UCLouvain

Astroparticle physics at UCLouvain's CP3

11th CosPa meeting | ULB | Brussels | 29.10.2021

Astroparticle

Cosmology

Muography

Gravitational waves

Gwenhaël de Wasseige and Joris van Heijningen

on behalf of many researchers at UCLouvain

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Astroparticle

Cosmology

Compact sources

Environmental studies

Primordial sources

Muography

Gravitational waves

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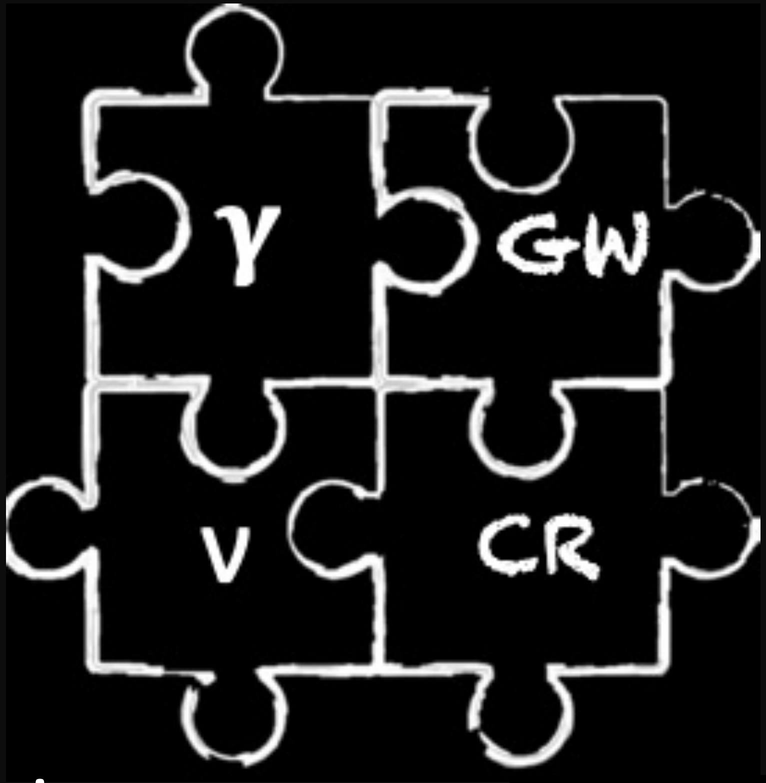
on behalf of many researchers at UCLouvain

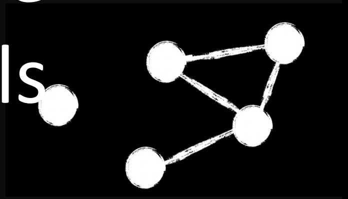
Neutrino

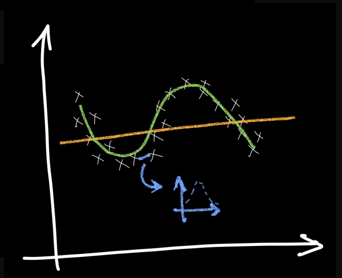
In short:

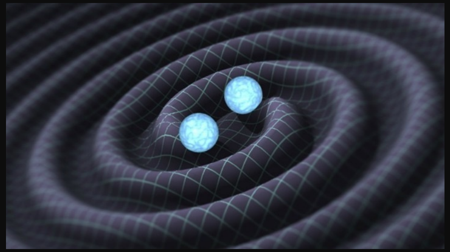
- Reconstruction tools
- Event selections
- Data analyses
- Alert systems
- Science communication

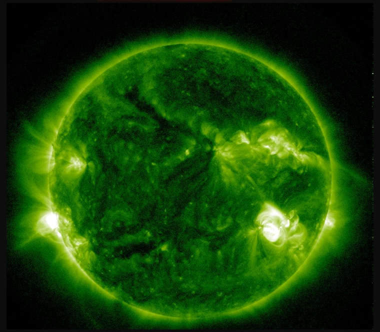
Data science tools



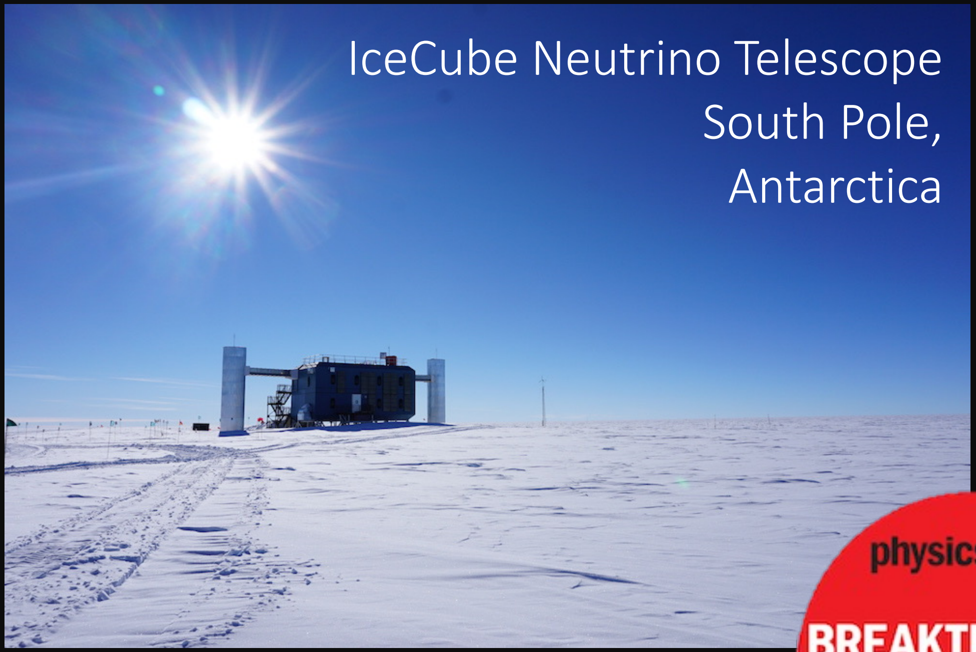




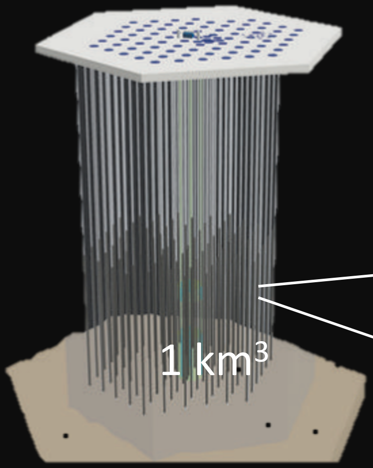


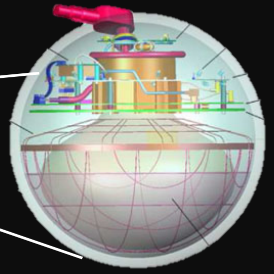


Astrophysical transients

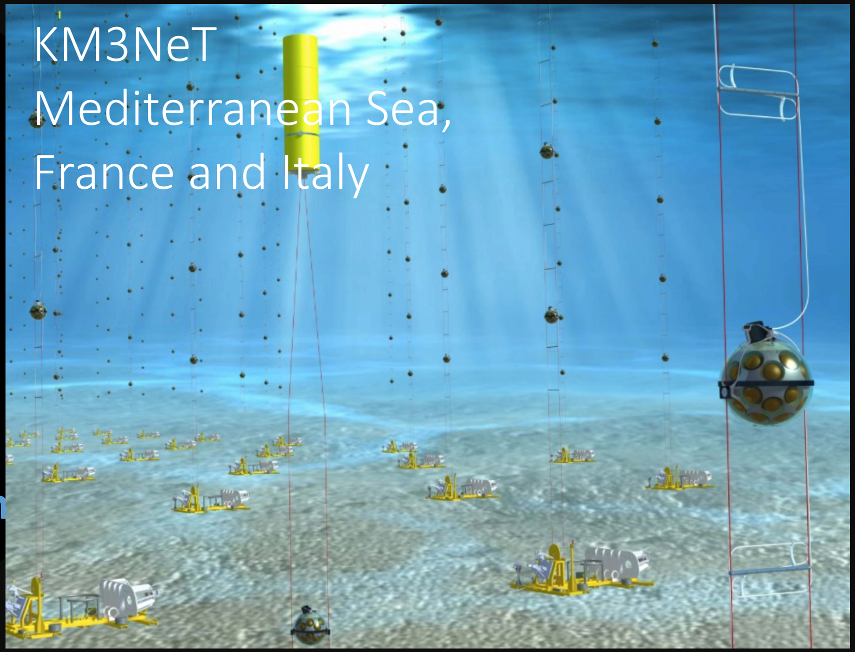


5160 sensors

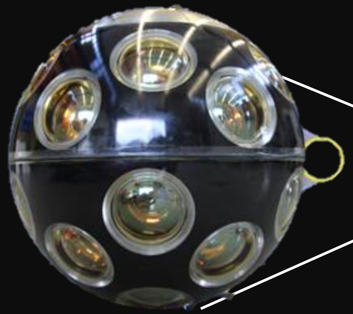


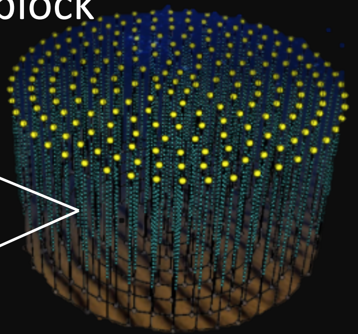


8 ARCA in operation
+ 15 in April

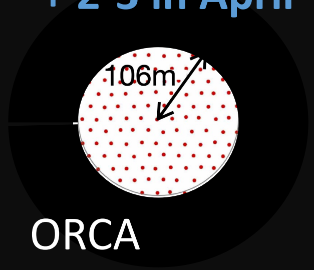


2070 sensors/block





6 ORCA in operation
+ 7 in November
+ 2-3 in April



<u>Running for 10 years in its full configuration</u>

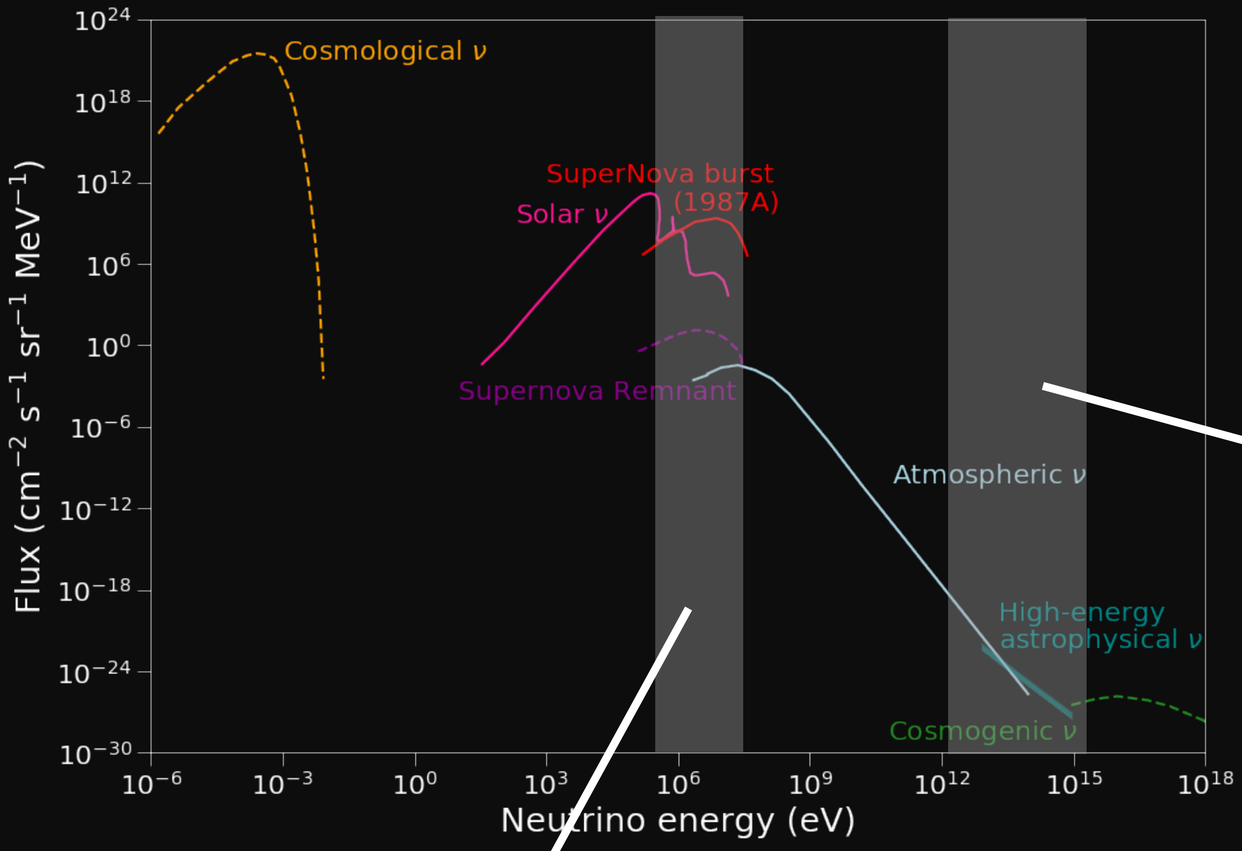
Coming extensions:

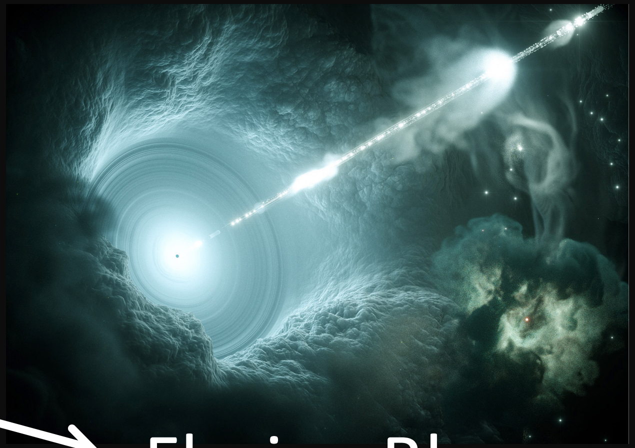
Upgrade + Gen2

<u>Final configuration:</u>

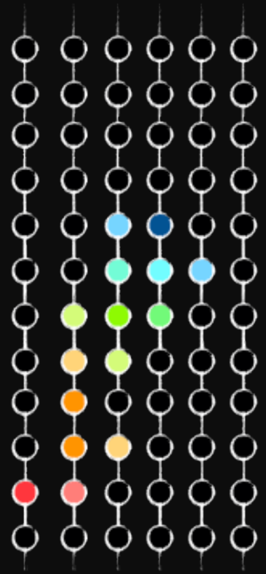
ORCA 115 Detection Units (DUs)

ARCA 2 X 115 DUs

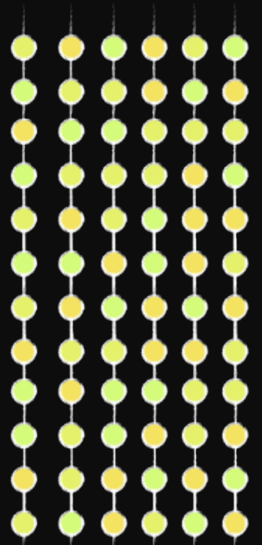


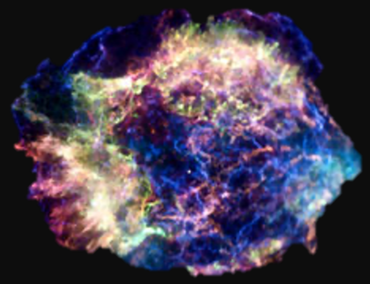


Flaring Blazar



Tidal Disruption Event

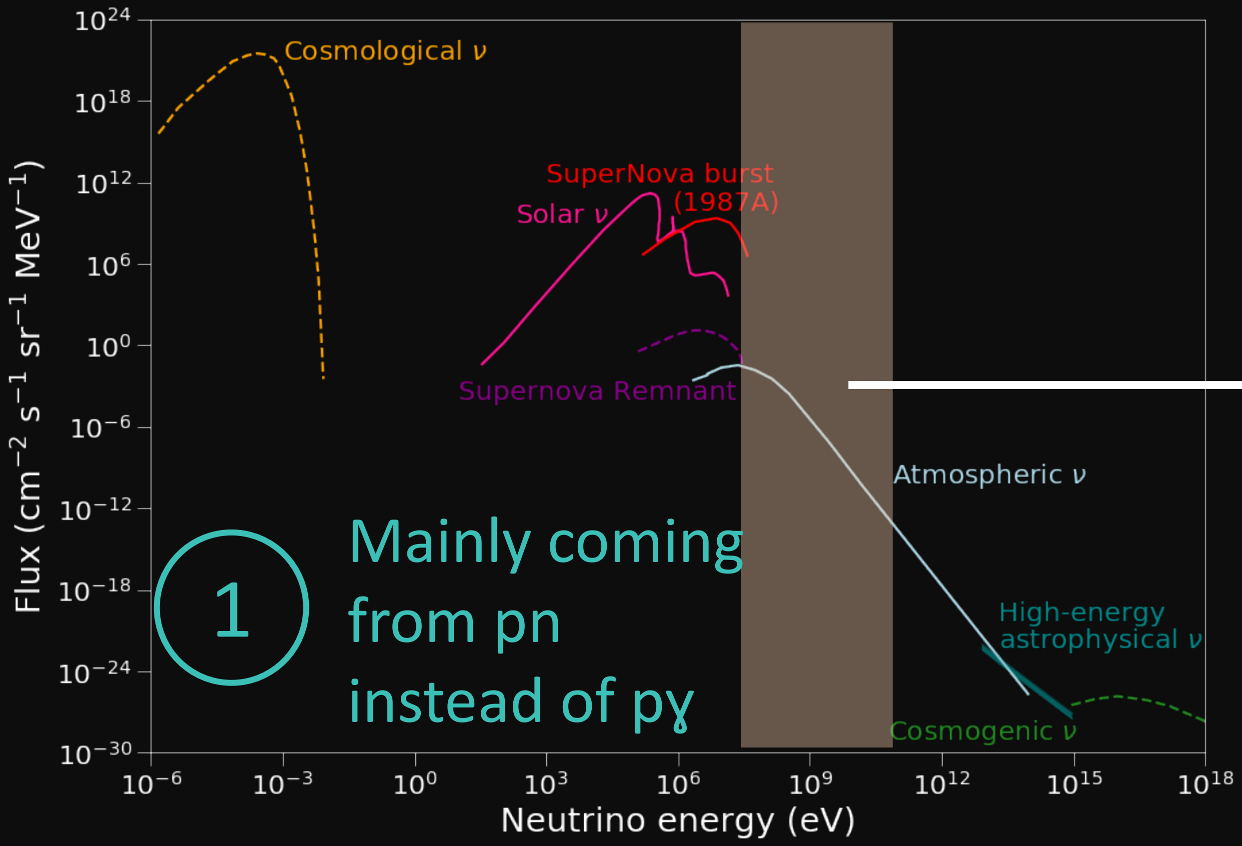




Core Collapse Supernova

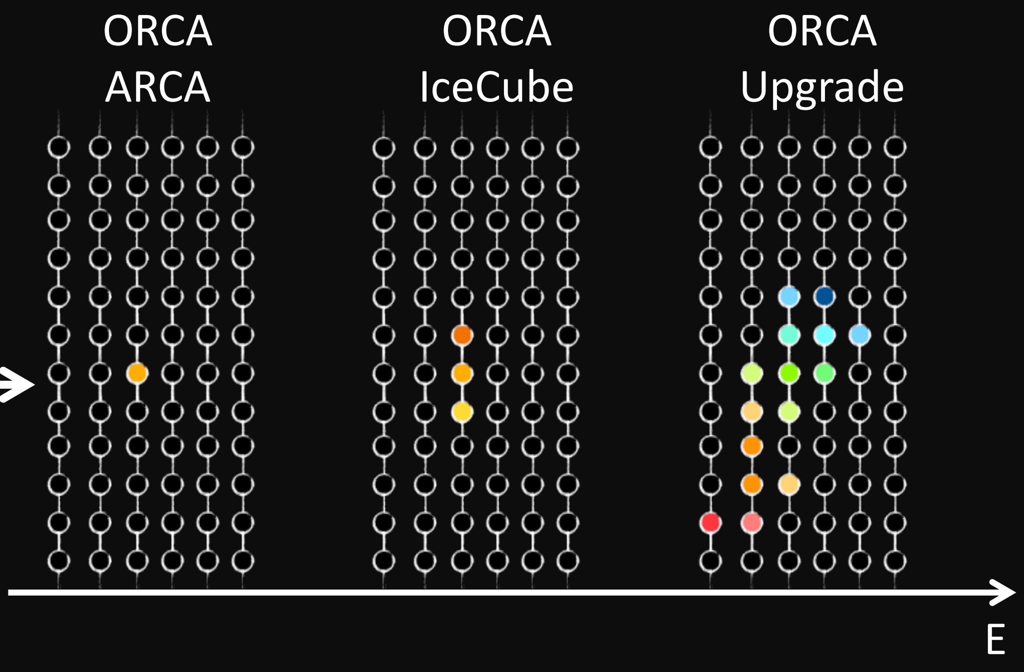
Identification of other sources

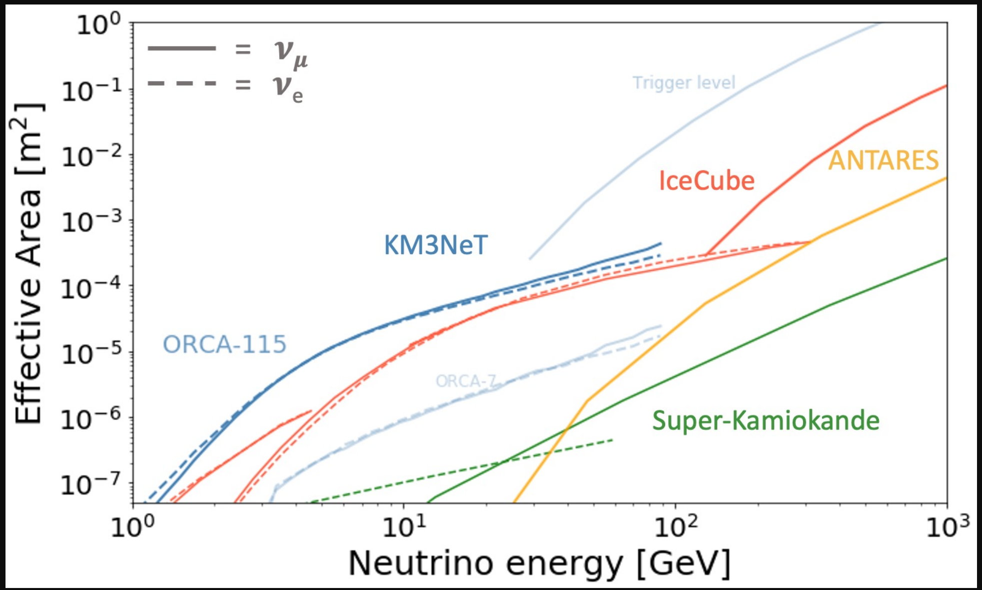
Loading



1

Mainly coming from pn instead of pγ



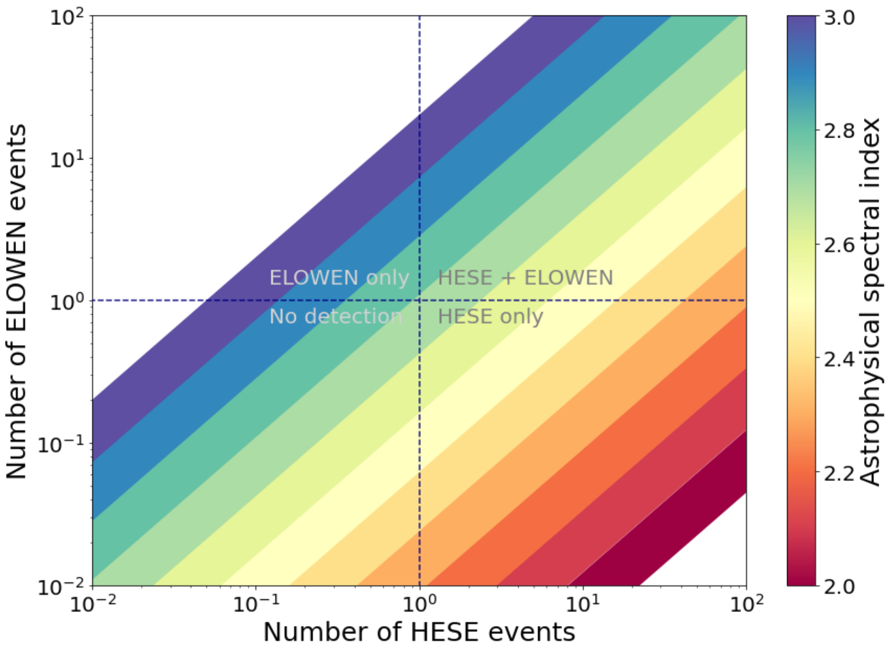


Why going to lower energies?

