

Gamma Rays and Dark Matter

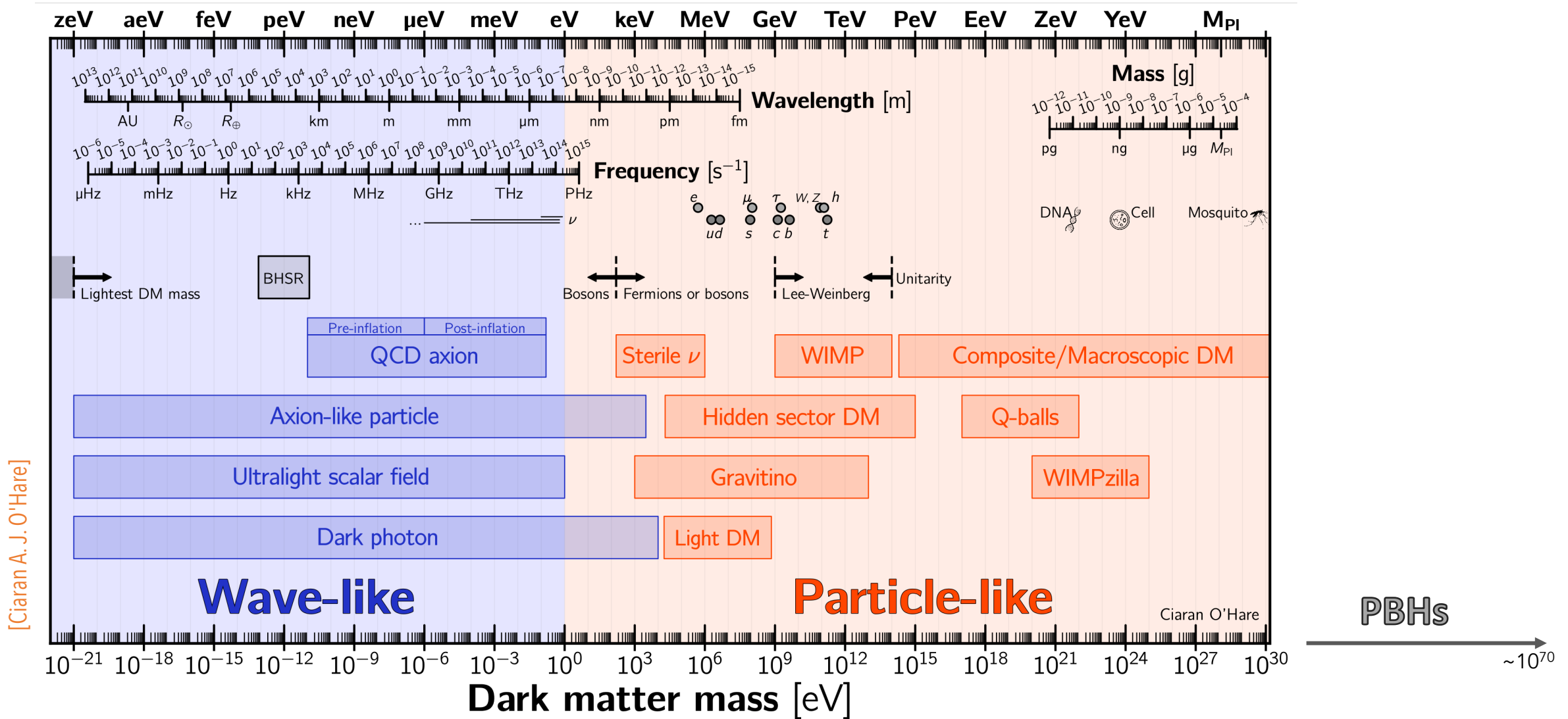
status and prospects

Dr. Milena Crnogorčević

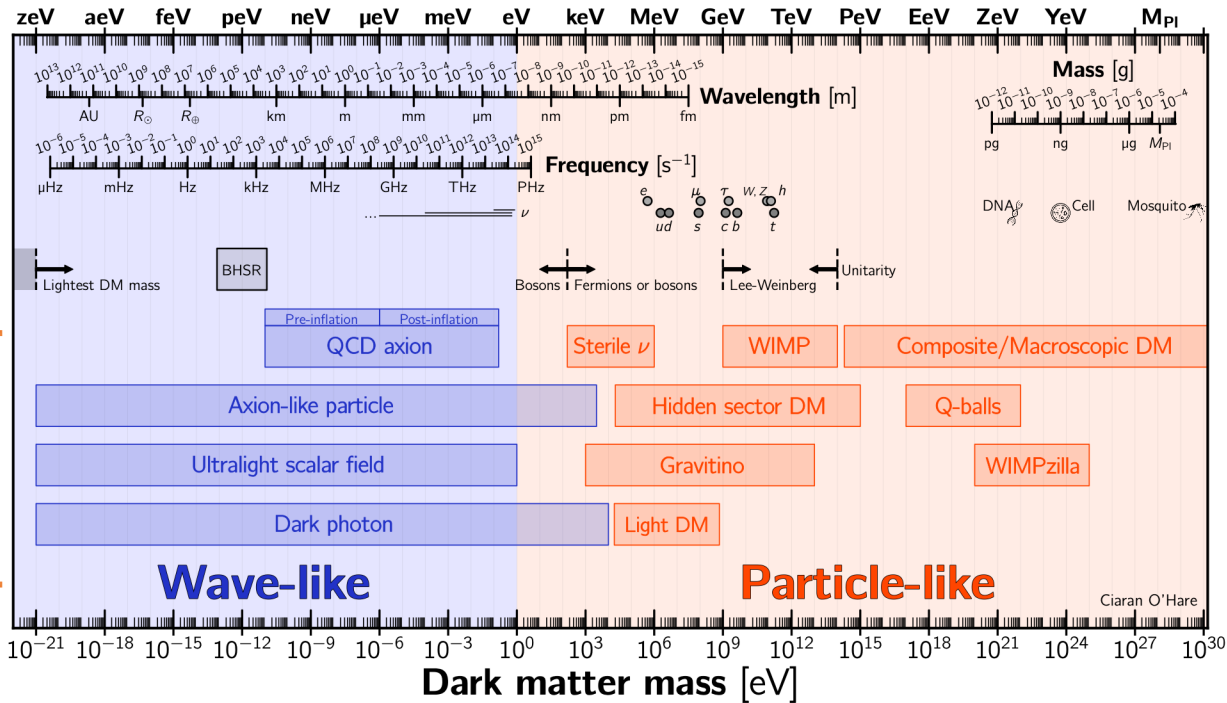
Postdoctoral Fellow at the Oskar Klein Centre, Stockholm University

milena.crnogorcevic@fysik.su.se

Dark Matter Landscape: A Theorist's View

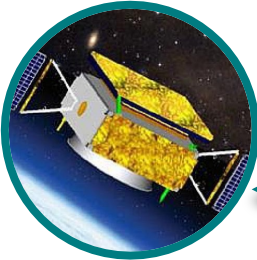
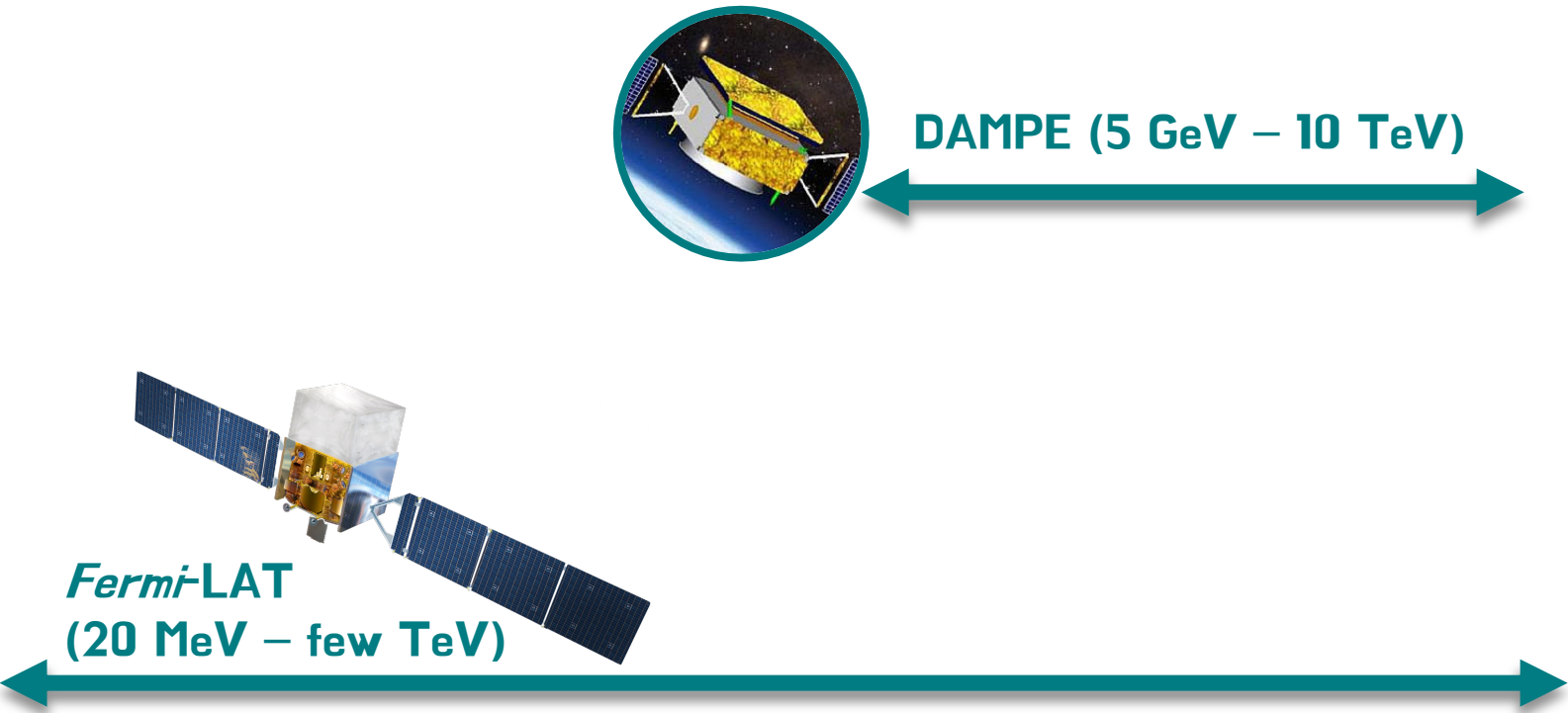


Dark Matter Landscape: A Theorist's View

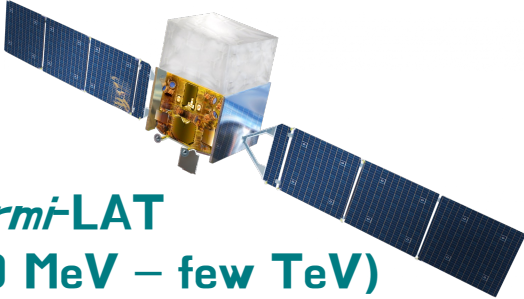


Our search strategies are inherently *biased*

1. **model dependency bias:** theory guides our search strategies
2. **observational bias:** disparity between the data we have and the data we need
3. **identifiable signature bias:** required for observation



DAMPE (5 GeV – 10 TeV)



