Hot coronae around spiral galaxies: Probing the first principles of galaxy formation

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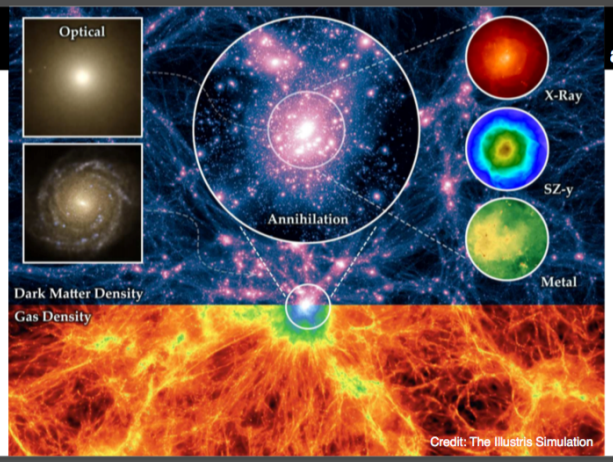
Fundamental questions

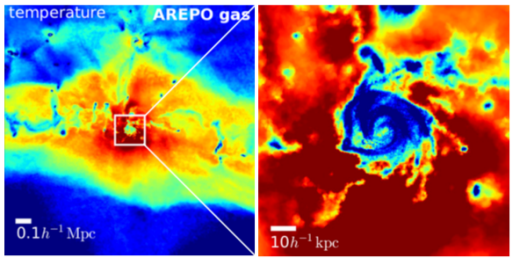
- How do galaxies get their gas and transform into stars?
- How do supermassive black holes alter the evolution of galaxies?
- How are galaxies and their surroundings enriched by metals?



Hot coronae around spiral galaxies

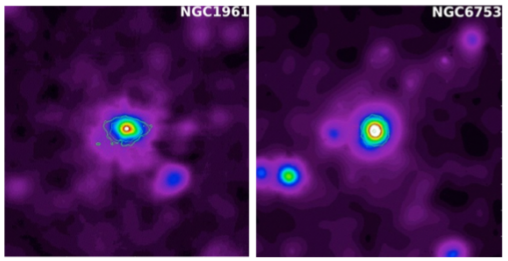
- Fundamental prediction of all galaxy formation models
- In massive galaxies quasi-static X-ray coronae emerge
- Isolated spirals are powerful probes of galaxy formation models

Simulated coronae



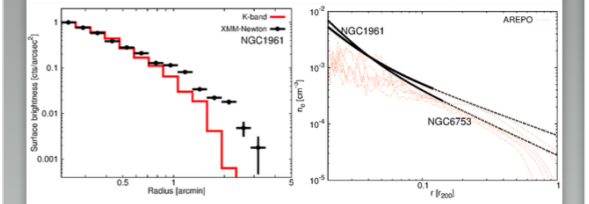
- Simulated gas temperature maps at $z = 2$ (Vogelsberger et al. 2012), showing the rise of hot X-ray coronae with sub-keV temperatures
- Hot-mode accretion dominates from z<2, and 60% of the total gas is in the form of hot coronae between 1<z<2.
- Most stars at z=0 arise from gas accreted in the hot mode

Observed coronae



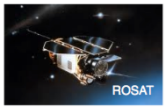
- Extended hot X-ray coronae with $kT \approx 0.6$ keV are detected around two massive spiral galaxies at $D \approx 50$ Mpc ($z \approx 0.012$)
- Hot gas with kT ≈ 0.6 keV is detected out to 60 kpc radii
- Luminosity of the hot gas between 20-60 kpc is 6 x 10^{40} erg/s

Challenges



- With present-day X-ray telescopes, demanding observations are required to detect the most luminous and nearby coronae.
- Complete census of coronae must be obtained in the local Universe
- X-ray coronae must be explored out to z=2, near the peak of cosmic star formation, when the first hot coronae emerged

X-ray Surveyor



- Sub-arcsecond spatial resolution is required to spatially resolve the coronae — 100 kpc at z=2 corresponds to 12"
- In the local Universe short observations (30 ks) will provide precise gas density, temperature, and abundance profiles
- At z=2 a 200 ks observation will collect 500 counts to measure the temperature, density and overall morphology of the hot gas

