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ET ITALY
Einstein Telescope

# A TeRABIT network for the Einstein Telescope in Italy

Alberto Masoni
INFN Cagliari

March 2024

Taipei – Academia Sinica

Credit: Jim Watson/AFP/Getty

# Acknowledgments:

**Pia Astone Stefano Bagnasco**
**Marica Branchesi Mauro Campanella**
**Alessandro Cardini Michele Punturo**

WHAT (is TeRABIT)

WHO (partners & Infrastructures)

WHERE (operates)

WHEN (present status & timescale)

WHY( relevance for Einstein Telescope in Italy)

ET ITALY Einstein Telescope

# WHAT (is TeRABIT)

**Te**rabit network for
**R**esearch and
**A**cademic
**B**ig data in
**It**aly

Aim: Build an **integrated system of Research & Innovation Infrastructures** within the Pan-European Research Infrastructures framework

Funded with 41 M€ within the Mission 4 – Education & Research - of the Italian National Recovery plan. Part of the Next Generation EU program

# Vision

- ✓ Create a **distributed, hyper-connected, hybrid HPC-Cloud environment** that offers services designed to meet the needs of research and innovation.
- ✓ The environment will leverage, federate and strengthen the three existing research infrastructures: **GARR-T, PRACE-Italy** and **HPC-BD-AI** (HPC-Big Data-Artificial Intelligence) with the existing capabilities of connections to other national and European research infrastructures and data spaces through GÉANT

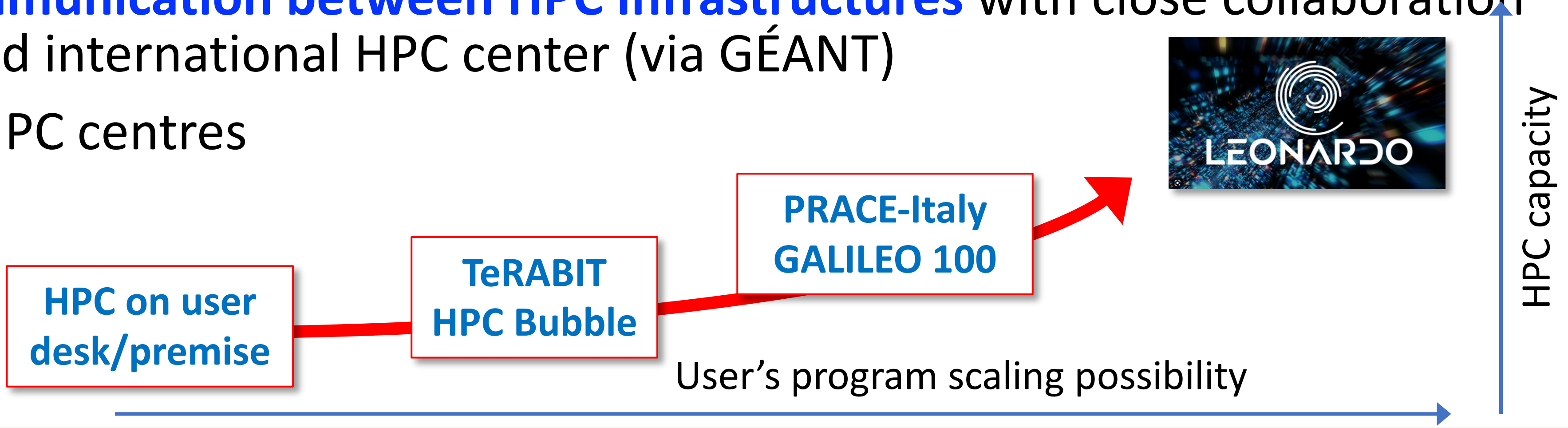
# Main objectives

- ✓ Enable widespread **data transfer, up to Terabits per second**, and services on a national scale in Italy, with particular focus on southern and island regions, all connected to Europe
- ✓ **Innovate the central HPC node of PRACE-Italy**, maintaining the Tier-1 level.
- ✓ **Innovate the HPC services** offered to researchers, beyond the centralized calculation model, adding distributed "HPC-Bubbles" (see also keynote speech on Alps Cloud-native HPC at the Swiss National Supercomputing Centre by Riccardo Di Maria – Improving HPC through clouds - )

# Planned impact of the project

- Infrastructures **strengthening**
- **Tighter integration** between **network, data** and **HPC services** with common services
- **Innovative HPC services** (bubbles), modular and increasing HPC/ML capacity between the "edge", where the users and its data are, and PRACE-Italy, in synergy with ICSC (Leonardo)
- **Federation and communication between HPC Infrastructures** with close collaboration with the national and international HPC center (via GÉANT)
- as PRACE and EuroHPC centres

**Key requisites**
**Data (cured)**
**Competences**



# WHO (partners)

Applicant : INFN (National Institute of Nuclear Physics)
Coapplicant: OGS (National Institute of Oceanografy and experimental Geophysics)
Unfunded participants: Consortium GARR, CINECA
Principal Investigator INFN: Mauro Campanella
Principal Investigator OGS: Stefano Salon

# WHO (Research Infrastructures involved)

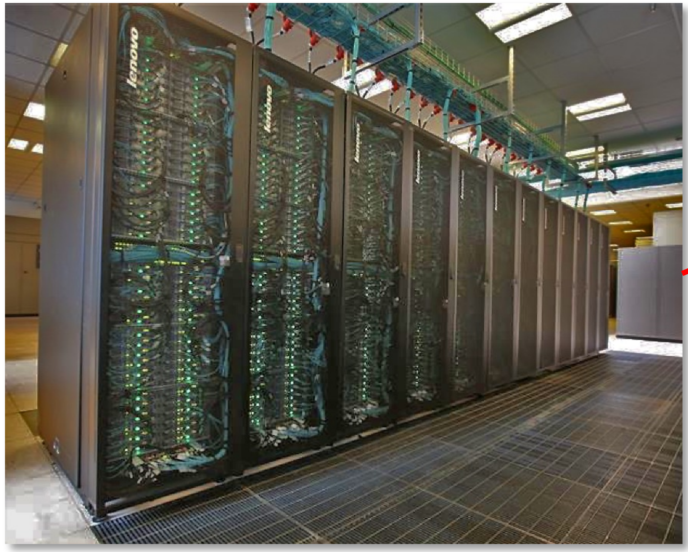
# The Research Infrastructures involved (as of today)

