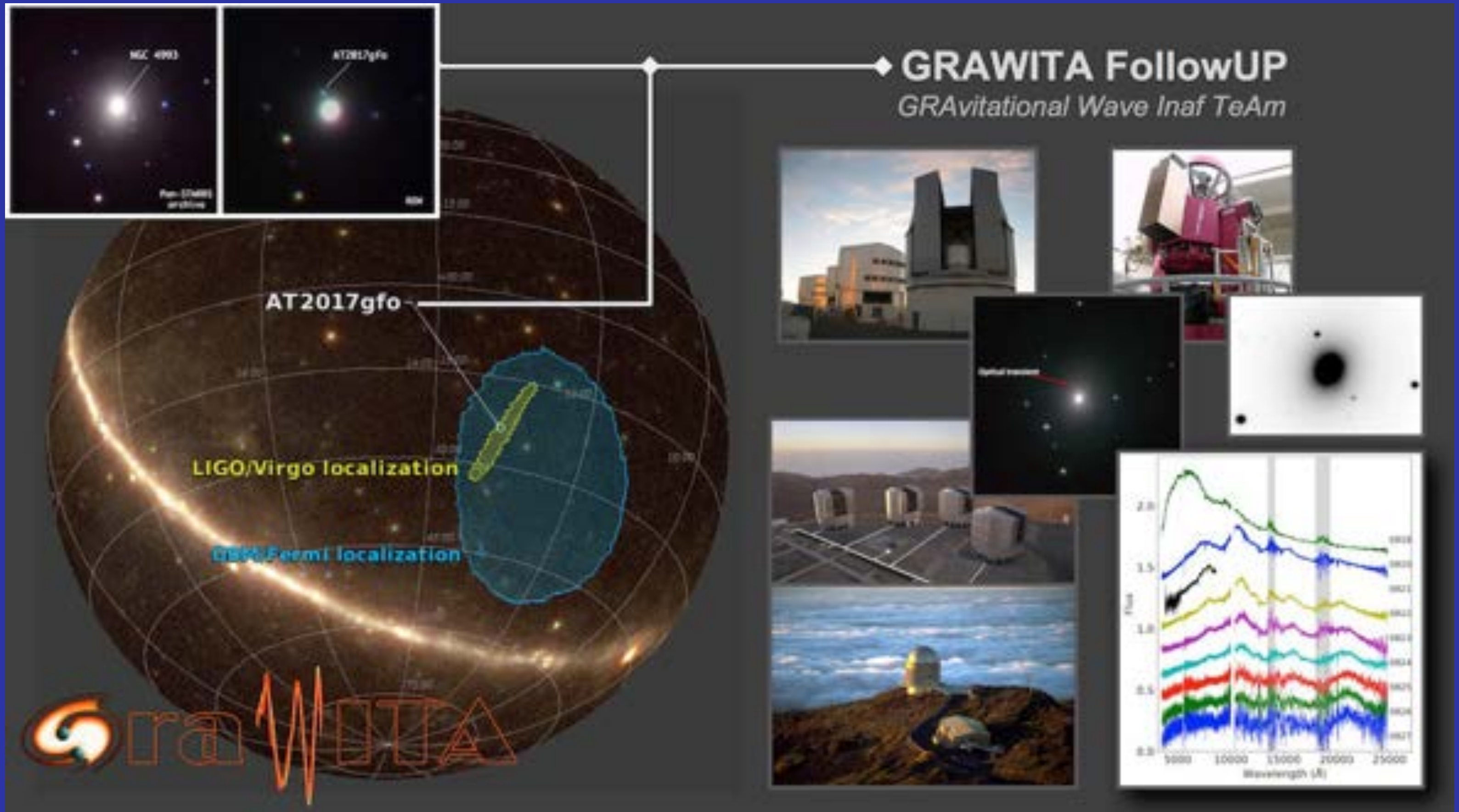
GRAWITA

Programma

E. Brocato on behalf of GRAWITA



https://grawita.inaf.it

GRAvitational Wave Inaf TeAm

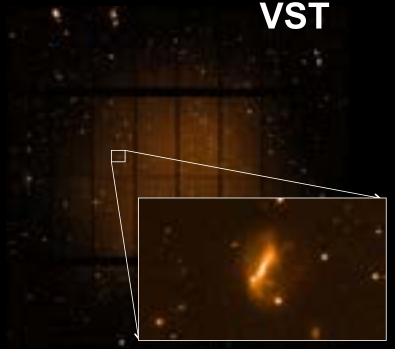
The route for the EM counterpart

STEP 1
Search & Detect
Transients in the ***skymap*** provided by LVC have to be discovered and measured *as soon as possible*

Telescopes with large FoV distributed at different latitudes/longitudes

Computing Facilities with fast and smart software to select a handful of transients

VST



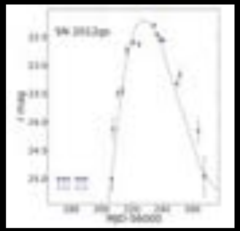
STEP 2
Observe & Characterize
The detected transients have to be observed to infer their nature

Telescopes for prompt spectroscopy of selected candidates at different latitudes/longitudes

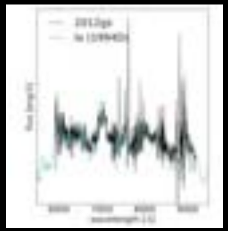
TNG

STEP 3
Follow & Study
Follow-up at all observable λ for an adequate time to study the physical properties of the
EM counterparts of GW

Telescopes with large collecting area to obtain light curves and spectral features of the EM counterparts of GW



time



λ

- Proposals (ToO)
- Observing strategies
- Team 24H/7d
- Data reduction
- Procedures to search transients in wide field images
- Data analysis and interpretation
- …..

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INAF
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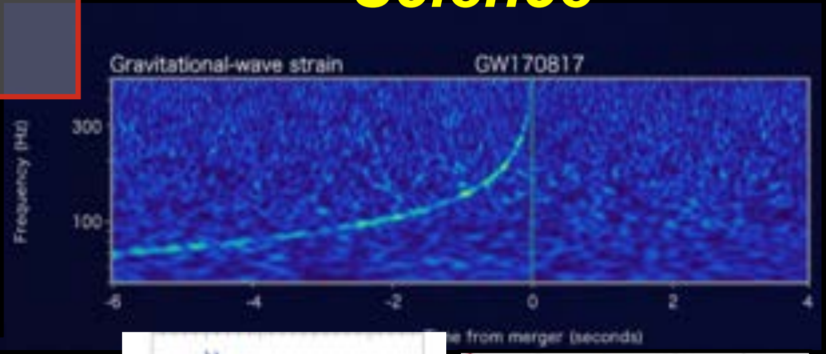
NS-BH/NS-NS merger physics
host galaxy identification
formation history
kilonova identification

