Angular Momentum and the FORMATION OF GMCs

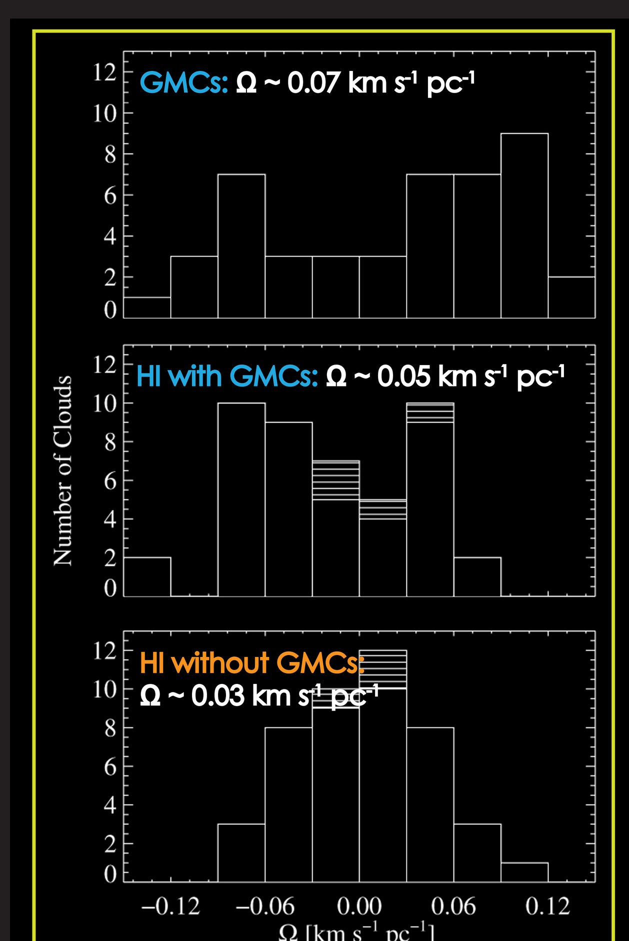
Nia Imara, PhD

Harvard-Smithsonian Center for Astrophysics ❖ nimara@cfa.harvard.edu

– ABSTRACT –

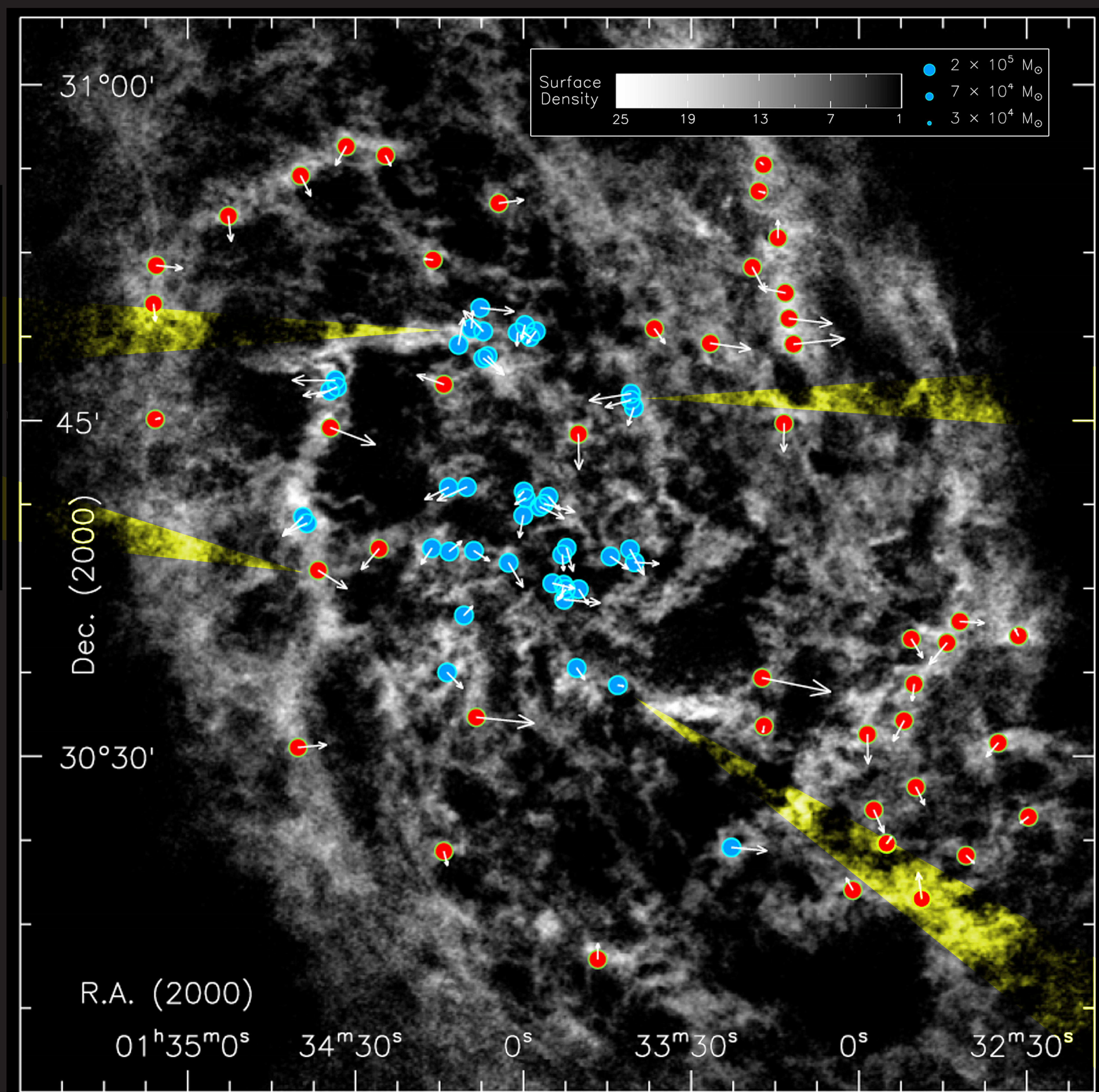
In **Imara, Bigiel & Blitz (2011)**, I present an analysis comparing the properties of 45 giant molecular clouds (GMCs) in M33 and the atomic hydrogen (HI) with which they are associated. High-resolution Very Large Array observations are used to measure the properties of HI in the vicinity of GMCs and in regions where GMCs have not been detected. The majority of molecular clouds coincide with a local peak in the surface density of atomic gas, though 7% of GMCs in the sample are not associated with high surface density atomic gas. The mean HI surface density in the vicinity of GMCs is 10 M_{Sun} pc^{-2} and tends to increase with GMC mass as $\Sigma_{HI} \sim M_{GMC}^{0.27}$.

Thirty-nine of the 45 HI regions surrounding GMCs have linear velocity gradients of 0.05 km s^{-1}. If the GMC gradients are due to rotation, 53% are counterrotating with respect to the local HI. And if the linear gradients in these local HI regions are also from rotation, 62% are counterrotating with respect to the galaxy. If magnetic braking reduced the angular momentum of GMCs early in their evolution, the angular velocity of GMCs would be roughly one order of magnitude lower than what is observed. Atomic gas not associated with GMCs has gradients closer to 0.03 km s^{-1} pc^{-1}, suggesting that events occur during the course of GMC evolution that may increase the shear in the atomic gas.

