LUNCH WITH ZWICKY'S – PT2

Michele Doro, University of Padova

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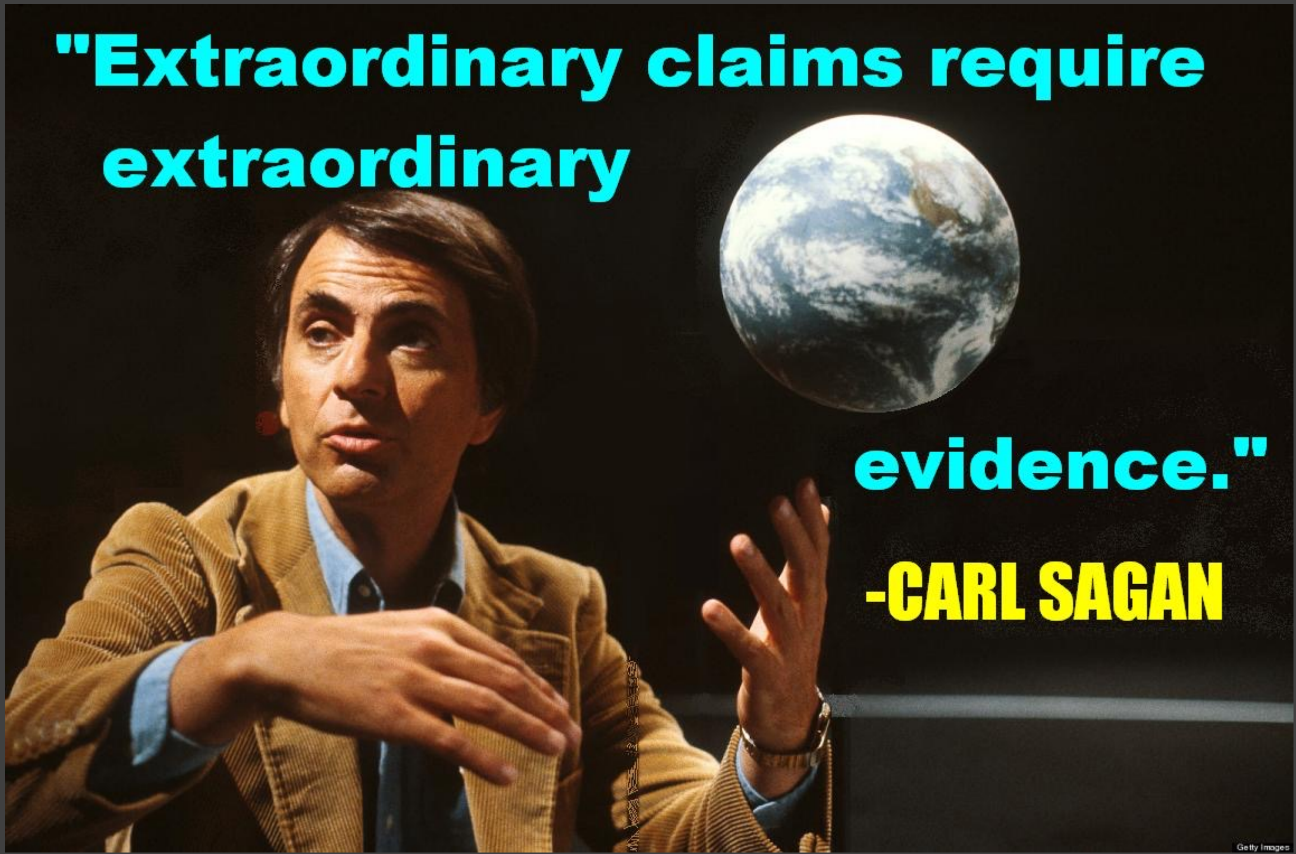
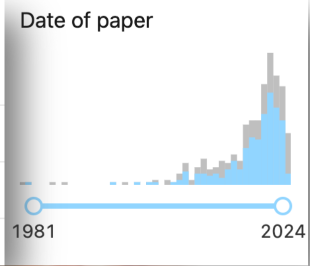
OUTLINE OF PT2



- ALPs
- PBH
- MM
- LIV

	Citeable
Papers	268
Citations	13,438
h-index	60
Citations/paper (avg)	50.1



AXION LIKE PARTICLES

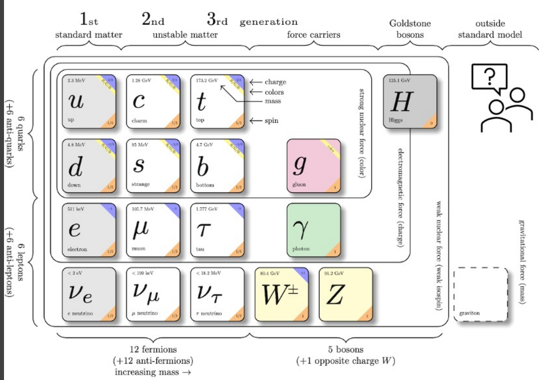
Be prepared to wash dishes

Recipe in coll. with Ivana Batkovic (PD),
Muneeb Shoaib (PD), Giacomo d'Amico (Uni Bergen)

3

HOUSTON, WE HAVE A STRONG CP PROBLEM

STANDARD MODEL



- ? Matter-antimatter asymmetry
- ? Neutrino oscillations
- ? **Strong CP problem**
- ? **Dark matter**

By D. Galbraith and C. Burgard

Courtesy I. Batkovic

Strong CP problem

- R.D. Peccei and H. Quinn; 1977.
- Spontaneously broken global symmetry
- S. Weinberg and F. Wilczek; 1978.

Axion

$$m_a \simeq 6 \times 10^{-6} \frac{10^{12}\,\mathrm{GeV}}{f_a}$$

Dark matter

- Produced in the early Universe:

Dark Matter Axion

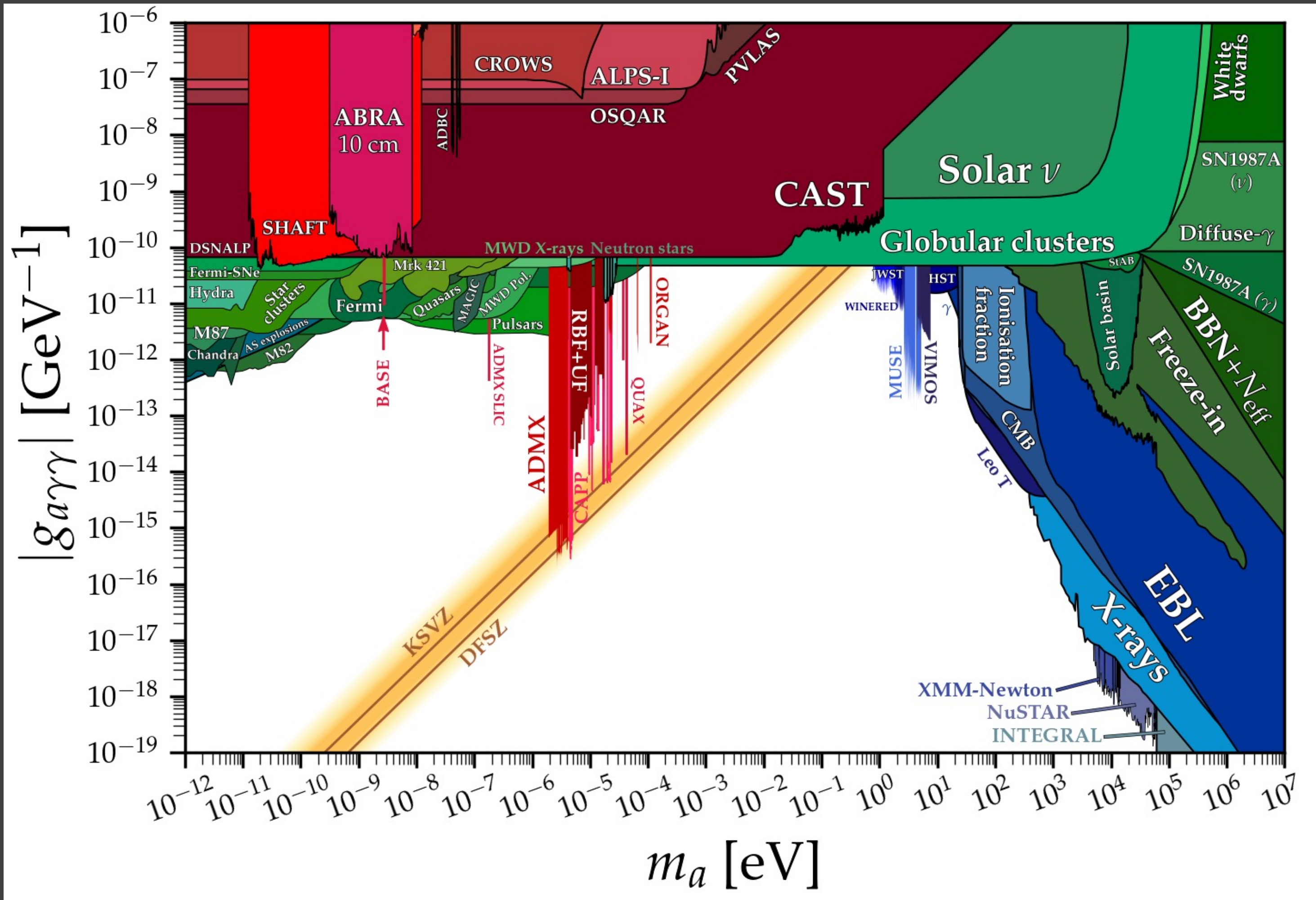
$$g_{a\gamma\gamma} < \left(\frac{m_a}{1\ \mathrm{neV}}\right)^{\frac{1}{2}} \mathrm{GeV}^{-1}$$

Axion-like particles (ALPs)

- Pseudo-Nambu-Goldstone bosons emerging from different theories
- Mass and coupling are independent

NOT FOUND IN SUPERMARKET

https://cajohare.github.io/AxionLimits/



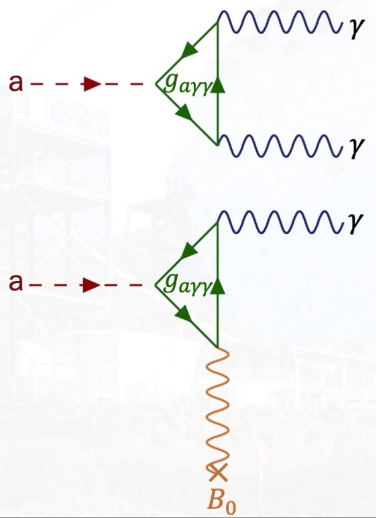
- Cosmological limits (blue)
- Lab limits (red)
  - Shine through the wall
  - Plasma
  - Cavities

ALP-PHOTON CONVERSION IN B'S

- Observable through interaction with photons
- Extremely important for detection of axion

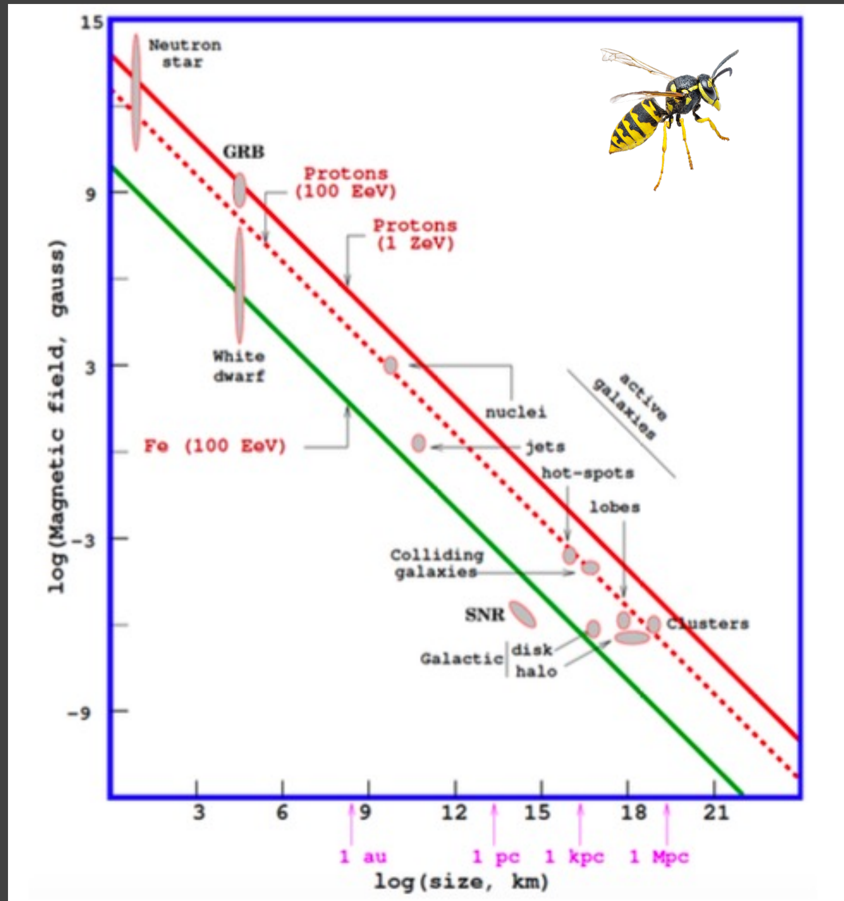
- Magnetic field is "enabling mixing" between a VHE photon and an axion:

$$\mathcal{L}_{a\gamma\gamma} = -\frac{g_{a\gamma\gamma}}{4} F_{\mu\nu}\tilde{F}^{\mu\nu} a = g_{a\gamma\gamma}\vec{E}\cdot\vec{B}a$$



Courtesy I. Batkovic

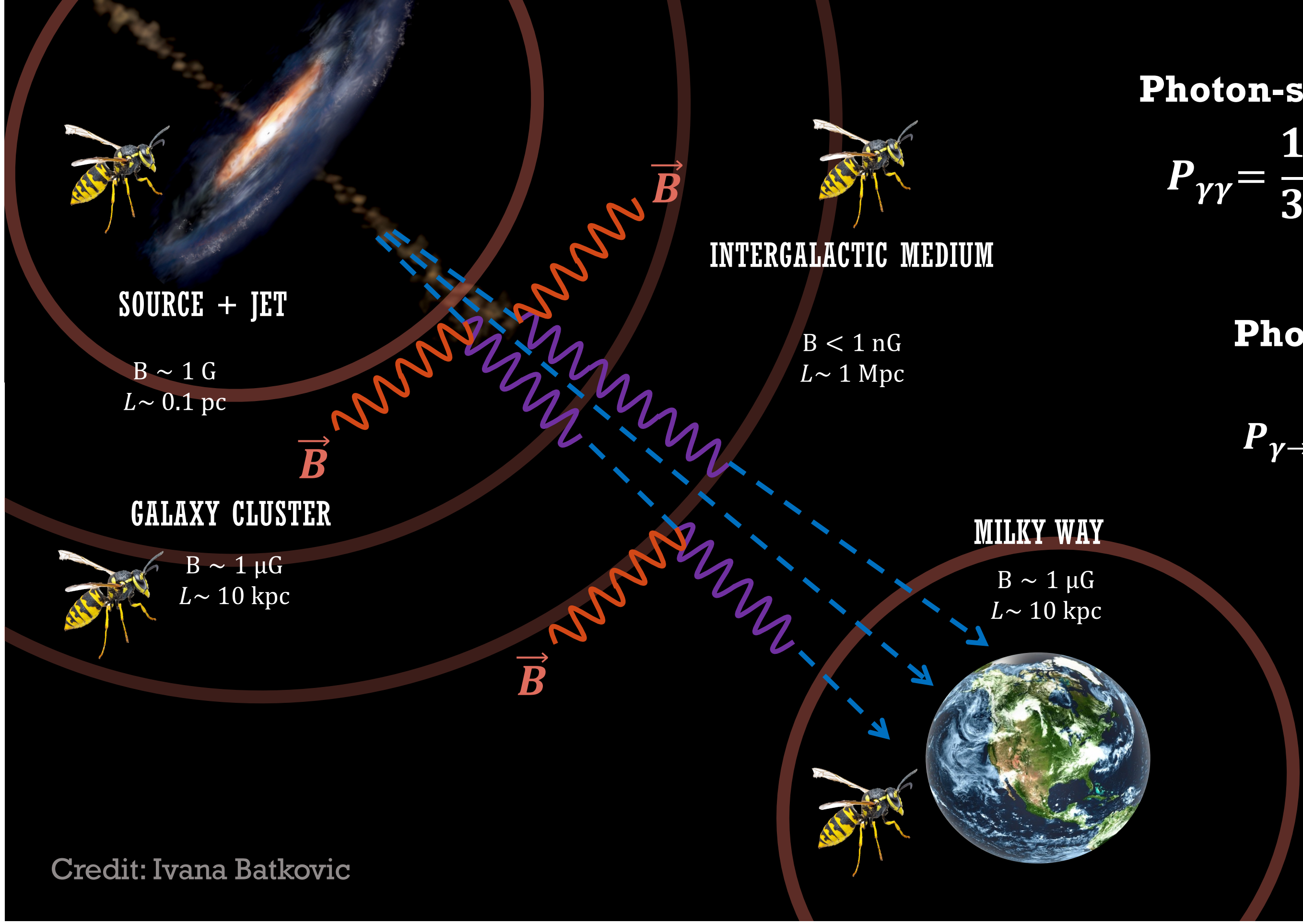
Spot the best for ALP conversion!



