Observed Acceleration of Gas Clouds in the Fermi Bubbles

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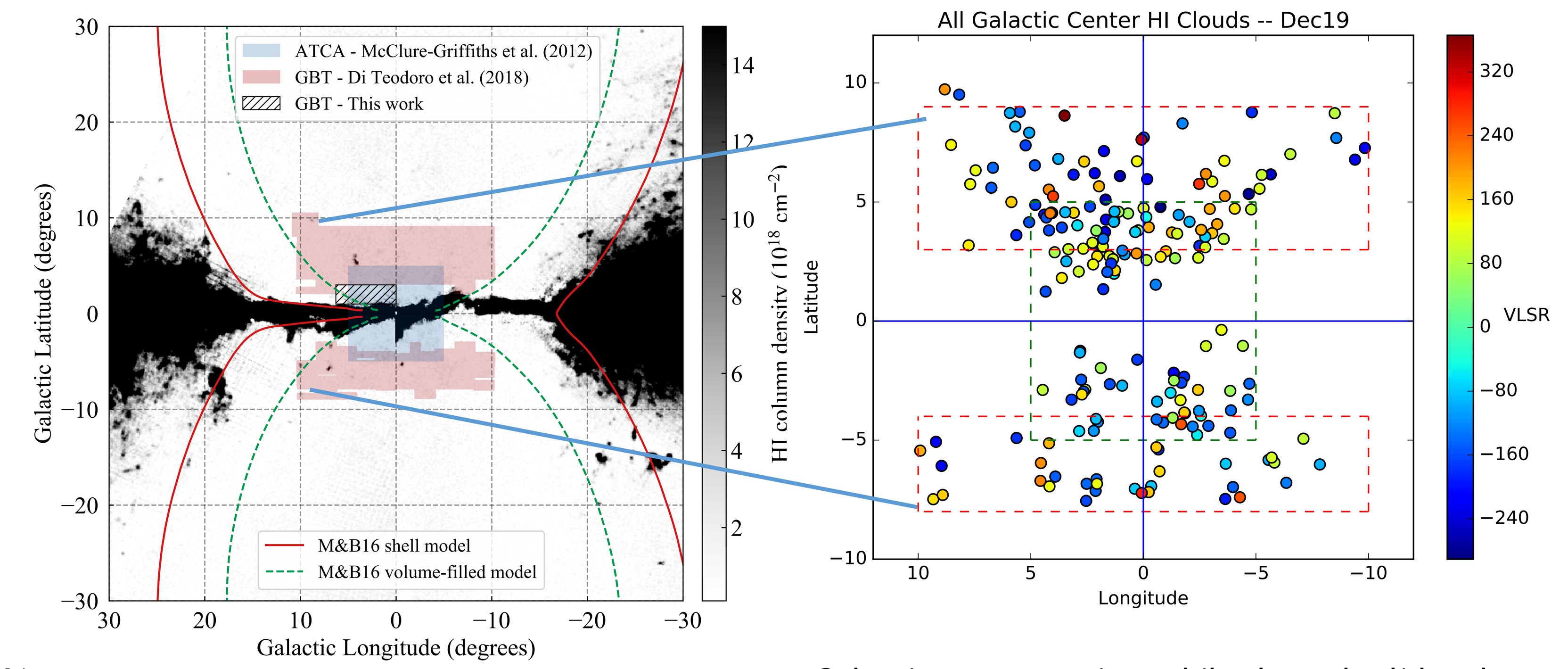
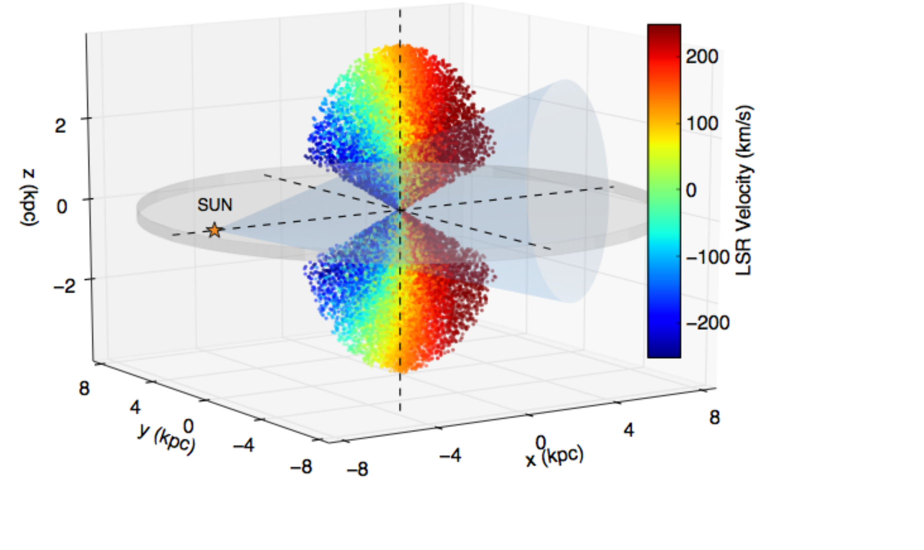
ABSTRACT

