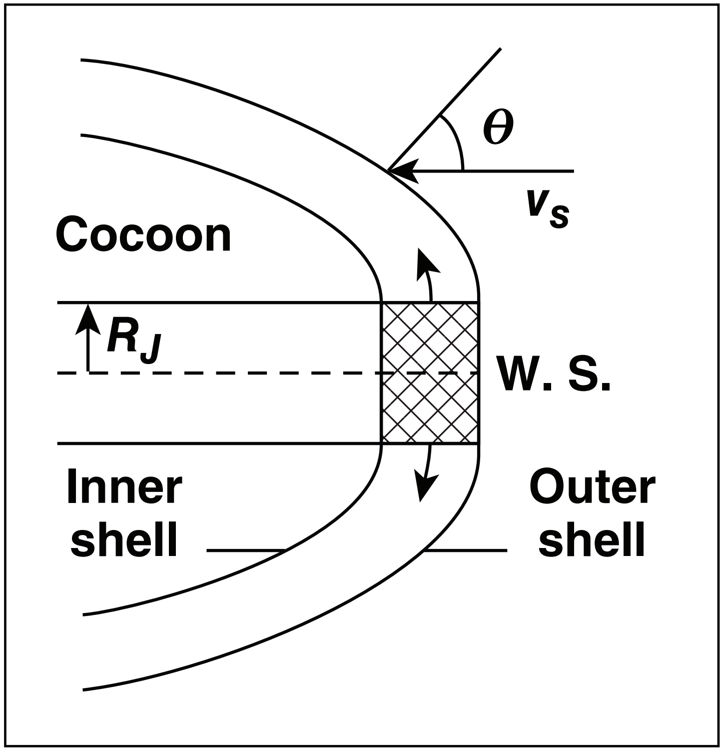
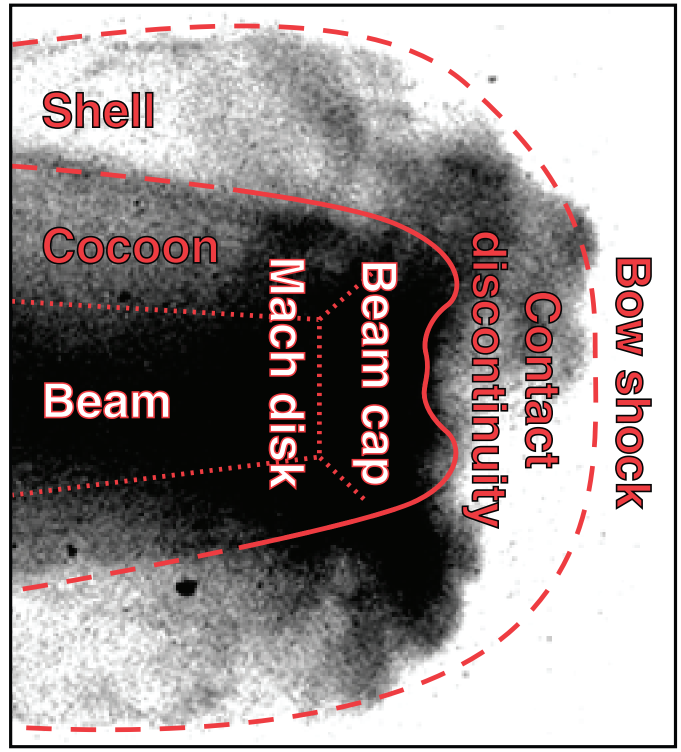
OMEGA Jets Possess Features Predicted By Astrophysical Models



Energy-driven model



Experimental radiograph

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Summary

OMEGA experiments study early-time jet evolution relevant to astrophysical systems

- Experimental jet features are compared to energy-driven and momentum-driven astrophysical models.
  - the bow-shock shape is constant in time, as predicted by an energy-driven astronomical model
  - jet shells are self-similar out to a length of 12-jet radii