EuroHPC Joint Undertaking

PRACE — PARTNERSHIP FOR ADVANCED COMPUTING IN EUROPE

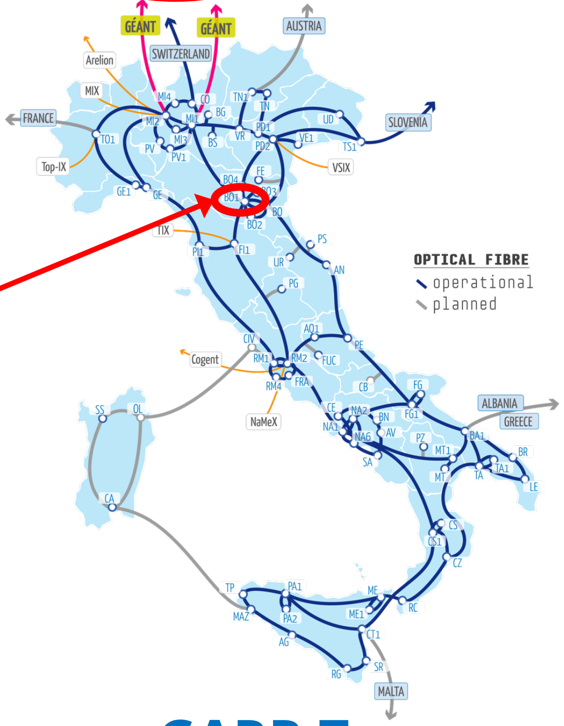
GÉANT

WLCG — Worldwide LHC Computing Grid

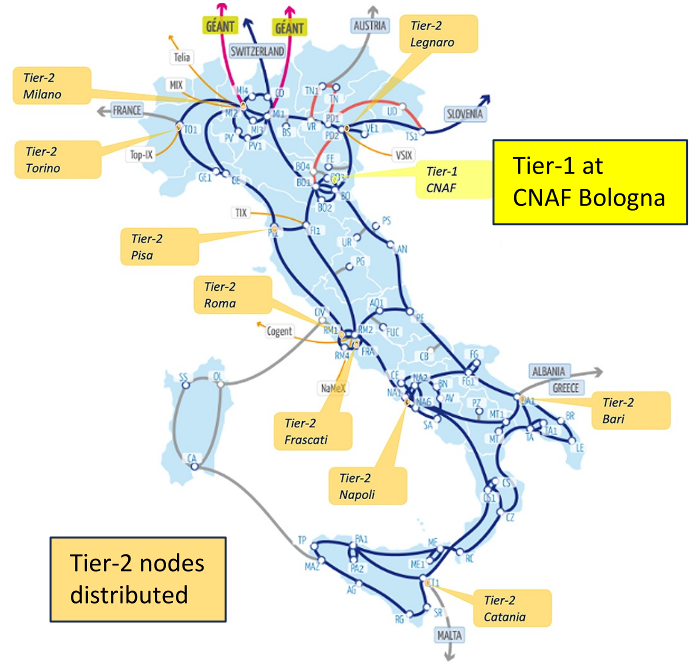


Galileo100 - HPC, Hosted by CINECA - Bologna

**PRACE-Italy**




**GARR-T**




**HPC-BD-AI**

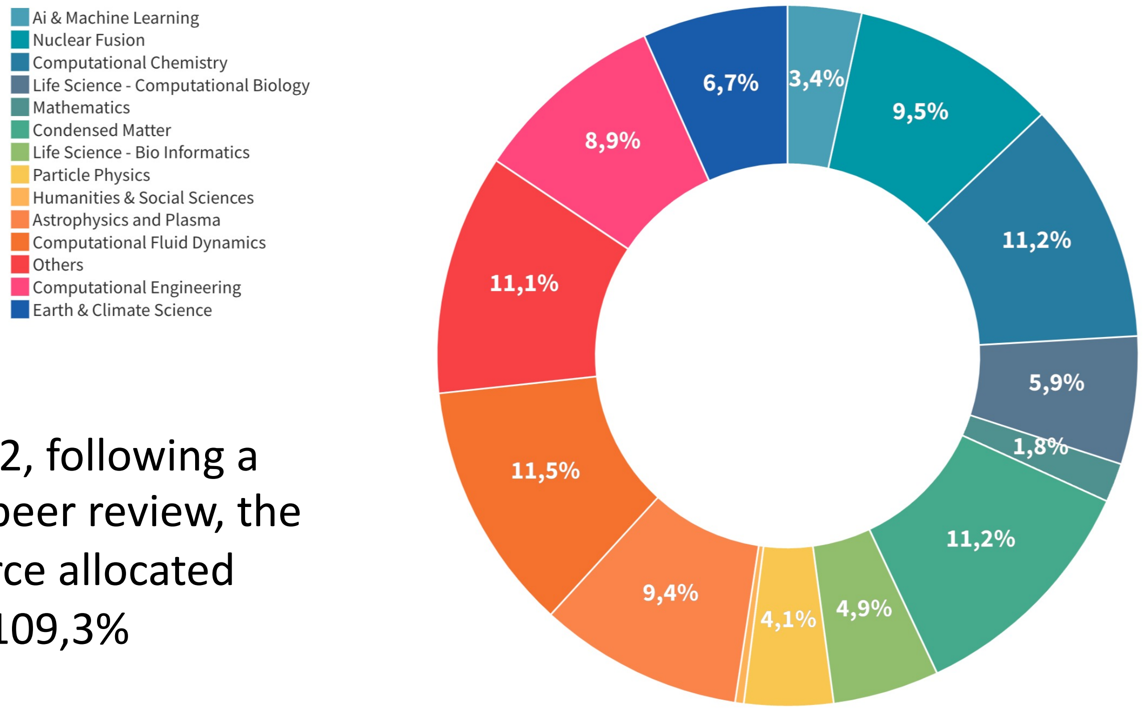
# Use of PRACE-Italy

Most represented scientific domains:

- ✓ Computational chemistry
- ✓ Condensed matter physics
- ✓ Computational fluid dynamics

## Scientific domains

Scientists use Cineca computational resources within all scientific disciplines. The most represented three are Computational Chemistry, Condensed Matter Physics and Computational Fluid Dynamics, with about11% each, followed by Nuclear Fusion (10%), Computational Engineering, Astrophysics, and Plasma Physics with more than 9% each.




In 2022, following a strict peer review, the resource allocated were 109,3%

# PRACE-Italy capacity **at TeRABIT end (2025)**

| Cloud | HPC | Storage |
|---|---|---|
| OpenStack Cloud partition | 564 computing nodes (CPU/GPU, 0.5 to 2TB SSD) | Ceph Block, Object |
| 7000 vCPUs | 28.000 CPUs | 22PB |

| | NET INCREASE |
|---|---|
| Capacity | x 4.0 |
| Storage | x 2.5 |

| Cloud | Storage |
|---|---|
| OpenStack Cloud partition<br>• HPC – CPU partition: 280+ comp. nodes, 70000+ cores, 3+ PFlops<br>• Cloud – GPU partition: 70+ comp. nodes, 20000+ cores, GPU HBM: 20+ GB/GPU, DDR: 2x aggregated HBM | Ceph Block, Object |
| 100.000 vCPUs | 34 PB |

Integrated in TeRABIT infrastructure, access to federated services

Community advantages:

- New user communities => expected increase of users benefitting
- TeRABIT user exploitation and use cases (e.g. sensors *to* HPC-Bubbles *to* G100++ *to* ICSC)
- Synergy within TeRABIT consortium for user training and support
- Move HTC workloads from HPC to Cloud, reducing pressure on HPC queues

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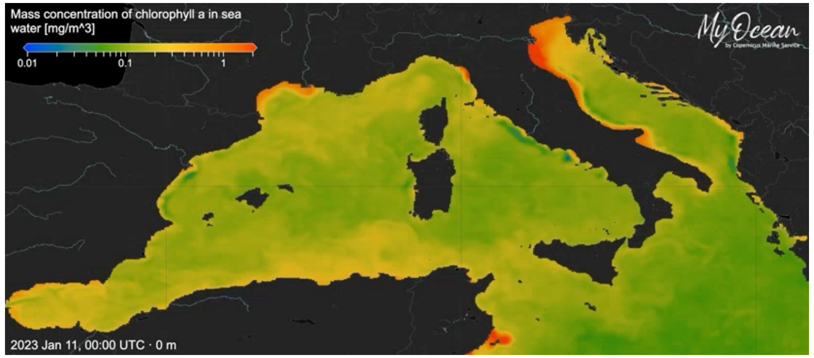
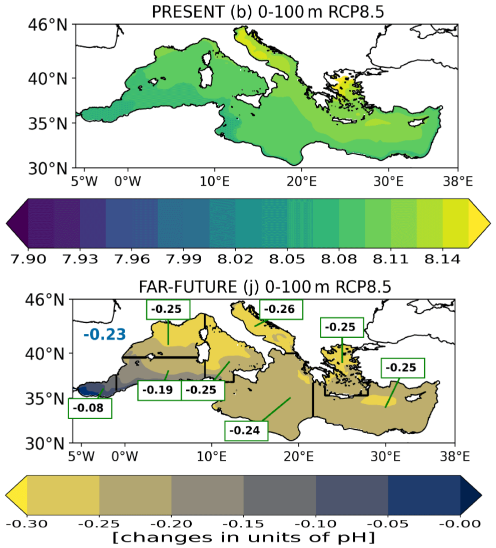
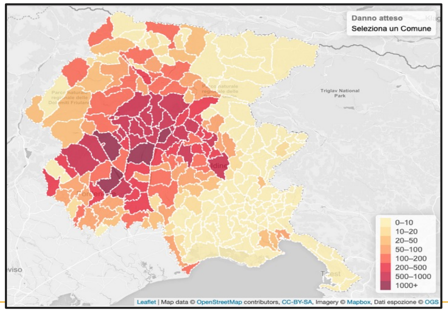
# OGS as user of PRACE-Italy

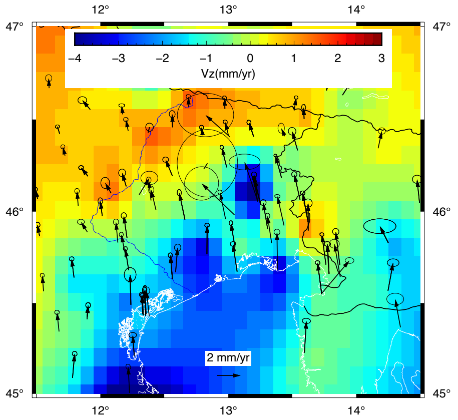
- Operational oceanography and digital twins in the Mediterranean Sea and North Adriatic in the Copernicus context
- Climate change scenarios and multi-scale effects on marine, coastal and lagoon ecosystems
- Regional Earth System modeling for carbon cycle analysis
- Regional seismic monitoring (also through GNSS data processing), probabilistic risk assessment and production of damage scenarios
- 3D simulation of seismic wave propagation in complex geological structures

