Searching for Dark Matter Annihilation in the Smith High-Velocity Cloud

Alex Drlica-Wagner

G. Gómez-Vargas, J. Hewitt, T. Linden, L. Tibaldo
on behalf of the Fermi-LAT Collaboration

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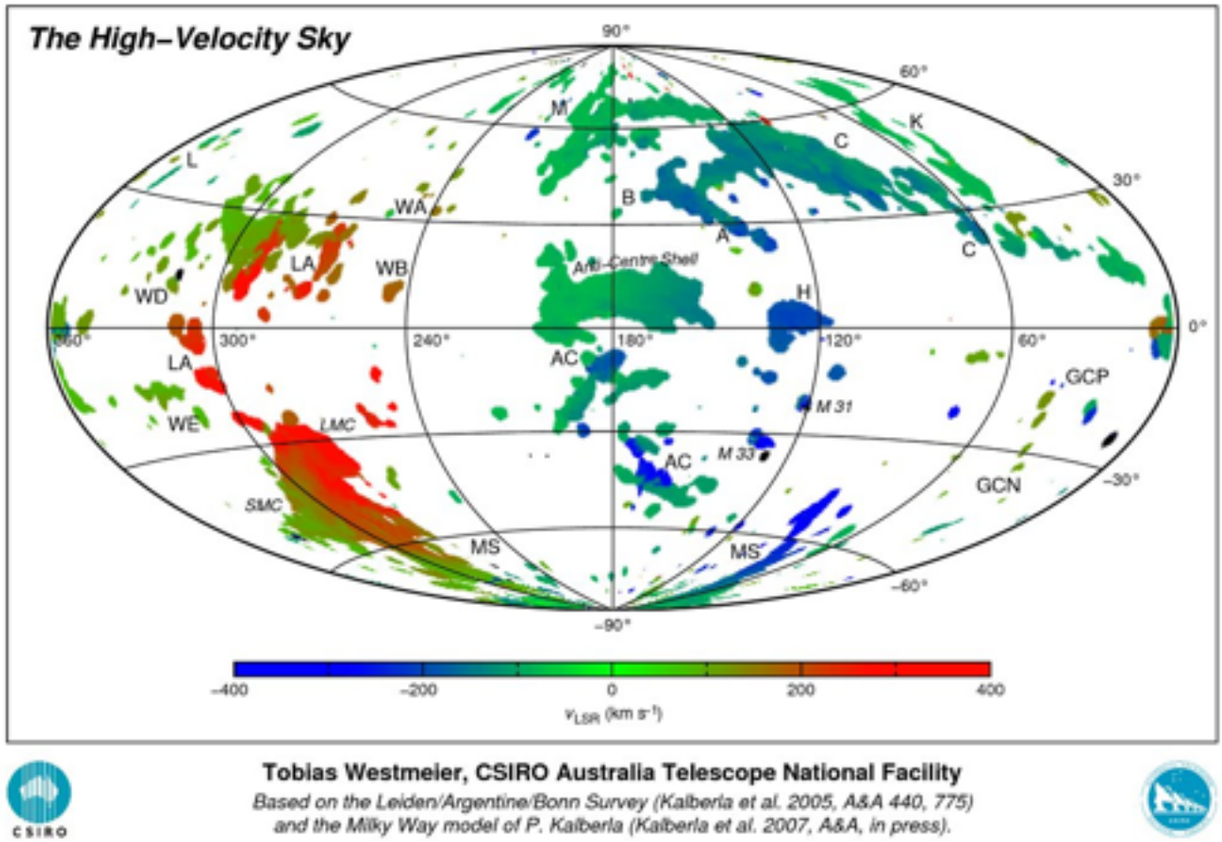
High-Velocity Clouds (HVCs)

- **HVCs are coherent over-densities of HI covering ~40% of the sky.**
- **They are kinematically separable from Galactic disk gas (v ~ 10^2 km/s)**
- **The origin of HVCs is unclear and may differ from object to object**
  - **Ejected from the Galactic disk?**
  - **Stripped from the Magellanic Clouds?**
  - **Accreted during galaxy formation?**



