Cosmic Rays International Seminar - Gallipoli, Sep. 14-16, 2015

Cosmic radiation 2020: an INFN perspective

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Talk content

- INFN and the Cosmic radiation
  - The INFN Commission 2
  - Running projects
  - The future: a multi-messenger perspective
    - Protons and Nuclei
    - UHECR
    - High energy photons
    - Gravitational waves
    - Neutrinos
    - Low energy photons: CMBR and Dark Energy probes

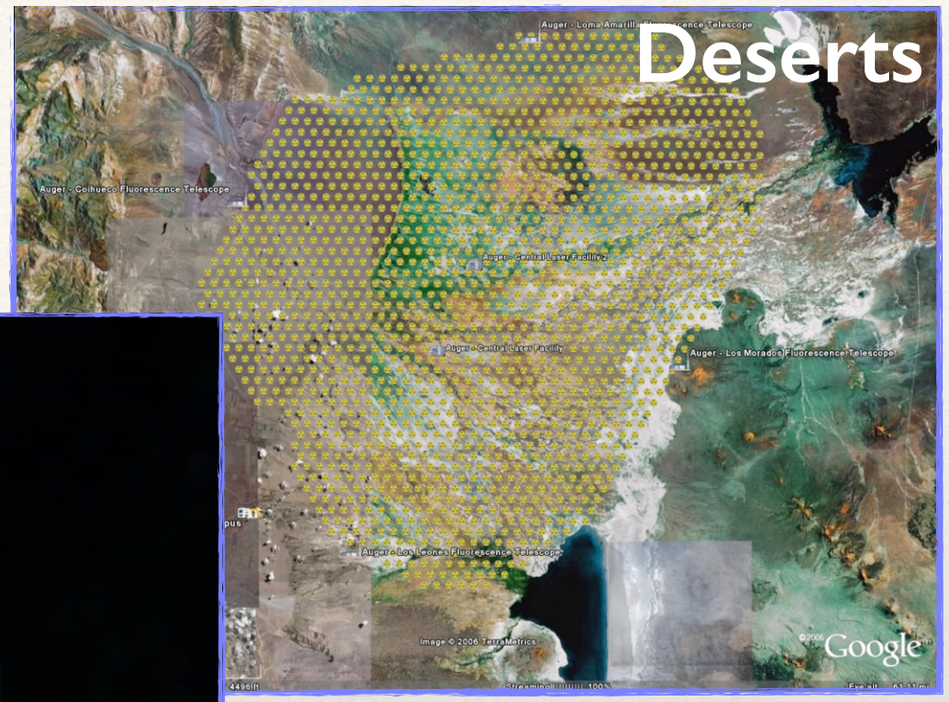
INFN SCIENTIFIC ORGANIZATION

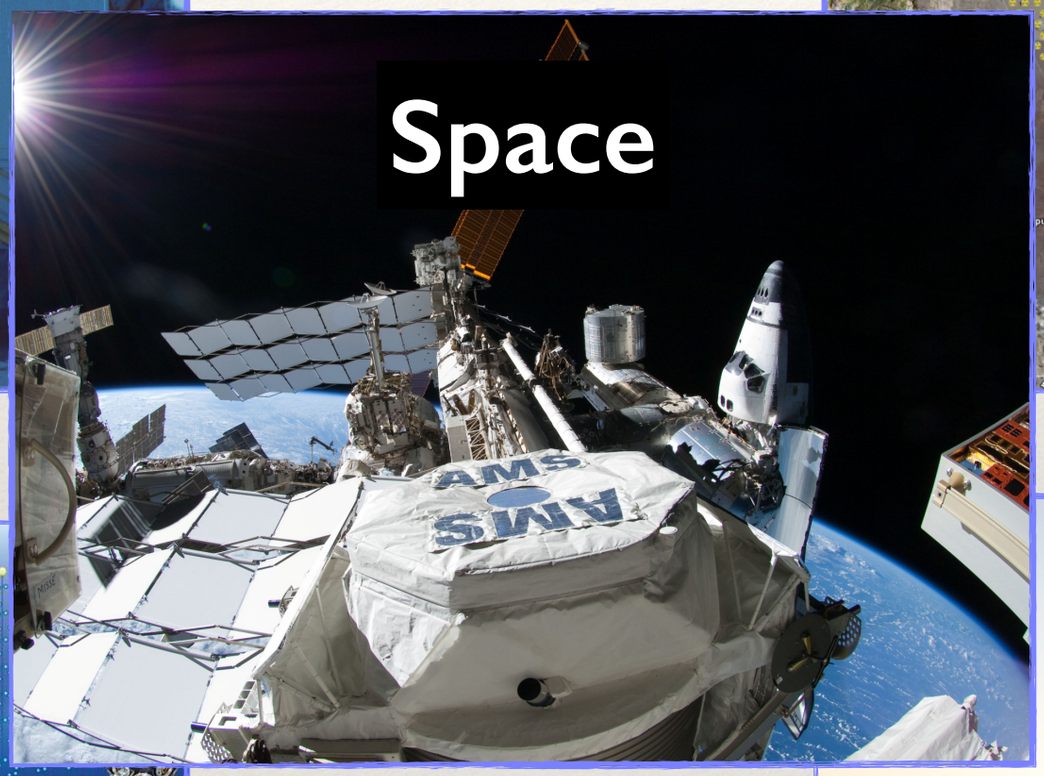
- INFN [3670 FTE, research staff + university associates]
  - 5 “Commissioni Scientifiche Nazionali”
    - CSN1 : Particle Physics with Accelerators — 19.8 M€ — 796 FTE
    - **CSN2: Astroparticle and Fundamental Physics — 12.3+9 M€ — 726 FTE**
    - CSN3: Nuclear Physics — 9.2 M€ — 494 FTE
    - CSN4: Theory — 2.7 M€ — 991 FTE
    - CSN5: Technology — 5.3 M€ — 663 FTE

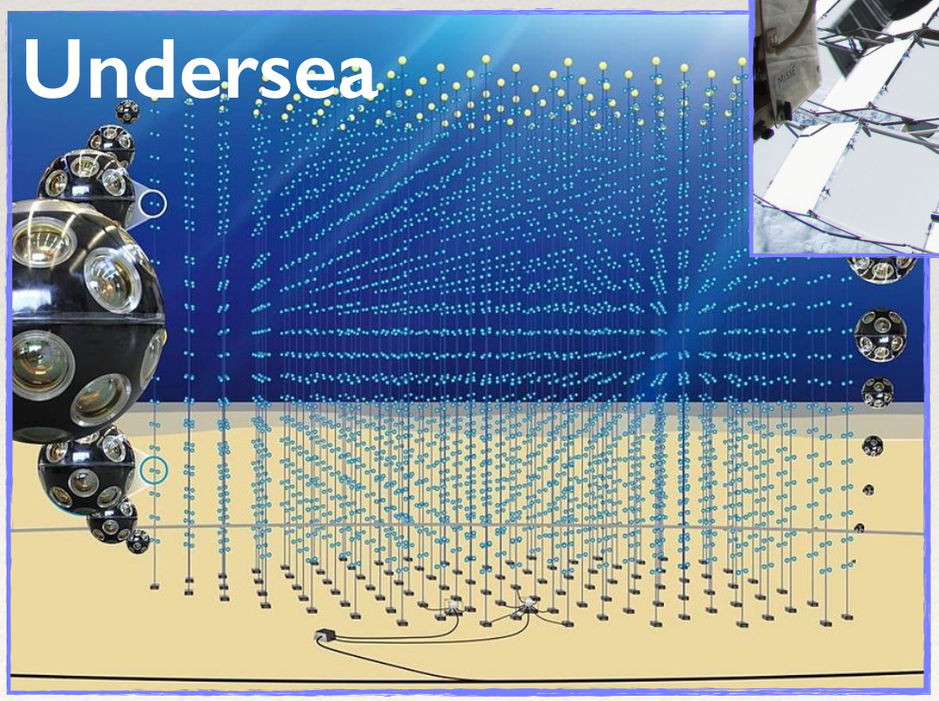
2015

- CSN2: **Astroparticle and Fundamental Physics**
  - 4 main areas of scientific activity (new structure, 2015)
    - 1) Neutrino Physics
    - **2) Radiation from the Universe**
    - 3) The Dark Universe
    - 4) Gravitational Waves, Gravity and Quantum Physics

Many diverse places







CSN2 and Cosmic Radiation

- **Cosmic Radiation** is a keystone of CSN2 activity
  - Related to <u>all fields</u> of interest of the CSN2

Neutrino Physics

Radiation from the Universe

Gravitational waves, Gravity and Quantum Physics

The Dark Universe

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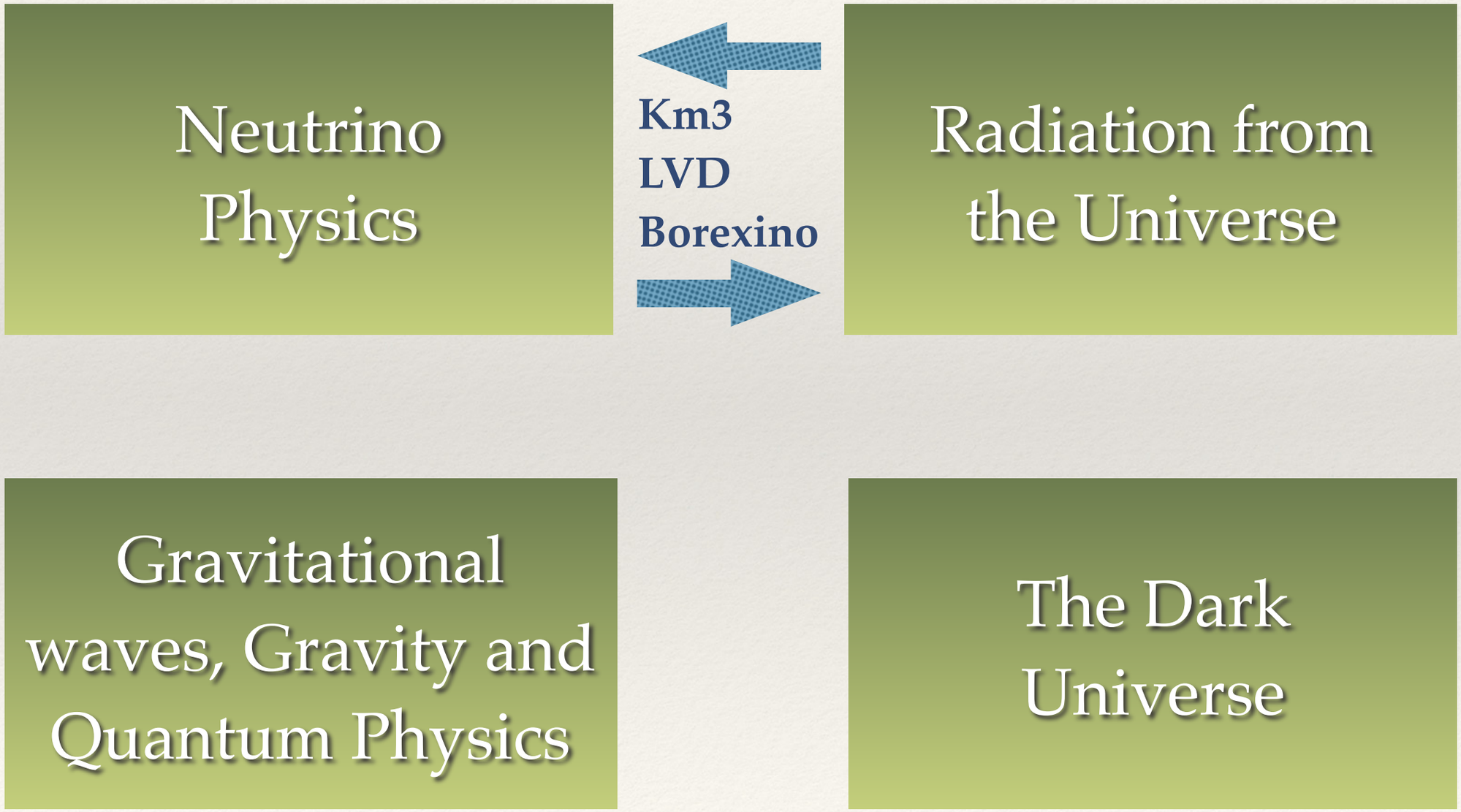

