Multi-Messenger and Time-Domain Astronomy

The LSTs: built to observe cosmic explosions as they happen



David Paneque

Max-Planck-Institut für Physik, Munich

CTAO LST sub-array inauguration · La Palma · 16 October 2026

Why do we need these two new astronomies?



Extreme cosmic sources emit power through different channels and energies

→ **Multi-messenger astronomy**



Many extreme cosmic sources are variable, from years down to seconds

→ **Time-domain astronomy**



Act I

Gamma rays: the link

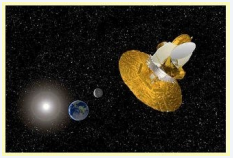
between time-domain and multi-messenger astronomy

Gamma rays: the crucial link between time-domain astronomy and multi-messenger astrophysics

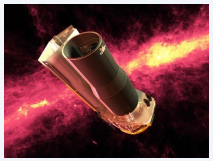
Light: from radio to gamma rays



Radio



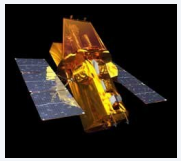
Microwave



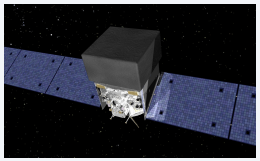
Infrared



Optical



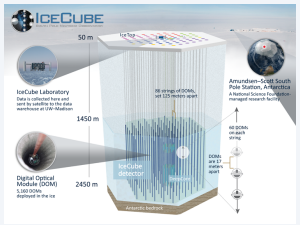
X-rays



GeV



TeV H.E.S.S., MAGIC, LSTs, VERITAS, LHAASO



Neutrinos

IceCube, KM3NeT



Gravitational waves

LIGO, Virgo, KAGRA



Cosmic rays

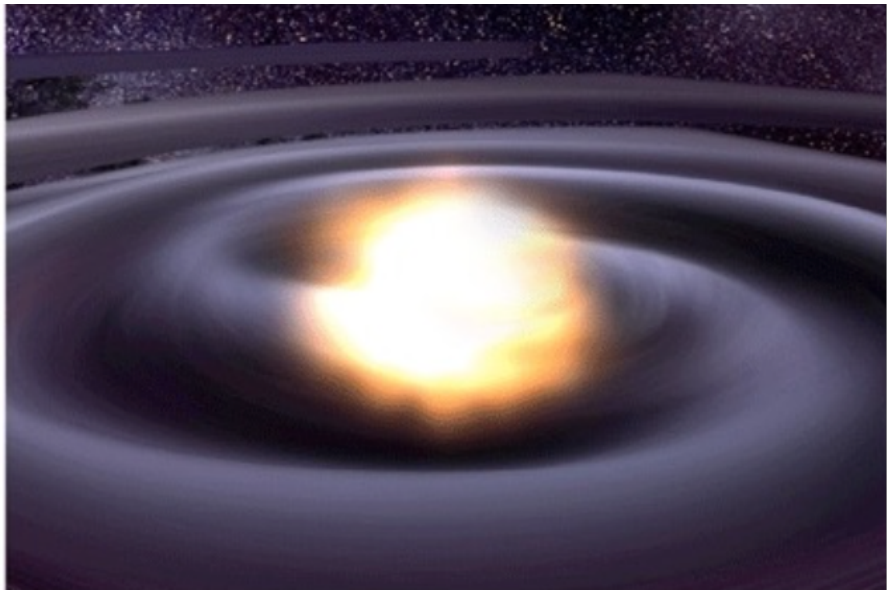
Pierre Auger, Telescope Array: bent by magnetic fields, no pointing back

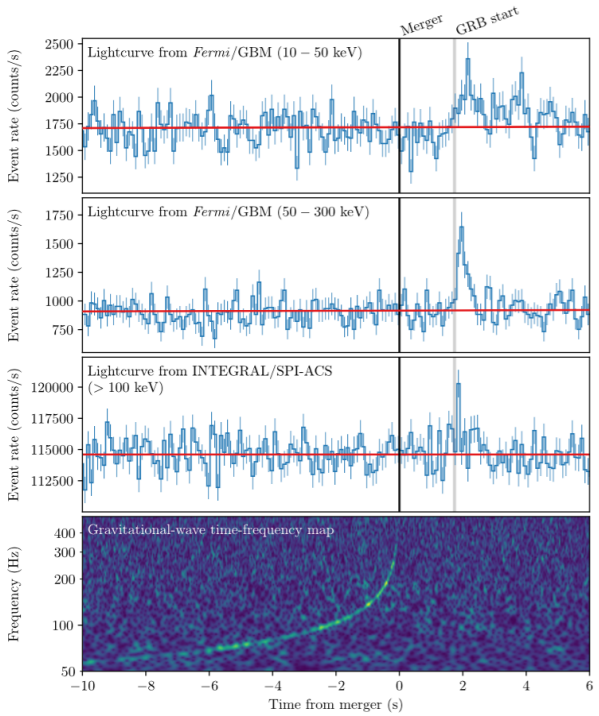
Most energetic light, and still easy to catch: the bridge between the messengers and time

2017: gravitational waves + a gamma-ray burst

GW170817

Mentioned by Kajita this morning



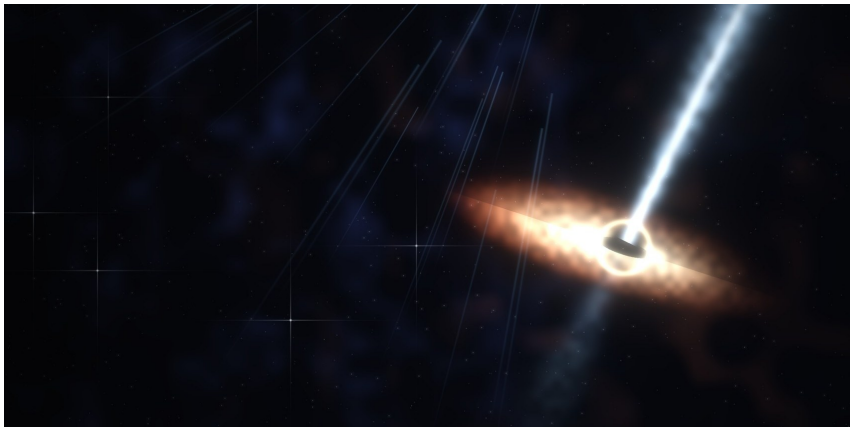


- Two neutron stars merge, 130 million light-years away
- 1.7 s later: a burst of gamma rays (Fermi-GBM, INTEGRAL)
- Then a kilonova, followed by about 70 observatories

Abbott et al. 2017, ApJL 848, L12 · Abbott et al. 2017, ApJL 848, L13

2017: a neutrino and a flaring gamma-ray blazar

Mentioned by Zanin this morning



A blazar: a black-hole jet pointing at us

22 Sept 2017
IceCube detects a ~290 TeV neutrino

Within hours
Fermi-LAT: the blazar TXS 0506+056 is flaring

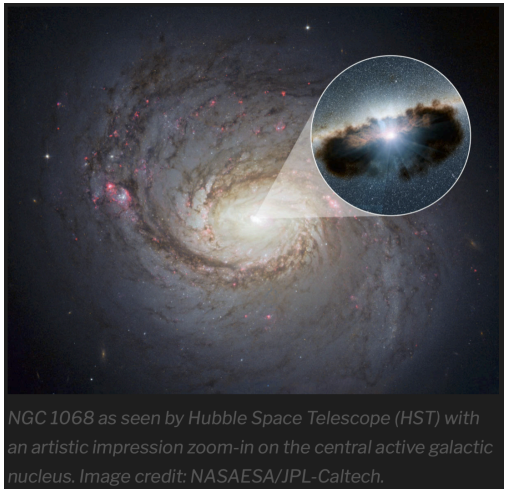
Within days
MAGIC detects it at TeV energies

Nine years on, still the best blazar–neutrino association

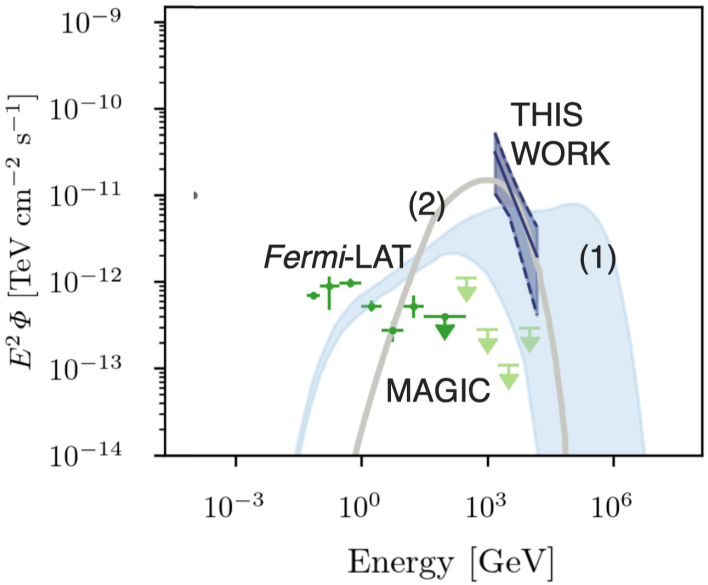
IceCube Coll. et al. 2018, Science 361, eaat1378 · MAGIC Coll. (Ansoldi et al.) 2018, ApJL 863, L10

2022: neutrinos without gamma rays

Mentioned by Zanin this morning



NGC 1068 as seen by Hubble Space Telescope (HST) with an artistic impression zoom-in on the central active galactic nucleus. Image credit: NASAESA/JPL-Caltech.

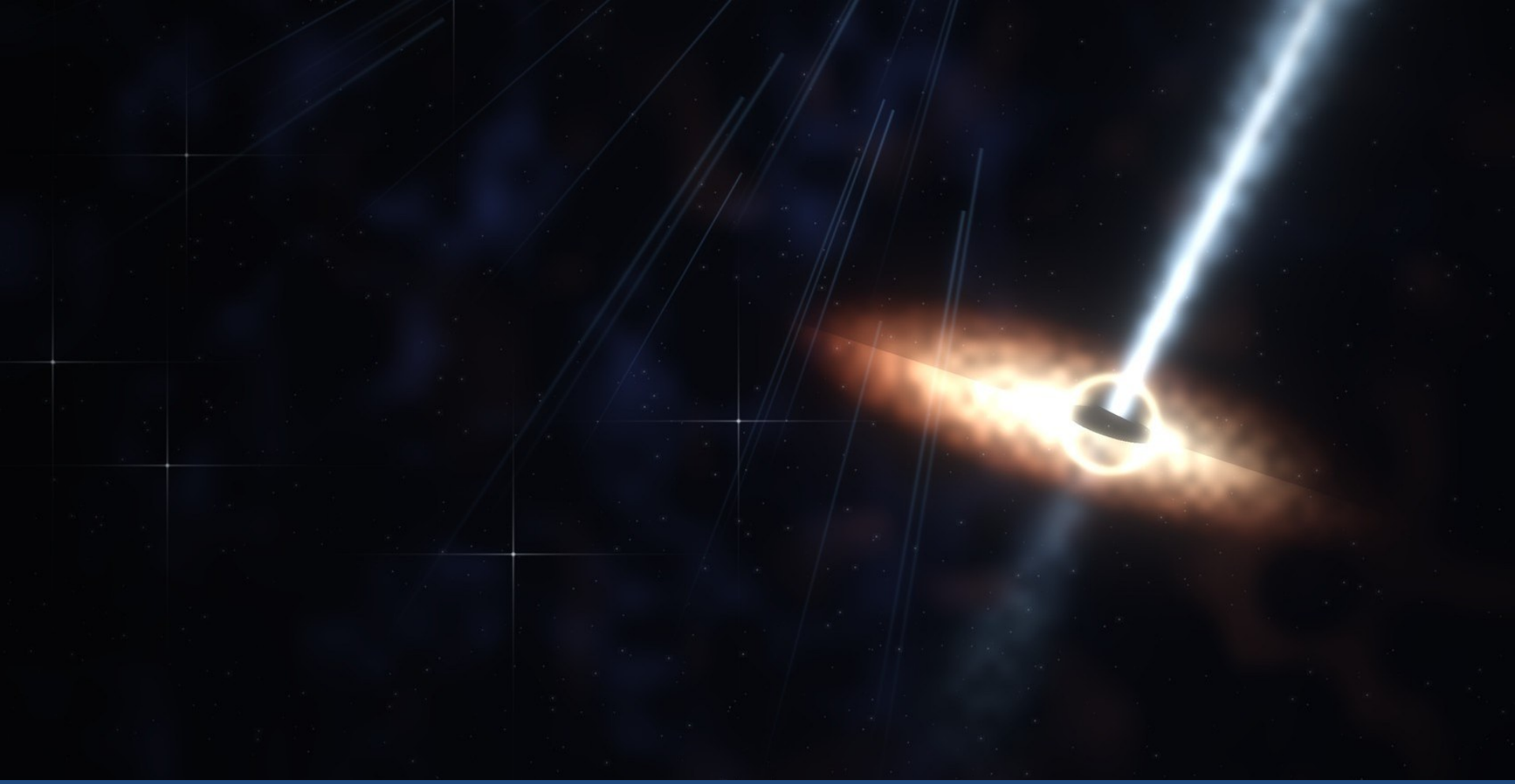


A crucial TeV result can be a non-detection

- NGC 1068: the hottest spot in the IceCube sky (4.2σ)
- MAGIC: no TeV gamma rays → neutrinos from a compact core, opaque to gamma rays
- NGC 4151 (2025): the same picture

Gamma rays (*both detections and non-detections*) play a fundamental role in time-domain & multi-messenger astronomy

IceCube Coll. (Abbasi et al.) 2022, Science 378, 538 · MAGIC Coll. (Acciari et al.) 2019, ApJ 883, 135 · MAGIC Coll. (Abe et al.) 2025, A&A 702, A38

