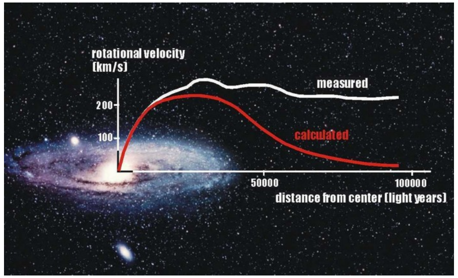
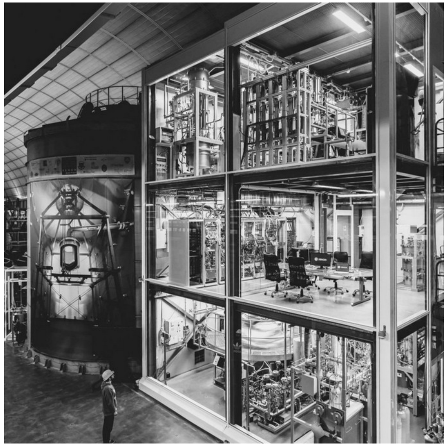
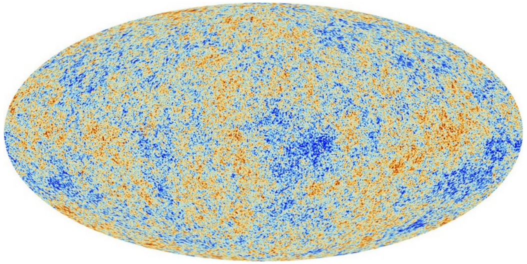
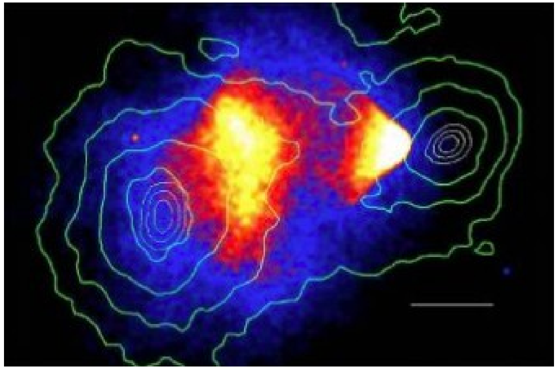
Esperimenti di fisica fondamentale



Dark Matter



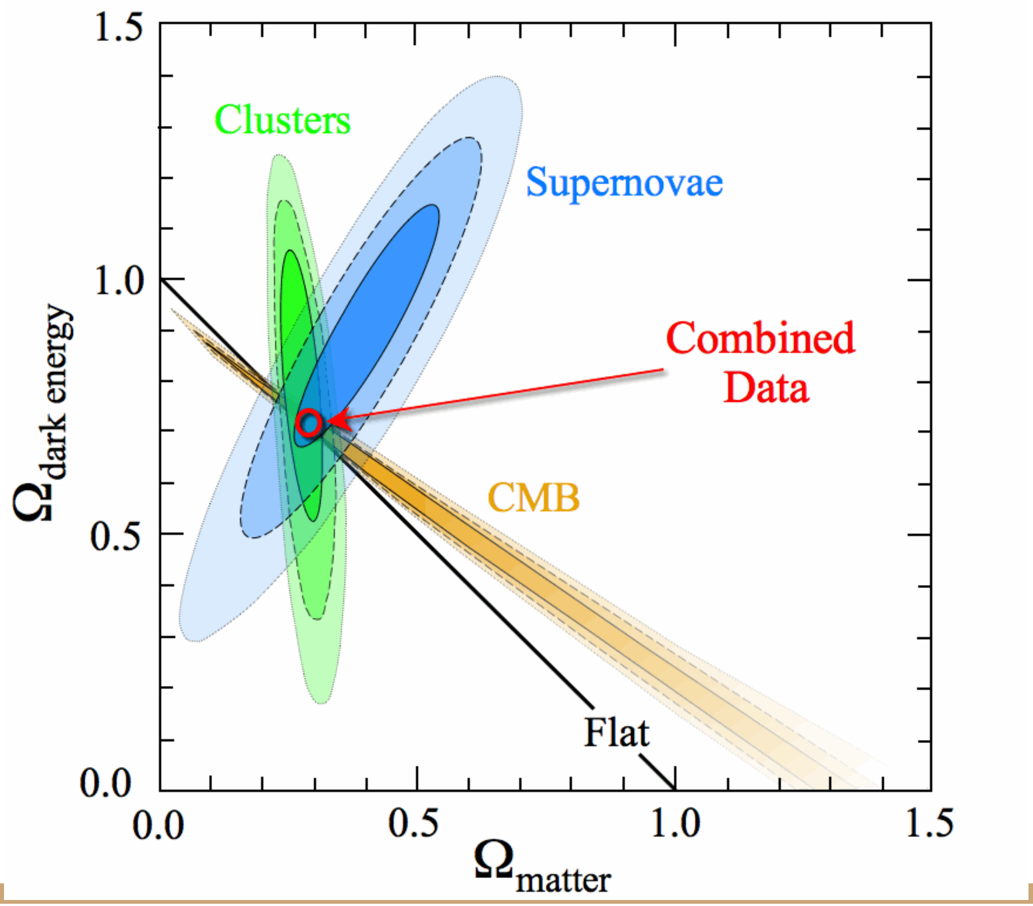


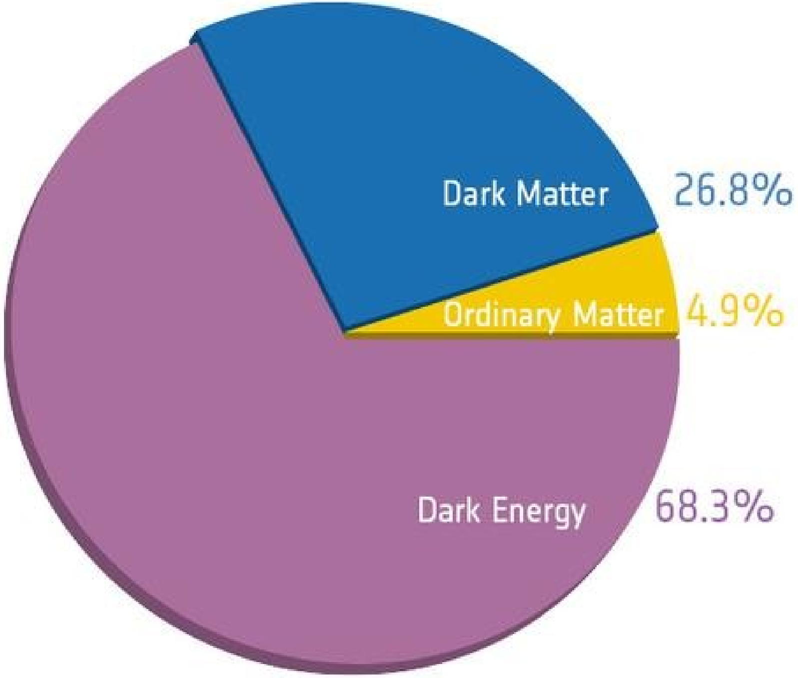


Andrea Molinario

Giornate INAF RSN4

Dark Matter


1.5
1.0
0.5
0.0
0.0
0.5
1.0
1.5
$\Omega_{dark\ energy}$
Ω_{matter}
Clusters
Supernovae
Combined
Data
CMB
Flat


Dark Matter
26.8%
Ordinary Matter
4.9%
Dark Energy
68.3%

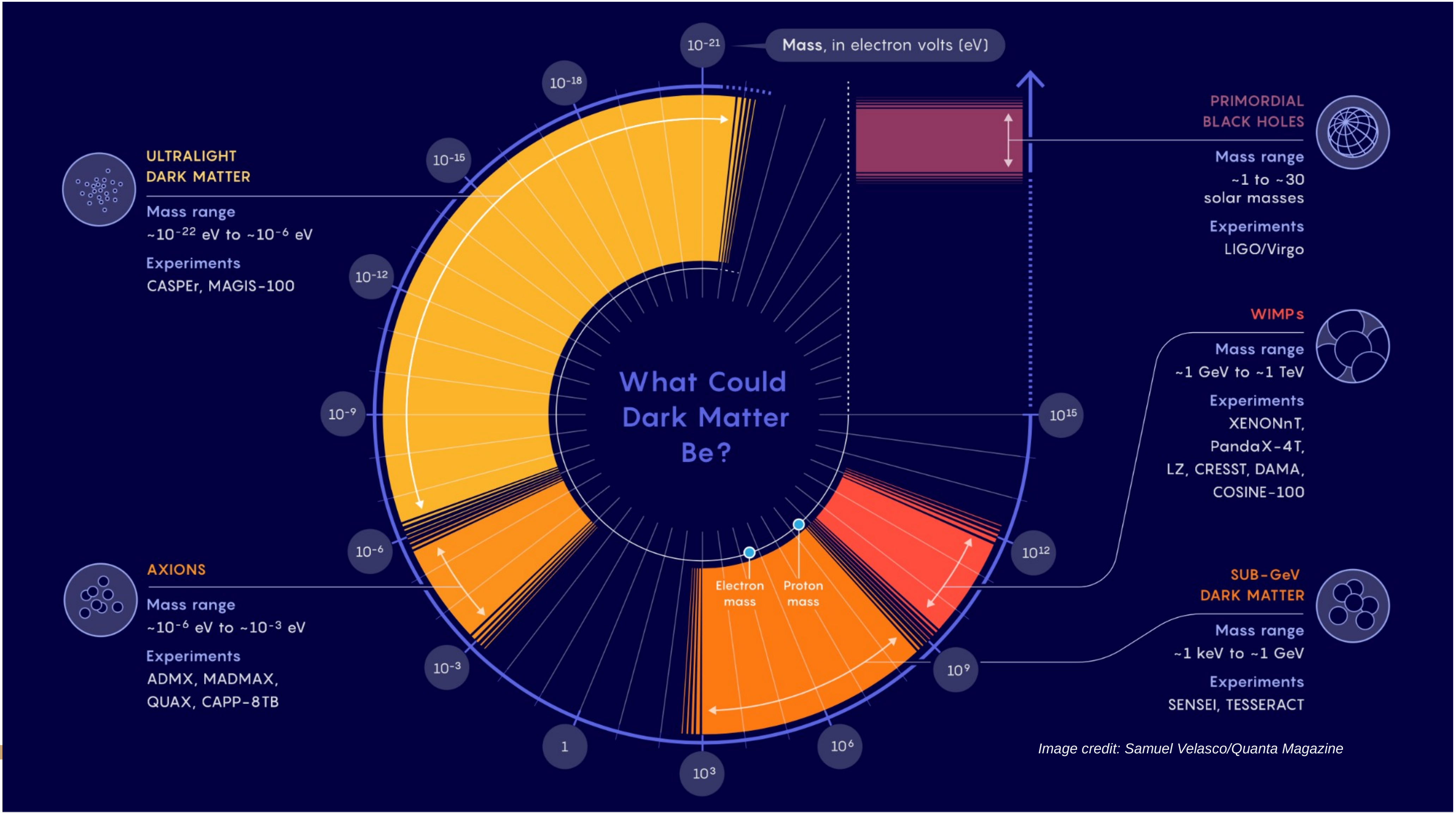
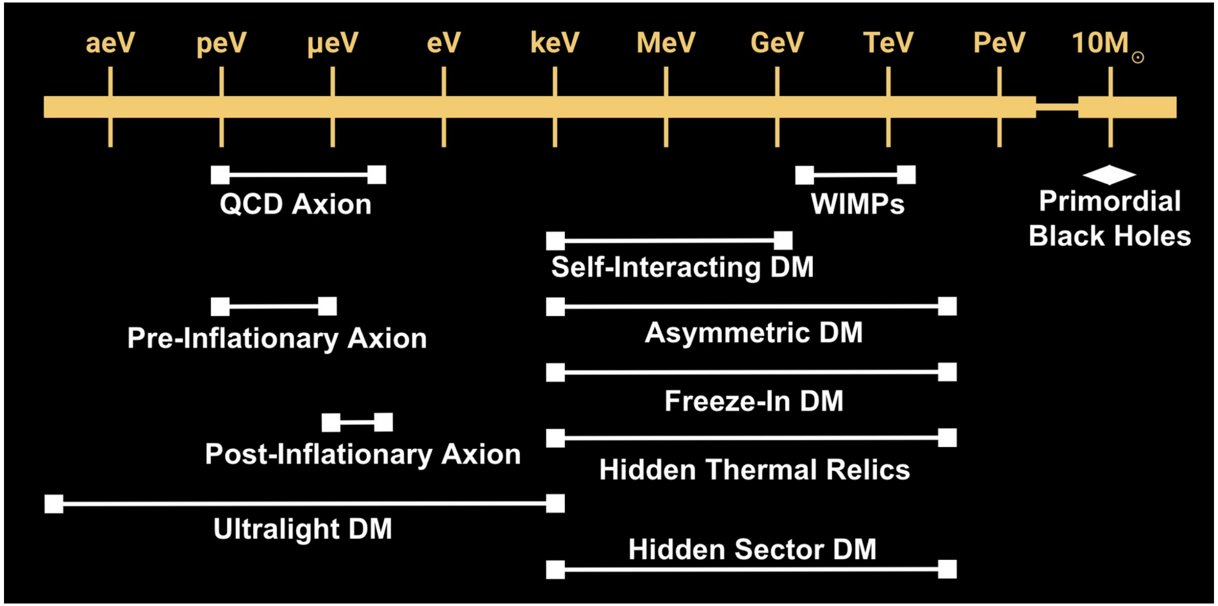
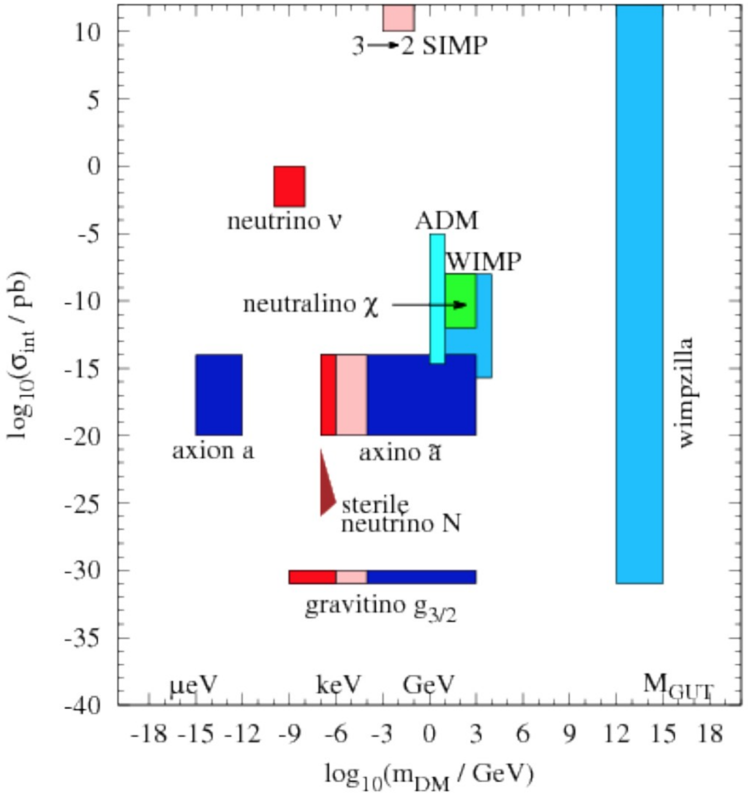


