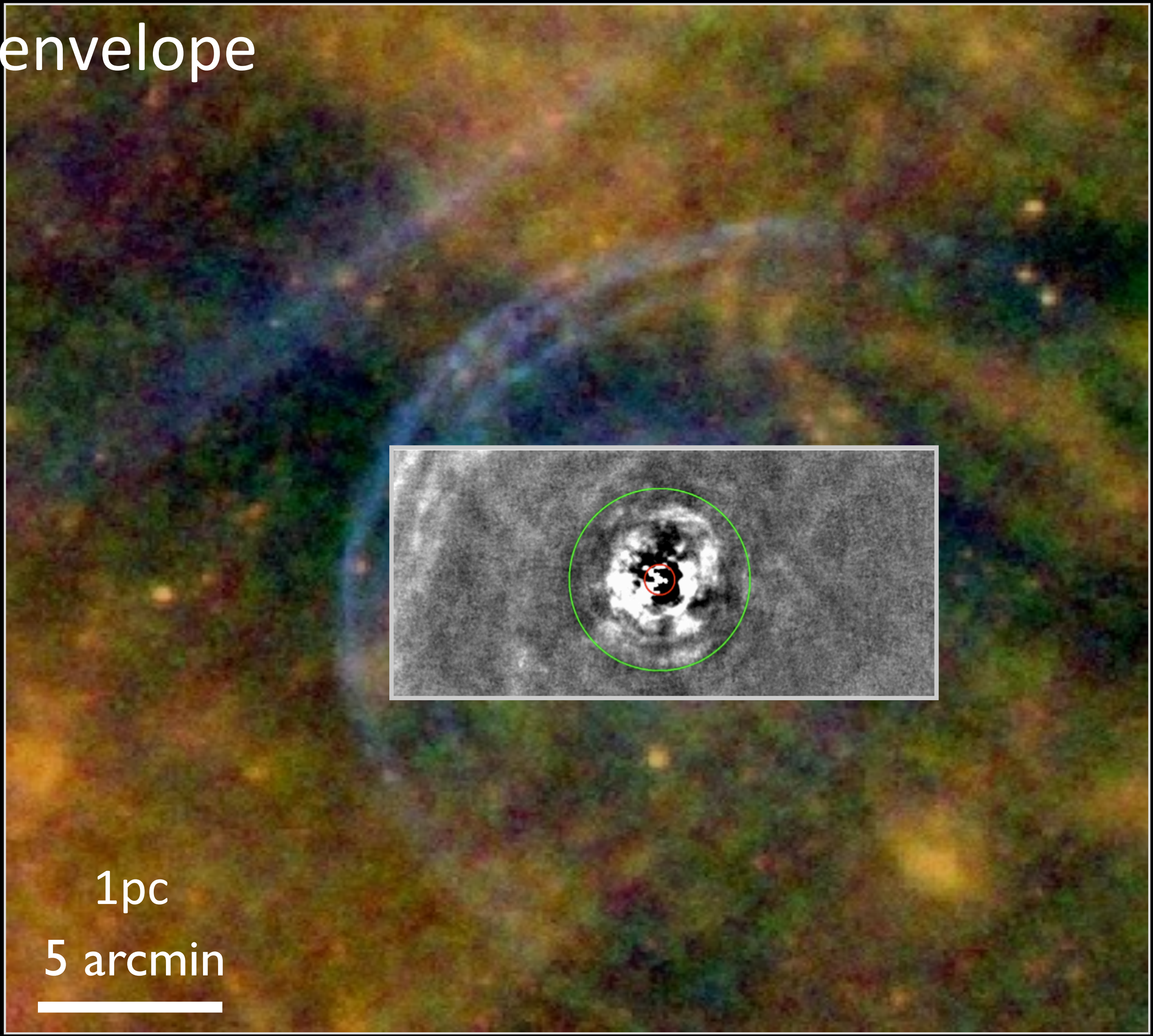
Intermediate envelope



Betelgeuse

Herschel 70-250 μm, Decin et al. 2012

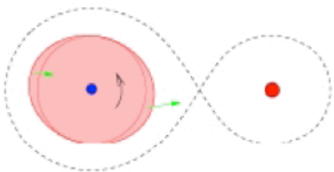
Outer envelope



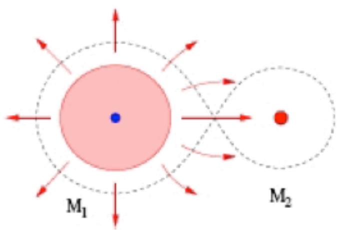
Betelgeuse

Herschel 70-250 μm, Decin et al. 2012

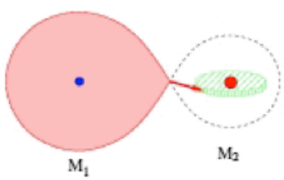
Different types of binary interactions



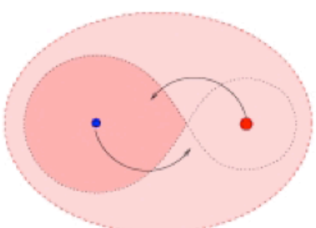
tidal interaction



wind accretion & tidally enhanced winds



Roche-lobe overflow



common envelope evolution

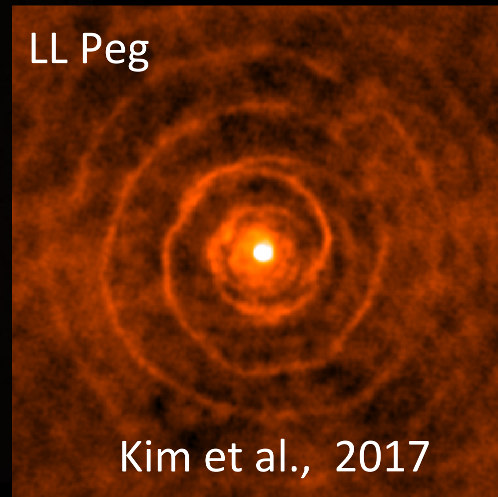
Figure from Pols, 2005

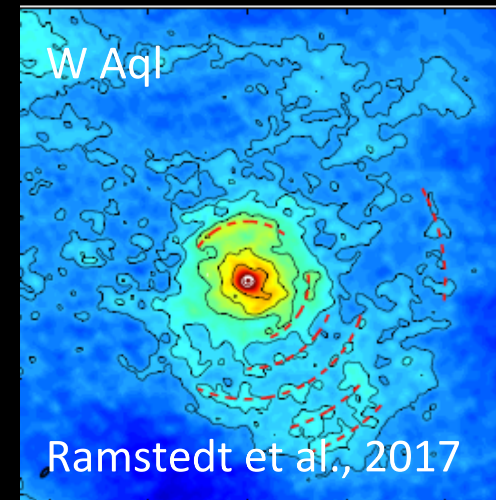
Wind Roche lobe overflow

- AGB star mass: 1.6 $M_\odot$
- Companion: 0.25 $M_\odot$
- Separation: 60 AU

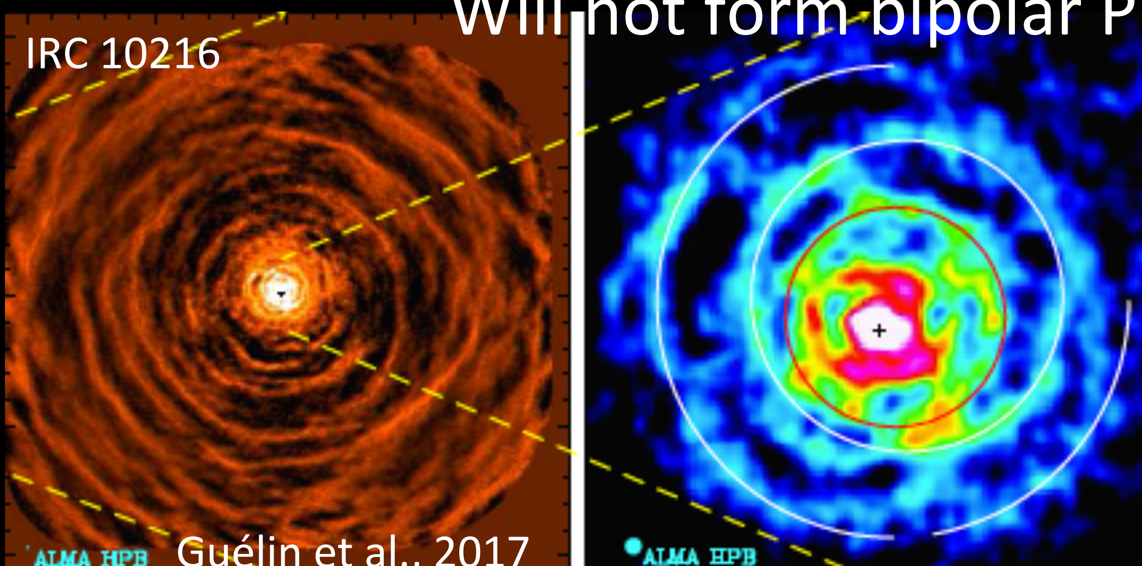
Mohamed and Podsiadlowski, (2007)

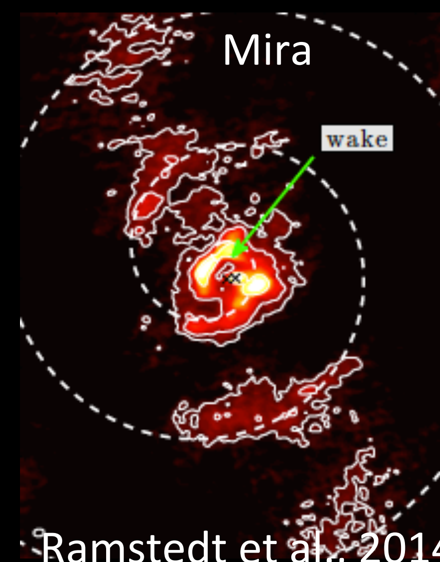
ALMA: spirals formation due to binaries



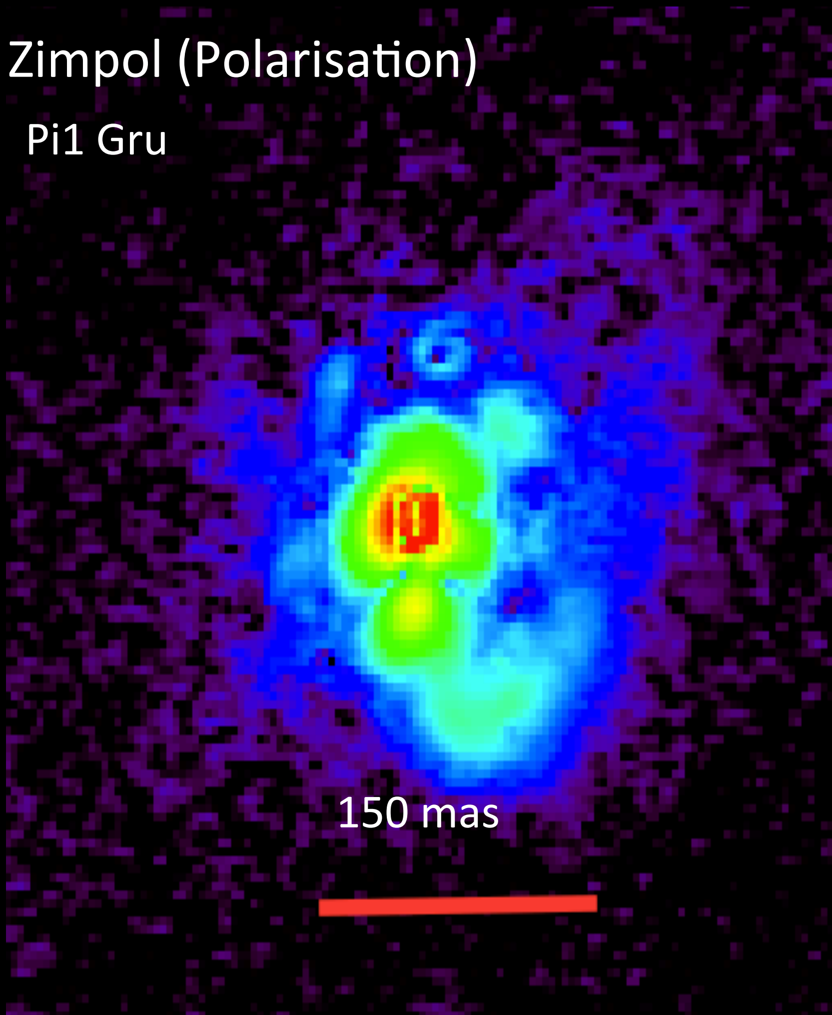


Will not form bipolar PNe?





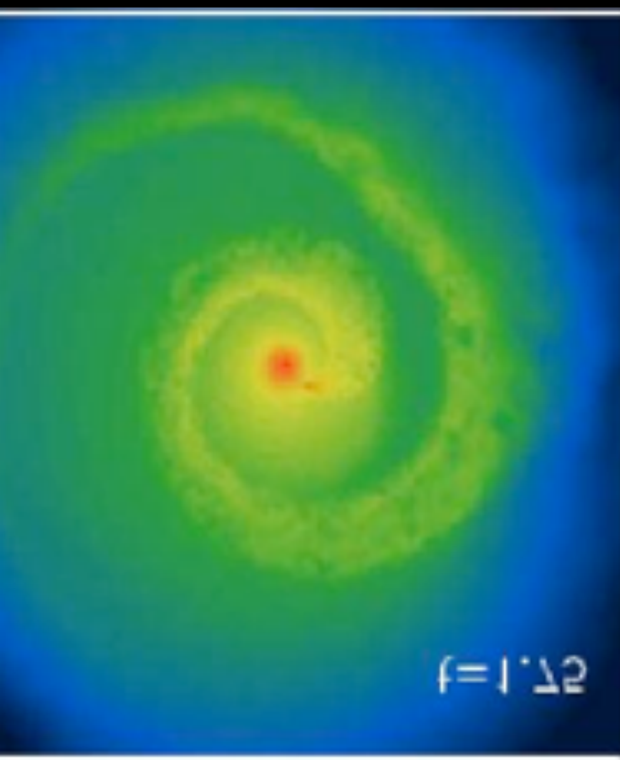
Spirals and SPHERE/VLT

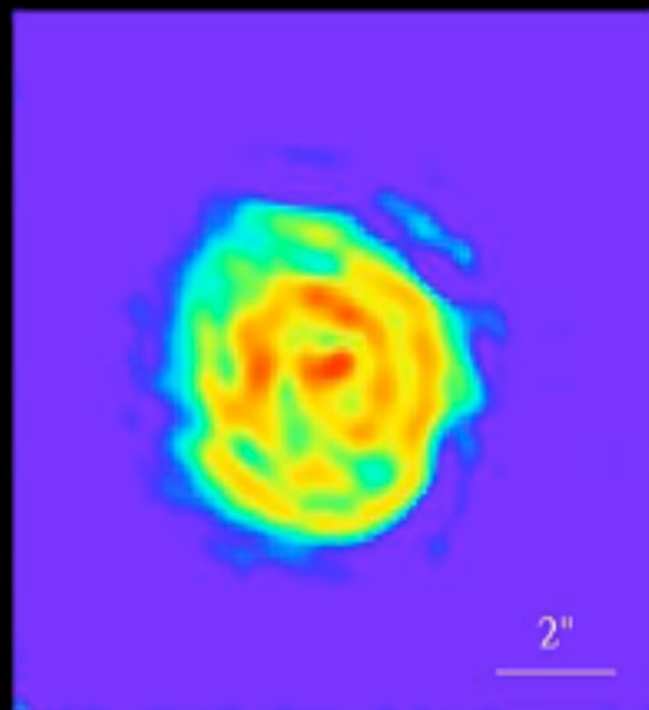


- Pi1 Gru (nearby AGB star with distant companion)
- Spiral pattern: nearby companion?
- Looked for the binary in R Scl (Maercker's spiral): companion non detected

Lagadec et al. (in prep)

AFGL 4106: spiral



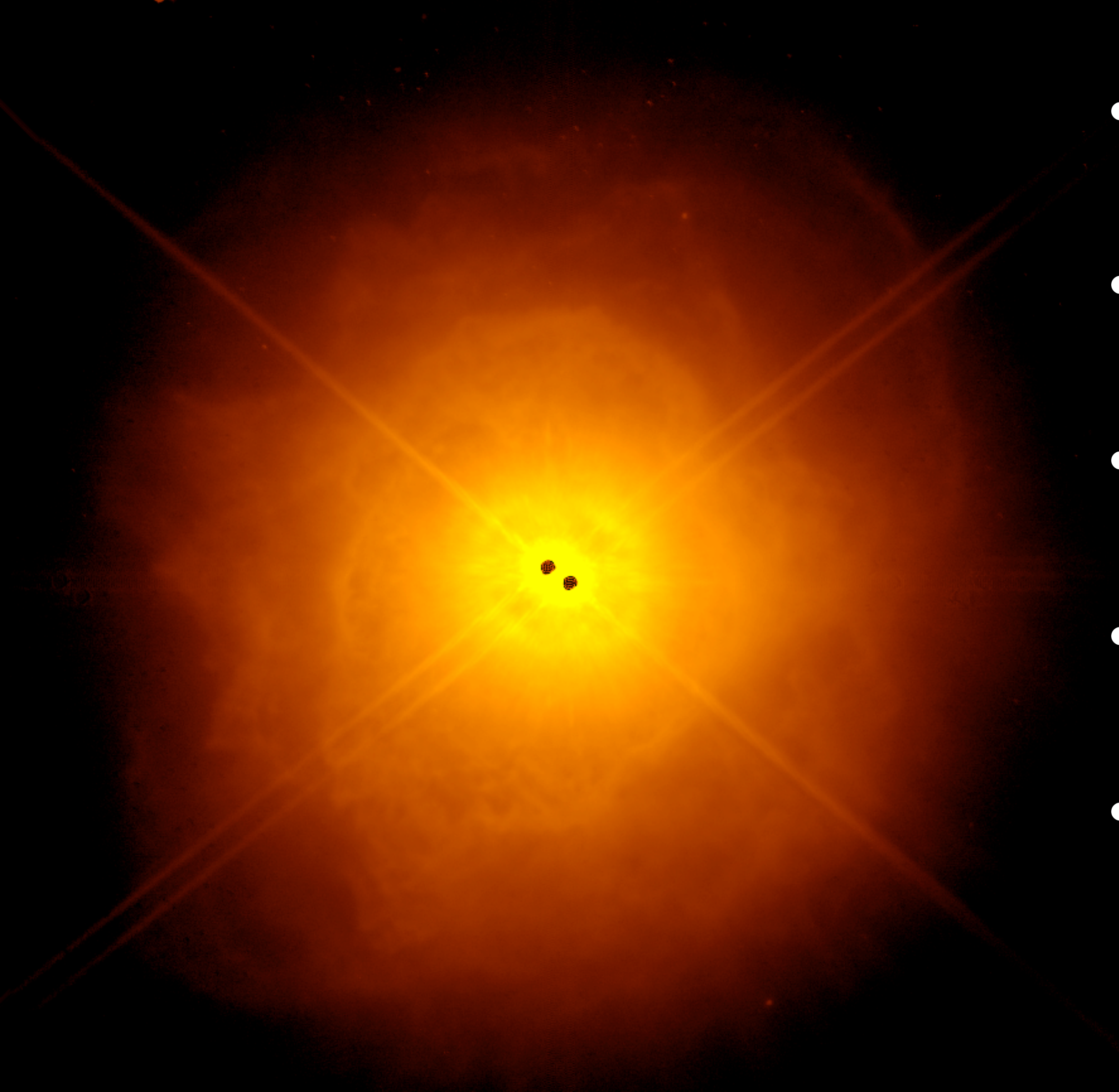


- Massive evolved star
- Spectroscopic binary
- Spiral mapped in the IR
- Expected separation: 0.3"

Lagadec et al., 2013

Lagadec et al., in prep

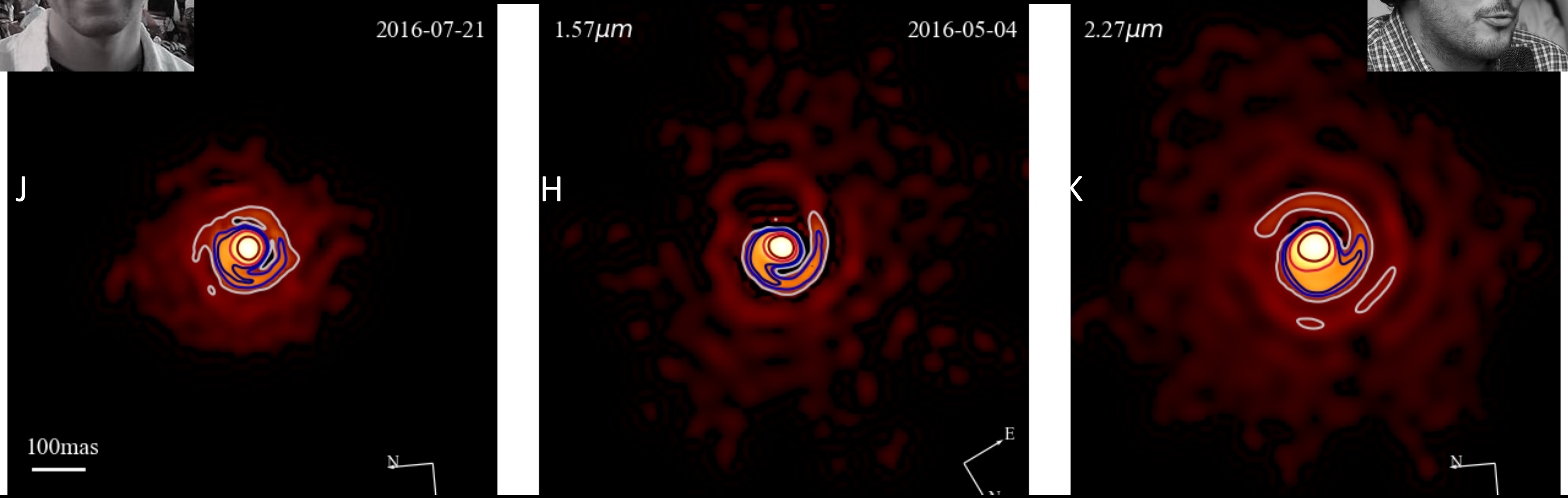
AFGL 4106: binary



- Massive evolved star
- Spectroscopic binary
- Spiral mapped in the IR
- Expected separation: 0.3”
- Bingo!