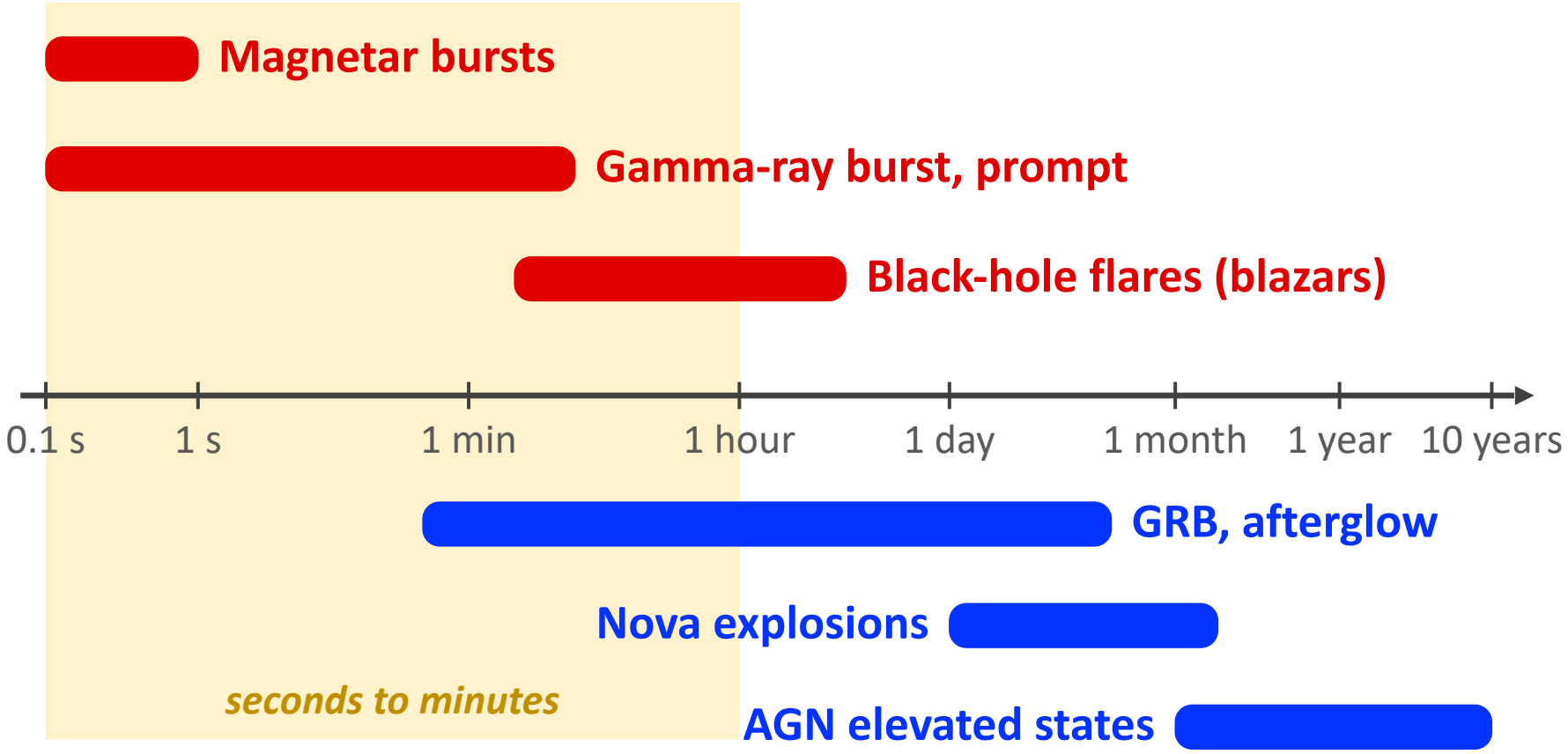


Act II

The Universe does not wait

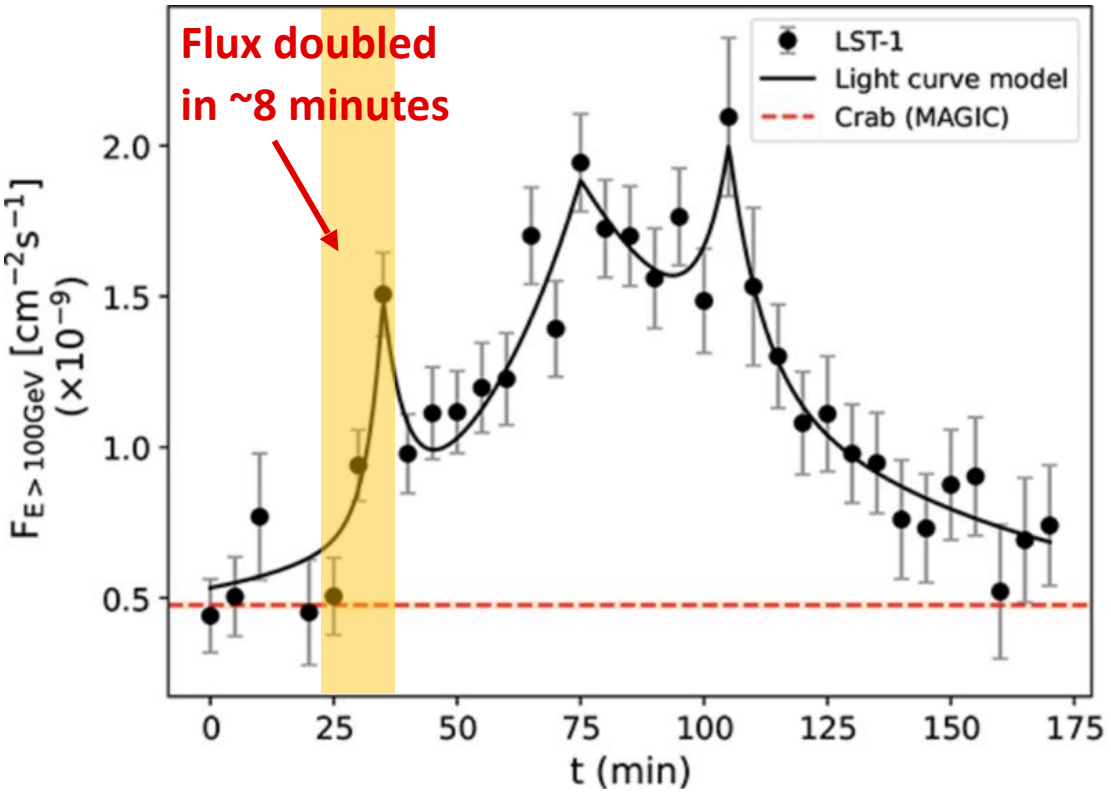
Flares in minutes, explosions in seconds

The high-energy sky flickers on every timescale



Much of the action is over in seconds to minutes:
you have to be FAST and you need SENSITIVITY to detect it

LST-1 already catches minute-scale flares



LST-1, 20 October 2022, above 100 GeV, 5-minute bins

8.3 ± 2.5 min

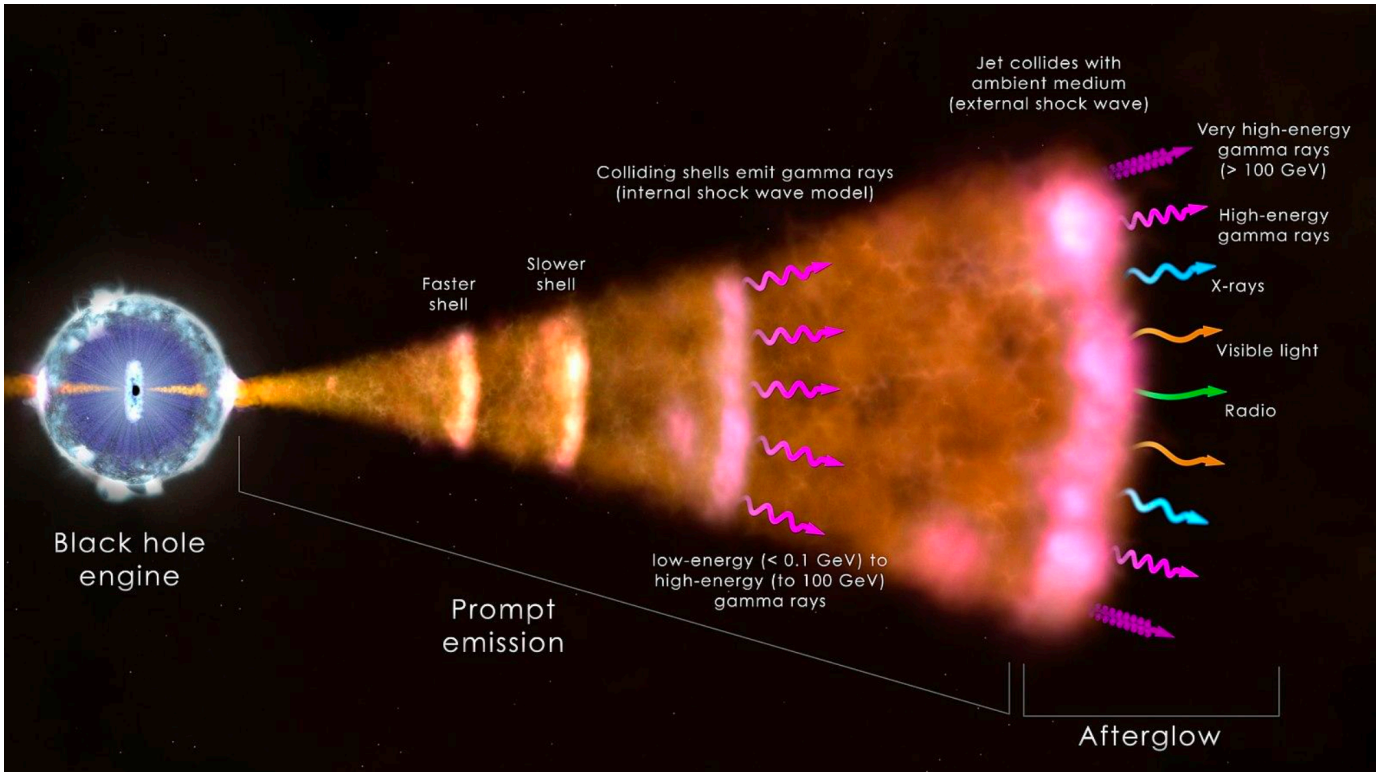
flux-doubling time

- **BL Lacertae, October 2022**
- Peak: ~4.4 times the Crab Nebula, the "standard candle" of TeV astronomy

Fast variability points to a compact region of emission

CTAO-LST Coll. (Abe et al.) 2026, A&A 710, A41 (light curve: Fig. 2)

Gamma-ray bursts: the most powerful explosions



- A flash of seconds (prompt) and a glow that fades (afterglow)
- Satellites catch one almost every day; most are billions of light-years away

Illustration: NASA/GSFC · Fermi-GBM: ~240 GRBs per year (von Kienlin et al. 2020, ApJ 893, 46)

Twenty years of silence

Cherenkov telescopes observed hundreds of GRBs, with no detection until 2019. Two big challenges:



Random place, random time

The alert comes from a satellite; the telescope must move fast. Every second counts.

→ Be FAST



Billions of light-years away

The extragalactic background light (EBL) absorbs the most energetic gamma rays on their way to us.

→ Go LOW in energy

Need the lowest possible energies, ideally below 100 GeV

15 January 2019: the silence is broken

First time detection of a GRB at sub-TeV energies; MAGIC detects the GRB 190114C

ATel #12390; *Razmik Mirzoyan on behalf of the MAGIC Collaboration*
on 15 Jan 2019; 01:03 UT
Credential Certification: Razmik Mirzoyan (Razmik.Mirzoyan@mpp.mpg.de)

Subjects: Gamma Ray, >GeV, TeV, VHE, Request for Observations, Gamma-Ray Burst

Referred to by ATel #: 12395, 12475

Tweet

The MAGIC telescopes performed a rapid follow-up observation of GRB 190114C (Gropp et al., GCN 23688; Tyurina et al., GCN 23690, de Ugarte Postigo et al., GCN 23692, Lipunov et al. GCN 23693, Selsing et al. GCN 23695). This observation was triggered by the Swift-BAT alert; we started observing at about 50s after Swift T0: 20:57:03.19. The MAGIC real-time analysis shows a significance >20 sigma in the first 20 min of observations (starting at T0+50s) for energies >300GeV. The relatively high detection threshold is due to the large zenith angle of observations (>60 degrees) and the presence of partial Moon. Given the brightness of the event, MAGIC will continue the observation of GRB 190114C until it is observable tonight and also in the next days. We strongly encourage follow-up observations by other instruments. The MAGIC contact persons for these observations are R. Mirzoyan (Razmik.Mirzoyan@mpp.mpg.de) and K. Noda (nodak@icrr.u-tokyo.ac.jp). MAGIC is a system of two 17m-diameter Imaging Atmospheric Cherenkov Telescopes located at the Observatory Roque de los Muchachos on the Canary island La Palma, Spain, and designed to perform gamma-ray astronomy in the energy range from 50 GeV to greater than 50 TeV.

