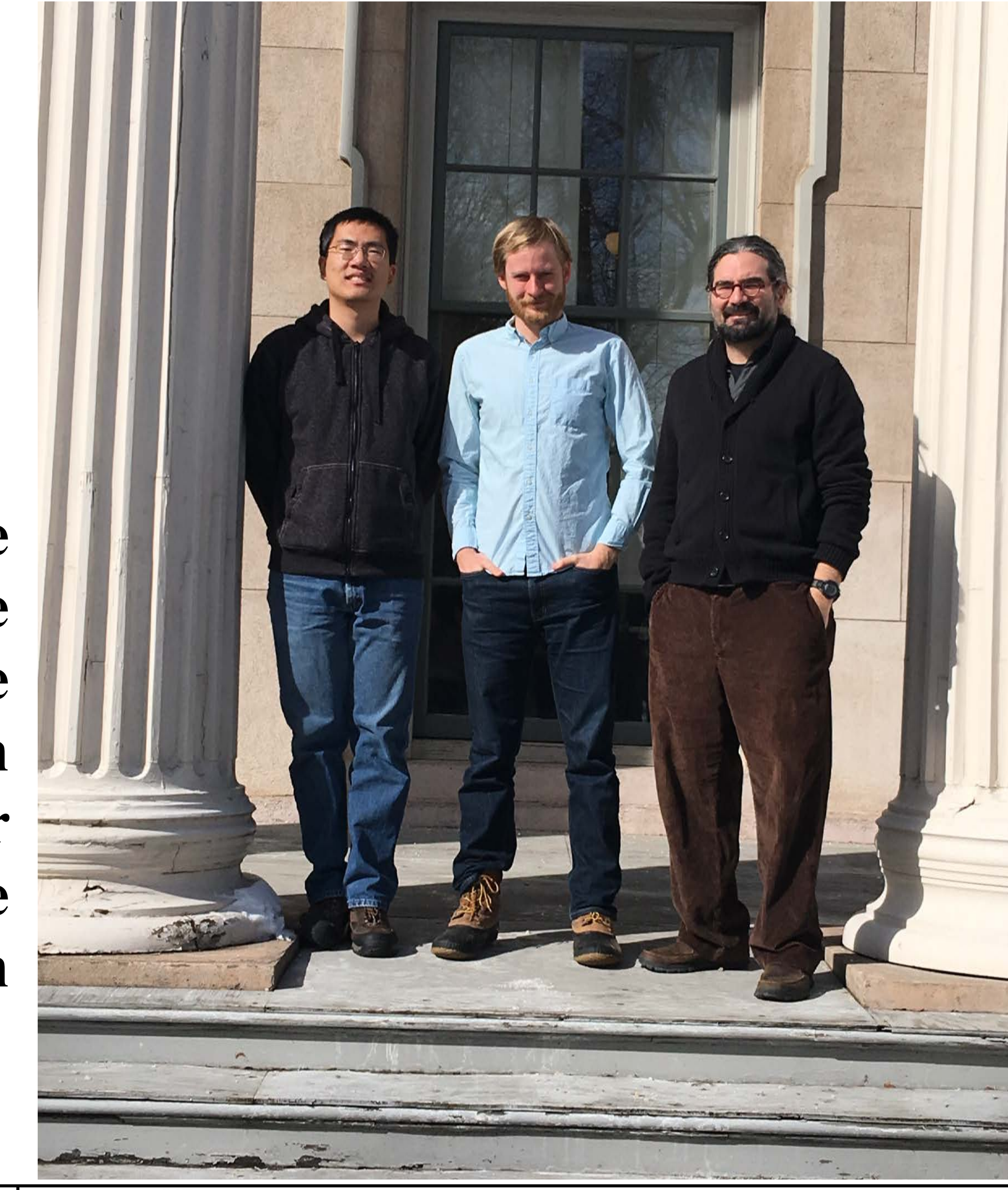
The CARMA Orion Survey

Shuo Kong[1], Jesse R. Feddersen[1], Héctor G. Arce[1], and the CARMA Orion team.
[1]Yale Email: shuo.kong@yale.edu

Abstract

Here we present the initial results from the CARMA Orion survey. The survey includes degree-size mosaics of molecular line emission from both the Nobeyama 45m single-dish telescope and the CARMA interferometer. The mosaics cover a number of famous regions, including the integral-shape filament, the Orion KL region, the Orion Bar, L1641-N, L1641-C, etc. We combine the single-dish data and the interferometer data in the uv-plane, producing an unprecedented view of the molecular gas distribution, kinematics, excitation, etc. Practical details of the data combination method are given in the paper. Here we show a brief introduction to the data qualities and statistics, with the aim of fostering follow-up scientific studies.