Image credit: Samuel Velasco/Quanta Magazine

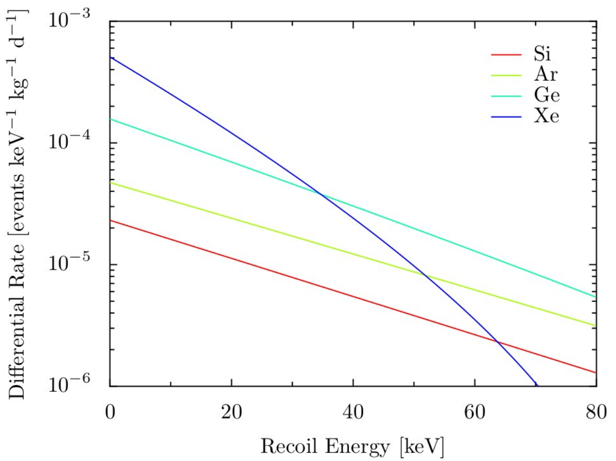

aeV
peV
μeV
eV
keV
MeV
GeV
TeV
PeV
10M☉
QCD Axion
WIMPs
Primordial Black Holes
Self-Interacting DM
Pre-Inflationary Axion
Asymmetric DM
Freeze-In DM
Post-Inflationary Axion
Hidden Thermal Relics
Ultralight DM
Hidden Sector DM

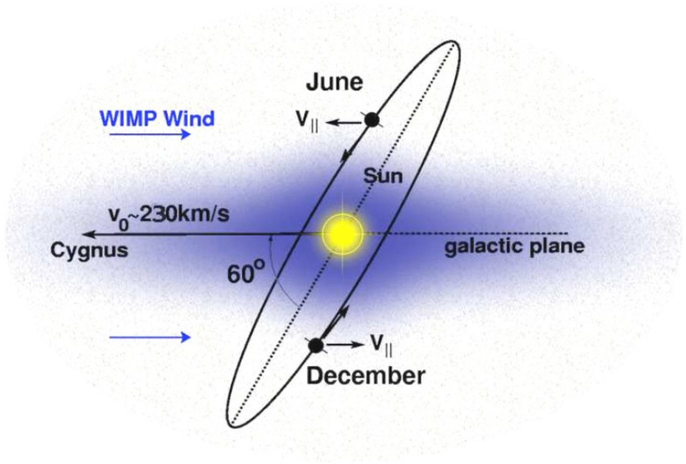

3→2 SIMP
neutrino ν
ADM
WIMP
neutralino χ
axion a
axino ã
sterile neutrino N
gravitino $g_{3/2}$
wimpzilla
μeV
keV
GeV
M_{GUT}
$\log_{10}(\sigma_{int} / pb)$
$\log_{10}(m_{DM} / GeV)$
10
5
0
-5
-10
-15
-20
-25
-30
-35
-40
-18
-15
-12
-9
-6
-3
0
3
6
9
12
15
18

WIMPs

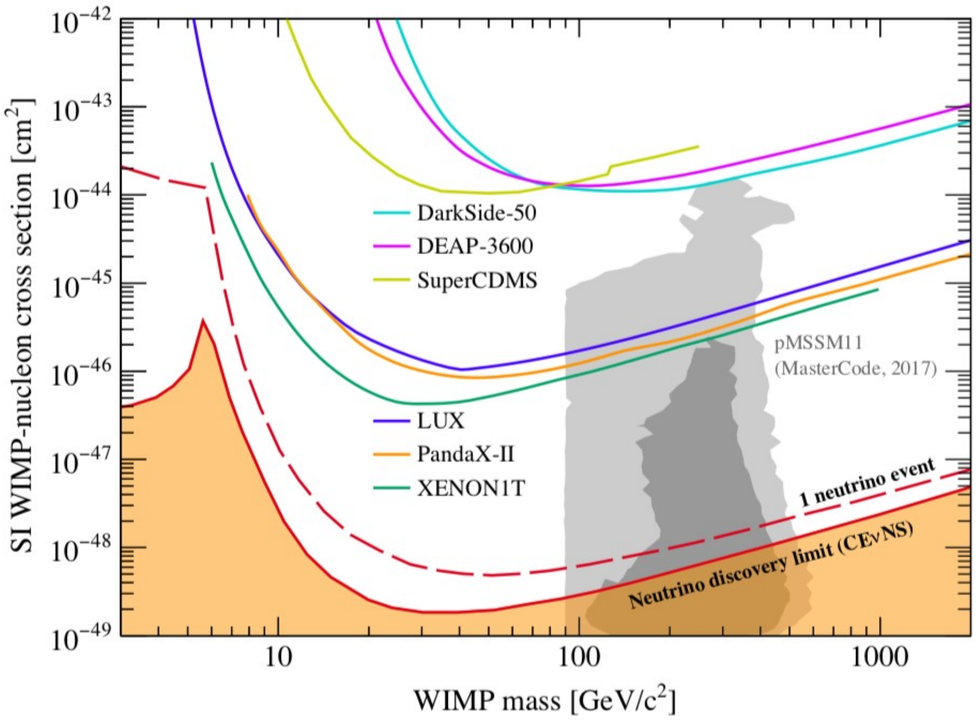
Weakly **I**nteracting **M**assive **P**articles

- Masses in the range few GeV - TeV
- Interaction cross section with ordinary matter at the electroweak scale
- Expected to induce nuclear recoils of few keV
- Seasonal modulation of the detection rate





Direct Searches



- **Rare** (<0.0001 /kg/day), **low-energy** (~keV) scattering of **thermal relics** (e.g. galactic WIMPs)
  - *Very sensitive detectors operating underground*
  - ***Elastic scattering off nuclei**, spin-independent, spin-dependent, EFT operators, inelastic scattering, electron scattering, annual modulation, signal directionality, …*

Slide di C. Ghag, IPA2022

Axions and axion-like particles

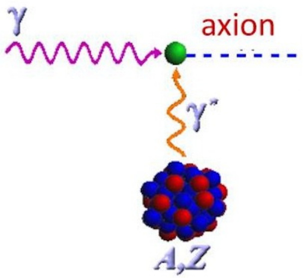
Required by the Peccei & Quinn solution of the “strong CP problem”

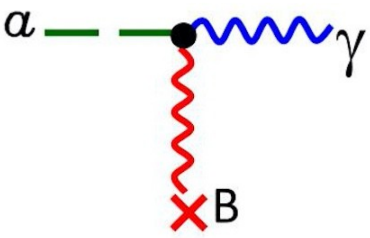
Predicted by several extensions of the standard model (e.g. string theory)

- neutral, spin 0
- weakly interacting
- mass proportional to coupling

- neutral, spin 0
- weakly interacting
- small mass (not related to coupling)

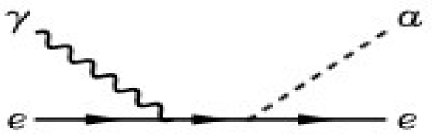
Coupling $\mathbf{g}_{a\gamma}$ with e.m. fields → “Primakov effect”



