Red Supergiants, Post-Red Supergiants, and Red Transients -- the Evidence for High Mass Loss Episodes

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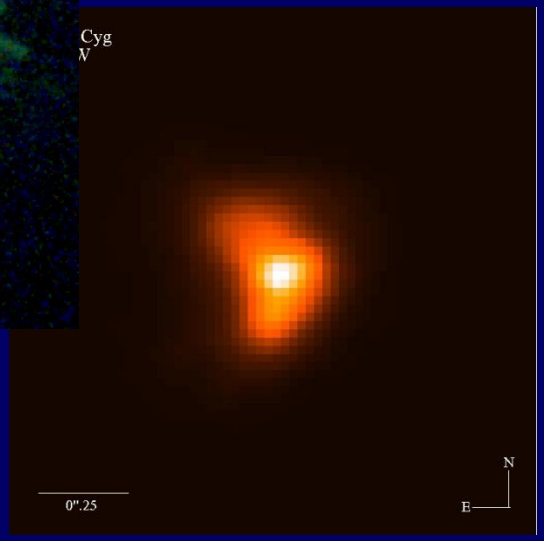
VY CMa

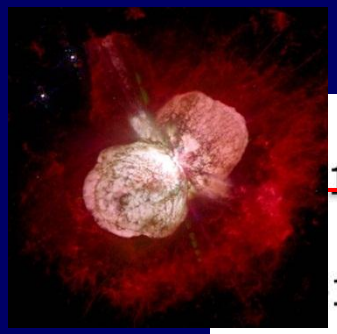


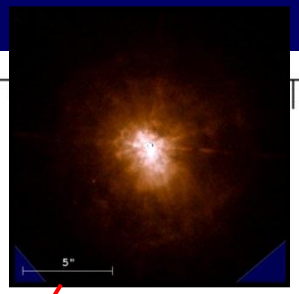
NML Cyg

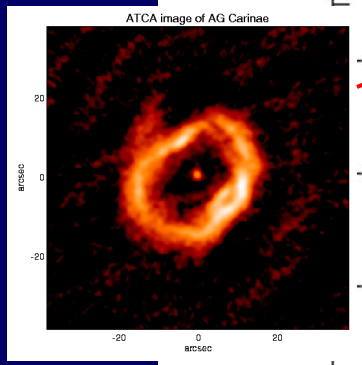
IRC +10420

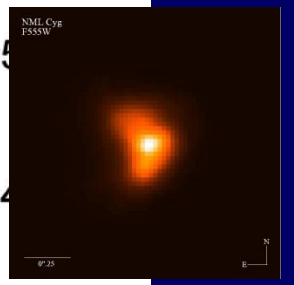
The Upper HR Diagram

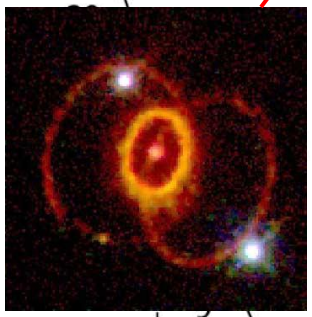
The evidence for episodic high mass loss events











VY CMa -- the extreme red supergiant, powerful OH/IR source

Distance ~ 1.3 kpc

Luminosity ~ 4 x 10^5 L_{sun}

Initial Mass ~ 30 -- 40 M_{sun}

Mass Loss rate 2 -- 4 x 10^{-4} M_{sun} / year

Size ~ 8 -- 10 A.U., or ~ 1500 -- 2000 R_{sun}

It is visible as a small red nebula
~ 10 arcsec across

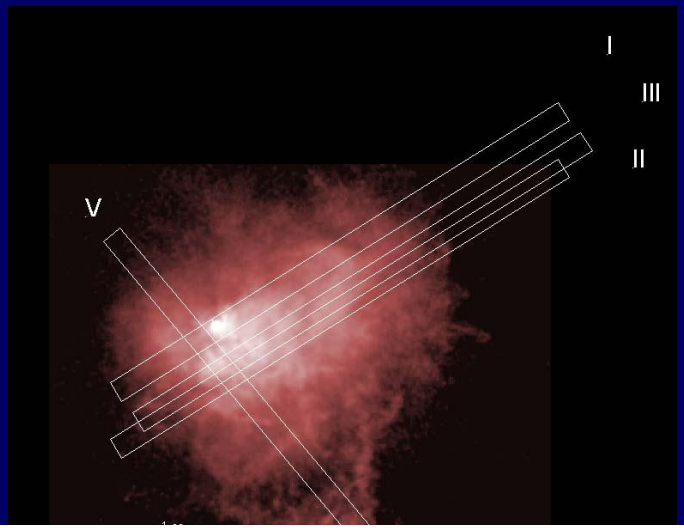
1” = 1500 AU

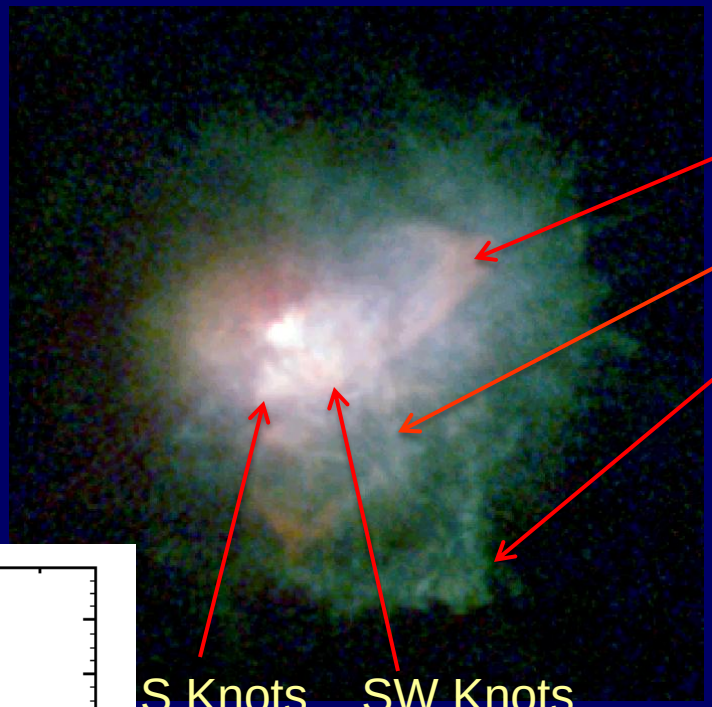
HST/WFPC2 images revealed complex environment – numerous knots, filamentary arcs, prominent nebulous arc

