Finanziato dall'Unione europea NextGenerationEU
Ministero dell'Università e della Ricerca
Italiadomani PIANO NAZIONALE DI RIPRESA E RESILIENZA
INFN Istituto Nazionale di Fisica Nucleare Laboratori Nazionali di Frascati

ARC-ETCRYO

- **INFN Sezione di Roma**
- **Sapienza Univ- Dip di Fisica**

E. Majorana

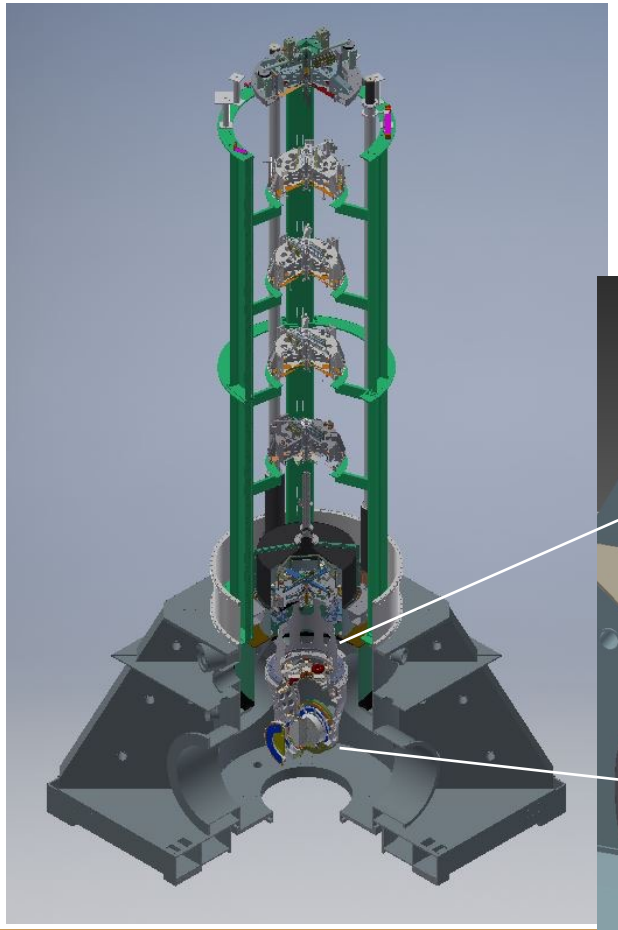
Operating Unit Board meeting

Roma, June the 22nd 2023

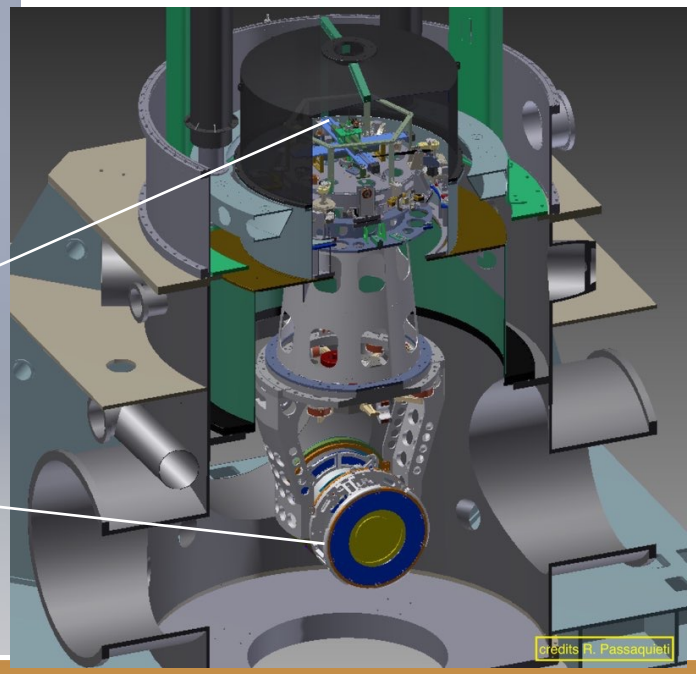
SPAIN-ITALY, meeting at
Cascina, Virgo-site

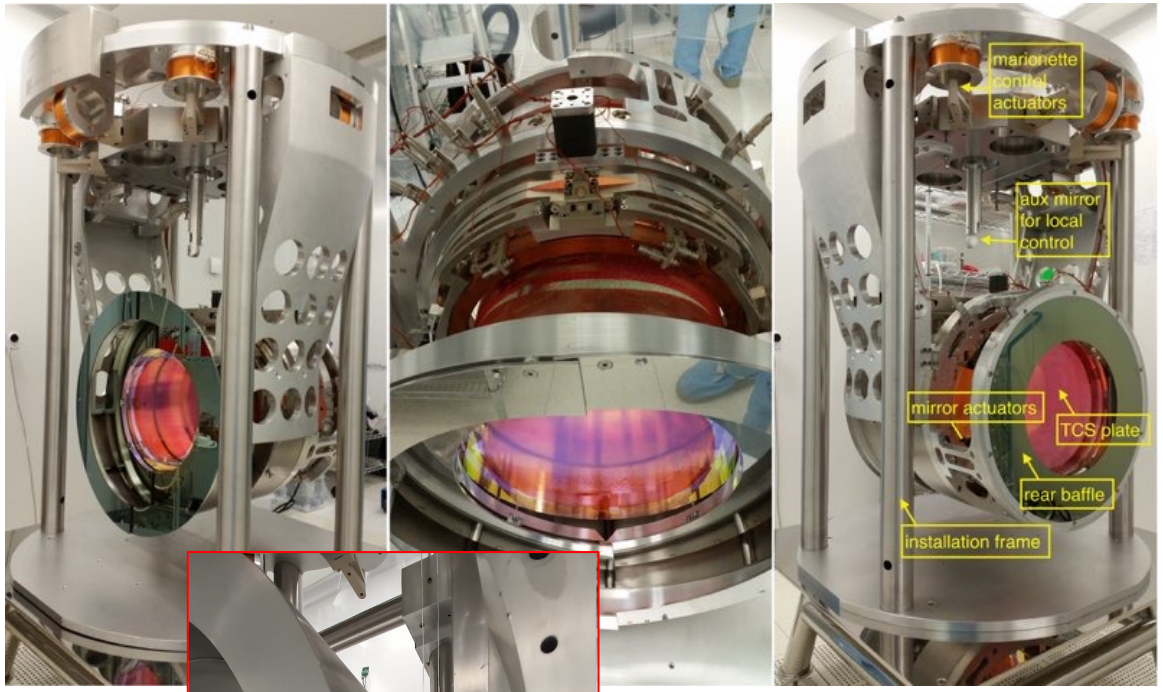
http://www.einstein-telescope.it

Payload development in Virgo: experience porting into cryogenics is not trivial



Virgo: Room Temperature suspension systems based upon diagonalized mechanics (partially tested in KAGRA)