HI 21cm emission studies with the **Green Bank Telescope (GBT) and Australia Telescope Compact Array (ATCA)** have identified about 200 neutral clouds that are entrained in the nuclear wind that created the Fermi Bubbles (McClure-Griffiths et al. 2013, ApJL, 770, L4; DiTeodorio et al. 2018, ApJ, 855, 33). The clouds are found up to nine degrees from the Galactic plane, have large non-circular velocities — in some cases greater than 300 km/s — and are not associated with the gravitationally-driven streaming motions found in the Galactic nucleus and bar. The cloud population kinematics is consistent with outflow from the Galactic nucleus.

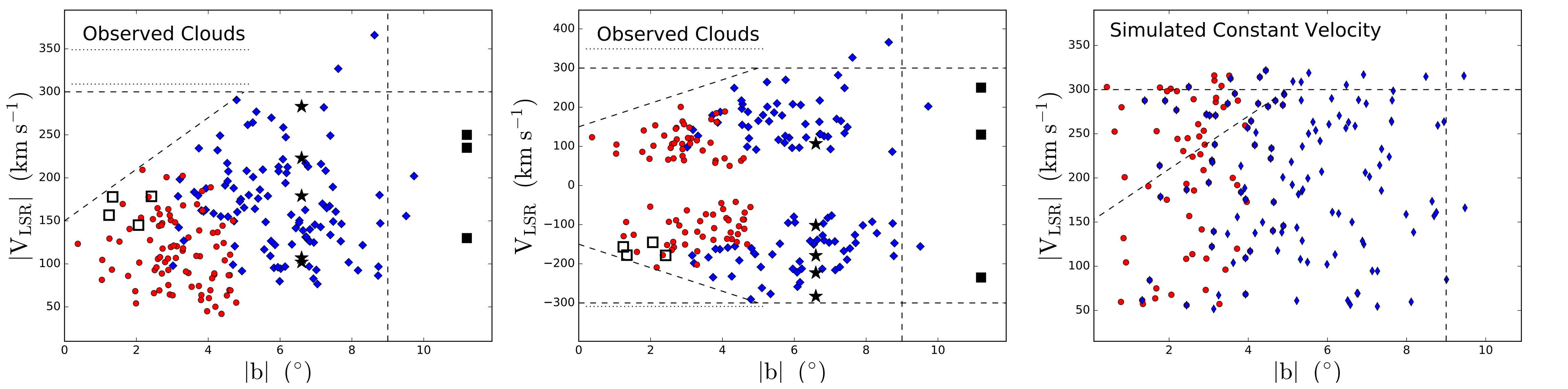
A analysis incorporating new data from the **GBT** shows that the clouds have an outflow velocity that must be accelerating from perhaps 175 km/s close to the Galactic Center, to greater than 300 km/s over a few kpc. The acceleration is observed at both positive and negative latitudes and for approaching and receding clouds. Acceleration is also consistent with the velocity structure of UV absorption lines measured against targets at lbl<12° behind the Fermi Bubbles. To reach their observed locations with these outflow velocities imply cloud lifetimes of 4 - 10 Myr. The surveys have not yet established the longitude and latitude limits of this population, or whether the outflow originates at a point or from an extended source. Will appear in ApJ **2019arXiv191106864L**