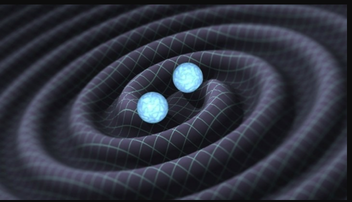
2

3

0.5-5 GeV

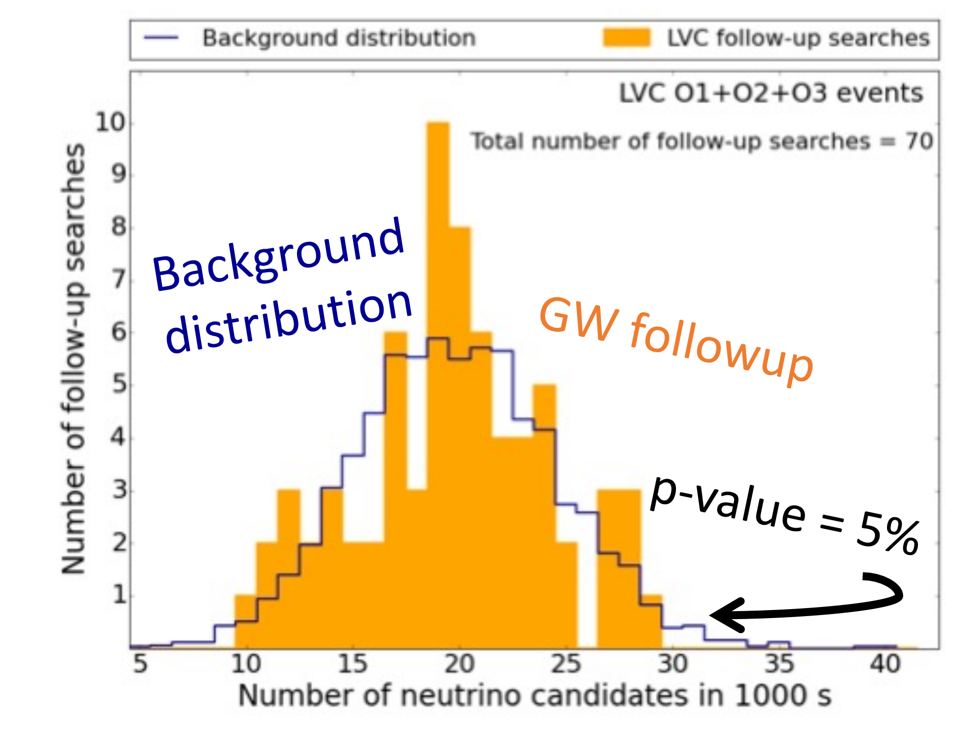


TeV-PeV scale



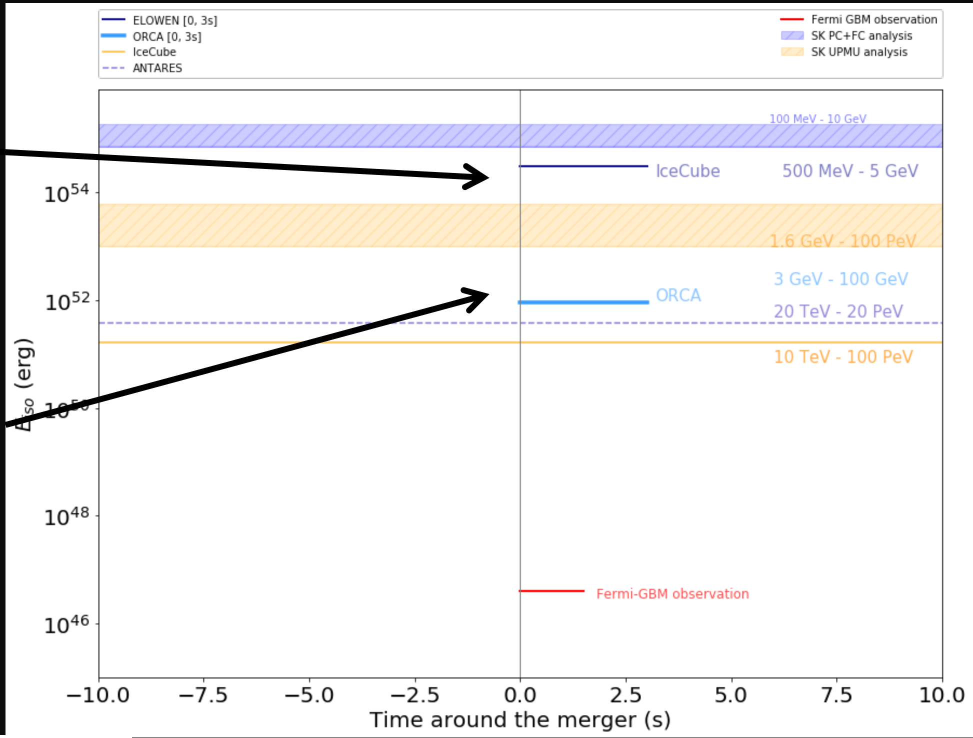
Compact binary mergers

ICECUBE

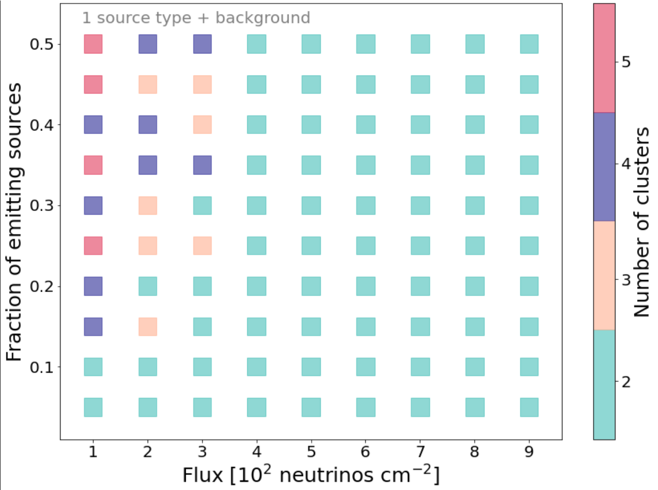


ICECUBE
Upper limit

KM3NeT
Sensitivity



ICECUBE + KM3NeT



Combination of different sites
= reduce the background
+ boost the astrophysical signal

UCLouvain

Muography

The CP3 muography team

https://cp3-git.irmp.ucl.ac.be/muographycp3

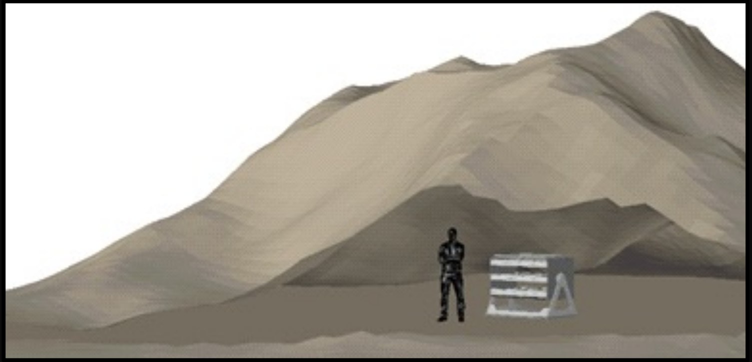
- Samip Basnet (PhD student)
- Eduardo Cortina (Professor) - also NA62
- Ishan Darshana (PhD student)
- Andrea Giammanco (Senior researcher) - also CMS
- Raveendra Karnam (Postdoc)
- Maxime Lagrange (PhD student)
- Marwa Moussawi (PhD student)
- Ilker Topuz (PhD student, *jointly with Tartu & GScan*)
- *New postdoc* funded by SilentBorder (H2020 project)
- (+ part-time contributions by other CP3 staff)

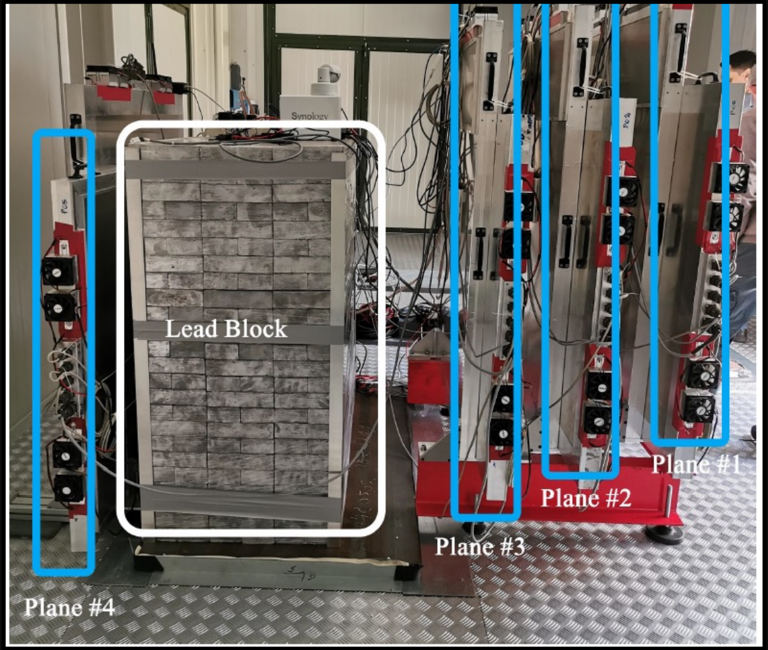
Muography to keep an eye on Mt. Vesuvius

- Members of CP3 are participating to the MURAVES experiment in Italy: MUon RAdiography of VESuvius, taking data since Dec. 2019

- MURAVES is a consortium of volcanologists of INGV and physicists of INFN, University Federico II Naples, University of Florence, UCLouvain (since 2019), UGent (since 2019)

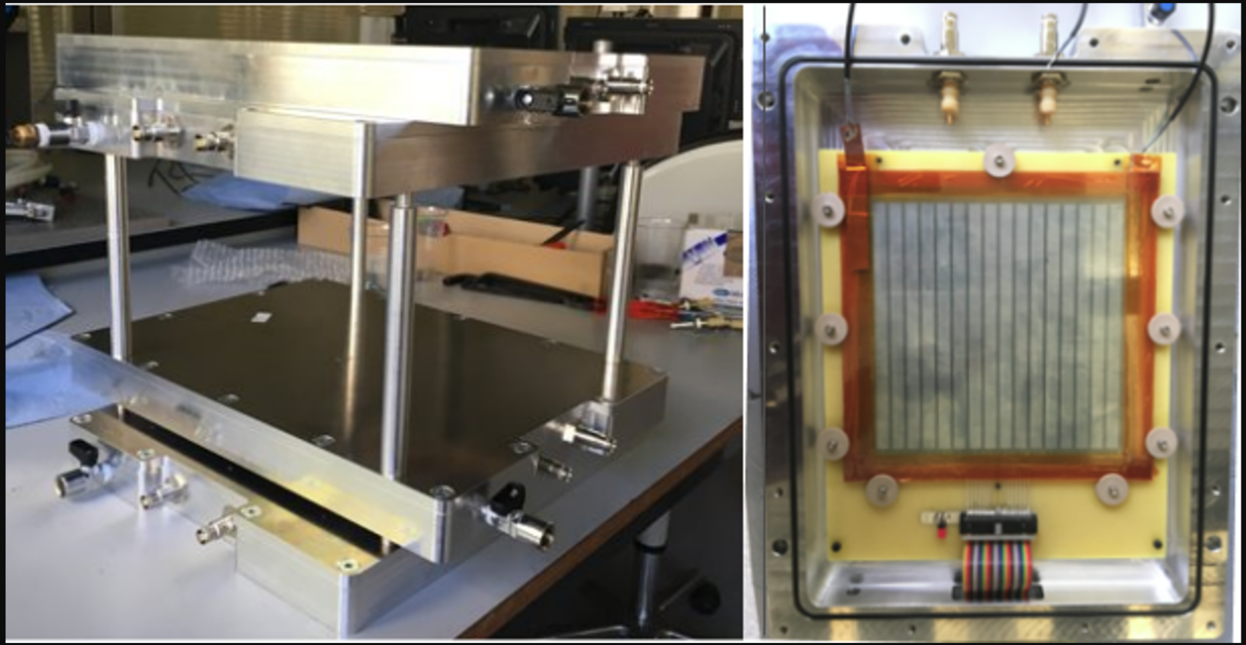
CP3 is taking care of end-to-end Monte Carlo simulations, and some analysis tasks.

