Exploring the transient hard X-ray/soft gamma-ray sky in the next decade

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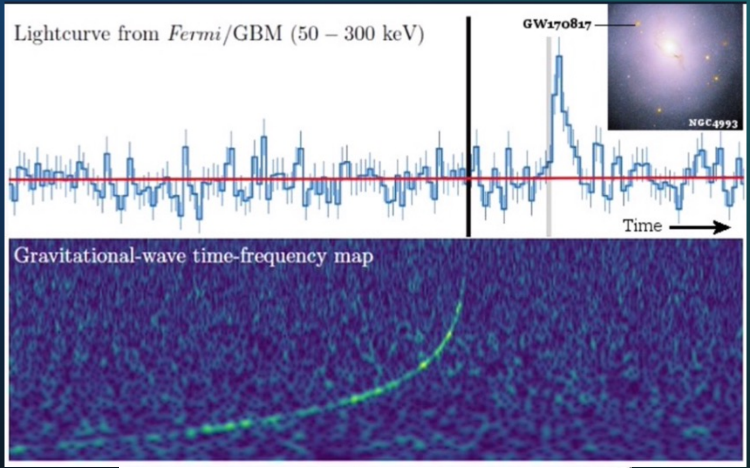
Talk summary

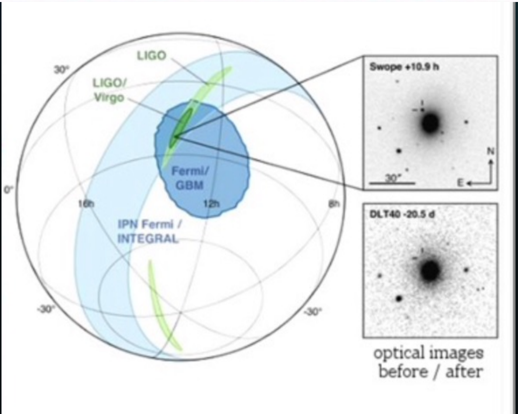
- Multi-messenger observational scenario for the next decade
- EM and GW facilities
- The GRINTA «fast mission» concept for a hard X-ray satellite
- GRINTA potential contribution to GRB science and synergy with other facilities

Relevance of GW/EM observations

Since 2017, after the discovery of GW from the BNS merger GW170817, it was fully realized the potential of joint EM/GW observations to probe an impressive breadth of astrophysical questions, e.g.:

- The value of standard cosmological parameters
- The origin of heavy elements
- The NS equation of state
- Testing of the weak equivalence principle
- Breaking the degeneracy between jet inclination and luminosity distance in GW parameter estimation





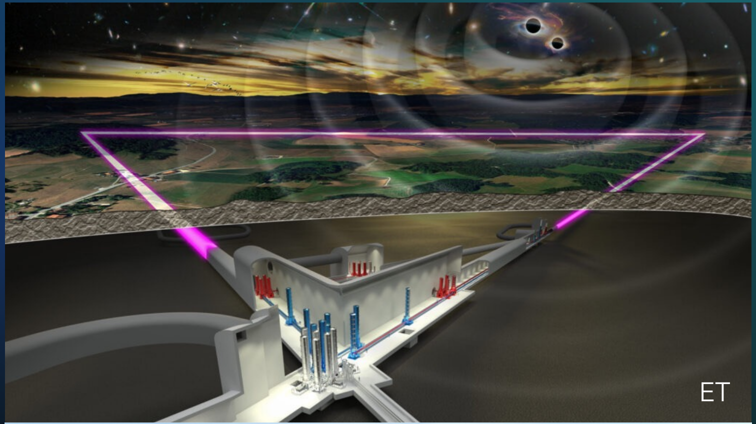
Joint GW/EM signal detection in the 30's

