Eliana Palazzi
INAF – OAS Bologna
on behalf of the GRAWITA
Collaboration

GRAvitational Waves Inaf TeAm

The role of SKA

GRAvitational Waves Inaf TeAm

The GRAWITA group is committed to taking part in the search and study of EM counterparts of GW events by using multi-wavelenght observational facilities.

Project milestones

05-12-2013... Monte Mario meeting INAF – LVC
2014............. MoU INAF-LVC signed
2014............. ToO proposals at VST, VLT, LBT, TNG....
2015............. Unsolicited project "GW Astronomy"
15-09-2015... First operational meeting/first GW detect
17-09-2015... VST observations of ***GW150914***
2016............. Founding member of the ePESSTO collaboration @NTT
17-08-2017... Detection and follow-up of the first EM counterpart - ***GW170817***
2018............. PRIN MIUR 2017 (INAF-RU) *submitted*
2018............. INAF prize for the results on GW170817
2018............. Founding member of the European **ENGRAVE** collaboration

GRAWITA Organization

P.I.: E. Brocato

Science Board: Branchesi, Brocato, Cappellaro, Covino, Grado, Palazzi, Possenti

Working groups:

1. Observational strategy and H24 Alert team
2. Search of EM counterpart in wide field images
3. Optical characterization and follow-up of candidate counterparts
4. Radio characterization and follow-up of candidate counterparts
5. High energy characterization and follow-up of candidate counterparts
6. Theory
7. Infrastructure

The GRAWITA team is currently composed by more than **70 members**, the vast majority from INAF Institutes

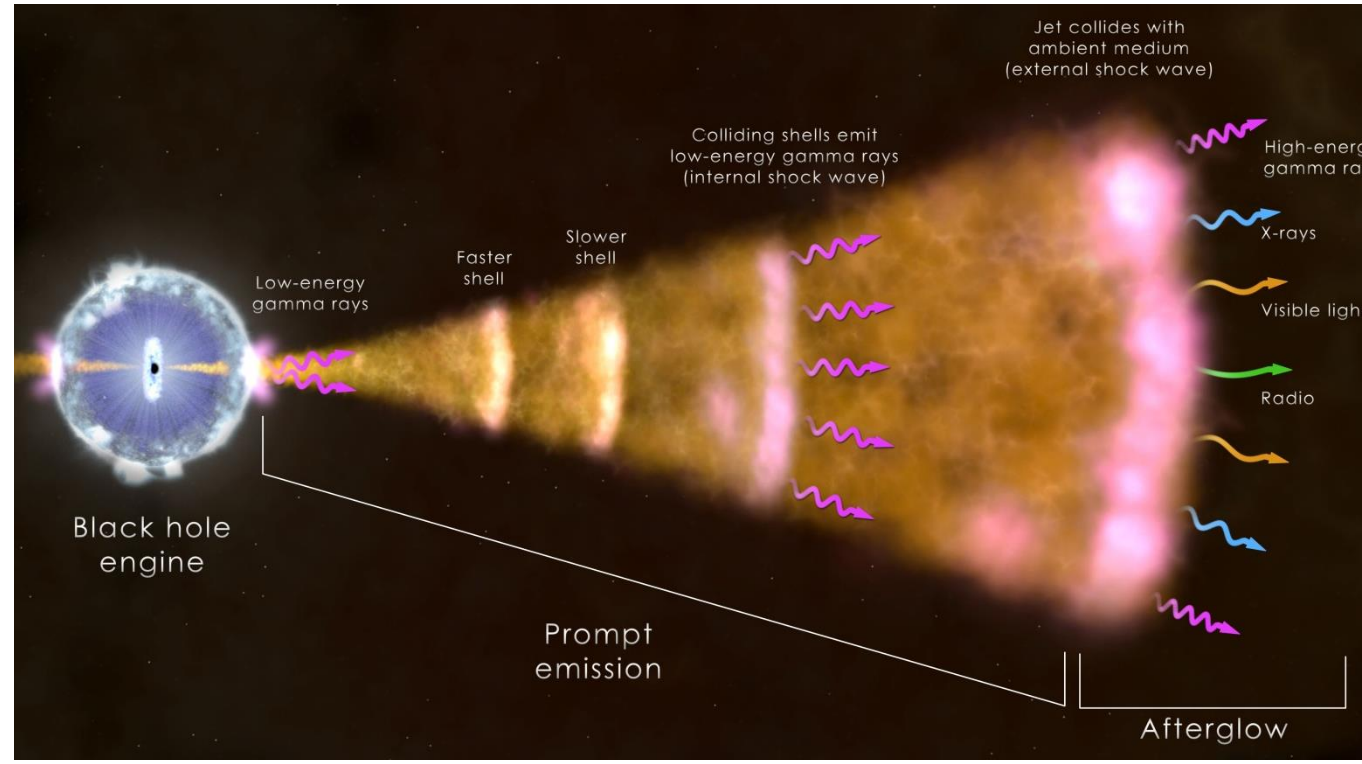
GRAWITA Immediate objective

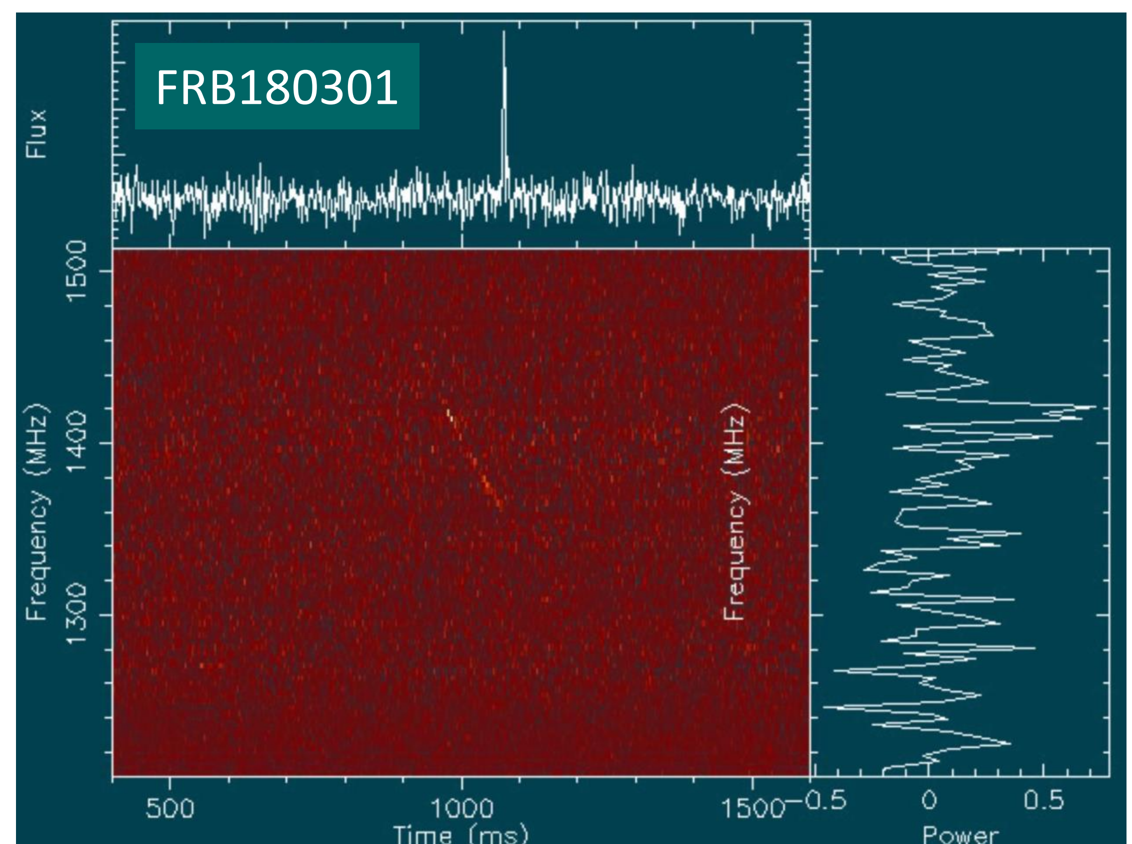
- helping to gain **access to top observing multi-wavelength facilities**
- enhancing the **visibility** of Italian researchers in international collaborations
- **setting up the infrastructure** for supporting observing programs, data analysis and astrophysical interpretation
- establish a **forum** for a broad discussion of scientific issues
- search and **submit fund applications**

GRAWITA KNOW HOW

- GRBs, FRBs and SNe studies and follow-ups
- Multi-wavelength observational strategies on transients sources
- Multi-wavelength data analysis
- Accurate Photometry in crowded fields
- Theoretical models and data interpretation

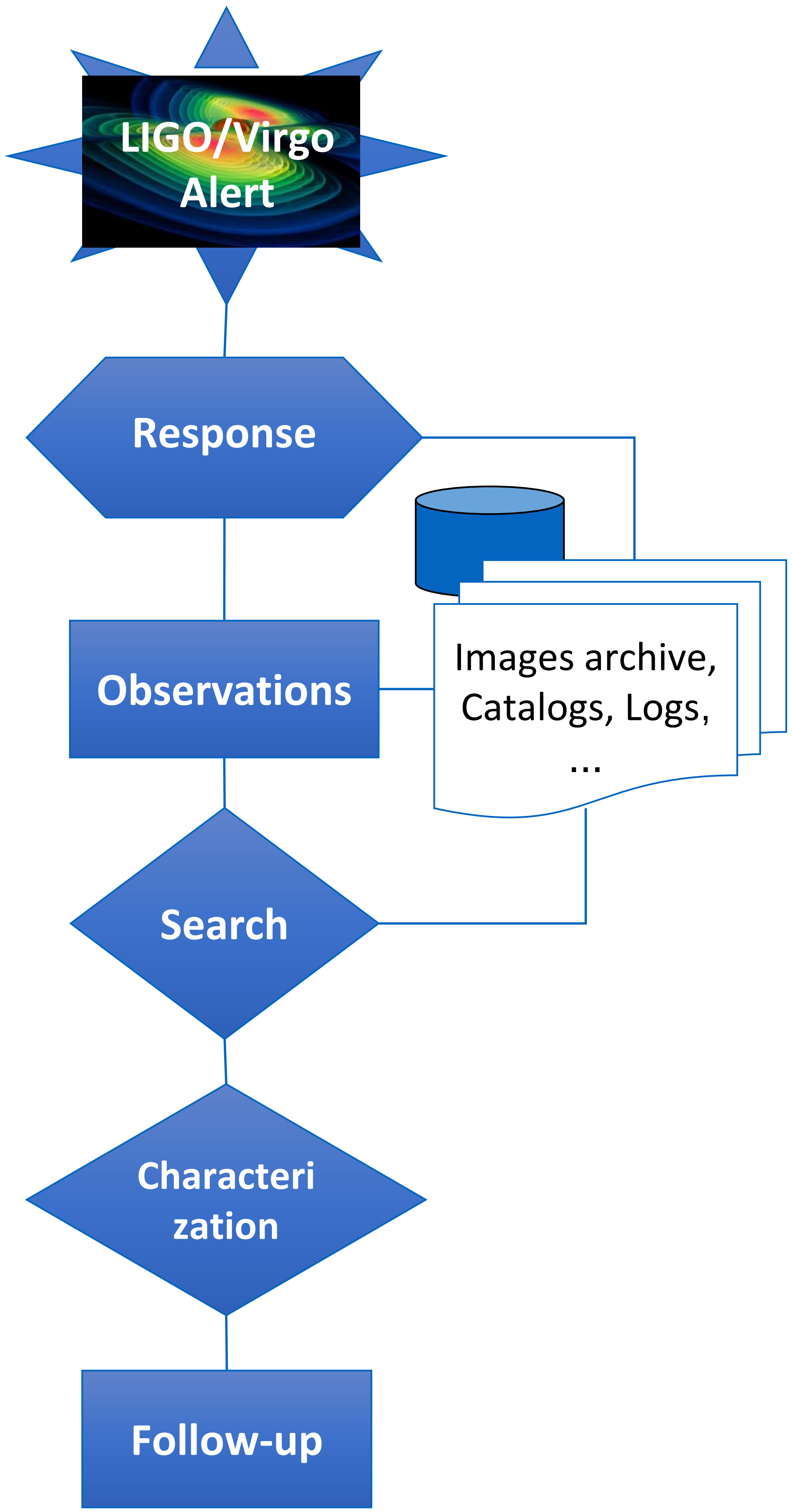
Credit NASA





Anderson 2018

The route to the EM counterpart detection



Telescopes with
large FoV
distributed at different
latitudes/longitudes

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

Telescopes for
prompt spectroscopy to characterize selected
candidates at different
latitudes/longitudes