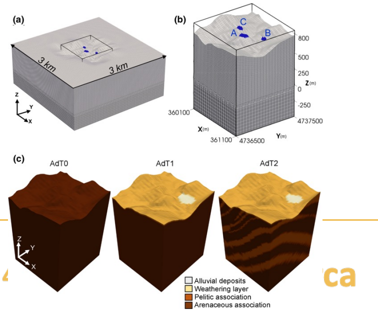



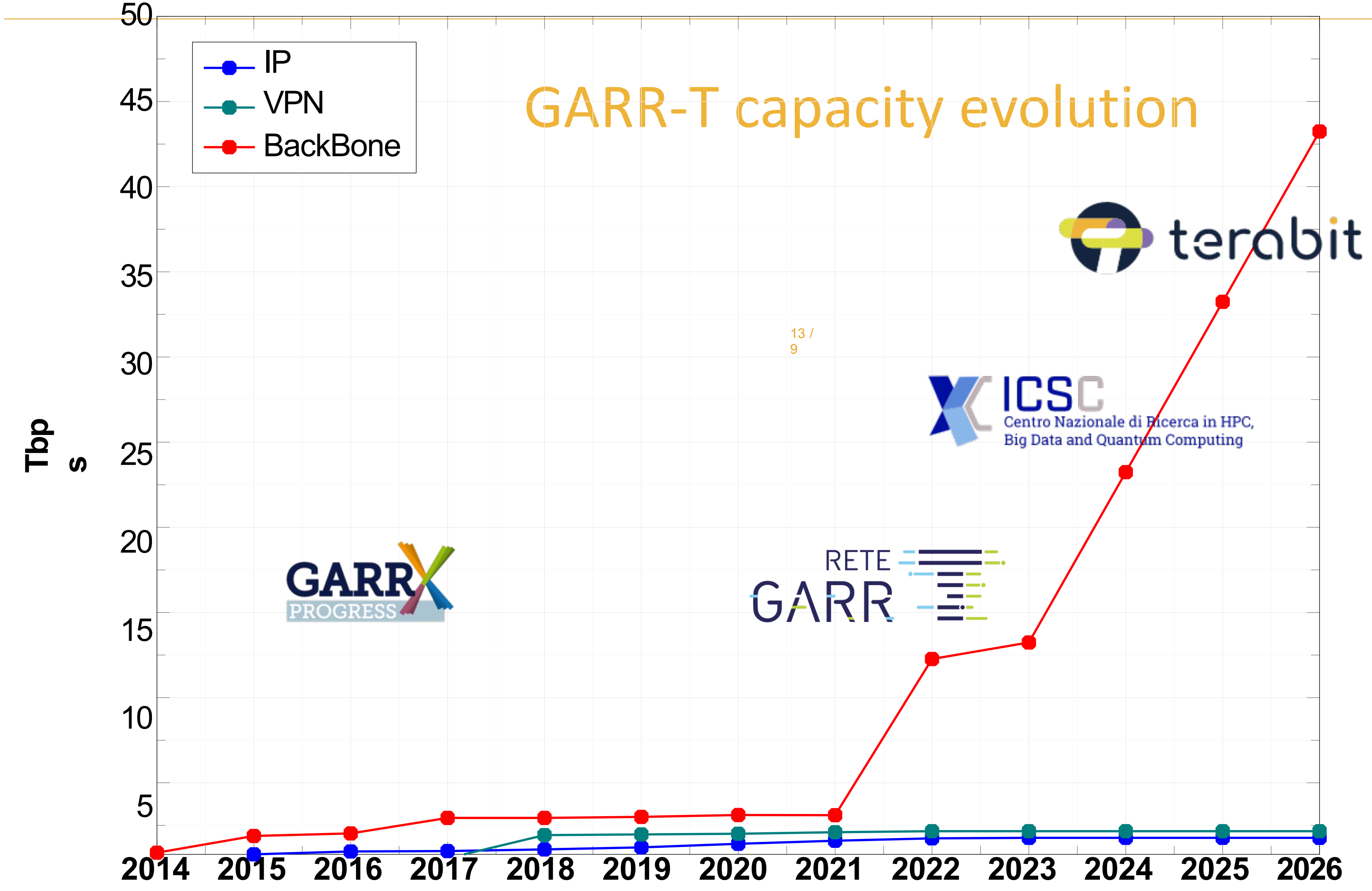

OGS






Dark Fibre 12,000 km

Submarine 1,000km (TeRABIT)

