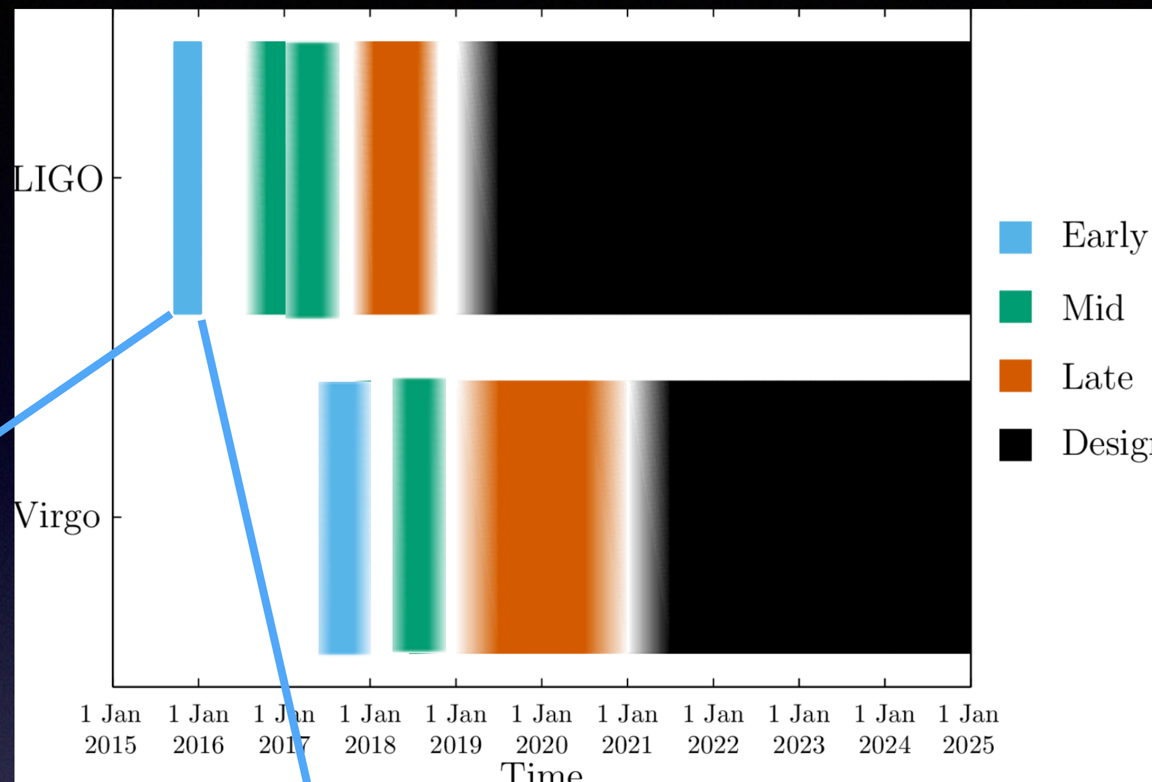
TNG: a key telescope to unveil GW counterparts

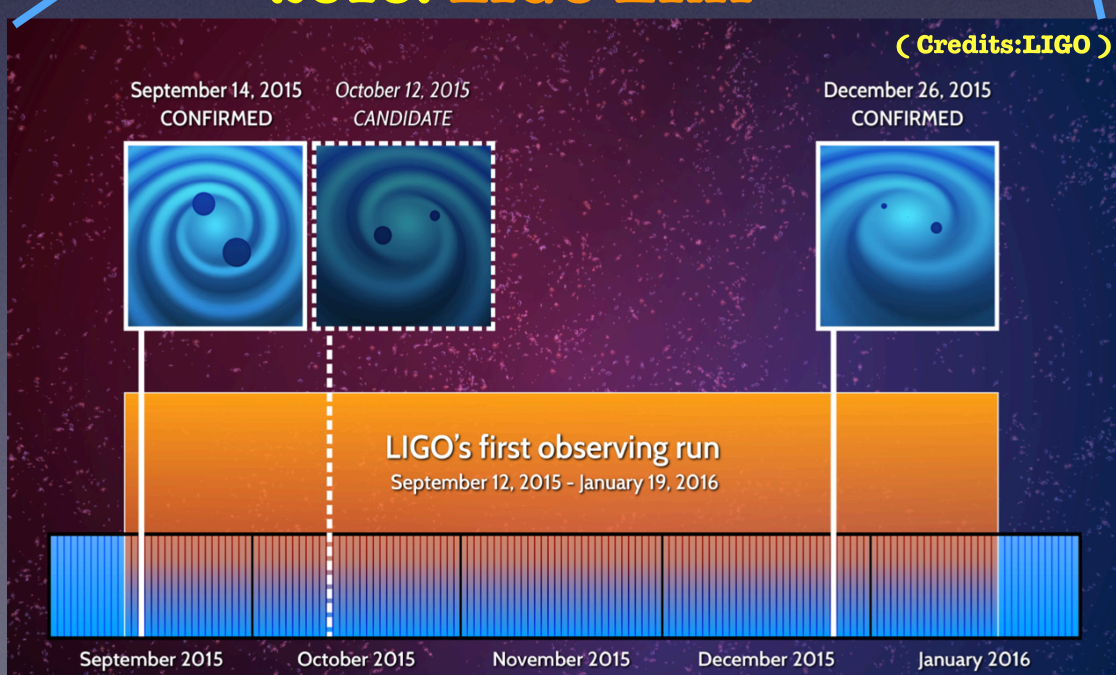
Silvia Piranomonte
INAF
Osservatorio Astronomico di Roma (ITALY)

