Formation and X-ray emission from Hot Bubbles in Planetary Nebulae

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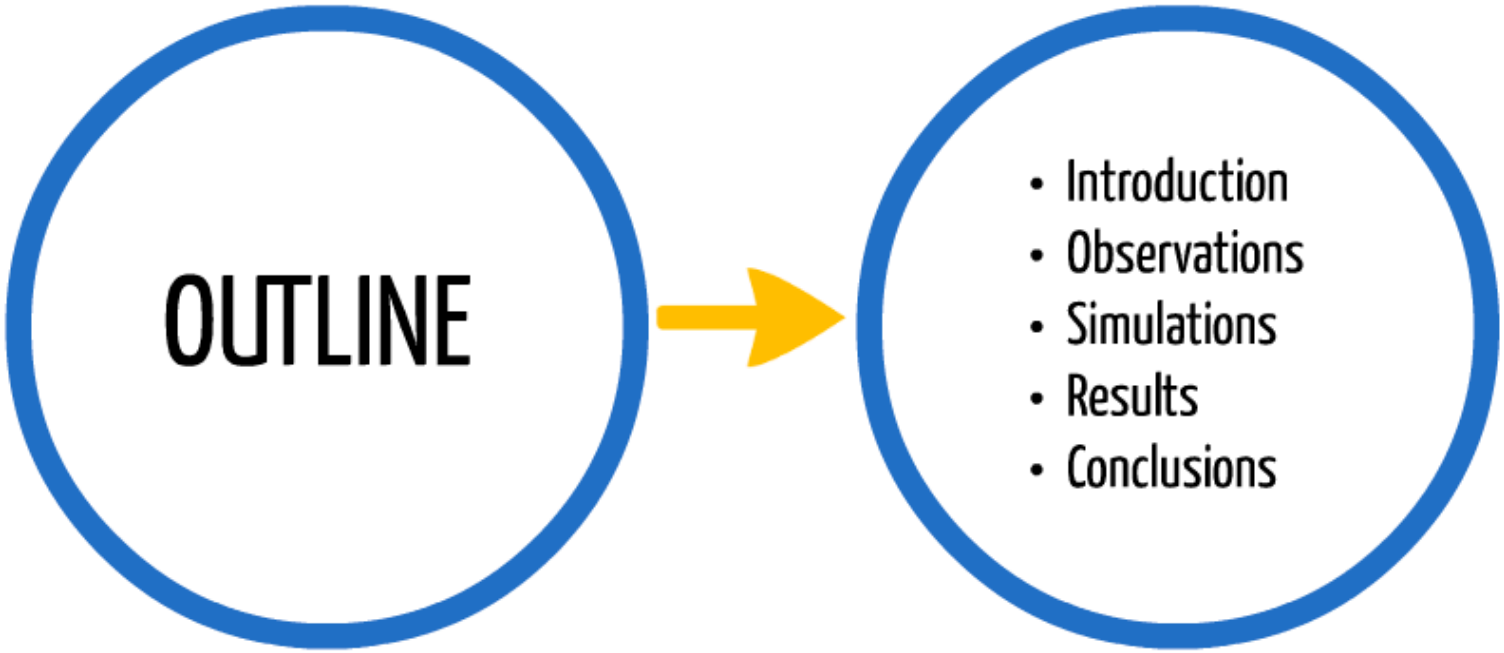
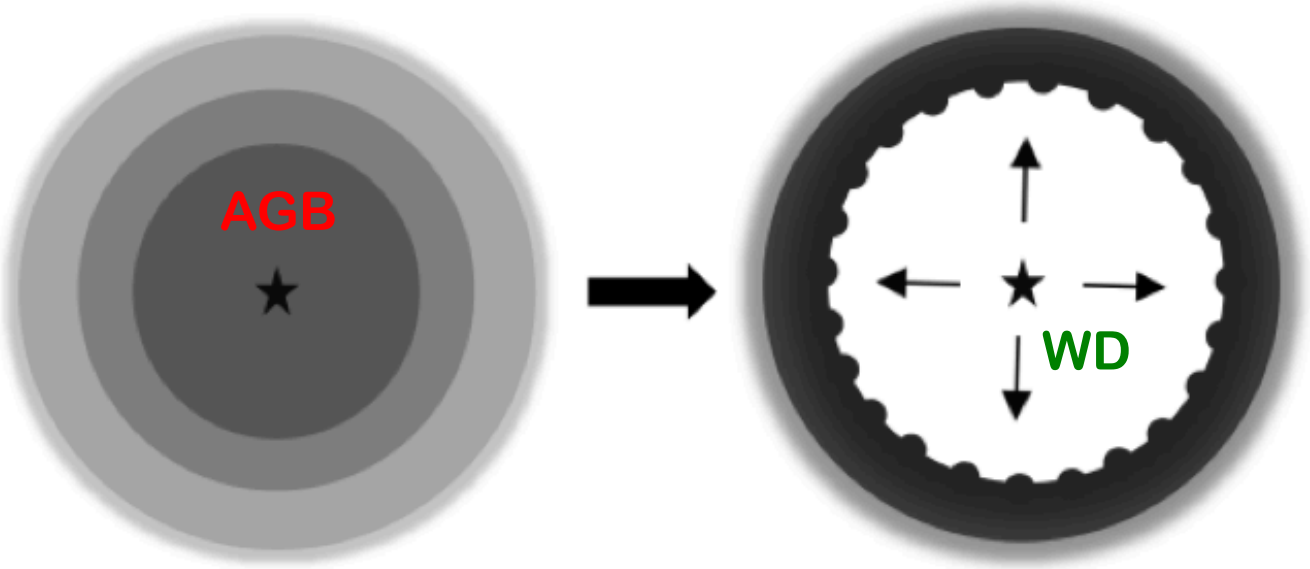


Introduction

A simple view of Planetary Nebulae (PNe) formation
INTERACTING STELLAR WINDS (ISW) scenario



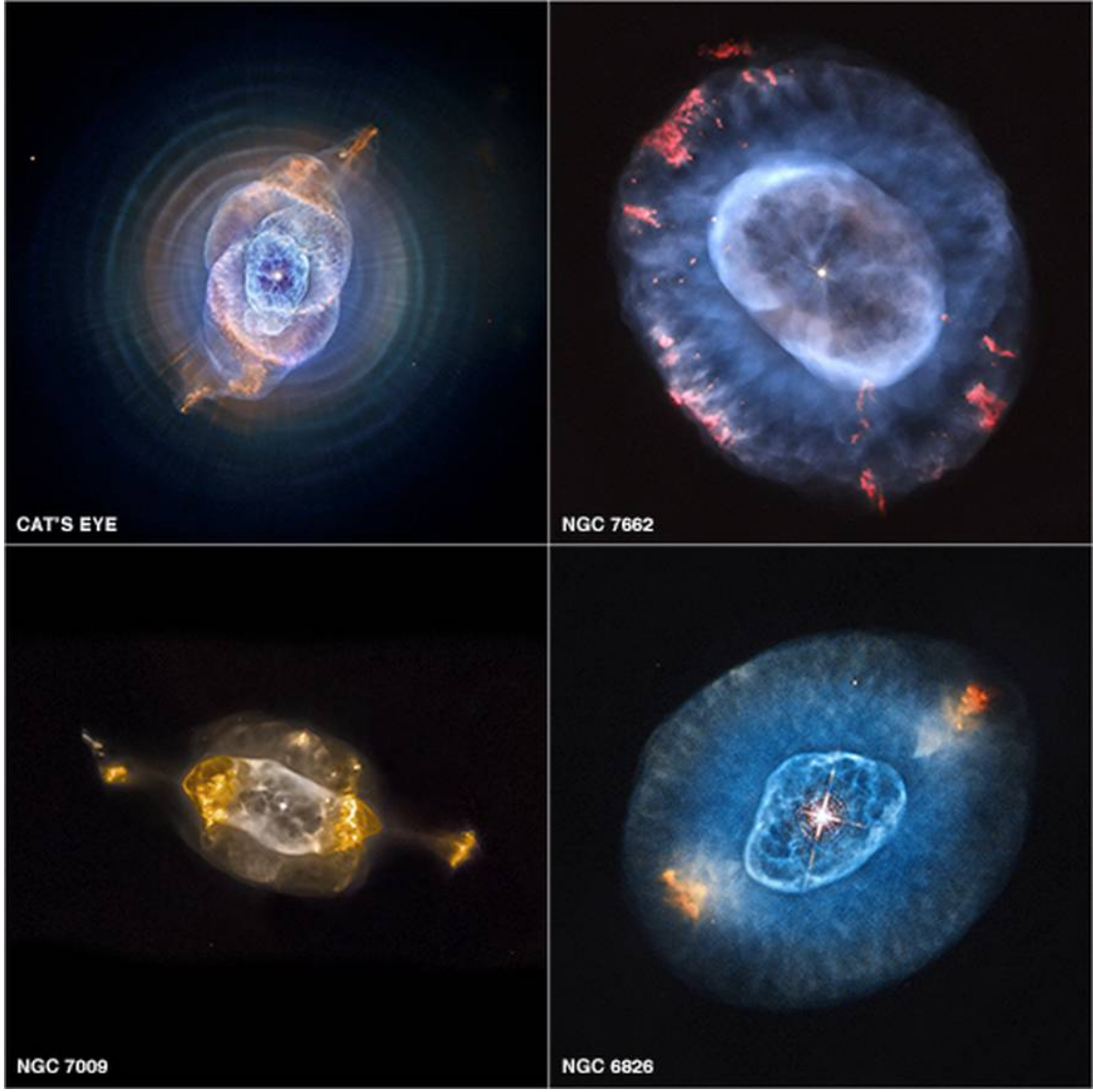
Kwok + (1978)
Balick (1987)

