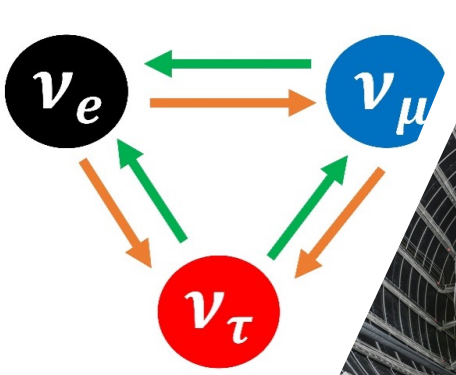
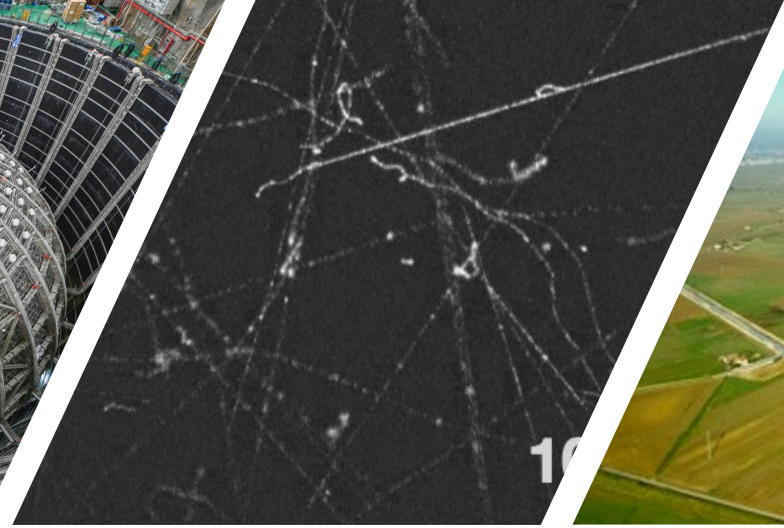


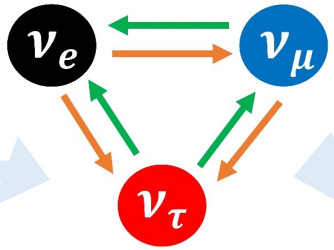
25th 1998-2023 INFN ROMA TRE

# la Fisica “senza gli acceleratori”

Ricerca di
Materia Oscura

DARKSIDE

CYGNO Experiment




JUNO

LEGEND

Neutrini

VIRGO

ET EINSTEIN TELESCOPE

Esperimenti per onde gravitazionali

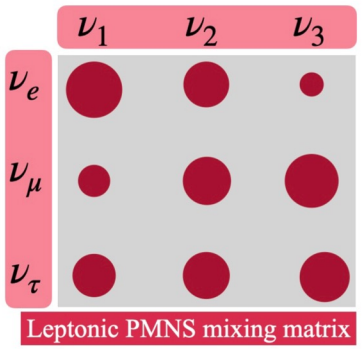
# The Flavor Problem: a question of numbers

## Mass hierarchies

$$m_d \ll m_s \ll m_b\,, \quad \frac{m_d}{m_s} = 5.02 \times 10^{-2}, \quad \frac{m_s}{m_b} = 2.22 \times 10^{-2}, \quad m_b = 4.18 \text{ GeV};$$

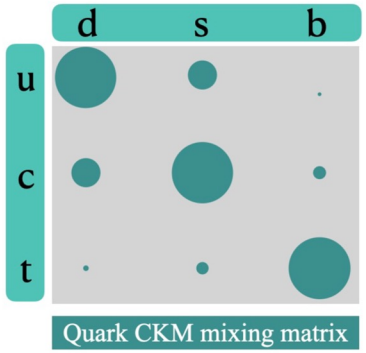
$$m_u \ll m_c \ll m_t\,, \quad \frac{m_u}{m_c} = 1.7 \times 10^{-3}, \quad \frac{m_c}{m_t} = 7.3 \times 10^{-3}, \quad m_t = 172.9 \text{ GeV};$$

## Fermion mixing



Leptonic PMNS mixing matrix

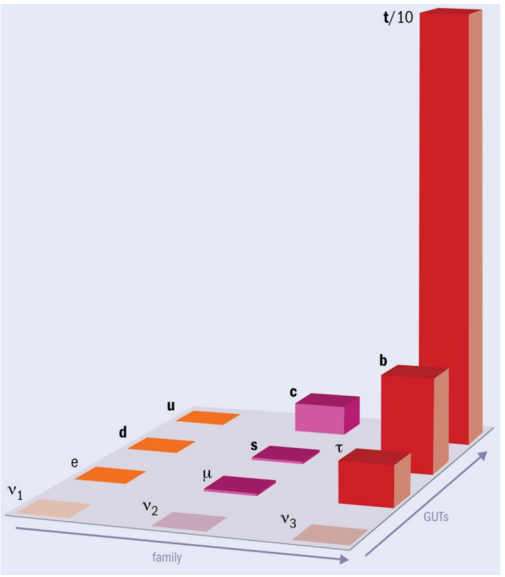
all mixing are large but the 1,3 element



Quark CKM mixing matrix

almost a diagonal matrix

very small neutrino masses




Numbers NOT predicted by the SM:

***New ingredients are needed***

# **The Flavor Problem:** some popular suggested solutions

- **(Old) Good ideas**

Smallness of neutrino masses:

***See-saw*** mechanism:

SM ⊕ heavy sterile neutrinos with mass $M_R$ $\quad m_{light} \sim \frac{(vev_{SM})^2}{M_R}$

**BUT no clue on mixing**

Mixing angles:

SM ⊗ flavour symmetries

**PMNS=** $\begin{bmatrix} 0.799\ldots0.844 & 0.516\ldots0.582 & 0.141\ldots0.156 \\ 0.242\ldots0.494 & 0.467\ldots0.678 & 0.639\ldots0.774 \\ 0.284\ldots0.521 & 0.490\ldots0.695 & 0.615\ldots0.754 \end{bmatrix}$

**BUT complicated scalar sector**

# **The Flavor Problem:** some popular suggested solutions

## - (Old) Good ideas

Smallness of neutrino masses:

***See-saw*** mechanism:

SM ⊕ heavy sterile neutrinos with mass $M_R$ $\quad m_{light} \sim \frac{(vev_{SM})^2}{M_R}$ **BUT no clue on mixing**

Mixing angles:

SM ⊗ family symmetries $\quad$ **PMNS=** $\begin{bmatrix} 0.799\ldots0.844 & 0.516\ldots0.582 & 0.141\ldots0.156 \\ 0.242\ldots0.494 & 0.467\ldots0.678 & 0.639\ldots0.774 \\ 0.284\ldots0.521 & 0.490\ldots0.695 & 0.615\ldots0.754 \end{bmatrix}$ **BUT complicated scalar sector**

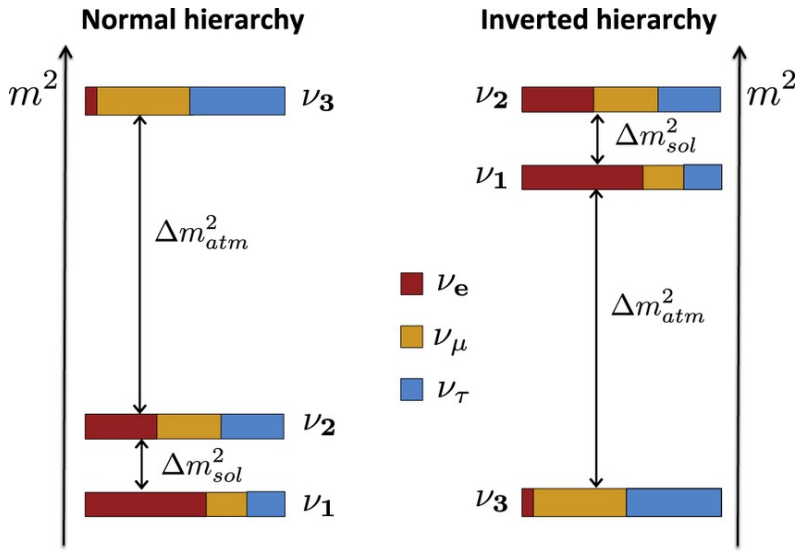
## - (New) Promising idea

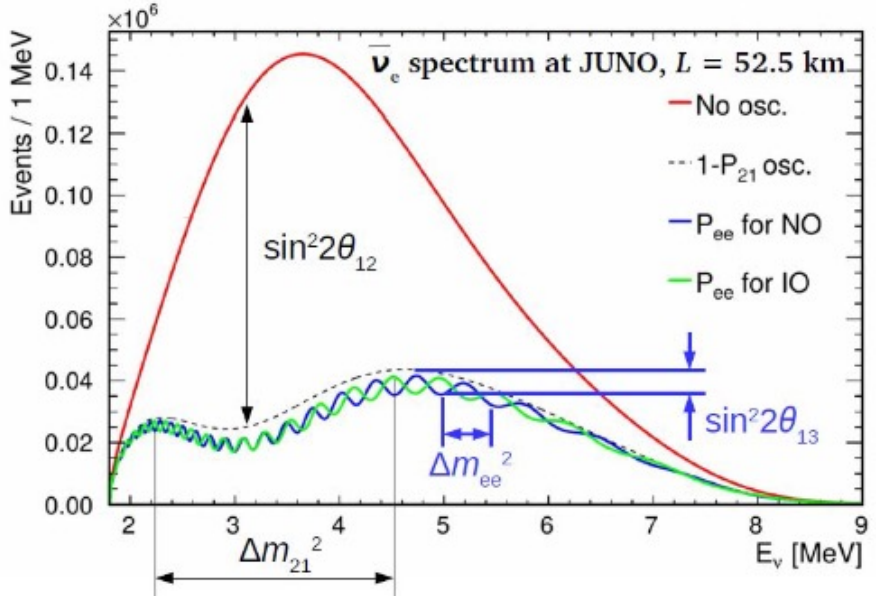
Modular Symmetry: theory invariant under transformations induced by suitable 2x2 matrices acting on a complex variable $\tau$