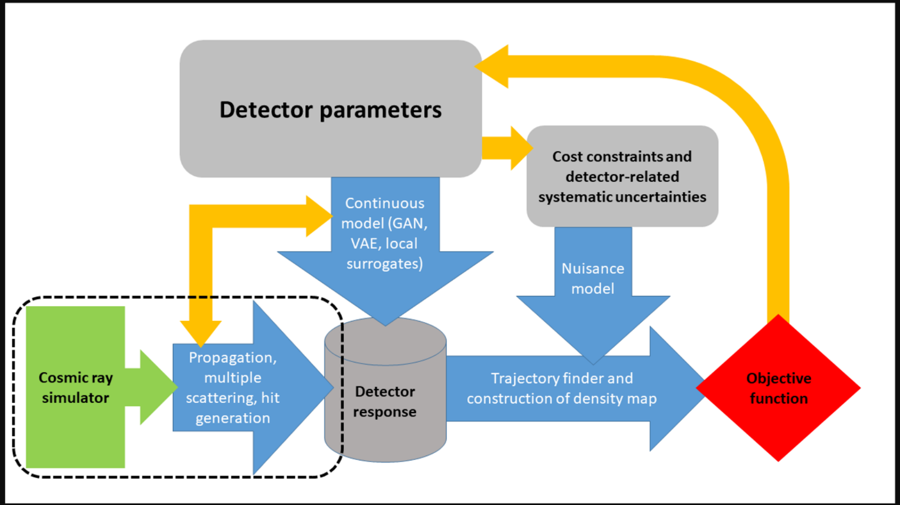




Portable muon telescope

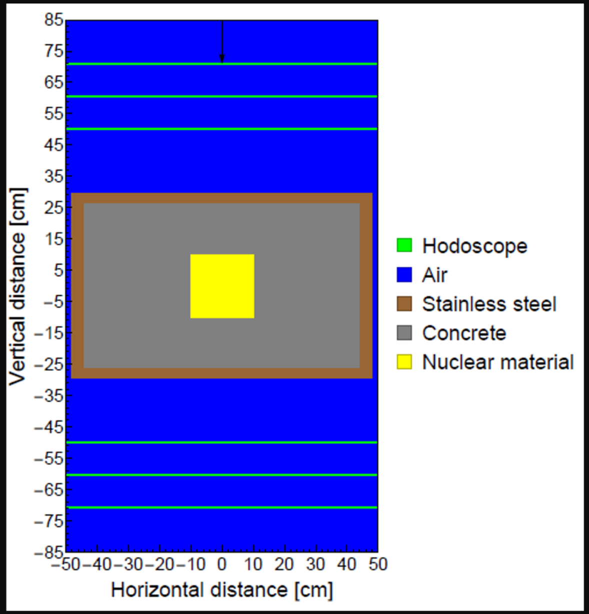
- ➢Modular, compact, light detector based on Resistive Plate Chambers;
- ➢Use cases: confined spaces with unfriendly logistics;
- ➢Local R&D project for detector and electronics;
- ➢Very recently submitted two patents related to this project.





MODE collaboration:

- Machine-learning Optimized Design of Experiments
- Developing general parametric simulation pipeline for muon tomography case studies



Gravitational wave research

The CP3 gravitational wave team

- **Permanent staff:** G. Bruno (V, A), C. Lauzin(I), C. Ringeval (T), J. van Heijningen (V, I)
- **Support**: A. Tanasijczuk (V, computing)
- **Postdoc:** P. Auclair (Th), F. Badaracco (V, I), E. Ferreira (I), A. Miller (V, A), M. Sieniawska (V, A), J. Suresh (V, A), D. Da Cunha (Th)
- **PhD student:** R. Cabrita (I, V), A. Depasse (V, A), F. De Lillo (V; A)

V = Virgo Member
A = Analysis
Th = Theory
I = Instrumentation

Anisotropic search in the stochastic GW background

Federico De Lillo
Jishnu Suresh

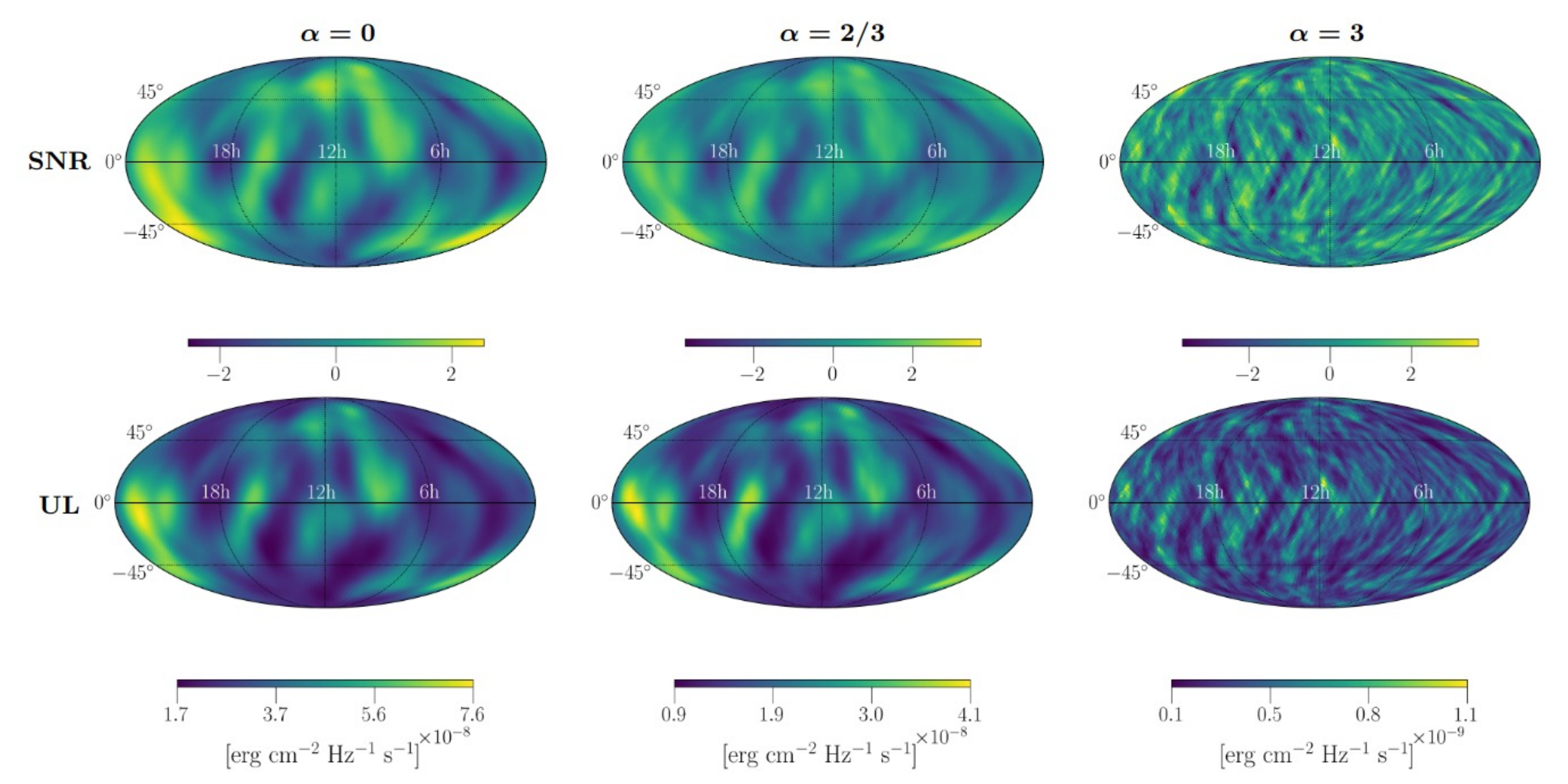
- The SGWB is a superposition of unresolved sources;
- Searches by correlating detector outputs;
  - Anisotropic: spherical harmonics (extended sources), **broadband radiometer** (point-like sources), narrowband radiometer (point-like, known sources);
  - Also search for specific signatures of cosmic strings models.

GW flux using O1,O2,O3 from LIGO only and GW energy flux model:

$$\mathcal{F}(f,\Theta) = \mathcal{F}_\alpha(\Theta)\left(\frac{f}{f_{\rm ref}}\right)^{\alpha-1}$$

, with

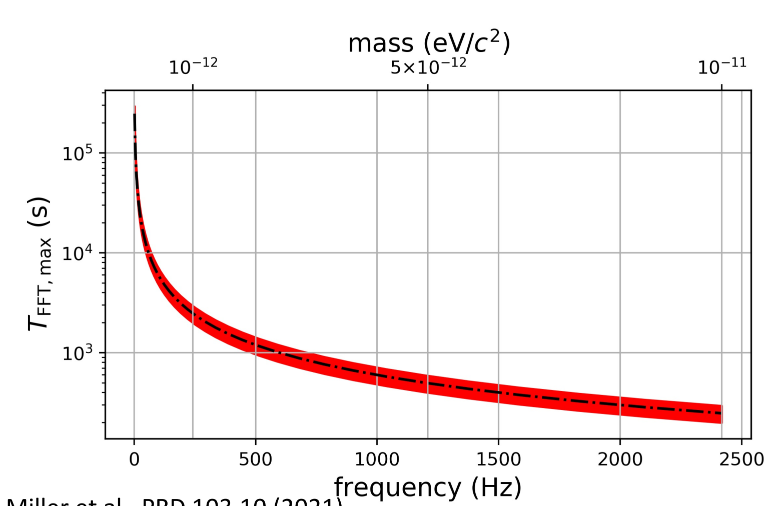
$$\mathcal{F}_\alpha(\Theta) = \frac{c^3\pi}{4G} f_{\rm ref}^2 \mathcal{P}(\Theta)$$



LVK collaborations, arXiv:2103.08520

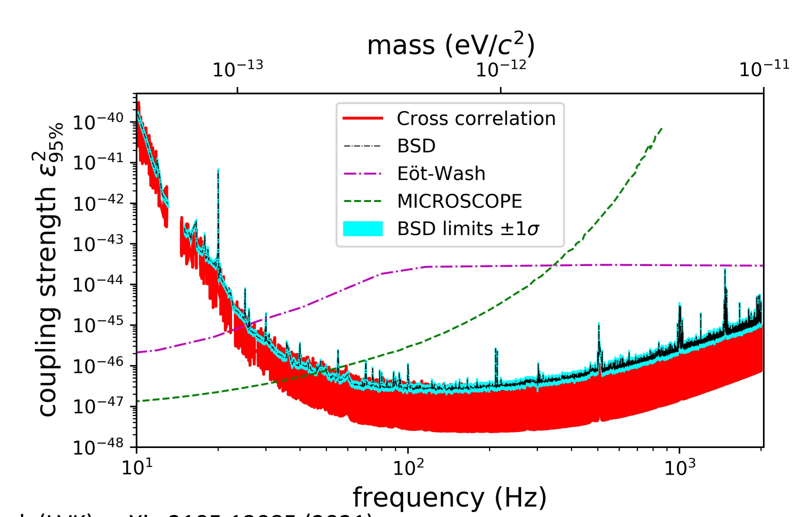
Searching for dark photon dark matter

- ➢Developed a method that carefully varies the Fast Fourier Transform length as a function of the expected frequency modulation caused by a dark photon signal;
- ➢Ran a search for dark photon dark matter in LIGO/Virgo/KAGRA data using a cross-correlation and excess power method (BSD), producing the best constraints on the coupling of dark photons to baryons for a wide range of ultralight dark photon dark matter;
- ➢Developing Wiener filter method to distinguish among types of dark matter interactions and better follow-up candidates returned in future searches (📝 Miller and Badaracco, in prep.)