AGB = asymptotic giant branch
WD= white dwarf

Observations

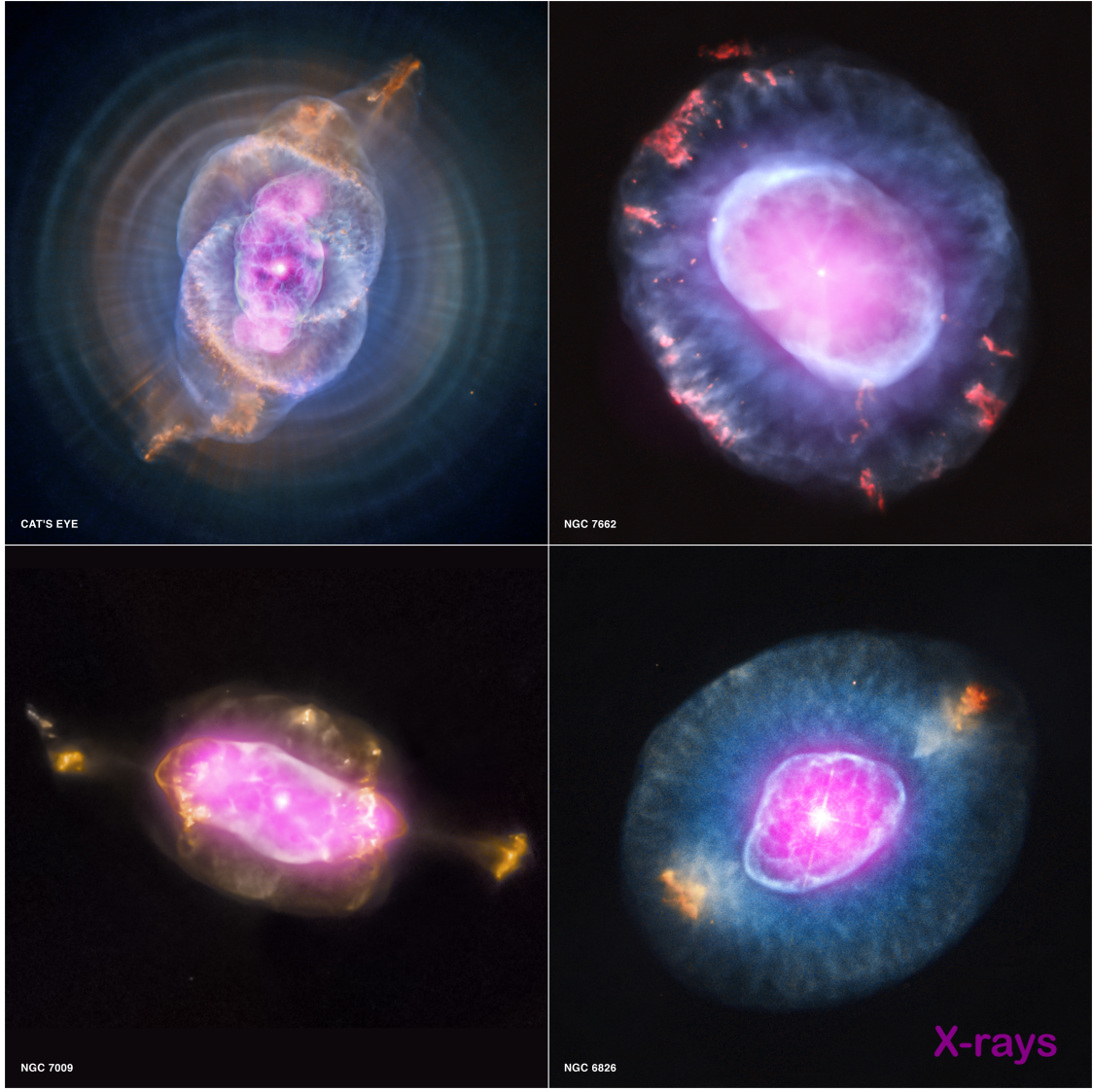
Kastner + (2012)
CHANPLANS
Chandra

- All PNe with d<1.5 kpc
- X-ray emission from 70 %
  - Diffuse
  - WD
  - Both



Observations

Diffuse X-ray emission

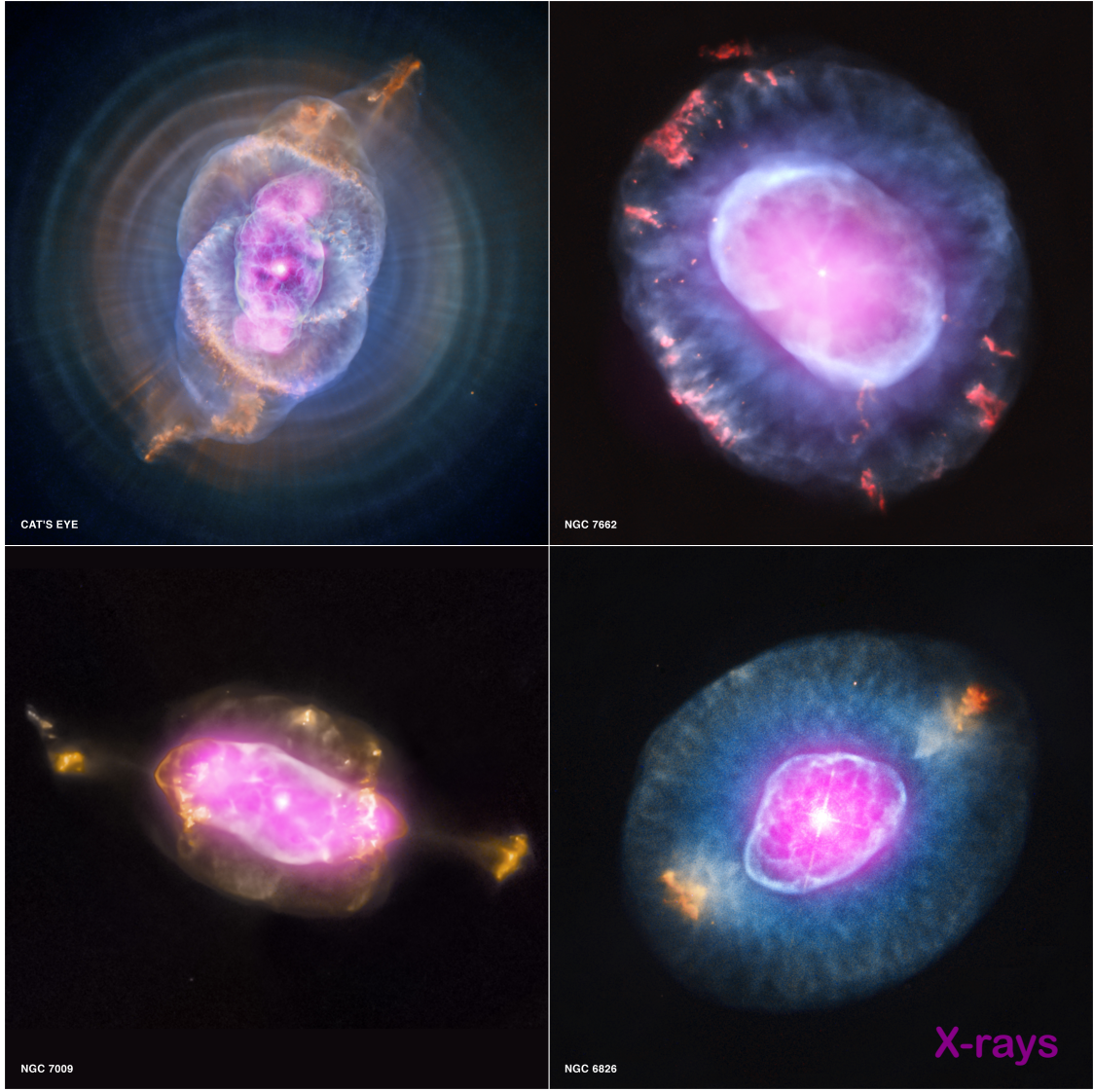


Observations

Diffuse X-ray emission

↓

Hot gas
$T \sim 10^6$ K



Shocked gas inside PNe should have

$$T \sim 10^7 - 10^8 \text{ K}$$

as (Dyson & Williams 1997)

$$T \sim V_\infty^2$$

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$$T \sim 10^7 - 10^8 \text{ K}$$

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$$T \sim V_\infty^2$$

In high contrast with the observed values

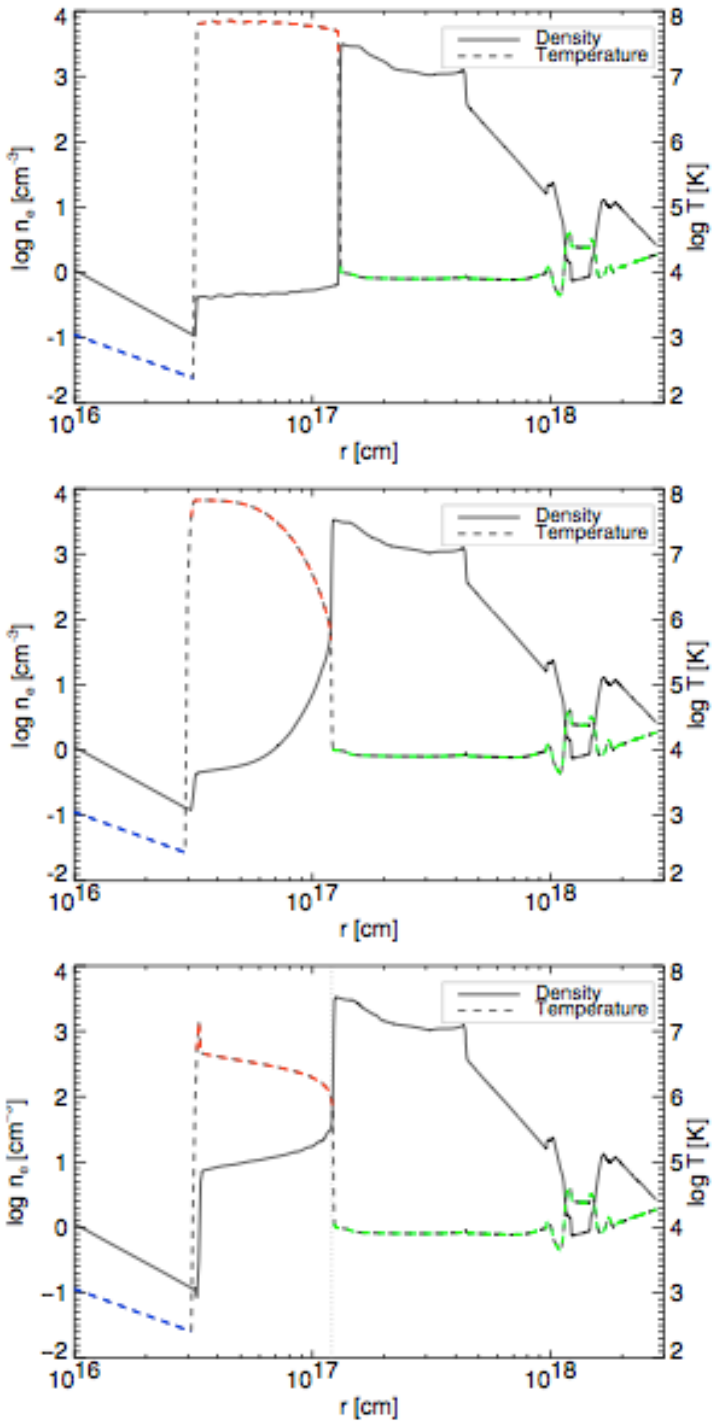
Simulations

Steffen + (2008)

