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CHANDRA OBSERVATIONS OF M 17, THE OMEGA NEBULA

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RESUMEN

Presentamos los primeros imágenes y espectros de rayos-X a alta resolución espacial de la nebulosa Omega, que se obtuvieron en una sola observación de 40 ksec con el espectrómetro de imagenes en el CCD avanzado a bordo del *Observatorio de Rayos-X Chandra* en marzo del 2002. Esta región rica en formación de estrellas masivas revela una mezcla compleja de fuentes puntuales y emisión de rayos-X difusa. La asociación OB está resuelta al nivel de segundos de arco en más de 900 fuentes. La emisión difusa de rayos-X suaves se extiende por toda la región H II y se resuelve separadamente de la población de fuentes puntuales. Lo más probable es que esta emisión extendida provenga de los vientos rápidos de las estrellas O que termalizan y forman choques en el medio ambiente.

ABSTRACT

We present the first high-spatial-resolution X-ray images and spectra of the Omega Nebula, obtained in a single 40 ksec observation with the Advanced CCD Imaging Spectrometer aboard the *Chandra X-ray Observatory* in 2002 March. This rich, high-mass star-forming region reveals a complex mix of point sources and diffuse X-ray emission. The OB association is resolved at the arcsecond level into more than 900 sources. Soft diffuse X-ray emission pervades the H II region and is resolved from the point source population. This extended emission is most likely from the fast O-star winds that thermalize and shock the surrounding media.

Key Words: **H II REGIONS — ISM: BUBBLES — STARS: WINDS, OUTFLOWS — X-RAYS: STARS**

1. INTRODUCTION

Massive-star-forming regions present a microcosm of starburst astrophysics, where stellar winds from O and Wolf-Rayet (WR) stars compete with supernovae (SNe) to carve up the neutral medium from which they formed and to return processed material to the ISM. High-resolution X-ray images may reveal a menagerie of objects, from protostars and OB/WR stars to wind-swept bubbles, superbubbles, chimneys, and supernova remnants. By studying a population of these fields with varying ages and stellar content with *Chandra* and *XMM-Newton*, we hope to resolve and characterize the X-ray stellar population and to detect and learn more about the origins of any diffuse emission that may be present. Overviews of this effort have been presented by Feigelson (2001) and Montmerle et al. (2003).

Here we concentrate on the recent 40 ksec *Chandra*/ACIS observation of M 17, a young (~ 1 Myr; Hanson, Howarth, & Conti 1997) high-mass star-forming region (HMSFR) at 1.6 ± 0.3 kpc (Nielbock et al. 2001) containing two O4 stars and several O5–O6 stars. Papers on the M 17 X-ray point-source population and the diffuse X-ray emission clearly detected in this field are in preparation.

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2. M 17, THE OMEGA NEBULA

M 17 is an edge-on version of the Orion K-L region, a blister on the edge of a giant molecular cloud (GMC) with an ultra-compact H II region (UCHIIR), water masers, and the massive, dense core M 17SW. The H II region is a strong, thermal, radio source, exhibiting high ionization. Its ionizing cluster has 100 stars earlier than B9 (Orion has 8); the earliest stars are a pair of O4 stars known as Kleinmann's Star (Kleinmann 1973).

Figure 1 shows the *ROSAT* PSPC observation of M 17 (left panel) and a Digitized Sky Survey (DSS) image (middle panel) for comparison. The ionizing OB stars are centered in a dark bay at roughly (18:20:32, −16:10:11) in the DSS image. The soft X-rays are spatially coincident with the bubble blown by the OB stars (seen as faint emission to the east of the bright nebula in the DSS image). The right panel shows a smoothed soft-band image of the *Chandra* observation. The field of view is smaller than the *ROSAT* image, but note the large number of point sources now resolved.

