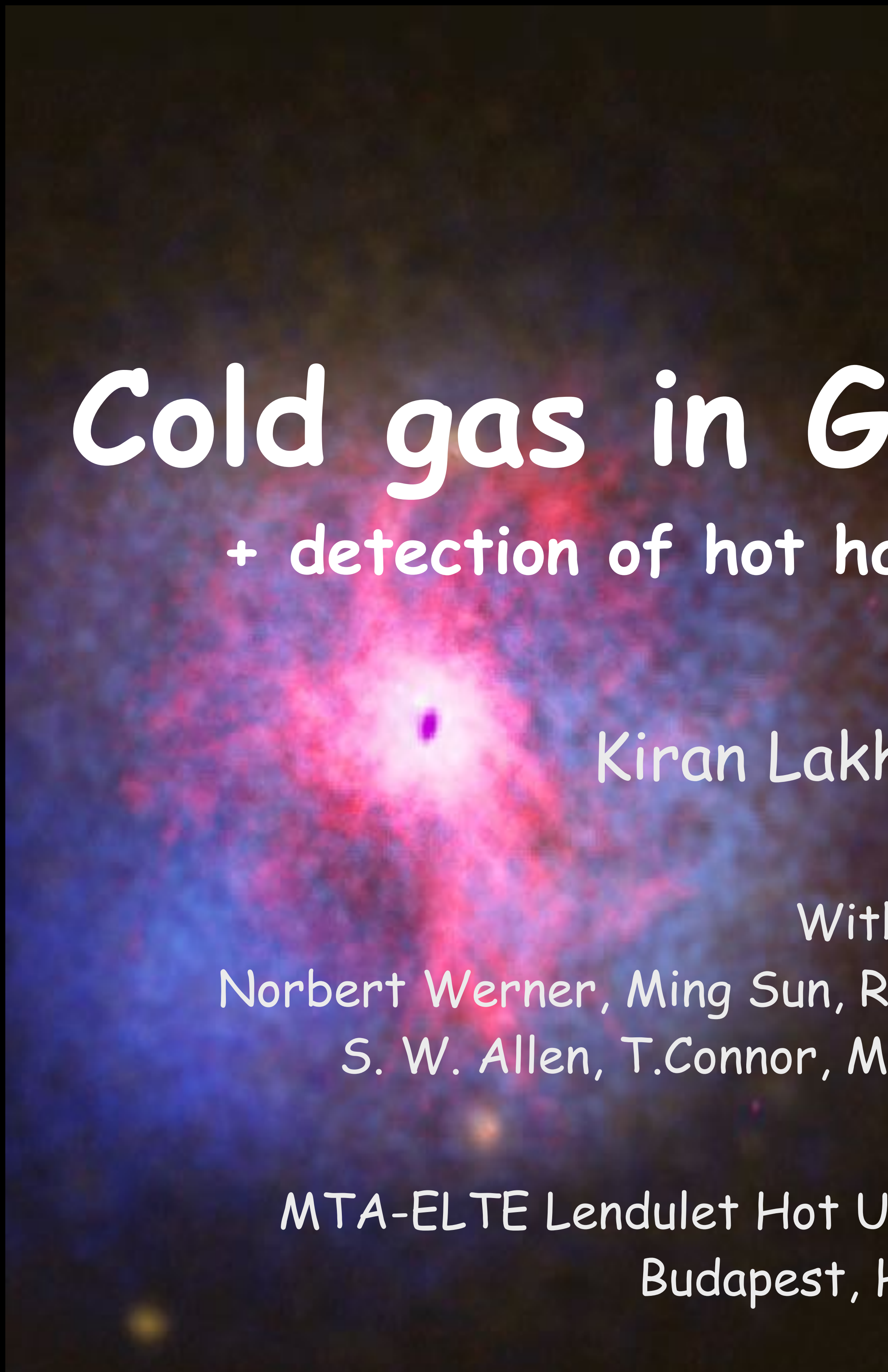

Cold gas in Giant ellipticals

+ detection of hot halos around red nuggets

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With

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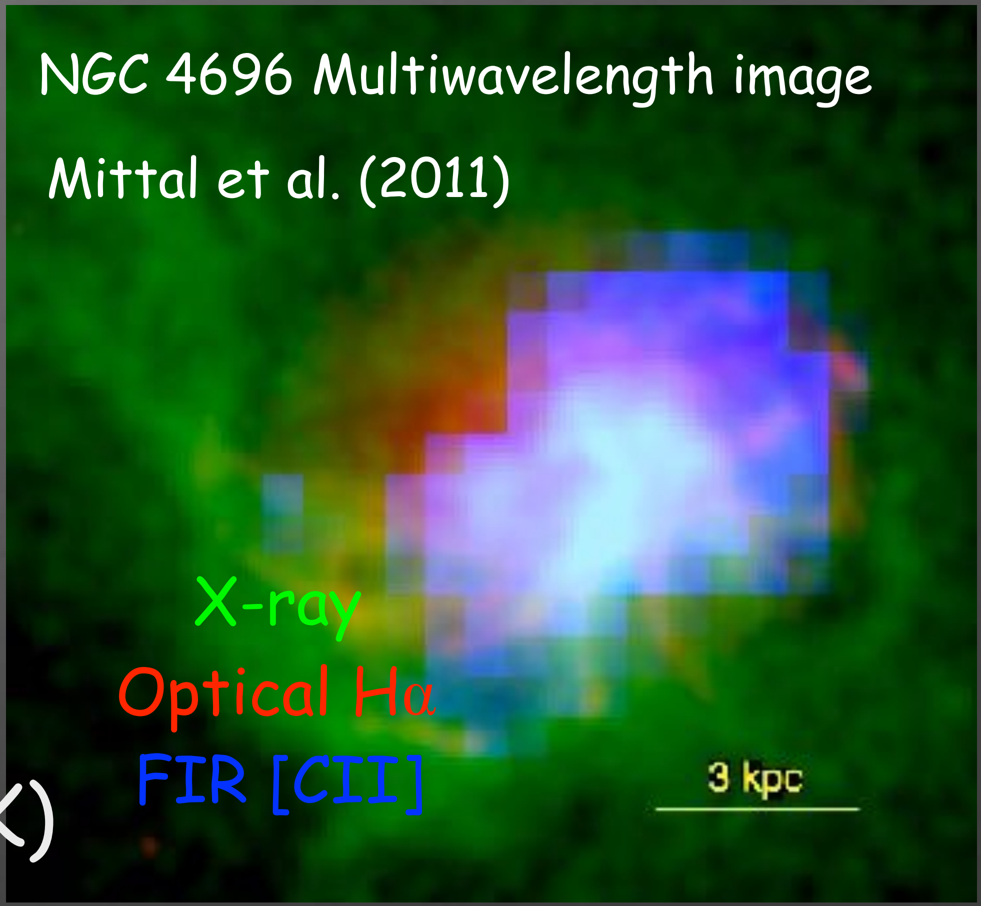
Giant Elliptical Galaxies

- Elliptical galaxies: 'Red and Dead'!!
- Very little star-formation; devoid of dust and gas

- Current picture: multi-phase ISM. Mostly in hot phase
- ~47% of giant ellipticals contain multiphase ISM.