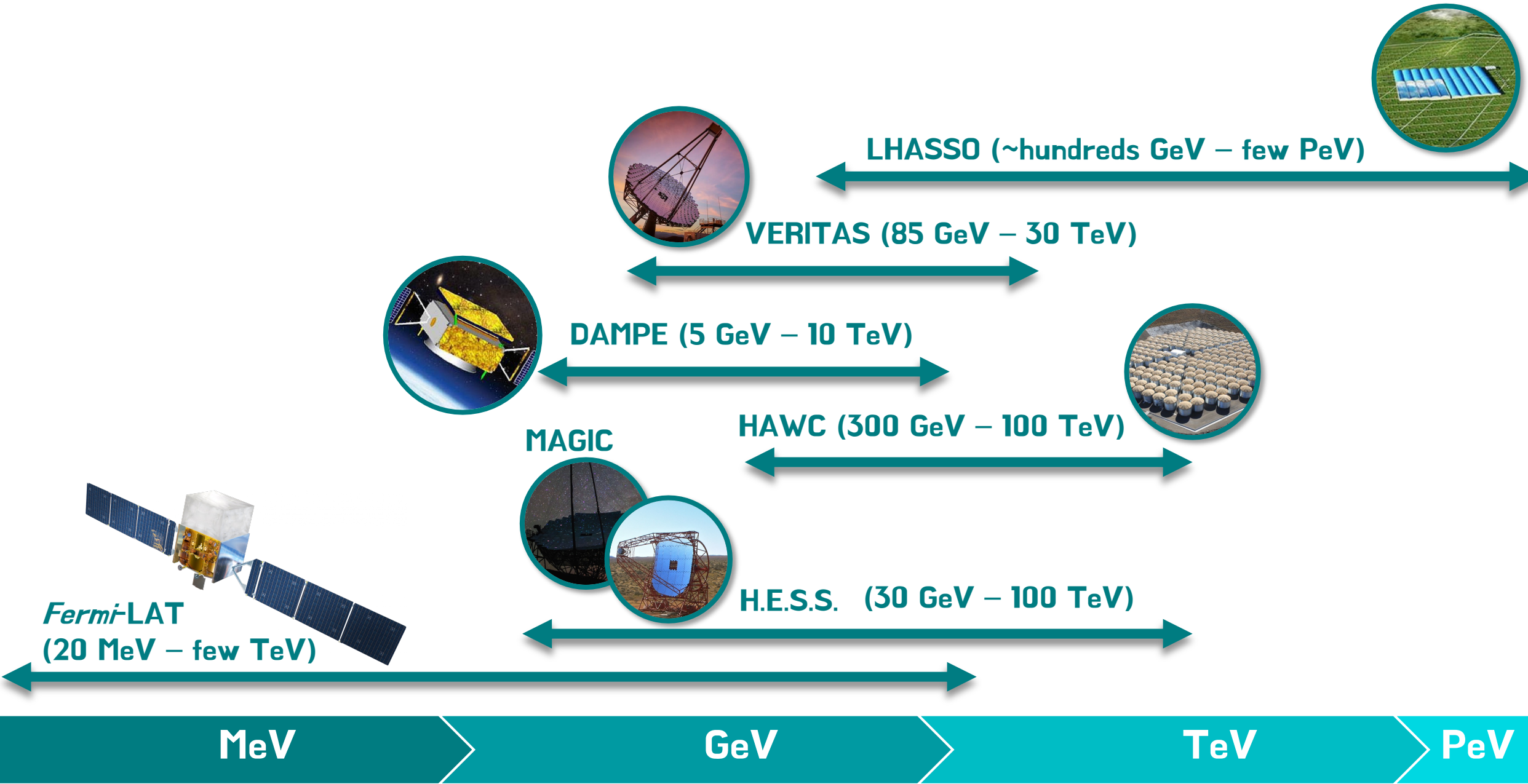
Fermi-LAT
(20 MeV – few TeV)

MeV

GeV

TeV

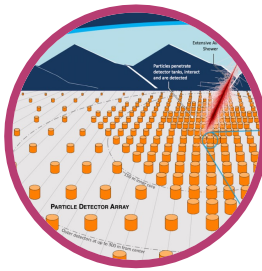
PeV



γ -rays (past/present)

γ -rays (future)

*approximate scale



SWGO (100 GeV – ~PeV)

CTAO (20 GeV – 300 TeV)

LHASSO (~hundreds GeV – few PeV)

VERITAS (85 GeV – 30 TeV)

DAMPE (5 GeV – 10 TeV)

HAWC (300 GeV – 100 TeV)

MAGIC

H.E.S.S. (30 GeV – 100 TeV)

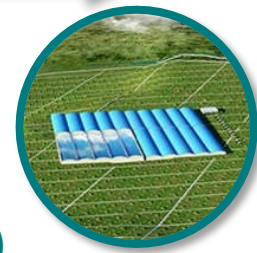
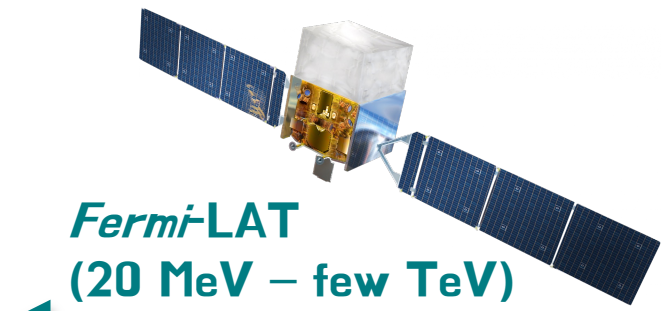
Fermi-LAT
(20 MeV – few TeV)

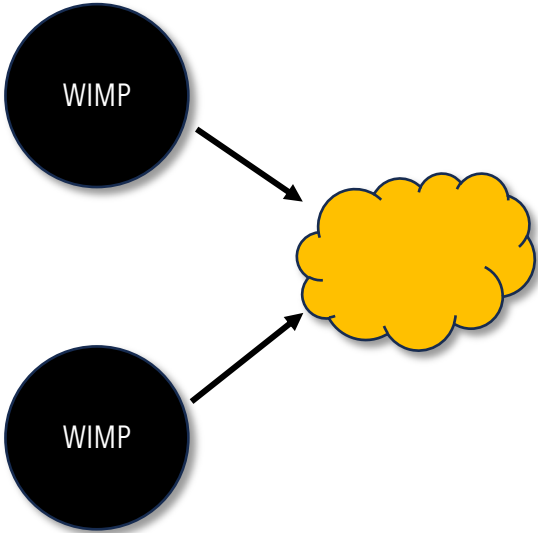
MeV

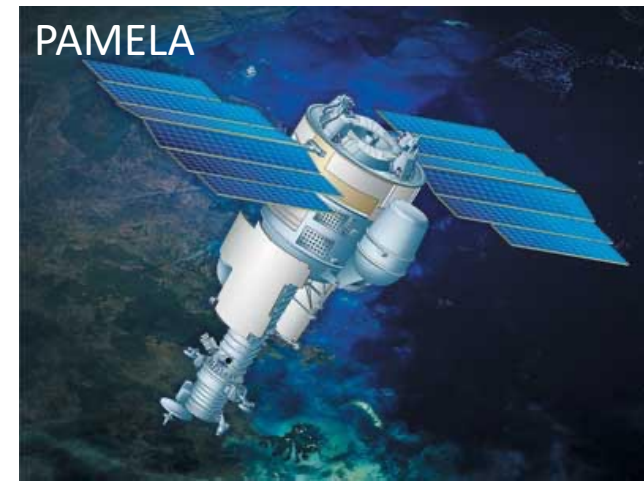
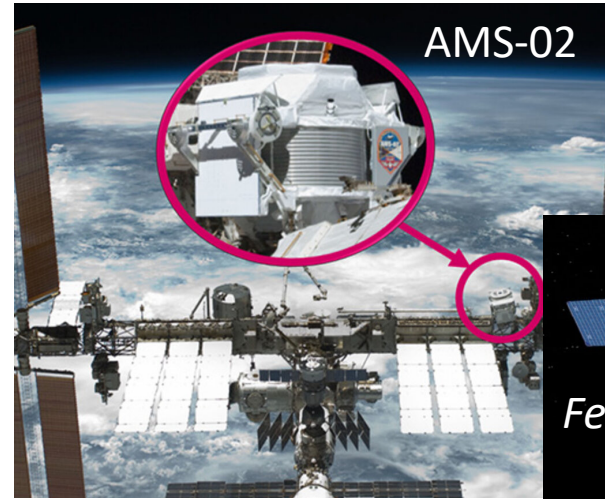
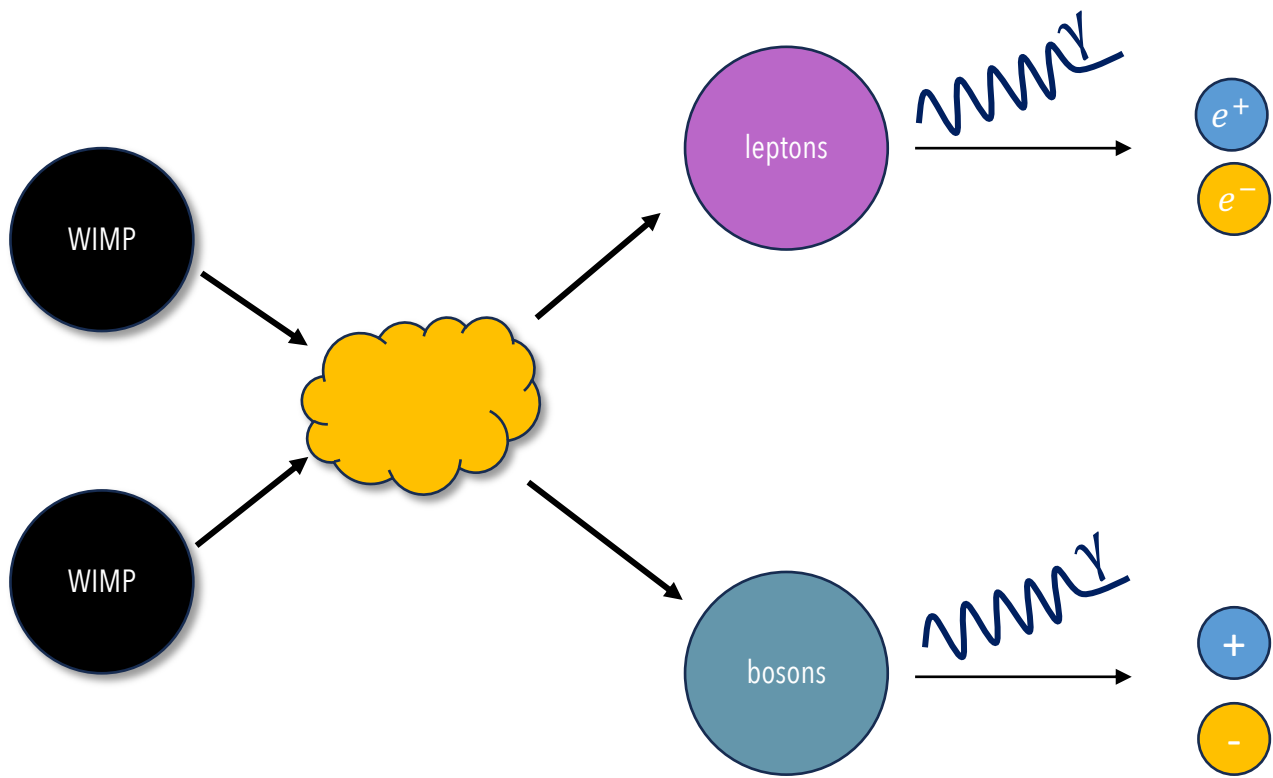
GeV

