X-raying galactic feedback in nearby disk galaxies

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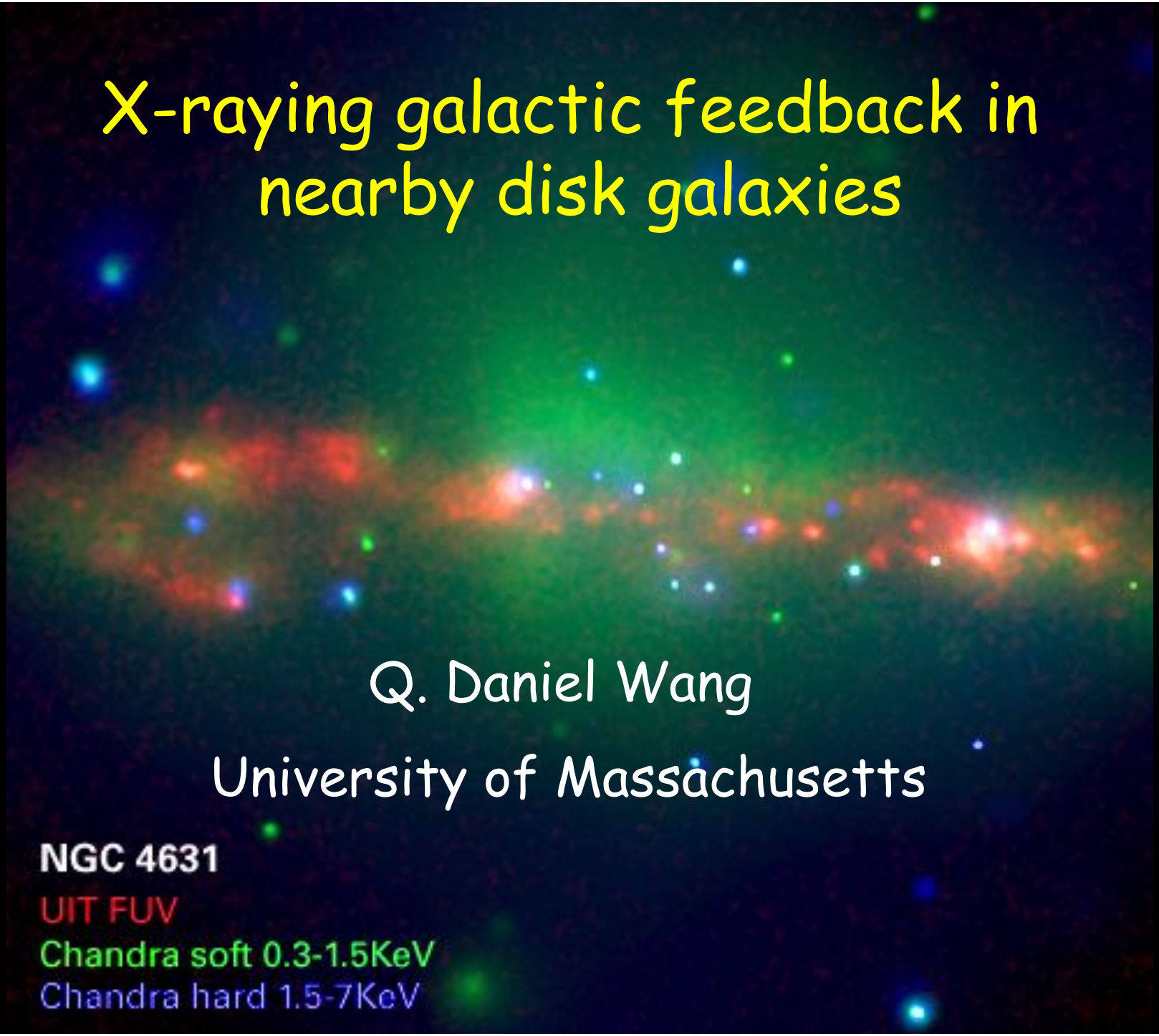
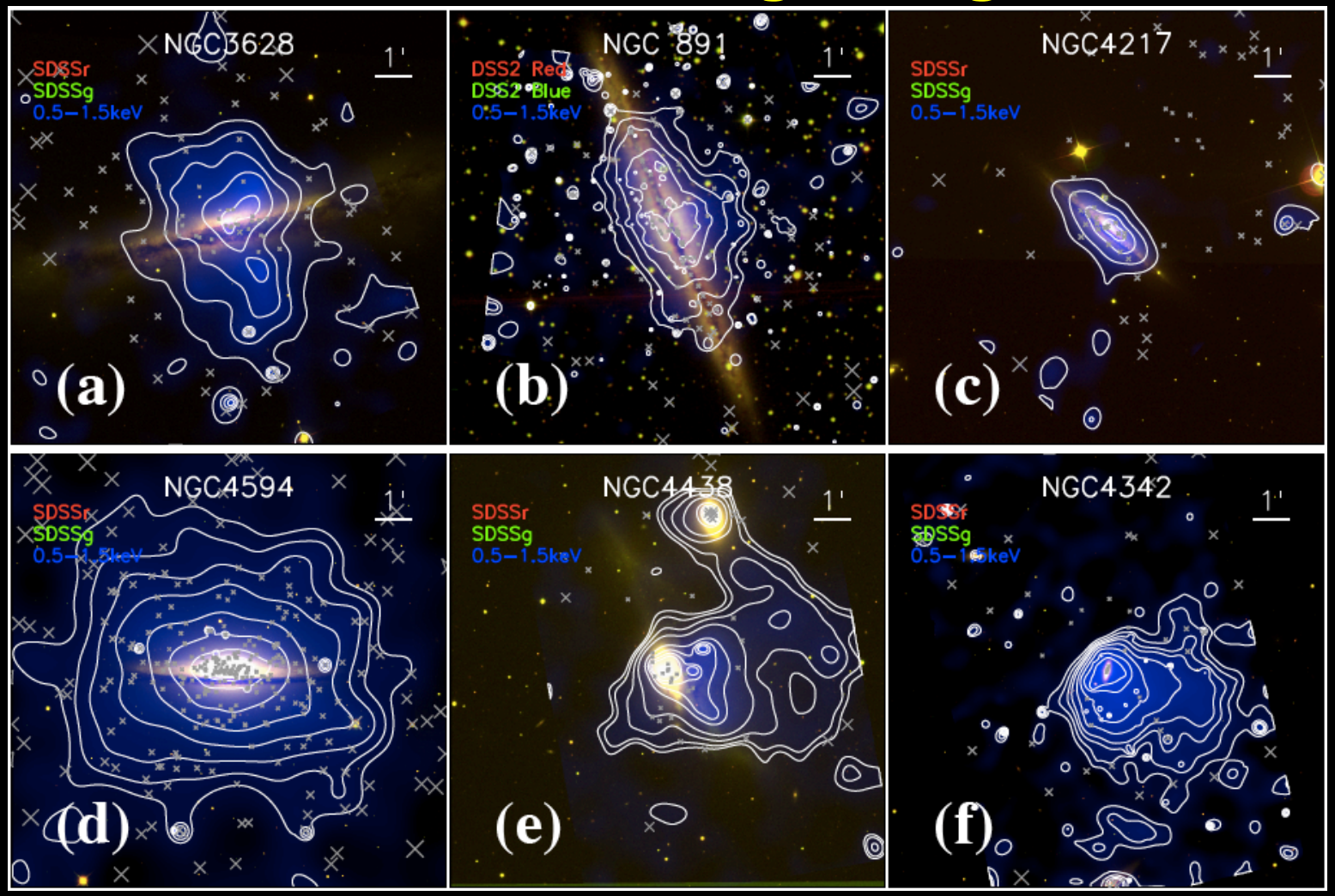
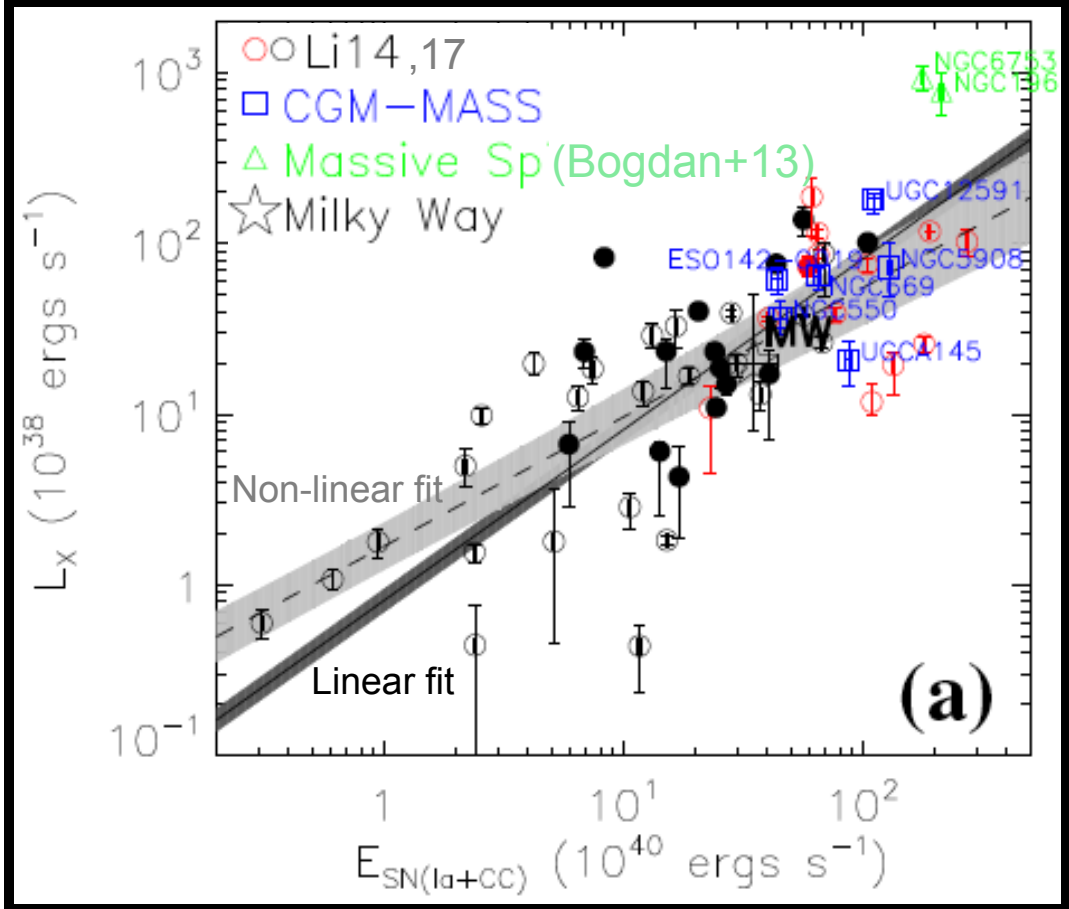


