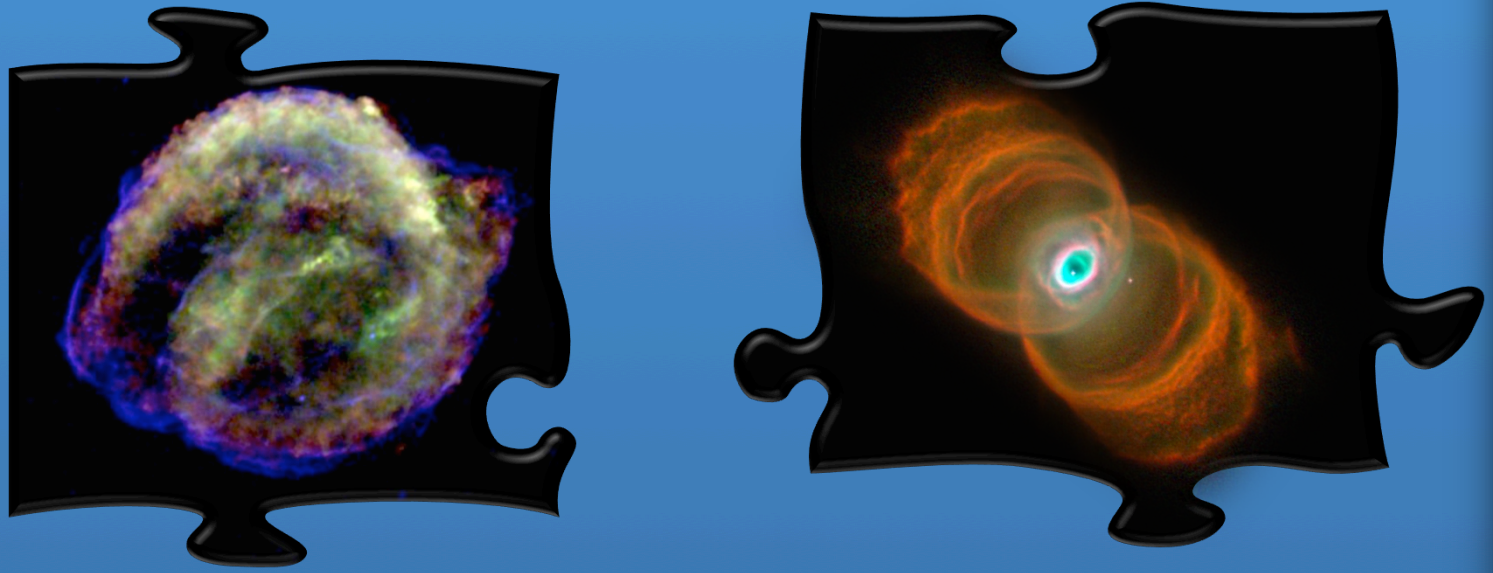
On the interaction of Type Ia SNRs with Planetary Nebulae

Alexandros Chiotellis

with: Panos Boumis, Eva Lefa and Sander Walg



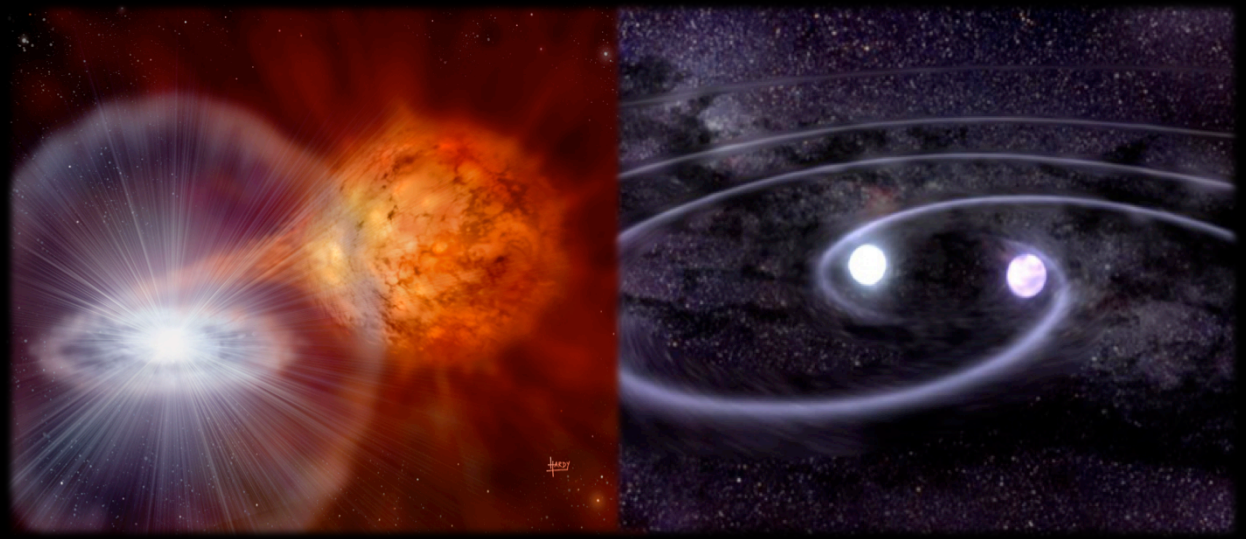
National Observatory of Athens

Chania June 2016

Type Ia Supernovae (SNe Ia)

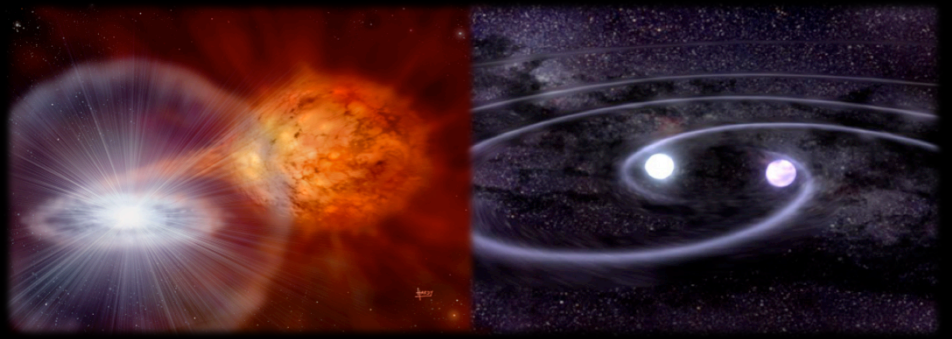
"Explosions of CO white dwarfs in binary systems, which get destabilized through mass accretion from the companion star"

Singe Degenerate Vs Double Degenerate



The importance of CSM
in the quest of theType Ia origin

Different paths of binary evolution which lead to Type Ia



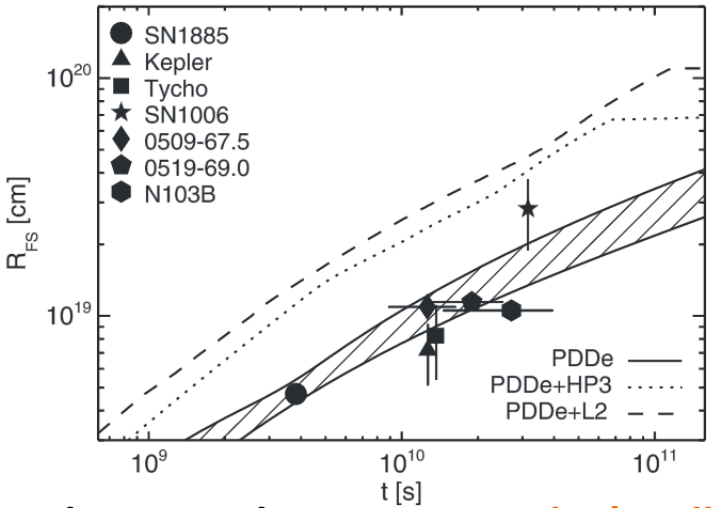
Different (or no) mass outflows from the progenitors
→ Ambient medium modification

Different:
- **Morphologies**
- **Dynamics**
- **Emissivity**
- **Spectra of SNRs**

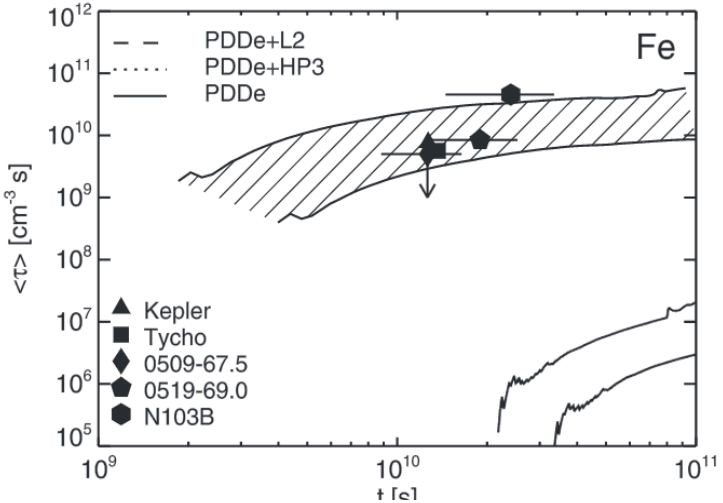
Observations
of nearby SNRs

Do type Ia SNRs interact with CSM?

