Outflows in protostellar clusters: a multi-wavelength, multi-scale view

Adele L. Plunkett[1], H. G. Arce[1], S. A. Corder[2], M. M. Dunham[1], D. Mardones[3]

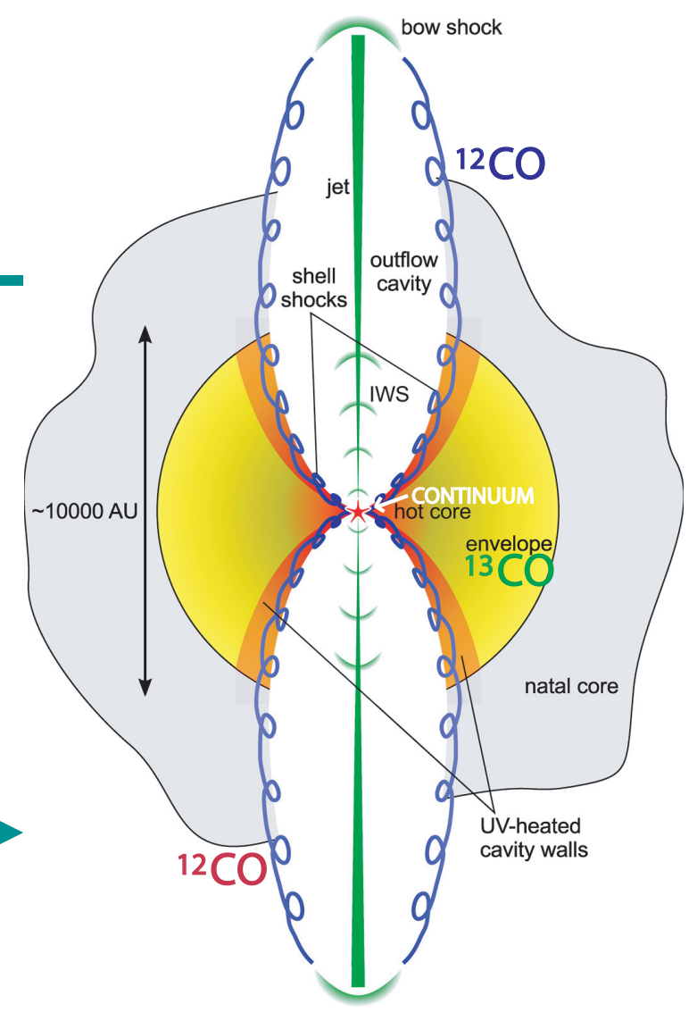
1-Yale University; 2-ALMA; 3-Universidad de Chile

Overview

While protostellar outflows are generally understood as necessary components of isolated star formation, further observations are needed to constrain parameters of outflows particularly within protostellar clusters. In protostellar clusters where most stars form, outflows impact the cluster environment by injecting momentum and energy into the cloud, dispersing the surrounding gas and feeding turbulent motions. Here we present several studies of very dense, active regions within low- to intermediate-mass protostellar clusters. Our observations include interferometer (i.e. CARMA) and single dish (e.g. FCRAO, IRAM 30m, APEX) observations, probing scales over several orders of magnitude.

Based on these observations, we calculate the masses and kinematics of outflows in these regions, and provide constraints for models of clustered star formation. These results are presented for NGC 1333 by Plunkett et al. (2013, ApJ accepted), and comparisons among star-forming regions at different evolutionary stages are forthcoming.

Our study focuses on Class 0 & I outflow-driving protostars found in clusters, and we seek to understand their impact on the protocluster environment. To the right, we label several tracers important to our study of cores (i.e. continuum), outflows (^{12}CO) and their impact on the envelope and cloud (^{13}CO). Further, the temperature structure of these components is determined by observing several energy-level transitions of these molecules.
(Figure 5 of van Dishoeck et al. 2011)



Interferometer and Single Dish Combination

Why:

To recover flux over a range of spatial scales in the region

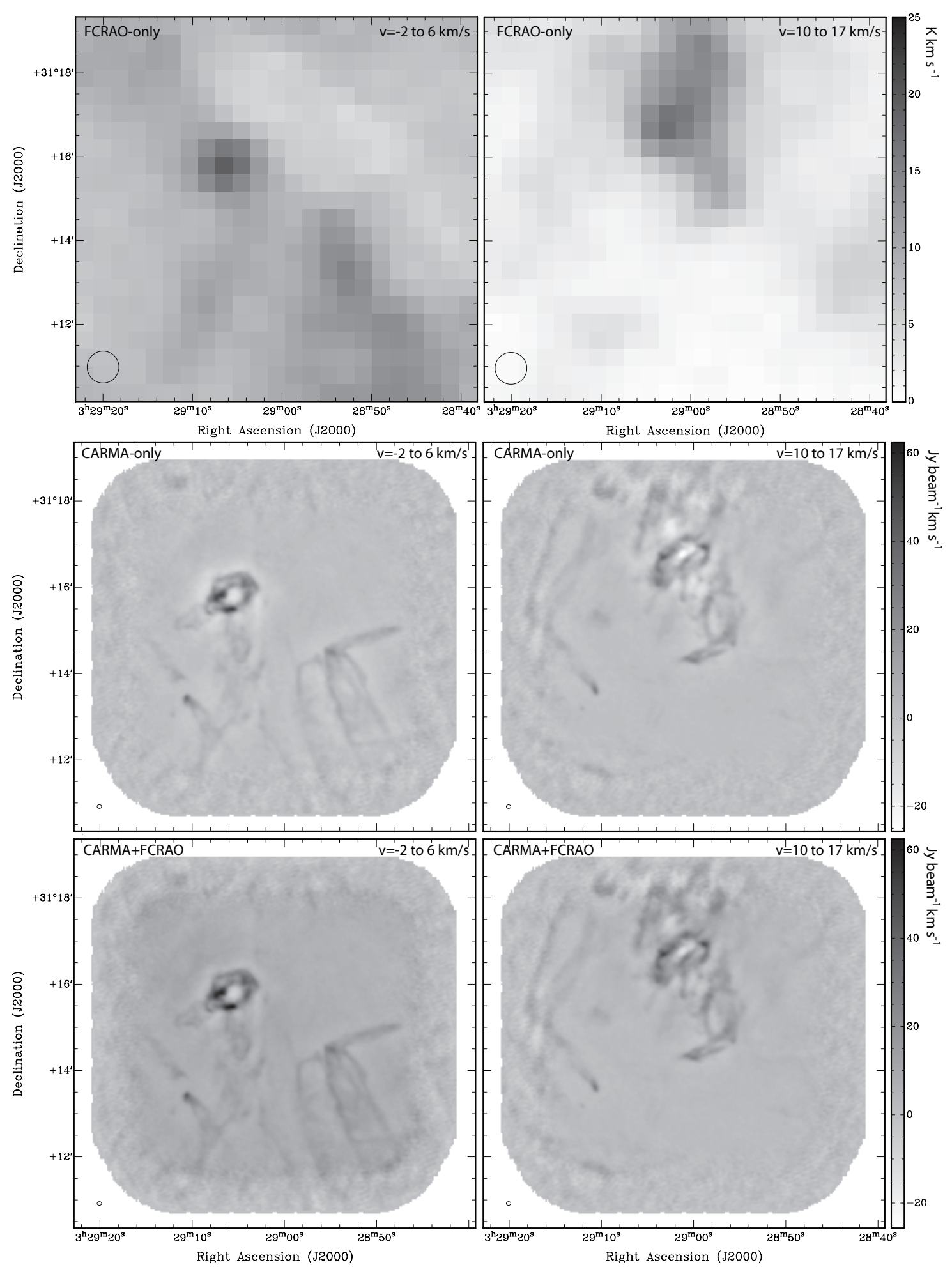
How:

Joint deconvolution method (Stanimirovic 2002), using the analysis package MIRIAD.

Example:

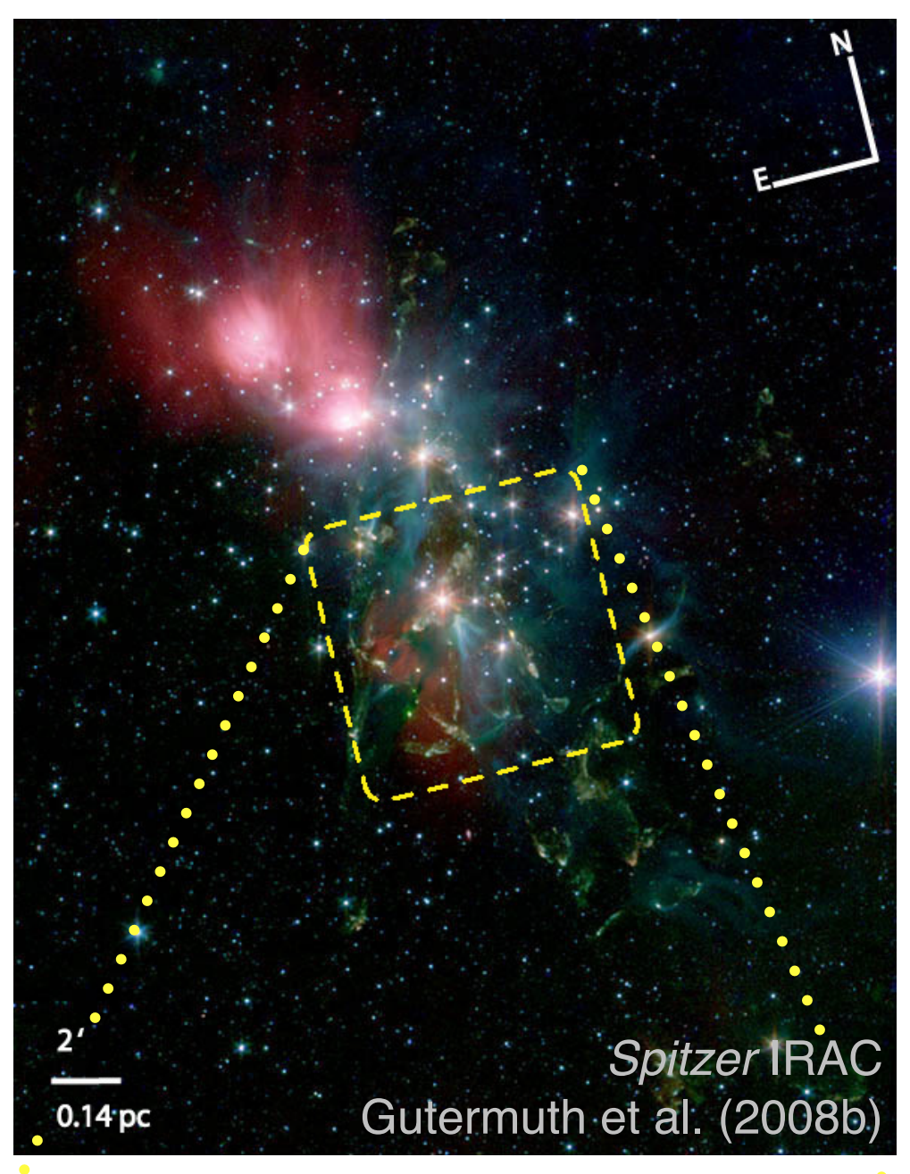
We mapped NGC 1333 using CARMA with a resolution of ~5" (or 0.006 pc, 1000 AU) in order to detect outflows and associate them with their driving sources.

The single dish FCRAO map of NGC 1333 is used to recover the flux over larger spatial scales (up to the map size of ~8', or 0.5 pc) that is resolved out by the interferometer.

