Outflows and star-formation feedback from young stellar objects in NGC 1333

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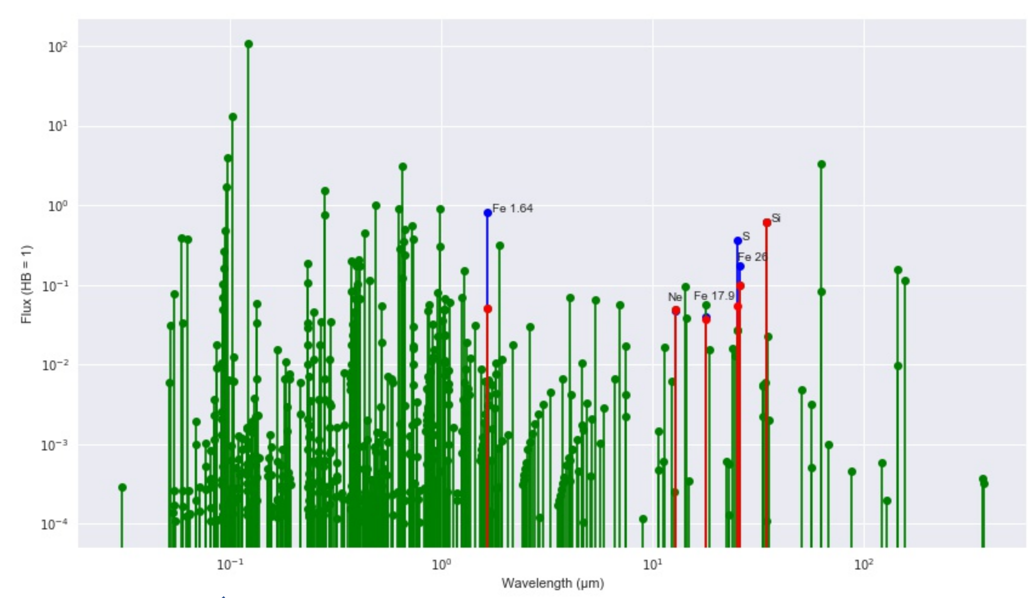
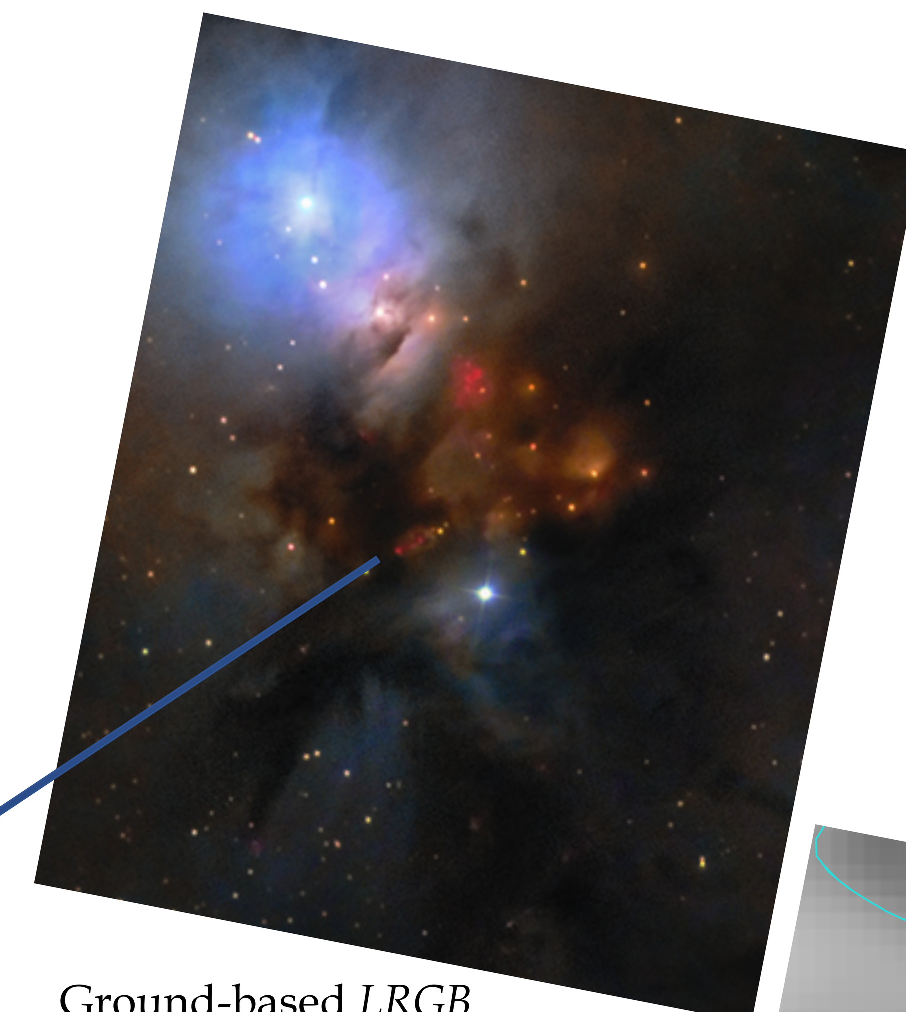
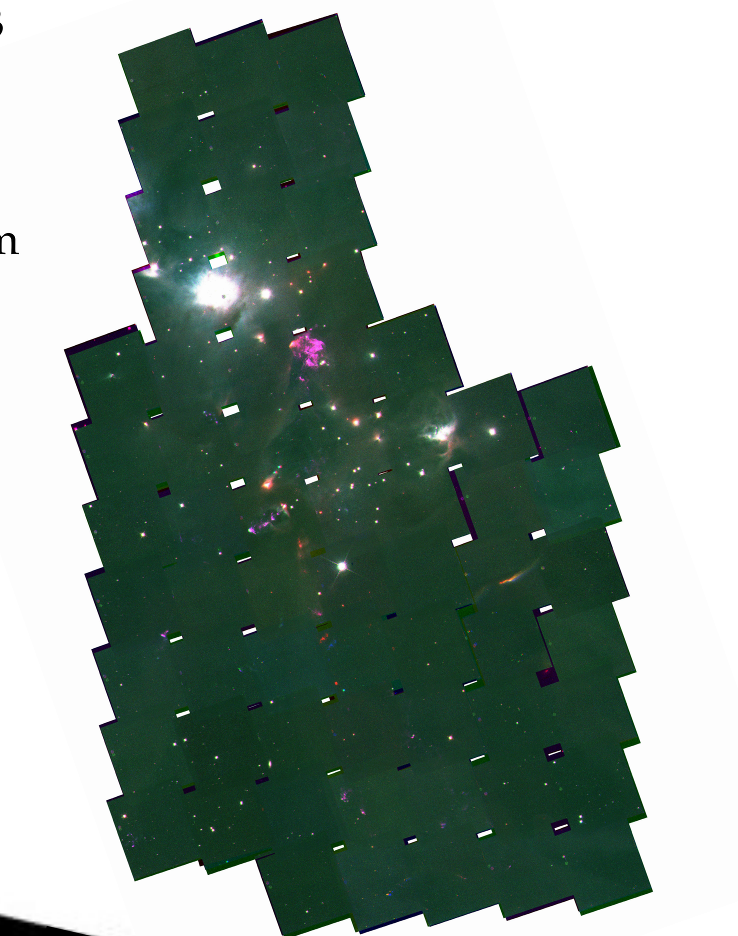
NGC1333 is an active star-forming region in Perseus particularly rich in Class 0 and Class I protostars. Many of its protostars are associated with extensive bipolar outflows. We have mapped the entire NGC 1333 complex (~ 400 square arcmin) in near- and mid- infrared spectral lines which trace the interaction of these outflows with the surrounding molecular cloud, using the Spitzer Space Telescope Infrared Spectrograph and the Hubble Space Telescope Wide-Field Camera 3. Along these outflows are shocked regions, from which we can use the spectral line emission by important coolants to make accurate rate measurements of the mass, momentum, and kinetic energy deposited into the surrounding cloud. Thereby we can learn about star-formation feedback: the near-future star-formation rate in, and the fate of, the NGC 1333 cloud.



