Gamma rays from the littlest galaxies

Tracing Accretion and Dark Matter in the Low-Mass Universe

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ECAP Seminar
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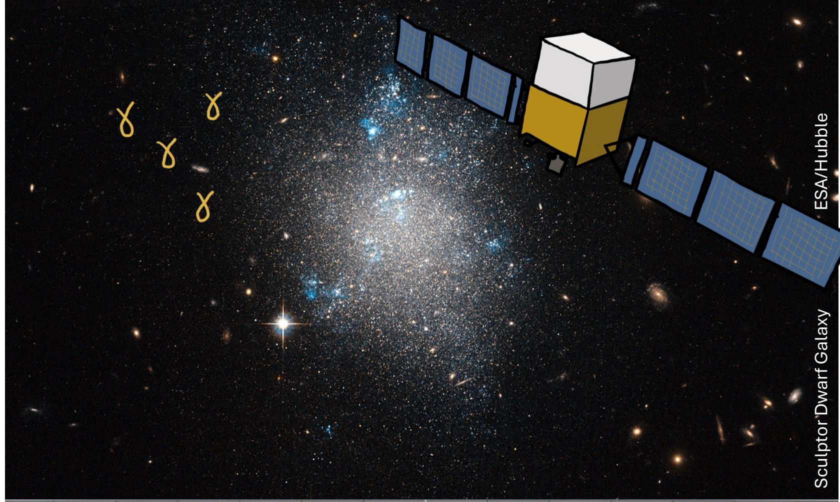
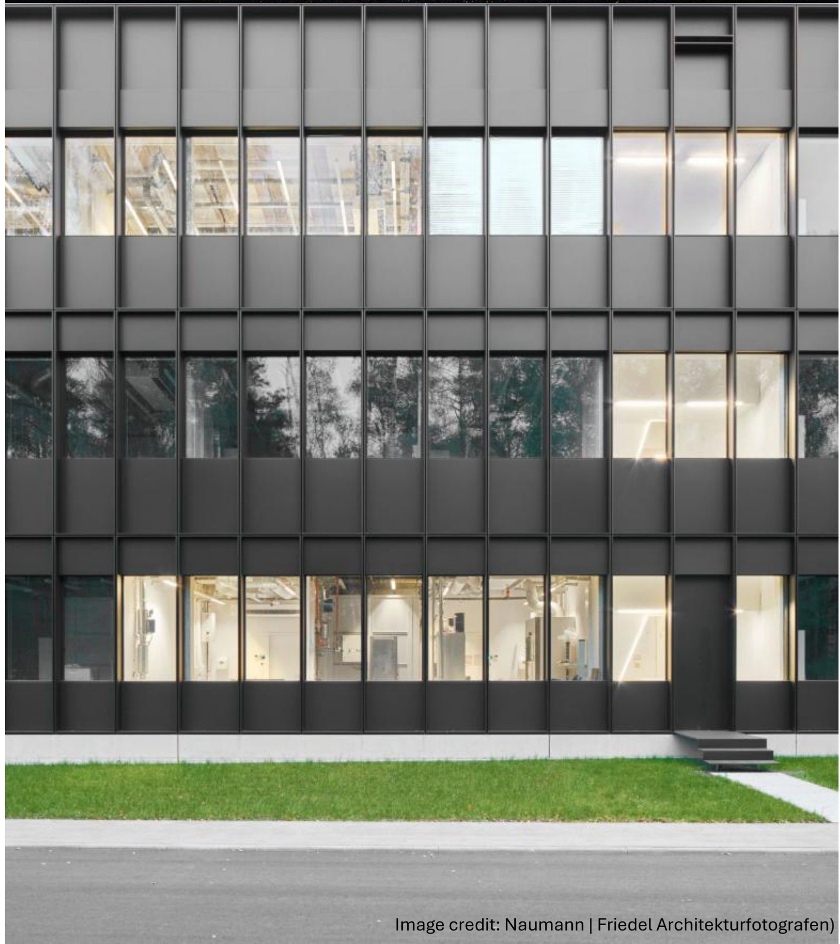




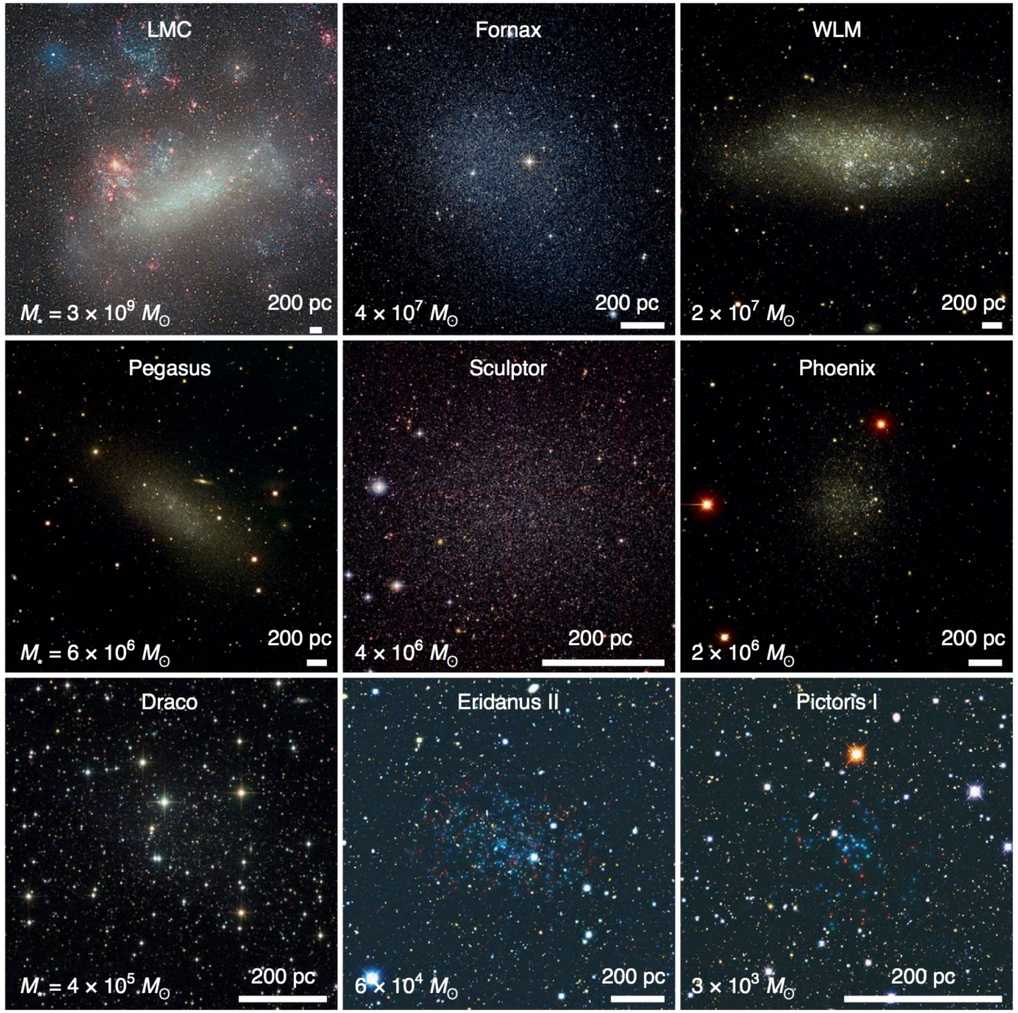
Dwarf galaxies

→ Low-mass galaxies:

tens of $M_{sun} < M_{stellar} < 3 \times 10^9\, M_{sun}$

→ At the forefront of current/future observational efforts:

- Near-field cosmology (*Gaia*, DES, Rubin/LSST)
- Early Universe & Reionization (JWST)
- Accretion & Feedback (Athena, AXIS, SKA, ngVLA)
- Fundamental physics & dark matter (*Fermi*, IACTs, IceCube)



[Bullock & Boylan-Kolchin 2017]

Representative sample of the Local Group dwarf galaxies.

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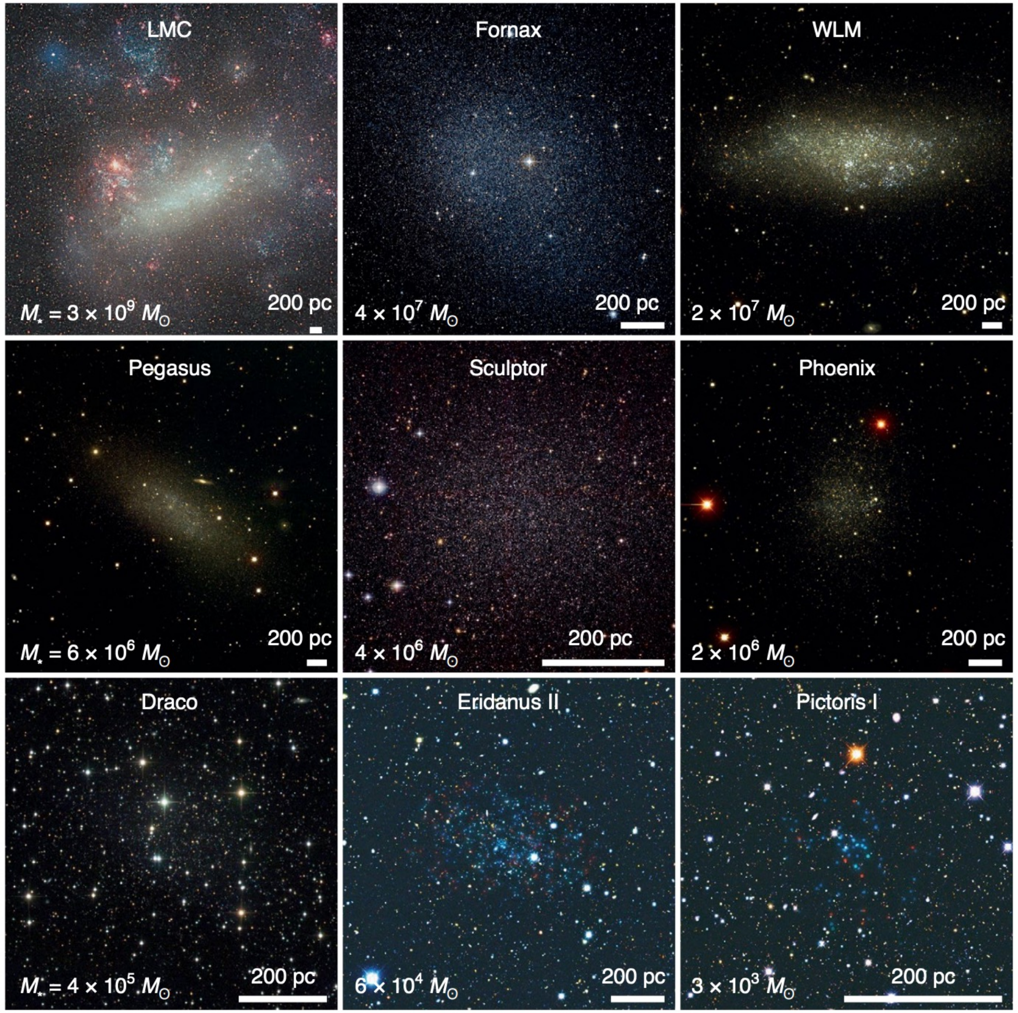
Dwarf galaxies: bridges between **large scale structure**, **galaxy formation**, & **fundamental physics**.



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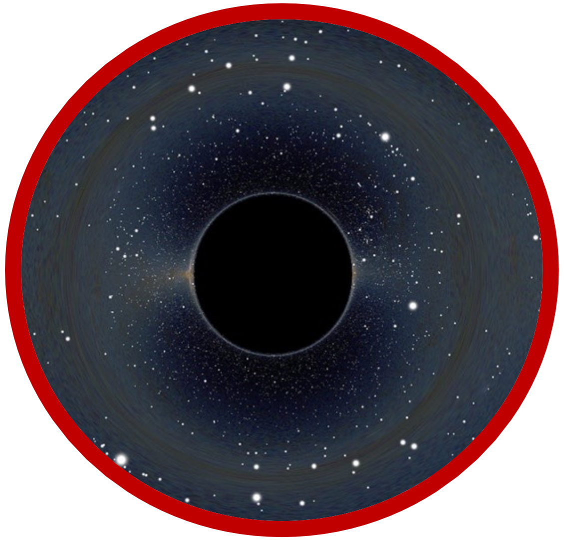
Dwarf galaxies, big questions



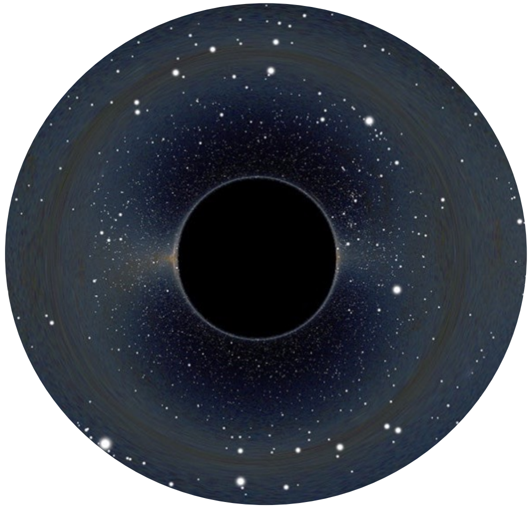
How did the first black holes form?

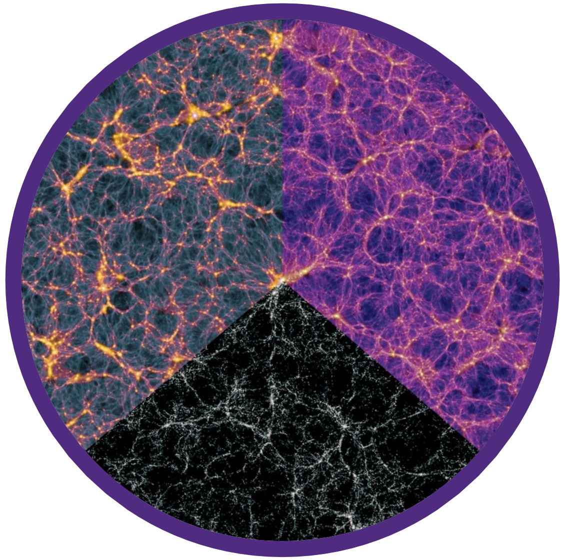
✓ *preserve signatures of seed formation*

✓ *test lower limits of BH-galaxy scaling relations*

✓ *probe accretion physics in low-mass regime*

Dwarf galaxies, big questions





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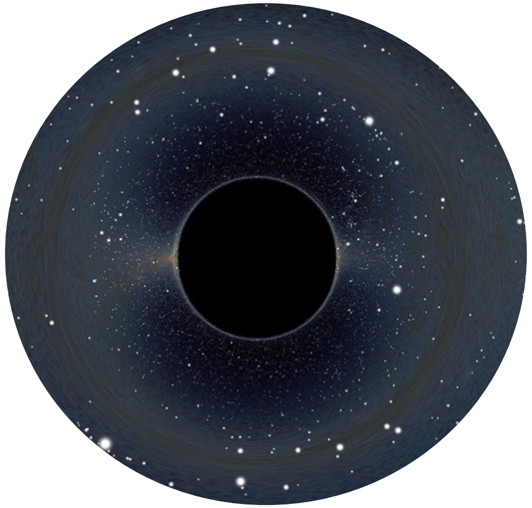
✓ *high dark matter densities*

✓ *min. baryonic contamination in some types*

✓ *test λCDM predictions at smallest scales*

Dwarf galaxies, big questions



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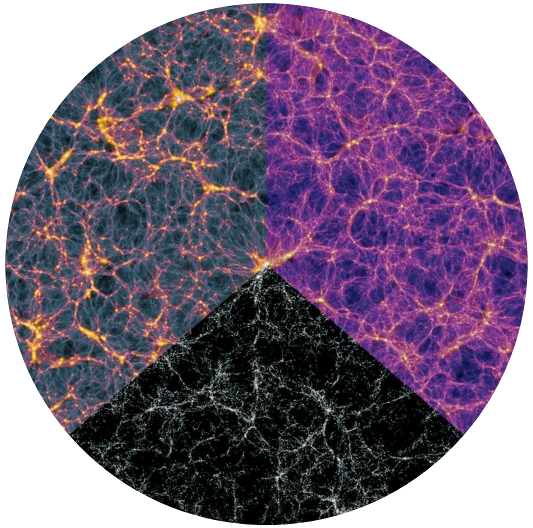


What is the nature of dark matter?

✓ high dark matter densities

✓ min. baryonic contamination in some types

✓ test λCDM predictions at smallest scales

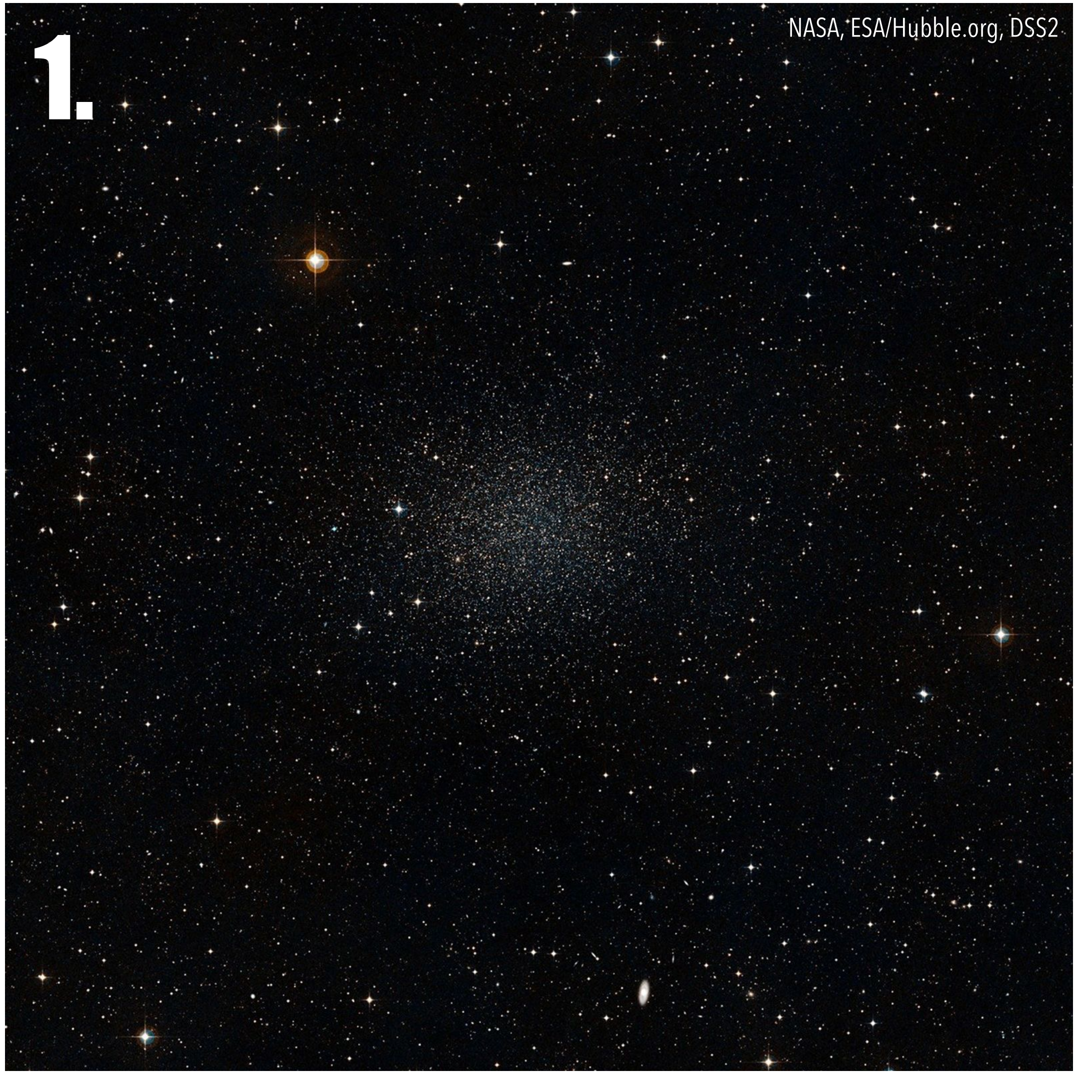
How do galaxies evolve?

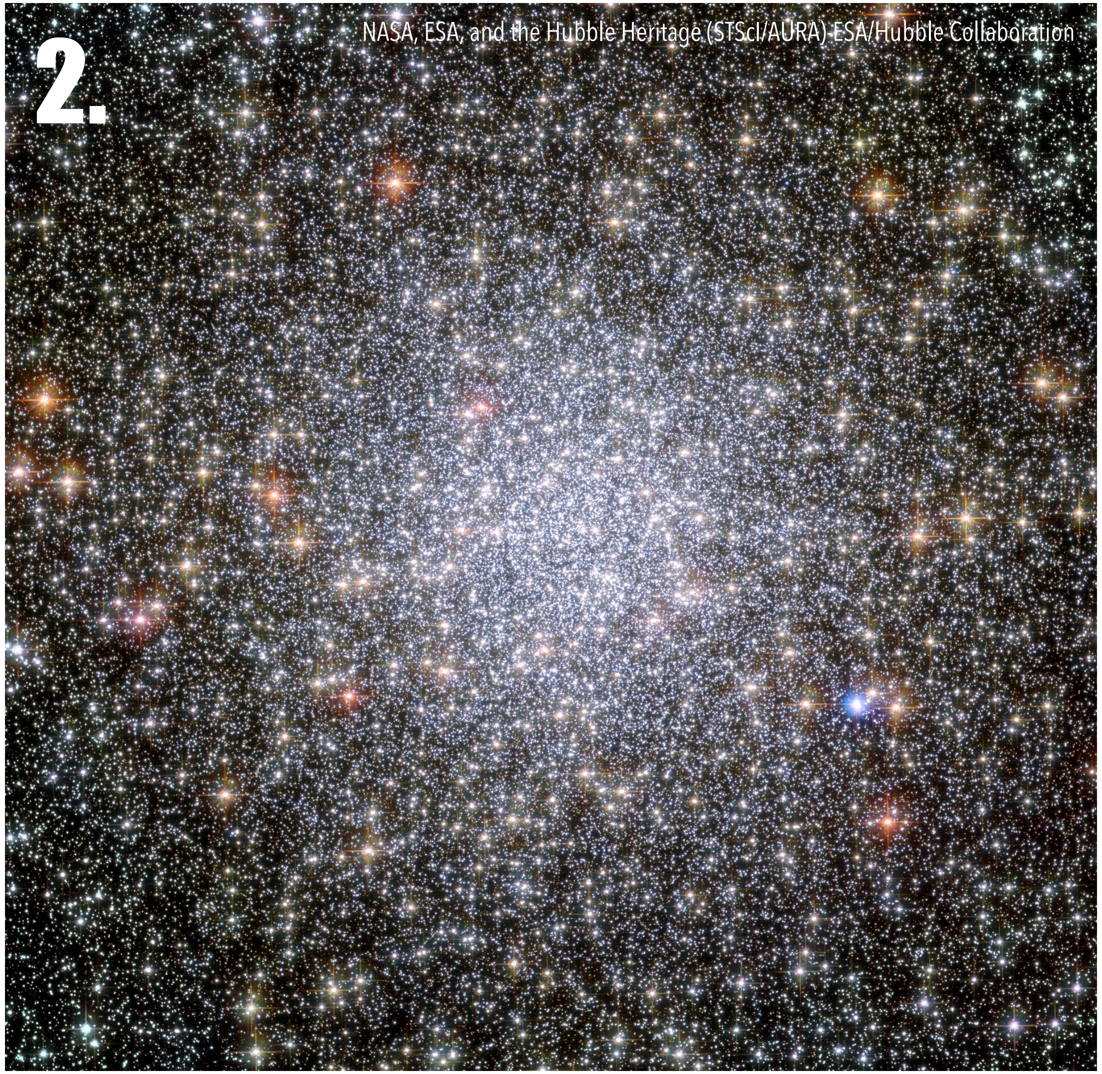
✓ stress-test feedback models in shallow potentials

✓ preserve imprints of reionization and early enrichment

✓ challenge numerical simulations at resolution limits

Dwarf or not?

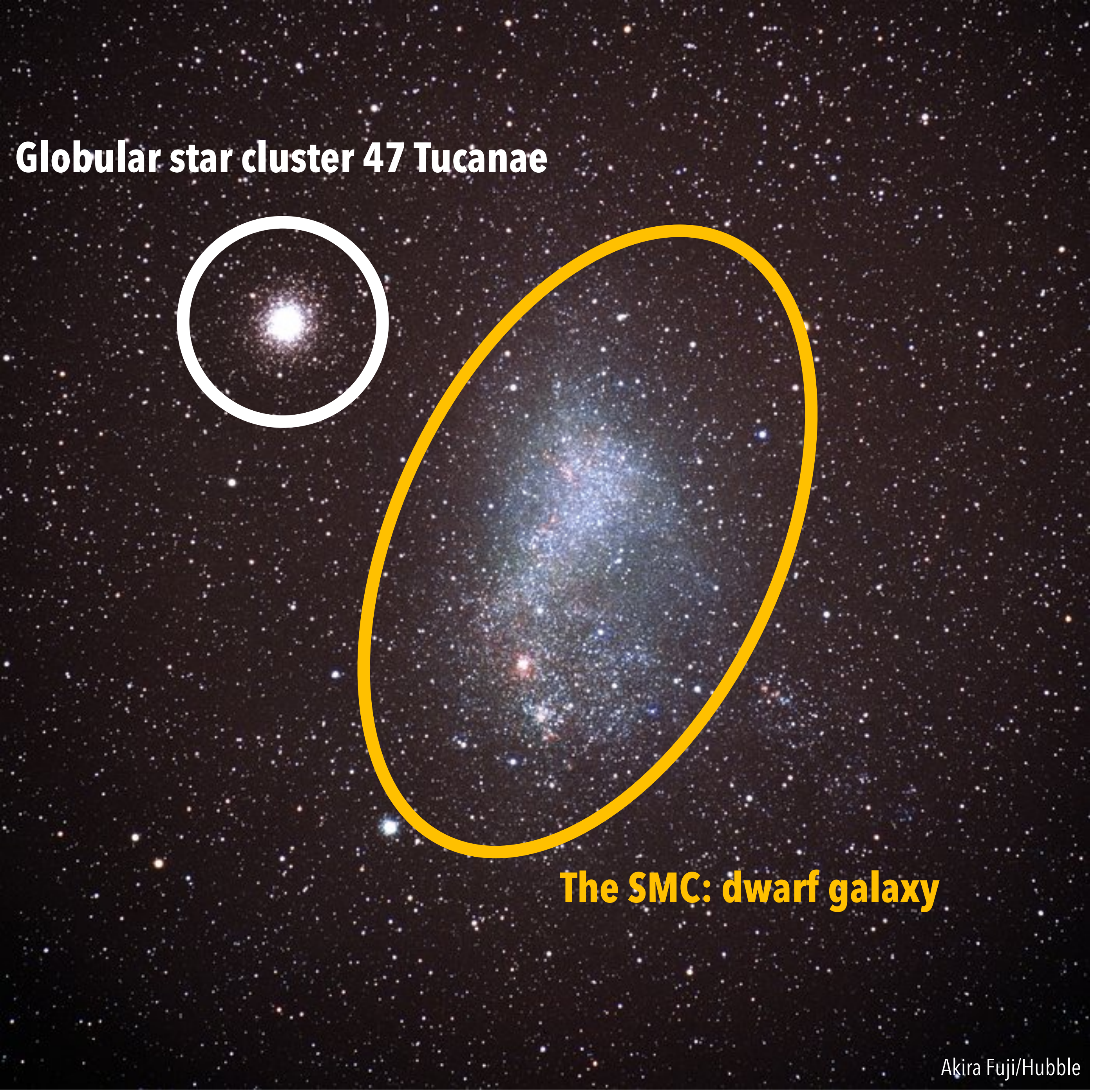

NASA, ESA/Hubble.org, DSS2
1.


NASA, ESA, and the Hubble Heritage (STScI/AURA)-ESA/Hubble Collaboration
2.

Dwarf or not?