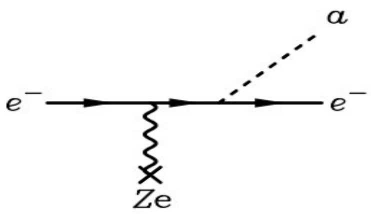


Coupling $\mathbf{g}_{ae}$ with electrons

Compton

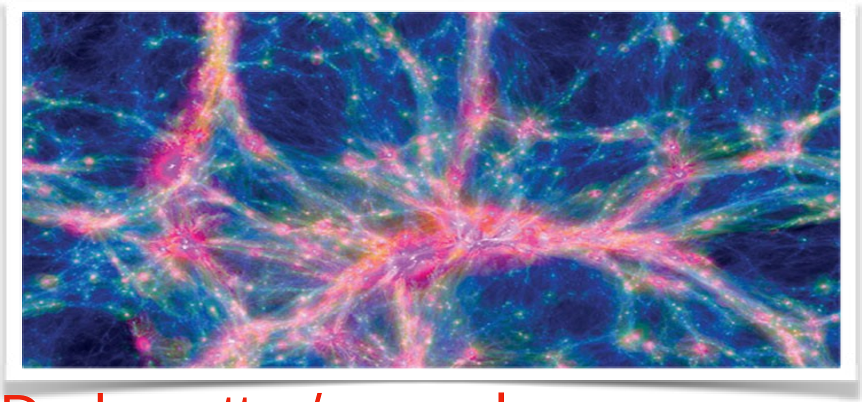


Bremsstrahlung

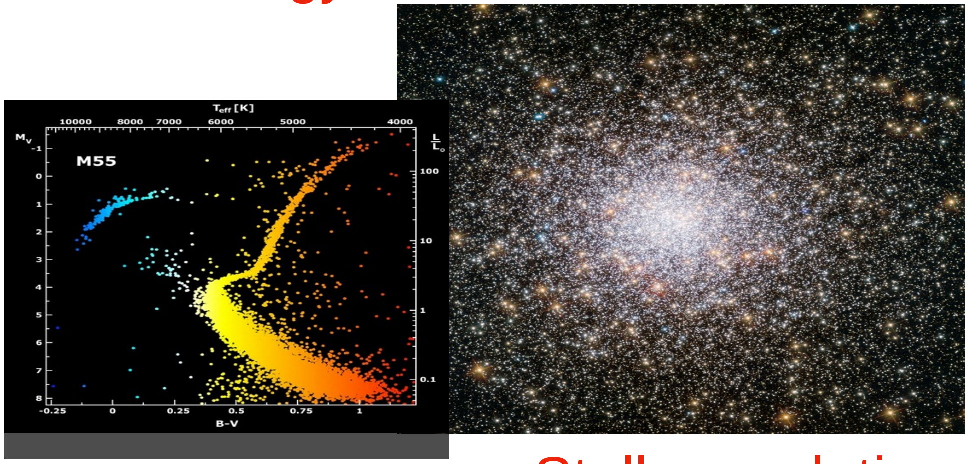


Slide di F. Tavecchio, M. Civitani, O. Straniero, F. Finelli

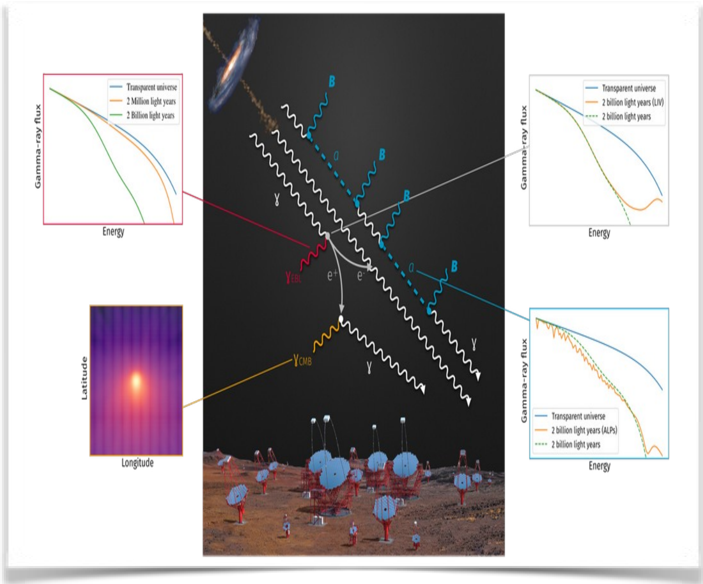
Axions: astrophysics and cosmology



Dark matter/cosmology



Stellar evolution

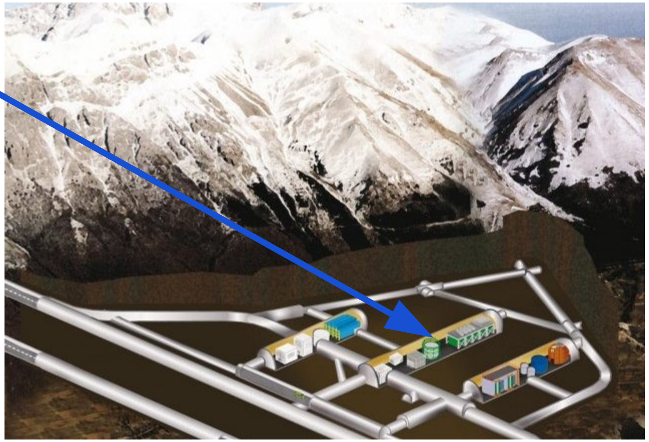


Photon propagation

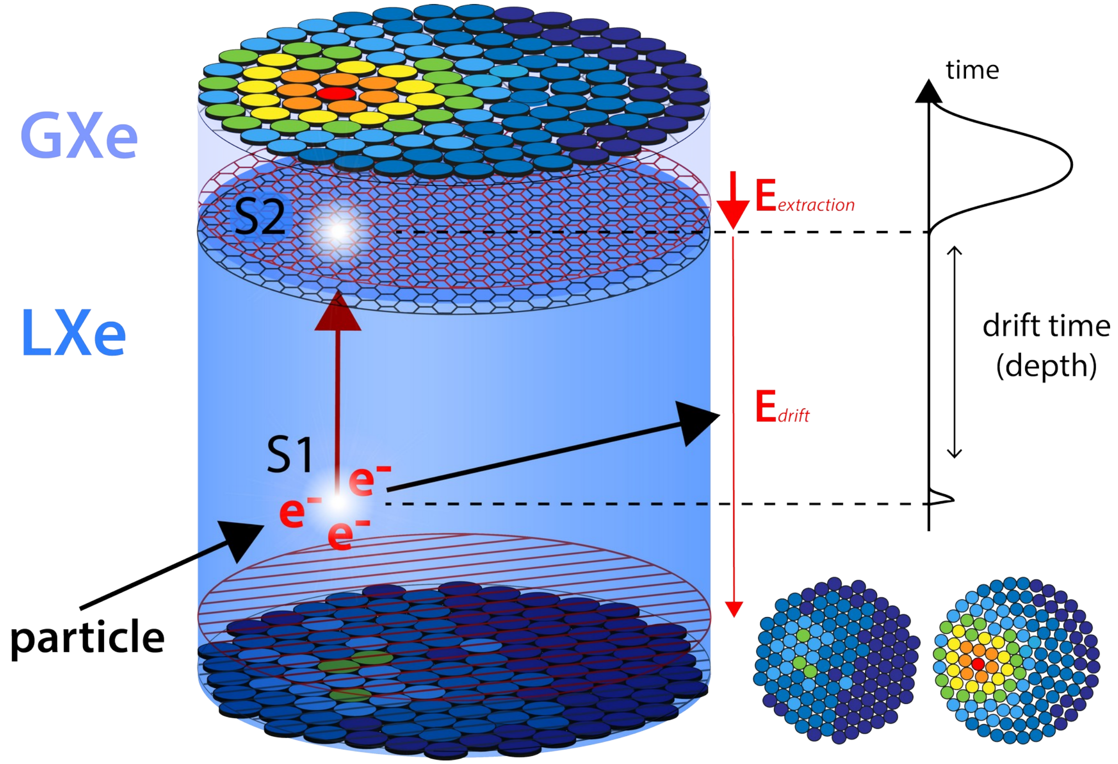
Slide di F. Tavecchio, M. Civitani, O. Straniero, F. Finelli

The XENON Project at Gran Sasso

- All detectors of XENON Project operated underground at Laboratori Nazionali del Gran Sasso (Italy)
- 1.4 km rock coverage (3800 m w.e.) provides factor 10^6 reduction of μ flux



Dual-phase XENON TPC



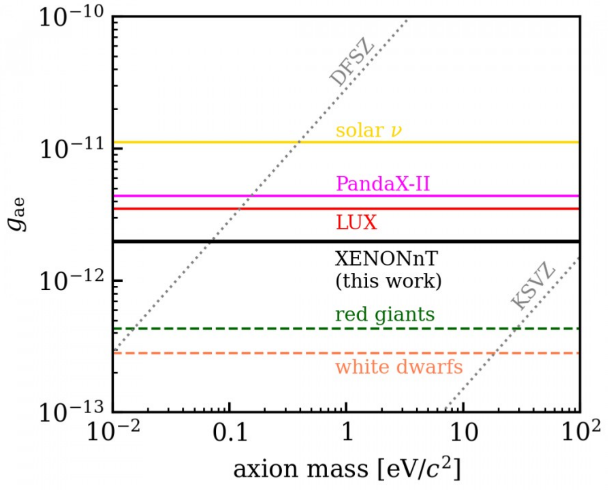
- S1 prompt scintillation
- S2 proportional to ionization
- S2/S1 to discriminate nuclear recoils (NR) and electronic recoils (ER)
- 3D position reconstruction
- Low energy threshold
- Energy reconstruction combining S1 and S2

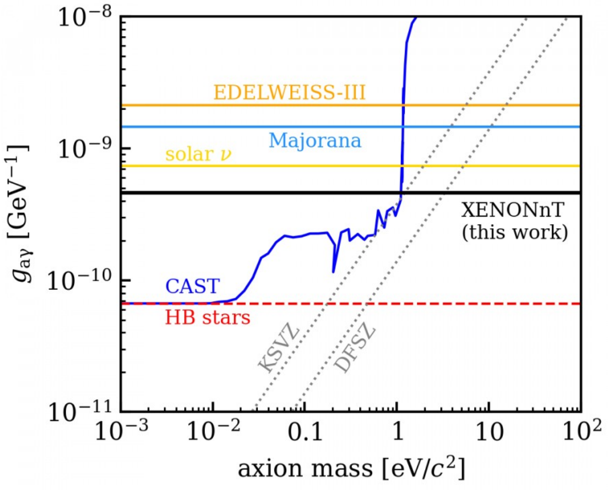
Ideal for dark matter and rare processes search

The XENON Project at Gran Sasso

- Ricerca interazioni di WIMPs negli eventi di tipo rinculo nucleare
- Il livello di background è tale da consentire anche ricerca interazioni di assioni e ALPs negli eventi tipo rinculo elettronico

- Progetto finanziato INFN, in presa dati





E. Aprile et al., Phys. Rev. Lett. 129, 161805 (2022)

The XENON Project at Gran Sasso

- Walter Fulgione (OA Torino)
- Andrea Molinario (OA Torino)
- Gian Carlo Trinchero (OA Torino)

Responsabilità del veto di muoni di XENONnT → riduzione del fondo indotto da muoni

Partecipazione al veto di neutroni di XENONnT → riduzione del fondo di neutroni

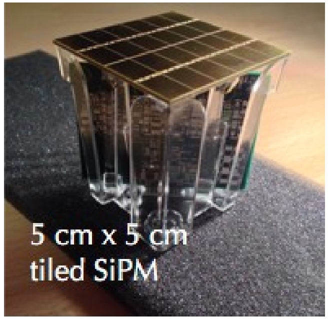
Analisi dei dati di bassa energia

The Global Argon Dark Matter Collaboration

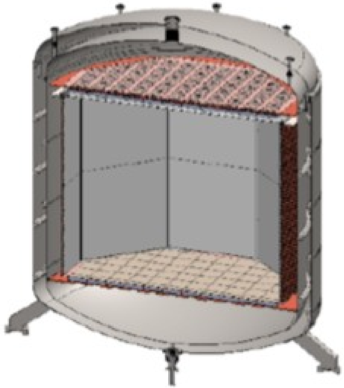
Realizzazione di vari rivelatori ad argon liquido (LAr) indipendenti tra loro per aumentare la sensibilità a interazioni di WIMPs di diversi ordini di grandezza

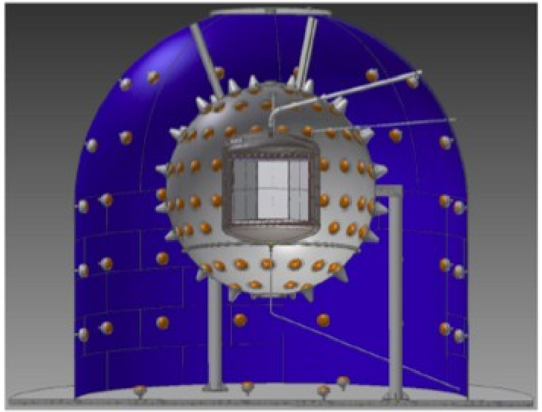
- ***DarkSide-50:*** 50 kg di LAr in TPC doppia fase, installato 2012
- ***DarkSide-20k:*** 23 t di LAr in TPC doppia fase, in costruzione al Gran Sasso
- ***DEAP-3600:*** 3.6 t in singola fase, in operazione a SNOLab (Canada)
- ***Argo:*** 360 t di LAr in doppia o singola fase

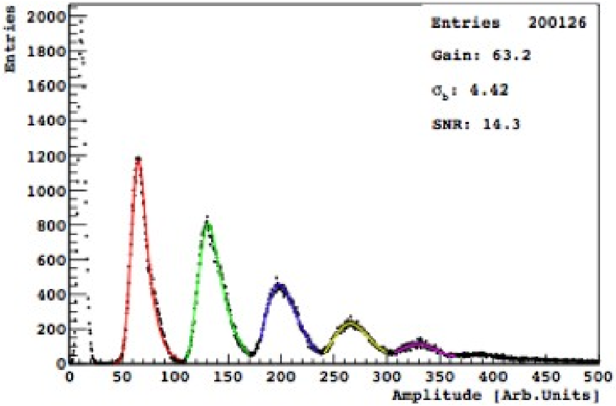
DARKSIDE-20k



- **DarkSide-20k**
  - *>400x scale-up from DarkSide-50 for 23 ton LAr 2-phase TPC*
  - *Design employs large-area cryogenic SiPMs for light readout*
  - *Ops. planned from ~2025; 5+ year exposure*
  - *Alternative target useful for (high-mass) WIMP confirmation*
    - *Sensitivity comparable to LZ/XENONnT at high masses*







Slide di C. Ghag, IPA2022

Sensibilità a ν da supernova

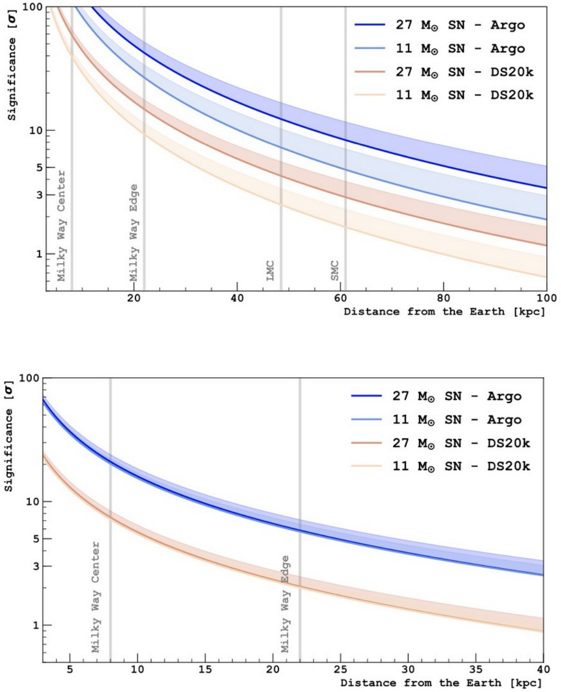


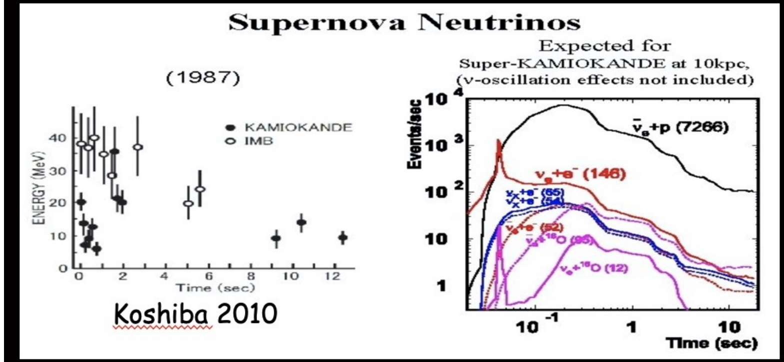
Figure 5. Top. DarkSide-20k and Argo significance to 11-$M_\odot$ and 27-$M_\odot$ SNe (top) and to its neutronization burst only (bottom), as a function of the distance, assuming the standard background hypothesis (solid line) and (band) lower contamination of ^{39}Ar up to a factor of 10 less. Vertical lines represent the distance from the Earth of the Milky Way center and farthest edge, and of Large (LMC) and Small (SMC) Magellanic Clouds.

