The Chandra ACIS Survey of M33 (ChASeM33): Investigating the Hot Ionized Medium of NGC604

R. Tüllmann[1], T. J. Gaetz[1], P. P. Plucinsky[1], P. Ghavamian[2], D. Breitschwerdt[3], M. Avillez[4], W. P. Blair[2], K. S. Long[5], T. G. Pannuti[6], P. Frank Winkler[7]

[1]Center for Astrophysics, Harvard University; [2] Dep. of Physics & Astronomy, Johns Hopkins University; [3] Institut für Astronomie, Universität Wien, Austria; [4] Dept. of Mathematics, University of Évora, Portugal; [5] Space Telescope Science Insitute, Baltimore; [6] Space Science Center, Morehead State University; [7] Dept. of Physics, Middlebury College, Middlebury

1. Introduction

We present ongoing results from the Chandra ACIS Survey of M33 (ChASeM33), a 1.4Ms deep survey to investigate the small and large-scale distribution of the Hot Ionized Medium (HIM), the source populations that shape it, and their mutual interaction. ChASeM33 (Plucinsky et al., 2007) provides the highest angular resolution yet achievable in X-ray astronomy (1") and has a limiting luminosity (absorbed) for point sources of 7E34 erg/s (0.35-8.0keV bandpass).

In the present study we focus on the diffuse extended X-ray emission from the giant HII-region NGC604. We present the deepest X-ray images (300ks) obtained to date of NGC604, extracted in different energy bands which reveal an unprecedented level of detail. We also show the first X-ray spectra of the diffuse emission (0.35-2.0keV) which allow us to constrain fundamental parameters of the ISM, such as gas temperatures, densities, or filling factors.

2. Results

The most striking results concern the spatial extent of the soft X-ray emission and the remarkably good morphological anti-correlation between the emission originating at soft and medium X-rays and Hα (see Fig. 1).

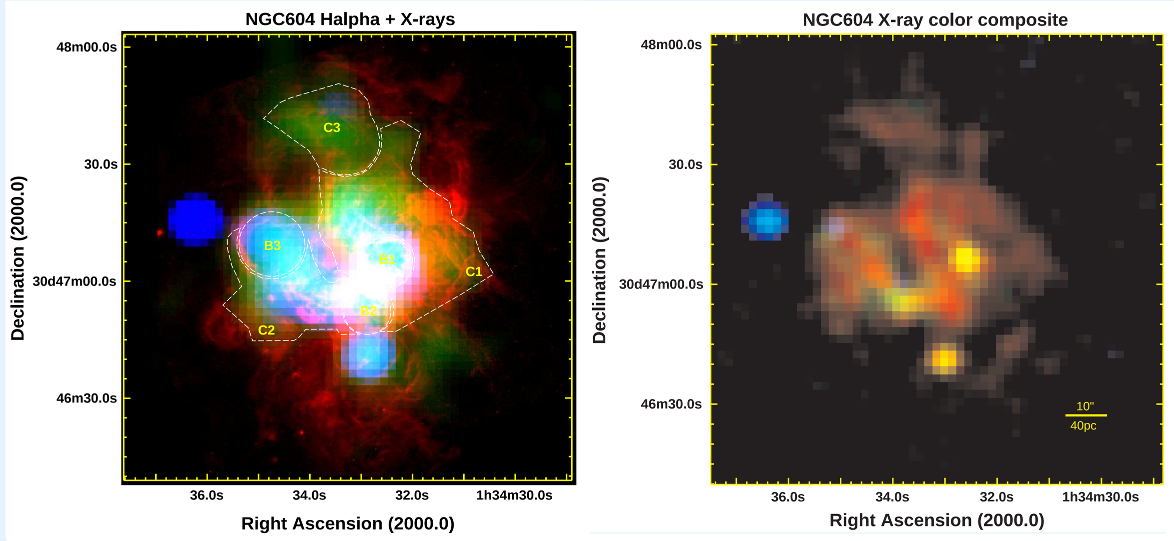

Fig. 1: Left panel: Morphological anti-correlation between Hα (red), soft X-rays (0.35-1.1 keV, green), and medium X-rays (1.1-2.6 keV, blue). Dashed lines highlight regions from which spectra were extracted. **Right panel:** RGB-image of NGC 604. 'Red' denotes the soft energy band (0.35 – 1.1 keV), 'green' medium energies (1.1 – 2.6 keV), and 'blue' hard energies between 2.6 – 8.0 keV. The image is binned to a resolution of 2".

