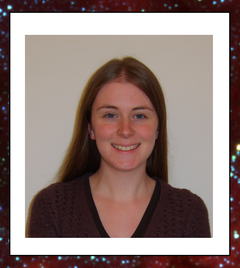


Does the Galactic centre cloud G0.253+0.016 violate star formation ~~laws~~ RELATIONS?

Katharine Johnston, Henrik Beuther, Steven Longmore, Jill Rathborne, Sarah Ragan
(Max Planck Institute for Astronomy, Liverpool John Moores and CSIRO)

ABSTRACT What are the initial conditions to form the most massive clusters in the Milky Way? The massive infrared dark cloud (IRDC) G0.253+0.016 contains 10^5 Msun of gas whilst being mostly devoid of star formation tracers. Could such a cloud be the precursor of the next Arches or Quintuplet cluster, as would be suggested by current star formation relations? To scrutinise the gas properties of this exceptional region, we have carried out a concerted SMA and IRAM 30m study of this enigmatic cloud in dust continuum, CO isotopologues as low-density tracers, as well as CH_3OH and SiO as shock tracers, to resolve its structure.

The IRDC G0.253+0.016

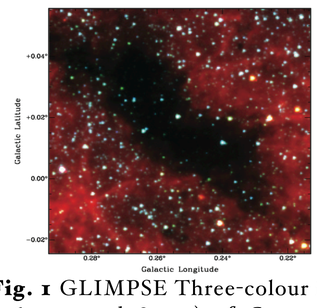


Fig. 1 GLIMPSE Three-colour image (3.6, 4.5, and 8 μm) of G0.253+0.016. From Figure 1 of Longmore+ 2012

Projected 45pc from the Galactic Centre

Mass: 1 - 2 x 10^5 Msun

Geometric mean **radius**: 2.8 pc

Peak **column density**:

4 g cm^{-2} -OR- 1.2 x 10^{24} cm^{-2} (H_2)

Number of stars > 16 Msun: ***Zero (should be > 30 according to Lada+ 2010)***

(Lis+ 1994, Lis+ 2001, Longmore+2012, this work)

The Galactic Centre Environment

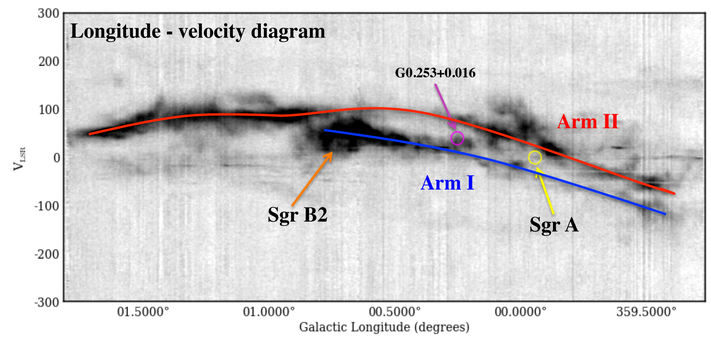


Fig. 6 HNC MOPRA 3mm survey of the Central Molecular Zone (Jones+ 2012) velocity vs Galactic longitude diagram. Arm I and Arm II were originally shown in Sofue+ 1995. Excluding more positive longitudes than Sgr B2, these two arms would trace an elliptical orbit in l-v space.

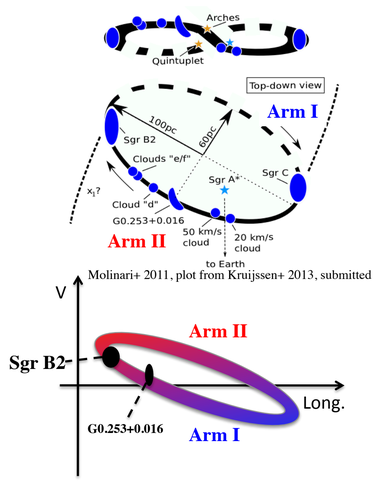


Fig. 7 Top left: Schematic of the dynamical picture put forward by Molinari+ 2011 (where the "twisted ring" observed in the far-IR with Herschel is interpreted as the stable X2 orbit of the barred Galactic potential). Bottom left: Schematic of the observed longitude-velocity diagram in Fig. 6. Top right: One alternative interpretation, which explains the observed l-v diagram.