Università degli Studi di Padova
Dipartimento di Fisica e Astronomia Galileo Galilei

Courtesy I. Batkovic

Astrophysical scenarios for photon/ALP conversions



Photon-survival probability

$$P_{\gamma\gamma} = \frac{1}{3}\left(1 - exp\left(-\frac{3}{2} N P_{\gamma\to a}\right)\right)$$

Photon conversion probability

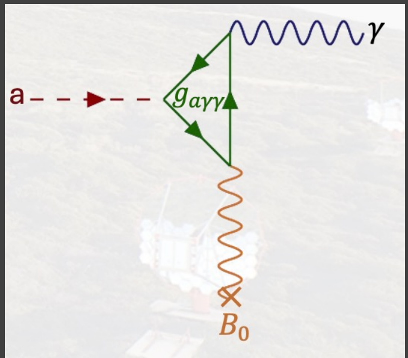
$$P_{\gamma\to a} = sin^2(2\theta)\, sin^2\left[\frac{g_{a\gamma}BL}{2}\sqrt{1+\left(\frac{E}{E_\gamma}\right)^2}\right]$$

Critical energy

$$E_{crit} = 2.5\ \mathrm{GeV}\,\frac{\left|m^2_{a,\mathrm{neV}} - \omega^2_{pl,\mathrm{neV}}\right|}{G_{11}B_{\mu\mathrm{G}}}$$

Credit: Ivana Batkovic

OBSERVABLES: SPECTRAL WIGGLES AND PHOTON RECOVERY



$$E_{crit} = 2.5\ \text{GeV}\frac{|m^2_{a,\text{neV}} - \omega^2_{pl,\text{neV}}|}{G_{11}B_{\mu\text{G}}}$$

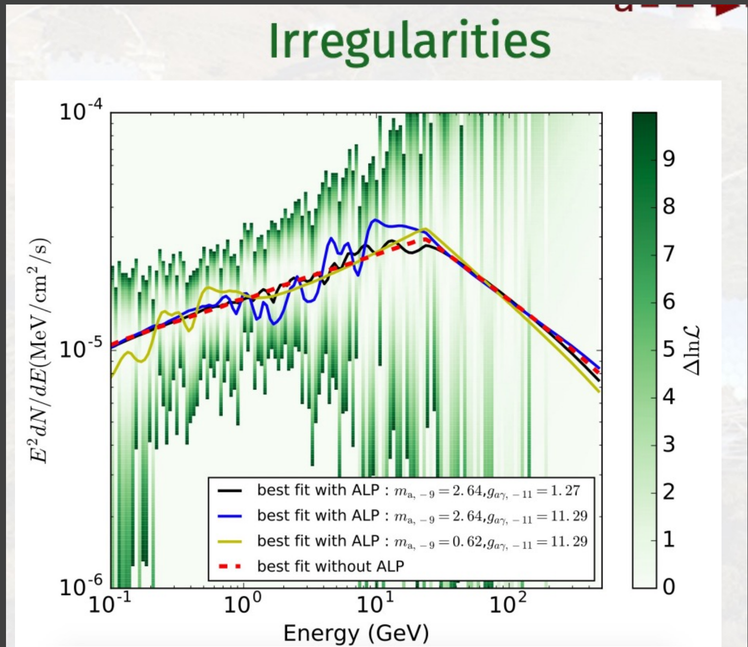


Figure 3: Spectrum fit of PKS2155-304 w & w/o ALPs, arXiv:1311.3148

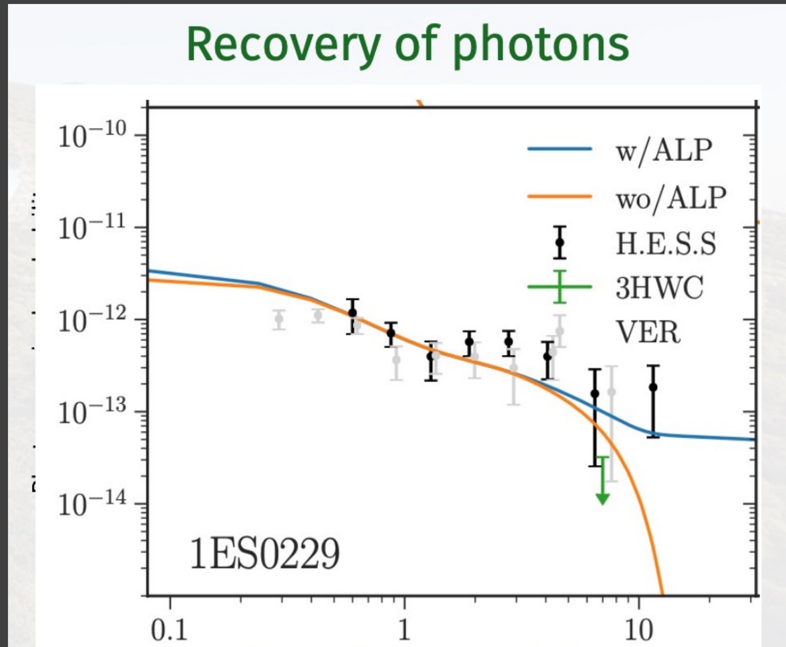


Figure 4: Simulated flux spectra w & w/o ALPs; Jacobsen et al., arXiv:2203.04332

GeV-TeV band

10/100-TeV band

GAMMAALPS

Manuel Meyer https://gammaalps.readthedocs.io/en/latest/index.html

$$\frac{d\Phi_{obs}}{dE} = \frac{d\Phi_{int}}{dE} \times P_{\gamma\gamma}^{a,EBL}(E_\gamma; m_a, g_{a\gamma}, B; z)$$

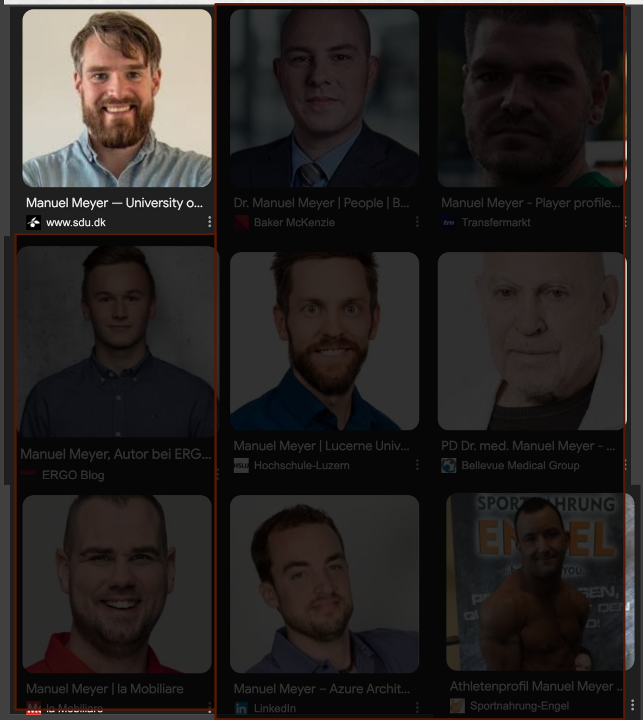
Observed flux

Intrinsic flux

Gamma-ray energy

Ambient magnetic field

Source's redshift



Who is the right MM?

- Calculates the oscillation probability between photons and axion-like particles (ALPs) in various astrophysical environments
- A.k.a. computes the equation of transport

Tutorials

Calculate photon-ALP mixing in different environments

These tutorials demonstrate the usage of gammaALPs for different astrophysical environments:

- Mixing in a homogeneous magnetic field | *mixing_single_cell.ipynb*
- Mixing in Gaussian turbulence field: Perseus cluster and from NGC 1275 | *mixing_ICM_Gaussian_Turbulence.ipynb*
- Mixing in structured cavity field: Perseus cluster and from NGC 1275 | *mixing_ICM_structured_field.ipynb*
- Mixing in the intergalactic magnetic field (IGMF) | *mixing_IGMF.ipynb*
- Mixing in AGN jet with simple toroidal magnetic field | *mixing_AGN_jet_simple.ipynb*
- Mixing in AGN jet with helical and tangled magnetic field | *mixing_HelicalTangled_jet.ipynb*
- Mixing in the Galactic magnetic field using the Jansson & Farrar model | *mixing_gmf.ipynb*

GAMMAALPS

```
[1]: #!pip install gammaALPs
```

We start of with the usual imports:

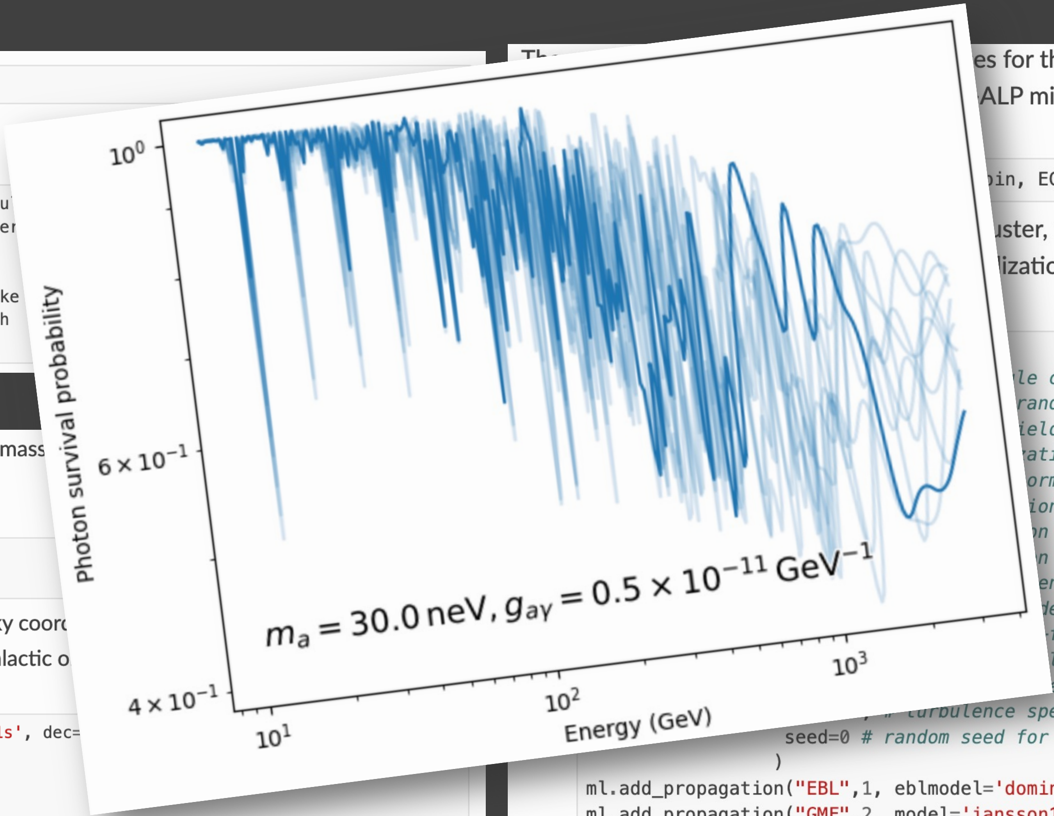
```
[2]: from gammaALPs.core import Source, ALP, Modu
     from gammaALPs.base import environs, transfer
     import numpy as np
     import matplotlib.pyplot as plt
     from matplotlib.patheffects import withStroke
     from ebltable.tau_from_model import OptDepth
     from astropy import constants as c
```

And initialize an ALP object, which stores the ALP mass
$10^{-11}\mathrm{GeV}^{-1}$).

```
[3]: m, g = 1.,1.
     alp = ALP(m,g)
```

Next, we set the source properties (redshift and sky coord
can be taken form your favorite catalot for extragalactic o

```
[4]: ngc1275 = Source(z=0.017559, ra='03h19m48.1s', dec=
     print (ngc1275.z)
     print (ngc1275.ra, ngc1275.dec)
     print (ngc1275.l, ngc1275.b)

0.017559
49.950416666666655 41.51166666666666
150.57567432060083 -13.261343544296324
```



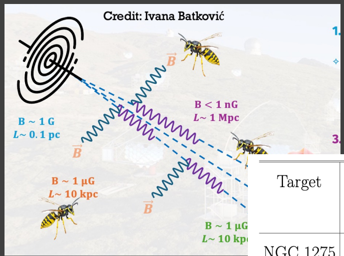
es for the ALP, our source, the initial polarization, and the
ALP mixing

```
in, EGeV = EGeV)
```

uster, the EBL, and the Galactic magnetic field. By
izations of the magnetic field.

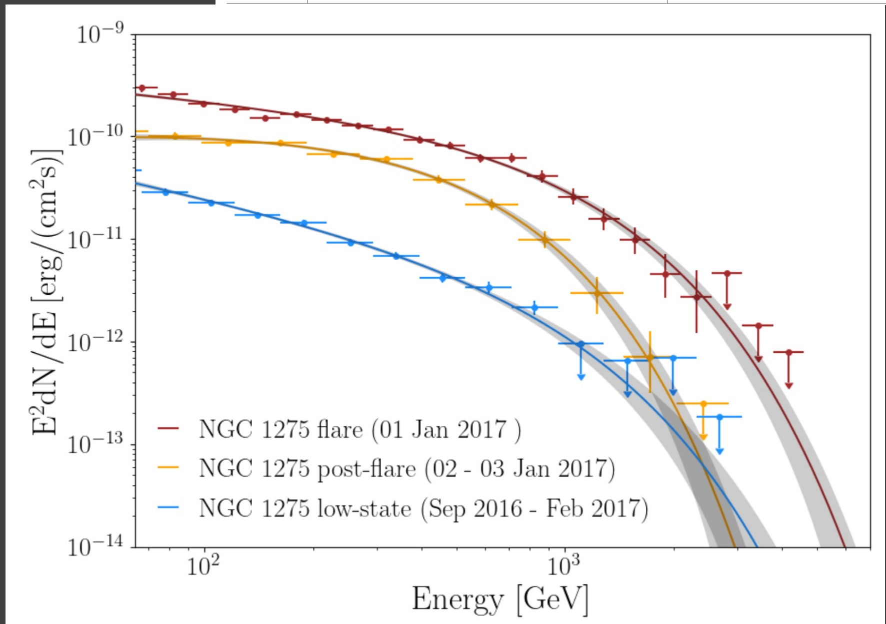
```
le counted from the source.
random B-field realizations
ield in muG
ation of electron density in cm-3
ormalization of electron density, see Churazov et a
ion of the cluster in kpc
n density parameter, see Churazov et al. 2003, Eq
n density parameter, see Churazov et al. 2003, Eq
ensity parameter, see Churazov et al. 2003, Eq. 4
density parameter, see Churazov et al. 2003, Eq. 4
-field with electron denstiy
lence scale in kpc^-1, taken from A2199 cool-core
ence scale, taken from A2199 cool-core cluster,
# turbulence spectral index, taken from A2199 cool-core cluster
seed=0 # random seed for reproducability, set to None for random seed.
)
ml.add_propagation("EBL",1, eblmodel='dominguez') # EBL attenuation comes second, after bea
ml.add_propagation("GMF",2, model='jansson12') # finally, the beam enters the Milky Way Fie
```

CLUSTER OF GALAXIES – E.G. PERSEUS



MAGIC Coll, Phys.Dark Univ. 44 (2024)

Target	Date	Duration [h]	$N_{\rm on}$	$N_{\rm off}$	$N_{\rm exc}$	$\mathcal{S}$	Spectrum	Γ	$\Phi_0/10^{-10}$ [cm^{-2} s^{-1} TeV^{-1}]	E_k [TeV]
NGC 1275	1 Jan 2017	2.5	6632	6703	4397	61.3	EPWL	-2.31 ± 0.06	12.2 ± 1.0	0.72 ± 0.11
	02-03 Jan 2017	2.8	4376	6060	2356	37.8	EPWL	-1.79 ± 0.14	11.4 ± 2.1	0.29 ± 0.04
	Sep 2016 - Feb 2017	36.0	28830	68943	5849	31.8	EPWL	-2.54 ± 0.13	1.1 ± 0.2	0.5 ± 0.12
Sum		41.3	39838	81706	12602	60.8	–	–	–	–



binned likelihood as follows

$$\mathcal{L}(g_{a\gamma}, m_a, \boldsymbol{\mu}, \boldsymbol{b}, B|\boldsymbol{D}) = \prod_{i,k} \mathcal{L}_{i,k}(g_{a\gamma}, m_a, \boldsymbol{\mu_i}, b_{i,k}, B|\boldsymbol{D}_{i,k}),$$

$$\mathcal{L}_{i,k} = \mathcal{P}\left(N_{\rm on}^{i,k} \mid s_{i,k} + \alpha\, b_{i,k}\right) \times \mathcal{P}\left(N_{\rm off}^{i,k} \mid b_{i,k}\right)$$