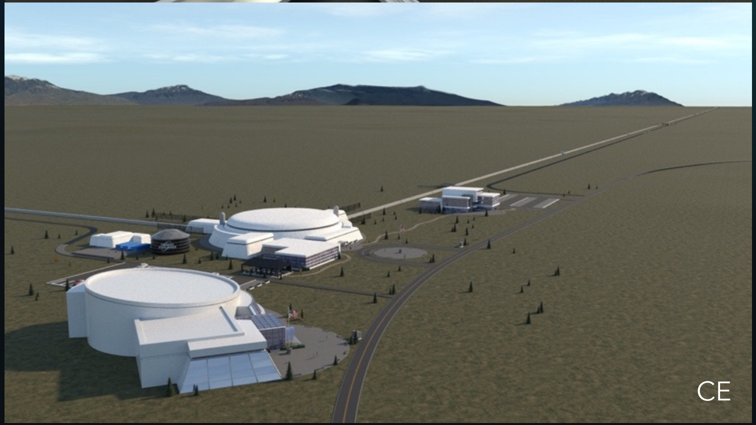
Predicted scenario for GW

- **Post O5, Voyager/A# upgrades to Adv.LIGO (>2030)**

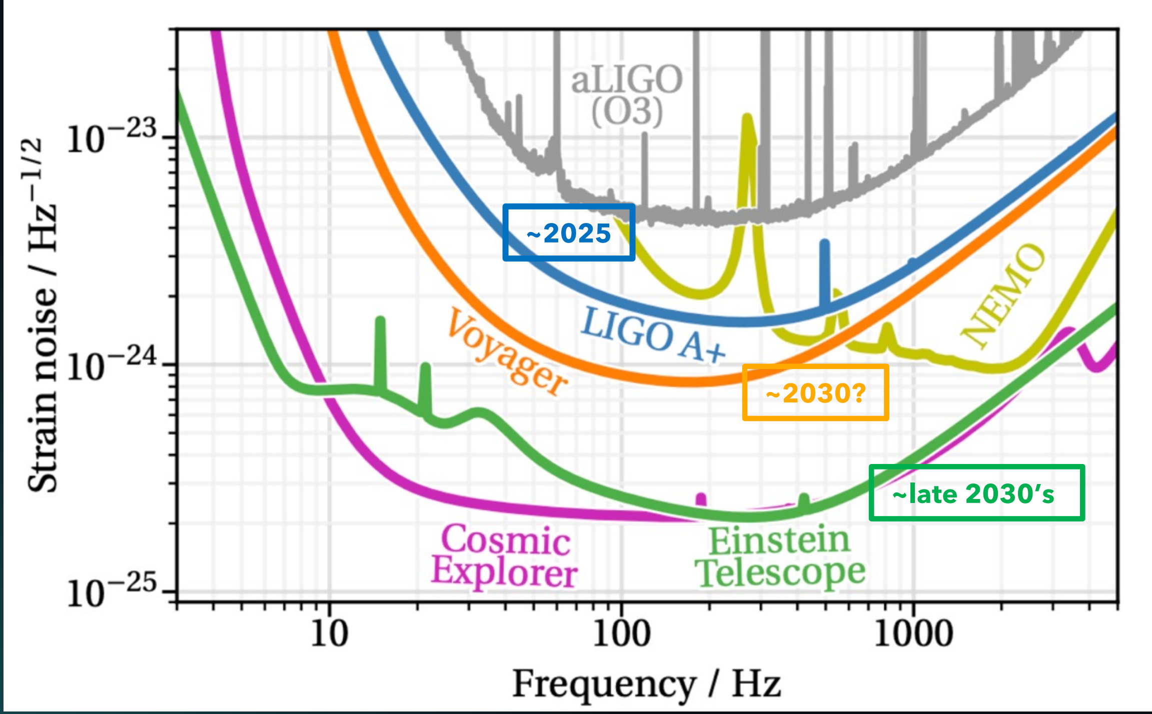
+Virgo (O5 sensitivity) + Kagra (O5 sensitivity)

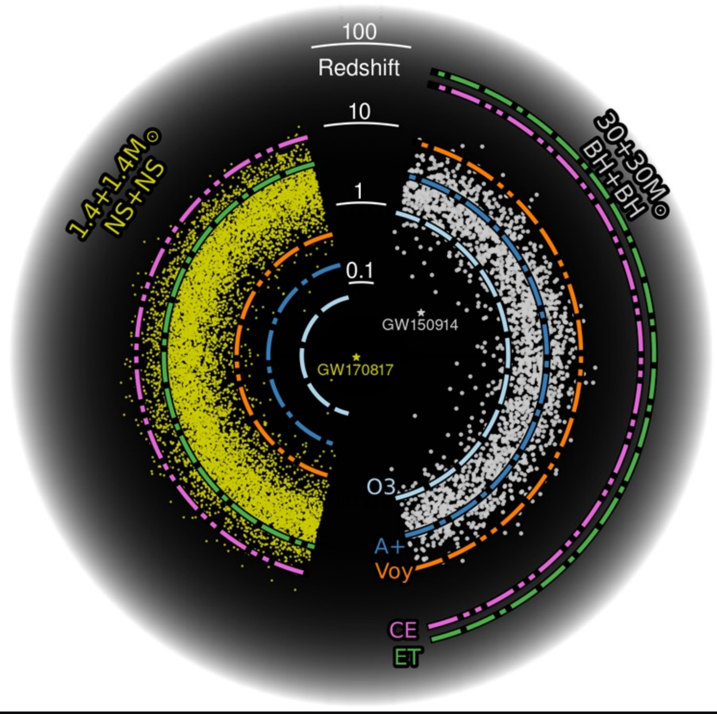
- **Einstein Telescope (>2035)**
- **Einstein Telescope + Cosmic Explorer (>2035)**
- **LISA (>2035)**





