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Black Holes and Massive Stars

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ABSTRACT

Black Holes in the centers of galaxies, and high mass protostars have much in common. Both are hard to observe directly. Radiation cannot escape from Black Holes, but we can observe the radiation from accreting material as it falls into the Black Hole. High mass stars form in dense dusty gas, but we can observe the thermal radiation, and molecular lines from the gas and dust heated by the protostar. Accretion in Black holes and high mass protostars is mediated by accretion disks which export angular momentum from the accreting matter, and drive powerful outflows or jets. In this research note we highlight high resolution observations of the Black hole in M87, and the disk around a young protostar in Orion.

Keywords: black holes, massive stars, disks and outflows

1. BLACK HOLE IN M87

We can observe the massive black holes in the Virgo galaxy, M87, and Sgra*, at the center of our own Milky Way using VLBI techniques at millimeter wavelengths. The Schwarzschild radii, $R_s = 2GM/c^2$ are 10 and 8 micro arcsec respectively for SgrA* ($\sim 4\ 10^6 M0$ at a distance 8 kpc), and the M87 black hole ($\sim 6.5\ 10^9 M0$ at a distance 16 Mpc) . We started these observations in the 1980's with Don Backer, Dick Plambeck, Berkeley graduate students, and a similar small team at Caltech using the Hat Creek and OVRO millimeter wave telescopes. Over the years we improved the technology and used more telescopes. The Event Horizon Telescope, https://eventhorizontelescope.org/, used radio telescopes around the world at a wavelength 1.3 mm, to obtain an angular resolution, $\lambda/earthdiameter = 1.3mm/8000km \sim 30$ micro arcsec, sufficient to model, and image the event horizon, in a collaboration led by Shep Doeleman at Harvard in 2019.

There are some nice movies from the NRAO web site of the M87 black hole:
https://public.nrao.edu/gallery/messier-87-the-very-first-image-of-a-black-hole/
And from Chandra of the M87 xray, optical and radio jet:
https://www.youtube.com/watch?v=gxC2jpugA9g

2. ORION - SOURCE I

The Kleinmann-Low Nebula in Orion, at a distance 415 pc is the nearest interstellar cloud in which massive ($M > 8\ M_\odot$) stars are forming. The two most massive stars in this region, Source I (SrcI) and the Becklin-Neugebauer Object (BN), appear to be recoiling from one another at 35-40 km s^{-1} suggesting that they were ejected from a multiple system via dynamical decay approximately 500 years ago. SrcI has a mass $\sim$15 $M_\odot$, with a rotating accretion disk and a molecular outflow that is prominent in SiO. The disk around SrcI has been well studied as it is the closest known disk around a high mass protostar. Recently dozens of spec-

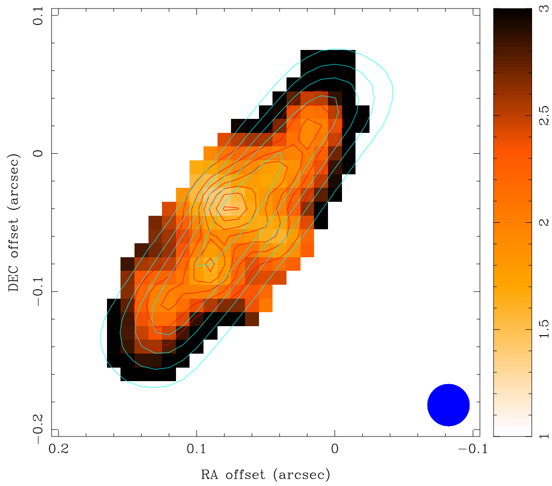

Figure 1. Spectral Index from 99 to 340 GHz. Red contour levels at 99 GHz: 200 400 600 800 1000 1200 1400 K. Blue contour levels at 340 GHz: 100 200 300 400 500 600 K. The color images shows the spectral index distribution. The 30 mas convolving beam FWHM is indicated in blue in the lower right.

