Inflating HUGE bubbles in our galaxy and others far, far away…

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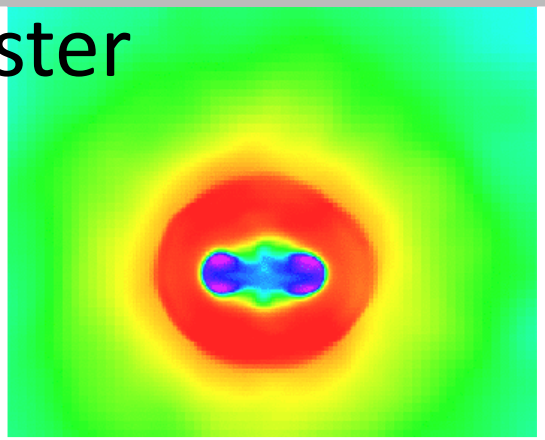
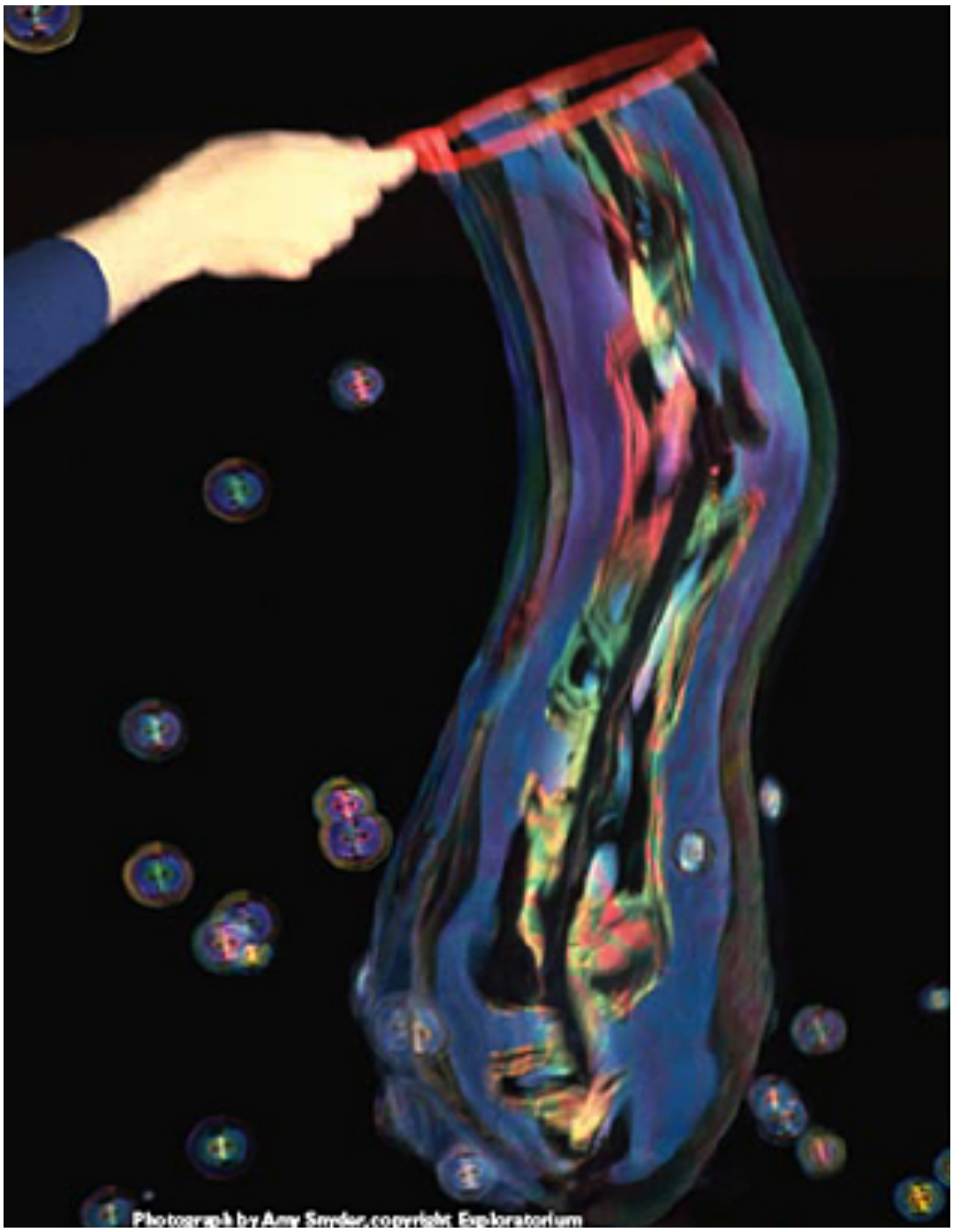
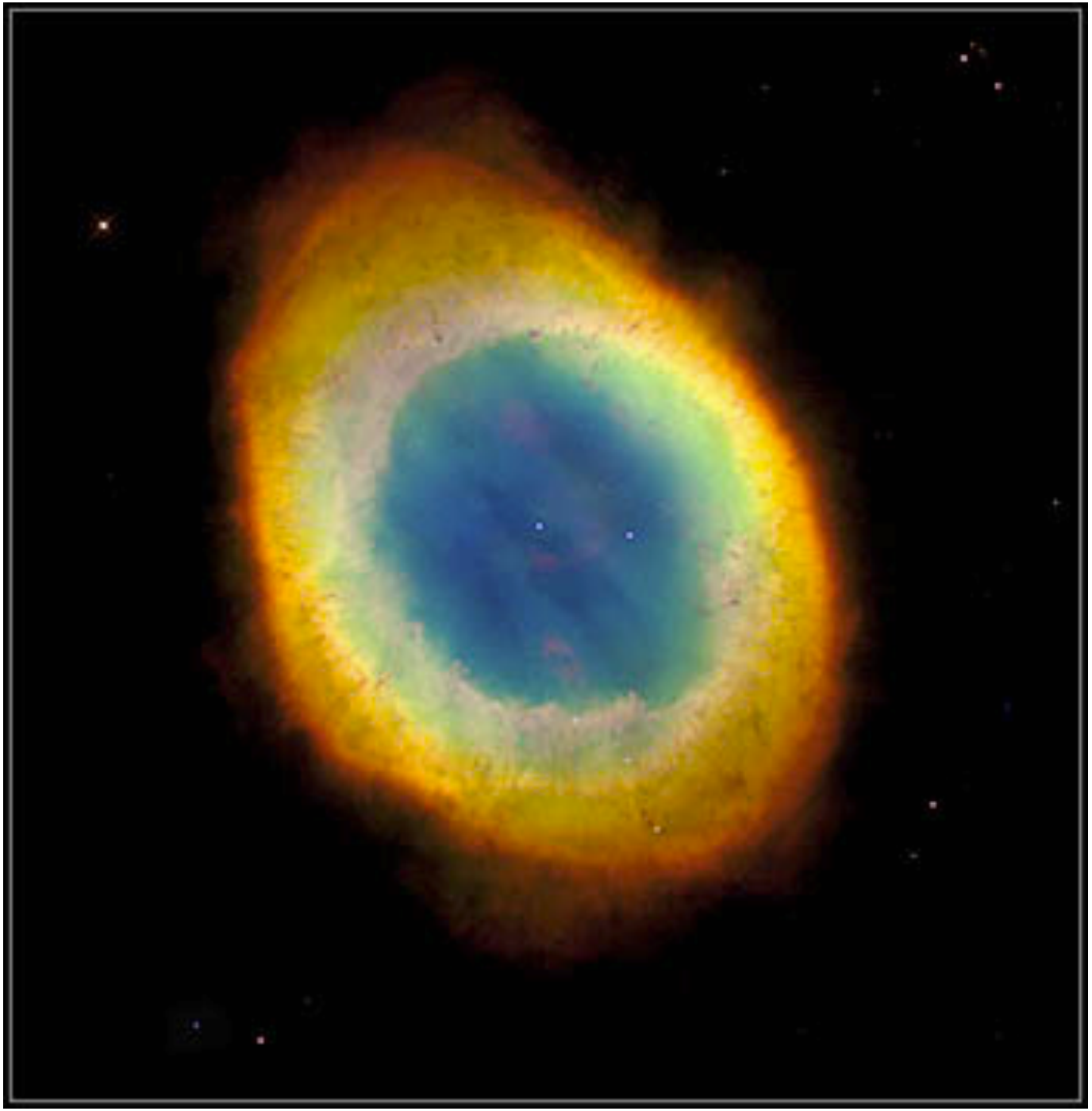
Department of Physics and Astronomy
University of Rochester

