Mass loss of Betelgeuse and evolved stars, from the photosphere to the ISM

Pierre Kervella
LESIA, Observatoire de Paris

Betelgeuse (and RSGs)

- ~10-20 M_{sun}, Teff ~ 3600 K, L > 100 000 L_{sun}
- R ~ 650 - 1000 Rsun
- Density ~ 40 mg/m^3 (Sun: 1400 kg/m^3)

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  Dust-gas coupling ?

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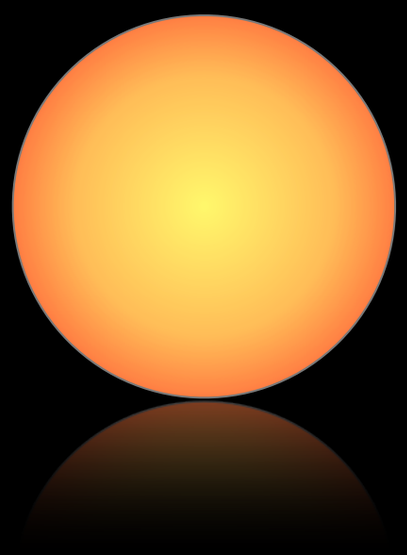
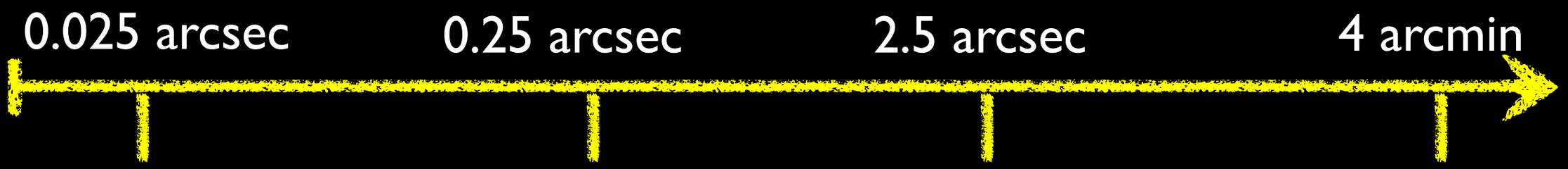
Betelgeuse

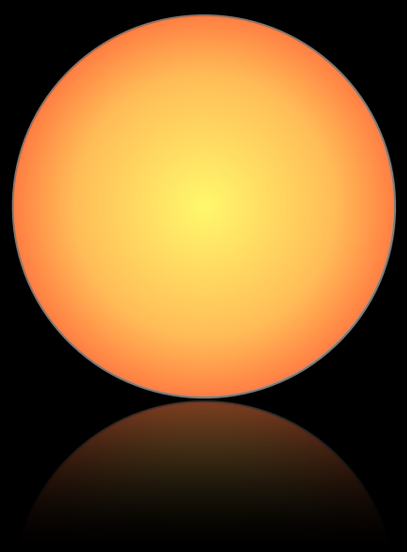
Photosphere



Betelgeuse



Photosphere



Betelgeuse

0.025 arcsec

0.25 arcsec

2.5 arcsec

4 arcmin

Internal envelope 1-10 R*

Photosphere

Betelgeuse

0.025 arcsec

0.25 arcsec

2.5 arcsec

4 arcmin

Photosphere

Internal envelope 1-10 R*

Intermediate envelope 10-100 R*

Betelgeuse

0.025 arcsec

0.25 arcsec

2.5 arcsec

4 arcmin

Photosphere

Internal envelope 1-10 R_*

Intermediate envelope 10-100 R_*

External envelope 100-10^4 R_*

MIS

Betelgeuse

Wind acceleration

0.025 arcsec | 0.25 arcsec | 2.5 arcsec | 4 arcmin

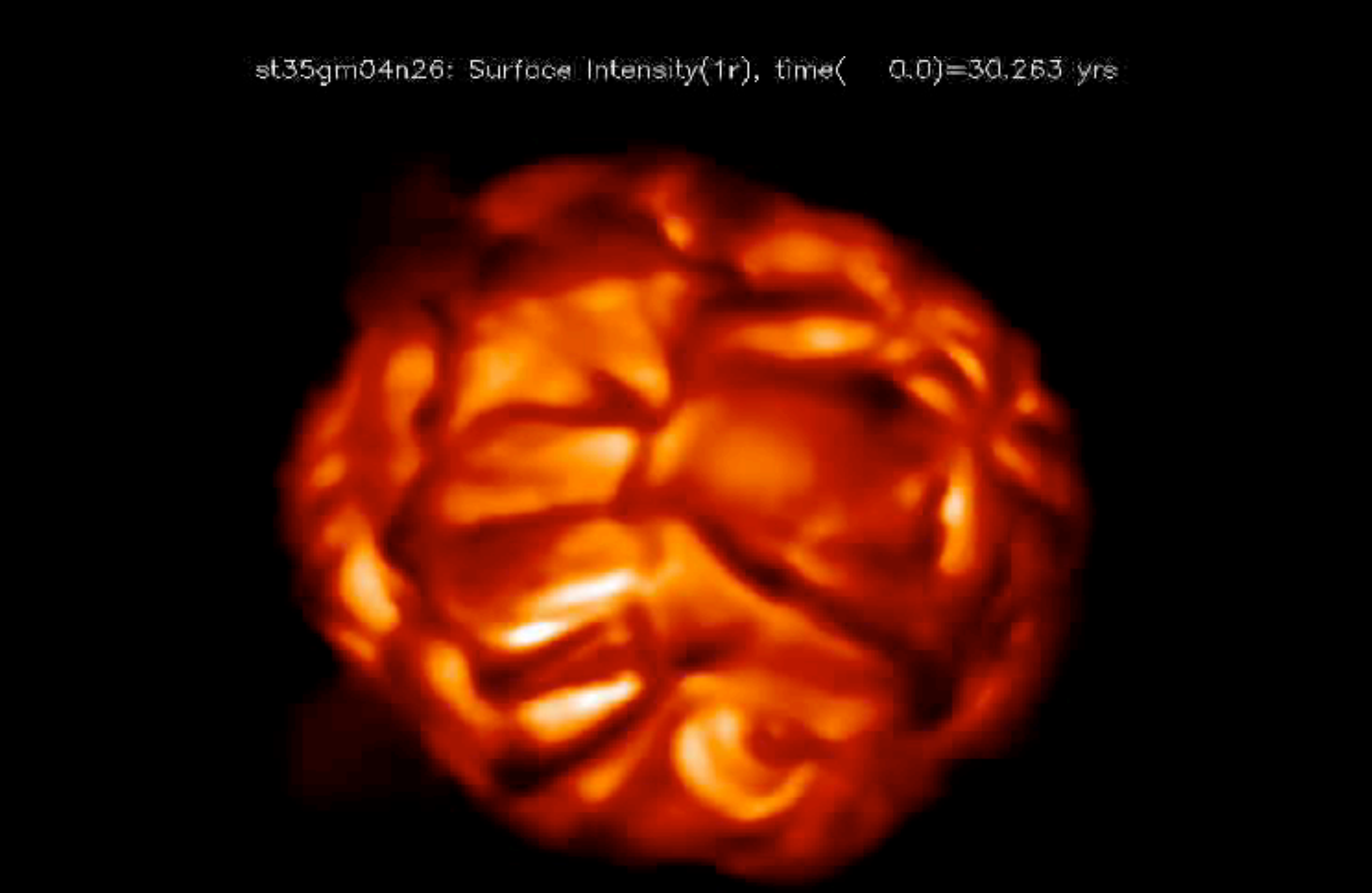
Photosphere

Internal envelope 1-10 R_*

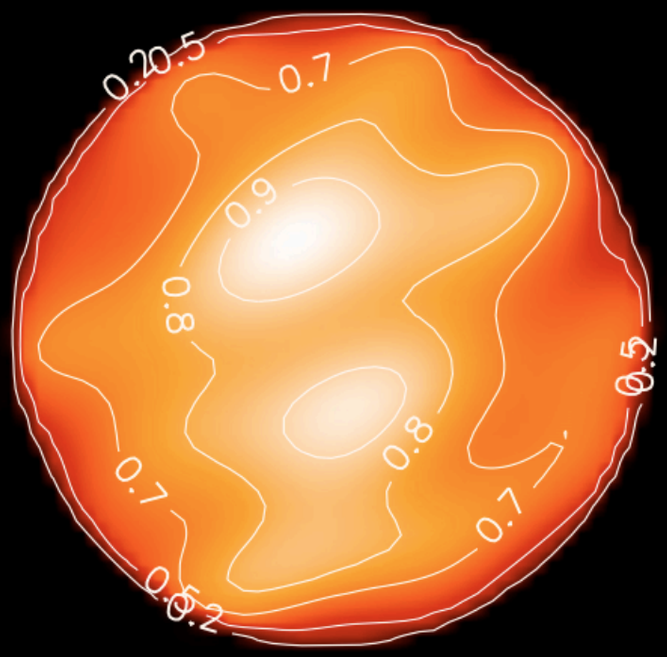
Intermediate envelope 10-100 R_*

External envelope 100-10^4 R_*

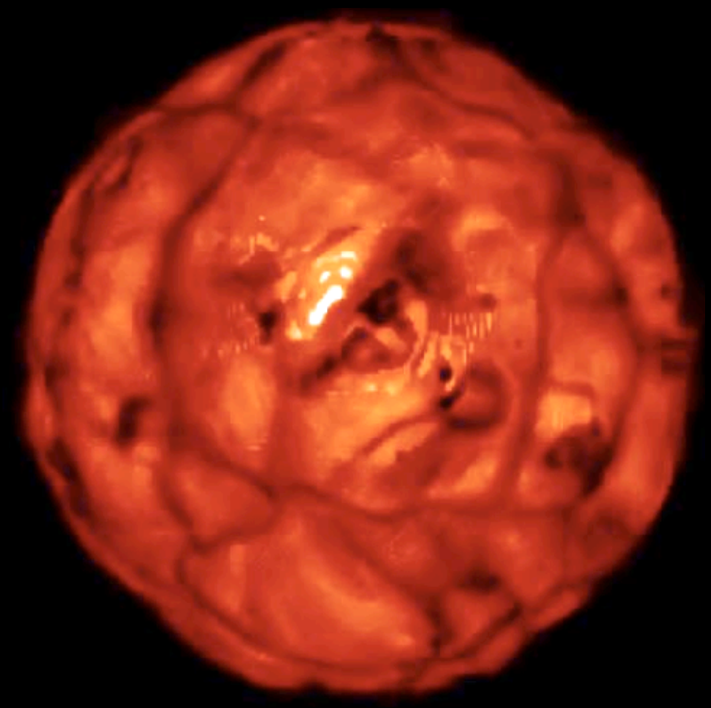
MIS



Visible 3D hydro simulation of Betelgeuse
B. Freytag (2002)

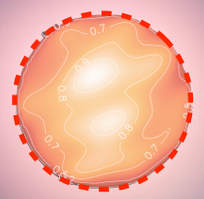


Interferometry
(1.64μm, Haubois et al. 2009)



Model
(1.64μm, Chiavassa et al. 2010)

