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 \( t_{\text{cool}} < t_{\text{dyn}} \)
infalls directly (rapid regime/cold flow)

If \( t_{\text{cool}} > t_{\text{dyn}} \)
hot hydrostatic corona

For \( L^* \) galaxies WF91 predicts:

\[ kT \approx 0.1 \text{ keV (soft X-ray)} \]

\[ L_x = 10^{41}-10^{43} \text{ erg/s} \]

**ROSAT** failed to detect any hot reservoirs. The few tens of X-ray detections from **Chandra/XMM** have mixed interpretations.
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.
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.
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...
Systems like M82 are not common (also in GIMIC)

Nor are they ideal tests of this paradigm...
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: $v_{\text{rot}}$ 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.

\[ f_{\text{star}} \text{ broadly consistent with Guo-White test (c.f. Lucio Mayer's talk yesterday)} \]

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

\[ Emission \text{ varies as } n^2, \text{ so x10 in density is x100 in X-ray luminosity.} \]
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.
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...
$L_X - T_X$ data for spirals and ellipticals

These normalisations are also remarkably similar.

Continuous $L_X - T_X$ relation over 7 dex in $L_X$!

Break at 1 keV (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.

Group/cluster data from Helsdon & Ponman 00; Mulchaey+ 03, Horner 01.
The accretion picture is consistent with $Z_X$

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.
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 disproportionately 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.