**Properties:**

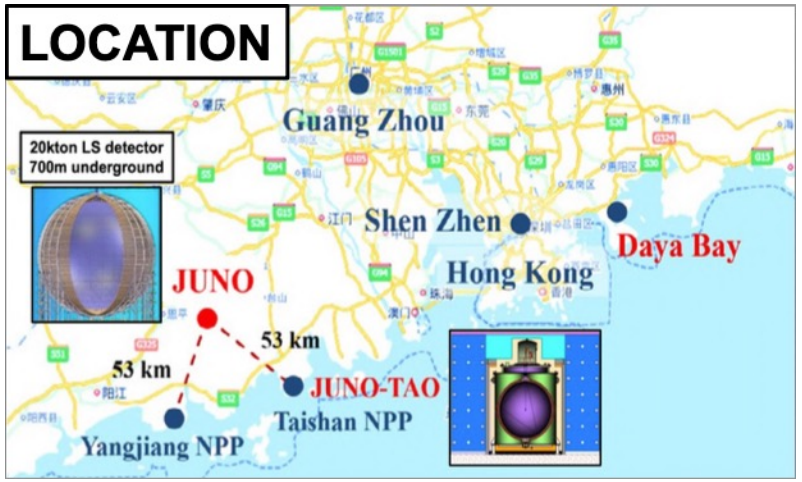
# small number of operators (few free parameters) → ***predictability***
# no new matter fields → ***minimality***
# no new scalar fields beside Higgs(es) → ***symmetry breaking dictated by the vev of τ***

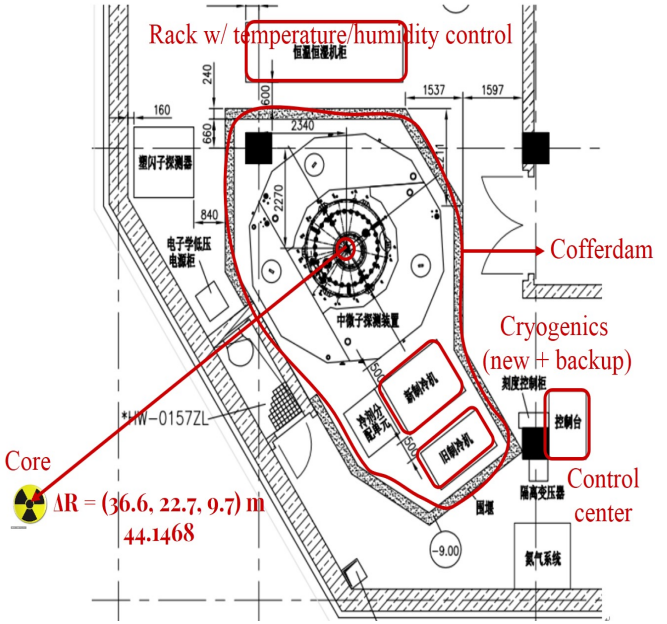
# The JUNO experiment

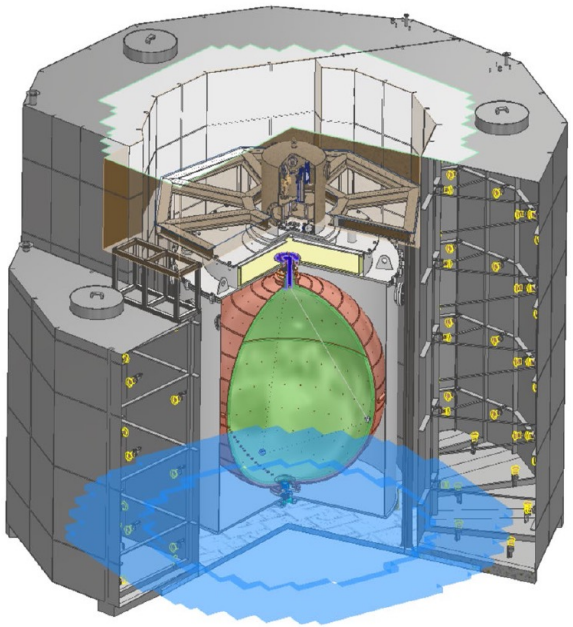



# The JUNO-TAO satellite detector



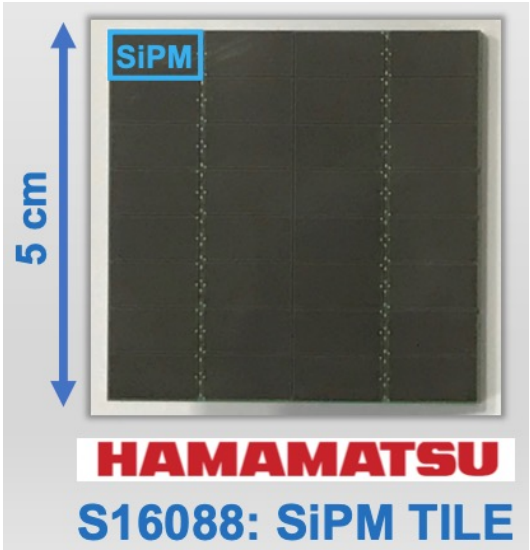



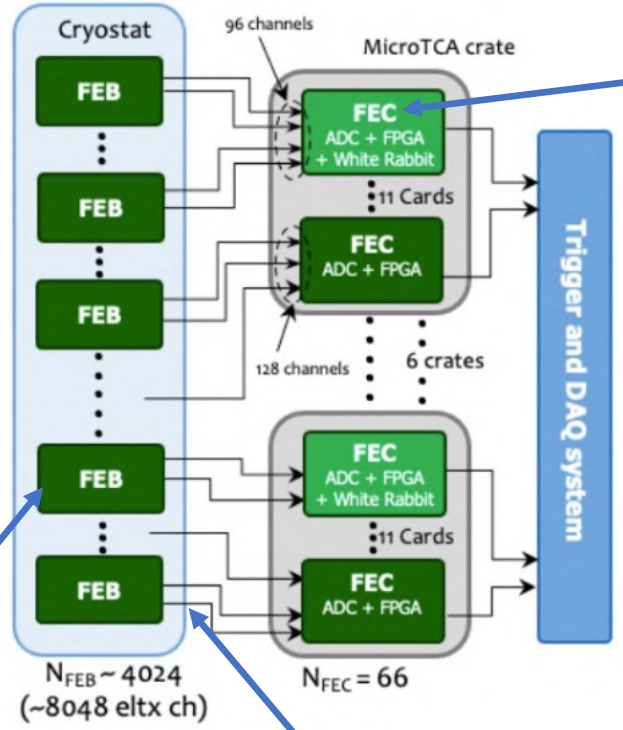

**T**aishan **A**ntineutrino **O**bservatory:
a ton-level, liquid scintillator (LS) detector.
**~10 m² of SiPMs at -50℃**
Measure reactor neutrino spectrum
with sub-percent E resolution.
Primary physics goal: **Model-independent reference spectrum for JUNO**