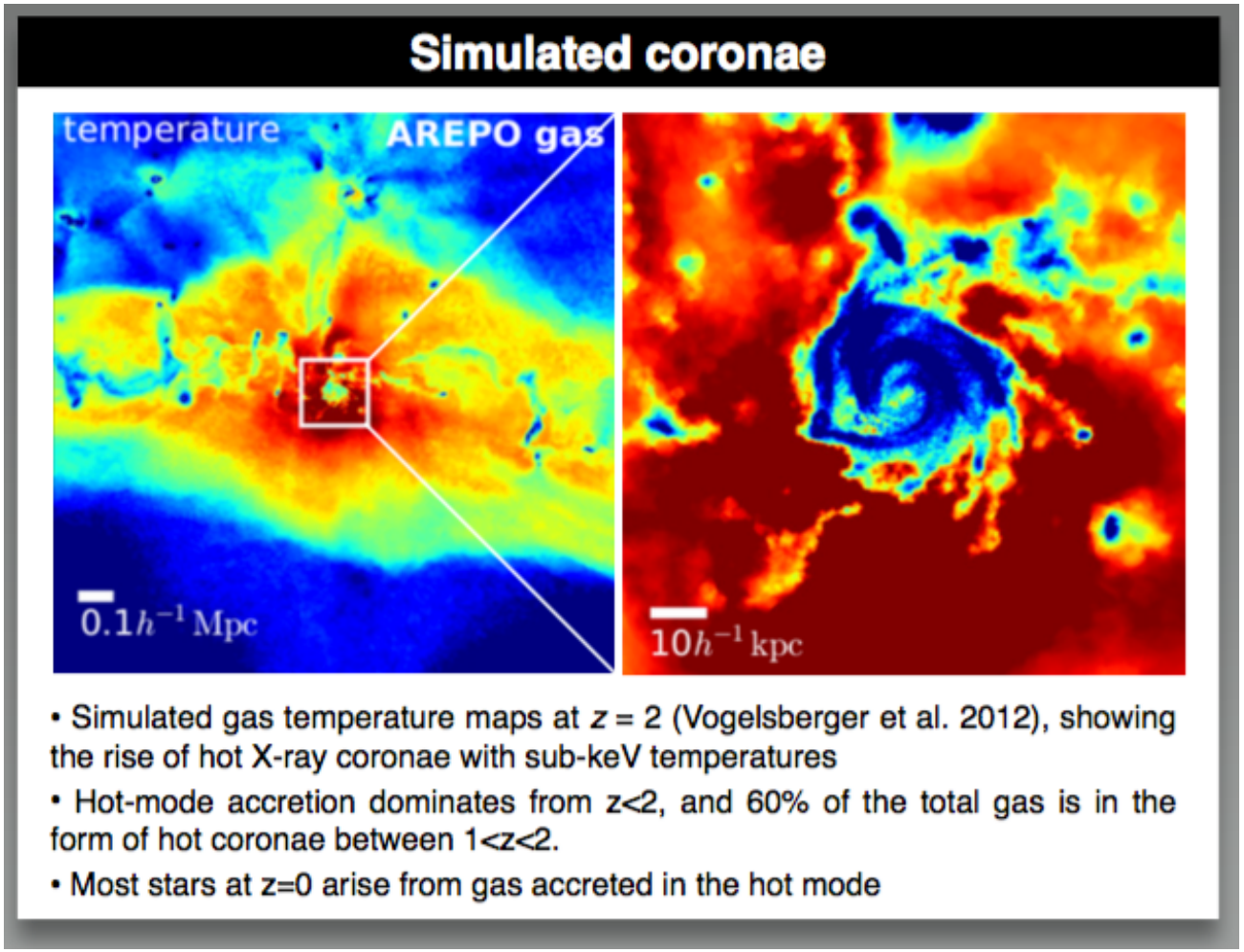
- **To understand galaxy formation in detail, it is essential to observationally probe the hot mode accretion and the evolution of coronae from z=2 to the present Universe**