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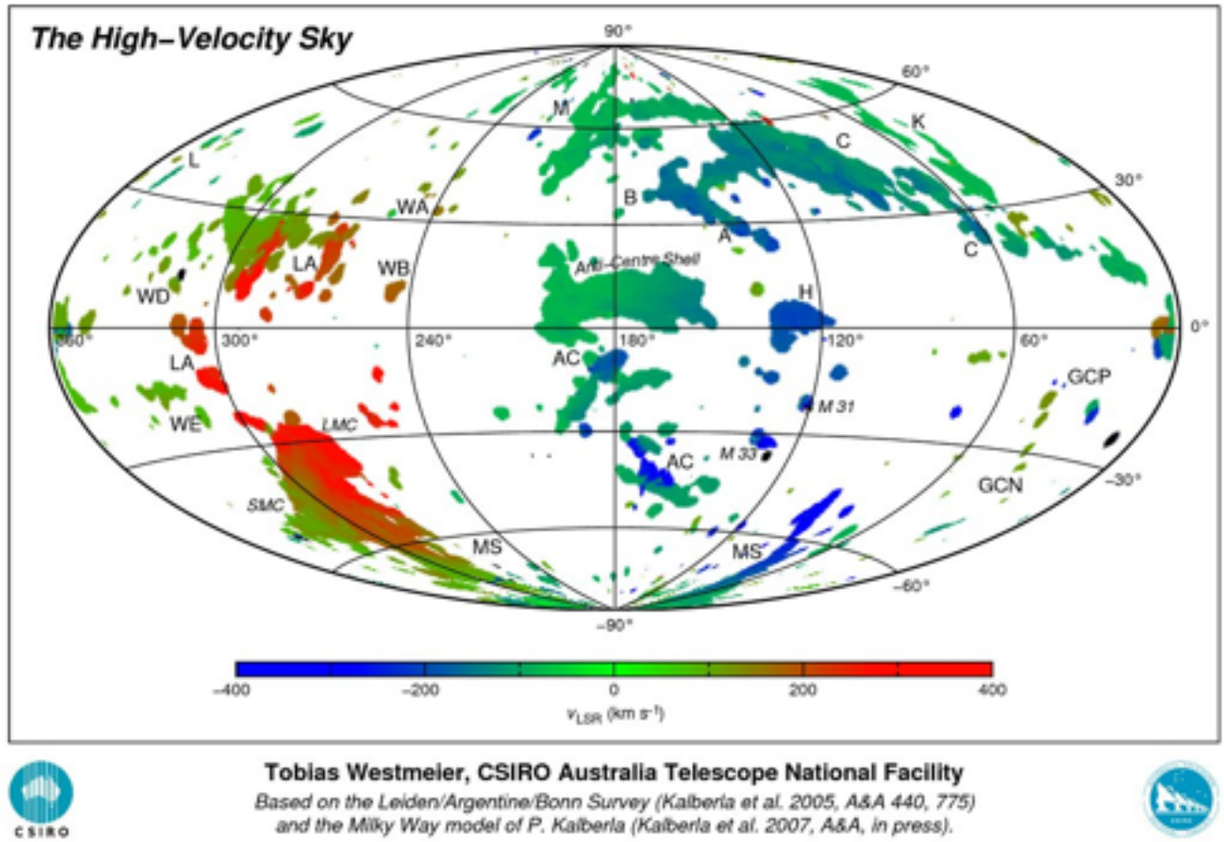
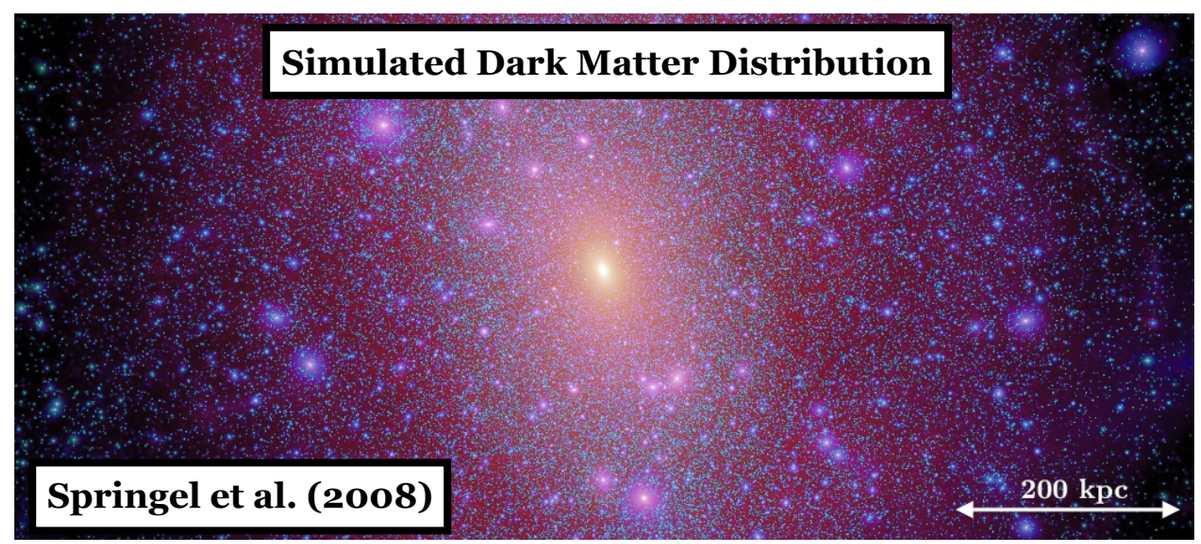
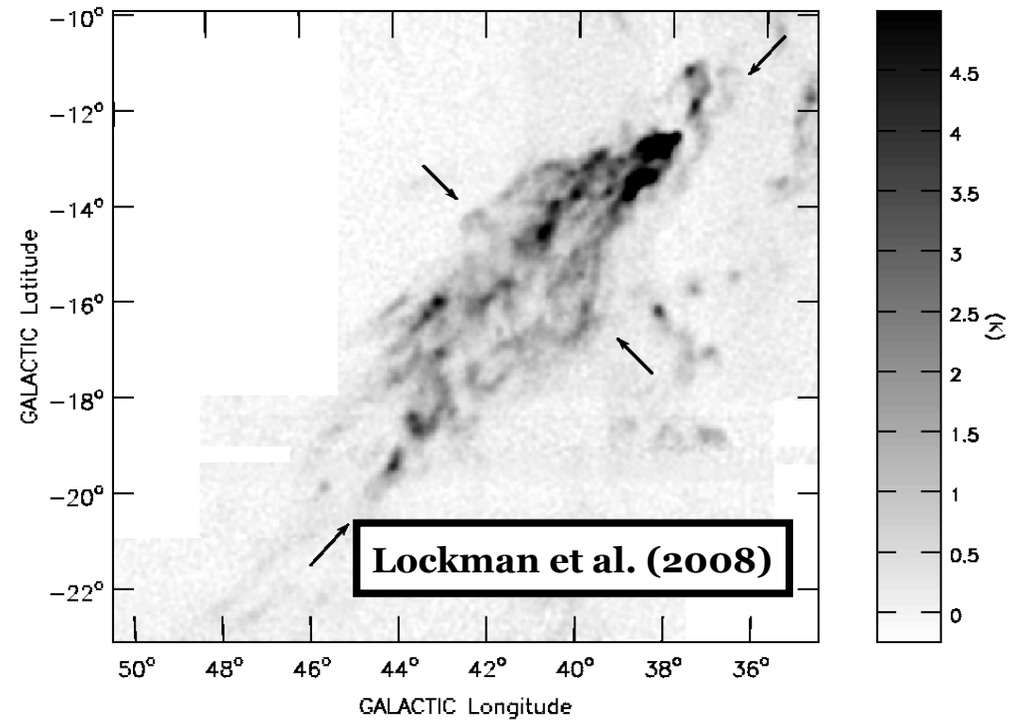
- **A sub-population of HVCs may inhabit dark matter halos that failed to form galaxies.**
- **Potential targets for indirect detection of dark matter annihilation**
  - **May trace nearby dark matter halos**
  - **Some gamma-ray emission expected from cosmic-ray interactions**





