Chandra's New View of Cluster Cooling Flows

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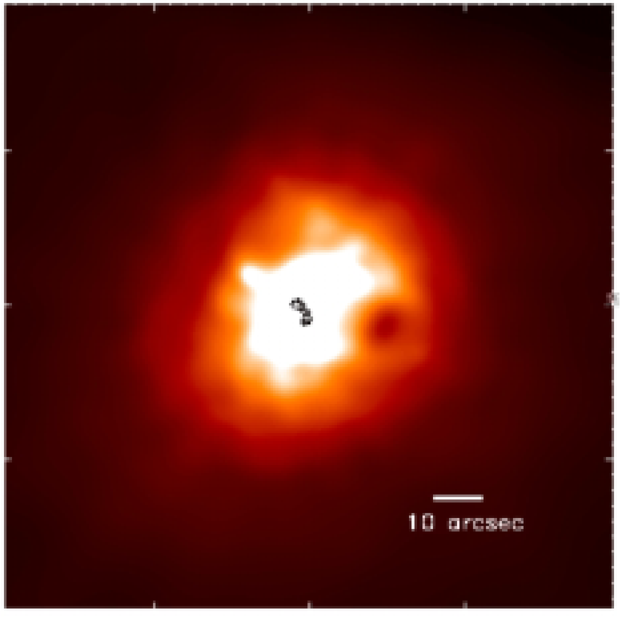
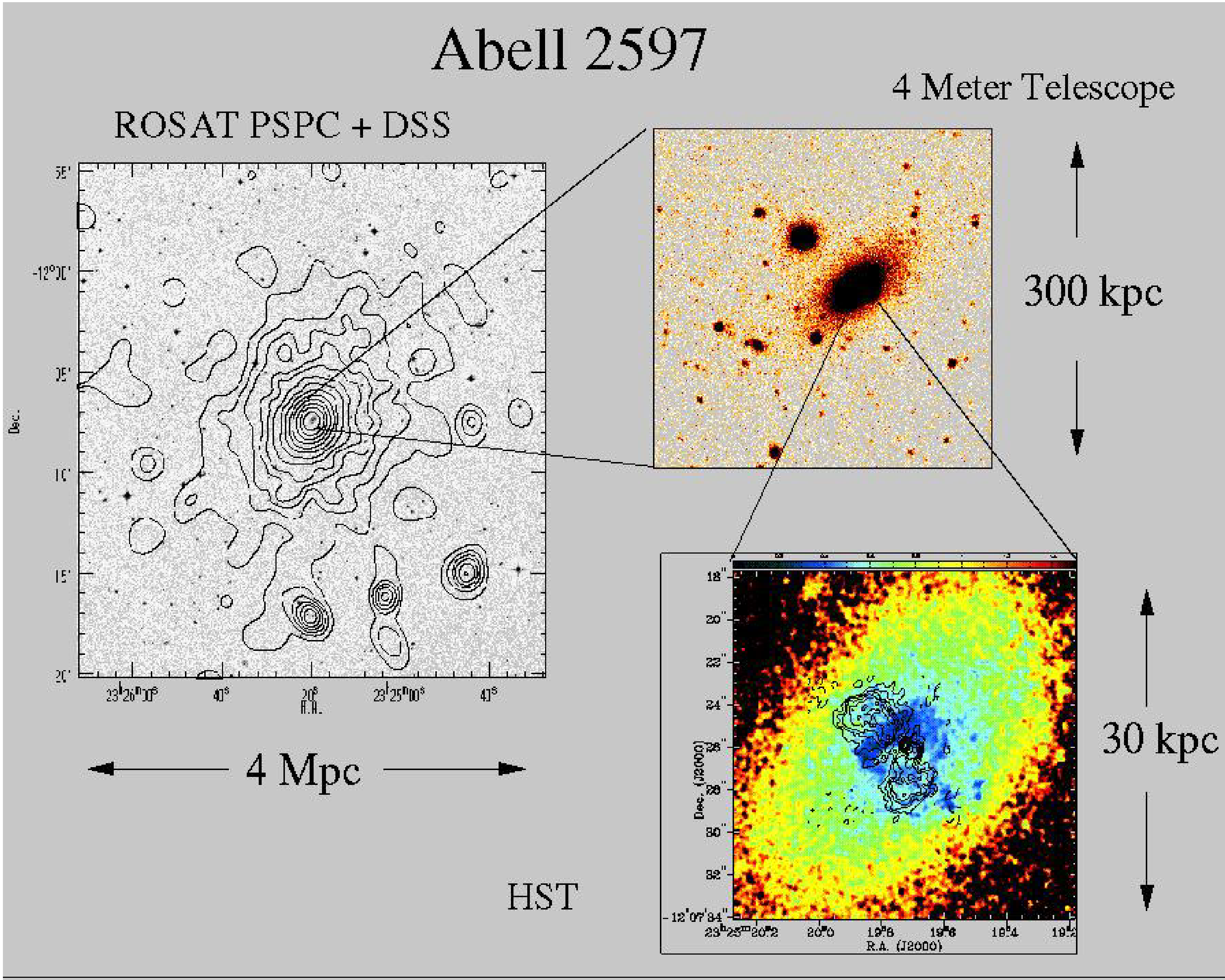


Four Years of Chandra Observations, Huntsville, AL September 16-18, 2003


Abell 2597
4 Meter Telescope
ROSAT PSPC + DSS
300 kpc
4 Mpc
HST
30 kpc
Dec.
R.A.
Dec. (J2000)
R.A. (J2000)

Outline

Einstein/Rosat Era:

-star formation & the cooling flow problem

-star formation histories inconsistent with steady cooling

Chandra & XMM Era:

-star formation associated with cool X-ray gas

-cooling rates & star formation rates converging

-reduced, self-regulated cooling

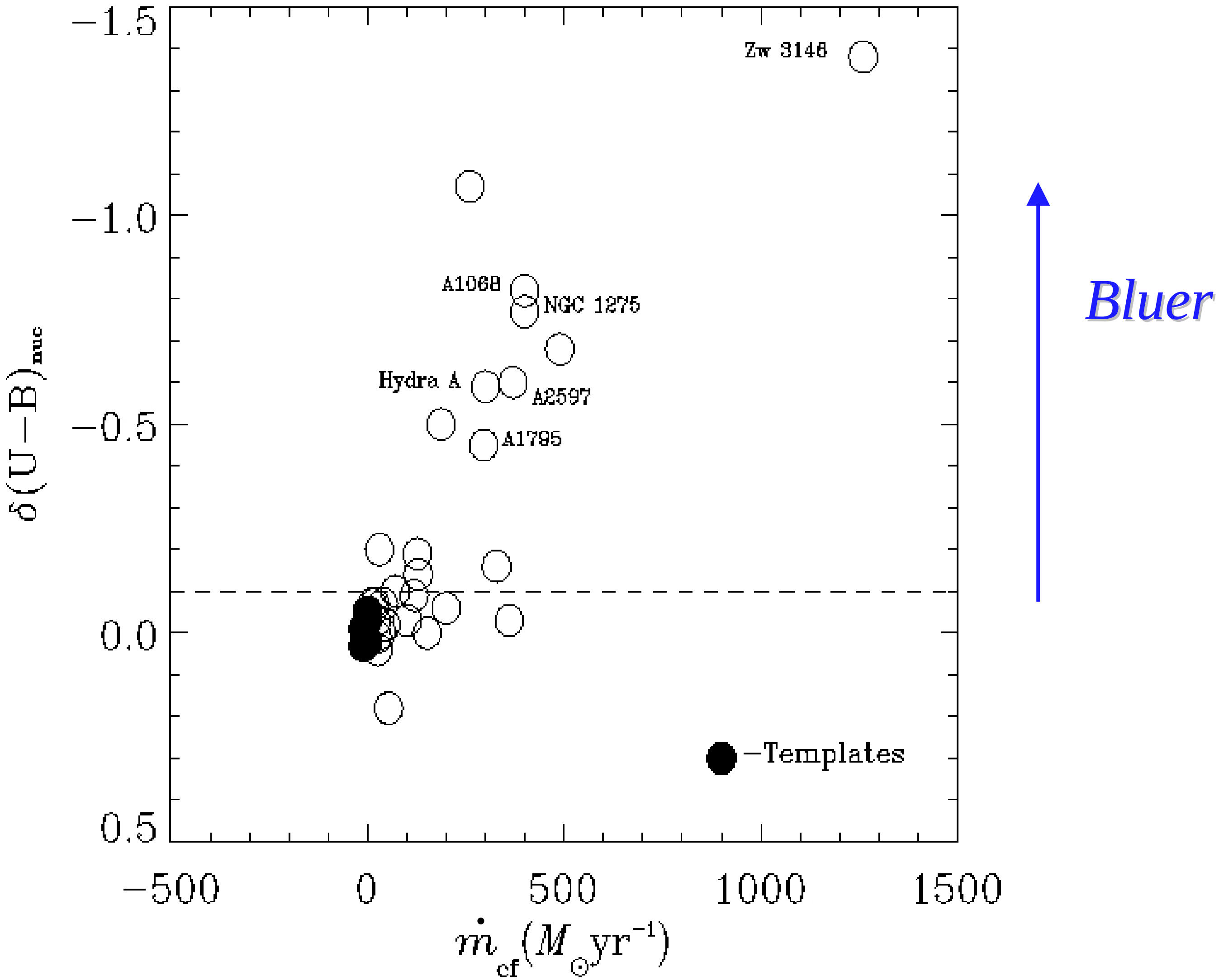
Collaborators

M. Wise (MIT)
C. Sarazin & L. Blanton (Virginia)
P. Nulsen & L. David (CfA)
& others….

At Ohio:

D. Rafferty, L. Birzan, M. Sharma

Blue Color Correlates with *Einstein/Rosat* Cooling Rates



JFN 87, MO 89

McNamara 97, 02

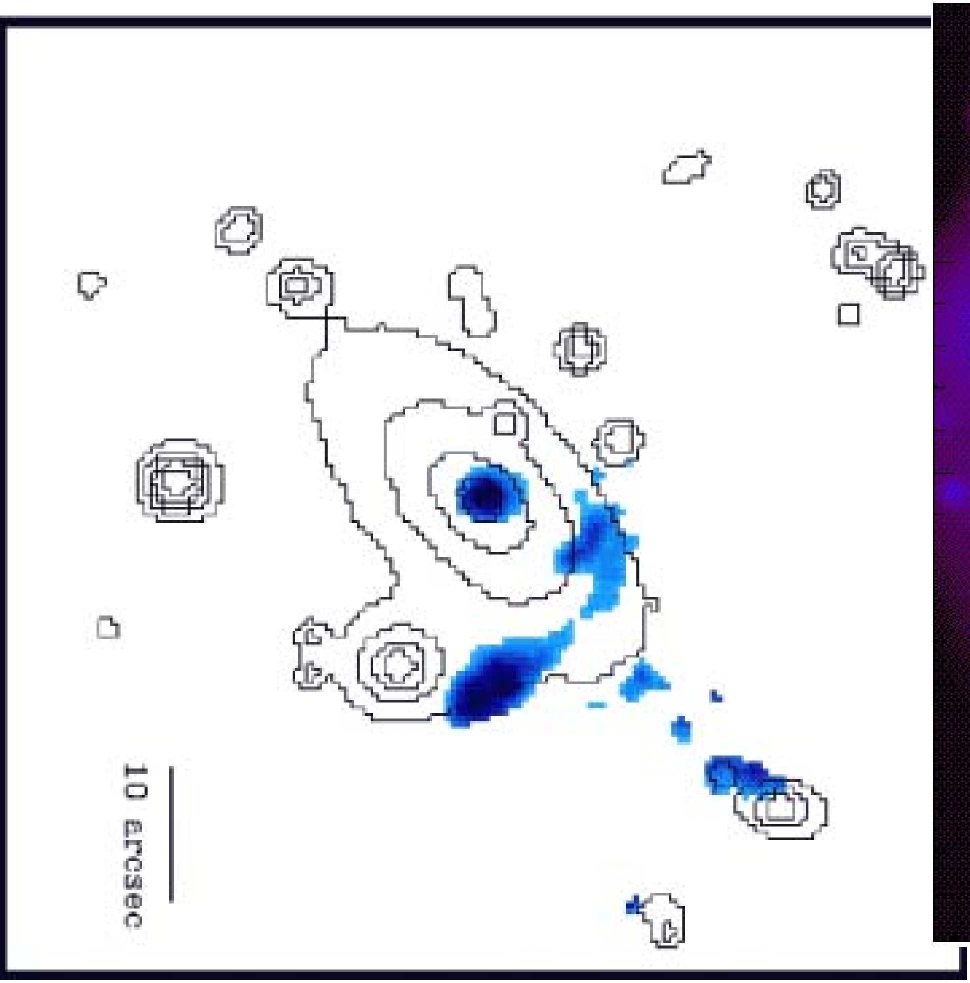
Star Formation Histories

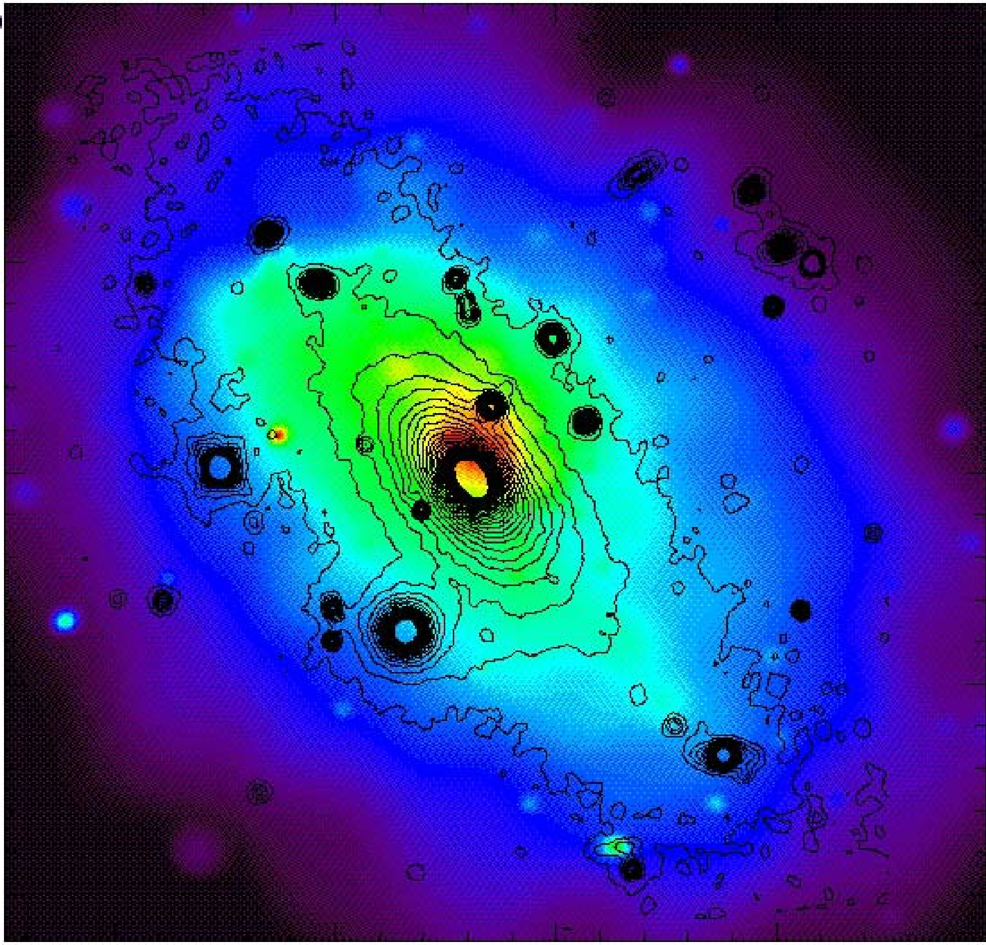
- Burst population: ages ~10 Myr or less
- Continuous or extended star formation with ages ~100 Myr
- Star formation rates ~ 1%-10% of ROSAT cooling rates

⇒ Inconsistent with long-lived, continuous
star
formation in a classical cooling flow

The “Cooling Flow Problem”