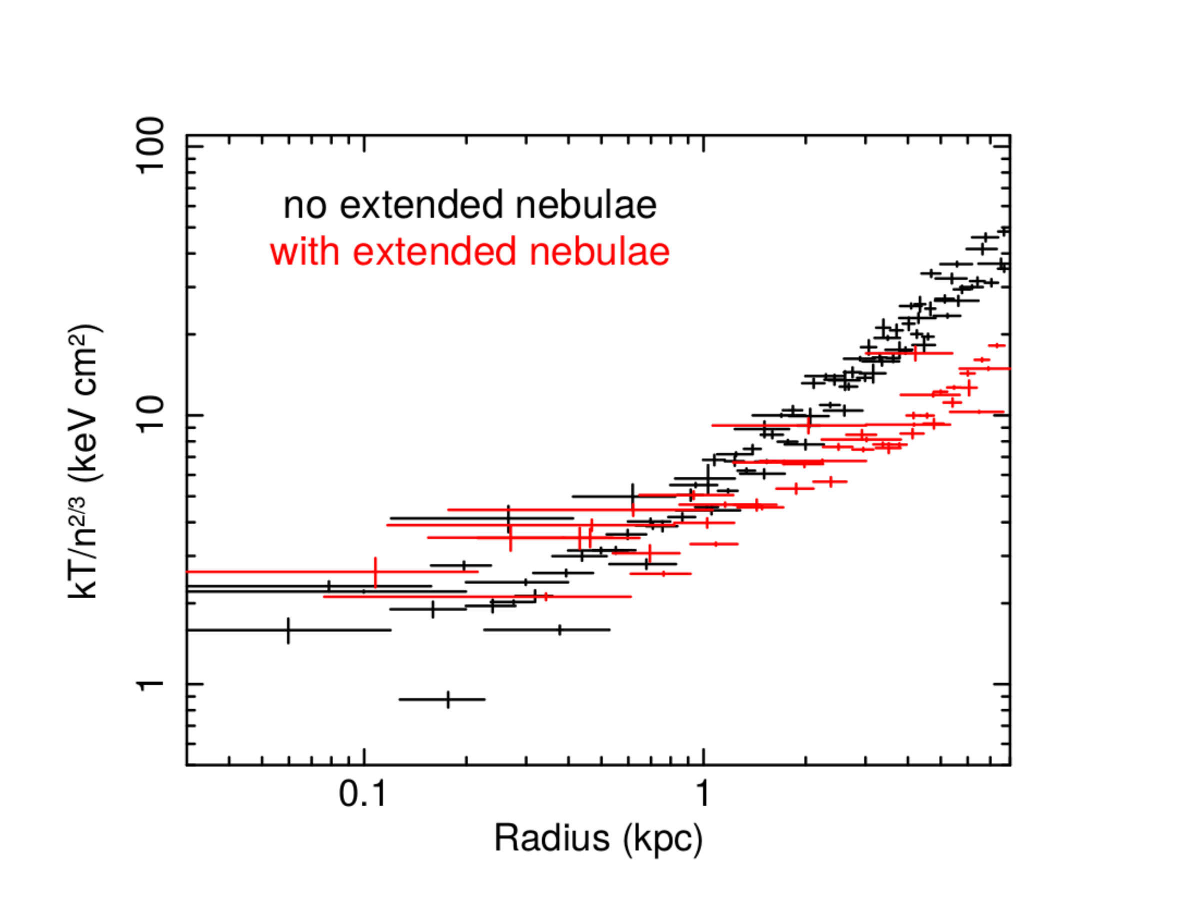
Cold gas in Giant ellipticals

- Co-spatial multiphase gas nebulae:
- **Hot:** Soft X-ray (T~10^7 K)
- Mod. Hot : FUV (T~10^5 K)
- **Warm:** Optical: Hα+[NII] (T ~ 10000 K)
  NIR: Warm H_2 clouds (T ~ 1000 K)
- **Cool: FIR [CII], [OI] lines** (T ~ 100 K)
- **Cold: Sub-mm (CO lines)**: Cold Molecular gas (T<50 K)



Hot gas origin of cold gas

Werner et al. (2014)



- Entropy profiles of 10 bright nearby ellipticals.
- Giant ellipticals with extended cold gas have smaller entropies
- Hot gas origin of cold gas.
- Larger unbiased samples required.

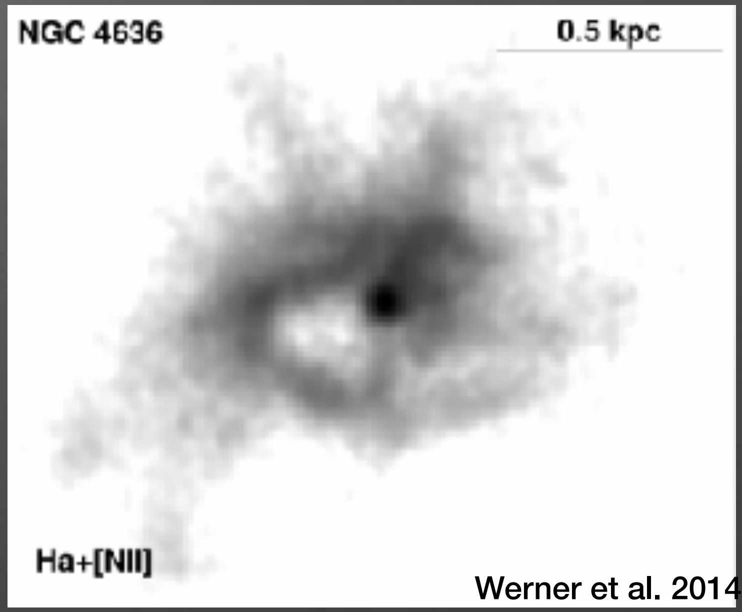
Aim:

Investigate the cold gas-hot gas connection and role of cold gas in AGN feedback cycle using Chandra X-ray observations a large sample of 49 X-ray and optically bright giant ellipticals.

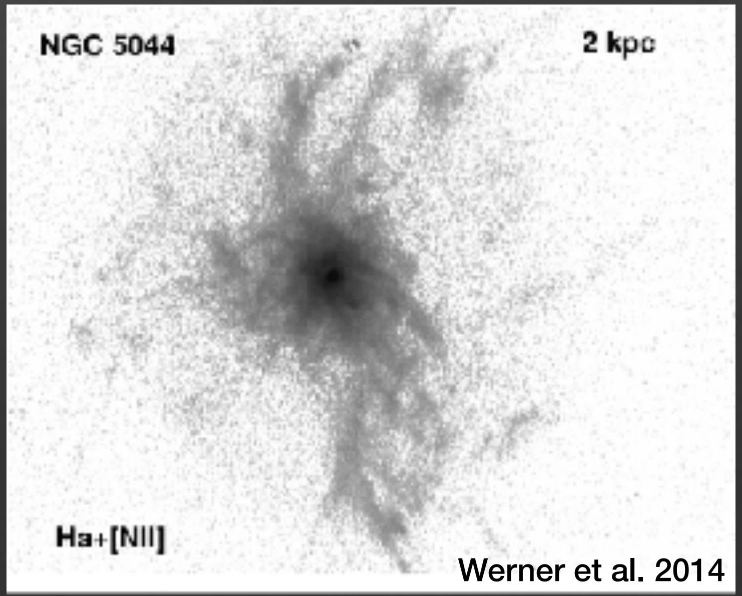
Galaxy Classification

Hα+[NII] images and spectra from SOAR/APO

- Cool Gas Free systems
  e.g., NGC 1399, NGC 1404
- Nuclear Emission: Size < 2 kpc
  e.g., NGC 4636
- Extended Cool Gas : Size ≳ 2 kpc
  e.g., NGC 5044
- Unsure : NGC 315



Werner et al. 2014



Werner et al. 2014

Data Analysis

- Point sources removed.