ATel #12390, sent at 01:03 UT, a few hours after the burst

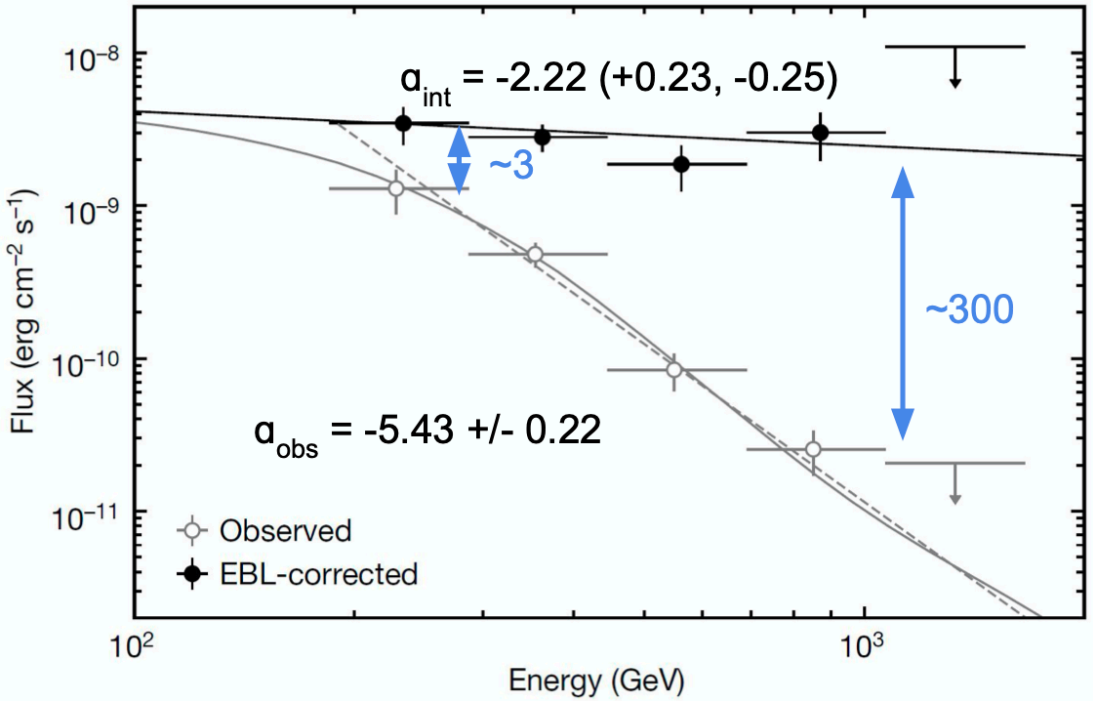
We wrote “>20σ”, to be conservative

Final analysis: >50σ

(in plain words: no doubt at all)

MAGIC Coll. (Acciari et al.) 2019, Nature 575, 455 · MAGIC Coll. (Acciari et al.) 2019, Nature 575, 459

EBL absorption in action: GRB 190114C (z=0.42)



×300

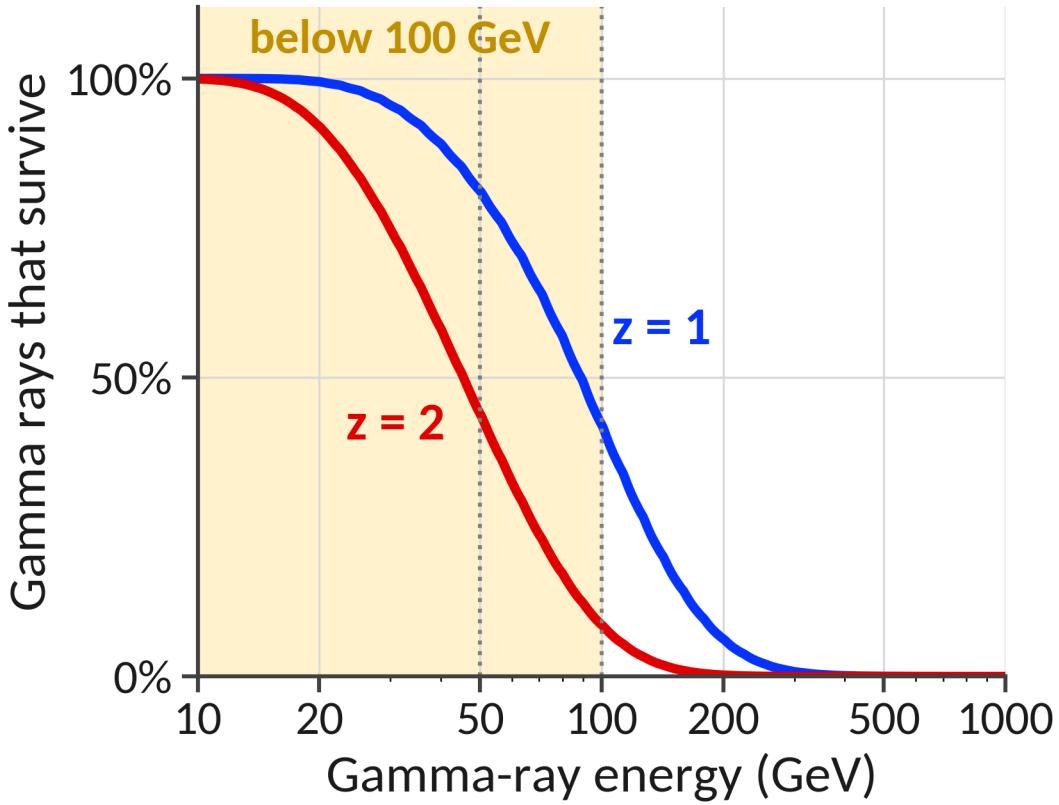
fewer photons at 1 TeV than what left the source

Its light left 4.6 billion years ago, when our Sun was being born

Sensitivity at 100 GeV and below is crucial to see distant sources

MAGIC Coll. (Acciari et al.) 2019, Nature 575, 455

The EBL: why we need to go below 100 GeV



- Gamma ray + EBL photon → electron–positron pair
- z = 1: 80% survive at 50 GeV, only 6% at 200 GeV
- z = 2: 44% survive at 50 GeV, only ~1% at 150 GeV

Below 100 GeV (even better: below 50 GeV), the distant Universe opens up. Only LSTs capable to observe z=2 sources !

EBL model: Saldana-Lopez et al. 2021, MNRAS 507, 5144

First detections of gamma-ray burst at TeV energies

Since January 15th 2019 (GRB190114C, z=0.42), the detection of 4 additional long GRBs have been announced at VHE energies

GRB 180720B (z=0.65), detected by **HESS** at 5 sigma

→ announced at the *CTA symposium*, **May 2019**

GRB 190829A (z=0.08), detected with **HESS** at 22 sigma

→ announced with *Astronomer's Telegram* on **Aug 30th, 2019**

GRB201216C (**z=1.1**), detected with **MAGIC** at 6 sigma

→ announced with *Astronomer's Telegram* on **Dec 17th, 2020**

→ **Most distant VHE gamma-ray source to date**

GRB 221009A (z=0.15), detected with **LHAASO** at >200 sigma

(**BOAT** →Brightest Of All Times) →announced with *GCN Circular* on **Oct 11th, 2022**

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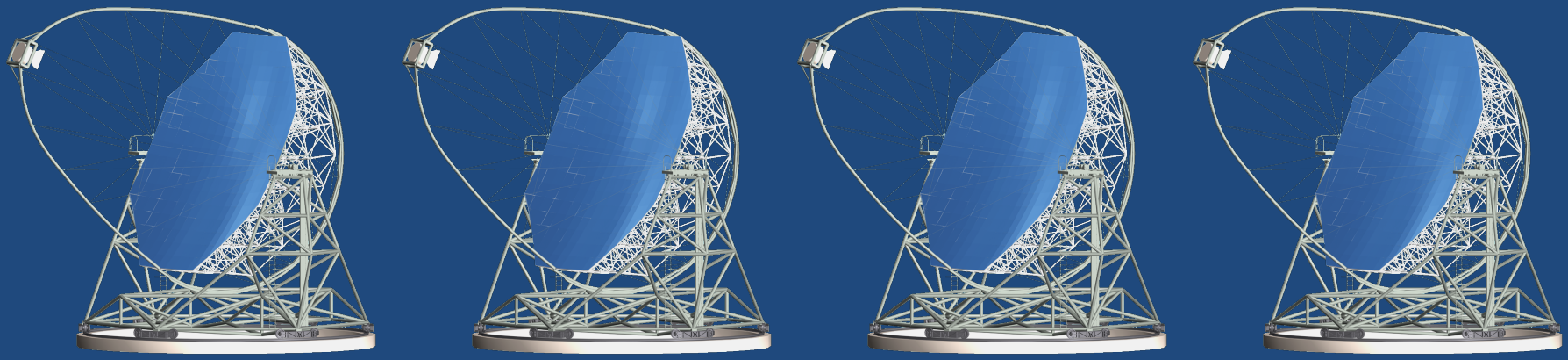
(**BOAT** →Brightest Of All Times) →announced with *GCN Circular* on **Oct 11th, 2022**

After decades of search, TeV GRBs now come "all at the same time"

Most can be explained within the Synchrotron self-Compton scenario

It seems SSC component is indeed common among long GRBs

→ Need more TeV GRBs: time will confirm/reject this testable scenario



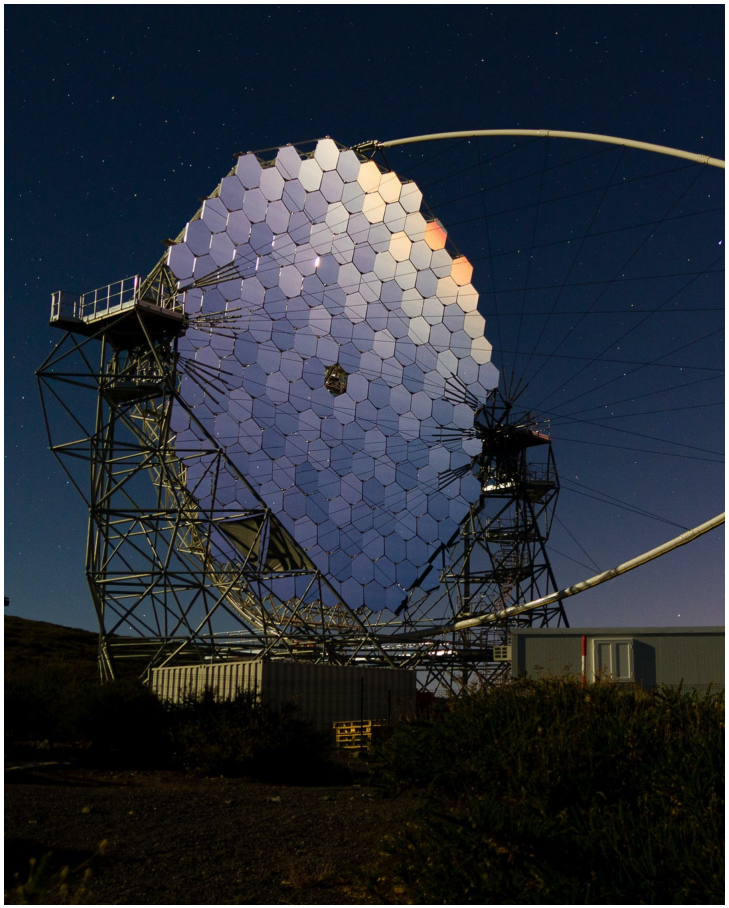
LST-1 LST-2 LST-3 LST-4

Act III

The CTAO-LST sub-array

Fast, far and big: designed for the transient Universe

The LST in numbers



23 m	dish: as wide as a tennis court is long
400 m²	of mirrors for faint flashes of blue light
45 m	tall: a 15-storey building
100 t	… that turns around in 20 seconds
1855	pixels, a billion snapshots per second

CTAO, LST technical specifications (www.ctao.org)

Fast: anywhere in the sky in 20 seconds



20 s

- Faster than it takes you to read this slide
- On target about a minute after a satellite alert, when the afterglow is brightest
- MAGIC pioneered fast slewing; the LSTs bring it to 23-metre dishes

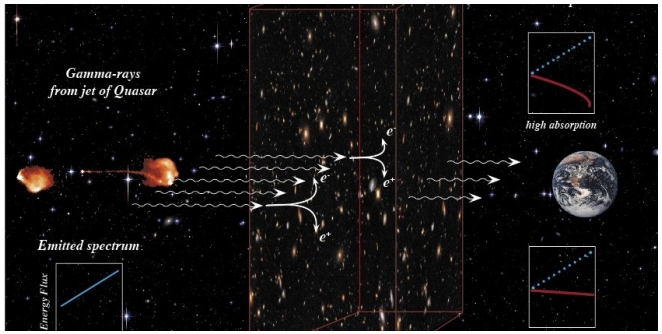
Sensitivity and availability are different features: the LSTs have both

CTAO, LST technical specifications (www.ctao.org)

Far: down to 20 GeV, to see through the EBL

20 GeV

lowest energy threshold in CTAO

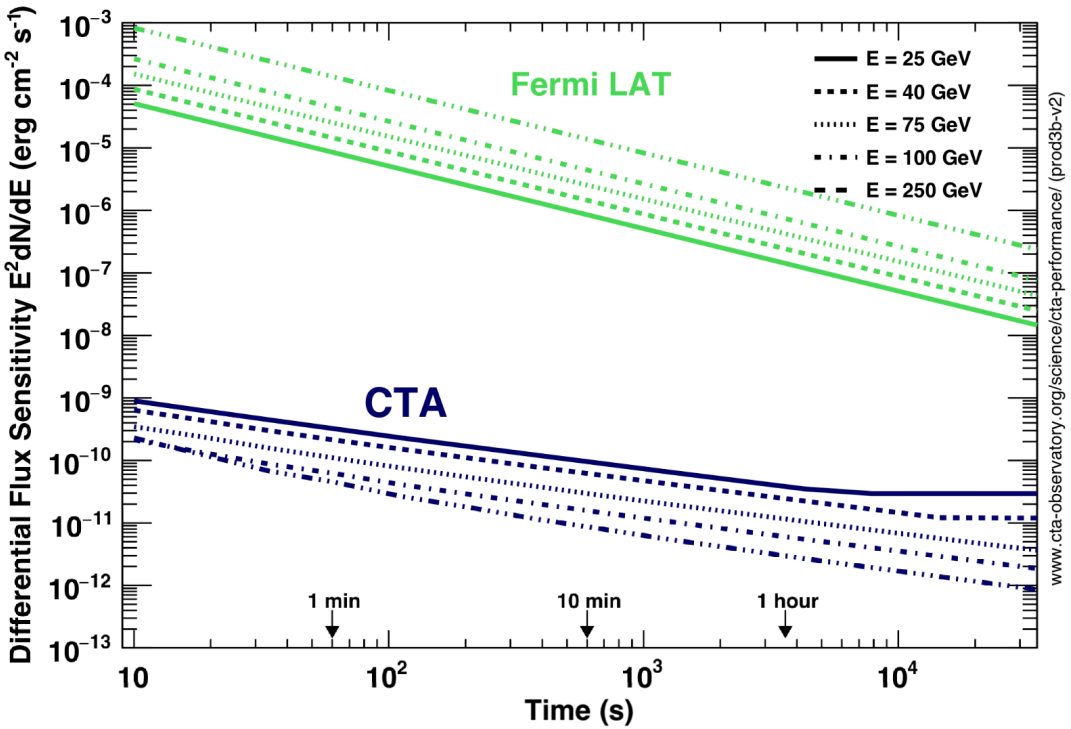


- **OP 313: discovered by LST-1 in December 2023**
- The most distant blazar ever seen at these energies (z ≈ 1)
- Its light left ~8 billion years ago:
  3 billion years before the Sun was born

