



Anomalies and Opportunities in Indirect Searches for Dark Matter

inspired by: [arXiv:1802.00636](https://arxiv.org/abs/1802.00636)

D.Gaggero & M.V.

MAURO VALLI

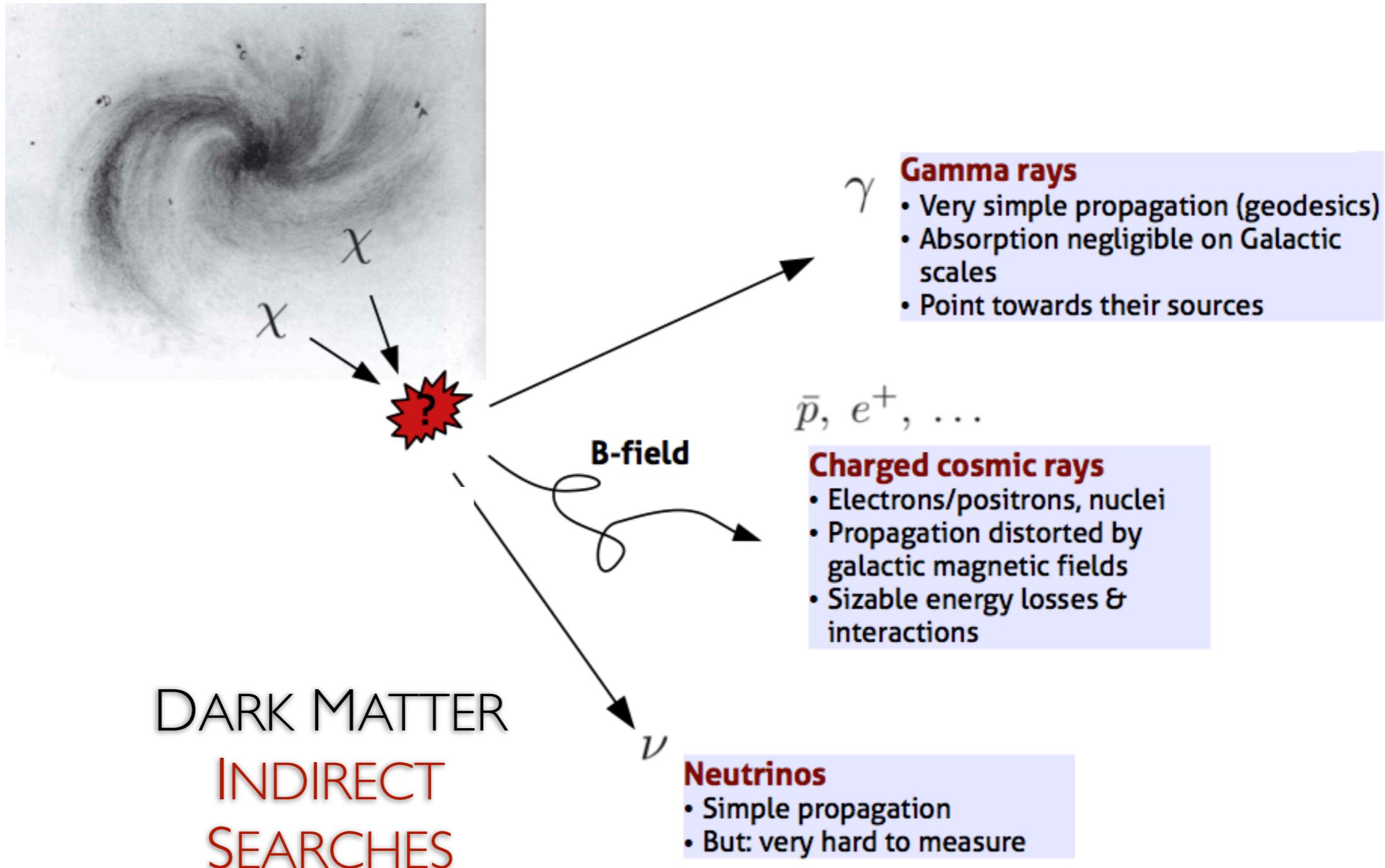
C.N. Yang Institute for Theoretical Physics

SIMONS
FOUNDATION

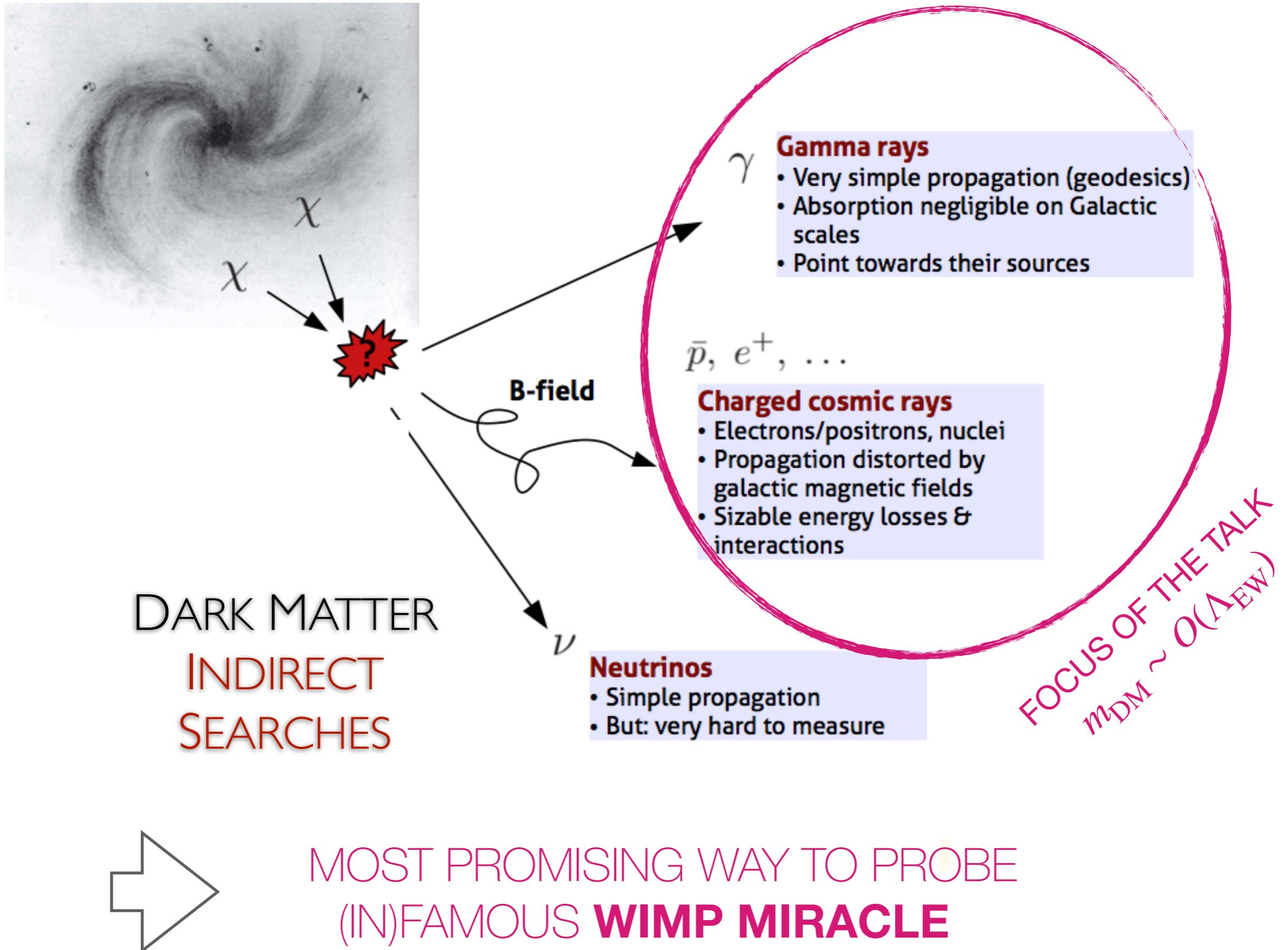


Stony Brook
University

LOOKING FOR EXOTICA IN THE SKY



LOOKING FOR EXOTICA IN THE SKY





... SEE ALSO :

PHYSICAL REVIEW D 98, 023016 (2018)

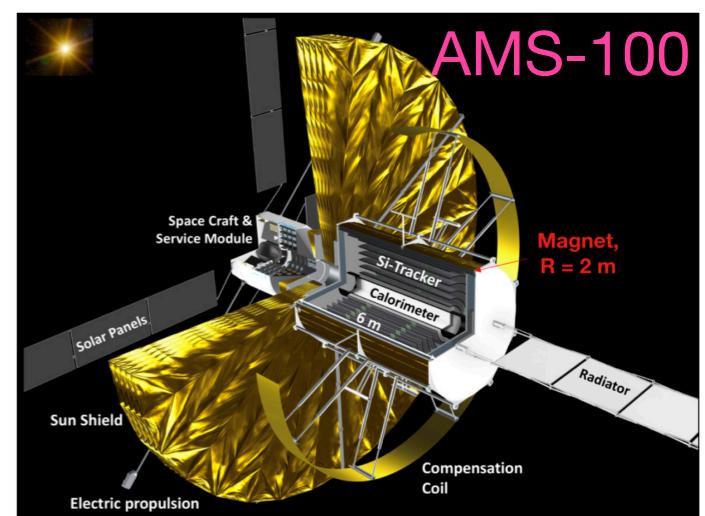
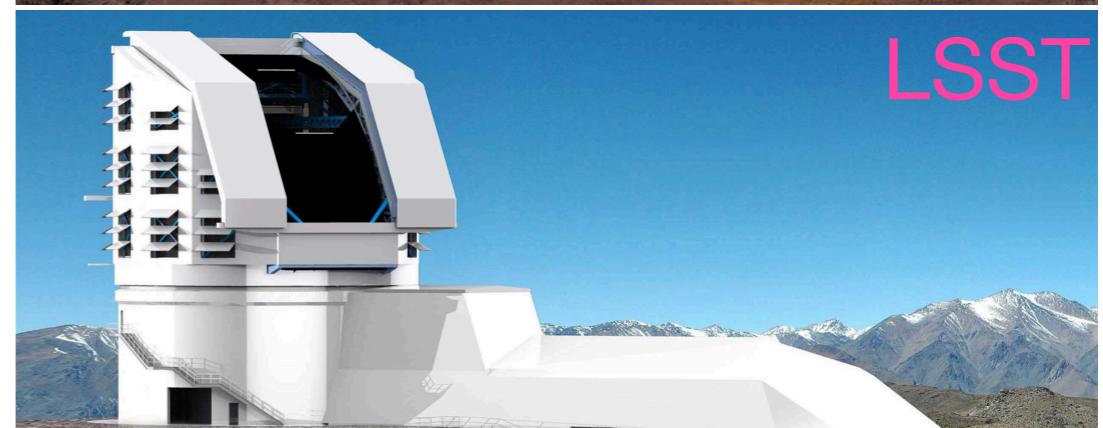
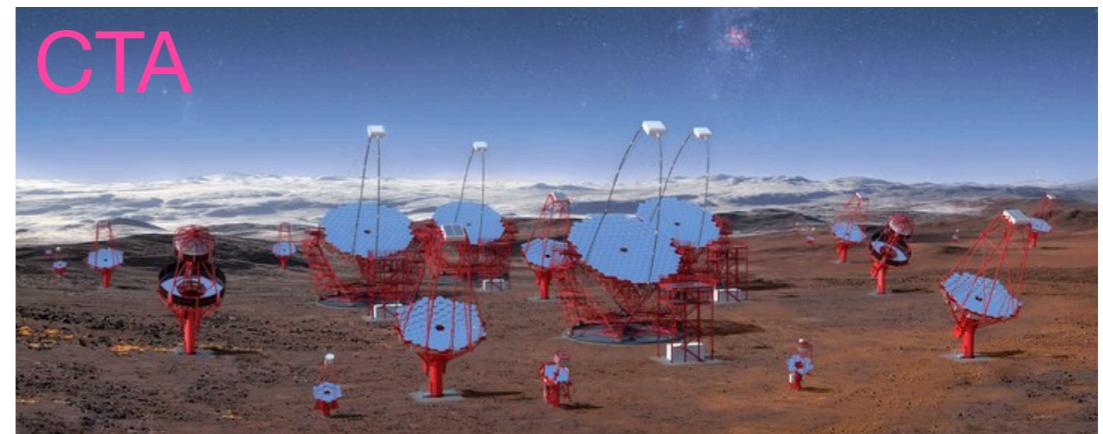
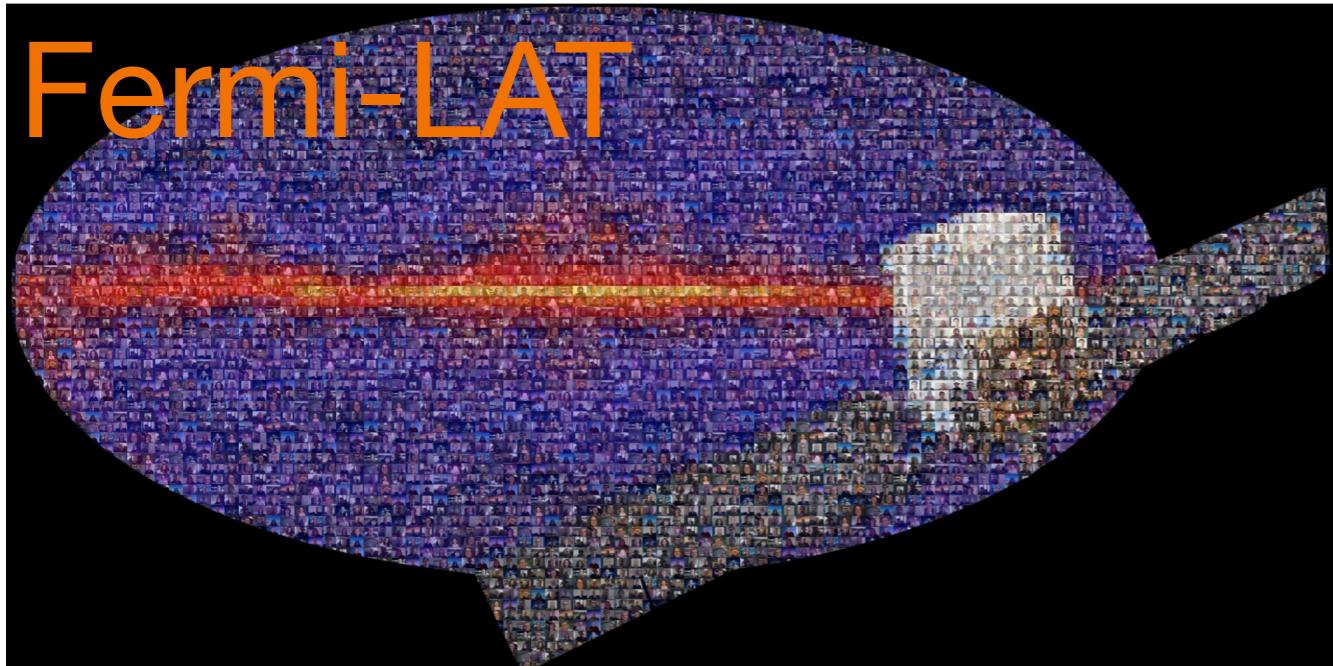
GeV-scale thermal WIMPs: Not even slightly ruled out