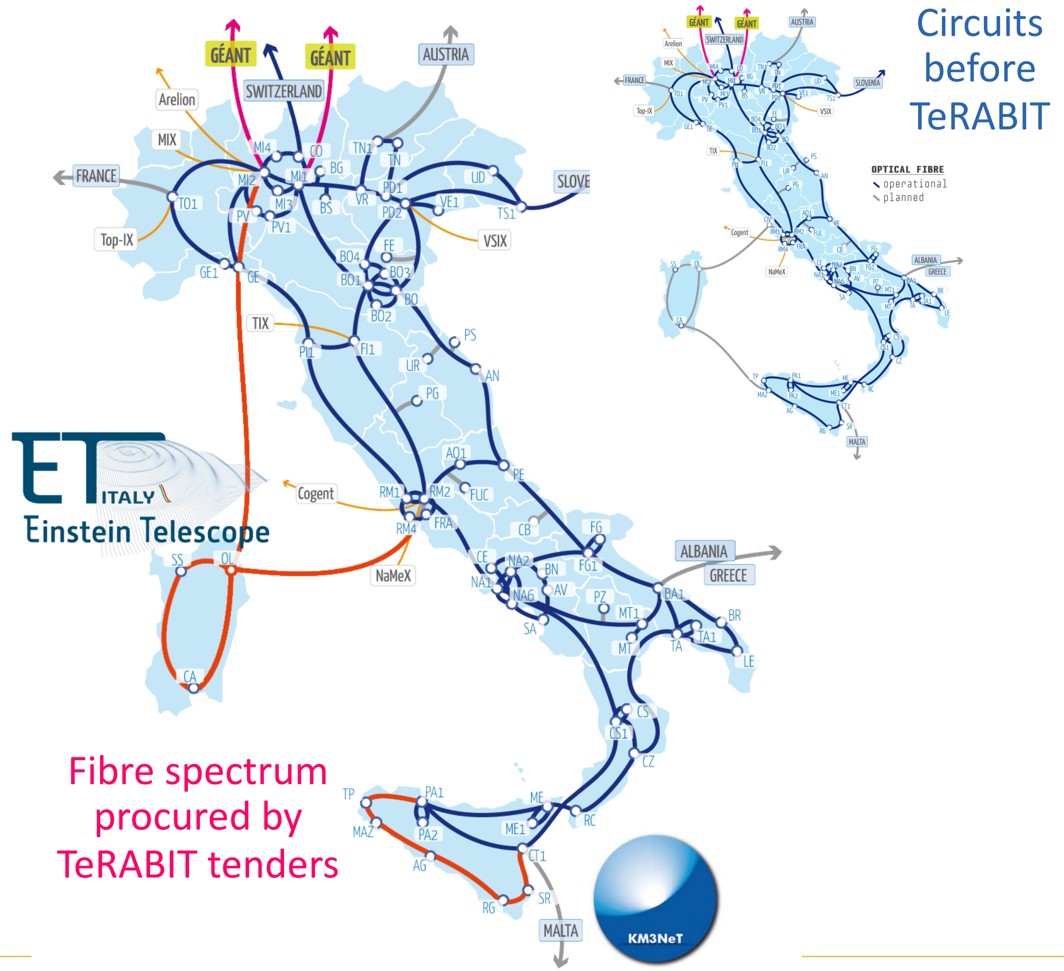
Backbone 30T, 50T+

Access 100G+, 400G+, 1T+

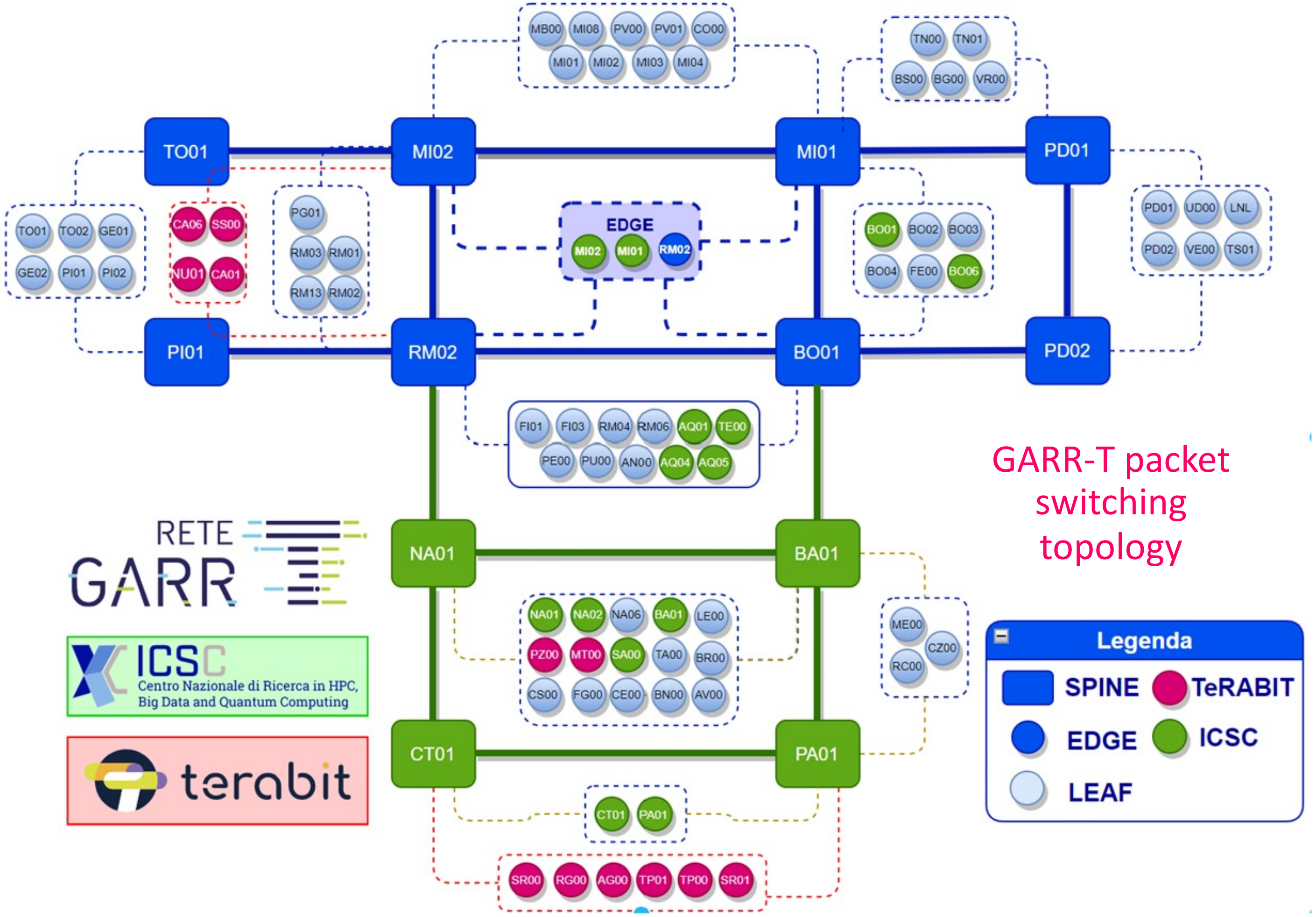
Global Connectivity

Experimental Infrastructure

# GARR-T Infrastructure evolution

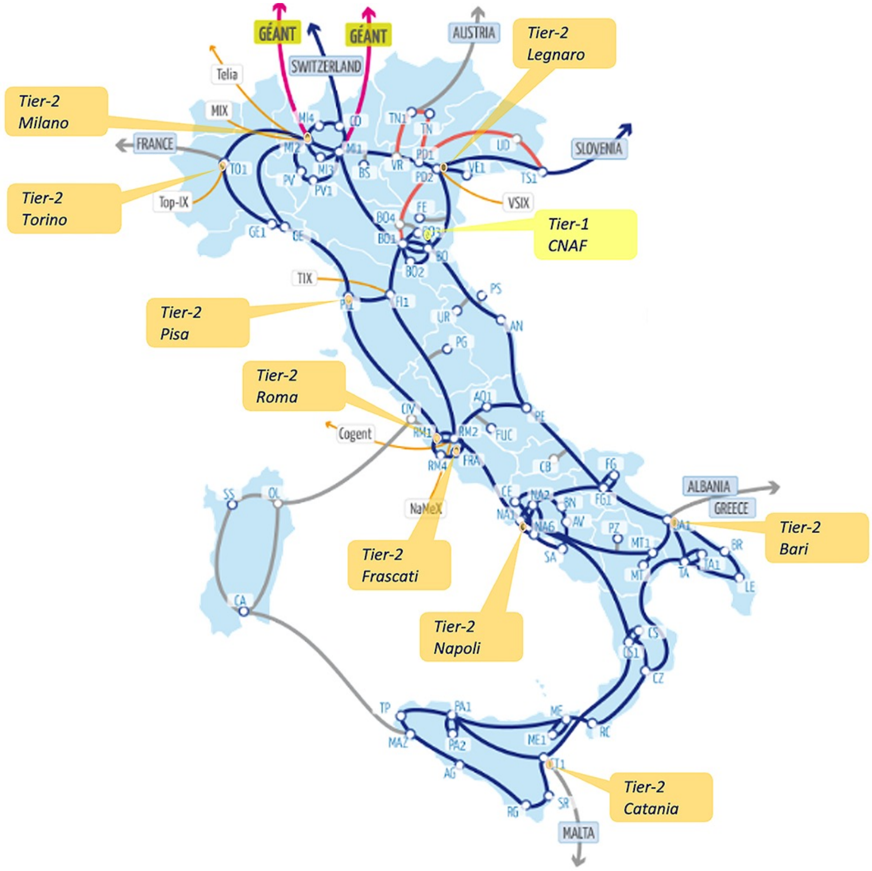


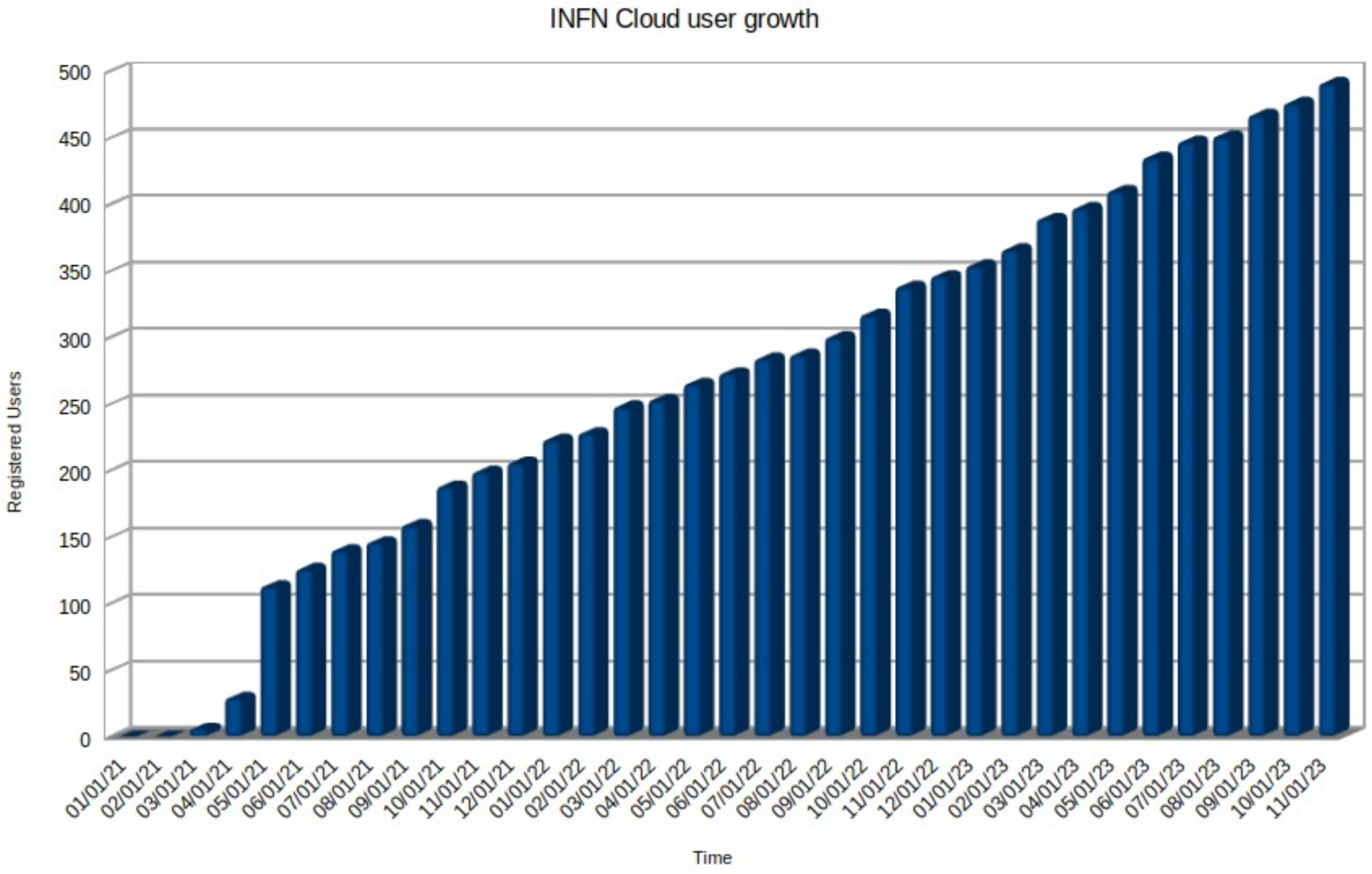

Fibre spectrum procured by TeRABIT tenders




GARR-T packet switching topology

# HPC-BD-AI user growth for cloud service from May 2021 to today



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# HPC-BD-AI evolution

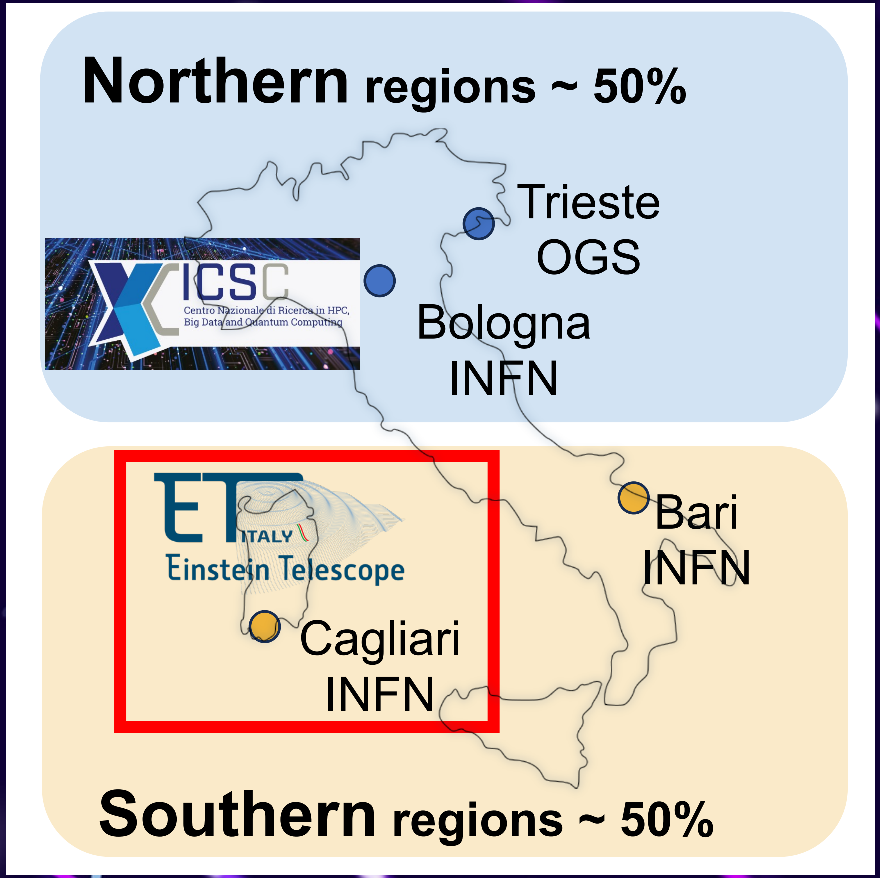
HPC bubbles specification and locations

HPC nodes HW: Type 1 : CPU only
Type 2 : CPU + GPU,
Type 3 : CPU + FPGA

Sites: CNAF, Bari, Napoli, Roma 1, Pisa, Padova, Torino, Milano Bicocca

Additional Storage:
Mass storage : CNAF
High performance storage : CNAF, Bari

# WHERE (operates)



# WHEN

## present status & timescale

- ✓ All personnel acquired and operational
- ✓ All Tenders assigned
- ✓ Network component in the executive phase

# GANTT – Activities for Bimesters

| | Bimester | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Jan Feb 2023 | Mar Apr 2023 | May June 2023 | July Aug 2023 | Sept Otc 2023 | Nov Dic 2023 | Jan Feb 2024 | Mar Apr 2024 | May June 2024 | July Aug 2024 | Sept Otc 2024 | Nov Dic 2024 | Jan Feb 2025 | Mar Apr 2025 | May June 2025 |
| Working Package | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
| **WP 1 - Project Management** | | | | | | | | | | | | | | | |
| **A1.1** - Project Management | | | | | | | | | | | | | | | |
| **A1.2** - Scientific Management | | | | | | | | | | | | | | | |
| **WP 2 - Italian Terabit Network** | | | | | | | | | | | | | | | |
| **A2.1** - Acquisition and deployment of Optical Fibres and Submarine | | | | | | | | | | | | | | | |
| **A2.2** - Transmission Layer and Open Line Systems | | | | | | | | | | | | | | | |
| **A2.3** - Packet Network and Network control | | | | | | | | | | | | | | | |