Interazione dei ν da supernova con scattering coerente su nuclei di Argon.

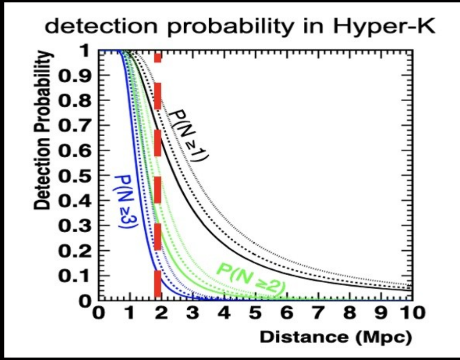
Studio della sensibilità dei futuri rivelatori a LAr: DarkSide-20k e Argo.

The DarkSide-20k collaboration et al., JCAP03 (2021) 043

Expected CC-SN/Neutrino rates



SNe within the Milky-Way ~ 10 Kpc, good statistics: few x10^3 ÷ few x 10^4 neutrinos/SN; but 1 SN ~ 50 years



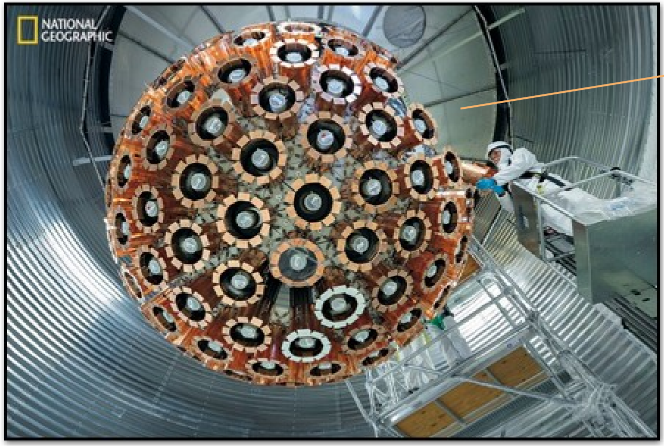
SNe within ~ LG of galaxies ~ 1 neutrino per SN and ~ 0.1 neutrinos per SN within the Virgo circle ~ 2 SN/yr

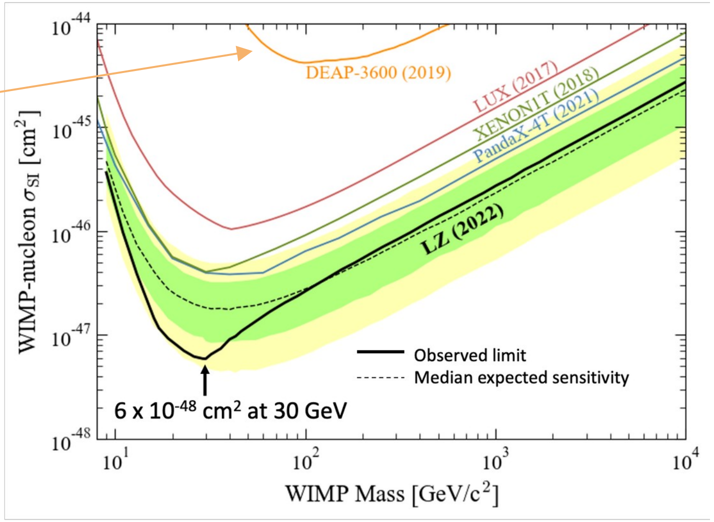
CC-SNe ~ Gpc:
~ 10^5 SNe/yr → < 1 neutrino/year
→ diffuse neutrino background

Slide di M. Della Valle

DEAP-3600

- Single phase LAr, 3.6 Ton (1 Ton fiducial); 255 8” PMTs
- Pulse shape discrimination (PSD) for particle ID
- *E_{th} ~ 39 keV determined by PSD (^{39}Ar β-decay, 1 Bq/kg, Q-value ~550 keV)*
- Promising initial (4.4 day) run but latest result suffers from ‘***neck backgrounds***’
  - 231 day exposure, S.I. limit above *3.9×10^{-45} cm^2* (2019)
  - Expect some improvement from PLR analysis (ongoing)





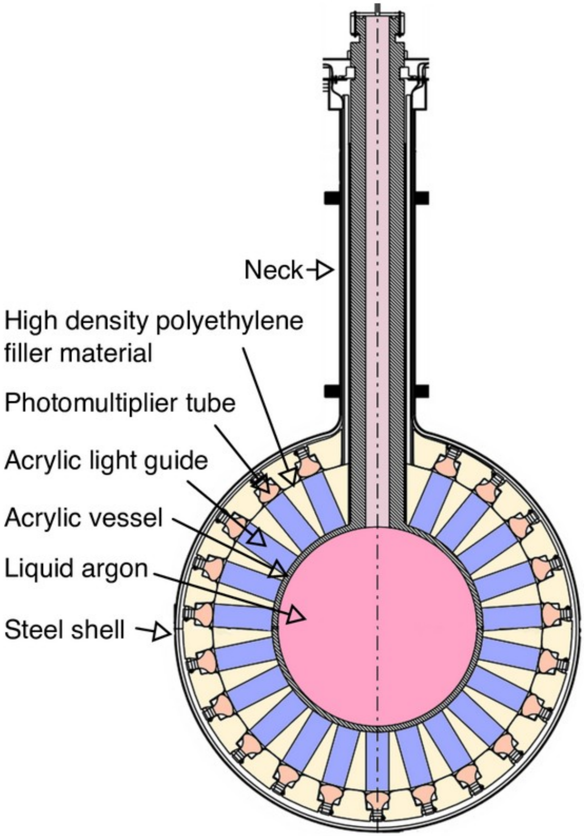
Slide di C. Ghag, IPA2022

Random Forest application to background rejection

The detector utilizes a 3600 kg mass of liquid argon as the dark matter target, which is contained in a spherical acrylic vessel. There is an opening at the top of the acrylic vessel where the cooling system is located, in the ***neck*** of the detector. The decay of alpha particles from components in this region can potentially mimic a WIMP signal, and so it is critically important to understand and mitigate this source of alpha backgrounds.

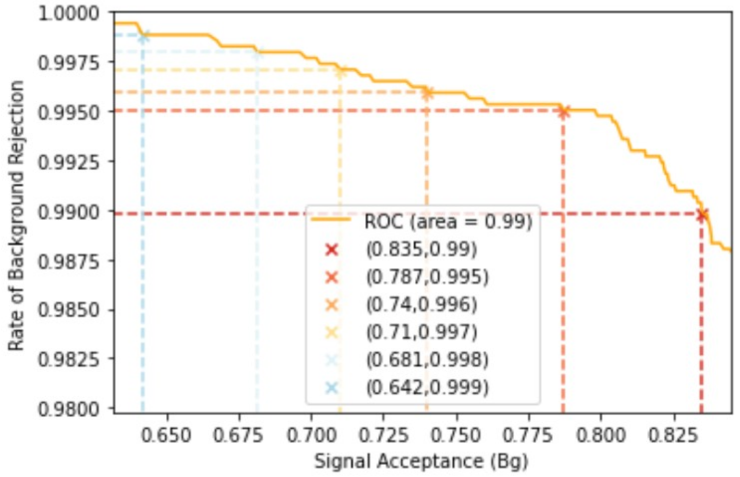
We are using a machine learning algorithm, in particular “Random Forest” (Breiman 2001) to select WIMPs and reject neck alphas.

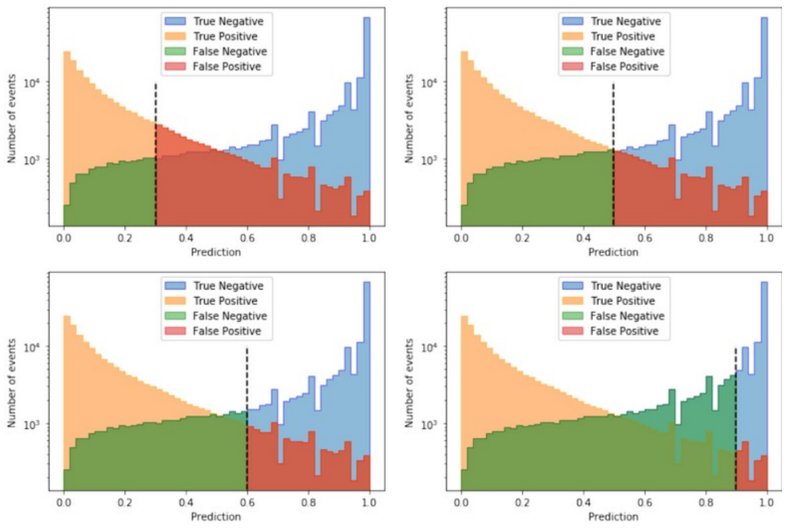
We used the same algorithm to identify discrepancy between real data and MC samples.
Recently we started the same analysis also for the rejection of dust alphas
Trained using simulated samples using high-level variables.



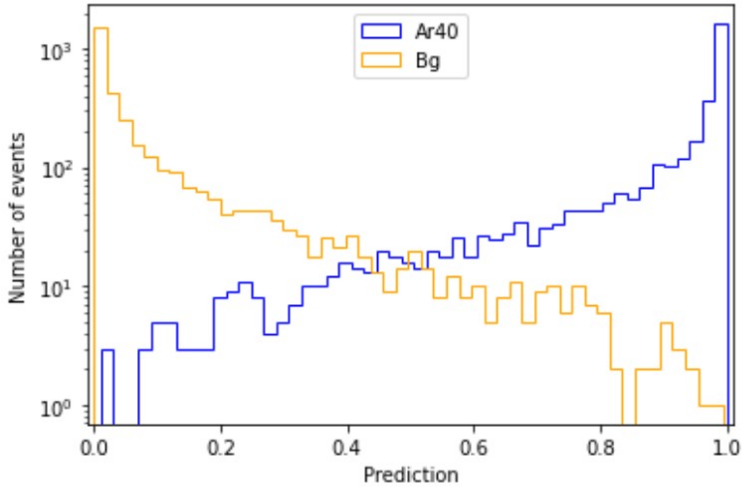
Slide di S. Cavuoti

Random Forest application to background rejection





Changing the threshold on the prediction affects the acceptance and the Bg rejection

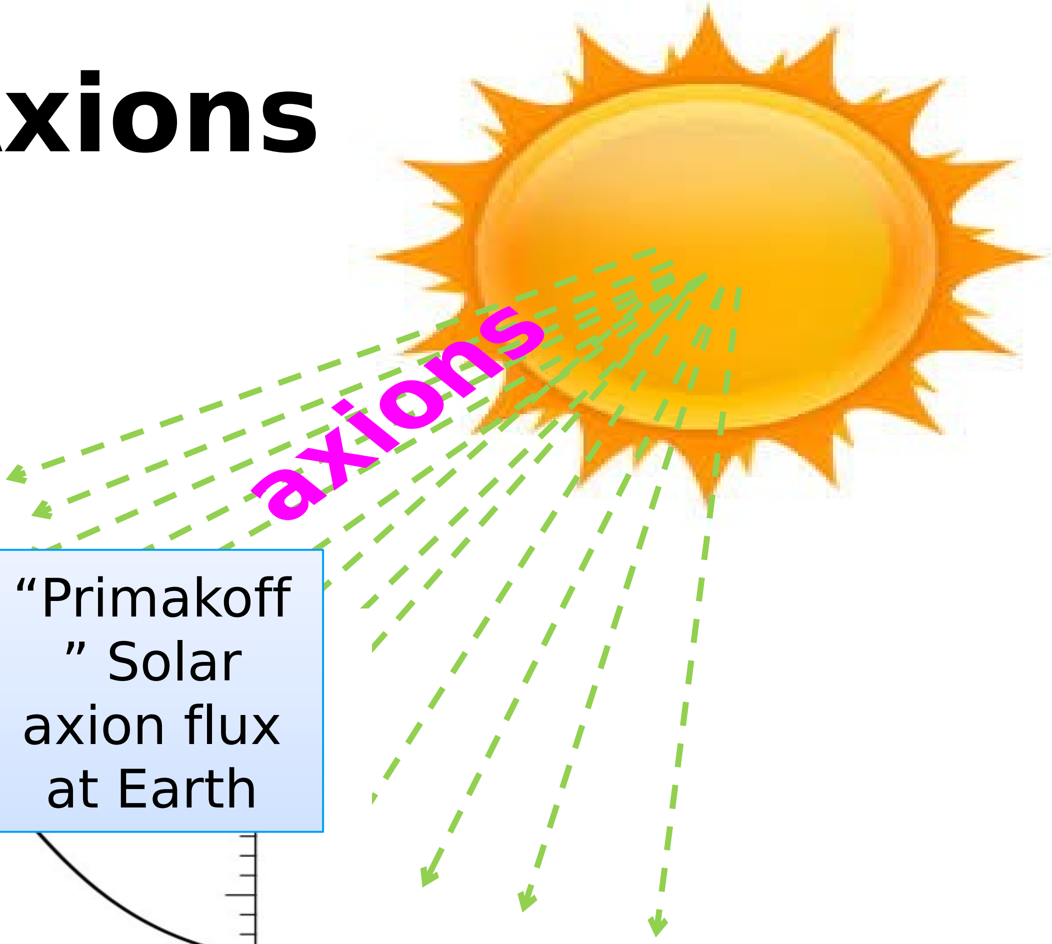


According to the latest results (under validation) we were able to reject 99.9% of neck alphas (meeting the requirement) by maintaining a signal acceptance of 64.2% on MC samples

