APERITIVO CON ZWICKY: UN BUFFET DI ASTROFISICA DELLE ALTE ENERGIE

Michele Doro, University of Padova

michele.doro@unipd.it

TODAY'S MENU

Meet our guest

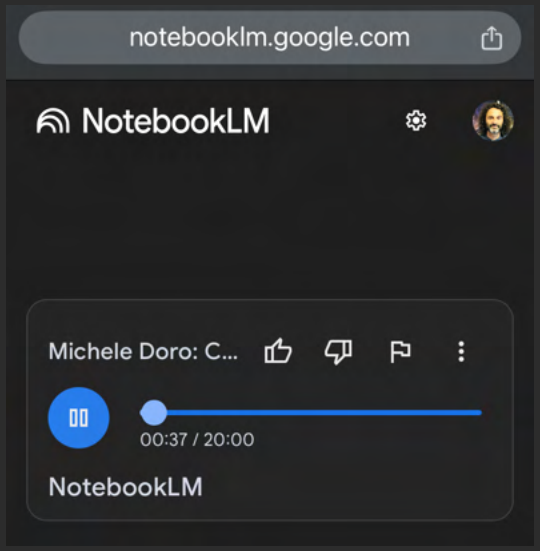
Our main ingredient: gamma rays

Review of kitchen tools

Menu: o dark matter,
o axion like particles,
o primordial black holes,
o magnetic monopoles
…we can skip some plates

Digestives

THE CHEF CREW ☺



- https://notebooklm.google.com/notebook/520db653-64f6-4925-9a90-98c3ad79e930/audio

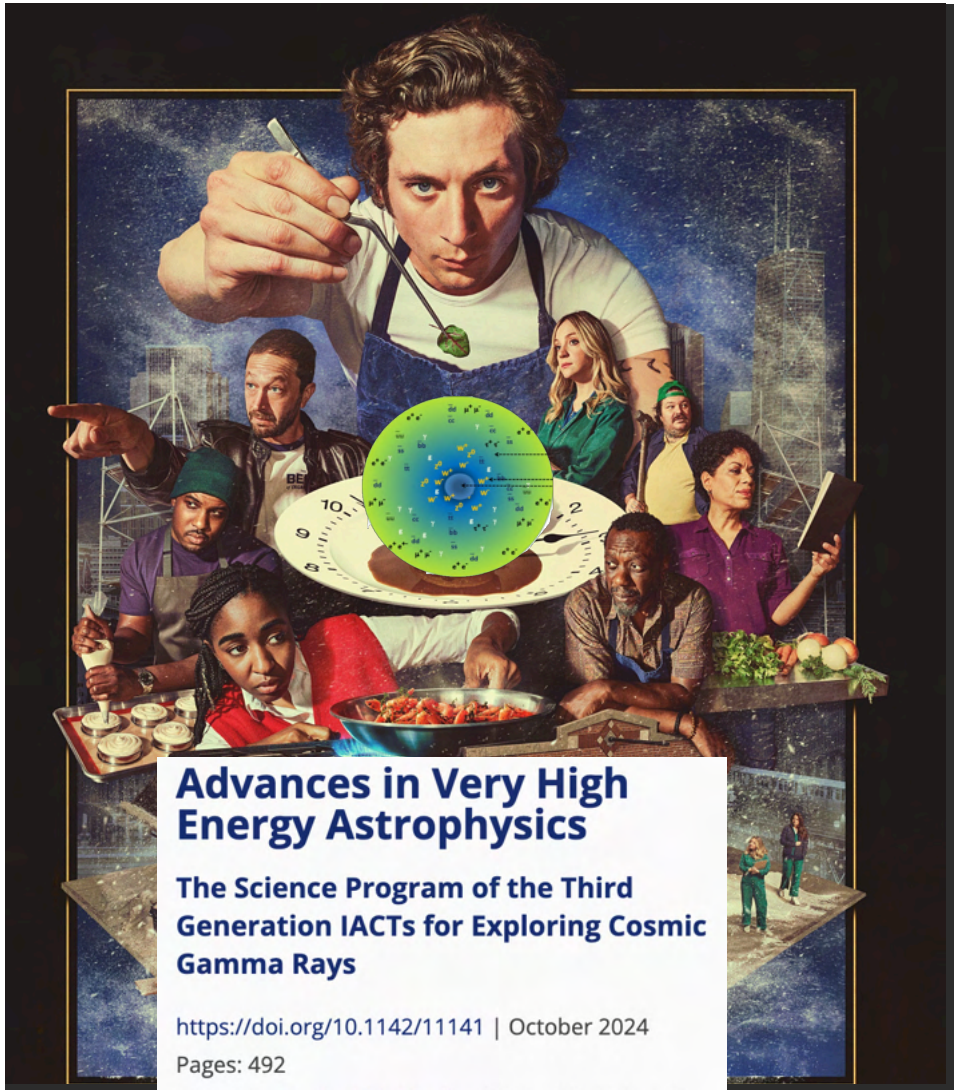
OUR GUEST: FRITZ ZWICKY

"Every two years, I make an important discovery."

1. Discovery of Dark Matter (1933)
2. Supernovae and Neutron Stars (1934)
3. Tired Light Hypothesis
4. Galaxy Clusters and Large-Scale Structure
5. Prediction of Gravitational Lensing (1937)
6. Systematic Supernova Searches
7. Development of Morphological Analysis

398-1974) was a
ıer. He worked
at the California
ınology
d the virial

Astronomers are spherical bastards.
No matter how you look at them
they are just bastards.



Advances in Very High Energy Astrophysics

The Science Program of the Third Generation IACTs for Exploring Cosmic Gamma Rays

https://doi.org/10.1142/11141 | October 2024

Pages: 492

Edited by: Reshmi Mukherjee (*Columbia University, USA*) and Roberta Zanin (*Cherenkov Telescope Array Observatory gGmbH, Italy*)

←Big recipe book

FROM OUR COOKBOOK

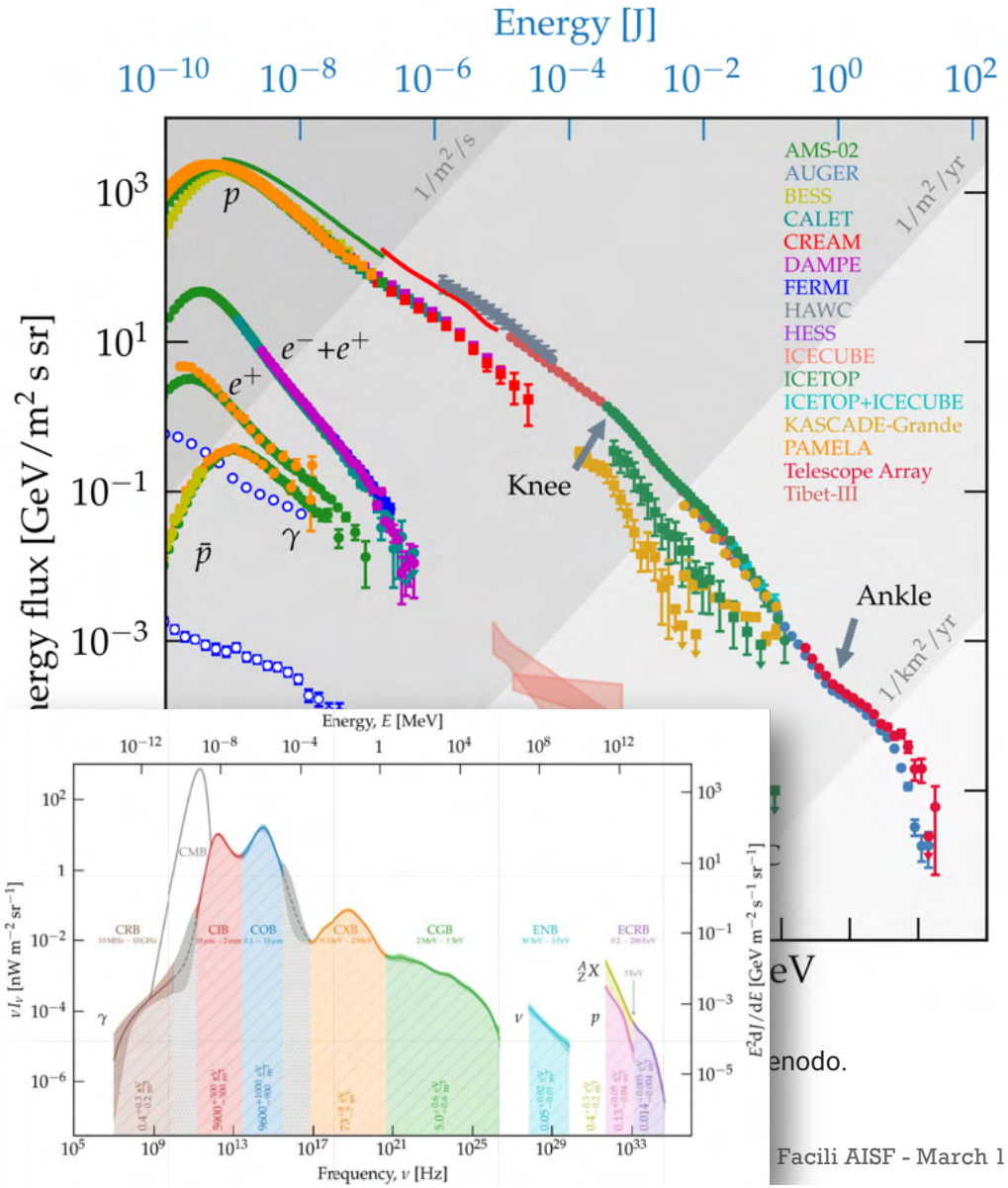
'Dark matter and fundamental physics with IACTs'

https://arxiv.org/abs/2111.01198

#1 GAMMA-RAY PROBES FOR FUNDAMENTAL PHYSICS

Why they are best suited for fundamental physics (and can't possibly do that at CERN)

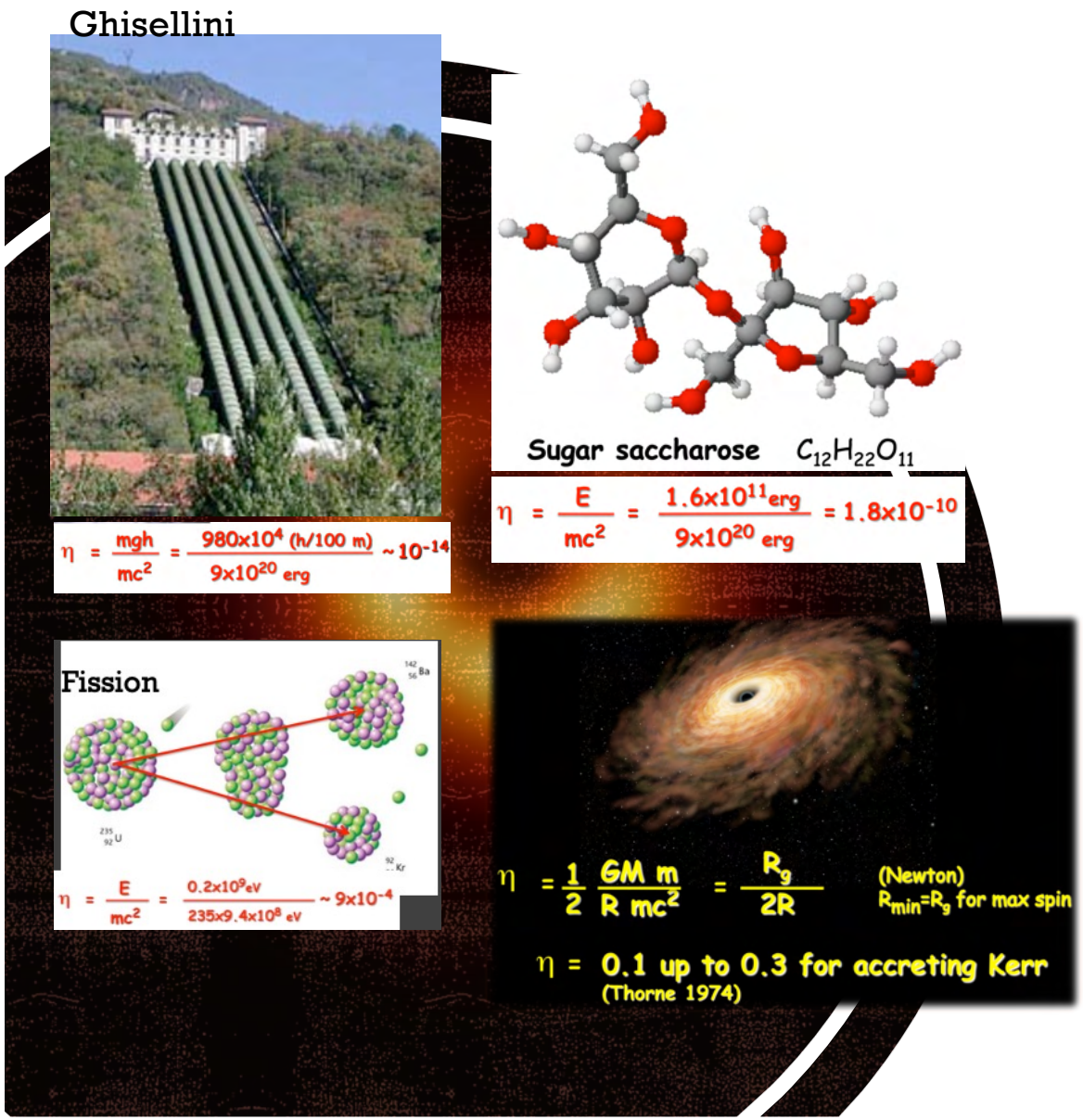
6



1/COSMIC RAYS: A NEVERENDING POWERFUL ENGINE

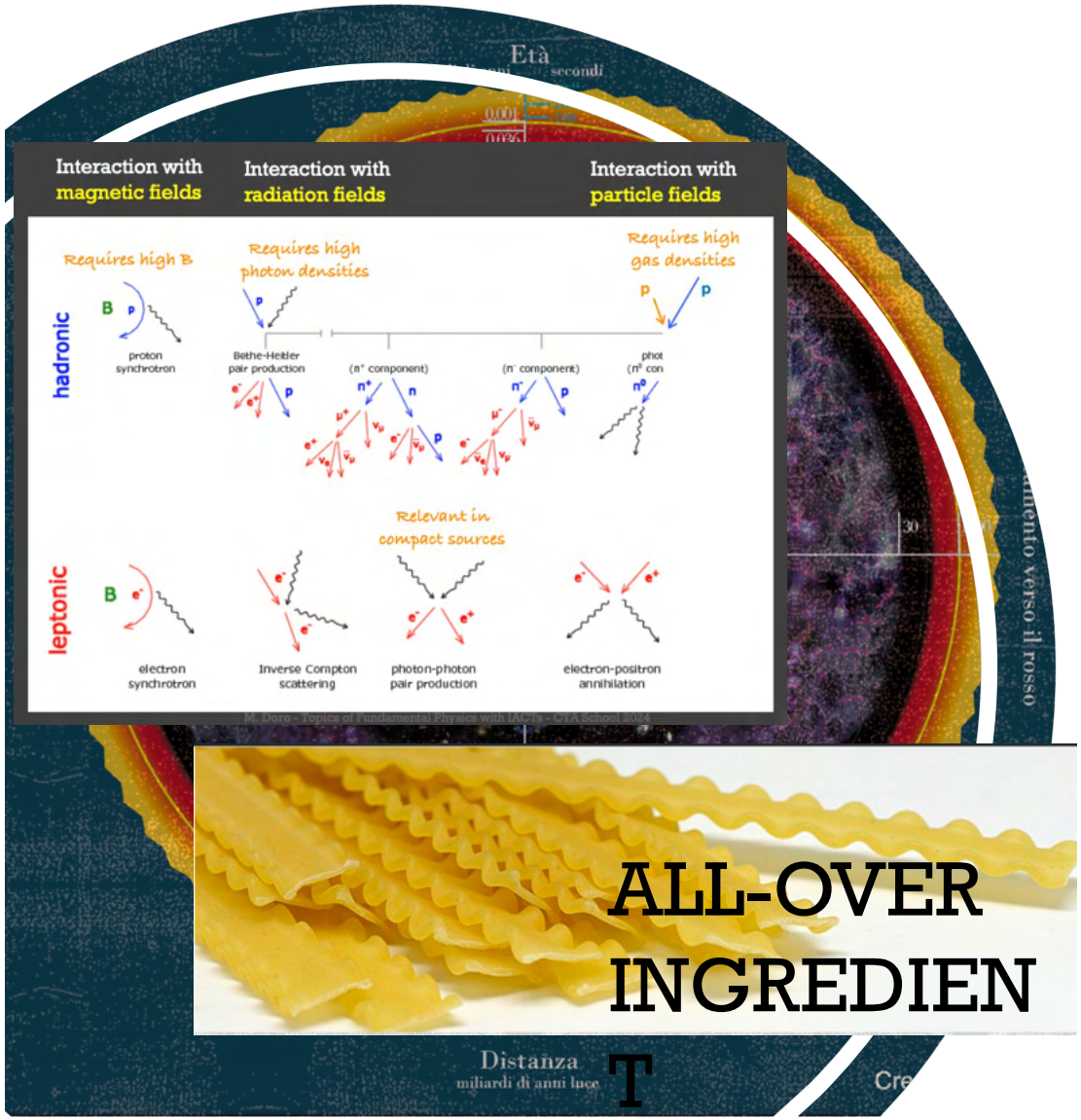
- Immense energy budget, e.g. a GRB can give 10^{53} erg
- Acceleration (and emission) for kyears
- Cosmic rays power up gamma rays

2/ A FUEL NAMED GRAVITY



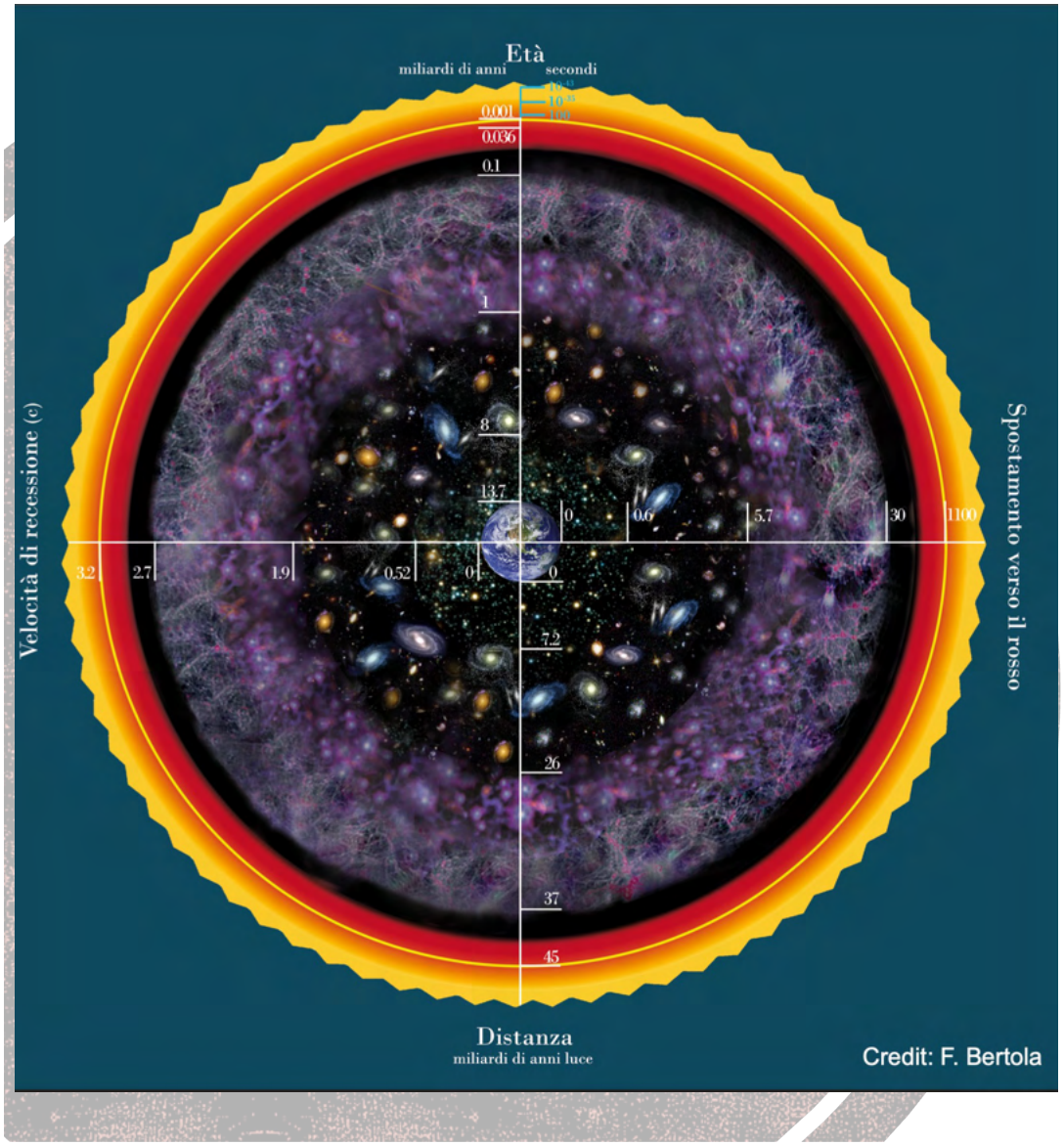
We can use the inevitable gravity infall

- Capture→ increase cross sections
- Energy budget → e.g. around BH, NS, GRB
- Efficient energy conversion



3/ A HUGE FIDUCIAL VOLUME

- Signals from CMB and further
- Direct signal and signal through-Universe
- There are several ‘beam dumps’

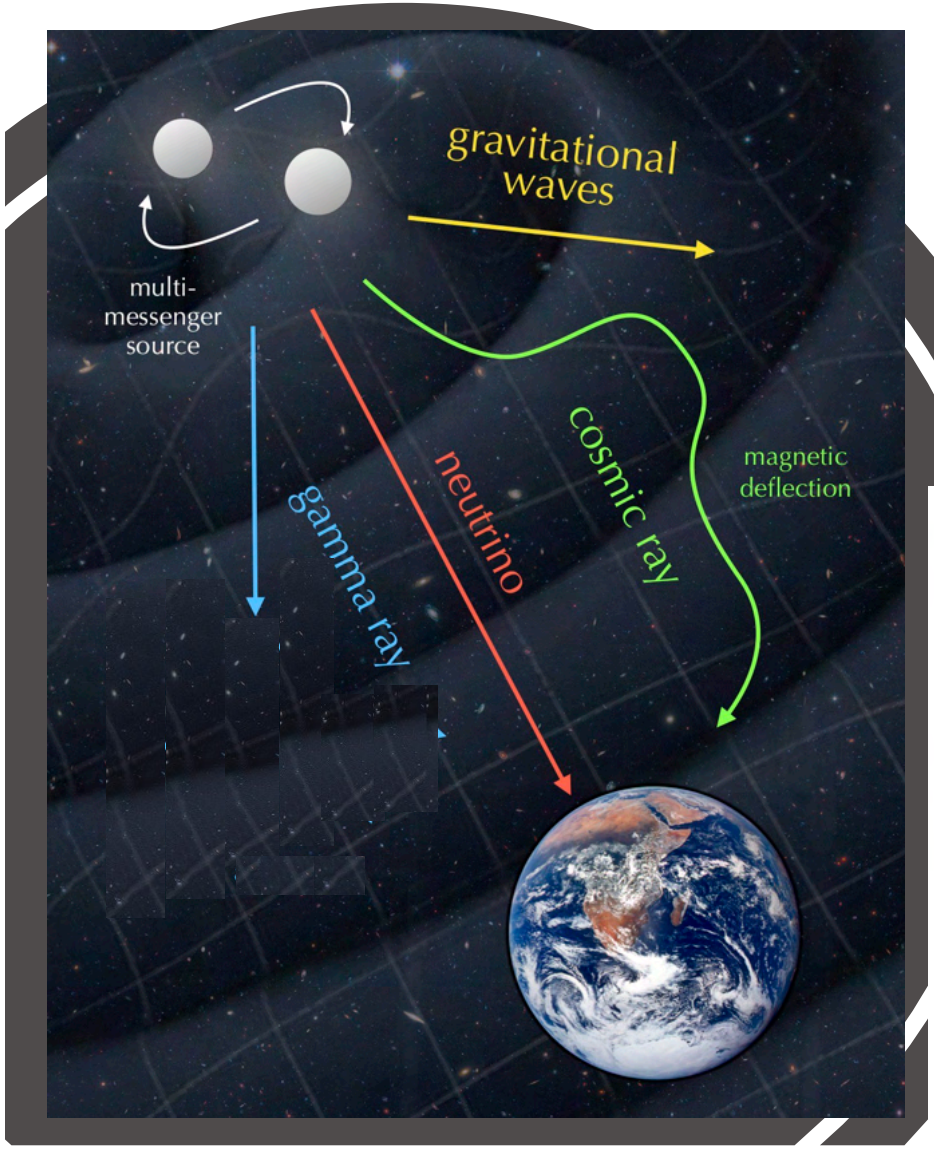


3/ TIME OF FLIGHT AND TRACKING

- Astrophysics events have time variability
- We can trace particle interactions from similar targets at different times
- Check when the Universe was different from now

4/ VARIOUS SENSING SYSTEM

- Cosmic rays → but deflected
- Neutrinos → but rare
- GW → indeed!
- GAMMA-RAYS → yes!