Planned GW detectors





Credits: https://cosmicexplorer.org/

Joint GW/EM signal detection in the 30's

Predicted scenario for EM (major facilities)

- **IR/Optical/UV**

JWST

Vera Rubin/LSST

ESO/ELT +US ELT Projects (GMT/TMT)

Nancy Grace Roman Space Telescope

Origins Space Telescope (>2035)

- **Radio**

SKA

Alma

ngVLA, ...

- **X-rays (2030-2035)**

(*maybe*) Einstein Probe & SVOM extended ops

X-rays (>2035)

NewATHENA

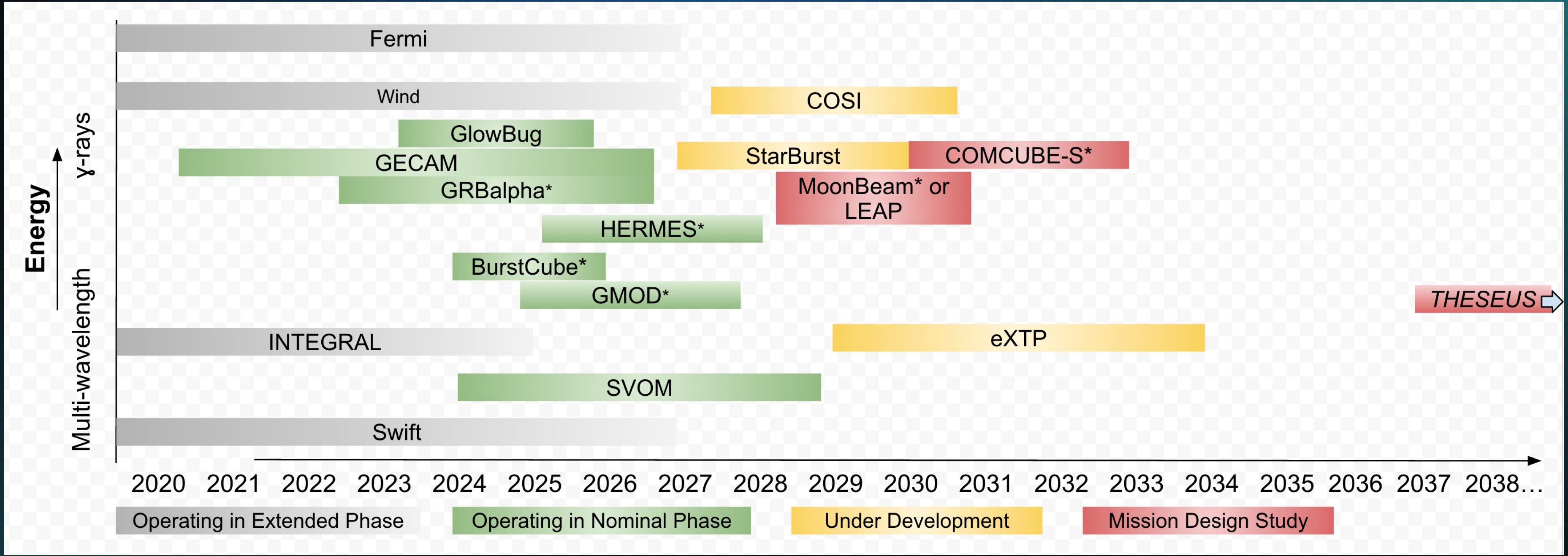
Lynx

(*maybe*) Theseus

Joint GW/EM signal detection in the 30's

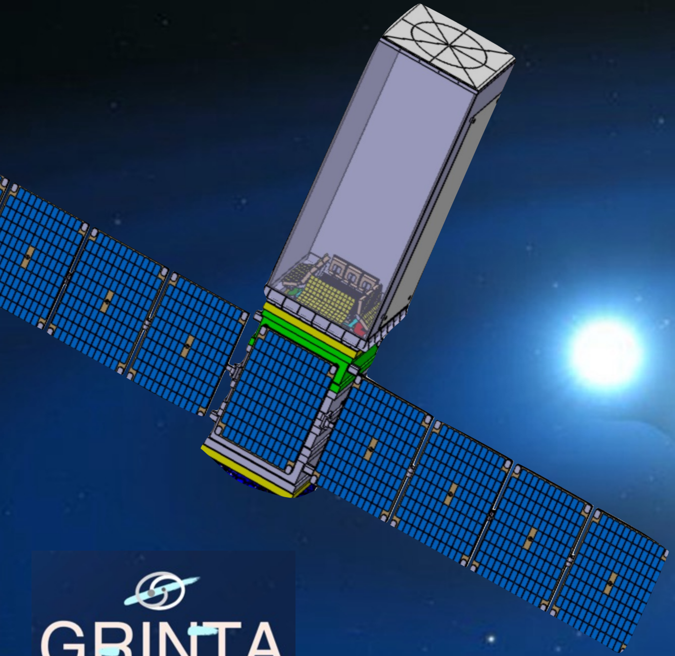
- > 2030 (post-O5): Several thousands of GW BNS detection per year up to z ~1
- Limit distance expected to increase to ~1 Gpc for NS/NS
- For many events, prompt follow-up by optical/UV telescopes will not be feasible
- Hard X-rays are needed! For both detection and localisation

HE (≥100 keV) missions scenario



No currently approved hard X-ray missions with imaging capabilities like *Swift*, *Fermi* and *INTEGRAL* in the 2030's

The GRINTA mission



- Main goals: GRB & multimessenger, Surveys
- Launch: >~mid 2030's
- Orbit: LEO equatorial (<5deg)
- Rapid repointing, light S/C

- GRB detection:
  Coverage ~8 sr FoV (0.02-10 MeV)
- Followup:
  Coverage 400deg^2 FoV (5-200 keV)
- #GRBs: ~570/yr (of which ~90 SGRBs/yr)
- Localization:
  <10 deg @90% confidence at first detection,
  30" after followup

- Proposed to ESA as candidate FAST mission in the 2021 Call

GRINTA

The Consortium

17 European research laboratories, 47 researchers, 8 countries

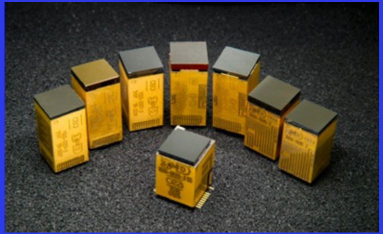
