Artist's impression of a relativistic jet of a GRB.
Credit: DESY, Science Communication Lab

NEW MESSENGERS & NEW PHYSICS

A Survey of the High-energy Universe

CoPS lunch talk
October 30, 2023

Milena Crnogorčević

"ME-E-E!"

- *Taylor Swift*

Artist's impression of a relativistic jet of a GRB.
Credit: DESY, Science Communication Lab

MILENA, THE GRADUATE STUDENT

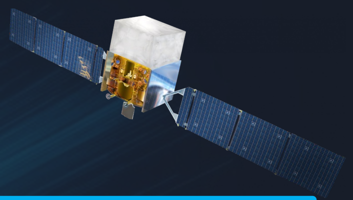
CoPS lunch talk
October 30, 2023

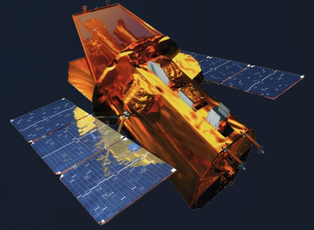
Milena Crnogorčević

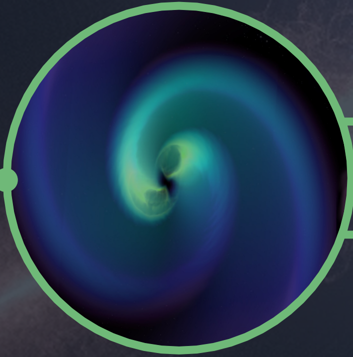
- Milena, the researcher
- Milena, the outreacher
- Milena, the person

MILENA, THE RESEARCHER

New Physics: ALPs x γ





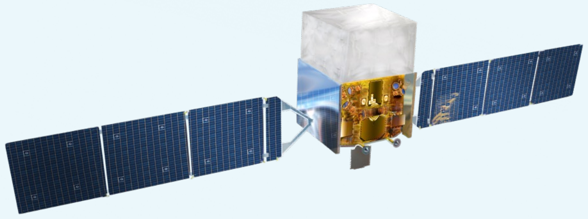


New Messengers I: GWs x γ

New Messengers II: ν x γ

OBSERVATORIES

Fermi



GBM: Gamma-ray Burst Monitor

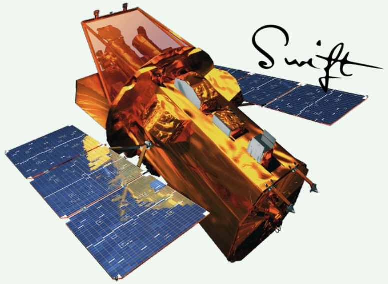
- FoV: entire unocculted sky
- 8 keV to 40 MeV
- 2300+ bursts (~1 every day or two)

LAT: Large Area Telescope

- Pair-production telescope
- FoV: 2.4 sr (~20% of sky)
- 20 MeV to >300 GeV

GBM: C. Meegan et al. 2009, LAT: Atwood et al. 2009

Swift



BAT: Burst Alert Telescope

- One of three instruments onboard
- FoV: ~ 2 sr
- Localization ~few arcmin
- 15 keV to 150 keV

Barthelmy et al. 2005

LIGO/*Virgo*/KAGRA

- LIGO: detectors in Hanford, WA, and Livingston, LA
- *Virgo*: Cascina, Italy
- KAGRA: Gifu Prefecture, Japan

- Michelson interferometer gravitational wave detectors

The LVK Collaboration (Abbott et al. 2009)

IceCube

- Neutrino detector located at the South Pole
- 5,000+ optical modules
- ~10 GeV to >1 EeV
- All-sky (Northern vs. Southern hemisphere)

The IceCube Collaboration (Aartsen et al. 2017)

PROJECT I.
SEARCHING FOR AXION-LIKE PARTICLES WITH *FERMI*

PROJECT II.
A JOINT *FERMI* & *SWIFT* ANALYSIS OF THE THIRD GRAVITATIONAL-WAVE OBSERVING RUN

PROJECT III.
CROSS-CORRELATING ICECUBE NEUTRINOS AND THE *FERMI* UNRESOLVED GAMMA-RAY SKY

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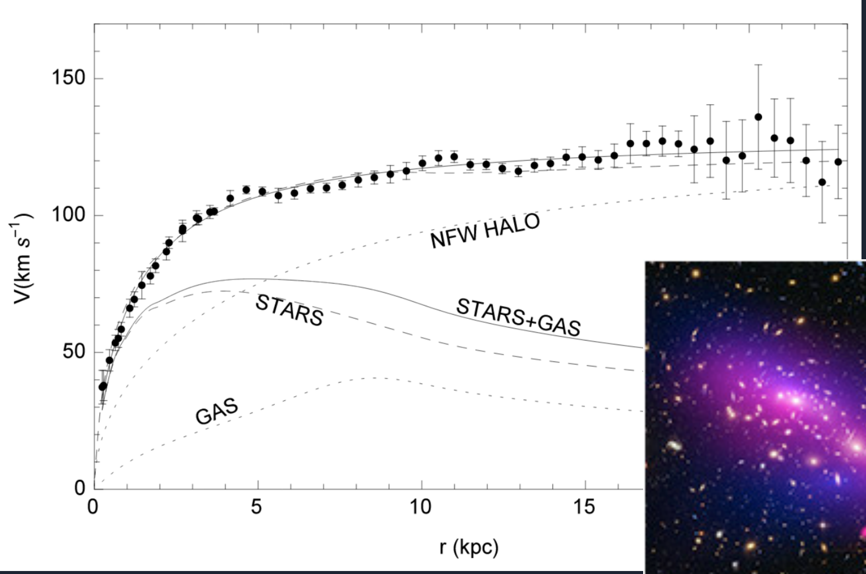
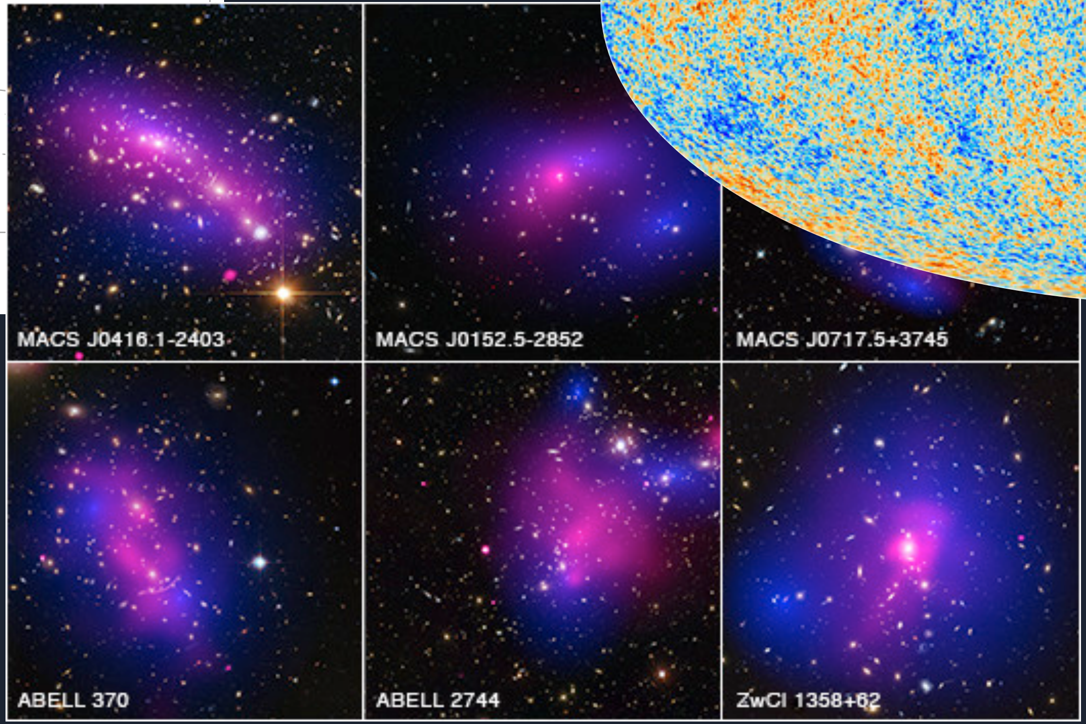
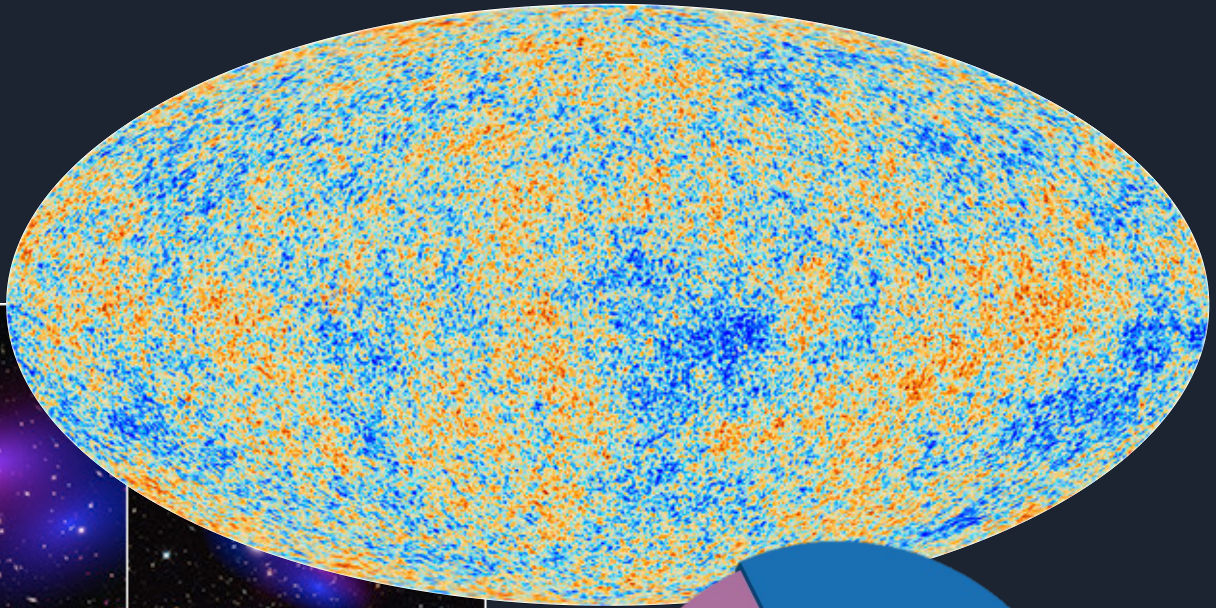
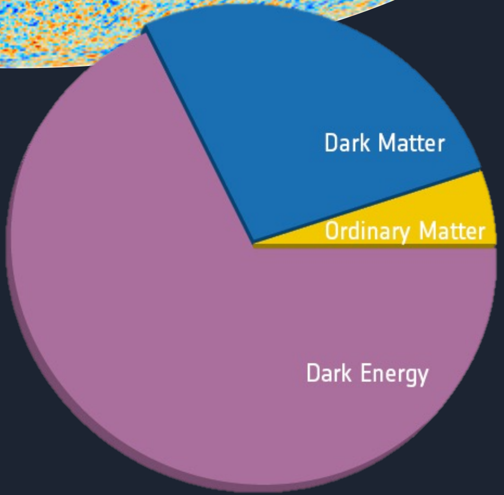
OVERWHELMING EVIDENCE FOR THE EXISTENCE OF DARK MATTER







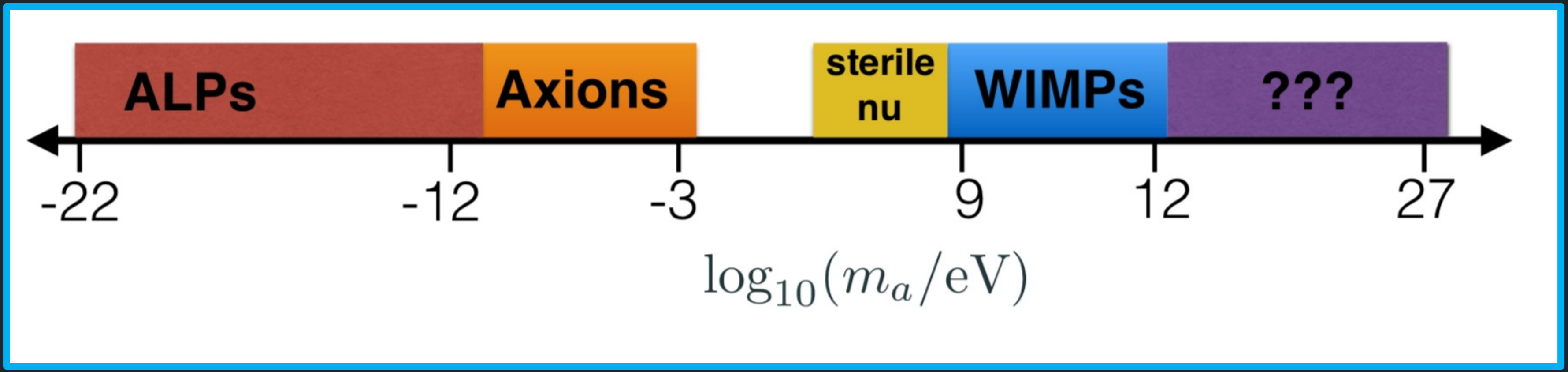


X-ray: NASA/CXC/Ecole Polytechnique Federale de Lausanne, Switzerland/D.Harvey & NASA/CXC/Durham Univ/R.Massey; Optical & Lensing Map: NASA, ESA, D. Harvey (Ecole Polytechnique Federale de Lausanne, Switzerland) and R. Massey (Durham University, UK)

WHAT ARE AXION-LIKE PARTICLES (ALPS)?

- Extension of the axion, a proposed solution of the strong charge-parity problem in QCD

- WISPs: weakly-interacting sub-eV particles (mass $\lesssim 10^{-10}$ eV)



WHAT ARE AXION-LIKE PARTICLES (ALPS)?

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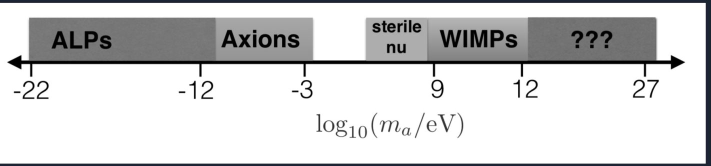
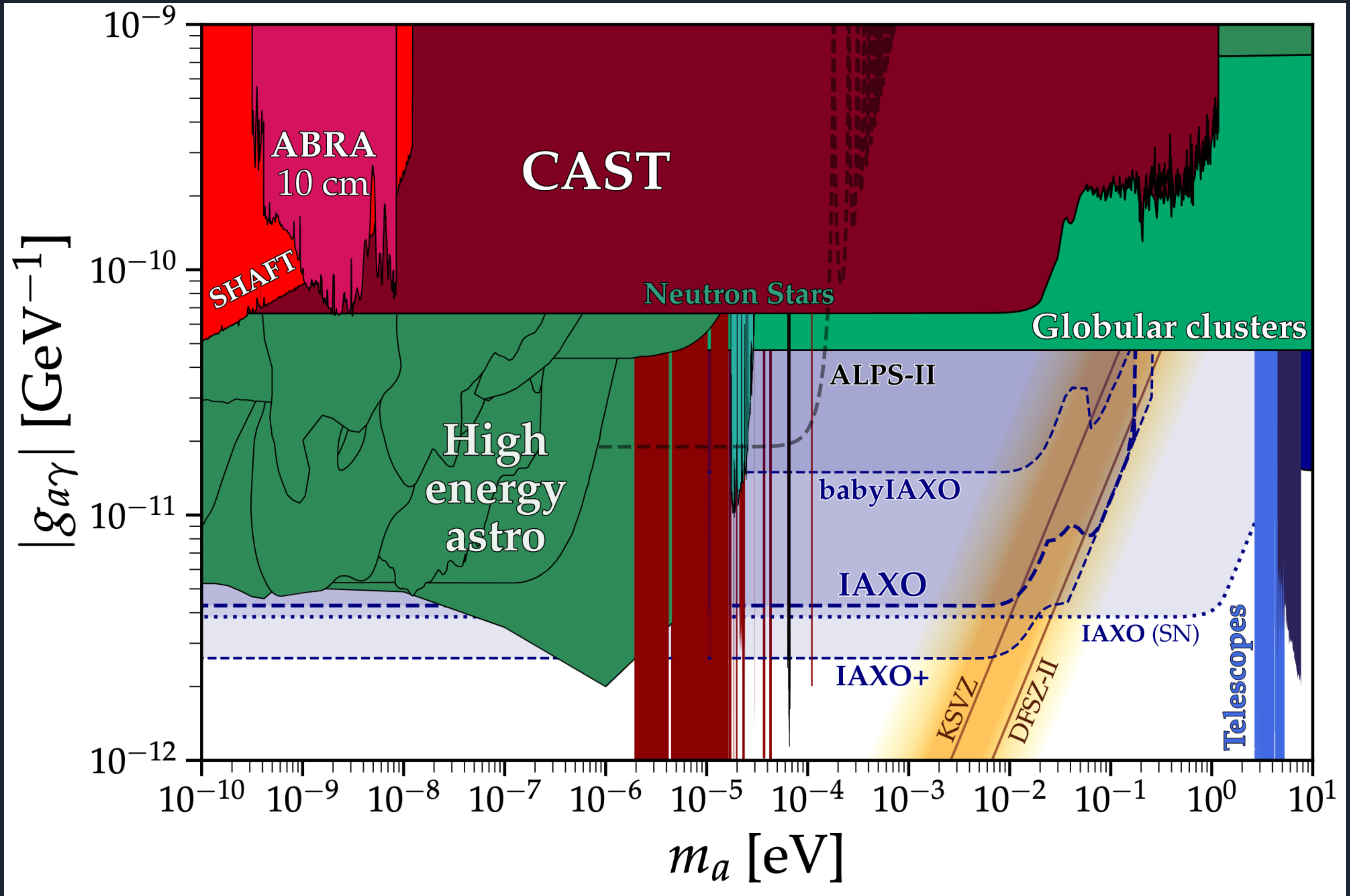


- Cold matter requirements:
  - ✓ feeble interactions with standard model particles
  - ✓ cosmological stability
  - ✓ Non-thermal production → cold

$$\rho_{a,0} \lesssim 1 \frac{keV}{cm^3} \frac{m_a(t_0)}{eV} \left(\frac{\theta(t_1)}{53\, TeV}\right)^2$$ → Dark Matter!



