The Hypergiant Masers: Episodic Mass Loss, Convective Activity and Magnetic Fields

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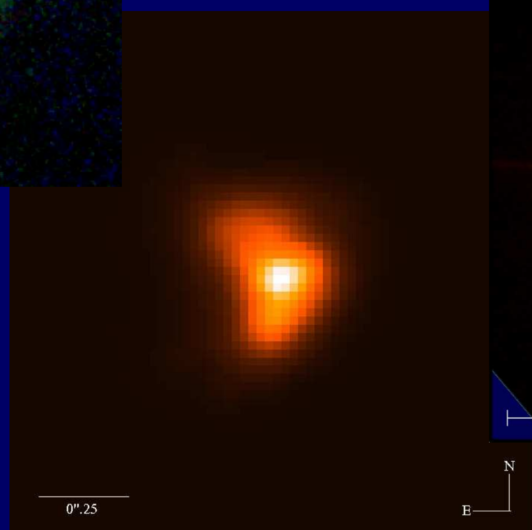
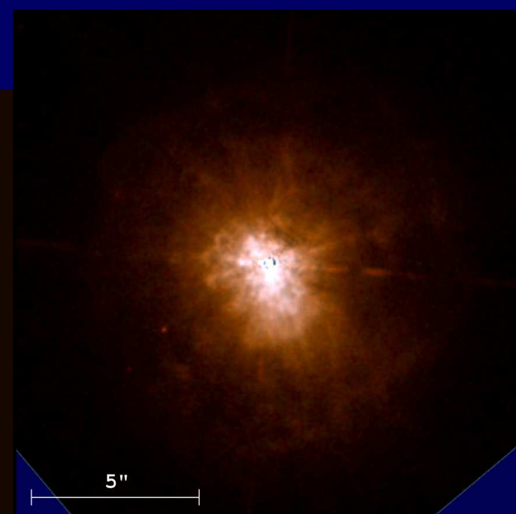
VY CMa

