Universitat Autònoma de Barcelona

Institut de Física d'Altes Energies

MAGIC
Major Atmospheric Gamma Imaging Cerenkov Telescopes

MAGIC Follow-up of Gravitational Wave Events

Artero Manuel
- for the MAGIC-GW team

@ Virtual Iberian Gravitational Wave Meeting
- October 19-20, 2020

OUTLINE

- MAGIC TELESCOPE SYSTEM
- MAGIC AUTOMATIC ALERT SYSTEM
- GW FOLLOW-UP STRATEGY
- MAGIC'S FOLLOW-UP OF GW EVENTS
- OUTLOOK

MAGIC Telescopes

- The MAGIC telescope system:
  - Two **Cherenkov telescopes** located at **La Palma**
  - Mirror diameter: **17 m**
  - FoV: **3.5 °**
  - Angular resolution: **0.1 deg @ 100 GeV**
  - Energy range: **50 GeV** to **50 TeV**
  - Pointing speed **~7 deg/s (~25 s for 180 deg**)
- Science cases for transient follow-ups:
  - GRBs (Gamma Ray Bursts)
  - Neutrino alerts
  - FRBs (Fast Radio Bursts)
  - Magnetars (Galactic origin)
  - Flaring AGNs
  - **GW (Gravitational Waves) -> signed MoU with LIGO/Virgo in 2014**
    - Rely on external triggers generated by large FoV instruments and distributed through the GCN (**Gamma-ray Coordinates Network)** system.

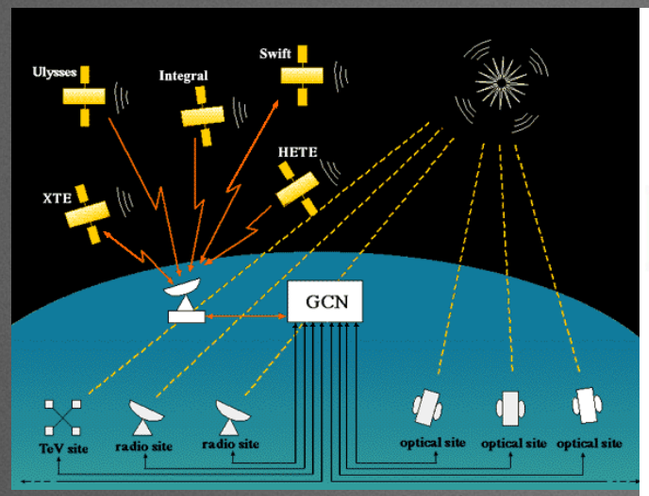

Image Credit: NASA

Automatic Alert System

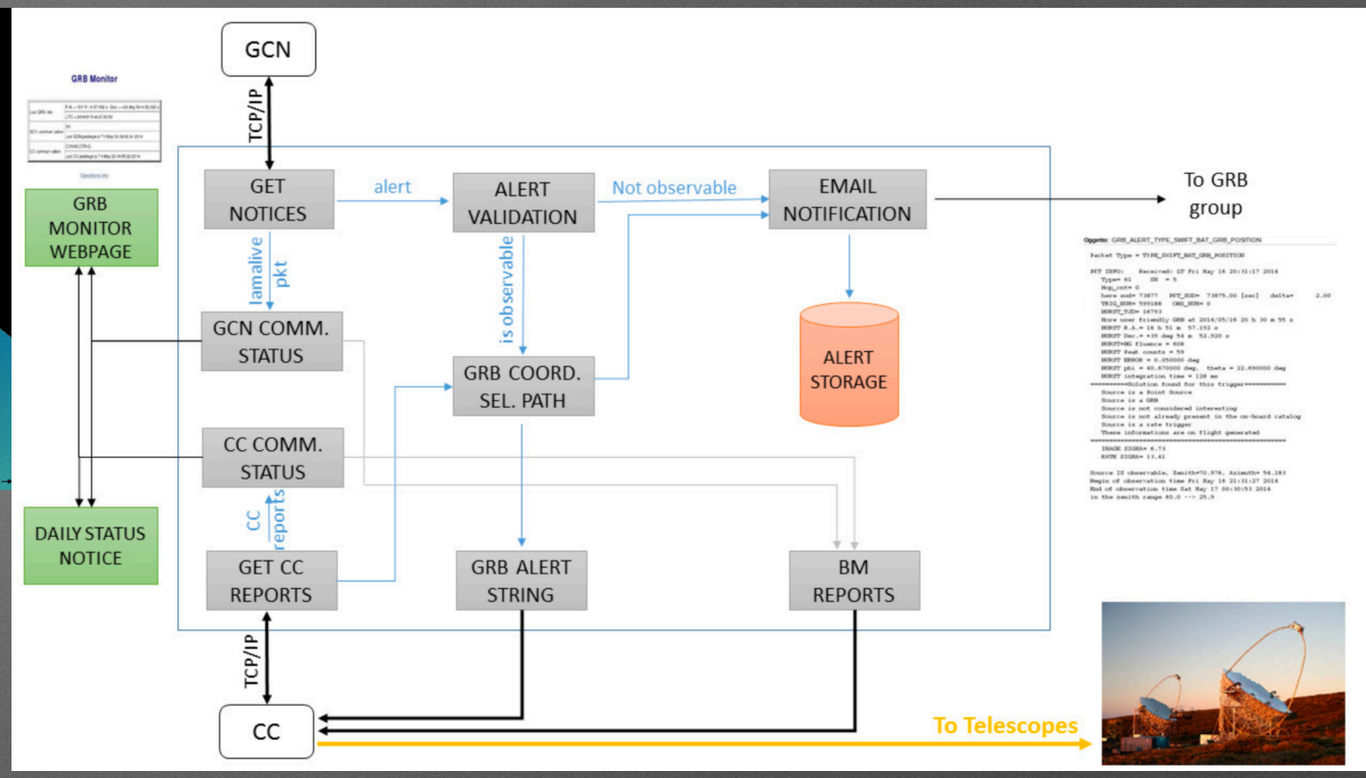

Image Credit: A. Carosi

- The MAGIC **Automatic Alert System (AAS)** is a multi-thread C program that manages the communication between **GCN** and the **Central Control software** of the MAGIC telescopes. Its main tasks consist of:
  - Receive and validate the alerts coming from the GCN
  - Decode the content of the alerts, in particular the **coordinates of the target**
  - Check the **visibility of the target** from the MAGIC site, according to **predefined criteria:**
    - Sun zenith > 103 deg
    - Zenith angle of target < 60 deg
    - Angular distance moon-target > 30 deg
    - Additional filters for Fermi-GBM alerts
  - If the target is observable, start the **automatic repointing procedure**.
- This workflow is currently used for GRB and neutrino alerts.