Chandra survey of diffuse X-ray emission from 53 edge-on galaxies



i > 60°, D < 30 Mpc (Li, J.-T. & Wang, Q.D. 2013a)

Lx vs. energy feedback rate



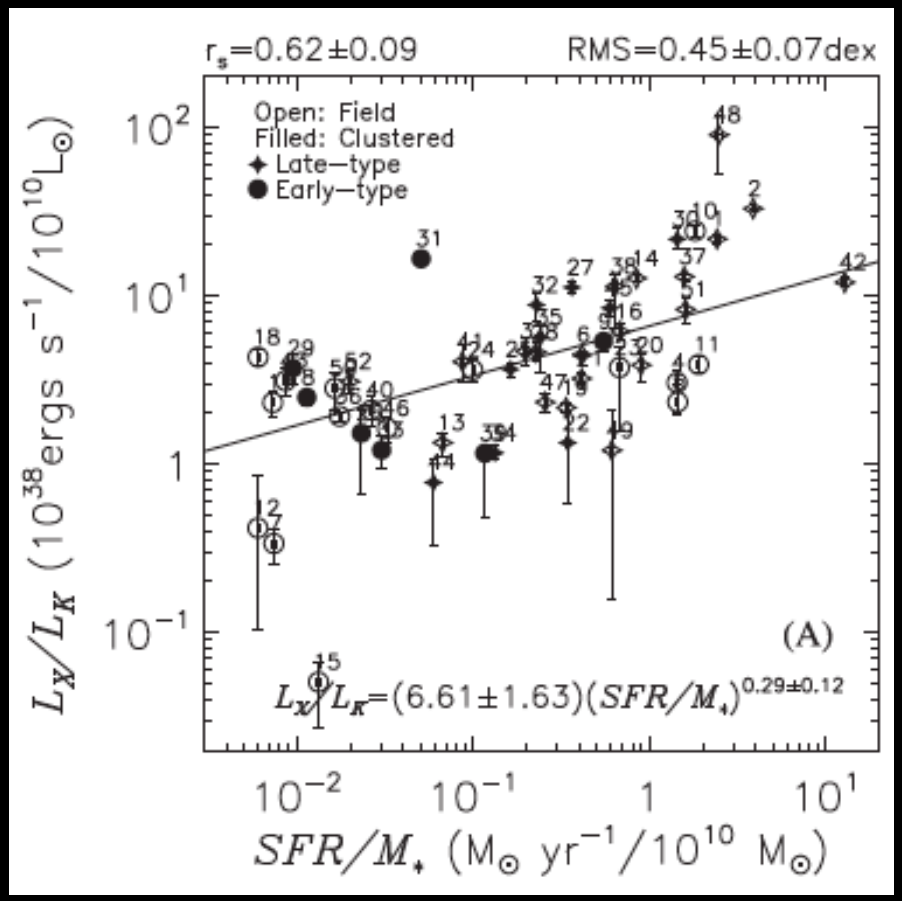
A strong correlation is seen between L_X – E_{SN}, including Type Ia SN mechanical energy input.

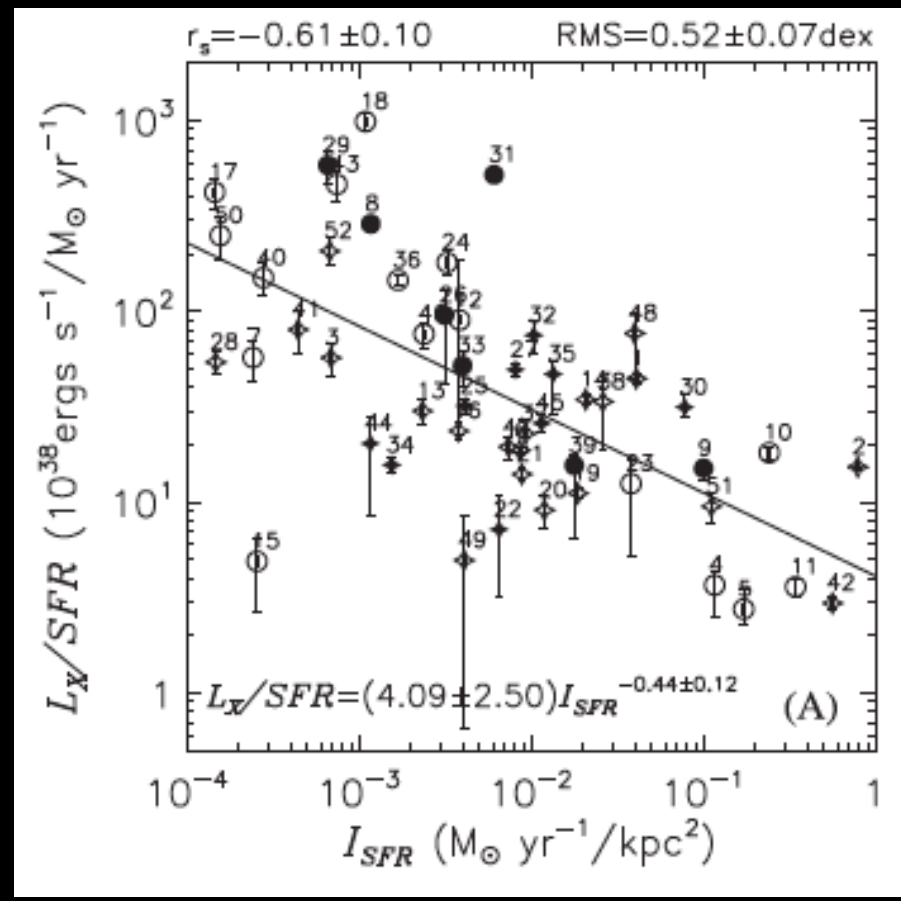
$L_X/\dot{E}_{SN}$ ~ 0.01 and is weakly correlated with the surface mass density of a galaxy disk.

So there is a missing energy problem!

Li, Bregman, QDW+ (2017)

Sub-linear correlation of the specific X-ray luminosity with the specific SFR



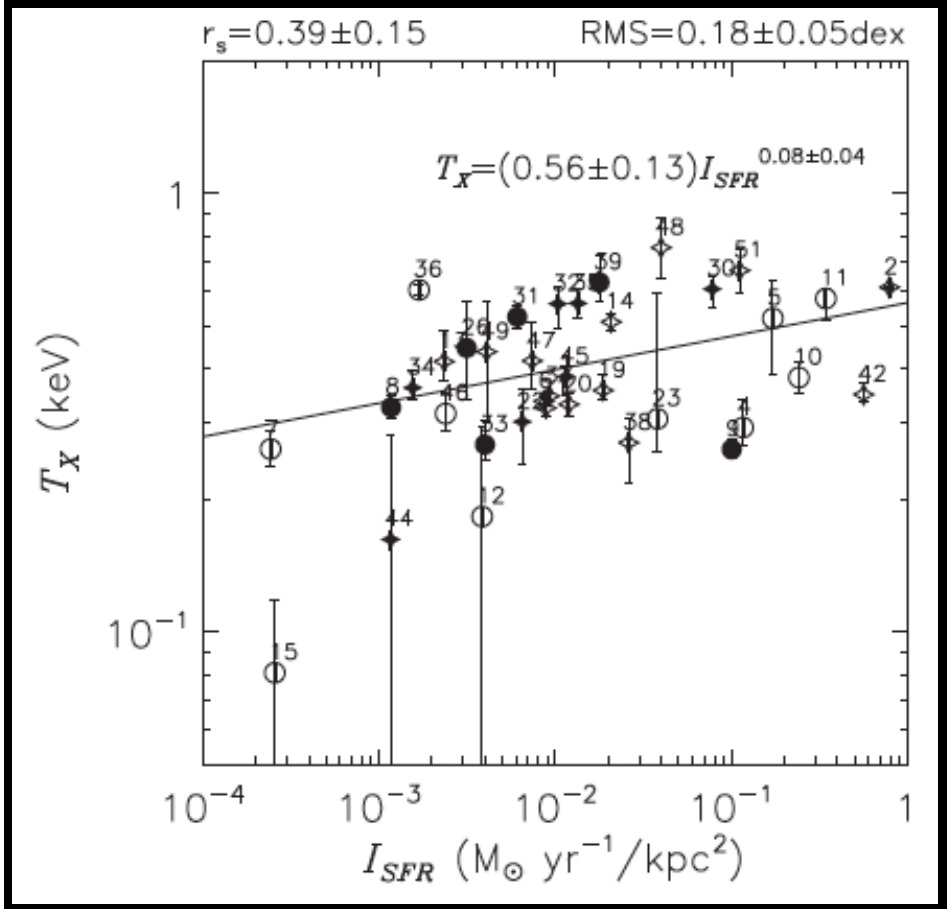


Commonly inferred linear correlation between L_X and SFR is largely due to the correlation of these two parameters with galaxy mass.