HE ASTROPH. BARBECUES ARE GEORGEUS!

#2 KITCHEN AND TOOLS

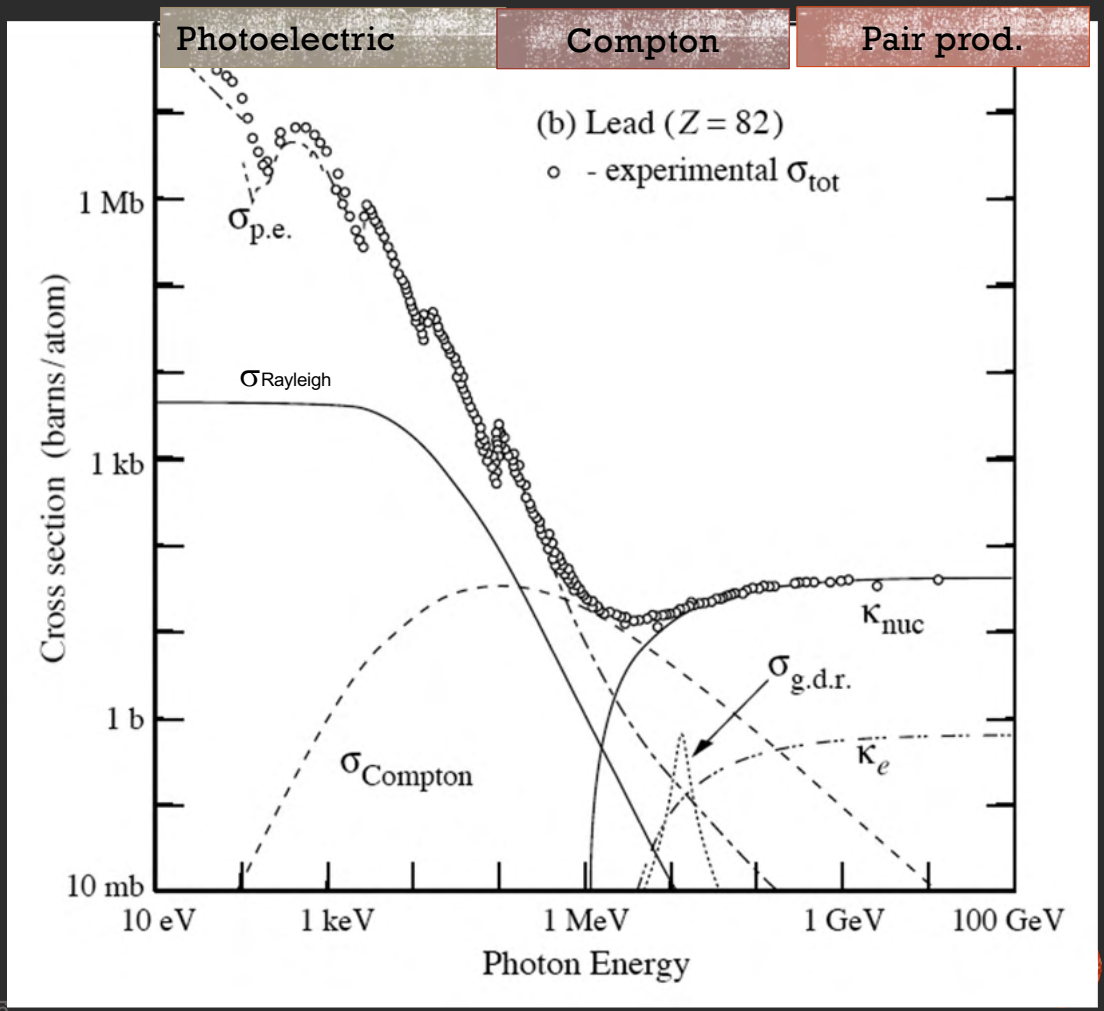
Some bought, some home-made

ASTRO-BIMBI DOES NOT EXIST

BUILD G-RAY DETECTOR?

100 GeV

- Energia: 1.602×10^{-8} J
- Massa: 1.782×10^{-25} kg
- Frequenza: 2.42×10^{25} Hz



GAMMA RAY (COSMIC-RAY) DETECTORS

ENERGY

<MeV range
Balloons-borne detectors

Just cosmic rays

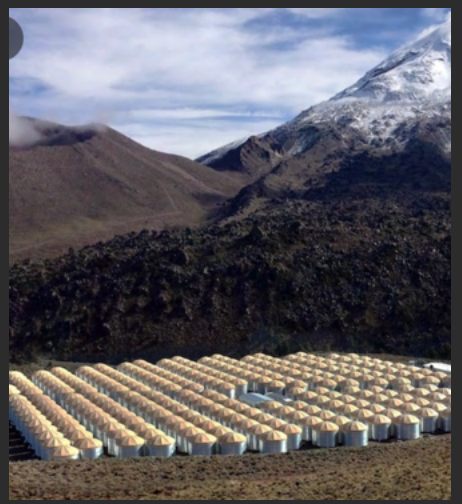
MeV-GeV range
Satellite-borne detectors

Fermi-LAT

TeV range
Ground-based detectors (light)

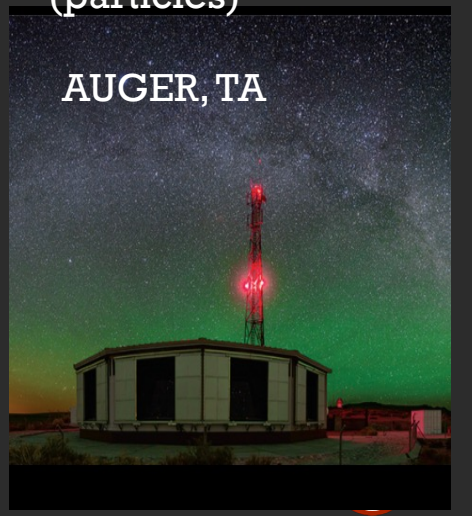
MAGIC,HESS, VERITAS, CTAO

TeV-PeV range
Compact Ground-based detectors (particles)



HAWC, LHATTES, SWGO

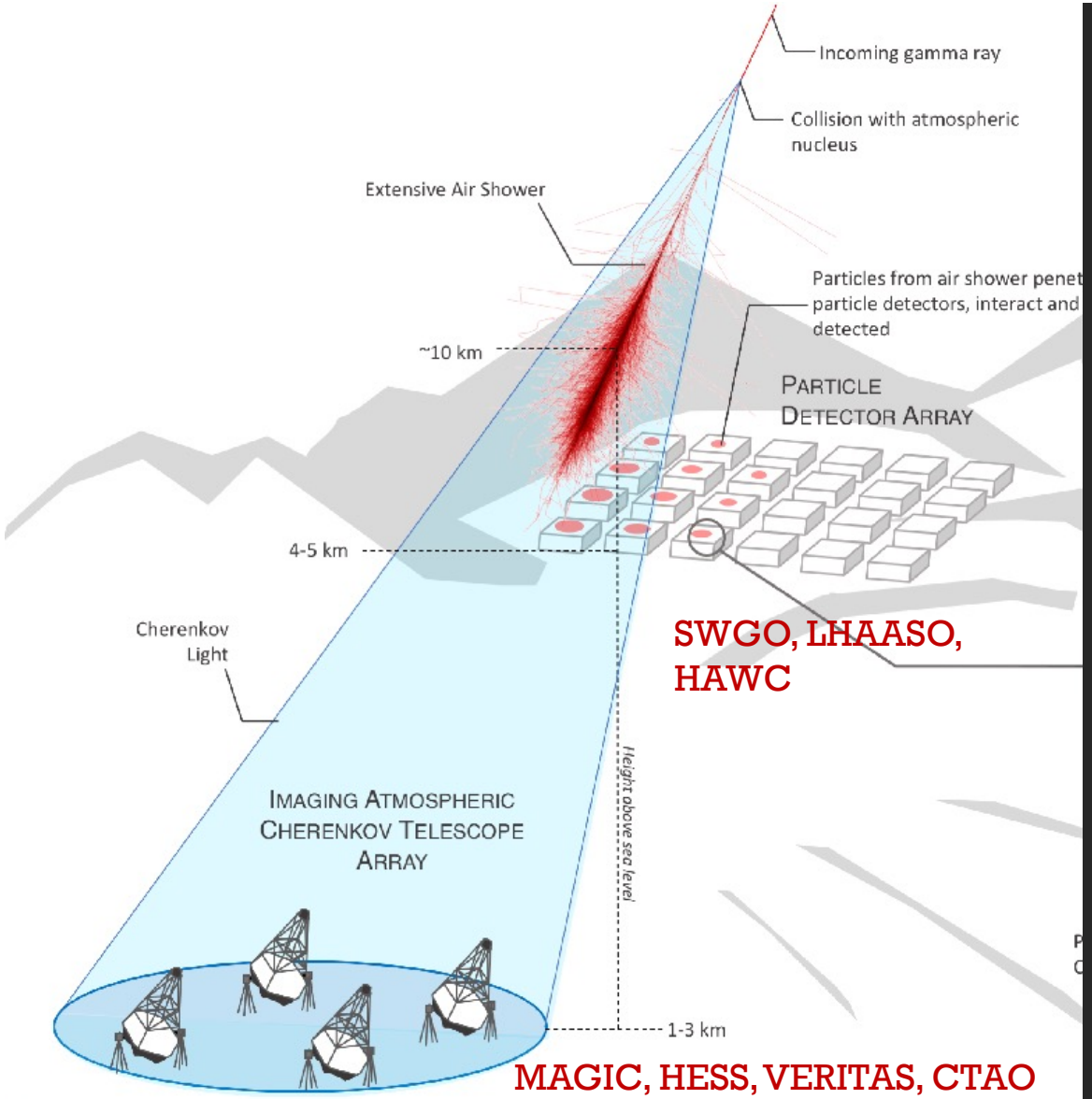
>PeV range
Wide Ground-based detectors (particles)



GAMMA-RAY SKY: "3 REVOLUTIONS IN 3 DECADES"

#2 CHERENKOV

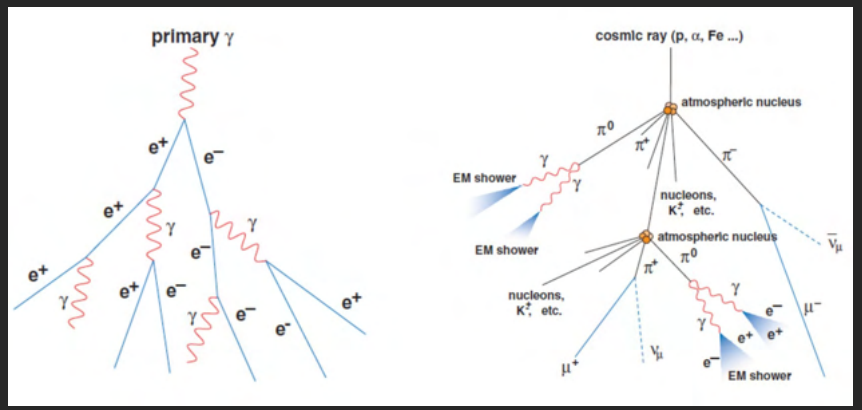
1 in 10^4

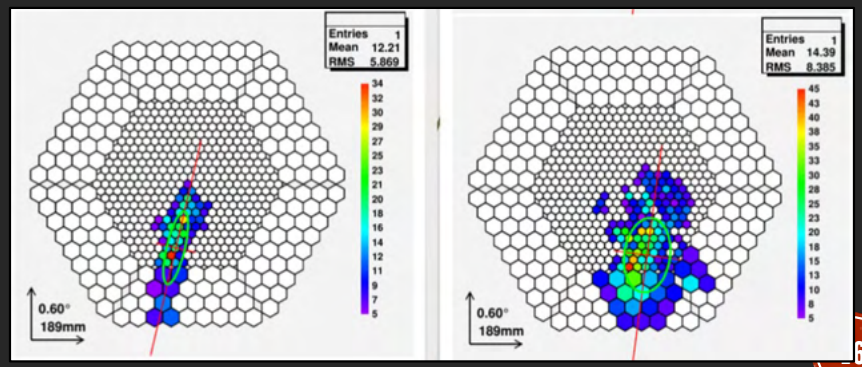


SWGO, LHAASO, HAWC

MAGIC, HESS, VERITAS, CTAO

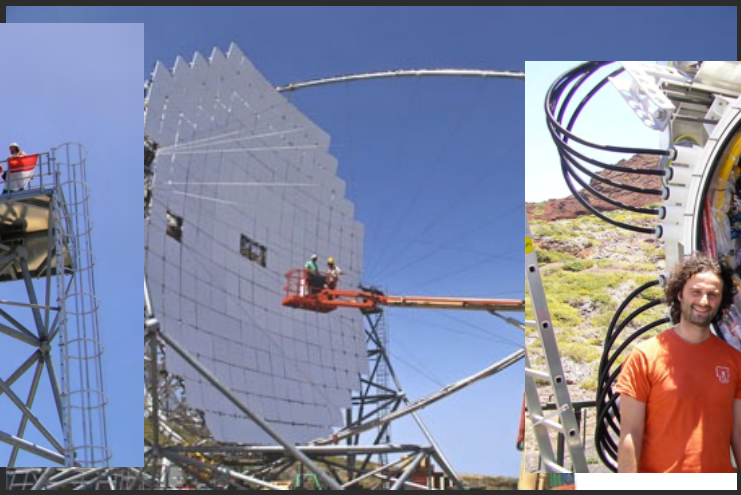
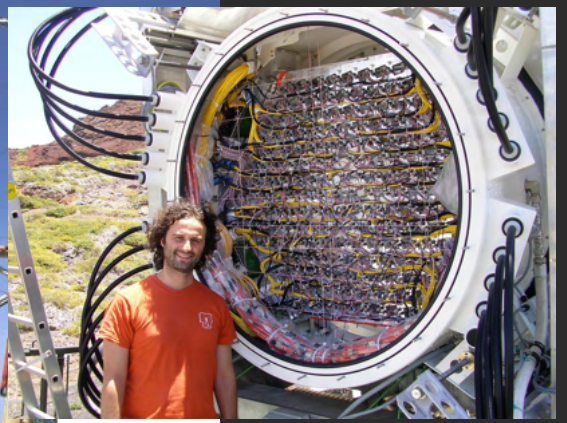
Shower image, 100 GeV γ-ray adapted from: F. Schmidt, J. Knapp, "CORSIKA Shower Images", 2005, https://www-zeuthen.desy.de/~jknapp/fs/showerimages.html