Multi-Messenger Science



Transient sources multi-wavelength campaigns

Accretion physics

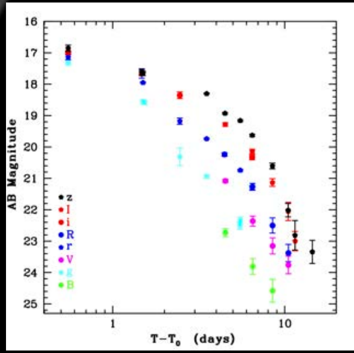
Jet physics

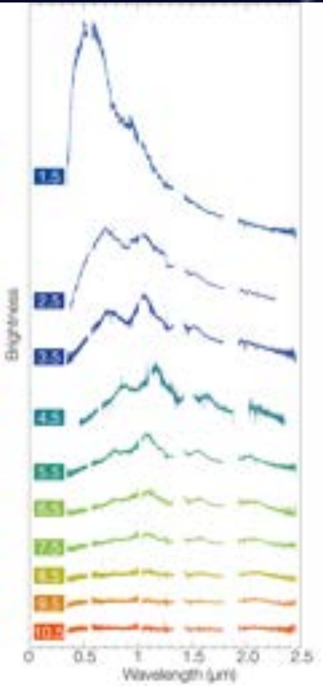
Star formation

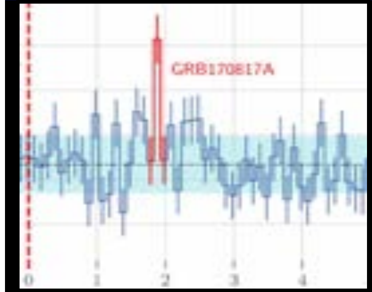
Physics of compact objects

Hubble constant

r-process element chemical abundances







Papers totally based on GRAWITA observations and/or leaded by GRAWITA and/or GRAWITA as partner of large collaborations:

12 papers, 2724 cited, 227 cit/paper

GRAvitational Wave Inaf TeAm

GRAWITA
Organization chart

Science Board
E. Brocato (P.I.),
E. Palazzi, E. Cappellaro,
A. Grado, M. Branchesi,
S. Covino, A. Possenti

WG1
24H/7d OPERATION TEAM
P. D'Avanzo

WG2
WIDE FIELD SEARCH
F. Getman

WG3
CHARACTERIZATION and FOLLOW-UP Optical and NIR
A. Melandri

WG4
RADIO Follow-up
M. Orienti

WG5
HIGH ENERGY Prompt and Follow-up
A. Bulgarelli

WG6
THEORETICAL MODELS
R. Ciolfi

WG7
ARCHIVING and WEB ACTIVITIES
L. Nicastro

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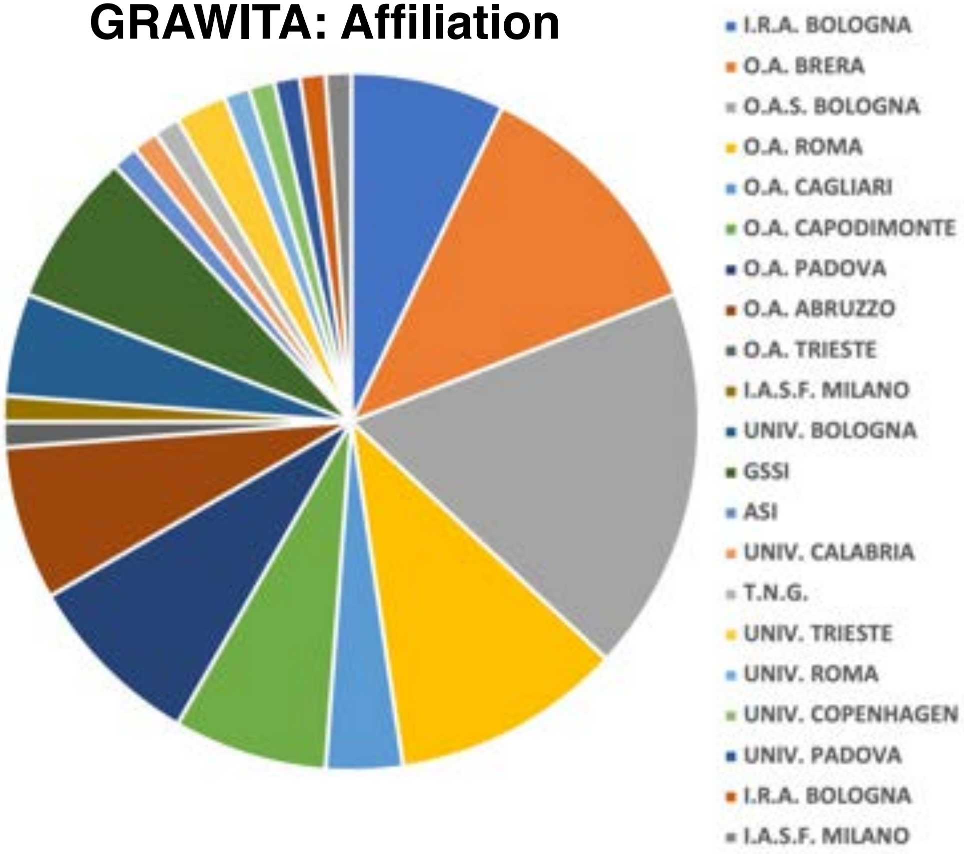
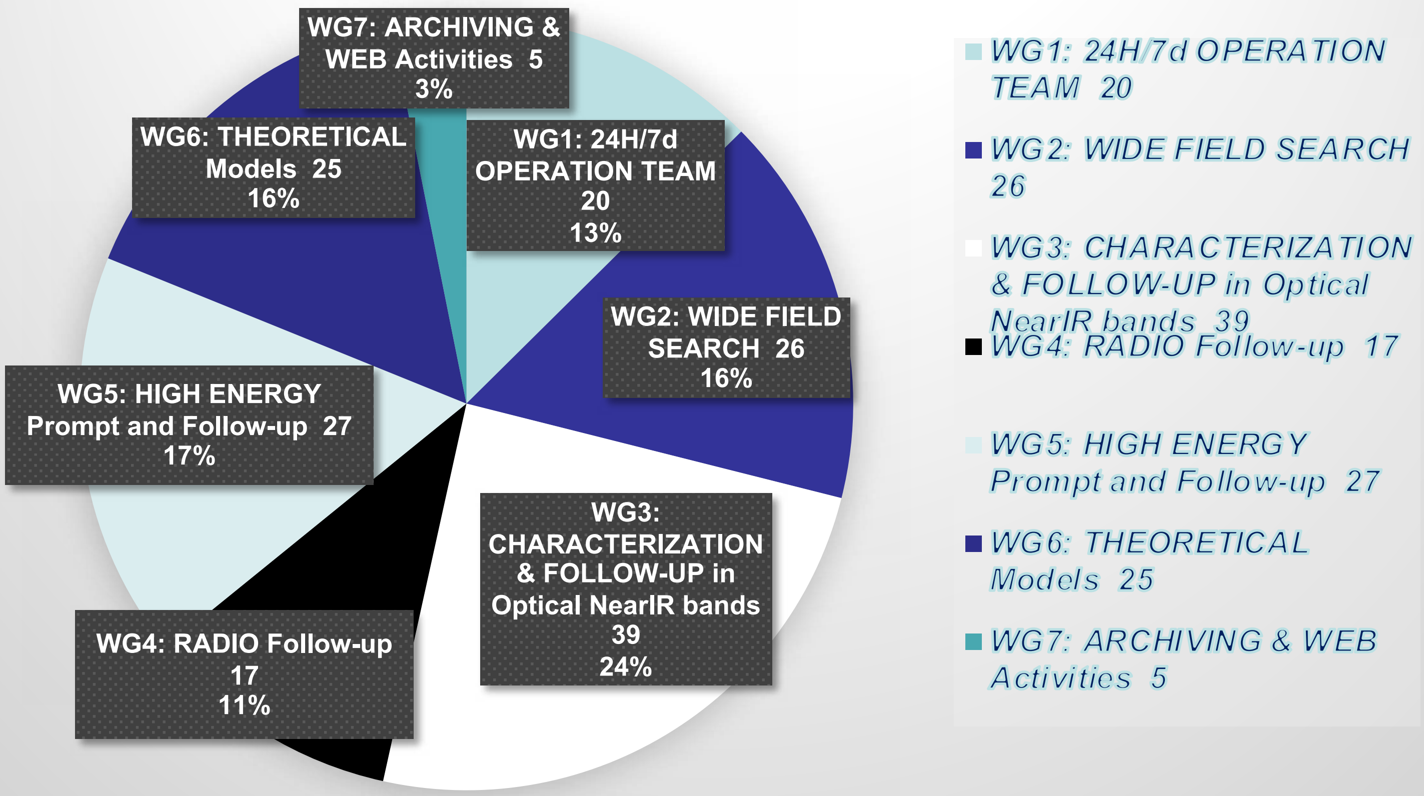
Human resources