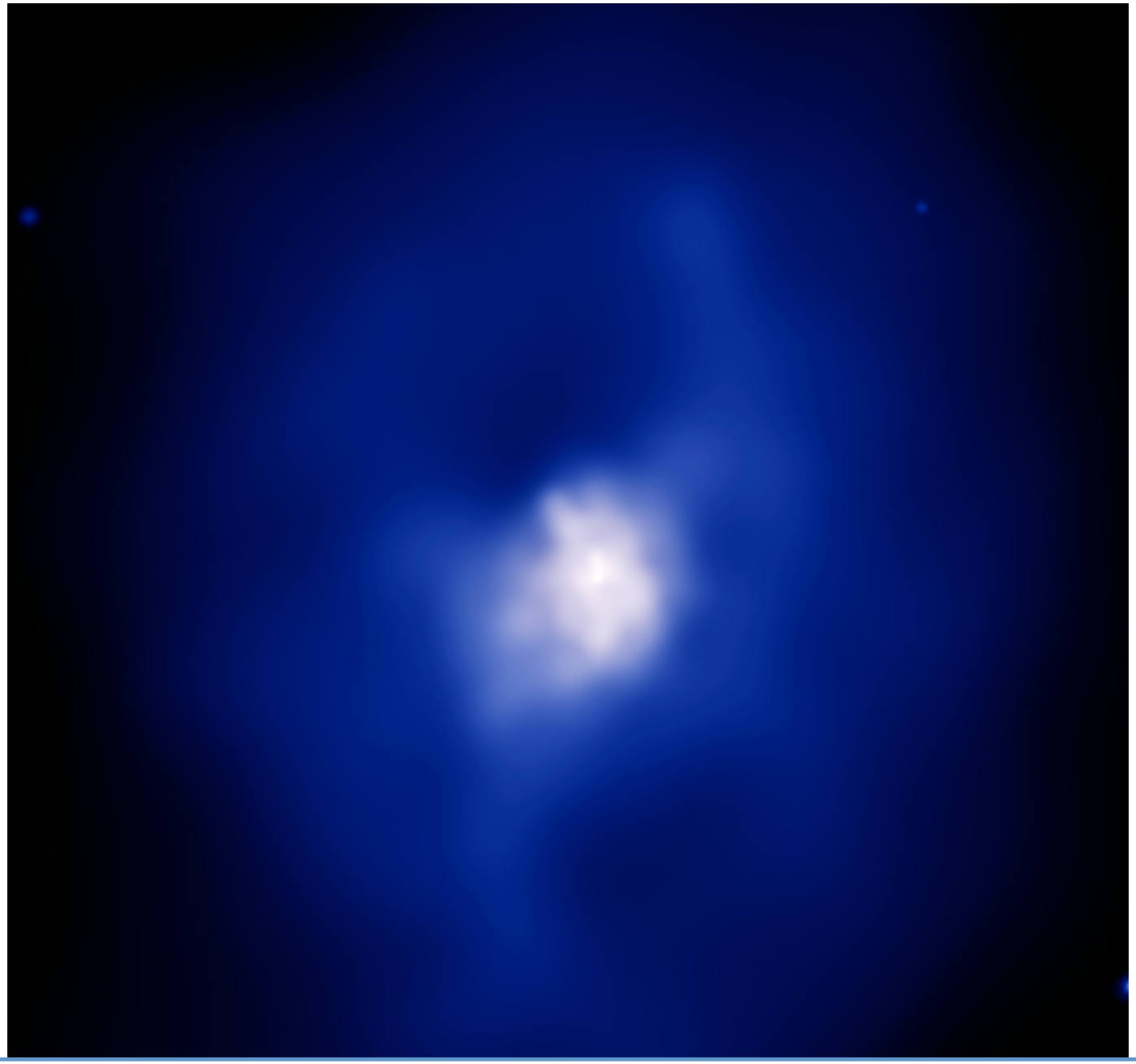


Rochester Astronomy Club, RIT, 3/4/11

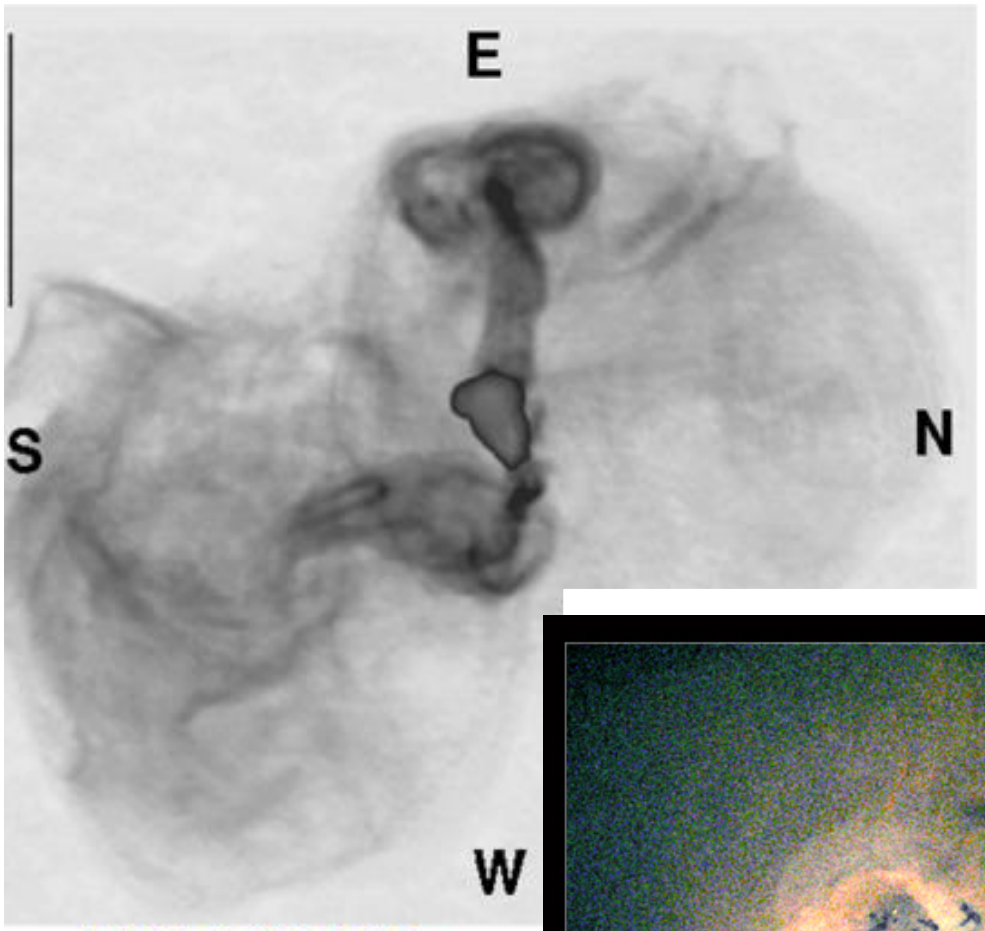

Photograph by Amy Snyder, copyright Exploratorium


RE/MA



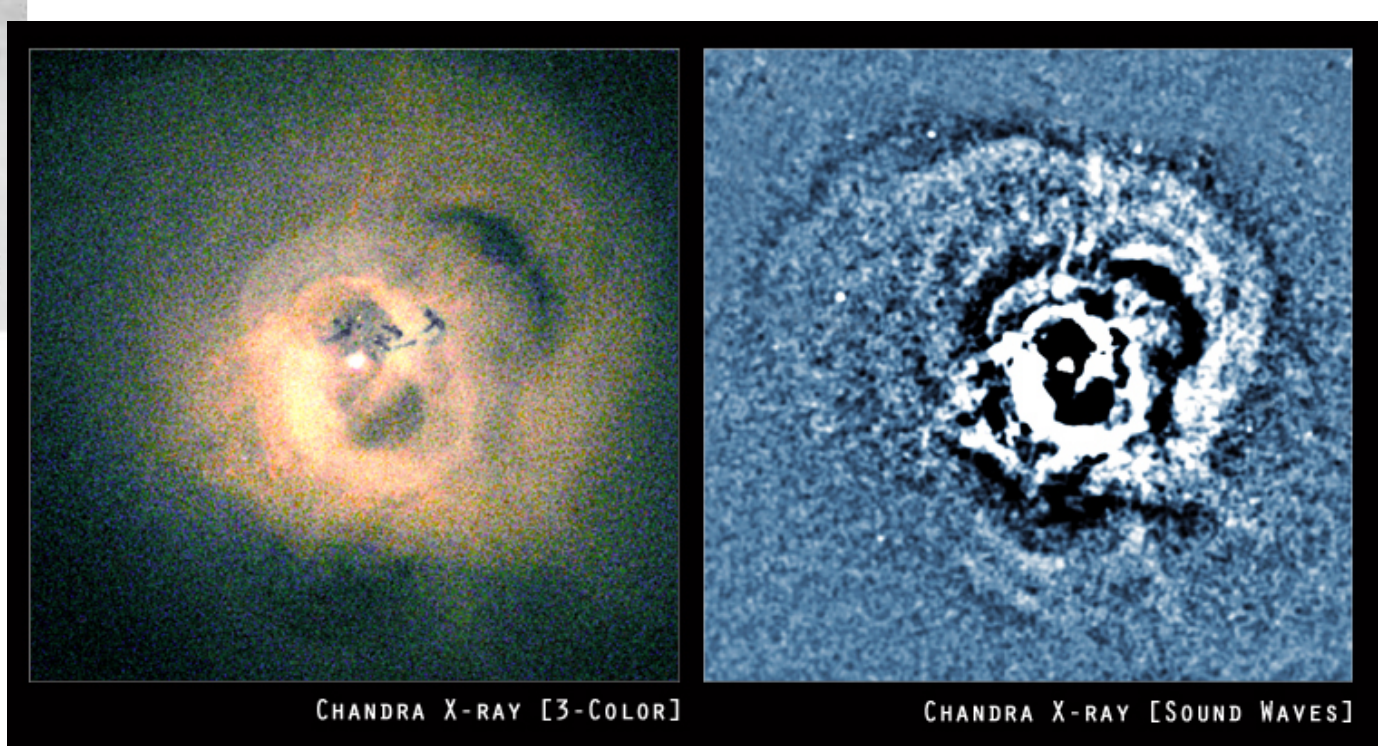


B McNamara

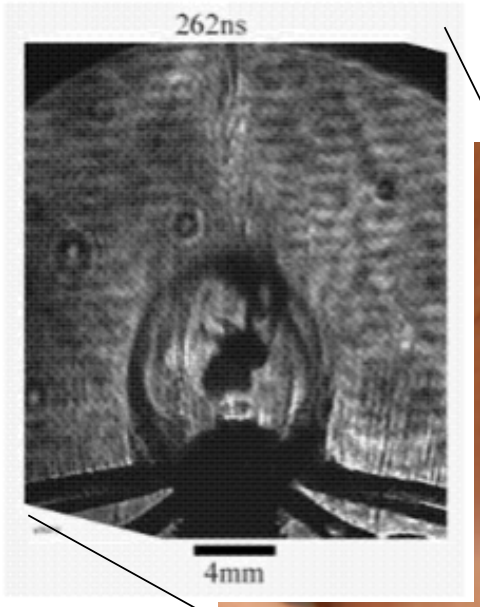


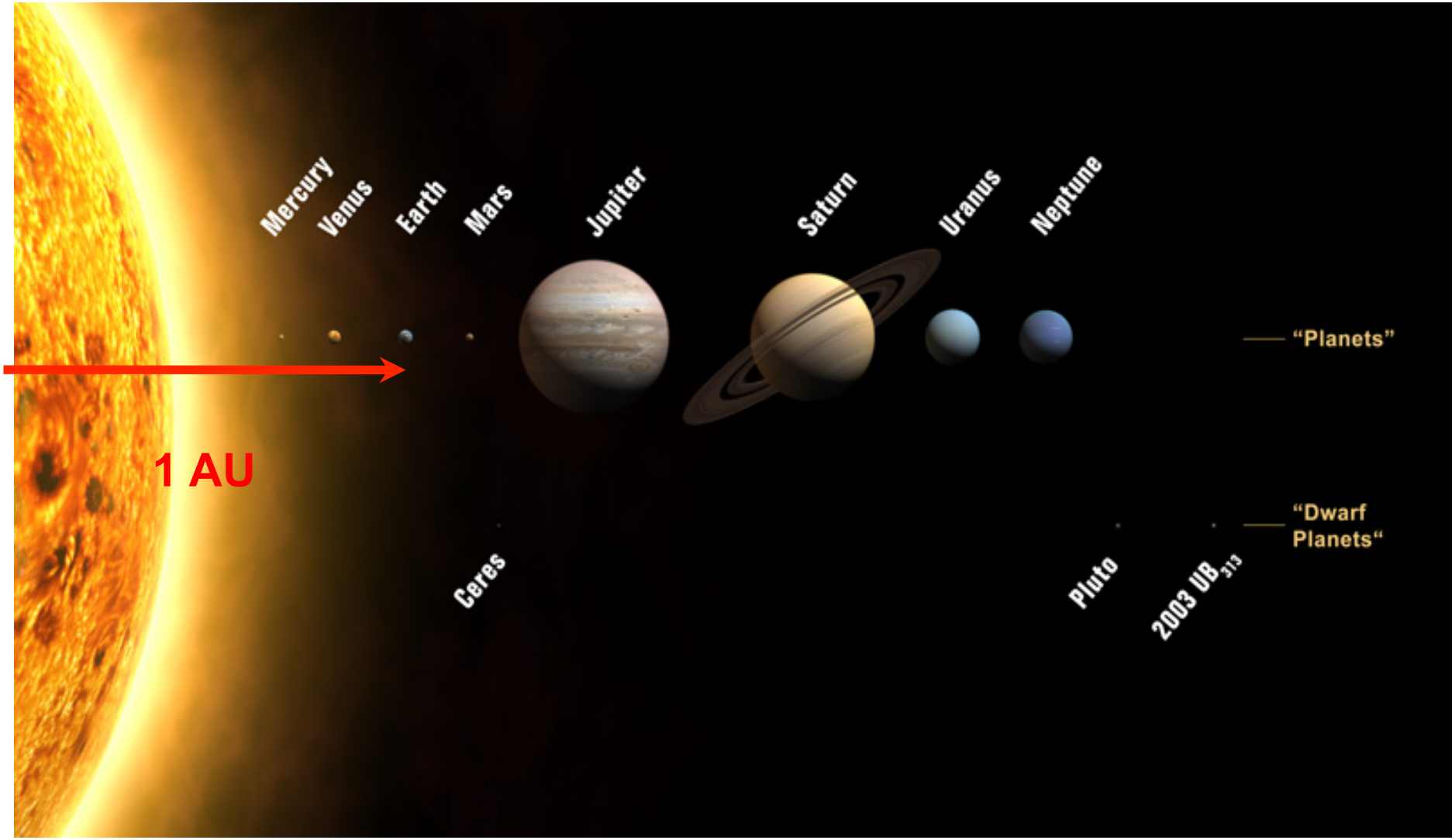
M87 at 327 MHz

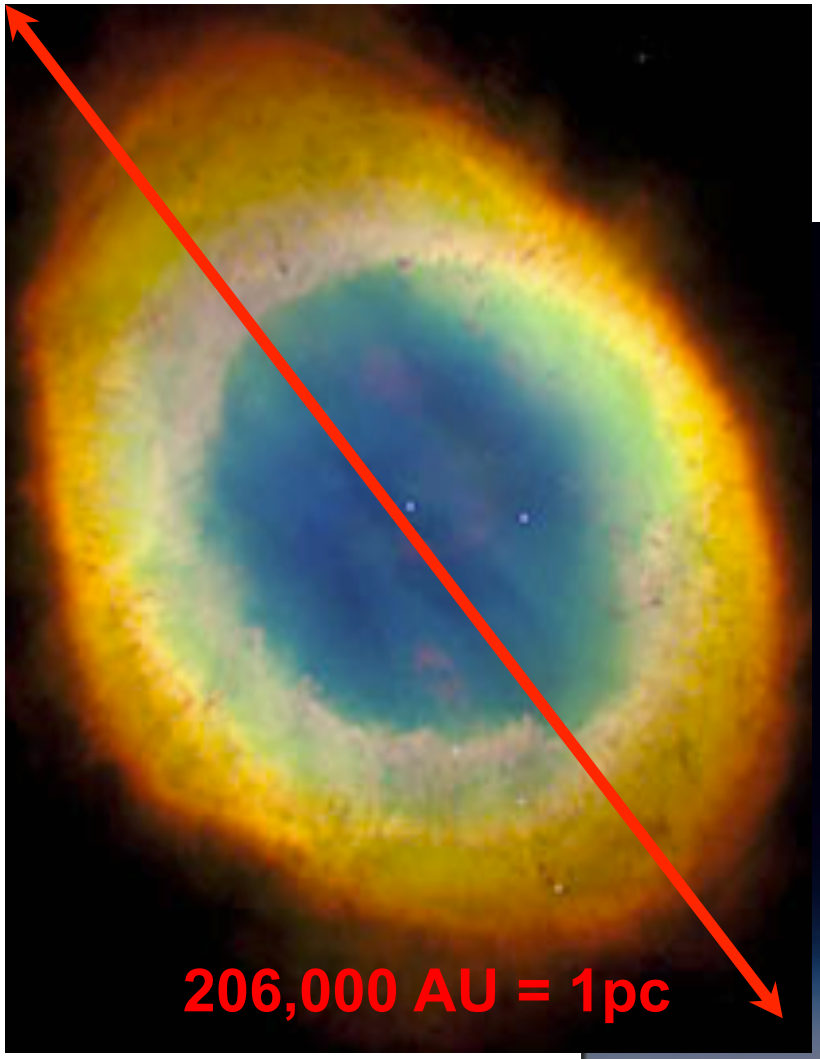
Churazov et al. 2002



A. Fabian et al.

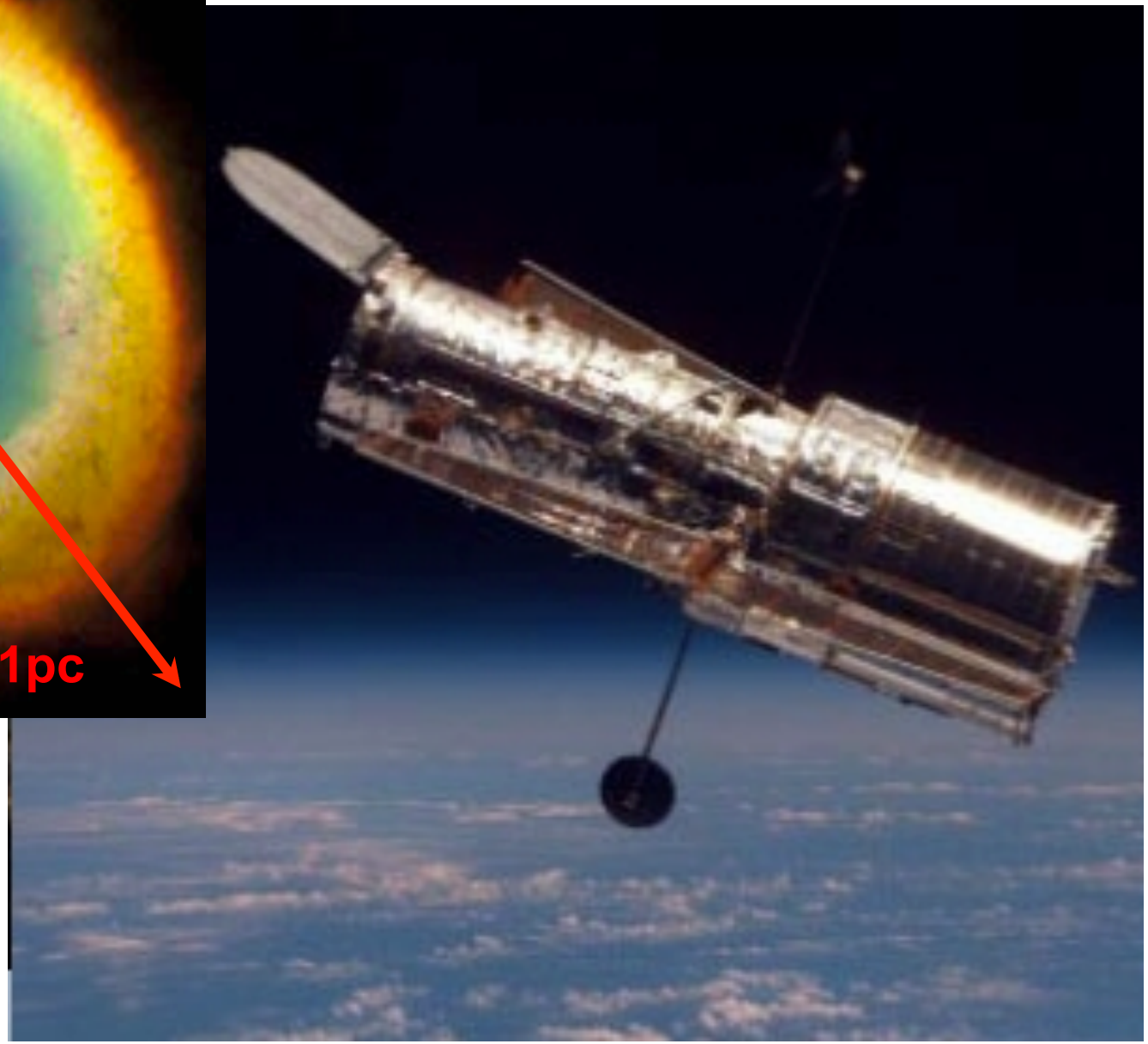

262ns
4mm


Mercury
Venus
Earth
Mars
Jupiter
Saturn
Uranus
Neptune
"Planets"
1 AU
Ceres
Pluto
2003 UB313
"Dwarf Planets"

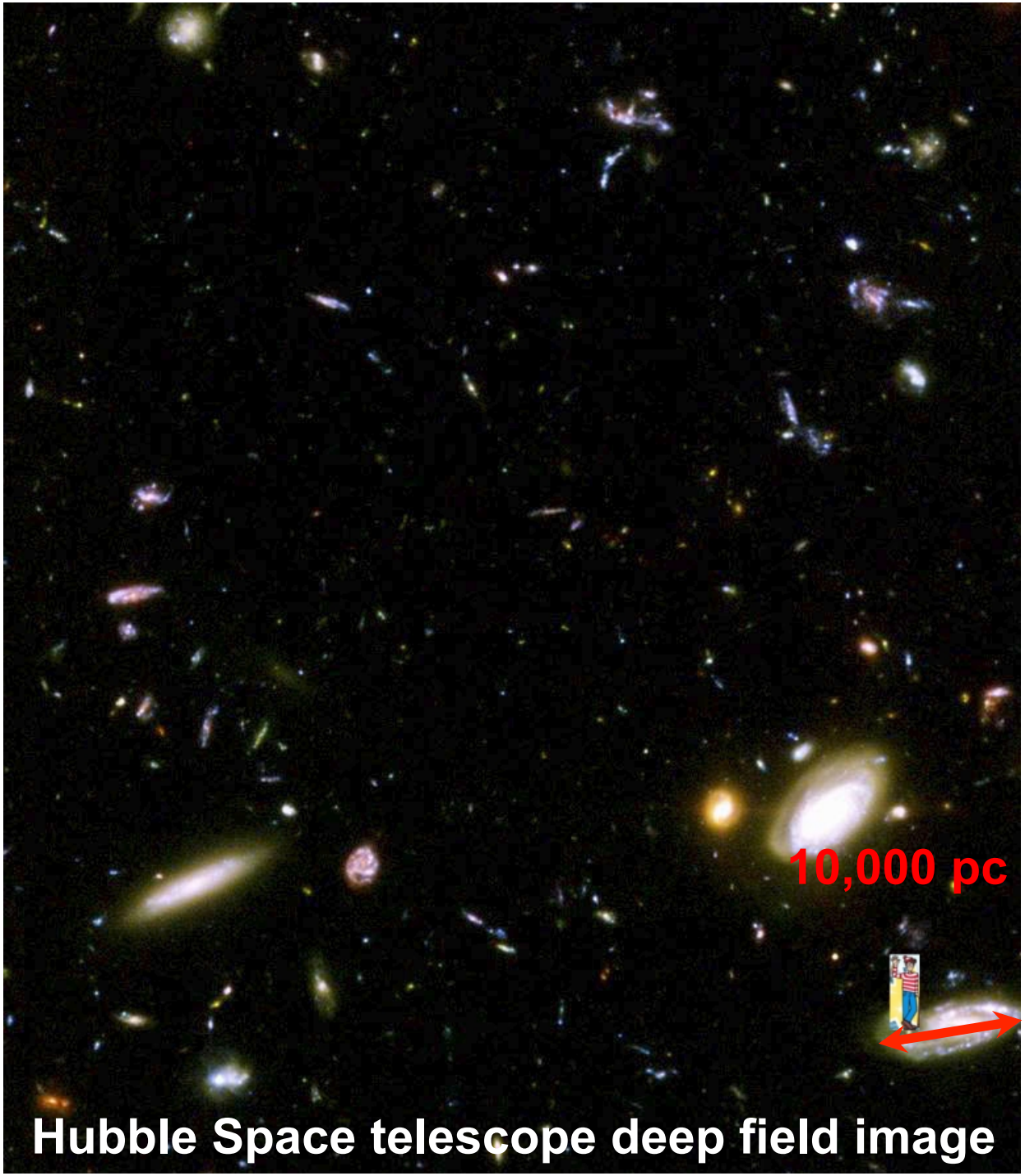


Planetary nebulae

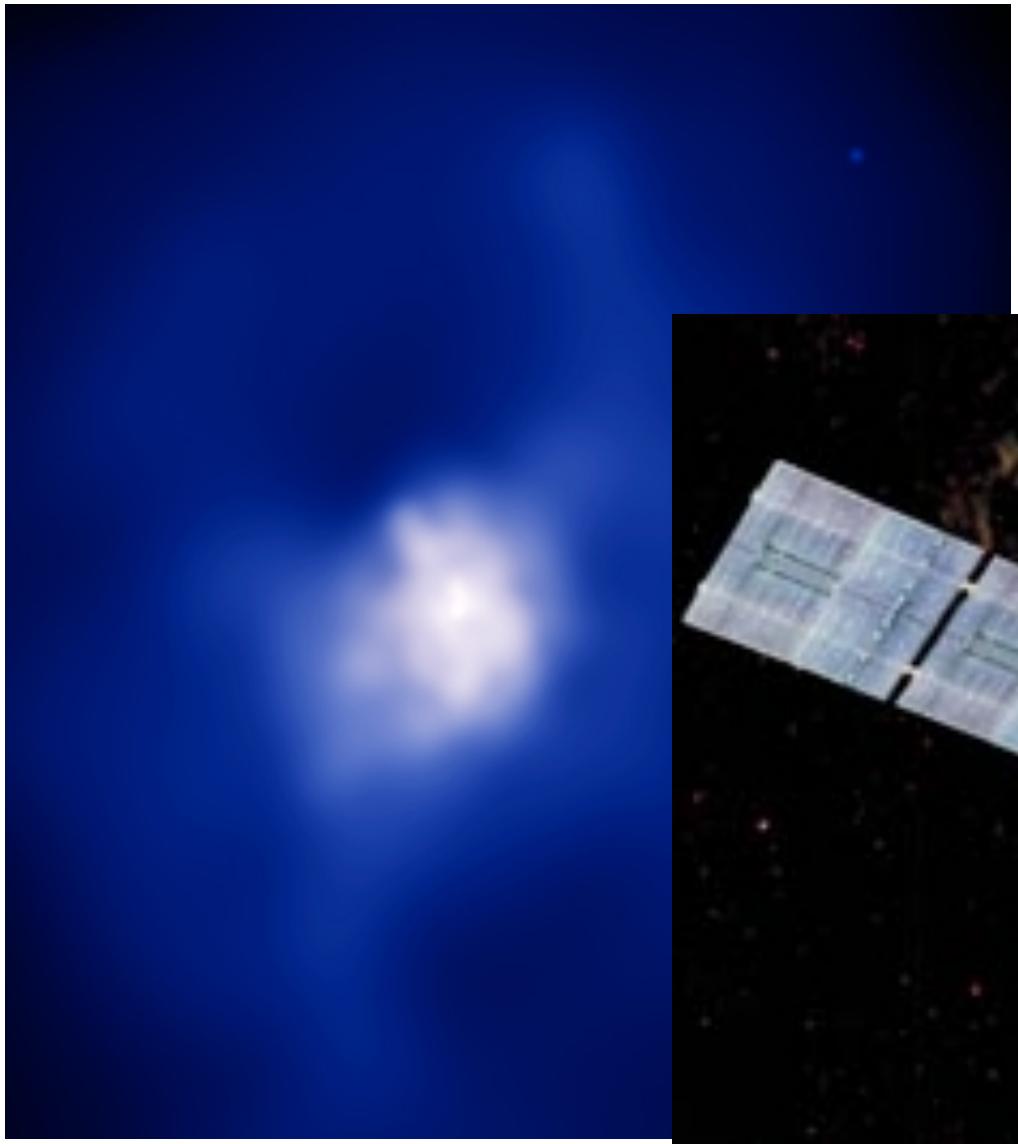
Hubble optical
Space telescope



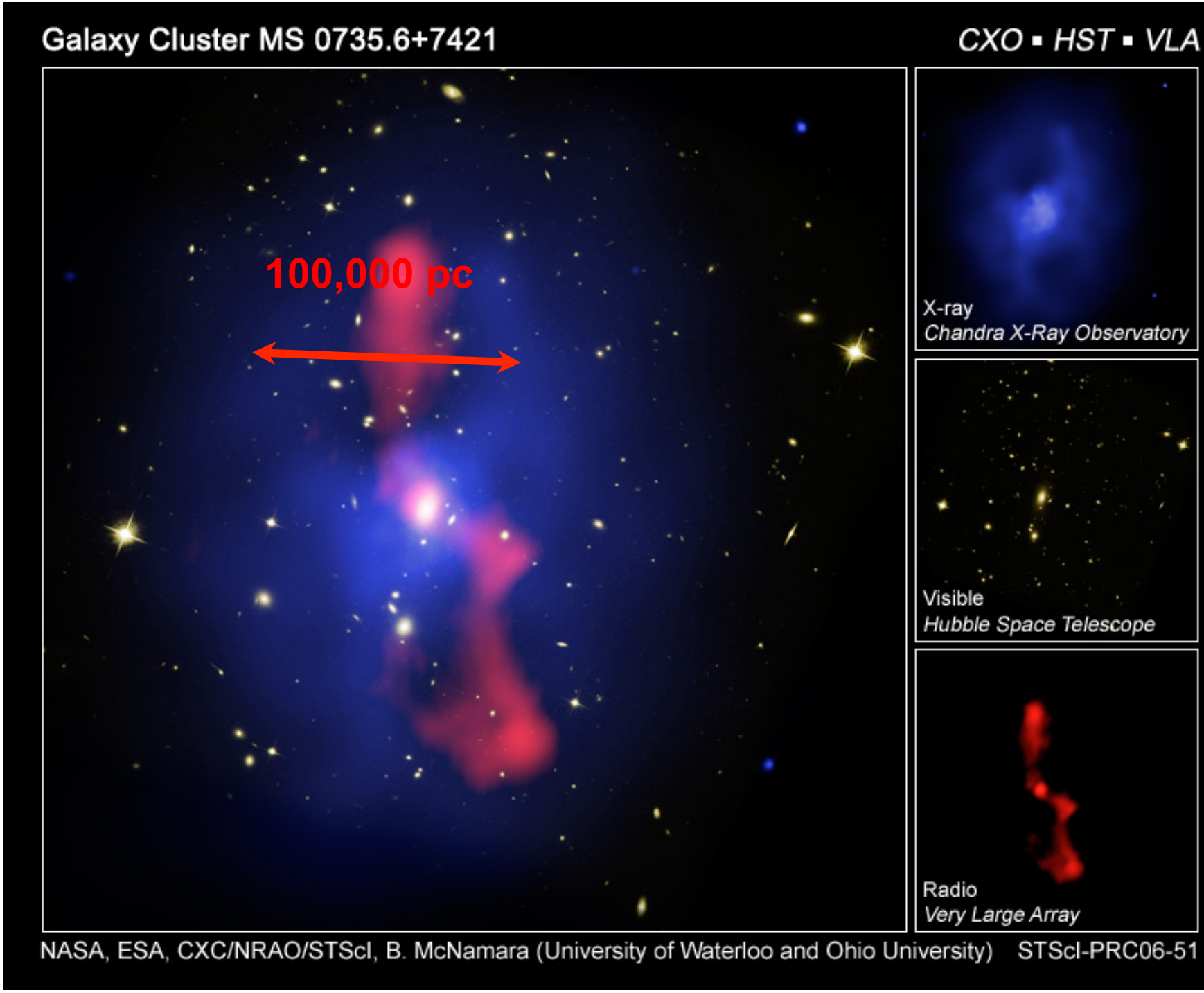
This is a cartoon not a telescope image



Hubble Space telescope deep field image



Chandra X-ray
Space telescope

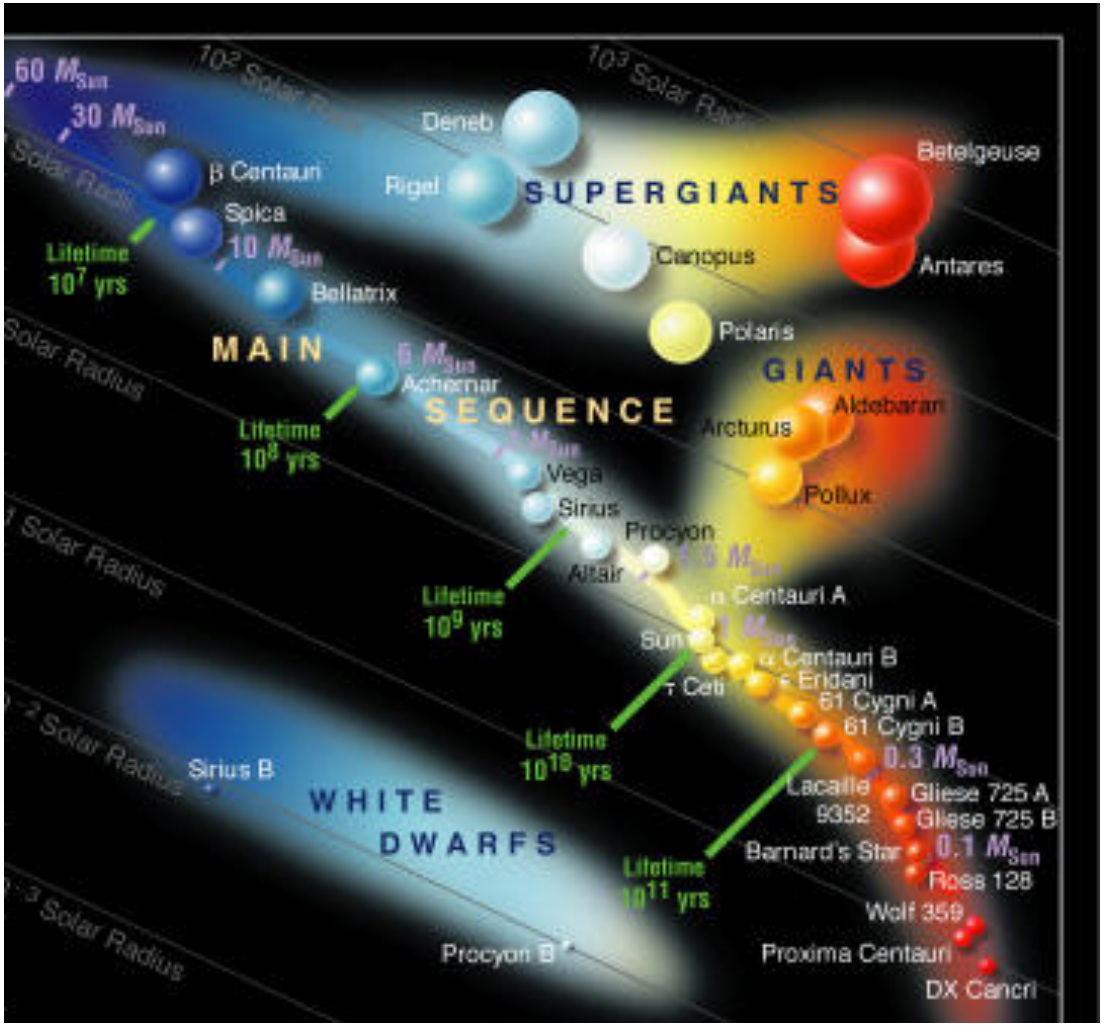

Galaxy Cluster MS 0735.6+7421
CXO ▪ HST ▪ VLA
100,000 pc
X-ray
Chandra X-Ray Observatory
Visible
Hubble Space Telescope
Radio
Very Large Array
NASA, ESA, CXC/NRAO/STScI, B. McNamara (University of Waterloo and Ohio University) STScI-PRC06-51

Radio telescope array

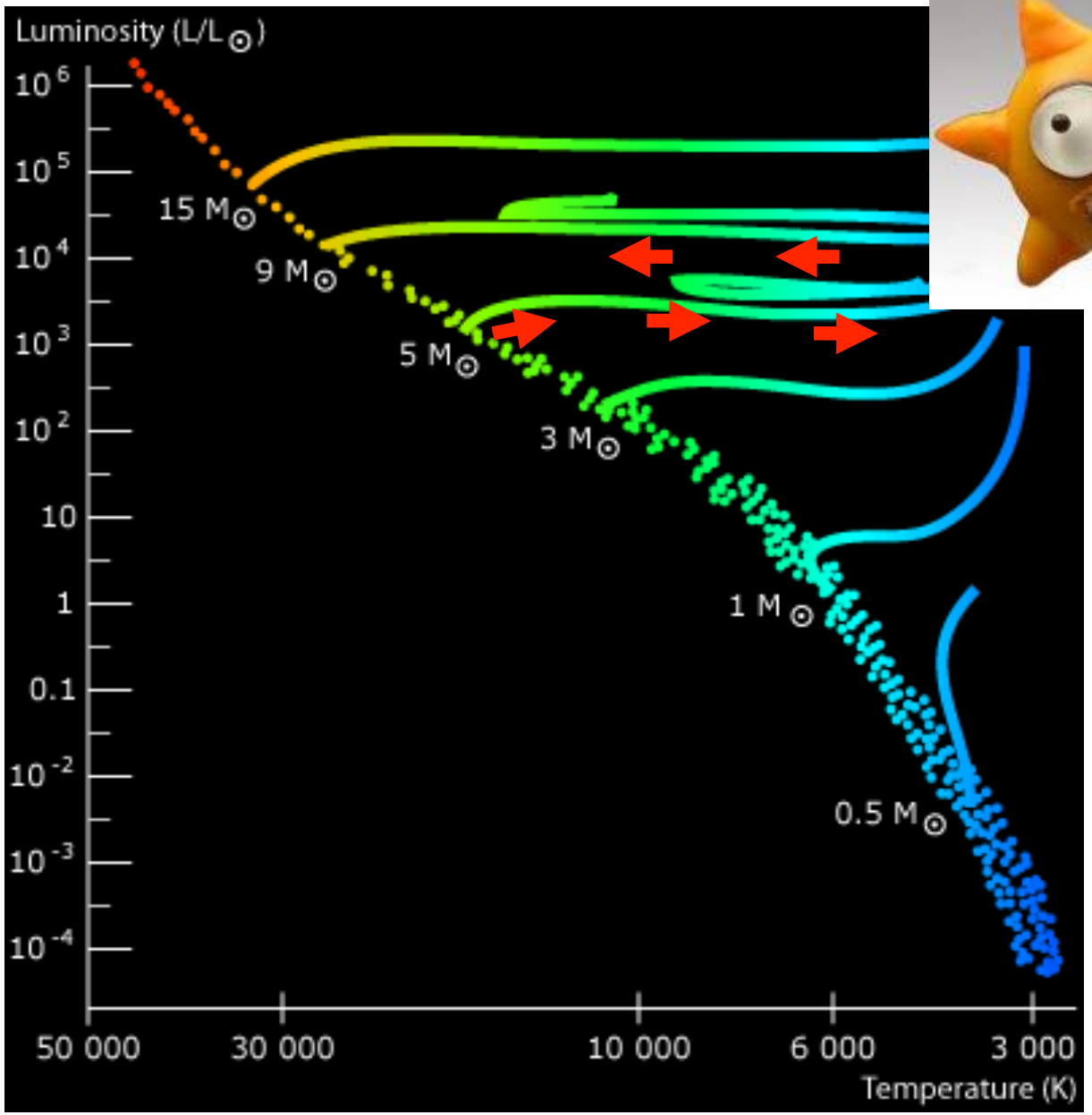
The very large array (VLA) in New Mexico

When are star bubbles formed?