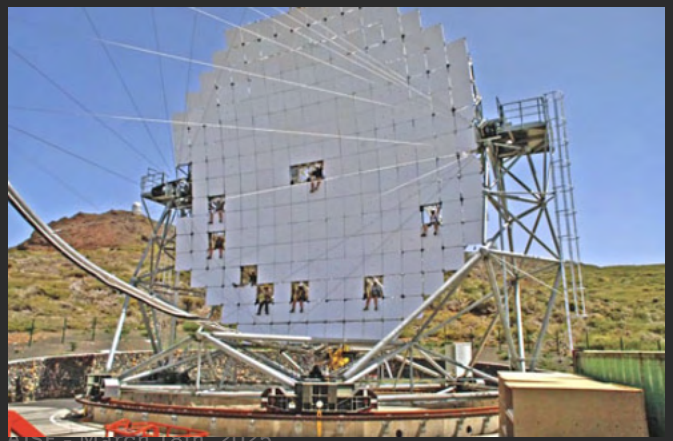




BEST PART OF MY PHD

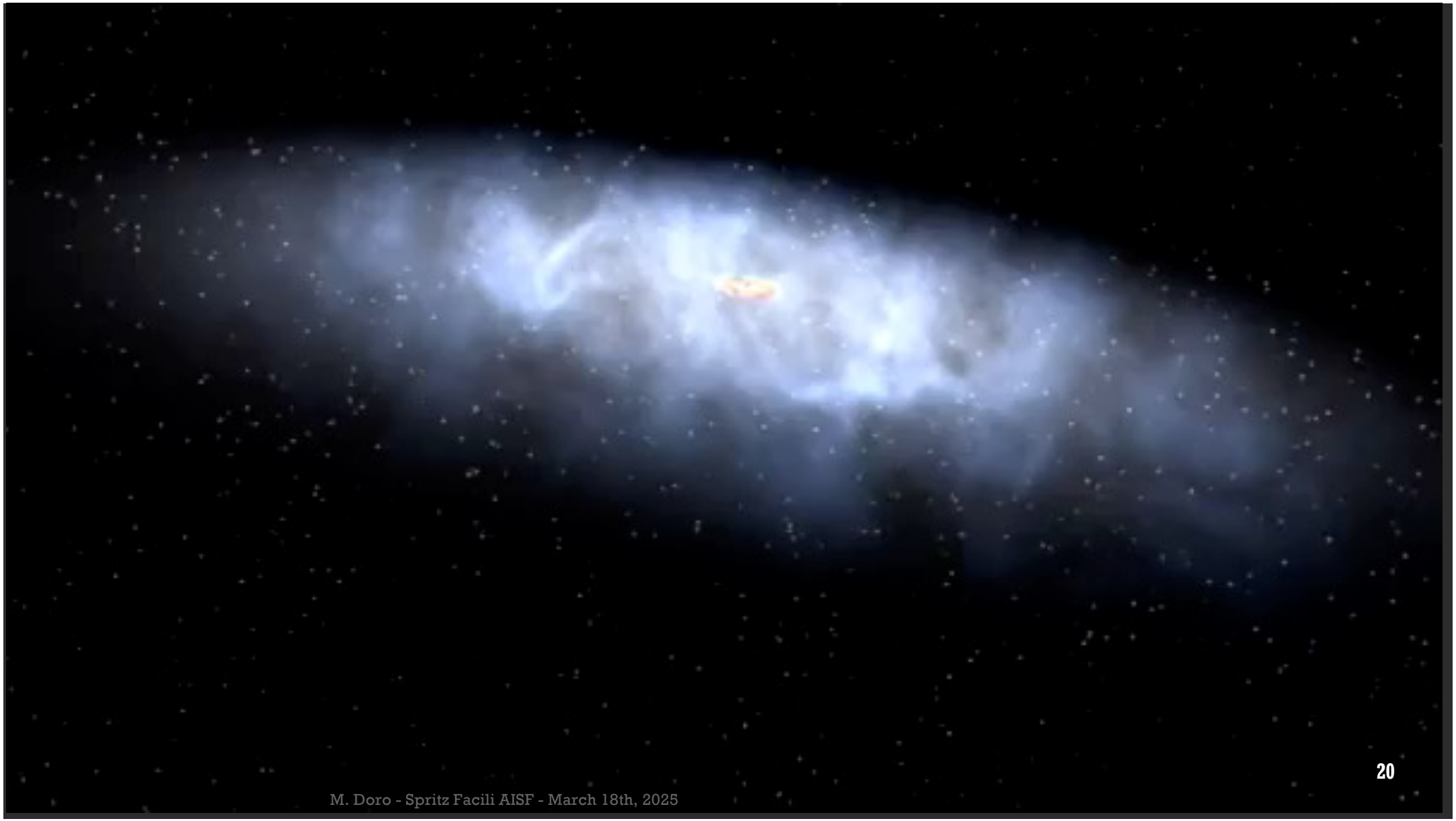


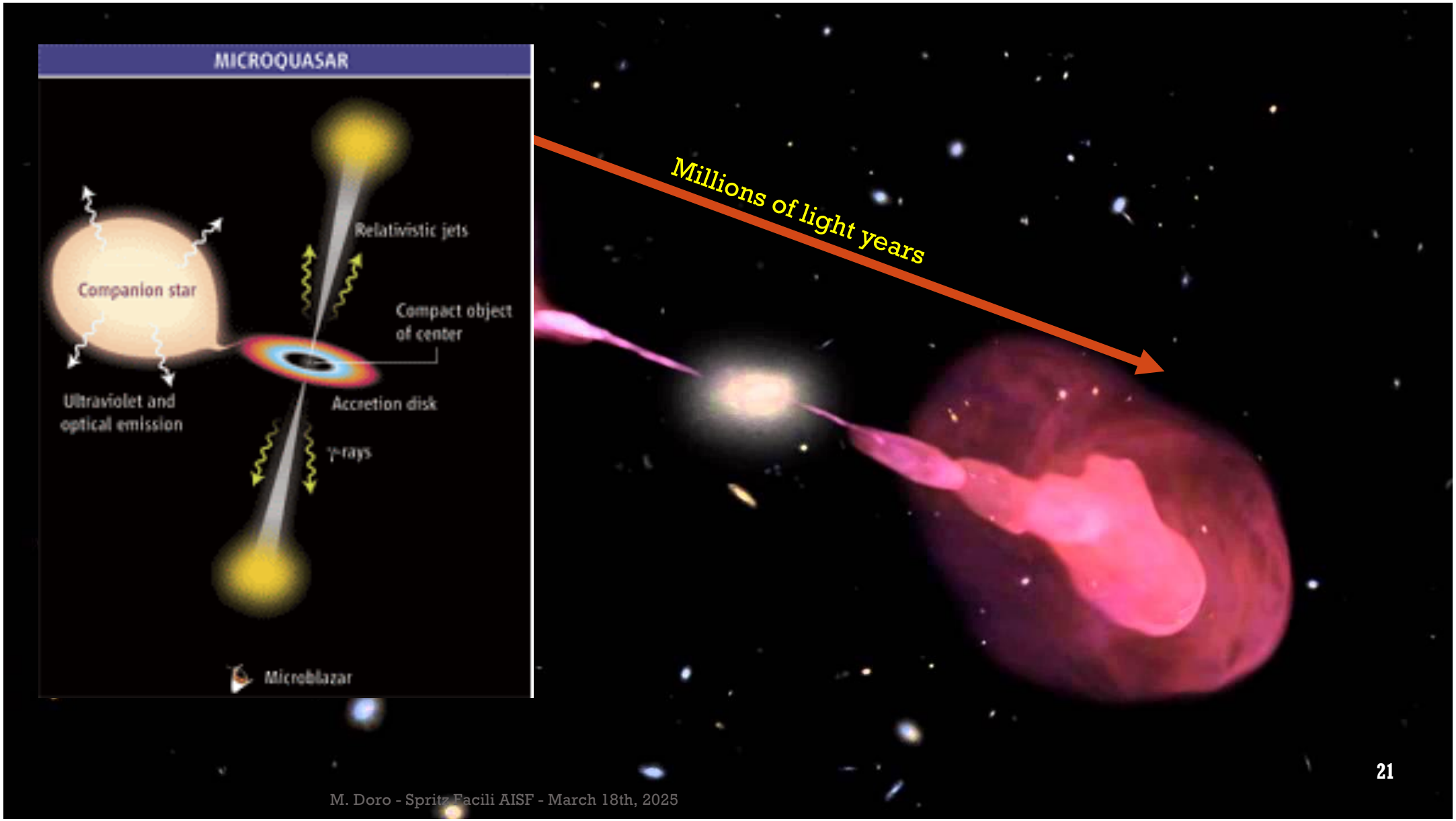



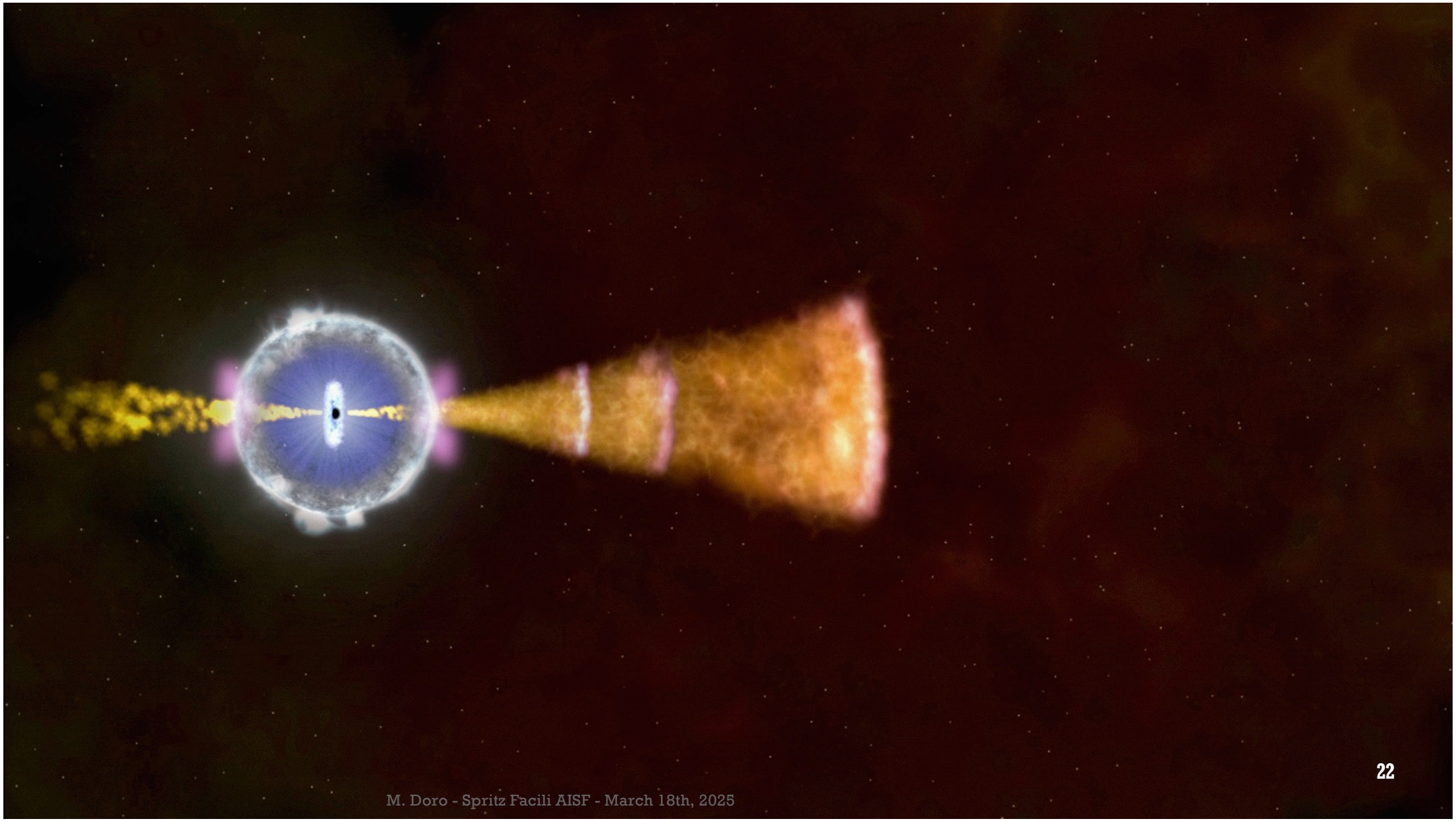


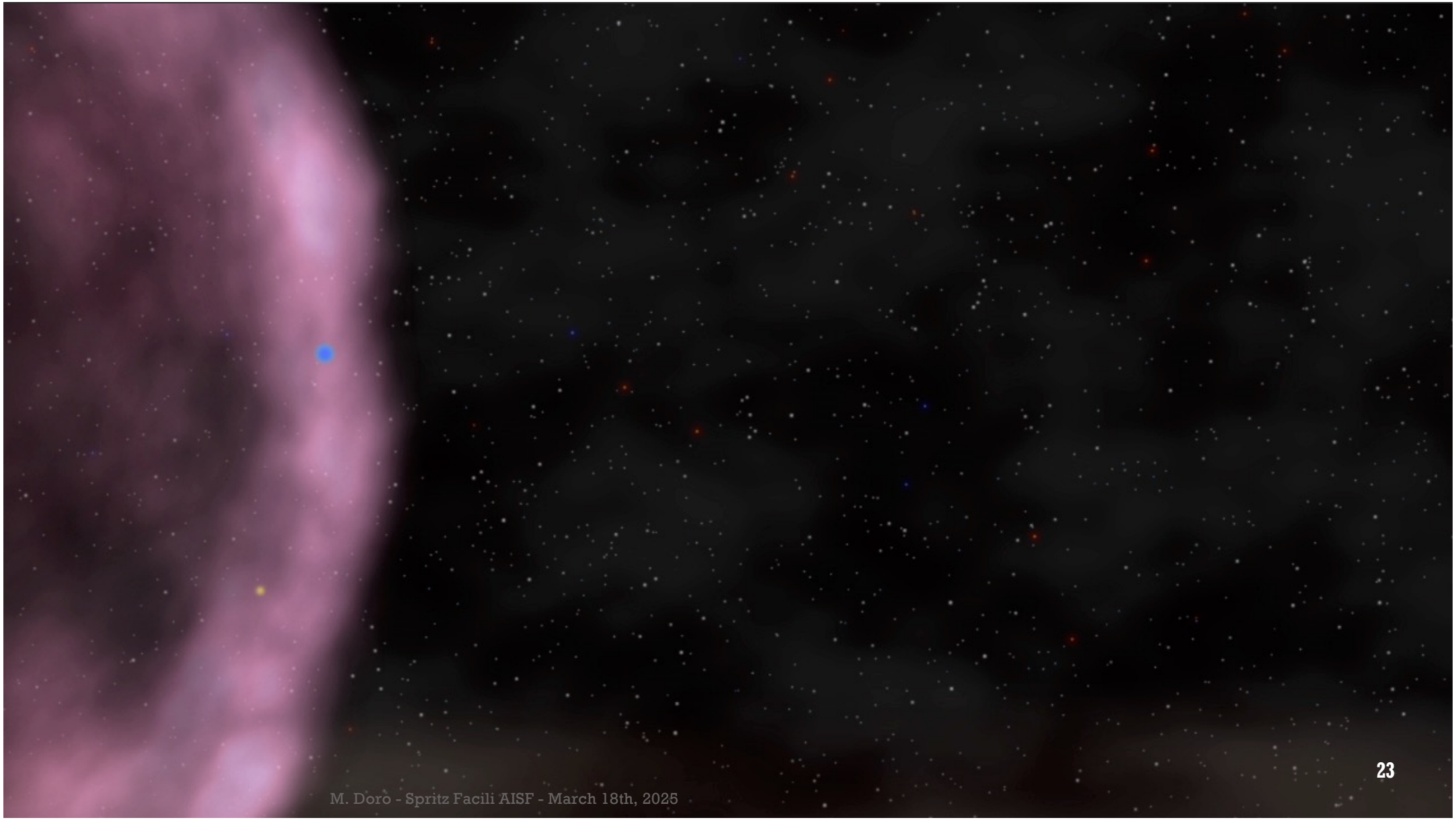

#2 TIME TO COOK

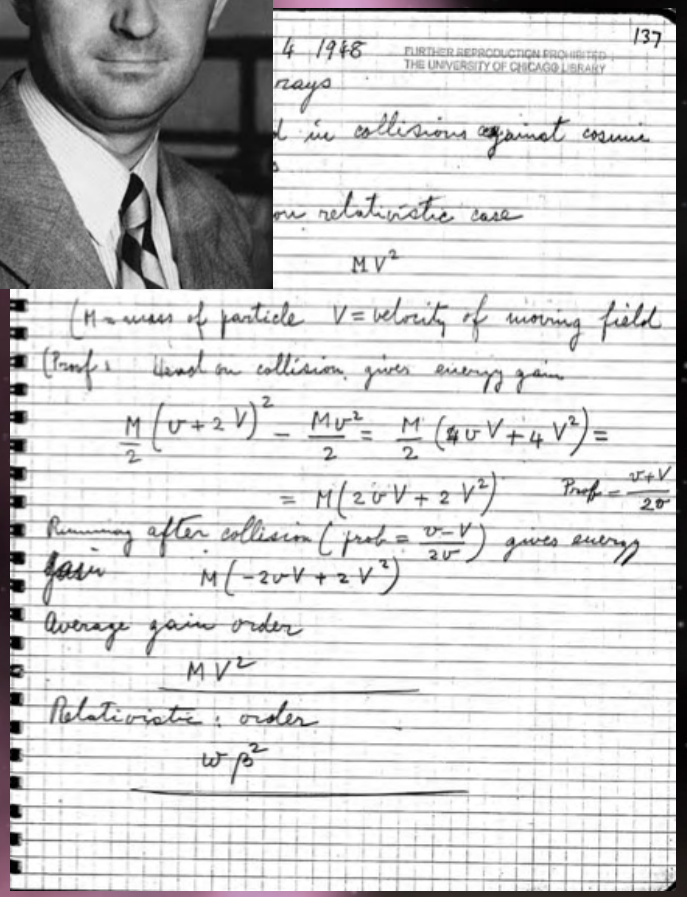

Radio-galaxies
GRBs
Blazar
FSRQs
Galaxy clusters
SNRs
PWN
Globular clusters
Pulsars
Binaries
Microquasars
Novae
Plasma
CR propagation
EBL
Energy budget
CR acceleration
IGMF
BHs
Jet
Shocks
Tony's
PIZZA PASTA GRILL
Astrophysical Tastes:
«Pizza Pasta Grill »




MICROQUASAR
Companion star
Relativistic jets
Compact object of center
Ultraviolet and optical emission
Accretion disk
γ-rays
Microblazar
Millions of light years







DIFFUSIVE SHOCK ACCELERATION – FERMI MECHANISM

- Original idea by Fermi 1948
- **Particles are accelerated by collisions with randomly moving magnetic clouds that swept up charged particles in the Inter-Stellar Medium (ISM)**

DARK MATTER

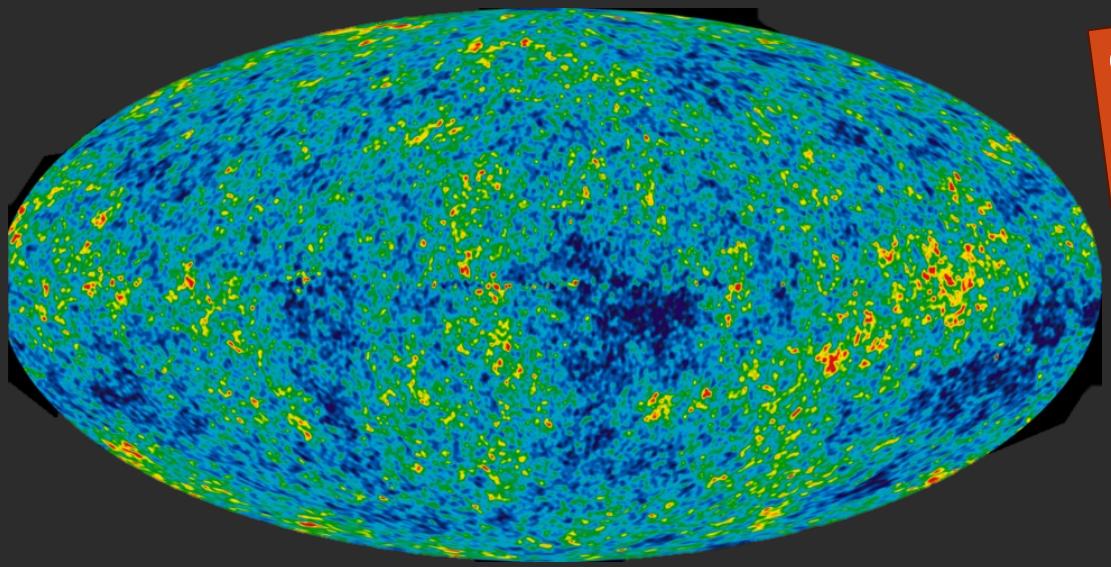
Better served cold

PARTICLES OR SOUP?

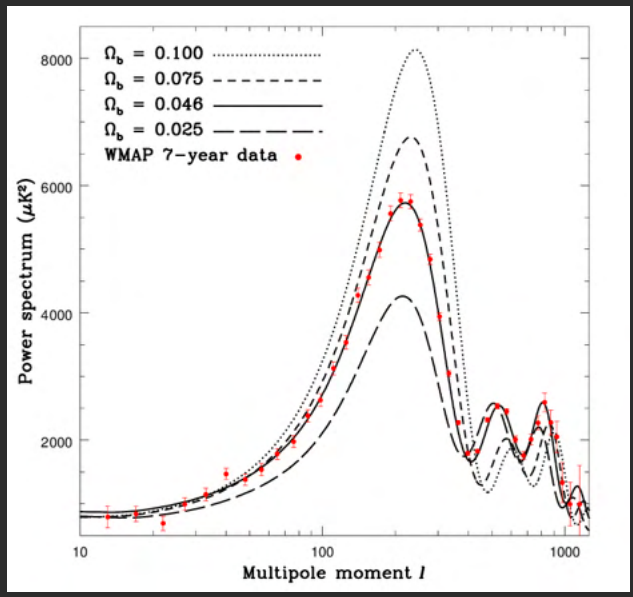
- Particle dark matter
- Modified theory of gravity (MoG) or Newtonian Dynamics (MoND)

There are even online ~~debates/~~fights:
https://youtu.be/dEsKnCx32L8?si=SvtPWxavhAHyM286

DON'T MESS WITH THE CMB INGREDIENT



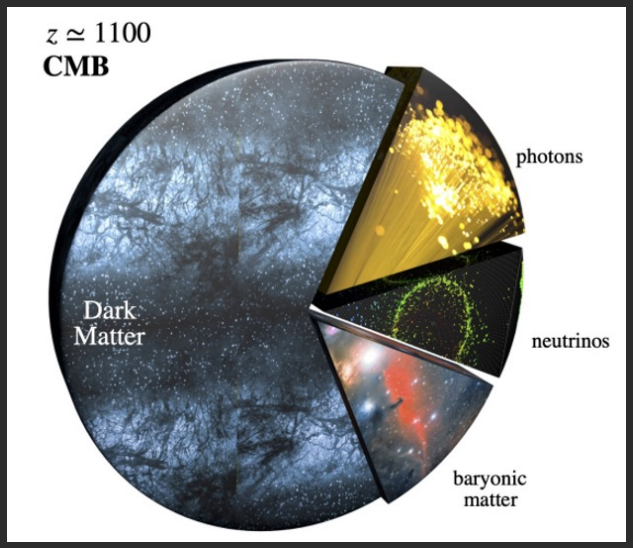
Cannot be explained with MOND

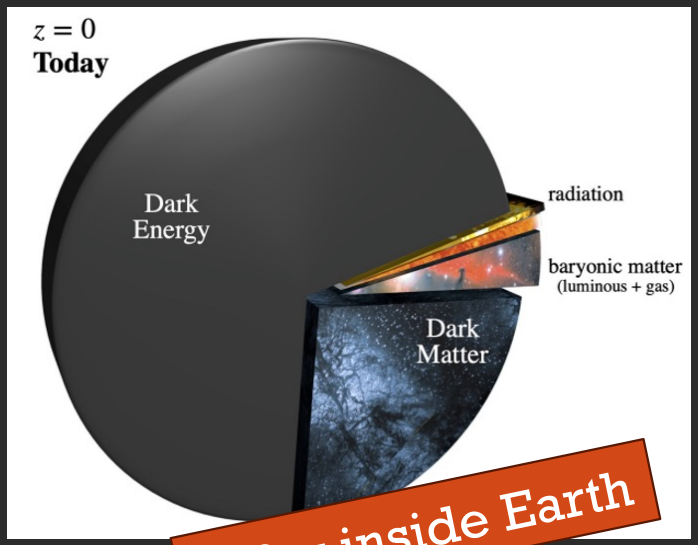


- 370,000 y from T0, photons separated from matter → Universe is transparent
- Electrons falls into atomic hydrogen (recombination)
- 100 GeV particle DM annihilation can ionize roughly 10% of the hydrogen in the universe!
- So this effect would be very visibile on CMB

