Outbursts from Supermassive Black Holes

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Bohringer, Begelman, Heinz, Owen, Eilek

Modeling the Supermassive Black Hole Driven Shocks in M87

Interaction between a SMBH and gas rich atmosphere

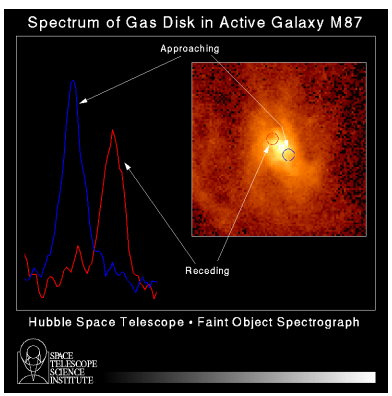
Shocks, Buoyant plasma bubbles, Jet, Cavities, Filaments

Old:

Messier, 1781 (March 18) => Age > 226 yr
Mean stellar age ~ 10 Gyr

Popular:

3436 papers (NASA ADS) => Most popular elliptical in the observable Universe

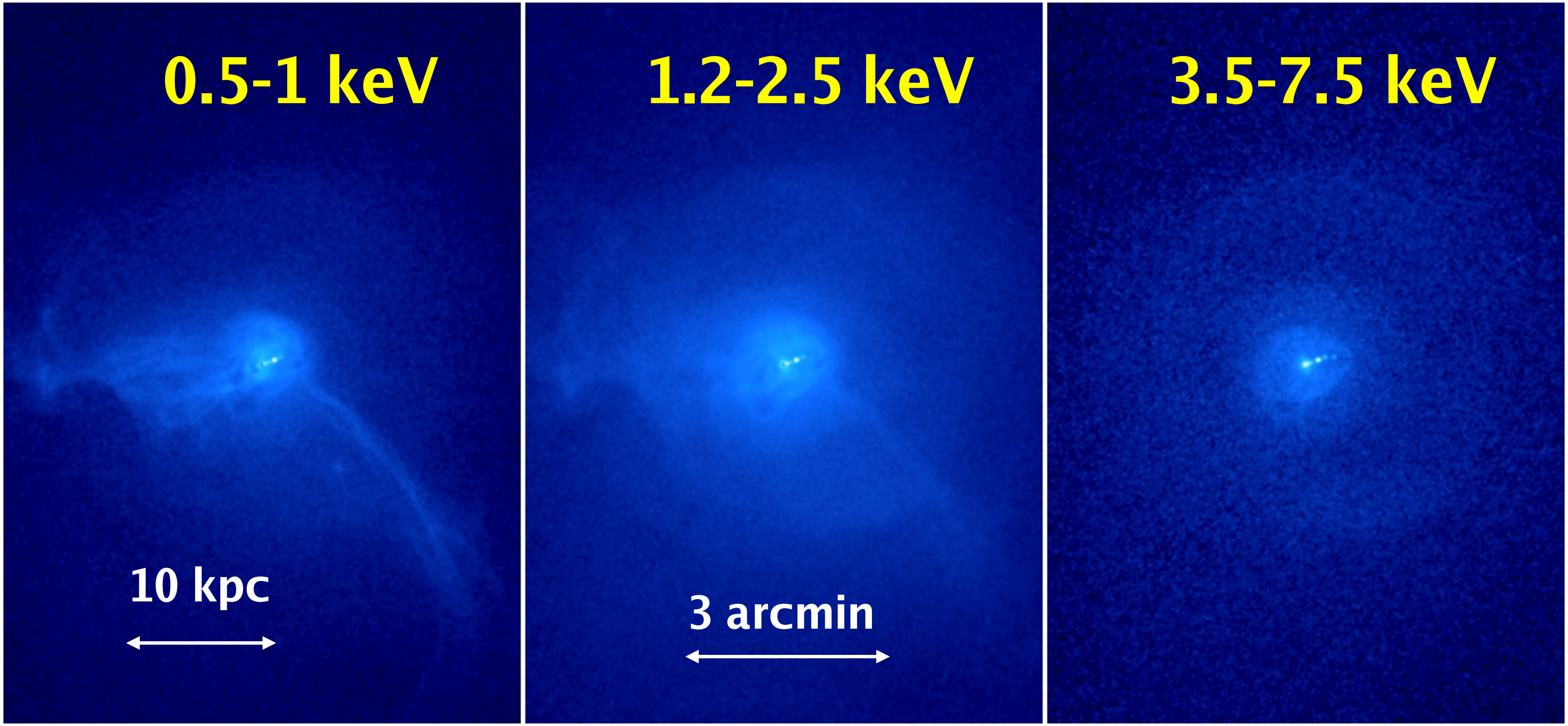


$M_{BH} \sim 3 \times 10^9 M_{sun}$

Macchetto+,97

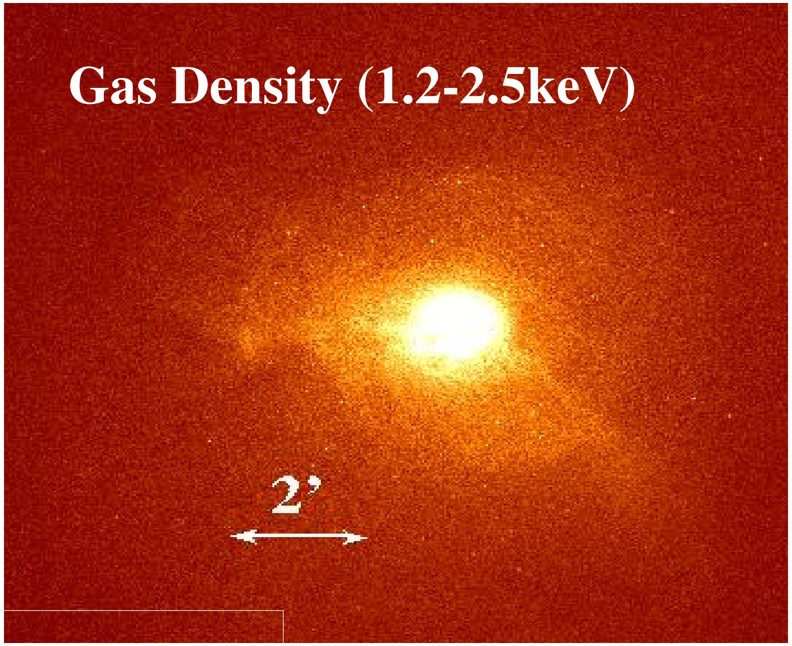
M87 from Chandra (500 ks; 9 obsids)

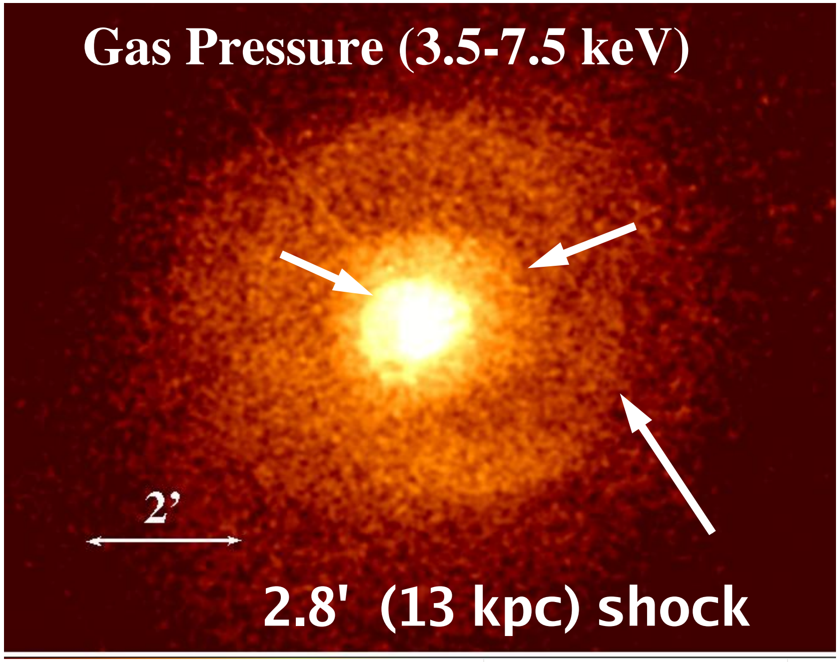
Spectacular filaments and a classical shock