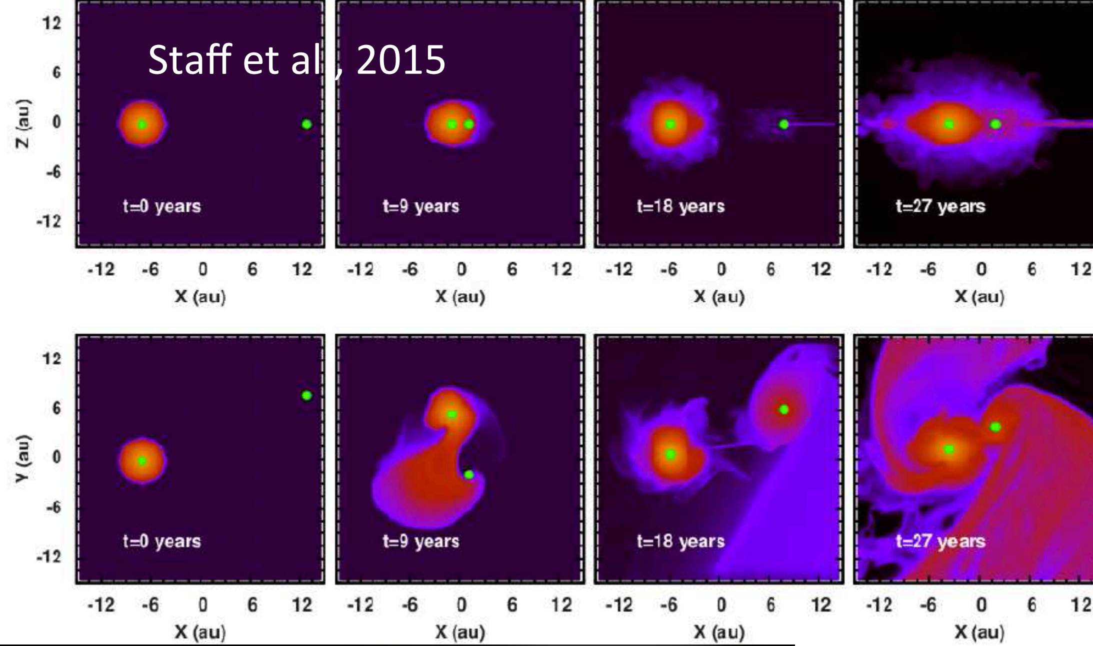
Lagadec et al., in prep

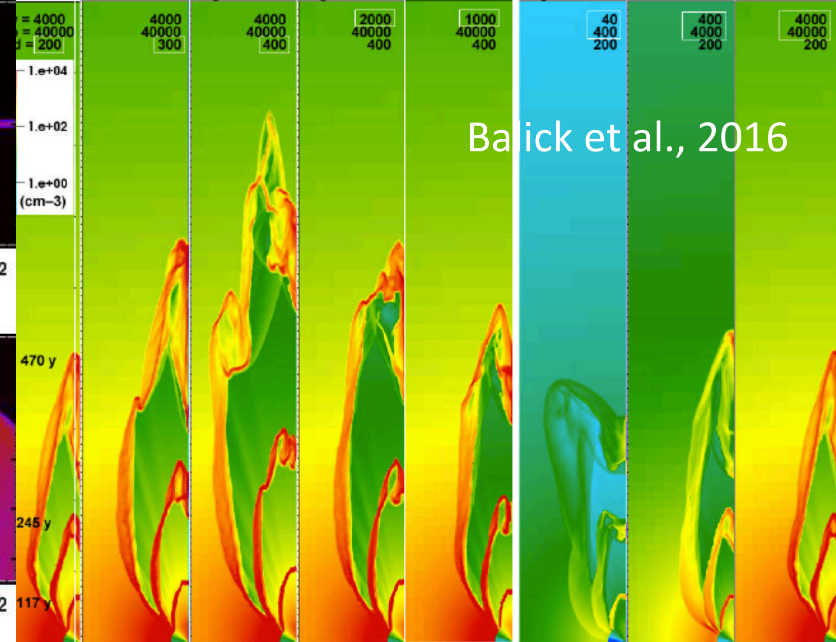
WR 104

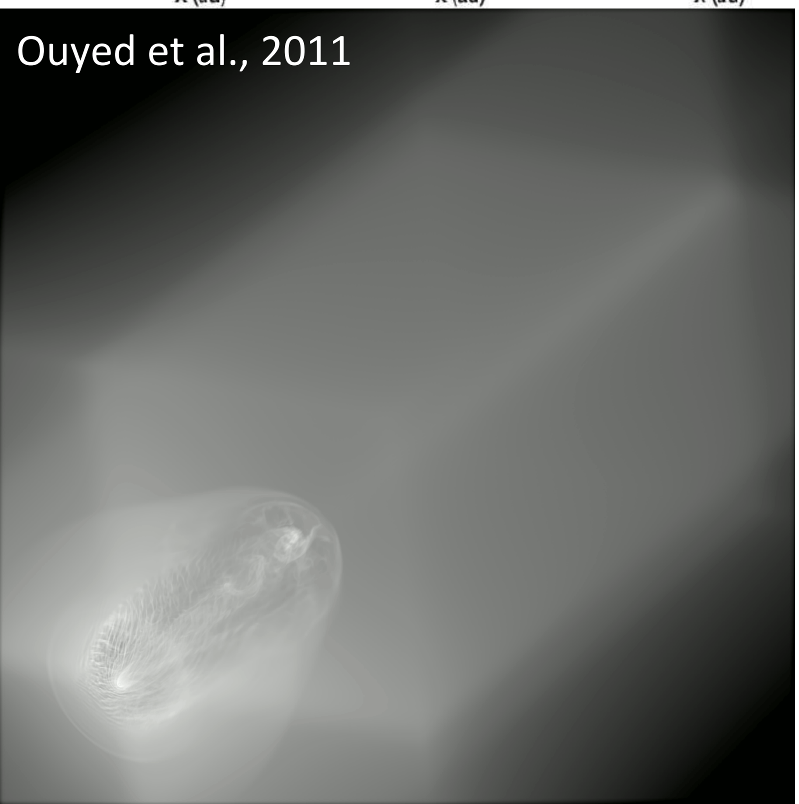


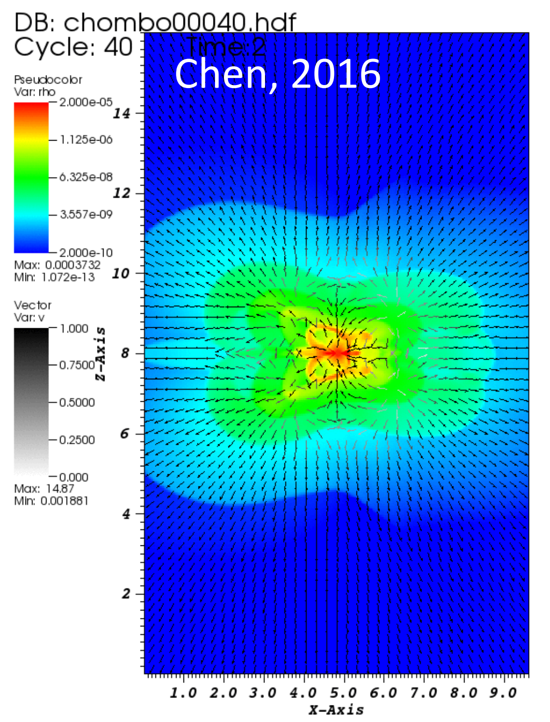
- Binary WC+O stars: dustars producing huge amounts of dust (10^{-6} M_{sun}/yr)
- Spiral due to wind collision
- First direct image ever
- Where is the shock/dust formation zone?
- Combination with AMBER/VLTI to map the inner parts

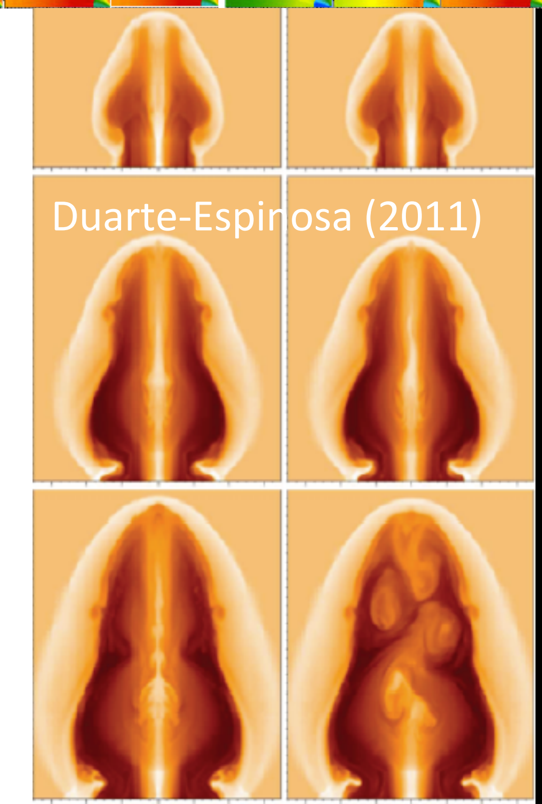
Soulain et al., submitted


Staff et al., 2015
Z (au)
Y (au)
X (au)
t=0 years
t=9 years
t=18 years
t=27 years

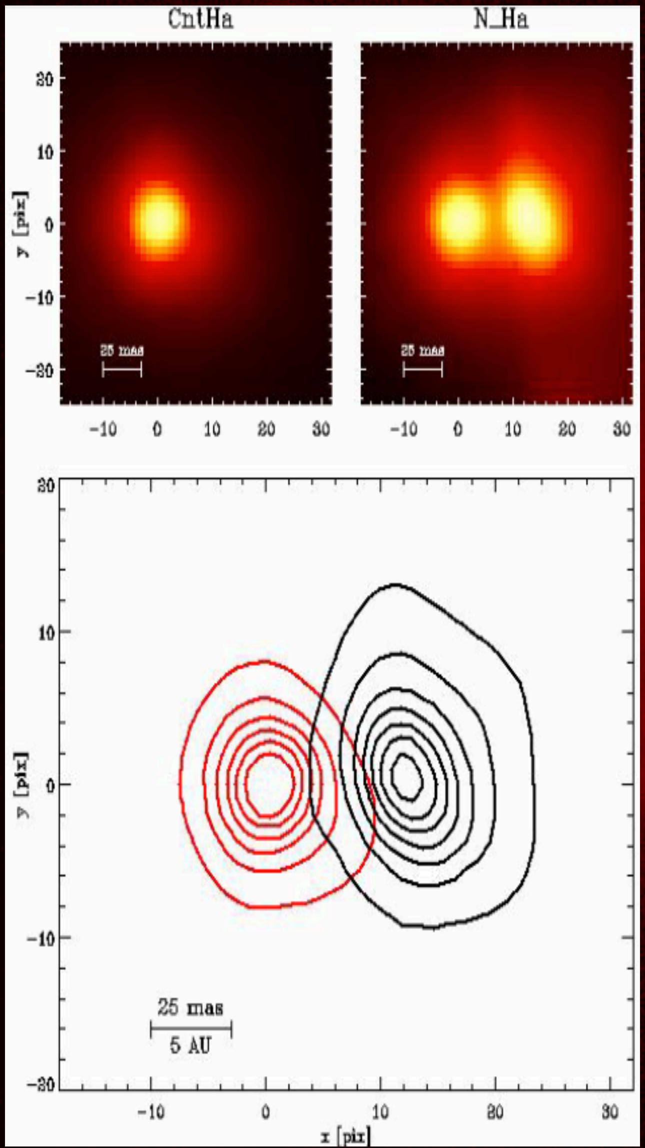

Balick et al., 2016
470 y
245 y
117 y
(cm−3)


Ouyed et al., 2011


DB: chombo00040.hdf
Cycle: 40
Chen, 2016
Pseudocolor
Var: rho
Vector
Var: v
Z-Axis
X-Axis


Duarte-Espinosa (2011)

Binaries and jets: R Aqr

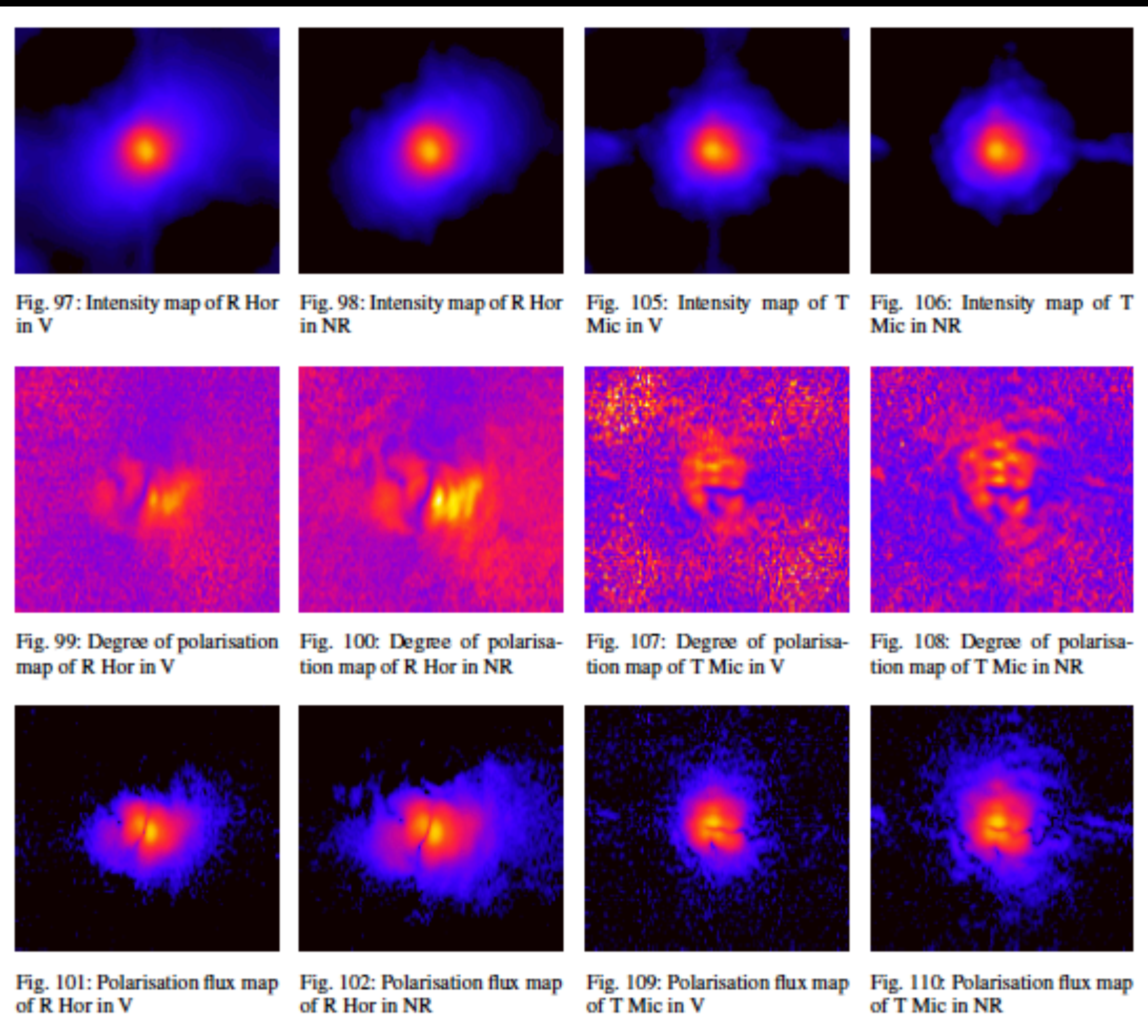


Jet carving the dust!

- Binary system with a red giant and a compact companion
- Binary system resolved for the first time (40mas=8au)
- Precessing jet from the secondary
- Polarimetry: jet is carving the dust
- Orbit being determined
- Benchmark for the physics of jets!
- ALMA observations to come: dynamics!

Schmid et al., in prep

AGB stars morphology

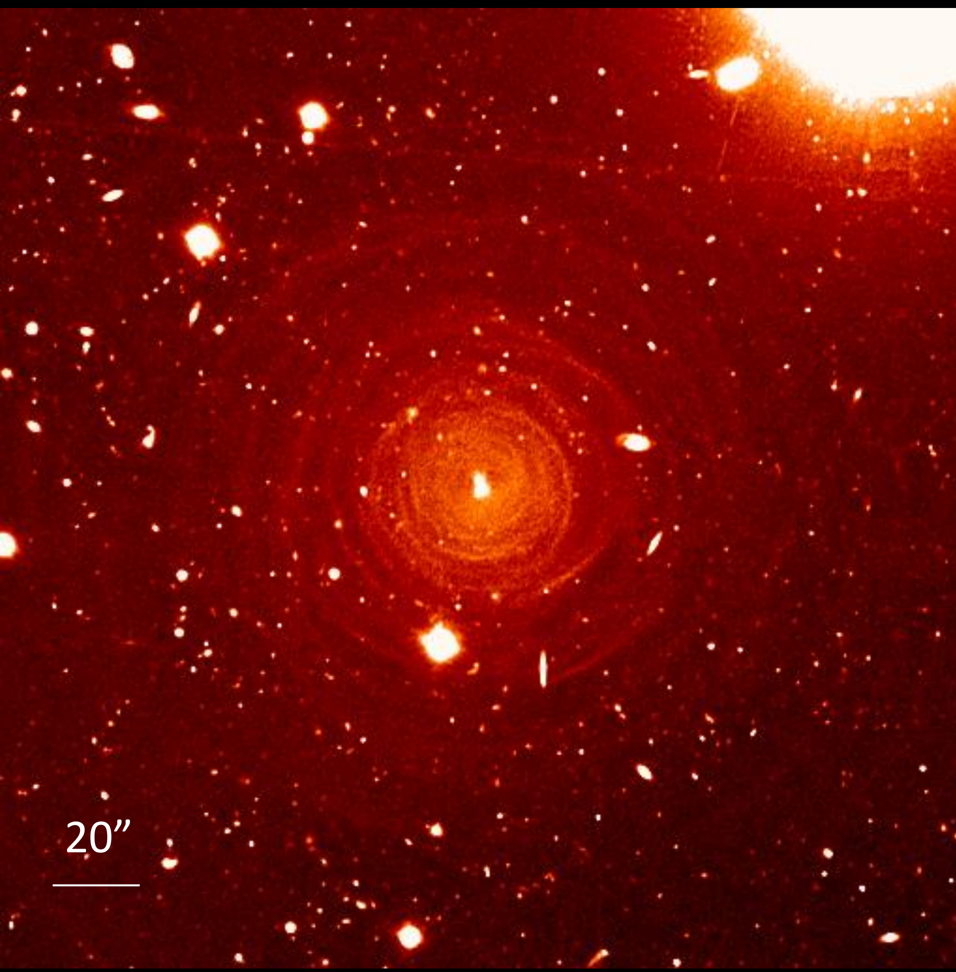


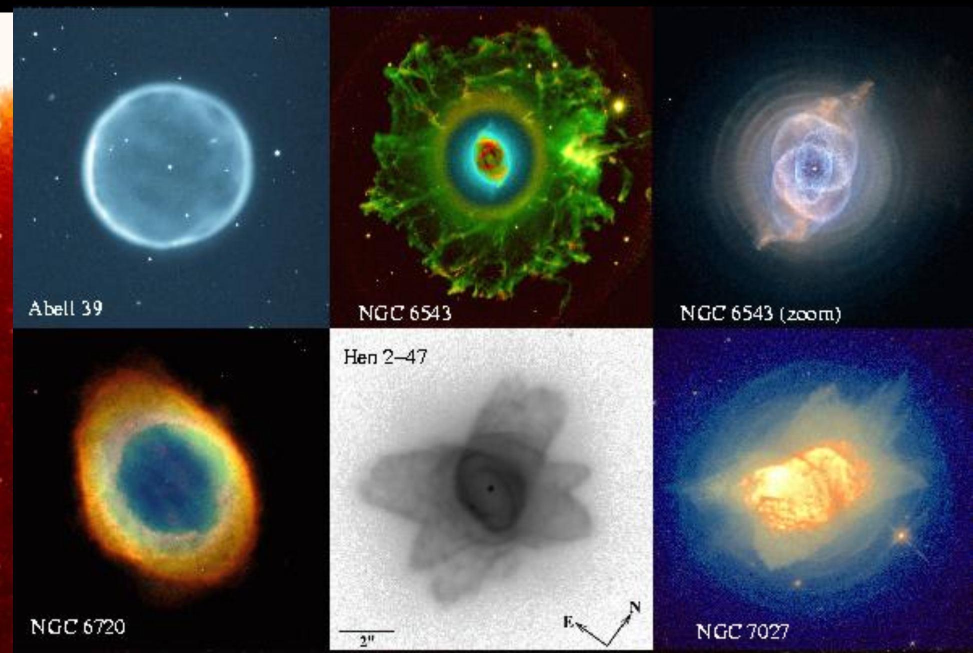
- Filler (bright targets, broad range of RA and Dec)
- 17 AGB stars observed
- V and R band filters
- ZIMPOL polarimetry