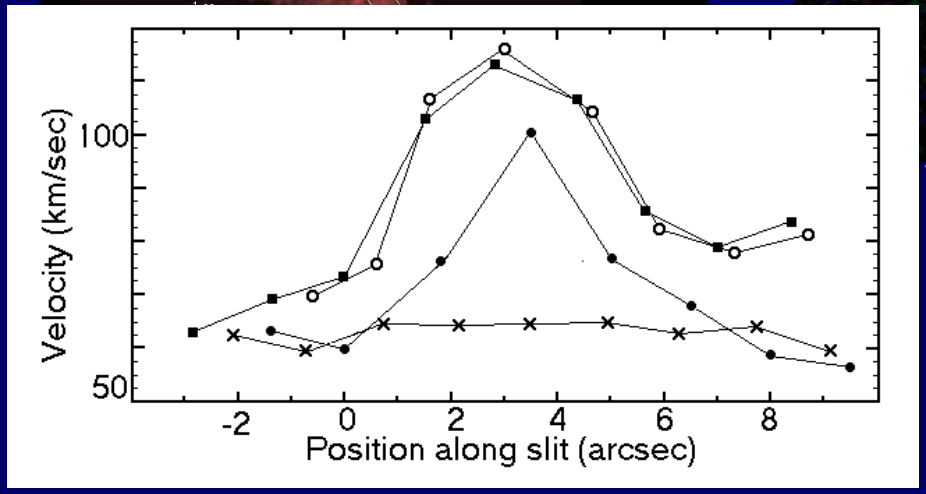
Due to multiple, asymmetric ejection episodes possibly from large-scale convective regions on the star.

Smith, Humphreys, Davidson, Gehrz, & Schuster, 2001

High Resolution, Long-Slit Spectroscopy --Keck HIRES Spectrograph





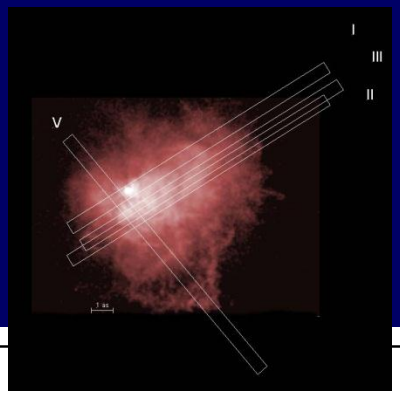


A strong velocity gradient from reflected absorption lines across the NW arc.

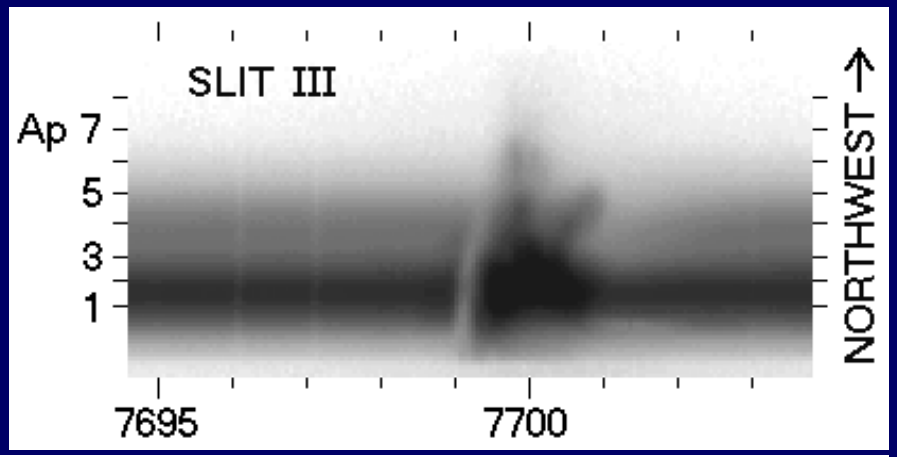
Expanding relative to star ~ 50 km/s ~ 500 year ago

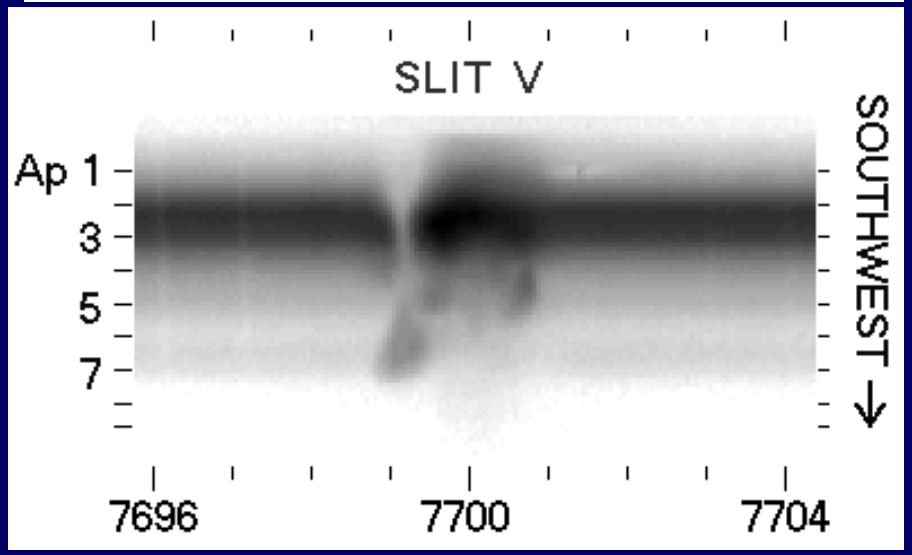
Humphreys, Davidson, Ruch & Wallerstein 2005