Enhance cool regions

Classical (text book) Shock





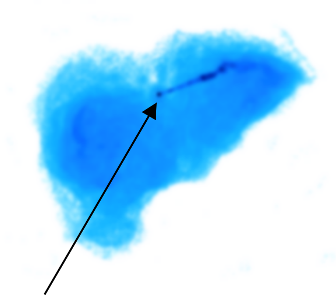
Density and temperature give independent and consistent measures of Mach number

M=1.2

See Forman+07 (ApJ, 665 1057) for details

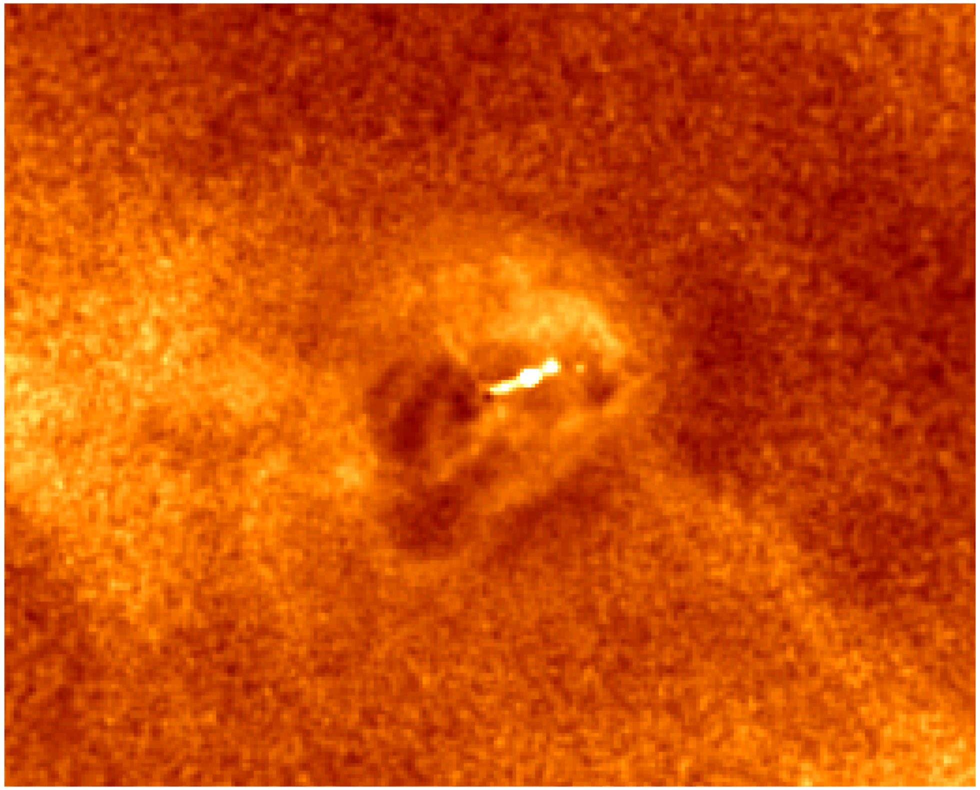
Central Piston

Radio Cocoon (6 cm)
Relativistic plasma
From SMBH