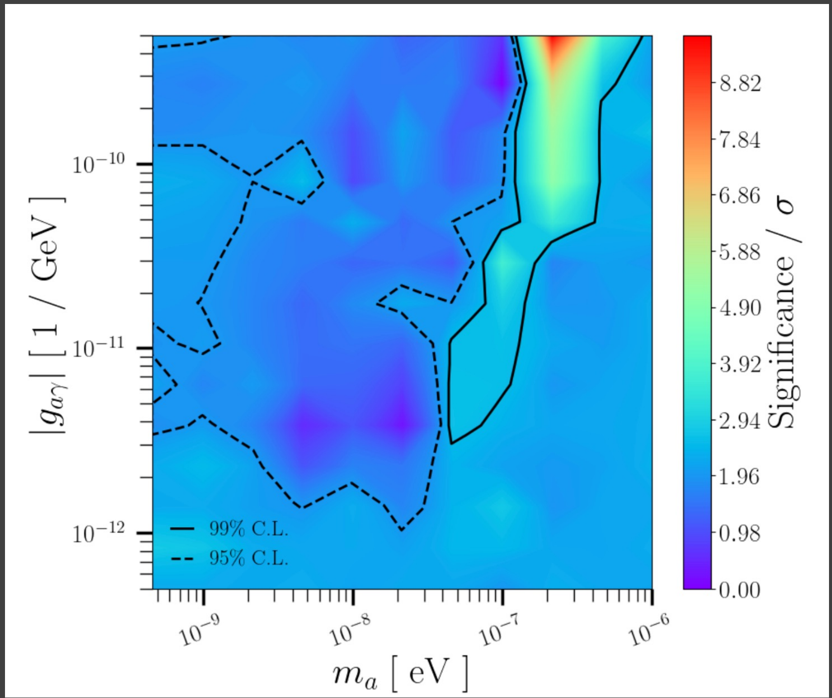
- μi are the SED nuisance parameters (flux amplitude, spectral index and cut-off energy
- bi,k are the expected background counts in the OFF region
- Di,k = (Ni,kon , Ni,koff) are the number of ON and OFF events observed in the k–th energy bin from the i–th sample

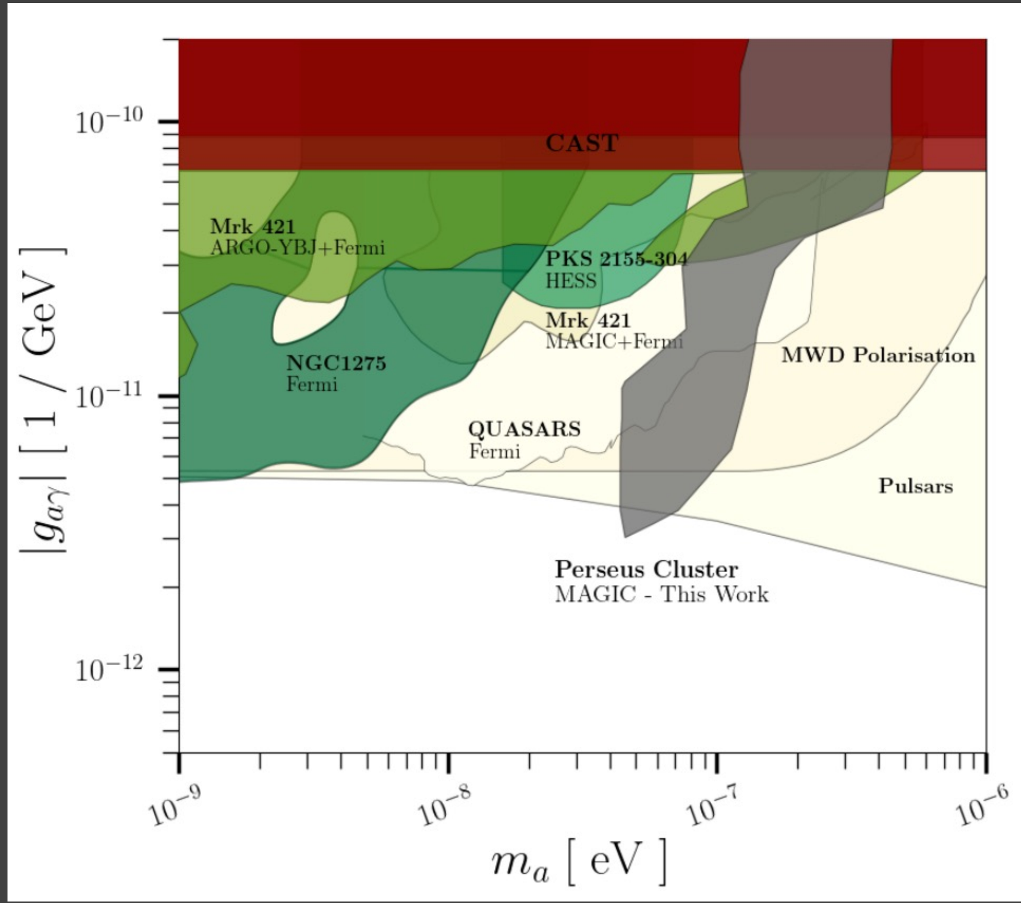
TS WITH WILKS CAVEATS

MAGIC Coll, Phys.Dark Univ. 44 (2024)

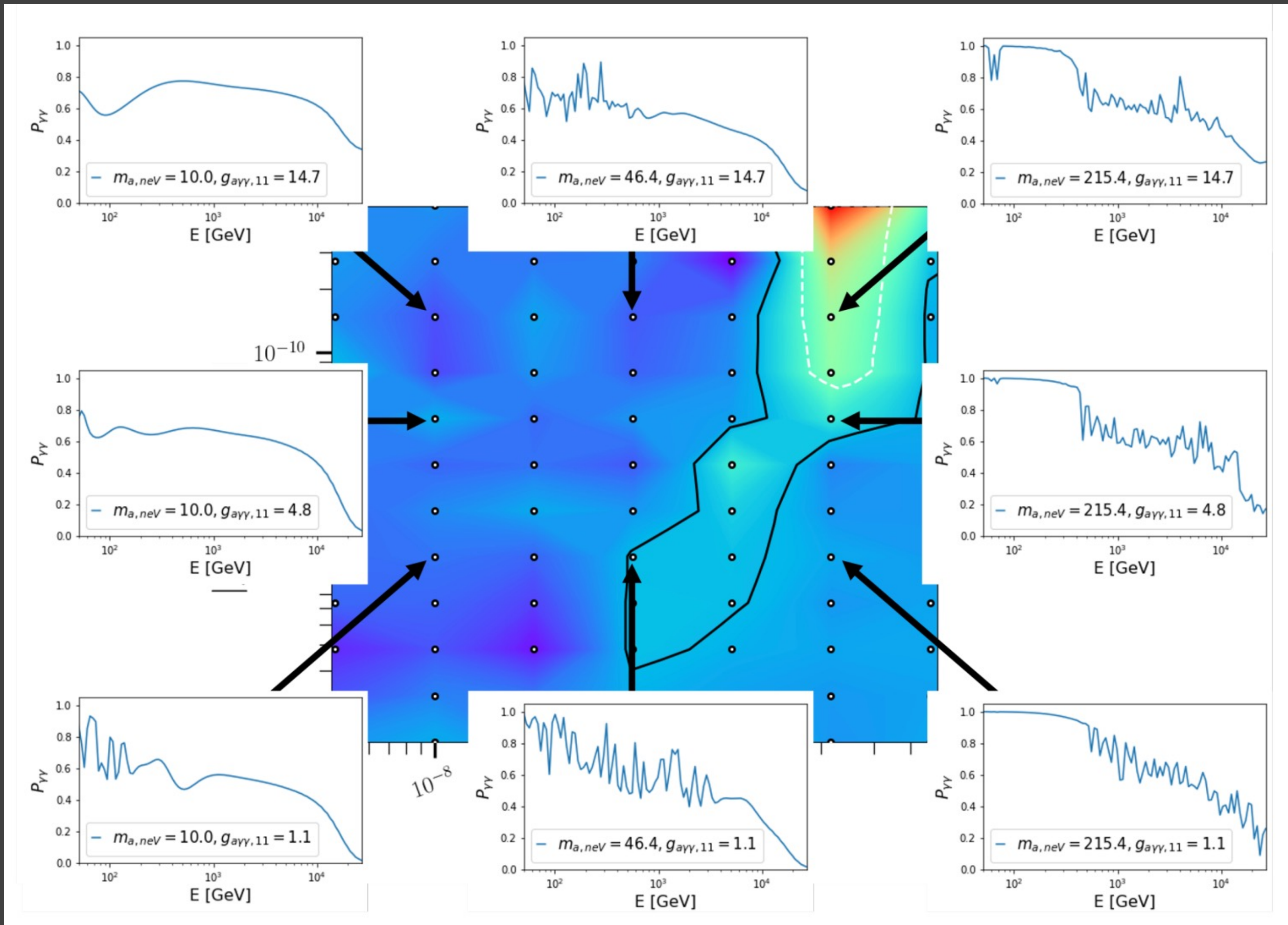
$$\mathcal{TS}(g_{a\gamma}, m_a) = -2\Delta \ln \mathcal{L}$$
$$= -2 \ln \frac{\mathcal{L}(g_{a\gamma}, m_a, \hat{\boldsymbol{\mu}}, \hat{\boldsymbol{b}}, \hat{B}|\boldsymbol{D})}{\hat{\mathcal{L}}},$$

where $\hat{\mathcal{L}}$ is the maximum value of the likelihood over the parameter space, while $\hat{\boldsymbol{\mu}}$ and $\hat{B}$





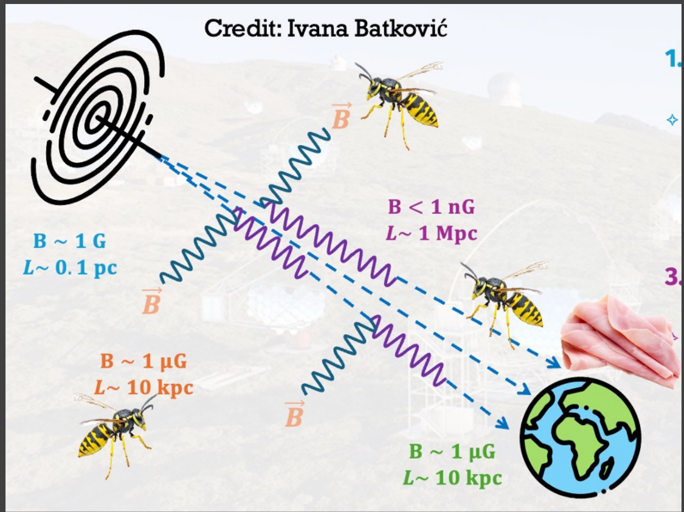
JUMPS MORE THAN WIGGLES



- IACTs constraints spectral-jumps, not wiggles

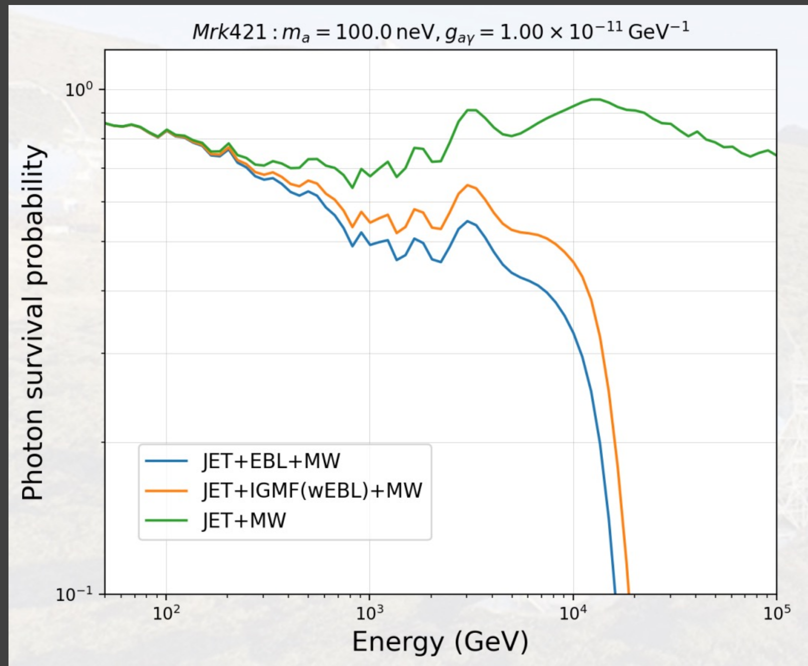
MAGIC Coll, Phys.Dark Univ. 44 (2024)

LST1 - BLAZARS



- LST-1 dataset: Mrk421, BLLac, Mrk501, …
- Combine them all and make a gammapy pipeline

Credit Batkovic



Need to model
- Intrinsic flux
- Magnetic field in jet
- Magnetic field in MW
- EBL

IN JETS

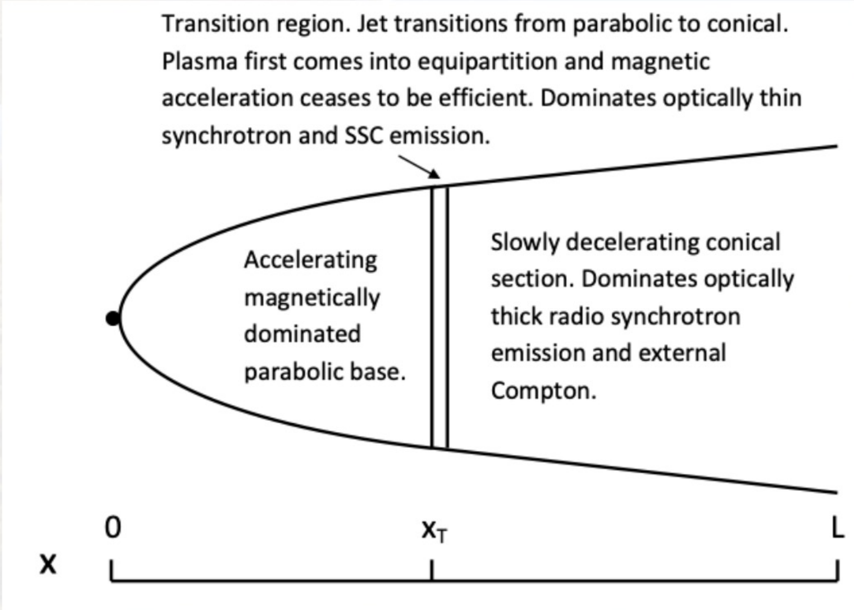
Source	z	r_T(pc)	r_{VHE}(pc)	r_{jet}(pc)	B_0(G)	α	r_T(pc)	g	$M(M_\odot)$	$n_0(cm^{-3})$*
Mrk 421	0.031	6.02	6.02	9.721×10^3	0.03	1.55	6.02	12	6.31×10^8	8.5×10^3
Mrk 501	0.034	0.3	0.3	3.240×10^3	0.8	1.68	0.3	9	3.16×10^7	4.5×10^4
BL Lac	0.069	0.12	0.12	16.204×10^3	2.68	1.95	0.12	8	1.26×10^7	8.0×10^5
1ES1959+650	0.048	0.96	0.96	3.241×10^4	1.88	1.6	0.96	8	1.00×10^7	7.2×10^2

*taken from Tavecchio et al. , MNRAS. **401,** 1570–1586 (2010)

New constraints on the structure and dynamics of black hole jets

William J. Potter, Garret Cotter (Aug 3, 2015)

Published in: *Mon.Not.Roy.Astron.Soc.* 453 (2015) 4, 4070-4088 • e-Print: 1508.00567

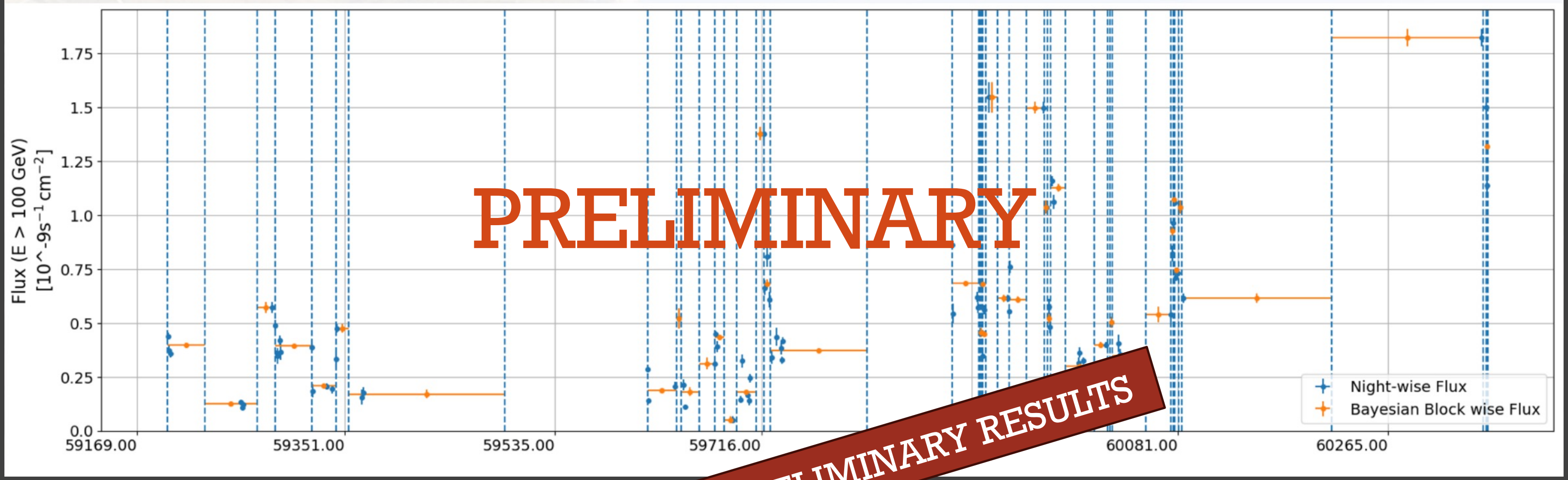


Important for the gammALPs:

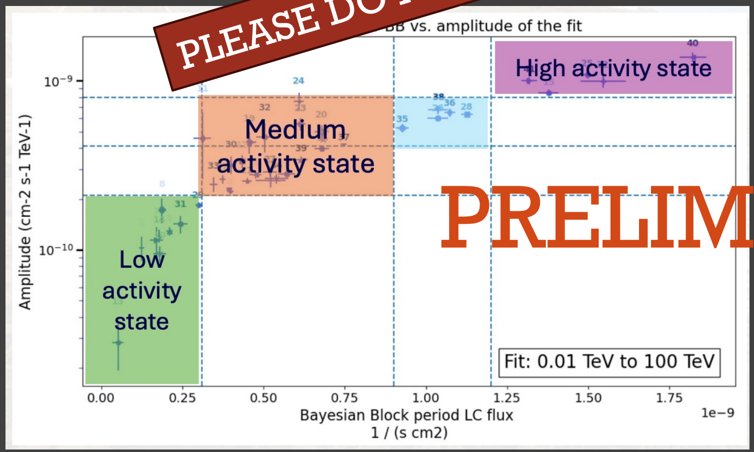
- Jet geometry is linearly scaled from the observations of M87 using the eff. BH mass
- Transition region is consequently defined to occur at $10^5\ r_T$
- At the same time, r_T (distance of the transition region from the BH), can be calcluated from the formula for the gravitational radius:

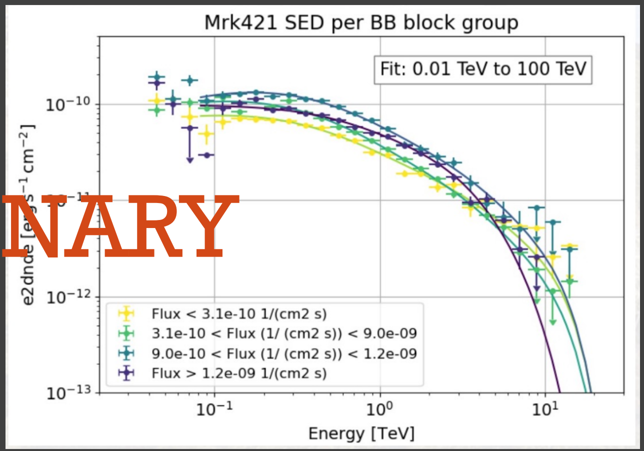
$$r_T = \frac{2MG}{c^2}$$

LC AND SED



PLEASE DO NOT DISTRIBUTE – PRELIMINARY RESULTS





Credit Batkovic

COMBINATION OF RESULTS

Credit Batkovic

Data storage - .ecsv files

- For each source, we store the relevant information
- Providing the likelihood, test statistic (TS) values and sigma values
- Once available, different sources can be combined for ALPs exclusions

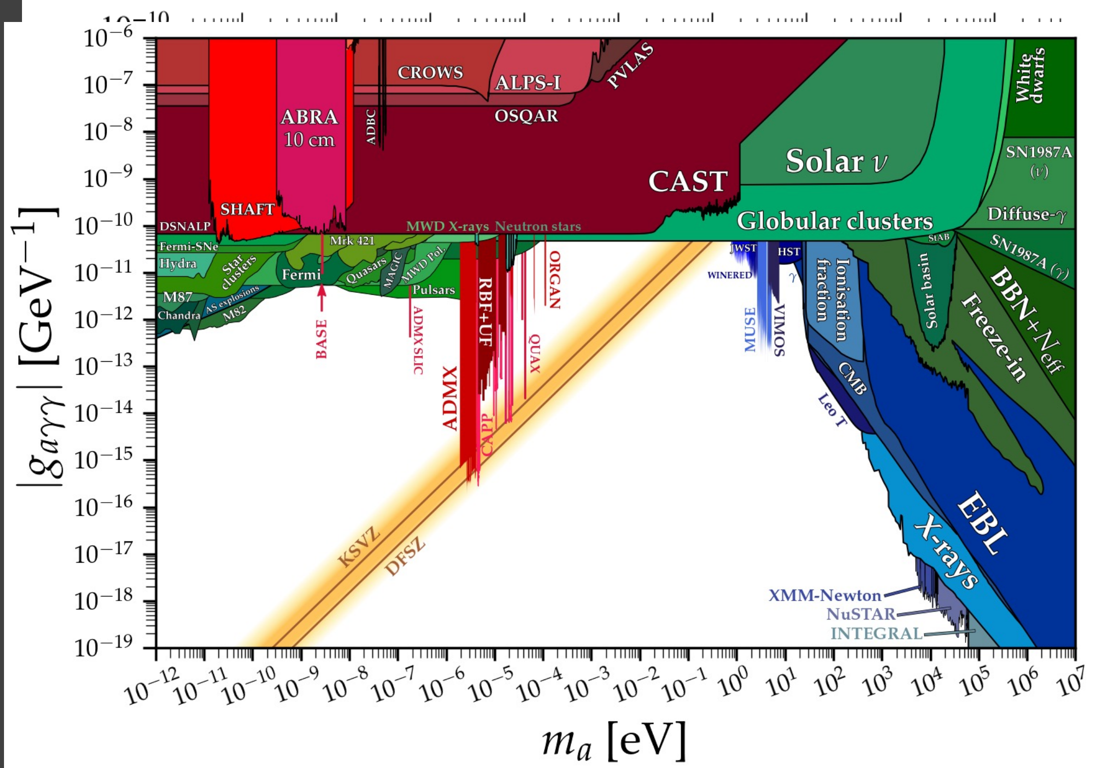
```
# %ECSV 0.9
# ---
# meta: !!omap
# - { Author: I. Batkovic }
# - { mail: ivana.batkovic@unipd.it }
# - { Date of file: 2024-16-05 }
# - { Source: Mrk421 }
# - { Source exposure: 82.8h }
# - { Source observation: 2020-13-12; 2024-12-02 }
# - { Instrument: LST1 }
# - { EBL model: Dominguez11 }
# - { B-field: JET (P&C) + EBL + MW (J&F12) }
# schema: astropy-2.0
# datatype:
# - {'name': 'm_a', 'unit': 'eV', 'datatype': 'float32', 'description': 'ALP mass'}
# - {'name': 'g_a\\gamma', 'unit': 'GeV', 'datatype': 'float32', 'description': 'ALP cross section'}
# - {'name': 'logL', 'unit': 'none', 'datatype': 'float32', 'description': 'log likelihood'}
# - {'name': 'TS', 'unit': 'none', 'datatype': 'float32', 'description': 'calibrated TS'}
# - {'name': 'z-score', 'unit': 'none', 'datatype': 'float32', 'description': 'z score'}

m_a     ;   g_a\gamma;  logL  ;    TS   ;    z-score
1.00e-09;   2.00e-12;   80.516 ;   28.569;   2.126;
2.15e-09;   2.00e-12;   80.528 ;   28.581;   2.125;
4.64e-09;   2.00e-12;   80.770 ;   28.823;   2.107;
```

REACH OF CTA

Sensitivity of the Cherenkov Telescope Array for probing cosmology and fundamental physics with gamma-ray propagation #4

CTA Collaboration • H. Abdalla (Potchefstroom U.) et al. (Oct 3, 2020)

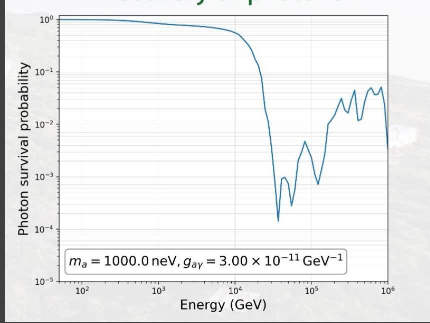
Published in: *JCAP* 02 (2021) 048 • e-Print: 2010.01349 [astro-ph.HE]



CTA can improve a lot because of
- Optimal energy resolution
- Improved sensitivity

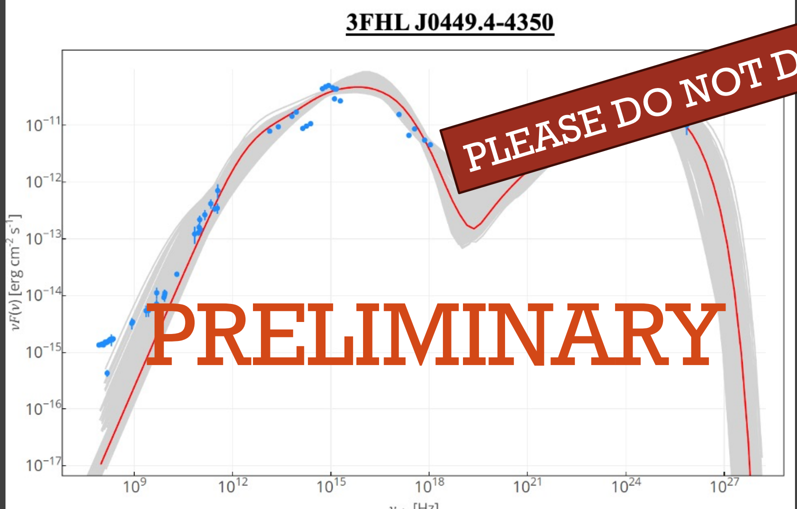
SWGO SEARCHES

Recovery of photons

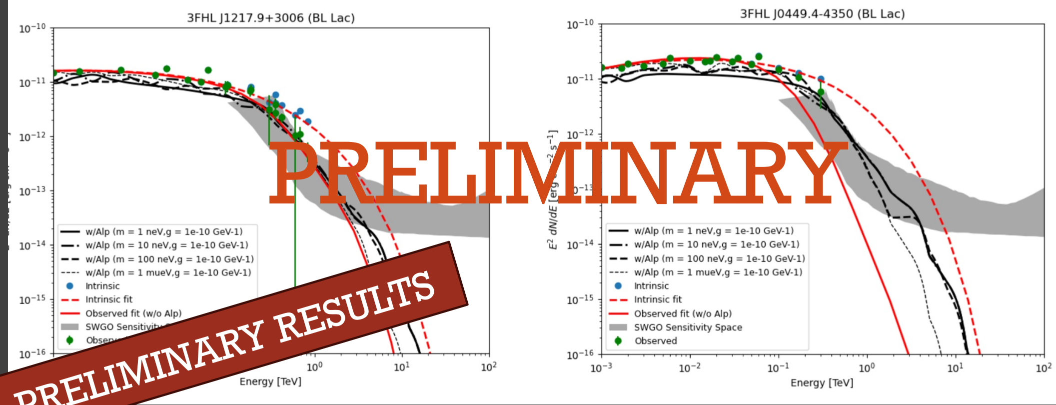


Photon recovery at 10's TeV

Modeling SED to extrapolate at 10's TeV

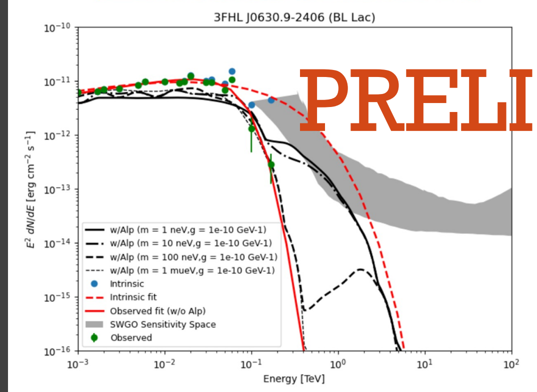


Detected (with and w/o ALP)

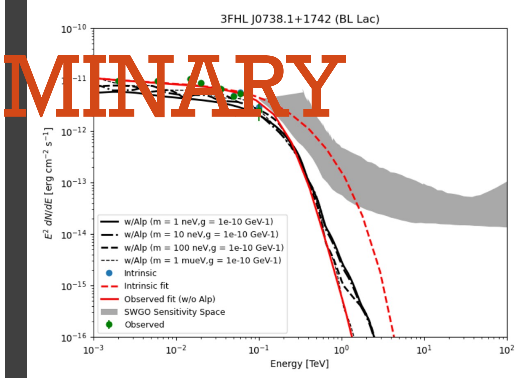


PLEASE DO NOT DISTRIBUTE – PRELIMINARY RESULTS

Detected with ALP



Not Detected



Credit Muneeb Shoaib (Padova)

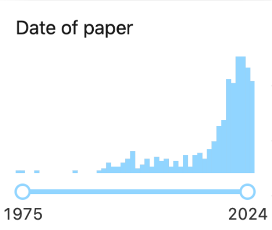
ALPS CONCLUSIONS

- Valid DM candidate (WISP, Weakly Interacting Slim Particle)
- Gamma-ray imprints: photon recovery, wiggles
- Very small signatures and important dependence of poorly known B-fields
- CTA pipeline being developed: results can be combined at LKL level

- If not for science, good to make dishes

PRIMORDIAL BLACK HOLES

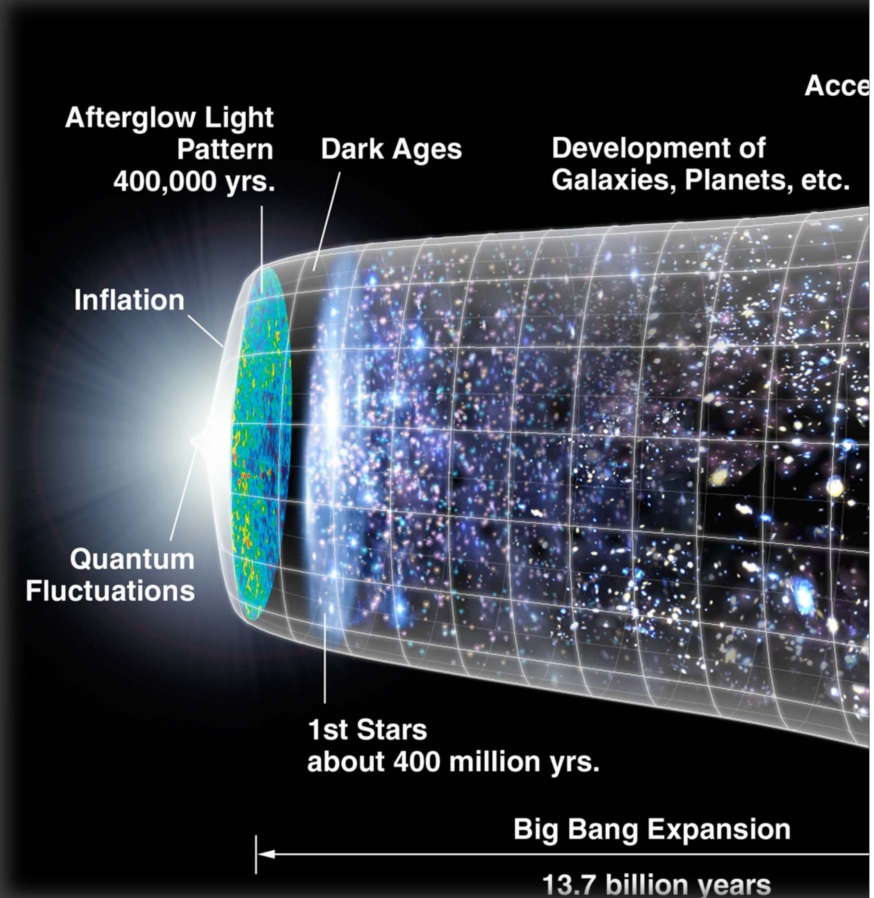
They pop!