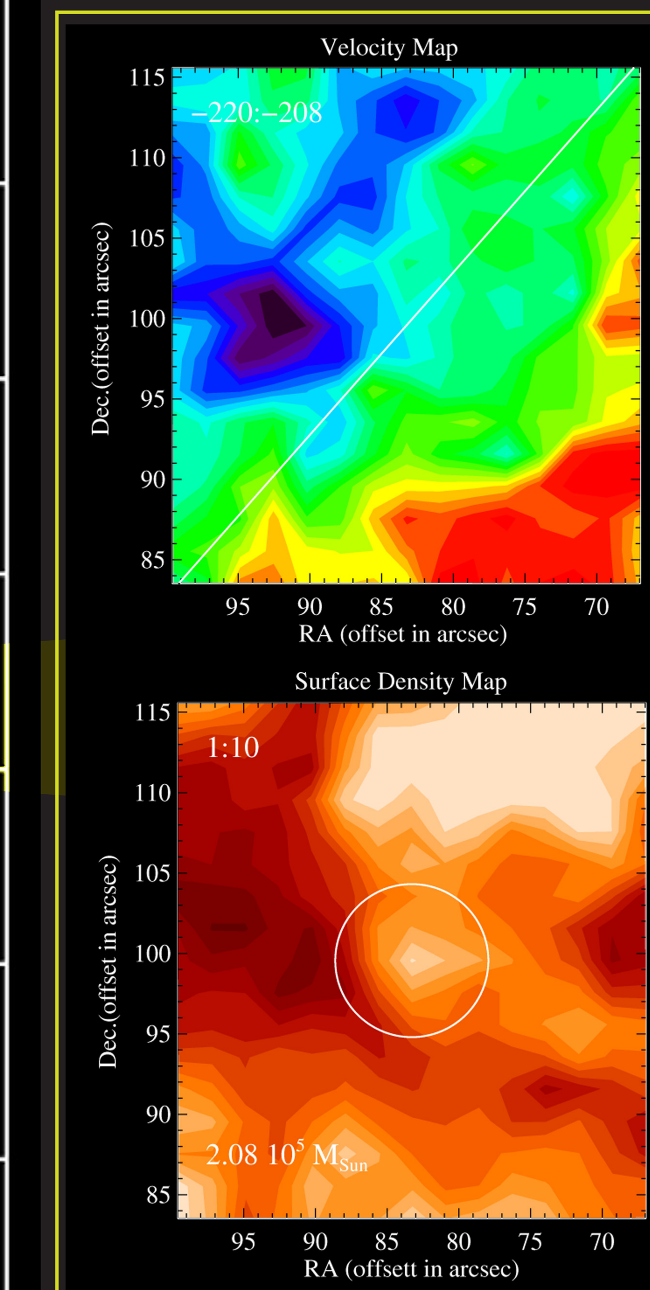


Gradient magnitudes for (a) GMCs, (b) HI clouds containing GMCs, and (c) HI clouds without observed GMCs in M33. Clouds having a position angle differing from the galaxy by more than 90 degrees are given negative values. The hatched portions of the histograms in panels (b) and (c) represent regions having nonlinear gradients.

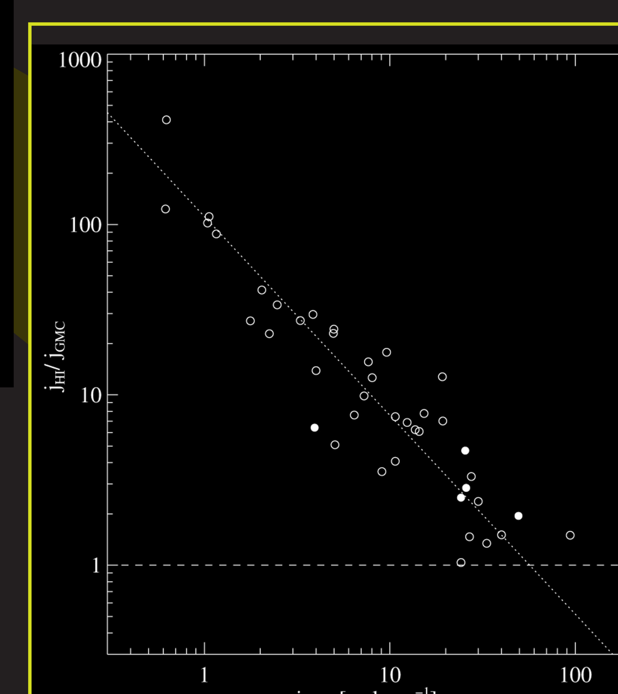
M33 – central 45′ × 45′ region. (VLA data courtesy of Thilker et al. 1997.) Gray-scale is 21-cm emission in units of M_{Sun} pc^{-2}. Molecular clouds are overlaid with area scaled to mass. Nearly all (93%) GMCs lay in regions of high-density HI. The galactic mean of Σ_{HI} is roughly 4 M_{Sun} pc^{-2}, while the mean value in the vicinity of GMCs is 10 M_{Sun} pc^{-2}. ***Thus high-density HI appears to be necessary but not sufficient for the formation of GMCs.***



