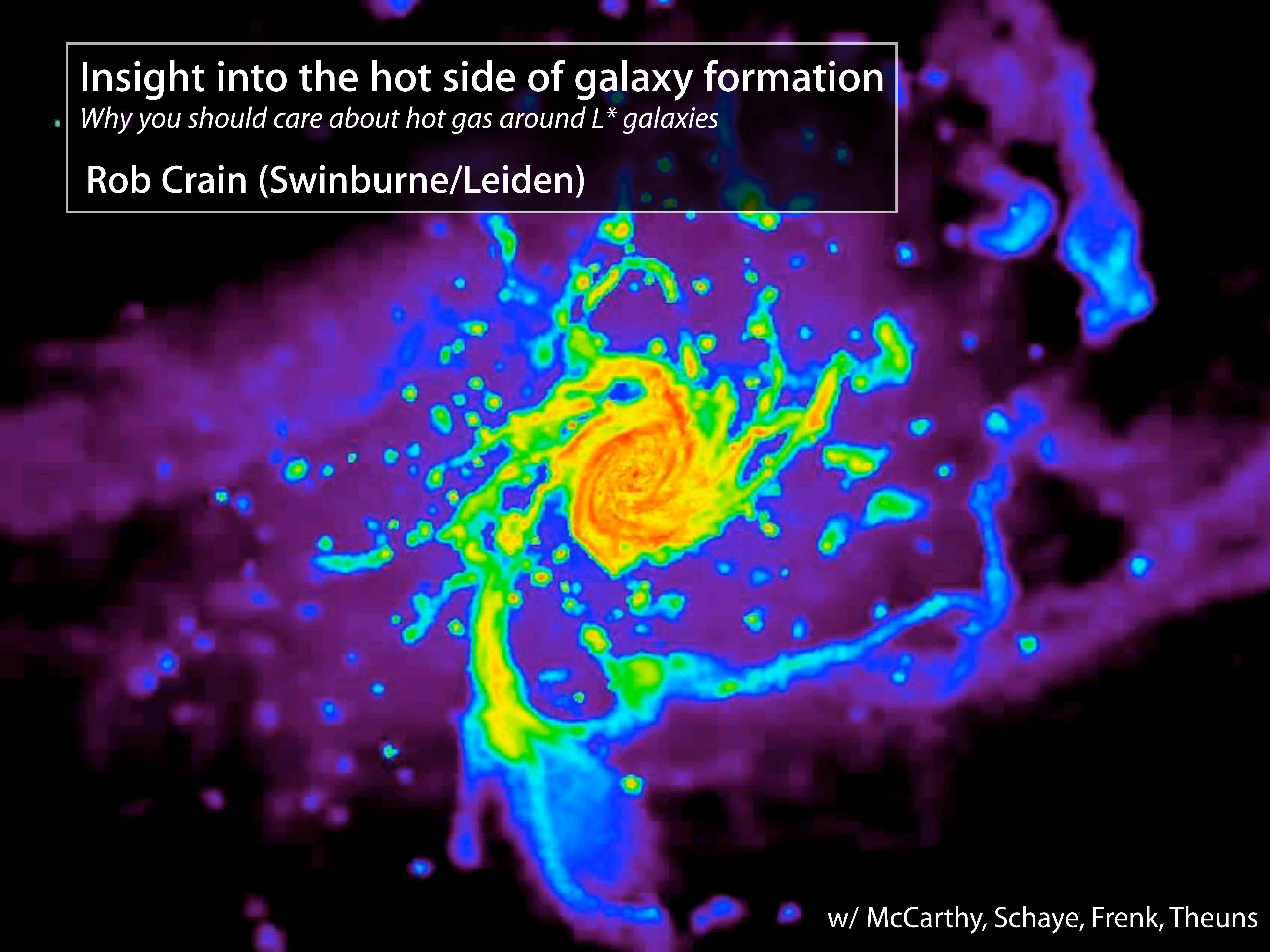
# Insight into the hot side of galaxy formation

*Why you should care about hot gas around L* galaxies*

Rob Crain (Swinburne/Leiden)



w/ McCarthy, Schaye, Frenk, Theuns

**All (semi-)analytic models appeal to circumgalactic gas reservoirs to fuel star formation**

# All (semi-)analytic models appeal to circumgalactic gas reservoirs to fuel star formation

If $\mathbf{t_{cool}} < \mathbf{t_{dyn}}$
infalls directly (rapid regime/**cold** flow)
If $\mathbf{t_{cool}} > \mathbf{t_{dyn}}$
**hot** hydrostatic corona

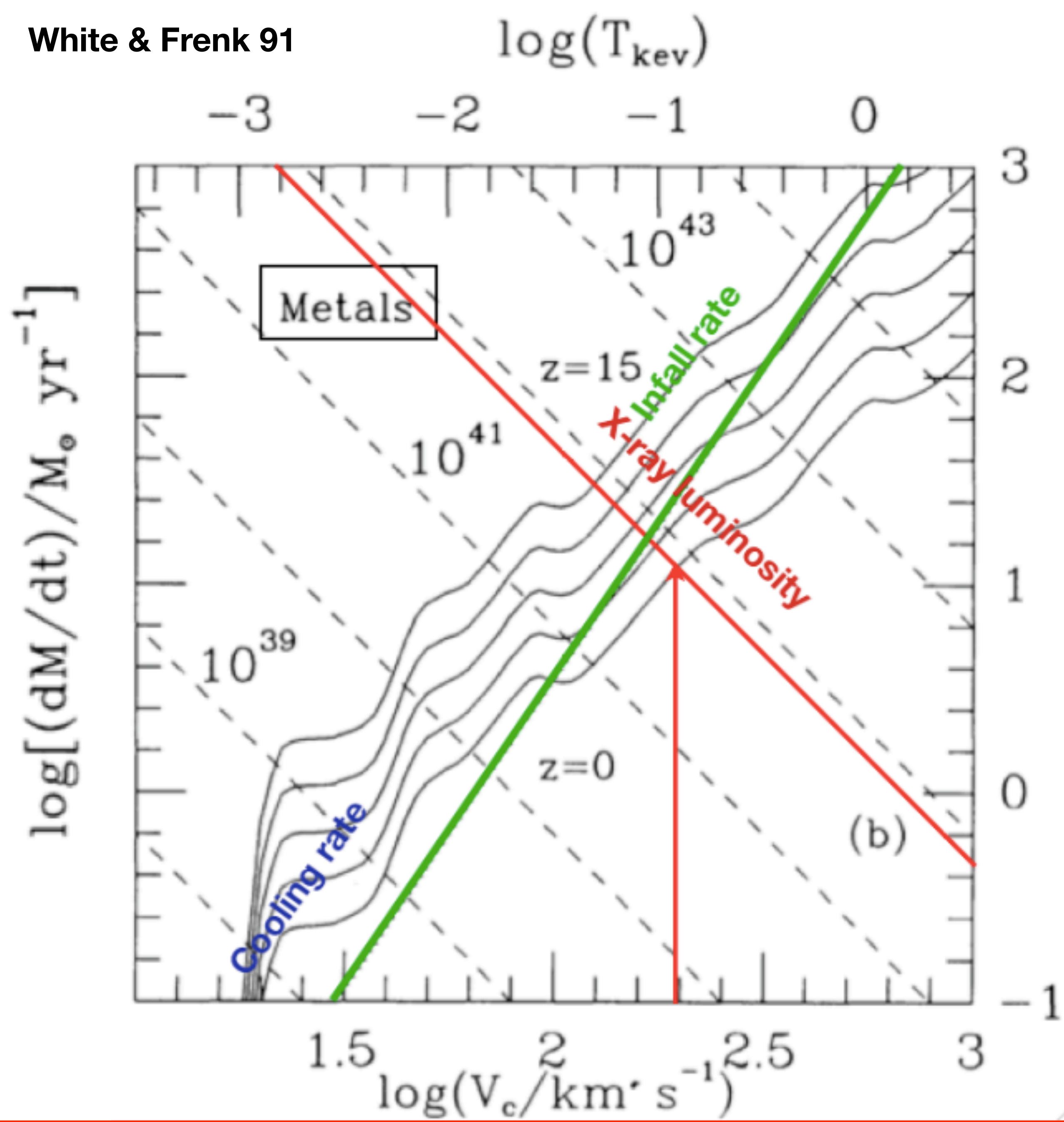
**For *L** galaxies WF91 predicts:**

kT~0.1 keV (soft X-ray)

$L_x$ = **$10^{41}$-$10^{43}$ erg/s !!!**

***ROSAT*** failed to detect any hot reservoirs. The few tens of X-ray detections from ***Chandra*/*XMM*** have mixed interpretations.

