3UTransat

A network of nano-satellites to survey the transient sky

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On behalf the IRAP team

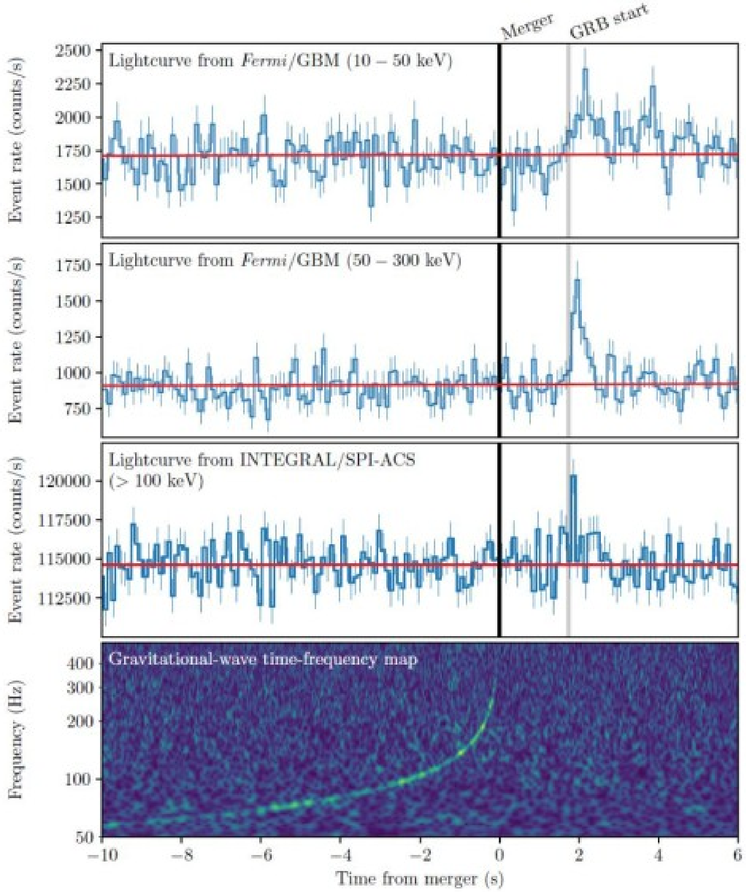
Time-domain & multi-messenger era

- Milestone in 2017 with the coincidental detection of GW 170817 (Ligo/Virgo) / GRB 170817A (Fermi/Integral)

- New time-domain facilities coming along in 2020s: e.g. LSST, CTA, SKA

- New very sensitive multi-messenger instrumentation that will need triggers for transients (e.g. ELT, JWST, Athena, LISA, ET)

- GW astronomy have strong connections with HE astrophysics, both involving compact objects.