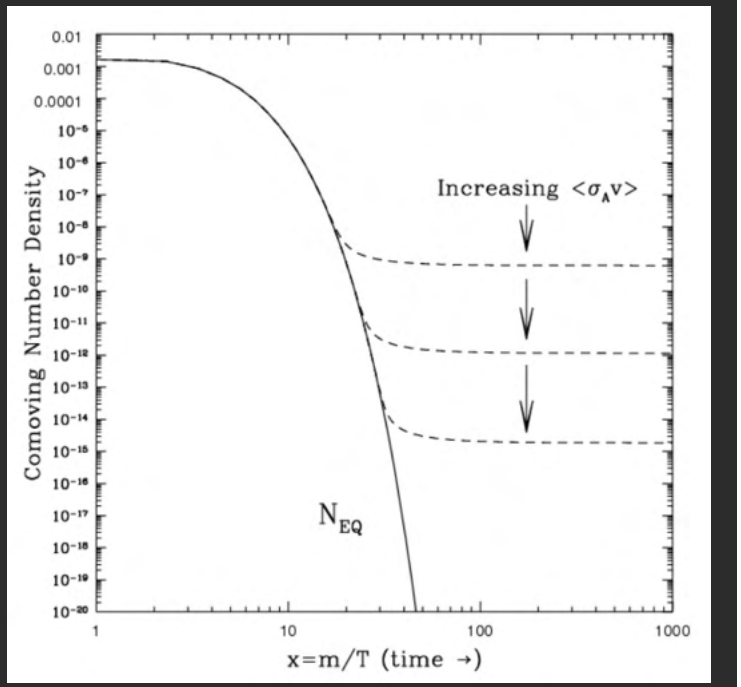
LET IT BAKE

Cirelli+ 2024





500 g inside Earth



Chemical equilibrium

$$\frac{dn}{dt} + 3Hn = (n_{\rm eq}^2 - n^2)\langle\sigma v_{\rm rel}\rangle$$

Freeze-out

$$dn/dt + 3(\dot{a}/a)n = 0$$

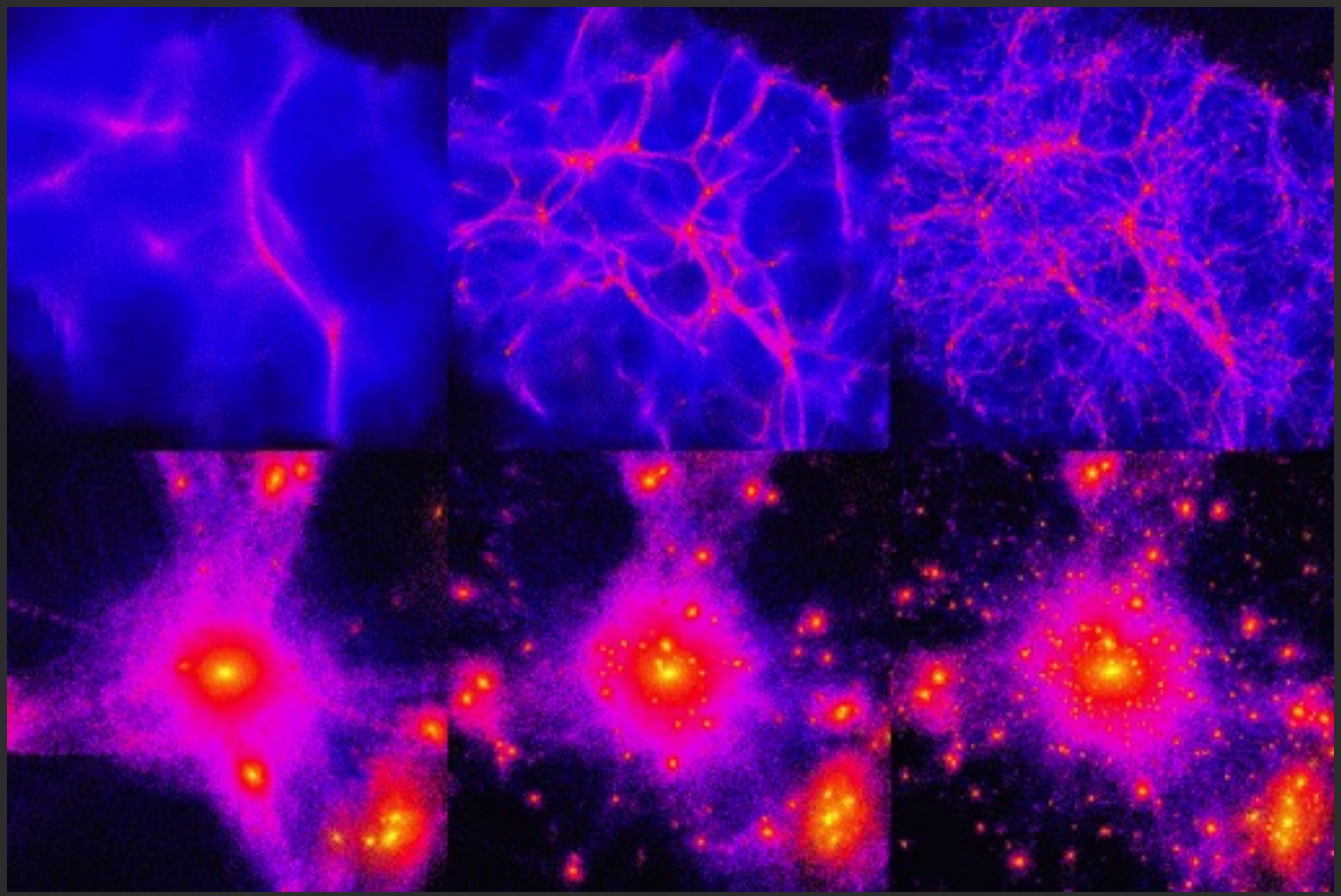
A lot of DM

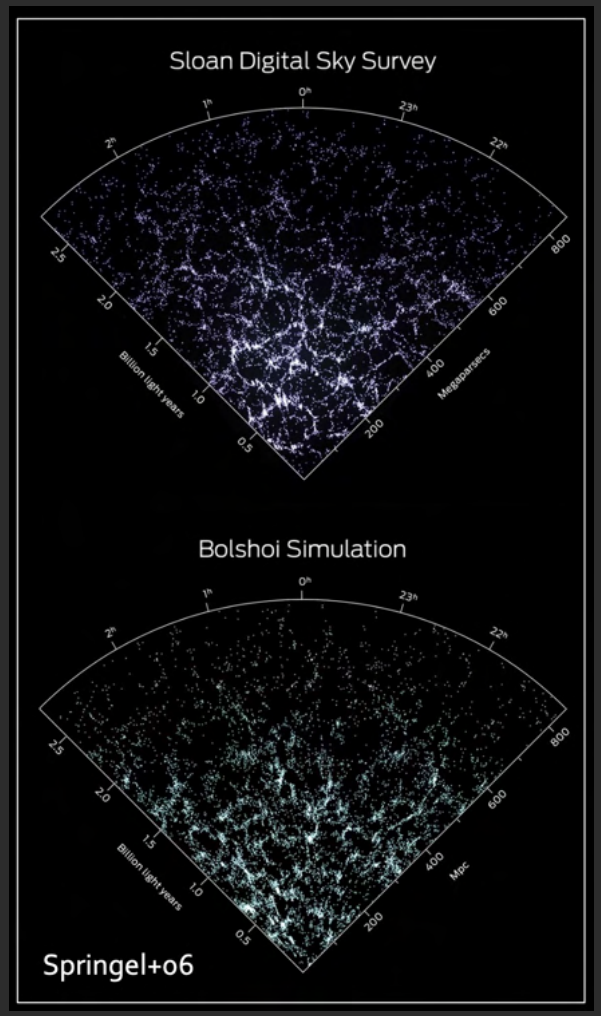
- ~25% of the Universe energy budget in dark matter
- ~80% of matter has always been dark

So much gravitation pull has serious consequences!

BAKING OPTIONS

Different mass, different evolution (N-body computer simulations)





Confirm COLD dark matter scenarios

OLD RECIPE IN FACT

F. Zwicky '30s

- Our guest Zwicky (1933) was (among the) first to claim strong evidences for DM
- Applying energy-balance from gas-theory on galaxies in galaxy-clusters

$$\langle v \rangle \sim \sqrt{\frac{GM_{\rm halo}}{R_{\rm halo}}}$$

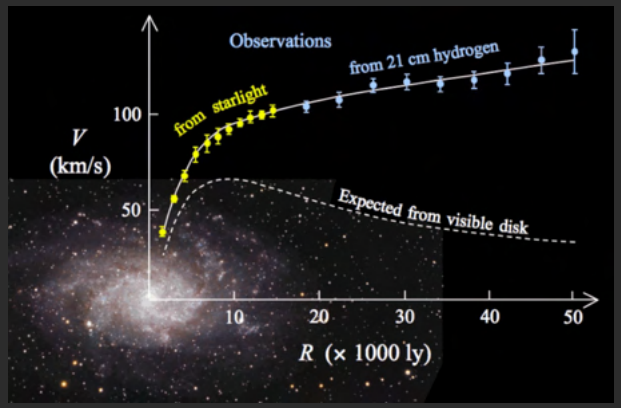
Coma cluster

"If this would be confirmed, we would get the surprising result that dark matter is present in much greater amount than luminous matter."

30 YEARS FORGOTTEN RECIPE AND THEN: VERA COOPER!

Vera Cooper Rubin '60s

- Vera applied similar argument to stars in galaxies, checking radial velocity



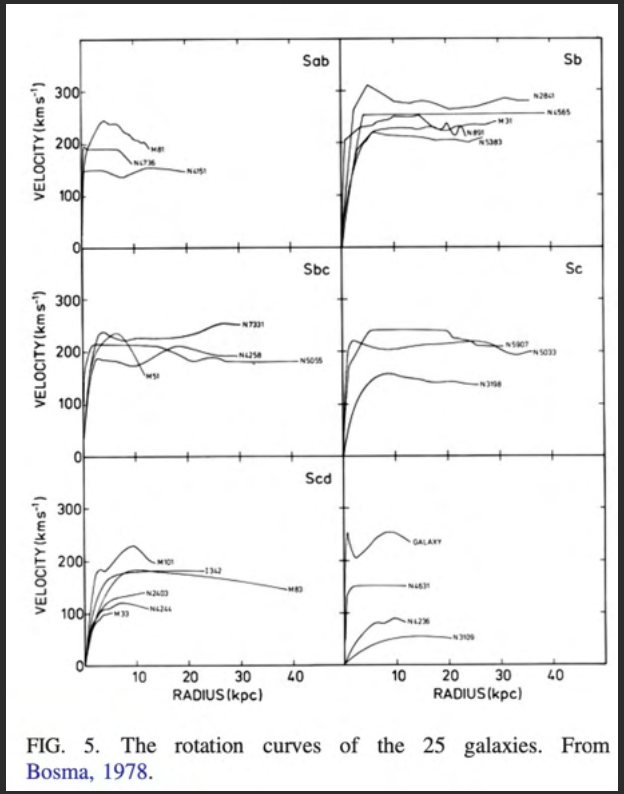
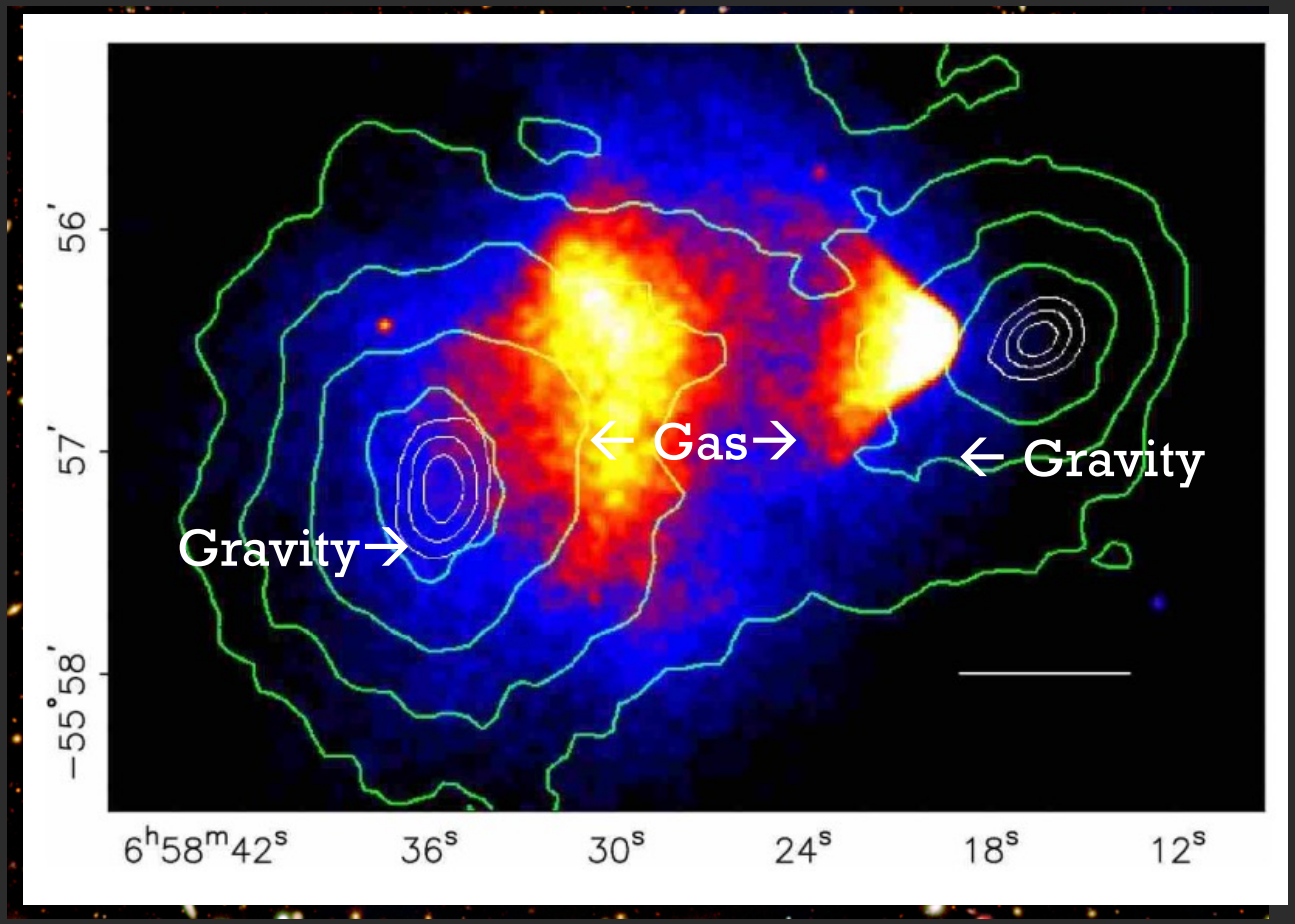


FIG. 5. The rotation curves of the 25 galaxies. From Bosma, 1978.

Vera Cooper (Rubin), Bosma (during PhD)

COLLISION-LESS: BULLET CLUSTER(S)



Non collisional matter is very weakly interacting!

Harvey et al. (2015) report the results on 72 similar merger: particle DM can be established with a significance of more than 7σ.

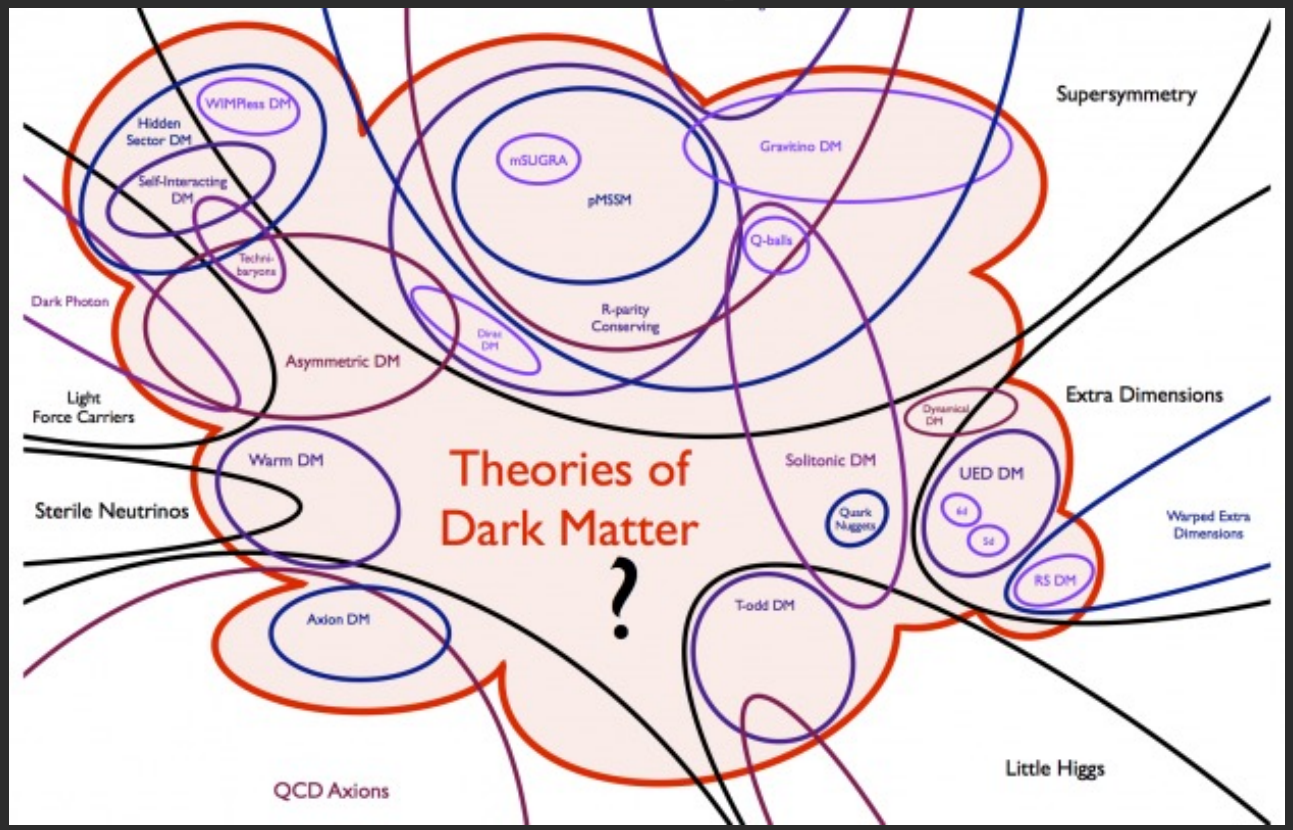
Cannot be explained with MOND

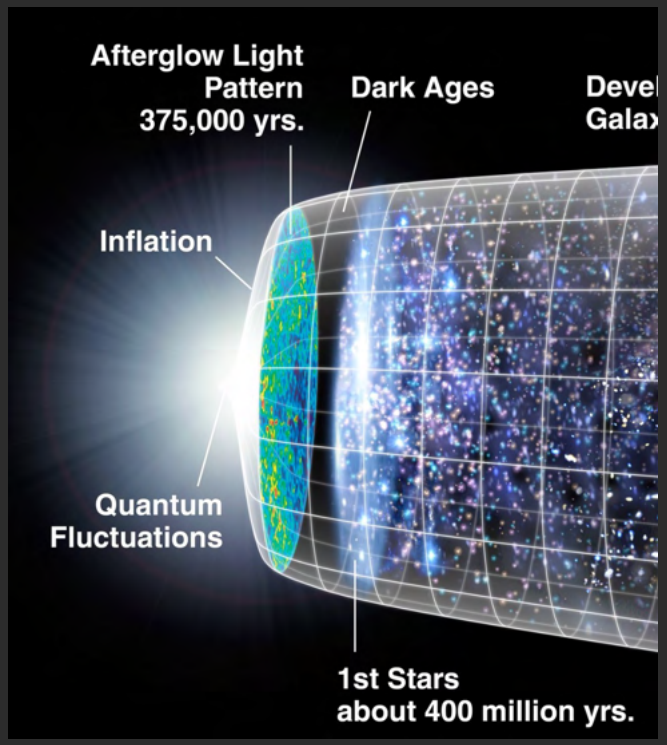
https://youtu.be/rLx_TXhTXbs

SM PARTICLES CANNOT BE DM, SO, A NEW PARTICLE?

Tim Tait

Many theories for DM



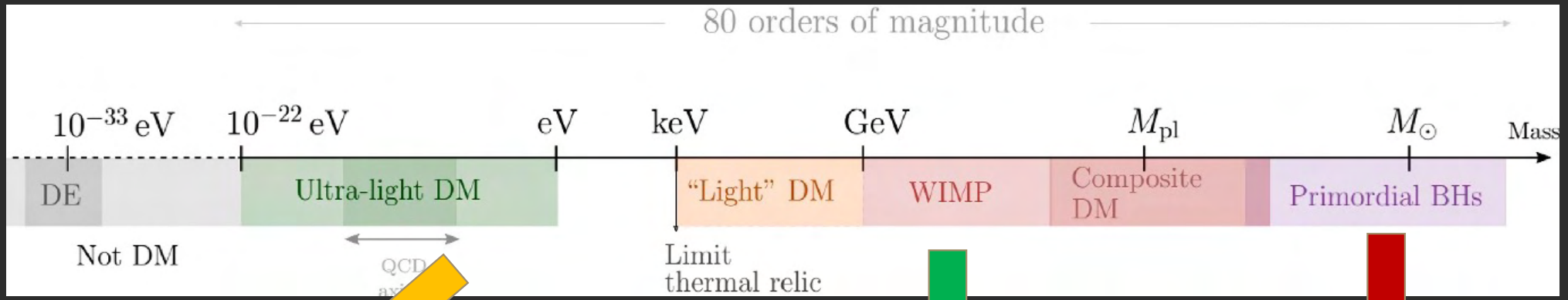


To convince Zwicky models must be natural, non ad-hoc

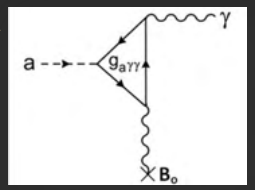
Several techniques according to DM mass and couplings to SM

CAN BE PROBED WITH GAMMA-RAYS

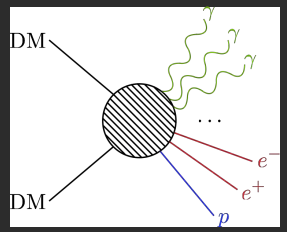
Elisa Ferreira 2021



While axions, signals can travel long distances in space and leave imprint in g-ray spectra



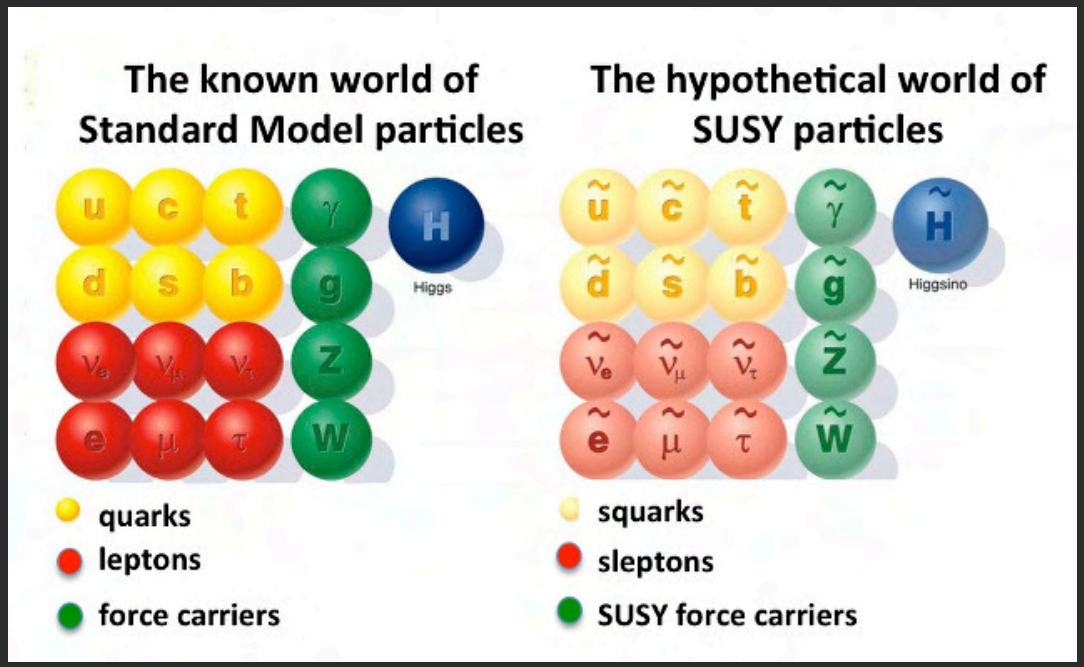
Annihilation/Decay of TeV DM in space



TeV emission during/after PBH evaporation

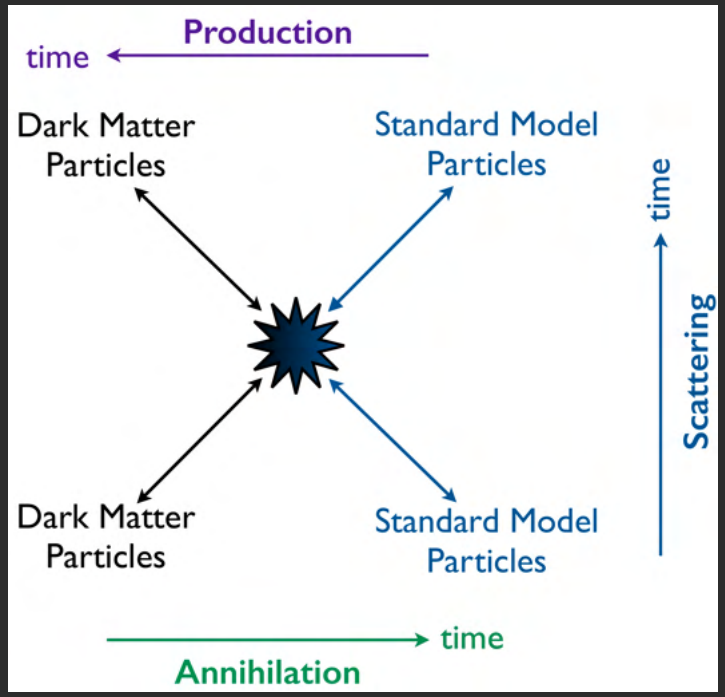
WIMP = Weakly-Interacting Massive Particle

SUPER SYMMETRY / WIMP

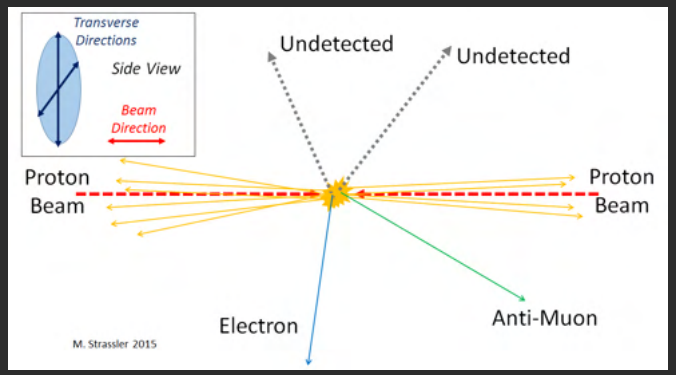


- Born to explain the Hierarchy Problem
- Provide natural dark matter candidates!
- Lightest Supersymmetric particle (LSP) is a 'natural DM candidate
- Neutralino, wino, higgsinos are prototype LSP

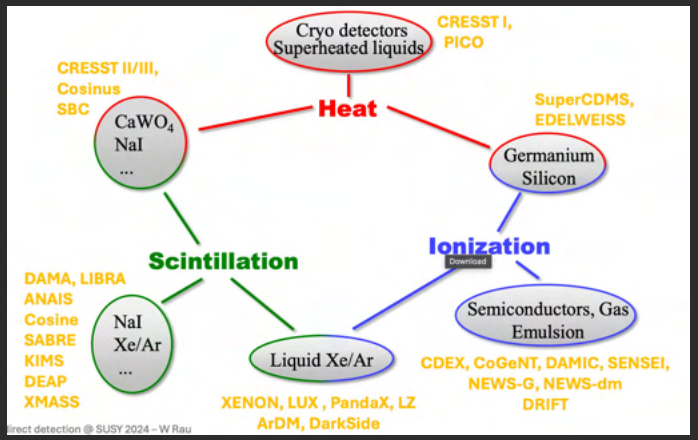
HOW TO DETECT IT: BREAK IT, SHAKE IT, MAKE IT



If some sort of interaction with SM Exists!