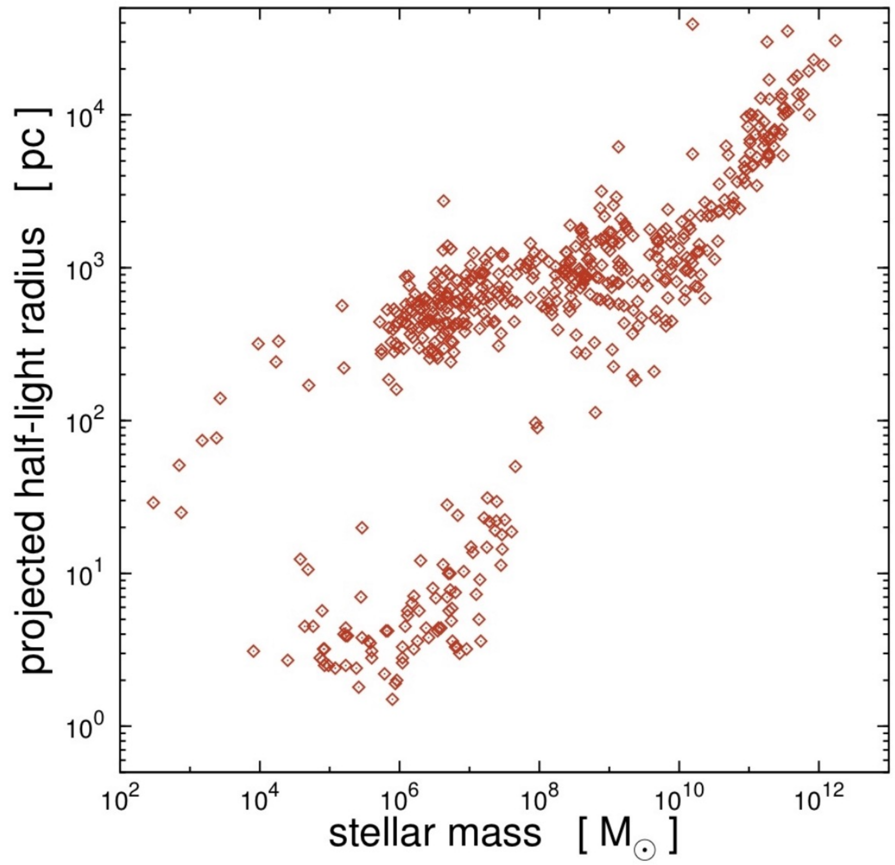

NASA, ESA/Hubble.org, DSS2
1.
Sculptor Dwarf Galaxy


NASA, ESA, and the Hubble Heritage (STScI/AURA)-ESA/Hubble Collaboration
2.
Globular cluster 47 Tucanae

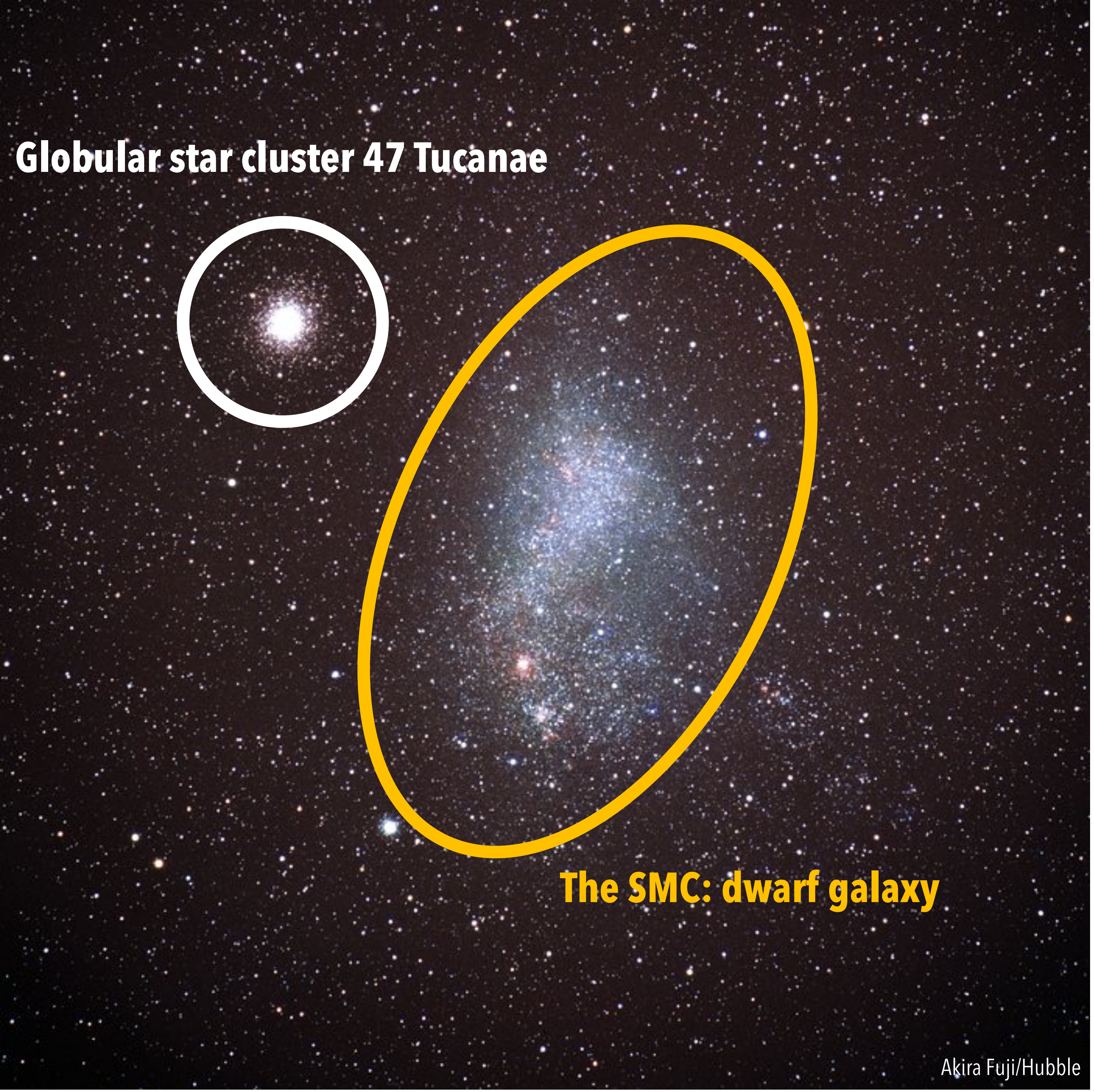


Classification of dwarfs... is complicated.

Historically: morphology



[Gilmore+ 2007, Willman & Strader 2012, McConnachie 2012, Lelli et al. 2016, Simon 2019]



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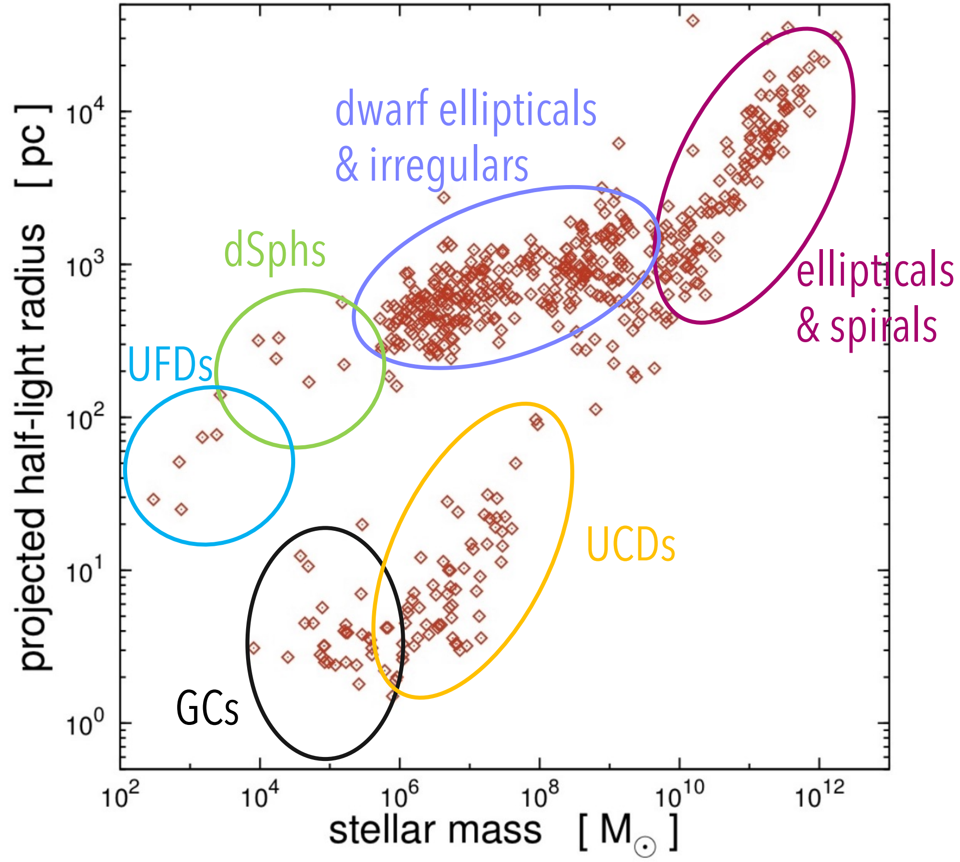

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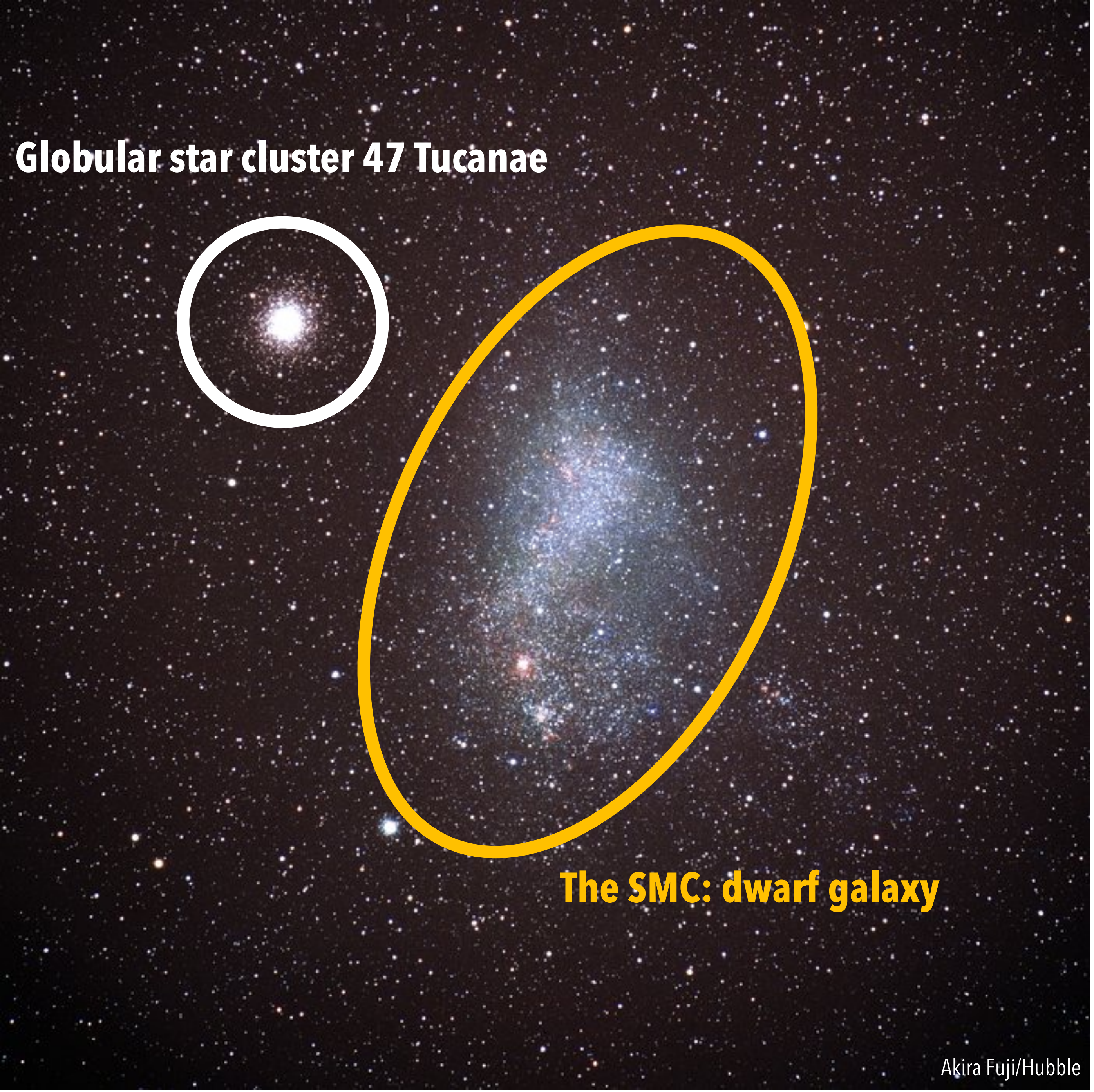

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Historically: morphology

Now:

→ dynamical M/L ratio (indicating DM content)

→ half-light radius

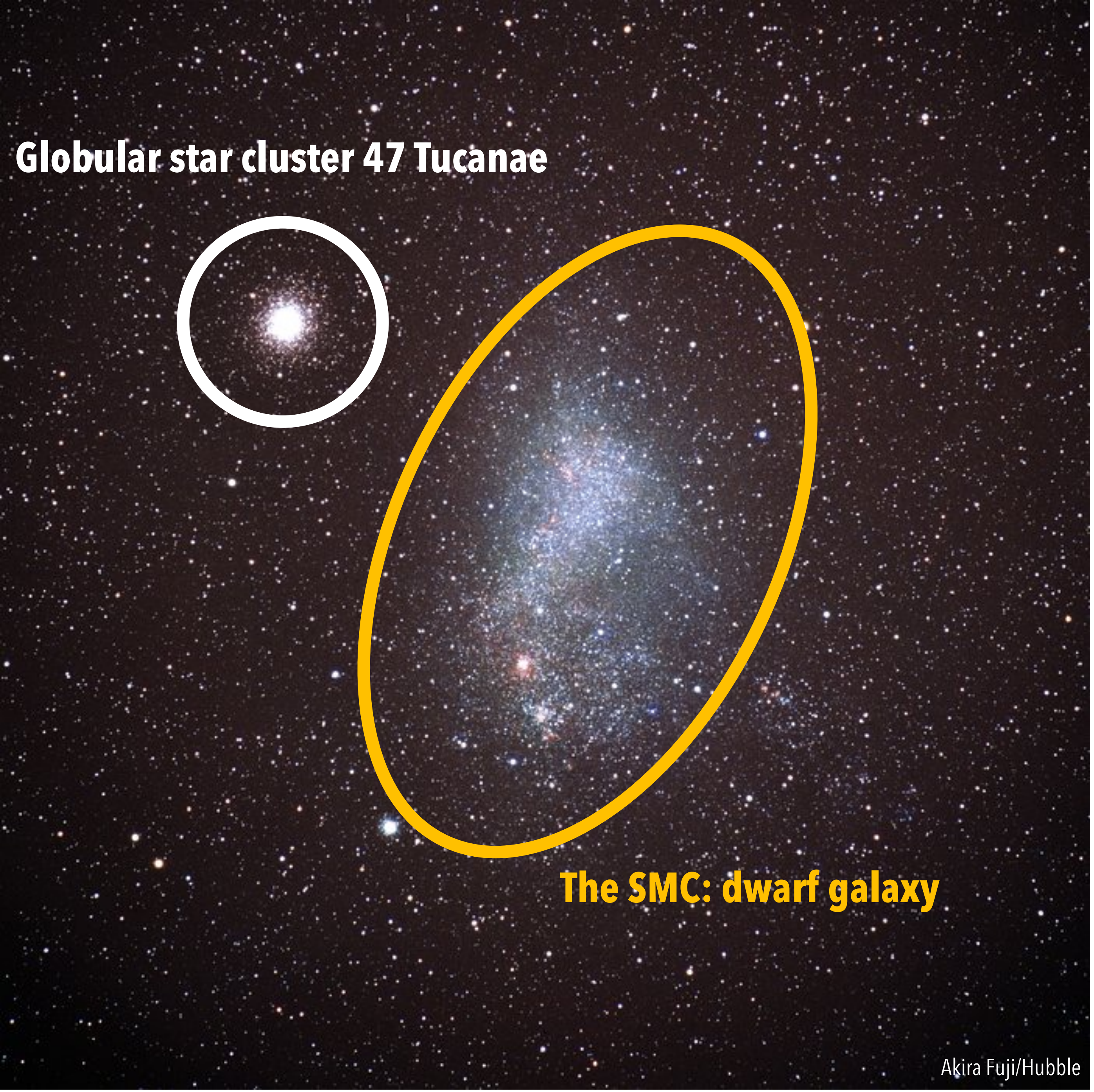
→ velocity dispersion measurements

→ stellar populations (age, metallicity)

→ relaxation time

→ tidal dwarfs + faint halo systems especially difficult

[Gilmore+ 2007, Willman & Strader 2012, McConnachie 2012, Lelli et al. 2016, Simon 2019]



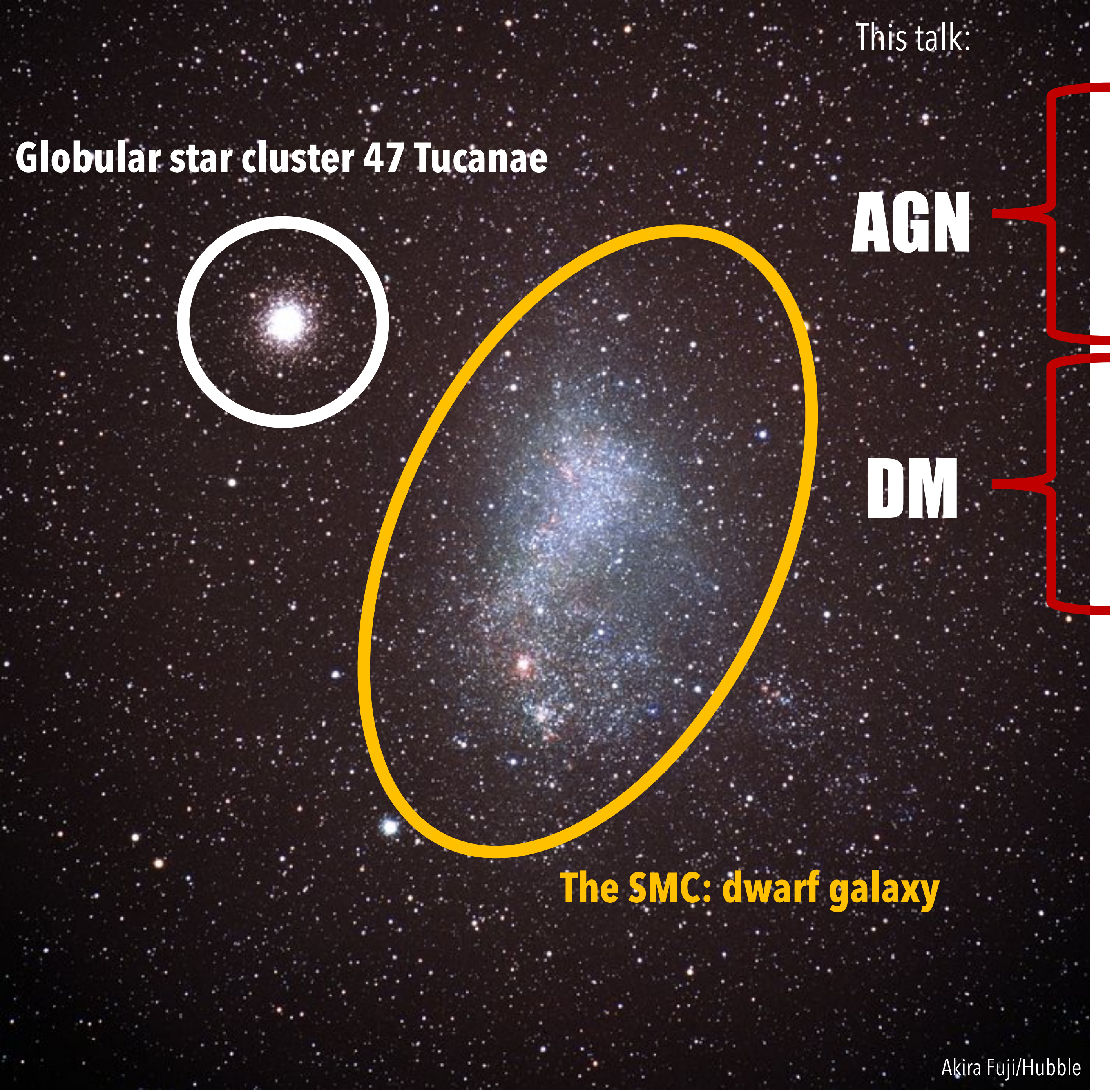
Dwarf elliptical galaxies (dEs)

Dwarf irregular galaxies (dIrrs)

Dwarf spheroidal galaxies (dSphs)

Ultrafaint dwarf galaxies (UFDs)

Ultracompact dwarf galaxies (UCDs)



e.g. Reines et al. 2013, Baldassare et al. 2015, 2023

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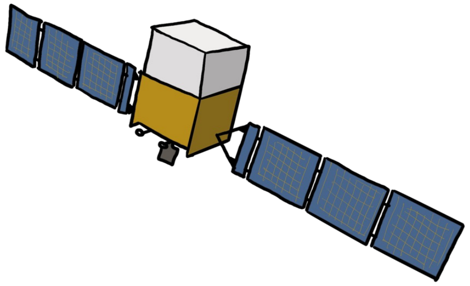
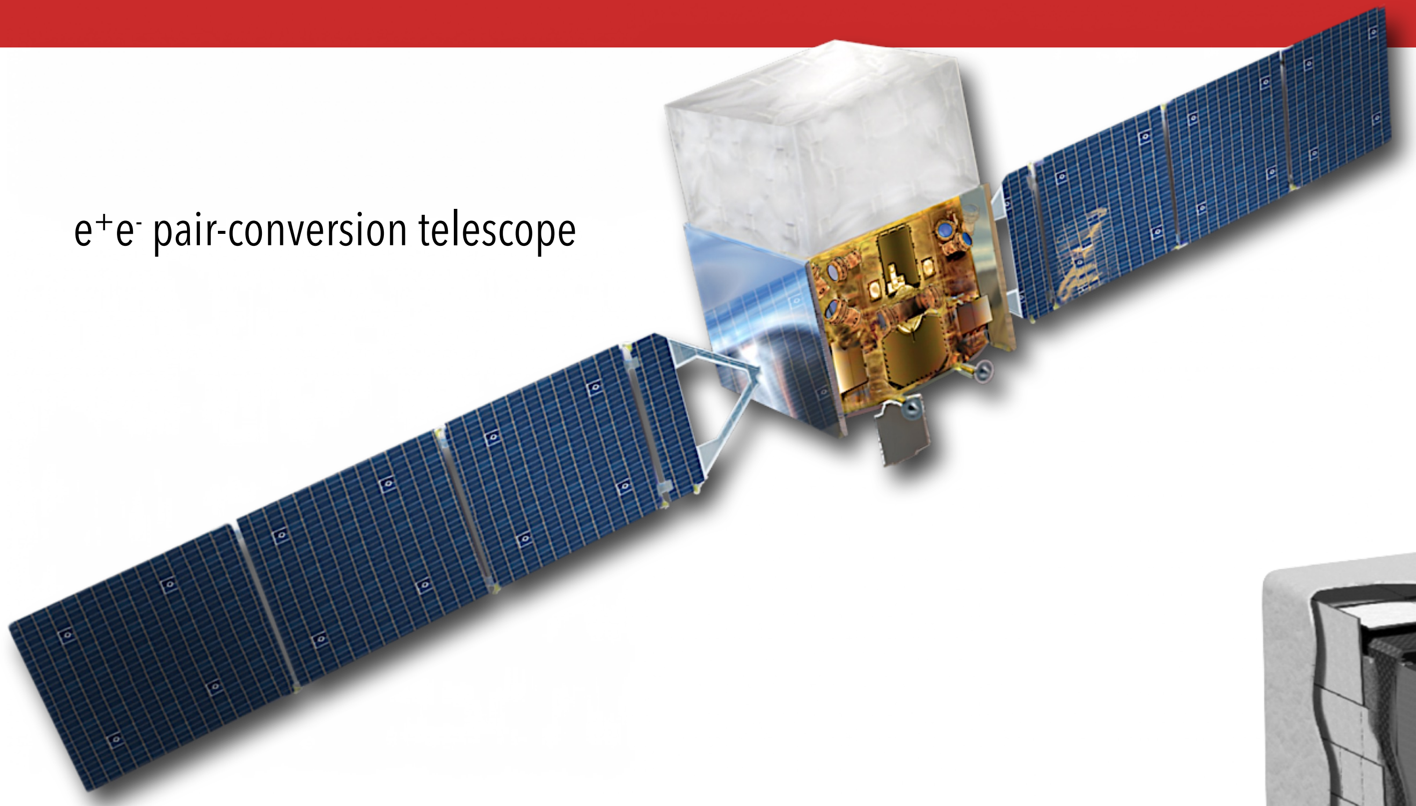


Obligatory slide on Fermi Large Area Telescope

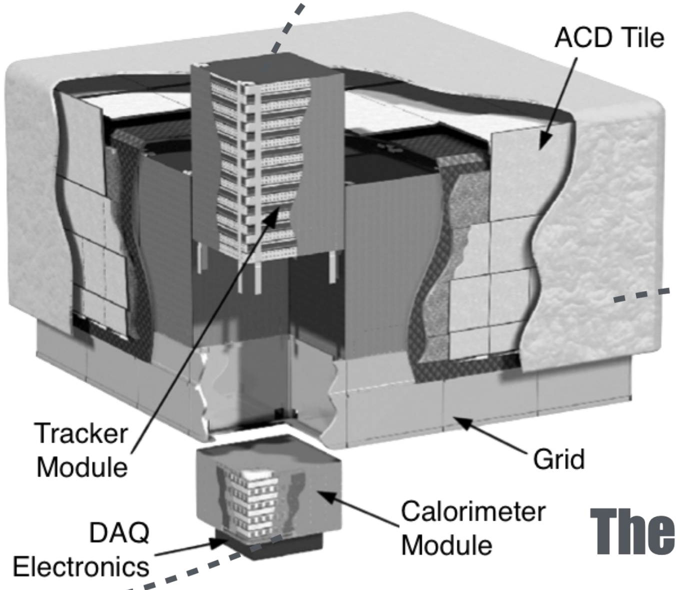


e^+e^- pair-conversion telescope

individual γ rays convert into e^+e^- pairs
→ tracks (localization) & deposited energy

…it also detects electrons.

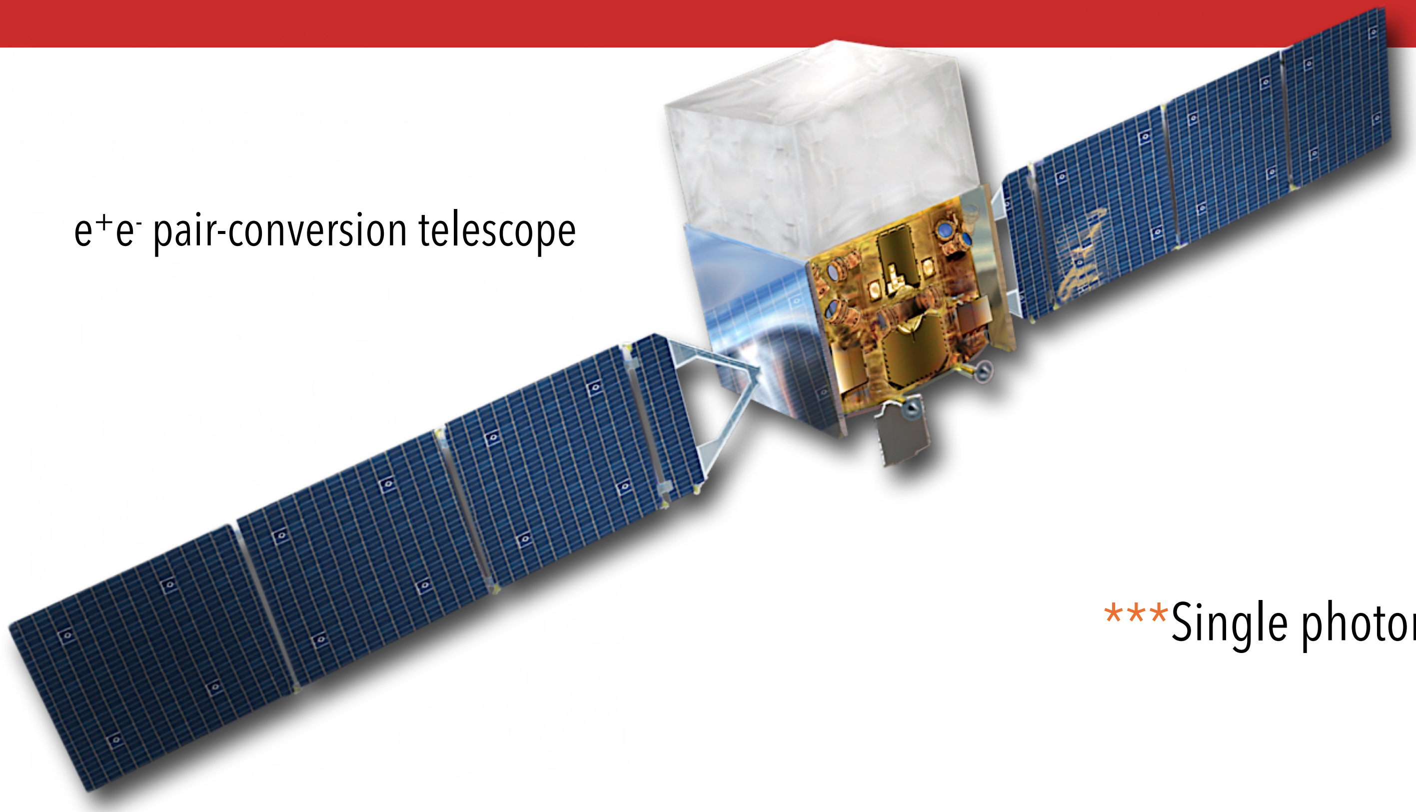
The Tracker-converter



The Anti-coincidence Detector

The Calorimeter

Obligatory slide on Fermi Large Area Telescope



e^+e^- pair-conversion telescope

*Energy range	20 MeV to > 300 GeV
**Field of View	2.4 sr (~1/5 of the whole sky)
***Single photon angular resolution	< 1 deg at 1 GeV
Timing accuracy	1 microsecond

**ideally suited for WIMP searches*
***whole sky every ~3 hours*
****point-source localization <0.5 arcmin*

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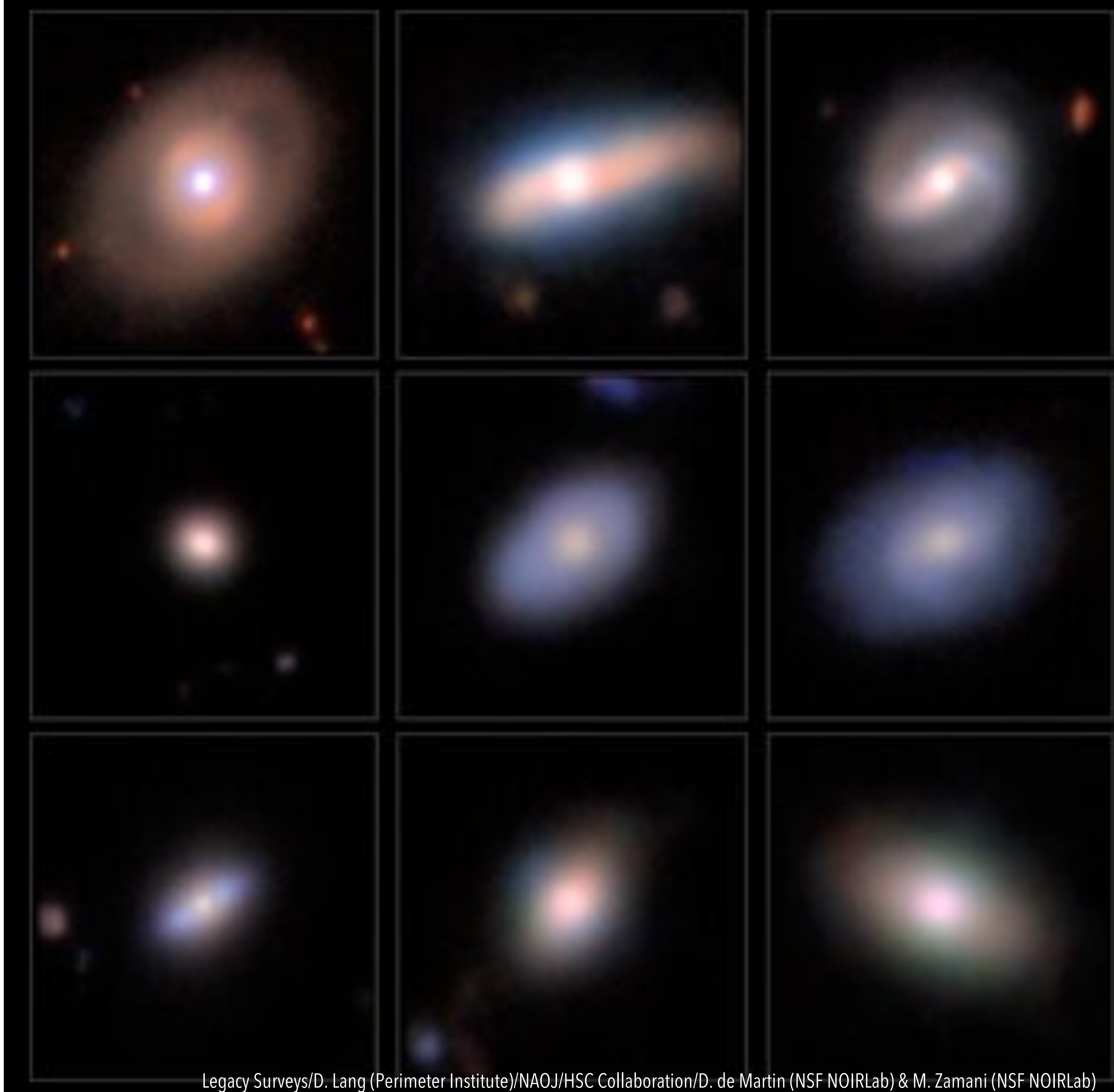
1.