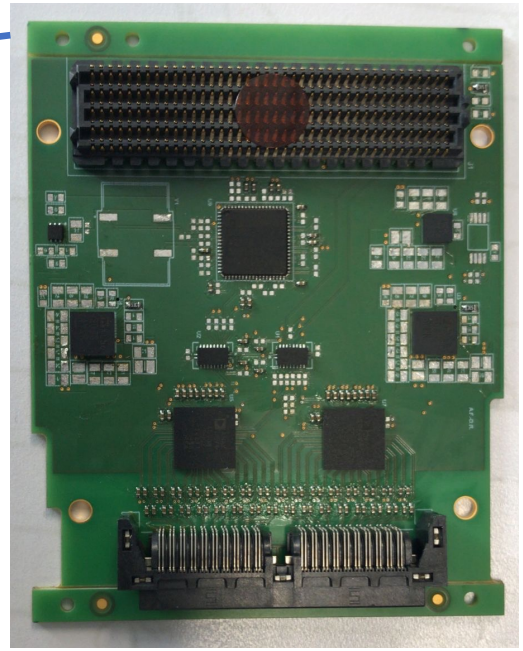
# The JUNO-TAO satellite detector

~4000 tiles → ~ 10 m$^2$

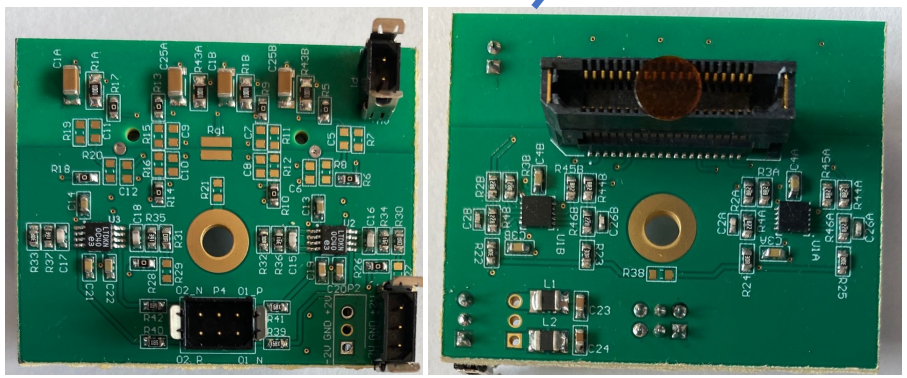


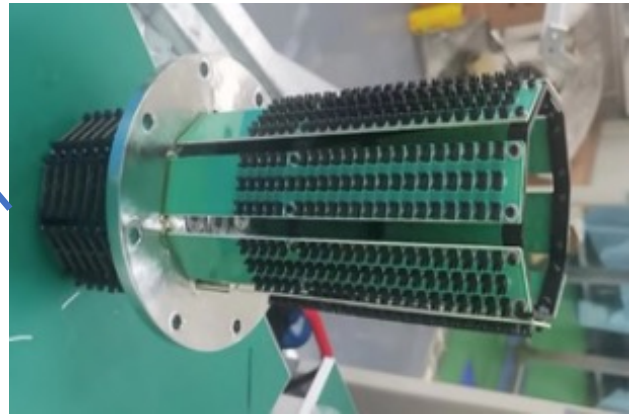

ADC



FEB

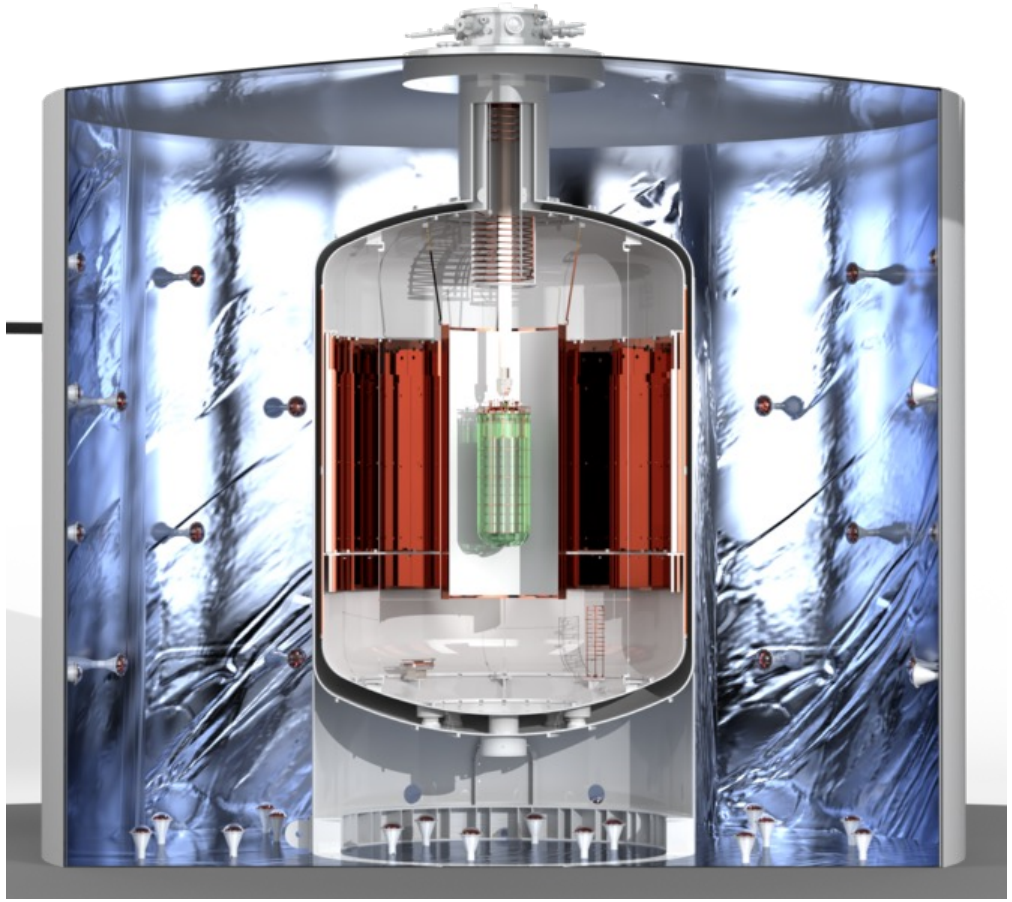


Flanges



# LEGEND

Large Enriched
Germanium Experiment
for Neutrinoless ββ Decay



25th 1998-2023 INFN ROMA TRE

LEGEND
Large Enriched
Germanium Experiment
for Neutrinoless ββ Decay

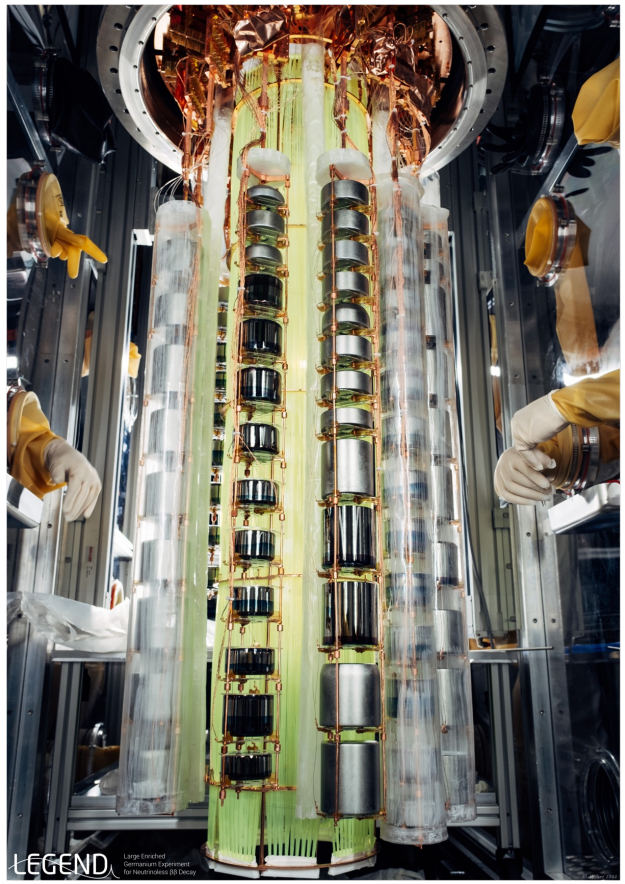
**Gruppo giovane** (4 anni), ma **<u>in crescita</u>**

- 5 FTE (4 staff + 1 post-doc + 1 dottoranda + alcuni laureandi)
- **1 infrastruttura criogenica locale "OLAF"**
- Vari articoli e proceedings


**<u>Ruoli di responsabilità</u>** scientifica:

- Run coordination (L200)
- E-scale analysis convener (L200)
- L3 FE electronics SIPM (L200 e L1000)

25th 1998-2023 INFN ROMA TRE




Attività HW e SW

**LEGEND-200:**

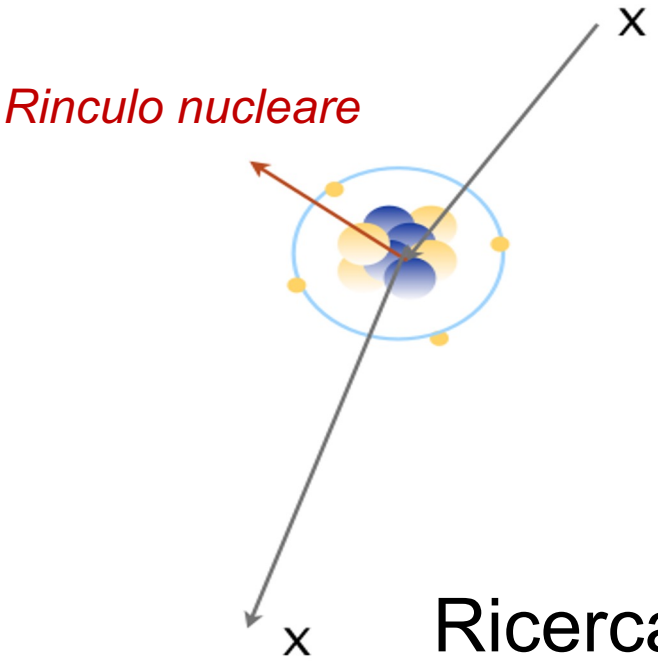
- Contributo al progetto e costruzione del **sistema di lettura in argon liquido**
- Guida delle **analisi** di scala e calibrazione **energia dei Germani**