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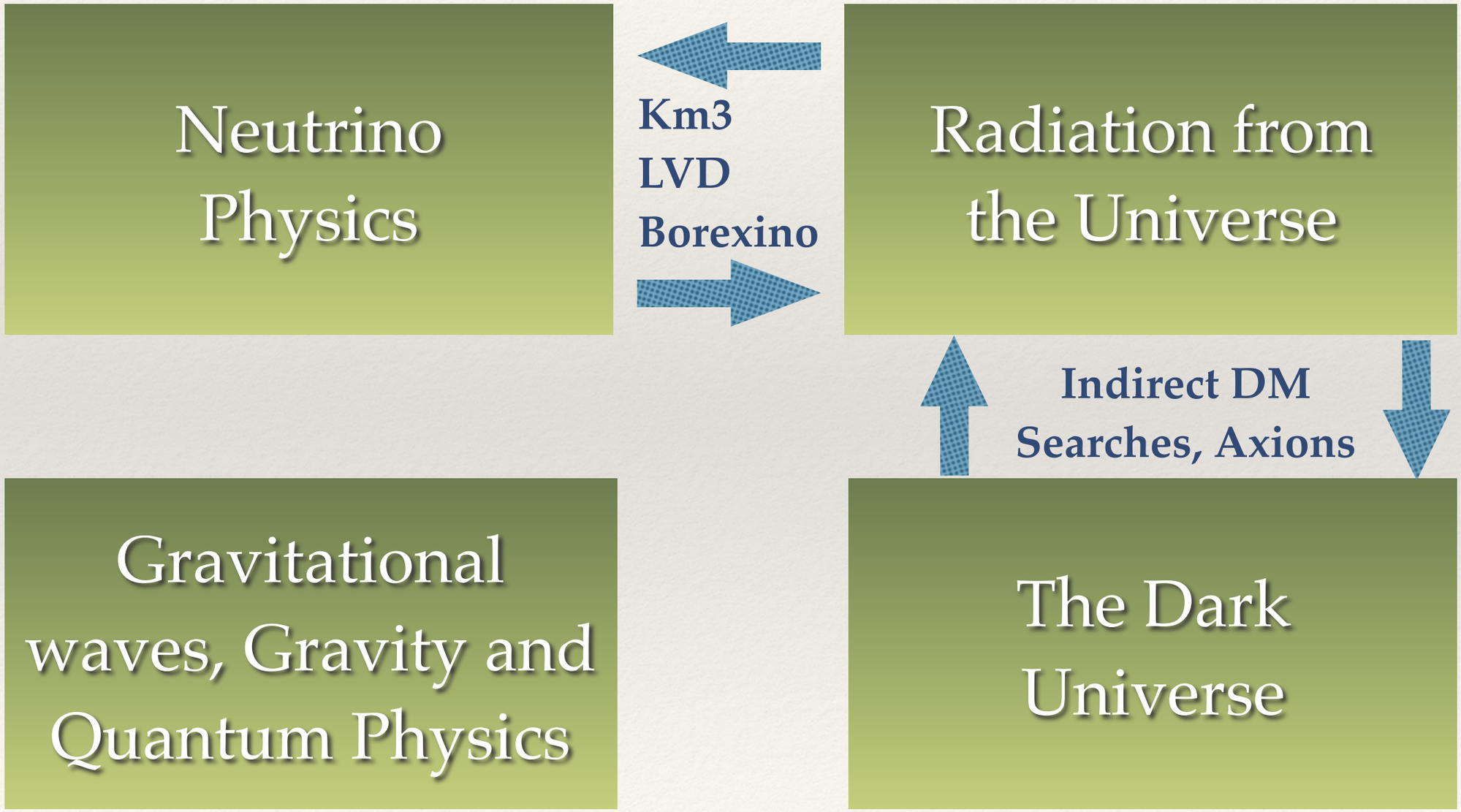

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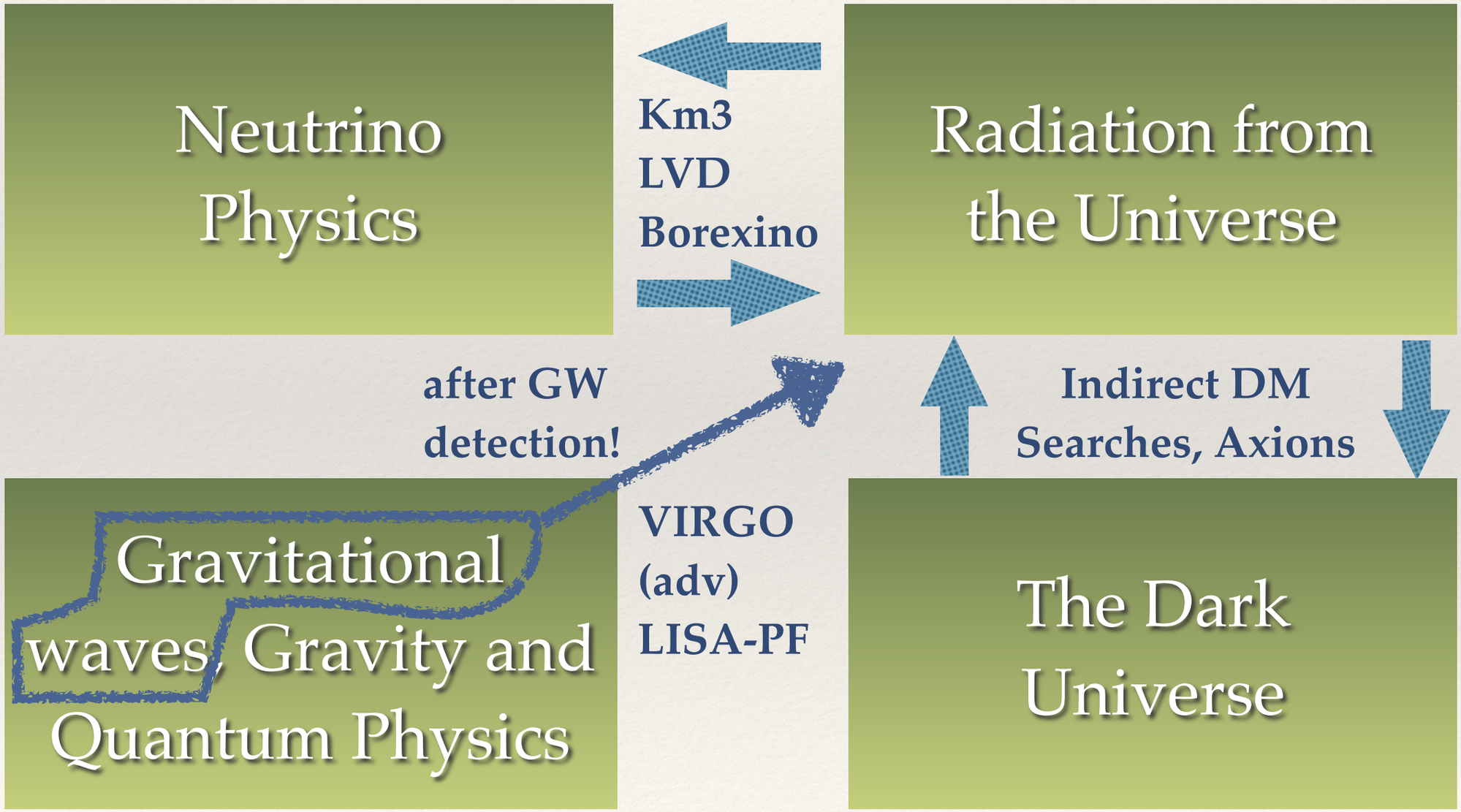
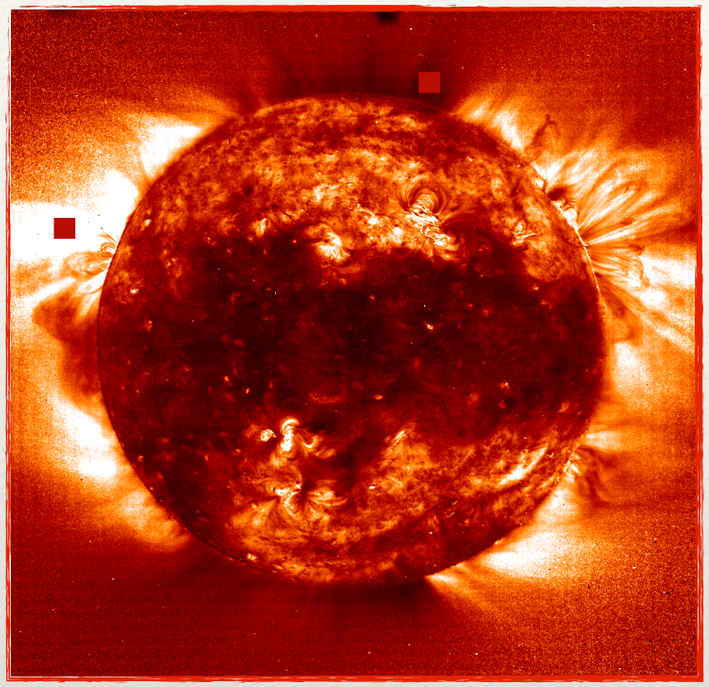


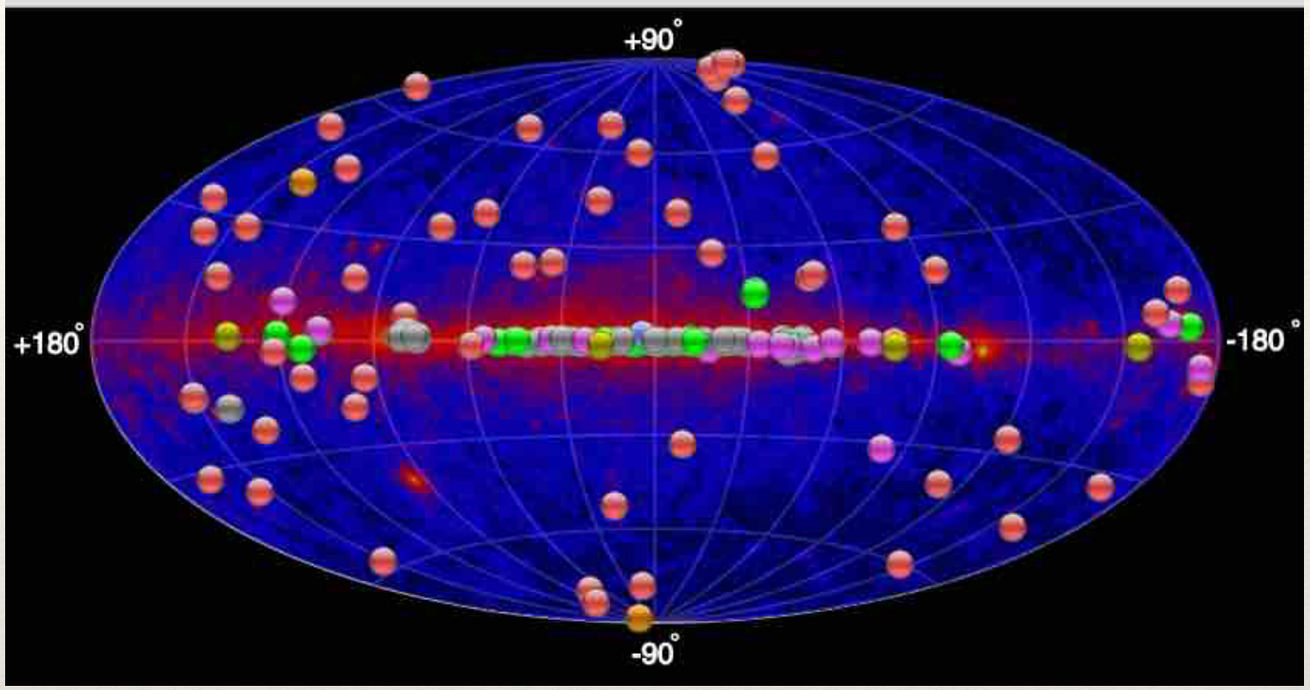
Toward the multi-messenger era: Work in Progress.....