X-ray emission (or mass-loading) efficiency of a galactic corona decreases with increasing surface SFR.

Wang+ (16)

Characteristic coronal temperature weakly correlates with specific SFR

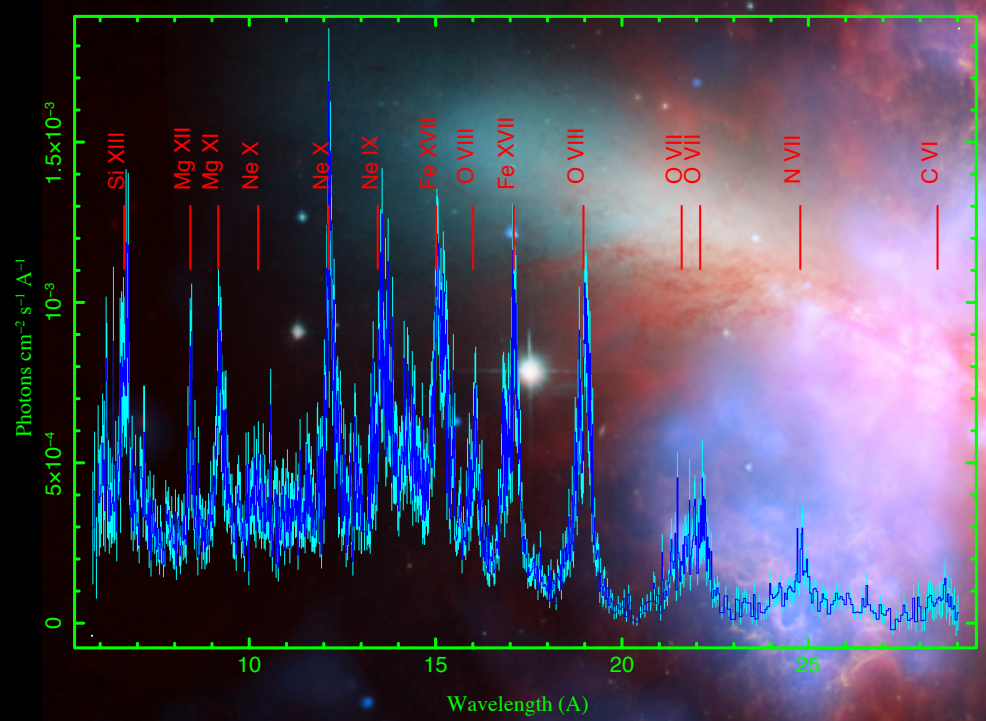


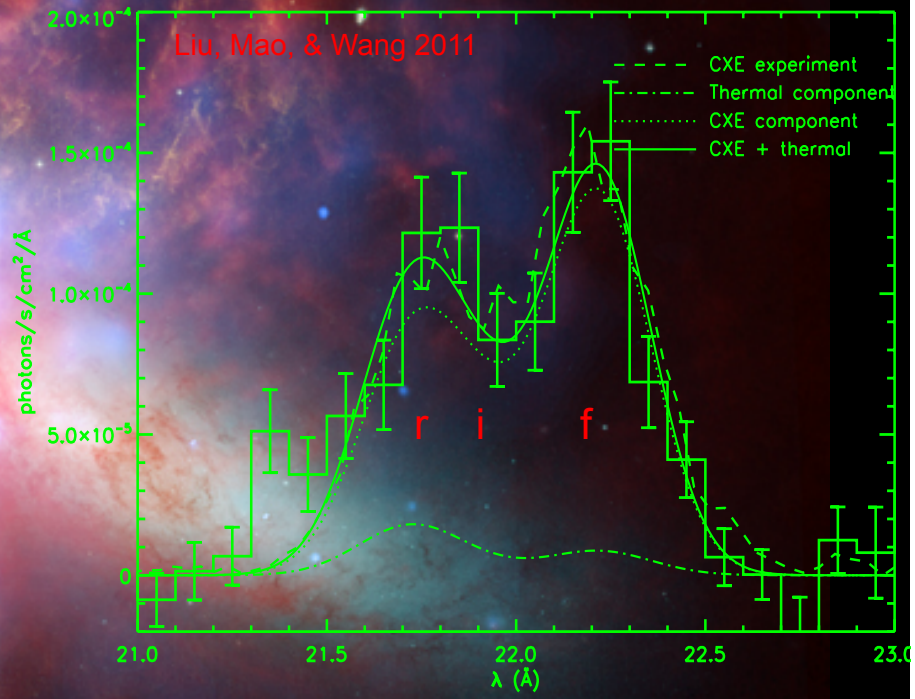
- Temperature estimate is biased by the soft X-ray contribution from a cooler component (e.g. via processes such as charge exchange; e.g. Liu et al. 2011, 2012; Zhang et al. 2014).
- This is consistent with the higher concentration of the X-ray emission toward the disks than what is predicted by simulations (Li et al. 14).

We really need to understand the nature of X-ray emission from galactic coronae!

Nature of the X-ray Emission: Line Spectroscopy

The resonance line is found to be weaker than the "forbidden"+"inter-recommbination" lines, which is not expected for thermal emission.

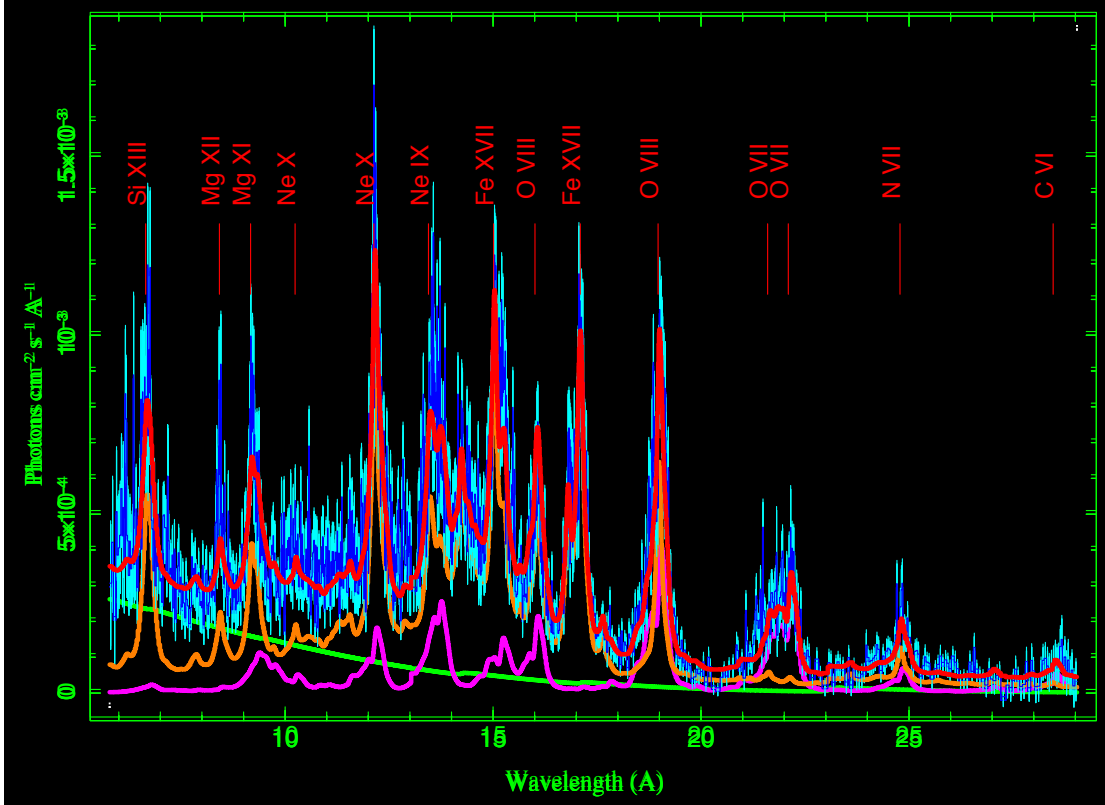




Composite of optical (HST), infrared (Spitzer), and X-ray (Chandra) images

X-ray arises at least partly from the interplay between the hot gas outflow and entrained cool gas clouds, as part of the mass-loading process!