GRINTA in a nutshell

Key Science Goals	• Understand the physics of mergers responsible for emission of gravitational waves • Probe the nature of jets and structure in gamma-ray bursts • Understand the physical processes driving the high energy transient phenomena and clarify their relationshipwith multi-messenger sources • Understand the physics of compact objects and characterize their populations (surveys)
Payloads	Two instruments: • Transient Event Detector (TED), 0.02 — 10 MeV, FOV ⟵ 8 sr • Hard X-ray Imager (HXI), 5 - 200 keV, FOV ⟵ 100sq.deg fully coded, 400sq.deg FWHM, source location accuracy ⟵ 30”
Mission Profile	• Vega-C, Low Earth orbit, < 5deg inclination • Duration: 2-year (nominal) + 3 years (extended) • Communication links: equatorial GS, optional intersatellite relay link (e.g. Globalstar, Iridium) • Optional cubesat (GIFTS) co-orbiting for all-sky coverage (not baselined - to be assessed in Phase 0)
Spacecraft	Study based on TAS-I NIMBUS platform: • 3-axis stabilized • Rapid repointing, slew time : 50°/min • Power : 490 W • Dry Mass : 289 kg • S-band/X-band (Malindi, Kourou)
Cost to ESA	ROM estimate marginally within ESA CaC, could be substantially reduced if S/C is already space qualified at the time of mission adoption

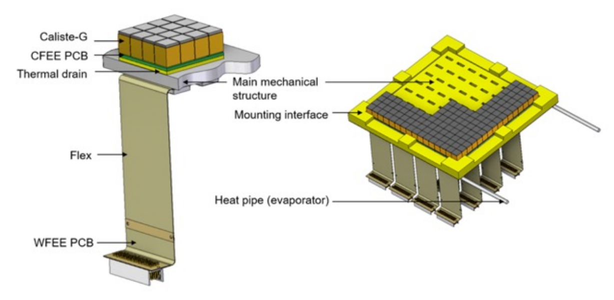
The GRINTA payload

Hard X-ray Imager (HXI)

- Coded mask instrument ($400\ deg^2$ FoV)
- Detection units based on Caliste modules (CdTe Schottky, already flight proven)
- Focal plane assembly has 16x16 modules, $900 cm^2$ detection area. Imaging pixel size = 1mm.