Automatic Alert System

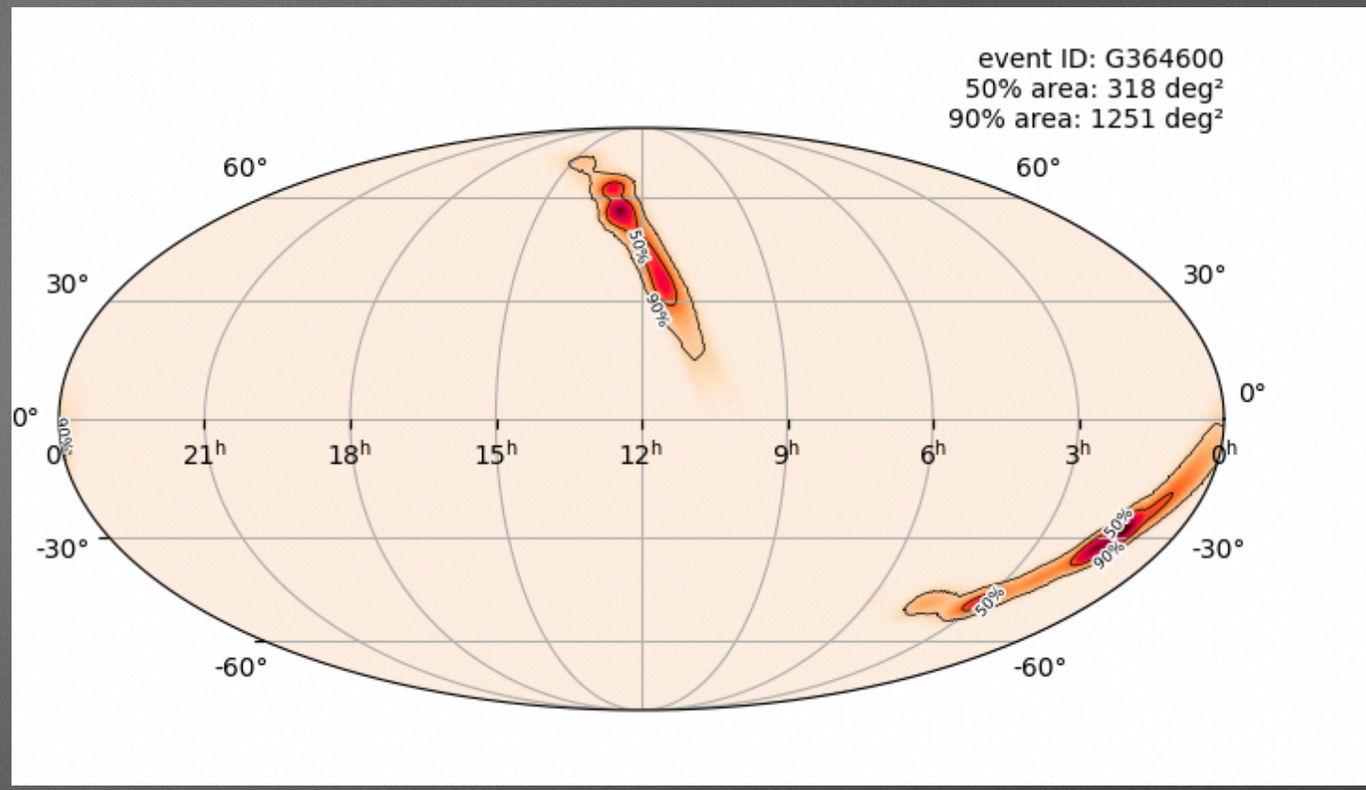

Image Credit: GraceDB

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What about GW alerts?!?

GW Follow-up Strategy

- *AUTONOMOUS FOLLOW-UP*
- *FOLLOW-UP OF IDENTIFIED TRANSIENTS*
- *OBSERVATION OF DELAYED EMISSION*

Image Credit: D. Lopez

GW Follow-up Strategy

Image Credit: D. Lopez

- ***AUTONOMOUS FOLLOW-UP***
  - 3-step Process for well localised events (~ 10° at 90% CL):
    1. Compute the visibility of the sky positions from the MAGIC site at different times.
    2. For those sky locations with good visibility, provide an ordered list of pointings. The order is given taking into account the galaxy catalogs (see next slides).
       An alternative approach is given in Patricelli et al. 2018, where the authors elaborate how to optimise the sequence and the duration of observations, thus maximising both the probability of a detection in a single snapshot and the coverage of the uncertainty region.
    3. Once the pointing list is defined, the telescopes will be repositioned to the targets position using the automatic procedure through the AAS

- *FOLLOW-UP OF IDENTIFIED TRANSIENTS*
- *OBSERVATION OF DELAYED EMISSION*

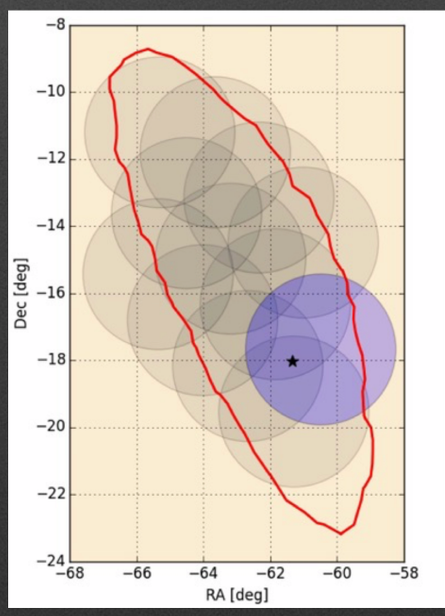
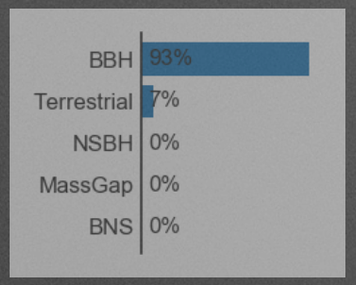


Image Credit: Patricelli et al. 2018

INTERLUDE I:

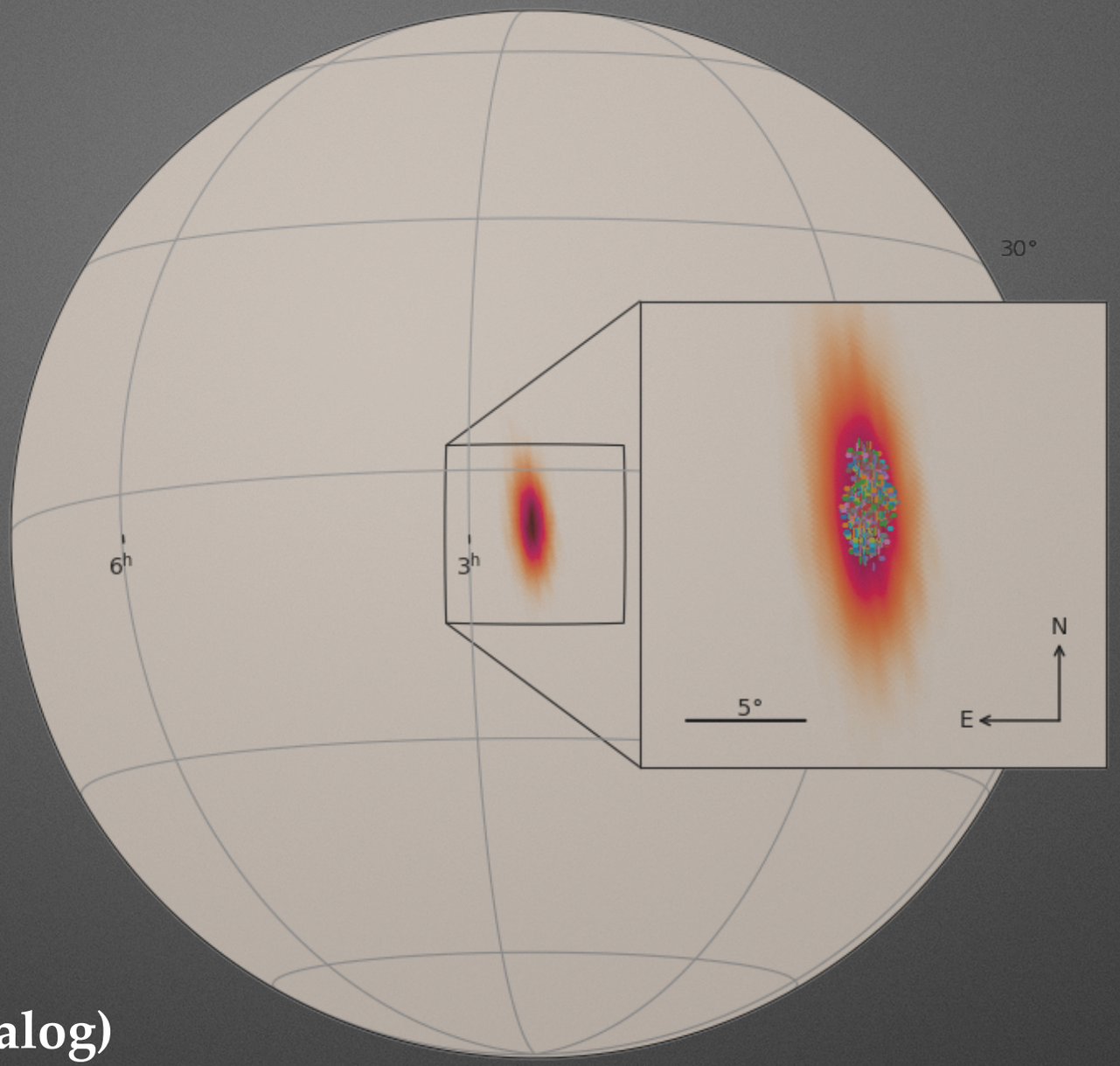
GALAXY RANKING



JUL 5. 2019

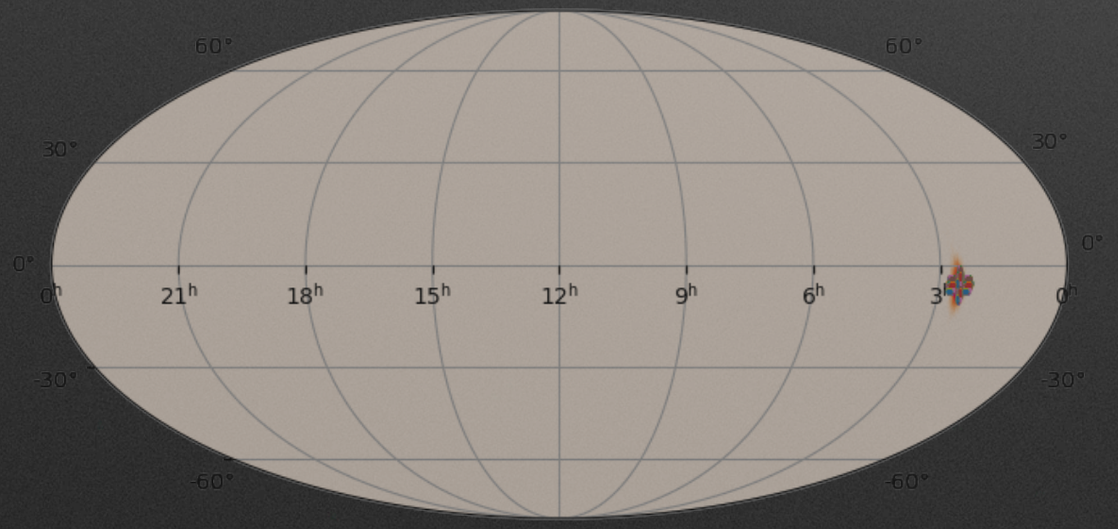
S190701ah

uncertainty region: 49 deg^2



10 % credible volume

164 Galaxies (GladeV2 catalog)



SDSSJ023056.22-070500.5
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SDSSJ023245.97-074639.5
SDSSJ023114.84-072908.4
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SDSSJ023327.59-061918.6
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SDSSJ022915.54-050521.4
SDSSJ022904.73-051618.7
SDSSJ023034.79-051044.1
SDSSJ023041.97-051055.7
SDSSJ023008.45-050550.3
SDSSJ023008.89-050554.4
SDSSJ023302.35-050535.9
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SDSSJ023411.67-050505.7
SDSSJ023102.63-044632.7
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SDSSJ023055.67-042154.5
SDSSJ023130.55-042046.7
SDSSJ023220.73-041927.4
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SDSSJ023059.68-035518.7
SDSSJ023235.83-035726.2
SDSSJ023333.93-033108.2
SDSSJ023325.70-032741.7
SDSSJ023051.49-052708.2
SDSSJ023338.67-051736.0
SDSSJ023346.48-051856.3
SDSSJ023032.00-045922.5
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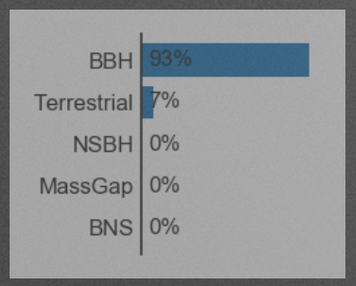
INTERLUDE I:

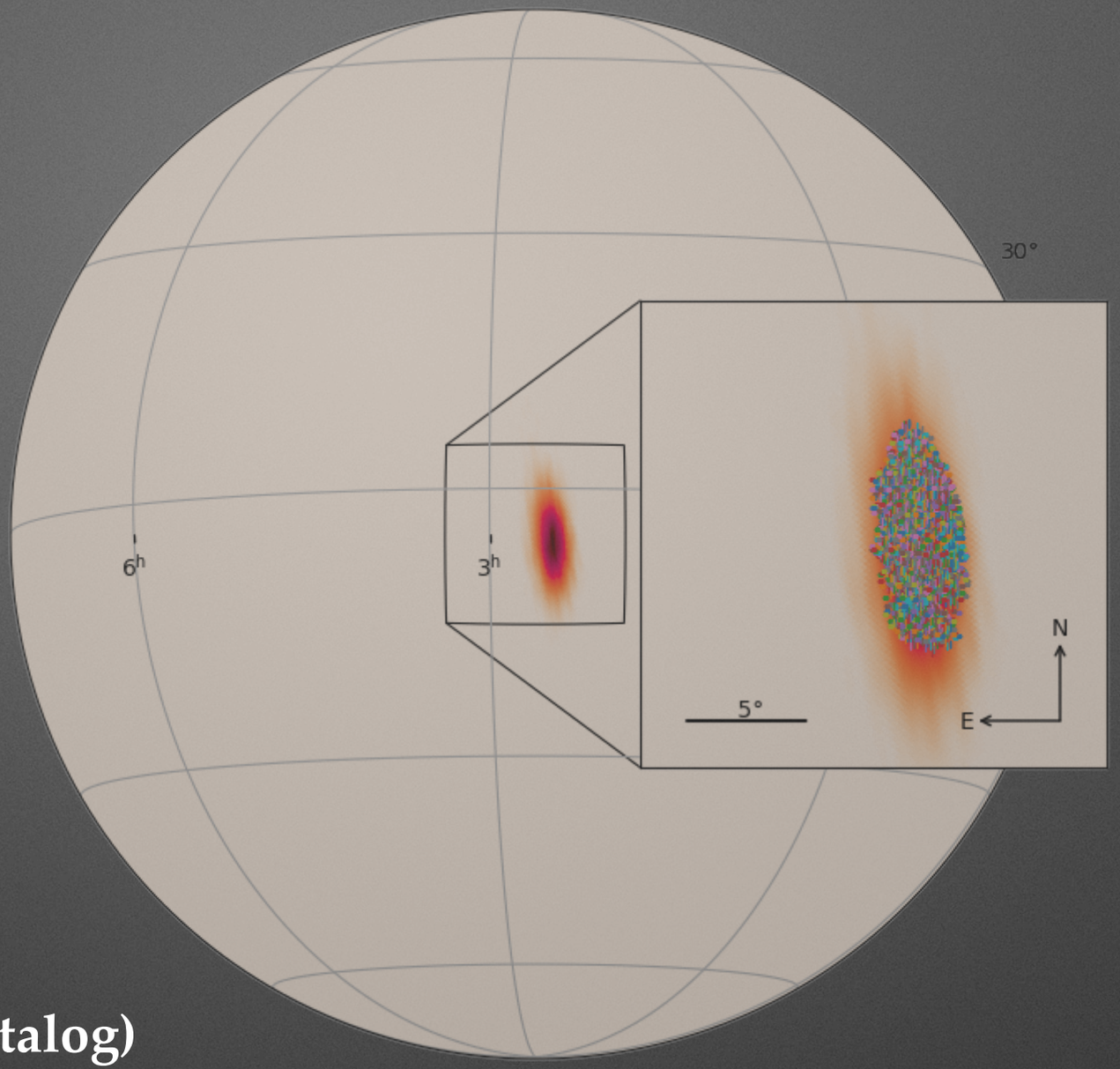
GALAXY RANKING



JUL 5. 2019

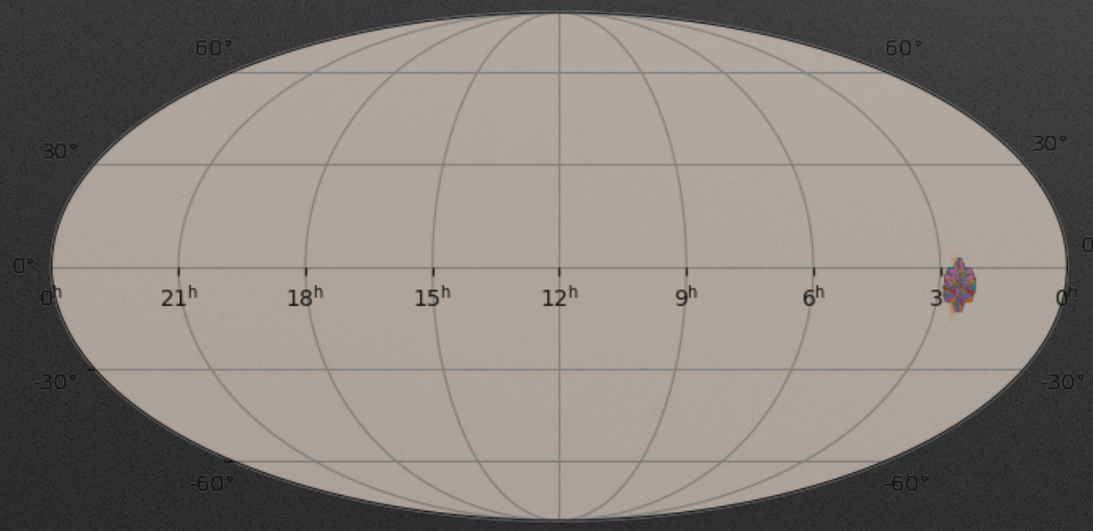
S190701ah

uncertainty region: 49 deg^2



50 % credible volume

1238 Galaxies (GladeV2 catalog)



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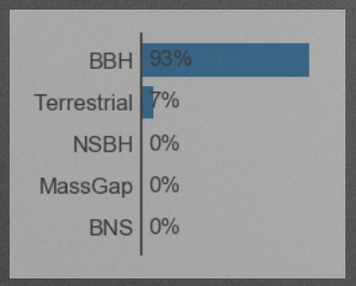

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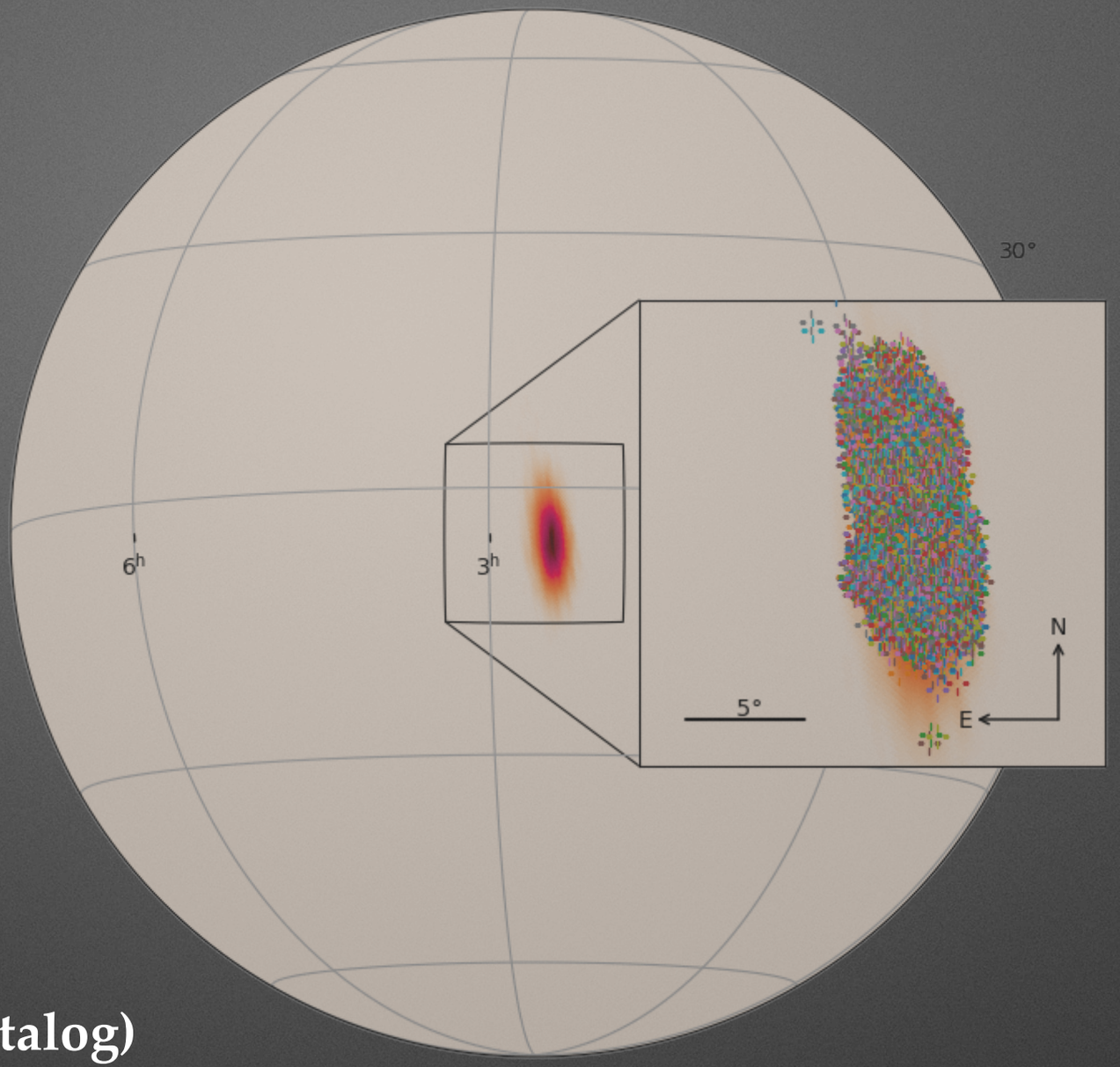
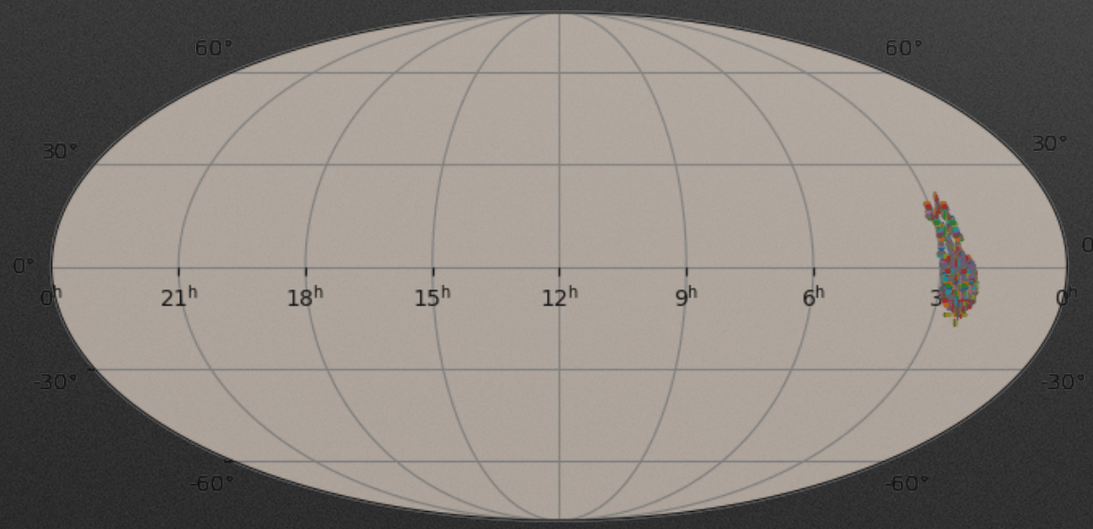


90 % credible volume

6464 Galaxies (GladeV2 catalog)



GW Follow-up Strategy

Image Credit: D. Lopez

- *AUTONOMOUS FOLLOW-UP*
- ***FOLLOW-UP OF IDENTIFIED TRANSIENTS***
  - This observational case falls in the standard automatic follow-up procedure if the putative EM counterparts are distributed through **GCN alerts**. Otherwise, if communicated through other channels (**ATels, GCN Circulars**), the observation of such counterparts will be scheduled accordingly.
- *OBSERVATION OF DELAYED EMISSION*