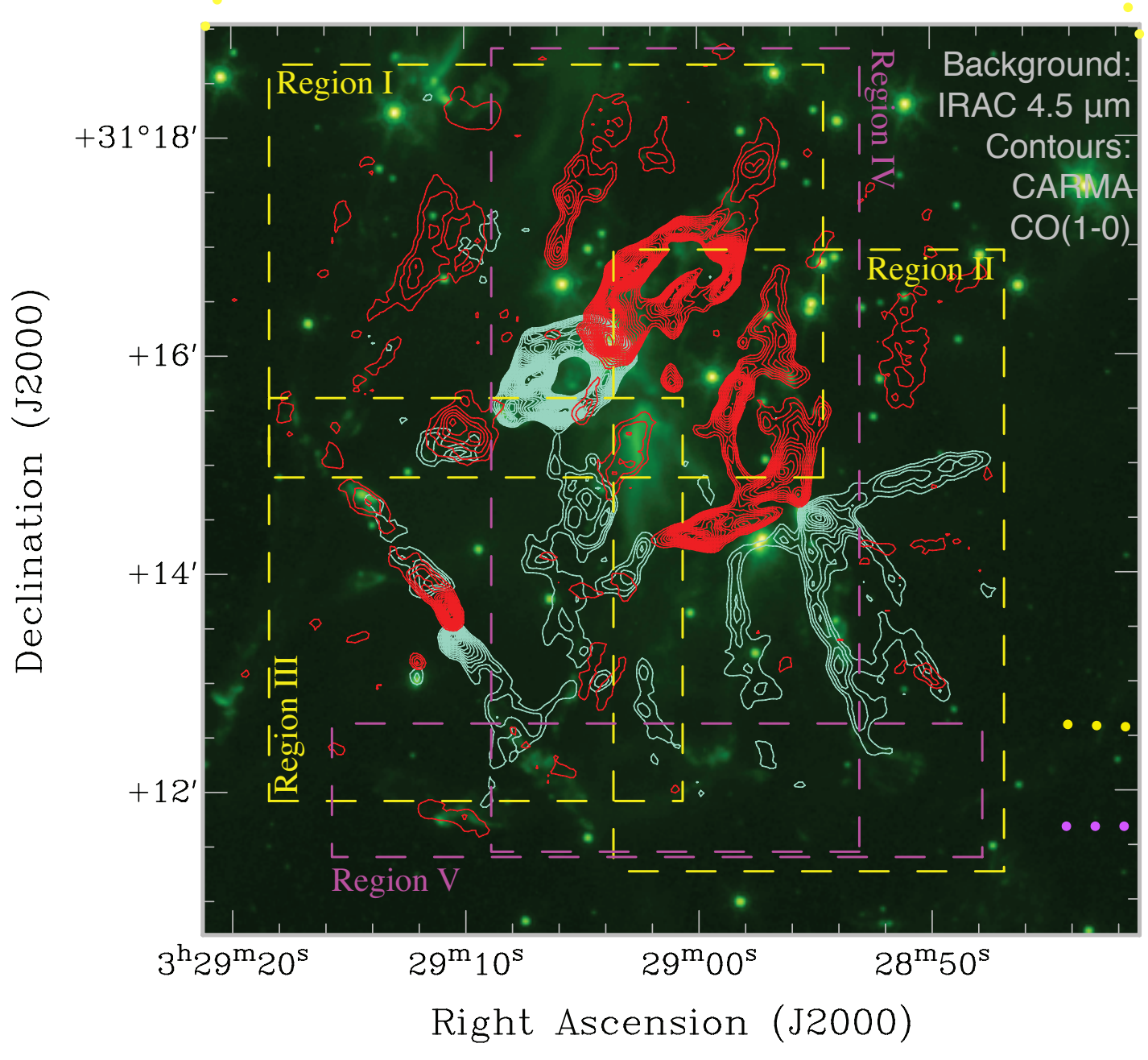


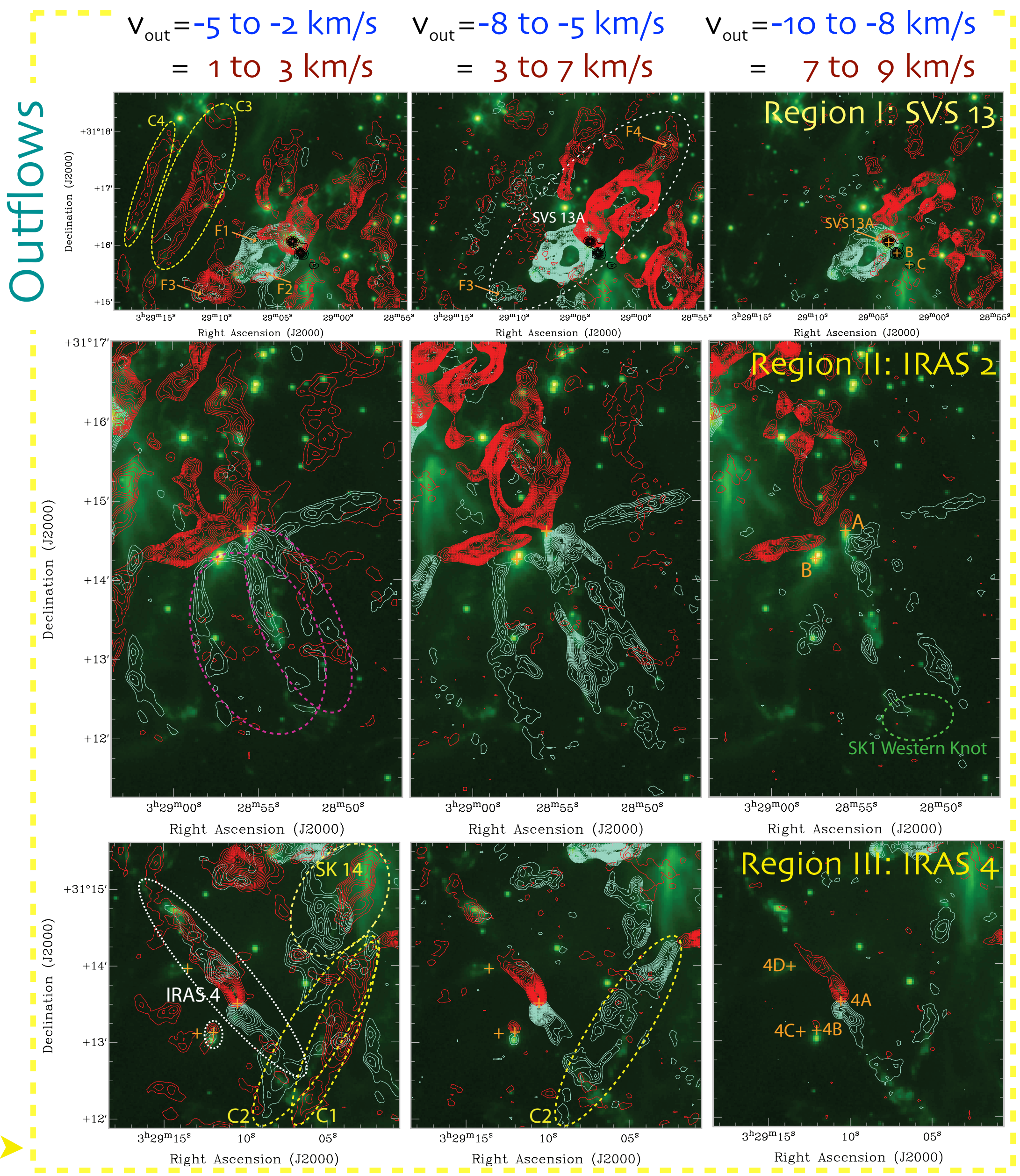
Case Study: NGC 1333

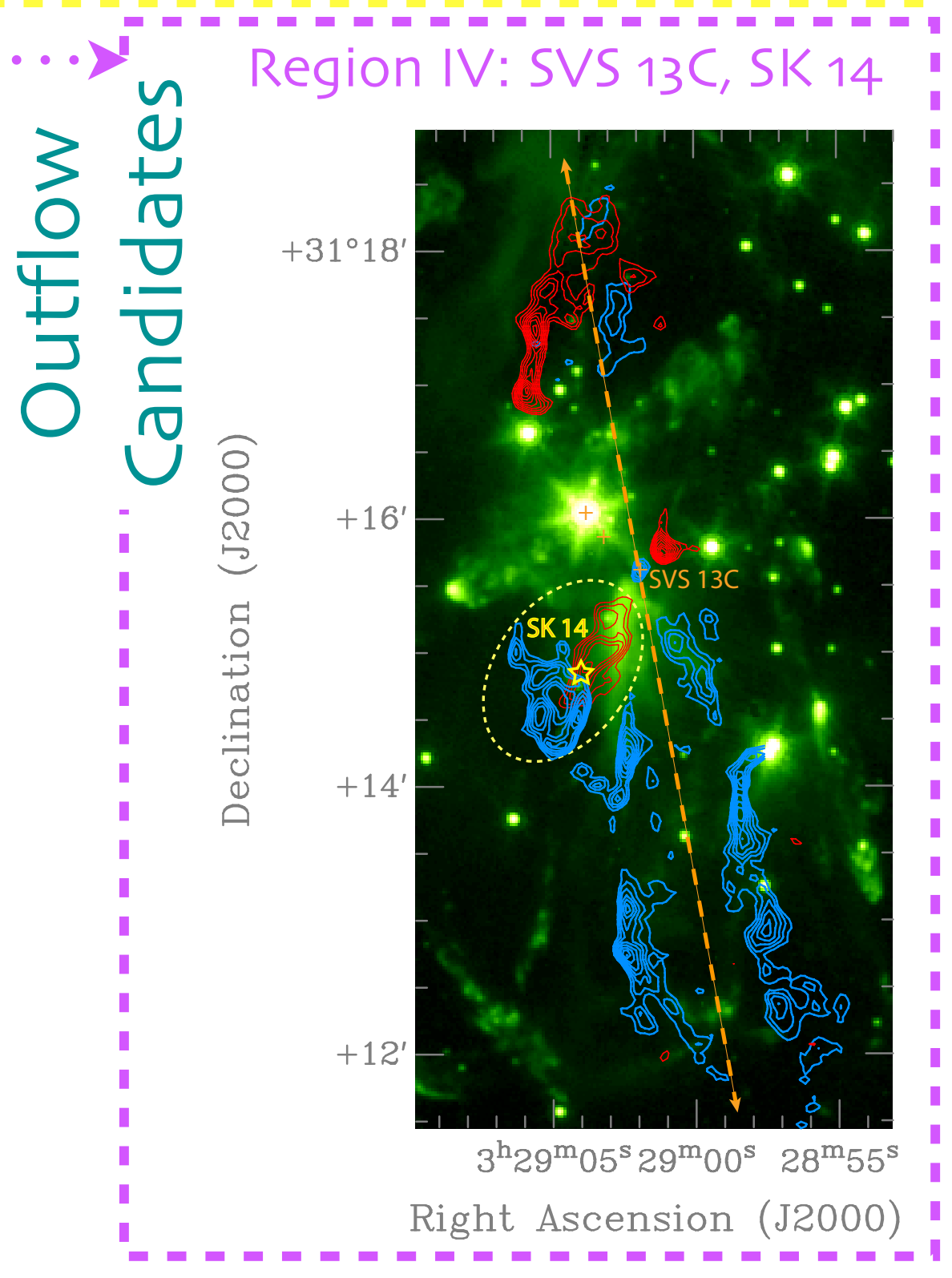
Plunkett et al. (2013, ApJ accepted)



<CARMA mapped region>







About NGC 1333

Location: Perseus; RA 03:29, dec 31:14
Distance: 235 pc (Hirota et al. 2008)
Age: ~10^6 years (Lada et al. 1996)

Members: 39 protostars, 98 pre-MS stars with disks, two late-B stars to north (Gutermuth et al. 2008b)

Significance: NGC 1333 is considered *the* prototypical cluster, commonly used to model clustered star formation and outflow-driven turbulence (e.g. Nakamura & Li 2007).