Introduction

Star formation (SF) in the Milky Way takes place in giant molecular clouds (GMCs) that can contain 10^5 $M_\odot$ of gas. A thorough understanding of GMCs has been a major goal in the subject of SF for decades. However, due to the complexity in GMCs, there are still many questions about the picture of SF process. One of them is rooted in the high dynamic range of SF, which spans from ~10 pc scale of GMCs all the way down to ~sub-AU scale of stars, corresponding to a factor of ~10^6 change in physical scales. Such high contrast in physical scales calls for high dynamic range observations. In this context, combining single-dish observations with interferometric observations can be very helpful by probing both large-scale structures of the GMC gas as well as small-scale details, thus providing a comprehensive pictureof the GMC and SF therein. The CARMA Orion project provides such a large-scale, high dynamic-range observation of CO isotopologues (Figure 1). The project includes ^{12}CO, ^{13}CO, and C^{18}O J = 1-0 maps of a 1x2 deg^2 region in Orion A using the Combined Array for Research in Millimeter Astronomy (CARMA) and the Nobeyama Radio Observatory 45 m telescope (NRO45). The broad goal of our program is to trace the gas kinematics from a scale of 7.2 pc down to about 0.02 pc (~4000 AU). Never before have images with such a large spatial dynamic range (~400) been obtained with a spatial resolution that can resolve individual protostellar envelopes.

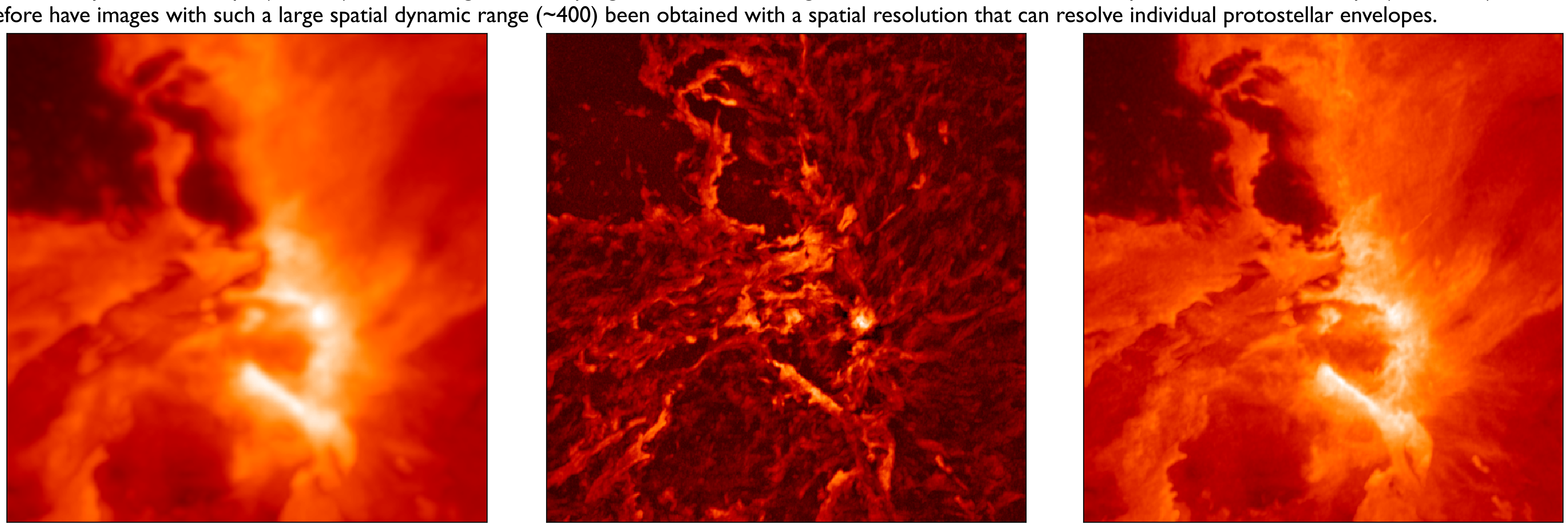


Figure 1: Left: NRO45 ^{12}CO(1-0) observations in the Orion KL region. Middle: CARMA observations in the same region. Right: combined data in the same region.