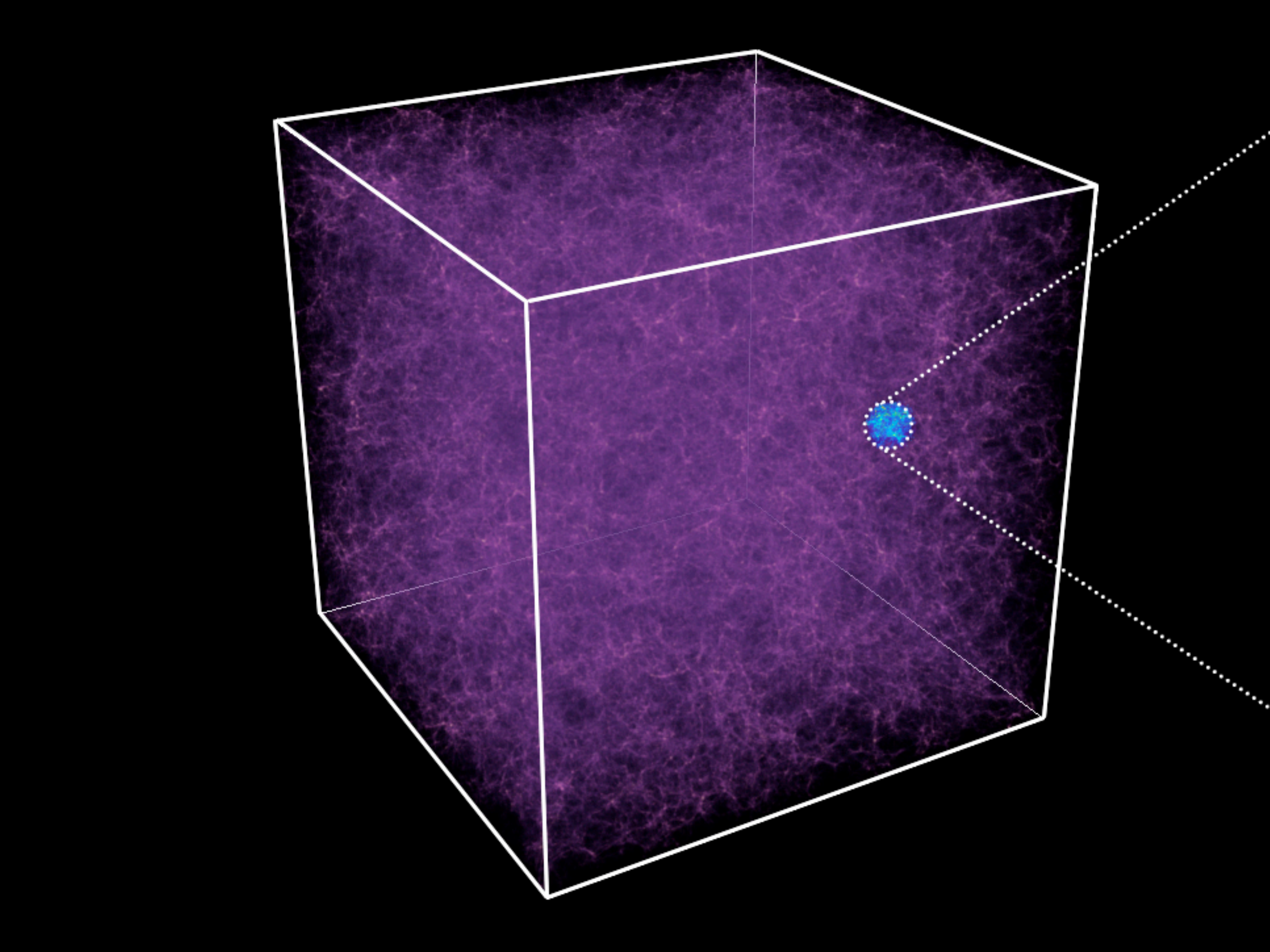
White & Frenk 91

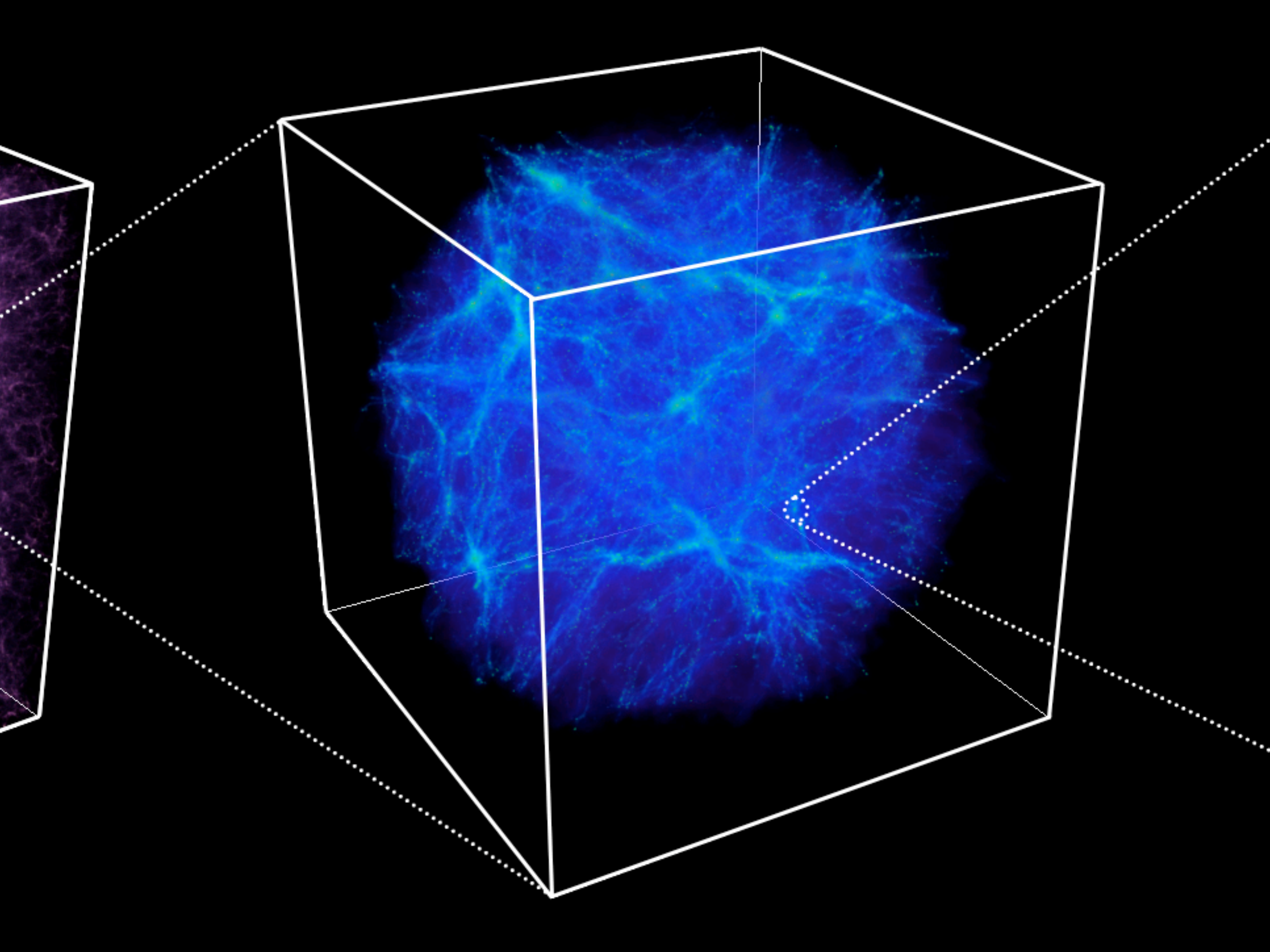


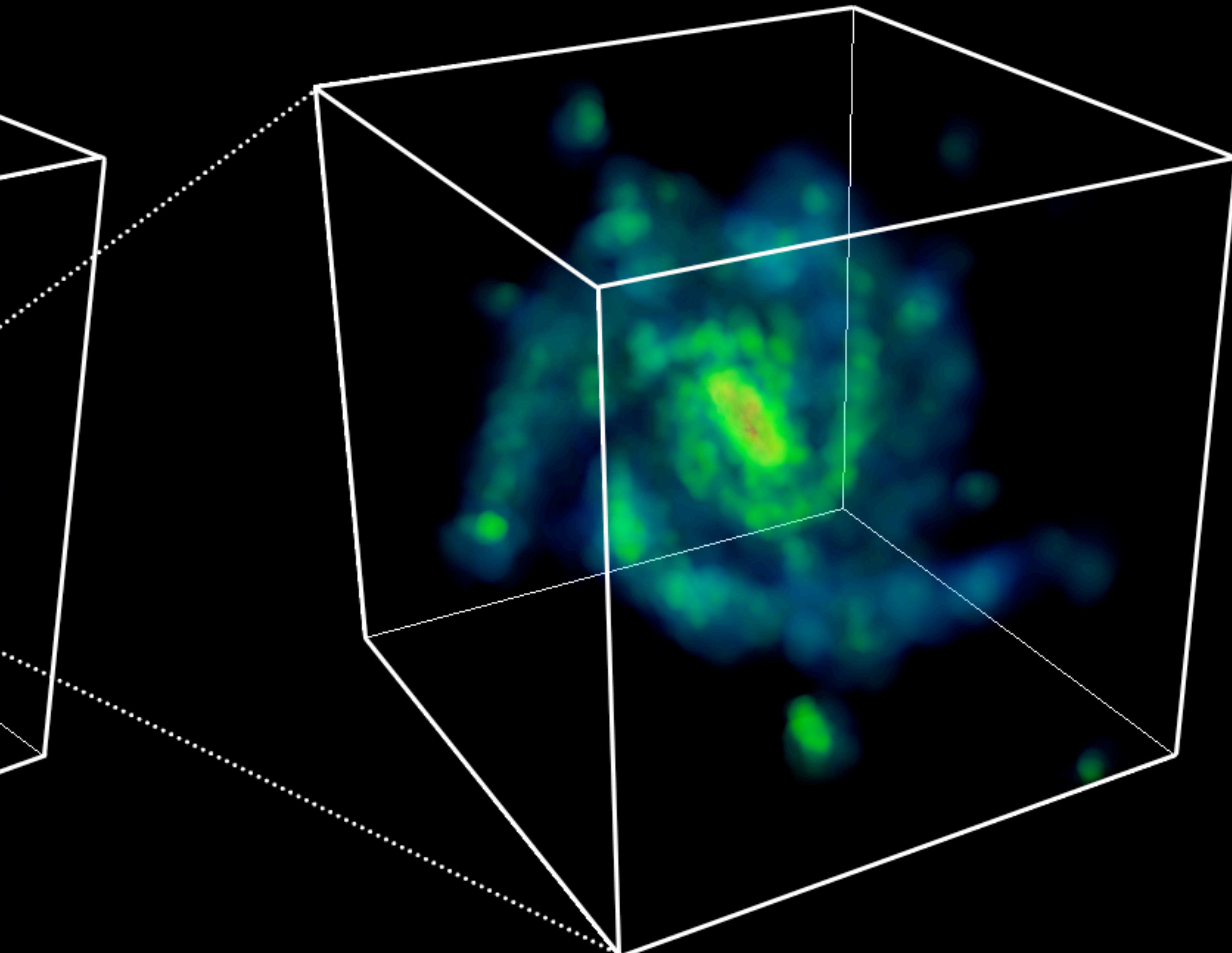
**The absence/faintness of X-ray detections of hot coronal gas associated with nearby spirals potentially signals a fundamental flaw in galaxy formation theory.**

I hope to convince you that with better modelling and some simple calculations:

**i) this perceived conflict is soluble**
**ii) the interpretation of X-ray observations of *L** spirals and ellipticals can be unified.