Low energy threshold = a window to the distant Universe

MAGIC & CTAO-LST Colls. (Abe et al.) 2026, A&A 712, A91 · CTA-LST Project (Abe et al.) 2023, ApJ 956, 80

Big: 10,000× Fermi-LAT for short flares



At 25 GeV, for a flare lasting a few minutes:

>10,000×

more sensitive than Fermi-LAT

Fermi-LAT: ~1 m² in space. LST: the atmosphere is the detector; the light pool covers ~6 football pitches

A unique possibility to study short-time phenomena at gamma rays

Funk & Hinton 2013, Astropart. Phys. 43, 348 · figure: CTA performance, prod3b-v2 (www.cta-observatory.org)

LST-1 has already delivered (observed flares and explosions)

Mentioned by Mazin this morning

CTAO-LST Coll. (Abe et al.)
2025, A&A 695, A152



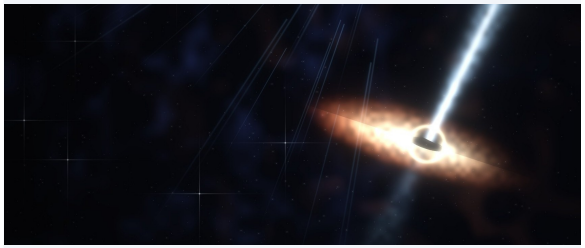
RS Oph nova (2021)
TeV protons in a
stellar explosion

CTAO-LST Coll. (Abe et al.)
2025, ApJL 988, L42



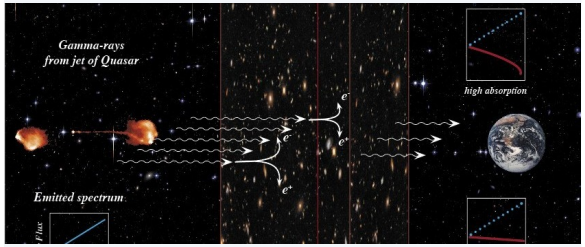
GRB 221009A (2022)
The “BOAT”,
under a full Moon

CTAO-LST Coll. (Abe et al.)
2026, A&A 710, A41



BL Lacertae (2022)
Flux doubling
in ~8 minutes

MAGIC & CTAO-LST Colls. (Abe et al.)
2026, A&A 712, A91



OP 313 (2023)
Distance record:
8 billion years

CTAO-LST Coll. (Abe et al.)
2026, A&A 706, A25

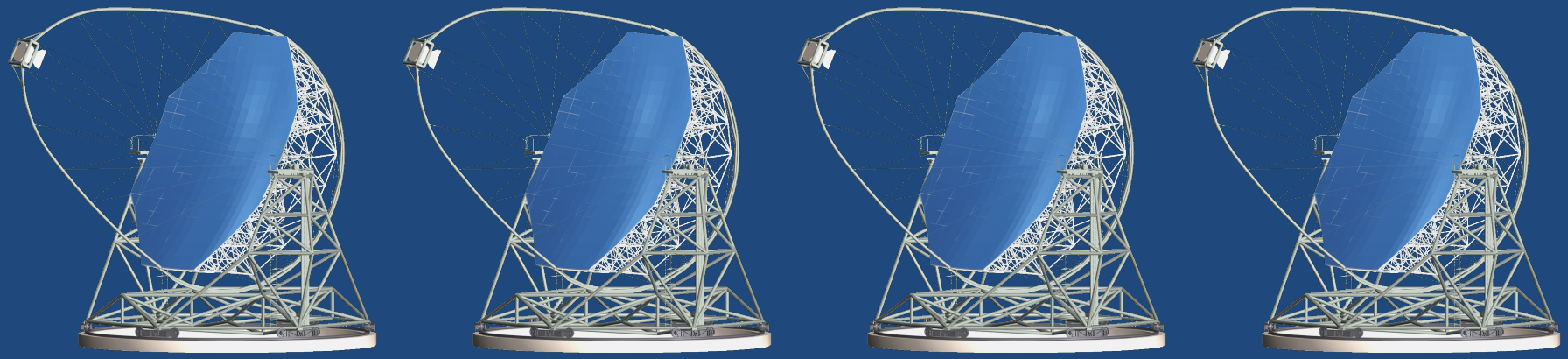


Magnetar SGR 1935
TeV limits on
0.1-second bursts

MAGIC & CTAO-LST Colls. (Abe et al.)
2026, PASP 138, 084101



GW alerts (2024)
Two black-hole mergers,
with MAGIC



LST-1 LST-2 LST-3 LST-4

Act III

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Act IV

A tsunami of alerts is coming…

The sky is about to send us millions of messages

We will have to react to millions of alerts

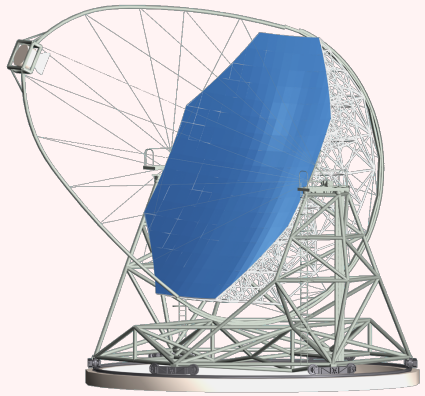
Optical: ~10 million per night
Vera C. Rubin Observatory (since June 2026)

Radio: ~900 FRBs per year (CHIME/FRB)
SKA, CHORD, DSA: tens of thousands per year

X-rays and gamma rays: hundreds per year
Fermi-GBM alone: ~240 GRBs per year

Neutrinos: ~30 per year
IceCube (KM3NeT and IceCube-Gen2 next)

Gravitational waves: ~1000 per year (O5)
Einstein Telescope: ~100,000 per year



The LSTs: the gamma-ray first responders

HUGE discovery potential in the next decade!

But we can only look at one at a time: choosing becomes an art

Findeisen et al. 2026, arXiv:2603.19541 · CHIME/FRB Coll. 2026, ApJS, arXiv:2601.09399 · Curtin et al. 2026, arXiv:2606.27546 · von Kienlin et al. 2020, ApJ 893, 46 · IceCube Coll. (Abbasi et al.) 2023, ApJS 269, 25 · Kiendrebeogo et al. 2023, ApJ 958, 158 · Maggiore et al. 2020, JCAP 03, 050

Singular events can rewrite entire fields in science



SN 1987A

23 February 1987

24 neutrinos in 13 s

- How massive stars die (core collapse): confirmed
- Within weeks: limits on neutrino mass and new particles
- Neutrino astronomy is born (Nobel Prize 2002)



GW170817

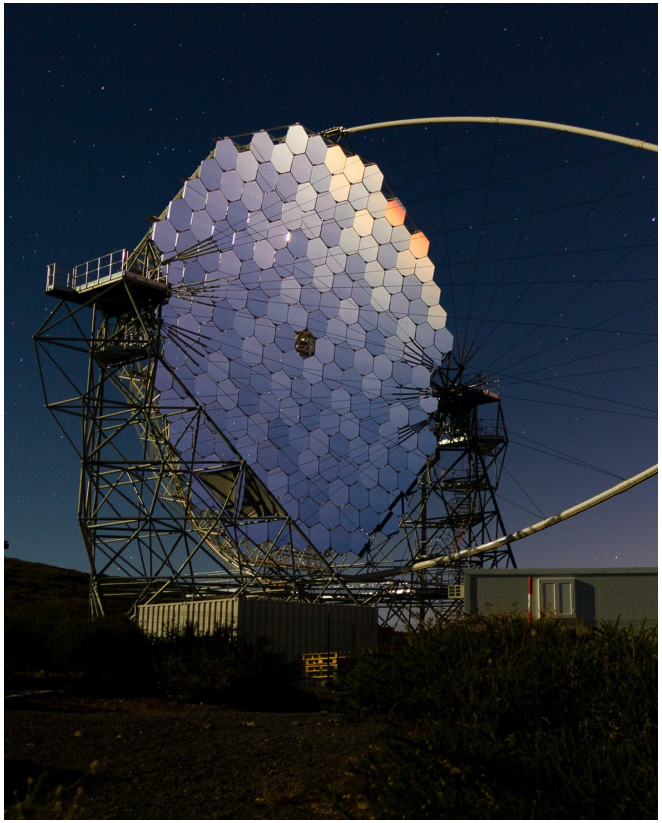
announced 9 years ago today

1.7 s between gravity and light

- Same speed, to a few parts in a million billion
- Within a day: many dark-energy theories ruled out
- Heavy metals forged in the merger
- A new ruler for cosmic expansion

Hirata et al. 1987, PRL 58, 1490 · Bionta et al. 1987, PRL 58, 1494 · Abbott et al. 2017, ApJL 848, L13 · Abbott et al. 2017, Nature 551, 85

The next one will arrive unannounced



The next event of this class will arrive unannounced.

Whether it becomes a measurement or a footnote will again depend on which instruments are watching when it does.

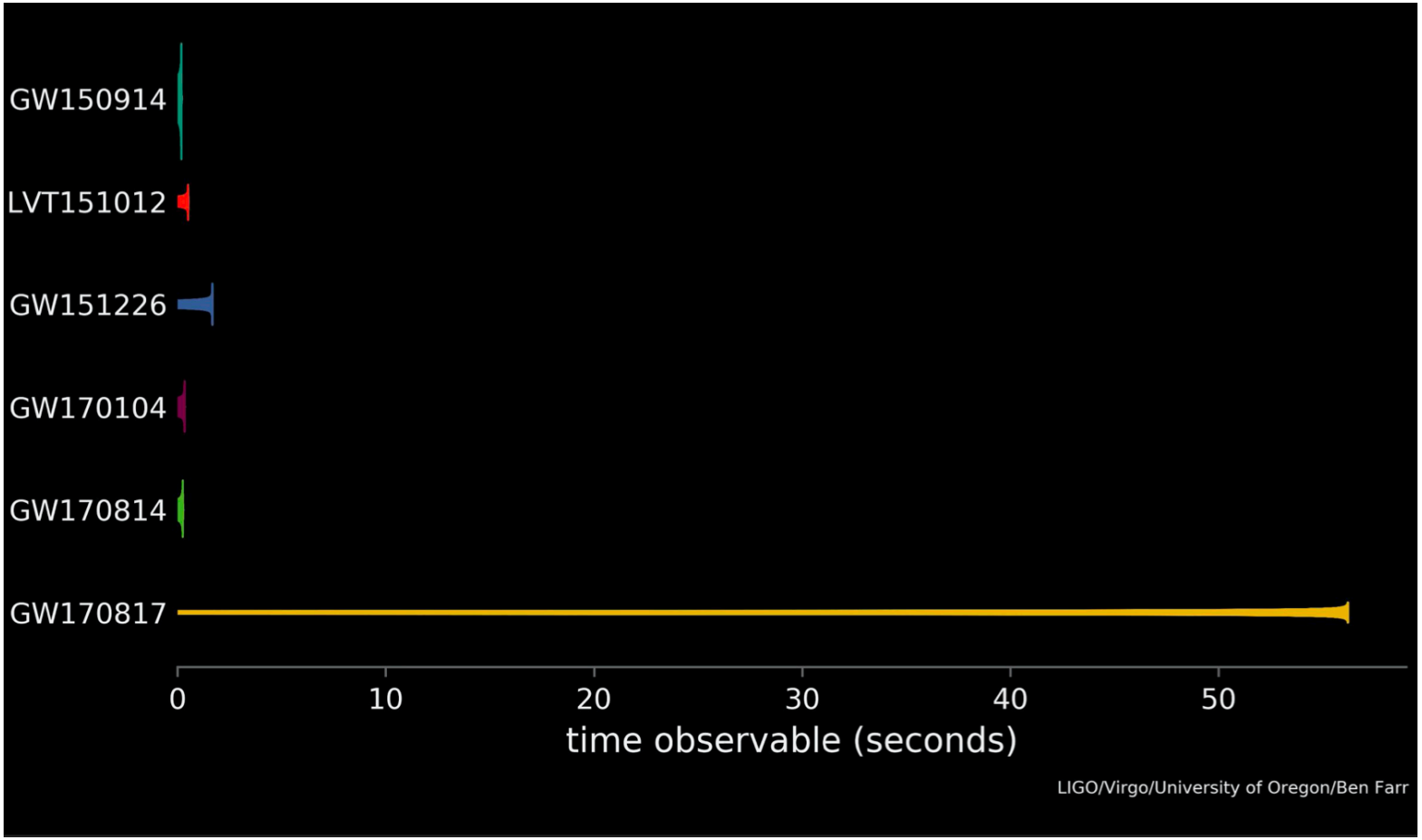
A warning comes first: neutrinos or gravitational waves