- INAF : **64 researchers** (59 staff, 5 AdR) (**6 FTE/yr** for the period 2021-23)
- INAF ASSOCIATES: 20 researchers (GSSI, Universities) (~0.6 FTE/yr)

GRAWITA: Affiliation



GRAWITA: Number of People per Working Group



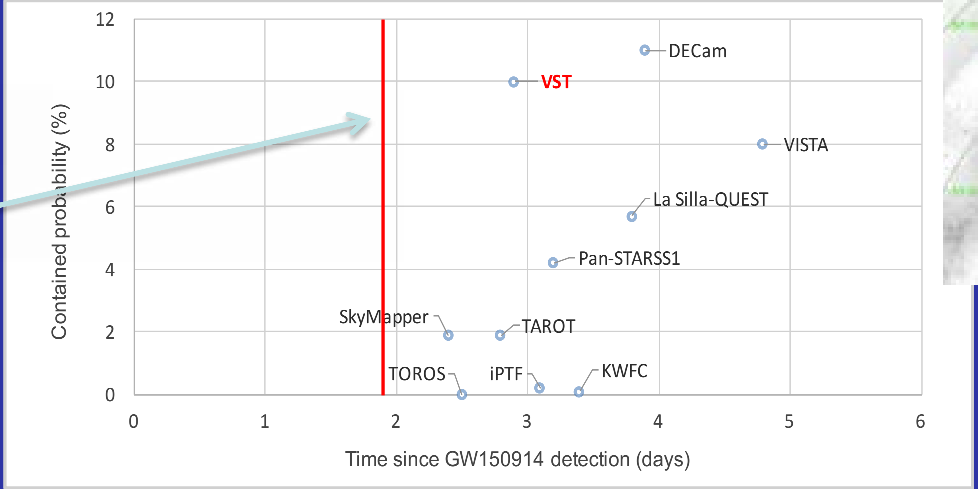
GRAvitational Wave Inaf TeAm

Response to the first GW event (GW150914)

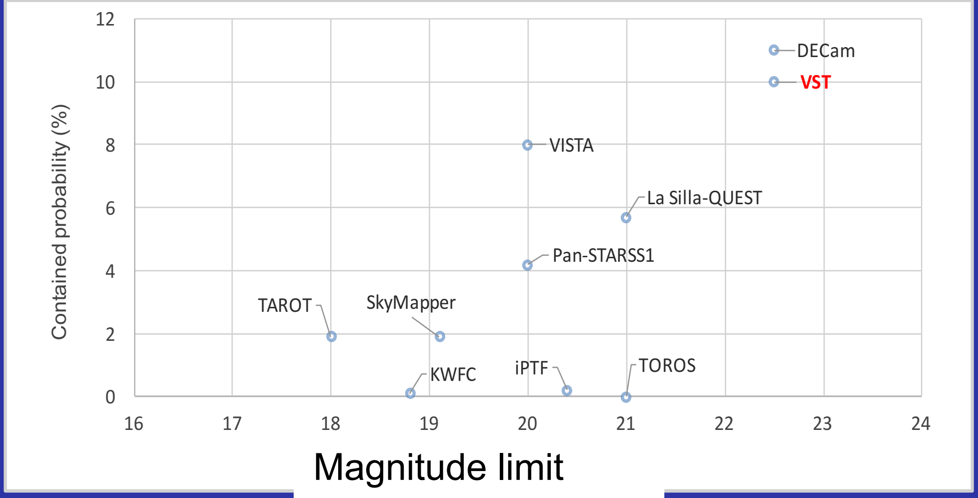
VST survey performance

LVC alert

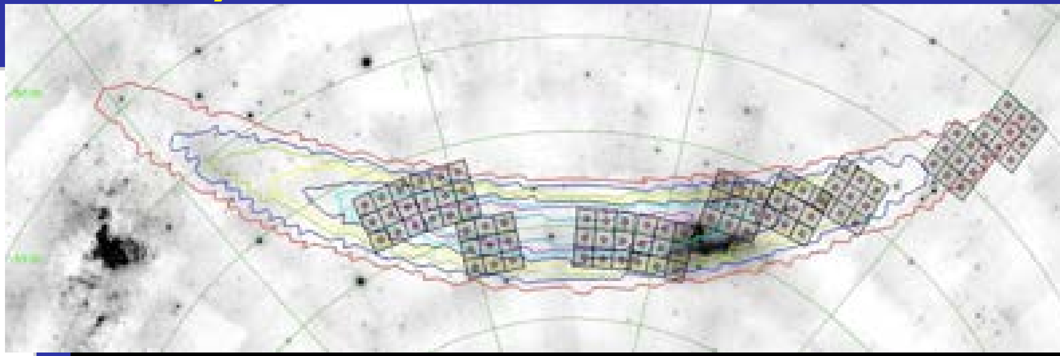
Contained probability vs Time response



Contained probability vs limiting magnitude



Data from Abbott et al 2016



GW150914 ~ 600 deg^2
GW151226 ~ 1000 deg^2
GW170104 ~ 1200 deg^2
GW170608 ~ 520 deg^2

(90% credible areas)