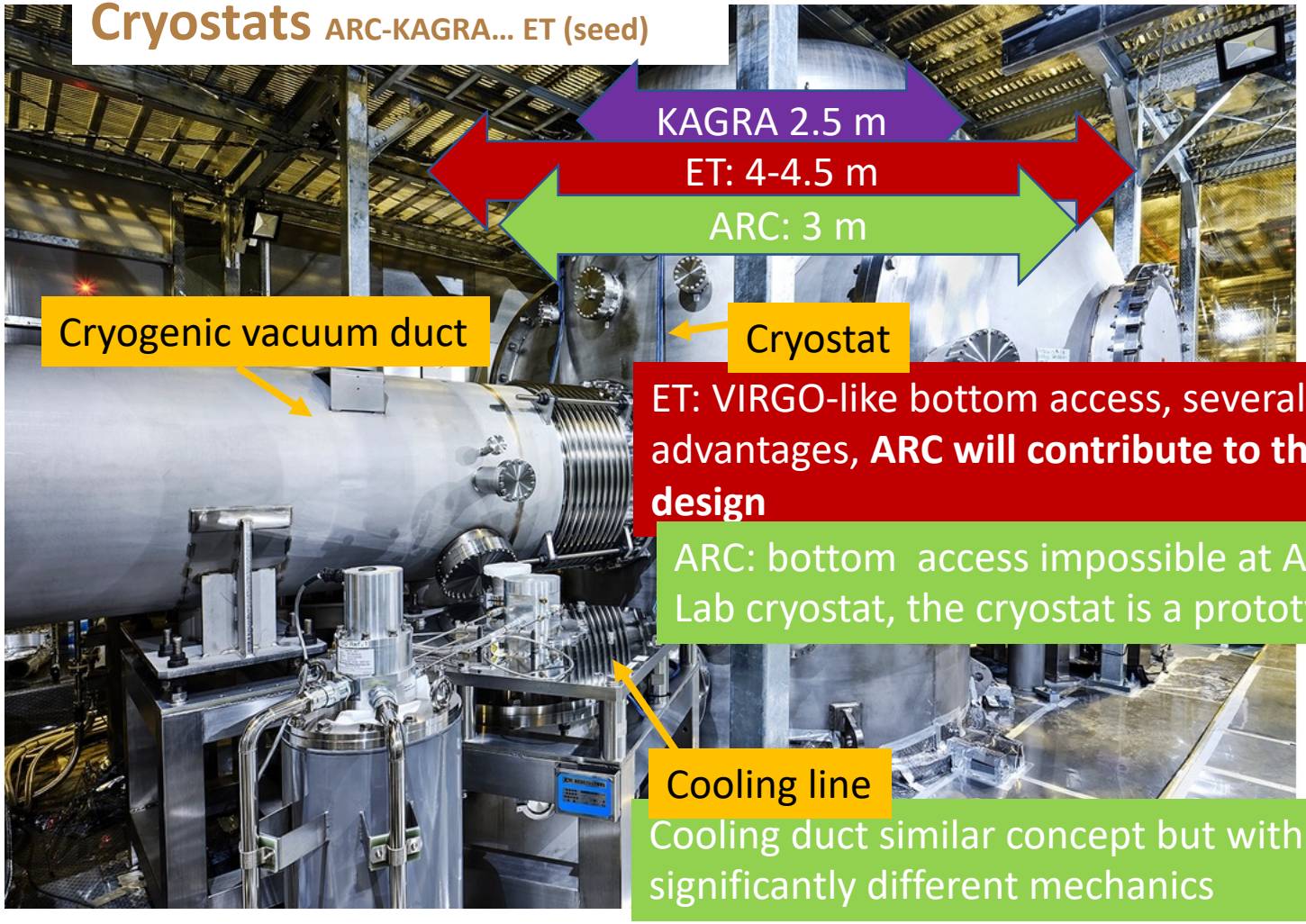




AdV+ in 2024 will adopt 105 kg mirrors

ET envisaged in 2010 220 kg mirrors !

Cryostats ARC-KAGRA... ET (seed)



ET: VIRGO-like bottom access, several advantages, **ARC will contribute to the design**

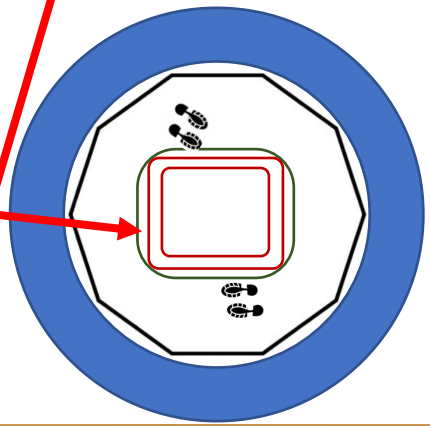
ARC: bottom access impossible at ARC Lab cryostat, the cryostat is a prototype

Cooling duct similar concept but with significantly different mechanics

Design under development upon local cryogenics expertise and

- through ET-Virgo (VAC-CRYO)
- through close collaboration with KAGRA

- Notice: not a table-top cryostat, suitable for Large mass payloads



ISB CRYO CRYOSTAT

Follow-up minutes,

- VAC is already well integrated
- Edited (S. Grohmann and others),
- They are about to constitute a baseline document
- Interactions with Suspension and BIM foreseen
- We ask the ISB to set up a cross-divisional working group for the ET-LF TM tower design

ISB CRYO PAYLAOD (just at a glance)

PARAMETERS

Cooling concept	Monolithic	Marionette Monolithic	He-II filled	Mirror Silicon	Sapphire
Mass (kg)	200	220	200	200	220
Suspension length (m)	1.0	1.0	1.0	1.2	1.2
Suspension diameter (mm)	8.1	6.5	8.3	3.0	2.3
Suspension material (-)	Silicon	Sapphire	Ti, He-II	Silicon	Sapphire
Bulk loss angle (-)	1×10^{-9}	3×10^{-9}	1×10^{-6}	1×10^{-9}	3×10^{-9}
Temperature (K)	15	17	2	15 . . . 20	20 . . . 23

MATERIAL PARAMETERS USED FOR TWO MAIN CONFIGURATIONS

TABLE III: Physical properties of silicon and sapphire at 20 K and metals at 2 K. Some of the indicated references comprise temperature dependencies, which are included in the STN model presented in the Sections VI and VII.

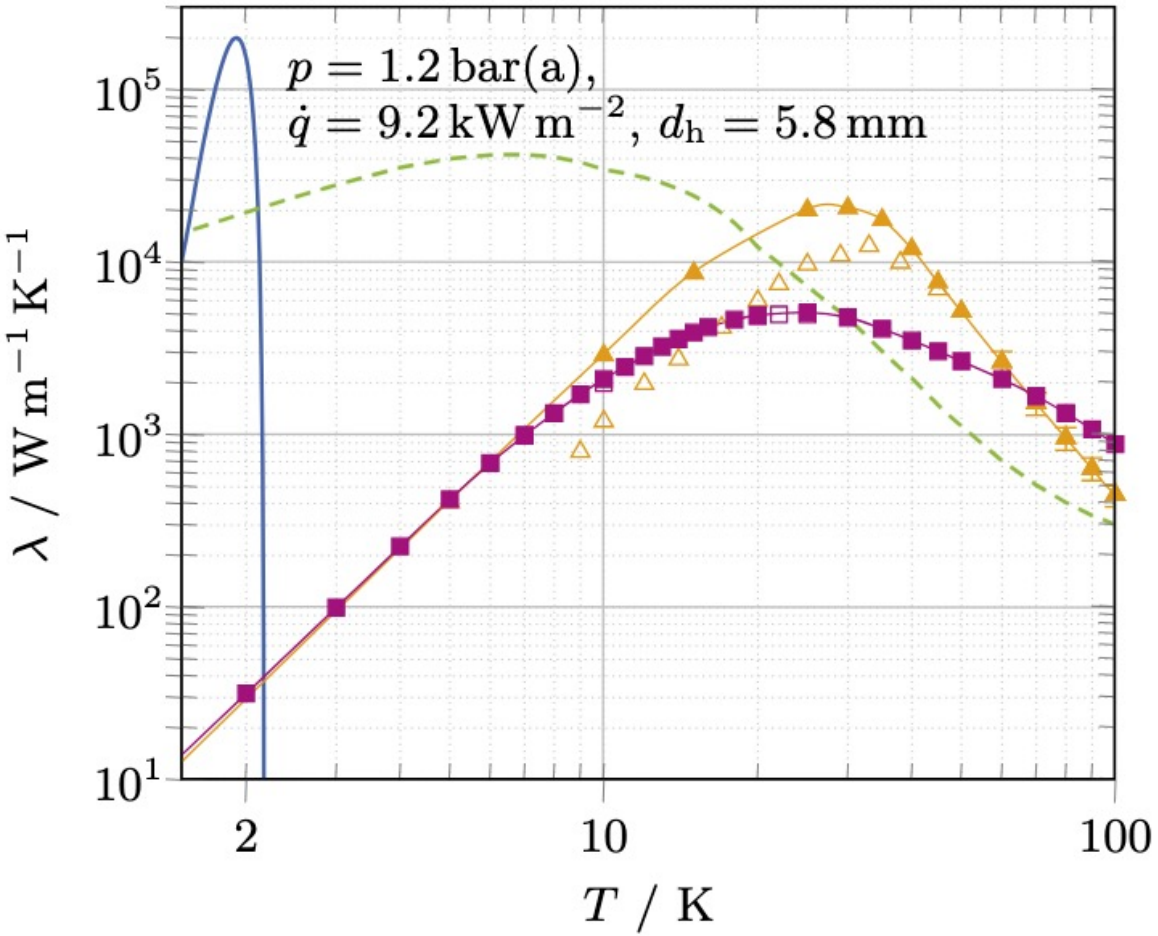
	Silicon	Sapphire	Ti6Al4V	Titanium	Al5056[a]
T (K)	20	20	2.0	2.0	2.0
ϕ_{bulk} (-)	1×10^{-9} [8] [b]	3×10^{-9} [10]	1×10^{-4} [11] [c]	1×10^{-6} [12]	2.5×10^{-8} [13]
σ_{y} (MPa)	230 [14] [d]	400 [15] [d]	1600 [16]	1200 [16]	280 [16]
$\lambda(T)$ (W/m/K)	4940 [17]	6000 [18]	0.22 [19]	2.5 [19]	2.0 [20]
$c_{\mathrm{p}}(T)$ (J/kg/K)	3.40 [21]	0.69 [22]	0.01 [19]	0.12 [19]	0.10 [23]
$\alpha(T)$ (1/K)	-2.9×10^{-9} [24]	1.3×10^{-8} [25]	6.0×10^{-6} [26]	5.5×10^{-8} [26]	14×10^{-6} [16]
β (1/K)	-7.9×10^{-6} [27] [e]	-4.4×10^{-6} [28] [e]	-4.6×10^{-4} [29] [e]	-4.6×10^{-4} [29] [e]	1.2×10^{-4} [30]
E (GPa)	130 [31] [f]	360 [32] [f]	127 [33] [f]	130 [16]	81 [30]
ρ (kg/m^3)	2330 [34]	3980 [34]	4540 [19]	4540 [19]	2660 [19]
α_{surf} (m)	5×10^{-13} [9]	5×10^{-13} [g]	0.0	0.0	0.0