M_{BH}~$3x10^9$ M_{sun}
Macchetto+97

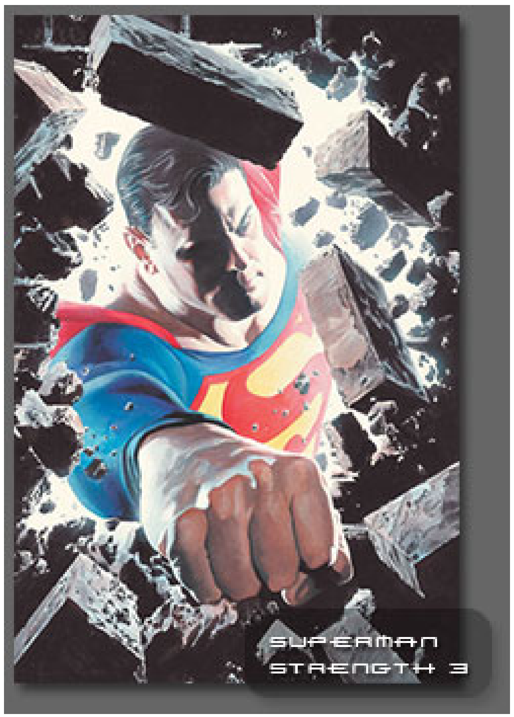
X-rays
Thermal plasma



~20 kpc

What kind of shock/outburst?

Fast energy release

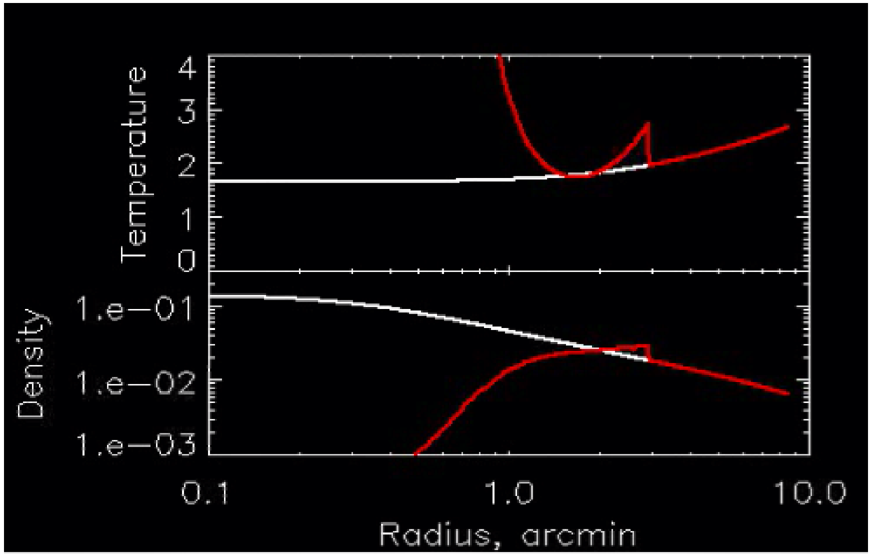


Slow energy release

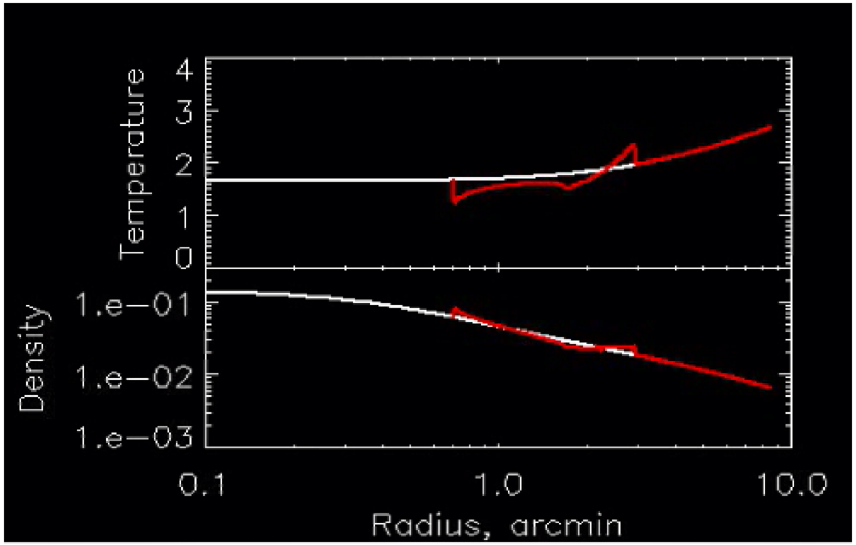
$$M \gg 1$$

Instantaneous energy release (Superman) (Sedov-Taylor)