Starburst in Abell 1068

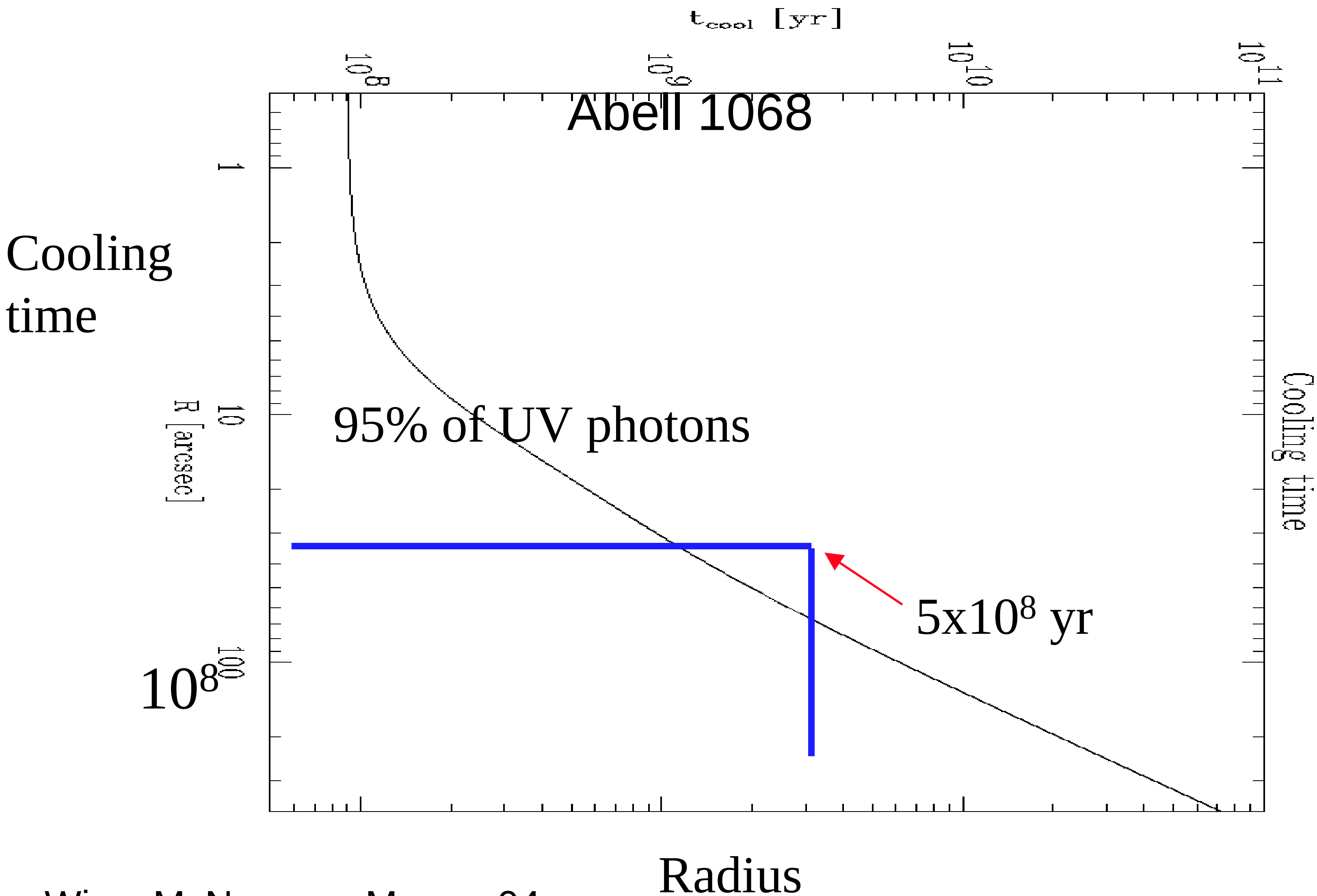




$\dot{M} < 140\ M_o\ yr^{-1}$

McNamara, Wise, Murray 04

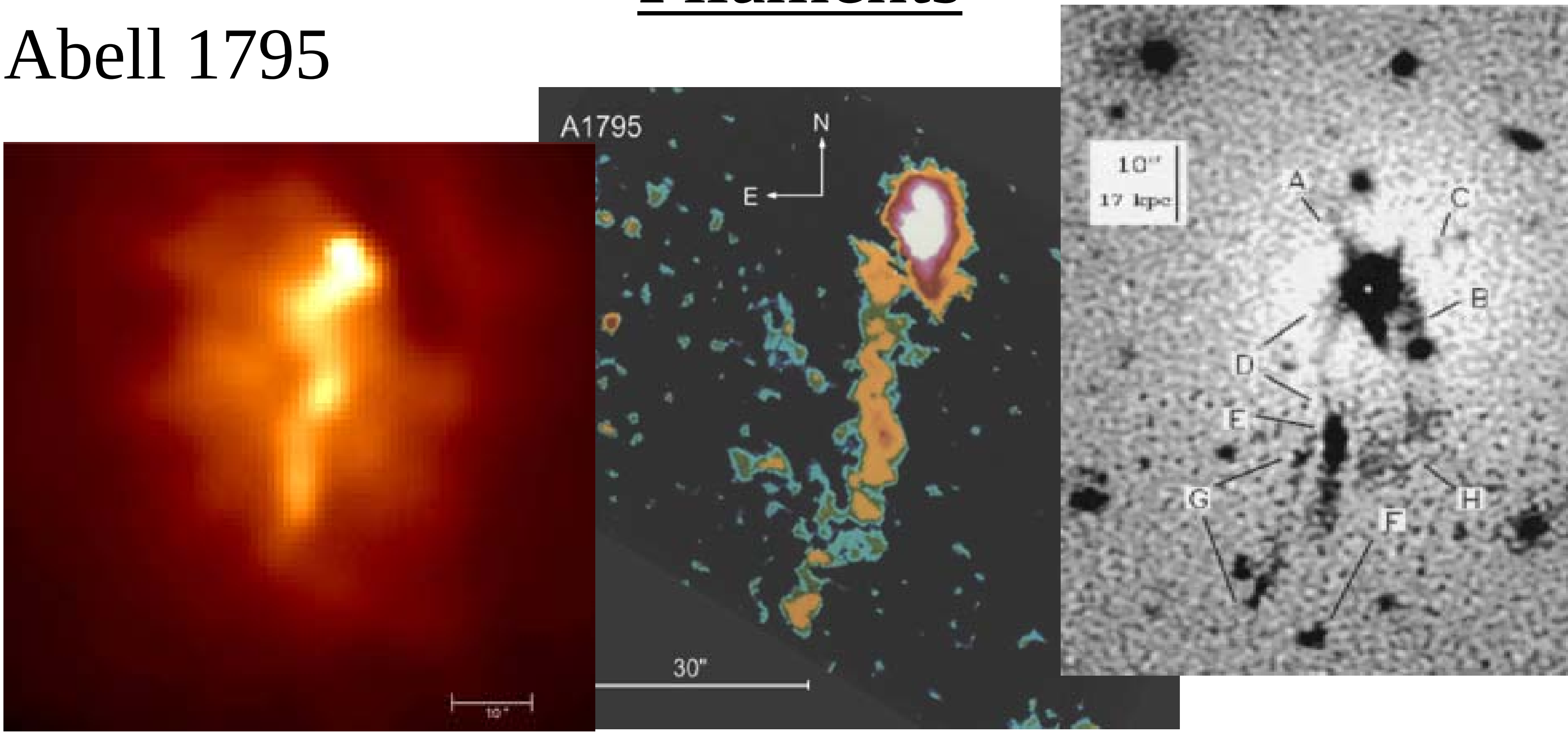
Star Formation Peaks in Regions of Short Cooling Time