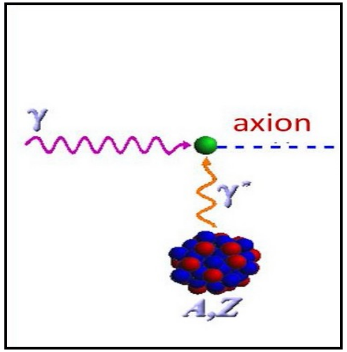
Slide di S. Cavuoti

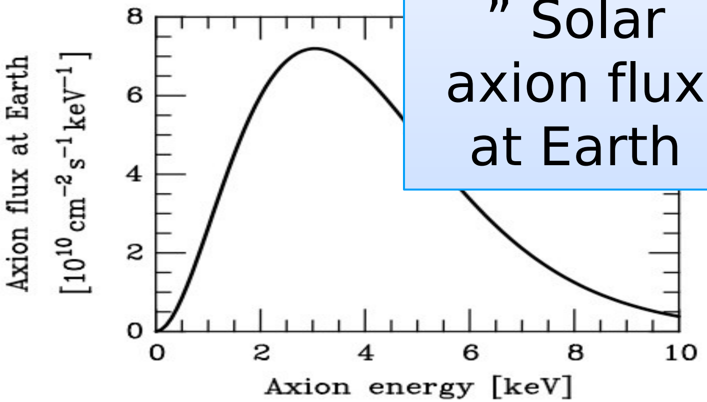
Solar Axions

Solar axions produced by photon-to-axion conversion of the solar plasma photons in the solar core



“Primakoff” Solar axion flux at Earth



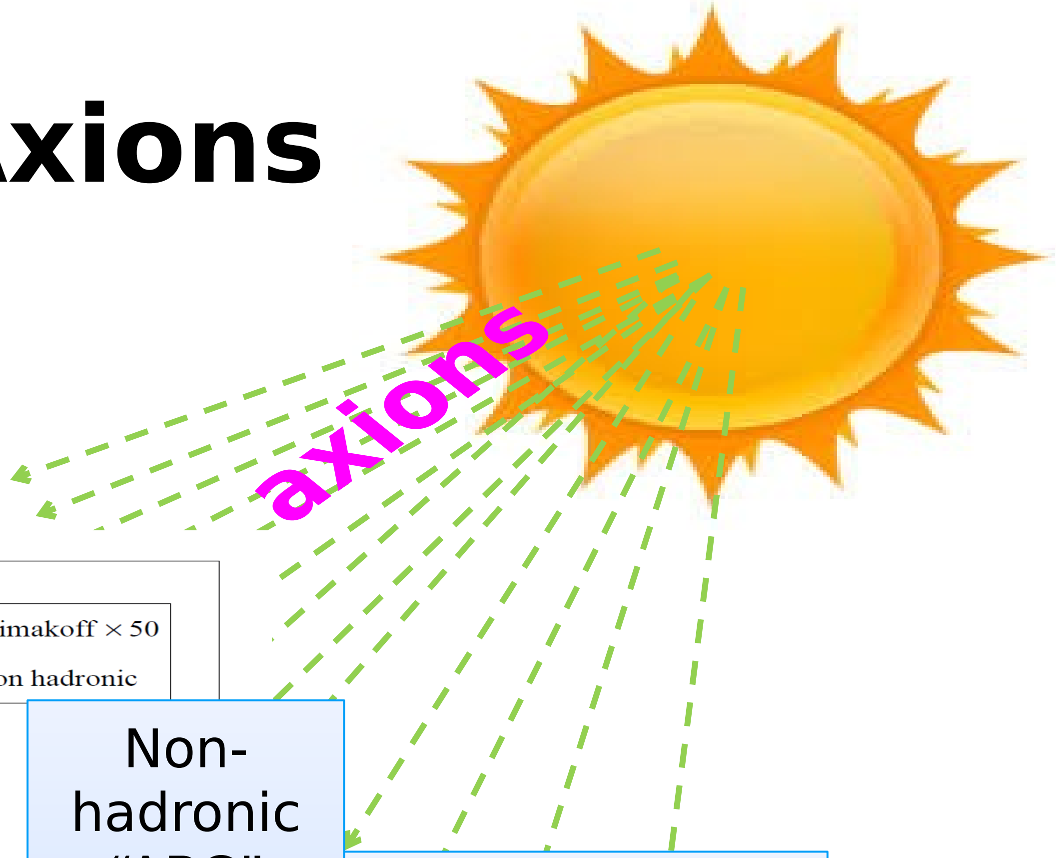


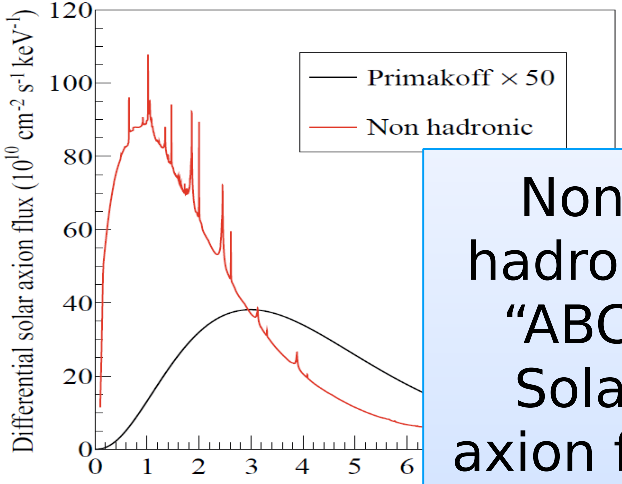
Slide di F. Tavecchio, M. Civitani, O. Straniero, F. Finelli

$$\frac{d\Phi_a}{dE} = 6.02 \times 10^{10}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}\ \mathrm{keV}^{-1}\ g_{10}^2\ E^{2.481} e^{-E/1.205}$$

Solar Axions

Solar axions produced by photon-to-axion conversion of the solar plasma photons in the solar core





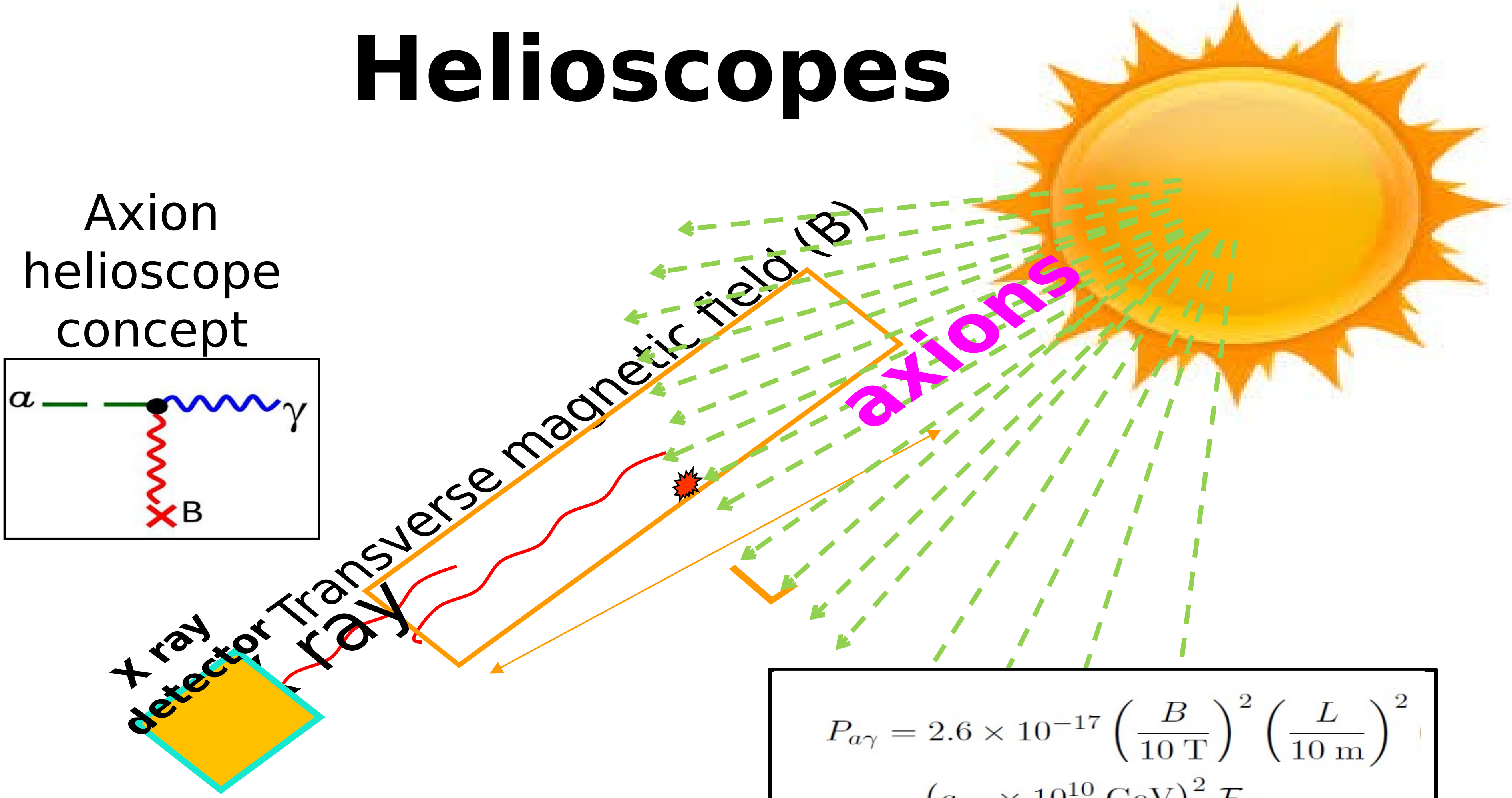
Non-hadronic "ABC" Solar axion flux at Earth

* if the axion couples with the electron (g_{ae})
(non hadronic axion)

Slide di F. Tavecchio, M. Civitani, O. Straniero, F. Finelli

Helioscopes

Axion helioscope concept

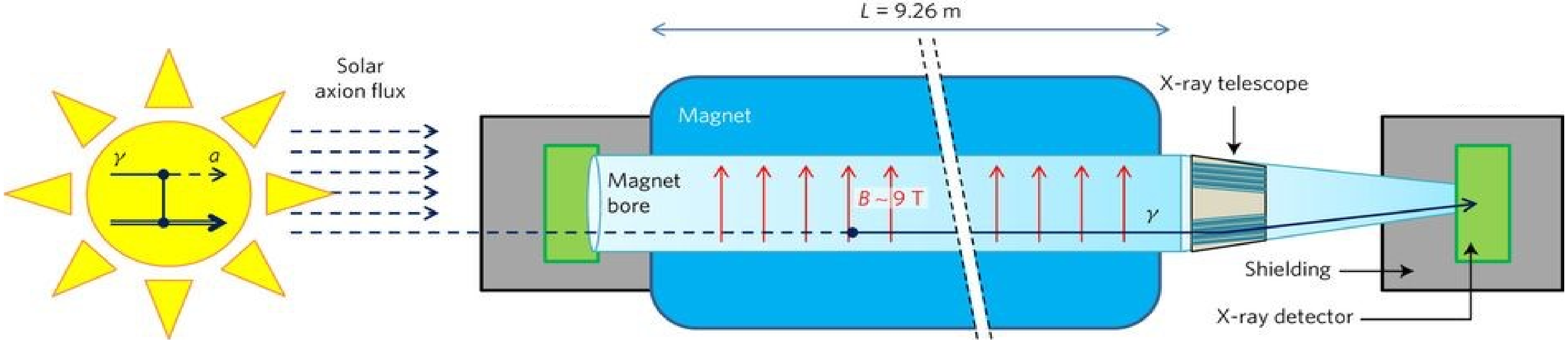


$$P_{a\gamma} = 2.6 \times 10^{-17} \left(\frac{B}{10\ \mathrm{T}}\right)^2 \left(\frac{L}{10\ \mathrm{m}}\right)^2 \left(g_{a\gamma} \times 10^{10}\ \mathrm{GeV}\right)^2 \mathcal{F}$$

