pPNe: Lobe-Shaping Models & HST Images

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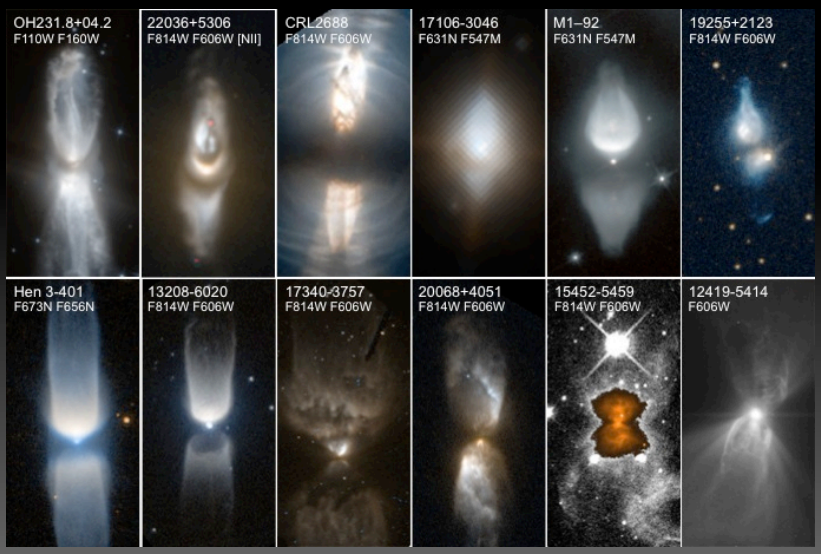
Extra special thanks!

Bruce Balick
U. Washington

ProtoPNe: Prototypes



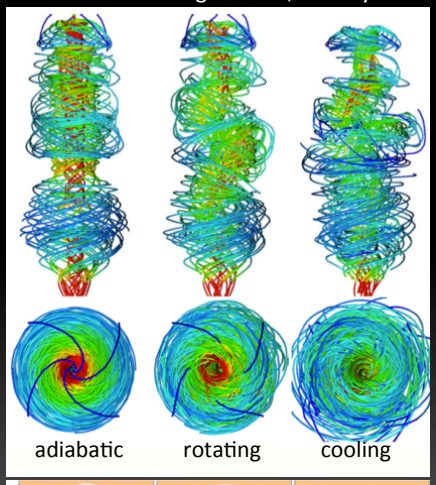
Detailed MHD Models of Wind Confinement and Flow Launching

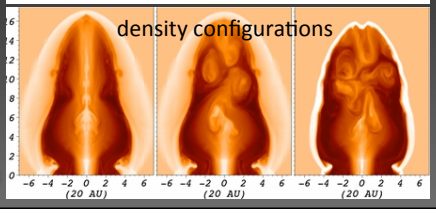
On the Structure and Stability of Magnetic Tower Jets

Huarte-Espinosa et al 2012ApJ...757...66H

Instabilities convert jets into dense eddies

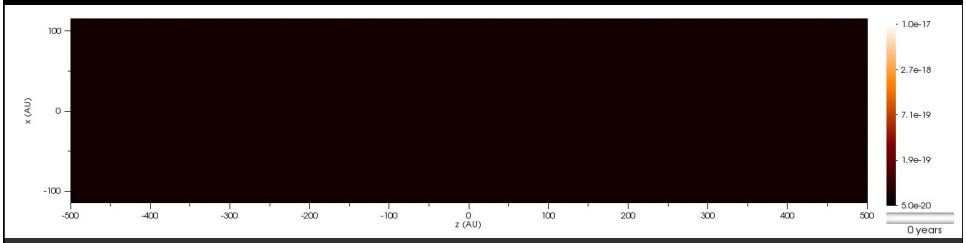
field configurations, t=118 y





MHD Launch Models (ctd.)

Highly collimated jets formed from isotropic winds into an (imposed) poloidal field



(animation)

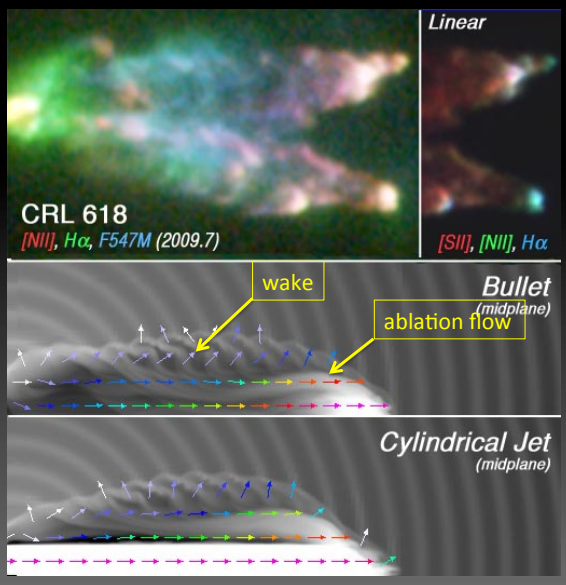
A. Ciardi,[1] T. Vinci,[2] J. Fuchs,[2] B. Albertazzi,[2] C. Riconda,[2] H. Pépin,[3] and O. Portugall[4]

This just in!

