COMPLET(E)ING THE STAR-FORMATION HISTORY OF THE RHO-OPH REGION

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Abstract

We propose to use XMM to characterize the members of a little-known cluster of stars lying within and near a ring of heated dust around the B-star ρ-Oph. The stars in this cluster are likely to be young enough to be X-ray active, but old enough to be hard to identify as pre-main-sequence using near-infrared surveys alone. We are particularly interested in this cluster because morphological evidence shows the shell surrounding the brightest star in the cluster ρ-Oph to be impinging on the dense gas 2 pc to its south, which itself is *currently* forming a cluster of stars. Unfortunately, this very young cluster to the South, and the dense gas immediately around it, are usually called by the name "ρ-Oph," even though the real star ρ-Oph lies 2 pc (1 degree) to the North. Thus, in a few confusing words, our proposal seeks to determine, by measuring positions, and likely masses and ages of young stars, whether the formation of the "real" r-Oph cluster may have triggered the formation of the "famous " cluster known as "ρ-Oph" 2 pc to its South.

Scientific Motivation

The interaction of newly formed stars with their parent cloud, particularly in the case of massive stars, can have significant consequences for the subsequent development of the cloud. Hot, massive stars will cause cloud disruption through their ionizing flux as well as through the momentum in their stellar winds. Alternatively, given the right conditions in the cloud, stellar winds may also cause the collapse of cloud cores and induce further star formation. Whether star formation does happen sequentially, prompted by previous generations of such events, or they all happen quickly in one dynamic time scale causing cloud dispersion along the way is a fundamental question under debate (Elmegreen 2000; Hartmann et al. 2001; Tassis & Mouchschovias 2004).

The "ρ-Oph" Cluster

Located only 125pc (de Geus et al. 1989) from the Sun, the Ophiuchus molecular cloud is one of the most conspicuous nearby regions where low- and intermediate-mass star formation is taking place (Wilking 1992). The westernmost core, L1688, harbors a rich cluster of young stellar objects (known as the "ρ–Oph"[1] cluster; see Figure 1) at various evolutionary stages and is distinguished by a high star-formation efficiency (Wilking & Lada 1983 - hereafter WL83). Gas and dust in this dense molecular core region have been extensively mapped (WL83; Loren 1989; Motte et al. 1998).

The stellar content of the "ρ–Oph" cluster has also been observed at wavelengths ranging between the X-ray and the radio band. In X-rays, Einstein and ROSAT surveys revealed highly variable sources associated with magnetically-active young stars (Montmerle et al. 1983, Casanova et al. 1995). In the near-infrared, several surveys (e.g. Barsony et al. 1997) have discovered more than 200 low-luminosity embedded sources. In the centimeter radio continuum range, several VLA surveys have resulted in the discovery of more than 20 radio-emitting YSOs (e.g. Leous et al. 1991). The Spitzer IRAC observations reveal more proto-star candidates, most likely embedded in dense gas (L. Allen private communication).

The star ρ–Oph, however, is located one degree to the north and is not a member of the "ρ–Oph" cluster. Much less is known about the gas and stars around the star ρ–Oph. In the next section, we will discuss why the region around the star ρ–Oph is important for understanding the star formation history of the whole ρ–Oph region.

The ρ-Ophiuchi Ring

As part of the COMPLETE[2] Survey of nearby star forming regions, we have recently constructed new temperature and thermal-emission (column density) maps of the Ophiuchus region from IRAS Sky Survey Atlas

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[1] In this proposal, we refer to the your star cluster in L1688 with quote marks, because the *star* ρ–Oph is 1 degree to the north , approximated centered in ring under study.

[2] **Co**-**O**rdinated **M**olecular **P**robe **L**ine, **E**xtinction and **T**hermal **E**mission; http://cfa-www.harvard.edu/COMPLETE

(ISSA) 60 and 100 μm images, and we were surprised to find ring of warm (37K) dust located approximately 1° to the north of the ρ–Oph star-forming region (Figure 1; Li et al. 2004).