**LEGEND-1000:**

- Partecipazione all'R&D per il sistema di veto in argon atmosferico contro neutroni cosmogenici
- Infrastruttura per i test finali del FE dei Germani

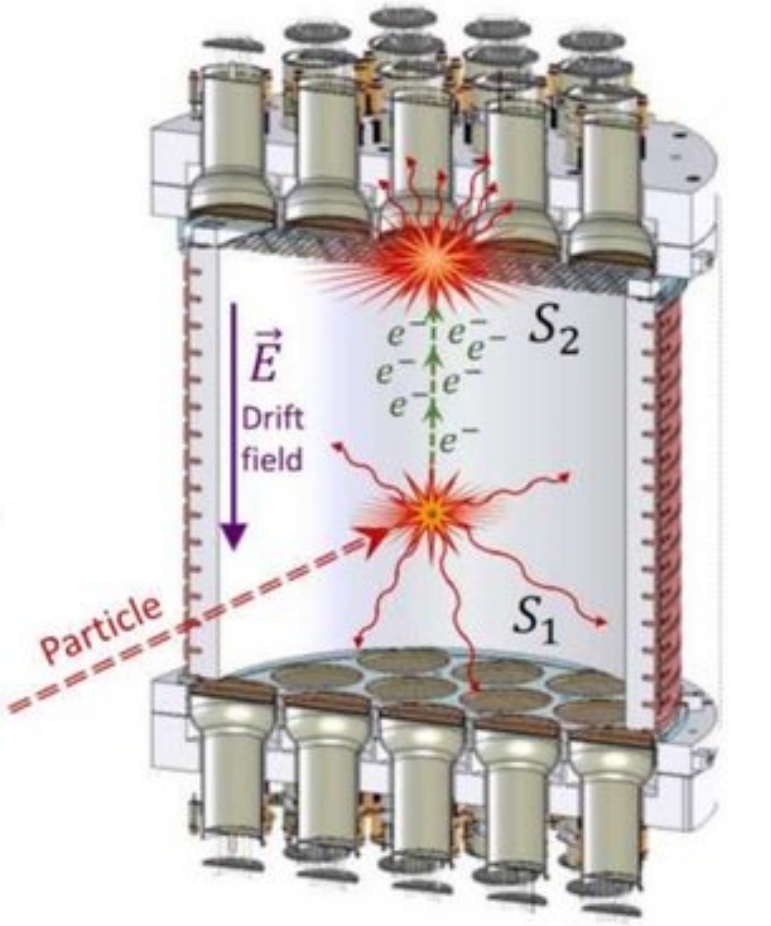
Ricerca di
Materia Oscura





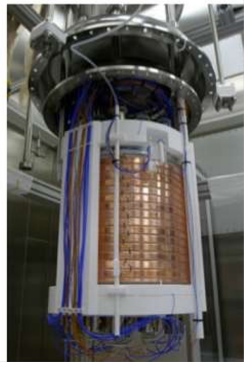

Ricerca Diretta

# DarkSide



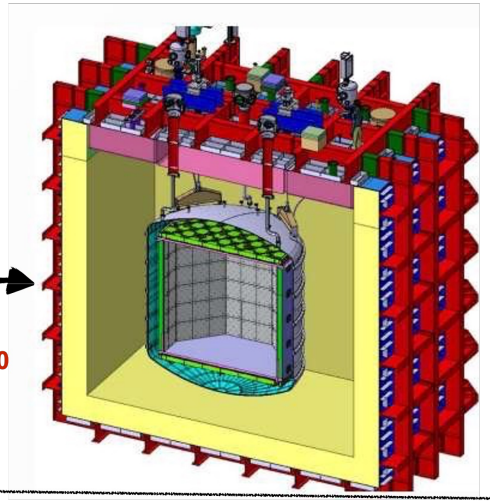

**DarkSide-10**

**DarkSide-50**

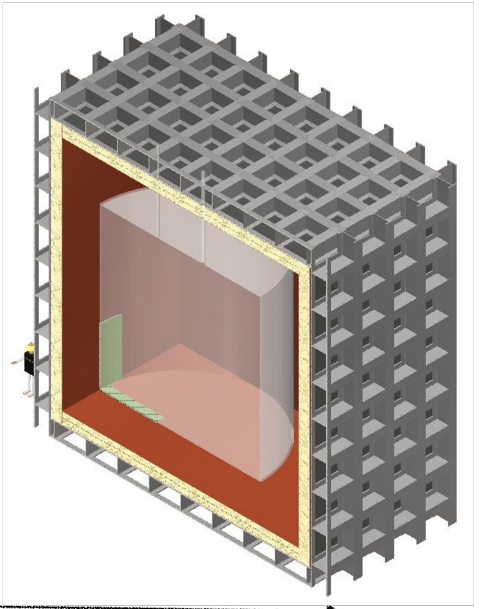


x 1000

**DarkSide-20k**



**ARGO**



2011

2013-2018 at LNGS
0.03 t.yr exposure

2025+
200 t.yr target exposure

2030+
3000 t.yr target exposure

**Installation started in Hall C at LNGS**

# DarkSide: Low-Energy Calibration at INFN - CT

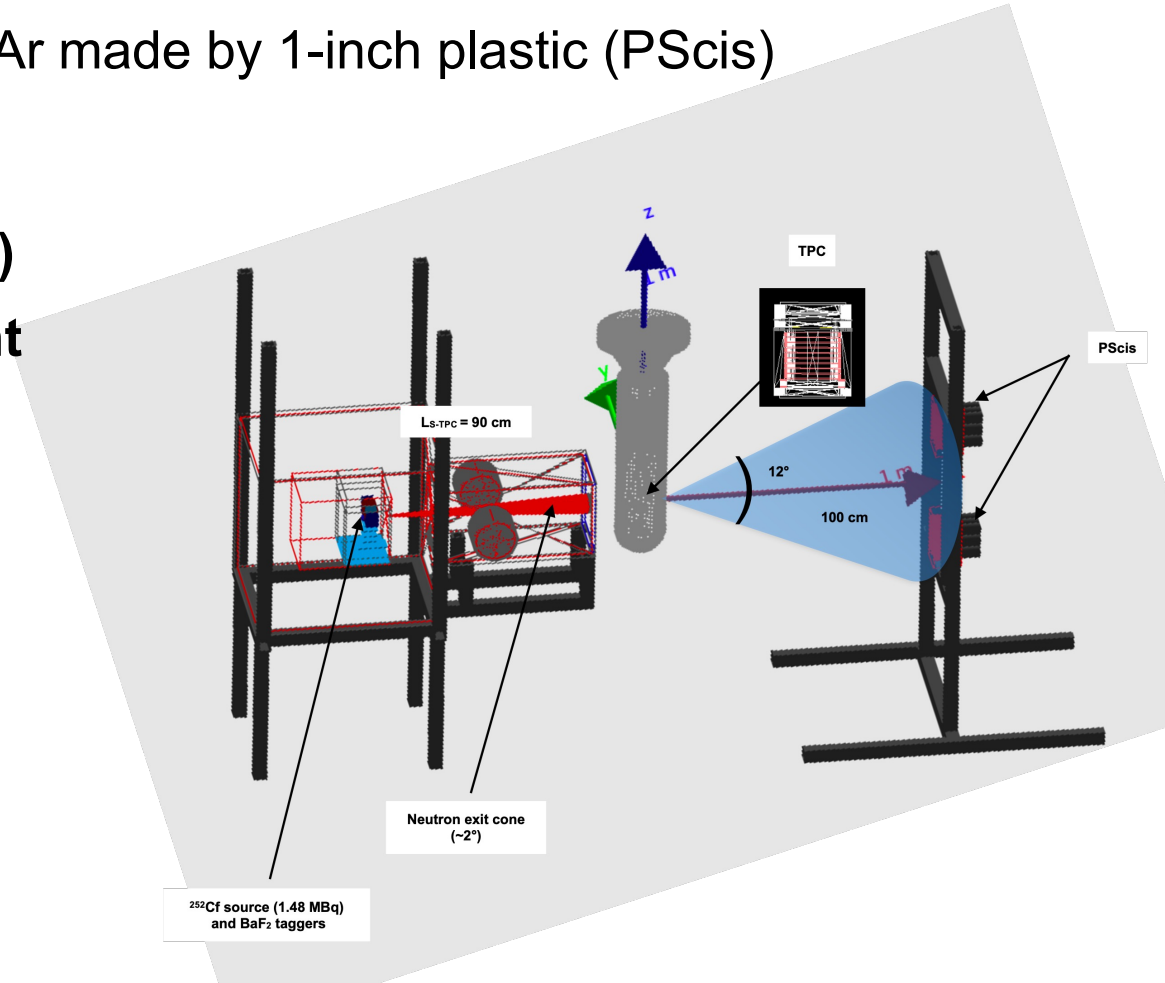
## ReD: Low-energy recoil measurements (few keV) by using a $^{252}$Cf neutron source