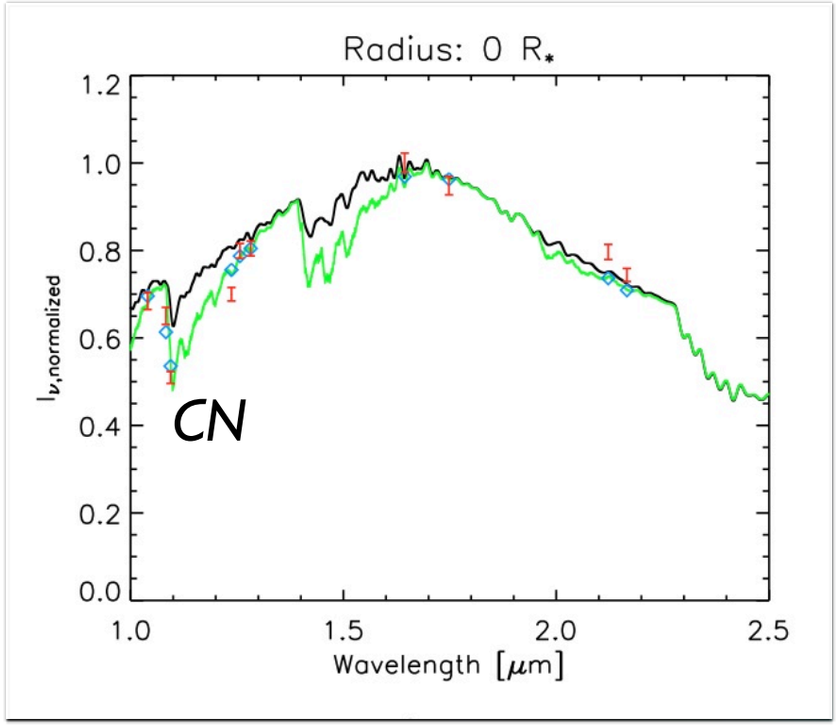
50 mas

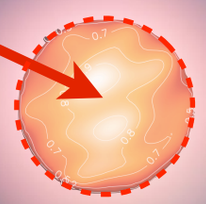


100 mas

NACO (2009)
1.0 - 2.2 μm

Kervella et al. 2009, A&A, 504, 115





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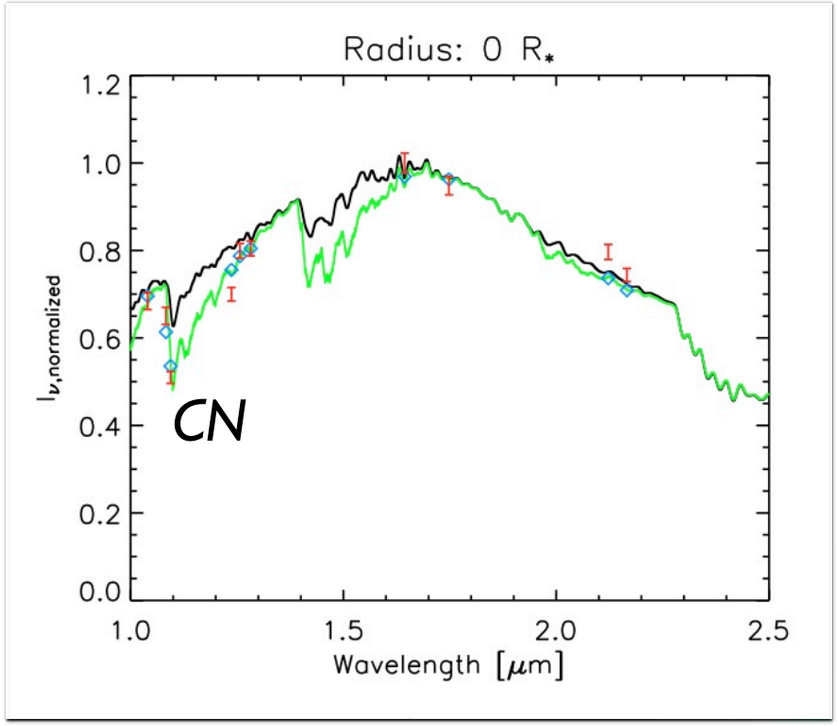

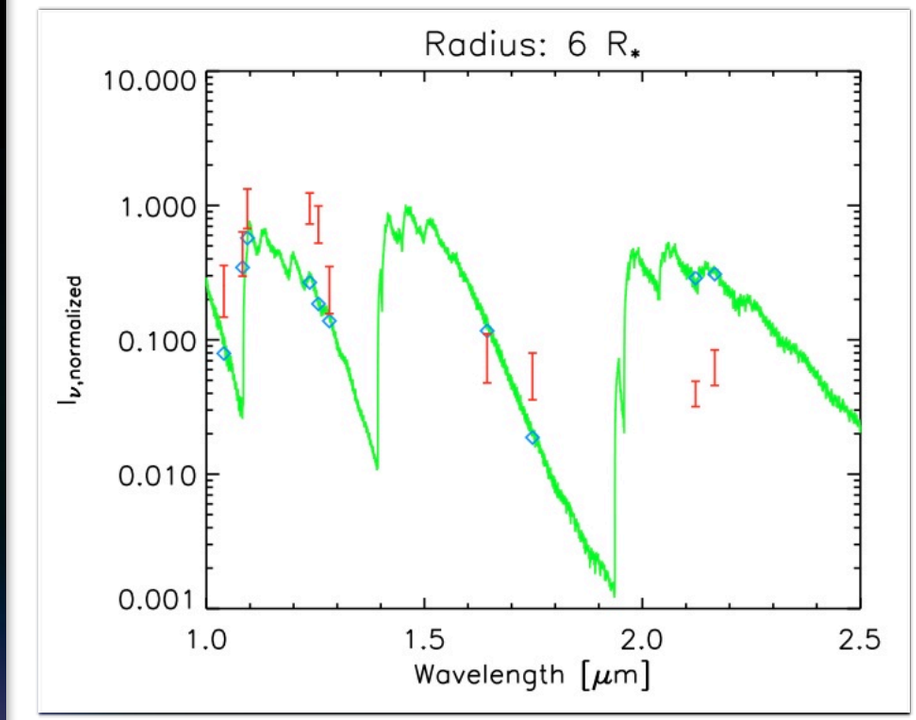

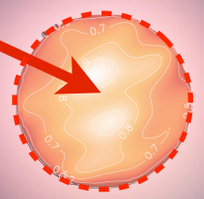

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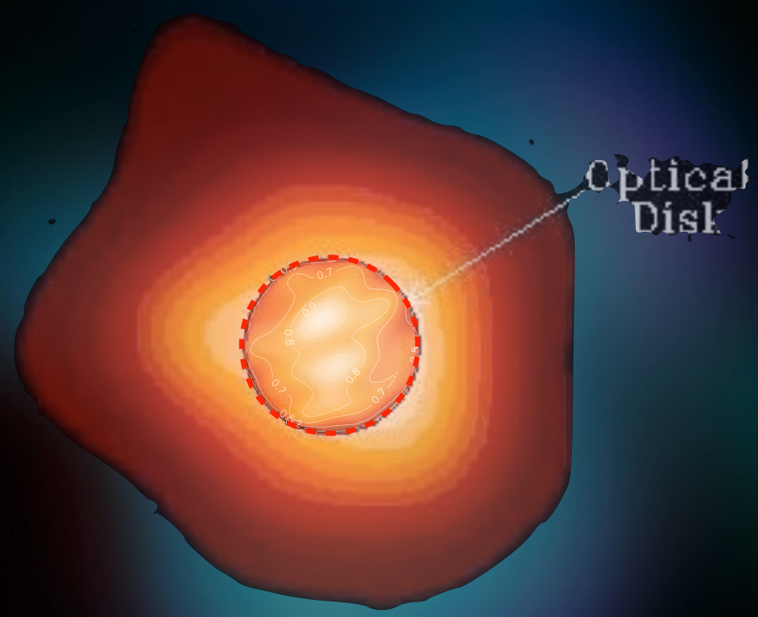