Slide di F. Tavecchio, M. Civitani, O. Straniero, F. Finelli

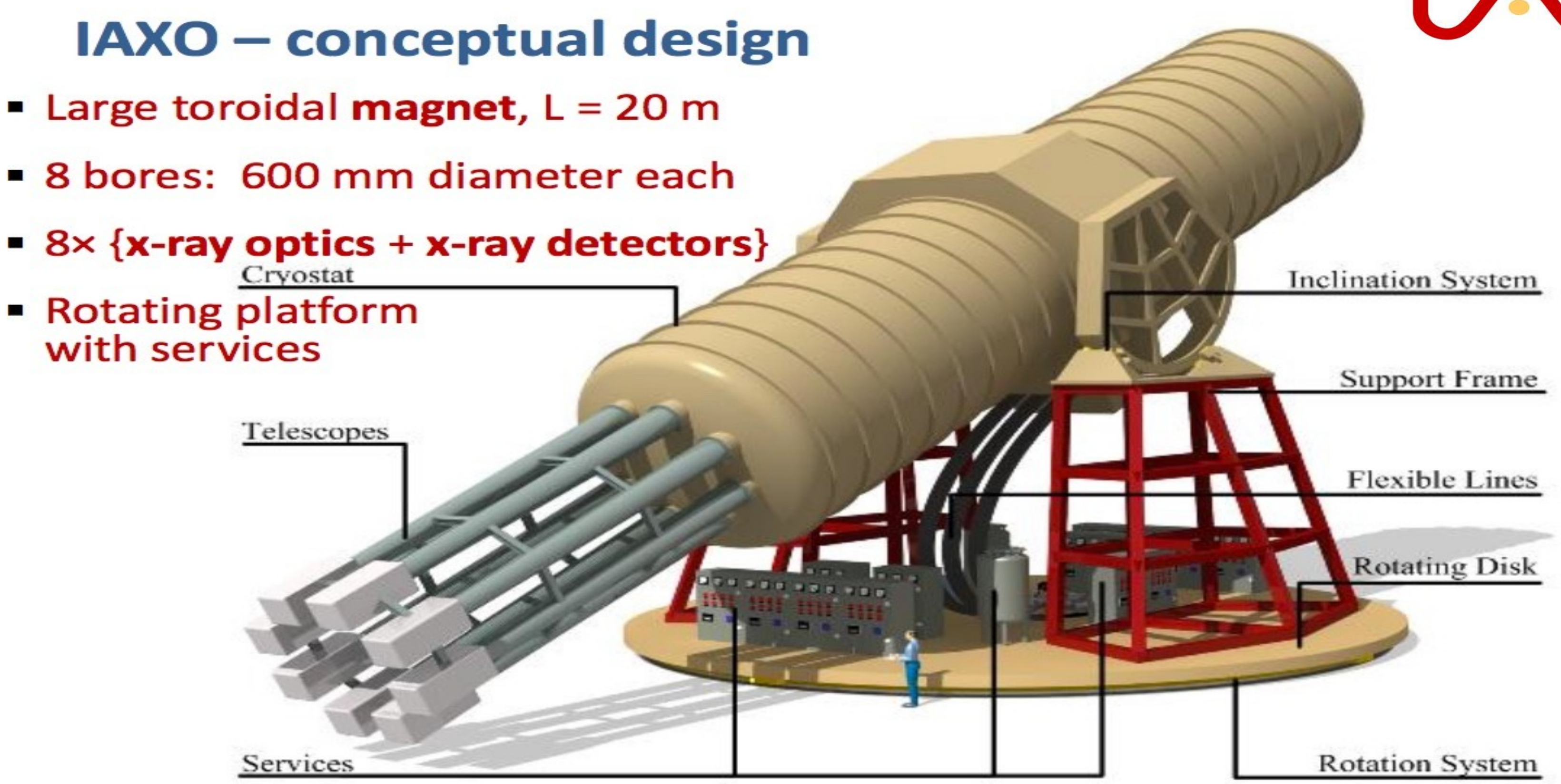
Helioscopes

A concrete realization



Slide di F. Tavecchio, M. Civitani, O. Straniero, F. Finelli

The future: IAXO



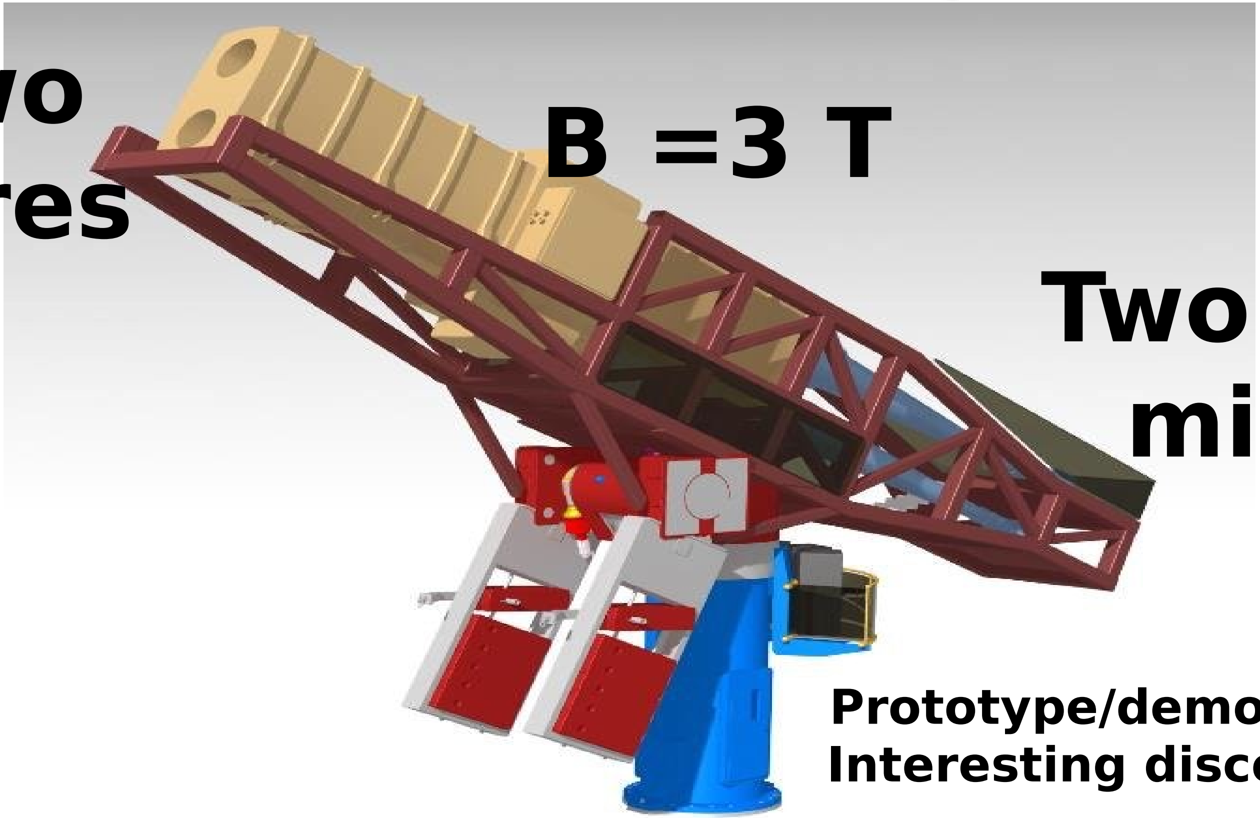
Slide di F. Tavecchio, M. Civitani, O. Straniero, F. Finelli

The near future: Baby-IAXO

Two bores

B =3 T

Two 70 cm mirrors



Prototype/demonstrator but Interesting discovery space!

Slide di F. Tavecchio, M. Civitani, O. Straniero, F. Finelli

Baby IAXO

14. Organizzazione del team

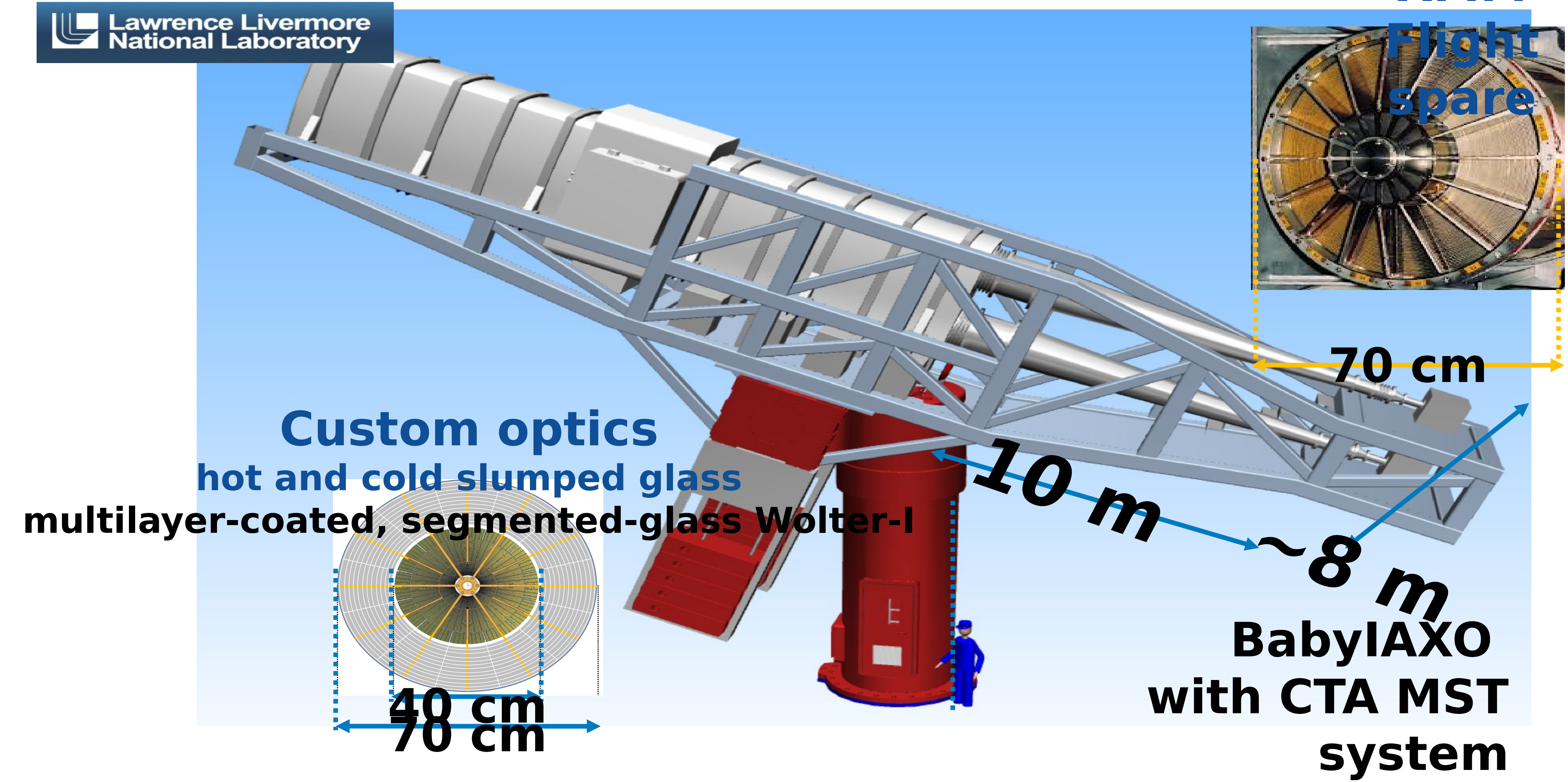
La compagine INAF che partecipa al progetto e' naturalmente suddivisa in due gruppi strumentali (ottiche X, calibrazione detector) e un gruppo di supporto scientifico.

-Gruppo ottiche: Il gruppo coinvolto nella ottiche di BabyIAXO e' composto da personale staff con solide competenze nella progettazione, realizzazione, allineamento e calibrazione di ottiche X (attualmente anche impegnati su altri progetti come eXTP, ATHENA, Lynx). In particolare, la tecnologia di formatura a freddo impiegata per la realizzazione del moduli dell'ottica 'ibrida', e' un processo ideato e brevettato da componenti del team, che possono efficacemente gestire end-to-end la realizzazione delle ottiche. Due ulteriori unita' di personale tecnico a contratto potranno coprire le fasi più' strettamente implementative.