Wise, McNamara, Murray 04

Star Formation Associated with X-ray Filaments

Abell 1795



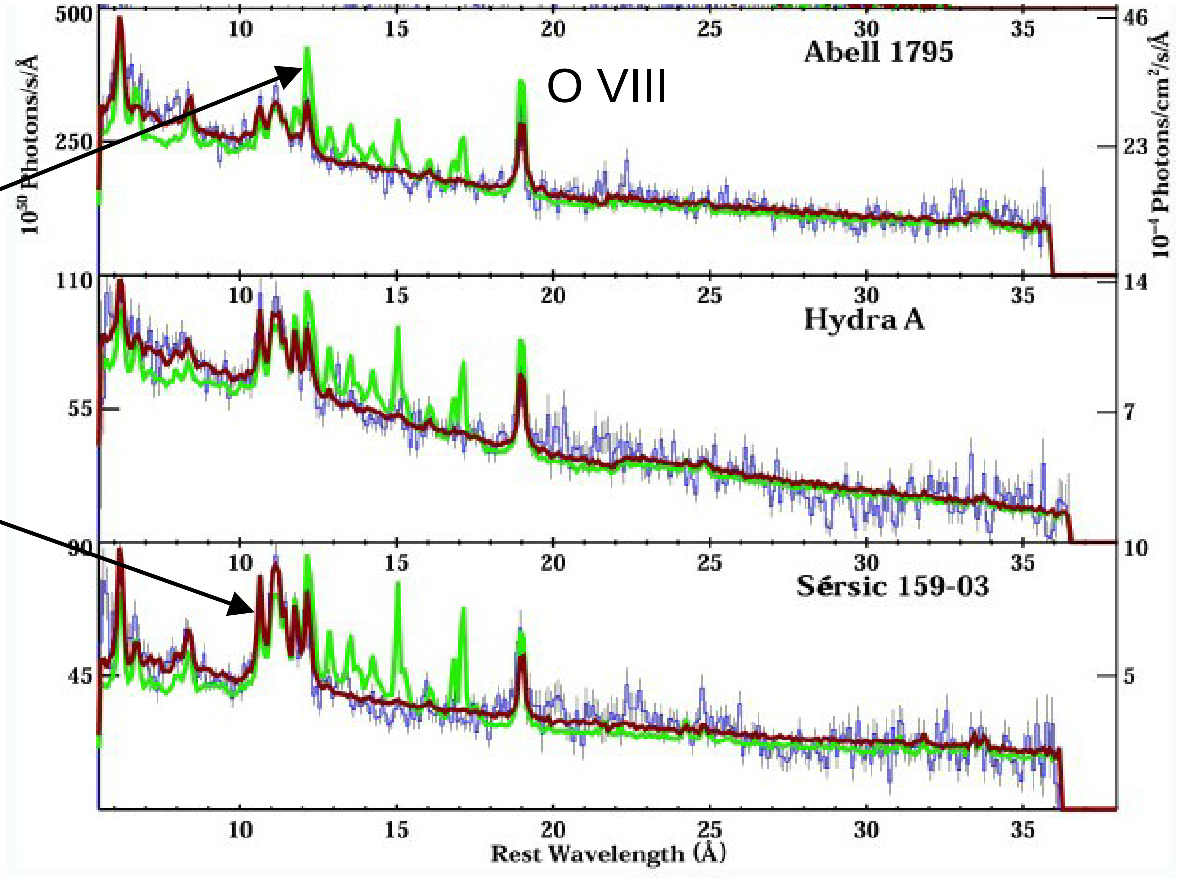
X-ray: Fabian et al. (2001) Nebular emission: Cowie et al. (1983)

Star formation: McNamara et al. (1996)