GW Follow-up Strategy

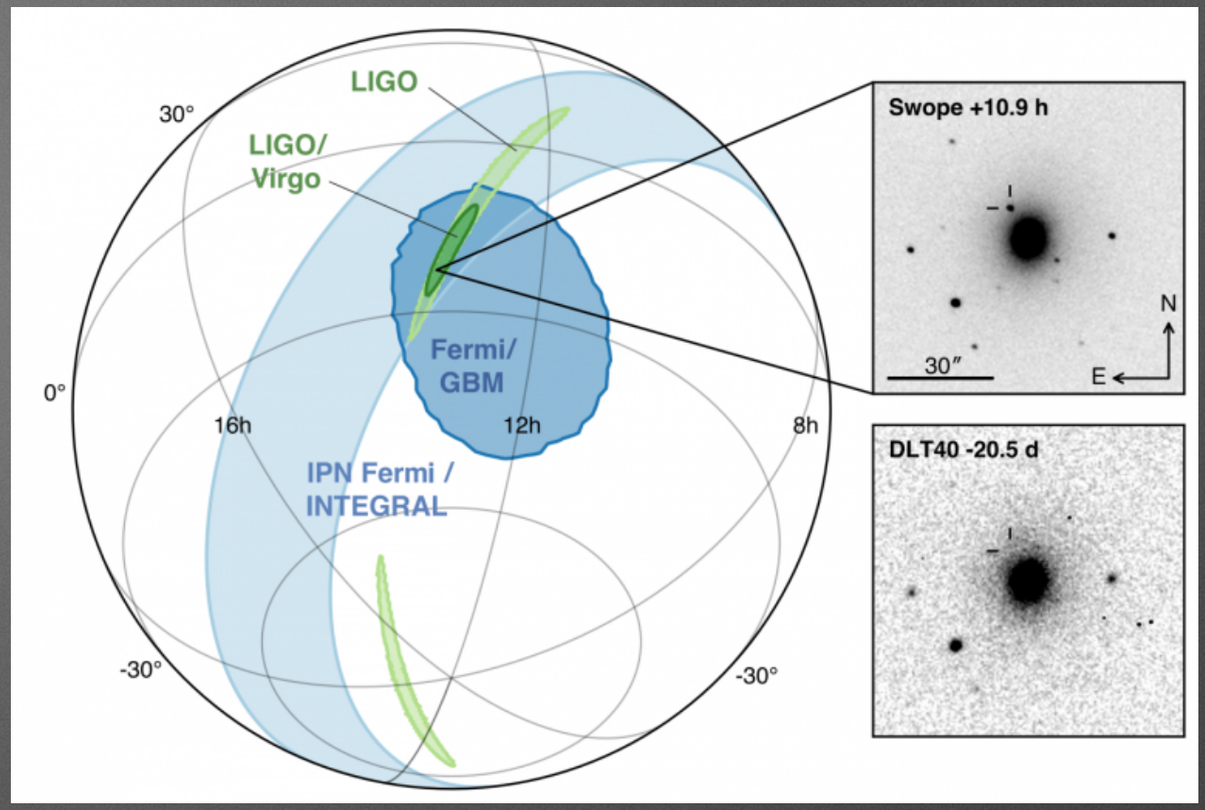


Image Credit: Abbott+ (GRAWITA), 2017

- *AUTONOMOUS FOLLOW-UP*
- *FOLLOW-UP OF IDENTIFIED TRANSIENTS*
- *OBSERVATION OF DELAYED EMISSION*
  - In the case an **off-axis GRB** is associated to the GW signal, a **delayed EM emission** on timescales of **weeks/months** is expected, as happened in the case of **GW170817/GRB 170817A.** These observations will be scheduled as information from EM partners will define the best time windows.

GAMMA RAY BURSTS

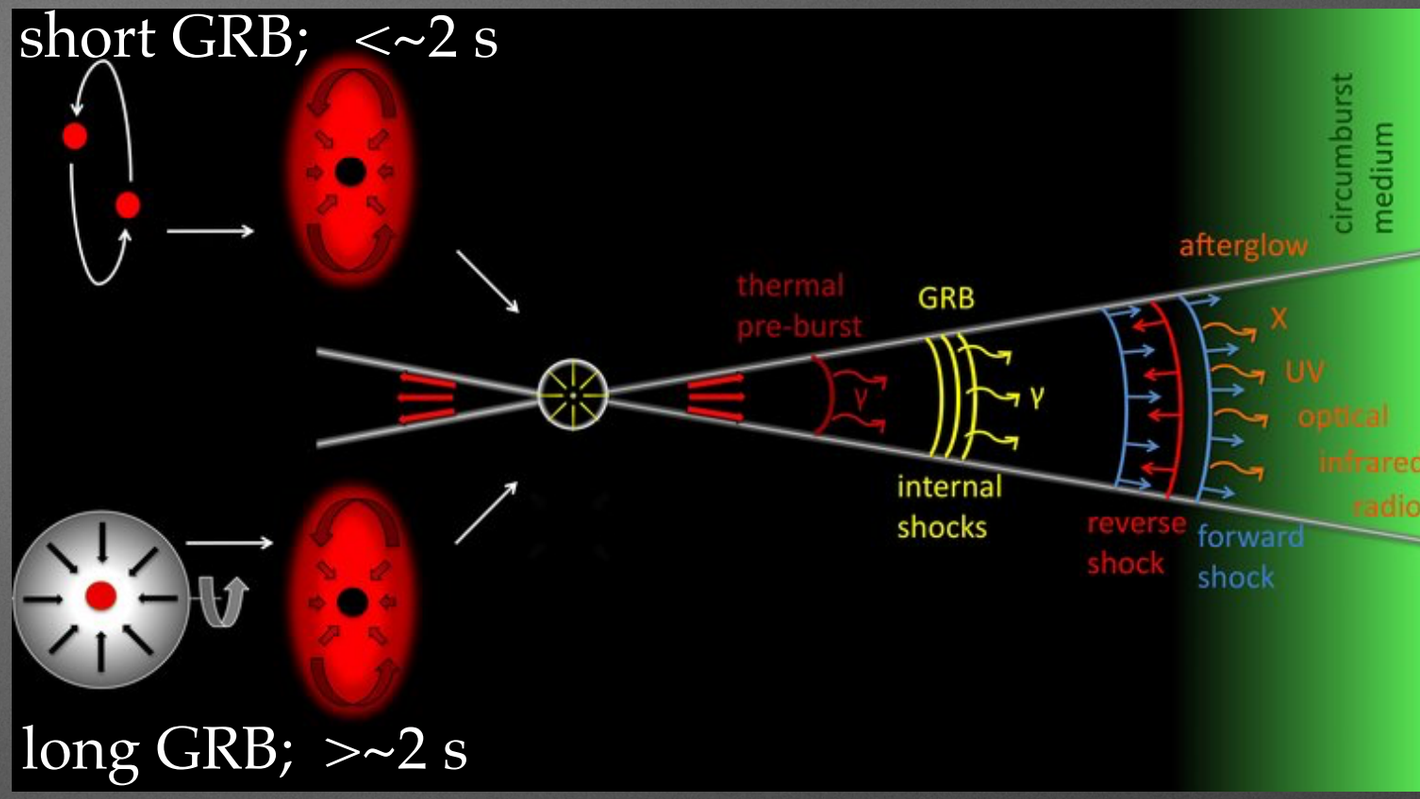


Image Credit: adapted from A. Gomboc 2012

TEV DOMAIN

GRBs & MAGIC

- *GRB190114C*
- *GRB160821B*

GAMMA RAY BURSTS

TEV DOMAIN

GRBs & MAGIC

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.