Solid conduction on payload
Envisaged feasibility

PhaseII LHe,
Long term, prototyping demonstrator studies

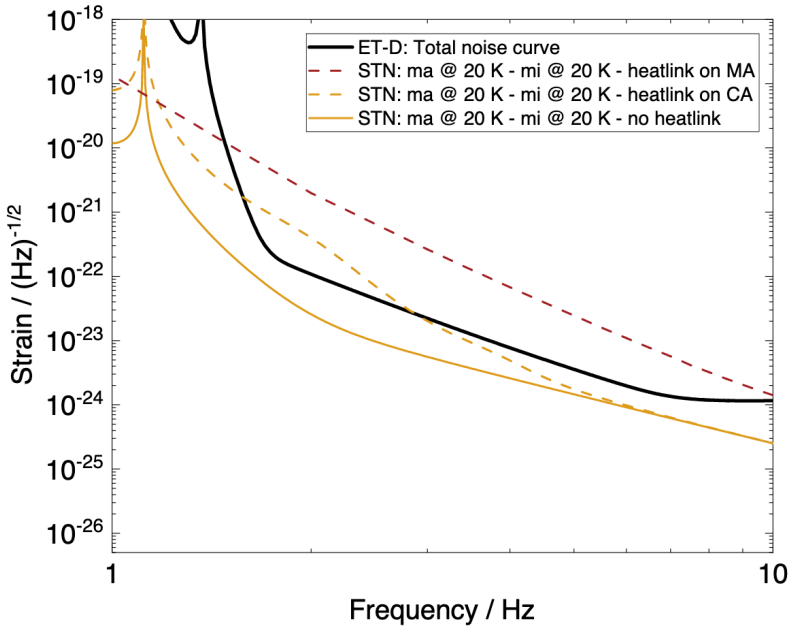
Two studies

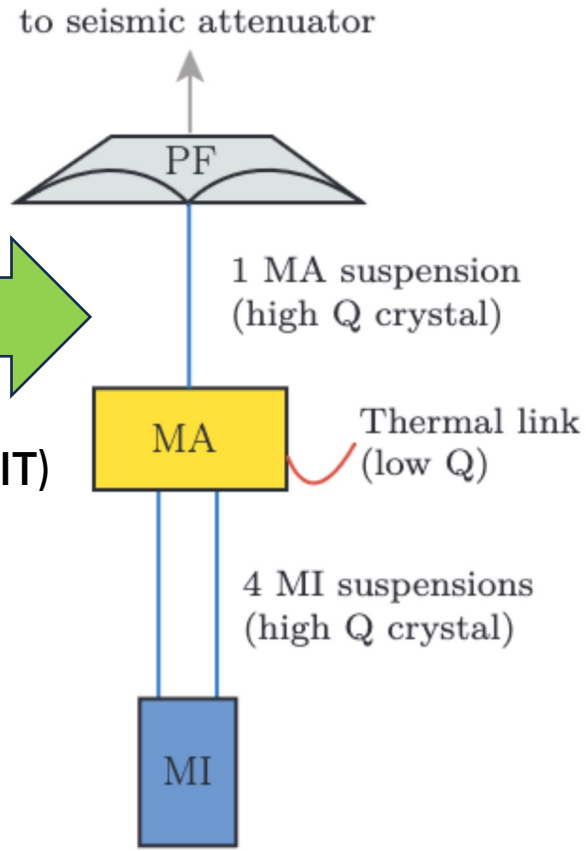
- Solid conduction on payload
  Envisaged feasibility (**mainly Rome**)
- PhaseII LHe,
  Long term, prototyping demonstrator studies (**mainly KIT**)

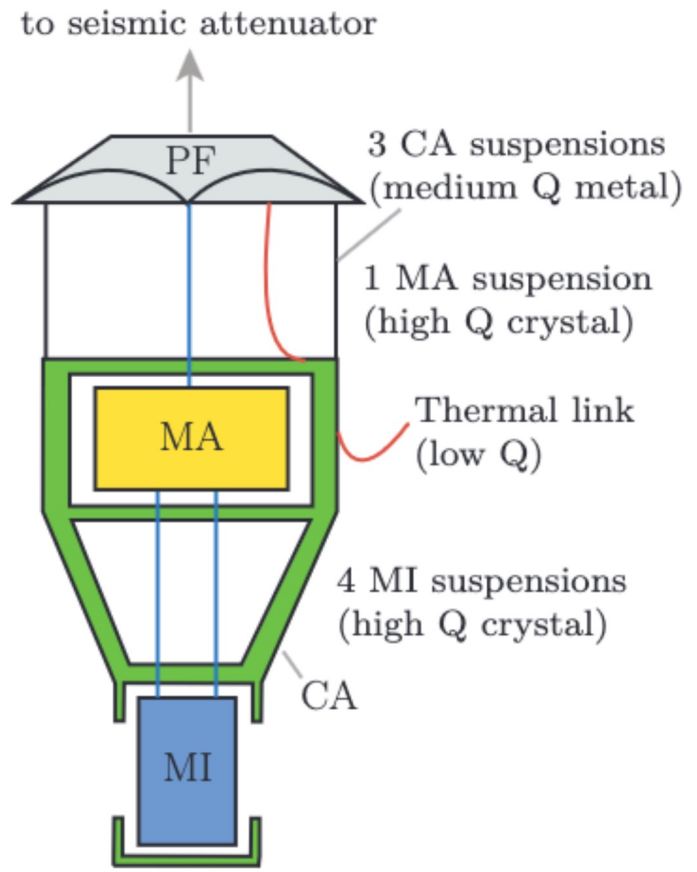


ET ISB CRYOGENICS

- Solid conduction on payload
  Envisaged feasibility (**mainly Rome**)
- PhaseII LHe,
  Long term, prototyping demonstrator studies (**mainly KIT**)