- Average properties: Spectra extracted from 10 kpc region around the X-ray peak

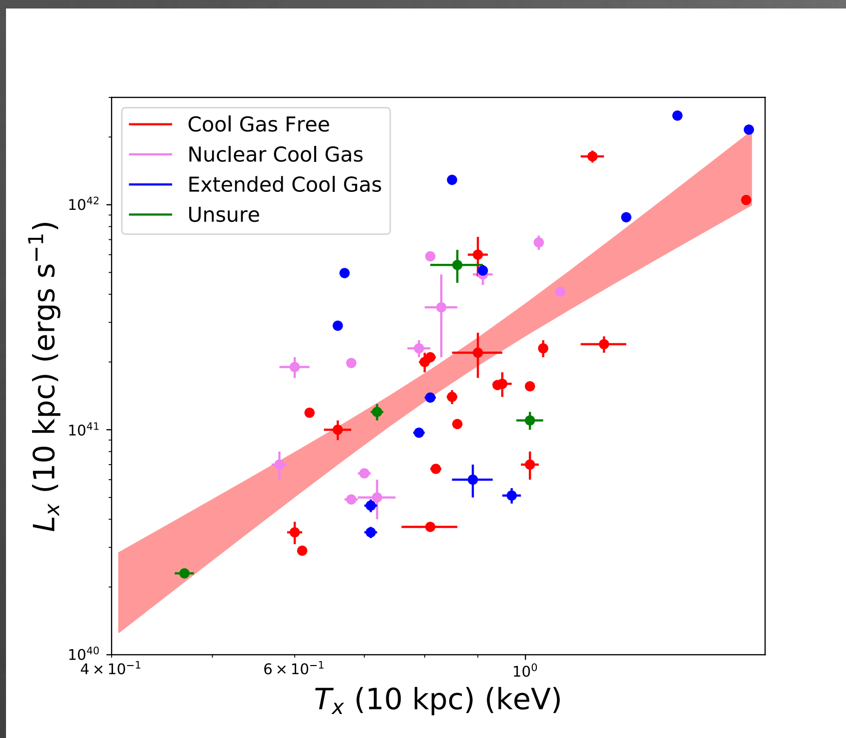
- **Deprojected radial TD profiles:** Spectra extracted from equal count annular regions centred on
  the X-ray peak; simultaneously

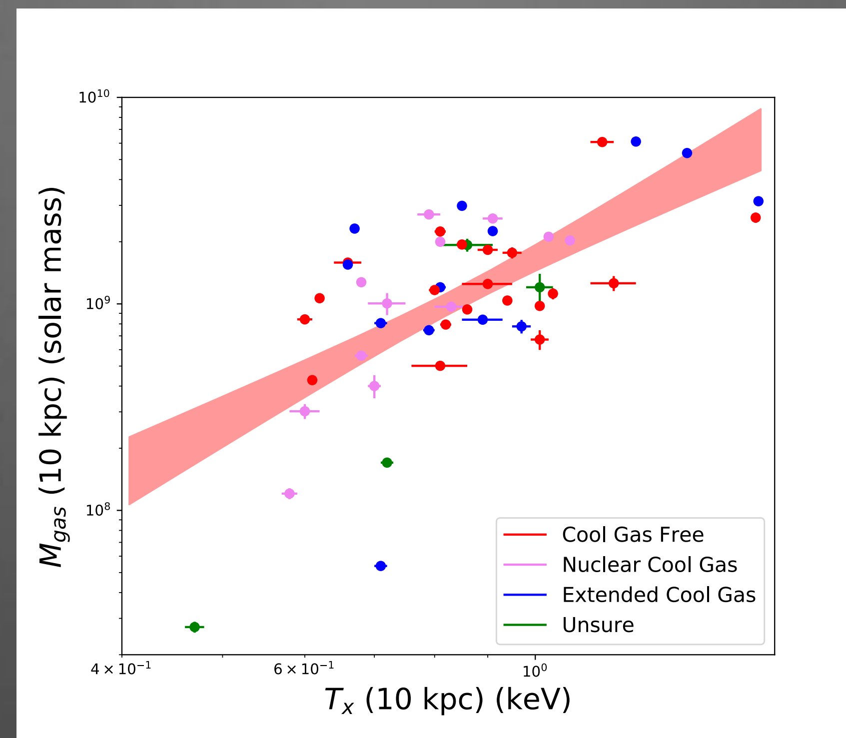
- n, kT (direct)

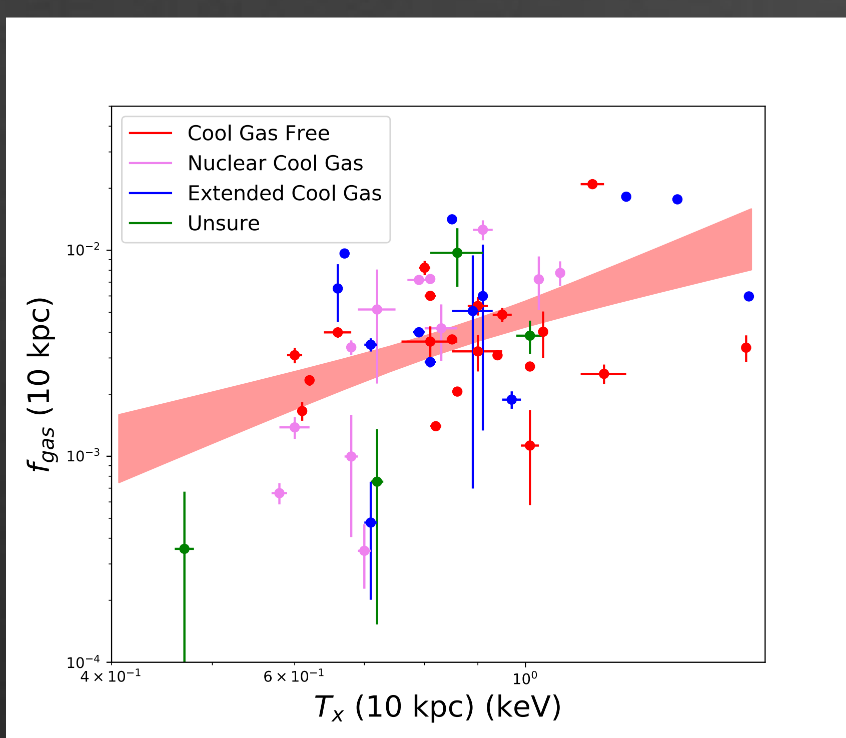
- K, P, t_{cool}, t_{cool}/t_{ff} (derived)
  L_x, M_{gas}, f_{gas}, Y_x