Miller et al., PRD 103.10 (2021)

FFT length accounts for Maxwell-Boltzmann distributed velocities of dark photons, such that this modulation is confined to one frequency bin

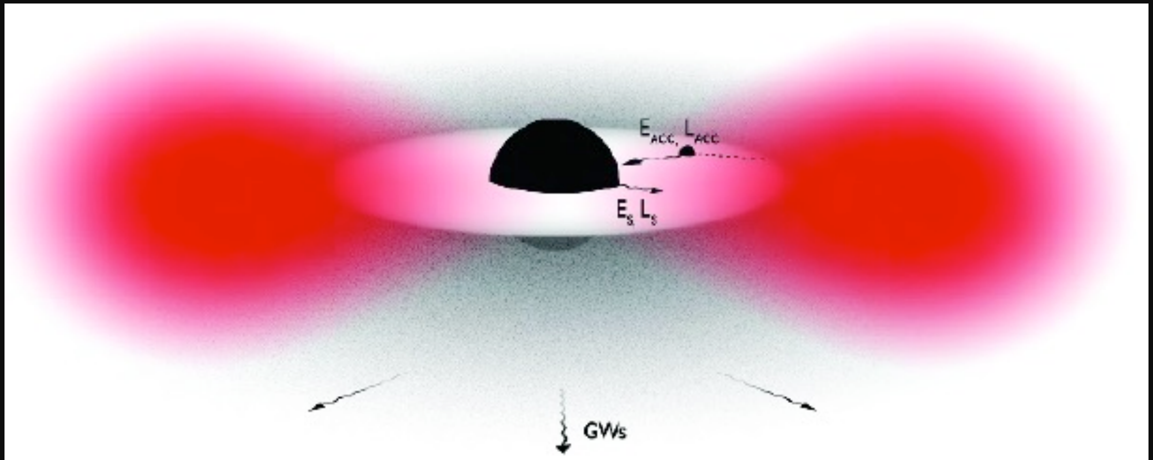


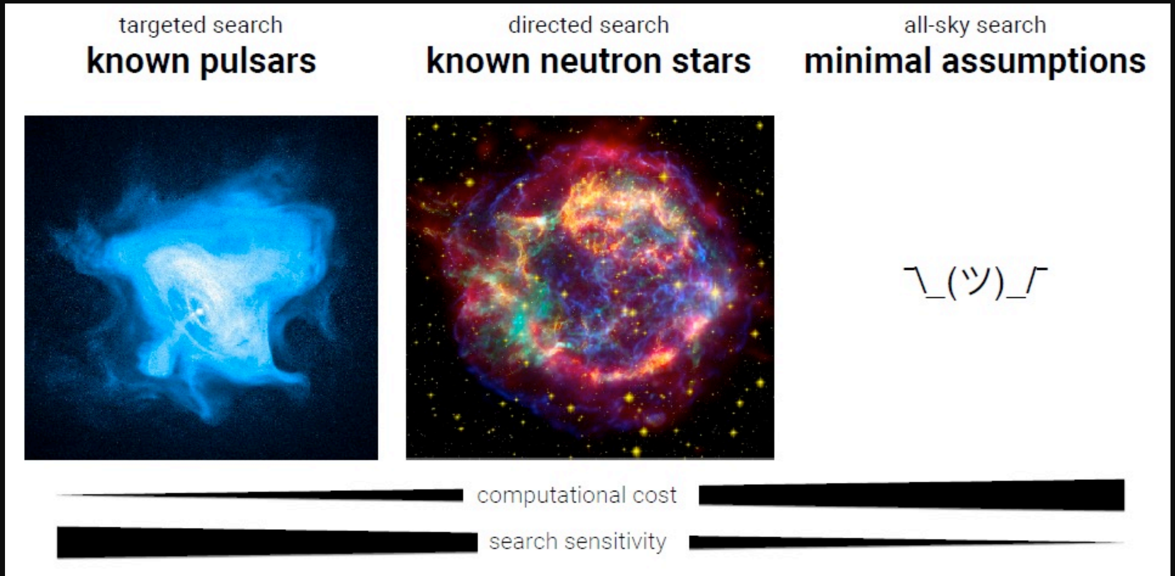
Constraints on the coupling strength of dark photons to baryons for each method used in the search, in comparison to existing dark matter experiments

Abbott et al. (LVK), arXiv:2105.13085 (2021)

Francesca Badaracco
Andrew Miller

Continuous waves from boson clouds





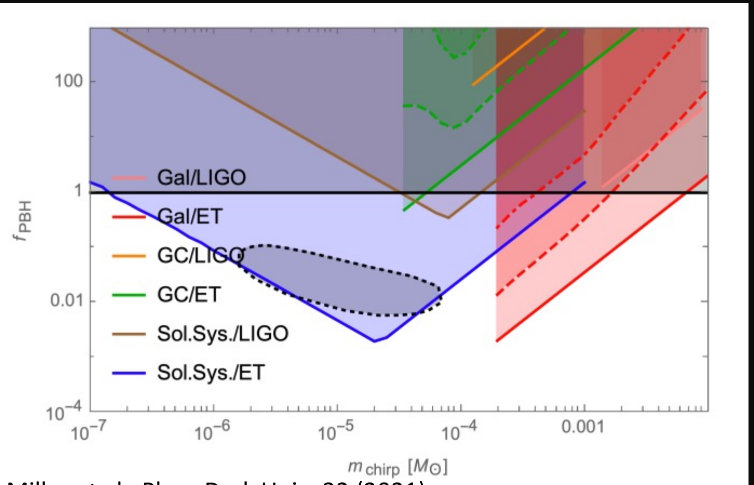
[NASA/CXC/SAO/F.Seward et al.][Courtesy NASA/JPL-Caltech]

- Dark matter can form clouds around black holes if its Compton wavelength is comparable to the size of the black hole
- Boson clouds can emit continuous gravitational waves as they annihilate after superradiance ($\Omega_b < \Omega_{BH}$)
- This system will emit quasi-continuous GW;
  - $\nu_{GW} \approx 2\ m_b$;
  - m_b sensitivity around $[10^{-13} - 10^{-11}]$ eV;
- Methods 📝 on vector boson clouds and search in advanced detector data for nearby galactic binaries is planned.

Antoine Depasse
Andrew Miller

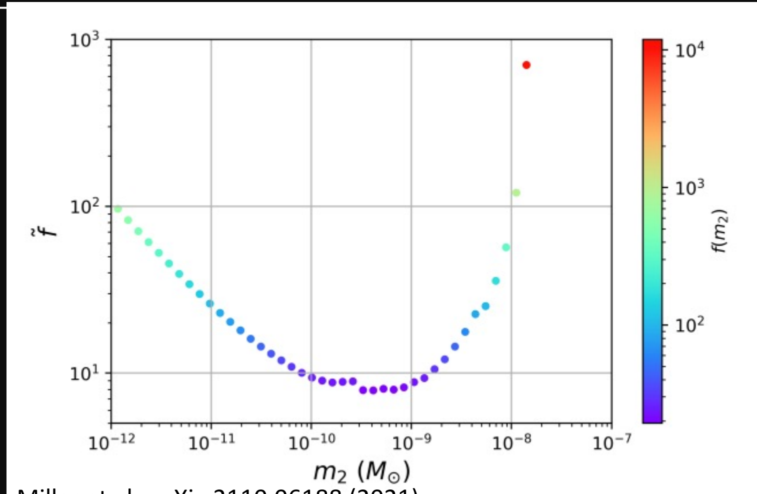
Constraining subsolar PBHs with CW searches

- Adapted (Generalized) Hough Transform to search for inspiraling sub-solar systems with chirp masses between 10^{-7} - 10^{-3} M_{sun}
  - Projected constraints on fraction of dark matter PBHs could compose, f_{pbh}, with Einstein Telescope
- Using continuous-wave upper limits from O3a, derived model-independent merger rates, and constrained quantity related to f_{pbh} for chirp masses of 10^{-7}-10^{-4} M_{sun} for equal-mass and asymmetric mass ratio binaries
- Working on applying the Hough to "mini-EMRI" systems detectable with LIGO/Virgo (with H. Guo, 📝 in prep.)



Miller et al., Phys. Dark Univ. 32 (2021)

Projected constraints at three distances: solar system, galaxy and galactic center for two PBH mass functions (solid and dashed lines)



Miller et al., arXiv:2110.06188 (2021)

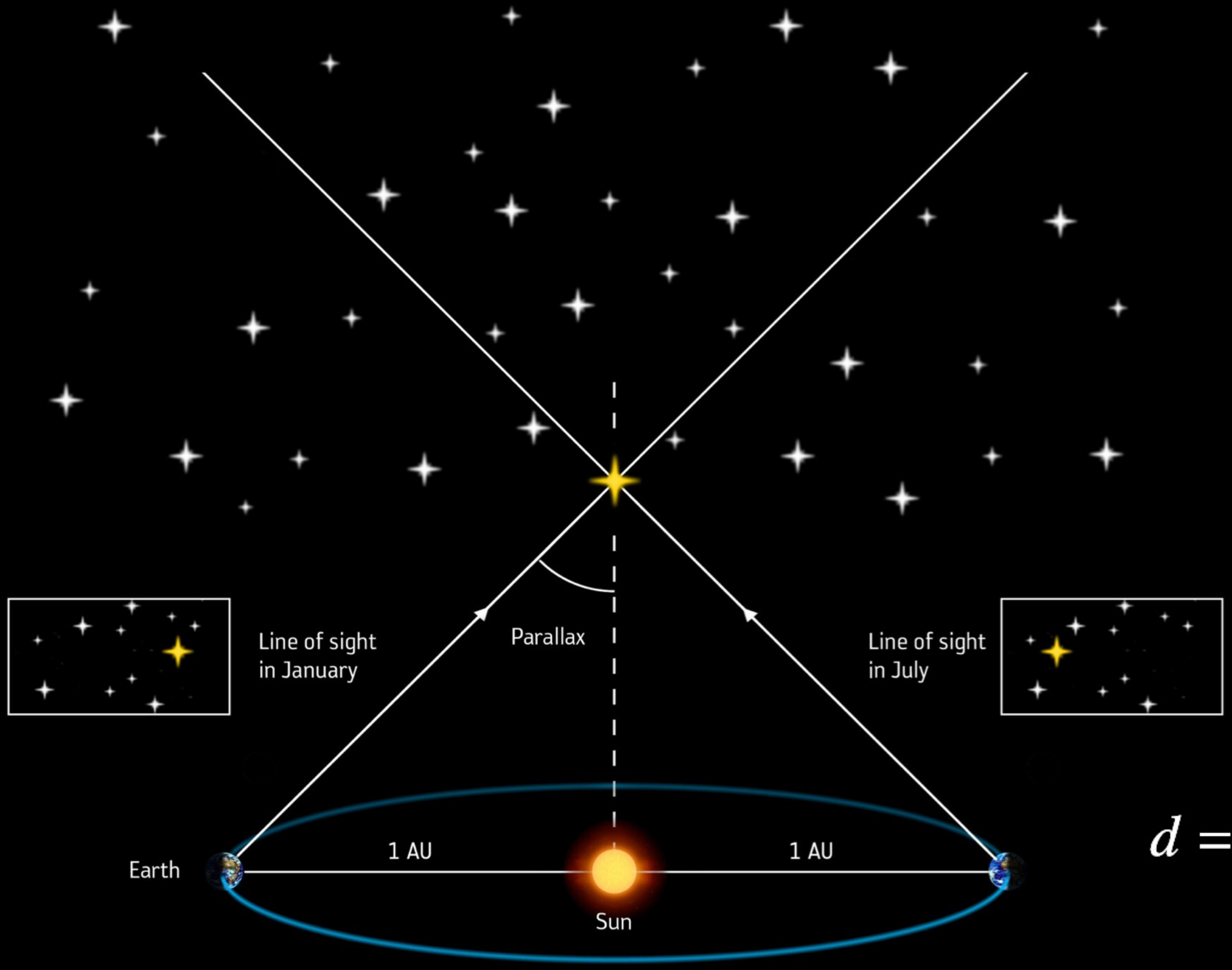
Actual constraints from O3a upper limits m_1=2.5 M_{sun} $f(m_2)$: PDF for m_2; assumes $f(m_1)$=1 and no rate suppression

Federico De Lillo
Andrew Miller
Sebastian Clesse (ULB)

Gravitational wave parallax

Magdalena Sieniawska
Andrew Miller

- Distance estimation method for the continuous gravitational wave sources;



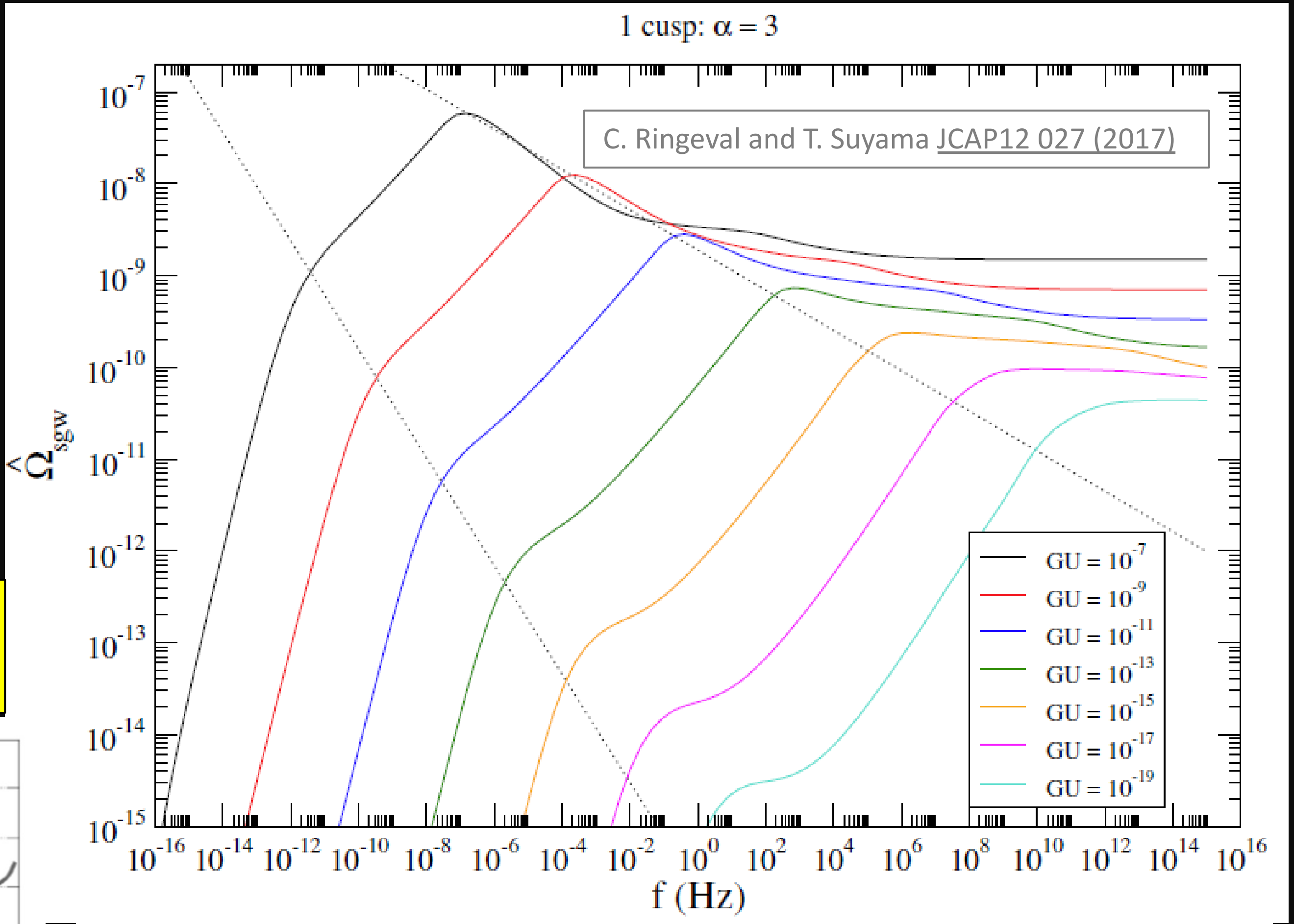
- Suitable for the near sources (how near?);
- Is it possible to measure parallax with the Frequency-Hough analysis method?
- What search grid/sky resolution do we need?