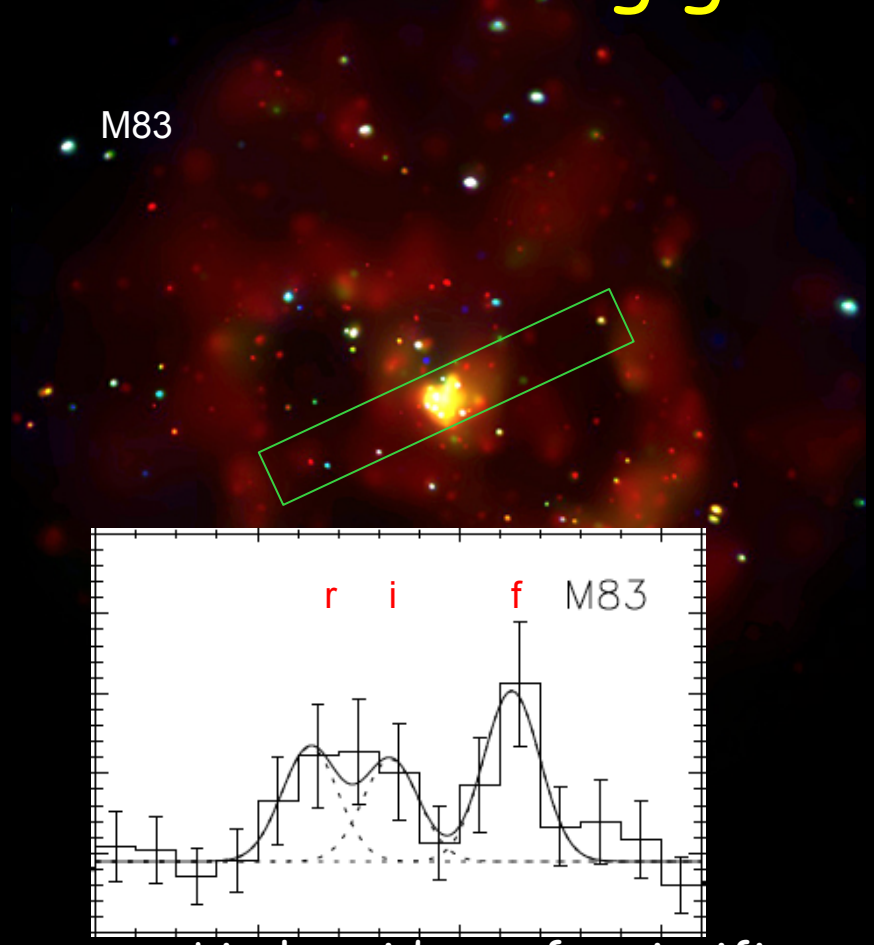
Thermal plasma+charge exchange model fit to the RGS spectrum of M82

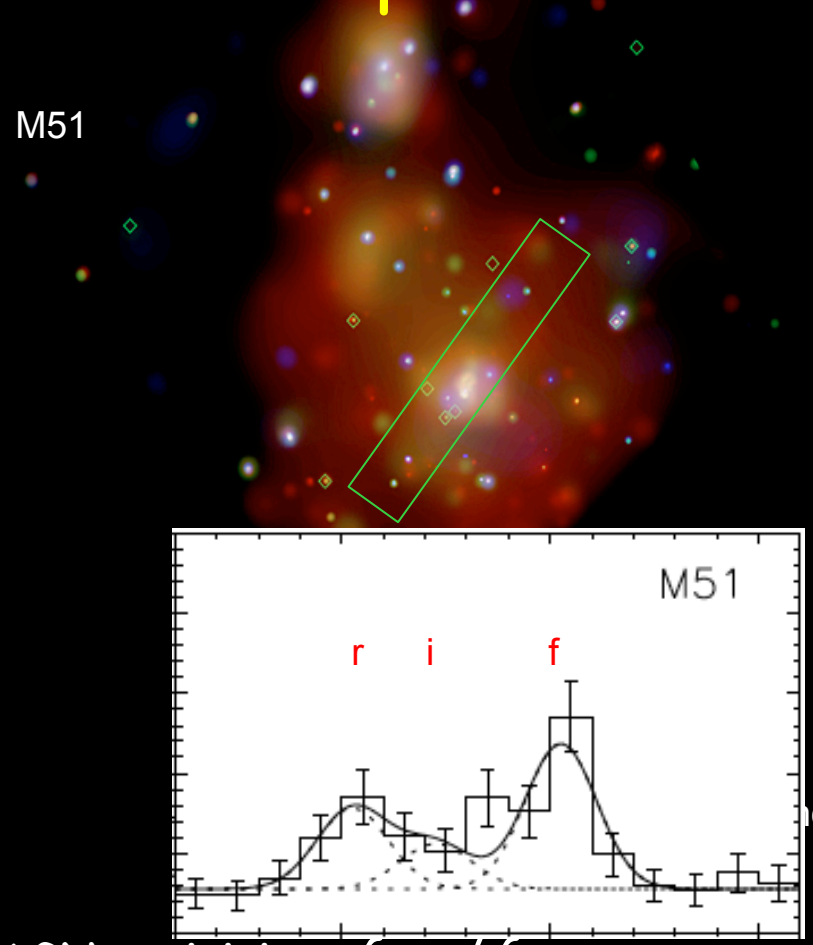


Zhang, Wang, Ji, Smith, & Foster (2014)

- Naturally explains the spatial correlation between hot and cool gas tracers.
- CX is proportional to the ion flux into the hot/cold gas interface.
- Accounting for the CX is important to determining the thermal and chemical properties of the hot plasma.

RGS Survey of nearby active star forming galaxies: examples



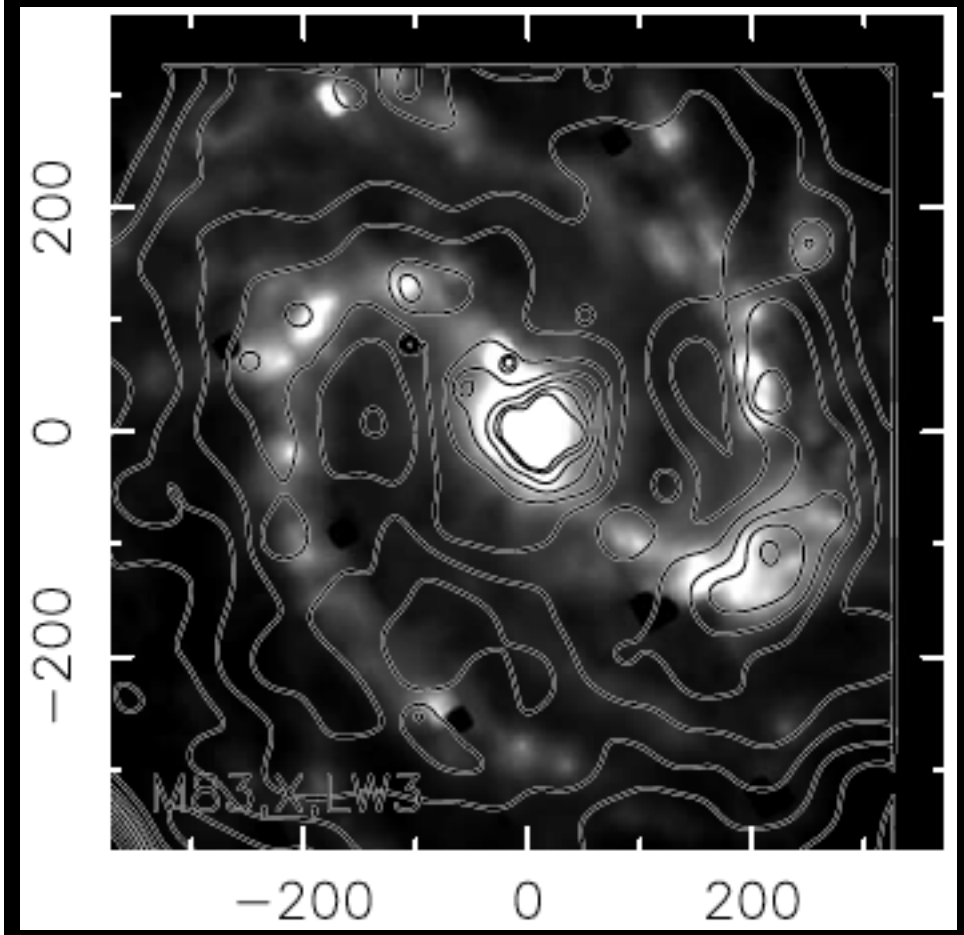


o et al.)

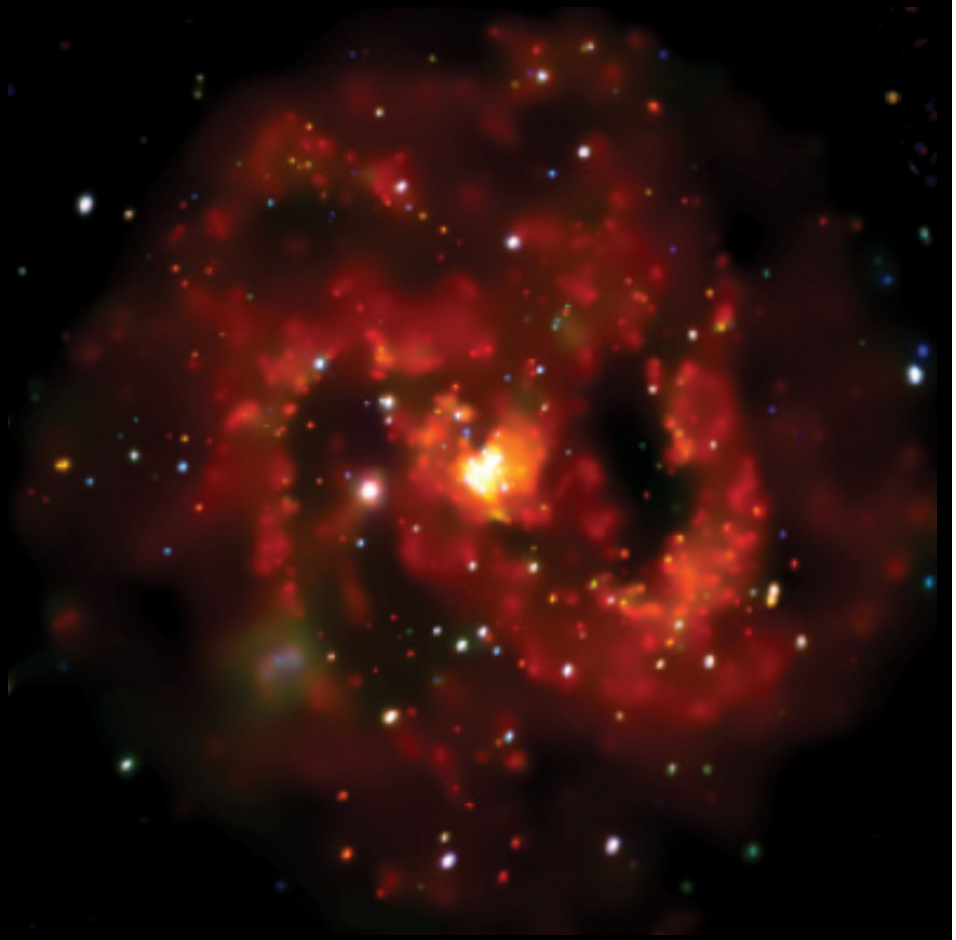
- Little evidence for significant AGN activities; f_{OVIII}/f_{OVII} ratios are similar to star bursts than AGNs
- Soft X-ray are spatially correlated with star forming regions