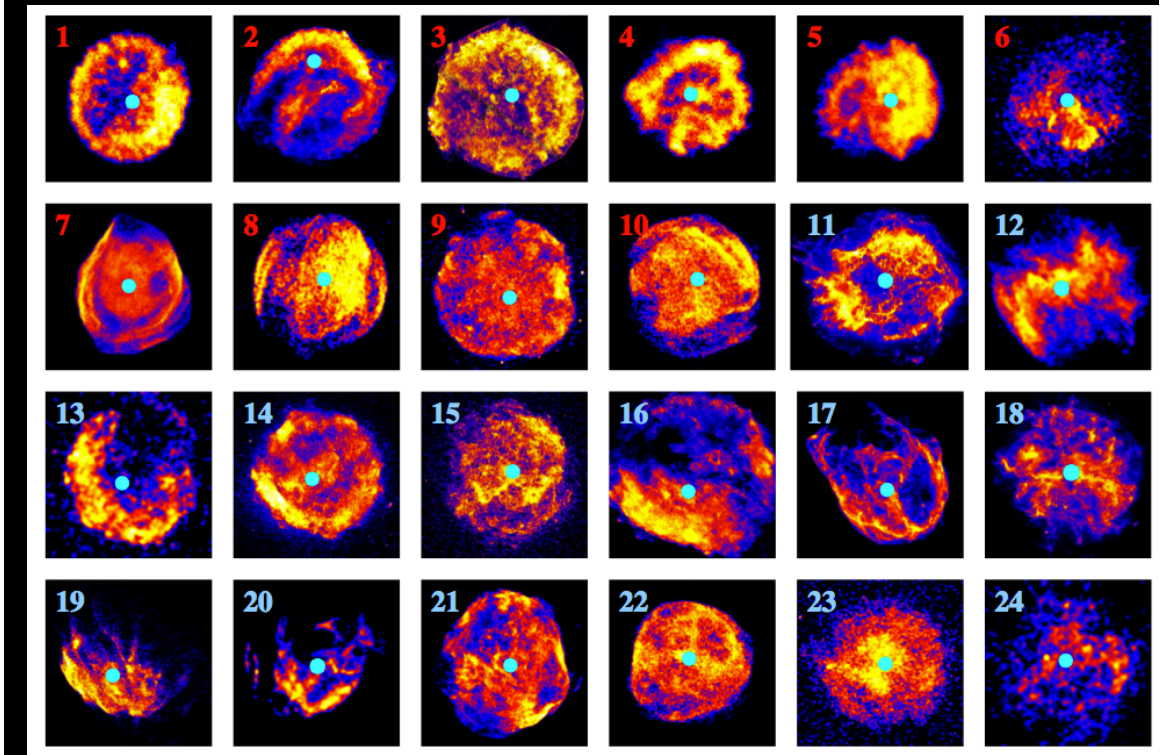
Generally speaking:



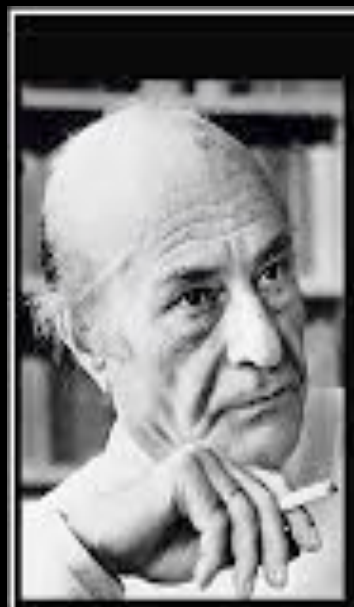
Badenes et al. 2007, yesterday's talk



- *Type Ia SNRs seem to evolve in a rather uniform ambient medium*



Lopez et al. 2009, **talk**



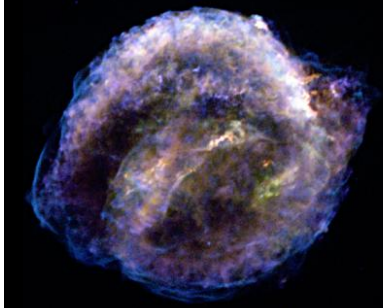
“You will come to learn a great deal if you study the Insignificant in depth”

(Odysseas Elytis)

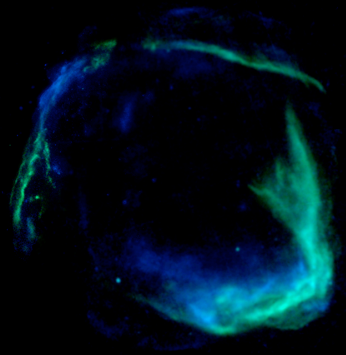
Nobel Prize in Literature

But zooming in nearby SNRs Ia

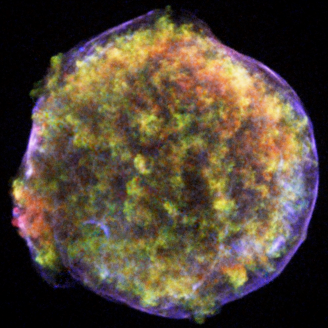
- *Several 'peculiarities' that cannot be explained by a SNR + uniform ambient medium scenario*



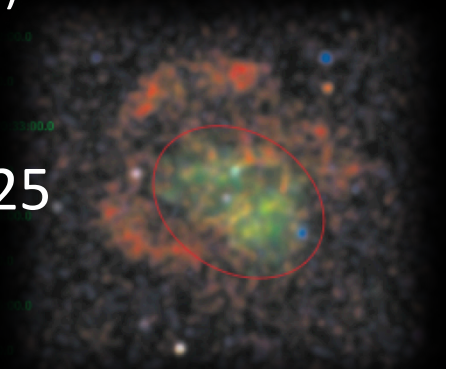
Kepler's SNR: Interaction with an asymmetric AGB bubble
(Chiotellis et al. 2012; Patnaude et al. 2012; Burkey et al. 2013)



RCW 86 : Interaction with a low density cavity
(Vink et al. 1997, Williams et al. 2011; Broersen et al. 2014)



Tycho's SNR : Interaction history with small dense bubble
(Dwarkadas & Chevalier 1998, Chiotellis et al. 2013)



Mature SNRs Ia: e.g. DEM L238, L249, MCSNR J0506−7025
Dense Fe rich cores explained by SNR + CSM interaction
(Borkowsky et al. 2006; Kavanagh et al. 2015)

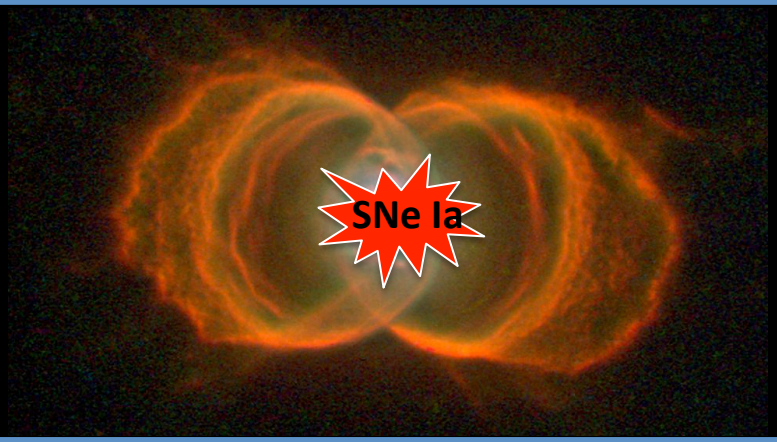
now the question is…

- *Is a circumstellar medium where:*

a) Its formation can naturally be explained by the binary evolution towards a SN Ia?

b) it can explain (some) properties observed in nearby SNRs Ia?