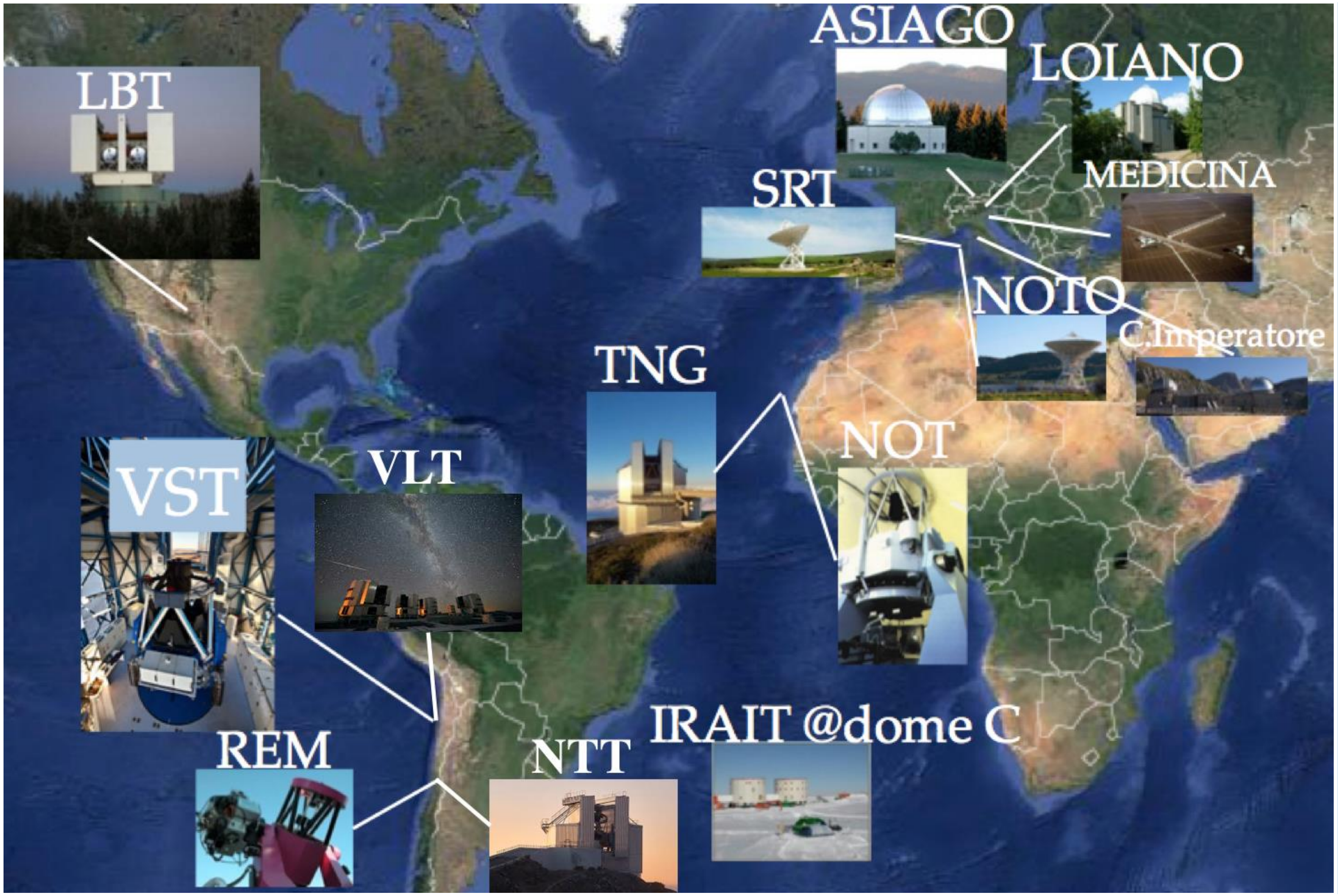
Telescopes with
large collecting area
to obtain light curves and
spectral features of
transients

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

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

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

GRAWITA Facilities



Visible:
VST, LBT, TNG +
small INAF telescopes
[REM, 1.82m + 1.2m (Asiago), 1.52m (Loiano), 0.9m C. Imperatore)

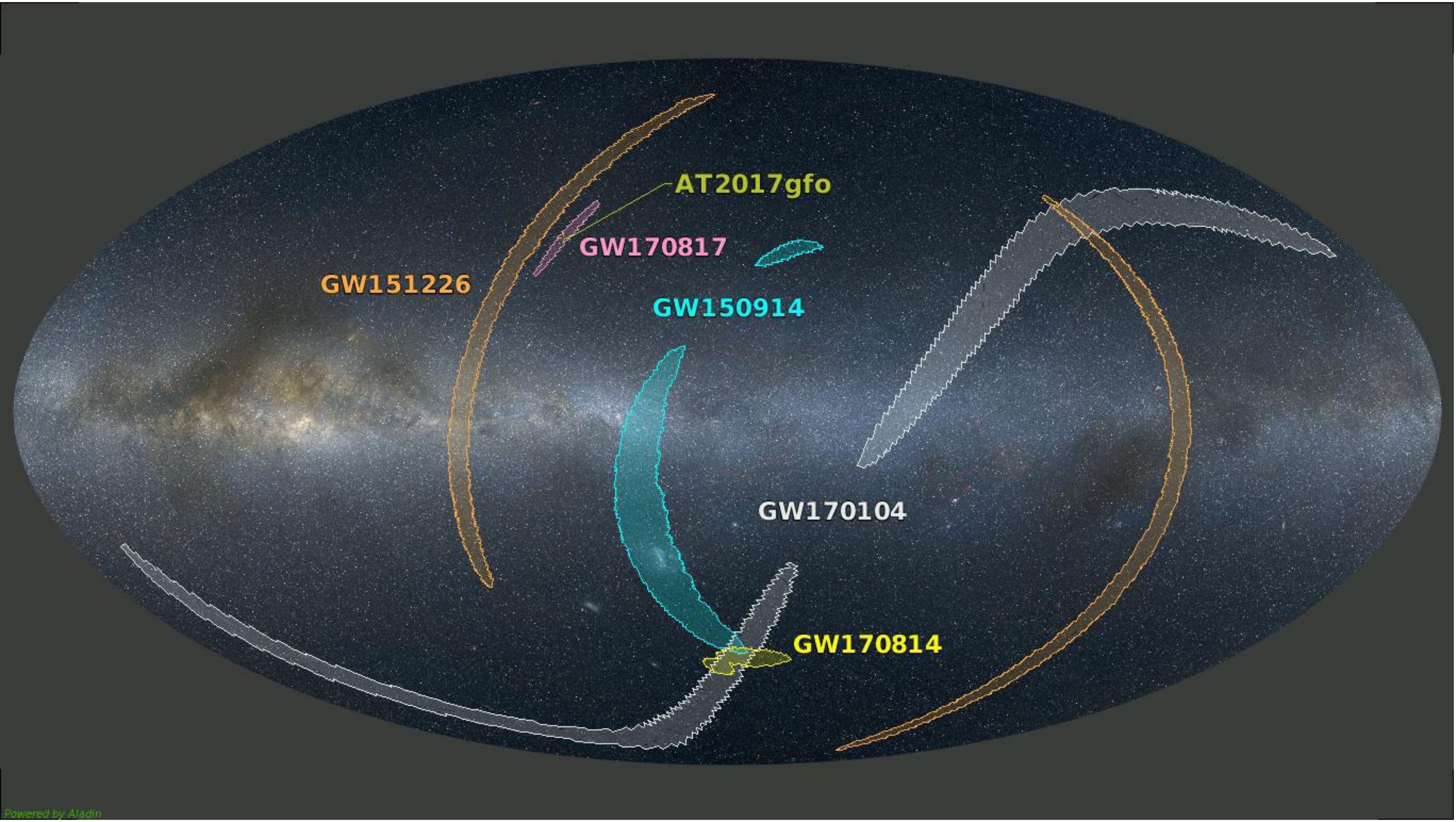
Near-mid IR:
1.1m AZT-24 (C. Imperatore)

Radio:
64m SRT (Cagliari)

Optical-Radio collaborations: VLT+ALMA+ATCA (ENGRAVE), ePESSTO (NTT), NOT, SAO (Ru)
High energy collaborations.: space (Swift, Chandra, INTEGRAL, AGILE) + ground (MAGIC, future ASTRI, CTA)
Positive interactions/collaborations during O1+O2: Pan-Starrs, iPTF, VISTA, HST…

The skymaps for the detected GW

Sky probability maps covering hundreds of square degrees



GW catalogue: http://chrisnorth.github.io/plotgw/

GRAWITA: observational strategies

Two foreseen observational strategies depending on the GW trigger characteristics

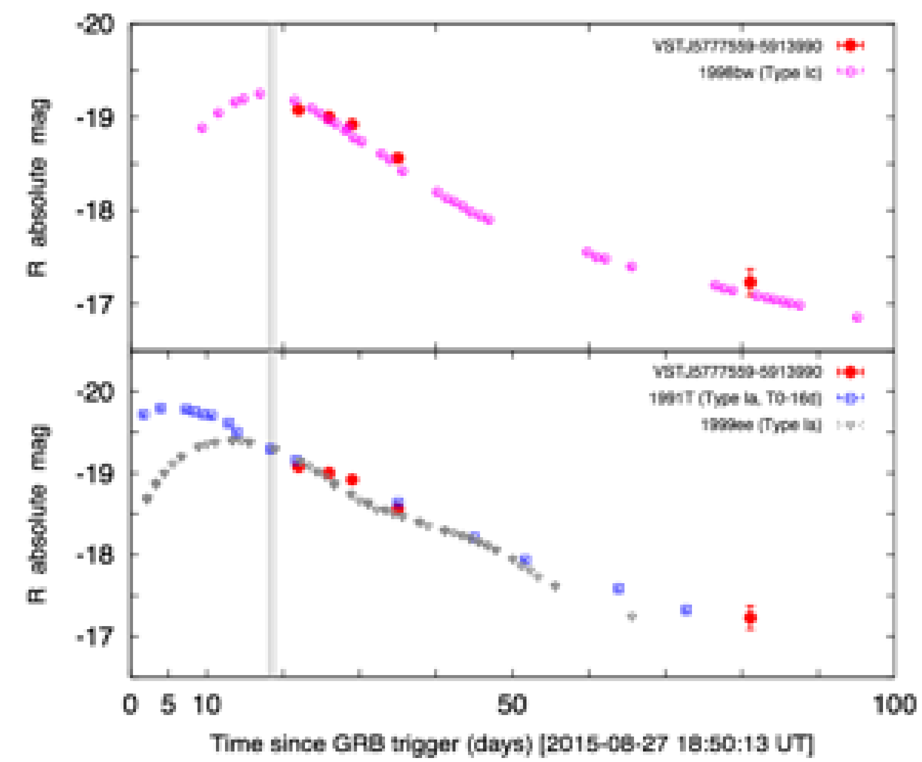
1. ***Search for transients using large FoV telescopes and characterization of the detected transients through:***
   a) temporal sampling, able to identify day-week timescale transients
   b) spectral energy distributions (SEDs) of the candidates.

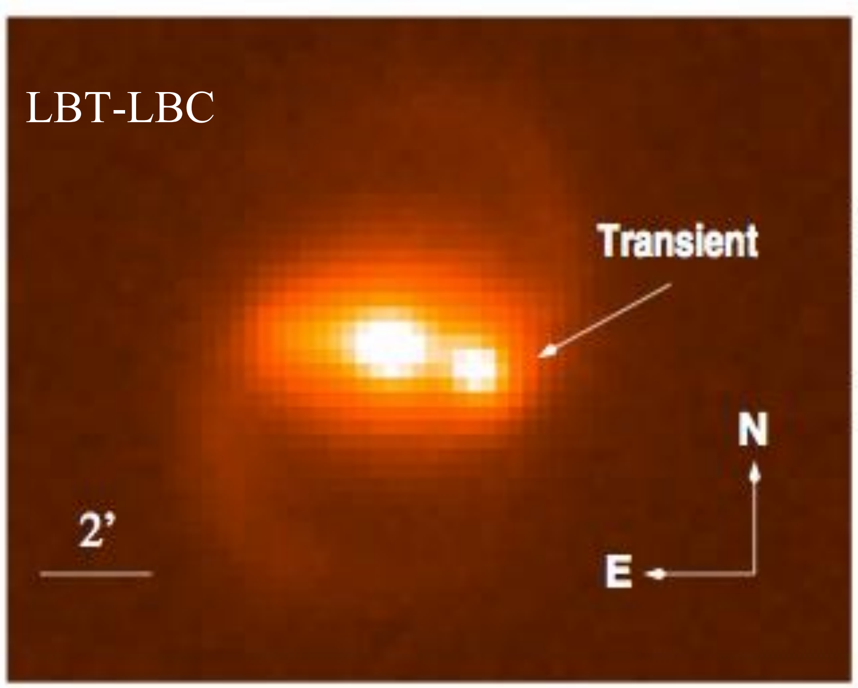
   Color selection and time evolution are possibly effective to pinpoint the best candidates for larger telescopes follow-up.

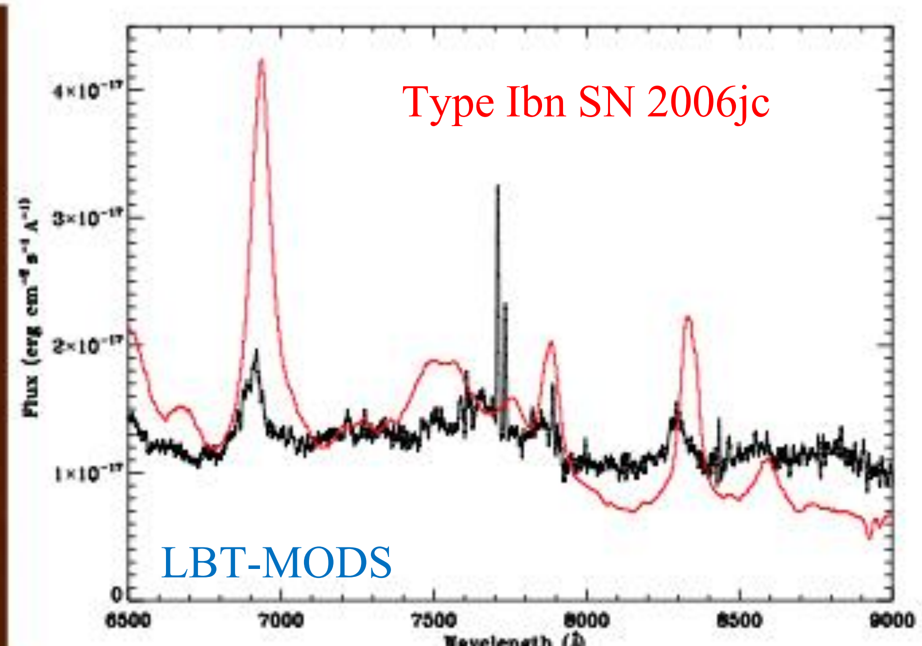
2. ***Galaxy targeting strategy:*** observe all putative host galaxies within the error region and the given distance of a GW event involving at least one neutron star. A quick monitoring (3-5 min depending on target distance) of the observable galaxies will spot any new bright transient.

