Cool Dust and the Mass Loss Histories of the Cool Hypergiants

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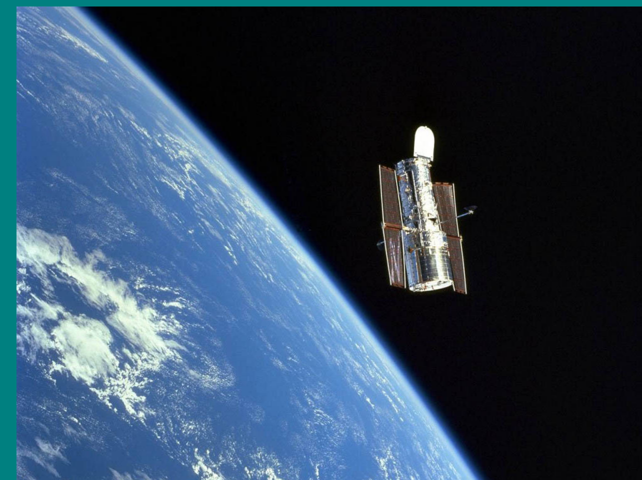
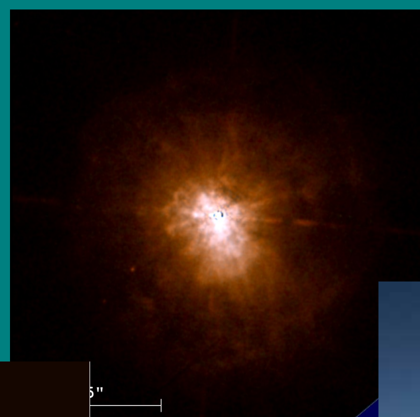
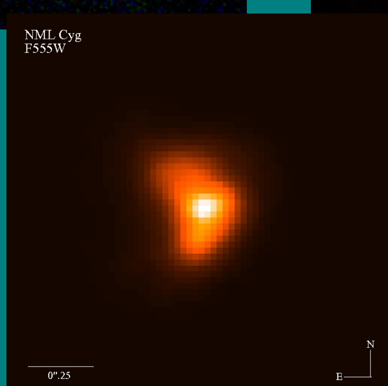
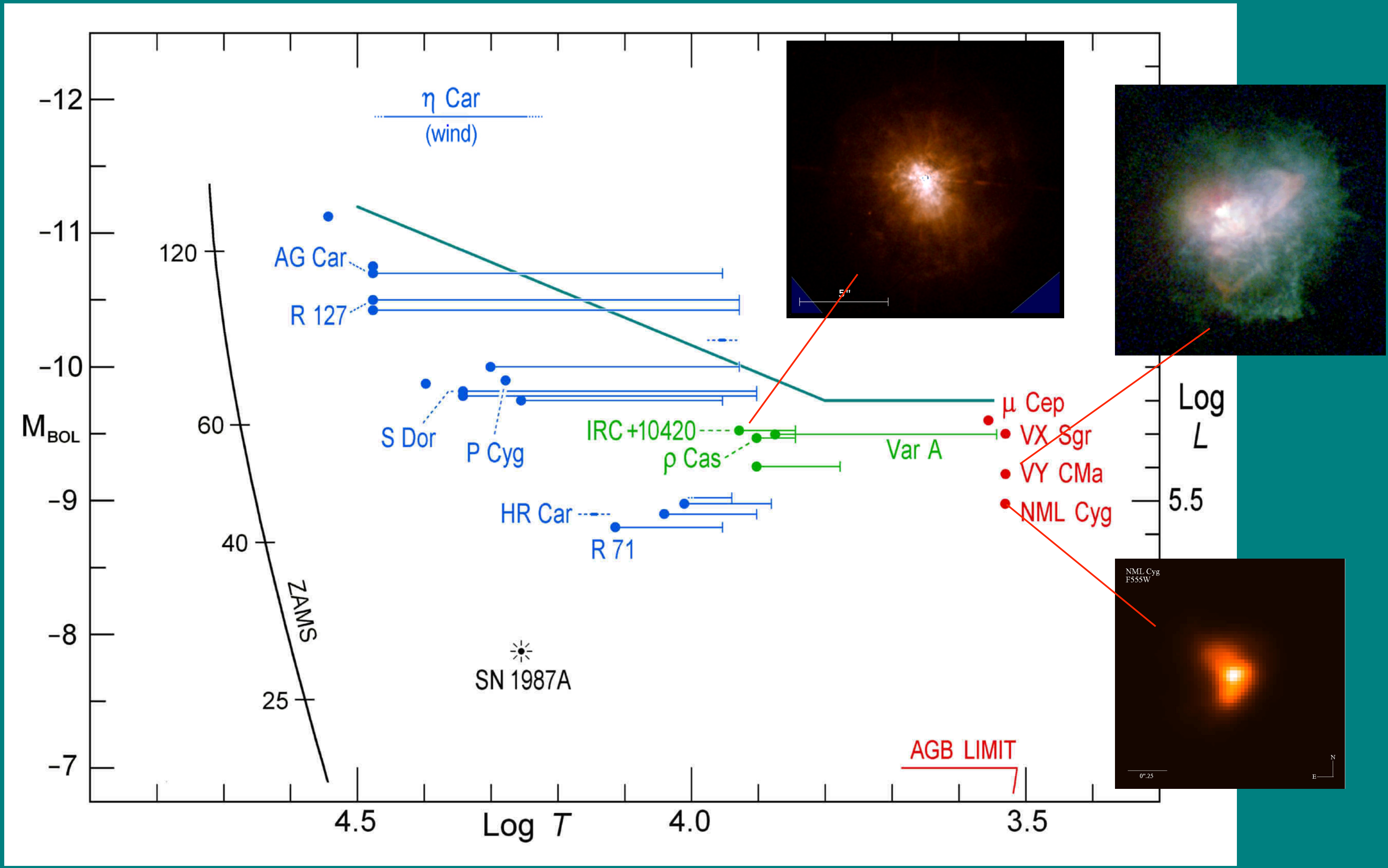






