The Dense Gas Fraction in the Central Molecular Zone in the Milky Way

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Abstract

The Central Molecular Zone (CMZ), a large reservoir of dense molecular gas occupying the central 500pc of the Milky Way, is an extreme star-formation environment where the validity of star formation prescriptions can be tested. The star formation rate (SFR) in the CMZ is about an order of magnitude lower than predicted by the currently accepted prescriptions. An international team lead by PIs Battersby and Keto conducted a survey from 2013-2016 called CMZoom using the Submillimeter Array (SMA) to characterize star formation within resolved molecular clouds in this extreme region. One of the main goals of this survey is to further quantify and understand the low SFR found in this region of the Galaxy. Here, we use the CASA software package to run synthetic observations of hydrodynamical simulations of molecular clouds and vary the observation parameters in such a way that we explore the real parameter space that was probed during the survey. The purpose of this is to investigate how the different observational parameters affect the resultant data. Afterwards, we estimate the "dense gas fraction" (DGF) found in regions across the CMZ. This estimate was found by using the interferometric flux from SMA and the single-dish flux from the Bolocam Galactic Plane Survey. We analyzed the effects that different locations of the CMZ had on these approximate DGF. With these simulations and DGF estimates, we are able to generate improved methods to analyze the data from this survey that will help understand star formation in an extreme environment.

Star Formation in the CMZ

Star Formation (SF): complex process involving different physical phenomena (gas density, temperature and turbulence).

Characteristics of SF Regions: depend on rate of gas dispersal and degree of central concentration.

-Proportional to amount of gas above a threshold of gas surface density or gas volume density

Issue: understand why the star formation seems to be lower than expected around galactic center.

Result: different scenarios have been suggested to determine the cause for this sudden reduction in SFR.