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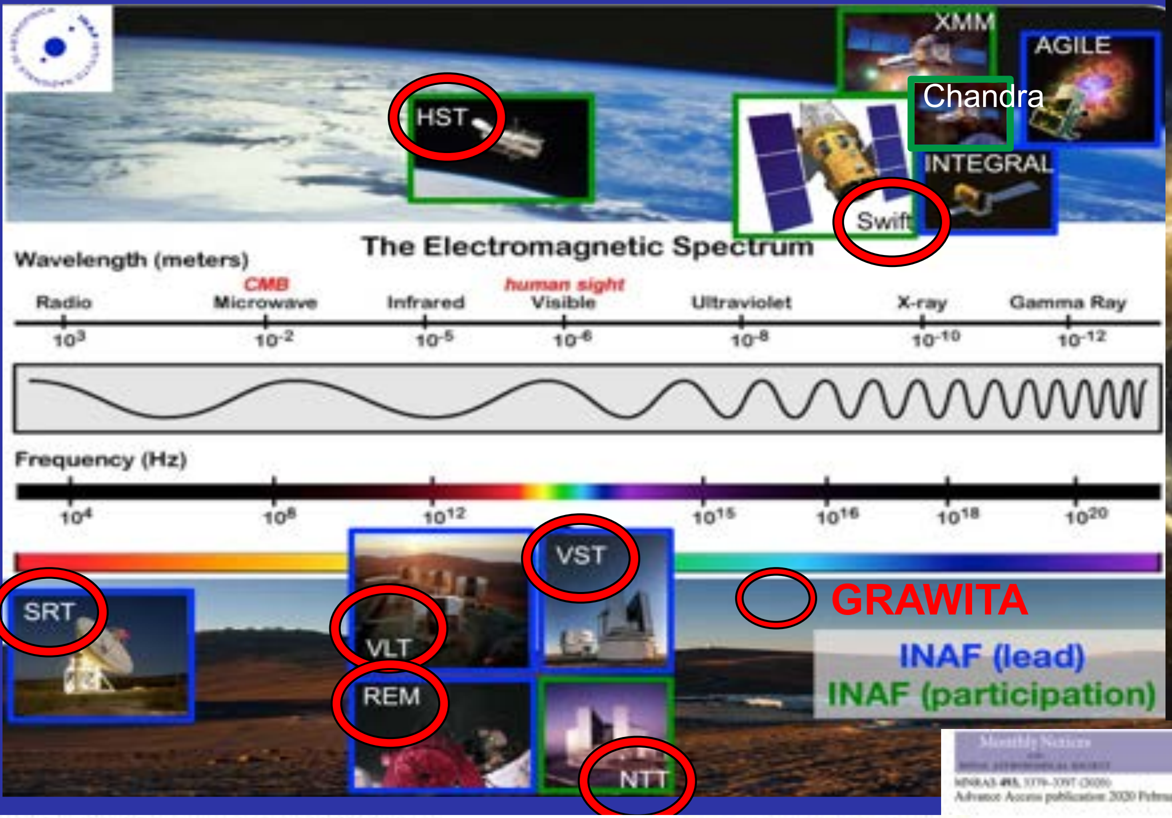
Response to GW170817



LETTER

Spectroscopic identification of r-process nucleosynthesis in a double neutron-star merger

nature astronomy LETTERS

The unpolarized macronova associated with the gravitational wave event GW 170817

S. Covino, K. Wiersema, Y. Z. Fan, K. Toma, A. B. Higgins, A. Melandri, P. D'Avanzo, C. G. Mundell, E. Palazzi, N. R. Tanvir, M. G. Bernardini, M. Branchesi, E. Brocato, S. Campana, S. di Serego Alighieri, D. Götz, J. P. U. Fynbo, W. Gao, A. Gomboc, B. Gompertz, J. Greiner, J. Hjorth, Z. P. Jin, L. Kaper, S. Klose, S. Kobayashi, D. Kopac, C. Kouveliotou, A. J. Levan, J. Mao, D. Malesani, E. Pian, A. Rossi, R. Salvaterra, R. L. C. Starling, I. Steele, G. Tagliaferri, E. Troja, A. J. van der Horst and R. A. M. J. Wijers

The Astrophysical Journal Letters, 848:L12 (59pp), 2017 October 20
OPEN ACCESS

Multi-messenger Observations of a Binary Neutron Star Merger

LIGO Scientific Collaboration and Virgo Collaboration, Fermi GBM, INTEGRAL, IceCube Collaboration, AstroSat Cadmium Zinc Telluride Imager Team, IPN Collaboration, The Insight-HXMT Collaboration, ANTARES Collaboration, The Swift Collaboration, AGILE Team, The 1M2H Team, The Dark Energy Camera GW-EM Collaboration and the DES Collaboration, The DLT40 Collaboration, GRAWITA: GRAvitational Wave Inaf TeAm, The Fermi Large Area Telescope Collaboration, ATCA: Australia Telescope Compact Array, ASKAP: Australian SKA Pathfinder, Las Cumbres Observatory Group, OzGrav, DWF (Deeper, Wider, Faster Program), AST3, and CAASTRO Collaborations, The VINROUGE Collaboration, MASTER Collaboration, J-GEM, GROWTH, JAGWAR, Caltech-NRAO, TTU-NRAO, and NuSTAR Collaborations, Pan-STARRS, The MAXI Team, TZAC Consortium, KU Collaboration, Nordic Optical Telescope, ePESSTO, GROND, Texas Tech University, SALT Group, TOROS: Transient Robotic Observatory of the South Collaboration, The BOOTES Collaboration, MWA: Murchison Widefield Array, The CALET Collaboration, IKI-GW Follow-up Collaboration, H.E.S.S. Collaboration, LOFAR Collaboration, LWA: Long Wavelength Array, HAWC Collaboration, The Pierre Auger Collaboration, ALMA Collaboration, Euro VLBI Team, Pi of the Sky Collaboration, The Chandra Team at McGill University, DFN: Desert Fireball Network, ATLAS, High Time Resolution Universe Survey, RIMAS and RATIR, and SKA South Africa/MeerKAT
(See the end matter for the full list of authors.)