A morphological comparison between X-ray, FUV, optical, and FIR emission suggests that the various (super)bubbles visible in Halpha are filled with hot X-ray emitting gas and are powered by the massive OB and WR-star associations in the center of NGC 604 (see also Fig. 2).

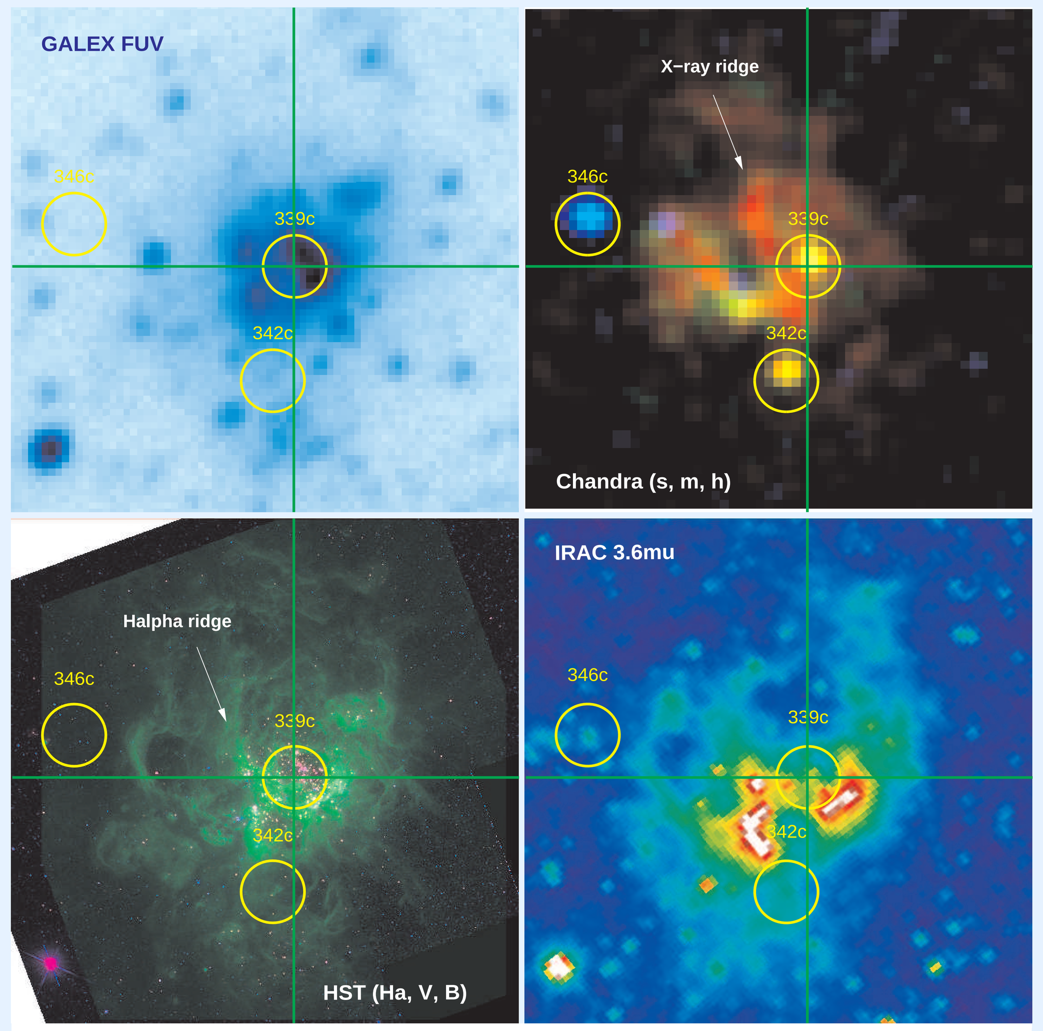

Fig. 2: Multi-wavelength comparison indicating that the (super)bubbles visible in Hα are filled with X-ray-hot gas and are powered by the central OB/WR-stars. Yellow circles represent detected Chandra point sources (taken from the ChASeM33 point source catalog (Plucinsky et al. 2007)).