SOFIA Telecon, November, 2011

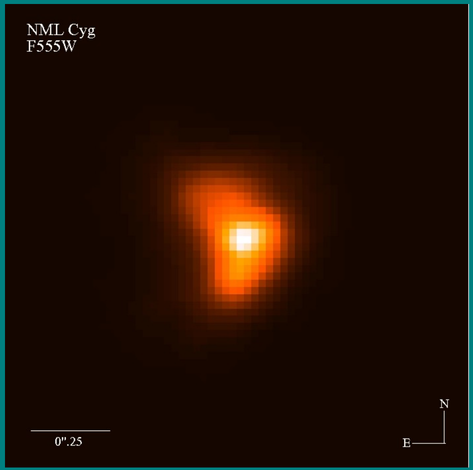
The Upper HR Diagram

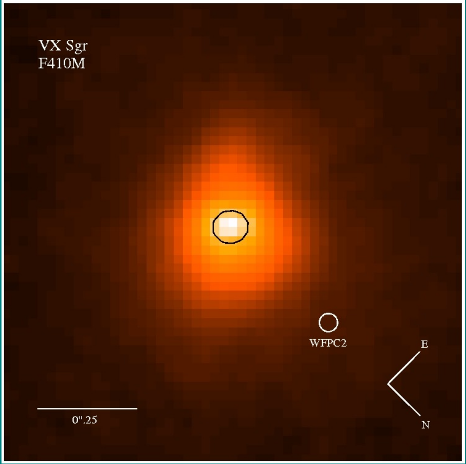


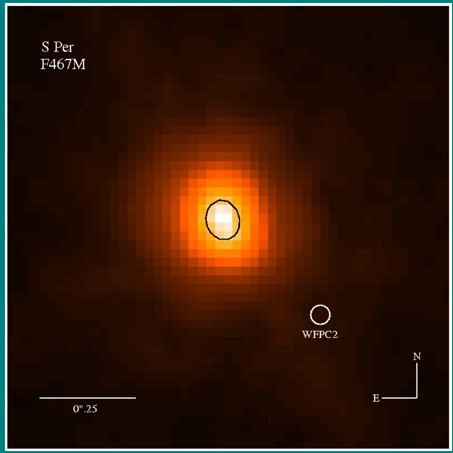
The evidence for episodic high mass loss events

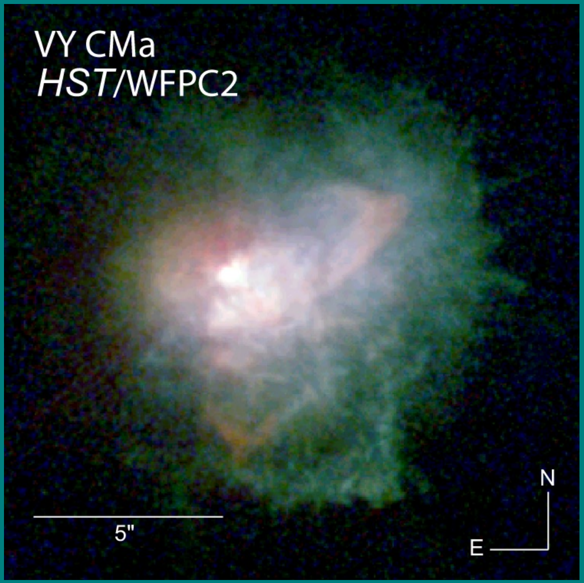
The Cool Hypergiants and the Supergiant OH/IR stars

The Red Supergiants





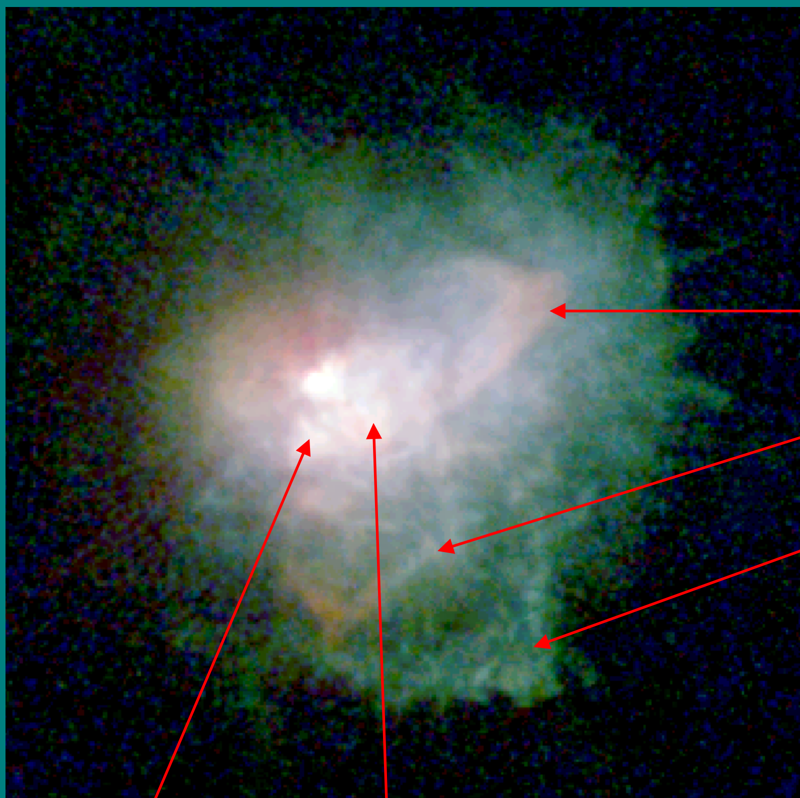




1" = 1500 AU

Complex structure in ejecta

Prominent arcs, numerous filaments and clumps of knots, strong maser source, mass loss rate 5×10^{-4}



