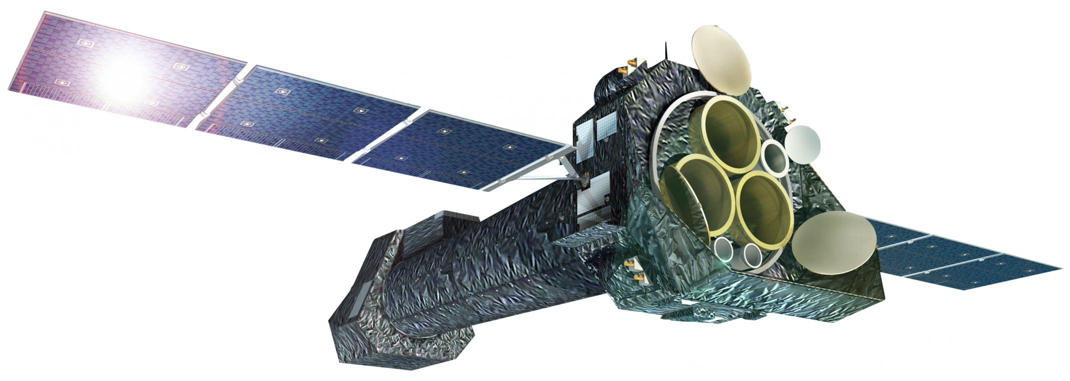

Studies of the Northern Disk of M31 with XMM-Newton

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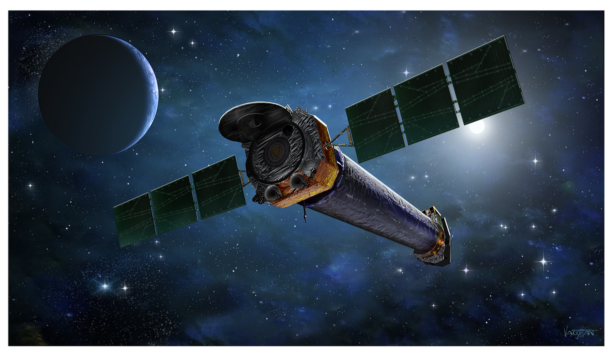
We present a comprehensive study of the northern disk of M31 using the strengths of three missions: the multi-band optical photometry from the **Hubble Space Telescope** (Panchromatic Hubble Andromeda Treasury, PHAT, Dalcanton et al., 2012, ApJS, 200, 18) to distinguish sources in M31 from foreground and background sources, the precise position from **Chandra X-ray Observatory** (Williams et al., 2018, ApJS, 239, 13; see also poster by M. Lazzarini) to associate an X-ray source with an optical source, and the X-ray spectral information from **XMM-Newton**.

The northern disk of M31 was observed with XMM-Newton in a large program (LP, Sasaki et al., 2018, A&A, 620, 28). After sources were identified based on comparisons with Hubble and Chandra data, we **determined the spectral properties of all detected XMM-Newton sources** by using hardness ratios and, if the statistics were sufficient, by analyzing the spectrum for each source. We also checked for variability. We identified 43 foreground stars and candidates and 50 background sources. Based on the hardness ratios, variability, luminosities, and comparison with the results of the Chandra/PHAT survey, we classify 24 hard X-ray sources as new candidates for X-ray binaries (XRBs). In total, we identified **34 XRBs and candidates as well as 18 supernova remnants (SNRs) and candidates** and compiled a complete list of X-ray sources down to a **flux limit of 7 x 10^{34} erg/s (0.5 – 2.0 keV)**.