| **A2.4** - Control and Services tailoring provision | | | | | | | | | | | | | | | |
| **WP 3 - PRACE - Italy** | | | | | | | | | | | | | | | |
| **A3.1** - HPC infrastructure requirements and co-design | | | | | | | | | | | | | | | |
| **A3.2** - HPC infrastructure evolution and deployment | | | | | | | | | | | | | | | |
| **WP 4 - Distributed federated Cloud** | | | | | | | | | | | | | | | |
| **A4.1** - Deployment of HPC Bubbles (North) | | | | | | | | | | | | | | | |
| **A4.2** - Deployment of HPC Bubbles (South) | | | | | | | | | | | | | | | |
| **A4.3** - Implementation of the PaaS Orchestration layer | | | | | | | | | | | | | | | |
| **A4.4** - Deployment of flexible caching solutions | | | | | | | | | | | | | | | |
| **WP 5 - Training and dissemination** | | | | | | | | | | | | | | | |
| **A5.1.1** - Exploitation and training of TeRABIT integrated infrastructure | | | | | | | | | | | | | | | |
| **A5.1.3** - Exploitation and training of TeRABIT integrated infrastructure | | | | | | | | | | | | | | | |
| **A5.1.3** - Exploitation and training of TeRABIT integrated infrastructure | | | | | | | | | | | | | | | |
| **A 5.2** - Dissemination of TeRABIT integrated infrastructure | | | | | | | | | | | | | | | |

All the Intermediate Objectives have been achieved according to the planning

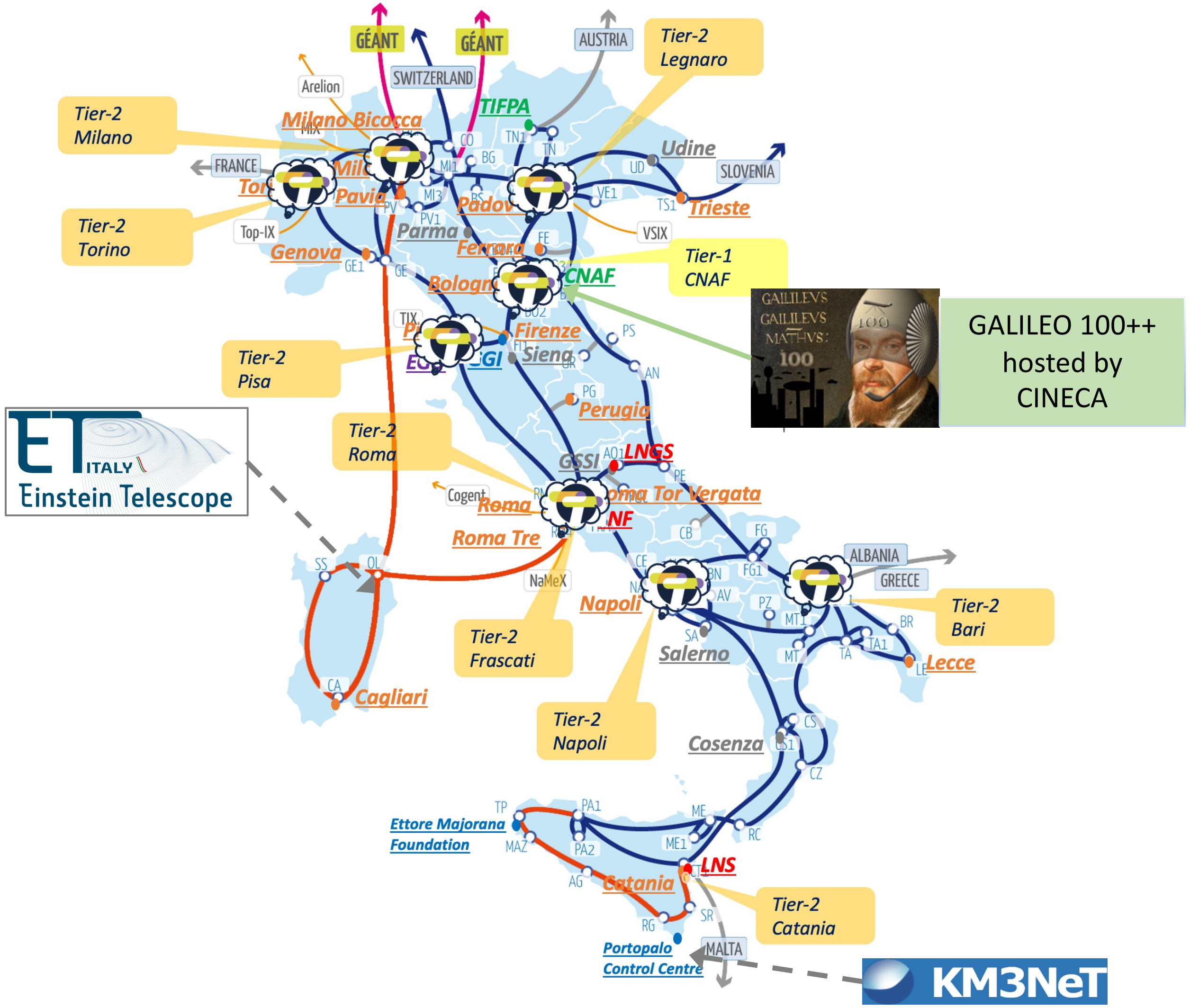
# TeRABIT final Infrastructures

The image shows the overlap of the expected final phyisical topologies of all three Research Infrastructures:

- GARR-T with (in red) the new fibres

- HPC-BD-AI with the HPC Bubbles locations

- PRACE-ITALY with the updated GALILEO 100 hosted at CINECA



# WHY

Enable widespread data transfer, up to Terabits per second, and services on a national scale in Italy, with particular focus on southern and island regions, all connected to Europe

Innovate the central HPC node of PRACE-Italy, maintaining the Tier-1 level.