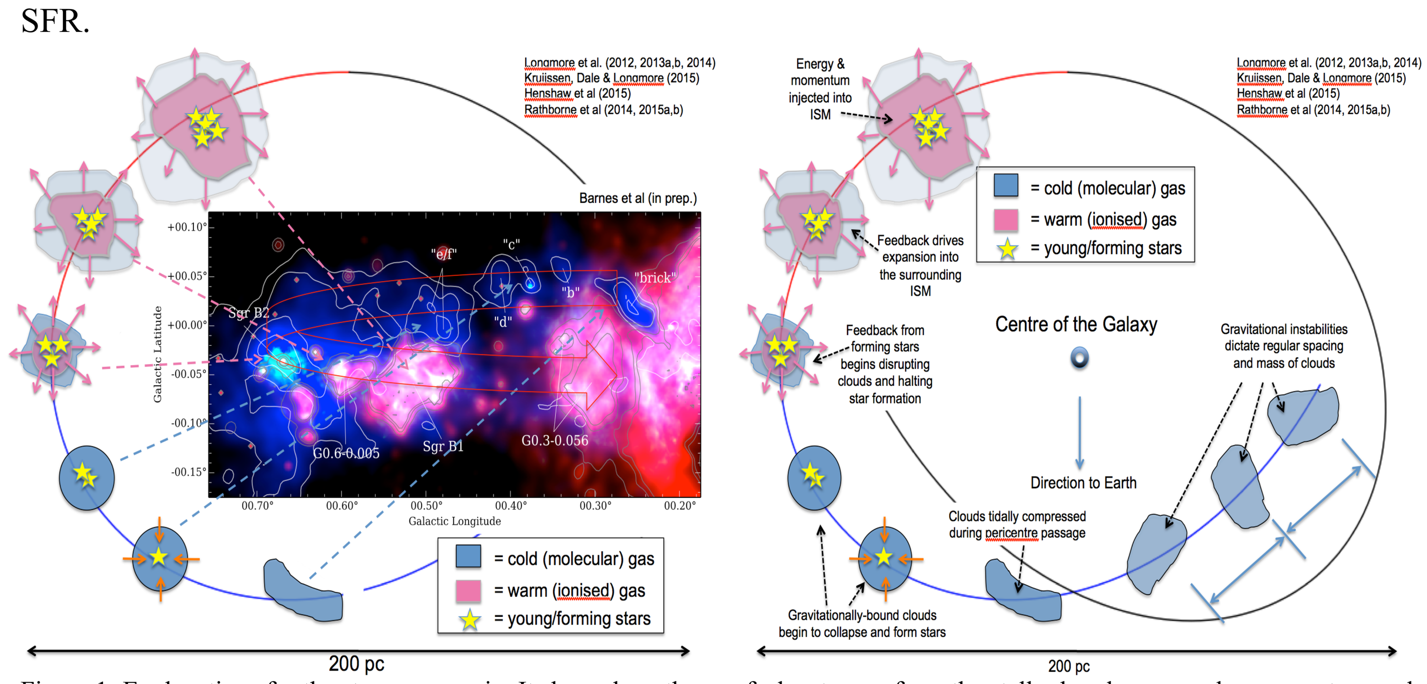

Figure 1: Explanations for the stream scenario. It shows how the gas feels a torque from the stellar bar, loses angular momentum and gets funneled toward the galactic center. The gas from the center seems concentrated in a ring-like structure orbiting the SBH Sgr A*.

Scenario: gas in a disk feels a torque from the stellar bar, loses angular momentum and gets funneled towards the Galactic center.

-Mass inflow likely occurs along the leading edge of the bar and the gas falls into a stellar-mass-dominated potential (not self-gravitating).

-Eventually, this gas mass builds up to the critical density threshold for gravitational instability and then undergoes rapid star formation and gas consumption. Afterwards, cycle starts again.