	Citeable
Papers	391
Citations	23,756
h-index	83
Citations/paper (avg)	60.8

FACTS

- Stellar black holes are generated by collapse of stars.
- In the early Universe, PRIMORDIAL black holes could form too:
  - Collapse of overdensities
  - Phase transition
- Mass range unknown, from tiny to HUGE
- They evolve!
  - Accretion, merging, interaction with DM
  - Evaporation (Hawking 1974)



PBH EVAPORATION

PBH mass depends on when created

$$M_{\rm PBH} \sim \frac{c^3\, t_{\rm H}}{G} \sim \left(\frac{t_{\rm H}}{10^{-23}\ {\rm s}}\right)\ 10^{15}\ {\rm g}$$

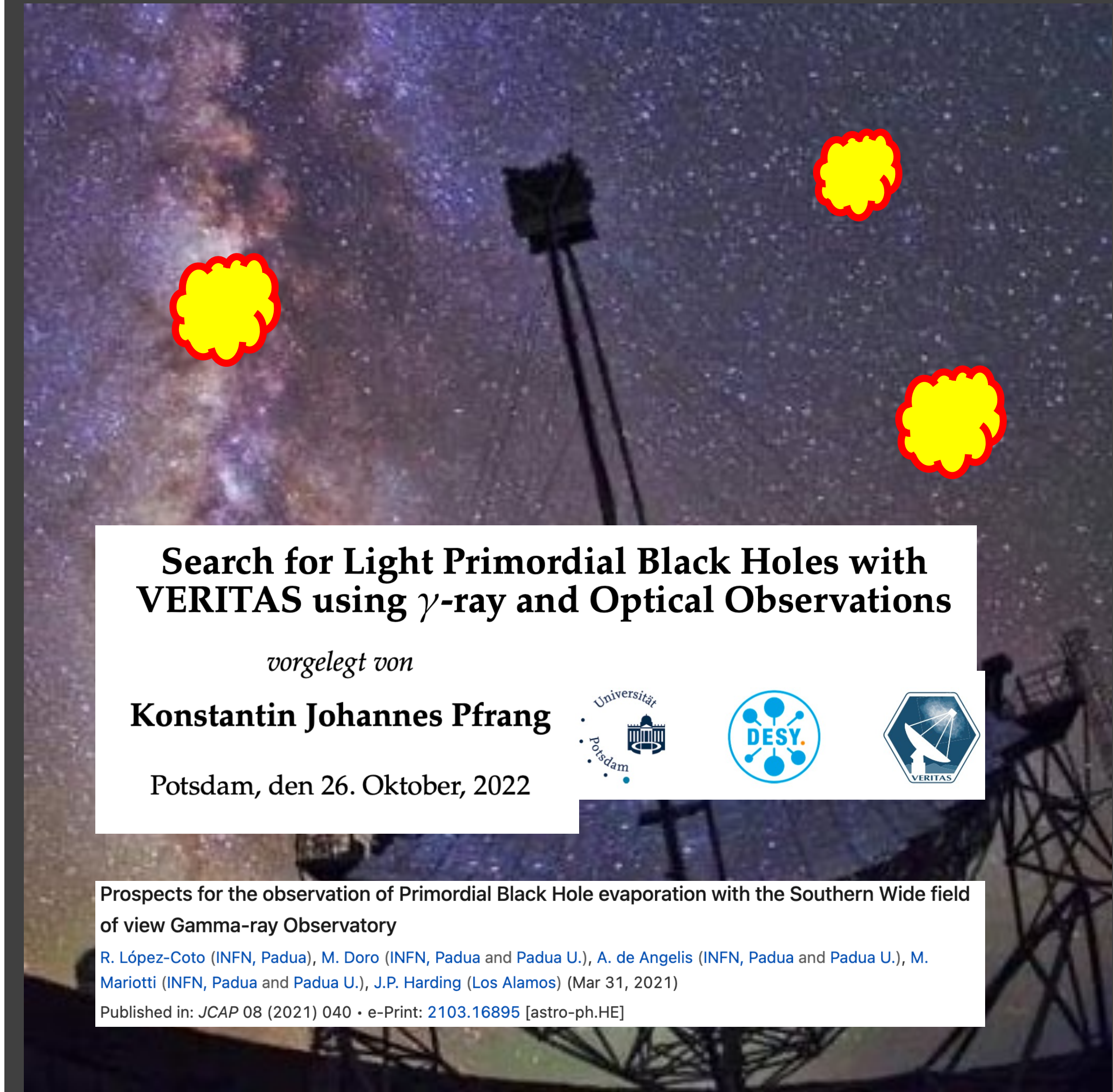
PBH temperature depends on its mass

$$T_{\rm BH}(M) = \frac{\hbar\, c^3}{8\pi\, G\, k_{\rm b}}\frac{1}{M} \sim 100\ \left(\frac{10^{15}{\rm g}}{M}\right)\ [{\rm MeV}]$$

PBH lifetime depends on its mass

$$\tau_{\rm BH}(M) = \frac{G^2 M^3}{\hbar\, c^4} \sim 10^{10}\ \left(\frac{M}{10^{15}{\rm g}}\right)^3\ [{\rm yr}]$$

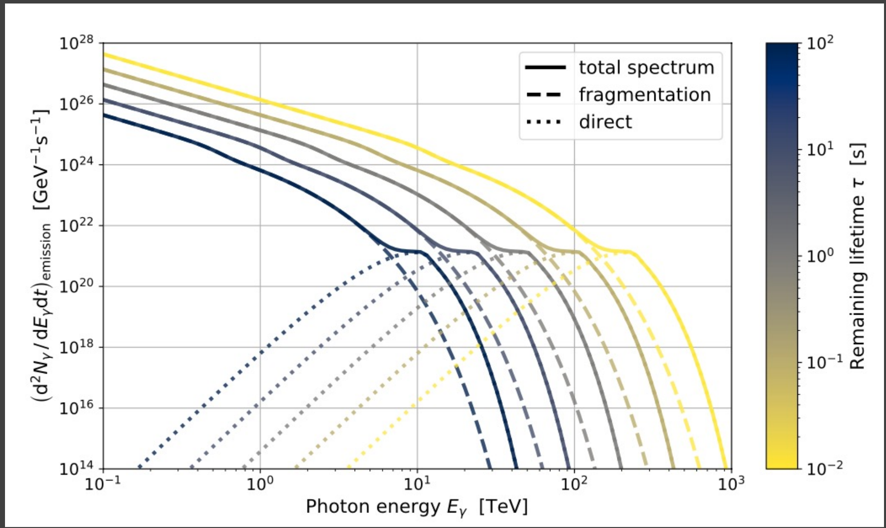
- At the end of its life, when it evaporates, PBH emits all kind of particles
- Happening now only if Mass=10^{15} g
- With increasing temperatures, larger-mass particles can be created
- Always accompanied with gamma-rays

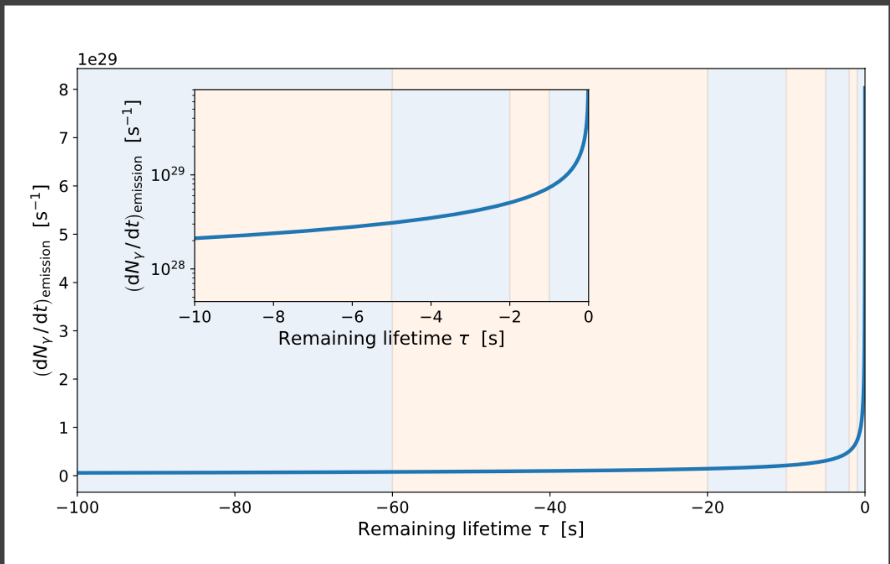


BURSTS!

- Evaporating PBHs would appears as short (seconds) bursts somewhere in the sky…
- Serendipity discovery, if you are ready!
- IACTS: Must looks into archive data!
- SFDs: serendipity

MODEL A SED AND LC





Pfrang 2023 PhD

$$\left(\frac{d^2N_\gamma}{dE_\gamma dt}\right)_{emission} = \left(\frac{d^2N_\gamma}{dE_\gamma dt}\right)_{frag.} + \left(\frac{d^2N_\gamma}{dE_\gamma dt}\right)_{direct}.$$

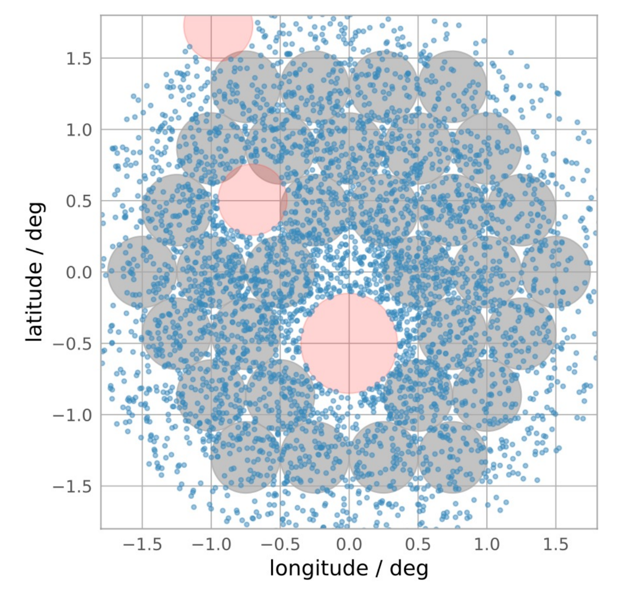
$$\left(\frac{d^2N_\gamma}{dE_\gamma dt}\right)_{frag.} = A x_\gamma^{-3/2}[1 - \Theta_S(x_\gamma - 0.3)] + B \exp(-x_\gamma)[x_\gamma(x_\gamma + 1)]^{-1}\Theta_S(x_\gamma - 0.3)$$

$$\left(\frac{d^2N_\gamma}{dE_\gamma dt}\right)_{direct} = \frac{1.13 \times 10^{19}\,\mathrm{GeV}^{-1}\mathrm{s}^{-1} x_\gamma^6}{\exp(x_\gamma) - 1} F(x_\gamma),$$

Pfrang 2023 PhD

Exact behaviour also depends on NDOF, so unique probe for new Physics

CAREFUL WHEN SEARCHING FOR PBH



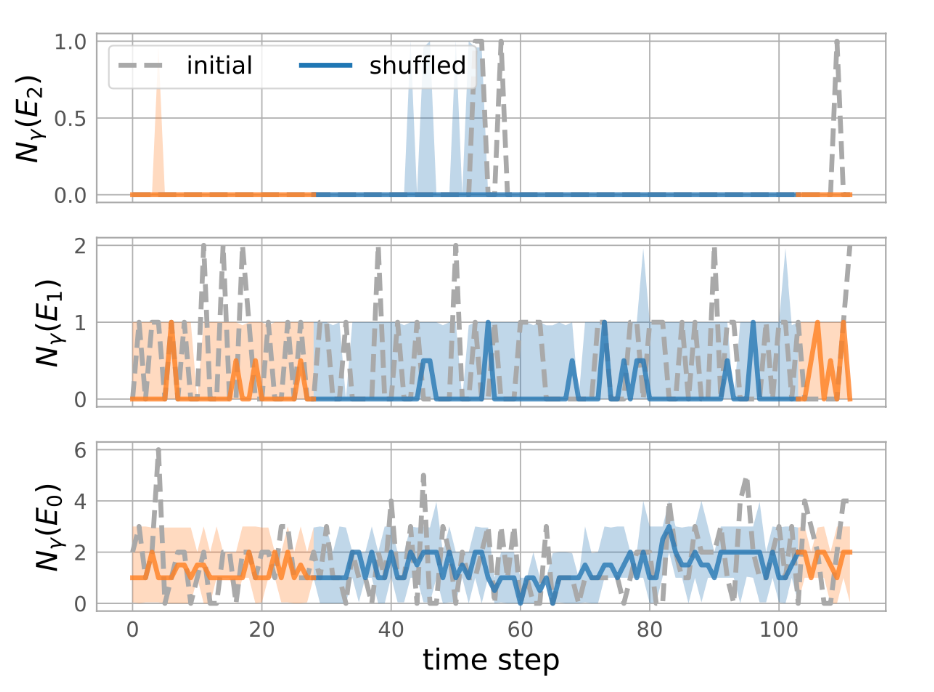
(a) The grey and red circles are the ROIs and exclusion regions respectively. The blue dots illustrate the origin of each γ-like event within this specific observing run.

Pfrang 2023 PhD

Search for clustered excess everywhere in the camera (different acceptance, trials)

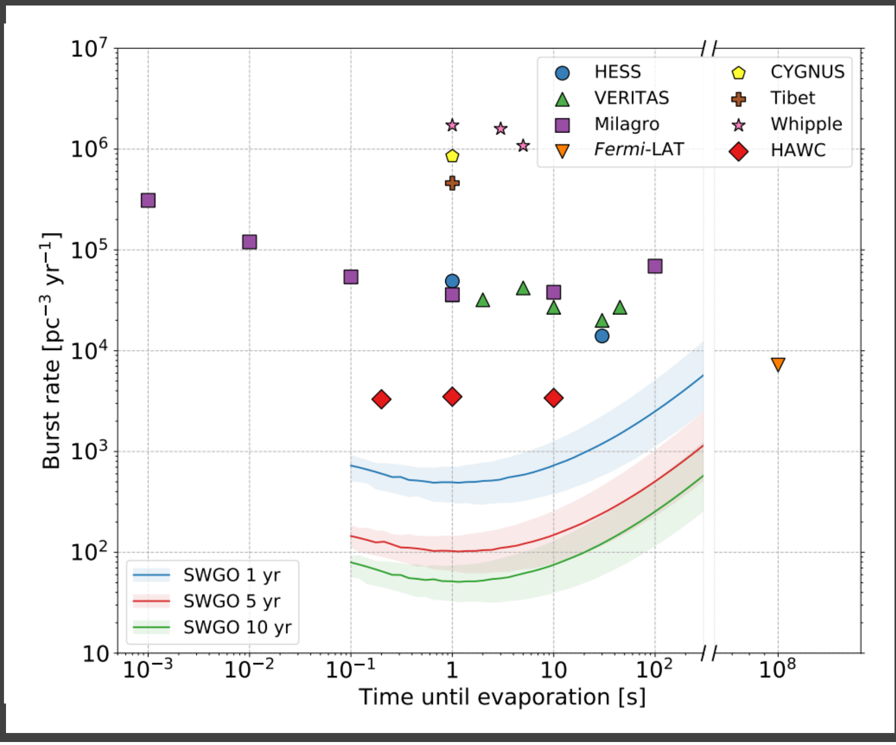
Search for clustered excess in time (trials, discountinued dataset)

Pfrang 2023 PhD



A MEAGRE LIMITS, BUT STILL.