AGBs not spherical at small spatial scale

Lagadec et al., in prep

Morphologies of AGB stars and Planetary Nebulae



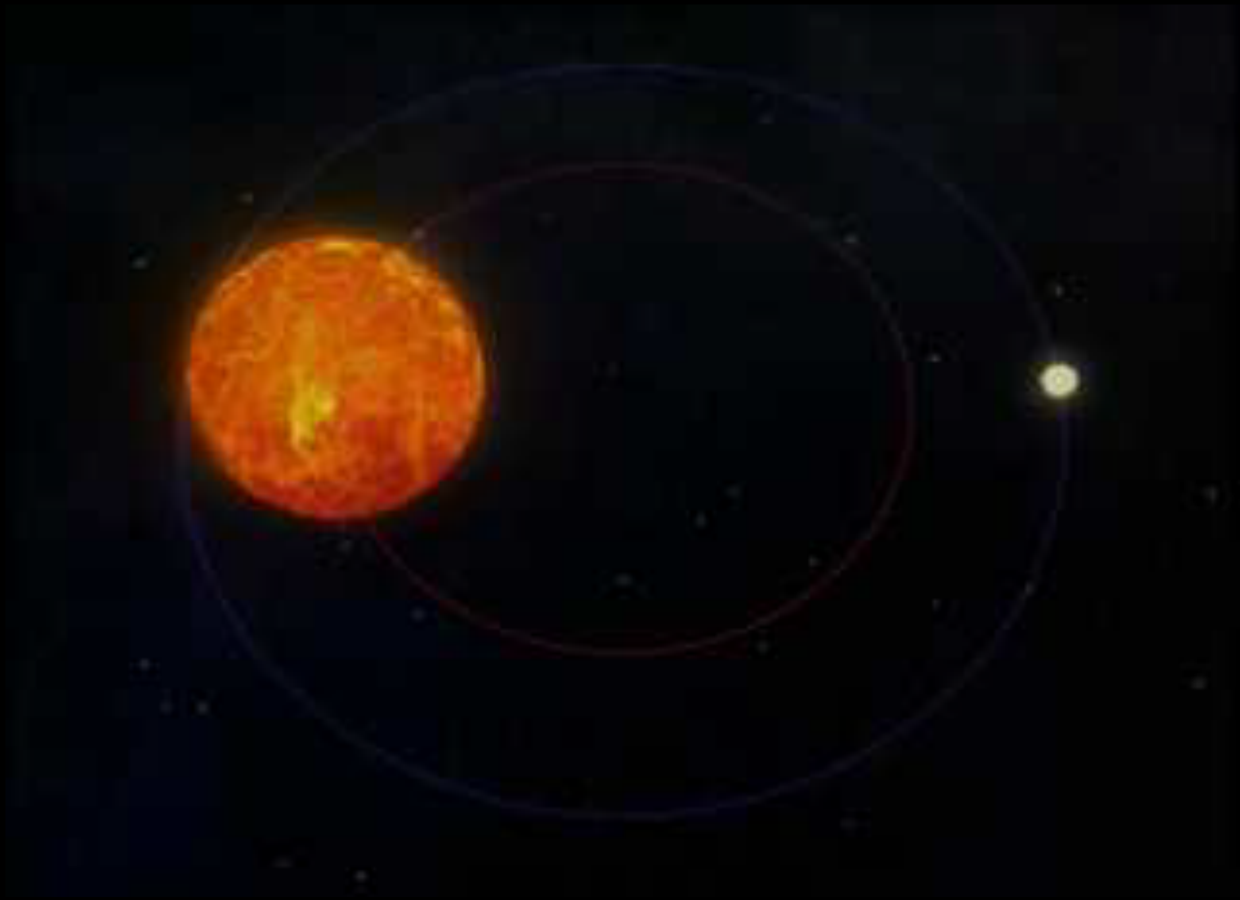


Almost no PPNe are spherical! (Sahai 1998, Lagadec 2011)

AGB star

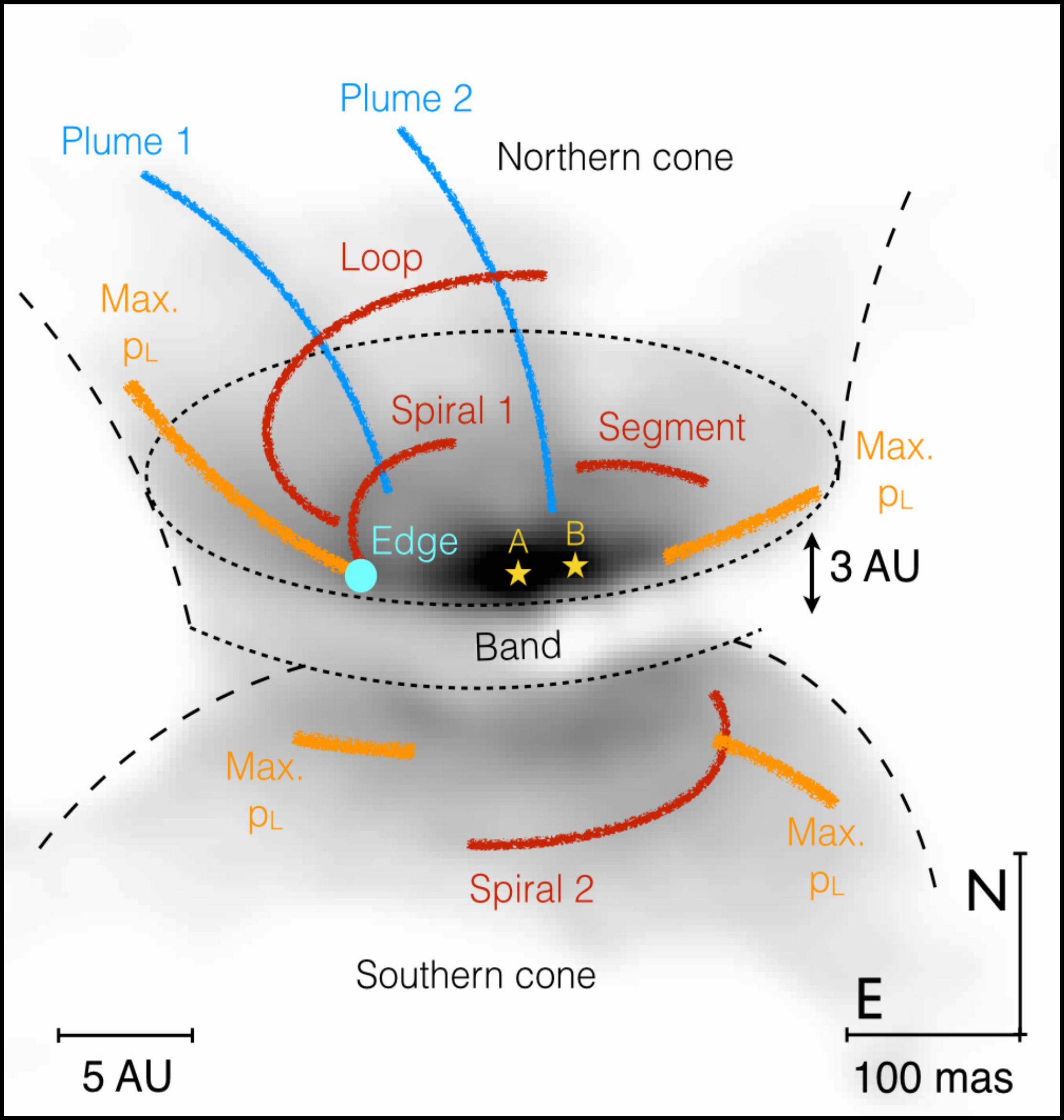
Different PNe

Influence of a compagion



Credit: StScI

L2 Puppis

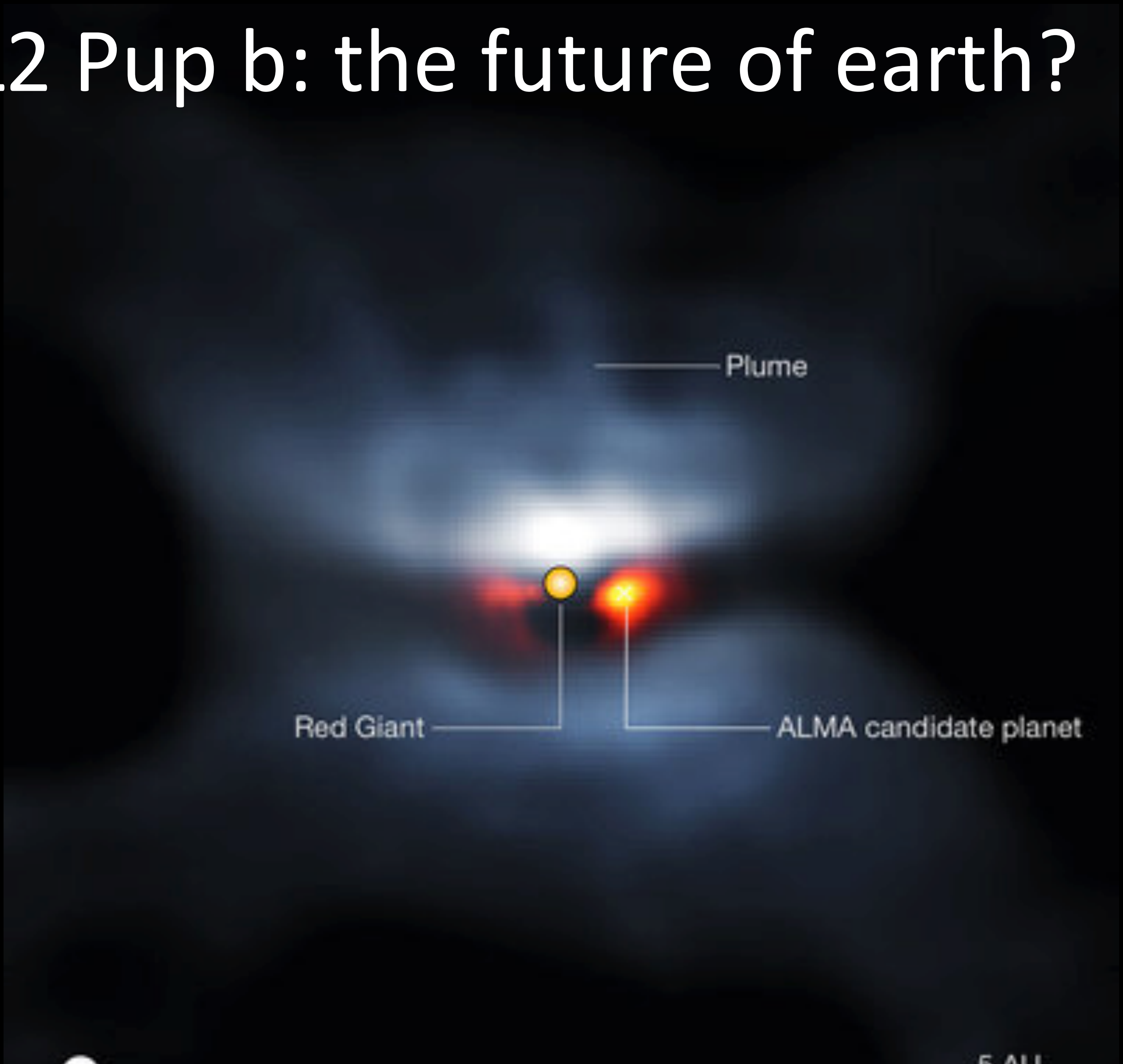


- Nearby AGB star (64 pc)
- Edgee-on disk seen with ZIMPOL
- Inner rim of the disk (6 AU) seen in P maps
- Secondary source at 2 AU
- Spiral patterns+ plumes

Kervella et al., 2015

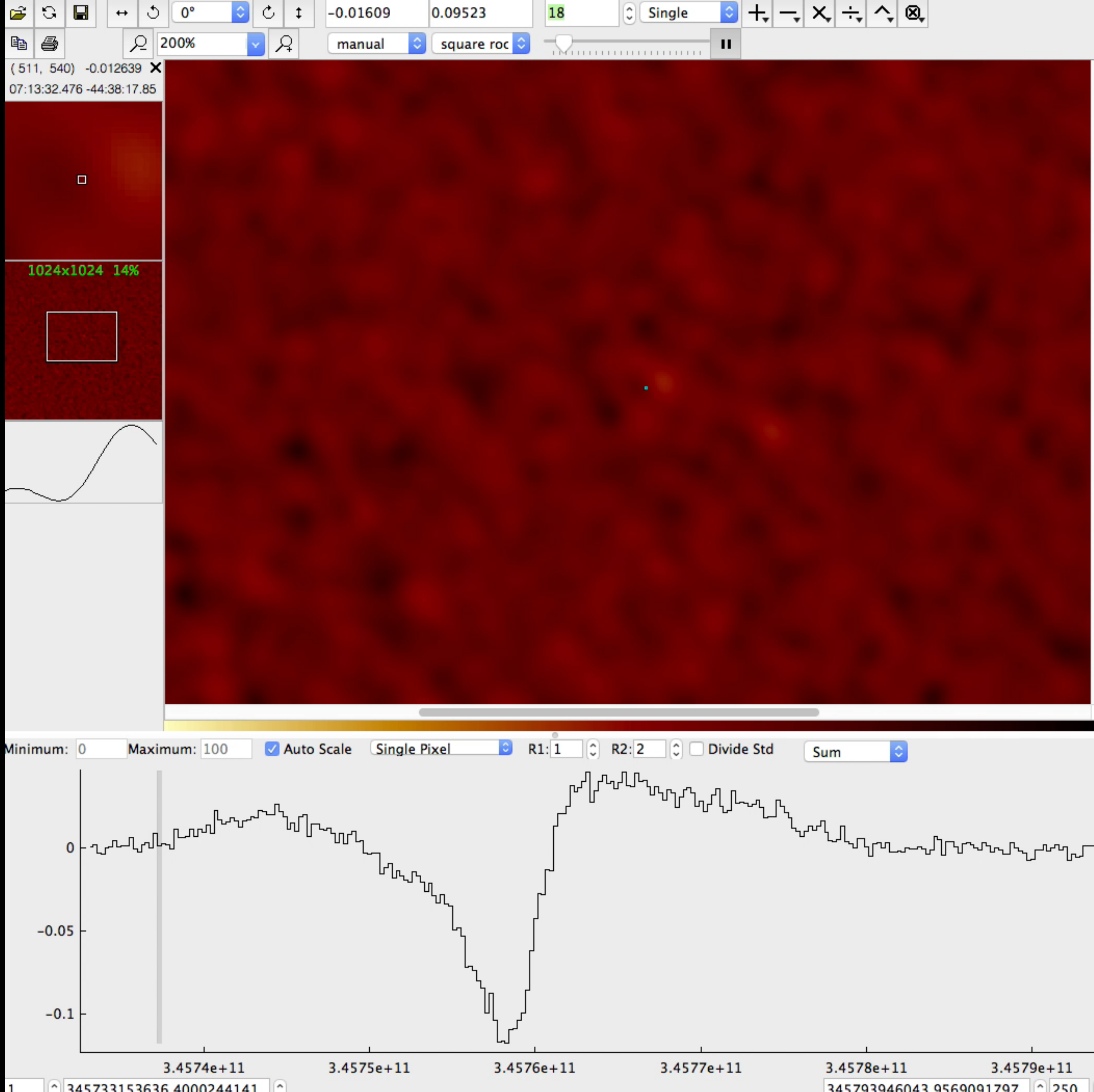
L2 Pup: the birth of a bipolar PN?

L2 Pup b: the future of earth?

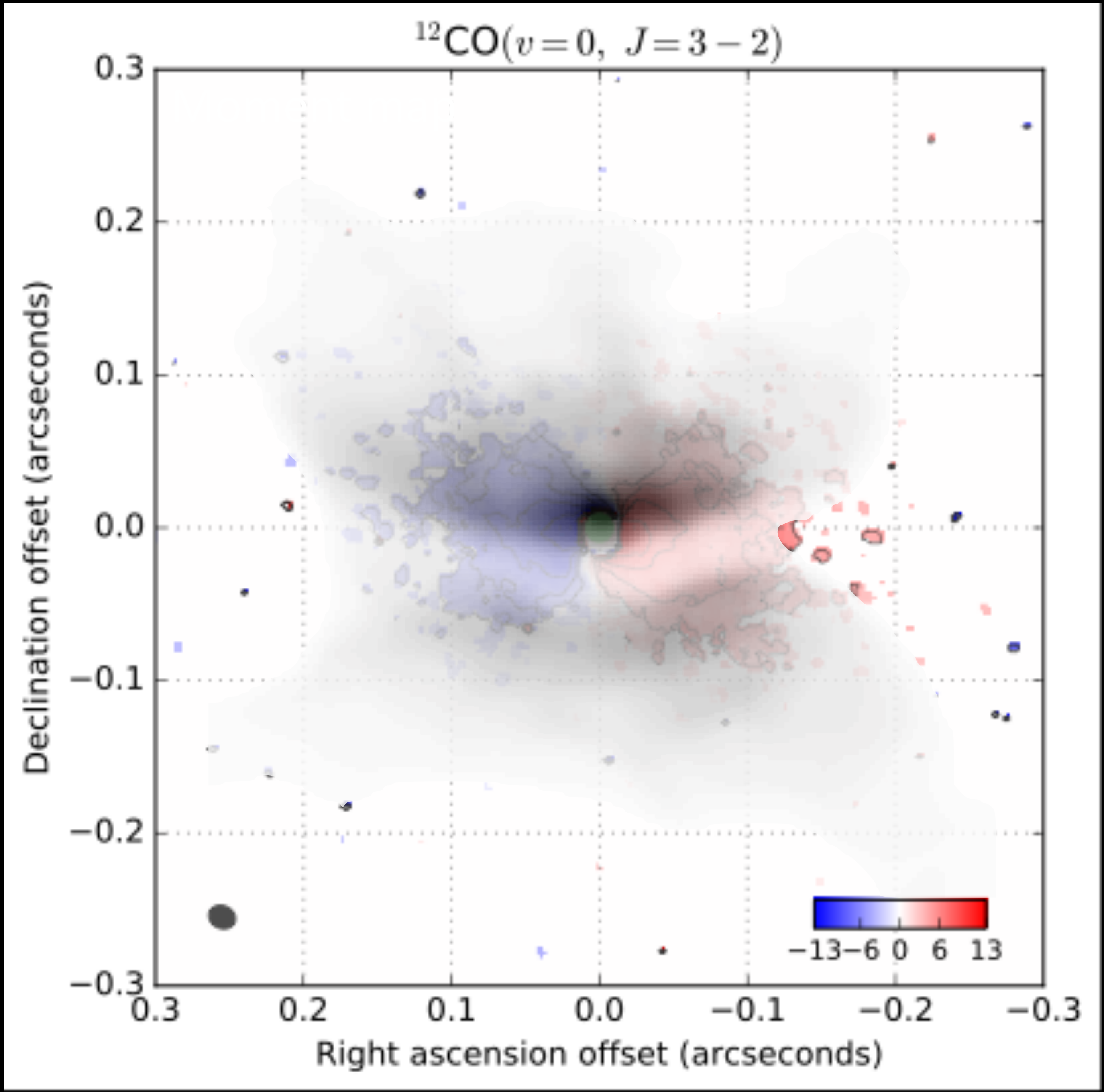


ALMA

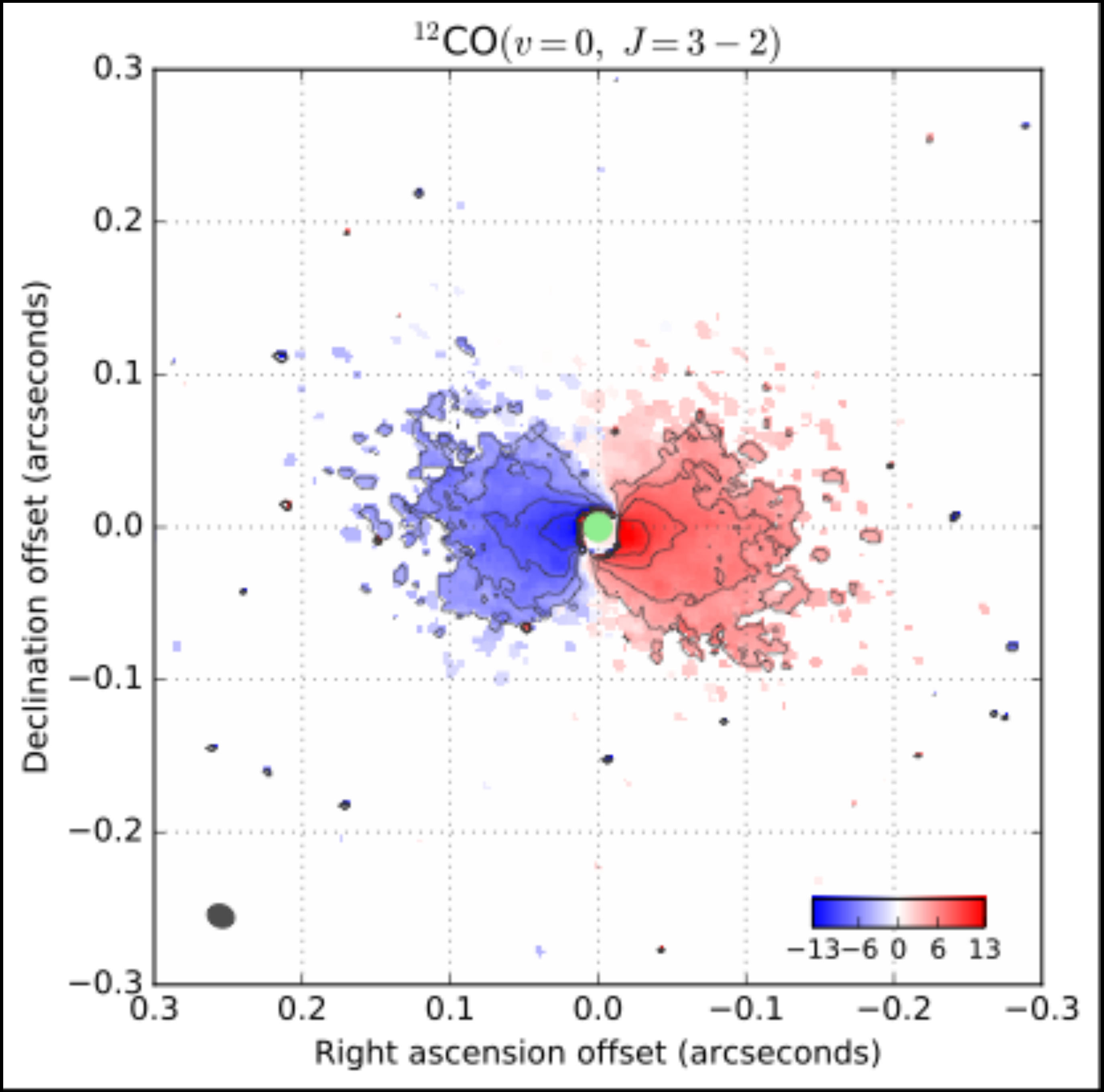
- Cycle 3, special extended configuration (16 km)
- Band 7, CO J=3-2 emission + others (346 GHz)
- Maximum angular resolution 0.015”



