Evolutionary diversity in a massive protocluster:
Subarcsecond (600 AU) imaging of NGC6334I from 6 cm to 0.8 mm

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Abstract

We explore the evolutionary diversity of the massive protocluster NGC 6334 I using comparable sub-arcsecond resolution (~600 AU at 1.6 kpc) imaging from centimeter to submillimeter wavelengths. Using the recently upgraded Jansky Very Large Array (VLA) at 6 cm, 1.5 cm, and 7 mm and the A and B configurations, we have detected all four members of the massive millimeter protocluster NGC 6334 I in at least one centimeter wavelength. Combined with Submillimeter Array (SMA) imaging at 1.3 mm and 0.86 mm, we analyze the continuum emission, disentangling the dust component from the various types of free-free emission from each object.

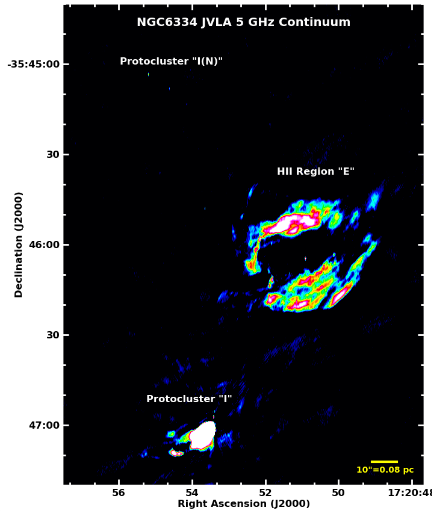

Fig 1: C-band (6 cm, 5 GHz) image from Jansky VLA: With an rms noise of ~20 microJy/beam, a dynamic range of 2200:1 and a bandwidth of 1 GHz, this image reveals the wide diversity of star forming activity across one parsec at the northeast end of the NGC6334 star forming complex. The shell-type HII region "E" is ionized by an O7.5 star (Rodriguez et al. 1982; Carral et al. 2002). This poster concentrates on new detections of the millimeter objects in source "I".

Fig 2a

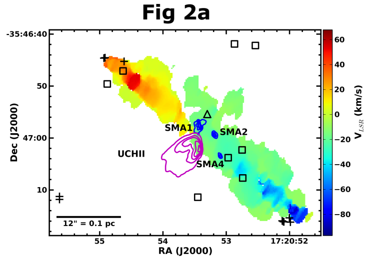

Fig 2a: Bipolar outflow: Moment 1 velocity field of CO(2-1), SMA1 is thought to drive the outflow. The 870 micron continuum is shown in blue contours and 5 GHz continuum is shown in magenta contours. Triangle and squares are 23 GHz & 44 GHz methanol masers (Gomez et al. 2010, Kurtz et al. 2004). Crosses are ammonia (3,3) masers from new B-configuration JVLA data (Brogan et al. in prep). We do not detect any ammonia (6,6) masers in our new data.

Overview of source I:

Adjacent to the well-known UC HII region, three compact millimeter continuum sources were discovered by Hunter et al. (2006) near the center of the high-velocity CO 2-1 bipolar outflow (Fig 2a). In the SMA 1.3mm spectra (Fig 2b), the two brightest sources, SMA1 and SMA2, are responsible for the hot core line emission and are likely to be centrally-heated by one or more protostars. In contrast, SMA4 is essentially a line-free continuum source, but it does contain a recently-discovered 22 GHz water maser (Fig 3a, 3b) .

Fig 2b

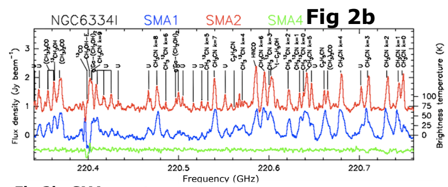

Fig 2b: SMA spectra: The two hot cores SMA1 and SMA2 contrast sharply with the featureless millimeter continuum source SMA4.

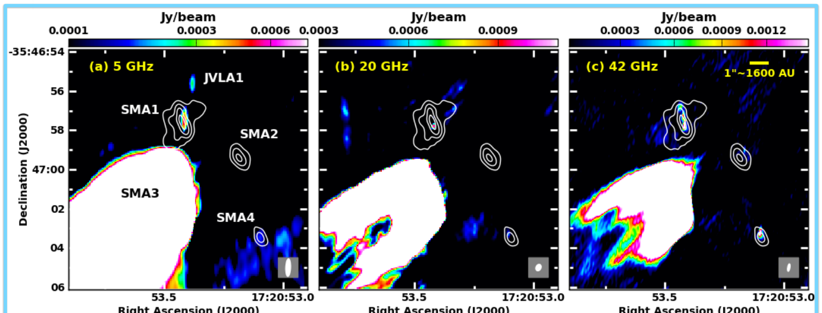

Fig 4abc: New JVLA detections: In all three panels, white contours show the SMA 342 GHz emission.
SMA1: The new centimeter source is point-like at 5 GHz (0.55mJy/b) and 20 GHz (1mJy/b), and is roughly coincident with the 342 GHz peak. Two more components are seen at 42 GHz, matching the 342 GHz morphology and likely due to dust emission.
JVLA1: Detected only at 5 GHz, this new (non-mm) source coincides with a cluster of water masers (Fig. 3a).
SMA2: A 0.9 mJy source is found at 42 GHz, but offset by ~0.5 arcsec from the 342 GHz peak (for ν^4 dust we should expect 0.5 mJy).
SMA4: A 2.6 mJy source is found at 42 GHz, coincident with the 342 GHz peak and consistent with ν^3 dust.