Bogdan et al., 2013, ApJ, 772, 97
Bogdan et al., 2013, ApJ, 772, 98
Bogdan et al., 2015, ApJ, 804, 72
Toft et al., 2002, MNRAS, 335, 799
Vogelsberger et al., 2012, MNRAS 425, 3024
Vogelsberger et al., 2014, Nature, 509, 177
White & Rees, 1978, MNRAS 183, 341
White & Frenk,1991, MNRAS, 379,52

Hot X-ray coronae around spirals

★ Basic prediction of galaxy formation models (White & Rees,1978)
★ Most luminous in massive galaxies

Luminous X-ray coronae *should be* detected around massive disk galaxies!



Hunt for hot X-ray coronae

★ Unsuccessful hunt for decades
★ All major X-ray telescopes involved

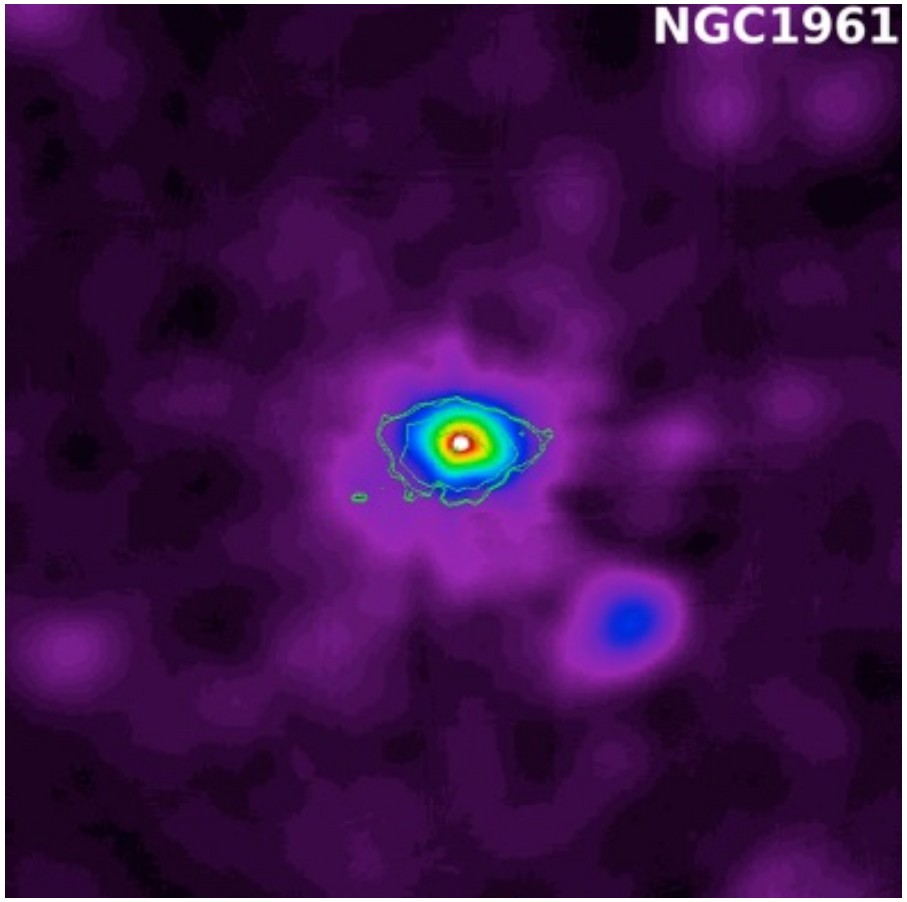
ROSAT

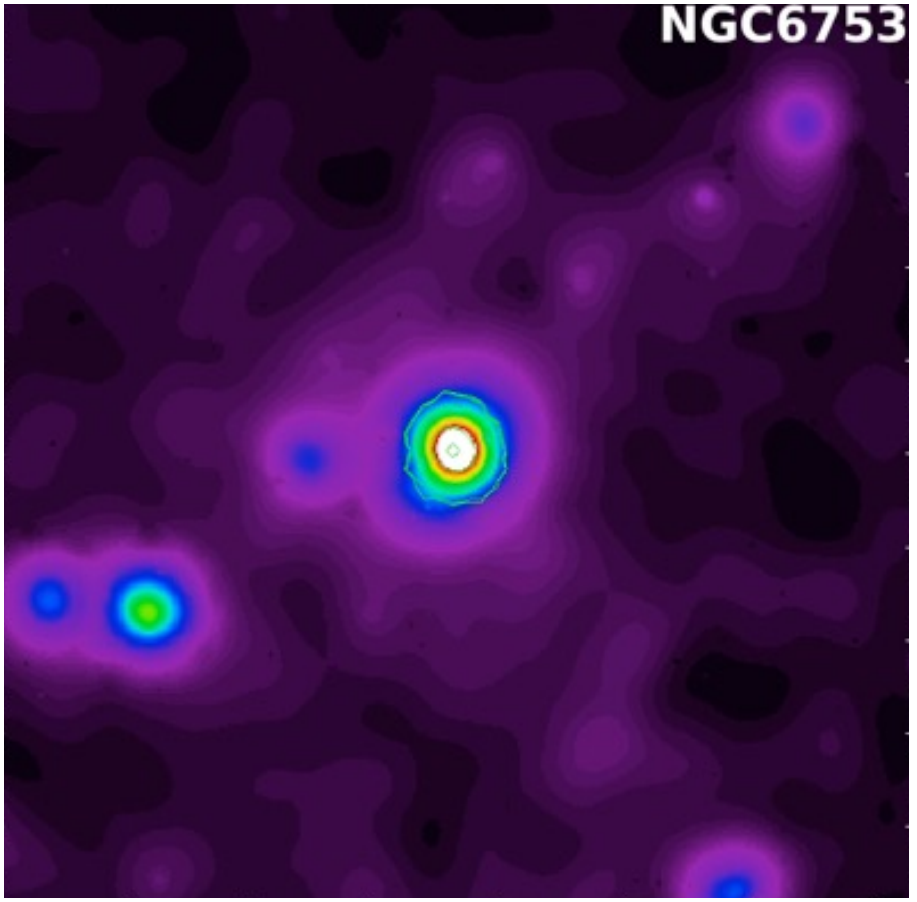
XMM-Newton

Chandra

★ Until very recently only upper limits obtained

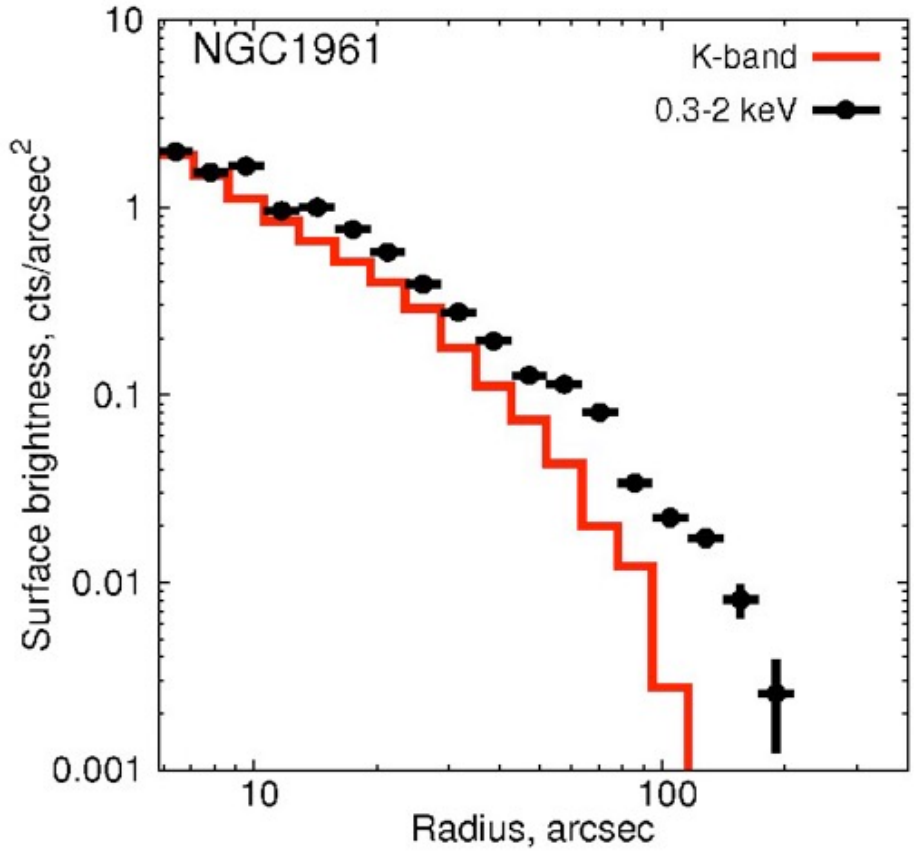
First detections of coronae around spirals