0°
-0.01609
0.09523
18
Single
200%
manual
square roc
(511, 540) -0.012639
07:13:32.476 -44:38:17.85
1024x1024 14%
Minimum: 0
Maximum: 100
Auto Scale
Single Pixel
R1: 1
R2: 2
Divide Std
Sum
0
-0.05
-0.1
3.4574e+11
3.4575e+11
3.4576e+11
3.4577e+11
3.4578e+11
3.4579e+11
1
345733153636.4000244141
345793946043.9569091797
250

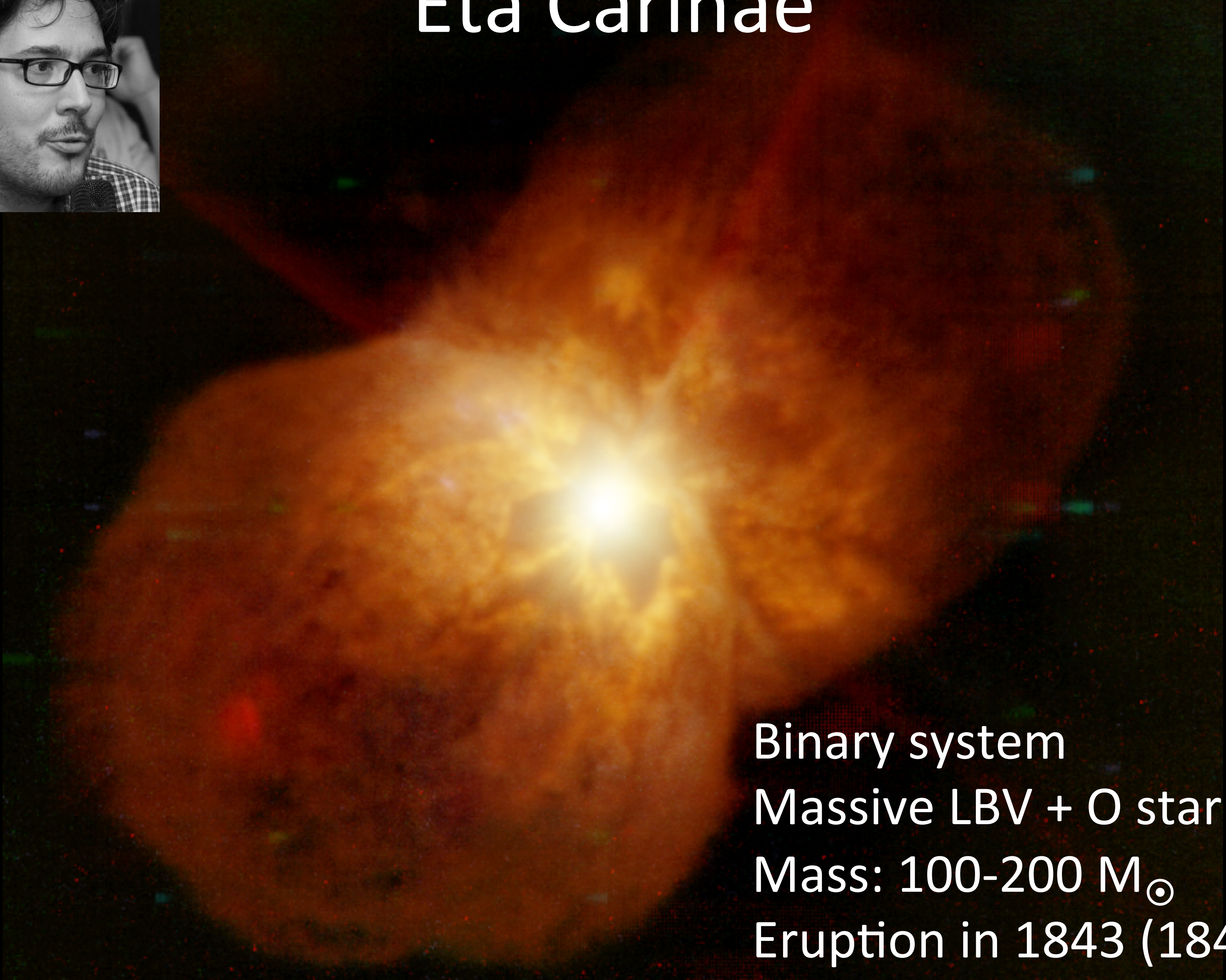


^{12}CO($v=0$, $J=3-2$)
0.3
0.2
0.1
0.0
−0.1
−0.2
−0.3
Declination offset (arcseconds)
0.3
0.2
0.1
0.0
−0.1
−0.2
−0.3
Right ascension offset (arcseconds)
−13 −6 0 6 13



$^{12}CO(v=0,\ J=3-2)$
Declination offset (arcseconds)
Right ascension offset (arcseconds)
0.3
0.2
0.1
0.0
−0.1
−0.2
−0.3
−13 −6 0 6 13

Eta Carinae



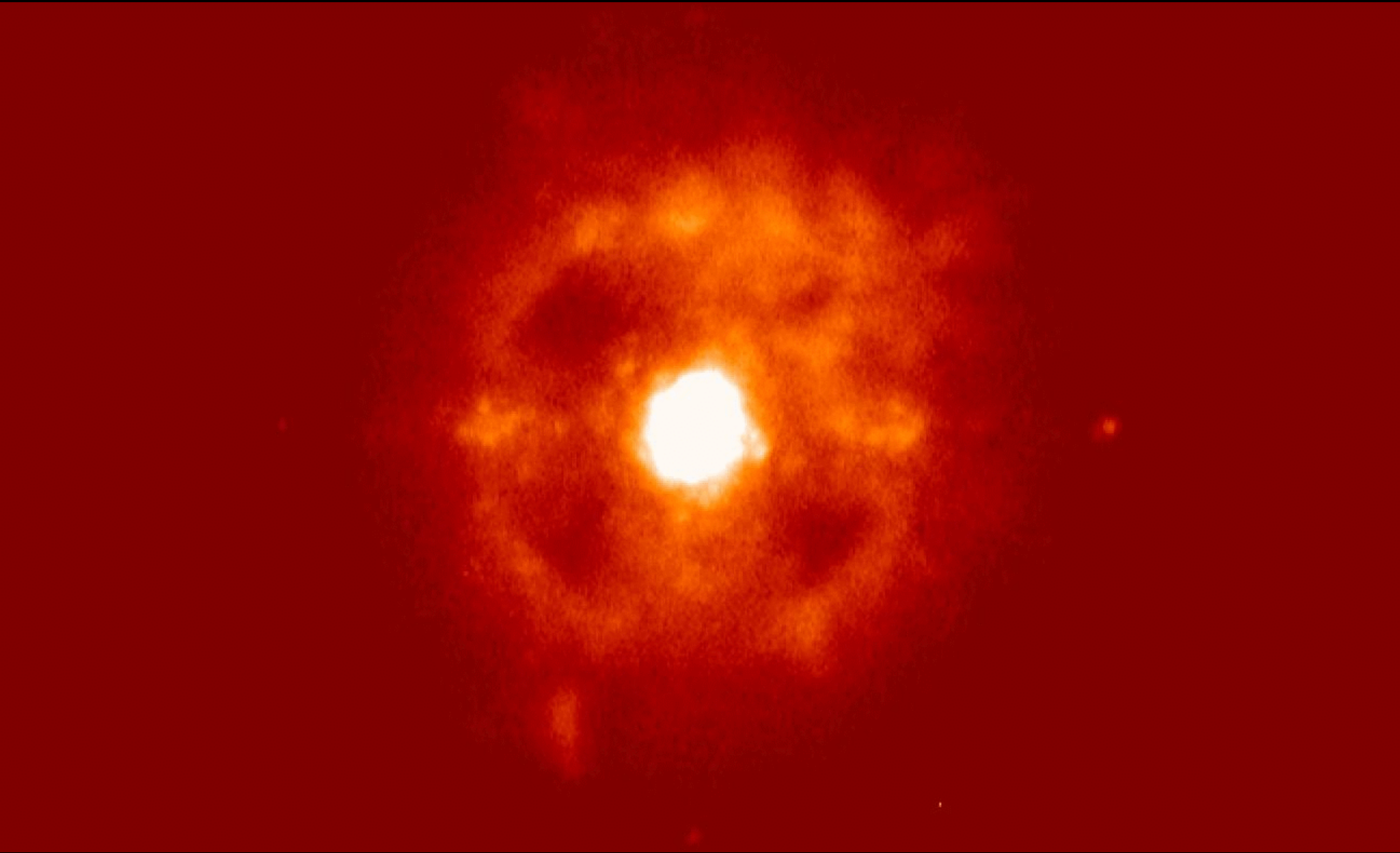
Binary system

Massive LBV + O star

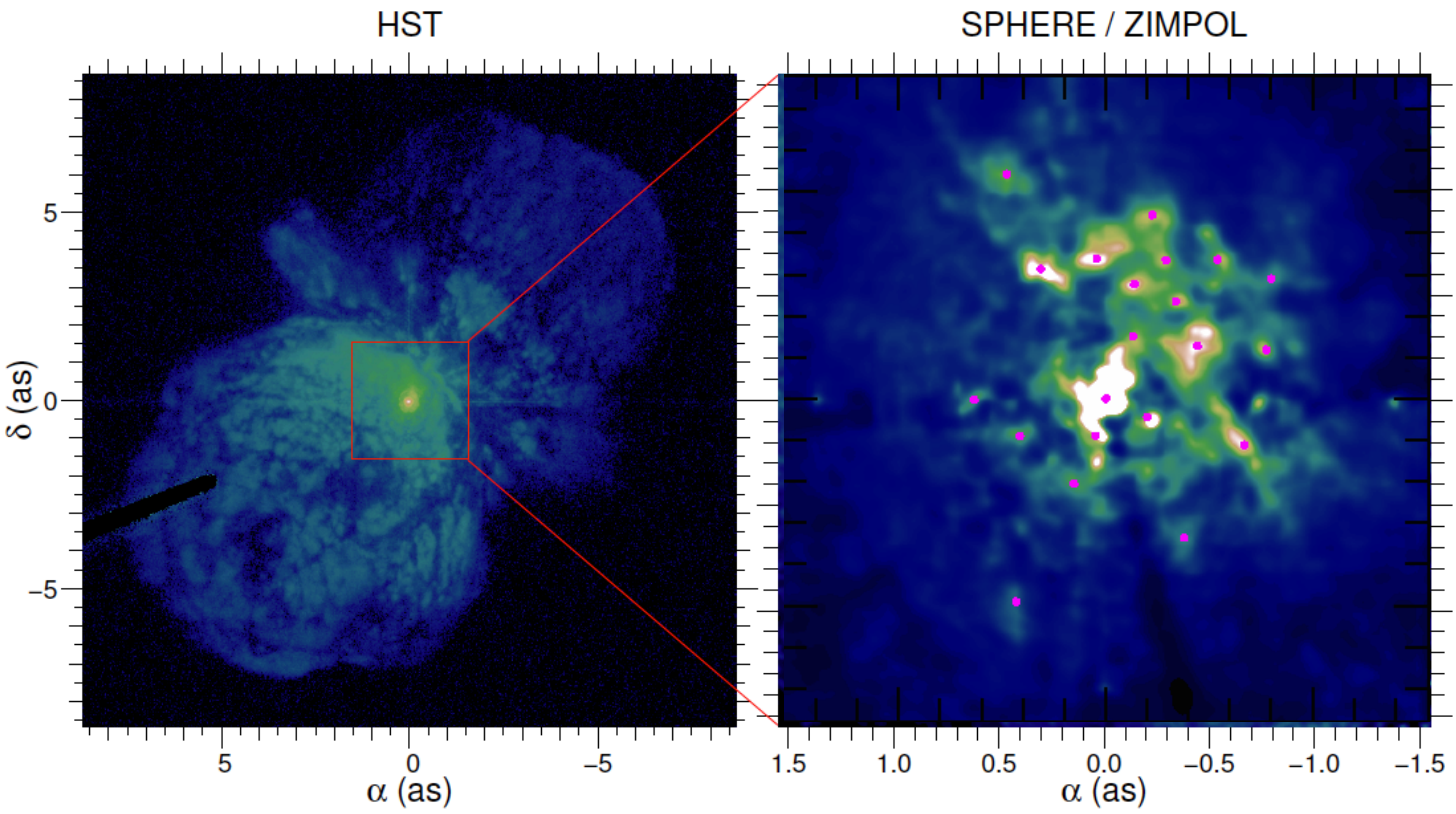
Mass: 100-200 $M_\odot$

Eruption in 1843 (1847?)

Eta Carinae: deconvolution

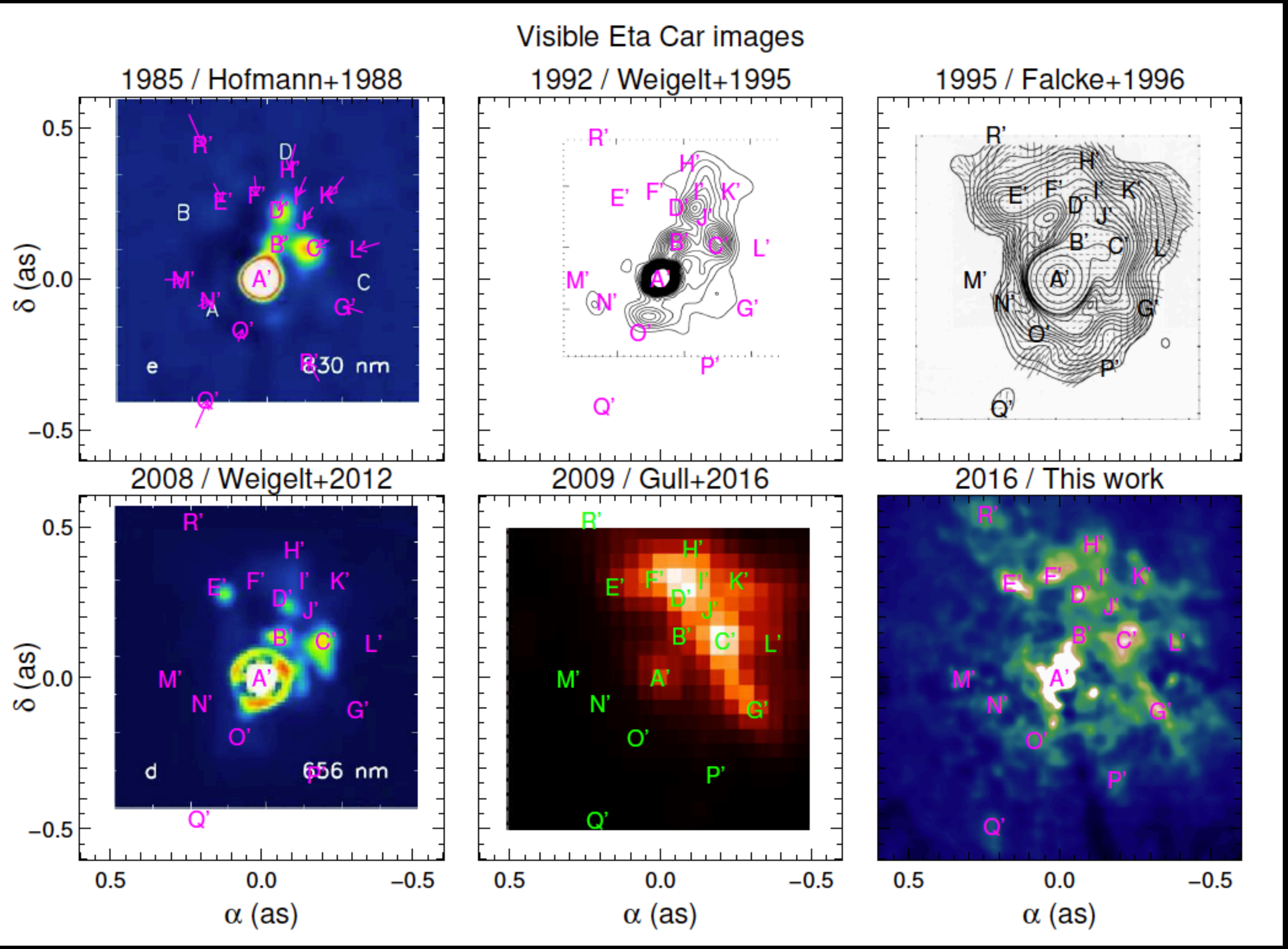


ZIMPOL: into the core of Eta Carinae



Millour, Lagadec et al (about to be submitted)

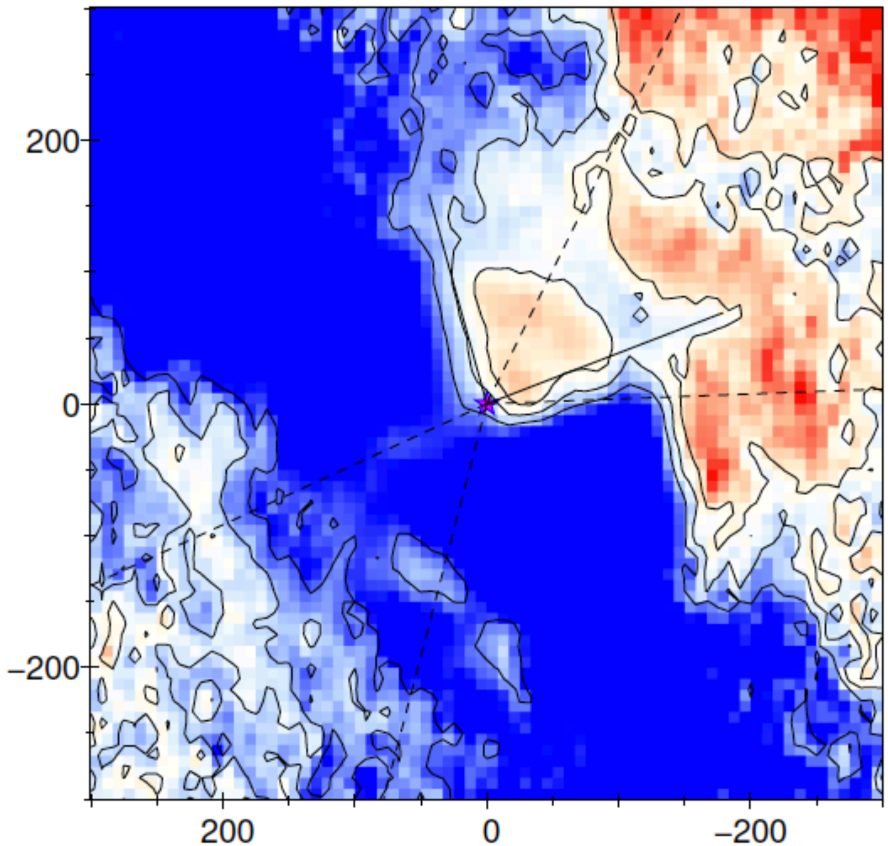
Eta Carinae in « slow » motion

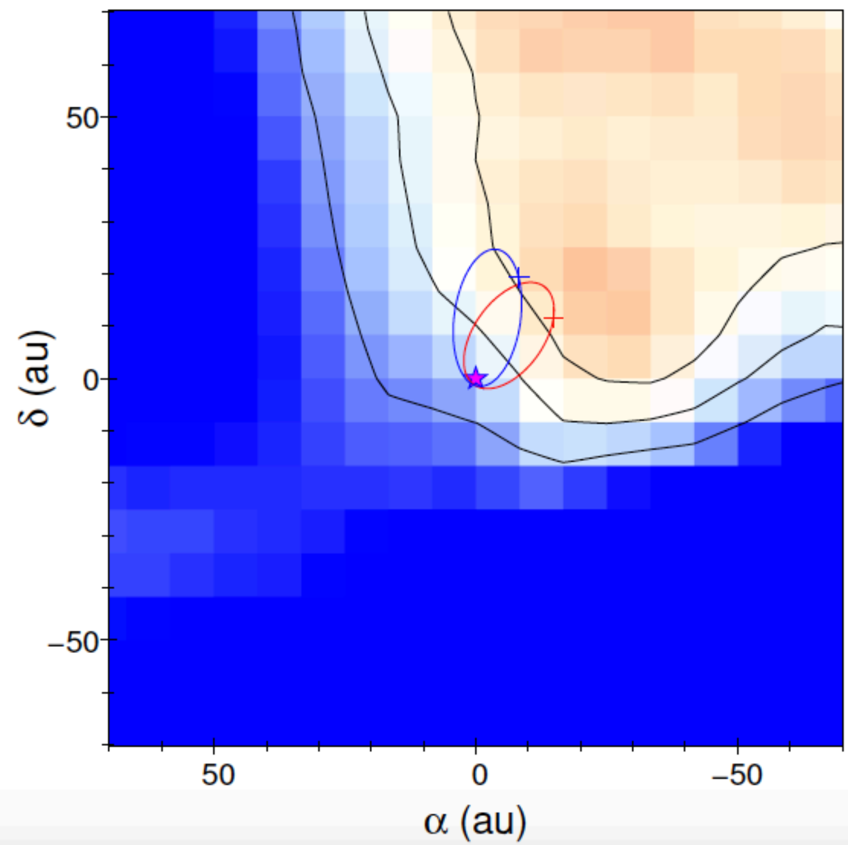


- Lesser eruption in 1890
- Blobs imaged since 1988
- Motion of the Weigelt blobs!