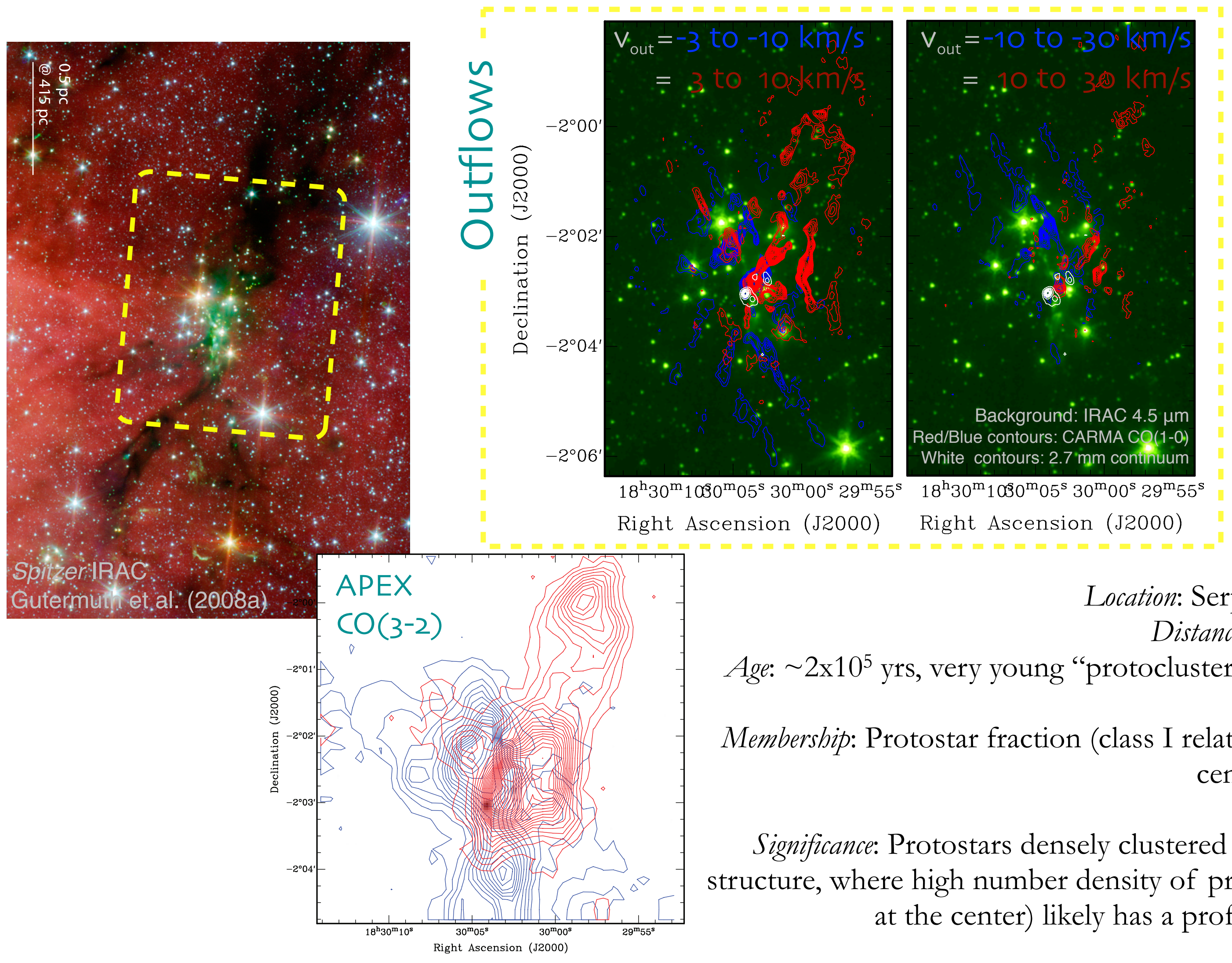
NGC 1333 Results

- Within NGC 1333, outflow kinetic energy, cloud gravitational energy and turbulent energy suggest that outflows act as an important agent for turbulence in the region, and over time could disrupt the most active region of the cloud.

- We identify outflows associated with 5 (of 7) Class 0 and 2 (of 4) Class I sources within the mapped region of NGC 1333.

- ~10-25% of the final mass of a protostar comprises the protostellar wind and may drive momentum in the cluster environment, and should be taken into account in models that investigate the impact of outflows during early protostellar evolution.

