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Synergy of multi-frequency studies from observations of NGC 6334I

Andreas Seifahrt[1], Sven Thorwirth[2], Henrik Beuther[3], Silvia Leurini[4], Crystal L Brogan[5], Todd R Hunter[5], Karl M Menten[2] and Bringfried Stecklum[6]

[1] Georg-August-Universität, Institut für Astrophysik, Friedrich-Hund-Platz 1, D-37077 Göttingen, Germany
[2] Max-Planck-Institut für Radioastronomie, Auf dem Hügel 69, D-53121 Bonn, Germany
[3] Max-Planck-Institut für Astronomie, Königstuhl 17, 69117 Heidelberg, Germany
[4] European Southern Observatory, Karl-Schwarzschild-Strasse 2, D-85748 Garching, Germany
[5] NRAO, 520 Edgemont Rd, Charlottesville, VA 22903, USA
[6] Thüringer Landessternwarte Tautenburg, Sternwarte 5, D-07778 Tautenburg, Germany

E-mail: `seifahrt@astro.physik.uni-goettingen.de`

Abstract. We combine multi-frequency observations from the millimeter to near infrared wavelengths that demonstrate the spatial distributions of H_2, CO, and NH_3 emission, which are all manifestations of various shocks driven by outflows of deeply embedded source(s) in NGC 6334I. In addition to the well-known northeast-southwest outflow we detect at least one more outflow in the region by combining observations from APEX, ATCA, SMA, *Spitzer* and VLT/ISAAC. Potential driving sources will be discussed. NGC 6334I exhibits several signs of active star formation and will be a major target for future observatories such as *Herschel* and ALMA.

1. Multi-frequency studies in NGC 6334I

NGC 6334 is a giant molecular cloud located at a distance of 1.7 kpc [1] in the southern galactic plane. Along a gas and dust filament of 11 pc, NGC6334 exhibits several luminous sites of massive star formation, as seen in the far-infrared [2] and radio continuum [3]. Emission from the sub-site NGC 6334I dominates the millimeter to the far infrared region [4]. A near-infrared image of the NGC 6334 is shown in Fig. 1, where we combine the *Spitzer* IRAC channels to a colour composite.

Single dish molecular line observations show NGC 6334I to be chemically rich, comparable in line density (and hence chemical complexity) to prototypical hot cores such as Orion-KL and Sgr B2(N) (e.g., [5, 6]). ATCA investigations of NH_3 emission up to the (6,6) inversion transition reveal the presence of warm gas [7]. SubMillimeter Array (SMA) continuum observations at 1.3 mm [8] resolve NGC 6334I into a sample of sub-cores of several tens of solar masses each, nicely demonstrating the formation of star clusters.

NGC 6334I has also been observed in the infrared [9]. In recent years, with the advent of the new generation of large optical/infrared telescopes of the 8–10-m class, several pioneering studies have been performed. Mid-infrared CTIO and Keck II imaging of NGC 6334I resolving the central UCHII region into two distinct sources was reported [10]. Magellan-Clay PANIC