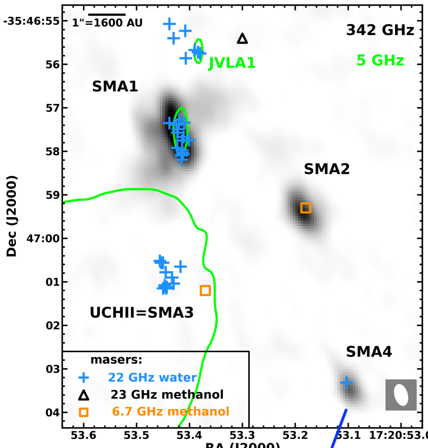

Fig 3a: Green contours show the 0.2 mJy/beam level of 5 GHz emission, with the 342 GHz emission in greyscale. Methanol maser positions are from Caswell (2009).

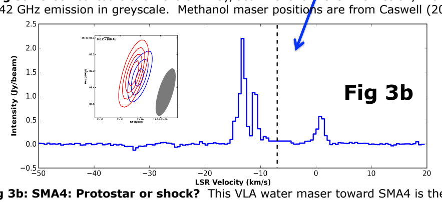

Fig 3b: SMA4: Protostar or shock? This VLA water maser toward SMA4 is the first detection of compact molecular line emission from this submillimeter continuum source. There is a 40 mas (70 AU) shift between the red (+1 km/s) and (-13 km/s) blue peaks, suggesting an enclosed mass of 2 solar, if Keplerian. Alternatively, it could be an outflow.

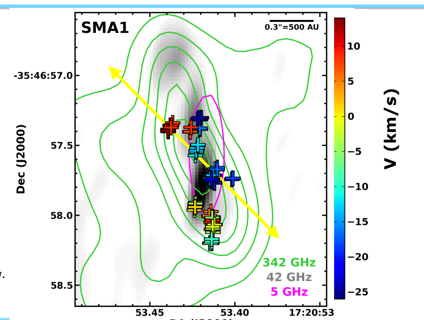

Fig 5: JVLA 42 GHz continuum contours overlaid with fitted water maser positions (epoch 2011.7), color-coded for velocity channel. The red and blue masers to the northeast and southwest of the continuum peak match the sense and orientation of the CO outflow, while the southern masers position-velocity gradient may indicate a disk around second protostar.

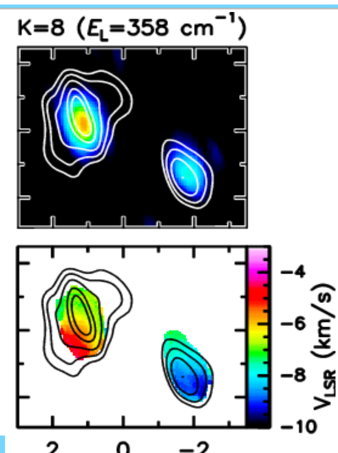

Fig 6: Integrated intensity and velocity field for CH_3CN 12-11, K=8 from the SMA very-extended configuration (beam~0.7"x0.5") showing a SSE-NNW velocity gradient across SMA1 in thermal gas. SMA 870 micron continuum (convolved to the 1.3mm beamsize) is also shown in contours.

Summary

- **Evidence for Multiple Protostars in SMA1:**
  - Multiplicity at Q-band: The 42 GHz image shows 3 separate sources within SMA1, matching the extensions seen in the 342 GHz continuum.
  - Multiple sites of water masers: The high velocity masers pinpoint the origin of the CO outflow to a protostar in SMA1 rather than SMA2. A second concentration of masers may trace a disk a second embedded protostar.
  - The 5 GHz/H2O maser source JVLA1 may trace a jet from another protostar.
- **Evolutionary sequence:**
  - Clearly, the UCHII region (SMA3) is the most evolved source. It lacks compact submillimeter continuum and molecular lines.
  - With the presence of 5 GHz emission, and multiplicity at 42 and 342 GHz and in water masers, SMA1 is the next oldest source.
  - SMA2 comes third, with a 6.7 GHz methanol maser and hot core emission comparable to SMA1 but with narrower line profiles. It has no 5 GHz emission, and the dust continuum emission (with spectral index of ~4) is more compact than SMA1.
- **What is SMA4?**
  - We see signs of star formation activity in SMA4 in the form of water masers. But its lack of thermal mm lines remains perplexing because the continuum brightness temperature is 80K (integrated flux/fitted size). The 7mm-1.3mm spectral index is ~2.9.