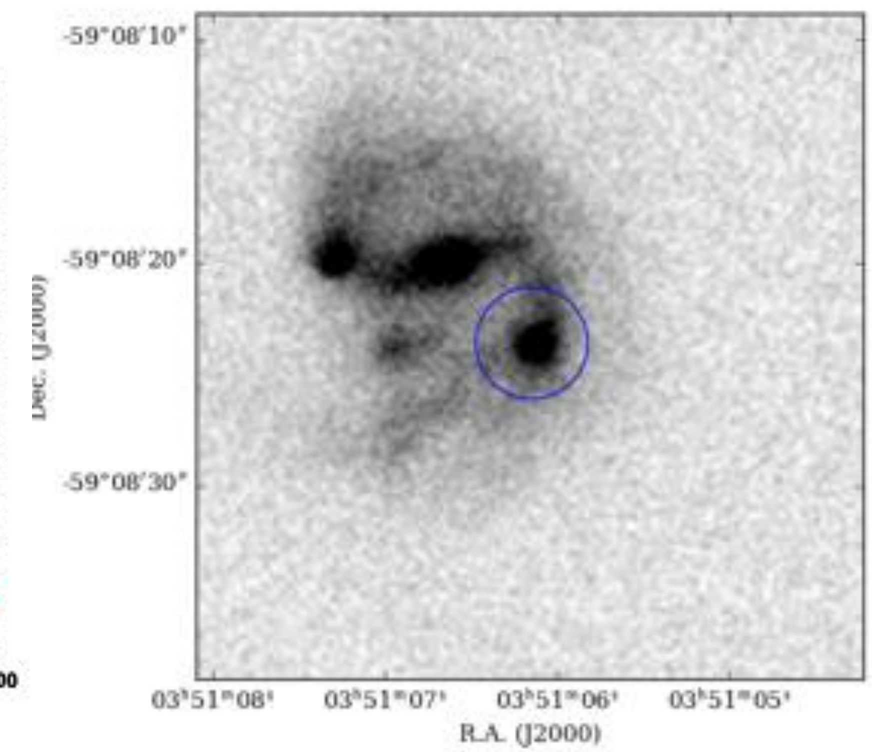
GRAWITA follow-ups

GRAWITA has participated to the follow-up campaigns during the first two LVC scientific runs (**O1 and O2**) **providing source characterization via spectroscopic** and **photometric observations** of several detected transients (e.g. *Brocato et al. 2018, Melandri et al. 2018, Grado et al. 2018, Pian et al. 2017*)





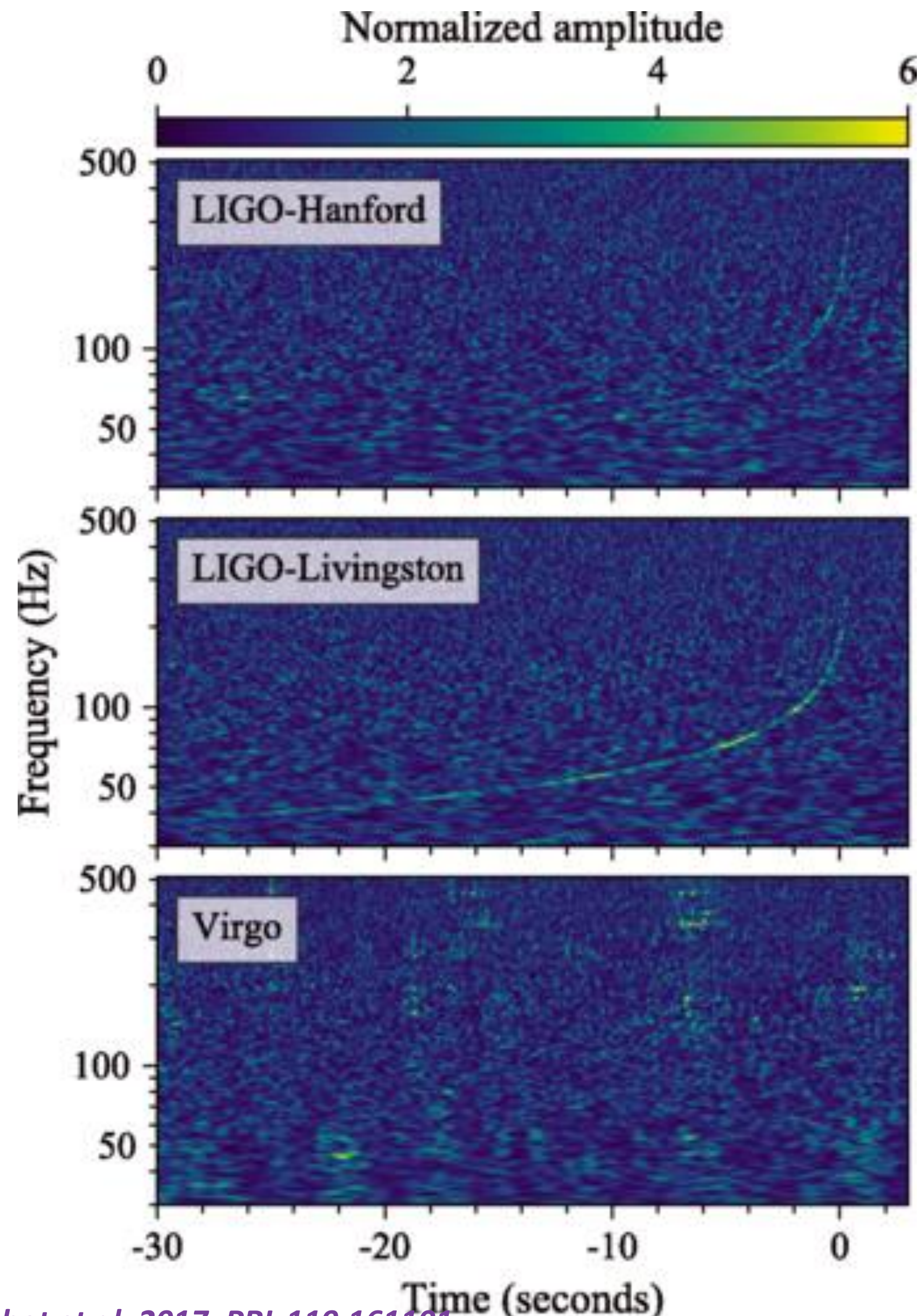




GW170817/GRB170817A

August 17, 2017 12:41:04 UT: **first detection of a binary neutron star (BNS) merger**

