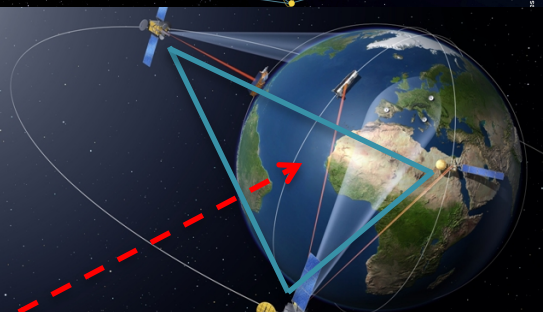


The HERMES project

High Energy Rapid Modular Ensamble of Satellites Probing Space-Time Quantum Foam and Hunting for Gravitational Wave Electromagnetic Counterparts

Luciano Burderi, University of Cagliari

Tiziana Di Salvo − University of Palermo

Andrea Sanna, Alessandro Riggio − University of Cagliari

Fabrizio Fiore, Alessandro Papitto − INAF – Rome Astronomical Observatory

and many others…

Please, visit our website:

http://hermes.dsf.unica.it

HermeS

The Multi−Messenger Astronomy Paradox

One of he most thrilling research field in Science:
the whole field based on ONE discovery: GRB 170817A - GW170817 connection

S1: within 2025 LIGO − Virgo − KAGRA GW antennas will provide:
detectability of NS−NS mergers events like GW170817 within ≅ 200 Mpc
localization within:
≅ 100 square deg (LIGO − Virgo)
≅ 10 square deg (LIGO − Virgo − KAGRA)
(quoting Marica Branchesi talk)

GBM would not have been able to detect an event like GRB 170817A but 60% fainter (quoting Peter Veres talk), which means roughly:
S2: Kilonova events seen at angles ≥ 25 degrees (quoting Eleonora Troja talk)
undetectable by GBM for D ≥ 1.4 × D(GRB 170817A) ≅ 60 Mpc

S1 + S2 ➔ No EM counterpart detected, no party!
(quoting George Clooney)

We need a All-sky Monitor at least 10×GBM Area for letting Multi−Messenger Astronomy to develop from infancy to maturity!

HERMES in a nutshell

High Energy Rapid Modular Ensemble of Satellites

Aims:

all Sky Monitor for fast and accurate detection of the position of bright, transient, high-energy events and All Sky Monitor of known bright sources (timing):

- **GRBs**
- **GW events**
- high-energy counterparts of **Fast Radio Bursts**
- flares from **Magnetars**
- fine GRB temporal structure to perform the **first dedicated experiment in Quantum Gravity**

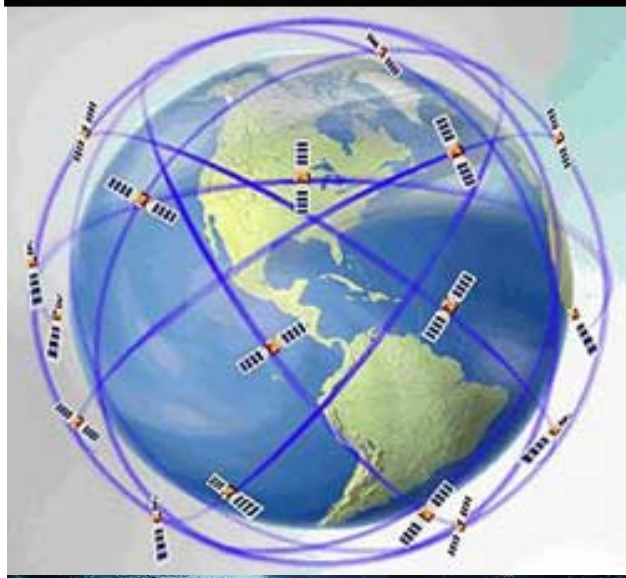
How:

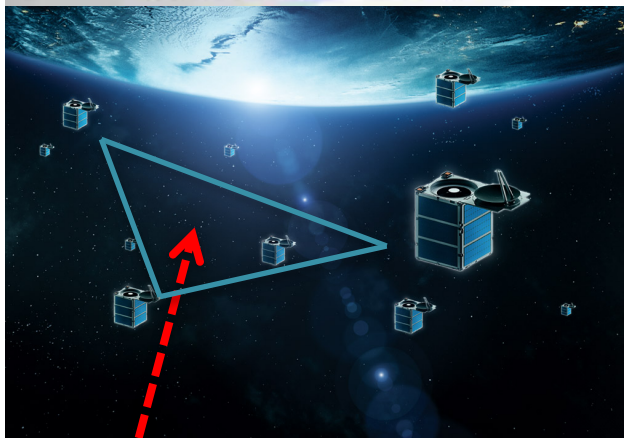
temporal triangulation of signals detected by a **swarm of LEO nano/micro satellites** equipped with:

- keV-Mev scintillators,
- sub μs time resolution
- temporal triangulation

Pros:

- modularity,
- limited cost,
- quick developement





Principles of temporal triangulation

Determination of source position through delays in Time of Arrival (ToA) of an impulsive (variable) signal over 3 (or more) spatially separate detectors

position of the source in the sky:
α, δ (2 parameters, $N_{PAR} = 2$)

$i = 1, \ldots, N_{SATELLITES}$
$j = 1, \ldots, N_{SATELLITES}$

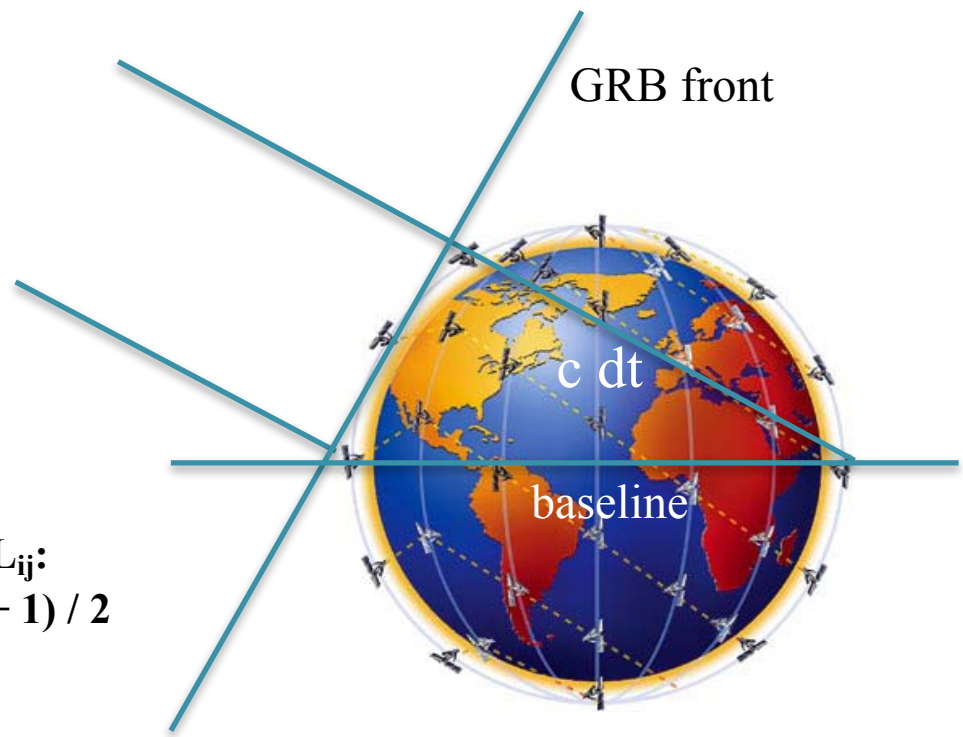
$DEL_{ij} = ToA(i) - ToA(j)$

$DEL_{ij} = - DEL_{ji}$; $DEL_{ii} = - DEL_{jj} = 0$

Number of (non trivial) different DEL_{ij}:
$N_{DELAYS} = N_{SATELLITES} \times (N_{SATELLITES} - 1) / 2$

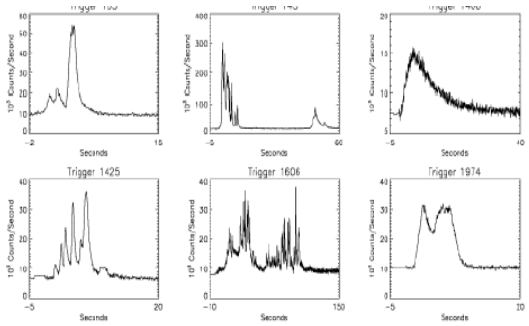
Number of independent DEL_{ij}:
$N_{IND} = N_{SATELLITES} - 1$

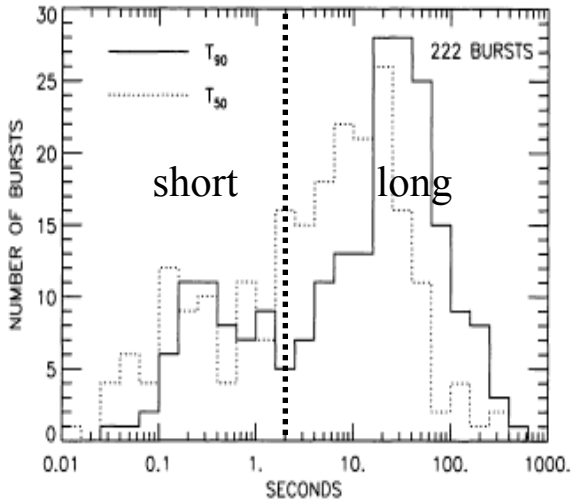
Accuracy in determining α and δ with $N_{SATELLITES}$:
$\sigma_\alpha \approx \sigma_\delta = c\ \sigma_{ToA}/\langle baseline \rangle \times (N_{IND} - N_{PAR} + 1)^{-1/2}$

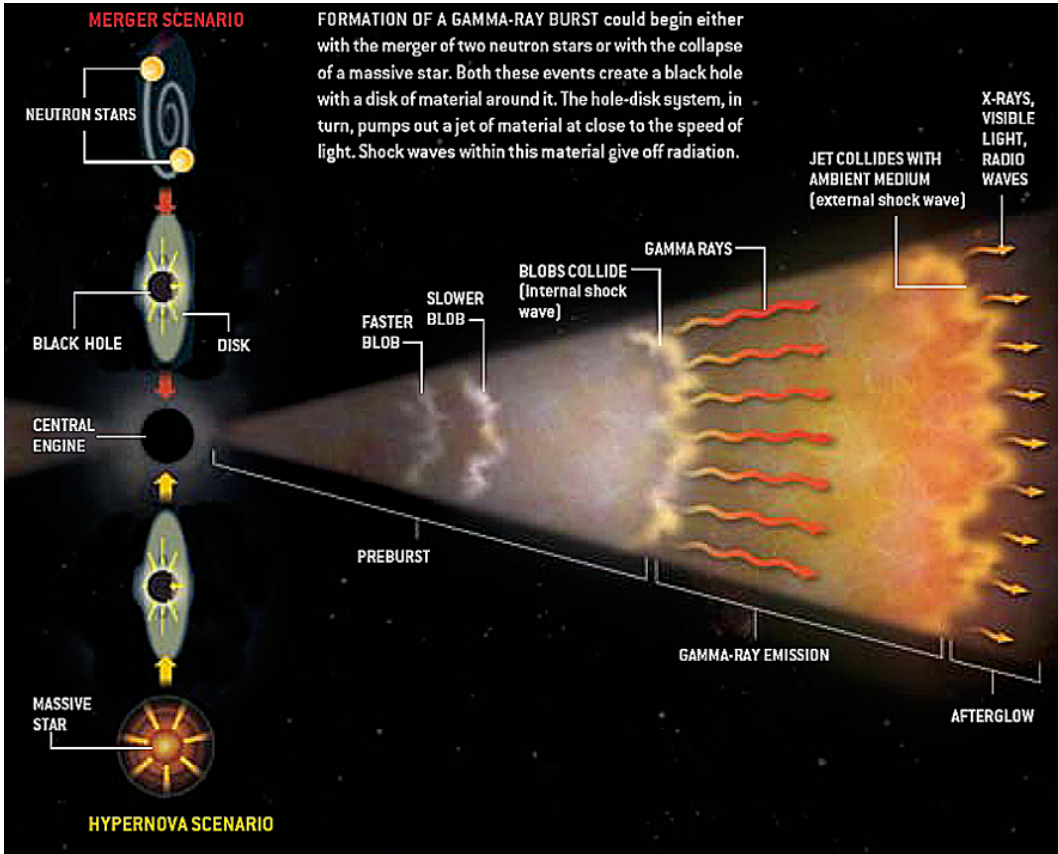


The Gamma-Ray Burst phenomenon

- sudden and unpredictable bursts of hard-X / soft gamma rays with huge flux
- most of the flux detected from 10−20 keV up to 1−2 MeV,
- fluences for very bright GRB (about 3/yr) 25 counts/cm^2/s (GRB 130427A 160 counts/cm^2/s)
- bimodal distribution of duration (0.1−1.0 s & 10.0−100.0 s)
- measured rate (by an all-sky experiment on a LEO satellite): ~0.8/day (estimated true rate ~2/ day)
- evidence of submillisecond structures







The Gamma-Ray Burst phenomenon

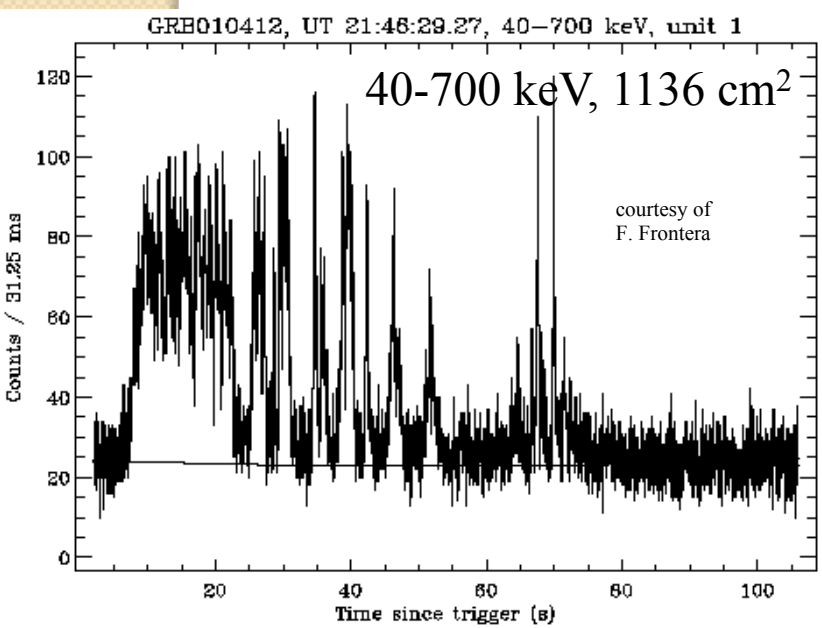
Millisecond variability (minimum variability time-scale, MacLachlan et al. 2013)