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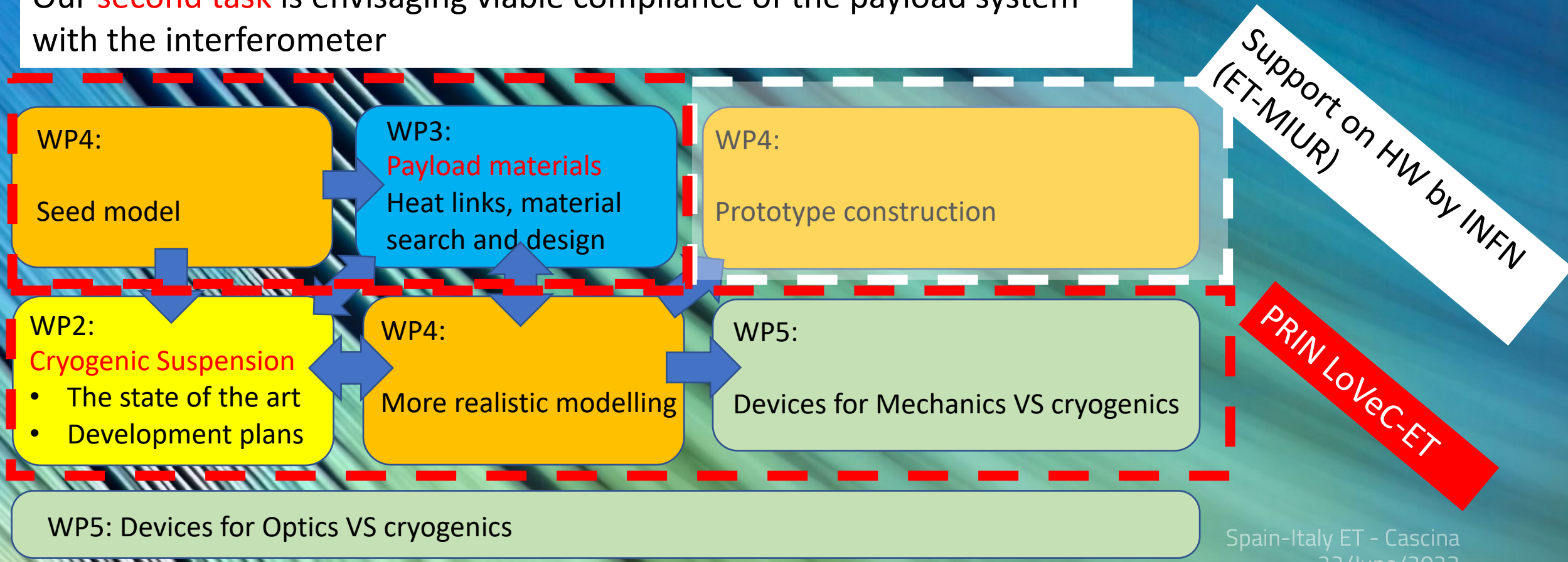
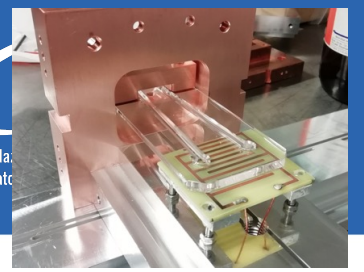
PRIN2020 LoVeC-ET
Low Frequency VS Cryogenics for ET

Our first task is envisaging viable solutions for the test-mass payload as a hardware system integrated in two very different apparatuses:

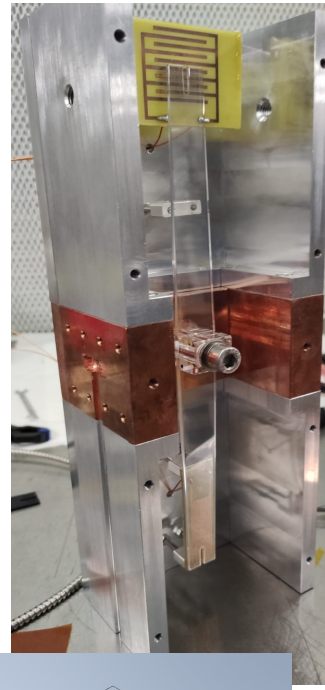
- The seismic attenuator
- The cryogenic system

Our second task is envisaging viable compliance of the payload system with the interferometer





Roma Sapienza (main WP1/4, hired personnel 1 PhD + 1y Engineer contract)



Hardware developments:

- Realization of new Viable sapphire blades integrated in the marionette starting from KAGRA model, purposes:

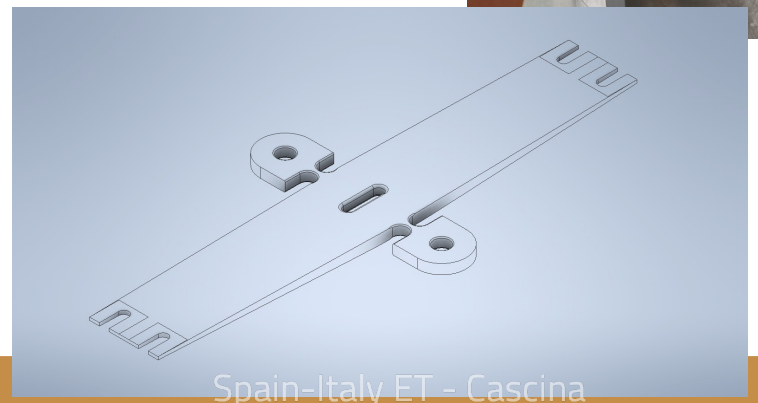
✓ Investigating low quality factors measured with the original (highest Q=1.5e5 in Roma)
➔ cause reasonably identified in the non monolithic structure at the clamp

✓ Investigating Breaking strength
➔ very promising results of bending breaking strength (ISO certified)

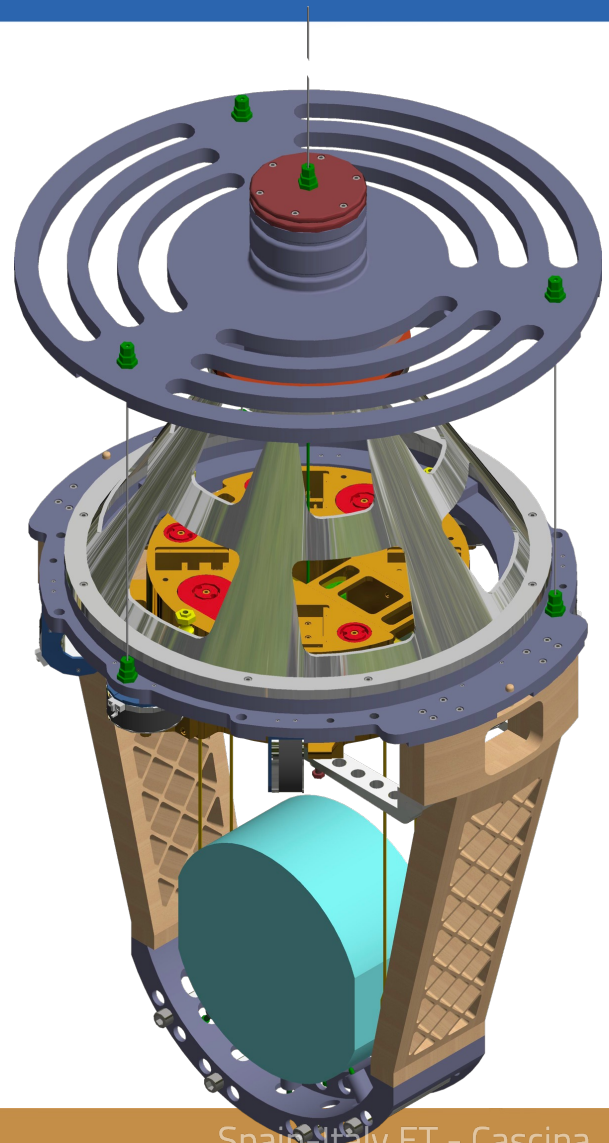
✓ Developing a new, larger blade meant for ET size ➔ manufacturing inquire