Innovate the HPC services offered to researchers, beyond the centralized calculation model, adding distributed "HPC-Bubbles

**Network capacity for Einstein Telescope in Italy**

# EINSTEIN TELESCOPE the future European Infrastructure for Gravitational Waves

Prompted by two extraordinary events

1)

Selected for a Viewpoint in *Physics*
PRL **116,** 061102 (2016) PHYSICAL REVIEW LETTERS week ending 12 FEBRUARY 2016

## Observation of Gravitational Waves from a Binary Black Hole Merger

B. P. Abbott *et al.**
(LIGO Scientific Collaboration and Virgo Collaboration)
(Received 21 January 2016; published 11 February 2016)

On September 14, 2015 at 09:50:45 UTC the two detectors of the Laser Interferometer Gravitatio[…] Observatory simultaneously observed a transient gravitational-wave signal. The signal sweeps […] frequency from 35 to 250 Hz with a peak gravitational-wave strain of $1.0 \times 10^{-21}$. It matches the […] predicted by general relativity for the inspiral and merger of a pair of black holes and the ringdown of the resulting single black hole. The signal was observed with a matched-filter signal-to-noise ratio of 24 and a false alarm rate estimated to be less than 1 event per 203 000 years, equivalent to a significance greater than $5.1\sigma$. The source lies at a luminosity distance of $410^{+160}_{-180}$ Mpc corresponding to a redshift $z = 0.09^{+0.03}_{-0.04}$. In the source frame, the initial black hole masses are $36^{+5}_{-4} M_{\odot}$ and $29^{+4}_{-4} M_{\odot}$, and the final black hole mass is $62^{+4}_{-4} M_{\odot}$, with $3.0^{+0.5}_{-0.5} M_{\odot} c^2$ radiated in gravitational waves. All uncertainties define 90% credible intervals. These observations demonstrate the existence of binary stellar-mass black hole systems. This is the first direct detection of gravitational waves and the first observation of a binary black hole merger.

# & the opening of Multimessenger Astronomy

2)

# A Telescope to look far in space & time

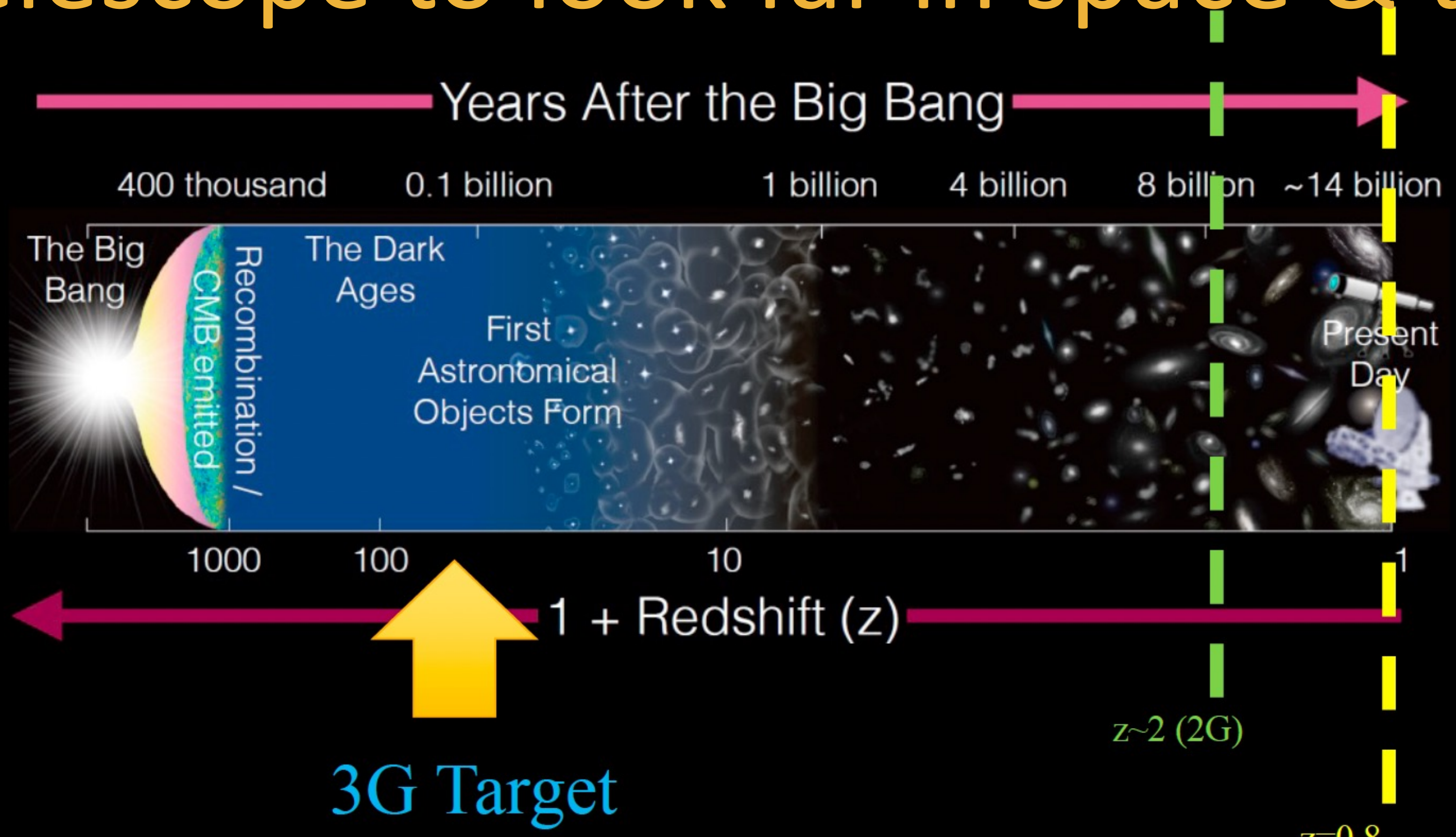
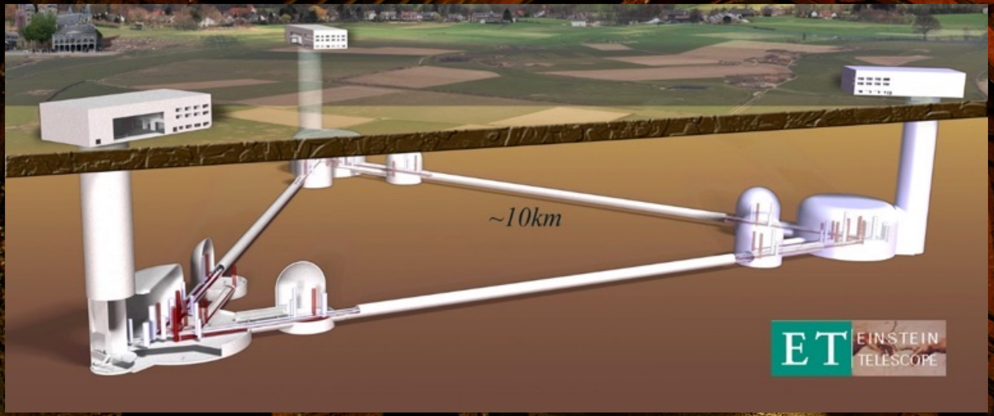