Short: 3 msec (wavelet techniques)

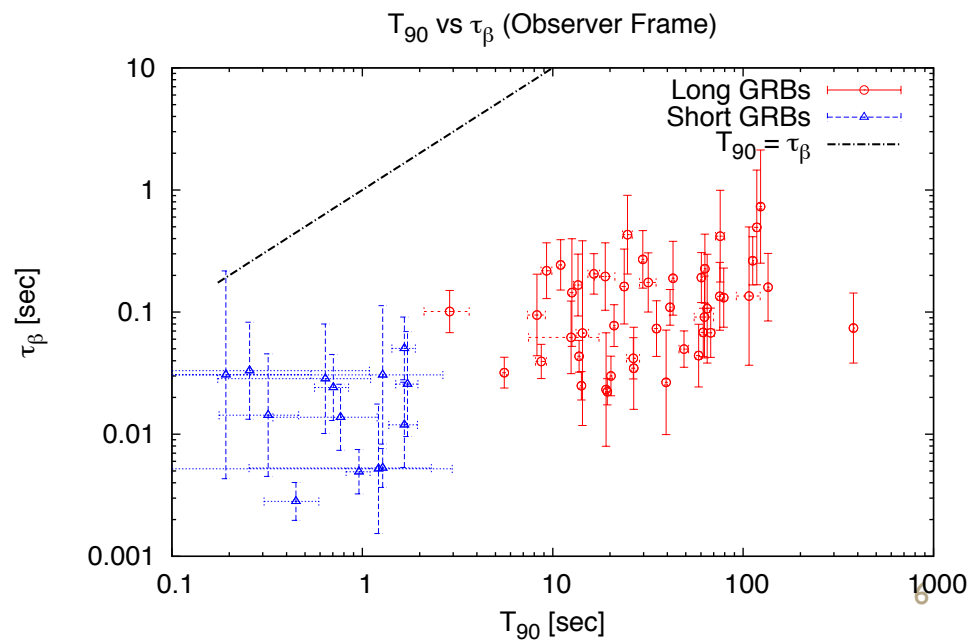
Long: 30 msec (wavelet techniques)

Internal shock model (ultarelativistic, $\gamma \approx 10^2 \div 10^3$, colliding shocks)

BeppoSAX GRBM data



Fermi GBM (8 keV - 40 MeV)



Number of GRB and Fluxes

Short GRBs:

Duration: 0.2 sec,

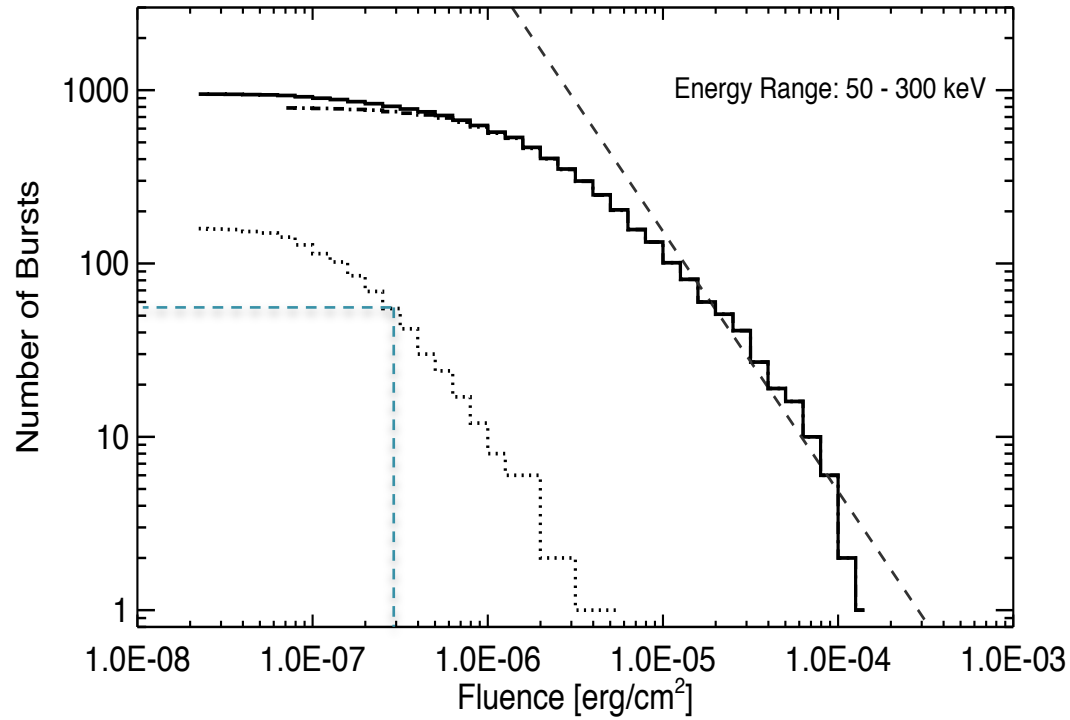
Counts (50-300 MeV): 8 c/cm^2/s

Averaged photon energy: (Emax x Emin)$^{1/2}$ = 122 keV

Fluence: 0.2 x 8 x 122 keV/cm^2 = 3 x 10^{-7} erg/cm^2

Fermi GBM - 4-years data

14 Short GRB burst per year with count rate > 8 c/s



Simulations of a bright Short GRB (50 – 300 keV)

Background: 0.43 c/s/cm^2/steradians

Background for 2 steradians FOV: 0.86 c/cm^2/s

Proton fluxes in LEO (580 km): 0.165 c/cm^3/s

Activation in equatorial LEO (580 km): $\leq$ 0.3 c/cm^3/s (not included)

Burst duration: 0.2 sec

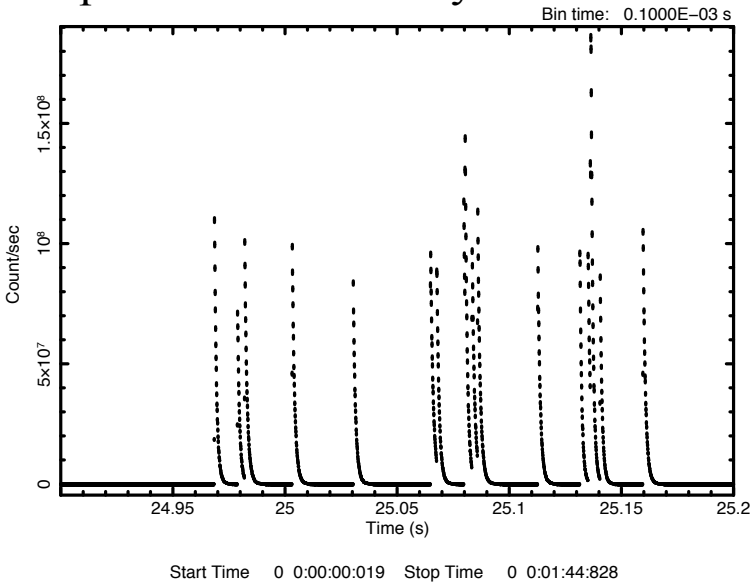
Source count rate: 7.875 ph/cm^2/s

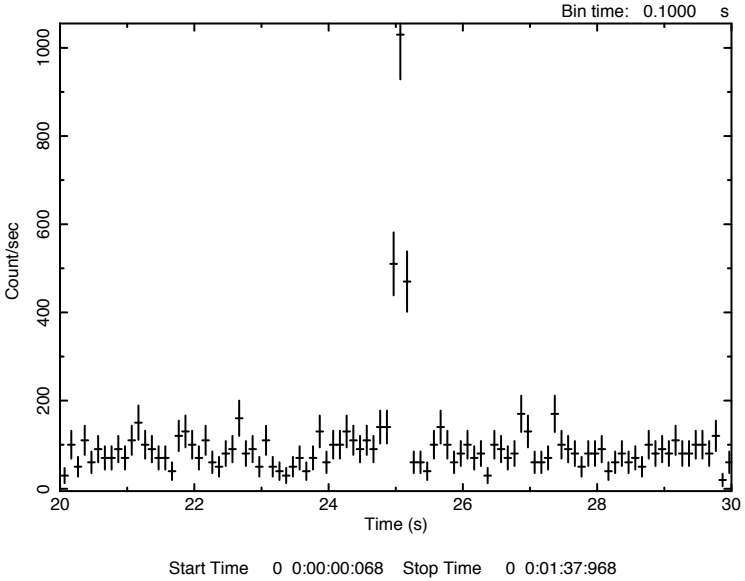
Total number of photons: 178

Exponential shot rate: 100 shot/s

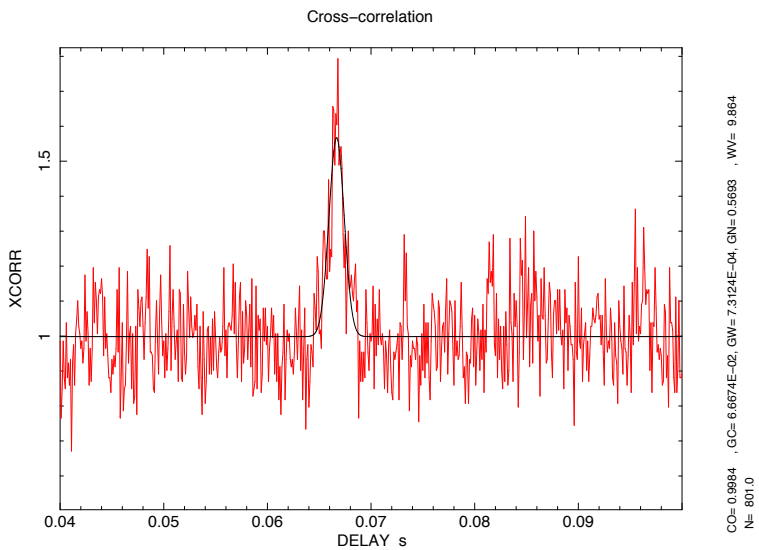
Exponential shot decay time: 1 msec

Band 50-300 keV
Effective area: 100 cm^2





Delays from cross-correlation analysis

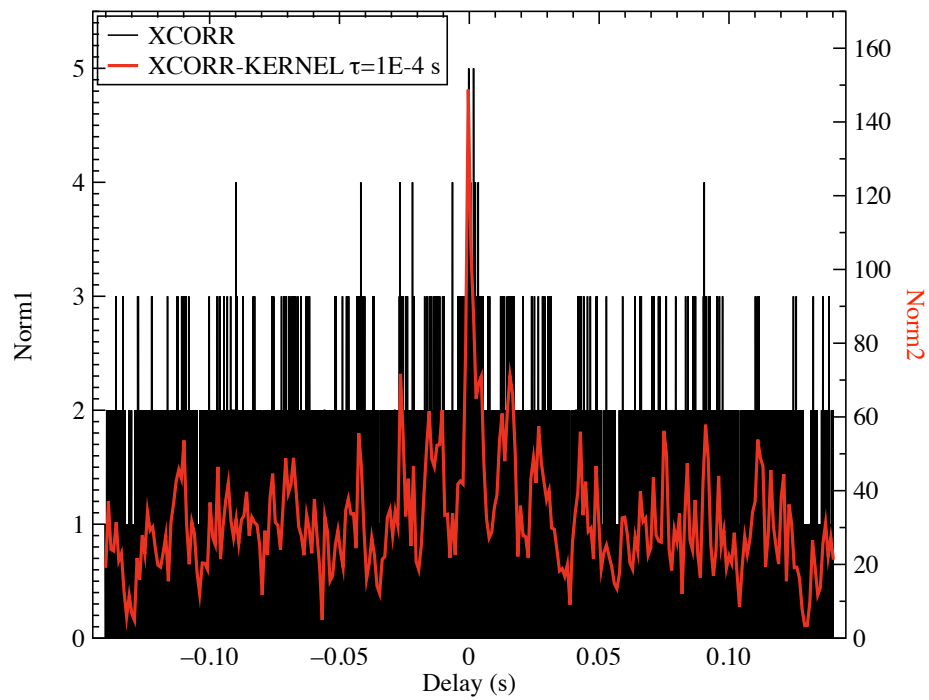


Temporal resolution: 200 μs
Standard CCF (red)

2 Lightcurves of a short GRB
$\Delta t = 0.25$ s
$A = 100$ cm²
$\varphi_{GRB} = 8$ phot/s/cm²
$\varphi_{BCK} = 0.8$ phot/s/cm²
$N_{PHOT} = 220$
$\lambda_{SHOT} = 100$ shot/s
$\tau_{SHOT} = 1$ ms
$\tau_{KERN} = 0.1$ ms

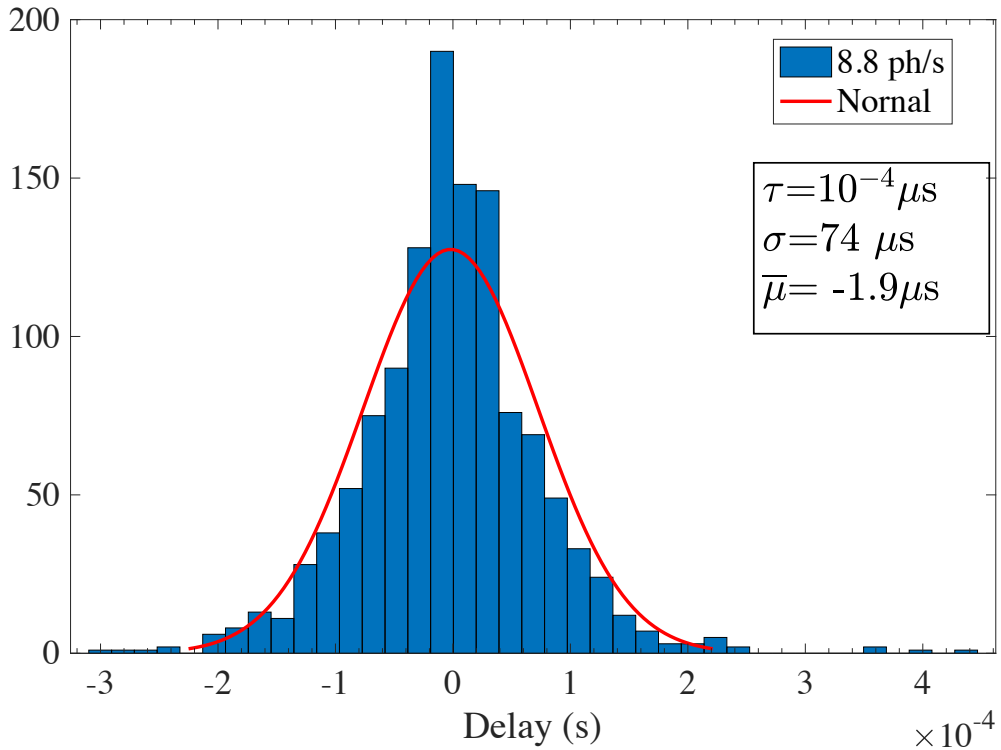
Temporal resolution: 1 μs
Standard CCF (black)
Kernel-modified CCF (red)