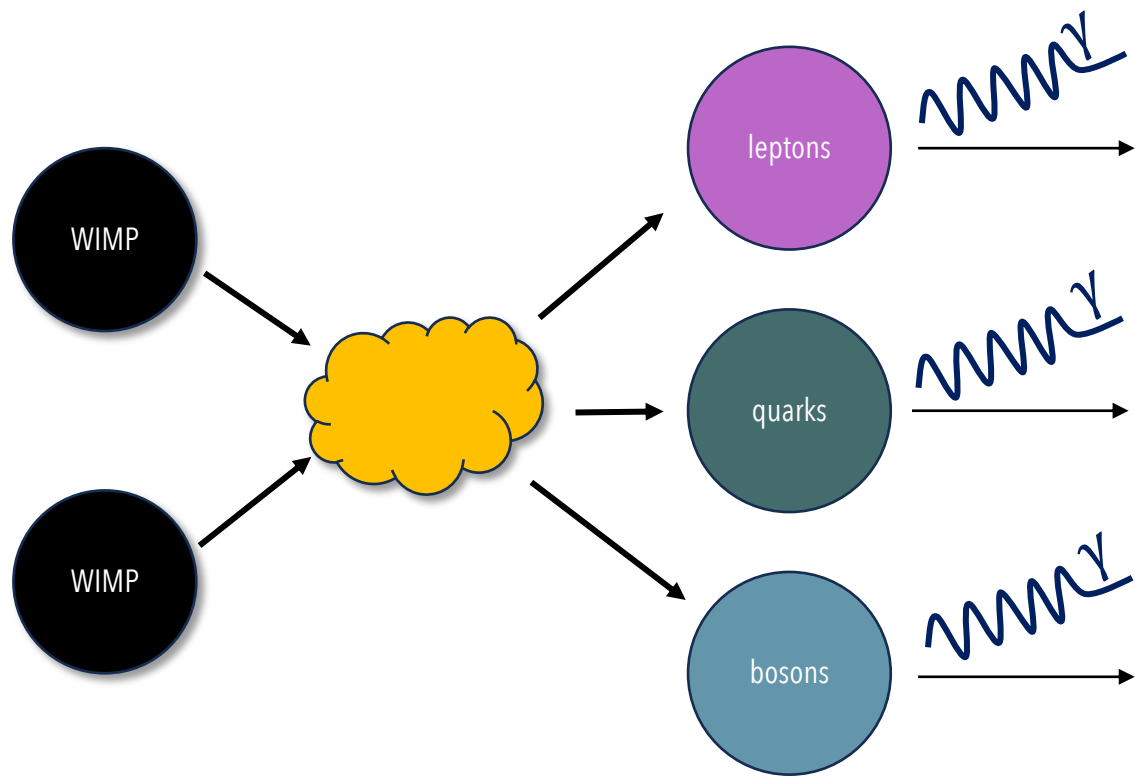
TeV

PeV









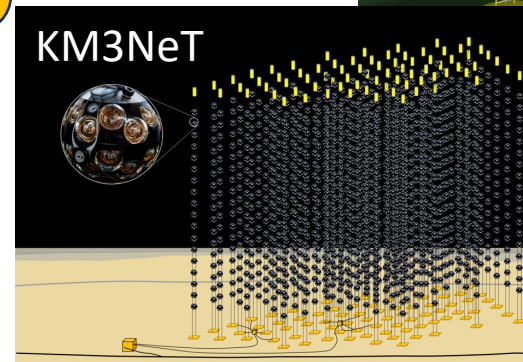
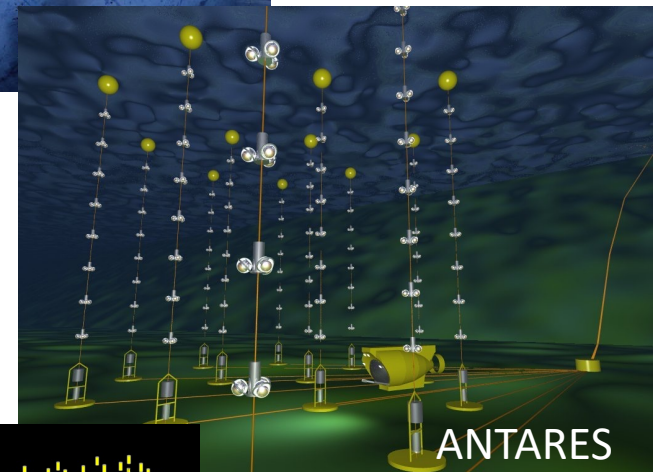
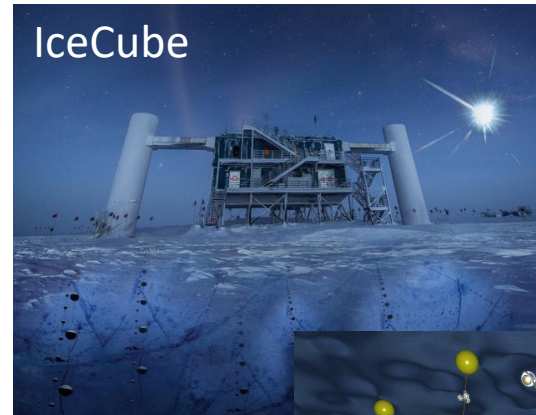
e^+

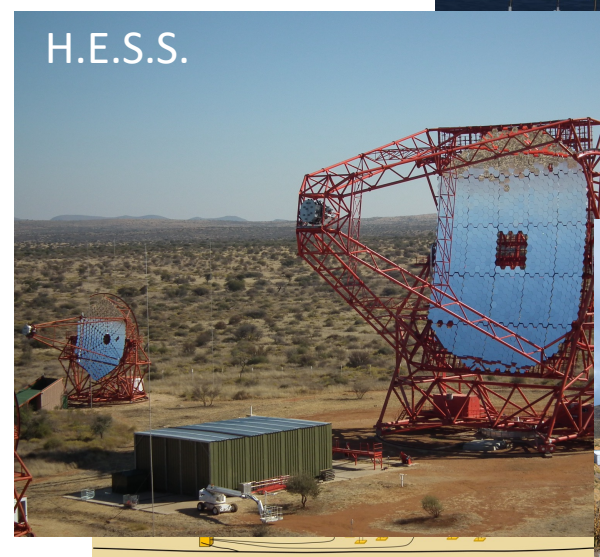
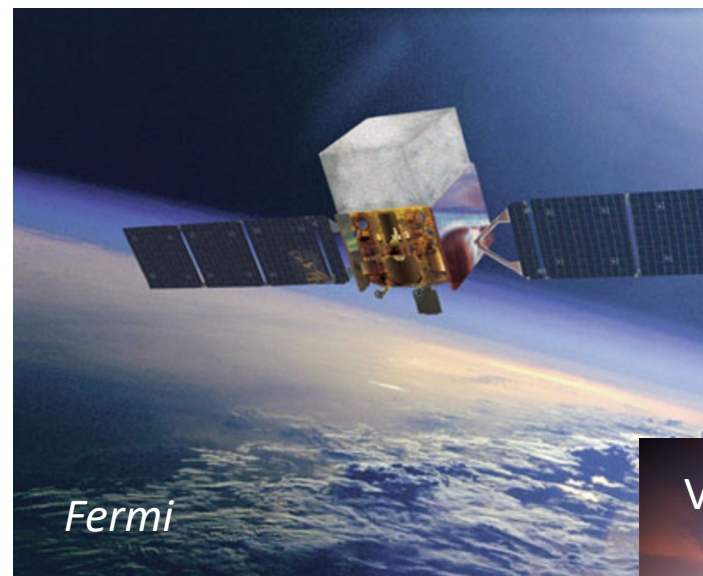
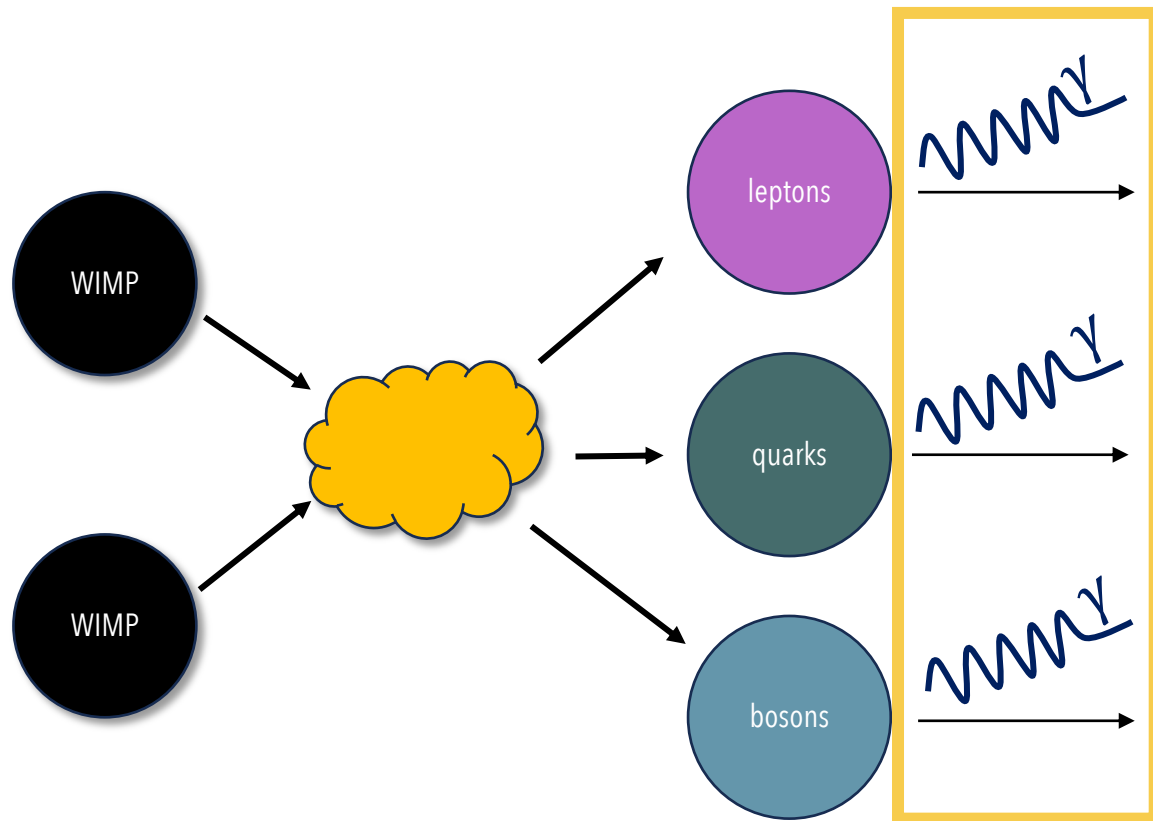
e^-

ν

+

-





What do we see?

...but not understand completely.

FERMILAB-PUB-09-494-A

**Possible Evidence For Dark Matter Annihilation In The Inner Milky Way From The
Fermi Gamma Ray Space Telescope**

Lisa Goodenough¹ and Dan Hooper^{2,3}

¹Center for Cosmology and Particle Physics, Department of Physics, New York University, New York, NY 10003

²Center for Particle Astrophysics, Fermi National Accelerator Laboratory, Batavia, IL 60510

³Department of Astronomy and Astrophysics, University of Chicago, Chicago, IL 60637

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OBSERVATIONS OF M31 AND M33 WITH THE FERMI LARGE AREA TELESCOPE:
A GALACTIC CENTER EXCESS IN ANDROMEDA?

M. ACKERMANN¹, M. AJELLO², A. ALBERT³, L. BALDINI⁴, J. BALET⁵, G. BARBIELLINI^{6,7}, D. BASTIERI^{8,9}, R. BELLAZZINI¹⁰,
E. BISSALDI¹¹, E. D. BLOOM¹², R. BONINO^{13,14}, E. BOTTACINI¹², T. J. BRANDT¹⁵, J. BREGEON¹⁶, P. BRUEL¹⁷,
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F. DE PALMA^{11,27}, R. DESIANTE^{13,28}, G. CHIARO⁹, N. DI LALLA⁴, F. DI MAURO¹², L. DI VENERE^{11,19}, T. GLANZMAN¹²,
S. FUNK²⁹, P. FUSCO^{11,19}, F. GARGANO¹¹, N. GIGLIETTO^{11,19}, F. GIORDANO^{11,19}, K. HAYASHI³³, M. GIROLETTI²⁵, G. JÓHANNESSEN³⁸,
D. GREEN^{15,30}, I. A. GRENIER⁵, L. GUILLEMOT^{31,32}, M. KUSS¹⁰, G. LA MURA⁹, S. LARSSON^{42,43}, L. LATRONICO¹³, J. LI⁴⁴,
T. KAMAE³⁹, J. KNÖDLSIEDER^{40,41}, A. K. H. KONG³⁵, S. MALDERA¹³, W. MITTHUMSIRI⁴⁵, A. MANFREDA⁴, P. MARTIN^{40,41},
M. N. MAZZIOTTA¹¹, P. F. MICHELSON¹², N. MIRABAL^{15,62}, E. NUSS¹⁶, T. OHSUGI⁴⁶, T. MIZUNO⁴⁶, M. E. MONZANI¹²,
A. MORSELLI⁴⁷, I. V. MOSKALENKO¹², M. NEGRO^{13,14}, M. PESCE-ROLLINS¹⁰, T. OHSAKI⁴⁶, N. OMODEI¹², E. ORLANDO¹²,
J. F. ORMES⁴⁸, D. PANEQUE⁴⁹, M. PERSIC^{6,50}, O. REIMER^{12,51}, M. SÁNCHEZ-CONDE^{43,52}, C. SGRÒ¹⁰, G. PRINCIPE²⁹,
S. RAINÒ^{11,19}, R. RANDO^{8,9}, M. RAZZANO^{10,63}, G. SPANDRE¹⁰, P. SPINELLI^{11,19}, K. TANAKA⁵⁴, L. TIBALDO⁵⁵, D. F. TORRES^{44,56},
E. J. SISKIND⁵³, F. SPADA¹⁰, J. C. WANG^{34,36,37}, K. S. WOOD^{58,61}, M. WOOD¹², G. ZAHARIJAS^{59,60}, M. ZHOU^{34,36,37},
E. TROJA^{15,30}, Y. UCHIYAMA⁵⁷

Draft version March 1, 2017

On The Gamma-Ray Emission From Reticulum II and Other Dwarf Galaxies

Dan Hooper^{1,2} and Tim Linden³

¹Fermi National Accelerator Laboratory, Center for Particle Astrophysics, Batavia, IL

²University of Chicago, Department of Astronomy and Astrophysics Chicago, IL

³Kavli Institute for Cosmological Physics University of Chicago, Chicago, IL

Possible Evidence For Dark Matter
Fermi Gamma

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F. LONGO^{6,7}, F. LOPARCO^{11,19}, A. K. H. B. ...