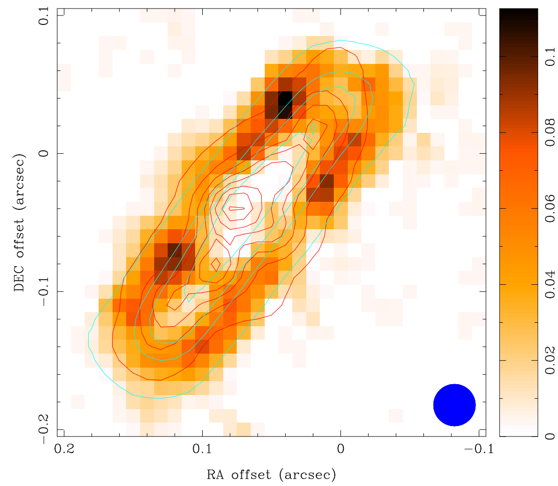

Figure 2. NaCl emission at 232.51 GHz integrated over an LSR velocity range (-30 to 30) km s^{-1}. Red contour levels at 99 GHz: 25 200 400 600 800 1000 1200 1400 K. Blue contour levels at 340 GHz: 25 200 300 400 500 600 K. The color image shows the NaCl distribution. The 30 mas convolving beam FWHM is indicated in blue in the lower right.

tral lines of NaCl and KCl were identified in this disk. We imaged the continuum and molecular line emission from Orion Source I (SrcI) with up to 30 mas (12 AU) resolution at 43, 99, 223, and 340 GHz in an attempt to probe the structure and chemistry of the circumstellar disk and bipolar outflow associated with this high mass protostar. Salt (NaCl) emission is visible where the dust is optically thin; it provides a unique tracer of the velocity field within the disk. All other molecules that we have mapped – H_2O, AlO, SiO, SiS, SO, and SO_2 – appear to originate primarily in the bipolar outflow. The base of the outflow is corotating with the disk. The molecular distributions suggest that Si and Al, released from dust grains in the disk, react with oxygen derived from H_2O to form SiO and AlO, and with SO and SO_2 to form SiS.

3. THE SRC I DISK

3.1. *Salt Emission*

Figure 2 shows NaCl emission at 232.51 GHz overlayed on contours of 99 GHz and 340 GHz continuum images. Salt emission is found in the dust layer at the surface of SrcI where there is a large spectral index gradient.

4. THE SRC I OUTFLOW

Figure 3, shows the SrcI molecular outflow mapped in SiO emission.

Figure 4, shows a three-color image of the 217.817 GHz SiS line. SiS shows a filamentary structure that is most prominent along the edges of the outflow.

5. CONCLUSIONS

The distributions of H_2O, SiO, AlO, and SiS lend strong support to a model in which dust grains are ablated and destroyed close to the disk surface, producing an oxygen rich outflow. The strong SiO maser emission, and AlO mapped in the outflow close to the disk, suggest that refractory grain cores as well as the grain mantles are destroyed.