2 Lightcurves of a short GRB
$\Delta t = 0.25$ s
$A = 100$ cm²
$\varphi_{GRB} = 8$ phot/s/cm²
$\varphi_{BCK} = 0.8$ phot/s/cm²
$N_{PHOT} = 220$
$\lambda_{SHOT} = 100$ shot/s
$\tau_{SHOT} = 1$ ms
$\tau_{KERN} = 0.1$ ms



Delays from cross-correlation analysis

Histogram of maxima of Kernel-modified CCF (1200 simulations of 2 short GRB)
$\Delta t = 0.25$ s; $\varphi_{GRB} = 8$ phot/s/cm^2; $\varphi_{BCK} = 0.8$ phot/s/cm^2; $\lambda_{SHOT} = 100$ shot/s;
$\tau_{SHOT} = 1$ ms; A = 100 cm^2; $\tau_{KERN} = 0.1$ ms; $N_{PHOT} = 220$; $\sigma_{CCF} = 74$ μs



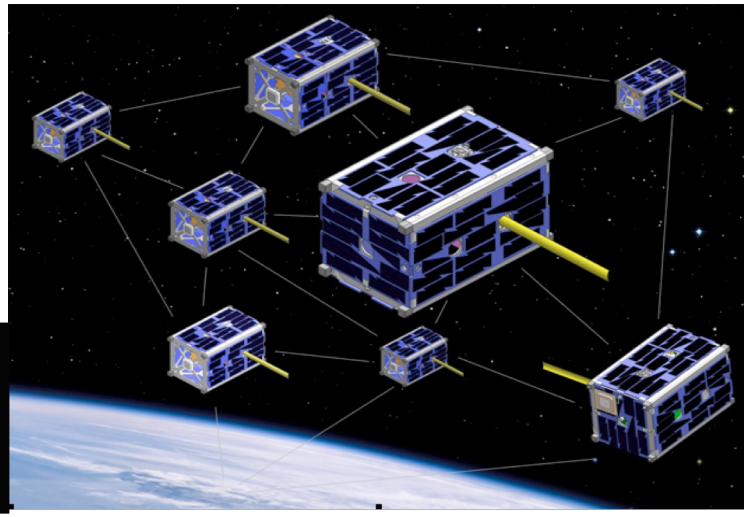
Cross-correlation accuracy:

- 3.0 ÷ 60 μsec (Long and Short GRB with millisecond time variability, 40% of bright)

$$\sigma_{\mathbf{ToA}} = 74\mu\mathrm{s}/\sqrt{\mathbf{N_{phot}/220}}$$

HERMES mission concept: a swarm of nano/micro satellites

Tens/hundreds nano/micro satellites
each equipped with ~300 cm^2 scintillators
(keV – MeV energy band)



HERMES experiment concept: temporal triangulation & increase the effective area

Perform temporal triangulation to derive positions of bright, transient, high-energy events

When a cross-correlation successful → add signal from different units
Total Area ~ 100 x (100-300 cm^2) ~ 1-3 m^2

→ First possibility to study GRB time structure on very short time scale (sub-μs ÷ ms) with excellent statistics

Determination of source position through delays

Accuracy in determining α and δ with $N_{SATELLITES}$:

$\sigma_\alpha \approx \sigma_\delta = c\ \sigma_{ToA}/\langle baseline\rangle \times (N_{SATELLITES} - 3)^{-1/2}$

$\sigma_{ToA} = 236\ \mu s/\ (N_{PHOT}/220)^{1/2}$

maximum baseline = 2 × (R_{EARTH} + $H_{SATELLITE}$) = 2 × (6371 + 580) km

<baseline> = maximum baseline / 2

N_{PHOT}(Bright Long GRB) ≈ 100 × N_{PHOT}(Bright Short GRB)

A = 100 cm² ➔ N_{PHOT}(bright short GRB) ≈ 220

Bright Short GRB

$\sigma_\alpha \approx \sigma_\delta = 35$ **arcmin (3 satellites)**

$\sigma_\alpha \approx \sigma_\delta = 5.1$ **arcmin (50 satellites)**

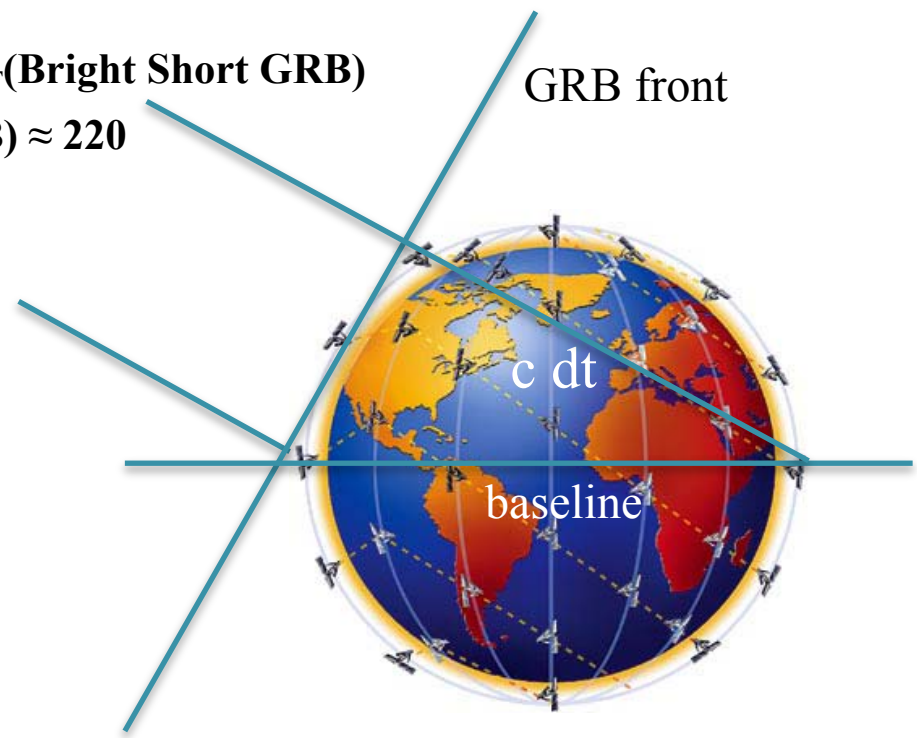
$\sigma_\alpha \approx \sigma_\delta = 3.5$ **arcmin (100 satellites)**

Bright Long GRB

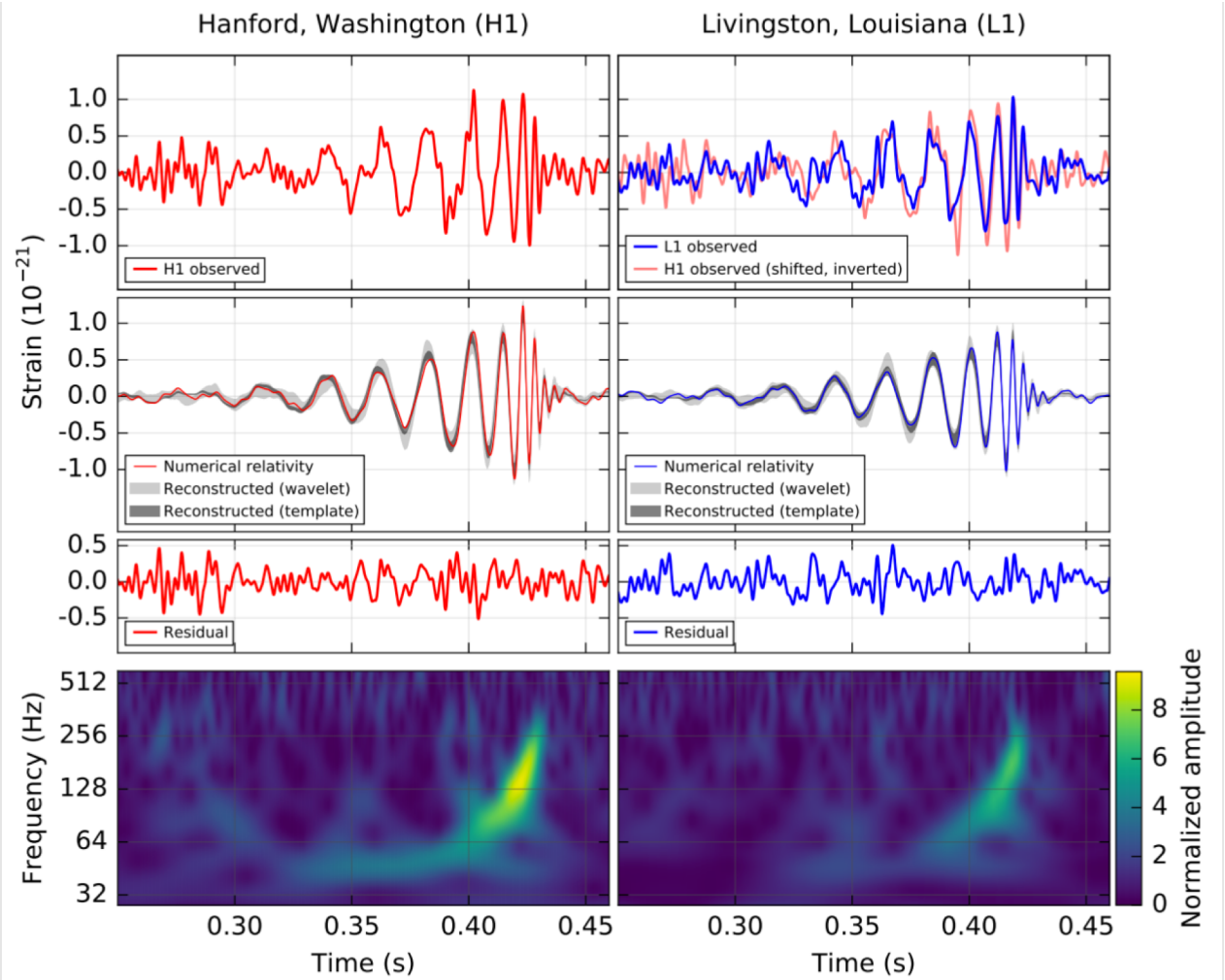
$\sigma_\alpha \approx \sigma_\delta = 3.2$ **arcminute (3 satellites)**

$\sigma_\alpha \approx \sigma_\delta = 32$ **arcsec (50 satellites)**

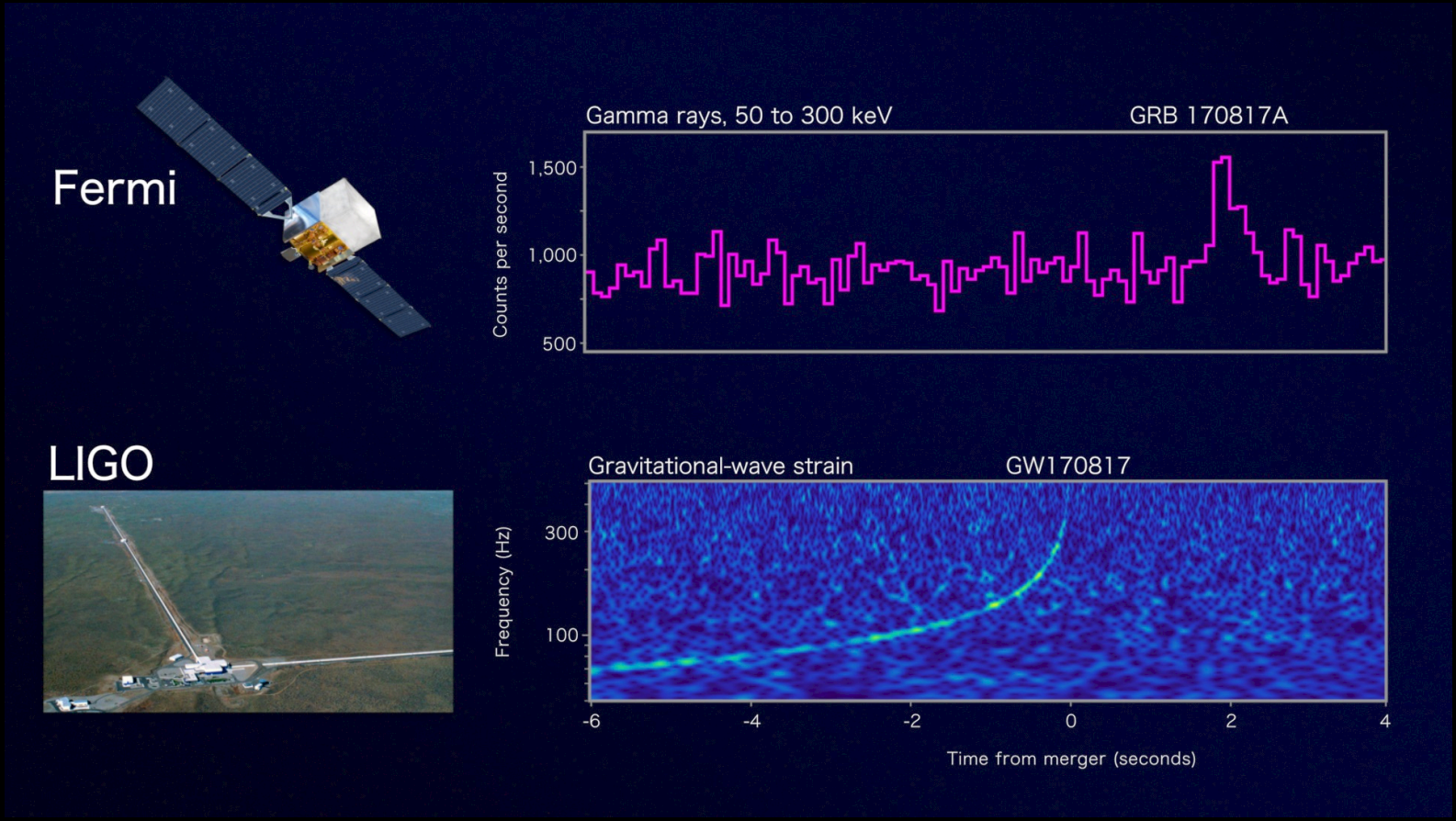
$\sigma_\alpha \approx \sigma_\delta = 22$ **arcsec (100 satellites)**