Received 2017 October 3; revised 2017 October 6; accepted 2017 October 6; published 2017 October 16

The Astrophysical Journal Letters, 854:L31 (7pp), 2018 February 20

A Precise Distance to the Host Galaxy of the Binary Neutron Star Merger GW170817 Using Surface Brightness Fluctuations

Michele Cantiello, J. B. Jensen, J. P. Blakeslee, E. Berger, A. J. Levan, N. R. Tanvir, G. Raimondo, E. Brocato, K. D. Alexander, P. K. Blanchard, M. Branchesi, Z. Cano, R. Chornock, S. Covino, S. Cowperthwaite, P. D'Avanzo, T. Eftekhari, W. Fong, A. S. Fruchter, A. Grado, J. Hjorth, D. E. Holz, J. D. Lyman, I. Mandel, R. Margutti, M. Nicholl, V. A. Villar, and P. K. G. Williams

Monthly Notices of the Royal Astronomical Society
MNRAS 493, 3379–3397 (2020)
Advance Access publication 2020 February 19

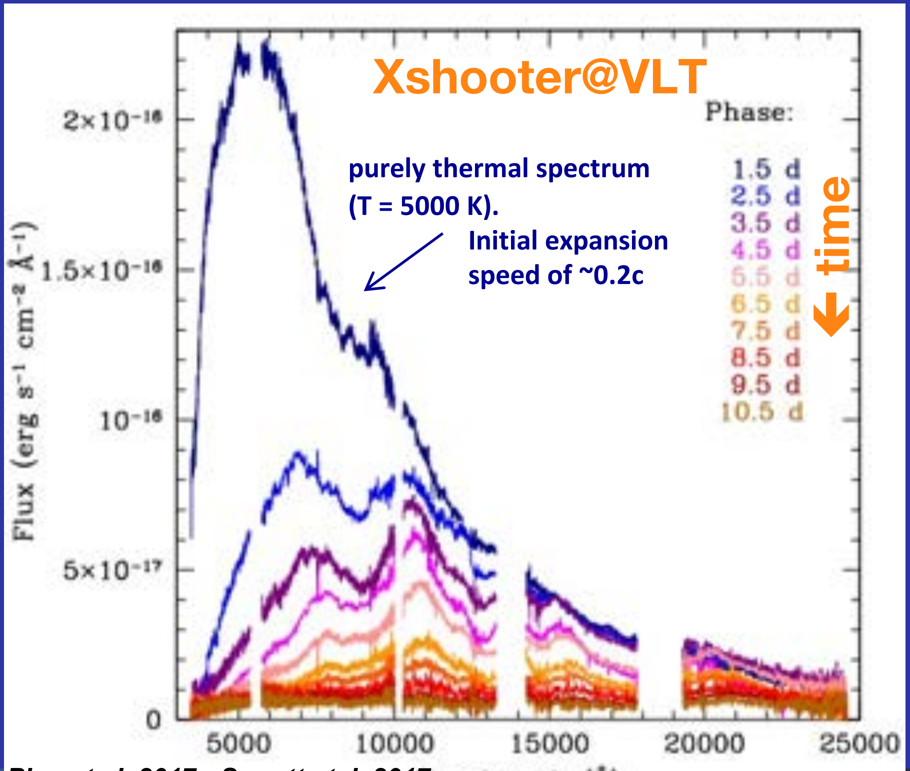
comparison between short GRB afterglows and kilonova AT2017 edding light on kilonovae properties

Rossi, G. Stratta, E. Maiorano, D. Spighi, N. Masetti, E. Pala Gardini, A. Melandri, L. Nicastro, E. Pian, M. Branchesi, M. Dadina Testa, E. Brocato, S. Benetti, R. Ciolfi, S. Covino, V. D'Elia, Grado, L. Izzo, A. Perego, S. Piranomonte, R. Salvaterra, J. Selsing Tomasella, S. Yang, D. Vergani, L. Amati and J. B. Stephen
on behalf of the Gravitational Wave Inaf TeAm (GRAWITA)

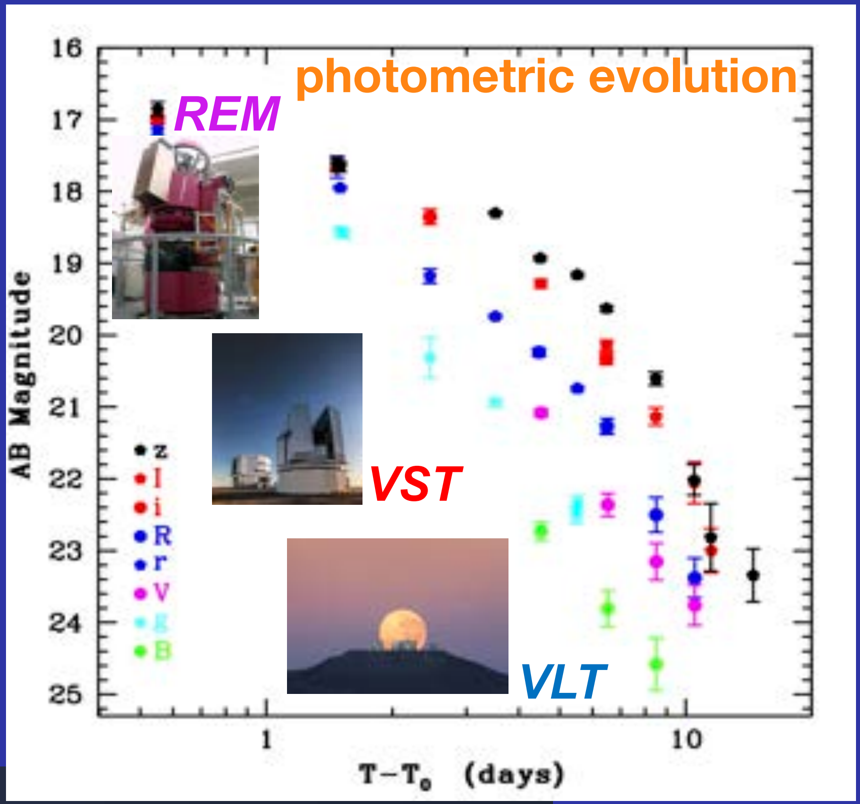
GRAvitational Wave Inaf TeAm

Response to GW170817

These data revealed signatures of the ***radioactive decay of r-process nucleosynthesis*** providing the ***first spectral identification of the kilonova emission*** due to coalescence of two neutron stars



Pian et al. 2017; Smartt etal. 2017



GRAvitational Wave Inaf TeAm

GRAWITA

LBT
VST
TNG
NOT
REM
NTT(ePessto)
Asiago
Loiano
Campo Imperatore
Savelli (unical)
SRT
Medicina+Noto
EVN+Merlin
SWIFT

ENGRAVE

Xshooter@VLT
MUSE@VLT
FORS2@VLT
HAWK-I@VLT
NACO@VLT
ALMA
HST
GTC

Governing Council
Marica Branchesi
Enzo Brocato
Paolo D'Avanzo
Jens Hjorth (DARK, DK)
Peter Jonker (NL)
Elena Pian (I)
Stephen Smartt (UK)
Jesper Sollerman (S)
Danny Steeghs (UK)
Nial Tanvir (UK) Chair

Executive Committee
Om Salafia
Andrew Levan (NL)
Kate Maguire (IRL)
Daniele Malesani (DK)
Susanna Vergani (F)

Leaders of working group		+ Instrument scientist
WG-IMG	M.T. Botticella	+ A. Melandri (FORS2)
WG-SPEC	L. Izzo	+ S. Benetti (FORS2)
WG-EPO	S. Piranomonte	
WG-EXT	M.G. Bernardini	

http://www.engrave-eso.org

Observations in O3 and beyond:

During **O3 (1 Apr. 19 – 27 Mar. 20)** we carried out observational campaigns aimed at the search of e.m. counterparts and follow-up of promising e.m. candidate counterparts of **13 GW triggers**
O3a (LVC catalogue published) + O3b (LVC catalogue not yet published, events still pending confirmation)

