Tracking evolutionary processes in stellar disks in nearby dwarf galaxies from X-ray light

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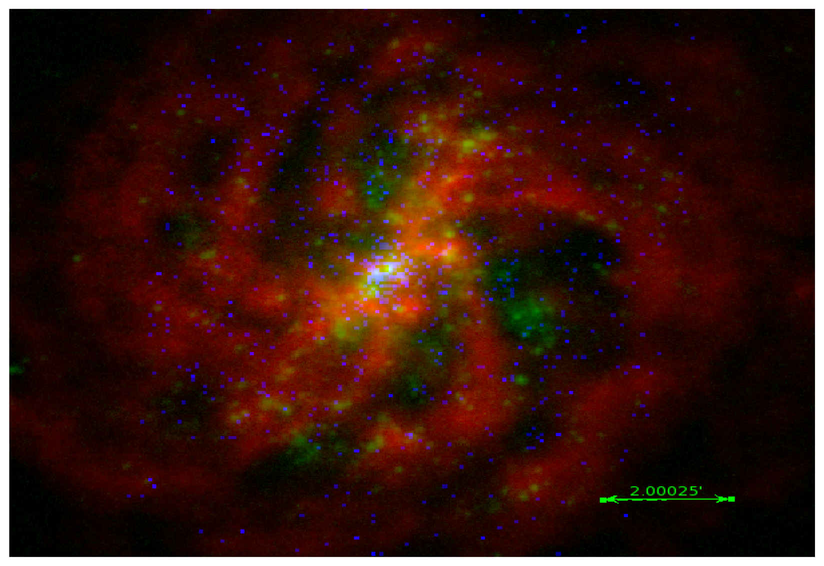
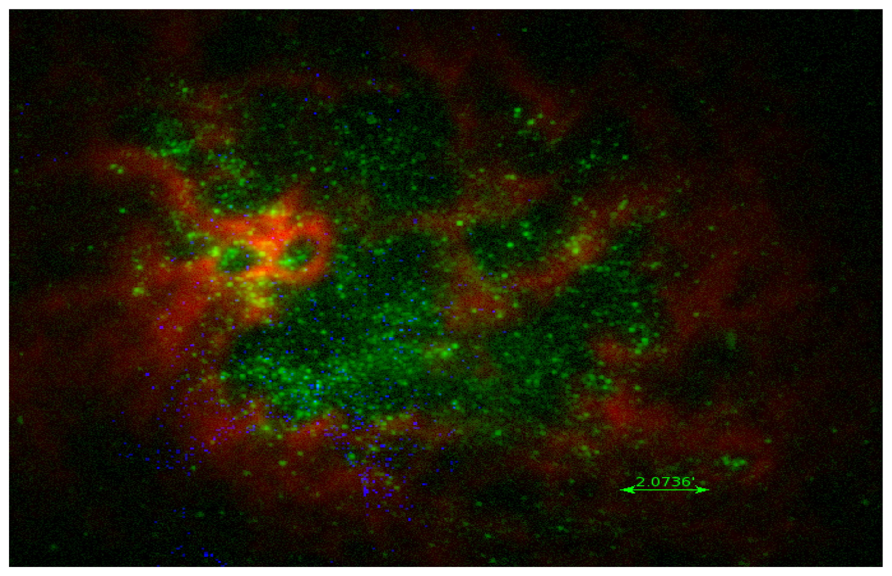
Abstract

We use X-ray imaging spectrophotometry from Chandra to trace hot gas in a sample of nearby dwarf irregular (dIrr) galaxies from the LITTLE THINGS (Local Irregulars That Trace Luminosity Extremes – The HI Nearby Galaxy Survey) survey (Hunter et al. 2012). We compared the radial distribution of X-radiation from hot gas to cold gas and star formation rate profiles. We also studied individual star-forming regions defined by HI holes and FUV brightness peaks. These comparisons help to determine if stellar feedback is efficient in driving shells and generating large bubbles in the low-pressure outer disks compared to the dense inner-disk environments where cooling times are short and energy input from stellar winds and supernovae is expected to be quickly radiated away.