- Neutrons of ~2 MeV kinetic energy more appropriate for $E_{rec}$ ~ few keV
- Neutron spectrometer to detect neutrons scattered off-Ar made by 1-inch plastic (PScis)
- Use $BaF_2$ as close fission tagger

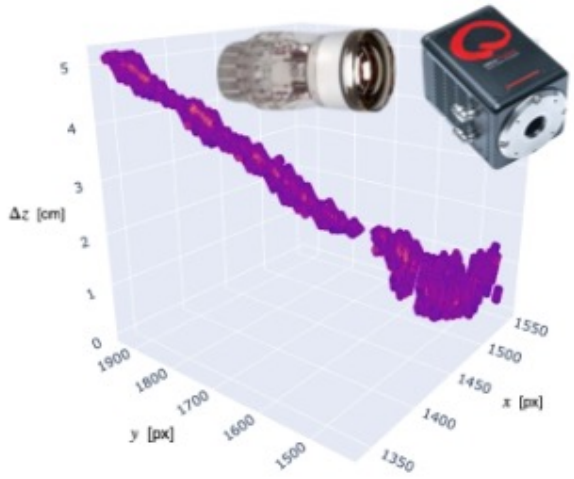
**<u>Strategy:</u> to tag the fission events (neutrons and γs) with $BaF_2$ detectors and measuring the time-of-flight in the "far" PScis**

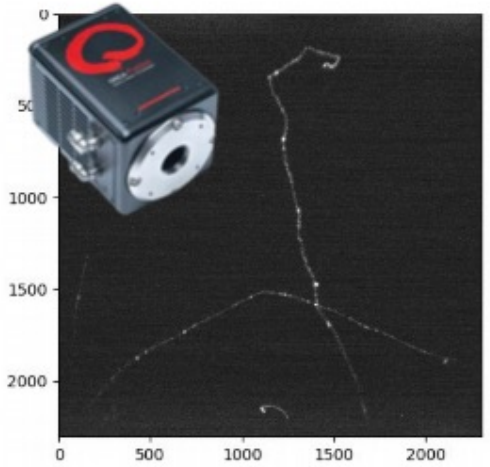
- Use the PSD and time of flight for the n/γ rejection