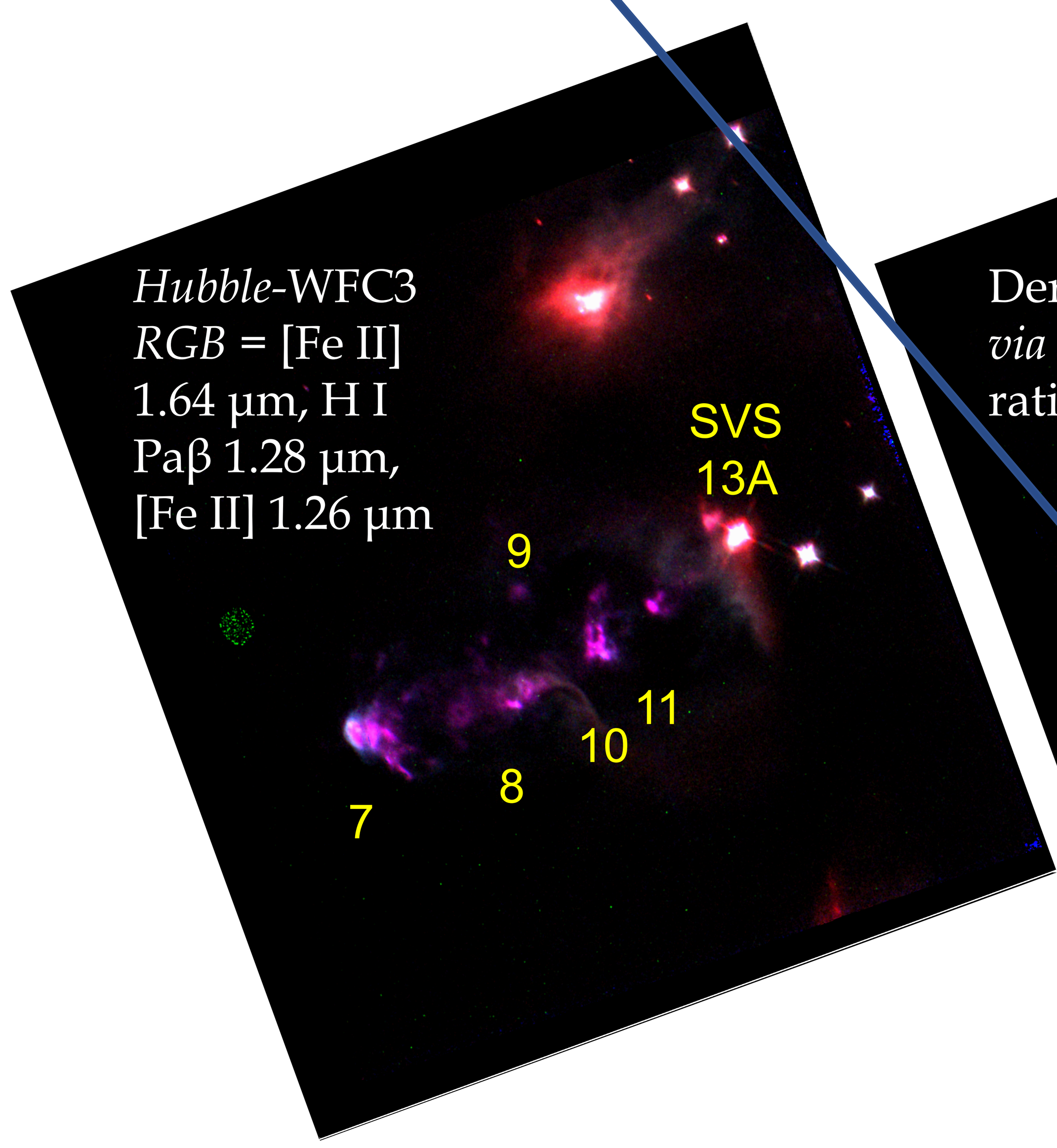


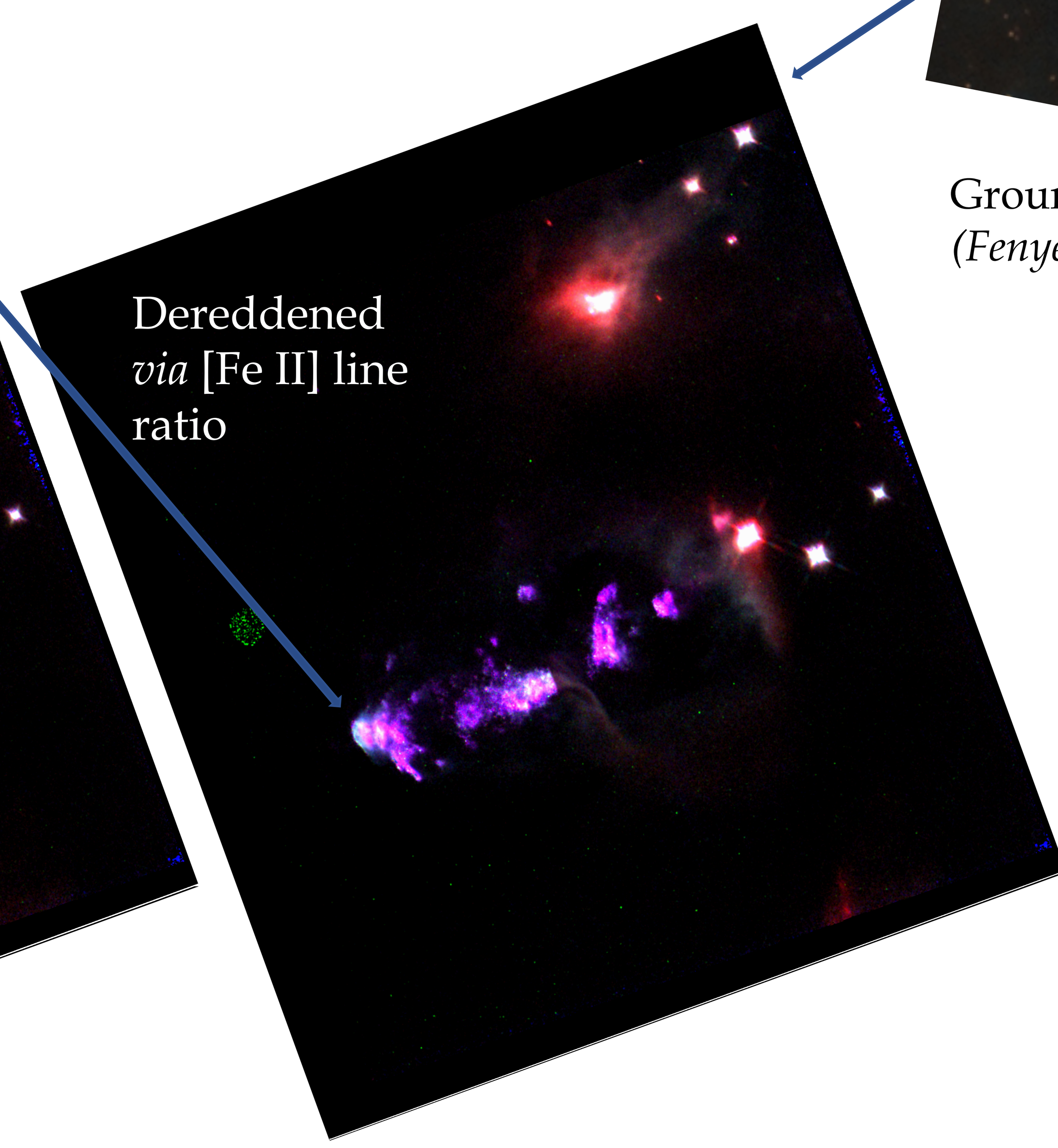
Ground-based *LRGB* *(Fenyes 2017)*