- **1D radiative-hydrodynamic simulations**

- **Detailed treatment on thes stellar wind parameters**

THERMAL CONDUCTION

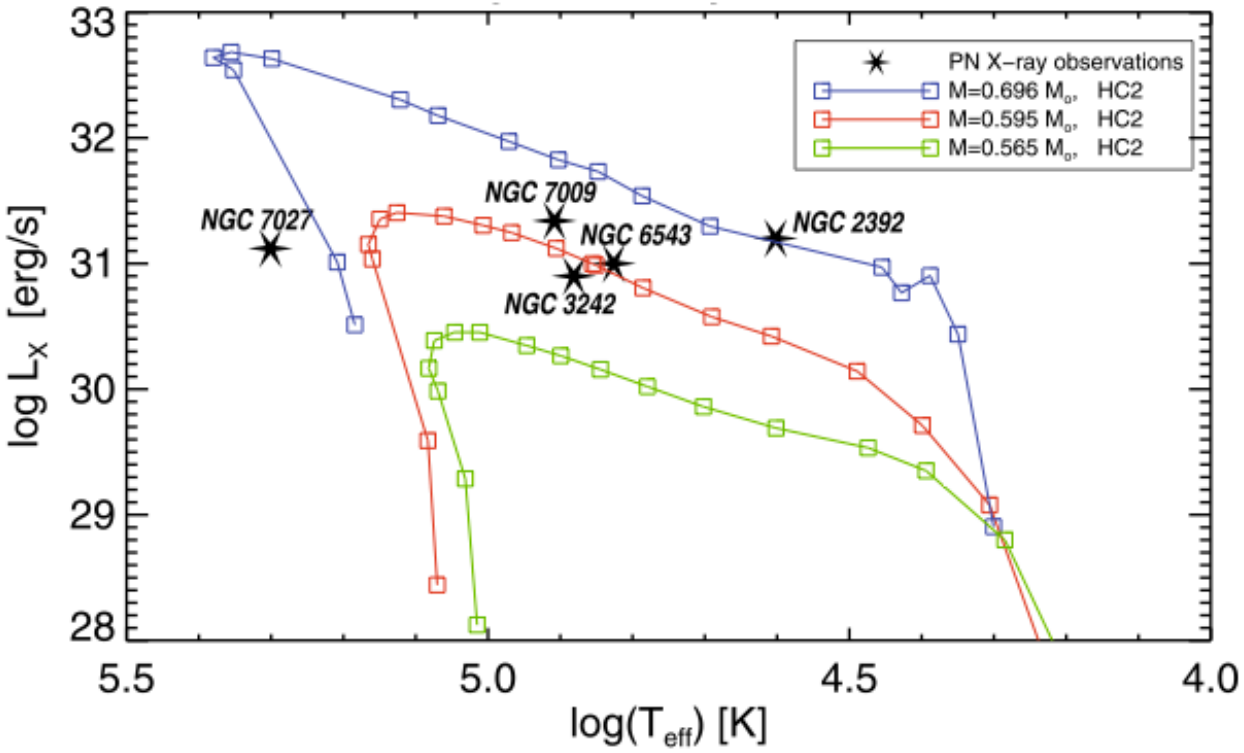


Simulations

Steffen + (2008)

- **1D radiative-hydrodynamic simulations**

- **Detailed treatment on the stellar wind parameters**



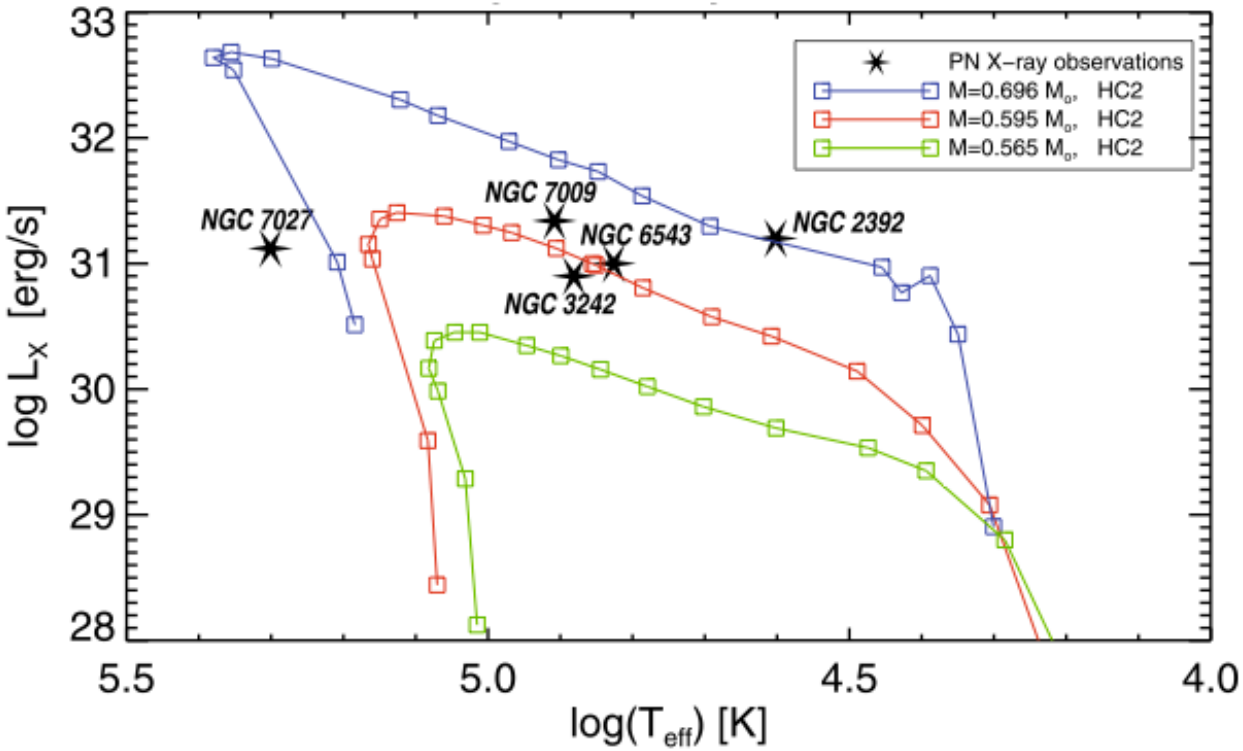
Simulations

Steffen + (2008)

- **1D radiative-hydrodynamic simulations**

- **Detailed treatment on the stellar wind parameters**

No realistic results are achieved if Thermal Conduction is not included.



Simulations

Our work: Toalá & Arthur in prep.

2D radiative-hydrodynamic simulations

Simulations

Our work: Toalá & Arthur in prep.