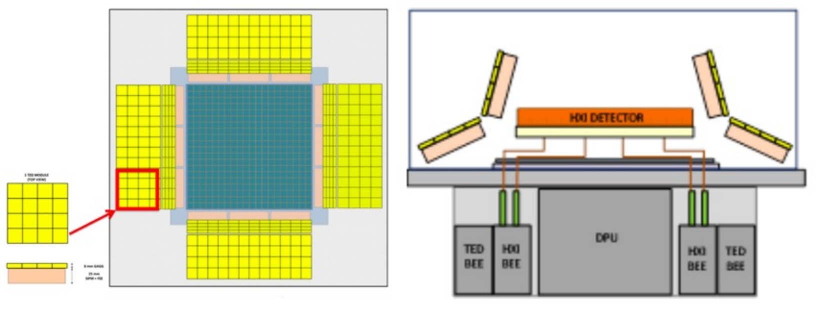


A set of Caliste modules. A version of them has been launched on Solar-Orbiter(TRL-9)

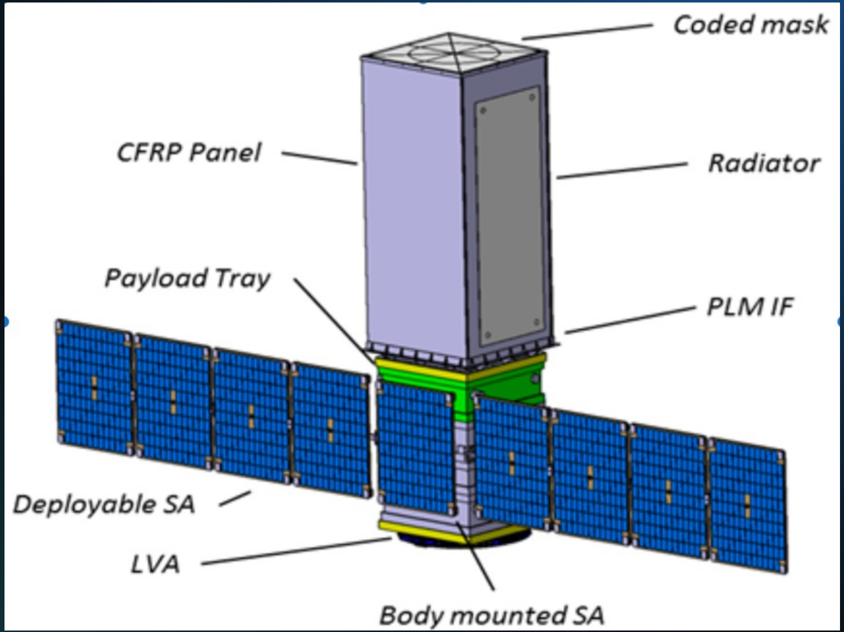


Transient Event detector (TED)

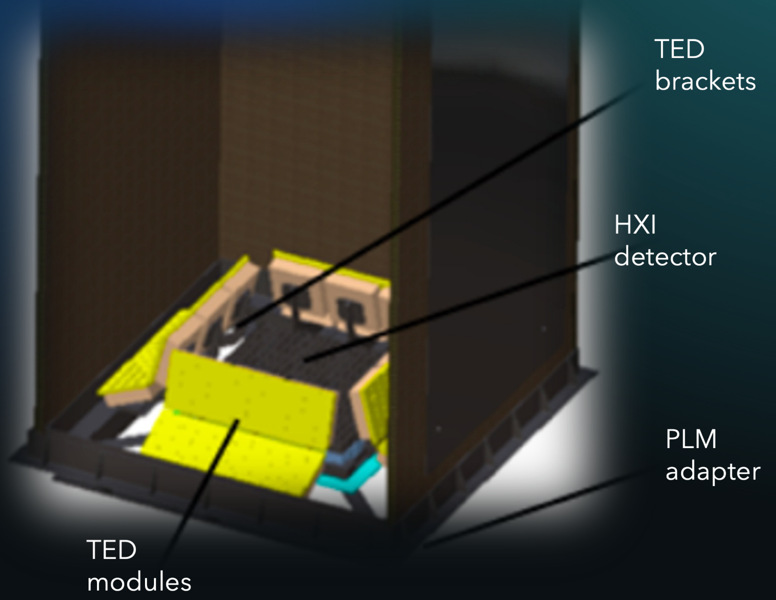
- 24 modules, each of $100 cm^2$ geometric area
- They are used on board to detect GRBs and other transients and send alerts to the DPU
- They also act as active AC system for the HXI detector plane
- Technology already flight proven, mainly on small-sats (e.g. GECAM, GRID, …)