Newton: Upper limits on Cooling

Standard model

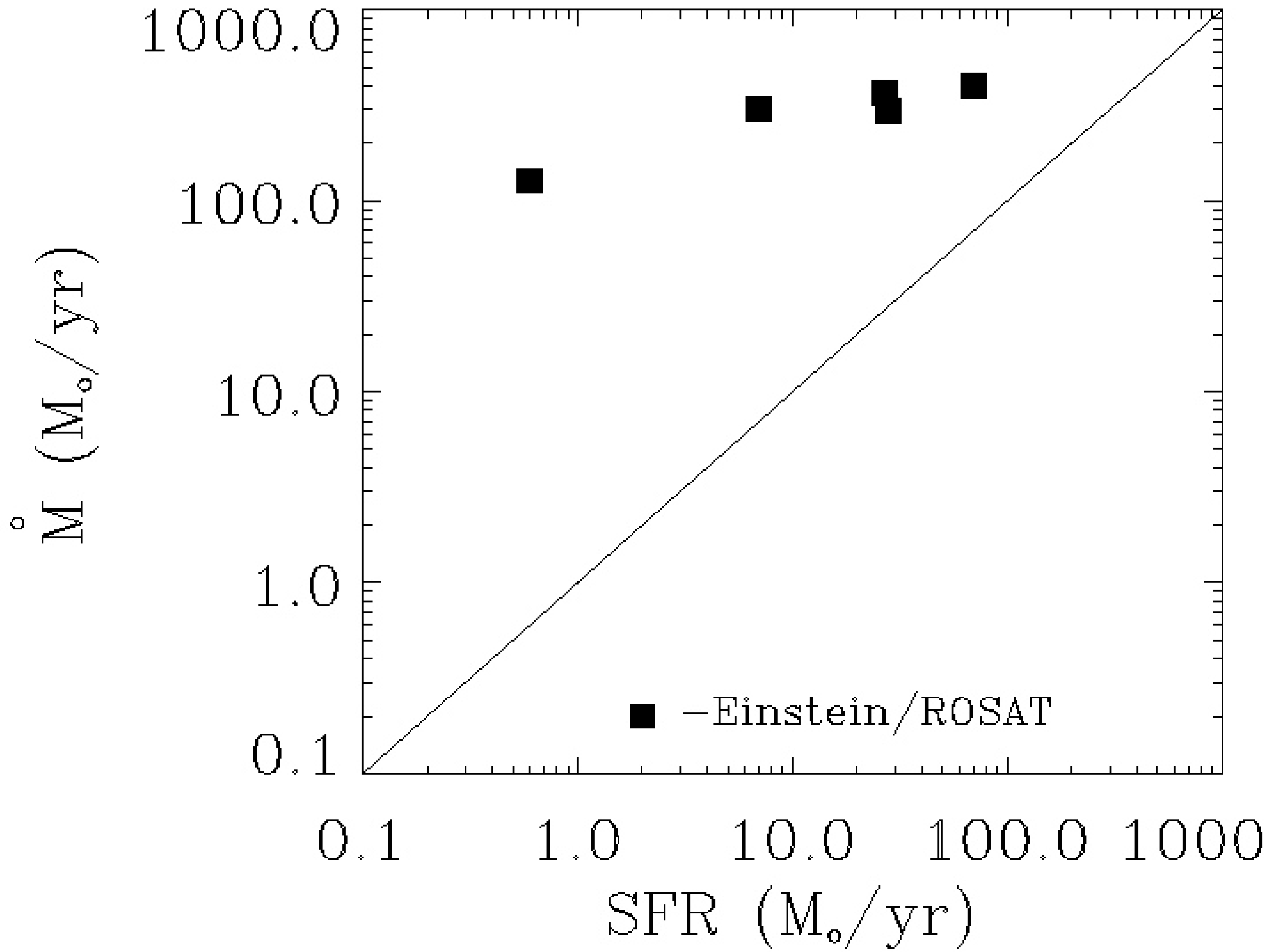
Best fit



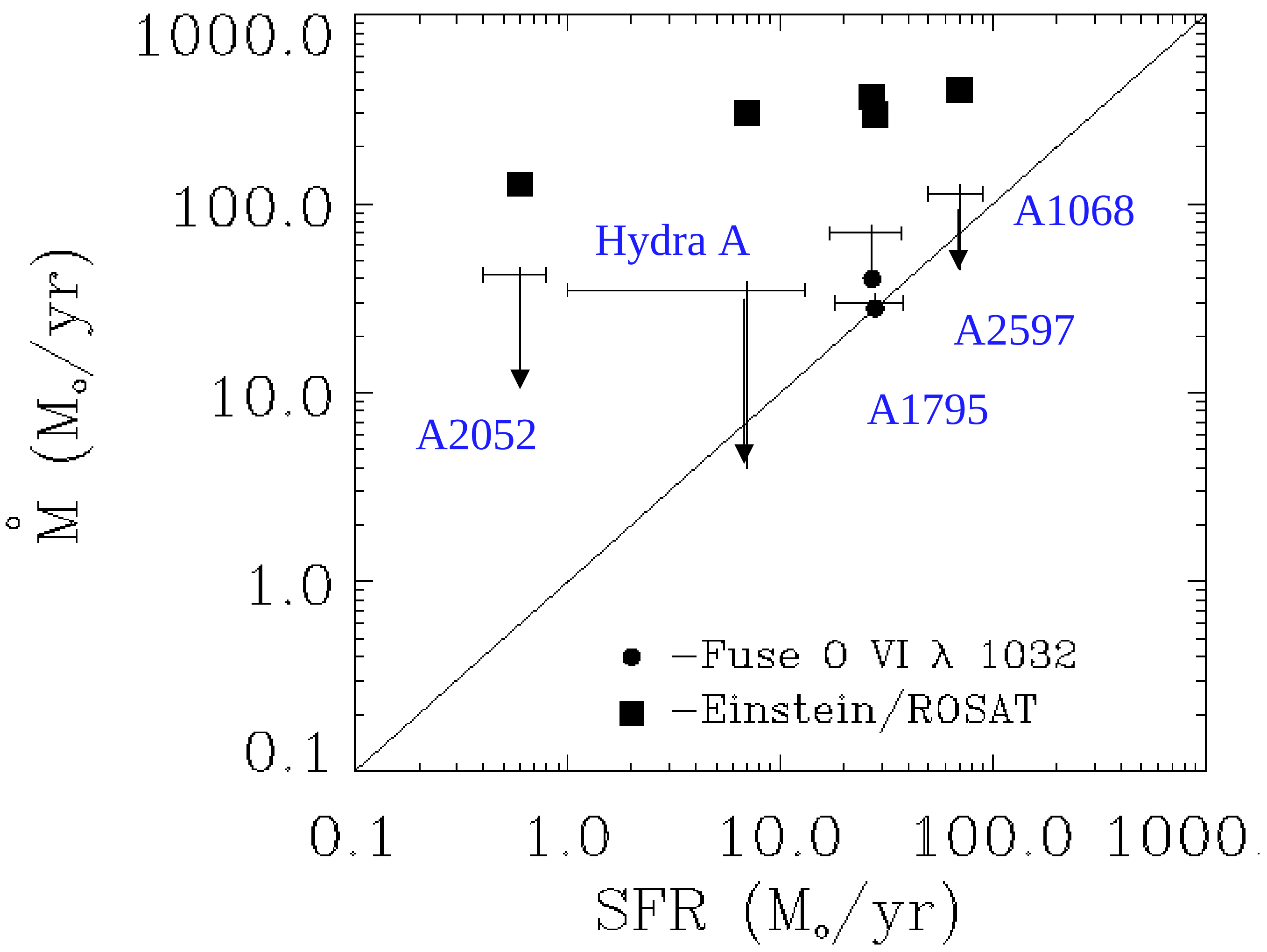
Cooling limits ~ 5-10 times lower than Einstein/ROSAT

Peterson et al. 2003

Cooling vs Star Formation



Cooling vs Star Formation

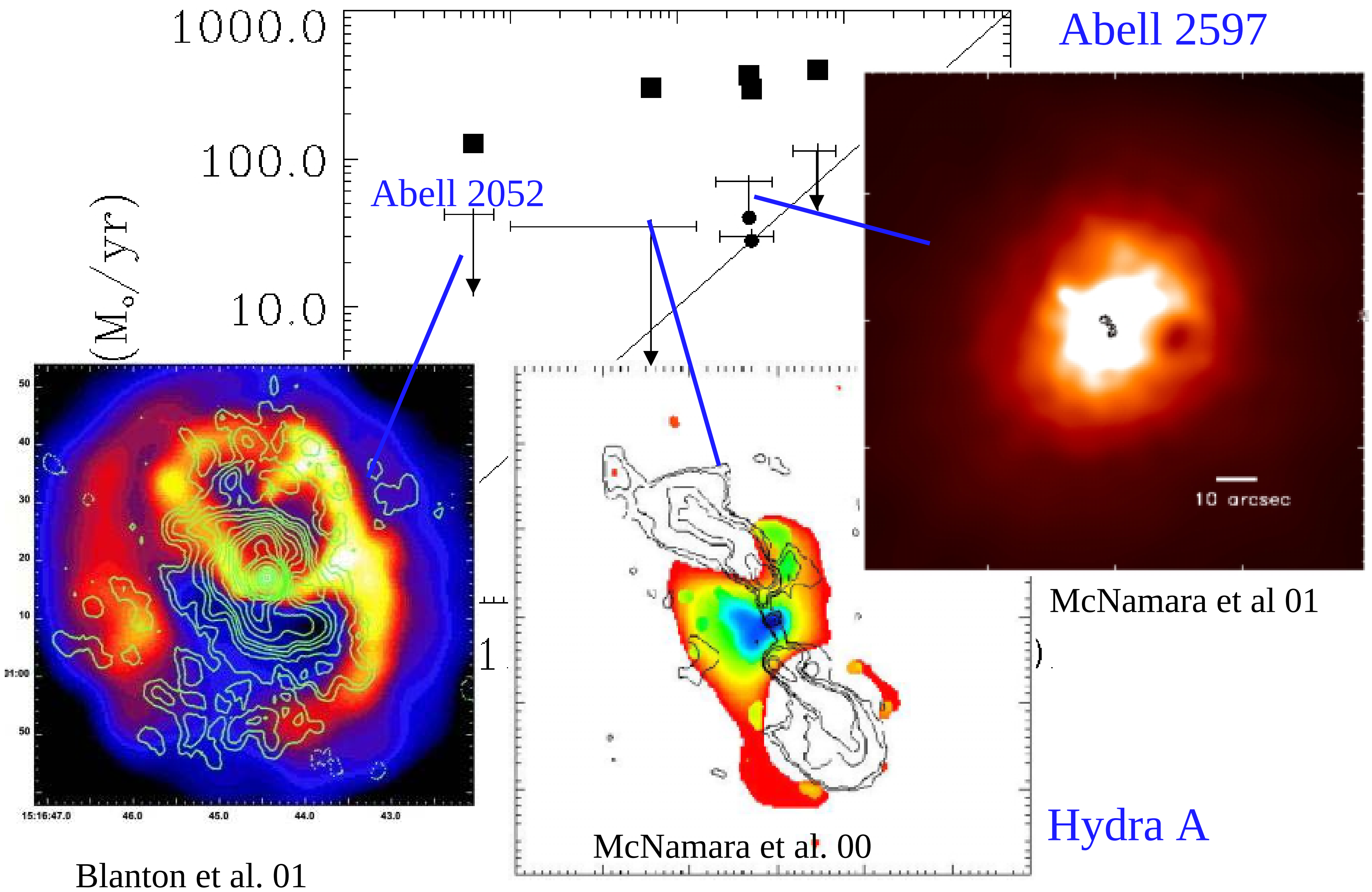


What is heating the gas?