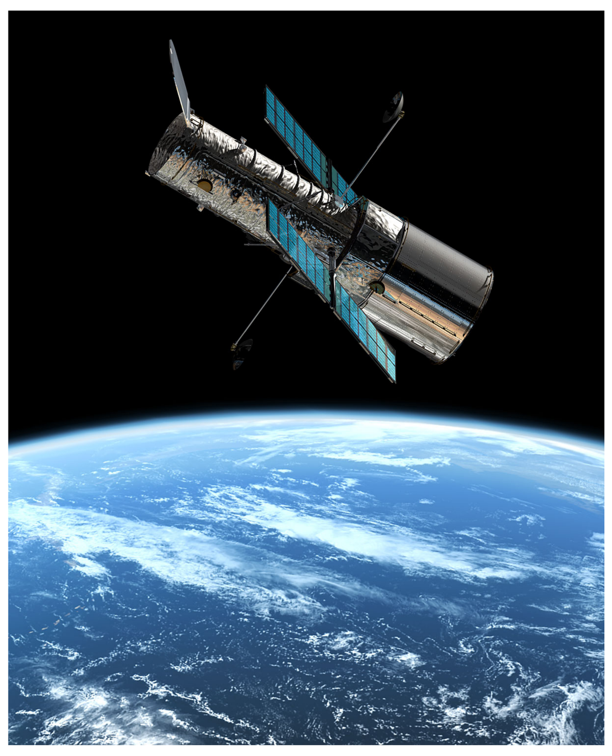


Table 1 List of XMM-Newton LP observations

ObsID	Field	Net Exposure Time
763120101	1	95 ks
763120201	1	51 ks
763120301	2	100 ks
763120401	2	68 ks