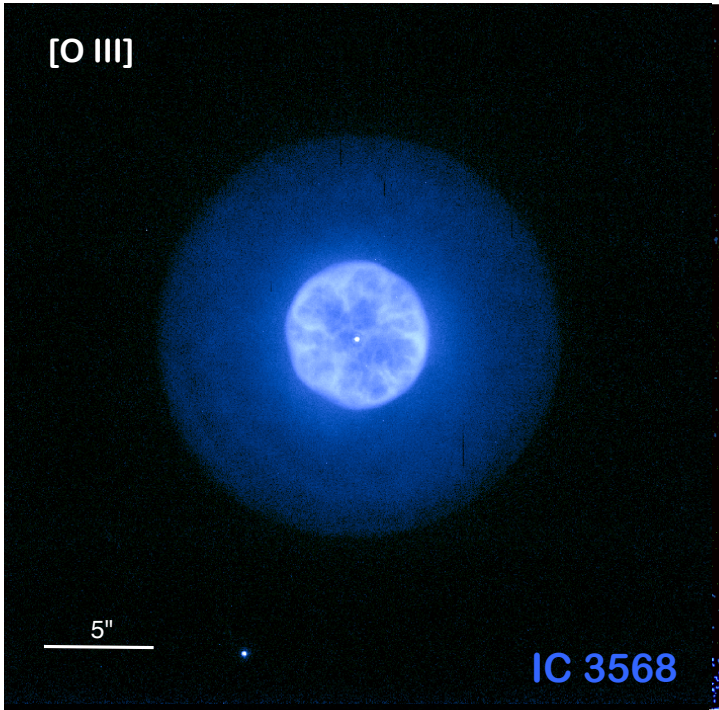
2D radiative-hydrodynamic simulations

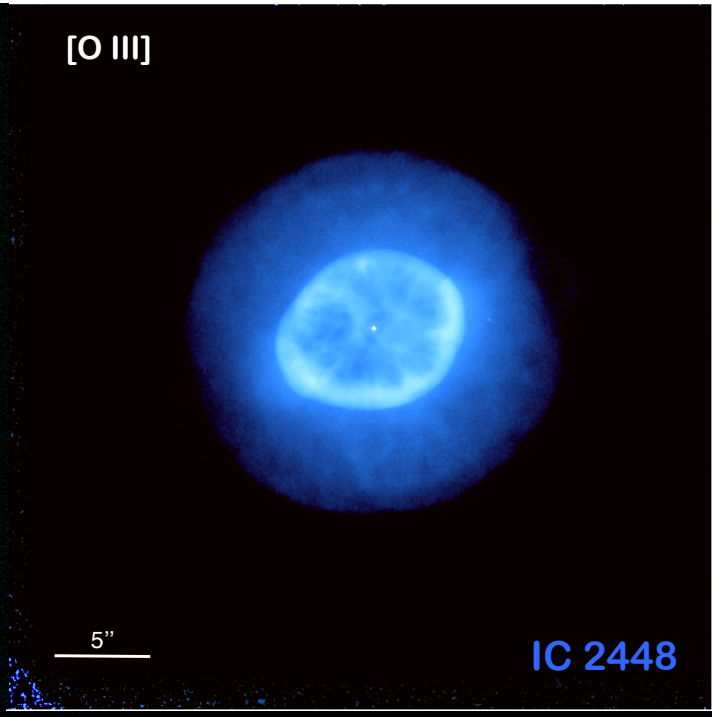
INSTABILITIES in Hot Bubbles

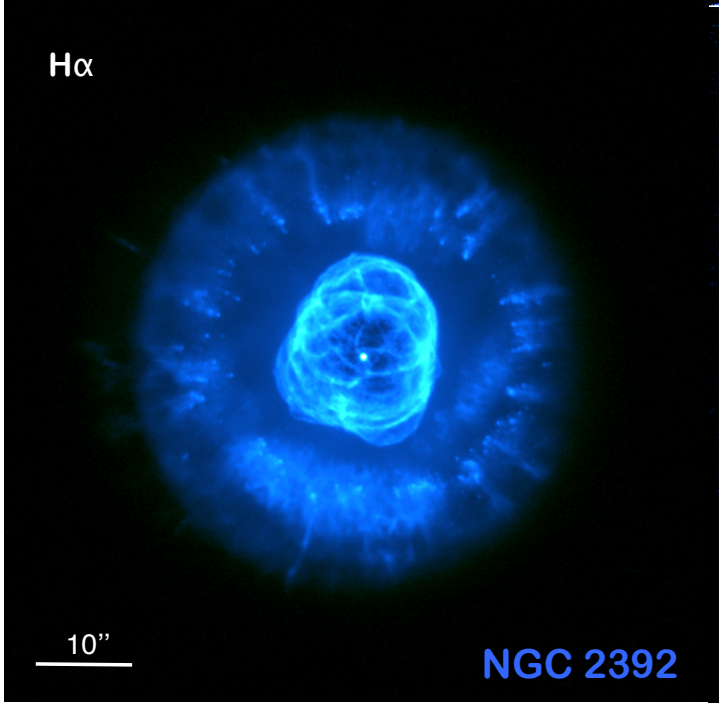
- **Velocity (WD)**
- **Density profile (AGB)**
- **Radiation field**

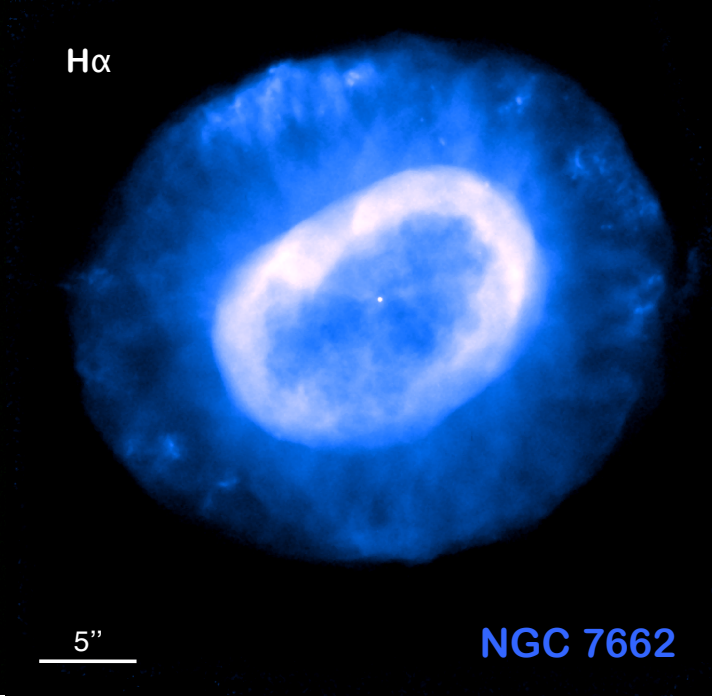
Some examples…

Hubble Images





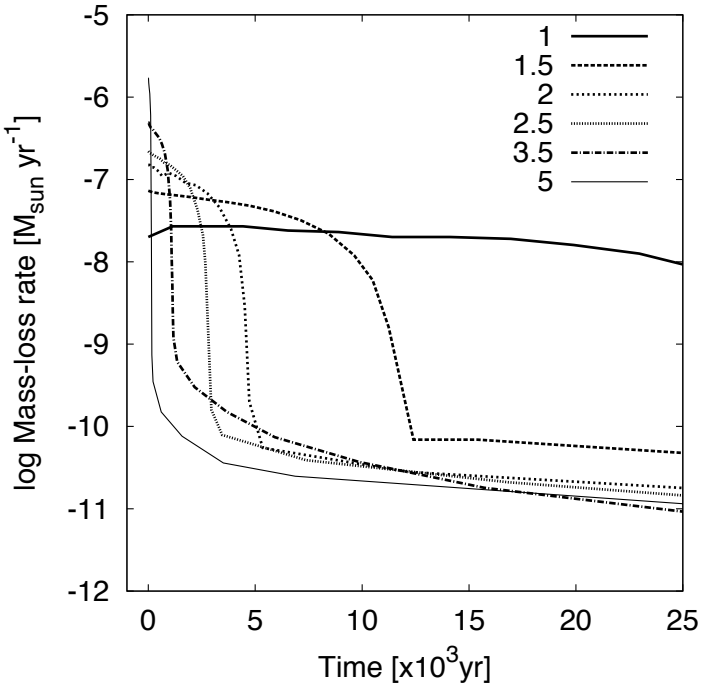


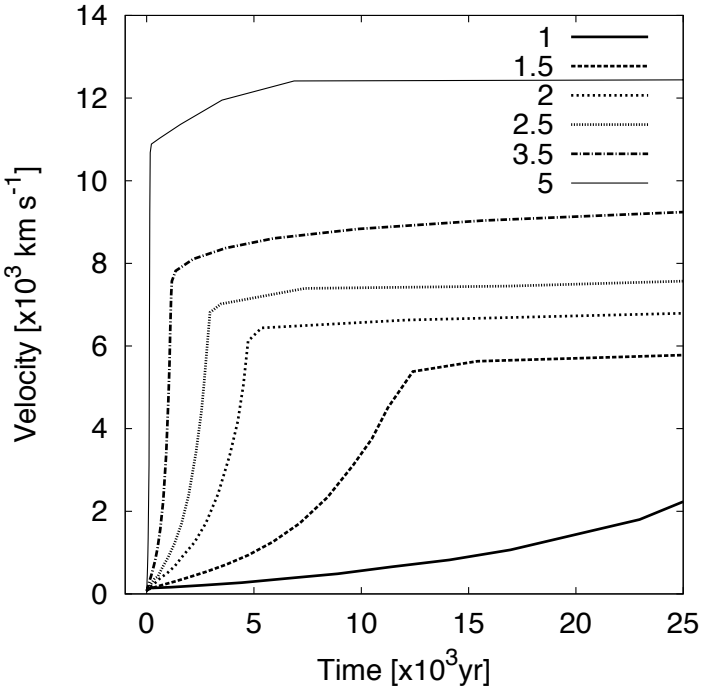


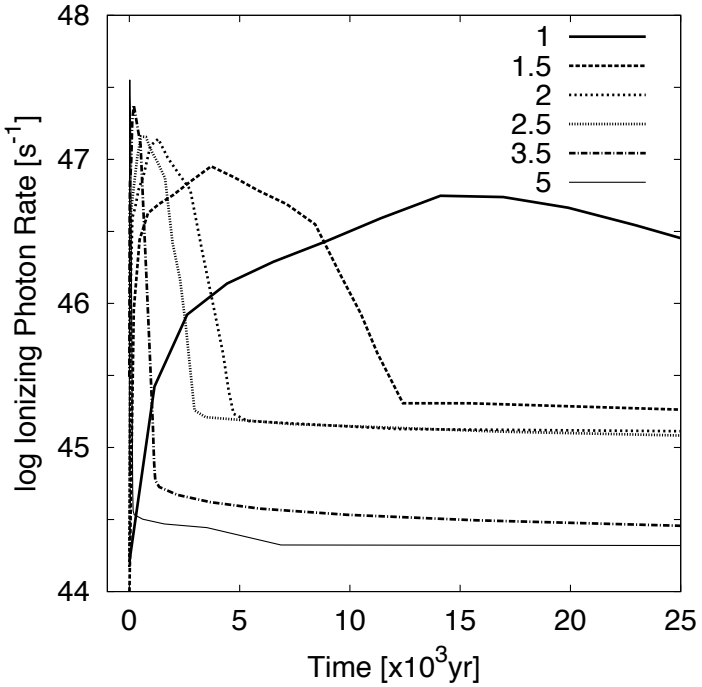
Results

Vassiliadis & Wood (1993,1994)
For AGB and WD phases

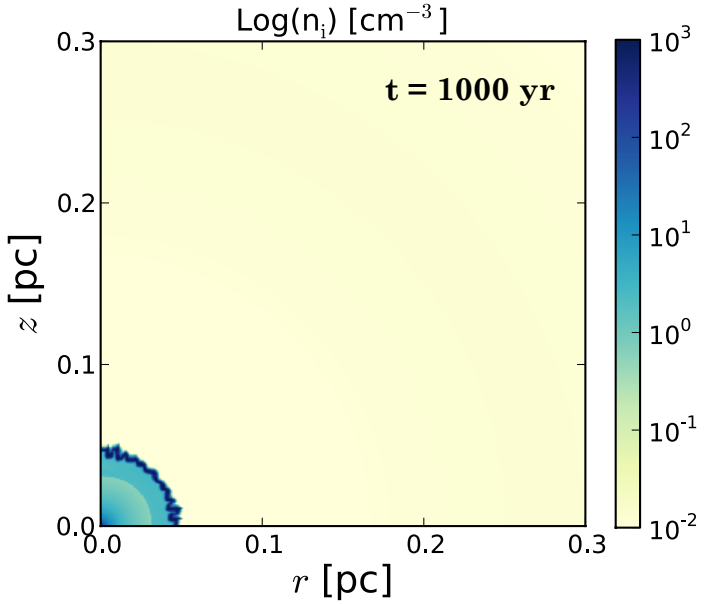
WM-Basic code
(Pauldrach + 2012, and references therein)

