Cluster-Quasar Bound:
3C186 a Quasar in a Massive Cluster at High Redshift

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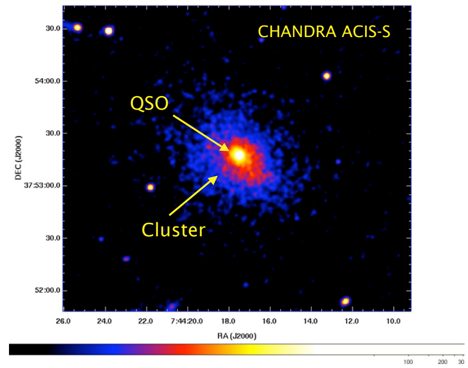


ABSTRACT:
We present a deep (200 ks) Chandra observation of an X-ray luminous galaxy cluster associated with the powerful (L ~10^{47} erg/s), high-redshift (z=1.067) Compact-Steep-Spectrum radio-loud quasar 3C186. The cluster temperature profile indicates that this is a cooling-core cluster with kT=3.1(+0.9/-0.6) keV in the central cooler regions of the cluster. We measure a high cooling rate within the core of about 470 (+115/-80) $M_\odot$/year, and a cooling time of 7.1±1.4 *10^8 years. The cooling gas is able to supply enough fuel to support growth of the supermassive black hole and to power the luminous quasar. The kinematic power of the central radio source is about factor of 10 lower than the quasar radiative power. This suggests that the radiation may provide greater heating in this cluster than the mechanical power of a radio source.

3C 186 X-ray Cluster Parameters:

• Cluster has an ellipsoidal shape and extends out to radii of at least ~60 arcsec (~500kpc)

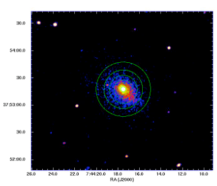
Surface Brightness fitting results:
β = 0.48 (+/-0.17)
R_{core} = 28 (+/-2) kpc
Central density = 0.08 cm^{-3}

NFW model parameters:
c_1=7.4 (+2.8/-2.3)
r_s=120 (+70/-40) kpc
δ_c=780 (+90/-60) km/s
r_{2500} = 283 (+18/-13) kpc

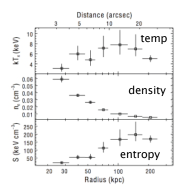
Cluster Mass
$M(r_{2500})$ = 1.02(+0.21/-0.14) * 10^{14} M_{sun}
Gas mass fraction =0.129 (+0.015/-0.016)

Cluster Luminosity
$L_{(0.5\text{-}2\ keV)}$=4.6±0.28*10^{44} erg/s

Cooling Core Cluster



7 annuli between 2.75-30 arcsec were used in spectral modeling of the X-ray cluster.

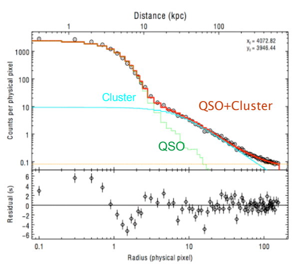


"deproject" Python model in Sherpa used to obtained deprojected temperature and density profiles.

Key Results

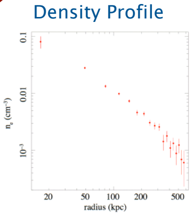
- Cooling Core X-ray Luminous Cluster at high redshift.
- Gas mass fraction typical to low z clusters suggesting no evolution of f_{gas} with redshift
- The cluster has a small cooling core (R_c=28kpc) with a short cooling time (t_{col} < 700 Myrs).
- Cooling rate of ~470 $M_\odot$/year
- Powerful RL quasar located in the center of a cooling core cluster.
- 5.5±0.9 kpc offset between the cluster centroid and the quasar position.
- Black hole growth might be closely related to the mass deposition from the cluster: ~0.5% of the cooling gas needed to grow BH by ~$10^9 M_{sun}$ within a cooling time of the cluster core.
- ~0.05% of the Quasar energy is needed to prevent cluster cooling during that time.
- QSO Radiation exceeds the kinematic power and may be the dominant heating source in this cluster.