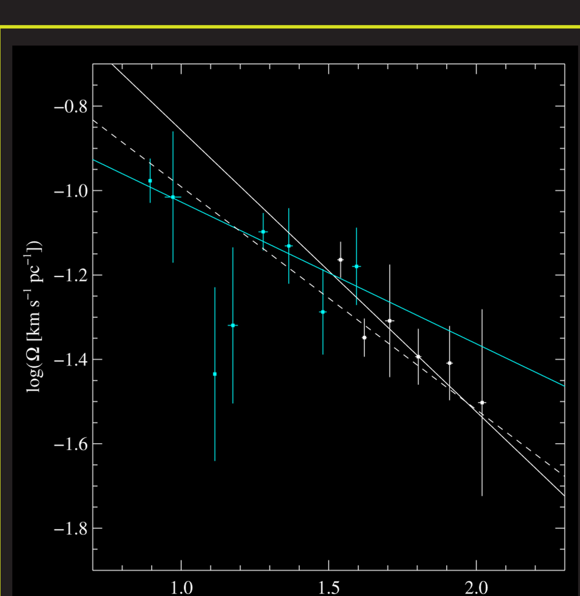
Directions of the gradients in the atomic gas are plotted for HI regions containing molecular clouds (blue) and for HI regions without observed molecular clouds (orange). The arrows point in the direction of increasing velocity and have lengths proportional to the gradient magnitude. The gradient directions of the individual velocity fields where GMCs are observed (or, where GMCs may potentially be in the process of forming) do not appear to make up a large-scale, systematic pattern.



Typical velocity- and surface-density maps for HI-GMC regions. The top figure shows the first-moment map of the HI with the gradient axis overlaid. The velocity range (top left corner) is in units of km s−1; red represents the maximum speed. The bottom figure is a surface density map of the HI overlaid with a circle matching to the size of the associated GMC; the 10 MSun pc−2 contour is overlaid in yellow. The range of HI surface densities (top left corner) is in units of MSun pc−2 , and the total HI mass in the region is written in the bottom left corner.



Ratio of specific angular momenta in atomic gas and GMCs, j_{HI}/j_{GMC}, vs. specific angular momentum in the 36 resolved GMCs. This plot shows that jHI > jGMC is always the case. The dotted line shows the least-squares fit to the data: $(j_{HI}/j_{GMC}) \sim j^{-1.17\pm0.05}$. The median j_{HI}/j_{GMC} is 13 and the average is 27. Data points for Milky Way GMCs are overplotted in filled circles (but are not included in the fit).



Gradient magnitudes observed in GMCs (white) and associated atomic gas (blue) as a function of size. The data are averaged in bin sizes of ΔR = 0.1 dex. The lines indicate least-squares, power-law fits to the data. For GMCs, $\Omega_{GMC} \sim R^{-0.3\pm0.2}$, and for HI, $\Omega_{HI} \sim R^{-0.7\pm0.2}$, where R_A is the accumulation radius. For GMCs and HI combined, $\Omega \sim R^{-0.5\pm0.1}$, which is the relationship found by Burkert & Bodenheimer (2000) for turbulent molecular cores.

Motivating Ideas

- ❖ What do the kinematic properties of GMCs tell us about their evolution?
- ❖ If GMCs are rotating, is their angular momentum consistent with current theories of GMC formation?
- ❖ M33 is ~850 kpc away and ~ face-on: a great astrophysical laboratory!
- ❖ Does HI surrounding GMCs have any distinguishing characteristics? E.g., do HI regions exist with the "right" amount of angular momentum (i.e., low, comparable to GMCs)? Possible solution: Search for gradients along "non-GMC" HI filaments and compare to HI where GMCs are observed.