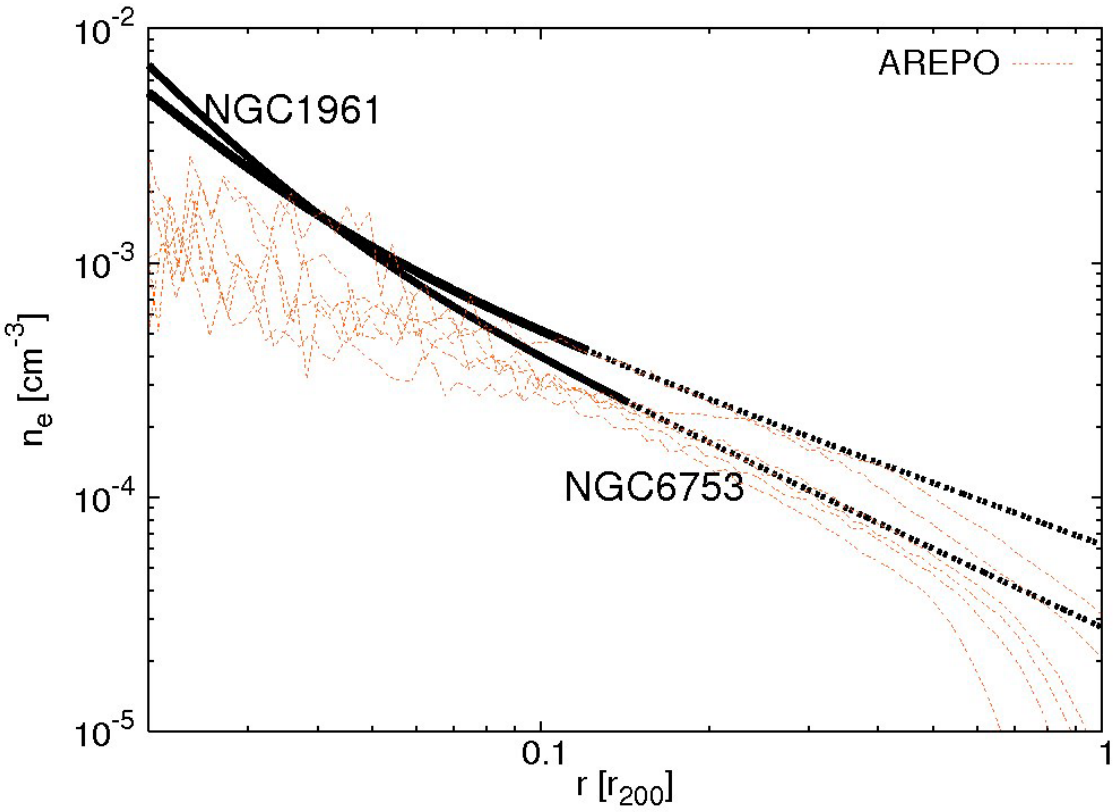




★ Extended hot coronae with kT~0.6 keV temperature
★ Hot gas extends out to 60 kpc radii

Challenges





★ Observations of coronae are extremely demanding
★ Complete census of hot coronae are needed in the local Universe
★ We must explore them up to z~2, when the first coronae emerged

First detections of coronae around spirals

X-ray Surveyor

- Sub-arcsecond spatial resolution is required to spatially resolve the coronae — 100 kpc at z=2 corresponds to 12”
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