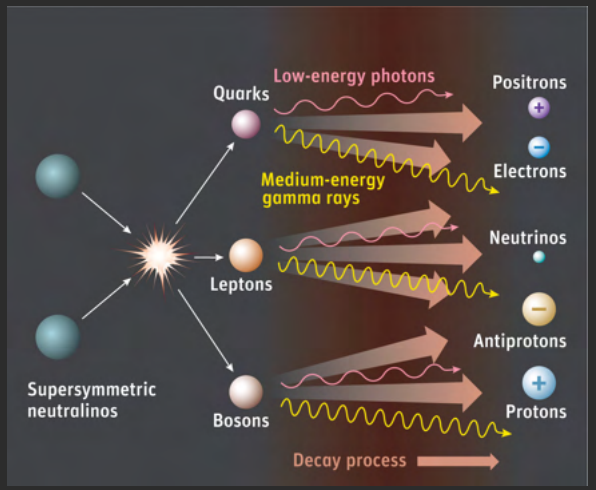


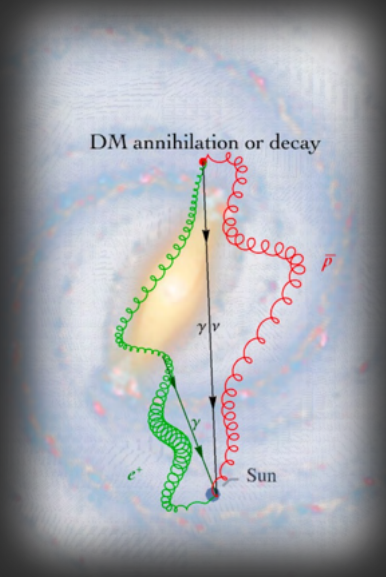
← Missing transverse energy in collisions



← Heat, scintillation, ionization in interactions with matter

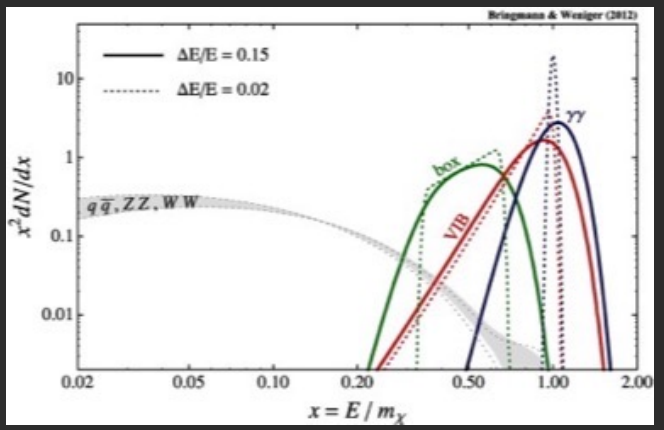
DM ANNIHILATIONS!



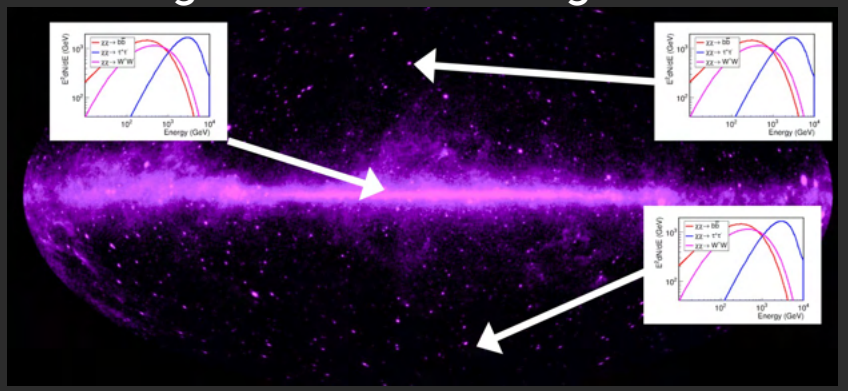


- DM would inject charged particles + radiation
  - Radiation go straight!
  - Antiparticles signature very interesting!

#1 Peculiarity of gamma-ray spectra (no astro-like)



#2 Same signal at different targets



#3 Know where to point the telescope!

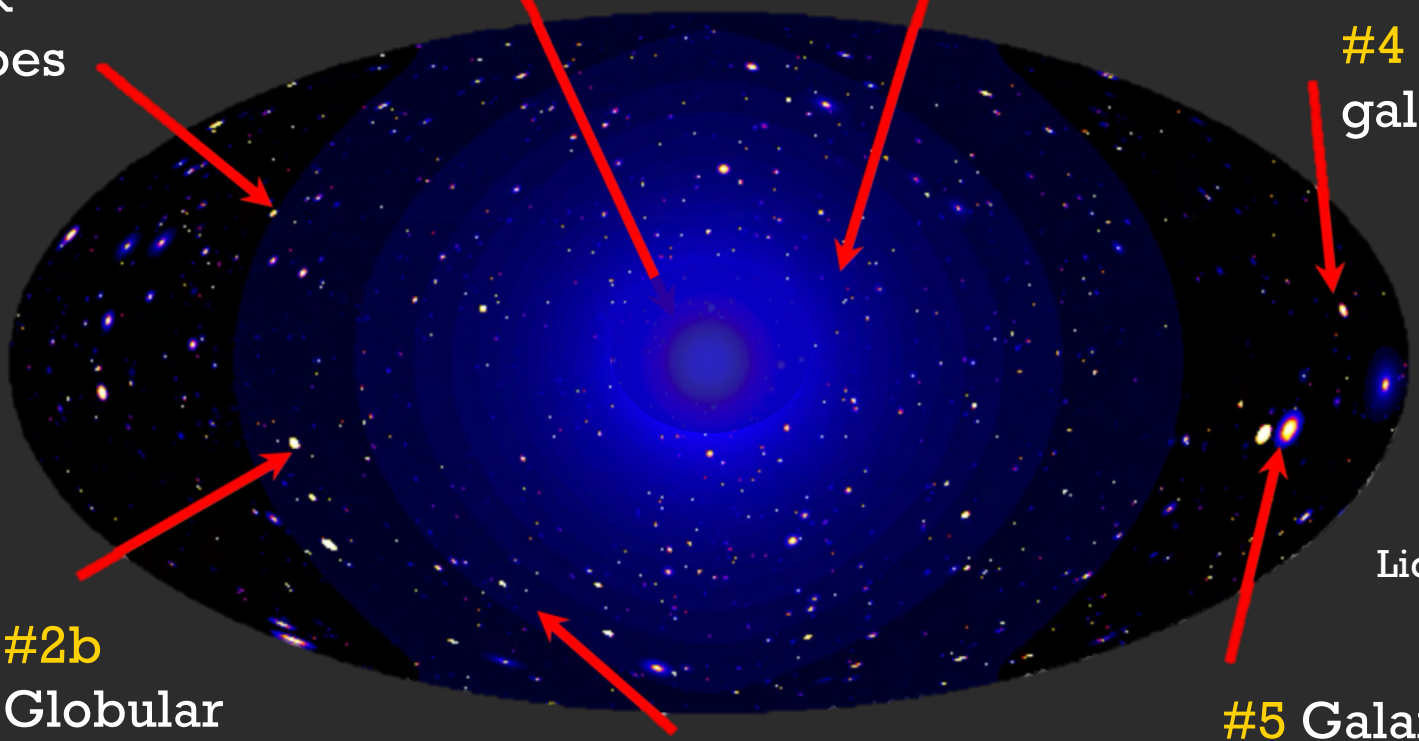
A POSSIBLE G-RAY DM SKY FROM WIMPS

#1 Galactic Center and halo

#3 Dark subhaloes

#4 Other galaxies

#2 Dwarf galaxies (MW satellites) Spheroidal and Irregular



Lidia Pieri+

#2b Globular clusters

#5 Galaxy clusters

#6 Diffuse signal, lines, holes in stellar streams, …

Gamma-rays

MD+ 2111.01198

Experiment	Location	Operation	Technology	Main focus	Energy range	Home	Ref.
HEAO-1	satellite	1977 → 1979	X-ray detectors	X/γ-rays	0.2 keV – 10 MeV	web	[466]
BAKSAN	Russia	1978 →	scintillation	neutrinos	1 GeV – 1 TeV	web	[467]
ROSAT	satellite	1990 → 1999	X-ray detectors	X-rays	0.1 – 2.5 keV	web	[468]
COMPTEL	satellite	1991 → 2000	HEP detectors	γ-rays	1 – 30 MeV	web	[469]
EGRET	satellite	1991 → 2000	HEP detectors	γ-rays	30 MeV – 30 GeV	web	[470]
CANGAROO	Australia	1992 → 2012	air Čerenkov	γ-rays	200 GeV – 3 TeV	web	[471]
HEAT	balloon	1994, 1995	HEP detectors	e^- & e^+	1 – 100 GeV	–	[472]
SUPER-KAM.	Japan						
AMANDA	South Pole						
AMS-01	Space shuttle						
BAIKAL-NT	Siberia						
CHANDRA	satellite						
XMM-NEWTON	satellite						
MILAGRO	New Mexico						
INTEGRAL	satellite						
HESS	Namibia						
VERITAS	Arizona						
MAGIC	Canary Islands						
SWIFT	satellite						
CREAM	Antarctic balloon						
SUZAKU	satellite						
ICECUBE	South Pole						
ANITA	Antarctic balloon						
PAMELA	satellite						
FERMI	satellite						
ANTARES	French riviera						
AMS-02	ISS						
NUSTAR	satellite						
TAIGA	Siberia						
HAWC	Mexico						
TIBET AS	Tibet						
CALET	ISS						
HITOMI	satellite						
DAMPE	satellite						
COSI-SPB	balloon						
HXMT	satellite						
ISS-CREAM	ISS						
MACE	Himalaya						
MICRO-X	New Mexico						
EROSITA	satellite						
LHAASO	China						
GAPS	Antarctic balloon						
KM3NET	Mediterranean						
CTA	North+South						
XRISM	satellite						
ADEPT	balloon						
BAIKAL-GVD	Siberia						
GAMMA-400	satellite						
DUNE	USA						
COSI	satellite						
HYPER-KAM.	Japan						
HERD	Chinese SS						
SKA	S.Africa+Australia	2020s?	radio telescope	radio	50 MHz – 30 GHz	web	[518]
INO-ICAL	India	2020s?	calorimeter	neutrinos	1 – 100 GeV	web	[519]
AMEGO	satellite	late 2020s?	HEP detectors	γ-rays	0.2 MeV – 10 GeV	web	[520]
APT	satellite	late 2020s?	HEP detectors	γ-rays	60 MeV – 1 TeV	–	[521]
ATHENA	satellite	early 2030s?	X-ray detectors	X/γ-rays	0.2 – 12 keV	web	[522]
AS-/E-ASTROGAM	satellite	2030s?	HEP detectors	γ-rays	0.1 MeV – 3 GeV	–	[523]
GRAND	high altitude deserts	2030s?	radio telescopes	neutrinos	100 PeV – 100 EeV	web	[524]
ALADINO	L2 point?	2035?	HEP detectors	charged CRs	→ 10 TeV	–	[525]
AMS-100	L2 point	2039?	HEP detectors	charged CRs	sub-GeV – 10 TeV	–	[526]
GECCO	satellite	proposed	HEP detectors	X/γ-rays	100 keV – 10 MeV	–	[527]
MAST	satellite	proposed	LAr satellite	γ-rays	100 MeV – 1 TeV	–	[528]
GRAMS	balloon/satellite	proposed	LAr detector	γ-rays/$\bar{d}$	200 keV – 200 MeV	–	[529]
SWGO	South America	proposed	water Cherenkov	VHE γ-rays	100 GeV – 10 PeV	web	[530]

Target	Year	Time [h]	IACT	Limit	Ref.
The Milky Way central region & halo					
MW Centre	2004	(48.7)	H.E.S.S.	Ann.	Aharonian et al. (2006)
MW Inner Halo	2004 – 2008	(112)	H.E.S.S.	Ann.	Abramowski et al. (2011)
		9.1		Ann.	Abramowski et al. (2015)
		254		Ann.	Abdallah et al. (2016)
		546	H.E.S.S.†	Ann.	Montanari et al. (2021)
		10	MAGIC	Decay	Ninci et al. (2019)
arf Satellite Galaxies					
		7.4	Whipple	Ann.	Wood et al. (2008)
		7.8	MAGIC‡	Ann.	Albert et al. (2008b)
		(18.4)	VERITAS	Ann.	Acciari et al. (2010)
		(49.8)		Ann.	Archambault et al. (2017)
		114		–	Kelley-Hoskins (2018)
		52.6	MAGIC	Ann.	Maggio et al. (2021)
		7.9	Whipple	Ann.	Wood et al. (2008)
		(18.9)	VERITAS	Ann.	Acciari et al. (2010)
		(60.4)		Ann.	Archambault et al. (2017)
		161		–	Kelley-Hoskins (2018)
		(11.0)	H.E.S.S.	Ann.	Aharonian et al. (2008)
		90		Ann.	Abramowski et al. (2014)
		(85.5)		Ann.	Abdalla et al. (2018a)
		9.6	H.E.S.S.	Ann.	Aharonian et al. (2009a)
		13.7	VERITAS	Ann.	Acciari et al. (2010)
		(13.6)		Ann.	Archambault et al. (2017)
		15.5	MAGIC‡	Ann.	Aliu et al. (2009)
		(11.8)	H.E.S.S.	Ann.	Abramowski et al. (2011)
				Ann.	Abdalla et al. (2018a)
		12.5		Ann.	Abramowski et al. (2014)
		(14.8)	H.E.S.S.	Ann.	Abramowski et al. (2011)
		(12.7)		Ann.	Abramowski et al. (2014)
		22.9		Ann.	Abdalla et al. (2018a)

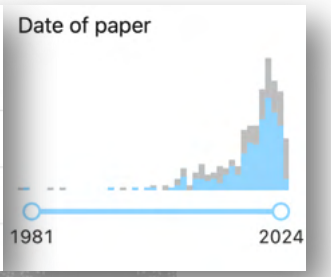
Time [h]	IACT	Limit	Ref.
ediate Mass Black Holes			
400	H.E.S.S.	Ann.	Aharonian et al. (2008a)
25	MAGIC‡	Ann.	Doro et al. (2007)
Globular Clusters			
0.2	Whipple	Ann.	Wood et al. (2008)
15.2	H.E.S.S.	Ann.	Abramowski et al. (2011)
27.2	H.E.S.S.	Ann.	Abramowski et al. (2011)
Other galaxies			
7.9	Whipple	Ann.	Wood et al. (2008)
6.9	Whipple	Ann.	Wood et al. (2008)
18.2	H.E.S.S.†	Ann.	Abdallah et al. (2021b)
Galaxy Clusters			
6.1	Whipple	–	Perkins et al. (2006)
13.5	Whipple	–	Perkins et al. (2006)
24.4	MAGIC‡	Ann.	Aleksić et al. (2010)
202.2	MAGIC	Decay	Acciari et al. (2018)
14.5	H.E.S.S.	Ann.	Abramowski et al. (2012)
18.6	VERITAS	Ann.	Arlen et al. (2012)
Line searches			
(112)	H.E.S.S.	Ann.	Abramowski et al. (2013c)
15.2	H.E.S.S.†	Ann.	Abdalla et al. (2016)
(254)	H.E.S.S.	Ann.	Abdalla et al. (2018b)
204	MAGIC	Ann.	Inada et al. (2021)
(157.9)	MAGIC	A.+D.	Aleksić et al. (2014)
(137.1)	H.E.S.S.	Ann.	Abdalla et al. (2018a)
(229.8)	VERITAS	Ann.	Archambault et al. (2017)
18.2	H.E.S.S.†	Ann.	Abdallah et al. (2021b)
Charged particles			
239	H.E.S.S.	–	Aharonian et al. (2008b, 2009b)
296	VERITAS	–	Archer et al. (2018)
14	MAGIC	–	Borla Tridon et al. (2011)
20	MAGIC	–	Colin et al. (2011)
1.2	VERITAS	–	Bird et al. (2016)

Grus II*	2018	11.3	H.E.S.S.†	Ann.	Abdalla et al. (2020)
Dark satellites					
1FGL J2347.3+0710	2010	8.3	MAGIC	–	Nieto et al. (2011a)
1FGL J0338.8+1313	2010-2011	10.7	MAGIC	–	Nieto et al. (2011a)
2FGL J0545.6+6018	2013-2015	8.5	VERITAS	Ann.	Nieto (2015)
2FGL J1115.0-0701	2013-2015	13.8	VERITAS	Ann.	Nieto (2015)
H3FHL J0929.2-4110	2018-2019	7.8	H.E.S.S.†	Ann.	Abdallah et al. (2021a)
3FHL J1915.2-1323	2018 – 2019	3.0	H.E.S.S.†	Ann.	Abdallah et al. (2021a)
3FHL J2030.2-5037	2018 – 2019	8.8	H.E.S.S.†	Ann.	Abdallah et al. (2021a)
3FHL J2104.5+2117	2018 – 2019	5.5	H.E.S.S.†	Ann.	Abdallah et al. (2021a)

Table 8.1 – Continued on next page

AXION LIKE PARTICLES

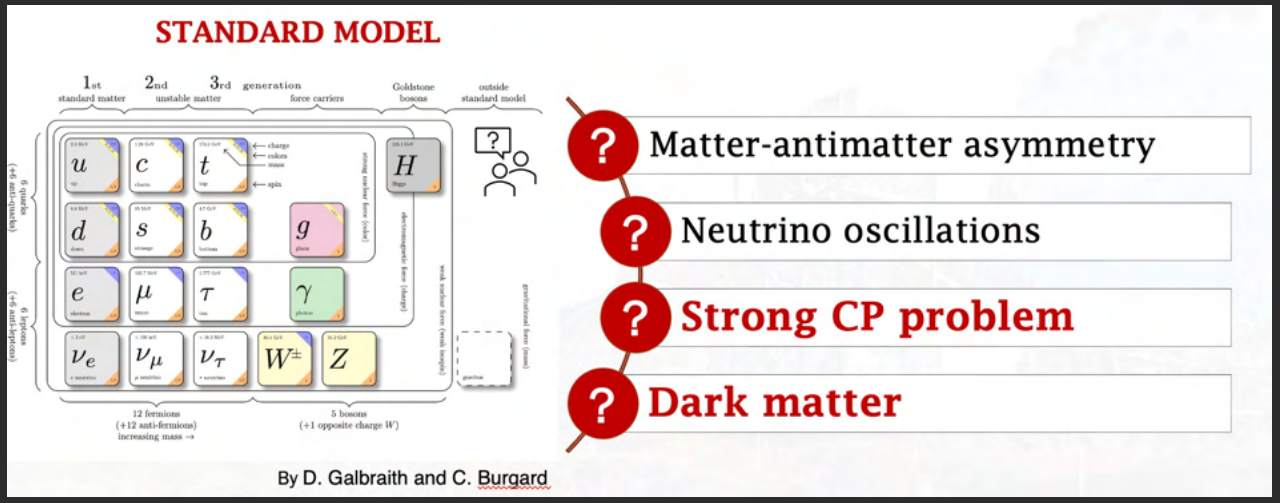
	Citeable
Papers	268
Citations	13,438
h-index	60
Citations/paper (avg)	50.1