-This model predicts that turbulent pressure decreases as gas makes its way towards the Galactic center, and the gas becomes self-gravitating.

Requires: that the dense gas fraction must increase, and that it would only occur within the central 100-pc ring.

-Precessing orbit comprised of multiple streams.

-There is a clear asymmetry in the distribution of dense gas in streams, with more dense gas being situated at positive longitudes.

Why the CMZ? It is an extreme environment similar to similar to other galaxies.

-Location: inner 500 pc of Milky Way

-Observational properties where SF can be tested: pressure, density, temperature and turbulence

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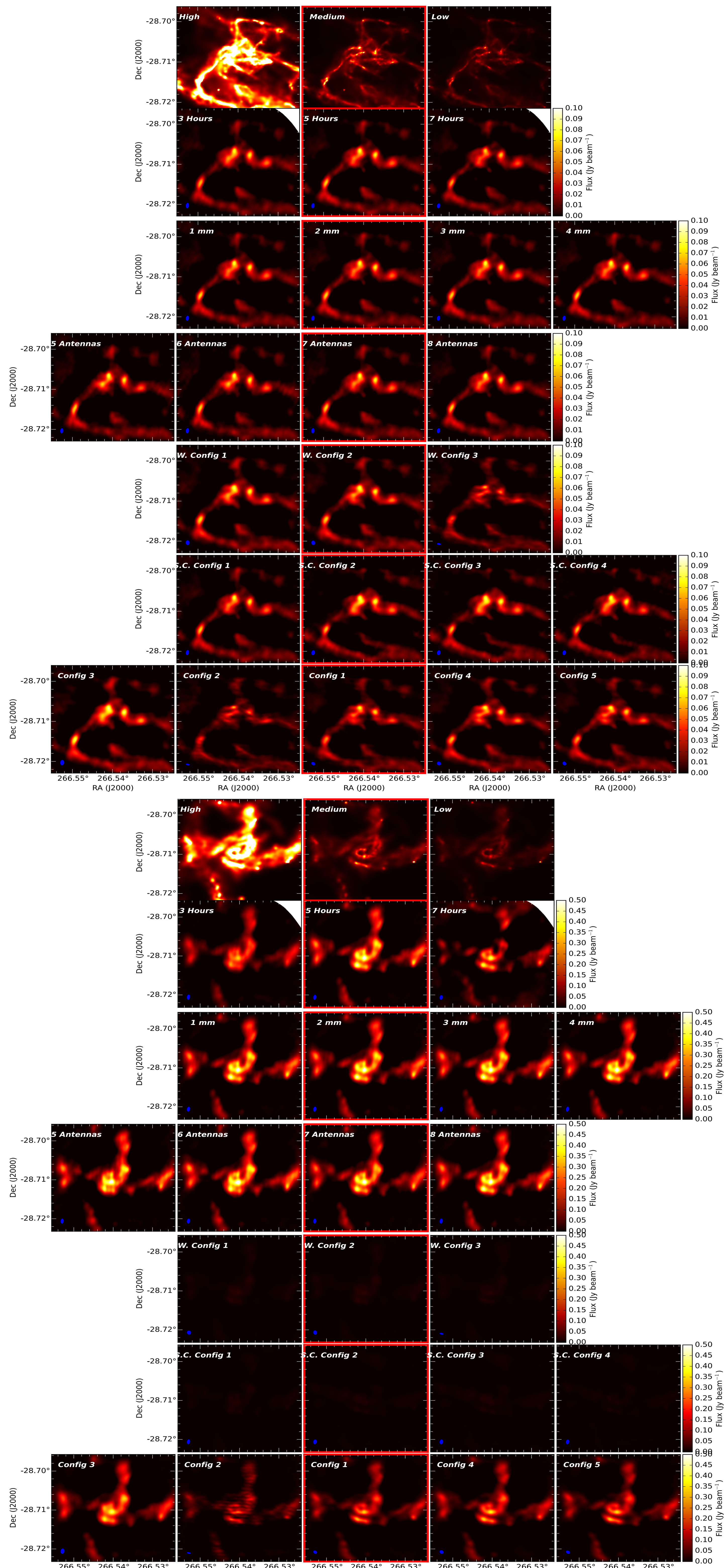