STARS (Sun mostly)



- ✔ Photons (even ~100 MeV γ)
- ✔ Solar neutrinos
- ✔ SN neutrino burst
- ? SN neutrino diffuse
- ✔ Cosmic Rays (solar wind)

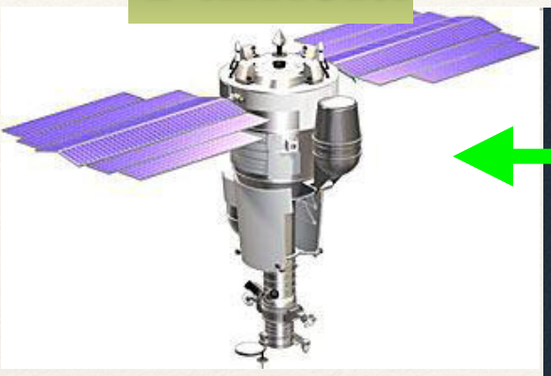
Compact objects, Unknown Objects, Diffuse

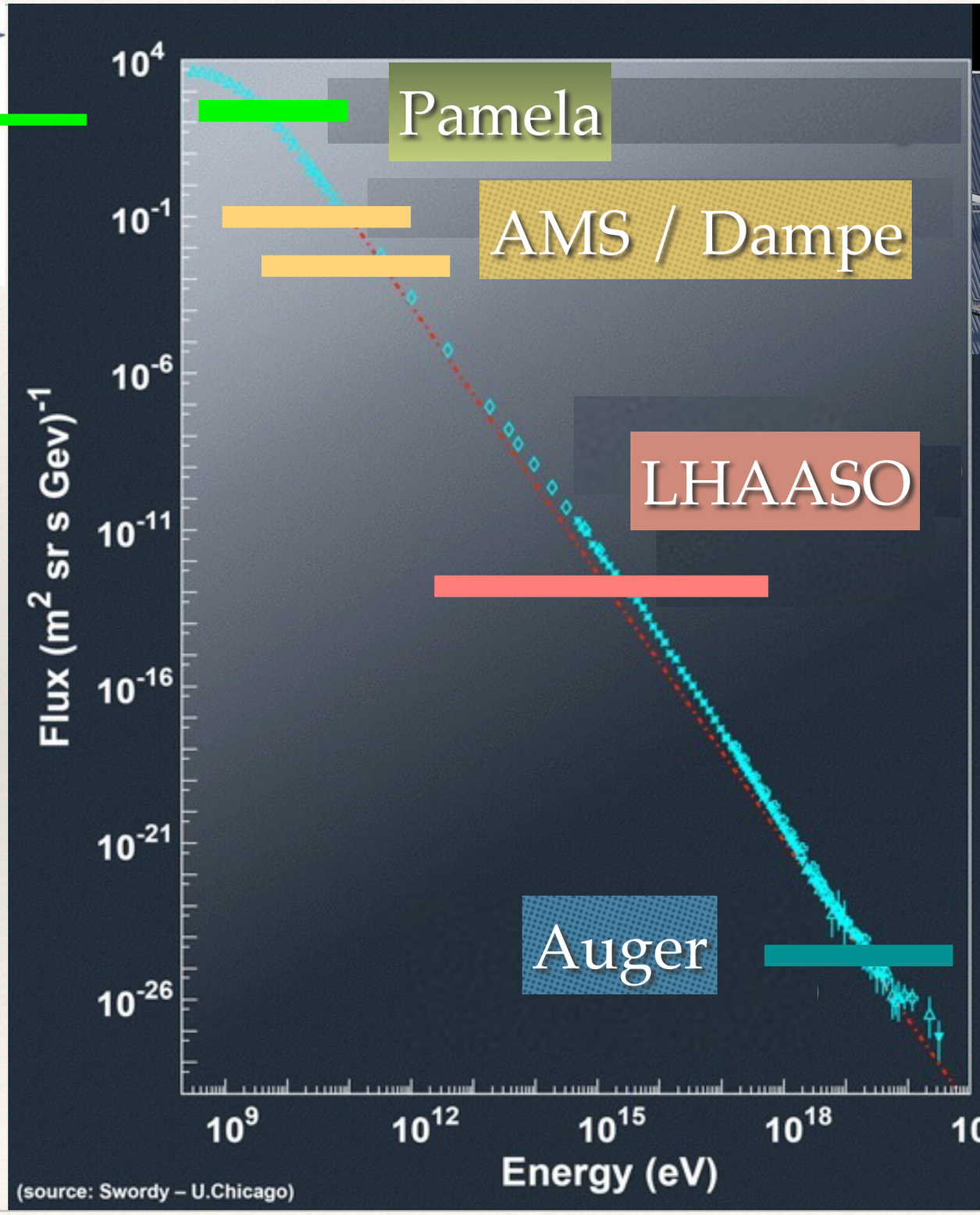


- ✔ Photons (from Radio to TeV γ)
- ? **PeV** photons
- ? **Neutrinos** ? PeV detected, No sources yet
- ? **Cosmic Rays** ? No clear sources yet
- ?? **Gravitational Waves** ? Only indirect detection
- ??? **Indirect Dark Matter Detection ?** Unclear
- ???? **Neutrino background.** No known path to it. (maybe indirect detection by EUCLID or similar)

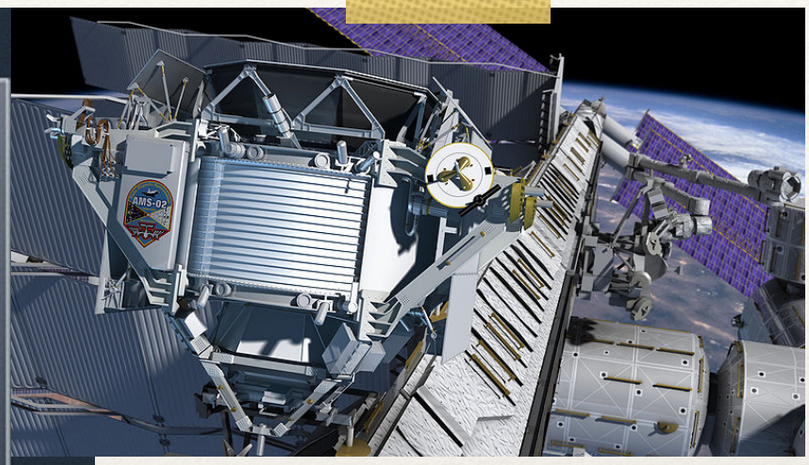
Charged particles: projects

Pamela

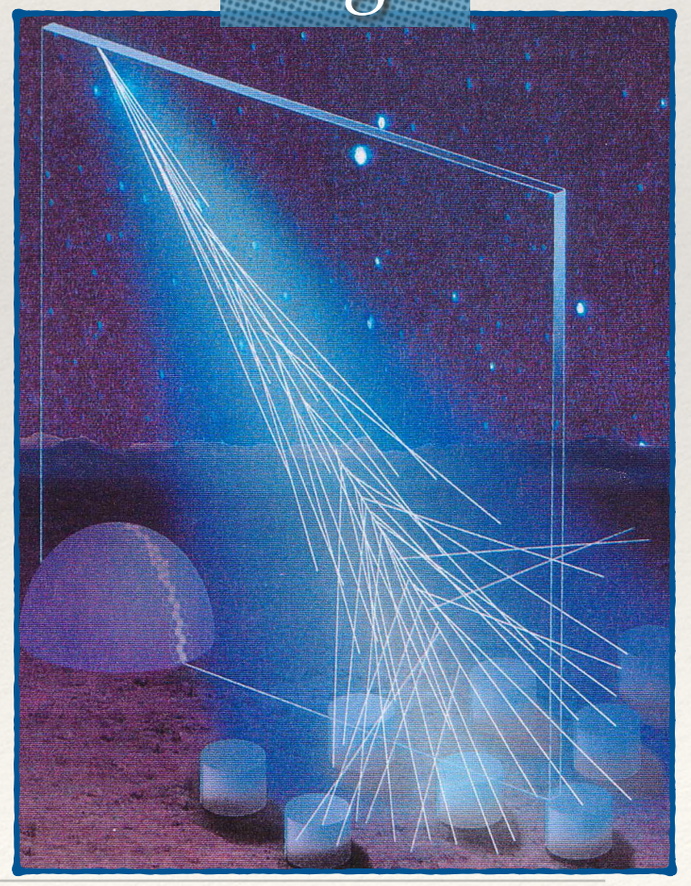




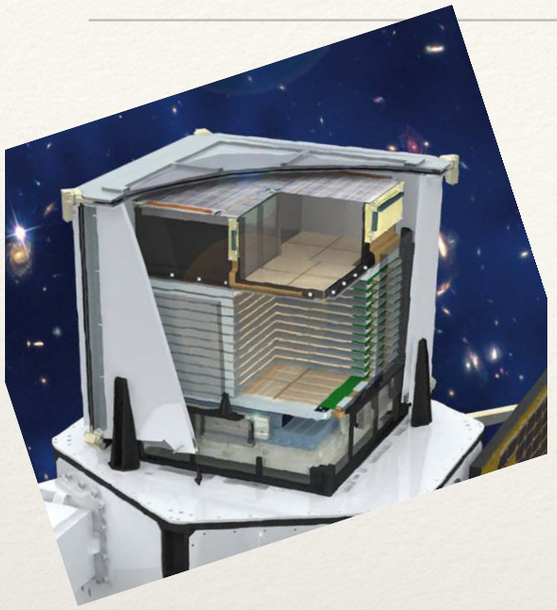
AMS



Auger



Flying detectors



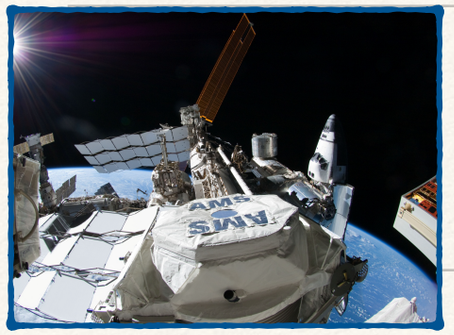
AGILE, 23-4-2006
Mainly X and γ

PAMELA, 15-6-2006
e+, e-, nuclei,
anti-p, anti-He

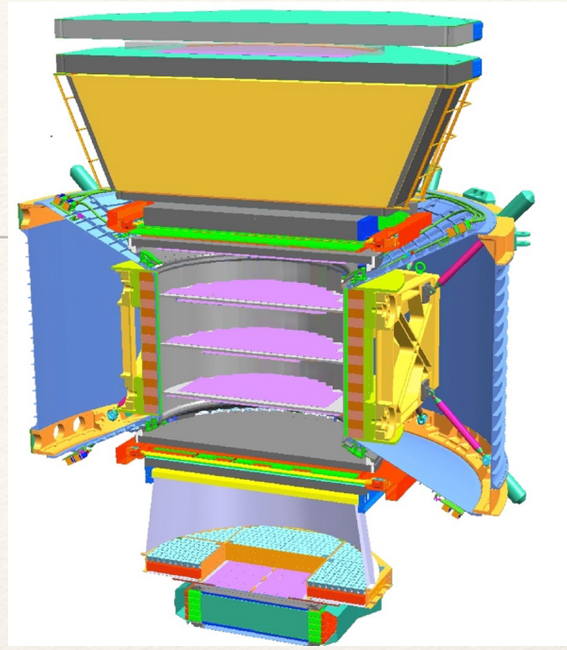
FERMI, 11-6-2008
Brand new γ sky,
but also electrons

AMS-02, 11-6-2011
Charged particles
up to 1 TeV

- 4 very successful missions with substantial Italian and particularly INFN contribution
  - Silicon detectors technology: know how from long standing accelerator experience
  - Data analysis, Detector simulations
  - Leading role on all projects

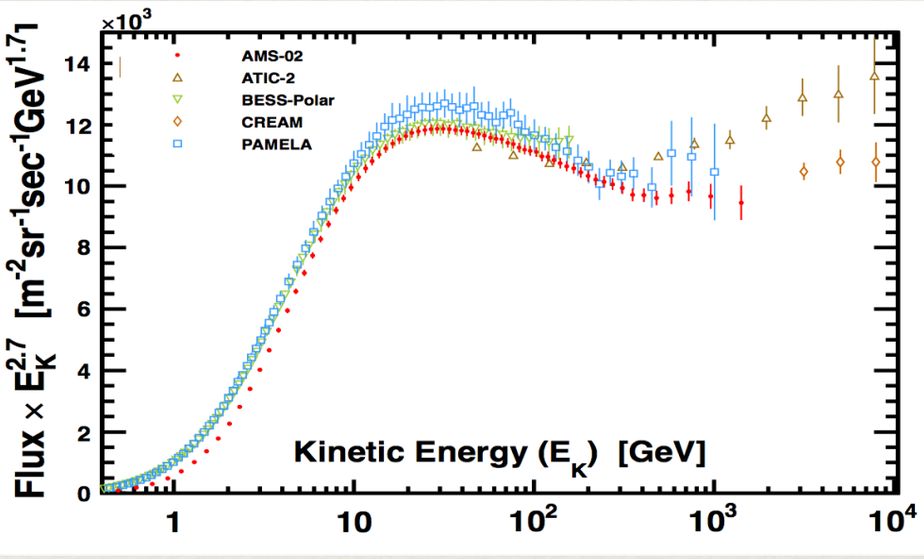


AMS-02

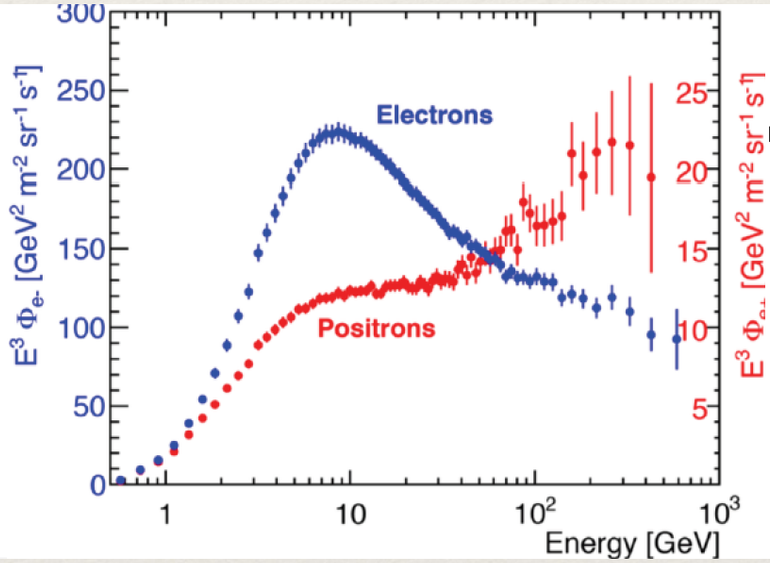


- 4 y of data taking (less than 50%)
  - **INFN support for 10 y (later we will see)**
  - An enormous amount of data