Liu, Wang, Mao (2012)

Tight correlation between Diffuse soft X-ray and star formation



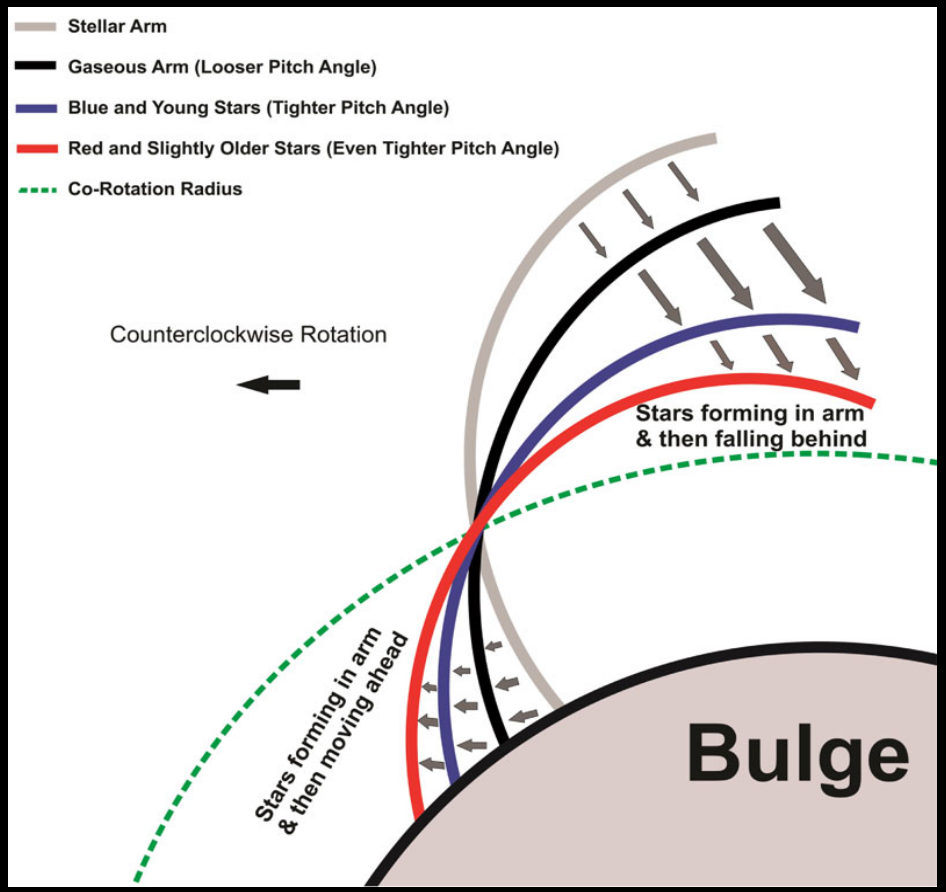
Diffuse X-ray contours on Hα image (Tyler+ 04)

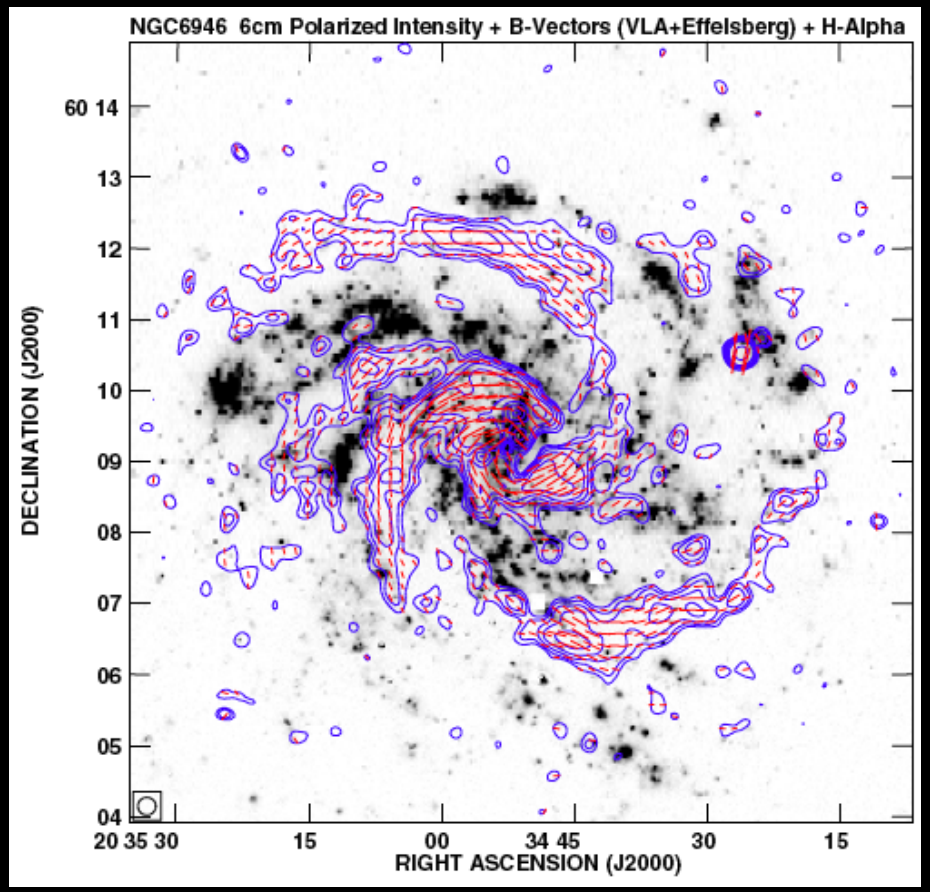


Deep Chandra image of M83 (Long+ 14)

Where is the feedback energy from massive stars of a few 10^7 yrs?