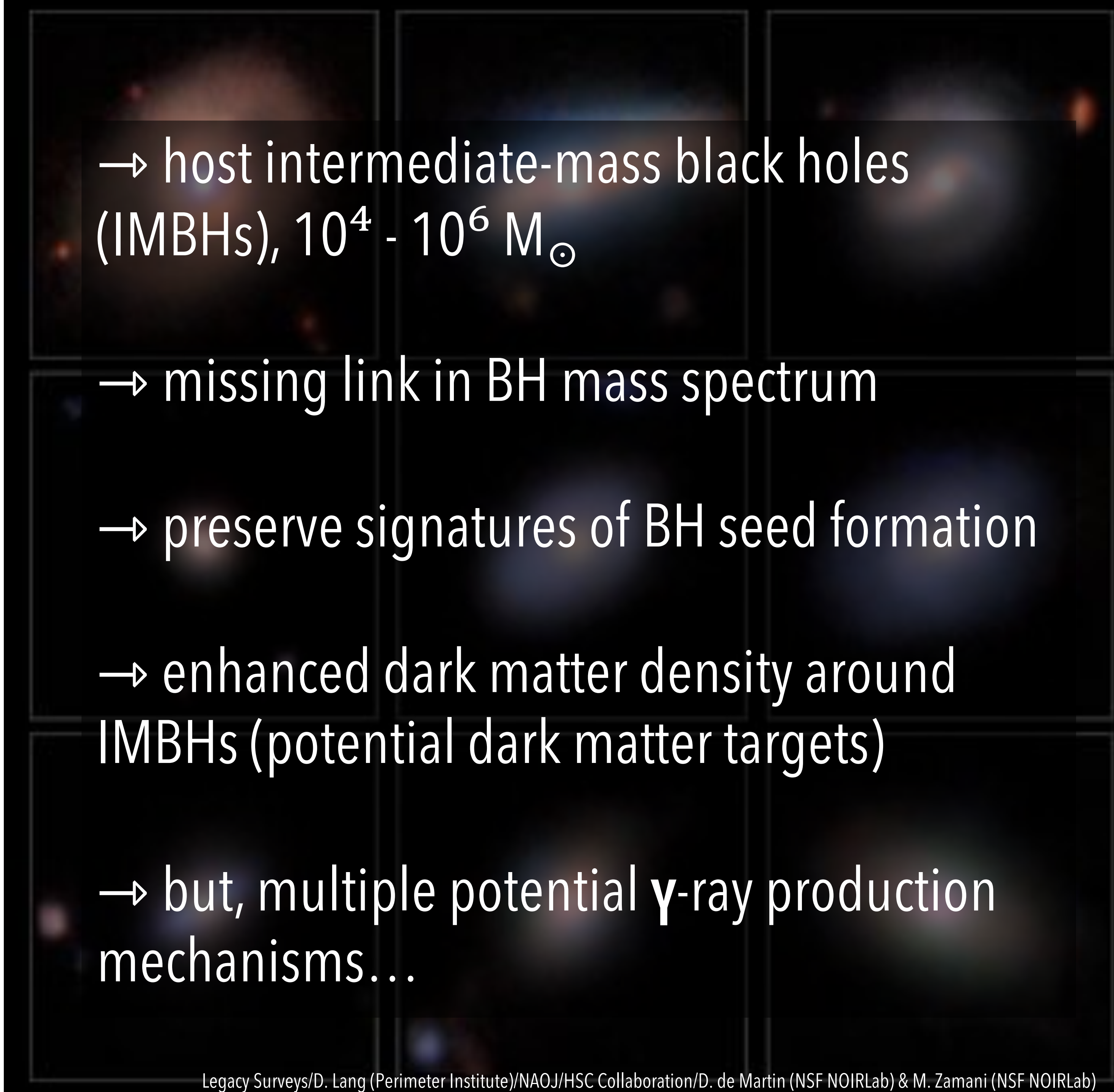
Dwarf AGN



Based on Crnogorčević+ 2025, arXiv: **2509.18239**

1.

Dwarf AGN



→ host intermediate-mass black holes (IMBHs), 10^4 - 10^6 $M_\odot$

→ missing link in BH mass spectrum

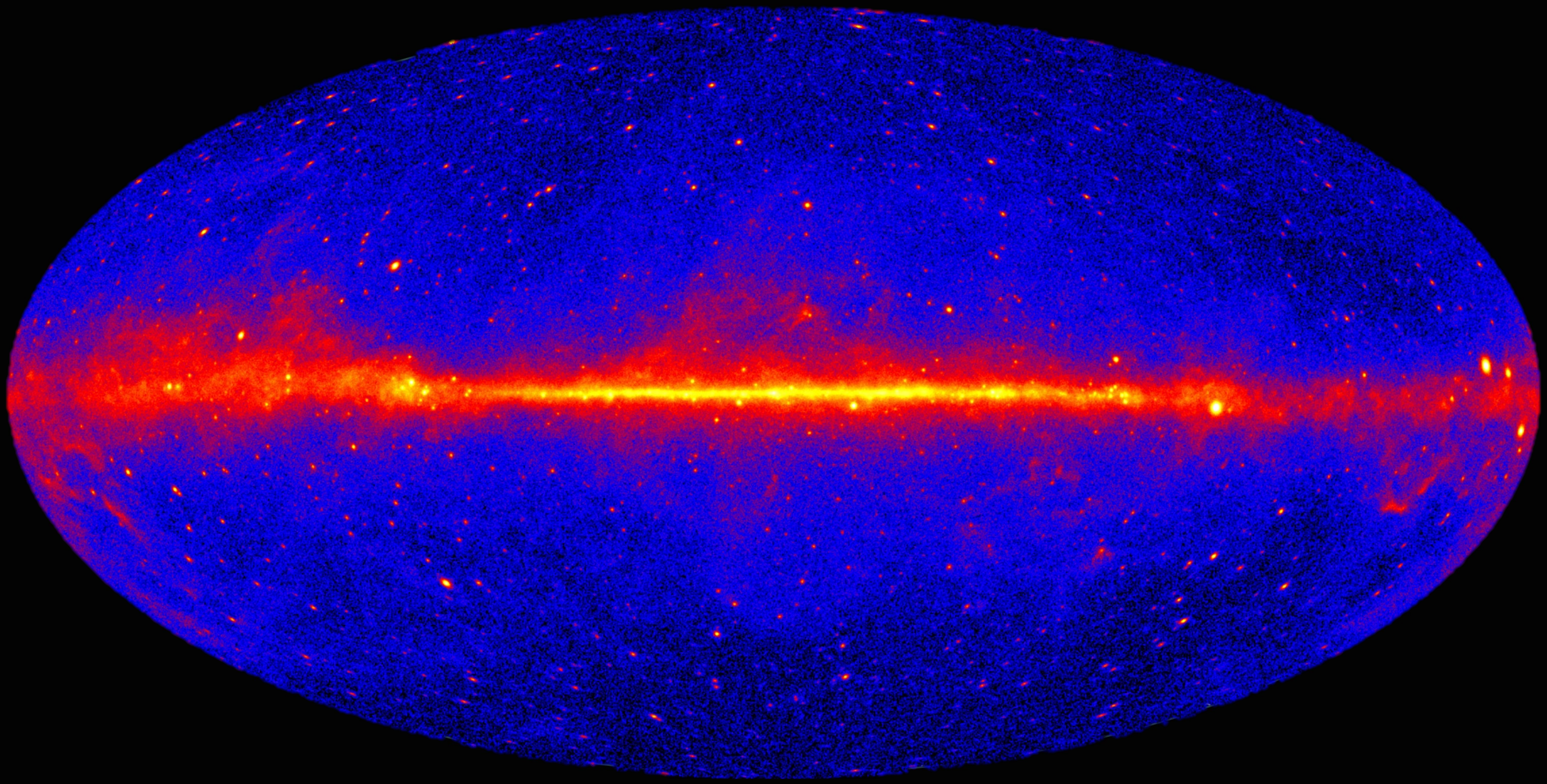
→ preserve signatures of BH seed formation

→ enhanced dark matter density around IMBHs (potential dark matter targets)

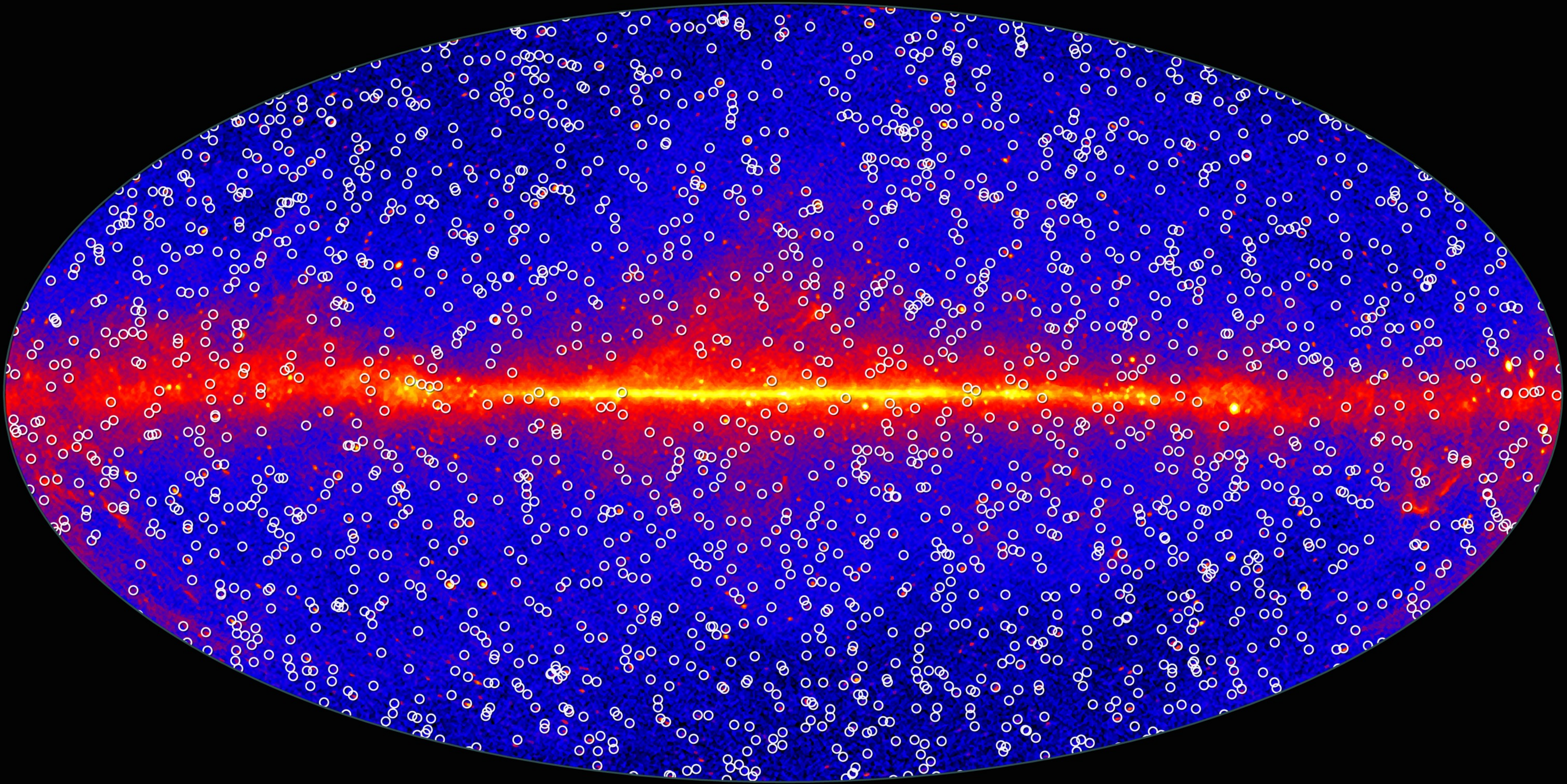
→ but, multiple potential **γ**-ray production mechanisms…

Legacy Surveys/D. Lang (Perimeter Institute)/NAOJ/HSC Collaboration/D. de Martin (NSF NOIRLab) & M. Zamani (NSF NOIRLab)

Based on Crnogorčević+ 2025, arXiv: **2509.18239**



Fermi-LAT Collaboration



Fermi-LAT Collaboration

Gammas from AGNs

Classical ways to produce γ-rays:

→ Accretion-related processes: Inverse Compton from corona/disk

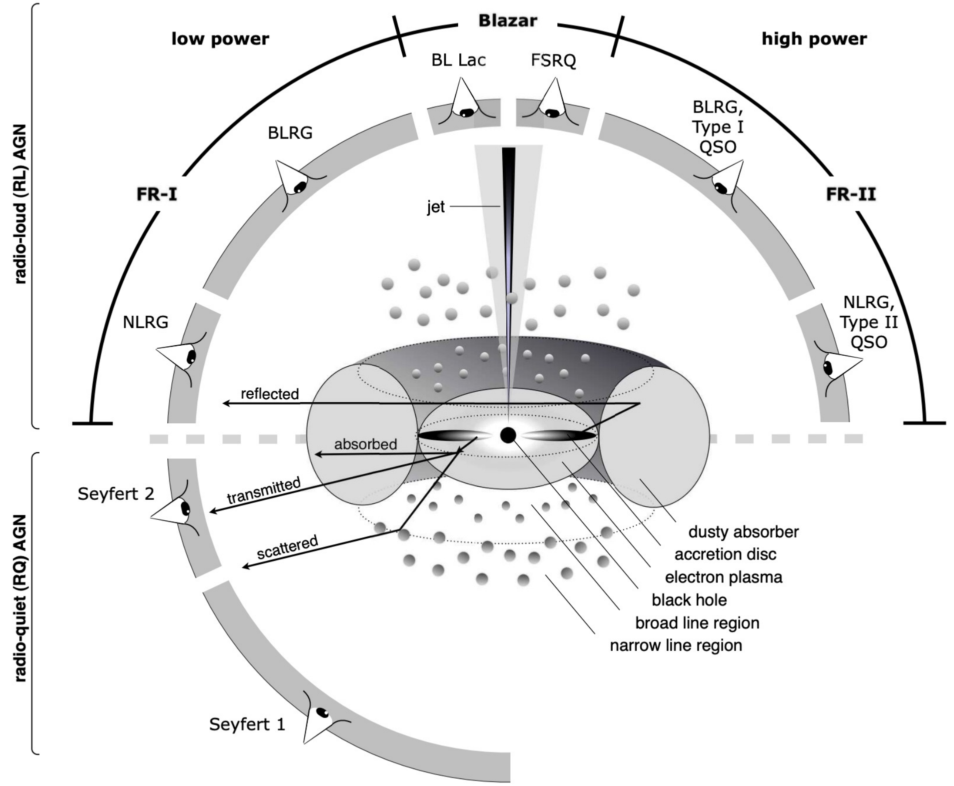
→ Misaligned jets: Reduced Doppler boosting → softer spectra

→ Cosmic-ray interactions: Star formation/supernova activity

→ AGN-driven outflows: Shocks in interstellar medium

New ways to produce γ-rays:

→ Dark matter annihilation: Enhanced density around IMBHs



[Beckmann & Shrader 2013]

Multiple mechanisms likely contribute: requires multiwavelength approach to disentangle

Some questions you may ask…

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→ Do gamma-ray emission mechanisms observed in massive galaxy AGN **scale down to IMBHs**?

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→ Can gamma-ray observations **distinguish between competing emission models**?

→ Are there **unique signatures** in IMBH systems not seen in SMBH-hosted AGN?

Dwarf AGN sample

MaNGA AGN dwarf galaxies (MAD) - I. A new sample of AGN in dwarf galaxies with spatially resolved spectroscopy

M. Mezcua[1,2]★, H. Domínguez Sánchez[3]

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[2] *Institut d'Estudis Espacials de Catalunya (IEEC), Carrer Gran Capità, 08034 Barcelona, Spain*

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Accepted 2024 January 24. Received 2024 January 8; in original form 2023 May 19

ABSTRACT

The finding of active galactic nuclei (AGN) in dwarf galaxies has important implications for galaxy evolution and supermassive black hole formation models. Yet, how AGN in dwarf galaxies form is still debated, in part due to scant demographics. We make use of the MaNGA survey, comprising ~10,000 galaxies at $z < 0.15$, to identify AGN dwarf galaxies using a spaxel by spaxel classification in three spatially-resolved emission line diagnostic diagrams (the [NII-, [SII]- and [OI]-BPT) and the WHAN diagram. This yields a sample of 664 AGN dwarf galaxies, the largest to date, and an AGN fraction of ~ 20% that is significantly larger than that of single-fiber-spectroscopy studies (i.e. ~ 1%). This can be explained by the lower bolometric luminosity ($< 10^{42}$ erg s^{-1}) and accretion rate (sub-Eddington) of the MaNGA AGN dwarf galaxies. We additionally identify 1,176 SF-AGN (classified as star-forming in the [NII]-BPT but as AGN in the [SII]- and [OI]-BPT), 122 Composite, and 173 LINER sources. The offset between the optical center of the galaxy and the median position of the AGN spaxels is more than 3 arcsec for ~62% of the AGN, suggesting that some could be off-nuclear. We also identify seven new broad-line AGN with log M_{BH} = 5.0 - 5.9 $M_\odot$. Our results show how integral-field spectroscopy is a powerful tool for uncovering faint and low-accretion AGN and better constraining the demographics of AGN in dwarf galaxies.

Key words: Galaxies: dwarf, active, accretion

Dwarf AGN sample

MaNGA AGN dwarf galaxies (M…
dwarf galaxies with spatial…

M. Mezcua[1,2★], H. …
[1] Institute of Space Scien…
[2] Institut d'Estudi…
3 Centro …

Accepted 202…

Draft version February 20, 2025
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Tripling the Census of Dwarf AGN Candidates Using DESI Early Data

Ragadeepika Pucha,[1,2] S. Juneau,[3] Arjun Dey,[3] M. Siudek,[4,5] M. Mezcua,[6,4] J. Moustakas,[7] S. BenZvi,[8] K. Hainline,[2] R. Hviding,[9,2] Yao-Yuan Mao,[1] D. M. Alexander,[10,11] R. Alfarsy,[12] C. Circosta,[13,14] Wei-Jian Guo,[15] V. Manwadkar,[16,17] P. Martini,[18,19,20] B. A. Weaver,[3] J. Aguilar,[21] S. Ahlen,[22] D. Bianchi,[23] D. Brooks,[14] R. Canning,[12] T. Claybaugh,[21] K. Dawson,[24] A. de la Macorra,[25] Biprateep Dey,[26,27] P. Doel,[14] A. Font-Ribera,[14,28] J. E. Forero-Romero,[29,30] E. Gaztañaga,[6,12,4] S. Gontcho A Gontcho,[21] G. Gutierrez,[31] K. Honscheid,[18,32,20] R. Kehoe,[33] S. E. Koposov,[34,35] A. Lambert,[21] M. Landriau,[21] L. Le Guillou,[36] A. Meisner,[3] R. Miquel,[37,28] F. Prada,[38] G. Rossi,[39] E. Sanchez,[40] D. Schlegel,[21] M. Schubnell,[41,42] H. Seo,[43] D. Sprayberry,[3] G. Tarlé,[42] and H. Zou[15]

ABSTRACT

Using early data from the Dark Energy Spectroscopic Instrument (DESI) survey, we search for AGN signatures in 410,757 line-emitting galaxies. By employing the BPT emission-line ratio diagnostic diagram, we identify AGN in 75,928/296,261 (≈25.6%) high-mass ($\log(M_\star/M_\odot) > 9.5$) and 2,444/114,496 (≈2.1%) dwarf ($\log(M_\star/M_\odot) \leq 9.5$) galaxies. Of these AGN candidates, 4,181 sources exhibit a broad Hα component, allowing us to estimate their BH masses via virial techniques. This study more than triples the census of dwarf AGN and doubles the number of intermediate-mass black hole (IMBH; $M_{\rm BH} \leq 10^6\ M_\odot$) candidates, spanning a broad discovery space in stellar mass ($7 < \log(M_\star/M_\odot) < 12$) and redshift ($0.001 < z < 0.45$). The observed AGN fraction in dwarf galaxies (≈2.1%) is nearly four times higher than prior estimates, primarily due to DESI's smaller fiber size, which enables the detection of lower luminosity dwarf AGN candidates. We also extend the $M_{\rm BH} - M_\star$ scaling relation down to $\log(M_\star/M_\odot) \approx 8.5$ and $\log(M_{\rm BH}/M_\odot) \approx 4.4$, with our results aligning well with …h previous low-redshift studies. The large statistical sample of dwarf AGN candidates from current …e DESI releases will be invaluable for enhancing our understanding of galaxy evolution at the …f the galaxy mass function.

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Dwarf AGN sample

DRAFT VERSION FEBRUARY 4, 2025
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X-Ray Bright Active Galactic Nuclei in Local Dwarf Galaxies: Insights from eROSITA

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[1] *Center for Astrophysics | Harvard & Smithsonian, 60 Garden Street, Cambridge, MA 20138, USA*
[2] *Max Planck Institut für Astronomie, Königstuhl 17, 69121 Heidelberg, Germany*

ABSTRACT

Although supermassive black holes (SMBHs) reside in the heart of virtually every massive galaxy, it remains debated whether dwarf galaxies commonly host SMBHs. Because low-mass galaxies may retain memory of the assembly history of their black holes (BHs), probing the BH occupation fraction of local dwarf galaxies might offer insights into the growth and seeding mechanisms of the first BHs. In this work, we exploit the Western half of the eROSITA all-sky survey (covering $20,000 \mathrm{deg}^2$) and compile a catalog of accreting SMBHs in local ($D < 200$ Mpc) dwarf galaxies. Cleaning our sample from X-ray background sources, X-ray binaries, and ultraluminous X-ray sources, we identify 74 AGN-dwarf galaxy pairs. Using this large and uniform sample, we derive a luminosity function of dwarf galaxy AGN, fitting it with a power law function and obtaining $\mathrm{d}N/\mathrm{d}L_\mathrm{X} = (15.9 \pm 2.2) \times L_\mathrm{X}^{-1.63\pm0.05}$. Measuring the offset between the dwarf galaxies centroids and the X-ray sources, we find that $\approx 50\%$ of the AGN are likely off-nuclear, in agreement with theoretical predictions. We compare the BH-to-stellar mass relation of our sample with the local and high-redshift relations, finding that our sources better adhere to the former, suggesting that local AGN across different mass scales underwent a similar growth history. Finally, we compare our sources with semi-analytical models: while our sample's shallowness prevents distinguishing between different seeding models, we find that the data favor models which keep SMBH in dwarf galaxies active at a moderate rate, motivating model improvement by comparison to AGN in the dwarf galaxy regime.