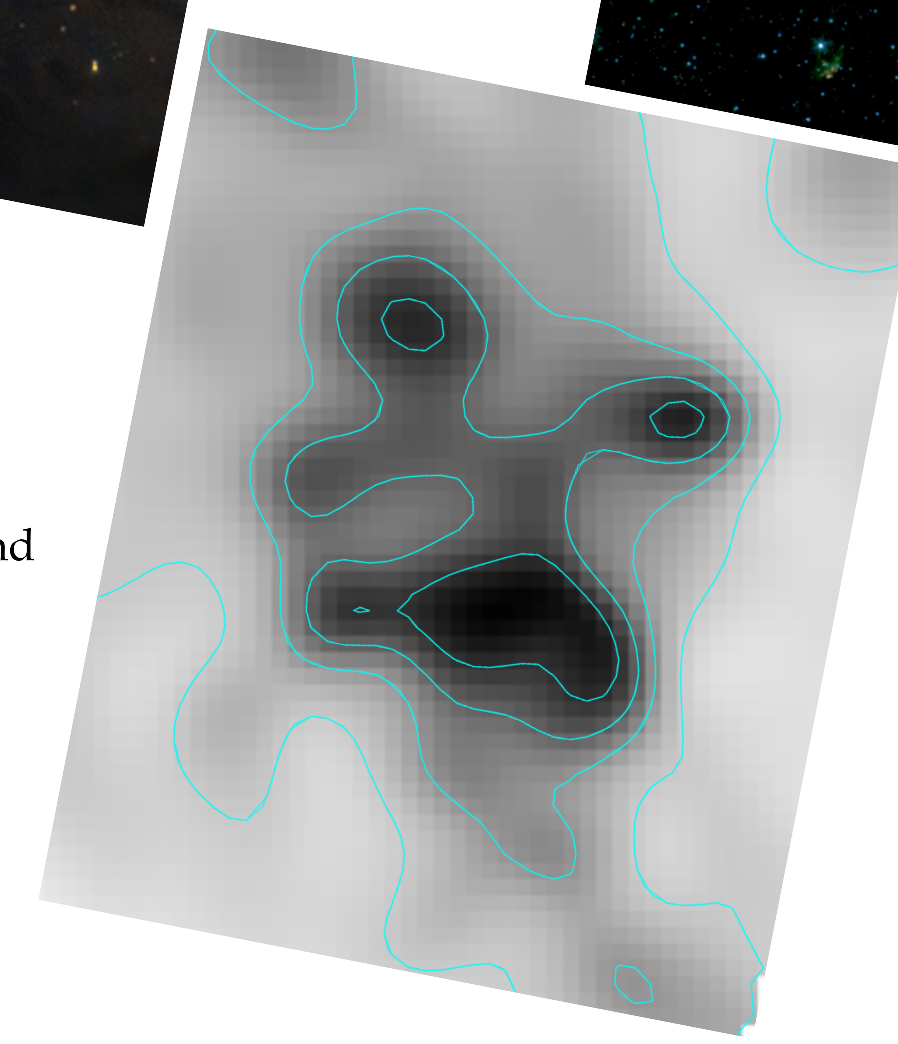
Spitzer-IRAC *RGB* = 8.0, 4.5, 3.6 µm (Gutermuth et al. 2007)