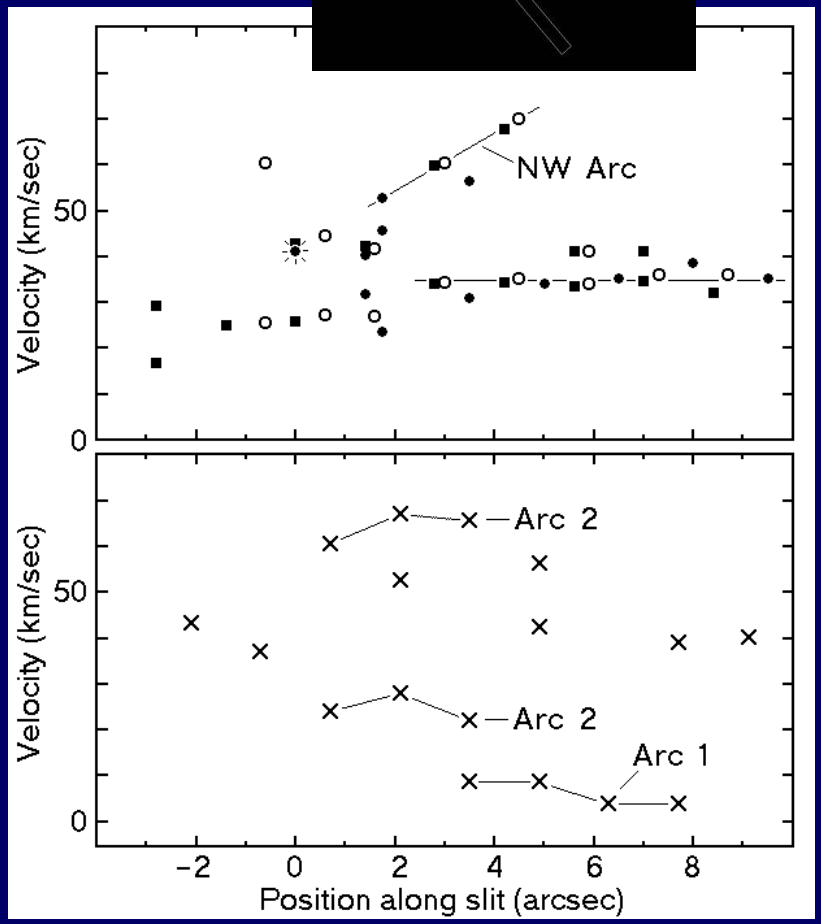
2D spectra of strong K I emission lines across the arcs



NW Arc





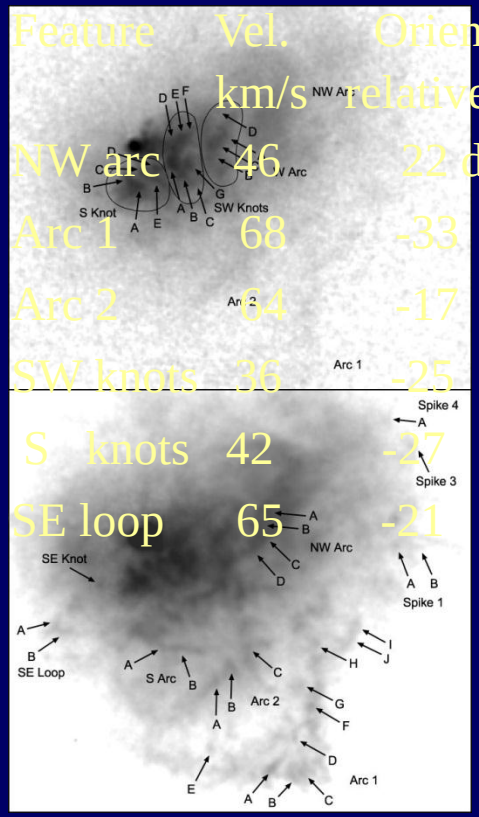


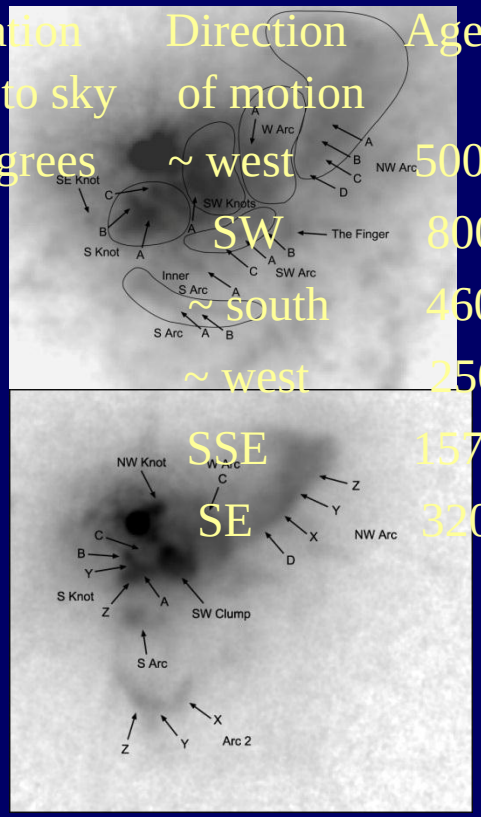
Arcs 1 and 2

2nd Epoch images with HST/WFPC2 in 2005

Measured the transverse motions V_T - shift in x and y positions between the two images. 66 positions

Radial Velocities at same positions K I em line (due to resonant scattering)





Feature	Vel. km/s	Orientation relative to sky	Direction of motion	Age (yrs)
NW arc	46	22 degrees	~ west	500
Arc 1	68	-33	SW	800
Arc 2	64	-17	~ south	460
SW knots	36	-25	~ west	250
S knots	42	-27	SSE	157
SE loop	65	-21	SE	320