Figure 2: Simulations from Region 1 (top) and Region 2 (bottom). Each box shows a different simulation. The red boxes show the fiducial values from the data sets of the CMZoom survey.

CMZoom Survey

Objective	Obtained	Can lead to
Conduct first large-scale, high-resolution survey of this region	Information about most massive and dense gas cores	Studies on effects that environmental conditions have on star formation

Simulations

The CMZoom Survey operated for 3 years, which made it subject to a large variation of observational parameters. We used simulations to investigate the effects of these parameters on our interferometric data sets.

Simulation Details

- Goal: test the effects that observational parameters have on different locations in CMZ.
- Ran on two different "snapshots" of a simulated cloud produced by numerical modeling by Kruijssen of a cloud progressing along the orbital stream of the CMZ.
- Three "original" files: a high flux field, a medium flux field and a low flux field.
- Simulations run: different total observing times, different weather conditions, different total number of antennas and different antenna configurations.
- In Region 2: altering the array configuration in our simulations caused a significant decrease in observed flux in some cases. We do not believe effect is real and are currently investigating the cause.

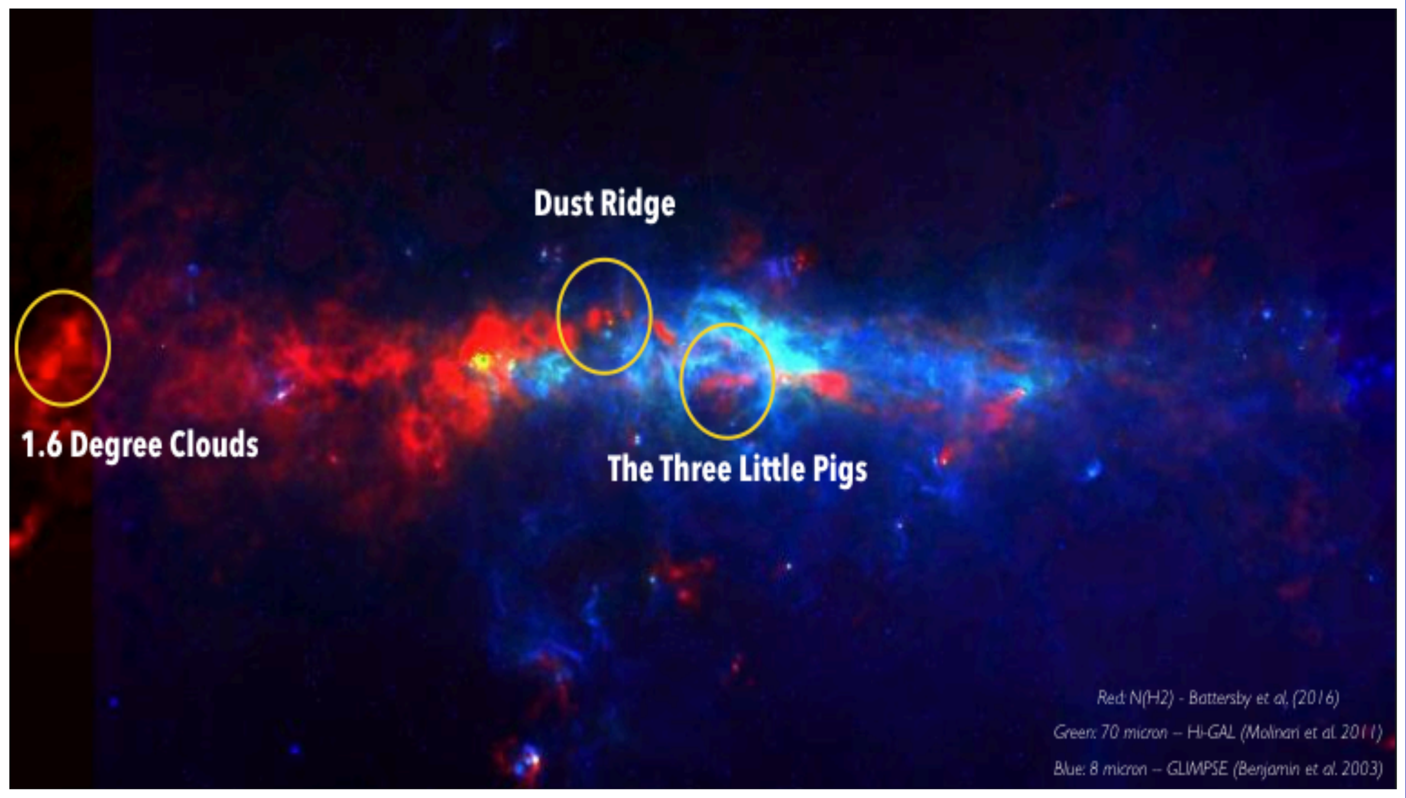

Figure 3: An image of the CMZ showing the regions that were used to determine the dense gas fraction approximation

The Dense Gas Fraction

Objective: compare the dense gas fractions of different locations.

Data used:

-Interferometric data from SMA (small scale structure)

-Single-dish data from Bolocam (large scale structure)

This provides an estimate for how much of total flux was recovered by interferometer:

Formula: Dense gas fraction = SMA flux / Bolocam flux

Obtained: a proxy to the dense gas fraction that is the most basic step and a rough estimate.

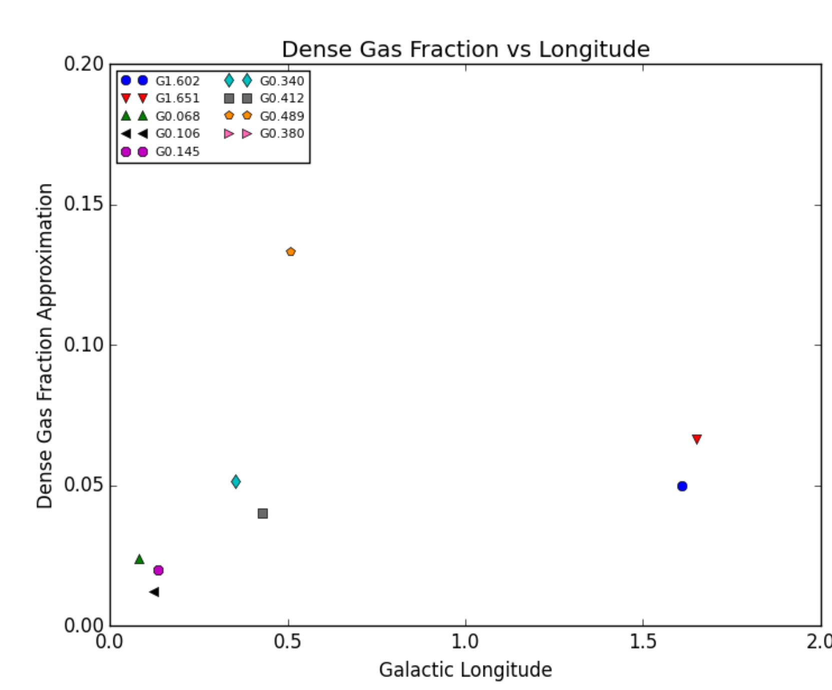

Figure 4: Our dense gas fraction approximation in different locations.

We used two different data sets to provide more information of the entirety of the effects of star formation. We found that the error was around 10%, mostly coming from calibration. This, however, is an imperfect measurement that requires more analysis. We hope to do this type of analysis to all our survey data.

Conclusions

The analysis that has been presented here represents a first step in characterizing the effects of different observational parameters on our survey data. Future analysis will focus on quantifying these effects. Meanwhile, we also take the first step in comparing the survey data with the stream scenario proposed by Longmore et al. (2013) by doing the dense gas fraction approximation and find that, as of now, the results seem to agree with this scenario. This also gives us an initial look to objects of interest. We can now do further analysis in these initial conditions, the simulation effects and the calibration in the dense gas fraction.

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