Tracing the feedback in in the downstreams of SF spiral arms

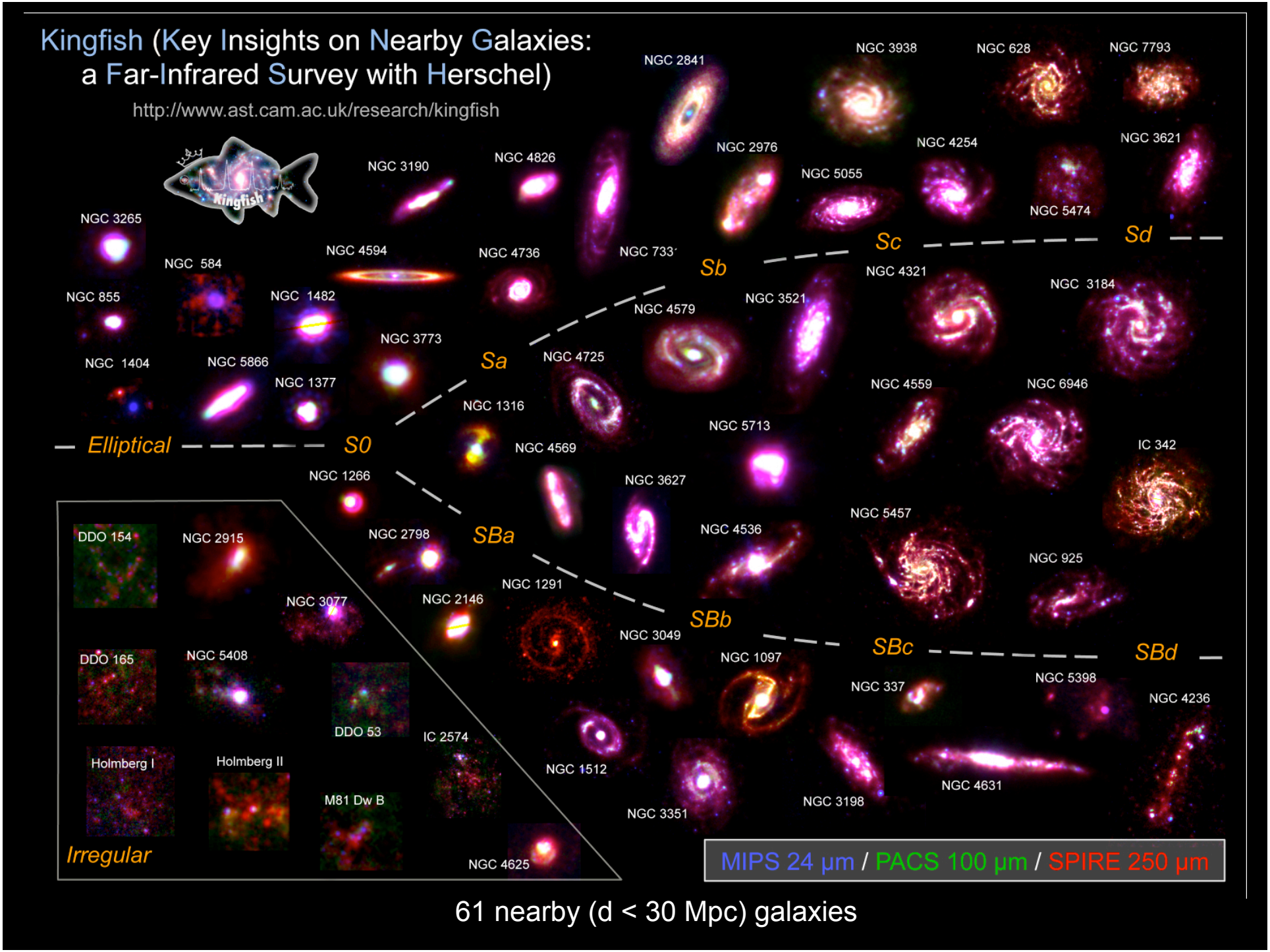




Indication for hotter gas in inter-arm regions with strong polarized radio emission from XMM obs (Weżgowiec+ 16).

Where is the feadback energy?

- Scenario I:
  - Consumed inside the arms (Tyler et al. 03)
  - But not emitted in X-ray (< a few %)
- Scenario II
  - Hot outflow may be ubiquitous in active SF regions and probably has T > 0.5 keV.
  - Observed soft X-ray emission arises most at interfaces between hot outflow and cool gas, explaining their strong correlation.
  - Hot outflow in inter-arm regions is hard to observe.



61 nearby (d < 30 Mpc) galaxies

Ongoing project: X-raying Kingfish galaxies

- X-ray atlas of nearby disk galaxies
- Multiwavelength comparisons:
  - Compare the spectral properties in on- and off-arm regions, as well as the off-galaxy background.
  - Specific X-ray source distribution relative to the arms.
- Comparison with zoom-in simulations of stellar feedback at time resolution better than ~10^7 yrs for > 0.3 Gyrs.

Scientific questions

- What fraction of the feedback energy can be converted to the thermal energy in star-forming regions?
- Under what condition does hot gas escape into galactic halos?
- How far can the gas go? How much? What is its dynamic state?
- How all these depend on (specific) SFR, galaxy mass, and environment?

Summary

- Nearby disk galaxies are excellent labs for multi-wavelength studying of the galactic feedback.
- Existing X-ray observations have shown various inconsistencies with predictions from simple-minded theories and simulations (Li, Wang, & Crain 14; Wang+16).
- Physical processes (such as CX, resonance scattering, and/or photo-ionization by present/previous AGNs), other than thermal emission, may need to be considered.
- Cosmic ray/magnetic field and dust cooling may play an important role in consuming the feedback.
- Data are available now to advance the field.

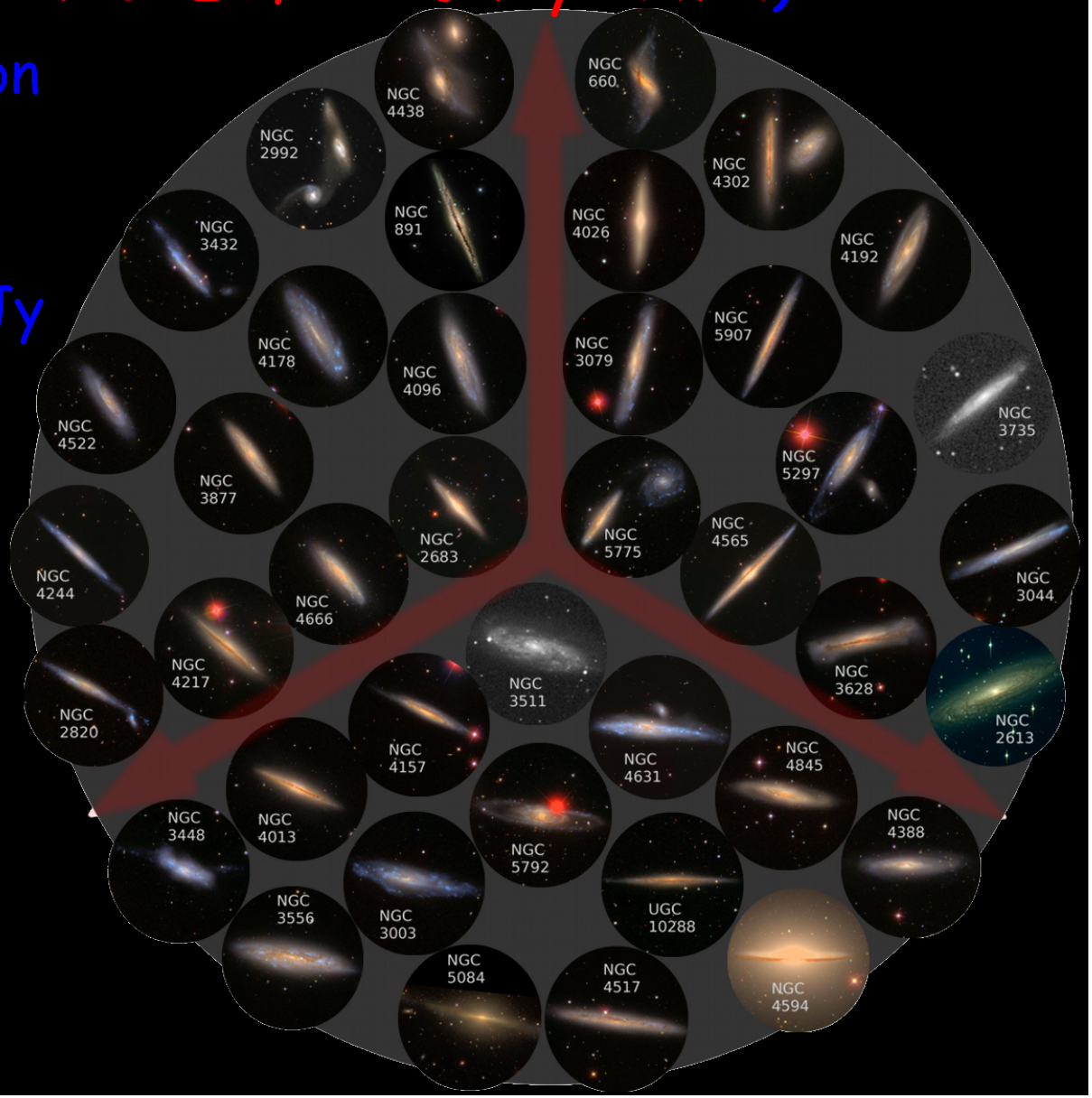
Continuum HAlos in Nearby Galaxies – an EVLA Survey (CHANG-ES; PI: Judy Irwin)