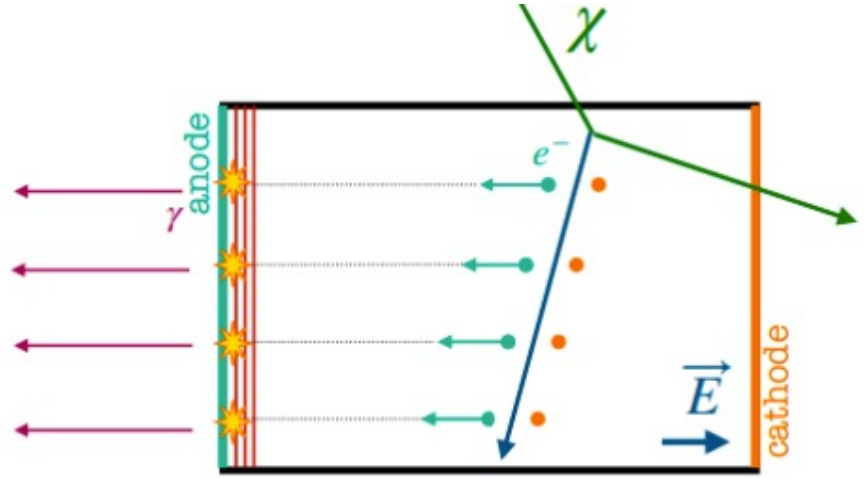
- Sensitivity down to 2-5 $keV_{NR}$

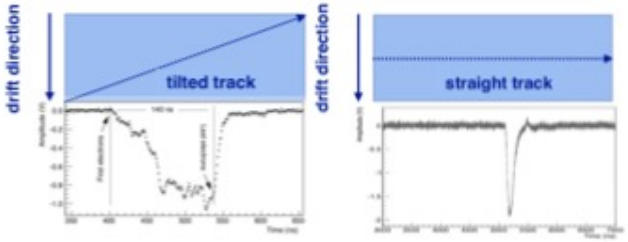


# CYGNO: a gaseous TPC with optical redout for *directional* DM searches

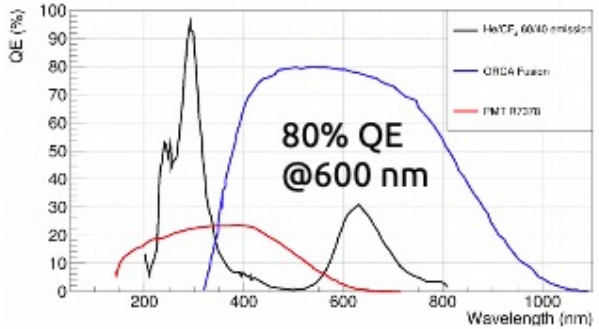




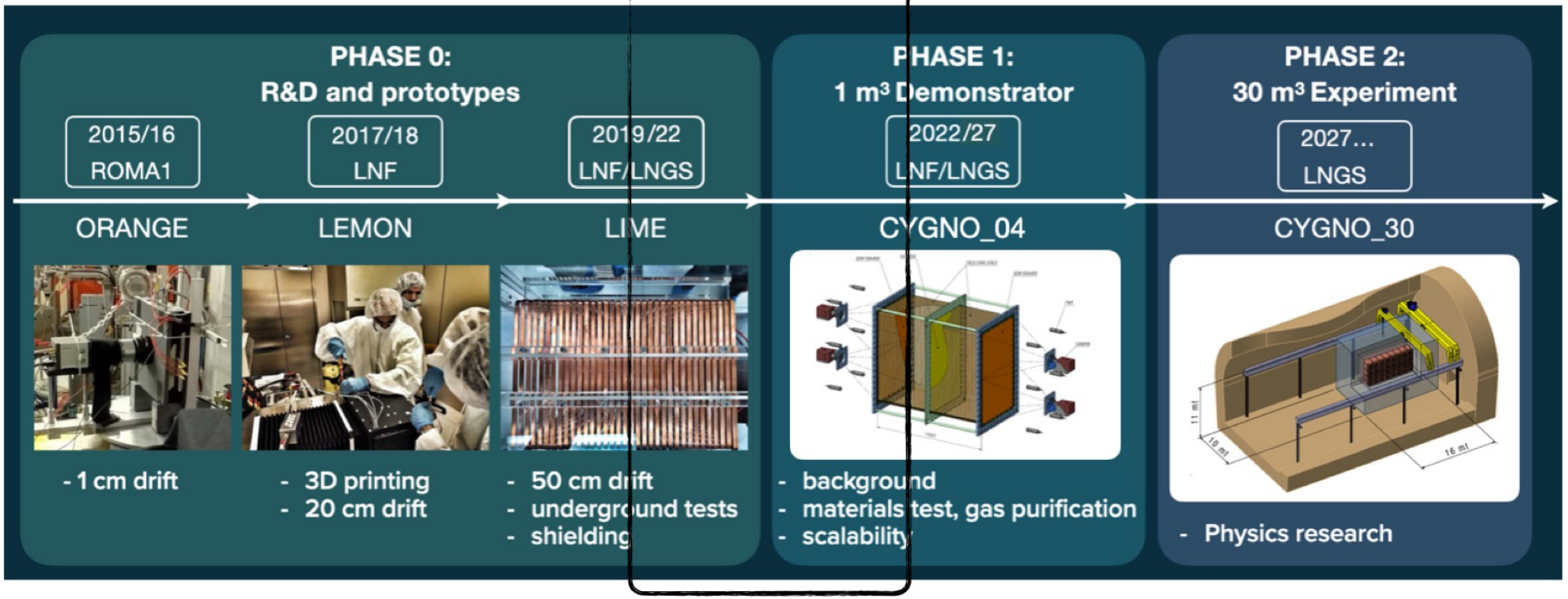

**PMTs:**
Energy, **z** component of track from time structure of signal

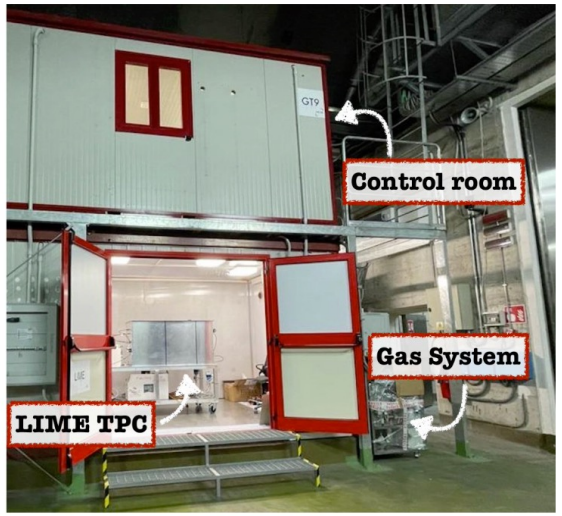



**sCMOS** camera:
Energy, **xy** track projection

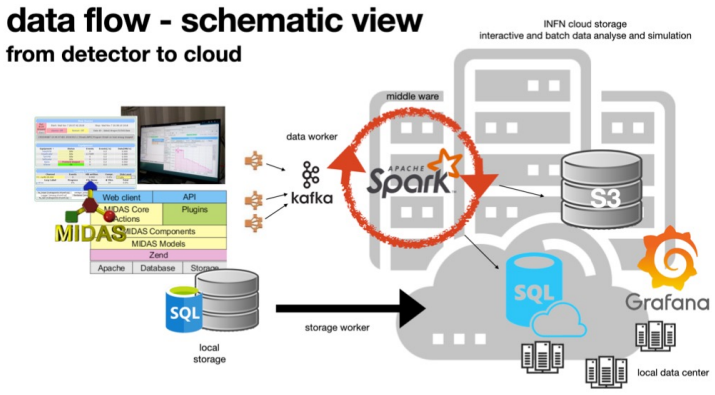
- He:$CF_4$ (60:40) at **atmospheric pressure**, GEM amplification, **optical readout** (sCMOS+PMT)
  - With suitable lenses we can **image large areas** O(1 $m^2$) with single sensor, with effective pixel area O(100 μm)
- **3D reconstruction** capability: directionality, particle ID, background rejection, fiducialization
- **Low threshold** (< 1 keV)