Combining $V_T + V_R \rightarrow V_{Tot}$

To

Or

Di

Ag

Humphreys, Helton & Jones, 2007, Jones, Humphreys, & Helton 2007

Asymmetric Mass Loss Events and the Origin of the Discrete Ejecta

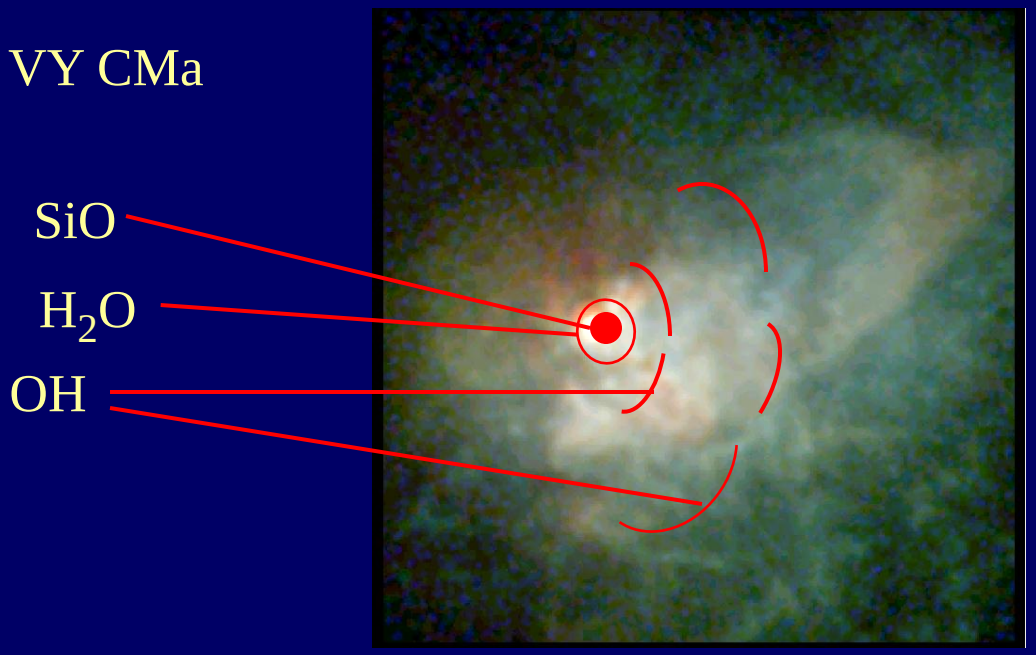
Images + Doppler and Transverse Velocities of VY CMa

Arcs and Knots are spatially and kinematically distinct; ejected in different directions at different times; not aligned with any axis of symmetry.

They represent localized, relatively massive (few x 10^{-3} M_{sun}) ejections

Large-scale convective activity
→ ***Magnetic Fields***

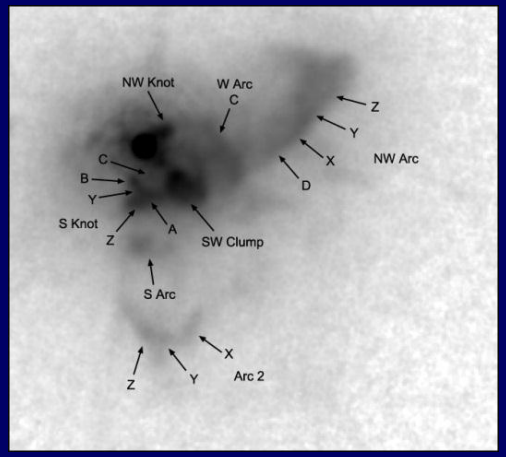
Masers Distribution on VY CMa

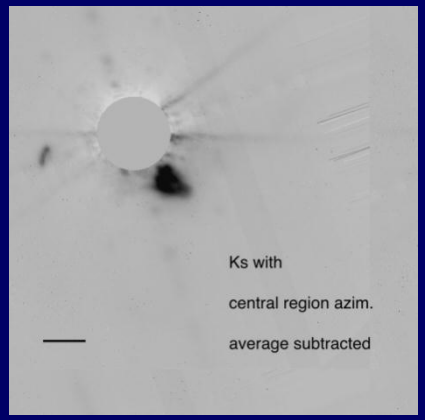


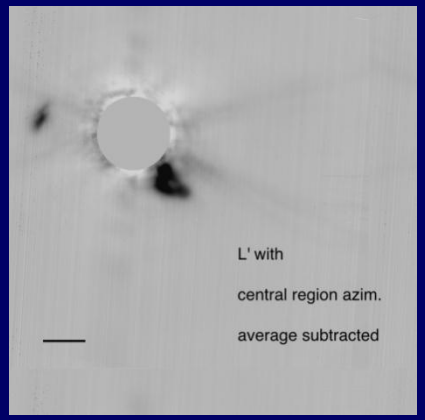
VY CMa -- circular polarization of H_2O (Vlemmings et al 2002, 2004), circular polarization of SiO (Barvainis et al 1987, Kemball & Diamond (1997), Zeeman splitting of OH (Szymczak & Cohen 1997, Masheder et al 1999)

