Percolator model for multipolar planetary nebulae

(The EMGIW model)

A wind-shell interaction model for multipolar planetary nebulae

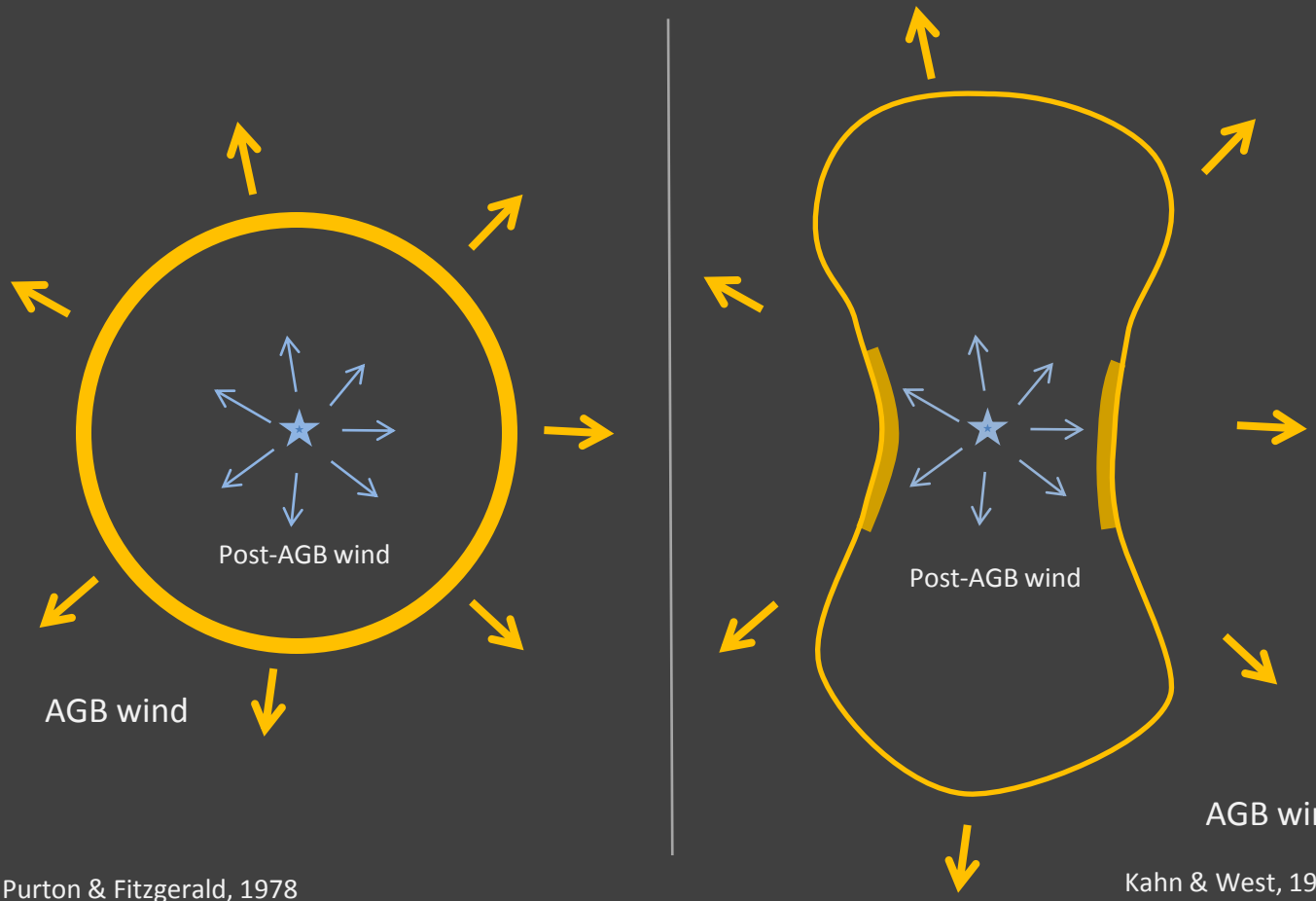
Wolfgang Steffen

IA-UNAM, Ensenada

W. Steffen, N. Koning, A. Esquivel, G. García-Segura,
Ma. T. García-Díaz, J.A. López, M. Magnor, 2013
2013MNRAS.436..470S

A long time ago:

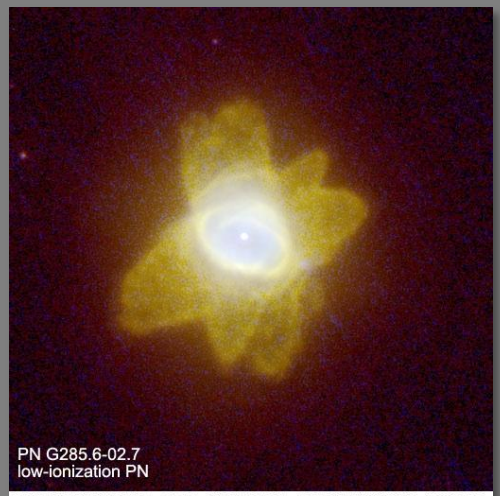
(Generalized) Interacting Winds Model



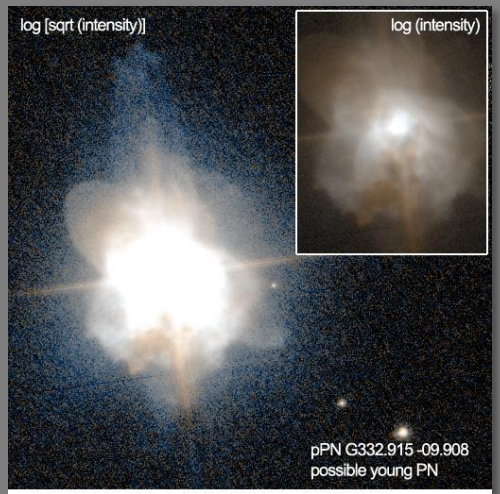
Kwok, Purton & Fitzgerald, 1978

Kahn & West, 1985

But then Hubble said, “Let there be…”: Multipolar PPNe

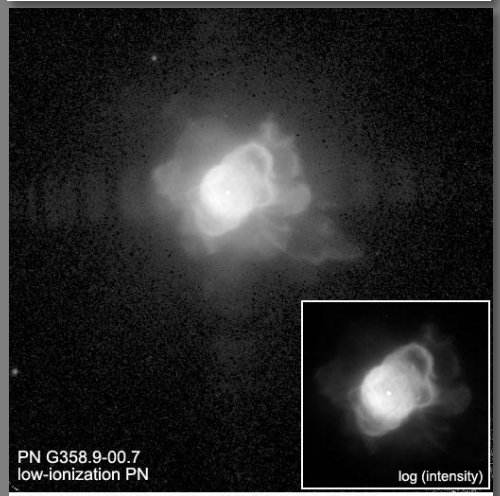


IRAS 10214-6017 [Hen 2-47, PN SaSt 2-5, 2MASS J10230914-6032422]
18 05 25.80 -28 22 04.2 (2000) FOV = 23.3" R:G:B = F658N:"F656N:F502N
WFPC2/PC Credit: PI: NOLL GO11090, NASA/ESA/STScI, Hubble Archives