$$d = \sqrt{\frac{K_{sky}}{\pi} R_{orb} T_{FFT} \left[\frac{\dot{f}}{\Omega_{orb} \cos(\beta)} + \frac{f_0 \Omega_{orb} R_{orb}}{c} \right] SNR}$$

Stochastic GW Background from Cosmic Strings

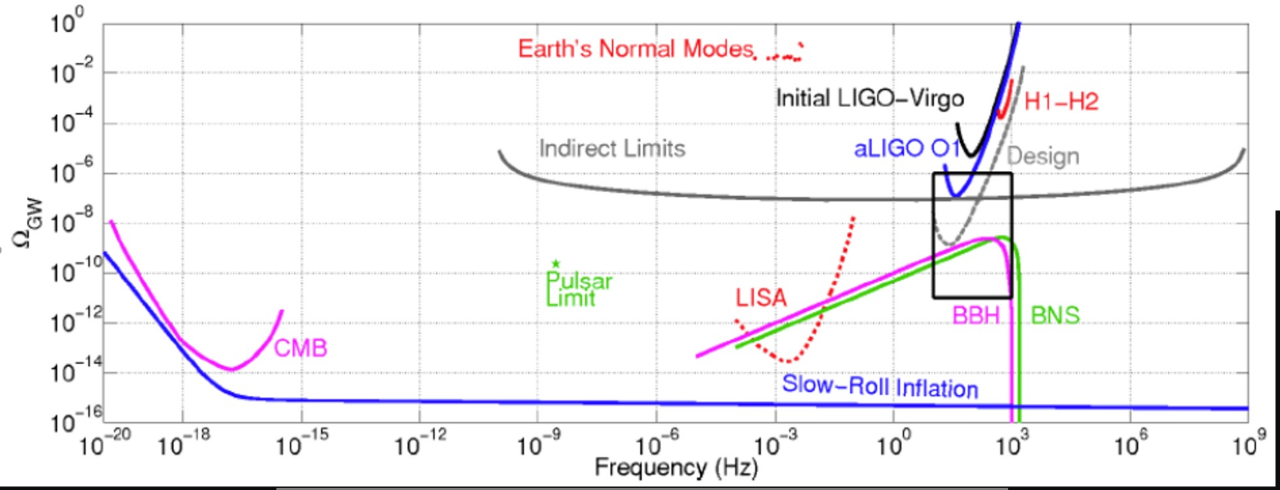
- ➢Topological defects that could have formed in the early Universe;
- ➢Predictions on average GW energy density in the universe from cosmic strings.

Christophe Ringeval
Disrael da Cunha



C. Ringeval and T. Suyama JCAP12 027 (2017)

Model	LIGO	EPTA	LIGO + EPTA
2C	$GU \leq 1.1 \times 10^{-10}$	$GU \leq 3.4 \times 10^{-11}$	$GU \leq 1.0 \times 10^{-11}$
LNK	–	$GU \leq 6.8 \times 10^{-11}$	$GU \leq 7.2 \times 10^{-11}$
HNK	$GU \leq 8.8 \times 10^{-14}$	$GU \leq 6.4 \times 10^{-12}$	$GU \leq 6.7 \times 10^{-14}$
MIX	$GU \leq 1.4 \times 10^{-8}$	$GU \leq 1.1 \times 10^{-11}$	$GU \leq 5.9 \times 10^{-12}$



B.P. Abbott et al., Phys. Rev. Lett. **118**, 121101 (2017)

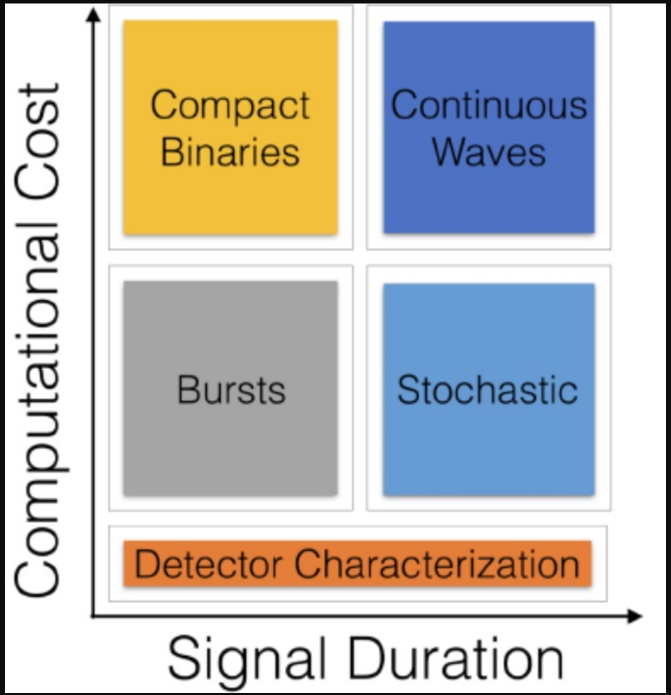
Computing efforts for the LIGO Virgo collaboration

Virgo **online** computing at EGO;

- ➢ Data collection, calibration and monitoring ($O(10^5)$ auxiliary channels)
- ➢ DetChar and data validation
- ➢ Low-latency searches (for public alerts)

Virgo **offline** computing at several centers, including UCLouvain;

- ➢ Common distributed computing
- ➢ Contribute CPU for opportunistic use



https://github.com/AndresTanasijczuk/SlurmDagman

June 2020 LIGO/Virgo CPU hours accounting (core hours)

	total
SURFsara	381 K
Nebraska-CMS	360 K
INFN-T1	349 K
PIC	200 K
LIGO_US_LSU_SuperMIC	179 K
UCSD CMS Tier2	171 K
MWT2 ATLAS UC	128.7 K
Georgia Tech	72.3 K
BelGrid-UCL	54.2 K
IN2P3-CC	33.5 K
SU ITS	22.8 K
AGLT2	20.8 K
LIGO-WA-CE	8.44 K
LIGO_US_LSU_QB2	7.81 K
LIGO-CIT-CE	7.50 K
Nebraska-Omaha	6.77 K
UWM - NEMO	5.42 K
ND_CAML	2.591 K
NIKHEF-ELPROD	1.541 K
LIGO-LA-CE	1.166 K

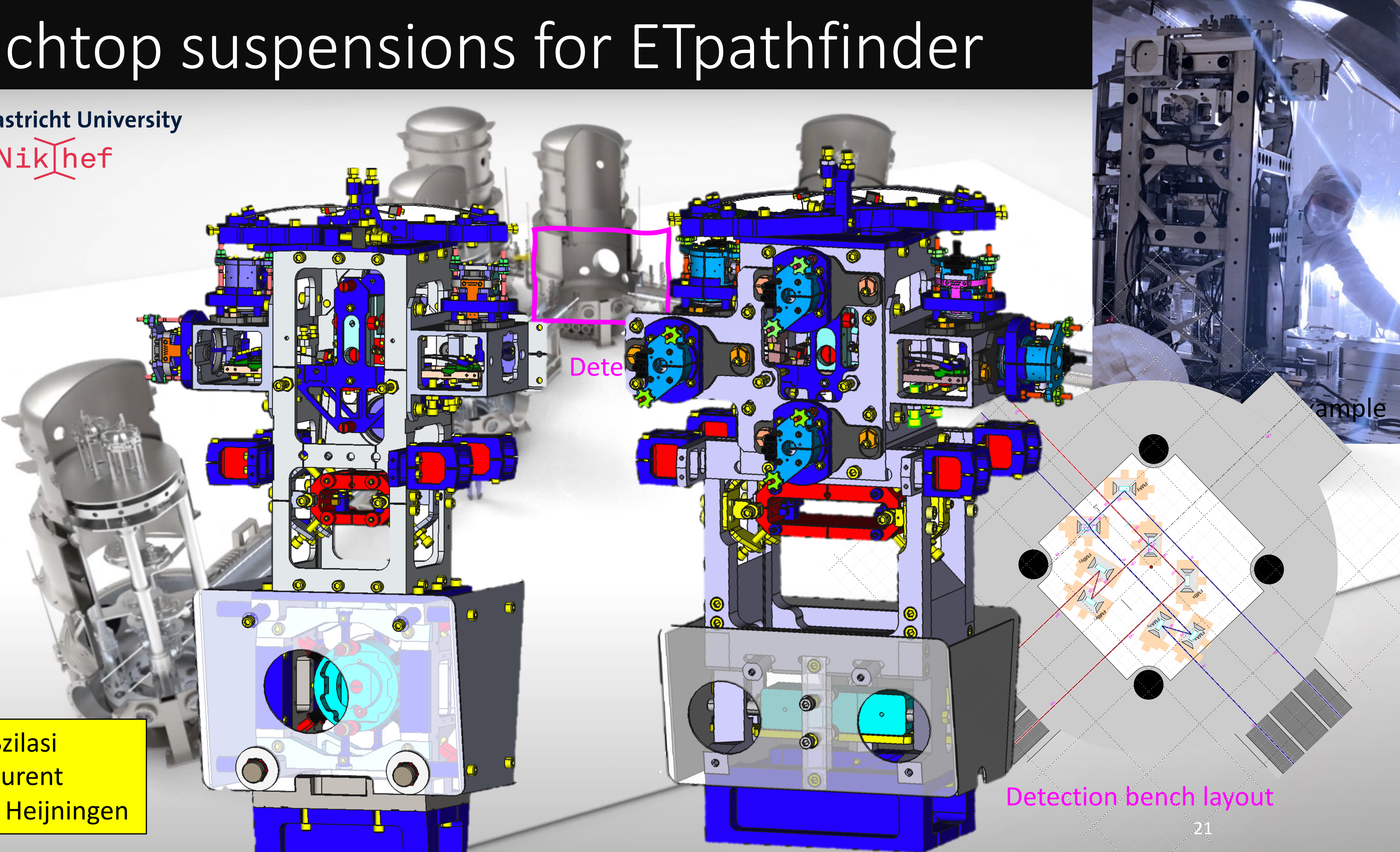
➢ Our **WLCG Tier2** accepts LVK jobs and was extended with 512 CPUs in March 2021 (ARC funded, +funding requested);

➢ **StashCache** origin deployed at UCLouvain in 100 TB storage server (ARC funding) – data transfer tests ongoing