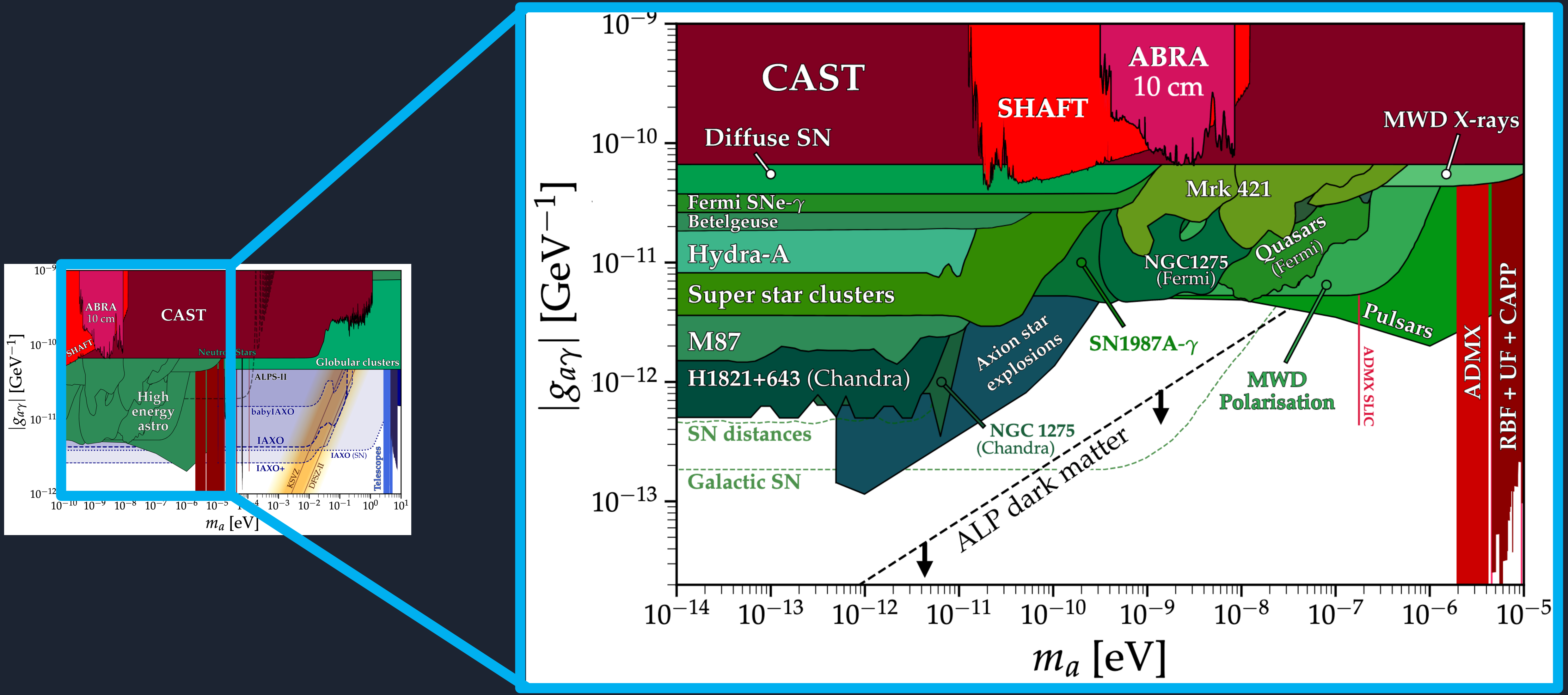
ALP's coupling to photons*

ALP's mass

*analogous to a WIMP cross-section

Plot produced using: https://cajohare.github.io/AxionLimits/

Project I: Introduction and Motivation



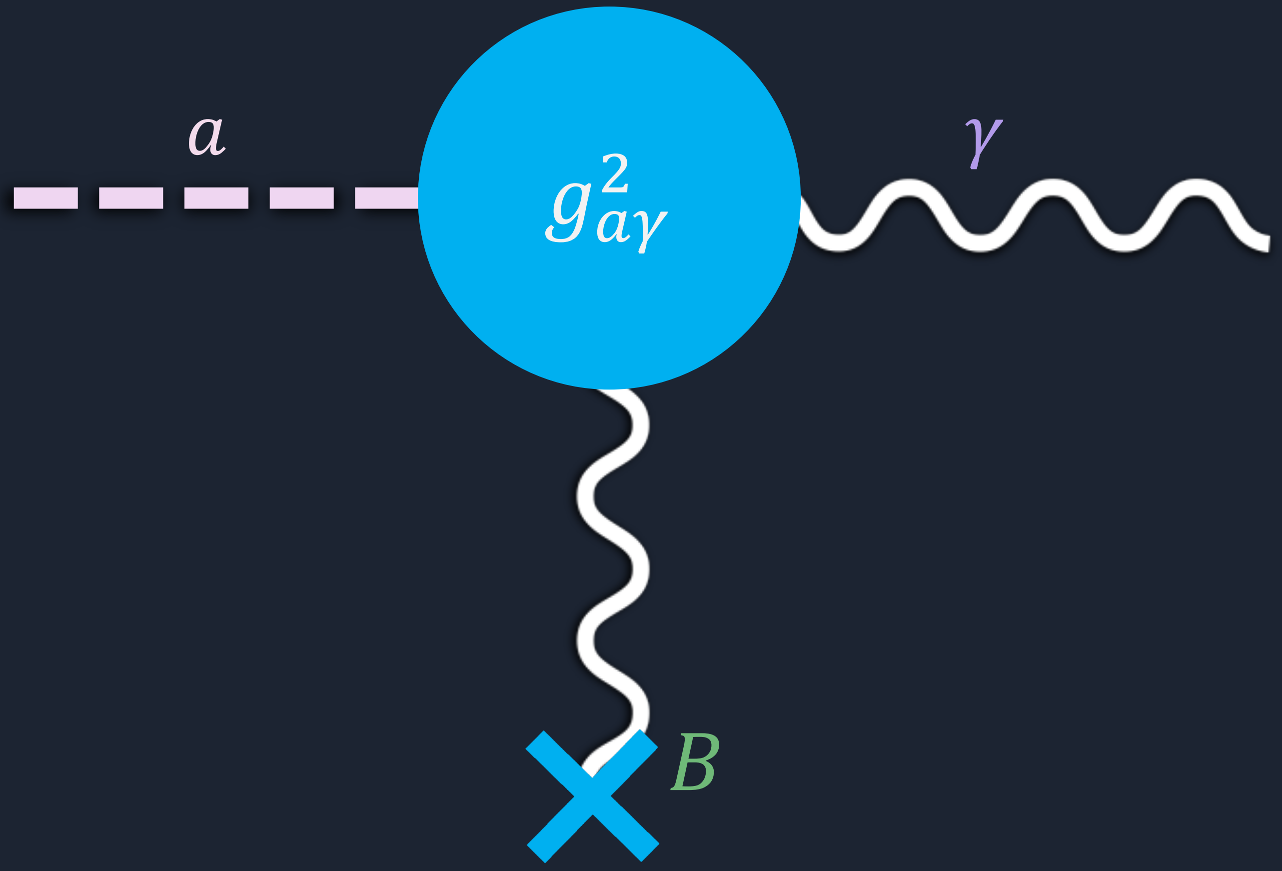
Plot produced using: https://cajohare.github.io/AxionLimits/

OBSERVING ALPS WITH GAMMA RAYS

- In the presence of an external magnetic field, B, ALPs undergo a conversion into photons:

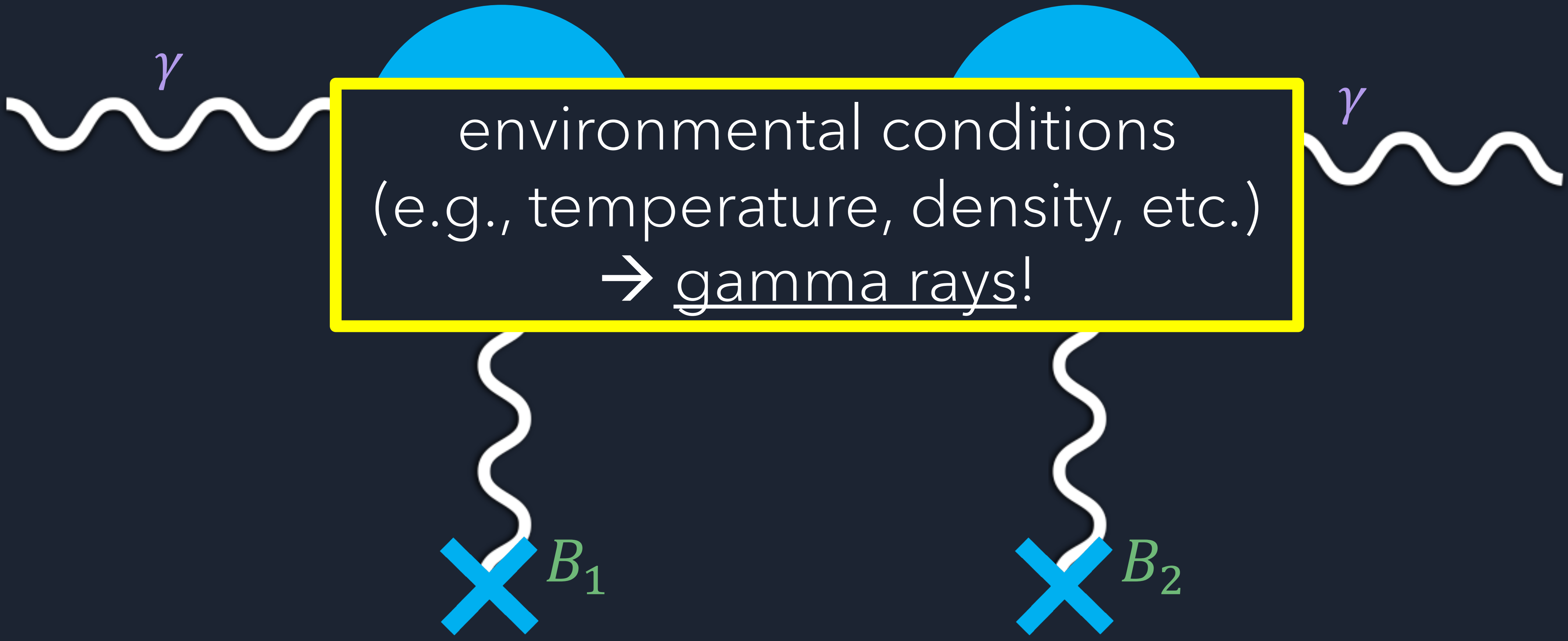
$$\mathcal{L}_{a\gamma} \supset g_{a\gamma}\, \mathbf{E} \cdot \mathbf{B}\, a$$

where $g_{a\gamma}$ is ALP-photon coupling rate, and a is the ALP field strength.



Primakoff process: converting ALPs into photons

OBSERVING ALPS WITH GAMMA RAYS



environmental conditions
(e.g., temperature, density, etc.)
→ gamma rays!

(production: Primakoff process)

(detection: inverse Primakoff process)

Primakoff process: converting ALPs into photons

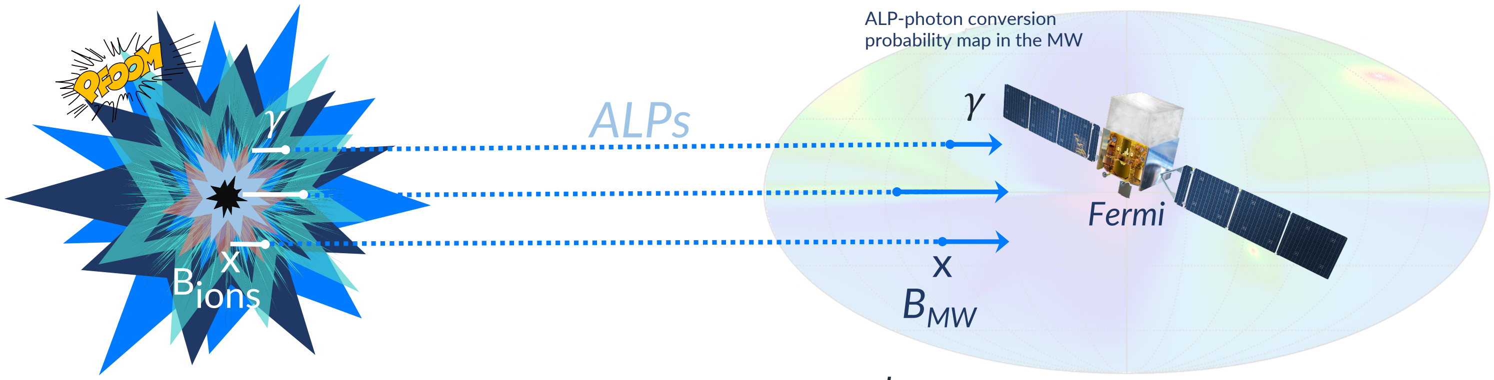
ALP…

is a viable dark-matter candidate

converts into photons in the presence of a magnetic field

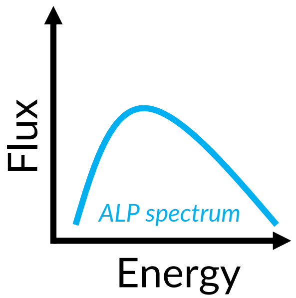
parameter space can be probed with gamma-ray observations

Project I: Physical System set-up

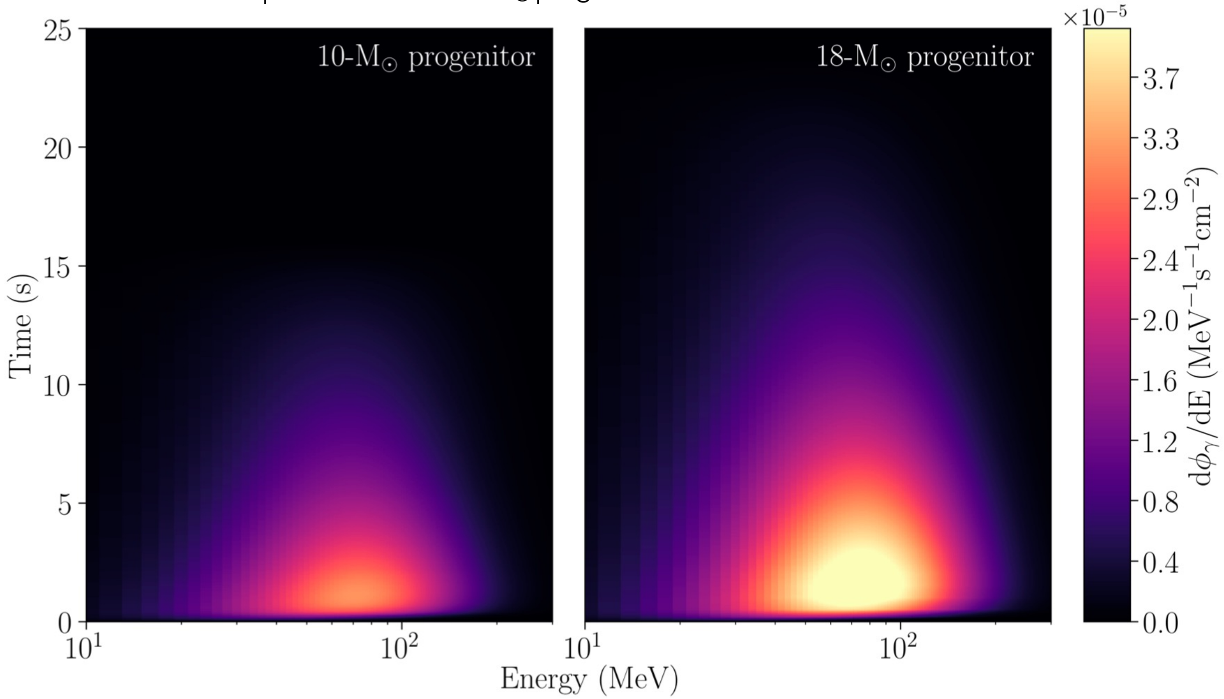


Primakoff Process
inside the CCSN core

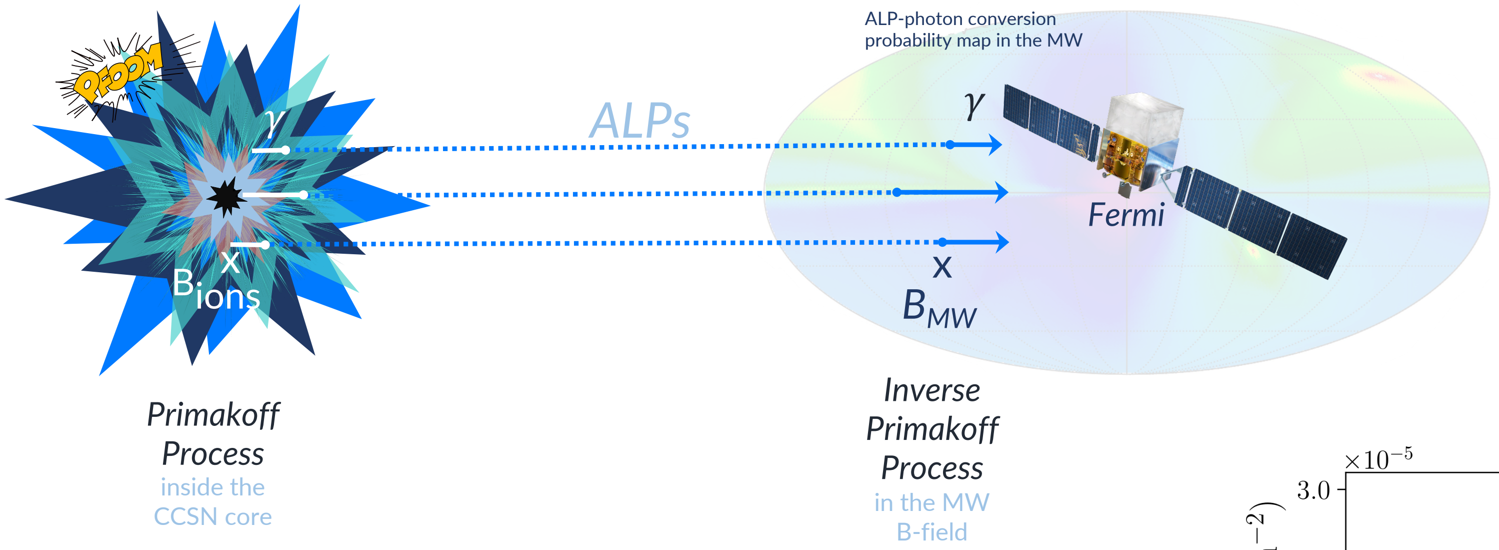
Inverse Primakoff Process
in the MW B-field

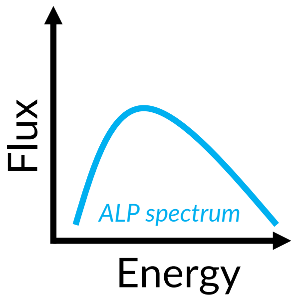


Observed evolution of the ALP-induced gamma-ray emission in time and energy in a core-collapse of a 10 and 18-M⊙ progenitor.