The LSTs: anywhere in the sky in 20 s, from 20 GeV

When it happens, the LSTs must be watching

Supernova alerts (SNEWS 2.0): Al Kharusi et al. 2021, New J. Phys. 23, 031201

Neutron-star mergers “sing” for longer

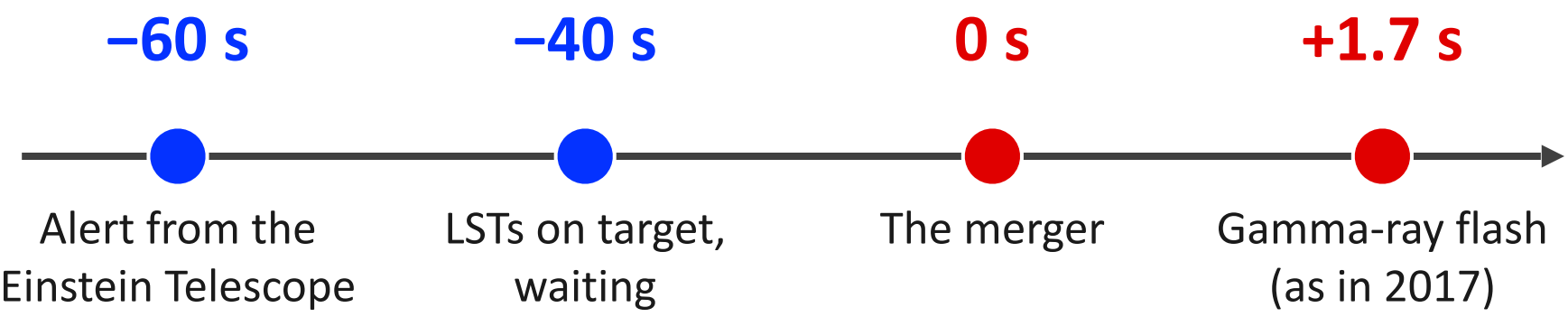


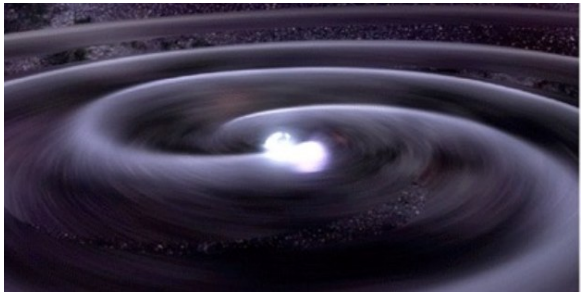
- Black holes: a fraction of a second in LIGO
- Neutron stars (GW170817): about one minute

Next-generation detectors: hours of signal → alerts before the merger

Abbott et al. 2017, PRL 119, 161101 · figure: LIGO/Virgo/U. Oregon/B. Farr

Watching two neutron stars collide, live



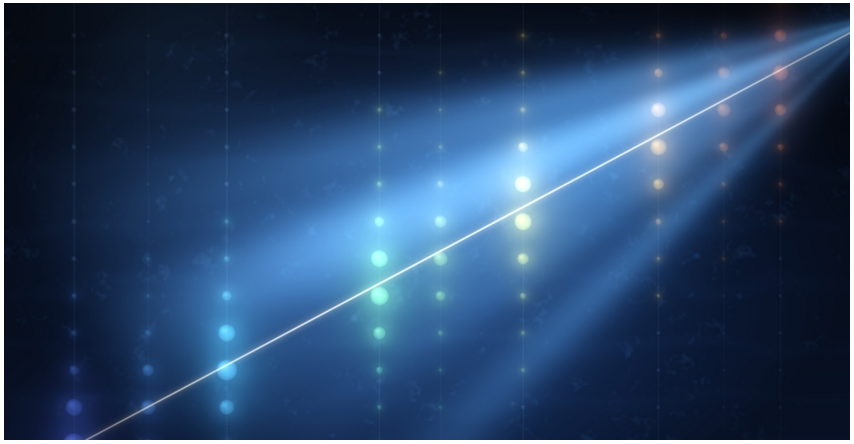


The LST sub-array can react even to a 1-minute pre-merger alert and be on target at the moment of the merger

For the first time, a telescope could be watching when it happens

Banerjee et al. 2023, A&A 678, A126

A neutrino arrives: LSTs on target in a minute



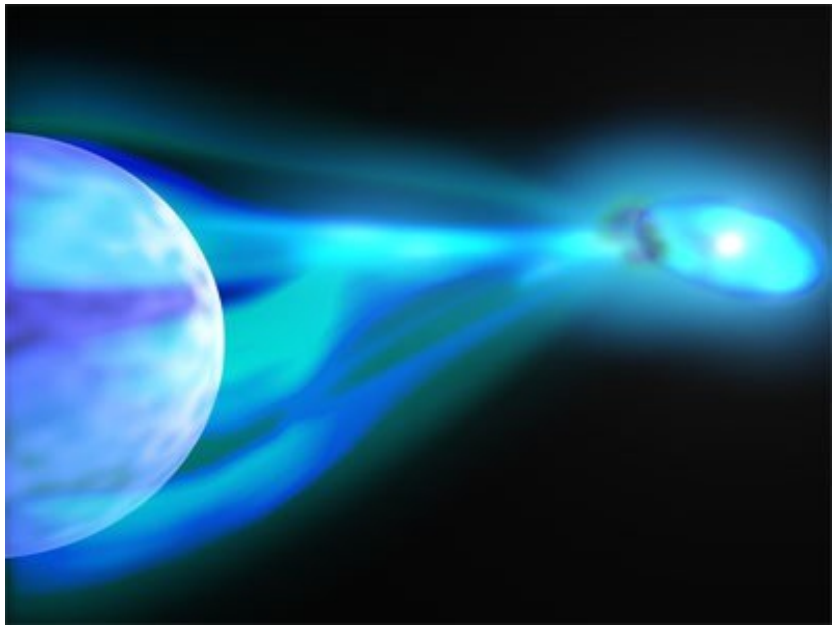
KM3-230213A: ~220 PeV, the most energetic neutrino ever seen

- IceCube and KM3NeT send alerts in real time
- Flaring blazar (TXS 0506+056) or hidden, gamma-dark core (NGC 1068)?
- LSTs answer in minutes, down to 20 GeV

A crucial TeV result can be a non-detection

KM3NeT Coll. (Aiello et al.) 2025, Nature 638, 376 · IceCube Coll. et al. 2018, Science 361, eaat1378 · IceCube Coll. (Abbasi et al.) 2022, Science 378, 538

The next nova, T CrB: we are waiting for it…

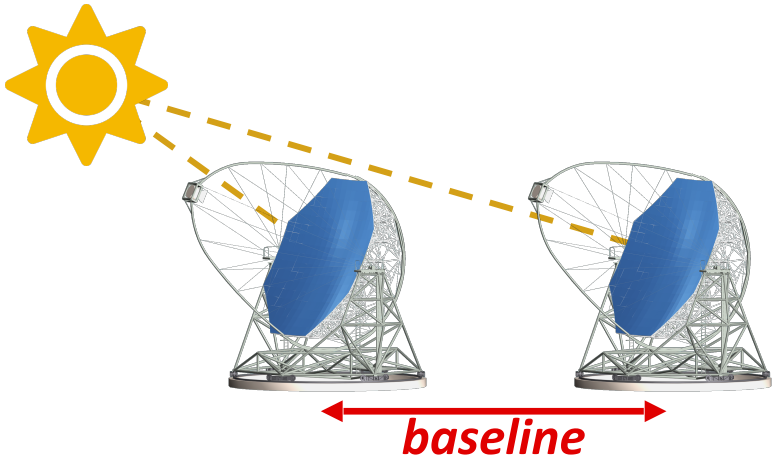


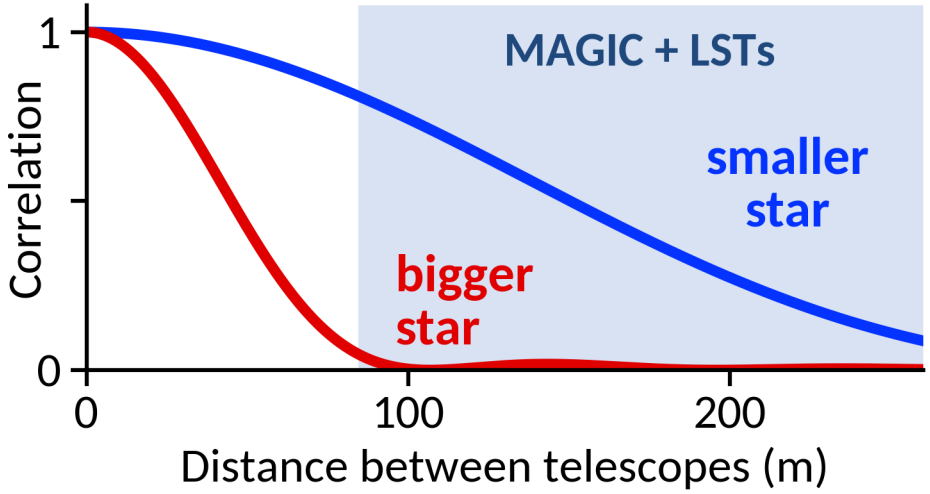
- Only 3,000 light-years away: a recurrent nova (~80 year period)
- Erupted in 1866 and 1946; the next one is overdue (most predictions have already expired)
- 3× closer than RS Oph (0.9kpc vs 2.7kpc) → ~10× brighter, <u>detected during 1 month</u>
- Protons up to PeV? Even neutrinos may be detectable

Please erupt at night, with no Moon, while visible from La Palma

Petruk et al. 2026, A&A 711, A96

Bonus: measuring the size of stars



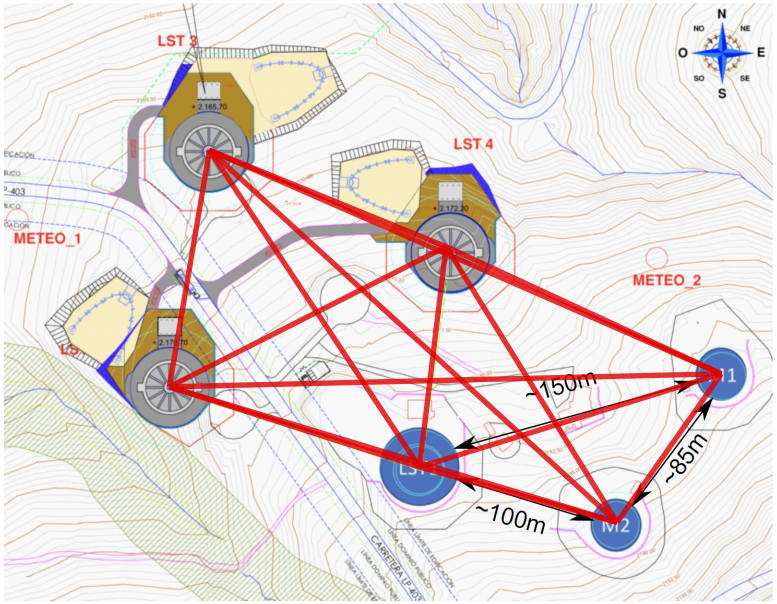


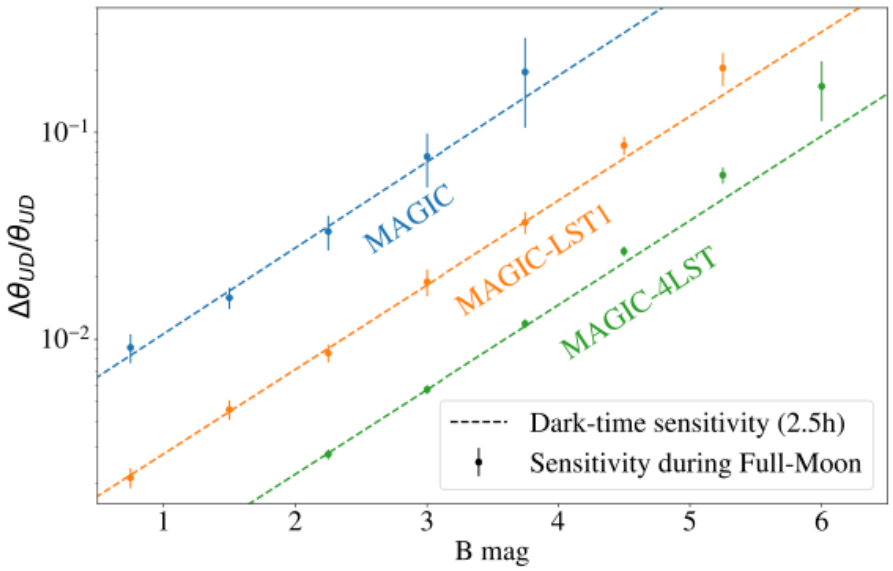
1. Starlight arrives in random "bunches" of photons
2. Big mirrors, nanosecond timing: both telescopes see the same bunches
3. The match fades with distance: faster for bigger stars

MAGIC already did it: 22 stars, some as small as fraction of milliarcsecond (—> a coin in Tokyo seen from La Palma)

Hanbury Brown & Twiss 1956, Nature 177, 27 · MAGIC Coll. (Abe et al.) 2024, MNRAS 529, 4387