- Ongoing realization of Marionette suspension clamp for a sapphire rod
- NEXT ribbon suspension studies

(with PG and URB, targeted to prototype payload realization)



INFN (main WP3, hired personnel 2 post-doc + 1y contract pending)



Seed modelling for payloads:

Thermal extraction modelling using Sapphire and Silicon

- *X. Koroveshi et al. Cryogenic payloads for the Einstein Telescope – Baseline design with heat extraction, suspension thermal noise modelling and sensitivity analyses arXiv:2305.01419v1*

✓ ET final targeted 220 kg
✓ Prototype targeted 150 kg (PF-Ma ~ Ma-Mi = 90 cm)

Materials for soft links:

✓ Material RRR measured as done at KEK
✓ Model for heat duct links done => manufacturing inquires

ROMA TOV (main WP5, hired personnel 1y contract)

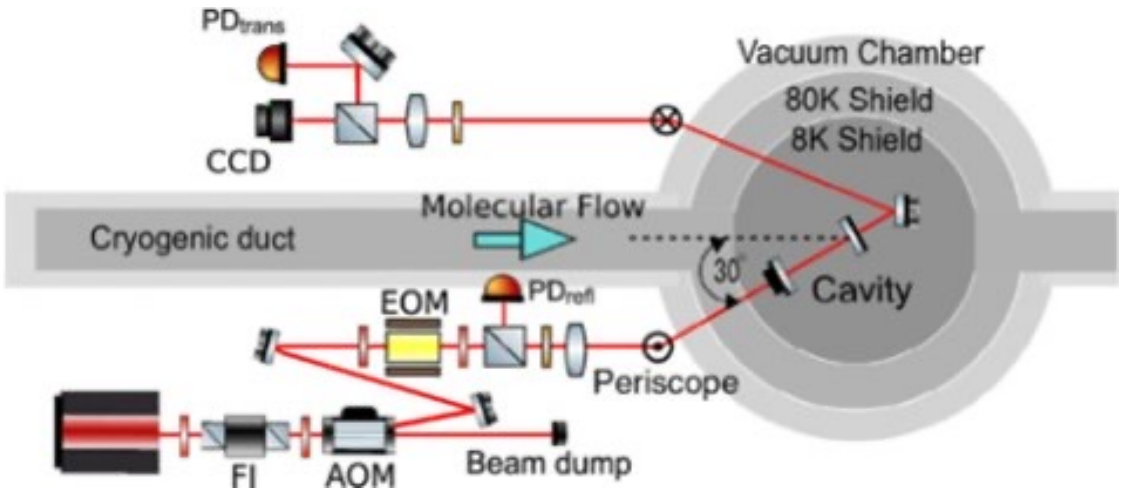
1. Payload sensing and actuation: design of a cryogenic facility for the characterization of sensors
2. Auxiliary sensing on cooling parts
3. Diagnostics of the test mass surface: design of a dedicated cryogenic FP readout scheme
4. Conditioning of the test mass surface: design of a conditioning scheme based on CO2 beam shaping

Cryo facility for testing sensors:

- Now at room temperature, then move to cryogenics
- FODS sensors as witnesses
- Hamamatsu InGaAs QPDs+1550 nm source scheme

Cryogenic surface diagnostics/conditioning:

- Pulse tube Cryostat hosting the surface + FP optical cavity readout scheme on bench (in the fig)
- Surface conditioning strategy requires shaping a CO2 beam source for localized heating



Hasegawa K et al, Phys Rev D 99, 022003 (2019)

PERUGIA (main WP2, called co-funded 3-y university position)

Hardware developments:

- ✓ Silicon suspensions quality factor, quality factor and prototyping
- ✓ HCB
- Ongoing DETACHABLE materials in semi-monolithic suspension clamping

URBINO (main WP2, co-funded 2y contract)

Hardware developments:

- Ongoing CO2 applications to develop suitable monocrystal suspension heads

A facility dedicated to Cryogenics development for ET at the Amaldi Research Center

- ARC, is entitled to prof. E. Amaldi due to his visionary ability to envisage the progress of experimental fundamental physics, ranging from nuclear, to particle, cosmic ray, space, to neutrino and, finally, GW research.
- In 2018, after the directional detection through LV network, the interdisciplinary excellence effort, pivoting on GW research, was funded at the Dep. of Physics of Sapienza Univ.
- ARC excellence center at the Dep. of Physics of Sapienza Univ. concluded its 5-year funding term in 2022, ~750 k€ for apparatus, building provided by Sapienza (finally delivered in April 23)
- ARC promotes FIVE interdisciplinary studies:

GW Data Analysis

MultiMessanger astrophysics

Quantum photonics

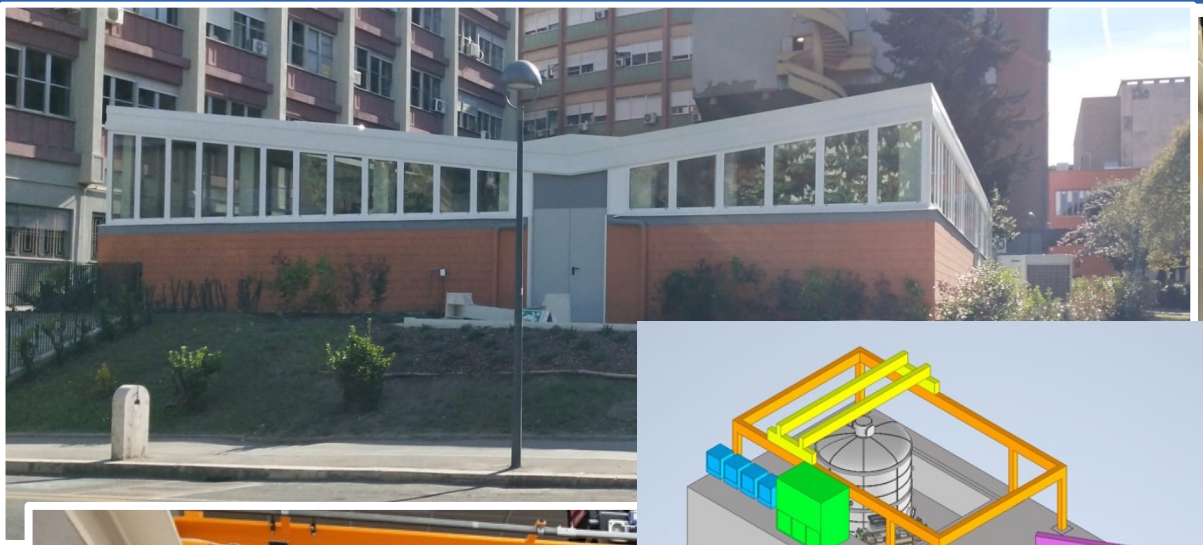
Surface Physics

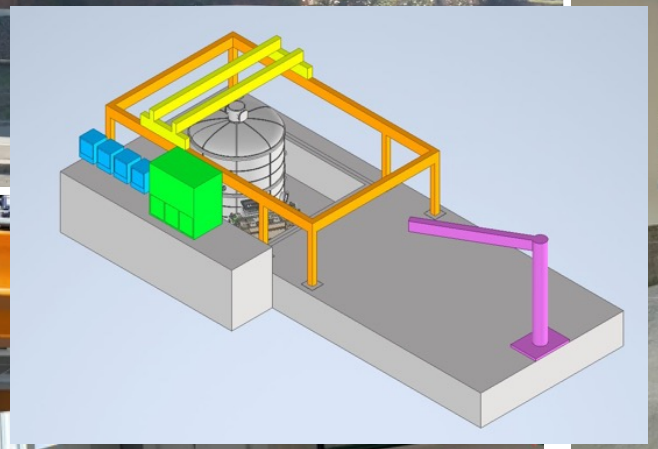
Cryogenics for ET

ETIC ARC-ETCRYO

The place


CU031
Edificio
dei Laboratori
Emilio Segrè
Facoltà di Scienze
matematiche, fisiche e naturali
Dipartimento di Fisica