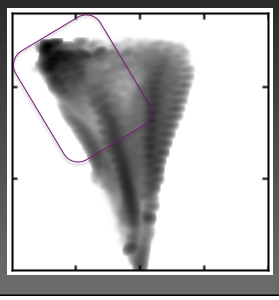
Lobe Paradigm 1: Bullets & Jets

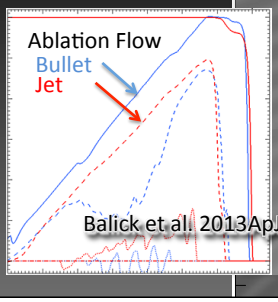
Axial flows: clumps and narrow jets. Produce bow shocks.
(Disks near the star are not important for shaping lobes.)

Bullets & Jets

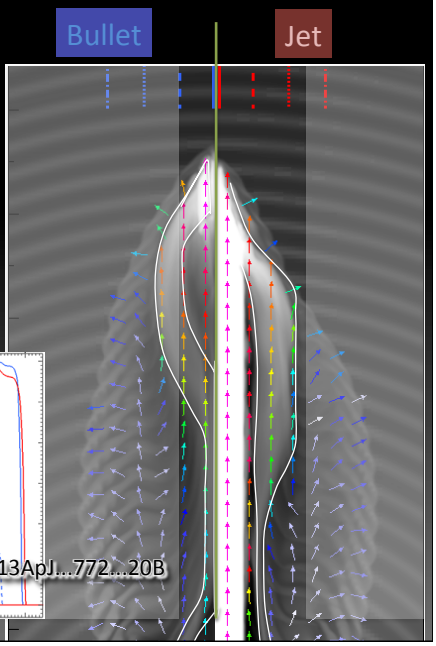


When "Hubble Flows" Aren't Really.

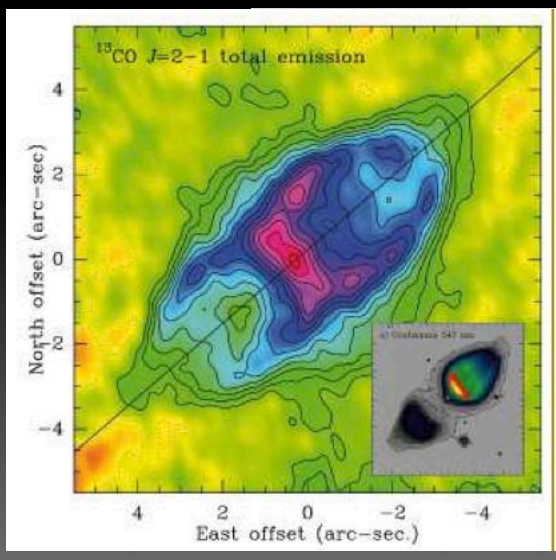


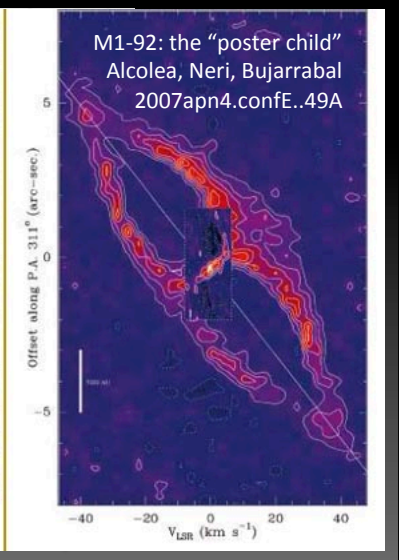


Balick et al. 2013ApJ...772...20B



Paradigm 2: Conical Winds





M1-92: the "poster child"
Alcolea, Neri, Bujarrabal
2007apn4.confE..49A

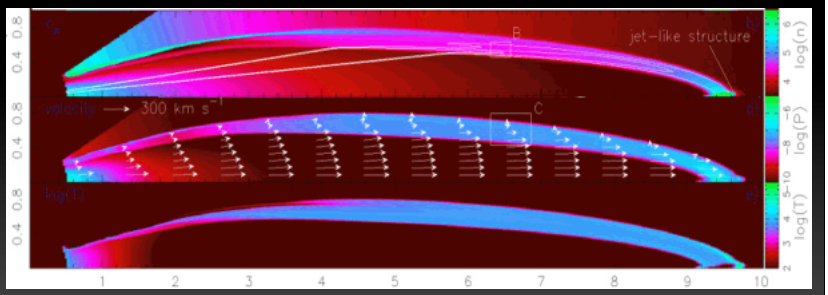
Paradigm 2: Conical Winds

The lobe interior is essentially swept out: empty, cold, monovelocity

Density

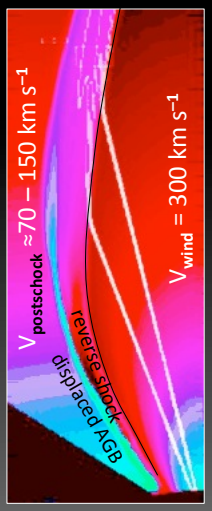
Streamlines & pressure

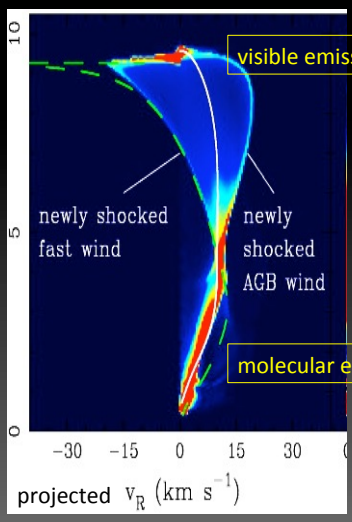
Temperature



Lee & Sahai, 2003 ApJ 586 319; 2D expanding grid

When "Hubble Flows" Aren't.