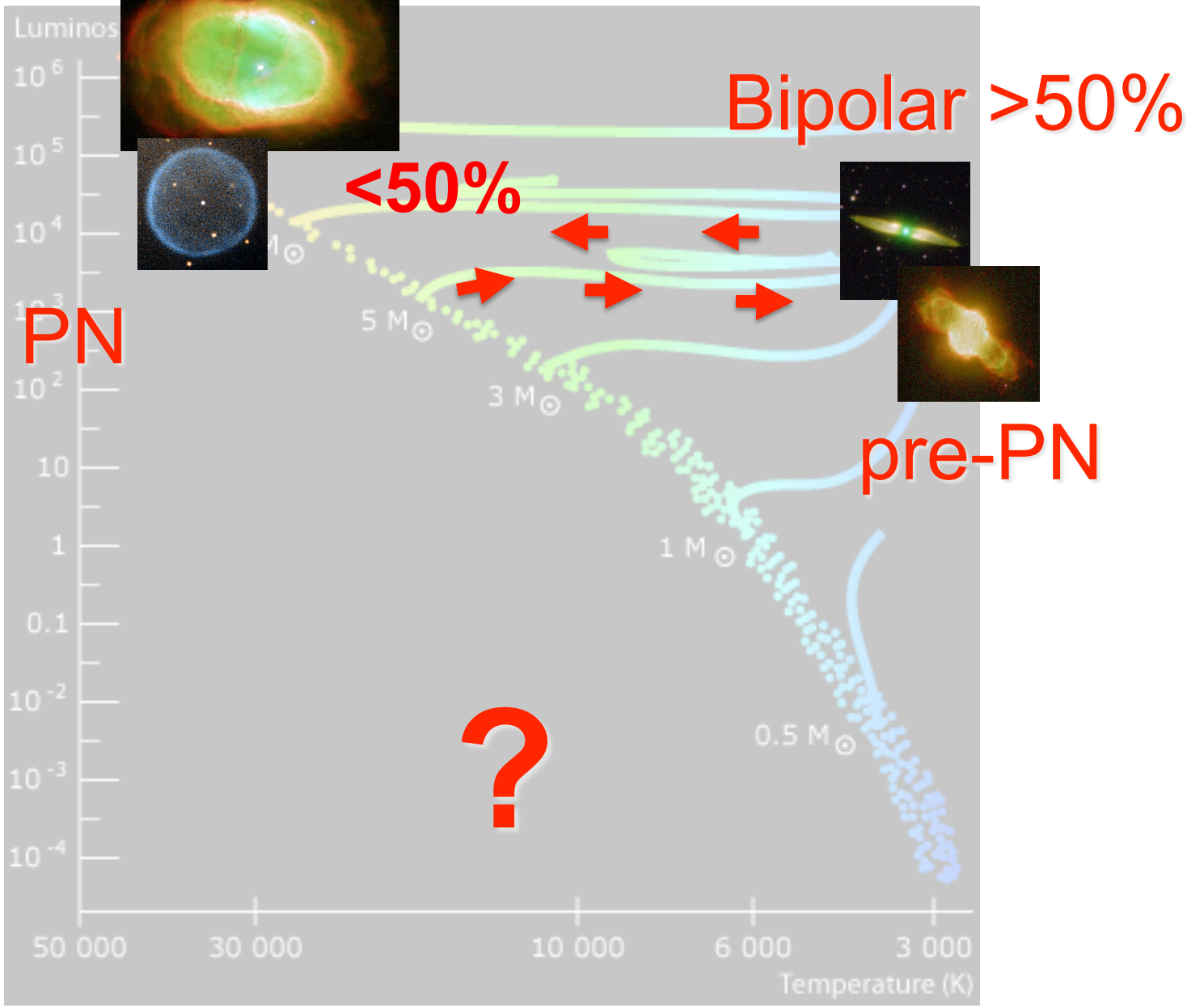
Do all stars form bubbles?


60 M_{Sun}
30 M_{Sun}
10^2 Solar Radius
10^3 Solar Radius
Deneb
Rigel
SUPERGIANTS
Betelgeuse
β Centauri
Spica
10 M_{Sun}
Lifetime
10^7 yrs
Canopus
Antares
Bellatrix
Polaris
MAIN
6 M_{Sun}
Achernar
GIANTS
SEQUENCE
Aldebaran
Arcturus
Lifetime
10^8 yrs
Vega
Pollux
Sirius
Procyon
Altair
Lifetime
10^9 yrs
α Centauri A
Sun
1 M_{Sun}
α Centauri B
ε Eridani
τ Ceti
61 Cygni A
61 Cygni B
Lifetime
10^{10} yrs
0.3 M_{Sun}
Sirius B
WHITE
DWARFS
Lacaille
9352
Gliese 725 A
Gliese 725 B
Barnard's Star
0.1 M_{Sun}
Ross 128
Lifetime
10^{11} yrs
Wolf 359
Proxima Centauri
Procyon B
DX Cancri

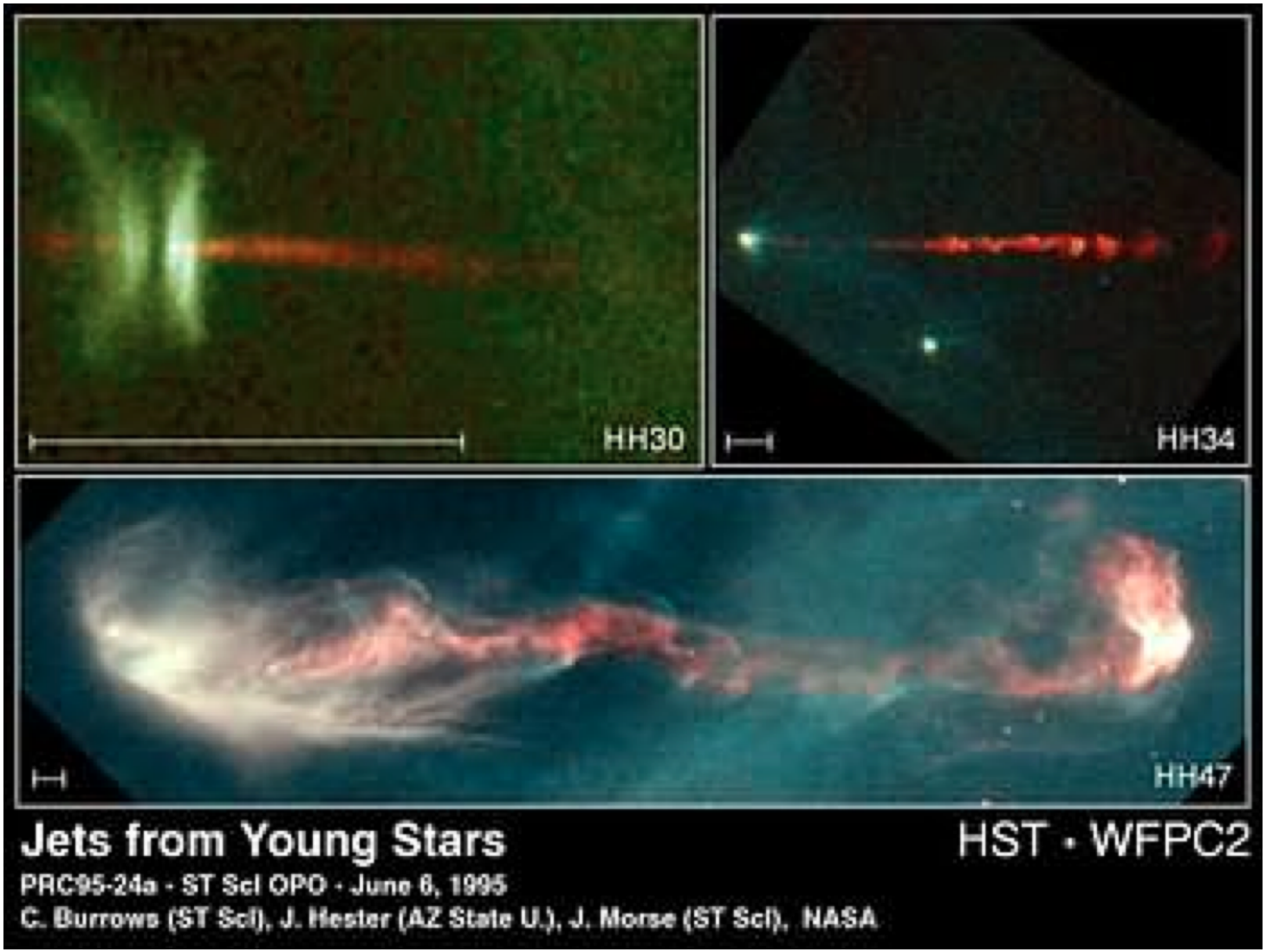
Asymptotic Giant Branch (AGB) stars

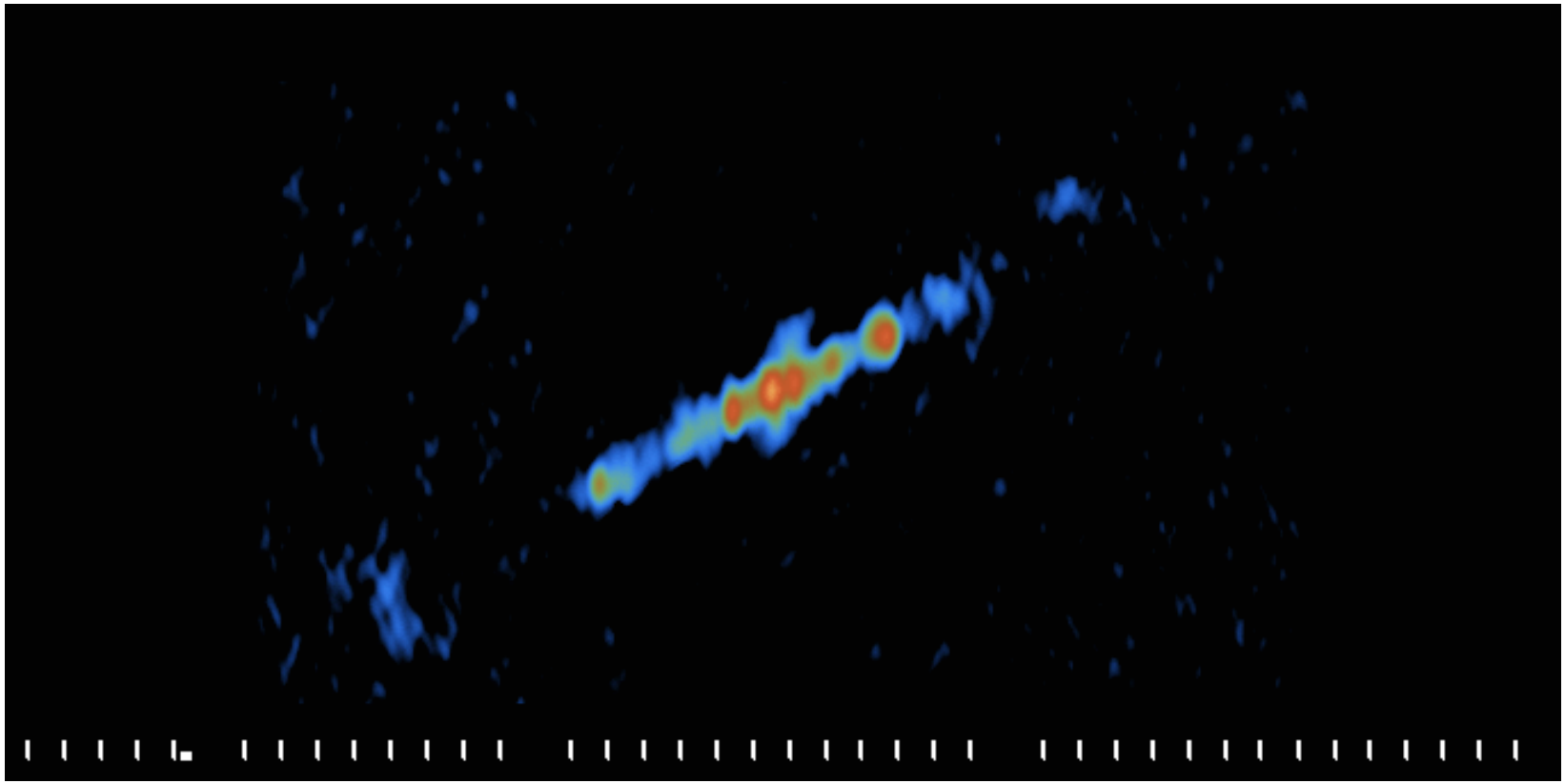


Asymptotic Giant Branch (AGB) stars



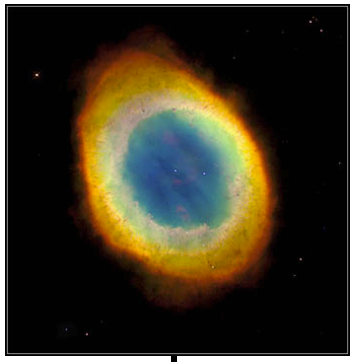
Jets

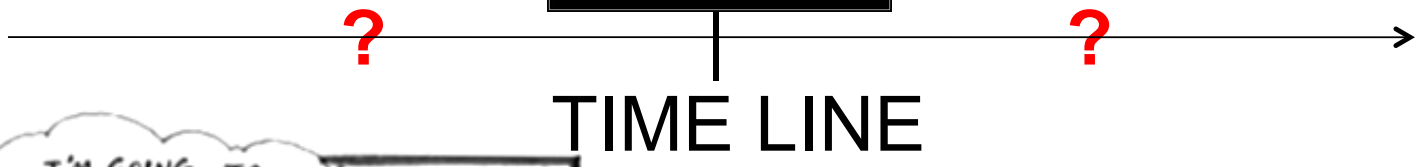

HH30
HH34
HH47
Jets from Young Stars
HST · WFPC2
PRC95-24a · ST ScI OPO · June 6, 1995
C. Burrows (ST ScI), J. Hester (AZ State U.), J. Morse (ST ScI), NASA



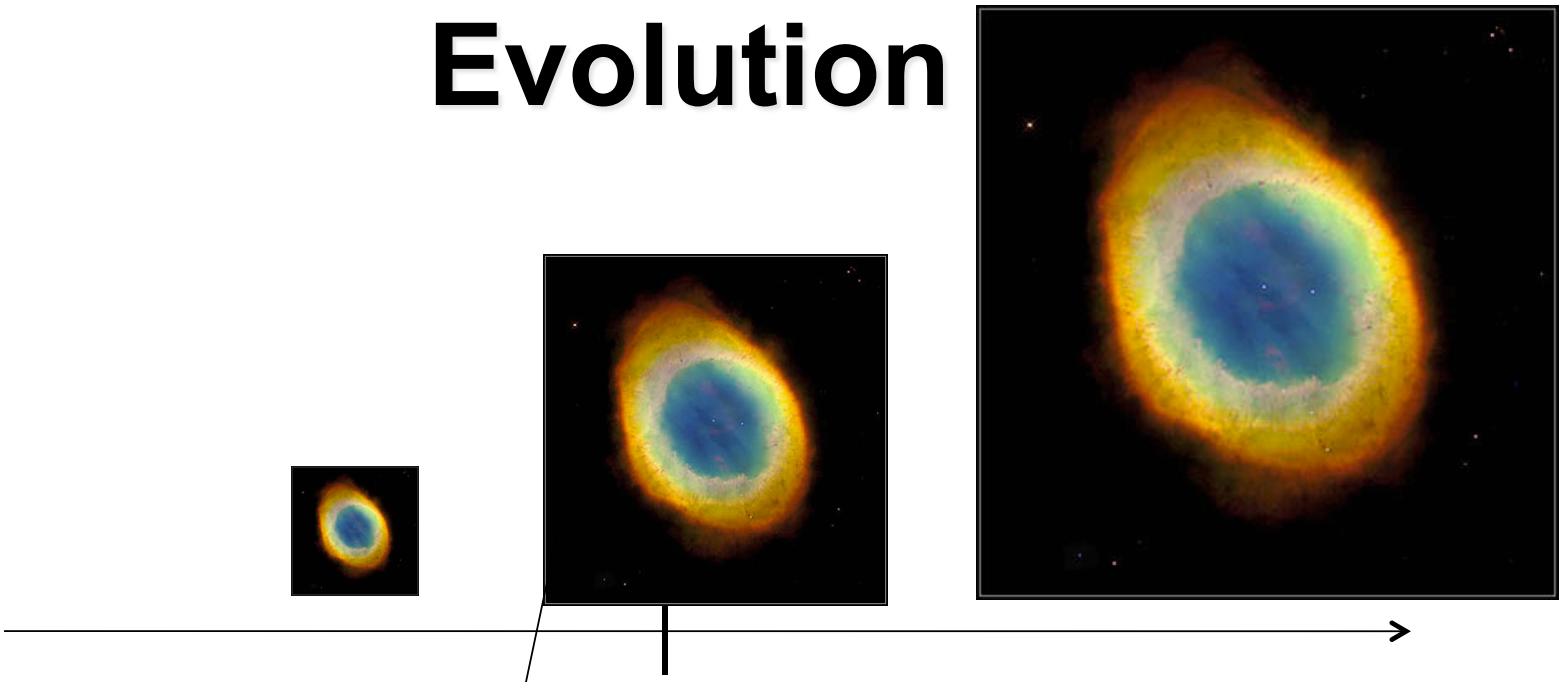
Jets from powerful binaries

Evolution





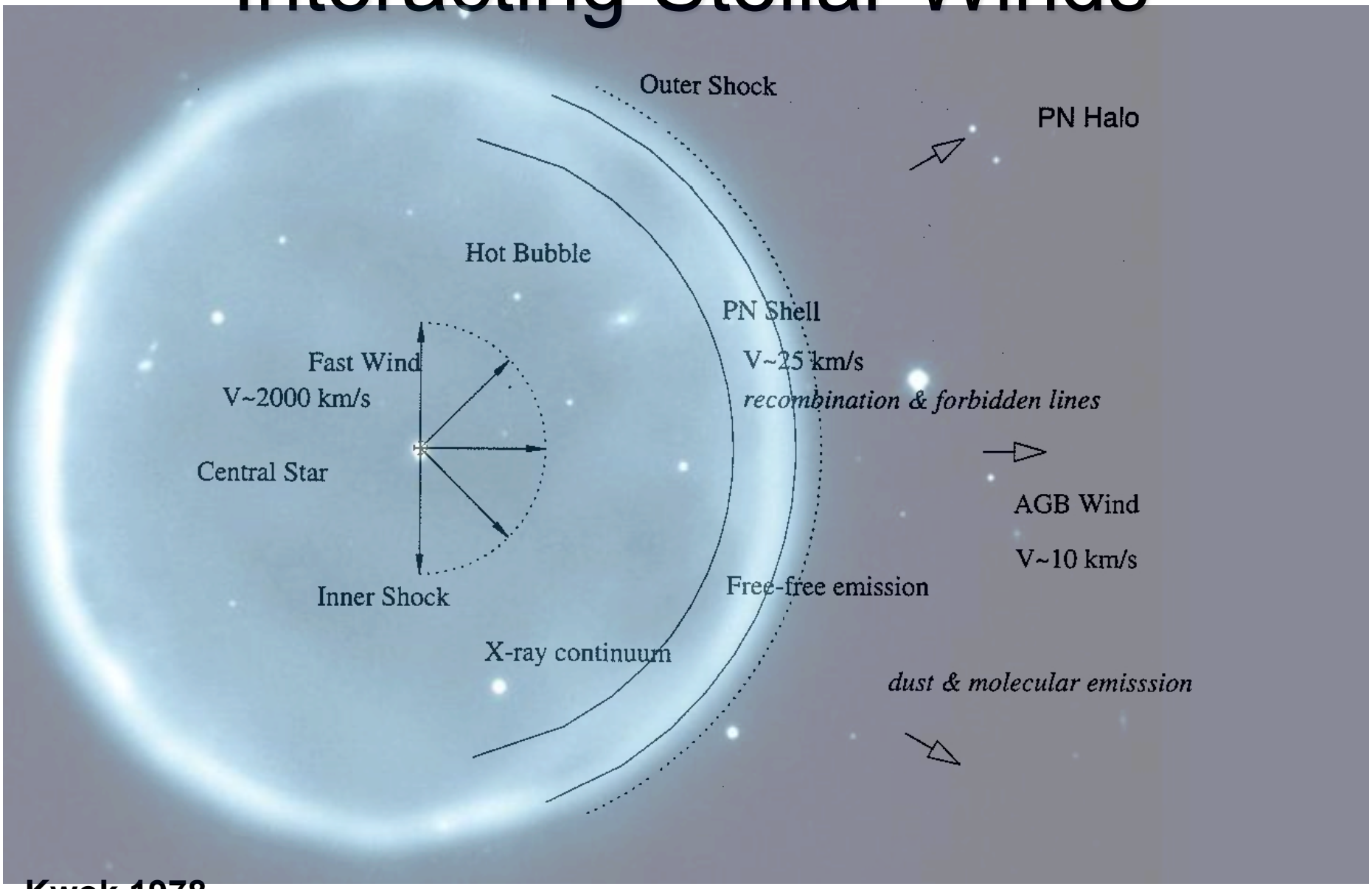
Evolution



TIME LINE

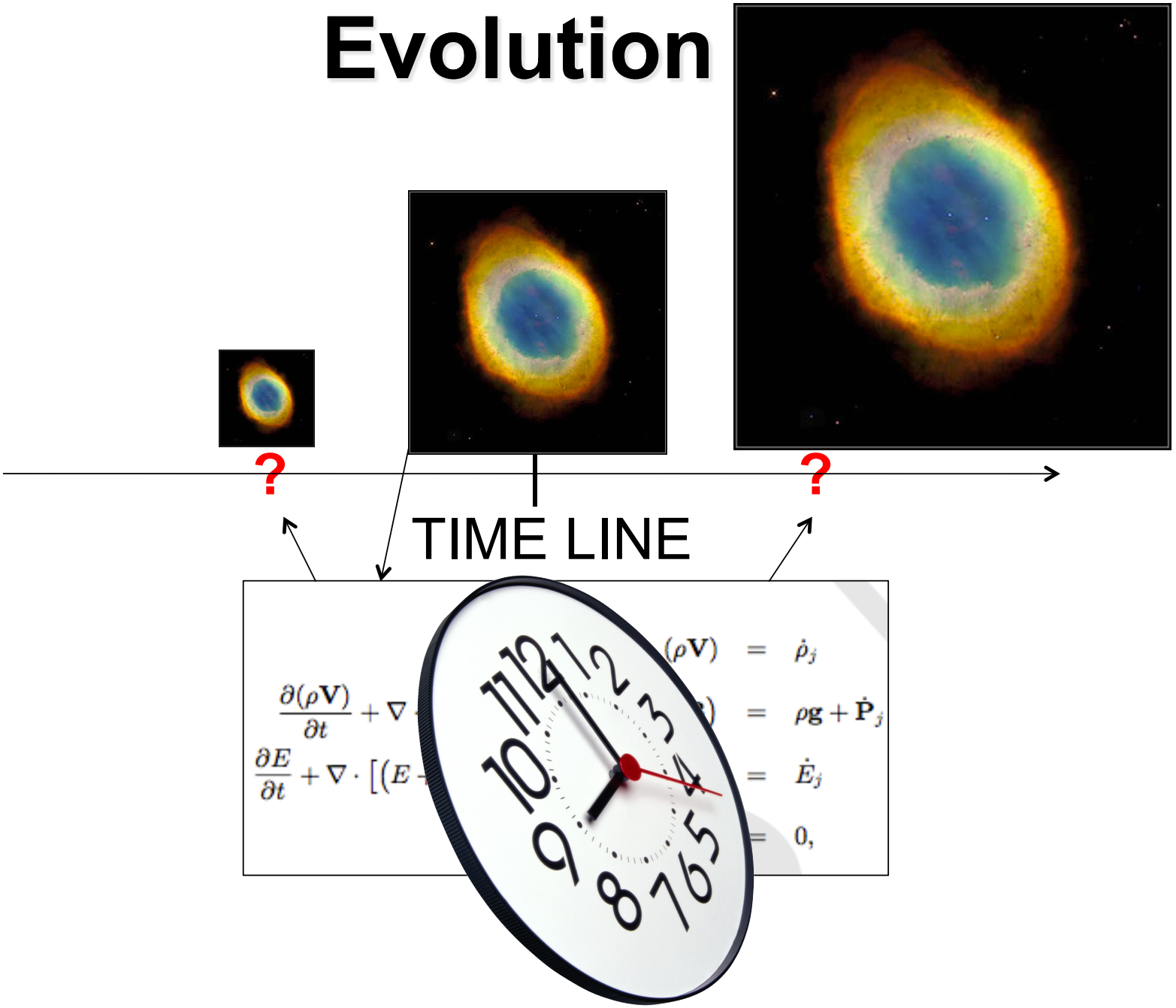
$$
\begin{aligned}
\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{V}) &= \dot{\rho}_j \\
\frac{\partial (\rho \mathbf{V})}{\partial t} + \nabla \cdot \left(\rho \mathbf{V}\mathbf{V} + p + B^2/2 - \mathbf{B}\mathbf{B}\right) &= \rho \mathbf{g} + \dot{\mathbf{P}}_j \\
\frac{\partial E}{\partial t} + \nabla \cdot \left[\left(E + p + B^2/2\right)\mathbf{v} - \mathbf{B}(\mathbf{v}\cdot\mathbf{B})\right] &= \dot{E}_j \\
\frac{\partial \mathbf{B}}{\partial t} - \nabla \times (\mathbf{V} \times \mathbf{B}) &= 0,
\end{aligned}
$$