- *GRB190114C* ***(AKA THE LONG-ONE)***
  - The observational conditions were unfavourable:
    - Pointing started at large zenith angle (**~55 deg**) and setting
    - Moonlight conditions
  - MAGIC detection triggered vast multi-wavelength follow-up efforts by many instruments/observatories:
    - **Gamma-rays:** Fermi-LAT, Fermi-GBM, AGILE
    - **X-ray:** Swift-XRT, XMM, NUSTAR, INTEGRAL, …
    - **Optical:** Swift-UVOT, NOT, GTC, VLT, LT, Pan-STARRS, NTT, GROND, REM, HST, …
    - **Radio**: VLA, ALMA, ATCA, RT-22, MeerKAT, GMRT
- *GRB160821B*

GAMMA RAY BURSTS

TEV DOMAIN

GRBs & MAGIC

- *GRB190114C*
- *GRB160821B* ***(AKA THE SHORTY)***
  - The observational conditions were unfavourable:
    - Moonlight conditions
  - Hint of detection on the short GRB160821B by MAGIC
    - S. Inoue, ICRC 2017; K. Noda, Texas Symposium 2017; Berti et al., 2019, Proc. MG15
    - z=0.16, recently associated to a kilonova (ejection of heavy elements by NS merger)
      - Lamb et al. 2019 arXiV:1905.02159, Troja et al. arXiV:1905.01290
  - **Possible signal. Potential implications for TeV follow-up of GWs, potential new insight into NS mergers.**

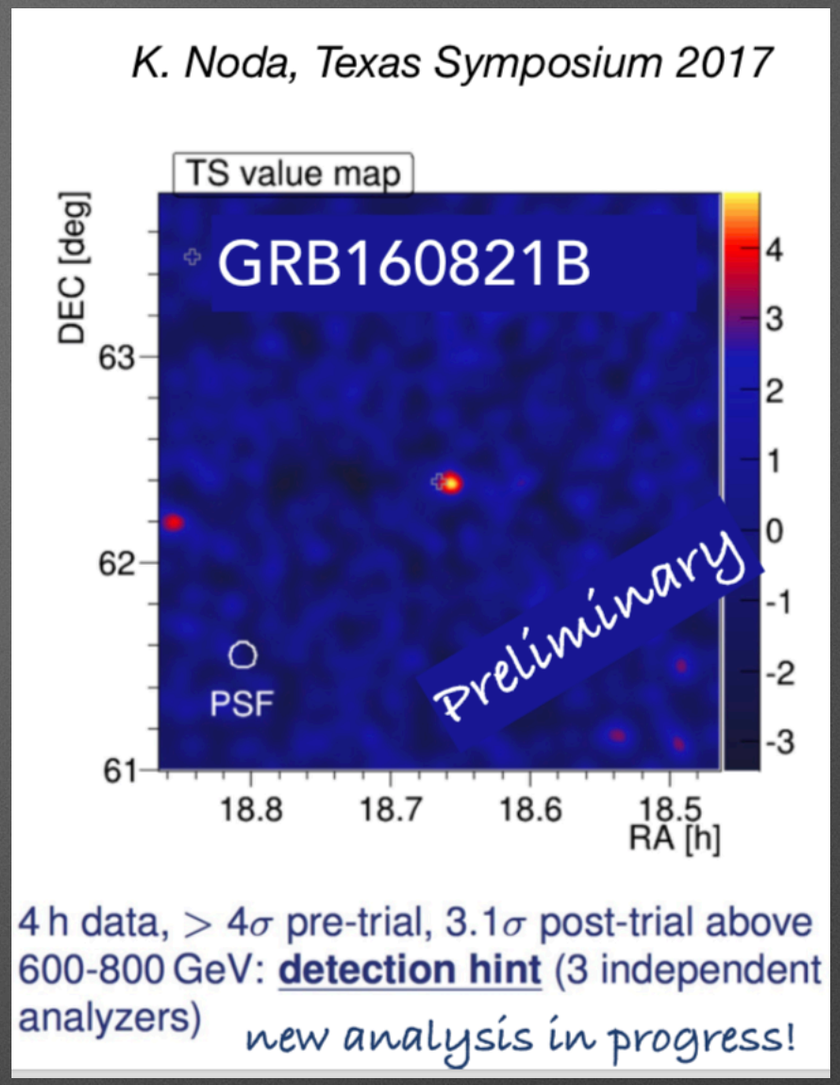


Image Credit: A. Stamerra

MAGIC Follow-up of GW Events

- *SCIENTIFIC OBSERVATIONAL RUNS*
  - *O-1*
  - *O-2*
  - *O-3*

MAGIC Follow-up of GW Events

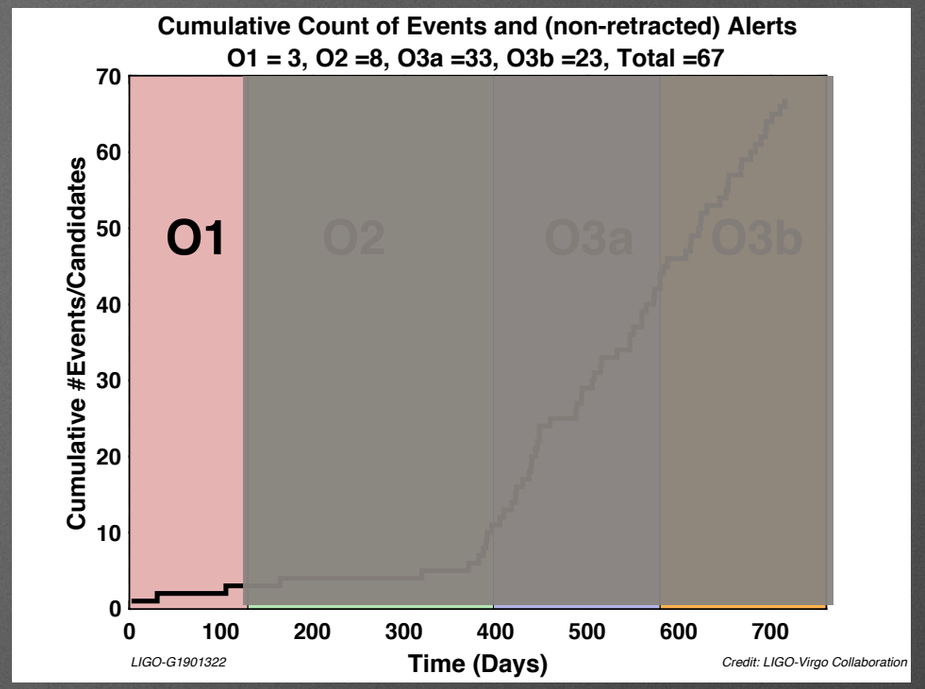
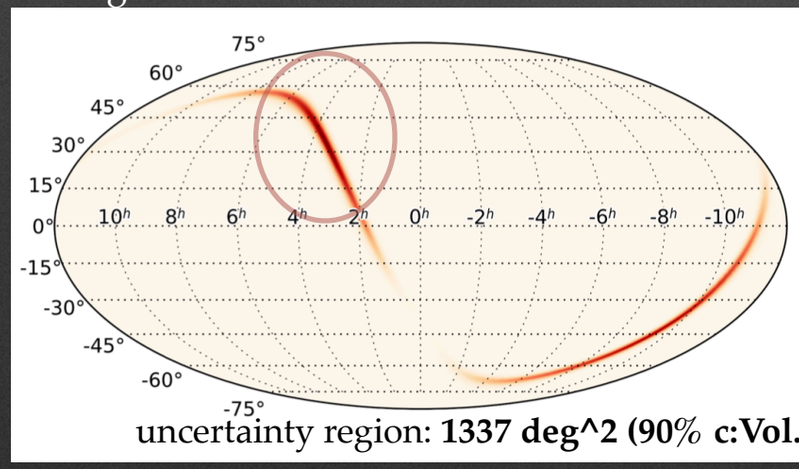


Image Credit: https://dcc.ligo.org

- *SCIENTIFIC OBSERVATIONAL RUNS*
  - *O-1*
    - Follow-up of **GW151226** (first and only IACT)
      - Four 2.5° x 2.5° regions pointed (hand-picked)
      - No excess signal found…
  - *O-2*
  - *O-3*