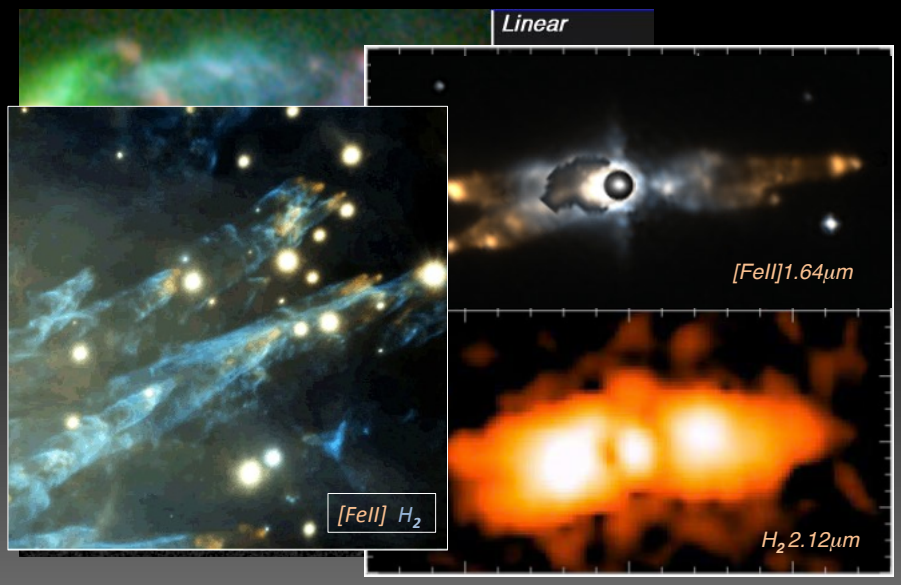




Note: shocks dissociate many molecules (H_2)

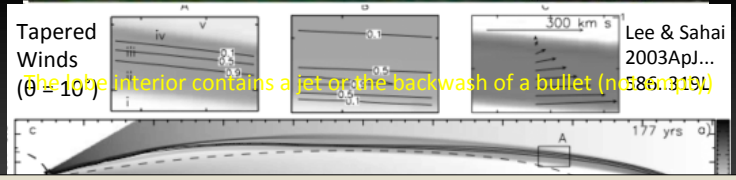
Lee & Sahai, 2003 ApJ 586 319; 2D, expanding grid

Case Studies of pPNe: CRL 618



Comparing HD Flow Paradigms

Tapered Winds ($\theta = 10°$)



Lee & Sahai 2003ApJ... 586..319L

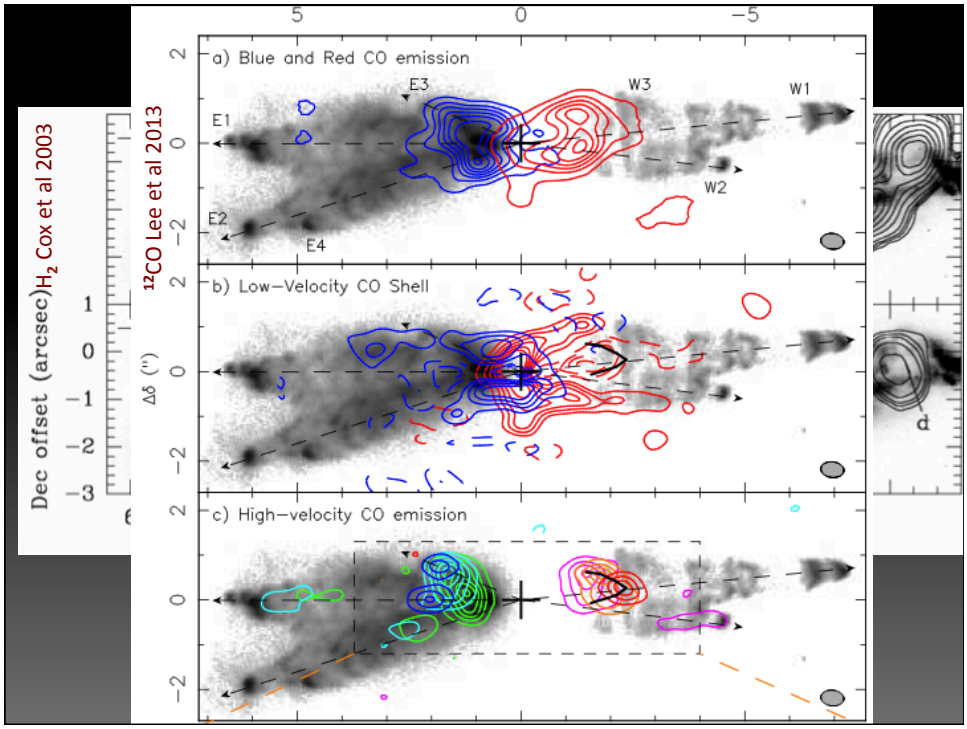
The lobe interior contains a jet or the backwash of a bullet (not shown)

Bottom Line: All paradigms work well for CRL618.