Interacting Stellar Winds

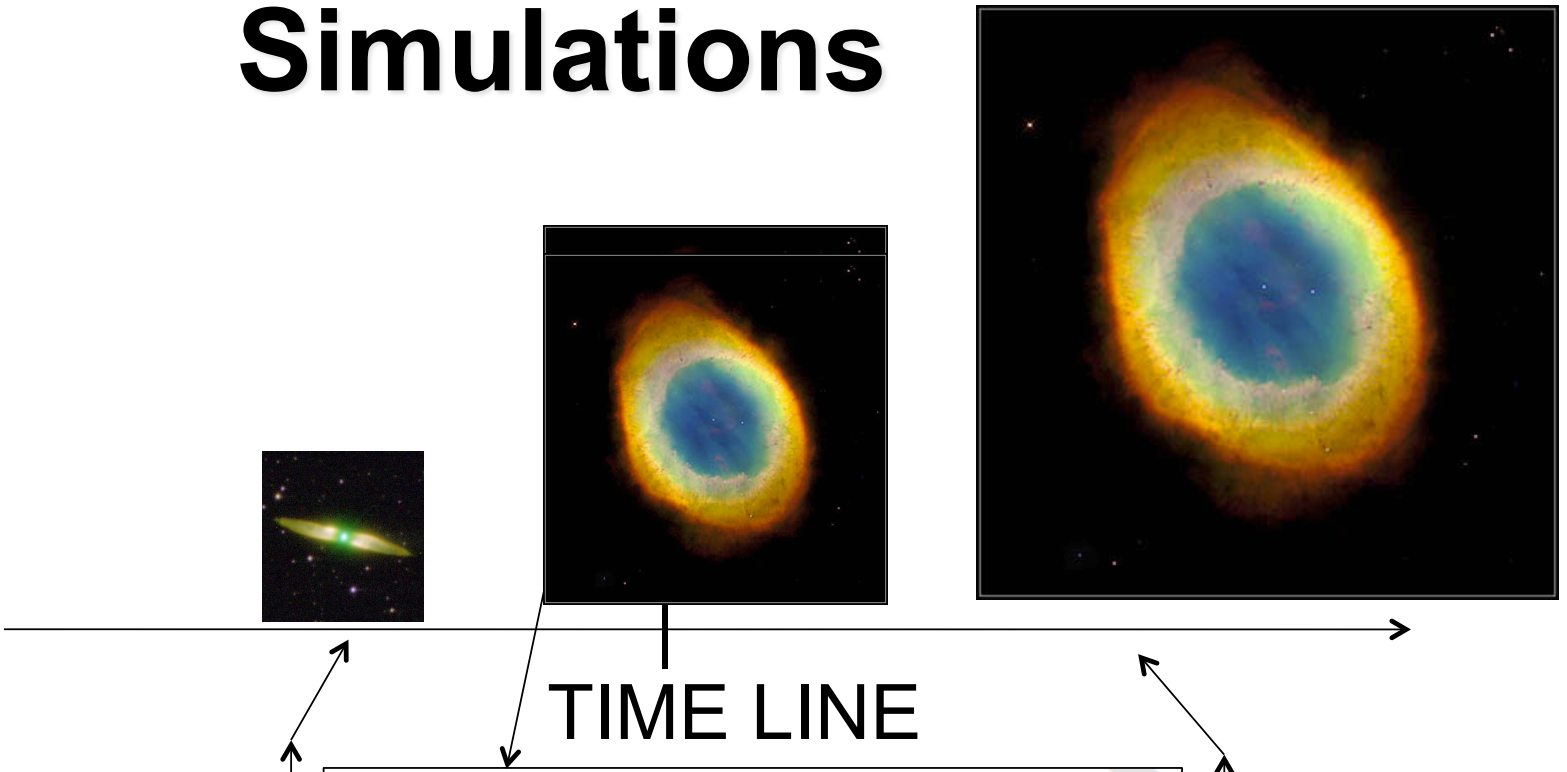


Kwok 1978

Evolution



Simulations



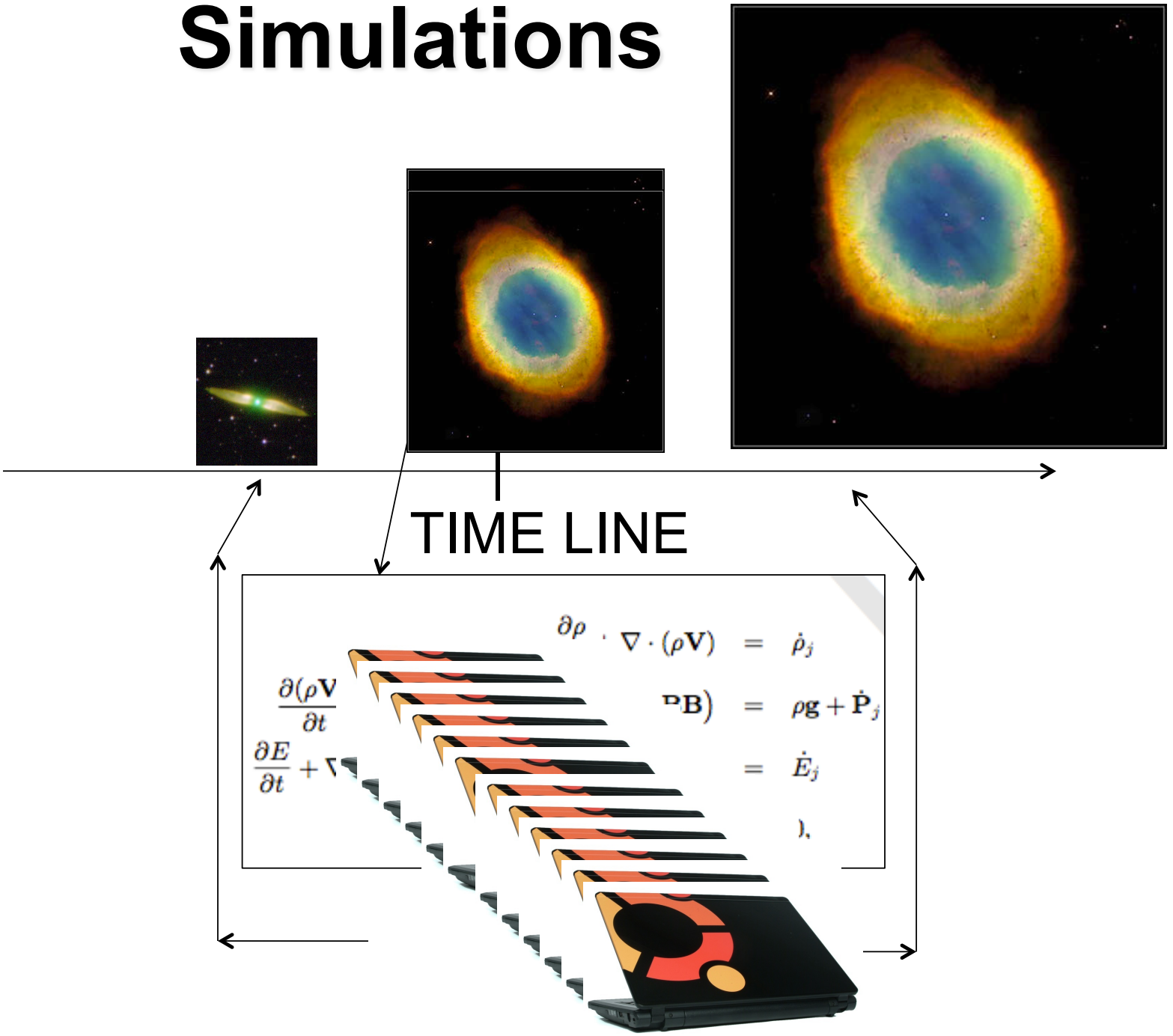
$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{V}) = \dot{\rho}_j$$

$$\frac{\partial (\rho \mathbf{V})}{\partial t} + \nabla \cdot \left(\rho \mathbf{V}\mathbf{V} + p + B^2/2 - \mathbf{B}\mathbf{B}\right) = \rho \mathbf{g} + \dot{\mathbf{P}}_j$$

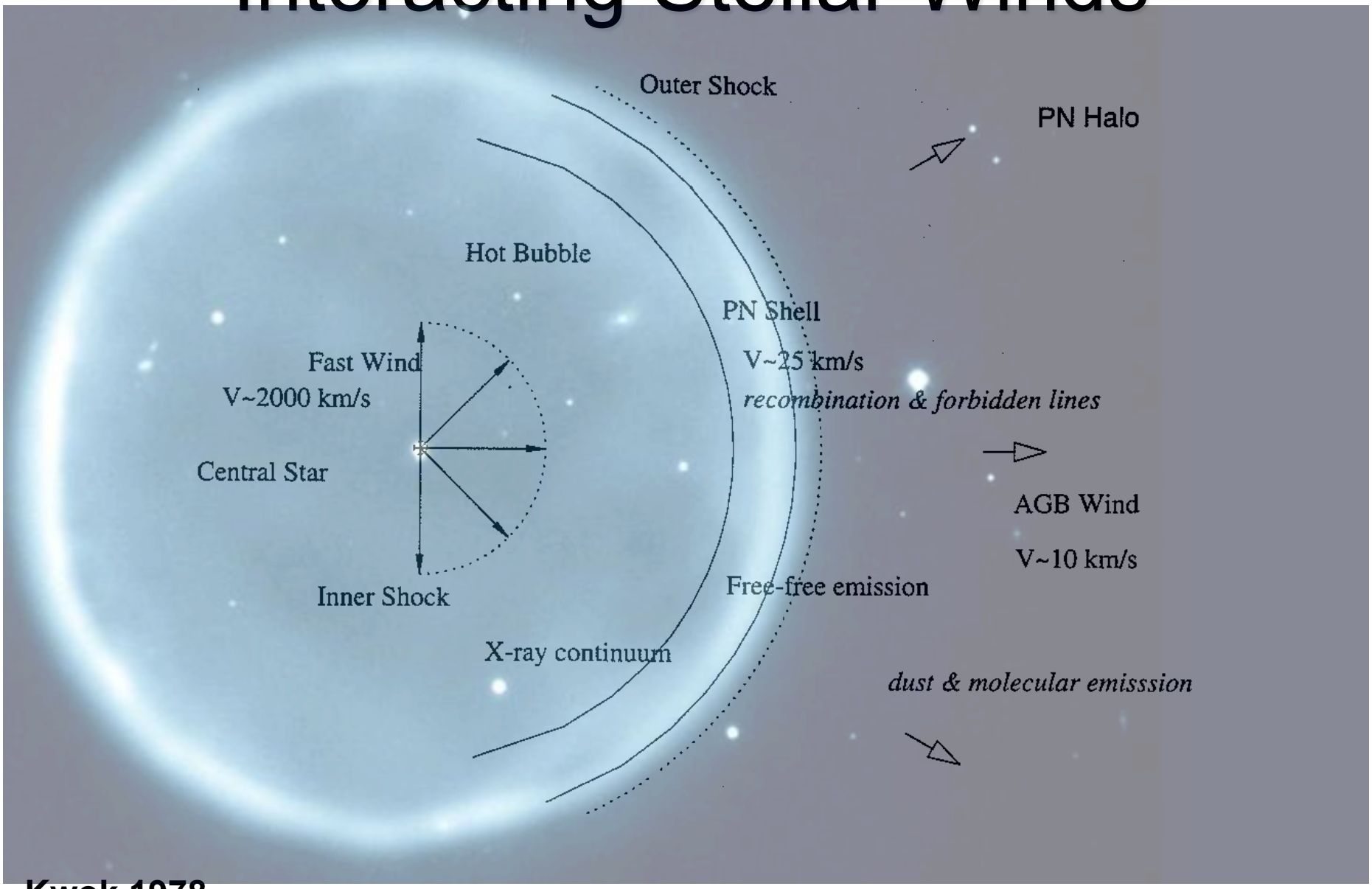
$$\frac{\partial E}{\partial t} + \nabla \cdot \left[\left(E + p + B^2/2\right)\mathbf{v} - \mathbf{B}(\mathbf{v} \cdot \mathbf{B})\right] = \dot{E}_j$$

$$\frac{\partial \mathbf{B}}{} \quad \nabla \times (\mathbf{V} \times \mathbf{B}) = 0,$$

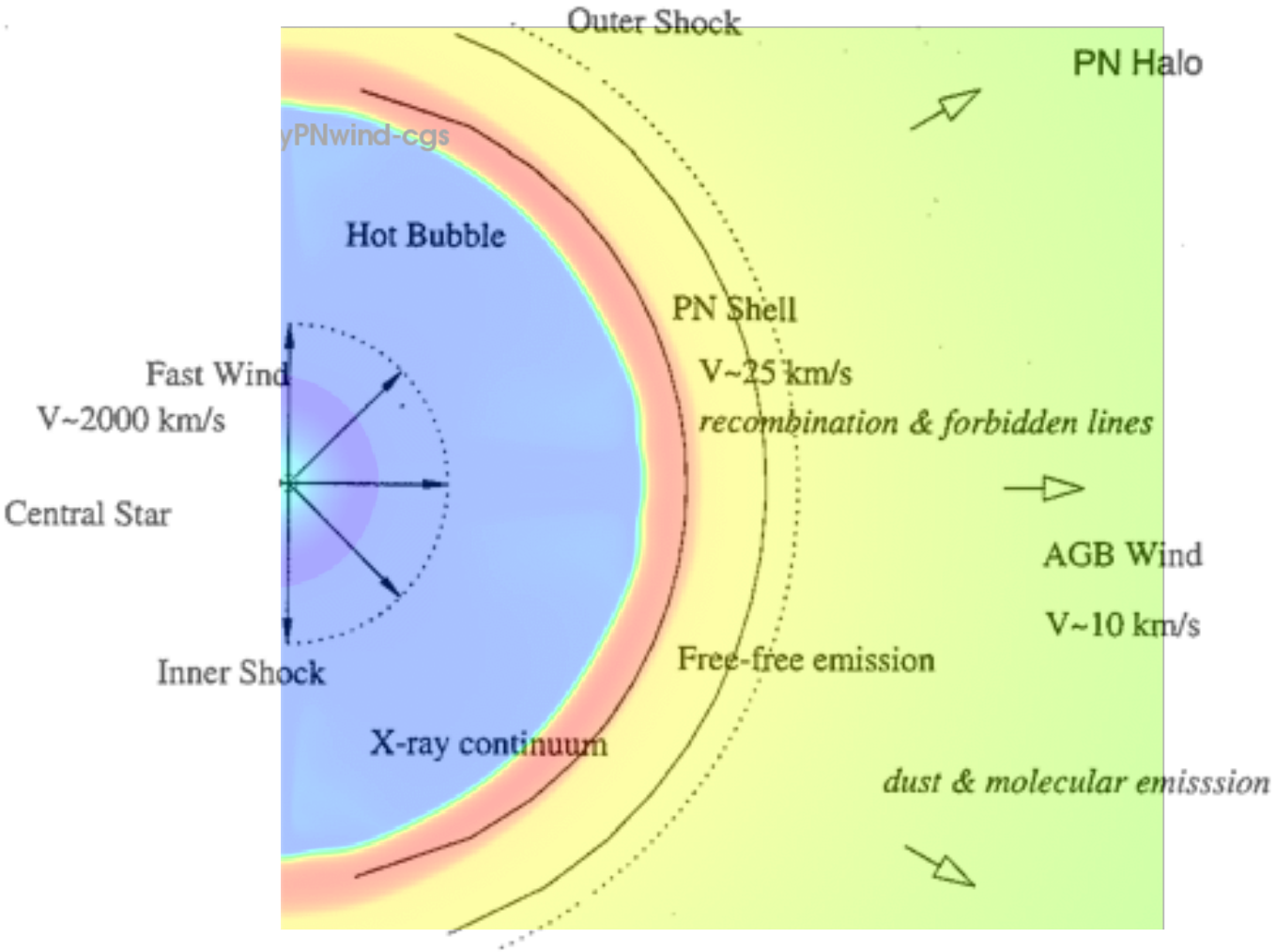
Simulations



Interacting Stellar Winds



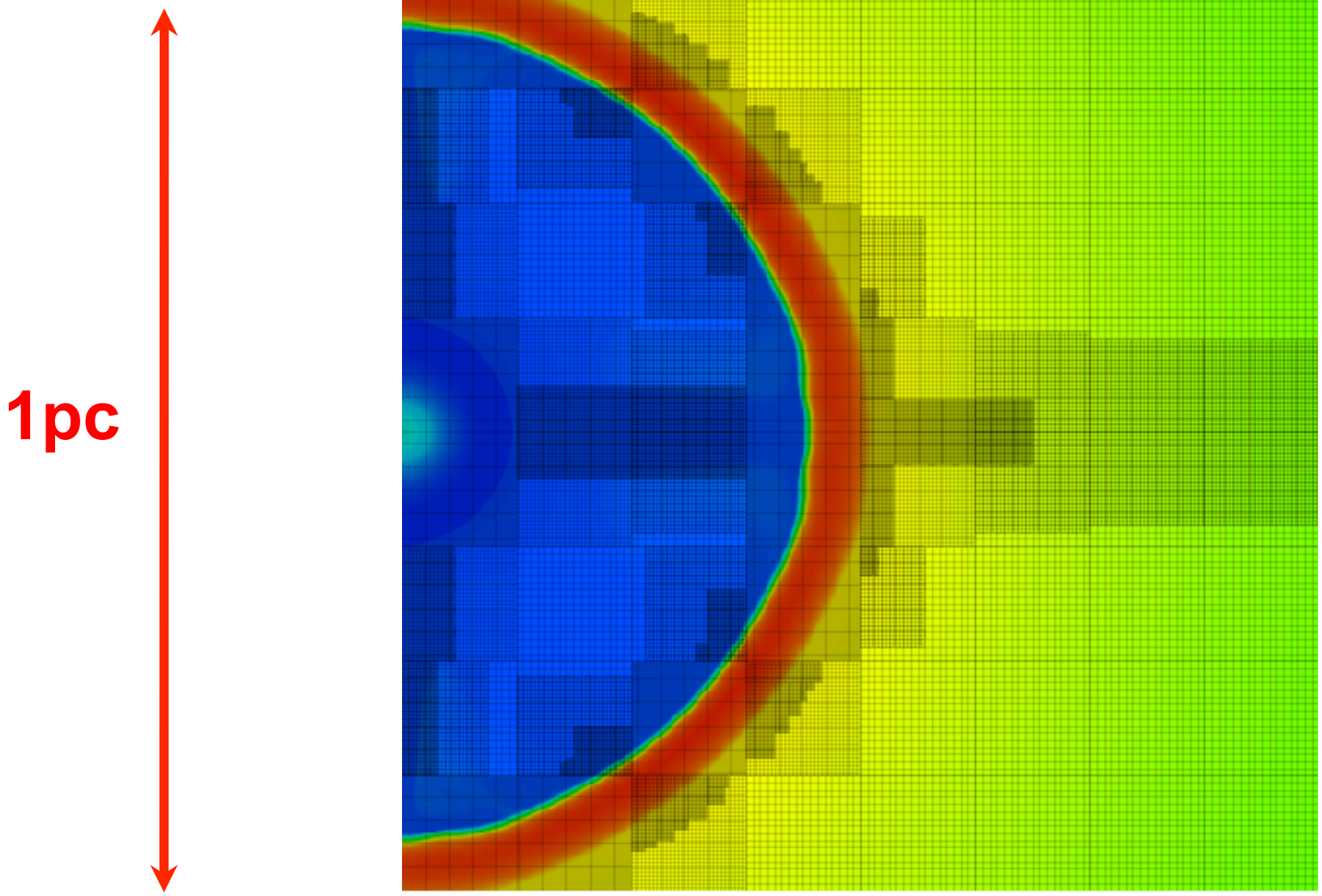
Kwok 1978


Outer Shock
PN Halo
yPNwind-cgs
Hot Bubble
PN Shell
V~25 km/s
recombination & forbidden lines
Fast Wind
V~2000 km/s
Central Star
AGB Wind
V~10 km/s
Free-free emission
Inner Shock
X-ray continuum
dust & molecular emisssion