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

Second epoch HST images

Measure transverse velocities combined with radial velocities long slit spectra (Keck) of K I em line

Total velocity, orientation, direction and age → 3D morphology

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

Humphreys, Helton & Jones, 2007

Jones, Humphreys, Helton et al 2007

3D Morphology and History of Asymmetric Mass Loss Events and Origin of Discrete Ejecta

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***

VY CMa -- circular polarization of H_2O (Vlemmings et al 2002, 2005),

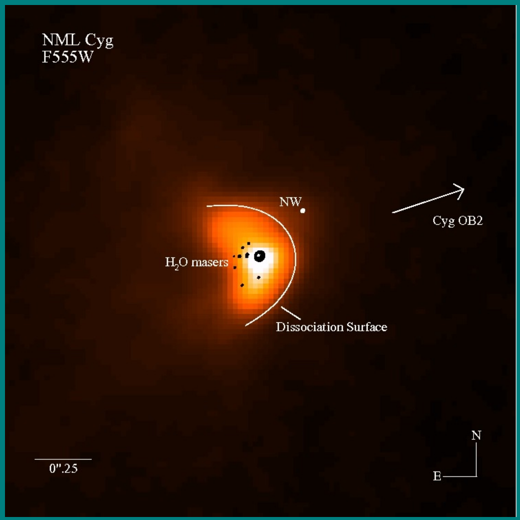
-- circular polarization of SiO (Barvainis et al 1987, Kemball & Diamond (1997),

-- Zeeman splitting of OH (Szymczak & Cohen 1997, Masheder et al 1999)

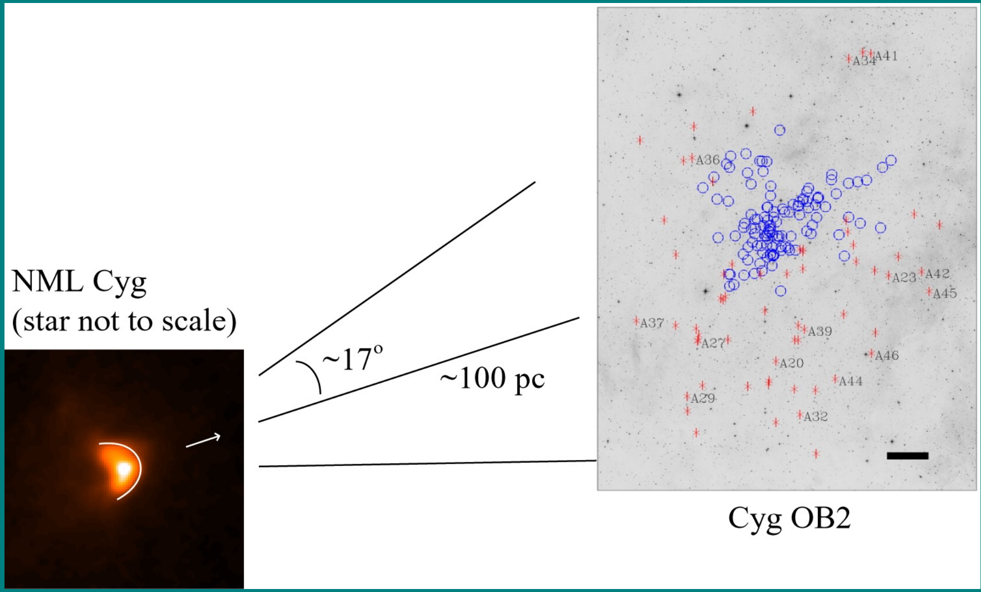
-> ~ 8 x 10^3 G at the star (extrapolating from OH masers at few x 1000 AU)

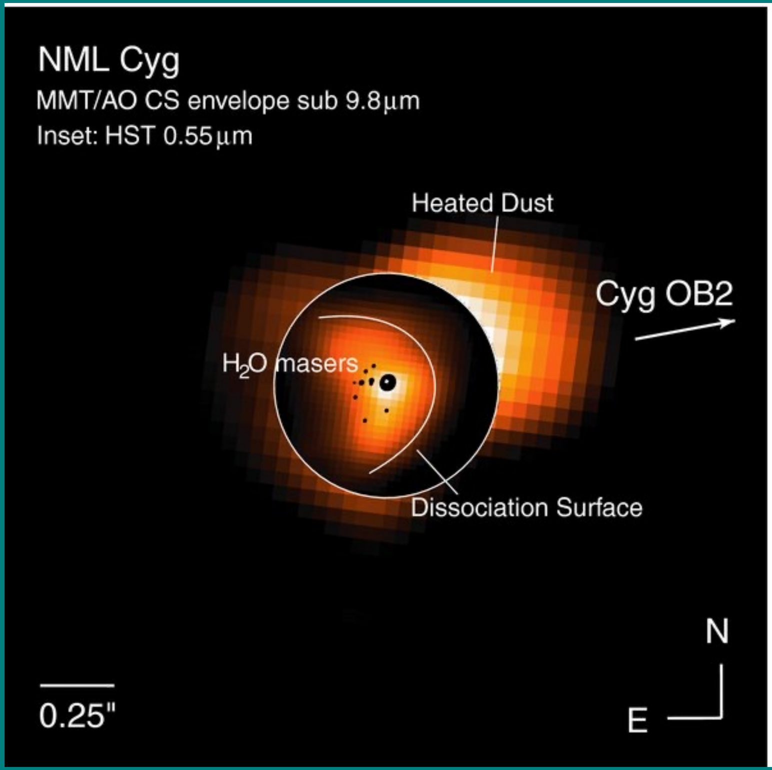
NML Cyg -- interacting with its environment