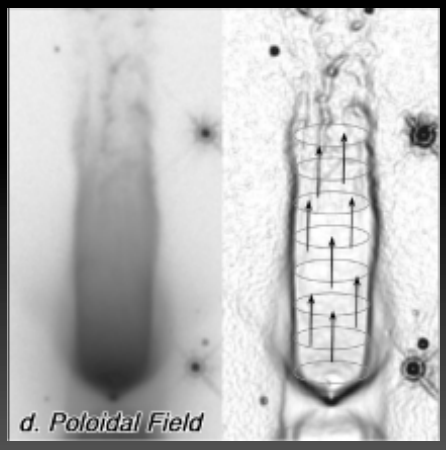
All predict a quasi-linear trend of Doppler shift and offset (for very different reasons).

Differences: Tapered flows require outflow mass (and emission) along the lobe perimeters.

Bullet/thin jet models place the emitting gas closer to the symmetry axis.



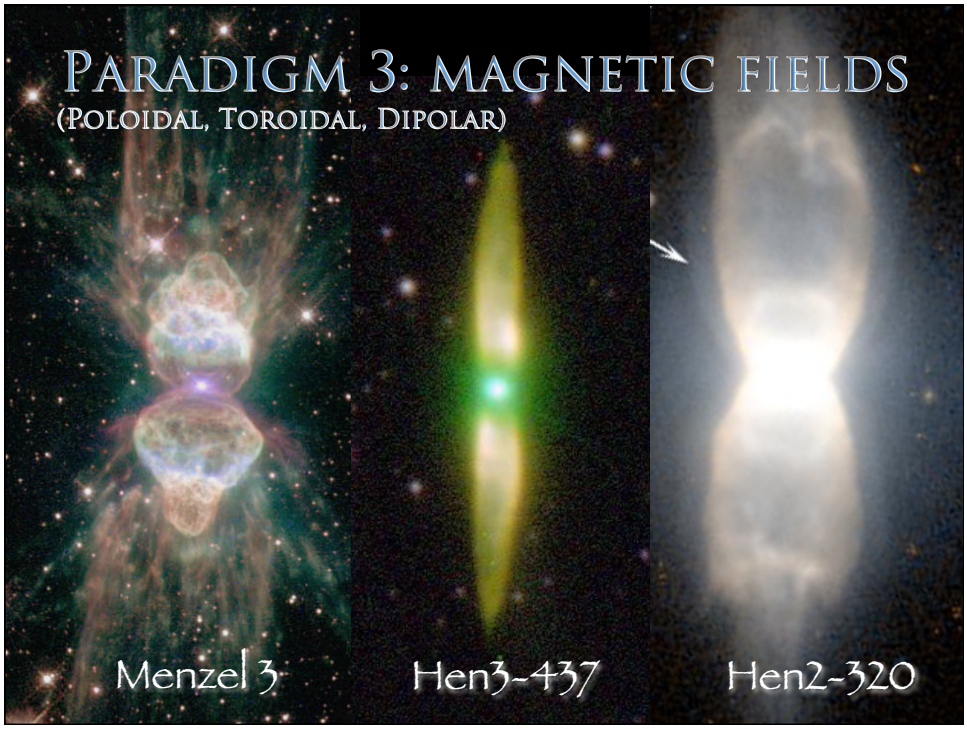
Paradigm 3: Magnetic shaping



Magnetic 'hoop stress': guide streamlines towards symmetry axis.
Does not produce narrow bow shocks unless a jet forms.

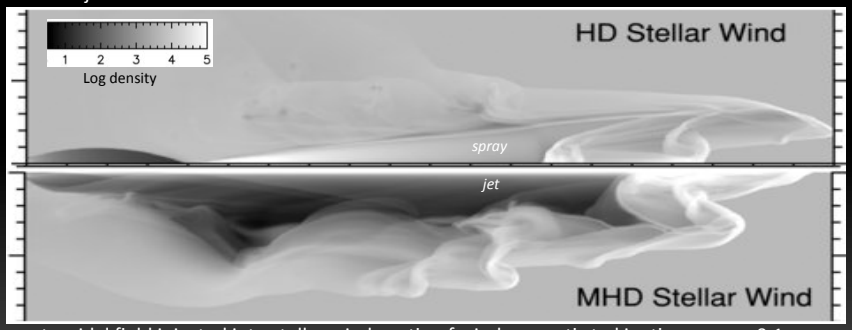
Paradigm 3: magnetic fields

(Poloidal, Toroidal, Dipolar)

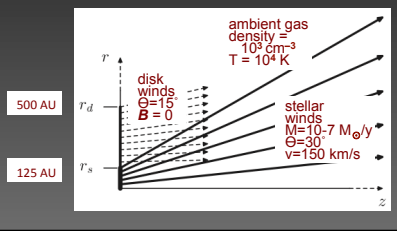


What fields do

no injected field

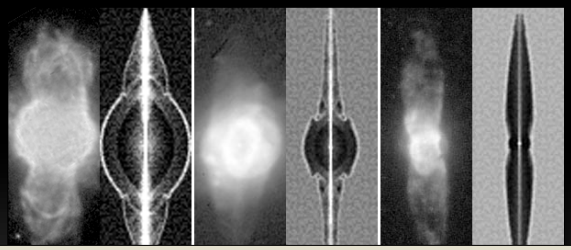


toroidal field injected into stellar winds, ratio of wind magnetic to kinetic energy = 0.1