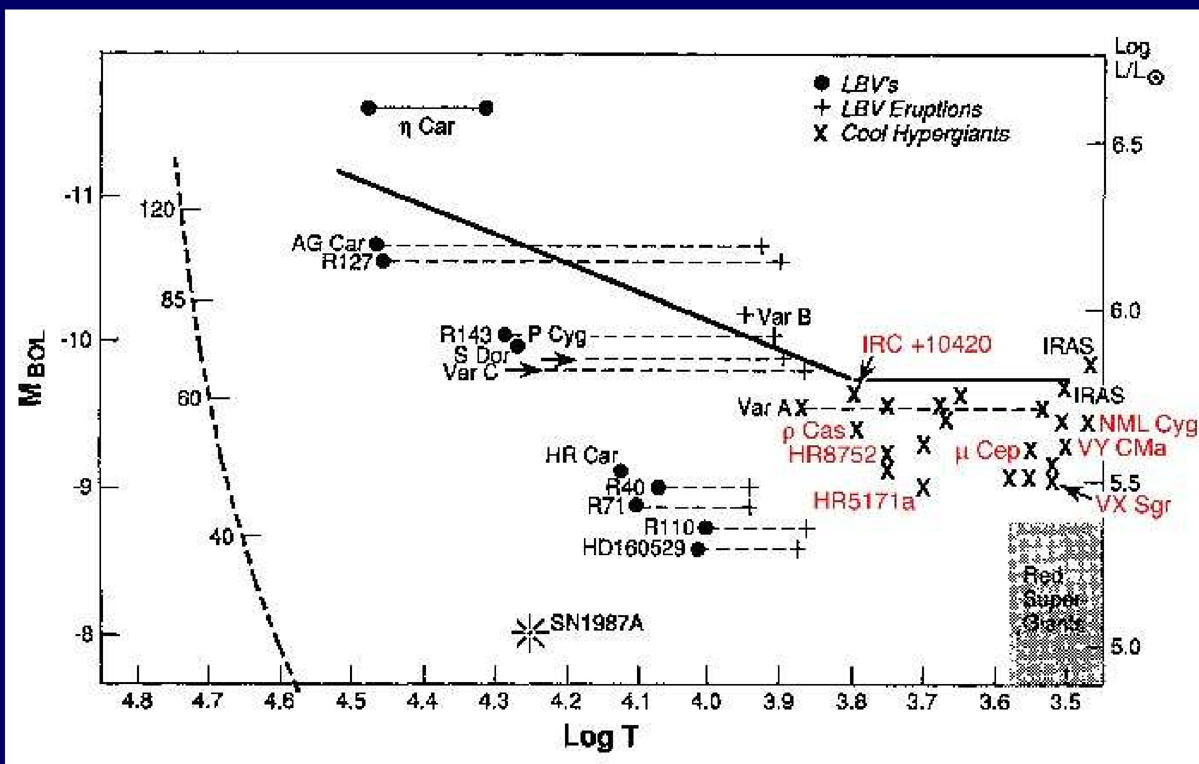


NML Cyg



IRC +10420

The Cool Hypergiants -- lie just below the upper luminosity envelope with spectral types A to M, high mass loss rates, photometric and spectroscopic variability, large infrared excess, and some with extended circumstellar ejecta



point sources:

μ Cep
ρ Cas
HR5171a
HR8752

extended sources + complex ejecta
VX Sgr
S Per
IRC +10420
NML Cyg
VY CMa

The Post Red Supergiant -- IRC +10420

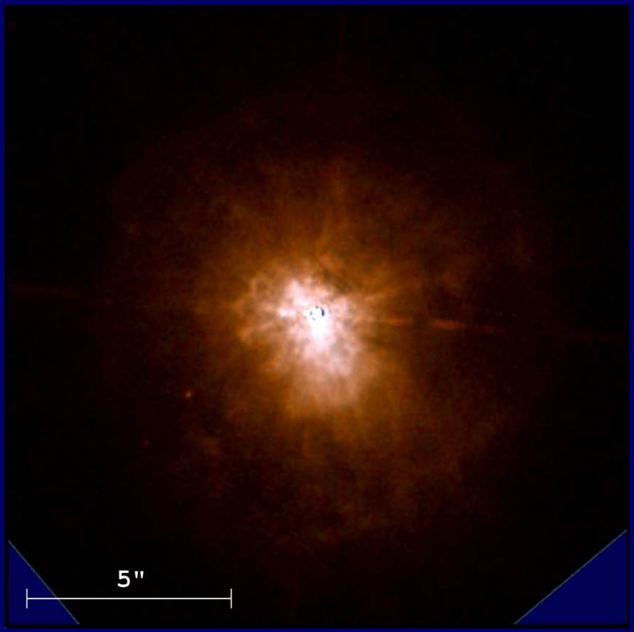
Strong IR excess

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

High mass loss rate 3-6 x 10^{-4}

One of warmest maser sources

Spectroscopic variation late F → mid A



1” = 5300 AU

Complex CS Environment

One or more distant reflection shells

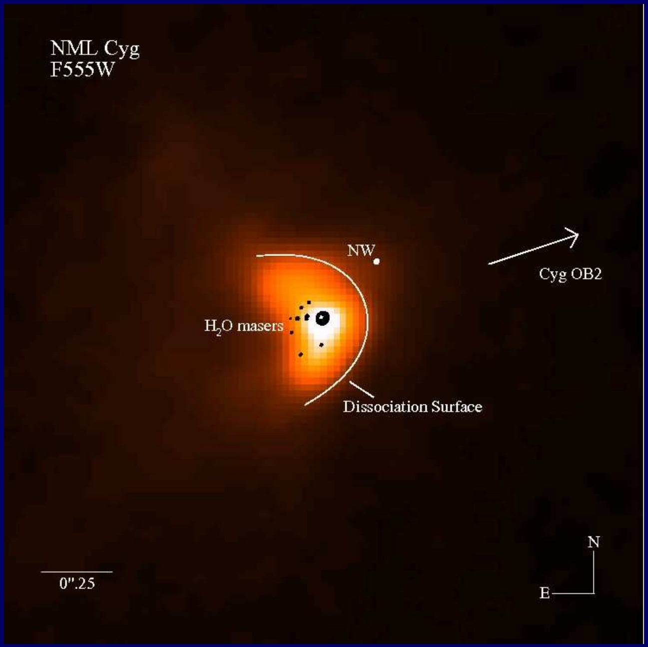
Within 2 “ – jet-like structures, rays, small nearly spherical shells or arcs