Millour, Lagadec et al (about to be submitted)

Eta Carinae: wind-wind collision zone?





ZIMPOL polarisation map

Polarisation map, with predicted orbits of the binary

Millour, Lagadec et al (about to be submitted)

Asteroids

- Relics of the solar system formation
- Knowing their density is important to better understand their physical structure
- Ground-based images+ rotation: cheap 3D structures
- Binaries: mass

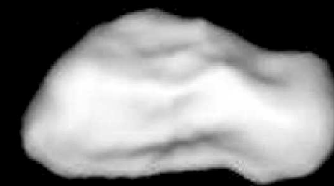
Asteroids

3D models

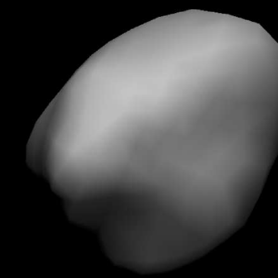
(951) Gaspra

(2867) Šteins

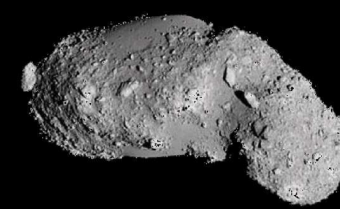
(25143) イトカワ



(21) Lutetia



Comparision with space mission’s observations

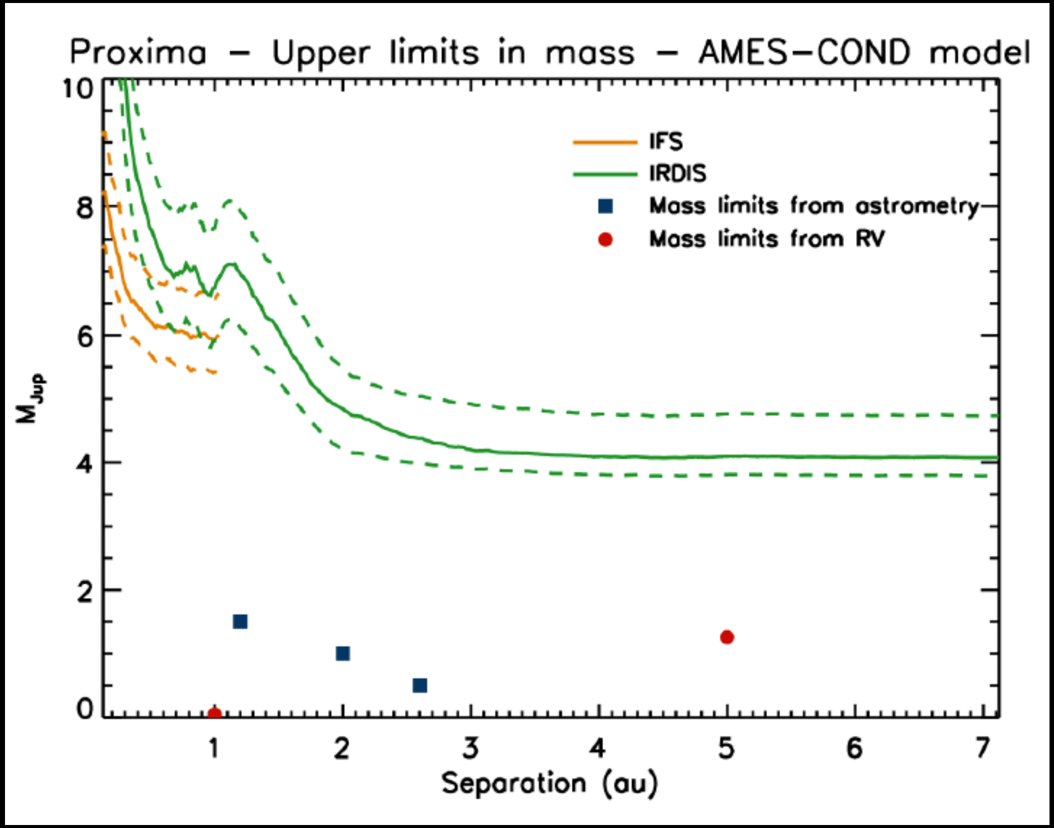


51 Daphne (ZIMPOL)

Large programme (Vernazza et al.) accepted

Carry et al., in prep

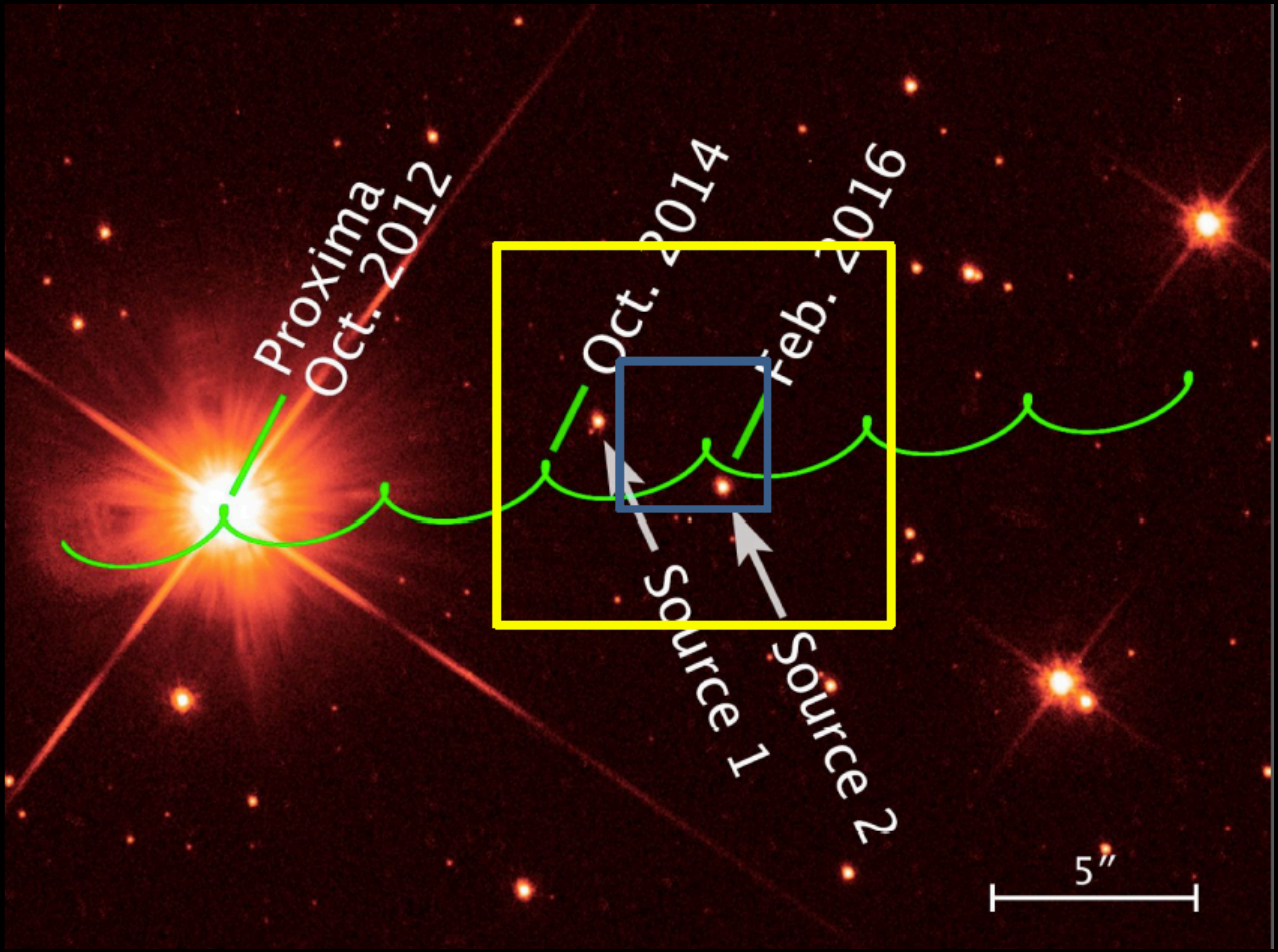
Proxima



- Trendy lately since the discovery of Proxima Cen b
- IRDIFS observations for more than 18 months
- Constraints on planets at large separation

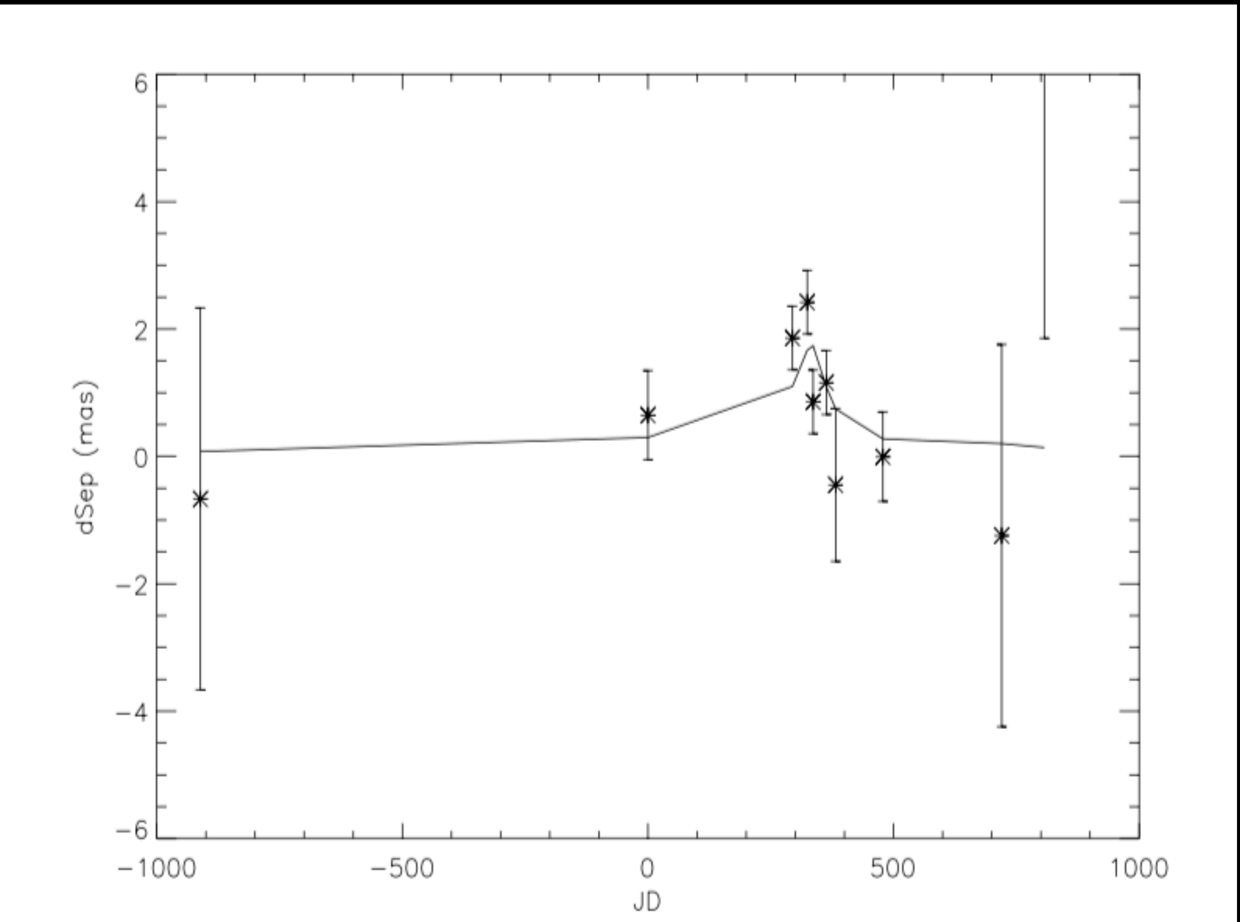
Mesa et al., 2016

Mass of Proxima Cen (Alice Zurlo, Marseille-ESO)



Astrometric shift up to 1.5mas expected

Mass of proxima!



Mass measured before (M-L)

0,12 $M_\odot$

Mass from lensing:0.145 $M_\odot$ (±0.05)

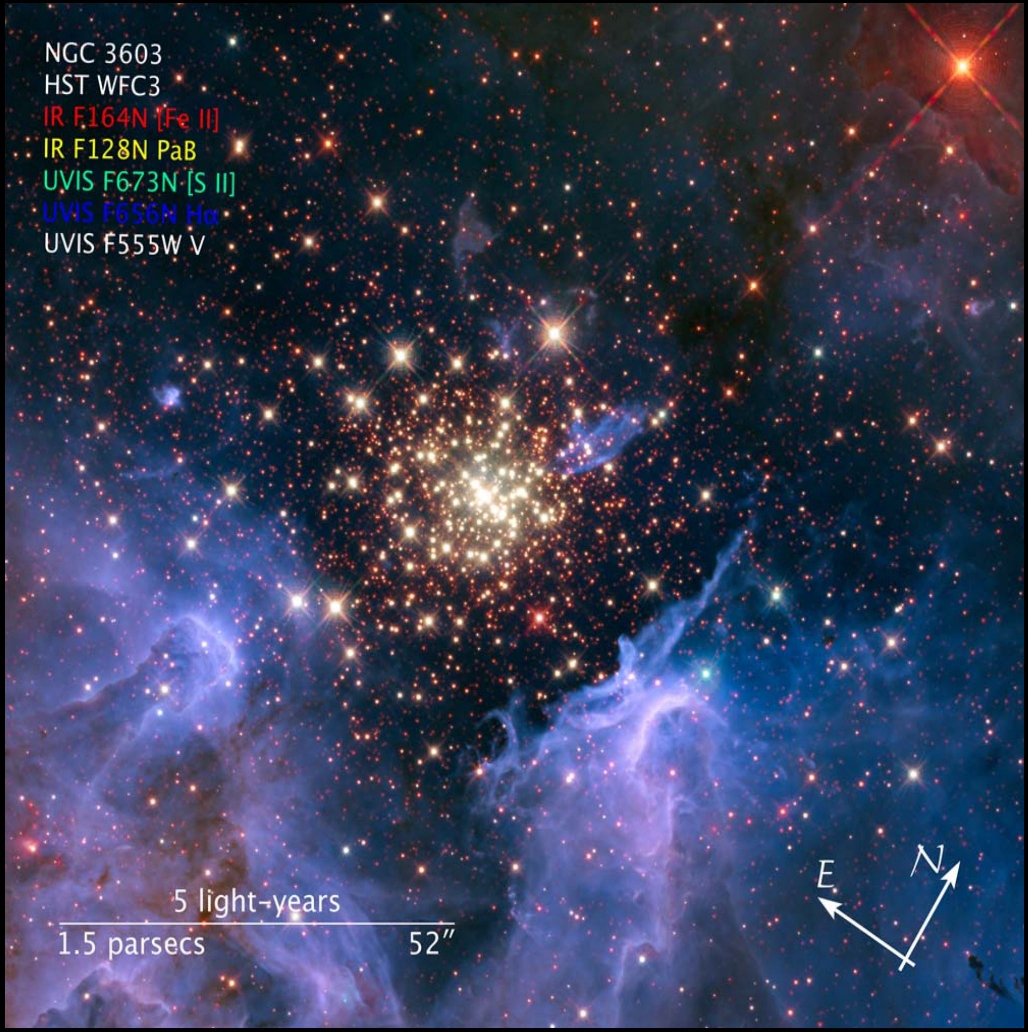
2nd star ever to be weighted by lensing!