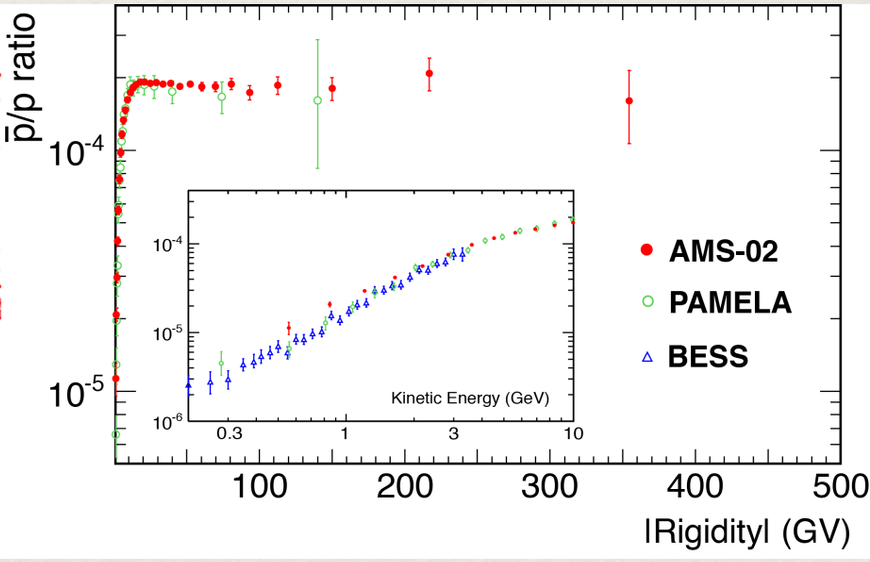
protons



electrons/positrons



proton/anti-proton



- Main effort in space until next generation

LHAASO

- Bridging direct space measurement with large ground based detectors

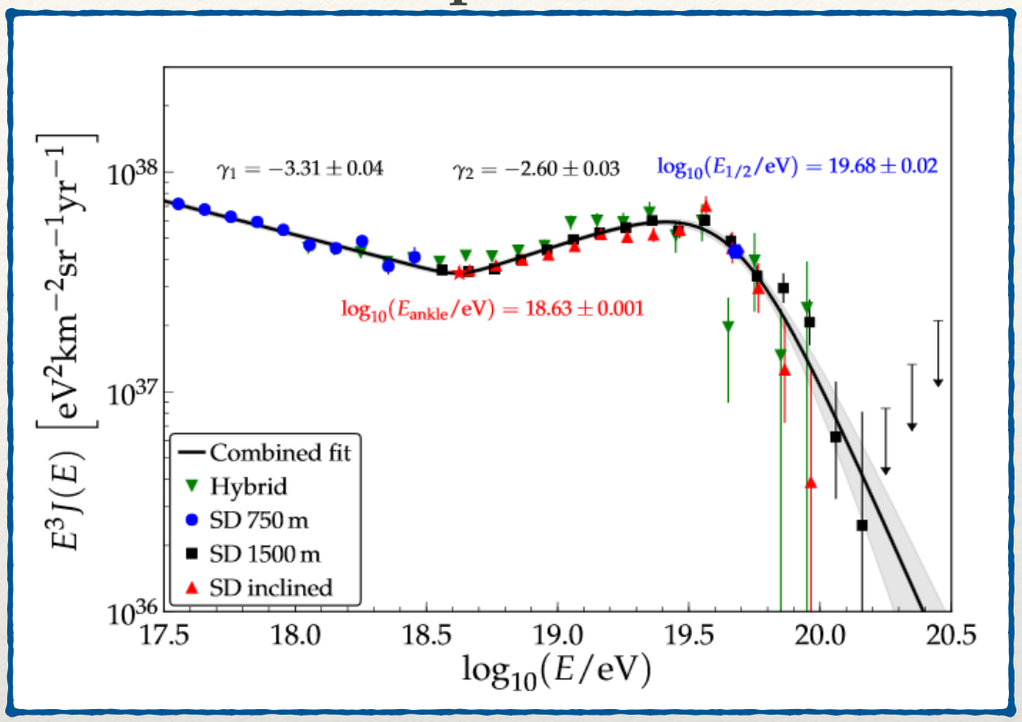
- **Goal 1: CRs around and above the knee 10^{12} - 10^{18} eV**
  - Understanding knee origin and disentangle galactic and possible extragalactic components
  - Composition around the knee is not understood completely, spectral index Z dependent
    - Simple diffusion models are challenged by data, and anisotropies are important

- **Goal 2: photons 10^{11} - 10^{15} eV**
  - Better or complementary to CTA for transients, GRB, all sky surveys, diffuse signal
  - Searching for PeVatrons (hot topic after PeV neutrino discovery)

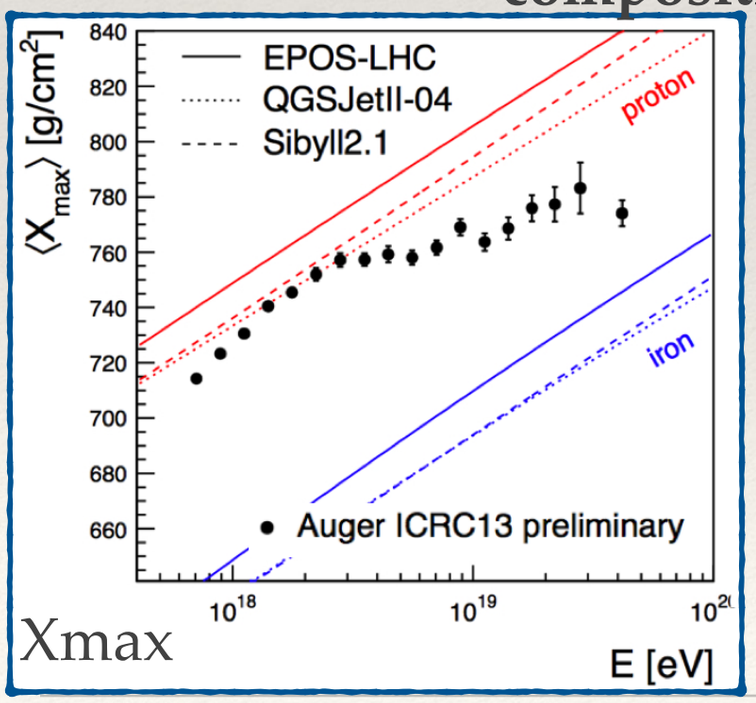
Auger (Prime)

- **AUGER** main result: **GZK works. Or not ?**
  - GZK or end of spectrum (maybe GZK in the sources)?
  - Heavy composition or systematics or new physics ?
  - Can we detect GZK photons ?
- Hardware upgrade to improve muon detection

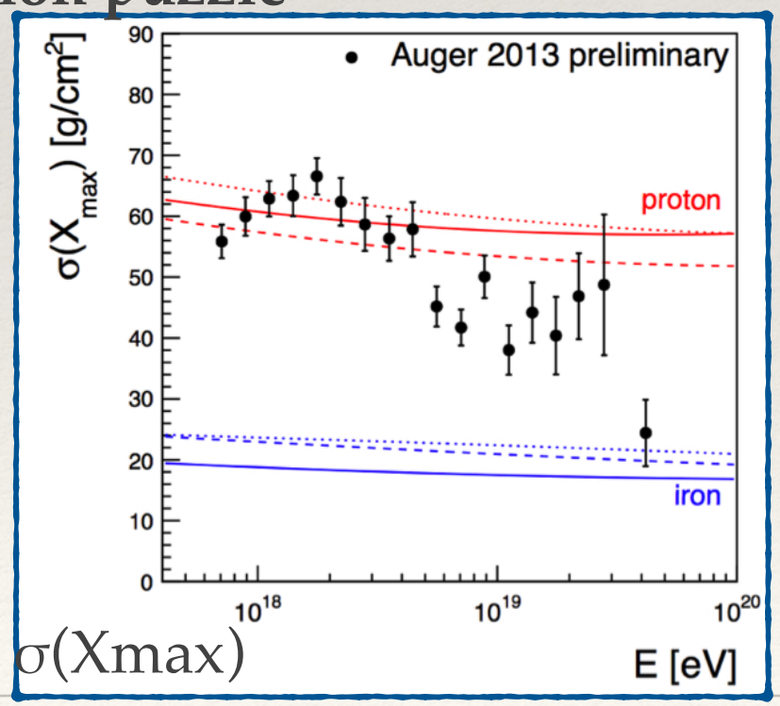
spectrum



composition puzzle

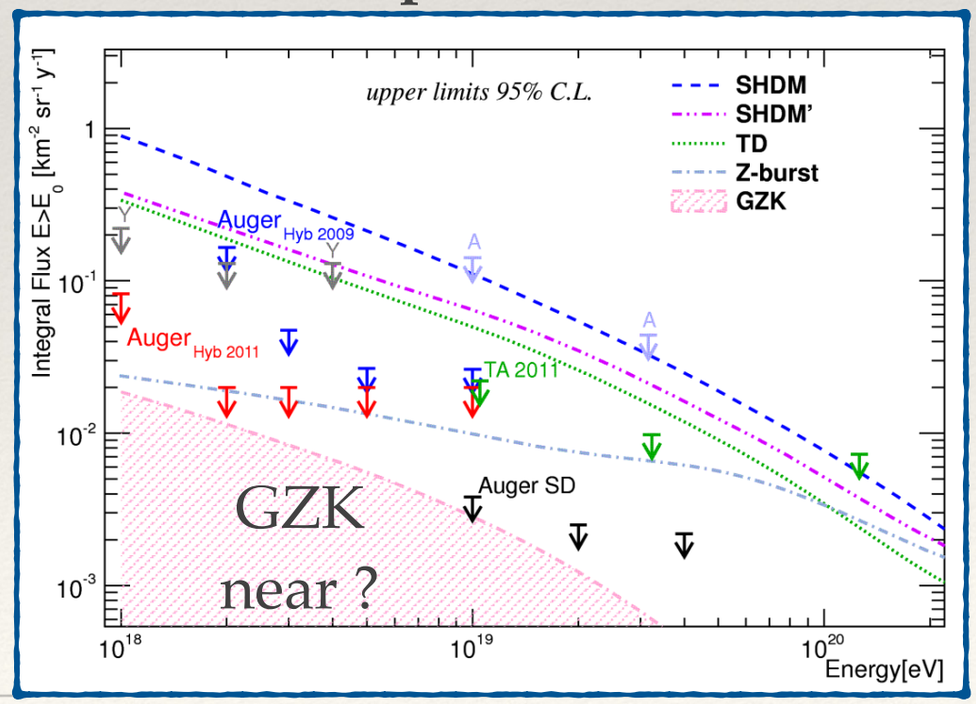


Xmax



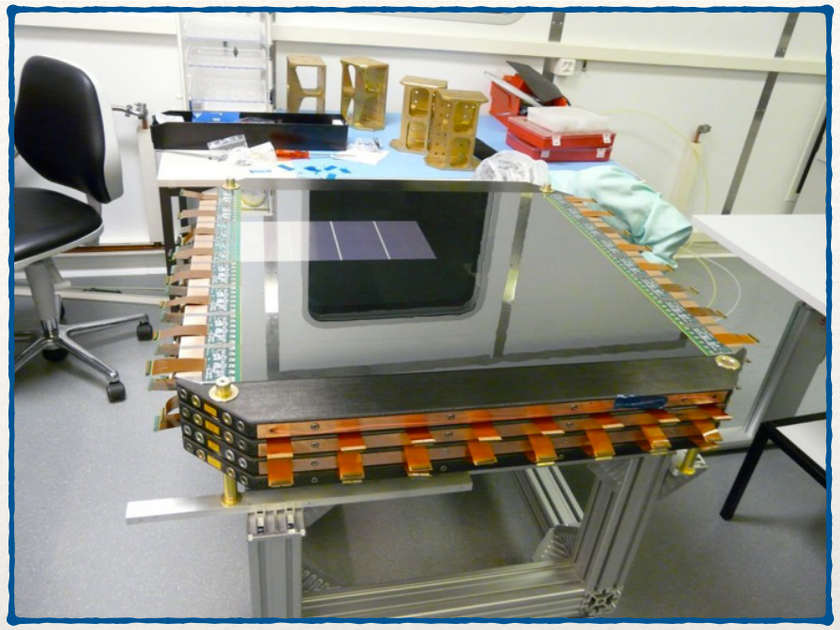
σ(Xmax)