After the end of O3 (due to the COVID pandemic) we focused our observational activities on the follow-up of KNe candidates found in surveys and of well-localised (< 50 deg^2) short GRBs found by Fermi/GBM. On this topic, we observed
2 KN candidates,1 short GRB, 1 candidate off-axis afterglow of a short GRB

*GRA*vitational *W*ave *I*naf *T*e*A*m

Observations in O3 and beyond:

The results of these activities have been published in:

- **30 GCN circulars**
- **1 ATel**
- **1Transient Name Server Classification Report**
- **1 refereed paper (Ackley+20, A&A, 643, A113) on S190814bv**

  BH + 2.6 M_{Sun} object, 90% area 19 deg^2, D = 240 Mpc -> VST, TNG wide-field and galaxy targeted search, TNG follow-up & classification of candidates, ENGRAVE coordinated campaign
- **2 papers in preparation**

A&A 643, A113 (2020)
https://doi.org/10.1051/0004-6361/202037669
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Astronomy & Astrophysics

Observational constraints on the optical and near-infrared emission from the neutron star–black hole binary merger candidate S190814bv*

K. Ackley, L. Amati, C. Barbieri, F. E. Bauer, S. Benetti, M. G. Bernardini, K. Bhirombhakdi, M. T. Botticella, M. Branchesi, E. Brocato, S. H. Bruun, M. Bulla, S. Campana, E. Cappellaro, A. J. Castro-Tirado, K. C. Chambers, S. Chaty, T.-W. Chen, R. Ciolfi, A. Coleiro, C. M. Copperwheat, S. Covino, R. Cutter, F. D'Ammando, P. D'Avanzo, G. De Cesare, V. D'Elia, M. Della Valle, L. Denneau, M. De Pasquale, V. S. Dhillon, M. J. Dyer, N. Elias-Rosa, P. A. Evans, R. A. J. Eyles-Ferris, A. Fiore, M. Fraser, A. S. Fruchter, J. P. U. Fynbo, L. Galbany, C. Gall, D. K. Galloway, F. I. Getman, G. Ghirlanda, J. H. Gillanders, A. Gomboc, B. P. Gompertz, C. González-Fernández, S. González-Gaitán, A. Grado, G. Greco, M. Gromadzki, P. J. Groot, C. P. Gutiérrez, T. Heikkilä, K. E. Heintz, J. Hjorth, Y.-D. Hu, M. E. Huber, C. Inserra, L. Izzo, J. Japelj, A. Jerkstrand, Z. P. Jin, P. G. Jonker, E. Kankare, D. A. Kann, M. Kennedy, S. Kim, S. Klose, E. C. Kool, R. Kotak, H. Kuncarayakti, G. P. Lamb, G. Leloudas, A. J. Levan, F. Longo, T. B. Lowe, J. D. Lyman, E. Magnier, K. Maguire, E. Maiorano, I. Mandel, M. Mapelli, S. Mattila, O. R. McBrien, A. Melandri, M. J. Michałowski, B. Milvang-Jensen, S. Moran, L. Nicastro, M. Nicholl, A. Nicuesa Guelbenzu, L. Nuttal, S. R. Oates, P. T. O'Brien, F. Onori, E. Palazzi, B. Patricelli, A. Perego, M. A. P. Torres, D. A. Perley, E. Pian, G. Pignata, S. Piranomonte, S. Podyachinda, A. Possenti, M. L. Pumo, J. Quirola-Vásquez, F. Ragosta, G. Ramsay, A. Rau, A. Rest, T. M. Reynolds, S. S. Rosetti, A. Rossi, S. Rosswog, N. B. Sabha, A. Sagués Carracedo, O. S. Salafia, L. Salmon, R. Salvaterra, S. Savaglio, L. Sbordone, P. Schady, P. Schipani, A. S. B. Schultz, T. Schweyer, S. J. Smartt, K. W. Smith, M. Smith, J. Sollerman, S. Srivastav, E. R. Stanway, R. L. C. Starling, D. Steeghs, G. Stratta, C. W. Stubbs, N. R. Tanvir, V. Testa, E. Thrane, J. L. Tonry, M. Turatto, K. Ulaczyk, A. J. van der Horst, S. D. Vergani, N. A. Walton, D. Watson, K. Wiersema, K. Wiik, Ł. Wyrzykowski, S. Yang, S.-X. Yi, and D. R. Young

Table 1. Summary of wide-field survey coverage and typical limiting magnitudes.

Telescope	Start MJD	Time after GW	Probability coverage	Limiting mag	Filter
ATLAS	58709.52	−8.7 h	99.8%	18.0	*c*
GOTO	58710.09	+5.0 h	89.6%	18.7	*L*
VST	58710.37	+11.5 h	60.7%	20.9	*r*
Pan-STARRS1	58710.528	+15.50 h	89.4%	20.6, 20.3	i_{P1}, z_{P1}
ATLAS	58710.60	+17.23 h	99.8%	18.0	*o*
GOTO	58711.09	+1.2 d	94.1%	18.1	*L*
VISTA-wide	58711.17	+1.3–3.4 d	94%	21.0	K_s
VISTA-deep	58711.24	+1.4 d	21%	22.0	K_s
VST	58711.2	+1.5 d	71.5%	21.9	*r*
ATLAS	58711.5	+1.6 d	99.8%	17.6	*o*
Pan-STARRS1	58713.5	+3.6 d	70.4%	21.9	z_{P1}
VST	58714.2	+4.3 d	87.7%	21.7	*r*
Pan-STARRS1	58716.5	+6.6 d	70.7%	23.0	z_{P1}
VST	58717.1	+7.2 d	87.7%	21.8	*r*
VISTA-wide	58719.05	+9.2–10.5 d	94%	21.2	K_s
VISTA-deep	58720.15	+10.3 d	21%	22.0	K_s
VST	58724.4	+14.5 d	87.7%	22.0	*r*
VISTA-wide	58750.1	+40–41 d	94%	21.0	K_s
VISTA-deep	58751.1	+41 d	21%	22.0	K_s

Notes. The start MJD refers to the start of observations on that night (for reference, the GW trigger occurred at MJD 58709.882). The given limiting magnitude is the median magnitude of the individual tiles that covered the probability listed. All times are in the observer frame.