on behalf of the GraWITA group

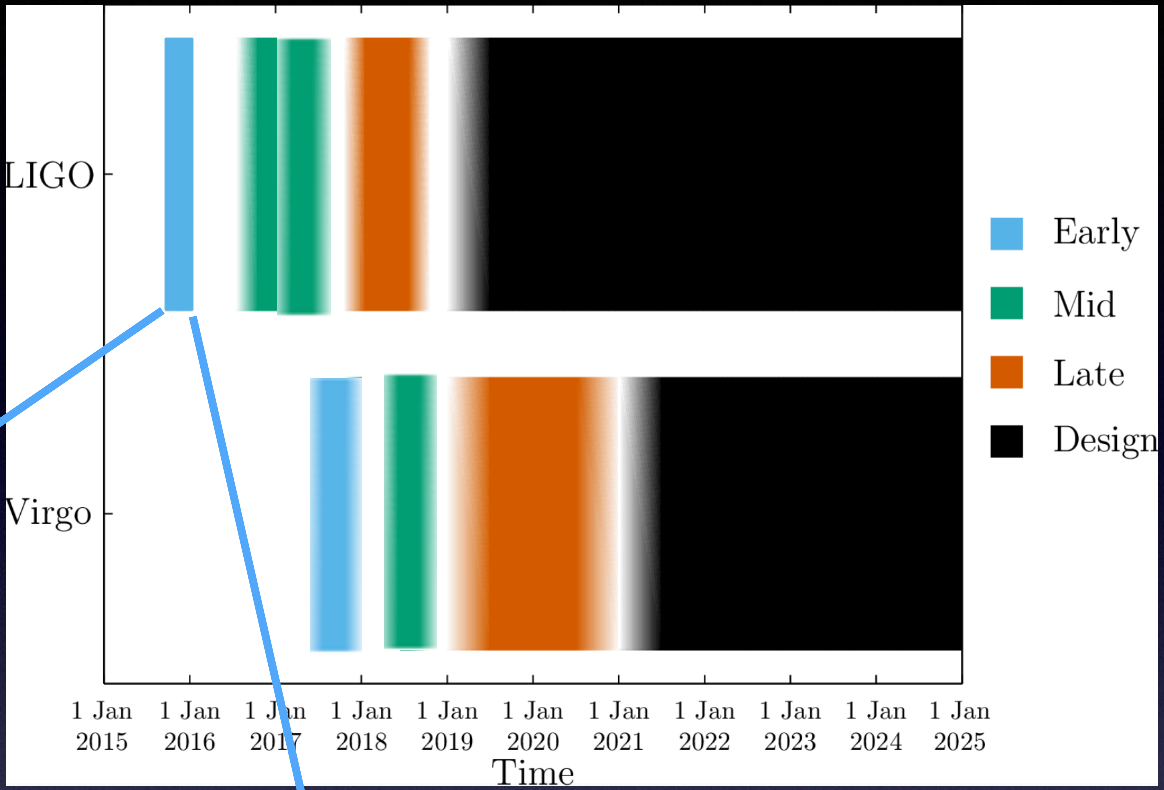
The GWs astronomy era



2016: LIGO ERA



The GWs astronomy era

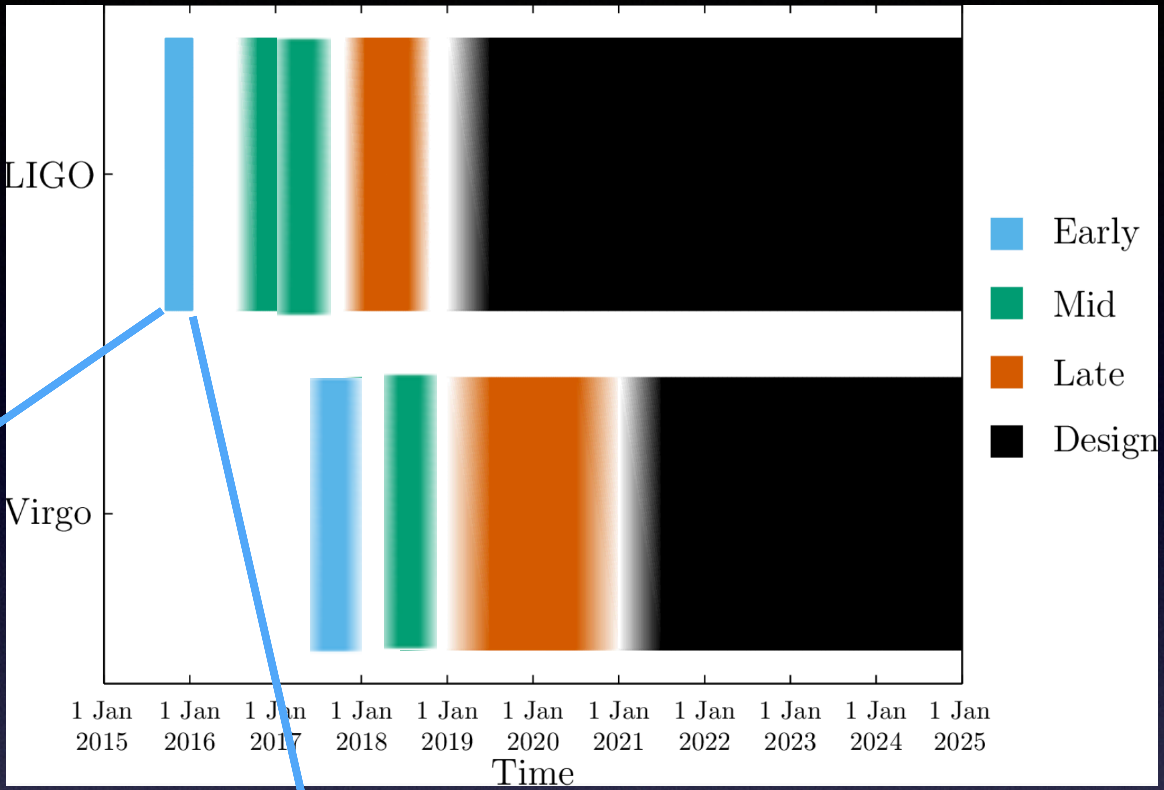


2016: LIGO ERA

Provides for the first time that:

1) "Heavy" stellar BH exist
2) Binary BH form in nature
3) BBH inspiral and merge within the age of the Universe

The GWs astronomy era



2016: LIGO ERA

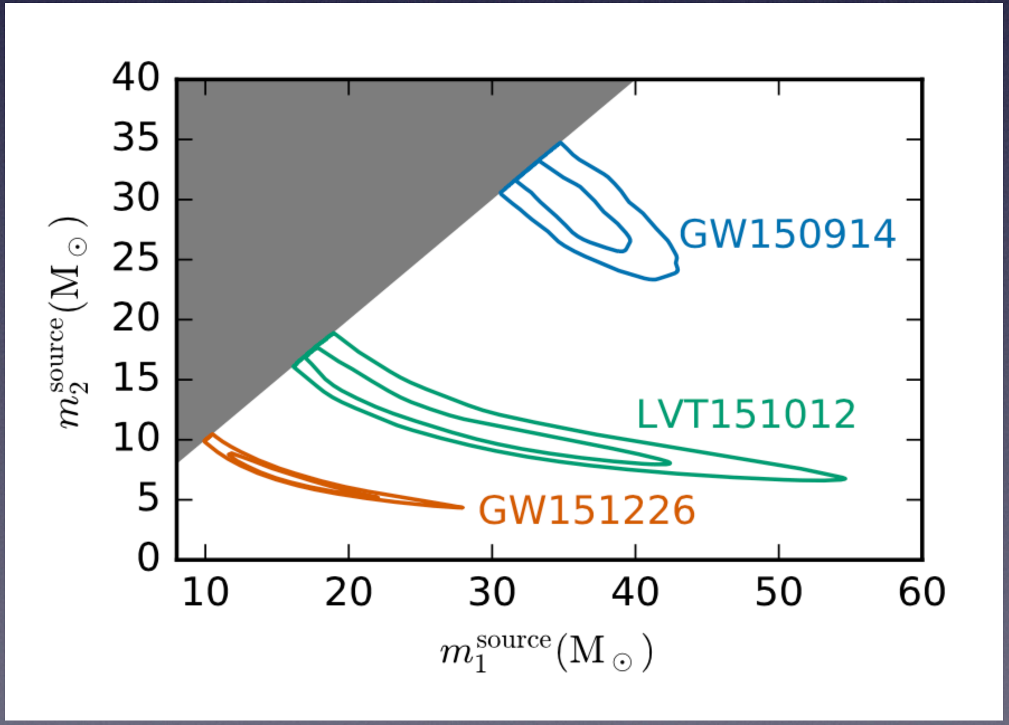
Provides for the first time that:
1) "Heavy" stellar BH exist
2) Binary BH form in nature
3) BBH inspiral and merge within the age of the Universe