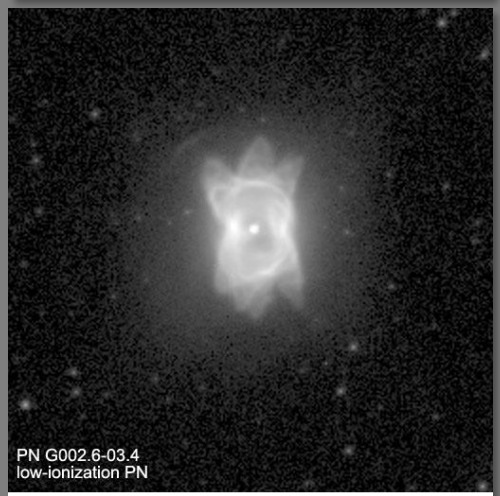


IRAS 17047-5650 [Hen 3-1333, PK 332-09 1, PN G332.9-09.9]
17 09 00.87 -56 54 48.0 (2000), FOV=12.8", R:G:B = F435W:comb:F606W
ACS/HRC, credit PI:SAHAI GO9463 NASA/ESA/STScI, Hubble Archives

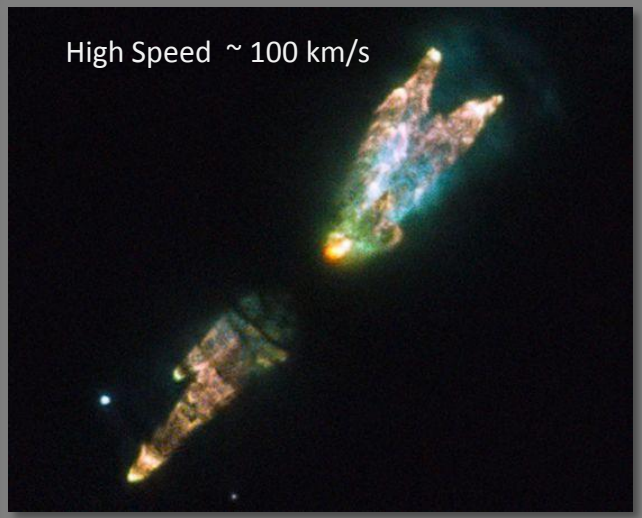
Egg Nebula



IRAS 17427-3010 [Hen 2-277, PN M 1-26, PN SaSt 2-17]
17 45 57.65 -30 12 00.6 (2000) FOV = 23.3" filter = F656N
WFPC2/PC Credit: PI: SAHAI GO6563, NASA/ESA/STScI, Hubble Archives



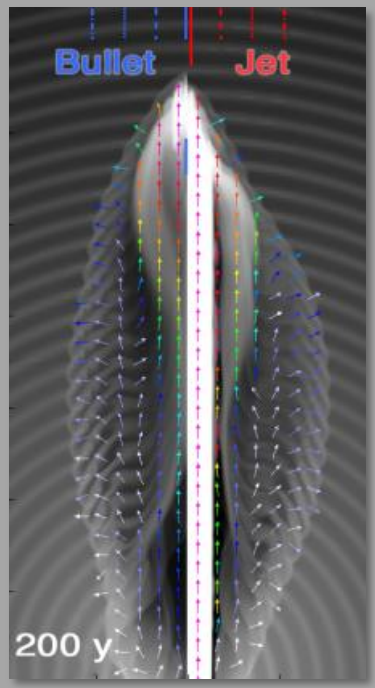
IRAS 18022-2822 [Hen 2-339, PN M 1-37, 2MASS J18052581-2822043]
18 05 25.80 -28 22 04.2 (2000) FOV = 11.6" (North not up) filter = F656N
WFPC2/PC Credit: PI: SAHAI GO6563, NASA/ESA/STScI, Hubble Archives



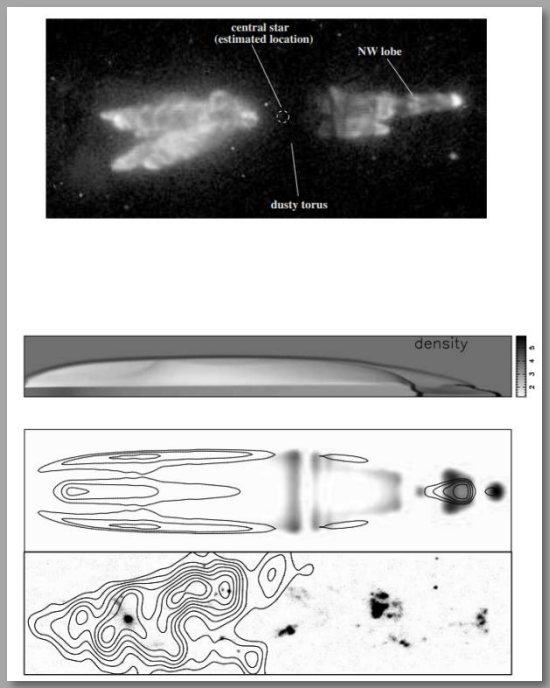
CRL 618

HST, NASA

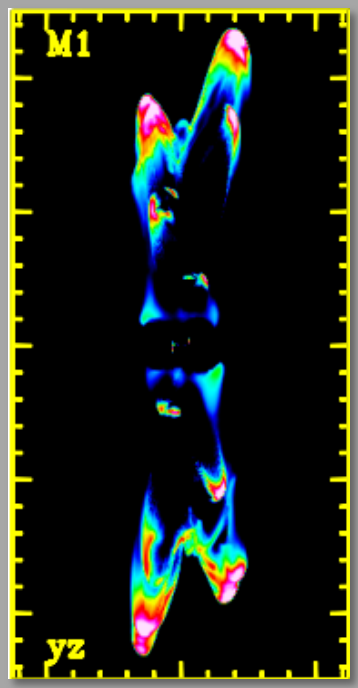
The usual suspects:
Jets from “Active Pn Nuclei” (APN jets)



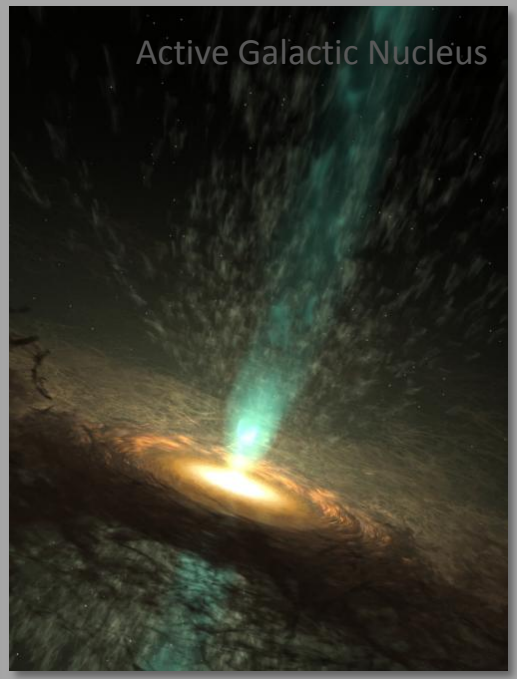
Balick et al., 2013



Lee & Sahai, 2004



Velázquez et al., 2011



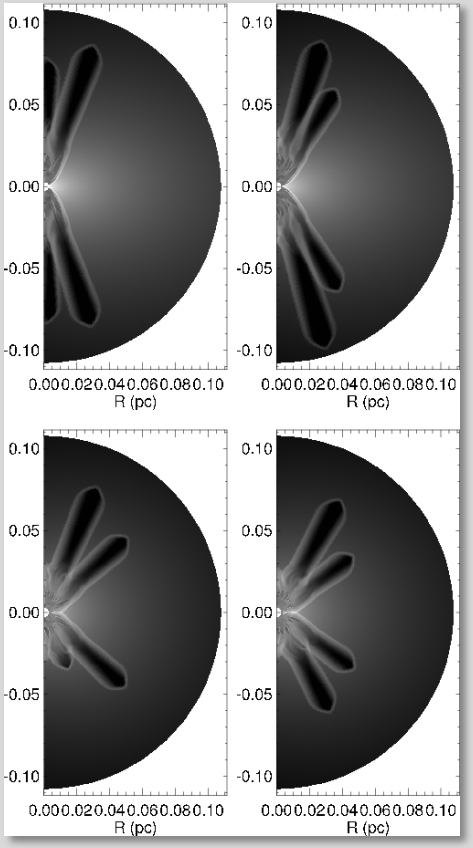
W.Steffen

If it's not a jet, the villain must be some kind of:

instability…

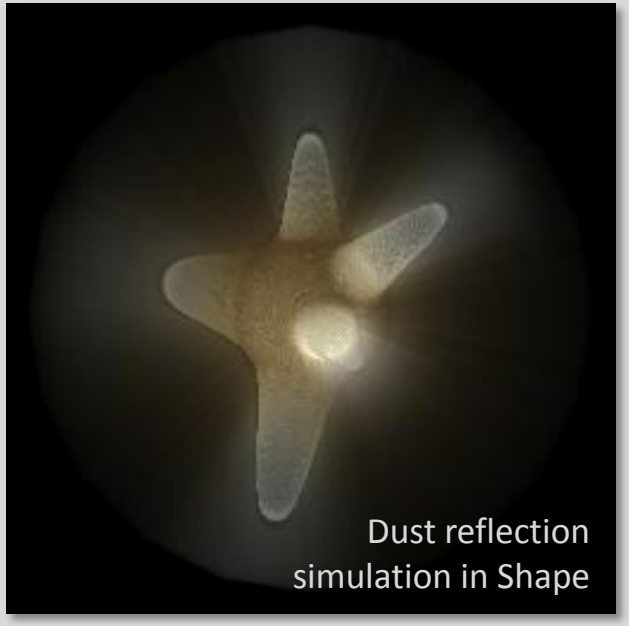
Instabilities in **photo-dissociation regions**

Low Speed < 10 km/s



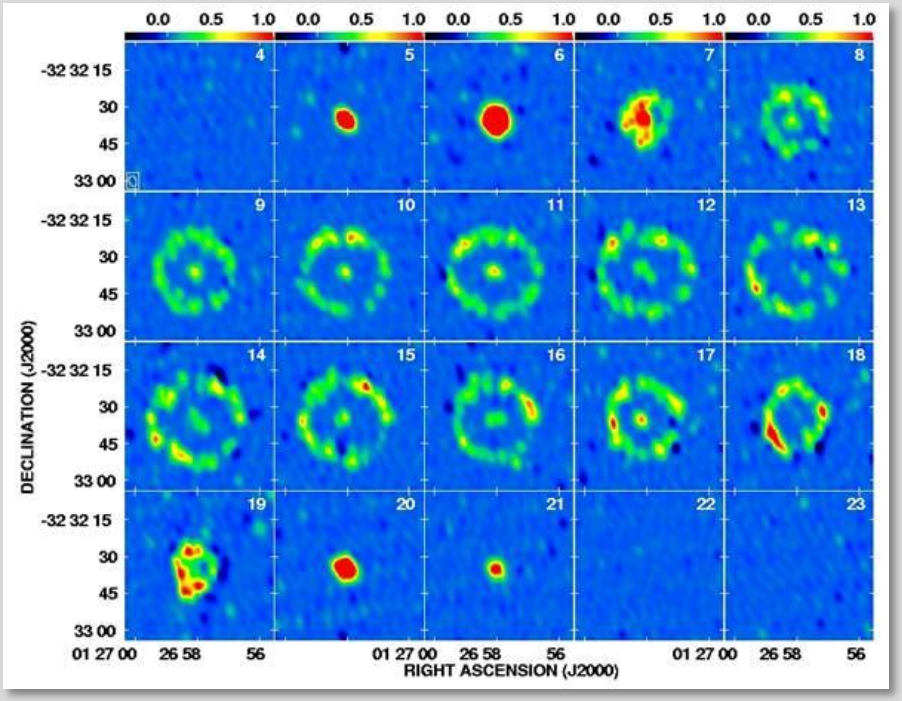
García-Segura, 2010

…and "illumination" (says: Sun)

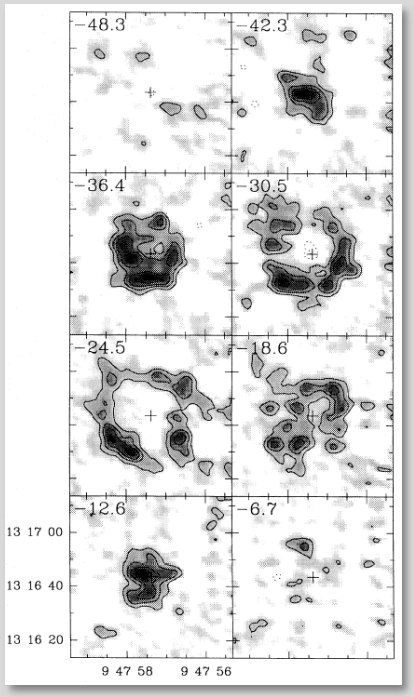


Consider this:

Innocent looking shells



Channel maps: SMA observation of CO,2-1 in carbon star R Scl.