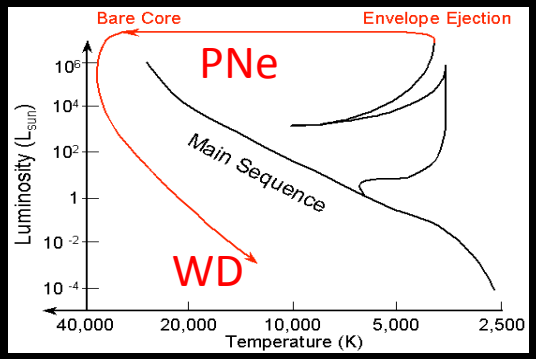
We suggest that such a CSM could potentially be represented by **Planetary Nebulae (PNe)**



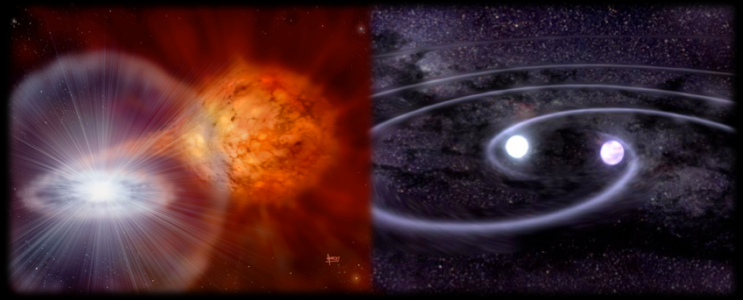
PNe as the origin of the CSM around SNe Ia

- *Motivation*:
  (see also Tsebrenko &Soker 2014)

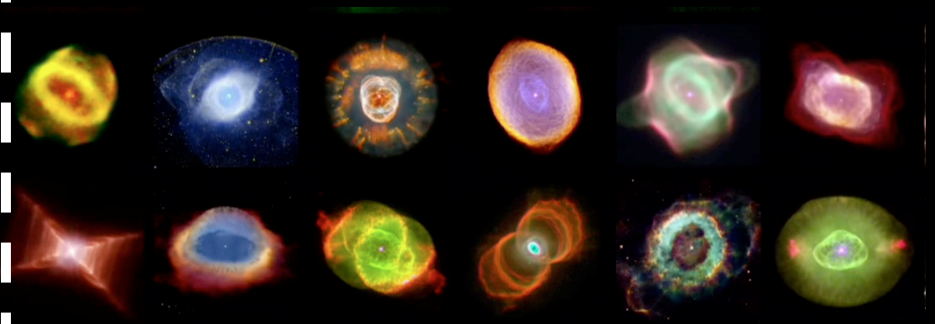
1) SNe Ia progenitors: one or two WDs → evolved through one/two PNe phase(s)



→ The SN Ia + PNe scenario host both the SD and DD paths

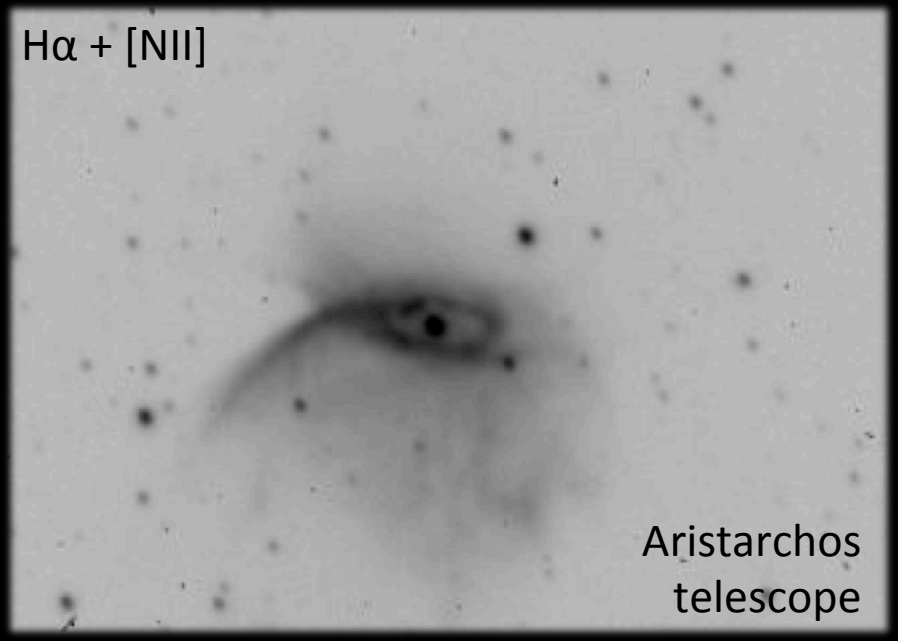


2) PNe come in several flavors → aligned with the observed SNe/SNRs Ia diversity



Extra boost in motivation…

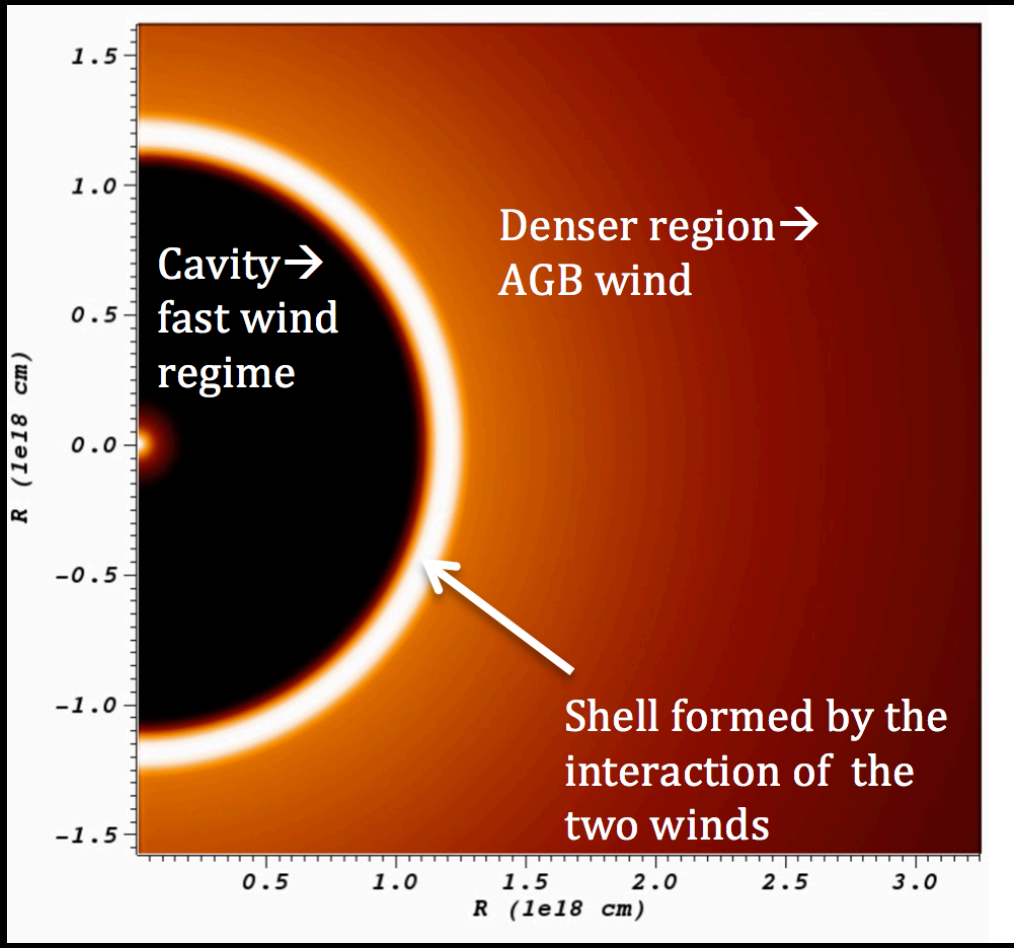
3) Henize 2–428: DD super-Chandra central binary
→ will merge triggering a SNe Ia
(Santander- Garcia et al. 2015)



Planetary Nebulae (PNe)

Interactive Stellar Wind theory (Kwok et al. 1978)