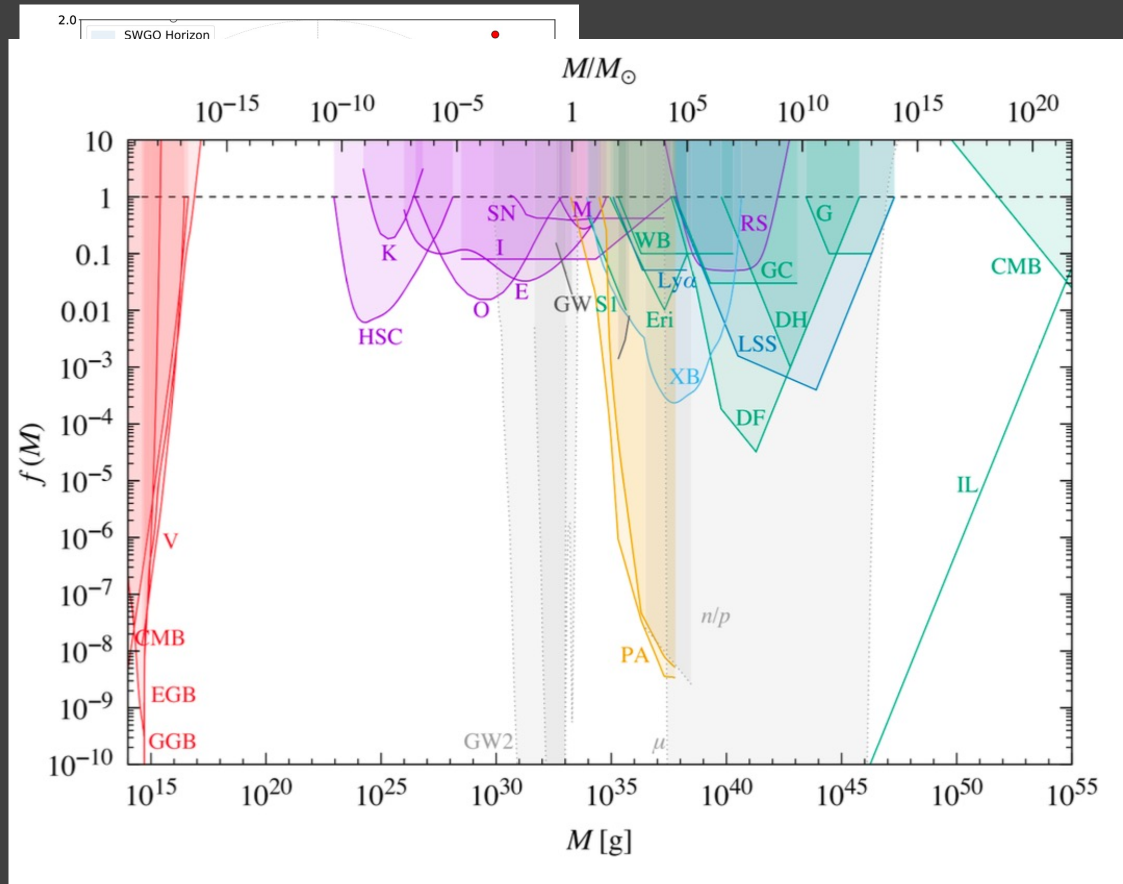
Still valid DM candidate for ‘asteroid mass size’ PBH



Prospects for the observation of Primordial Black Hole evaporation with the Southern Wide field of view Gamma-ray Observatory

R. López-Coto (INFN, Padua), M. Doro (INFN, Padua and Padua U.), A. de Angelis (INFN, Padua and Padua U.), M. Mariotti (INFN, Padua and Padua U.), J.P. Harding (Los Alamos) (Mar 31, 2021)

Published in: *JCAP* 08 (2021) 040 • e-Print: 2103.16895 [astro-ph.HE]



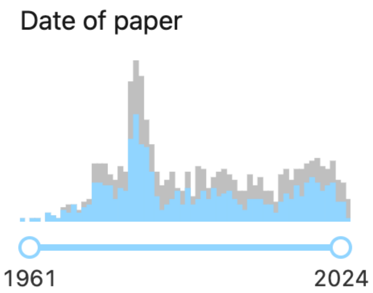
PBH CONCLUSIONS

- TeV gamma-rays can be seen when PBH evaporates
- PBHs evaporates now only if M=10^15g
- Serendipitous events, modeled only up to a certain extent and certainly a glorious one
- Pipelines must check for clustered events in time/space, with complex trial factors checks
- Modest results in all case, but worth having a look in CTA data

MAGNETIC MONOPOLES

Caution! Hot!

Recipe in coll. with Daniele Perri (SISSA) and Takeshi Kobayashi (SISSA)



	Citeable
Papers	595
Citations	23,256
h-index	69
Citations/paper (avg)	39.1

A GAME DURING ZWICKY'S LUNCH

- We give Zwicky a magnetic bar and ask him to break it in two
- Regardless how he will break the bar, two independent magnets will appear, with N-S poles in opposite directions
- This is how magnetic field in matter is generated
- Does Zwicky like this? Absolutely not

Maxwell's equations would be symmetric in electric/magnetic charge if there were the magnetic monopole!

$$\nabla \cdot \mathbf{E} = \frac{\rho}{\varepsilon_0}$$

$$\nabla \cdot \mathbf{B} = 0$$

$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$

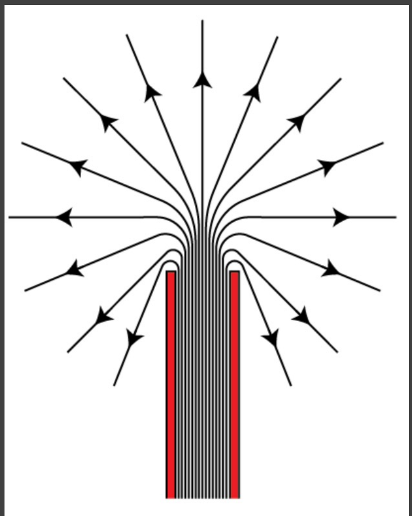
$$\nabla \times \mathbf{B} = \mu_0 \mathbf{j} + \frac{1}{c^2}\frac{\partial \mathbf{E}}{\partial t}$$

DIRAC'S CLASSIC MONOPOLE

Could have invited him at lunch, but he was even pickier than Zwicky.

- He was trying to find a way to have a natural explanation for the quantization of the electric charge
- In 1948 he proposed a model for a monopole made of one semi-infinite string solenoid with M=2.4 GeV
- The existence of magnetic monopoles is consistent with quantum theory once imposed the charge quantization condition:

$$g = 2\pi n/e = n g_D$$



Dirac *"One would be surprised if Nature had made no use of it"*

T'HOOFT AND POLIAKOV

- In 1974 'T Hooft and Poliakov proposed a model of monopoles as topological defects, which was naturally appearing during phase transitions
- Monopoles are inevitable predictions of Grand Unified Theories: SU(5) → SU(3) × SU(2) × U(1) → SU(3) × U(1)
- MM
  - GUT (early Universe) M>10^16 GeV
  - Intermediate Mass (later) M>10^6 GeV
- The 'T Hooft - Poliakov monopole is a zero-dimensional solitonic solution of the vacuum manifold.

It looks real fancy….

GUT AND INTERMEDIATE MM

Patrizii+ Ann.Rev.Nucl.Part.Sci. 65 (2015)

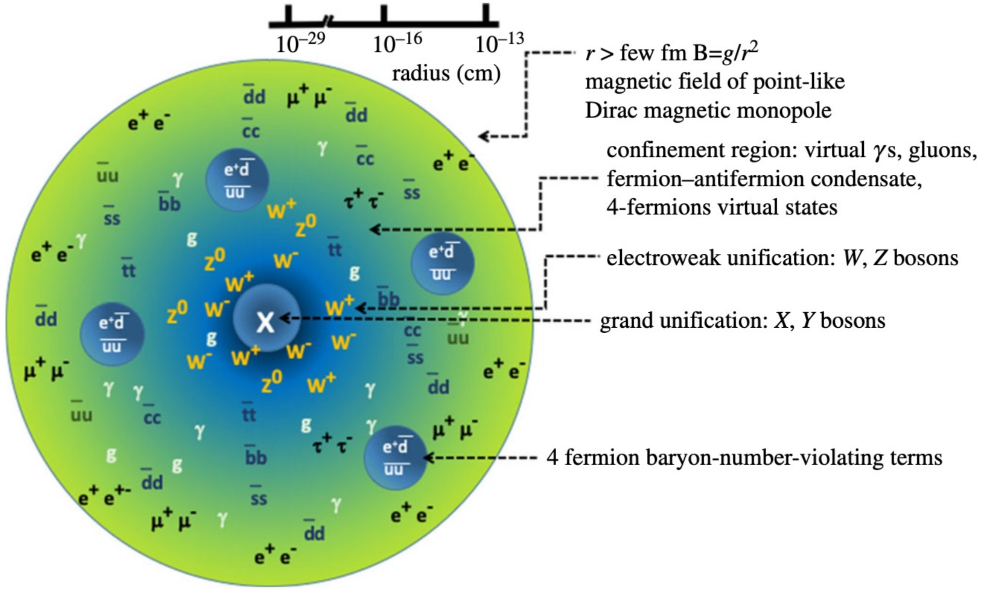


Figure 1. Qualitative picture of the internal structure of a GUT magnetic monopole (modified figure from [11]). The different regions are described in the text.

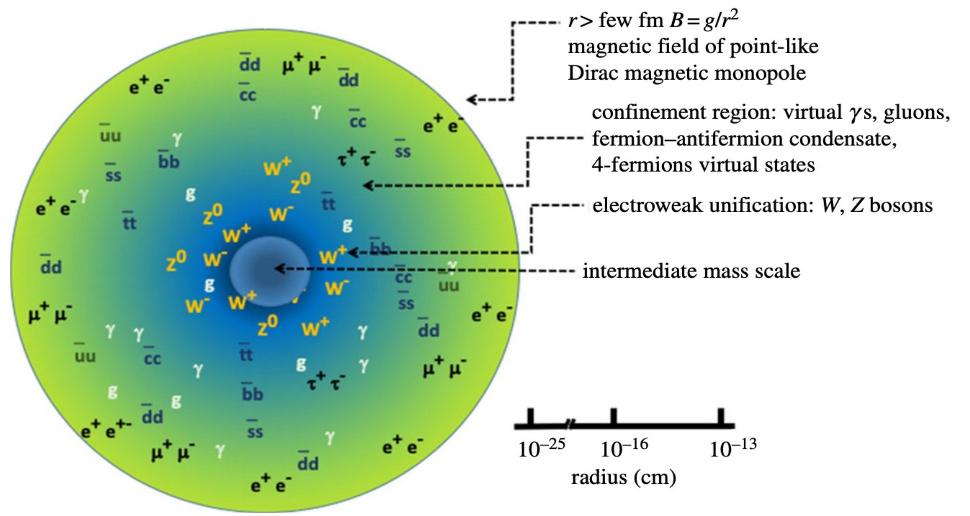


Figure 2. Qualitative picture of an 'intermediate mass magnetic monopole'. The inner region ($r \simeq 10^{-25}$ cm) corresponds to intermediate mass scales; inside this region, one finds the intermediate mass bosons responsible for the symmetry breaking. The outer regions are as in figure 1, but without terms violating baryon number conservation in the fermion–antifermion condensate.

Inside the core, the symmetry is restored and all the states of the GUT are excited.

AVOID TOO MANY MAGNETIC MONOPOLES

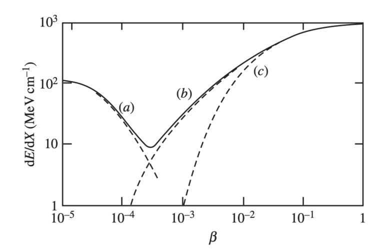
COSMOLOGICAL MONOPOLES indigestion

- Monopoles are produced in the early universe during phase transition.
- The abundance of produced monopoles can easily over-dominate the energy density of the universe.
- Inflation provides a good solution to the problem.

GALACTIC MONOPOLES indigestion/PARKER BOUND

- The Galaxy presents a magnetic field of ~muG
- The Galactic magnetic field accelerates the monopoles losing its energy;
- • The survival of the field provides a bound on the monopole flux today

ENERGY LOSS IN MATTER

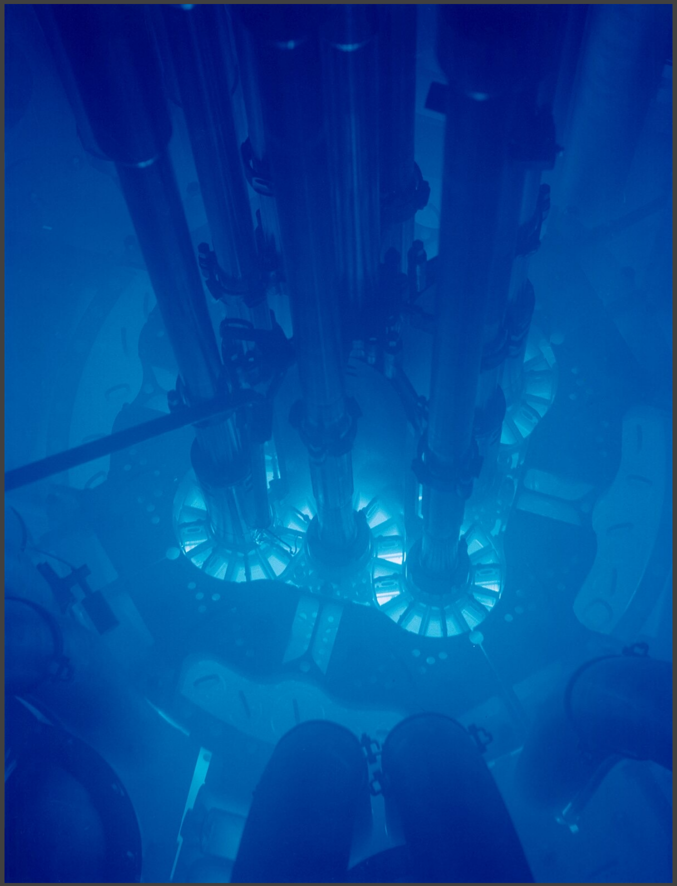


gy loss (in MeV cm^{-1}) mechanisms of $g = g_D$ MMs in liquid hydrogen versus β. Cu
hydrogen atom scattering; curve (b) corresponds to interactions with energy level
on energy loss [12].

Patrizii+ Ann.Rev.Nucl.Part. Sci. 65 (2015)

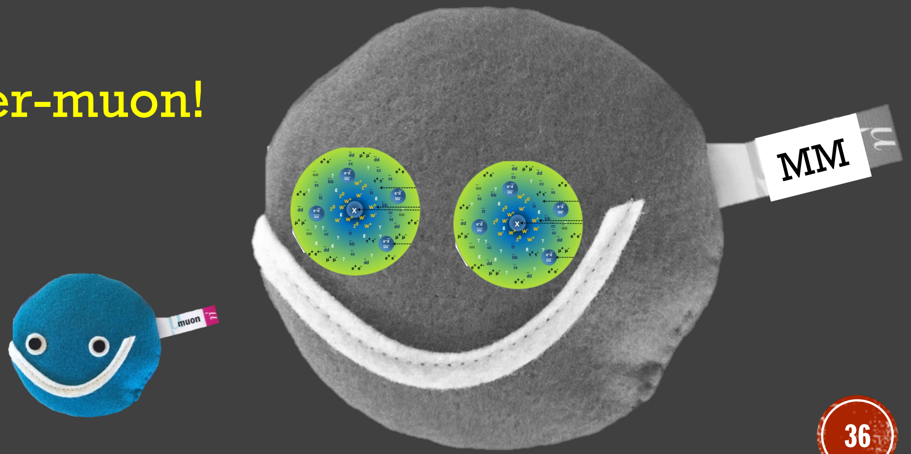
- When MMs cross a medium, the varying magnetic field induces a strong electric field. MMs are treated as electrically charged particles with an equivalent speed-dependent electric charge of $g\beta$.
- The search for MMs is naturally based on their speed at the detector.
  - For $\beta \gtrsim 10-3$ the energy loss is mostly through elastic collisions.
  - For $10-3 \lesssim \beta \lesssim 10-2$, the medium is seen as a free degenerate gas of electrons (energy level crossings)
  - Relativistic MMs with $\beta \geq 0.1$ ionize and excite atoms. The yield is ~ 4700 times that of a minimum ionizing particle.
  - Ultra-relativistic MMs, with $\gamma > 10$^4, lose energy mostly by pair production and photo-nuclear radiative processes

CHERENKOV LIGHT

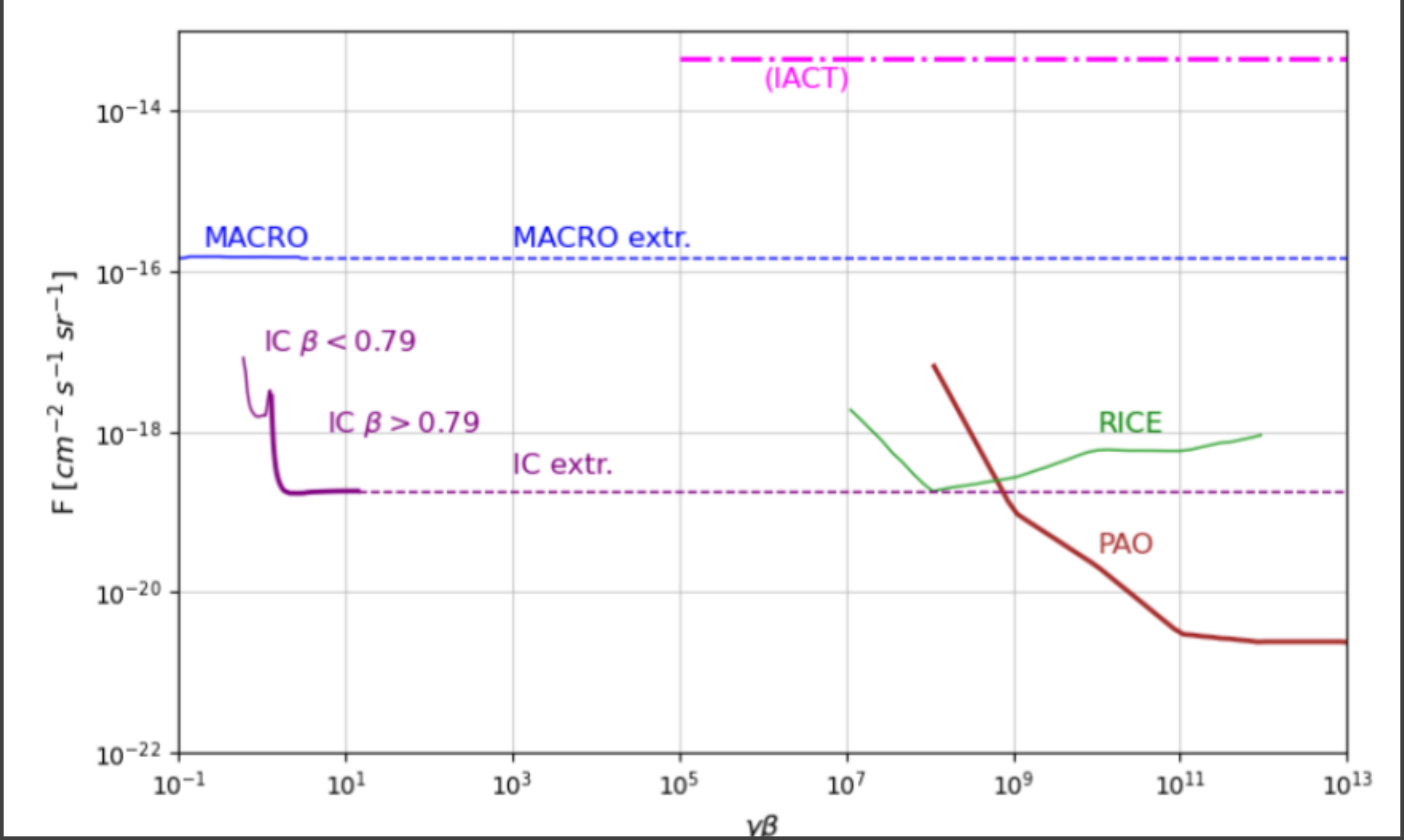


- If the medium is transparent, such as the Earth atmosphere or water or ice, also Cherenkov radiation can be generated either directly from the MM or from secondary ionized electrons.
- The Cherenkov photons yield of a MM would be (gD n/e)2 ≃ 4700 times more than that of a muon with same speed.
- Similarly, MMs emit fluorescence light

MM as a super-muon!