Collaborators

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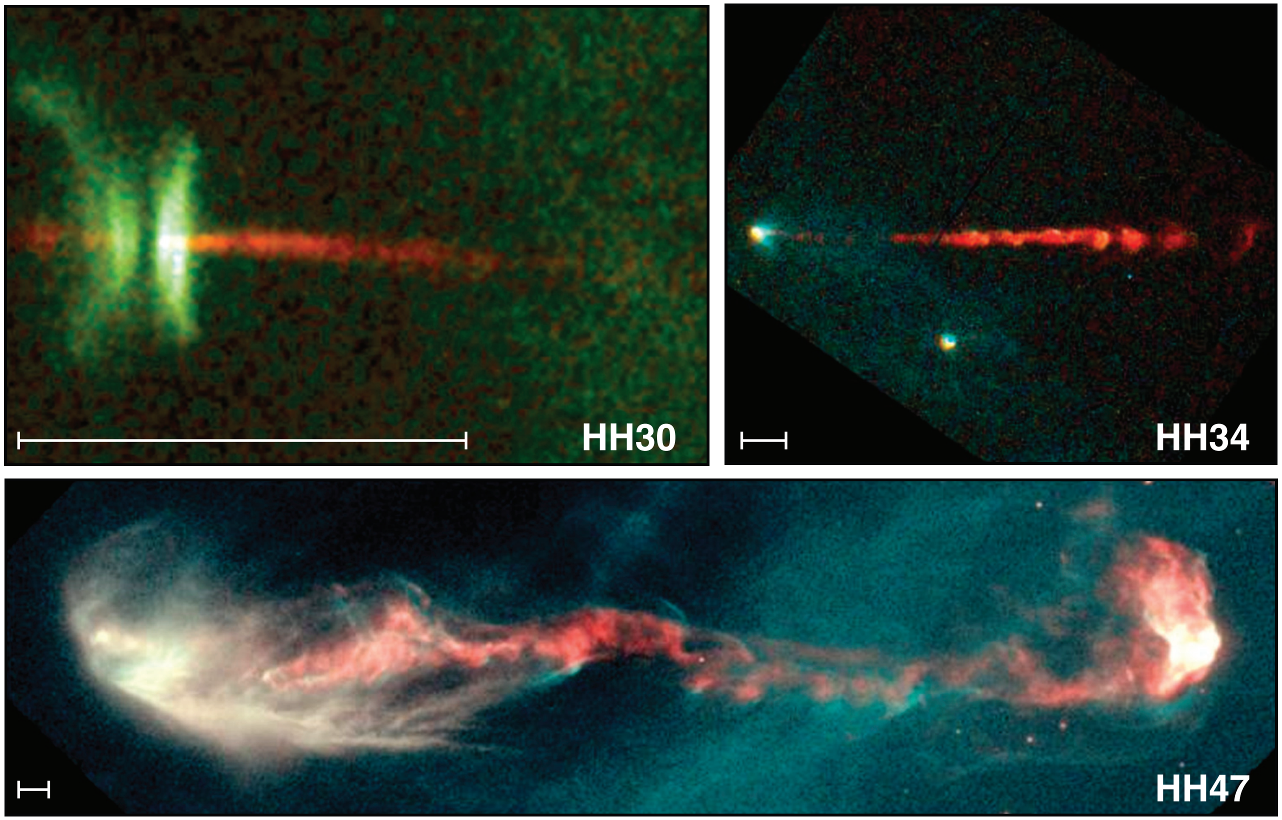
Motivation: Jets are ubiquitous in astrophysics



Jets from young stars

HST · WFPC2

PRC95-24a · ST ScI OPO · June 6, 1995
C. Burrows (ST ScI), J. Hester (AZ State U.), J. Morse (ST ScI), NASA

Observation limitations:

- Disk/dust obscuration near source
- Jets visible only when they are many jet-radii long
- Collimation even when jet turns

OMEGA jets are viewed early in time, within a few jet radii of the source.