Dwarf AGN sample

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→ X-rays sensitive to accretion

→ minimizes the contamination or line emission biases

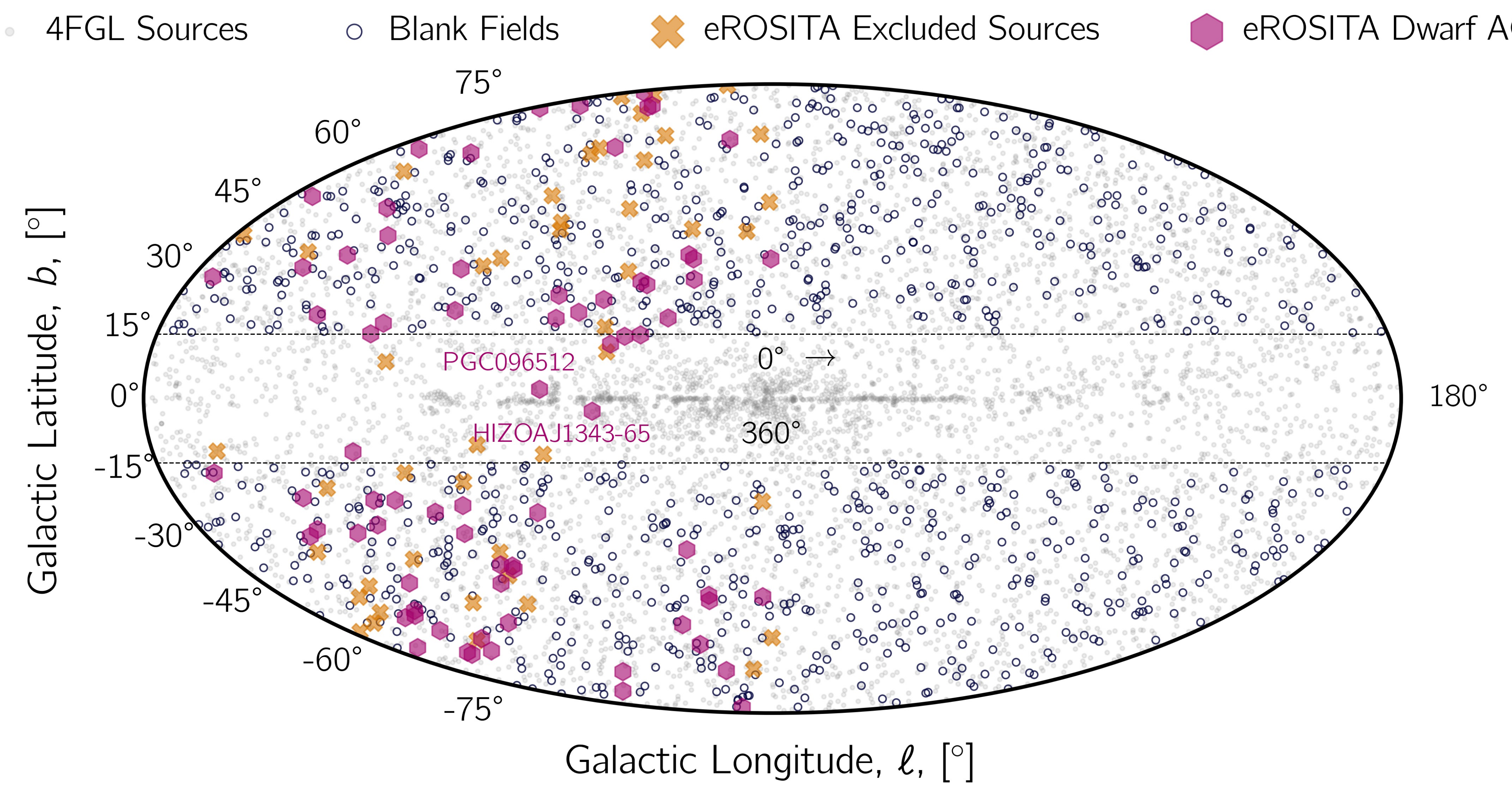
→ unbiased to obscuration of the AGN

→ closest sources (D < 200 Mpc)

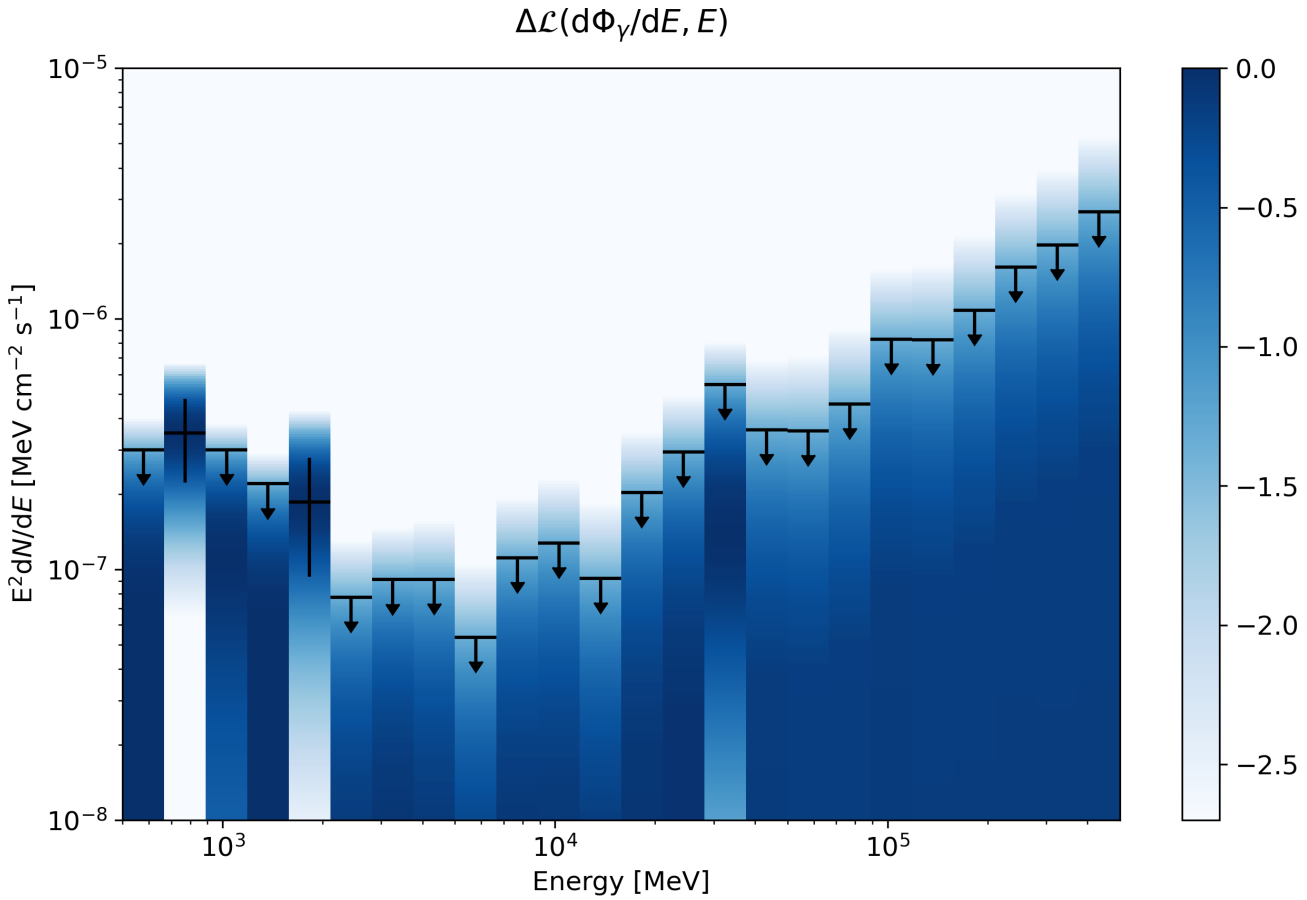
→ available control samples

→ almost… all-sky

Dwarf AGN sample



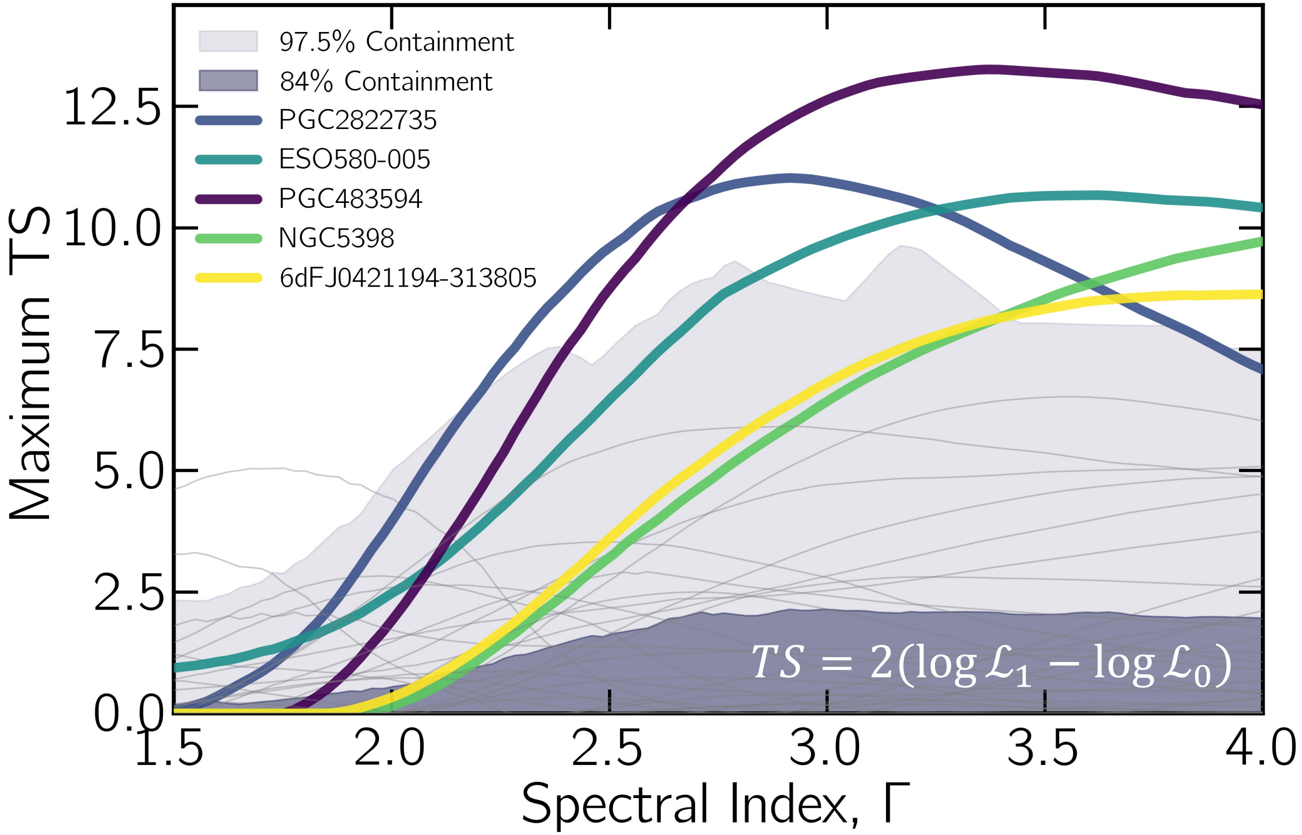
Individual Source Analysis



Example, PGC 2077238

- 15 years of Fermi-LAT Pass 8
- Energy range: 500 MeV – 500 GeV
- Event class: P8R3 SOURCE (evclass=128, evtype=3)
- Software: Fermipy v1.2.0 + Fermitools v2.2.0
- ROI: 10°×10° (model extended to 15°×15° for PSF spillover)
- Background sources from 4FGL-DR4
- Modeled as point source (unresolved at LAT resolution)
- Binned likelihood analysis per energy bin
- SED derived with fixed per-bin index $\Gamma = 2$

Individual Source Analysis: No Detection



Roughly, $\sqrt{TS}$ ~ detection significance (in σ).
TS = 25 corresponds to ~ 5 σ detection in LAT.

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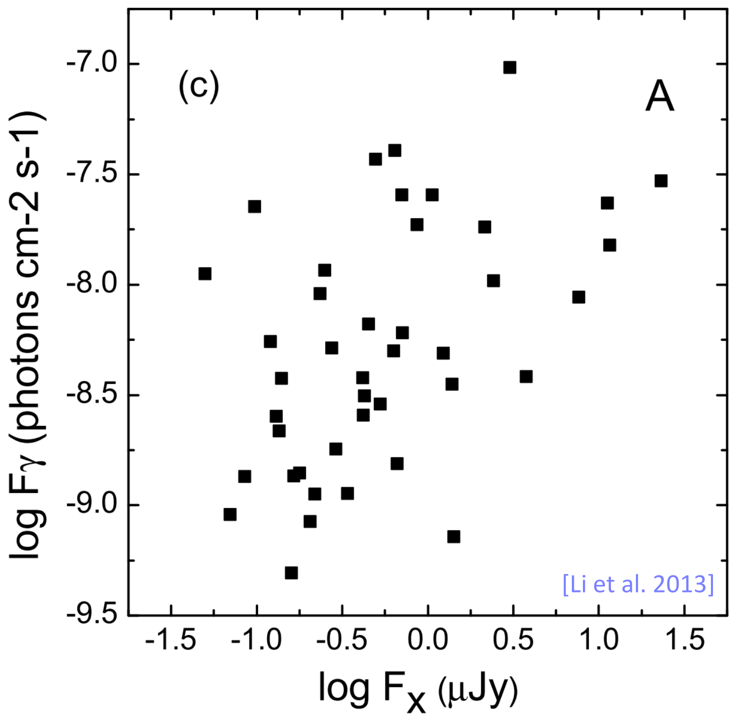
- Modeled as point source (unresolved at LAT resolution)
- Binned likelihood analysis per energy bin
- SED derived with fixed per-bin index **Γ** = 2

What does this no detection mean?

X-ray / γ-ray Scaling

- Empirical **BL Lac relation**



$\log F_\gamma = 0.42 \log F_X - 8.17$ (& scatter based on different states)

What does this no detection mean?

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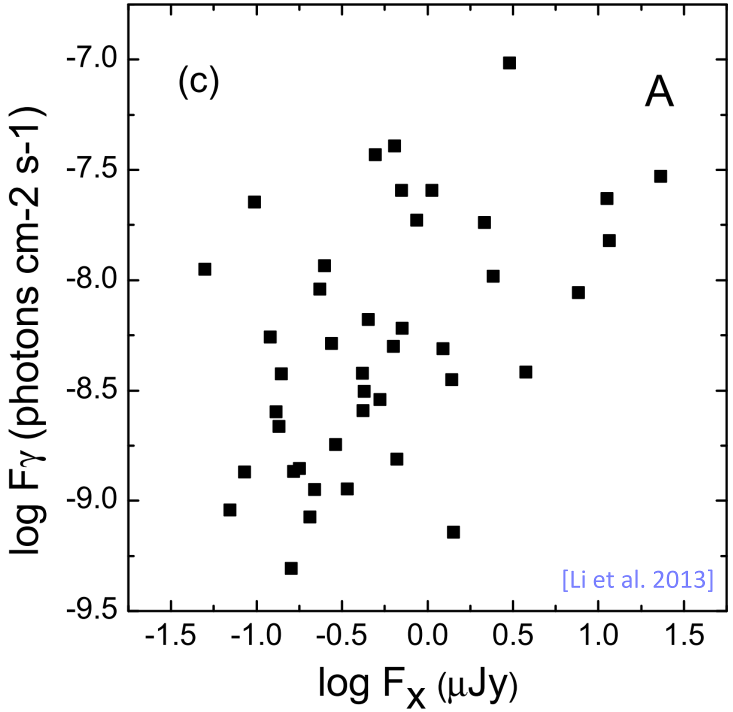
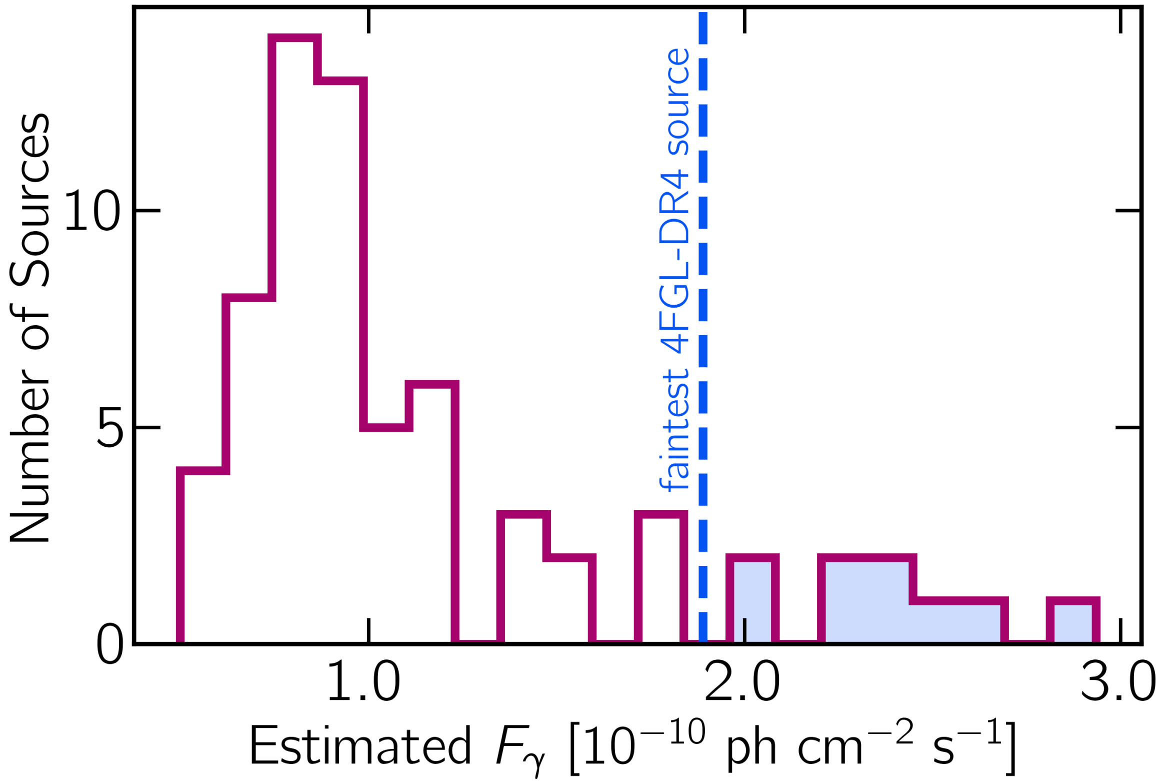


$\log F_\gamma = 0.42 \log F_X - 8.17$ (& scatter based on different states)

Most predicted fluxes fall just below LAT's sensitivity after 15 years



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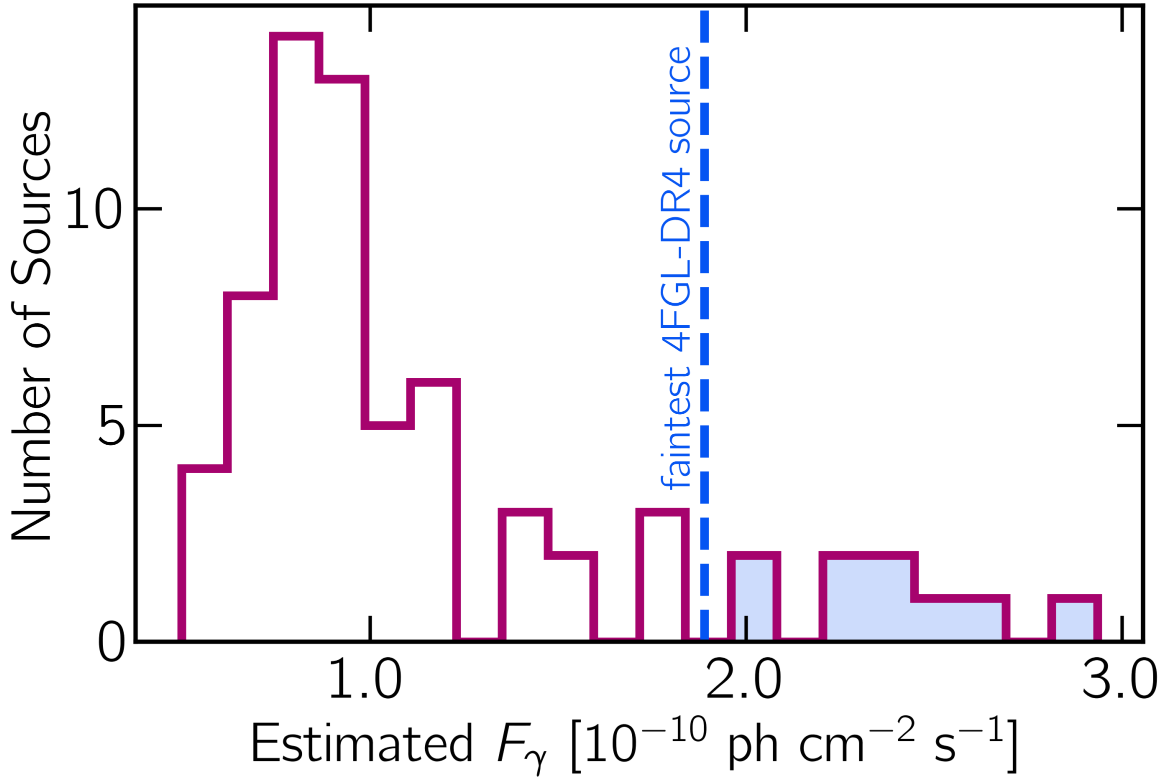


- No outliers detected → **BL Lac-like SSC emission likely suppressed**
- **Dwarf AGN are ≥ 7x less efficient** in producing gamma rays than BL Lacs (at fixed X-ray flux)
- **Possible causes:**
  - Weak or misaligned jets
  - Different accretion regimes
  - $\gamma\gamma$ absorption in denser environments

Joint Likelihood Analysis: Population-level Gamma-ray Signal

→ No significant individual detections

→ Use **joint-likelihood analysis**, summing log-likelihoods from all 67 sources (we excluded 7 sources due to their latitude/proximity to associated LAT sources)

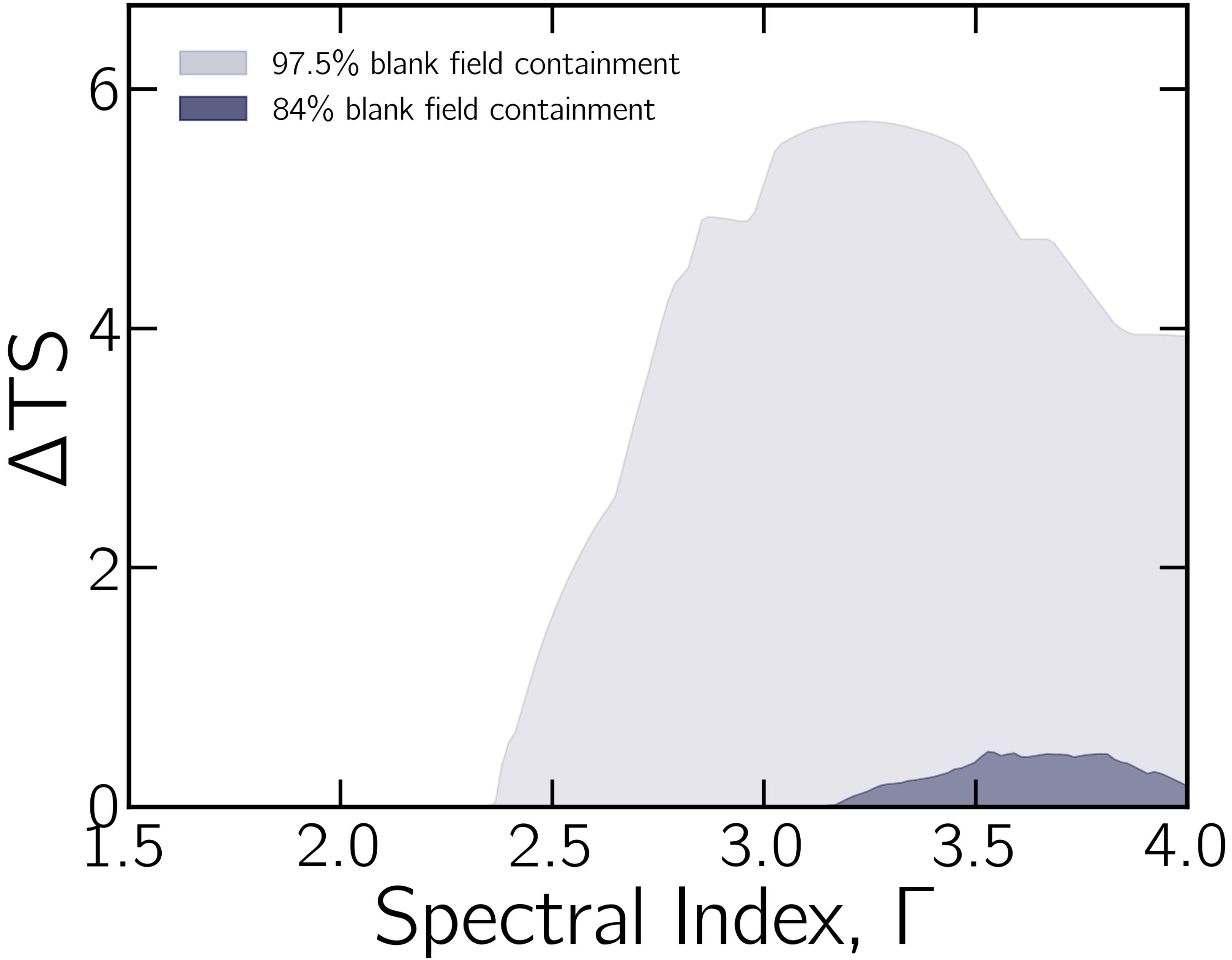
$$\log L_{total} = \sum_i \log L_i \left(c_i, \Gamma \mid D_i\right)$$

→ Common spectral shape (power law index **Γ**) across all sources

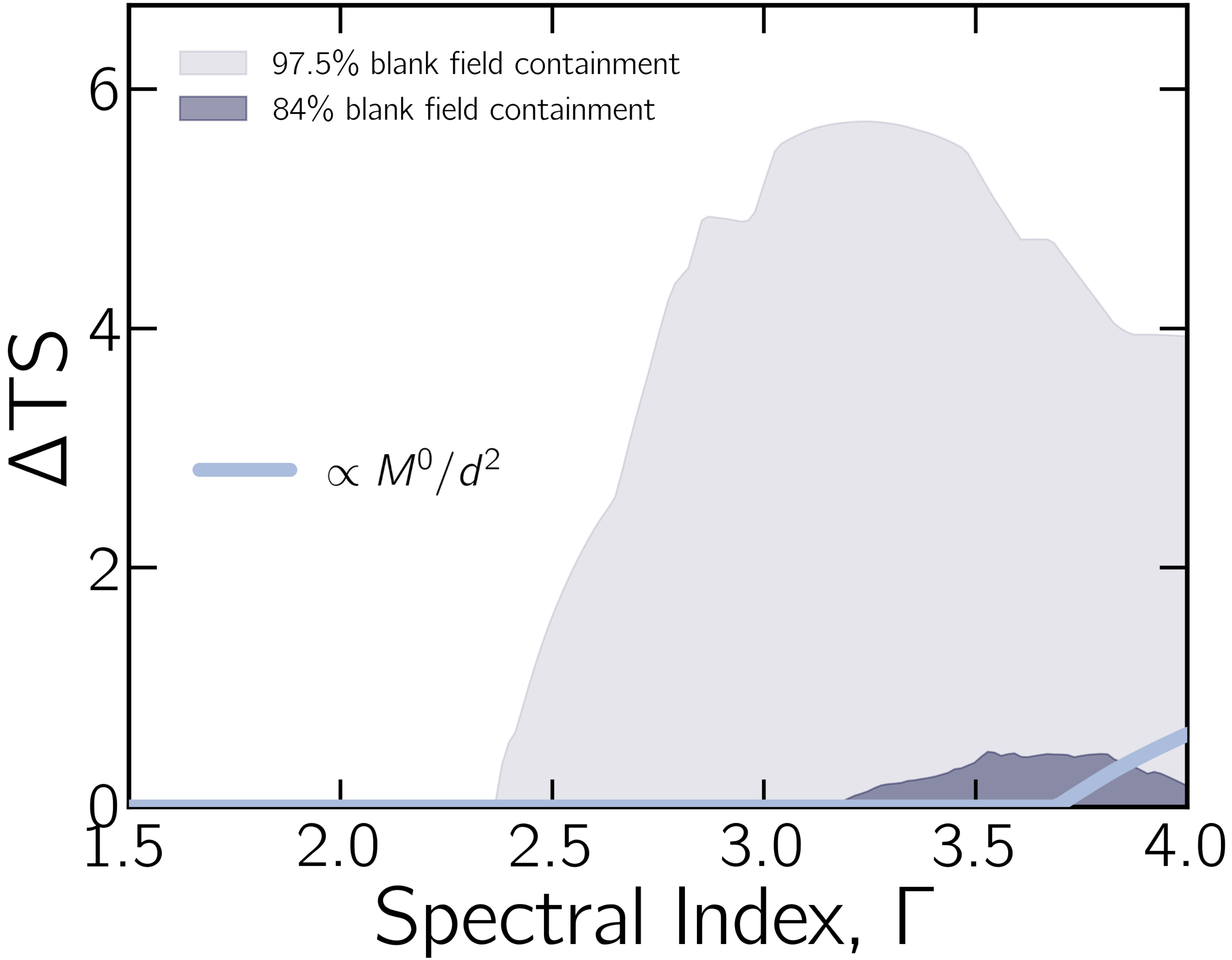
→ Source normalizations tied by physical weights w_i

→ Blank skies used for calibration

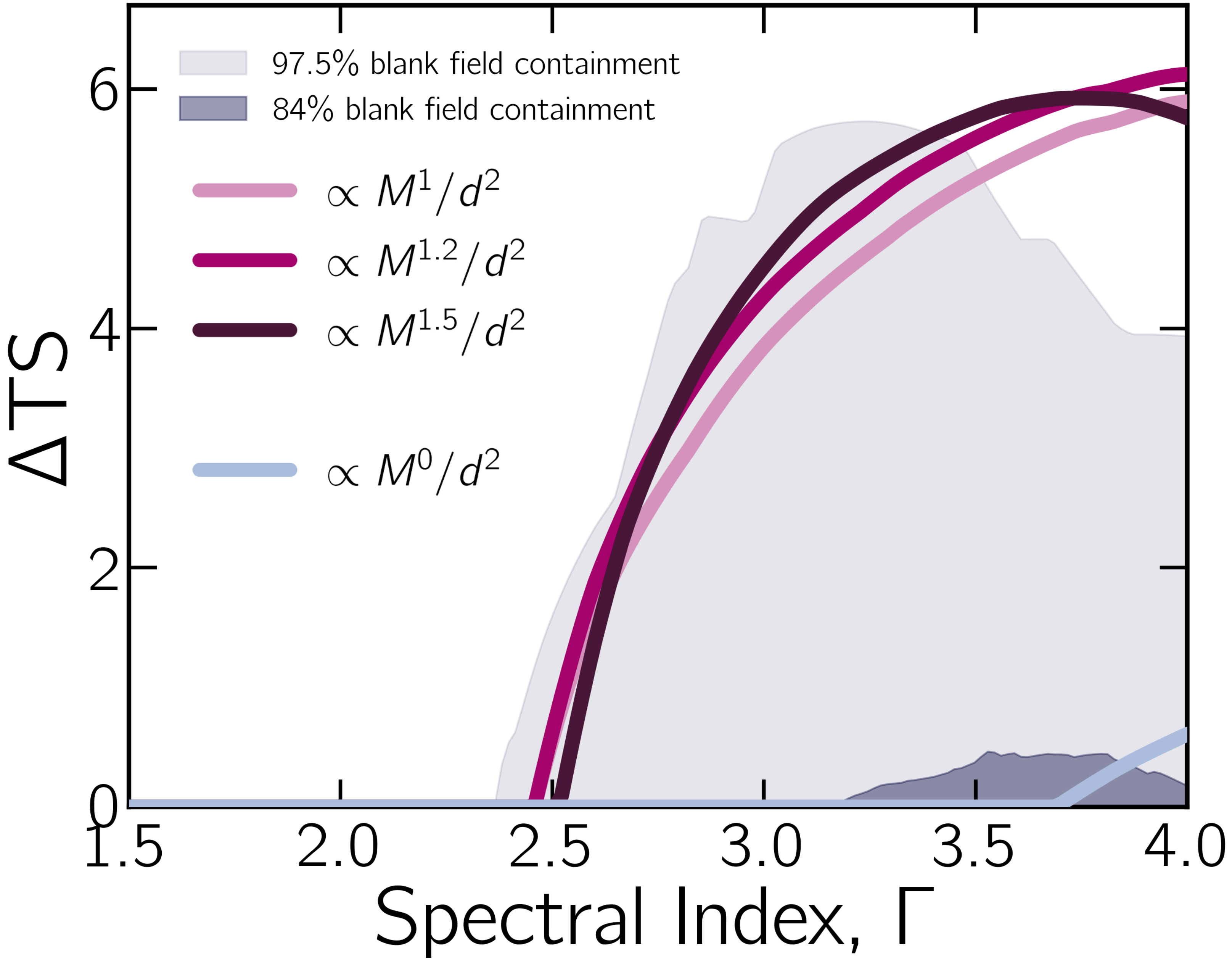
- **Advantages**
  - Retains background, exposure, and brightness differences
  - Statistically robust compared to simple stacking


97.5% blank field containment
84% blank field containment
6
4
2
0
ΔTS
1.5
2.0
2.5
3.0
3.5
4.0
Spectral Index, Γ

With IMBH mass derived from stellar mass–black hole mass relation (Reines & Volonteri 2015):



With IMBH mass derived from stellar mass–black hole mass relation (Reines & Volonteri 2015):