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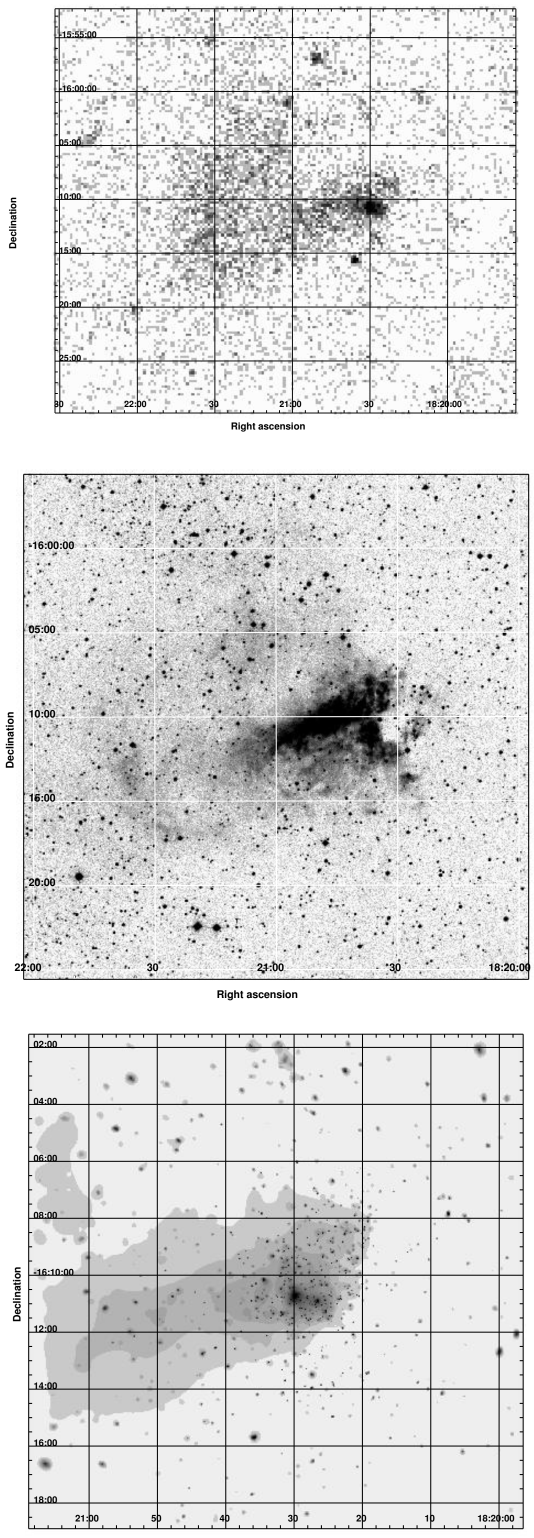

Fig. 1. Top: *ROSAT*/PSPC image of M 17 ($\sim 38' \times 43'$). Middle: Visible image of M 17 from the Digitized Sky Survey ($\sim 30' \times 30'$). Bottom: Smoothed *Chandra*/ACIS image of M 17, 0.5 to 2 keV, $\sim 17' \times 17'$.

2.1. *The Point Sources*

We study the point-source populations of HMSFRs in X-rays because they can help to determine cluster membership and because X-rays penetrate the obscuration, allowing us to study the pre-main-sequence (PMS: i.e., T Tauri, protostar) population (Feigelson & Montmerle 1999), which exhibits high magnetic field phenomena (flaring). We can also study X-ray properties of intermediate- and high-mass stars, such as variability and spectra (Schulz et al. 2001; Feigelson et al. 2002).

Figure 2 (left) shows a binned image of our data covering the full $17' \times 17'$ field of view of the ACIS-I array. The middle panel is a blow-up of the region just around the aimpoint; this illustrates the need for *Chandra*'s spatial resolution in these confused regions. We detect ~ 900 point sources, more than half with fewer than 20 counts. Simple spectral analysis was performed on the 348 sources with more than 20 counts. Absorptions range over $20 < \log N_{\rm H} < 24$, with $\langle \log N_{\rm H} \rangle = 22.2\,{\rm cm}^{-2}$ ($A_V = 8$ to $9\,{\rm mag}$). Plasma temperatures are often not well determined for the faintest sources. For the 195 sources with more than 30 counts, $0.4 < kT < 9.1\,{\rm keV}$, with $\langle kT \rangle = 3.2\,{\rm keV}$. Full-band (0.5 to 8 keV) X-ray luminosities, corrected for absorption, range over $29.6 < \log L_{\rm x} < 33\,{\rm erg\,s}^{-1}$, with $\langle \log L_{\rm x} \rangle = 30.9\,{\rm erg\,s}^{-1}$, for the 348 sources with more than 20 counts. We find 134 matches to NIR sources from Hanson et al. (1997). Roughly 100 sources show possible flaring, detected as variations in their X-ray lightcurves. Other sources may be variable, but presented too few counts to assess their variability.