E15241

OMEGA jet is formed by unloading material off a mid-Z (Al or Ti) plug embedded in a Tungsten washer

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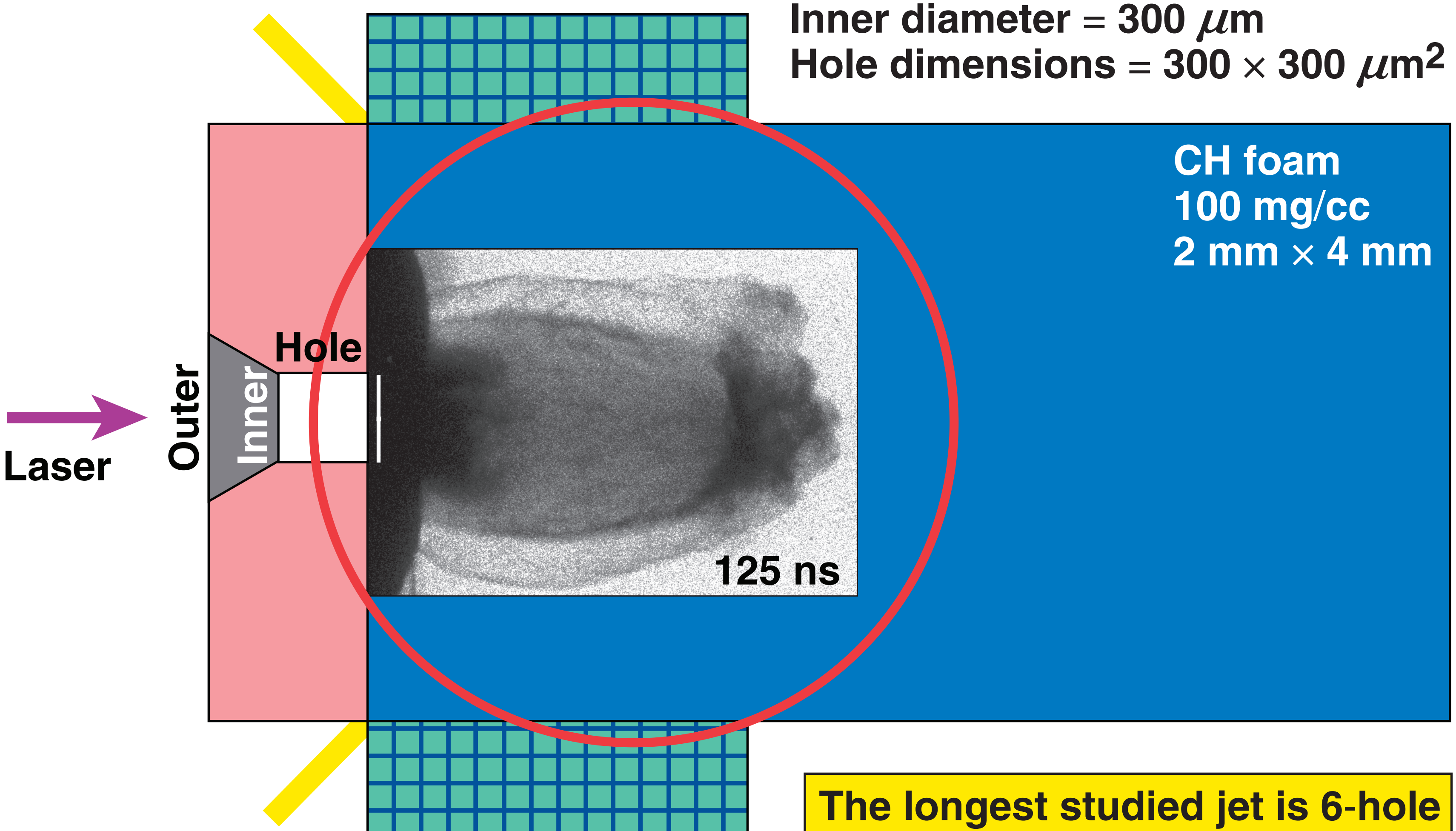
Outer diameter = 600 μm
Inner diameter = 300 μm
Hole dimensions = 300 × 300 μm^2



The longest studied jet is 6-hole diameters (12-jet radii) long.