The Smith Cloud

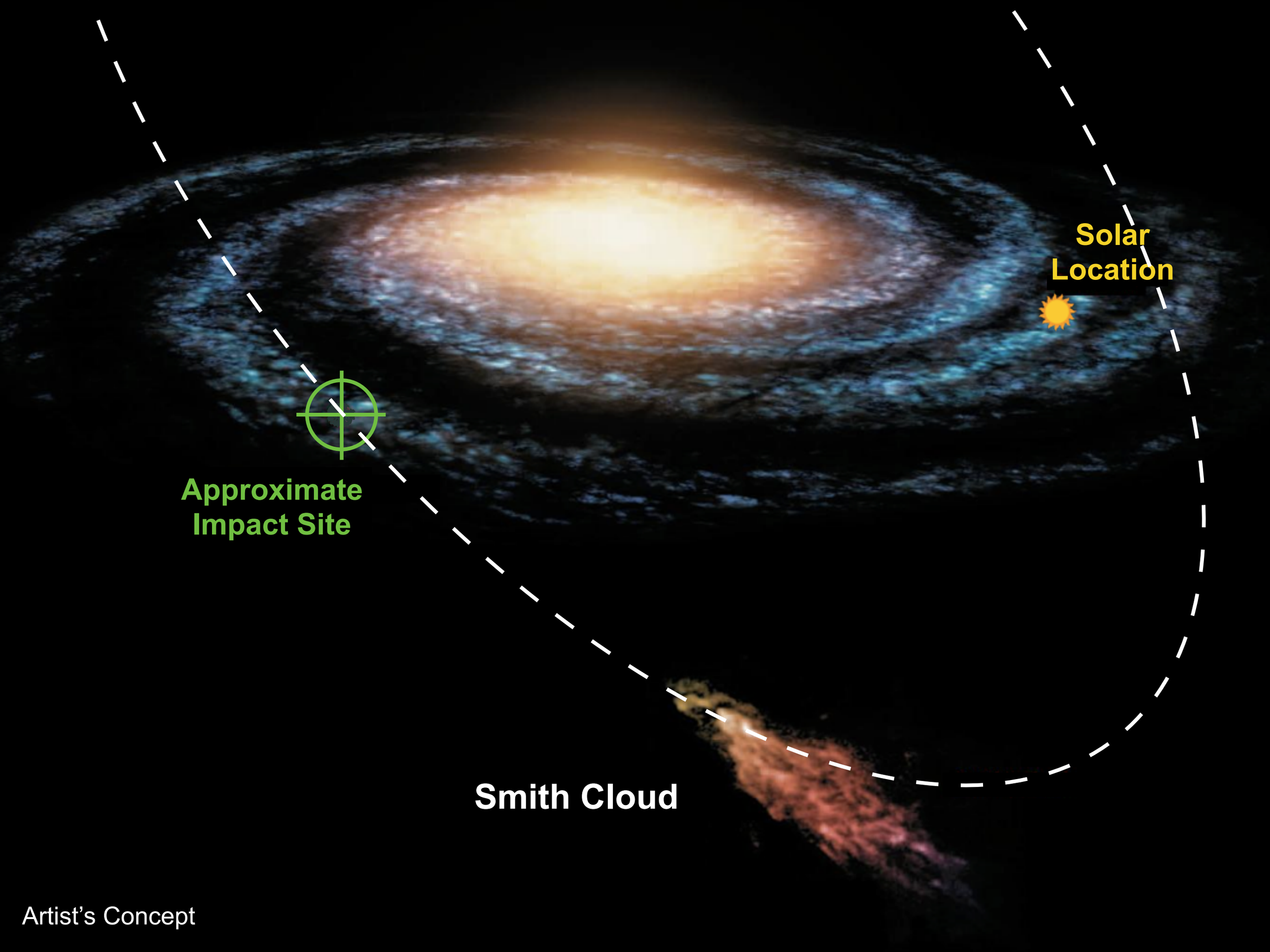
- The **Smith Cloud** is one of the best characterized HVCs (e.g., Lockman et al. 2008)
- Located at **(l,b) = (38.67, -13.41)** with an HI gas mass of **~10^6 $M_\odot$** (total gas mass >2×10^6 $M_\odot$)
- Accurate distance determination from
  - Stellar bracketing
  - Interaction with disk gas
  - H-alpha reflection from the Galactic disk
- The Smith Cloud resides at a heliocentric distance of **12.4 +/- 1.3 kpc** (nearest dwarf galaxy at 23 kpc).
- The **distance**, **direction of motion**, and **systemic velocity distribution** allow the 3D trajectory of the Smith Cloud to be determined



H I Properties of the Smith Cloud

Property	Value
l, b (deg)	38.67, −13.41
Distance (kpc)	12.4 ± 1.3
R (kpc)	7.6 ± 0.9
z (kpc)	−2.9 ± 0.3
T_b (K)	15.5
Δv (km s^{-1})	16.0
$N_{H\,I}$ (cm^{-2})	5.2×10^{20}
V_{LSR} (km s^{-1})	99 ± 1
H I mass ($M_\odot$)	$>10^6$
Projected size (kpc)	3 × 1

Note.—All but integral quantities apply to the direction of greatest $N_{H\,I}$ at the position $l, b = 38.67°, -13.41°$.



Artist's Concept

Smith Cloud Dark Matter

- The 3D trajectory of the Smith Cloud suggests that it passed through the Galactic disk ~70 Myr ago.