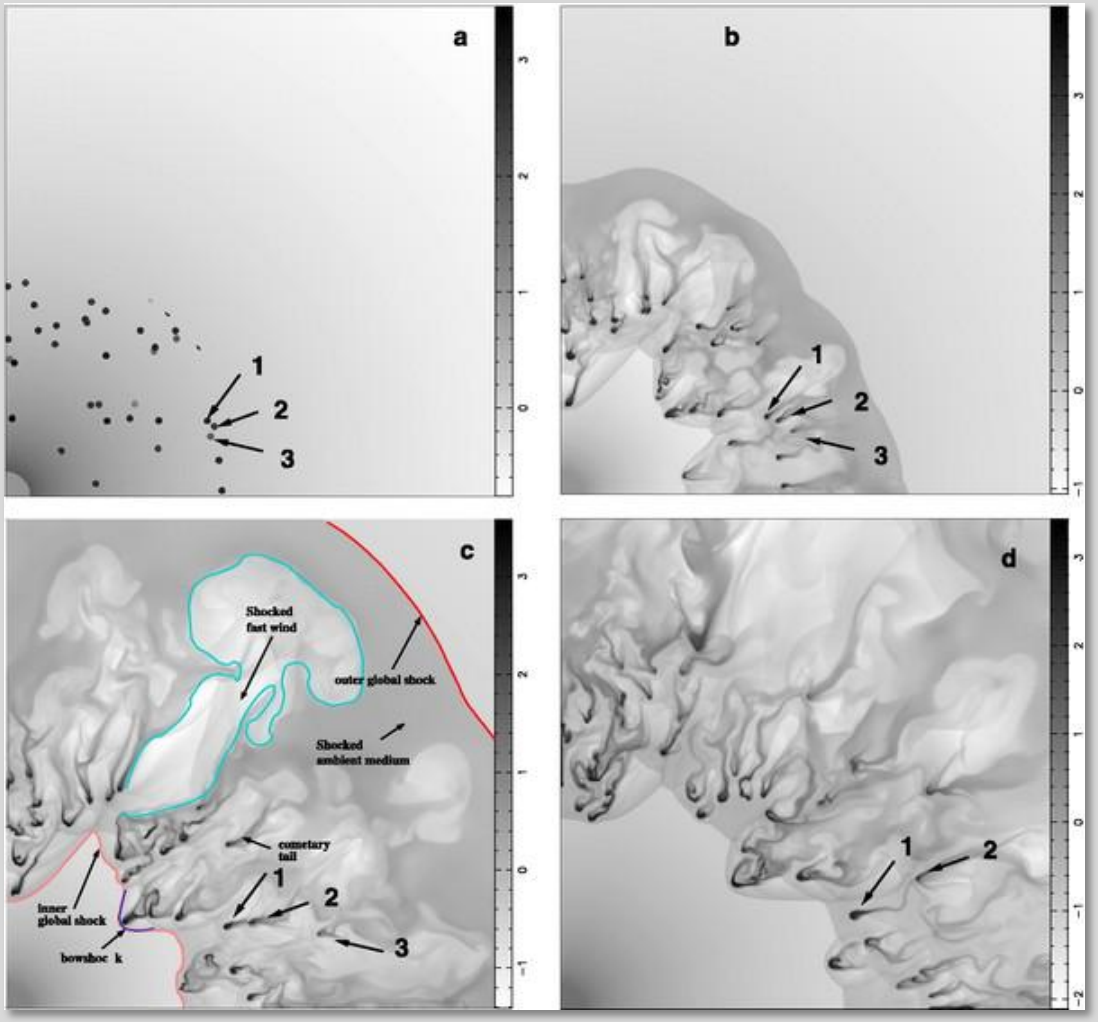


irc1065

See also ALMA maps by Sofia Ramstedt shown last Tuesday.

http://www1.ynao.ac.cn/~jinhuahe/

And this:
Percolating winds



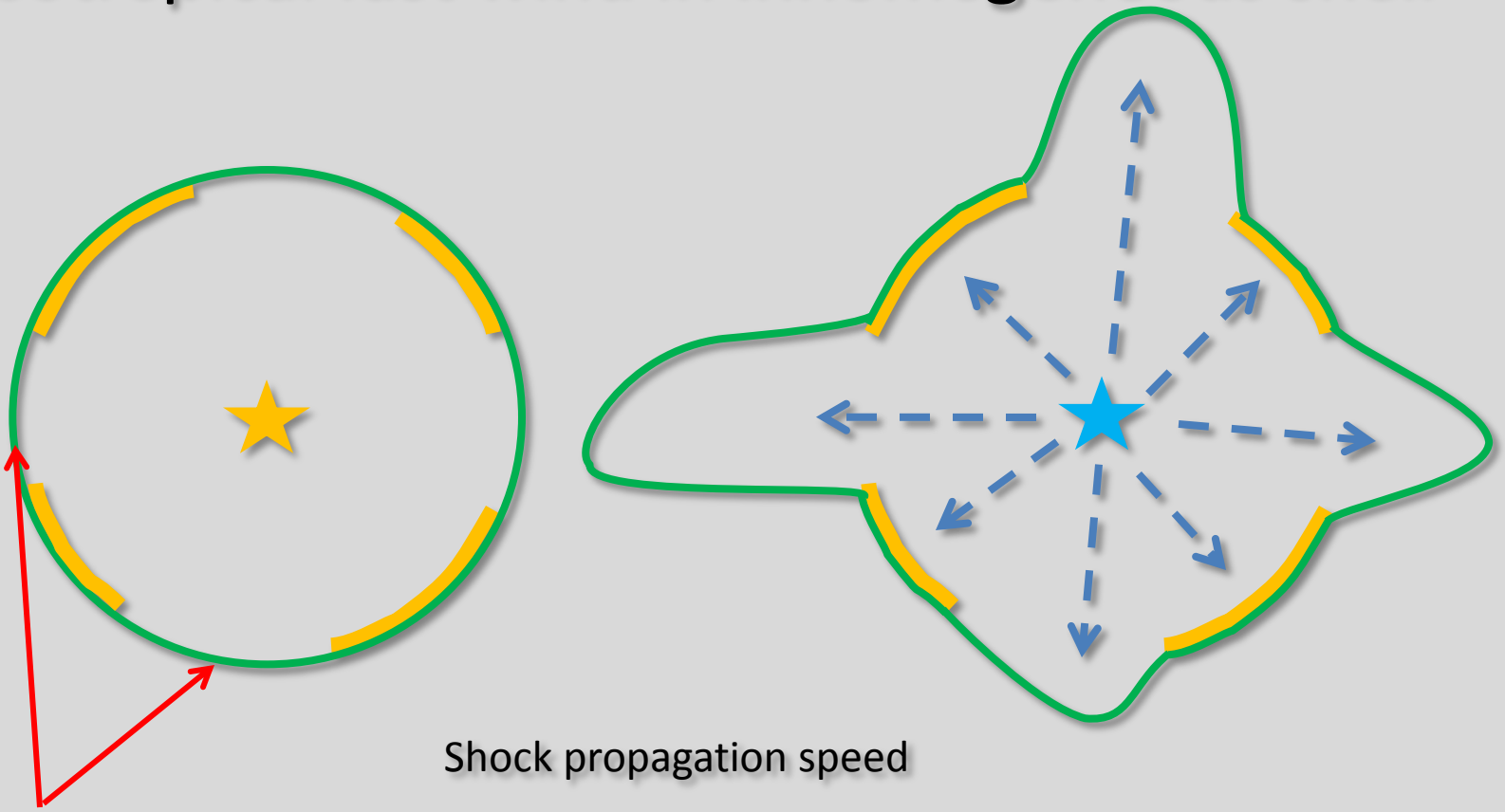
Steffen & López, 2004

Shock propagation speed

$$v_{cs} = v_w \left(\frac{\zeta \rho_w}{\rho_c}\right)^{1/2} = \frac{1}{r}\left(\frac{\zeta \dot{M}_w v_w}{4\pi \rho_c}\right)^{1/2}.$$

$$v_{cs} = 5.5 \text{ km s}^{-1} \left(\frac{\zeta^{1/2}}{\mu}\right) \times \left(\frac{\dot{M}_w}{10^{-5}\ M_\odot \text{ yr}^{-1}}\right)^{1/2} \left(\frac{r}{10^{18} \text{ cm}}\right)^{-1} \times \left(\frac{n_c}{10^4 \text{ cm}^{-3}}\right)^{-1/2} \left(\frac{v_w}{10^8 \text{ cm s}^{-1}}\right)^{-1/2}.$$