photons



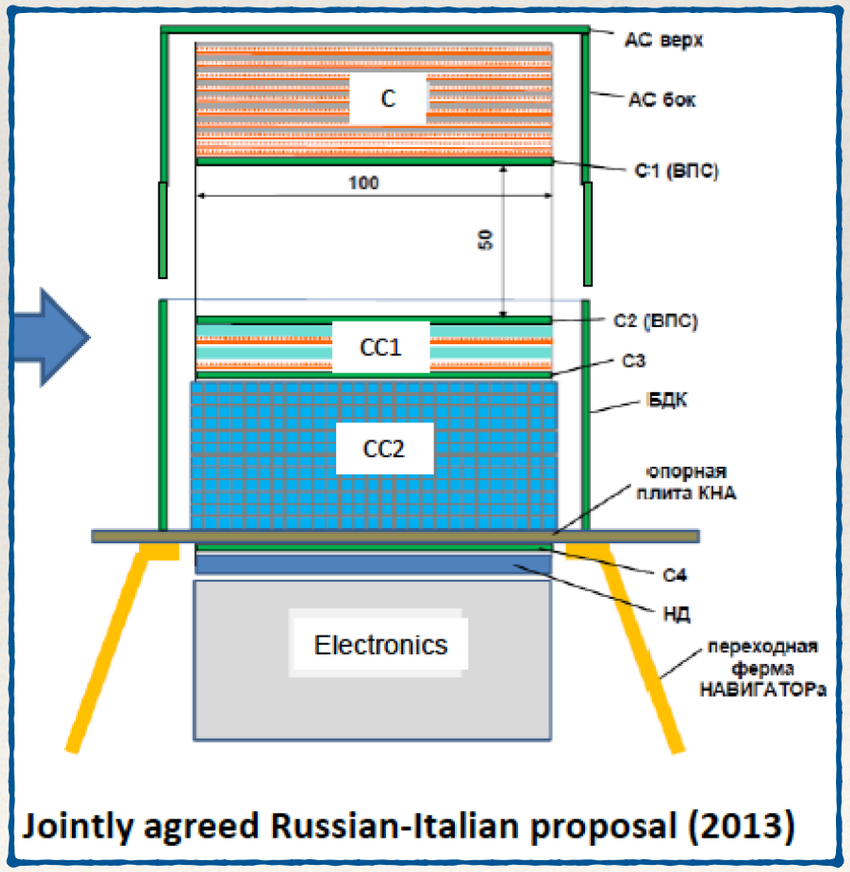
Future space detectors

- Follow up of Agile-Pamela-Fermi-AMS02
  - **Dampe**
    - Important synergy with CAS. Chinese fundings.
      - **2 GeV - 10 TeV e/γ** **30 GeV - 100 TeV CR**
    - Almost ready to fly



  - **Gamma-400**
    - Tracker + Innovative calorimetry (calocube)
      - **100 MeV - 1 TeV e/γ** 2% energy resolution, **10 TeV e⁻**
        Light nuclei up to the knee 1000 TeV
        - Excellent hadron / electron separation
      - **High acceptance calorimeter**

  - **HERD**
    - INFN R&D effort just starting now



Jointly agreed Russian-Italian proposal (2013)

Charged particles: future prospectives

- UHECR: **AUGER-Prime**
  - Are there protons or nuclei or both ?
  - End of spectrum or GZK ?
  - Do we understand primary interaction physics ?

Status
- ok in principle
- negotiation in progress

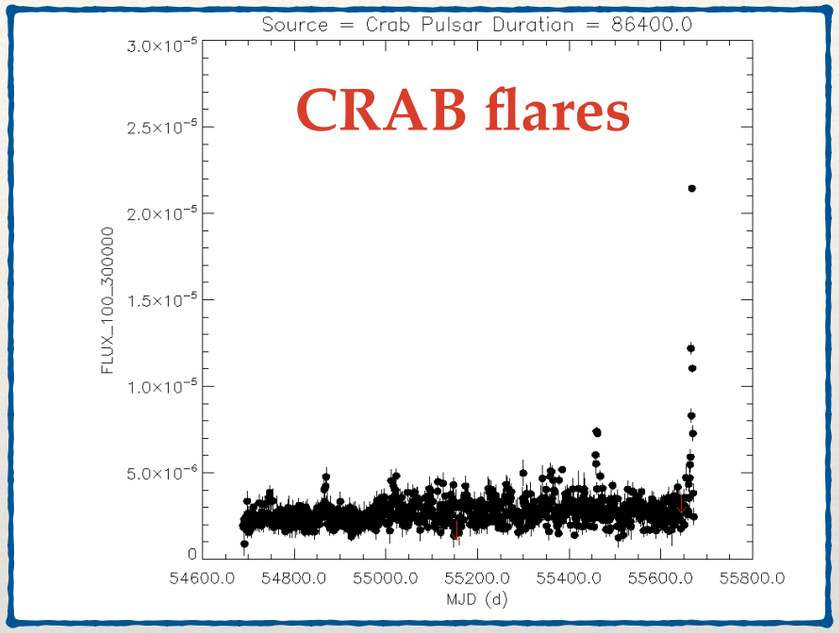
- **LHAASO**
  - Knee composition and spectral indexes
  - Light nuclei from extragalactic origin ?
  - Complementary to CTA on Photons

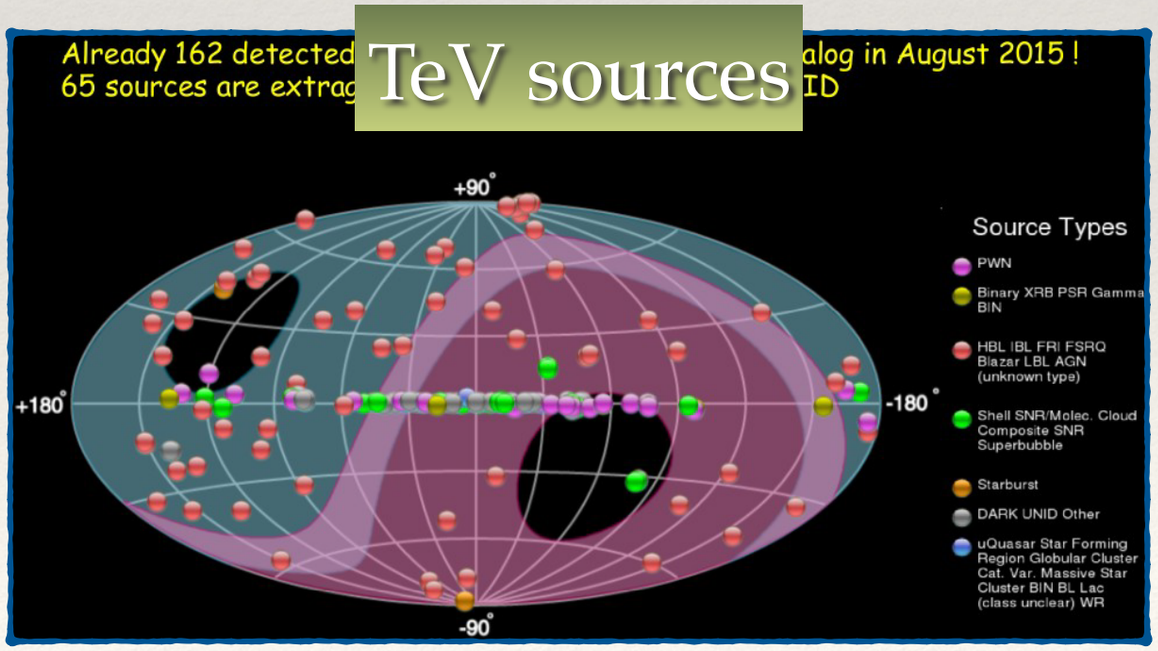
Status
- under discussion

- **Space: what next ?**
  - **DAMPE ready to go.**
  - **Future: Herd or Gamma-400 ?**
    - Current effort on Gamma-400. Herd R&D effort just starting now
    - Unlikely we fund both. No decision yet. It will depend by community / finance / launch opportunities

γ sources and diffuse: science

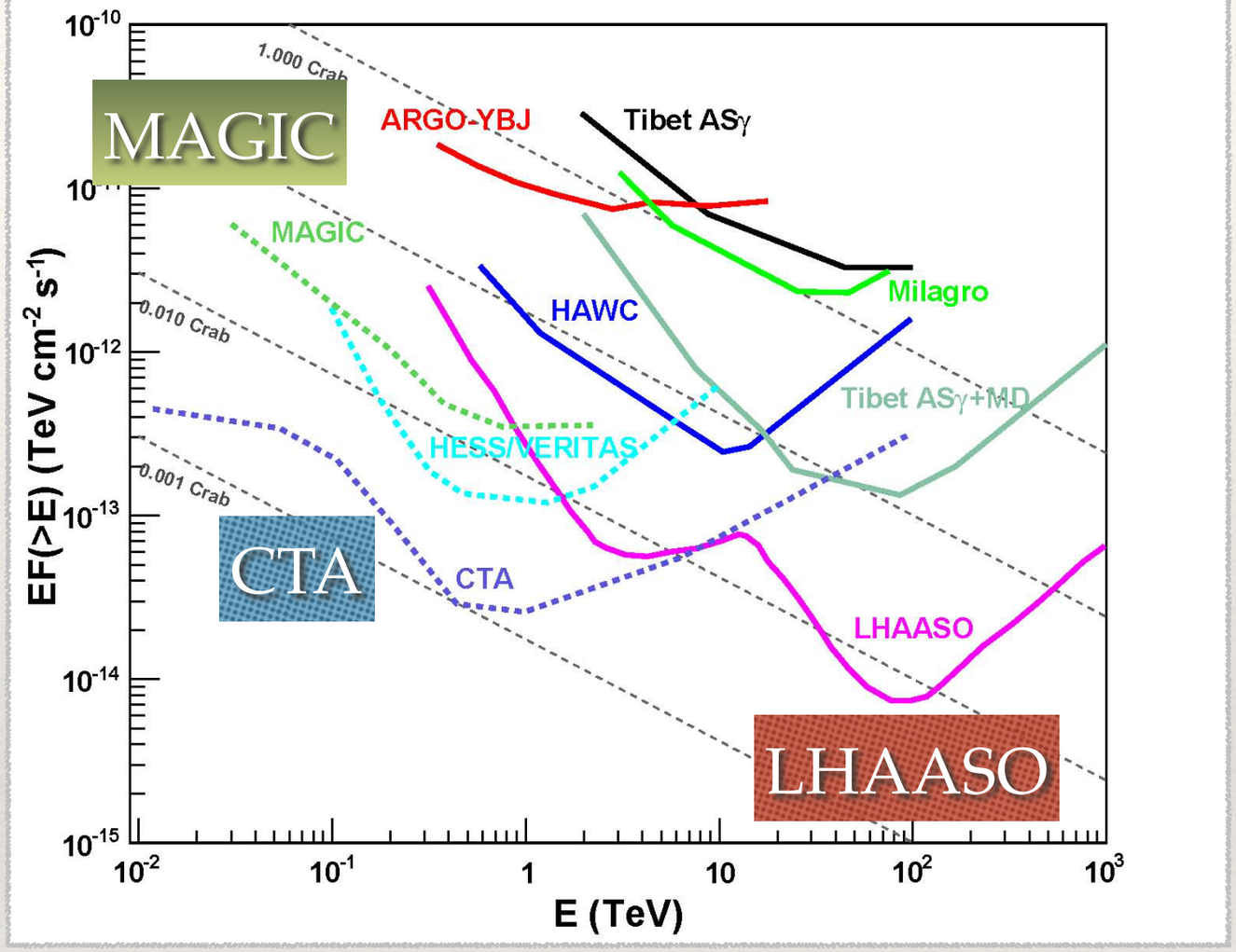
- The γ sky is rich, variable, galactic and extra-galactic
  - Old faithful stable CRAB is gone…
  - Fermi has changed completely the picture in the GeV - 100 GeV range
    - Pulsars, GRBs, SNRs, …
  - Many TeV sources found, potential CR acceleration sites
    - Neutrinos suggest Pevatrons must exist
  - Sensitivity for DM searches new physics, quantum gravity