ARC-ETCRYO BUDGET

Tot Budget (7% OH included)	OU	Apparati (7% OH included)	Personale (7% OH included)
4.666.419 €	INFN Roma1	4.162.750 €	254.895 €
	Sapienza Univ. Dip di Fisica		248.775 €

OU	Committed	RESIDUAL	GENERAL EXPENSES
INFN Roma1	3.760.285 €	130.135 €	50.000 €
Sapienza Univ. Dip di Fisica	207.239 €	25.261 €	

ARC-ETCRYO ETIC group

P. Puppo

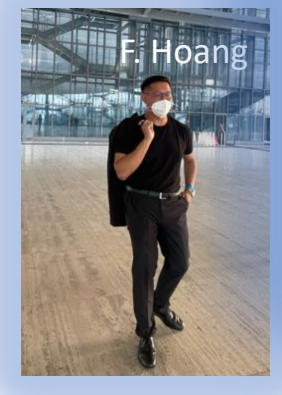
L. Naticchioni

S. Pirro

E. Majorana

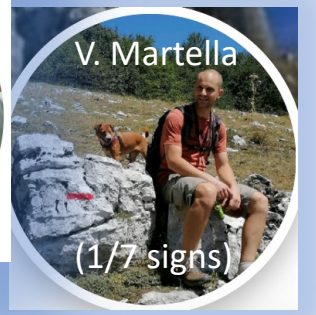
A. Cruciani

P. Rapagnani



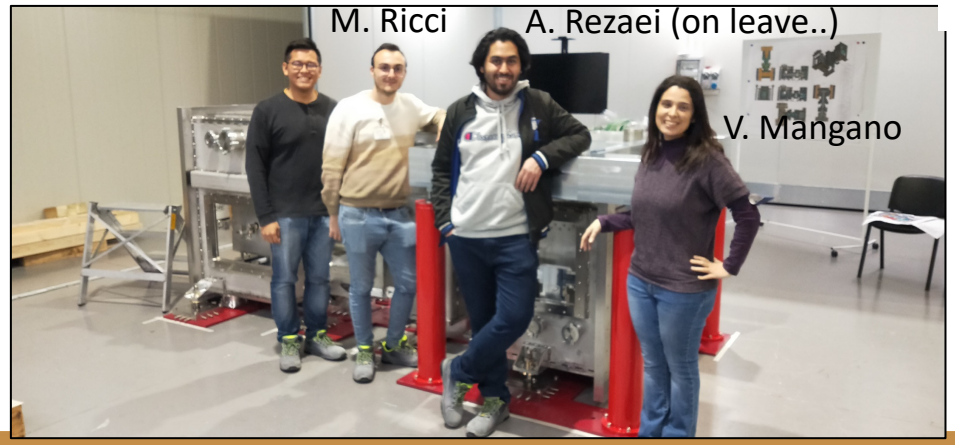
F. Hoang

E. Benedetti (26/6 signs)



V. Martella (1/7 signs)

(in July ?)



M. Ricci A. Rezaei (on leave..) V. Mangano

F. Ricci! (ext. coll.) D. Pasciuto

ETIC PI

Collaborators and advisors
T. Yamada (KEK)
N Kimura (ICRR)

Management

Project coordinator
E. Majorana

Project manager
L. Naticchioni

Administration

RUP office
INFN AC

Local administrative support
INFN Roma1

internal organization

WP1	WP2	WP3	WP4	WP5
Cryogenic and vibration sensing *S. Pirro*	Cooling lines *A. Cruciani*	Cryostat design *P. Rapagnani* *E. Majorana*	Payload prototype *P. Puppo*	Lab infrastructure and equipment *V. Mangano*
S. Pirro NFN LNGS *M. Ricci PhD* *E. Majorana* *ARC INFN POST-DOC ** *ETIC_INFN Technical* ***1** Ext support: KEK*	*P. Cruciani INFN* *M. Ricci PhD* *ETIC_INFN CTER* *ETIC_UNI TECHNOLOGIST1** ***2** Ext scientific support: ICRR,NAOJ*	*P. Rapagnani* *E. Majorana* *ETIC_INFN TECHNOLOGIST* *ETIC_UNI TECHNOLOGIST_2* *ARC POST-DOC* ***4** Ext.coll: EGO,KIT,ICRR,NAOJ*	*P. Puppo INFN* *L. Naticchioni INFN* *M. Ricci PhD* *ETIC_INFN TECHNOLOGIST* *ETIC_UNI TECHNOLOGIST* ***5** Ext.coll: LoVeC-ET, KEK,ILM*	*V. Mangano (INFN)* *ETIC_UNI TECHNOLOGIST1*

ARC-CRYOET infrastructure purpose

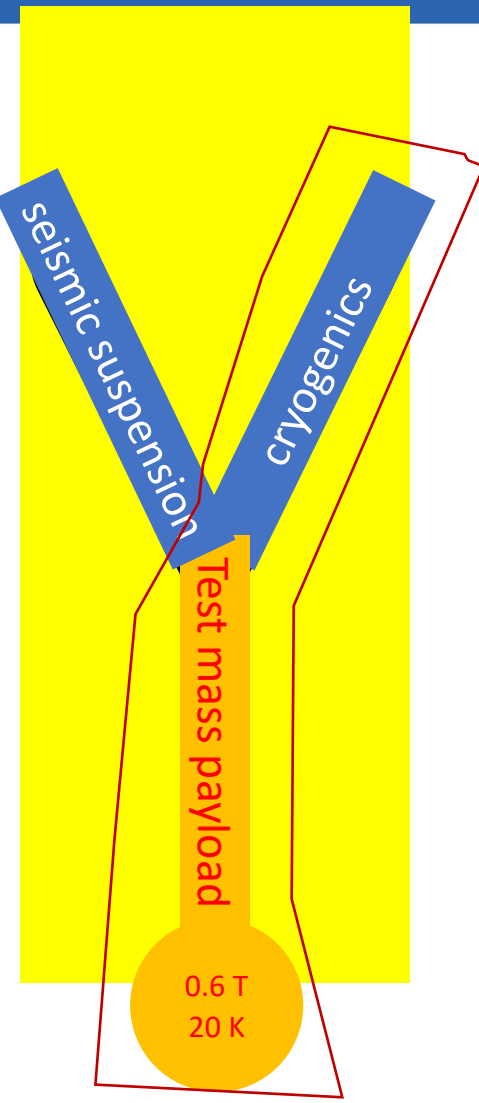
What do we want to study here ?

- Viable Cryogenic payload solutions
- Cooling large mass payloads through solid conduction

What is not included in the apparatus we are developing ?

Seismic Isolation. Due and crucial for actual ET design, modelling of payloads takes it into account. However, the mechanical and thermal performance of the suspensions embedded in the payload system, are not affected by Seismic Isolation system presence.

➔ Preserving the seismic isolation provided at the level of payload suspension point is the main constraint in cryogenic suspension system design.