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Dimensionless parameters place OMEGA jets in the stellar regime

Dimensionless Parameters	OMEGA Experiments	Young Stellar Objects	Planetary Nebulae
Jet density	10^{23}/cc	10^{8}/cc	10^{4}/cc
Ambient density	10^{21}/cc	10^{7}/cc	10^{1}/cc
Density ratio	~100	~10	~1000
Jet velocity (km/s)	12	10 to 100	~1000
Sound speed	3	100 to 1000	~10
Mach number	4	10 to 20	40 to 60

- Astrophysical ambient media typically have density profiles dependent on angle and distance from the source.
- The OMEGA experiments evolve in a homogeneous medium

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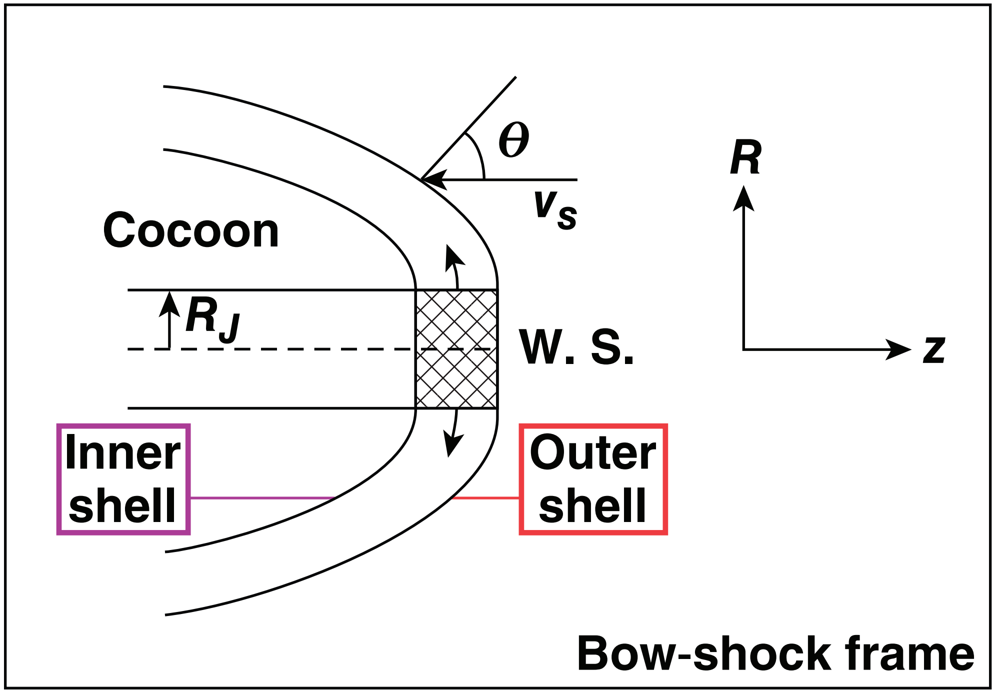
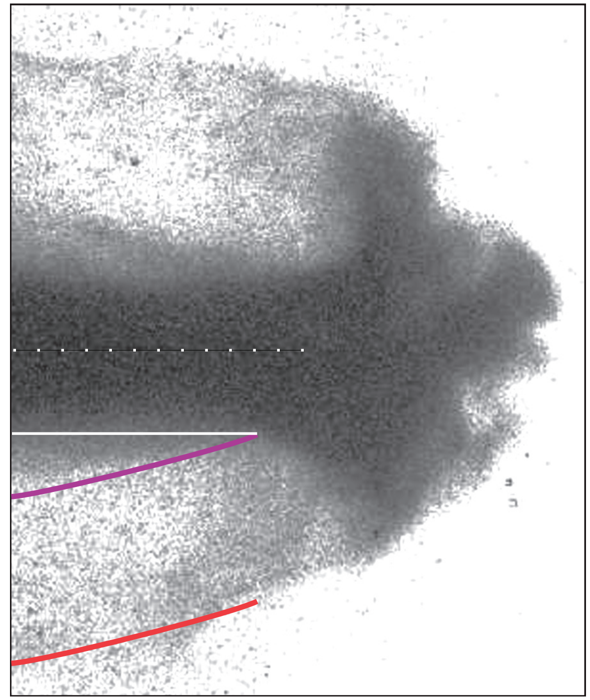
An energy-driven jet model* predicts forward shell shape





- The model solution depends only upon jet speed, radius, and jet and ambient density.
- Experimental radiograph showing beam, inner shell, and outer shell.