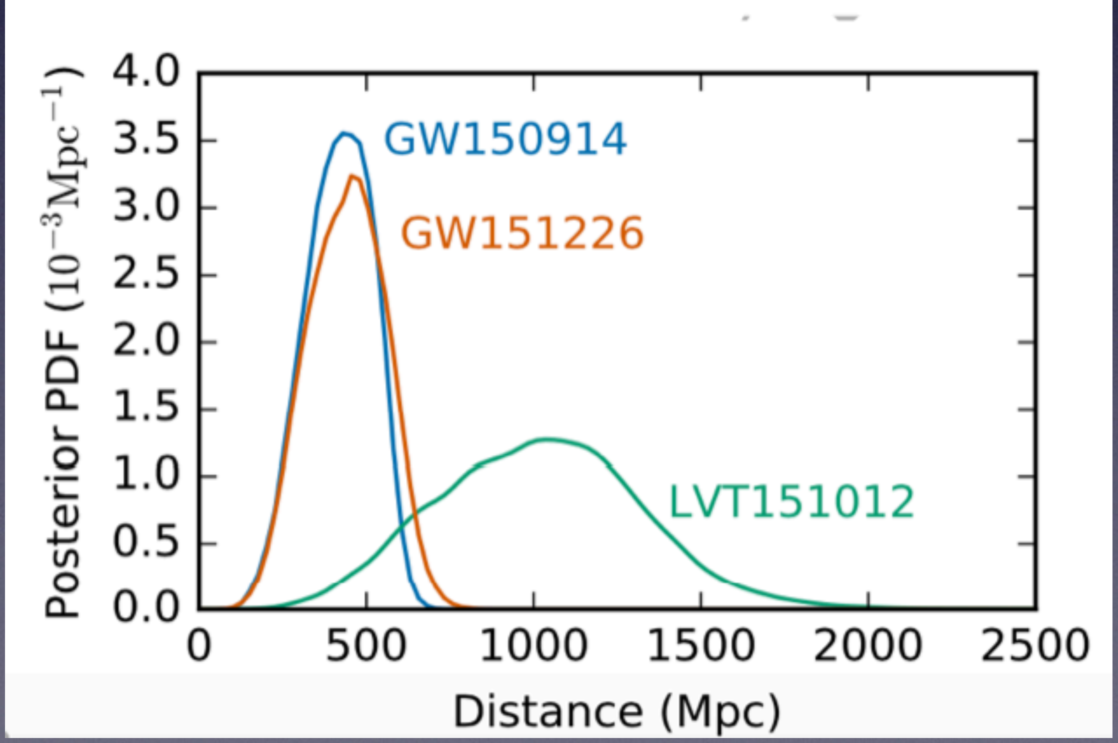
2017 —> 20??: LIGO + VIRGO ERA

(Try to) discover the UNKNOWN!!

BBH systems parameters

Event	GW150914	GW151226	LVT151012
Primary mass $m_1^{\rm source}/M_\odot$	$36.2^{+5.2}_{-3.8}$	$14.2^{+8.3}_{-3.7}$	23^{+18}_{-6}
Secondary mass $m_2^{\rm source}/M_\odot$	$29.1^{+3.7}_{-4.4}$	$7.5^{+2.3}_{-2.3}$	13^{+4}_{-5}
Luminosity distance D_L/Mpc	420^{+150}_{-180}	440^{+180}_{-190}	1000^{+500}_{-500}





The BBH Discovery

Where do BH forms?

Galaxy field
R~10 kpc,
N ~ 10^{10} stars

Dense environment star clusters
R~1-10 pc,
N ~ 10^{3-7} stars

How do they form binary systems?

ISOLATED BINARIES? | DYNAMICAL INTERACTION?

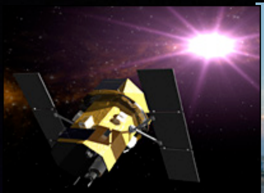
Both formation paths are consistent with GW150914 and GW151226
For GW150914, low metallicities are necessary.

* * *

Crucial: identify the host galaxy and study the GW source environment!!

Courtesy of M. Branchesi

Why we are interested in EM counterparts?



GW

- Mass
- Spins
- Eccentricity
- NS compactness and tidal deformability
- System orientations
- Luminosity distance
- Explosion asymmetry

Astrophysics side

- identify host galaxy (H_0, progenitors contstraint)
- connect to wealth of transients phenomenology (SN, GRB, new sources)
- uniquely constraint models: know masses, spin, orientation

GW physics side

- improve parameter estimation and detection
- cross correlate GW w/ EM searches
- gain factor in sensitivity and in rate

EM

- Energetics and beaming
- Magnetic field strength
- Precise (arcsec) sky localization
- Host galaxy
- Redshift
- Nuclear astrophyisics