2.2. *The Diffuse Emission Spectrum*

We removed the point sources that were detected in the M 17 field, then considered all remaining counts to be diffuse emission. We concentrated on the soft diffuse emission in the left half of the field, away from the highest concentration of underlying unresolved stars associated with the OB stars ionizing the nebula. There may be hard diffuse emission closer to the ionizing sources, but it is not spatially distinct from the stars and must be due at least in part to the unresolved PMS population. M 17 is so young that corruption by SNe is unlikely, so the diffuse X-rays probably come from the OB winds interacting with each other and/or the nebular material.

An example spectral fit to part of the M 17 diffuse emission is shown in the right panel of Fig. 2. The best-fit (reduced $\chi^2 = 1.12$) model is a two-temperature thermal plasma, with components at 2

TABLE 1

DIFFUSE X-RAYS FROM HMSFRS[a]

Region	Distance (pc)	Diffuse X-rays Soft	Diffuse X-rays Hard	Earliest Star
Orion[b]	450	no	no	O6
Rosette	1600	yes	no	O4
Omega	1600	yes	maybe	O4
Lagoon[c]	1800	maybe	no	O4
Eagle	2000	no	no	O5
W 3[d]	2300	···	no	O5
Carina	2300	yes	no	O3/WR
NGC 3603[e]	7000	no	yes	O3/WR
W 51	7500	···	yes	O4
Arches[f]	8500	···	yes	O3/WR
30 Dor	50000	yes	no	O3/WR

[a]Many of these regions contain UCHIIRs or high-mass protostars, so the "earliest star" is approximate and notes the earliest spectral type given in the literature.

[b]Feigelson et al. (2002) [c]Rauw et al. (2002) [d]Hofner et al. (2002) [e]Moffat et al. (2002) [f]Yusef-Zadeh et al. (2002).

and 6 million degrees, $N_{\rm H} = 5 \times 10^{21}\,{\rm cm}^{-2}$ ($A_V = 2.5$), and a soft-band X-ray luminosity (corrected for absorption) of $9 \times 10^{32}\,{\rm erg\,s}^{-1}$ at 1.6 kpc. Other regions show similar spectra and similar fit parameters; we find no change in temperature as a function of distance from the ionizing stars. The total soft-band X-ray luminosity for the entire region is $\geq 3 \times 10^{33}\,{\rm erg\,s}^{-1}$.

3. M 17 IN CONTEXT

To further the efforts of Feigelson (2001) (Table 1), we would like to put the M 17 diffuse emission in a broader context by comparing it to diffuse emission from other star-forming regions. Table 1 provides a sampling of HMSFRs observed by *XMM* and *Chandra*; several other regions have recently been observed or will be soon, so this table will change substantially over the next year.

Soft diffuse X-rays are seen nearby, *if* there are very early O stars and low $N_{\rm H}$. We see little or no hard diffuse emission nearby, presumably because this is mostly resolved into the underlying PMS population. In more distant Galactic H II regions, the high $N_{\rm H}$ obscures soft X-rays, but they almost certainly are there, affecting the evolution of these embedded regions. Hard diffuse X-rays may be due to