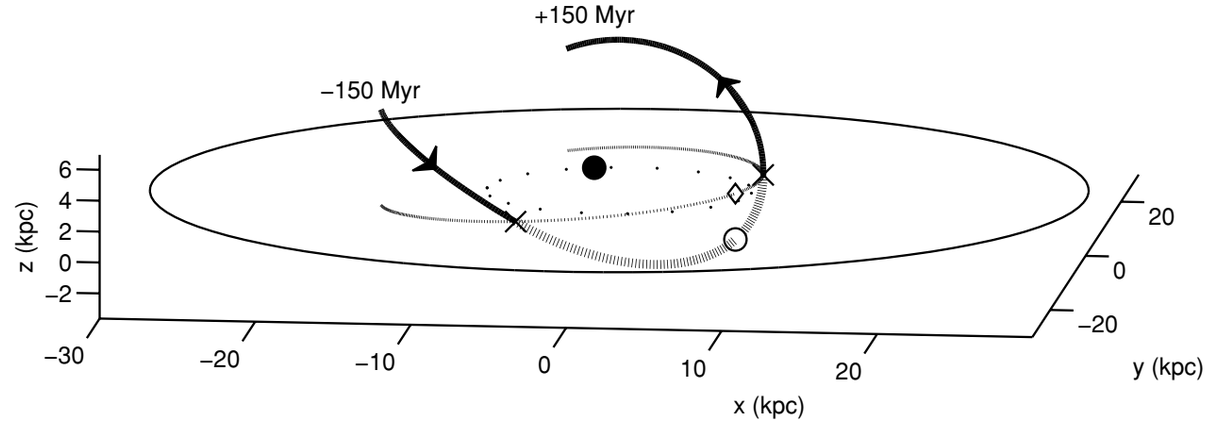
- The gaseous component of the cloud has a weak self-gravity and ram pressure forces would dissipate the cloud during a passage through the Galactic disk.

- This suggests that the Smith Cloud may be bound by a dark matter halo with tidal mass ~10^8 $M_\odot$ (Nichols & Bland-Hawthorn, 2009).

- Such a dark matter halo would extend to an angular radius of ~5° around the cloud.

- To mitigate the impact of tidal disruption, we conservatively model the dark matter annihilation signal from only the inner 1° of the halo.

Nichols & Bland-Hawthorn (2009)



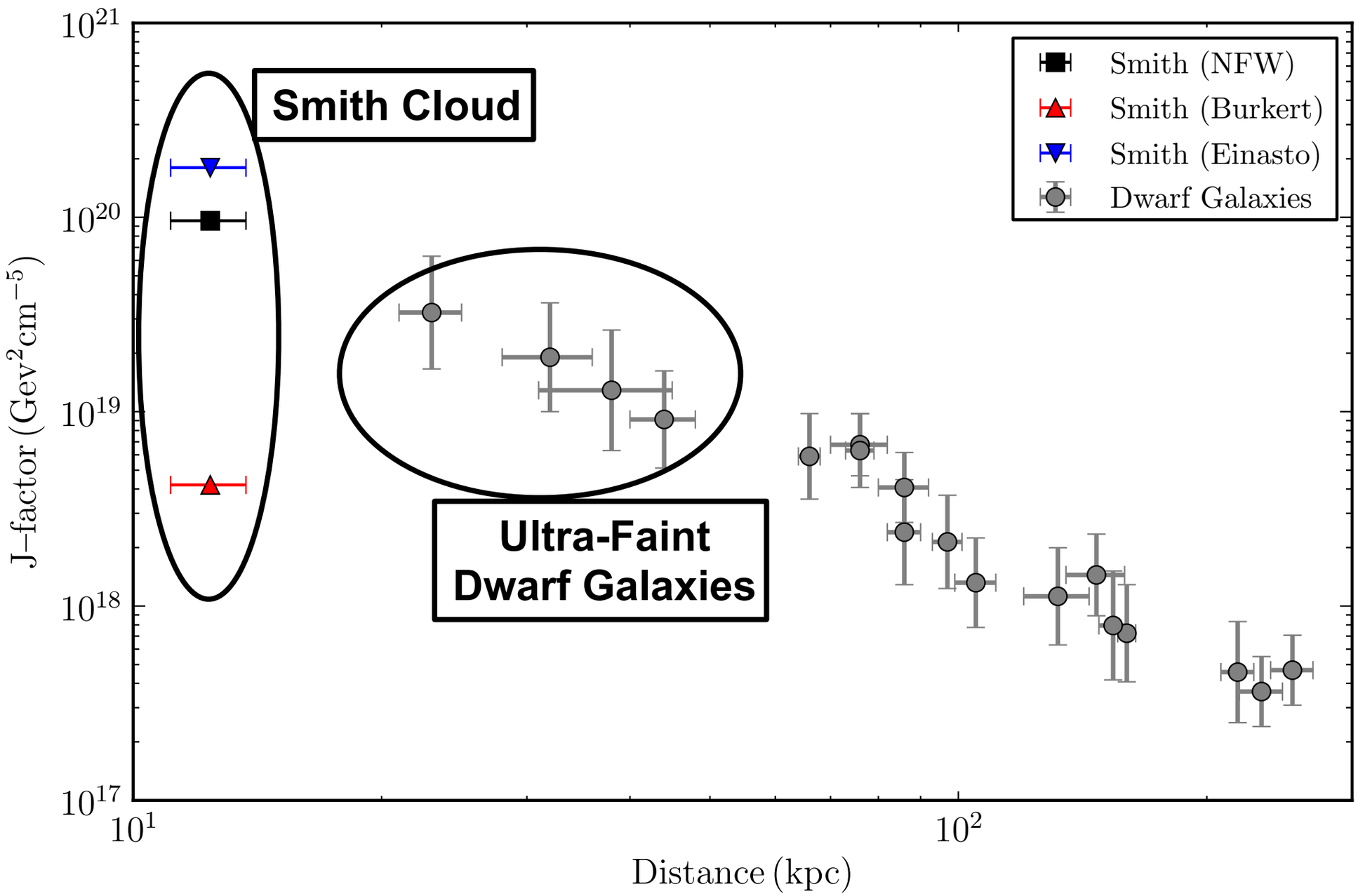
See Doug Spolyar's talk about Gaia...