*Ostriker *et al.*, Astrophys. J. 557, 443 (2001).

The energy-driven jet model predicts a simple shell shape

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Shell shape: $y = -\left(V_s / \beta C_s\right)\left[\left(R/R_{\text{jet}}\right)^3 - 3\left(R/R_{\text{jet}}\right) + 2\right] R_{\text{jet}}$

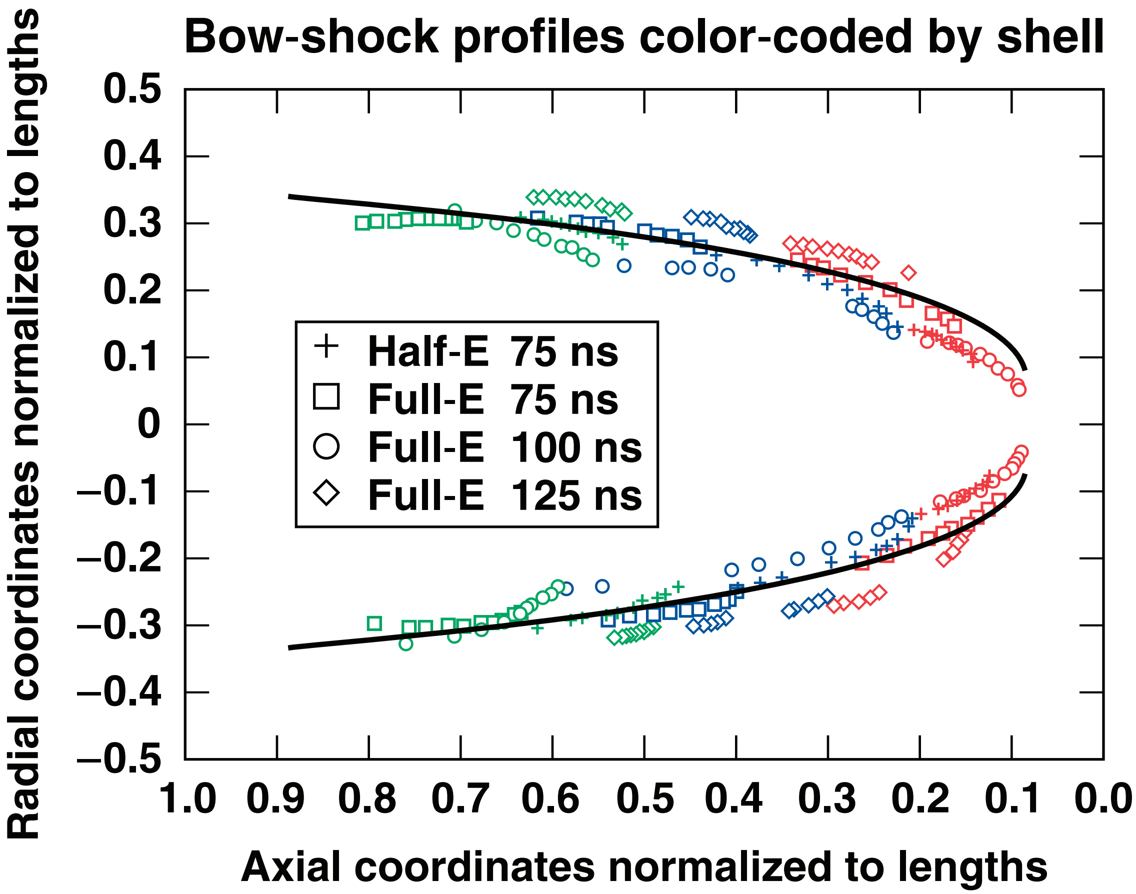
- **β is the only free parameter in the problem. Cooling from the working surface reduces the thermal sound speed by β, which increases the effective Mach number, equivalent to the radial-to-axial momentum ratio.**

$$V_z = \left(W/R_{\text{jet}}\right)^2 V_s, \quad V_R = \left(W/R_{\text{jet}}\right)^2 \beta C_s$$