Schuster, Humphreys & Marengo 2006



Optically obscured star embedded in a small asymmetric bean-shaped nebula,
strong OH/IR source
mass loss rate 6×10^{-5}
$L \sim 3.2 \times 10^{5}\ L_{sun}$

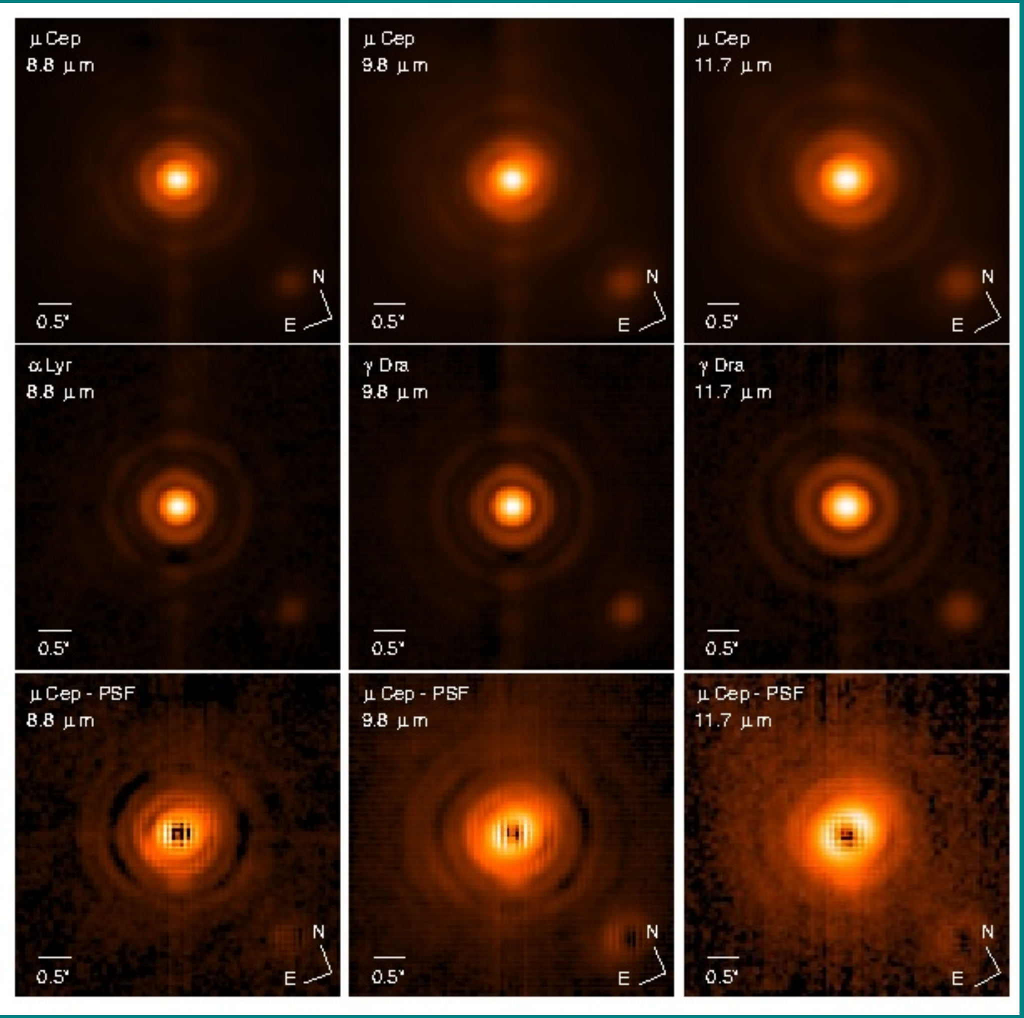




μ Cephei

No extended structure in HST images

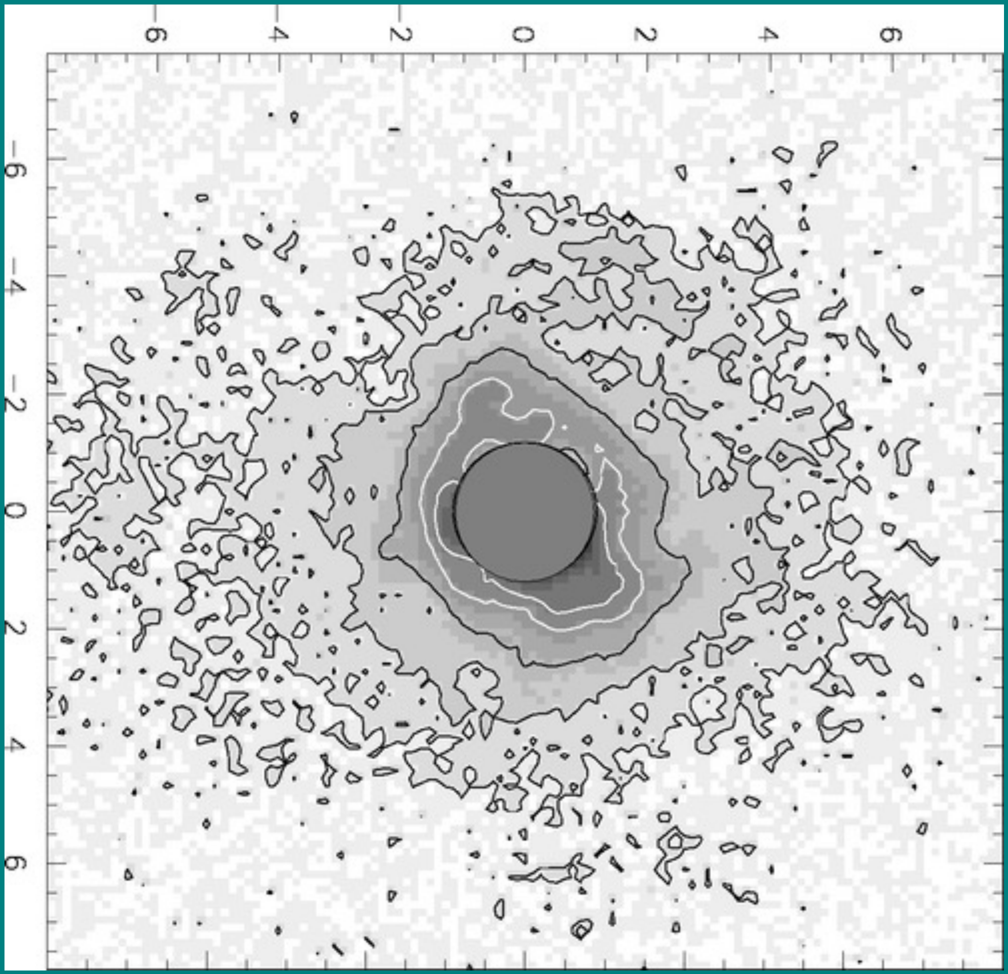
MMT/MIRAC – AO images at 8.8, 9.8 and 11.7 μ   (Schuster et al 2007 unpubl.)