Rebecca K. Leane,^{1,*} Tracy R. Slatyer,^{1,†} John F. Beacom,^{2,3,4,‡} and Kenny C. Y. Ng^{5,§}

Is a Miracle-less WIMP Ruled out?

Jason Arakawa , Tim M.P Tait

ANOMALIES & OPPORTUNITIES IN THE SKY

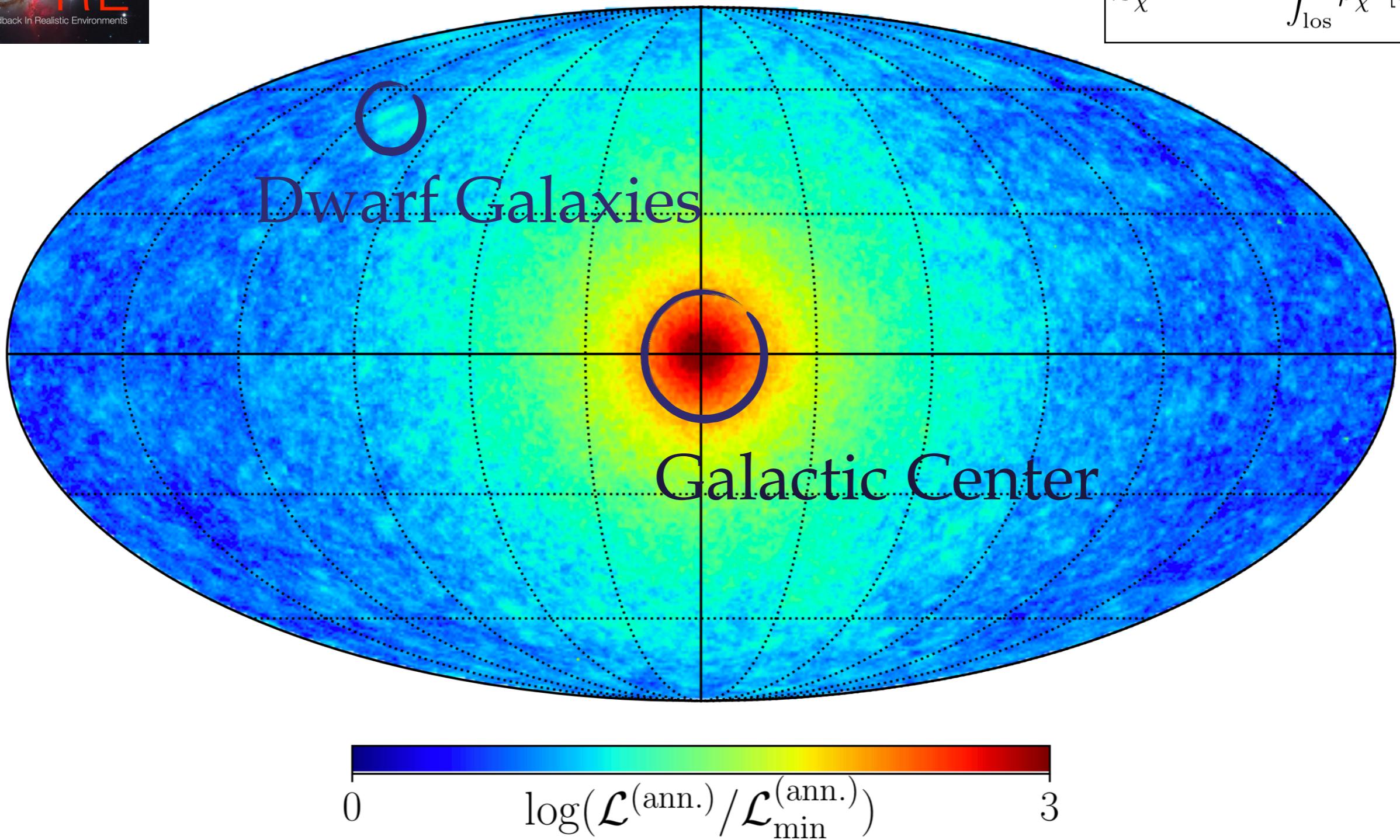


A MOLLVIEW OF THE DARK MATTER SIGNAL

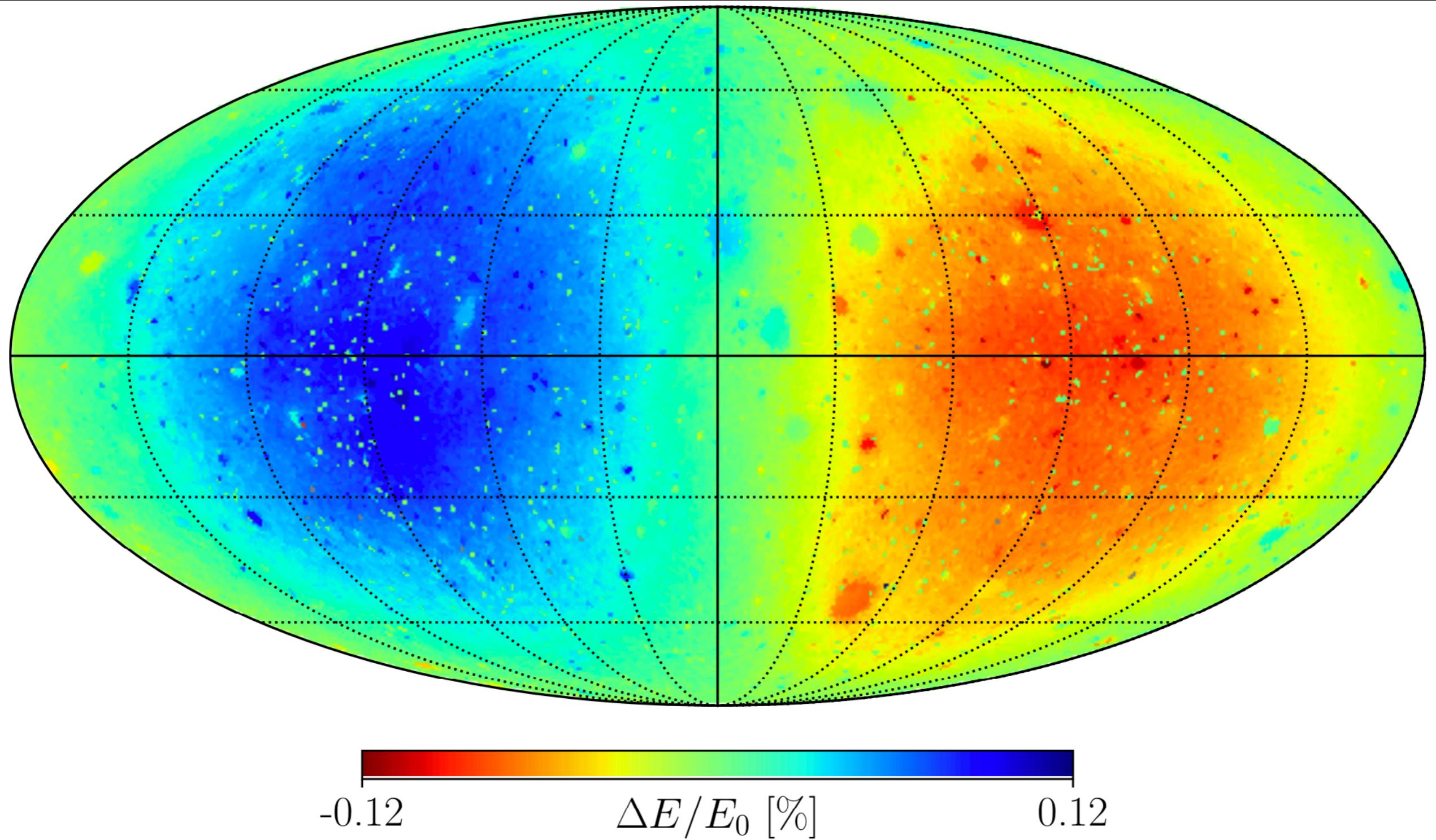


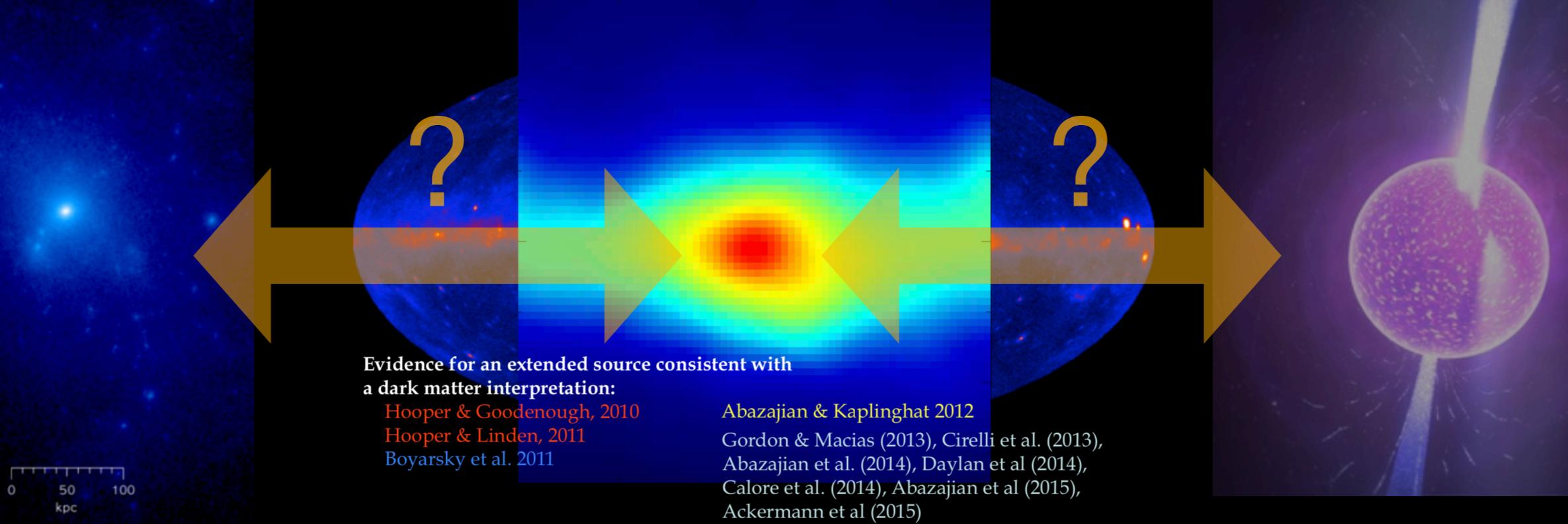
Dark Matter Annihilation