Piston - gradual energy release (Winnie)



Hot, low density gas



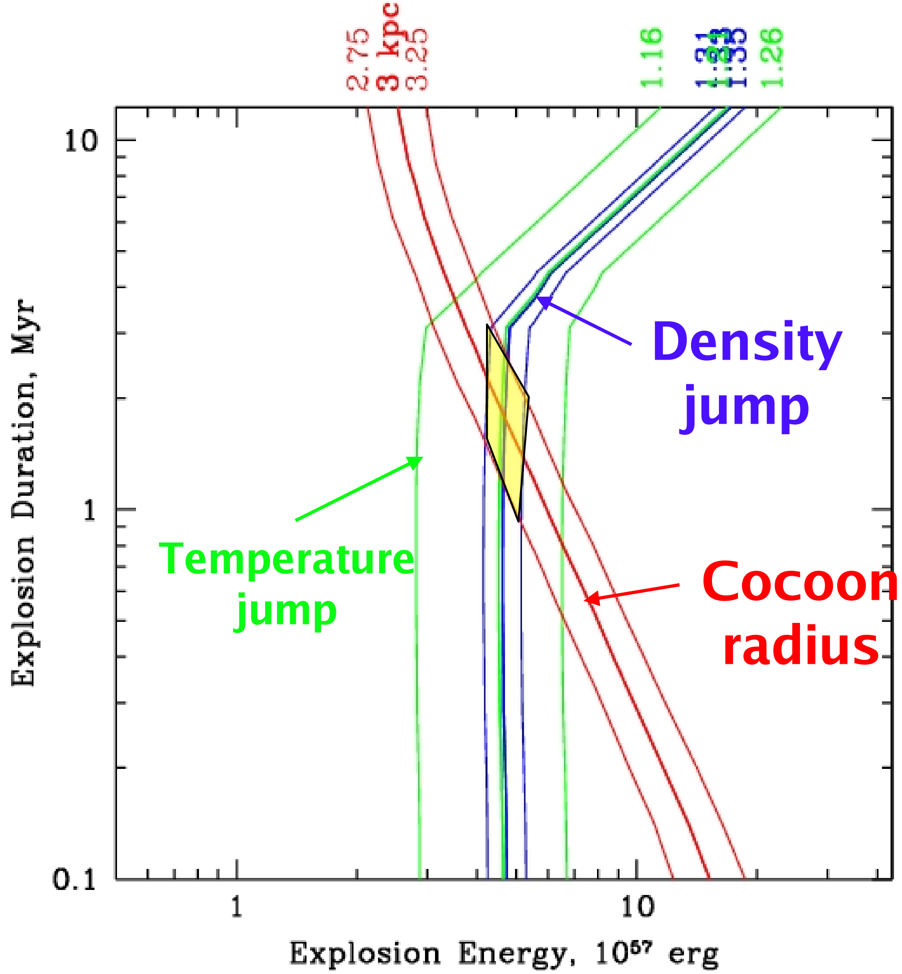
Cool, dense shell

- Absence of hot shocked region => gradual energy release
- Run grid of models to constrain:
  - Outburst duration
  - Outburst energy