The S/C and the Payload Module

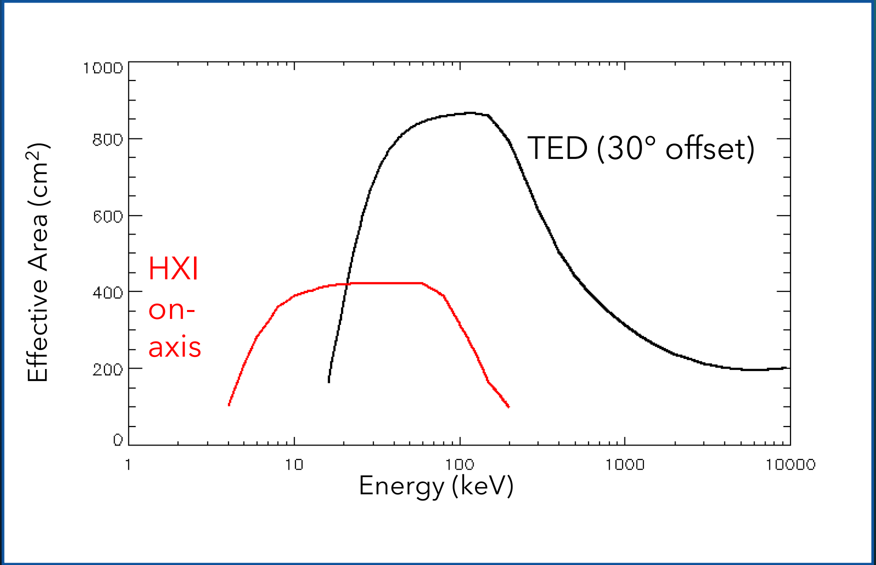


S/C study based on TAS-I Nimbus S/C



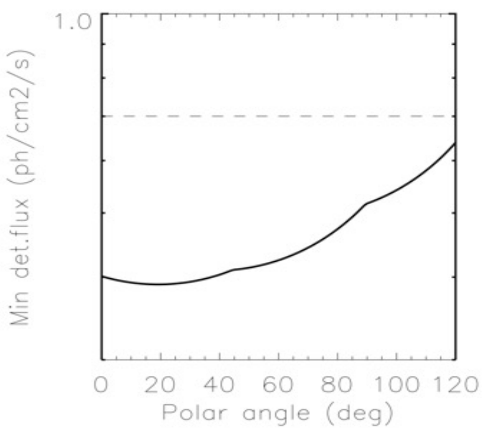
GRINTA performance summary

Characteristics	HXI Performances	TED Performances
Energy Range	5–200 keV	20 keV –10 MeV
Spectral Resolution (FWHM)	1 keV @ 60 keV	~25% @60 keV ~10% @500 keV
Field of View	$29° x 29°$ Total FoV	~ 8 sr
Angular Resolution	3.8’	N/A
Source location accuracy (10σ)	30”	5°
Sensitivity (5sigma, 10^4s)	Energy range: 5 – 50 keV, 6×10^{-4} ph/cm²/s; 50 – 200 keV, 3×10^{-3} ph/cm²/s; 5 – 200 keV, 3.5×10^{-3} ph/cm²/s	$< 0.5\,\mathrm{ph/cm^2/s}$ in 50–300 keV

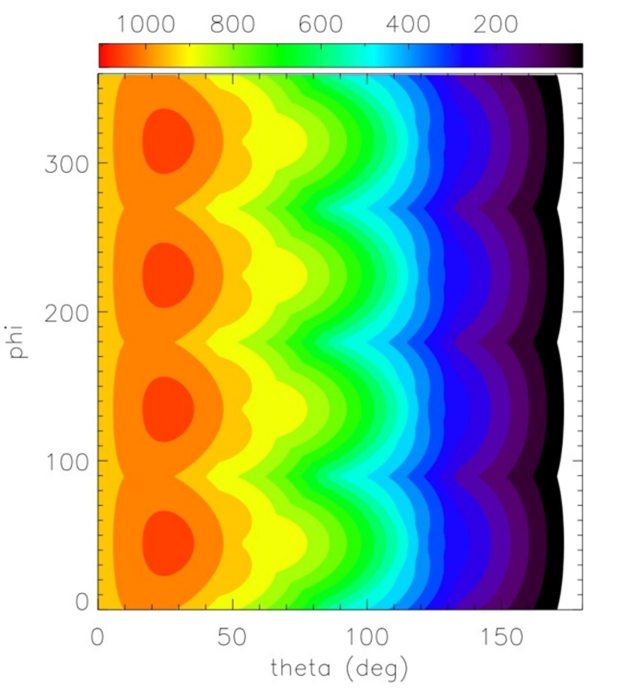


TED sky monitoring

Source Type	Detections/Year
Short GRBs	90
Long GRBs	480
Magnetars	60
Galactic Transients	90



