SMA Legacy Survey of the Central Molecular Zone

Cara Battersby

Eric Keto (CfA), Qizhou Zhang (CfA), Xing ‘Walker’ Lu (CfA), Mark Graham (Southampton), Jens Kauffmann (Bonn), Thushara Pillai (Bonn), John Bally (CU-Boulder), Steve Longmore (Liverpool), Daniel Walker (Liverpool), Diederik Kruijssen (MPA), Adam Ginsburg (ESO), Nimesh Patel (CfA), Volker Tolls (CfA), Luis C. Ho (Peking Univ.)

Red N(H₂) (Battersby+ in prep.), Green 70 micron (Hi-GAL, Molinari +2011), Blue: 8 micron (GLIMPSE, Benjamin+2003)
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Team:

CfA: Cara Battersby, Eric Keto, Qizhou Zhang, Xing ‘Walker’ Lu, Mark Graham (Southampton), Nimesh Patel, Volker Tolls

Bonn: Jens Kauffmann, Thushara Pillai

University of Colorado, Boulder: John Bally

Liverpool: Steve Longmore, Daniel Walker

MPA: Diederik Kruijssen

ESO: Adam Ginsburg

Peking University: Luis C. Ho
Almost no signs of active star formation!

1.3x10^5 M_☉ in < 3 pc

“The Brick”

T ~ 20 K

M ~ 10^5 M_☉

Σ_{H2} ~ 1 g cm^{-2}

Longmore et al. 2012; Rathborne et al. 2014; Johnston et al. 2014, etc. etc. etc.
Almost no signs of active star formation!

$1.3 \times 10^5 \, M_\odot$ in $< 3$ pc

"Bricklet D"

$T \sim 20 \, K$

$M \sim 10^5 \, M_\odot$

$\Sigma_{H_2} \sim 1 \, g \, cm^{-2}$
SMA Legacy Survey of the Central Molecular Zone

- Large primary beam, high angular resolution, large bandwidth $\rightarrow$ detect (pre-) star-forming cores
- First sub-pc (0.2 pc) survey of dense, molecular gas in the CMZ $\rightarrow$ 1.3 mm dust continuum + spectral line
SMA Legacy Survey of the CMZ

- 230 GHz (1.3 mm)
- 240 arcmin² (above $N(H_2) = 10^{23}$ cm⁻² or $3 \times 10^{22}$ cm⁻²)
- 4” (0.2 pc) resolution, $\Delta v \sim 1.1$ km/s
- Dust continuum + spectral lines ($H_2CO$, $^{12}CO$, $^{13}CO$, $C^{18}O$, SiO, CH$_3$OH, CH$_3$CN, etc.): 8 GHz bandwidth
- 3 mJy RMS continuum, 0.4 K
- 500 hours (50 subcompact, 450 compact/custom)
- Complement with single-dish (APEX, CSO) observations
SMA Legacy Survey of the CMZ

- Identify dense cores
- Search for embedded star formation

- 230 GHz (1.3 mm)
- 240 arcmin$^2$ (above $N(H_2) = 10^{23}$ cm$^{-2}$ or $3 \times 10^{22}$ cm$^{-2}$)
- 4″ (0.2 pc) resolution, $\Delta v \sim 1.1$ km/s
- Dust continuum + spectral lines ($H_2CO$, $^{12}CO$, $^{13}CO$, $C^{18}O$, SiO, CH$_3$OH, CH$_3$CN, etc.): 8 GHz bandwidth
- 3 mJy RMS continuum, 0.4 K
- 500 hours (50 subcompact, 450 compact/custom)
- Complement with single-dish (APEX, CSO) observations
Column Density Map with contours at 3, 5, 10 x 10^{22} \text{ cm}^{-2} 
(cyan, blue, magenta)

Observed regions with green mosaics
Basic Science Questions:

1) What is the cause of the extremely low star formation efficiency (given the reservoir of dense gas) in the CMZ?

2) Is there an energy and SF cycle in the CMZ? Where does gas enter the CMZ?

3) Is SF induced by tidal compression by SgrA*?