Table 1
Summary of Smith Cloud Dark Matter Halo Parameters

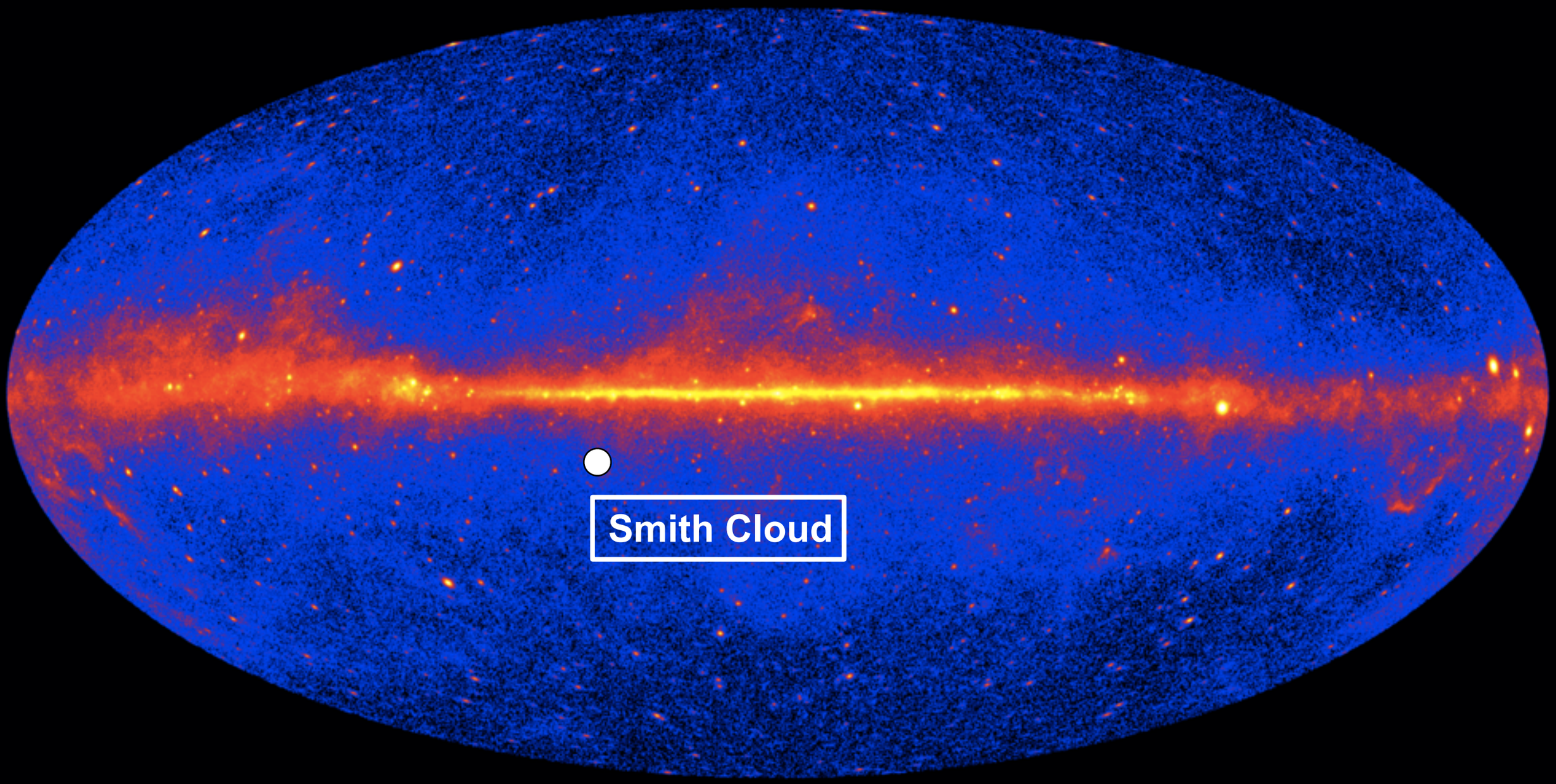
Profile	r_s (kpc)	ρ_0 ($M_\odot$ kpc^{-3})	$M_{\rm tidal}$ ($M_\odot$)	J-factor (GeV^2 cm^{-5} sr)
NFW	1.04	3.7×10^7	1.1×10^8	9.6×10^{19}
Burkert	1.04	3.7×10^7	1.3×10^8	4.2×10^{18}
Einasto	1.04	9.2×10^6	2.0×10^8	1.8×10^{20}

Note. Integrated J-factors are calculated over a solid-angle cone with radius 1° ($\Delta\Omega \sim 9.6 \times 10^{-4}$ sr).