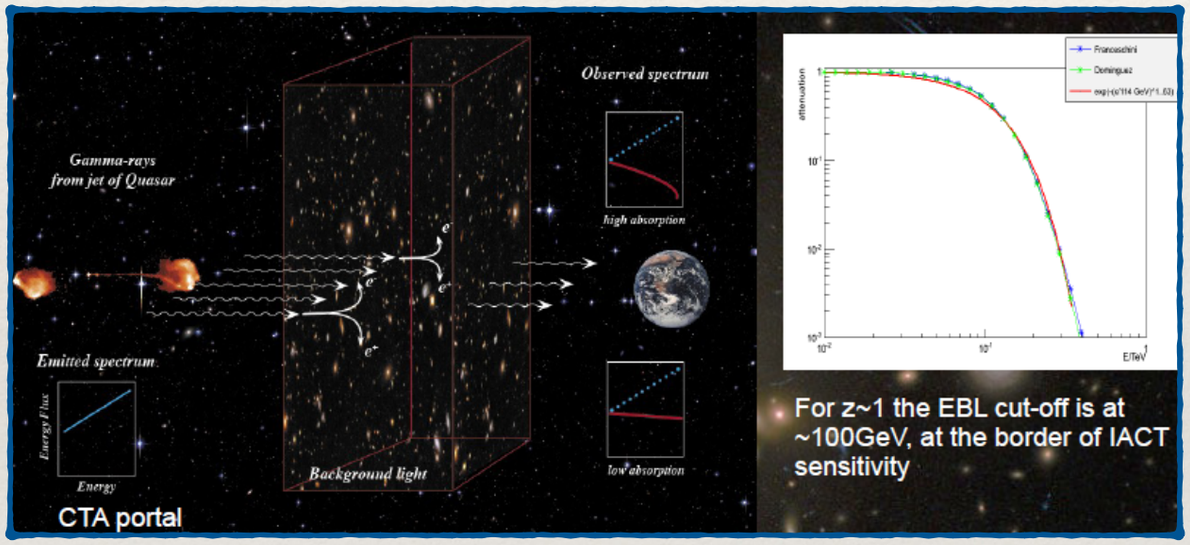
H.E. γs from ground detectors

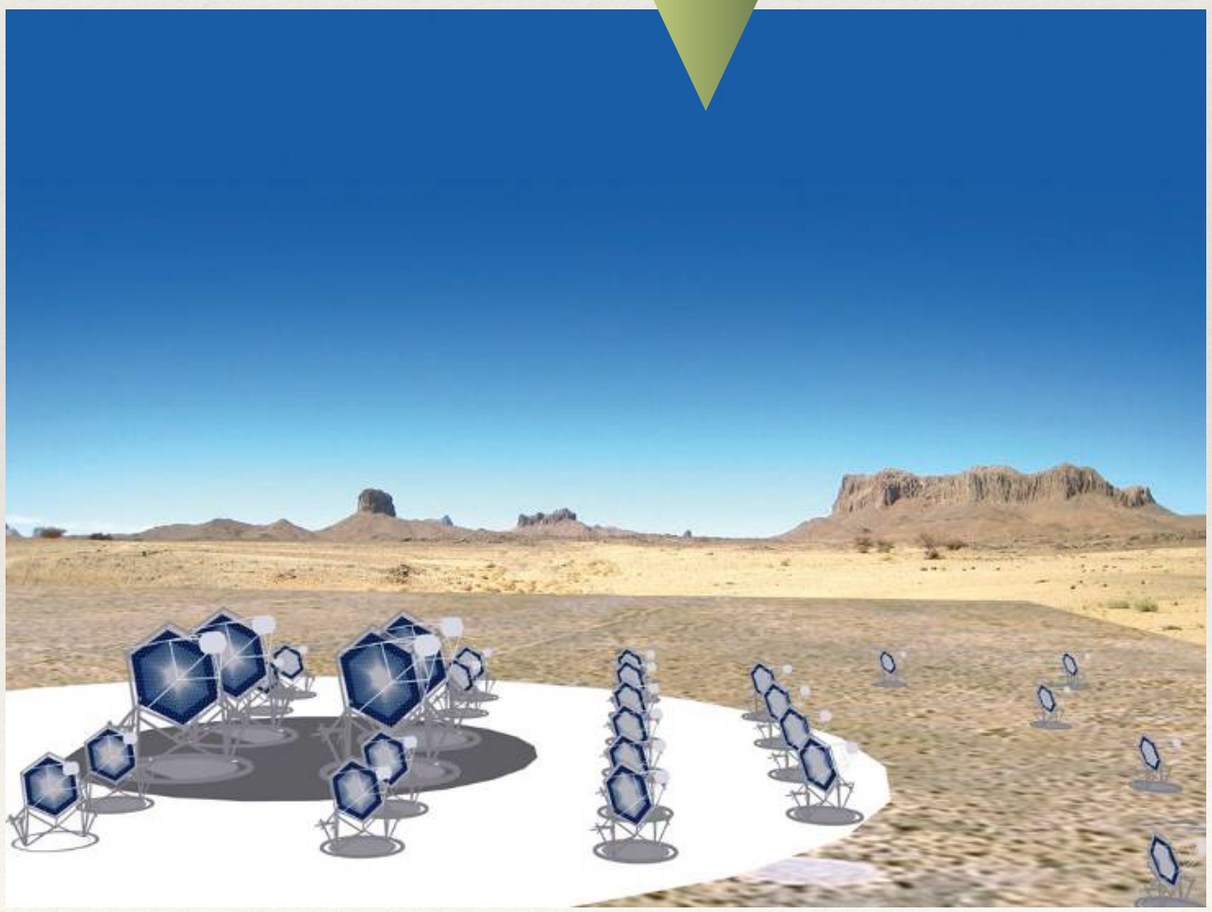
- **MAGIC**
  - **Running**, recently improved trigger, threshold down to 35 GeV
  - INFN support till beginning of CTA
- **CTA**
  - Pointing observatory 100 GeV - 100 TeV
  - Agreement with INAF for a coherent Italian effort (special fundings to INAF)
  - INFN scope: trigger, electronics for LT
  - Building on MAGIC experience: Canary Islands site approved besides Chile !
- **LHAASO**
  - Large FoV and duty cycle
  - More sensitivity above 10 TeV and knee CR physics too
  - Complementary with CTA with better sensitivity at high energy and transient detection capability
  - Scope: physics, simulations, analysis: building on ARGO experience



From Magic to CTA

- Present: Magic with 2 γ telescopes in Canaries
  - Reduced threshold down to 30 GeV
  - Most distant γ source ever observed
  - Gravitational lensing with H.E. γ





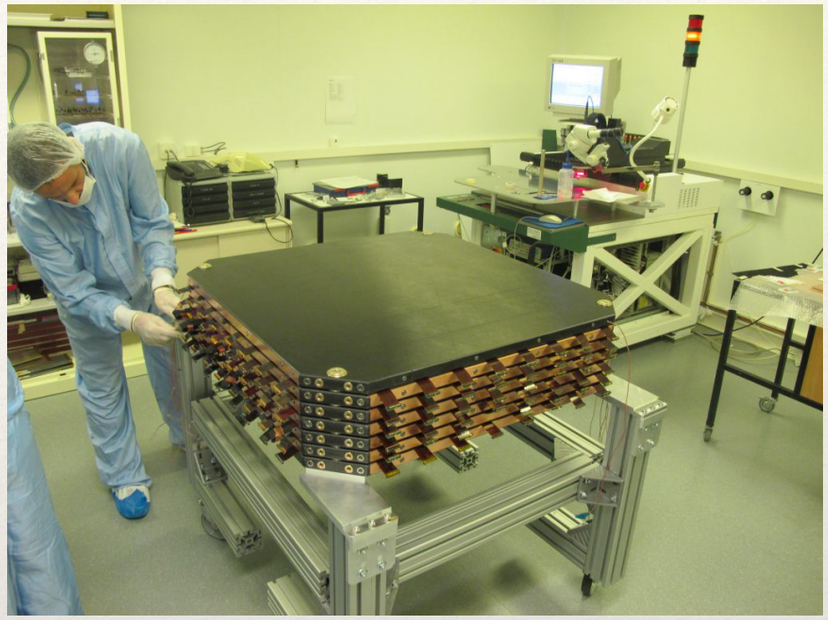
- The future is CTA, a Global project
  - Large Italian effort INAF + INFN
    - INAF already joined GmbH, INFN will do soon
  - Chile and Canaries sites selected
    - Good synergy with ESO and MAGIC sites

γ from space detectors

- INFN support to **Fermi** ok till 2018
  - New contract with ASI in progress.

- **DAMPE**: extension of energy range up to 10 TeV
  - Launch Dec. 2015

DAMPE tracker

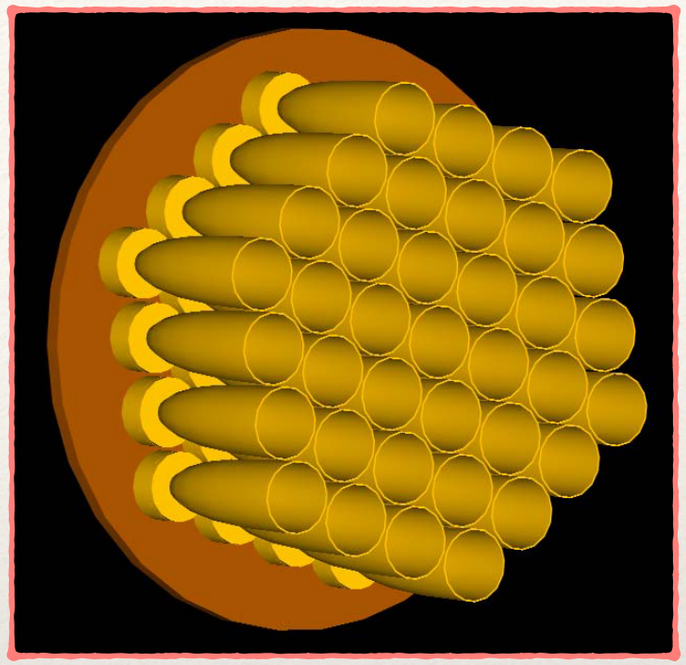


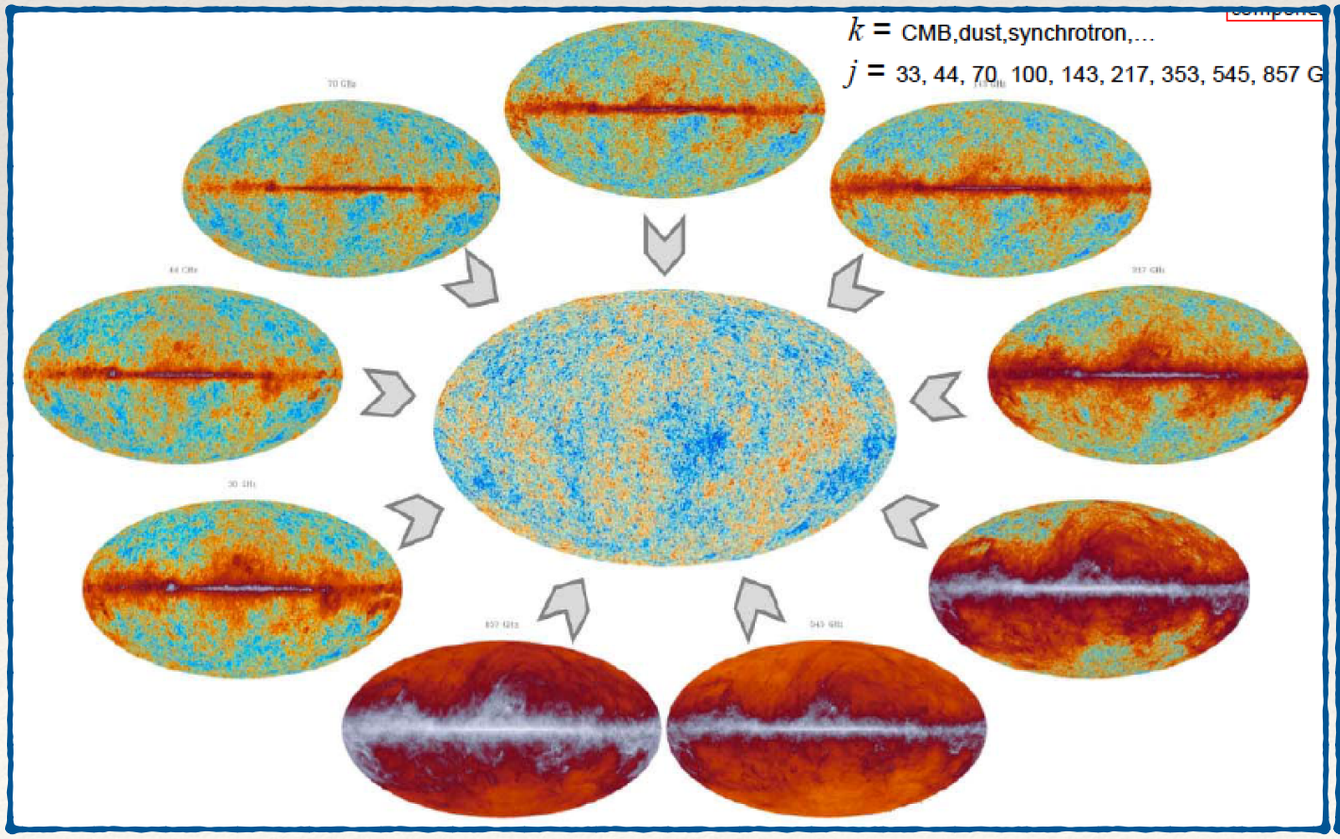
- **Polarisation (astro-particle related)**
  - **X-rays: new polarimeters developed in Pisa.**
  - **LSPE:** balloon mission for CMBR polarisation benefit from INFN technology on micro-bolometers