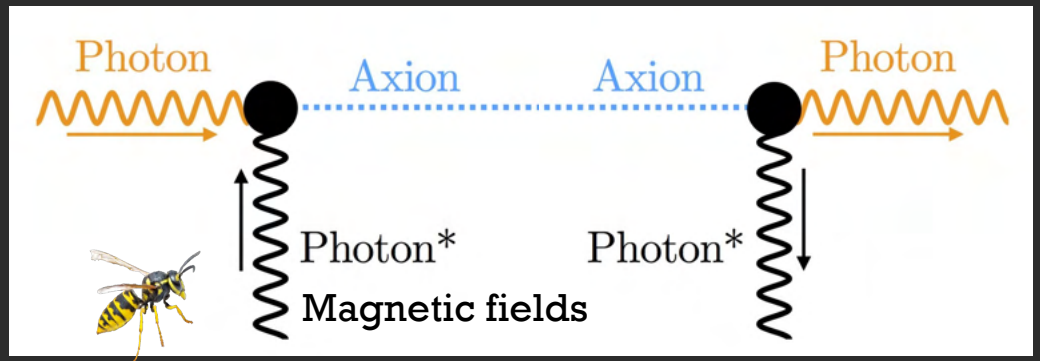
Be prepared to wash dishes

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

HOUSTON, WE HAVE A STRONG CP PROBLEM



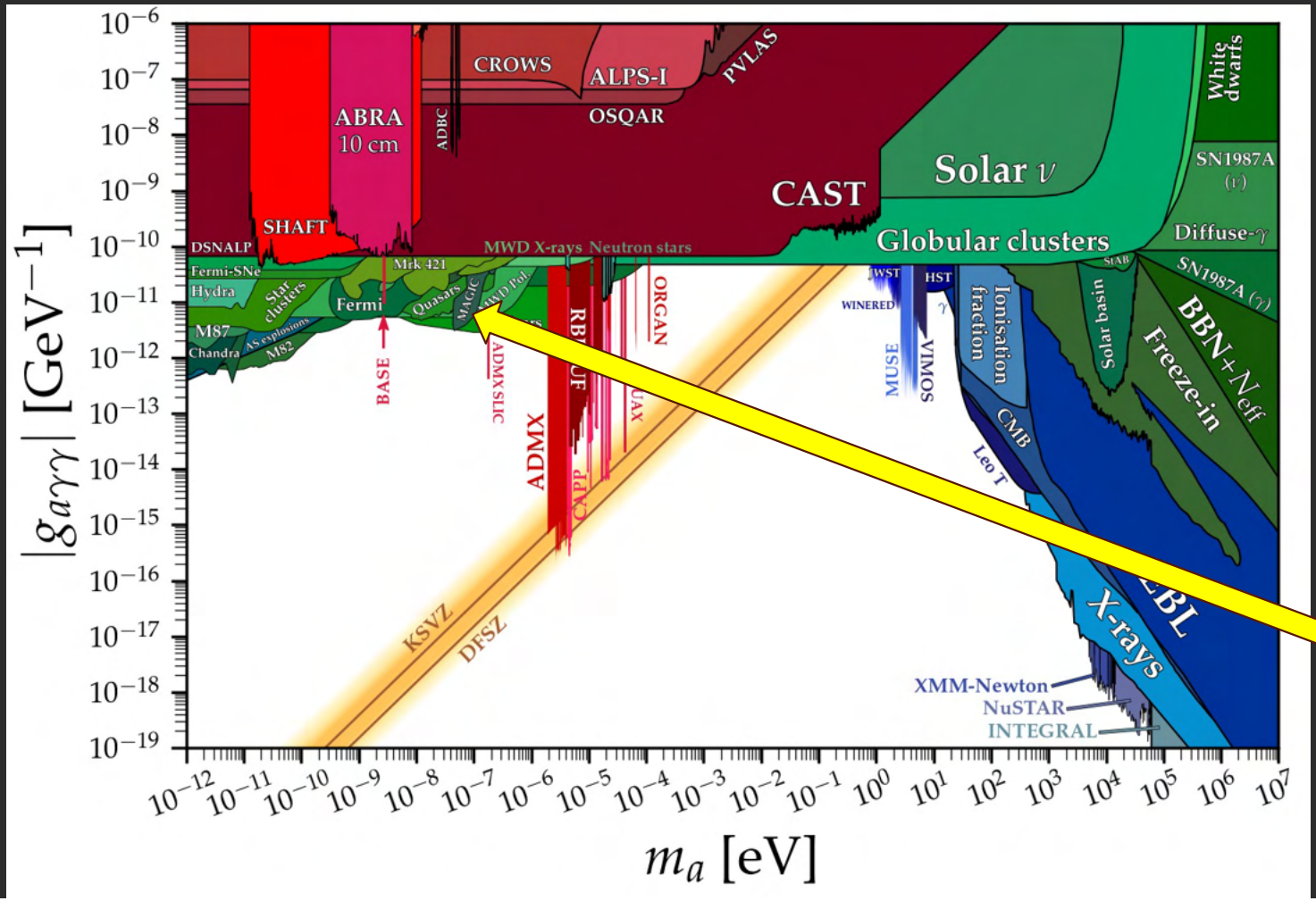
Credit: I Batkovic

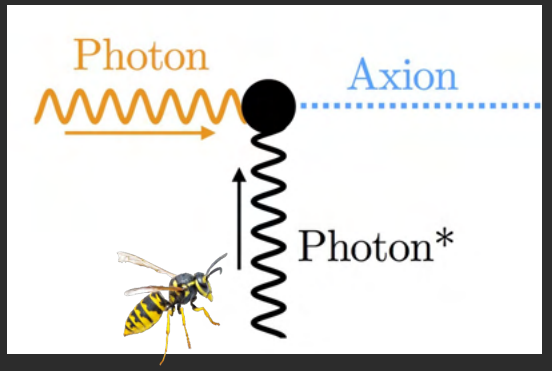


Peccei/Quinn

NOT FOUND IN SUPERMARKET

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

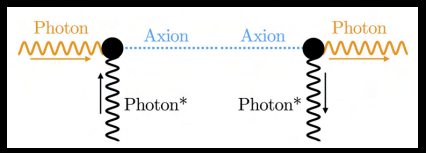




- Cosmological limits (blue)
- Lab limits (red)
- Telescopes (green)

2/ w/ PhD student in my group

COSMIC BEE-FIELDS



SOURCE + JET

B ~ 1 G
L~ 0.1 pc

$\vec{B}$

INTERGALACTIC MEDIUM

B < 1 nG
L~ 1 Mpc

$\vec{B}$

GALAXY CLUSTER

B ~ 1 μG
L~ 10 kpc

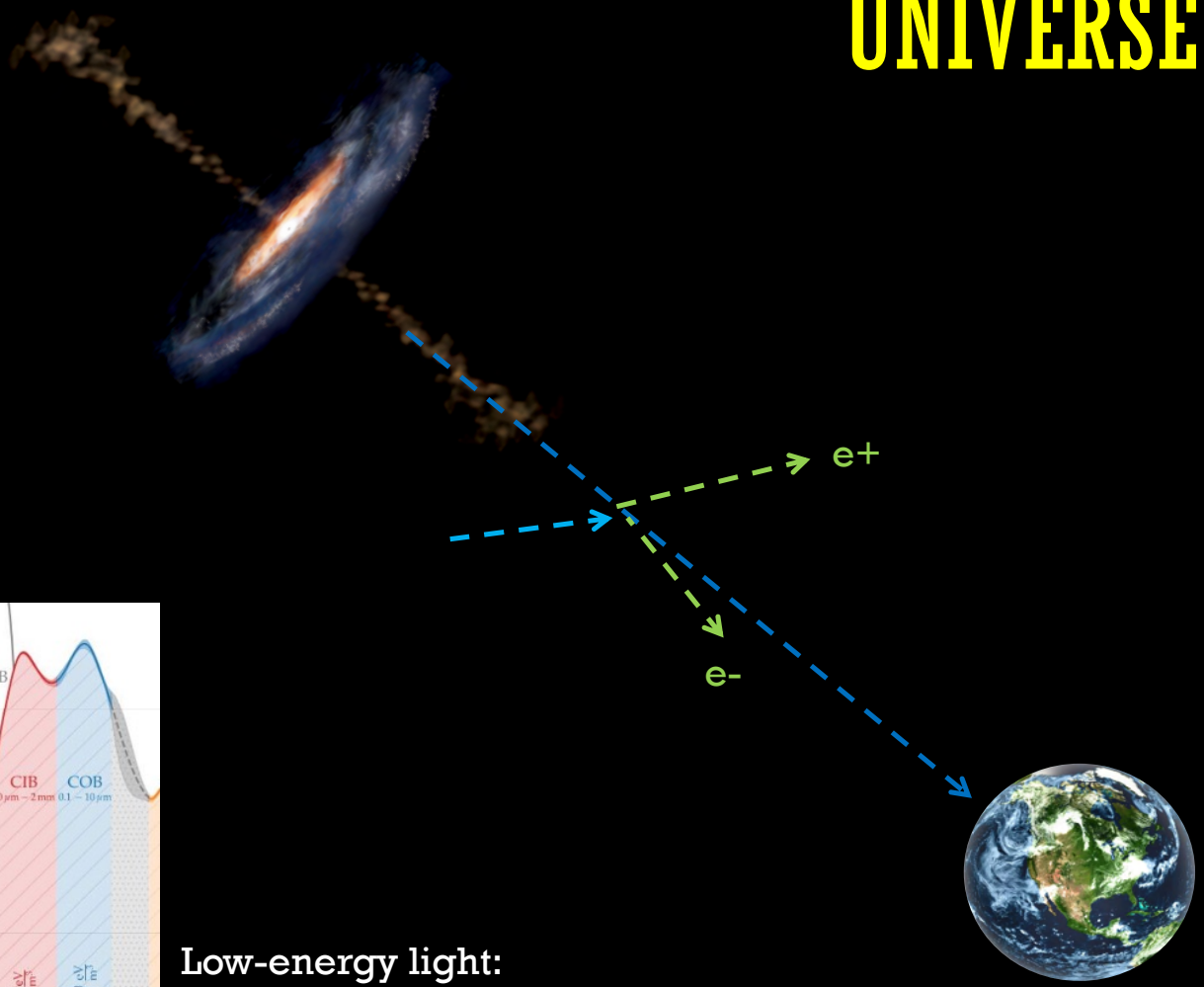
$\vec{B}$

MILKY WAY

B ~ 1 μG
L~ 1 kpc

Credit: Ivana Batkovic

UNIVERSE TOO TRASPARENT

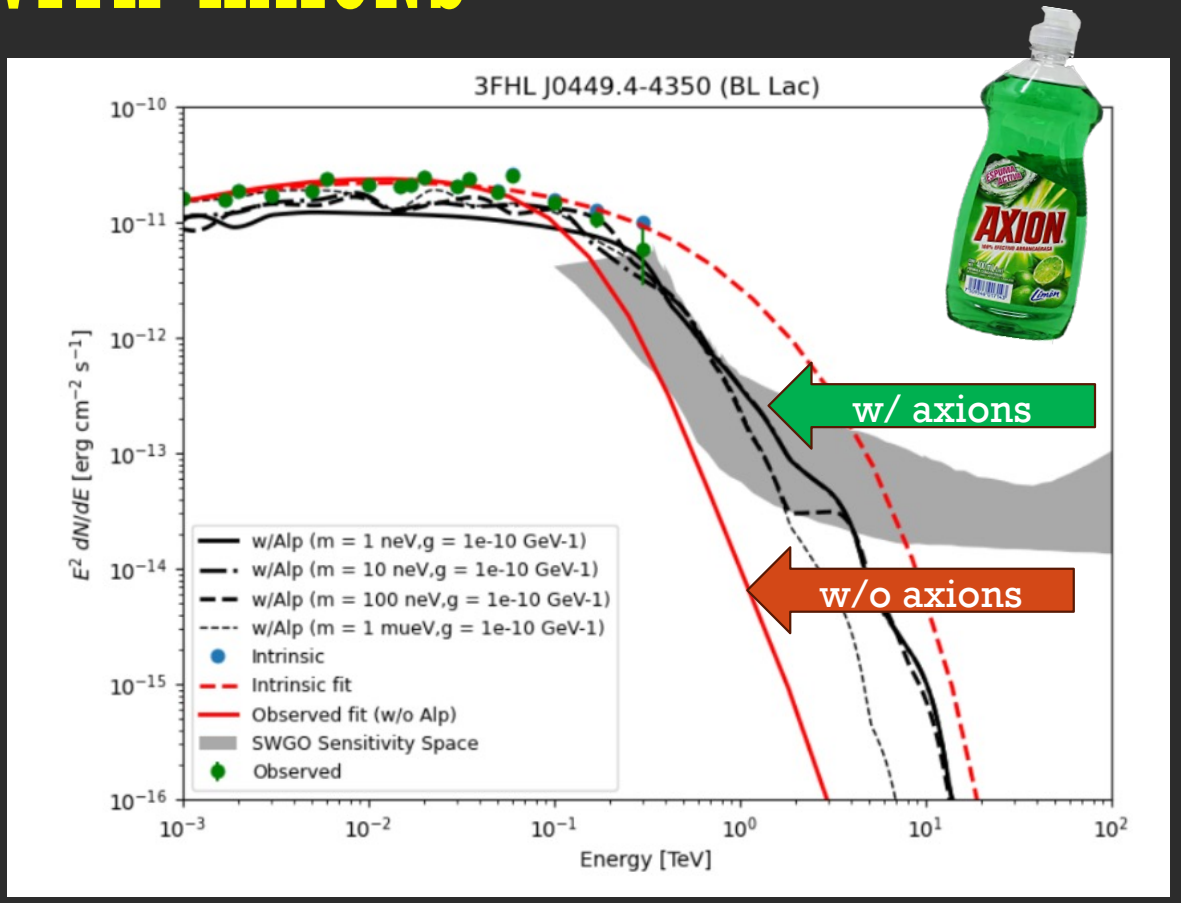


Low-energy light:
Extragalactic background

- TeV light is absorbed in space from far-away sources
- Pair-production of electron and positrons
- Since 2005 we started to see too far-away sources:universe is too trasparent!

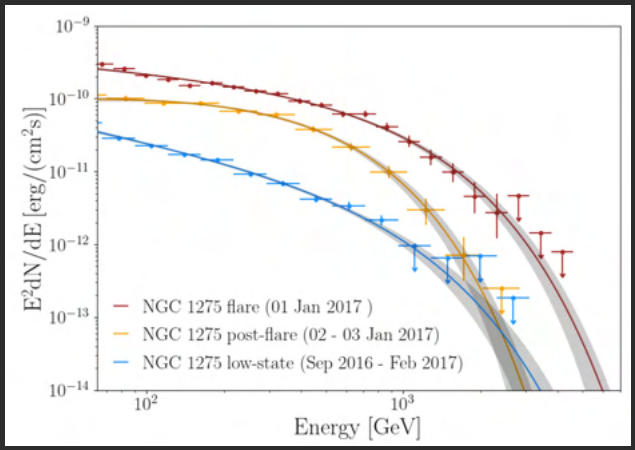
A STAIN TO CLEAN WITH AXIONS

- Axion-like particles reduce the universe trasnparency!



w/ Muneen Shoaib – MSc thesis

STATISTICS AT WORK



Likelihood

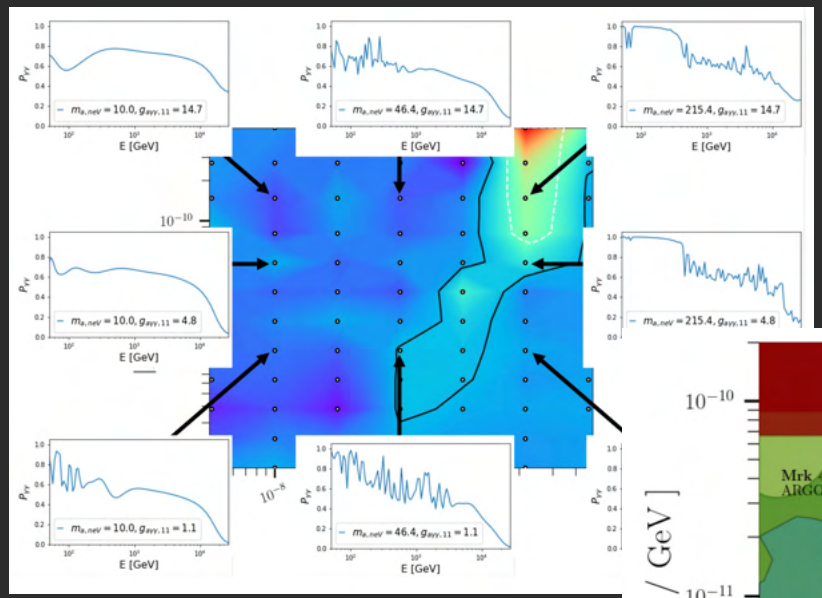
$$\mathcal{L}(g_{a\gamma}, m_a, \boldsymbol{\mu}, \boldsymbol{b}, B|\boldsymbol{D}) = \prod_{i,k} \mathcal{L}_{i,k}(g_{a\gamma}, m_a, \boldsymbol{\mu_i}, b_{i,k}, B|\boldsymbol{D}_{i,k}),$$

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

Lkl-ratio test statistics

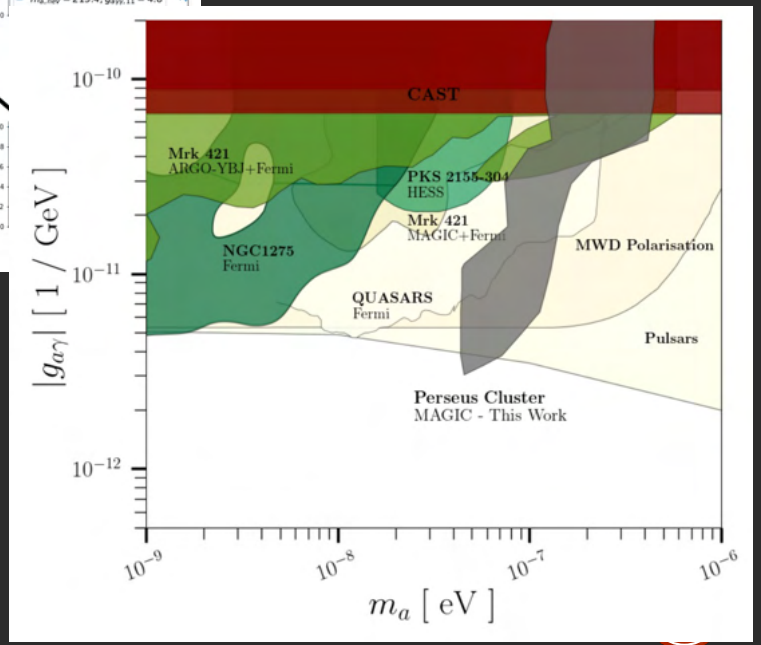
$$\mathcal{TS}(g_{a\gamma}, m_a) = -2\Delta \ln \mathcal{L}$$
$$= -2 \ln \frac{\mathcal{L}(g_{a\gamma}, m_a, \hat{\boldsymbol{\mu}}, \hat{\boldsymbol{b}}, \hat{B}|\boldsymbol{D})}{\hat{\mathcal{L}}},$$

Level of confidence for exclusion of null hypothesis



← Explore the parameter space

Phys.Dark Univ. 44 (2024) 101425



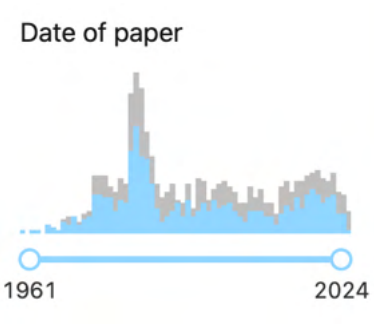
→ Exclude models ☺

STILL HUNGRY?

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

MAGNETIC MONOPOLES

Sweet!



	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!

$$\nabla \cdot \mathbf{E} = \frac{\rho}{\varepsilon_0}$$
$$\nabla \cdot \mathbf{B} = 0$$

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

THE COOKS

- Natural explanation for the quantization of the electric charge
- Magnetic charge:

$$g = 2\pi n/e = ng_{\mathrm{D}}$$

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

1974 'T Hooft and Poliakov

Monopoles are inevitable predictions of Grand Unified Theories:

SU(5) → SU(3) × SU(2) × U(1) → SU(3) × U(1)

GUT AND INTERMEDIATE MM

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

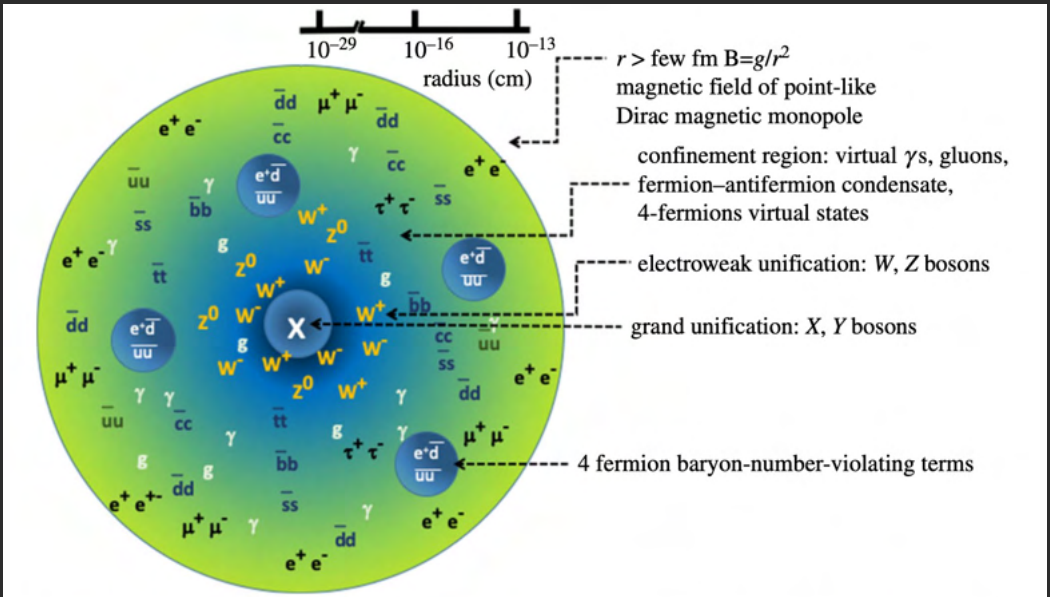
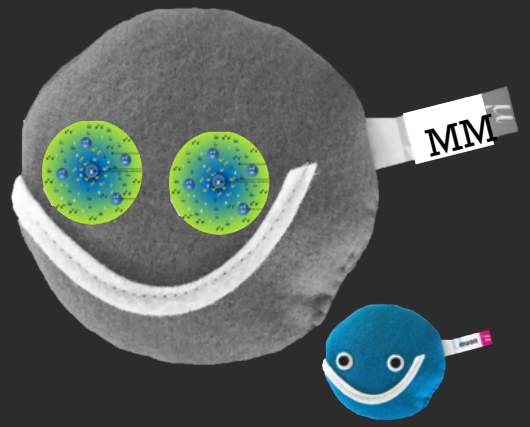


Figure 1. Qualitative picture of the internal structure of a GUT magnetic monopole (modified figure from [11]). The different regions are described in the text.