Andres Tanasijczuk

Benchtop suspensions for ETpathfinder

Maastricht University
Nikhef

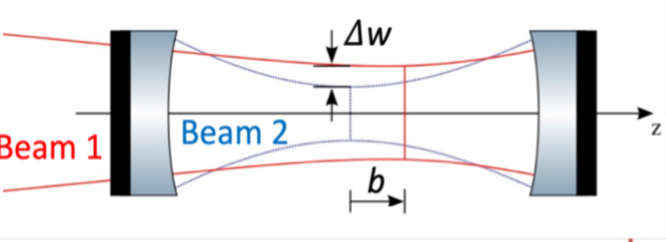


Detection bench layout

Nicolas Szilasi
Hervé Laurent
Joris van Heijningen

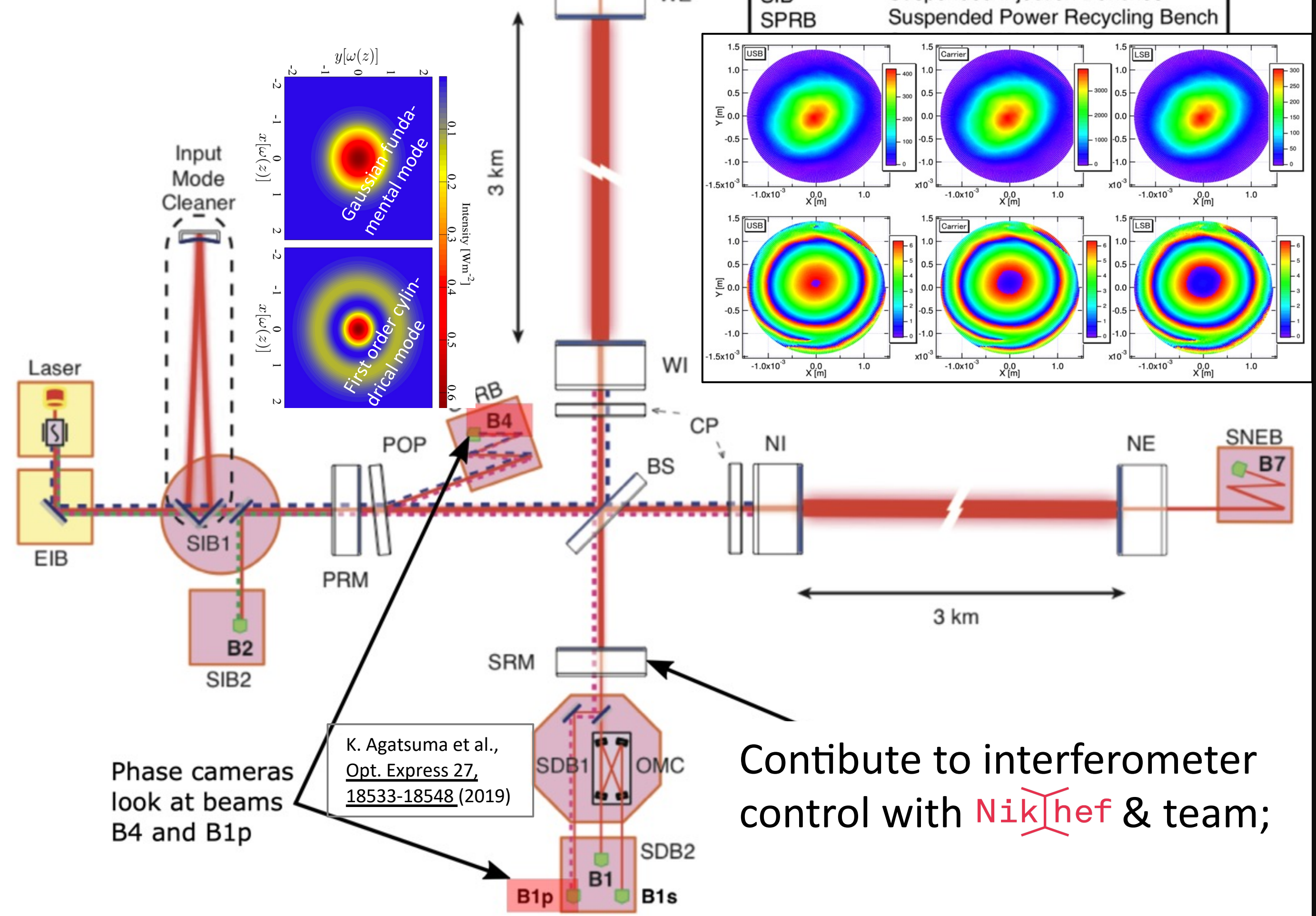
Mode mismatch mitigation for Advanced Virgo

Ricardo Cabrita
Joris van Heijningen



Mode matching (MM)

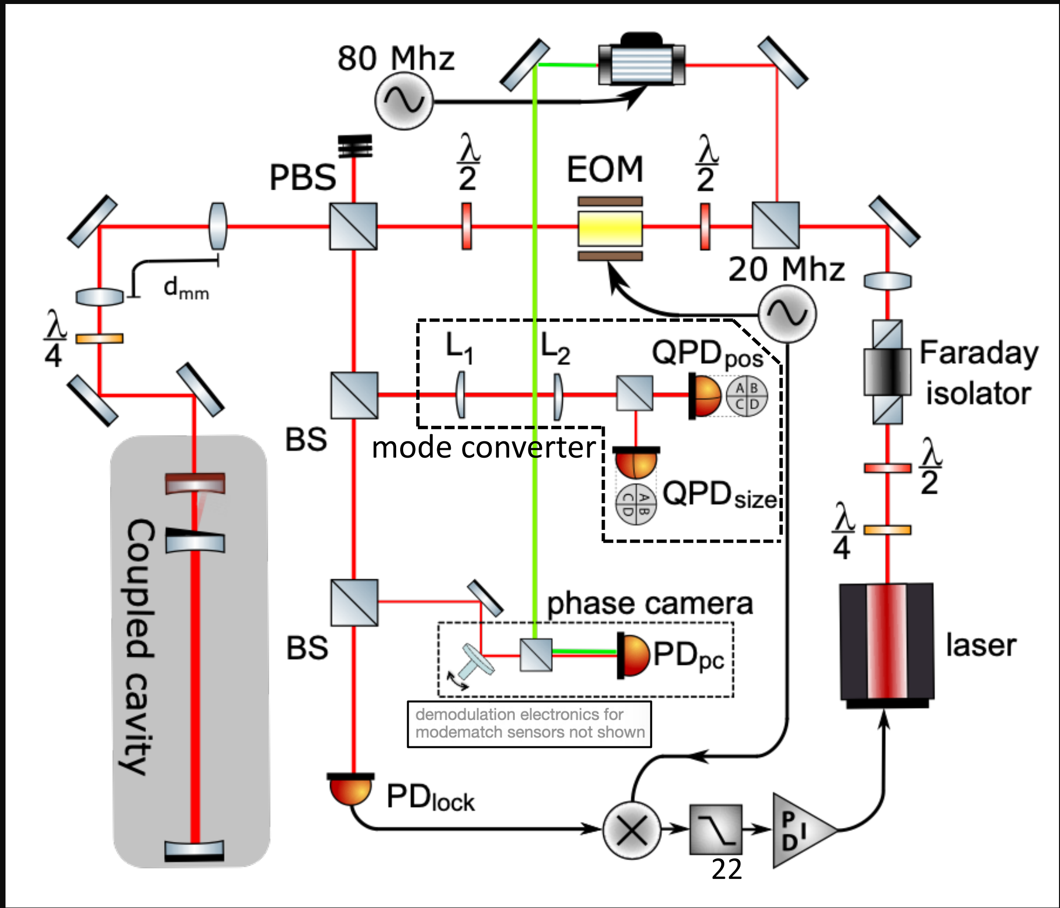
- Setup at UCLouvain to test MM techniques at 1550nm;
- Phase camera to indentify out-of-phase cylindrical modes.



Phase cameras look at beams B4 and B1p

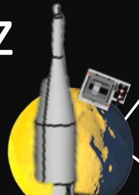
K. Agatsuma et al., Opt. Express 27, 18533-18548 (2019)

Contibute to interferometer control with Nikhef & team;



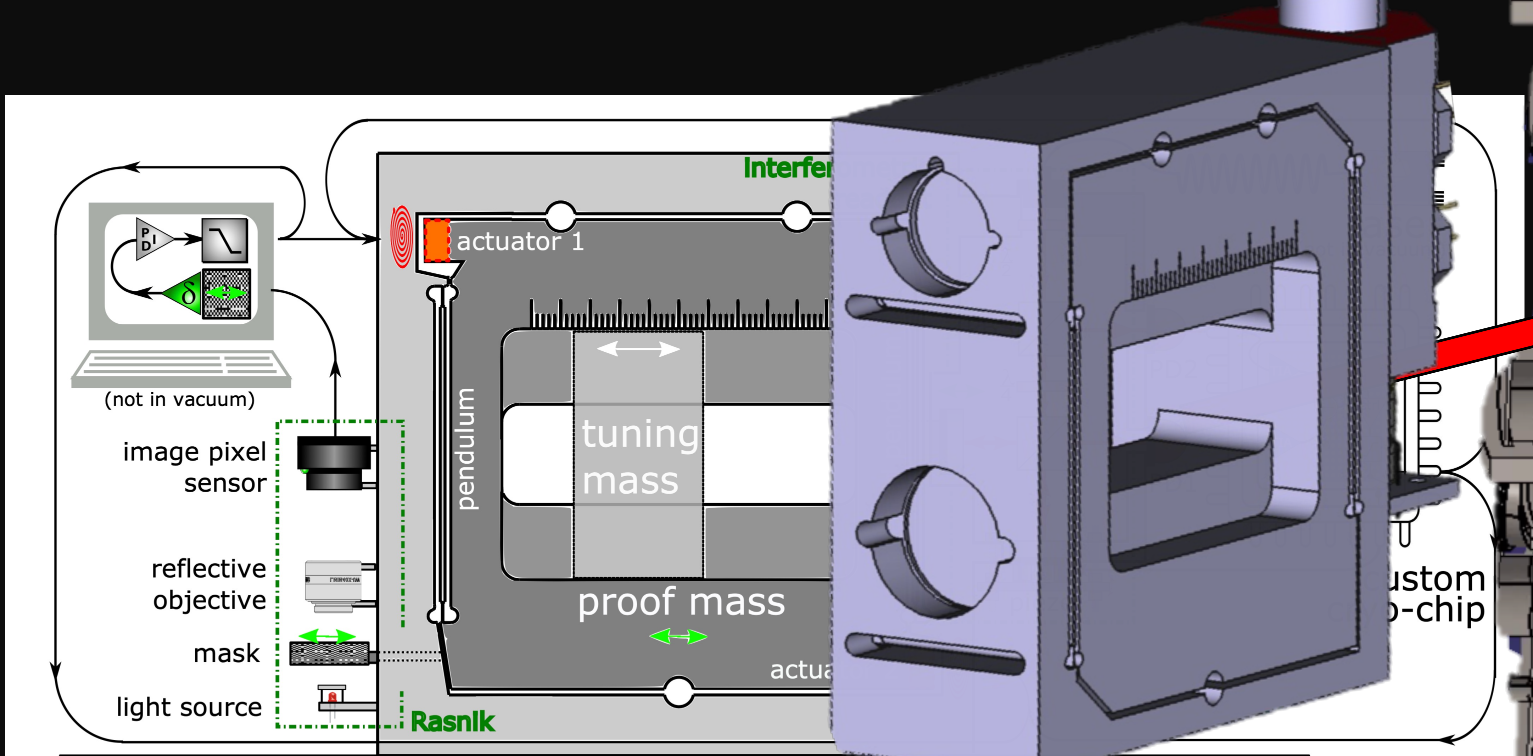
Cryogenic inertial sensors for E-TEST

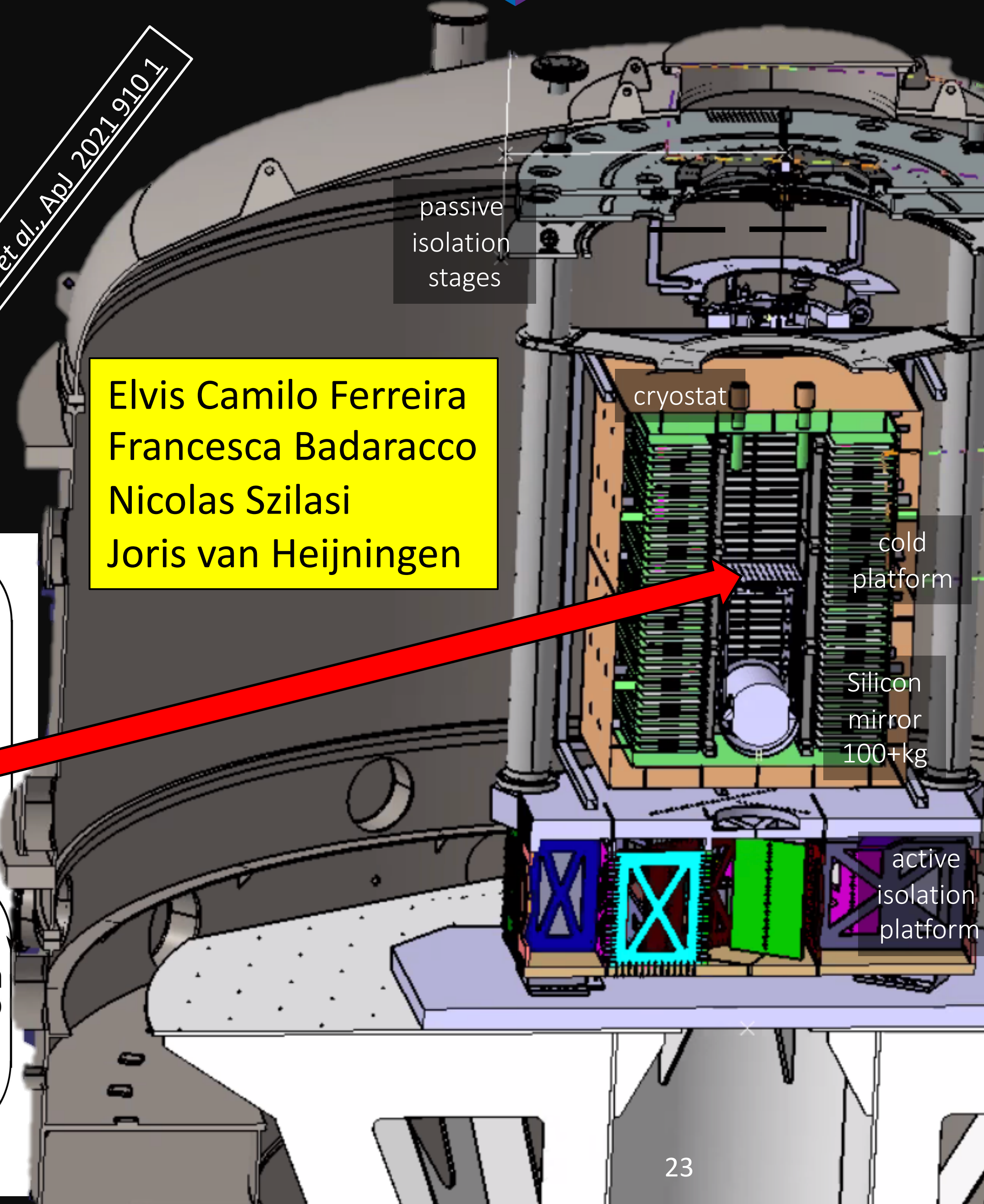
- Mechanics made out of Niobium (Nb), fully superconducting at T = 5 K;
- We expect fm/√Hz sensitivity from 1 Hz onwards, interesting for ET and LGWA;
- Can monitor impact of cryocoolers.