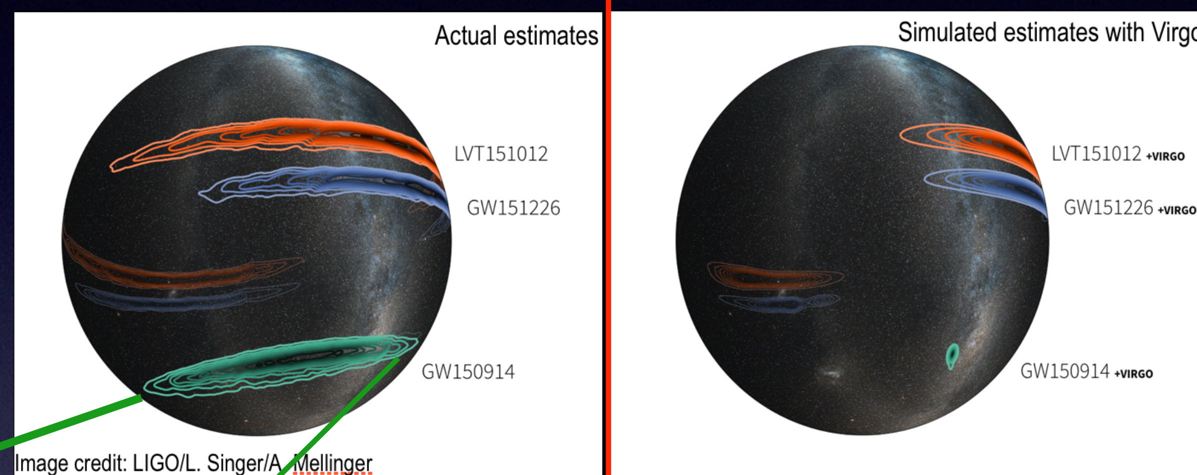
The need of multi-messenger astronomy

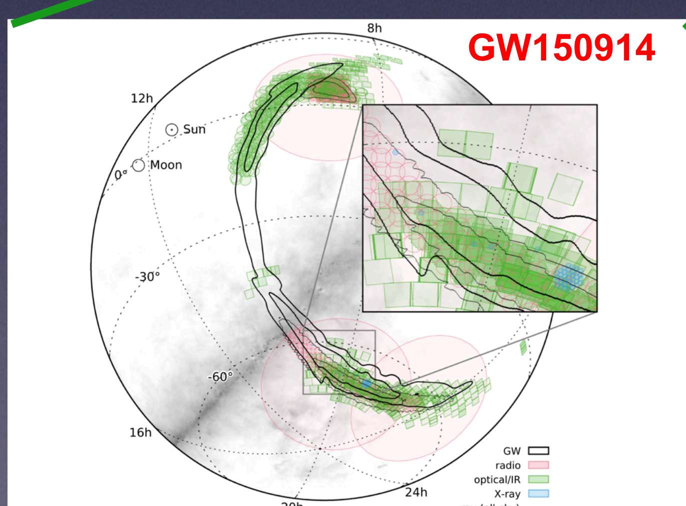
Sept 2015-Jan2016: O1 run

2017 - 2019 - 20??: Next Runs / discoveries?

Sky localizations:
90% credible areas of about

600 deg^2 GW150914
1600 deg^2 LVT151012
1000 deg^2 GW151226

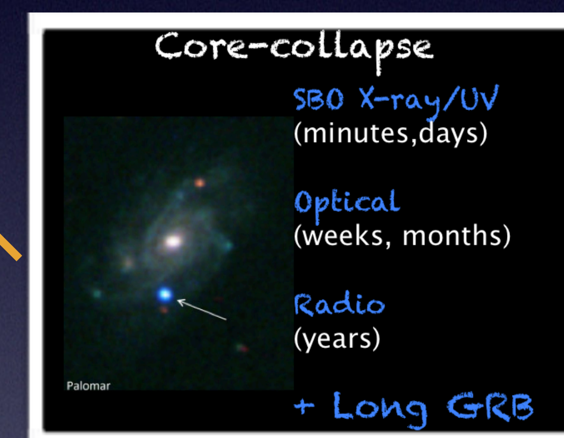




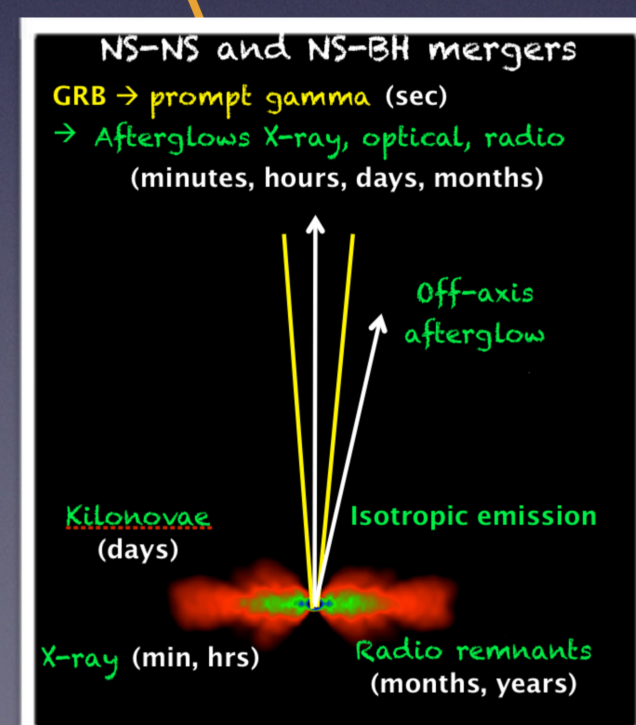
Gamma-ray
X-rays
Optical/NIR
Radio

no EM counterpart!