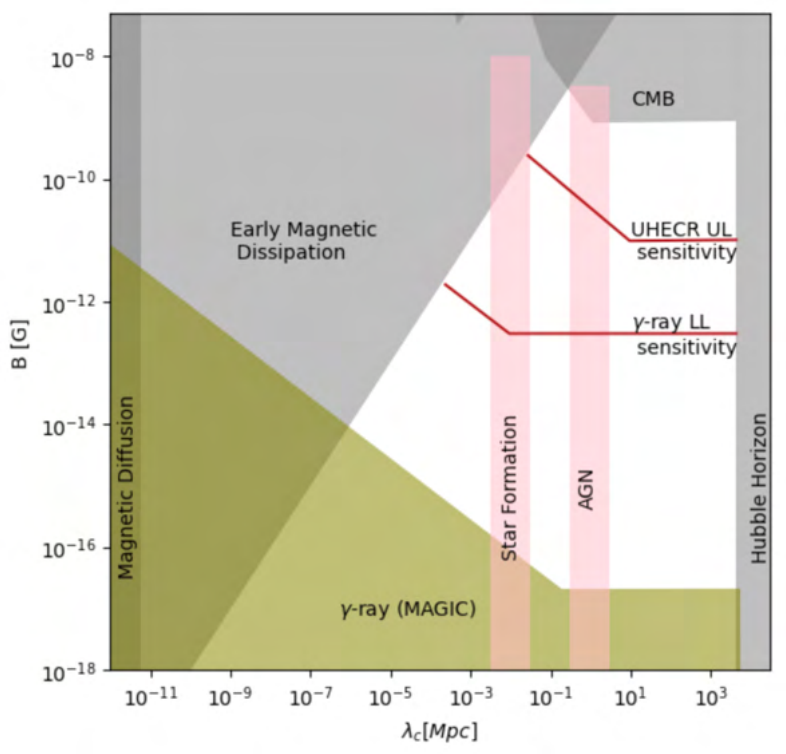
Inside the core, all the states of the GUT are excited.

- 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 $g\beta$.



HERE COMES ASTROPH: NEW DATA ON IGMF!

Perri, MD, Kobayashi, in prep.

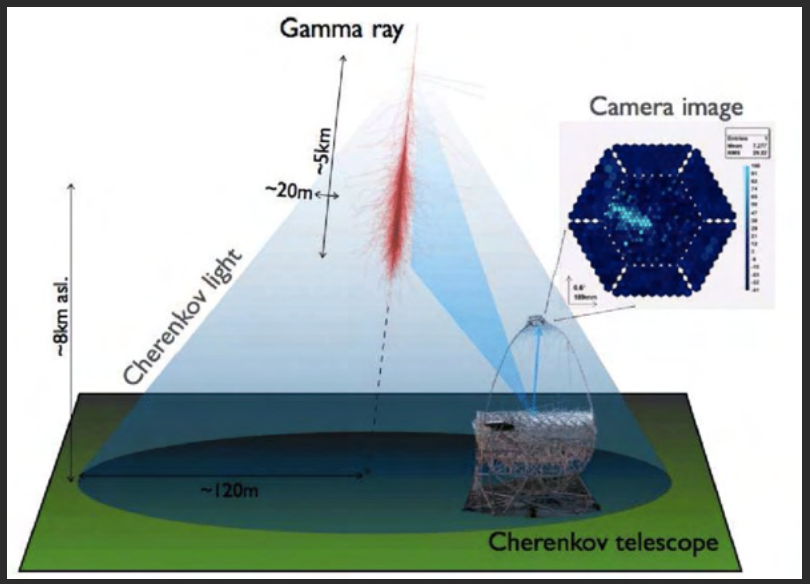


MMs are accelerated by MFs through the magnetic force as in the equation of motion

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

- Acceleration on intergalactic magnetic fields
- Acceleration in galactic magnetic fields…

IACTS



- Very peculiar signature from MM in IACTs:
  - Super-bright events
  - Double signals (from different zone of the atmosphere)
  - No confusion wrt gamma-rays

- Only preliminary studies from MSc thesis of Gerrit Spengler

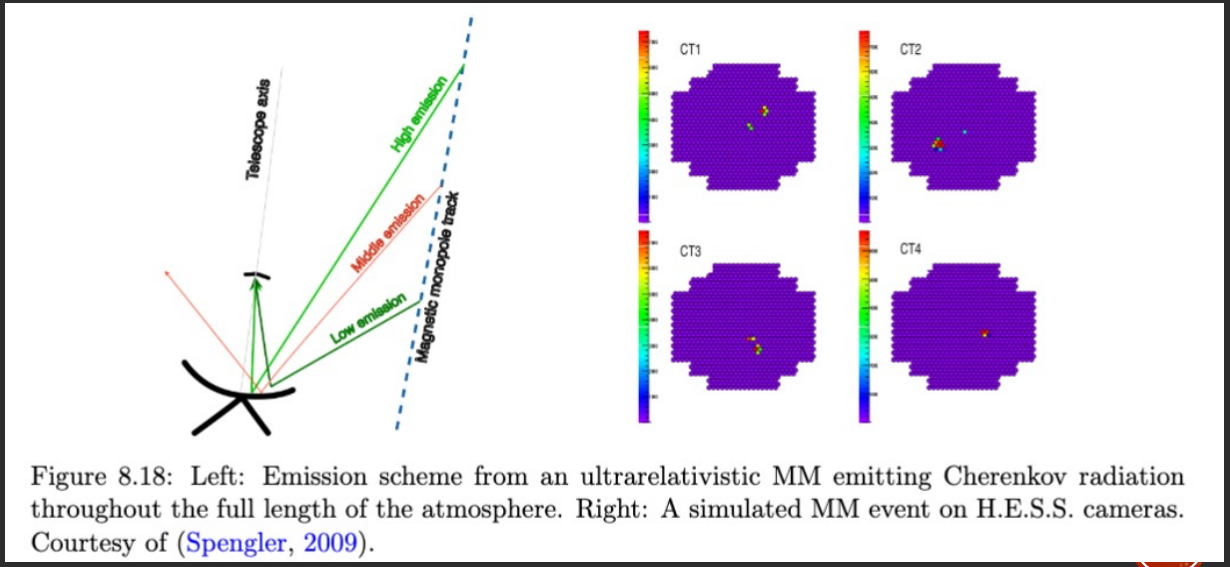
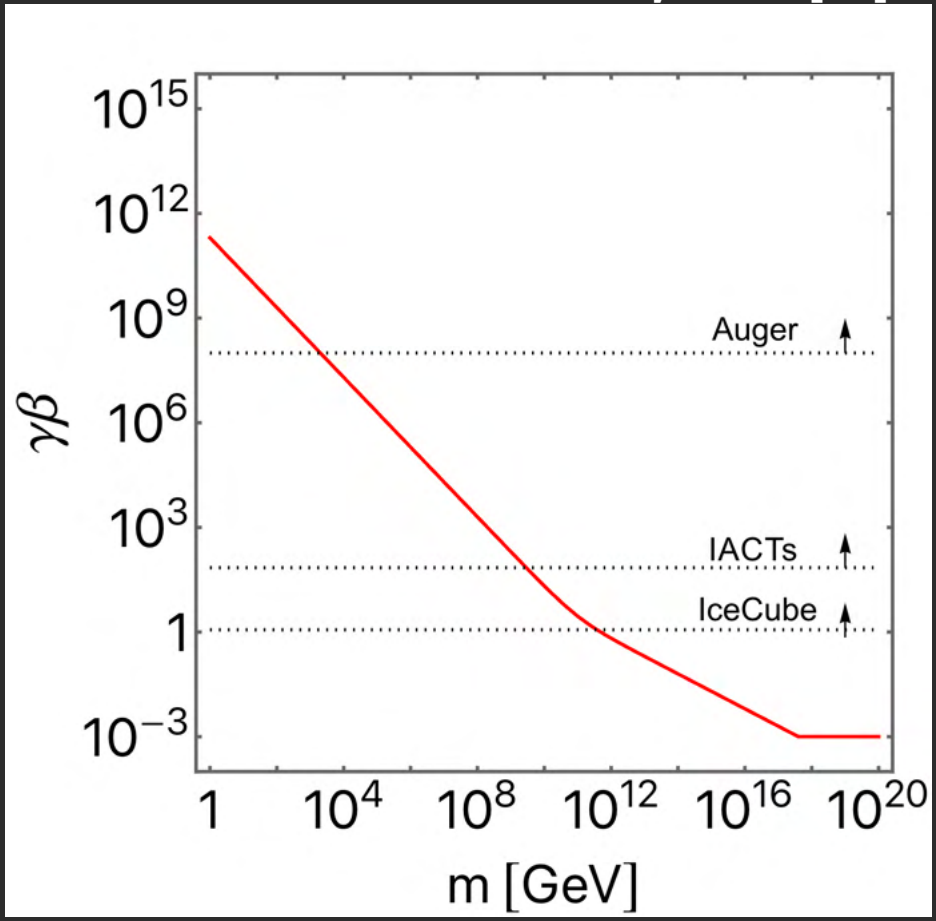


Figure 8.18: Left: Emission scheme from an ultrarelativistic MM emitting Cherenkov radiation throughout the full length of the atmosphere. Right: A simulated MM event on H.E.S.S. cameras. Courtesy of (Spengler, 2009).

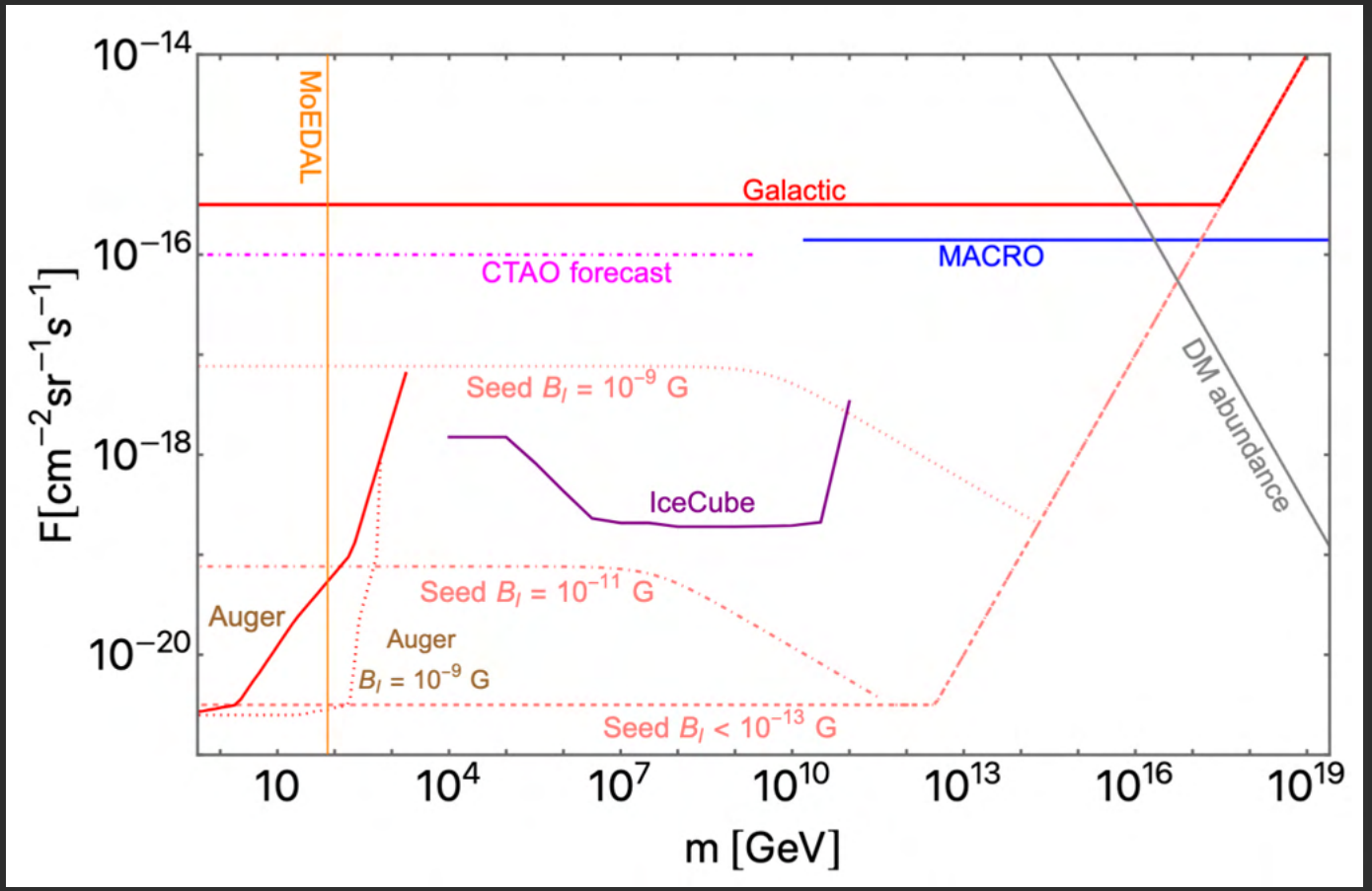
ALL CONSIDERERED

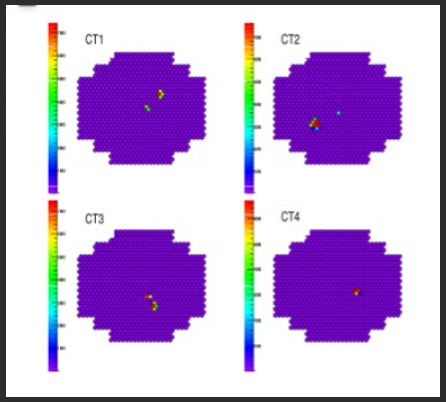
Perri, MD, Kobayashi, in prep.



- $\gamma\beta \sim v$ relativistic velocity
- If I know the acceleration I can have the connection between velocity now and mass

MM FLUX VS MASS LIMITS





Look for strange events in our data

Even if none found → valid limits

Perri, MD, Kobayashi, in prep.

Another complex recipe

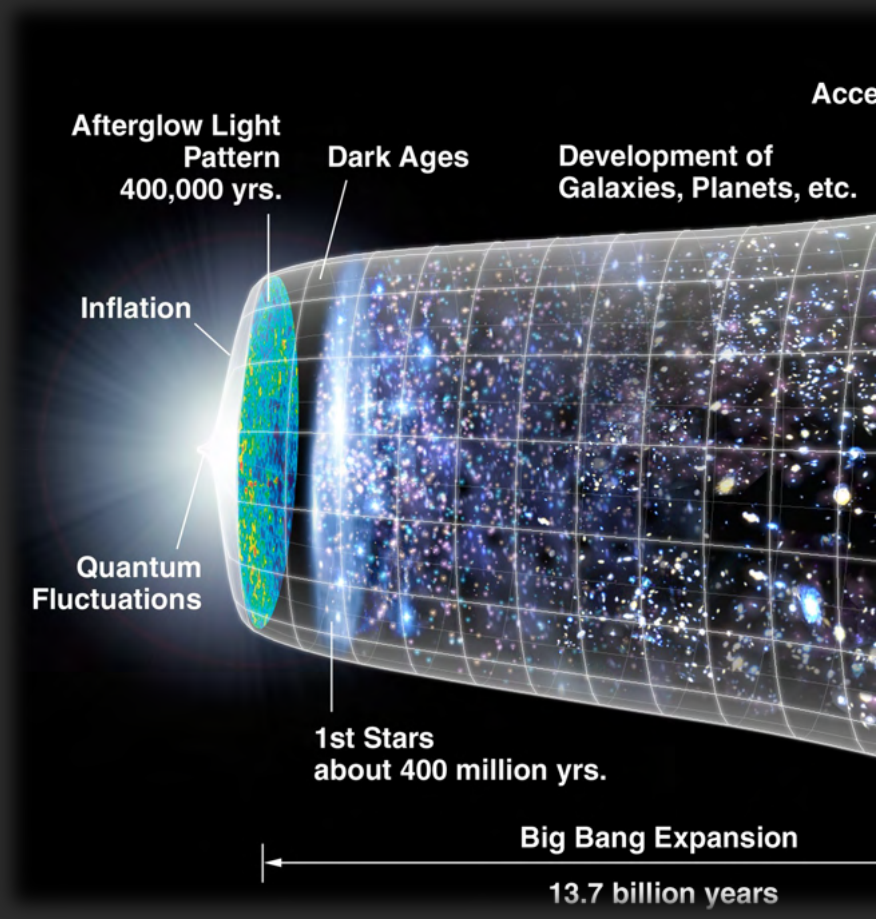
PRIMORDIAL BLACK HOLES

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 Planck Scale to star-scale
- They evolve!
  - Accretion, merging,
  - Evaporation (Hawking 1974)



PBH EVAPORATION

PBH mass depends on when created

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

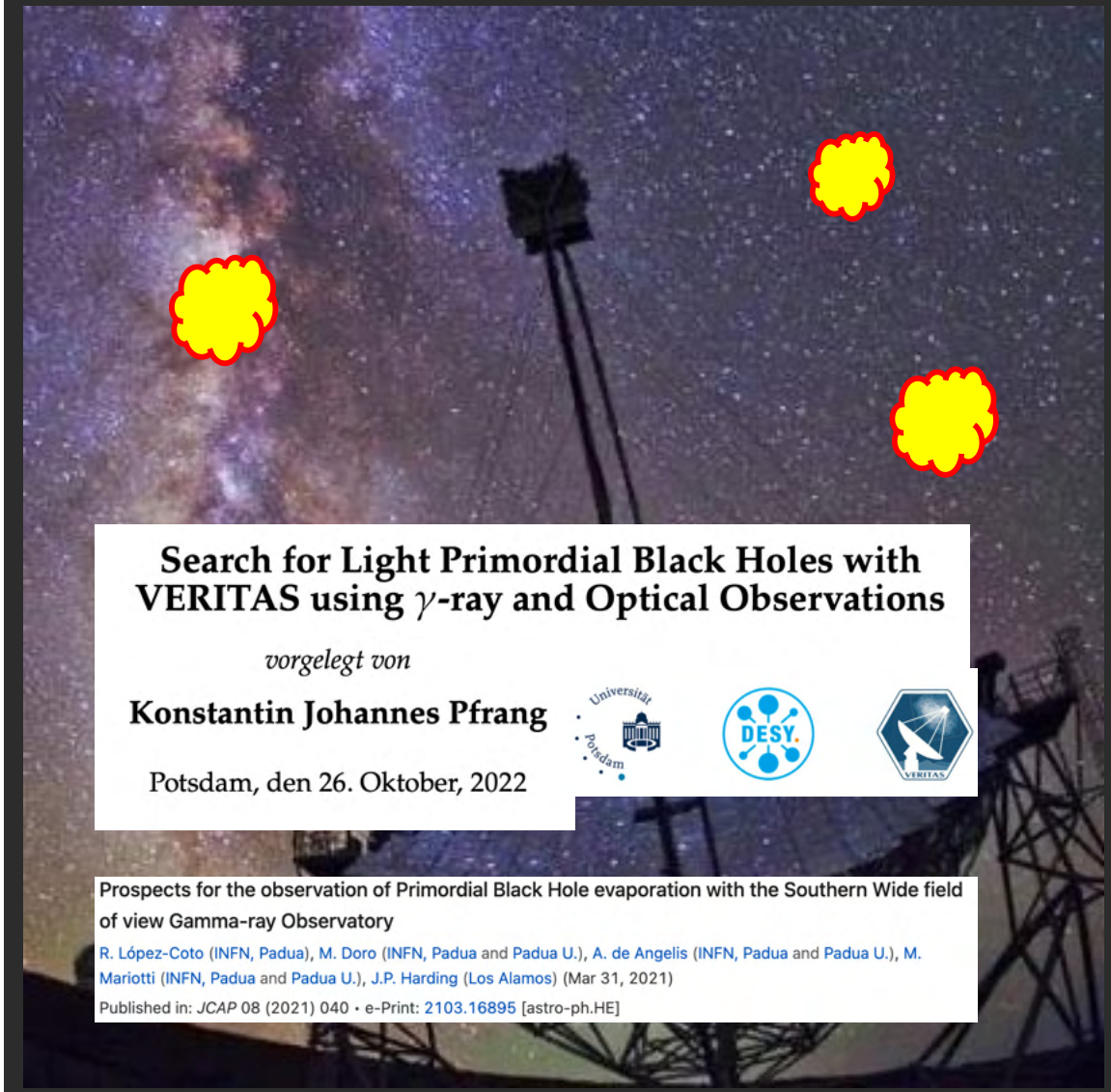
PBH temperature depends on its mass

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

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



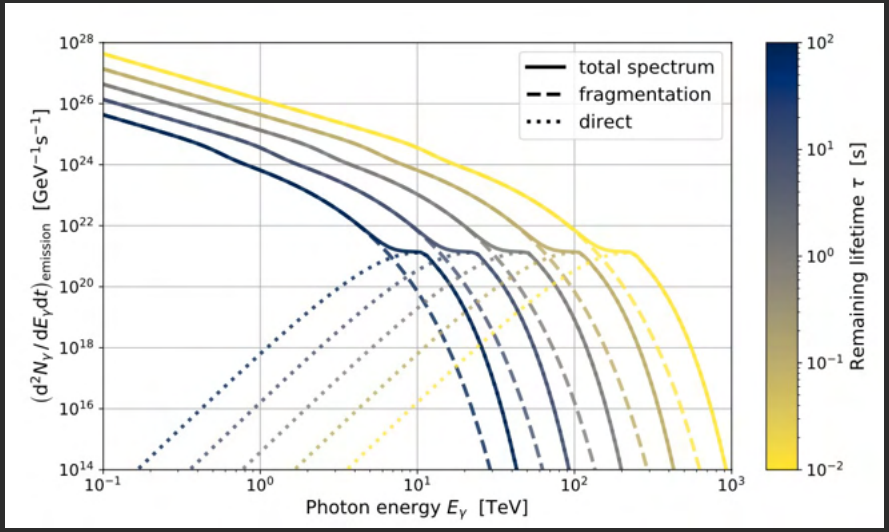
BURSTS!