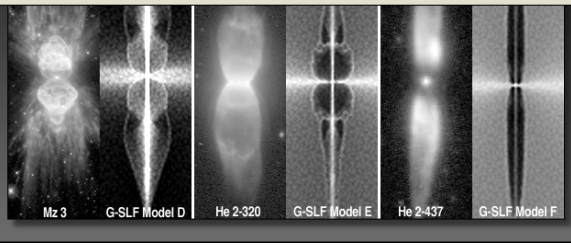
Dennis et al. 2009 ApJ, 707, 1485

Magnetized winds



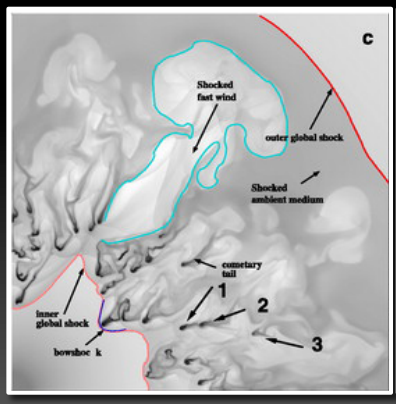
Radial winds sweep up toroidal surface fields, then form chimneys bounded by magnetic hoops. Lower panels presume dense external disks.

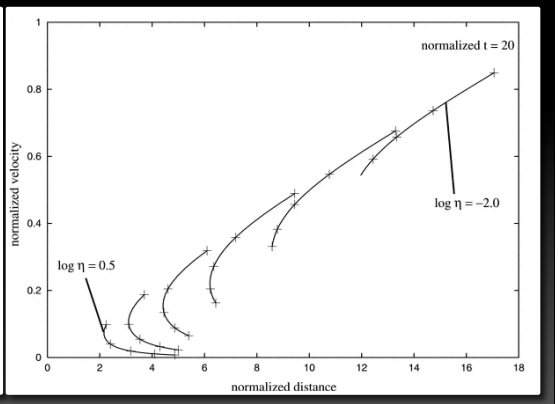
Bottom Line:
All toroidal models predict axial jets (possibly invisible) and elongated lobes.



Garcia-Segura, Lopez & Franco 2005 ApJ 618 91)

When "Hubble Flows" Aren't.

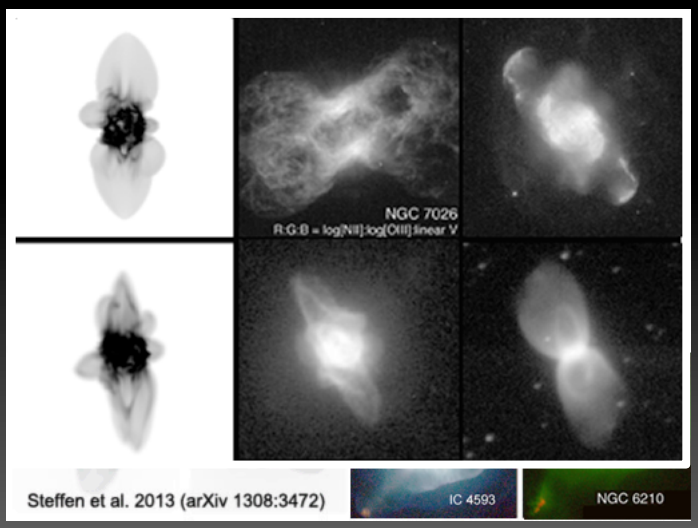




Merged ablation flows from multiple clumps.
This idea may apply very generally to nob-bipolar PNe

Steffen & López 2004ApJ...612..319S

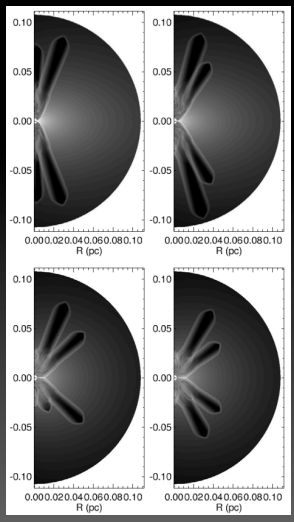
The "Porous Torus"



Left: simulations from W. Steffen et al. 2013, MNRAS (in press?)
Right: selected HST images of non-bipolar pPNe & PNe

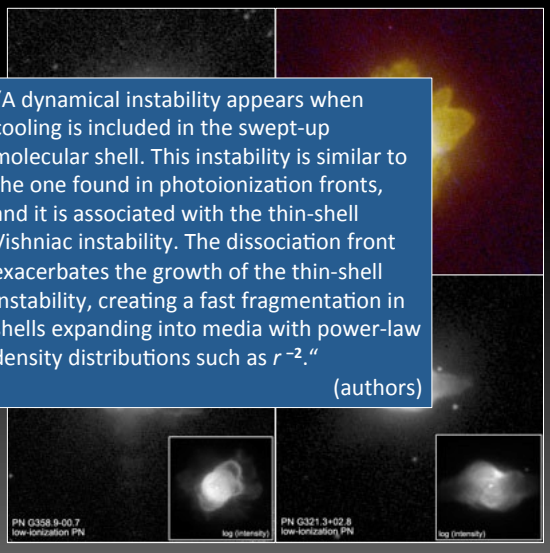
Forming Starfish

Garcia-Segura et al 2010 A&A 520 L5



Predicts blunt fingers but not necessarily in symmetric pairs

"A dynamical instability appears when cooling is included in the swept-up molecular shell. This instability is similar to the one found in photoionization fronts, and it is associated with the thin-shell Vishniac instability. The dissociation front exacerbates the growth of the thin-shell instability, creating a fast fragmentation in shells expanding into media with power-law density distributions such as r^{-2}."
(authors)