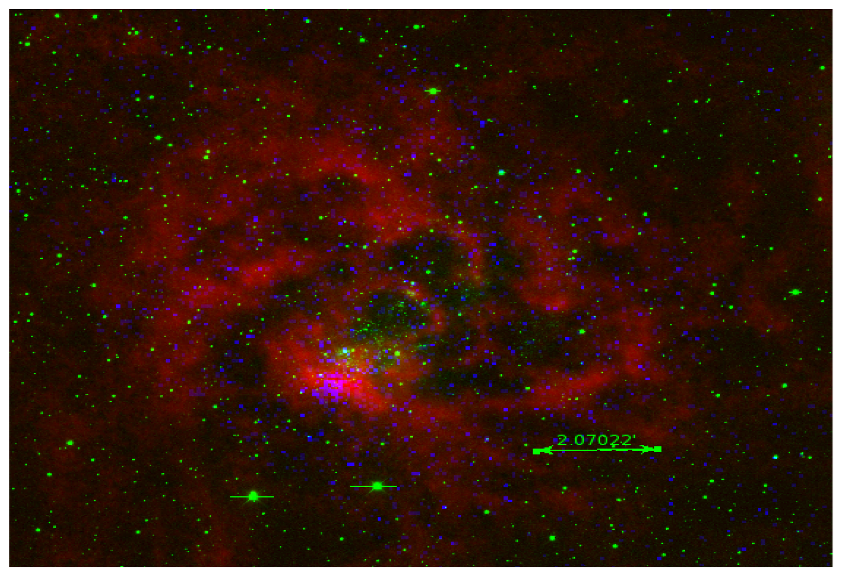
NGC 4214



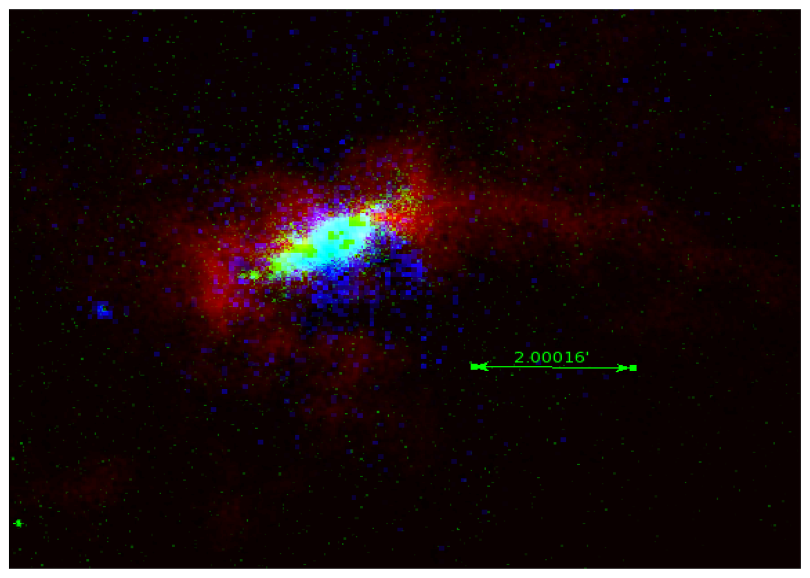
IC 1613



IC 10



NGC 1569



Three color images of our sample galaxies. Cold HI gas is shown in red, young star FUV emission in green, and hot gas X-ray emission in blue. NGC 1569 is a true starburst galaxy. NGC 4214 has an HII nucleus and IC 10 is classified as a BCD.

Tracing Evolutionary Processes

- Low-level star formation is observed in dIrr galaxies and in the outer disks of spirals even though the gas surface density is below the critical threshold for gravitational instability (Hunter et al. 1998). Perhaps stellar feedback, in the form of hot gas from massive star winds and supernovae, can drive shells and compress existing clouds to densities above the critical threshold. This sequential triggering along with random turbulence compression may dominate the star formation process in dIrrs and the outer region of spiral galaxies.
- **Why dwarf galaxies?** Dwarf Irregulars lack spiral density waves and rotate nearly as solid bodies. This helps to preserve sites of recent star formation instead of shearing them within about a dynamical time. These sites are often observed as shells and holes in the cold HI gas distribution. Furthermore, dIrrs have high gas fractions so that processes that trigger star formation should not be as strongly dependent on the underlying stellar structure as in giant spirals.
- **Why X-ray light?** X-rays directly trace the hot gas (T ~10^7 K) produced by stellar feedback 10 - 40 Myr from the onset of star formation. At low gas densities, cooling times are long and hot gas does mechanical work to sweep up the ISM into cool shells where new stars can form, resulting in low X-ray luminosities per unit mechanical luminosity input from SF. At high densities, radiative cooling dominates and star-forming regions are relatively X-ray bright. Therefore, we expect more X-ray emission from the dense inner regions compared to the outer regions of dIrrs.

