ALMA observes jet-cloud interactions in Minkowski's Object

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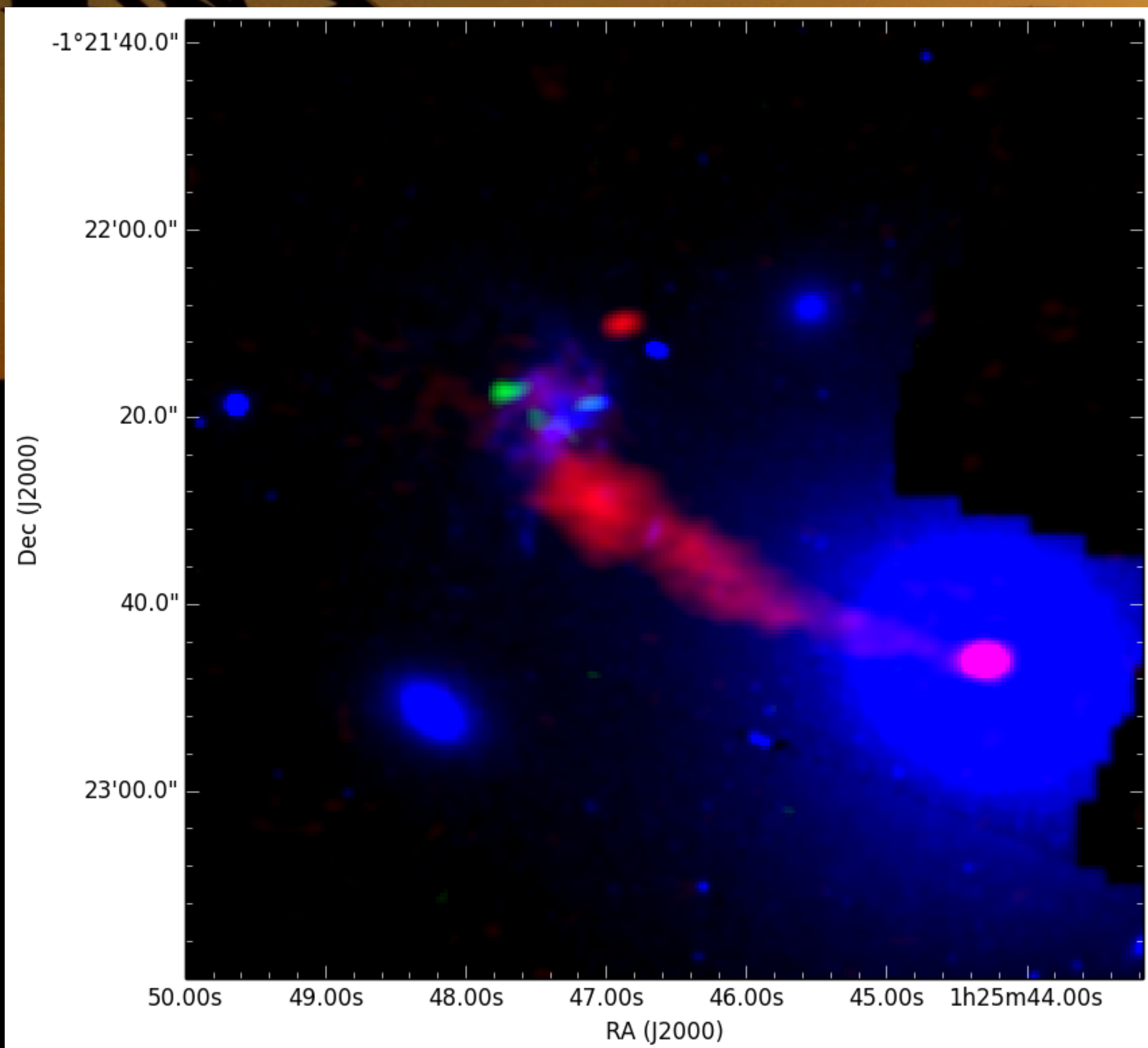

Figure 1: 110 GHz continuum in red, CO (1-0) total intensity in green, HST F555W optical in blue.

Minkowski's Object is a rare local example of a collision between a radio jet and a gas rich dwarf galaxy. It is one of the most well studied candidates for jet induced star formation, whereby the radio jet interaction overpressures gas clouds and triggers their collapse into stars. Minkowski's Object has been well studied in the optical and HI (Croft et al. 2006), but the nature of its molecular gas remained a mystery. Salome et al. (2015) obtained a limit on the CO emission using the IRAM 30m consistent with it lying well above the Kennicutt-Schmidt relation.