- **The width-to-length ratio is a function of age and these variables.**

$$\text{Width/length} \sim \left(R_{\text{jet}}/t\right)^{2/3} \left(\beta C_s\right)^{1/3} / V_s$$

An energy-driven astrophysical model is fit to experimental bow-shock profiles



Both radial and axial bow-shock-profile coordinates were normalized to jet length to remove the self-similarity indicative of a momentum-driven jet.

As predicted by the energy-driven astrophysical model, experimental bow-shock shape is constant in time.

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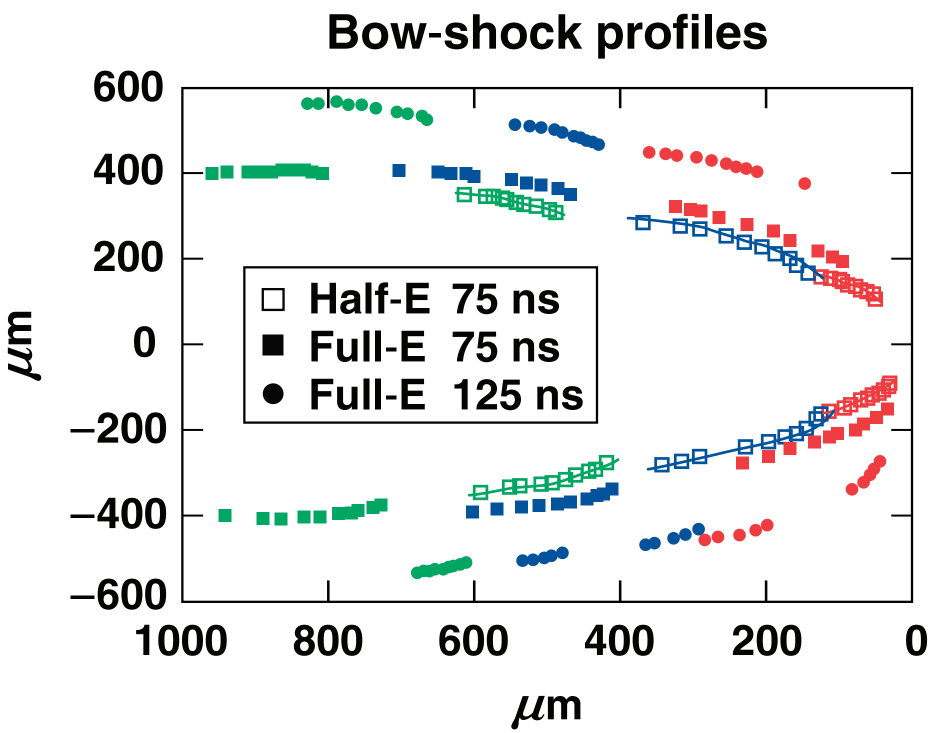
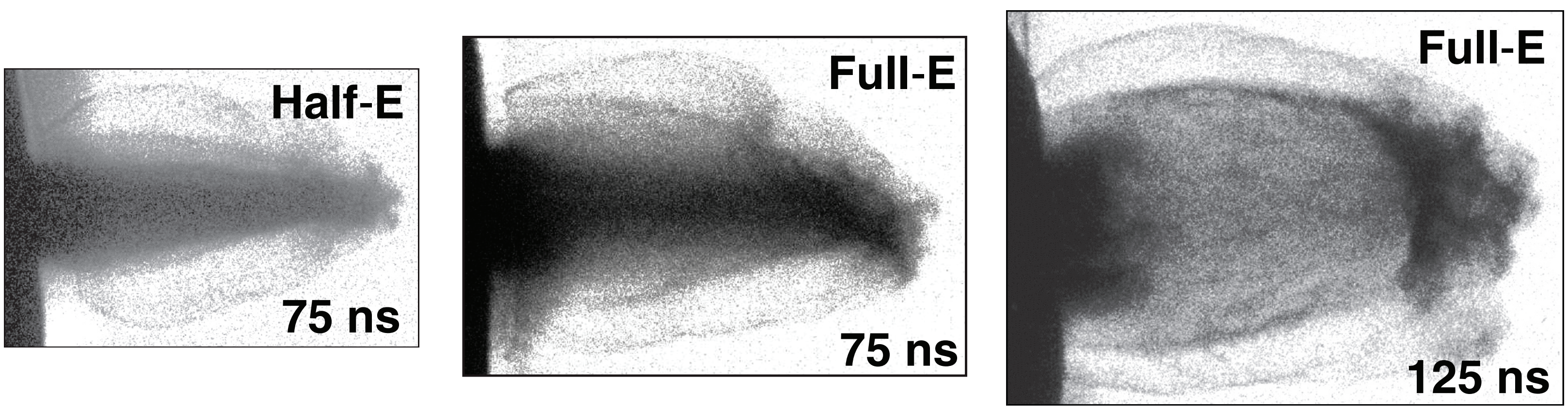
Self-similar behavior is typical of a momentum-driven jet