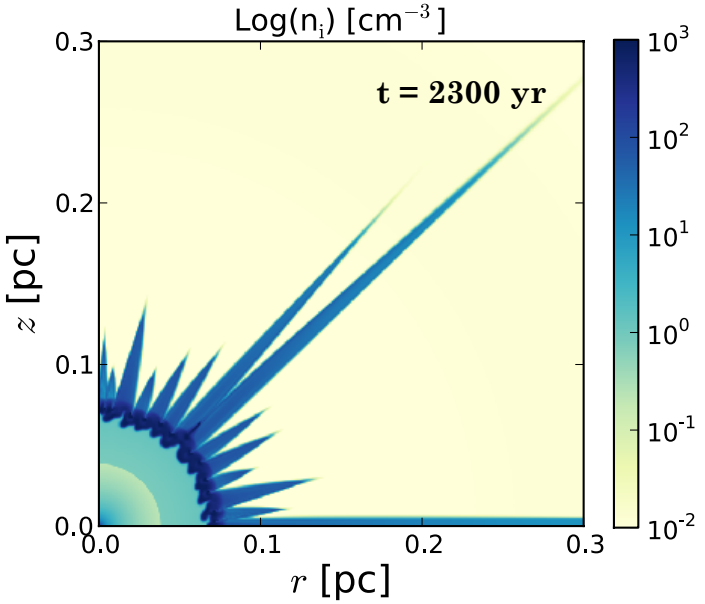


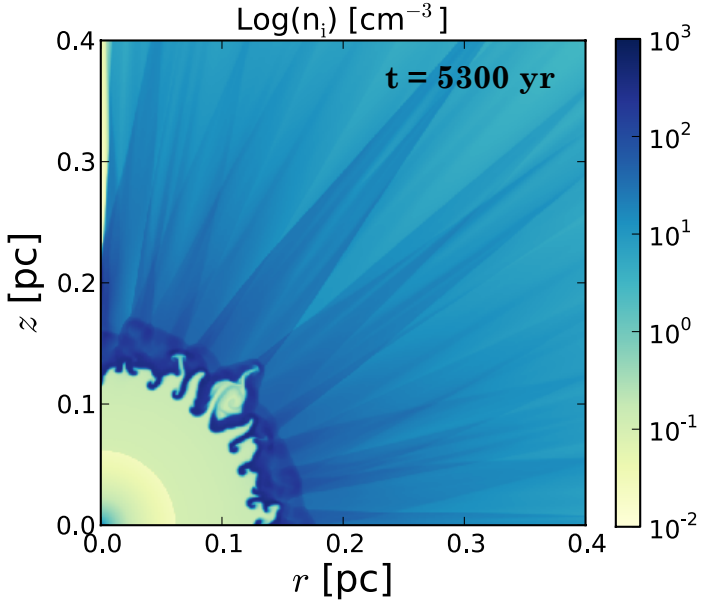


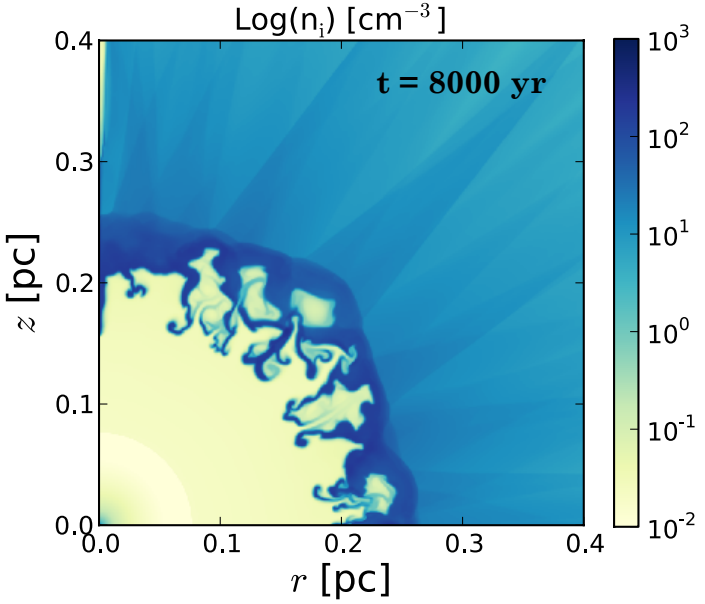


Results: 1.5 $M_\odot$

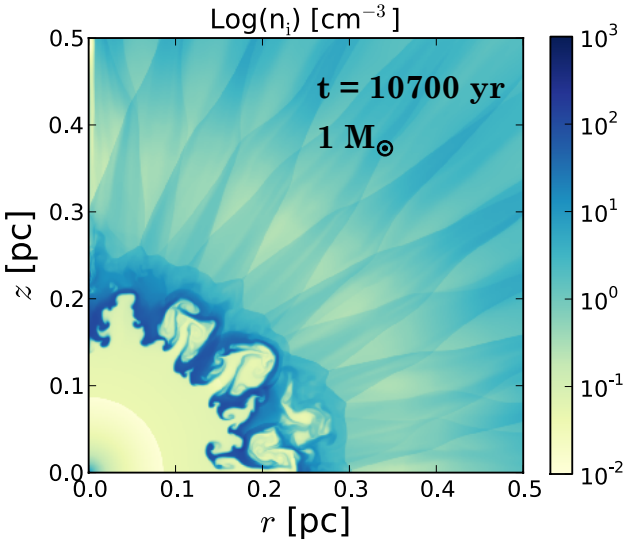


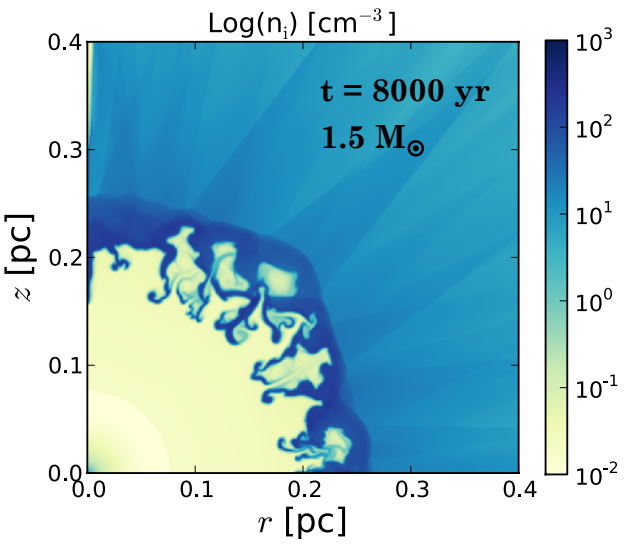


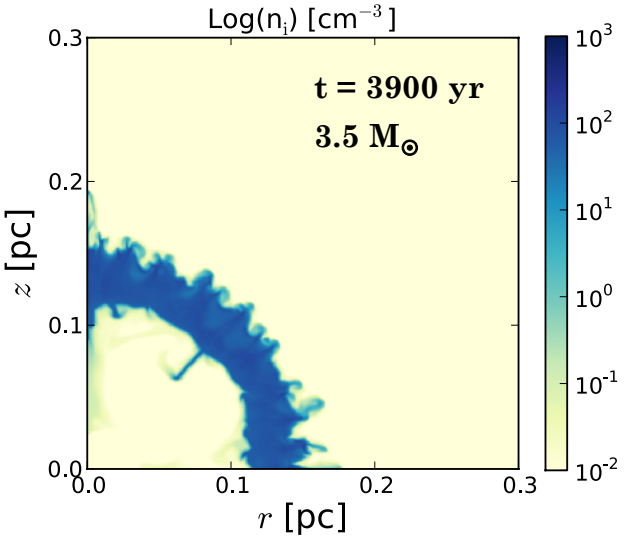


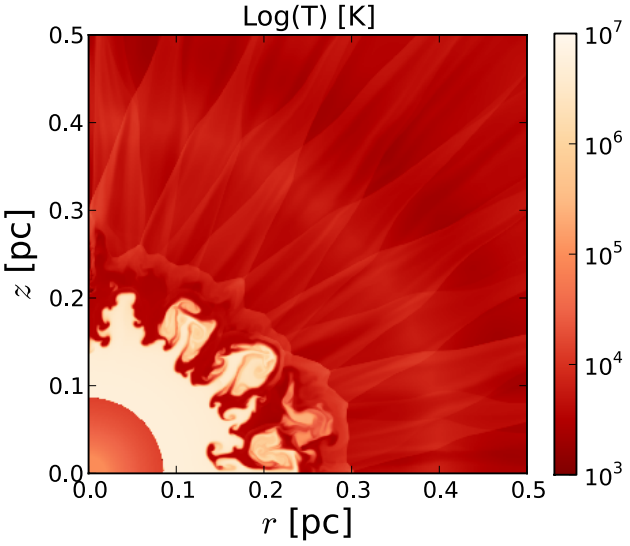


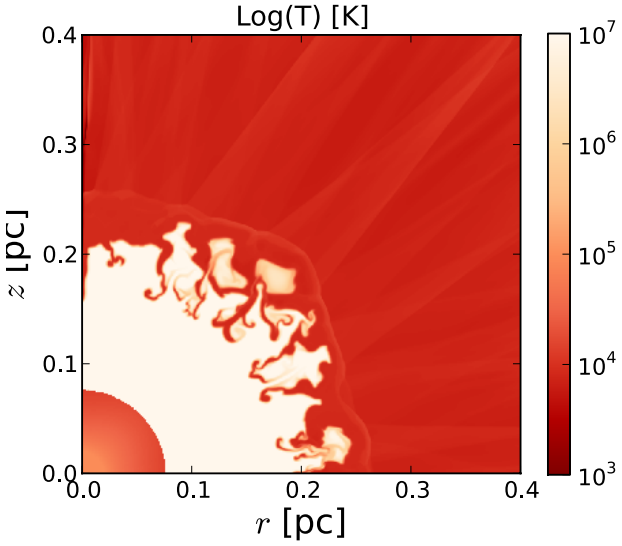
Results


Log(n$_i$) [cm^{-3}]
t = 10700 yr
1 M$_\odot$
z [pc]
r [pc]