MAGIC + LSTs: a game-changer





6 telescopes → 15 baselines

More telescopes → fainter stars

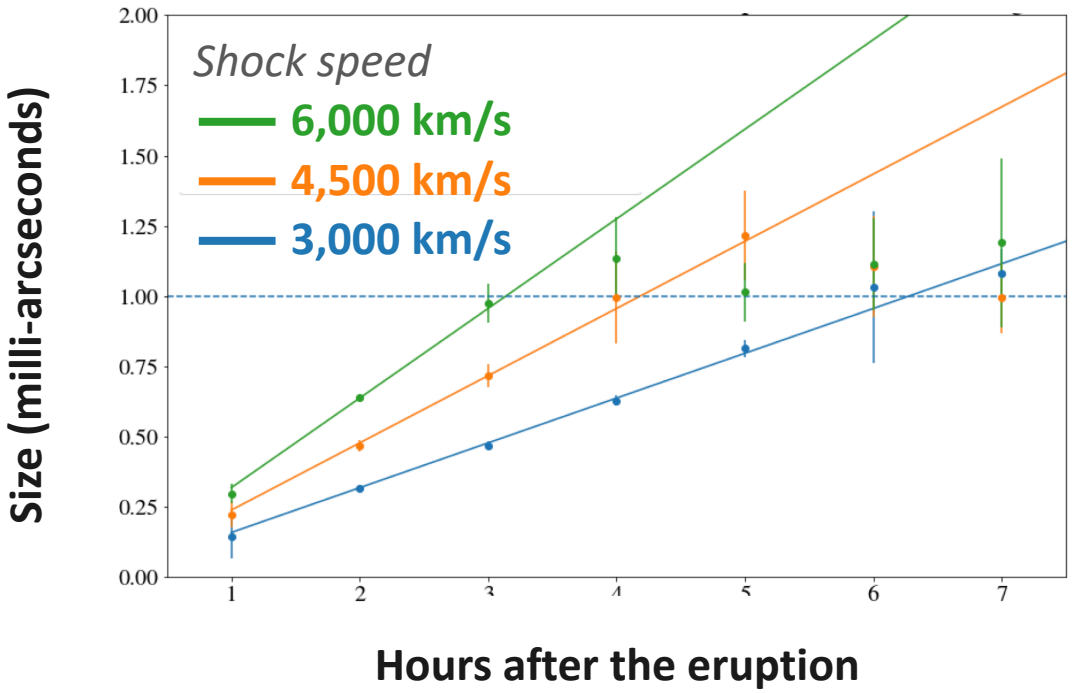
- MAGIC + LST-1: joint measurements since 2024
- LST upgrade: ERC grant MicroStars (PI: T. Hassan, CIEMAT)

For a relatively low investment, a new window for MAGIC and the LSTs

MAGIC Coll. (Abe et al.) 2024, MNRAS 529, 4387 · Jiménez Martínez et al. 2025, PoS(ICRC2025)935

T CrB: watching the explosion grow

Simulation: LST-1 + MAGIC, 10-minute snapshots



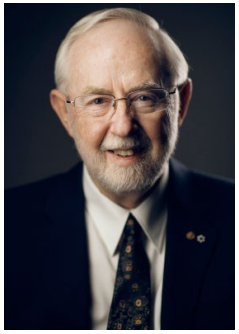
- The fireball: from ~0.25 to ~1 milli-arcsecond in a few hours
- Its size tells how much light bathes the shock: gamma rays from electrons or protons?
- Only in the first hours: then it is too big for our baselines (dashed line)

Same telescopes, same night: the gamma rays and the size of the explosion

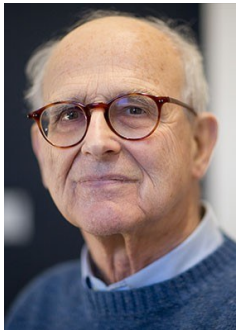
Simulation: J. Cortina et al., CTAO Symposium 2024 · A nova fireball with CHARA: Schaefer et al. 2014, Nature 515, 234

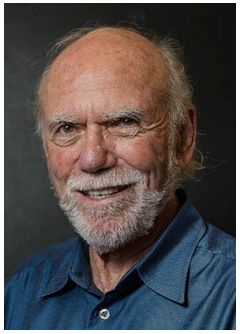
Breakthroughs come from new windows


Kajita


McDonald

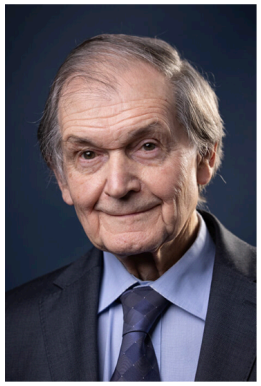
Neutrino oscillations (Nobel 2015)


Weiss


Barish


Thorne

Gravitational waves (Nobel 2017)


© Nobel Prize Outreach. Photo: Fergus Kennedy
Roger Penrose
Prize share: 1/2


© Nobel Prize Outreach. Photo: Bernhard Ludewig
Reinhard Genzel
Prize share: 1/4


© Nobel Prize Outreach. Photo: Annette Buhl
Andrea Ghez
Prize share: 1/4

Black hole formation and detection in our Galaxy (Nobel 2020)

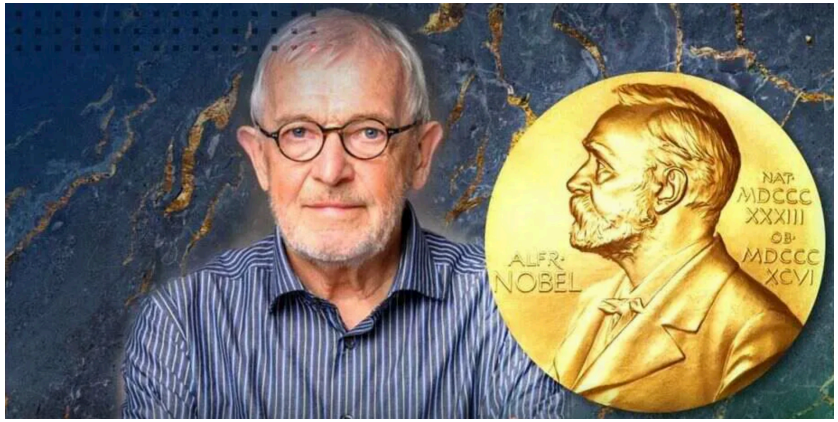
Recipe is always the same:

New instruments

+

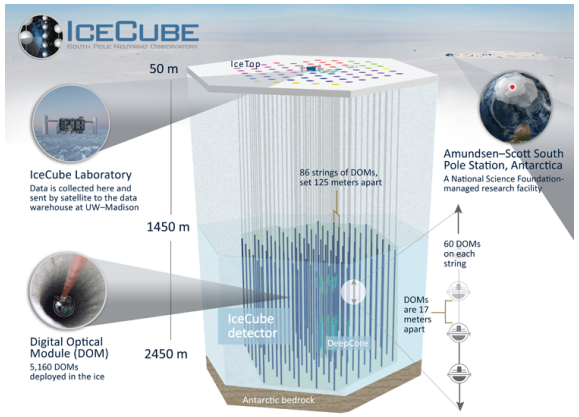
extreme environments that no laboratory on Earth can reproduce

Nobel Prize 2026: congratulations, Francis Halzen!



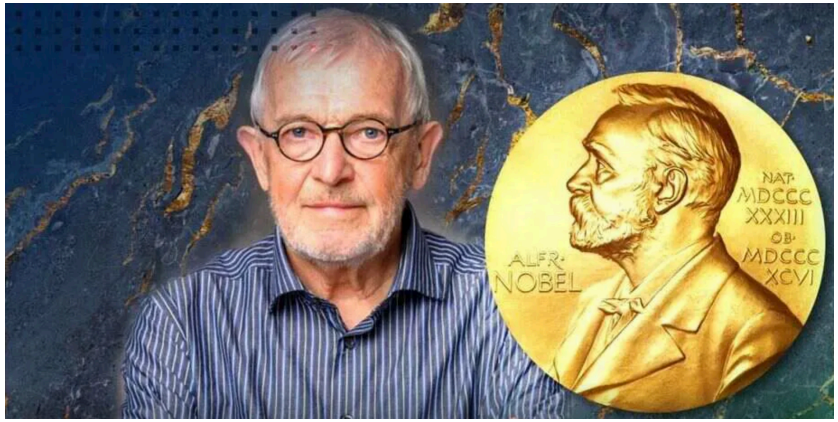
"for decisive contributions to the IceCube Neutrino Observatory and the discovery of high-energy neutrinos of astrophysical origin"

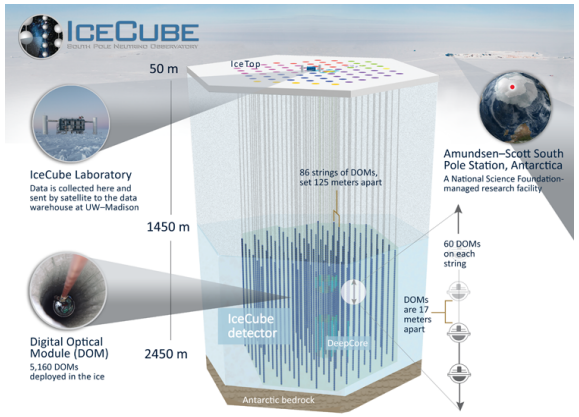
… and congratulations to the whole IceCube Collaboration!



Nobel Prize in Physics 2026, Royal Swedish Academy of Sciences, 6 October 2026 · IceCube Coll. 2013, Science 342, 1242856

Nobel Prize 2026: congratulations, Francis Halzen!





"for decisive contributions to the IceCube Neutrino Observatory and the discovery of high-energy neutrinos of astrophysical origin"

… and congratulations to the whole IceCube Collaboration!

- Where protons collide, neutrinos and gamma rays are born together
- Neutrinos —> proof of protons. Gamma rays —> when and where
- Example: TXS 0506+056, NGC 1068: studied with both messengers

Neutrino and gamma-ray astronomy: better together

Nobel Prize in Physics 2026, Royal Swedish Academy of Sciences, 6 October 2026 · IceCube Coll. 2013, Science 342, 1242856

A Nobel Prize for the CTAO-LST sub-array ?



A supernova in our Galaxy

Neutrinos warn us; the LSTs catch the gamma rays from the first hours



Two neutron stars merging

A pre-merger alert; the LSTs on target at the moment of the collision



Something nobody predicted

The biggest discoveries are often the unexpected ones

Catch one of these, and the next Nobel Prize may go to the LSTs

No Nobel Prize for gamma-ray astronomy yet… it is about time!

One prize, three gamma-ray instruments?



Fermi-LAT

The GeV sky, since 2008



LHAASO

PeV gamma rays, since 2021



CTAO LST sub-array

The fast sub-TeV sky, from now on

A Nobel Prize can be shared by up to three people: one from each?

No Nobel Prize for gamma-ray astronomy yet… it is about time!

Five things to remember

1. **The Universe is very dynamic (specially at high energies)**
   time-domain + multi-messenger astronomy

2. **Gamma rays are the link**
   the most energetic light, easy to catch, fast to follow

3. **CTAO LST sub-array is most suitable instrument: fast, far, big**
   20 s · 20 GeV · >10,000× Fermi-LAT for minute-long flares

4. **LST-1 has already delivered**
   nova protons, the BOAT, 8-minute flares, a z ≈ 1 record, GW follow-up

5. **A tsunami of alerts is coming**
   millions of alerts: the LSTs as gamma-ray first responders



Congratulations to the LST team!

The Universe will not wait. Let's get fully ready for it

Thank you

Backup

Backup slides

For questions

Photons are easy to catch

Neutrinos

- Barely interact: most fly straight through the Earth
- Need a cubic kilometre of ice (IceCube) or of sea water (KM3NeT)

NGC 1068: ~4σ in one decade (79 neutrinos)

Gamma rays

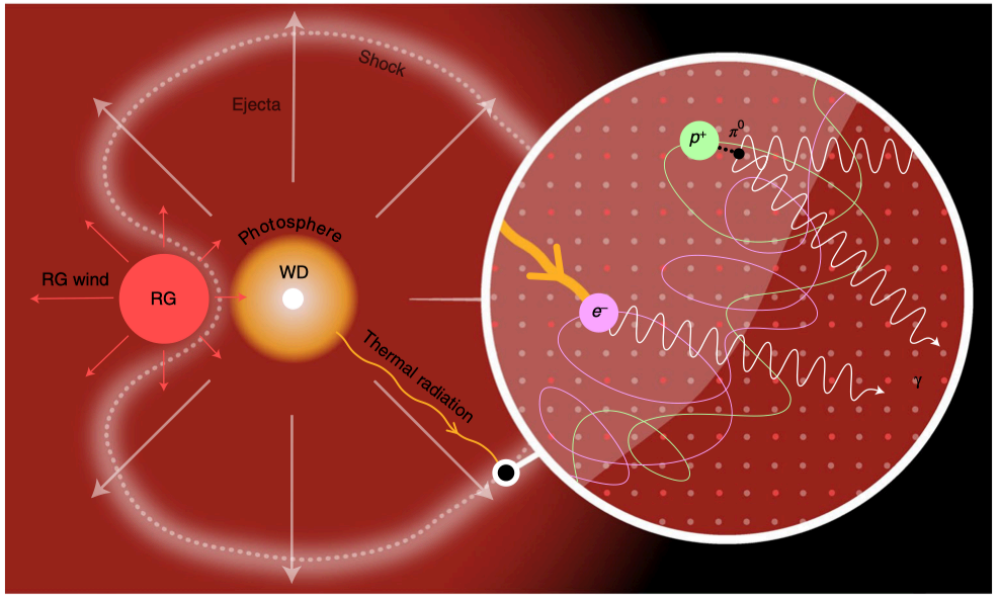
- Interact easily: the atmosphere stops them and turns them into a flash of light
- A telescope on a mountain top is enough

GRB 190114C: >50σ in 20 minutes (many hundreds of photons)

Gamma rays follow a source minute by minute: compare that light curve with the arrival times of one or a few neutrinos

IceCube Coll. (Abbasi et al.) 2022, Science 378, 538 · MAGIC Coll. (Acciari et al.) 2019, Nature 575, 455