- AGB: slow, dense stellar wind
- Contraction of AGB core: Fast, tenuous wind



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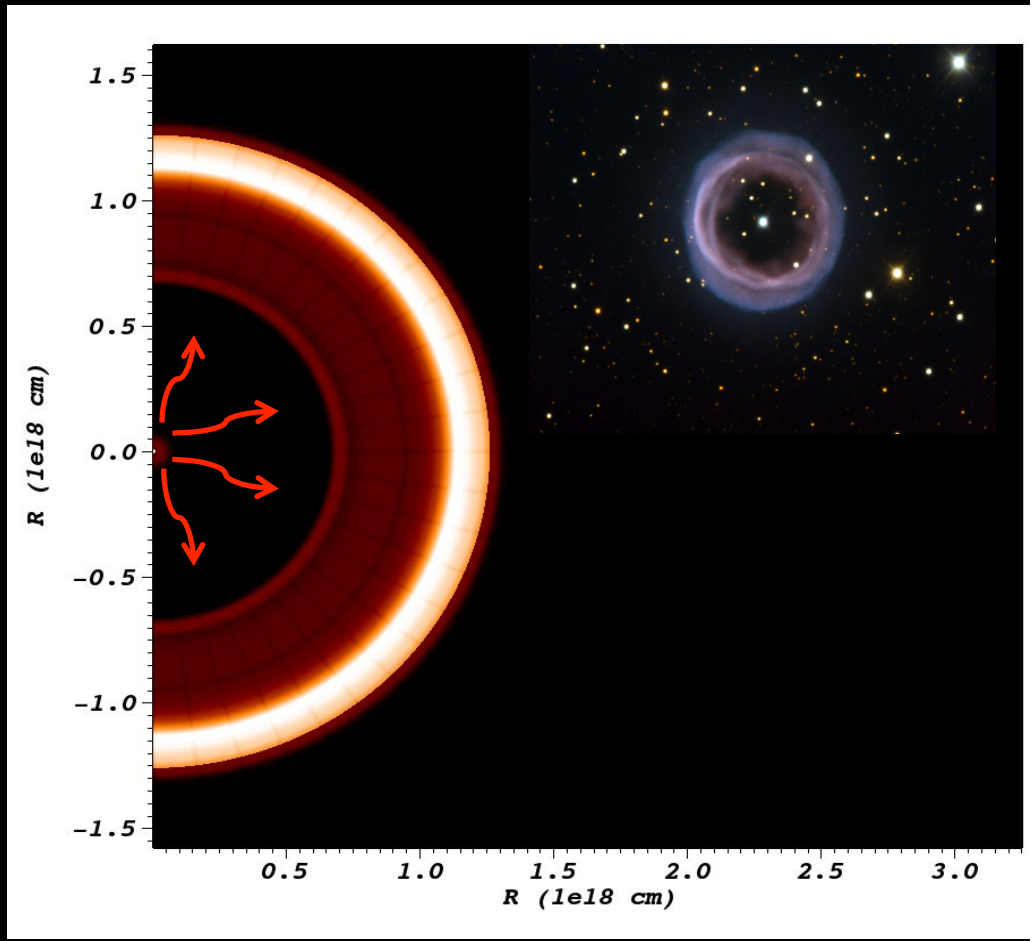

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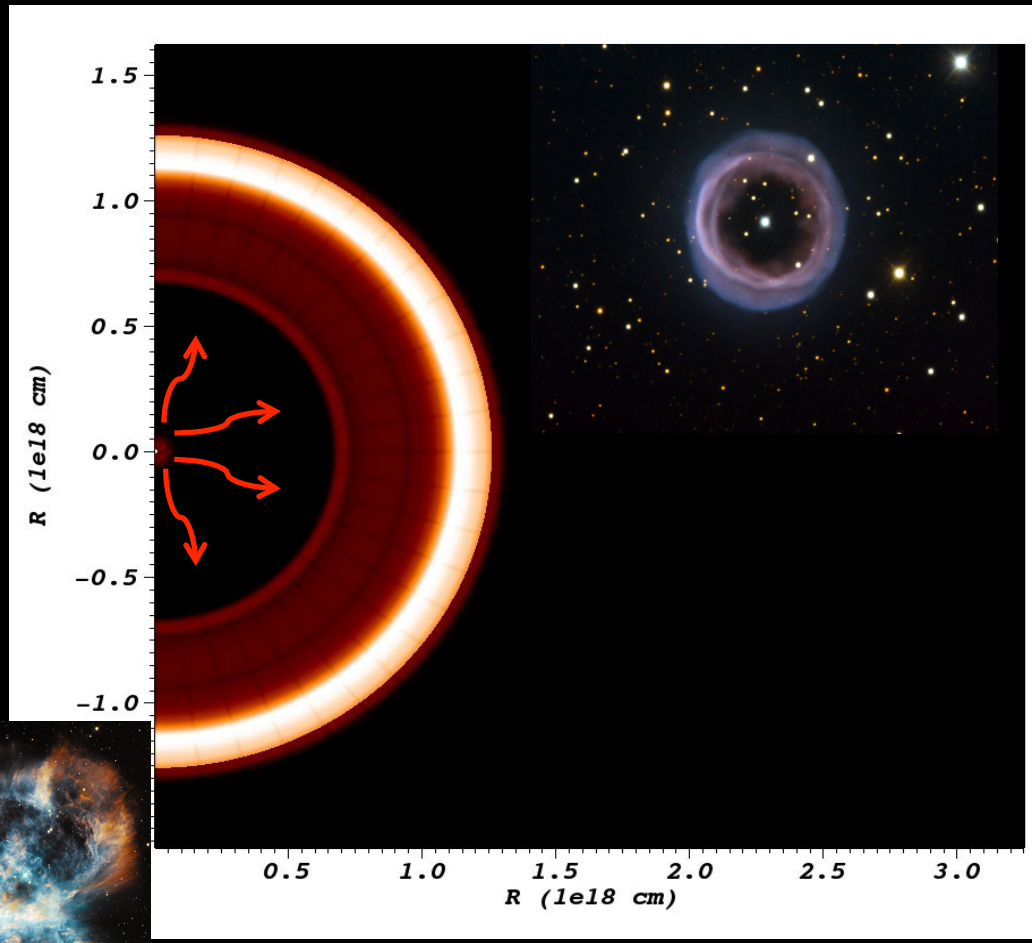
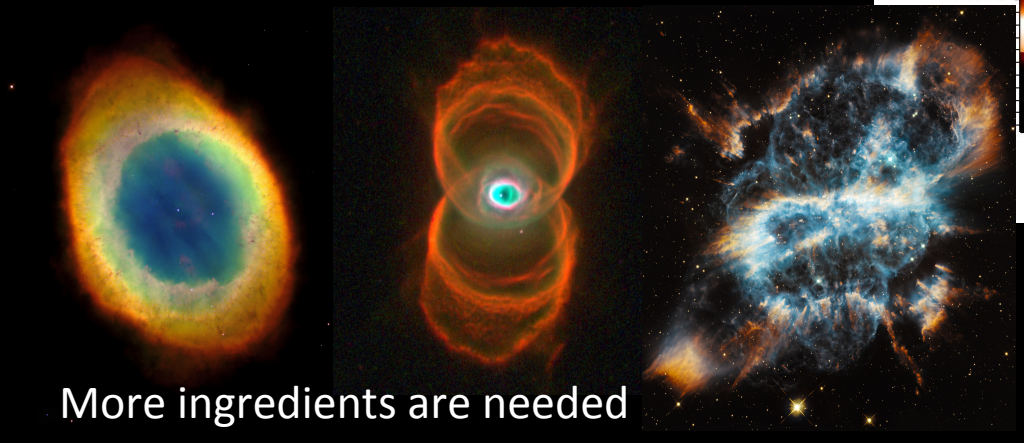
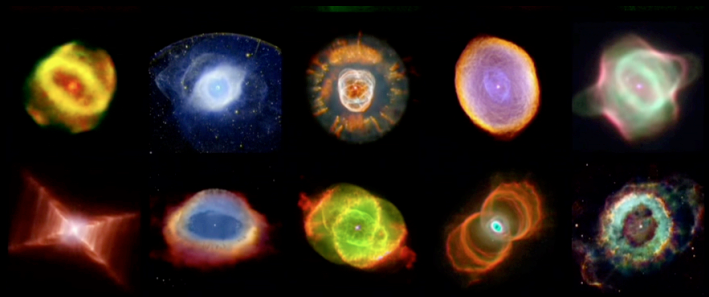




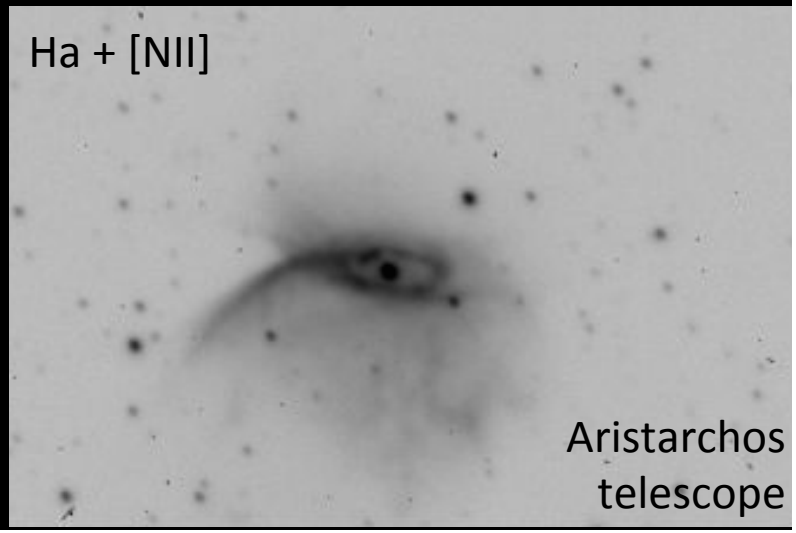
More ingredients are needed

How a SNR interacting with a PN looks alike?