Gravitational Waves detected by LIGO on September the 14th 2015 CHIRP shape and evolution



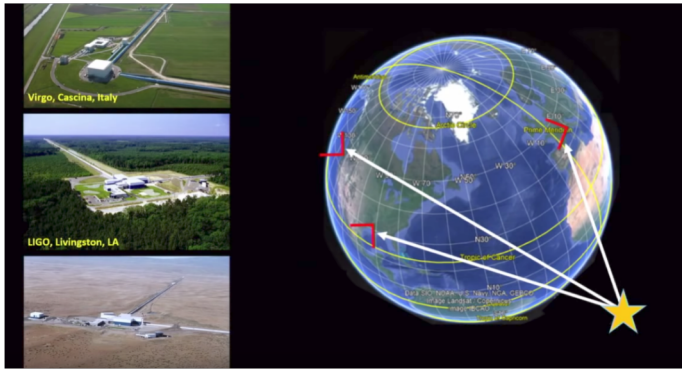
GW 170817 NS-NS coalescence: EM counterpart GRB170817



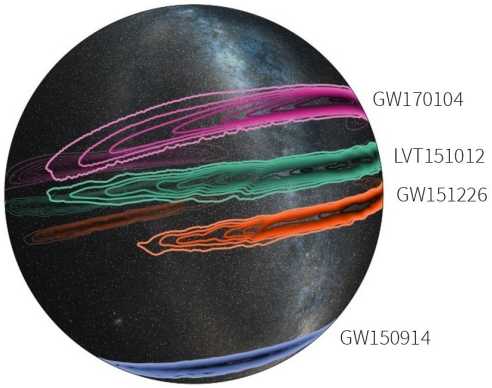
GW Triangulation & EM conterparts (Fermi GBM,INTEGRAL)

Large volumes to survey → too many candidates

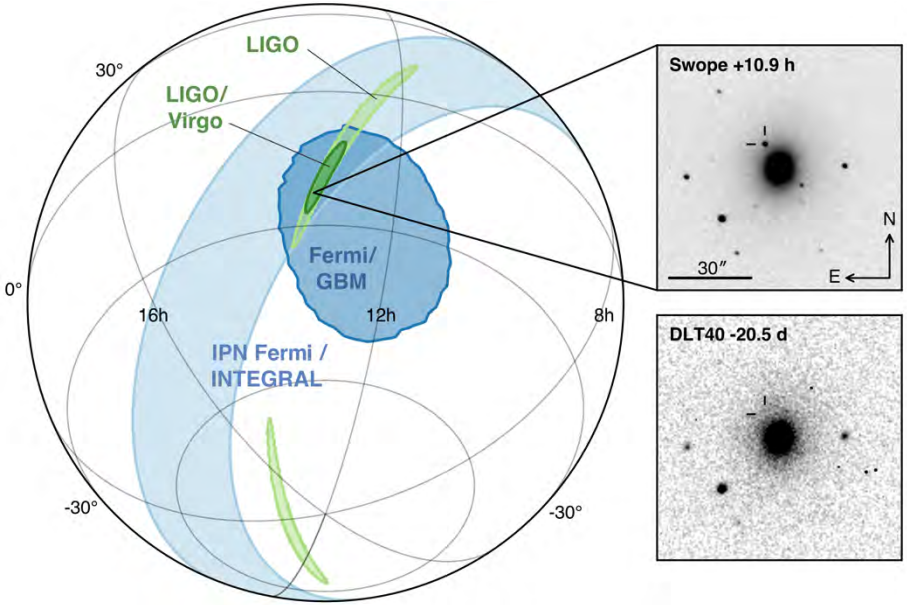
Successful strategy:
a) all sky continuous observations of HE transients
→ the probability of obsering an uncorrelated HE simultaneous event is negligible
b) improve the accuracy of source position
→ reduce the number of candidates



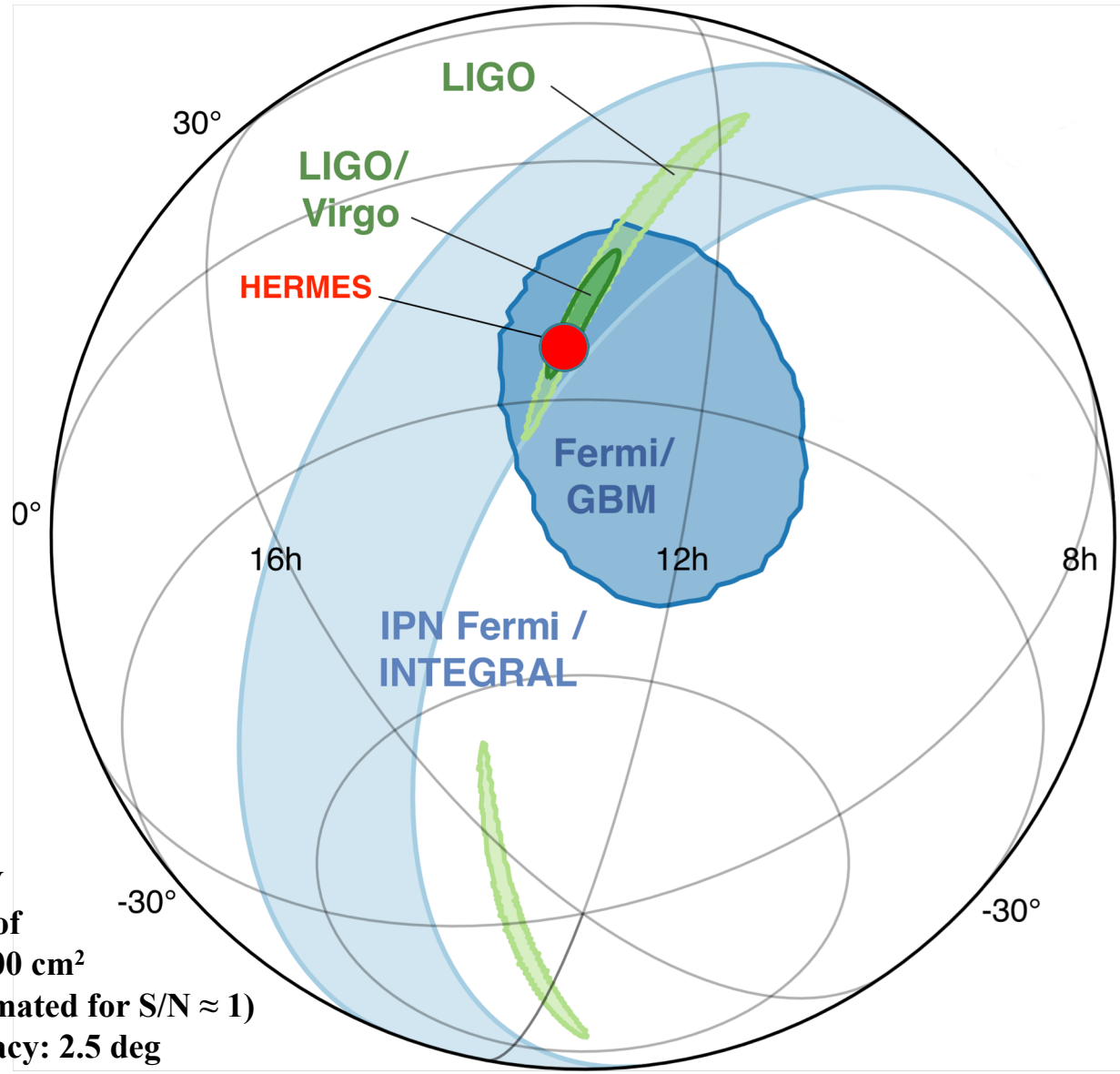
LIGO



LIGO + Virgo



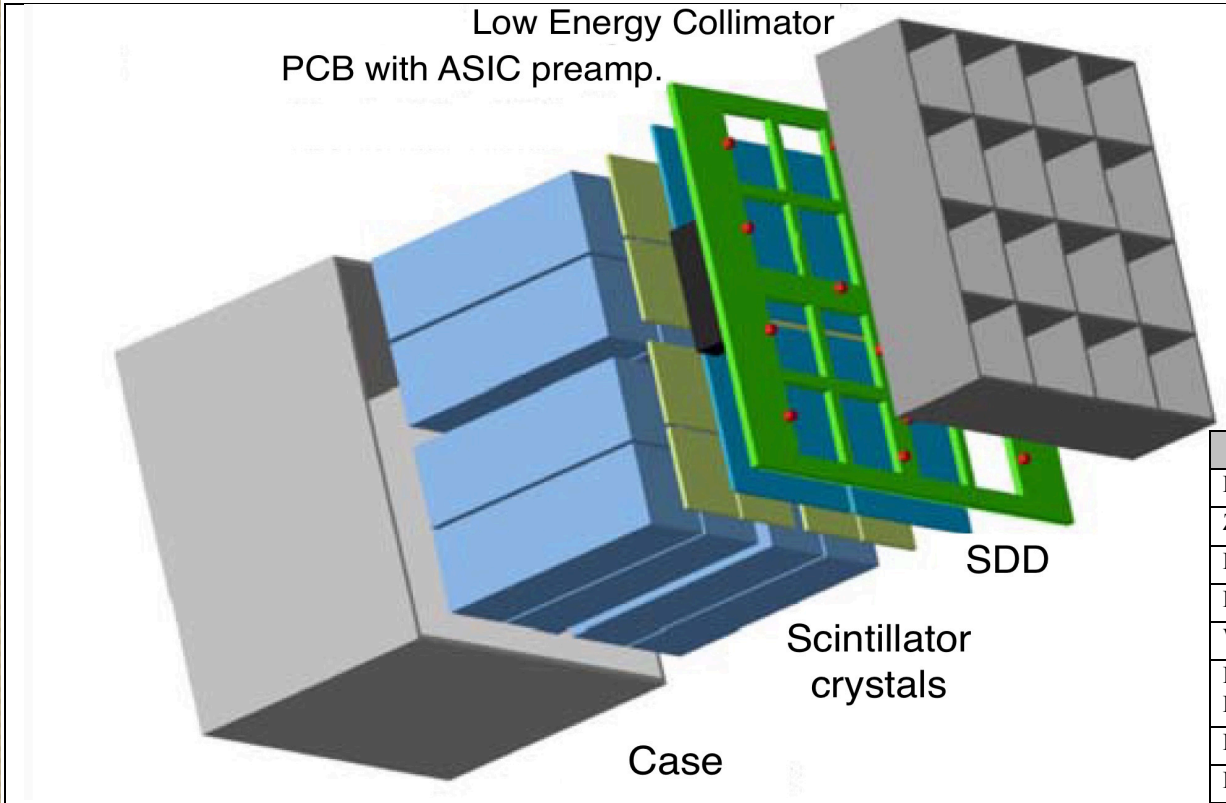
GW Triangulation & EM conterparts (Fermi GBM, INTEGRAL, HERMES Pathfinder)



band 50-300 keV
3 satellites each of
effective area: 100 cm^2
$\sigma_{ToA} \approx 1$ ms (estimated for S/N ≈ 1)
positional accuracy: 2.5 deg

HERMES Pathfinder Photon Detector Unit (PDU) and Modular Detector Unit (MDU = 4 PDU)

- Scintillator Crystal size: 2x2x1 cm
- Crystal type: GAGG (Gadolinium Aluminium Gallium Garnet)
- Photo detector: SDD (segmented: 4 SSD 1x1 cm)
- Energy range: 4 keV – few Mev with GAGG
- Energy resolution: ~ 15% at 30 keV
- Effective area: ~ 4 cm^2
- FOV: 2 steradians at low energies
- Temporal resolution: 0.01 – 0.1 μs



GAGG characteristics	
Density (g/cm3)	6.63
Zeff	52
Decay time (nsec)	92f – 174s
Photons/keV	56
Wavelength peak (nm)	520
Energy resolution (662 keV FWHM) (%)	5–6
Hygroscopic	No
Radioactive	No

Figure 1 Schematic view of one HERMES modular detector unit (MDU), made by four PDUs.