CURRENT WORLD-BEST LIMITS



IceCube = Relativistic MMs

PAO=Ultra Relativistic MMs

NEW! LL ON IGMF!

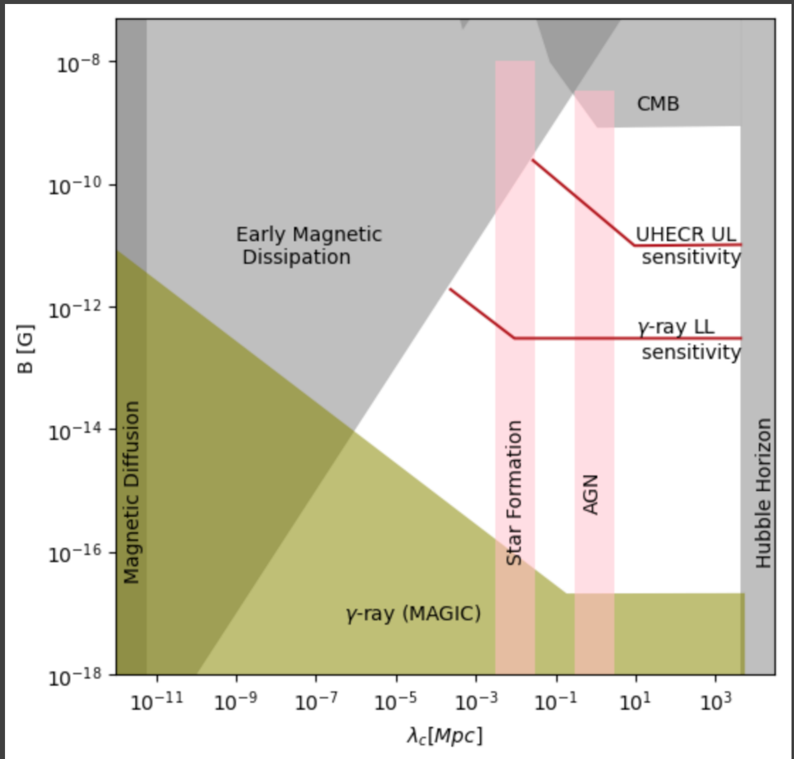
Monopole acceleration in intergalactic magnetic fields

Daniele Perri, Kyrilo Bondarenko, Michele Doro, Takeshi Kobayashi (D

e-Print: 2401.00560 [hep-ph]

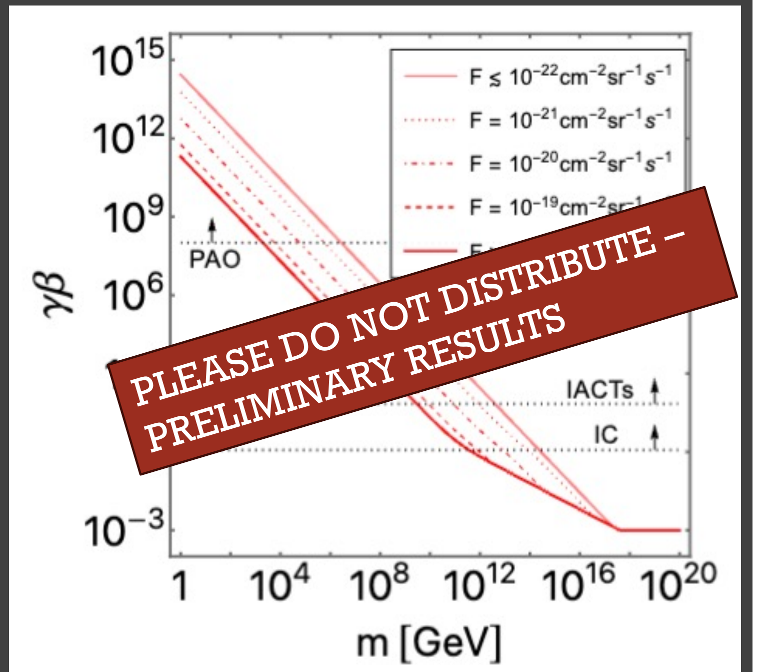
- Acceleration on IGMF
- Acceleration in GMF
- Depends on
  - MM mass
  - MM flux (back-reaction)

Perri, MD, Kobayashi, in prep.



MMs are accelerated by MFs through the magnetic force as in the equation of motion

$$m\frac{d}{dt}(\gamma \boldsymbol{v}) = g\mathbf{B},$$



(a) $B_I = 10^{-9}\ G,\ \lambda_I \gtrsim 1/H_0$.

IACTS

Gerrit Spengler, MSc

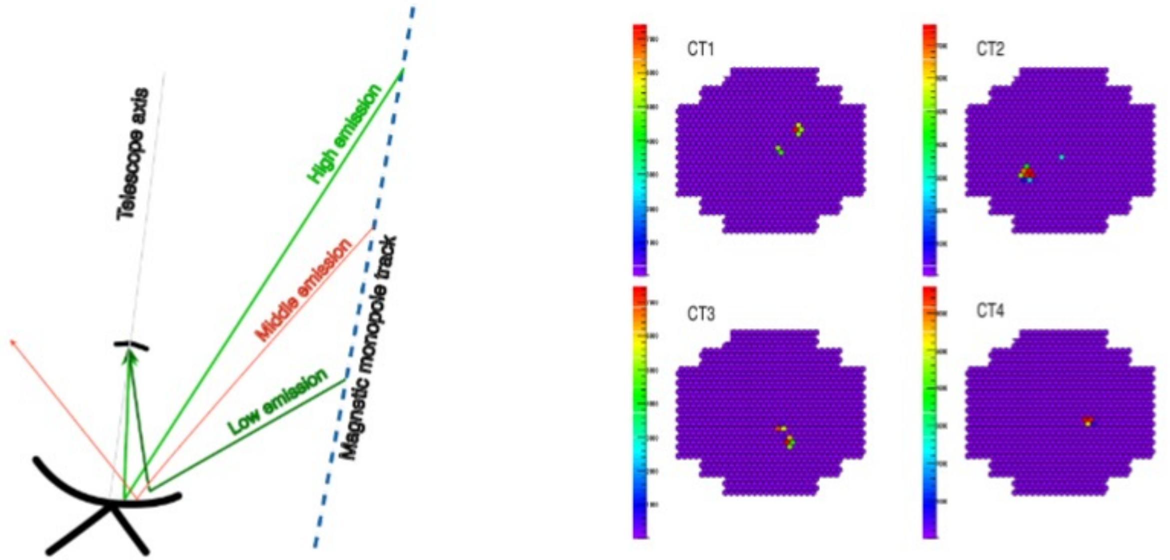


Figure 8.18: Left: Emission scheme from an ultrarelativistic MM emitting Cherenkov radiation throughout the full length of the atmosphere. Right: A simulated MM event on H.E.S.S. cameras. Courtesy of (Spengler, 2009).

MC simulations never carefully proven with IACTs

- This could be optimal for SST and Trinity

NEW MM LIMITS ON MASS

EMBARGO

- IACTs compete betwee PAO and IC
- Nobody is looking at it…welcome to do so!

MM CONCLUSIONS

- MM appears naturally in several GUT theories
- MM are too nice not to exist
- MM first justified inflation
- If (ultra) relativistic, they can be see with ground based gamma-ray/neutrino/cosmic ray detectors
- With IGMF and GMF model, one can built a relation mass-speed due to acceleration of MM in MFs
- IACTs can provide constraints between IC and PAO but need people searching for it

Thanks G. Damico

LORENTZ INVARIANCE

Calories depends on how fast you eat

SCALES

Credit D'Amico

Quantum mechanics

Microscopic physics

$10^{-20}\,m \longleftrightarrow 10^{-8}\,m$

LHC — Nature 464, 697-703 (2010)

Compton wavelength

$$r \sim \frac{\hbar}{mc}$$

General relativity

Macroscopic physics

$10^{-6}\,m \longleftrightarrow 10^{20}\,m$

PRL 98, 021101 (2007) — Assuming Dark Matter

Schwarzschild radius

$$r \sim \frac{G\,m}{c^2}$$

?

Quantum gravity

$$L_P = \sqrt{\frac{G\hbar}{c^3}} \sim 10^{-35}\,m \qquad M_P = \sqrt{\frac{c^5\hbar}{G}} \sim 10^{28}\,eV$$

$$E_P = 1.22 \cdot 10^{19}\ \mathrm{GeV}$$

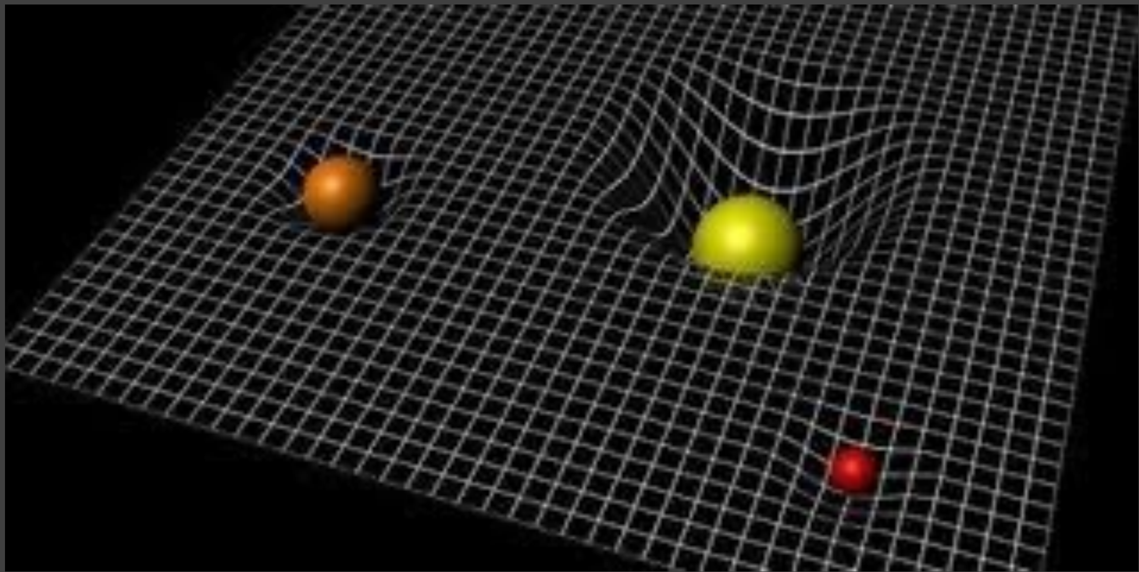
TOP-DOWN

- ✓ solving at once **all aspects** of the quantum-gravity problem
- ✗ formalisms of very high complexity
  lack of physical intuition about **observable** and potentially **testable features**

BOTTOM-UP

- ✗ describing only a **small subset** of the departures from standard physics that the quantum-gravity realm is expected to host
- ✓ producing better opportunities for **experimental testing**

THE TABLECLOTH



- Depending on the nature of the vacuum, photons could experience it differently
- Photon velocity could not be the costant c we know but depends varies in function of the photon energy c(E)

LORENTZ INVARIANCE VIOLATION

Credit D'Amico

$$E^2 = p^2 \times f(E, E_P)$$

Modified dispersion relation

Low energy limit

$$f(E, E_P) \sim 1 \quad \text{for} \quad E/E_P << 1 \longrightarrow$$

$$E_P = 1.22 \cdot 10^{19}\ \text{GeV}$$

High energy expansion

$$f(E, E_P) = \left[1 + \sum_{n=1}^{\infty} S_n \left(\frac{E}{E_{QG,n}}\right)^n\right]$$

photon energy

QG energy scale

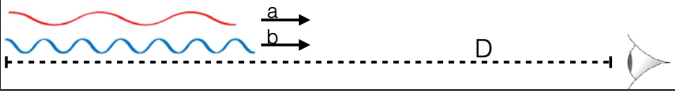
S = ±1

- If one modifies the energy dispersion of the photons, one also has:
  - Energy-dependent photon group velocity
  - Modified reaction thresholds
- Modified reaction cross-sections
- Vacuum birefringence
- Modified Compton scattering
- Modified synchrotron radiation
- …

TOF

$$v_\gamma = \frac{\partial E}{\partial p} \simeq c\left[1 + \sum_{n=1}^{\infty} S_n \frac{n+1}{2}\left(\frac{E}{E_{\mathrm{QG},n}}\right)^n\right]$$

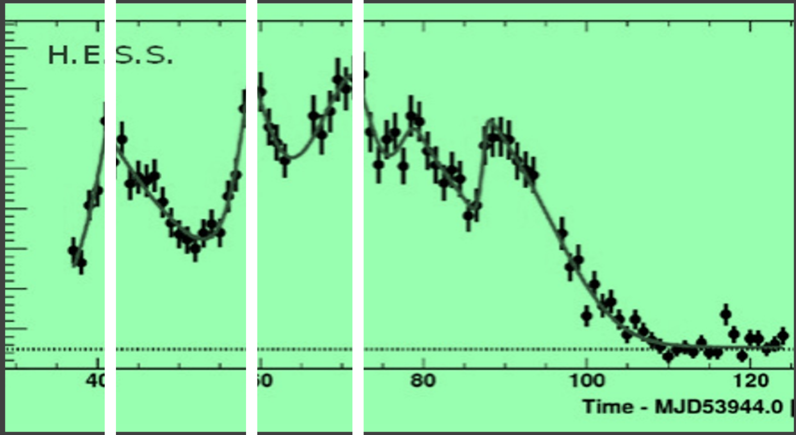
$$S_n = \begin{cases} +1, & \text{superluminal} \\ -1, & \text{subluminal} \end{cases}$$



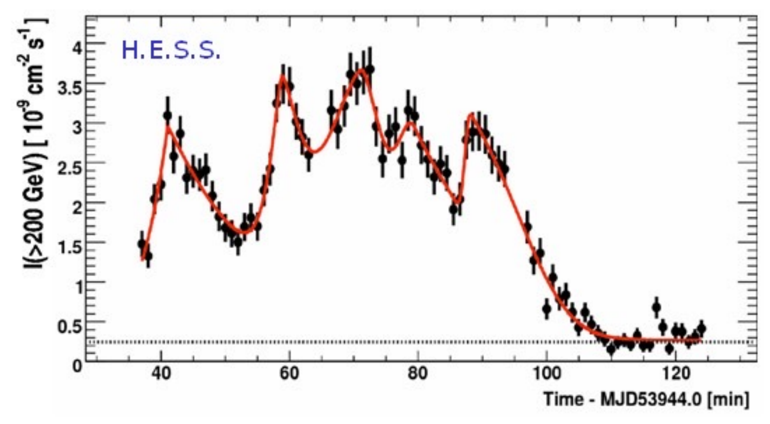
$$\Delta t_n \simeq \pm \frac{n+1}{2} \frac{E_2^n - E_1^n}{E_{QG}^n} D(z)$$

$$D(z) = \frac{1}{H_0} \int_0^z dz' \frac{(1+z')^n}{\sqrt{\Omega_m (1+z')^3 + \Omega_\Lambda}}$$

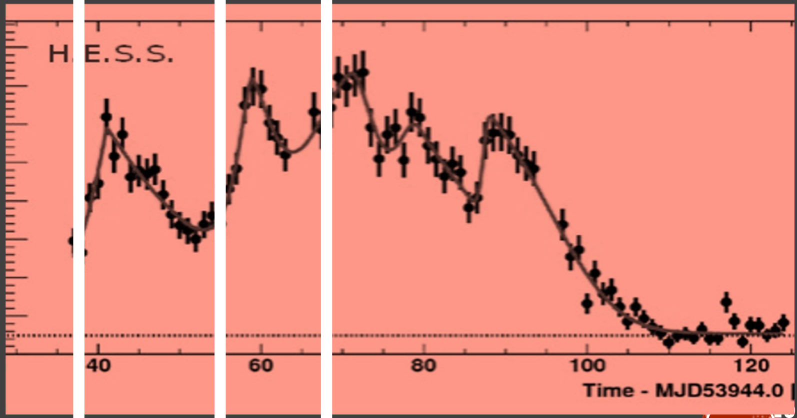
Select low energy photons



You take a variable source



Compare to high-energy photons



If you see a delay, lunch is in Stockholm

MAYBE DUE TO INTRINSIC VARIATIONS

arXiv > astro-ph > arXiv:1911.10377

Search...
Help | Adv

Astrophysics > High Energy Astrophysical Phenomena

[Submitted on 23 Nov 2019]

Modeling spectral lags in active galactic nucleus flares in the context of Lorentz invariance violation searches

Perennes Cédric, Sol Hélène, Bolmont Julien

arXiv > astro-ph > arXiv:2406.01182

Search...
Help | Ad

Astrophysics > High Energy Astrophysical Phenomena

[Submitted on 3 Jun 2024]

Separating source-intrinsic and Lorentz invariance violation induced delays in the very high energy emission of blazar flares

C. Levy, H. Sol, J. Bolmont

Aims: The aim of the present study is to explore how to disentangle energy-dependent time delays due to a possible Lorentz invariance violation (LIV) at Planck scale from intrinsic delays expected in standard blazar flares.