VLA 7mm continuum
NRAO/AUI / J. Lim, C. Carilli et al. 1998

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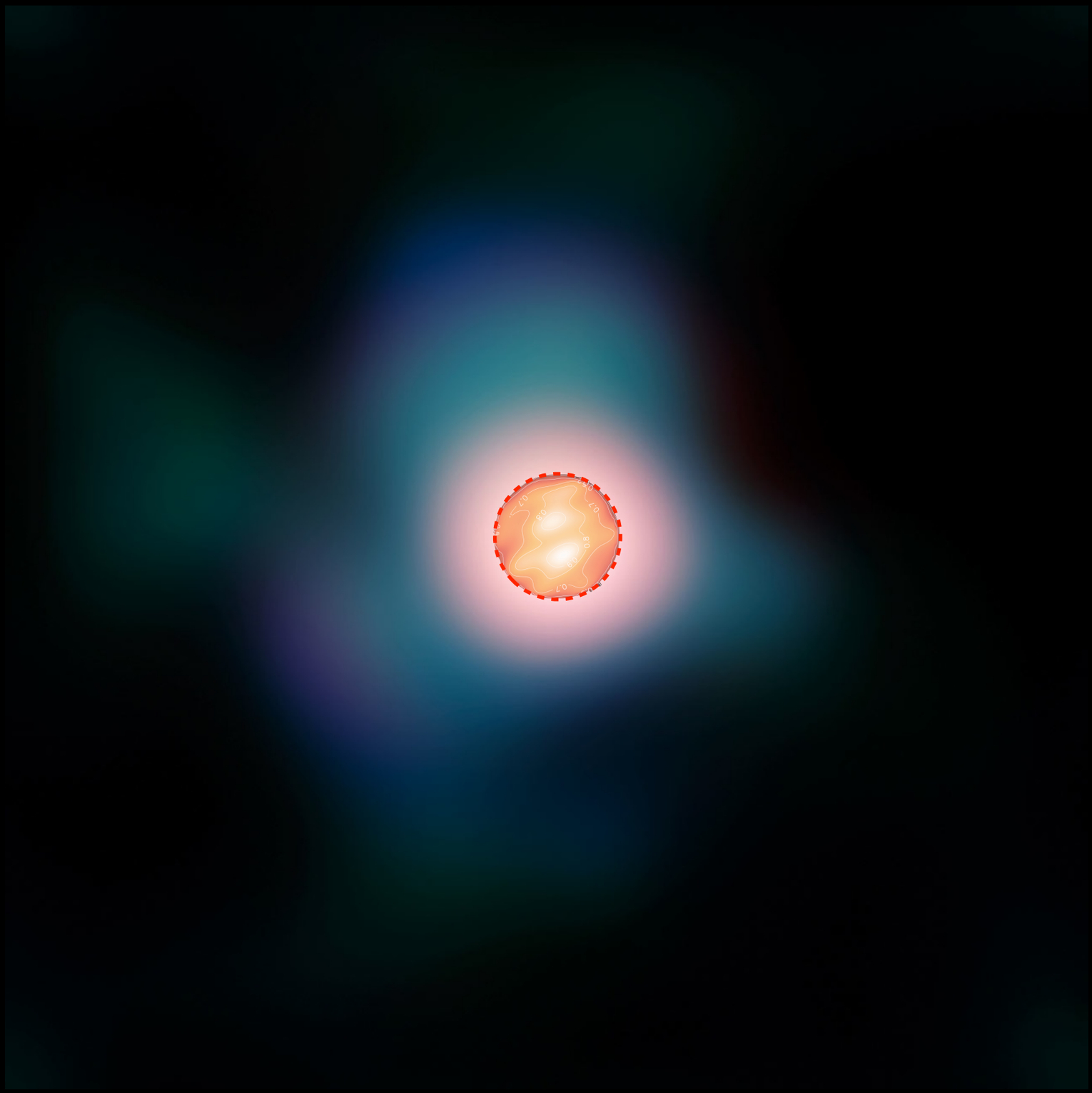
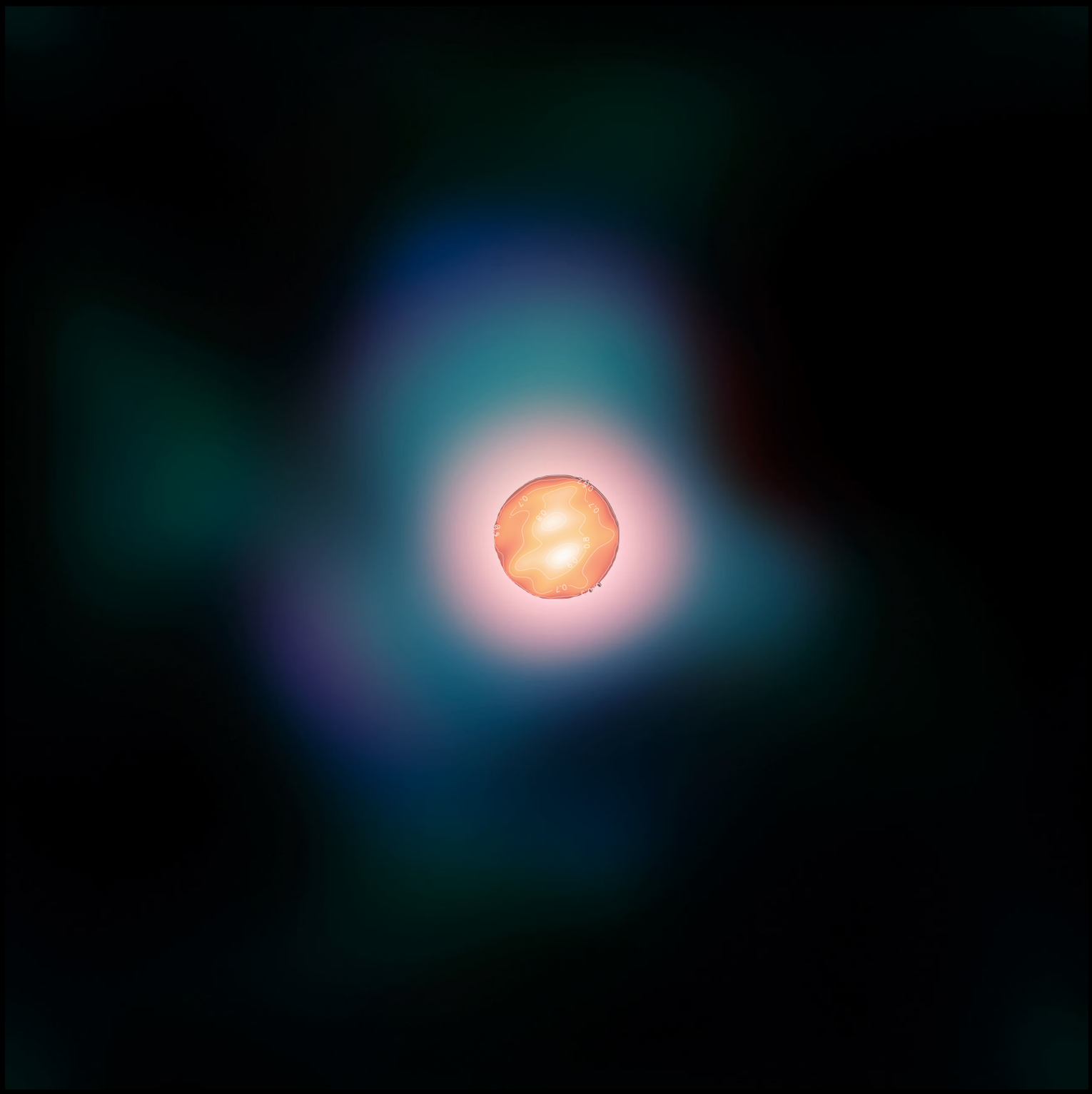
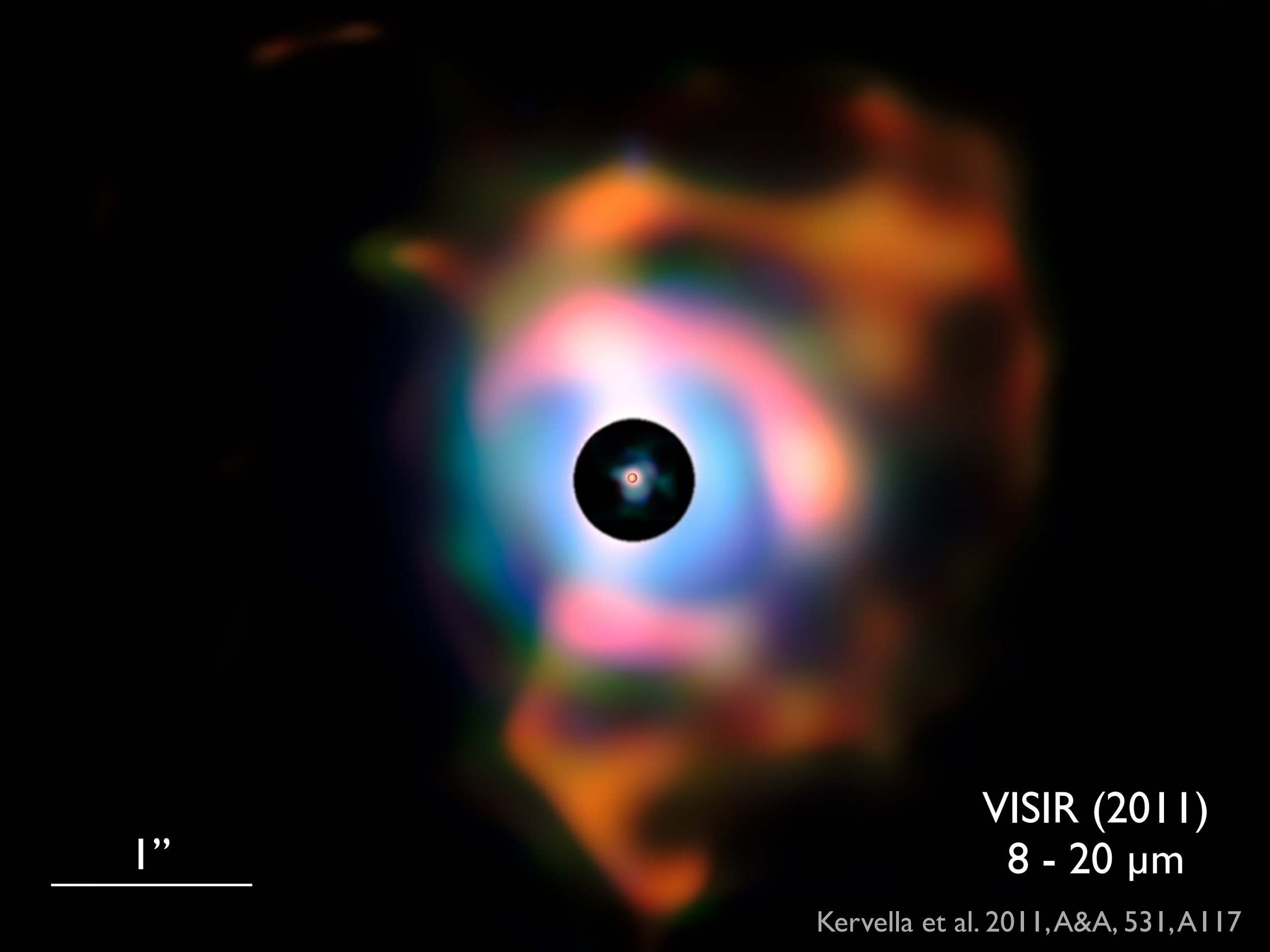
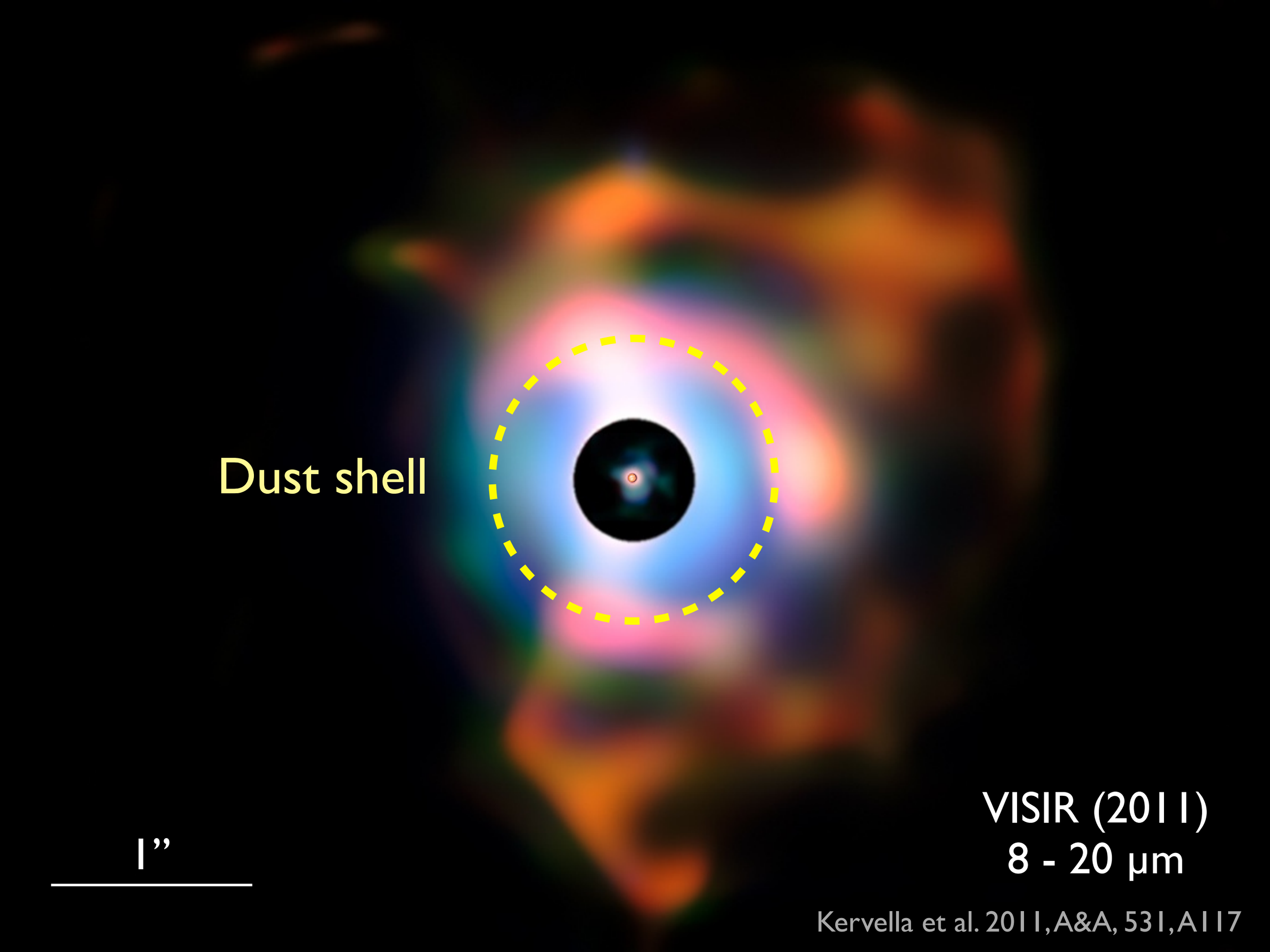
Kervella et al. 2009, A&A, 504, 115