- Heat conduction from hot outer layers
- Star formation: supernova explosions
- Cosmic rays

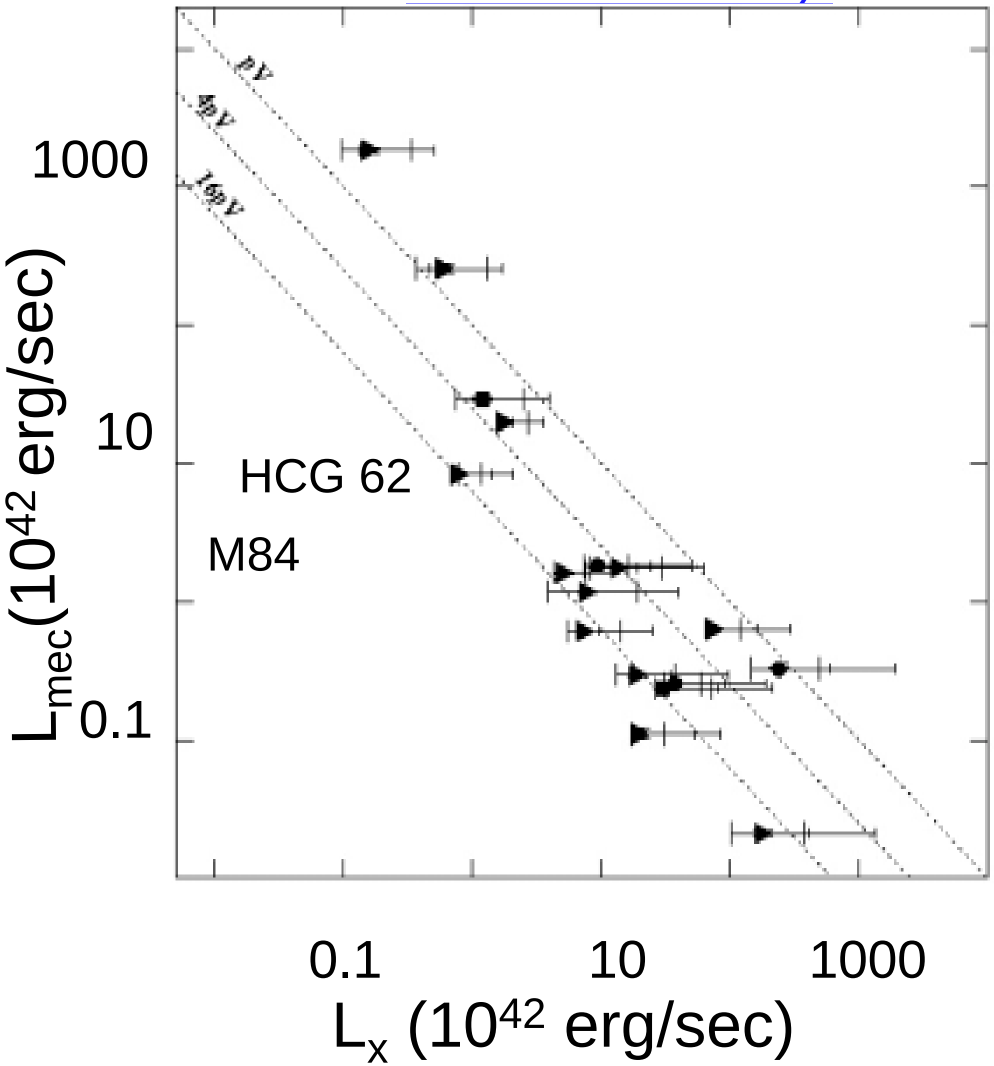
→ Radio-induced cavities

Feedback



1000.0
100.0
10.0
(M☉/yr)
Abell 2597
Abell 2052
Hydra A
10 arcsec
McNamara et al 01
McNamara et al. 00
Blanton et al. 01