de Wit et al. (2008) circumstellar nebula at 24.5 μ extending ~ 6 “

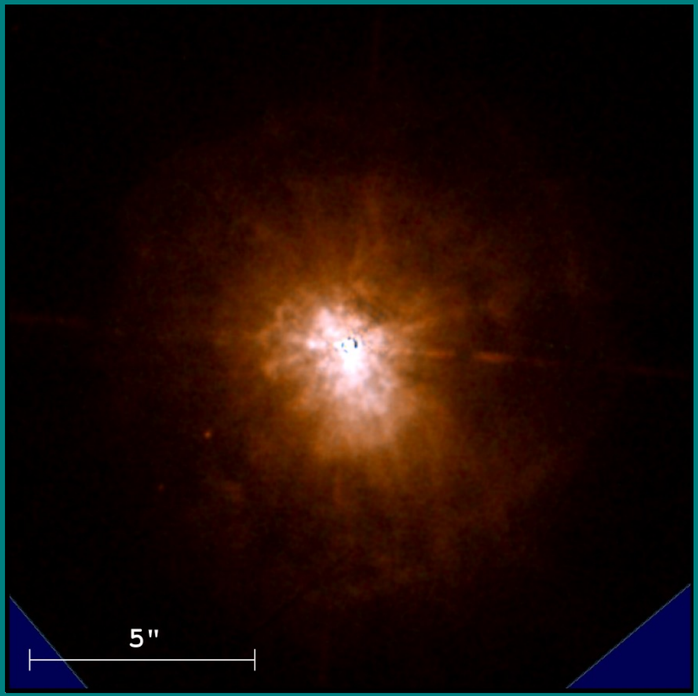
North

East



The Yellow or Intermediate-type Hypergiants ---

The Post-Red Supergiant IRC+10420



1" = 5300 AU

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

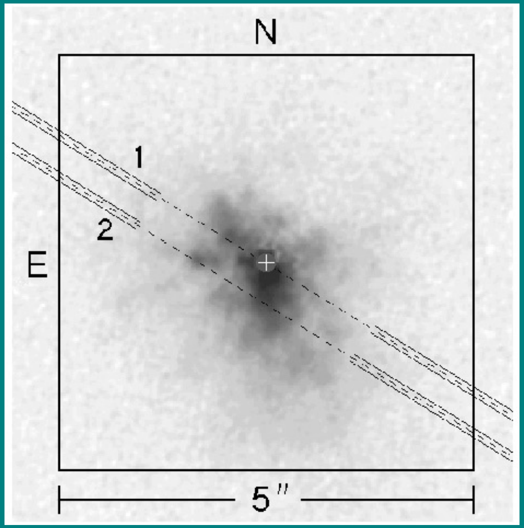
IRC +10420 -- circular polarization of OH (Nedoluha & Bowers 1992)