HERMES Pathfinder Detectors (3U nanosatellites)

Detectors on board of each nano satellite (3U)

- 16 PDU on each nanosatellite
- 2×2 array of 4 MDU (modular detector unit made by 4 PDUs) 64 cm^2 effective area per array

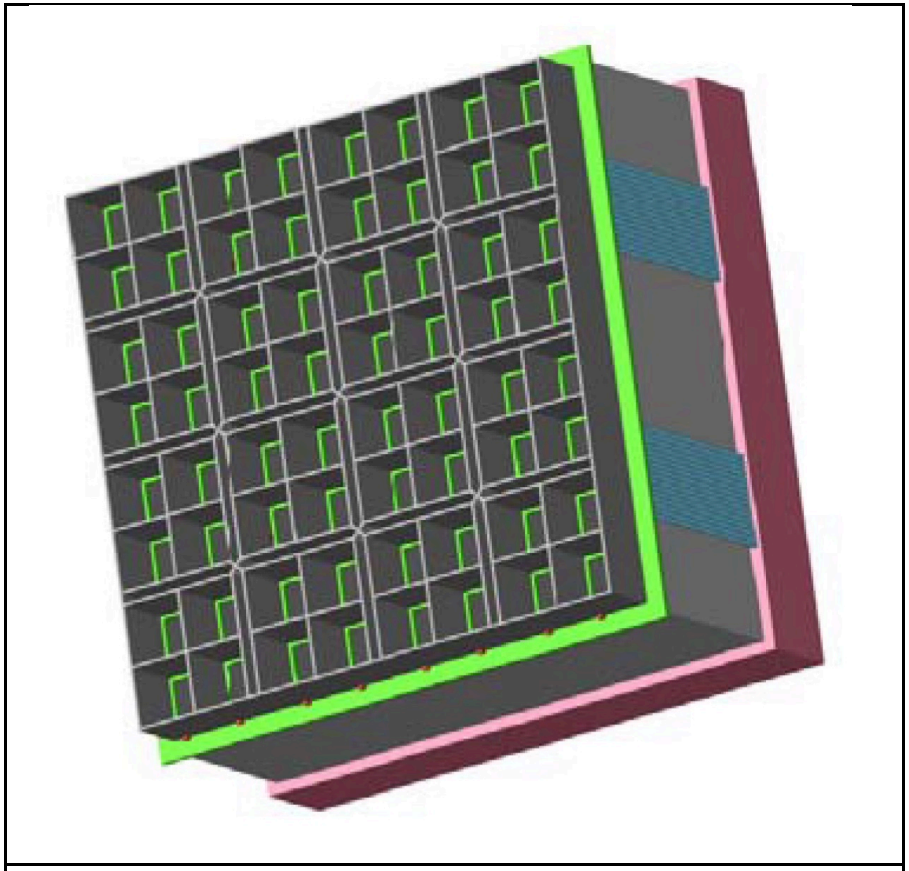


Figure 2: Schematic view of the payload

- Gyroscope Stability on 3 axes
- Collimators ≈ 2 steradians

On board Systems:

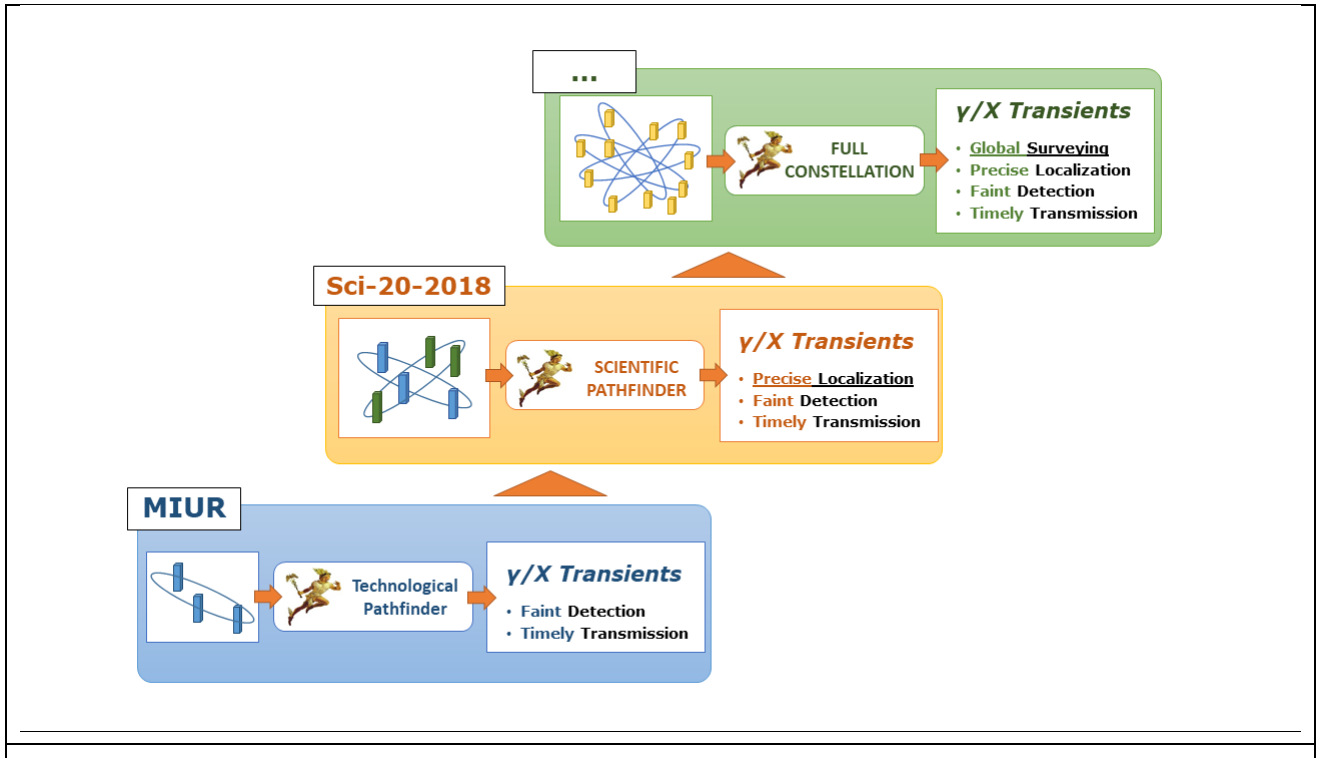
Data recording:

- continuous on temporary buffer
- trigger capability for data recording
- continuous download of data (VHF) for monitoring of known bright sources

Data download:

- VHF data transmission
- IRIDIUM constellation for data transmission

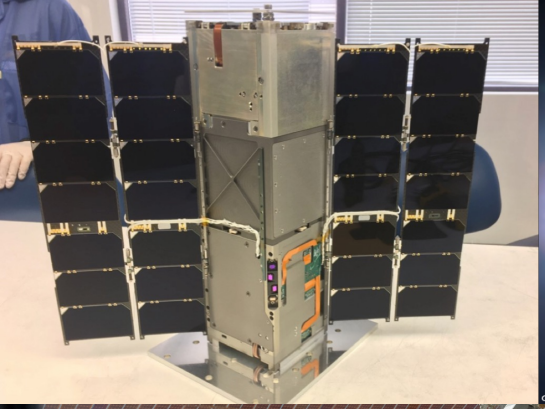
HERMES project development – incremental strategy

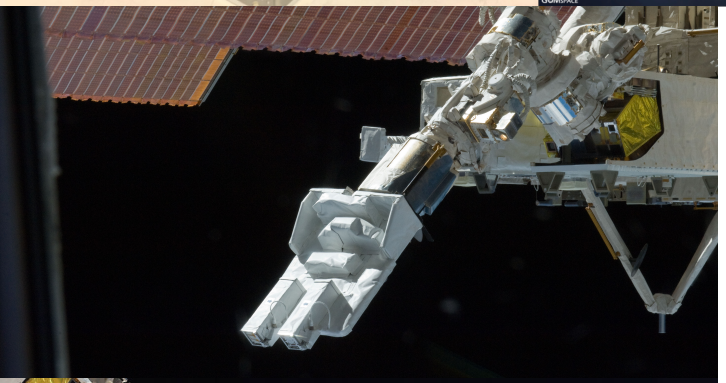


Funding status at 2018, July the 17th

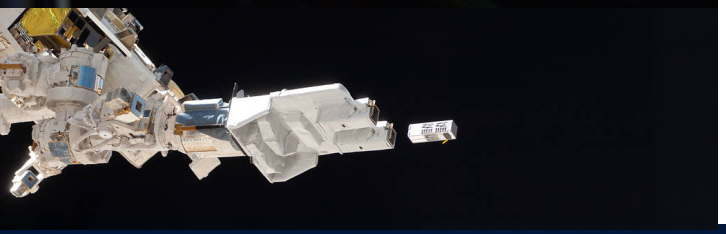
ASI (Italian Space Agency) – 23/12/2016:	€ 500,000
MIUR (Italian Ministry of University and Research) and ASI – 29/11/2017:	€ 1,650,915 (MIUR)
	€ 815,085 (ASI)
EU Horizon 2020 – Call: H2020-SPACE-2018-2020 – 17/07/2018:	€ 3,318,450
ASI (Italian Space Agency) – internal funding 05/02/2019	€ 1,900,000
Total Funding (at 14/02/2019):	**€ 8,184,450**

The HERMES Project: performances of subsequent missions





JEM Small Satellites Orbital Deployer (JSSOD) of JAXA on ISS



Launch of Cubesat from JSODD

Startup OneWeb
640 nanosat in LEO
production:
15 nanosat/week

Starlink (Space X)
12,000 satellites by mid-2020

Pathfinder + Scientific:

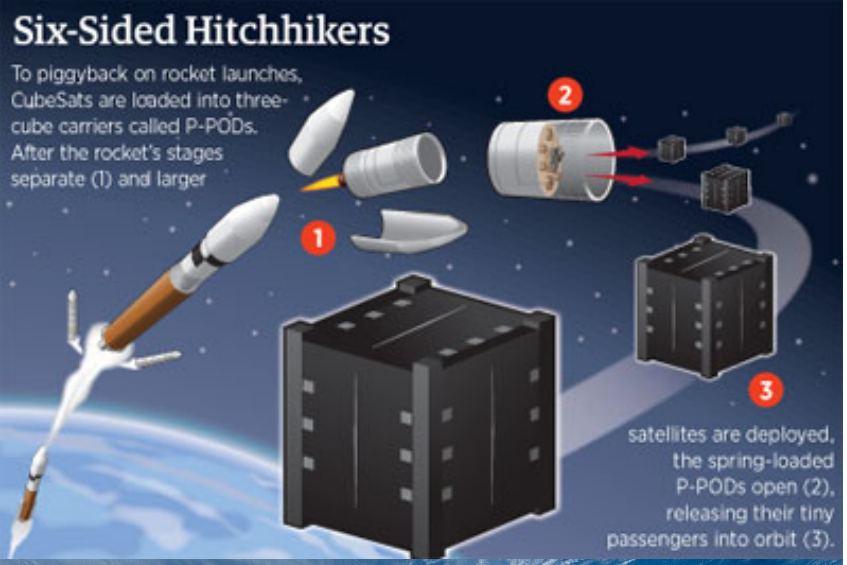
- 8/10 3U Cubesats piggyback of bigger satellites launched from ISS
- 1/2 detectors located on ISS
- ~ 10 arcminutes position of ~ 35 Short 250 Long GRB/year

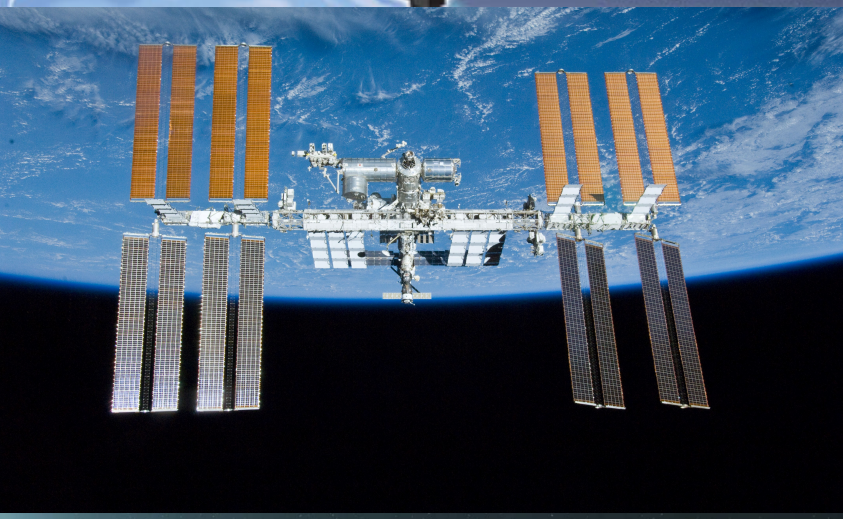
Full configuration:

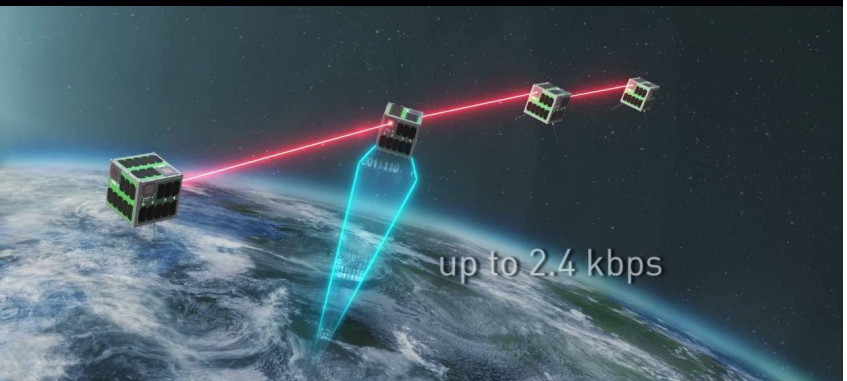
- ~50-100 3/12U Cubesats
- ~10 arcsec position of ~ 75 Short 500 Long GRB/year
- 1-3 m^2 collecting area

Future:

- ~(ten)thousands of detector
- From LEO to HEO, Moon and beyond
- (sub?)arcsec position, best quantum space time tests (see below)







VHF data download from a HERMES satellite

Why HERMES now

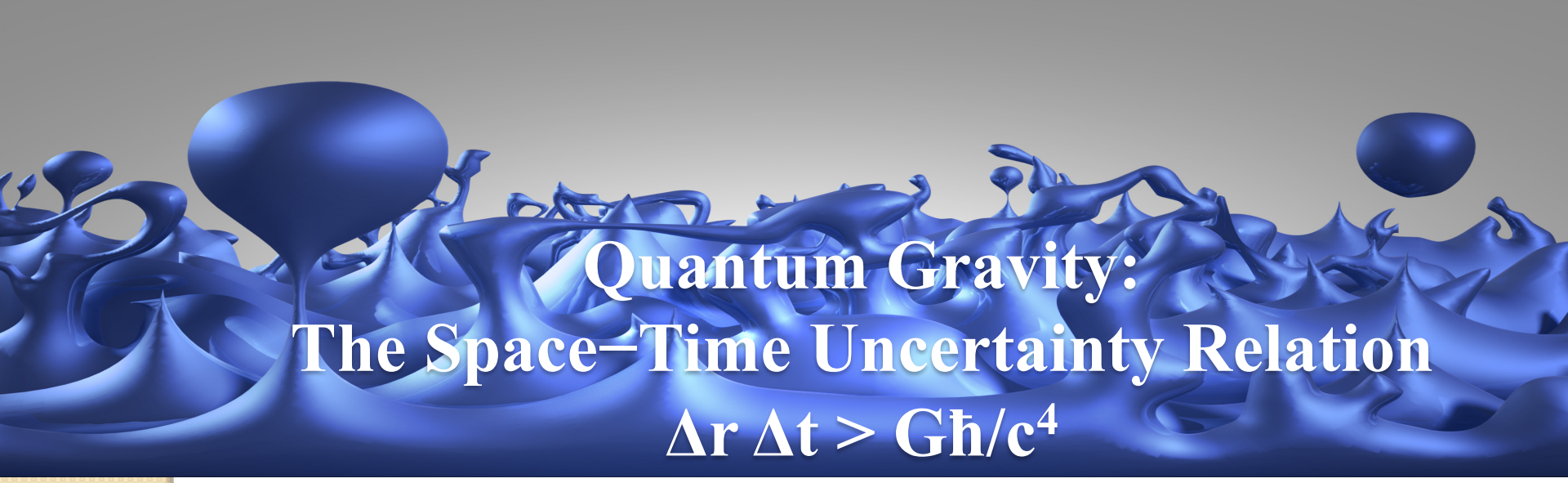
PROS:

- modularity (avoid single point failures, state-of-the-art hardware)
- limited cost (piggyback of bigger satellites, boarded on ISS with cargo refurnishment, off the shelf cheap hardware + in house components)
- quick development (< 5 years to fly first satellites)

Breakthrough scientific case:

- All-Sky Monitor in HE (keV-MeV)
- EM counterparts of GW events
- Study of GRB variability on unprecedented short temporal scale (sub-μs): physics of the inner engine
- First dedicated experiment of Quantum Gravity (see below)

HermeS



Quantum Gravity: The Space–Time Uncertainty Relation $\Delta r\, \Delta t > G\hbar/c^4$

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Quantum clock: A critical discussion on spacetime

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We critically discuss the measure of very short time intervals. By means of a *Gedankenexperiment*, w describe an ideal clock based on the occurrence of completely random events. Many previous though experiments have suggested fundamental Planck-scale limits on measurements of distance and time. Her we present a new type of thought experiment, based on a different type of clock, that provide furthe support for the existence of such limits. We show that the minimum time interval Δt that this clock ca measure scales as the inverse of its size Δr. This implies an uncertainty relation between space and time $\Delta r \Delta t > G\hbar/c^4$, where G, $\hbar$, and c are the gravitational constant, the reduced Planck constant, and th speed of light, respectively. We outline and briefly discuss the implications of this uncertainty conjecture

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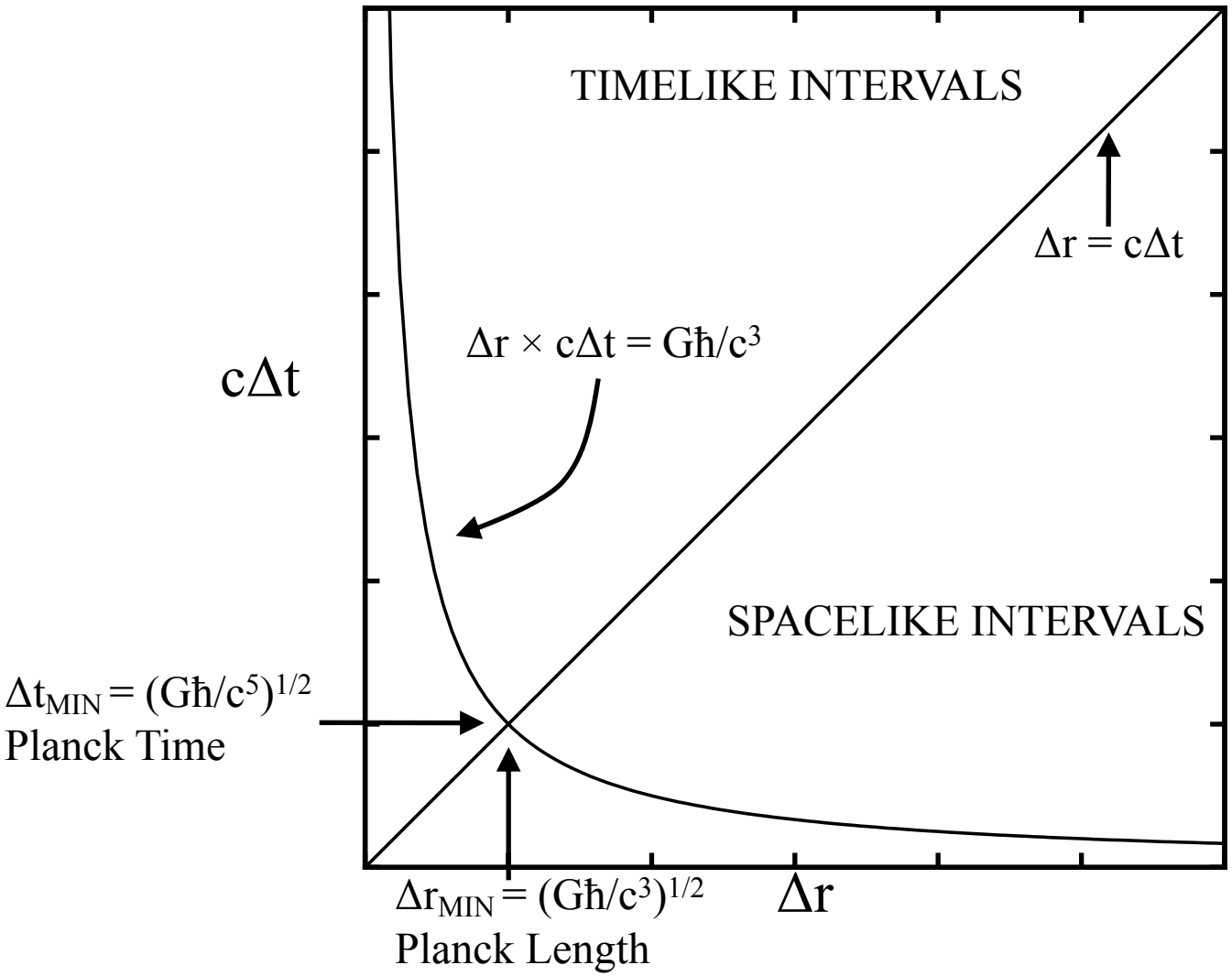
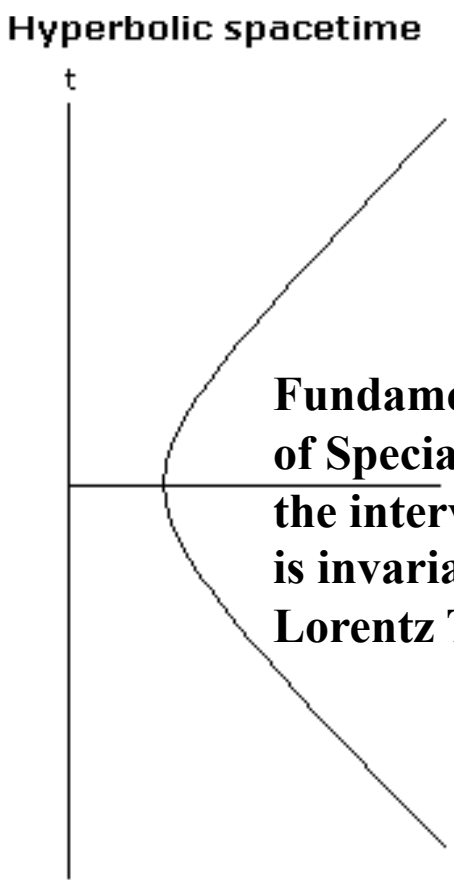
The Uncertainty Relation $\Delta r\,\Delta t > G\hbar/c^4$ and the space-time diagram for the intervals



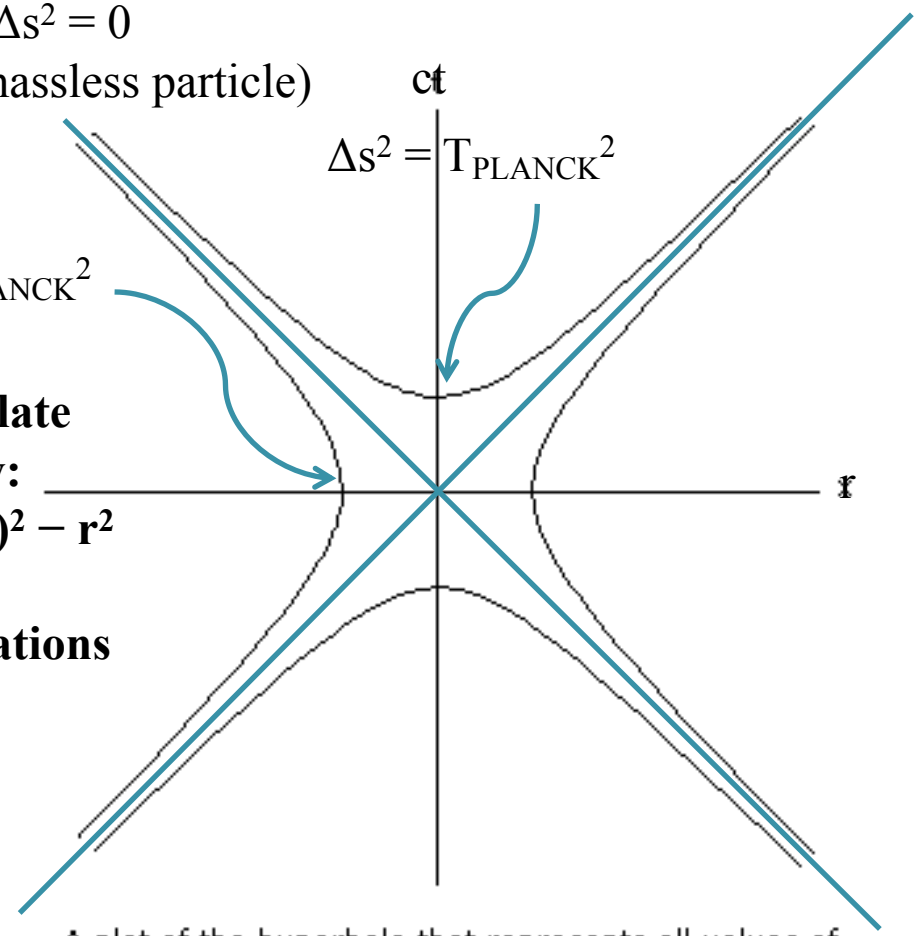
Geometrical Structure of Space−Time
Minkowski metric: preserving Lorentz Invariance

$\Delta s^2 = 0$

(light − massless particle)



The general form of a hyperbola

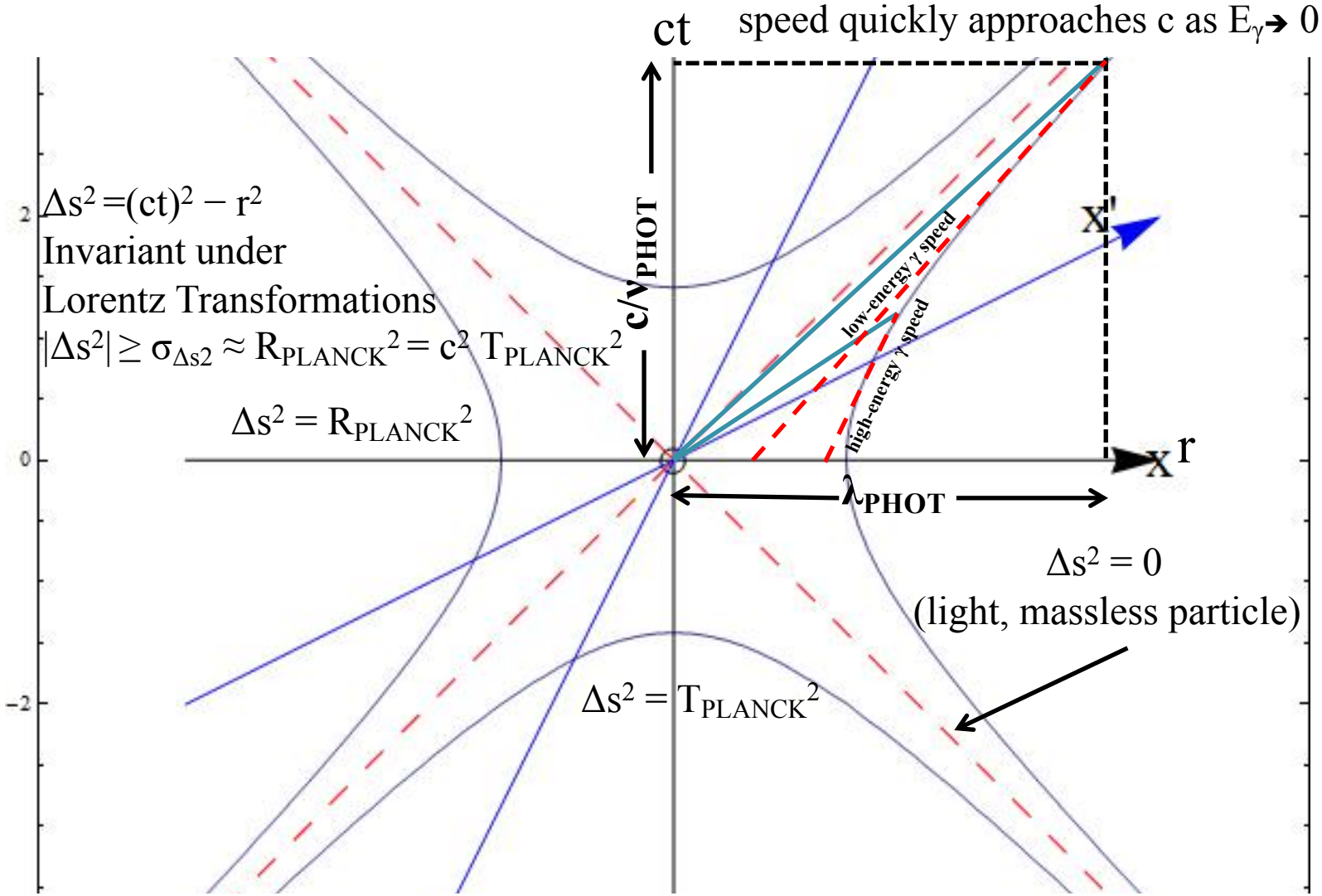


A plot of the hyperbola that represents all values of t and x that observers might measure for a given spacetime interval.