Sample Galaxies

- We picked four galaxies from the LITTLE THINGS sample (Hunter et al. 2012) from the Chandra data archives* which have substantial X-ray flux from within their optical disks. We used LITTLE THINGS data for star formation rates. The table below includes the 0.5-8.0 KeV diffuse X-ray luminosity, L_X, and the star formation rate per unit area derived from FUV imaging, SFR^{FUV}.

Galaxy	*D (Mpc)*	*L_x (erg s^{-1}) X 10^{37}*	*SFR^{FUV} (M_{SUN} yr^{-1} kpc^{-2})*
NGC 4214	*3.0*	*7.2*	*0.08*
NGC 1569	*3.4*	*4.9*	*0.97*
IC 1613	*0.7*	*3.4*	*0.01*
IC 10	*0.7*	*1.5*	*…*

References:
1) Hunter et al. 2012, AJ 144, 143
2) Zhang et al. 2012, AJ 143, 47
3) Bagetakos et al. 2010, AJ, 141, 23
4) Hunter et al. 1998, ApJ, 493, 595

Major Findings and Conclusions

Comparison of X-ray, and HI morphologies with recent Star Formation Rates (SFRs) :

- The X-ray surface brightness profile tends to follow the star formation derived from GALEX FUV photometry more closely than that derived from Hα, indicating X-rays trace the recent (<100 Myr) but not current (<10 Myr) star formation history (Fig-1)
- The X-ray surface brightness is often more centrally-peaked than the HI emitting cold gas. This may mean the hot gas is confined by surrounding dense cold gas and radiates much of its energy content.

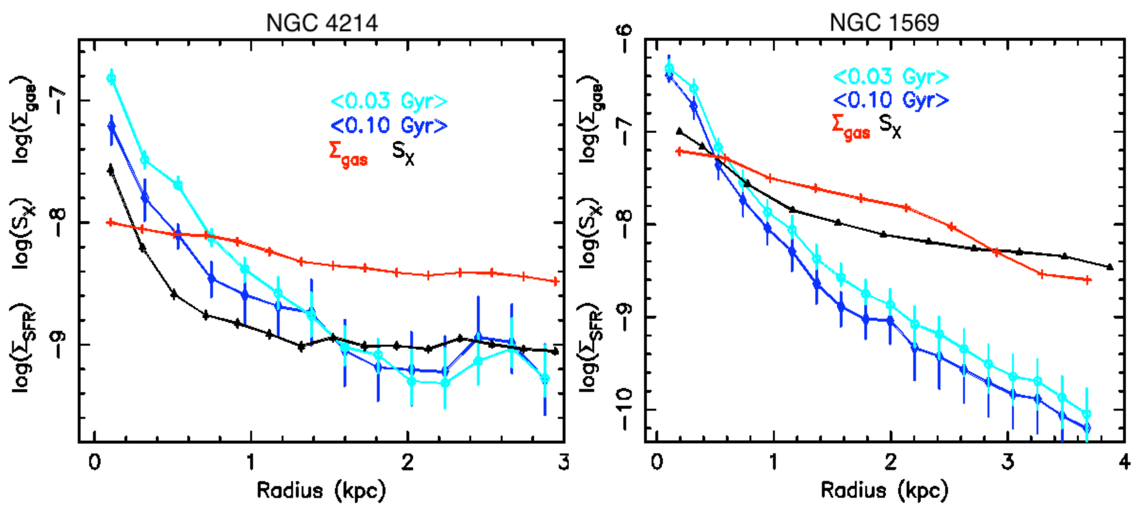


Figure-1: Radial profiles of the X-ray surface brightness is compared to the HI and to the most recent SFRs (<30 and <100 Myr) as derived by Zhang et al. 2012.

- *The X-ray surface brightness seems to follow the <100 Myr star formation traced by FUV. The centrally-peaked X-ray surface brightness indicates strong radiative cooling.*

Study of HI holes :

- Bagetakos et al. 2011 mapped the HI holes in NGC 4214. We found only 6 of 56 holes had an X-ray excess greater than 3 sigma above the mean. (Fig-2)
- HI holes with high X-ray excesses are typically young (<20 Myr) and have the highest mechanical energies injected by star formation activity. These holes are located in high density regions near the galaxy center, where gas is trapped, and cools by emitting X-rays. The holes in the outer region, where the hot gas can expand adiabatically, show no significant X-ray excess.