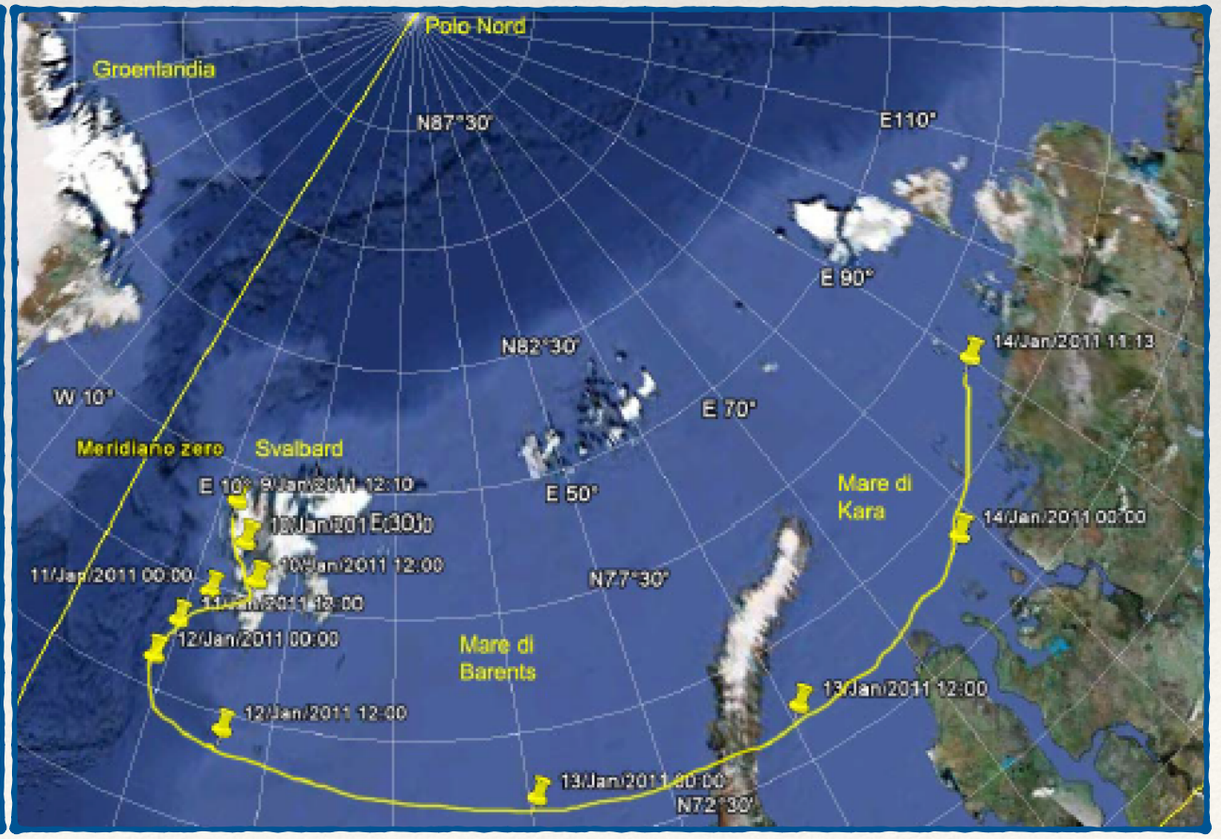
- X-rays physics. A tool for understanding sources
  - LOFT: Did not go through yet, but strong INFN interest

Polarised CMBR

- LSPE: Large Scale Polarisation Explorer
  - Multifrequency B mode search with a balloon instrument
  - Neutrino technology (bolometers) + TES + KIDS
    - **5 channels** (40 - 250 GHz) on a rotating detector
    - Angular resolution 1.5°-2.3° Sky coverage: 20-25%
    - Sensitivity: ~ **10 μK** equivalent noise





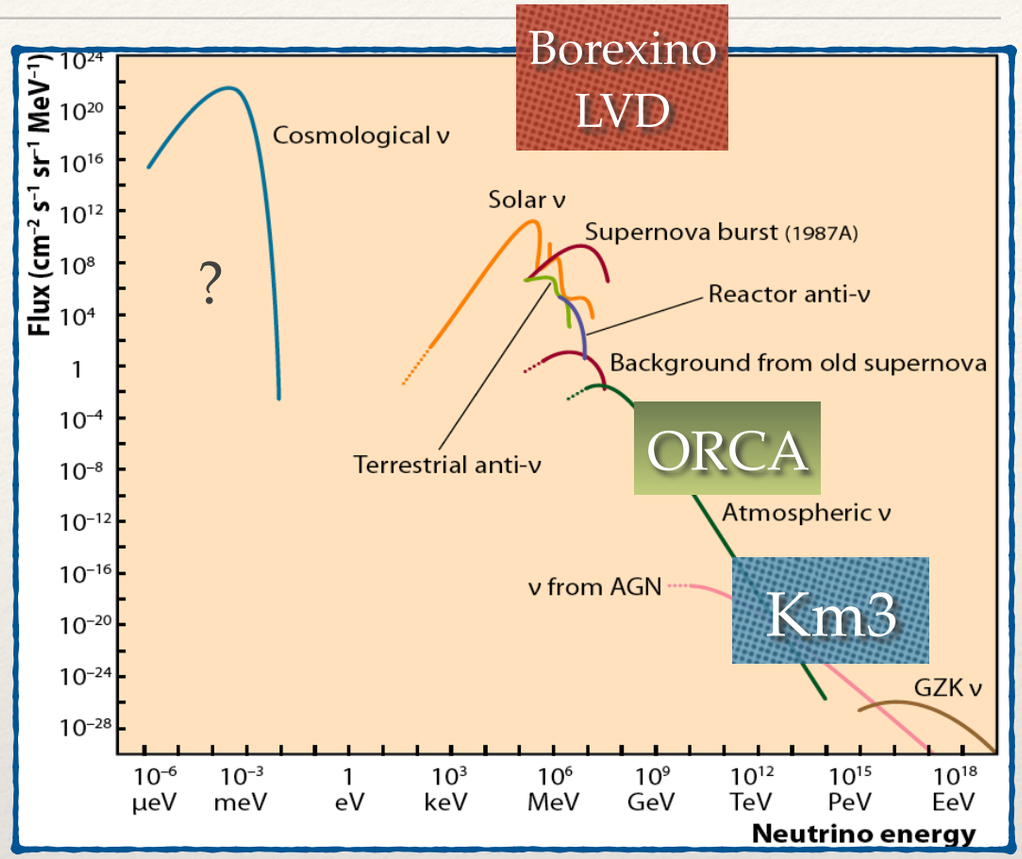


High energy neutrinos

- After **Ice Cube discovery,** increased interest for a high energy neutrino observatory in the Mediterranean
  - 24 M€ investment close to completion.
  - 8 towers and xx strings will be deployed in water in 2015/2016
  - New fundings necessary to complete
- Synergy with Toulouse site on ORCA
  - ORCA may find neutrino hierarchy
  - Waiting for good news from France

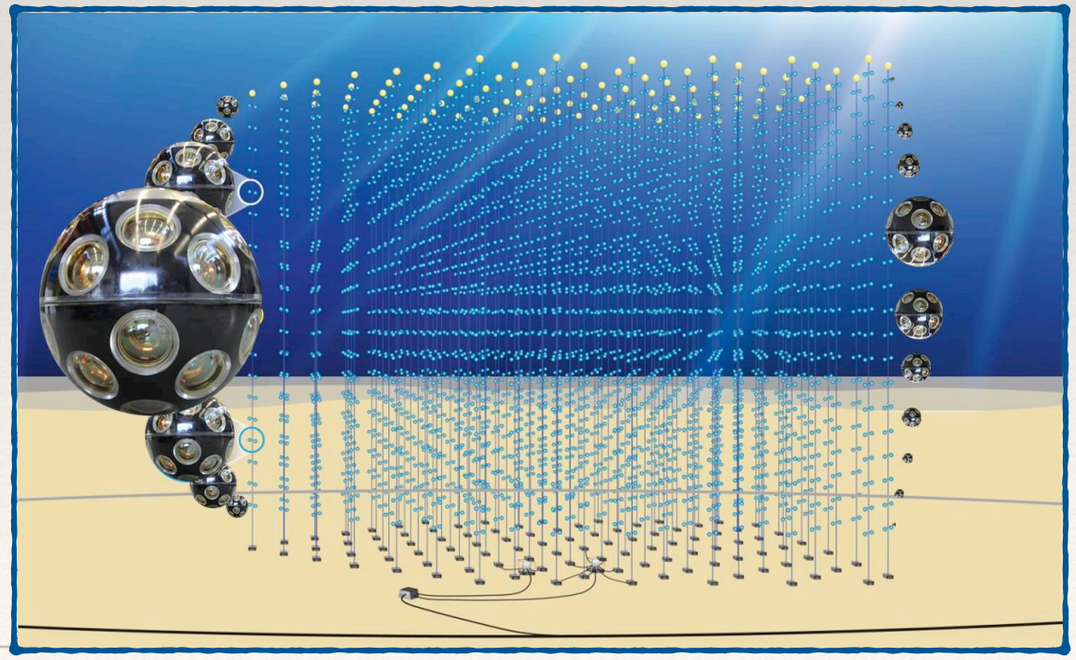
Neutrinos

- Low energy neutrinos (solar, SN, terrestrial) covered by Borexino / LVD at LNGS
- **Deep sea detectors for:**
  - Neutrino astronomy in the Mediterranean: **Km3Net**
  - Atmospheric neutrinos (hierarchy): **ORCA**
- Both **high priority,** only partially funded so far
  - Work in progress



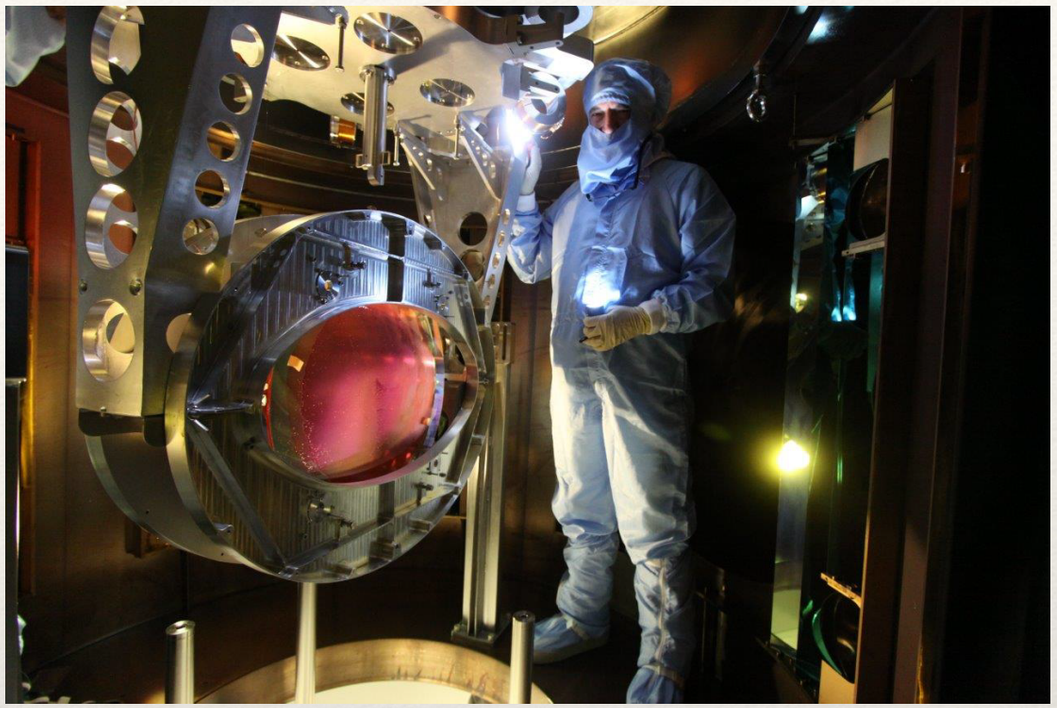
Tower (2014)