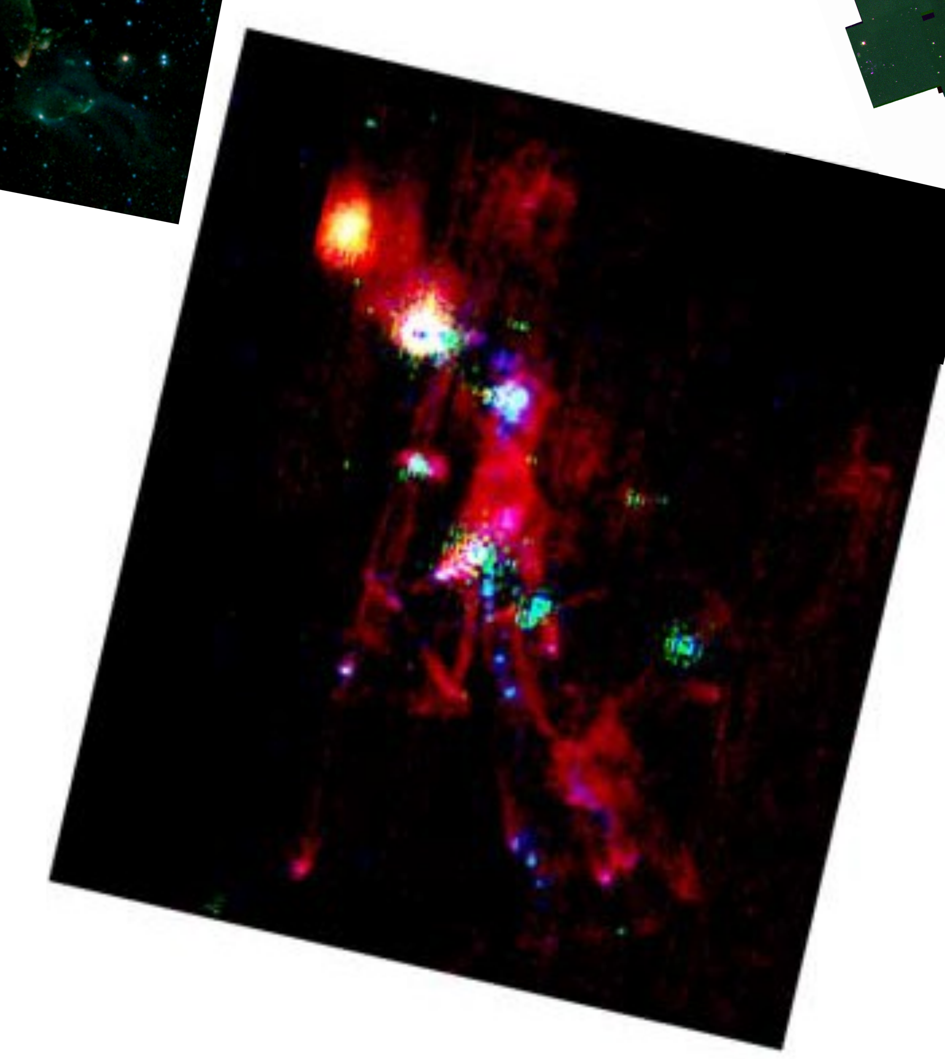
Hubble-WFC3 *RGB* = [Fe II] 1.64 µm, H I Paβ 1.28 µm, [Fe II] 1.26 µm (this work)