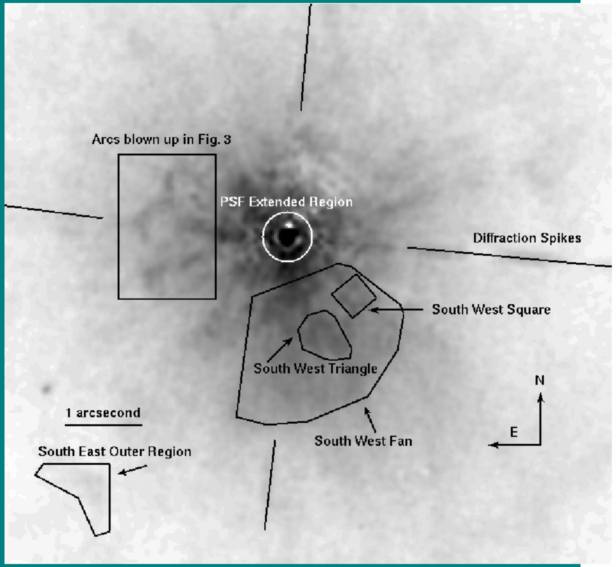
-> ~ 3 x 10^3 G at the star

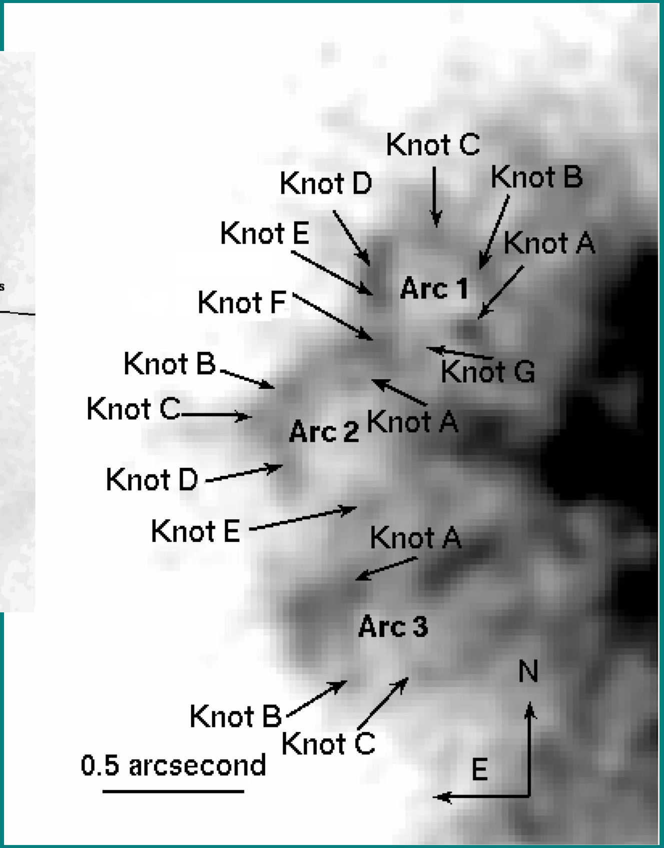
Jones et al 1993
Oudmaijer et al 1994, 1996
Humphreys, Smith, Davidson, Jones, et al.1997
Humphreys, Davidson & Smith, 2002

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

spectra from HST/STIS



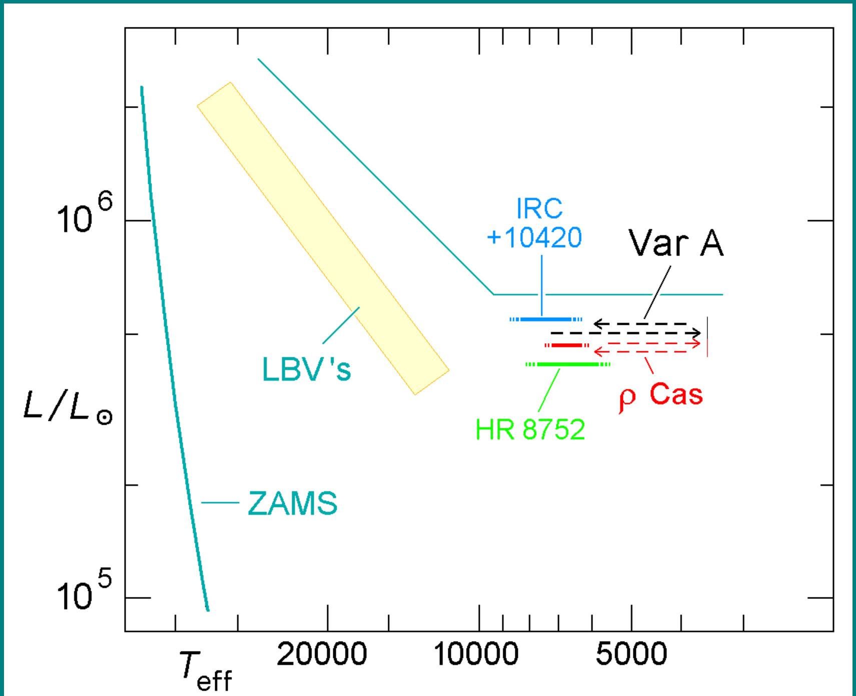




Numerous, arcs, knot ejected at different times (100- 400 yrs), directions, and all within a few degrees of plane – viewing nearly pole-on

Semi-circular arcs – expanding bubbles? or loops?