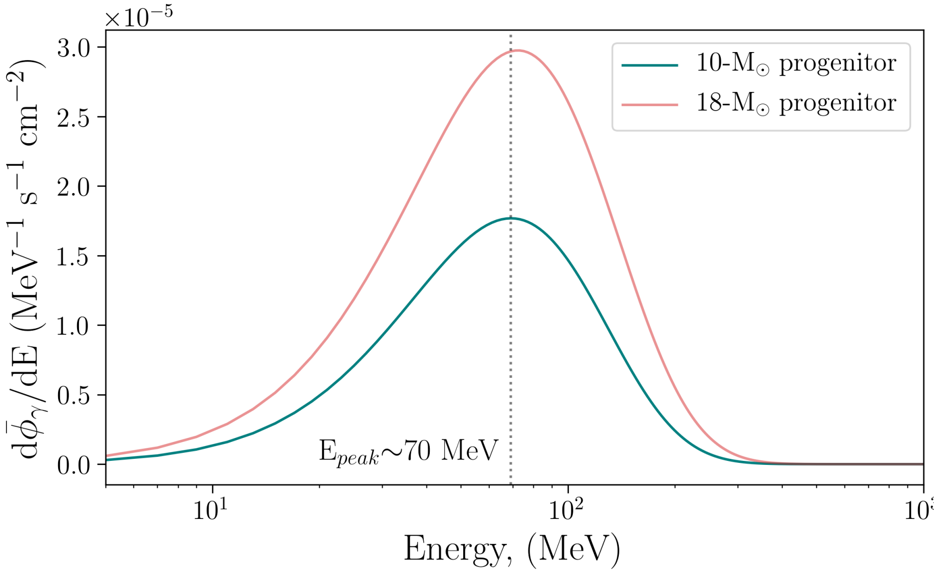


Project I: Physical System set-up



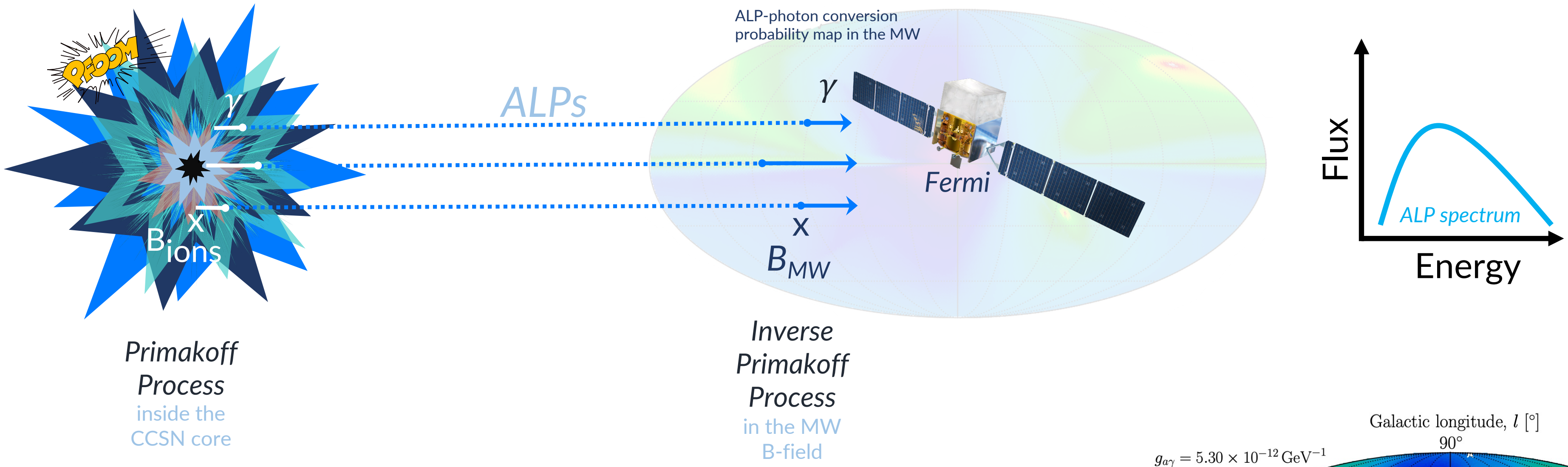


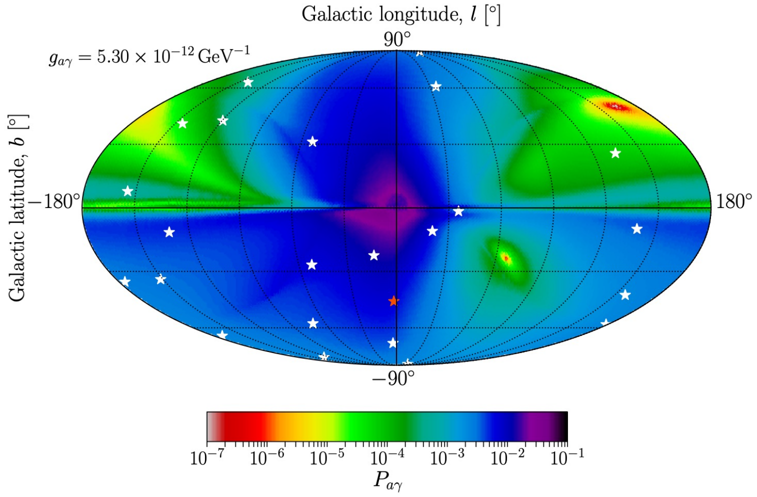
- **Motivation:** ALPs are theorized to have a unique spectral signature in the prompt gamma-ray emission of CCSN. No other known physical processes are predicted to produce such a signature.



The observed ALP-induced gamma-ray spectrum for 10 and 18-M$_\odot$ progenitors averaged over 10 seconds.

Project I: Physical System set-up

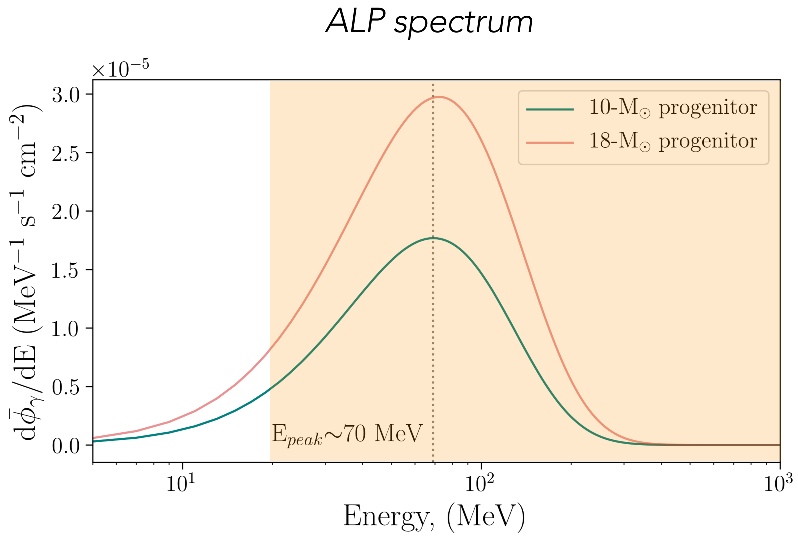


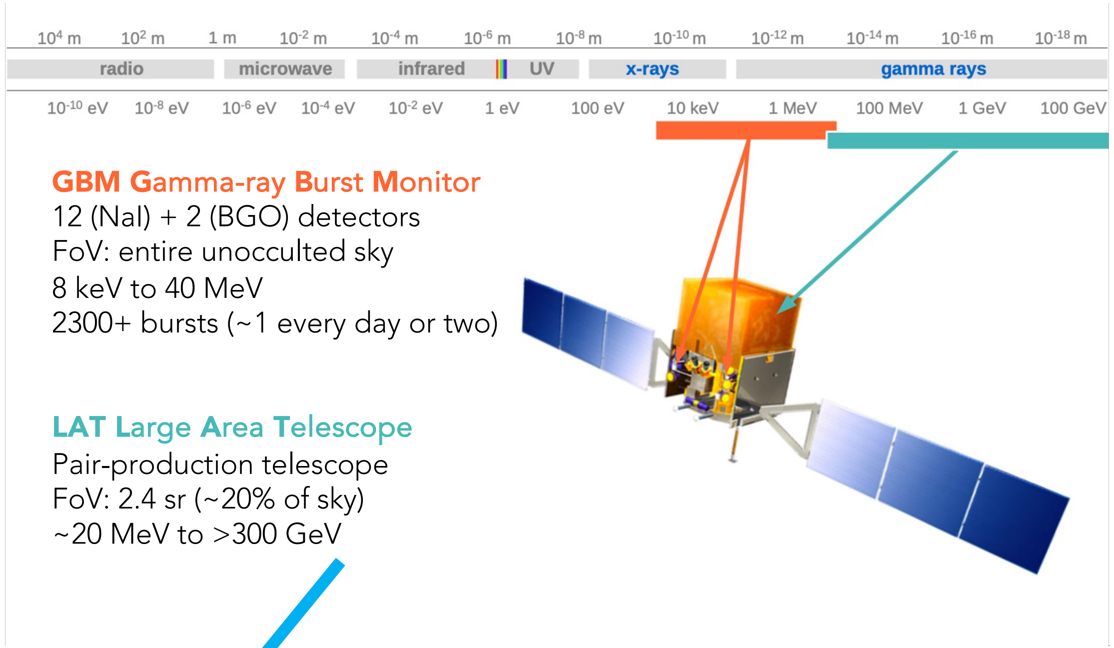


ALP-photon conversion probability map in the Milky Way's magnetic field.

- **Motivation:** ALPs are theorized to have a unique spectral signature in the prompt gamma-ray emission of CCSN. No other known physical processes are predicted to produce such a signature.
- **Assumptions:** magnetic fields: only considering the MW magnetic field, neglecting IGMF
- **CCSN – Gamma-ray Bursts relationship**

Project I: Physical System set-up





LAT LOW ENERGY (LLE) TECHNIQUE

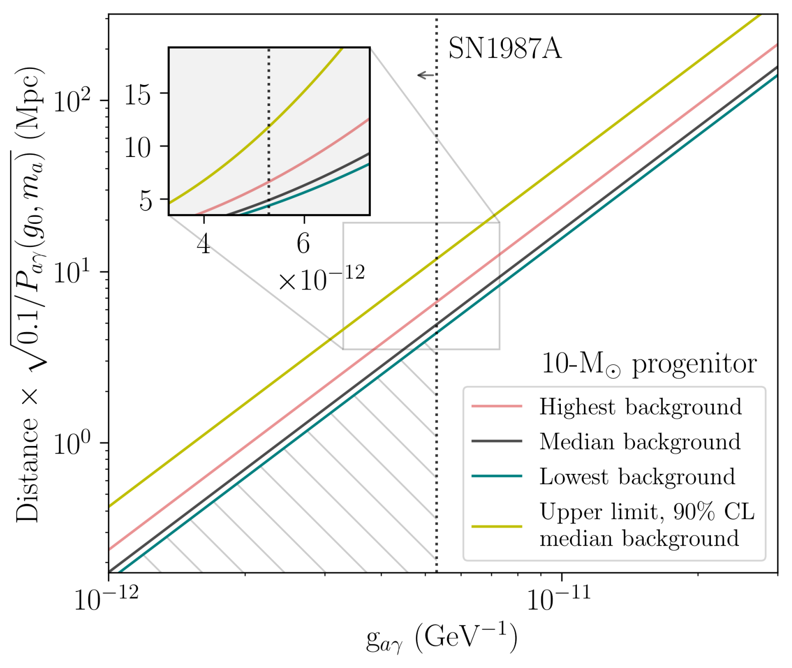
- Standard LAT analysis: >100 MeV vs. LLE analysis: > 20 MeV
- LLE: maximizing the effective area of the LAT instrument in the low-energy regime
- More signal, but also more background

Solar-flare LLE analysis: arXiv:1304.5559

QUESTION 1: *HOW SENSITIVE IS LLE TO DETECTING AN ALP BURST?*

Reported in: Crnogorčević et al. 2021 (PRD, arXiv:2109.05790)

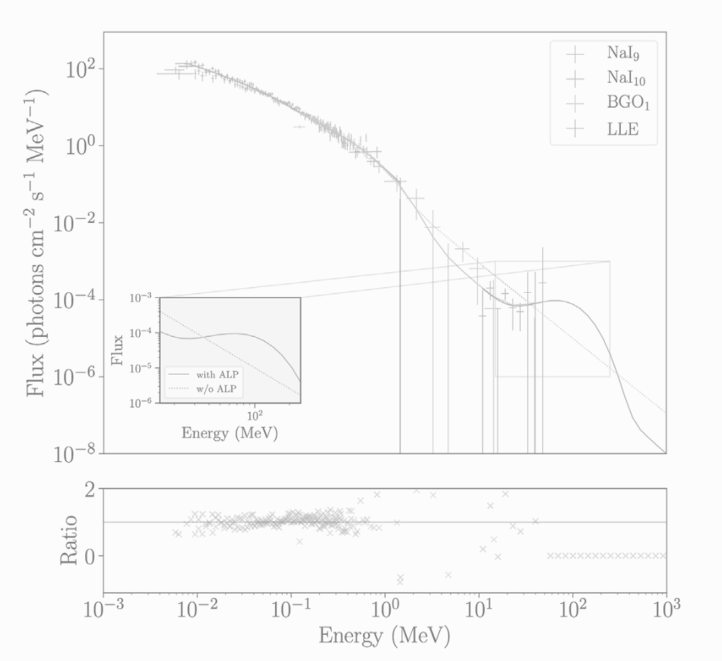
Fermi-LLE Sensitivity



- LLE can reach up to ~10 Mpc (comparable to the standard LAT analysis)
- Results strongly driven by the dominating background & decreased A_{eff} at high incidences
- *Method: signal injection simulations*

Crnogorčević et al. 2021 (PRD, arXiv:2109.05790)

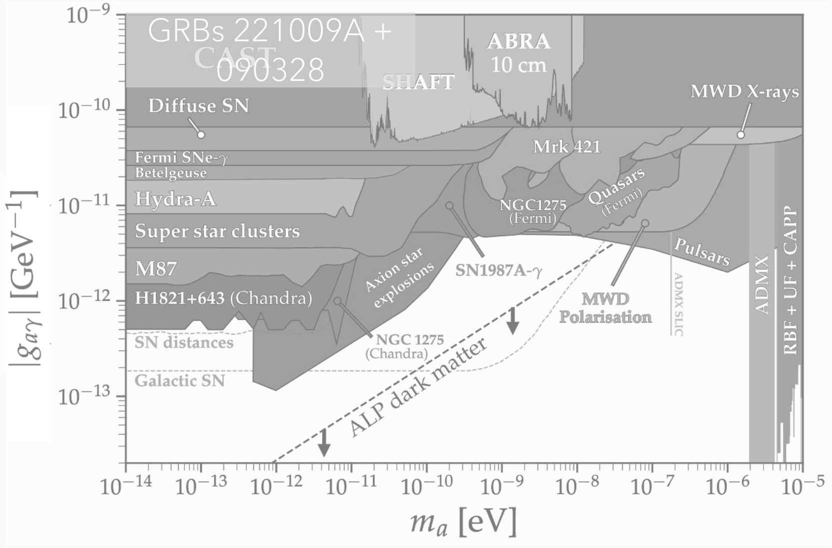
GRB searches



- No excess signal found.
- 24 long GRBs that pass the selection criteria.
- GRB 101123A at ~2.4 σ. Trials factor → p~0.3.
- *Method: model comparison*

Crnogorčević et al. 2021 (PRD, arXiv:2109.05790)

GRB Precursors



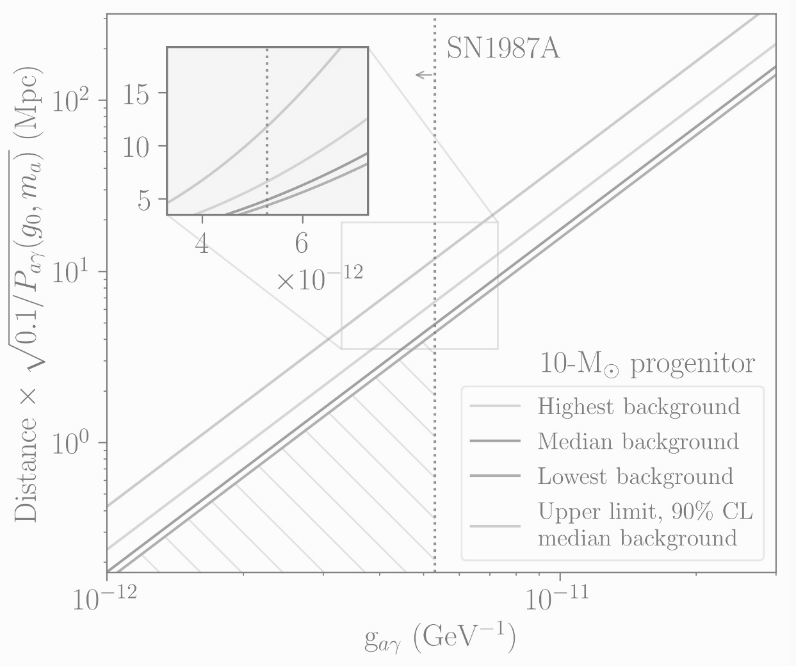
- No significant detections.
- From the ALP amplitude we calculate upper limits.
- *Method: model comparison*

Crnogorčević et al. 2023 (under review)

QUESTION 2: *HAVE WE ALREADY SEEN ANY ALP EMISSION IN LLE GRBS?*

Reported in: Crnogorčević et al. 2021 (PRD, arXiv:2109.05790)

Fermi-LLE Sensitivity



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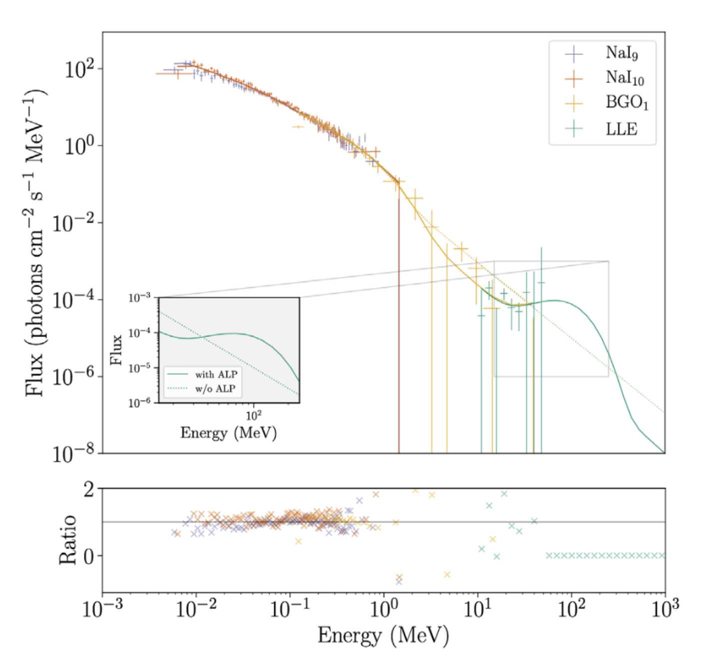

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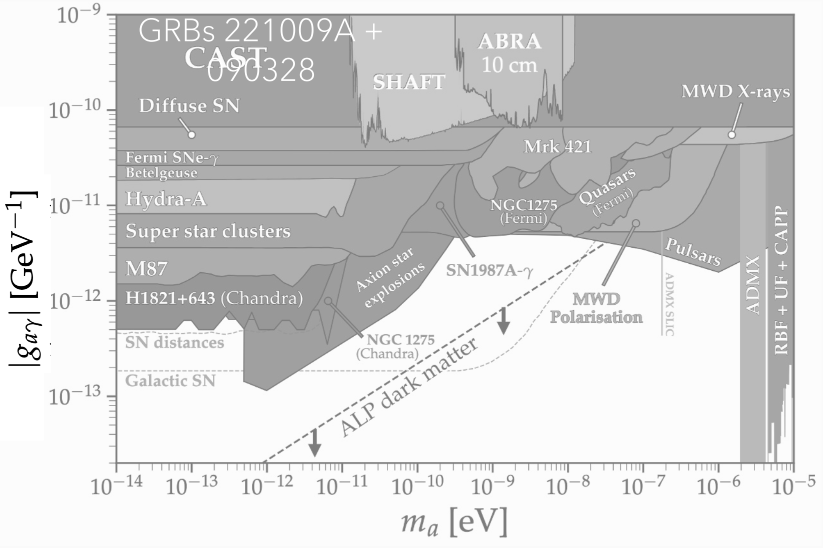

