The unusual X-ray morphology of NGC 4636:

cavities, off-center outbursts and shocks revealed by deep Chandra observations

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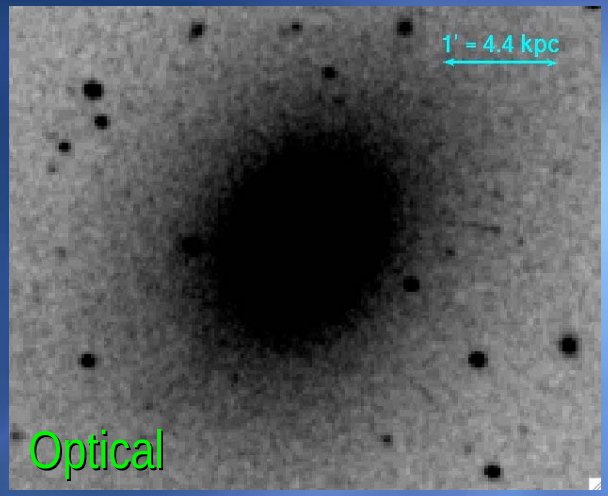
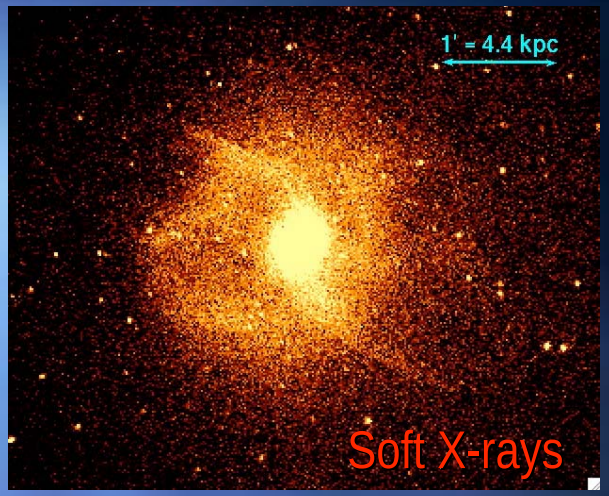
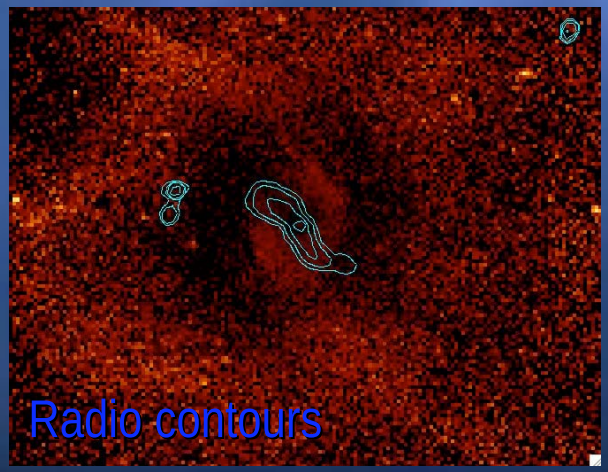
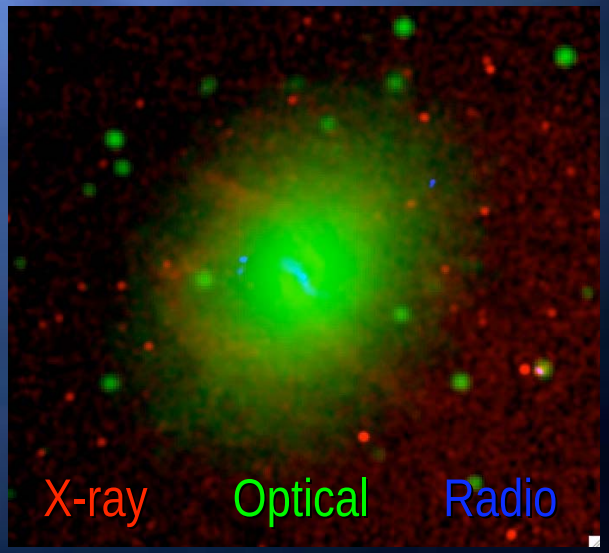
NGC 4636