Optical Module



Gravitational waves

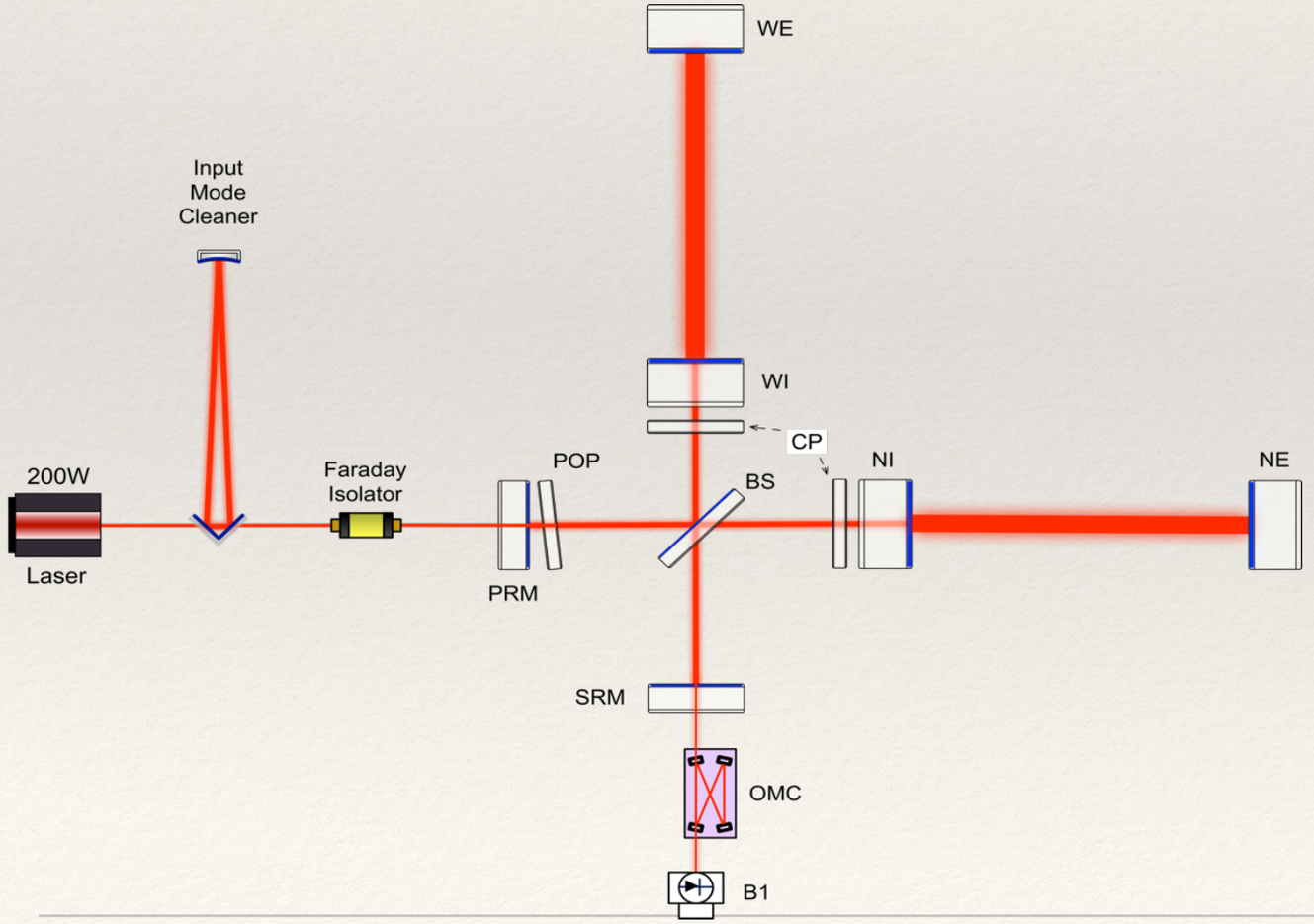
- **Step 1: we need discovery!**
  - **Virgo-Ligo** Adv. program almost ready to go



- **Step 2: Birth of GW astrophysics**
  - How many events with Adv detectors ?
    - Large uncertainty: 0.4 < events < 400 y
  - Future
    - Einstein Telescope for relatively high frequency observatory
    - LISA-PF ready for launch: key step toward low frequency observatory
- Multi-messenger observation with GW might be real in the next decade
  - Joint effort with optical, radio, γ, neutrino detectors
- R&D effort for new technologies (atom interferometry on ground or space)

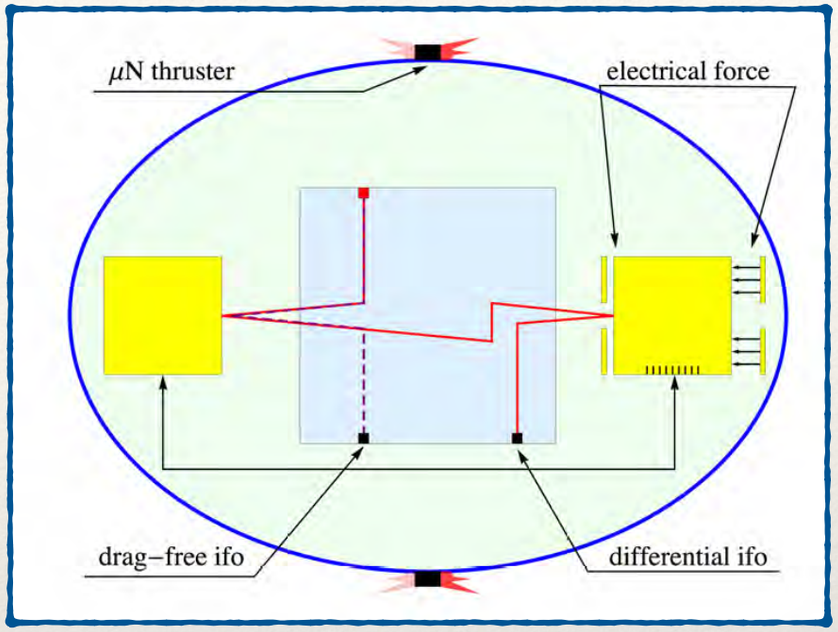
Virgo Advanced

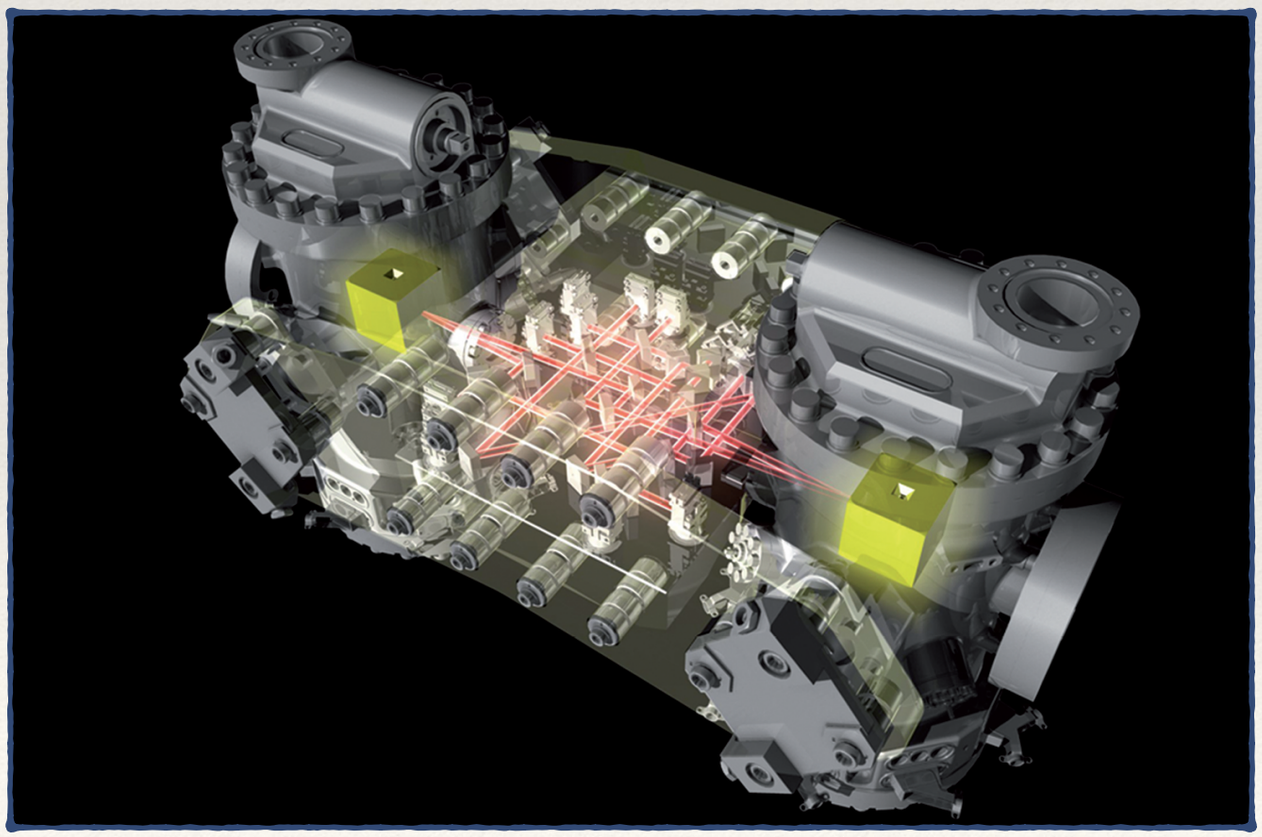
- One of the main INFN efforts
  - EGO + CSN2
  - Strong synergy and agreement with LIGO
  - ~ 8M€/y
  - We must find waves …… Ready for data in 2016

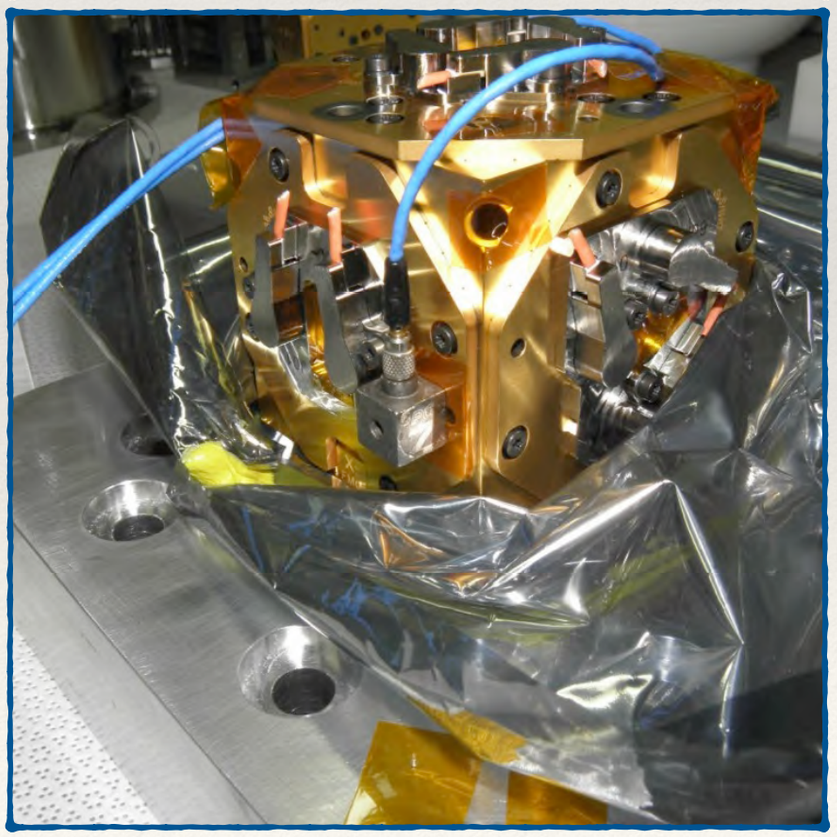


LISA-PF

- Goal: **validate the concept of "no-touch" satellite**
- Two Au-Pt masses in the same satellite
  - One free falling, the second one controlled by low-frequency electrostatic system
  - Launch in Dec. 2015







Conclusions

- A rich menu of activities cover all potential messengers now or in the near future
  - Photons from micro-wave to γ
  - Charged from GeV up to GZK
  - Neutrinos from 100 keV up to GZK
  - Gravitational waves still missing detection, but we are ready for that

- A strong program toward true multi-messenger observations for:
  - Astrophysics
  - Cosmology
  - Dark Matter Search
  - New physics and Unexpected results