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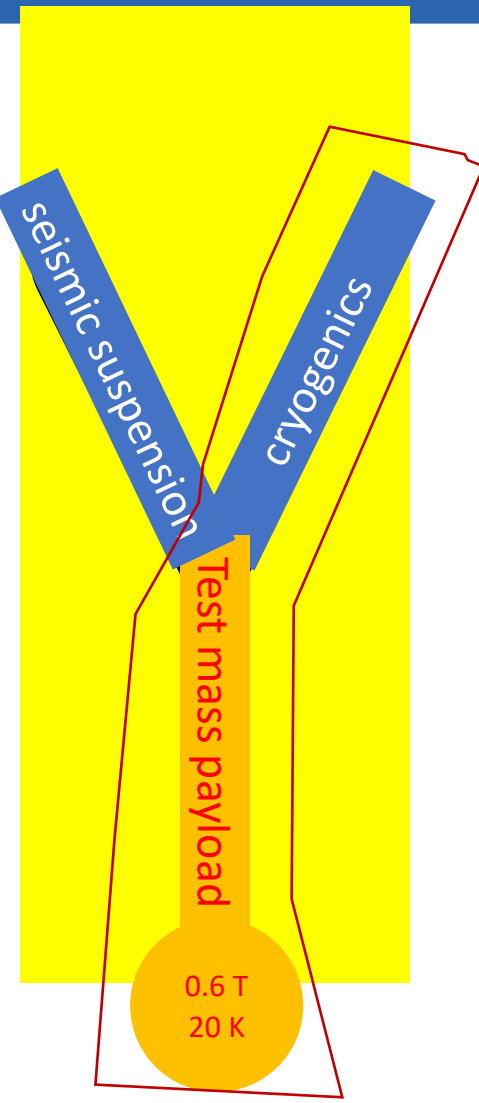
➔ Practical studies cannot directly to an ideal design conceived on the back of the envelope 15 years ago, as we have first to investigate the viable mechanical solutions to extract the heat.
➔ Initial/advanced cryogenic payload design is the only way to start with the TDR

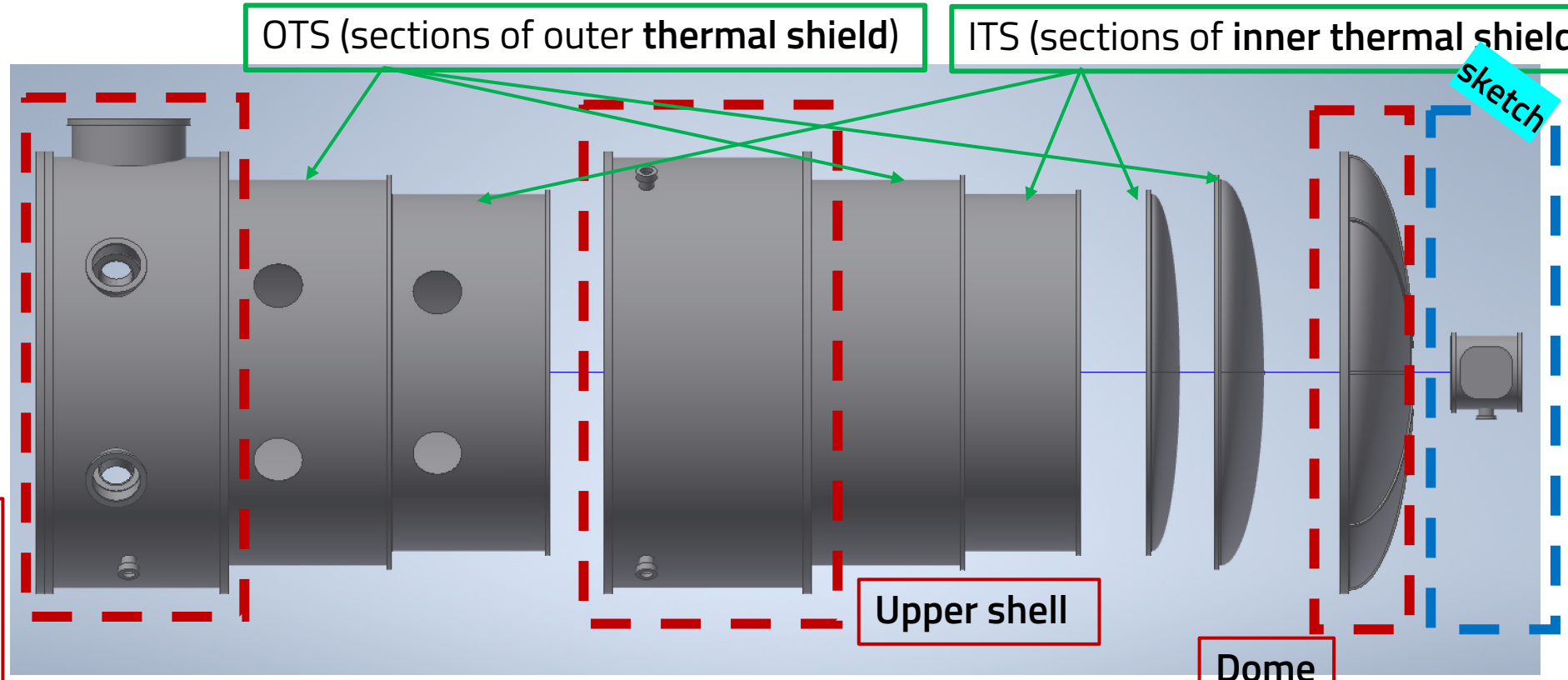


ARC-CRYOGENICS partner projects

- **PRIN LoVeC-ET** (Low frequency Versus Cryogenics for ET), Majorana
  - PRIN payload prototype (including Silicon): partners: Sapienza, PG, URB TOV, INFN
- **KAGRA** (a continuous collaborative exchange since some decades), we
  - discuss any cryogenic payload issue and solutions,
  - exchange receive relevant hints concerning cryogenics, technical noise and sensing devices
- **KIT** Karlsruhe Institute of Technology, Grohman
  - Long-term plans for payloads and cryostats
- **ETIC-CAOS** INFN, H. Vocca
  - Room Temperature developments for seismic attenuator interferometric facility
- **INFN Investment CSN5** at Napoli branch (L. Di Fiore)
- **EGO Vacum & Cryogenics**, A. Pasqualetti
  - Waiting for the ARC cryostat operation, we plan to use the facility at EGO
- **INFN Cuore and Cupid**, Pirro and Cruciani
  - Directly involved in ETIC, they are spending significant and precious FTE with us
- **Pathfinder LASBOT** (Large All Sapphire Based Optical Technology), G-P Cagnoli
  - A project proposal dedicated to exploit the excellent properties of sapphire for the payload

WP3_INFN-RM1_T006
WP3_INFN-RM1_T007
WP3_INFN-RM1_T008
➔ Examining quotations

C75 (75% sized) cryostat at ARC: block schematic



WP3_INFN-RM1_T009

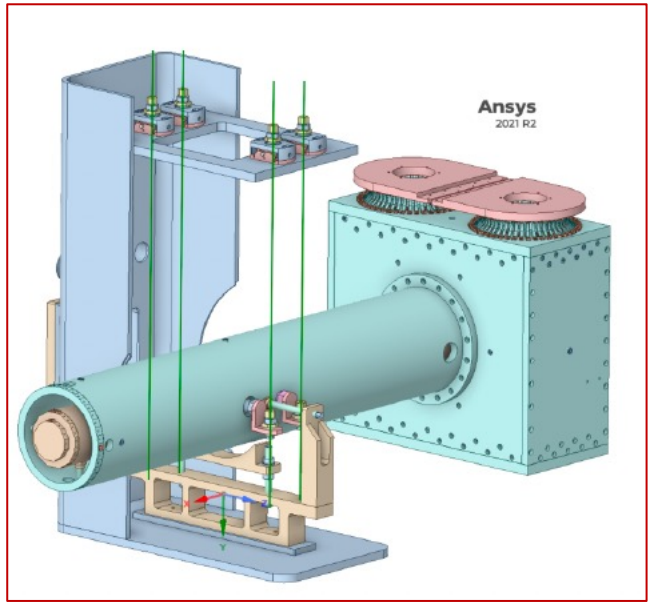
Cooling lines

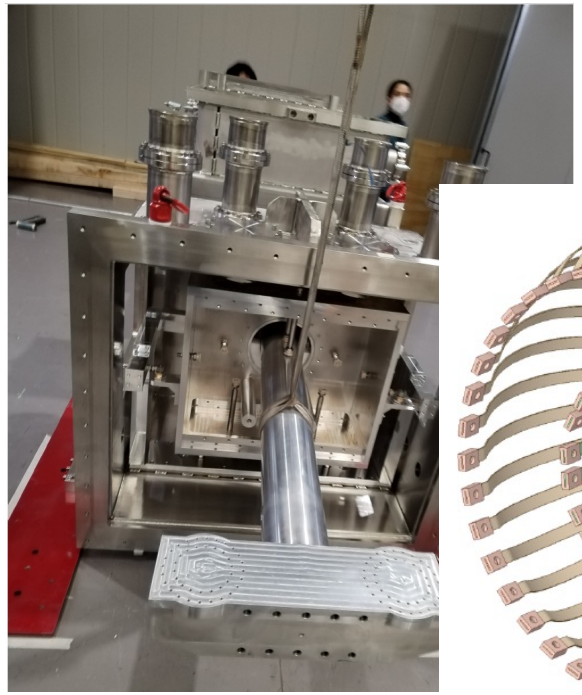
(The first one is built by ARC funds)