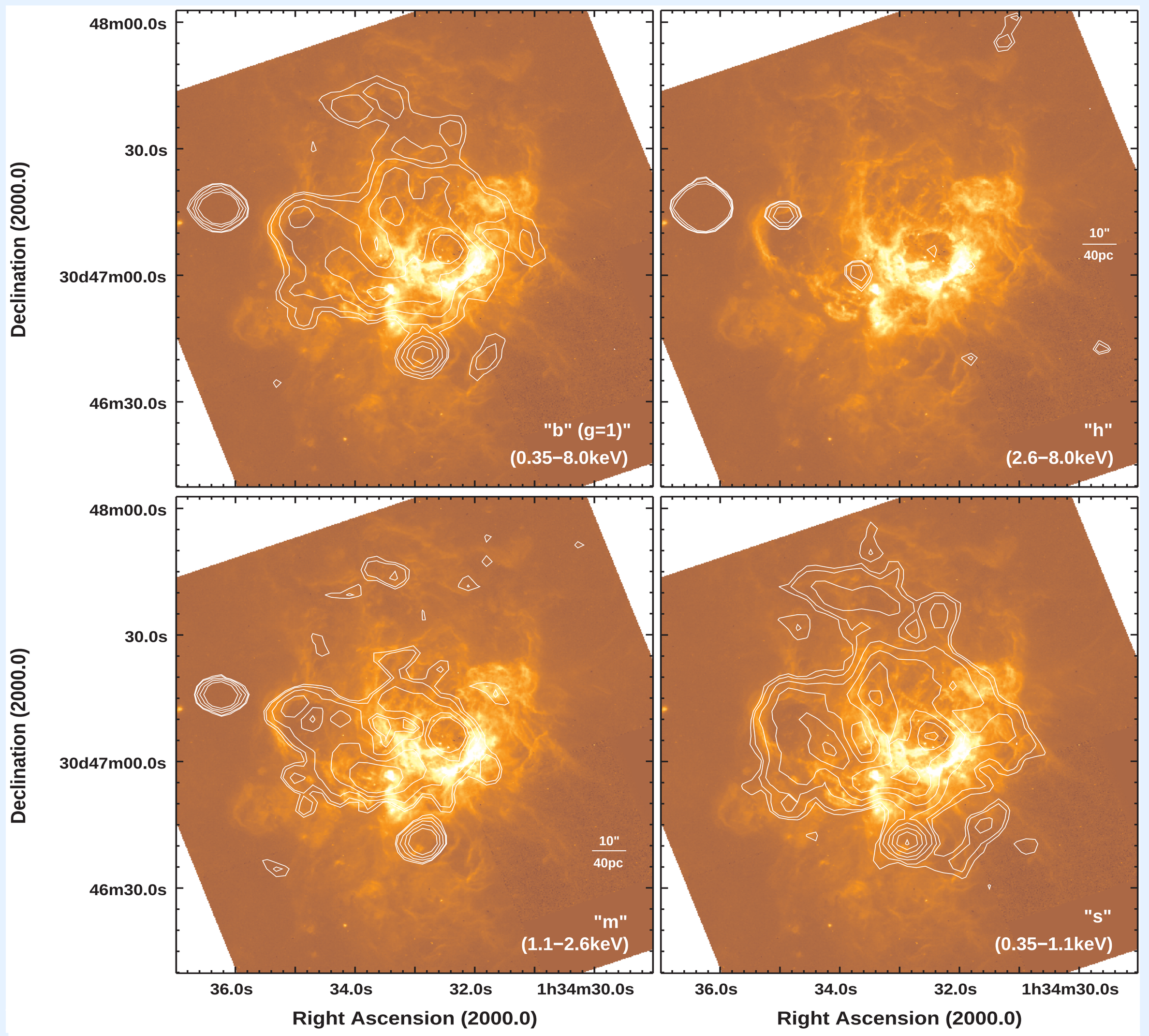

Fig. 3: ACIS-I contour maps are smoothed with a gaussian filter of FWHM = 2.0" and are overlaid onto a HST-Hα-image of NGC 604.