Smith Cloud J-Factor

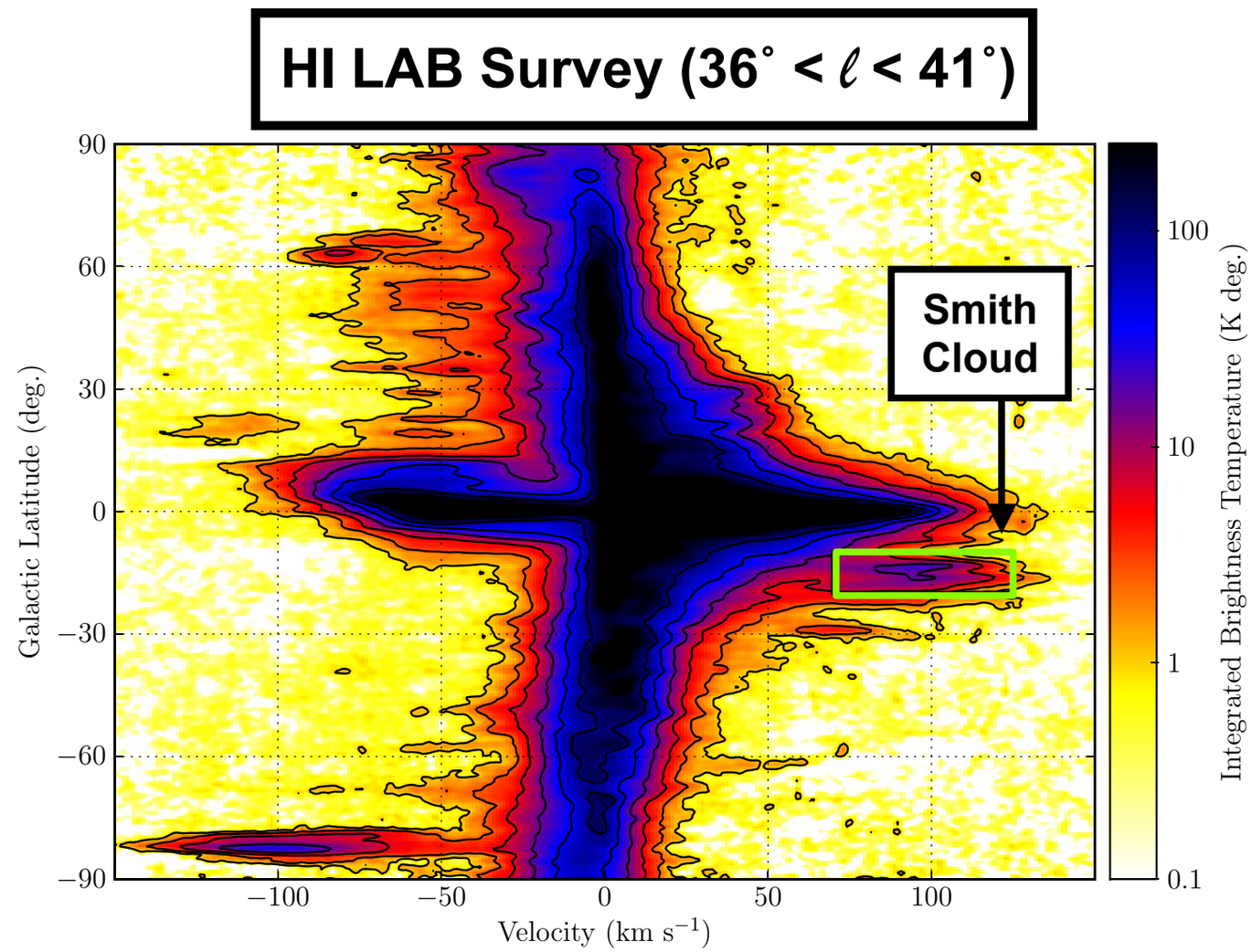


5-Year LAT All-Sky Map

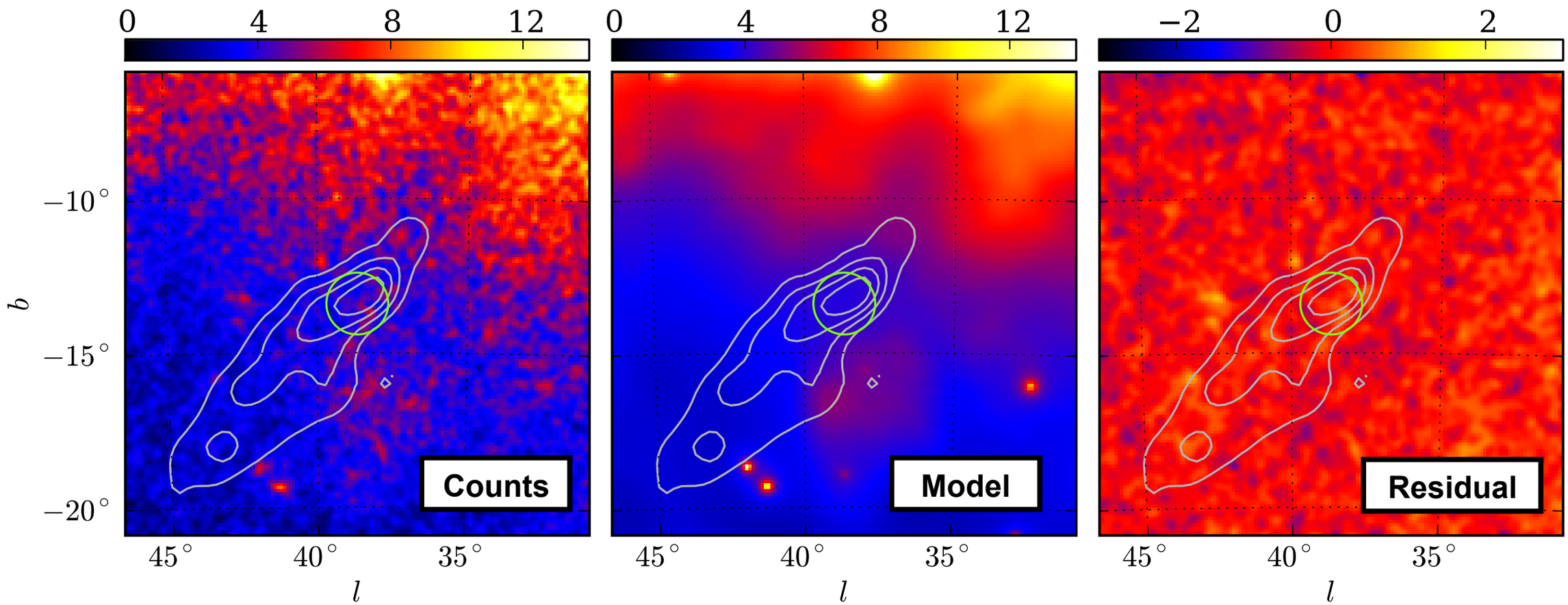


Diffuse Modeling

- **The standard LAT Galactic interstellar emission model includes the Smith Cloud gas as a cosmic-ray target.**
- **Remove this component from the foreground model to search for excess emission.**
  - **Remove target gas in the velocity range from 70–125 km/s from a 5˚x 5˚ region surrounding the the Smith Cloud.**
  - **Correct for a dark gas contribution using SFD dust map.**
  - **Run GALPROP to produce templates for the hadronic, bremsstrahlung, and inverse-Compton gamma-ray emission.**
- **Similar to the procedure used to analyze M31 and the Magellanic Clouds (Ackermann et al. 2012)**