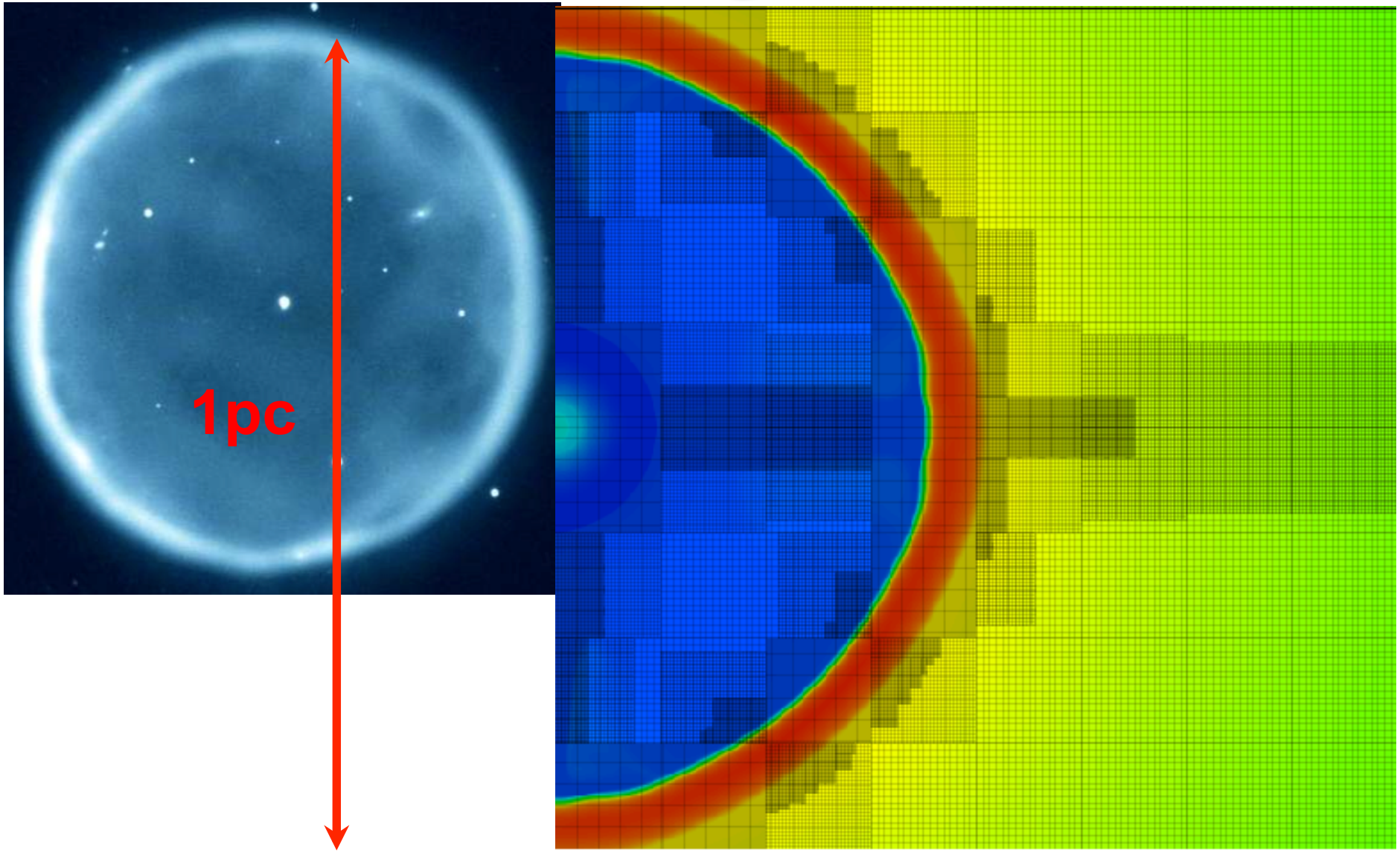
Simulations

http://clover.pas.rochester.edu/trac/wiki/WikiStart

The grid



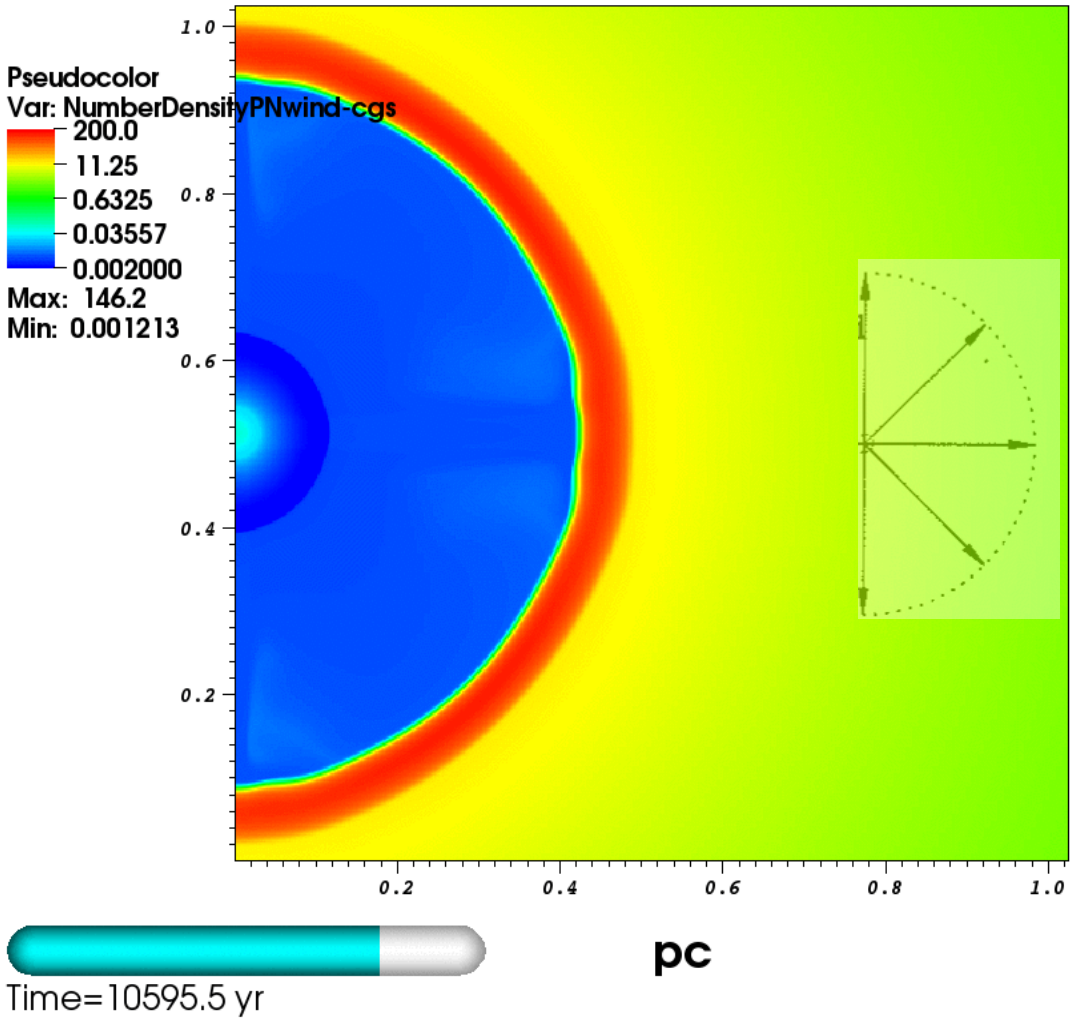
The grid



AGB spherical

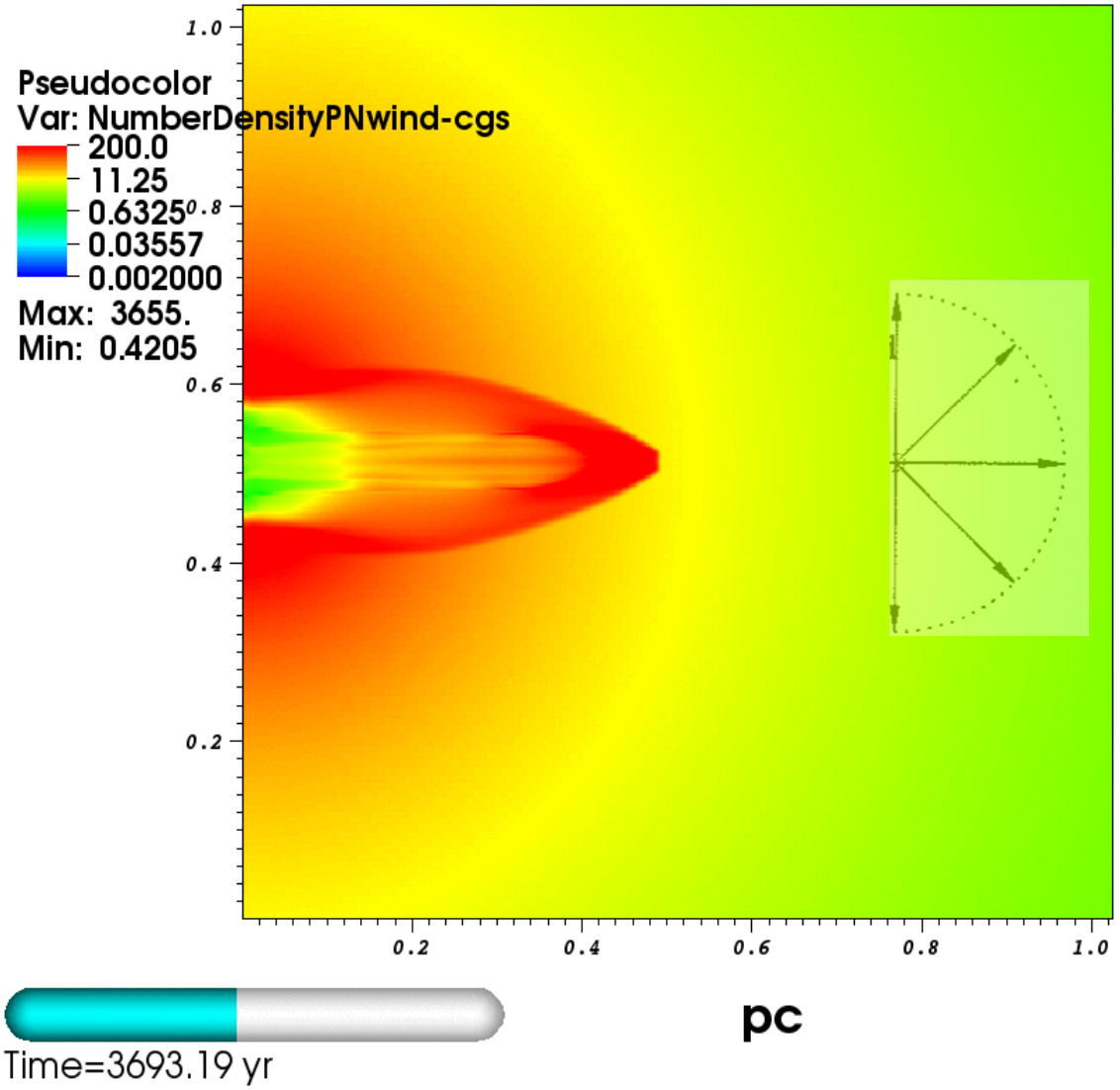
↓

Spherical wind



AGB
spherical

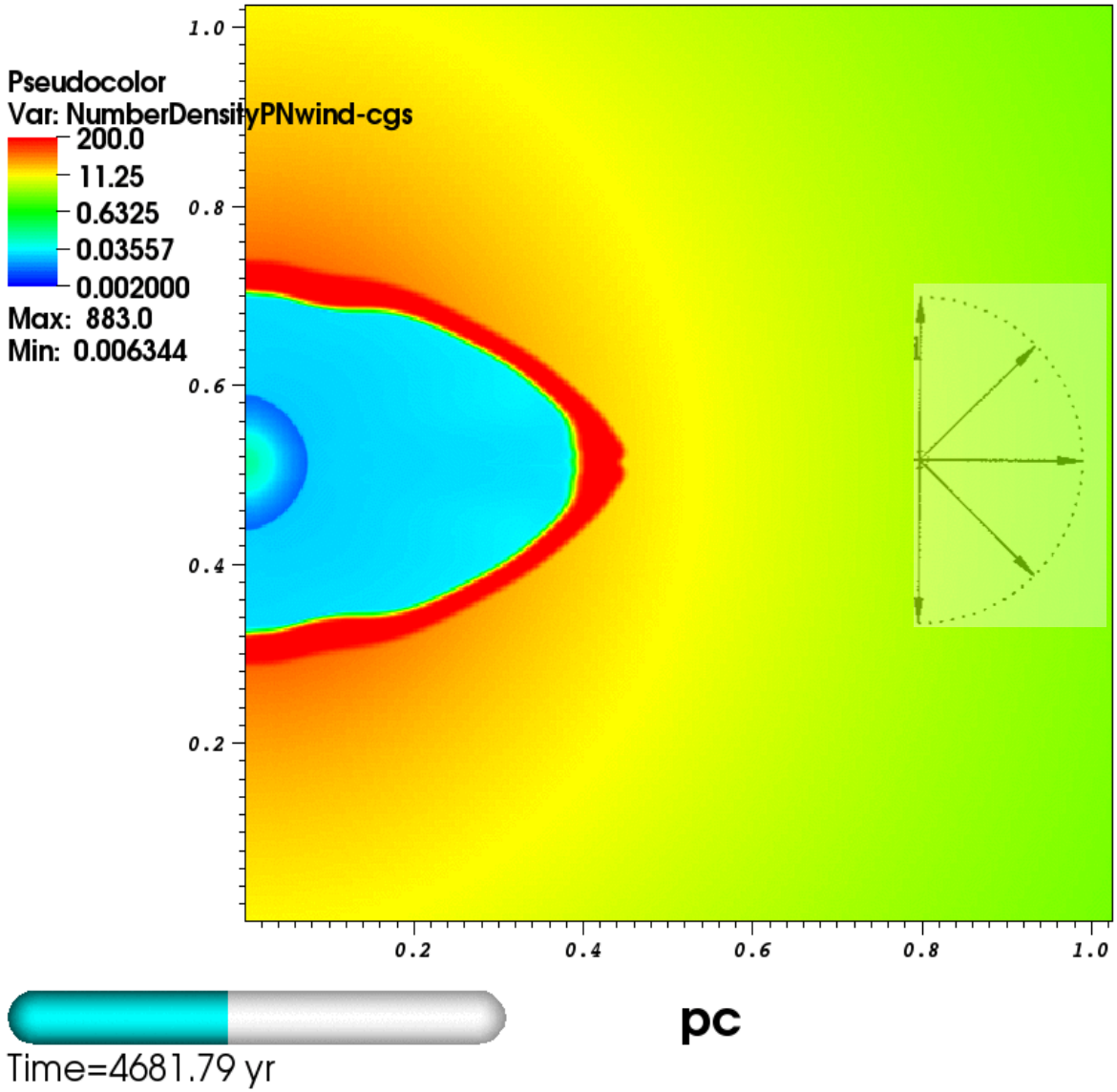
Jet



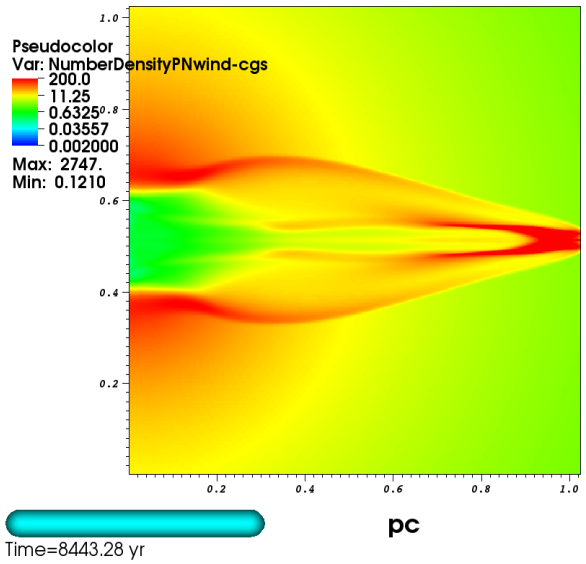
AGB spherical

Jet

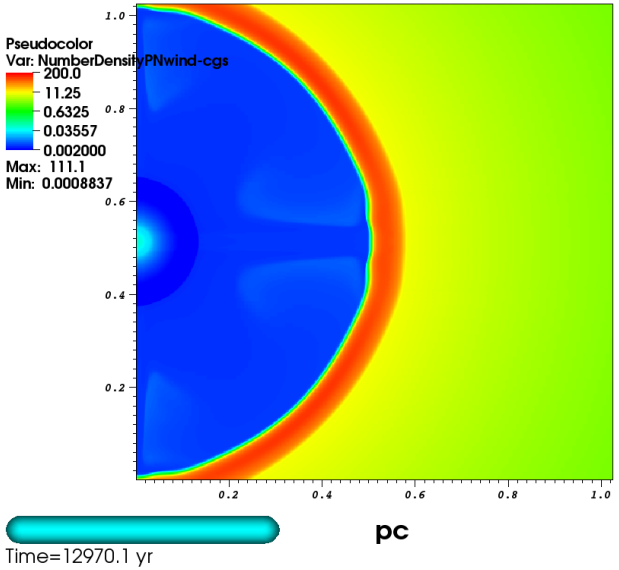
Spherical wind



Aspect ratios

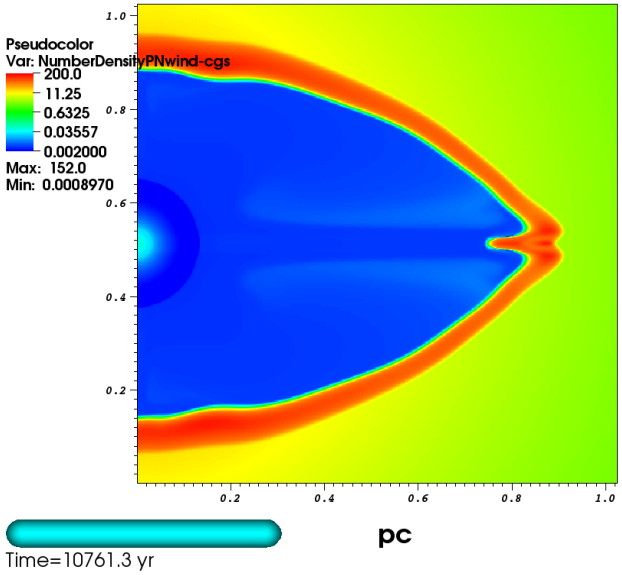


6.25



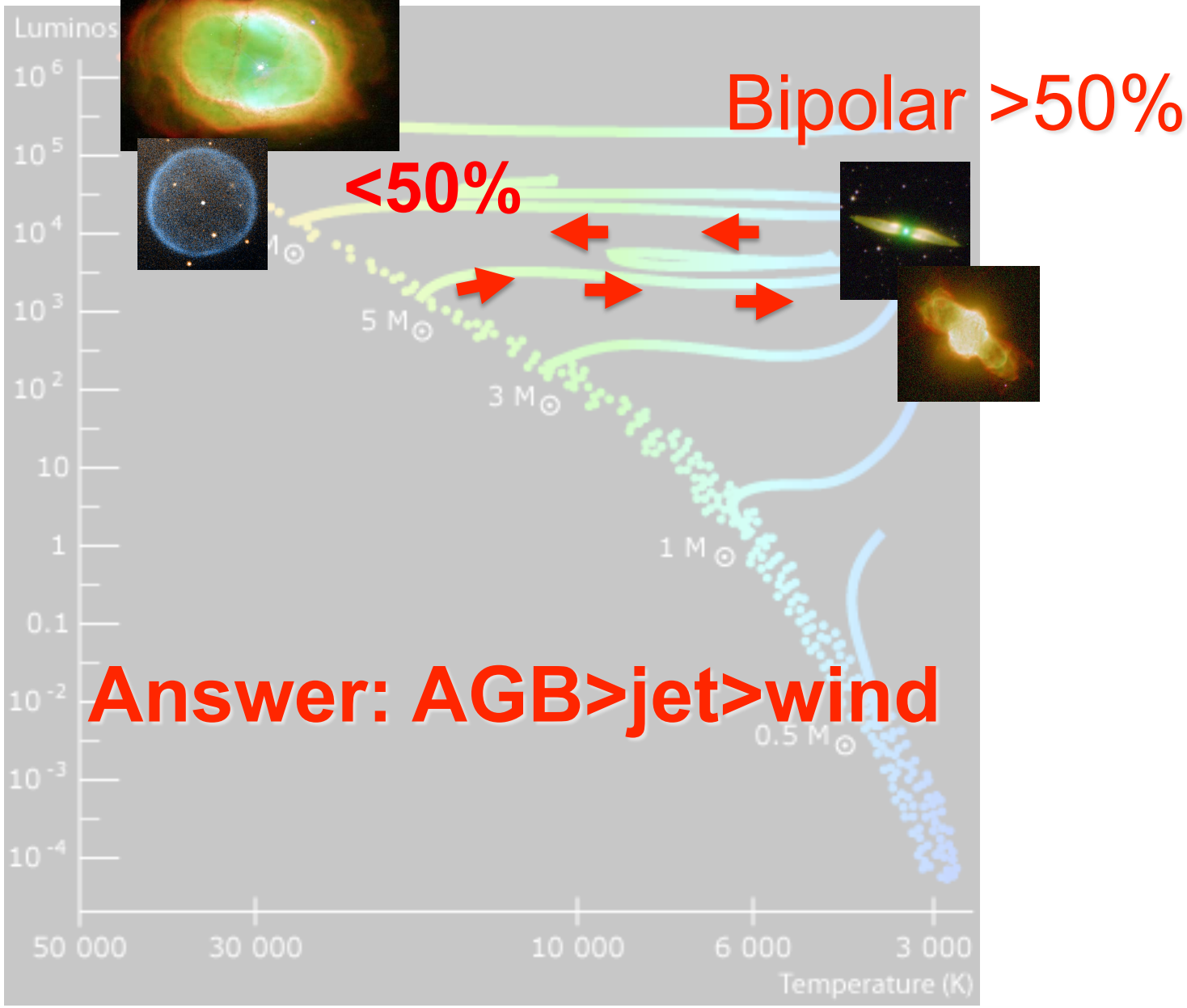
1

Different timescales



2.1

Asymptotic Giant Branch (AGB) stars

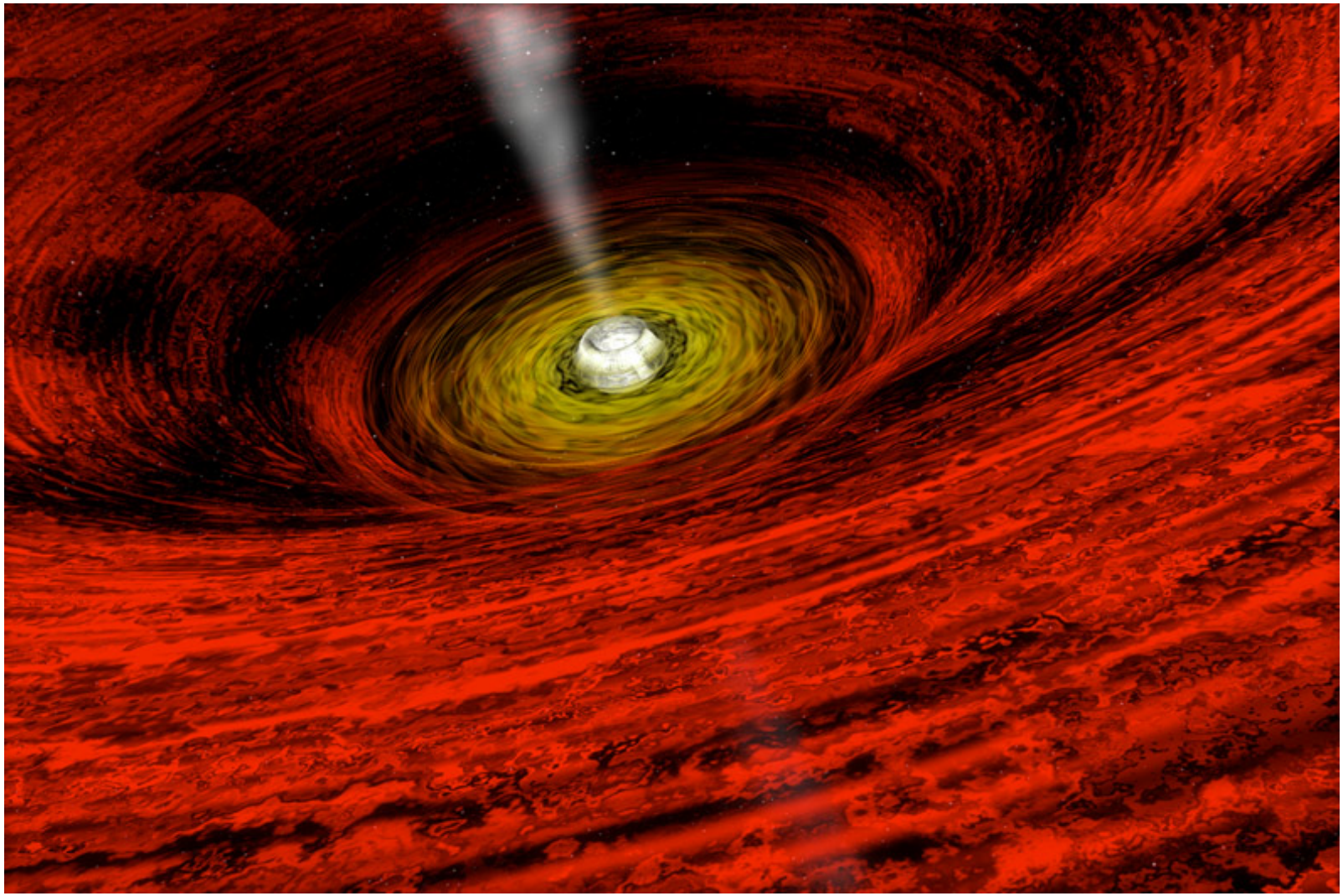


Jets. Got it!

These ones?

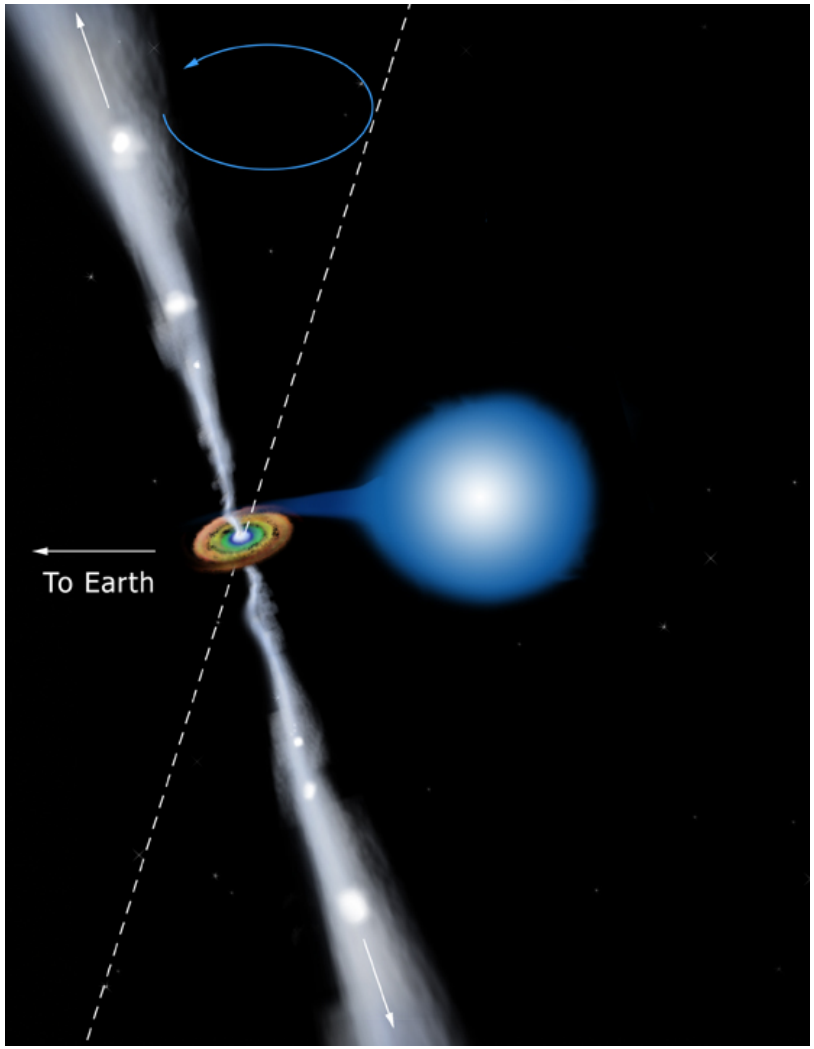
NO. Astrophysical jets.

How are astrophysical jets formed?