$$\mathcal{L}_\chi^{\text{dec.}(\text{ann.})} = \int_{\text{los}} \rho_\chi^{(2)}[r(\vec{s})] d\vec{s}$$

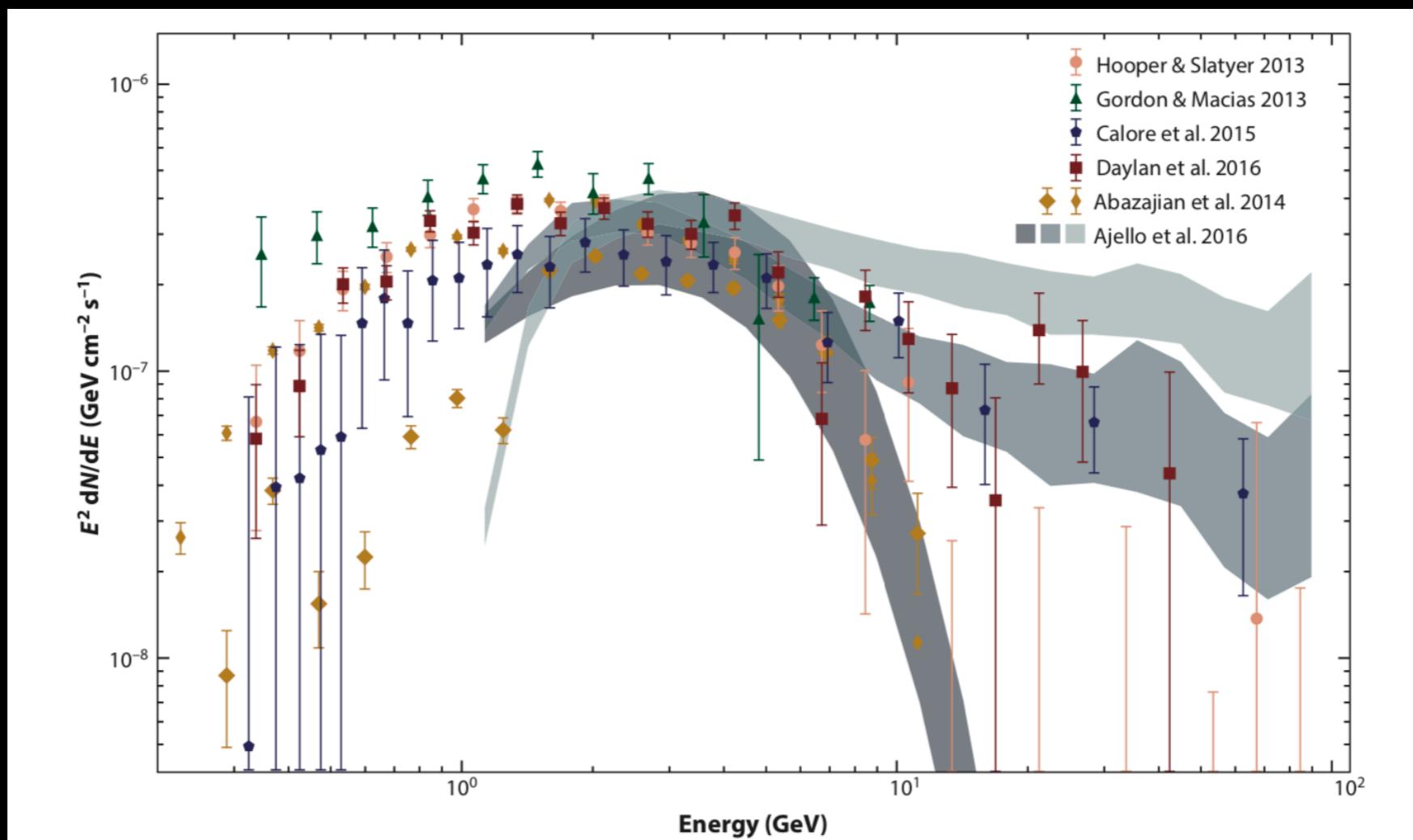


IF WE WERE TALKING ABOUT LINE SIGNALS, INTERESTING
EXTRA DIAGNOSTIC: **DOPPLER ENERGY SHIFT**

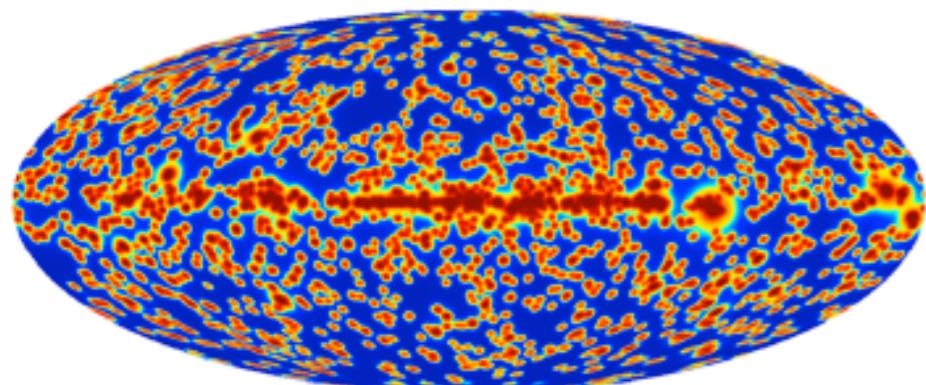




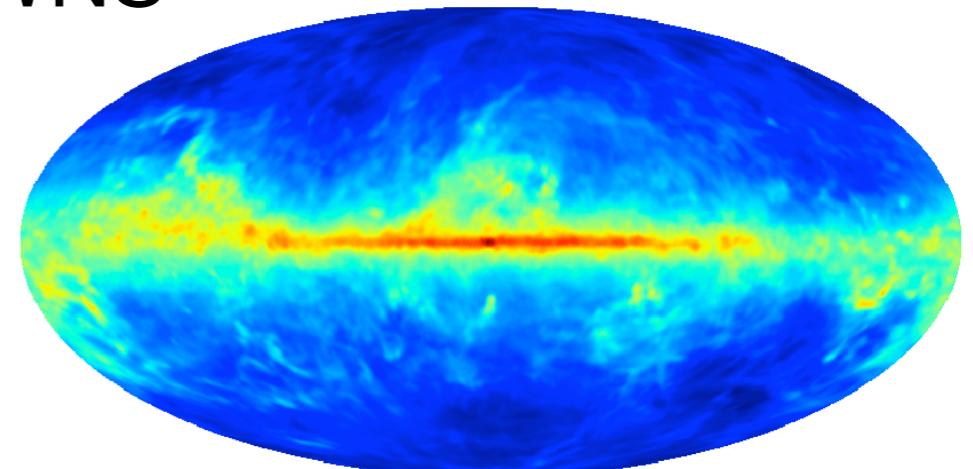
S. Murgia – *Ann. Rev. Nucl. Part. Sci.* 70 (2020)