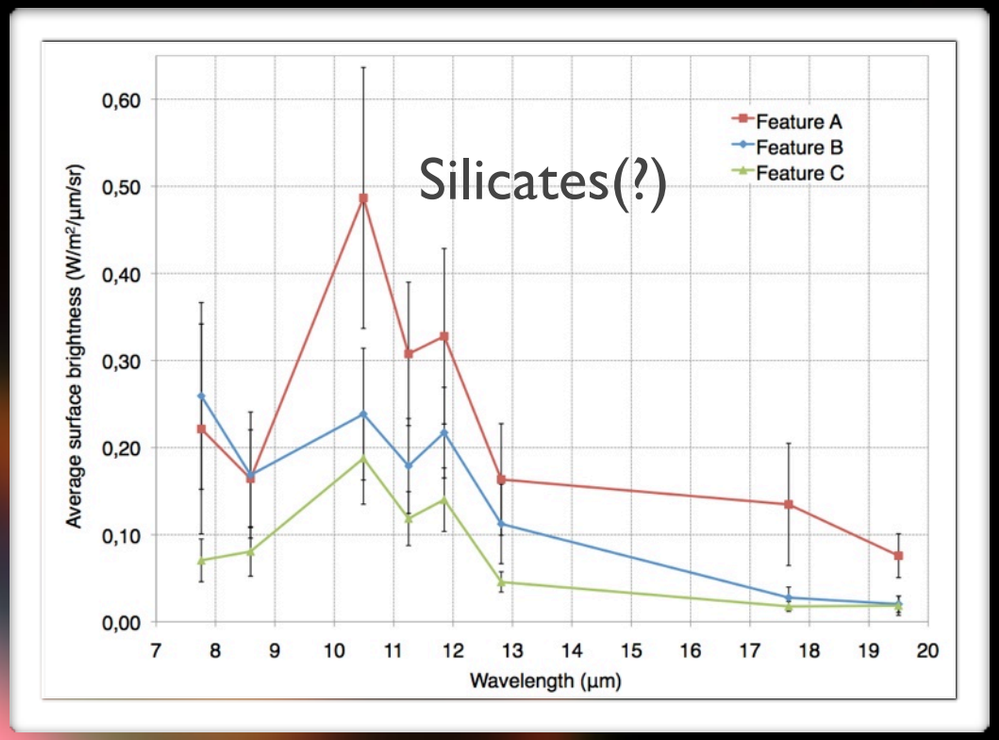




Kervella et al. 2011, A&A, 531, A117



Kervella et al. 2011, A&A, 531, A117



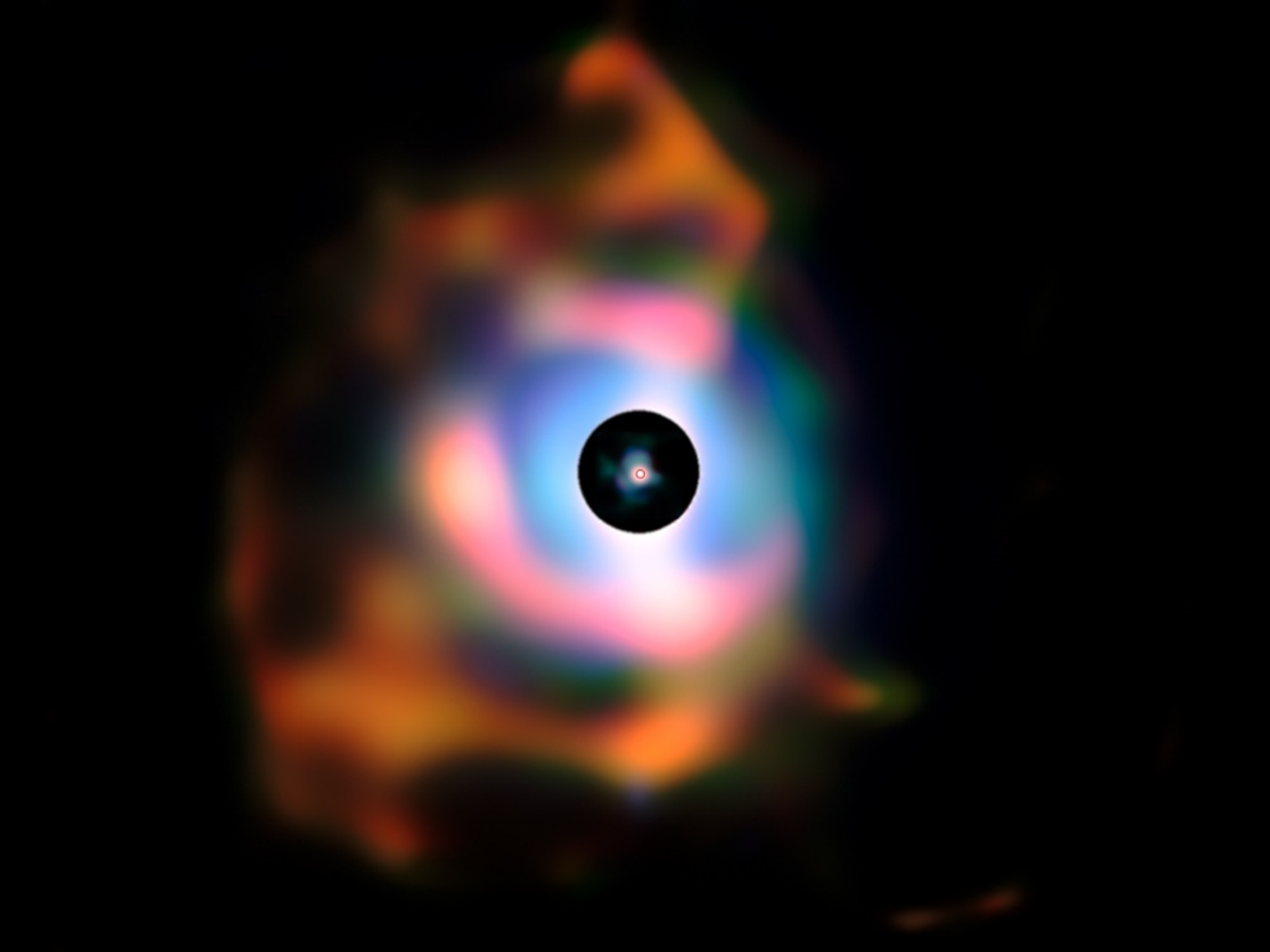
Dust shell

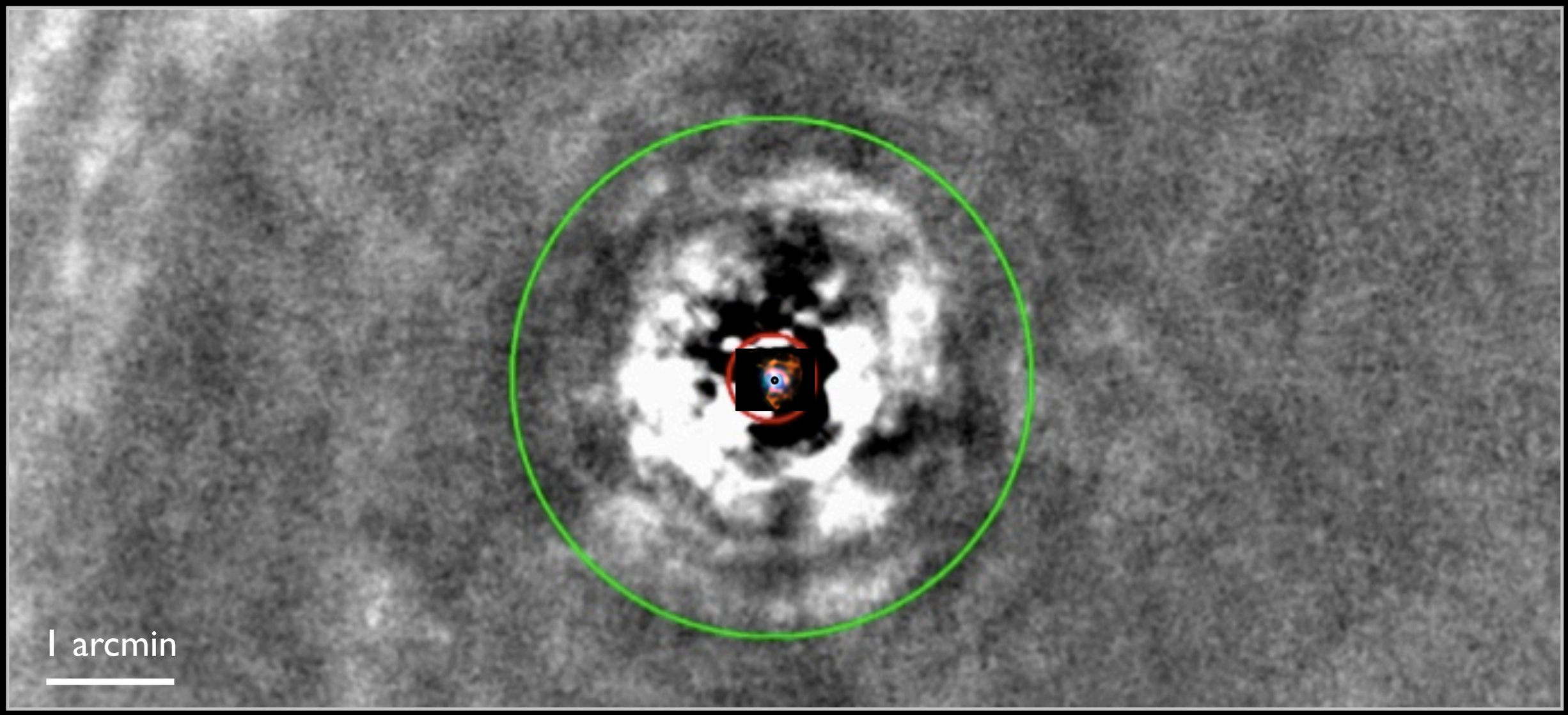
A

1”