**







X-ray coronae in simulations of disc galaxy formation

Robert A. Crain, Ian G. McCarthy, Carlos S. Frenk, Tom Theuns & Joop Schaye

# Please see the movie at the URL:

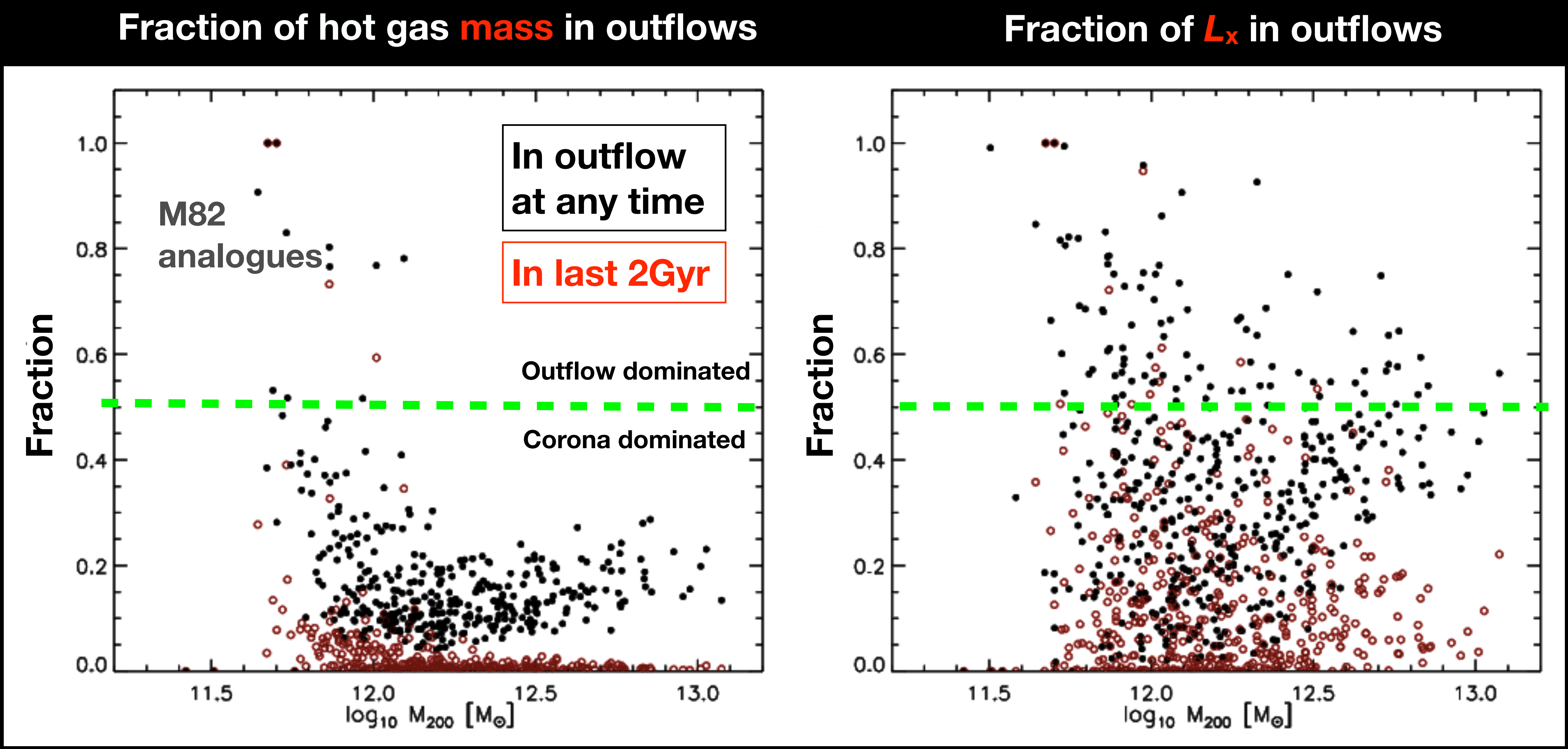
http://pulsar.swin.edu.au/~rcrain/GIMIC_XRAY/Movies/Density_and_APEC_h264.mov

**GIMIC traces ~500 galaxies like this at once.**

**Each galaxy is resolved with 100,000 particles.**

...see Crain et al. (2009, 2010)