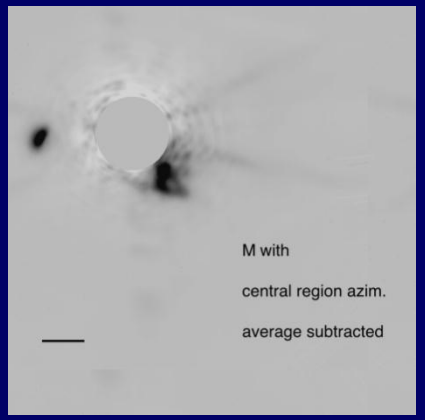
-> **10^4 G at the star**

Recent Results from LMIRCam (2 – 5mm) on the LBT with AO

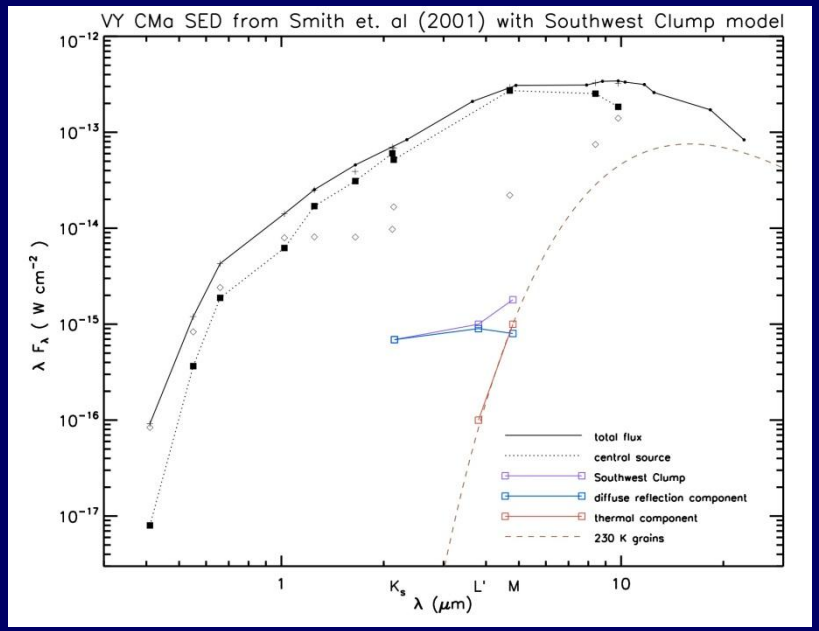








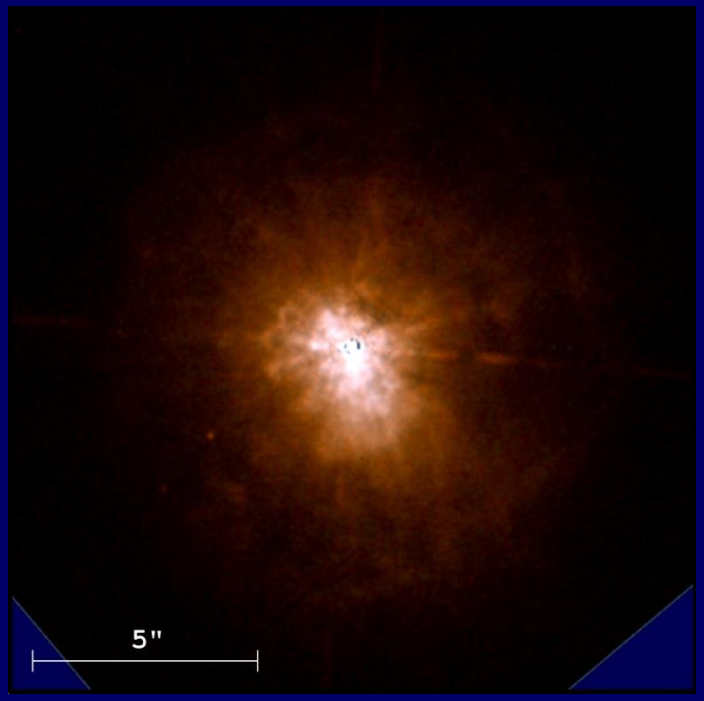
The SW clump – in the visible resolved into individual knots but very red and dusty. In the near-IR an unresolved knot . Ejected about 500 yrs ago.



Model as optically thick diffuse reflection at K plus ½ flux from thermal emission at M .
Mass loss 7 x 10^{-4} Msun

Shenoy et al. 2012

The Yellow or Intermediate-type Post Red Supergiant IRC +10420



1” = 5300 AU

Strong IR excess
L ~ 5 x 10^5 L_{sun}
High mass loss rate 3-6 x 10^{-4}
Warmest maser source
Spectroscopic variation late F → mid A

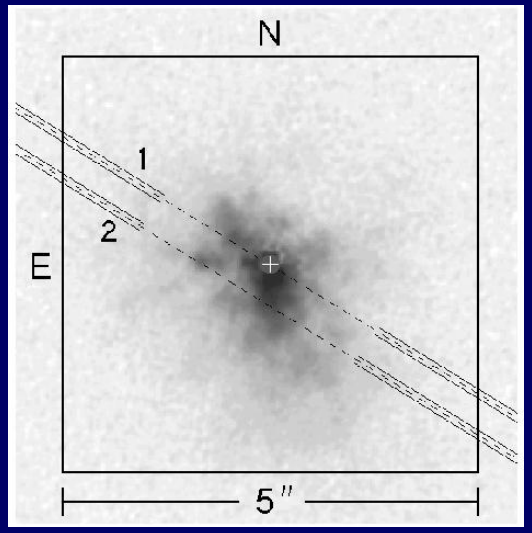
Complex CS Environment
One or more distant reflection shells ejected ~3000 yrs ago

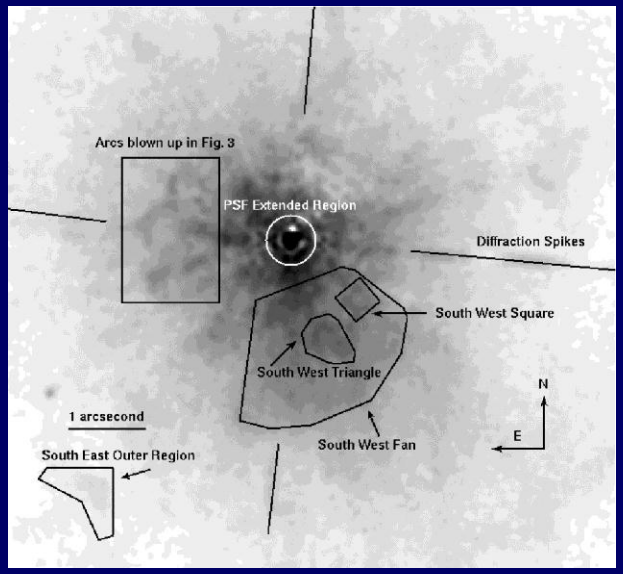
Within 2 “ – jet-like structures, rays, small nearly spherical shells or arcs
Evidence for high mass loss ejections in the past few hundred years

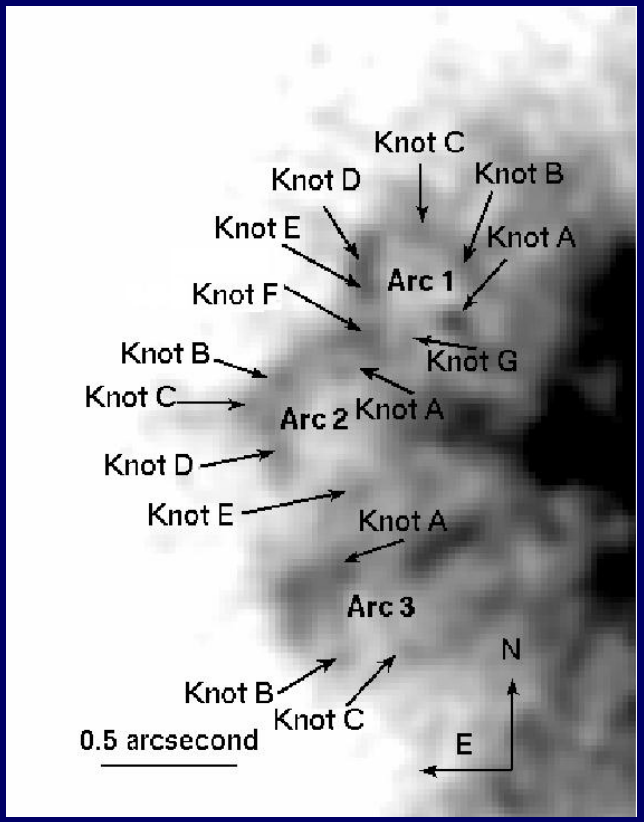
Jones et al 1993
Oudmaijer et al 1994, 1996
Humphreys, Smith, Davidson, Jones, et al.1997
Humphreys, Davidson & Smith, 2002