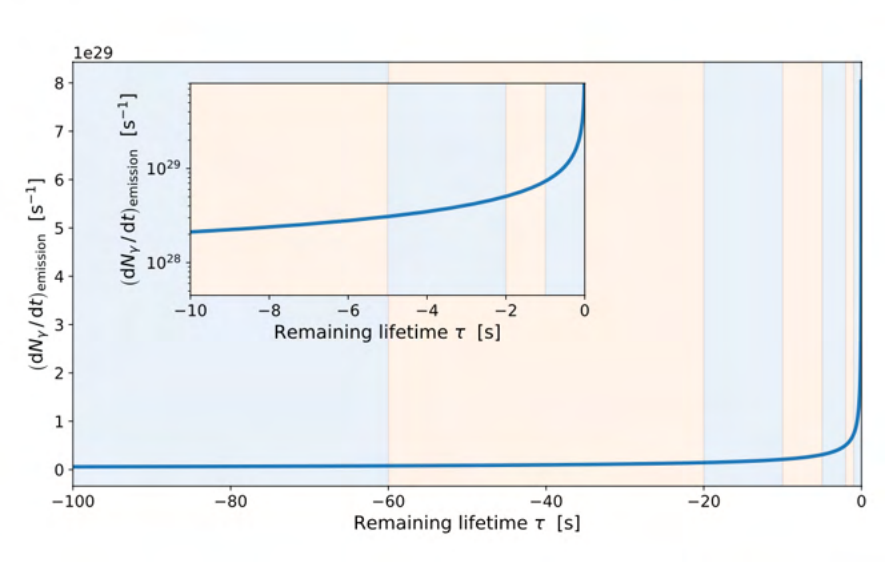
- Evaporating PBHs would appears as short (seconds) bursts somewhere in the sky…
- Serendipity discovery, if you are ready!
- IACTS: Must looks into archive data!
- SFDs: serendipity

MODEL A SED AND LC

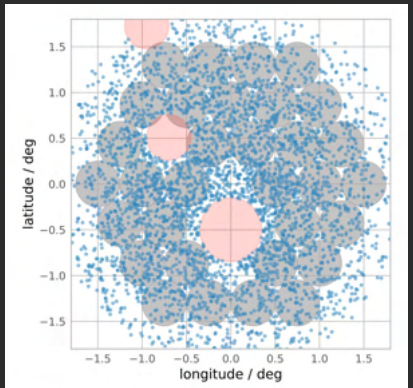
Pfrang 2023 PhD

$$\left(\frac{\mathrm{d}^2N_\gamma}{\mathrm{d}E_\gamma \mathrm{d}t}\right)_{\text{emission}} = \left(\frac{\mathrm{d}^2N_\gamma}{\mathrm{d}E_\gamma \mathrm{d}t}\right)_{\text{frag.}} + \left(\frac{\mathrm{d}^2N_\gamma}{\mathrm{d}E_\gamma \mathrm{d}t}\right)_{\text{direct}}$$



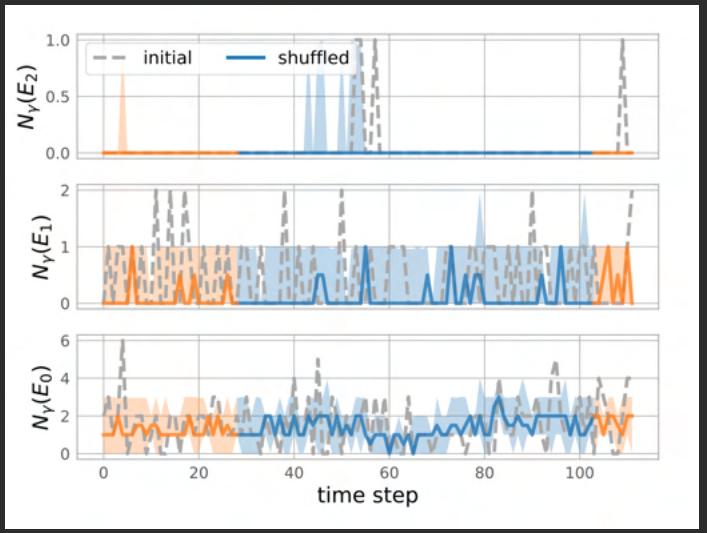


Complex analysis (need a full PhD to do it)



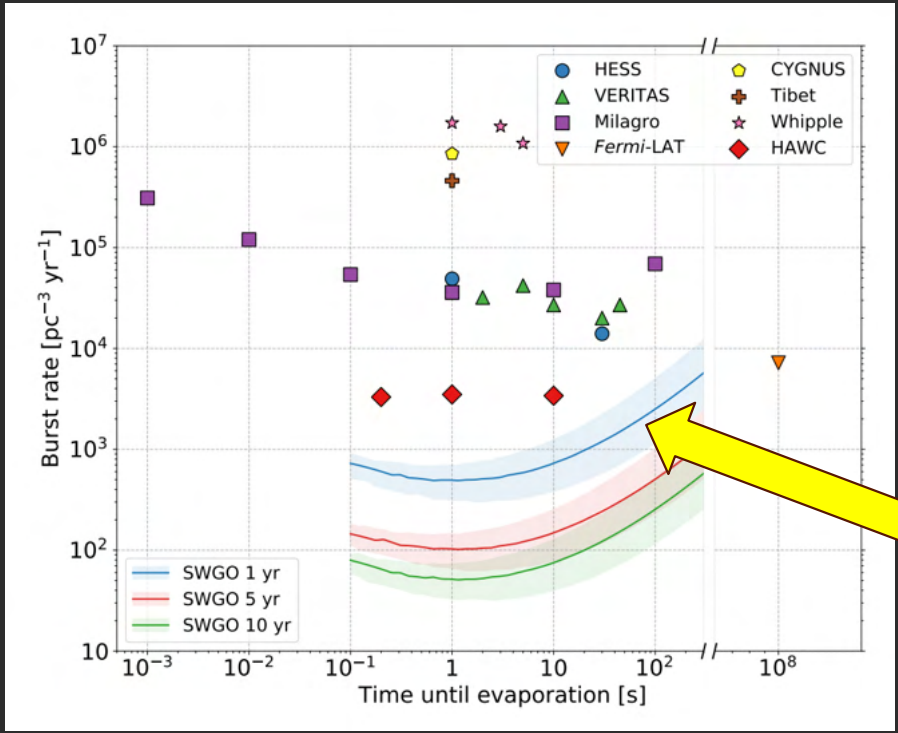
(a) The grey and red circles are the ROIs and exclusion regions respectively. The blue dots illustrate the origin of each γ-like event within this specific observing run.

Search for clustered excess in the camera



Search for clustered excess in time

A MEAGRE LIMITS, BUT STILL.



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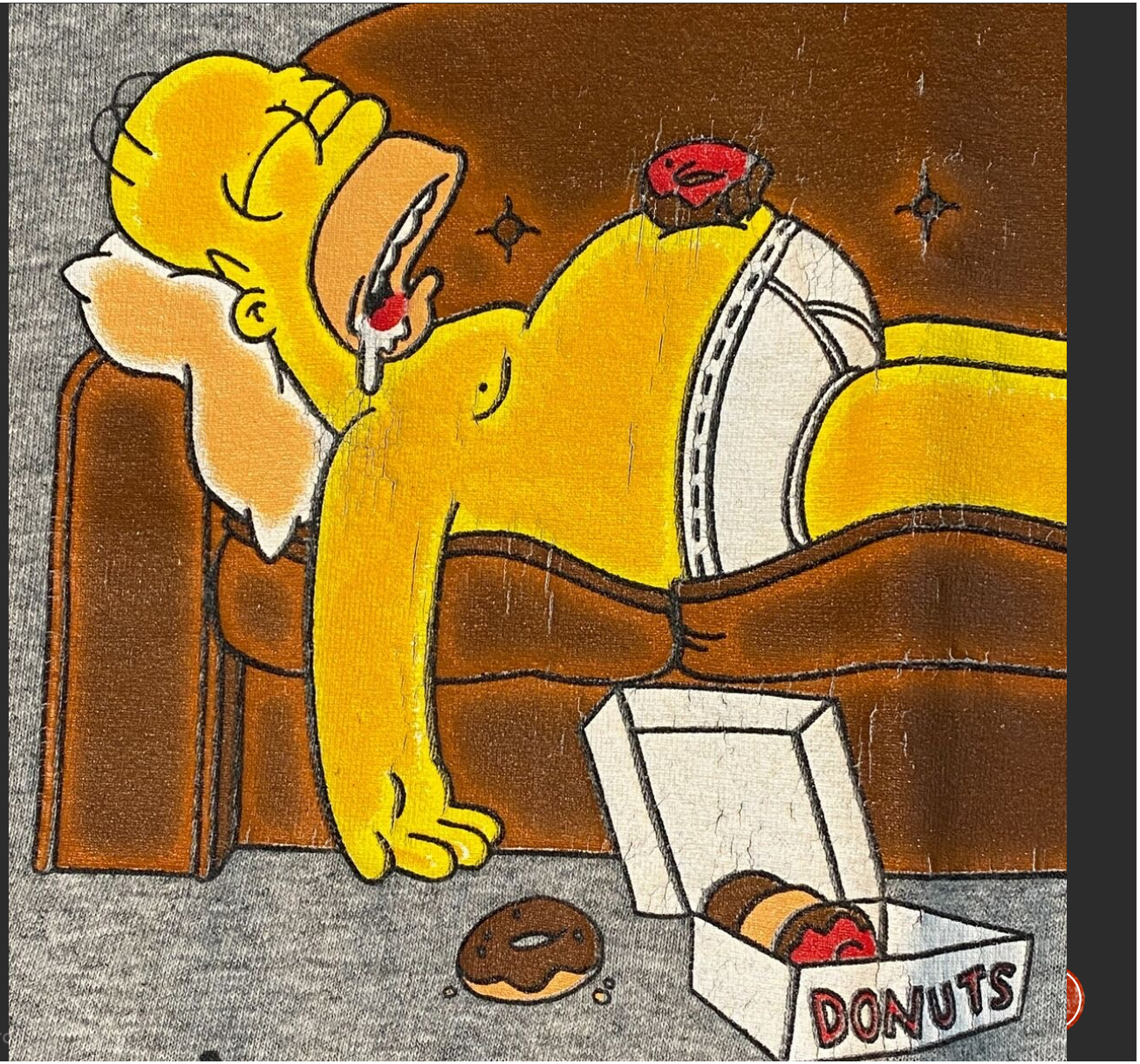
- Again, we looked into the data and found no 'bursts'

w/ postdoc in our group

NO MORE FOOD!



ZWICKY! SPRITZ IS READY!

“Fritz, what do you say?"

DARK MATTER AND NEW PHYSICS IS AMAZING SEARCH

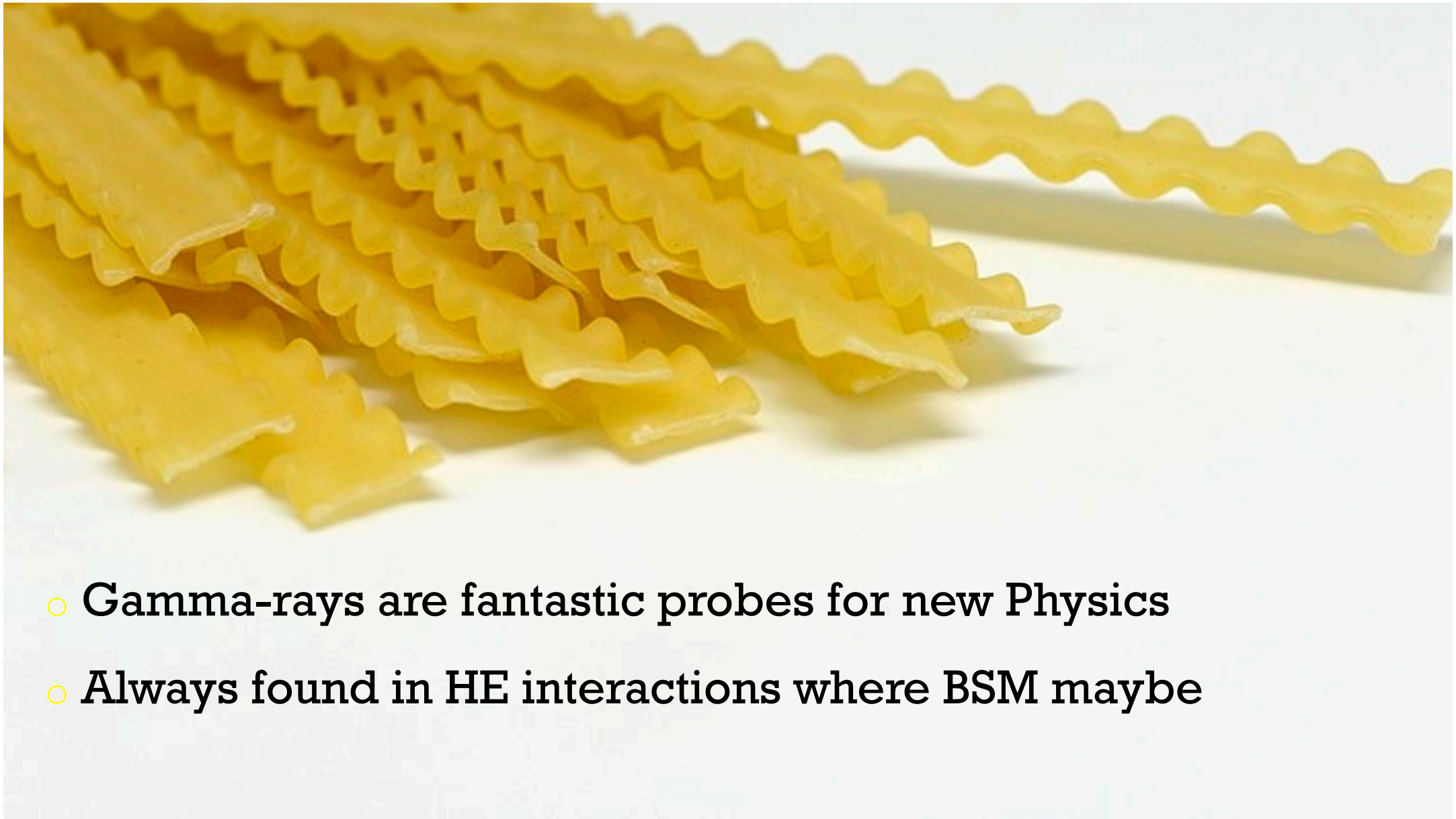
Dark Matter

Song by Pearl Jam

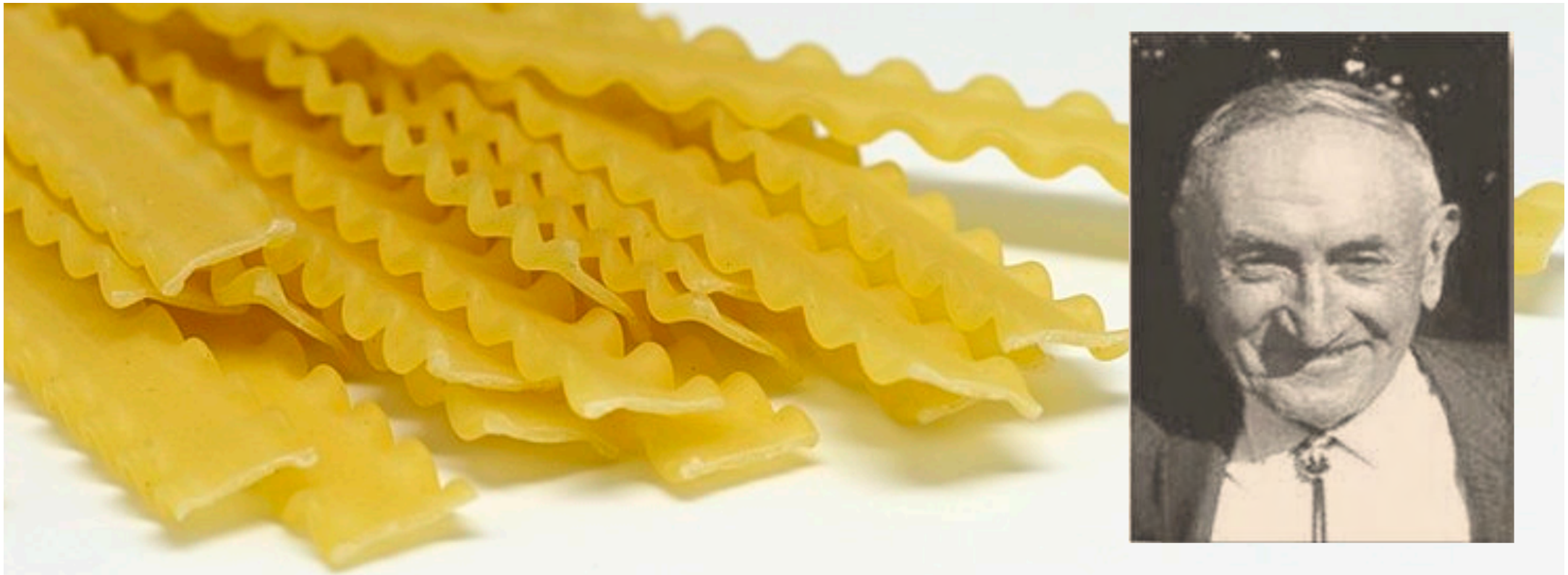
Lyrics

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



- Gamma-rays are fantastic probes for new Physics
- Always found in HE interactions where BSM maybe



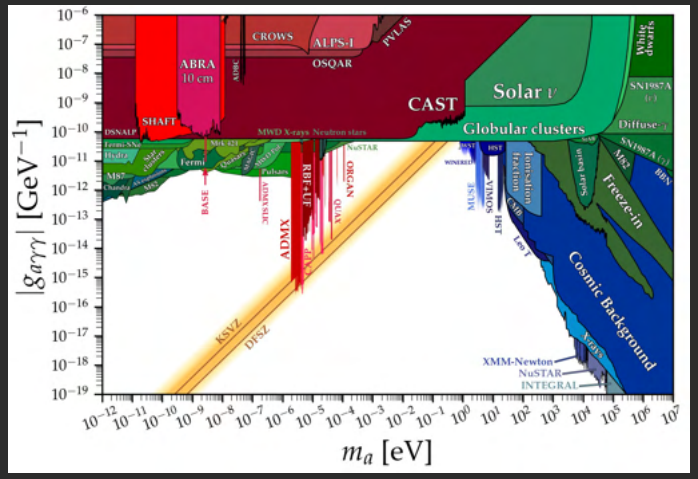
- RECIPES ARE PROMISING
  - Tens of astro-laboratories with varying distance, age, energy, B-field, stability pick your favorite
  - Several theories BSM involving gamma-rays (decay, annihilation, conversion) pick your guy

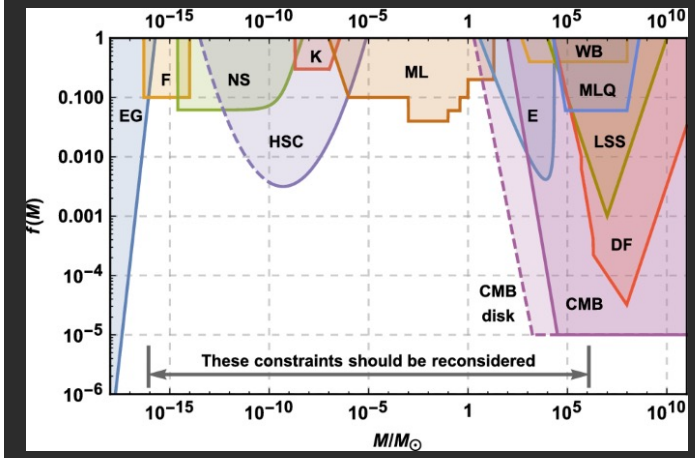
HOWEVER, EMPTY PLATES

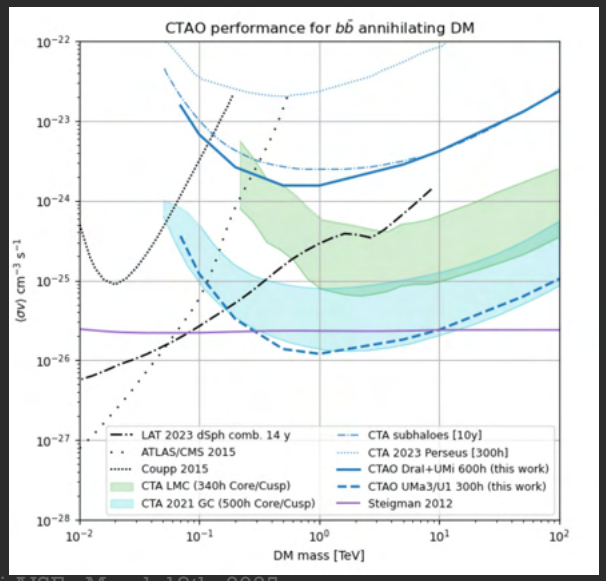
Is that only bad? What do we learn?

LIMITS!

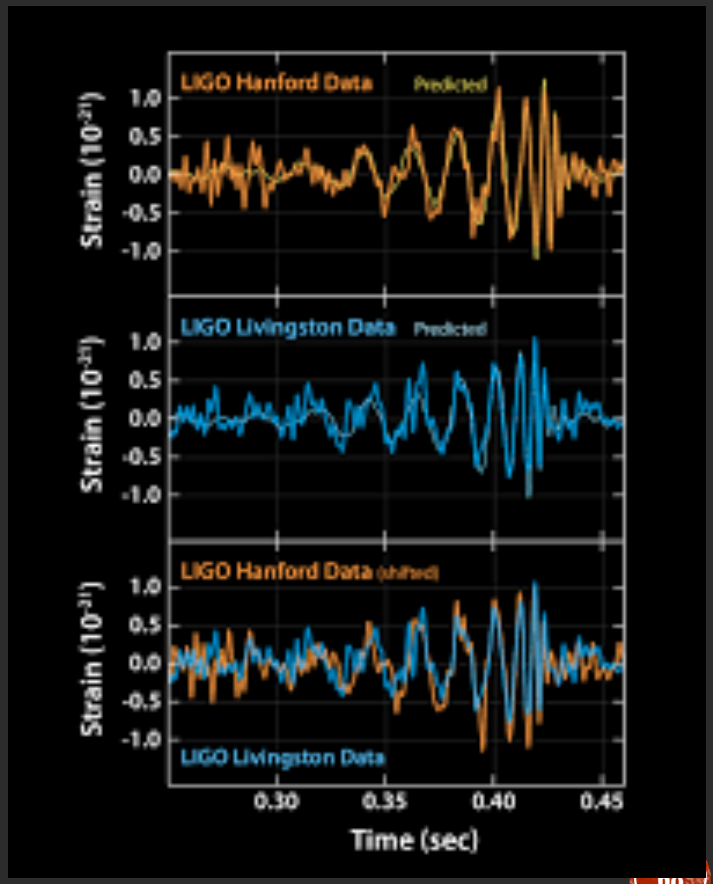
No results is strong results





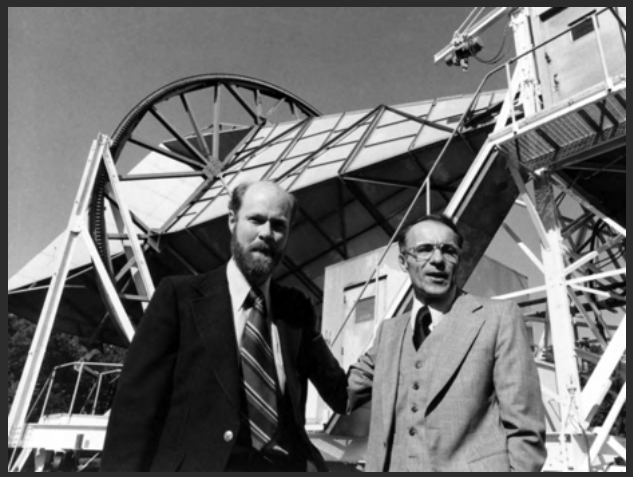


25 years of instrument development to detect the first GW



SERENDIPITY IN LEFT-OVER

- We love data!



Discovery of CMB

Discovery of FRBs

- Maybe for you to find

SPRITZ TIME NOW

THANKS!