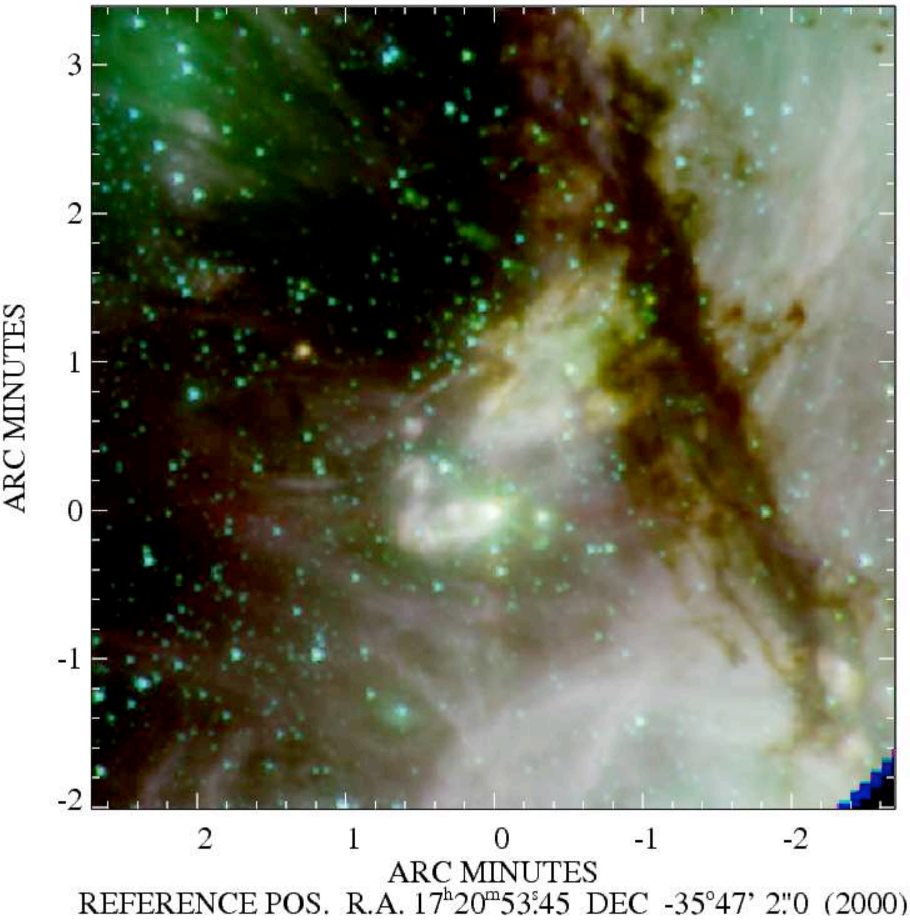

Figure 1. Colour composite from *Spitzer* IRAC observations (P.I. Fazio, 'Deep IRAC Imaging of High Mass Protostars') in 3.6μm (blue), 4.5μm (green) and 5.8μm (red). Data source: SPITZER archive facility.

near-IR ($JHKs$) observations identified a high-mass young star, IRS1-E, as the powering source of the UCHII region [9].

Given its rich observational history, NGC 6334I is on its way of becoming one of the very few templates of high-mass star formation in the entire sky. It will also be a major target for future observatories such as *Herschel* and ALMA.

We demonstrate here the synergy obtained from combining published studies from multi-frequency observations with a so far unpublished high resolution VLT/ISAAC image of shocked H_2 gas surrounding the central source of NGC 6334I (see Fig. 2). We identify five knots in the immediate vicinity of NGC 6334I and denote them by α, β, γ, δ, and ϵ (see Fig. 3). While three out of these five H_2 knots were previously known [11], two new knots (γ and δ) could be identified. Their counterparts may lie well hidden behind the UCHII region (see Fig. 4). Two of the previously known knots (α and β) coincide nicely with CO (4-3) emission lobes detected with APEX [12] (see Fig. 5). At least one of the new H_2 knots coincides also with NH_3 maser emission (see Fig. 6), as is the case for the previously known knots, demonstrating the power of combining multi-frequency observations to reveal the morphology of outflows from deeply embedded sources.