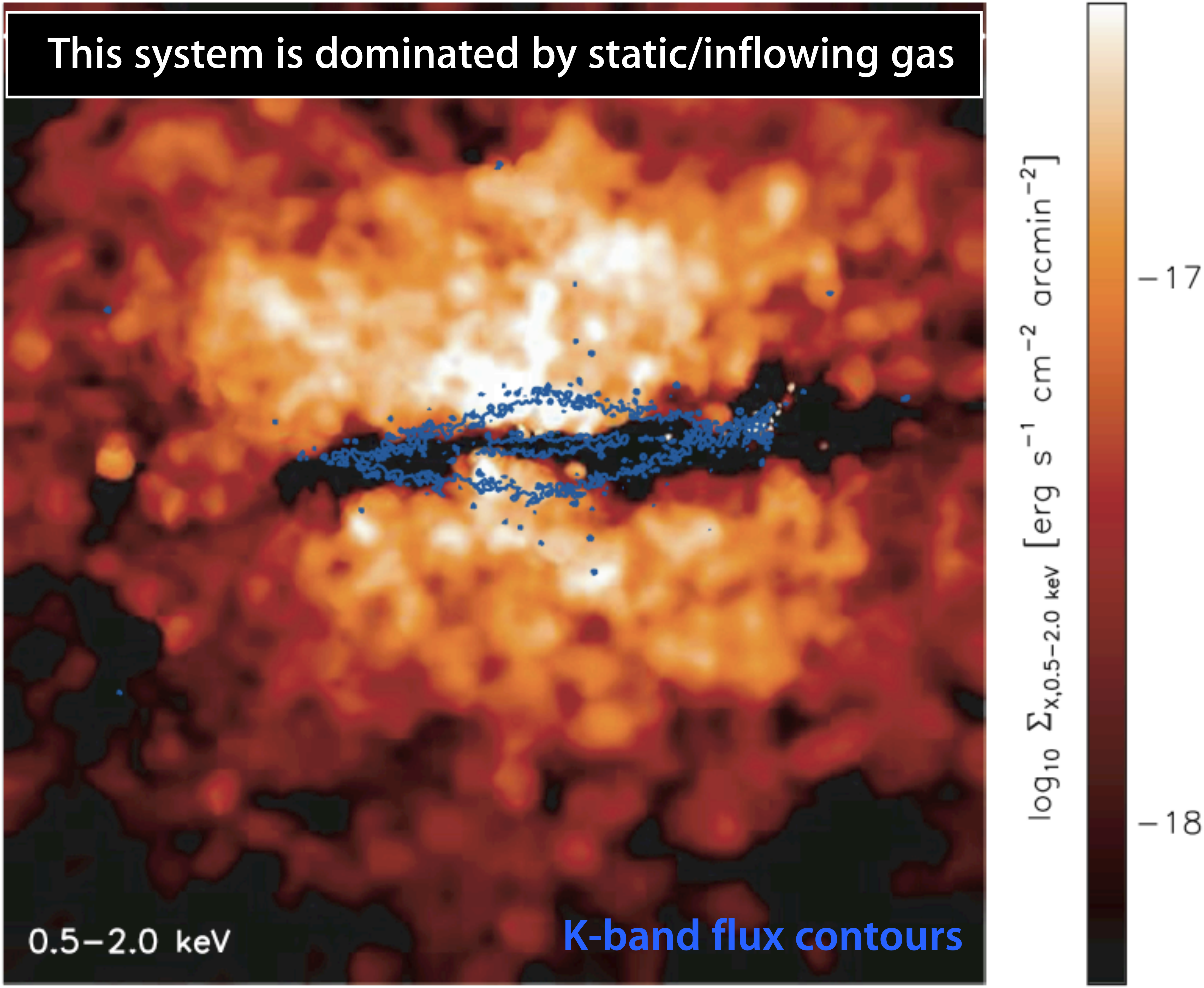
# X-ray emission from spirals: is it just outflows?




Little X-ray gas (by mass) is in outflows. Mass dominated by hydrostatic corona.

Outflows contribute disproportionately to $L_X$, but generally sub-dominant.

→ Outflows are disproportionately luminous, but the corona dominates

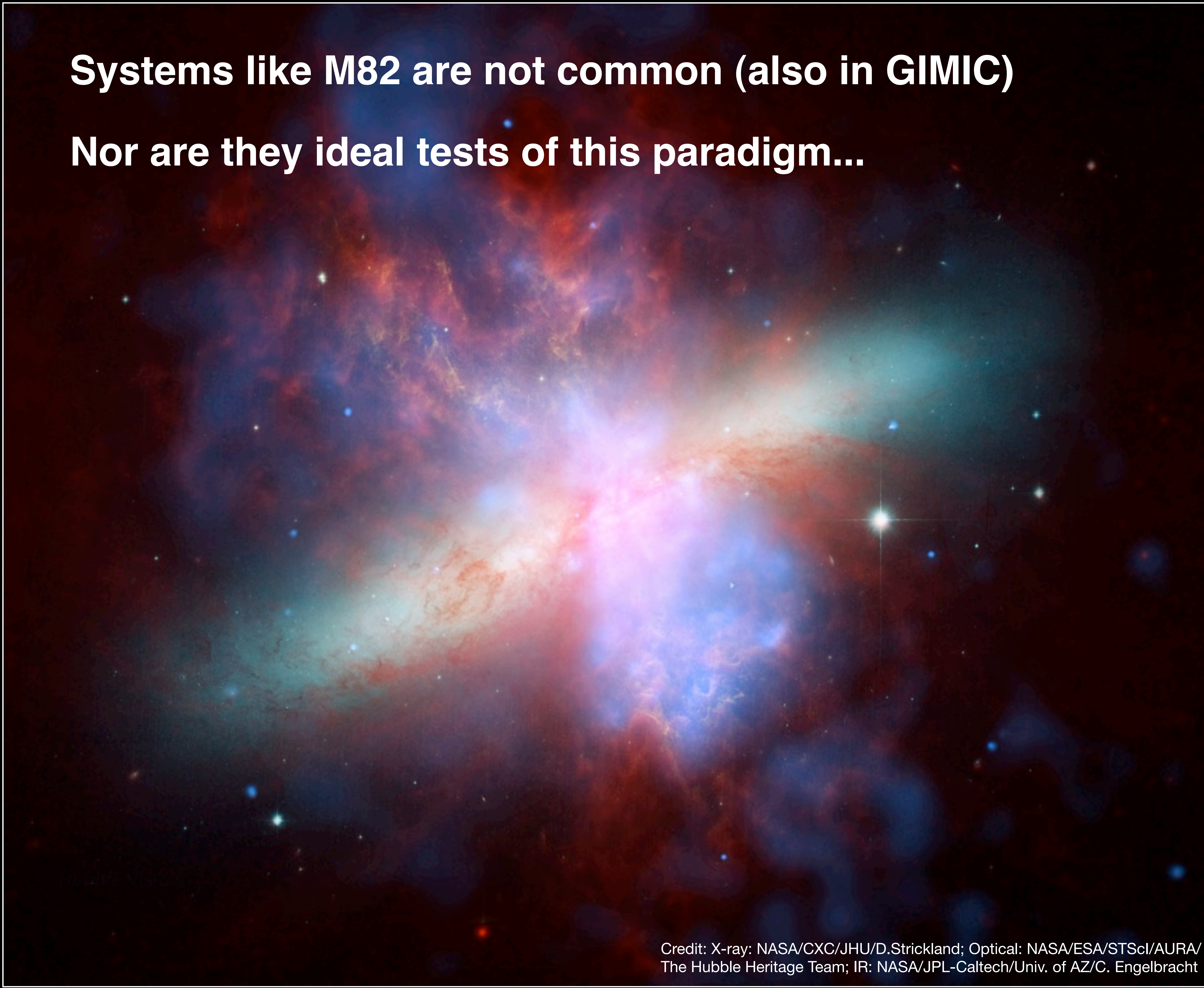

This system is dominated by static/inflowing gas
0.5−2.0 keV
K-band flux contours
log10 Σx,0.5−2.0 keV [erg s−1 cm−2 arcmin−2]
−17
−18

X-ray emission from spirals: is it just outflows?

NO!

## Systems like M82 are not common (also in GIMIC)

## Nor are they ideal tests of this paradigm...



Credit: X-ray: NASA/CXC/JHU/D.Strickland; Optical: NASA/ESA/STScI/AURA/
The Hubble Heritage Team; IR: NASA/JPL-Caltech/Univ. of AZ/C. Engelbracht