- It deepens
  1) properties of the PN
  2) the time delay between the PN formation and the SN Ia explosion

- We use as a model the PN **Henize 2–428** to simulate the general PN structure
- $t_{delay} < t_{dyn,PN}$



Formation of a bipolar PN

- 2D hydrosimulations
- Code AMRVAC (Keepens + '04)

Wind Formalism

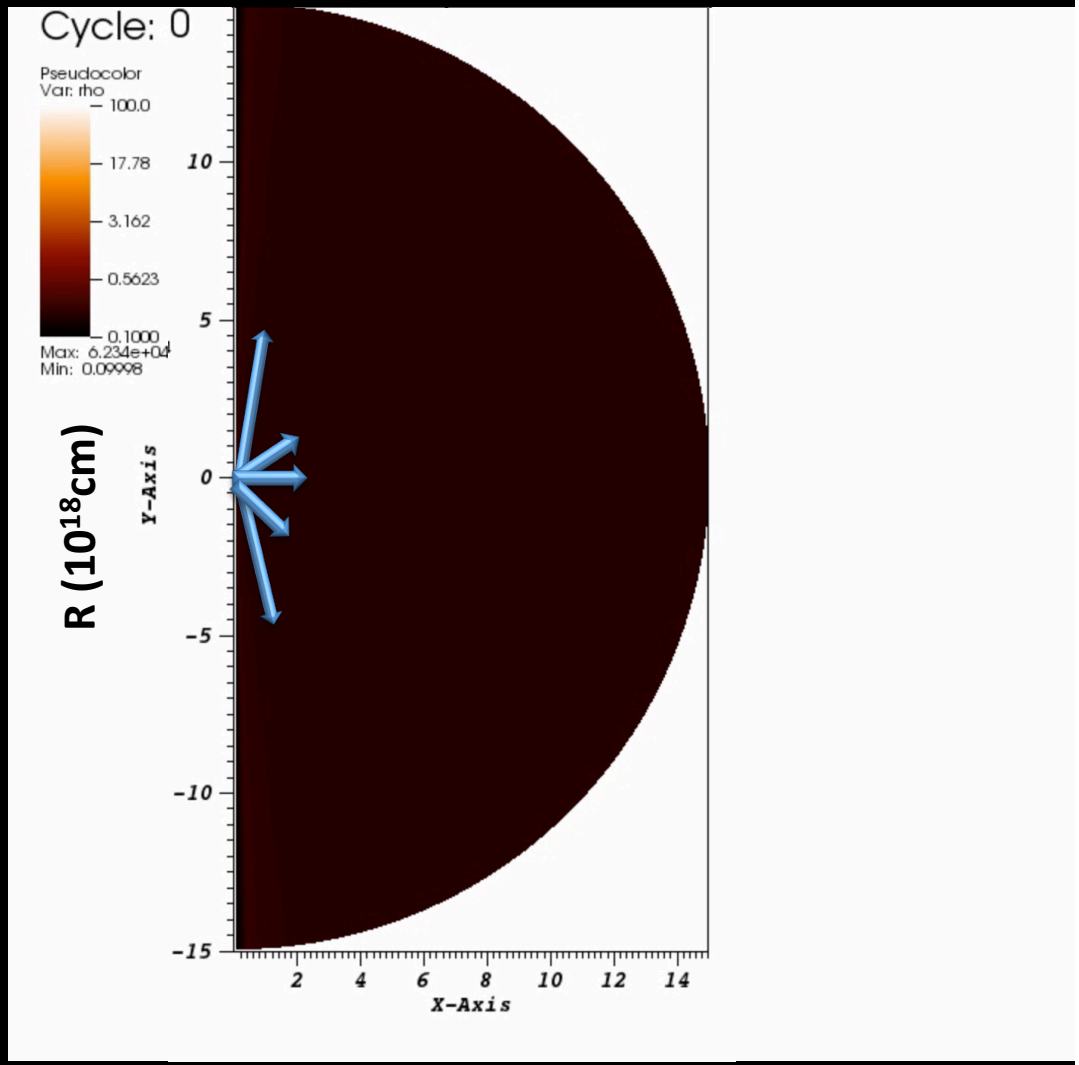
- Asymmetric wind is imposed as an inflow at the inner boundary
- Asymmetry described by trigonometrical function following Garcia-Segura+ '99

$$\rho(\theta) = (-\Omega \sin(\theta)^{\lambda} + 1)^{\mu} \times (\dot{M}_p / 4\pi\ u_p r^2)$$

$$u(\theta) = (-\Omega \sin(\theta)^{\lambda} + 1)^{\nu} \times u_p$$

Ω,μ,ν,λ = constants

→ Determine the density/velocity contrast from poles to equator and their angular gradient



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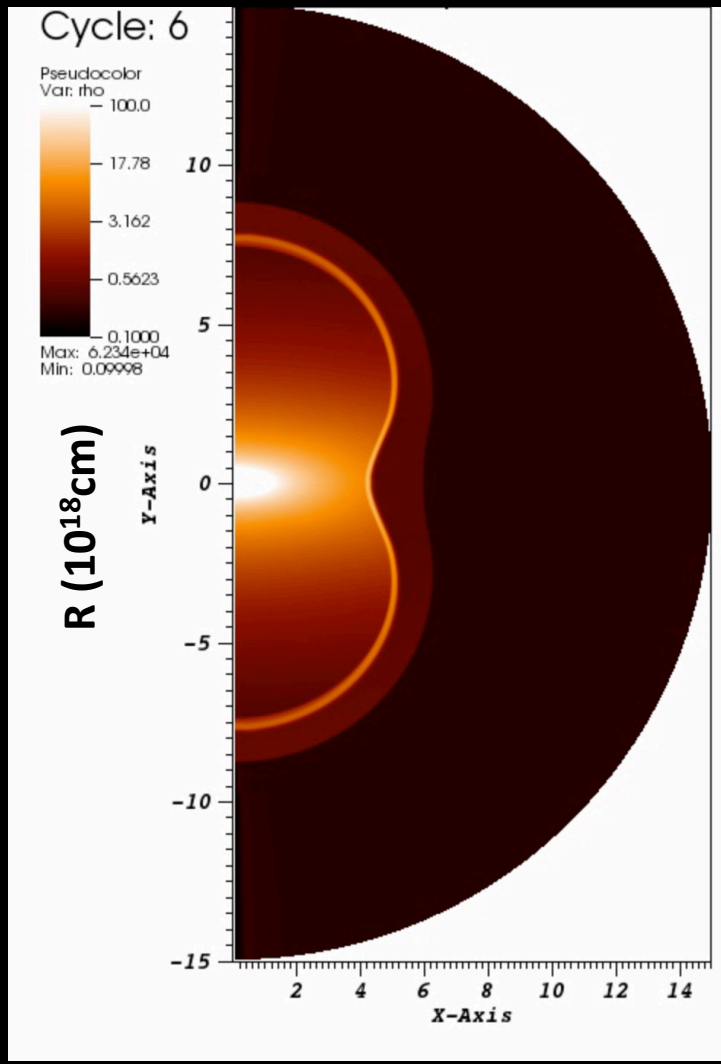
1rst step AGB wind