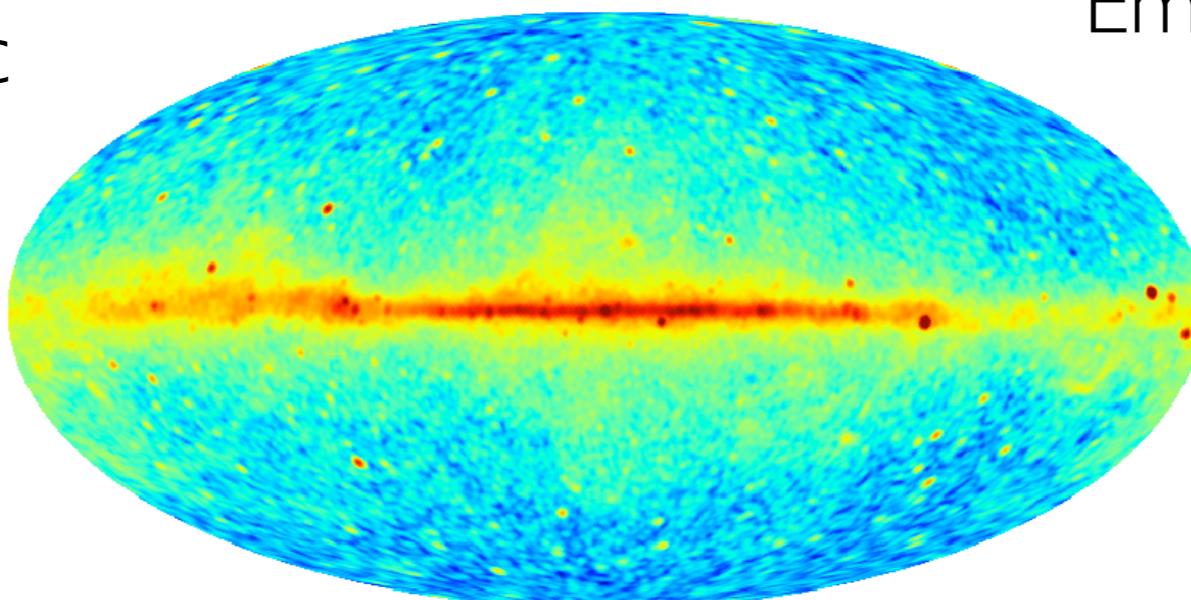
KNOWN (UN)KNOWNS



Point Sources
+ Extragalactic

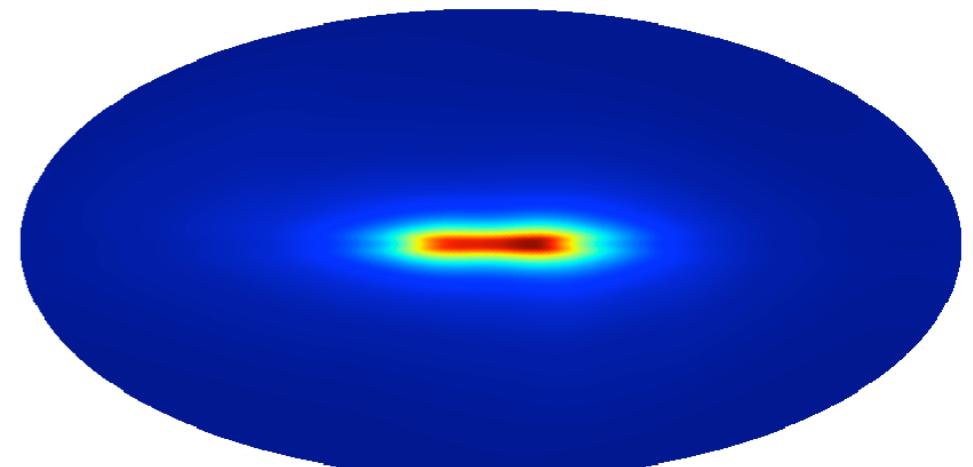


Emissivity map from
gas templates

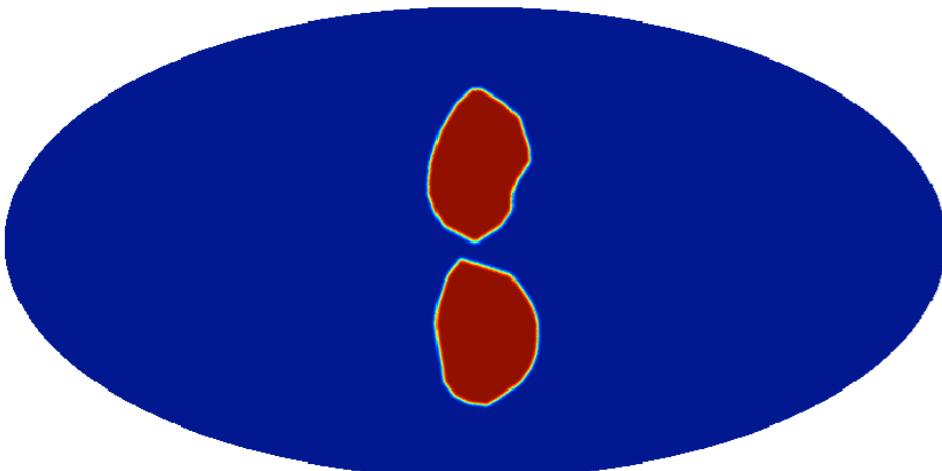


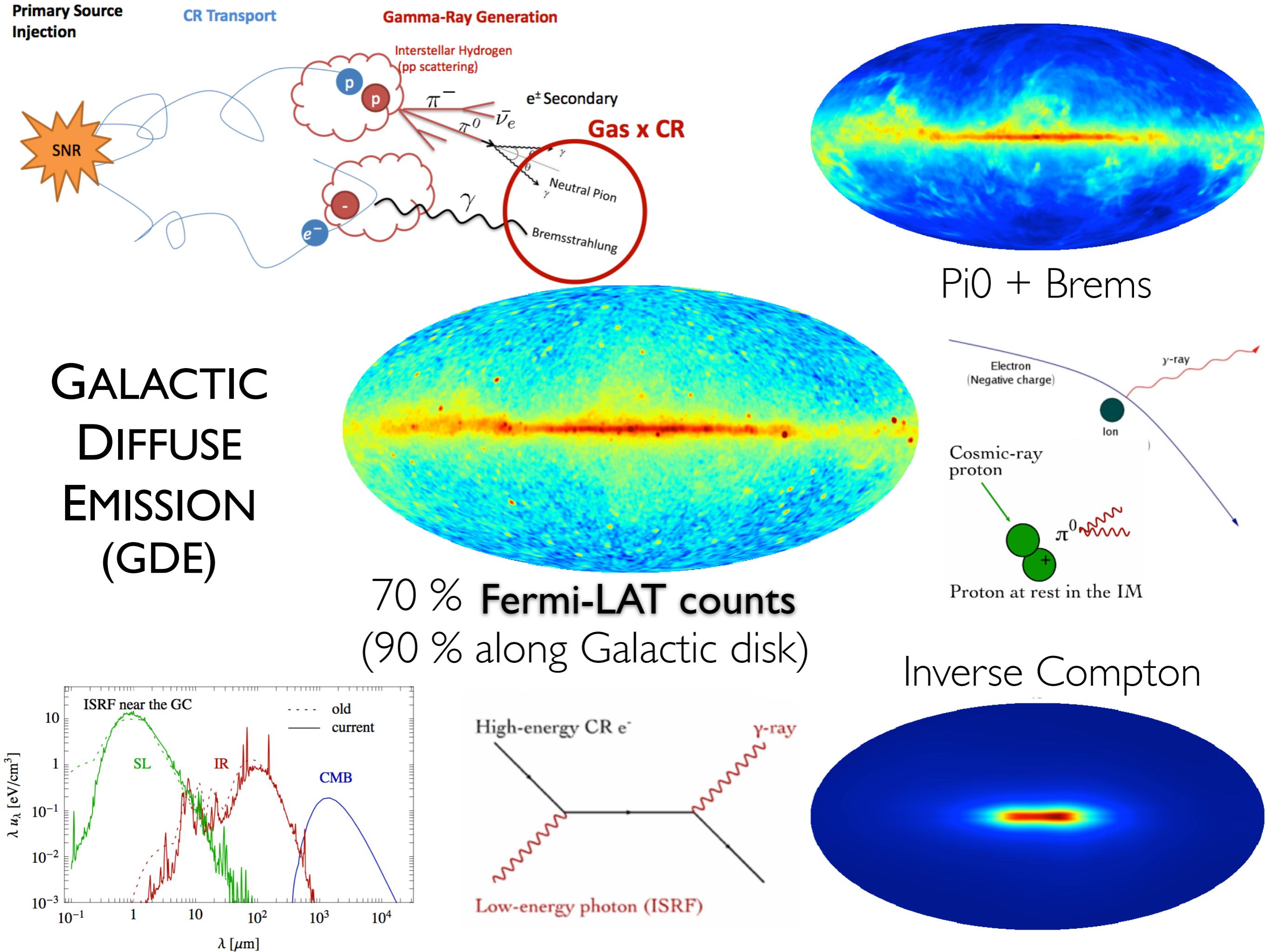
**Fermi-LAT
counts**

Structures, e.g.,
Fermi Bubbles

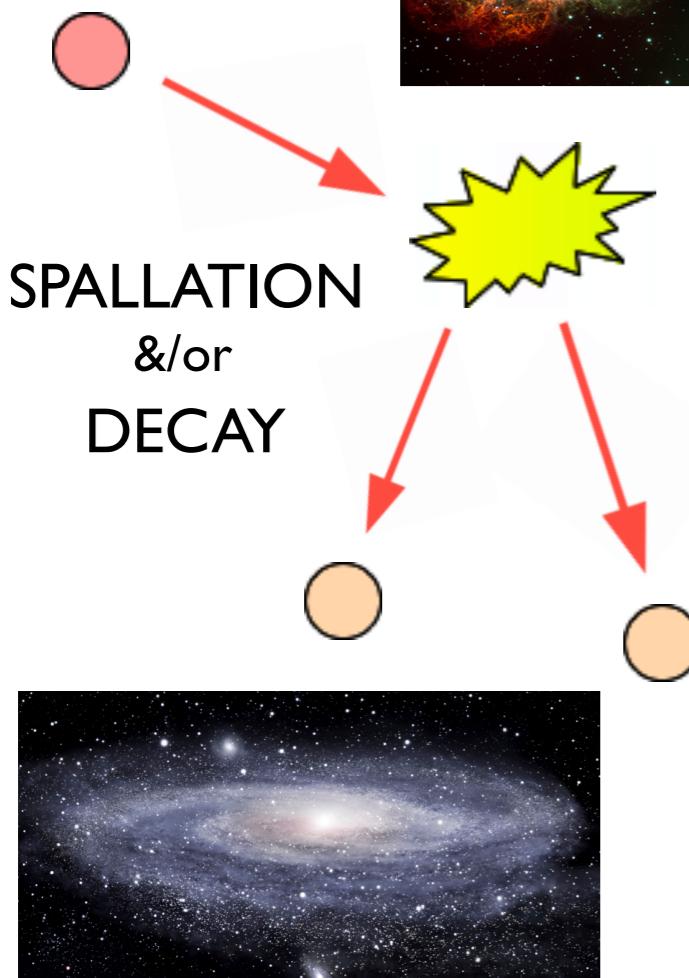


Emissivity map from
Interstellar Radiation Field

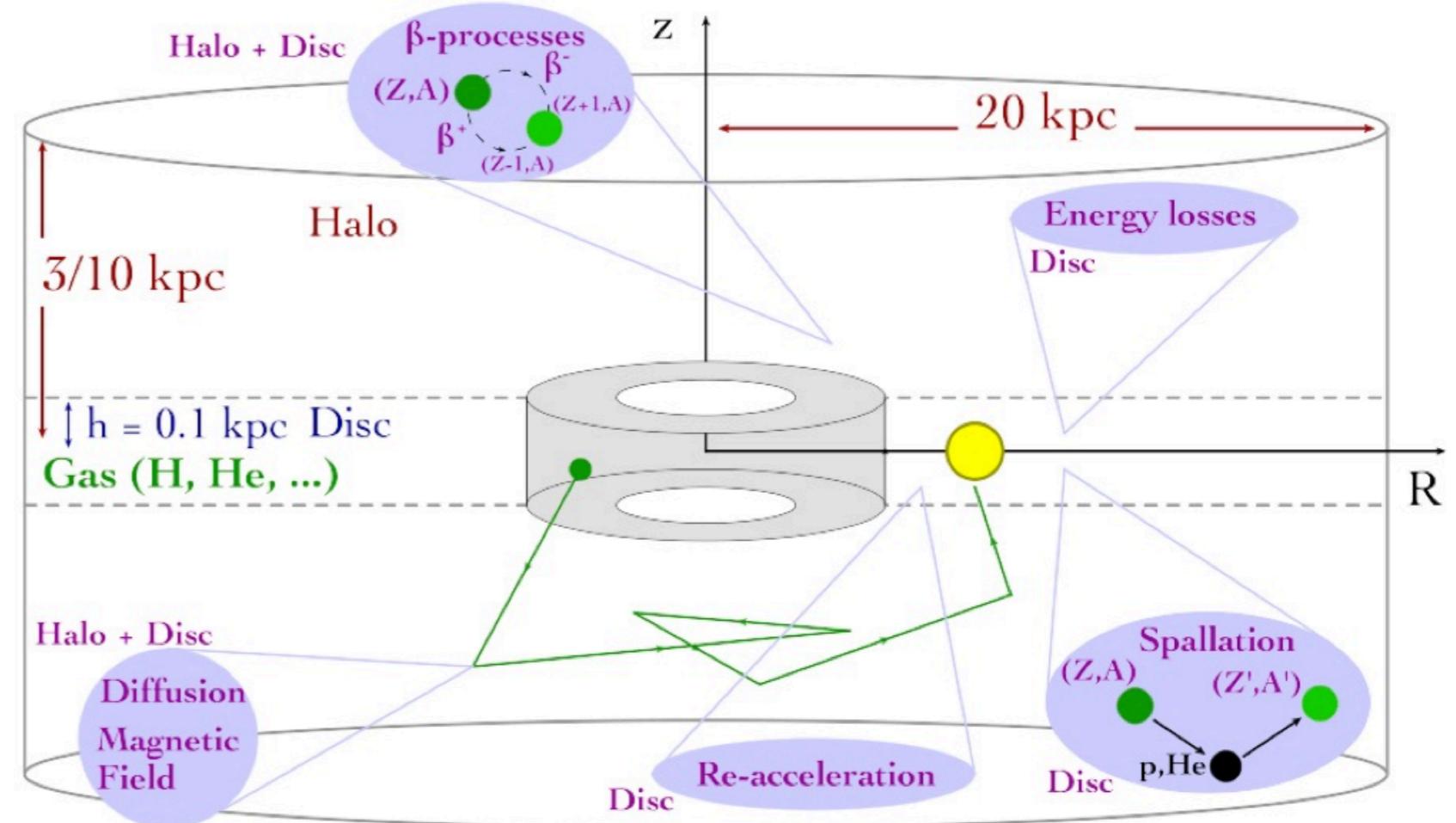




ACCELERATION FROM SOURCES



SPALLATION
&/or
DECAY

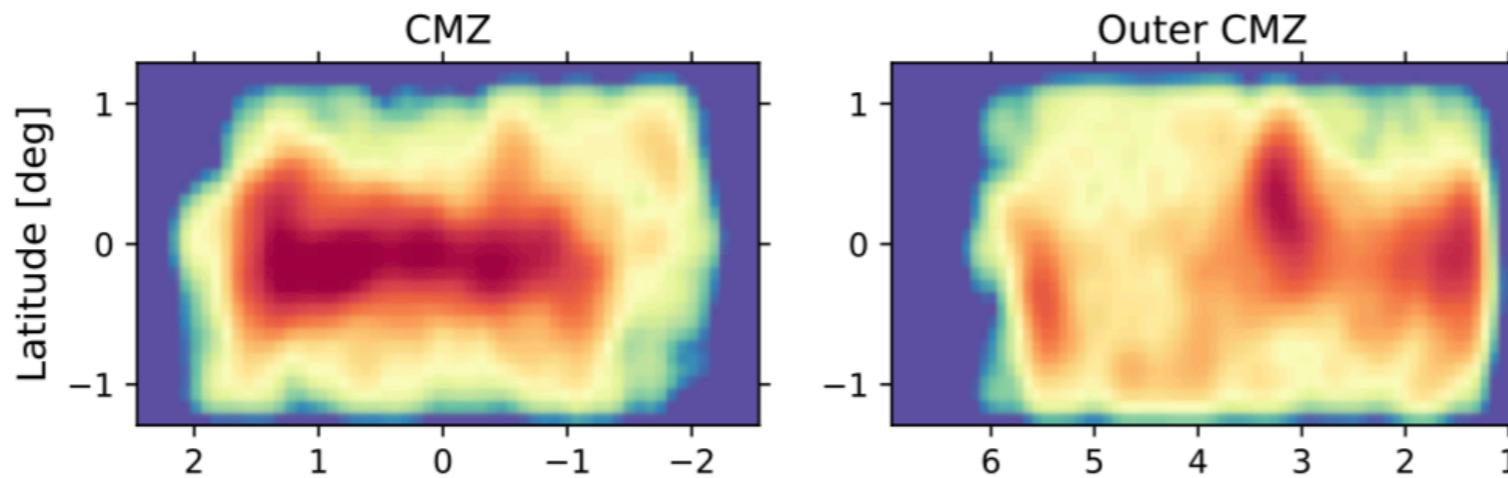


Phenomenology of cosmic-ray (CR) propagation in the Galaxy

$$\begin{aligned} \frac{\partial \mathcal{N}_i(\vec{x}, p, t)}{\partial t} &= \nabla \cdot (D_{\vec{x}\vec{x}} \nabla \mathcal{N}_i - \vec{v}_c \mathcal{N}_i) - \frac{\partial}{\partial p} \left(\dot{p} \mathcal{N}_i - \frac{p}{3} (\nabla \cdot \vec{v}_c) \mathcal{N}_i \right) \\ &+ \frac{\partial}{\partial p} \left(p^2 