-Gruppo calibrazioni: Il gruppo coinvolto nelle calibrazioni di BabyIAXO e' lo stesso gruppo che ha calibrato con successo i rivelatori ad immagine di IXPE che funzionano in una banda di energia equivalente. Il responsabile locale e' Paolo Soffitta (Responsabile scientifico italiano di IXPE), Fabio Muleri (Calibration leader), Sergio Fabiani (Calibration scientist), Alessandro Di Marco (Calibration scientist). Partecipano inoltre Enrico Costa (dirigente di ricerca) ed Alda Rubini (tecnico elettronico) .

-Gruppo scienza: i gruppi coinvolti nello studio degli aspetti astrofisici sono principalmente concentrati ad OA Abruzzo (astrofisica stellare), OAS Bologna (cosmologia) e OA Brera (alte energie). In vista del coinvolgimento in BabyIAXO si intende stimolare una maggiore sinergia tra le varie sedi, attraverso progetti di ricerca comuni.

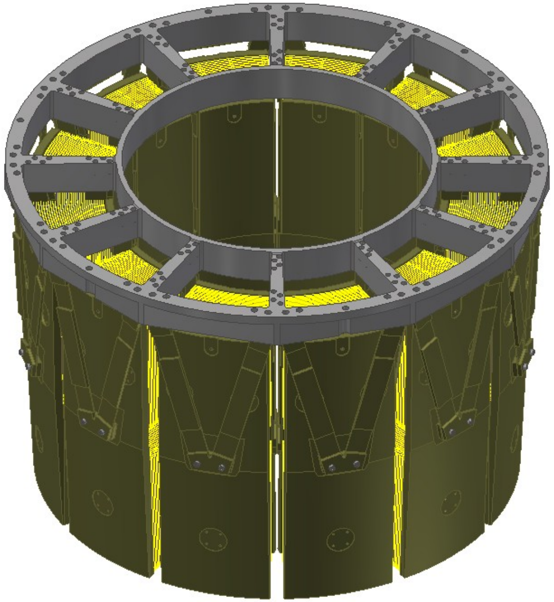
Mirrors



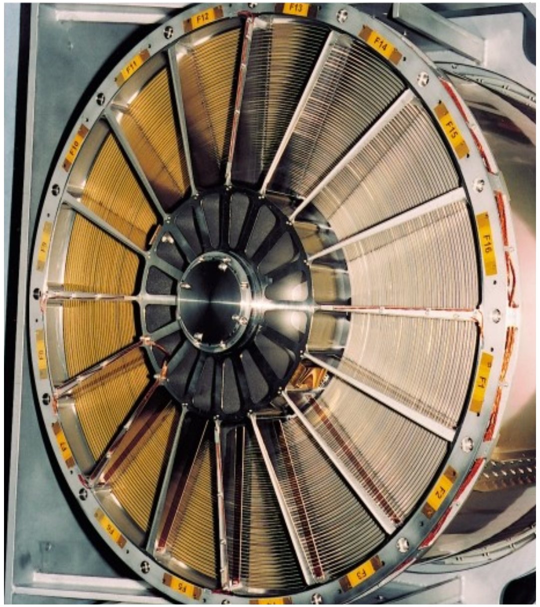
XMM
Flight
spare
70 cm
Custom optics
hot and cold slumped glass
multilayer-coated, segmented-glass Wolter-I
10 m
~8 m
40 cm
70 cm
BabyIAXO
with CTA MST
system

INAF contribution to x-ray optics

Outer corona for ‘custom x-ray optic module'



Support for XMM usage



???    ??? Proposed for a large grant (2022)

- Not founded -

Slide di M. Civitani

Fundamental physics from astrophysical data (FUPA)

- **Participants:**
  - INAF staff: Galanti (PI, 0.3 FTE); Bonnoli (0.1+0.2 FTE); Ghirlanda; Ghisellini; Landoni; Tavecchio (0+0.2 FTE)
  - INAF associates: Caraveo; De Angelis (0.1 FTE); Roncadelli (1 FTE)

- **Involved Infrastructures:** Amazon; AMEGO; ASTRI; COSI; CTA; e-ASTROGAM; Fermi-LAT; IAXO; IXPE; MAGIC

- **Research Grants:** Mini Grant, INAF, 20k euro (PI: Galanti), 2022

- **Objectives:**
  - Explaining astrophysical phenomena starting from first principles
  - Use astrophysical data to study fundamental physics, mainly in terms of

    1) axion-like particles (ALPs); 2) Lorentz Invariance Violation (LIV)

Slide di G. Galanti

Fundamental physics from astrophysical data (FUPA)

- **ALPs** light neutral pseudo-scalar bosons, predicted by superstring theories, interacting with photons in the presence of external magnetic fields and producing astrophysical effects:
  - Photon-ALP oscillations – similar to massive neutrino oscillations (De Angelis+2011)
  - Increase of the Universe transparency (De Angelis+2011; Galanti+2018)
  - Solution of two VHE astrophysical problems:
    - Observation of photons from FSRQs with $E > 20$ GeV (Tavecchio+2012)
    - BL Lac VHE spectral anomaly (Galanti+2020b)
  - Blazar spectral alterations (Tavecchio+2015; Galanti+2019)
  - Variation of photon polarization (Galanti 2022b; Galanti+2022)
  - Measure of emitted photon polarization through photon-ALP interaction (Galanti 2022a)
  - Possible explanation of the detection of GRB 221009A (Galanti+2022a,b)

- **LIV** predicted by quantum theories of gravity and producing astrophysical effects:
  - Variation of the behavior of standard physics processes (Tavecchio+2016)
  - Increase of the Universe transparency (Tavecchio+2016; Galanti+2020a)
  - Blazar spectral alterations (Tavecchio+2016; Galanti+2020a)

Slide di G. Galanti

Fundamental physics from astrophysical data (FUPA)

- **Publications starting from the formation of the team:** 1) Galanti & Roncadelli, PRD 98, 043018 (2018); 2) Galanti & Roncadelli, JHEAp 20, 1 (2018); 3) Galanti, Tavecchio, Roncadelli & Evoli, MNRAS 487, 123 (2019); 4) Galanti, Tavecchio & Landoni, MNRAS 491, 5268 (2020); 5) Galanti, Roncadelli, De Angelis & Bignami, MNRAS 493, 1553 (2020); 6) Galanti & Roncadelli, Universe 8(5), 253 (2022); 7) Cenedese, Franceschini & Galanti, MNRAS 516, 216 (2022); 8) Galanti, PRD 105, 083022 (2022)

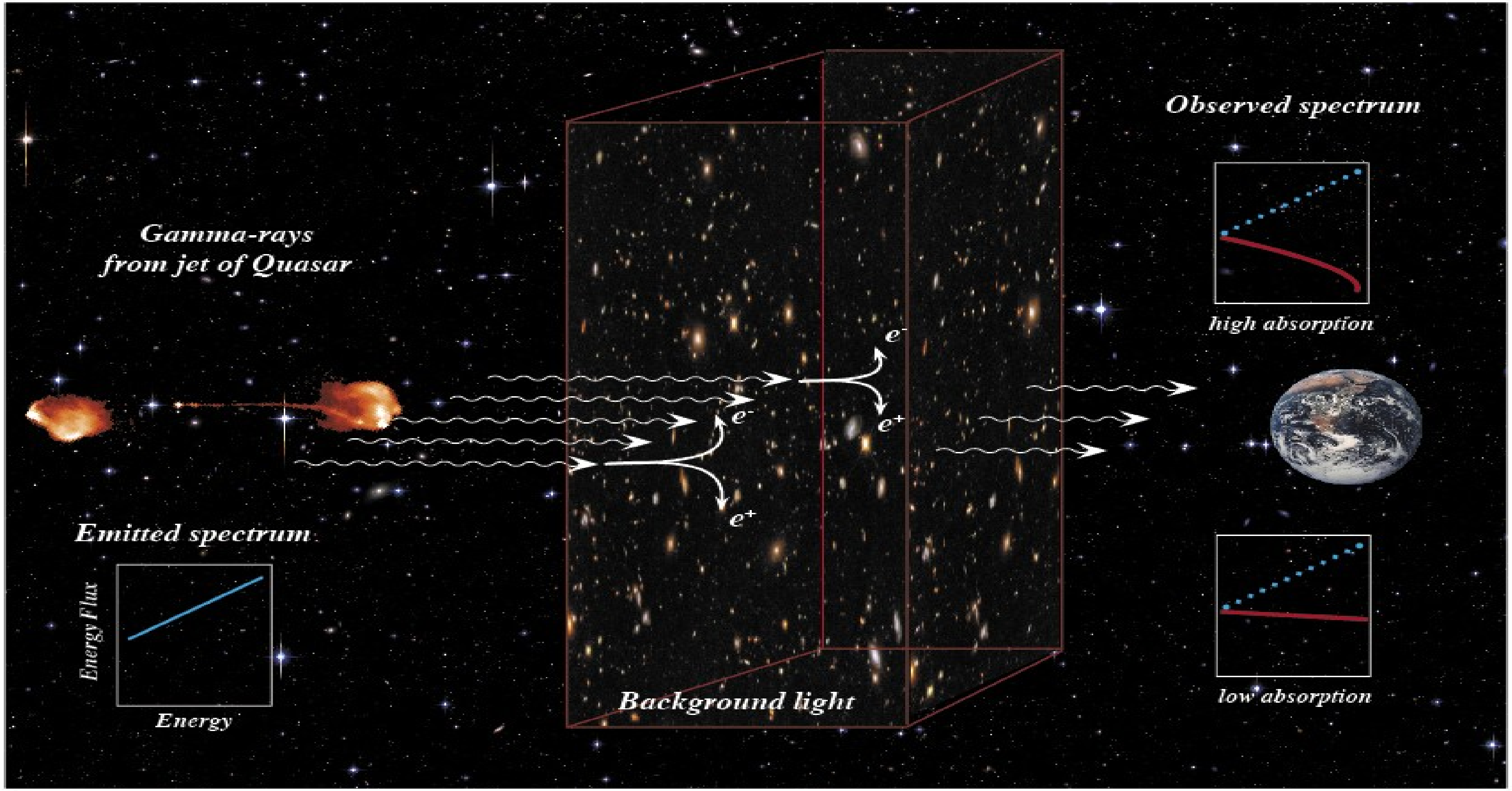
- **Submitted papers:** 1) Galanti [arXiv:2202.11675]; 2) Galanti, Roncadelli & Tavecchio [arXiv:2202.12286]; 3) Galanti, Roncadelli & Tavecchio [arXiv:2210.05659]; 4) Galanti, Roncadelli & Tavecchio [arXiv:2211.06935]

- **INFN-INAF press release:** Galanti et al., MNRAS 493, 1553 (2020)

  (https://www.media.inaf.it/2020/03/03/blazar-bignami/)