Observations

The CARMA mosaic was carried out between 2013 to 2014 under the key project: c1061 (PI: Carpenter). Molecular lines ^{12}CO(1-0, 115 GHz), ^{13}CO(1-0, 110 GHz), and C^{18}O(1-0, 109 GHz) were included in the spectral setup. In total, the mosaic footprint covers the Orion A cloud between R.A.(J2000) = (05^{h}33^{m}07^s, 05^{h}38^{m}46^s) and DEC.(J2000) = (-07°12'40", -04°48'27"). The total project time amounts to roughly 650 hours. The observation used the CARMA 15-element array which includes six 10m antennas and nine 6m antennas. We applied the standard calibration procedures. Two array configurations (D,E) were adopted in the project, with a uv-coverage encompassing 3-40 kλ (λ being 2.6 mm at 115 GHz), corresponding to angular scales 5"-70". The resulting synthesized beam size using the data from these two CARMA configurations is ~6".

Between December 2007 and February 2017, we carried out mapping observations in ^{12}CO(1-0, 115 GHz), ^{13}CO(1-0, 110 GHz), and C^{18}O(1-0, 109 GHz) toward the Orion A GMC with a 25-beam receiver, BEARS, and new 4-beam receiver, FOREST, which is a dual polarization sideband separating SIS receiver on the NRO45 telescope. The telescope beam size is ~14" at 115 GHz. Due to the gridding of the OTF mapping, the final imaging resolution is ~21".