BH-BH mergers?
E_{GW} ~0.02 $M_\odot c^2$



E_{GW} ~10^{-8} - 10^{-4} $M_\odot c^2$



E_{GW} ~0.02 $M_\odot c^2$

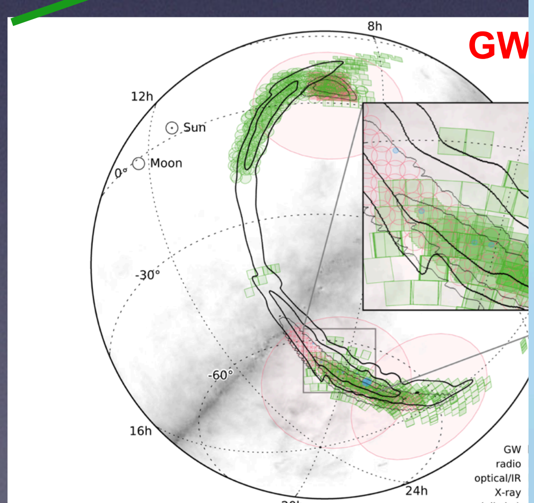
The need of mult

Sept 2015-Jan2

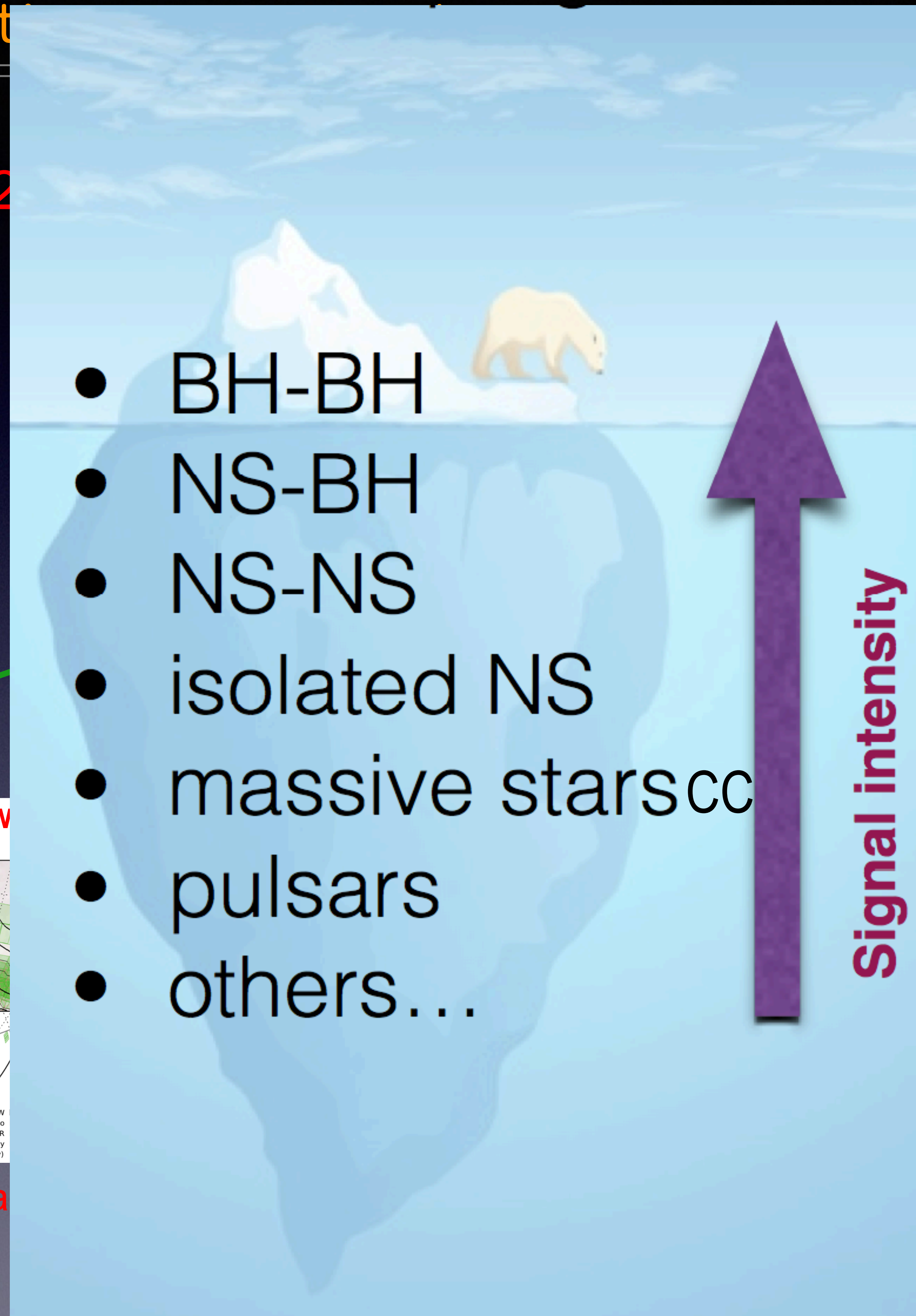
20??: Next Runs /
overies?

Sky localizations:
90% credible areas of about

600 deg^2 GW150914
1600 deg^2 LVT151012
1000 deg^2 GW151226



no EM counterpa



BH-BH mergers?
E_{GW} ~0.02 $M_o c^2$

E_{GW} ~10^{-8} - 10^{-4} $M_o c^2$

E_{GW} ~0.02 $M_o c^2$

GRAWITA: GRAvitational Wave Inaf TeAm

GRAWITA Goals:

The present research group is committed to taking part in the search and the study of electromagnetic counterparts of the GW events by using different observational facilities.

Know-how:

Time Domain Astronomy, Observational Strategy, Image analysis, Accurate Photometry in crowded fields, GRB astronomy, Supernovae, Data Interpretation, Theoretical models

Project milestones

05-12-2013...first meeting INAF – LVC
2014………...MoU INAF-LVC signed / early Team submitted PRIN INAF
2014………...VST as ToO facility
2015.............Early activities Proposals / fund raising
07-07-2015…Unsolicited project "Gravitational Wave Astronomy …" approved
15-09-2015... First operational meeting
17-09-2015... ESO-VST observations of GW150914
28-12-2015... ESO-VST observations of GW151226
30/12/2015-04/03/2016...TNG and LBT characterization of transients
03-2016........ Joint paper with LVC on ***GW150914***

GRAWITA PAPERS

Abbott et al. 2016: Localization and broadband follow-up of the gravitational-wave transient GW150914
Abbott et al. 2016: Supplement: Localization and broadband follow-up of the gravitational-wave transient GW150914
Pian et al. 2016: Optical photometry and spectroscopy of the low-luminosity, broad-lined Ic supernova iPTF15dld
Brocato et al. 2017: VLT Survey Telescope Observations of the gravitational wave source GW150914 - in prep
GRAWITA PAPER II 2017: EM Follow-up and Characterization of GW151226 event - in prep

Who we are

INAF OA Roma: **E.Brocato (P.I.)**, S. Piranomonte, L. Pulone, V. Testa, L. Stella, M. Lisi, S. Ascenzi, G. Israel, P. Casella, G. Iannicola.
INAF OA Napoli: **A. Grado**, F. Getman, L. Limatola, M Botticella, M. della Valle, M. Capaccioli, P. Schipani
INAF IASF Bologna: **L. Nicastro,** E. Palazzi, A. Rossi, L. Amati, L. Masetti, A. Bulgarelli, G. De Cesare
INAF OA Milano: **S. Covino**, S. Campana, G. Tagliaferri, P. D'Avanzo, A. Melandri, G. Ghisellini, G. Ghirlanda, R. Salvaterra
INAF OA Padova: **E. Cappellaro**, L. Tomasella, S. Yang
University of Urbino: **M. Branchesi**, G. Stratta, G. Greco
SNS Pisa: **E. Pian**, A. Stamerra, F. Longo, M. Razzano, G. Pivato, B. Patricelli, G. Cella
INAF OA CAGLIARI: A. Possenti, M. Burgay
ASI Science Data Center: **L.A. Antonelli**, V. D'Elia , G. Giuffrida, S. Marinoni, P. Marrese

GRAWITA: GRAvitational Wave Inaf TeAm

GRAWITA Goals:

The present research group is committed to taking part in the search and the study of electromagnetic counterparts of the GW events by using different observational facilities.