4) Can we find precursors to the most massive stars in the Galaxy?
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\( N(\text{H}_2) \)
70 \( \mu \text{m} \)
8 \( \mu \text{m} \)
1.3 mm dust continuum
Dan Walker, in prep.
1.3 mm dust continuum
Dan Walker, in prep.
$N(H_2)$

70 µm

8 µm
1.3 mm dust continuum
Dan Walker, in prep.
1.3 mm dust continuum
Xing ‘Walker’ Lu, in prep.
Basic Science Questions:

1) What is the cause of the extremely low star formation efficiency (given the reservoir of dense gas) in the CMZ? – measure the Temp, turbulence…

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N(H₂)
70 µm
8 µm
Mark Graham
Southampton Master’s Student
N(H$_2$)
70 µm
8 µm

3 pc
$N$-PDF of G0.145-0.086

$\eta \equiv \ln (N/\langle N \rangle)$

$\langle N \rangle = 2.473 \times 10^{22}$

$\sigma_\eta = 0.402$

$\beta = 1.75$
N(H₂)
70 µm
8 µm
$N$-PDF of G0.106-0.082

$\eta \equiv \ln(N/\langle N \rangle)$

$\langle N \rangle = 3.465 \times 10^{22}$

$\sigma_\eta = 0.394$

$\beta = 1.75$
N(H₂)
70 µm
8 µm
$N$-PDF of G0.068-0.075

$\eta \equiv \ln\left(\frac{N}{\langle N \rangle}\right)$

- $\langle N \rangle = 1.93 \times 10^{22}$
- $\sigma_\eta = 0.592$

$\beta = 1.75$

$3\sigma$
Basic Science Questions:

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**Figure 1:** A model from Kim et al. (2011) illustrating the migration of gas in a barred galaxy from $x_1$ orbits onto $x_2$ orbits to form a 100 – 500 pc radius circum-nuclear ring which co-rotates with the bar. Angular momentum dissipation drives gas towards the nucleus where the gravitational potential of the galaxy may compress it. As the critical density for gravitational collapse is reached, star formation may ignite in the inner ring.
Simulation from Kim et al. (2011). Migration of gas in a mildly barred galaxy
Simulation from Kim et al. (2011). Migration of gas in a mildly barred galaxy
Preliminary Core mass estimates, assuming 20 K

A: 400 M☉  
B: 150 M☉  
C: 140 M☉  
D: 130 M☉
We are seeing interesting structures AND a LOT of variation between regions that otherwise look similar.
Basic Science Questions:

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Current Projects Overview
Survey overview, dense core catalog: Battersby and Keto
Column Density PDFs: Graham and Battersby
X1 orbit analysis: Bally
Cloud Structure and SFRs with the extended Press-Schecter Formalism: Keto
Deeply Embedded High-mass Star Formation in the CMZ Clouds: Lu and Zhang
Testing models of CMZ morphology: Kruijssen
Temperature Structure of CMZ Clouds: Kauffmann and Pillai
Isolated Massive Star Formation in the Galactic Center: Pillai
Bricklets -- evolution of YMCs in the dust ridge: Walker and Longmore
Metal cores in the CMZ: Longmore
$N$-PDF of G1.651-0.050

$$\eta \equiv \ln\left(\frac{N}{\langle N \rangle}\right)$$

$\langle N \rangle = 1.848 \times 10^{22}$

$\sigma_\eta = 0.470$

$\beta = 1.75$
$N$-PDF of G1.602+0.018

\[ \eta = \ln\left(\frac{N}{\langle N \rangle}\right) \]

$\langle N \rangle = 3.049 \times 10^{22}$

$\sigma_\eta = 0.414$

$\beta = 1.75$
The Wild West of Star Formation

$\Delta v \sim 10x$ higher
$n \sim 10-100x$ higher
High temperatures, ubiquitous exotic molecules

N(H$_2$)
70 $\mu$m
8 $\mu$m
Pilot – PI: Xing (Walker) Lu
New orbital models from Co-Is Kruijssen and Longmore (Kruijssen et al. 2015)
New orbital models (Kruijssen+ 2015)
3pc

1.3 mm dust continuum

Dan Walker, in prep.