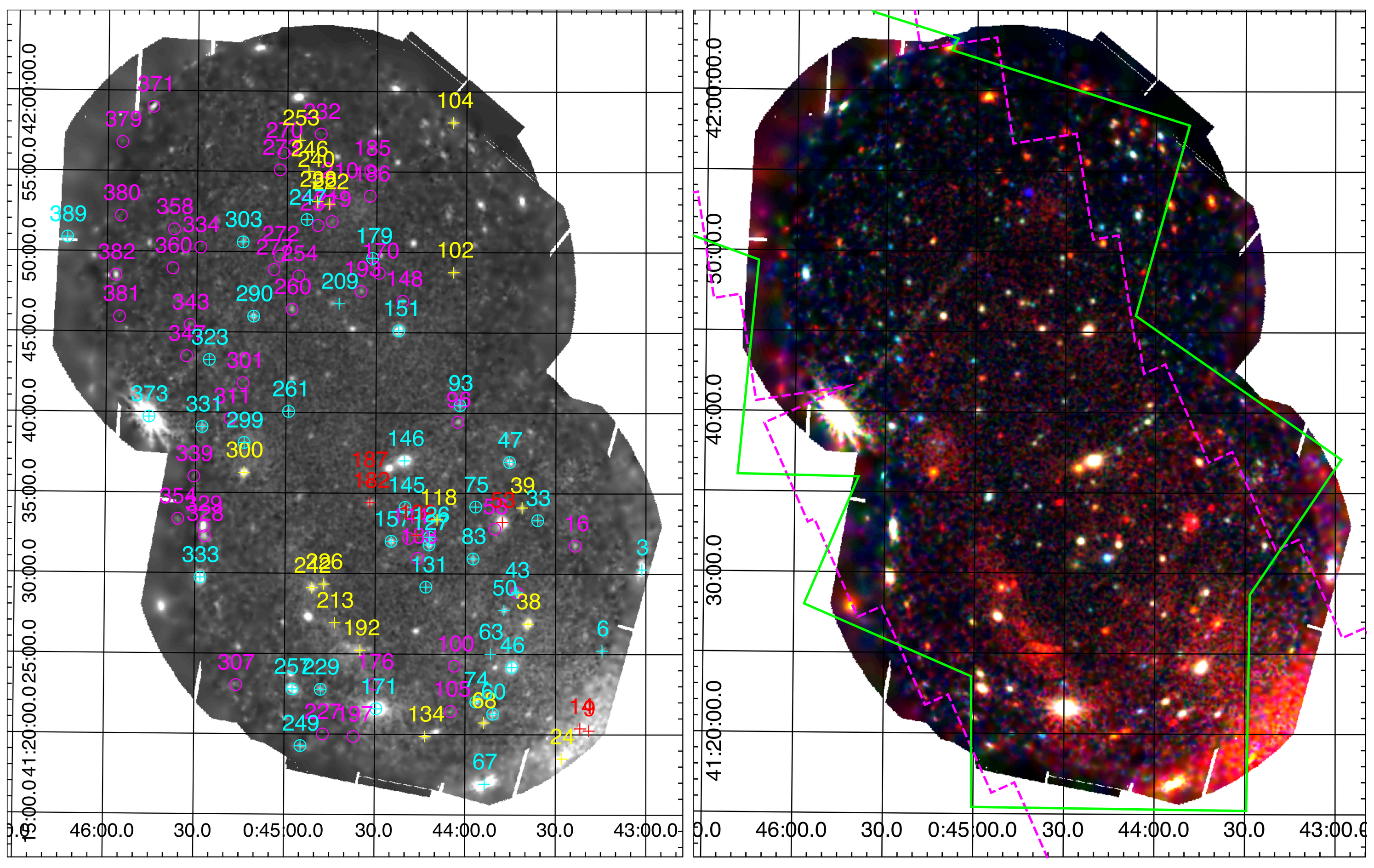


Fig. 1 *Left*: Exposure-corrected mosaic image of the XMM-Newton LP observations of the northern disk in the energy band 0.2 – 1.0 keV with classified sources: cyan for XRBs and candidates, yellow for SNRs and candidates, red for supersoft sources (SSSs) and candidates. *Right*: Three-color image (red: 0.2 – 1.0 keV, green: 1.0 – 2.0 keV, blue = 2.0 – 12.0 keV) with the footprints of the Chandra and the PHAT surveys shown by solid green line and dashed magenta line, respectively. All images are shown in log-scale.

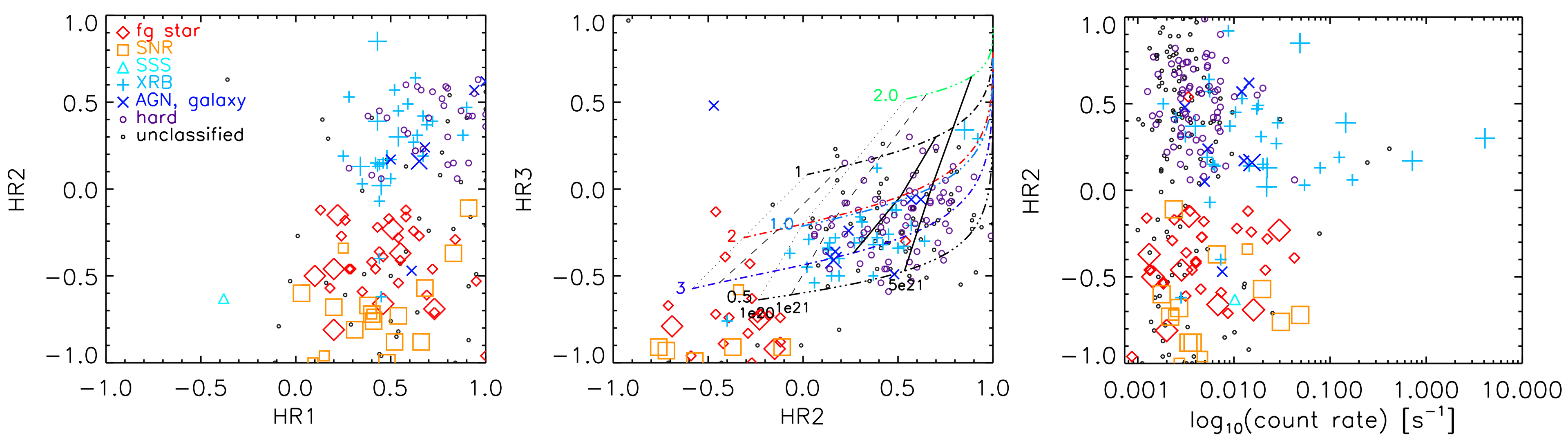


Fig. 2 Hardness ratio (HR) diagrams and HR2 vs. count rate diagram for sources in the northern disk. Small symbols for candidates, large symbols for confirmed classifications. Black dots are used for unclassified sources. In the HR2-HR3-diagram lines indicate the predicted position for sources with a power-law spectrum (dash-dotted lines) for Γ = 1 (black), 2 (red), 3 (blue) and a disc black-body spectrum (dashed-dot-dotted lines) for kT = 0.5 keV (black), 1.0 keV (light blue), 2.0 keV (green) for different absorbing foreground N_H (thin dotted for 10^{20} cm^{-2}, dashed for 10^{21} cm^{-2}, and thick solid for 5×10^{21} cm^{-2}).