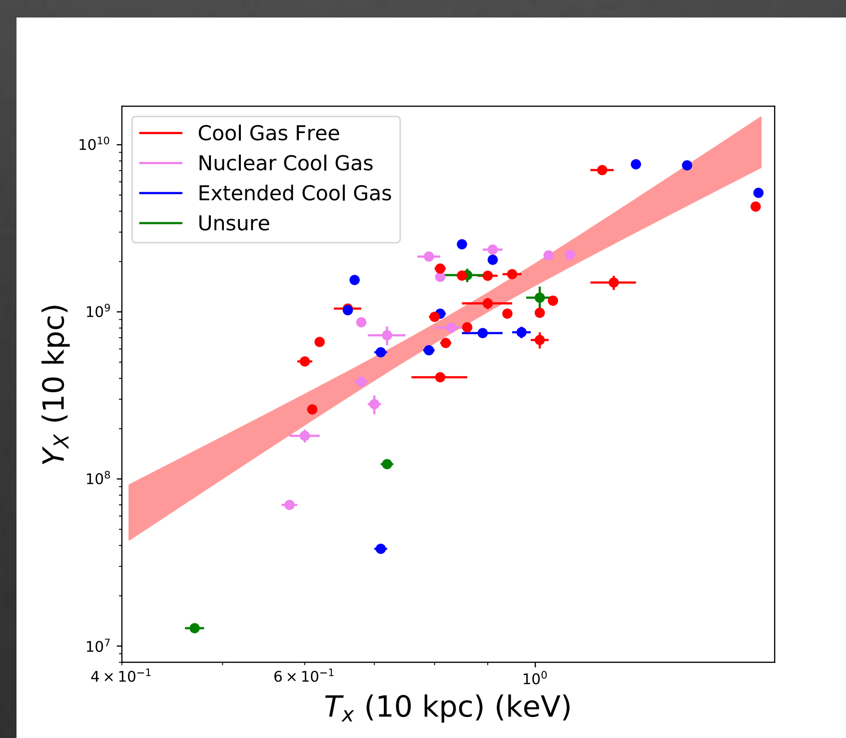
Global properties

L_X, M_{gas}, f_{gas}, Y_X vs. T_X



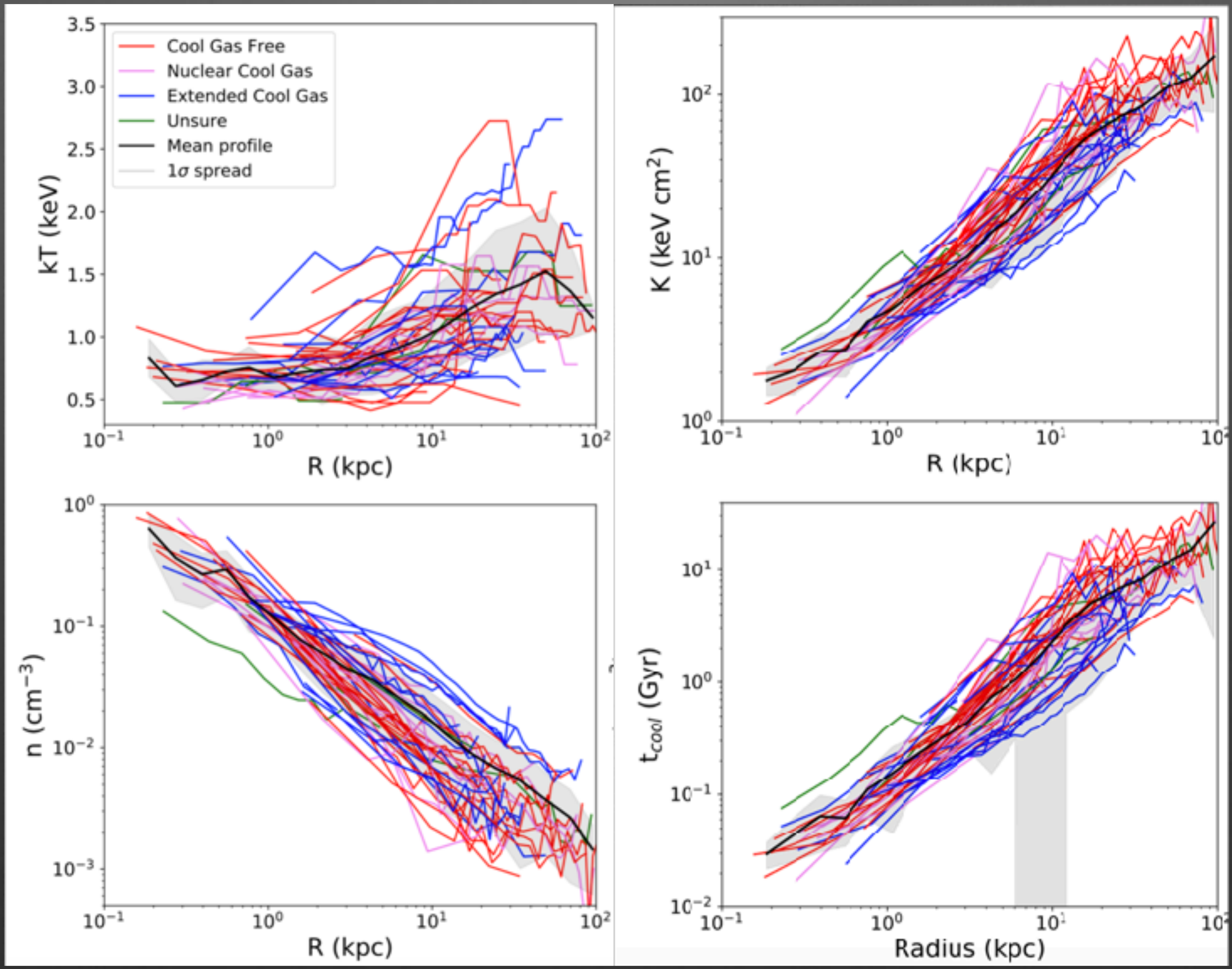




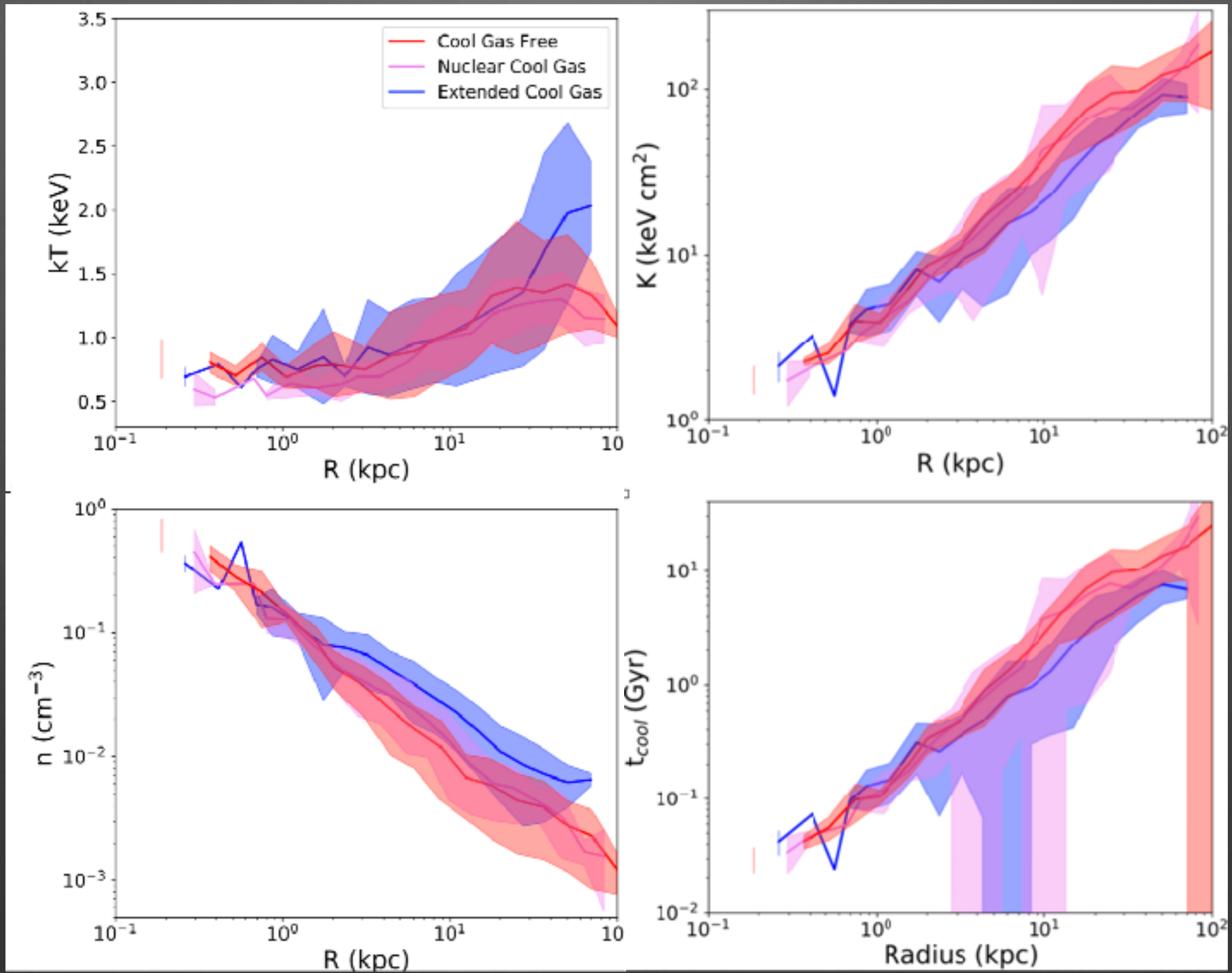


- No evident correlation b/w presence/extent of cool gas and the global properties of the galaxies
- $f_{gas} \propto T_X$
  Corr. Coeff. ~ 0.48±0.12
- Hot halos more likely in more massive systems