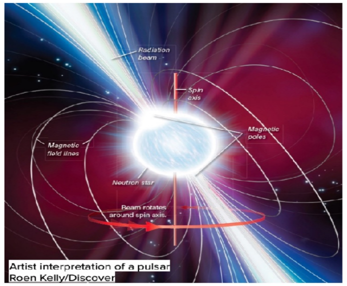
WHICH SOURCE

3 ingredients are needed for a LIV study

$$\Delta t_n \simeq \pm \frac{n+1}{2}\frac{E_2^n - E_1^n}{E_{QG}^n} D(z)$$

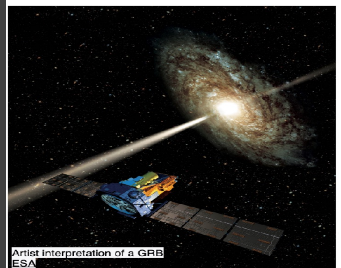
Time variability — High energy — Long distance

Pulsars



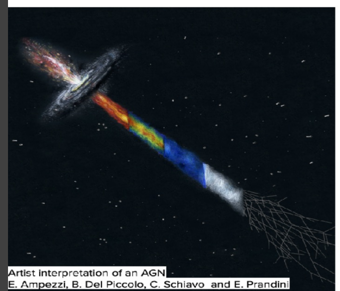
Time variability	High energy	Long distance
A lot!	Yes!	No

Gamma-ray bursts



Time variability	High energy	Long distance
Yes, if you catch the prompt emission	Not very good because of EBL	Yes!

Active Galactic Nuclei



Time variability	High energy	Long distance
Yes, when they are flaring	Not very good because of EBL See talk by Jelena on Tuesday!	Yes!

Credit D'Amico

INGREDIENTS

Credit D'Amico

Constraints on Lorentz invariance violation from the extraordinary Mrk 421 flare of 2014 using a novel analysis method
MAGIC Collaboration • S. Abe (Kamioka Observ.) et al. (Jun 11, 2024)
e-Print: 2406.07140 [astro-ph.HE]

Things needed:

- Events list with time and energy
- IRF of the telescope
- A background template
- A **Light Curve template for the intrinsic emission**
- A likelihood!

The most important but also difficult to get!

P.D.F. of detecting a **signal** event with a given estimated **energy** and arrival **time**

$$\mathcal{L}(\eta_n, I) = \prod_{i}^{N_{on}} \left(\frac{N_{on} - N_{off}}{N_{on}} \cdot f_s(t_i, E_i \,|\, \eta_n, I) + \frac{N_{off}}{N_{on}} \cdot f_b(t_i, E_i) \right) \cdot P(I)$$

Parameter for LIV delays

P.D.F. of detecting a **background** event with a given estimated **energy** and arrival **time**

LIKELIHOOD

Credit
D'Amico

$$\mathcal{L}(\eta_n, I) = \prod_i^{N_{on}} \left(\frac{N_{on} - N_{off}}{N_{on}} \cdot f_s(t_i, E_i \,|\, \eta_n, I) \; + \; \frac{N_{off}}{N_{on}} \cdot f_b(t_i, E_i) \right) \cdot P(I)$$

$$f_s(t, E_{est} \,|\, \eta_n, I) \propto \int_0^{\infty} dE \; \Phi_1(E) \cdot \Phi_2(t - \Delta t(E; \eta_n, z)) \cdot F(E) \cdot A_{eff}(E) \cdot G\,(E_{est}, E)$$

Intrinsic spectrum

Intrinsic LC

LIV delay

EBL attenuation

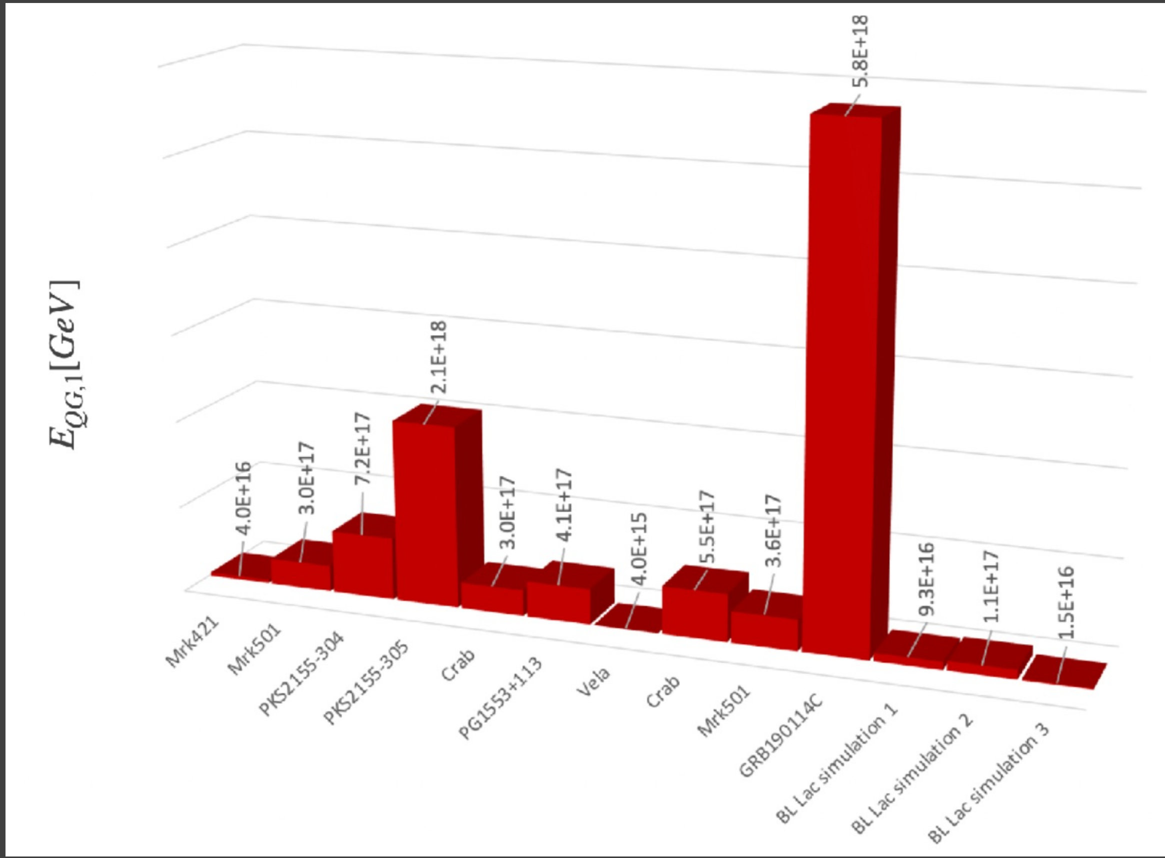
Coll. Area

Energy dispersion

APPLIED ON SEVERAL TARGETS

Credit
Jelena Striskovic

- Pulsars
  - Crab: MAGIC & VERITAS (Otte 2011; Zitzer 2013; Ahnen+ 2017)
  - Vela: H.E.S.S. (Chrétien+ 2015)
- Flaring AGN
  - Markarian 501 2005 flare: MAGIC (Albert+ 2008; Martinez & Errando, 2009)
  - PKS 2155-304 2006 flare: H.E.S.S. (Aharonian+ 2008; Abramowski+ 2011)
  - PG 1553+113 2012 flare: H.E.S.S. (Abramowski+ 2015)
- Gamma-ray Bursts
  - GRB 190114C: MAGIC (Acciari+ 2020)

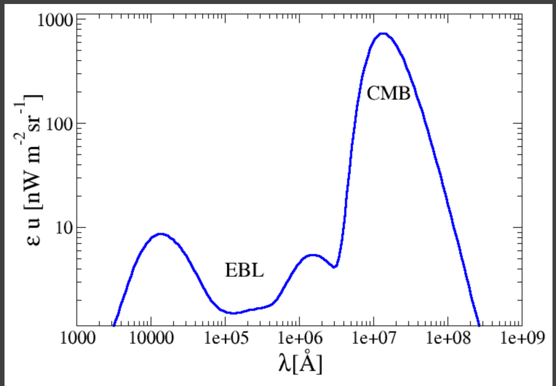


Strongest constraints from LAT

Constraints on Lorentz invariance violation from *Fermi*-Large Area Telescope observations of gamma-ray bursts

V. Vasileiou, A. Jacholkowska, F. Piron, J. Bolmont, C. Couturier, J. Granot, F. W. Stecker, J. Cohen-Tanugi, and F. Longo
Phys. Rev. D **87**, 122001 – Published 4 June 2013

PAIR PRODUCTION THRESHOLD AND CROSS-SECTION

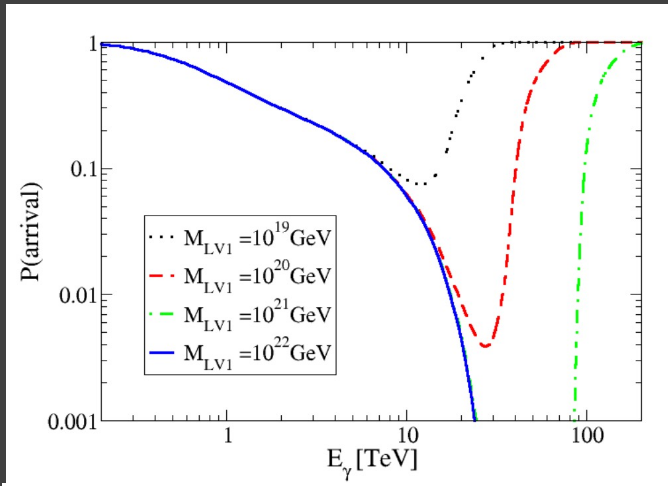


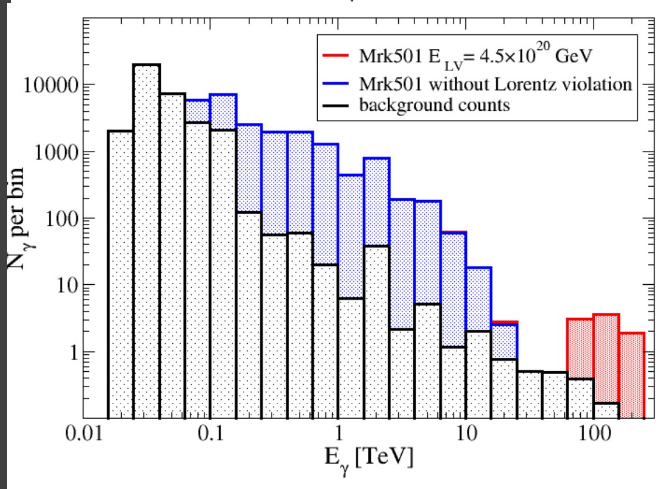
$$\gamma_{VHE} + \gamma_{EBL} \rightarrow e^{+} + e^{-}$$

Issues with Universe trasparency

LIV can mitigate this by increasing optical depth

If LIV, photon has 'effective mass' which changes $\sigma_{\gamma\gamma}$

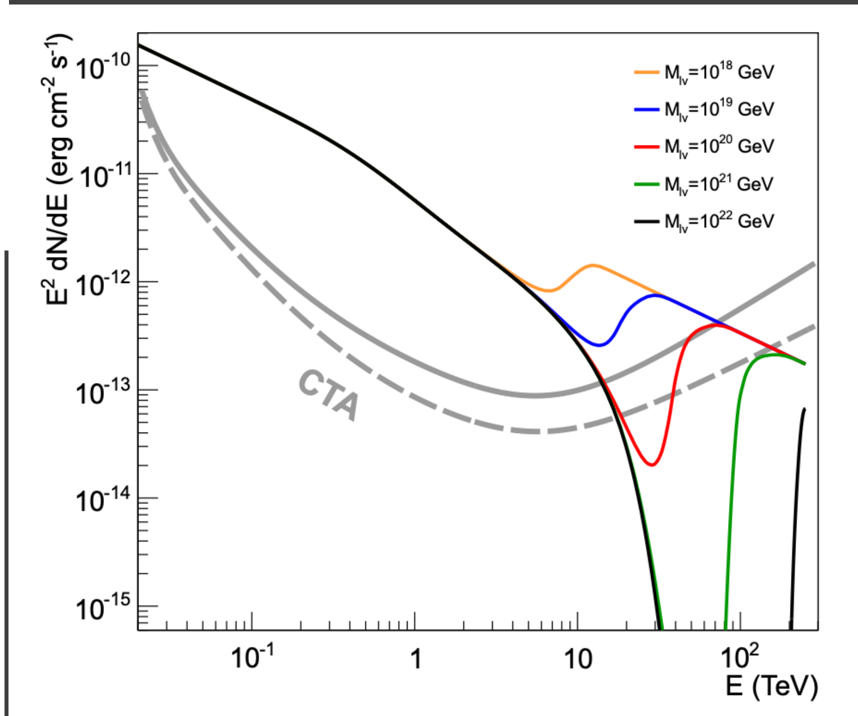




CAP 06 (2014) 005

The CTA Sensitivity to Lorentz-Violating Effects on the Gamma-Ray Horizon

M. Fairbairn,[a] A. Nilsson,[b] J. Ellis,[a,c] J. Hinton,[d] R. White[d]



LIV CONCLUSIONS

- LIV alters time of flight and cross-section for pair production
- TOF: Several targets: flaring AGNs, GRBs, pulsars
- PP: needs high energy reach
- Need to know the LC, and to have a large lever arm (low-large energies)
- Gamma rays provide world-best constraints at Planck scale

ZWICKY! LUNCH IS READY!

"Fritz, what do you say?"

LET'S PUT SOME MUSIC AND WINE

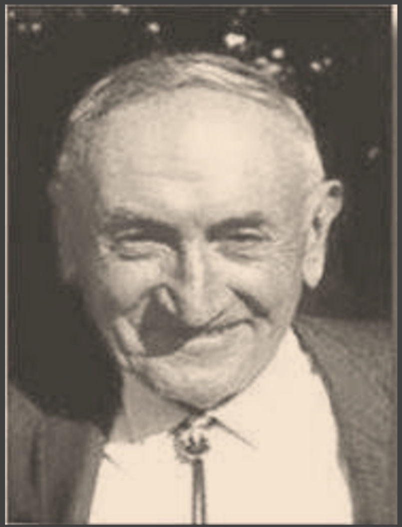
Dark Matter

Song by Pearl Jam

Lyrics

Steal the lights from our eyes
Drain the blood from my heart
We're in all of this dark matter

Take the breaths from my chest
Break the thoughts in our minds
We're losing time, dark matter



THE RECIPES ARE PROMISING!

- Tens of astro-laboratories with varying distance, age, energy, B-field, stability → pick your favorite
- Several theories BSM involving gamma-rays (decay, annihilation, conversion) → pick your guy

BUT ON THE TABLE →

NO SEARCH IS LEFT-OVER

- The search for new Physics is challenging
- Very tiny effects, and complex modeling
- Null results move search as well as positive results

- History showed us that new physics can be found in existing unexplained data, e.g. CMB, so…

REALLY, IT'S NOT TRASH

- CTA must ensure that no BSM effects are overlooked:
  - Is trigger reject BSM events?
  - Is reconstruction rejecting BSM?
  - Is analysis tailored?
- Pro:
  - Several searches do not need pointing
  - Often unique and best limits
- Cons:
  - Very long and subtle analyses

AFTER DINNER, HAVING DRINKED TOO MUCH, GOING BACK HOME

Thanks!