$n_{ISM} = 0.2\ cm^{-3}$

$\dot{M}_p = 10^{-5} M_{\oplus} yr^{-2}$

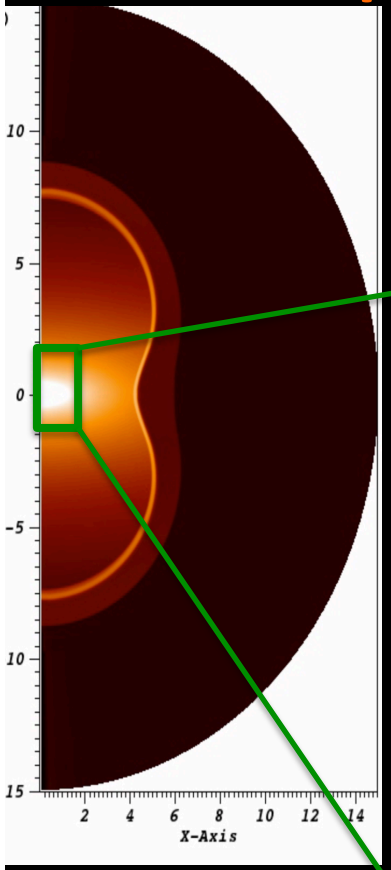
$u_p = 10\ km/s$

$\Omega = 0.9, \quad \lambda = 2,$

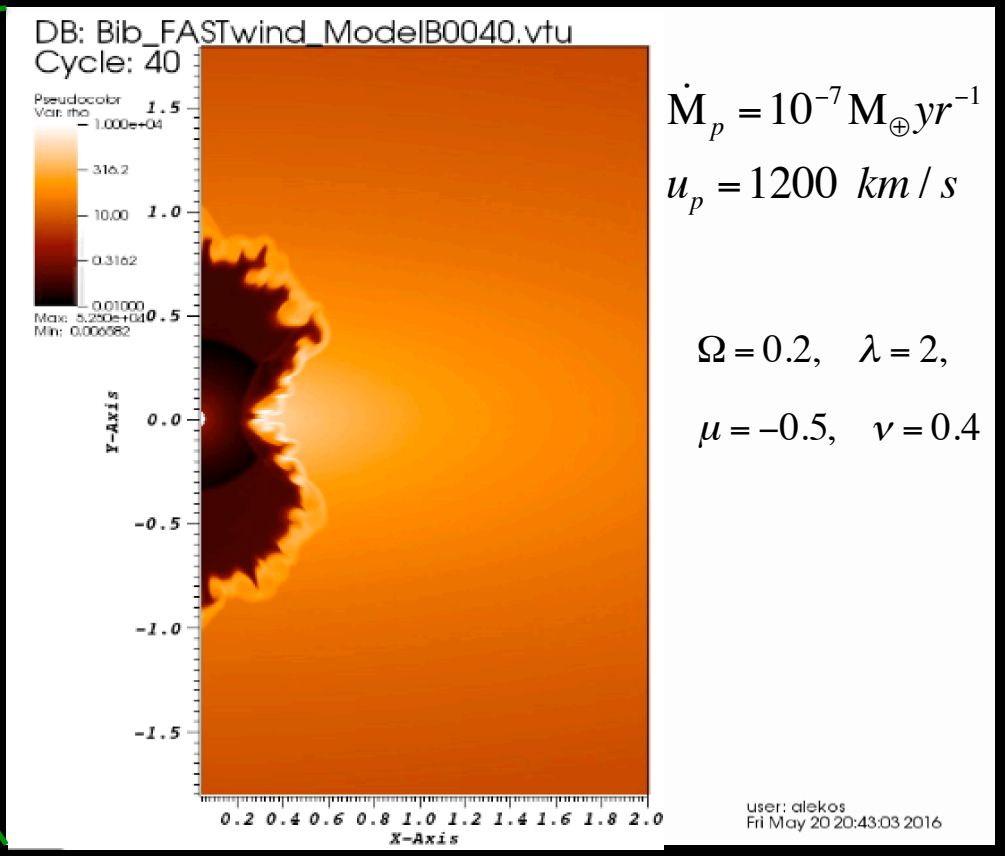
$\mu = -0.9, \quad \nu = 0.4$

$\frac{\rho_{eq}}{\rho_p} = 7.9 \ ; \quad \frac{u_{eq}}{u_p} = 0.4$

Formation of a bipolar PN



2nd step fast wind



$$\dot{M}_p = 10^{-7} M_\oplus yr^{-1}$$

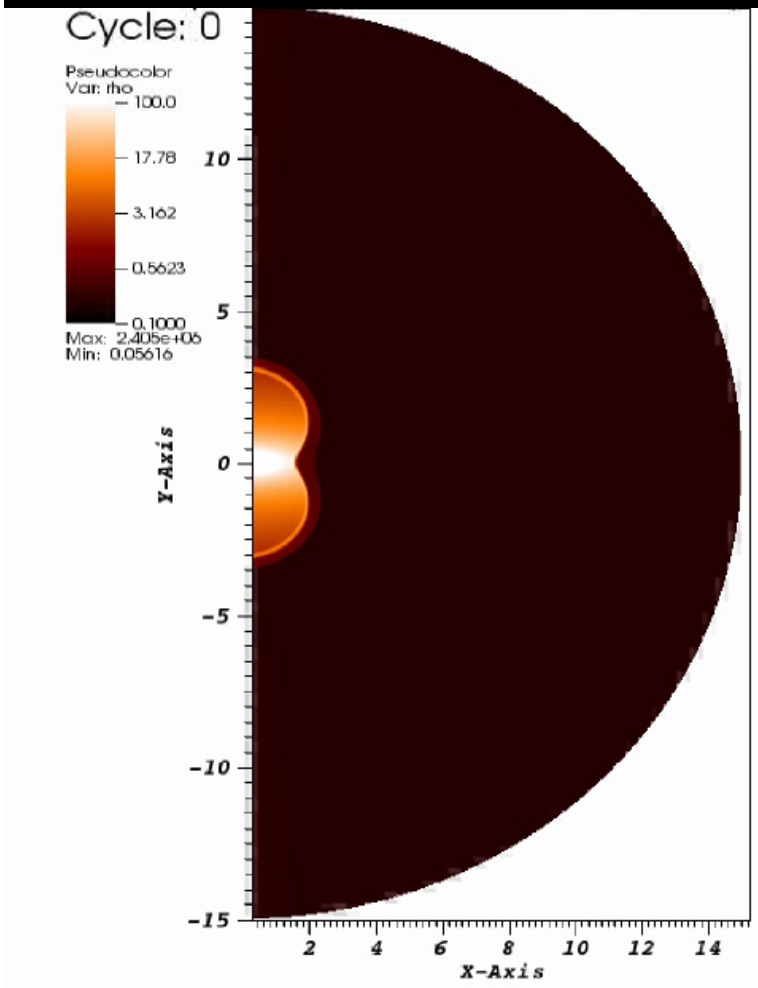
$$u_p = 1200 \ km/s$$

$$\Omega = 0.2, \quad \lambda = 2,$$

$$\mu = -0.5, \quad \nu = 0.4$$

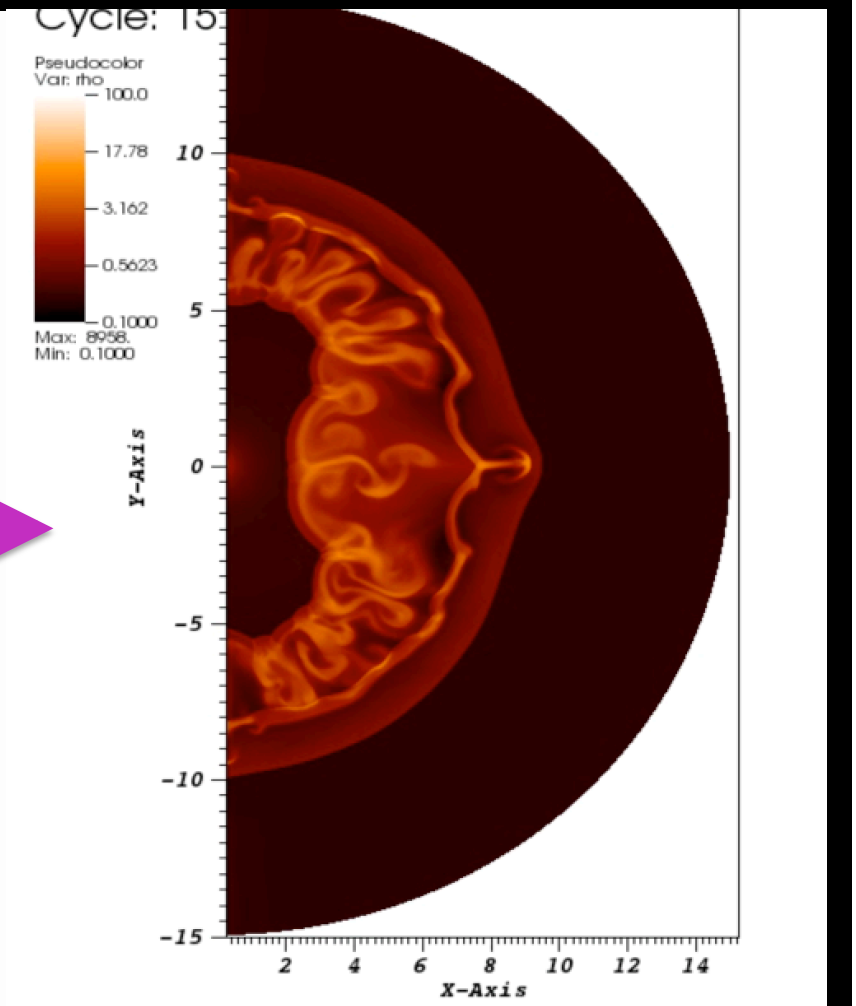
Interaction of a SN Ia with the surrounding PN

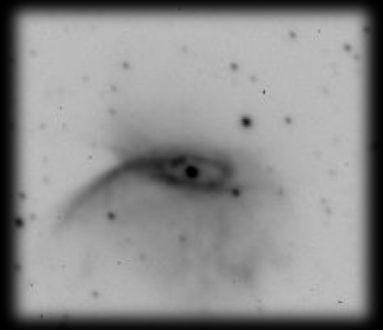
3rd step introduction of SN Ia



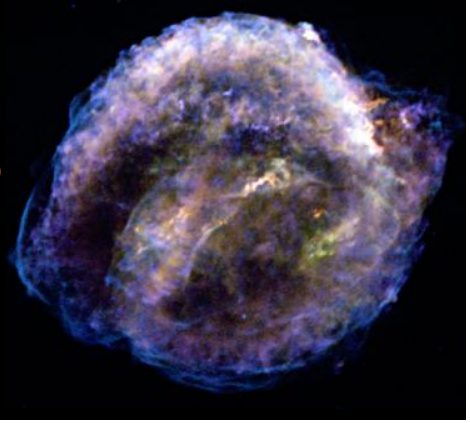
SN ejecta:
Power law, n=7

E_{ej}=1.2 foe
M_{ej} = 1.4 M_{sun}





Which nearby SNRs Ia such a scenario can explain?