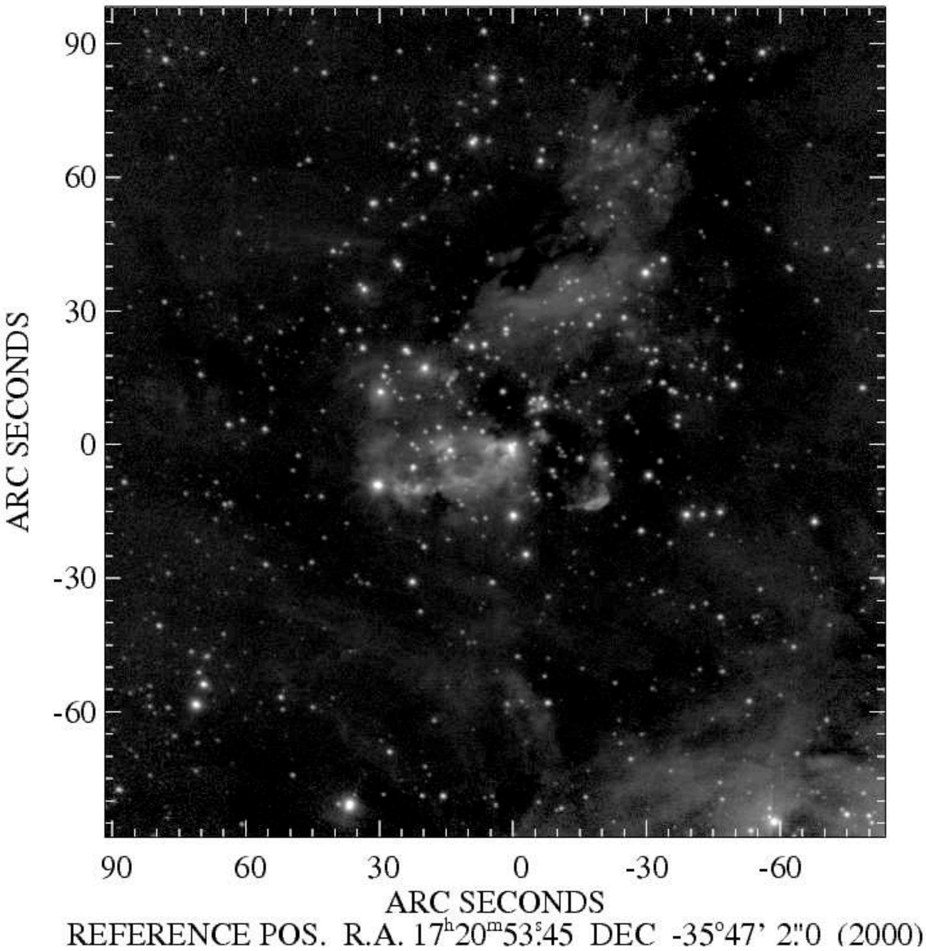

Figure 2. VLT/ISAAC observations in H_2 (2.12μm) and Brγ (2.17μm) combined to one image. The spatial resolution is ~0.5 arcsec.

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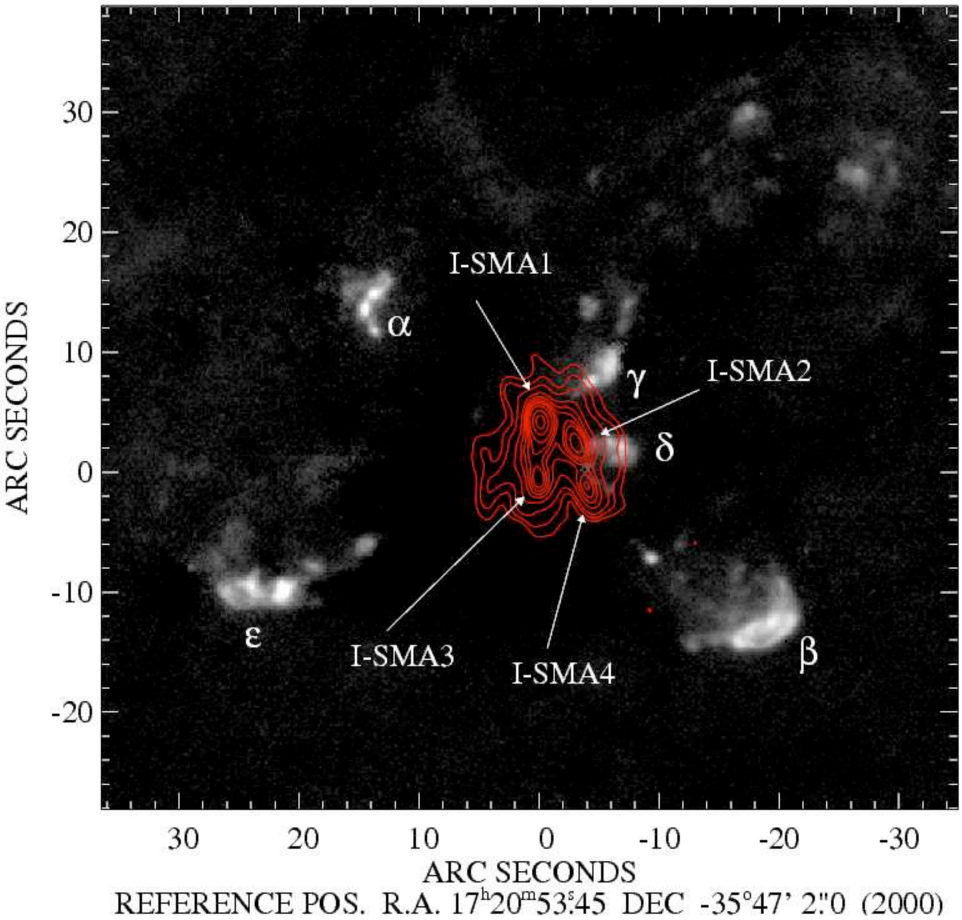

Figure 3. The composite, obtained by subtracting the VLT/ISAAC 2.17μm image from the 2.12μm image (see Fig. 2), shows five H_2 knots in the immediate vicinity of NGC6334I. We denote these knots by α, β, γ, δ, and ϵ. Overplotted as red contours are SMA observations from [8] showing four 1.3 mm continuum sources, denoted by I-SMA 1-4.