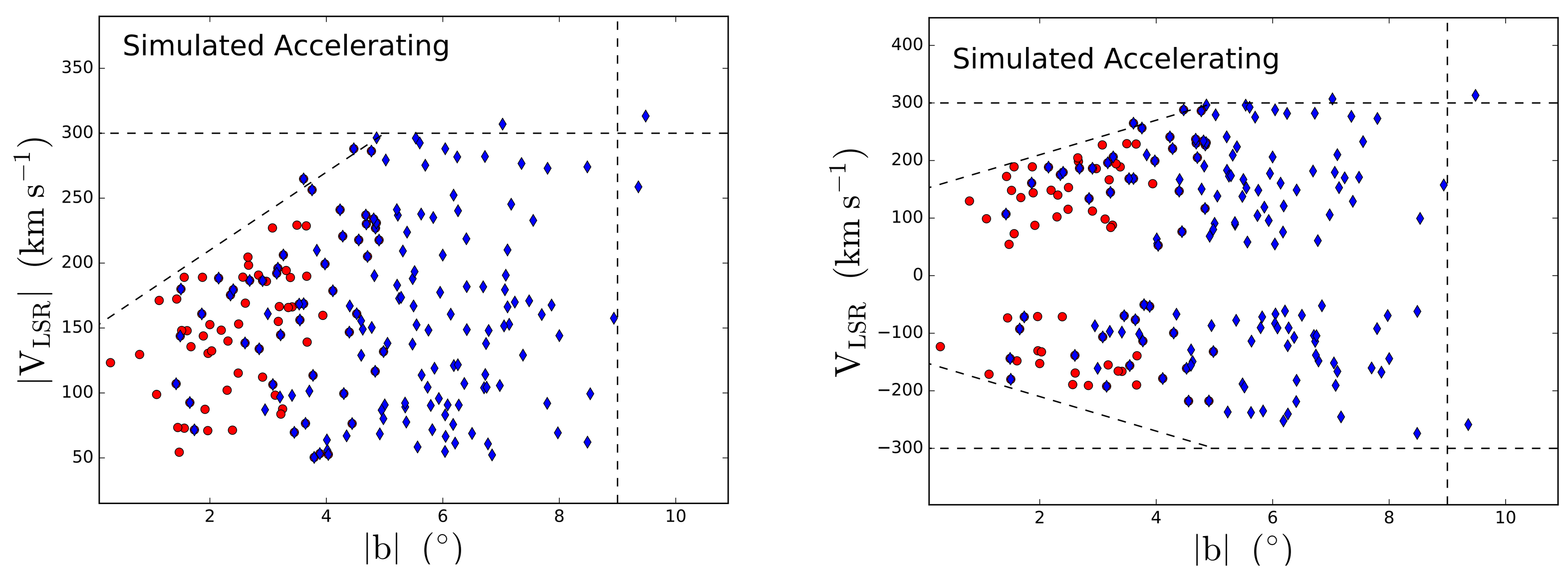
LEFT: The greyscale shows the HI column density at the Galactic tangent points while the red solid and green dashed curves mark the shell and volume-filled regions of the Fermi bubble from the model of Miller & Bregman (2016) derived from x-ray emission. The color shaded areas mark the regions surveyed for HI clouds in the ATCA and GBT surveys.
RIGHT: The detected HI clouds color-coded by their LSR velocity. The chaotic distribution of velocities shows no sign of Galactic rotation, but is characteristic of an outflow. Dashed lines mark the approximate boundaries of the two surveys.



Schematic from Di Teodoro et al. (2018) of the kinematics of clouds flowing from the Galactic center.