We used all existing XMM-Newton data to create a source-excised mosaic, which gives the most detailed view of the hot interstellar medium (ISM) in a grand-design spiral galaxy such as our own to date. We performed a spectral analysis of the extended X-ray emission using our deep LP observations. The temperature of the hot ISM varies from ***kT* = 0.1 – 0.3 keV in the ring up to *kT* = 0.6 keV in a superbubble**. We show that the **massive stars** in the northern disk, in particular, in the 10 kpc star-forming dust ring, **supply sufficient energy to heat the ISM** to X-ray emitting temperatures via stellar winds and supernovae (Kavanagh et al., arXiv:1910.12754).

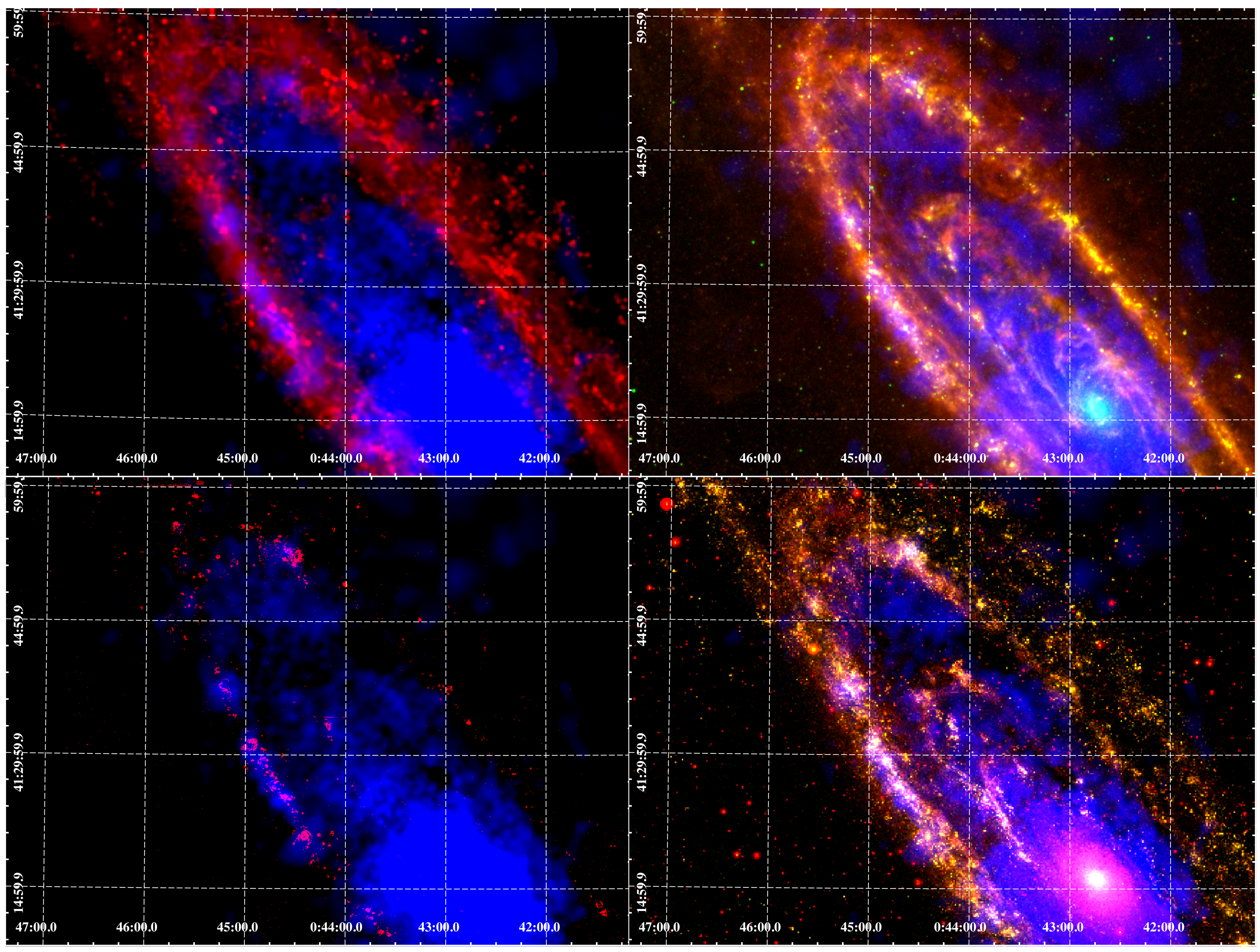


Fig. 3 Multi-wavelength comparison of the ISM in the northern disk of M31. The 0.3 – 0.7 keV XMM-Newton image of the diffuse emission is shown in blue. All X-ray sources have been excised and filled. Top-left: HI (red, Braun et al., 2009, ApJ, 695, 937). Top-right: dust seen at 250 µm (red) by Herschel SPIRE (Pilbratt et al., 2010, A&A, 518, L1) and at 24 µm (green) by Spitzer MIPS (Werner et al., 2004, ApJS, 154, 1). Bottom-left: Continuum-subtracted Hα (red) from the Local Group Galaxy Survey (Massey et al., 2006, AJ, 131, 2478). Bottom-right: population of massive stars, seen in NUV (red) and in FUV (green) by Galex (http://galex.stsci.edu/GR6/).