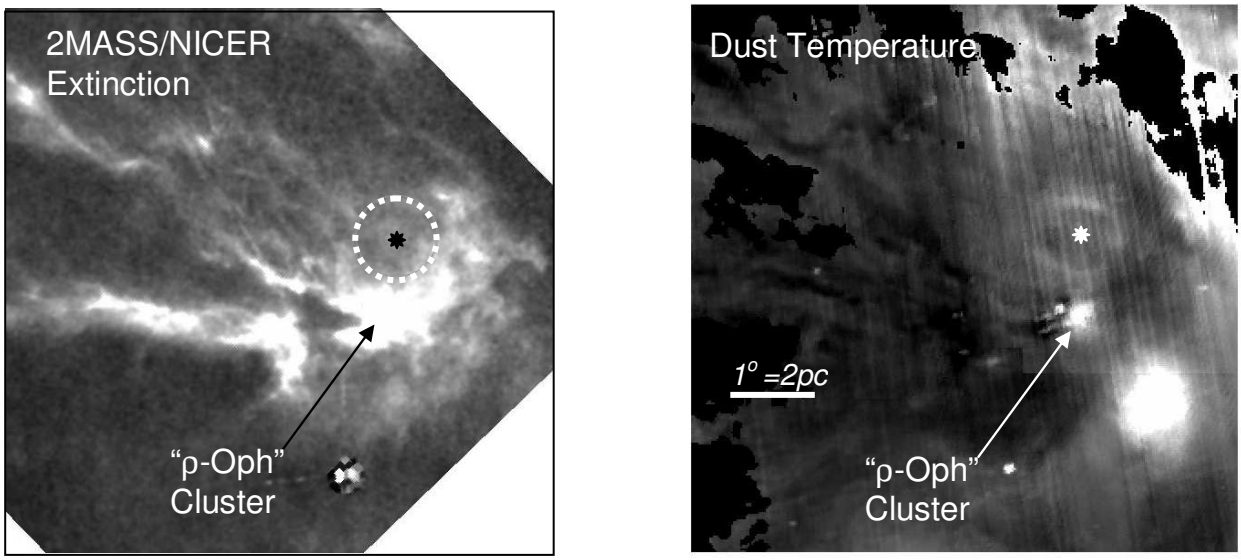
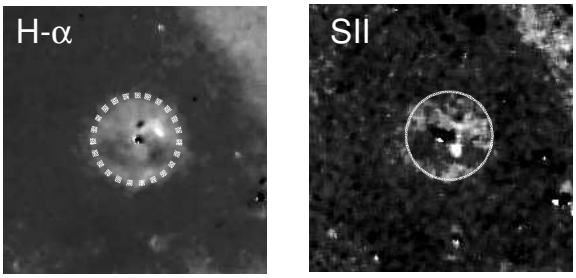


Figure 1: The two upper panels, taken from the COMPLETE Survey, show extinction based on 2MASS data and dust temperature based on IRAS 60 and 100 μm flux. The star symbol in both panels shows the position of the B-star ρ-Oph and the ROSAT source 1RXSJ162554.5-233037 (see text). The prominent warm ring around this "starred" position is also associated with shell-like ionized gas emission, shown in the panels at right (SHASSA data, courtesy J. Gaustad). The cluster *known as* "ρ-Oph" is actually 1 degree (2 pc) to the *South* of the star ρ-Oph.



Comparison with the extinction map from 2MASS (Alves et al. 2004 as part of COMPLETE) shows that the ***ρ-Ophiuchi ring*** sits inside a "nook" of high-extinction (i.e. cold dense material) on the northern edge of ρ-Oph. In fact, this ring was reported by Bernard et al. (1993) in a discussion of the far-infrared emission from Ophiuchus and Chamaeleon, but they did not investigate its nature or possible progenitor. The ring is roughly centered on the young BIV star, ρ–Oph, which also powers an oft-photographed bright nebula. The SHASSA[3] H-α image shows a circular limb-brightened nebulosity, indicating that the IRAS dust ring is possibly due to a powerful stellar wind or HII region, most likely from ρ–Oph itself. The [SII] emission also shows a bubble coincident with the H-α. A preliminary look at the ratio between H-α and [SII] intensities suggest the existence of a shock front, which is consistent with absorption line studies of CH and CH^+ toward the star ρ–Ophiuchi (de Geus 1992).