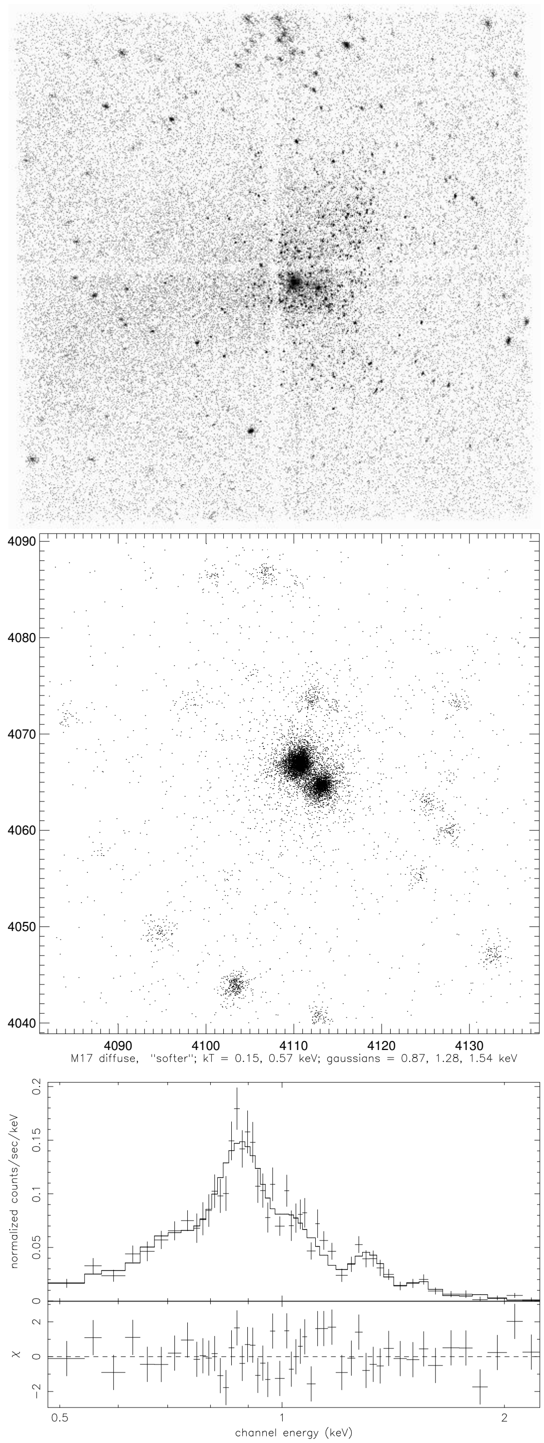

Fig. 2. Top: *Chandra*/ACIS full-band (0.5 to 8 keV) image of M 17, binned at 4×4 pixels to show the entire ACIS-I array and scaled to emphasize the > 900 point sources detected in the field. Middle: Scatter plot of ACIS events near the aimpoint of the observation. The axis spacing is one ACIS pixel (∼ 0.5″). The O4-O4 binary known as Kleinmann's Star is clearly resolved. Bottom: Spectrum of part of the M 17 diffuse emission. Other regions give similar results.

the underlying IMF of PMS stars, UCHIIRs, SNe, wind collisions, or other means.

Out of the Galactic plane, we see soft X-rays again because $N_{\rm H}$ is reduced. There is no hard diffuse component in the central cluster R 136 in 30 Doradus, perhaps because the PMS flares are too faint to be detected at 50 kpc in the short (20 ksec) ACIS observation. The superbubbles there are not detected above 2 keV (Townsley et al. 2002). In 30 Dor and other extragalactic HMSFRs, SNe complicate the picture, adding to, or dominating, the soft X-ray emission (Chu 1997).

In summary, *Chandra* has resolved soft diffuse emission from the underlying stellar population in Galactic H II regions and 30 Doradus. This diffuse emission is not seen in every H II region; its presence seems to require very early O stars. Theories to explain the soft diffuse emission must accommodate a range of plasma temperatures (1 to 10 MK with multiple components), low luminosities ($L_{\rm x} \sim 10^{32}$ to 10^{33}), and center-filled morphologies. Hard diffuse emission may be present in some regions, but it is not spatially distinct from the underlying stellar population and is probably made up at least in part of unresolved PMS stellar X-rays. M 17 is the best example so far of diffuse soft X-ray emission almost certainly caused by O stars; this diffuse emission is clearly detected and resolved from the point source population by *Chandra*.

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