Log(n$_i$) [cm^{-3}]
t = 8000 yr
1.5 M$_\odot$
z [pc]
r [pc]


Log(n$_i$) [cm^{-3}]
t = 3900 yr
3.5 M$_\odot$
z [pc]
r [pc]


Log(T) [K]
z [pc]
r [pc]


Log(T) [K]
z [pc]
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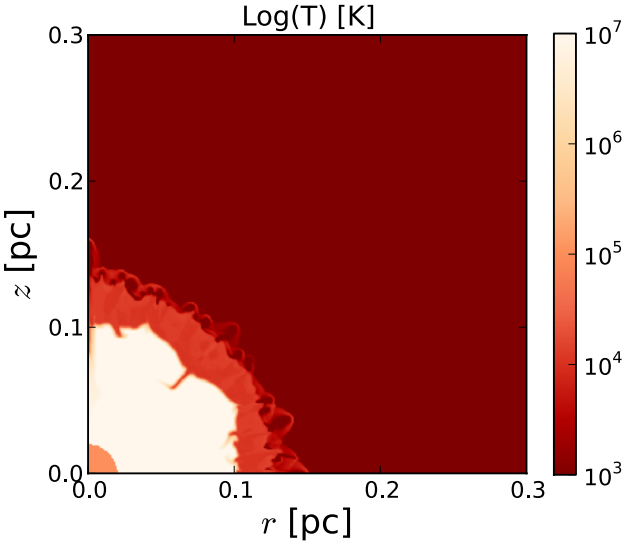
Log(T) [K]
z [pc]
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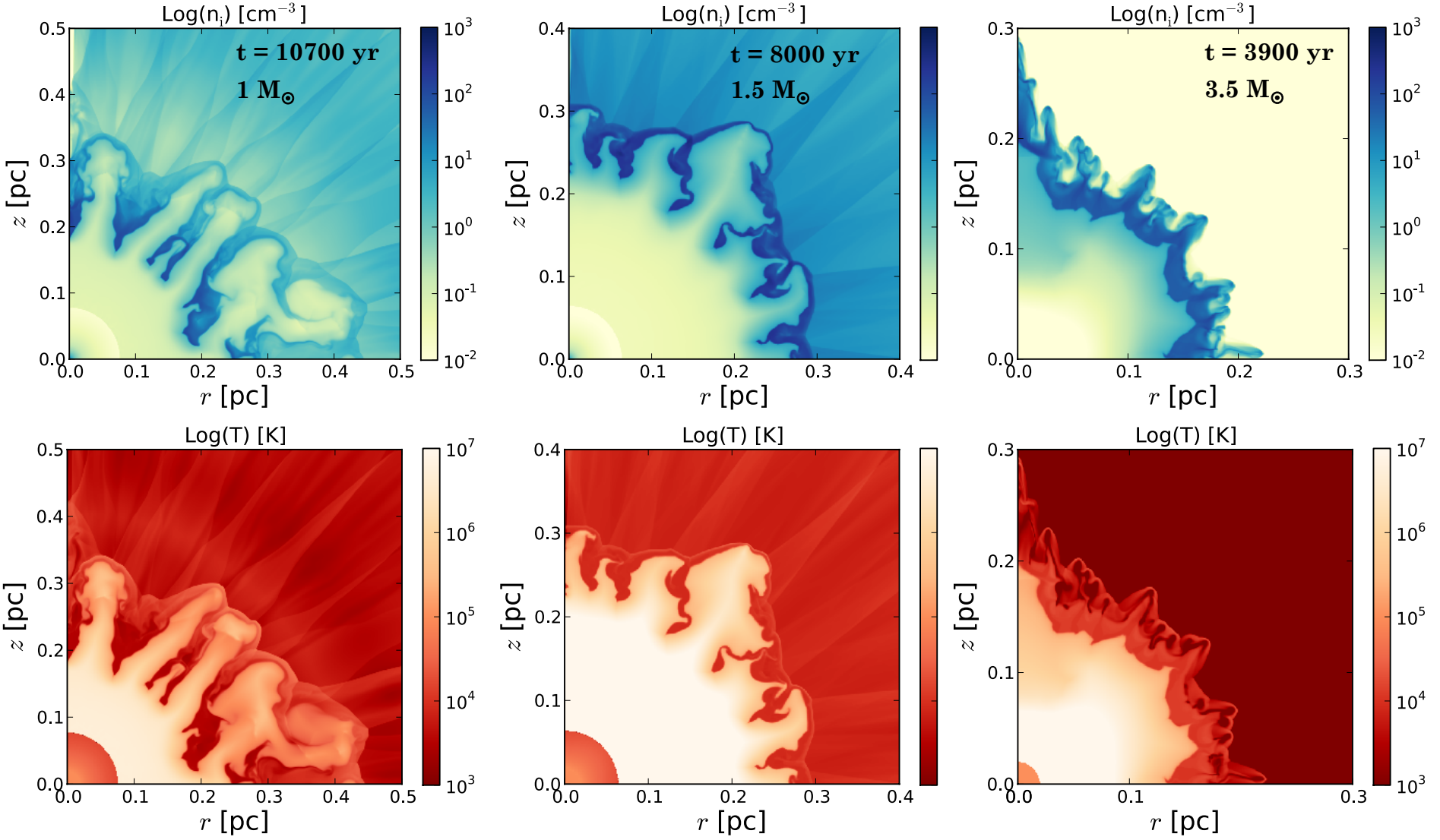
Results