Binary Overflows & Winds

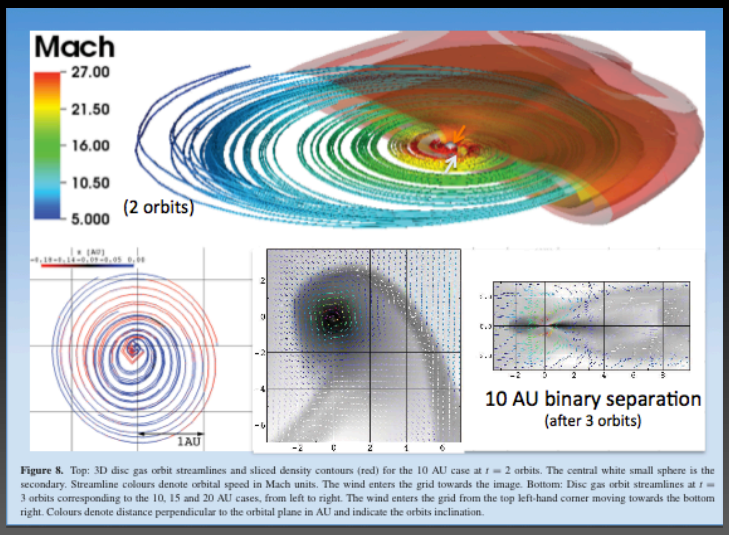
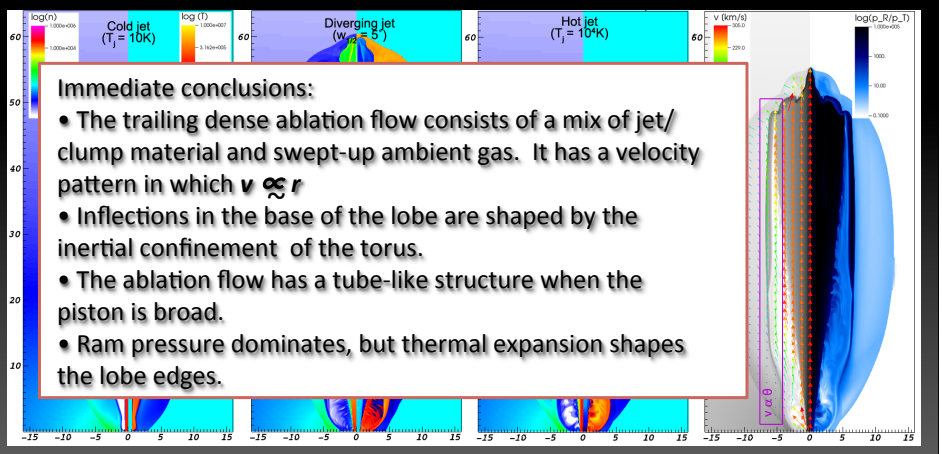


Figure 8. Top: 3D disc gas orbit streamlines and sliced density contours (red) for the 10 AU case at $t = 2$ orbits. The central white small sphere is the secondary. Streamline colours denote orbital speed in Mach units. The wind enters the grid towards the image. Bottom: Disc gas orbit streamlines at $t = 3$ orbits corresponding to the 10, 15 and 20 AU cases, from left to right. The wind enters the grid from the top left-hand corner moving towards the bottom right. Colours denote distance perpendicular to the orbital plane in AU and indicate the orbits inclination.

Huarte-Espinosa et al. 2013MNRAS.433..295H

Parameter Studies

Baseline: Jet r=500 pc, v=300 km/s, n=40,000 cm^{-3} , T = 10 K
Ambient=torous+AGB wind, T=10 K, n=400 cm^{-3}



Immediate conclusions:
- The trailing dense ablation flow consists of a mix of jet/ clump material and swept-up ambient gas. It has a velocity pattern in which $v \propto r$
- Inflections in the base of the lobe are shaped by the inertial confinement of the torus.
- The ablation flow has a tube-like structure when the piston is broad.
- Ram pressure dominates, but thermal expansion shapes the lobe edges.

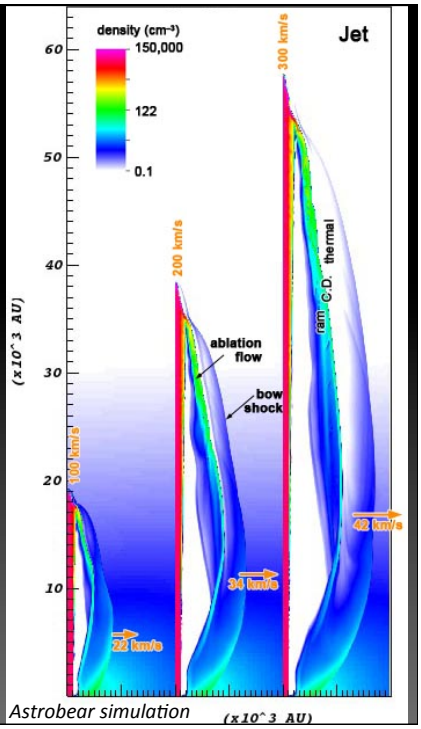
Astrobear simulation

K. Brooks, M. Huarte-Espinosa, B. Balick, A. Frank, R. Murugan, in progress

Astrobear Hydro models of three thin (cylindrical) jets at 100, 200, 300 km/sec.