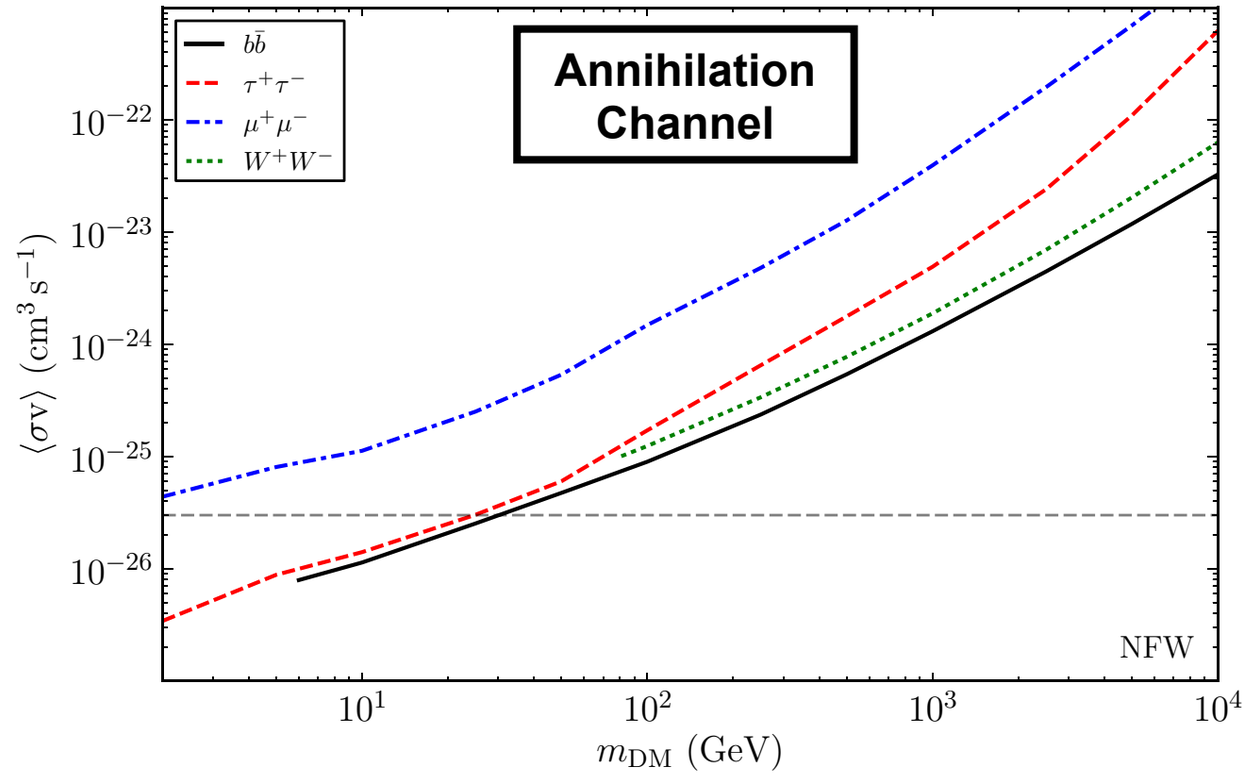
LAT Analysis

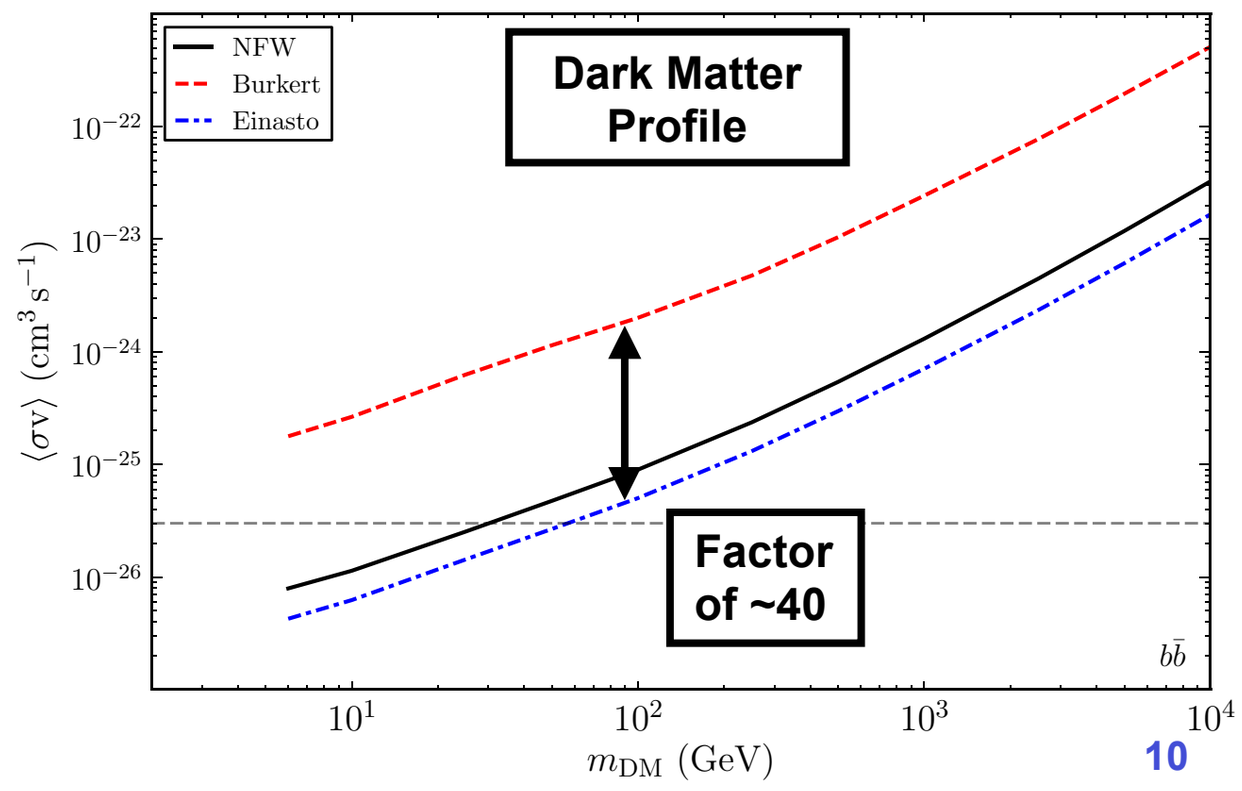


- **5-year binned likelihood analysis from 500 MeV to 500 GeV over a 15˚x15˚ ROI surrounding the Smith Cloud (P7REP_CLEAN_V15).**
- **Likelihood model includes 2FGL sources, the custom diffuse Galactic foregrounds, and a local isotropic component modeled with a broken power-law.**
- **Set bin-by-bin limits on the gamma-ray flux from the Smith Cloud using a spatially-extended model of the dark matter annihilation signal.**
- **No significant excess found for any of the spatial or spectral models tested (maximum TS = 4.7)**

Dark Matter Constraints

- **Calculate dark matter constraints for four prototypical annihilation channels.**
- **Constraints on cuspy (NFW or Einasto) profiles can probe the thermal relic cross section.**
- **Cored (Burkert) profiles yield constraints that are a factor of ~40 higher.**