D_{pp} \frac{\partial \mathcal{N}_i}{\partial p} \frac{1}{p^2} \right) + Q(\vec{x}, p, t) - \frac{\mathcal{N}_i}{\tau_{\text{spal}}} - \frac{\mathcal{N}_i}{\tau_{\text{dec}}} \end{aligned}$$

A FEW GENERAL REMARKS ...

I)

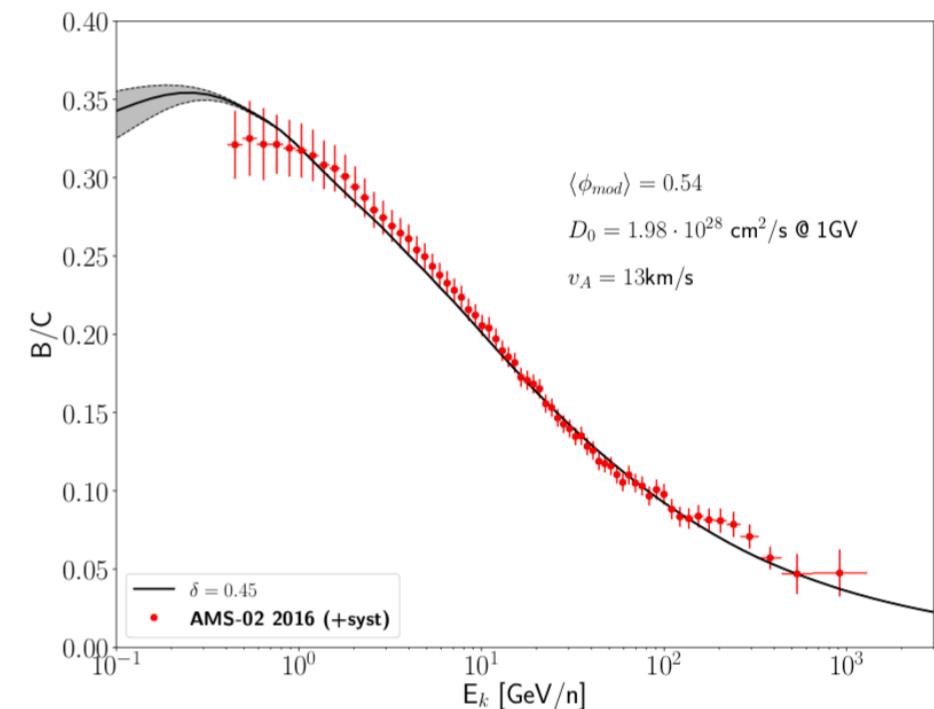


Uncertainties on 3D distribution of atomic & molecular gas + interstellar radiation field hard to quantify !

II)

CR transport oversimplified,
i.e. minimal modeling to fit
local measurements ...
Then, extrapolation of
its validity to entire Galaxy!

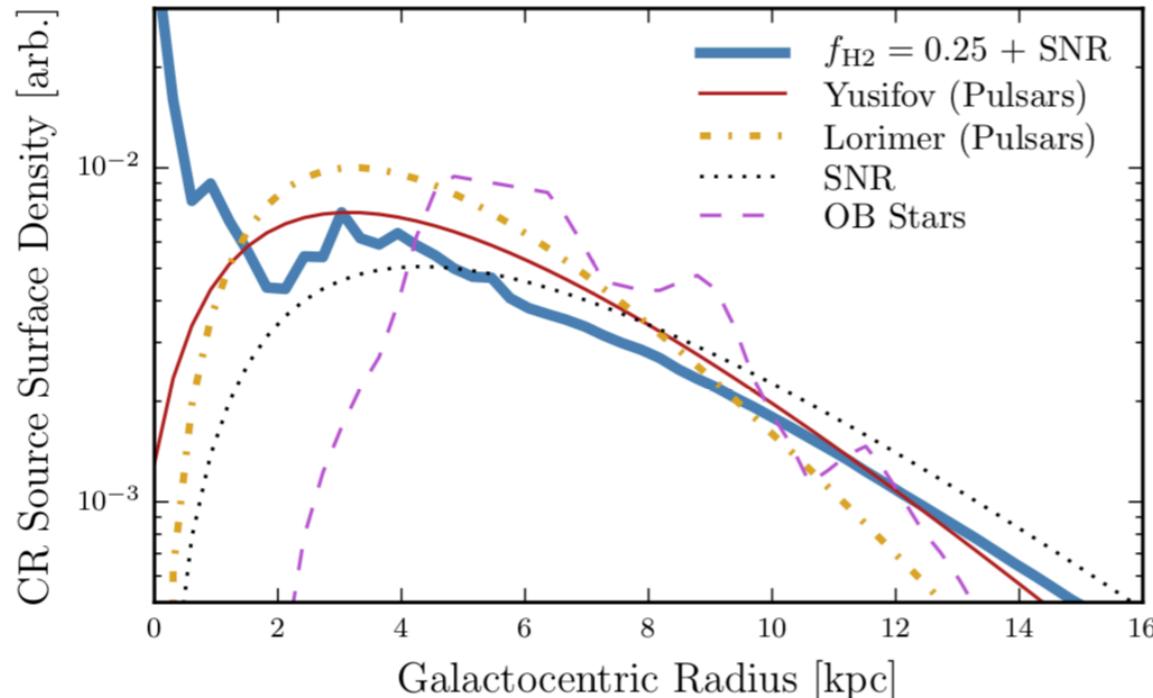
In this regard, the gamma-ray sky may help us learn more on CR propagation in the Galaxy



III)

Many template fitting analyses unphysical in the spectrum
(+ no info from non-Poissonian / wavelet analyses)

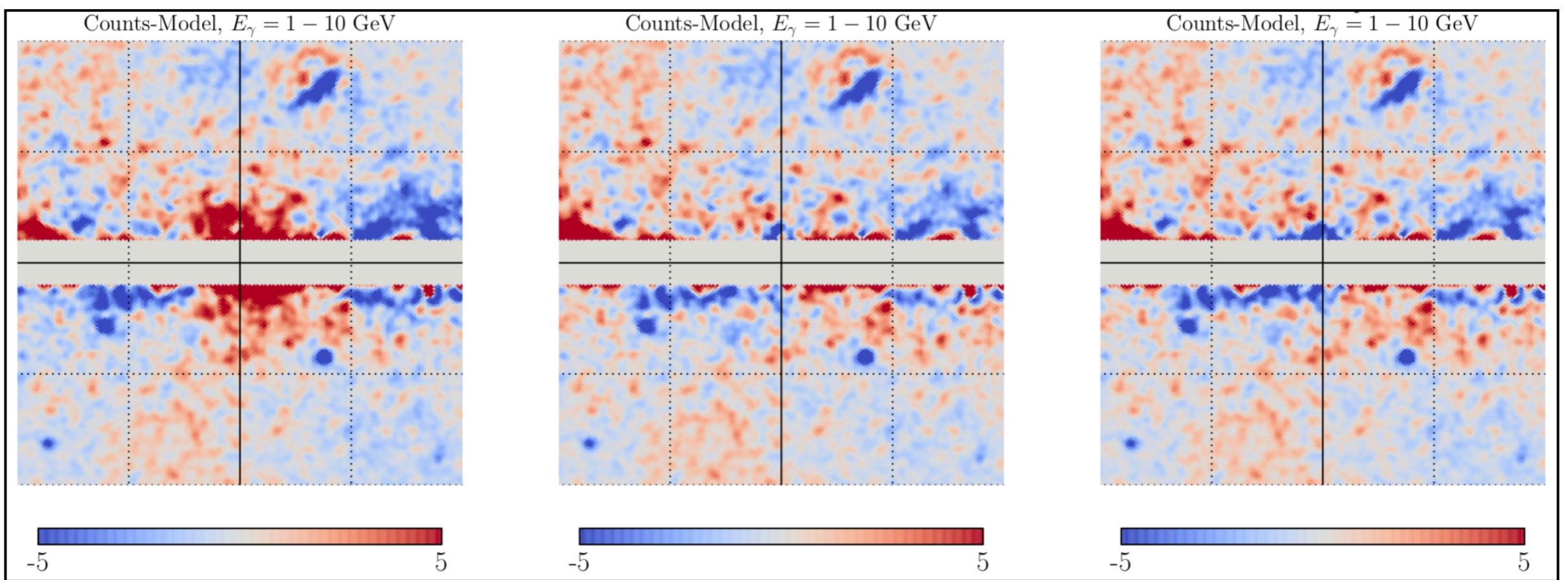
... A SPECIFIC REMARK FOR THE GC



In almost ALL analyses, CR source distribution assumed to drop towards the GC ... WHY?!?!