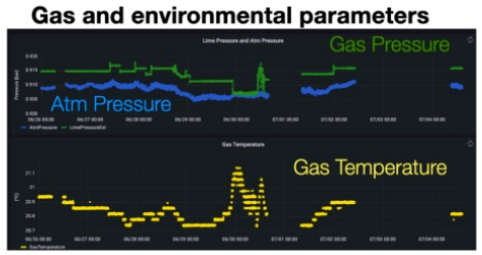
# The CYGNO timeline

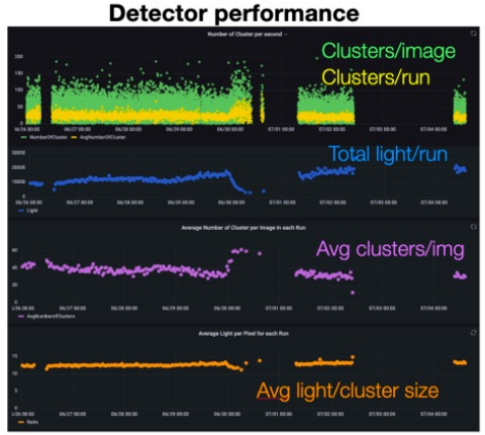


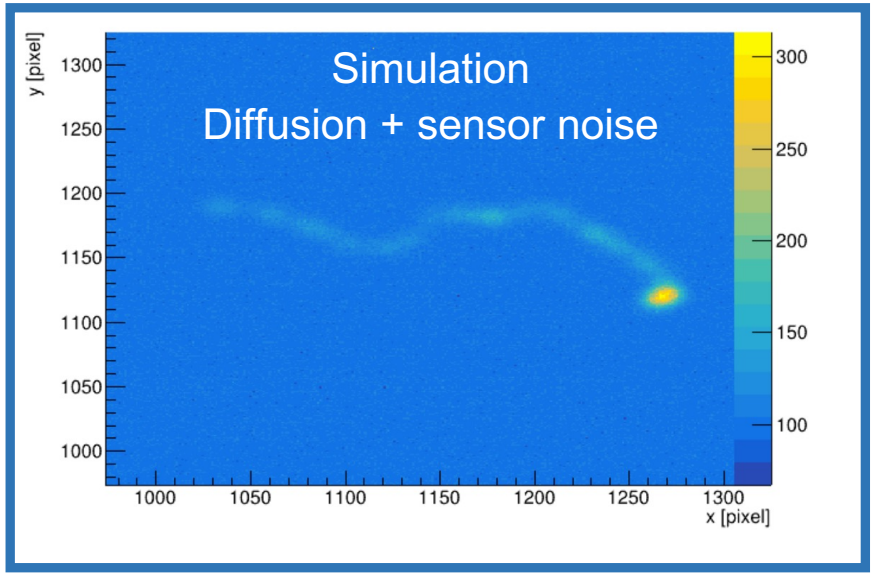



# Attività in CYGNO a Roma Tre



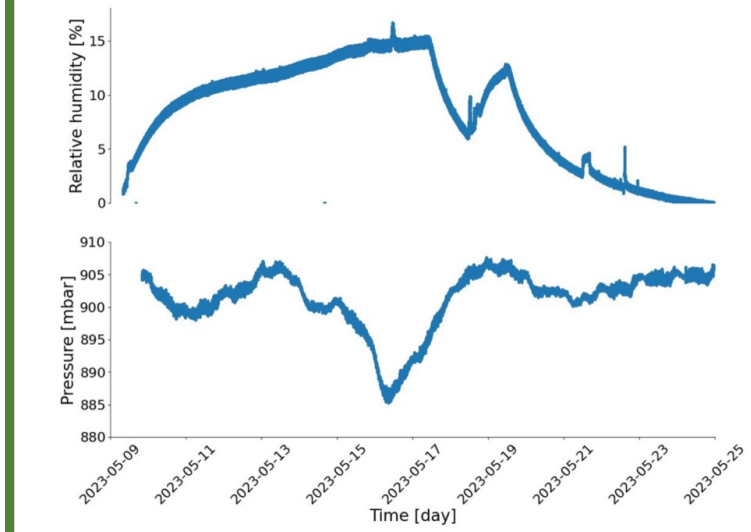



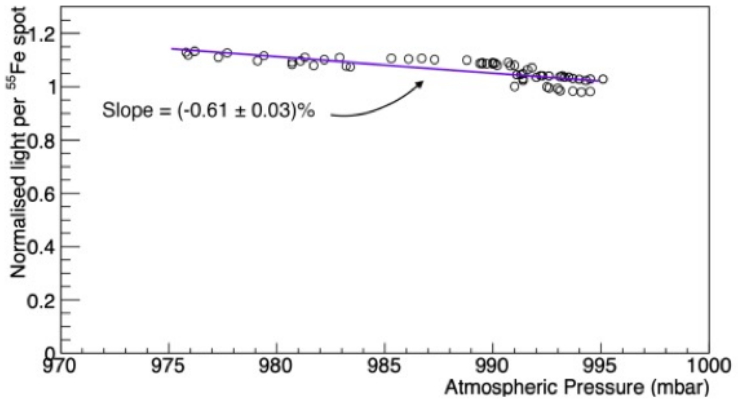



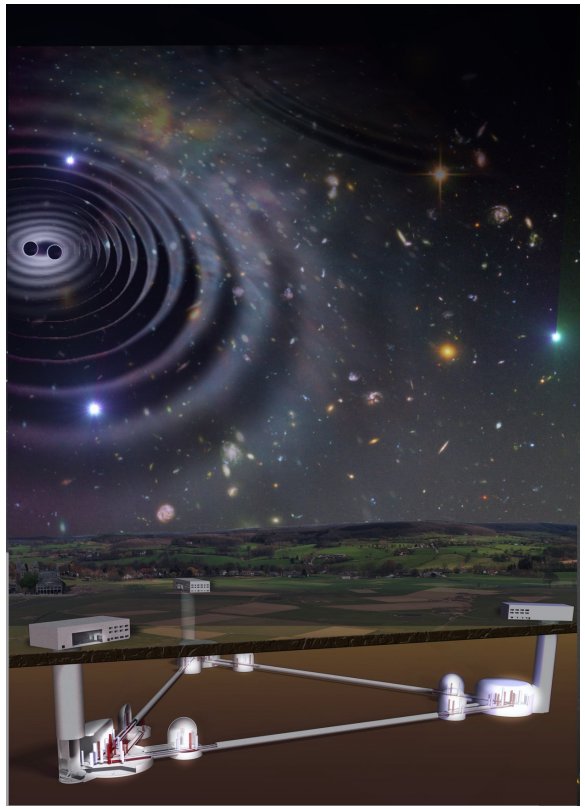




- "Middleware"
- Simulazione/Digitizzazione
- Ricostruzione
- Slow control

  → Detector stability





VIRGO

ET EINSTEIN TELESCOPE

# Esperimenti per onde gravitazionali

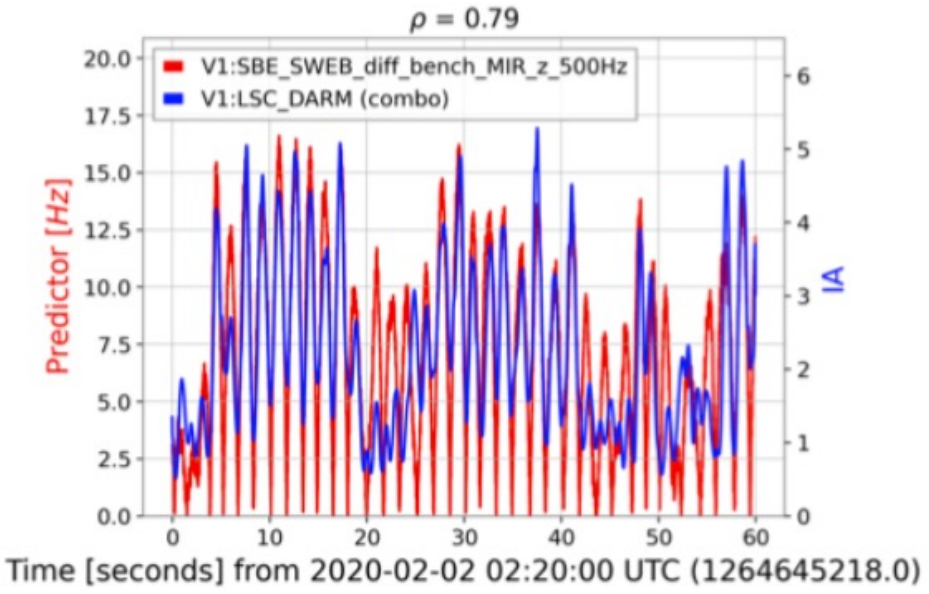
25th 1998-2023 INFN ROMA TRE

# Scattered Light Daily Monitoring System

Method for the characterization of the noise from Scattering Light that can lower the sensitivity, based on adaptive algorithms

**Methodology**

- Lowpass filter differential arm motion DoF (DARM) time series,
- Apply pytvfemd adaptive algorithm to obtain DARM's oscillatory modes (IMF)
- Mode's envelope is the **instantaneous amplitude IA(t) of the arm oscillatory modes**
- Compute **correlation $\rho$ between IA(t) and the predictor** f_arch [Hz] for a given optic
- **Predictor:** obtained from position data x(t) of optical component
- Considering 60s interval: a time series of 1440 values of $\rho$ is obtained each day
- **Daily monitoring: Compare $\rho$ time series with seismometer data** in the microseismic band (0.1-1Hz)

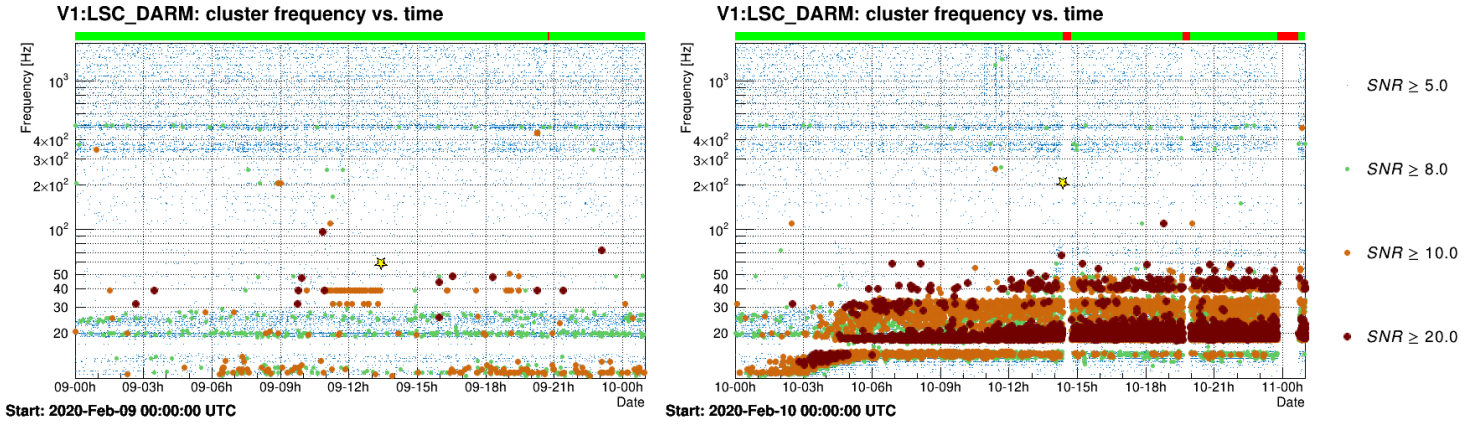



Predictor: tracks scattered light arches appearing in DARM spectrogram

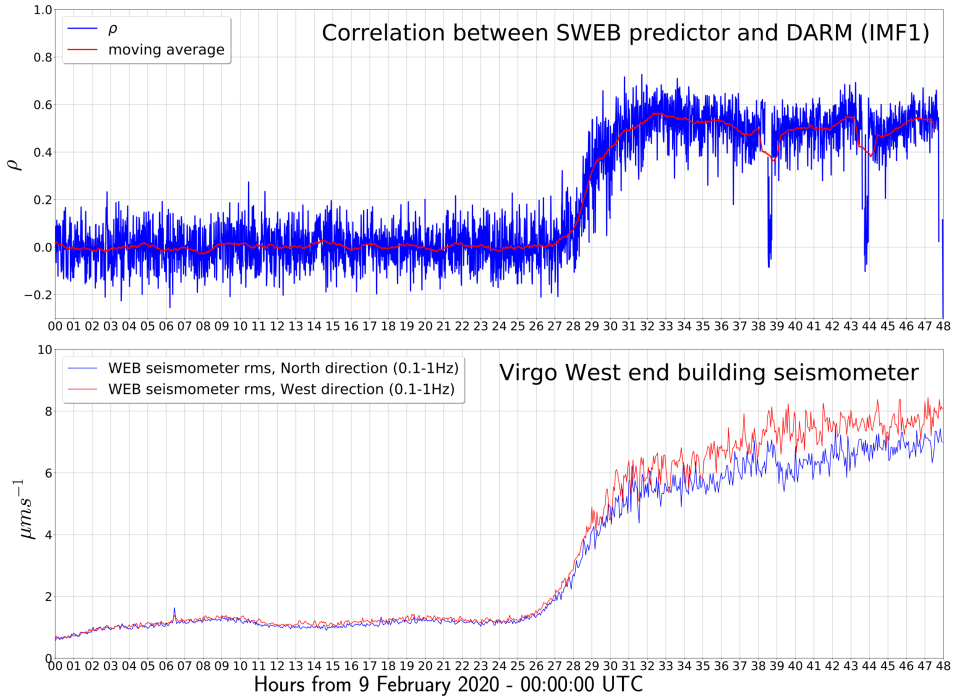
$$f_{arch}(t) = \frac{2|v(t)|}{\lambda}$$

# Example: Daily monitoring of Scattered light from Virgo Suspended West End Building (SWEB) during O3

Noise in Virgo DARM increases in a specific moment (2020/02/10 03h)



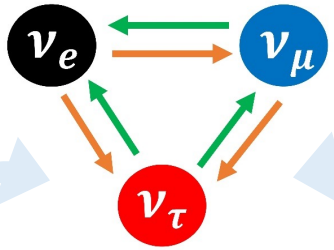

Source identified and monitored




The monitoring system allows to continuously monitor multiple optics, possible sources of SL. Will run during O4 on Condor.

For each optic to be monitored —> 1440 parallel jobs per daily analysis

*Pytvfemd is used. Is available at https://pypi.org/project/pytvfemd/ (Stefano Bianchi, PhD)*