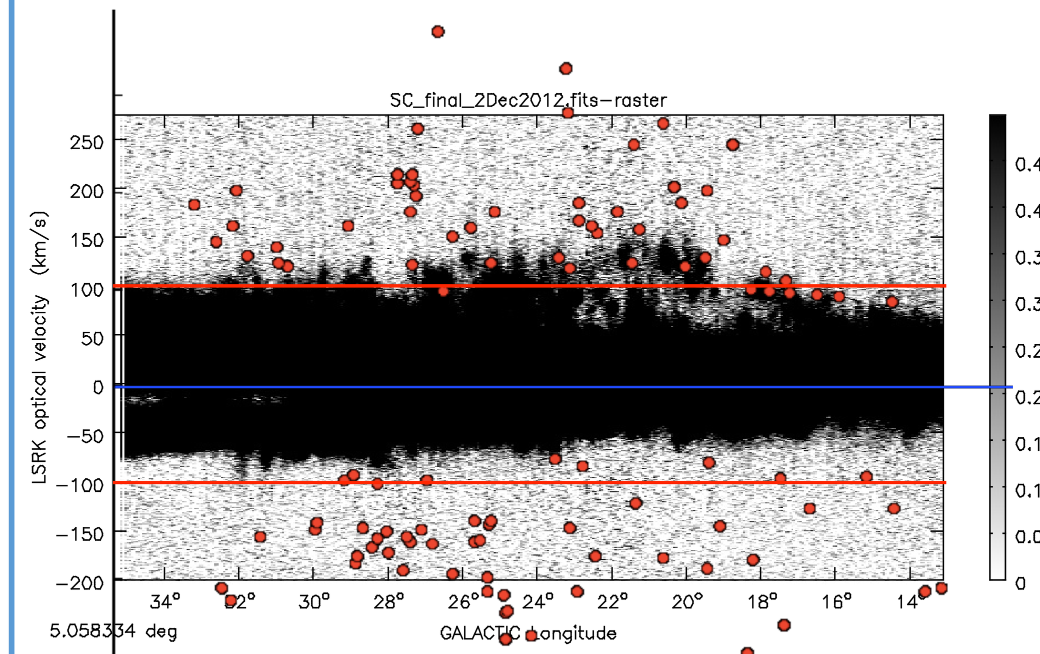
LEFT: The |VLSR| of clouds detected in the ATCA survey (red circles) and GBT survey (blue diamonds) as a function of the absolute value of the Galactic latitude. The absence of clouds in the range 200 - 300 km/s at |b| < 5° defines the kinematic anomaly. Open squares are new GBT detections made in the region of the ATCA survey, showing that the anomaly appears in data from both telescopes.
CENTER: Same data displayed separately for approaching and receding clouds. The kinematic anomaly appears in both sets.
RIGHT: Expected |VLSR| vs |b| for a cloud population with a uniform expansion velocity away from the Galactic center. A uniform expansion velocity does not produce a kinematic anomaly.
Black stars and rectangles show UV absorption components detected along sight lines that pierce the Fermi bubbles (Fox et al 2015; Savage et al 2017).



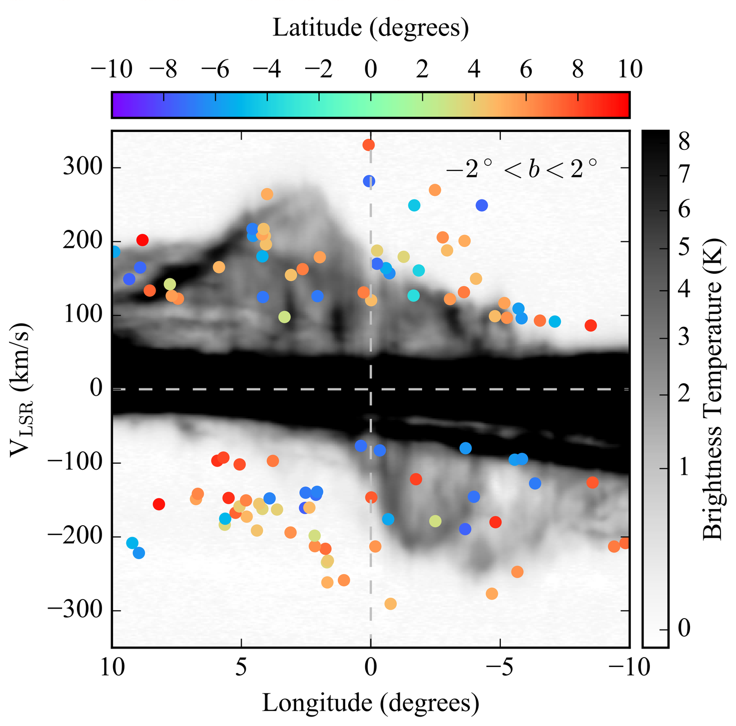
LEFT: Simulated |VLSR| vs. |b| for a cloud population flowing outward in an opening angle of 145° with an outflow velocity that varies linearly from 175 km/s at b=0° to 330 km/s for clouds 3.5 kpc from the Galactic center. It reproduces the kinematic anomaly.
RIGHT: Same data where the approaching and receding clouds are shown separately.

Why are we sure that the HI clouds are entrained in the Nuclear Wind?