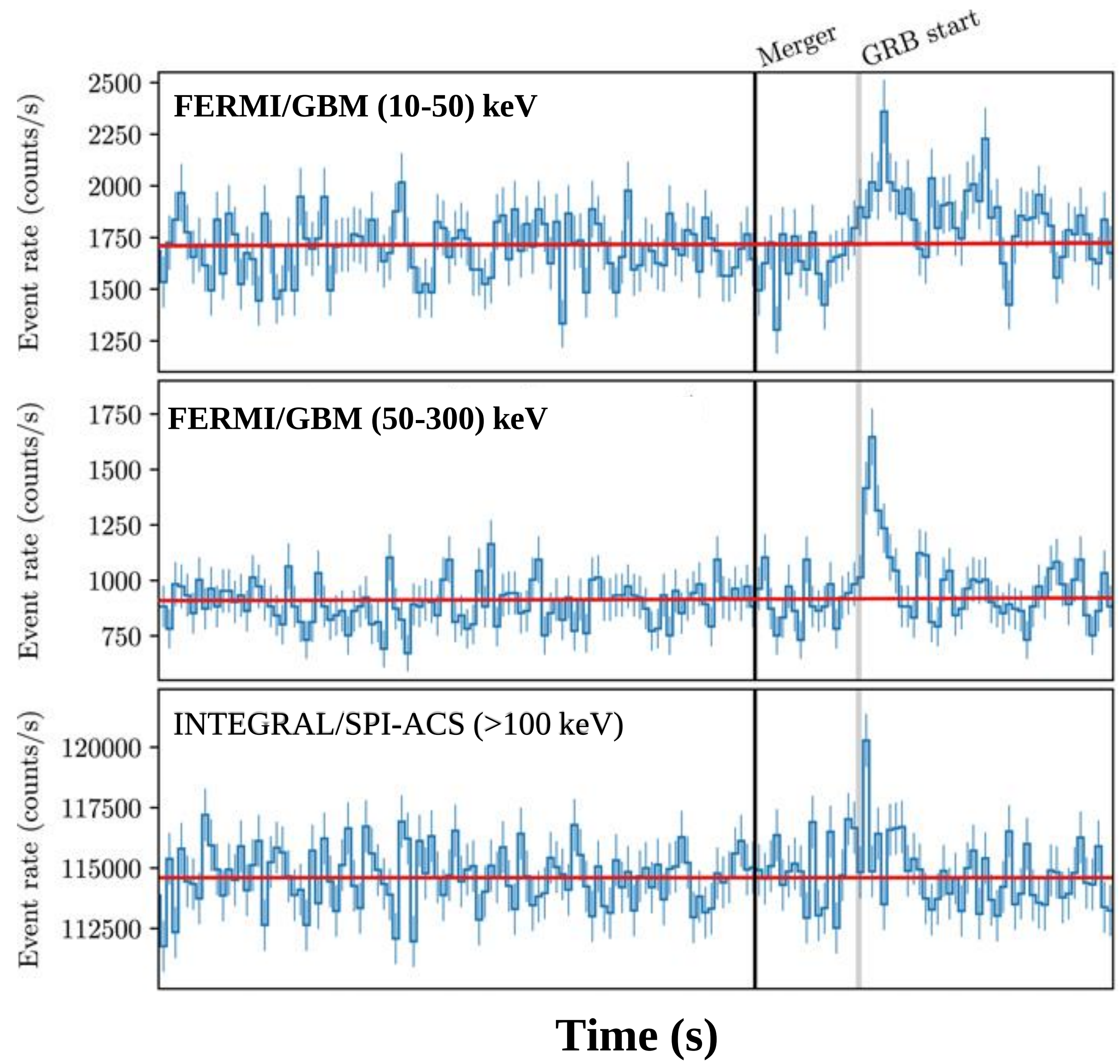
GW170817



Abbot et al, 2017, PRL 119,161101

August 17, 2017 12:41:04 + 1.74s UT: **detection of a short gamma ray burst**

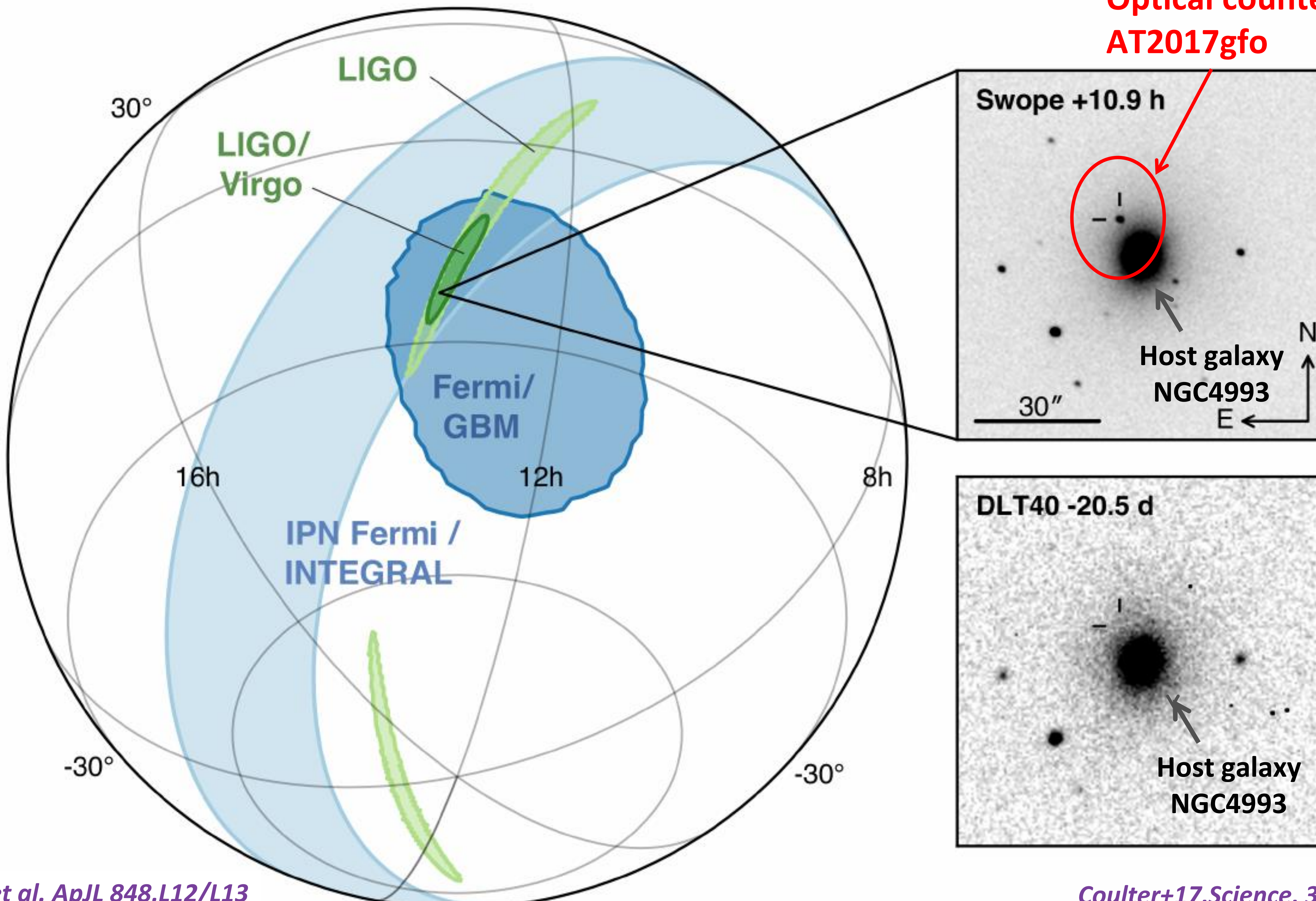
GRB170817A



Goldstein et al, 2017, Savchenko et al 2017

GW170817/GRB170817A

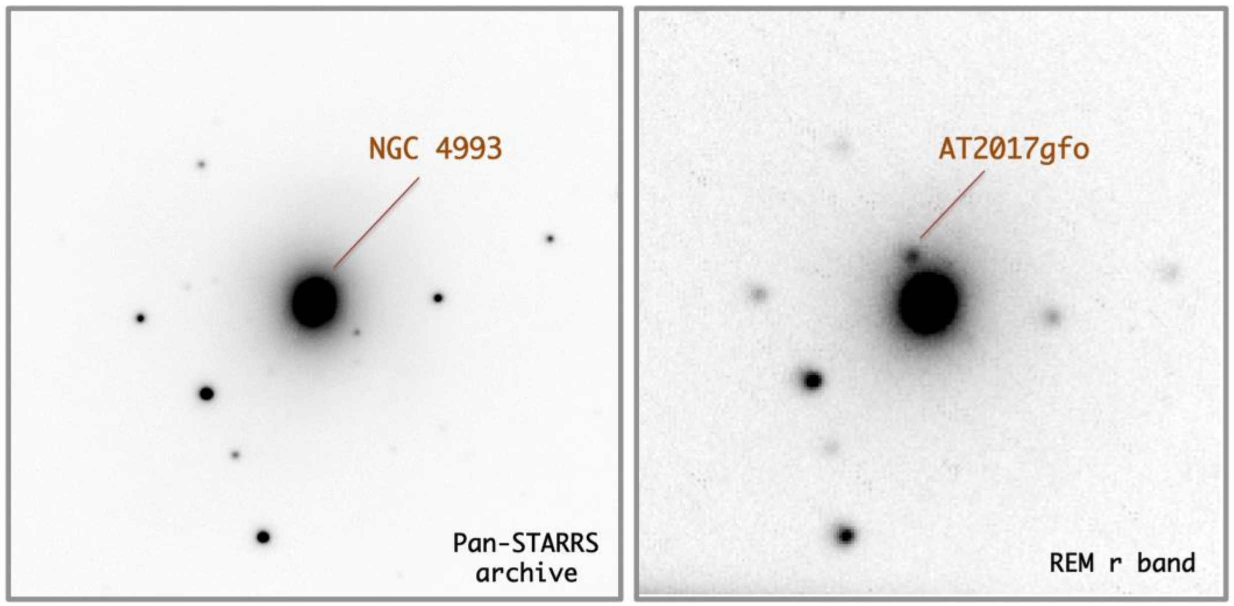
OPTICAL counterpart detection ~ 11 hours after GW trigger