- One of the most X-ray luminous 'normal' elliptical galaxies: $L_X \sim 2 \times 10^{41}$ ergs s^{-1}
- Located in the outskirts of the Virgo Cluster, at a distance of 15 Mpc (Tonry et al. 2001)
- Already studied in the X-ray wavelengths by Chandra & XMM-Newton (e.g. Jones et al. 2002, O' Sullivan et al. 2005)









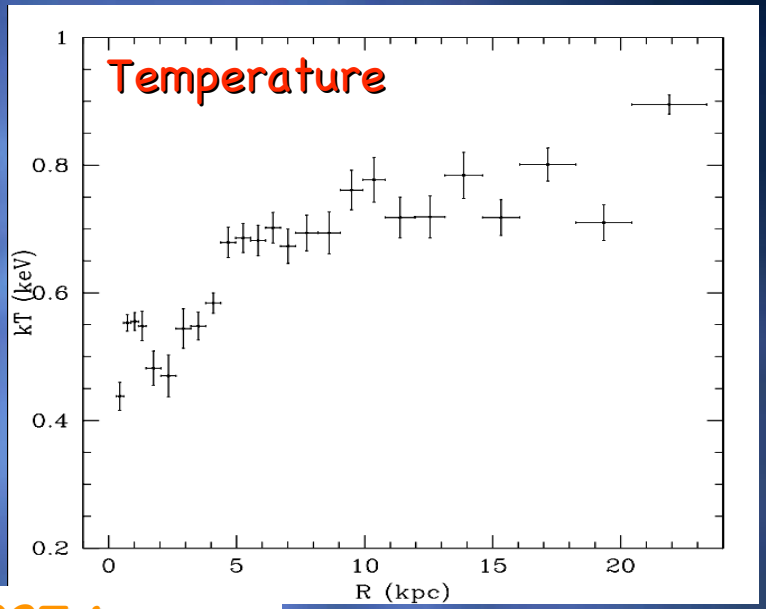
Chandra data preparation

- ACIS-I (2 observations: 150 ks) and ACIS-S (1 observation: 52 ks) data reprocessed with CIAO 3.4 applying:
  - Newest ACIS gain maps
  - Time-dependent ACIS gain correction
  - ACIS CTI correction, etc.

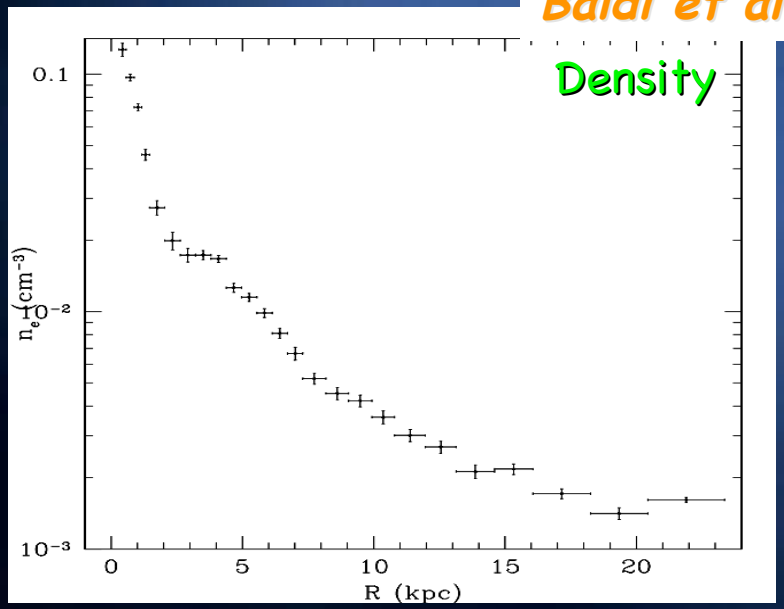
- Removal of high background flaring period:
  - ACIS-I: T_{clean} = 149 ks
  - ACIS-S: T_{clean} = 37 ks