J. Harms et al., ApJ 2021 910 1

Elvis Camilo Ferreira
Francesca Badaracco
Nicolas Szilasi
Joris van Heijningen

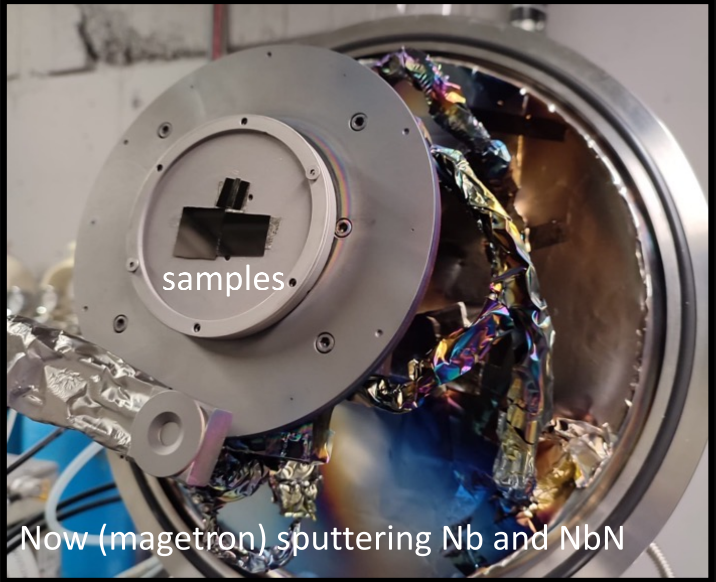




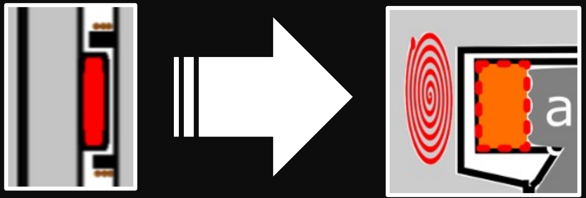
A. Bertolini et al.,2006, NIM A, 556, pp 616-623 JVvH, 2020, JINST 15 P06034

Current research on inertial sensor

Collaboration with Innovative Coating Solutions (Belgium) for custom superconducting coils.

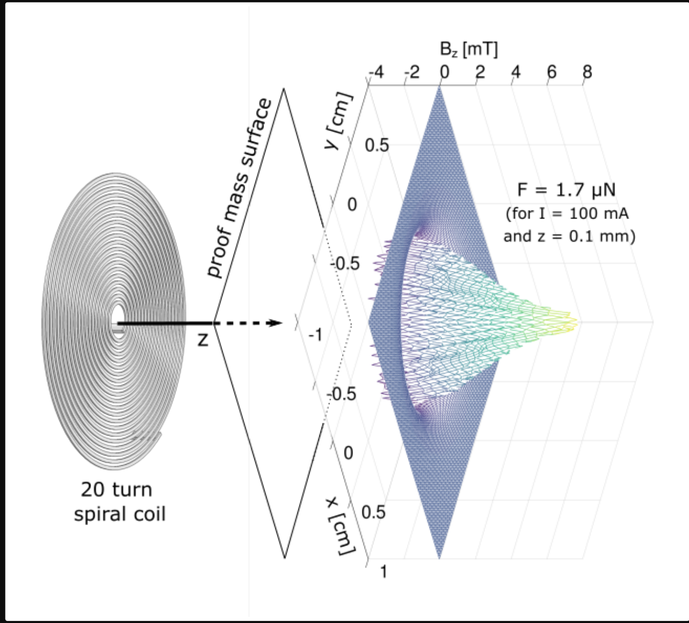


Superconductivity collaboration and testing with Andrea Perali (UniCam) and Filip Tavernier (KULeuven), respectively

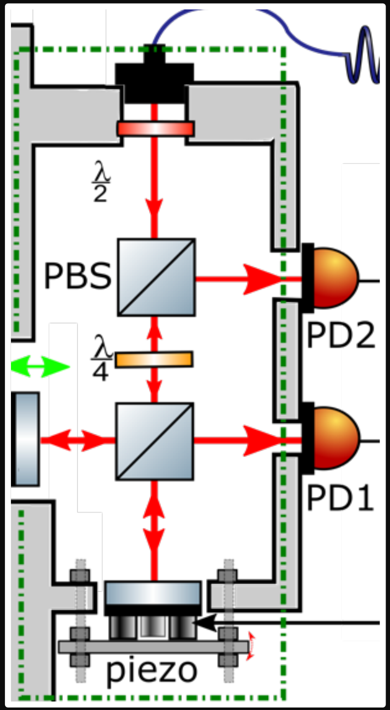


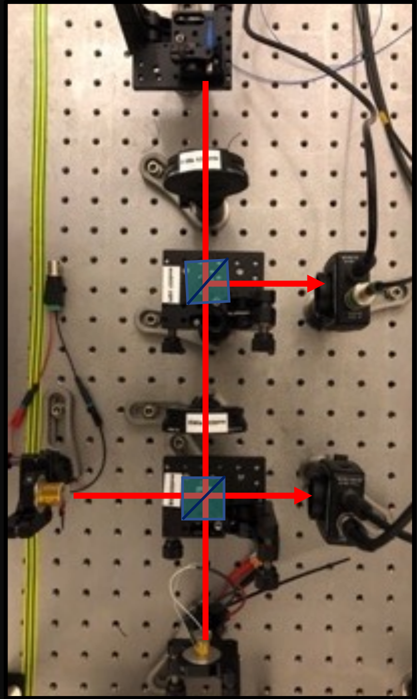
Coil-magnet

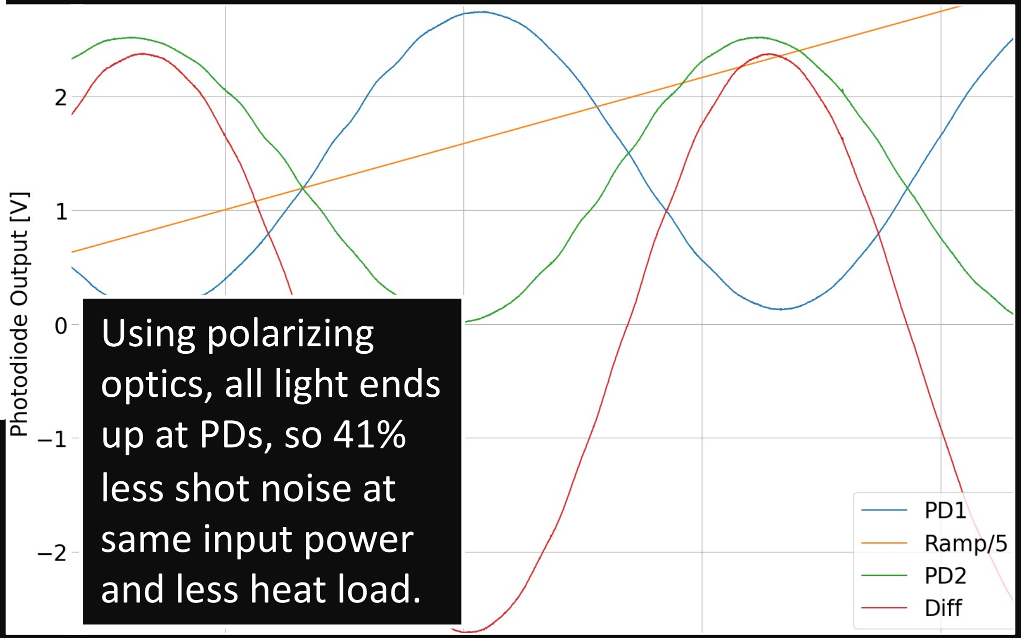
Superconducting coil



Magnetic pressure on proof mass by Meissner effect





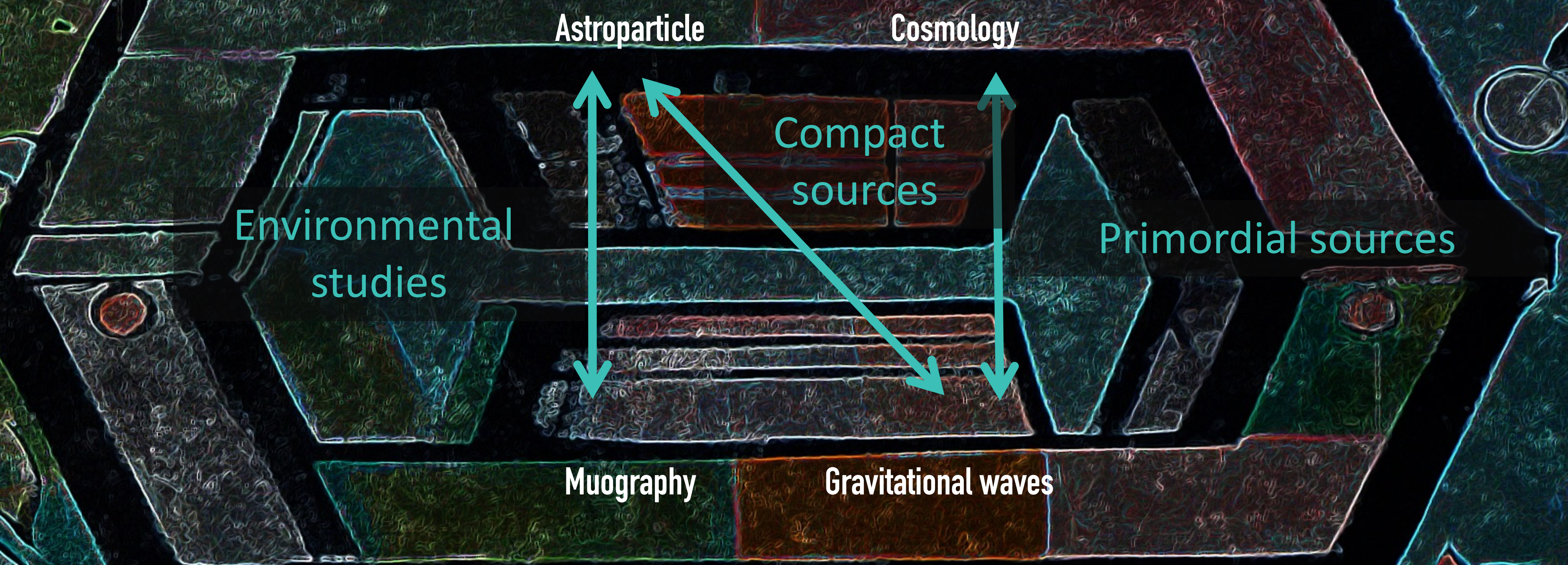


Using polarizing optics, all light ends up at PDs, so 41% less shot noise at same input power and less heat load.

UCLouvain

Astroparticle physics at UCLouvain's CP3

11th CosPa meeting | ULB | Brussels | 29.10.2021



Gwenhaël de Wasseige and Joris van Heijningen

on behalf of many researchers at UCLouvain