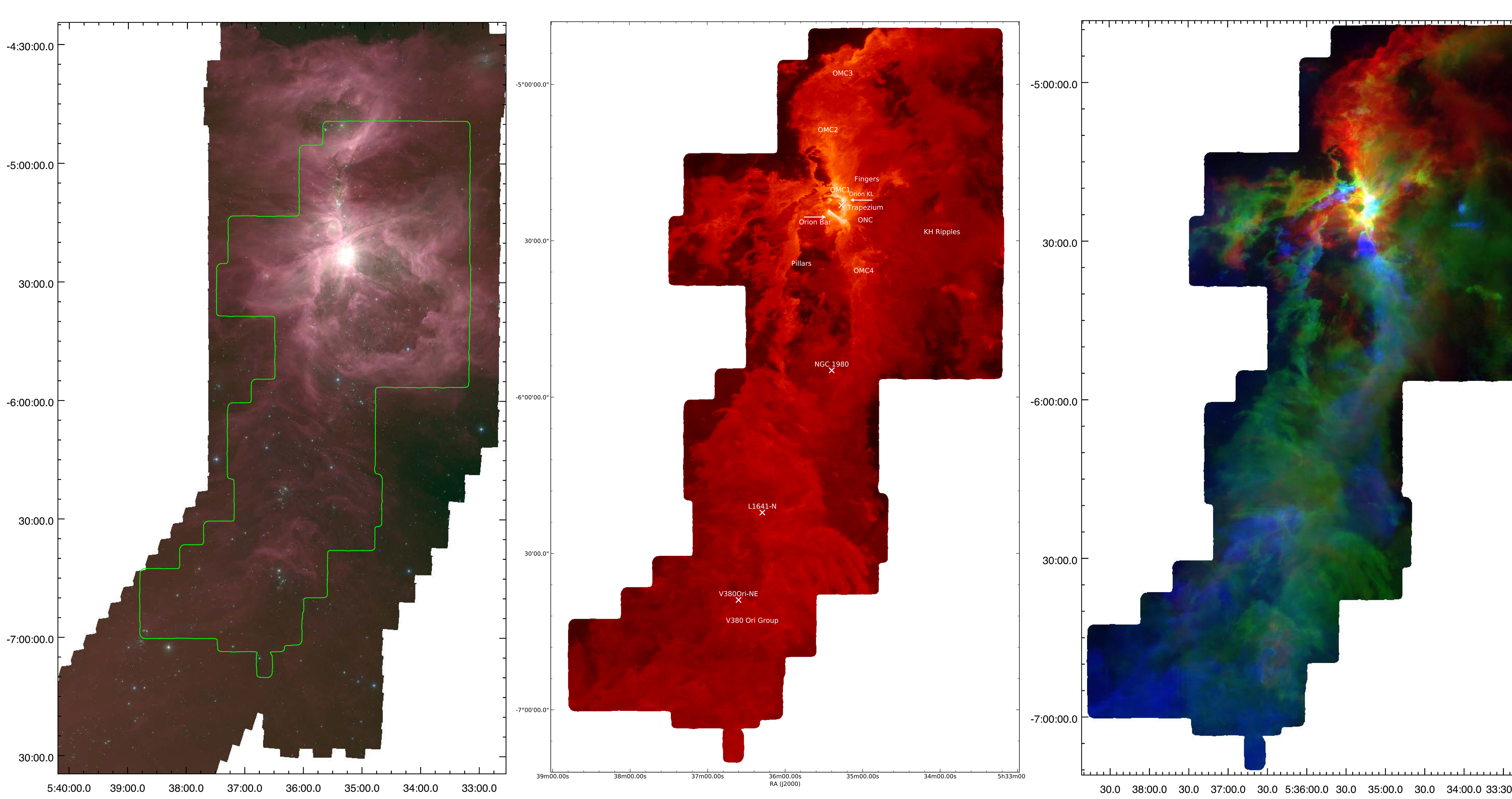


Figure 2: Left: combined data footprint (green polygon) in the Orion A molecular cloud. The background false color image is a composite of Spitzer IRAC 8μm (red), 4.5μm (green), 3.4μm (blue) data (provided by Gutermuth R.). Middle: combined peak intensity map in the same region. The synthesized beam size is ~8". The combined image sensitivity is T_{mb} ~ 0.8 K. Right: false color image combined from three velocity-range integrated intensity maps. The synthesized beam size is ~8".

Results and Summary

Figure 2 shows the observation coverage (Left) and resulting combined images for ^{12}CO(1-0) data (peak intensity image in the middle and velocity-range integrated intensity on the right). The map extends from the OMC-3 and OMC-2 regions in the north (at a declination of about -5°) to the V380 Ori Group (i.e., NGC 1999) and L1641-C region in the south, spanning about 2 degrees in declination. Widespread, complex structures can be seen in the maps. The false color image shows a combination of three velocity-range integrated intensity maps (4.8 - 7.1 km s^{-1} in blue; 7.3 - 9.6 km s^{-1} in green; 9.8 - 12.1 km s^{-1} in red). At the same time, we also have the combined data for ^{13}CO(1-0) and C^{18}O(1-0). We will use these data to study the turbulence, outflows, shell and bubbles, filamentary structures, etc. We will also compare the gas kinematics provided by the molecular line cubes with the kinematics of the star clusters. We expect a fruitful outcome of scientific results to be obtained from the dataset.