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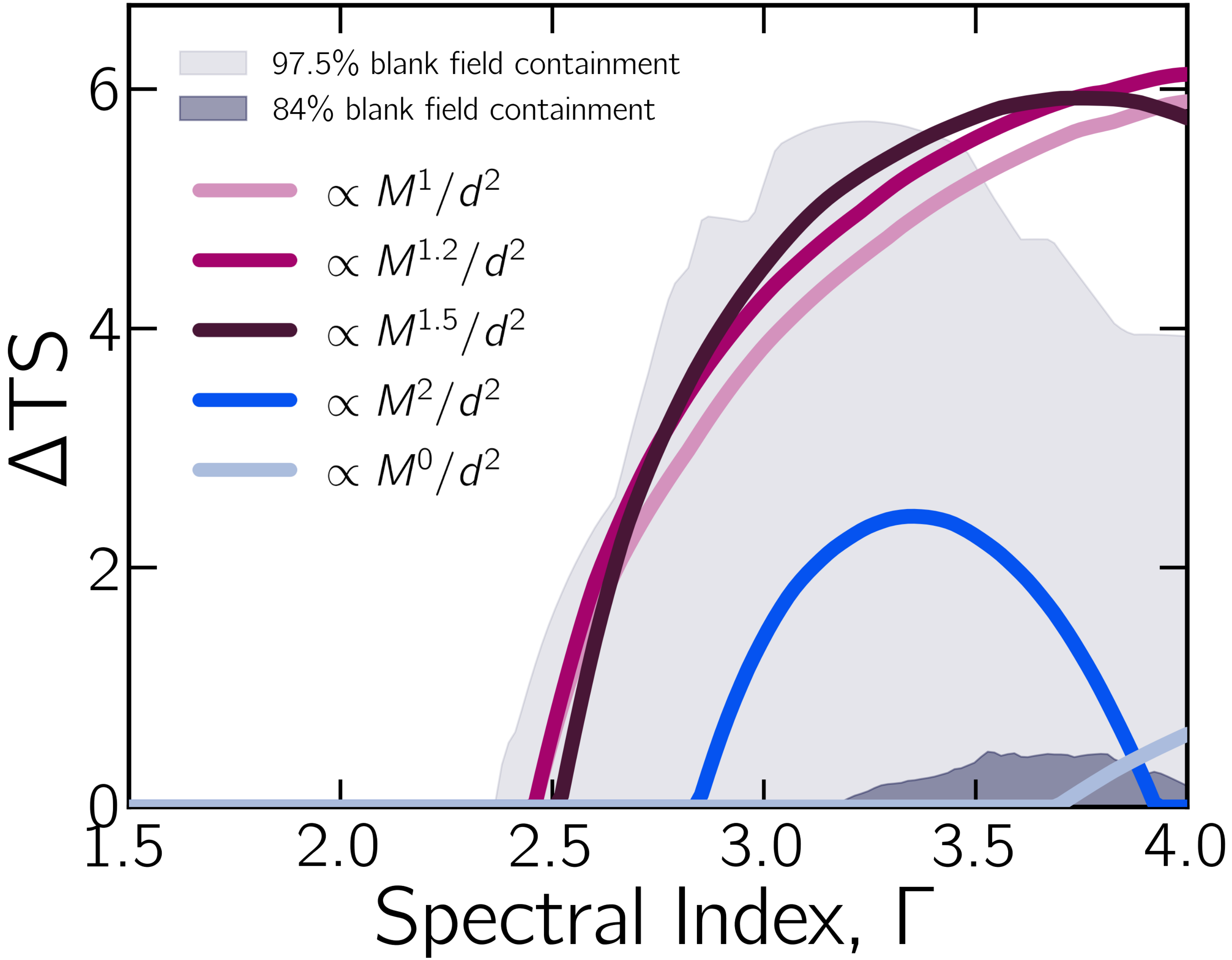
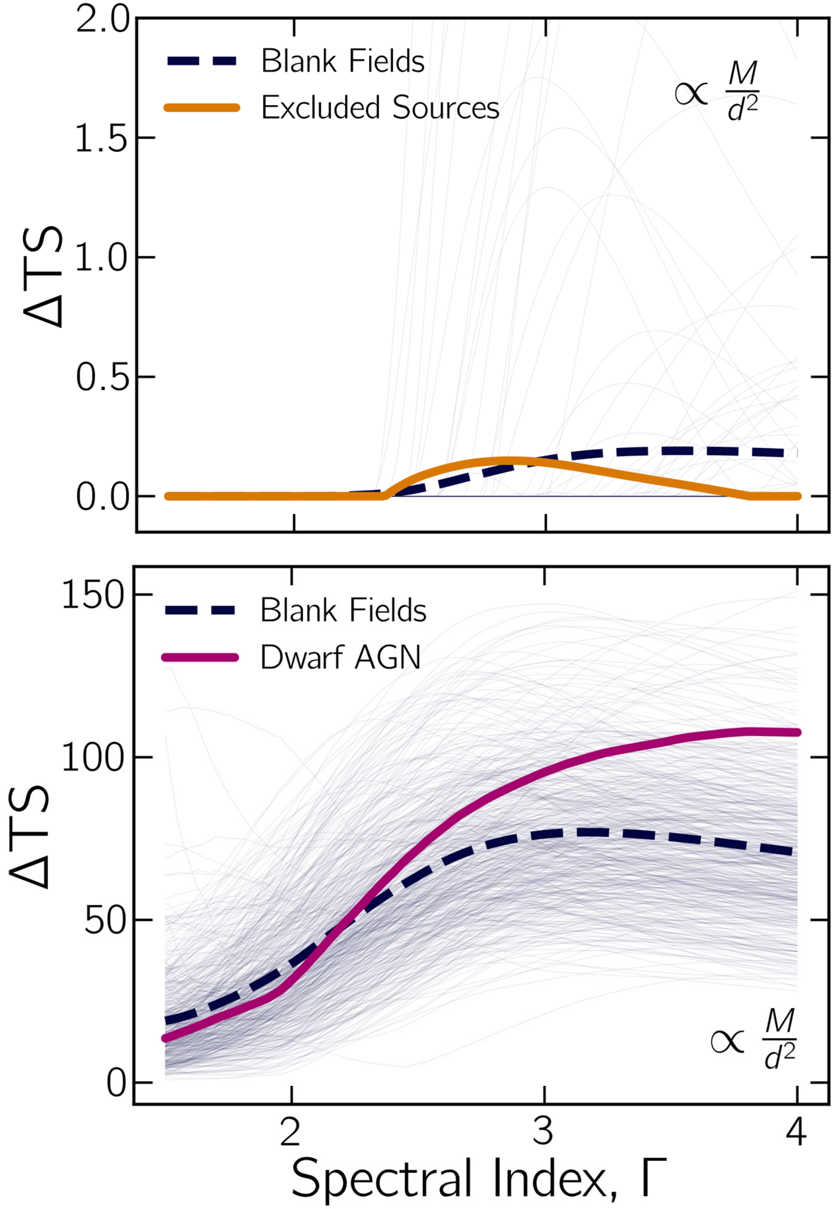


With IMBH mass derived from stellar mass–black hole mass relation (Reines & Volonteri 2015):



Interpretation:

→ Suggestive—but not conclusive—evidence that **γ**-ray emission may scale with IMBH mass

→ Spectrum significantly softer than typical blazars (**Γ** ≈ 2–2.5)

→ Possible explanations:

- Coronal or accretion-disk Comptonization
- Weak or misaligned jets
- **γγ** absorption or host star formation contamination

→ Verified against 400 blank-field ensembles and excluded-source control sample

→ Similar soft peak appears when extended down to 100 MeV (but with inflated significance ⟶ likely systematics)


Fornax Dwarf Galaxy, ESO/Sky Survey 2

2.

dSphs

2.

dSphs

→ most dark-matter dominated systems known in the Universe

→ 61 dwarf satellites identified so far in the Milky Way, more on the horizon

→ nearby (furthest 460 kpc), some within single-digit kpc

→ not much astrophysical background, inactive

Fornax Dwarf Galaxy, ESO/Sky Survey 2

dSphs

DM γ-ray flux

$$\frac{d\Phi}{dE}$$

=

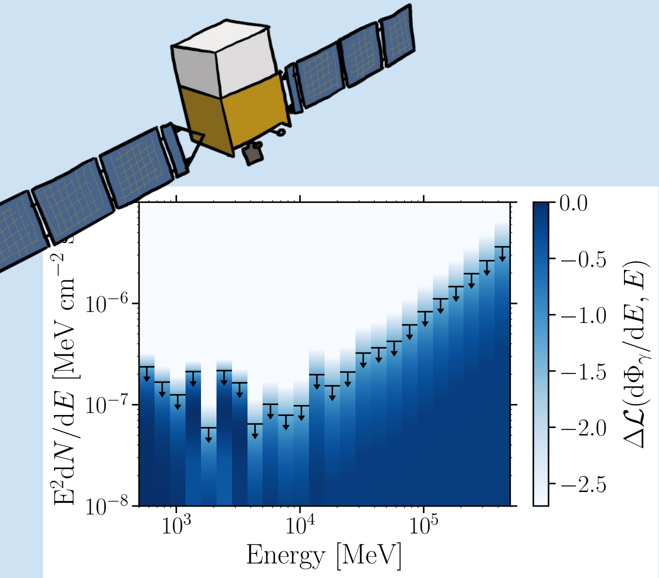
astrophysics J-factor

$$\int_{\Delta\Omega,\mathrm{los}} \rho_{DM}^2$$

×

particle physics

$$\frac{\langle\sigma v\rangle}{2M_{DM}^2}\sum B_i \frac{dN_\gamma}{dE}$$

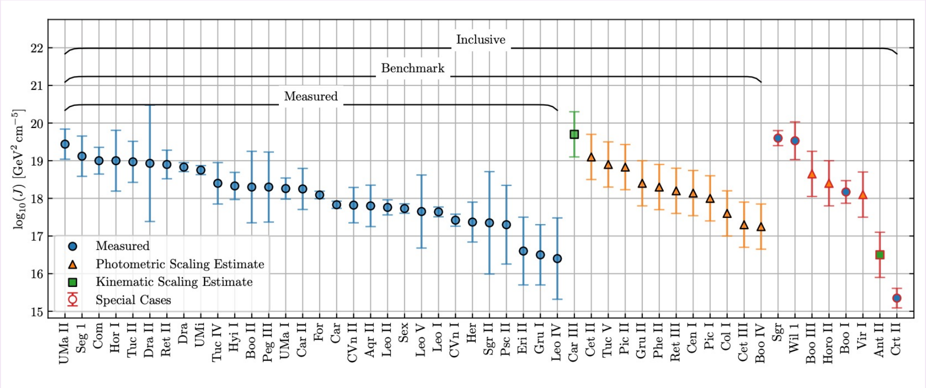


Ursa Major III [MC & Linden 2023]

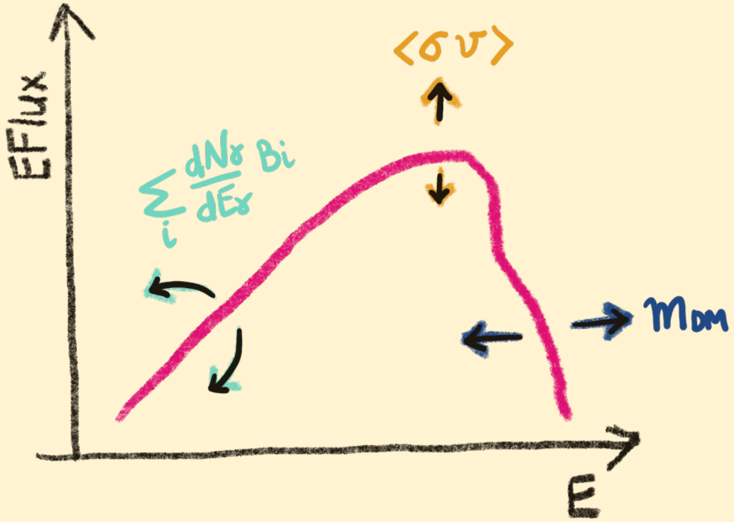
Dark matter content determined from stellar velocity dispersion

– **Classical dwarfs**: spectra for several thousand stars

– **Ultra-faint dwarfs**: spectra for fewer than 100 stars

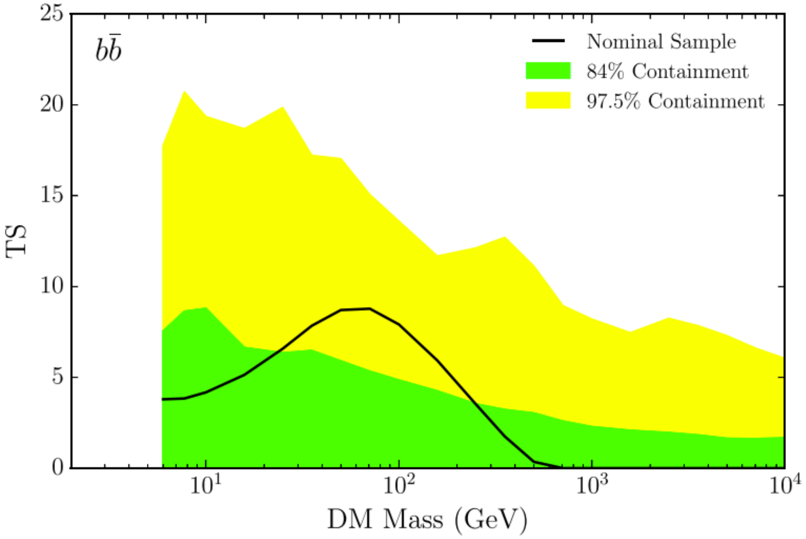


J-factors [Fermi-LAT Collaboration 2024]



Combined dSph Analyses

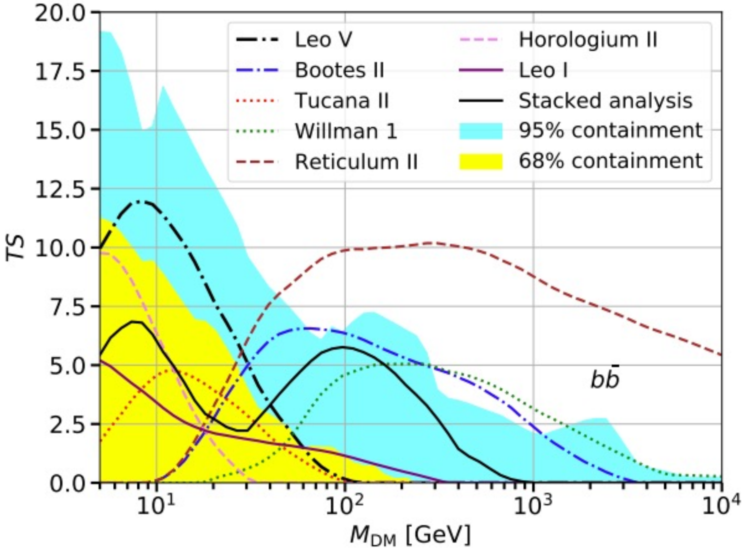
6 years



$< 2\,\sigma$

[Fermi-LAT Collaboration '17]

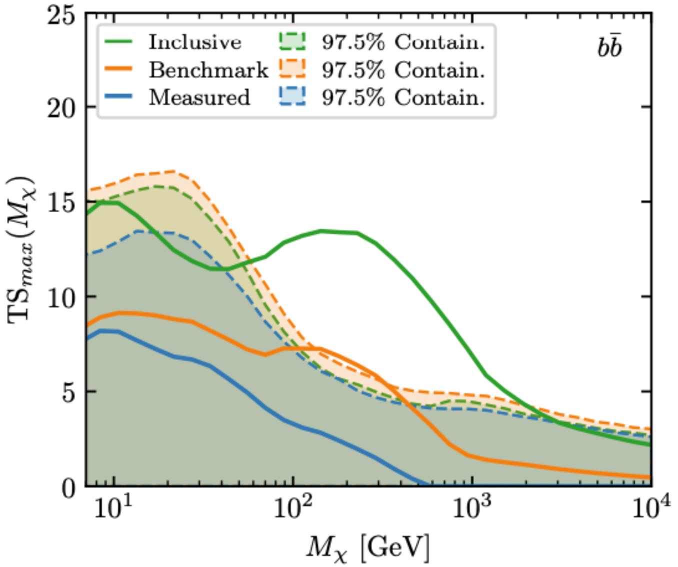
11 years



$\lesssim 2\,\sigma$

[Fermi-LAT Collaboration '21]

14 years

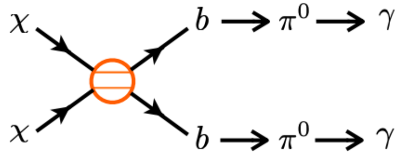


$\gtrsim 2\,\sigma$

[McDaniel+ '24]

Shaded regions: blank-field analysis

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



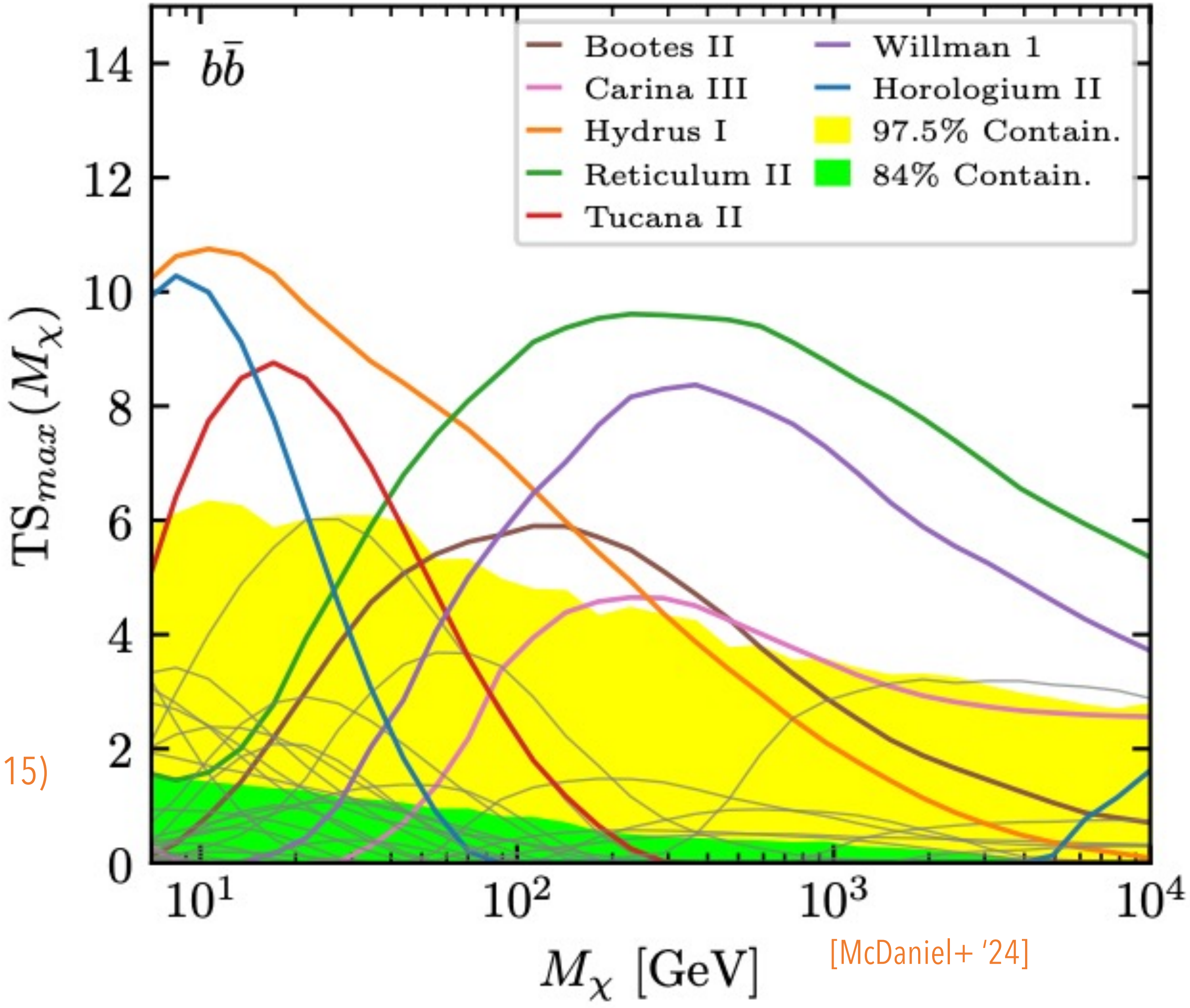
Combined dSph Analyses

(2024)

→ 7 dSphs with local significance > 2σ

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

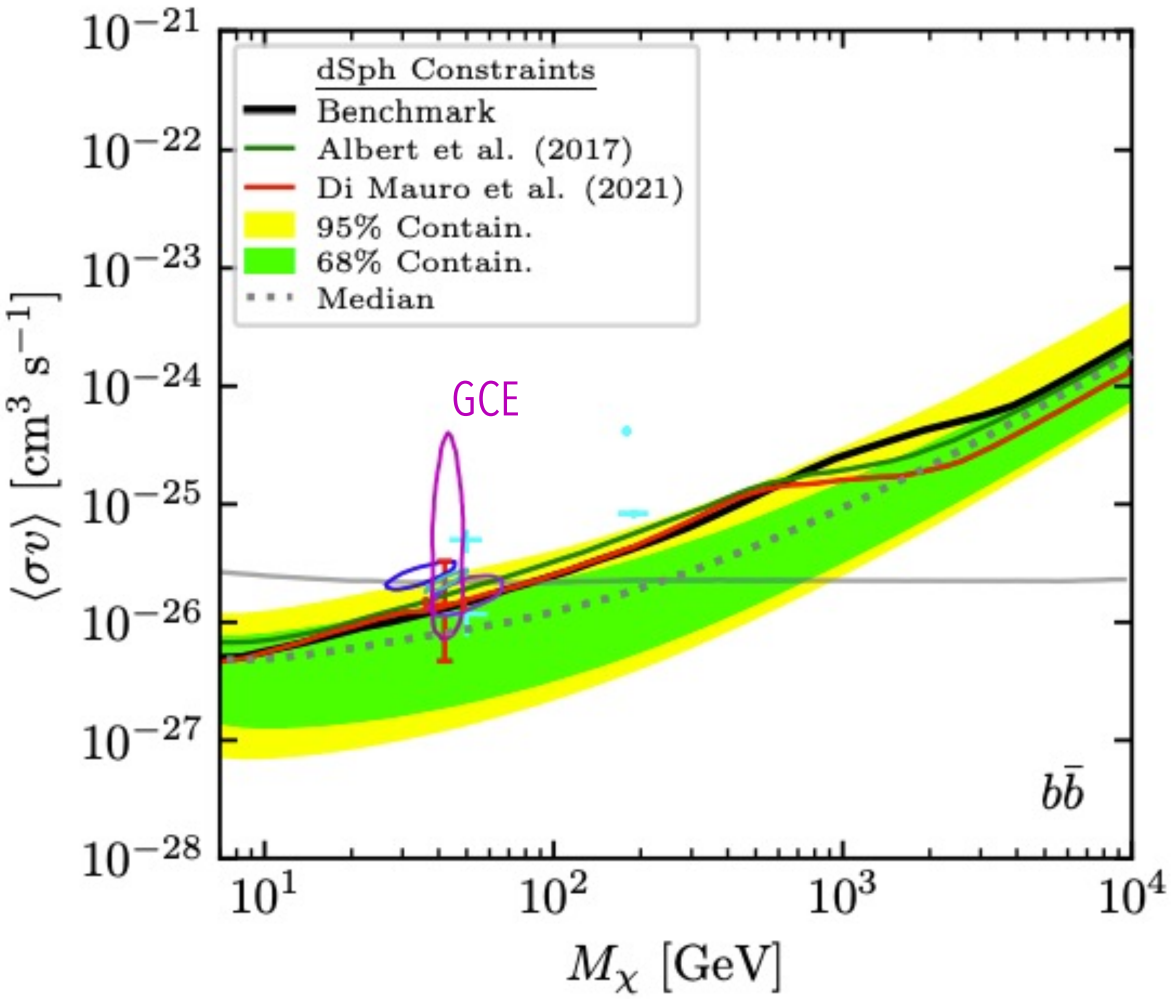
Ret II (DiMauro+ '21, Albert+ '17, Geringer-Sameth+ '15, Hooper & Linden '15)
Tucana II, Willman 1, Horologium II, Bootes I (DiMauro+ '21)



[McDaniel+ '24]

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

Limits on the parameter space



[McDaniel+ '24]

→ Trials factor reduces significance to 0.5 σ.

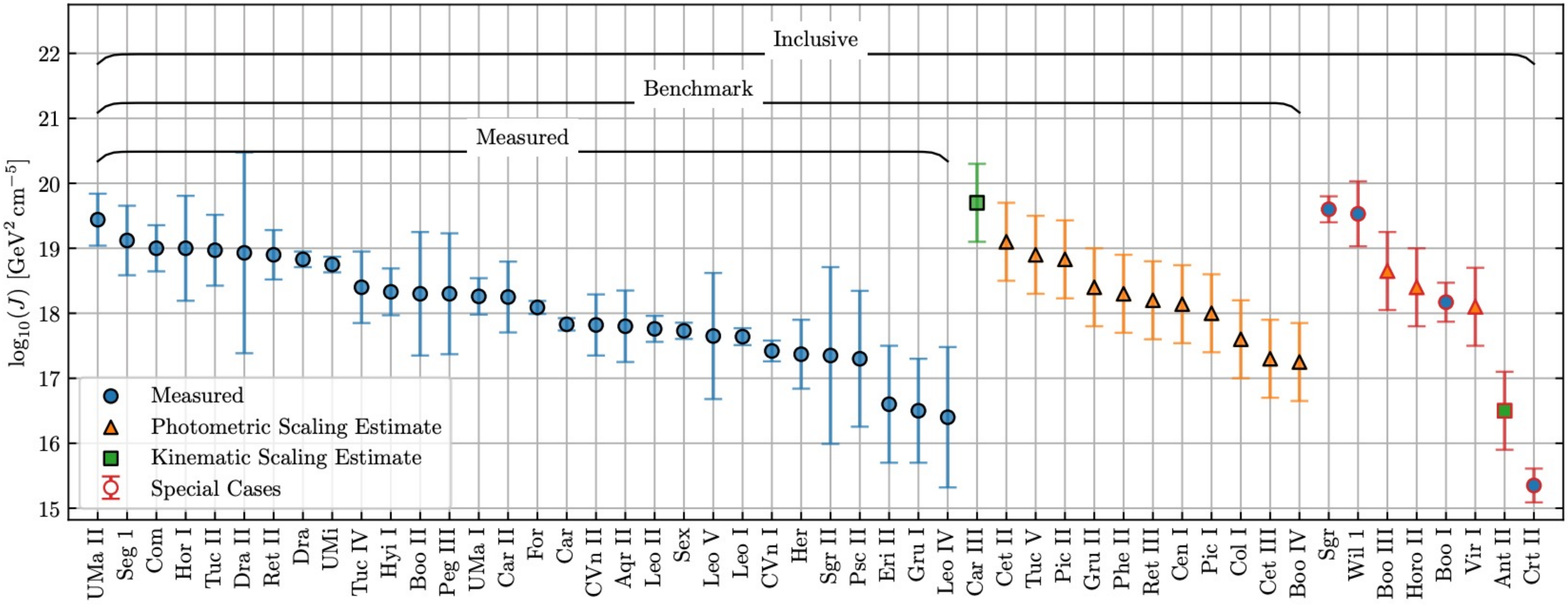
Observations:

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

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

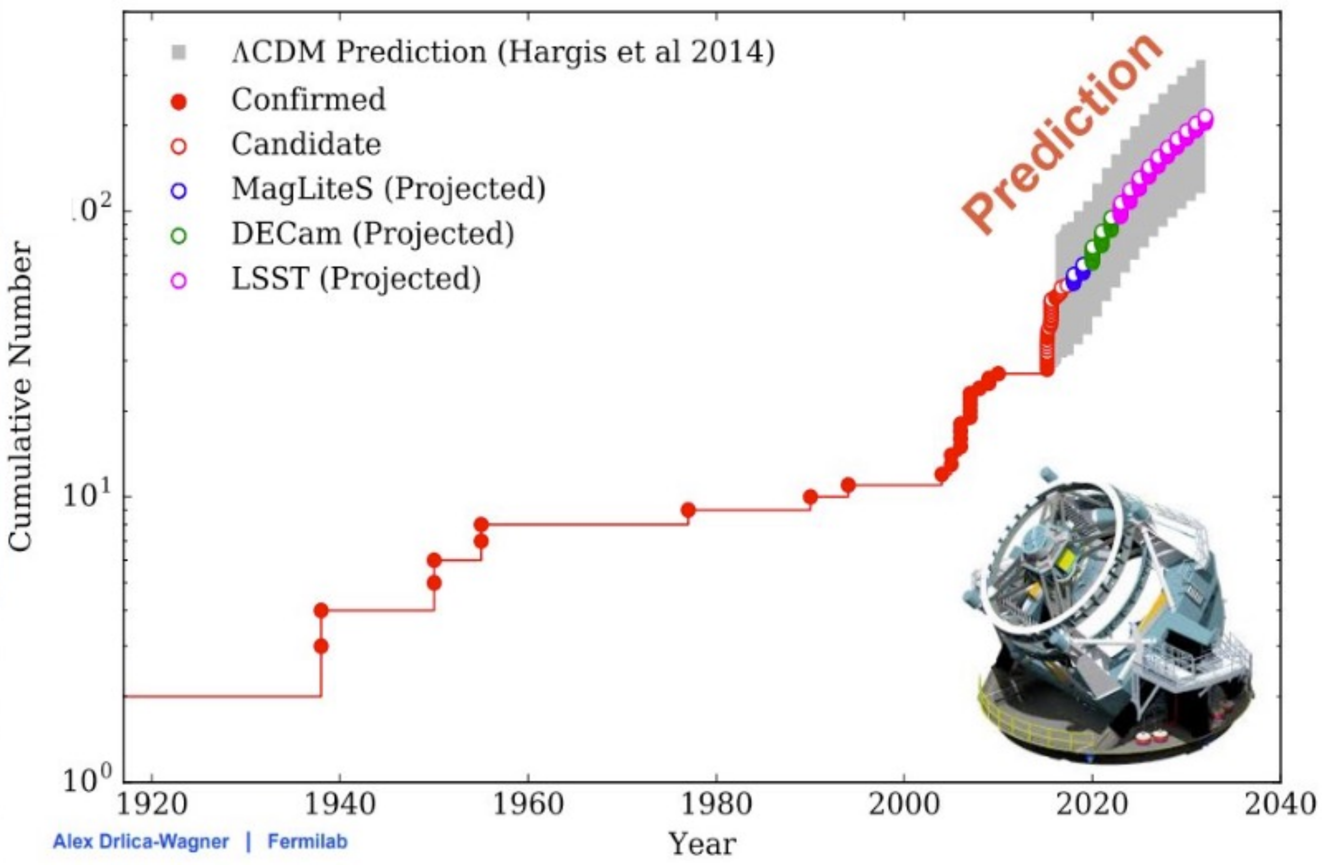
J-value calculations are… hard

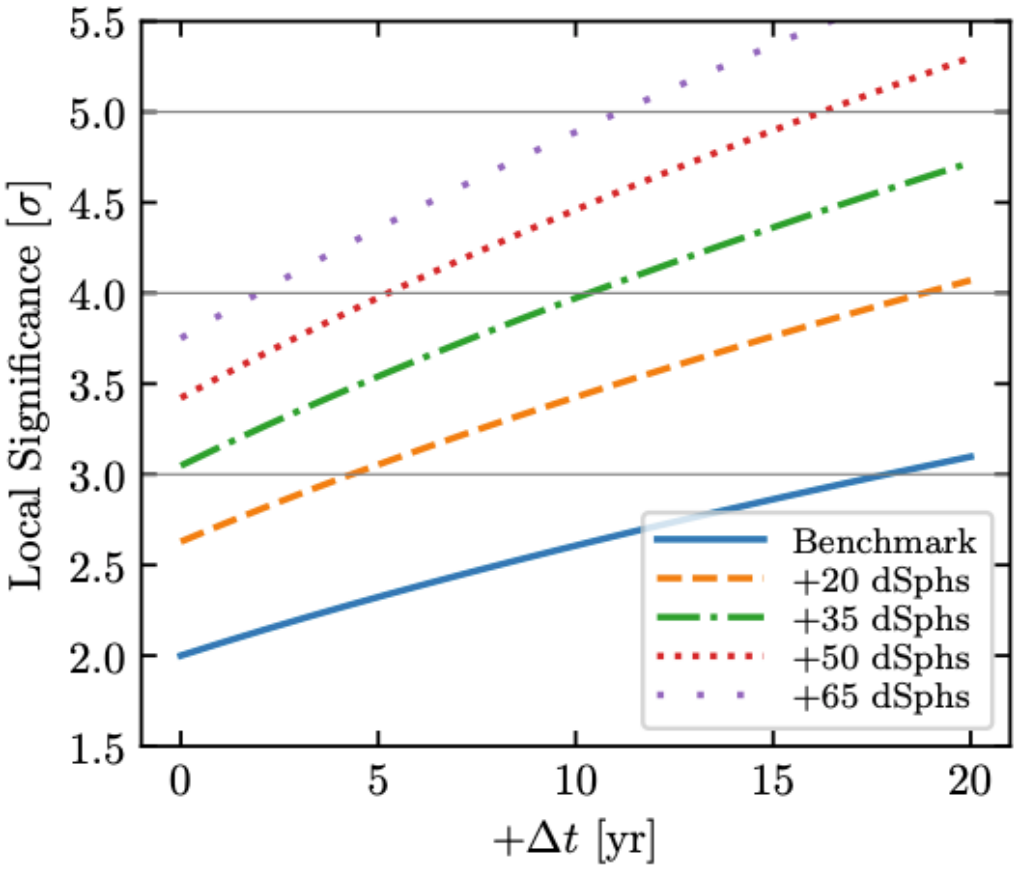
[McDaniel+ '24]



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.]