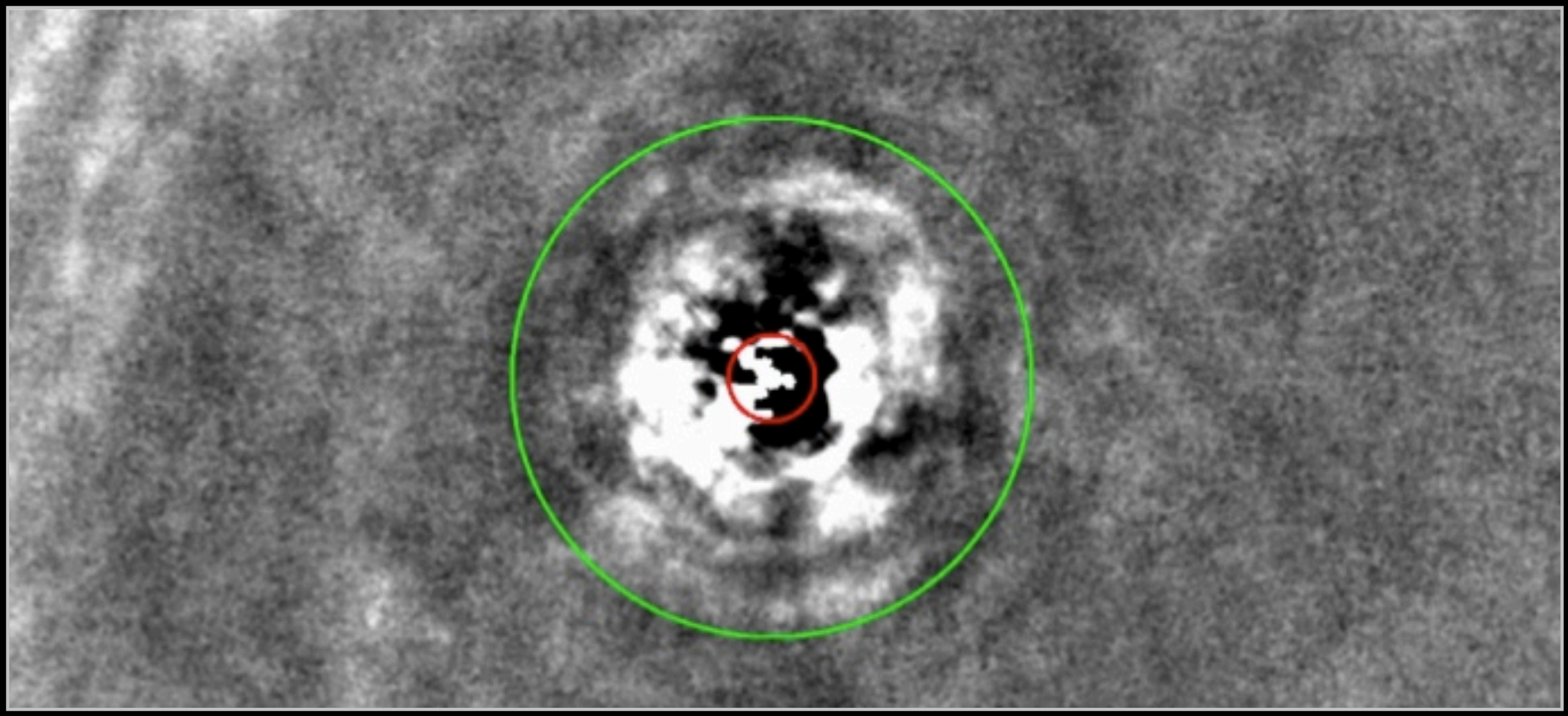
VISIR (2011)
8 - 20 µm

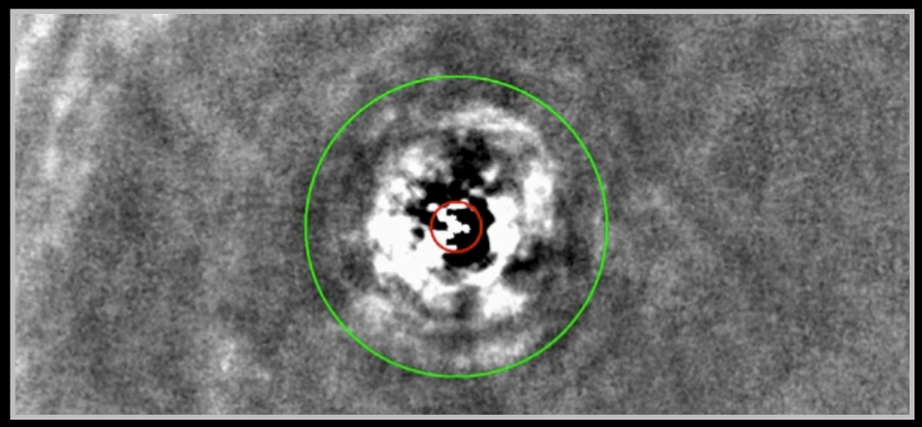
Kervella et al. 2011, A&A, 531, A117

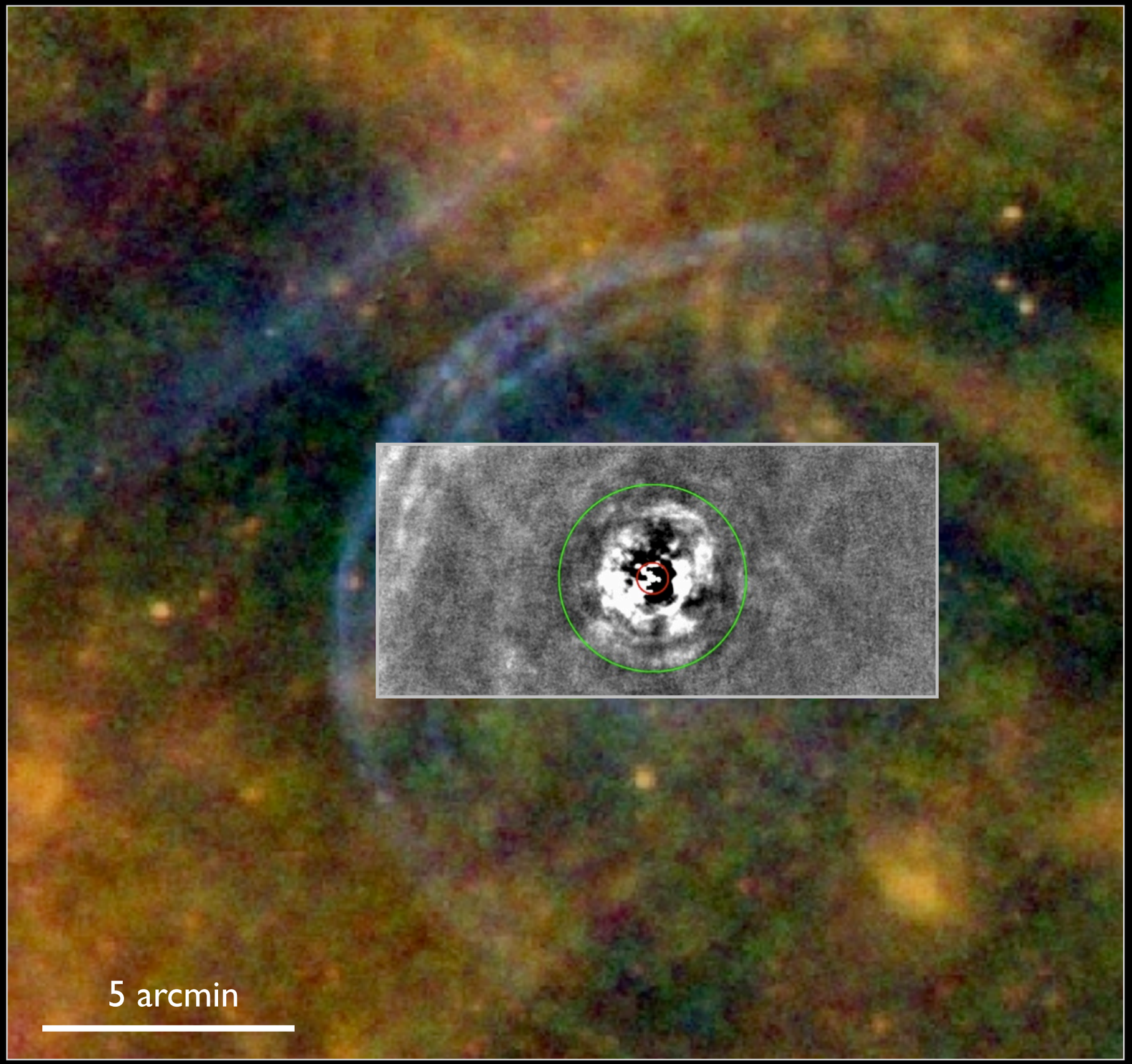




Decin et al. 2012, A&A, 548, A113







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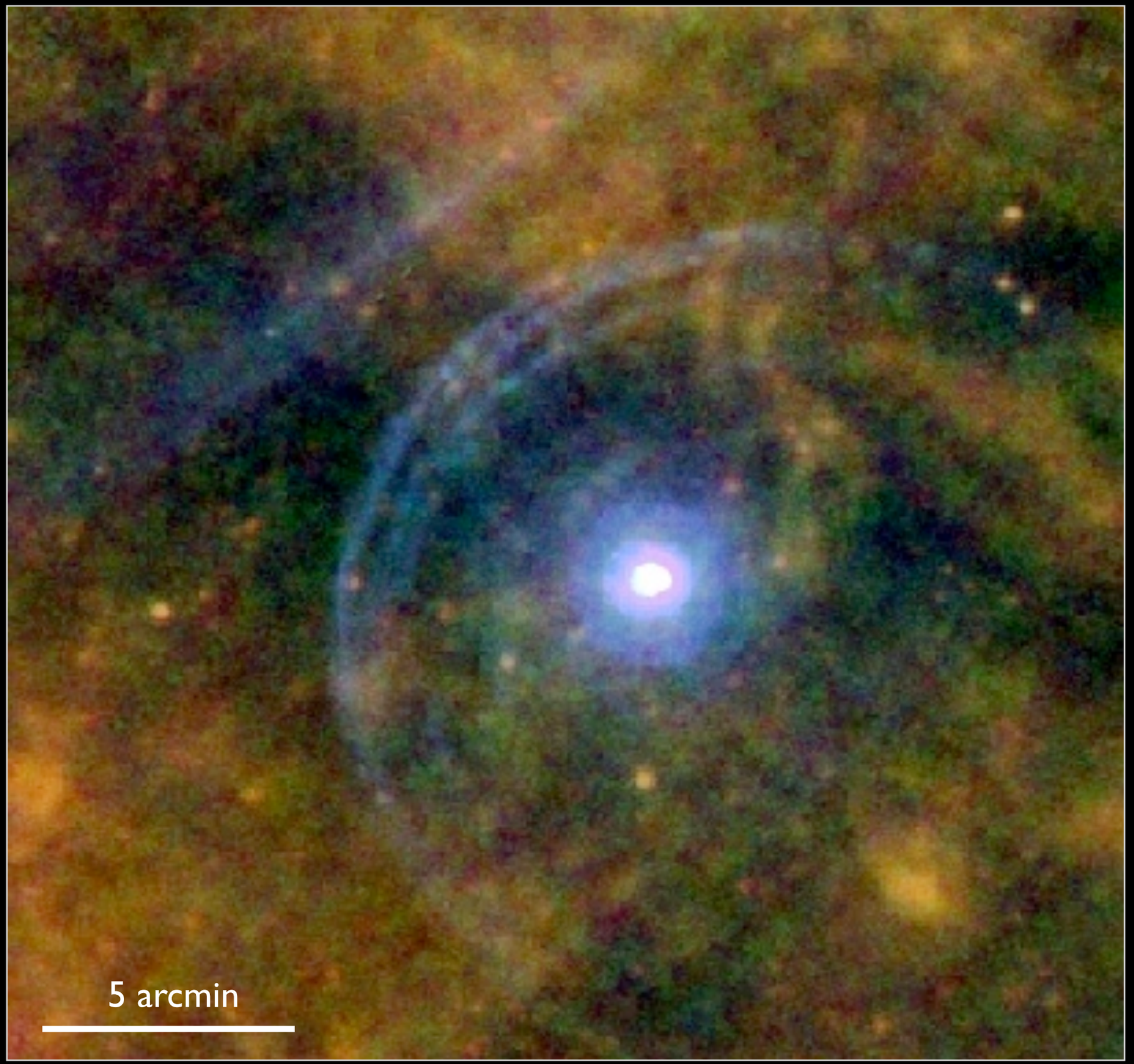
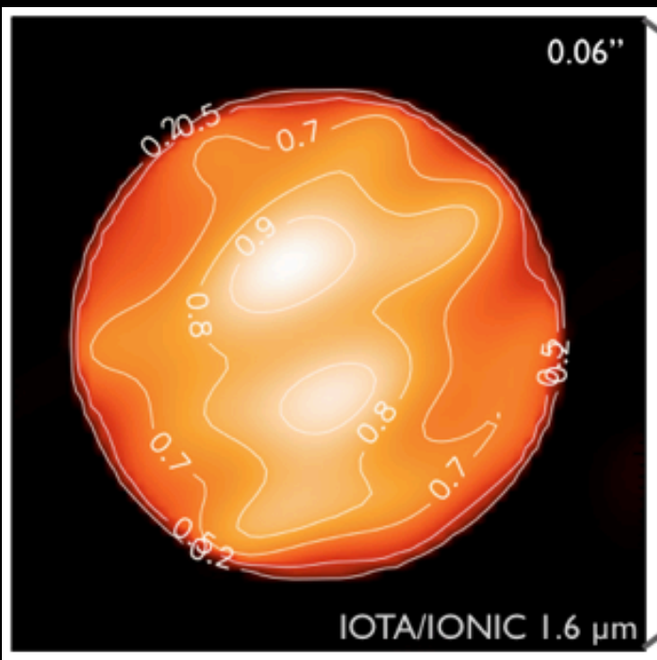
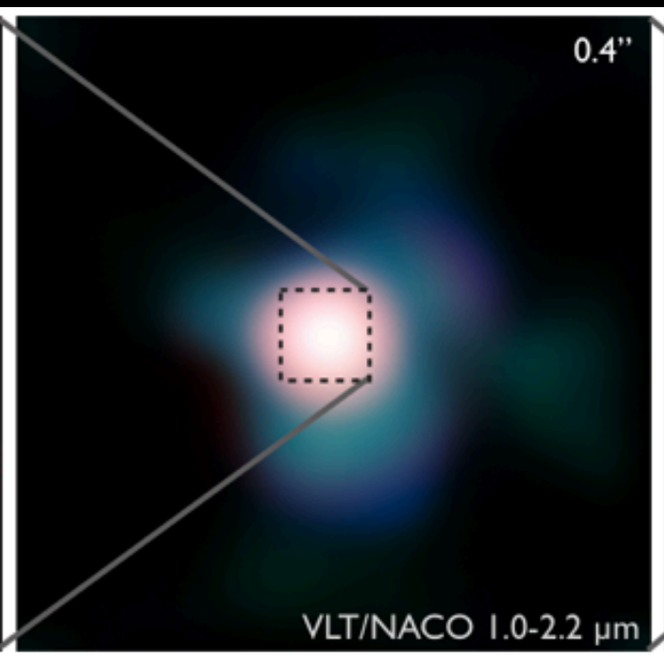
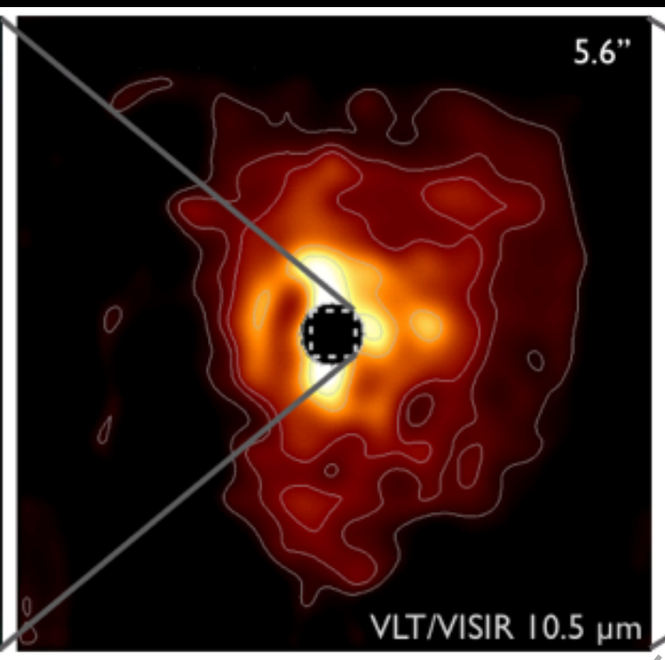