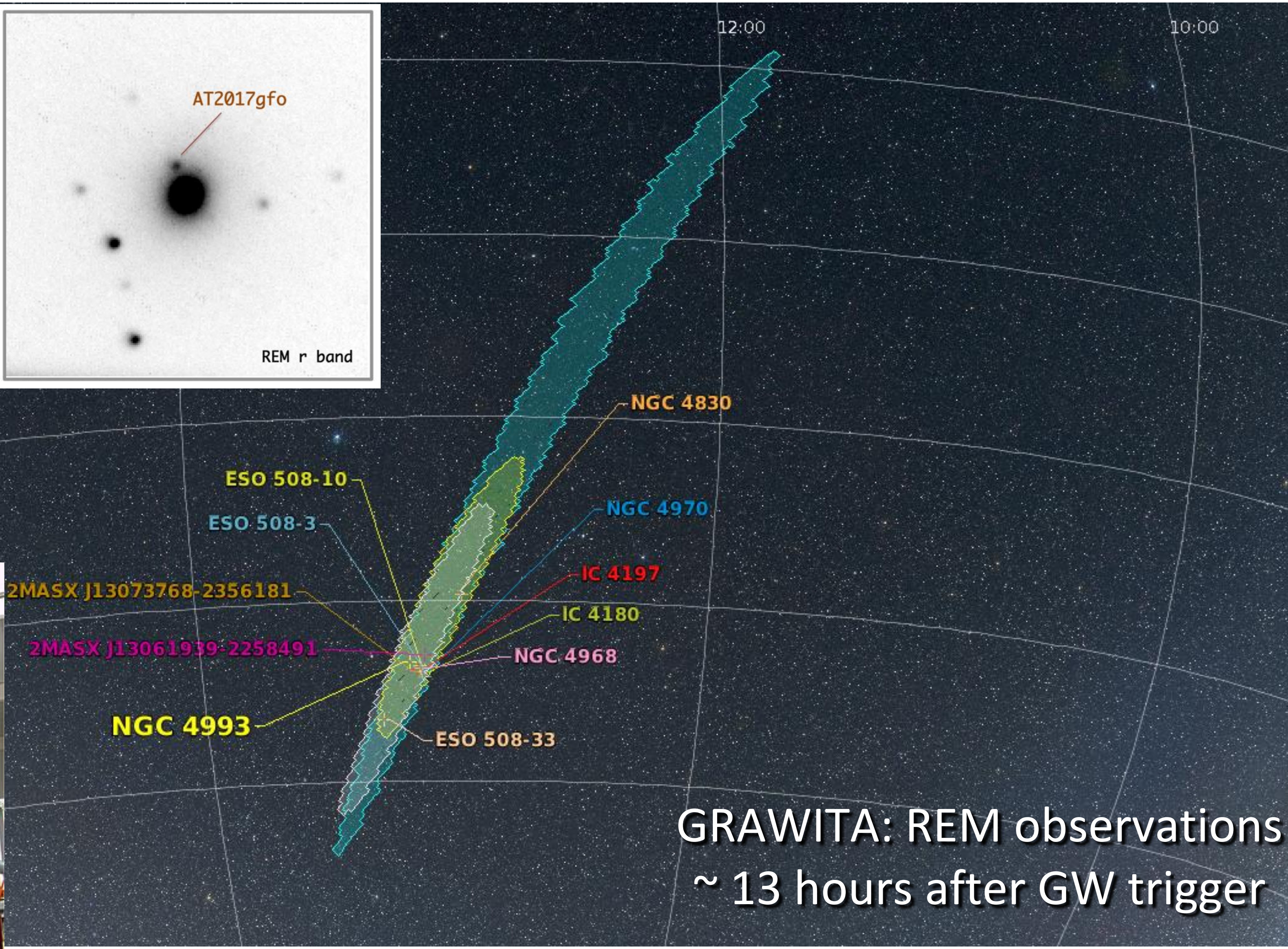


Abbott et al. ApJL 848,L12/L13

Coulter+17,Science, 358,1156

GW170817: GRAWITA follow-up

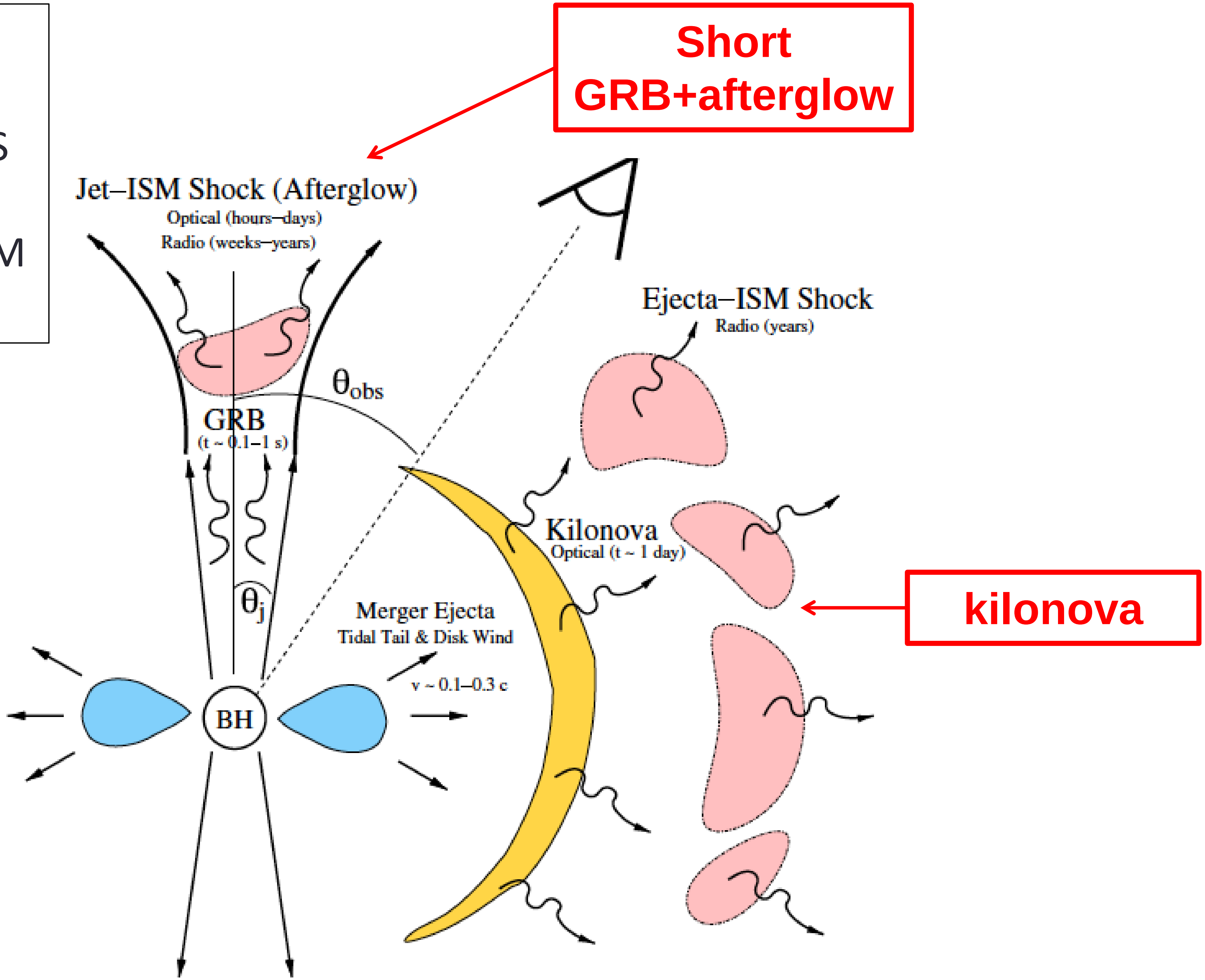




REM @ ESO La Silla

CBC coalescence: Expected Scenario

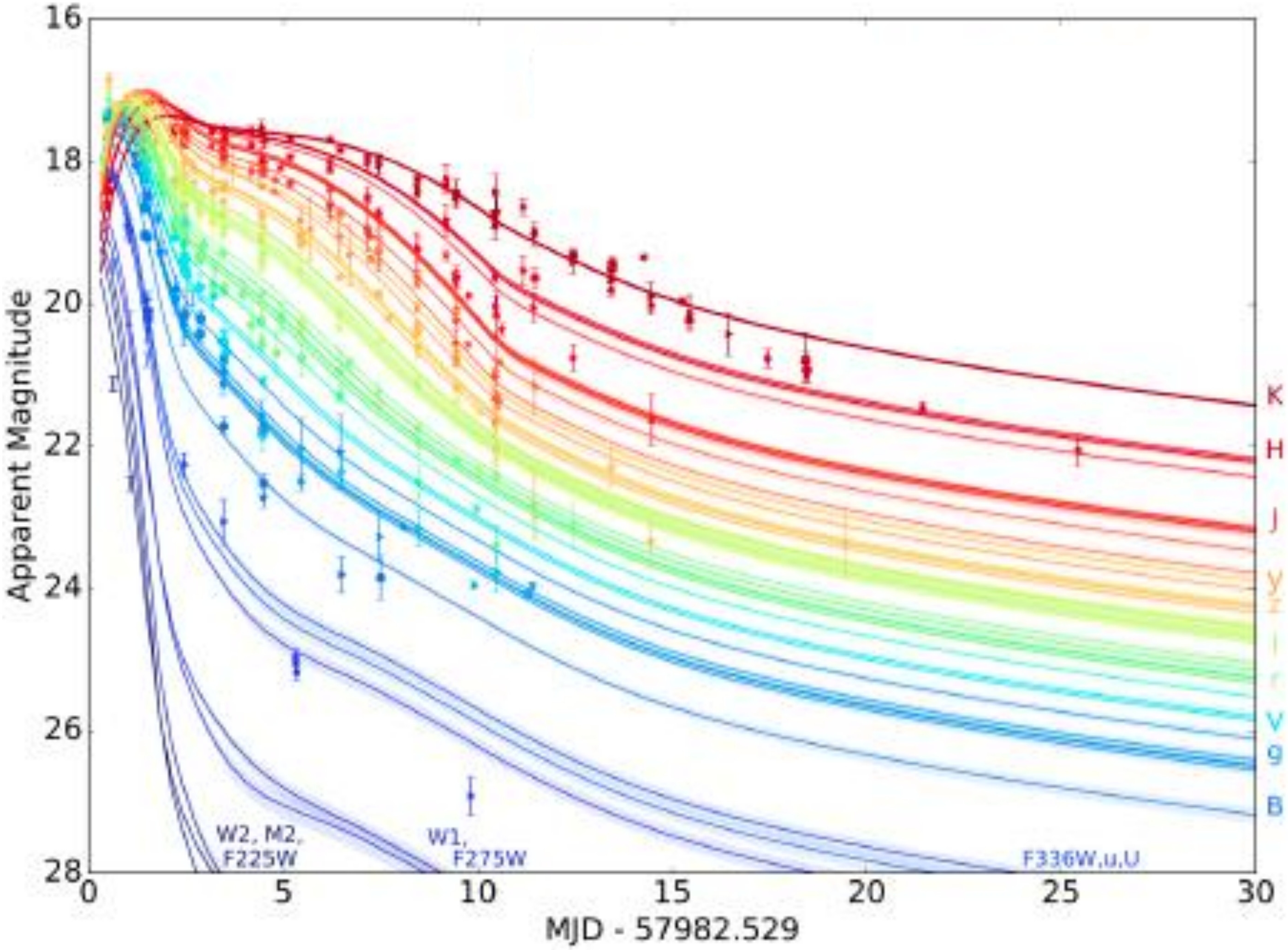
Expected scenario for compact binary coalescence (CBC: NS-NS or NS-BH) before GW170817: two main EM emission components



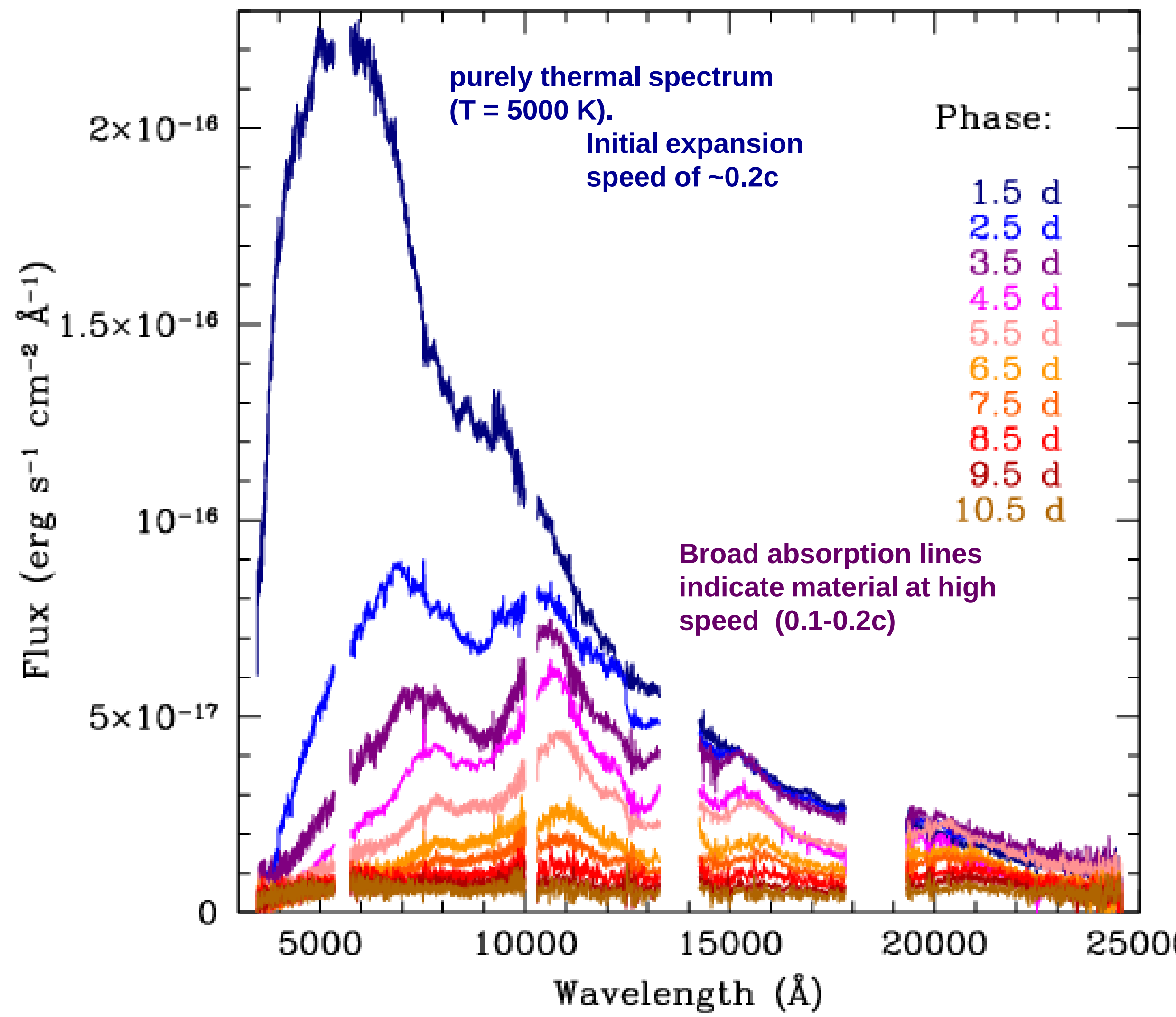
Metzger & Berger 2012

GW170817: the Kilonova component

First evidence of a **Kilonova** and its BLUE and RED components



Villard et al. 2017

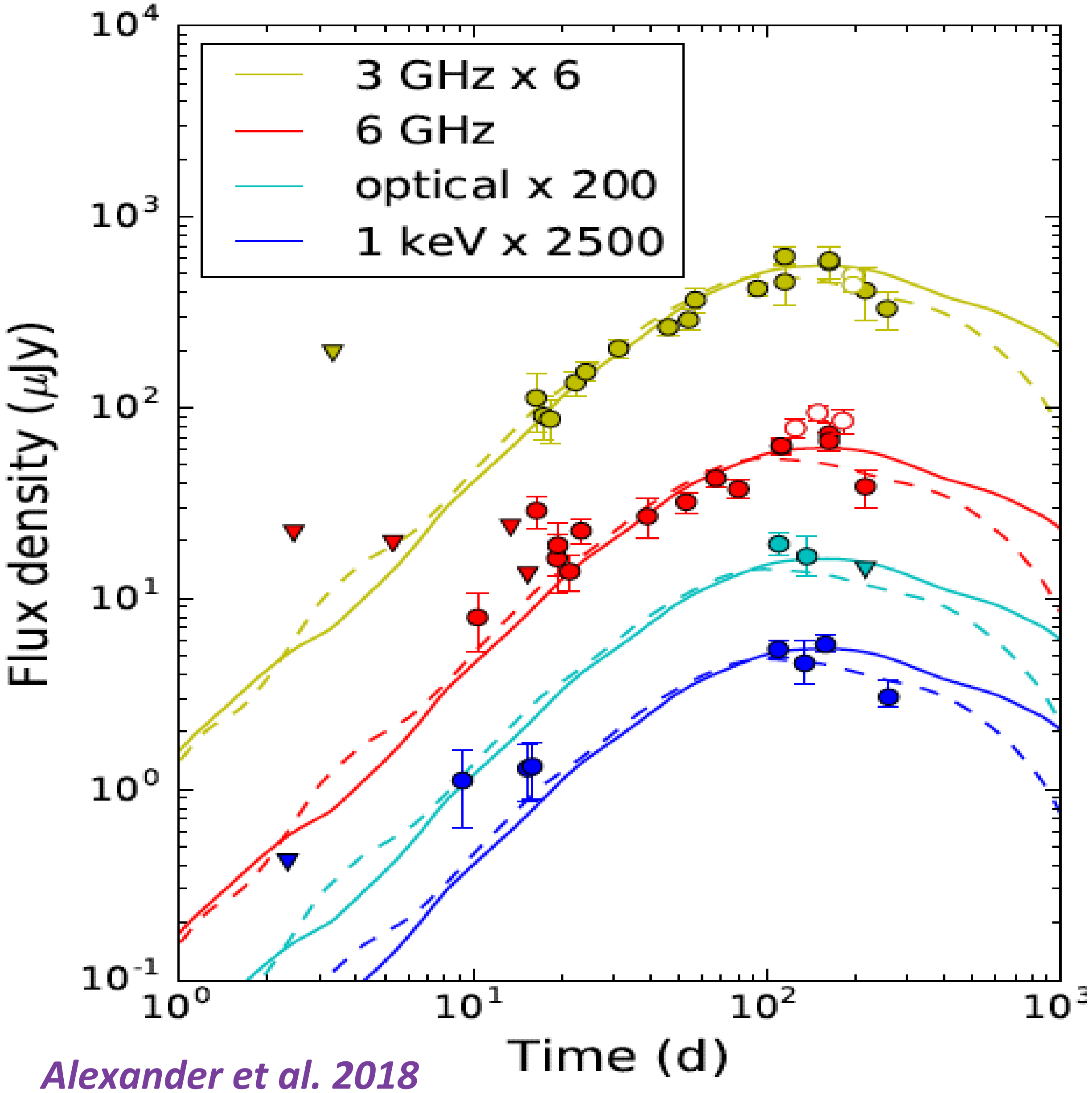


Pian et al. 2017

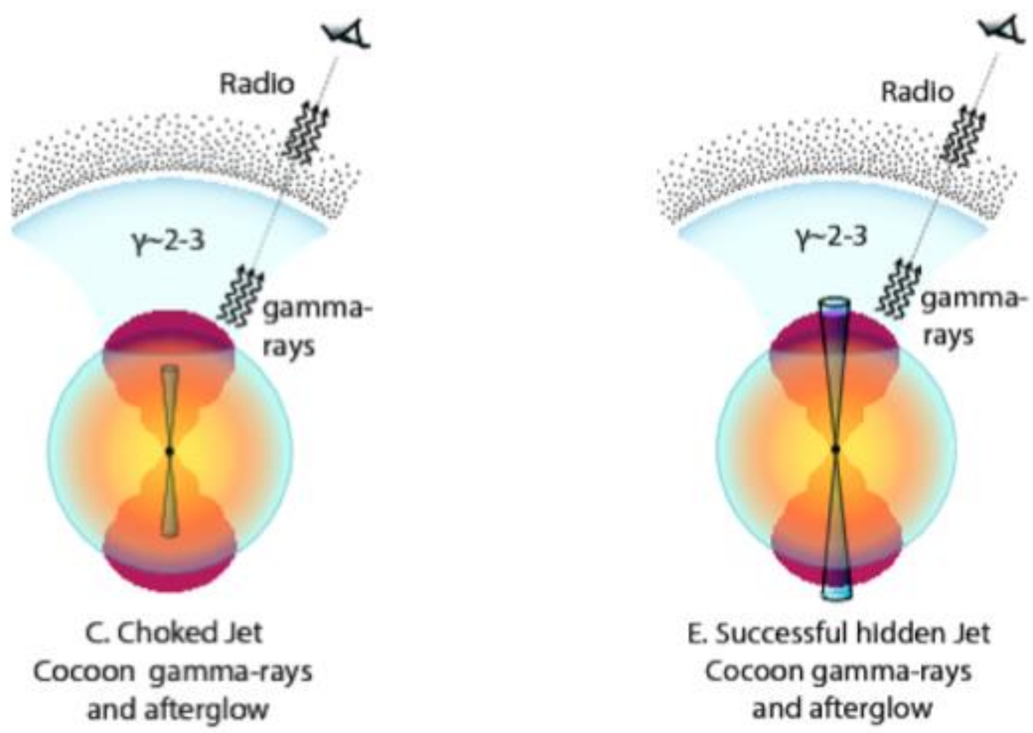
GRAWITA has provided significant contribution to the characterization of the kilonova associated with GW 170817 providing imaging and exceptional high quality spectroscopic data from VLT-Xshooter (*Pian et al. 2017*) as well as host galaxy NCG4993 distance estimation from surface brightness studies (*Cantiello et al. 2018*)