Future of dSph DM searches





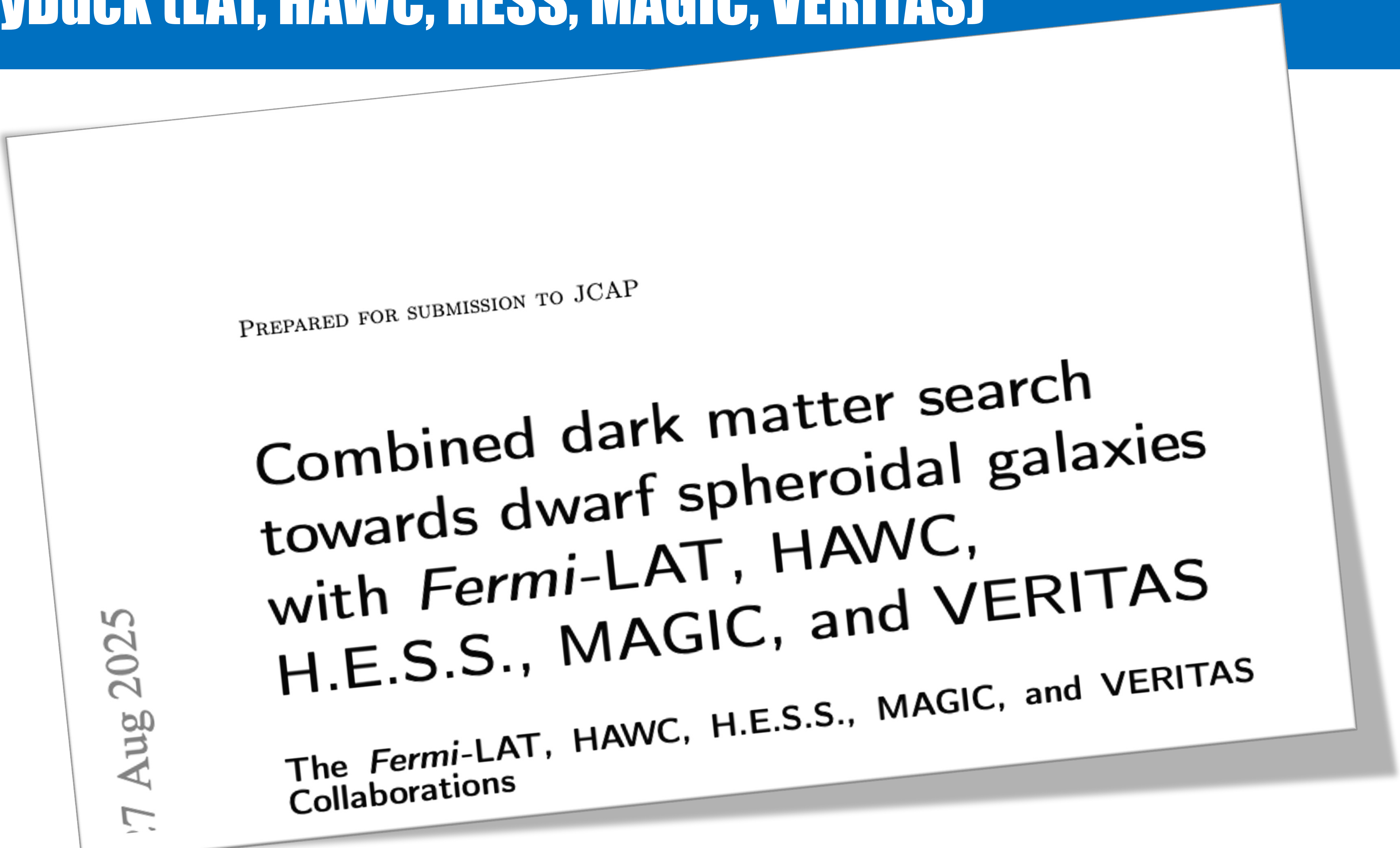
[Fermi-LAT Collaboration '24]

GloryDuck (LAT, HAWC, HESS, MAGIC, VERITAS)

- Perform multi-instrument and multi-target analysis to obtain the most sensitive and robust results
- Joining likelihoods across instruments is challanging
- Focus: dSphs
- Limits driven by LAT sensitivity
- Legacy analysis of the current-generation gamma-ray instruments

GLORY DUCK

GloryDuck (LAT, HAWC, HESS, MAGIC, VERITAS)

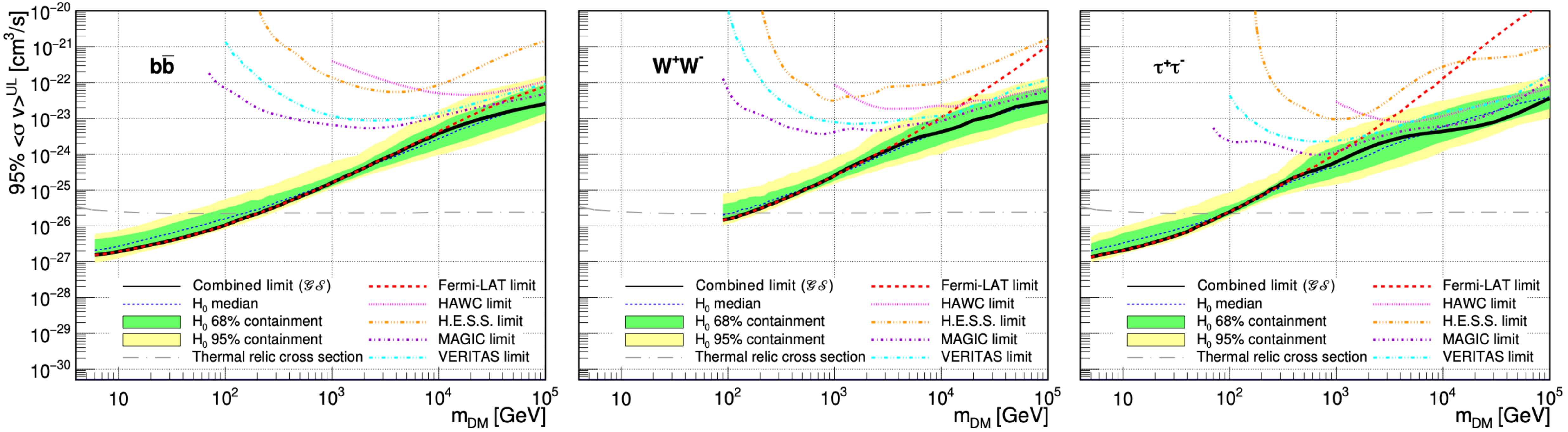

Prepared for submission to JCAP

Combined dark matter search towards dwarf spheroidal galaxies with *Fermi*-LAT, HAWC, H.E.S.S., MAGIC, and VERITAS

The *Fermi*-LAT, HAWC, H.E.S.S., MAGIC, and VERITAS Collaborations

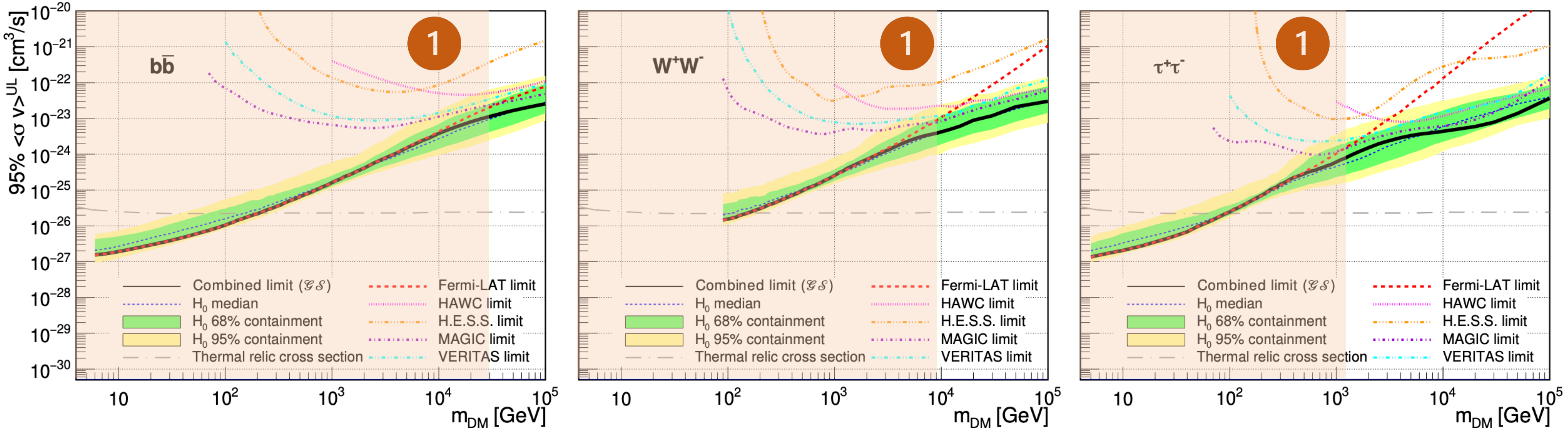
7 Aug 2025

GloryDuck (LAT, HAWC, HESS, MAGIC, VERITAS)



As reported in Celina Armand TeVPA '22 talk.

GloryDuck (LAT, HAWC, HESS, MAGIC, VERITAS)

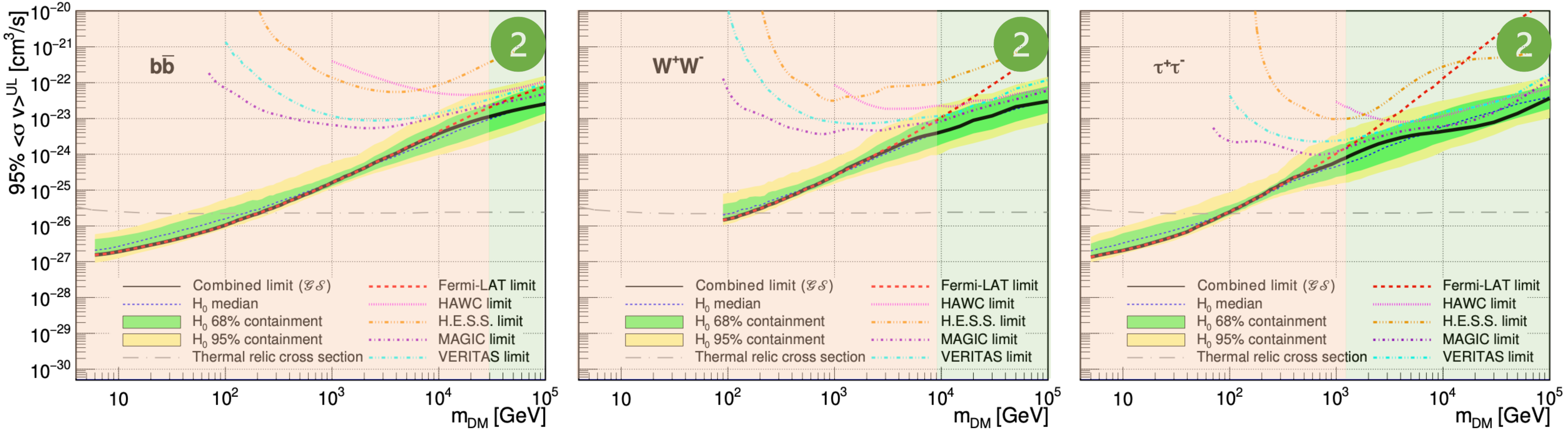


Dominated by *Fermi* LAT 1

As reported in Celina Armand TeVPA '22 talk.

GloryDuck (LAT, HAWC, HESS, MAGIC, VERITAS)

GLORY DUCK



HAWC, HESS, MAGIC, VERITAS take over 2

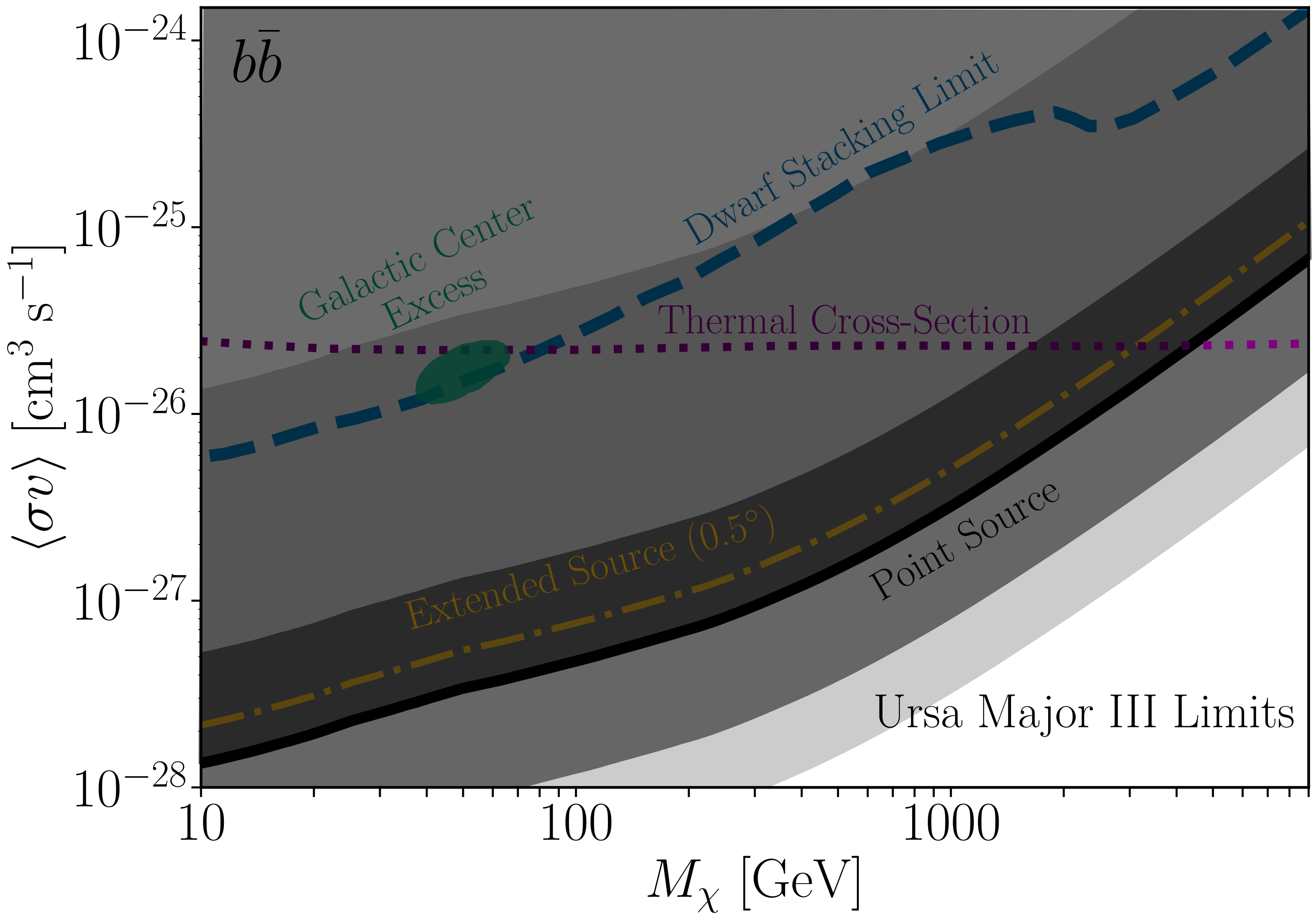
dark matter subhaloes, stellar streams, tidal disturbance/stripping of dwarfs, dark matter spikes, brown dwarfs, etc.

As reported in Celina Armand TeVPA '22 talk.

How many dwarf galaxies do we *really* need?

Maybe just one, but a good one?

Ursa Major III



[MC & Linden '23]

Ursa Major III

[Discovery: Smith+ 2023]

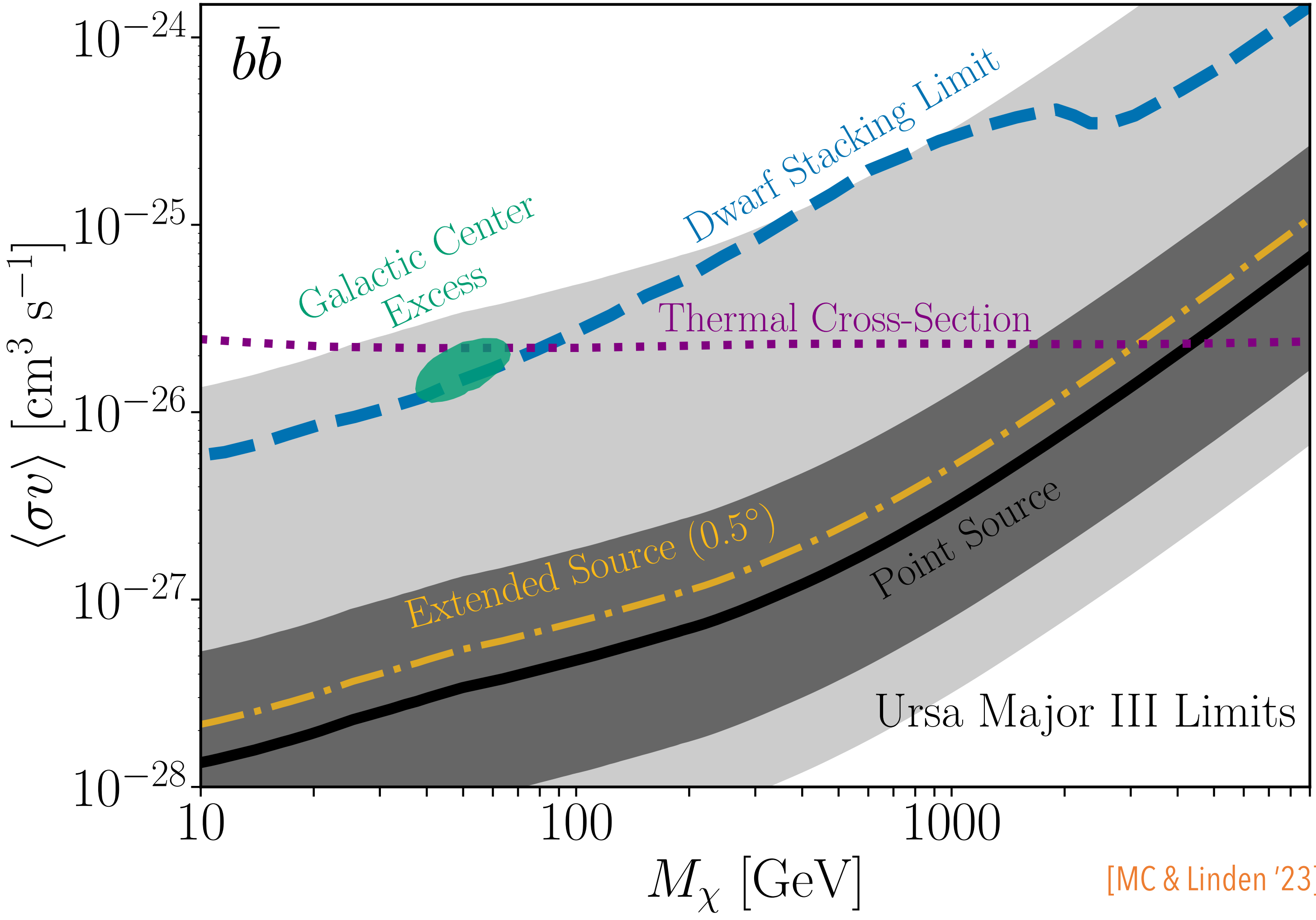
[J-factor: Errani+ 2023]

→ Unstable unless large DM content

→ Nearby (~10 kpc)

→ Strong constraints on DM annihilation

→ Confirming the dark matter density requires deeper optical surveys



[MC & Linden '23]

No Observational Evidence for Dark Matter Nor a Large Metallicity Spread in the Extreme Milky Way Satellite Ursa Major III / UNIONS 1

William Cerny,[1] Daisy Bissonette,[2] Alexander P. Ji,[2,3,4] Marla Geha,[1] Anirudh Chiti,[2,3] Simon E.T. Smith,[5] Joshua D. Simon,[6] Andrew B. Pace,[7] Evan N. Kirby,[8] Kim A. Venn,[5] Ting S. Li,[9] and Alice M. Luna[2,3]

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[5] *Department of Physics and Astronomy, University of Victoria, Victoria, BC, V8P 1A1, Canada*
[6] *Observatories of the Carnegie Institution for Science, 813 Santa Barbara St., Pasadena, CA 91101, USA*
[7] *Department of Astronomy, University of Virginia, 530 McCormick Road, Charlottesville, VA 22904 USA*
[8] *Department of Physics and Astronomy, University of Notre Dame, 225 Nieuwland Science Hall, Notre Dame, IN 46556, USAA*
[9] *Department of Astronomy and Astrophysics, University of Toronto, 50 St. George Street, Toronto ON, M5S 3H4, Canada*

ABSTRACT

The extremely-low-luminosity, compact Milky Way satellite Ursa Major III / UNIONS 1 (UMaIII/U1; $L_V = 11\ L_\odot$; $a_{1/2} = 3$ pc) was found to have a substantial velocity dispersion at the time of its discovery ($\sigma_v = 3.7^{+1.4}_{-1.0}$ km s^{-1}), suggesting that it might be an exceptional, highly dark-matter-dominated dwarf galaxy with very few stars. However, significant questions remained about the system's dark matter content and nature as a dwarf galaxy due to the small member sample ($N = 11$), possible spectroscopic binaries, and the lack of any metallicity information. Here, we present new spectroscopic observations covering $N = 16$ members that both dynamically and chemically test UMaIII/U1's true nature. From higher-precision Keck/DEIMOS spectra, we find a 95% confidence level velocity dispersion limit of $\sigma_v < 2.3$ km s^{-1}, with a ∼120:1 likelihood ratio favoring the expected stellar-only dispersion of $\sigma_* \approx 0.1$ km s^{-1} over the original 3.7 km s^{-1} dispersion. There is now no observational evidence for dark matter in the system. From Keck/LRIS spectra targeting the Calcium


Draft version October 6, 2025
Typeset using LaTeX **twocolumn** style in AASTeX6…

…remained
…member sample
…information. Here, we present
…both dynamically and chemically test
…DEIMOS spectra, we find a 95% confidence
…, with a ~120:1 likelihood ratio favoring the expected
… over the original 3.7 km s^{-1} dispersion. There is now no
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DES-2025-0921
FERMILAB-PUB-25-0714-LDRD

Draft version October 14, 2025
Typeset using LaTeX **twocolumn** style in AASTeX631

Ultra-Faint Milky Way Satellites Discovered in Carina, Phoenix, and Telescopium with DELVE Data Release 3

C. Y. Tan[1,2,3], W. Cerny[4,*], A. B. Pace[5,*], J. A. Sharp[1,6], K. Overdeck[1,6,3], A. Drlica-Wagner[7,1,6,3], J. D. Simon[8], B. Mutlu-Pakdil[9], D. J. Sand[10], A. M. Senkevich[11], D. Erkal[11], P. S. Ferguson[12], F. Sobreira[13,14], K. R. Atzberger[5], J. L. Carlin[15], A. Chiti[6,1], D. Crnojević[16], A. P. Ji[1,6], L. C. Johnson[17], T. S. Li[18], G. Limberg[1], C. E. Martínez-Vázquez[19], G. E. Medina[18], V. M. Placco[20], A. H. Riley[21,22], E. J. Tollerud[23], A. K. Vivas[24], T. M. C. Abbott[24], M. Aguena[25,26], O. Alves[27], D. Bacon[28], S. Bocquet[29], D. Brooks[30], D. L. Burke[31,32], R. Camilleri[33], J. A. Carballo-Bello[34], A. Carnero Rosell[35,26,36], J. Carretero[37], T.-Y. Cheng[38], Y. Choi[20], L. N. da Costa[26], M. E. da Silva Pereira[39], T. M. Davis[33], J. De Vicente[40], S. Desai[41], P. Doel[30], S. Everett[42], B. Flaugher[43], J. Frieman[6,43,1], J. García-Bellido[44], D. Gruen[29], G. Gutierrez[43], S. R. Hinton[33], D. L. Hollowood[45], D. J. James[46], K. Kuehn[47,48], S. Lee[49], J. L. Marshall[50], J. Mena-Fernández[51], F. Menanteau[52,53], R. Miquel[54,37], J. Myles[55], M. Navabi[11], D. L. Nidever[56], R. L. C. Ogando[57,58], A. A. Plazas Malagón[31,32], A. Porredon[40,59], S. Samuroff[60,37], E. Sanchez[40], D. Sanchez Cid[40,61], I. Sevilla-Noarbe[40], M. Smith[62], E. Suchyta[63], M. E. C. Swanson[52], V. Vikram[64], A. R. Walker[24]
And A. Zenteno[24]
(DELVE and DES Collaborations)

We checked…no emission in *Fermi*…

Segue into conclusions

Dwarf AGN

→ No individual detections in **γ** rays – emission suppressed or shifted to softer spectra.
→ Joint-likelihood hints at mass-dependent **γ**-ray scaling with IMBHs – warrants deeper (preferably MeV) study.

dSphs

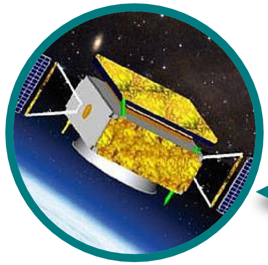
→ Combined analyses remain consistent with limits; hints persist but are statistically marginal.
→ Next-generation surveys (Rubin/LSST, DECam, etc.) will expand the dSph census and improve sensitivity.

Looking forward

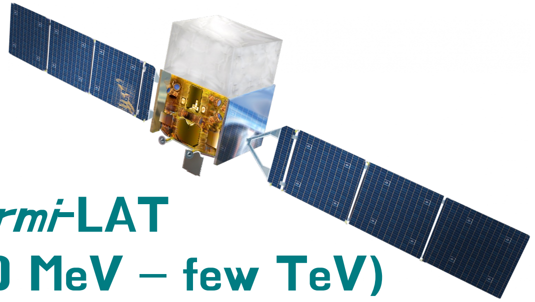
→ Joint, multi-instrument efforts (LAT, HAWC, H.E.S.S., MAGIC, VERITAS) set the stage for a legacy analysis of the **γ**-ray sky.
→ The smallest galaxies may be our ticket to fame.