RS Oph: a nova accelerating TeV protons

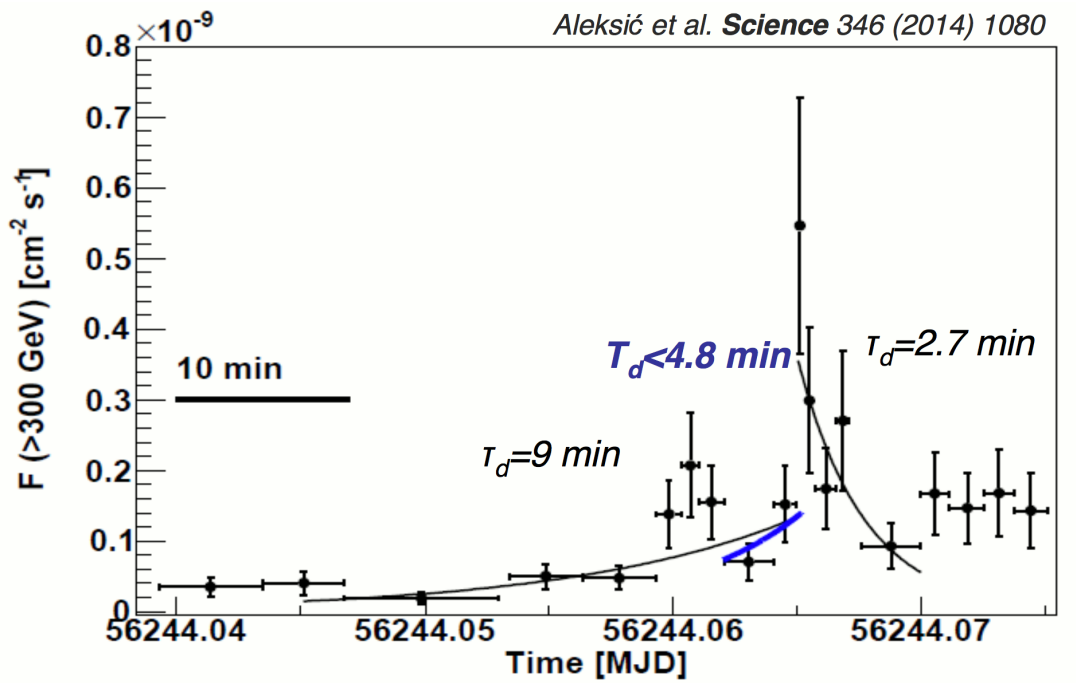


White dwarf + red giant; erupts every 15 to 20 years

- 2021: first nova ever seen at TeV energies (H.E.S.S., MAGIC, LST-1)
- The gamma rays reveal accelerated protons
- LST-1: from day 1, down to ~30 GeV; proton energies grow from ~0.3 to ~1.6 TeV in 4 days

MAGIC Coll. (Acciari et al.) 2022, Nat. Astron. 6, 689 · H.E.S.S. Coll. (Aharonian et al.) 2022, Science 376, 77 · CTAO-LST Coll. (Abe et al.) 2025, A&A 695, A152

Black-hole lightning



< 5 min

flux-doubling time at TeV energies (radio galaxy IC 310)

- Black hole of ~300 million Suns: its horizon is as large as Jupiter's orbit
- Light needs ~50 min to cross it

The flaring region is smaller than the black hole itself!

MAGIC Coll. (Aleksić et al.) 2014, Science 346, 1080

The “BOAT”, under a full Moon



- GRB 221009A: the Brightest Of All Time
- LHAASO caught the early TeV afterglow (>60,000 photons)
- LST-1: observed 1.3 days later, under full Moon
- A jet with a narrow, ultra-fast core inside a wider, slower sheath

Observing when others cannot: a MAGIC tradition, continued by the LSTs

LHAASO Coll. 2023, Science 380, 1390 · CTAO-LST Coll. (Abe et al.) 2025, ApJL 988, L42

GRBs: from a handful to a population

5

TeV GRBs detected so far
(2018–2022)

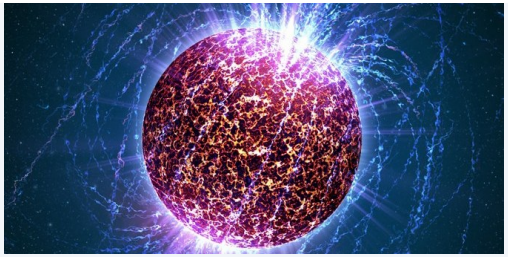
~4 per year

expected with CTAO

- Early afterglows at tens of GeV: exactly where the LSTs excel
- Distant bursts ($z > 1$), despite the EBL
- A first firm TeV detection of a short GRB? (MAGIC hint: GRB 160821B)

Ashkar et al. 2024, ApJ 964, 57 · MAGIC Coll. (Acciari et al.) 2021, ApJ 908, 90

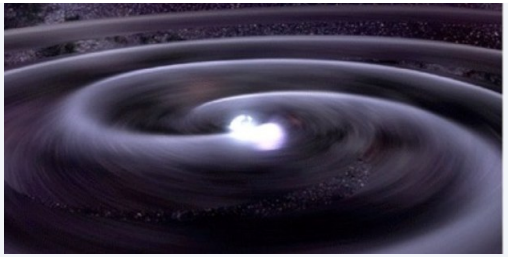
Rehearsals for the big events



Magnetar SGR 1935+2154

- Nine X-ray bursts, 0.1-second windows
- TeV flux < 1/1000 of the X-ray flux

CTAO-LST Coll. (Abe et al.) 2026, A&A 706, A25



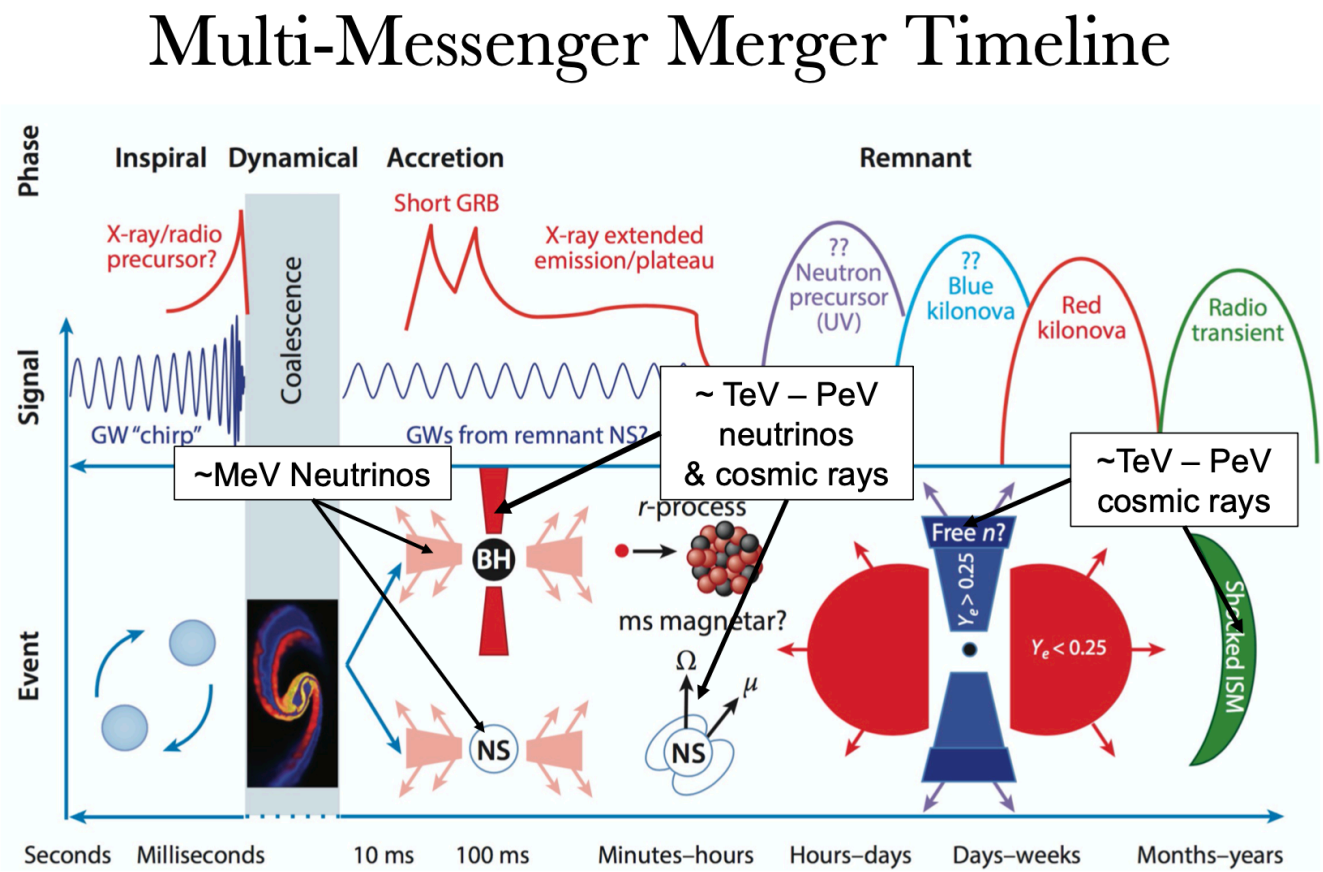
Gravitational-wave alerts

- GW240615: best localisation ever
- GW241125: possible Swift counterpart
- No TeV signal: first limits

MAGIC & CTAO-LST Colls. (Abe et al.) 2026, PASP 138, 084101

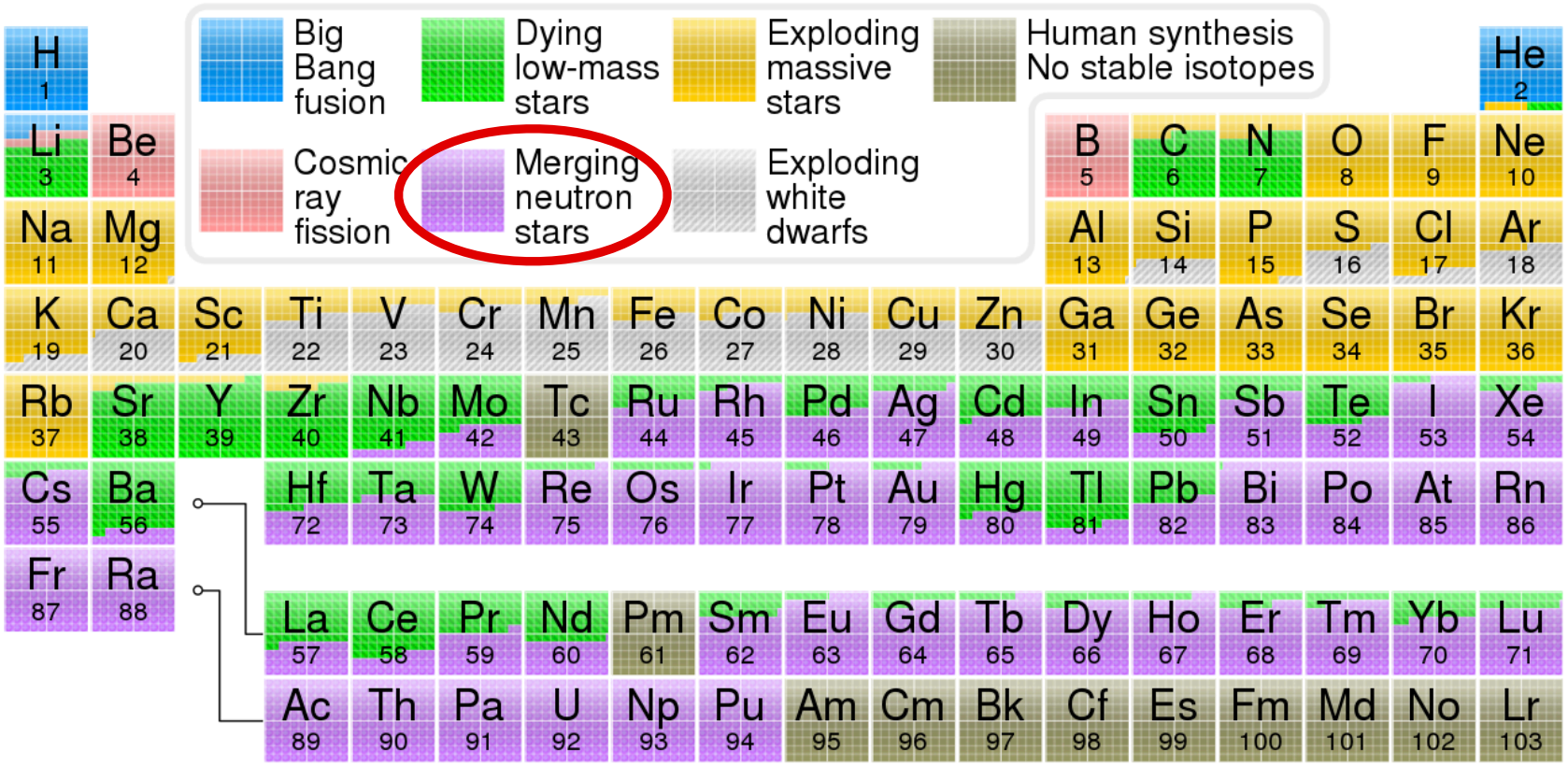
The fast-alert machinery is in place: waiting for the big one