GRB170817: the Afterglow component

Observed multi-wavelength afterglow emission up to ~300 d



Alexander et al. 2018



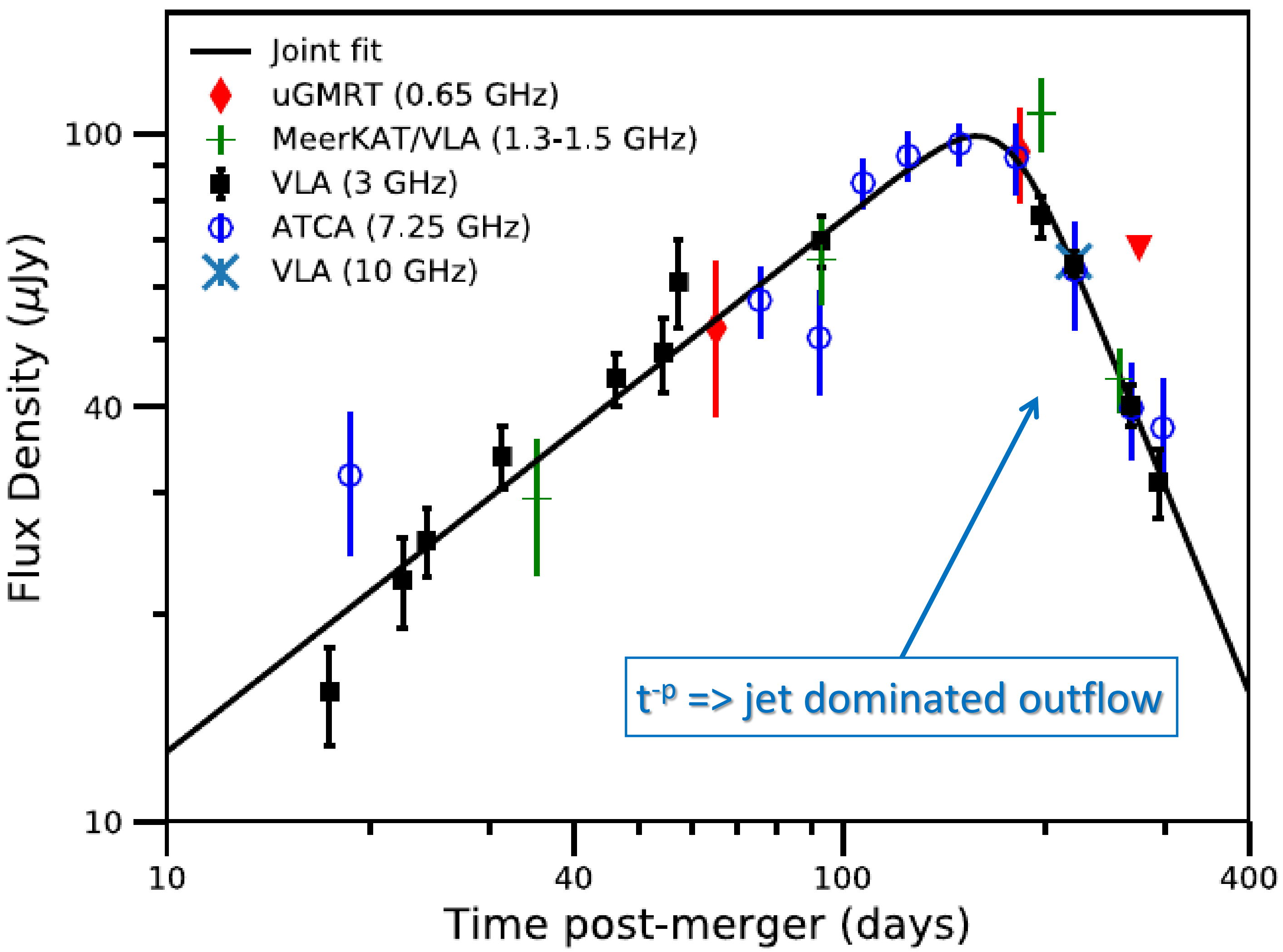
Mooley et al. 2017

Multi-wavelength afterglow light curve consistent with two types of structured jet model:

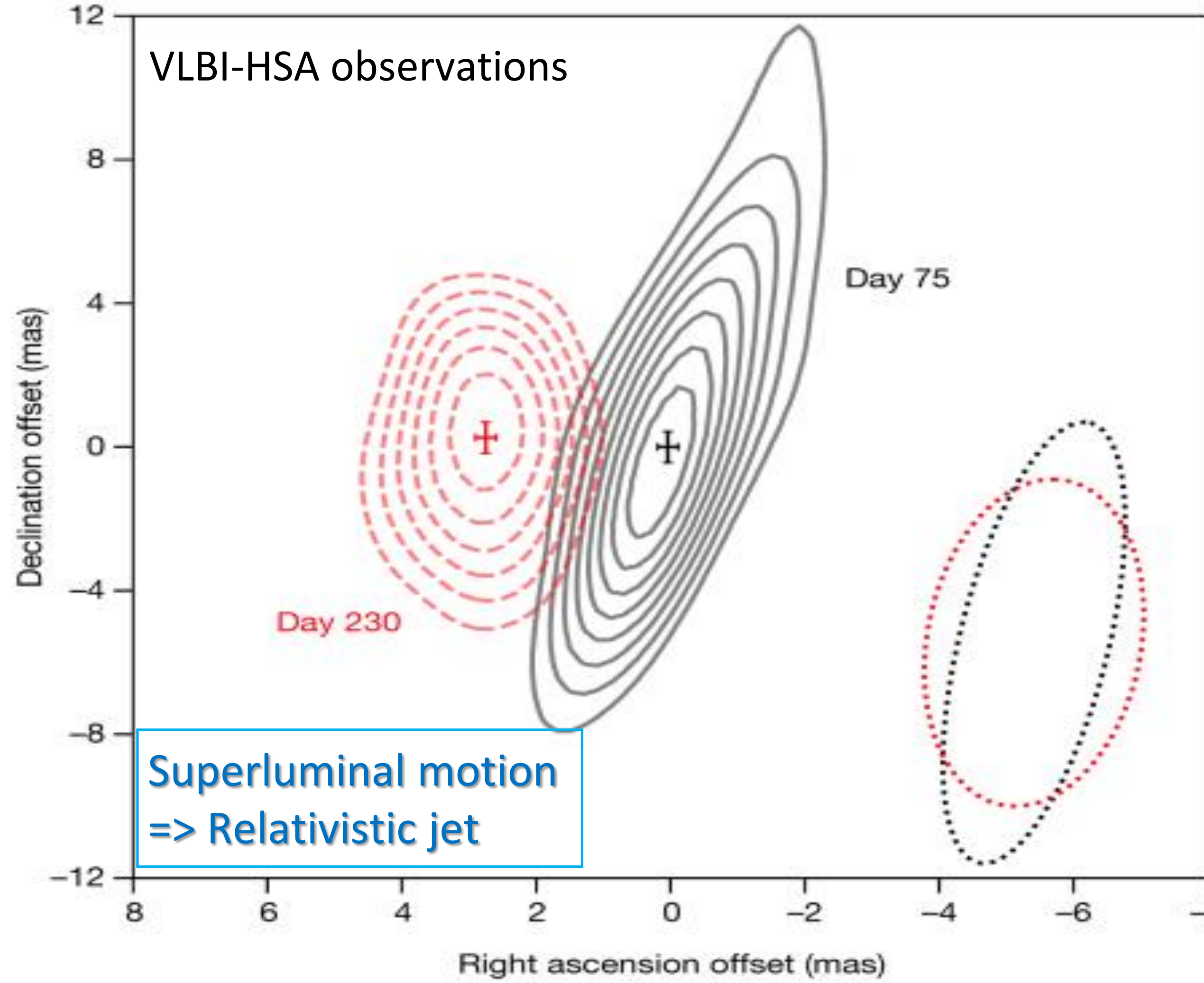
- **Chocked jet + cocoon**
- **Successful jet + cocoon**

GRB170817: the Radio Afterglow

Mooley et al. 2018 ApJ



Mooley et al. 2018 Nat.
Ghirlanda et al. 2018



Afterglow emission comes from the structured relativistic jet which progressively decelerates and then enters the line of sight.

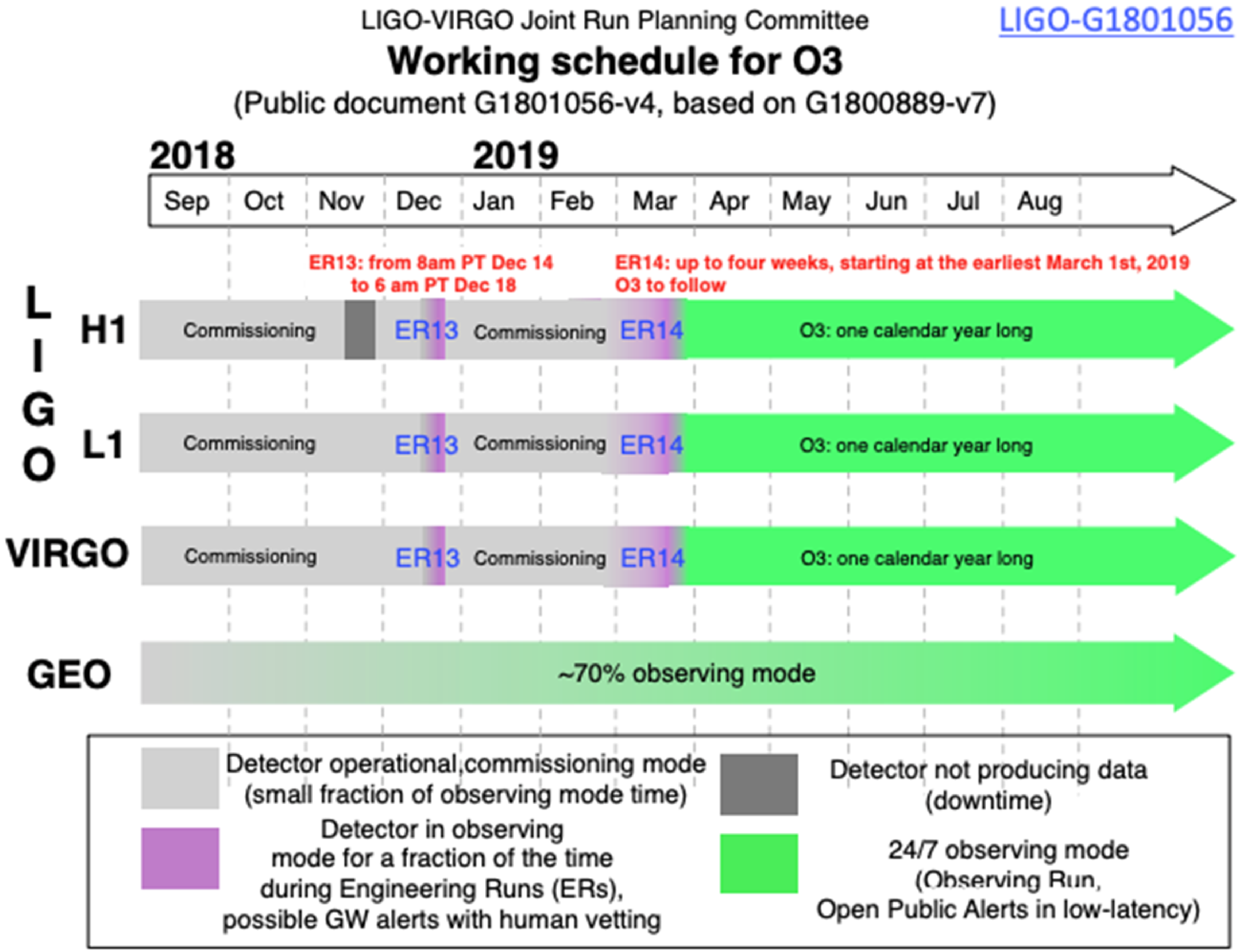
Ghirlanda talk

GW170817/GRB170817A: summary

GW170817 electromagnetic counterparts detection has initiated the era of **multi-messenger astronomy** and has enable to better understand several issues, among which:

- First direct evidence of the **association of short GRBs with BNS**
- First **detailed study of GRB jet structure** and opening angle
- First **detection** of the predicted **off-axis afterglow**
- First **compelling kilonova observations**
- First **NS-NS merger/kilonova association**
- First **detailed study of kilonova emission**
- First signature **of r-process nucleosynthesis** which likely **produce the heaviest elements** in the Universe
- First direct observational evidence for the **launching of relativistic jets in BNS mergers.**

Future Perspective: LVC O3 run



LIGO-G1801056

From LVC open call on 15-11-2018

BNS:

- 1/month-1/yr
- Median 90% credible localization 120-180 deg^2
- 12-21% <20 deg^2

https://www.ligo.caltech.edu/page/observatory-status

ENGRAVE Collaboration

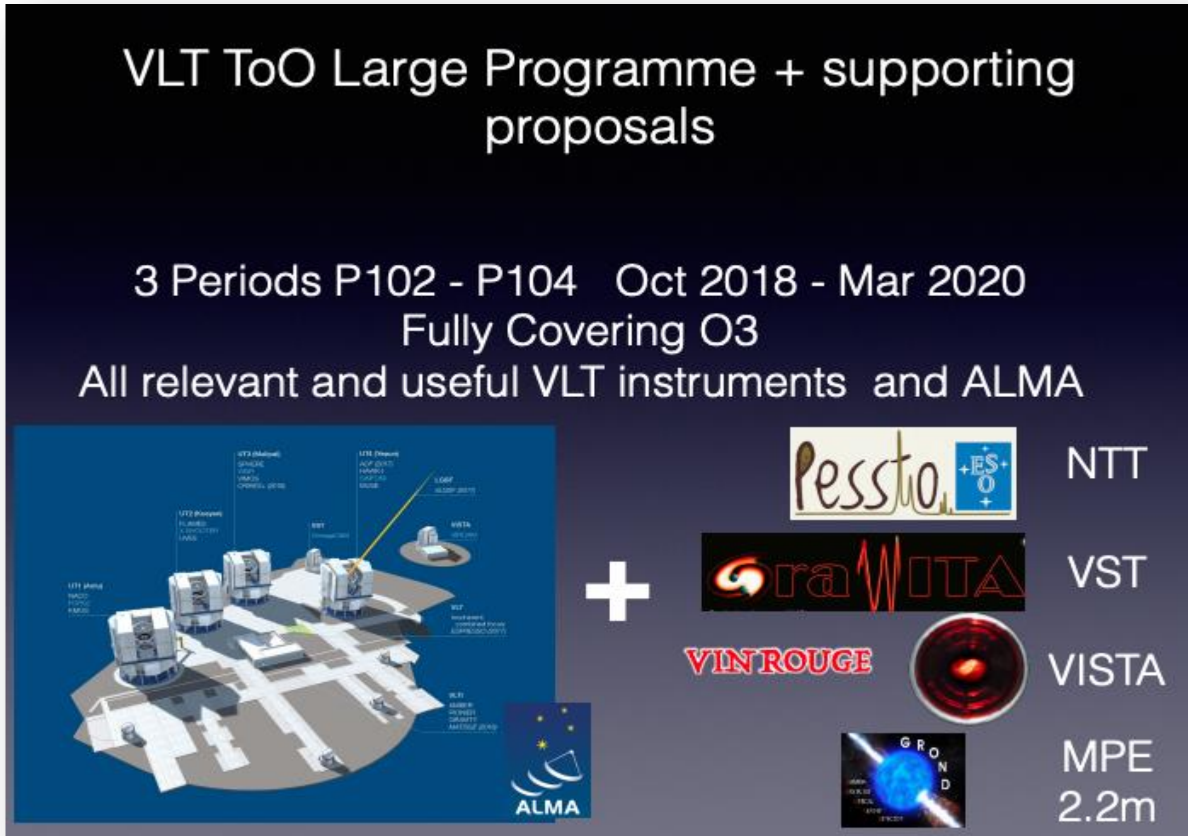
ENGRAVE - Electromagnetic counterparts of gravitational wave sources at the Very Large Telescope

http://www.engrave-eso.org

- **ENGRAVE** collects major groups across ESO member states that have used the **ESO** facilities, including VLT,ALMA,NTT,VST to perform **follow-up** observations of the **electromagnetic counterpart of gravitational wave (GW) events**

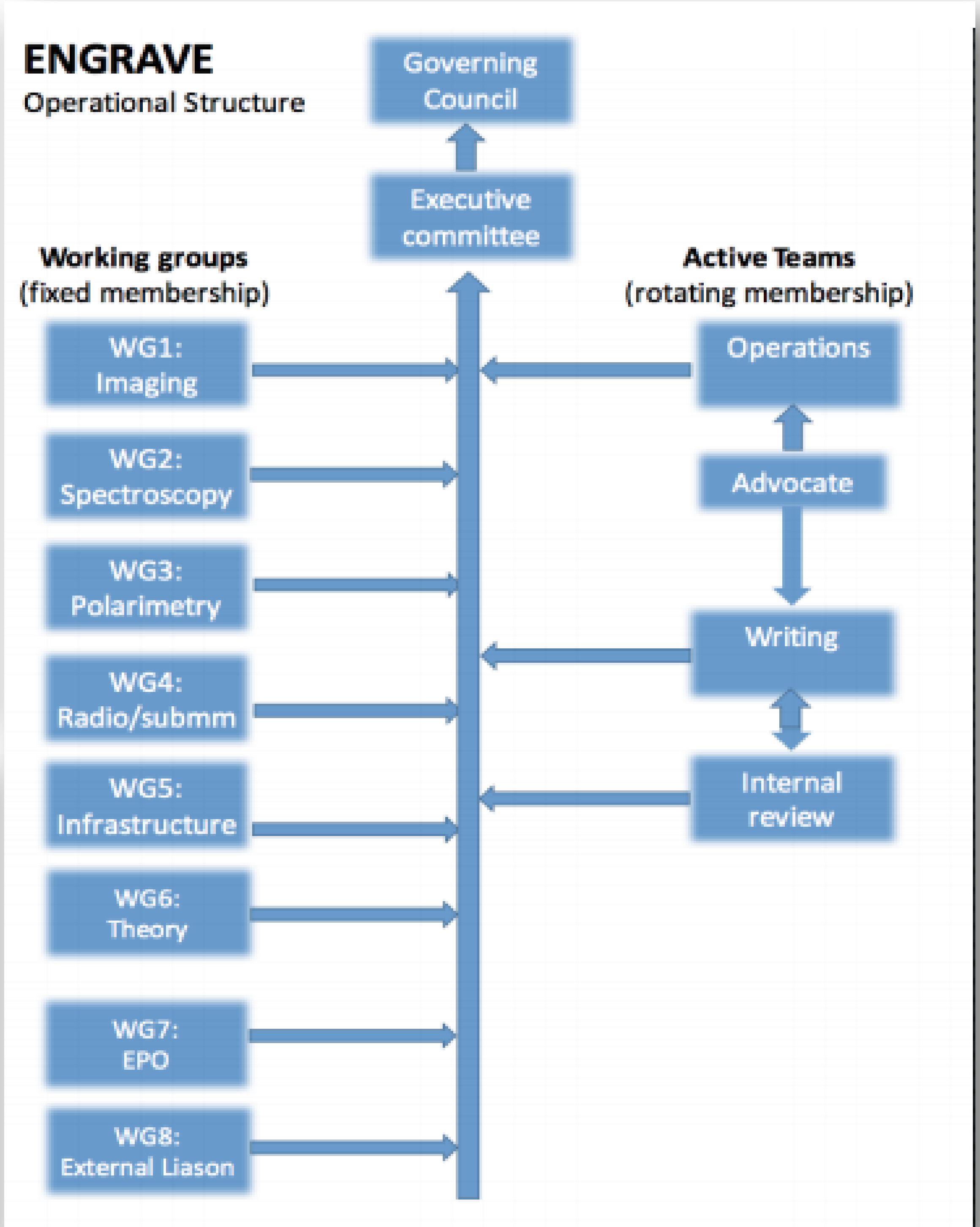
- **ENGRAVE and GRAWITA are complementary as well as synergic**: GRAWITA search+first characterization of candidate counterparts inside the LVC skymap ENGRAVE will perform deep, high quality follow-up of best candidates

ENGRAVE Collaboration



THE CONSORTIUM – 223 MEMBERS AND GROWING

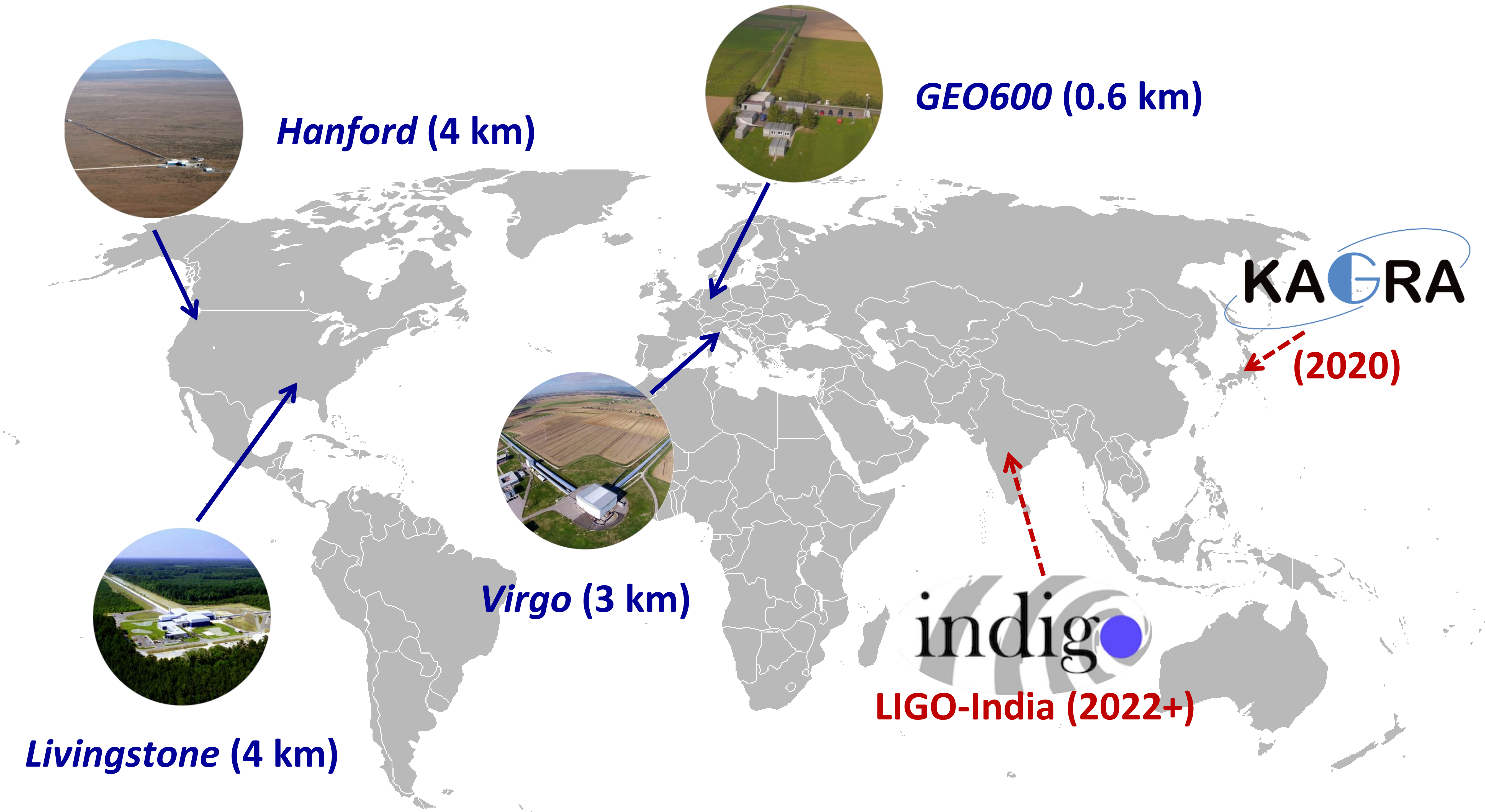
Amati **Anderson** Antier **Ascenzi** Ashall **Barbarino** Belloni **Benetti** Bensch **Bernardini** Bersier **Berton** Bloemen **Blondin** Bolmer **Botticella** Branchesi **Brennan** Brocato **Brusa** Bruun **Bufano** Bulgarelli **Bulla** Callis **Campana** Cannizzaro **Cano** Cantiello **Cappellaro** Carini **Casella** Castro-Tirado **Chassande-Mottin** Chen **Christensen** Cikota **Cimatti** Ciolfi **Clark** Congiu **Copperwheat** Covino **Cutter** D'Avanzo **D'Elia** Dadina **Dall'Ora** De Cesare **De Pasquale** de Ugarte Postigo **Della Valle** Dennefeld **Dessart** Dhillon **di Serego Alighieri** Diehl **Eappachen** Evans **Eyles** Fairhurst **Fan** Fiore **Flörs** Fraser **Frohmaier** Fynbo **Gal-Yam** Galbany **Gall** Galloway **Gendre** Ghirlanda **Gillanders** Giunta **Gomboc** Gompertz **González-Gaitán** Goobar Grado **Greco** Greiner **Gromadzki** Groot **Gutiérrez** Götz **Heintz** Higgins **Hirai** Hjorth **Horesh** Hu **Hunt** Inserra **Irwin** Izzo **Japelj** Jerkstrand **Jin** Jonker **Kankare** Kann **Kerzendorf** Klose **Kobayashi** Koerding Kostrzewa-Rutkowska **Kotak** Kuncarayakti **LIMONGI** Lamb **Lanzuisi** Leloudas **Lena** Levan **Longo** Lunnan **Lyman** Magee **Maguire** Maiorano **Malesani** Mandel **Mandhai** Mapelli **Marsh** Martone **Masetti** Mattila **McBrien** McMahon **Melandri** Milvang-Jensen **Molinari** Moran **Moresco** Mullaney **Møller** Nagao **Nelemans** Nicastro **Nissanke** Nordin **O'Brien** O'Neill **Oates** Onori **Osborne** Paladino **Palazzi** Palmerio **Pastorello** Patat **Patricelli** Peiris **Perego** Perez **Torres** Perley **Pian** Pignata **Piranomonte** Podsiadlowski **Possenti** Pulone **Pumo** Ragosta **Raimondo** Ramsay **Ravasio** Razzano **Reynolds** Rossi **Rosswog** Roy **Rubin** Ruiter **Sabha** Salafia **Salmon** Salvaterra **Savaglio** Sbordone **Schady** Schipani **Schroetter** Schulze **Seitenzahl** Selsing **Shingles** Sim Skillen **Smartt** Smith **Smith** Sollerman **Stanway** Starling **Steeghs** Stella **Stratta** Stritzinger **Sullivan** Taddia **Tagliaferri** Talia **Tanvir** Testa **Thöne** Tomasella **Tucker** Turatto **Ulaczyk** Vergani **Vergani** Vielfaure **Walton** Watson **Wiersema** Wojtak **Wyrzykowski** Yang **Young** van der Horst