3D Morpholgy of IRC +10420 – 2nd epoch images from HST

spectra from HST/STIS





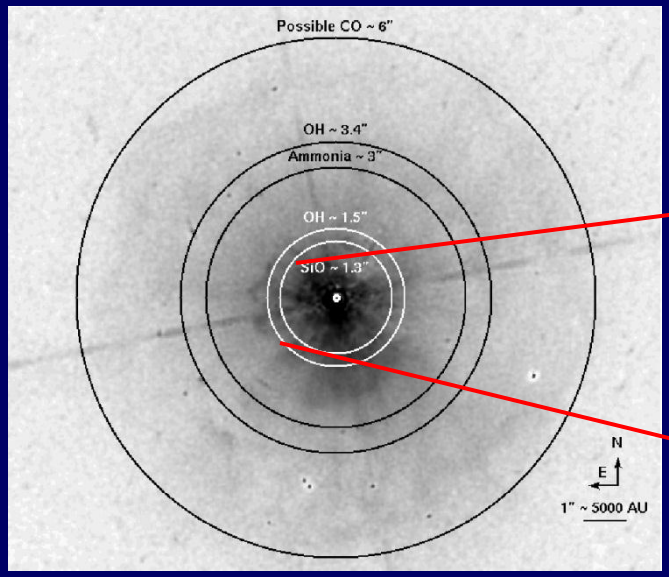


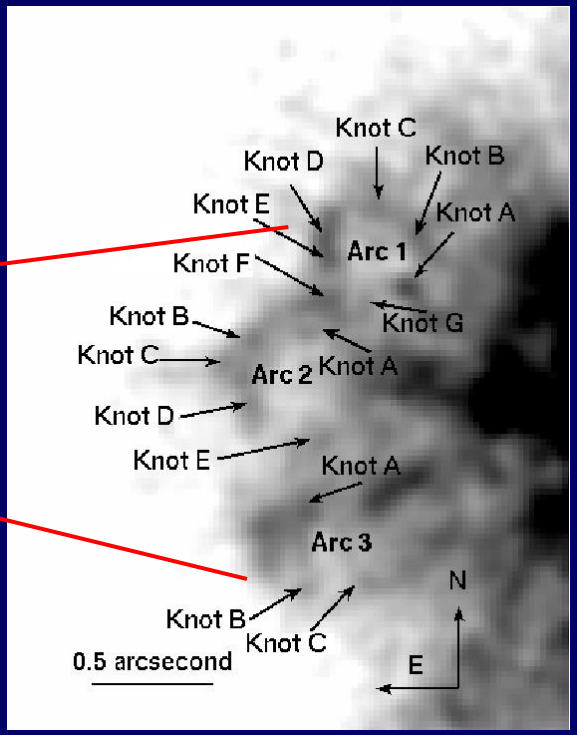
Numerous, arcs, knots ejected at different times (100-400 yrs), directions, and all within a few degrees of plane – viewing nearly pole-on

Semi-circular arcs – expanding bubbles? or loops?