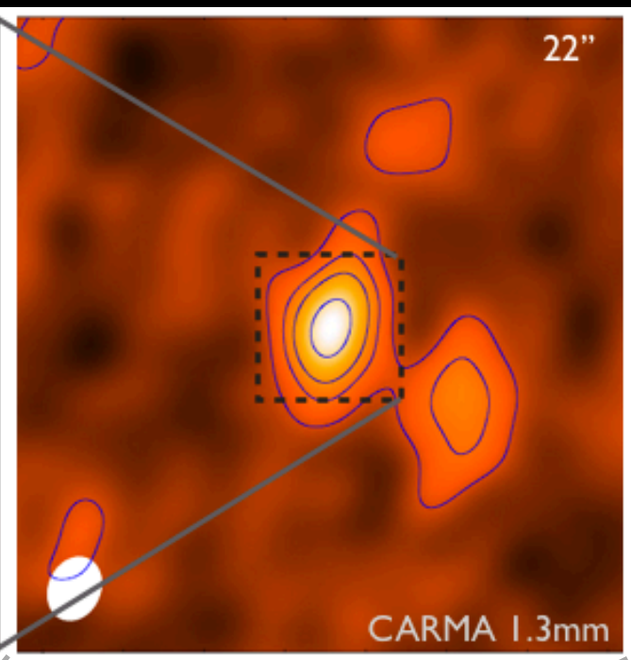
Decin et al. 2012, A&A, 548, A113

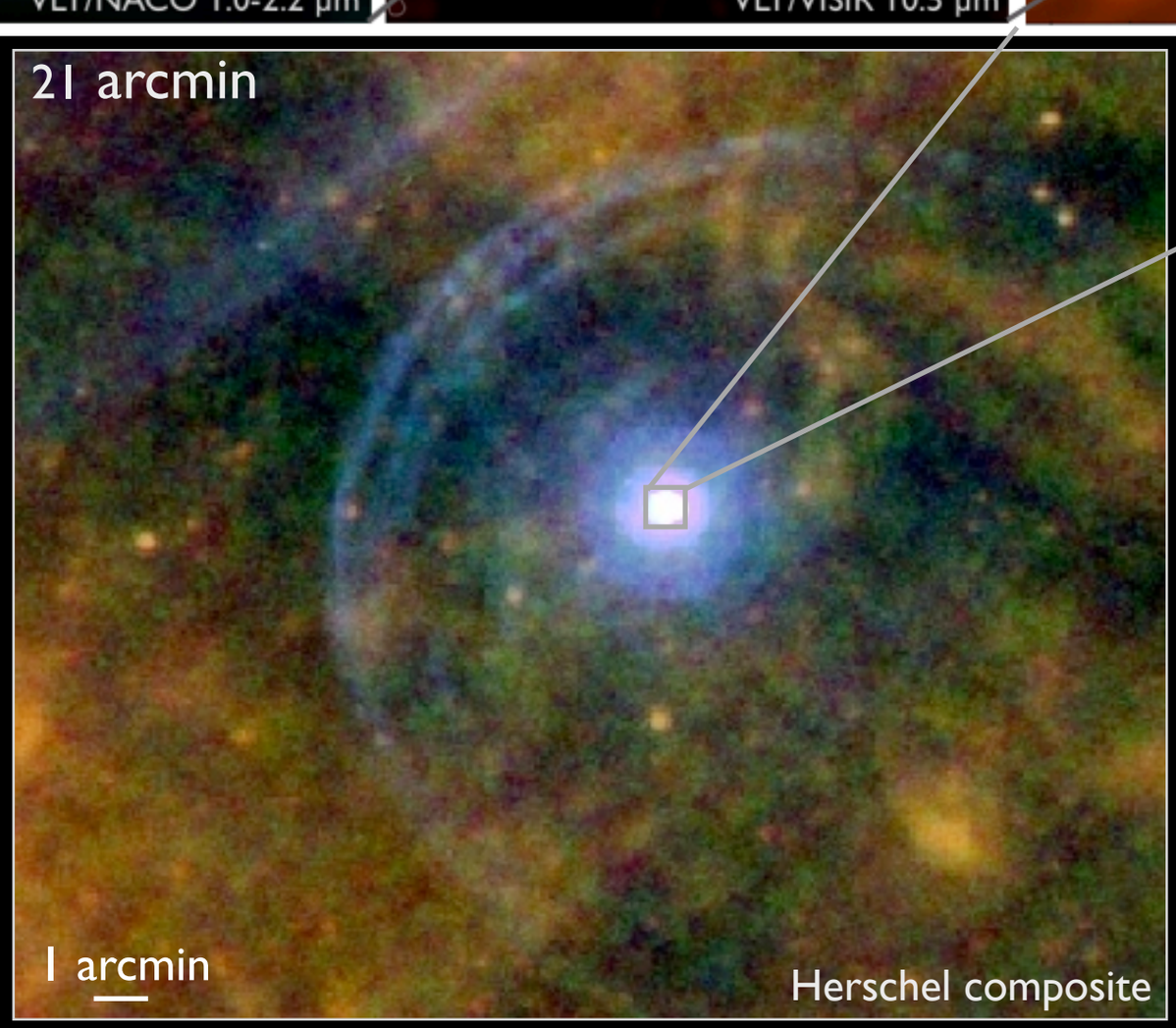
Overview of α Ori's environment



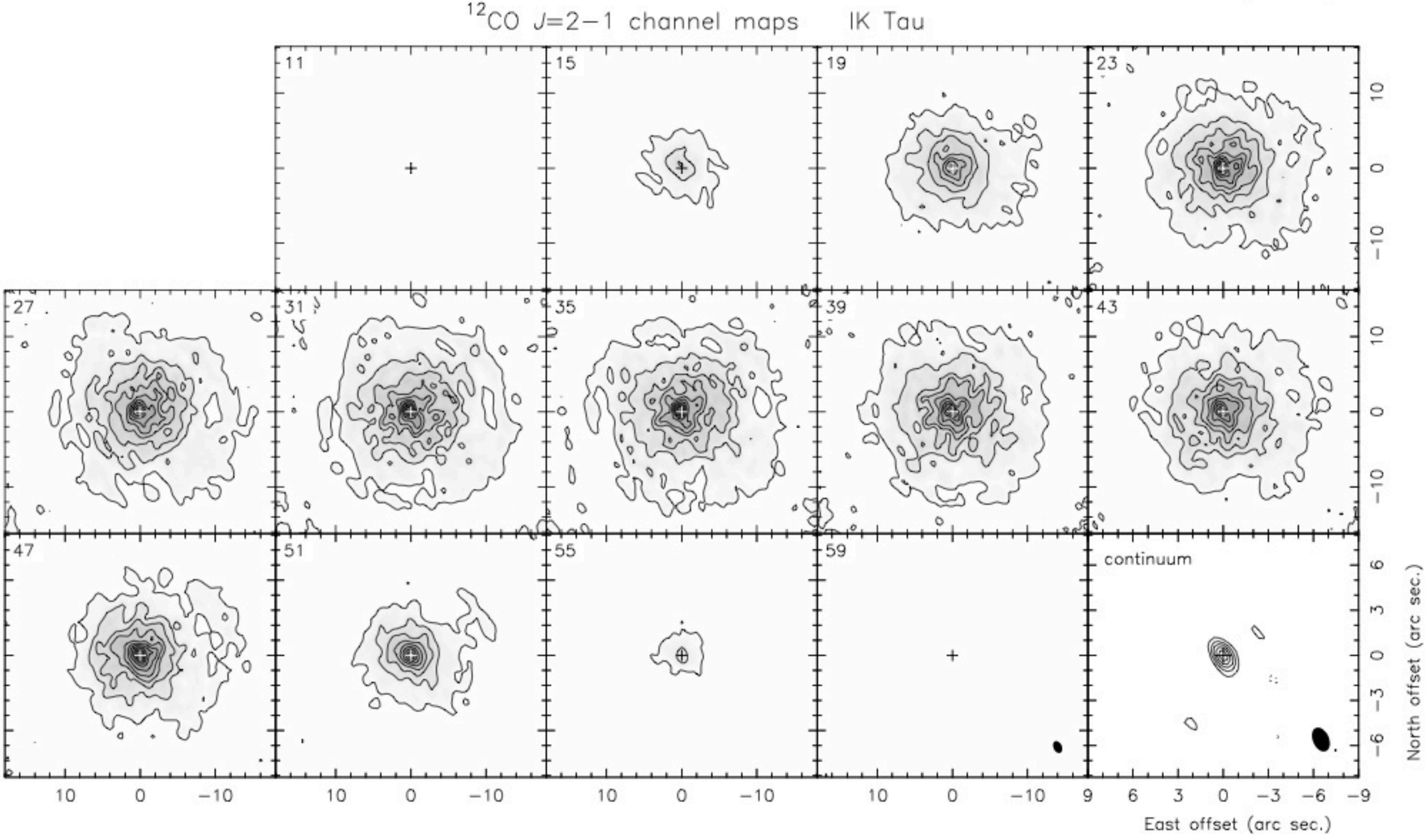








The Mira star IK Tau

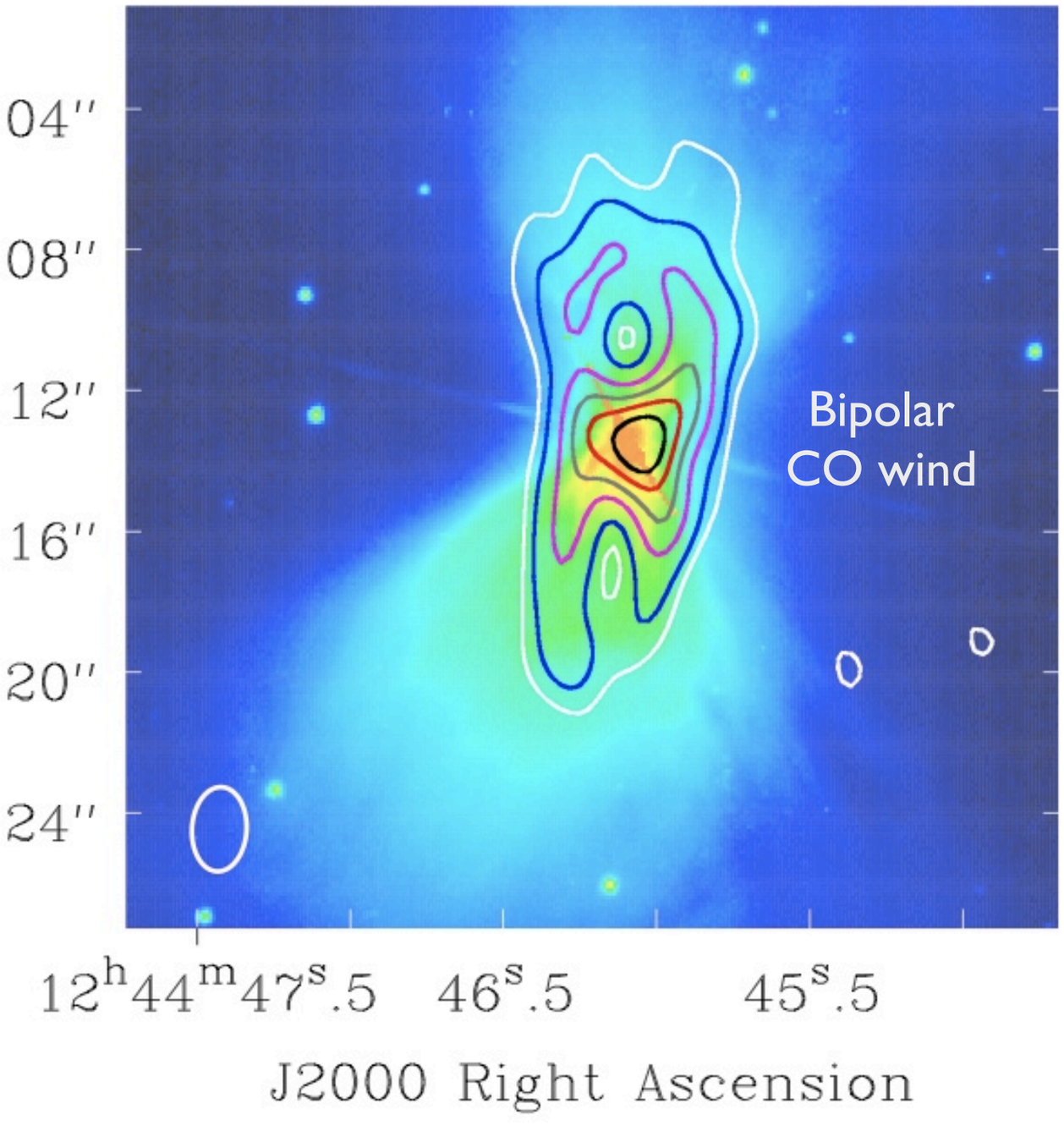