The presence of a probable HII region suggests that the star ρ–Oph is probably still relatively young, and it would therefore be located near to its birthplace and, assuming a Salpeter-like IMF, within a cluster of several hundred low or intermediate mass stars. If this is the case, then this cluster would comprise a significant fraction of the total young stars in the region, and its existence of would provide strong evidence for an earlier epoch of star formation in Ophiuchus, suggesting a scenario where the formation of the cluster associated with the B star ρ–Oph trieggered the formation of the "ρ–Oph" cluster 2 pc to the South.

In summary, the ρ–Ophiuchi ring region combined with the ρ-Oph clouds could become an ideal lab for studying sequential star formation due to their near distance and wealth of multi-wavelength observations availale.

[3] Southern H-alpha All Sky Survey Atlas; http://amundsen.swarthmore.edu/SHASSA/

For the ring region, the COMPLETE team has been mapping the gas at FCRAO and the dust at JCMT (Johnstone et al. 2004). XMM would provide crucial information, currently missing, on the nature of the young cluster likely associated with the star ρ-Oph.

Why Use XMM?

The wide-field X-ray imaging telescopes of XMM are suitable for detecting nearby clusters in a large area with considerable extinction and modest source density.

The existence of a bright nebula and high extinction in the region has made it difficult to search for a cluster associated with ρ-Ophiuchi through Optically. An H-α survey by Wilking et al. (1987) found just a few stars close to ρ-Ophiuchi, but the more recent SHASSA H-α image and 2MASS K-band images of the area surrounding the star seem to show an over-density of stars. However, neither H-α or 2MASS observations can be used as an unbiased method to identify young stars. Both H-α and K-band excess are strong evidence for the presence of disks, but this criterion will miss "older" pre-main-sequence stars (e.g. weak line T-Tauri stars, wTTs) which have already shed most of their circumstellar material. WTTSs are well-known to have X-ray emission due to energetic processes on their surfaces, thought to be related to their dynamic magnetic fields, and X-rays have the added advantage of being able to penetrate the high line-of-sight extinction towards regions of recent star formation. For these reasons it has become popular to search for young stars in the X-ray (e.g. Glassgold et al. 2000 and refs. therein).

XMM observations would also help clarity the origin of the ρ-Ophiuchi ring by provide spectral information of sources located near the ring center. In particular, the ROSAT source 1RXSJ162554.5-233037 (Figure 2) discovered by Snowden et al. (1994) in a pointed observation has well-determined Hardness Ratio 2=1.0 and Hardness Ratio 1=0.6, which make it an excellent candidate to be some kind of "exotic" compact object (e.g. neutron star, accreting binary). Furthermore, with only a small dose of imagination, one can see that most of the ROSAT sources discovered around ρ-Ophiuchi lie on another ring, concentric to the IRAS ring (see the small circle in Figure 2). Are these indications of a supernova event or other triggering events? The XMM-Newton observations proposed below will easily reveal whether or not this "ring" pattern in the ROSAT sources is real.

Since most targeted X-ray observations of this region to date have been of the cluster in the dense ρ-Oph cloud (e.g. Grosso et al. 2000; Imanishi et al. 2001), we intend to utilize large field of view and spectral capability of XMM to study the stellar content of the ρ-Ophiuchi ring in order to add a crucial piece of puzzle of the star formation history of the whole region.