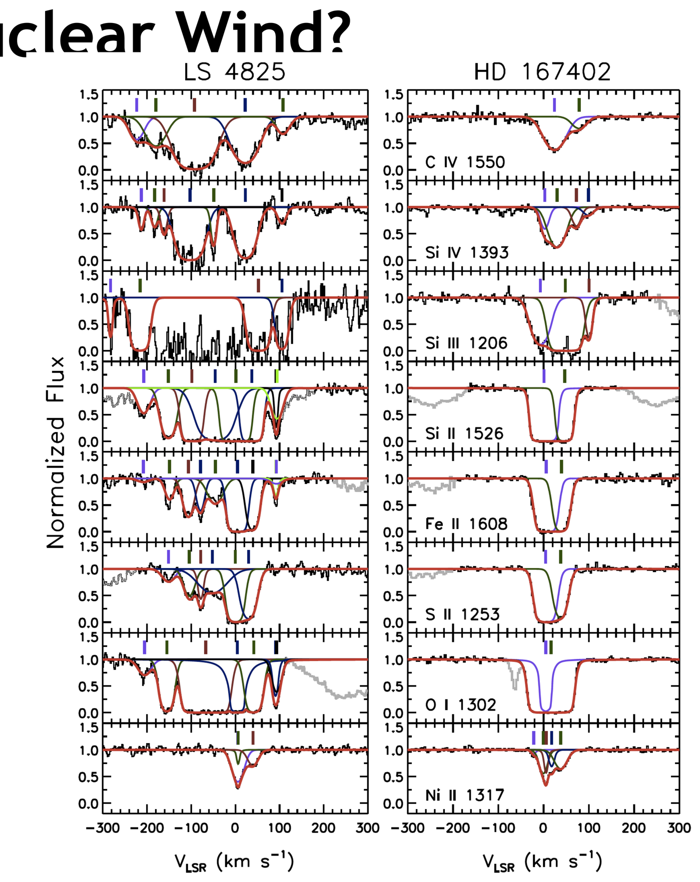
There are three reasons



1. Their kinematics is unlike anything else in the Milky Way. This figure shows the longitude-velocity distribution of HI over a 20° region around longitude 30° (grey scale). HI emission is confined to within ±150 km/s of zero LSR. The red dots show the velocities of the clouds detected toward the Fermi bubbles. They have an extremely wide spread in VLSR that is not observed elsewhere.



2. Their kinematics are unrelated to the well-known non-circular motions in the Galactic center arising from gas response to the bar potential. Here the HI averaged over |b|<2° (grey scale) is compared with the kinematics of the clouds. They are clearly separate populations.



3. HST UV absorption spectra toward two adjacent stars at l,b = 1.7°-6.6°. The foreground star (spectra on the right) at d < 7 kpc shows absorption from gas in circular rotation only, while the star at d = 21 kpc (left) shows an enormous range of velocity associated with the nuclear wind.

The Bottom Line

Clouds are found throughout the survey region
Mass in Outflowing HI Clouds: ~10^6 M⊙
Outflow Velocity: 175 → 330 km/s
Cone Opening Angle: 140°- 150°
dM/dt ≤ 0.1 M⊙/yr
Luminosity: 5×10^{39} ergs/s over 10 Myr
Cloud lifetime: 4 - 10 Myr
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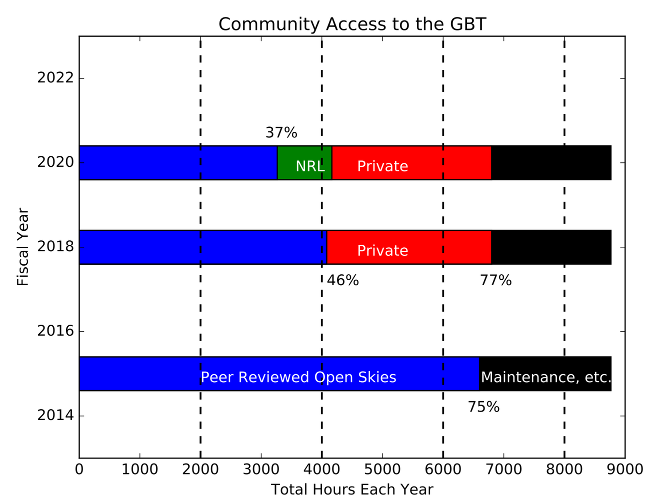

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REFERENCES: Di Teodoro, E.M. et al. 2018, ApJ, 855, 33; Fox, A. J. et al. 2015, ApJL, 799, L7; Lockman, F.J. & McClure-Griffiths, N.M. 2016, ApJ, 826, 215; Miller, M.J. & Bregman, J.N. 2016, ApJ, 829, 9; Savage, B.D. et al. 2017, ApJS, ,232, 25.

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