Outburst Energy vs. Duration

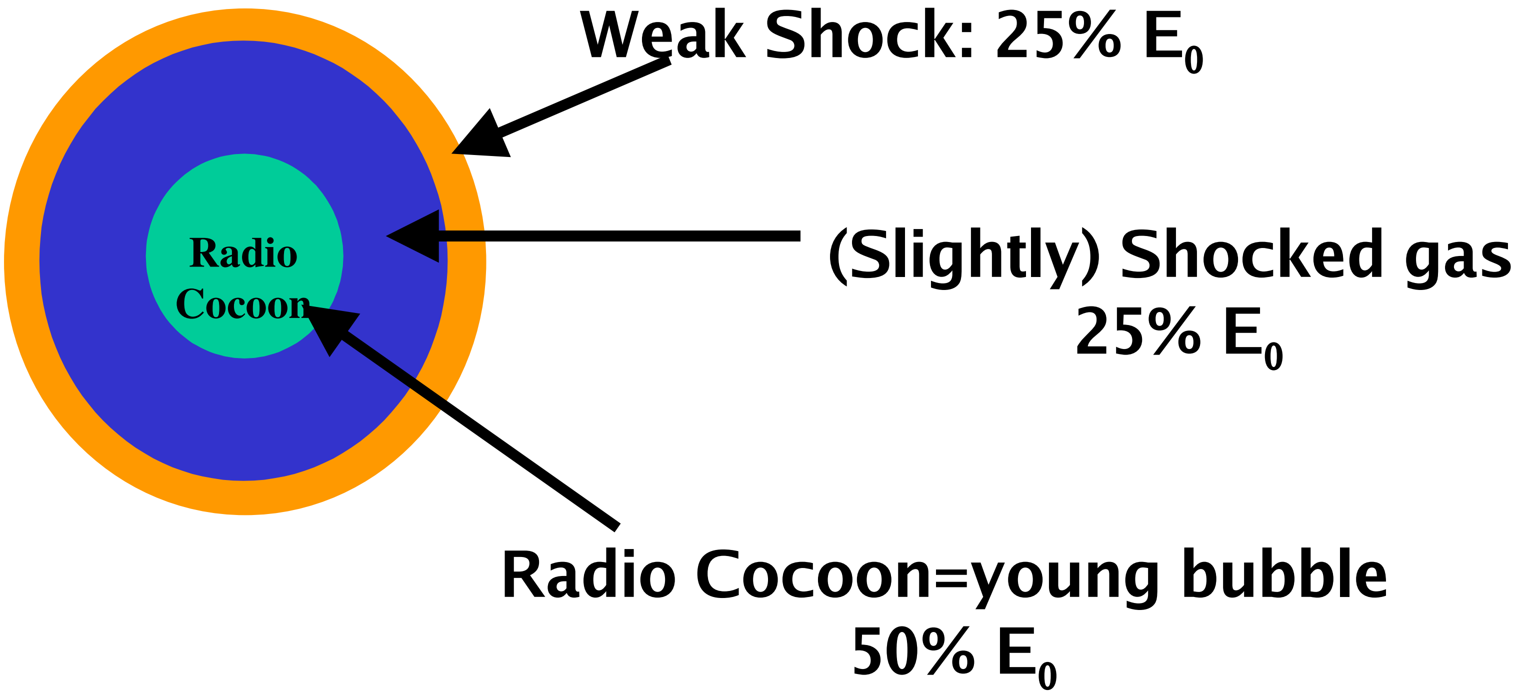
Temperature Jump
T_2/T_1=1.21±0.05
Density jump
ρ_2/ρ_1=1.33±0.02