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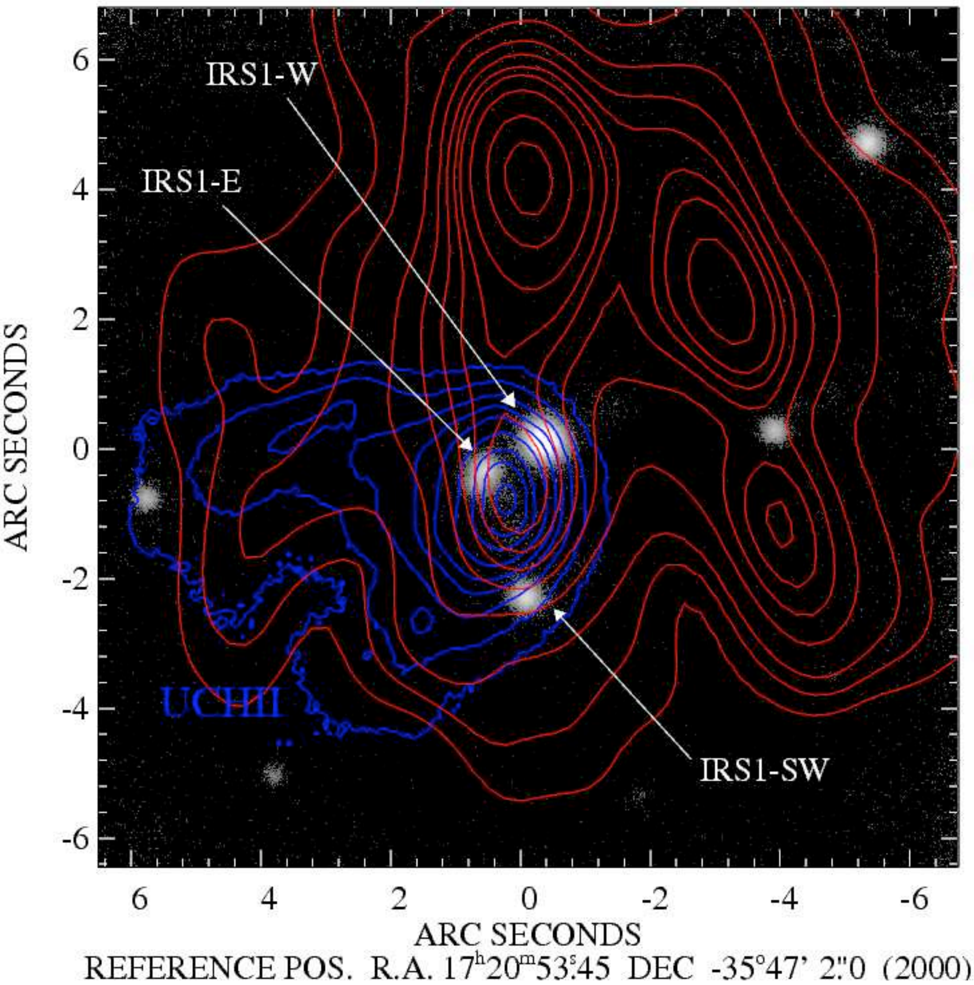

Figure 4. VLT/NACO H-band image, overplotted with the 1.3 mm contours of [8] (red contours) and 3μm continuum emission from a NACO L-band image (blue contours). Three point sources in the NACO image coincide with the 1.3mm source I-SMA3. We adopt the nomenclature of [9]. With a morphology similar to the centimeter continuum, the L-band emission traces the UCHII region, which might be driven by the star IRS1-E.