Fundamental Postulate of Special Relativity: the interval $\Delta s^2 = (ct)^2 - r^2$ is invariant under Lorentz Transformations

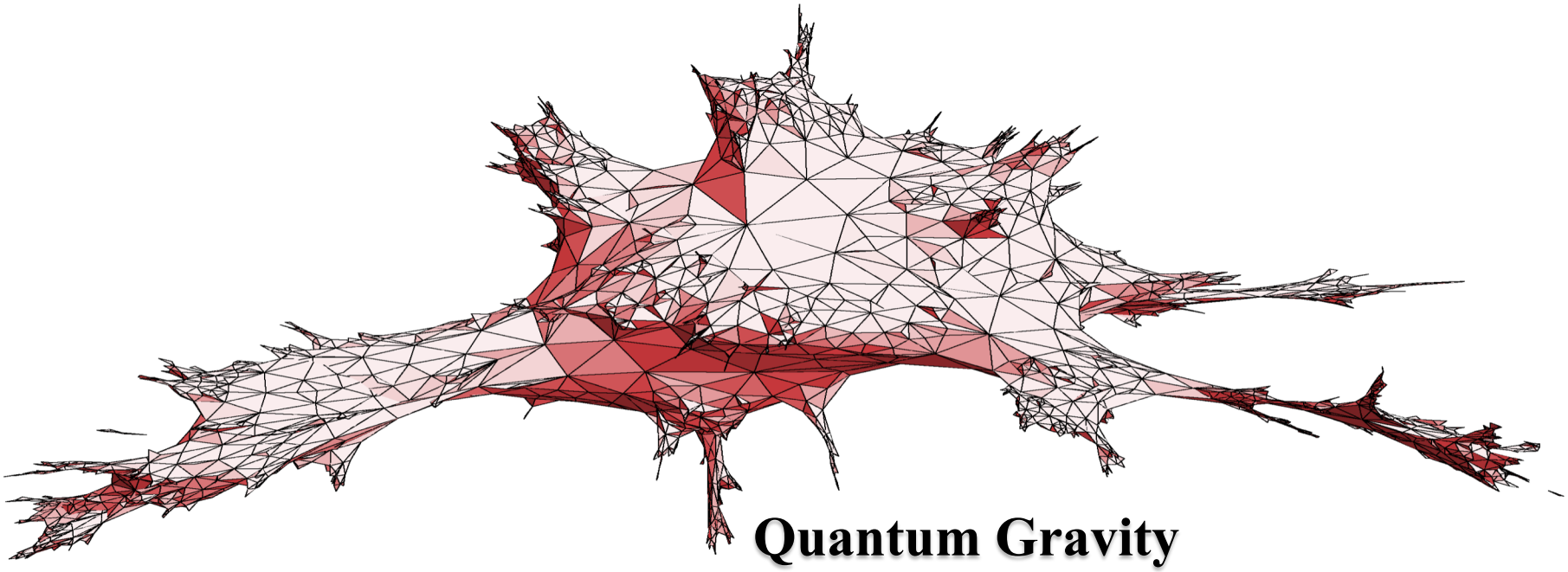
The new Uncertainty Relation and the Minkowski metric: preserving Lorentz Invariance

speed quickly approaches c as $E_\gamma \rightarrow 0$

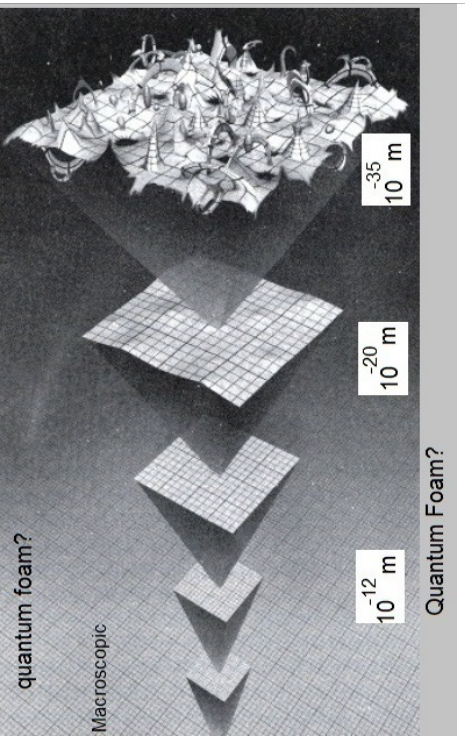


Massive Photons? (Proca action)

Massless Particles ⟶ Lorentz Invariance, not *vice versa!*



Quantum Gravity
(Massive Photons or Lorentz Invariance Violation)



MP or LIV predictions:

$|v_{phot}/c - 1| \approx \xi\, E_{phot}/(M_{QG}\, c^2)^n$

$\xi \approx 1$

n = 1,2 (first or second order corrections)

$M_{QG} = \zeta\, m_{PLANCK} \quad (\zeta \approx 1)$

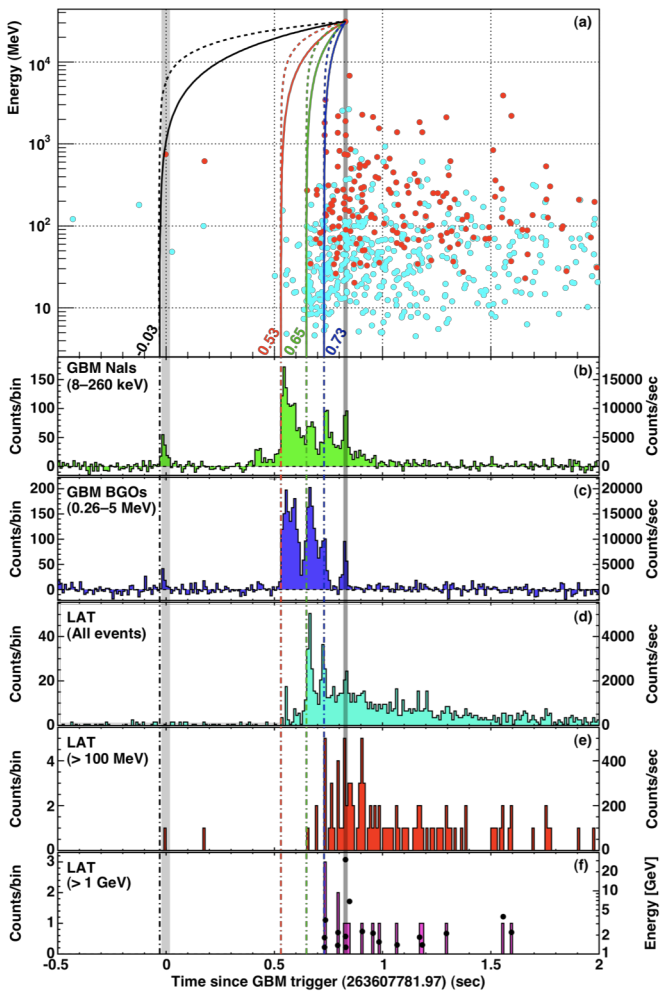
$m_{PLANCK} = (hc/2\pi G)^{1/2} = 21.8\ 10^{-6}$ g

Implications for travel time of photons:

$$\Delta t_{MP/LIV} = \xi\, (D_{TRAV}/c)\, [\Delta E_{phot}/(M_{QG}\, c^2)]^n$$

$$D_{TRAV}(z)=(c/H_0)\int_0^z d\beta\, (1+\beta)/[\Omega_\Lambda+(1+\beta)^3\, \Omega_M]^{1/2}$$

GRB & Lorentz Invariance Violation (LIV) with Fermi



Fermi GBM & LAT detection of short ($\Delta T<1$ s) GRB 090510
$z = 0.903(3)$, $d = 1.8 \times 10^{28}$ cm
($\Omega_\Lambda = 0.73$, $\Omega_M = 0.27$, $h = 0.71$)
(Abdo et al. 2009)

"Cleanest" constraints based on one photon detected at 31 GeV
$\Delta t_{31Gev} \leq 859$ ms (+30 ms because GRB started 30 ms before 0)
$\delta t/\delta E \leq 30$ ms/GeV (35 Mev – 31 GeV)

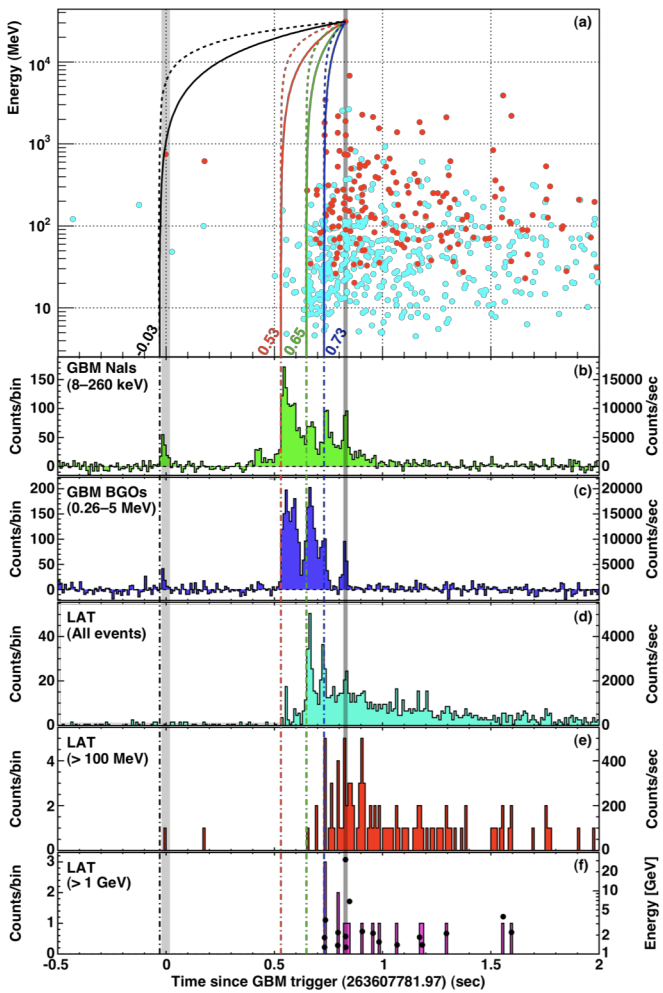
LIV predictions:
Relative Locality Models (Freidel, Smolin 2011): $\xi = ½$; n=1

Data of GRB 090510 imply:
$M_{QG} \geq 0.595\ m_{PLANCK}$ ($\Delta t_{31Gev} \leq 859 + 30$ ms; $E_{ph} \geq 28$ GeV)
$M_{QG} \geq 0.610\ m_{PLANCK}$ ($\delta t/\delta E \leq 30$ ms/GeV)

Caveats, assumptions:
i) photon at 31 GeV emitted after $t_{START\ GRB} = -30$ ms (not before)
ii) physical delays in emission process (e.g. comptonization) not considered

Solution to effectively probe SpaceTime structure:
cross-correlation of GRB lightcurves at different (close) energies

GRB & Lorentz Invariance Violation (LIV) with Fermi



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Solution to effectively probe SpaceTime structure:
cross-correlation of GRB lightcurves at different (close) energies

GRB & Lorentz Invariance Violation (LIV) with Fermi

Robust Constraint on Lorentz Violation Using *Fermi*-LAT Gamma-Ray Burst Data

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Abstract

Models of quantum gravity suggest that the vacuum should be regarded as a medium with quantum structure that may have non-trivial effects on photon propagation, including the violation of Lorentz invariance. *Fermi* Large Area Telescope (LAT) observations of gamma-ray bursts (GRBs) are sensitive probes of Lorentz invariance, via studies of energy-dependent timing shifts in their rapidly-varying photon emissions. In this paper we analyze the *Fermi*-LAT measurements of high-energy gamma rays from GRBs with known redshifts, allowing for the possibility of energy-dependent variations in emission times at the sources as well as a possible non-trivial refractive index *in vacuo* for photons. We use statistical estimators based on the irregularity, kurtosis and skewness of bursts that are relatively bright in the 100 MeV to multi-GeV energy band to constrain possible dispersion effects during propagation. We find that the energy scale characterizing a linear energy dependence of the refractive index should exceed a few $\times 10^{17}$ GeV, and we estimate the sensitivity attainable with additional future sources to be detected by *Fermi*-LAT.

$$M_{QG} = \zeta\, m_{PLANCK}$$

$$\zeta \geq 27$$

Conclusions:

index for photons. Depending on the method of consolidation of the results for individual sources, we find that the energy scale M_1 characterizing a linear energy dependence of the refractive index should exceed either 8.4×10^{17} GeV or 2.4×10^{17} GeV. We have also made

GRB & Quantum Gravity

$$\Delta t_{MP/LIV} = \xi\,(D_{TRAV}/c)\,[\Delta E_{phot}/(M_{QG}\,c^2)]^n$$

$$D_{TRAV}(z)=(c/H_0)\int_0^z d\beta\,(1+\beta)/[\Omega_\Lambda+(1+\beta)^3\,\Omega_M]^{1/2}$$

$$\frac{dN_E(E)}{dA\,dt} = F \times \begin{cases} \left(\frac{E}{E_B}\right)^{\alpha} \exp\{-(\alpha-\beta)E/E_B\}, & E \le E_B, \\ \left(\frac{E}{E_B}\right)^{\beta} \exp\{-(\alpha-\beta)\}, & E \ge E_B. \end{cases}$$

$$E_{CC\,Short} = 50\mu s/\sqrt{N_{phot}/221}$$

Short GRB – 8.00 (0.86 BCK) c/s $(50 \div 300$ **keV)** $\Delta t = 25$ **s**
$A = 10^4$ **cm**$^2 \rightarrow$ **100 nano – satellites of** $A = 10^2$ **cm**^{2}

Energy band MeV	E_{AVE} MeV	N ($\beta = -2.5$) photons	$E_{CC}(N)$ μs	N ($\beta = -2.0$) photons	$E_{CC}(N)$ μs	ΔT_{LIV} ($\xi = 1.0$, $\zeta = 1.0$) μs z = 0.1	μs z = 0.5	μs z = 1.0	μs z = 3.0
0.005 – 0.025	0.0112	3.80×10^4	3.80	3.02×10^4	4.30	0.04	0.25	0.51	1.42
0.025 – 0.050	0.0353	1.40×10^4	6.20	1.17×10^4	6.90	0.13	0.72	1.46	4.10
0.050 – 0.100	0.0707	1.10×10^4	7.10	9.98×10^3	7.40	0.27	1.43	2.93	8.21
0.100 – 0.300	0.1732	8.98×10^3	7.90	1.00×10^4	7.40	0.66	3.51	7.19	20.10
0.300 – 1.000	0.5477	2.07×10^3	16.40	3.82×10^3	12.00	2.09	11.11	22.72	63.56
1.000 – 2.000	1.4142	2.63×10^2	45.60	8.20×10^2	26.00	5.40	28.68	58.67	164.12
2.000 – 5.000	3.1623	1.07×10^2	71.90	4.92×10^2	33.50	12.07	64.12	131.19	367.00
5.000 – 50.00	15.8114	3.52×10^1	125.40	2.95×10^2	43.30	60.35	320.62	656.00	1834.98