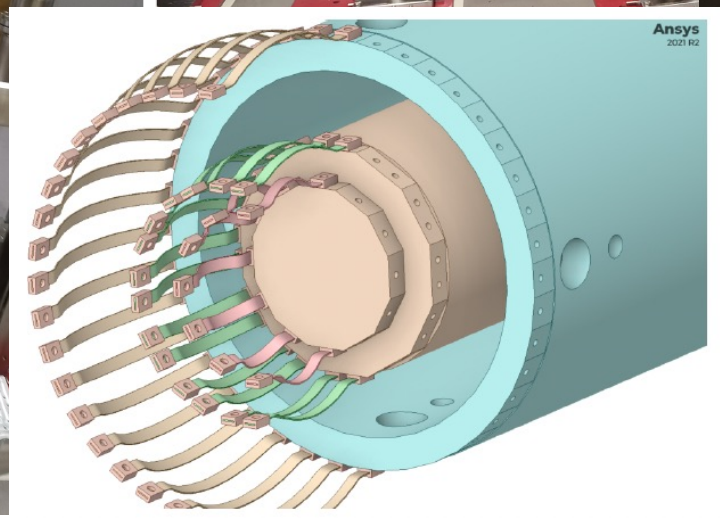
2 big call for tenders:

- Examining quotation for the second one
- CRYOCOOLERS, purchaseing going on

1 smaller tenders: high conductivity links by summer 23



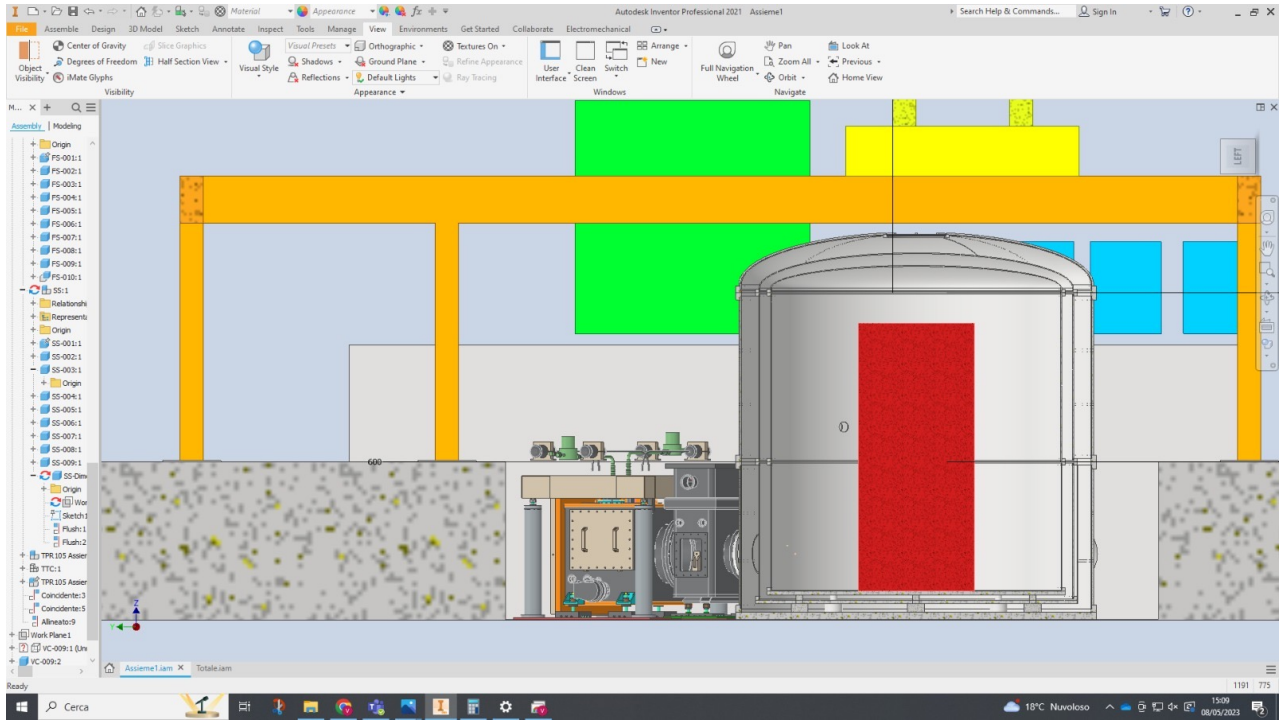


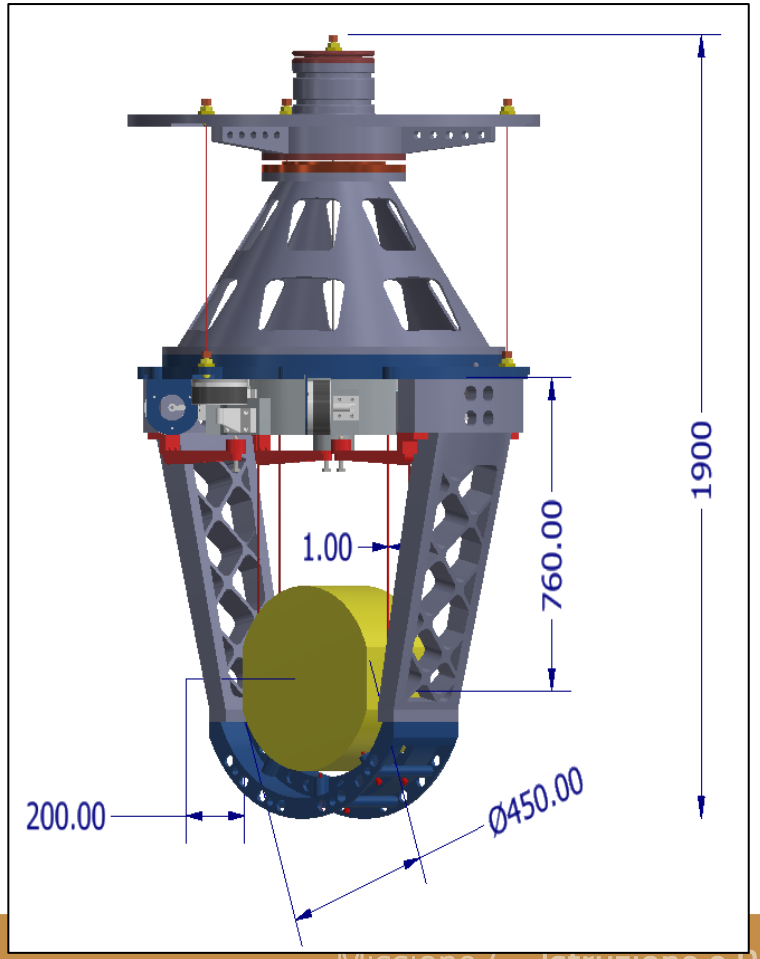


WP3_INFN-RM1_T018

Prototype payload size test mass ~150 kg dummy

- Metal parts June/Jul ➔ call for tenders)
- Sapphire parts still under feasibility/negotiation





MOST CRUCIAL DEMONSTRATORS NEEDED

- Crystalline suspension for marionette (how-to under study)
- Strength of HCB at the tips of crystalline suspension elements (marionette/mirror) (started)
- Development of crystalline suspension elements heats (e.g. anchors) ((started)

- Wireless DC tilt control of marionette (just some ideas on the paper)