uncertainty region: **1337 deg^2 (90% c:Vol.)**

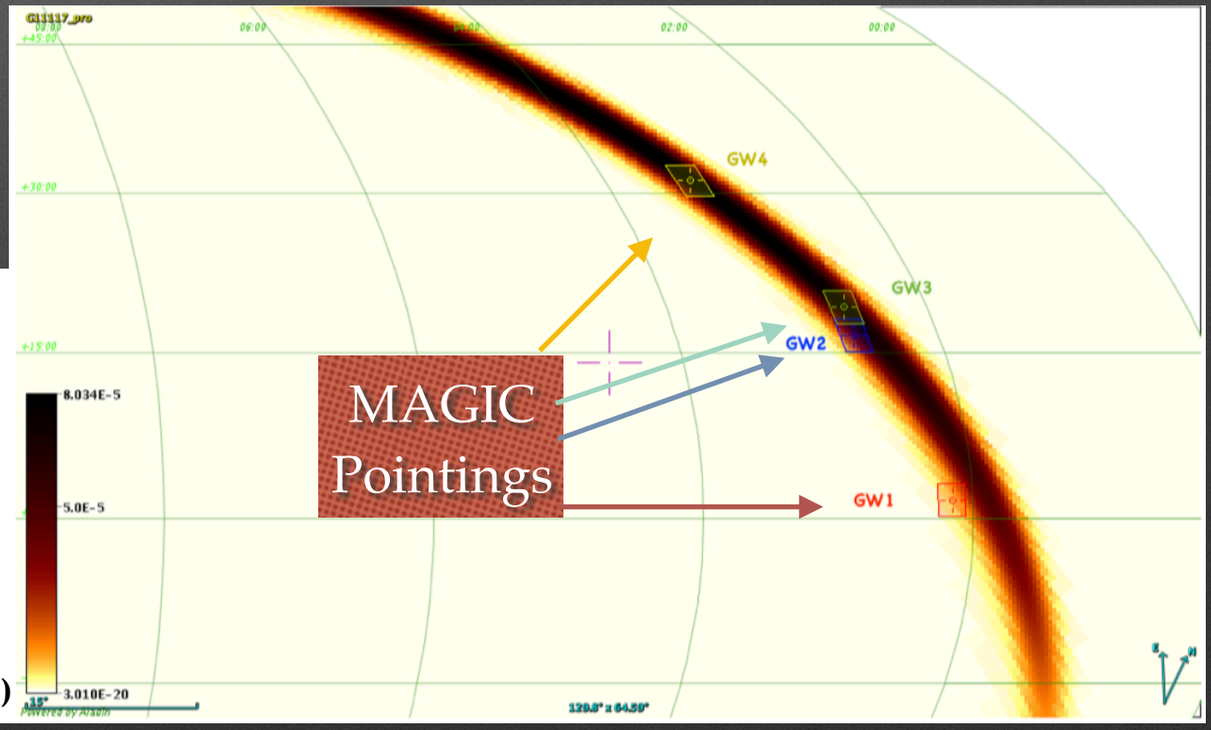


Image Credit: De Lotto et al., Proc. New Frontiers in Black Hole Astrophysics, IAU Symposium 324 (2016)

MAGIC Follow-up of GW Events

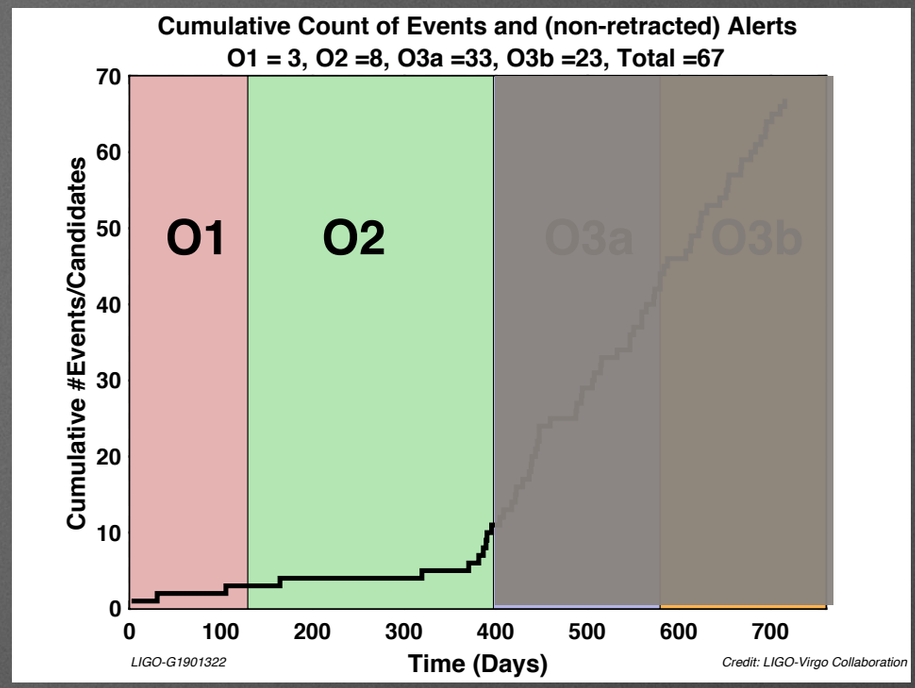


Image Credit: https://dcc.ligo.org

- *SCIENTIFIC OBSERVATIONAL RUNS*
  - *O-1*
  - *O-2*
    - Follow-up of **two** events (analysis ongoing…)
  - *O-3*

MAGIC Follow-up of GW Events

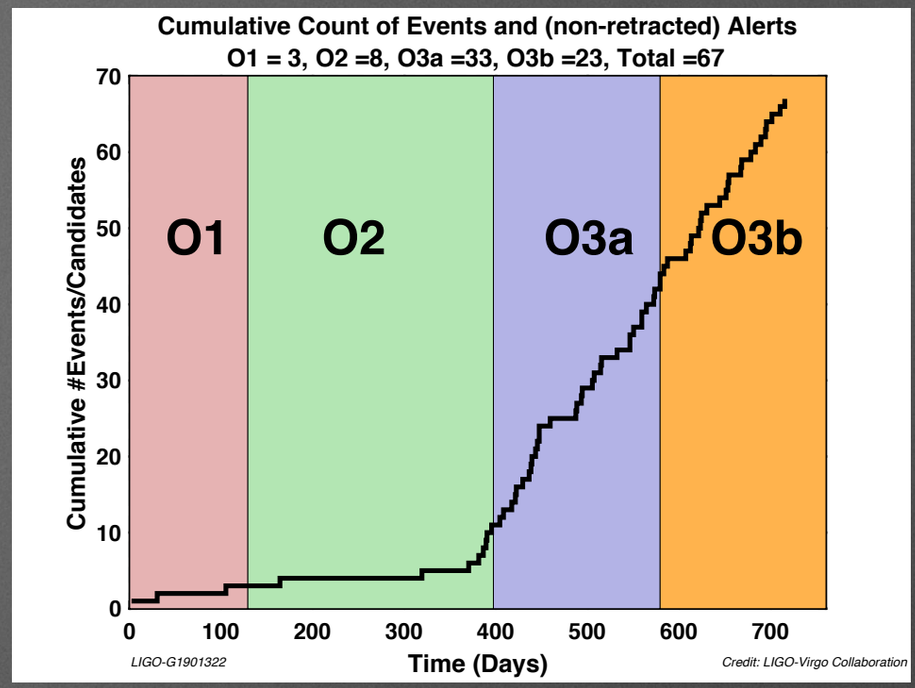


Image Credit: https://dcc.ligo.org

- *SCIENTIFIC OBSERVATIONAL RUNS*
  - *O-1*
  - *O-2*
  - *O-3*
    - *56 SOURCE CANDIDATES:*
      - ***7 BNS***
      - ***5 NSBH***
      - *37 BHBH*
      - *4 MASS GAP*

Extensive follow-up campaigns
by ever-growing MWL community

Since no reliable counterparts
& uncertainty region too wide
-> no follow-up by MAGIC

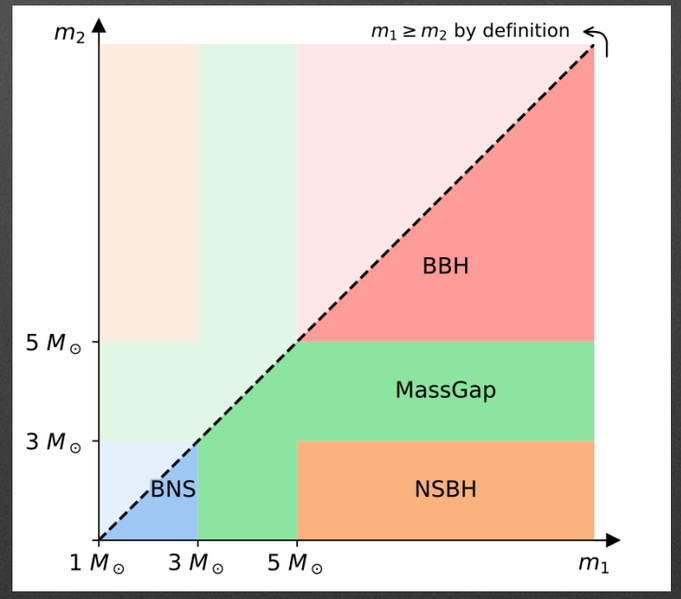


Image Credit: B. P. Abbott et al. 2020

MAGIC Follow-up of GW Events

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What about GW190814?!?