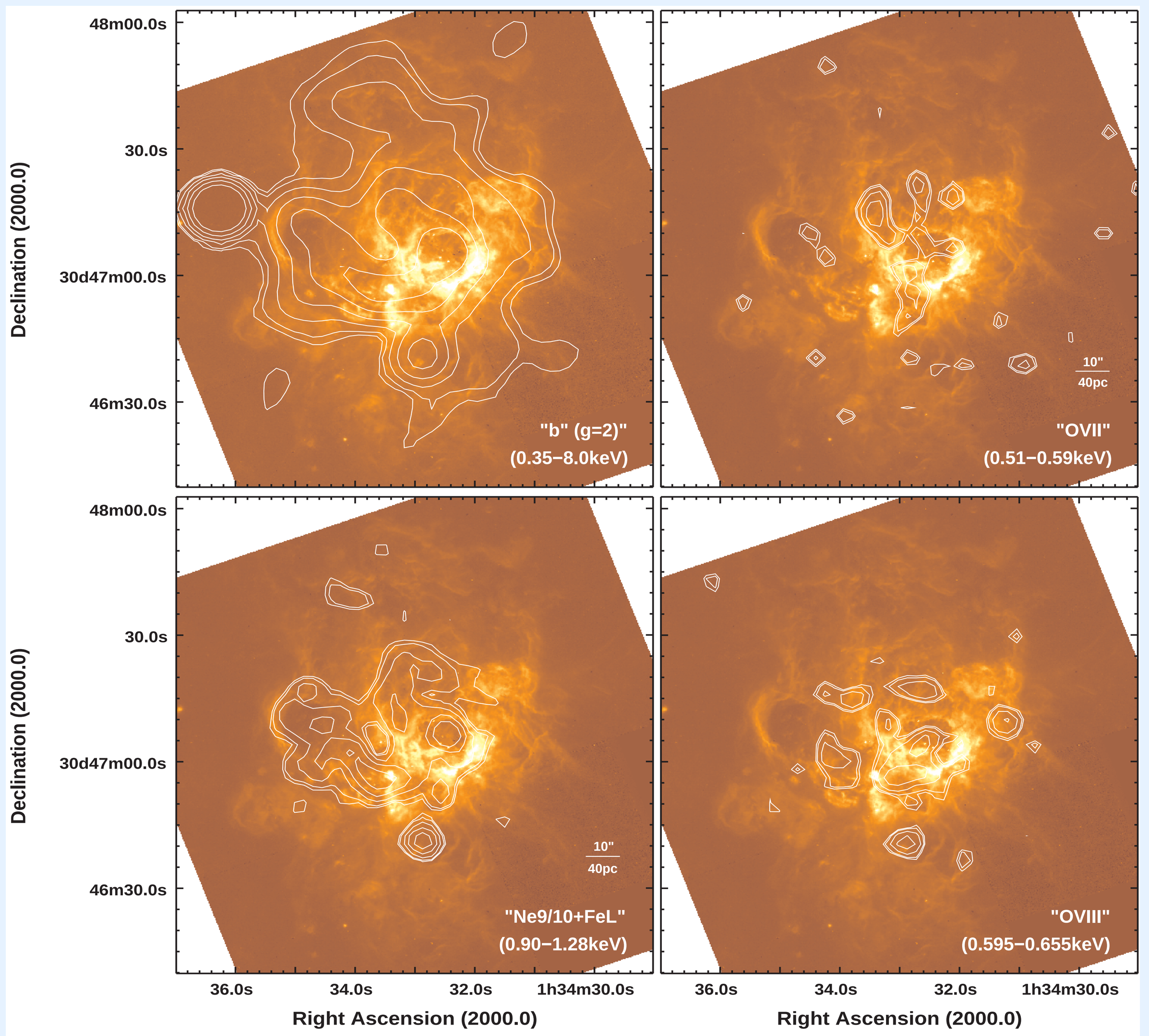

Fig. 4: The "broad"-contour map (upper left) has been smoothed with a gaussian filter of 4" to highlight the overall extent of the X-ray emission.