~2 years of IRDIFS observations

Zurlo et al., submitted

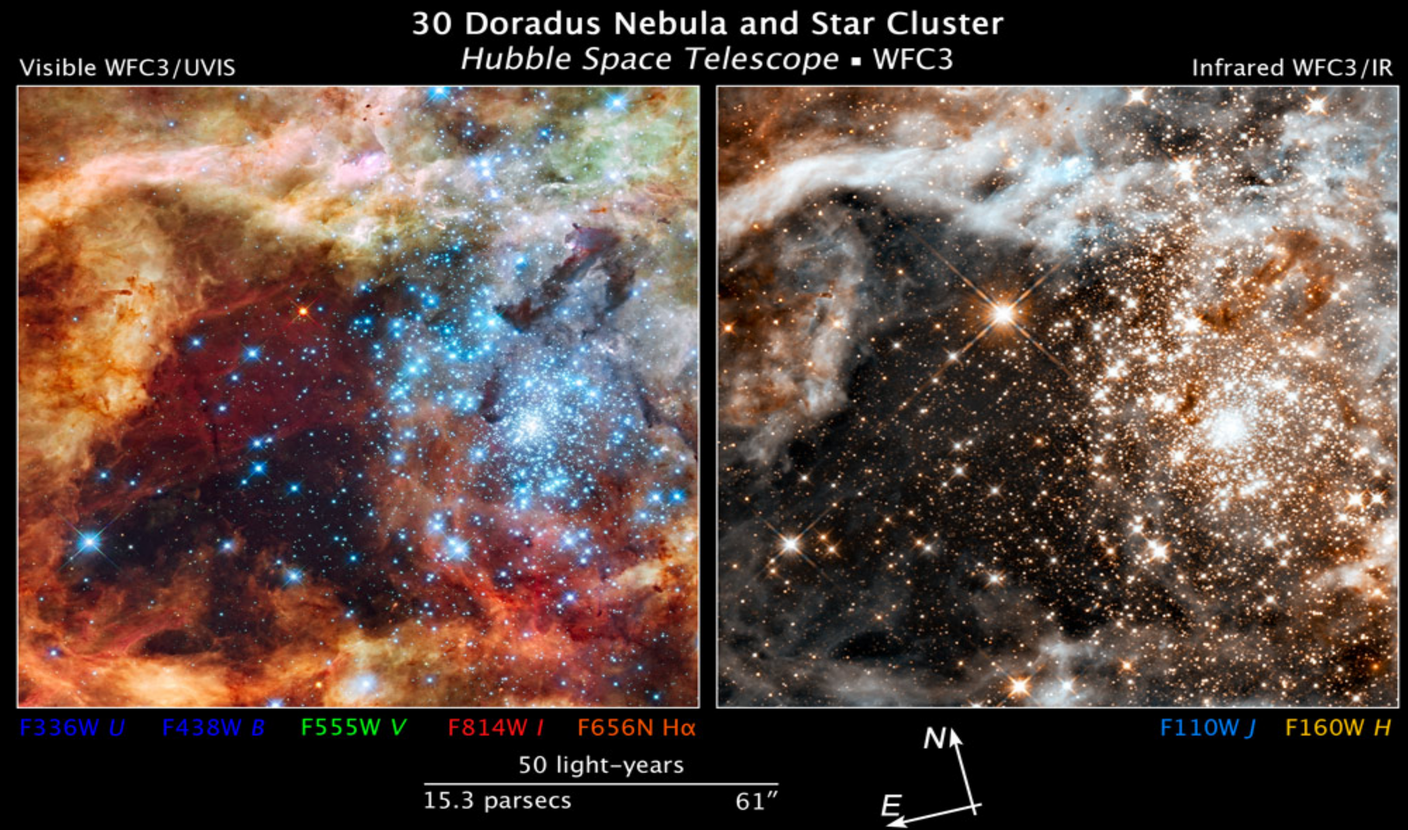
NGC3603

- Most massive visible cluster in our Galaxy
- Age ~ 2 Myr
- M_{phot} ~ 1.2E+4 M_{sun}
- D~ 6.3 kpc



R136

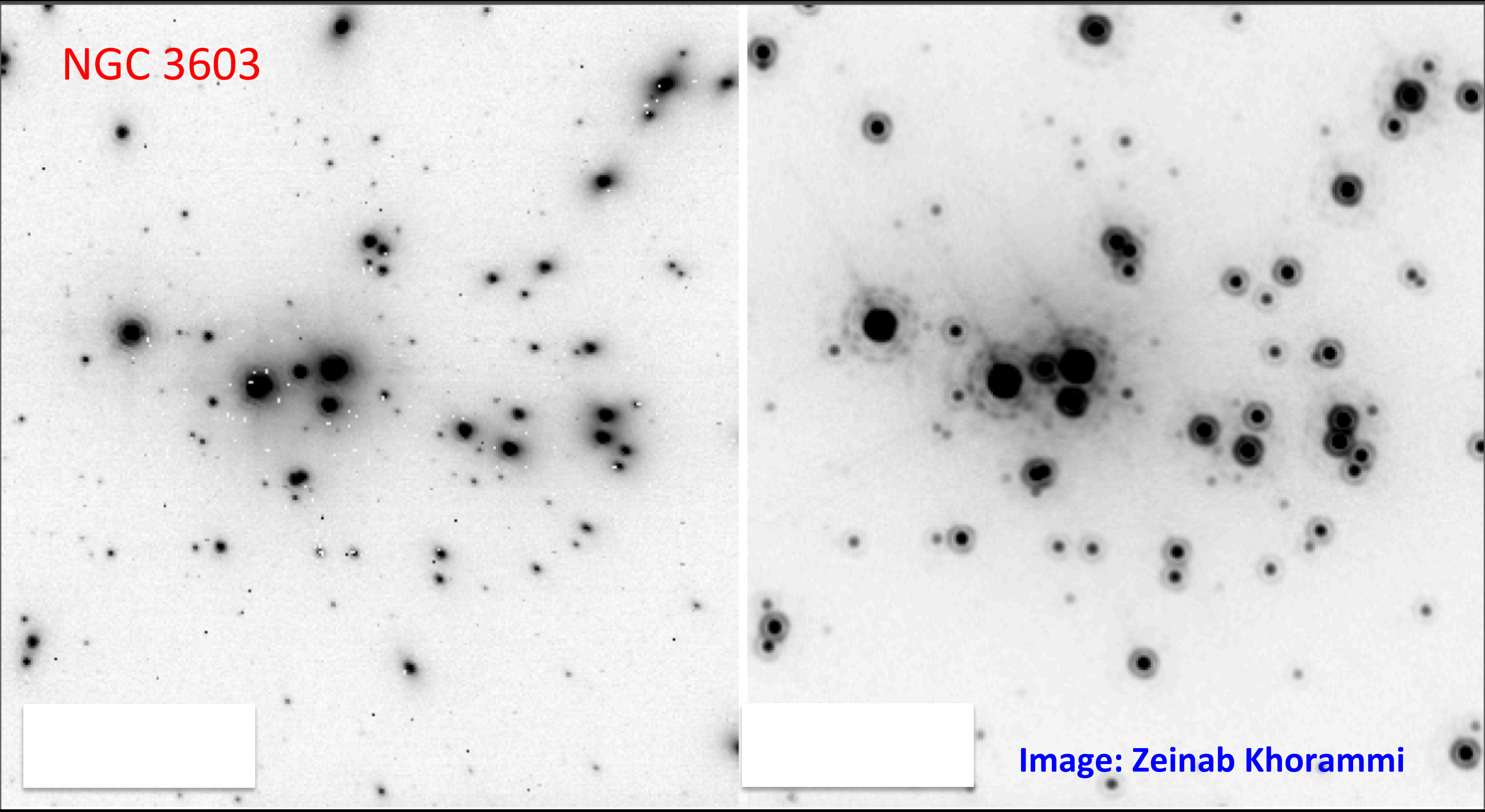
- Age ~ 3 Myr ; M_{phot} ~ 1.0E+5 M_{sun}
- D~ 50 kpc



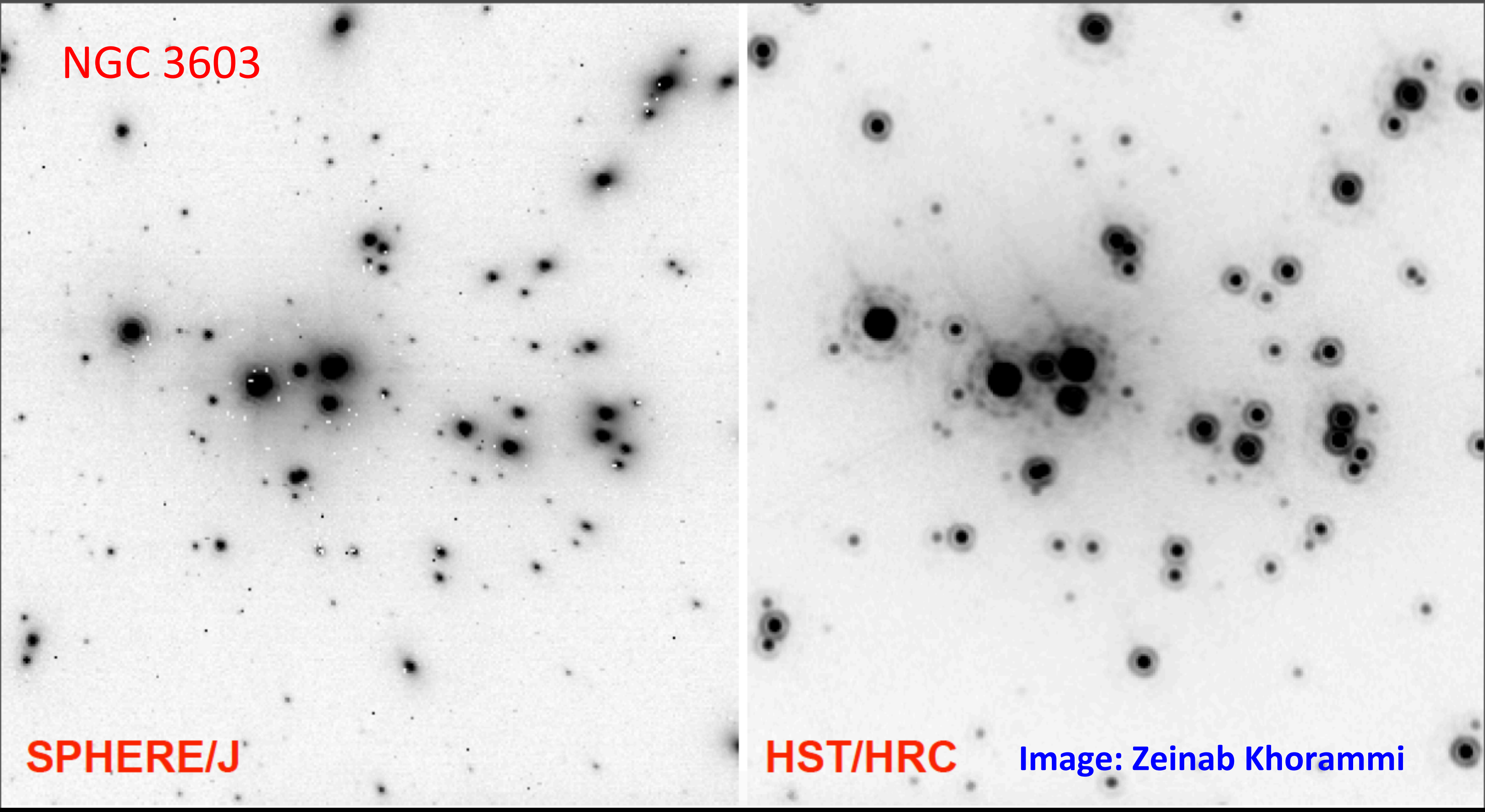
Goals

- Prototype of compact starburst clusters: study the binary fraction and verify the mass segregation scenario
- Dual IRDIS imaging: well suited to extract simultaneously the astrometric shift of a binary system due to the spectral types of its components.

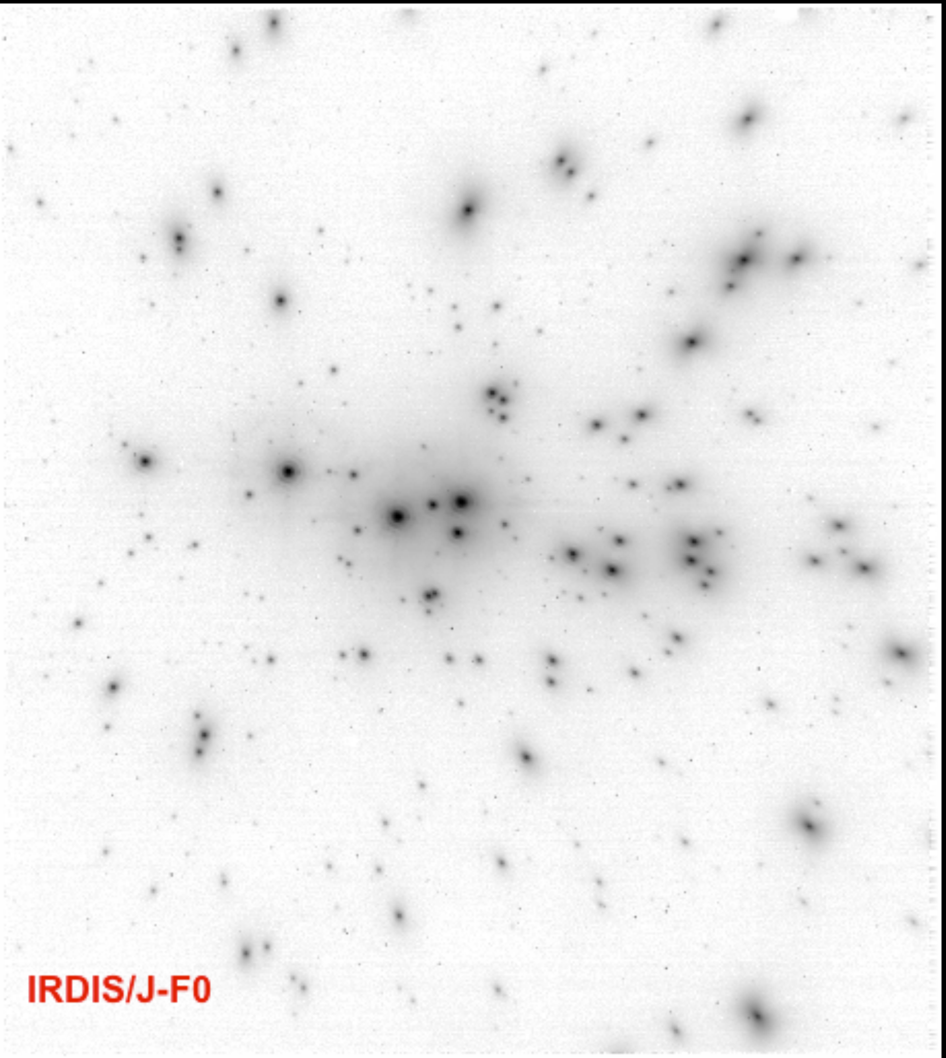
SPHERE vs HST



Resolution: better than the HST!

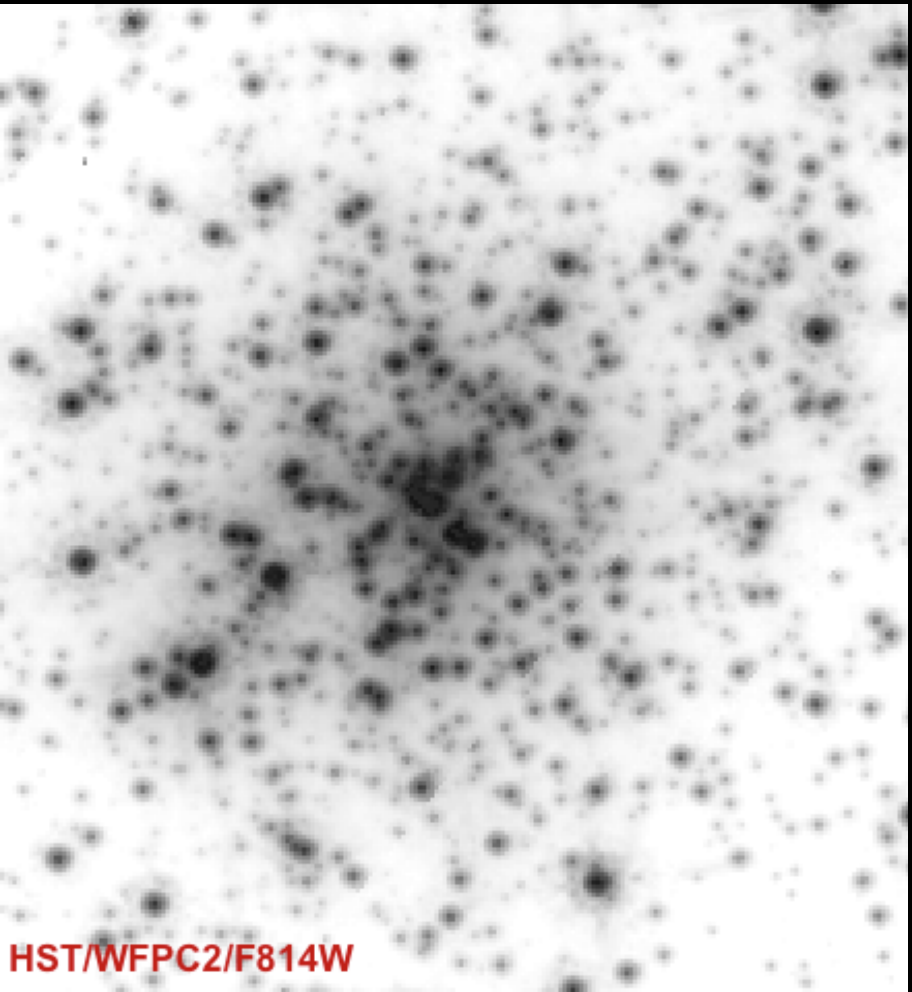


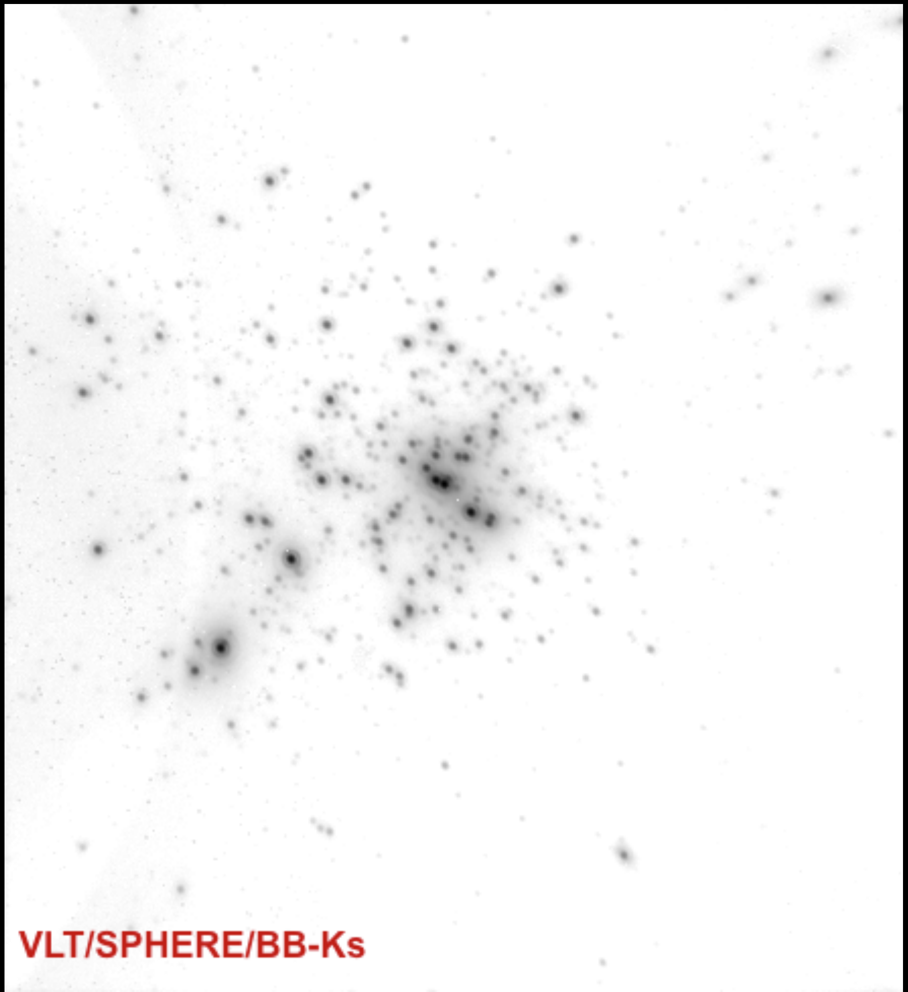
NGC 3603 (Khorrami)



- Map of the core of the cluster
- Extinction maps
- MF in the core
- No segregation?