Deprojected radial profiles



Average Profiles



Cool Gas preferred in high n, low K, low t_{cool} galaxies

Conditions supporting multiphase gas

- Low entropy outside the core (K_{20})
  (Werner et al. 2014)

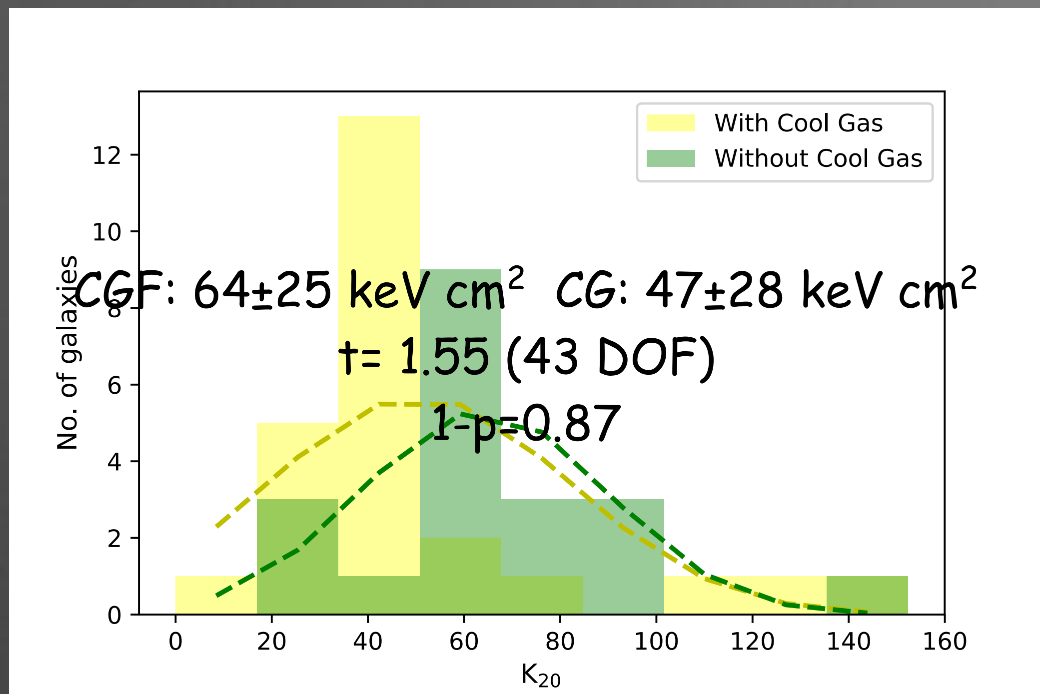
- Shallow entropy gradient (α_K)
  (Werner et al. 2014, Voit et al. 2017)

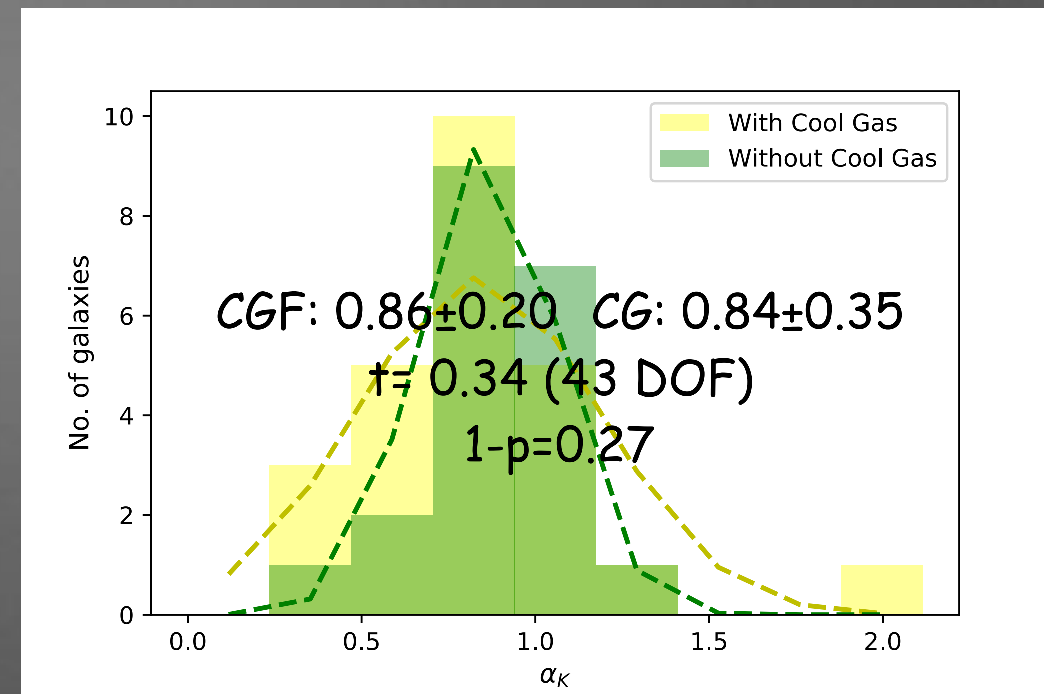
- Low min(t_{cool}/t_{ff})
  (Gaspari et al. 2012, McCourt et al. 2012, Sharma et al. 2012)

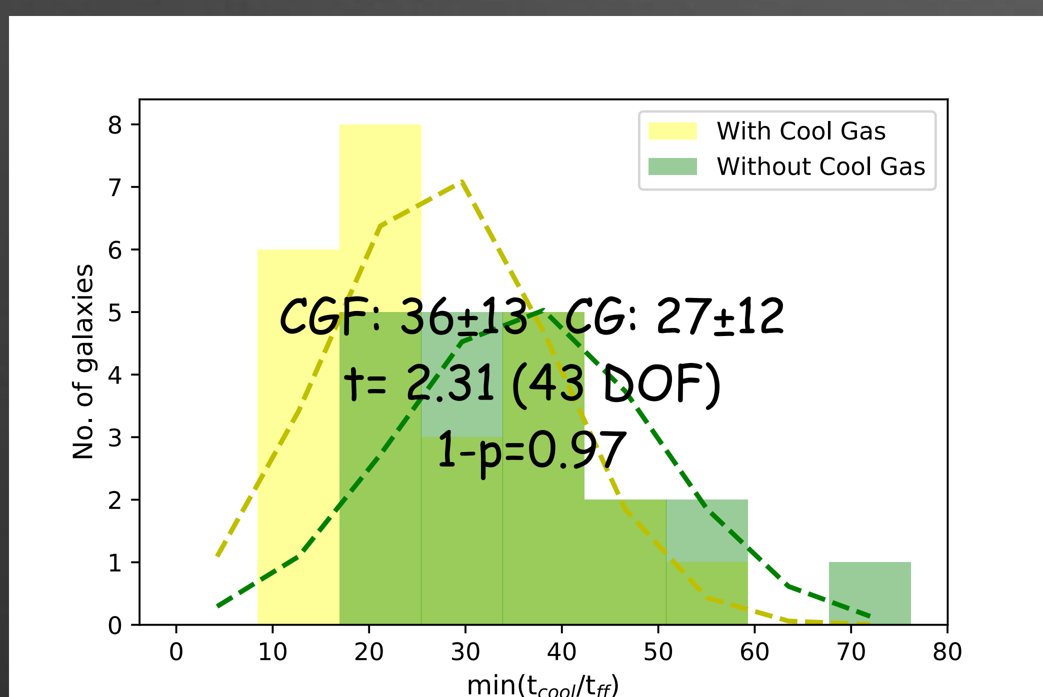
- High Gas motions
  (Gaspari et al. 2017)