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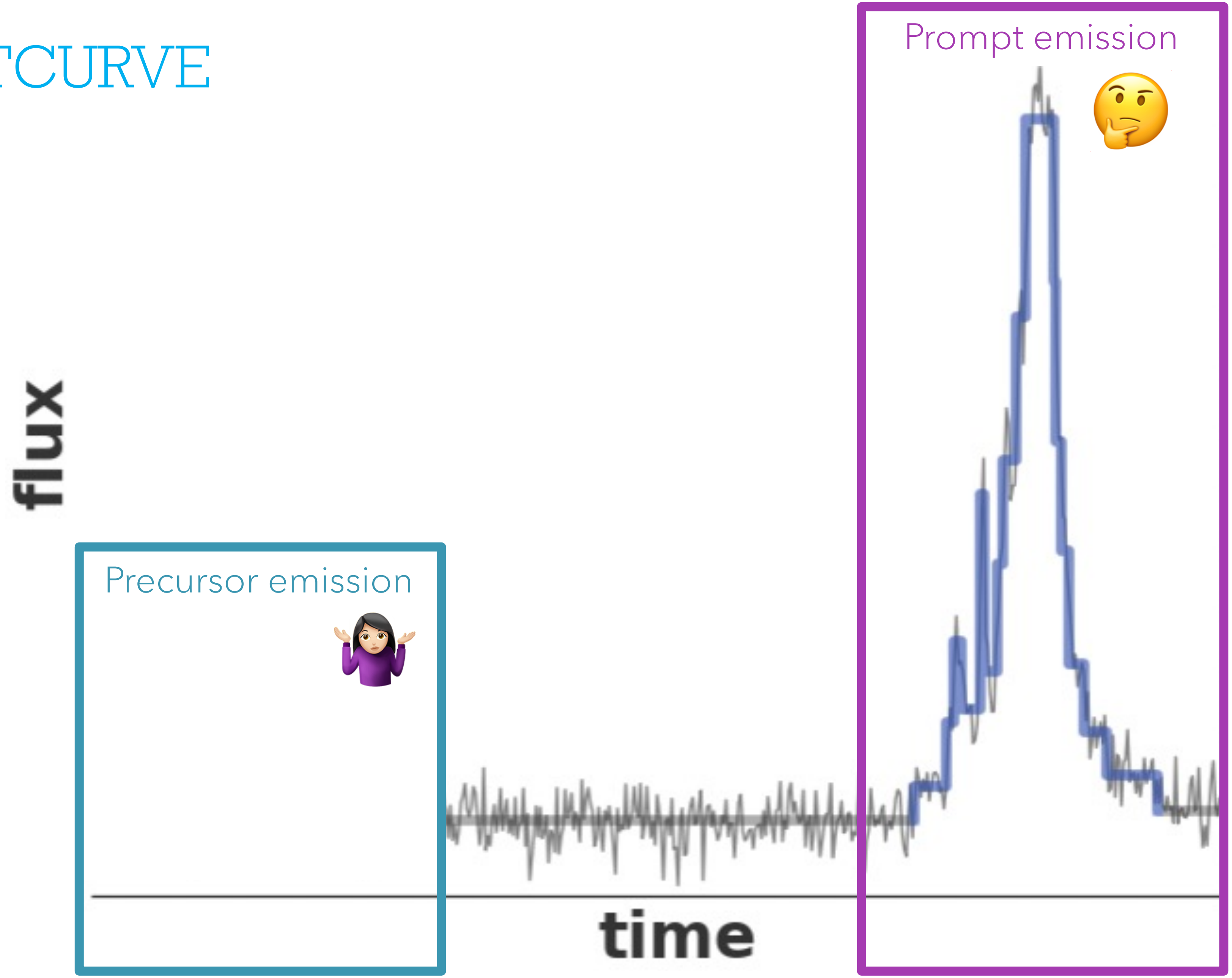
Crnogorčević et al. 2023 (under review)

QUESTION 3: *WHEN SHOULD WE SEARCH FOR ALPS FROM GRBS?*

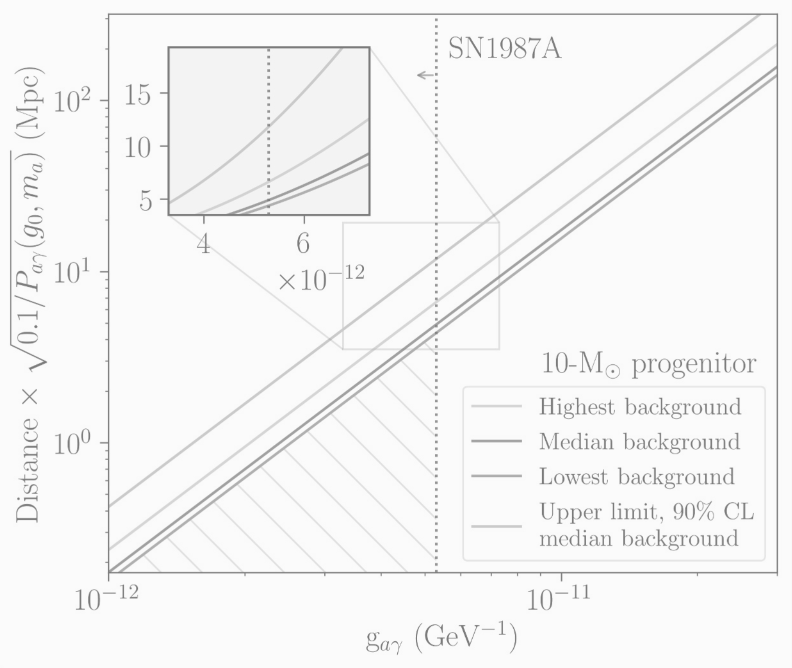
Fermi GI Program, Cycle 15; PI: Crnogorčević

Reported in: Crnogorčević et al. 2023 (under *Fermi*-LAT review)

GRB LIGHTCURVE



Fermi-LLE Sensitivity



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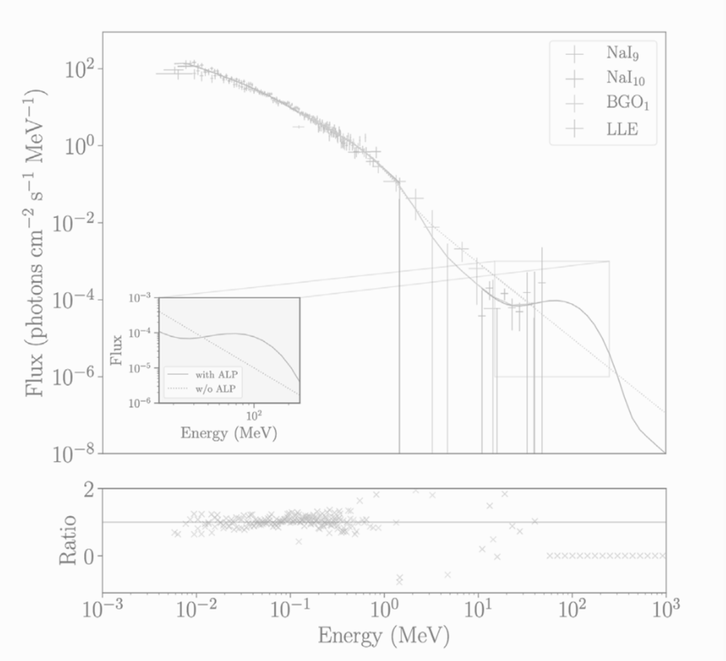

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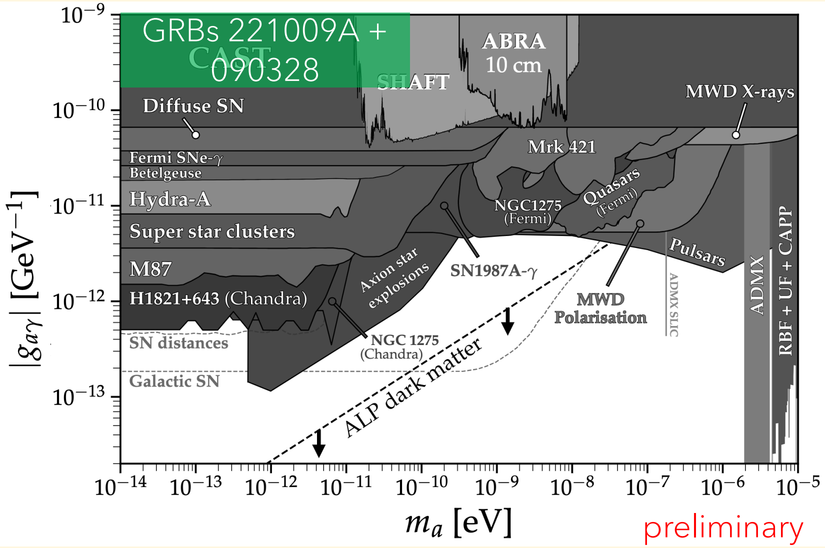

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Crnogorčević et al. 2023 (under review)

Project I (sneak peak): What's next?

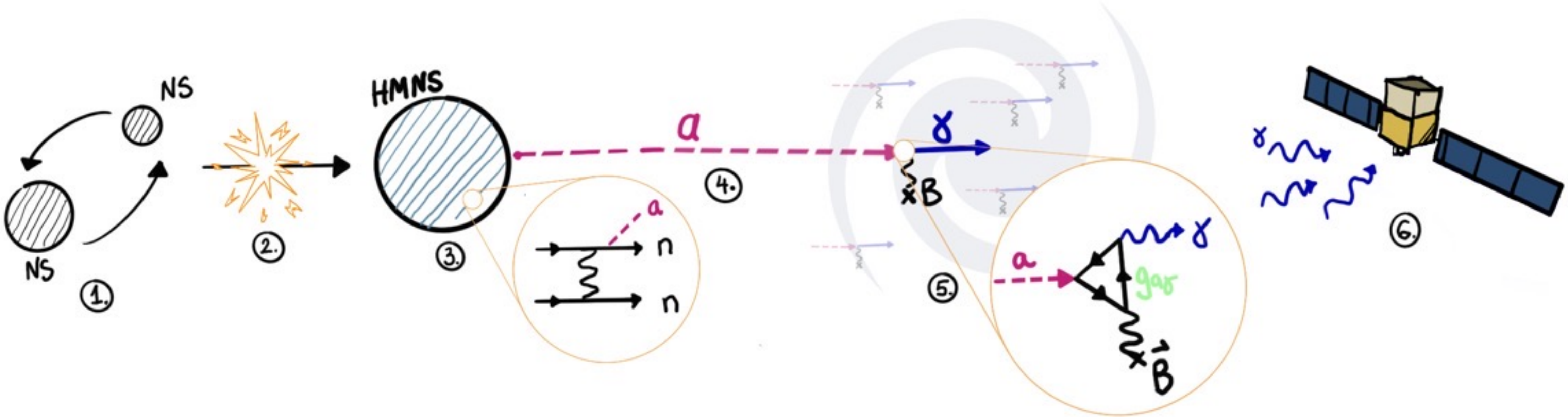

Figure description: (1) Two neutron stars (NS) orbit each other until the (2) merger, followed by (3) the formation of a hypermassive neutron star (HMNS). There, ALPs are produced via the neutron-neutron bremsstrahlung process. Once produced, ALPs travel undisturbed (4), until they reach the magnetic field of the Milky Way (5). In the Milky Way's magnetic field, ALPs convert into gamma-rays, which then can be detected by *Fermi* (6).

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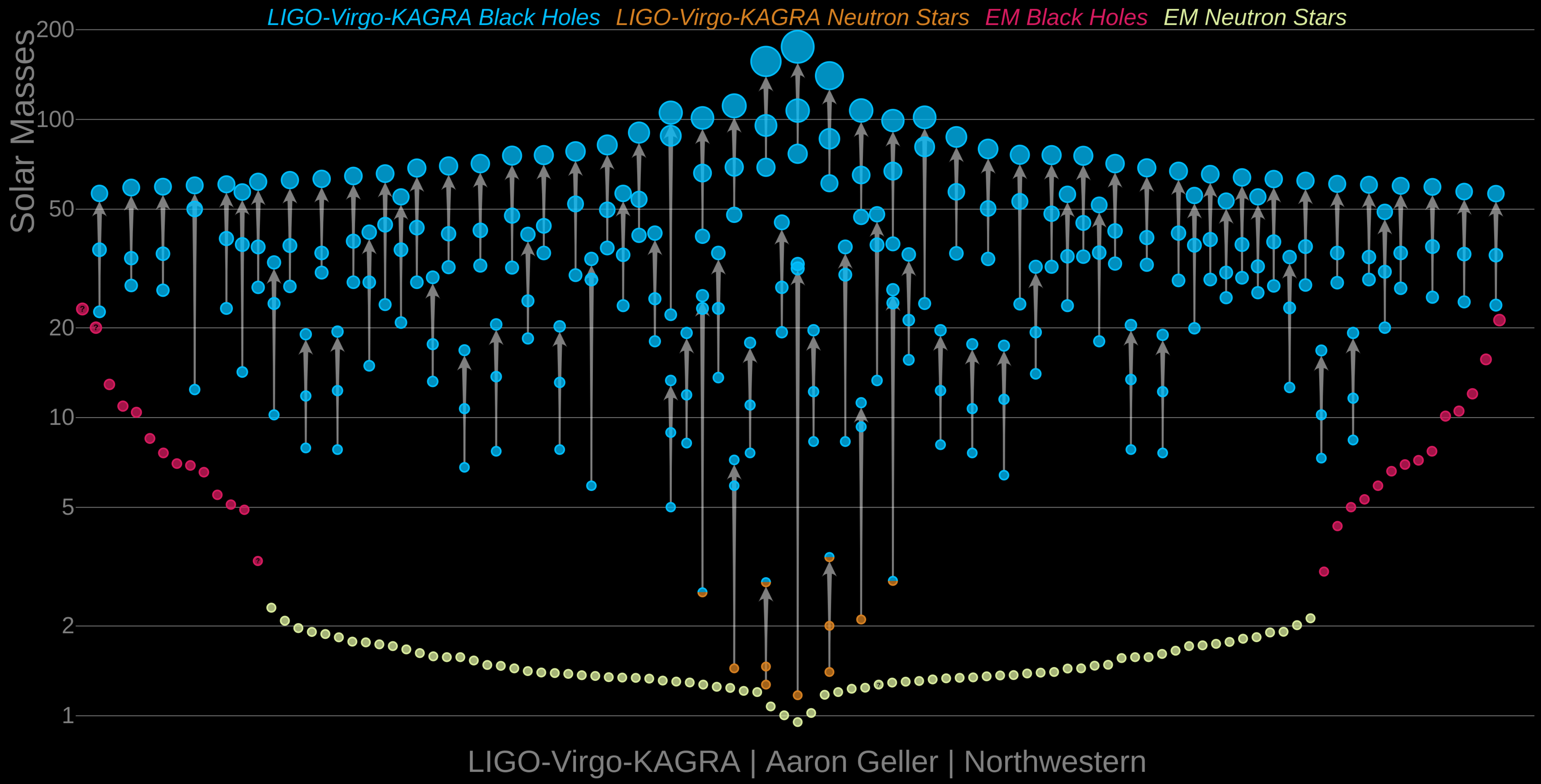
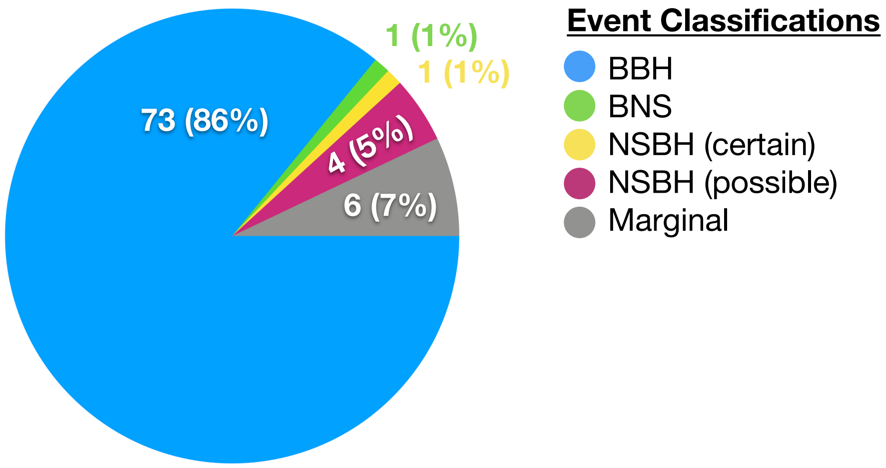
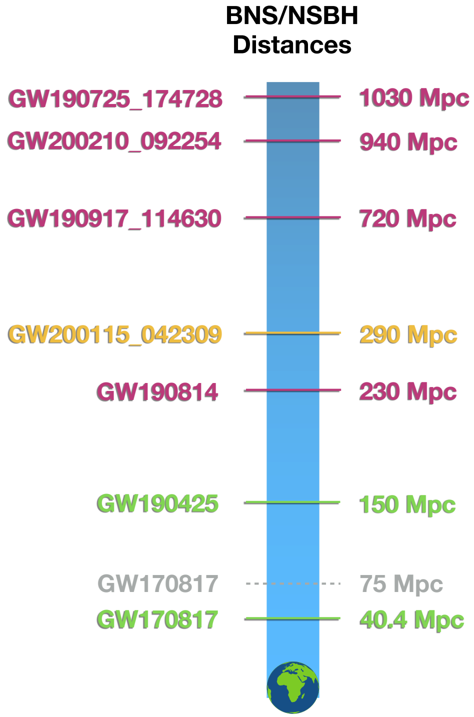
Masses in the Stellar Graveyard



O3: THE THIRD OBSERVING RUN

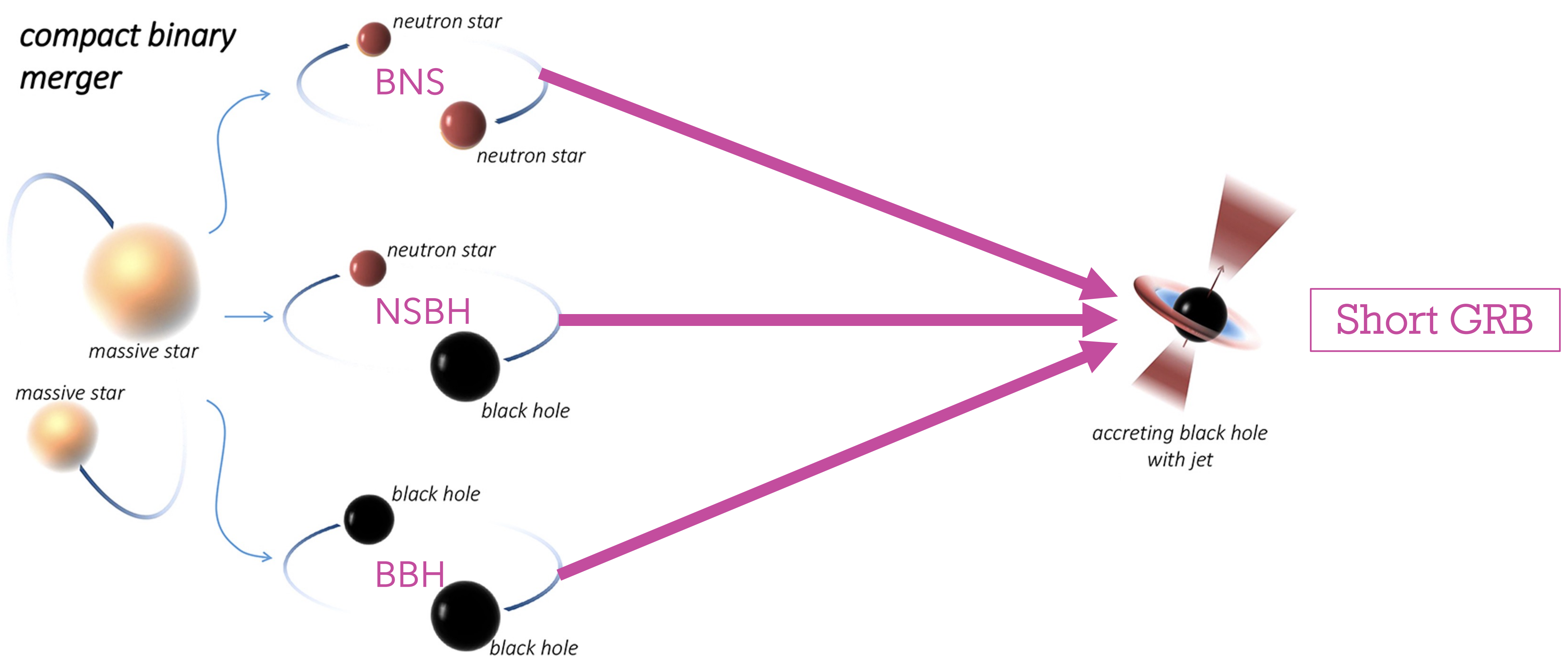
Third LIGO/Virgo observing run (O3): April 2019 -- March 2020 (commissioning break in October 2019)



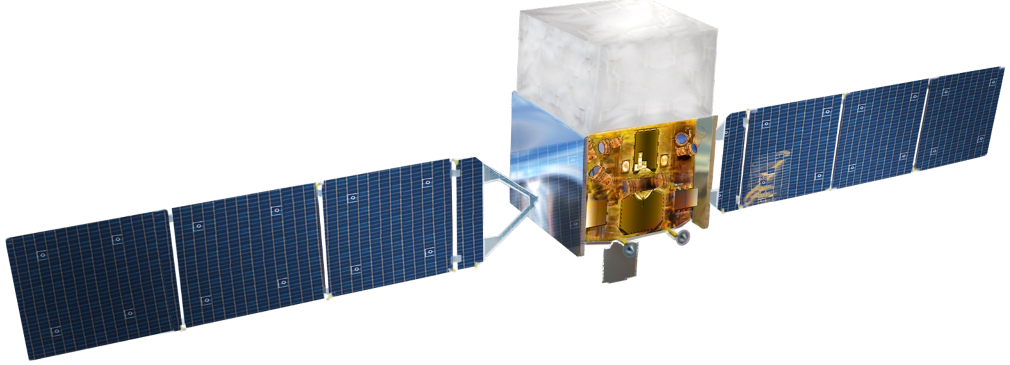


75 Mpc = the maximum distance where Fermi-GBM could detect GW170817

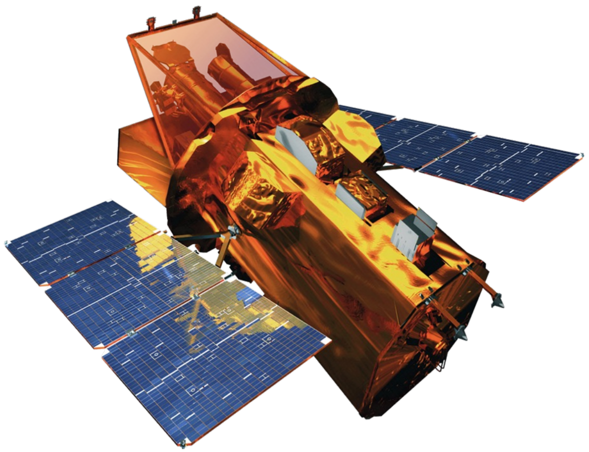
WHERE TO SEARCH FOR GWs: COMPACT BINARY MERGERS



Bartos & Kowalski, 2017



+



Why *Fermi* GBM?