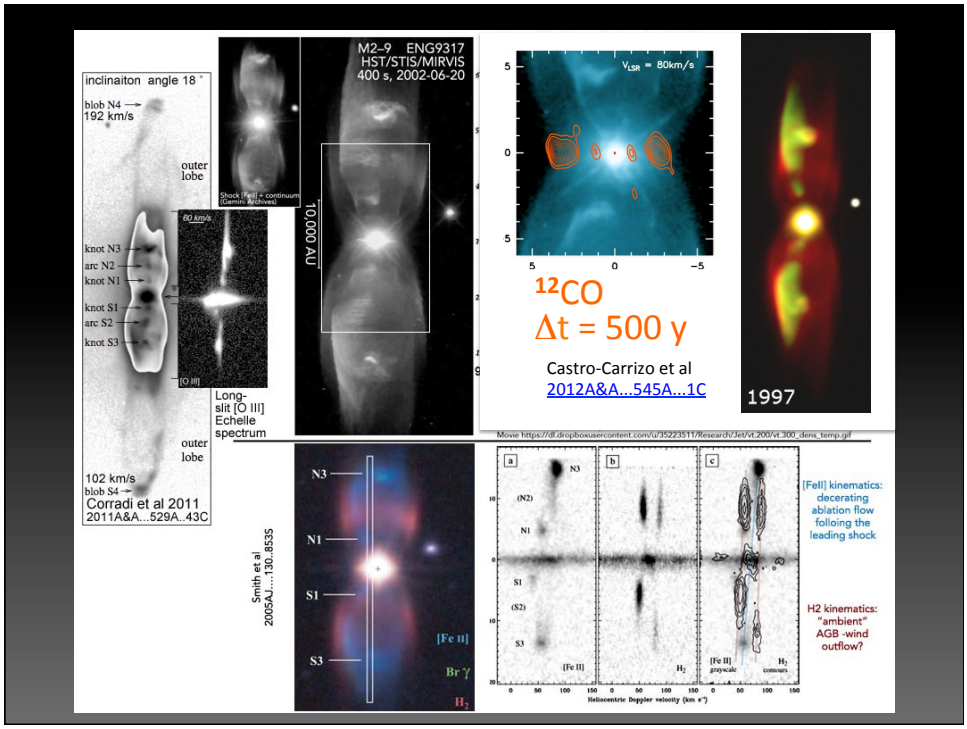
Jet Radius: 500 AU
Jet Density: 40,000 cm^{-3}
Jet Temp: 10 K
Ambient density:{ 400 $[(r^{-2})$ + torus] + 1} cm^{-3}

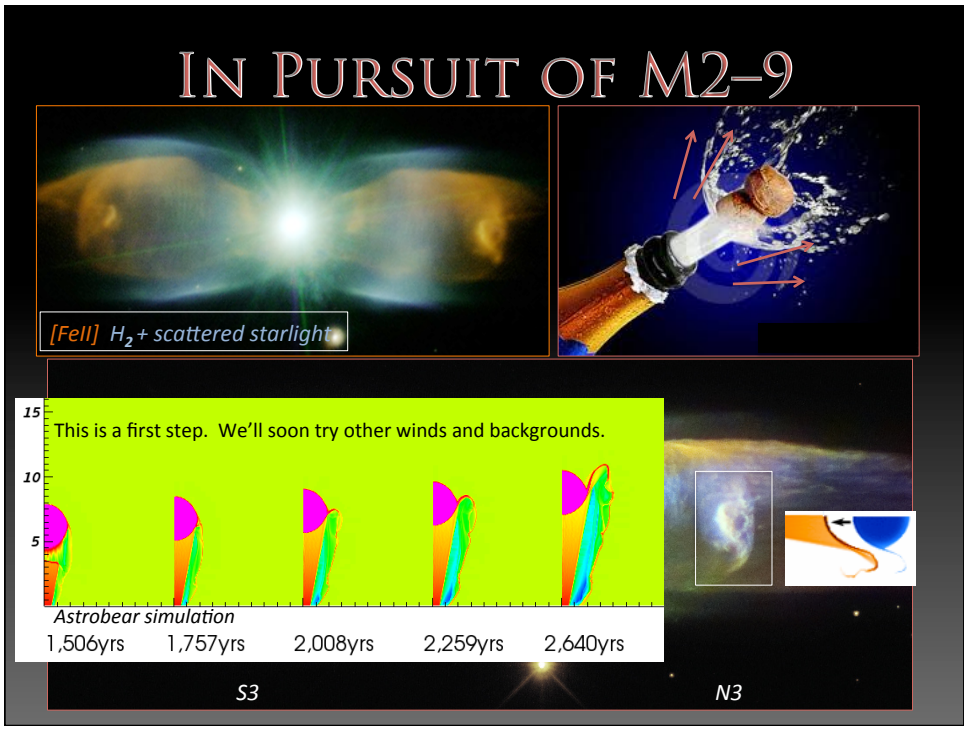
Immediate conclusions:
- Starlight scatters primarily from compressed dust in the ablation flow and the displaced ambient gas at the base.
- The C.D. (though which there are no flows) lies at the outer edge of the ablation flow.
- Lateral expansion is the largely result of the thermal expansion of a hot sheath created by the hot gas trapped between the ablation flow and the outer bow shock.