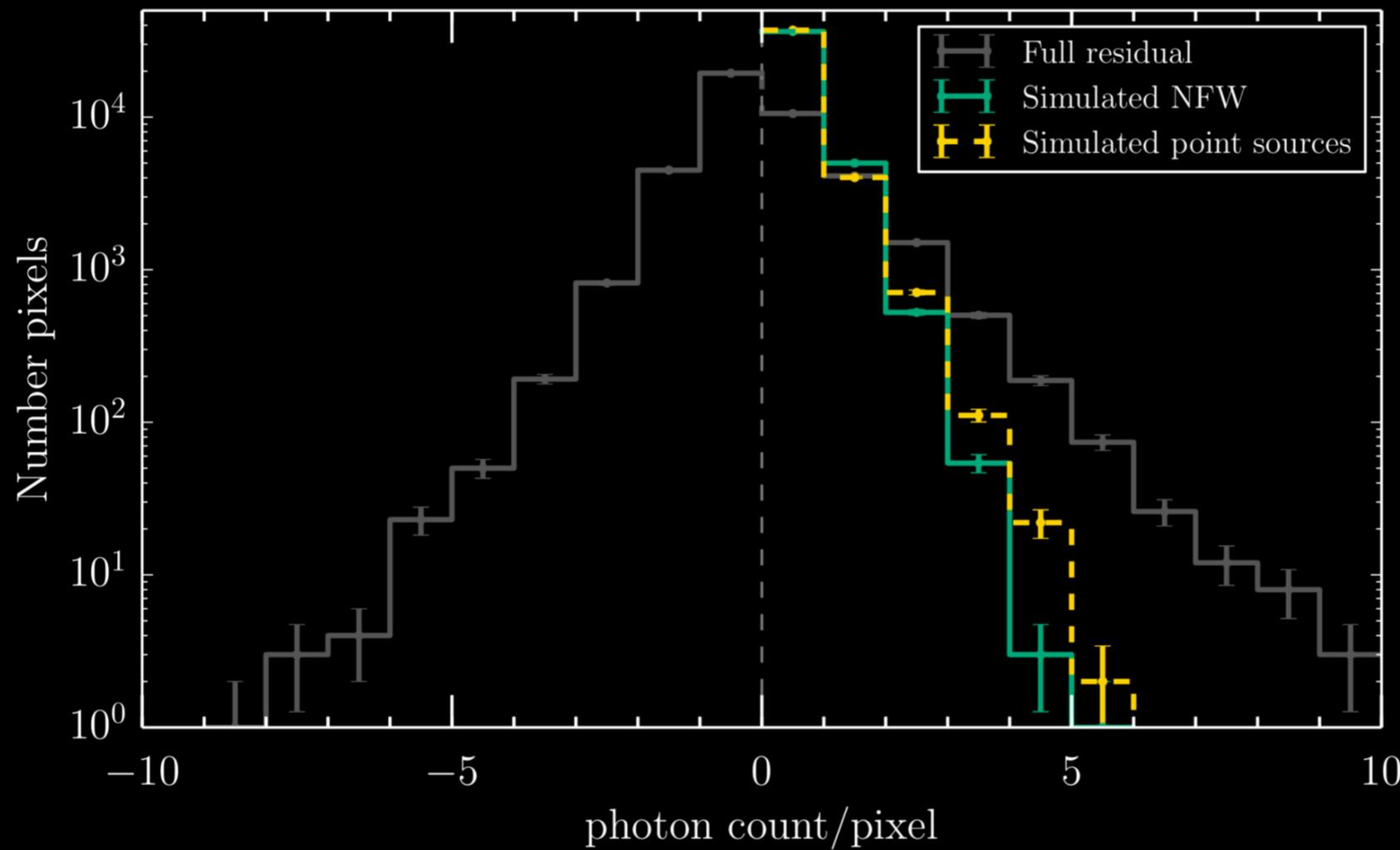
Few notable exceptions I am aware of:

- my work: D.Gaggero et al. , *JCAP 12 (2015) 056*
- E.Carlson, T.Linden, S.Profumo , *PRL 117 (2016) 11*
- Fermi-LAT Coll. , *Astrophys.J. 840 (2017) 1*



Q: Should we care about all this?

S.Horiuchi, M.Kaplinghat, A.Kwa – *JCAP* 11 (2016) 053



YES!

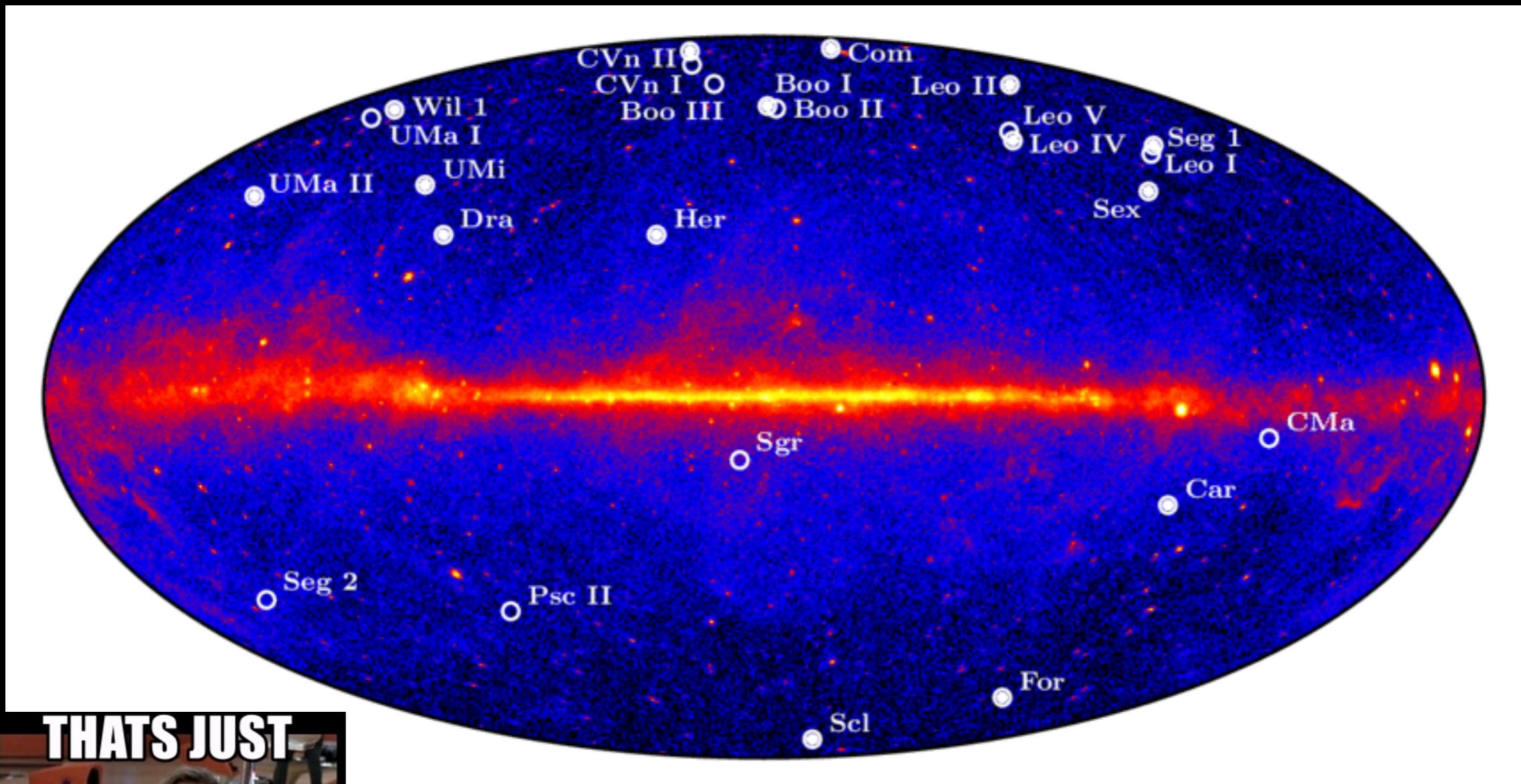
GDE MISMODELING CAN **DRASTICALLY** AFFECT GCE INTERPRETATION

See also more recent discussion in:

Y.Zhong et al. – *PRL* 124 (2020) 23

R.Leane, T.R.Slatyer – *PRL* 125 (2020) 12

So, how to confirm or disprove such a potential discovery of Dark Matter?



**LOOK @ MILKY WAY SATELLITES
IN THE GAMMA-RAY SKY!**

MY OPINION, MAN

DWARF SPHEROIDAL MASS MODELING

Collisionless Boltzmann equation : $\frac{\partial f_\star}{\partial t} + \vec{v} \cdot \nabla_{\vec{x}} f_\star - \nabla_{\vec{x}} \Phi_{\text{tot}} \cdot \nabla_{\vec{x}} f_\star = 0$

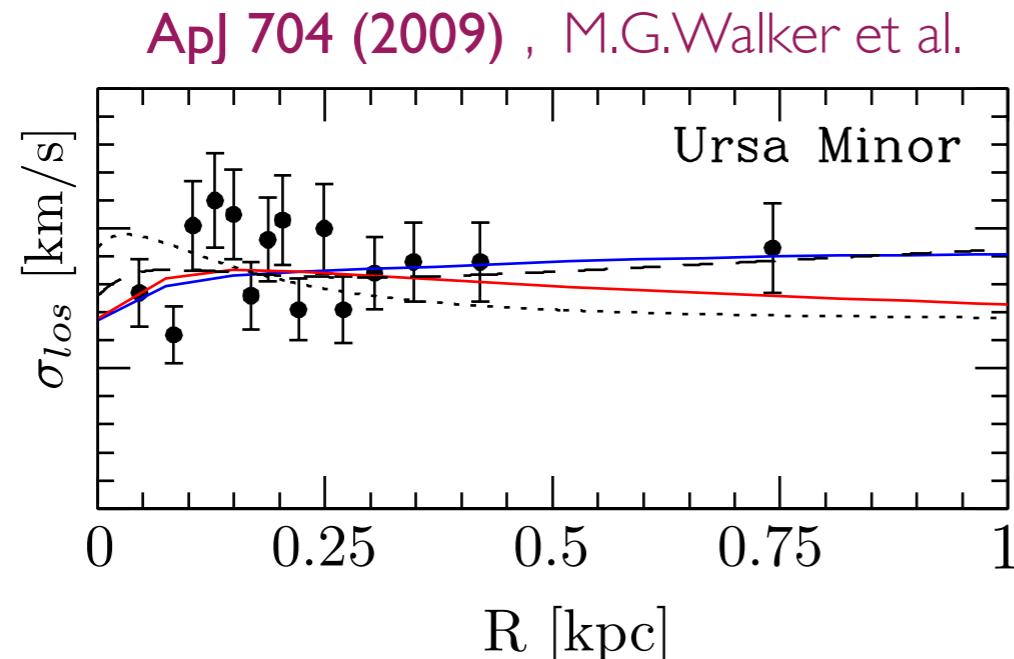
- 1) DYNAMICAL EQUILIBRIUM
- 2) SPHERICAL SYMMETRY

Evolution of phase-space density of star in dSph galaxy, tracing Dark Matter

2nd MOMENTS OF BOLTZMANN EQ.:

$$(\rho_\star \sigma_{\star r}^2)' + 2\beta_\star \rho_\star \sigma_{\star r}^2 = -\rho_\star \Phi'_{\text{tot} \simeq \text{DM}}$$

HOW THIS CONNECTS TO OBSERVATIONS?