\+ ~full-sky field of view
\+ energy coverage spanning the peak of GRB emission

Why *Swift* BAT?

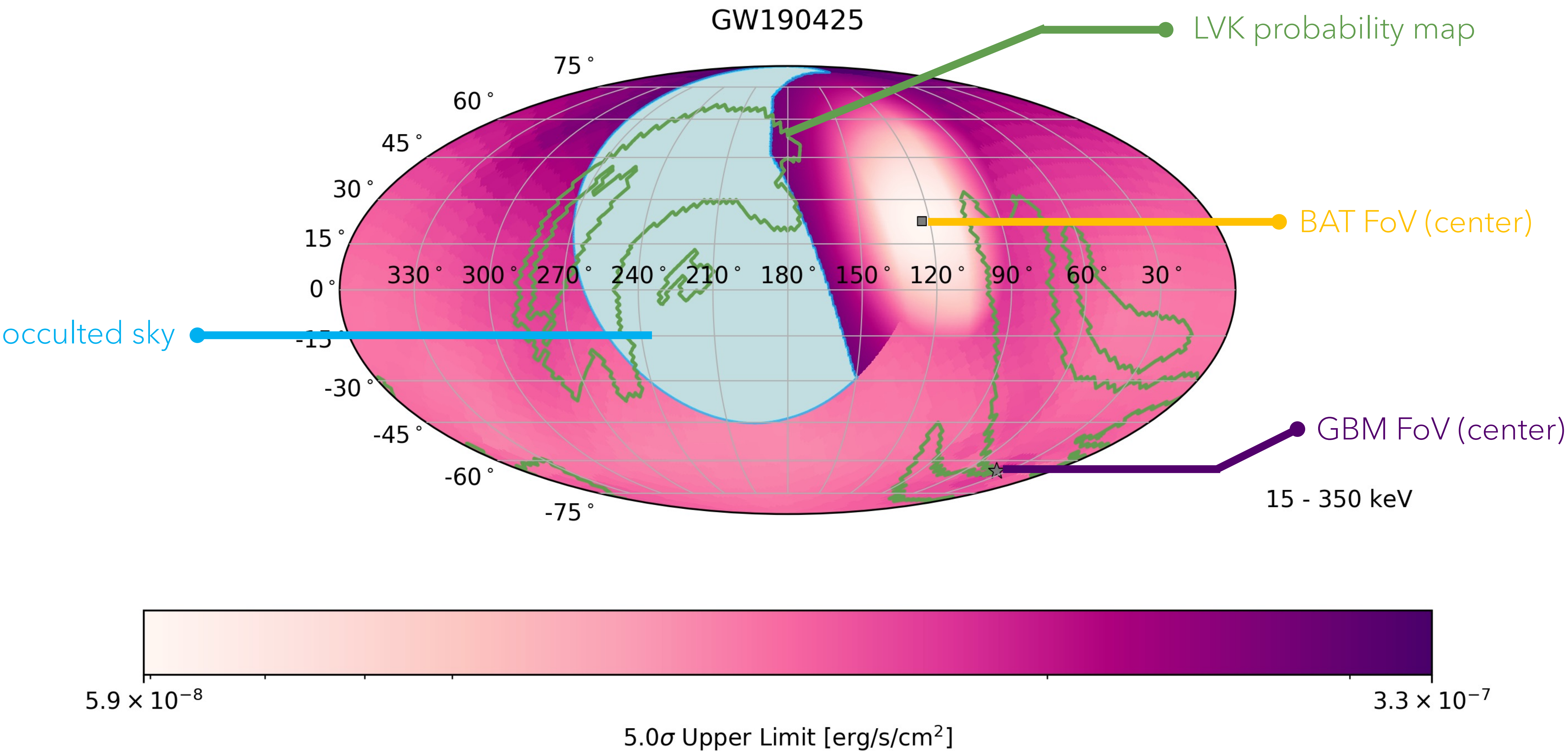
\+ excellent localization sensitivity (~arcminute for detected GRBs)
\+ energy coverage overlaps with the low-energy end of *Fermi* GBM

QUESTION: *DID WE SEE ANY GAMMA-RAY EMISSION IN SPATIAL AND TEMPORAL CORRESPONDENCE TO THE LVK O3 EVENTS?*

Fletcher et al. on behalf of GBM, Crnogorčević et al. on behalf of BAT, and LVK, 2023 (under review)

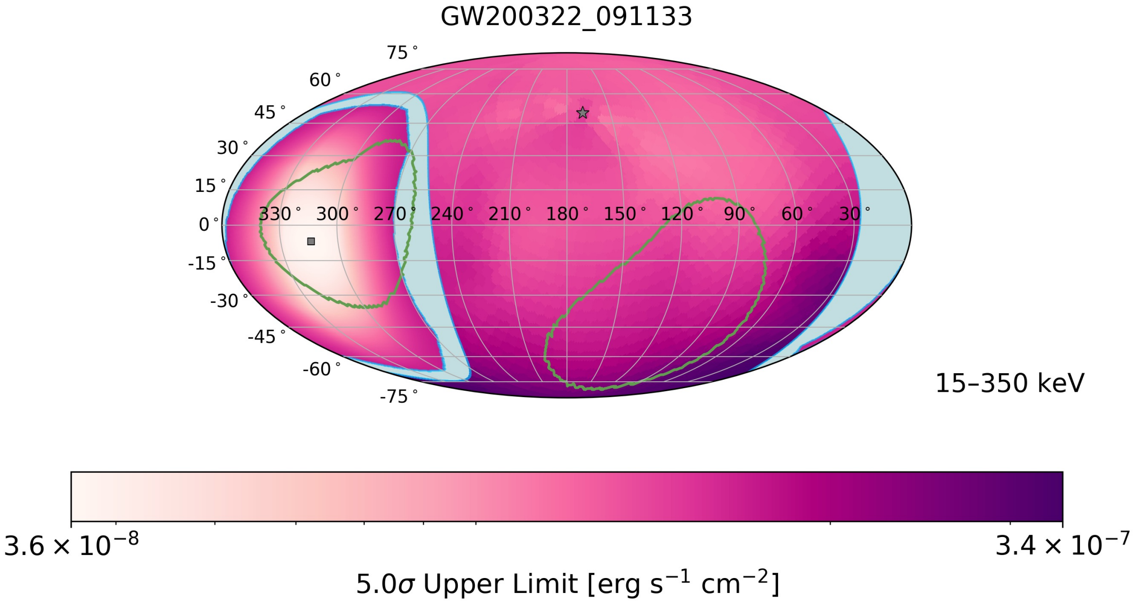
We report *no* significant coincidence discoveries in O3; neither with *Fermi*-GBM, nor *Swift*-BAT

Project II: GWs x Gamma rays

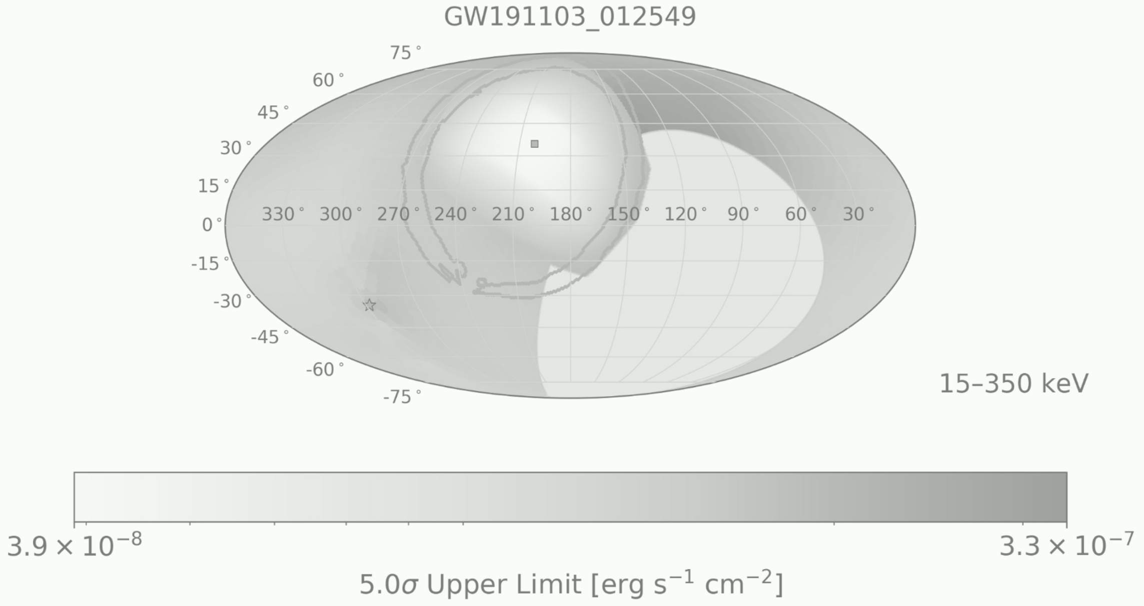


Combining the upper limits

Choosing the most constraining limit for each point in the sky (independent measures from GBM & BAT)



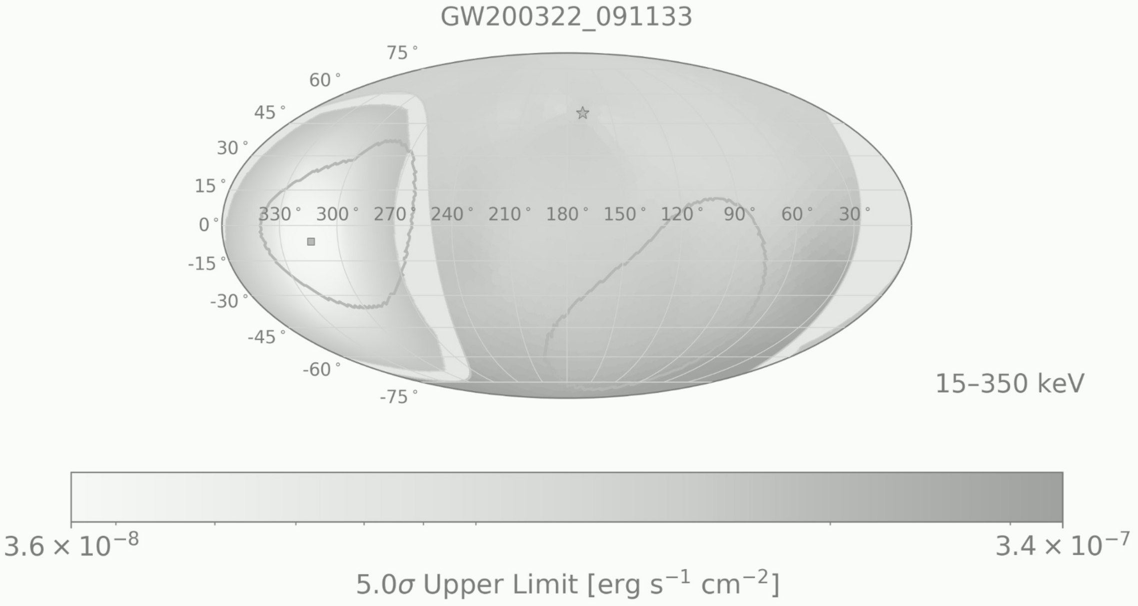
BAT ensures more sensitivity when the GW trigger is inside its FoV

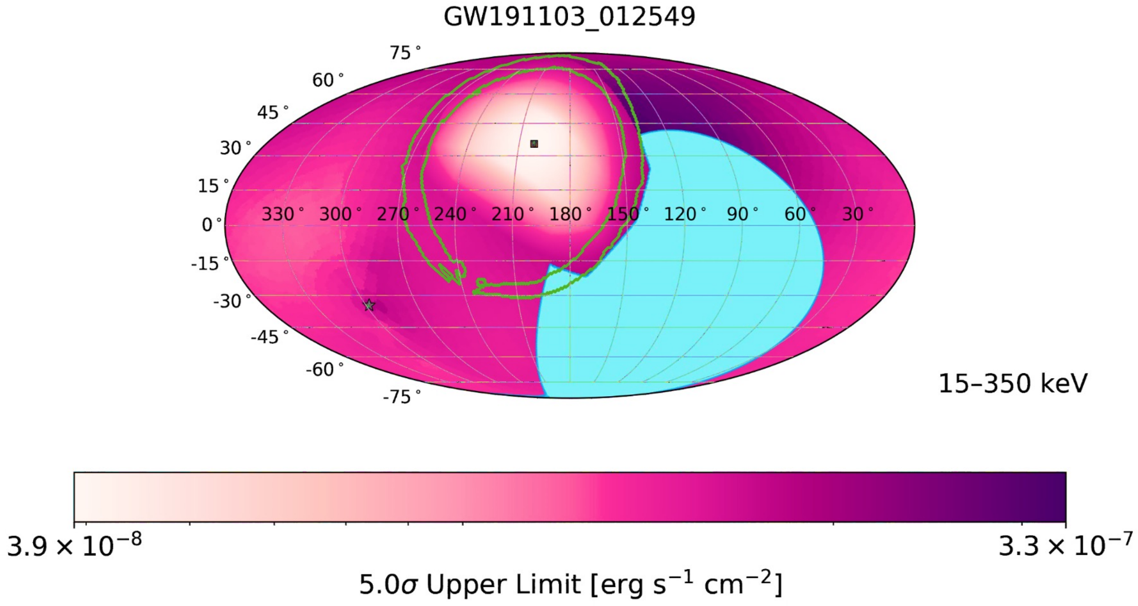


GBM's ensures a more likely coverage of the GW trigger with its large FoV

Combining the upper limits

Choosing the most constraining limit for each point in the sky (independent measures from GBM & BAT)