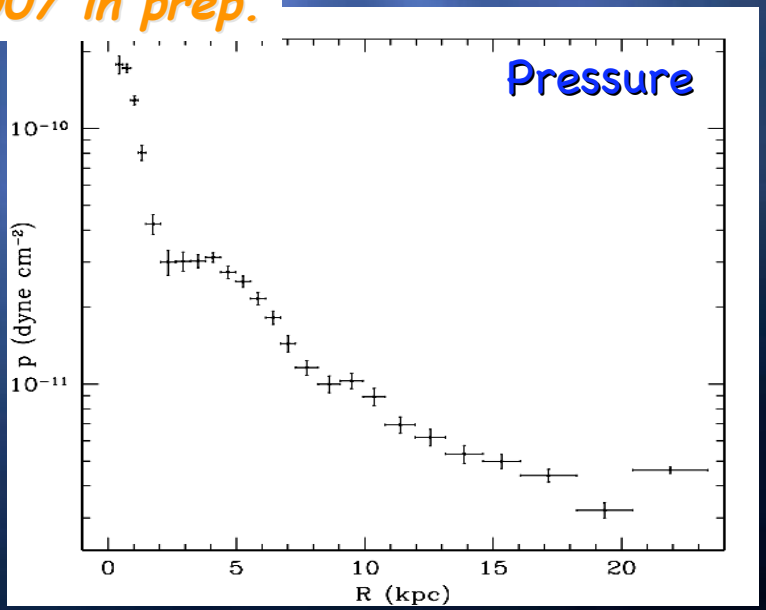
NGC 4636: global X-ray properties

- The temperature profile shows evidence of a cooling core; several substructures are detected as well.
- The density and pressure profiles show a strong central peak and a 'plateau' located at 2 kpc < r < 4.5 kpc from the center



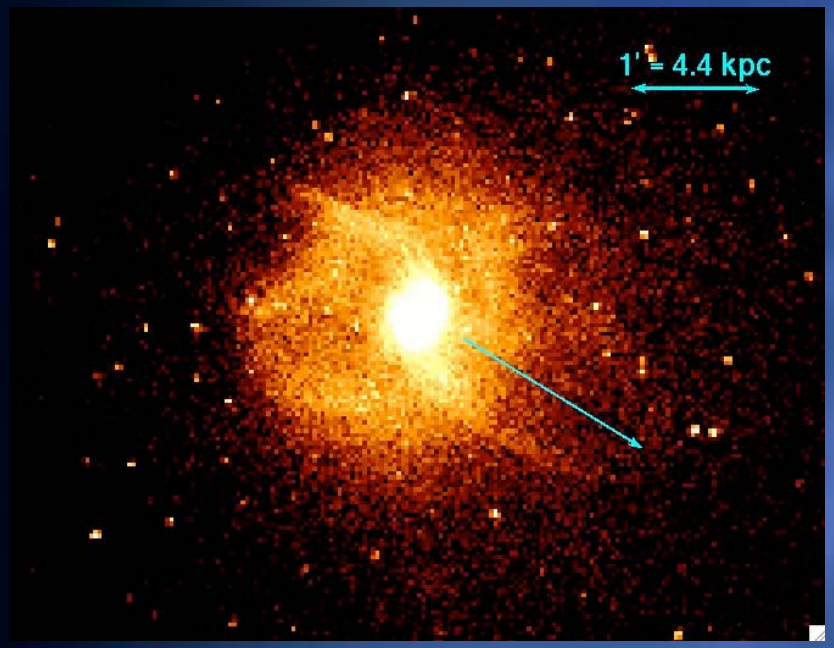
Baldi et al. 2007 in prep.