The schematic in Fig. 7 shows that the side of the ring containing G0.253+0.016 should be predominantly redshifted, whereas we observe it to be in the predominantly blueshifted side.

Therefore the Molinari+ 2011 picture does not agree with the dynamics in the observed l-v diagram.

Possible alternatives include an orbit with the major axis parallel with the bar.

SMA and IRAM 30m Observations

SMA Continuum and Line Observations

- SMA compact array configuration
- Two 4 GHz sidebands at 218.9 & 230.9 GHz (1.37 & 1.3mm)
- 6-pointing mosaic
- Spectral resolution of 0.812 MHz or 1.1 kms^{-1}
- Resolution ~4'' x 3'' (~0.15 pc), largest angular scale ~21''
- rms ~70 mJy/beam for lines, 2.5 mJy/beam in continuum

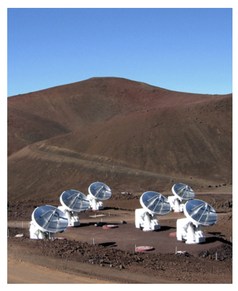
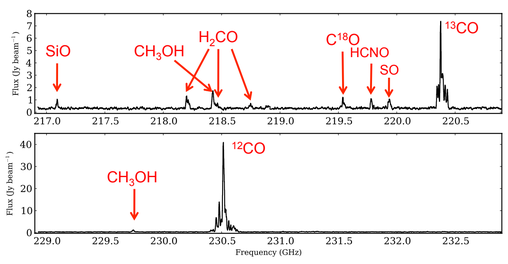


Fig 2. (right): SMA detected lines
SiO, CH_3OH, HNCO, SO - shock tracers
^{12}CO, ^{13}CO, $C^{18}O$, - Diffuse gas tracers
H_2CO - Dense gas tracer, temperature probe



IRAM 30m Line Observations

- Two 8 GHz sidebands placed at 217.3 and 233.0 GHz
- EMIR with FTS backend
- OTF mapping of 3′ x 4′ area (in RA/Dec resp.)
- Spectral resolution of 0.2 MHz or 0.3 kms^{-1}
- Resolution ~12'' (~0.5 pc)
- rms ~ 2 Jy/beam

Does G0.253+0.016 Violate Currently Proposed Star Formation Relations?

Dust Emission

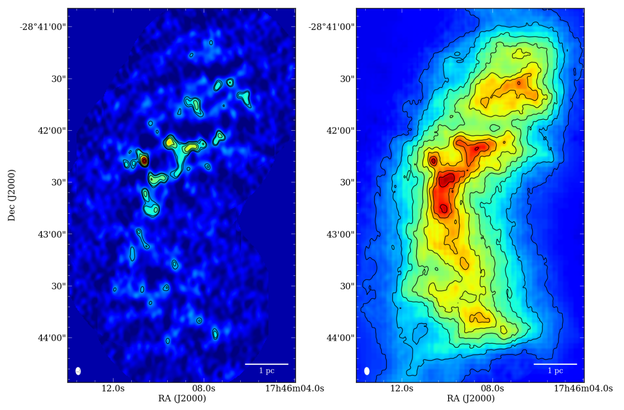


Fig. 8 **Left:** 230.9 GHz or 1.3mm SMA dust continuum emission. **Right:** Combined SMA and scaled SCUBA 450μm dust emission.

Column Density PDF of G0.253+0.016

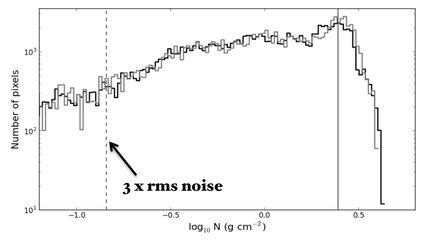


Fig.9 Column density Probability Density Functions (PDFs) derived from the SCUBA 450μm emission **(grey histrogram)** and the combined SMA and scaled SCUBA 450μm **(black histogram)**.

Column density PDF has unusual plateau of gas at lower densities.

No power-law tail at higher densities.

Can turbulence explain zero observed massive stars?