Total visual extinction, from 2MASS background star counts (Gutermuth et al. 2007); contours at A_V = 5, 10, 15, 20 magnitudes.



Spitzer-IRS *RGB* = H_2 $S(1)$ 17.0 µm, [Fe II] 26.0 µm, [Si II] 34.8 µm (this work)

NGC1333: context and new observations (on a common scale and orientation, above)

We used both low- and high-spectral-resolution modes of the IRS in a raster-scan of the spectrograph slits across NGC 1333. We used DASH mode (Momcheva et al. 2016) for the HST observations, with additional staring-mode exposures in regions of highest total extinction.

In the new spectral-line images we detect six lines of [Fe II] (1.26, 1.64, 17.9, 24.5, 26.0, 35.4 µm), eight pure-rotational lines of H_2 (28.2, 17.0, 12.3, 9.67, 8.03, 6.91, 6.11, 5.51 µm), and lines of [Si II] 34.8 µm, [S I] 25.3 µm, [Ne II] 12.8 µm, and H I Paβ 1.28 µm. Example images shown at top right. We can discern some 17 distinct outflow/shock systems in the images.

Example: HH 7-11 with *Hubble*-WFC3 and MAPPINGS 5 (data above)

HH 7-11 is a well-known chain of Herbig-Haro objects along the SVS 13A outflow.

- HH objects systematically more deeply embedded closer to SVS 13A: A_V = 3 – 9, i.e. lying behind 16%-51% of the cloud.
- Typical preshock parameters from model fits to dereddened line intensities: $n(H_2)$ = 3000 cm^{-3}, v = 60 km sec^{-1}, B = 27 µG, abundances near solar.
- In particular: HH 7
    - Matching [Fe II] 1.64, 17.9, 26 µm, [Si II] 34.8 µm, [Ne II] 12.8 µm
    - Preshock parameters: $n(H_2)$ = 1600 cm^{-3}, v = 60 km sec^{-1}, B = 18 µG
    - Close to the near surface of the cloud – significant contribution to disruption

Preliminary results: current energy and momentum injection rates, dynamical times

The star-count derived total extinction indicates that the NGC 1333 molecular cloud mass is 350 M_* and its binding energy about 10^{46} erg. CO maps indicate that its total turbulent energy is about 2 ×10^{45} erg (Quillen et al. 2006). From the new observations:

- Taking outflow speed = terminal shock speed, jet dynamical times = 300 – 10,000 years.
- Total outflow momentum and energy injection rates: 1.4×10^{-3} M_* km sec^{-1} year^{-1}, and 2×10^{41} erg year^{-1}.

Thus the outflows can *currently* drive turbulence, as concluded by Quillen et al. (2006) for relic outflows seen in mm-wave CO. If they remain so numerous for another 10^4 years, they may disrupt the cloud..