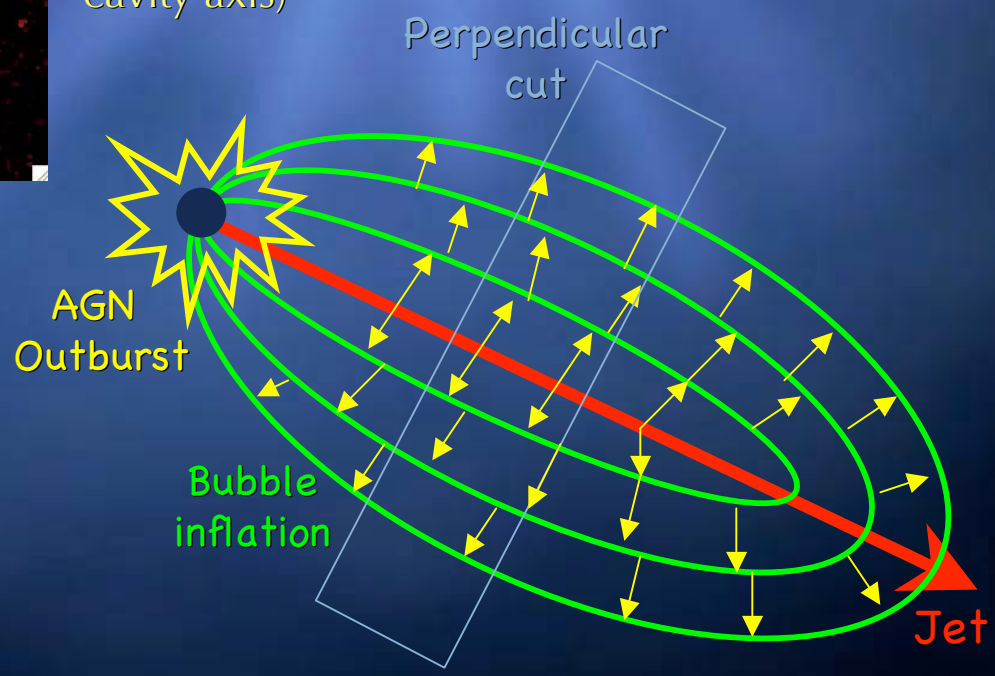


The SW X-ray 'bubble'

comparison with a shock model



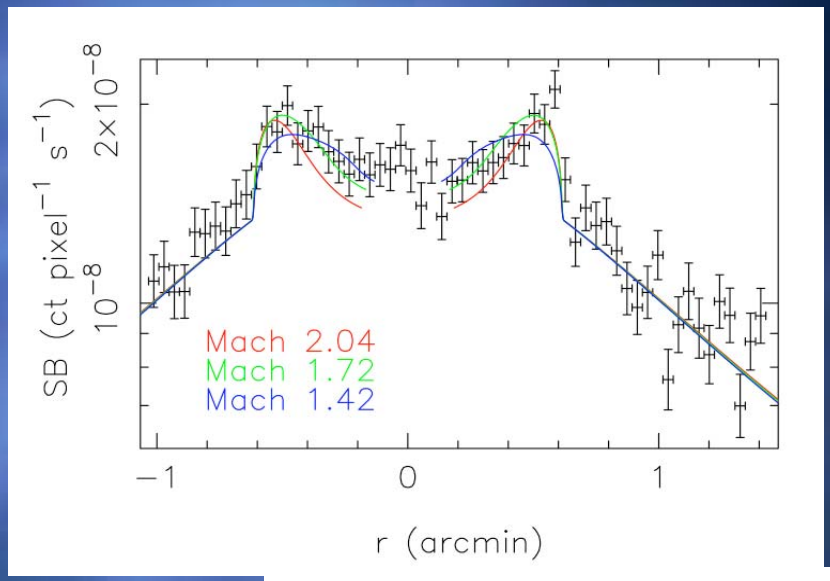
- In an outburst, jet propagates rapidly from the AGN; assumed in plane of the sky
- Long thin cavity created by jet then inflates in all directions
- Perpendicular to axis, expansion has approximate cylindrical symmetry; assumption of a long thin cavity (explosive outburst along cavity axis)