Selection of 35 edge-on galaxies with

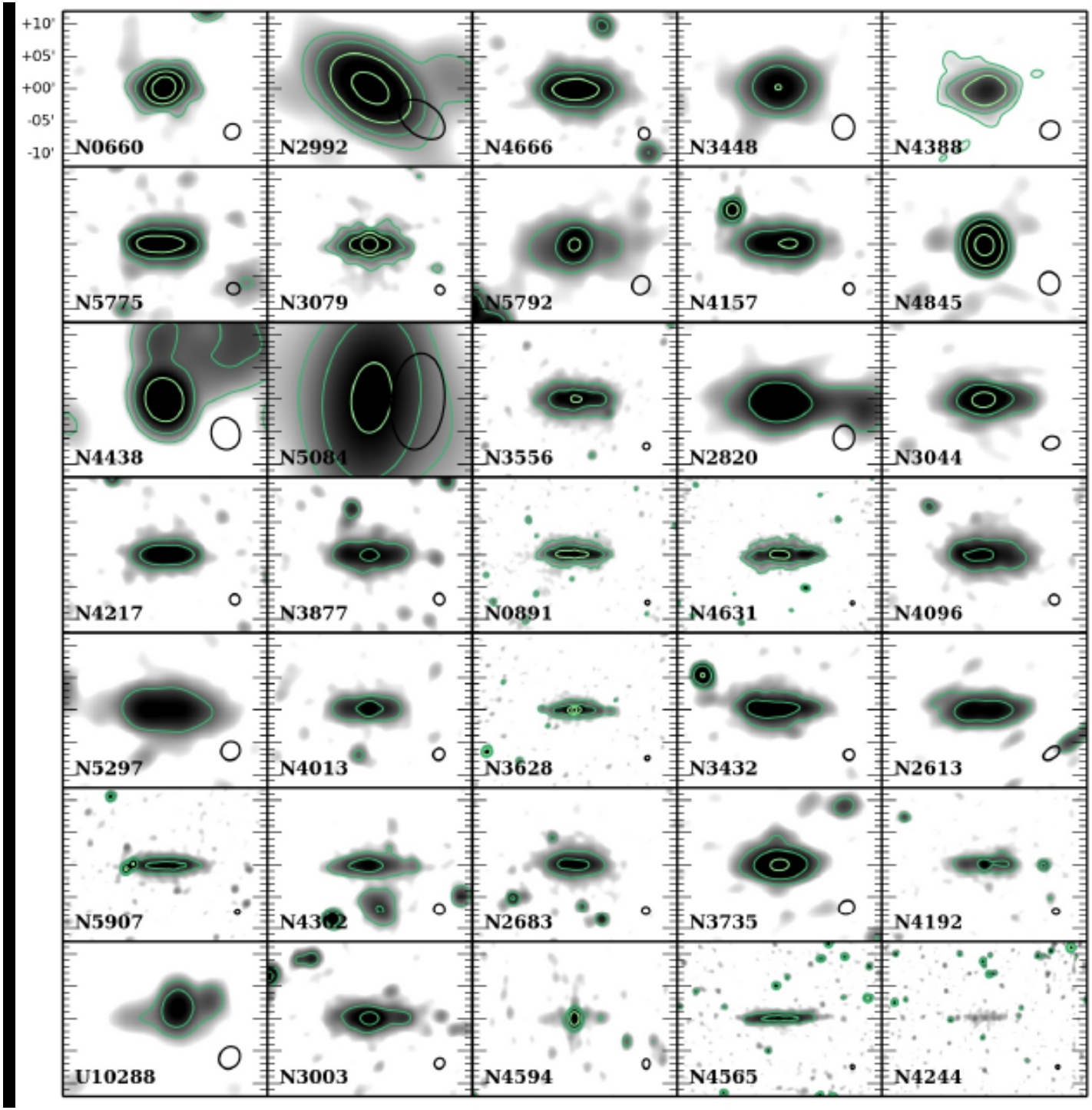
inclination > 75°

1.4 GHz fluxes > 20 mJy

$4' \leq D_{25} \leq 15'$,

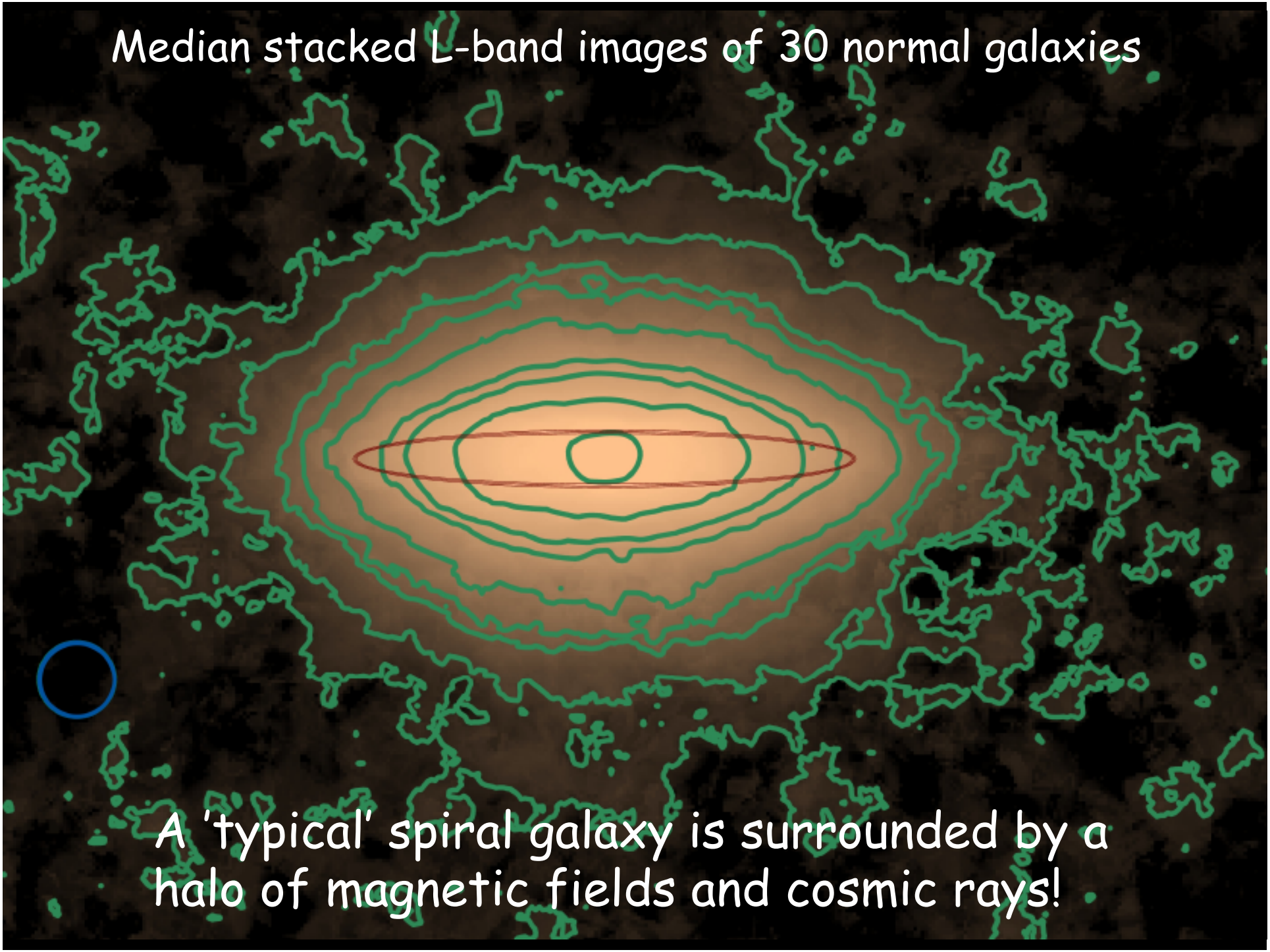


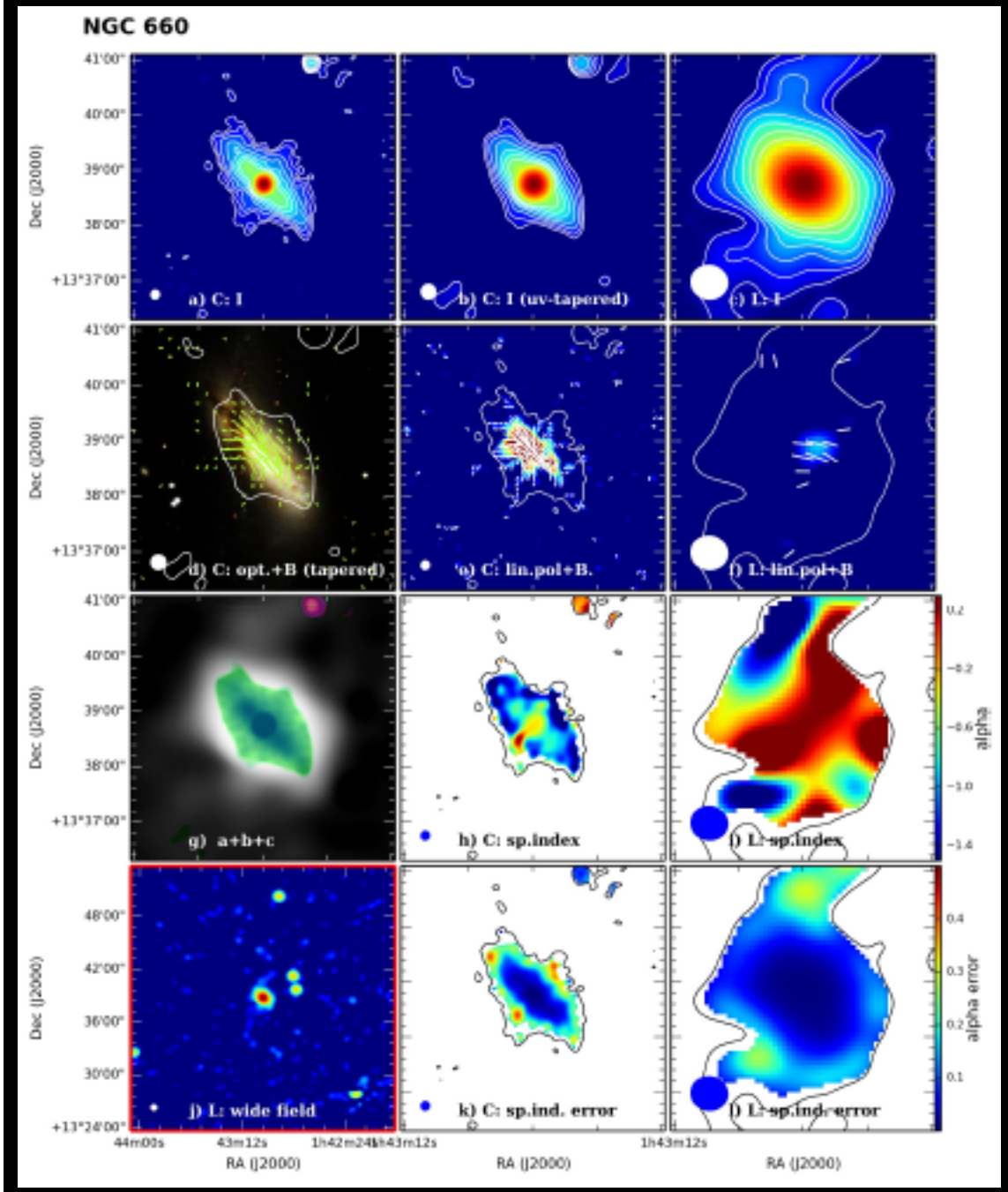
All (> 400 hrs) data have been taken in L and C bands centered at 1.5 and 6 GHz and in the B, C & D arrays, all 4 Stokes. Plus GBT observations.