Know-how:

Time Domain Astronomy, Observation... analysis, Ac... in crowded... astronomy, Supernovae, Data Interpretation, Theoretical models

Project milestones

05-12-2013...first meeting INAF – LVC
2014………...MoU INAF-LVC signed / early Team submitted PRIN INAF
2014………...VST as ToO facility
2015.............Early activities Proposals / fund raising
07-07-2015…Unsolicited project "Gravitational Wave Astronomy …" approved
15-09-2015... First operational meeting
17-09-2015... ESO-VST observations of GW150914
28-12-2015... ESO-VST observations of GW151226
30/12/2015-04/03/2016...TNG and LBT characterization of transients
03-2016........ Joint paper with LVC on ***GW150914***

see also www.grawita.inaf.it

...nt GW150914
...transient GW150914
Pian et al. 2016: Optical photometry and spectroscopy of the low-luminosity, broad-lined Ic supernova iPTF15dld
Brocato et al. 2017: VLT Survey Telescope Observations of the gravitational wave source GW150914 - in prep
GRAWITA PAPER II 2017: EM Follow-up and Characterization of GW151226 event - in prep

Who we are

INAF OA Roma: **E.Brocato (P.I.)**, S. Piranomonte, L. Pulone, V. Testa, L. Stella, M. Lisi, S. Ascenzi, G. Israel, P. Casella, G. Iannicola.
INAF OA Napoli: **A. Grado**, F. Getman, L. Limatola, M Botticella, M. della Valle, M. Capaccioli, P. Schipani
INAF IASF Bologna: **L. Nicastro,** E. Palazzi, A. Rossi, L. Amati, L. Masetti, A. Bulgarelli, G. De Cesare
INAF OA Milano: **S. Covino**, S. Campana, G. Tagliaferri, P. D'Avanzo, A. Melandri, G. Ghisellini, G. Ghirlanda, R. Salvaterra
INAF OA Padova: **E. Cappellaro**, L. Tomasella, S. Yang
University of Urbino: **M. Branchesi**, G. Stratta, G. Greco
SNS Pisa: **E. Pian**, A. Stamerra, F. Longo, M. Razzano, G. Pivato, B. Patricelli, G. Cella
INAF OA CAGLIARI: A. Possenti, M. Burgay
ASI Science Data Center: **L.A. Antonelli**, V. D'Elia , G. Giuffrida, S. Marinoni, P. Marrese

GRAWITA PROJECT: Hunting the EM counterpart of the GW source

GW EM counterpart research

Coll. with
HIGH ENERGY FACILITIES

Search of Temporal coincidence with Fermi/GBM and INTEGRAL/SPI

X-ray counterpart with Swift/BAT and INTEGRAL/IBIS

GRAWITA PROJECT

GRAWITA: GRAvitational Wave Inaf TeAm

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**

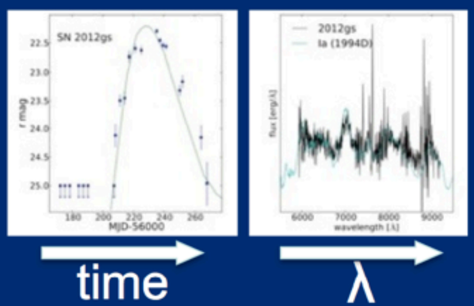
Telescopes with **large FoV** distributed at different latitudes/longitudes

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

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

Telescope	Proposal approved	Proposal Submitted PI
VST	ToO	Cappellaro \Grado
LBT	ToO	Palazzi
TNG	LongTerm '16-'18	Piranomonte
NOT	ToO	Pian
VLT	ToO	Pian
SRT	ToO	Possenti
REM	ToO	Campana
It Antartic Tel	yes	Col Brocato

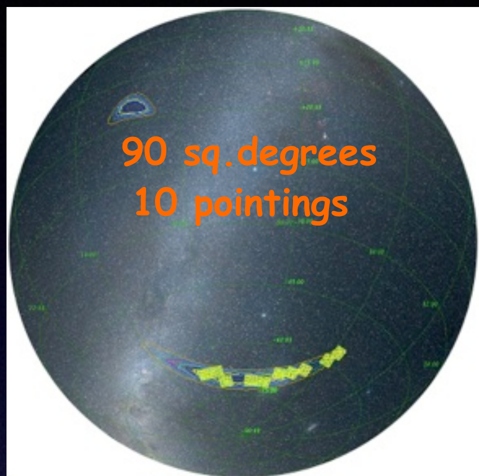
Note: *HST, VISTA, Swift - proposals accepted with GRAWITA Cols.*



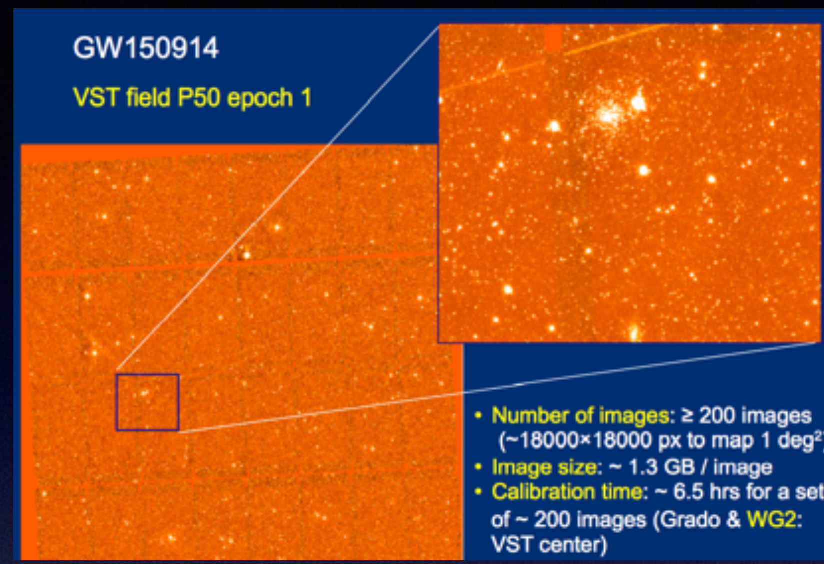
Science Validation…
Data Papers…
Time Domain Astronomy