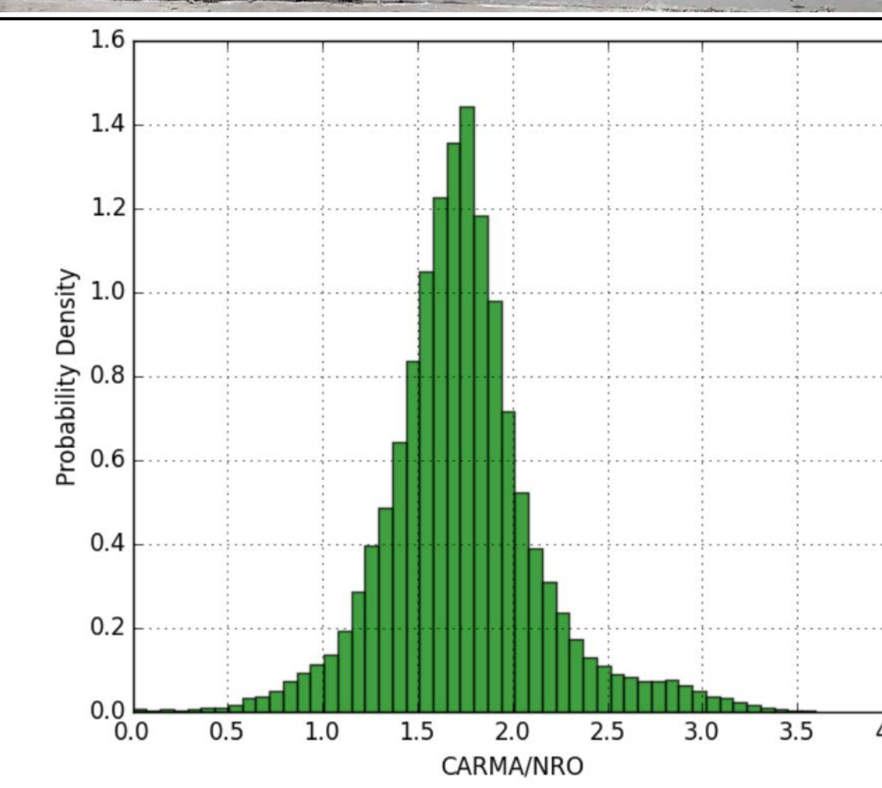


Figure 3: flux density ratio between CARMA and NRO45 images.

Data Combination Between CARMA and NRO45

To combine the NRO45 data with the CARMA data, we first need to be certain that the flux scale of the two datasets match. We modify both datasets so that both maps are sensitive to the same range of spatial scales. By selecting visibilities in the overlapping uv-coverage and comparing the flux in the images obtained in the two data sets, we can determine a flux scale factor F_{CARMA}/F_{NRO45}. We obtained the ratio of intensities between the two dirty maps for each pixel with a signal-to-noise ratio greater than 20 within the region of interest. Plots of the distribution of the ratio for different regions and channels show that they all have a gaussian-like distribution with a peak (average) value of about 1.6 for 12CO (Figure 3). We thus adopted a flux scale factor of 1.6 for ^{12}CO(1-0).

We multiply the flux scale factor to the NRO45 cube. Then, we de-convolve the NRO45 cube with the NRO45 beam, followed by de-mosaicking into the different CARMA mosaic pointings. For each pointing we obtain visibilities as if they were observed using a set of randomly generated baselines (following a gaussian distribution, Figure 4) that mimic the response of the NRO45. The number of points mostly depends on the value we assume for the NRO45 visibility integration time and the requirement that the sensitivity per pixel in uv space for NRO45 visibilities be similar to that of the CARMA visibilities in the uv-range in which they overlap (3-6 kλ). We then merge all the modeled NRO45 visibility files together, followed by a joint de-convolution (clean) with the CARMA data (Figure 5).