Tiffany, Humphreys, Jones & Davidson 2010

Maser distribution



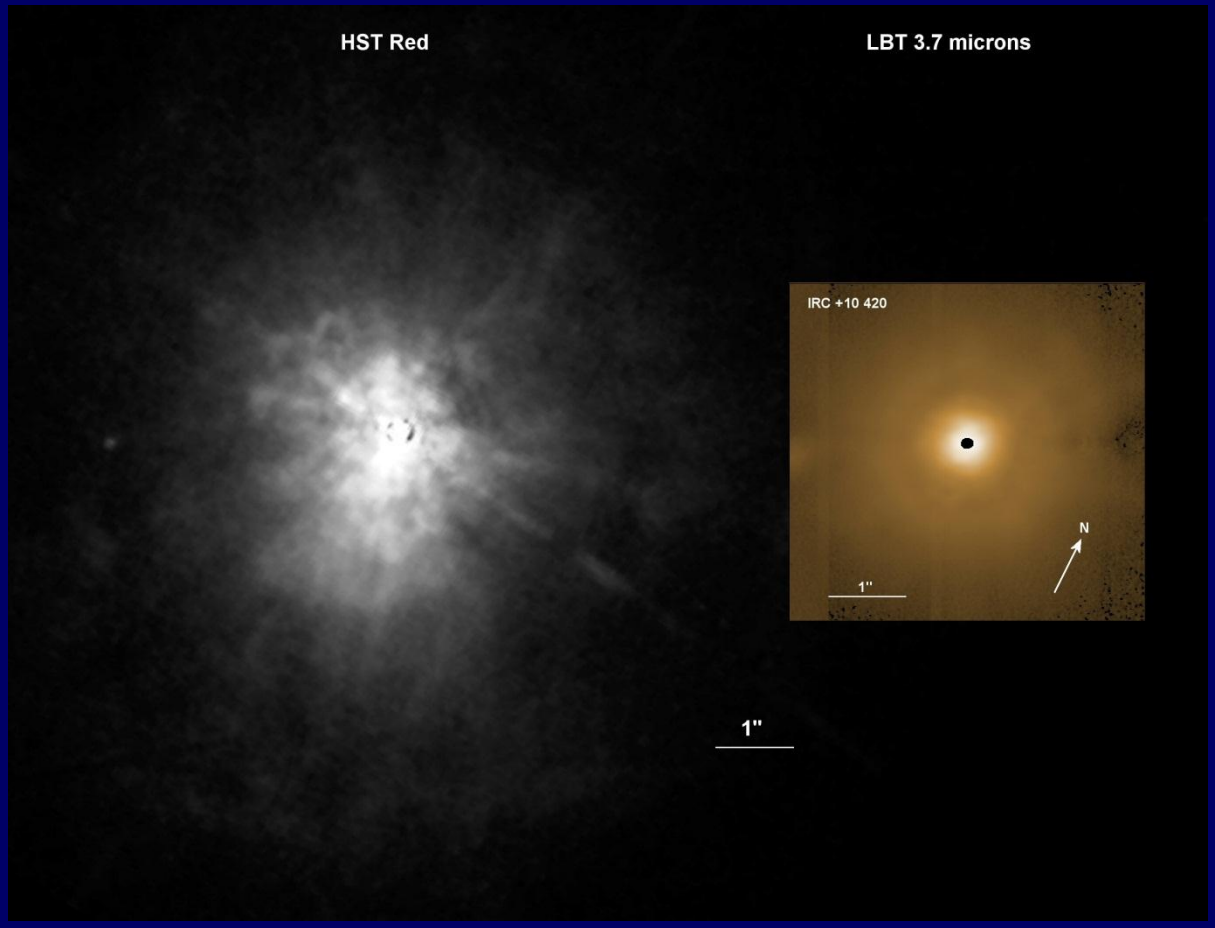


IRC +10420 -- circular polarization of OH (Nedoluha & Bowers 1992)

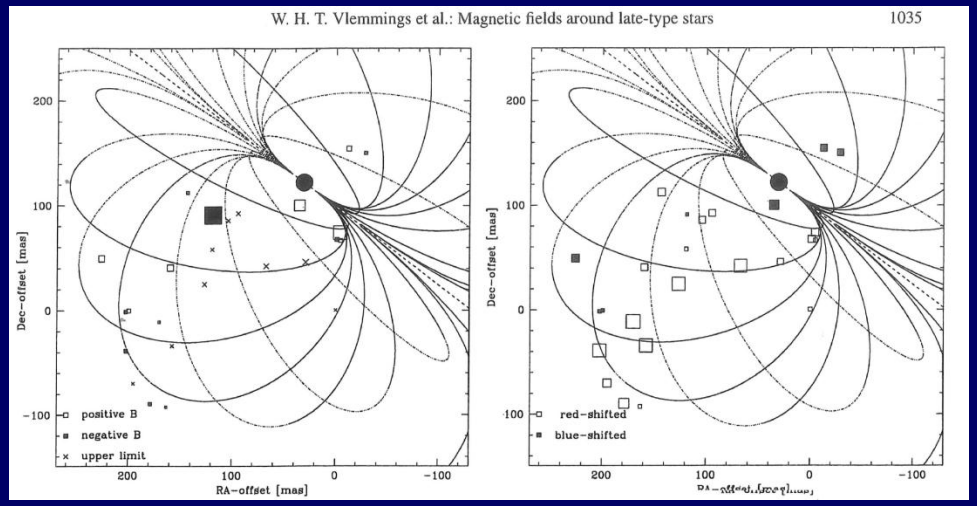
-> 3 x 10^3 G at the star

Arcs and loops associated with surface activity

Recent LBT/LMIRcam image



Conclusion – The mass loss histories of VY CMa and IRC+10420 are dominated by episodic high mass loss events. These discrete events are probably associated large scale surface activity, i. e. convective cells and magnetic fields.



VX Sgr – dipole magnetic field Vlemmings et al.

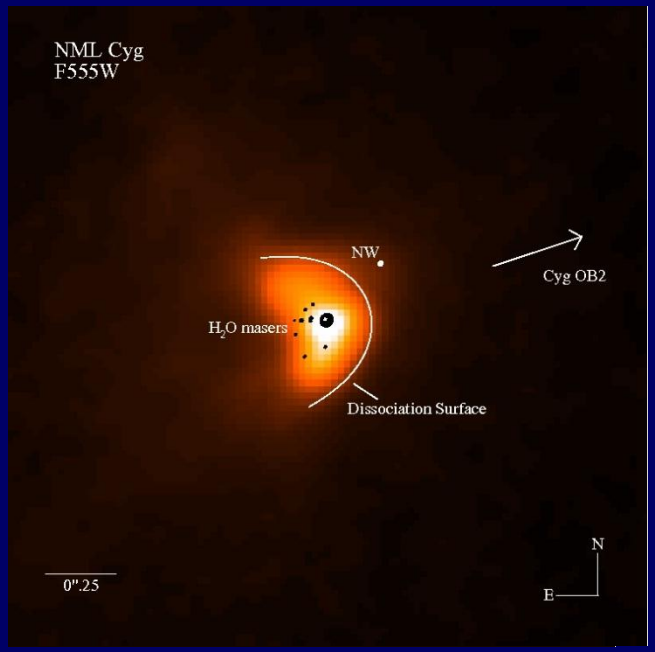
NML Cyg – Interacting with Its Environment

Optically obscured star embedded in a small asymmetric bean-shaped nebula, strong OH/IR source

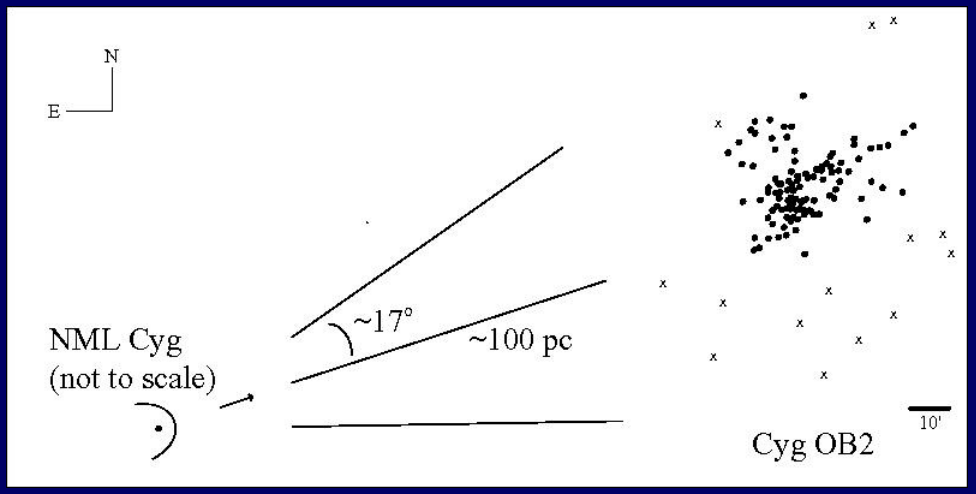
mass loss rate 6×10^{-5}

$L \sim 5 \times 10^{5}\ L_{sun}$

Similar in shape to HII contours (30” away) due to interaction of RSG wind with ionizing photons hot stars in Cyg OB2