Evidence for high mass loss ejections in the past few hundred years

OH maser emission peculiar, varying intensity, distributed 1.3 – 1.5” from star

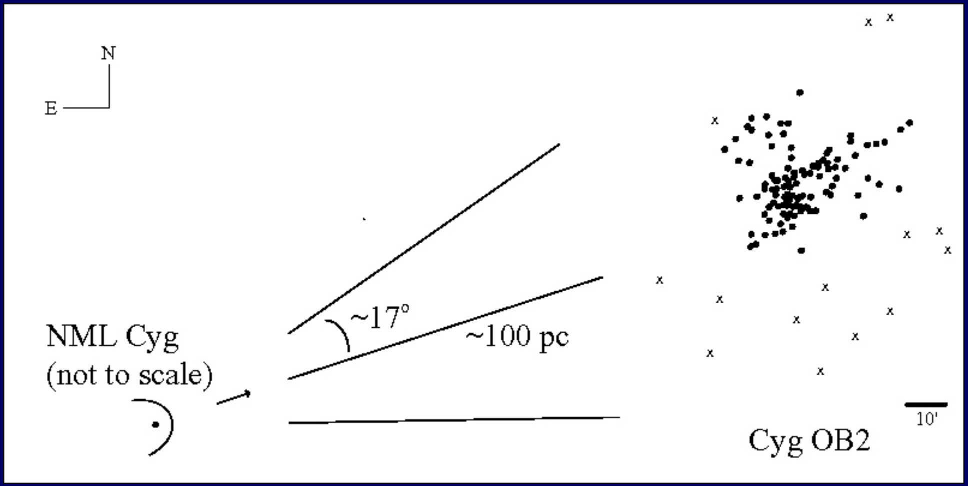
NML Cyg – Interacting with Its Environment

Optically obscured star embedded in a small asymmetric bean-shaped nebula, strong OH/IR source
mass loss rate 6 x 10^{-5}
L ~ 5 x 10^5 L_{sun}



0”.25 = 500 AU

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



Schuster, Humphreys & Marengo (2006) showed this is the molecular photodissociation boundary

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

10”

Mass loss rate 4 x 10^{-4}

L ~ 5 x 10^{5} L_{sun}

Famous asymmetric red nebula, > 10” across, visible in small ground based telescopes.

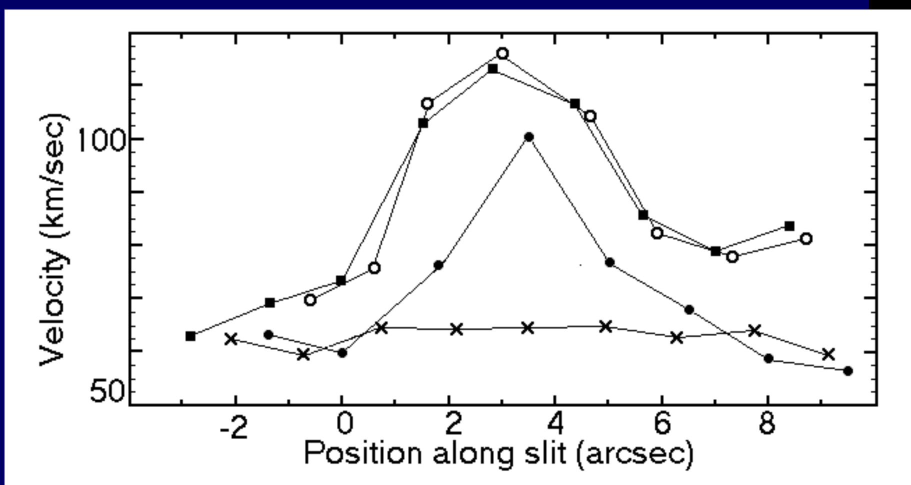
HST/WFPC2 images revealed complex environment – numerous knots, filamentary arcs, prominent nebulous arc