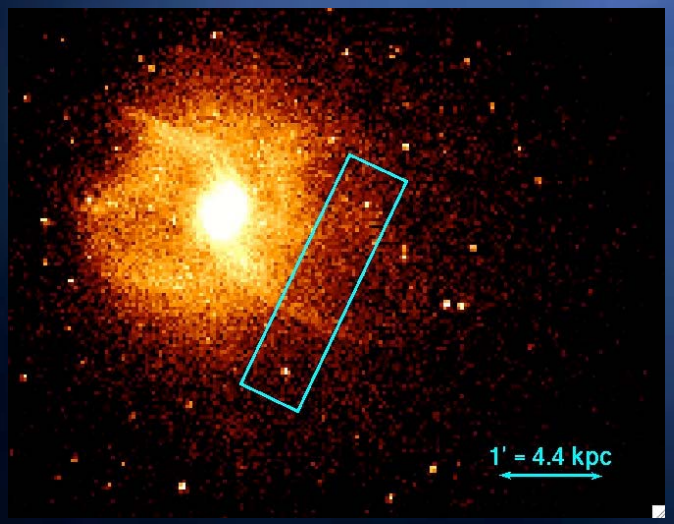
- Numerical hydro-dynamical shock model
- Model Pre-shock density profile uses cut perpendicular to the radius
- Gas starts in hydrostatic equilibrium with a pre-shock temperature kT = 0.65 keV

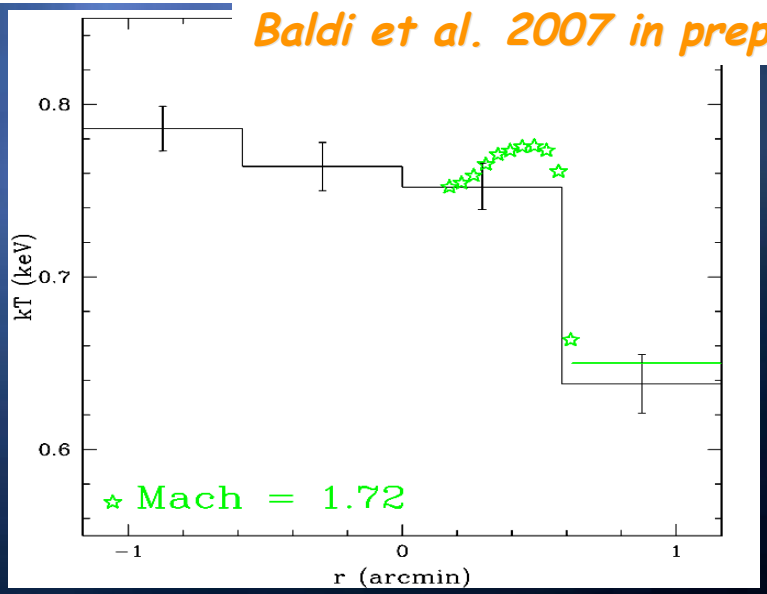
The SW X-ray 'bubble':
results from a shock model

- Shock strength determined by matching observed SB(r) to projected model
- Temperature profile in agreement with shock model predictions
- Physical parameters derived:
  - Age ~ 2.2 x 10^6 yrs
  - Total energy required to produce the shock ~ 10^{56} ergs
  - Enthalpy 4pV ~ 10^{56} ergs



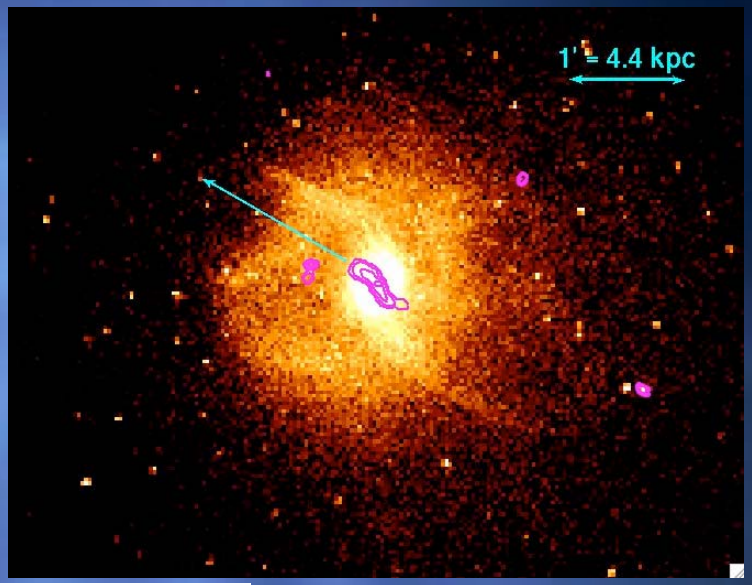
Baldi et al. 2007 in prep.