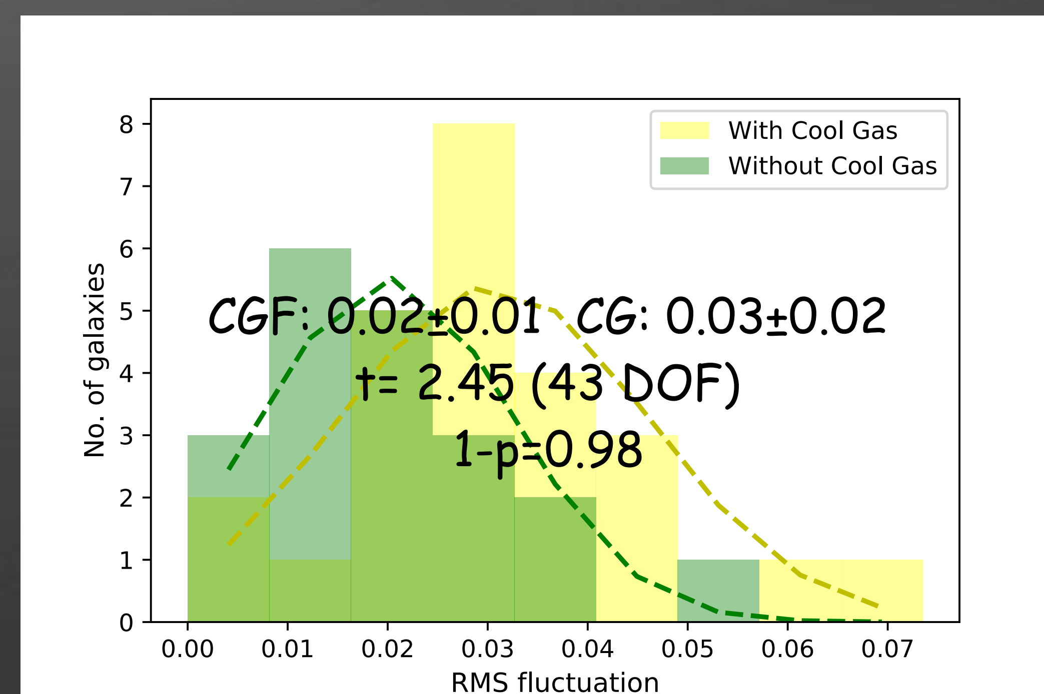
Obtained K_{20} and α_K from entropy profile fitting.
min(t_{cool}/t_{ff}) directly from the reprojected T, n profiles
Gas Motions using rms fluctuations in X-ray images

Cooling Instability Criteria



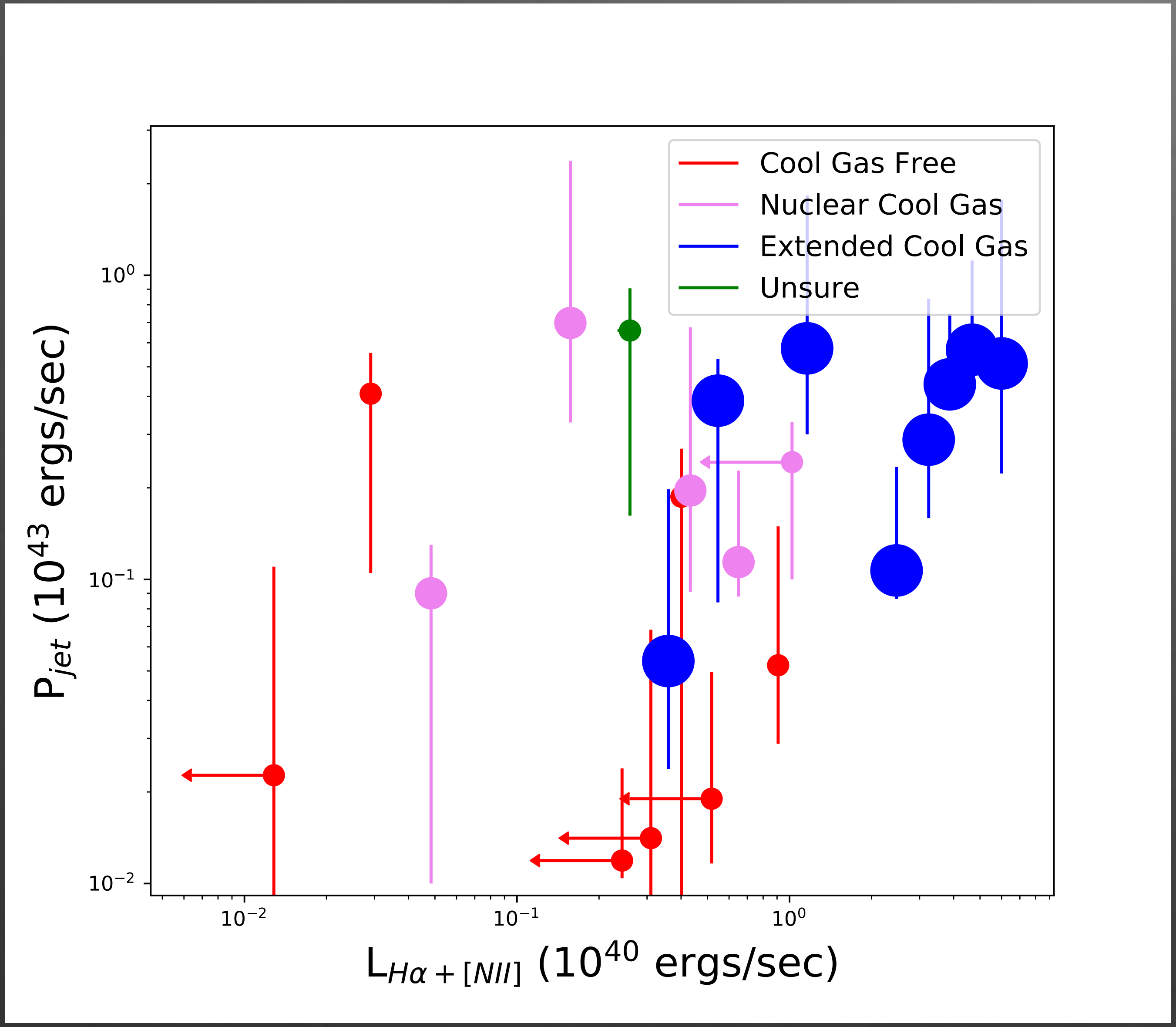






Cool gas preferred in galaxies with low K_{20}, low min(t_{cool}/t_{ff}) and high rms fluctuations.

Pjet vs. H-alpha



Hint of a weak positive correlation between P_{jet} and $L_{H\alpha+[NII]}$!!
Pearson's Coeff. ~ 0.39 (0.27)
Albeit with significant spread.

CCA-P_{jet} Hysteresis cycles

HD simulations
(Gaspari et al. 2012,2018; Prasad et al. 2015)

Summary

- X-ray observations of a sample of 49 nearby bright elliptical galaxies analysed
  Hot gas-cold gas correlations investigated to understand the origin of the cool gas and its role in the AGN feedback cycle. Galaxies classified based on $H\alpha$+[NII] emission presence/extent.

- No evident correlation b/w presence/extent of cool gas and the global properties of the galaxies.