CrossM

Fermi-LAT Observations of γ -Ray Emission toward the Outer Halo of M31

Christopher M. Karwin¹ , Simona Murgia¹ , Sheldon Campbell¹, and Igor V. Moskalenko² 

¹Department of Physics and Astronomy, University of California, Irvine, CA 92697, USA; ckarwin@uci.edu, smurgia@uci.edu

²Hansen Experimental Physics Laboratory and Kavli Institute for Particle Astrophysics and Cosmology, Stanford University, Stanford, CA 94305, USA

imos@stanford.edu

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SAHARIJAS^{59,60}, SIMONE¹¹,
D. F. TORRES^{44,56},
M. ZHOU^{34,36,37}

Possible Evidence For Dark Matter
Fermi Gamma-ray

Gamma-Ray Emission From Reticulum II and Other Dwarf Galaxies

Legacy Analysis of Dark Matter Annihilation from the Milky Way Dwarf Spheroidal Galaxies with 14 Years of *Fermi*-LAT Data

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A. MORSE

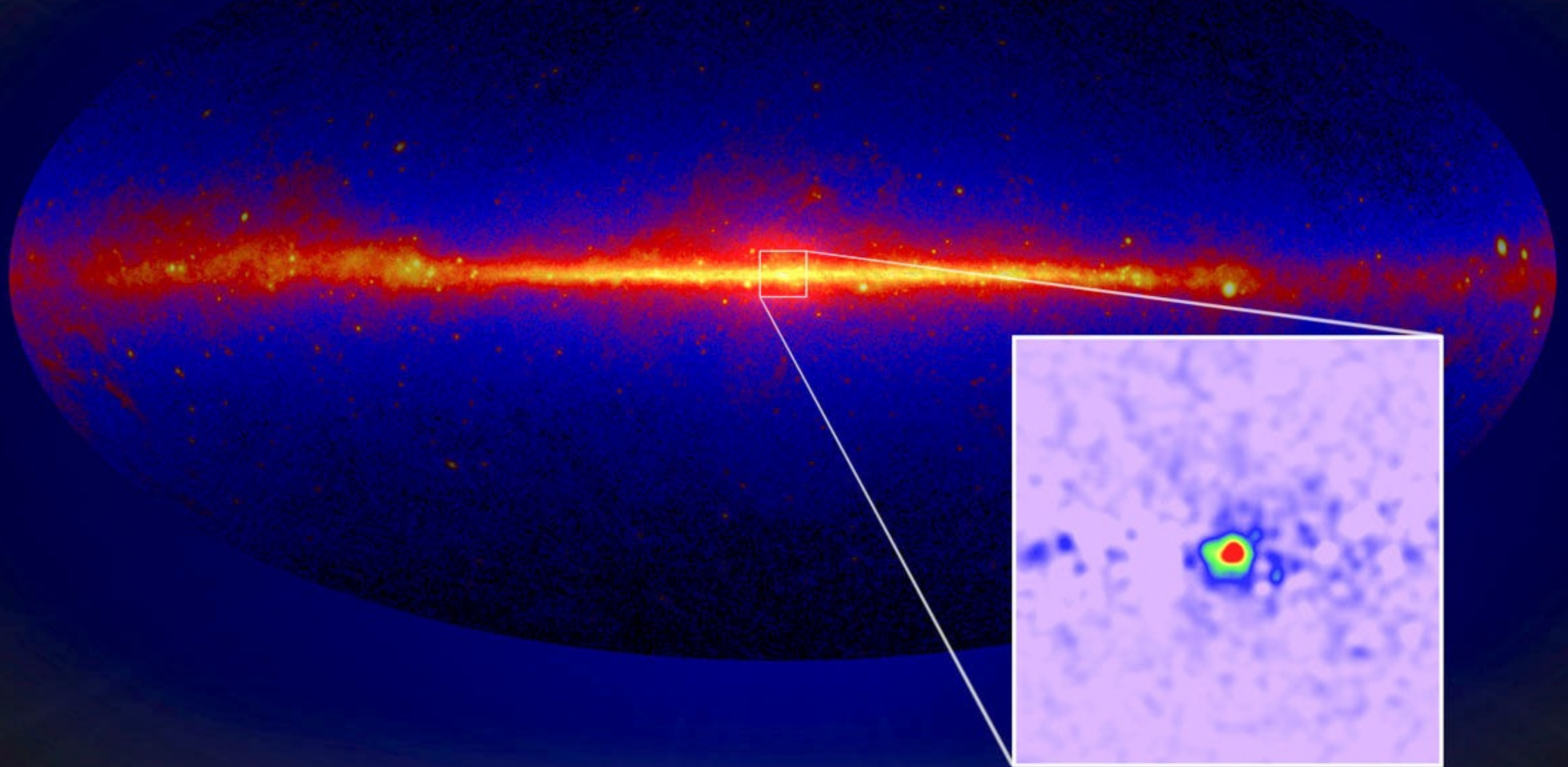
Tim Linden³
Batavia, IL
Alex McDaniel* and Marco Ajello
Department of Physics and Astronomy, Clemson University, Clemson, SC, 29631, USA
Christopher M. Karwin
NASA Postdoctoral Program Fellow, NASA Goddard Space Flight Center, Greenbelt, MD, 20771, USA
Mattia Di Mauro
Dipartimento di Fisica, Università di Torino, Via P. Giuria 1, 10125 Torino, Italy and
Istituto Nazionale di Fisica Nucleare, Sezione di Torino, Via P. Giuria 1, 10125 Torino, Italy
Alex Drlica-Wagner
Fermi National Accelerator Laboratory, P.O. Box 500, Batavia, IL 60510, USA
Kavli Institute for Cosmological Physics, University of Chicago, Chicago, IL 60637, USA and
Department of Astronomy and Astrophysics, University of Chicago, Chicago IL 60637, USA
Miguel Sánchez-Conde
Instituto de Física Teórica, IFT UAM-CSIC, Departamento de Física Teórica,
Universidad Autónoma de Madrid, ES-28049 Madrid, Spain
(Dated: November 10, 2023)

Fermi-LAT Observations of

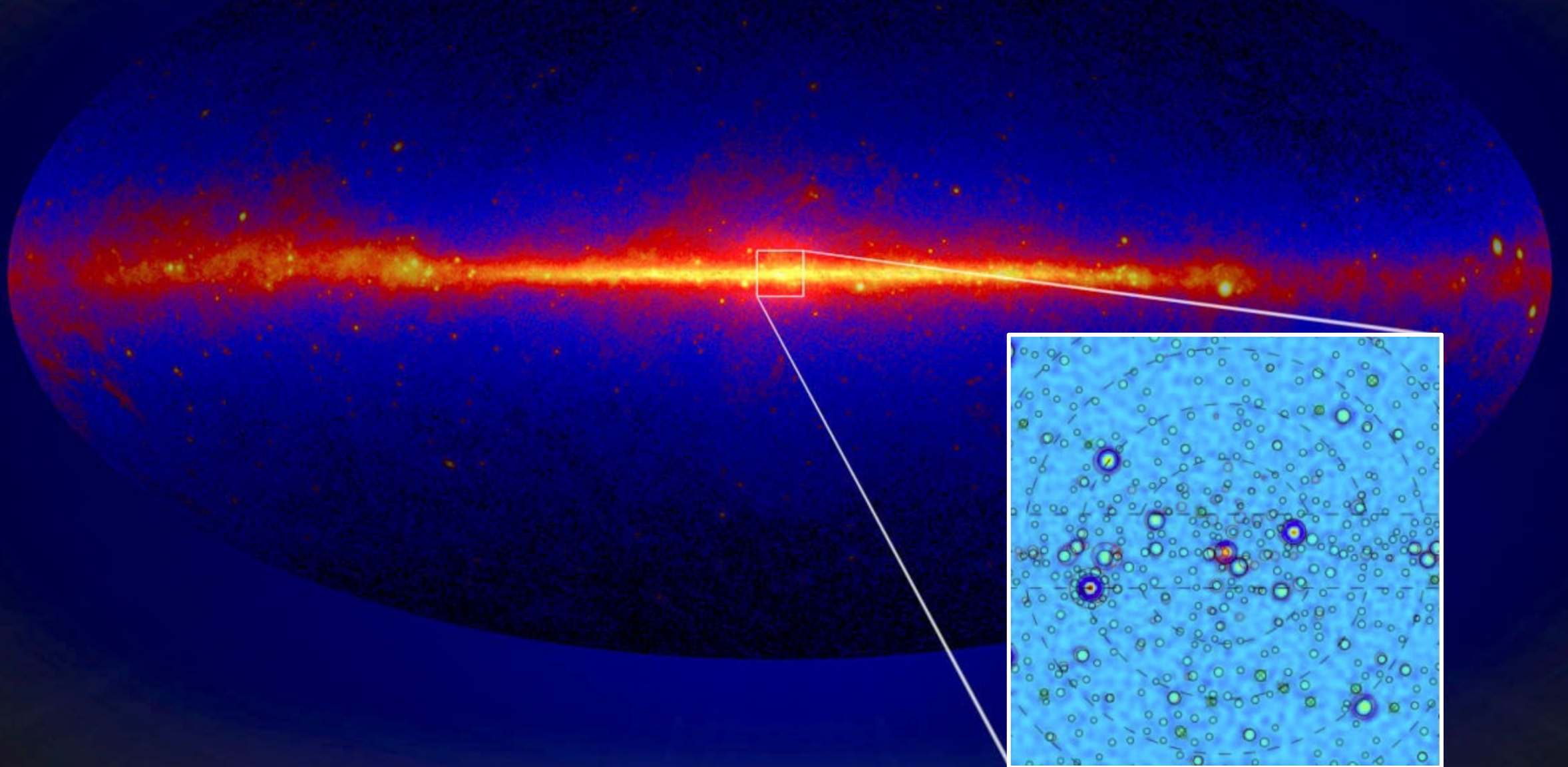
Christopher M. Karwin¹, Simo
¹ Department of Physics and Astronomy, Un
² Hansen Experimental Physics Laboratory and Kavli In

Received 2019 March 19;

The Galactic Center Excess

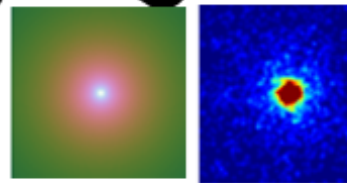
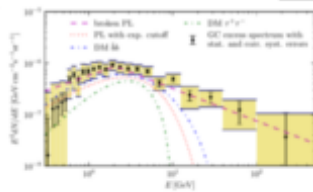
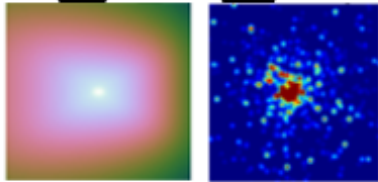
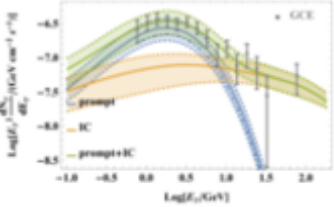
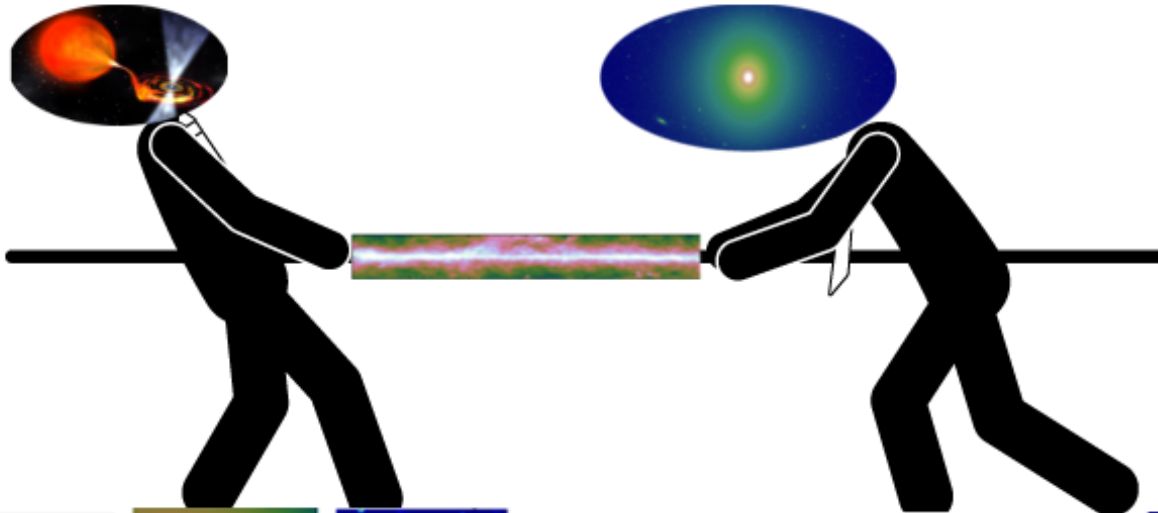