Serpens South



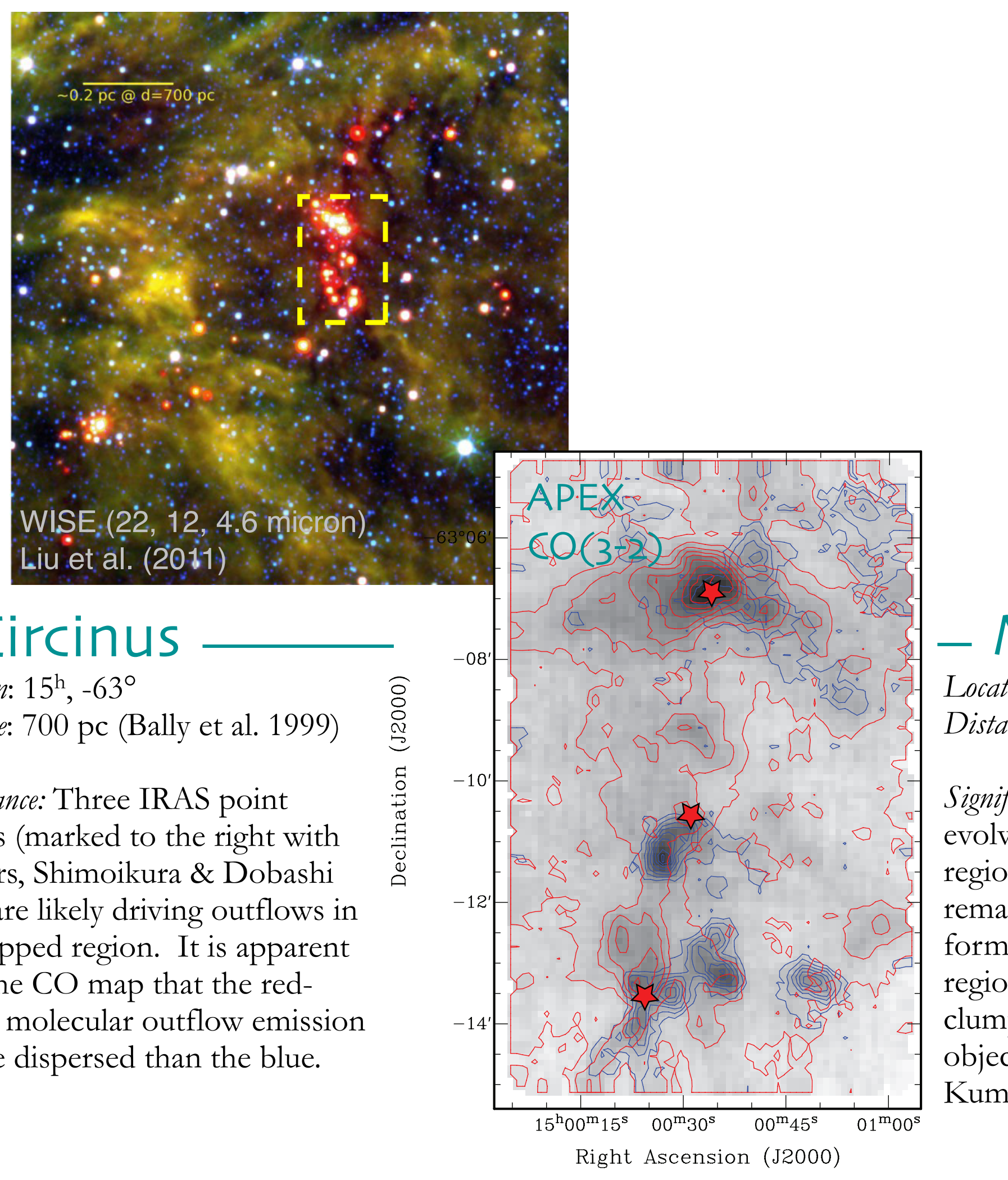
About

Location: Serpens; RA 18:30, dec -02:02
Distance: 415 pc (Dzib et al. 2010)
Age: ~2x10^5 yrs, very young "protocluster" (Gutermuth et al. 2008a)

Membership: Protostar fraction (class I relative to all YSOs) of 80% at center (Nakamura et al. 2011)

Significance: Protostars densely clustered along a central filamentary structure, where high number density of protostars (reaching 430 pc^{-2} at the center) likely has a profound impact on the cloud.