6. ACKNOWLEDGEMENTS

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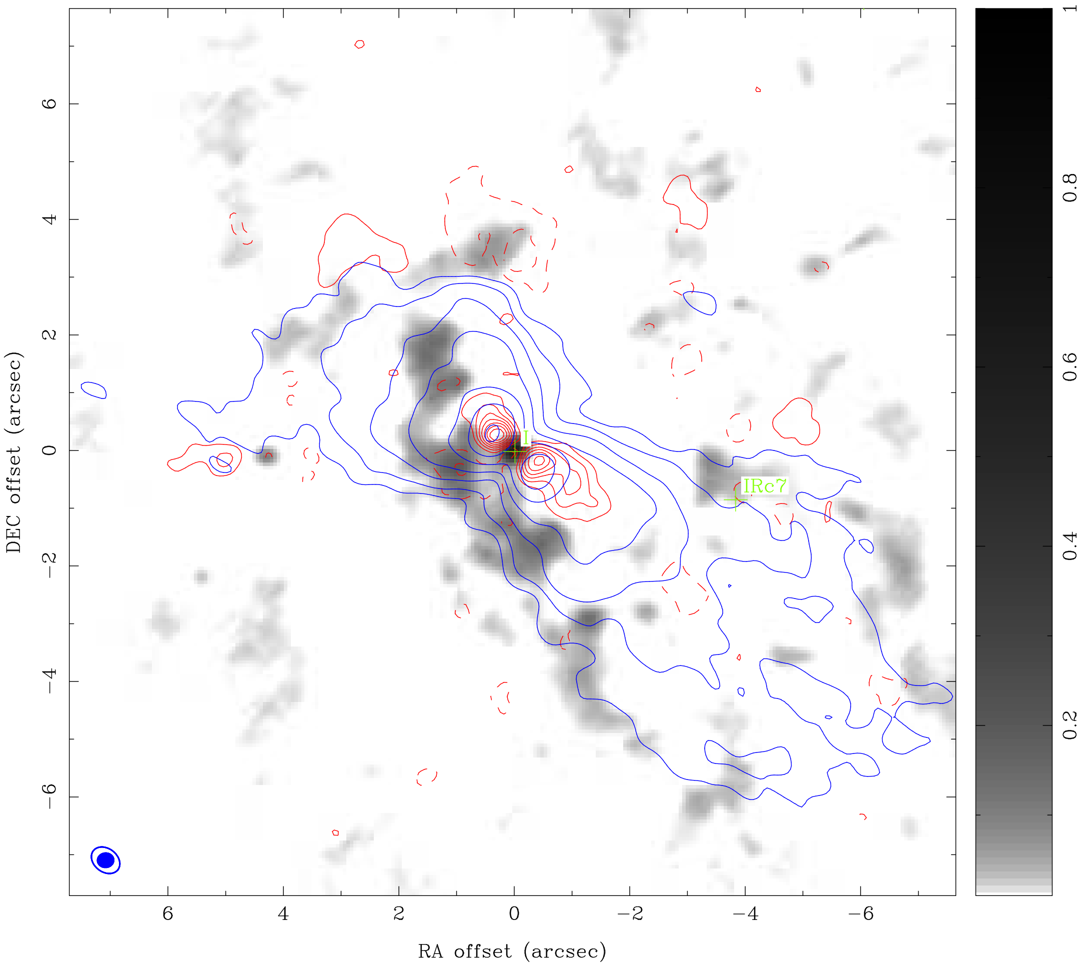

Figure 3. Continuum emission around the edges of the SiO J=2-1 v=0 line (Blue contour levels 0.05 0.1 0.2 0.4 0.8 1.6 3.2 Jy/beam (746 K/Jy), integrated over -10 to + 20 km/s). Red contours map the integrated emission over 11 km/s from an unidentified line at 354.4945 GHz. Contour interval 14.8 K. The grey scale image shows the continuum emission at 348 GHz (141 K/Jy). The convolving beams, 0.28 × 0.26 ″ for the unidentified line and continuum emission, and 0.54 × 0.41 ″ for the SiO are indicated in blue in the lower left.

(Tokyo), Brett McGuire (NRAO), John Bally (Boulder), and Ciriaco Goddi (Leiden) using the JVLA and ALMA telescopes.

7. RESEARCH OPPORTUNITIES

Massive star formation is still poorly understood, but images of molecular line emission offer important clues to the formation and evolution of massive stars and their environment. Recent high sensitivity and high resolution images of high mass star formation regions from telescope arrays such as the ALMA and JVLA telescopes, are available for more detailed analysis.