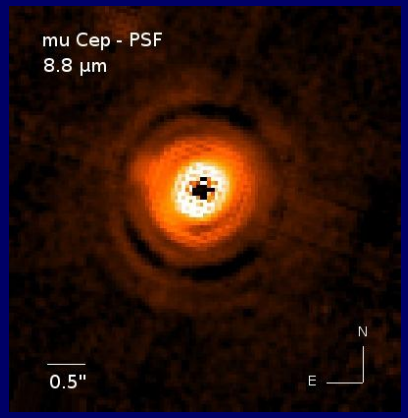


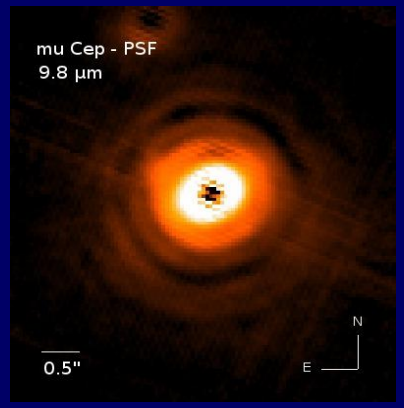
0”.25 = 500 AU

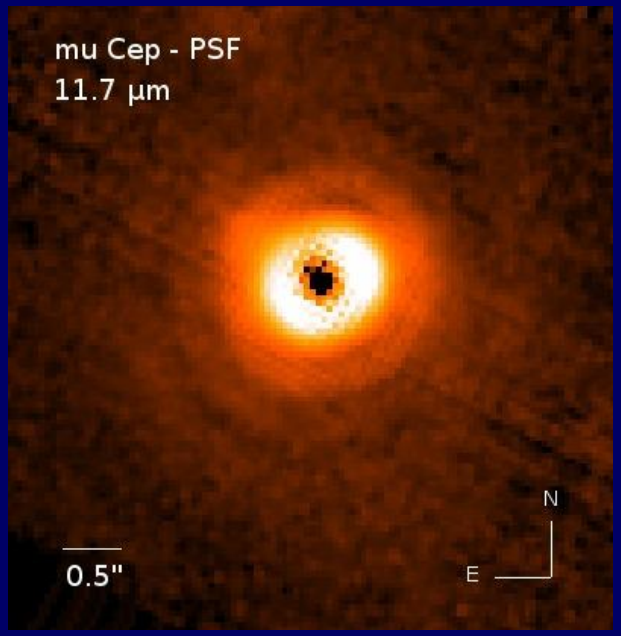


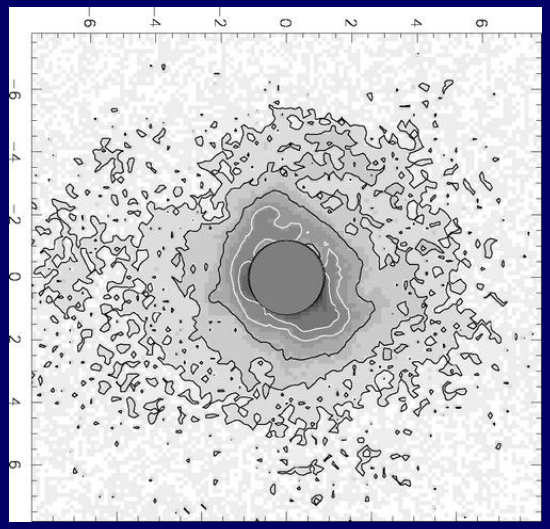
Schuster, Humphreys & Marengo (2006) , Schuster et al. (2009) showed this is the molecular photodissociation boundary

Recent results on μ Cep – 9 -12 μm imaging MMT/MIRAC









De Wit et al. 2008 25 μm image

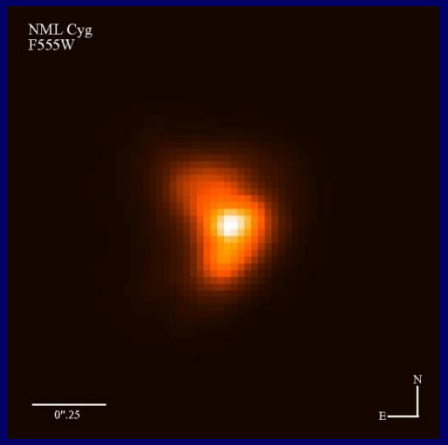
Observations in progress ---

LBT LMIRcam(2 – 5μm), LBTI/AO (8 – 12μm) – VY CMa, IRC+10420

MMT MIRAC(8 – 12μm), MMTPol -- S Per, VX Sgr, IRC+10420 plus several RSGs

Collaborators

Kris Davidson
Andrew Helton
George Herbig
Terry J. Jones
Gerald Ruch
Dinesh Shenoy
Nathan Smith
George Wallerstein



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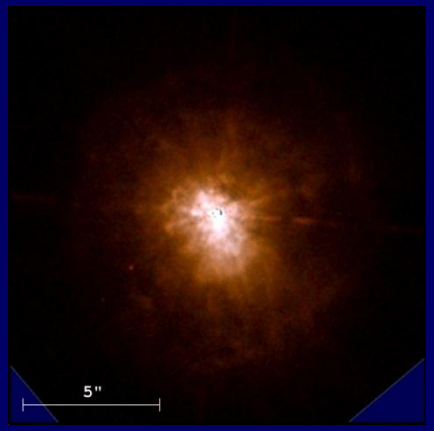
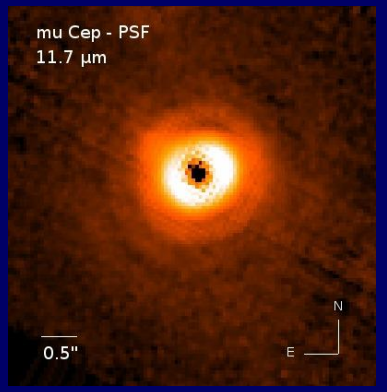


NGC 300 OT

Luigi Bedin
Howard Bond
Alceste Bonanos
Kris Davidson
Berto Monard
Jose Prieto
Fred Walters



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