X-ray Surface Brightness

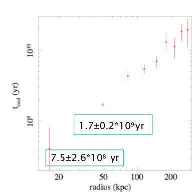


Cluster emission dominates outside 1.5 arcsec central region and exceeds the bkg emission up to 40 arcsec distance from the QSO.

Density Profile



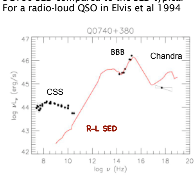
Cooling Time Profile



- Quasar luminosity L_{bol} ~10^{47} erg/s
- Quasar Radio Power L_{radio}~10^{46} erg/s
- Black Hole Mass ~10^9 M_{sun}

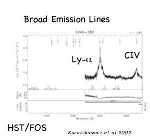
3C 186: Radio-Loud Quasar: SED

3C186 SED compared to the SED typical For a radio-loud QSO in Elvis et al 1994



Strong Big Blue Bump (BBB)
L_{BBB} = 5.7 x 10^{46} erg/s
Assuming $L_{BBB} \propto L_{Edd}$
=> $Mass_{BH}$ = **4.5 x 10^8 M_{sun}**
CIV FWHM (Kuraszkiewicz et al 2002)
=> $Mass_{BH}$ = **3.2 x 10^9 M_{sun}**
Required Accretion Rate: **10 Msun/yr**

Broad Emission Lines



Compact Steep Radio Spectrum (CSS)
Radio loudness: Log(F_{5GHz}/B) = 4.3
=> **Higher** than for a typical RL QSO
α_{ox} = 1.74 => weaker X-rays
X-ray Luminous:
L_x(2-10 keV) ~ 1.2x10^{45} erg/s

3C186: Jet Power

Pressure in Radio Lobes assuming equipartition => 10^{-8} erg/cm^3

Thermal Pressure of the Cluster Medium:
for kT=3.1 keV n=0.08g/cm^3
nkT = 4*10^{-10} erg/cm^3

Radio Source over-pressured: P_{radio} > $P_{cluster}$

Using equipartition measurements and assuming the volume of a radio lobe of 10^{66}cm^3 we estimated **total jet power at P_{jet} = 10^{58}erg** The instantenous **average jet power is 6*10^{44} erg/s** for the age of a radio source 5*10^5 years

P_{jet}> $P_{cluster}$
P_{jet} < $P_{radiation}$

Cluster Heating

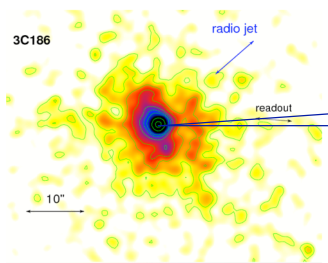
Energy Required to compensate Cluster Cooling:
Mass (r < 45kpc) = 3.3*10^{11} M_{sun}
E_{heat} ~ (1keV/1GeV) M c^2 ~10^{-6} M c^2 ~6*10^{59} erg

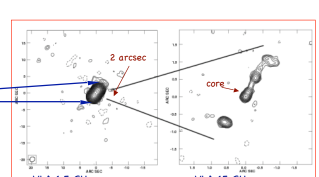
Quasar with L_{bol}~ 10^{47} erg/s can supply enough energy to heat the cluster in **2*10^5 years** if 100% efficient. But for the cooling time of **~7*10^8 years only a small fraction (<0.05%)** of the Quasar Power is needed.

What heats the Cluster?

1/ Jet Power lower than the Quasar Radiation Power:
L_{jet} ~ 2.5*10^{45} erg/s < L_{rad} ~10^{47} erg/s
2/ Compact Radio Source R_{size} < 30 kpc
=> Radiation may be more important than kinematic power for heating this cluster.

3C 186: Radio Morphology





Compact Radio Source: Size: 2 arcsec ≈16 kpc
Radio peaks: 0.3 GHz L (radio) ≈10^{46} erg s^{-1}
Young Radio Source ! Age: ≈ 5x10^5 yrs (Murgia et al 1999)

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