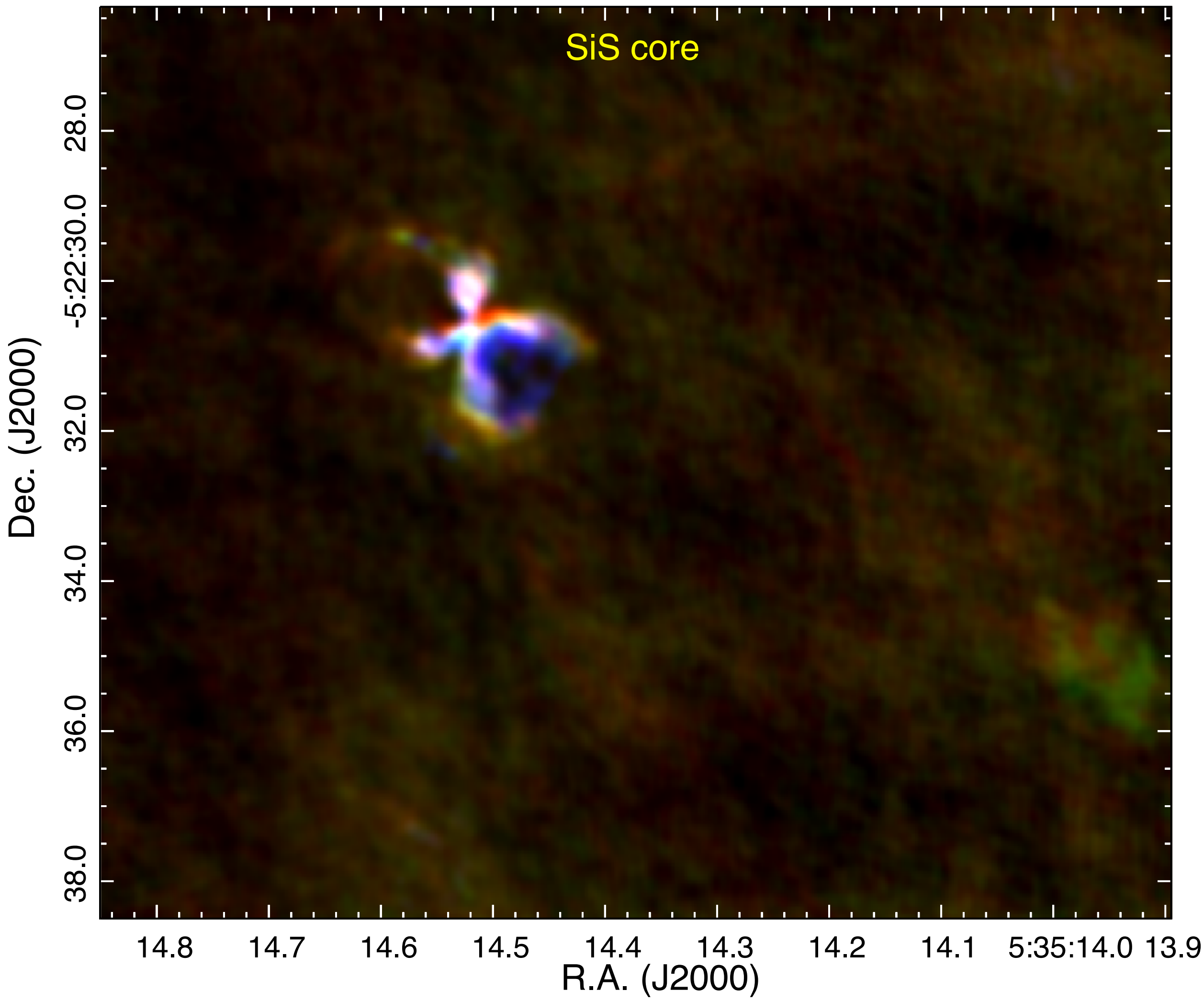

Figure 4. Three-color image of SiS (217.81766 GHz) emission. Blue -3 to -1 km/s, Green 0 km/s, Red +1 to +3 km/s. The velocity ranges are chosen to highlight the enhancement of SiS emission around the SrcI outflow in the SiS core.