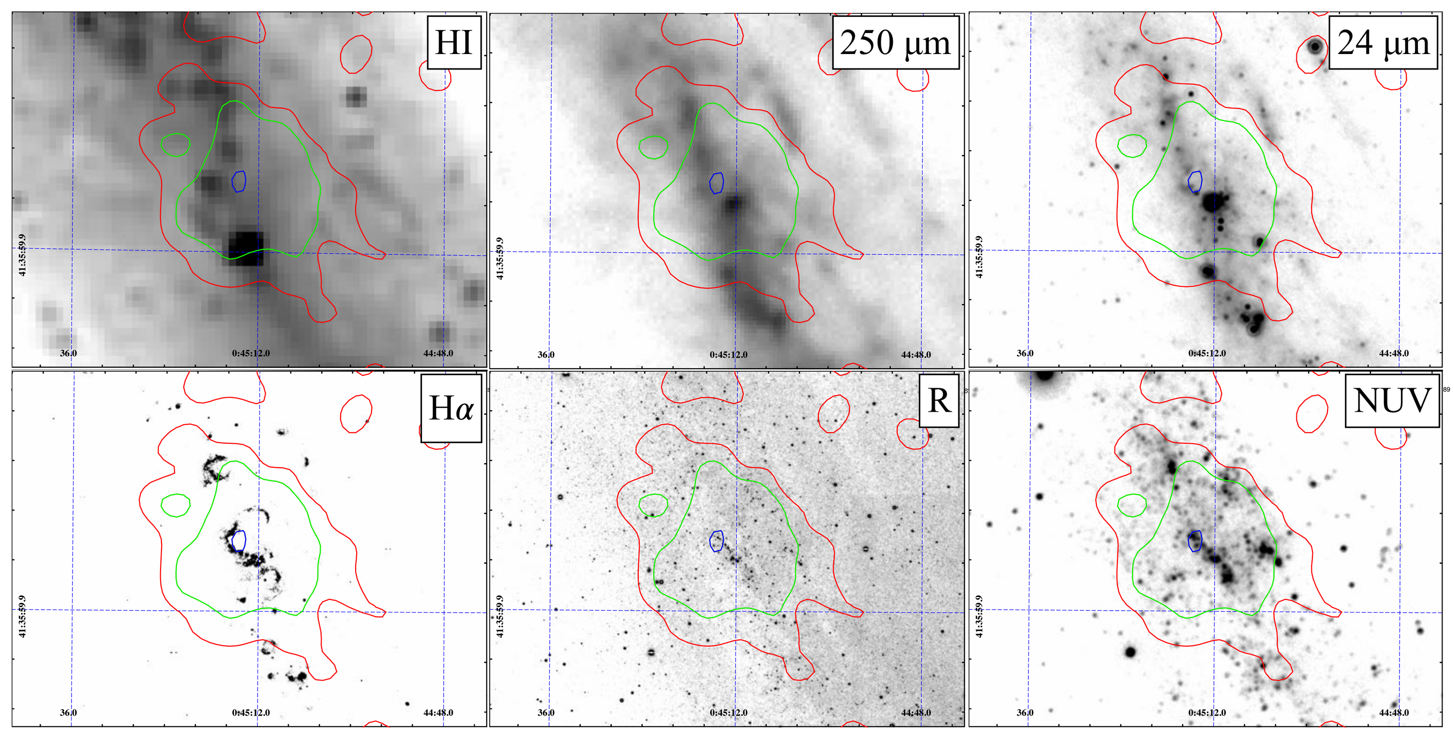


Fig. 4 Multi-wavelength view of a superbubble in the inner dust ring with contours for the X-ray emission (red: 5σ, green: 10σ, blue: 20σ above the average background).

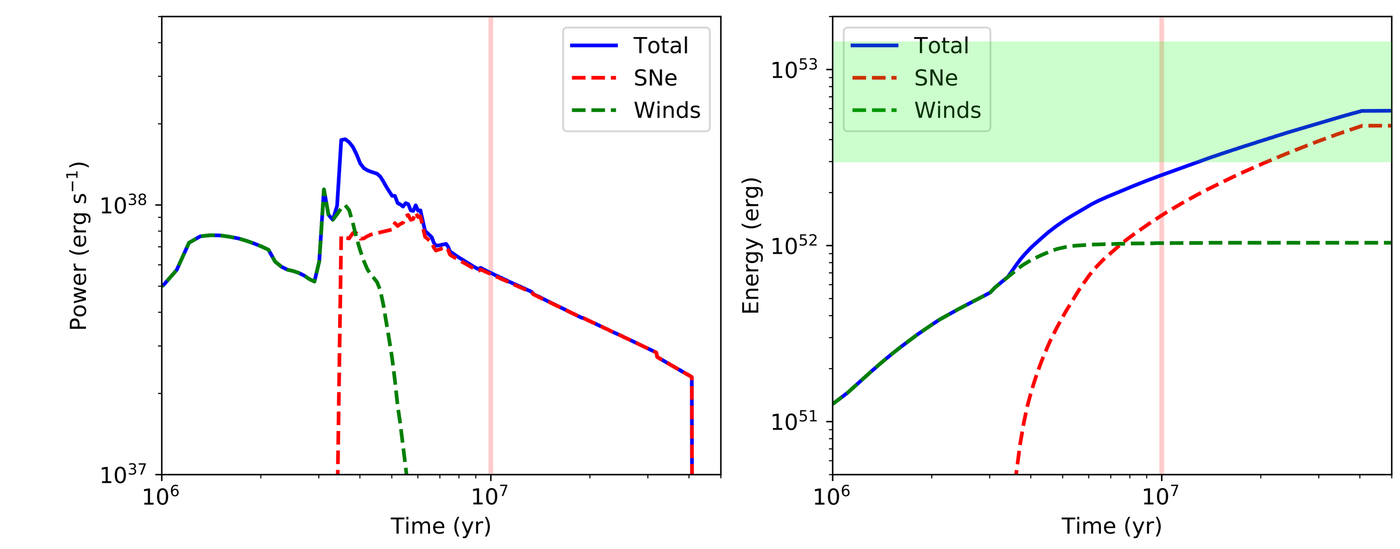


Fig. 5 Stellar wind and supernova power (left) and energy (right) inputs determined with Starburst99 calculations (Leitherer et al., 1999, ApJS, 123, 3; Leitherer et al., 2010, ApJS, 189, 309) for the extended emission region shown in Fig. 4. The green area shows the thermal energy of the X-ray emitting gas, the light red lines show the age range of the stellar populations estimated from the comparison of the PHAT photometric data to isochrones and evolutionary tracks derived from the PARSEC isochrone database (Tang et al., 2014, MNRAS, 445, 4287, and references therein).

Acknowledgement This research is funded by the DFG through the grants SA 2131/5-1 and 12-1 and by BMWi/DLR through the grant FKZ 50 OR 1510.