We obtained ALMA data in Cycle 3 (2015.1.00570.S), successfully detecting the CO 1-0 line (green in Fig 1). As a bonus, we detected 110GHz radio continuum from the jet (in red).

By the numbers:

L'_{CO}~2-3x10^5 K km/s pc^2

M_{mol}~1-20x10^6 $M_\odot$

(lower number using MW α, higher using Narayanan et al. 2012 formula which gives α=75)

M_{HI}~5x10^8 $M_\odot$ (Croft et al. 2006)

M_*~2x10^7 $M_\odot$ (Croft et al. 2006)

SFR=0.47 $M_\odot$/yr (Salome et al. 2015)

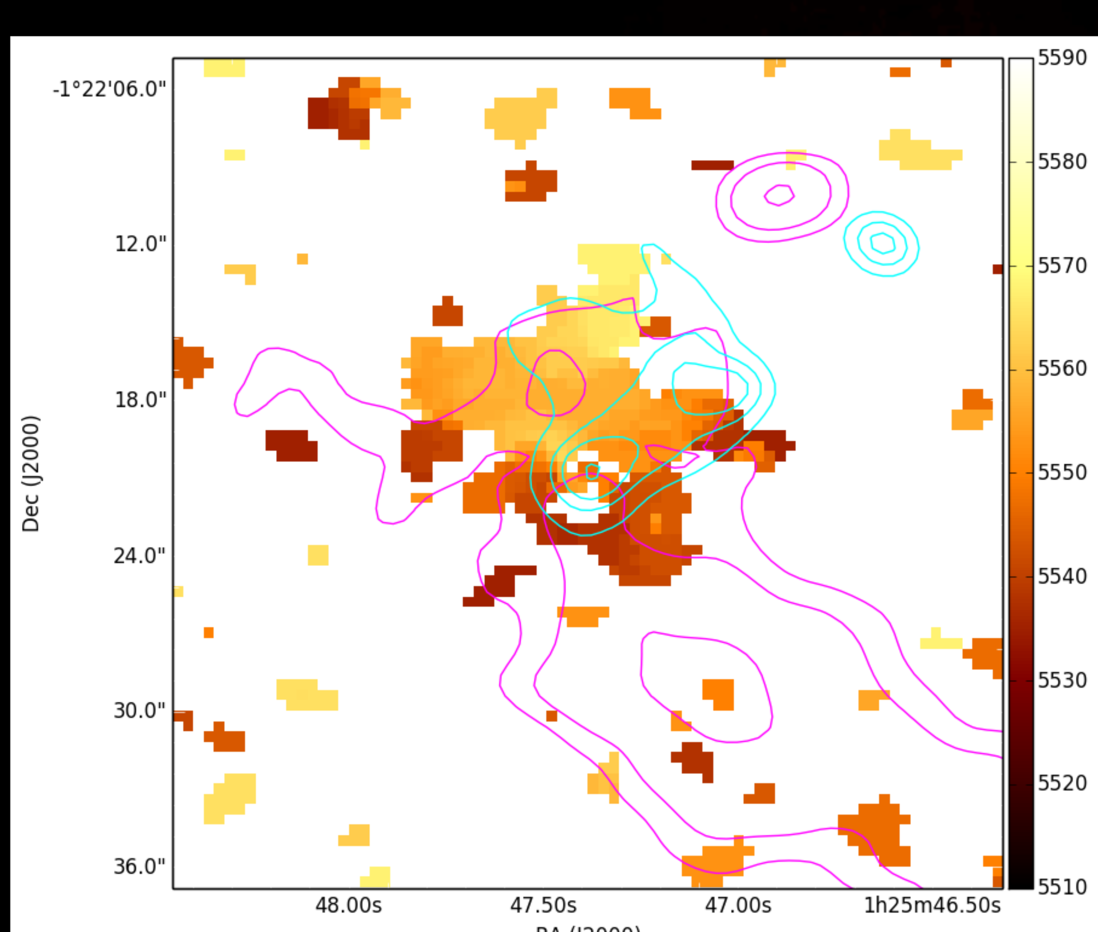

Figure2 : CO 1-0 velocity (moment 1) map with 110 GHz continuum contours (magenta) and contours of Hα emission .