Tiffany, Humphreys, Jones & Davidson 2010



ρ Cas F8p Ia

HR 5171A G8 Ia

HR 8752 G0-5 Ia

Var A in M33 F: I (--M)

ρ Cas – famous shell ejection episodes, 1945-47,1985-87, 2002

develops TiO bands, very high but temporary mass loss ($\sim 10^{-2}$), quickly returns to its normal F-type supergiant spectrum → formation of an optically thick wind

Abundances indicate it is evolved star, post RSG

No visible CS ejecta, Near-IR AO -- negative

FORCAST Program on SOFIA

VY CMa

VX Sgr

S Per

μ Cep

IRC+10420

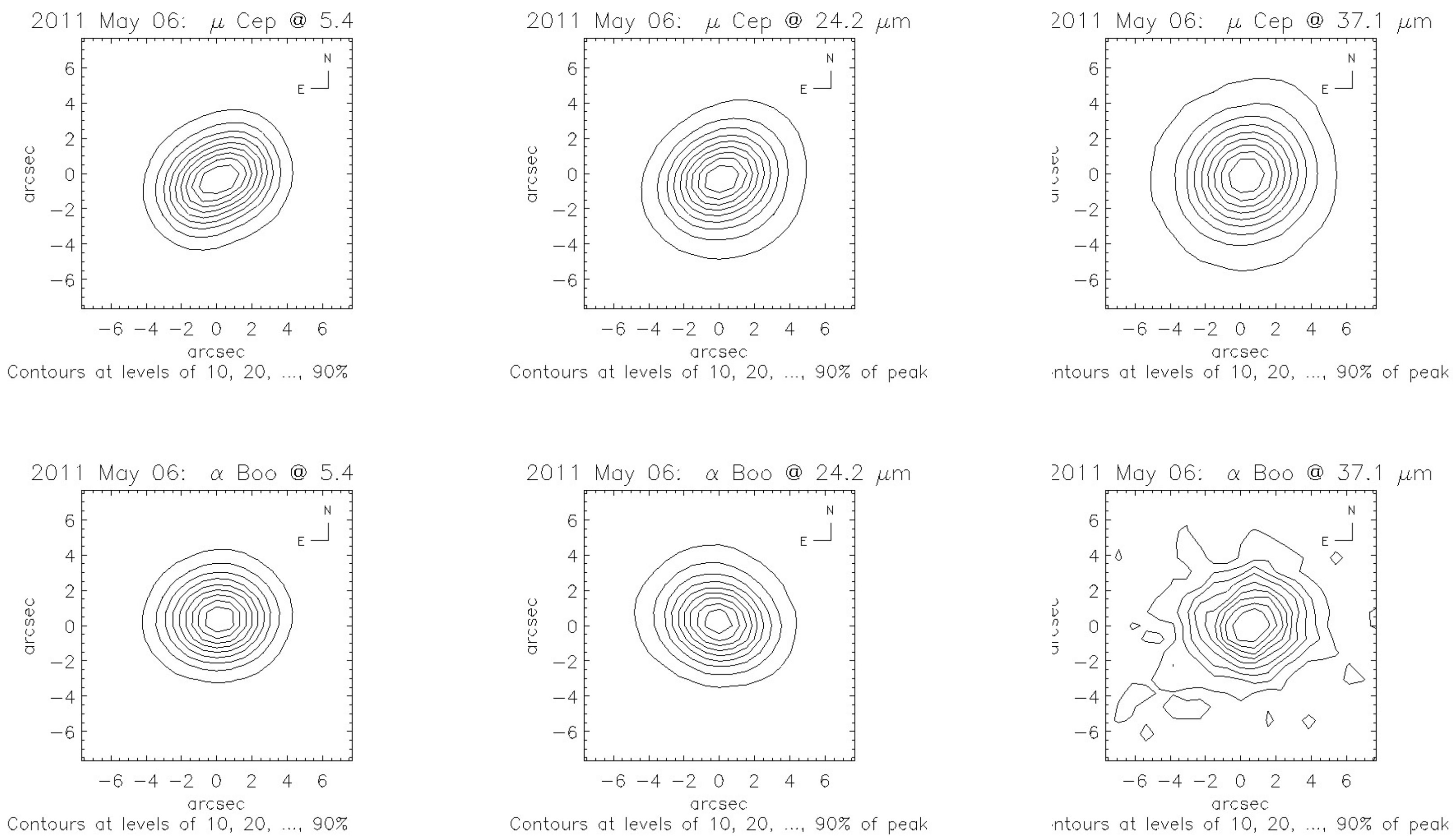
ρ Cas

at 5.4. 8.6, 11.1, 19.7, 24.2, 31.5, 34.8, 37.1 μ

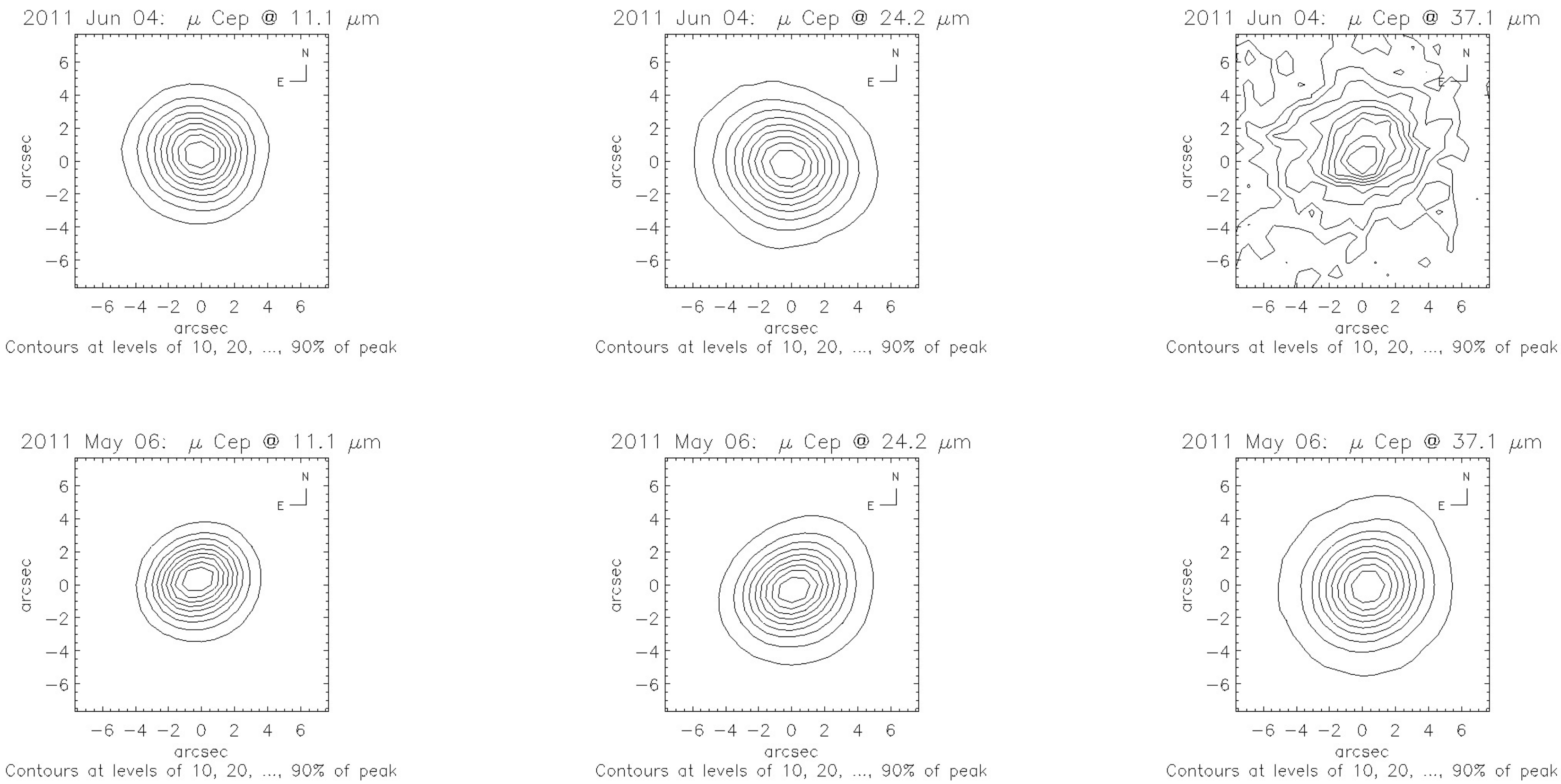
(5.4 and 8.6 flux only) , using chop and nod

Only μ Cep was observed

May 06, 2011 Instrument problems – air turbulence in telescope cavity



June 06 observations (11.1, 19.7, 24.2, 34.8, 37.1 μ

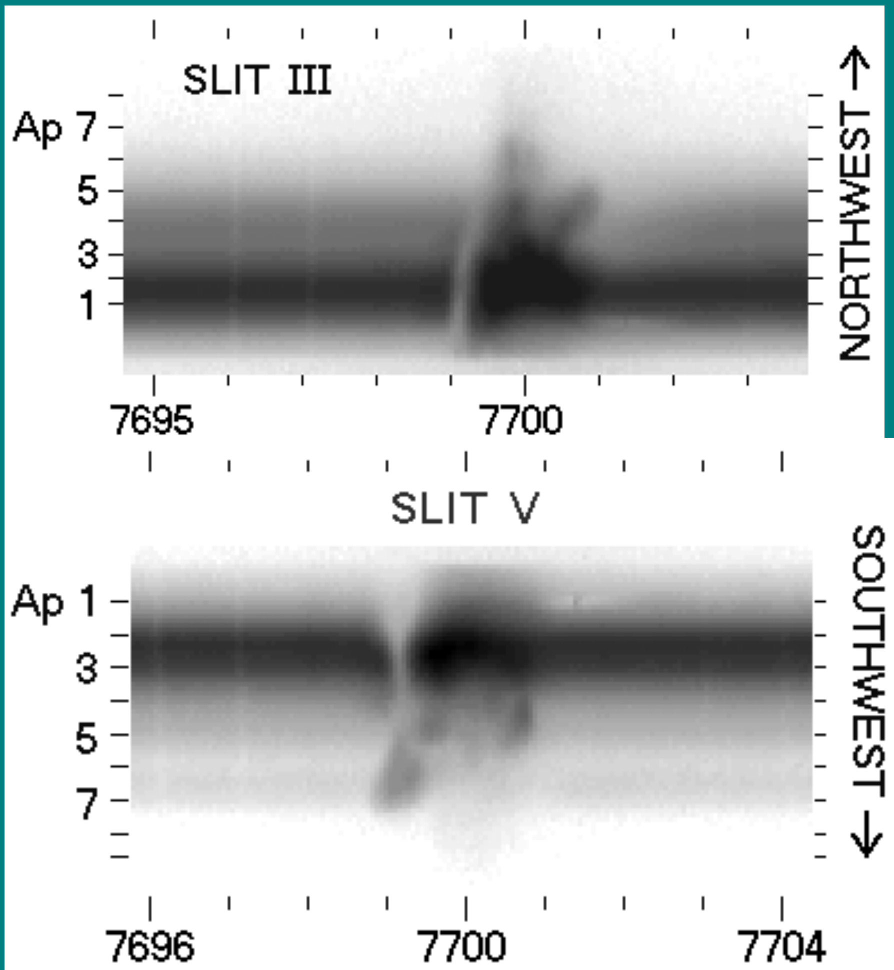


Extra slide

2D spectra of strong K I emission lines across the arcs (Keck – HiRes)

Humphreys, Davidson, Ruch & Wallerstein 2005

NW Arc



Arcs 1 and 2