- **Uncertainty in the dark matter profile dominates over other systematic and statistical uncertainties.**

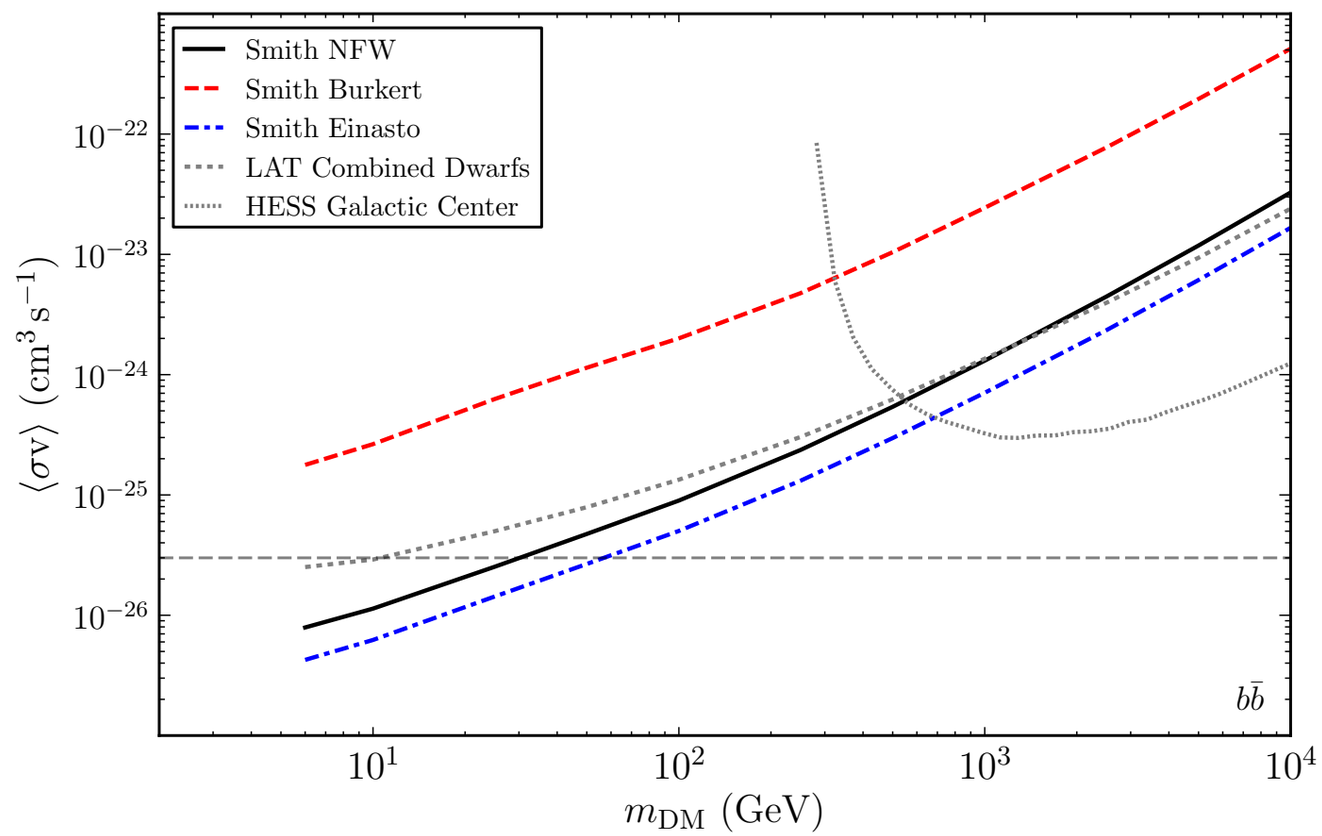




Conclusions

- **High-velocity clouds provide an exciting new target for indirect detection.**
- **More than 500 HVCs have been detected surrounding the Milky Way (though the Smith Cloud is currently somewhat special).**
- **It may be possible to perform a combined search on the population of HVCs**
- **The Fermi-LAT monitors the entire sky, thus new targets classes provide a compelling method to improve our sensitivity to dark matter annihilation with existing data.**

Comparison with other Indirect Searches



Ackermann et al. (2014)

Abramowski et al. (2011)

Smith Cloud References

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- Lockman, F. J., et al. 2008, ApJL, 679, L21 [arXiv:0804.4155]
- Nichols, M., & Bland-Hawthorn, J. 2009, ApJ, 707, 1642 [arXiv:0911.0684]
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