Virial mass:

$$M_{\rm vir} = \frac{5R\sigma_v^2}{G\alpha_{\rm vir}} \longrightarrow \bar{\rho} = \frac{5R\sigma_v^2}{G\alpha_{\rm vir}V}$$

$$\longrightarrow \rho_{\rm th} \propto \sigma_v^2$$

Threshold column density:

$$N_{\rm th}' = N_{\rm th}\left(\frac{\sigma_{\rm G0.25+0.02}}{\sigma_{\rm Gal.disk}}\right)^2$$

~16 km/s

~2.5 km/s

$N_{\rm th} = 0.024\,{\rm g\,cm^{-2}}$ (Lada et al. 2010)

New threshold column density:

$$N_{\rm th}' \sim 1\,{\rm g\,cm^{-2}}$$

Mass above new threshold and number of YSOs (0.18 YSOs / Msun):

$$M_{\rm th}' \sim 1.6\times10^5 M_\odot \qquad N_{\rm YSO} \sim 2.9\times10^4$$

Number of YSOs > 15 Msun given Kroupa IMF:

Still 24! (but zero observed! Lis+ 1994)

Therefore G0.253+0.016 is still lacking in star formation for its mass!

Possible Solutions:

Evolution: *other studies have looked at more evolved clouds, or clouds smoothed over a large area and thus time.*

There is not one absolute column density threshold for SF*, but a "critical overdensity factor"* (e.g. Krumholz & McKee 2005, Padoan & Nordlund 2011, Kruijssen+ 2013, submitted)

Evidence for Cloud Collisions

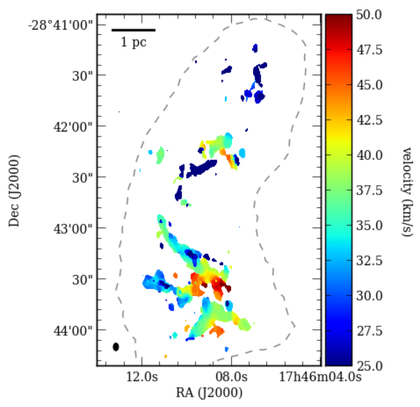


Fig. 3 CH_3OH first moment map (intensity-weighted average velocity)

Shock tracer CH_3OH shows a large velocity gradient across three filaments in the south of G0.253+0.016.

The velocity gradient would require 4 x 10^4 Msun of mass within a ~10" or 0.4 pc radius to accelerate the gas.

However, this mass is not detected in our 1.3mm continuum observations (see Fig. 8), therefore a cloud collision scenario could instead explain the gradient.

Three dimensional rendering of the field (Fig. 5) in P-P-V space shows that another cloud centred at 70 km/s is likely to be the colliding with G0.253+0.016.

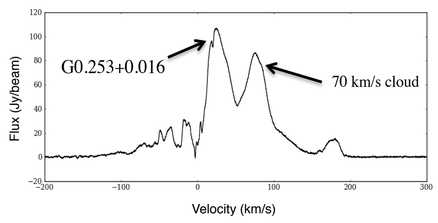
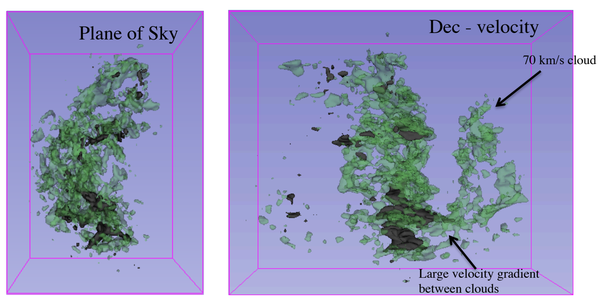


Fig. 4 IRAM 30m ^{12}CO emission integrated over obsered 4'x3' field.

Fig.5 3D rendering of G0.253+0.016. Black: CH_3OH Green: ^{13}CO



CONCLUSIONS

1. Shock tracers and dynamics point to cloud collision for G0.253+0.016.

2. Proposed Molinari+ 2011 100pc ring does not agree with observed position-velocity structures.

3. Unusual column density PDF (and no obvious power-law tail, consistent with no SF)

4. Absolute column density threshold modified for Galactic Centre turbulence is not sufficient to explain the lack of massive stars (although critical overdensity factor may work instead).

Please email any questions or comments to:
johnston@mpia.de