Put them together:
Isotropical fast wind in inhomogeneous shell

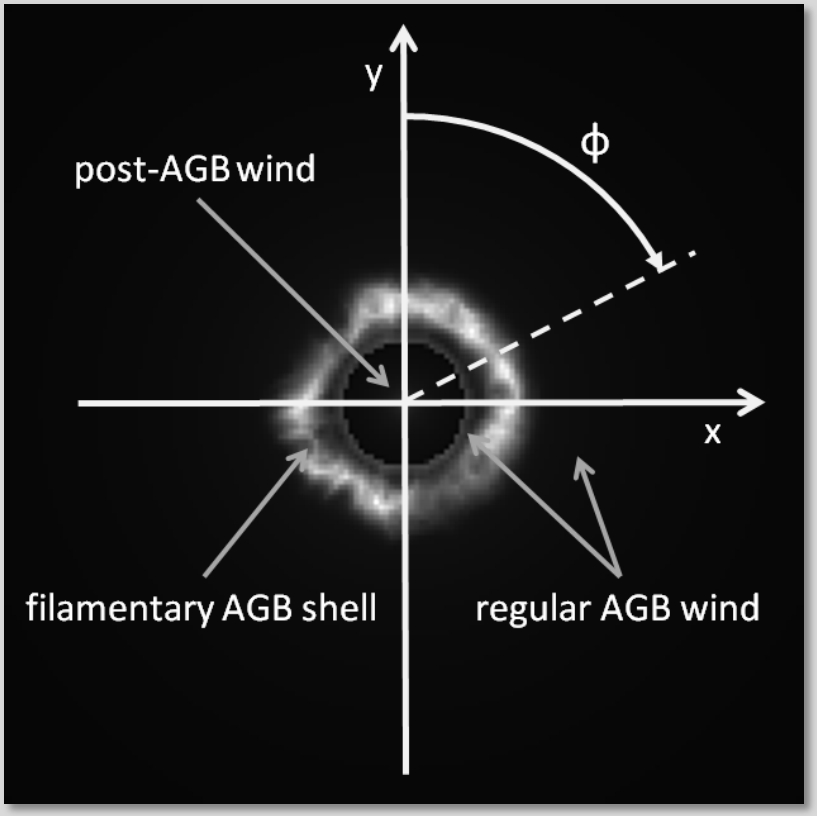


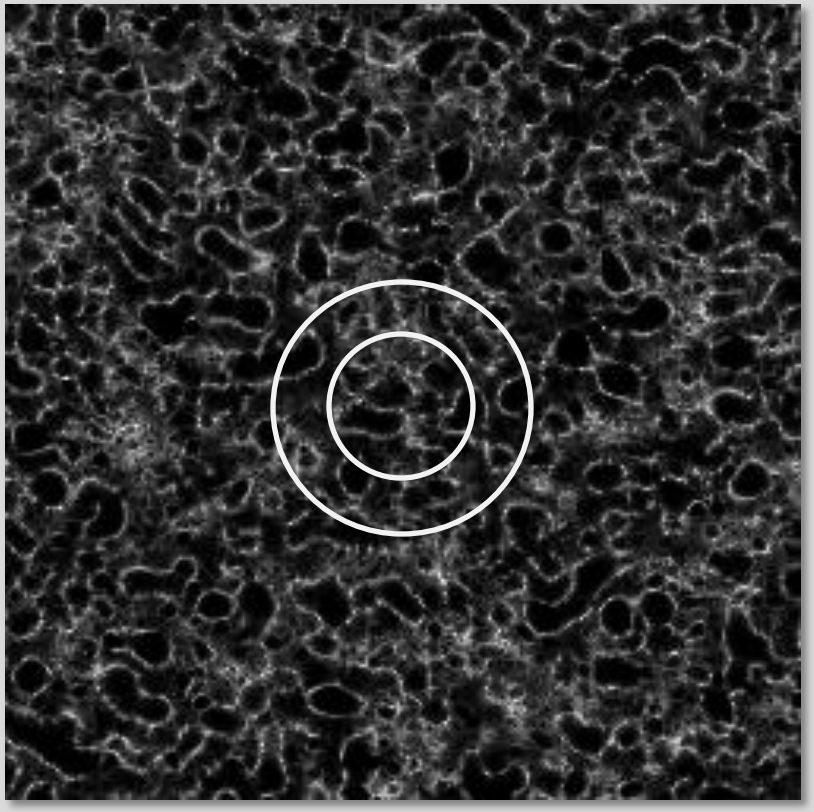
Low density regions

Shock propagation speed

$$v_{cs} = v_w \left(\frac{\zeta \rho_w}{\rho_c}\right)^{1/2} = \frac{1}{r}\left(\frac{\zeta \dot{M}_w v_w}{4\pi \rho_c}\right)^{1/2}.$$

Then set it up:



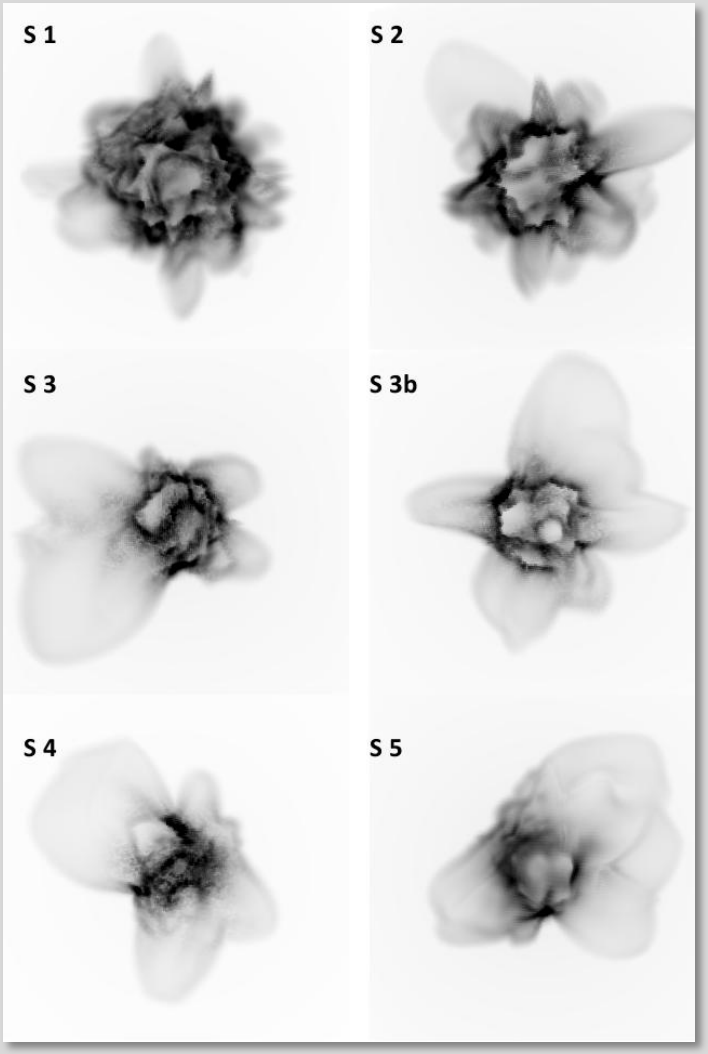


New Shape hydrodynamics module: Use filamentary 3D texture

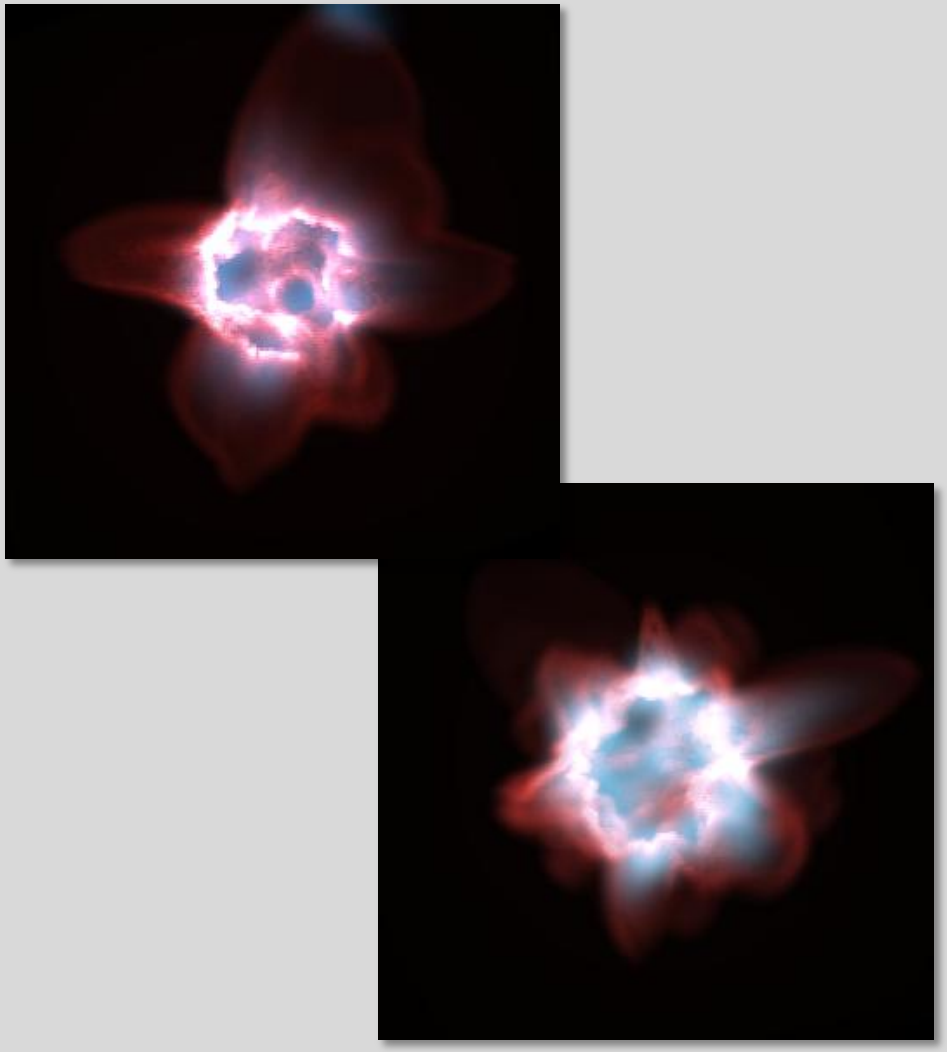
Uniform Eulerian grid at 256^3 resolution

Steffen, Koning, Esquivel et al., 2013, in press

To get this:
Multi-polar planetary nebulae

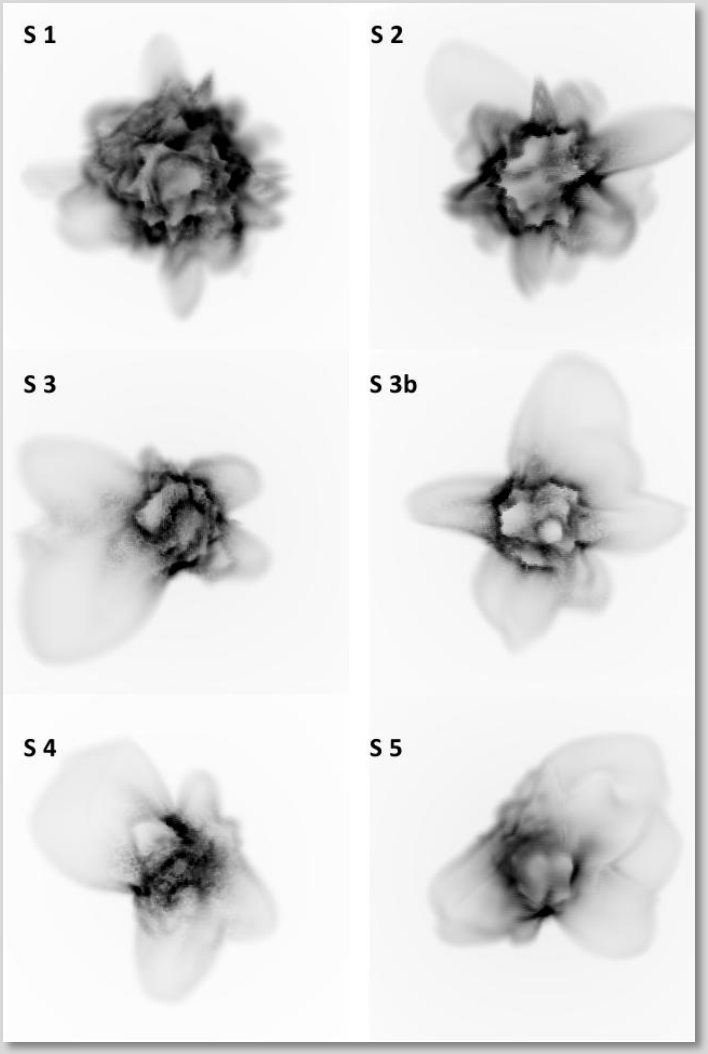


Changing size scale of density fluctuations

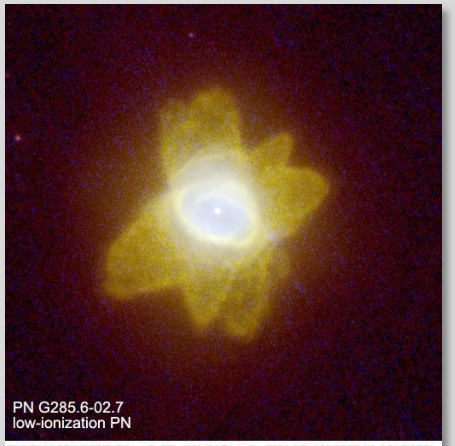


Steffen, Koning, Esquivel et al., 2013, in press

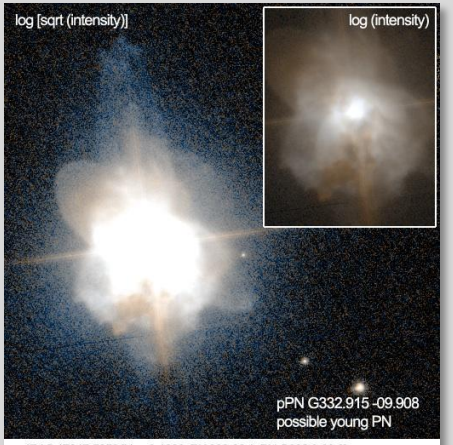
Compare with:
real multi-polar planetary nebulae



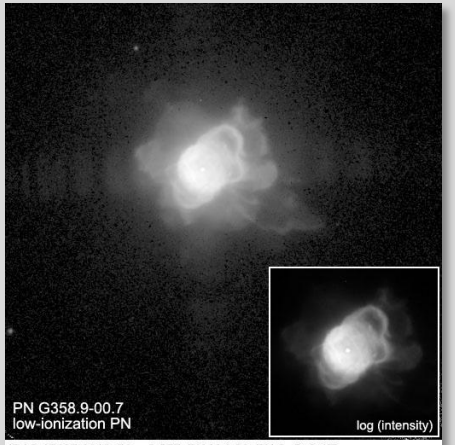
Changing size scale of density fluctuations