IRAM PdBI+30m, 1.3mm

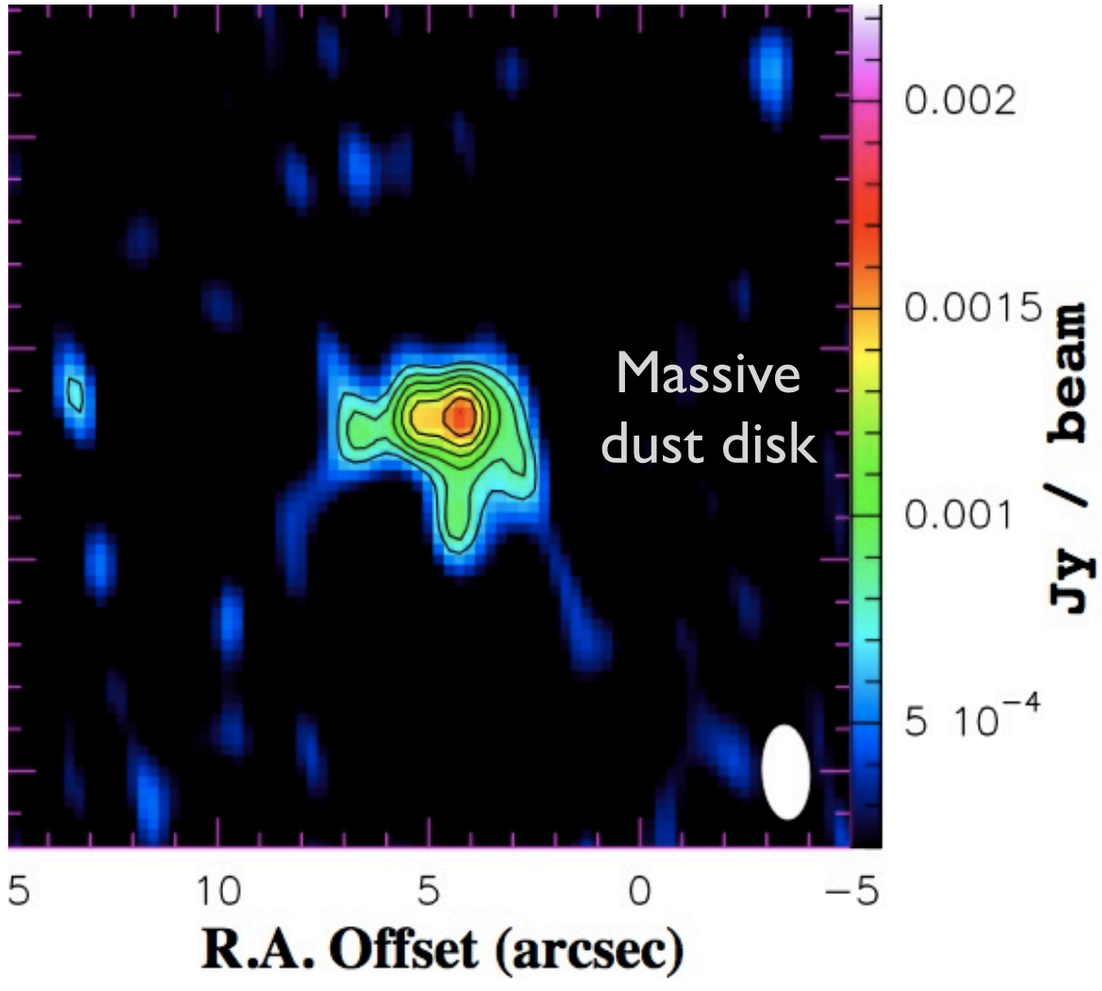
Castro-Carrizo et al. 2010, A&A, 523, A59

The Boomerang

HST WFPC2 F606W
ALMA CO J=2-1 band 6 (1.3mm)

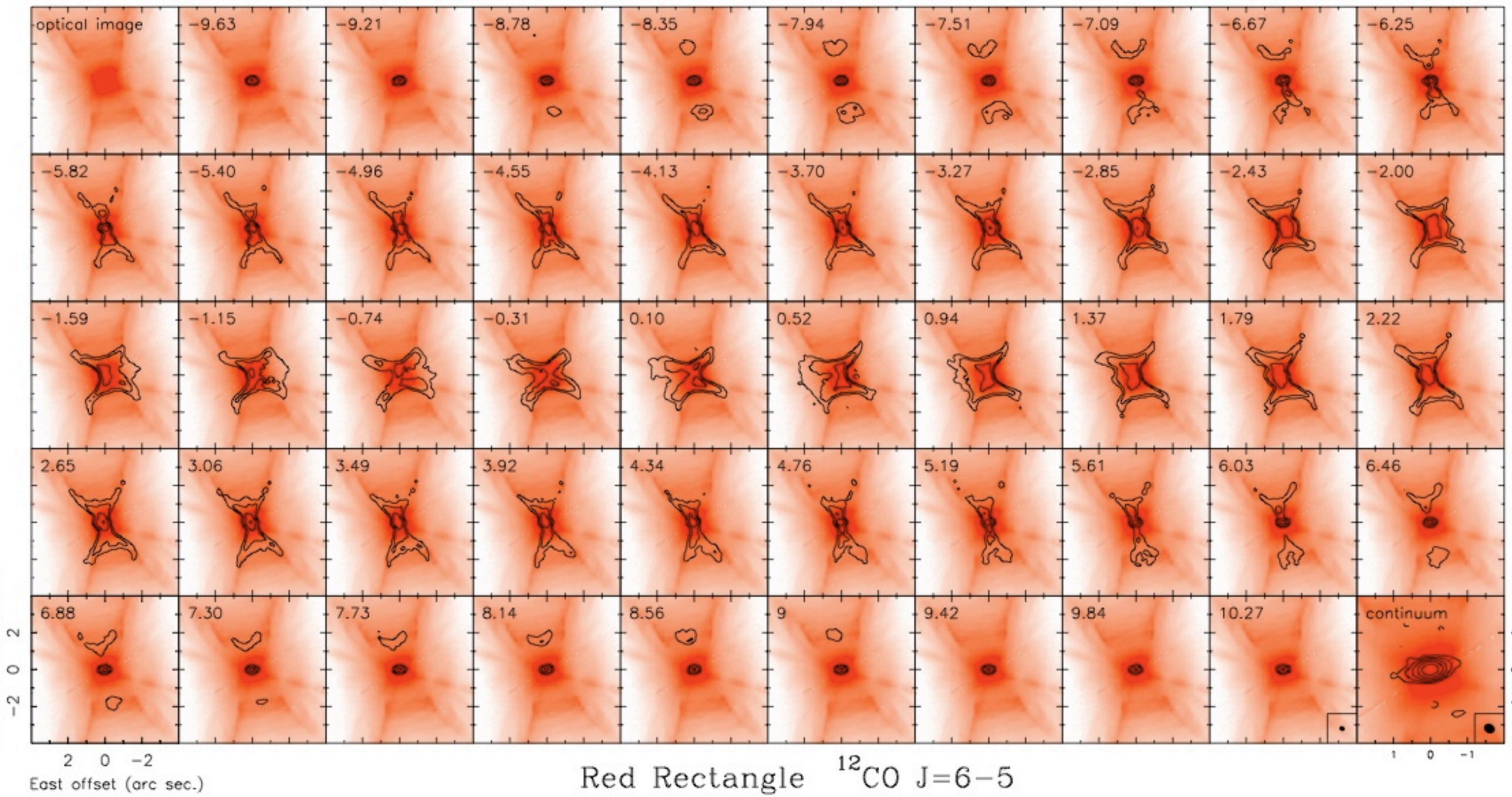


Continuum (1.3mm)