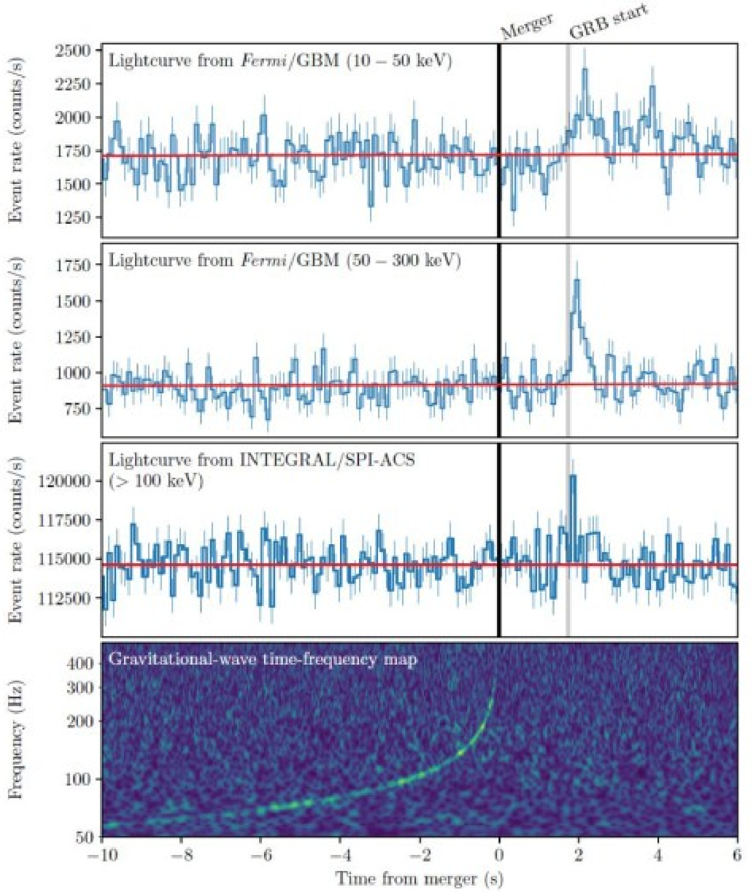
GW – EM scientific prospects

- **Black holes:**
  - Study of the populations of compact objects and formation paths:
    - Demography of BH: mass distribution, accreting/quiescent, isolated/in binary, fraction BH vs NS
    - BH growth
  - GW sources:
    - GR tests (velocity of GW)
    - Origin of measured delay between GW & EM signals
    - Source geometry & proprieties
    - Energetics in EM vs GW
  - GRB physics
  - Fraction of mass in BHs – impacts on dark matter
  - BH growth and co-evolution with host galaxies – cosmological impacts on formation of large structures
- **Neutron stars:**
  - EoS of supra-nuclear matter
  - r-process & enrichment of ISM/IGM by heavy elements
  - SGR/magnetar activity
  - GRB physics

Time-domain & multi-messenger era

- Milestone in 2017 with the coincidental detection of GW 170817 (Ligo/Virgo) / GRB 170817A (Fermi/Integral)
- New time-domain facilities coming along in 2020s: e.g. LSST, CTA, SKA
- New very sensitive multi-messenger instrumentation that will need triggers for transients (e.g. ELT, JWST, Athena, LISA, ET)
- GW astronomy have strong connections with HE astrophysics, both involving compact objects.
- GW detectors enable to survey continously all the sky.

=> Necessity to develop HE instrumentation with continuous and all-sky coverage to work in synergy with GW (& neutrino) detectors



Network of nano-satellites

- 2 types of philosophy: sensitive instruments covering a modest fraction of the sky (e.g. *Swift*/BAT, *SVOM*/ECLAIRs) and less sensitive and « all-sky » instruments (e.g. *Fermi*/GBM, *SVOM*/GRM)

- A network of nano-satellites could achieve **both** by increasing the number of satellites over time, but for a much cheaper cost:

  - Building nano-satellites is cheaper, could be achieved over shorter timescales and offers more flexibility;

  - More accessible to small countries and/or labs/universities with less space instrumentation capabilities => **increase collaborative work / share risks**;

  - **Each satellite could embark a science payload with a modest effective area** (a few 10^2 cm^2)
    - *Fermi*/GBM detects > 200 GRBs/yr with 12 detectors, each with a 126 cm^2 EA, while *SVOM*/GRM will have 3 detectors with a 200 cm^2 EA each.

  - **Science goals: reach localization accuracy of a few dozen of sq. degrees**
    - Compliant with FoV of ground telescopes designed to search for EM counterparts of GW events

Network of nano-satellites

- Several projects of nano-satellite networks proposed to detect GRBs or TGFs (Terrestrial Gamma-ray Flashes): GRBCube/BlackCAT (USA), Camelot (Japan, Hungary), HERMES (Italy, Europe), GRID (China), IGOsat (France/APC), ...

- **IRAP wants to participate to the development of a european/international nano-satellite network to work in synergy with GW, neutrino and EM (ground/space) missions (LSST, Ligo/Virgo, CTA, SKA, CHIME, Km3NET, IceCube, Athena, LISA, etc.).**

- **Flying the first satellites is crucial to demonstrate our science & technical capabilities to operate such nano-satellite networks.**

The project 3UTransat

- 3UTransat = **3U** cosmic **Tran**sient **sat**ellites
- 1 U = 10 x 10 x 10 cm^3
- Baseline: 10 (TBC) 3U–satellites
- Project idea from discussions within the Galaxie, Haute Energie & Cosmologie group at IRAP
- Involvement of a few IRAP scientists/engineers + CNES
- Project proposal submitted to CNES prospectives => positively reviewed by CNES working groups

  => **Kick-off of a phase 0 in March 2020 with the help of CNES/PASO** (Plateau d’Architecture des Systèmes Orbitaux)

Project drivers

- **Same design of the science payload for each satellite of the network**

- **Design** has to be kept as **simple** as possible, to be **efficient**, **reliable** and **compact** (3U format)
  - Once consolidated, design could be made public.