run O1: GRAWITA response

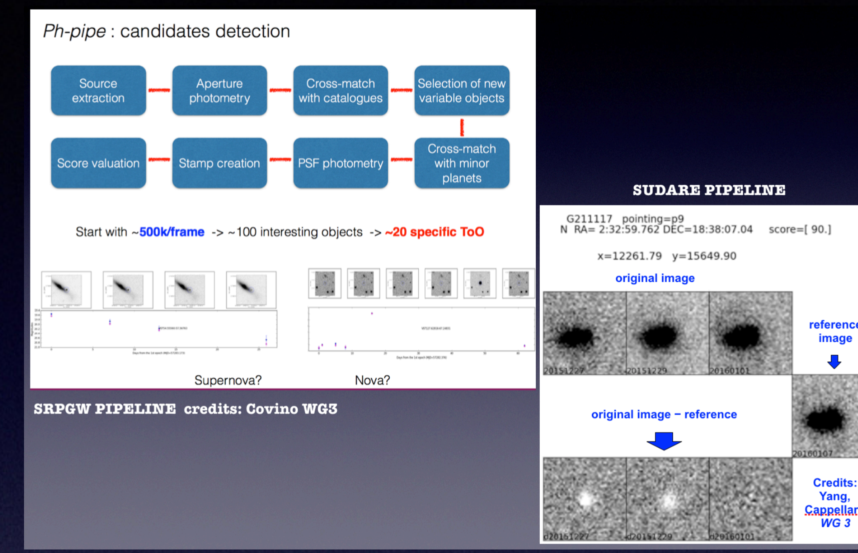
1. Observations



2. Search

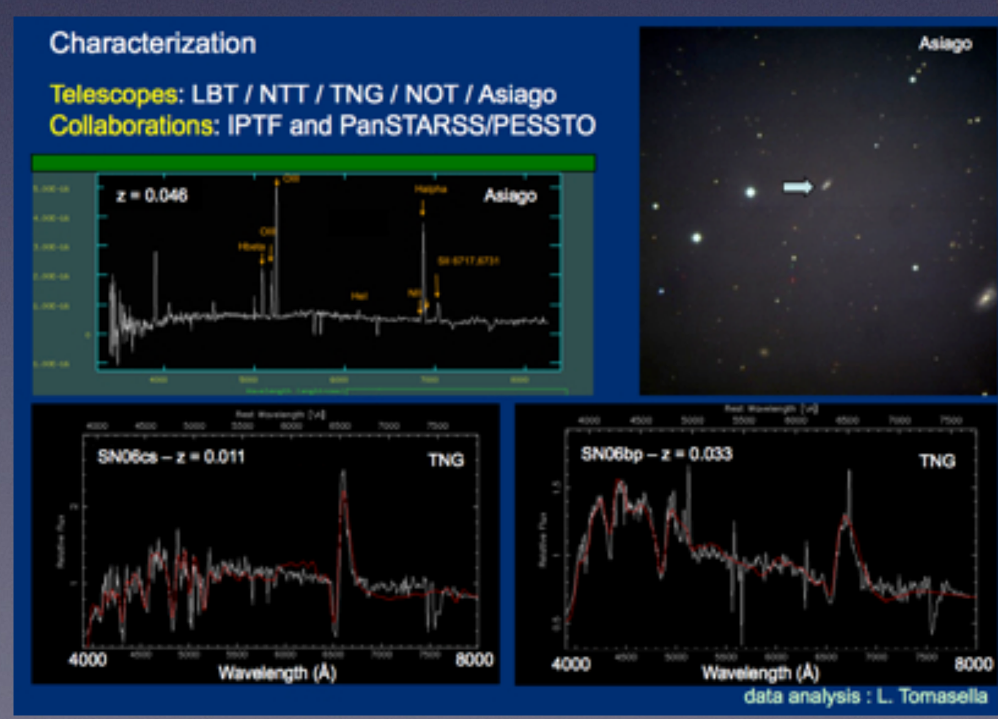


3. Search



Start with ~**500k/frame** -> ~100 interesting objects -> **~20 specific Too**

4. Characterization and follow-up

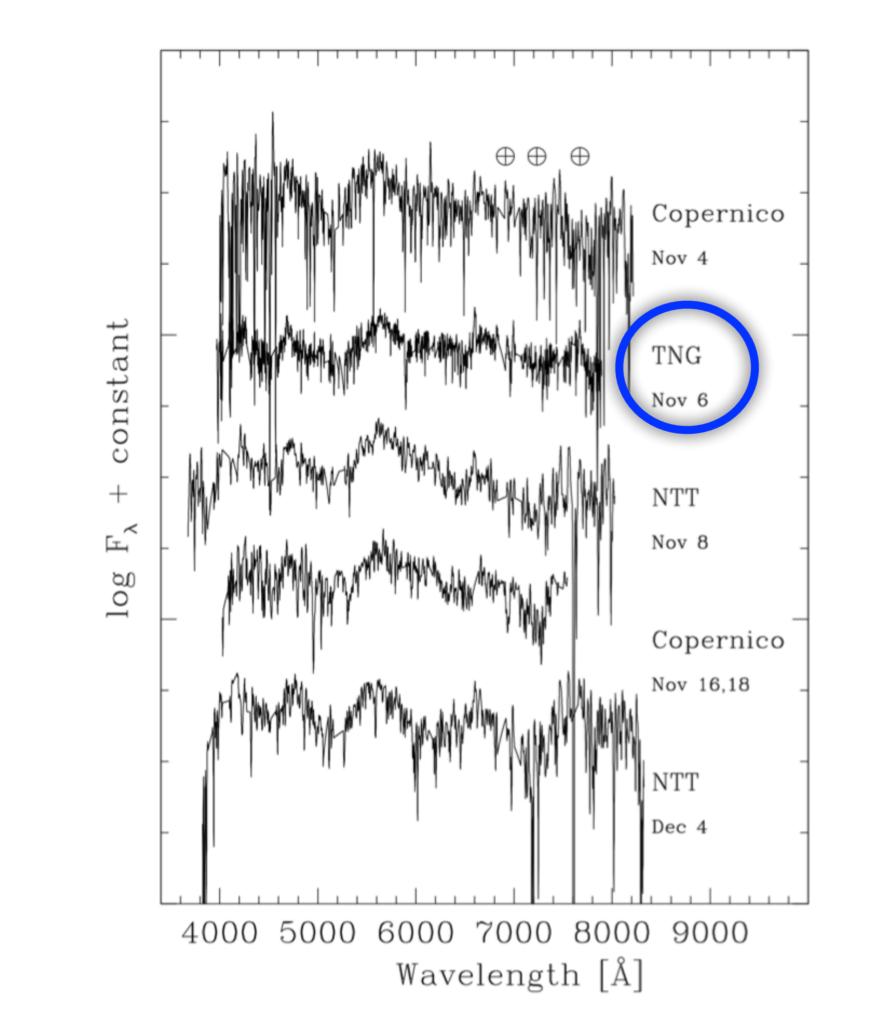


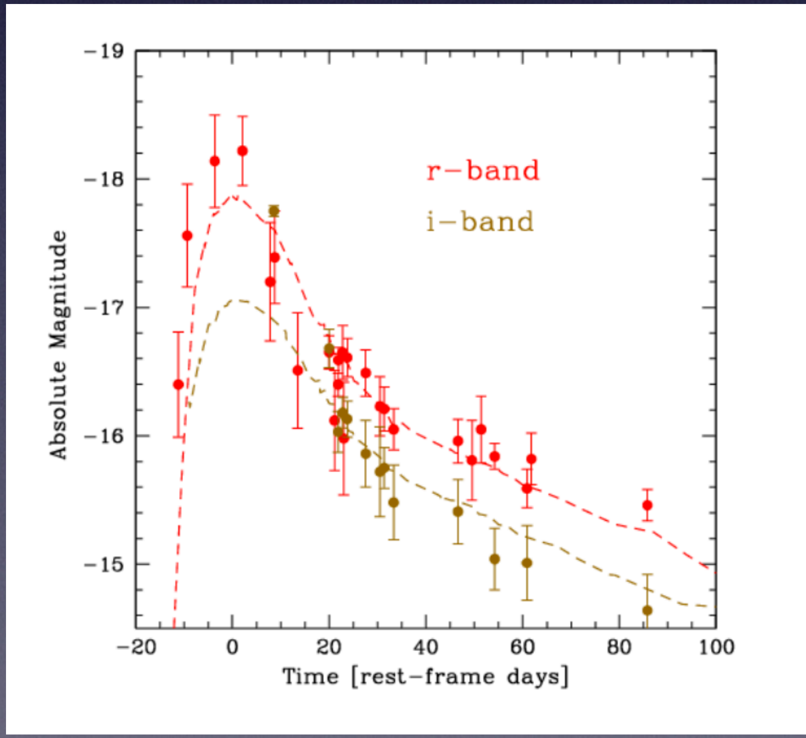
Collaborations with high energy facilities and iPTF, PANSTARRS,/PESSTO

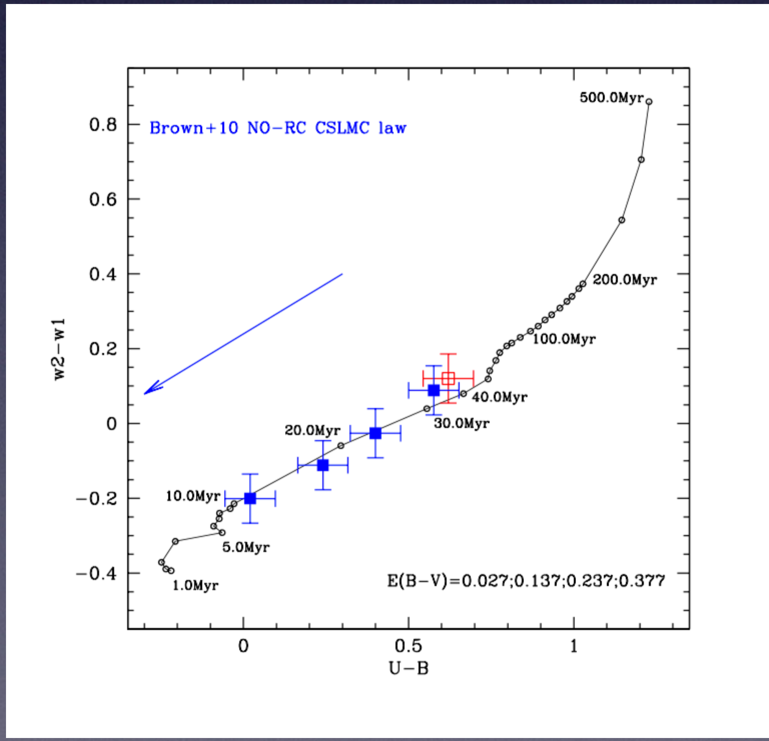
Results of GW follow-up – GRAWITA PROJECT

Cooperation between iPTF/***GRAWITA/LSQ/Pan-STARRS/SWIFT.***
Transient iPTF15dld discovered by iPTF (GCN18497),
identified as a Supernova Type Ic by GRAWITA (GCN18563)
Information on the environment can be obtained by Swift/UVOT

Pian et al. 2016







Results of GW follow-up – GRAWITA PROJECT

Pan-Starrs: transient PS15-dpn identified
(Smith et al GCN 18786)

GRAWITA: photometric data with VST@ESO

