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:
- \( \mu \) Cep
- \( \rho \) 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
$L \sim 5 \times 10^5 \ L_{\text{sun}}$
High mass loss rate $3-6 \times 10^{-4}$
One of warmest maser sources
Spectroscopic variation late F $\rightarrow$ mid A

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

1” = 5300 AU
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 $6 \times 10^{-5}$
$L \sim 5 \times 10^5$ $L_{\text{sun}}$

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) showed this is the molecular photodissociation boundary
VY CMa -- the extreme red supergiant, powerful OH/IR source

Mass loss rate $4 \times 10^{-4}$
$L \sim 5 \times 10^5 \, L_{\text{sun}}$

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

Due to multiple, asymmetric ejection episodes possibly from large-scale convective regions on the star.
A strong velocity gradient from reflected absorption lines across the NW arc.

Expanding relative to star $\sim 50$ km/s

$\sim 500$ year ago
2D spectra of strong K I emission lines across the arcs

NW Arc

Arens 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 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 →

Arcts 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_{\text{sun}}) ejections

Large-scale convective activity

Magnetic Fields

VY CMa  -- circular polarization of H_{2}O (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
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