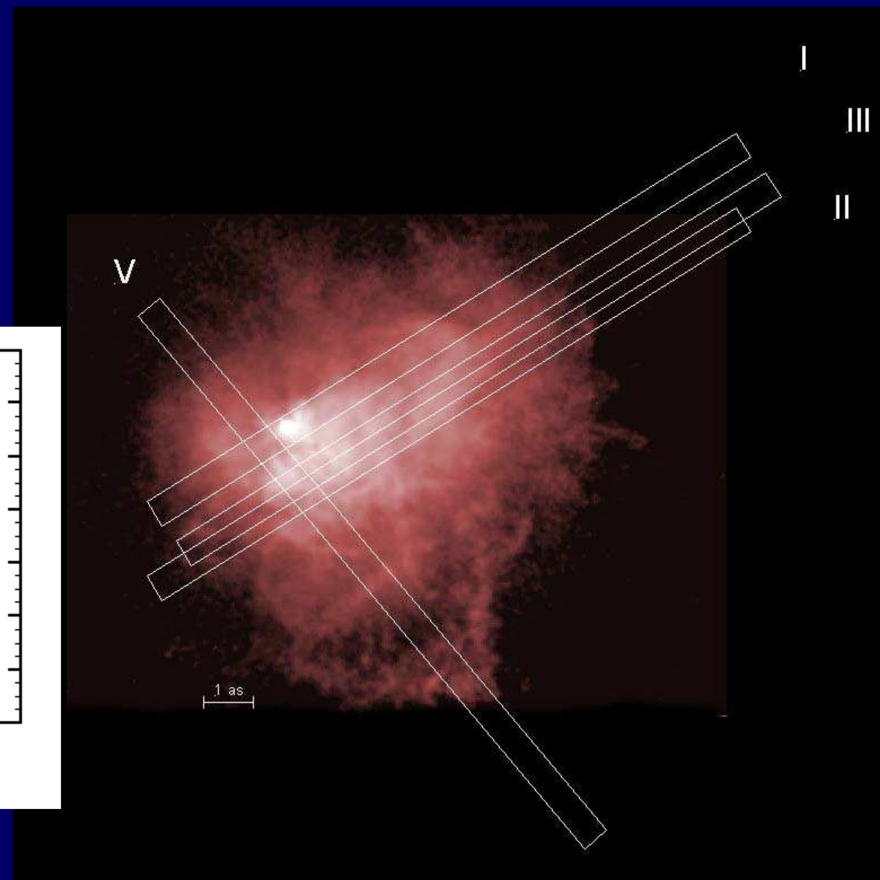
1” = 1500 AU

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

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

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



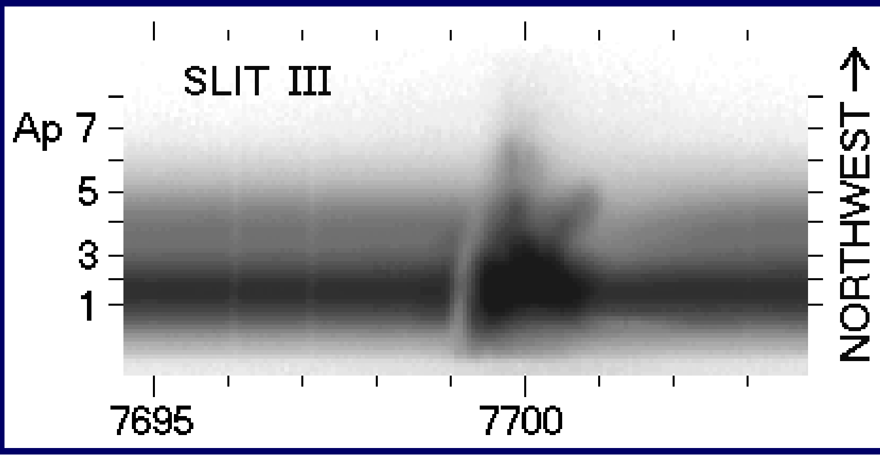


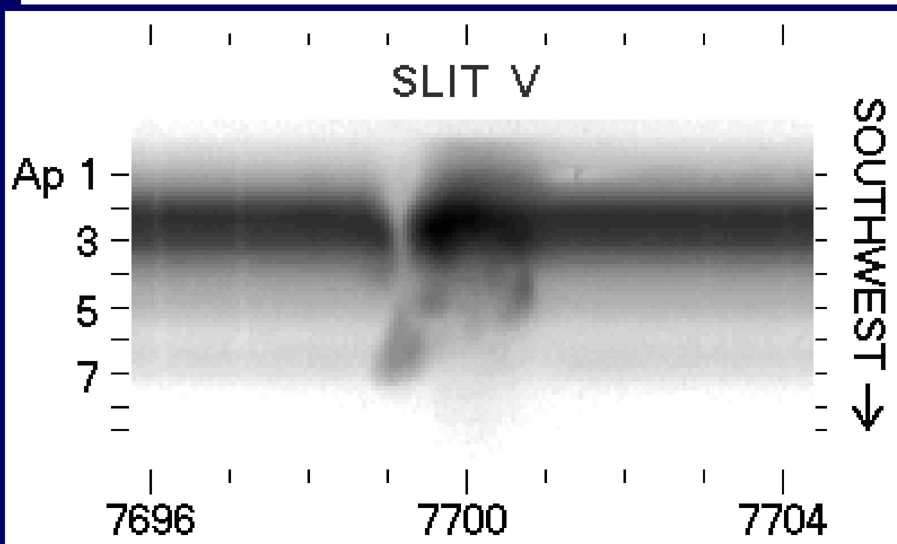
Expanding relative to star ~ 50 km/s

~ 500 year ago

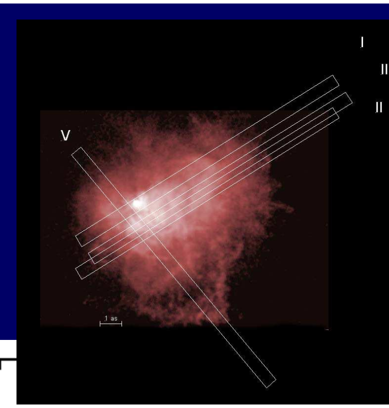
2D spectra of strong K I emission lines across the arcs