The Galactic Center Excess



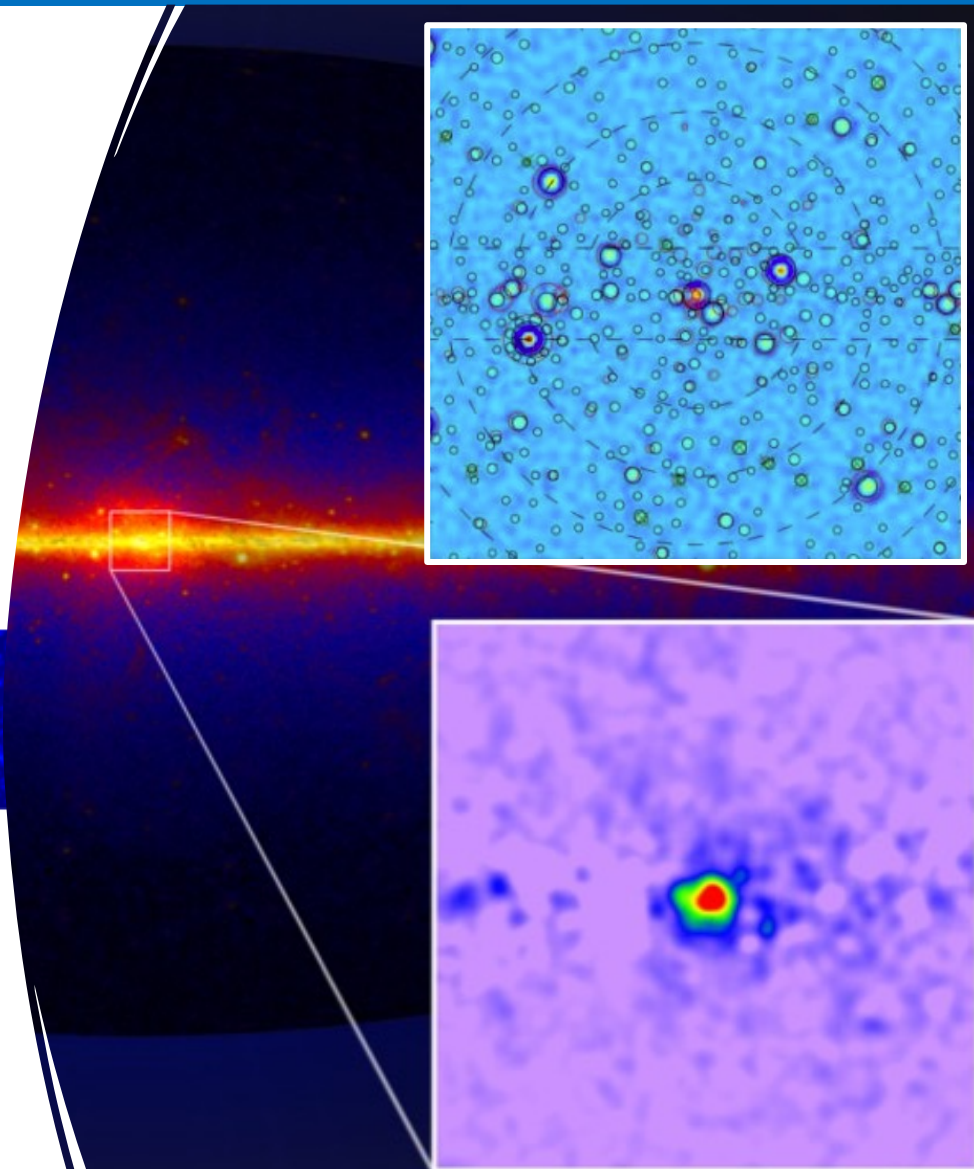
Gamma rays from the Galactic Center

c: Silvia Marconi

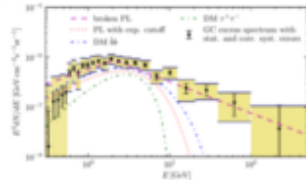
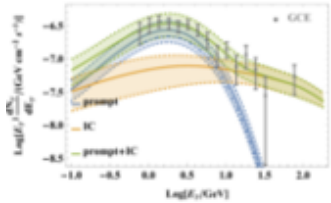
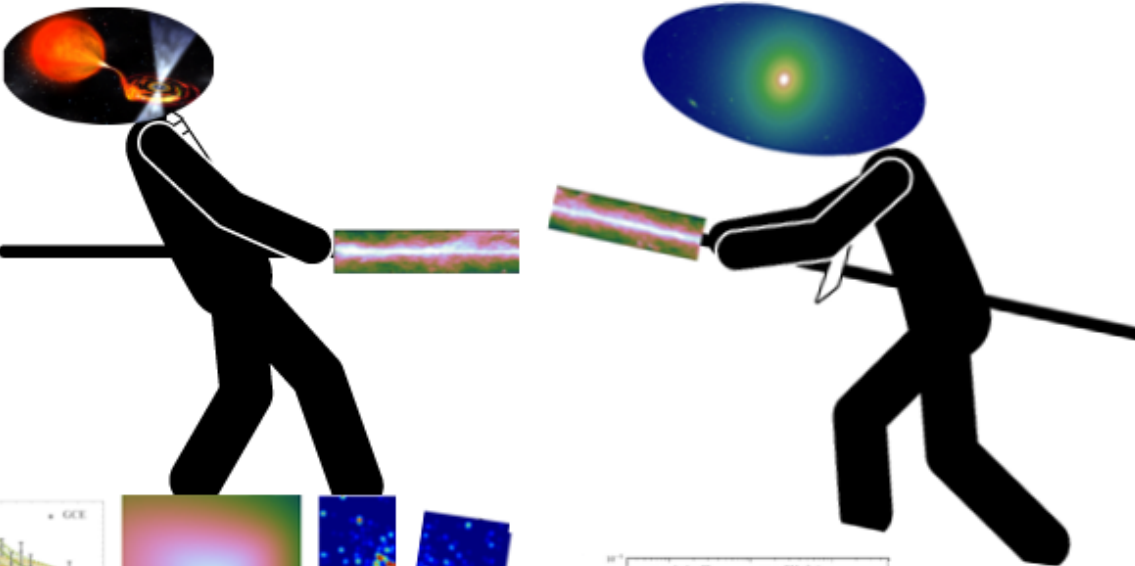


- **Well-established bright excess in gamma rays (peaking at 1--3 GeV) detected in LAT**
- **Morphology: clumpy vs. smooth?**

Hooper, Goodenough (2009, 2010) Hooper, Linden (2011), Abazajian, Kaplinghat (2012) Gordon, Macias (2013) Daylan, et al. (2014), Calore, Cholis, Weniger (2014) Murgia, et al. (2015) Ackermann et al. (2017), Lee+ '15, '16, Bartels+ '16, Buschmann+ '20, Leane & Slatyer '19, Zhong+ '19, Leane & Slatyer '20a,b], most recently List+ 2025...



Gamma rays from the Galactic Center

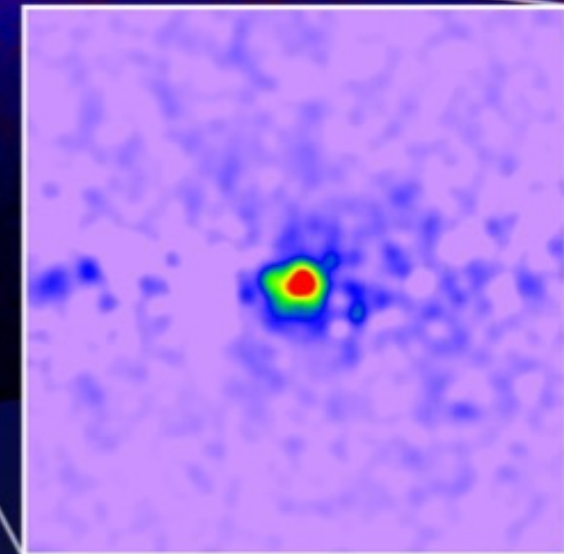
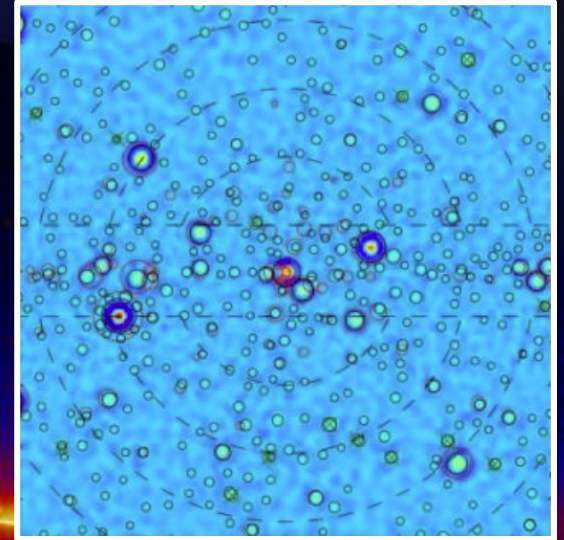


-Did we reach the instrumental limits? What about theoretical models?

Diffuse models are not representative of the data

Confirming pulsars: future detections of radio emission by MeerKat and SKA

Confirming dark matter: check for signals elsewhere (or build a better instrument?)

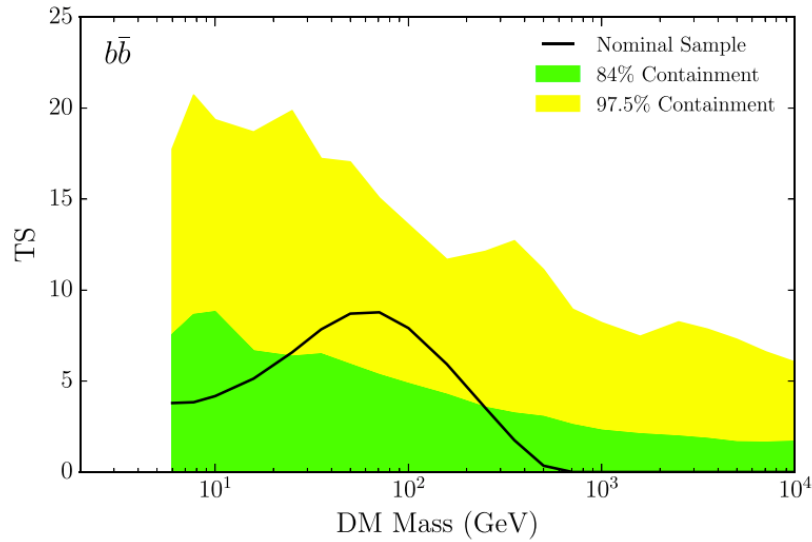




dSphs

Combined dSph Analyses

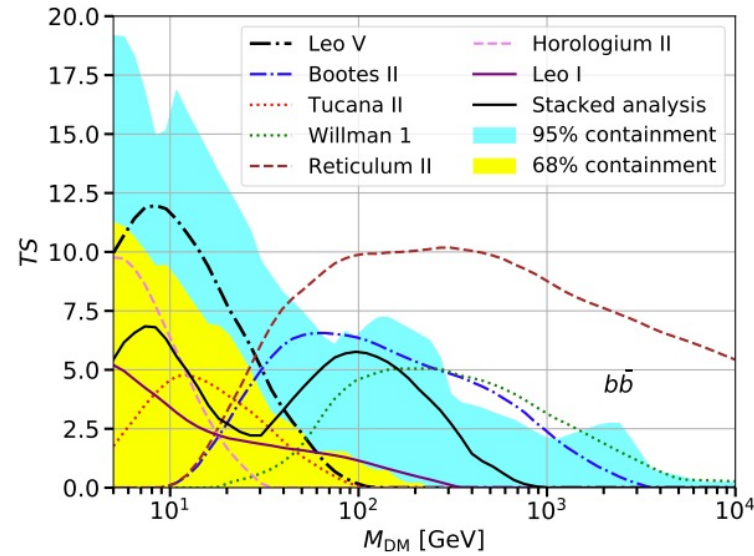
6 years



$< 2\sigma$

[Fermi-LAT Collaboration '17]