Modeling evolution about Kepler's SNR surrounding CSM:

1) Morphology**,** dynamics of SNR and chemical composition of CSM: **AGB wind bubble** (Chiotellis+ 2012)

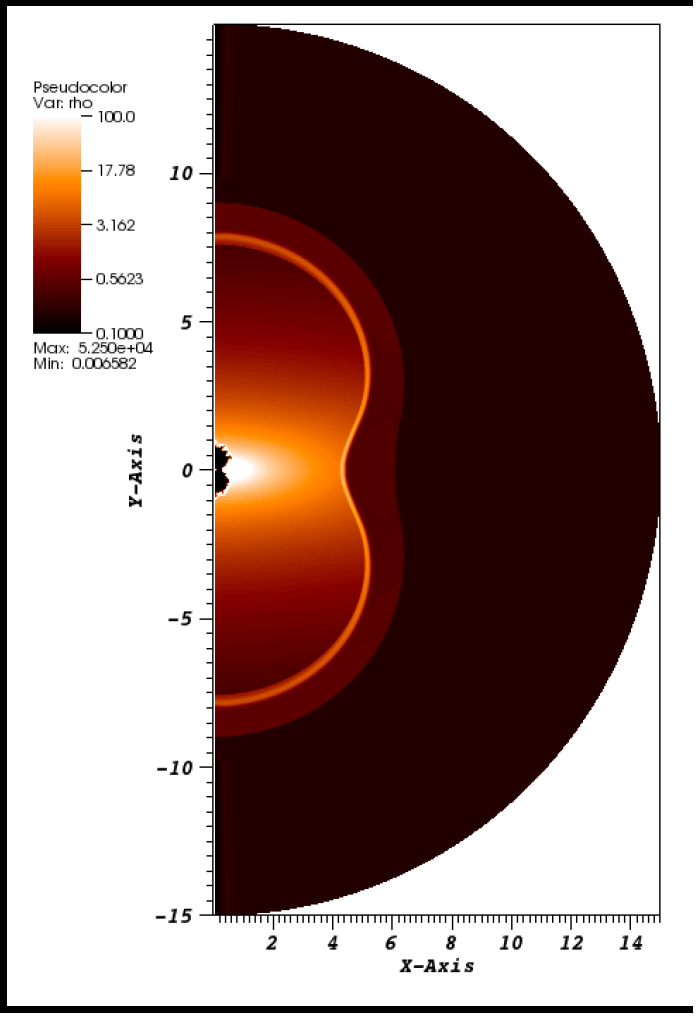
→ Observational verification from IR observations (Williams+ 2012)

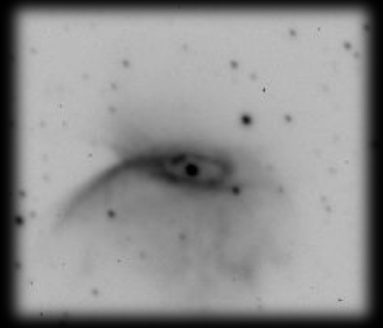
2) Dynamics + Xray spectrum**:** **AGB wind + cavity** (Patnaude+ 2012)

3) Shocked CSM also in the center of the SNR: **AGB+ WD and disk distribution of CSM** (Burkey+ 2013)

4) There is **no such an AGB star** at the center of the SNR (Kerzendorf+ 2013)

All of these properties demanded by Kepler's modeling can be hosted by a PN structure around the explosion center





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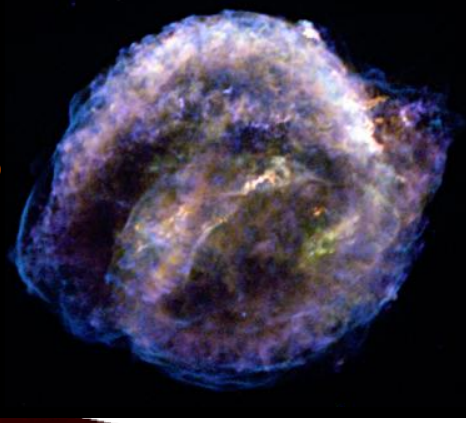

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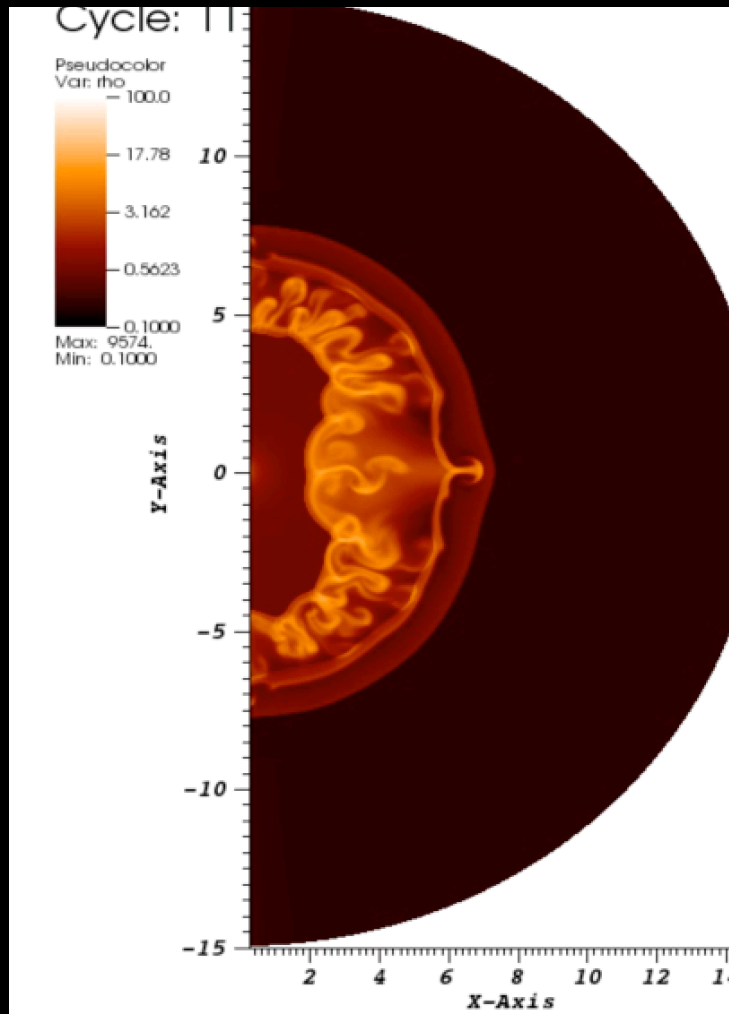
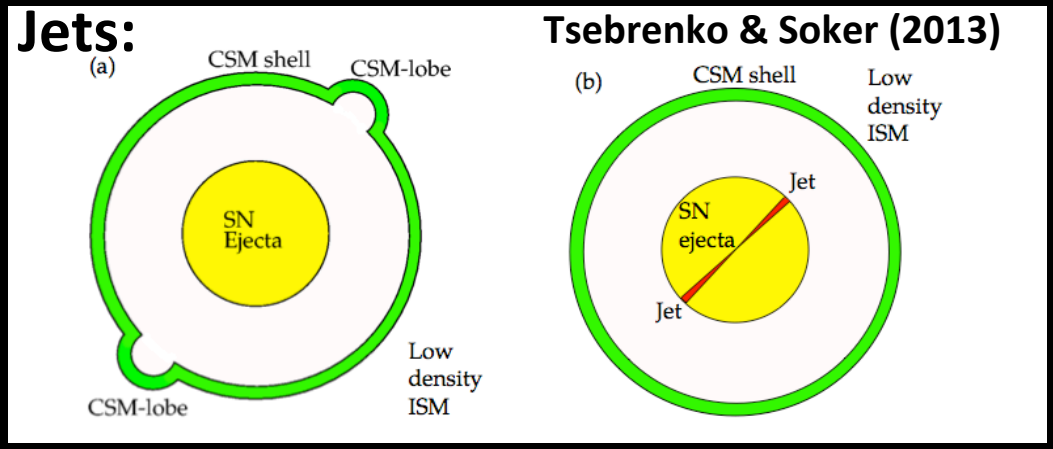
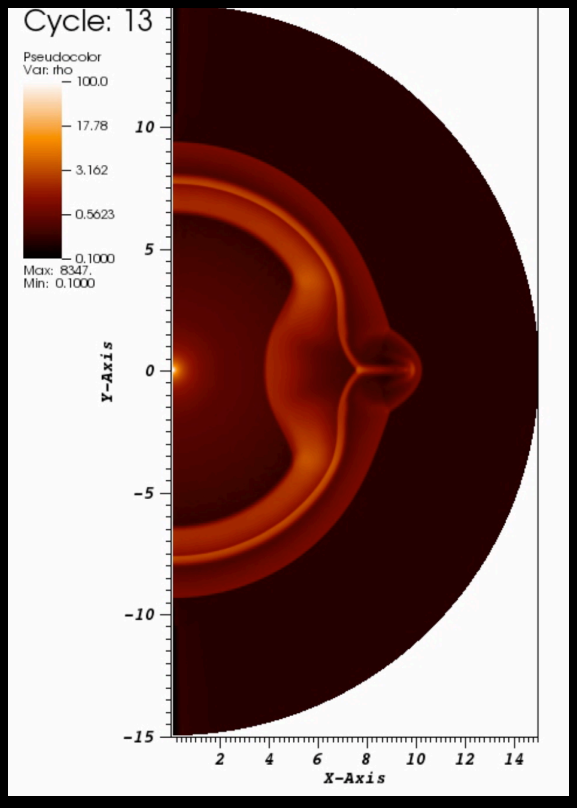
The resulting SNR reveals density enhancement at the equatorial plane