This is a cartoon not a telescope image

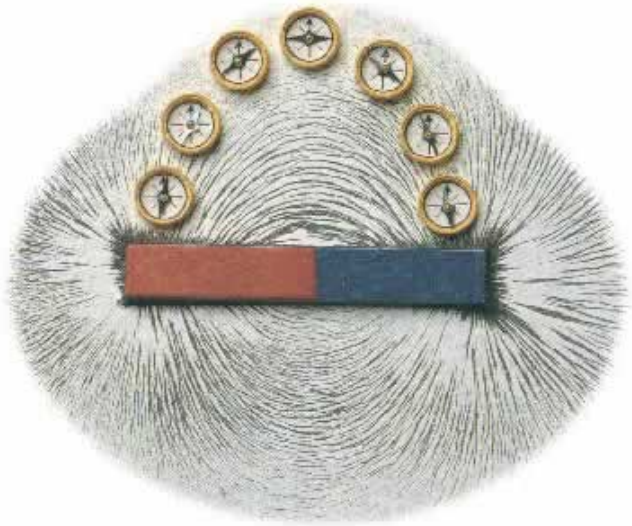
Jets are formed by gravity, rotation and magnetic fields

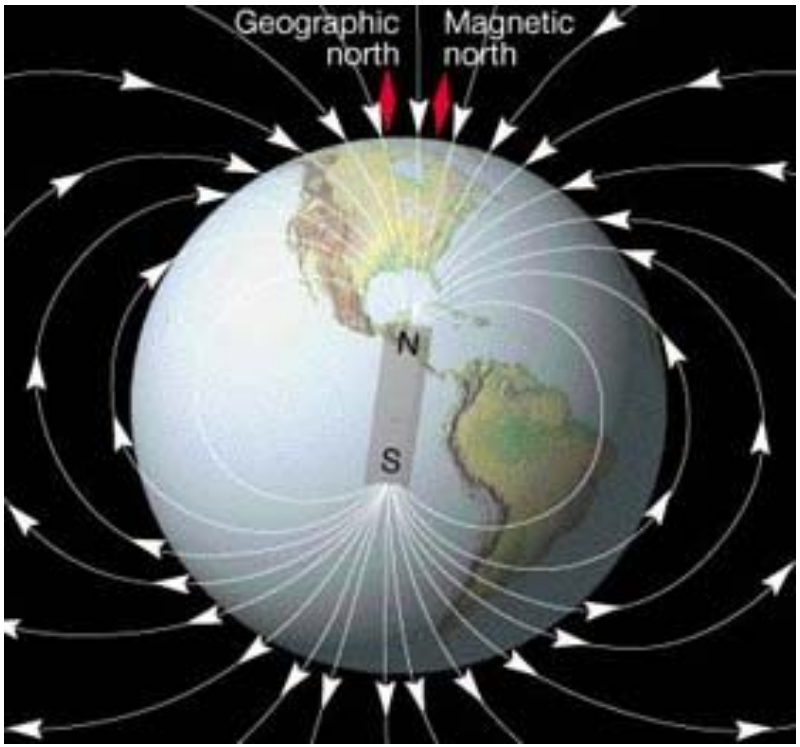


Accretion disk

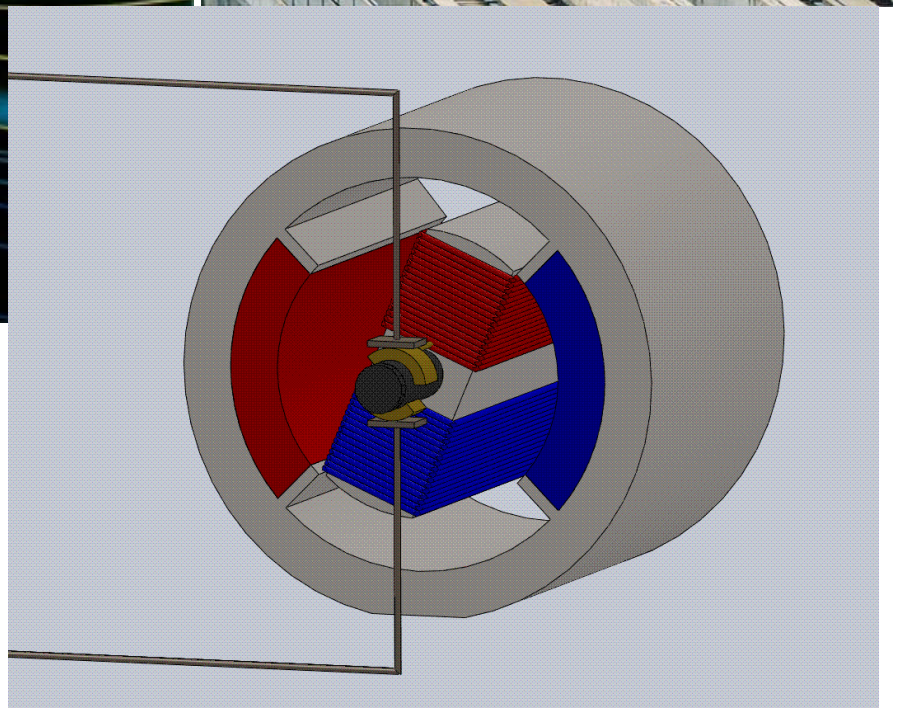
(remember it for your scrabble games or to impress your friends)

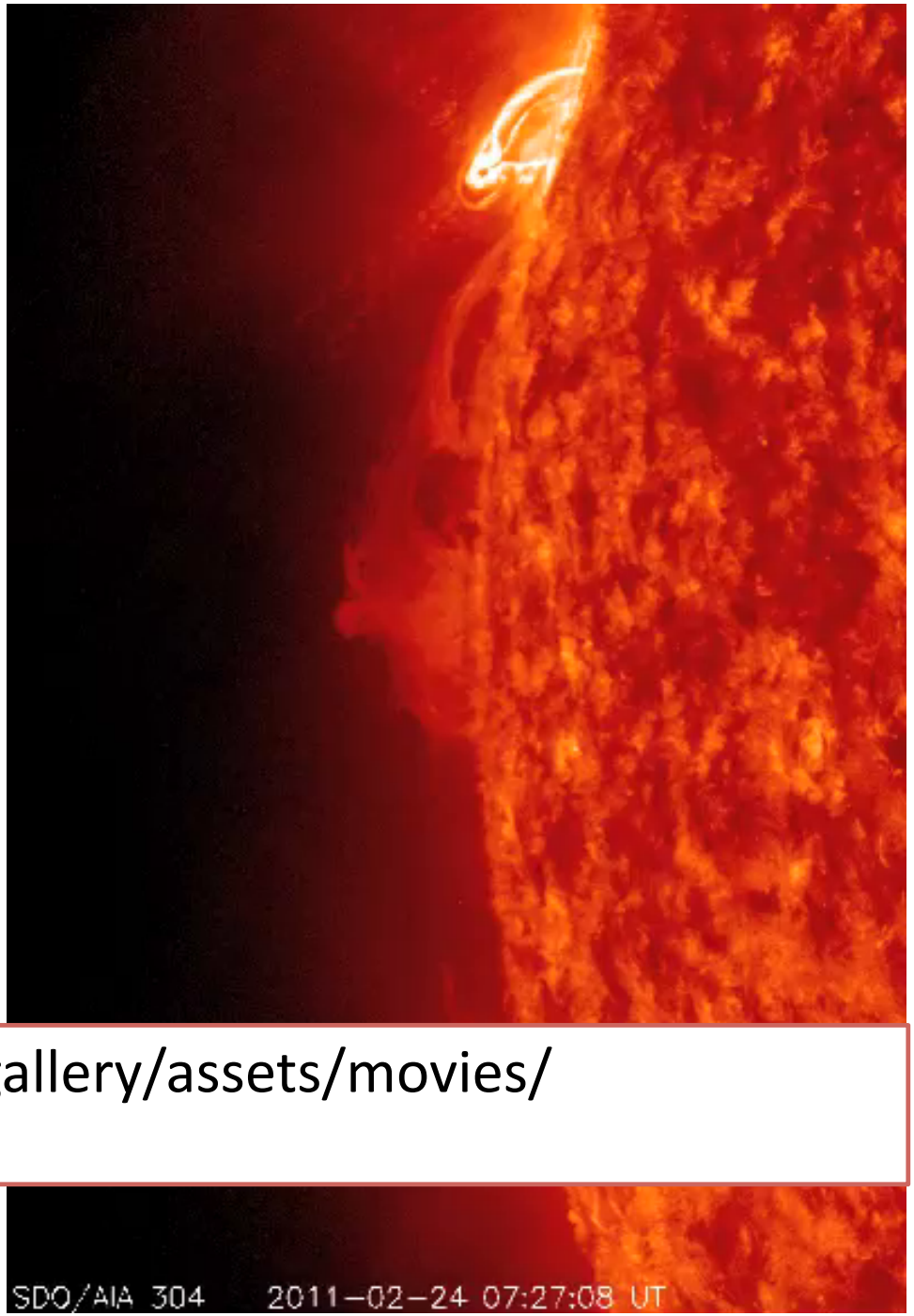
Magnetic fields exist.





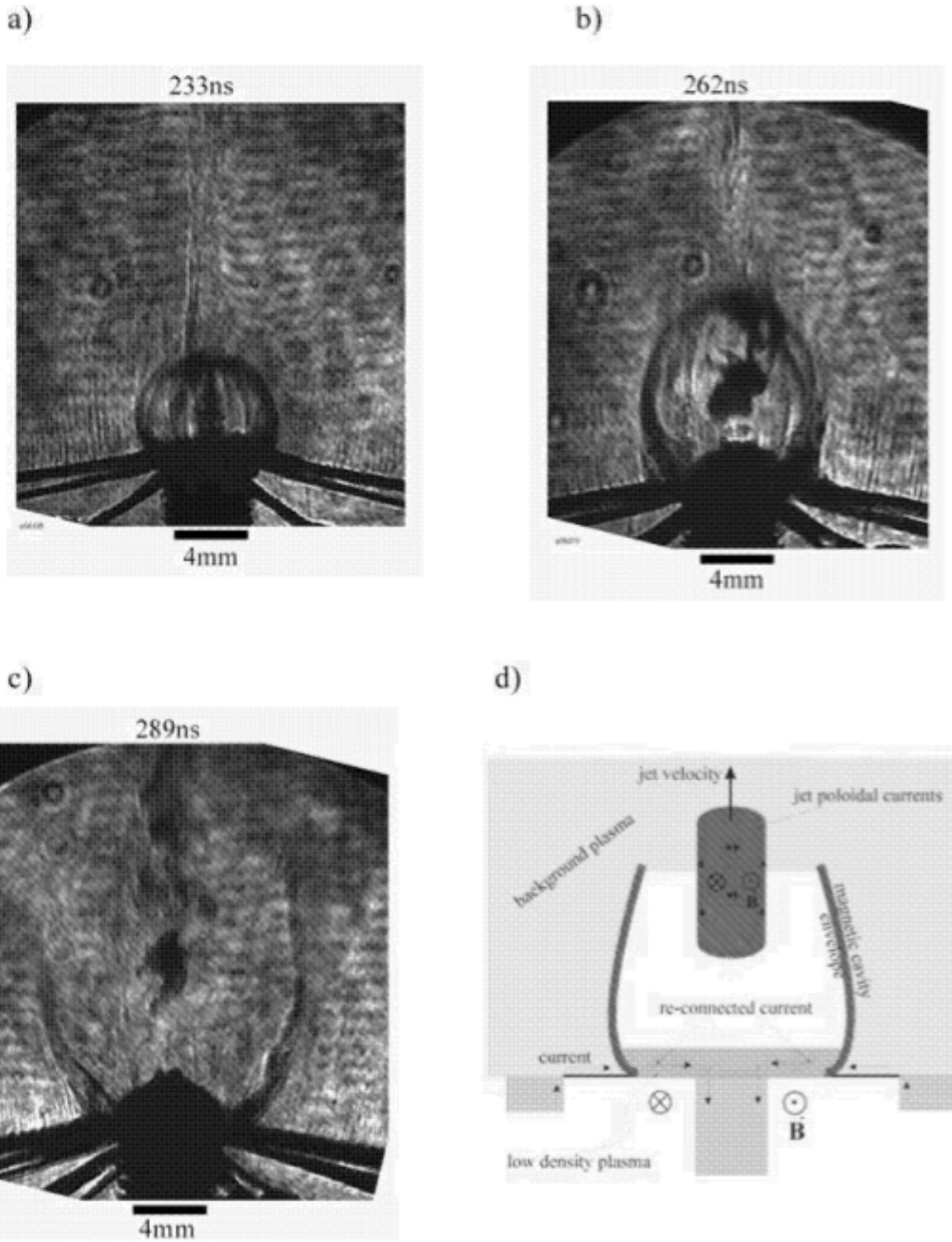
Magnetic fields exert forces

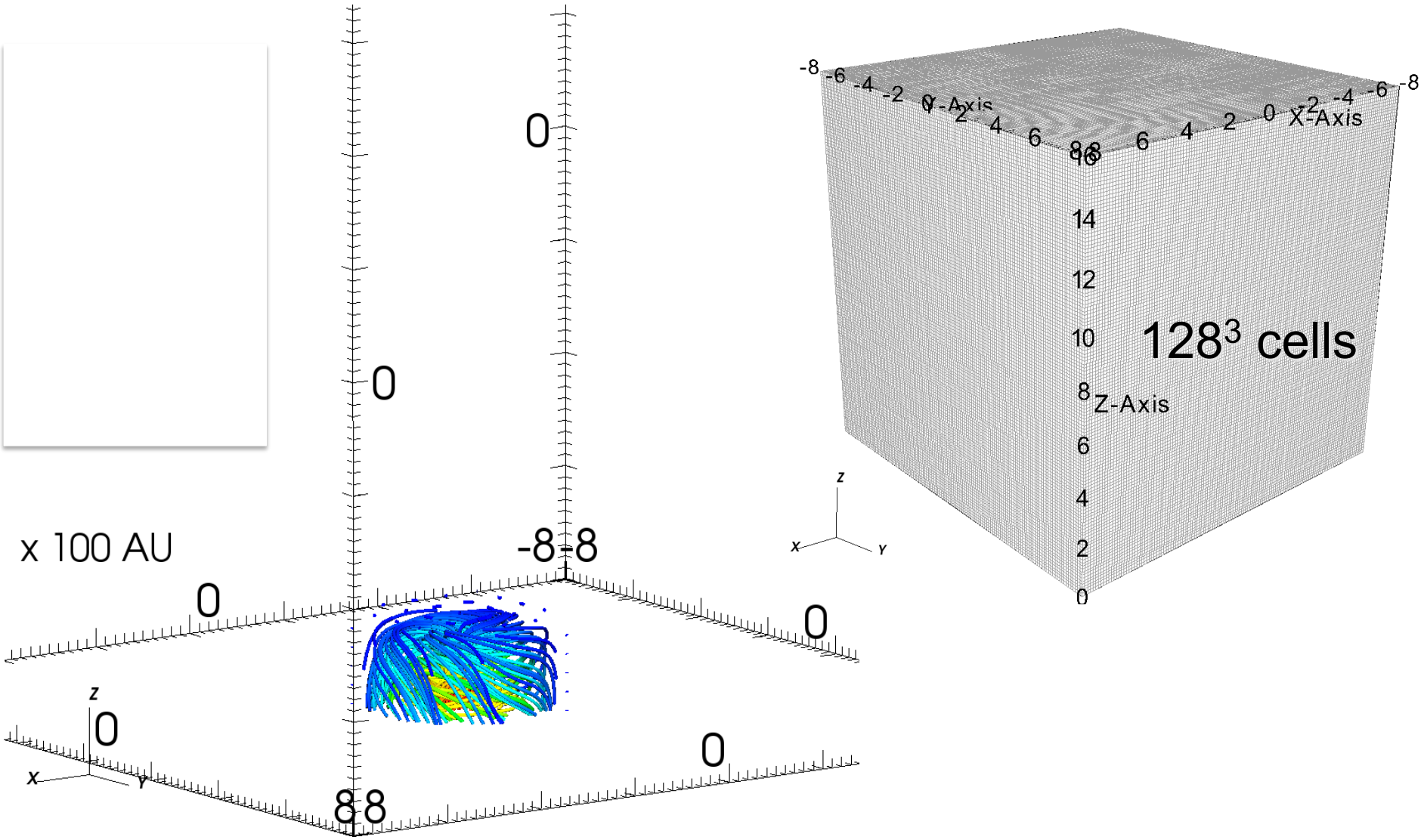




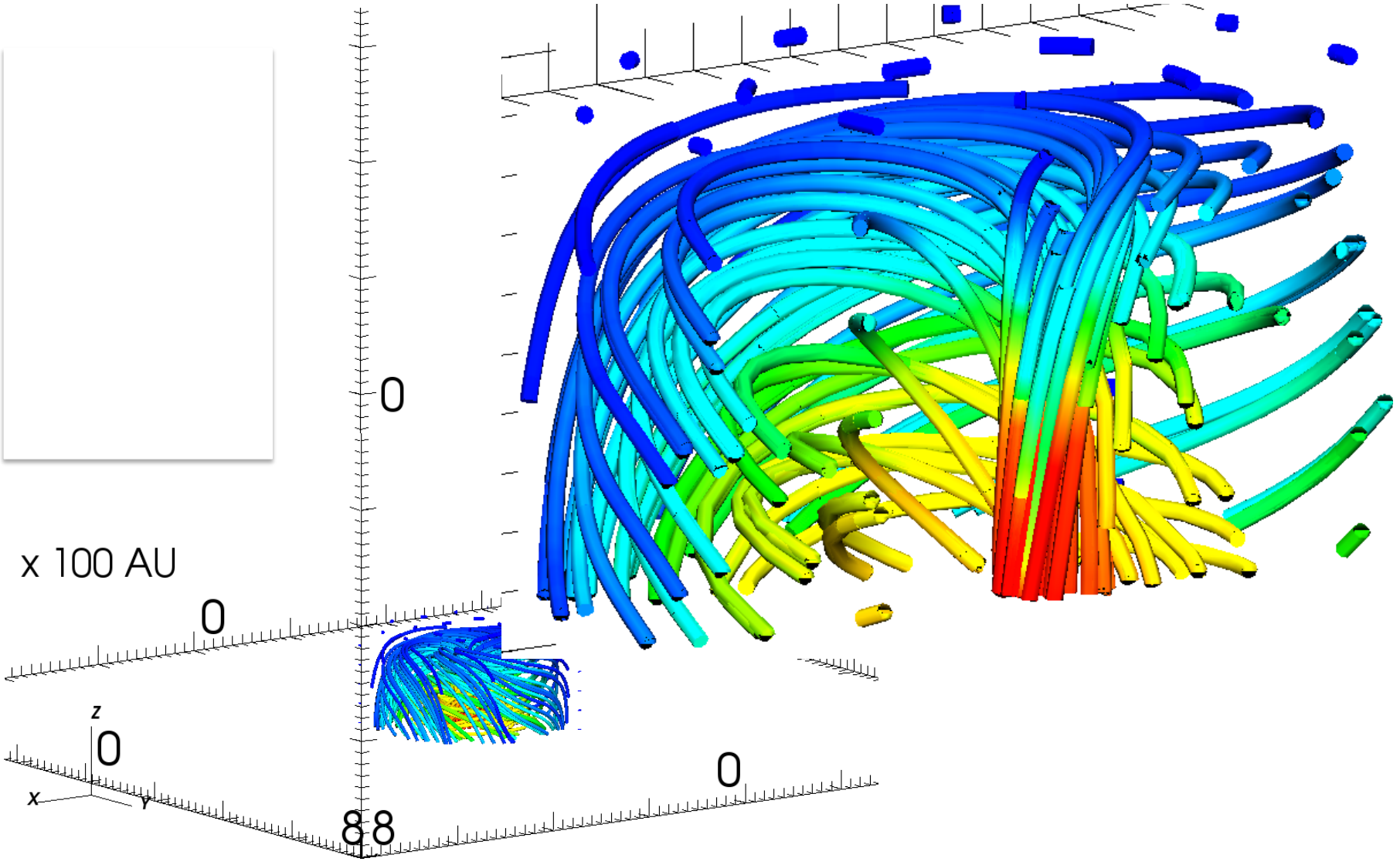
http://sdo.gsfc.nasa.gov/gallery/gallery/assets/movies/20110224_monster_prom.mp4

Bubbles filled with magnetic fields in lab experiments
(Lebedev et al. 2005).