Astrobear simulation

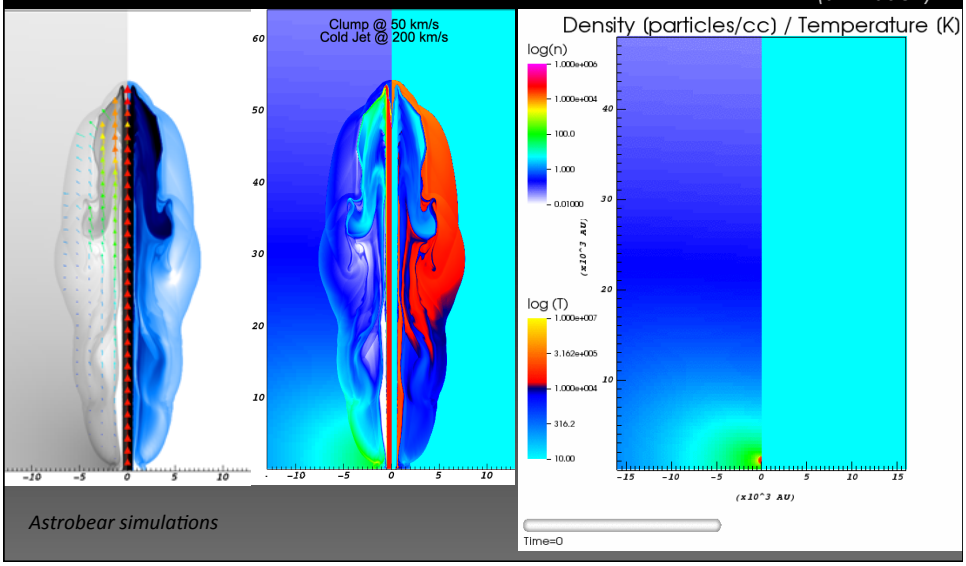
Looking Forwards


inclinaiton angle 18 °
blob N4
192 km/s
outer lobe
knot N3
arc N2
knot N1
knot S1
arc S2
knot S3
[O III]
Long-slit [O III] Echelle spectrum
outer lobe
102 km/s
blob S4
Corradi et al 2011
2011A&A...529A..43C
M2–9 ENG9317
HST/STIS/MIRVIS
400 s, 2002-06-20
10,000 AU
Shock [FeII] + continuum (Gemini Archives)
Smith et al 2005AJ....130..8535
N3
N1
S1
S3
[Fe II]
Br γ
H2
^{12}CO
Δt = 500 y
Castro-Carrizo et al
2012A&A...545A...1C
1997
[FeII] kinematics: decerating ablation flow folloing the leading shock
H2 kinematics: "ambient" AGB -wind outflow?
Heliocentric Doppler velocity (km s⁻¹)


In Pursuit of M2–9
[FeII] H2 + scattered starlight
This is a first step. We'll soon try other winds and backgrounds.
Astrobear simulation
1,506yrs
1,757yrs
2,008yrs
2,259yrs
2,640yrs
S3
N3

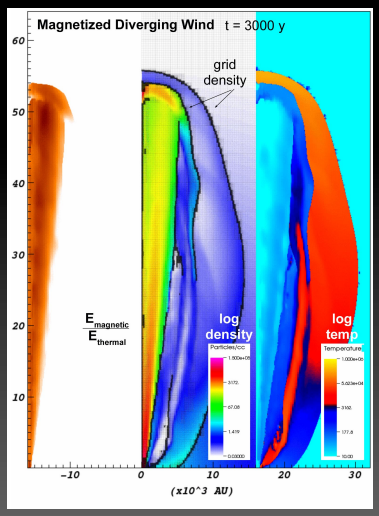
Coming: Detailed HD

(animation)



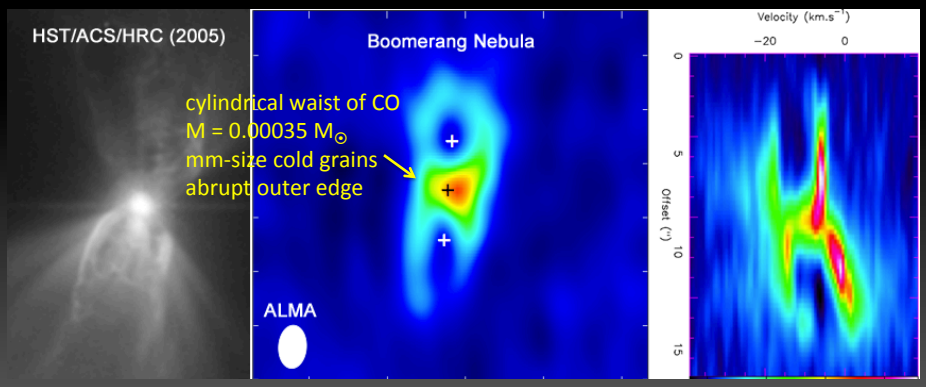
Astrobear simulations

Coming: Detailed MHD



"Astrobear"; Huarte-Espinosa & Frank, in development

Coming: Molecular Imaging



Sahai et al., Xarchiv 1308.4360 (August 2013)

Coming: Mid, FAR-IR Imaging & Spectroscopy