Image credit: NAOJ/ALMA http://alma.mtk.nao.ac.jp/

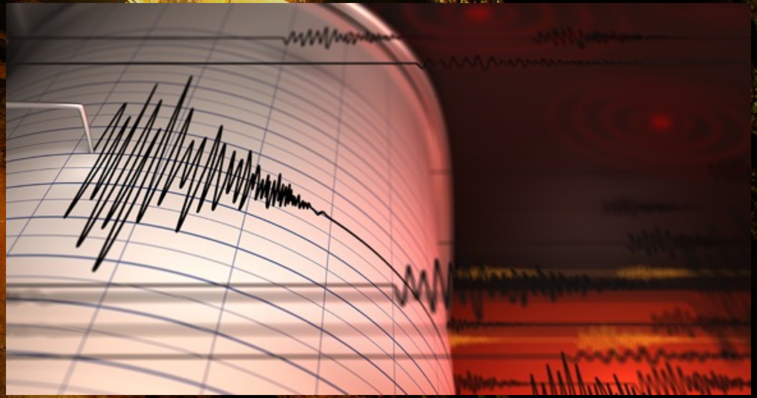
# Larger & Underground

EINSTEIN TELESCOPE




SENSITIVITY improves with arms length

→From 3 km in VIRGO to <u>10 km ET</u>



UNDERGROUND to fight sismic and antropic noise

→ <u>200 m underground</u>

# TWO CANDIDATE SITES

ET EINSTEIN TELESCOPE

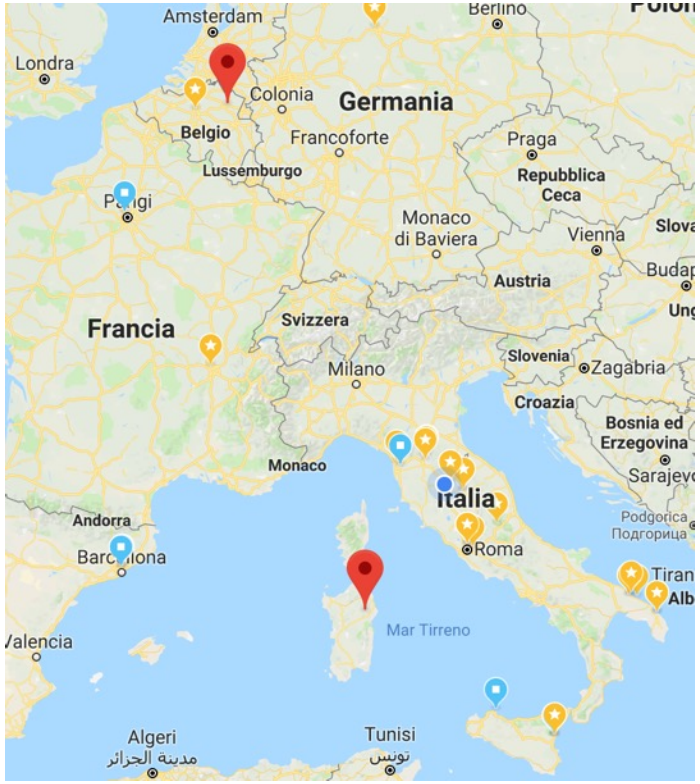
Under discussion:

Single site triangular geometry

Two sites L geometry (LIGO like)

Dedicated EU project for the evaluation.

Outcome Expected in 2026




- ❑ Euregio Meuse Rhine The Netherlands
- ❑ Sardinia Italy

Both supported by the respective regional & national governments

# TeRABIT for Einstein Telescope in Italy

ET ITALY
Einstein Telescope

## The combination of an extraordinary site & a long standing know how

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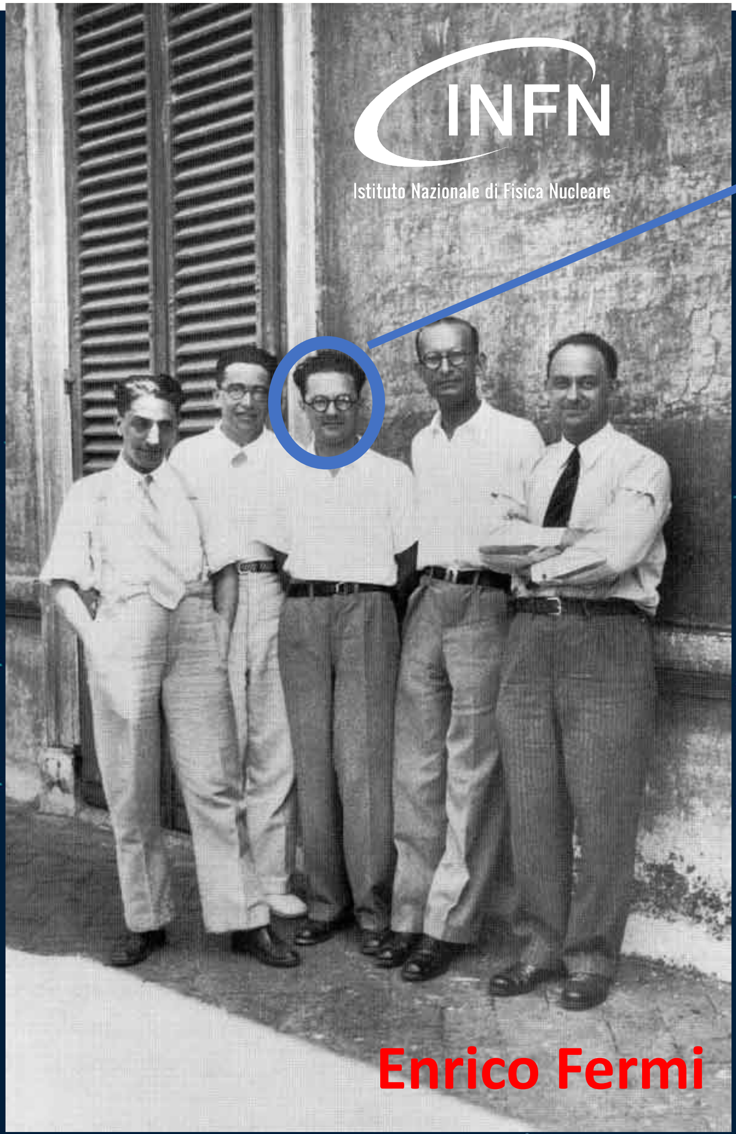
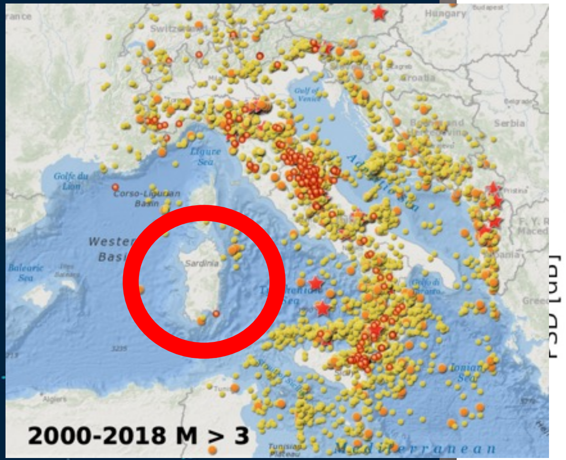


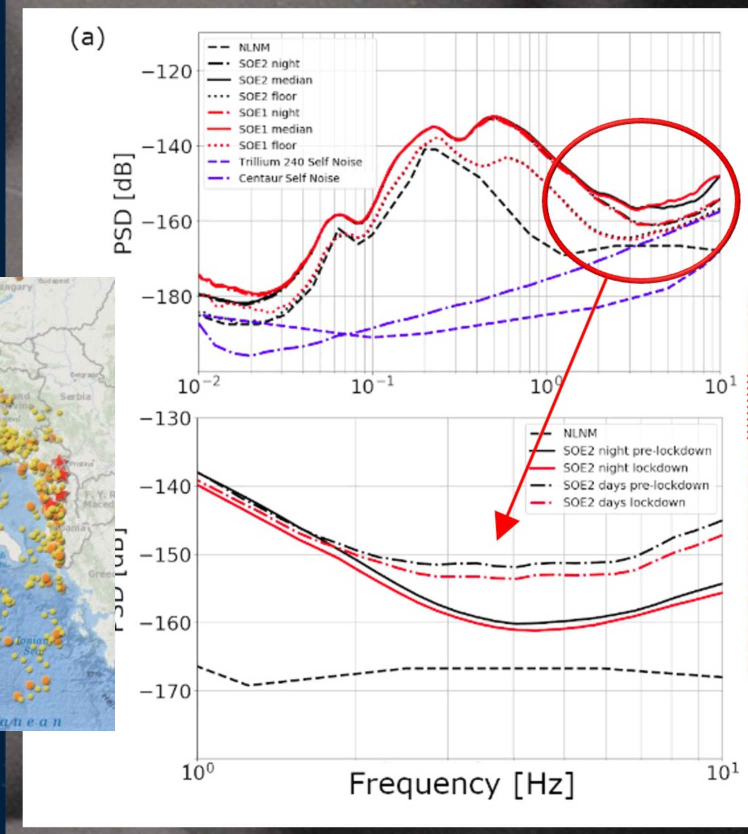

# Edoardo Amaldi

One of the Founding Fathers of INFN CERN and ESA
Pioneer in GW research

NO relevant seismic activity in Sardinia
Low populated area → Low anthropic noise
In the region 1-10 Hz Sos Enattos is one of the best sites worldwide

From his heritage the expertise leading to VIRGO, operating in Italy near Pisa.




https://doi.org/10.1785/0220200186

# COMPUTING FOR GW

# A few numbers

**Raw data size:** about 120TB per month of observation per observatory

- Includes all control channels from the instrument
- Transferred to custodial storage for safekeeping
- Raw data don't grow much with increasing sensitivity (they do grow with instrument complexity: 1.5× from O3 to O4)

**"Aggregated" data for analysis:** 10TB/year per observatory

- Includes the single physics channel h(t) and summary "data quality" information
- Distributed to computing centres for low-latency and offline analysis
- Published to GWOSC after proprietary period