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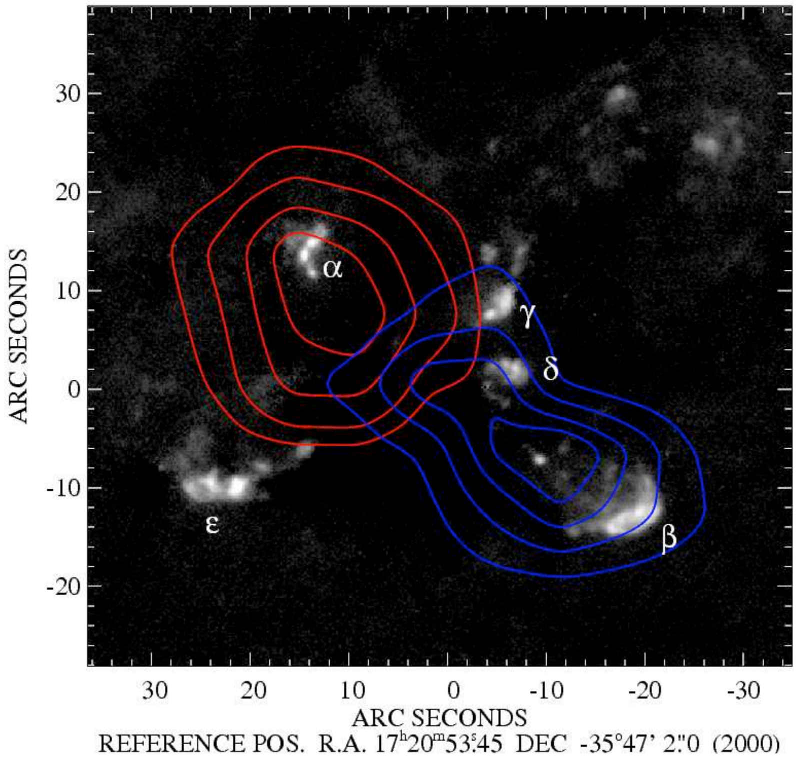

Figure 5. VLT/ISAAC H_2 (2.12μm) emission. Overplotted are APEX observations from [12], showing CO (4-3) emission in the +7 to +55 km/s (red) and −78 to −15 km/s (blue) ranges. Both CO lobes coincide well with the H_2 lobes α and β.

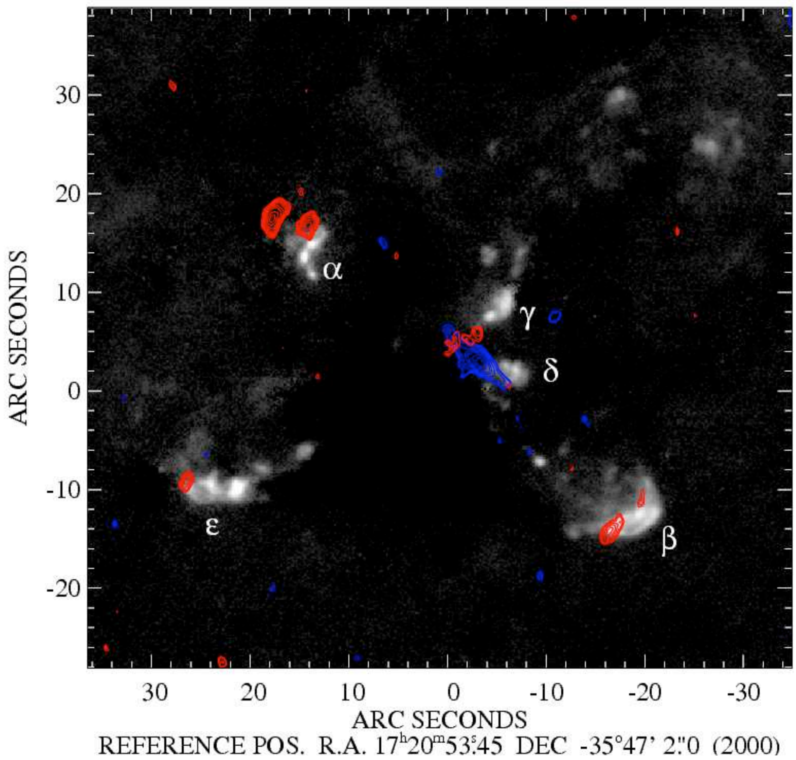

Figure 6. VLT/ISAAC H_2 (2.12μm) emission. Overplotted are ATCA observations from [13] showing NH_3 (3,3) and (6,6) maser emission (red and blue contours, respectively). Note the correlation between the (3,3) emission and the H_2 lobes α, β, and ϵ. The central NH3 (3,3) emission feature seems to connect the H_2 lobe γ with the 1.3 mm source I-SMA I (see Fig. 3).