GRB & Quantum Gravity

$$\Delta t_{MP/LIV} = \xi\,(D_{TRAV}/c)\,[\Delta E_{phot}/(M_{QG}\,c^2)]^n$$

$$D_{TRAV}(z)=(c/H_0)\int_0^z d\beta\,(1+\beta)/[\Omega_\Lambda+(1+\beta)^3\,\Omega_M]^{1/2}$$

$$\frac{dN_E(E)}{dA\,dt} = F \times \begin{cases} \left(\frac{E}{E_B}\right)^{\alpha} \exp\{-(\alpha-\beta)E/E_B\}, & E \le E_B, \\ \left(\frac{E}{E_B}\right)^{\beta} \exp\{-(\alpha-\beta)\}, & E \ge E_B. \end{cases}$$

$$E_{CC\,Short} = 50\mu s/\sqrt{N_{phot}/221}$$

Short GRB – 8.00 (0.86 BCK) c/s $(50 \div 300$ **keV)** $\Delta t = 25$ **s**
$A = 4 \times 10^4$ **cm**$^2 \rightarrow$ **400 nano – satellites of** $A = 10^2$ **cm**^{2}

Energy band MeV	E_{AVE} MeV	N ($\beta = -2.5$) photons	$E_{CC}(N)$ μs	N ($\beta = -2.0$) photons	$E_{CC}(N)$ μs	ΔT_{LIV} ($\xi = 1.0$, $\zeta = 1.0$) μs z = 0.1	μs z = 0.5	μs z = 1.0	μs z = 3.0
0.005 – 0.025	0.0112	1.52×10^5	1.90	1.21×10^5	2.15	0.04	0.25	0.51	1.42
0.025 – 0.050	0.0353	5.60×10^4	3.10	4.68×10^4	3.45	0.13	0.72	1.46	4.10
0.050 – 0.100	0.0707	4.40×10^4	3.55	3.99×10^4	3.70	0.27	1.43	2.93	8.21
0.100 – 0.300	0.1732	3.59×10^4	3.95	4.00×10^4	3.70	0.66	3.51	7.19	20.10
0.300 – 1.000	0.5477	8.28×10^3	8.20	1.53×10^4	6.00	2.09	11.11	22.72	63.56
1.000 – 2.000	1.4142	1.05×10^3	22.80	3.28×10^3	13.00	5.40	28.68	58.67	164.12
2.000 – 5.000	3.1623	4.28×10^2	35.95	1.97×10^3	16.75	12.07	64.12	131.19	367.00
5.000 – 50.00	15.8114	1.41×10^2	62.70	1.18×10^3	21.65	60.35	320.62	656.00	1834.98

GRB & Quantum Gravity

$$\Delta t_{MP/LIV} = \xi\,(D_{TRAV}/c)\,[\Delta E_{phot}/(M_{QG}\,c^2)]^n$$

$$D_{TRAV}(z)=(c/H_0)\int_0^z d\beta\,(1+\beta)/[\Omega_\Lambda+(1+\beta)^3\,\Omega_M]^{1/2}$$

$$\frac{dN_E(E)}{dA\,dt} = F \times \begin{cases} \left(\frac{E}{E_B}\right)^{\alpha} \exp\{-(\alpha-\beta)E/E_B\}, & E \le E_B, \\ \left(\frac{E}{E_B}\right)^{\beta} \exp\{-(\alpha-\beta)\}, & E \ge E_B. \end{cases}$$

$$E_{CC\,Long} = 5\mu s/\sqrt{N_{phot}/22150}$$

$$E_{CC\,Short} = 50\mu s/\sqrt{N_{phot}/221}$$

Long GRB – 8.00 (0.86 BCK) c/s $(50 \div 300$ **keV)** $\Delta t = 25$ **s**
$A_{TOT} = 10^4$ **cm²** $\rightarrow$ **100 nano – satellites of** $A = 10^2$ **cm²**

Short GRB – 8.00 (0.86 BCK) c/s $(50 \div 300$ **keV)** $\Delta t = 25$ **s**
$A = 10^6$ **cm²** $\rightarrow$ **10,000 nano – satellites of** $A = 10^2$ **cm²**

Energy band MeV	E_{AVE} MeV	N ($\beta = -2.5$) photons	$E_{CC}(N)$ μs	N ($\beta = -2.0$) photons	$E_{CC}(N)$ μs	ΔT_{LIV} ($\xi = 1.0$, $\zeta = 1.0$) μs z = 0.1	μs z = 0.5	μs z = 1.0	μs z = 3.0
0.005 – 0.025	0.0112	3.80×10^6	0.38	3.02×10^6	0.43	0.04	0.25	0.51	1.42
0.025 – 0.050	0.0353	1.40×10^6	0.62	1.17×10^6	0.69	0.13	0.72	1.46	4.10
0.050 – 0.100	0.0707	1.10×10^6	0.71	9.98×10^5	0.74	0.27	1.43	2.93	8.21
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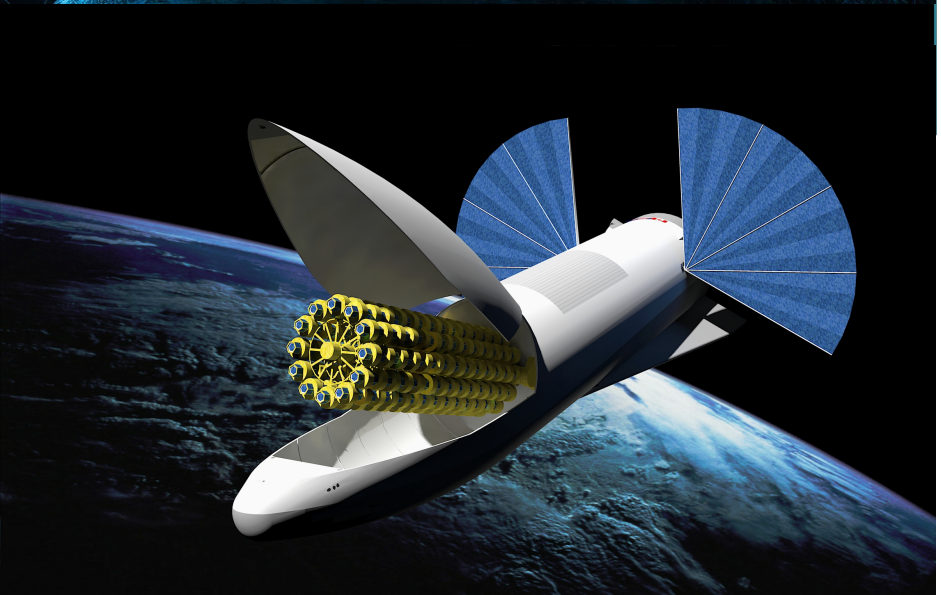
5.000 – 50.00	15.8114	3.52×10^3	12.54	2.95×10^4	4.33	60.35	320.62	656.00	1834.98

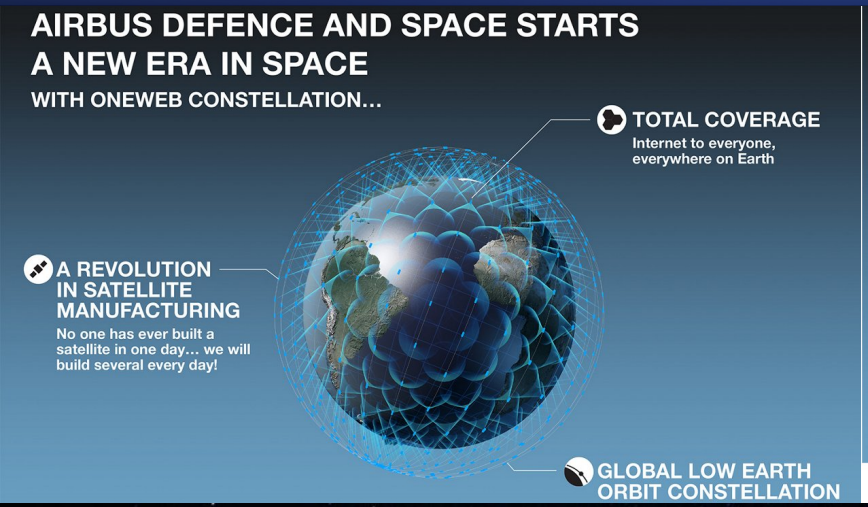
HERMES Next Generation – Starlink

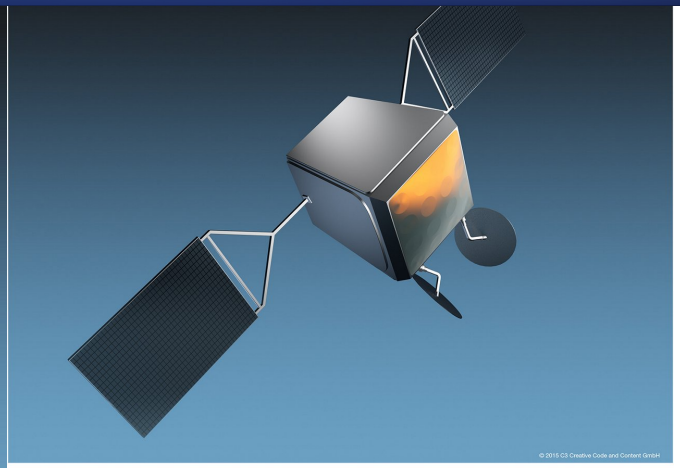


Starlink Constellation 12,000 sats
SpaceX (Elon Musk)

- 4425 @ 1200 km (completed by 2024)
- 7518 @ 340 km
- up to 1,000,000 fixed satellite earth stations (february 2019)
- optical inter–satellite links
- 100 ÷ 500 kg satellites (mass production)
- **board a 100 cm^2 effective area GAGG crystal – SDD photodetector (position sensitive + coded mask?) module on each satellite**
- **120 m^2 effective area All Sky Monitor!**

HERMES Next Generation – OneWeb





Facts & Figures

size

less than 150 kg
weight

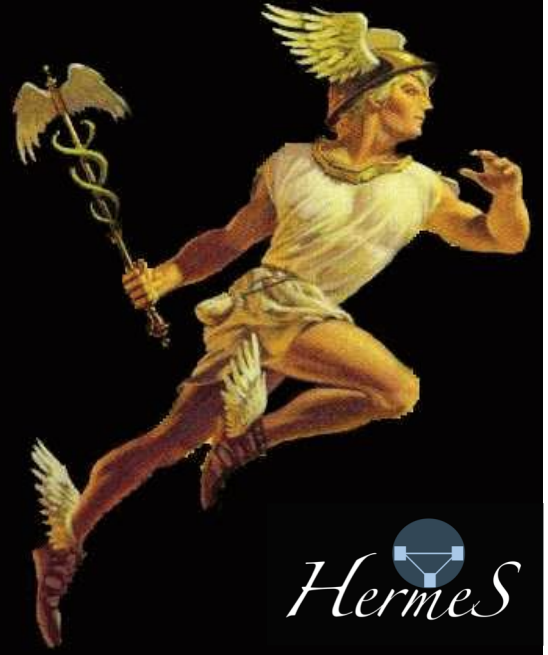
up to 4
built every day

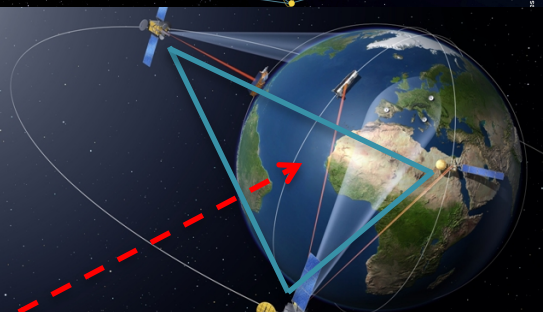
900
satellites to be built

OneWeb Constellation 640 sats

Virgin Galactic (Richard Branson) – Arianespace – Airbus Defence and Space

- 640 @ 1200 km
- 150 kg satellites (mass production)
- **board a 100 cm^2 effective area GAGG crystal – SDD photodetector (position sensitive + coded mask?) module on each satellite**
- **6.4 m^2 effective area All Sky Monitor**





Conclusions: the HERMES project

All sky monitor of High Energy Sources (keV – MeV): GRB, Magnetar, high energy counterparts of GW & FRB, detection & monitoring of transient sources, timing of X-ray pulsators, etc.

- Accuracy in positioning of brigth GRB/GW: ~ 7÷60 arcsec
- 1 – 3 m^2 effective area
- Energy resolution: 15% at 30 keV
- Temporal resolution: ≥ 10 nanoseconds

Quantum Gravity: probing the structure of space-time

Time lags caused by prompt emission mechanism:

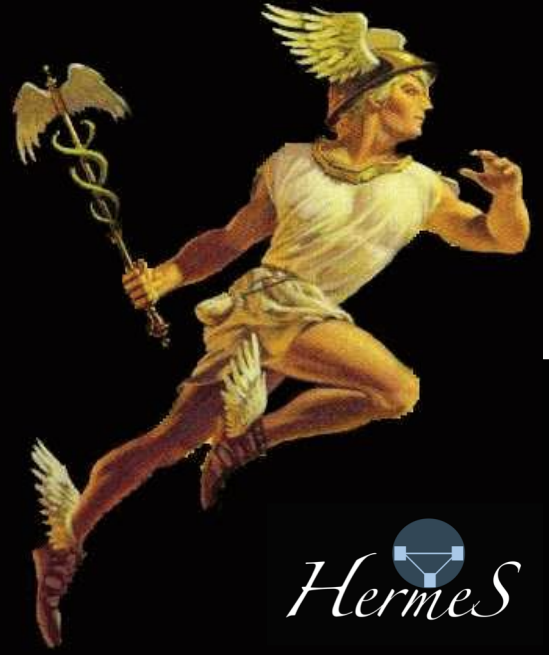
- complex dependence from E_{phot}(Band II) and E_{phot}(Band I)
- independent of $D_{GRB}(z_{GRB})$

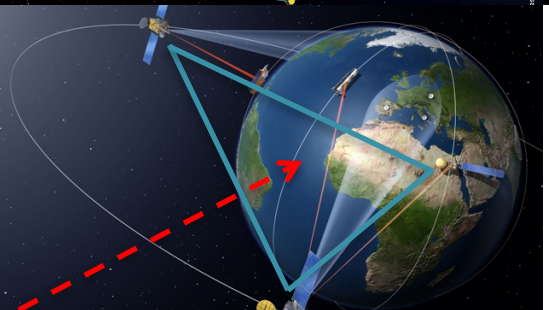
Time lags caused by Quantum Gravity effects:

- $\propto |E_{phot}(\text{Band II}) - E_{phot}(\text{Band I})|$
- $\propto D_{GRB}(z_{GRB})$

The two effects can be disentangled with:

- Δt_{QGR} (HERMES)
- z_{GRB} (optical, follow-up observations of host galaxy)





The HERMES project: the movie

Please, visit our website:
http://hermes.dsf.unica.it

That's all Folks!