Extra bonus… ears formation





➢ ***Ears can be formed by an interaction of the SNR with a bipolar structure.***

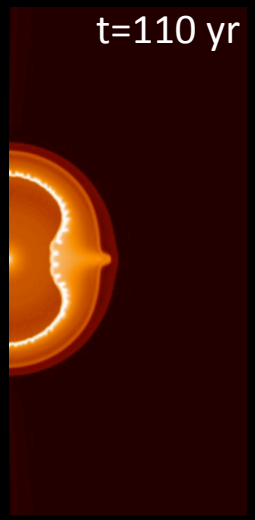
<u>The advantages of this scenario are:</u>

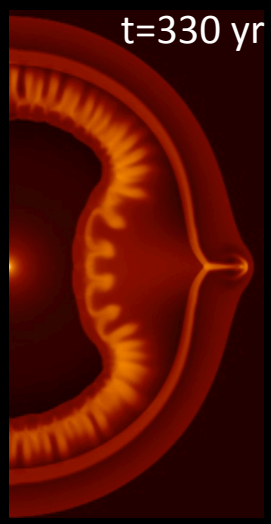
- No 'extra ingredients' are needed
- Ears formed at the equator instead of the poles: This geometry is aligned with the CSM distribution
- No extremely large PNe (R~ 2 -3.5 pc) are needed

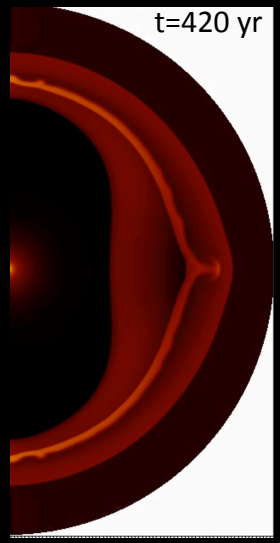
SNRs with 'ears' → Interaction history with bipolar CSM

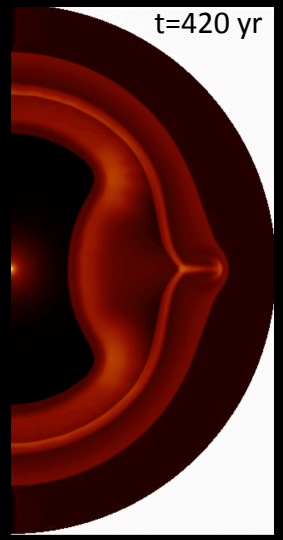
G19+0.3

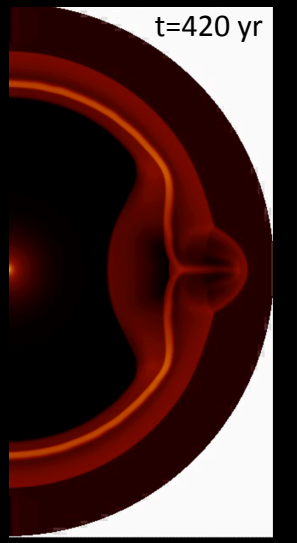
The final ears' morphology mainly depends on:
- The geometry of the bipolar CSM
- The density contrast of the CSM – ISM
- The evolutionary state of the SNR











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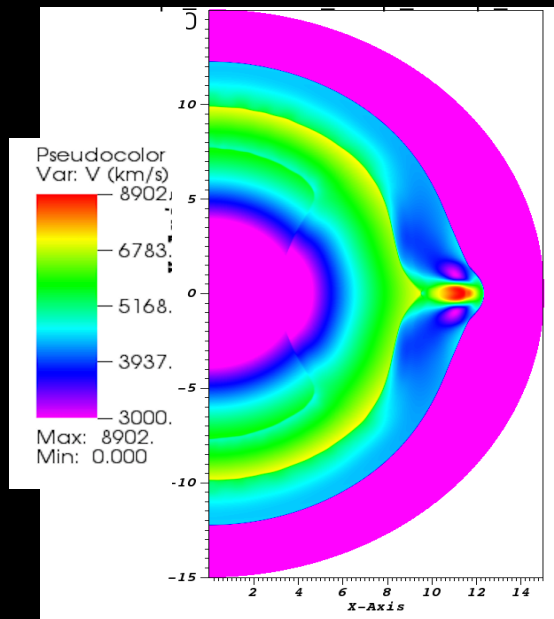
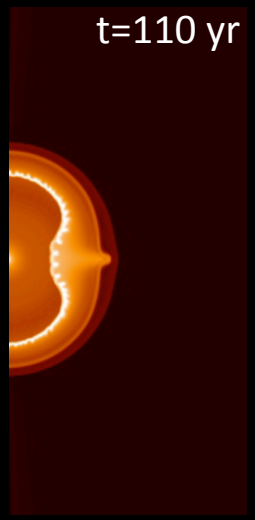
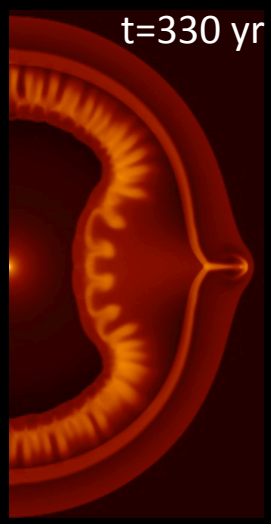


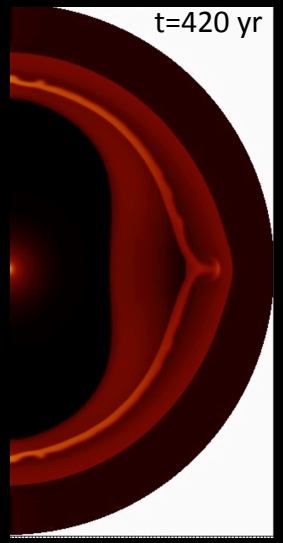
- It looks like a jet

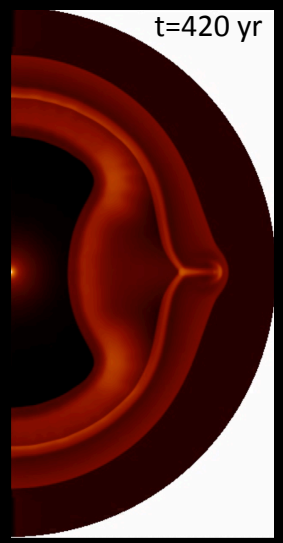
- It moves like a jet

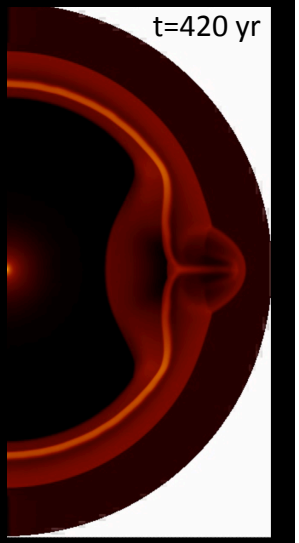
-But it is **not** a jet!











Summary

- Model of SNe Ia + PNe:

→ *PNe seems promising candidates for the CSM observed around SNe Ia as*

- ✧ Can naturally be explained by the SN Ia binary evolution theory
- ✧explain SNe/SNRs Ia diversity

- Henize 2-428 the progenitor of Kepler's SNR?
  - ✧Bridges all the demands of theoretical models:
    - ✧CSM composition and distribution
    - ✧ Aligned to the demands imposed by the X-ray spectra
    - ✧Explains the SNR 'ears' formation
  - ✧Detailed 3D modeling is needed (in preparation)

- SNRs revealing antisymmetric lobes (ears)
  - ✧Interaction history with a bipolar circumstellar structure (also applicable for core collapse SNe)
  - ✧Ears are formed in the equatorial plane of the progenitor binary (and not at the poles as the jets theory demands)