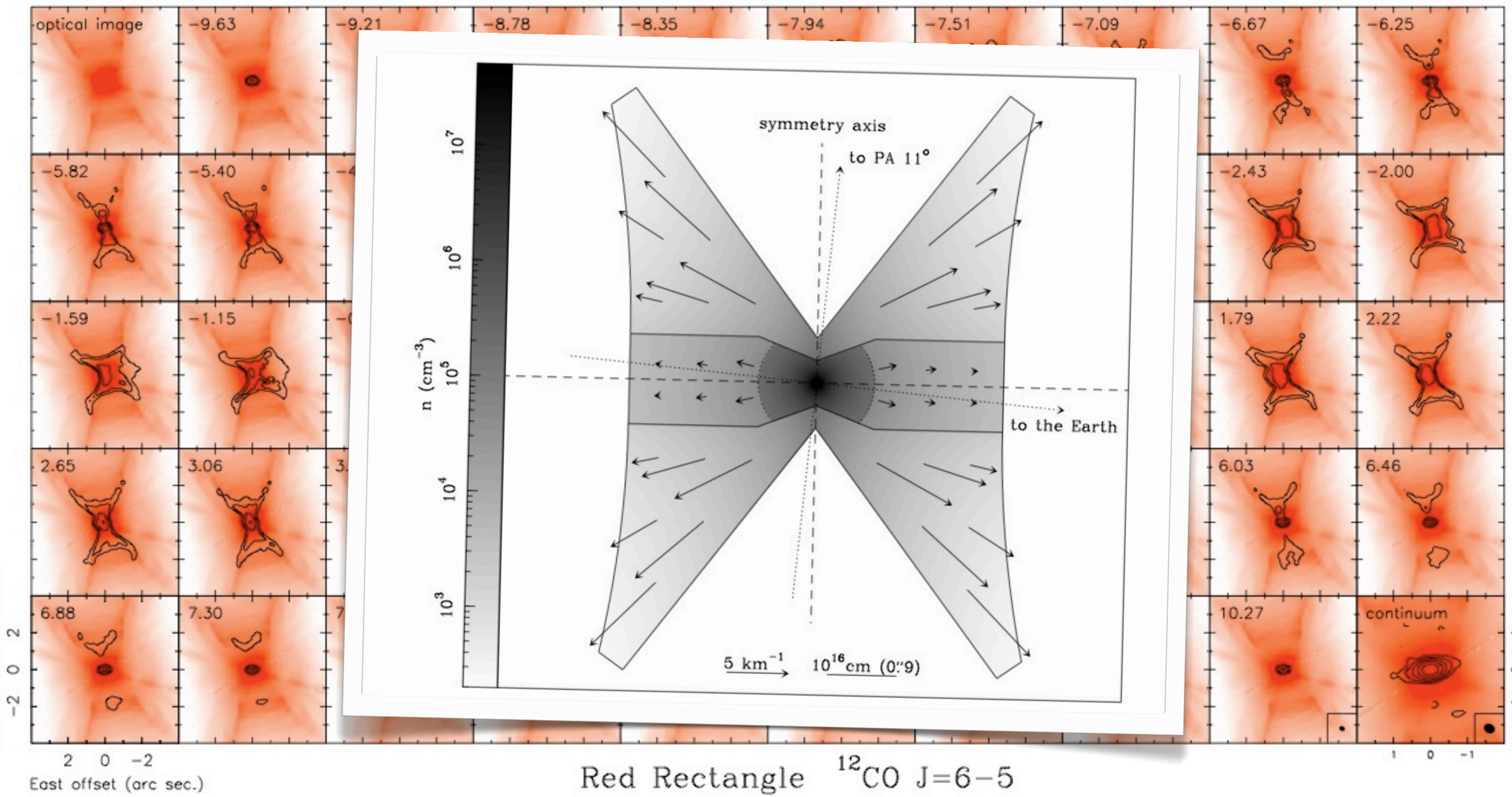
Sahai et al. 2013, ApJ, arXiv:1308.4360

The Red Rectangle



Bujarrabal et al. 2013, A&A, 457, L11

The Red Rectangle



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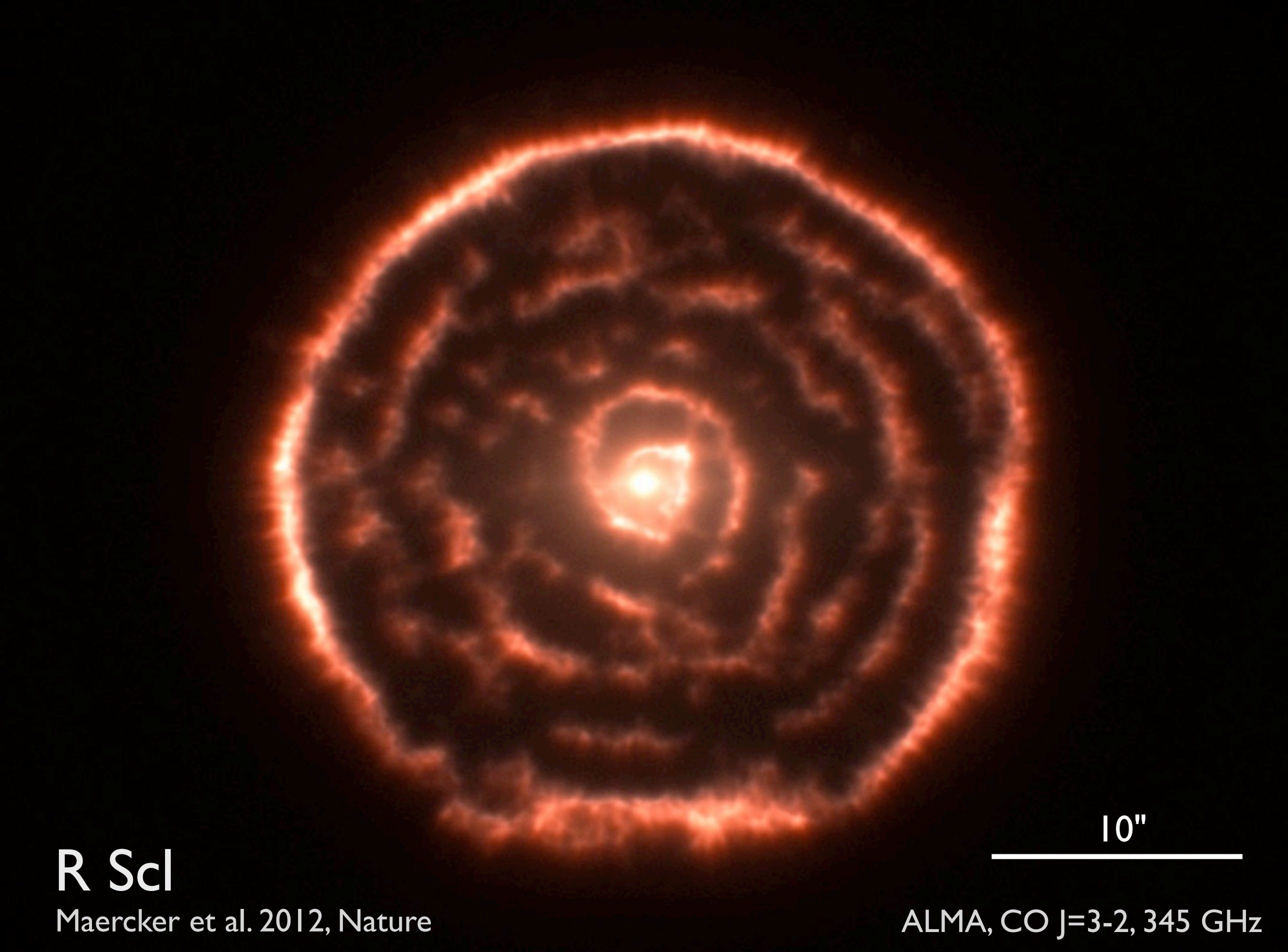
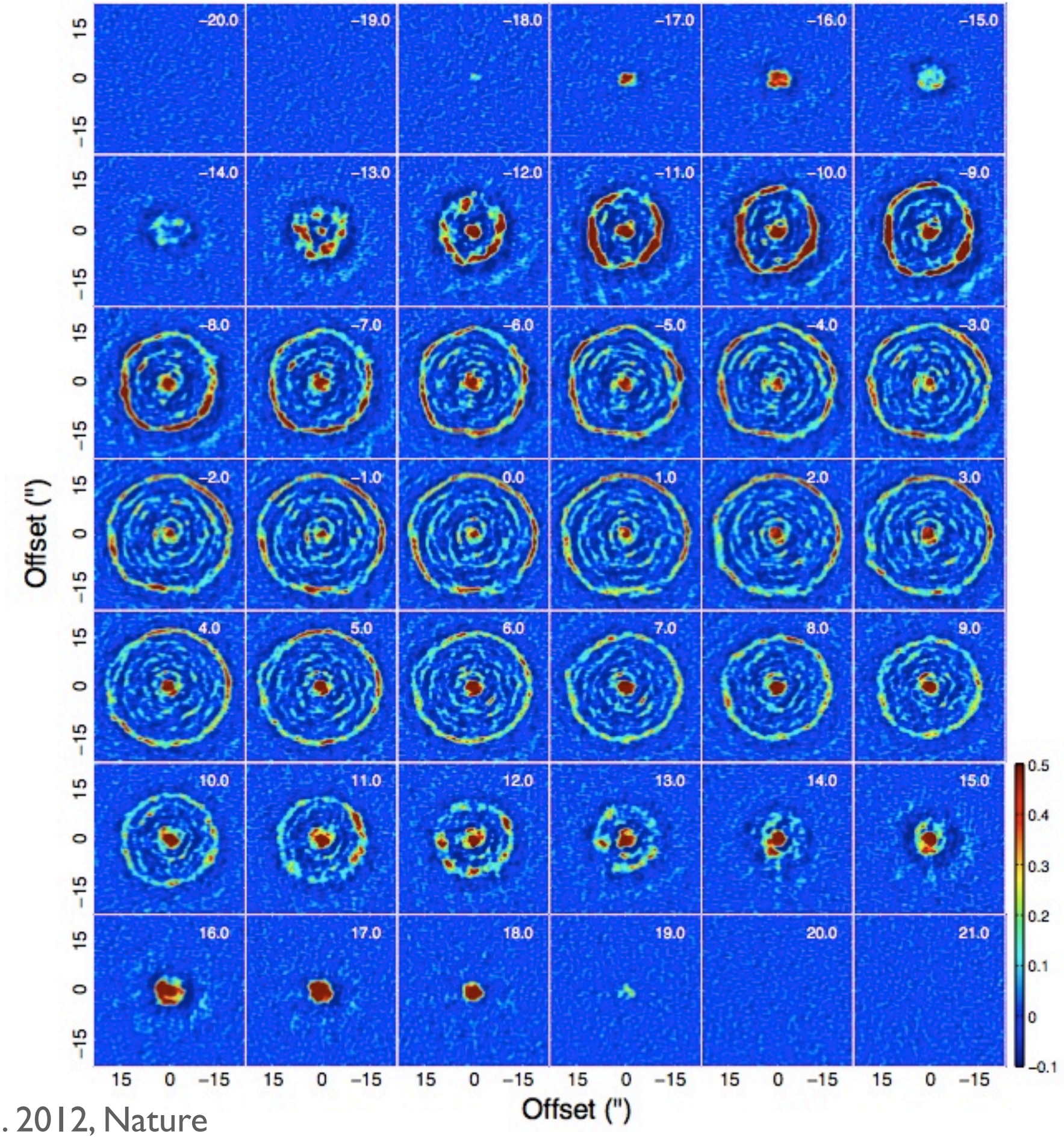


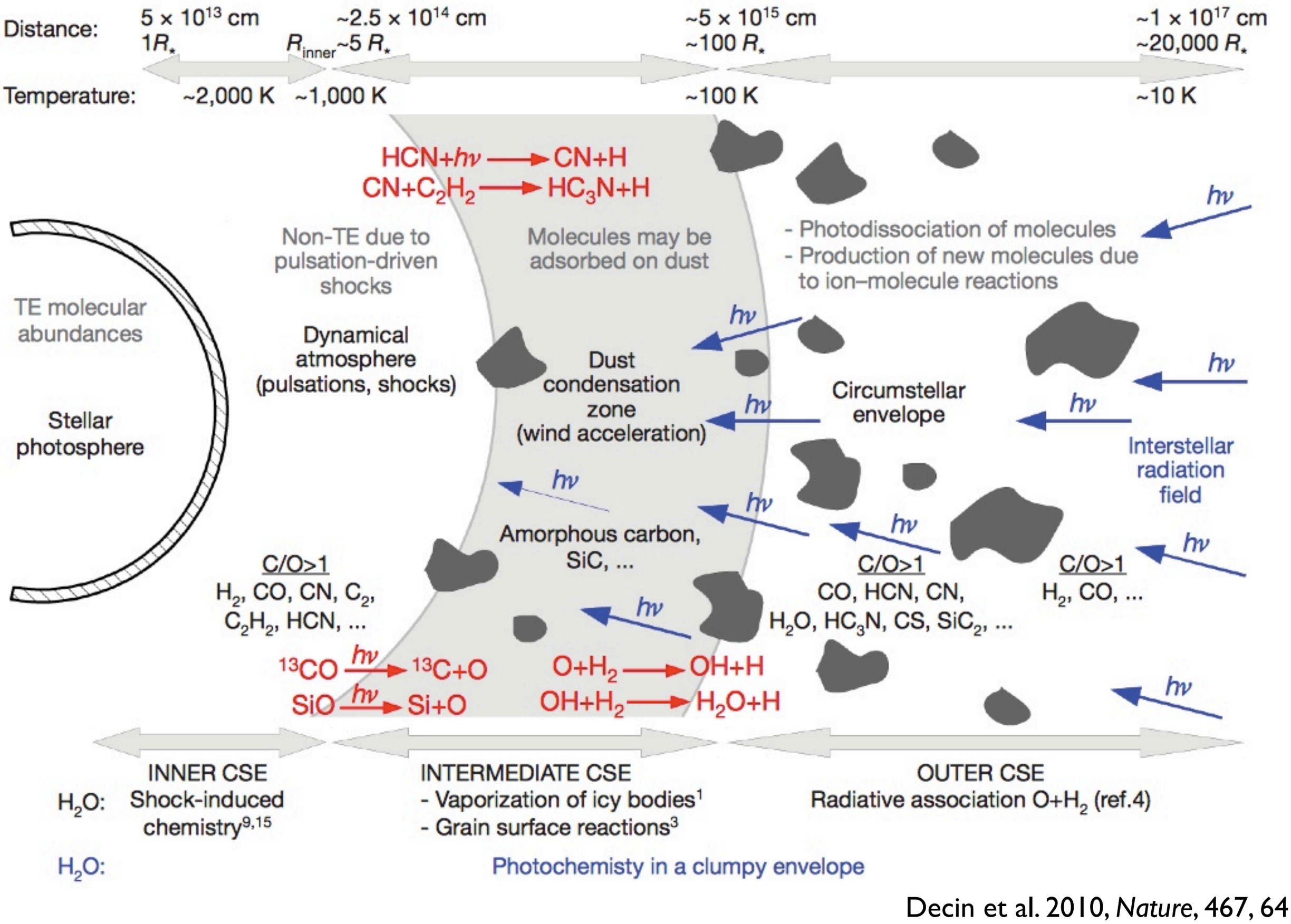
R Scl

Maercker et al. 2012, Nature

ALMA, CO J=3-2, 345 GHz



Maercker et al. 2012, Nature



Decin et al. 2010, *Nature*, 467, 64