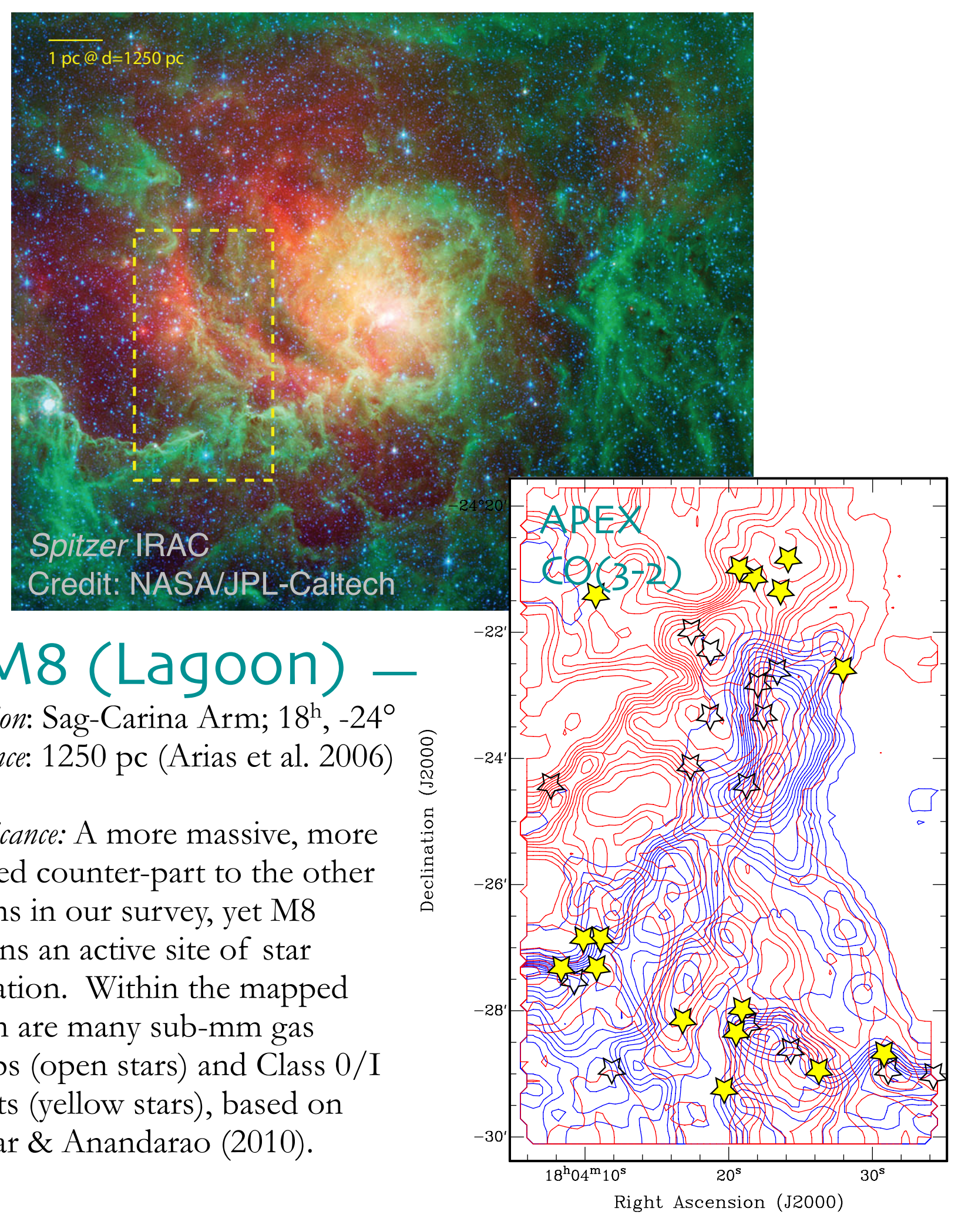
Circinus and M8



Circinus

Location: 15^h, -63°
Distance: 700 pc (Bally et al. 1999)

Significance: Three IRAS point sources (marked to the right with red stars, Shimoikura & Dobashi 2011) are likely driving outflows in the mapped region. It is apparent from the CO map that the red-shifted molecular outflow emission is more dispersed than the blue.



M8 (Lagoon)

Location: Sag-Carina Arm; 18^h, -24°
Distance: 1250 pc (Arias et al. 2006)

Significance: A more massive, more evolved counter-part to the other regions in our survey, yet M8 remains an active site of star formation. Within the mapped region are many sub-mm gas clumps (open stars) and Class 0/I objects (yellow stars), based on Kumar & Anandarao (2010).

Summary

- Similar analyses of the regions Serpens South, Circinus and M8 are ongoing. How do the outflow characteristics apparent in NGC 1333 evolve with, depend on, and/or affect their surrounding environments?

- Preliminary analysis of Serpens South suggests that at least four sources are driving outflows from within a region much more dense and active than the region we mapped in NGC 1333.

- Single-dish observations of Circinus and M8 provide evidence of outflow activity, and with higher-resolution mosaic observations we will associate driving sources and molecular outflow emission across several parsecs.

- The extent to which we can identify outflows and their driving sources may correlate with the evolutionary state of the cluster environment, and the possibility for outflows to disrupt the cloud over time.

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