L-band images scaled to a common WISE 22 micron size, ordered by SFR surface density

Wiegert et al. (2015)


Median stacked L-band images of 30 normal galaxies
A 'typical' spiral galaxy is surrounded by a halo of magnetic fields and cosmic rays!

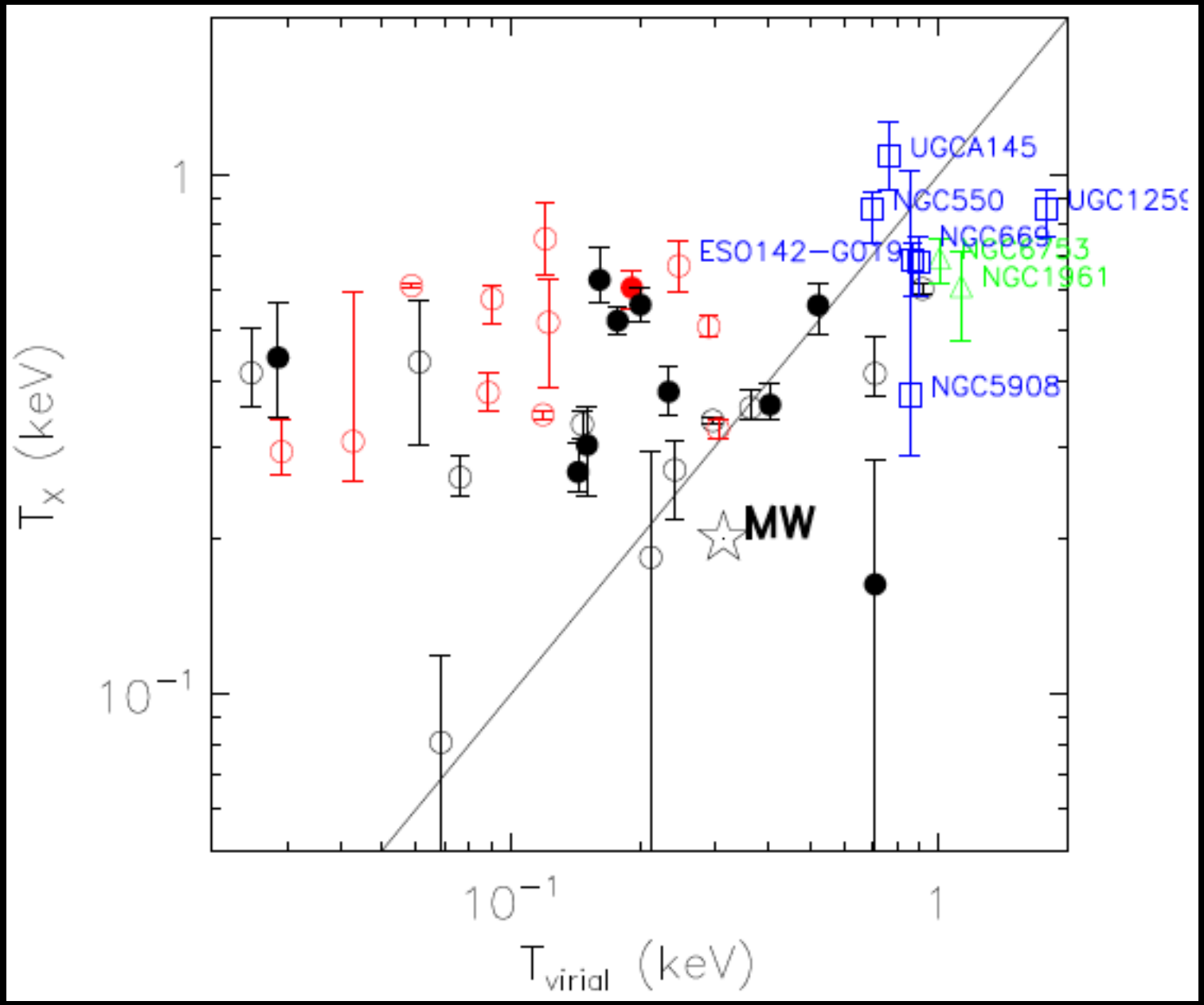


A lot more information is available in the data:

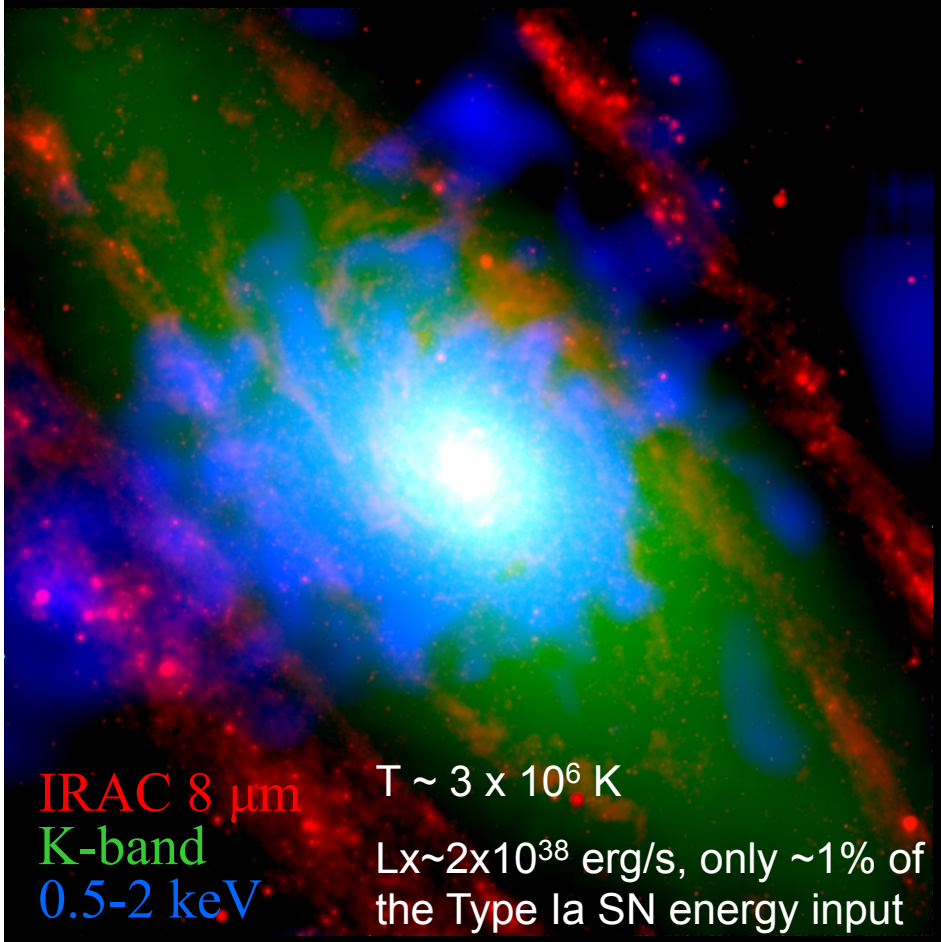
- Intensity images at various resolutions
- Spectral index
- Polarization
- Faraday's rotation
- AGNs
- Dependence on galaxy environment.

Allowing for a comprehensive exploration of the magnetized CGM.

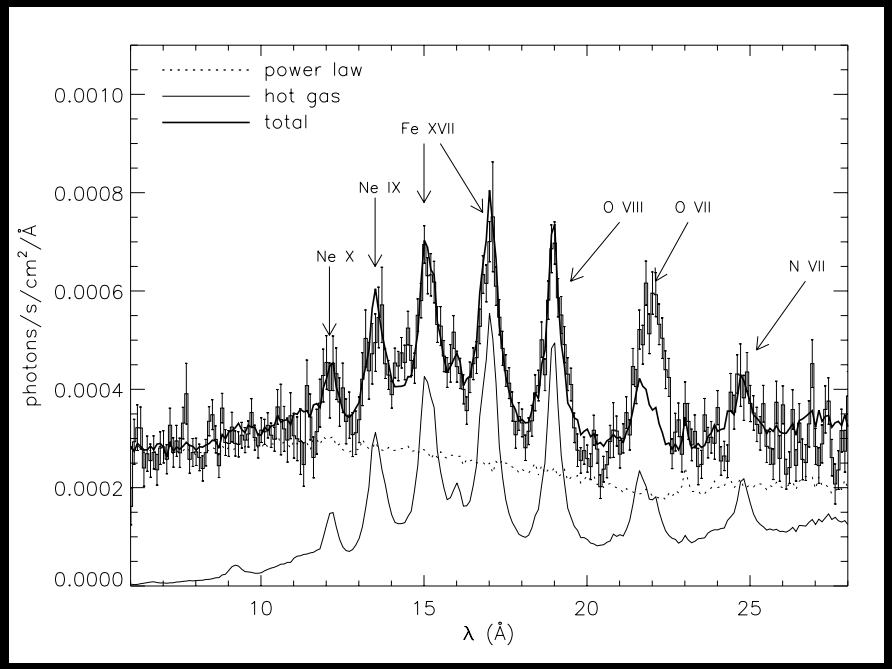
Wiegert et al. (2015)


UGCA145
NGC550
UGC1259
NGC669
NGC6753
NGC1961
ESO142−G079
NGC5908
MW
1
10^{-1}
10^{-1}
1
T_x (keV)
T_{virial} (keV)

XMM-Newton RGS spectrum of the stellar bulge of M31



Li & Wang 2007



Strong deviation of the OVII Kα triplet from the thermal model: the forbidden line at 21.80 Å is much stronger than the resonance line at 21.60 Å.

Liu, Wang, Li, & Peterson 2010