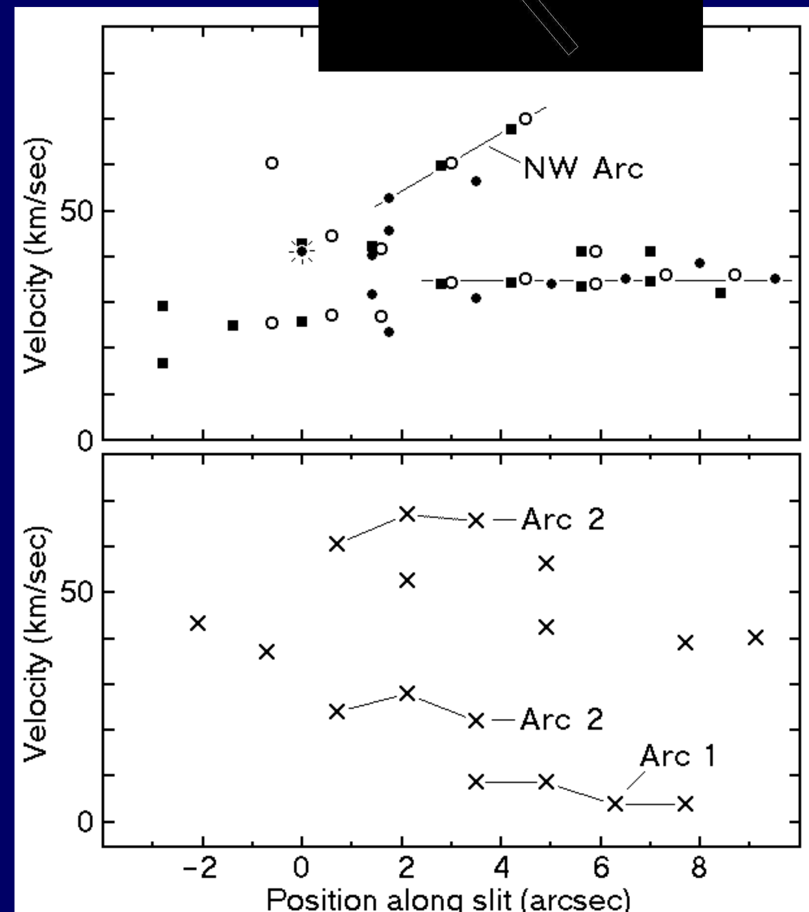
NW Arc



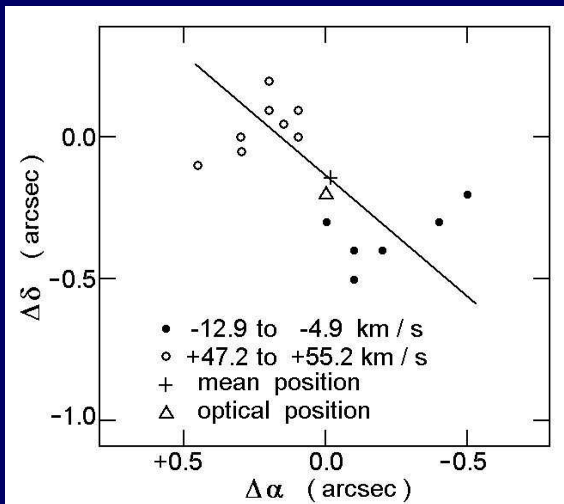


Arcs 1 and 2

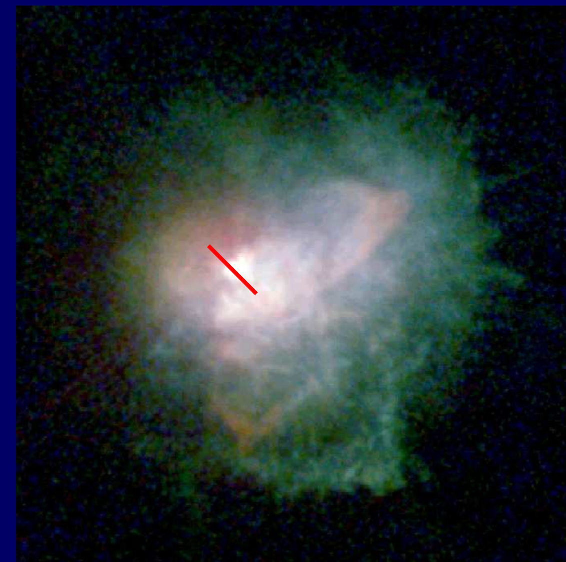


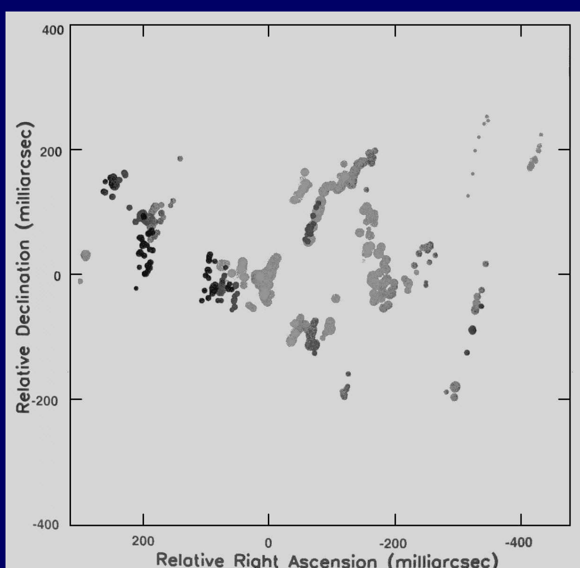


Geometry of the Ejecta -- Comparison with Maser Maps



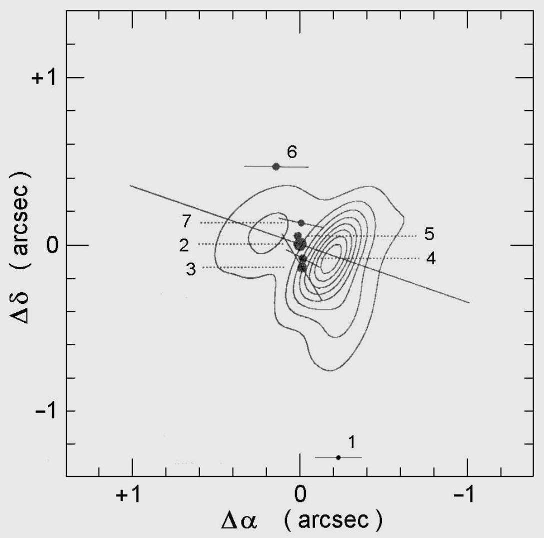
OH maser peaks
Bowers et al 1983



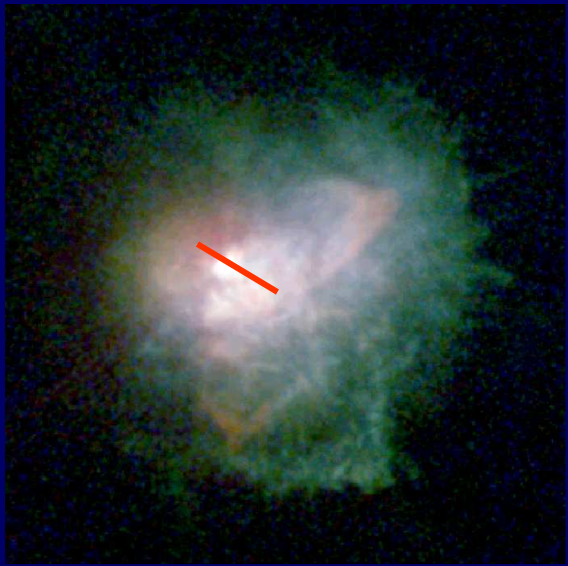


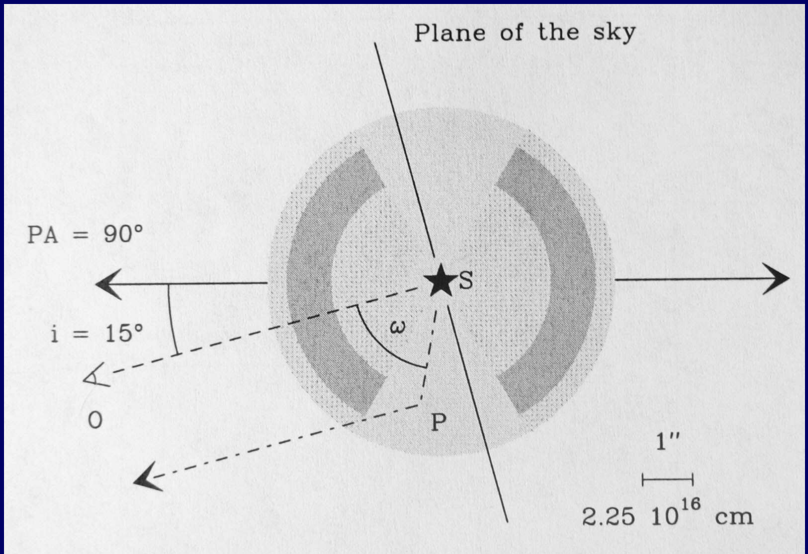
H2O masers
Richards et al 1998

Comparison with Maser maps