Technical Requirements and Justification

First, we seek to detect many new sources unseen by ROSAT with three overlapping 15ks observations (Figure 2). The XMM-Newton visibility checker shows no problem with observing this region of Ophiuchus in this way. In 15 ks, XMM can obtain about 100 counts from a source with an unabsorbed flux of about 10^{-13} ergs cm^{-2} sec^{-1} at the distance of the cloud. Assuming an absorbing column $N_H = 10^{22}$ cm^{-2}, we thus expect to detect 75% of stars at ~0.3 $M_\odot$. (Using our high quality 2MASS extinction map shown in Figure 1, we will be able to get accurate absorbing column.) Such sensitivity would facilitate detection of more than 50 sources. The data would also provide positions better than ROSAT to these sources allowing a much better examination of their spatial arrangement (the smaller ring?) and identification of their proper 2MASS counterparts if any.

Second, the proposed XMM observations will provide spectral characteristic for bright sources, particularly 1RXSJ162554.5-233037. ROSAT saw a count rate in 1RXSJ162554.5-233037 of about 0.016 cps. Using PIMMS we modeled this source as a Gamma=2 power law with $N^H = 10^{22}$ cm^{-2}. The estimated count rate is 0.76 in the PN with the medium filter and 1.33 cps in the sum of the EPIC+MOS2 detectors. We fit the simulated spectrum of the central object and were able to recover the power-law and column to less than 5%. Iron emission will be easy to detect if present. Pileup will be small, only about 4%. Most of the sources in the ROSAT field are as bright as 1RXSJ162554.5-233037, so similar quality spectra will be obtained. The time resolution of the PN detector gives us sensitivity to periods slower than 150 ms, appropriate to detect all but the very youngest (<10 kyr) rotation-powered pulsars. With about 10,000 counts per observation in the PN detector and assuming a sinusoidal pulse profile, a blind periodicity search will be sensitive to pulsed fractions as small as 10%. We could improve this by another factor of ~2 if the pulse shape is narrow or if the three observations are closely spaced in time.

In summary, the three pointing proposed here would be adequate to detect the real ρ-Oph cluster and characterize the spectral properties of bright sources.

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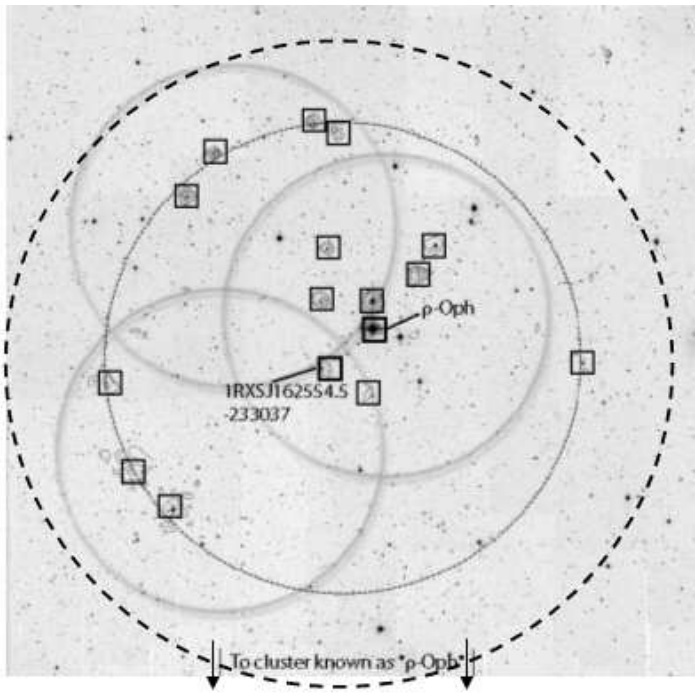

Figure 2: 2MASS image overlaid with ROSAT contours of 0.3, 0.5, 1.0, 1.5, and 3.0 counts/arcsec. The dotted circle is 1° across and shows the location of the r-Ophiuchi ring. The smaller squares are possible ROSAT sources, some of which seems to lie on a smaller circle. The three overlapping circles indicate proposed XMM pointing fields, which cover major portions of the ring region rich in X-ray souces.

Previous XMM Observations

PI has no previously scheduled XMM time.

Relevant Recent Publications

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