R 136 (Khorrami)

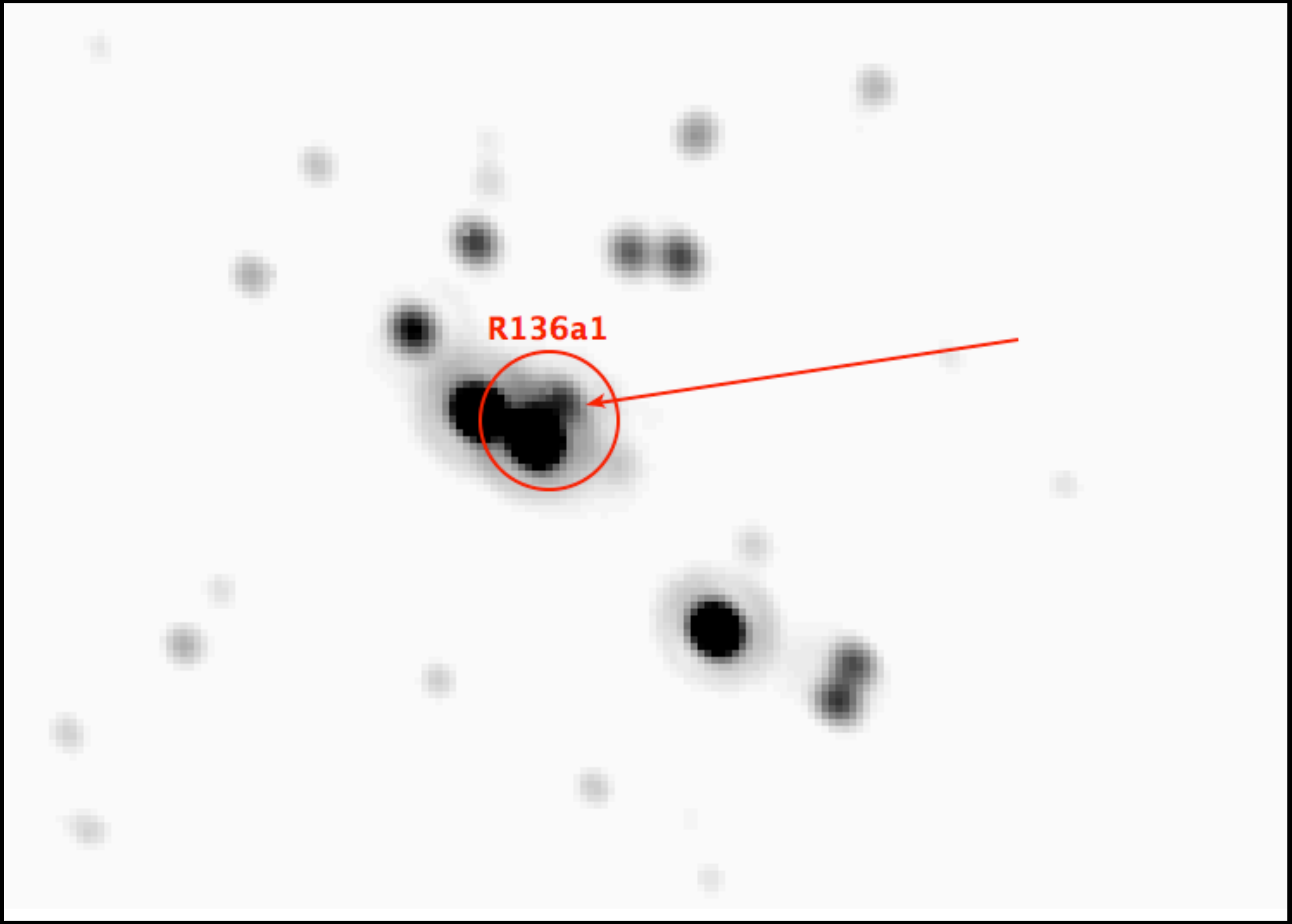




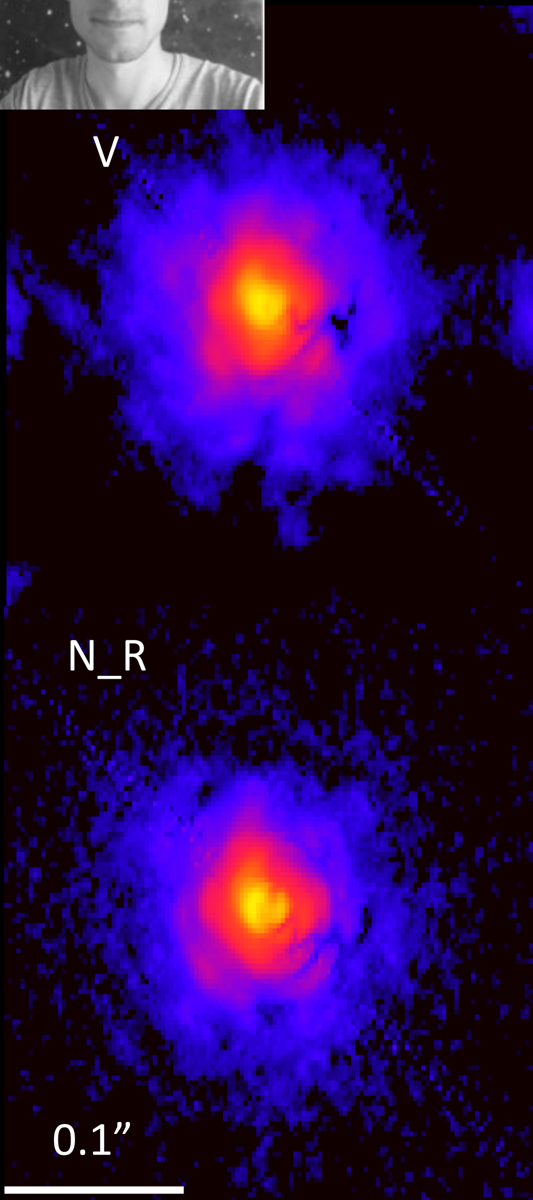
R136 a1

- Most massive star known in the universe 265 Msun
- Important for top part of the IMF (limit usually accepted: 150 Msun)
- Pair-instability SNe in the vicinity of the MW?

Is R136 A1 a binary??

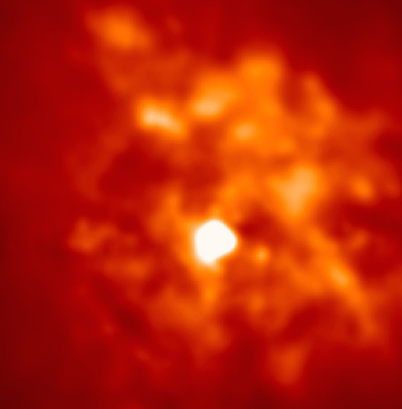
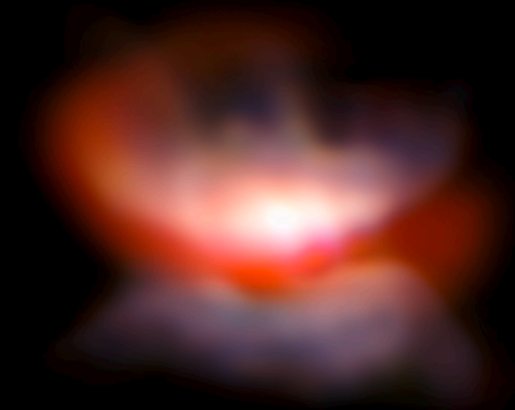
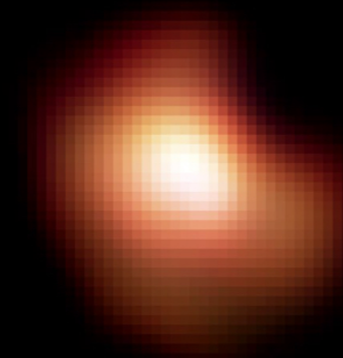
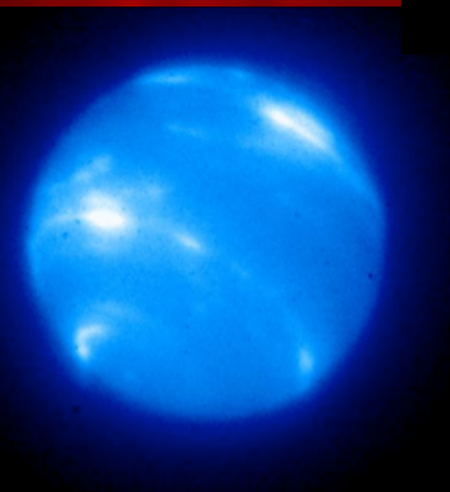
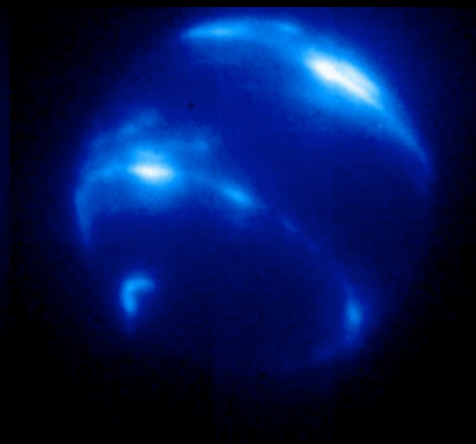
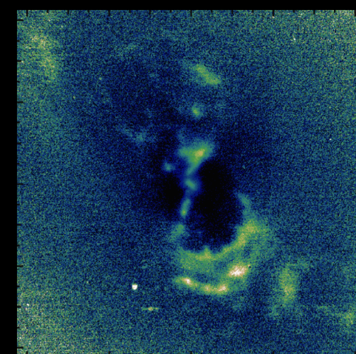
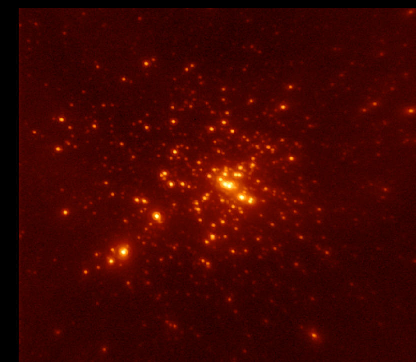


Cepheids

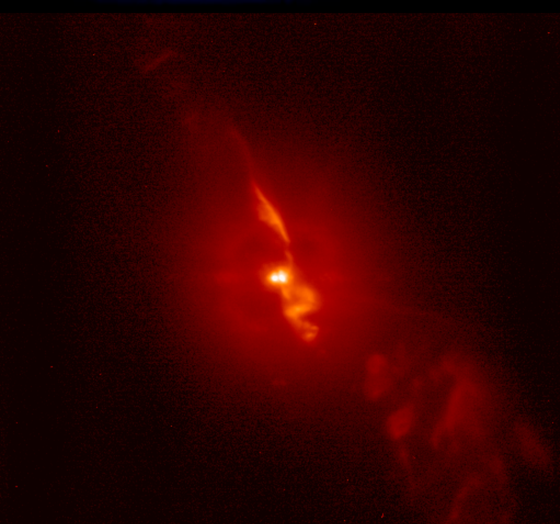


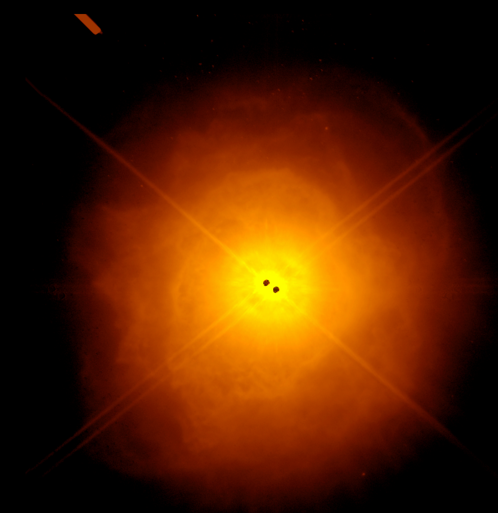
- Envelopes? (would affect the flux measurement and thus the PL relation)
- Companion? (same, and color effects)
- Observations of L Pup and Y Oph

Thèse de Vincent Hocdé (avec Nicolas Nardetto)

Thank you!





Z Cma (S. Antoniucci, Rome)

- Binary system (0.1” sep):

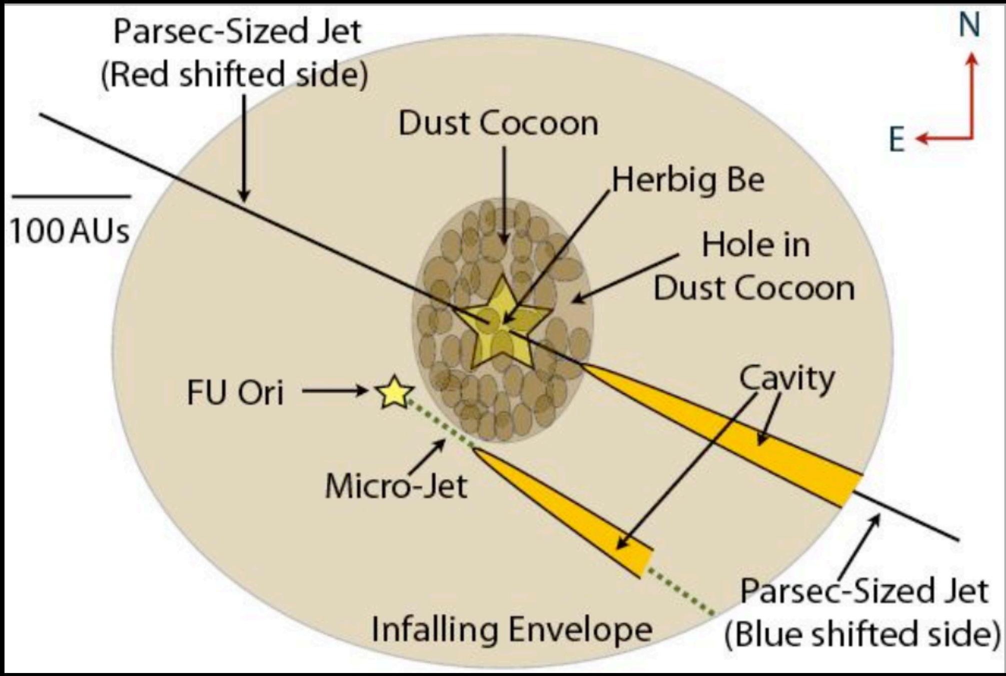
FU Ori and eruptive Herbig Be (EXor)

Unique to study ejection of matter in young stars with outbursts due to accretion (2008-2010)

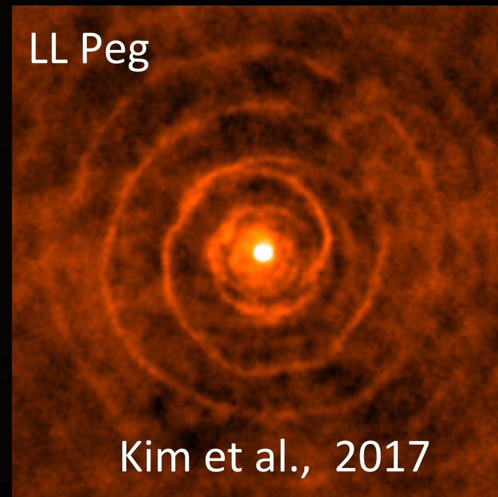
<u>Connection accretion-ejection?</u>

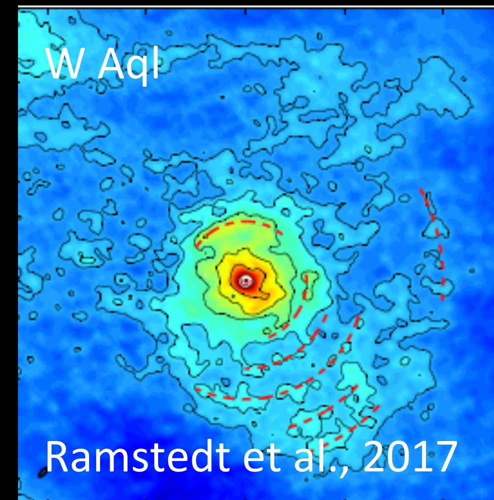
<u>Magneto-centrifugal scenario for intermediate mass?</u>

<u>Interaction disk-jets?</u>

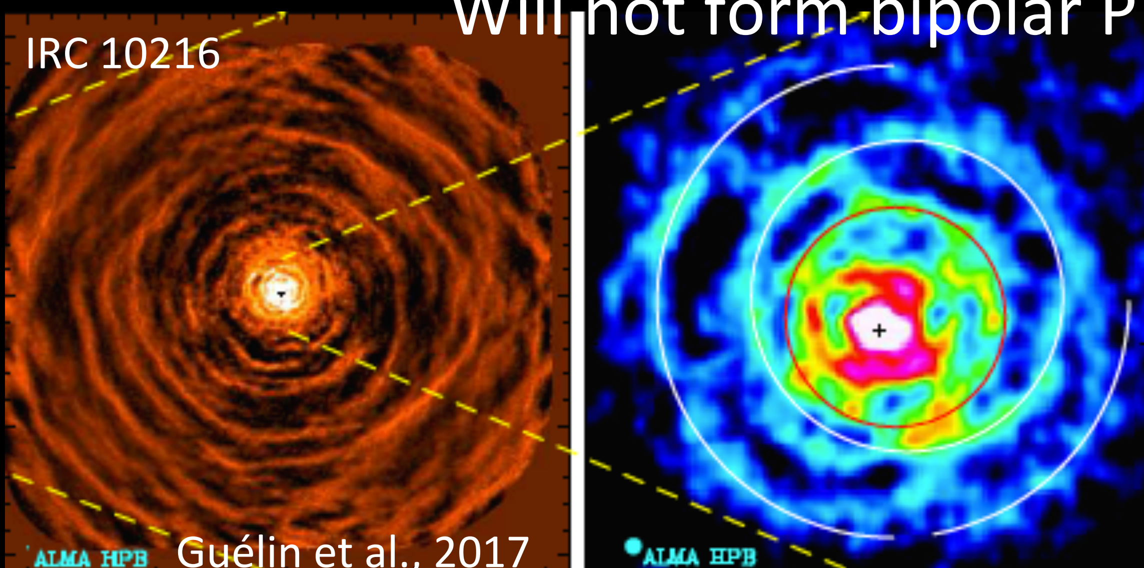


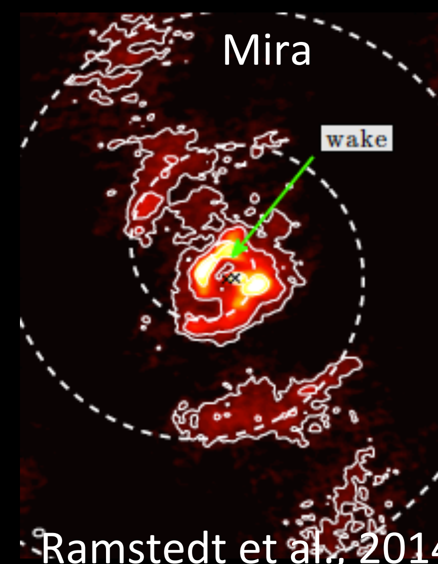
ALMA: spirals formation due to binaries





Will not form bipolar PNe?





Goals of “Other Science”

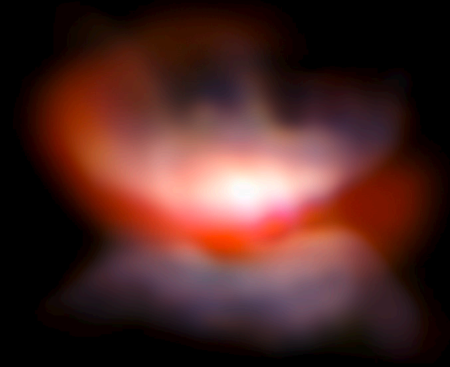
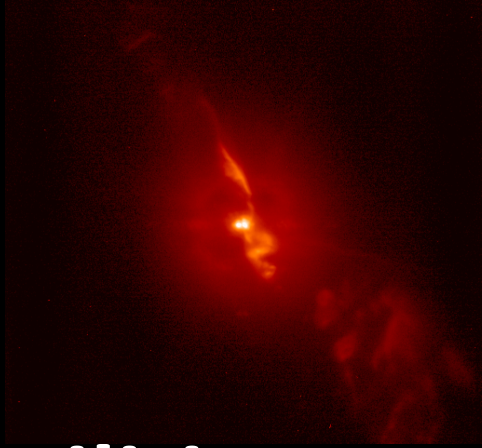
- Science cases non related to planets/disks
- Show the community that SPHERE is versatile
- A few temporal monitoring programs
- Short program that should then lead to successful open time proposals

Starburst region R 136 and NGC 3602

- Best place to find the most massive stars: young starburst massive clusters
- BUT we should be careful about :
- M_{tot} high enough so IMF can sample up to $M > 100\ M_{sun}$
- Should be young enough for massive stars Age < 3-4 Myr
- Should be close enough (spatially resolved)

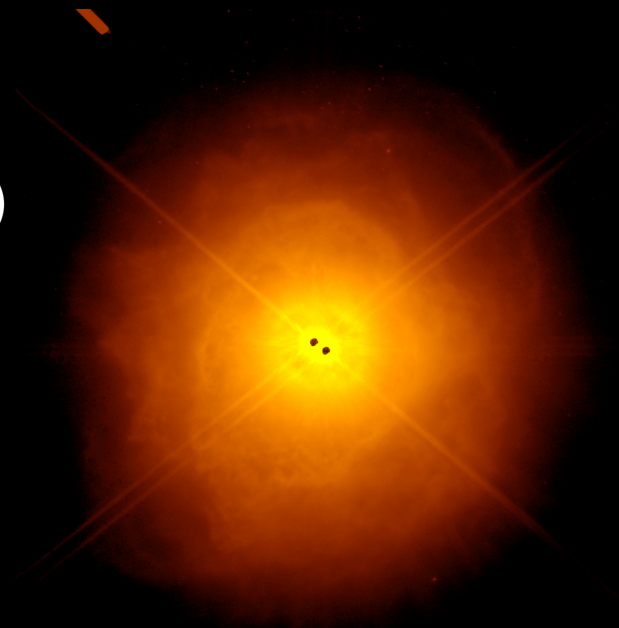
Conclusions and perspectives

- SPHERE is opening a new window on the sky:lots of exciting topics/questions to be answered
- Promising results for AGB stars, extended circumstellar environments, jets, binaries, solar system objects
- More to come!!