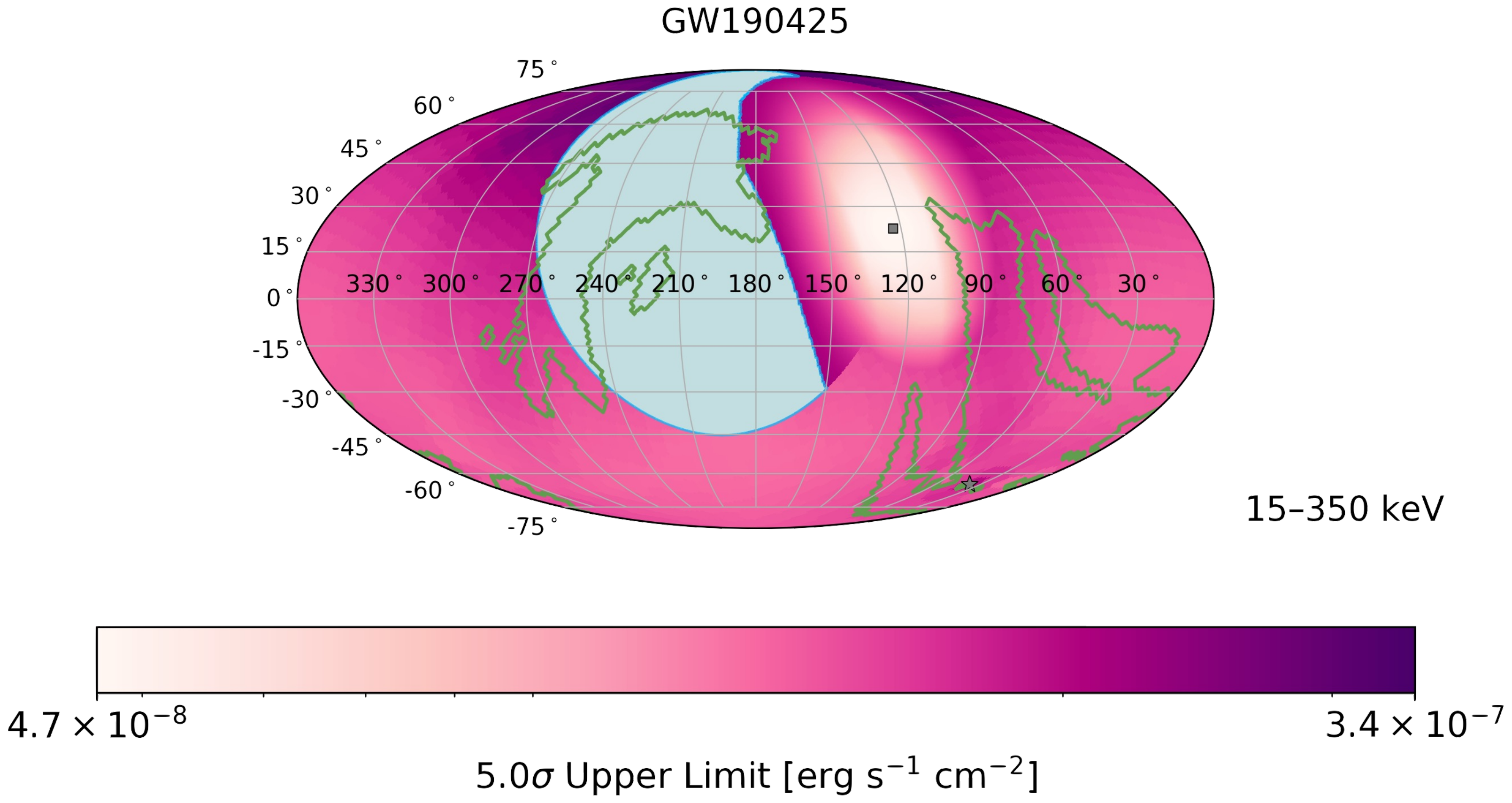


BAT ensures more sensitivity when the GW trigger is inside its FoV

GBM's ensures a more likely coverage of the GW trigger with its large FoV

Honorable mention: BNS GW190425

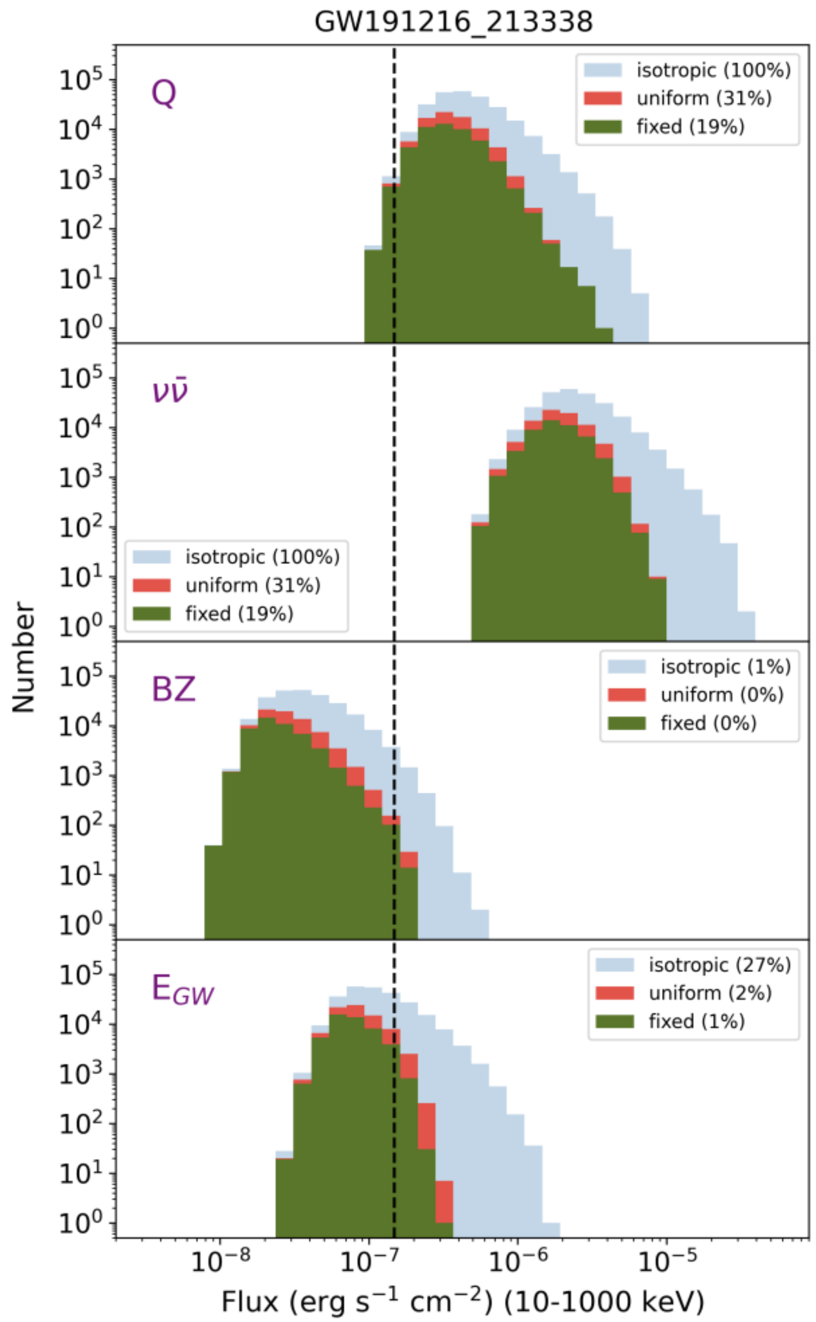
Choosing the most constraining limit for each point in the sky (independent measures from GBM & BAT)



- BNS 190425 is 4 times further away than BNS 170817
- GBM/BAT only see ~60% of the GW localization region
- Inclination angle poorly constrained

What can we do with upper limits?

Limits on the EM emission from BBH mergers



PROJECT I.
SEARCHING FOR AXION-LIKE PARTICLES WITH *FERMI*

PROJECT II.
A JOINT *FERMI* & *SWIFT* ANALYSIS OF THE THIRD GRAVITATIONAL-WAVE OBSERVING RUN

PROJECT III.
CROSS-CORRELATING ICECUBE NEUTRINOS AND THE *FERMI* UNRESOLVED GAMMA-RAY SKY

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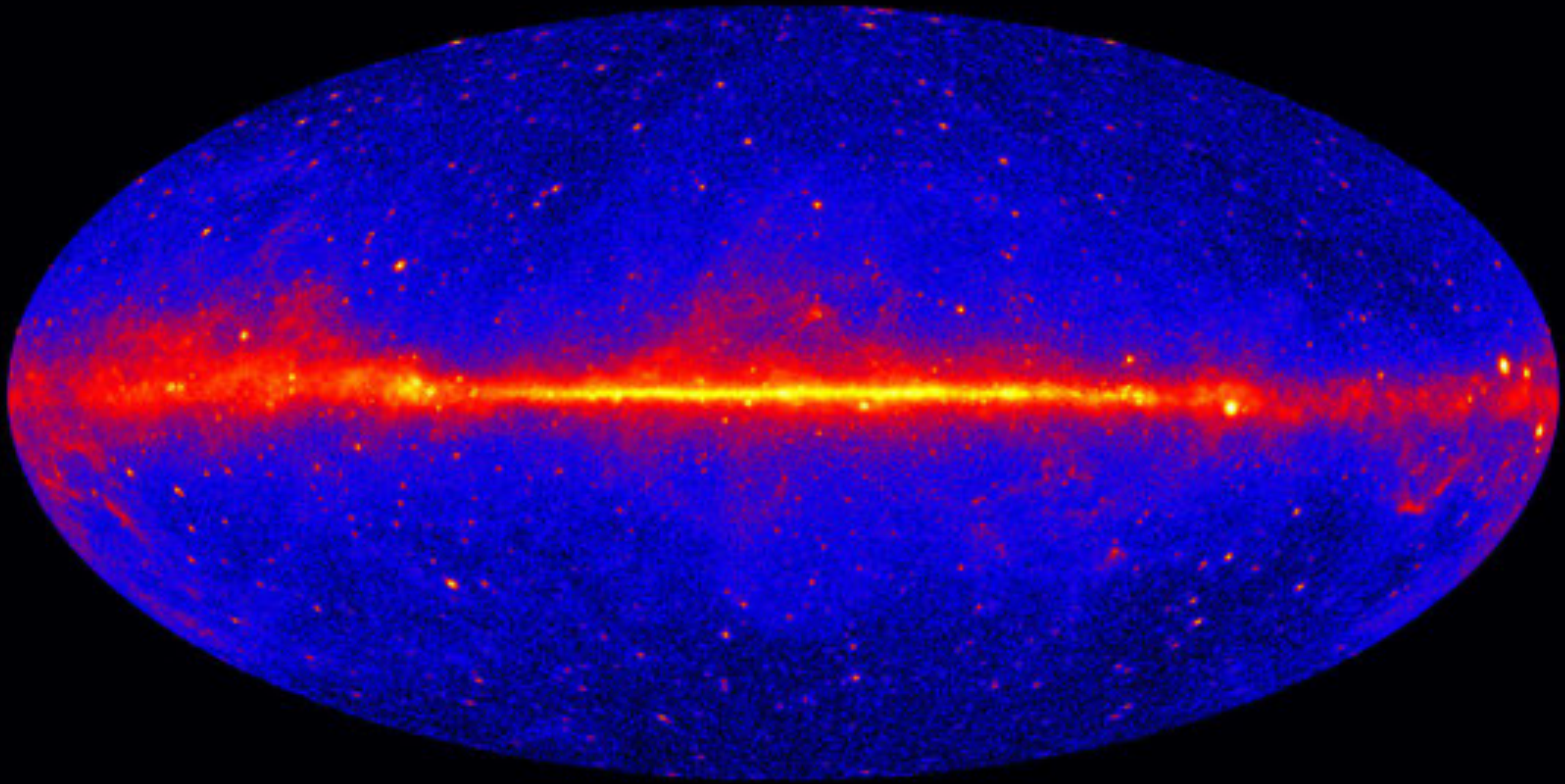
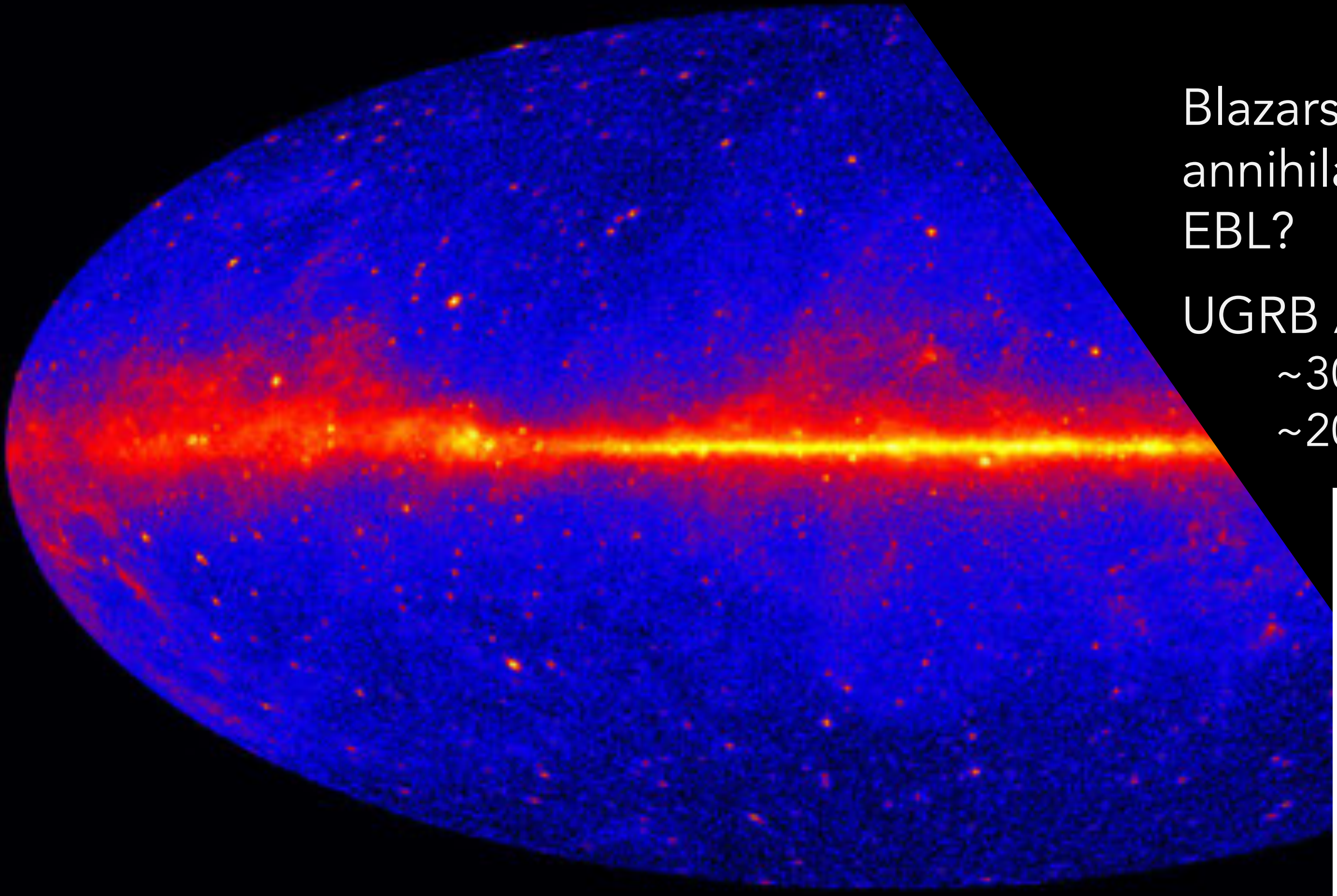
Project III: Neutrinos x Gamma rays



Project III: Neutrinos x Gamma rays

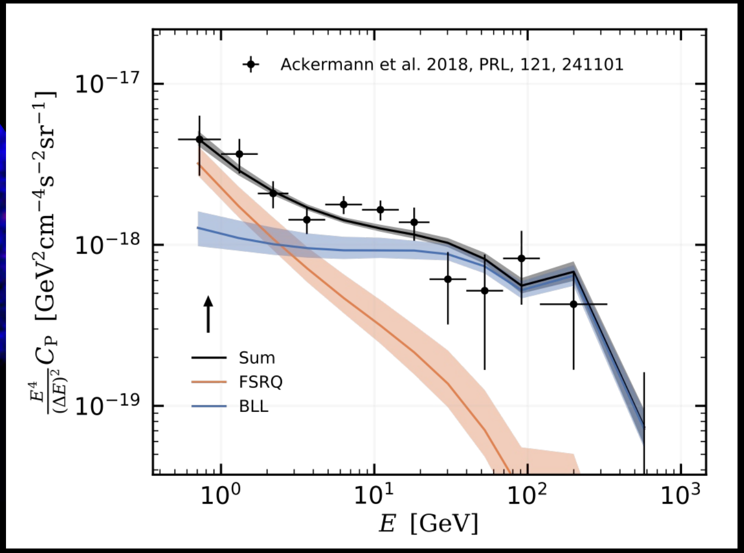
The Unresolved Gamma-ray Background (UGRB) ~20%



Blazars? Star-forming galaxies? DM annihilation? Photon interactions with EBL?

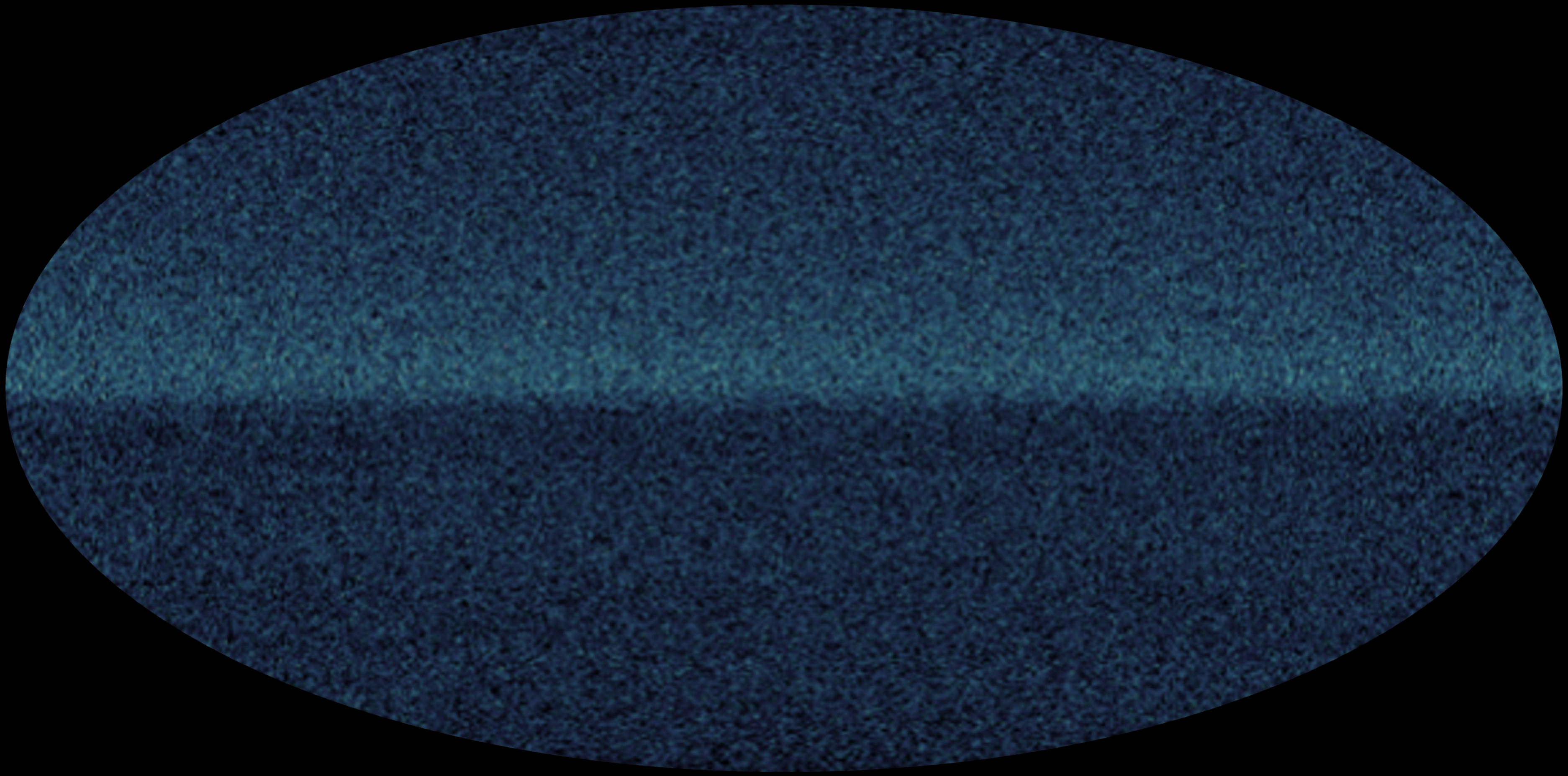
UGRB Anisotropy: 100% FSRQ + BLL

- ~30% between 10 and 100 GeV
- ~20% below 1 GeV



Korsmeier et al. 2022

Ptoject III: Neutrinos x Gamma rays



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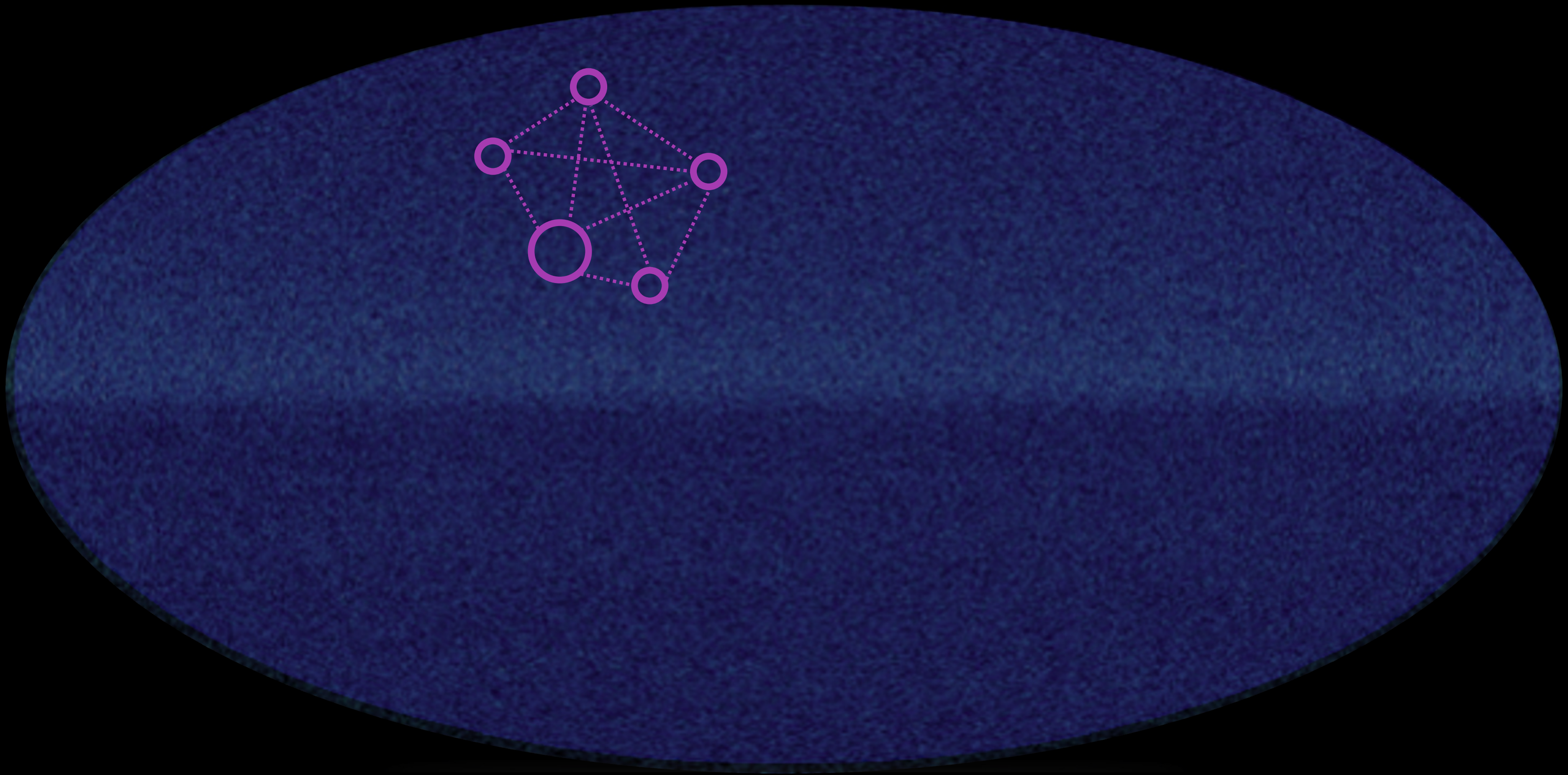