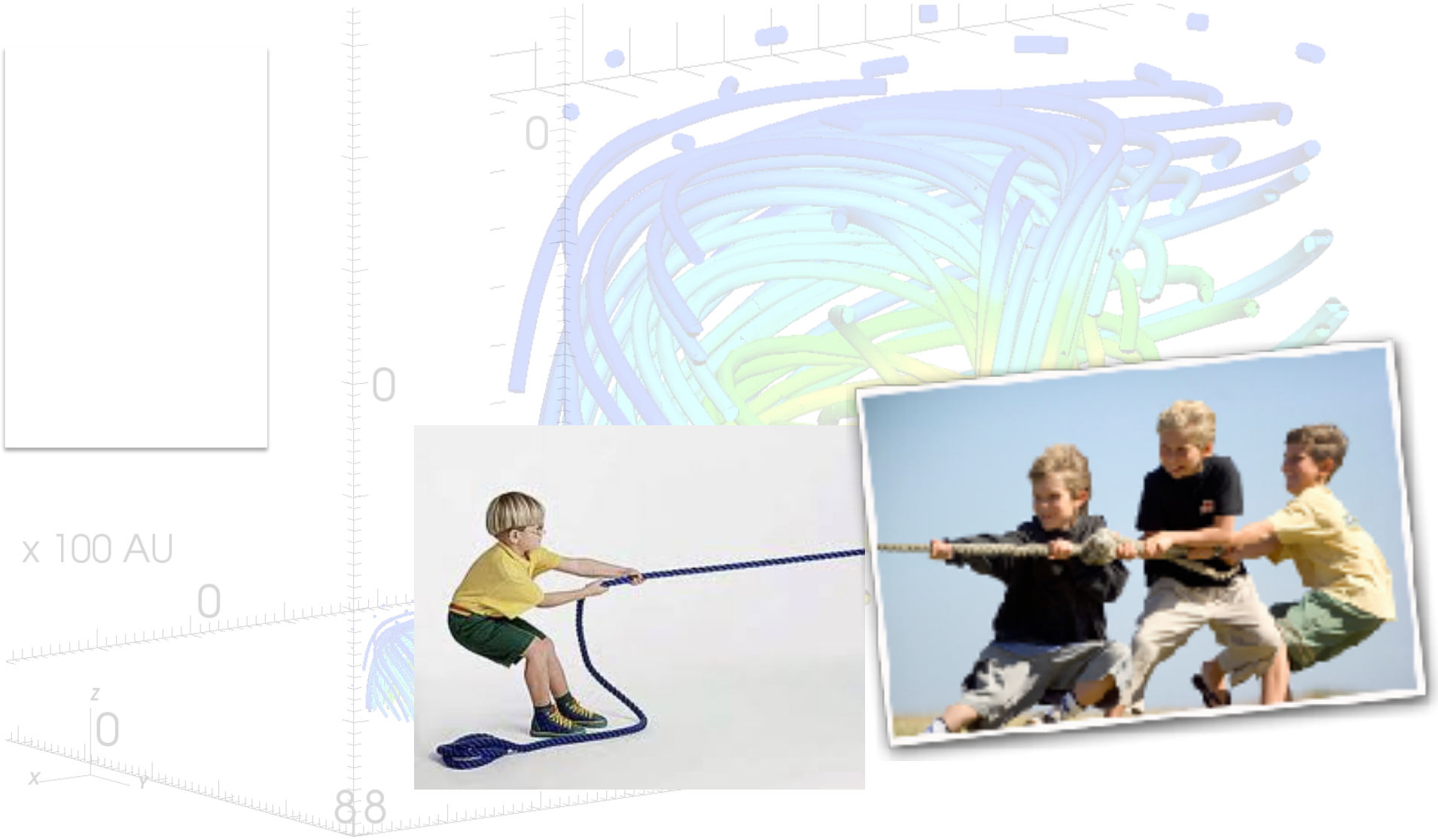




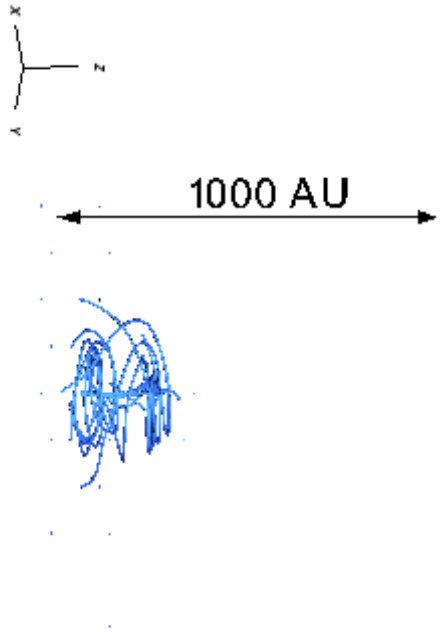
Initial magnetic fields

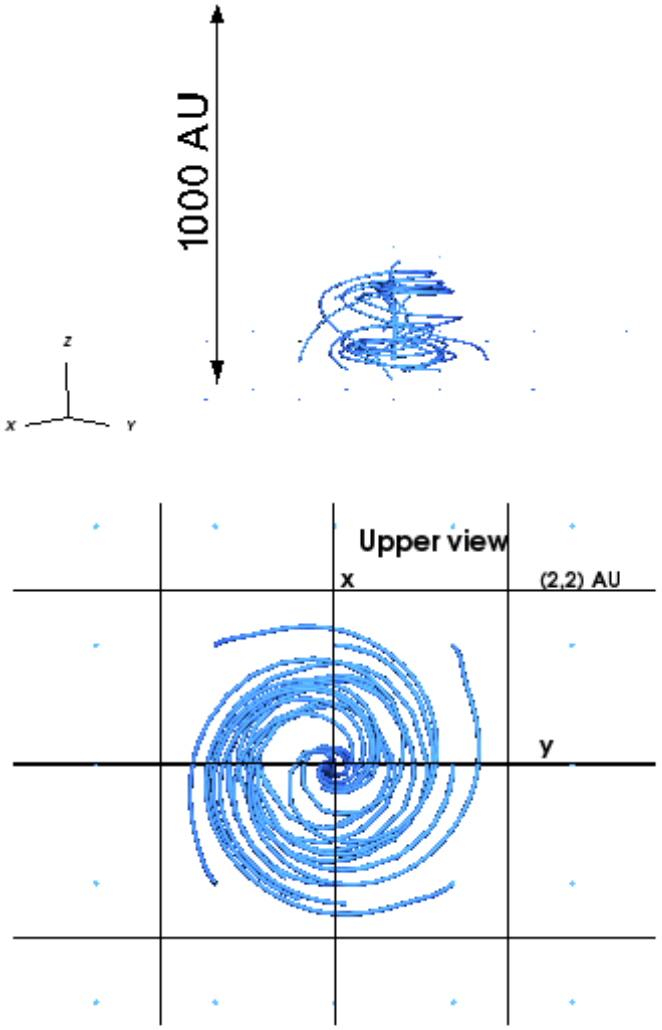


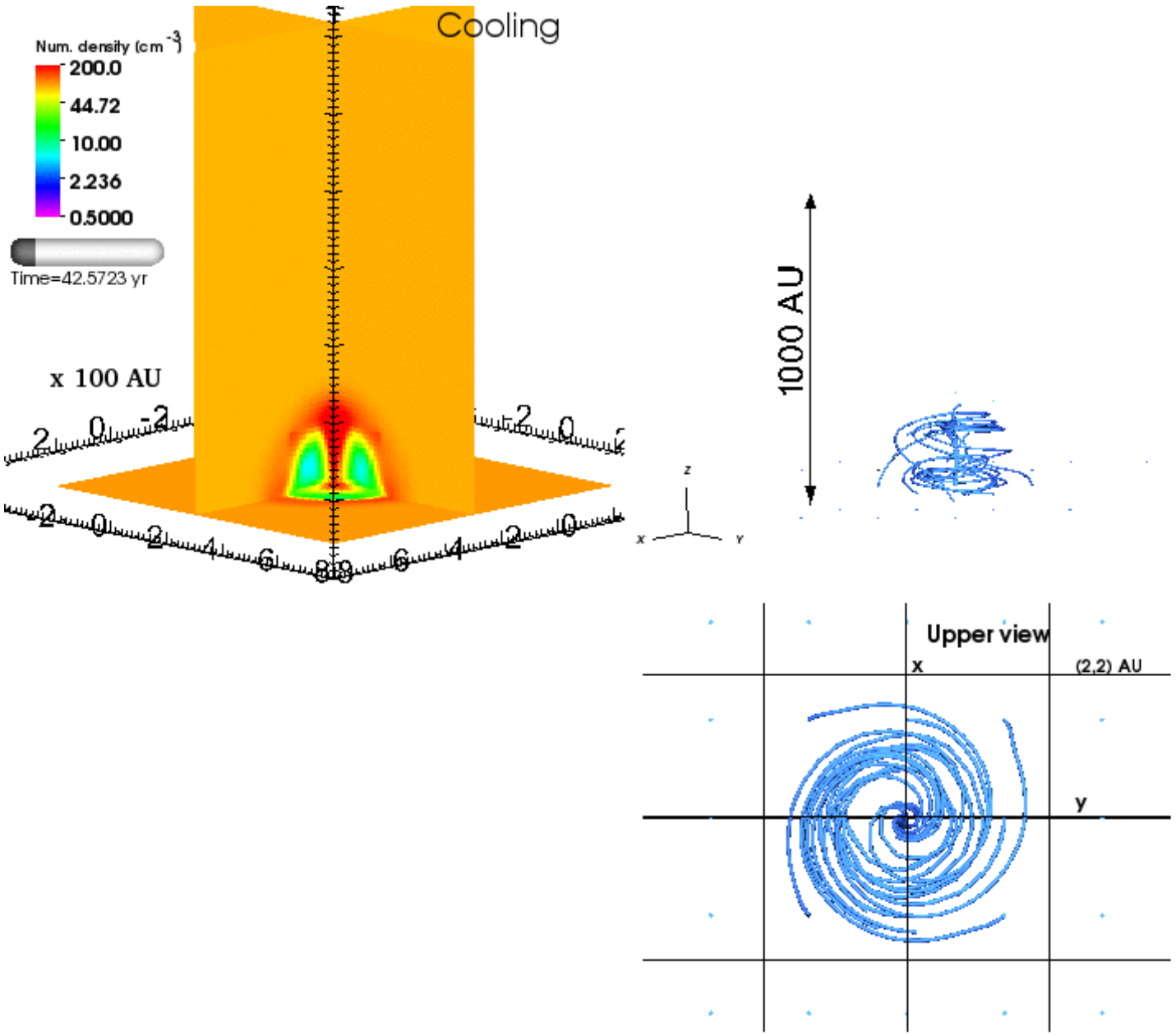
Initial magnetic fields



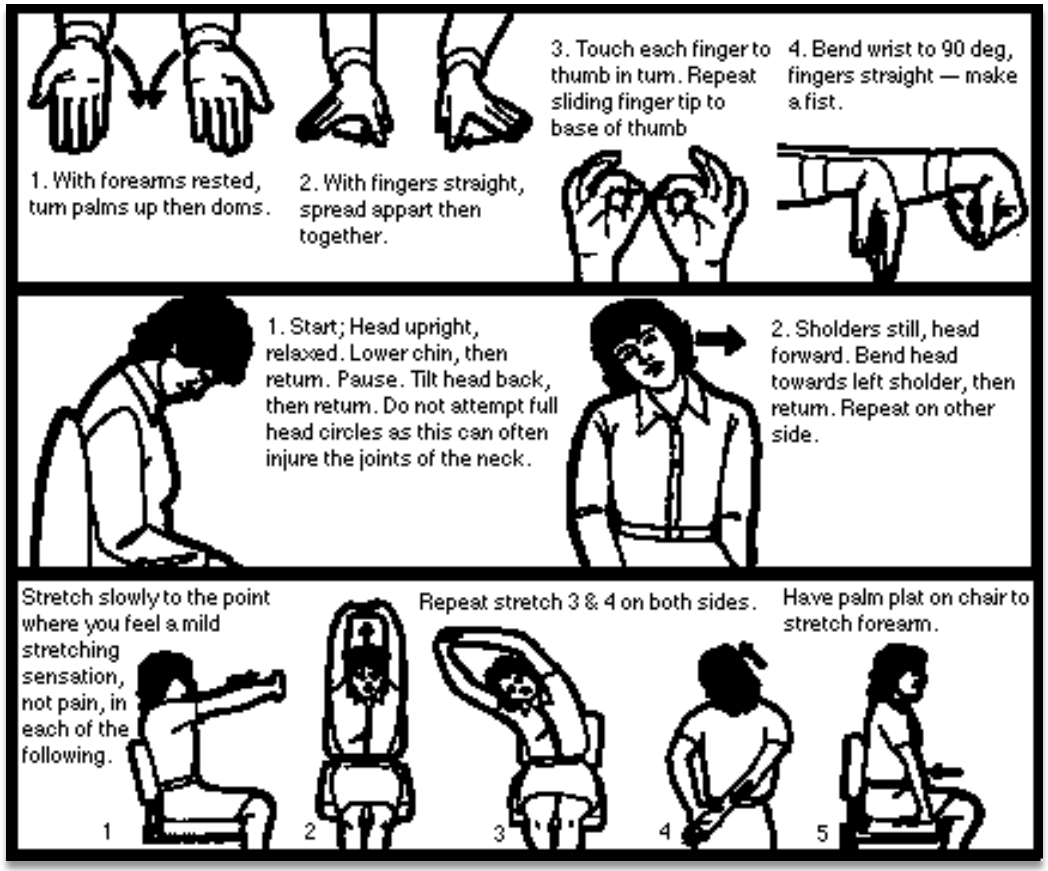
Force differences lead to motion


X
Z
Y
1000 AU


1000 AU
z
x
y
Upper view
x
(2,2) AU
y

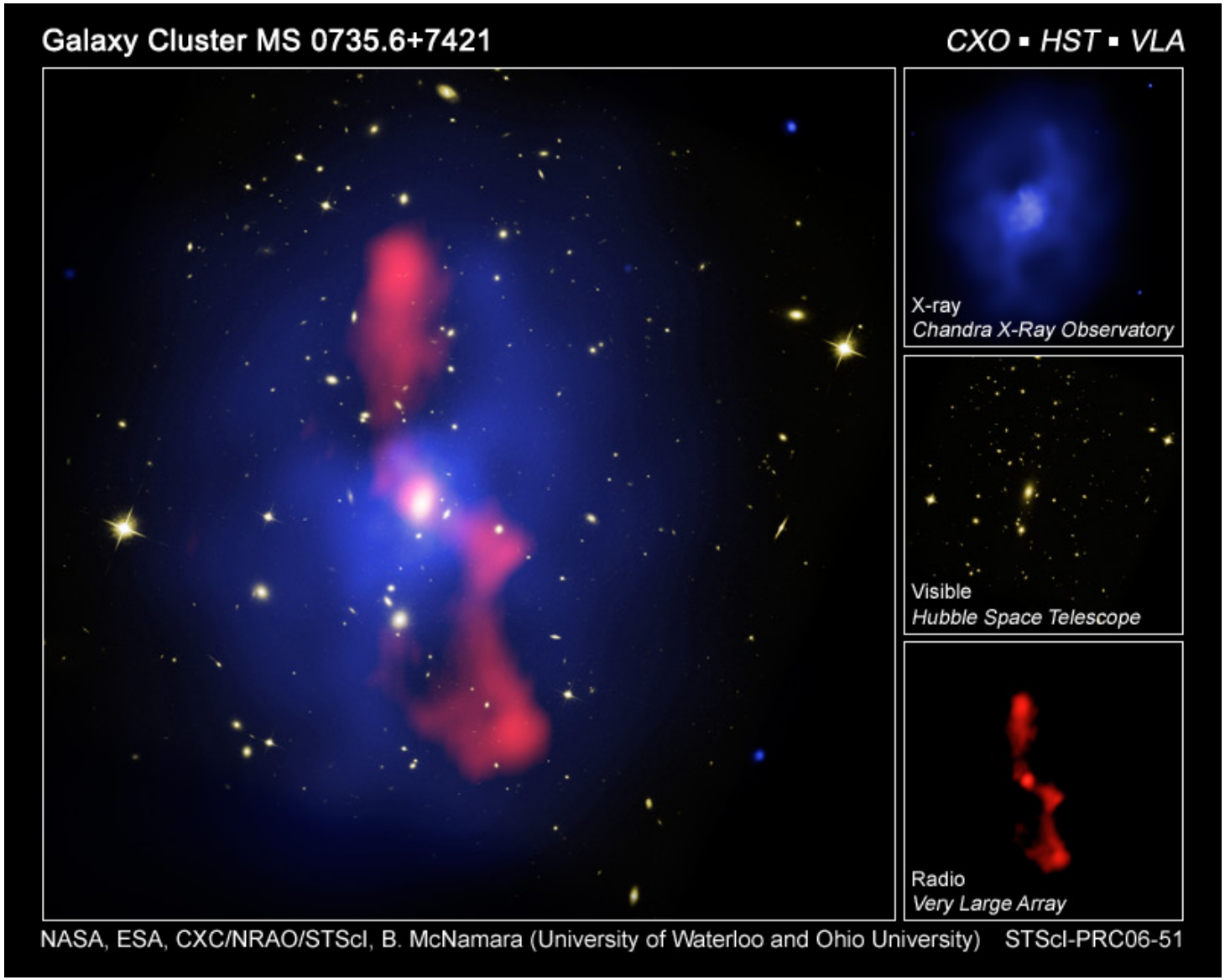

Cooling
Num. density (cm^{-3})
200.0
44.72
10.00
2.236
0.5000
Time=42.5723 yr
x 100 AU
1000 AU
z
x
y
Upper view
x
(2,2) AU
y

Before you sleep (again)…

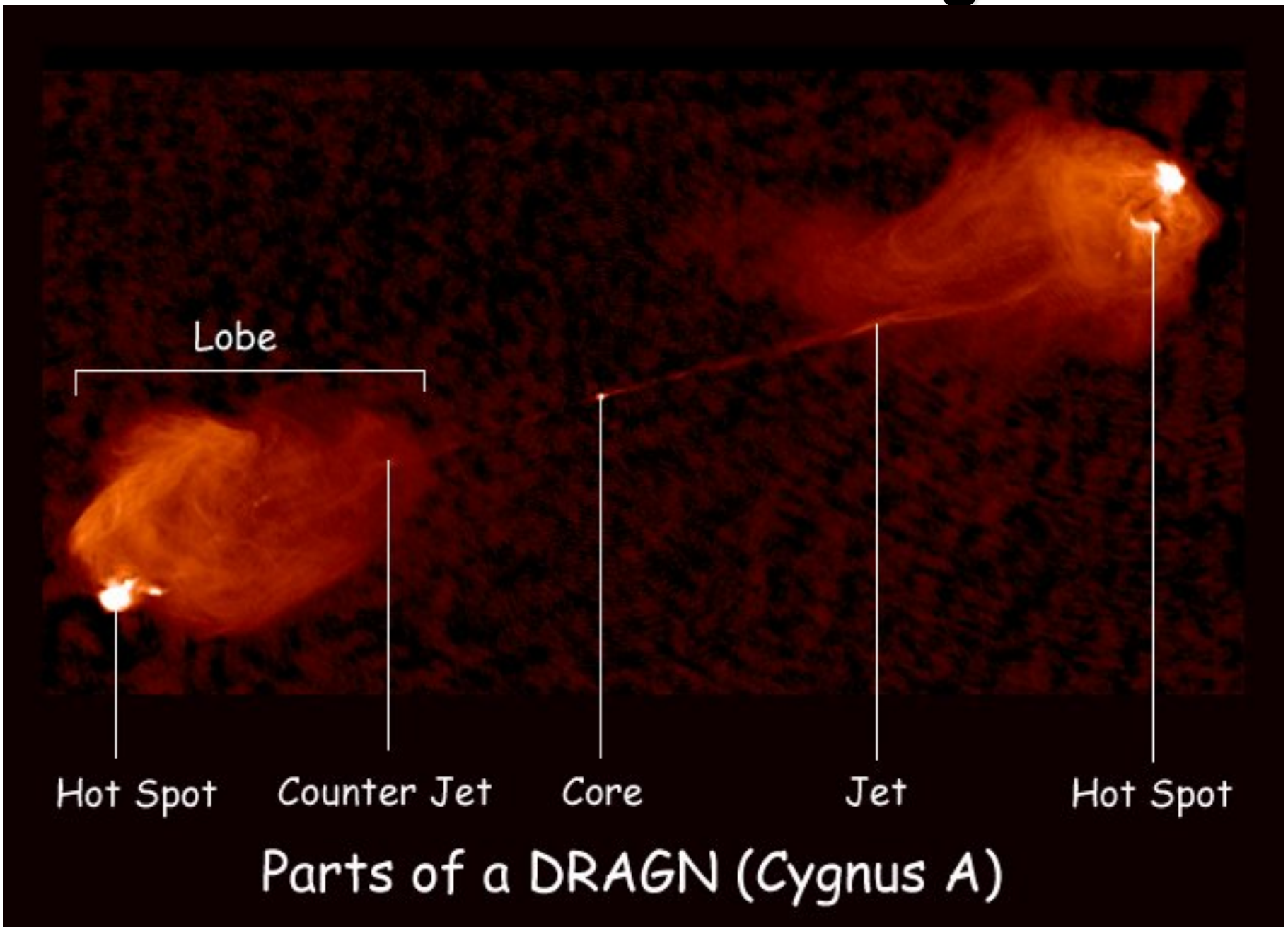


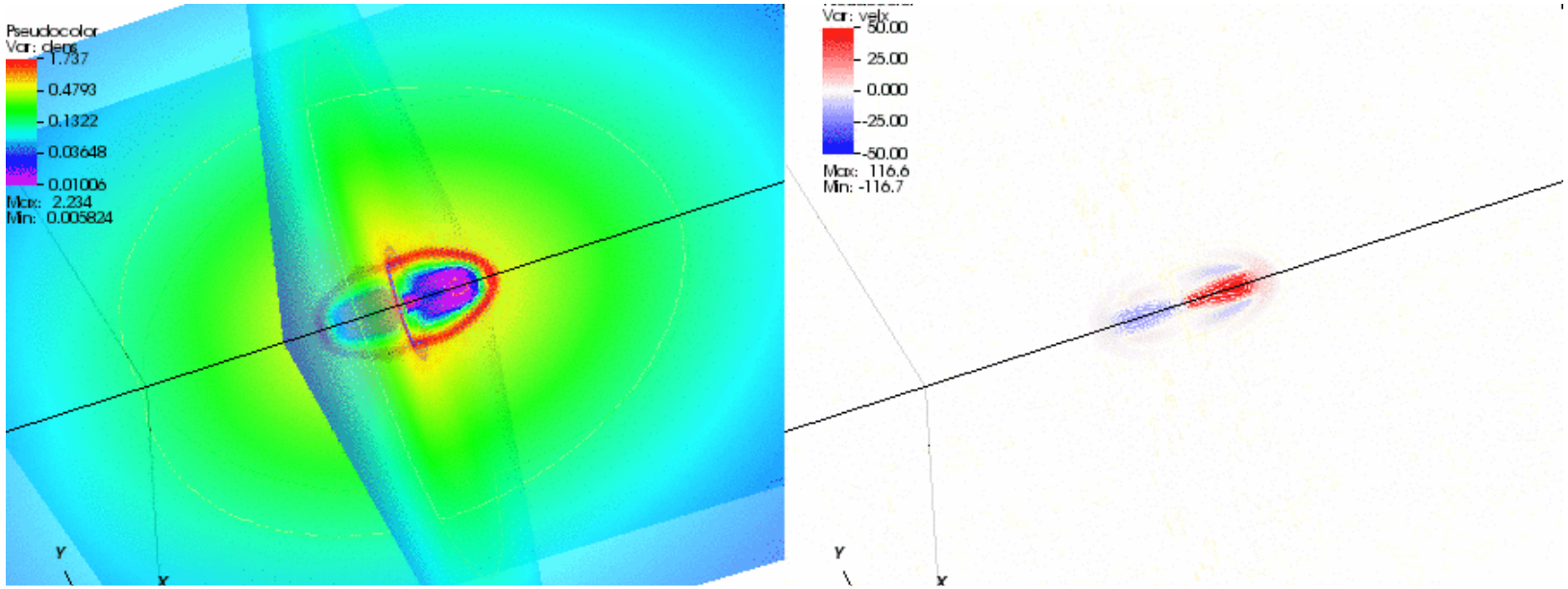
Now this one

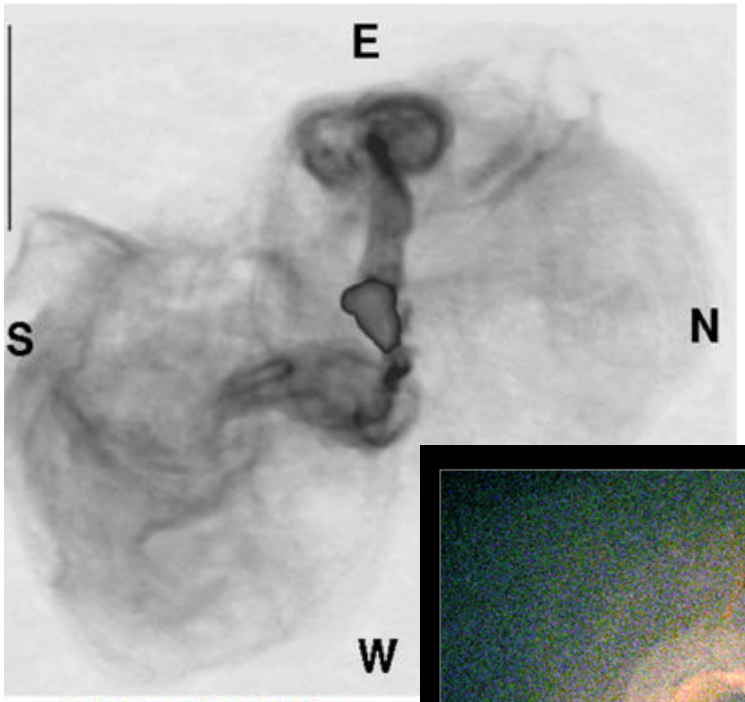
Magnetic fields in radio galaxy bubbles



Radio galaxies

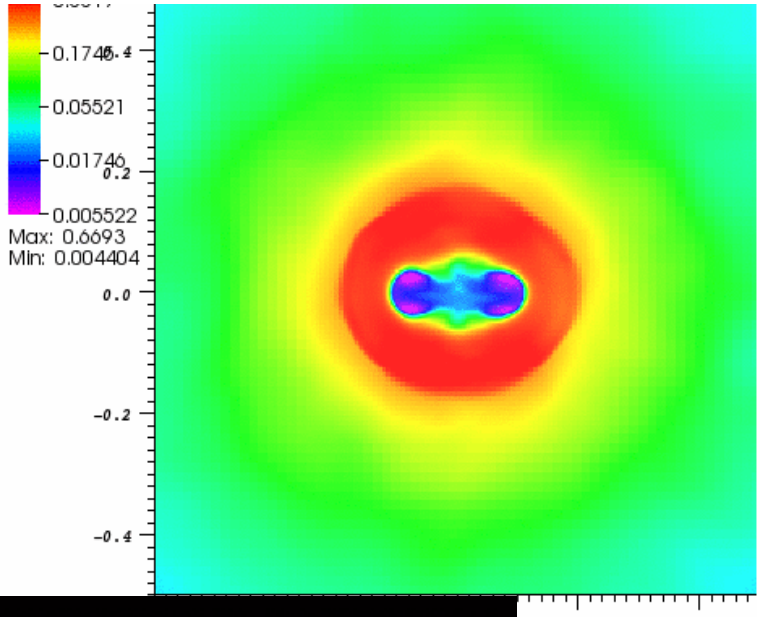


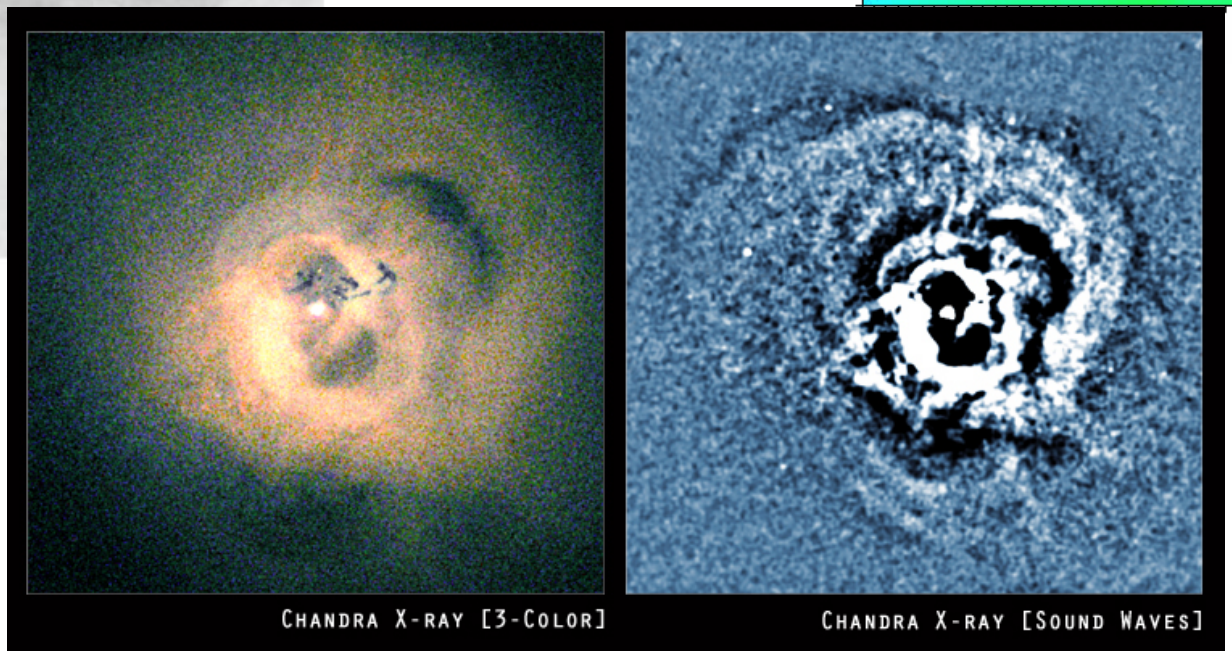

Pseudocolor
Var: depth
1.737
0.4793
0.1322
0.03648
0.01006
Max: 2.234
Min: 0.005824
Y
X
Var: velx
50.00
25.00
0.000
-25.00
-50.00
Max: 116.6
Min: -116.7
Y
X