Spectroscopy \rightarrow Dispersion

$$\sigma_{los}(R) \Leftrightarrow \sigma_{los}(\beta_\star, \Phi_{\text{DM}})$$

Stellar anisotropy - DM
degeneracy problem! 😕

DWARF SPHEROIDAL MASS MODELING

Collisionless Boltzmann equation : $\frac{\partial f_\star}{\partial t} + \vec{v} \cdot \nabla_{\vec{x}} f_\star - \nabla_{\vec{x}} \Phi_{\text{tot}} \cdot \nabla_{\vec{x}} f_\star = 0$

- 1) DYNAMICAL EQUILIBRIUM
- 2) SPHERICAL SYMMETRY

Evolution of phase-space density of star in dSph galaxy, tracing Dark Matter

K. Andrade, M.Kaplinghat, M.V. – work in progress

BEYOND STANDARD JEANS ANALYSIS:

$$f(E, L) = n_f \ h(E) \ g(L)$$

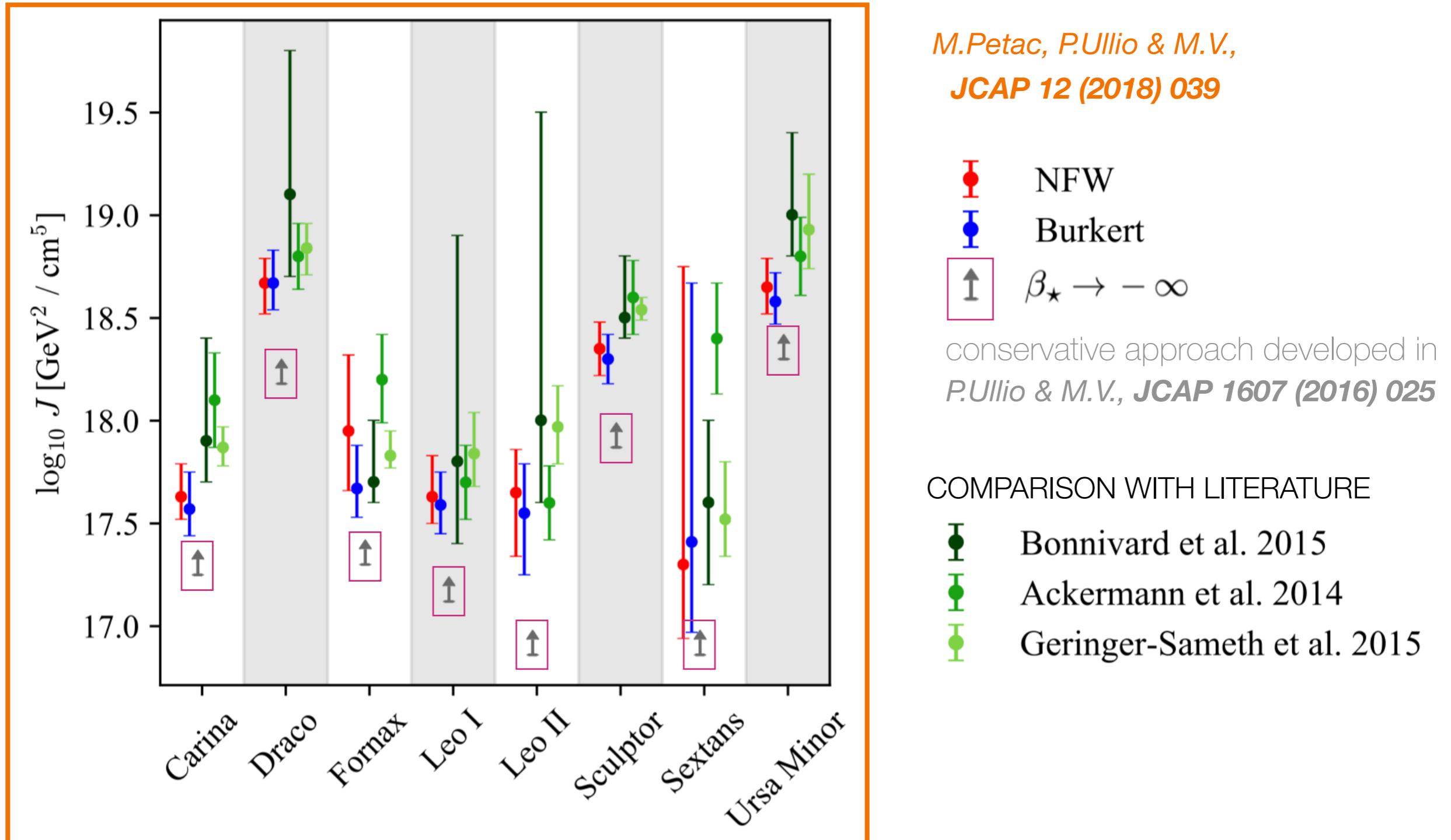
$$h(E) = \begin{cases} (1 - \frac{E}{\Phi_{\text{lim}}})^e E^a (E_c^q + E^q)^{d/q}, & E < \Phi_{\text{lim}} \\ 0, & E \geq \Phi_{\text{lim}} \end{cases}$$

$$g(L) = \left(\left(\frac{L}{L_\beta} \right)^{\frac{b_0}{\alpha}} + \left(\frac{L}{L_\beta} \right)^{\frac{b_1}{\alpha}} \right)^\alpha$$

O(10) PARAMETERS, e.g.: $\{r_s, v_s, \Phi_{\text{lim}}, e, a, q, E_c, d, L_\beta, b\}$

REPRESENTATION OF THE STATE OF THE ART

$$J \equiv \int_{\Delta\Omega} d\Omega \int_{\text{l.o.s.}} d\ell \rho_{\text{DM}}^2(\vec{x})$$

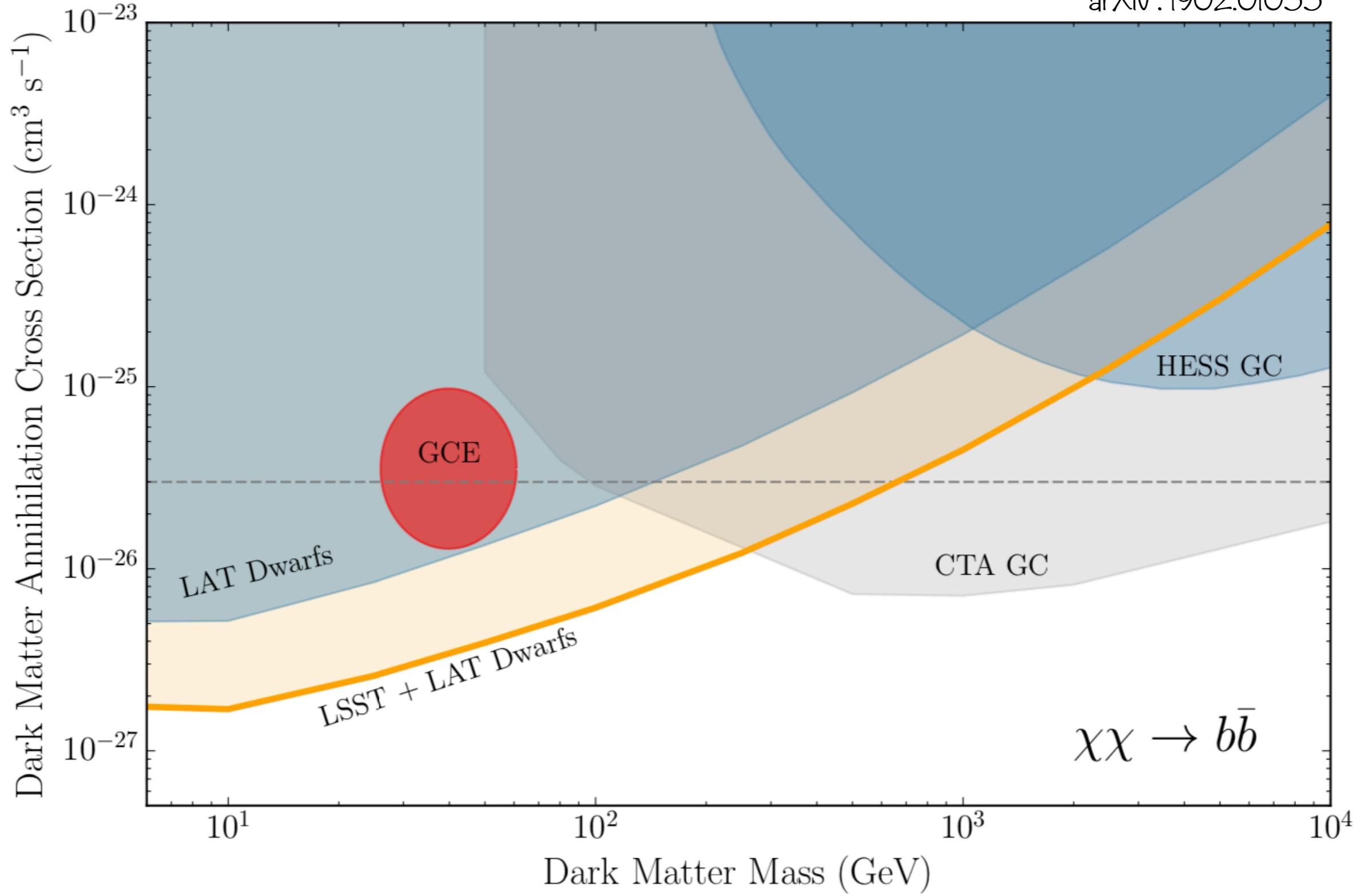




Probing the Fundamental Nature of Dark Matter with the Large Synoptic Survey Telescope

LSST Dark Matter Group

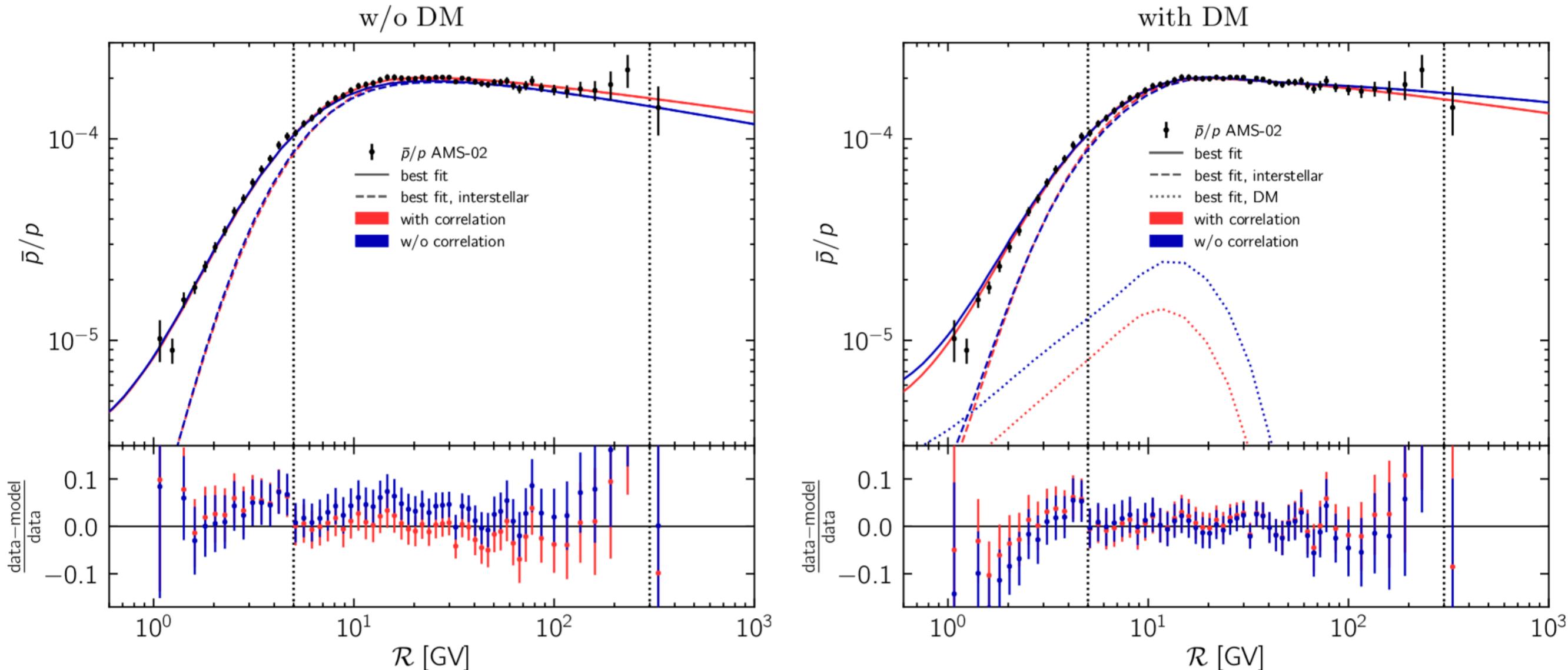
arXiv : 1902.01055



ANYTHING ELSE IN LINE WITH GCE ?