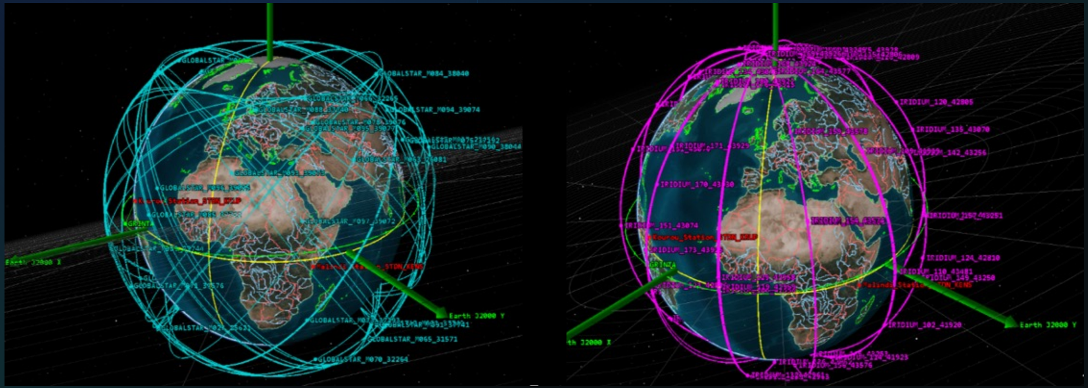
TED sensitivity compared to Fermi/GBM



Exposed area as a function of polar angle

GRINTA Operational Concept

- Basic operational modes:
  (a) Safe mode (b) Survey (c) Follow-up
- Fast slew towards the target (50^{o} in < 60'')
- Follow-up triggered by TED localisation of an event or by external (ground or satellite) alert
- Re-orientable solar panels
- S/C communication via both GS and satellite constellations (necessary to reduce delays down to ~min timescale)