Cocoon radius
R_{piston}= 3±0.25 kpc



Duration = 1-3 Myr
Energy = 4-6 x 10^{57} ergs
Age = 12 Myr

Outburst Balances Radiation

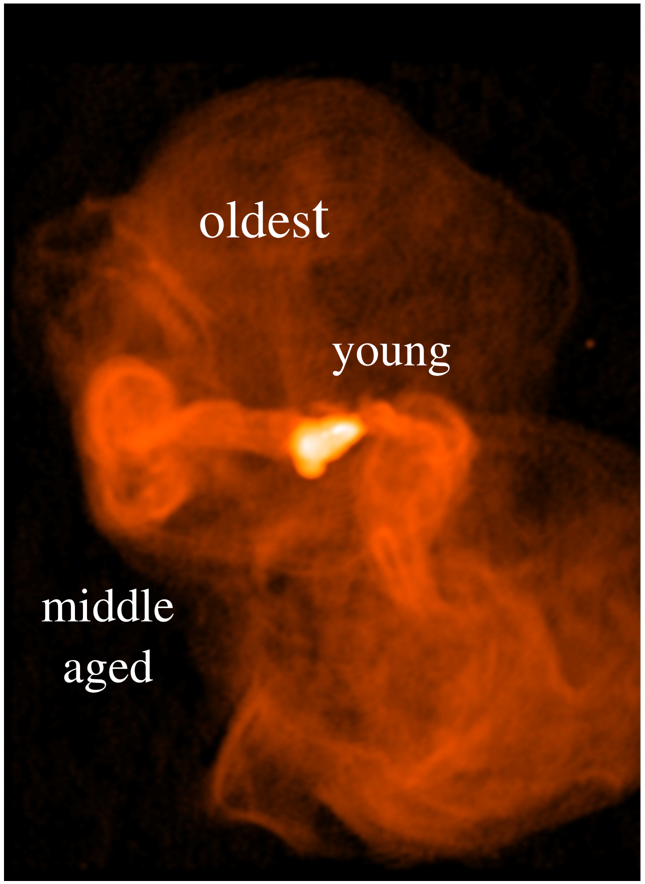


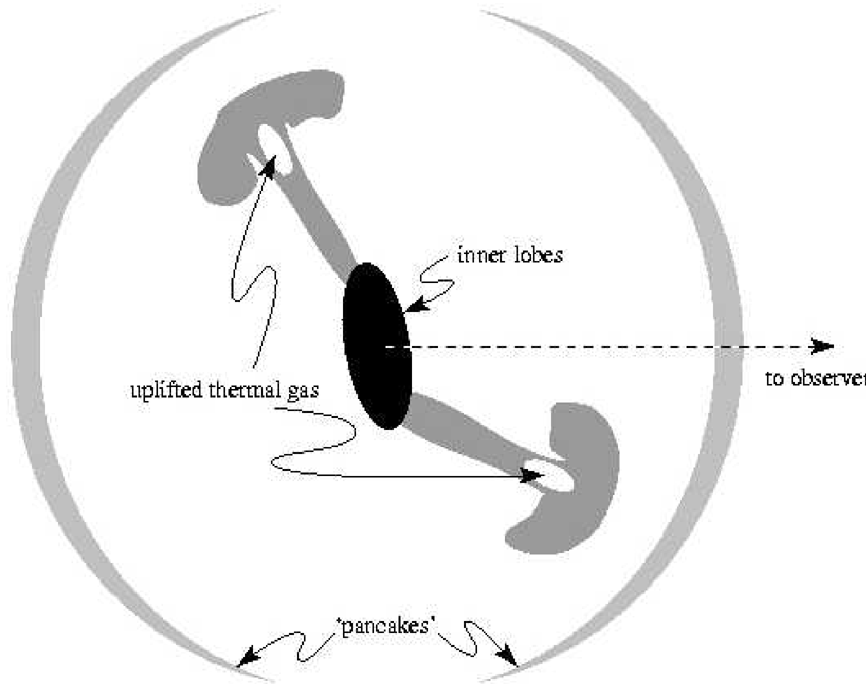
Solution to "cooling flow problem"

L_{rad} (10^{43} erg/s $\approx L_{outburst}$ (E_0/age=10^{43}erg/s)