This week → Dry run

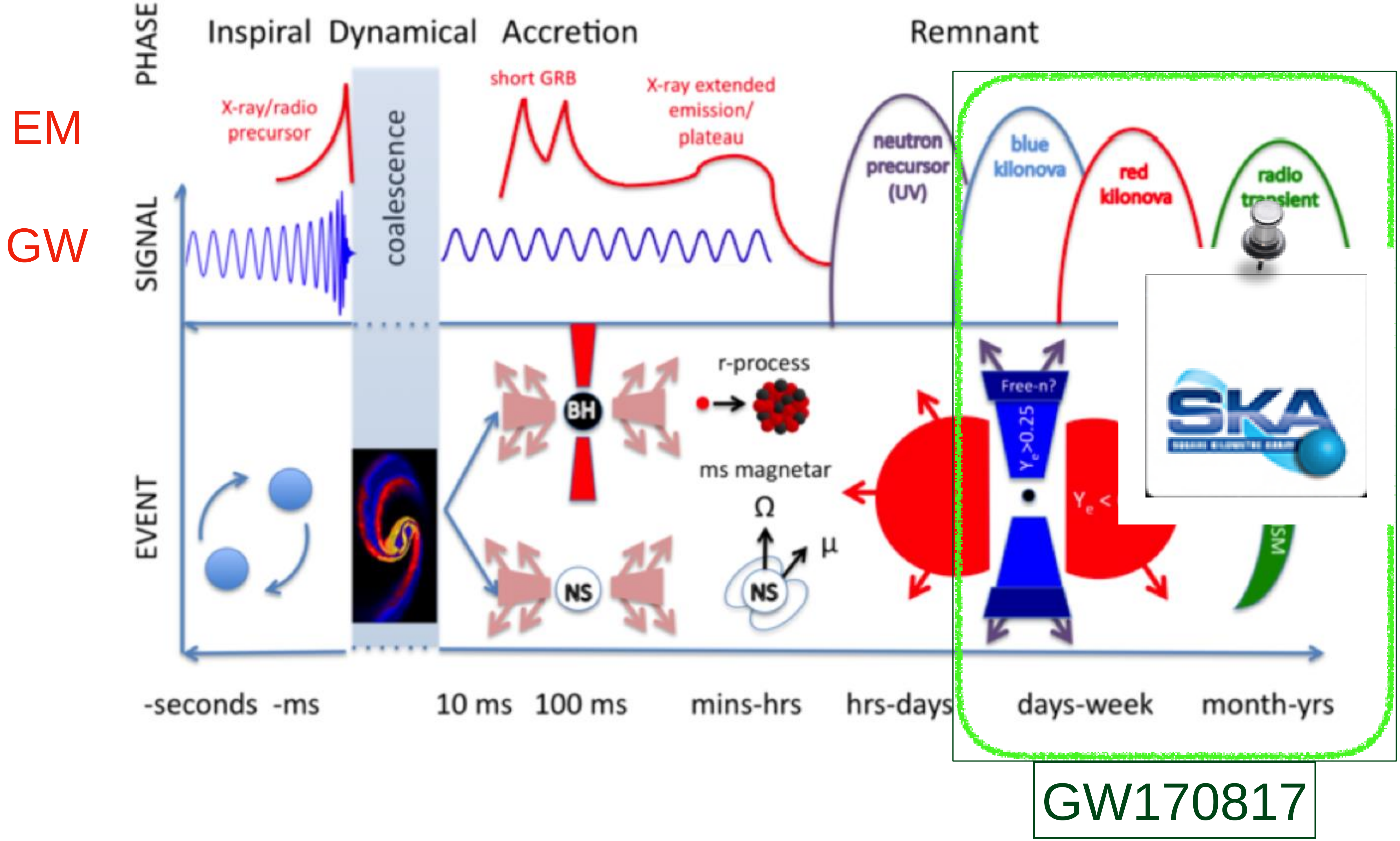
Aim: to practice and test the triggering procedure and fix any critical issue before real events

Future Perspective: GW detectors 2020+



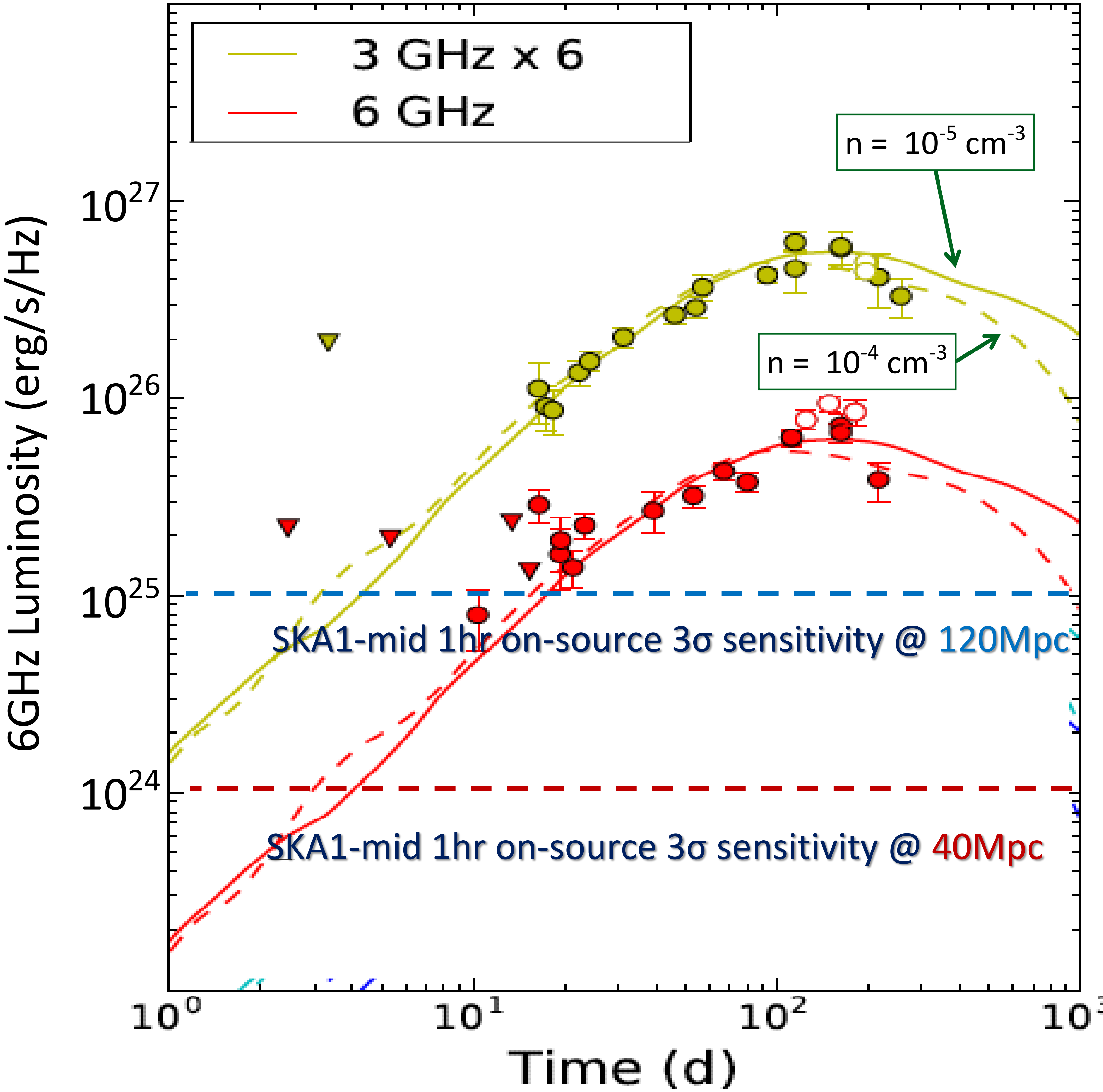
- BBH detection rate: 50 – 500 /year (< 400 Mpc)
- BNS detection rate: 10 – 300 /year (< 200 Mpc)
- Localization more than 10 times better, ~ 10 deg^2

The role of SKA



Fernandez & Metzger 2016, ARNPS 66

The role of SKA



Adapted from Alexander et al. 2018

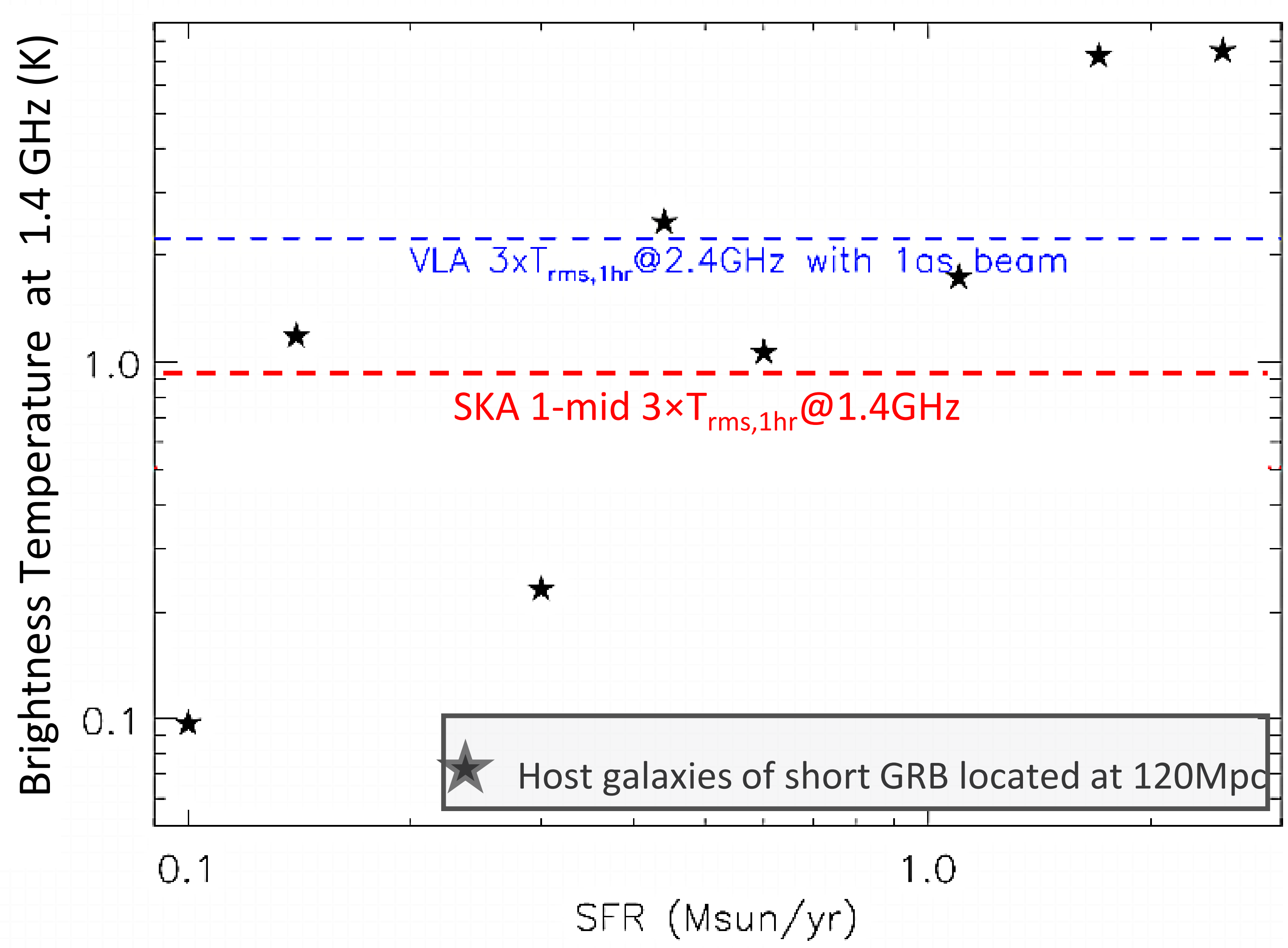
SKA 1–mid rms ~1μJy in 1 hr @ 4.6 – 8.5 GHz

- Probe GW170817-like radio counterparts up to a distance horizon > 120 Mpc
- Detect the KN radio emission years after the GW trigger measuring the ejecta properties and the circumbinary density

Ghirlanda talk

The role of SKA

Resolved observations of Host Galaxies of CBC mergers within a distance of 120 Mpc



Combined with other MWL observations allow to:

- gain clues on the progenitors of the CBC
- assess the presence or absence of a spatial association with star formation
- map the distribution of offsets of the EM counterparts within their host galaxy

Adapted from Corsi et al. 2018

Conclusions

- Radio emission provides information on the **energetics of the explosion, the geometry of the ejecta, as well as the environment of the merger**.

- The spectral and temporal evolution of such emission, coupled with MWL observations, are likely to **constrain several proposed models.** According to the most accredited models **SKA will come online by the time the emission from the Kilonova radio emission from GW170817** and possible future LIGO/Virgo BNS merger events **reach the peak**.

- **SKA**, at least 10 times more sensitive than the current instruments, **will be able to detect radio counterparts as faint as GW170817/GRB170817A up to ≈120–190 Mpc** (LIGO and Virgo nominal sensitivities) and **will allow to resolve and study their host galaxies.**

- **SKA** will have an effective role in **Time Domain Astronomy** by **complementing the MWL observations** of the large number of transients detected during the EM counterpart searches thus allowing to better characterize them.