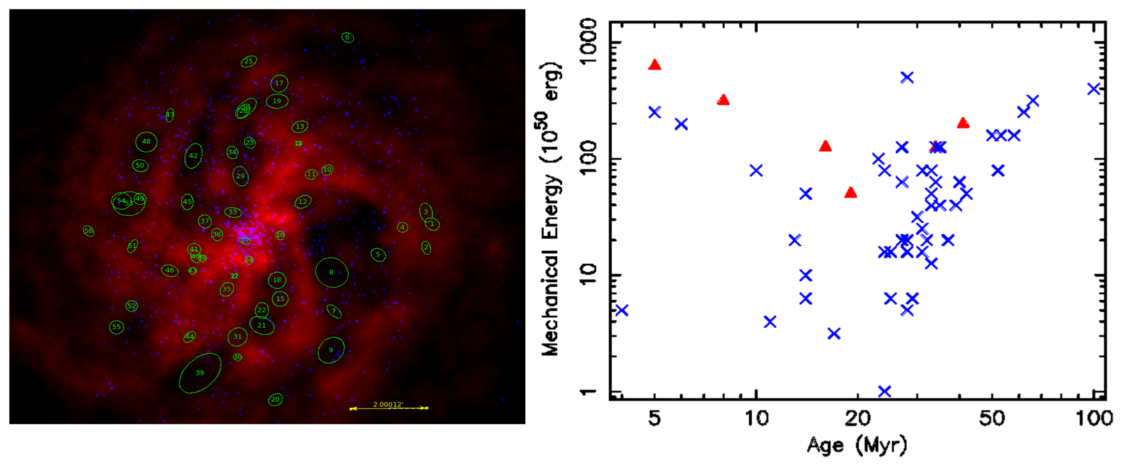
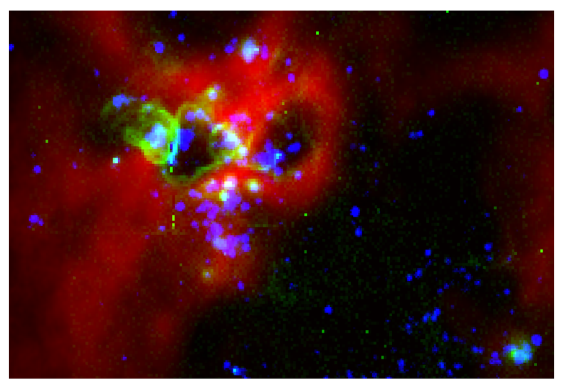


Figure-2: (left) Location of HI holes superimposed on HI(red) and X-ray(blue) image. (Right) Mechanical energy input needed to create the HI holes is shown against their age (from Bagetakos et al. 2011). Highlighted in red are those holes with significant X-ray excesses.

- *Only young, highly-active, star-forming regions (traced by HI holes) in NGC 4214 show an excess of X-ray light.*

Study of individual SF regions :

- The study of individual SF regions in these dwarf galaxies often show very little X-ray flux. For instance, the most active star-forming region in IC 1613 (Fig-3) shows no significant X-ray excess. This may be because
  - I. The hot gas does PdV work rather than radiating in these low density environments.
  - II. The SF regions are too young or old to produce hot gas through supernovae or stellar wind shocks.
  - III. The SF activity is too low to produce sufficient numbers of massive stars.



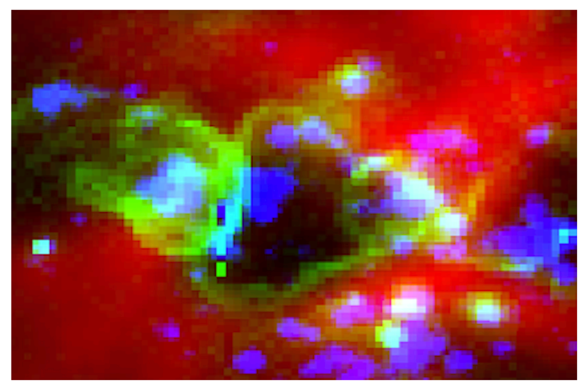


Figure-3: Close-up composite of the major star-forming region in IC 1613. HI (red), Hα (green) and FUV (blue). There is no excess X-ray emission from any of these structures.

- *Individual star-forming regions show very little X-ray flux. Typically, less than 5% of the available mechanical energy is radiated in X-rays. This makes tracing evolutionary processes with X-ray light difficult.*

★ http://asc.harvard.edu/cda/
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