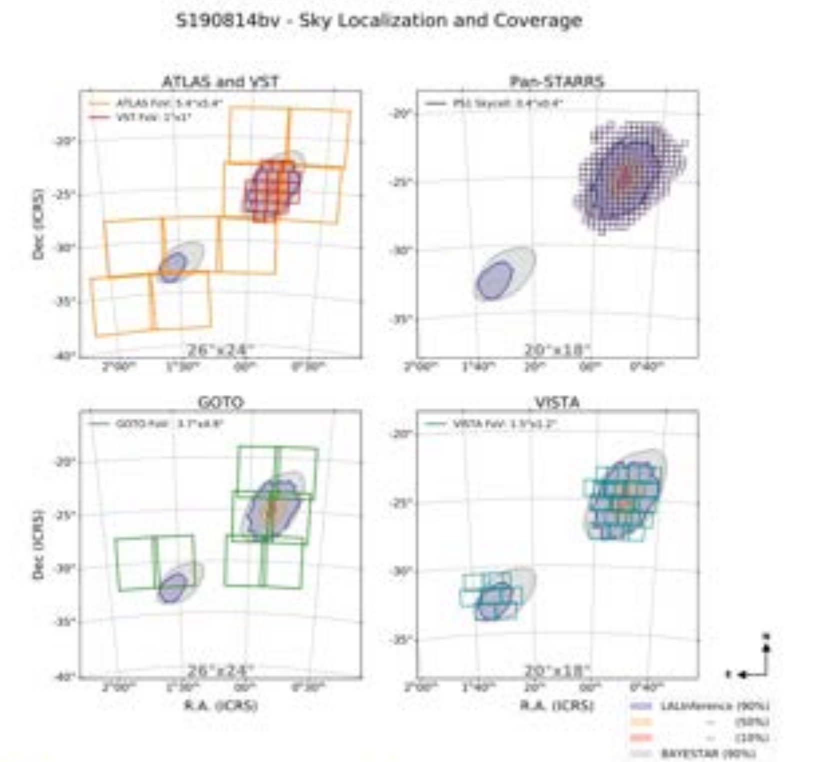

Fig. 1. Coverage maps from the wide-field surveys as listed in Table 1 with the probability contours of the initial skymap (BAYESTAR) and the refined skymap LALInference.

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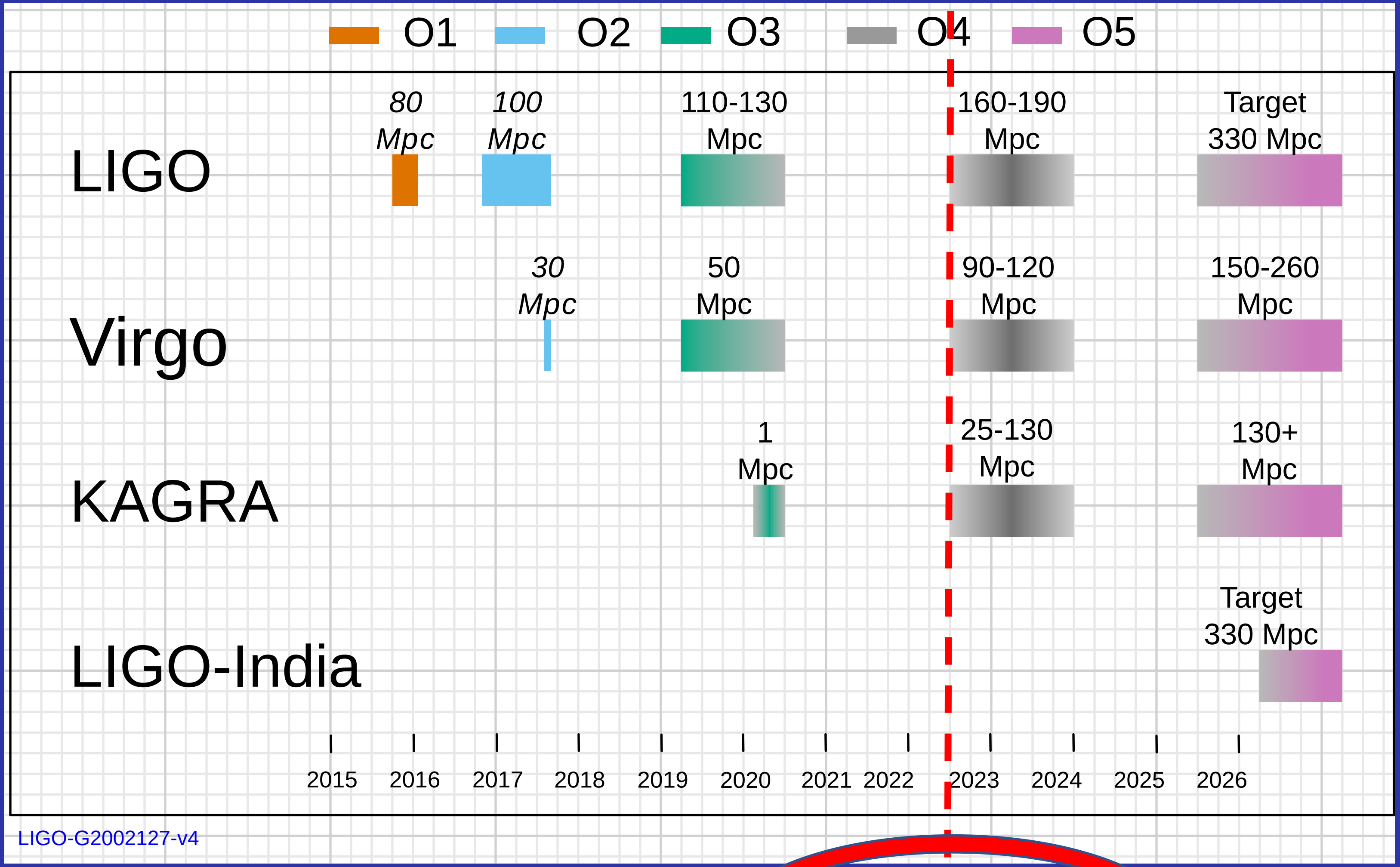


Abbott et al. 2020, LRR

Starting of 04 not before June 2022

O4 volume = 3*O3 volume
O5 volume = 15*O3 volume

Courtesy of M. Branchesi

LOCALIZATION

		BNS Area (deg^2) 90% c.r.	NSBH Area (deg^2) 90% c.r.	BHBH Area (deg^2) 90% c.r.
O3	HLV	270^{+34}_{-20}	330^{+24}_{-31}	280^{+30}_{-23}
O4	HLVK	33^{+5}_{-5}	50^{+8}_{-8}	41^{+7}_{-6}

RATE

Observation Run	Network	Expected BNS Detections	Expected NSBH Detections	Expected BBH Detections
O3	HLV	1^{+12}_{-1}	0^{+19}_{-0}	17^{+22}_{-11}
O4	HLVK	10^{+52}_{-10}	1^{+91}_{-1}	79^{+89}_{-44}

EXPECTED NUMBER OF DETECTIONS FOR O3 and O4 detection counts per one-calendar-year observing run. Detection: SNR > 4 in at least two detectors and network SNR > 12