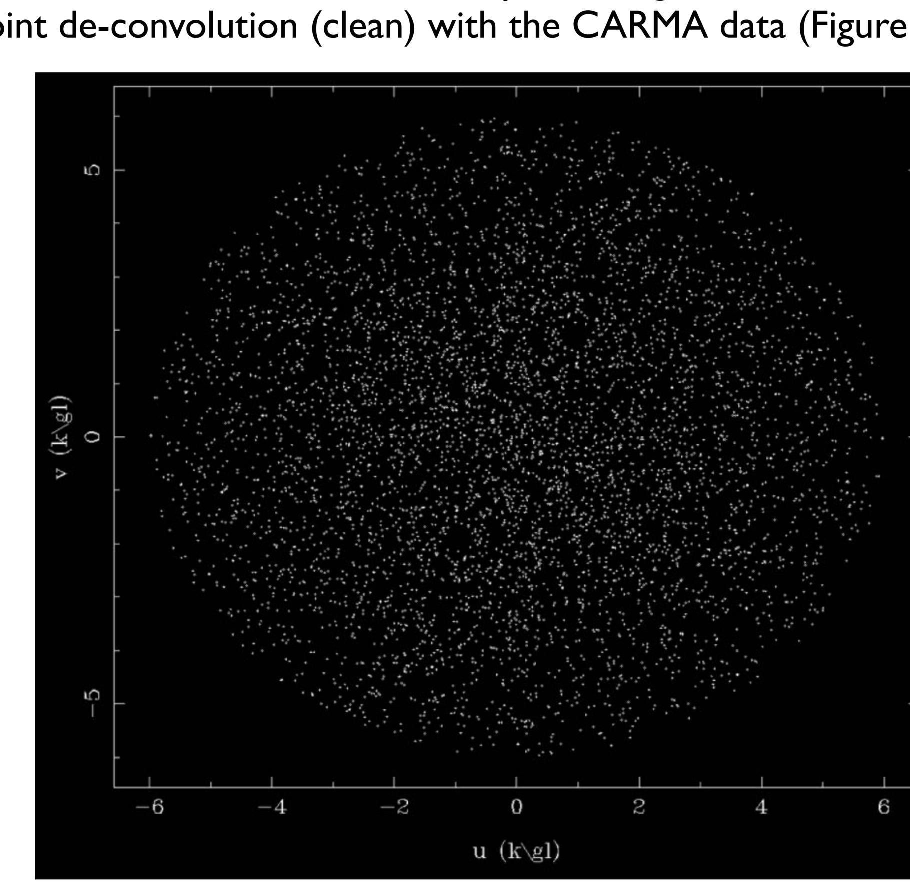


Figure 4: NRO45 Gaussian uv-sample with a FWHM ~3.5 kλ.

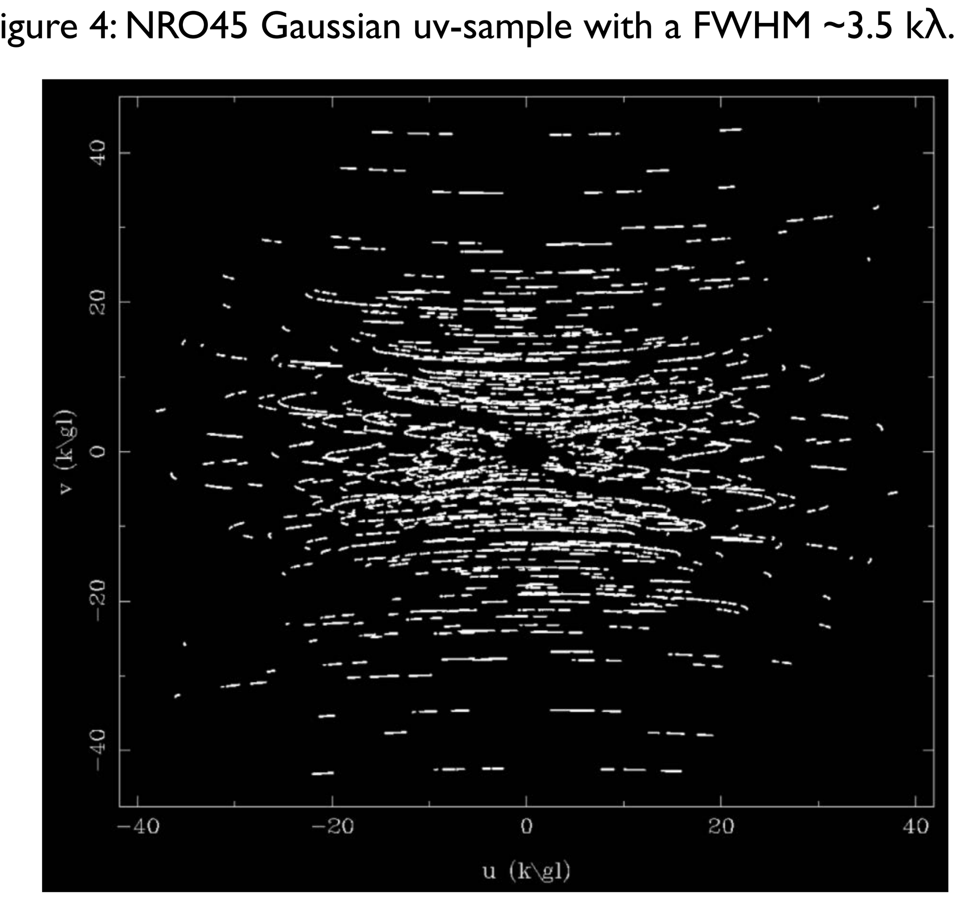


Figure 5: CARMA uv-coverage (configurations D+E).