- Experimental jets narrow at the base.
- Half- and full-energy jets at 75 ns have same w/l ratio.
- 125-ns jet is wider than the 75-ns jet.



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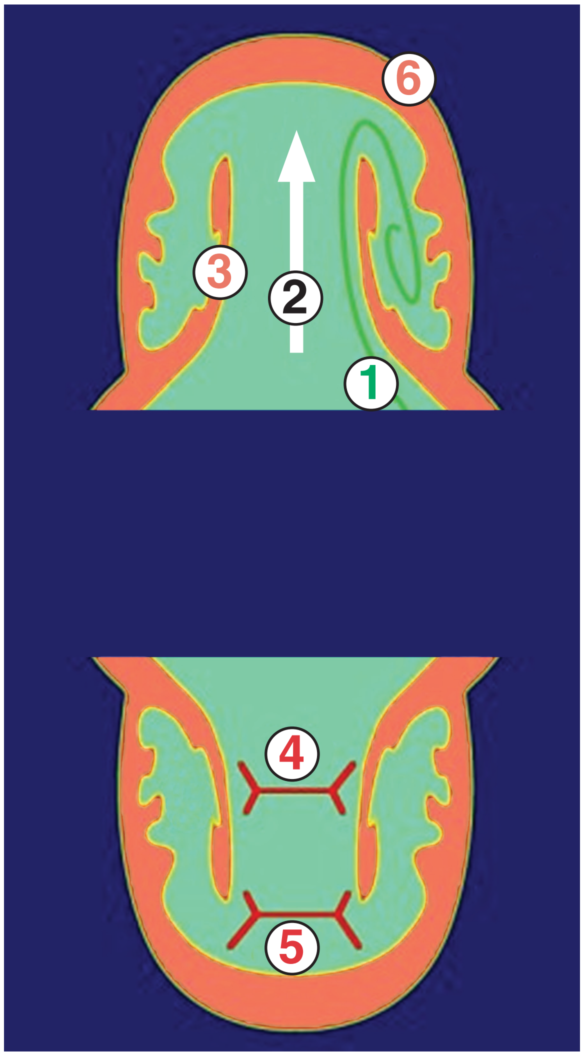
Planetary nebulae may be energy- or momentum-driven



- Streamline (1) showing flow through the beam (2) back into the cocoon (3)
- Multiple working surfaces (4) and (5)
- Thick shell (6) with smooth inner and outer surfaces
- Icke predicts that high-mass stars produce PNe that cannot cool quickly, so they are "energy-driven." Lighter stars produce highly-compressible "momentum-driven" PNe.

OMEGA jets behave like an intermediate case, implying moderate heat loss (by conduction).

Icke, Europhysics News 34, No. 1 (2003).

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