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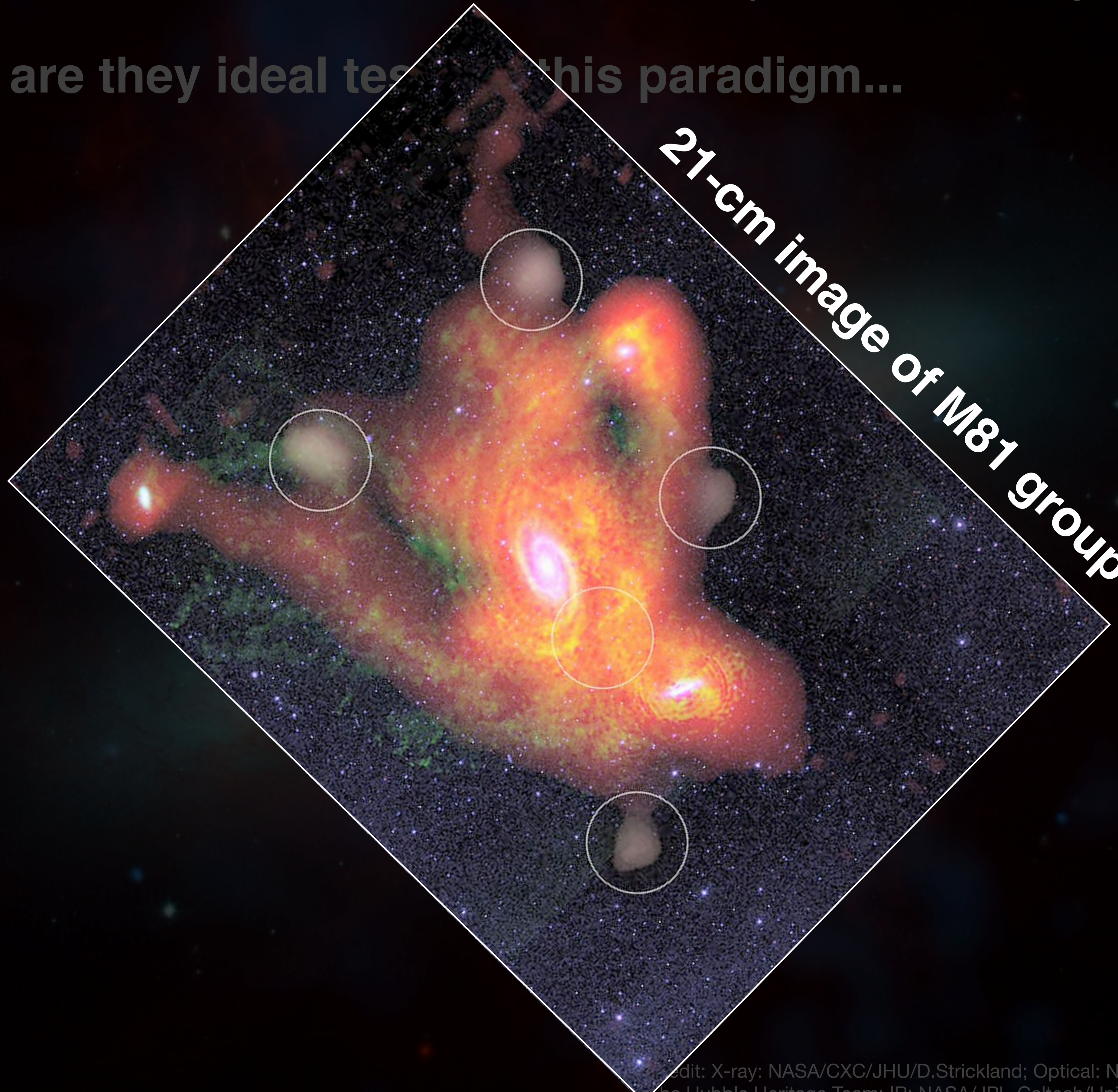
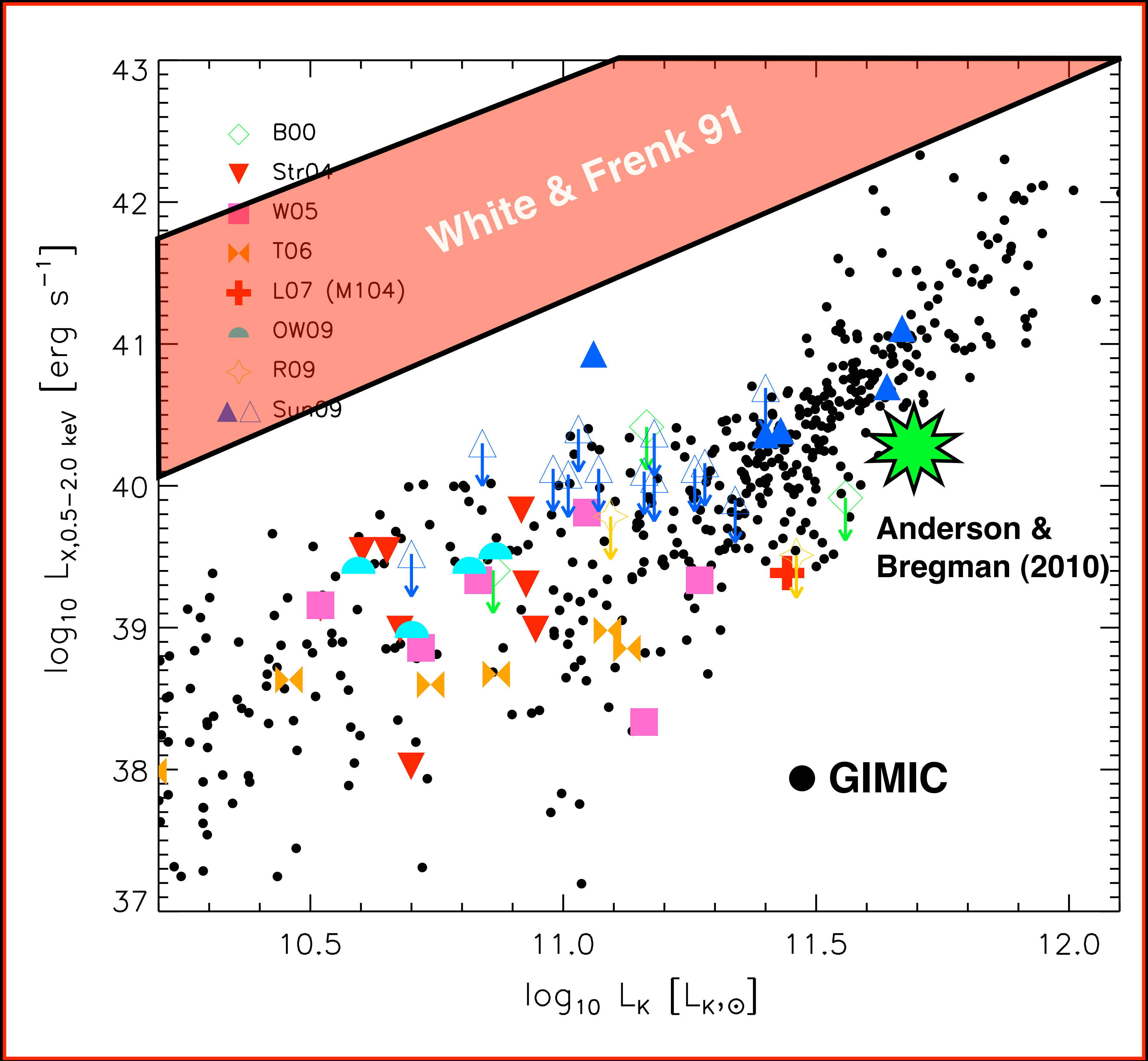



edit: X-ray: NASA/CXC/JHU/D.Strickland; Optical: NASA/ESA/STScI/AURA/
he Hubble Heritage Team; IR: NASA/JPL-Caltech/Univ. of AZ/C. Engelbracht

# X-ray luminosity vs. *K*-band luminosity



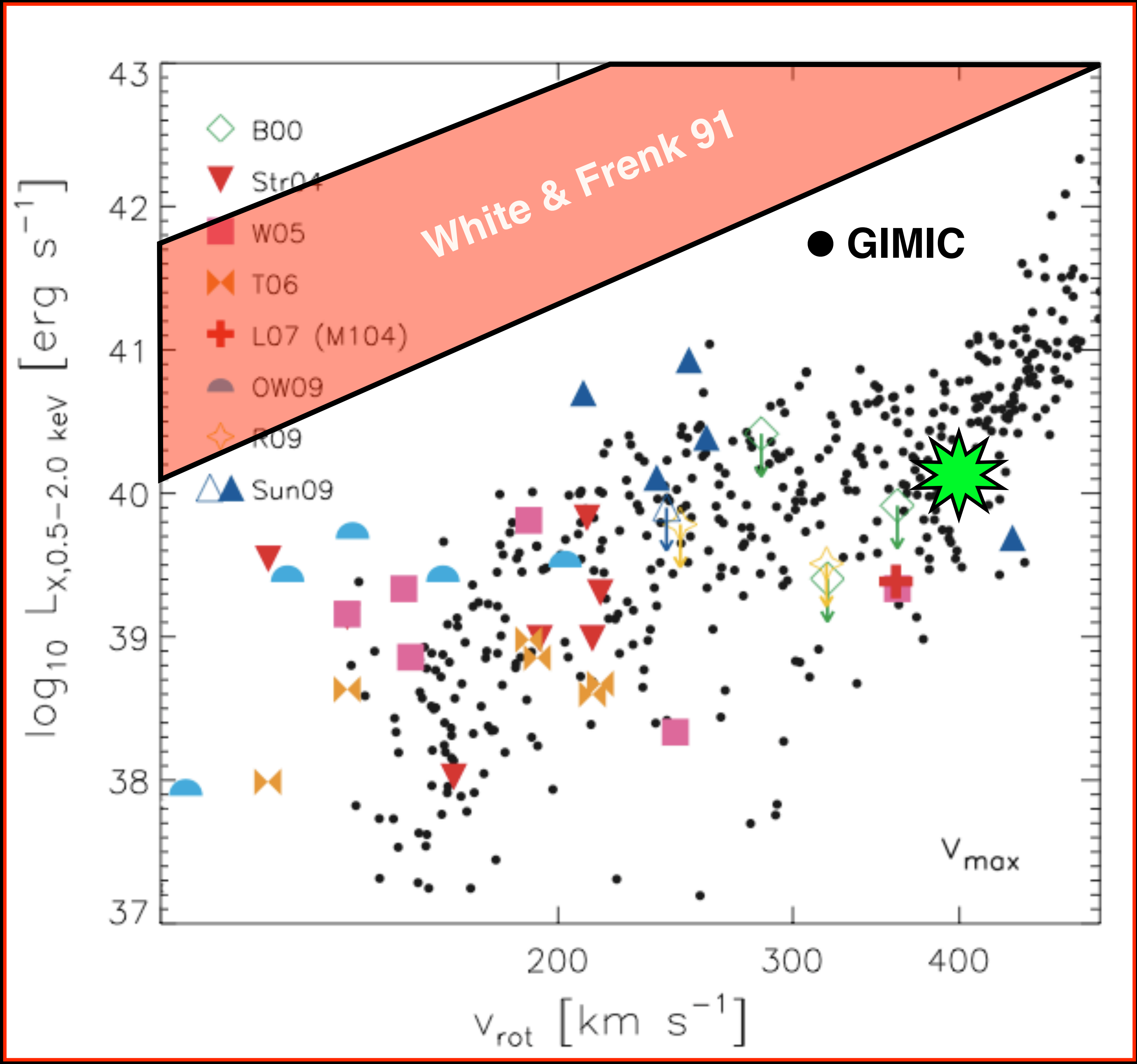

**Data and simulation are in remarkable agreement.**

**This is an ab initio gasdynamical simulation with no ad-hoc tuning!**

Quoted $L_X$ is from **diffuse gas** only: point sources removed by spatial excision and spectral subtraction