γ-rays (past/present)

*approximate scale



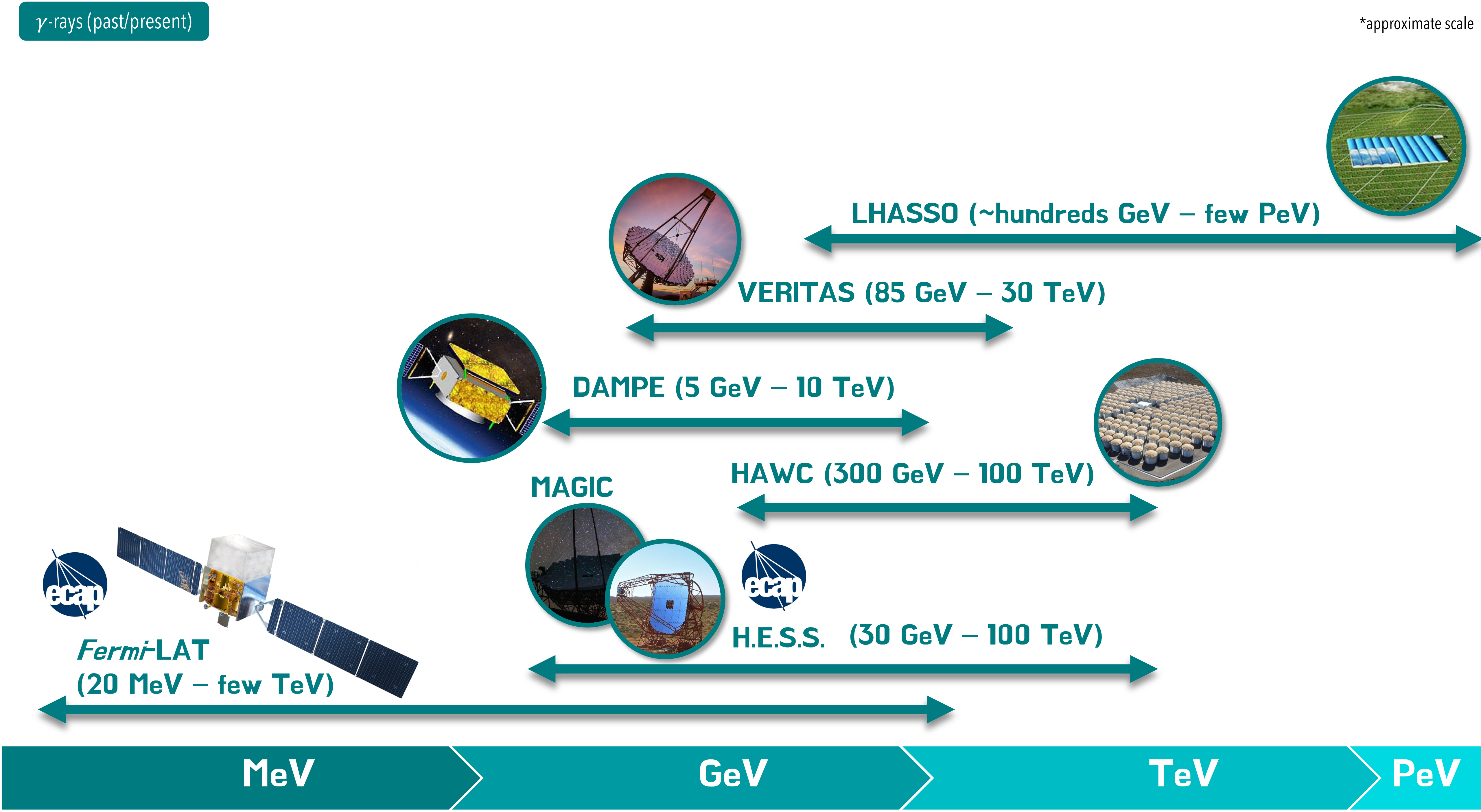
DAMPE (5 GeV – 10 TeV)

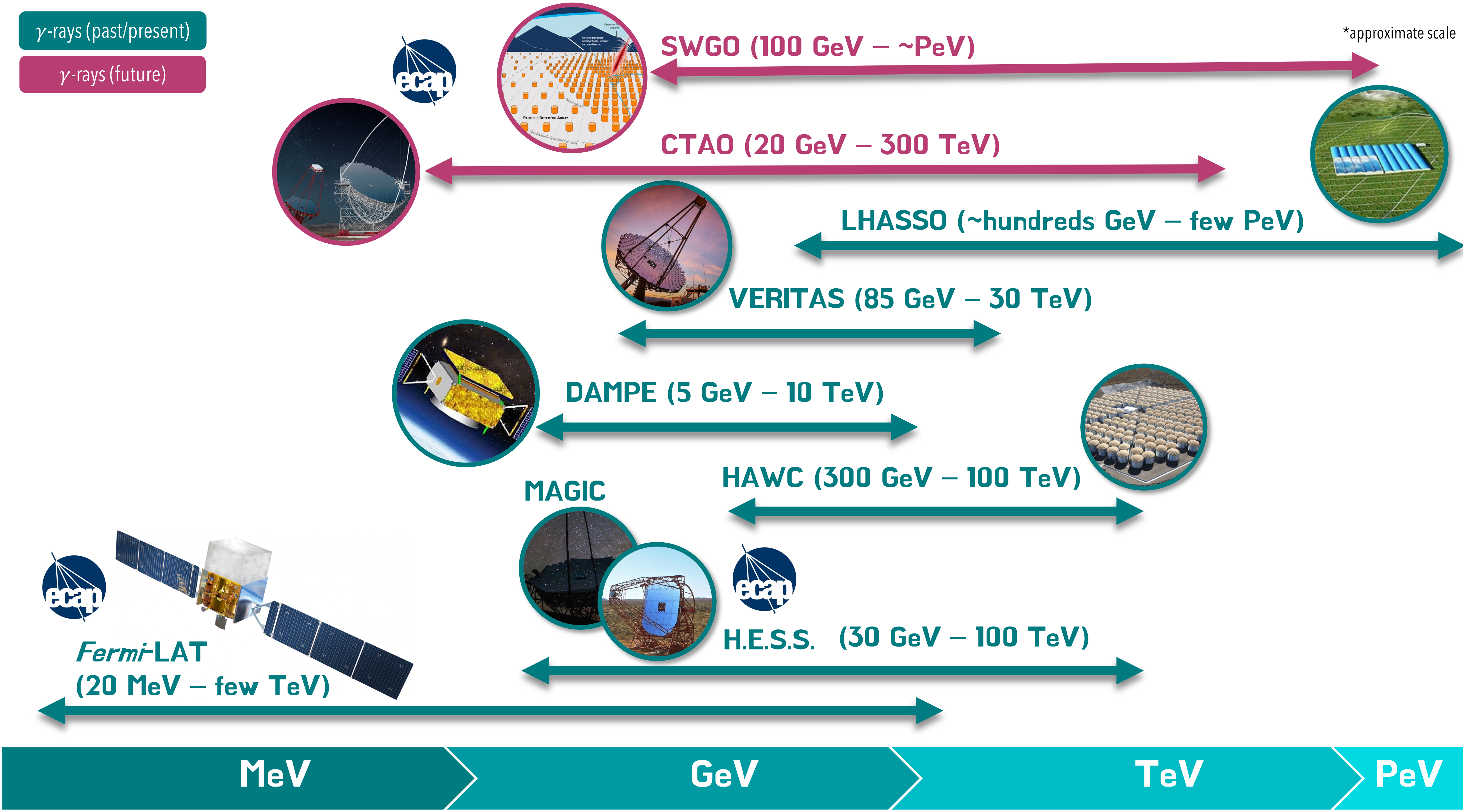


Fermi-LAT
(20 MeV – few TeV)

MeV GeV TeV PeV

γ-rays (past/present)



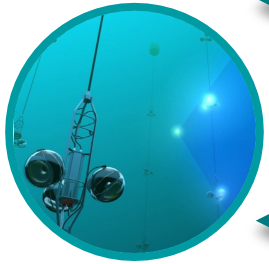


γ-rays (past/present)
γ-rays (future)
*approximate scale
SWGO (100 GeV – ~PeV)
CTAO (20 GeV – 300 TeV)
LHASSO (~hundreds GeV – few PeV)
VERITAS (85 GeV – 30 TeV)
DAMPE (5 GeV – 10 TeV)
HAWC (300 GeV – 100 TeV)
MAGIC
H.E.S.S. (30 GeV – 100 TeV)
Fermi-LAT
(20 MeV – few TeV)
ecap
ecap
ecap
MeV
GeV
TeV
PeV

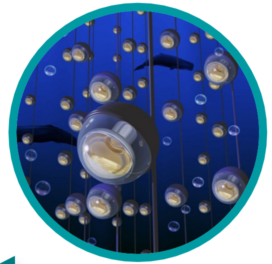
νs (past/present)

*approximate scale

IceCube (50 GeV – several PeV)



ANTARES (50 GeV – 100 TeV)



KM3NeT/ARCA (100 GeV – several PeV)

KM3NeT/ORCA (1 – 100 GeV)

MeV | GeV | TeV | PeV

νs (past/present)

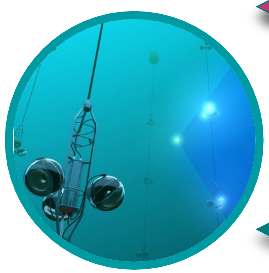
νs (future)

*approximate scale

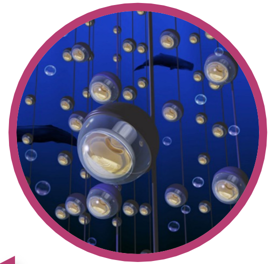
IceCube-Gen2
In the works: 8 km^3 + radio

IceCube (50 GeV – several PeV)

IceCube Upgrade



ANTARES (50 GeV – 100 TeV)



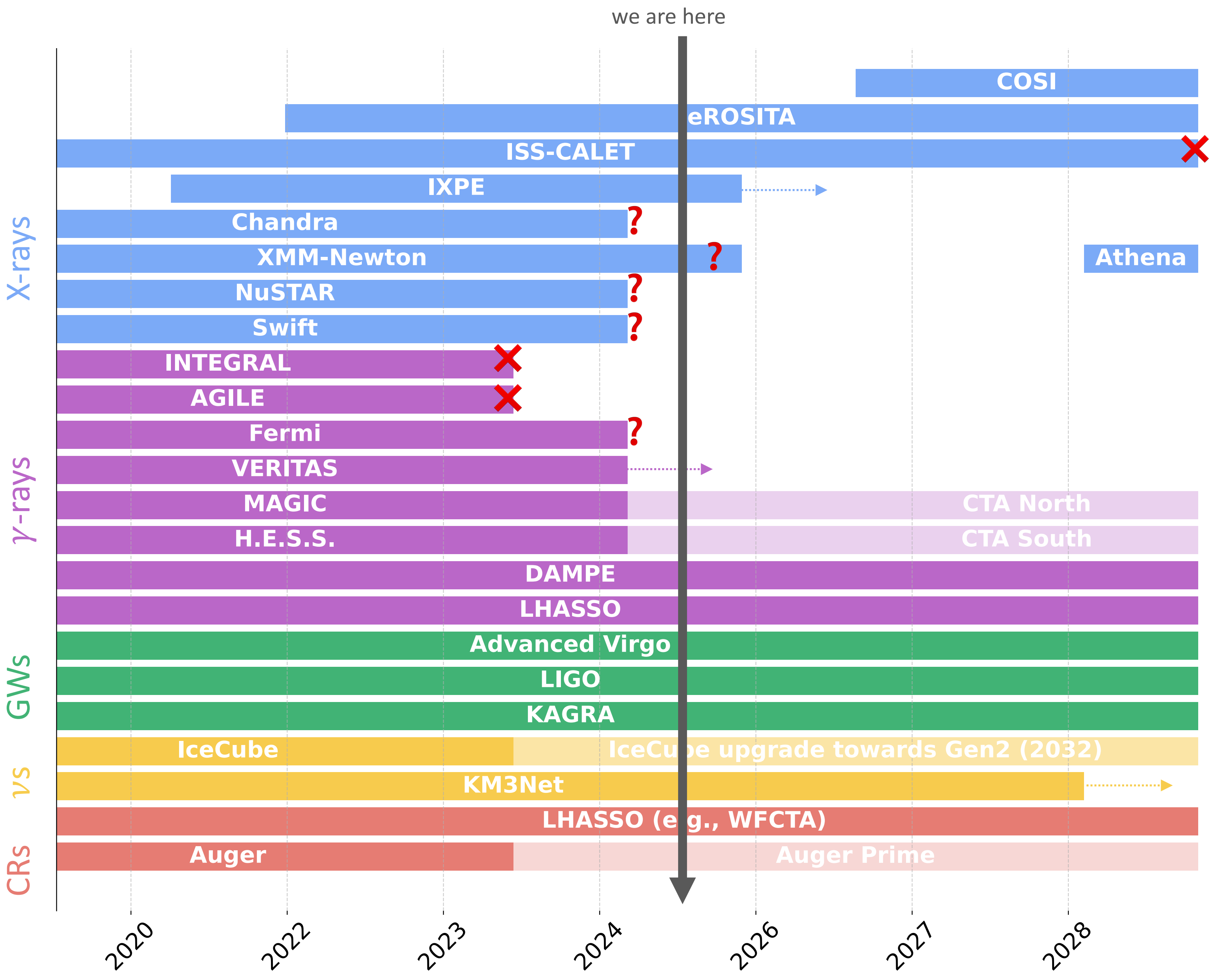
KM3NeT/ARCA (100 GeV – several PeV)

ORCA

KM3NeT

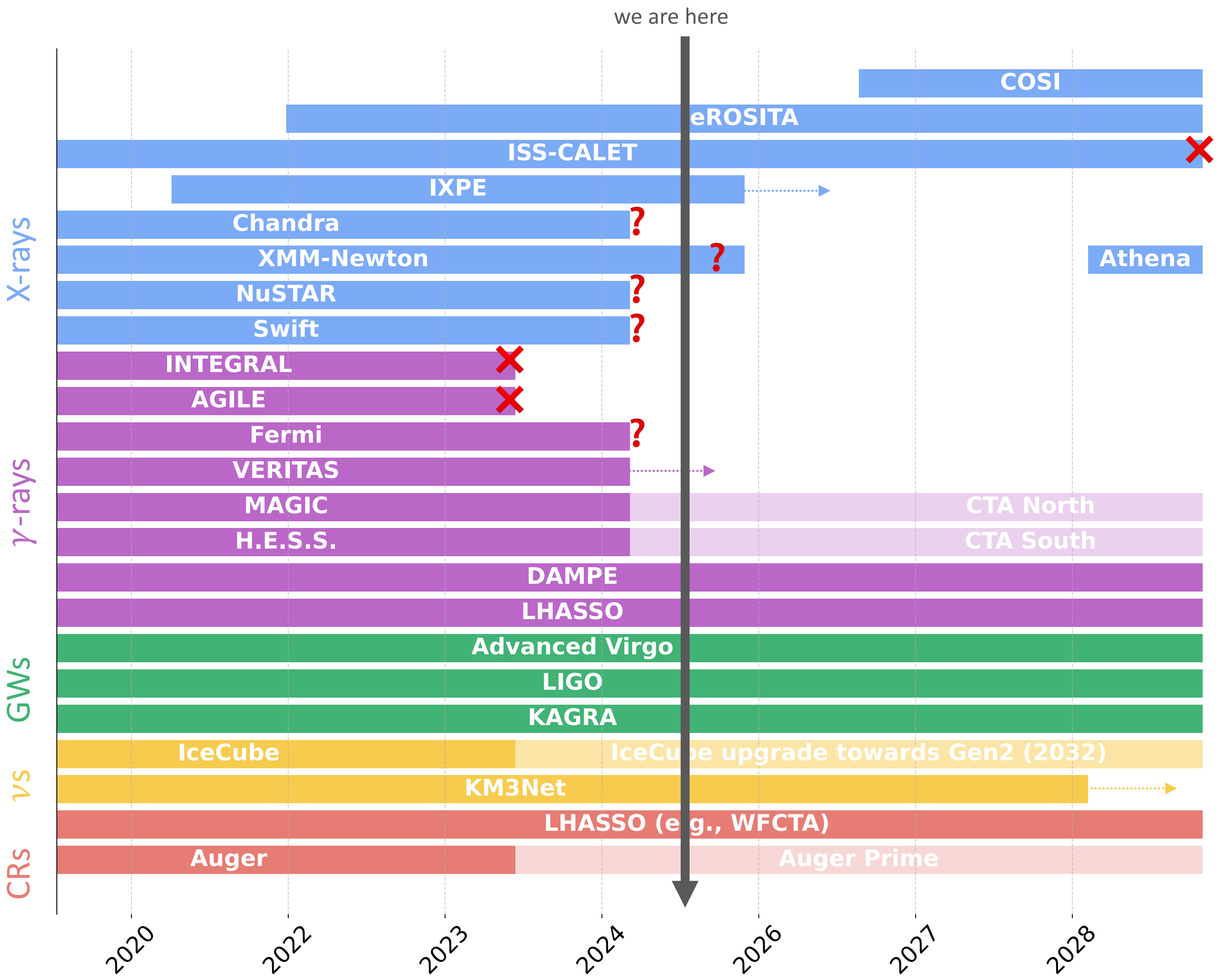
KM3NeT/ORCA (1 – 100 GeV)

MeV GeV TeV PeV



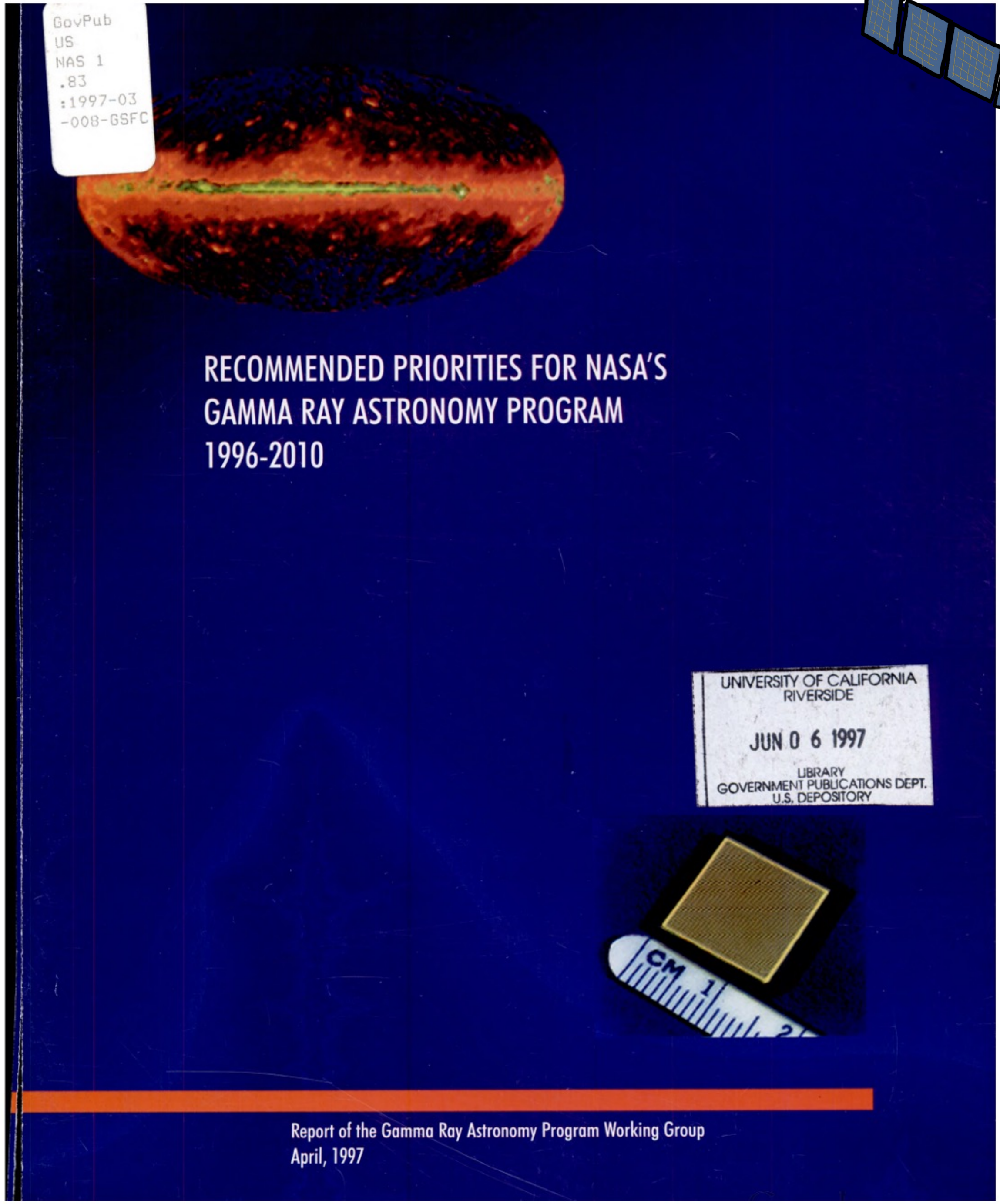
newASTROGAM
AMEGO
AMEGO-X
…

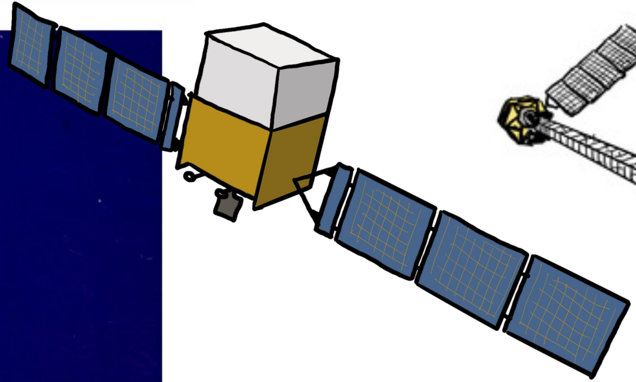
VLAST?
HERD?

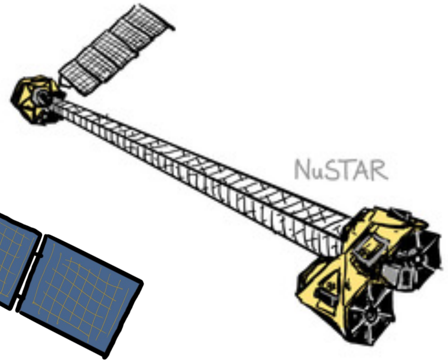


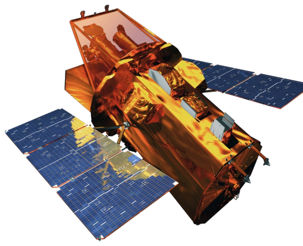
~~newASTROGAM~~
~~AMEGO~~
~~AMEGO-X~~
...

VLAST?
HERD?

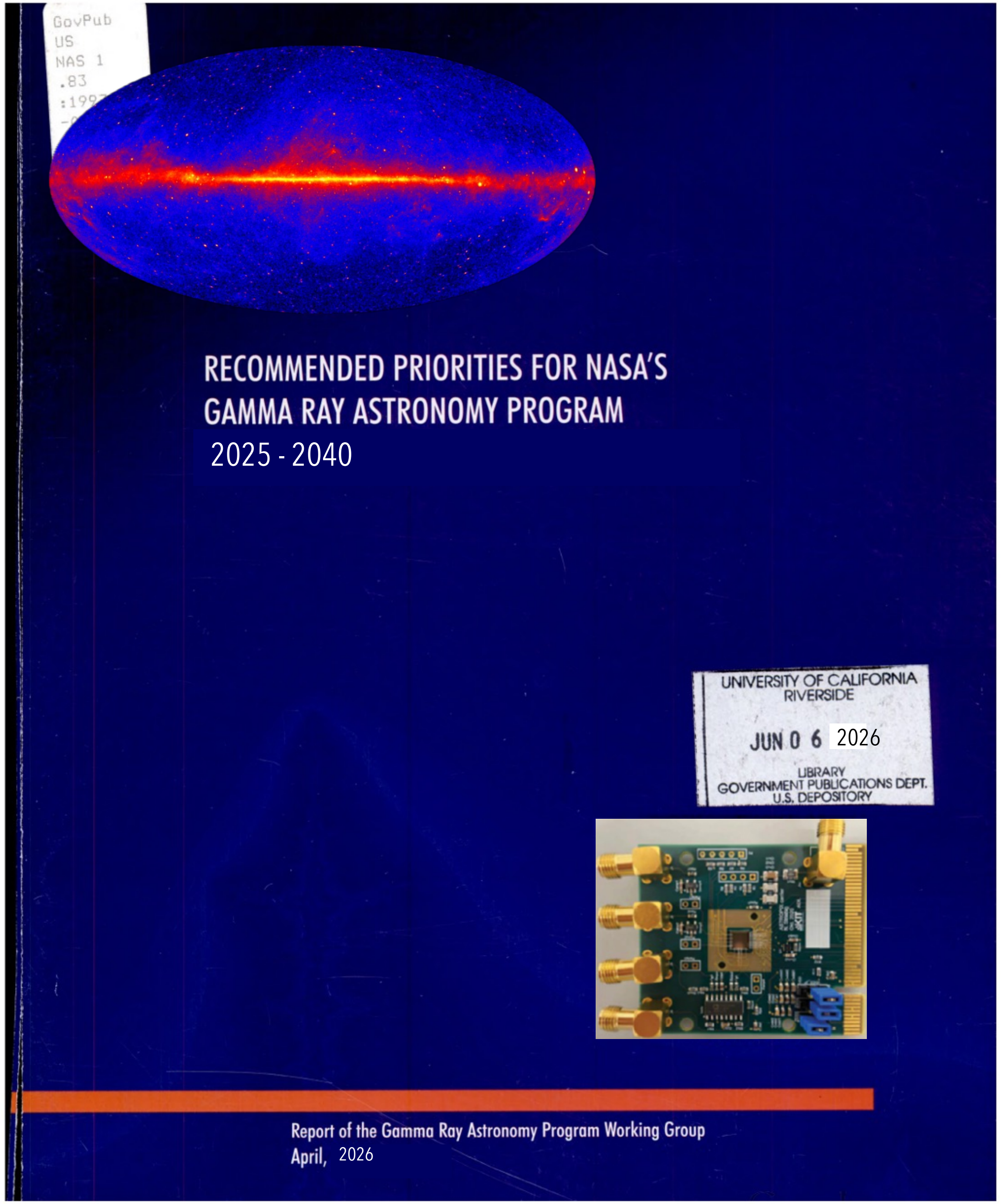








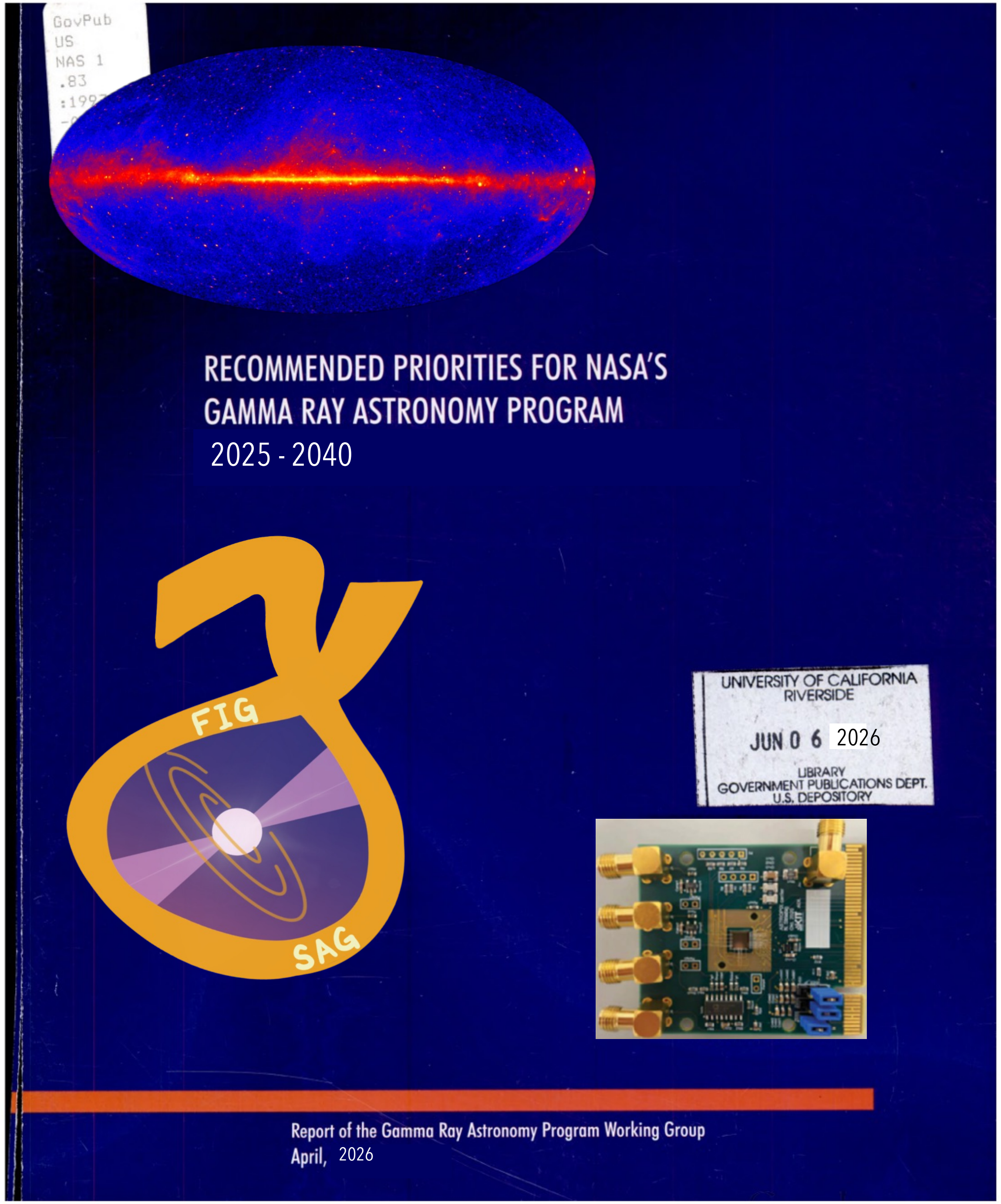
- Intermediate Missions: Fermi, NuSTAR and now COSI
- MIDEX and SMEX: Swift and NICER
- Technology: a robust technology development program (SiPMs, new scintillators, upgraded silicon detectors, etc)
- Balloons (+ CubeSats!): long duration balloons enabled COSI, LEAP, etc.
- Data Analysis & Theory: mainly supported through GI programs
- TeV Astronomy: VERITAS, HESS, HAWC, and MAGIC.