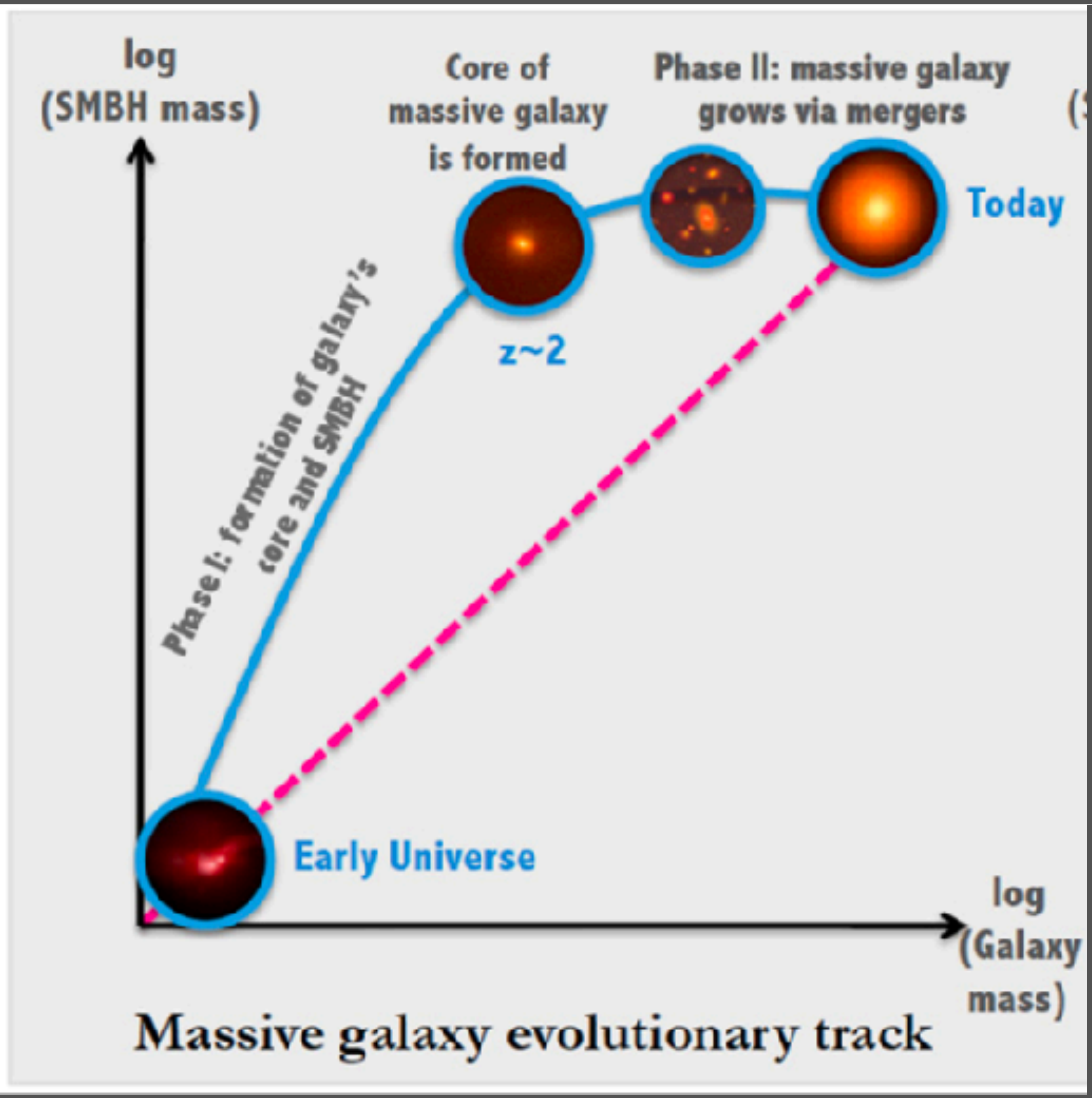
- Presence of cool gas preferred in systems with high densities, low entropies (K_{20}) & cooling times, low min(t_{cool}/t_{ff}) and high gas motions.

- The K_{20}, min(t_{cool}/t_{ff}), and RMS fluctuations of the cool gas poor and cool gas rich galaxies found to belong to two statistically different populations with 96%, 97% and 98% probabilities, respectively.

- Large scatter and overlaps seen in TD properties seem to be due to short feedback cycles of the low mass systems.

- Weak positive correlation in P_{jet}-$L_{H\alpha+[NII]}$

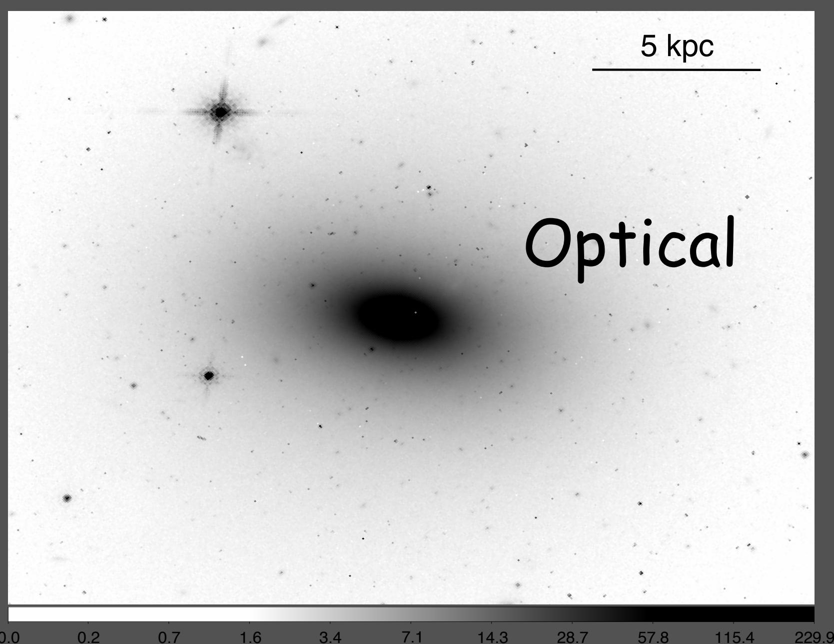
RED AND DEAD GIANT ELLIPTICAL GALAXIES

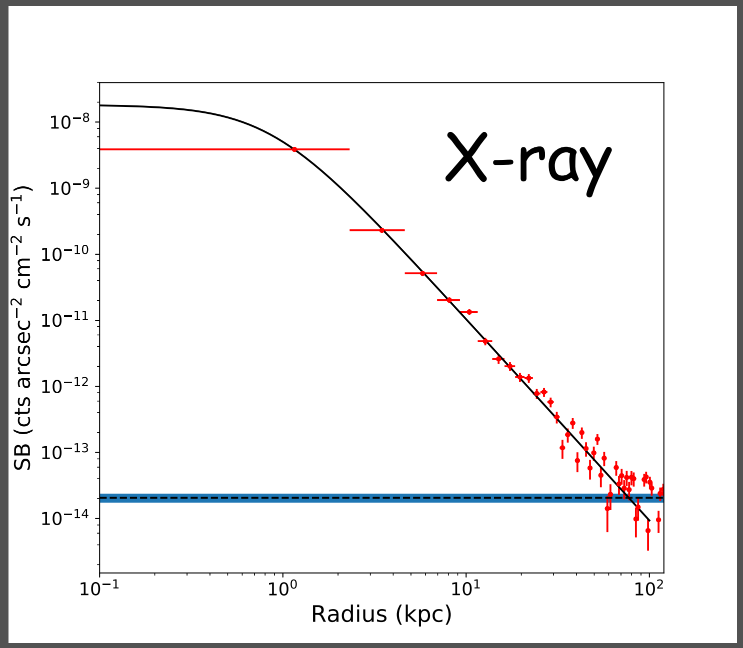


Ferre-Mateu et al. (2017)