X-ray Luminosity vs Mechanical Luminosity

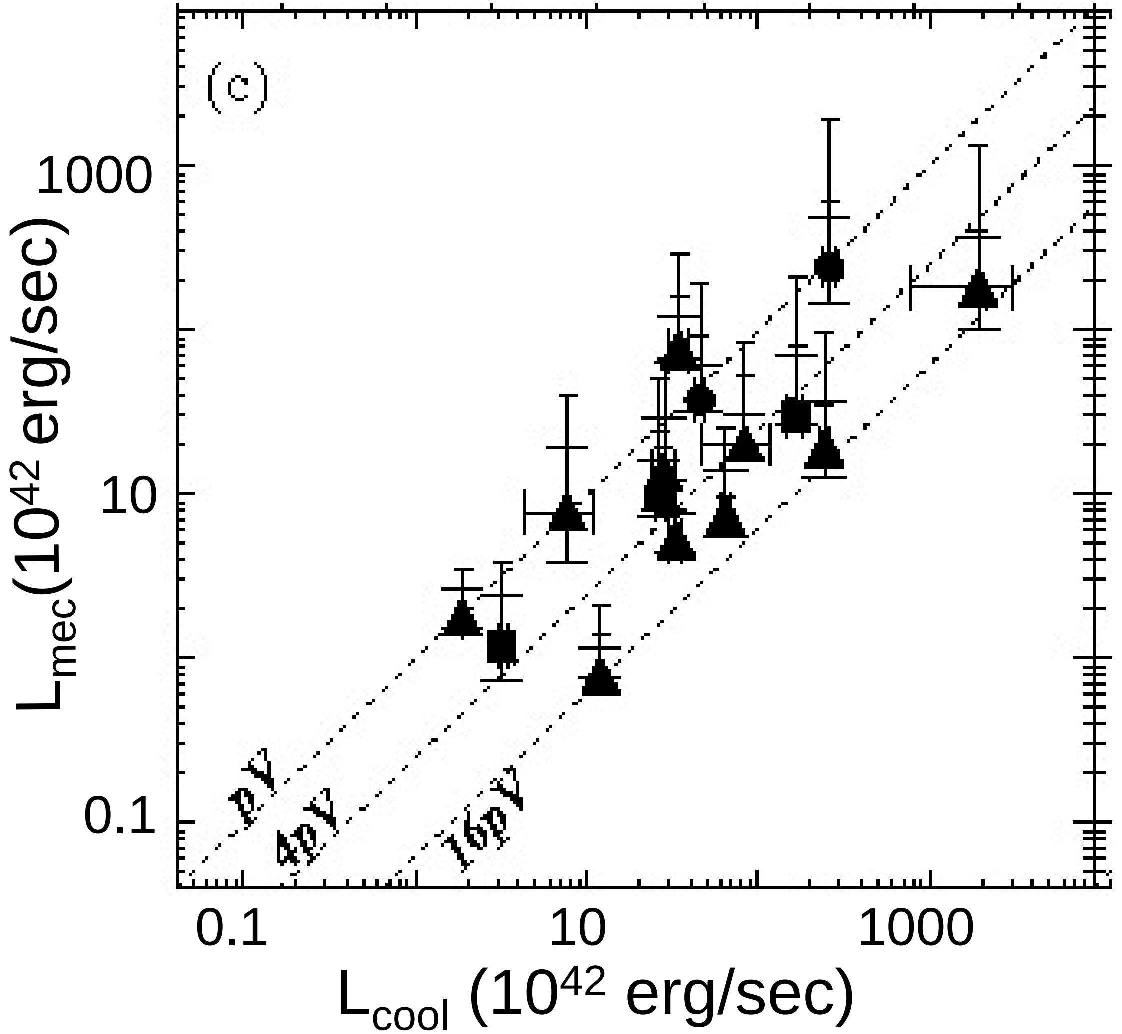


t_{cool}<7.7 Gyr

z<1.0

Birzan, Rafferty, McNamara, Wise, & Nulsen in prep.

Cooling Luminosity vs Mechanical Luminosity



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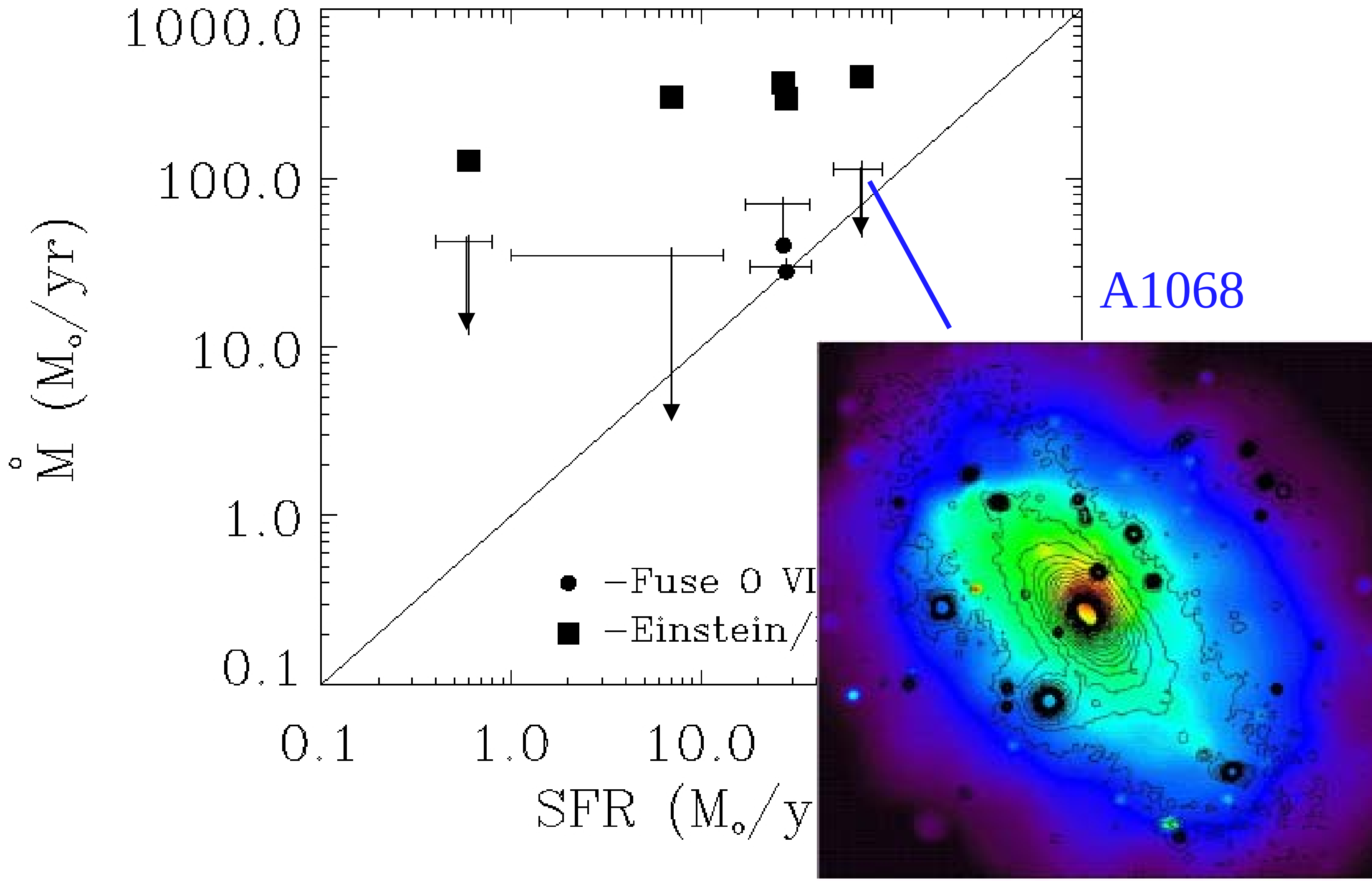
Classical Cooling Flow



Summary

Star Formation Histories

- Burst mode of star formation $t_* \sim 10^7$ yr
- Continuous mode $t_* \sim 10^8$ yr
- Inconsistent with continuous accretion for $>10^9$ yr

New Trends from Chandra/XMM

- Star formation follows regions where $t_c < 5 \times 10^8$ yr
- Star formation rates and cooling rates converging
- Heating important in many objects

→ *Self-regulated Galaxy Formation*