M87 at 327 MHz

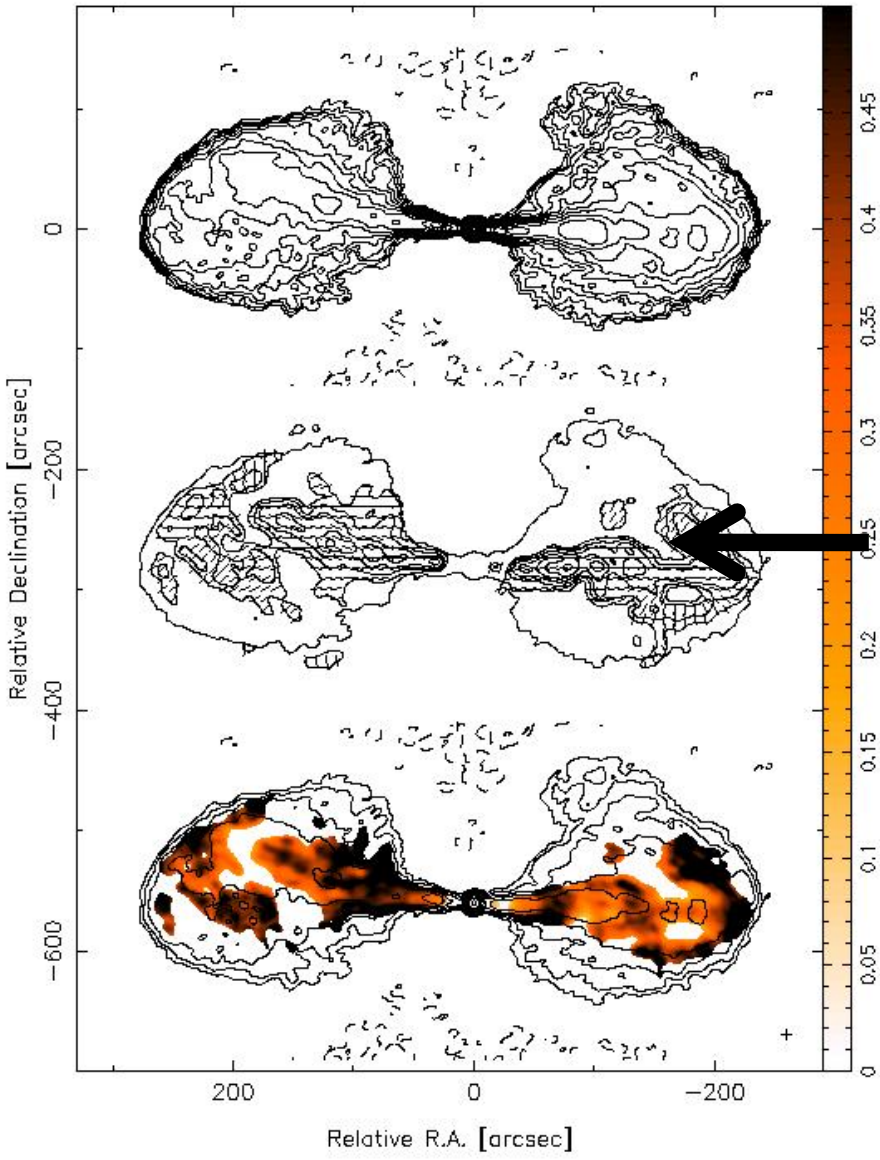
Churazov et al. 2002





A. Fabian et al.

Radio galaxy NGC 4261 (what a name, huh!?)

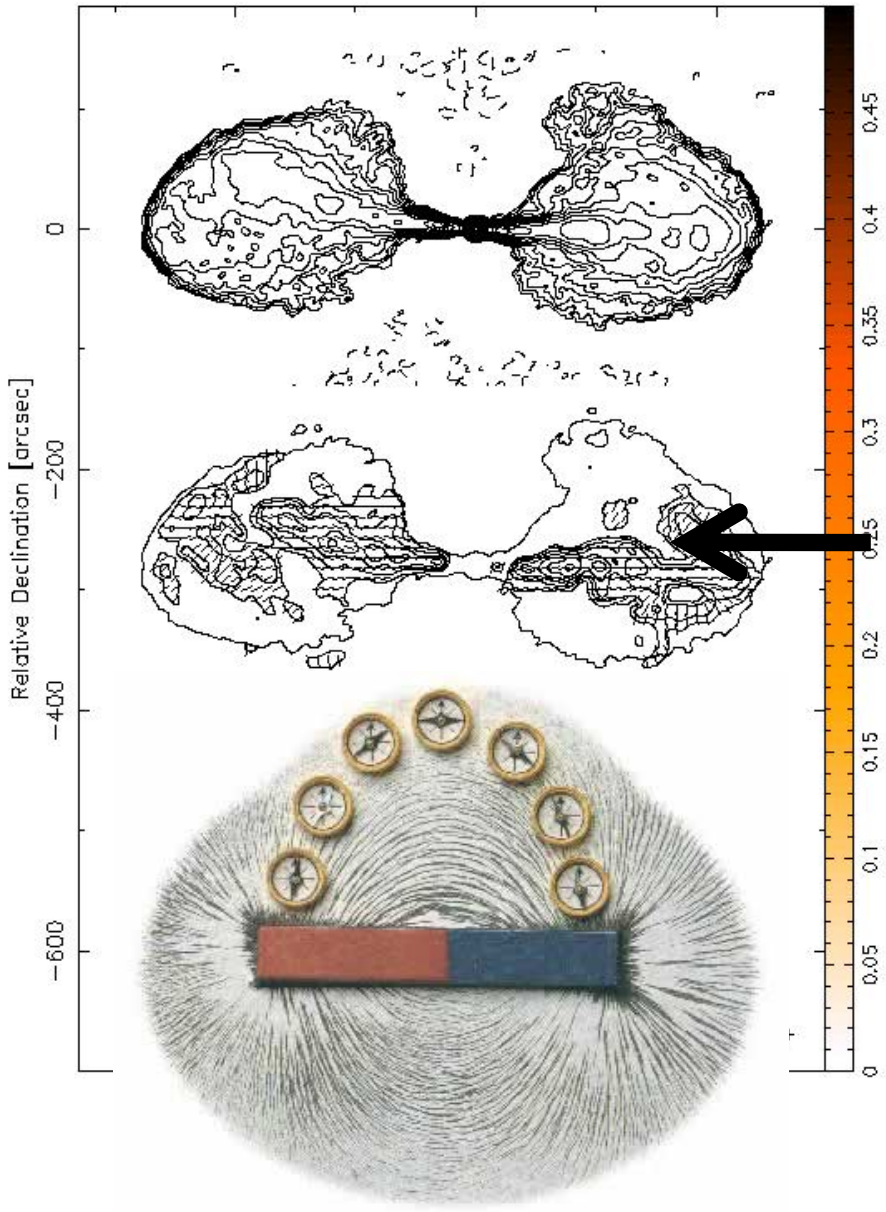


Polarization map

Teddy Cheung

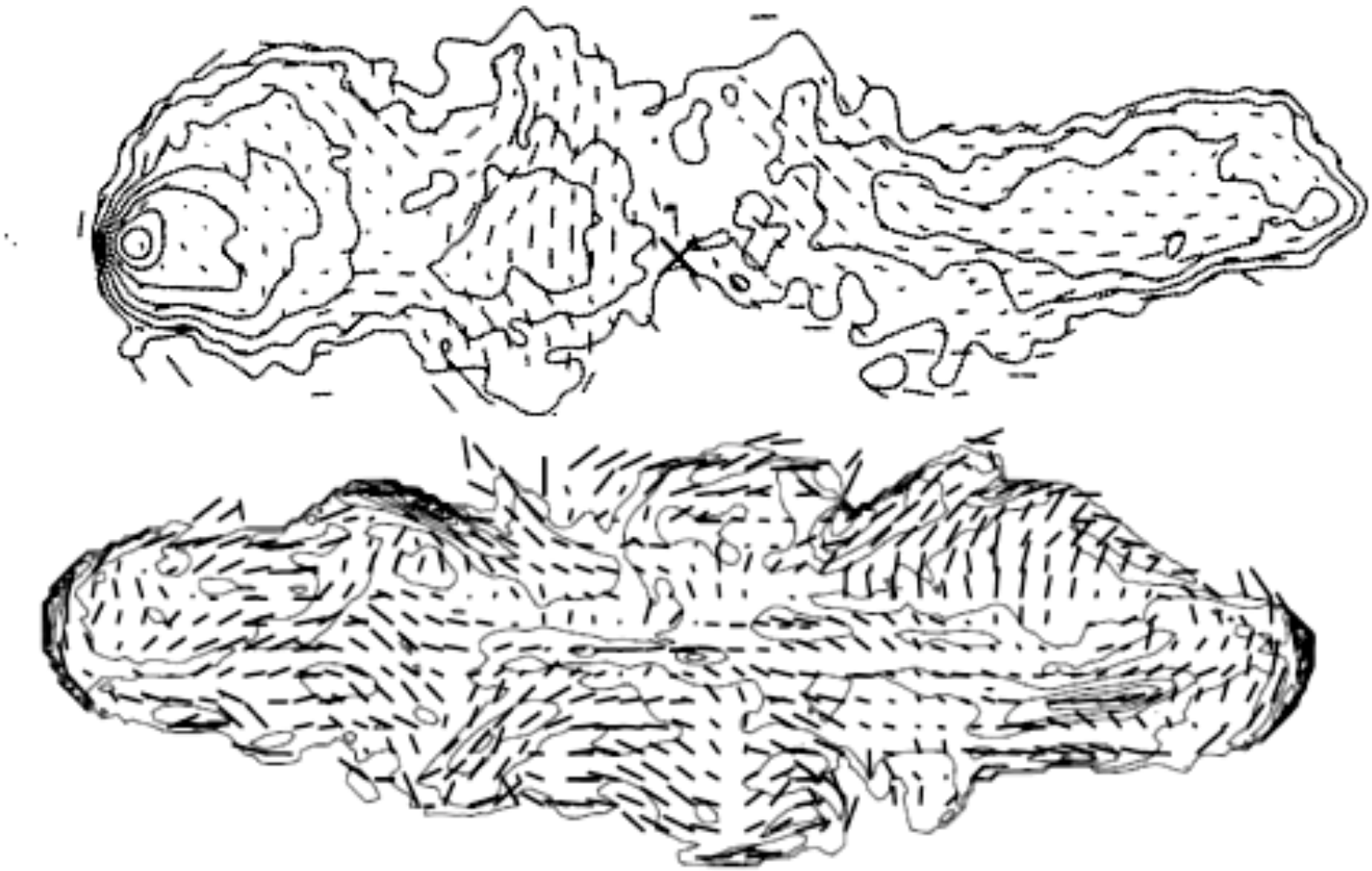
Radio galaxy NGC 4261 (what a name, huh!?)

How does it change in time **?**



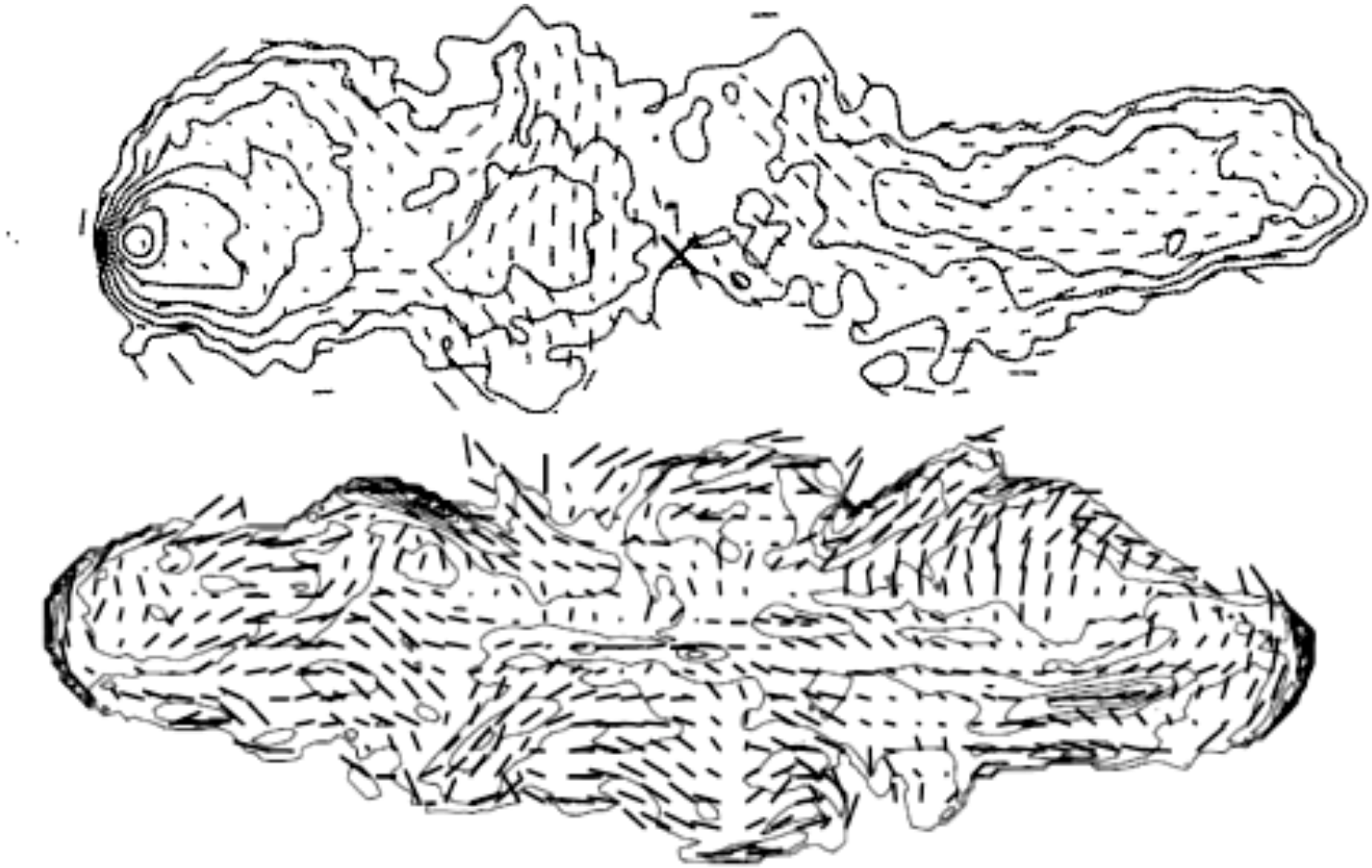
Polarization map

Teddy Cheung



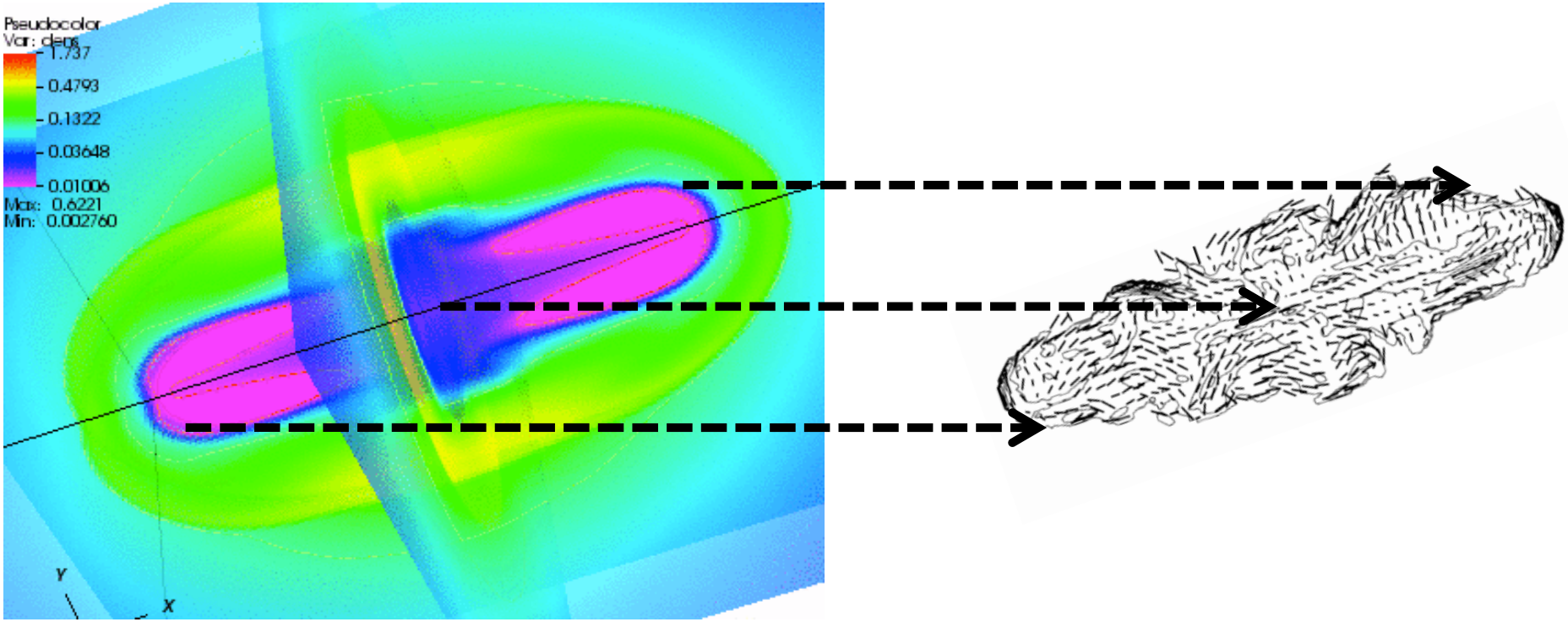
Observation or simulation?

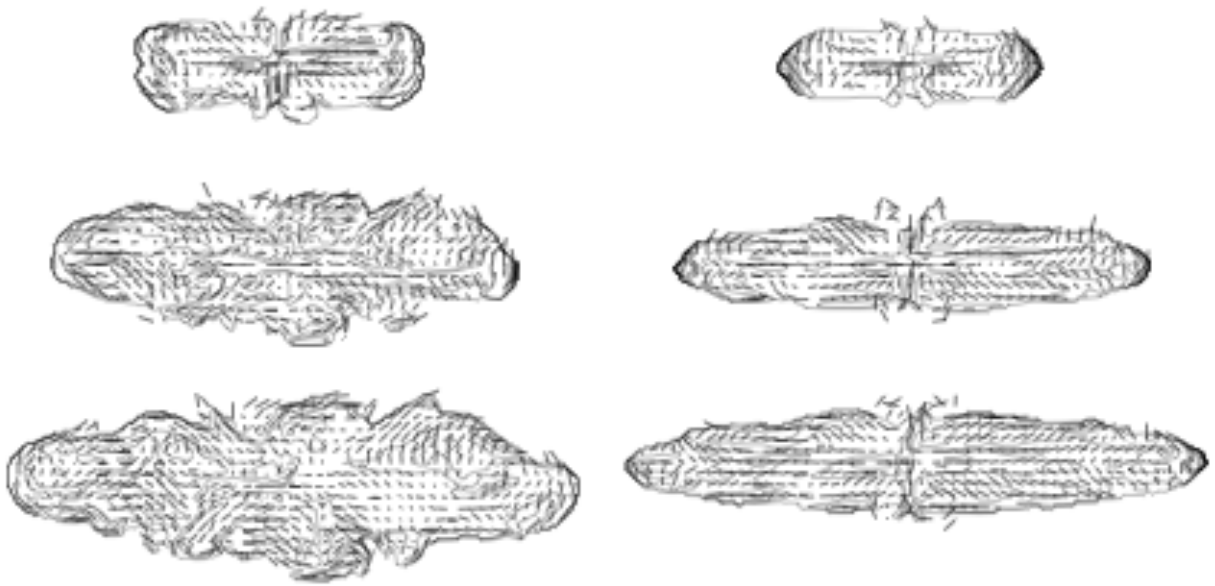
Observation



Simulation

Synthetic observations



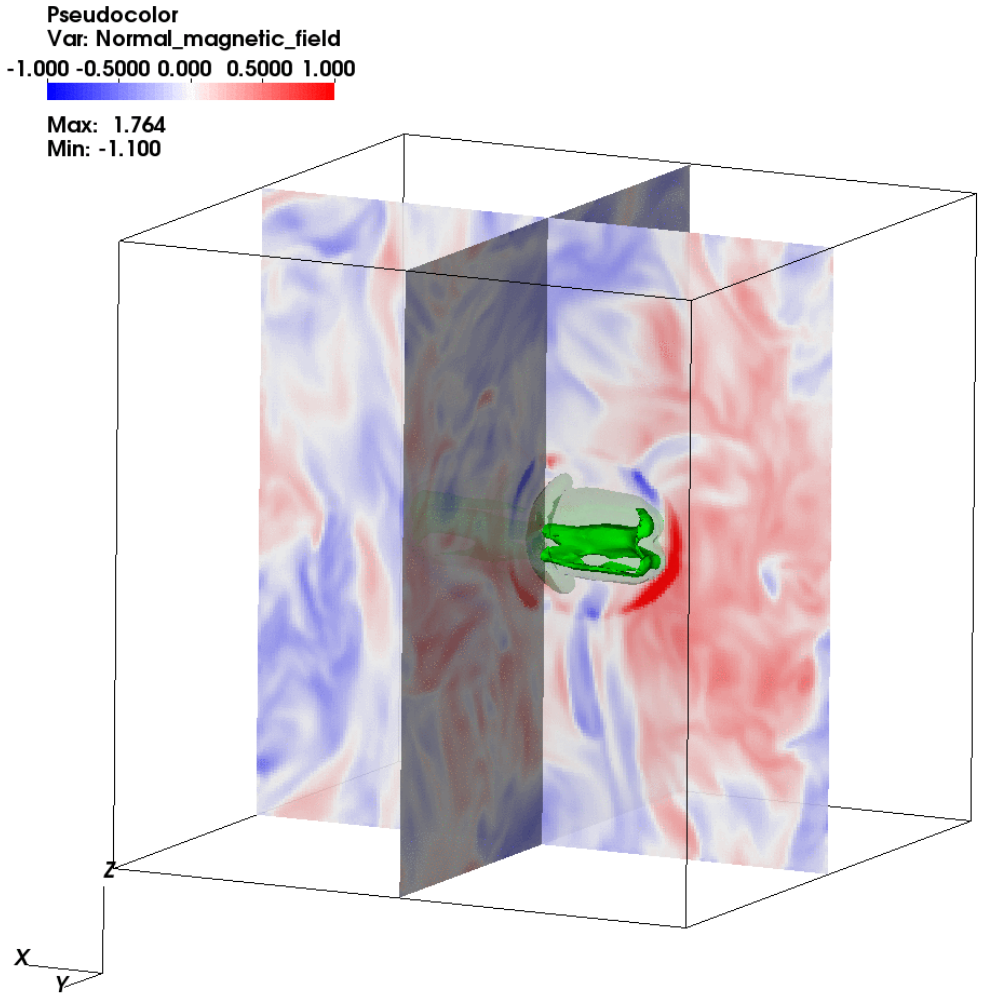


Time

Myr


30°
60°
90°

We can also study how astro bubbles affect their surrounding ambient. This is a modern topic in Astrophysics, called “Feedback”.



Jets

Ambient Mag fields

Summary

-Some stars in our galaxy form jets and bubbles.

-Radio galaxies, far, far away, form huge jets and bubbles as well.

-Jets and bubbles can be produced in the lab and in computer simulations.

-With simulations we can study the **evolution** of the shape, the growth, the density, the velocity, the magnetic fields and the energy of bubbles and their surrounding media.

THANKS!

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Joel H. Kastner, RIT
Raghvendra Sahai, NASA JPL

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