Best Model: $E_0=5\text{x}10^{57}$ ergs; Age~12 Myr Δt~2Myr

Three Generations of Buoyant Bubbles

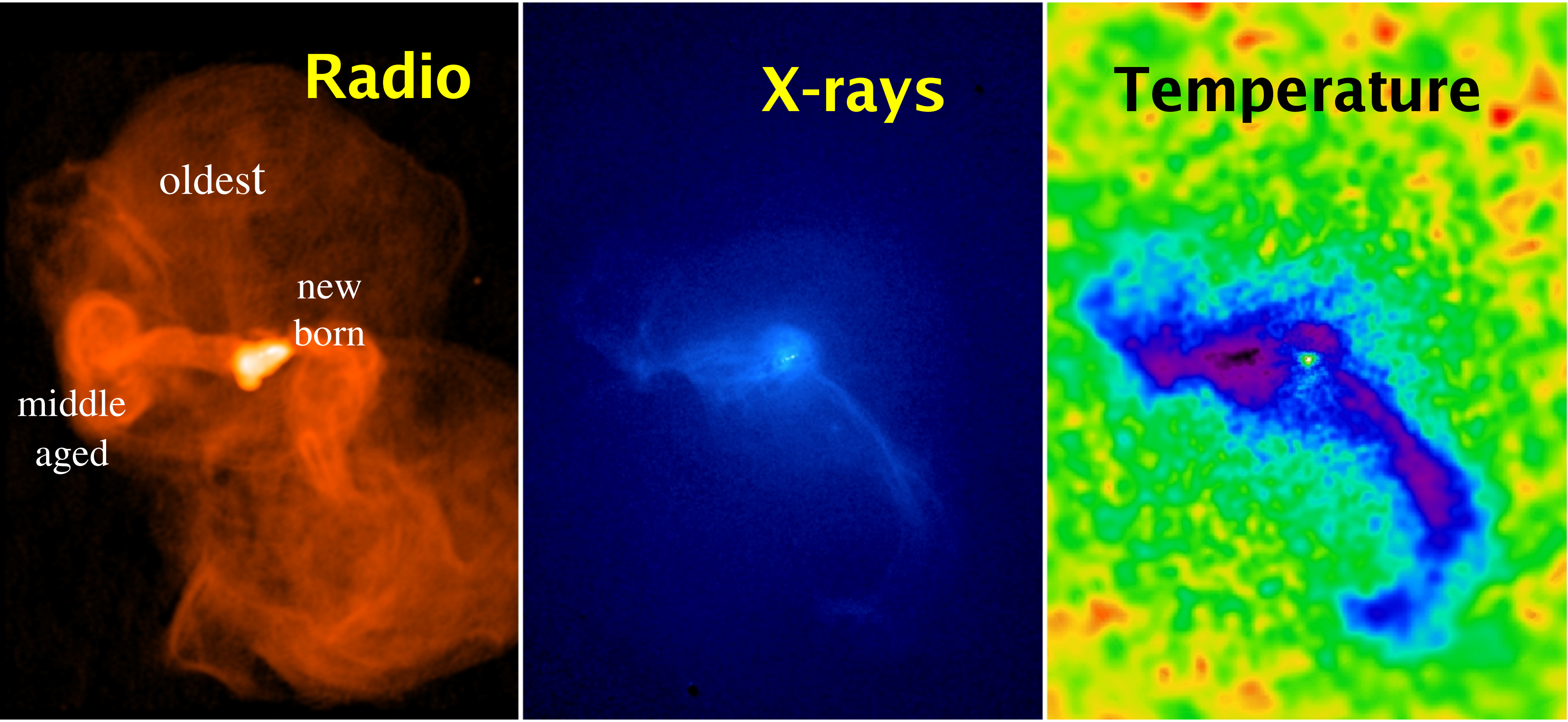




Owen+00
Churazov+01

Broadly consistent with 3 generations of buoyantly rising bubbles
Youngest active now!

Effects of Buoyant Bubbles on ICM



Buoyant bubbles generate cool, X-ray arms
Uplift cool gas

Owen+00
Churazov+01
Belsole+01
Molendi 02
Forman+05,+07

Shocks and Bubbles in M87

- Detect shock (X-ray) and driving piston (radio)
  - Classical (textbook) shock M=1.2 (temperature and density independently)
  - Outburst constrained by:
    - Size of driving piston (radius of cocoon)
    - Measured T_2/T_1, ρ_2/ρ_1 (p_2/p_1)
- Outburst Model
  - Age ~ 12 Myr
  - Energy ~ 5×10^{57} erg
  - Bubble 50%
  - Shocked gas 25% (25% carried away by weak wave)
  - Outburst duration ~ 1-3 Myr
- Outburst energy "balances" cooling (few 10^{43} erg/sec)
- AGN outbursts - key to feedback in galaxy evolution, growth of SMBH
  - e.g., Ciotti & Ostriker 07, Sazonov+05, Croton+06

Thank you

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