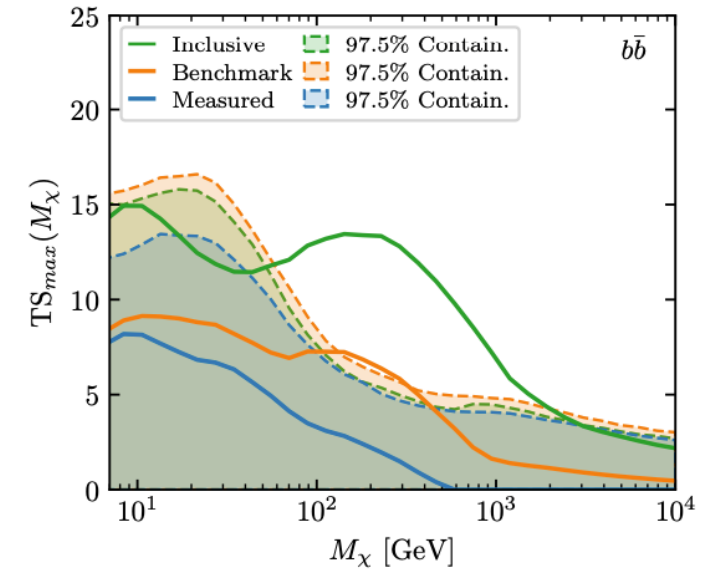
11 years



$\approx 2\sigma$

[Fermi-LAT Collaboration '21]

14 years



$\approx 2\sigma$

[Fermi-LAT Collaboration+ '24]

Shaded regions: blank-field analysis

Think: $\sqrt{TS} \sim \sigma$

Combined dSph Analyses

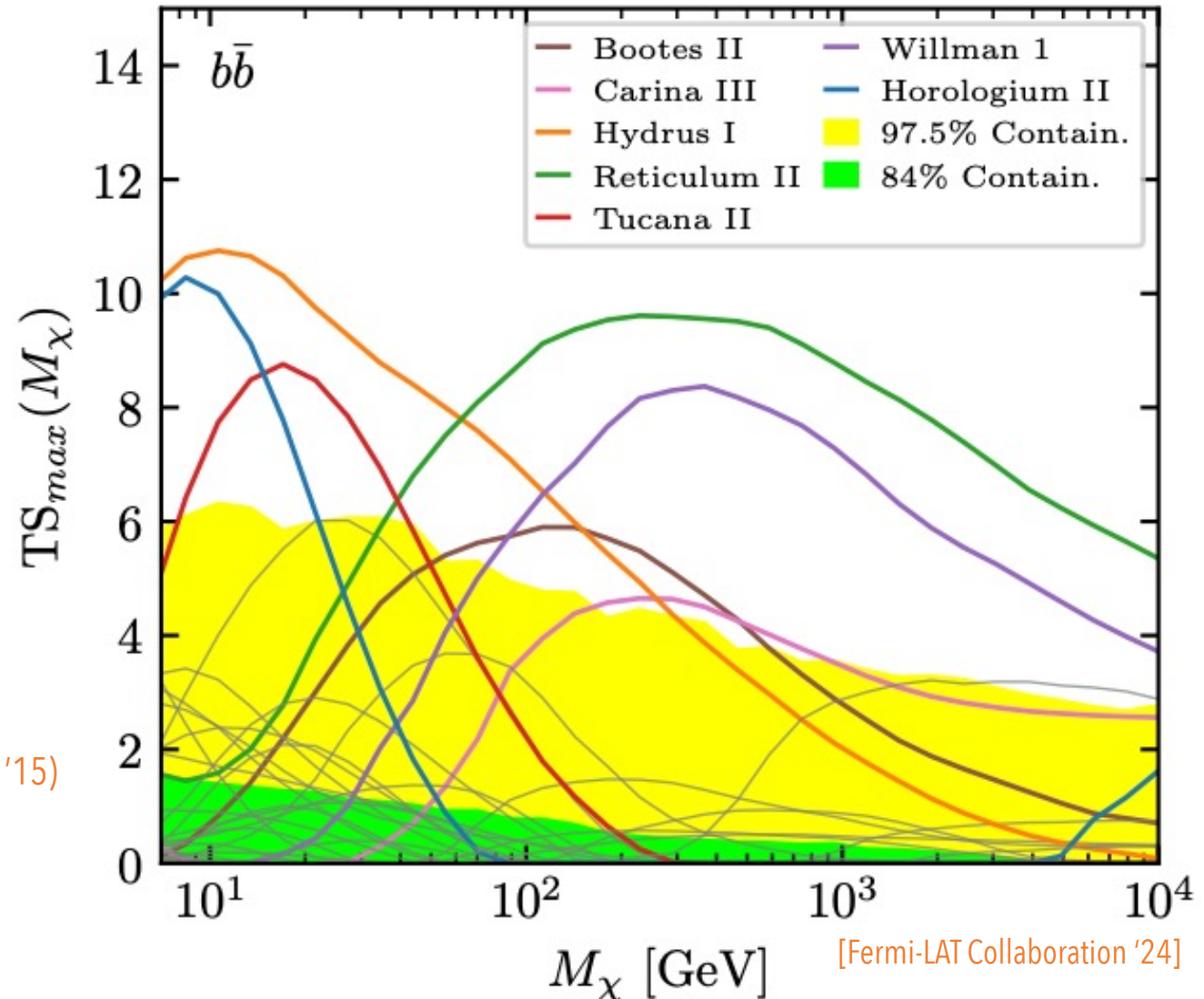
(2024)

→ **7 dSphs with local significance $> 2\sigma$**

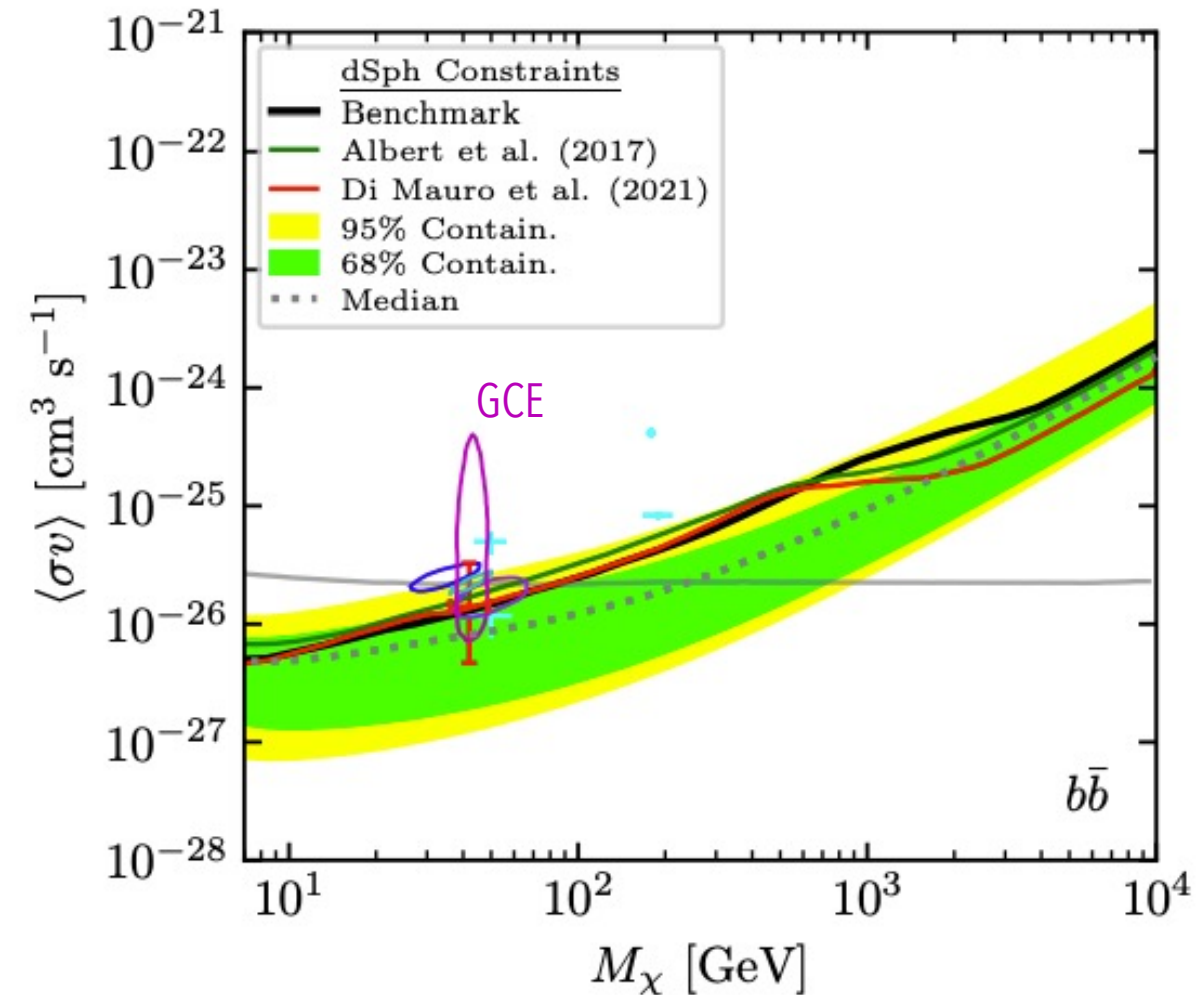
... not the first time: some marginal significance reports in the past.

Ret II (DiMauro+ '21, Albert+ '17, Geringer-Sameth+ '15, Hooper & Linden '15)
Tucana II, Willman 1, Horologium II, Bootes I (DiMauro+ '21)

Think: $\sqrt{TS} \sim \sigma$



Limits on the parameter space



→ Trials factor reduces significance to 0.5σ .