SiO emission appears bipolar but masers are N/S





Recent (Muller et al 2007) CO map is bipolar but with a very large opening angle

Masers and CO emission to do not present a consistent image of the geometry and do not align with the optical features.

Asymmetric Mass Loss Events and the Origin of the Discrete Ejecta

Images + Doppler 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

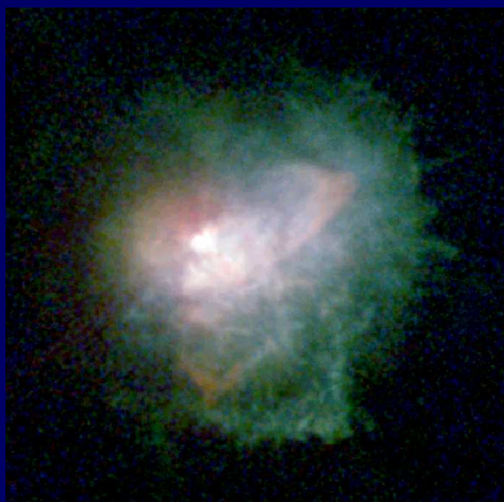
VY CMa -- circular polarization of H_2O (Vlemmings et al 2002, 2004),
-- circular polarization of SiO (Barvainis et al 1987, Kemball & Diamond (1997),
-- Zeeman splitting of OH (Szymczak & Cohen 1997, Masheder et al 1999)

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

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

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

Collaborators



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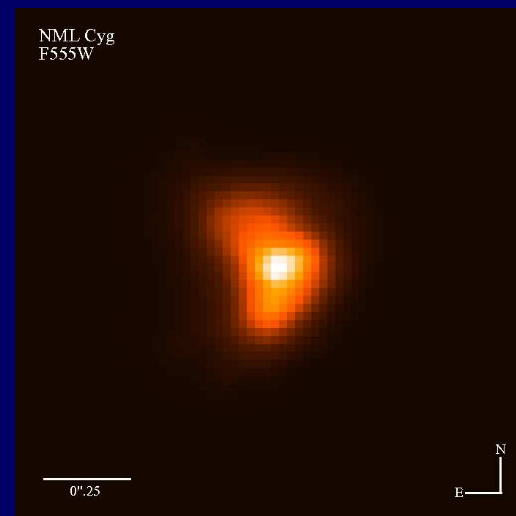

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