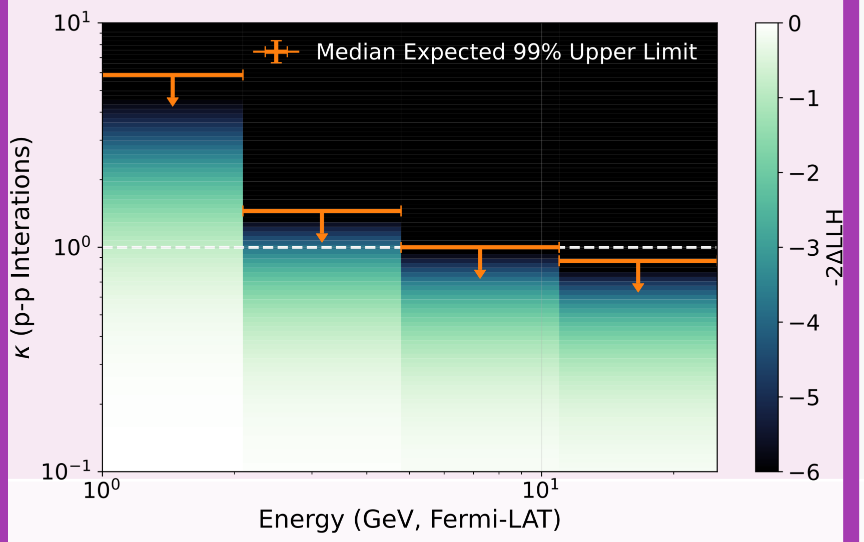
No cross-correlation signal identified

QUESTION 1: *WHAT FRACTION OF THE TOTAL NEUTRINO FLUX IS PRODUCED IN BLAZARS?*

Negro, Crnogorčević, et al. 2023 (submitted, arXiv:2304.10934)

Project III: Neutrinos x Gamma rays

Simulations



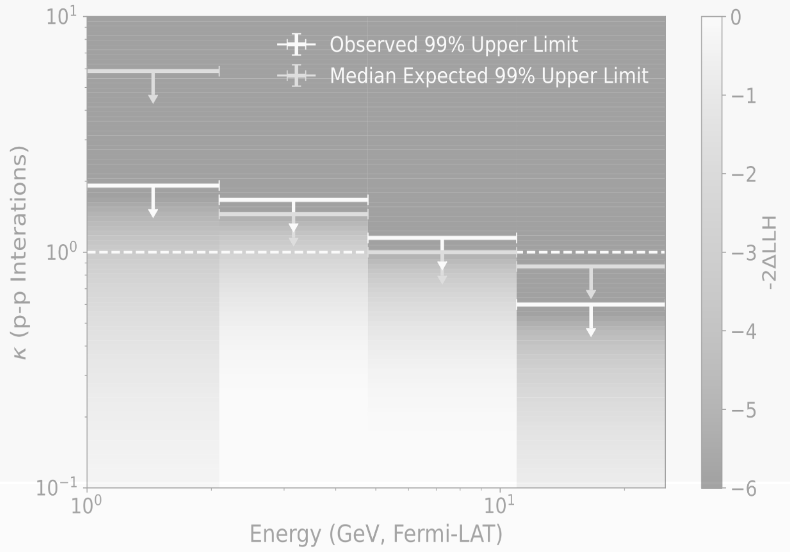
- Gamma rays produced in p–p interactions (Feng & Murase 2021):

$$E_\nu^2 \frac{dN_\nu}{dE_{nu}} \approx \frac{1}{2}\left(E_\gamma^2 \frac{dN_\gamma}{dE_\gamma}\right), \text{ at } E_\nu \approx \frac{E_\gamma}{2}$$

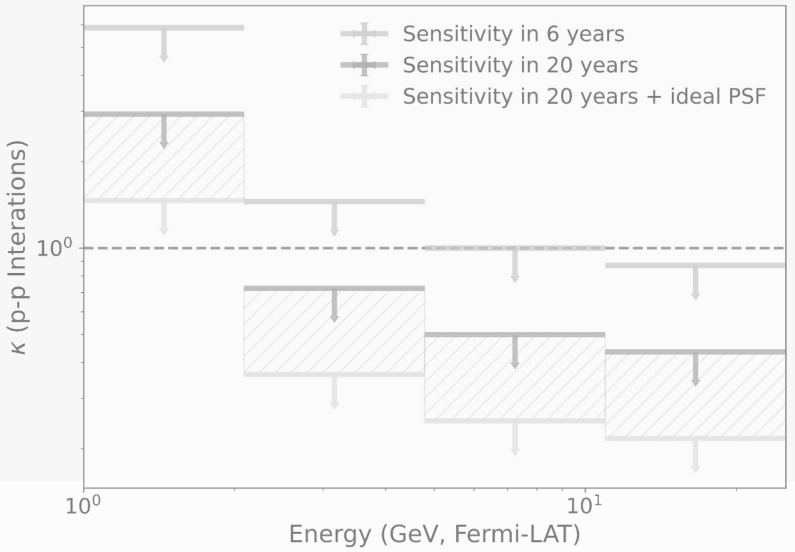
- Injecting the neutrino signal:

$$E_\nu^2 \frac{dN_\nu}{dE_{nu}} \approx \frac{\kappa}{2}\left(E_\gamma^2 \frac{dN_\gamma}{dE_\gamma}\right), \text{ at } E_\nu \approx \frac{E_\gamma}{2}$$

Observations

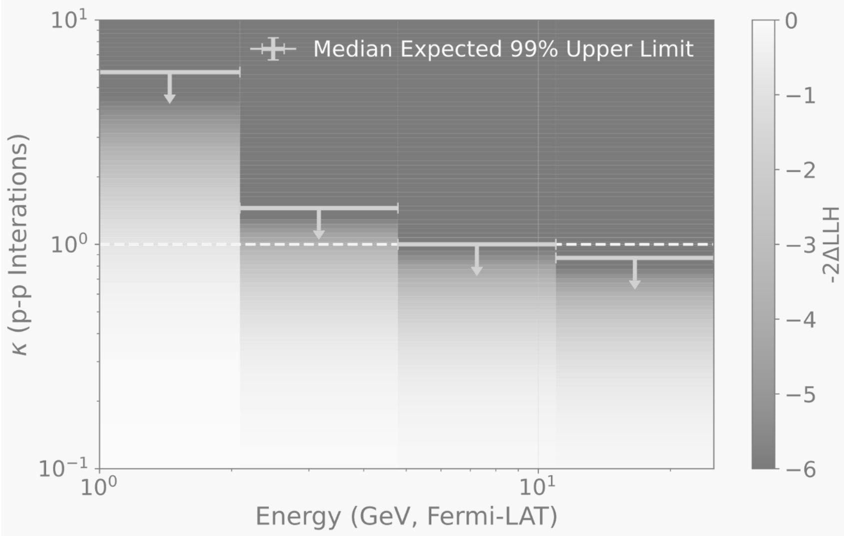


Predictions



Negro, Crnogorčević, et al. 2023 (ApJ, submitted)

Simulations



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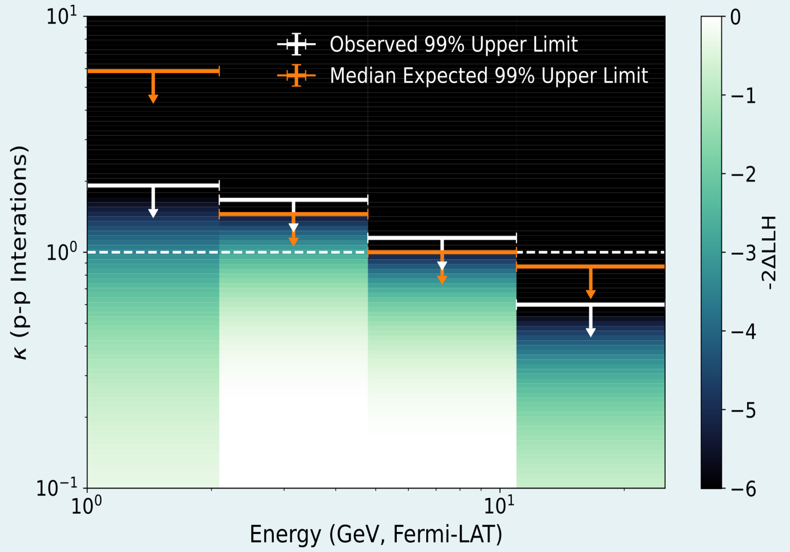
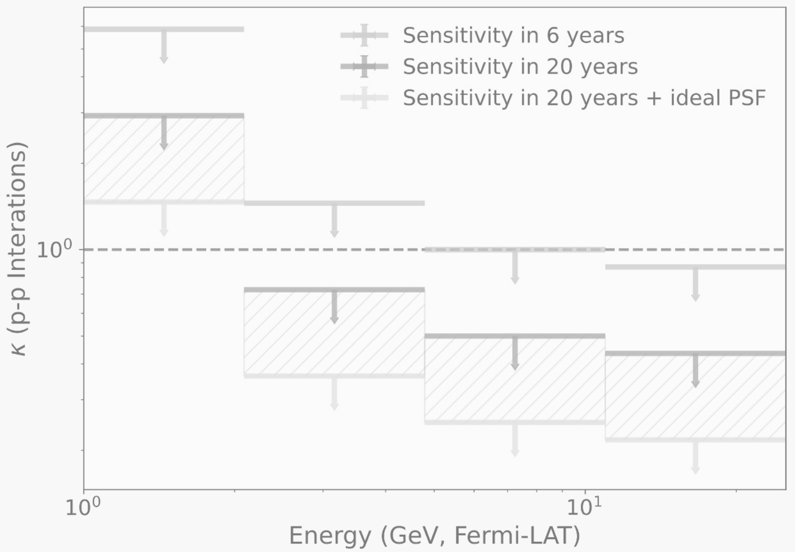
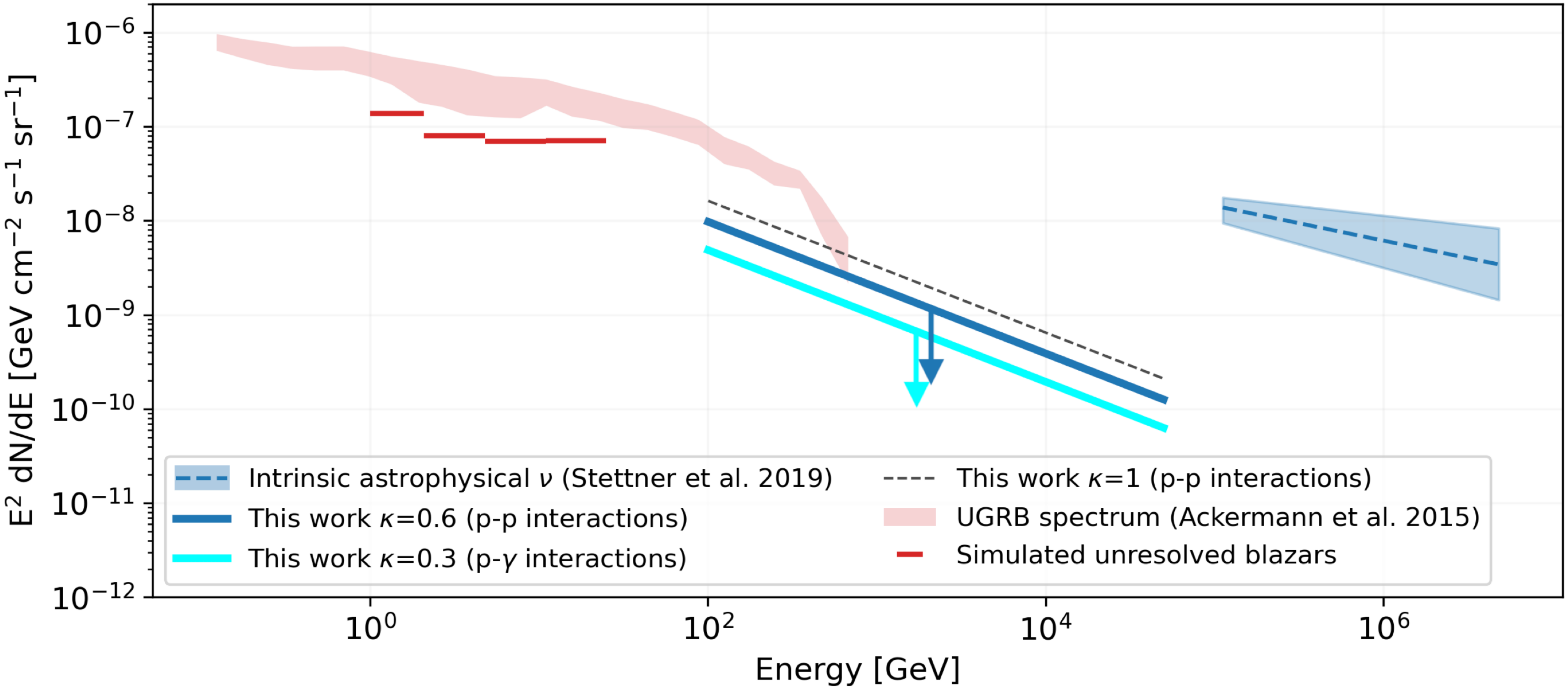


- IceCube 6-year map and *Fermi*-LAT 12 years of data
- Constraining limits in the last energy bin: $\kappa < 0.6$

Predictions



UPPER LIMITS ON THE ν_{ASTRO} FLUX



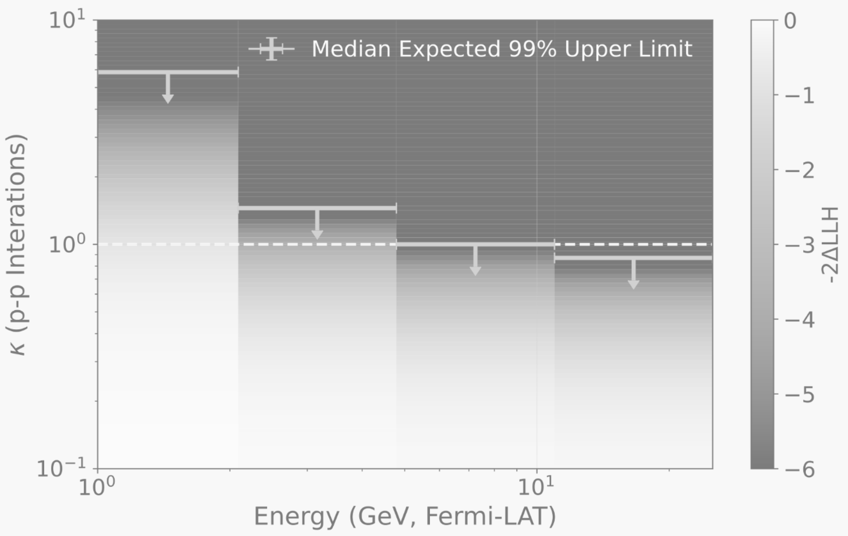
→ Unresolved blazars contribute ~1% at 100 TeV and ~10% at 1 TeV

QUESTION 3: *WHAT DO WE PREDICT?*

Negro, Crnogorčević, et al. 2003 (submitted/accepted? ApJ)

Project III: Neutrinos x Gamma rays

Simulations



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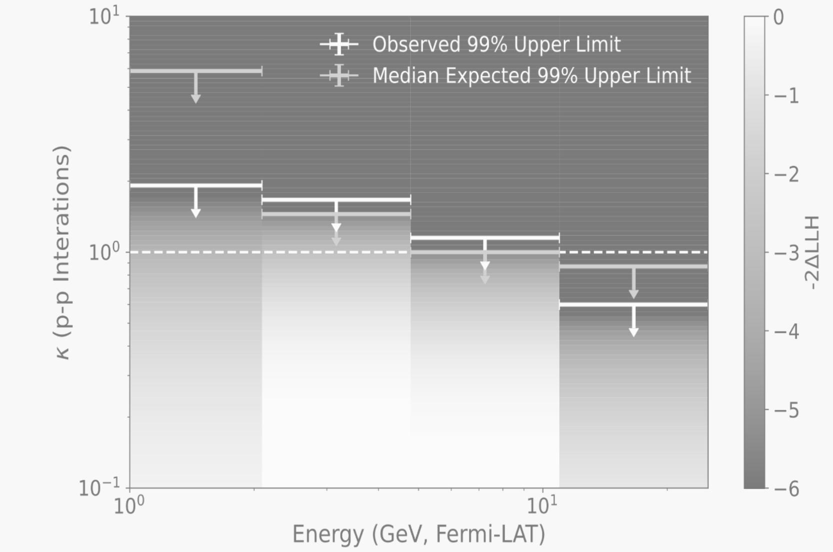

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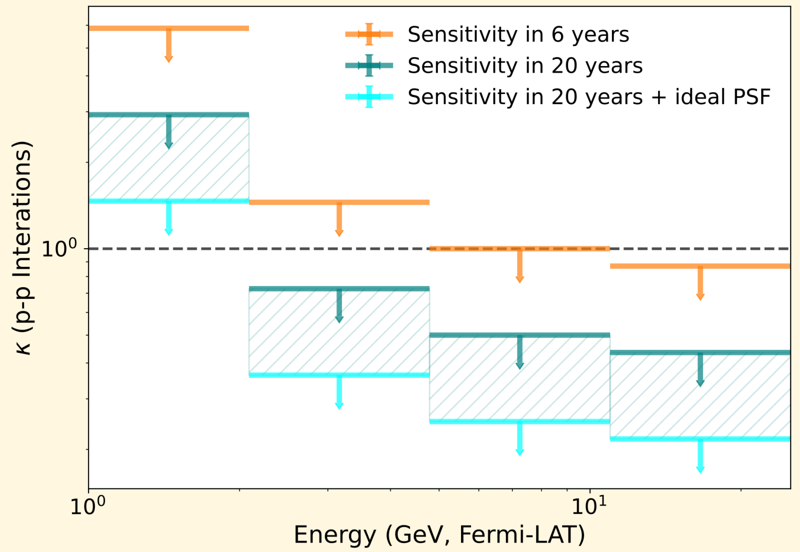


- Keeping the *Fermi*-LAT UGRB emission the same
- Changing the IceCube statistics (alone, and with PSF)