Hot atmospheres surrounding a relic red nugget

Mrk 1216

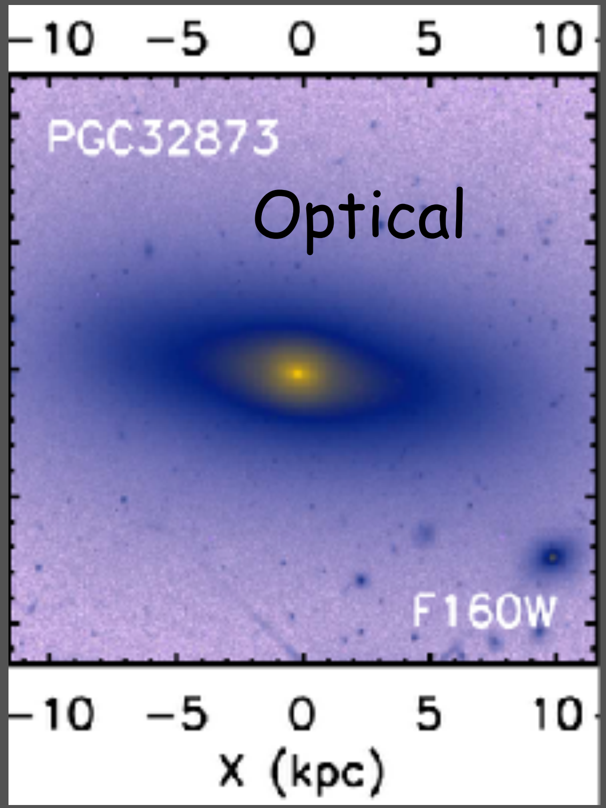


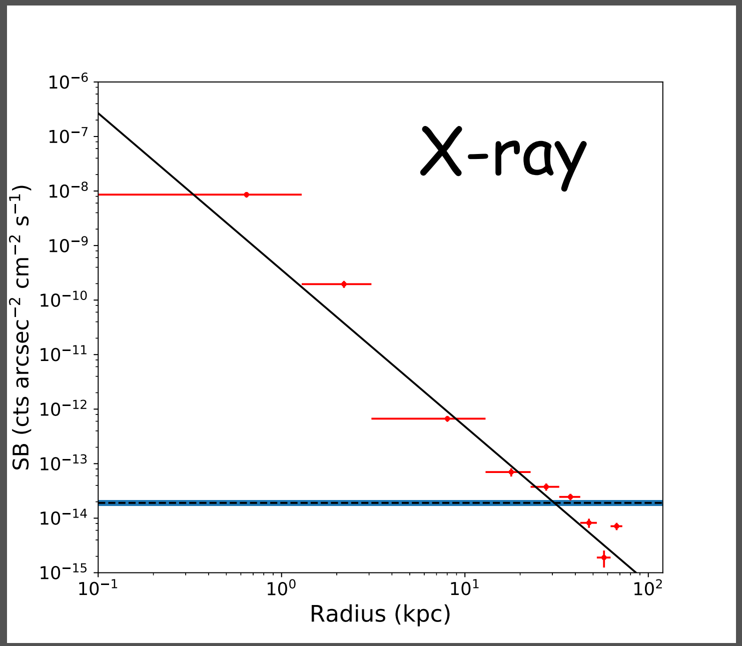


$M_{stellar}$ = (2.0 ± 0.8) × 10^{11} $M_\odot$
R_e=2.3 ± 0.1 kpc
Age = 12.8±1.5 Gyr
D = 97 Mpc
(Ferre-Mateu et al. 2017)

L_X = 6.9 × 10^{41} erg s^{-1}
within r<10 kpc
(Werner, Lakhchaura et al. 2017)

PGC32873

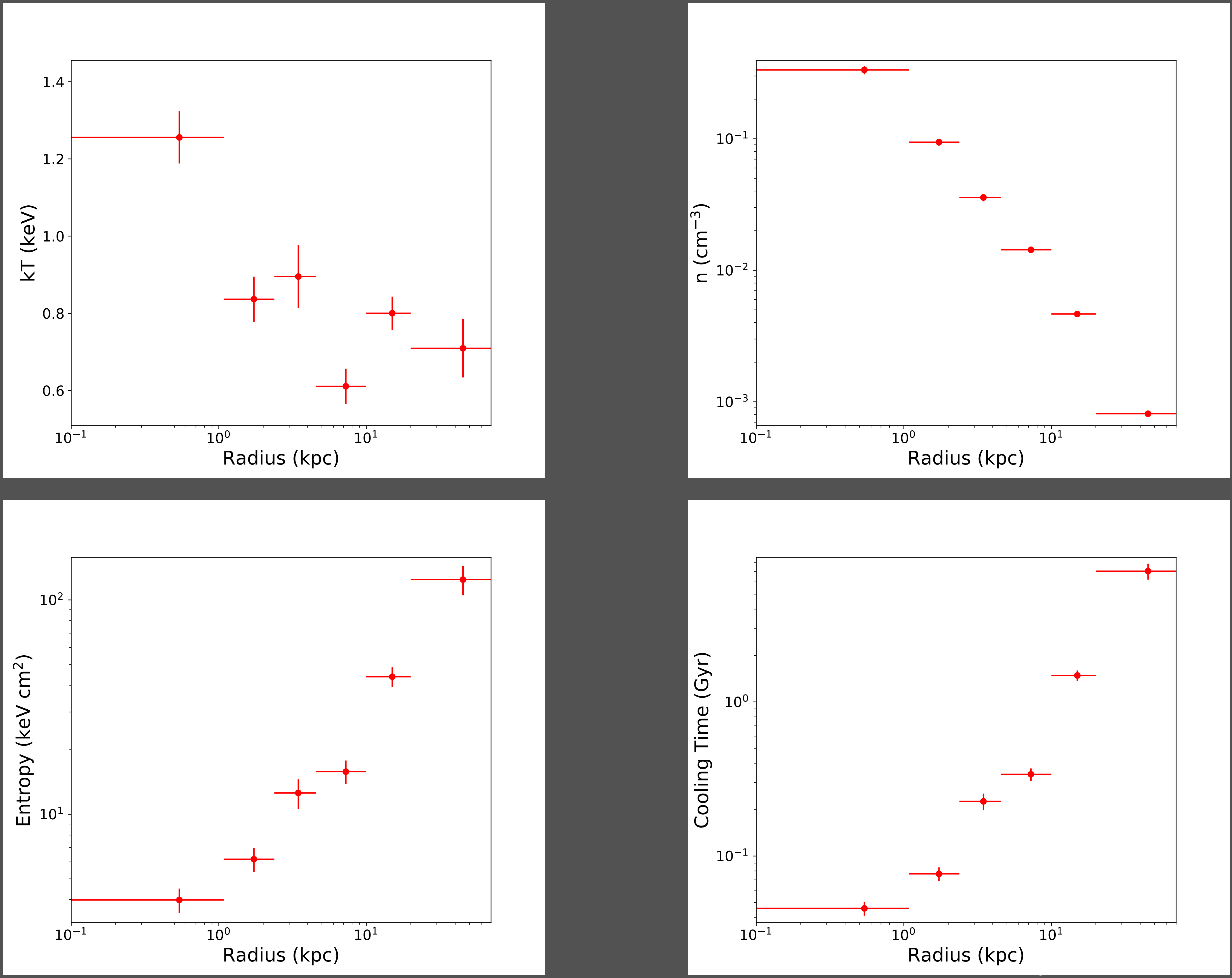




$M_{stellar}$ = (2.3 ± 0.9) × 10^{11} $M_\odot$
R_e=1.8 ± 0.2 kpc
Age = 12.7±1.6 Gyr
D = 108 Mpc
(Ferre-Mateu et al. 2017)

L_X = 5.3 × 10^{40} erg s^{-1}
within r<10 kpc
(Werner, Lakhchaura et al. 2017)

Mrk 1216 TD profiles



al. 2017

Hot atmosphere surrounding a relic red

- The first detection of an X-ray emitting atmosphere surrounding such a relic galaxy
- The hot atmospheres extend far beyond the stellar populations.
- The presence of an X-ray atmosphere with a short nominal cooling time and the lack of young stars indicate the presence of a sustained heating source, which prevented star formation since the dissipative formation of the galaxy 13 Gyrs ago - **radio-mechanical AGN feedback**

Werner, Lakhchaura et al. 2017

Thanks.

"The expert in anything was once a beginner."

–Unknown