Is there a NE 'bubble'?

- The symmetry of the X-ray arms and the radio morphology suggests the presence of a NE 'bubble'
- 'Bubble' not clearly visible from our X-ray data
- SB (r) and kT(r) consistent with the SW 'bubble' and a shock model
- Physical parameters are expected to be similar



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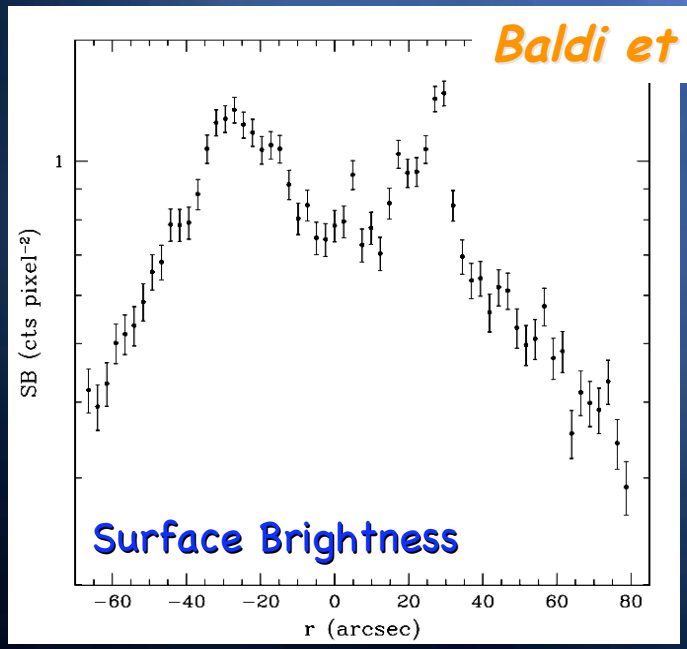

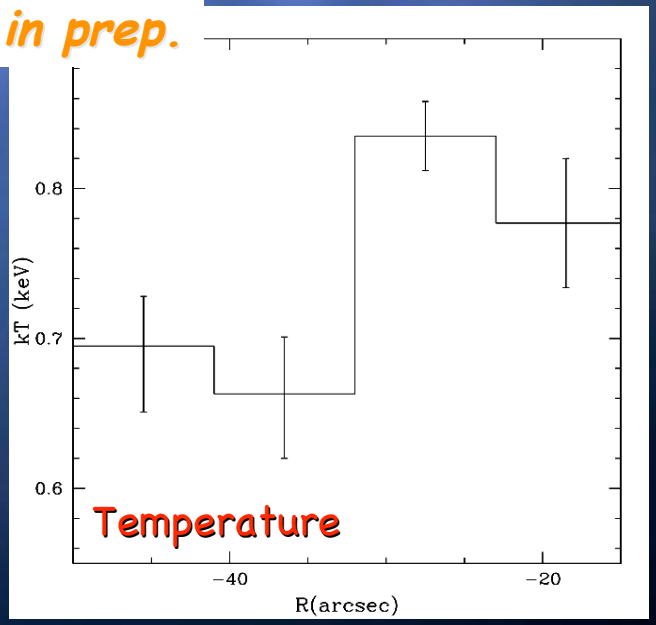

Summary

- Complex X-ray structure observed:
  - Cavities created by now extinct jet
  - Probably plasma filled cavities
  - Age ~ 2.2 x 10^6 yrs
- Central cavity around (now) weak radio source (~ 1.4 x 10^{38} ergs s^{-1})
- Detect unambiguous signature of a shock in the SW bubble
  - 1.4 < Mach < 2.0 shock
  - Total energy required to produce the shock ~ 10^{56} ergs
  - SW cavity enthalpy (4pV) ~ 10^{56} ergs
- Hints of the existence of a NE bubble:
  - SB profile and temperature jump observed consistent with shock measured around SW cavity

Keep the faith !!!

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