JUNO

LEGEND

Neutrini

Ricerca di
Materia Oscura

DARKSIDE

CYGNO
Experiment

VIRGO

ET EINSTEIN TELESCOPE

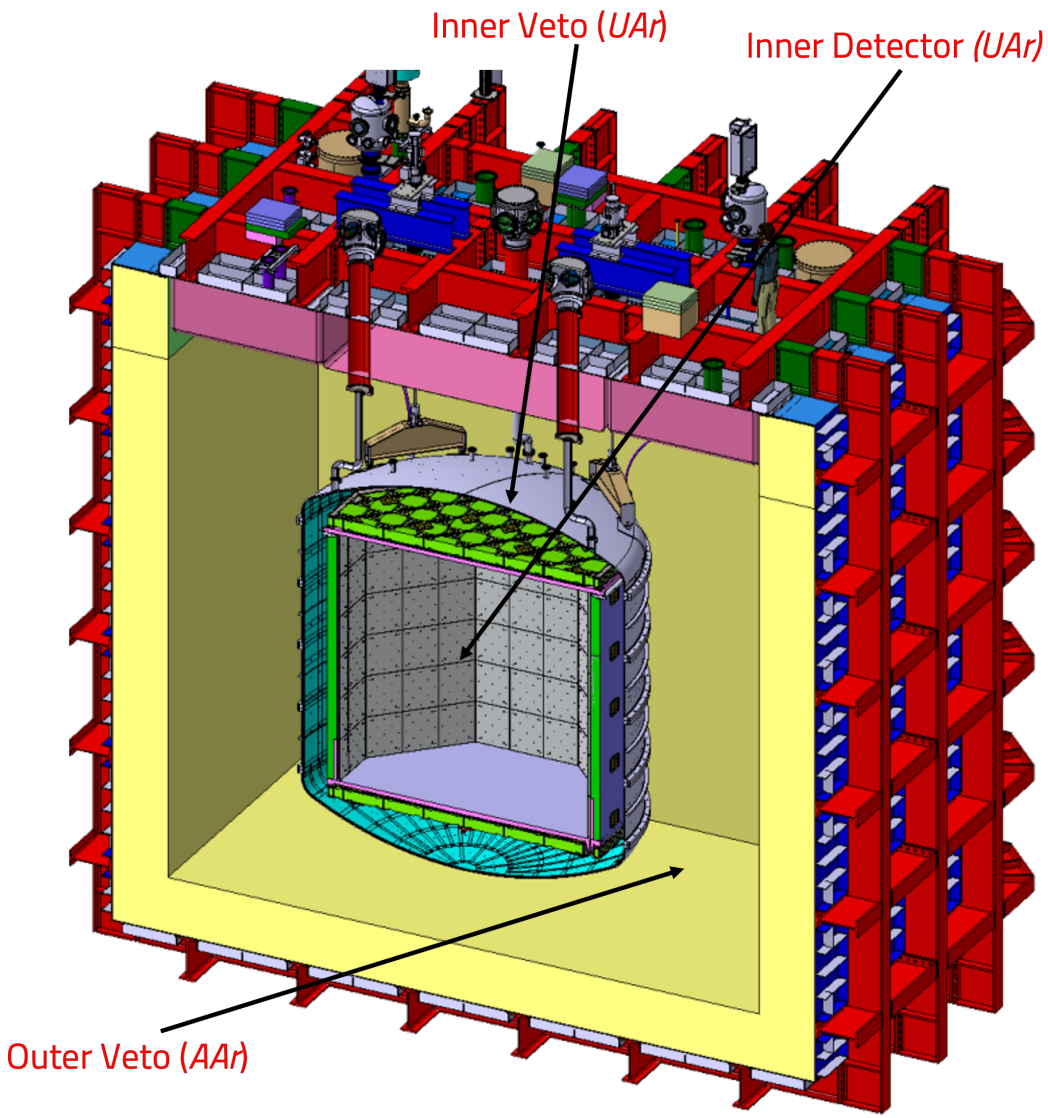
Esperimenti per onde gravitazionali

***Grazie per l'attenzione!***

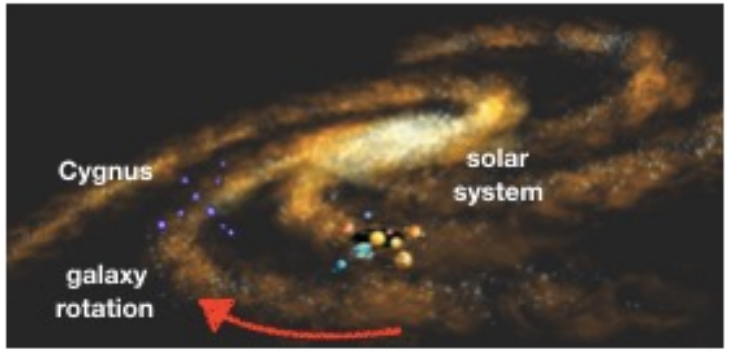
# ***Additional Material***

# DarkSide-20k: overview

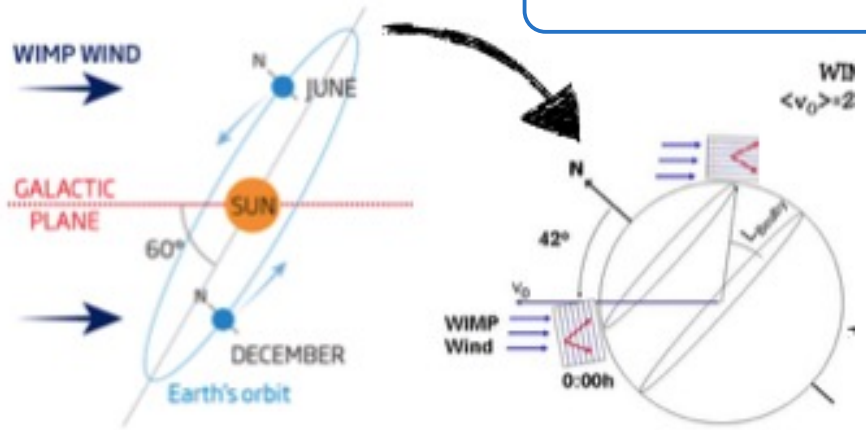
- ProtoDune-like cryostat instrumented like a muon veto (8x8x8 $m^3$)
- Titanium vessel separating Atmospheric Argon (AAr) from Underground Argon (UAr)
- WIMP detector fiducial volume of ~ 20 tonnes (~50 tonnes total) of UAr, depleted in $^{39}Ar$
- Active neutron veto integrated into the TPC structure via gadolinium-loaded acrylic (PMMA)
- **Silicon PhotoMultipliers (SiPMs) as photo detection devices (total area ~ 26 $m^2$)**



WIMP flux
(<v>~220km/s)

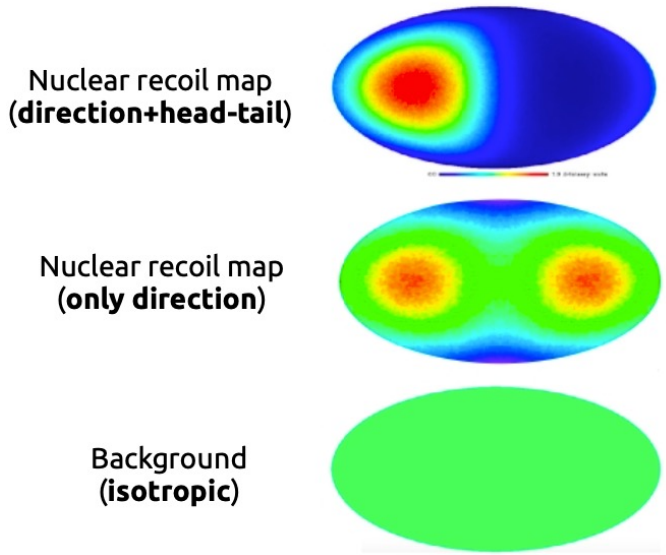



few % DM flux
annual
modulation



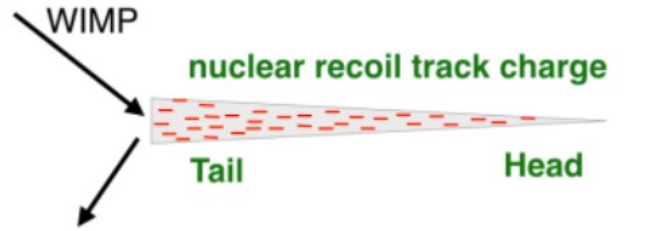

- Anisotropy in the angular distribution of nuclear recoils;
- **No background can mimic it**.

A. M. Green et. al, Astropart. Phys. 27 (2007) 14




**<u>Directional discrimination</u>** is the only way to:

- **Unambiguously identify a DM signal**
- Searching beyond the neutrino floor
- Moreover:
  - Properties of the solar neutrino flux;
  - DM halo properties (DM astronomy).




NR (partially) retain the direction

# *References*


- **Alessandro Longo, Stefano Bianchi,** Guillermo Valdes, Nicolas Arnaud, **Wolfango Plastino**, *Scattered light monitoring system at the **Virgo** interferometer*: performance improvement and automation based on O3 data. **Currently submitted to CQG**.
- **Stefano Bianchi, Alessandro Longo**, Guillermo Valdes, Gabriela González, **Wolfango Plastino**, *gwadaptive scattering: an automated pipeline for scattered light noise characterization.* Classical and Quantum Gravity 39.19 (**2022**): 195005.
- **Alessandro Longo, Stefano Bianchi,** Guillermo Valdes, Nicolas Arnaud, **Wolfango Plastino,** *Daily monitoring of scattered light noise due to microseismic variability at the **Virgo** interferometer*. Classical and Quantum Gravity 39.3 (**2021**), 035001.
- **Alessandro Longo, Stefano Bianchi, Wolfango Plastino**, Nicolas Arnaud, *Scattered light noise characterization at the **Virgo** interferometer with tvf-EMD adaptive algorithm*. Class. Quantum Grav. 37, 145011, **2020**.

---

- **Alessandro Longo**, **Stefano Bianchi**, **Wolfango Plastino**, Kouseki Miyo, Takaaki Yokozawa, Tatsuki Washimi, and Akito Araya, *Local Hurst Exponent Computation of Data from Triaxial Seismometers Monitoring **KAGRA***. Pure and Applied Geophysics 178.9 (**2021**): 3461-3470.
- **Alessandro Longo**, **Stefano Bianchi**, **Wolfango Plastino** et al., *Adaptive denoising of acoustic noise injections performed at **Virgo** Interferometer*. Pure and Applied Geophysics 177, 3395–3406, **2020**.
- **Alessandro Longo**, **Stefano Bianchi**, **Wolfango Plastino** et al**.,** *Fractal analysis of data from seismometer array monitoring **Virgo** Interferometer*. Pure and Applied Geophysics 177, 2597-2603, **2020**.