GW localization error

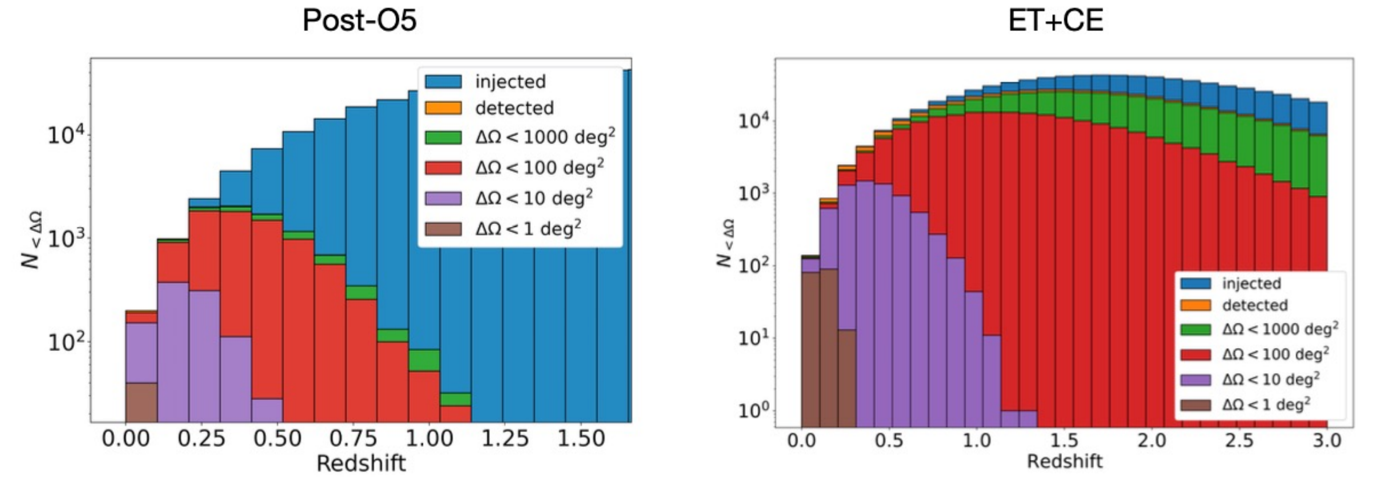


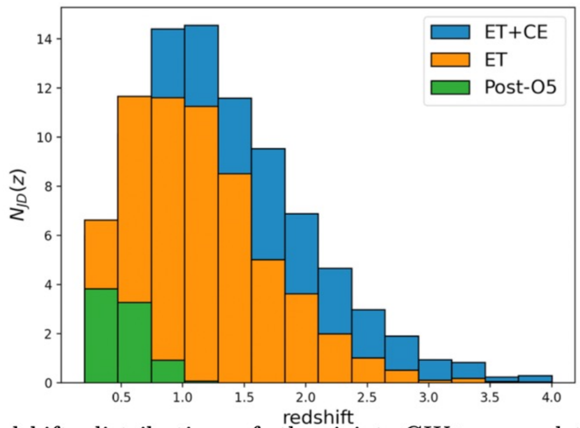
Fig. 2 Sky localisation for BNS signals considering two scenarios of GW detector network. The sky localization uncertainty is reported as 90% level of confidence. The normalisation of the histograms corresponds to one year of detections.

Most GW detected events in the post-O5 scenario will have localization error < 100 deg^2 (Ronchini+22)

BNS mergers detection rates

Scenario	GW network	N_{JD}	N_{JD}/N_γ
2G+	LIGO-L + LIGO-H + LIGO-I + Virgo + Kagra	1^{+2}_{-1}	$< 2\%$
Post O5	3 Voyager + Virgo + Kagra	9 ± 4	$12^{+6}_{-4}\%$
ET	Einstein Telescope	63^{+12}_{-17}	$65 \pm 8\%$
ET+CE	Einstein Telescope + Cosmic Explorer	86^{+21}_{-17}	$94^{+3}_{-4}\%$

Number of joint GW+γ-ray detections of BNS mergers for one year of observation of *GRINTA*/TED observing in survey mode in synergy with different GW networks. N_{JD}/N_γ is the fraction of short GRBs that will have also a detected GW signal.



Redshift distribution of the joint GW+γ-ray detections with *GRINTA*/TED. The histograms are normalised to one year of observations.

GRINTA contribution to GRB science

TED will detect about 90 short GRBs per year

- Almost half will be detected by HXI in γ/X-ray (down to 5 keV)

  → measure the source spectra probing the emission mechanims

- HXI sub-arcmin sky-localization will drive the multi-wavelenght follow-up by ground and identification of the host galaxy

  → complete picture of the relativistic jet and interaction with

  the environment

GW/GRB: post O5, ~10 detection per year in survey mode and another tens by follow-up of GW signals

- Evaluate the fraction of BNS able to produce a jet
- Jet structure by detecting off-axis GRBs (pointing GWs)
- Detect X-ray signature to identify the nature of the merger remnant
- Understand the role of NS-BH mergers as short GRB progenitor
- With 2+3 years mission → cosmology with H_0 at 1 percent level and test of modified gravity

Synergy with other facilities

- Provide accurate locations of the events to follow-up with IR/optical/UV telescopes. Measurements of redshifts by IR/optical followup of SGRBs will have impact on cosmology (H_0 measurements) and fundamental physics (e.g. theories of modified gravity)
- Followup with optical/UV to investigate the relative contribution of mergers and core-collapse SNae to the r-process (connection to cosmic-ray science, origin of heavy elements).
- Investigation of alerts generated by radio, optical and VHE (e.g. SKA, Vera Rubin, CTA), including subthreshold searches. Events from GRBs, TDEs, FRBs,…
- Search for HE neutrino counterparts in the error regions of neutrino telescopes: IceCube Gen2, KM3NET…
- Perform joint studies of the hard X-ray and TeV emission (e.g. blazar flares) with GRINTA and CTA
- Follow-up and localization of many astrophysical transients
- Investigation of HE unidentified sources for thousands of objects (e.g. sources already detected by INTEGRAL, Swift, Fermi, eRosita, …)

Localization is the key!

Summary

- GRINTA is a natural evolution of the successful, currently operational missions: Fermi, INTEGRAL, Swift, with an innovative operational approach
- It represents an outstanding opportunity to complement the GW post-O5 and neutrino 2nd generation detectors with EM measurements in the 2030's.
- It will provide wide sky coverage in hard X-rays, currently the most effective choice for the detection and prompt localization of short GRBs from binary mergers at large distances
- The detection of tenths/hundreds of joint EM/GW events will provide breakthrough discoveries in fundamental physics, cosmology, relativistic jet formation and structure, gravity theories, etc.
- GRINTA will detect a very large sample (~500/year) of long GRBs to provide deeper insights into the progenitors, central engines and jet structures associated with massive stellar collapses.
- It will provide broad band coverage to study accretion and ejection phenomena in compact sources, covering an important gap in the decade
- It will work in synergy with other ground and space facilities, spanning from radio to UHE gamma-rays to study the most energetic phenomena