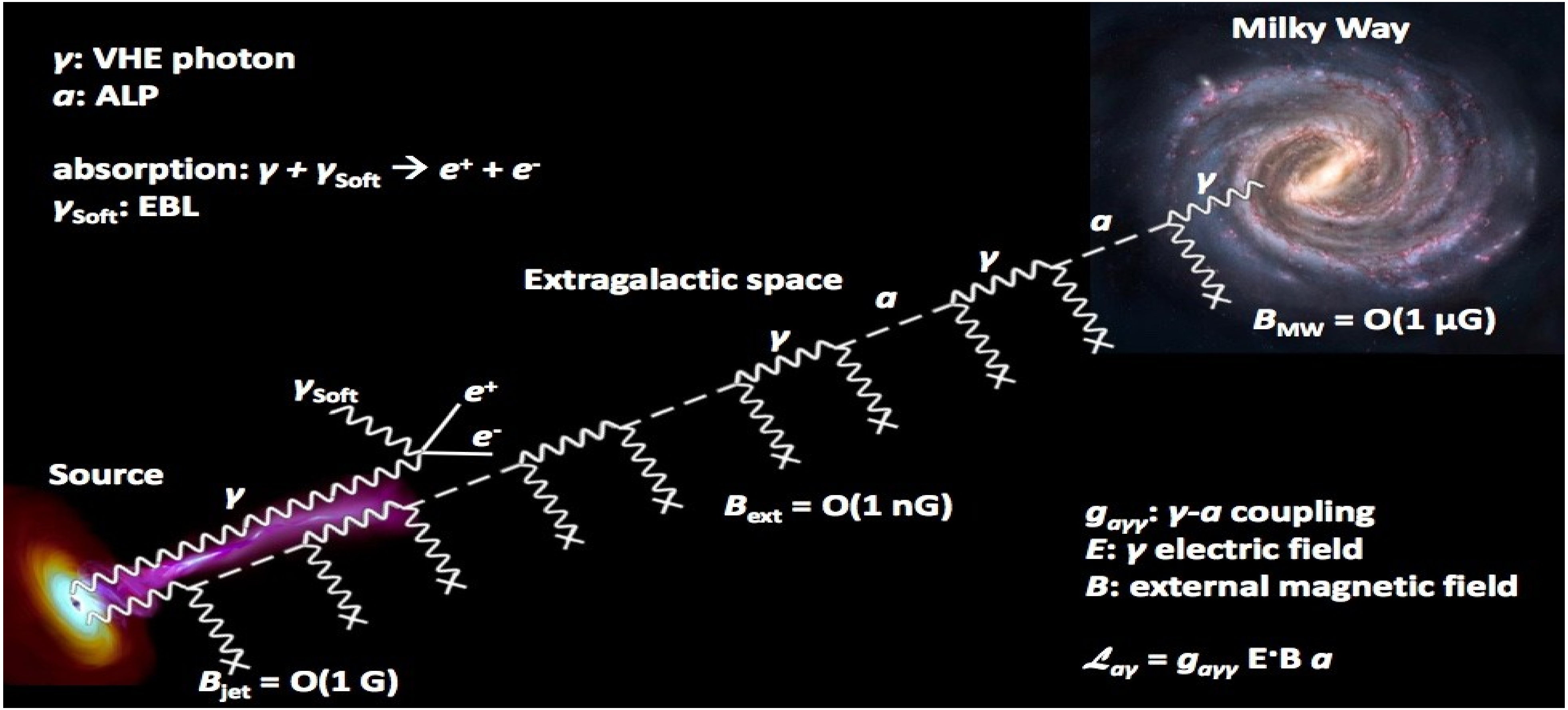
Slide di G. Galanti

Reduced cosmic opacity



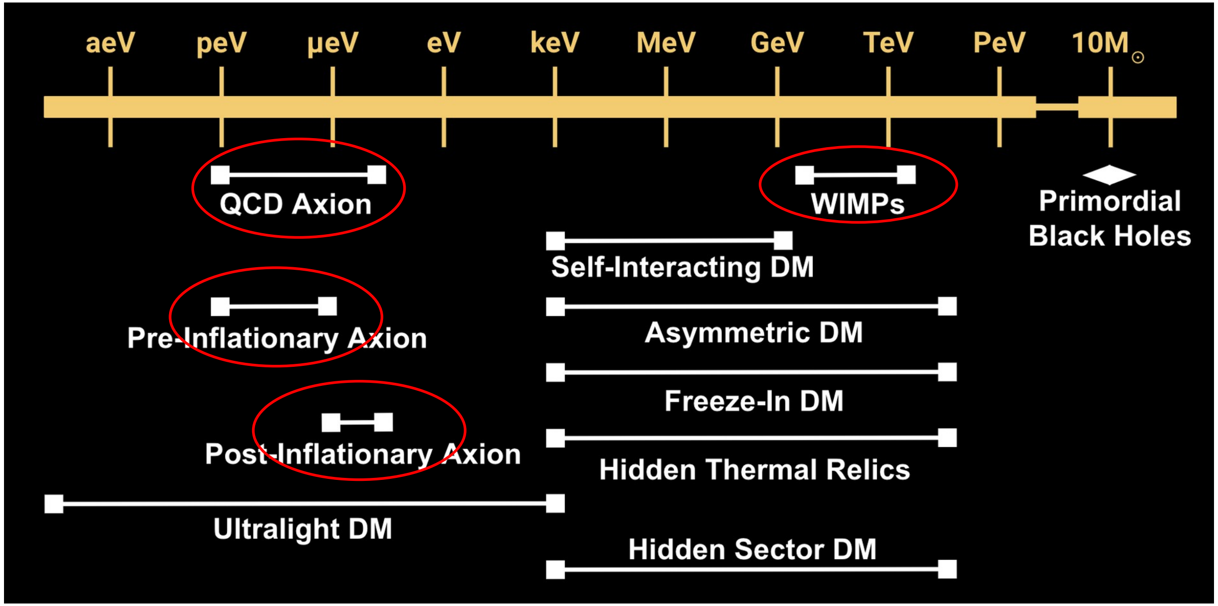
Slide di F. Tavecchio, M. Civitani, O. Straniero, F. Finelli

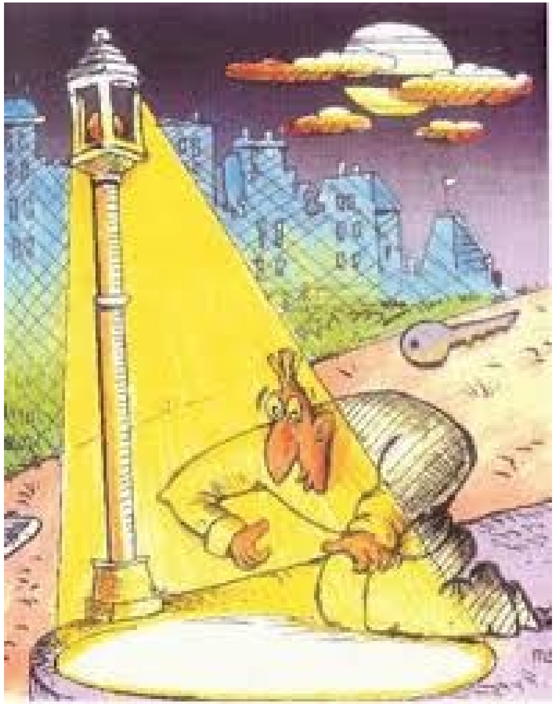
Reduced cosmic opacity



Slide di F. Tavecchio, M. Civitani, O. Straniero, F. Finelli

“L’effetto lampione”





Attenzione:
Il rischio è di cercare solo dove è più “facile” farlo!

Collegamenti con altri RSN

Presentazioni di S. Cristiani e S. Ettori alle Giornate INAF di RSN1.

“Large scale structures and physics of matter”

- Formazione ed evoluzione di galassie e clusters di galassie
- Test delle predizioni di modelli di dark matter

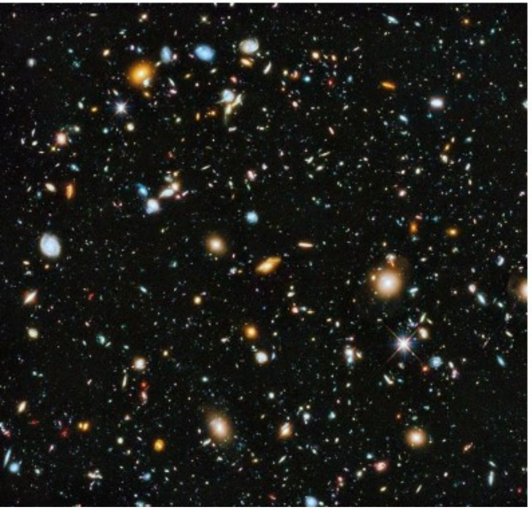
8. Formation and Evolution of Galaxies and Cosmic Structures

Keywords: Galaxies and AGN, Clusters of Galaxies, IGM and reionization

Key Question:

What are the physical processes driving the assembly and the evolution of structures on scales of galaxies up to clusters of galaxies?

- **Properties of first galaxies and black holes. Sources responsible for the reionization(s)**
- **Origin and fate of galaxies, the galaxy stellar mass function and morphological differentiation.**
- **Feedback processes among the different components of galaxies (stars, gas, dust) and AGN. Role of DM halos.**
- **External and internal mechanisms (environment and relationship with the Cosmic Web) regulating the efficiency of star formation and the structural parameters of galaxies.**
- **Census and distribution of mass/energy in large-scale structures (hot baryons, AGN-ICM connection, turbulence, non-thermal phenomena and their relationship with the thermal phenomena mapped in X-ray and with the Sunyaev-Zeldovich effect).**



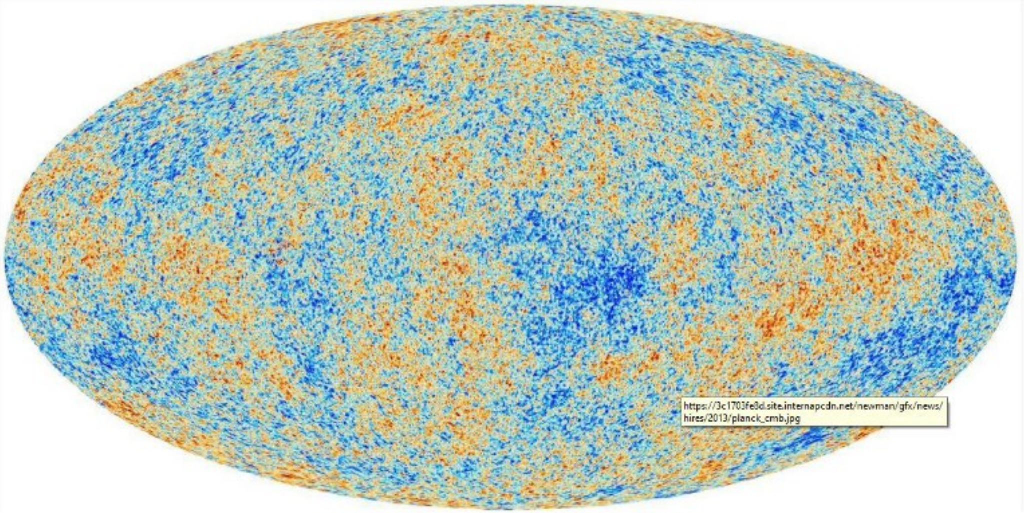
INAF Strategic Vision
June 2019

9 Cosmology and Fundamental Physics

Keywords: Geometry of the Universe, Cosmological parameters, Dark Matter, Dark Energy, Fundamental Physics.

Key questions:

- **The nature of Dark Matter**
- **The nature of Dark Energy**
- **Understanding gravity on large cosmological scales**
- **Initial conditions of Cosmology**
- **Fundamental interactions and constants of Physics**
- **The cosmic distance ladder and the Hubble constant debate**



Slide di S. Cristiani

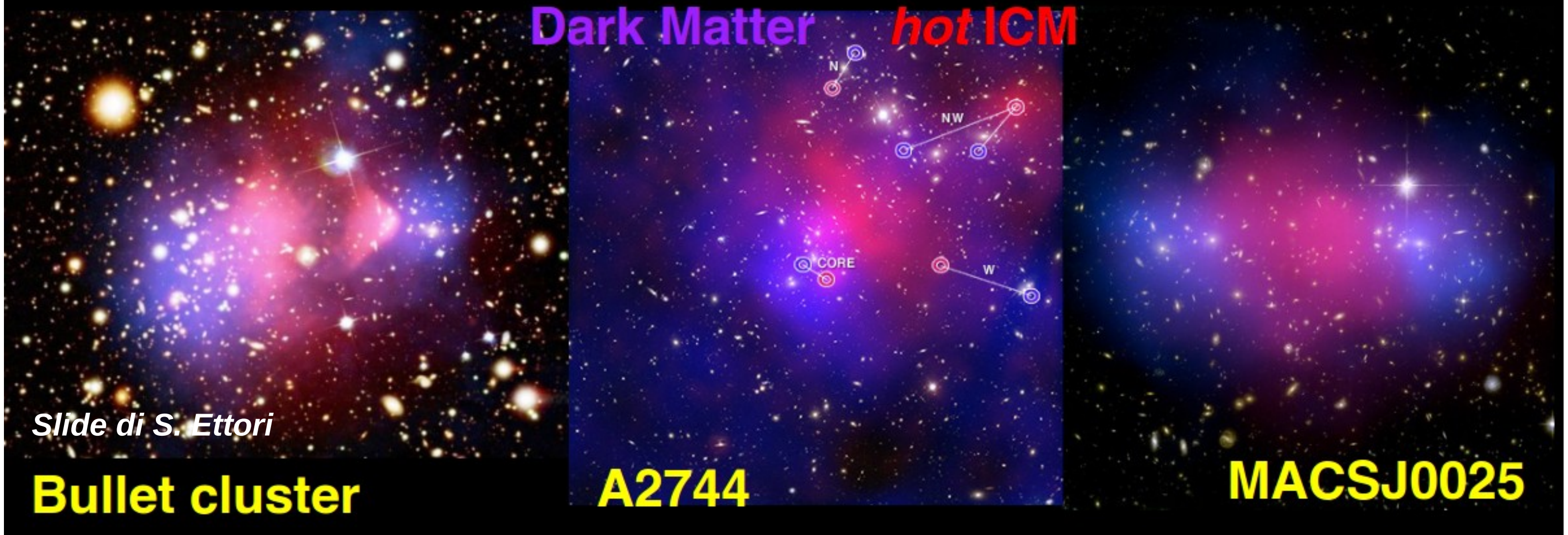
Formation: models of gravity

- ***The largest gravitationally-bound structures in the universe***

- ***"dunkle Materie"*** (Zwicky 1933)

~80% of total mass; ~15% hot gas; few % stars

➔ Laboratories to test predictions for DM models (C/SI/fuzzy, decaying DM, MOND; role of substructures)



Conclusioni

- Approcci diversi e complementari al problema
- Collegamenti con altri RSN
- Finanziamenti degli esperimenti da INFN

- Possibile aumentare partecipazione INAF?
- Come coordinare le diverse attività?

Conclusioni

- Approcci diversi e complementari al problema
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Grazie a tutti i colleghi che hanno fornito il materiale!