Abbott et al. 2020, LRR

Courtesy of M. Branchesi

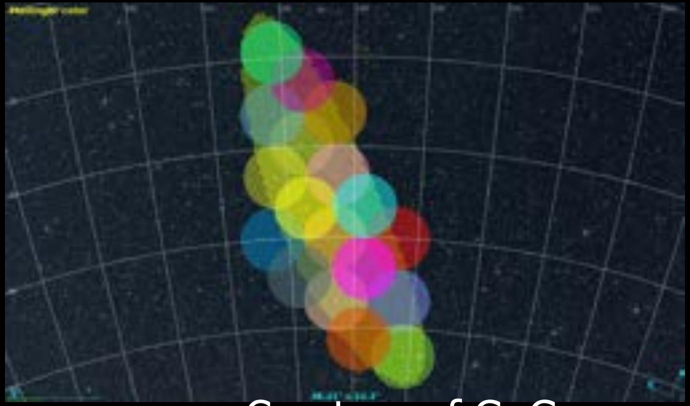
GraWITA

GRAvitational Wave Inaf TeAm

INAF

VRO-LSST **Search** **Target of Opportunity mode !**

- LARGE Field of View (9.6 deg^2) for transient search
- Horizon increased ==> fainter sources (> 24.5)
- Galaxy-targeted observations are often not efficient



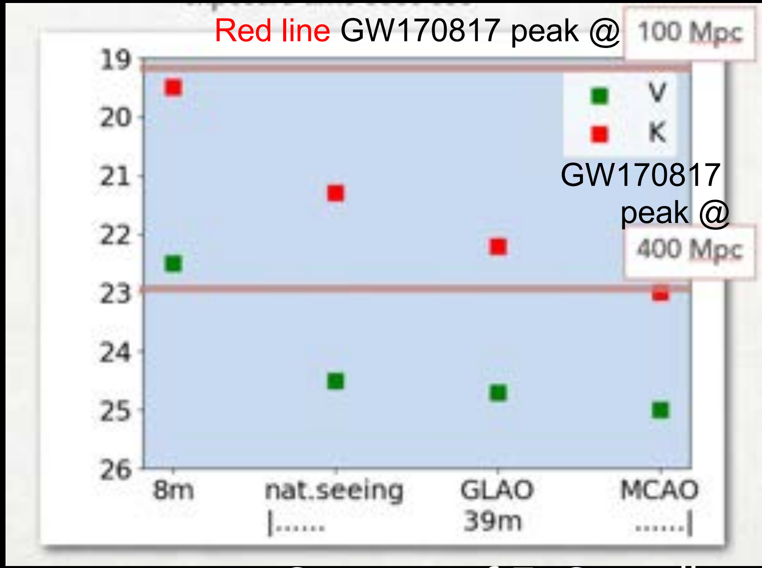
Courtesy of G. Greco

To completely cover the skymap of GW170817
LSST needs less than 20 tiles/pointing (not optimized) to reach r~24.5

E-ELT **Follow-up** **Target of Opportunity mode !**

Spectroscopy

Spectral resolution 5000
magnitude for limit S/N=5
exp. time 3600 sec



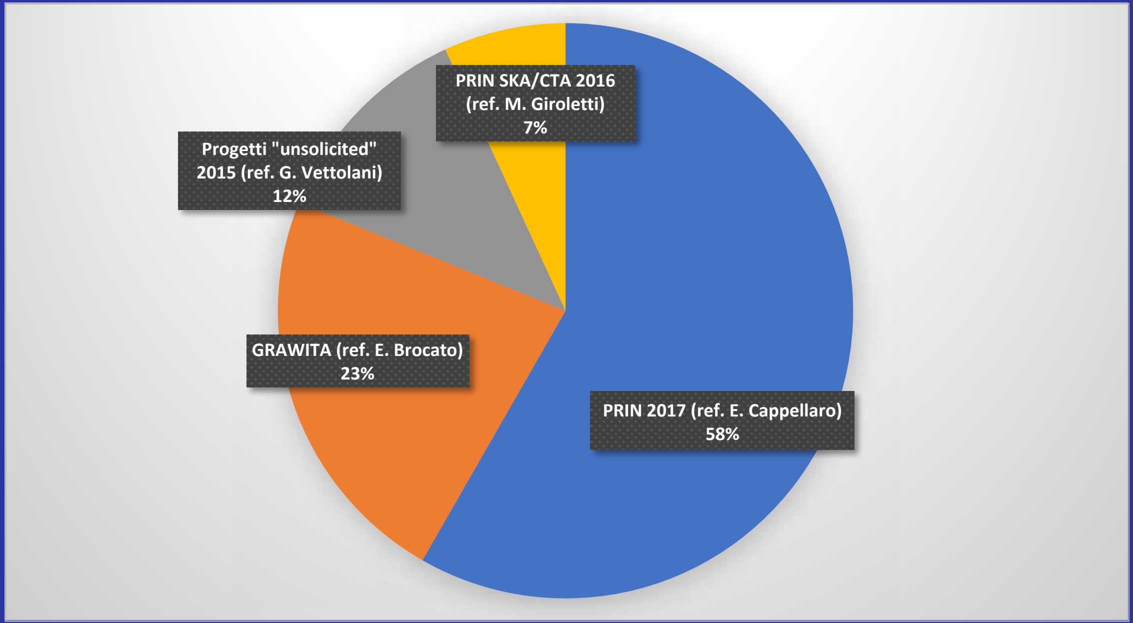
Courtesy of E. Cappellaro

Other fundamental players e.g. SOXS@NTT, MOONS@VLT, JWST, THESEUS, MeerKAT, ATHENA, SKA, CTA..

GRAvitational Wave Inaf TeAm

Financial resources

	Keuro
• PRIN 2017: The new frontier of Multi-Messenger Astrophysics: follow-up of electromagnetic transient counterpart of gravitational wave sources (ref. E. Cappellaro)	510
• GRAWITA (ref. E. Brocato)	200
• Progetti "unsolicited" 2015 (ref. G. Vettolani)	105
• PRIN SKA/CTA 2016: Towards the SKA and CTA era: discovery, localization, and physics of transient sources (ref. M. Giroletti)	60



The expenditure forecast is guided by the objective of maintaining and improving the level of excellence achieved by GRAWITA in period 2014-2021. GRAWITA has 65 INAF member plus a dozen of associates from Italian universities, we evaluated that running cost (networking, hardware) and Human Resources i.e. regular turnover (and formation) of young researchers is requiring a budget of the order of 150 keuro/year.

GraWITA

GRAvitational Wave Inaf TeAm

INAF ISTITUTO NAZIONALE DI ASTROFISICA

Criticalities

- Financial/human resources: formation of young researchers (general problem)
- Science: intrinsic high-risk science (new field astrophysics, possibility of breakthrough discovery)
- Facilities: GW interferometers are increasing their discovery horizon, present ground based e.m. facilities will have problem to observe e.m. counterparts of GW sources.

Perspectives: Gravitational waves come from astrophysical sources

- To be ready for the next runs O4+O5 (HLVK) (several proposals submitted in these days)
- To improve the scientific and technological interaction between the GW communities of INAF and INFN
- To develop astrophysical scenarios and science cases exploiting the huge efforts on the next generation of GW interferometers (ET, CE, LISA, LGWA)
- To promote a 'forum' of the GW astrophysical community to facilitate the exchange of info with the aim of improving the INAF leadership on the multi-messenger astrophysics

Thank you !