- Development of the project (from preliminary studies to building the instrument) over short timescales
  - **goal: launch a demonstrator including 2–3 (TBC) satellites in 2022 to work during the GW run O4!**

  - Rest of the nano-satellites launched progressively and/or accretion of other satellites through collaborations

- No onboard trigger – **detection and localization algorithms on ground**
  - downloaded data to be available to the ground segment in less than 2 h after the burst occured
  - Data: counts per energy band and per timescale « continously » transmitted to the ground

- Launches to be « opportunistes » => likely in quasi-polar orbits => limit satellite duty-cycle
  - Orbital data provided by CNES – use of our mission simulator to assess and optimize instrument & network performances
  - Study effects on the technical side (thermal impacts, power consumption, ...)

Project drivers

- **Change the way to analyse data**: consider the network as a unique detector – see next slides

- Development of **a collaborative ground segment** able to gather heterogeneous data coming from other nano-satellite networks and satellites in order to compute the GRB detectability and localization

  - Need to **define basic specifications on data format/type** in order to fully exploit these data

  - **No constrain on the design of the satellite and science payload for collaborators**

  - **All data available within the collaboration**

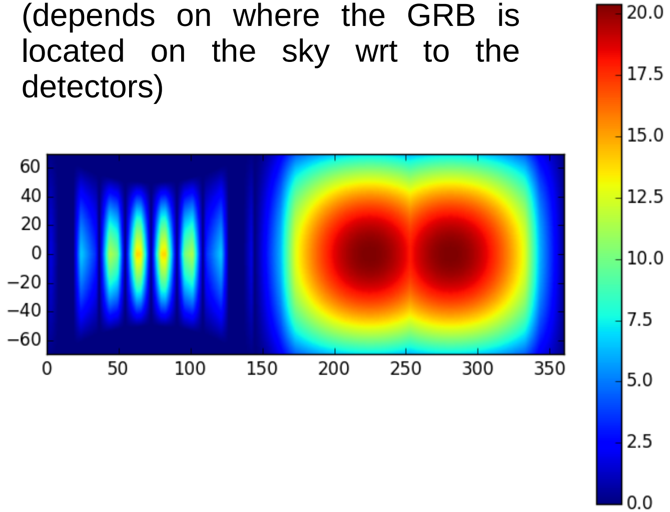
  - **On-going discussions with CNES/DIA** (Direction de l'Innovation, des Applications et de la Science) to find potential collaborators

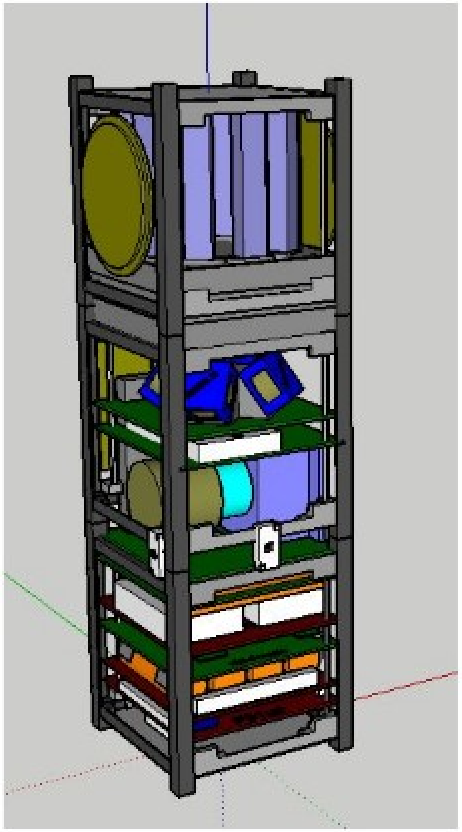
=> If interested, contact us ogodet@irap.omp.eu

Science payload

- 1-D localization (based on coded mask technic)
- Baseline: 10 NaI(Tl) scintillators each coupled with SiPM + readout electronics Included in 1 U (TBC)
- Energy range = 15 – 150 keV (TBC)
- Different pointing direction help improving the source localization

Spatial response of 1 detector (depends on where the GRB is located on the sky wrt to the detectors)