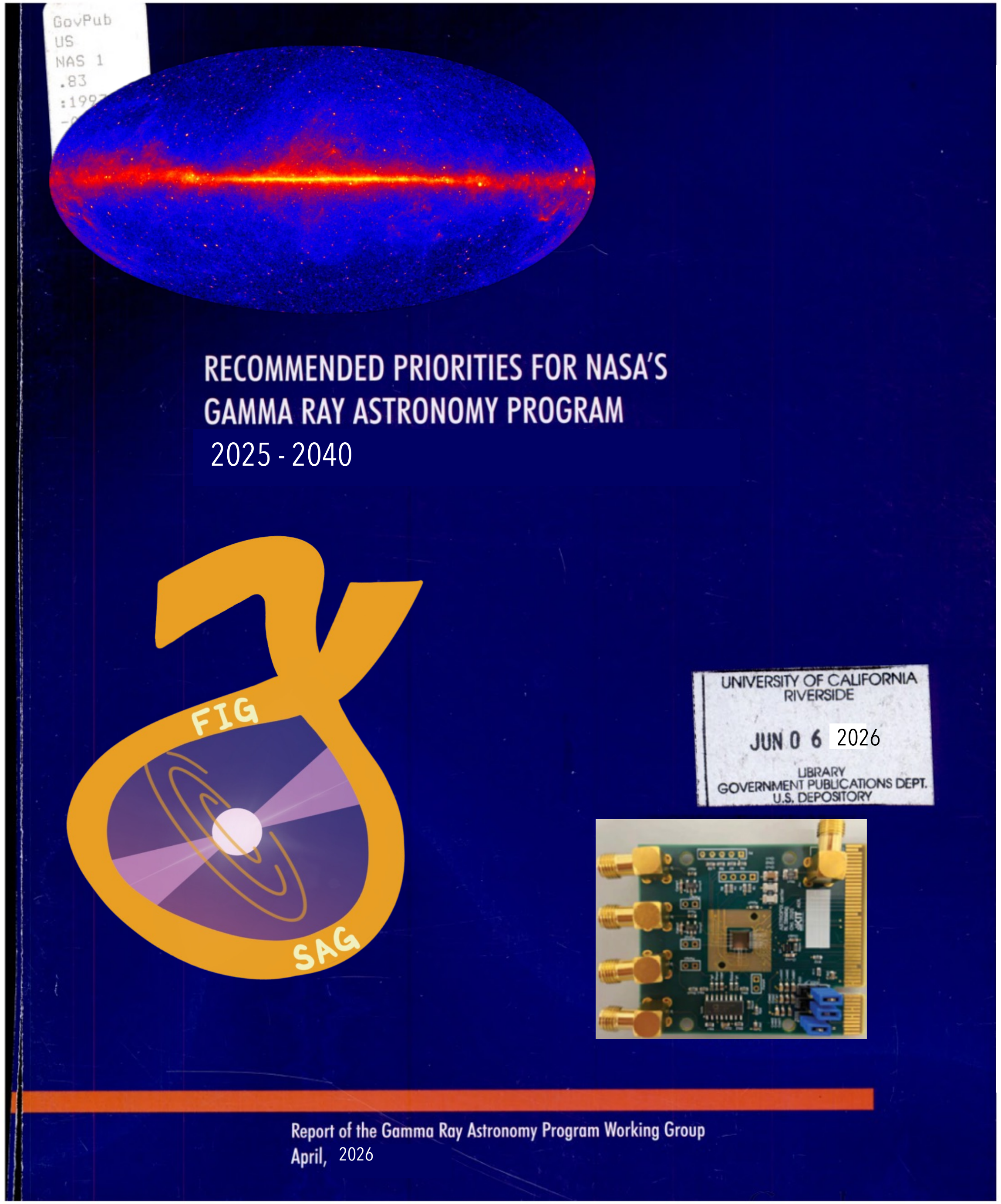
RECOMMENDED PRIORITIES FOR NASA'S
GAMMA RAY ASTRONOMY PROGRAM
2025 - 2040

Report of the Gamma Ray Astronomy Program Working Group
April, 2026

[insert your space-based gamma-ray wish list]



[insert your space-based gamma-ray wish list]



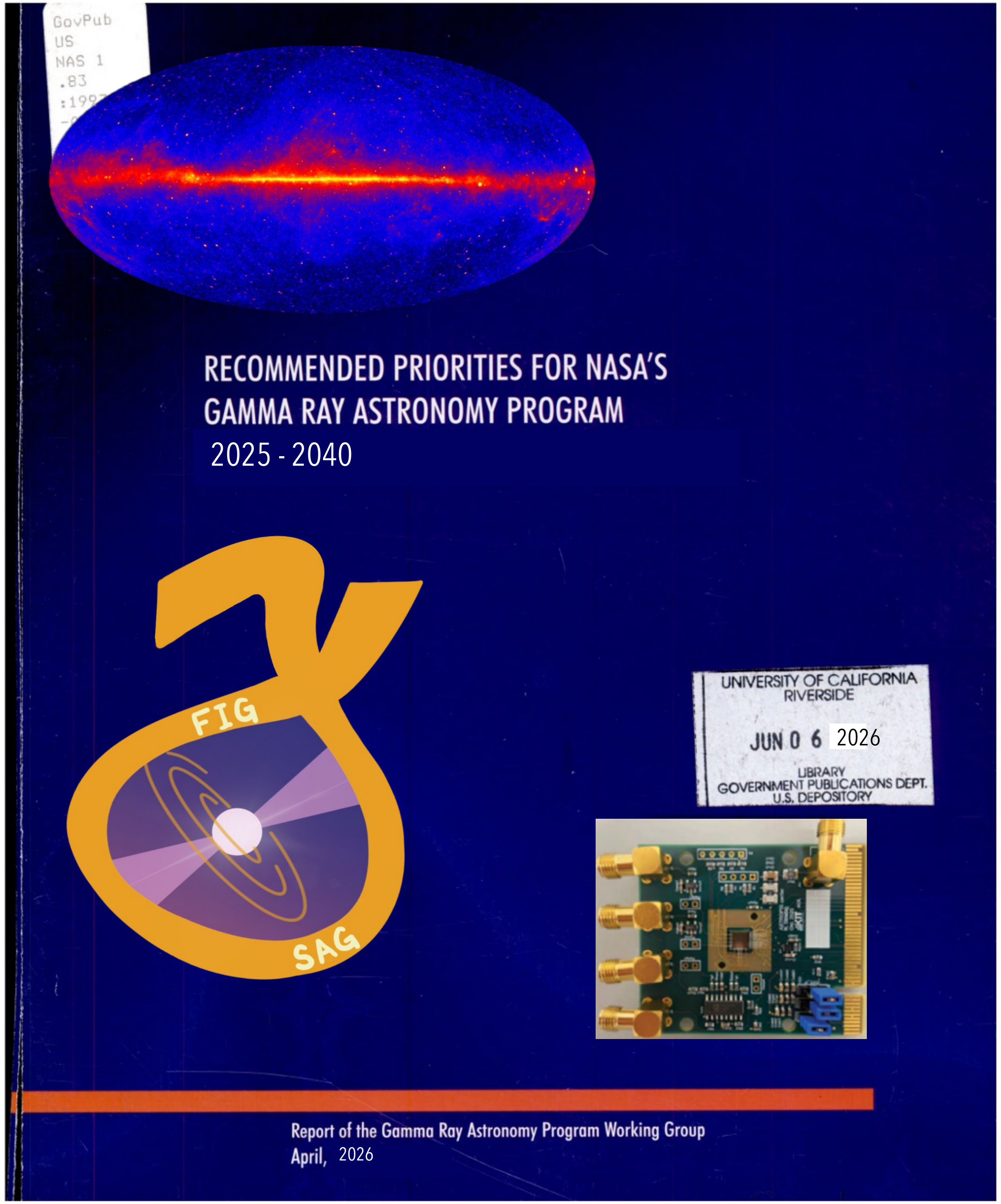
Submitted to the NASA Astrophysics Advisory Committee by

The Future Innovations in Gamma Ray Science Analysis Group

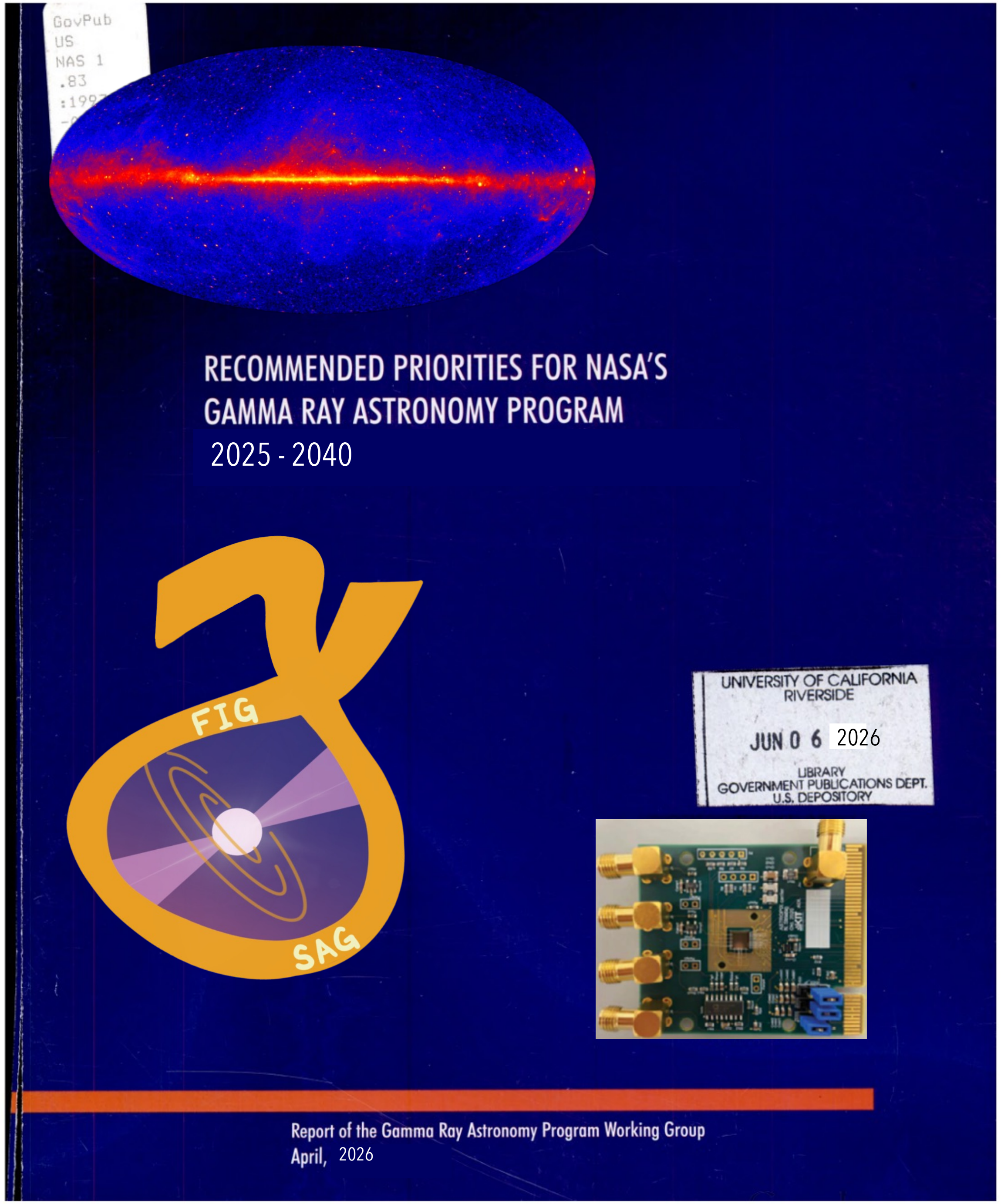
Future Innovations in Gamma Rays SAG: A Report on Gamma-ray Science Objectives Beyond 2025

Chris Fryer[1], C. Michelle Hui[2], Paolo Coppi[3], Milena Crnogorcevic[4], Tiffany R. Lewis[5], Marcos Santander[6], and Zorawar Wadiasingh[7]

[1]Los Alamos National Laboratory
[2]NASA Marshall Space Flight Center
[3]Yale University
[4]Stockholm University
[5]Michigan Technological University
[6]University of Alabama, Huntsville
[7]University of Maryland, College Park

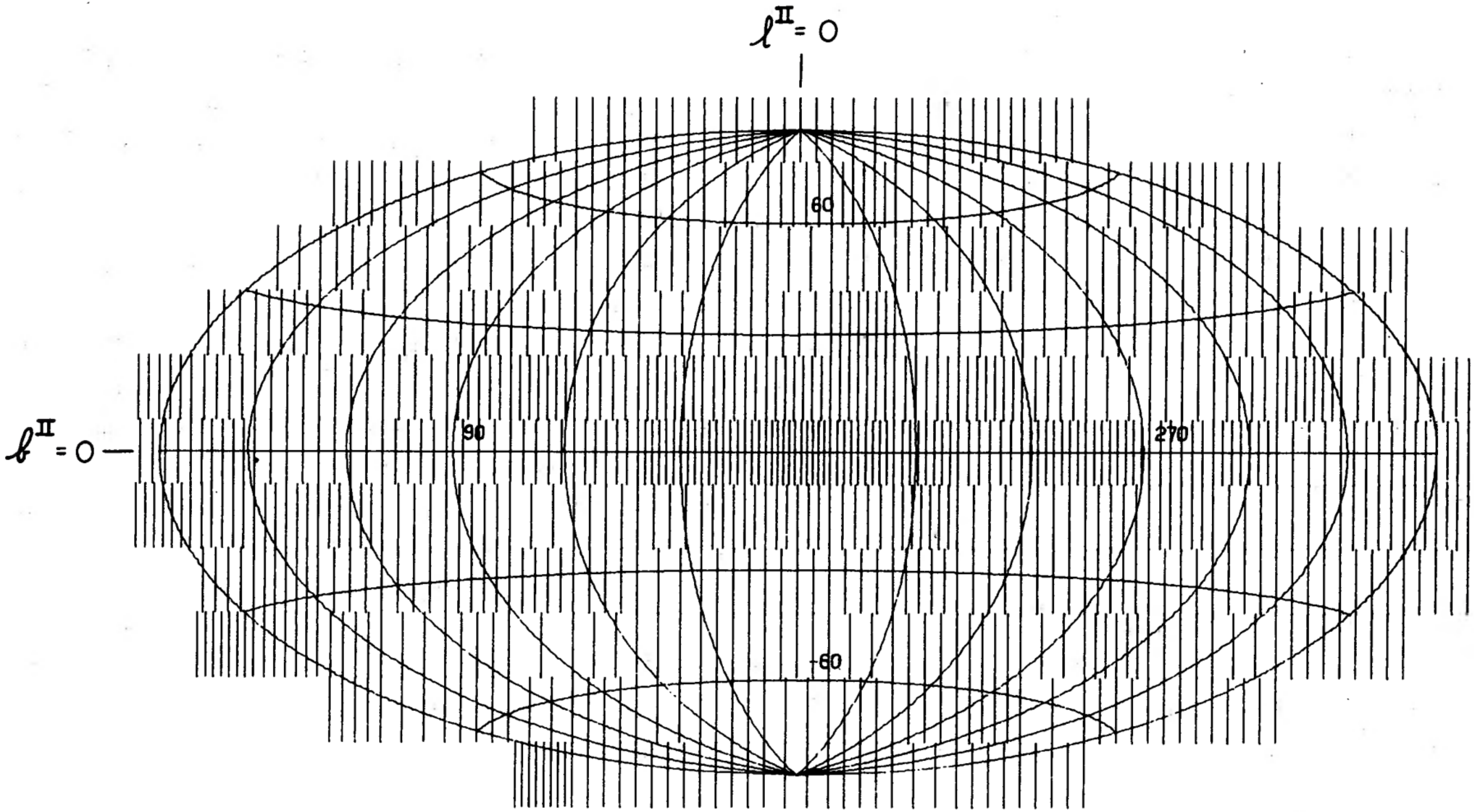


- Overview - purpose & limitations in scope
- Context - state of the field & progress since the 2020 Decadal
- Key Science Opportunities that Require Gamma-ray Observations
    - Nuclear Decay requires high angular resolution & high sky coverage
    - GRBs need high sky coverage & fast alerts
    - Blazars need high effective area & polarization
    - Pulsar Timing Arrays need high precision timing and high angular resolution
    - Dark Matter
- Theory & computation - are currently limited by lack of precision in observables
- Technology Advancement - a lot has happened that has not flown
- Mission Capabilities & Infrastructure - the success of missions requires that the surrounding infrastructure function appropriately.

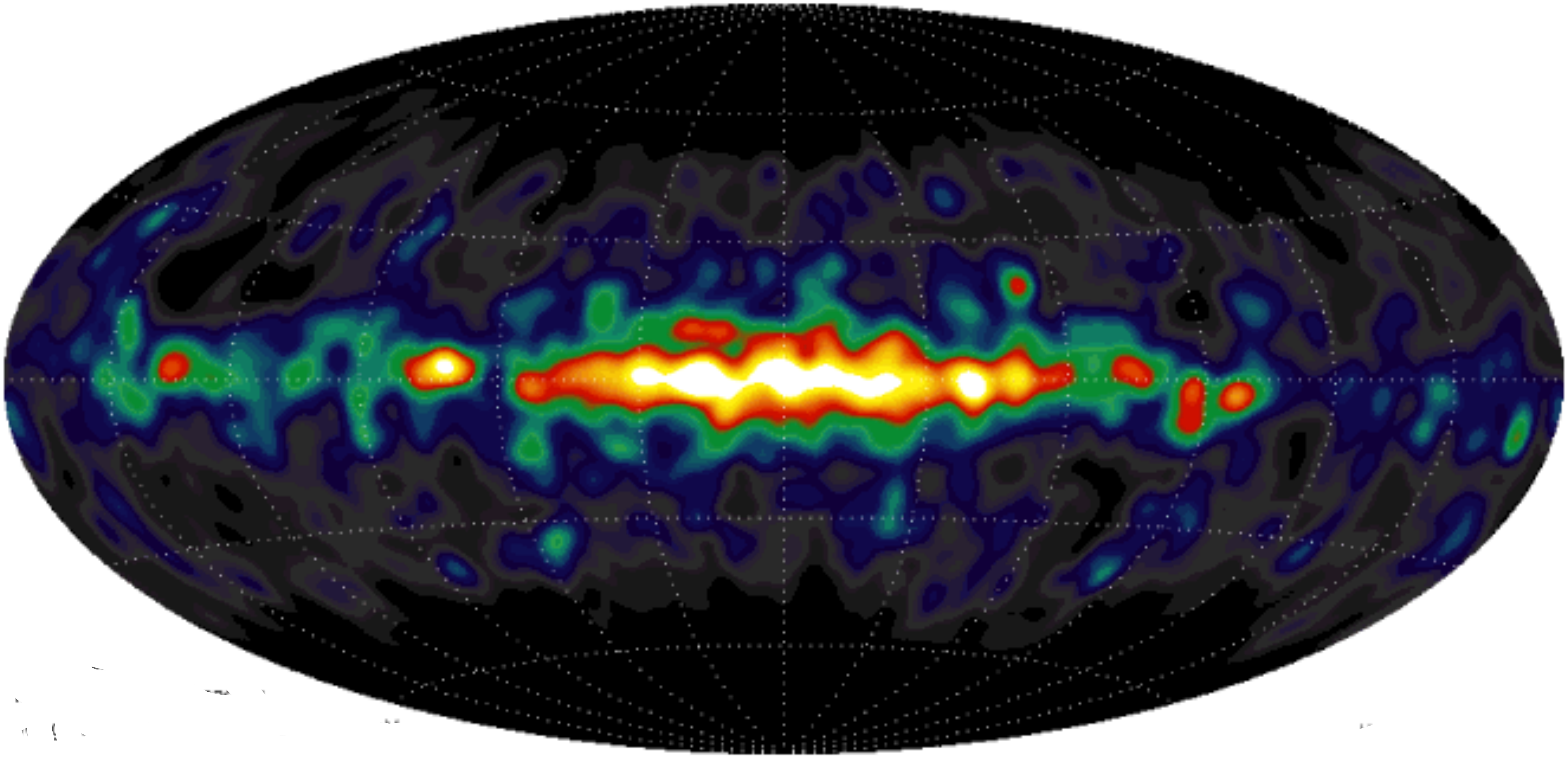


JHEAP Special Issue

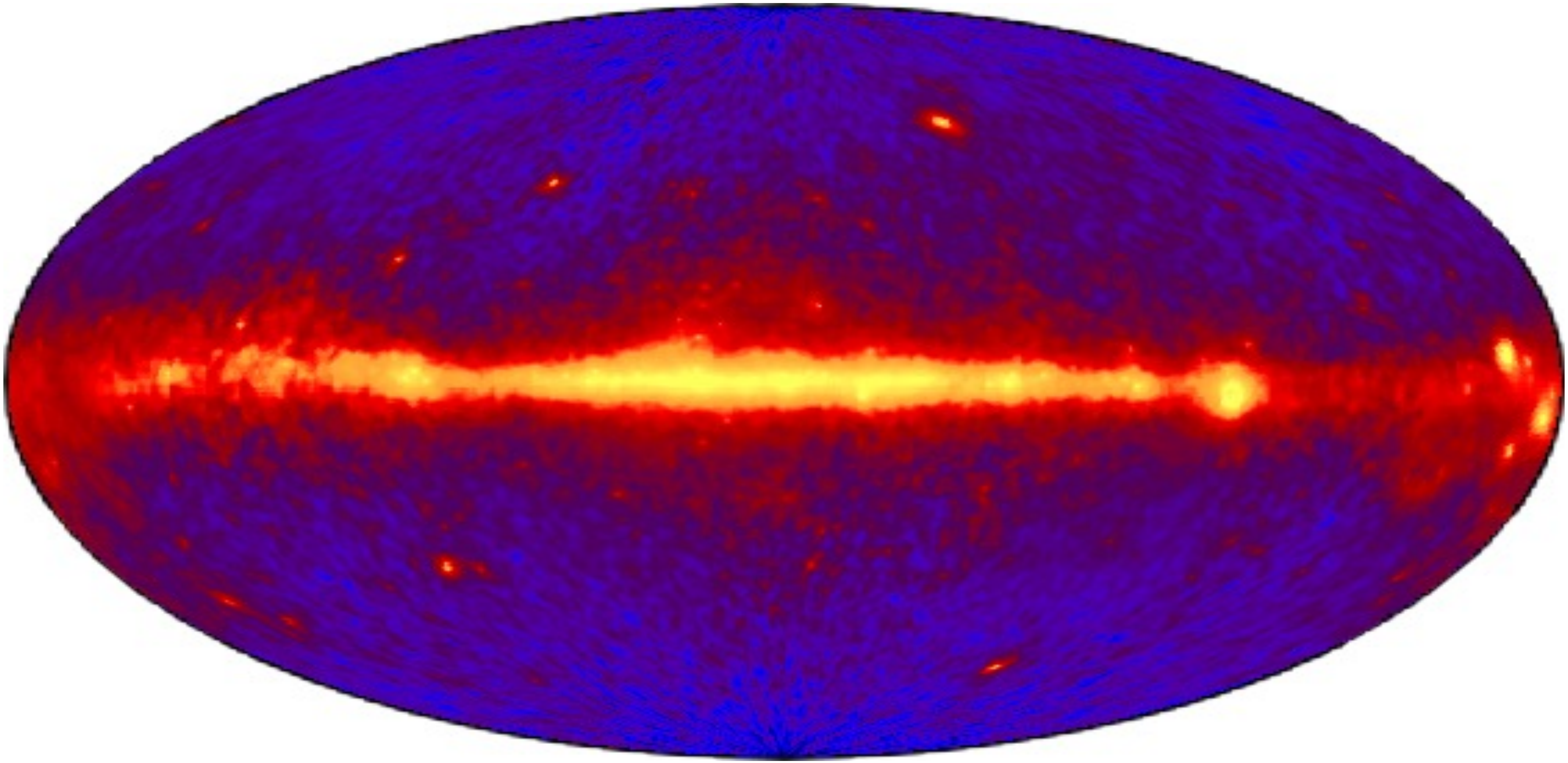
- Provides a place to document supporting work and credit authors of individual plots, studies and strategic arguments.
- Currently accepting manuscripts **until 7 Nov 2025** (likely extended)
- If you are intending to submit an article and have not been in touch with us, please reach out now.
- If you have an idea of something you would like to help us demonstrate, then please let us know.



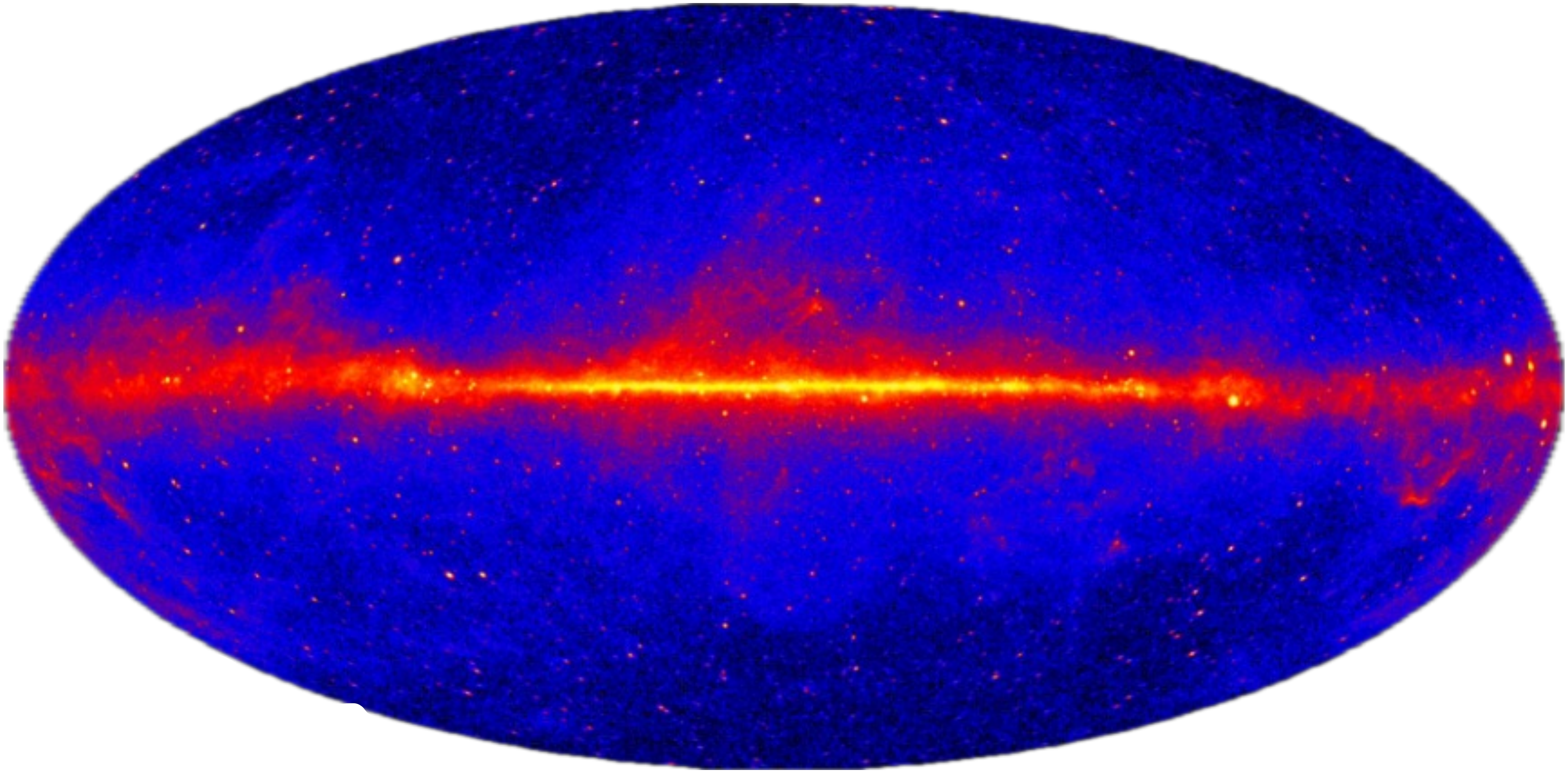
1968, Orbiting Solar Observatory, OSO-3 (~50 MeV)



2000, COMPTEL (onboard CGRO), 1–30 MeV



2000, EGRET (onboard CGRO), above 100 MeV



2020, LAT (onboard *Fermi*), above 500 MeV

Physics of the Cosmos

Exploring fundamental questions regarding the physical forces of the universe

Due to the lapse in federal government funding, NASA is not updating this website. We sincerely regret this inconvenience.

Future Innovations in Gamma Rays (FIG SAG)

Website	https://pcos.gsfc.nasa.gov/sags/figsag.php
Slack Workspace	https://docs.google.com/forms/d/e/1FAIpQLSfsgnb1OUQ3jISGiIM_3abQsKoHvzlgWBZP3meMXJxUwRHI5w/viewform
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News

22 September 2025

Final Reminder: PhysCOS Second Early Career Workshop on 23-25 September 2025

» Details