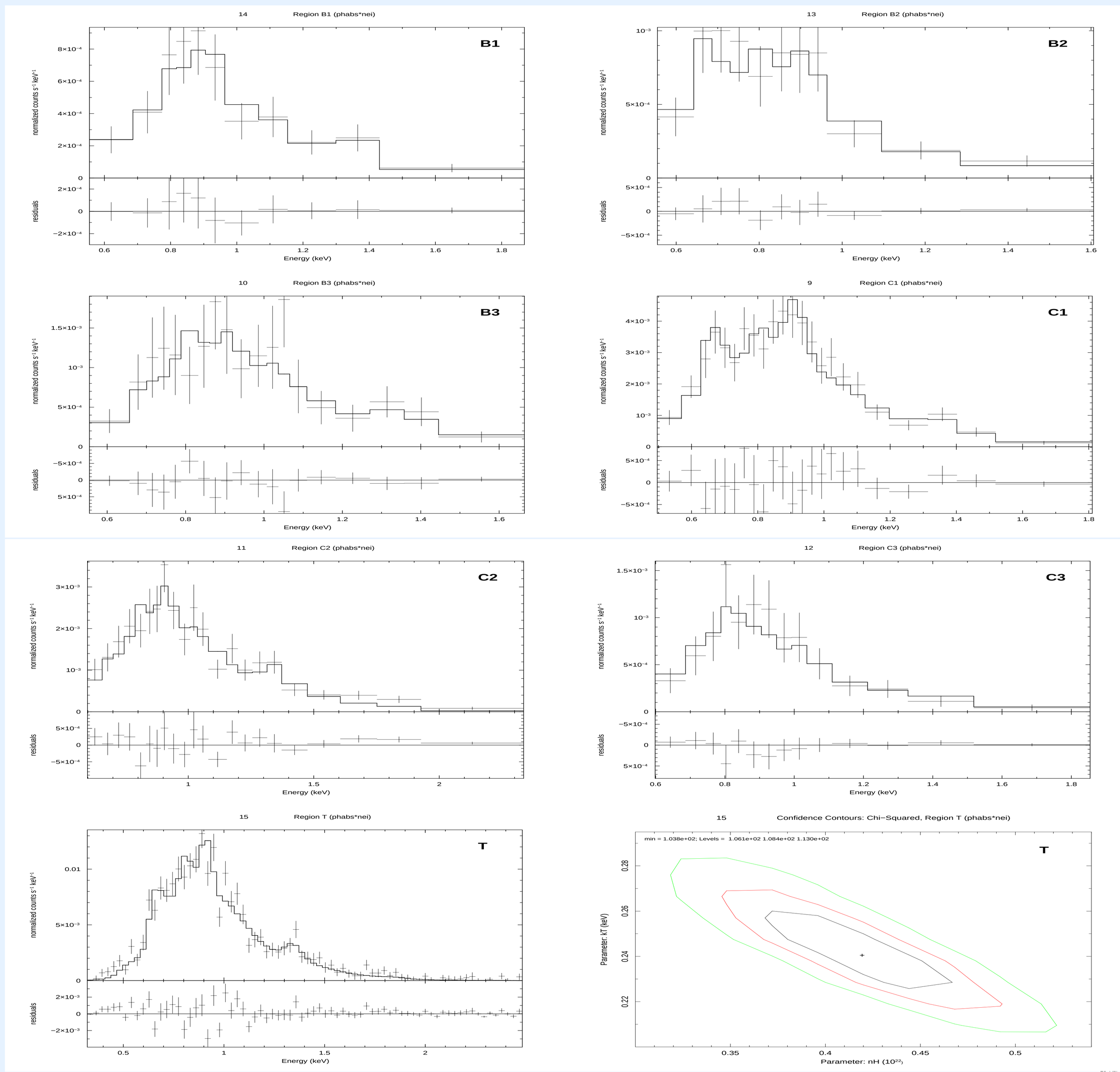

Fig. 5: Spectra extracted from regions shown in Fig. 1 cover the range from 0.35 - 2.5 keV. 90%-confidence contours are plotted for the total diffuse emission (label 'T').