The multi-messenger timeline of a merger



Fernández & Metzger 2016, Annu. Rev. Nucl. Part. Sci. 66, 23

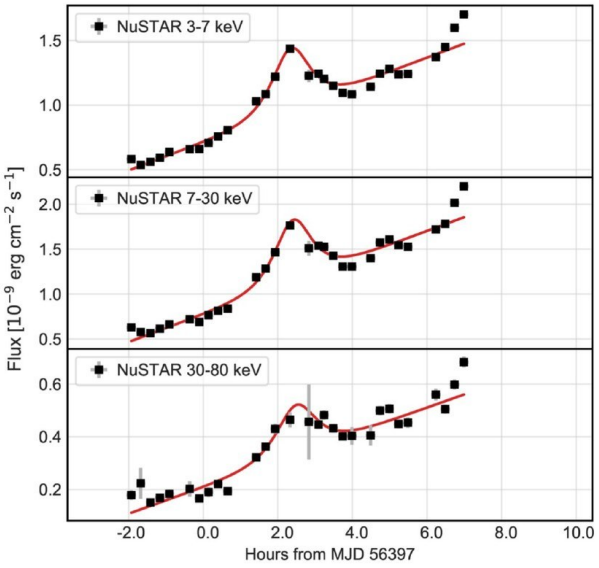
Why care? The gold in your ring

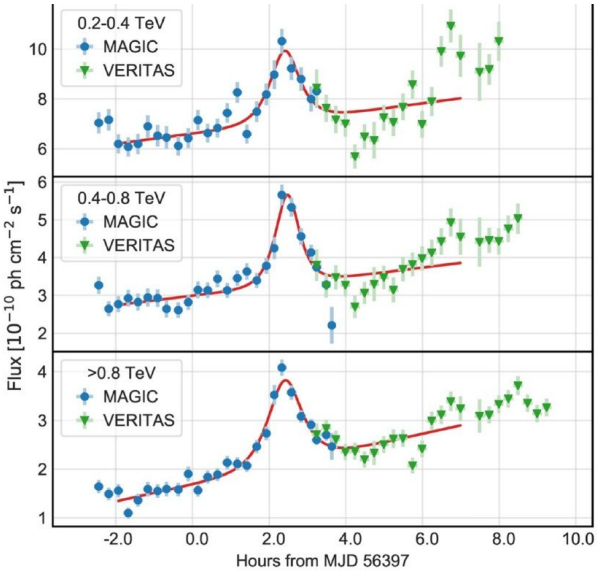


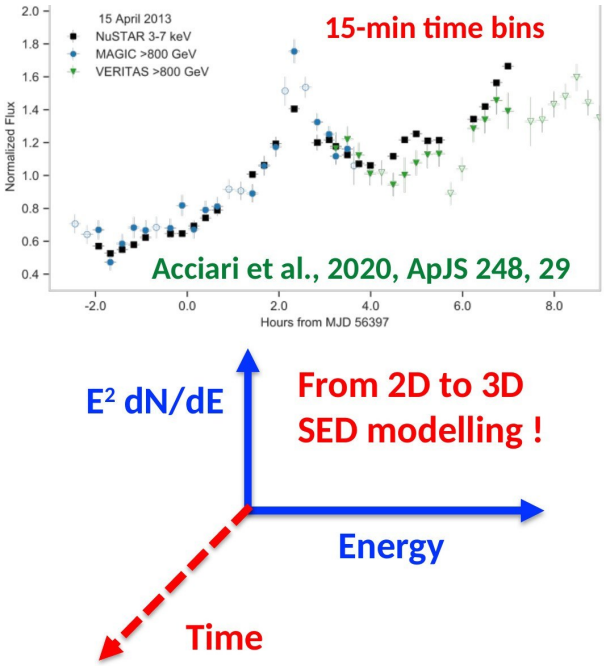
Much of the gold and platinum on Earth was probably forged when neutron stars merged

Periodic table of origins: Johnson 2019, Science 363, 474

AGN: Time profile of emission break degeneracies







- Mrk 421, April 2013: 240 broadband spectra, 15 minutes apart
- **With the LSTs: minute-by-minute spectra down to 20 GeV, also for distant quasars**

Temporal information can break many model degeneracies

MAGIC Coll. et al. 2026, ApJ 998, 6 · Acciari et al. 2020, ApJS 248, 29

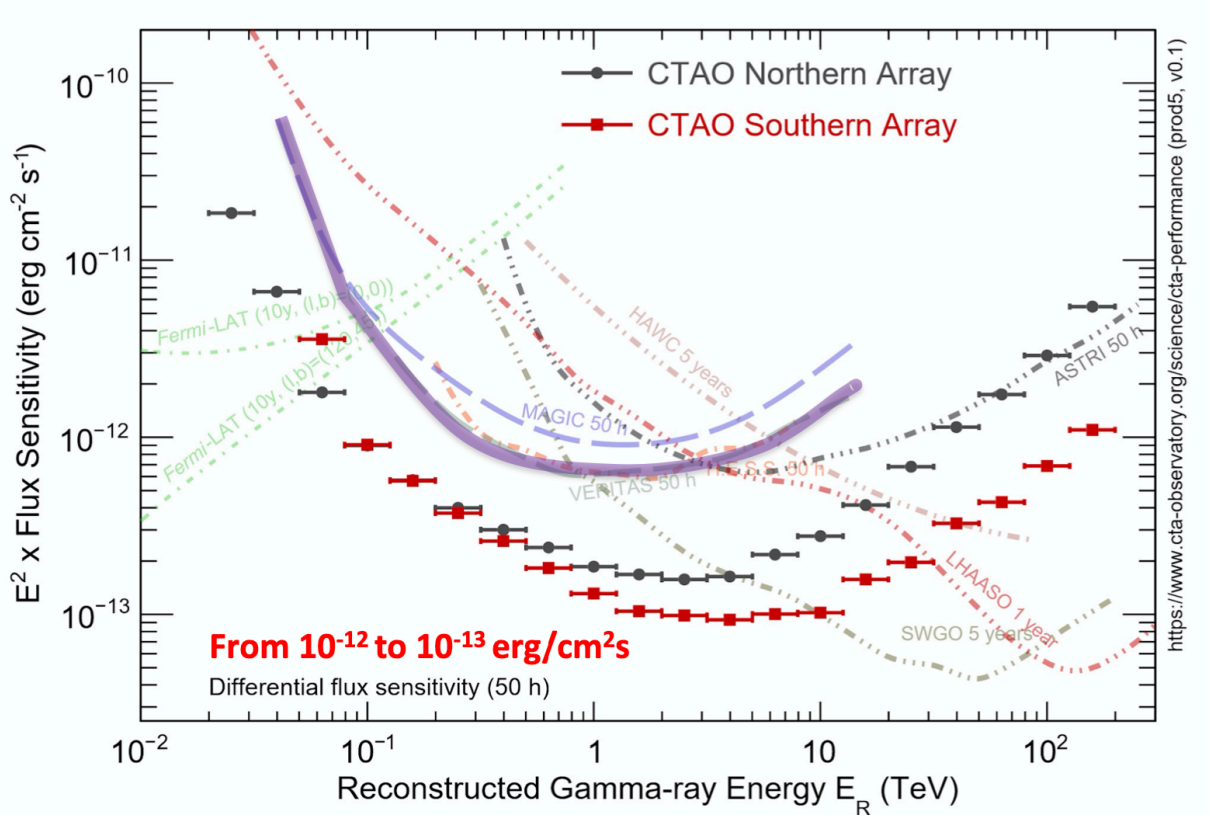
Space, Cherenkov telescopes, air-shower arrays

	Fermi-LAT	IACTs	LHAASO
Duty cycle	~85%	~10%	~90%
Field of view	20–60°	2–4°	30–40°
Effective area	~1 m^2	~10^5 m^2	~10^4–10^6 m^2
Energy range	0.02–300 GeV	20 GeV–100 TeV	1 TeV–10 PeV
3% Crab (point)	—	~3 hours	~5 years

Complementary: air-shower arrays rule above 10 TeV; IACTs for sub-TeV transients

Sitarek 2022, Galaxies 10, 21

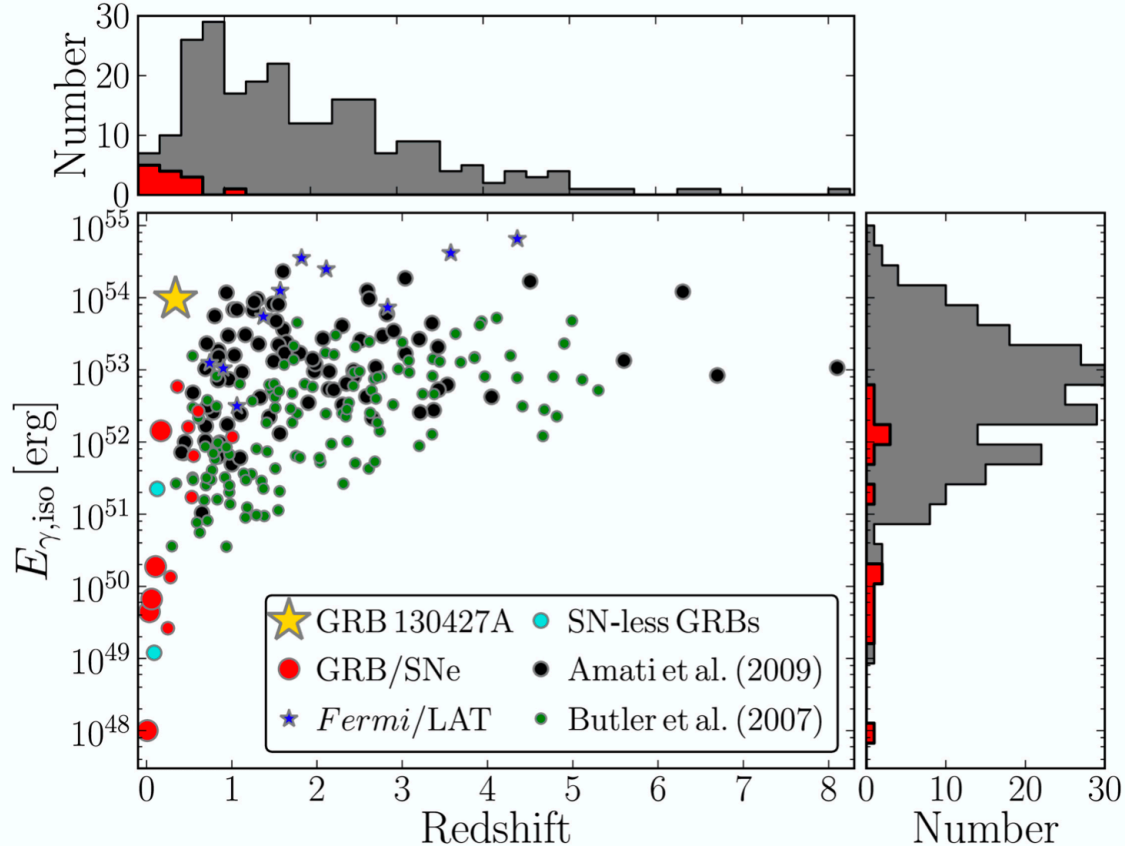
CTAO sensitivity (50 hours)



- About 5× better than the current Cherenkov telescopes
- Wider energy range: 20 GeV to 300 TeV
- Below ~100 GeV: the LSTs

CTAO performance, prod5 (www.ctao.org)

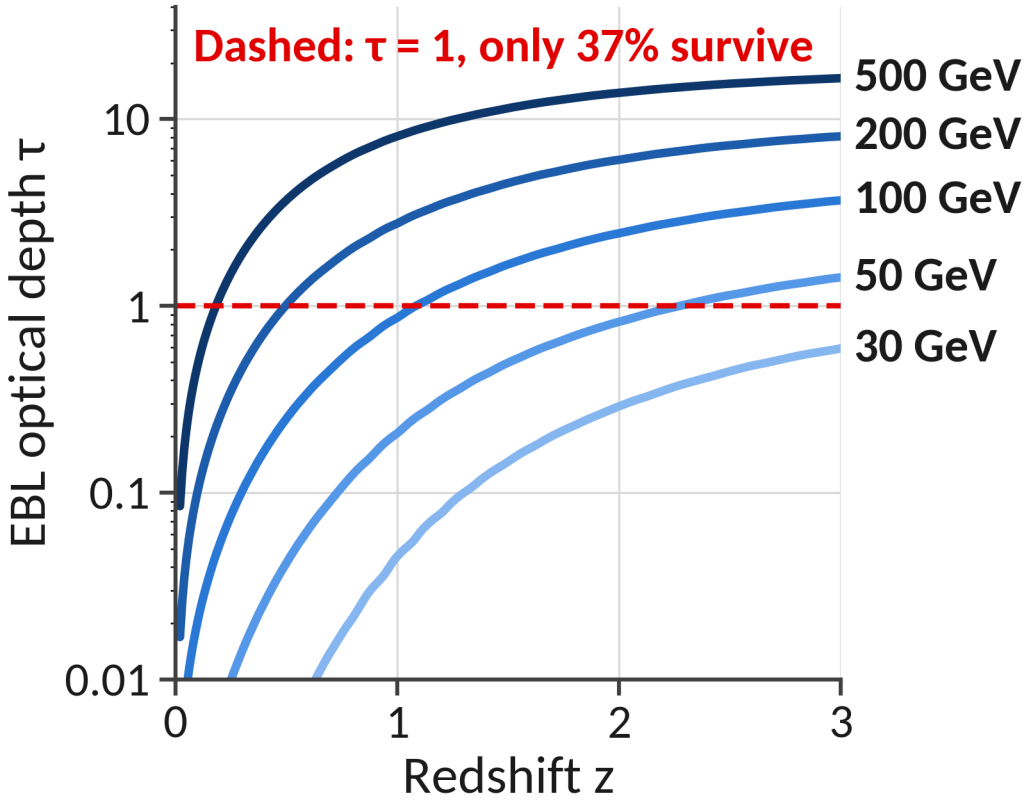
Most GRBs are far away



- Most GRBs come from redshift > 1
- Their light left more than 7.9 billion years ago, when the Universe was less than half its present age
- → the low energy threshold of the LSTs is essential

Levan et al. 2016, Space Sci. Rev. 202, 33

The EBL: why we need to go below 100 GeV



- Gamma ray + EBL photon → electron–positron pair
- z = 1: 80% survive at 50 GeV, only 6% at 200 GeV
- z = 2: 44% survive at 50 GeV, only ~1% at 150 GeV

Below 100 GeV (even better: below 50 GeV), the distant Universe opens up

EBL model: Saldana-Lopez et al. 2021, MNRAS 507, 5144