PROJECT I.
SEARCHING FOR AXION-LIKE PARTICLES WITH *FERMI*

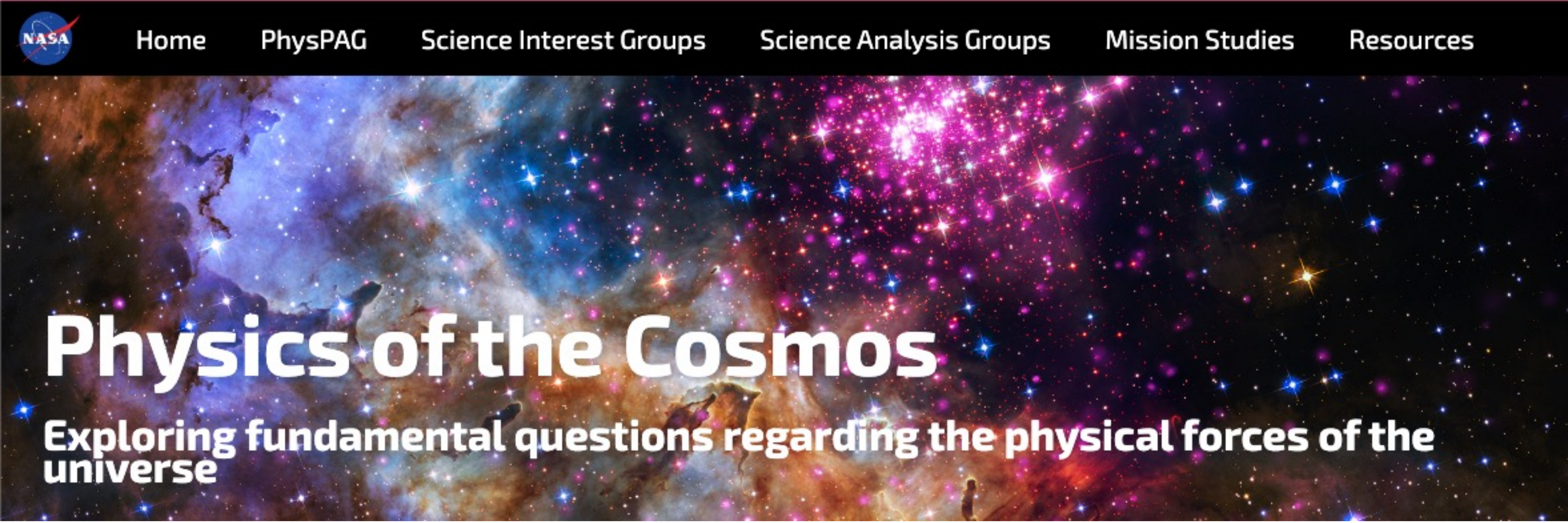
MC et al. 2021 (PRD), MC et al. 2023 (under LAT review)

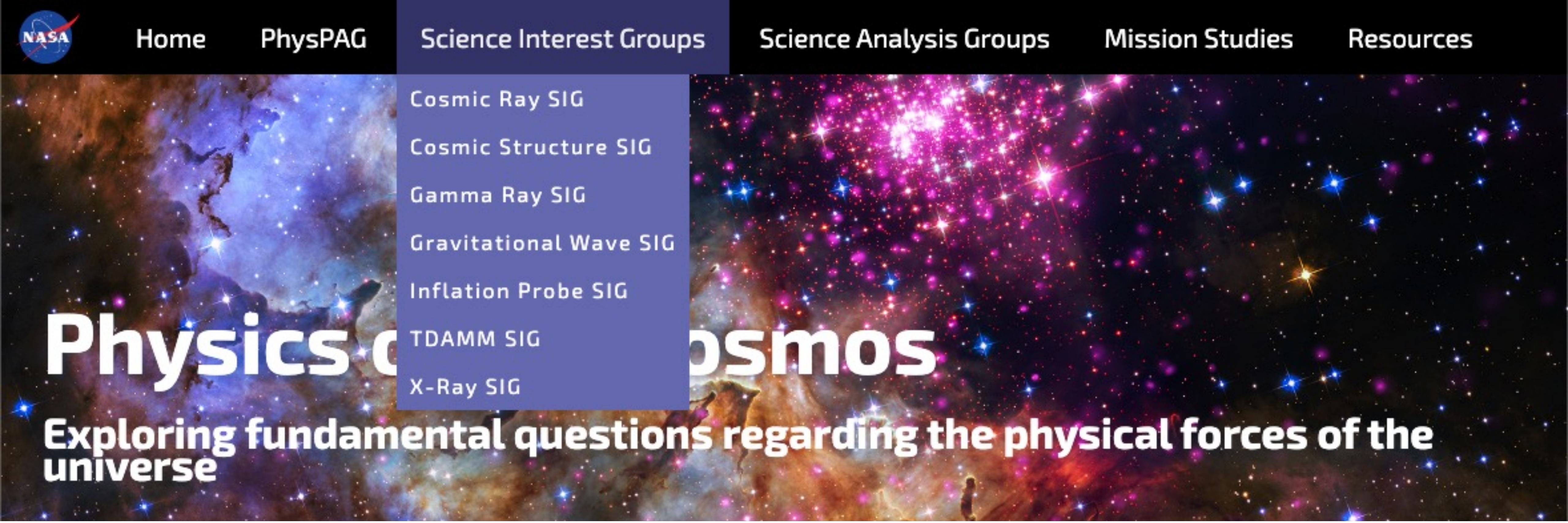
PROJECT II.
A JOINT *FERMI* & *SWIFT* ANALYSIS OF THE THIRD GRAVITATIONAL-WAVE OBSERVING RUN

Fletcher et al. on behalf of GBM, MC et al. for *Swift*-BAT, and LVK, 2023 (ApJ)

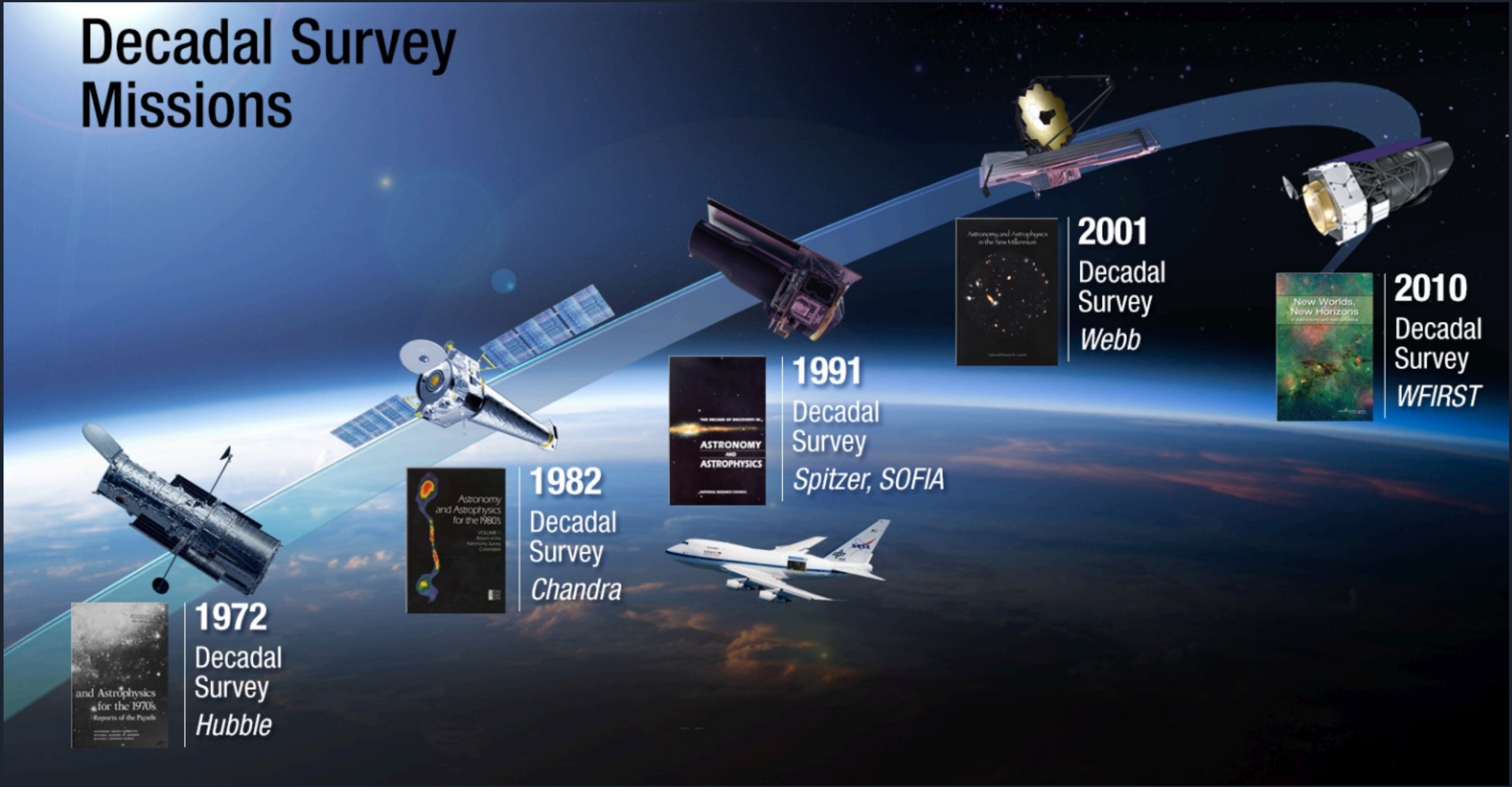
CHAPTER III.
CROSS-CORRELATING ICECUBE NEUTRINOS AND THE *FERMI* UNRESOLVED GAMMA-RAY SKY

Negro, MC, et al. 2023 (ApJ)


NASA
Home
PhysPAG
Science Interest Groups
Science Analysis Groups
Mission Studies
Resources
Physics of the Cosmos
Exploring fundamental questions regarding the physical forces of the universe



Astrophysics Decadal Survey!



Decadal Survey Missions
1972 Decadal Survey Hubble
1982 Decadal Survey Chandra
1991 Decadal Survey Spitzer, SOFIA
2001 Decadal Survey Webb
2010 Decadal Survey WFIRST
and Astrophysics for the 1970's Reports of the Panels
Astronomy and Astrophysics for the 1980's
ASTRONOMY AND ASTROPHYSICS
New Worlds, New Horizons

Future Innovations in Gamma-ray Science

Lead Chairs: Chris Fryer & Michelle Hui
Co-chairs: Paolo Coppi, Milena Crnogorčević, Tiffany Lewis, Marcos Santander, and Zorawar Wadiasingh

- Gamma-ray Science Priorities:

Identify opportunities uniquely afforded by gamma-ray observations.

- Gamma-ray Mission Capabilities:

Which science objectives are only done or best done by space-based gamma-ray missions, considering the current missions in extended operation and funded missions in development.

- Technology Investment:

What new technologies/methodologies exist and what is needed to achieve the science priorities.

- Theory and Analysis Needs:

What advances do we need to make in theory and analysis to achieve the science priorities.

- Synergies with Other Programs:

How do these goals tie to the broader astrophysics and physics community. What are the timelines to align with current priorities in multi-messenger astronomy.

Future Innovations in Gamma-ray Science

- Gamma-ray Science Priorities:

Identify opportunities uniquely afforded by gamma-ray observations.

- Gamma-ray Mission Capabilities:

Which science objectives are only done or best done by space-based gamma-ray missions, considering the current missions in extended operation and funded missions in development.

Planning toward 2040s

- Theory and Analysis Needs:

What advances do we need to make in theory and analysis to achieve the science priorities.

- Synergies with Other Programs:

How do these goals tie to the broader astrophysics and physics community. What are the timelines to align with current priorities in multi-messenger astronomy.

Lead Chairs: Chris Fryer & Michelle Hui
Co-chairs: Paolo Coppi, Milena Crnogorčević, Tiffany Lewis, Marcos Santander, and Zorawar Wadiasingh

Planning toward 2040s

Official launch: Winter AAS meeting

https://forms.gle/VBijBgapMRwJm9dU6

MC: Michael, do you think I can fit 60 slides into 20 minutes?

MC: Michael, do you think I can fit 60 slides into 20 minutes?

MK: PLEEEEEEEEASE DON'T

MK: PLEEEEEEEEASE DON'T

AW: Well, I would be impressed.

Astronomy Community Engagement

UMD ASTRO

GRAD MAP

Graduate Resources Advancing Diversity with Maryland Astronomy and Physics

MILENA, THE OUTREACHER

Speaker: Professor Jim Gates (UMCP Physics)
Title: Equity Versus Excellence: A False Dichotomy in Science and Society

Speaker: Mangala Sharma (NSF)
Title: Astronomy and Science Diplomacy

Speaker: Gina Quan and Stephen Secules
Title: Using Student Perspectives to Understand Equity in STEM Education

Speaker: Maggie McAdam (UMD)
Title: Technology and Belonging on Campus: Perspectives from Underrepresented Students

Speaker: Alexis Williams, Ph.D. & Courtney Cook, M.S. (UMD/TLTC & Women's Studies)
Title: Pro-Disability Teaching: Removing the Deficit Model

Speaker: Kory Kreimeyer (FDA)
Title: Data Science at the FDA

Speaker: Dr. Rachel Ivie and Dr. Anne Marie Porter (AIP/SRC)
Title: "The Representation and Retention of Women in Physics and Astronomy"

Speaker: UMD Office of Diversity & Inclusion
Title: How to Have Crucial Diversity Conversations

Speaker: Patrick Banner and Adam Ehrenberg
Title: Mental Health Task Force

Speaker: Kelly Fast (NASA HQ)
Title: "Lemons are for Lemonade"

Speaker: Various + Special Guest Dr. Daus
Title: Thirty Meter Telescope Discussion III

Speaker: Laura Blecha (UMD)
Title: Why Science is Political

Speaker: Dr. Jeffrey Silverman (Samba TV, Data Scientist)
Title: From Astrophysics to Data Science

Speaker: Pradip Gatkine, Carolyn Kierans, Nathan Roth, Geoffrey Ryan, Eliza Kempton, Drake Deming
Title: "Postdoc Panel: Applying for Postdoc Positions in Astronomy"

Speaker: William Sedlacek, PhD (Prof Emeritus UMD)
Title: Limitations of the GRE and GPA in Selecting and Evaluating Graduate Students: What Alternatives are There?

Full schedule of past seminars: https://www.astro.umd.edu/events/past/bang/

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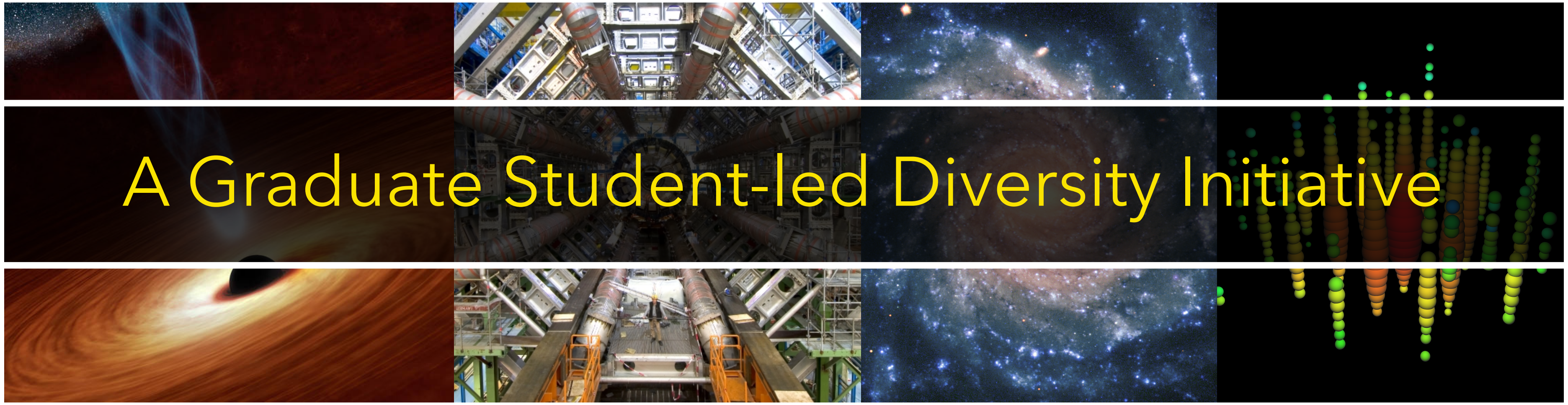
mentoring MP program

UMD ASTRO EDI Committee

BANG! (Better Astronomy for a New Generation!)

GRAD MAP

Graduate Resources Advancing Diversity with Maryland Astronomy and Physics



Milena Crnogorčević – Co-lead (ASTR)
Andrew Guo – Co-lead (PHYS)
Amy Steele – Advisor (ASTR)

NSF

UNIVERSITY OF MARYLAND

GROWTH
Global Relay of Observatories Watching Transients Happen

GRAD MAP

Graduate Resources Advancing Diversity with Maryland Astronomy and Physics

Program Goals

1. **Improve representation of and climate for minorities** in the UMD Physics and Astronomy Programs

2. **Build a diverse collaborative community** amongst the Physics and Astronomy faculty, graduate students, and undergraduate students at UMD and nearby Minority Serving Institutions (MSIs)

3. **Provide graduate students mentoring experience** with a diverse group of students and experience developing and implementing a program that improves diversity.

GRAD MAP

Graduate Resources Advancing Diversity with Maryland Astronomy and Physics

UNIVERSITY OF MARYLAND 1856

Sep - Nov — Fall Collaborative Seminar Series

Visit local HBCUs and MSIs

Oct — Open House

Evening of research at UMD advertising the WW

Jan — Winter Workshop (WW)

~7 - day workshop at UMD

June - Aug — Summer Scholars

Research experience for Winter Workshop alumni

GRAD MAP

Graduate Resources Advancing Diversity with Maryland Astronomy and Physics

Sep - Nov

Fall Collaborative Seminar Series

- Visi … MSIs
- Res … ssors
  (on
- Gra
- Tim
  netw

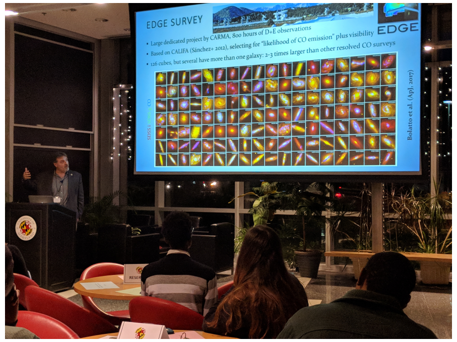
Schools we tend to visit:

Baltimore City Community College
Howard University
Montgomery College
Morgan State University
Norfolk State University
Prince George's Community College

6

Oct Fall Open House

- An evening event at UMD
- Research talks by UMD professors
- Grad students discuss:
  - preparing for grad school
  - grad school life
  - career paths with PhD
- Time for informal discussions, networking (and dinner!)
- Encourage students to apply for the Winter Workshop



GRAD MAP

Graduate Resources Advancing Diversity with Maryland Astronomy and Physics

Winter Workshop

- Learn research basics
  - scientific computing, coding (Python)
- Start an original research project with a University of Maryland advisor
- Complete an REU/summer internship application
- Learn about graduate schools and how to apply
- Spend a weekend at the Greenbank Telescope and observe
- Visit local research labs at Goddard, APL, NIST, UMD, etc.

2018 Cohort

Not pictured: Duha Awad

2020 Cohort

GRAD MAP

Graduate Resources Advancing Diversity with Maryland Astronomy and Physics

June-Aug

Summer Scholars

- 10-week funded summer research program hosted at UMD
- Weekly check-in meetings, journal clubs, and career advancement trainings
- Final research presentations
- Partner with other REU programs at UMD
- Travel funding for external presentations


2017 Cohort

N. Feleke final presentation, 2020

Speaker: Professor Jim Gates (UMCP Physics)
Title: Equity Versus Excellence: A False Dichotomy in Science and Society

Speaker: Mangala Sharma (NSF)
Title: Astronomy and Science Diplomacy

Speaker: Gina Quan and Stephen Secules
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BANG! (Better Astronomy for a New Generation!)

UMD ASTRO
EDI Committee

Astronomy
Community
Engagement

Milena, the person

Chapter 7: Conclusions

They say all's well that ends well.

Taylor Swift

At last, we have arrived at our final destination—for now. What have we found? Well, not much—if anything. To many, this dissertation is simply a story of upper limits. Nevertheless,

CONCLUSIONS

- Using *Fermi* GBM triggers and sub-threshold searches, and *Swift* BAT's data to search for coincident **γ**-ray emission with the GWTC-3 events, we found no statistically significant EM counterparts
- We calculated the flux upper limits for both GBM and BAT and present joint upper-limit skymaps
- Theoretical implications: BBH emission models
- Paper soon to be submitted (under the collaborations' review)

- Getting ready for O4!