**Crain et al. (2010)**

# X-ray luminosity vs. disc rotation velocity

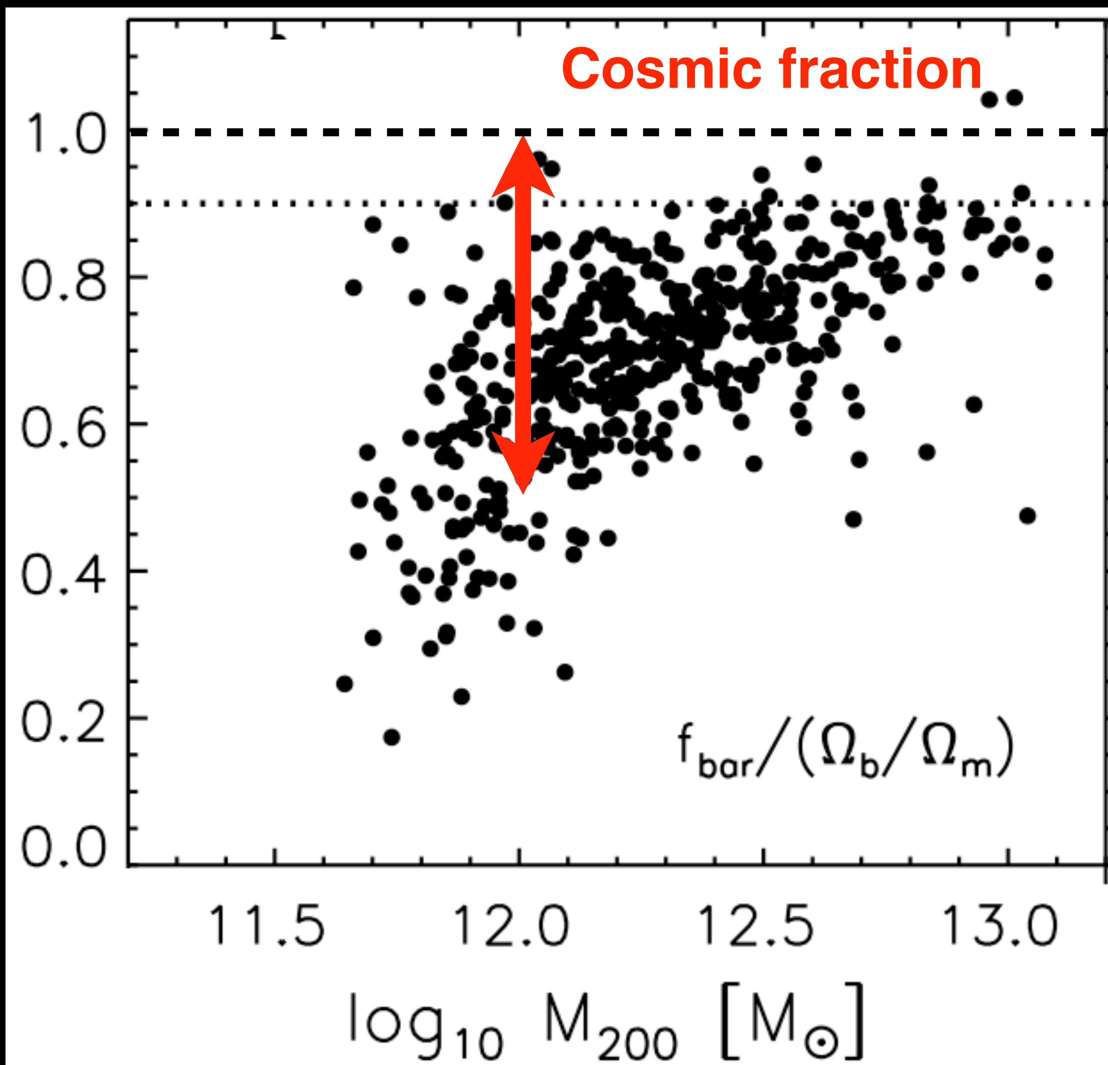


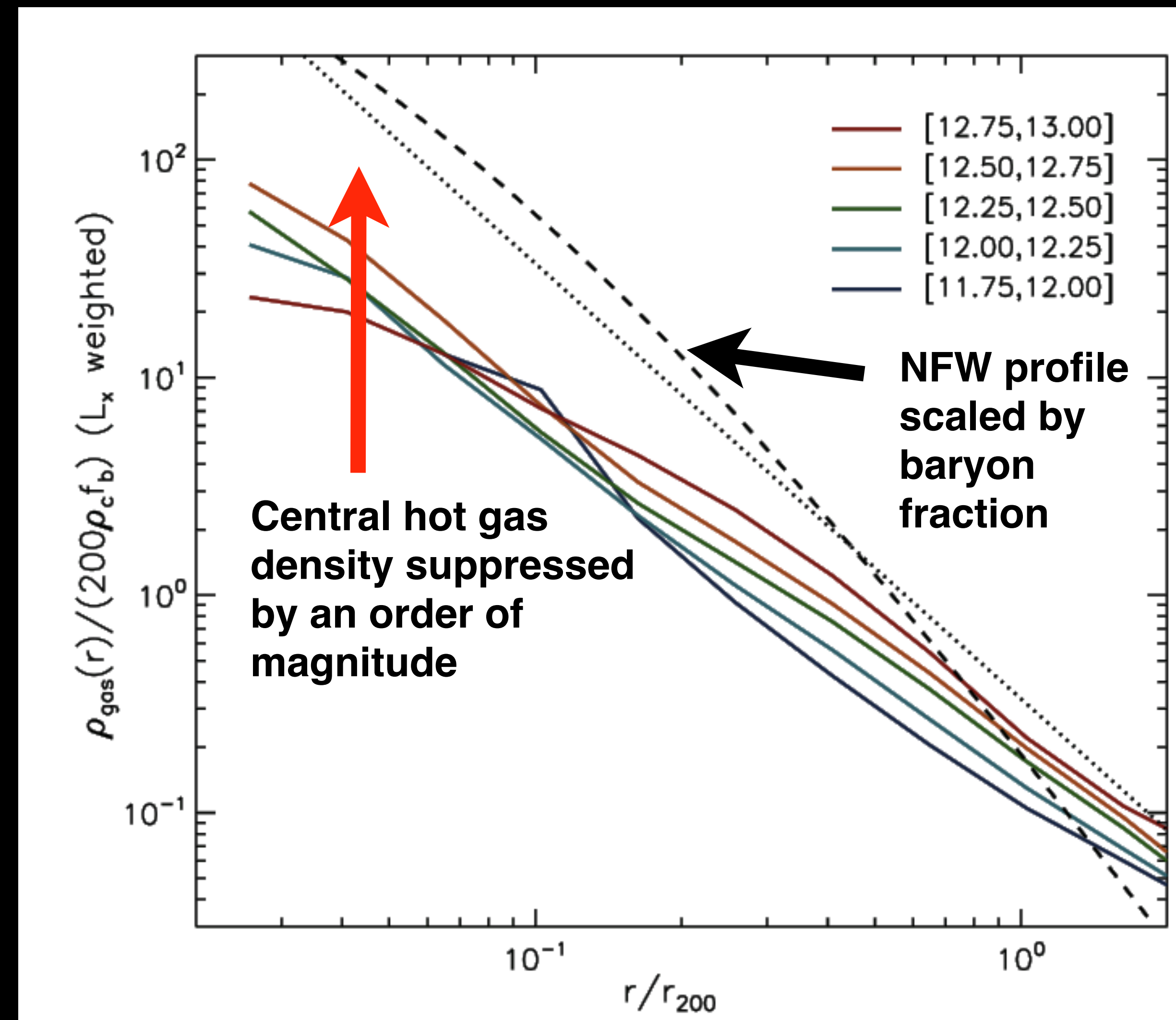

**Data and simulation similarly agree.**

**More *fundamental* test: $v_{rot}$ is a better proxy for halo mass.**

**Crain et al. (2010)**

# Why is GIMIC so different to WF91?




**50% of baryons are ejected from Milky Way mass haloes in GIMIC.**

***f*star broadly consistent with Guo-White test (c.f. Lucio Mayer's talk yesterday)**

**Ejection is preferentially central, because feedback impacts on low entropy gas.**

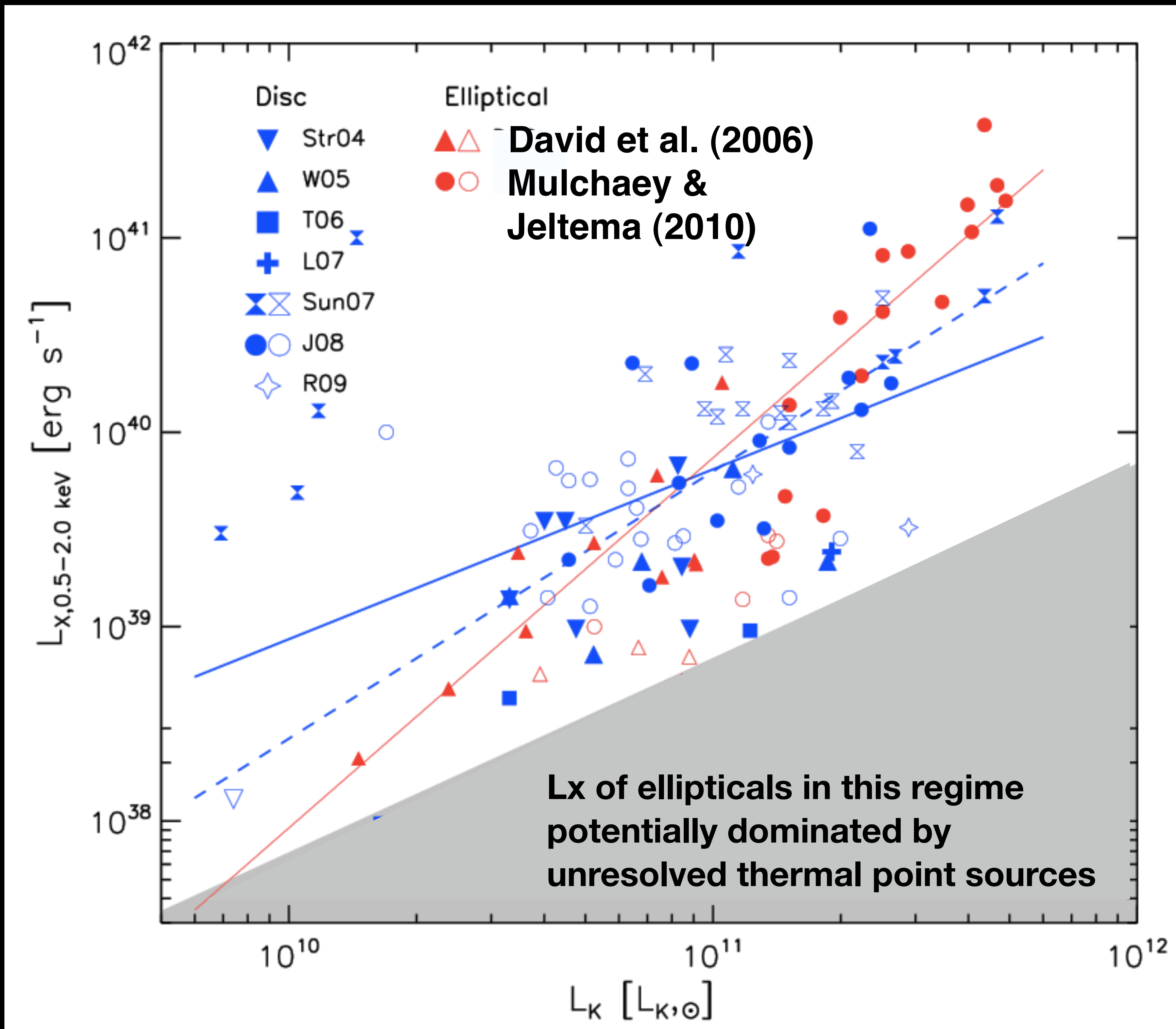
**Emission varies as $n^2$, so x10 in density is x100 in X-ray luminosity.**

I hope to convince you that with better modelling and some simple calculations:

**i) this perceived conflict is soluble**

**ii) the interpretation of X-ray observations of *L** spirals and ellipticals can be unified.**

# $L_X$ - $L_K$ data for spirals and ellipticals



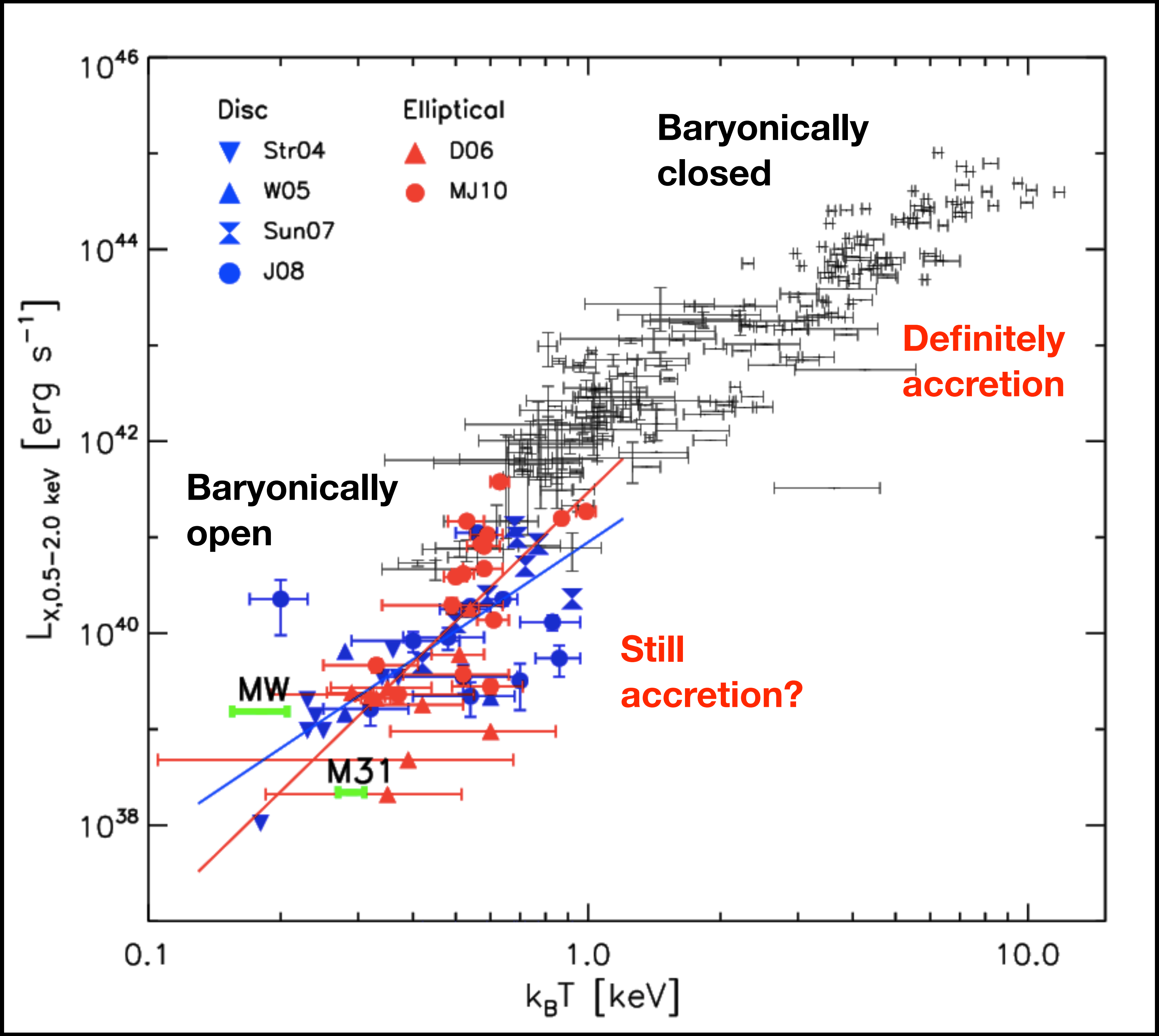

Relationships have **statistically similar normalisation** (slopes differ marginally).

This is **at odds** with the notion of an internal origin for the X-ray luminous gas e.g. SNe-II in spirals, SNe-Ia/AGB in ellipticals: energetics are **incompatible**.

We can make a more fundamental check, where S/N allows...

Crain et al. arXiv:1011.1906

# $L_X$ - $T_X$ data for spirals and ellipticals




Group/cluster data from Helsdon & Ponman 00; Mulchaey+ 03, Horner 01.

$T_X$ probes potential in same place we probe $L_X$.

These normalisations are also **remarkably similar**.