GW190814

AUG 14. 2020

S190814bv

GW190814 visibility for august 2019 ZA : 0-35 degrees Site:
MAGIC (-17.2, 28.7)
RA=1:0:0, DEC=-24:-59:-58 MJD from 58696 to 58727

august

	Period 205																	Period 206															
UT↓ - Day&rarr	30	31	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	1	2
19:00	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
19:30	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
20:00	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
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03:00(+)	65	64	64	63	63	62	62	61	61	60	60	60	59	59	58	58	58	57	57	57	56	56	56	56	55	55	55	55	55	54	54	54	54	54	54
03:30(+)	61	61	60	60	59	59	59	58	58	57	57	57	56	56	56	56	55	55	55	55	55	54	54	54	54	54	54	54	54	54	54	54	54	54	54
04:00(+)	58	58	57	57	57	56	56	56	56	55	55	55	55	55	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	55	55
04:30(+)	56	55	55	55	55	55	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	55	55	55	55	55	56	56	56	57
05:00(+)	*	*	*	*	*	54	54	54	54	54	54	54	54	54	54	54	54	54	55	55	55	55	55	56	56	56	56	57	57	57	58	58	58	59	59
05:30(+)	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
06:00(+)	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
06:30(+)	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
07:00(+)	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Day	30	31	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	1	2
Dark hours	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
(+) Change of date	Tot. dark hours in september 2019: 0																																		

Image Credit: A. Stamerra

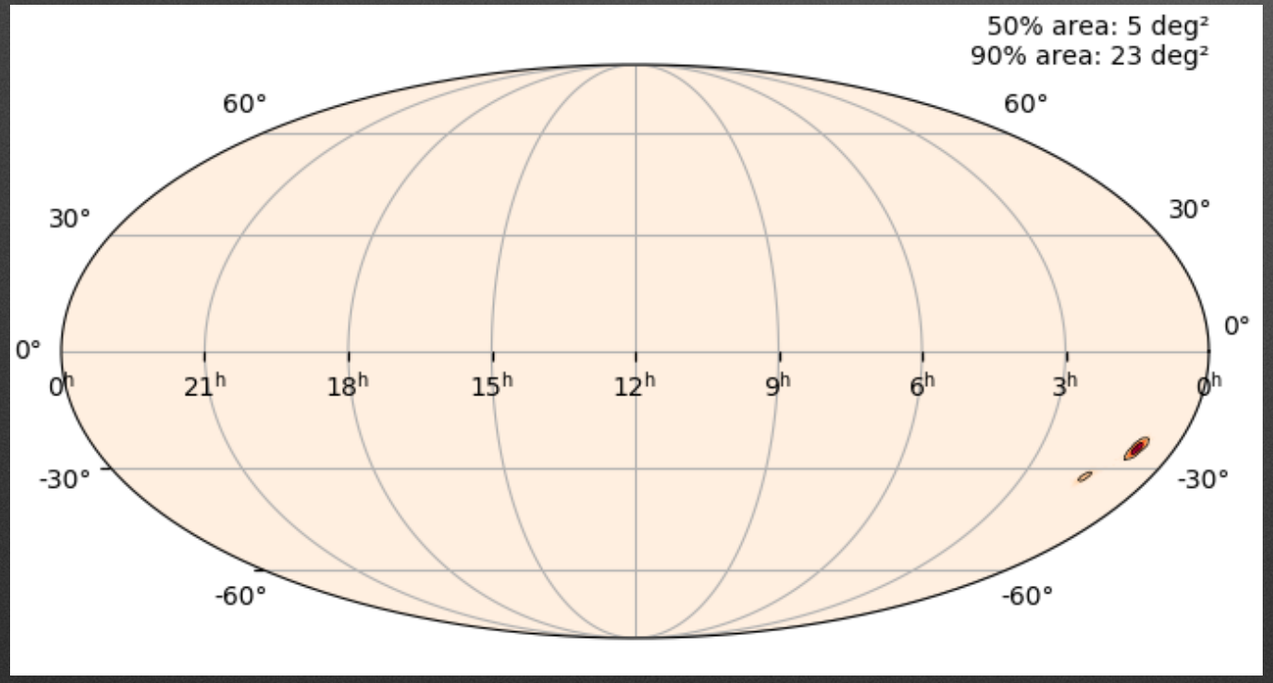

Image Credit: GraceDB

Due to the **limited duty cycle** of an IACT like MAGIC, for each GW event, depending on the information available, the benefit of performing the follow-up is evaluated. In the case of a confirmed EM counterpart, these observations have **highest priority** over other targets and so they should be performed as soon as possible. In the opposite case, when no EM counterpart is found, priority is given to the observations related to the other scientific projects.

Outlook

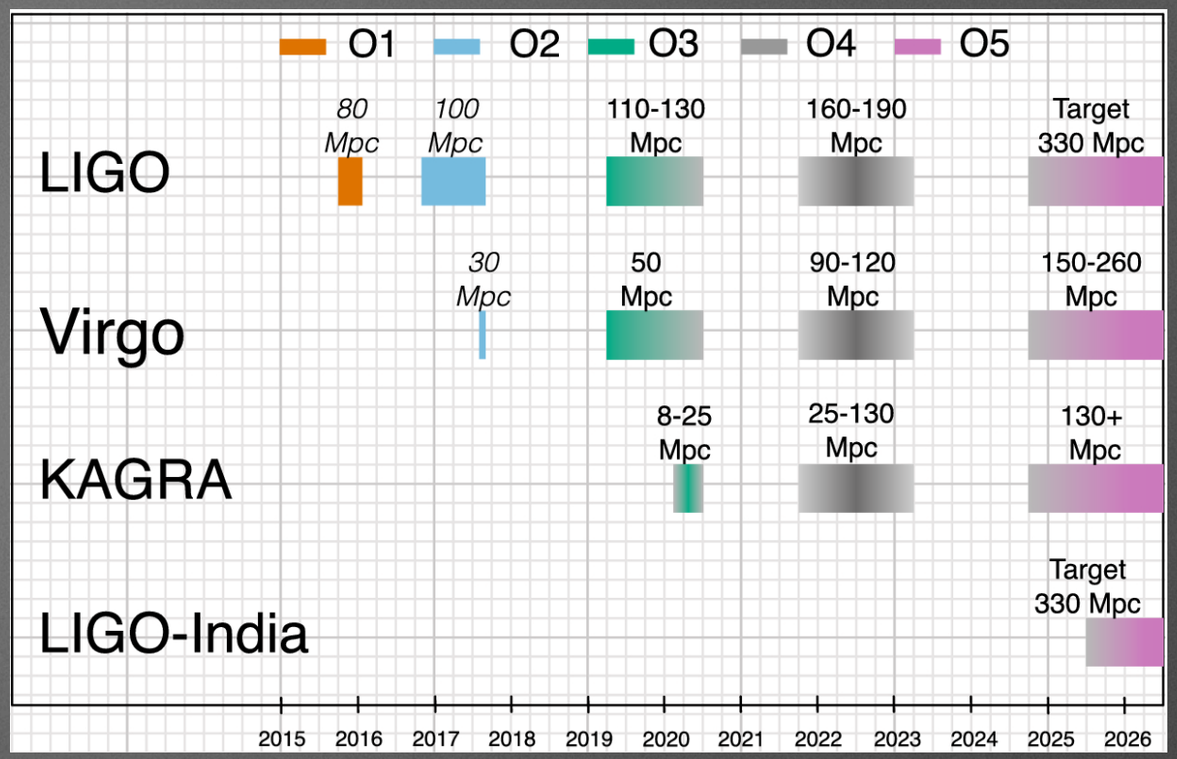

Image Credit: B. P. Abbott et al. 2020

- *STRENGTHEN & ESTABLISH BONDS WITH EXTERNAL OBSERVATORIES/EXPERIMENTS*
- *AUTOMATISATION OF THE FOLLOW-UP PROCEDURES FOR THE SCANNING AND GALAXY TARGETED APPROACHES.*
- *LOOKING FORWARD TO O-4 WITH KAGRA*

THANK YOU FOR YOUR ATTENTION!
QUESTIONS?

BACKUP

- DETECTING CHERENKOV LIGHT
  - HTTPS://WWW.CTA-OBSERVATORY.ORG/ABOUT/HOW-CTA-WORKS/