Table 1: Derived physical parameters (diffuse emission only)

Region (1)	unabs. Flux 10^{-14} (erg s^{-1} cm^{-2}) (2)	kT (keV) (3)	T 10^6 (K) (4)	$n_e t$ 10^{12} (cm^{-3} s) (5)	K 10^{-5} (cm^{-5}) (6)	red. χ^2 (dof) (7)	n_e (cm^{-3}) f_V 0.1	0.5	0.8
C1	2.27±0.32	0.325±0.075	3.77±0.87	1.277±	1.770±0.258	1.891 (20)	–	–	–
C2	1.23±1.13	0.810±0.095	9.40±1.10	0.104±	0.373±0.196	1.772 (18)	–	–	–
C3	0.41±0.14	0.567±0.145	6.58±1.68	0.240±	0.193±0.075	0.258 (11)	–	–	–
B1	0.31±0.08	0.616±0.168	7.15±1.95	0.174±	0.125±0.042	0.652 (08)	0.23	0.10	0.08
B2	0.54±0.16	0.536±0.209	6.22±2.42	0.087±	0.123±0.033	0.795 (08)	0.29	0.13	0.10
B3	0.59±0.16	0.685±0.168	7.95±1.95	0.145±	0.225±0.044	0.630 (16)	0.20	0.09	0.07
T	5.27±0.39	0.663±0.016	7.69±0.19	0.111±	1.619±0.091	1.938 (54)	–	–	–

Notes: Col. (1): All spectra were extracted from eventlists cleaned from point sources to trace the pure diffuse emission. Col. (2): Unabsorbed fluxes are derived from the 0.35 - 2.0 keV energy band. All uncertainties are given on a 90%-confidence level. Cols. (3) and (4): Plasma temperatures are derived using Xspec and a (*phabs* × *nei*)-model and freezing the neutral hydrogen column density at $N_H = 5.21 \times 10^{20}$ cm^{-3} (González Delgado & Pérez 2000). A conversion from (keV) → (K) is achieved, using T (K) $= 1.16 \times 10^7 kT$ (keV), with kT being the energy of a thermal source. Col. (5): Ionization time scale calculated by the NEI-model. Uncertainties are unconstrained. Col (6): The normalization constant is defined as $K = \frac{10^{-14}}{4\pi D_A^2} \int n_e n_H \, dV$, where D_A is the angular size distance to the source (cm), and n_e and n_H are the electron and hydrogen densities (cm^{-3}), respectively. Col. (7) gives the reduced χ^2 and the degree of freedom of the fit. The last three columns list electron densities calculated for 3 different volume filling factors.

3. Conclusions

- Soft X-ray emission is substantially more extended along the N-S axis of NGC604 than previous measurements indicate. Its spatial extent amounts to 93" (= 372 pc) and thus reaches almost the full extent of the Hα-emitting gas (∼424 pc).
- NEI-plasma temperatures derived from spectral fits (Fig. 5) are in agreement with expectations for superbubbles driven by SNe and stellar winds (e.g., Breitschwerdt 2004).
- There is a remarkably good anti-correlation between warm and hot ionized gas (see e.g., bubble B3).
- For electron densities $n_e \leq 0.1$ cm^{-3} we obtain high filling factors ($f_{HIM} \sim 0.8$). This is reasonable given the lack of photoionized gas in these regions (Tenorio-Tagle et al. 2000).
- All cavities (C1-C3) and bubbles (B1-B3) are filled with X-ray hot gas (see Figs. 3 and 4).
- Bubble B3 seems to be shadowed from the main site of star formation and appears like a closed shell, filled with hot gas. We speculate that a break-out has not yet occured.
- The X-ray-ridge visible in cavity C1 next to the Hα-ridge (Fig. 2) can likely be attributed to gas being shocked as it impinges onto the Hα-ridge.
- As the high-pressure wind-driven X-ray gas is able to penetrate the whole volume (cf. emission in cavity C3) it seems plausible to assume break-out of hot gas on large scales (see also Tenorio-Tagle et al. 2000).

This work is supported by NASA Chandra award number GO6-7073A.