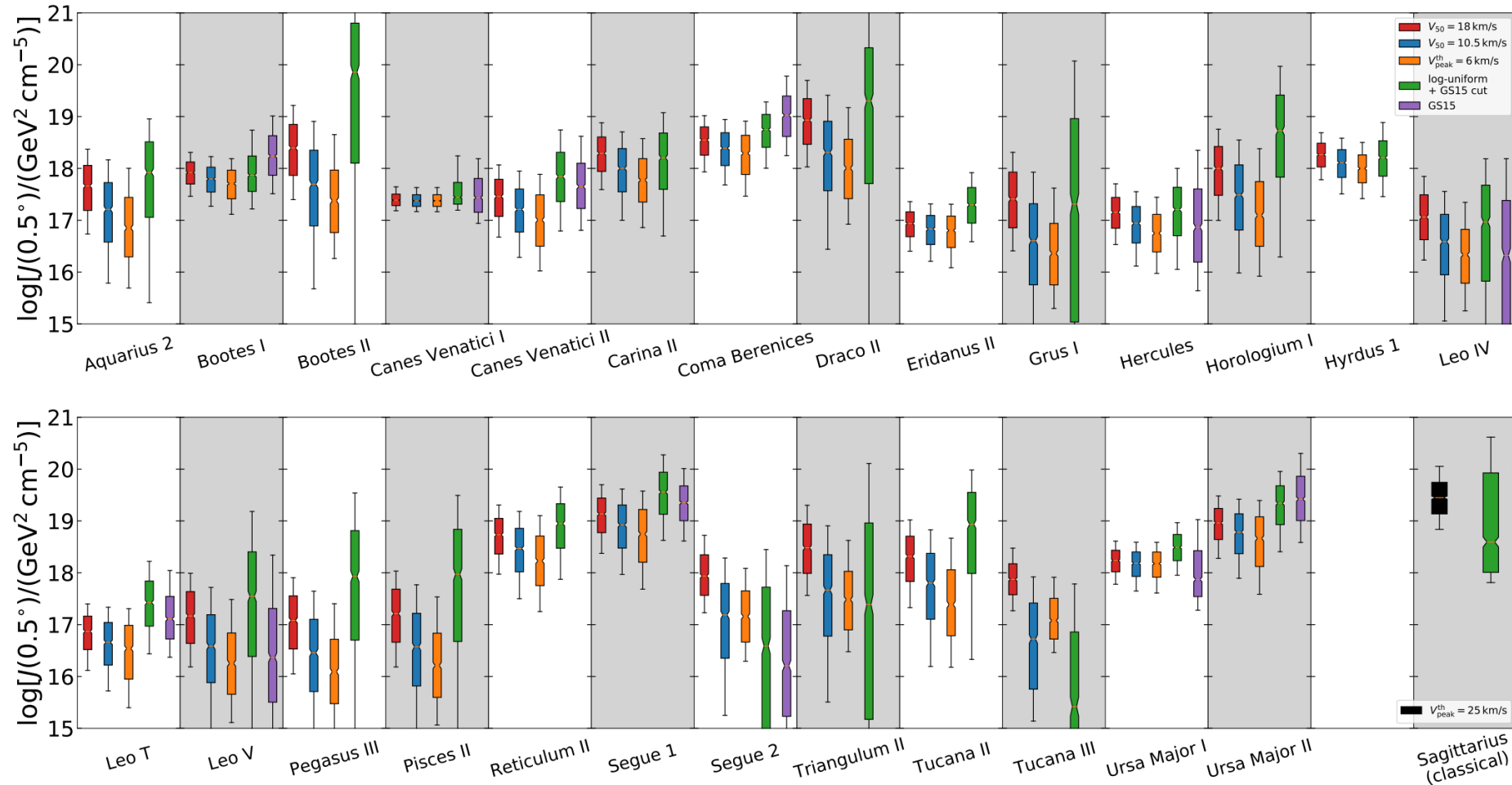
Observations:

→ generally consistent with previous limits; still in *tension* with the GCE results

→ cannot rule out DM due to the uncertainties in galactic center analysis (DM profile and interstellar diffuse model) or uncertainties in J-factor modeling

J-factor uncertainties

Ando+ 2020



Many underlying assumptions: dark matter distribution models, parametric/non-parametric approaches, observational limitations – can result in at least a factor of few difference to the real value. [e.g., [Bonnivard+ '15](#), [Geringer-Sameth+ '15](#), [Hayashi+ '16](#), [Ando+ '20](#), etc.]

How many dwarf galaxies do we *really* need?

How many dwarf galaxies do we *really* need?

Maybe just one, but a good one?

Ursa Major III

[Discovery: Smith+ 2023]

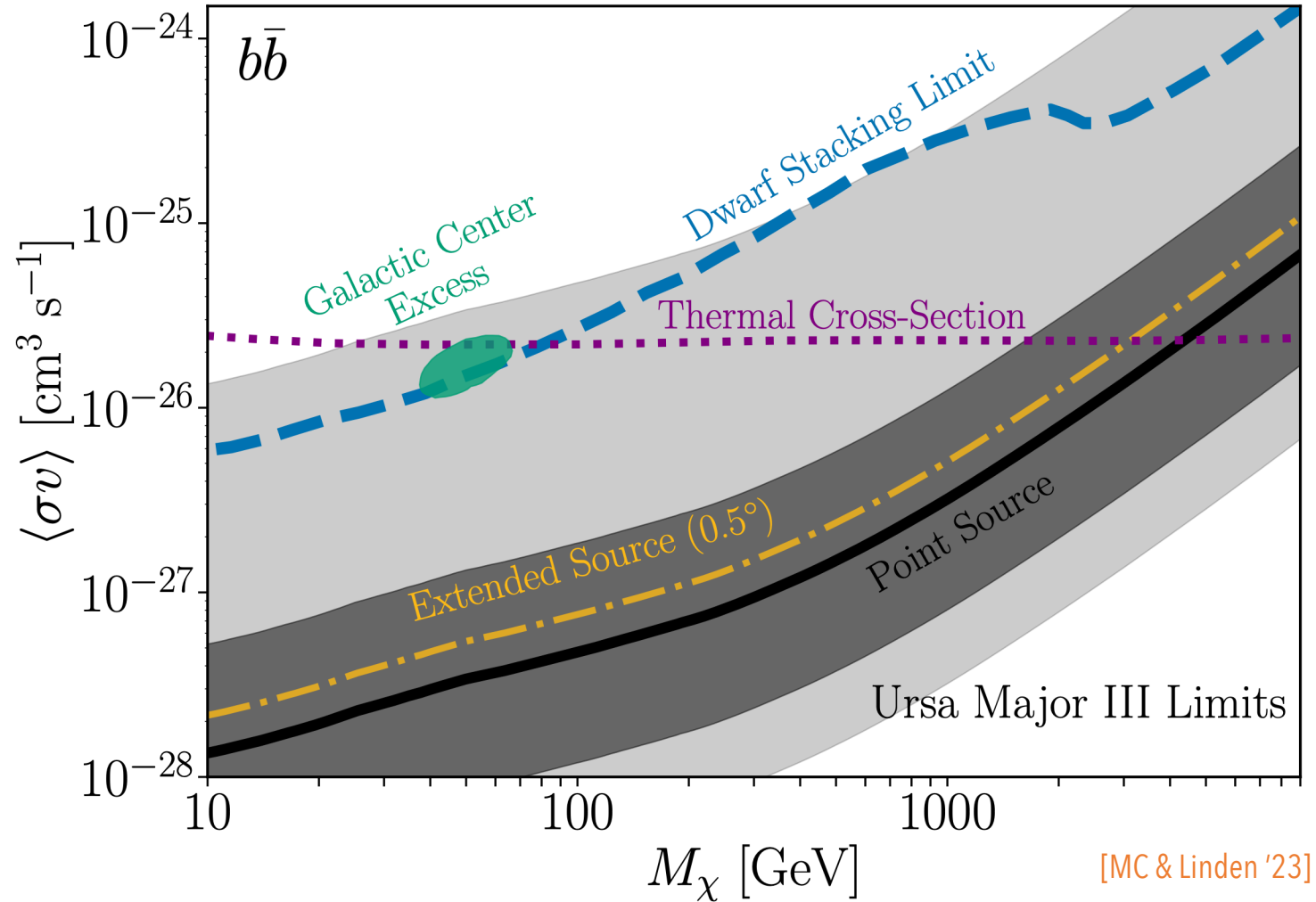
[J-factor: Errani+ 2023]

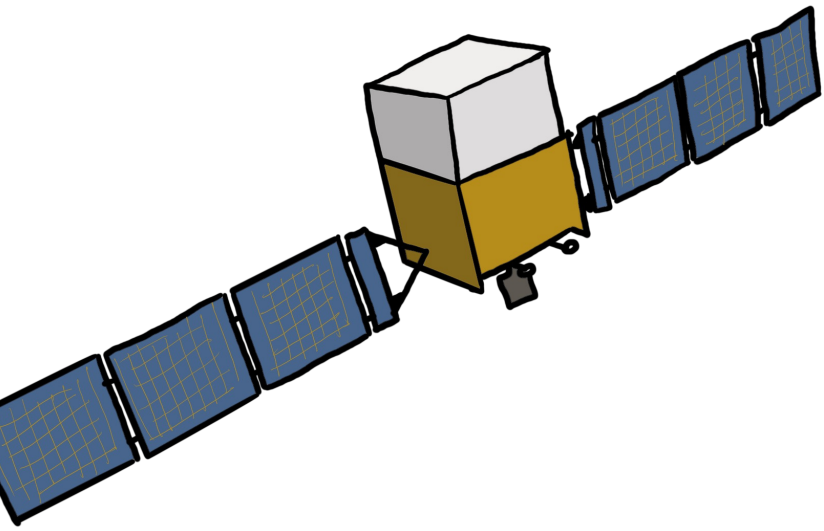
→ Unstable unless large DM content

→ Nearby (~ 10 kpc)

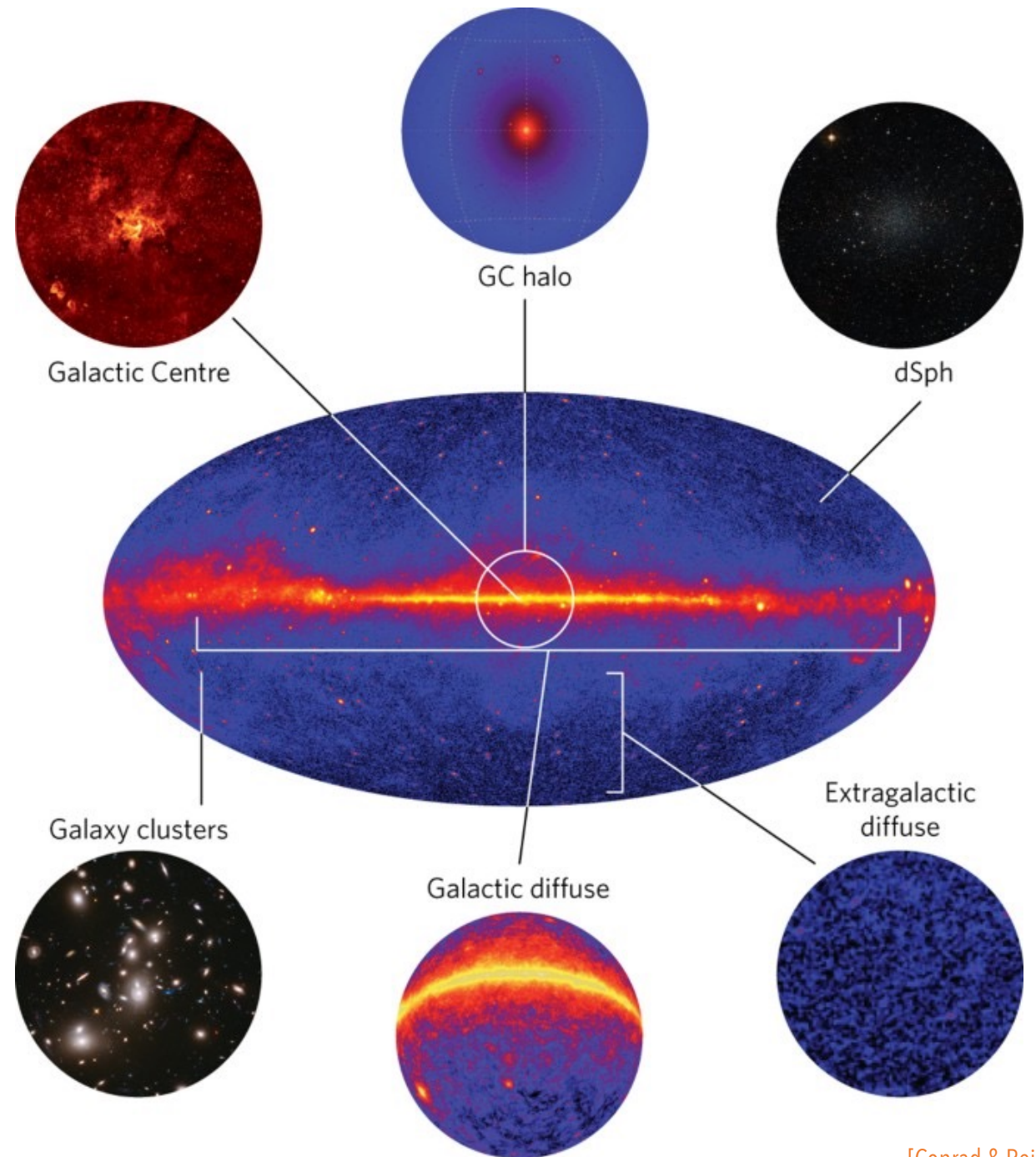
→ Strong constraints on DM annihilation

→ *Confirming the dark matter density requires deeper optical surveys*





DM targets



Also: Solar System (Sun, Jupiter), brown dwarfs, exoplanets, etc.
Nguyen+ 25, 26, Leane+ 23, Blanco+ 24, 25, etc.