THE ANTI-PROTON CHANNEL

J.Heisig et al., *arXiv: 2005.04237*

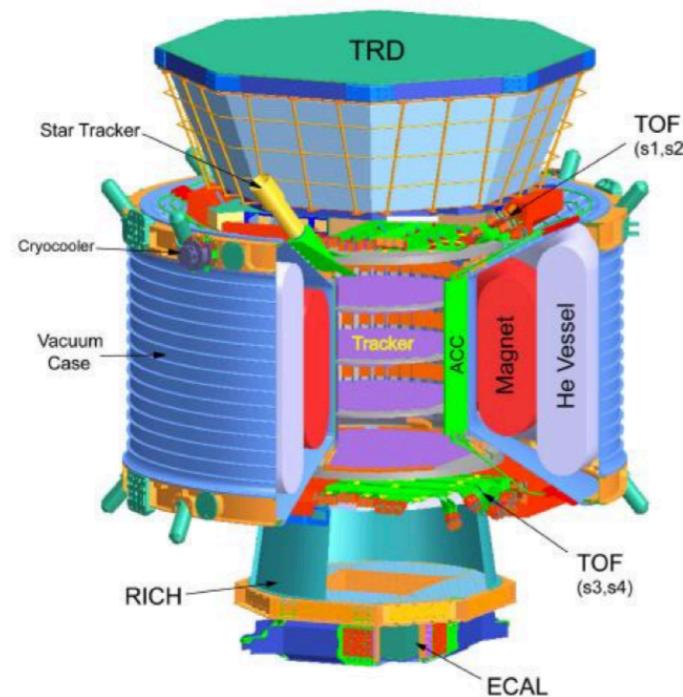


MILD EVIDENCE FOR SAME DM INTERPRETATION AS FOR THE GCE.
UNCERTAINTIES FROM CR TRANSPORT + ANTI-P CROSS SEC

EXTRA COMPLICATION: HOW TO PROPERLY TREAT AMS-02 SYSTEMATIC ERRORS?

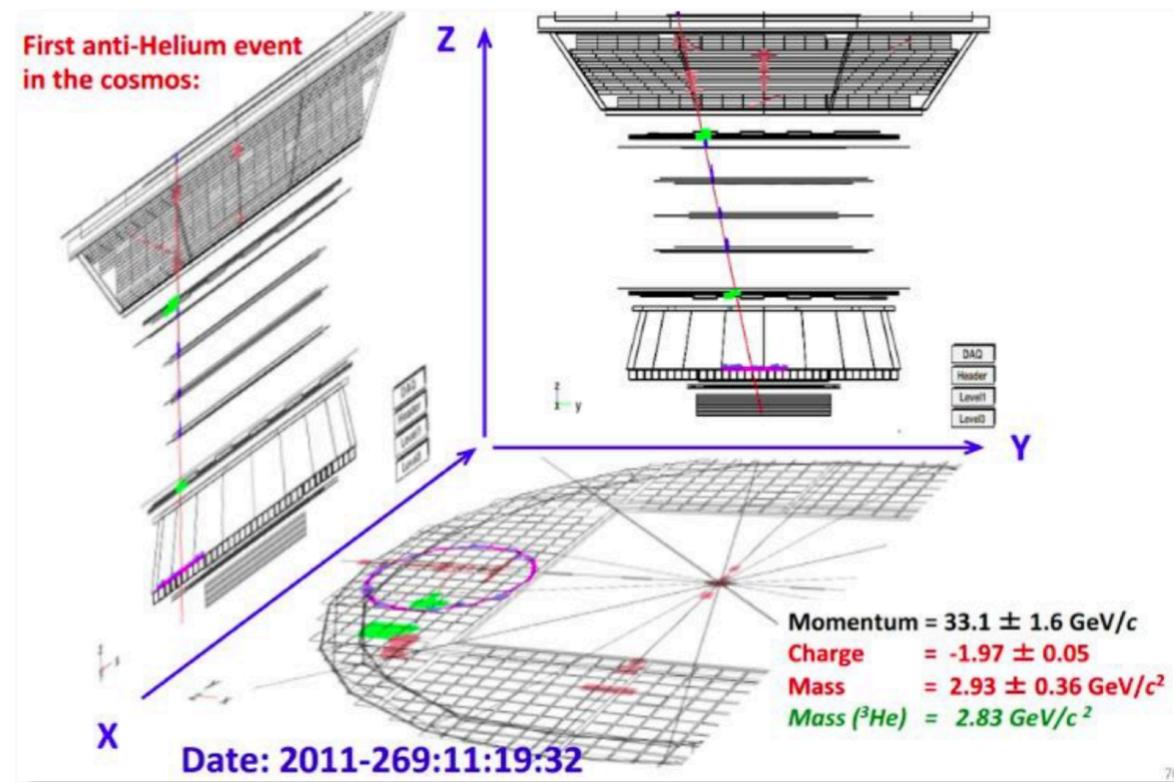
WHAT ABOUT ANTI-NUCLEI?

RUMORS FROM AMS-02 ABOUT POSSIBLE \bar{D} , \bar{He} DETECTION !

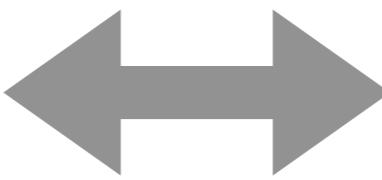
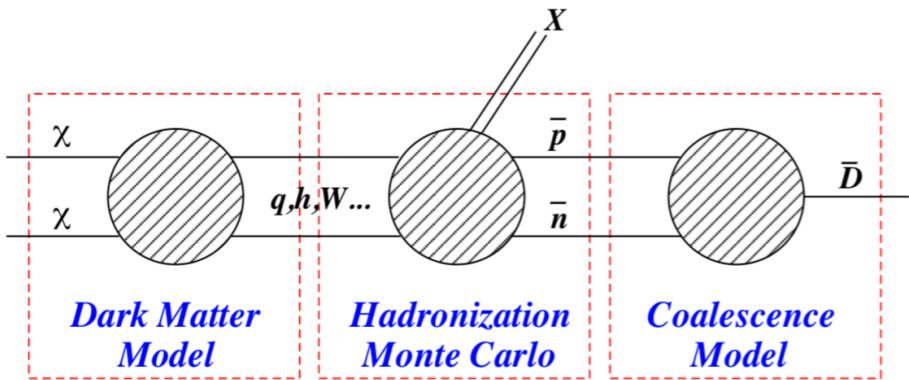


- AMS has been in operation on the ISS since May 2011

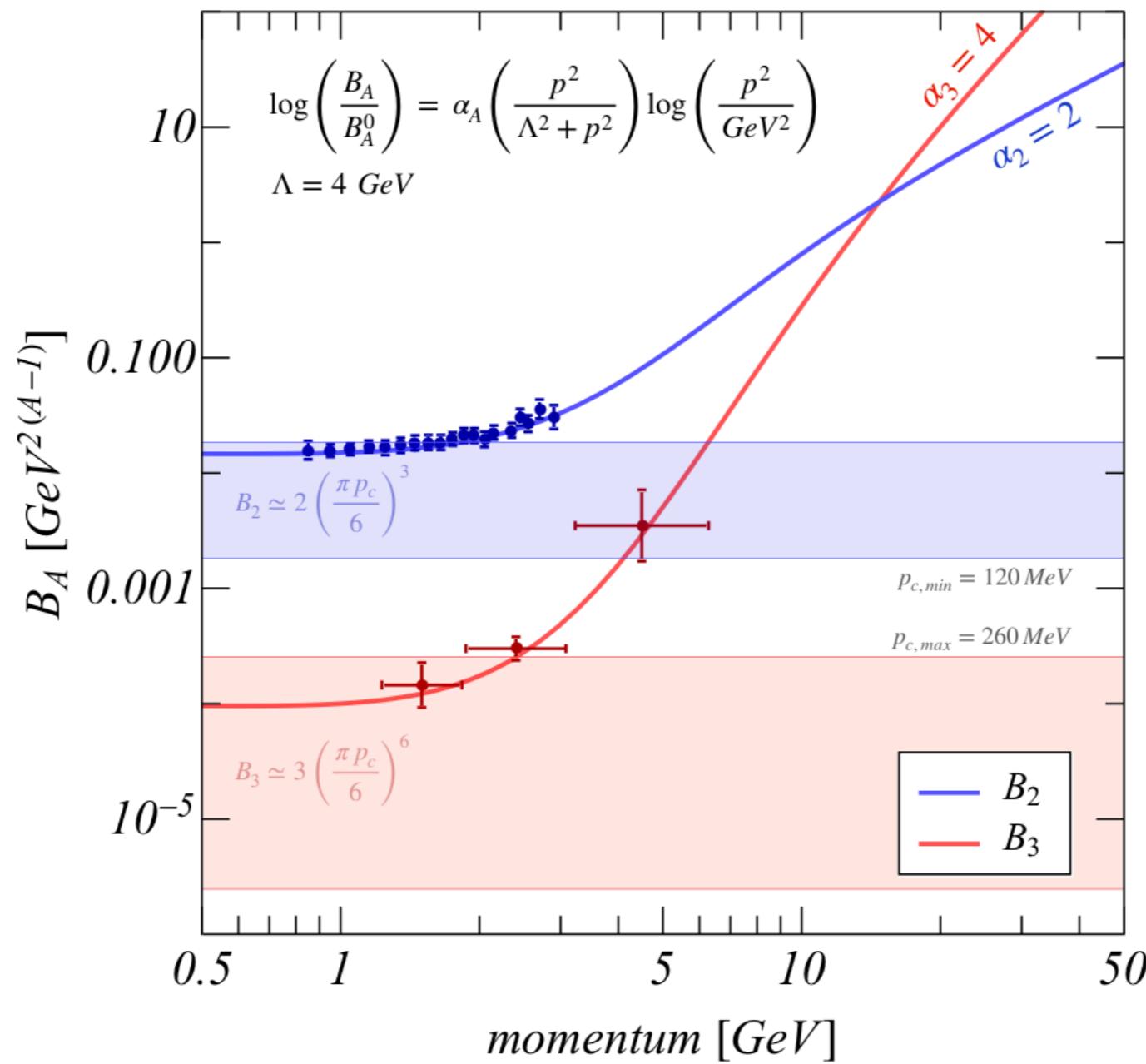
Ting, CERN May 2018: <https://indico.cern.ch/event/729900/>



- NEARBY ANTI-STARS / ANTI-CLOUDS
V.Poulin, P.Salati, I.Cholis, M.Kamionkowski, J.Silk, PRD 99 (2019) 9
- AD-HOC DM THEORY SELECTION RULES
J.Heeck & A.Rajaraman, J. Phys. G 47 (2020) 10
- LARGE MODIFICATION IN $\bar{\Lambda}_b$ DECAYS
M.W.Winkler & T.Linden, PRL 126 (2021) 10



ENERGY DEPENDENCE IN
NUCLEAR COALESCENCE?



ANY RELATION WITH YET-TO-BE-CONFIRMED AMS ANTI-NUCLEI EVENTS?



Take Home

- Indirect Searches for Dark Matter are still kickin' & alive!
- The GeV excess still represents a very interesting signal to fully uncover and understand
- Dwarf spheroidals will be key to prove / disprove the Dark Matter interpretation of the GC excess
—> *promising reach thanks to Fermi-LAT + LSST*
- Anti-proton channel also interesting: keep an eye on ...
- If anti-nuclei events confirmed, a potential groundbreaking discovery lacking as of now of a solid explanation!