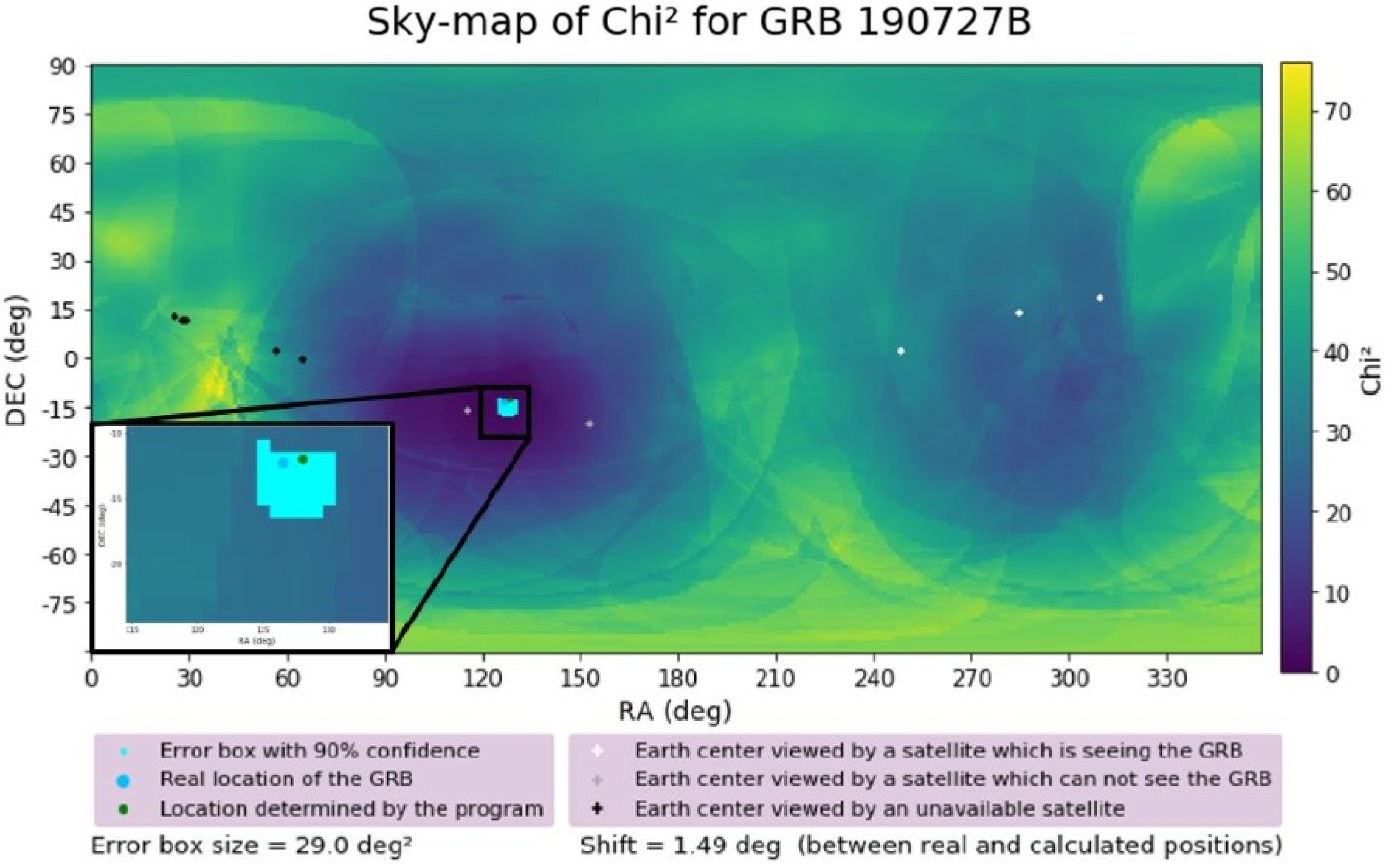




Science payload

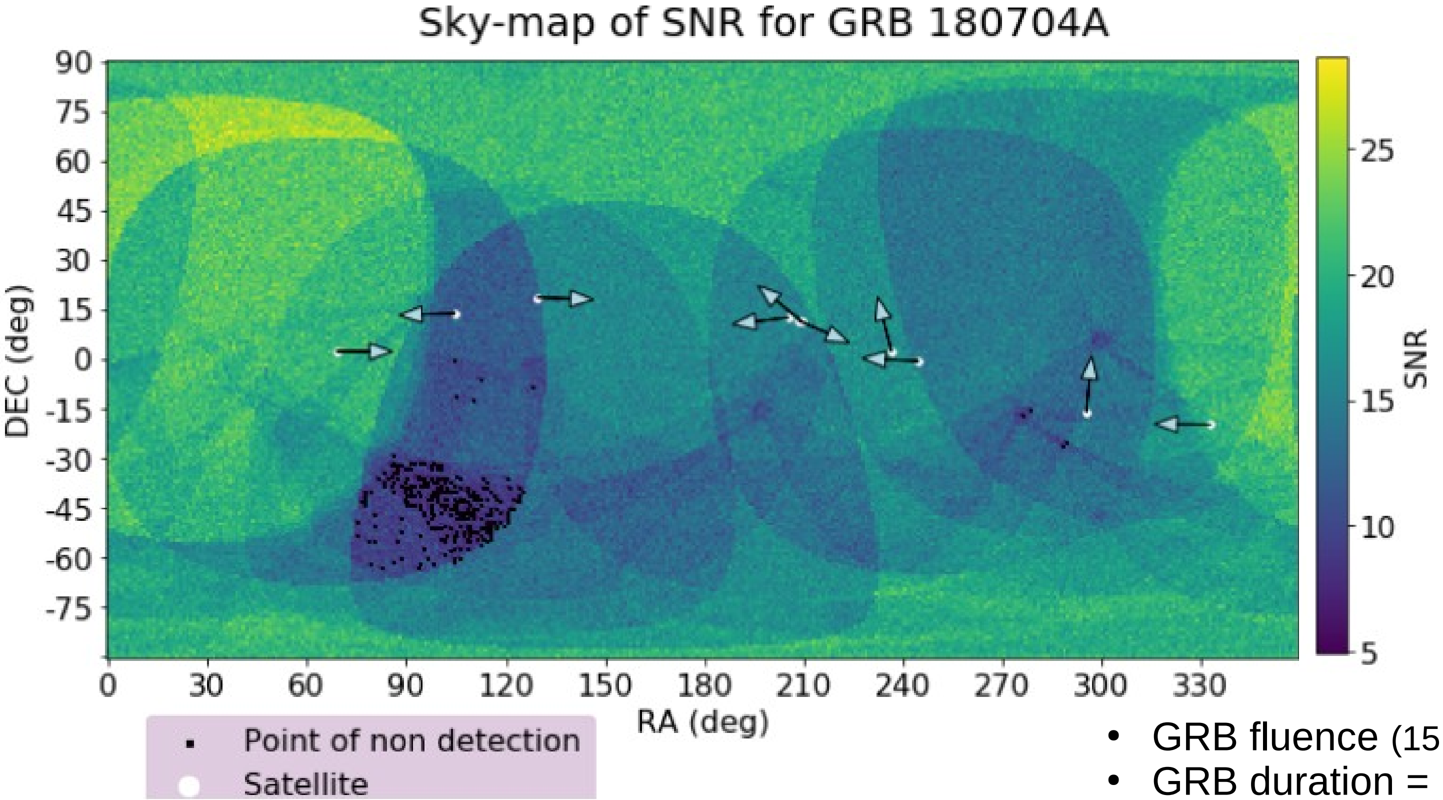
- Development of **a dynamical mission simulator** at IRAP taking into account: CNES orbital data + instrument geometry + network configuration + expected background noise + *Swift/Fermi* GRB database as inputs – work in progress
  - Assess network performances (number of detections, localization accuracy) as a function of inputs
  - Enable to optimize design of science payload

- Localization principle:
  - Divide the sky in N cells
  - Compute how the GRB will be seen by the nano-satellite network in a given configuration for each cell
  - Compare this to the observed signal => compute χ^2 map to identify GRB localization
  - Redo the same analysis in a continuous way (repetition frequency TBD)



GRB fluence (15 – 150 keV) = 1.8 10^{-5} erg cm^{-2}
GRB duration = 40 s

10 satellites
10 NaI detectors per satellite
Orbit with i = 15°
Random pointing direction
Satellites randomized along the orbit
Simulations by J-B Barneix



- GRB fluence (15 – 150 keV) = 6.2×10^{-6} erg cm^{-2}
- GRB duration = 19.7 s
- 10 satellites
- 10 NaI detectors per satellite
- Orbit with i = 15°
- Random pointing direction (arrows)
- Satellites randomized along the orbit
- Detection SNR = 8
- Simulations by J-B Barneix