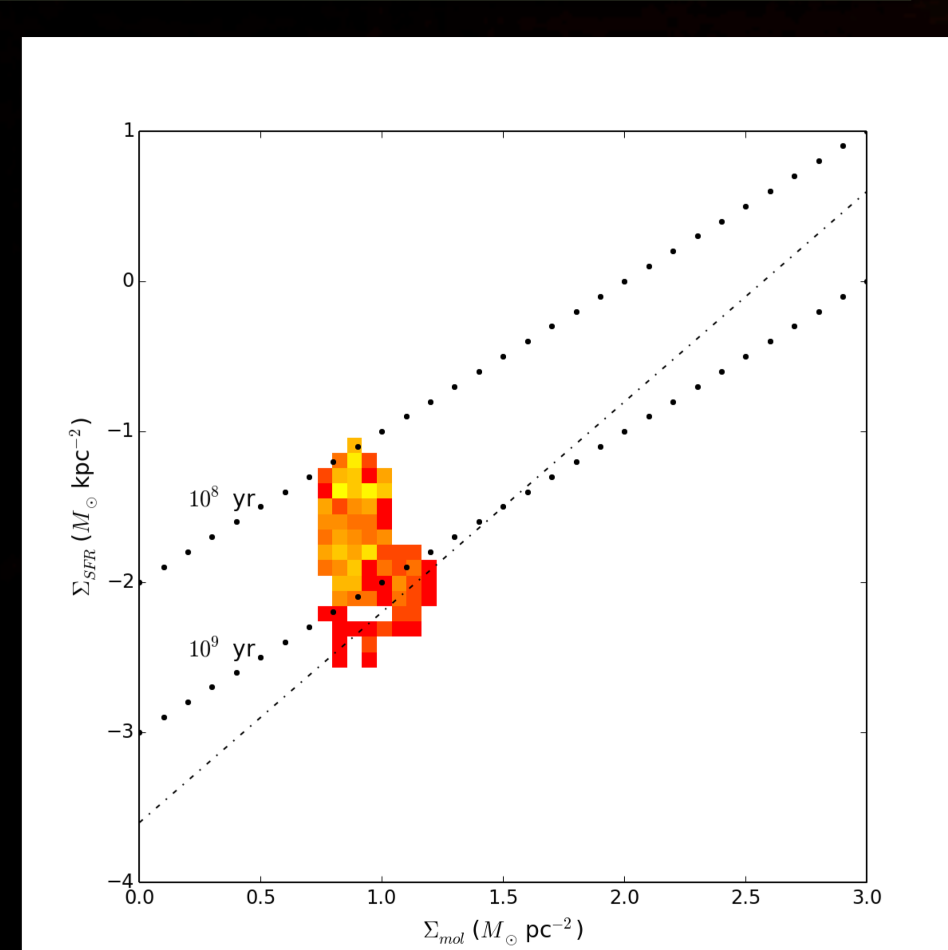

Figure3 : 2D histogram of the molecular gas surface density vs star formation surface density (α=75). The dot-dash line is the Kennicutt-Schmidt relation, dotted lines indicate gas depletion timescales.

Results:

1. Jet is clearly interacting with the galaxy's ISM – not a chance projection.
2. Spatial anti-correlation of synchrotron, CO and Hα emission is consistent with scenario in which the jet shocks the ISM, with shocks bypassing those dense molecular clouds that are yet to be consumed by star formation (e.g. Rees 1989; Wagner et al. 2012).
3. There is only weak evidence for entrainment of gas in the jet - if it is occurring the velocity imparted to the molecular clouds is only ~10km/s.
4. Even assuming a high α~75,most of the the star forming gas in Minkowski's Object is still above the Kennicutt-Schmidt (KS) relation for normal galaxies, and has a short gas depletion time (~10^{8}yr).
5. The gas which is closer to the KS relation is on the downstream side of the interaction.

Results seem consistent with jet-induced star formation hypothesis. Perhaps jets can transform galaxies with positive as well as negative feedback.

References:
Croft, S. et al. 2006, ApJ 647, 1040
Narayanan, D. et al. 2012, MNRAS, 421, 3127
Rees, M.J. 1989, MNRAS, 239, 1
Salome, Q. et al. 2015, A&A, 574, A34
Wagner, A. et al. 2012, ApJ, 757, 136