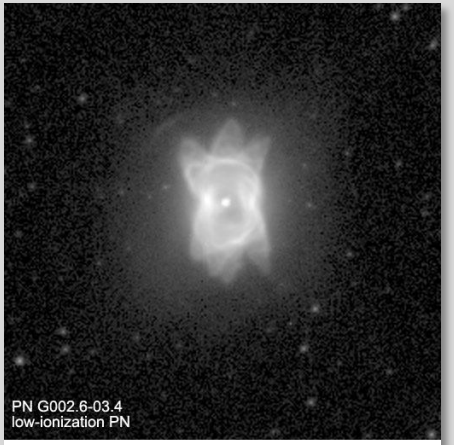
IRAS 10214-6017 [Hen 2-47, PN SaSt 2-5, 2MASS J10230914-6032422]
18 05 25.80 -28 22 04.2 (2000) FOV = 23.3" R:G:B = F658N:"F656N:F502N
WFPC2/PC Credit: PI: NOLL GO11090, NASA/ESA/STScI, Hubble Archives



IRAS 17047-5650 [Hen 3-1333, PK 332-09 1, PN G332.9-09.9]
17 09 00.87 -56 54 48.0 (2000), FOV=12.8", R:G:B = F435W:comb:F606W
ACS/HRC, credit PI:SAHAI GO9463 NASA/ESA/STScI, Hubble Archives

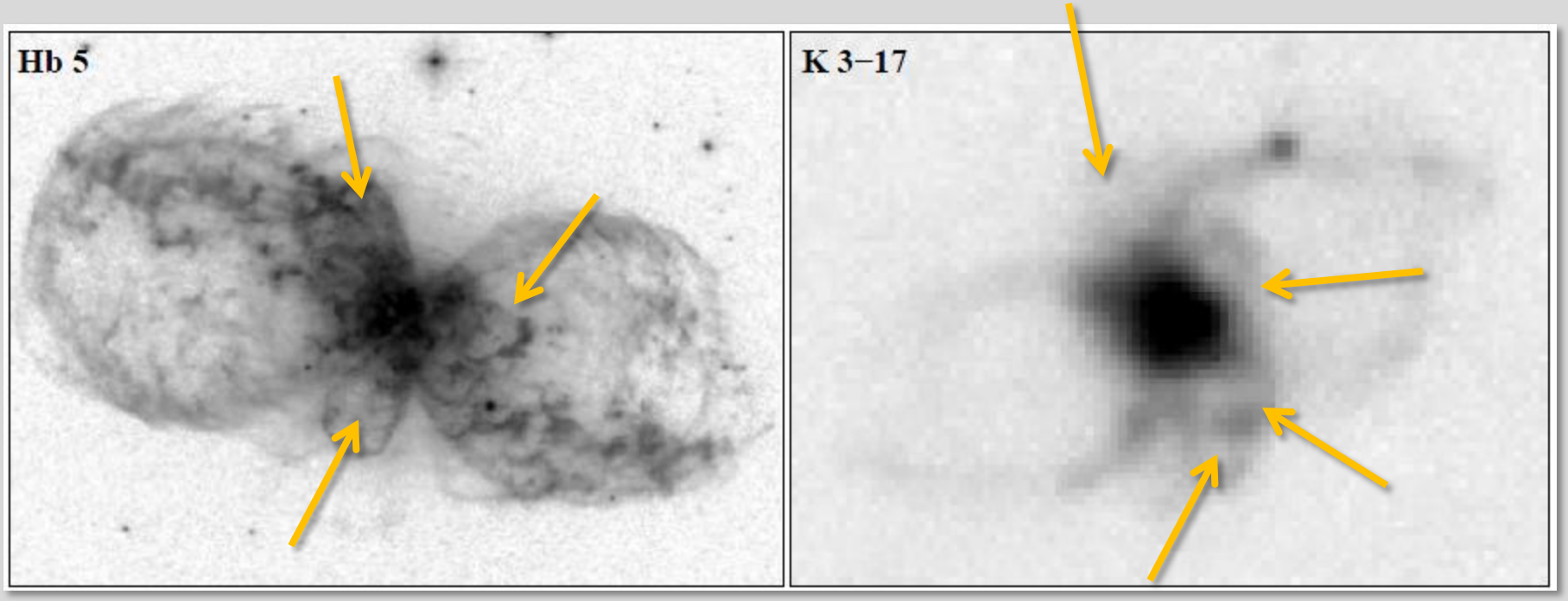


IRAS 17427-3010 [Hen 2-277, PN M 1-26, PN SaSt 2-17]
17 45 57.65 -30 12 00.6 (2000) FOV = 23.3" filter = F656N
WFPC2/PC Credit: PI: SAHAI GO6563, NASA/ESA/STScI, Hubble Archives



IRAS 18022-2822 [Hen 2-339, PN M 1-37, 2MASS J18052581-2822043]
18 05 25.80 -28 22 04.2 (2000) FOV = 11.6" (North not up) filter = F656N
WFPC2/PC Credit: PI: SAHAI GO6563, NASA/ESA/STScI, Hubble Archives

Go further: Hubble 5 and K3-17

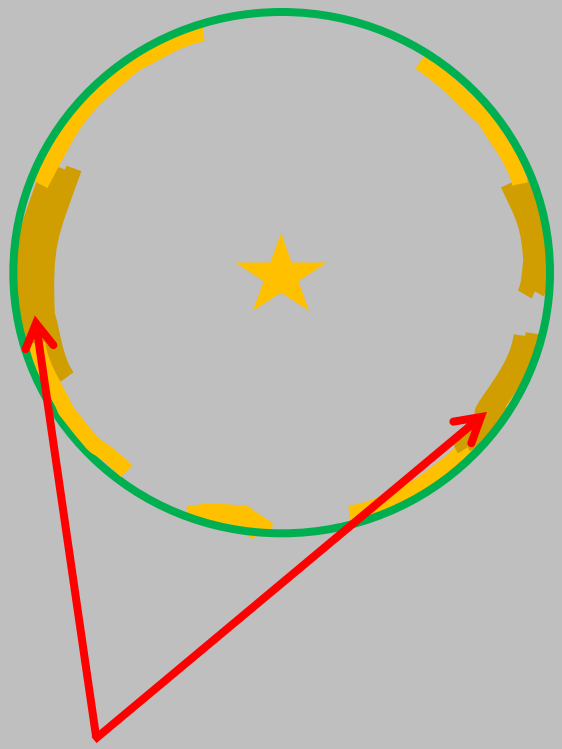


Secondary lobes

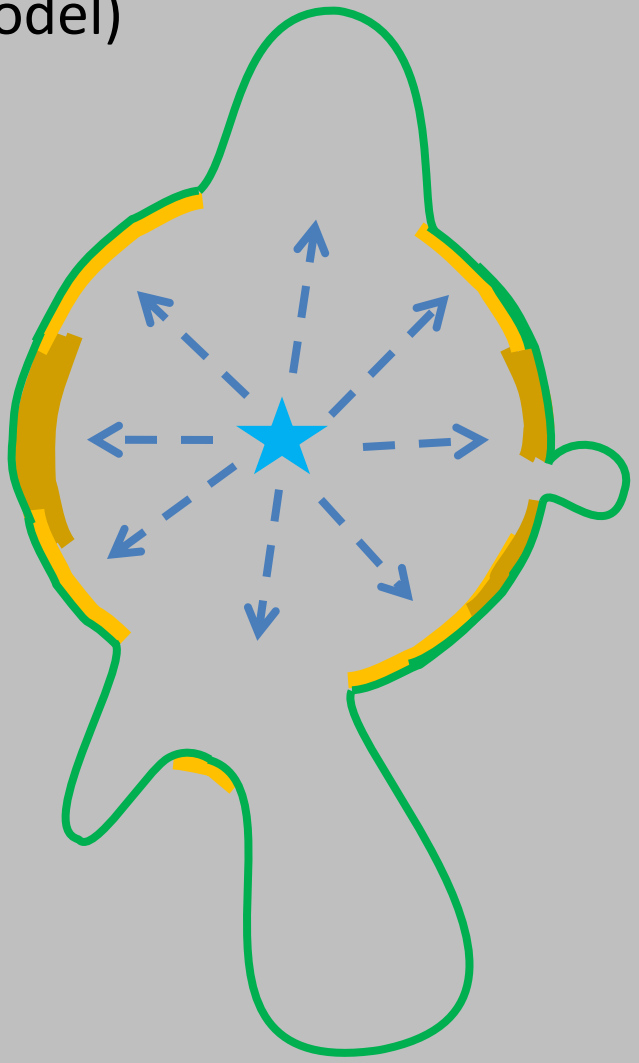
Get some hints from the past:

Equatorially enhanced shells

(The EMGIW model)



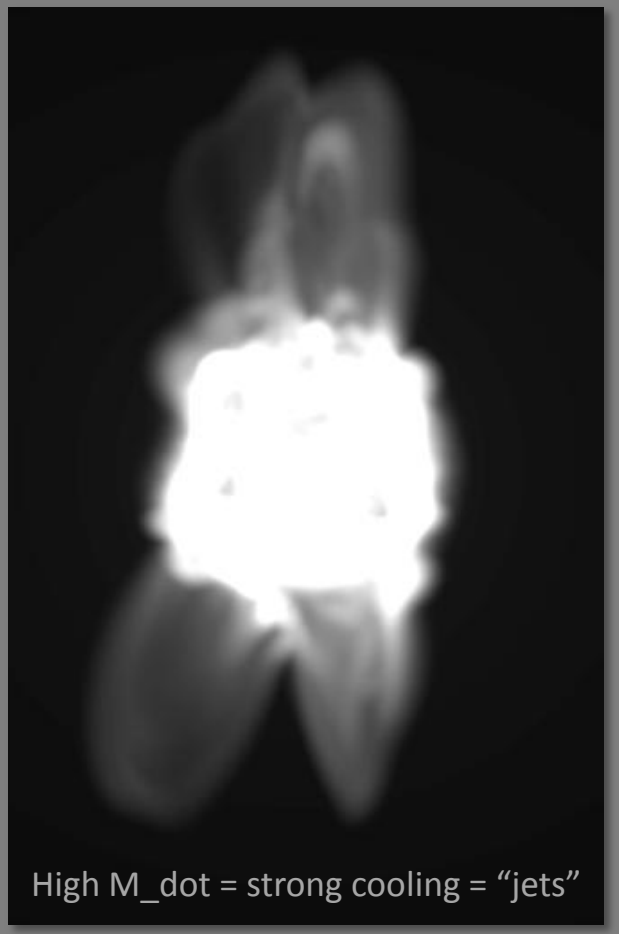
Equatorial density enhancement



Make some lucky “mistakes”:

Jet collimation far from the CS

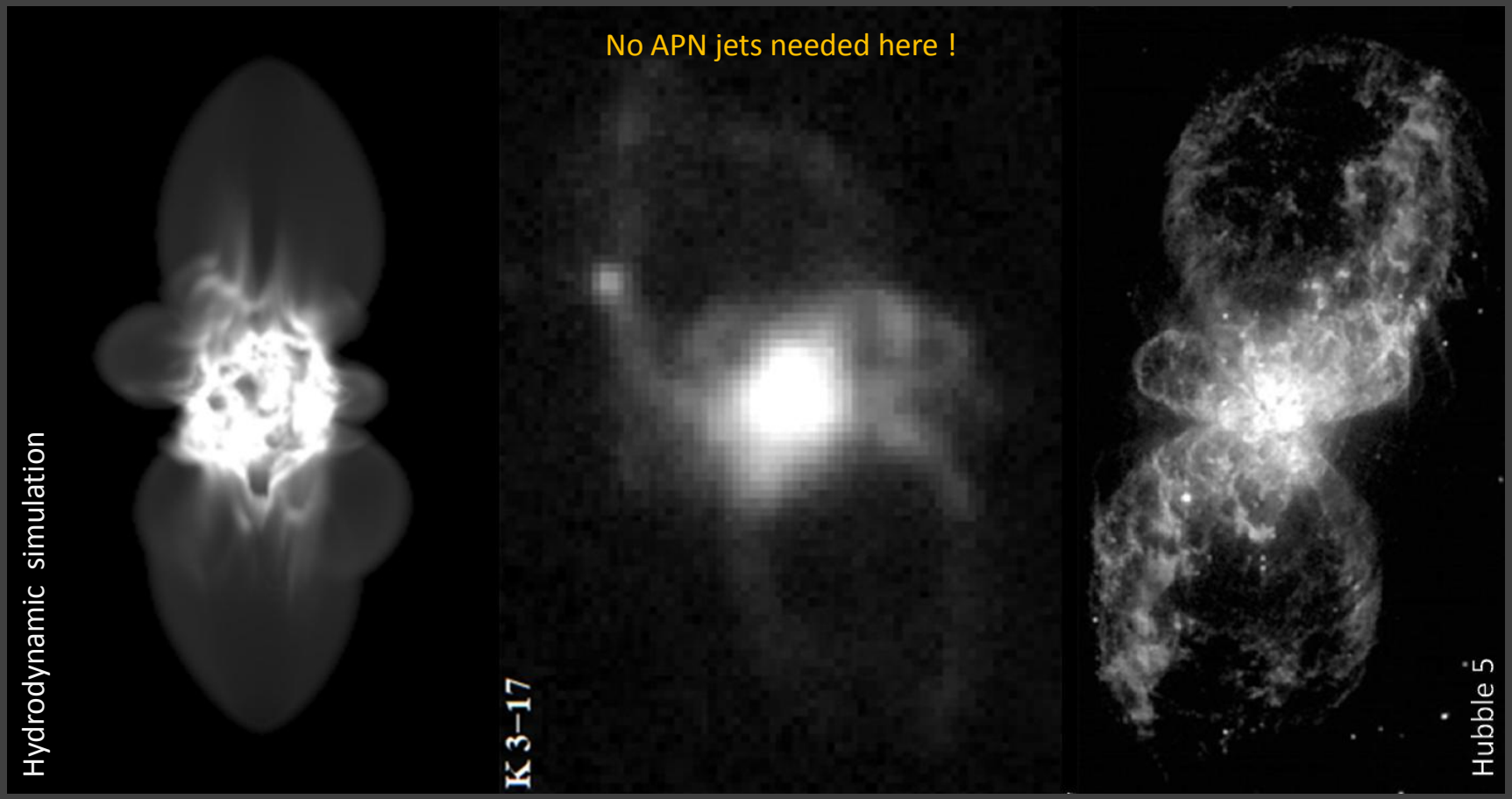
IRAS 19024+0044



Steffen, Koning, Esquivel et al., 2013, in press

After “some” playing around, finally:

Secondary lobes



Steffen, Koning, Esquivel et al., 2013, in press

Summary

- ***Multipolar PNe can be obtained from an isotropic fast wind interacting with a spherical shell of inhomogeneous density (Percolator model)***

- First application of 3D interactive hydrodynamics module in Shape

- Many multipolar planetary nebulae do not need jets from the central star system (i.e. no APN jets)

- Secondary lobes can also be generated with this new model adding an equatorial density enhancement

- Jets can be formed and collimated far from the central star

SHAPE v5

Get your science in Shape !