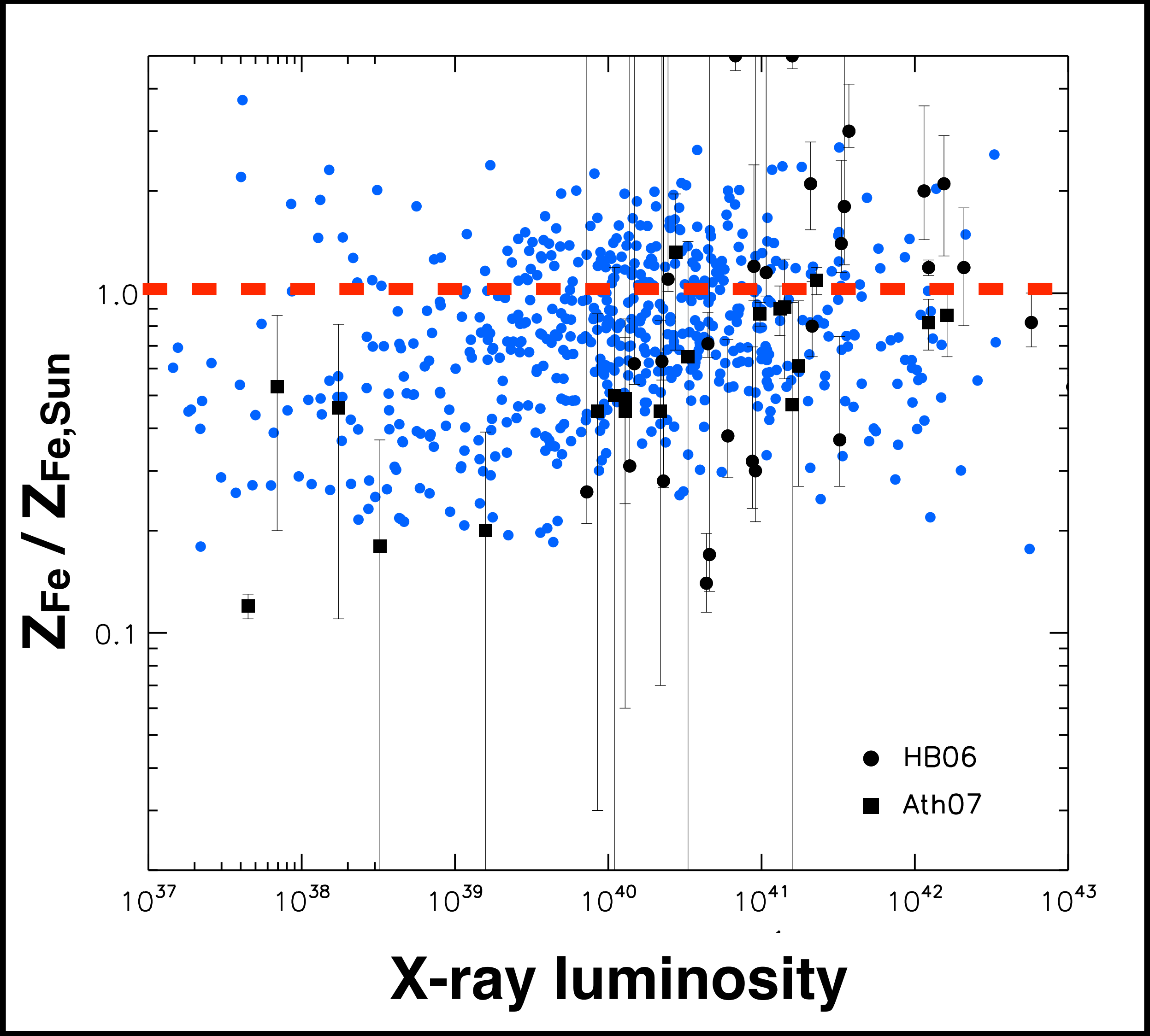
Continuous ***$L_x$-$T_x$*** relation over **7 dex** in ***$L_x$***!

Break at 1keV (c.f Dave et al 2002; Dai et al 2010) indicative of **transition** from baryonically open to baryonically closed haloes.

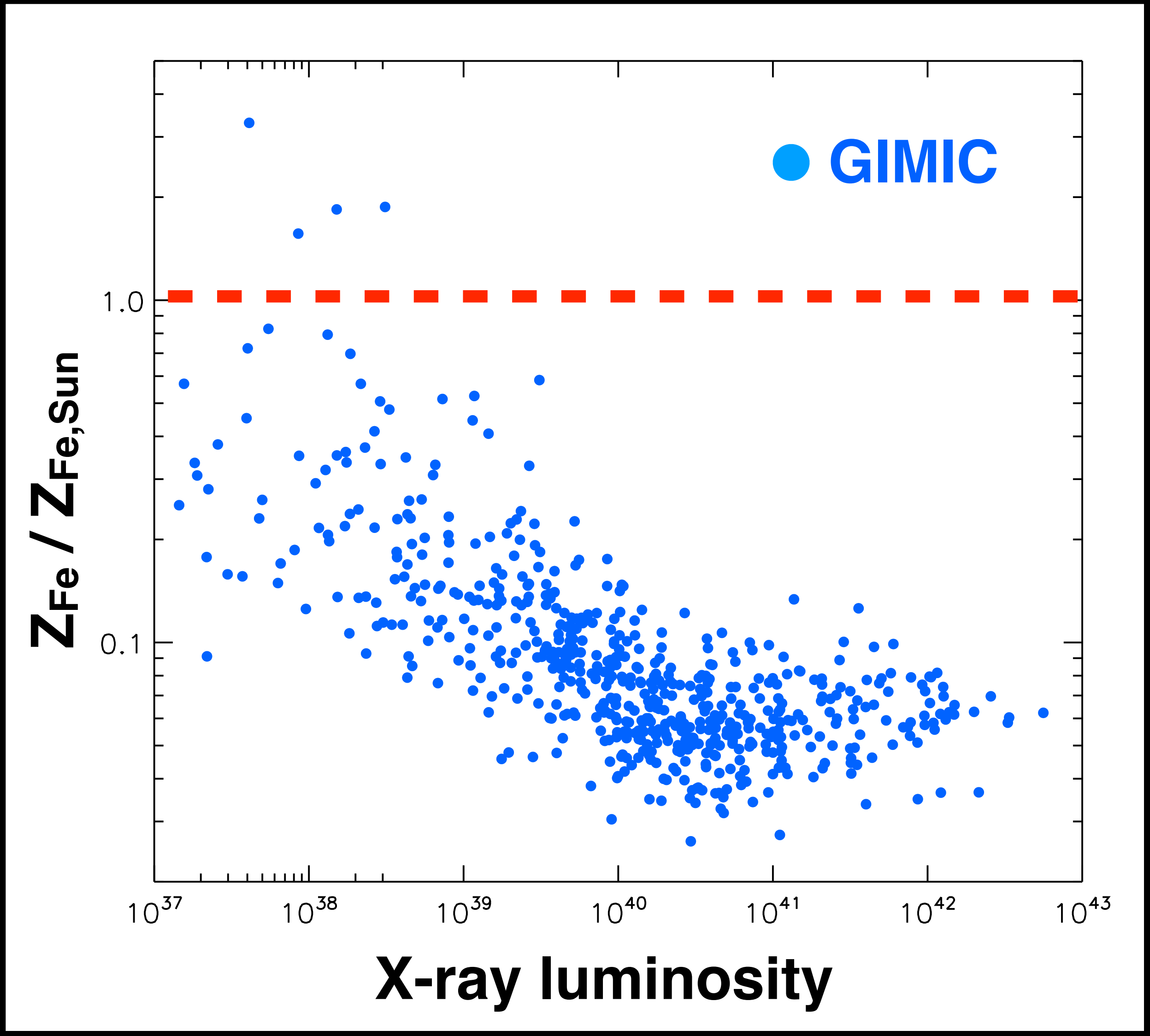
Infer a common origin of hot gas in discs and ellipticals: **accretion** during galaxy assembly.

# The accretion picture is consistent with $Z_X$

**X-ray luminosity weighted**




**Mass weighted**




The luminosity-weighting of X-ray measurements **biases** the perceived metallicity of coronal gas.

Systems that appear to have solar metallicity are typically < 0.1 solar. Entirely **compatible** with accretion.

**RAC in prep**

# Summary

## Hot galactic coronae are a key prediction of galaxy formation theory

Gasdynamical simulations now **reproduce** the (limited) X-ray samples

(Semi-)analytic models overpredict X-ray luminosities by 1-2dex:

- gas fraction of haloes suppressed by entropy injection at z~1-3
- gas is less concentrated than dark matter

## X-ray emission typically dominated by a quasi-static corona

Simulations produce M82 analogues, but they are **rare**

Outflowing gas is **disproportionally** X-ray luminous

## Hot haloes of *L** discs and ellipticals follow same scalings

New observational result that is **incompatible** with standard interpretation

Indicates common origin: most plausibly **accretion** from the IGM.