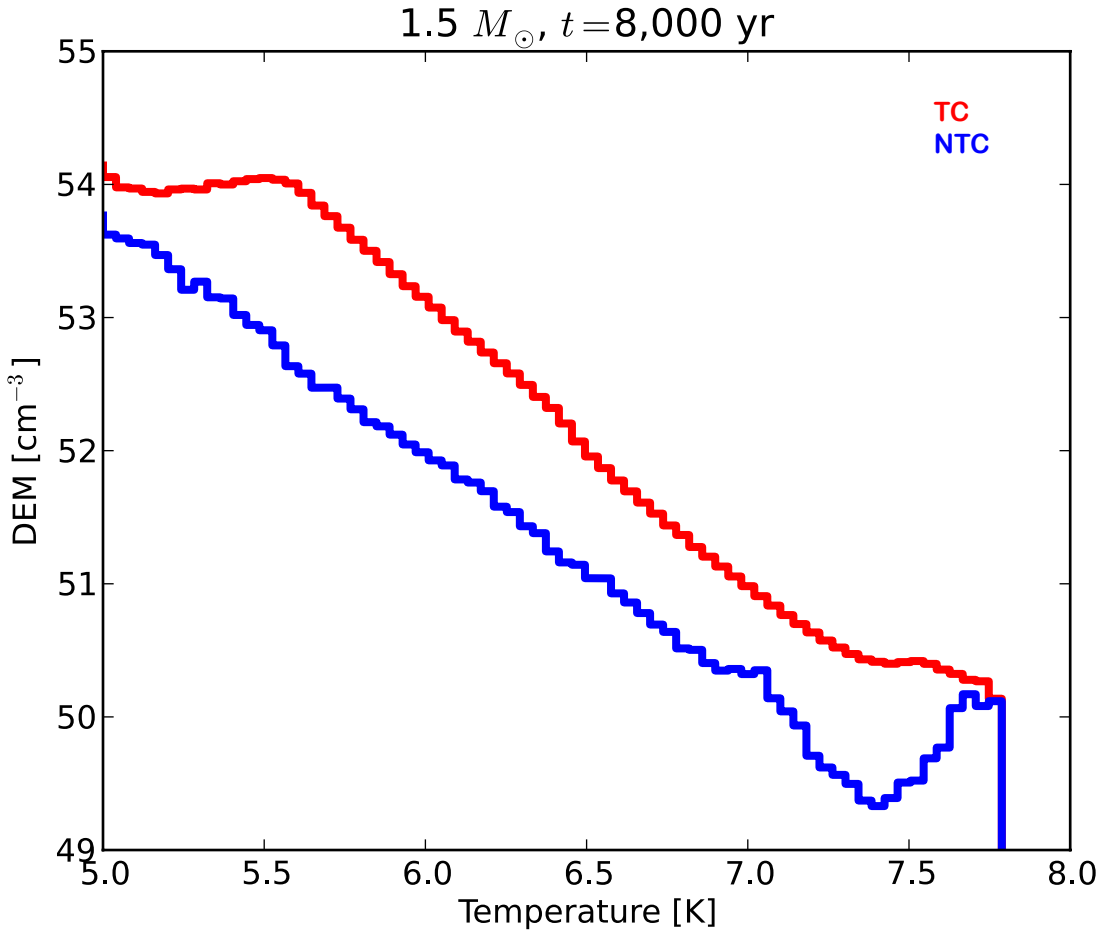
Thermal Conduction



Results

Synthetic X-ray Emission

CHIANTI database



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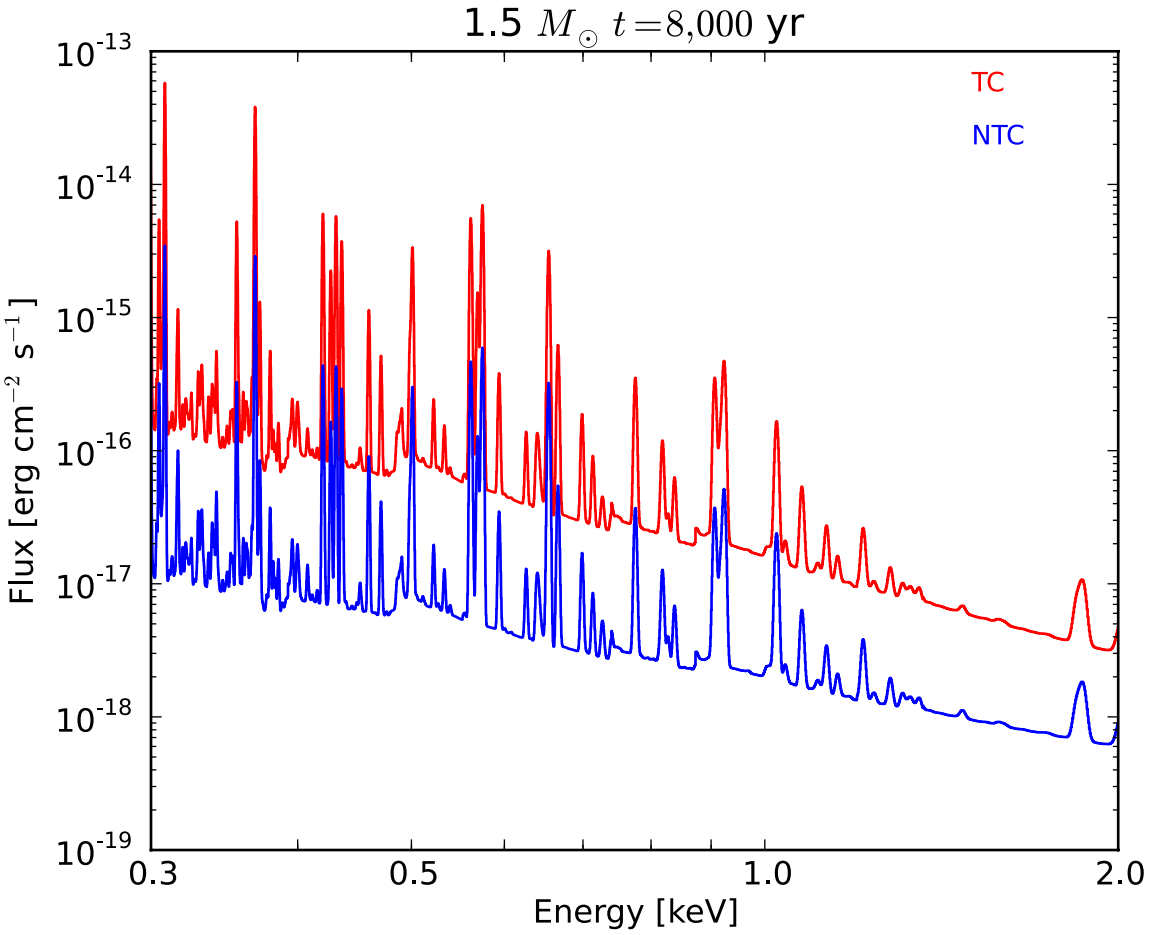
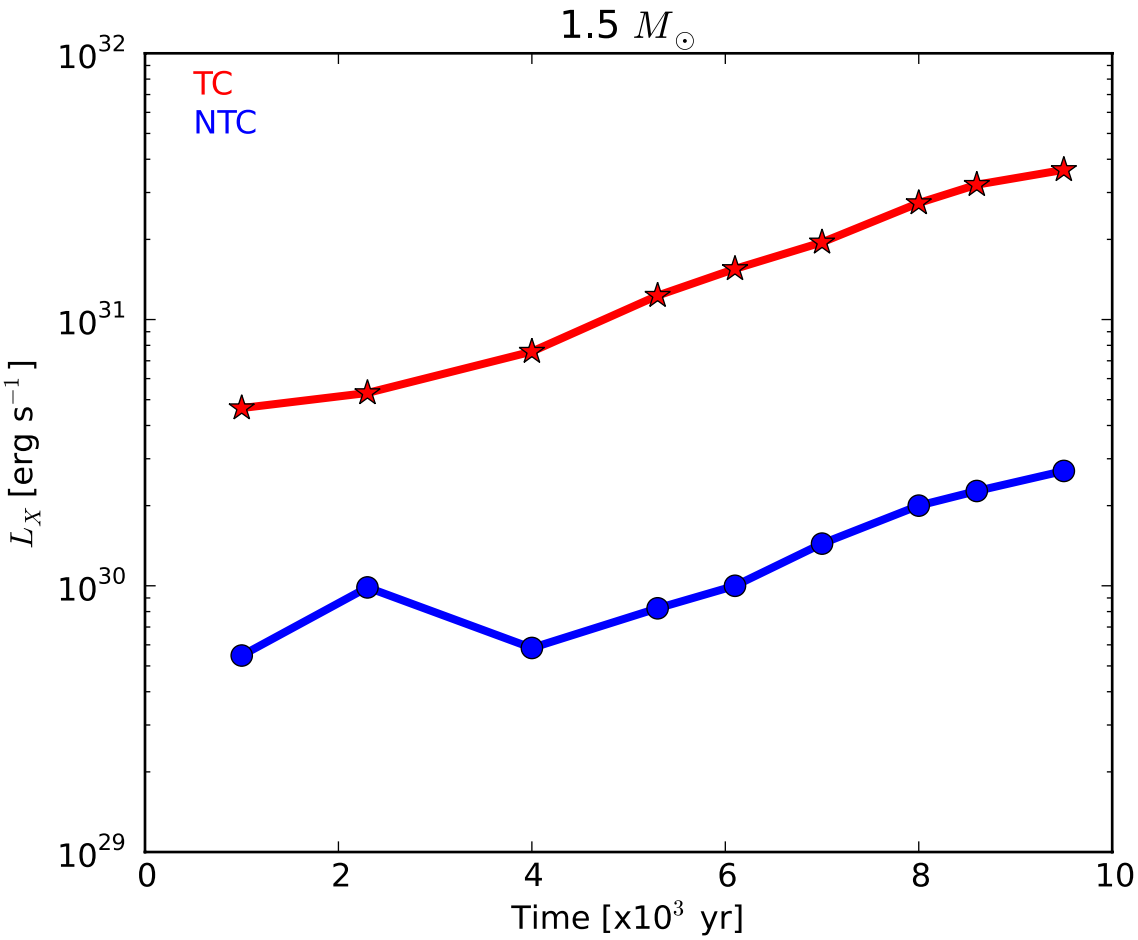


Results

1.5 $M_\odot$

L_X [0.3 – 2 keV]



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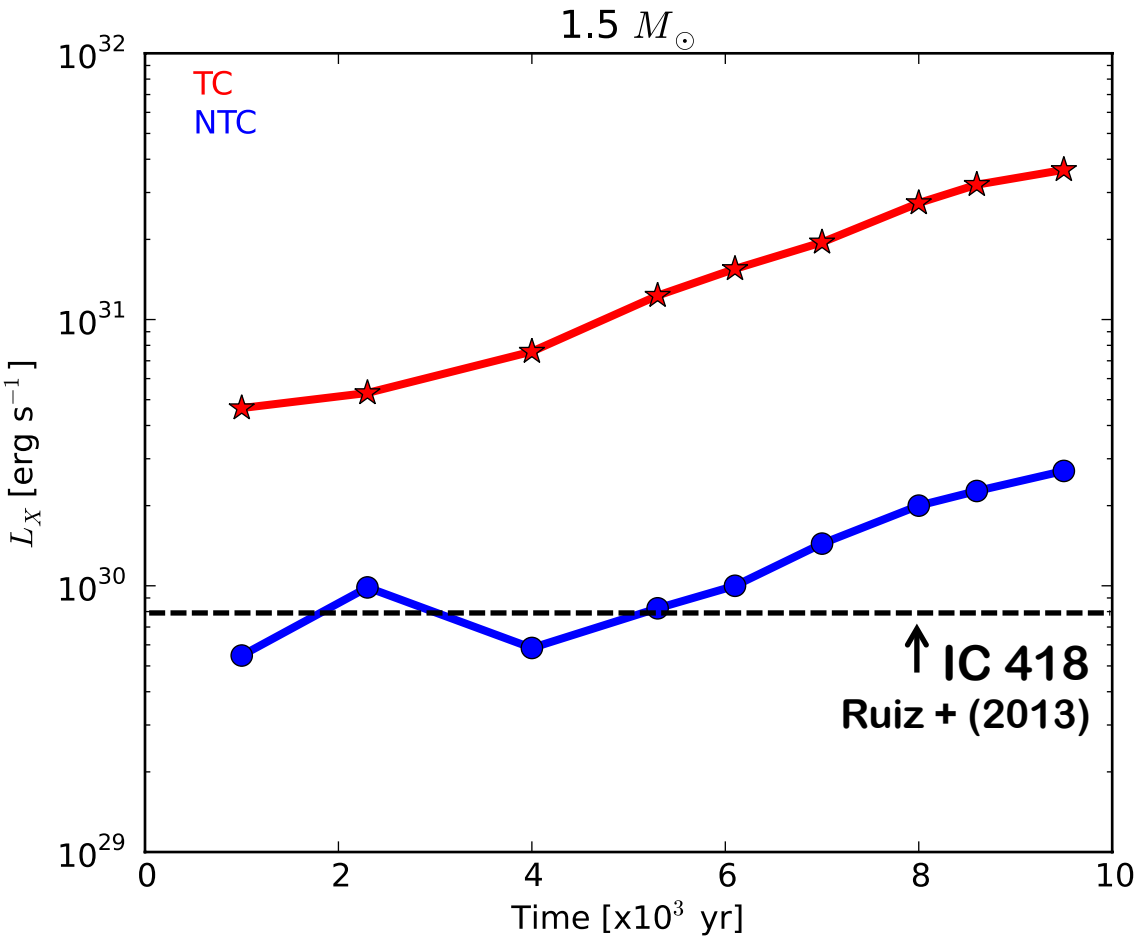