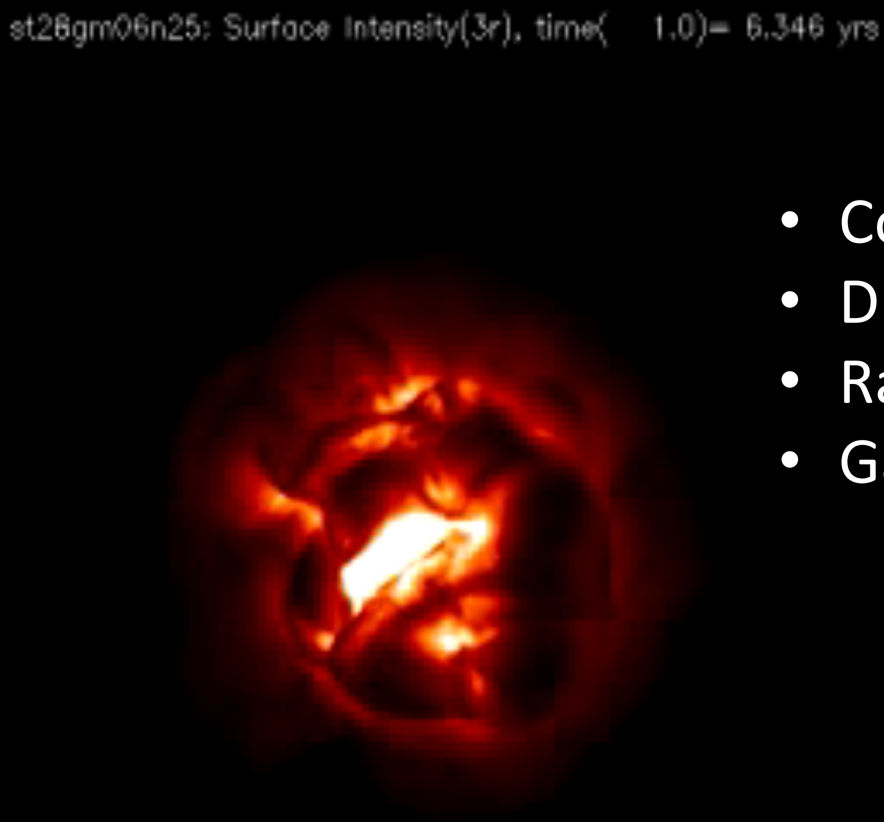




Mission and ground based facilities for the observations of AGB-SAGB and massive stars

Eric Lagadec
Lagrange laboratory
(Observatoire de la Côte d’Azur)

Mass-loss process

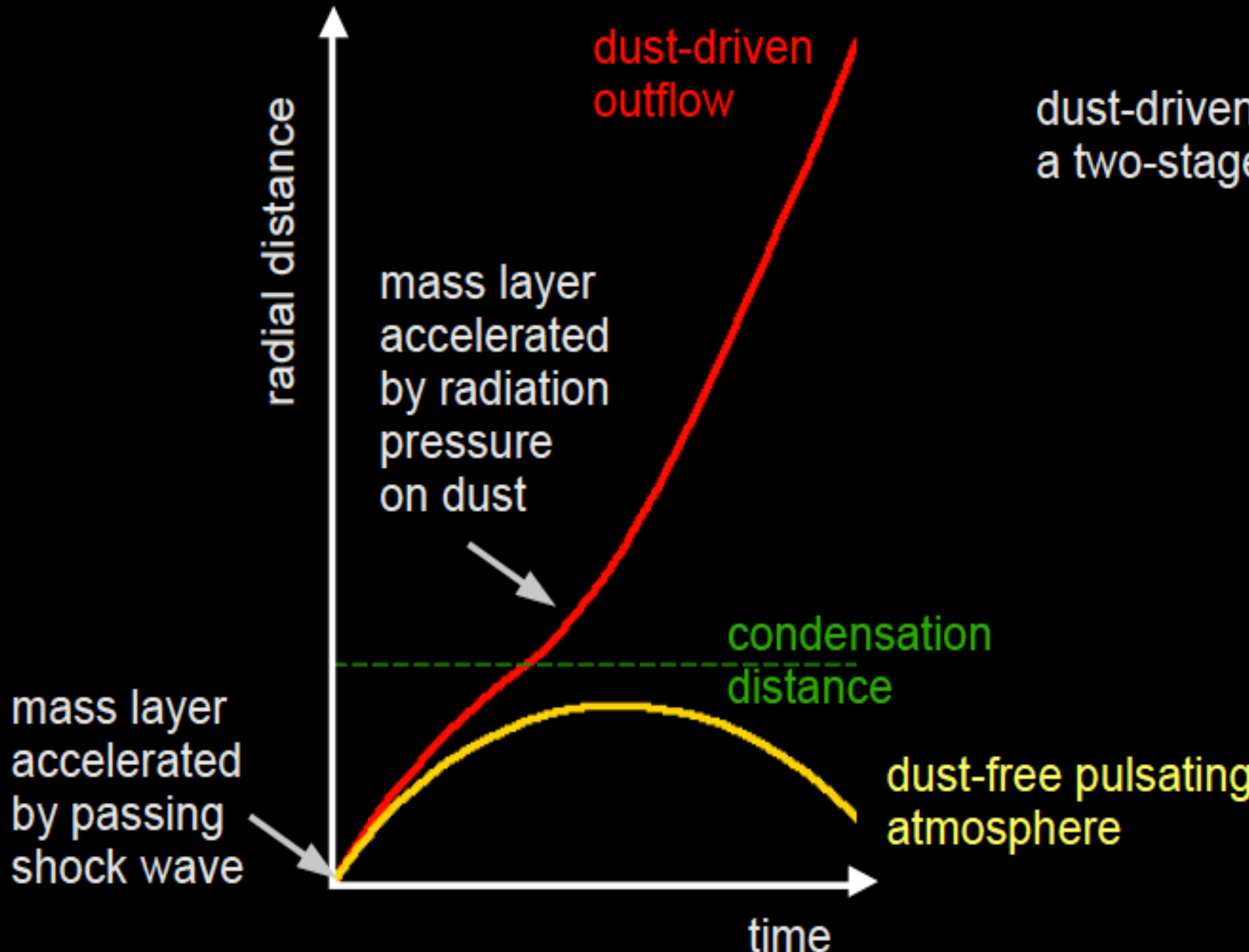


- Convection and pulsation: shocks
- Dust formation behind the shocks
- Radiation pressure: acceleration
- Gas dragged via collisions

Borrowed to S. Hoefner

A two step mechanism

dust-driven wind:
a two-stage rocket

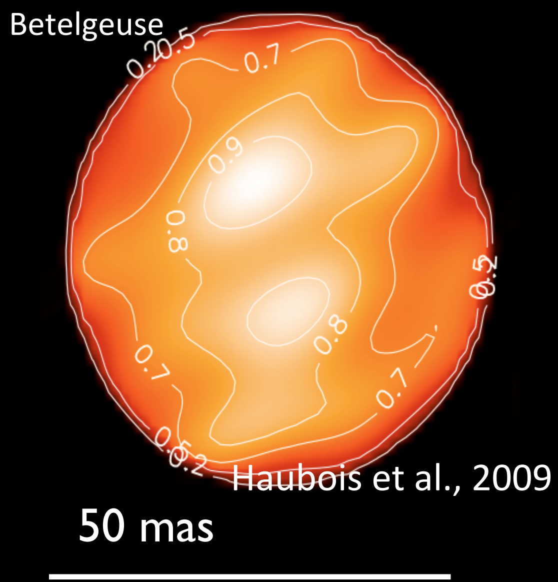


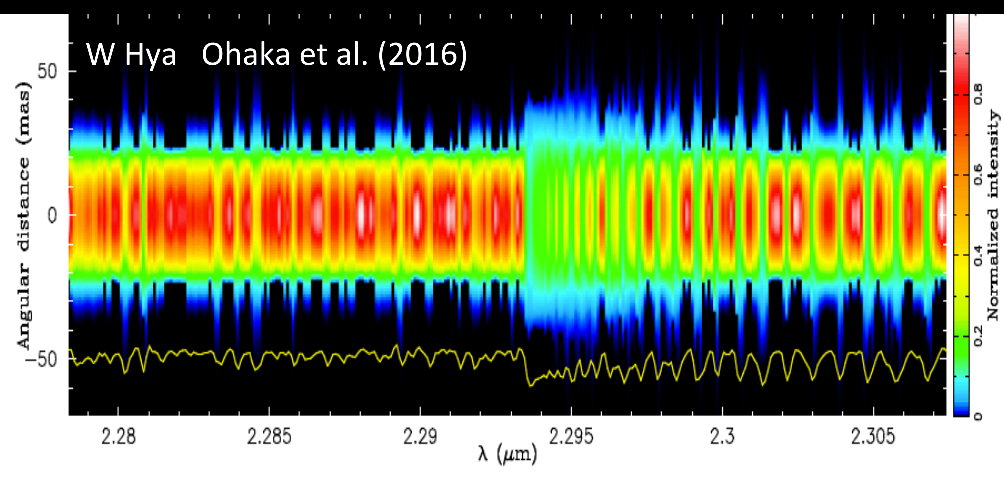
What can high angular resolution tell us about the mass-loss mechanism?

- Interferometry: extension of the atmosphere, gas dynamics, convection, dust formation
- Extreme AO+polarisation: grain size, convection
- Time series: link pulsation+ convection with shocks and dust formation

IR interferometry of AGBs and RSGs

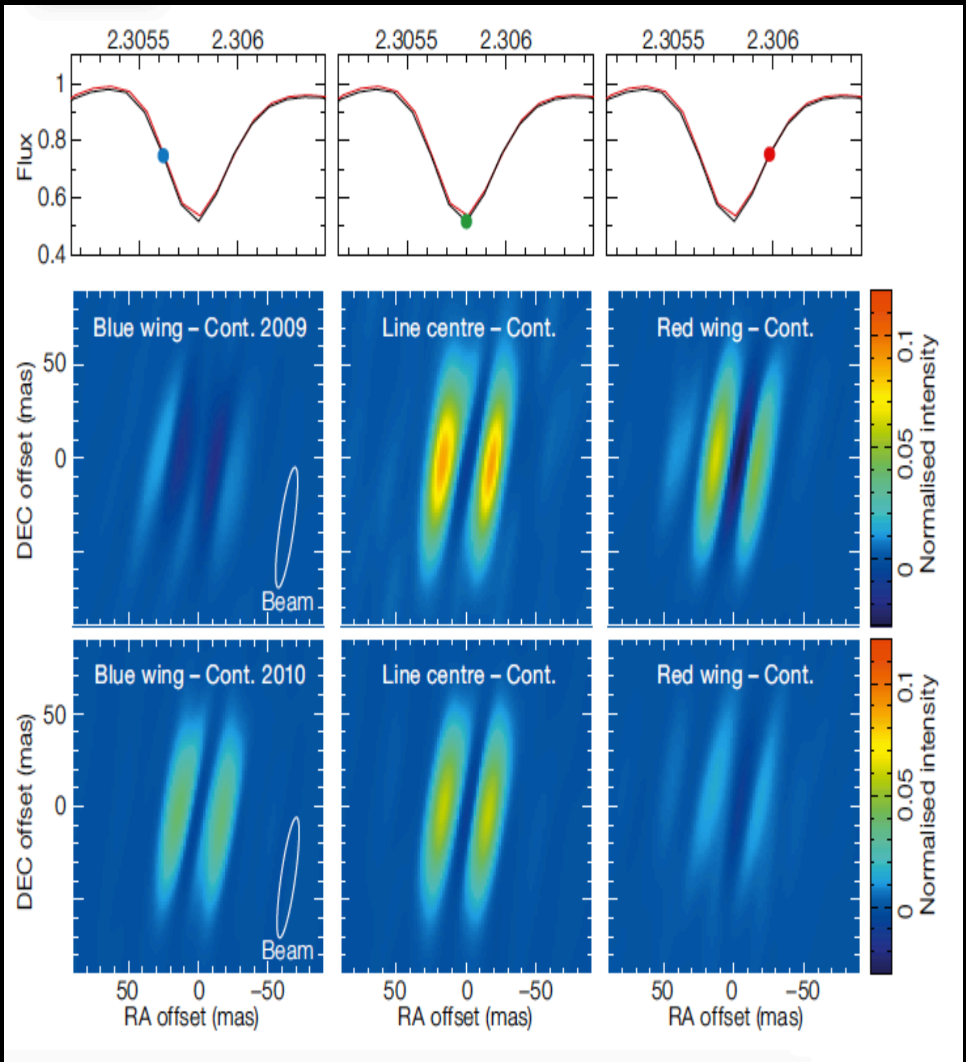
- Imaging capibilities: can resolve convective cells!
- Spectral resolution: map MOLSPHERE and study gas dynamics
- MIR: map dust formation





Resolution down to 1 mas!! can even map the surface of some stars

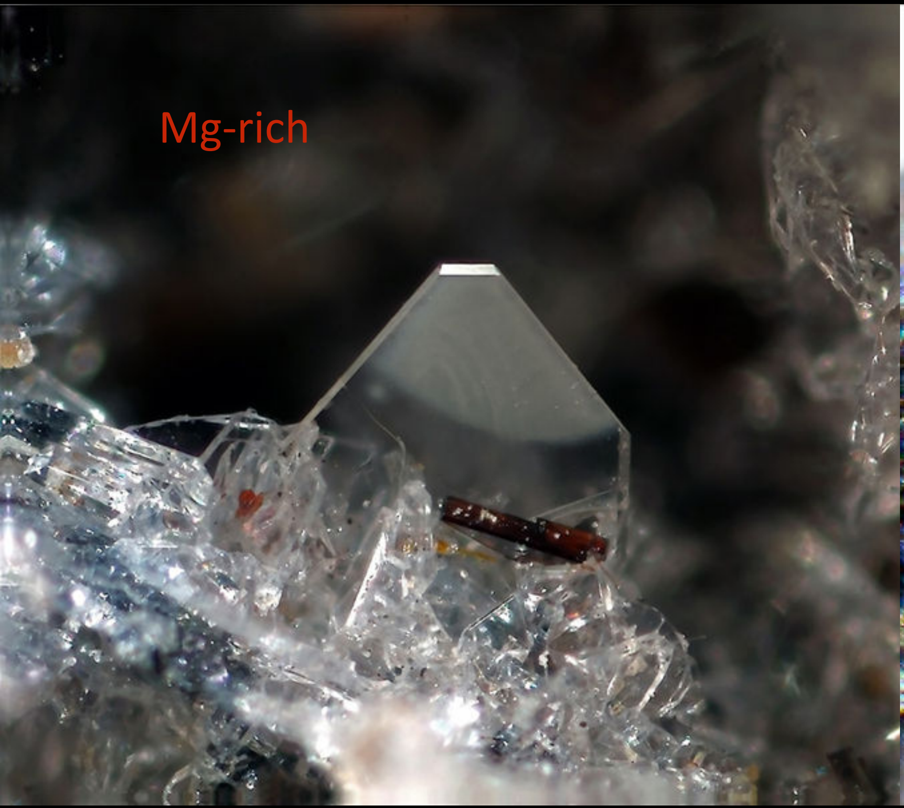
NIR interferometery: convection



- Atmosphere appears different across the CO line profile
- Inhomogeneous velocity field
- Changes within a year
- Seen also in Betelgeuse

Antares: Ohnaka et al., 2015

Problem for O-rich dust!



Can form close to the star
but transparent

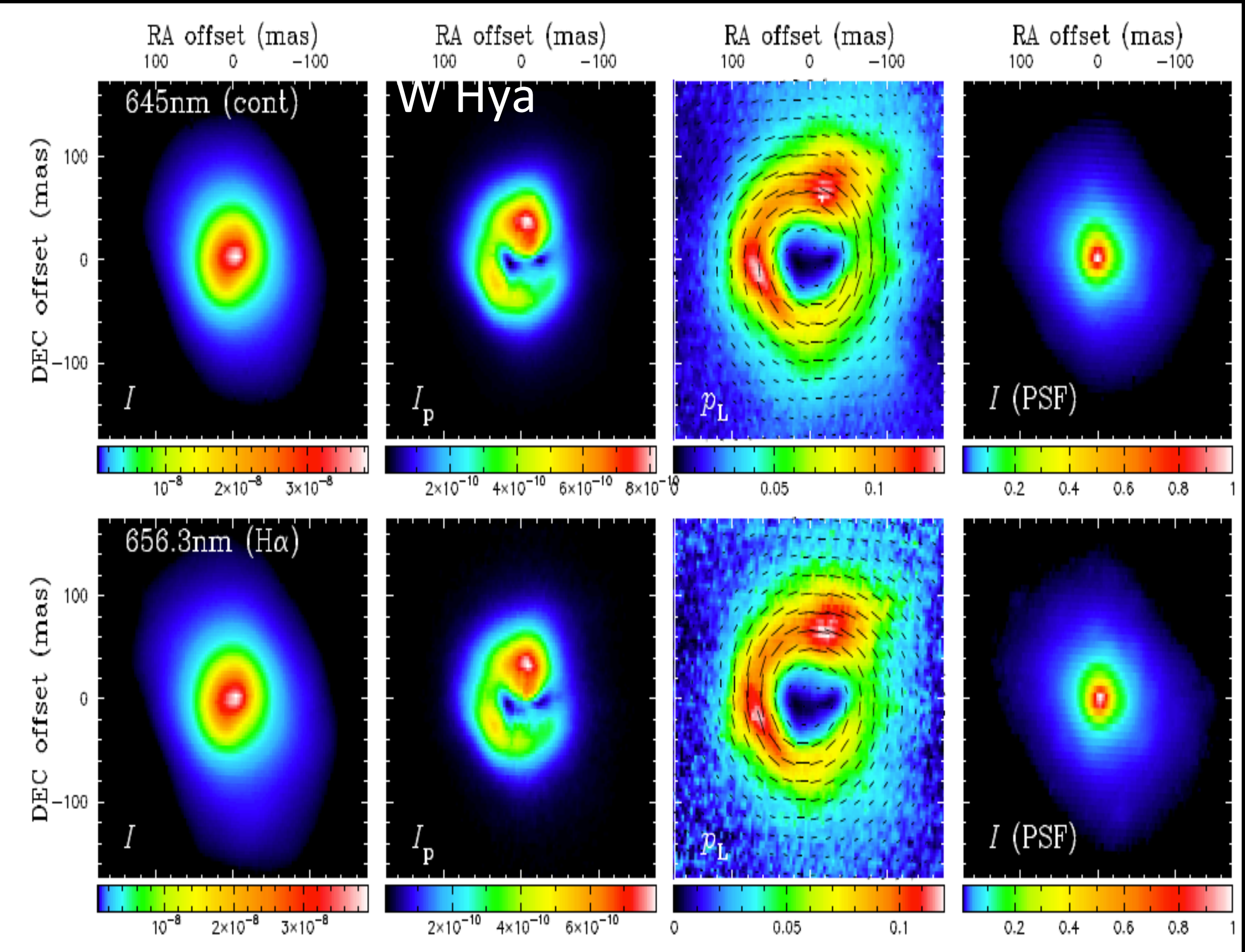
Form too far from the star
for radiation pressure to work

Woitke et al., 2003

Scattering by large grains

- If grains are large (similar to the peak wavelength, a few microns) scattering can trigger the mass loss (Hoefner, 2008)

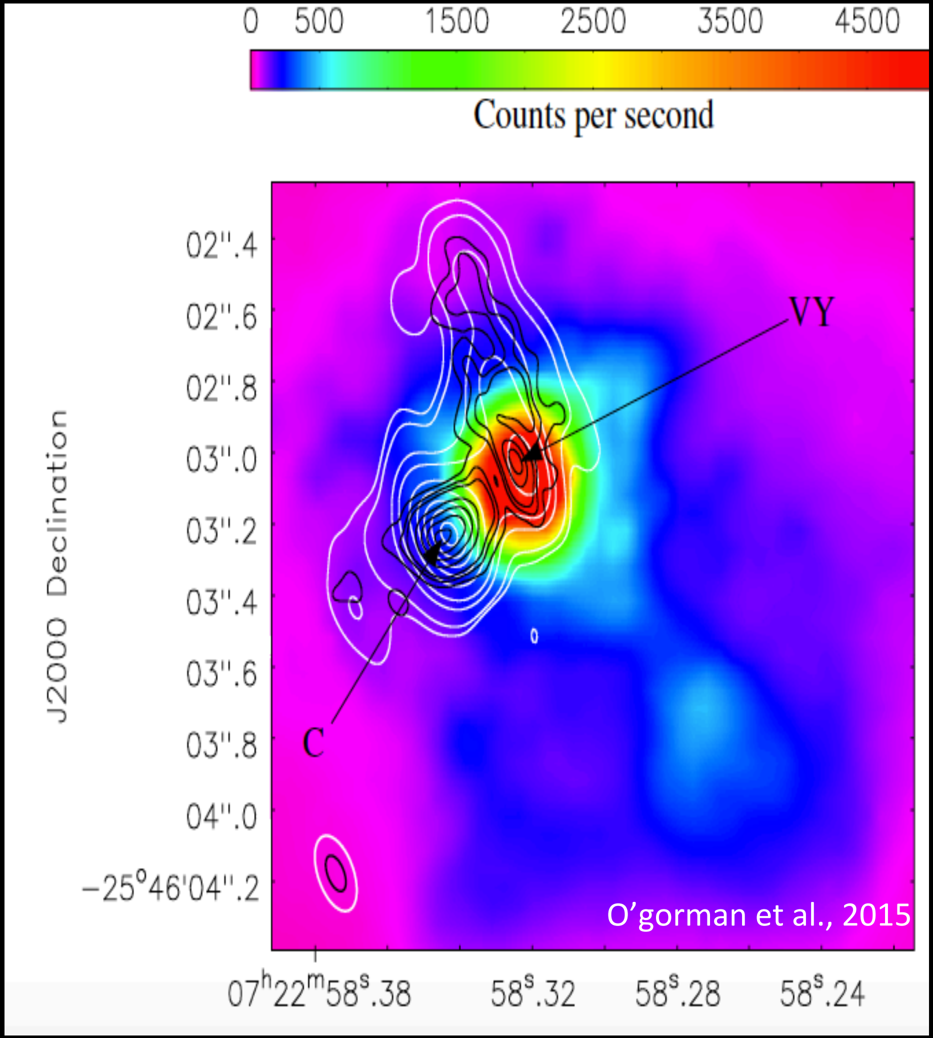
Large grains seen by SPHERE/VLT



Three clumpy dust clouds
Dust, neutral and ionised gas coexist within 2-3 R*
Large grains (0.4-0.5 microns)
Consistent with scattering by large grains
Consistent with convection

Ohnaka et al., 2016

Non spherical mass loss: extra momentum?



ALMA observations of VY Cma (RSG)
Two massive dust clumps
Continuated, directed mass loss over 30-50 years (not compatible with convection)
Magnetic field?
Third stage for the mass-loss rocket?
Fried Egg nebula with ALMA: similar spur? (Wallstrom et al., 2016)