TARGET

CURRENT STATUS

FUTURE

Galactic Center

Bright GeV excess; disputed

Diffuse re-modelling; sub-threshold source ID

Dwarf spheroidals

Thermal $\langle\sigma v\rangle$ excluded below 100 GeV

LSST/Rubin: hundreds of new dSphs/a few good ones/JLA

Galaxy clusters

Strong limits (high-latitude halo, groups)

J-factor + CR systematics

DM subhaloes

Candidates in LAT unassociated sources

ML identification + Gaia follow-up

Galactic halo

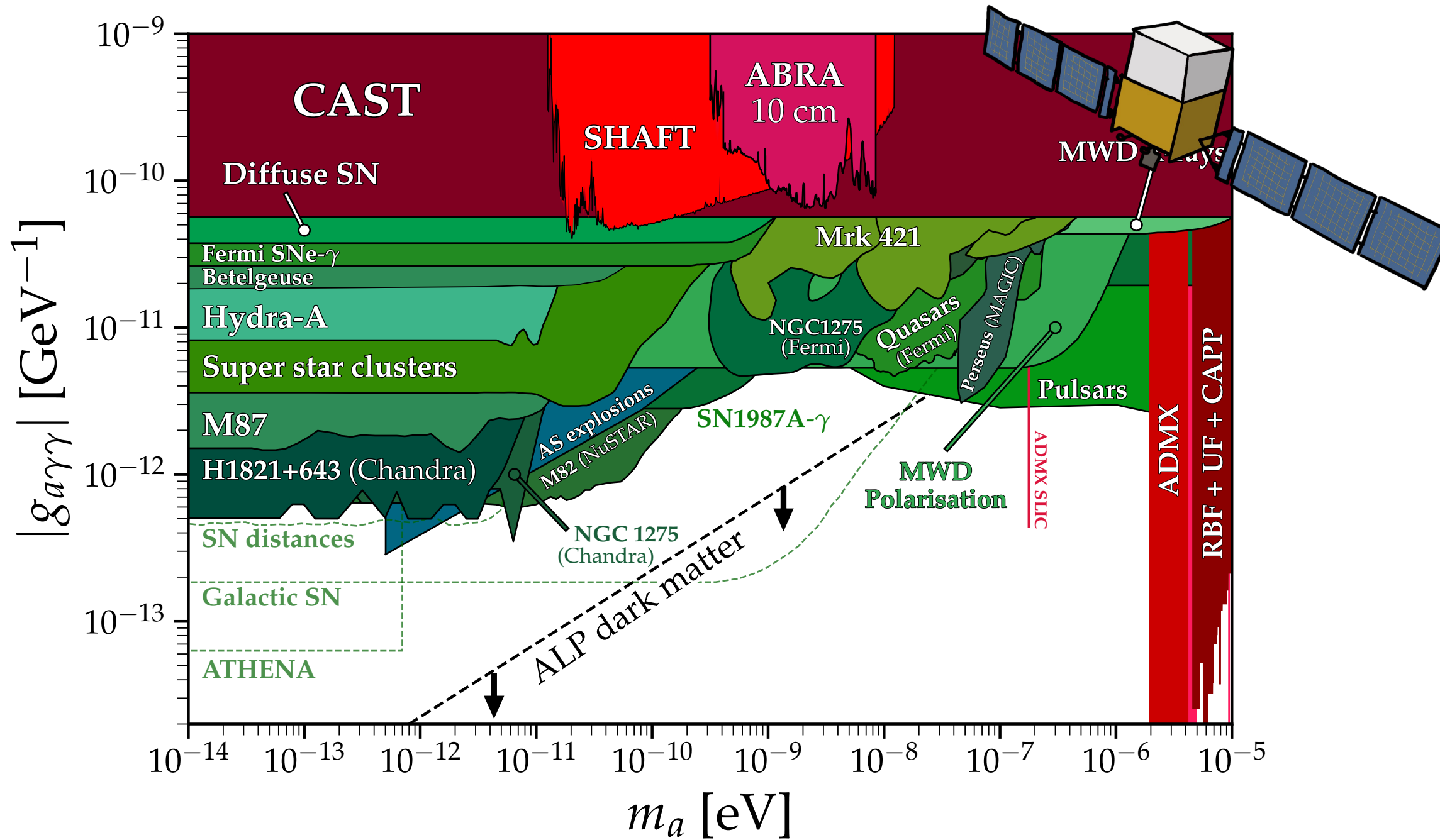
Most constraining at $E > 1$ TeV (HESS)

CTAO improves HESS by up to $\times 10$

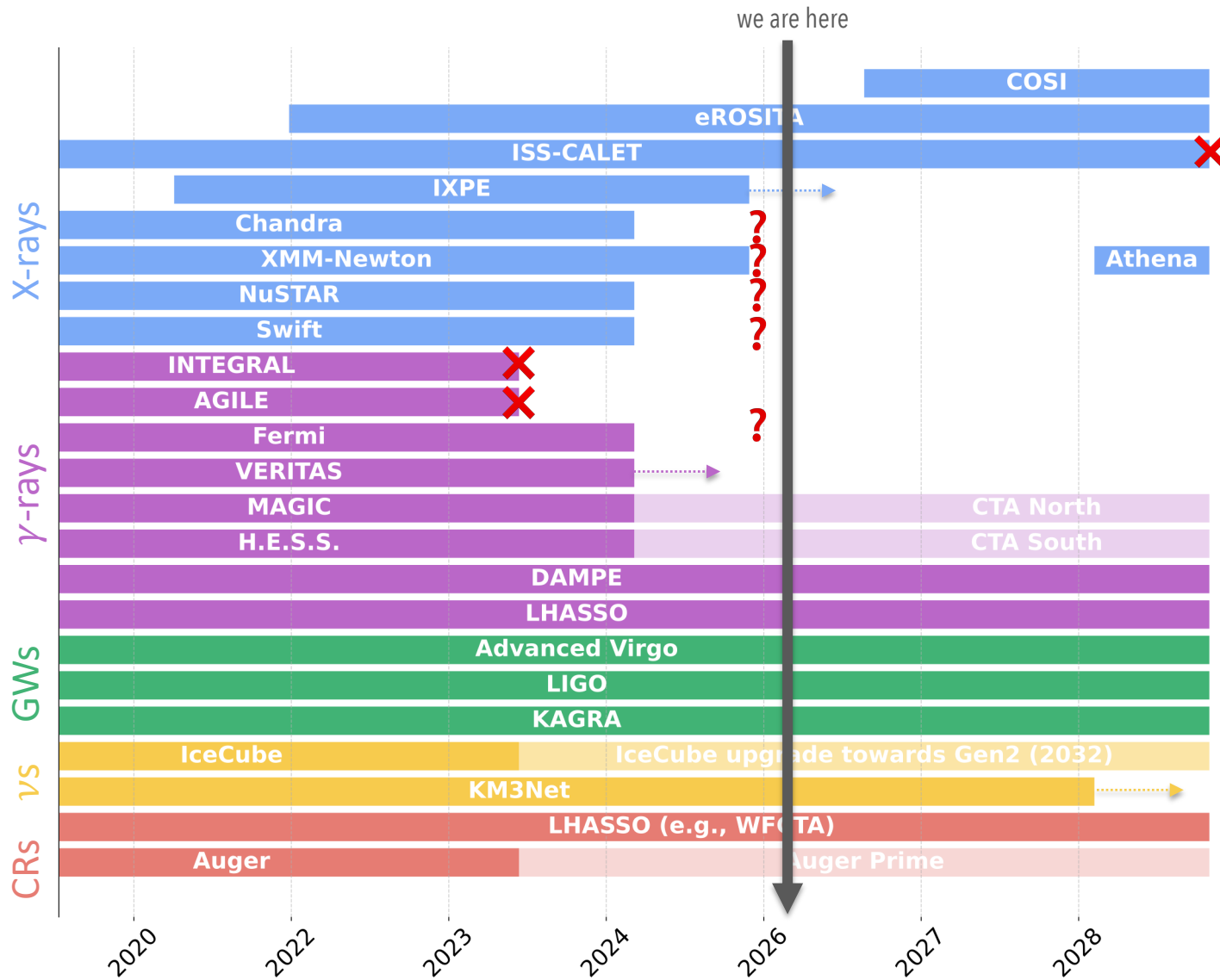
MeV / sub-GeV sky

Largely unexplored

AMEGO-X, e-ASTROGAM, VLAST

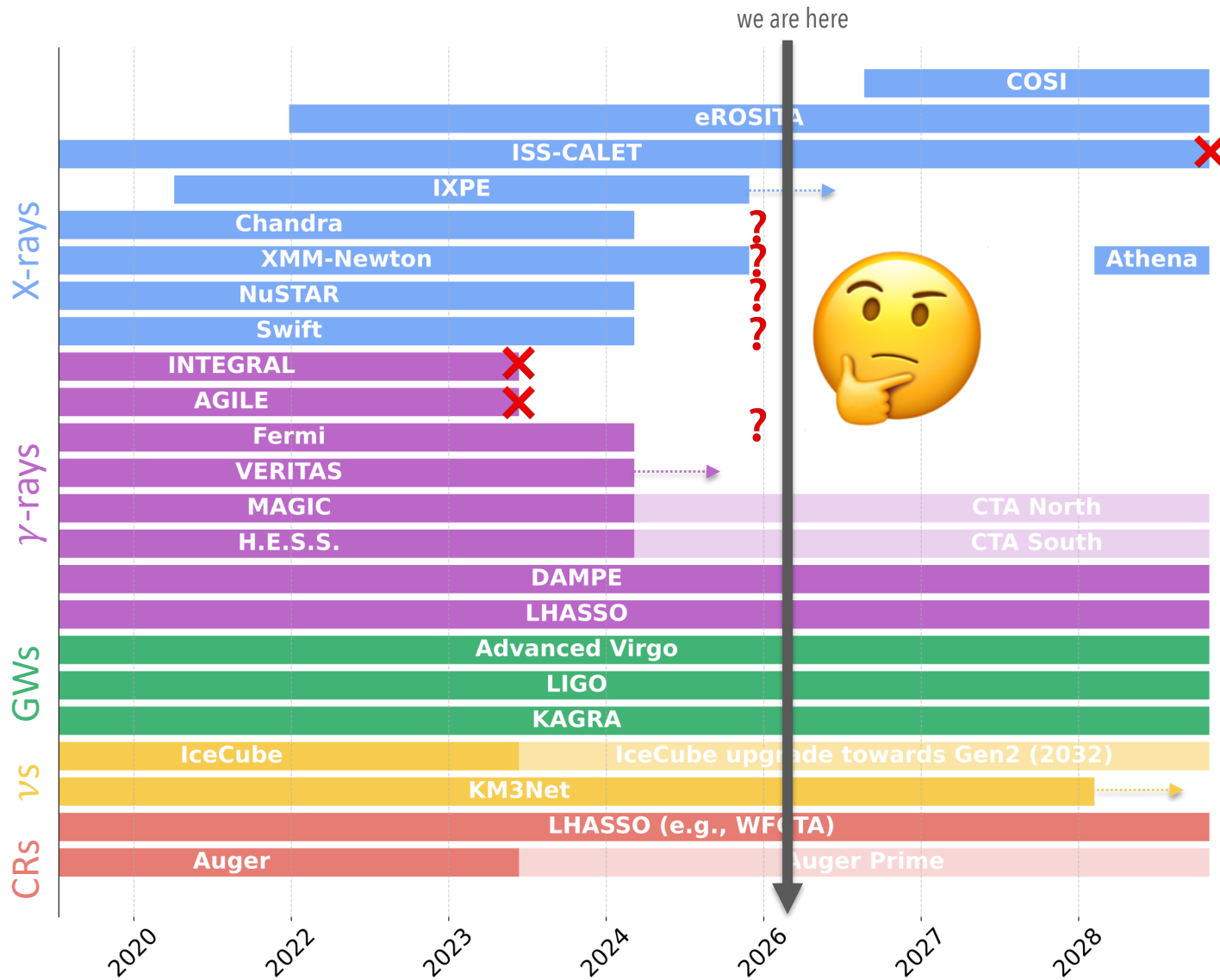


Dark Matter Landscape: An Instrumentationalist's View



e-ASTROGAM
 AMEGO
 AMEGO-X
 ...
 VLAST?

Dark Matter Landscape: An Instrumentationalist's View



e-ASTROGAM
 AMEGO
 AMEGO-X
 ...
 VLAST?



Future Innovations in Gamma rays

Science Analysis Group

... to explore gamma-ray science priorities, necessary capabilities, new technologies, and theory/modeling needs drawing on the 2020 Decadal **to inspire work toward 2040.**