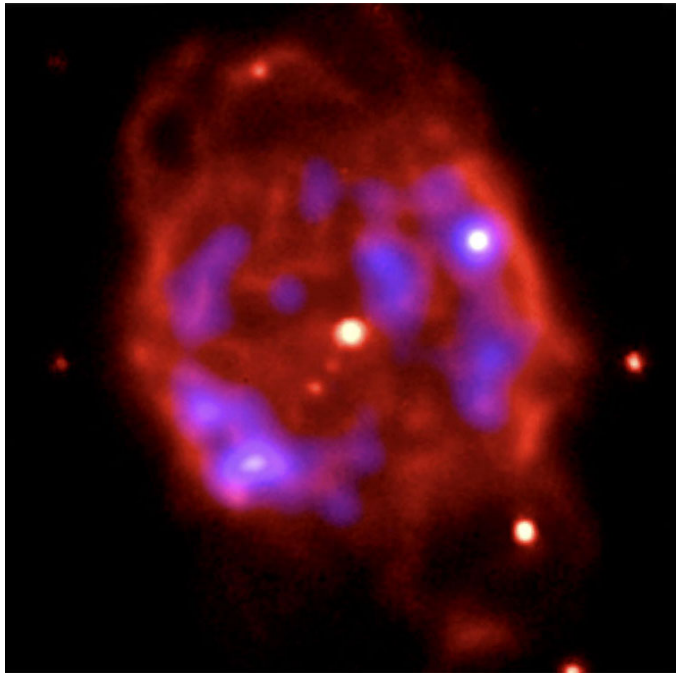
Conclusions/Comments

- **2D radiative-hydrodynamic simulations develop instabilities able to include mass in the hot bubble, reducing the temperature of the hot gas.**

- **Instabilities 'define' the early configuration of the ionized material**

- **Models without thermal conduction achieve to explain naturally the X-ray emission of some PNe.**

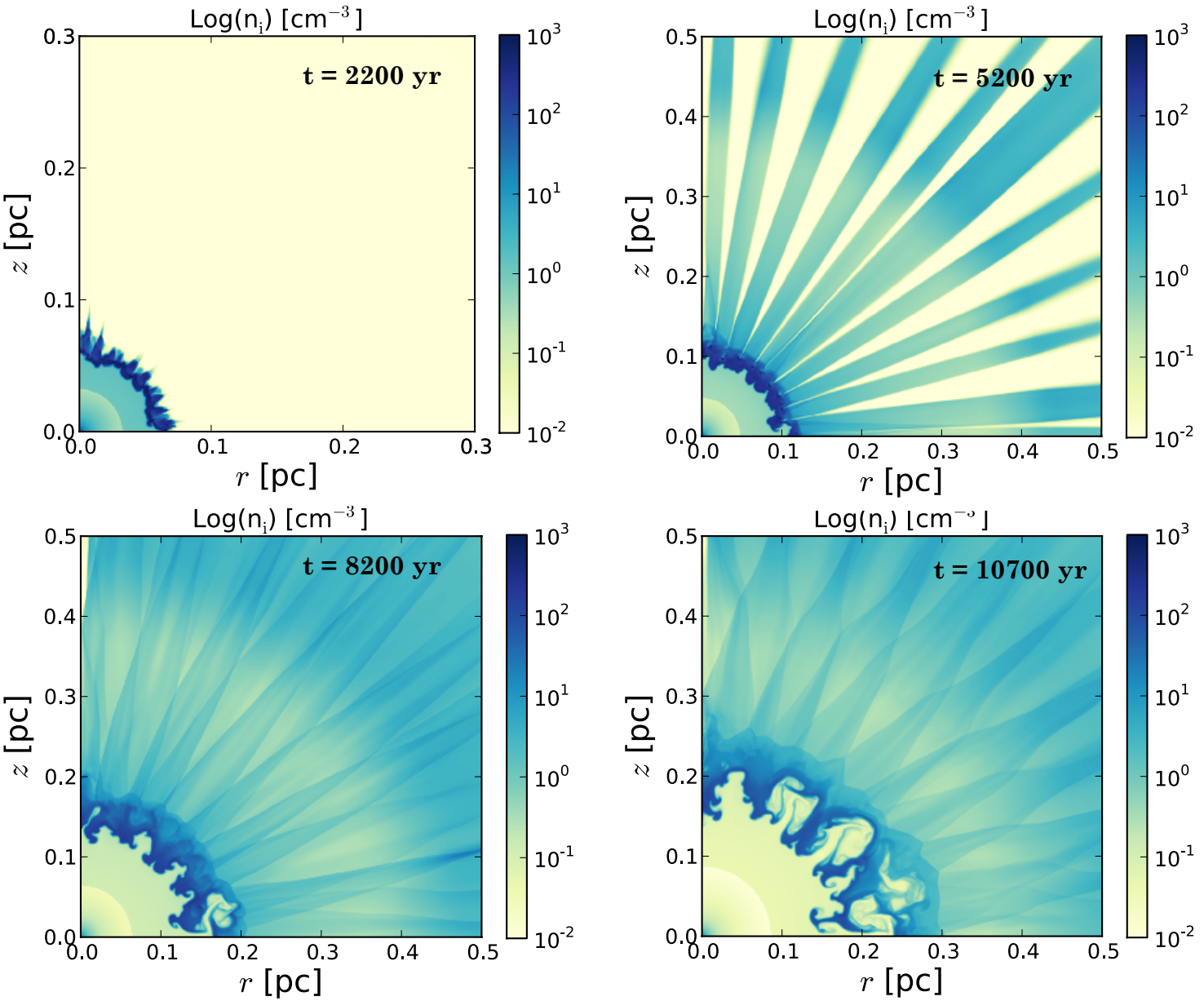
- **IF magnetic fields are important hydrodynamical instabilities should be important (NGC 40).**



Montez + (2005)

GRACIAS – THANK YOU

Hot Bubble Formation: 1 $M_\odot$



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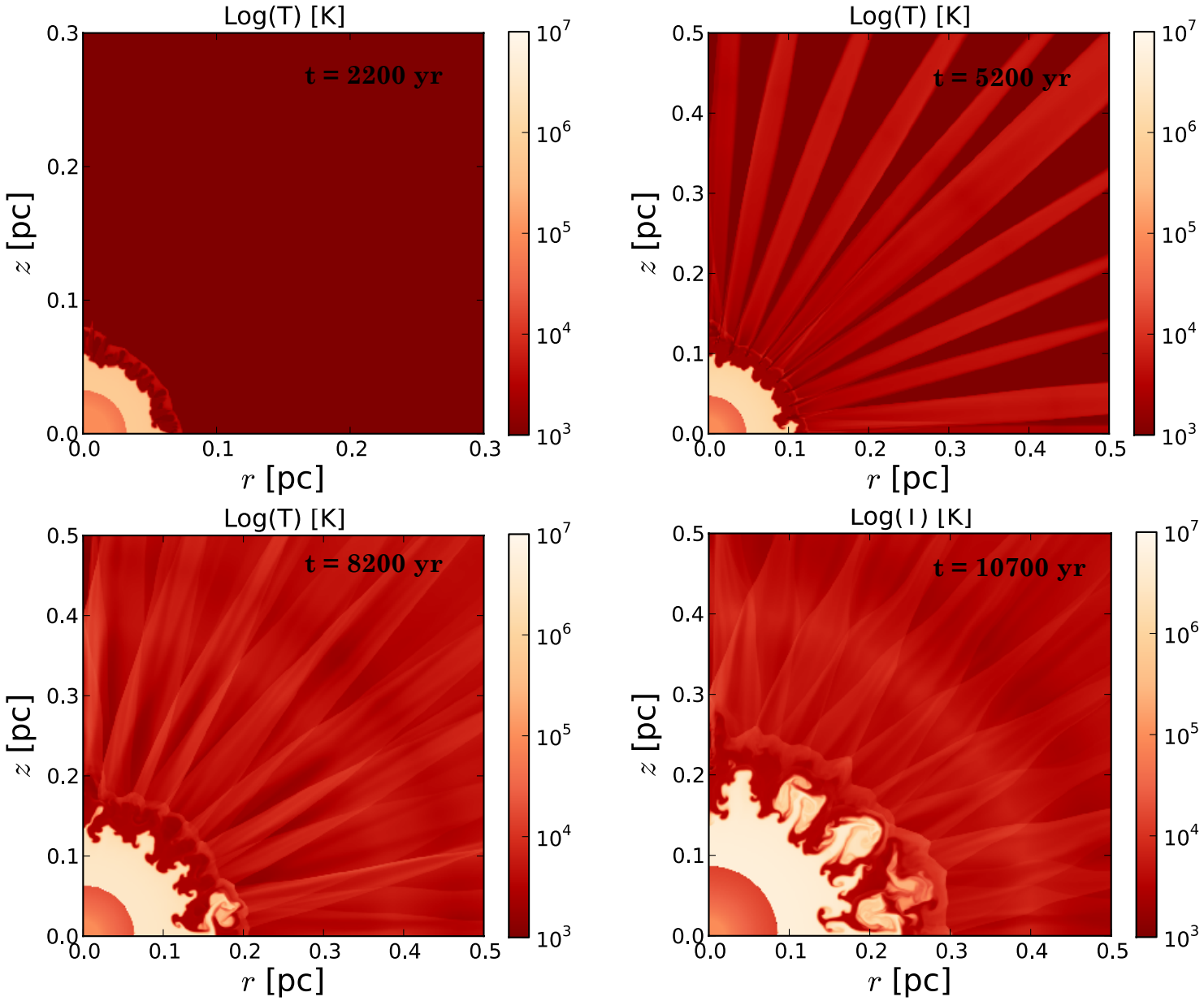

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