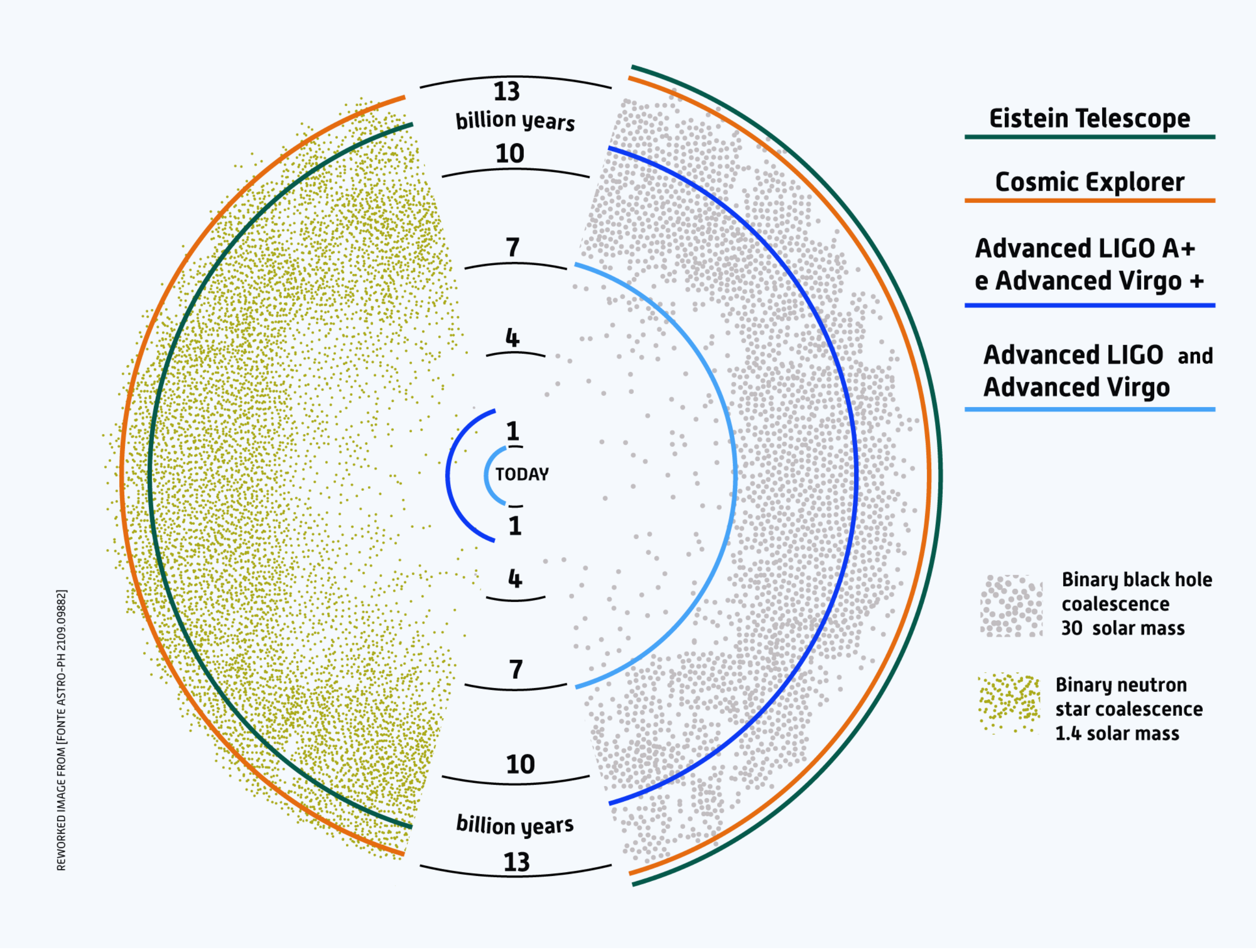
**Computing:** nearly $10^9$ CPU core hours

- to process O3 data, both low-latency and offline
- About 10% of one of the LHC experiments
- And this does grow with sensitivity!

**About 10% of an LHC experiment of today**

# Some challenges

- High candidate rates (CBC PE explodes)
- Overlapping signals
- Much larger parameter space to explore
- Long duration waveform for CBCs (memory use?)
- Environmental correlated noise (non-independent colocated detectors)
- ...



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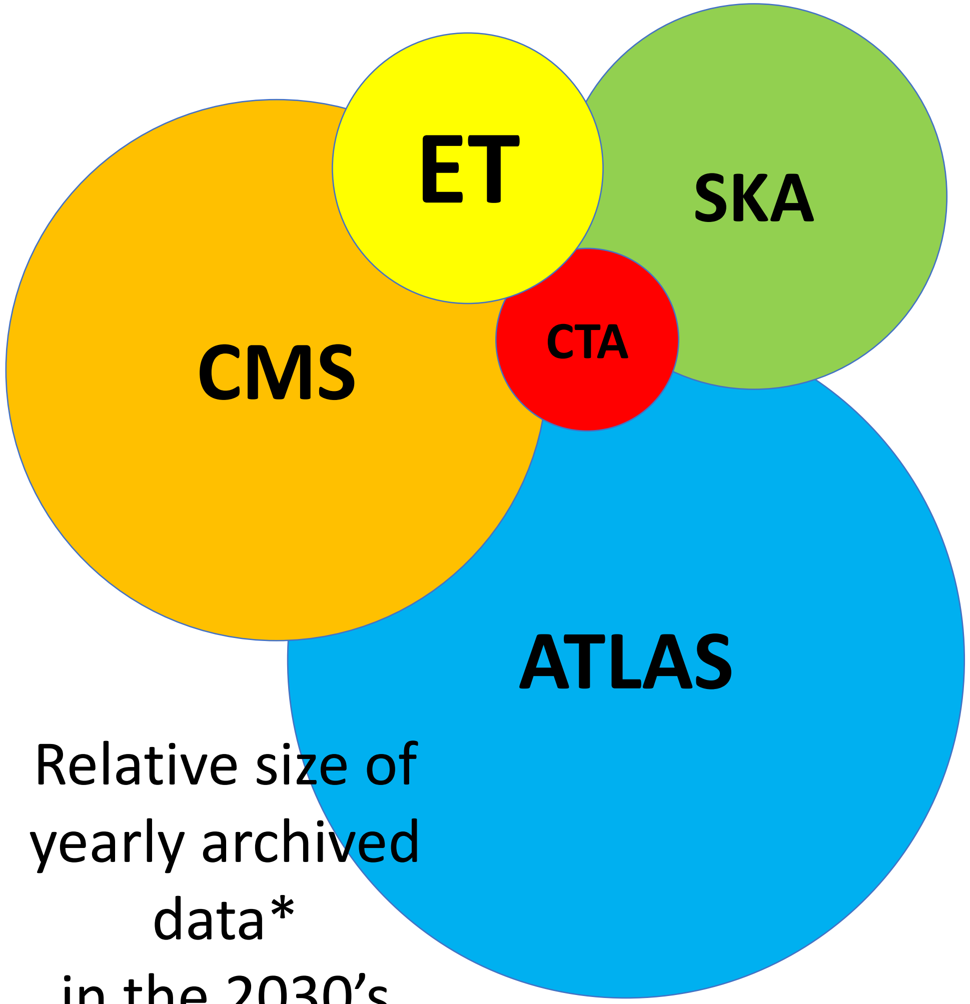
# ET data vs LHC data

Again: luckily, raw interferometer data don't grow much with increasing instrument sensitivity

- We're not exploding like HL-LHC!
- In ET we expect about few tens of PB of raw data per year (baseline 6-interferometer design, more control channels,…)
- No big deal today, piece of cake by 2035

However, the amount of useful scientific information encoded in the data does grow (a lot)




Relative size of yearly archived data* in the 2030's

# In Summary

**Current computing needs of the entire GW network are roughly (10%) of an LHC experiment of today**

In ET the event rate will be $10^3$ -$10^4$ times the current one

- Analysis of the "golden" events would already be within reach using current technologies
  - O(500) events per year = 12.5MHS06-y per year, the same order of magnitude of a LHC experiment in Run 4
  - Target: 1/10th of an LHC experiment in Run 4

**But: low-latency!**

# Role of TeRABIT for Einstein Telescope in Italy

ET ITALY Einstein Telescope

Provide data transfers, up to Terabits per second, between the site in Sardinia, and the other centers and laboratories in Sardinia, in Italy and Europe.

**IN THE EXECUTIVE PHASE**

In collaboration with a dedicated project funded by the Sardinia regional Government.

# In Conclusion:

ET ITALY Einstein Telescope

**THANK YOU**

alberto.masoni@ca.infn.it

- ✓ **TeRABIT** will provide support to a wide scientific community by **combining Network, HPC & Research Infrastructures** in Italy interconnected with EU RI
- ✓ **Project in Executive phase**
- ✓ **A strategic Role for Einstein Telescope in Italy**