Gemini: unusual spectra not characterized z~0.175
(Chambers et al GCN 18811)

GRAWITA: LBT observations imaging + spectra
PS15-dpn classified as SN Ibn similar to SN2006jc,
redshift confirmed (GCN 19145)

LBT
8mTelescope
(LBC-Blue)

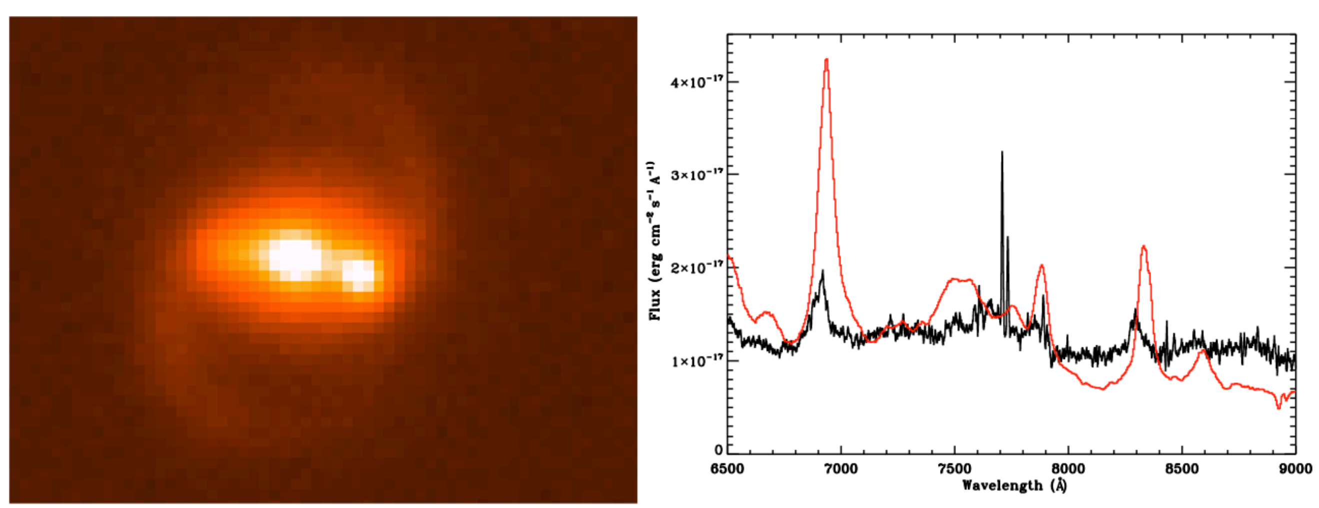


Fig. 2. Left Panel: r-sloan image of Pan-STARRS1 candidate taken with LBC-Blue, the transient and its host galaxy are very well detected.
Right panel: MODS1-Red spectrum extracted at the transient position . Narrow Hα, NII and OII emission lines from the host galaxy are cleary detected at a redshift of 0.1749. Based on a preliminary calibration, the spectrun show that the transient is a peculiar supernova of type Ibn similar to SN 2006jc (red spectrum) a few weeks after maximum (Pastorello et al. 2008).

LBT
8m Telescope
(MODS1-Red)

Results of GW follow-up — GRAWITA PROJECT

GRAWITA paperII 2016 in prep.

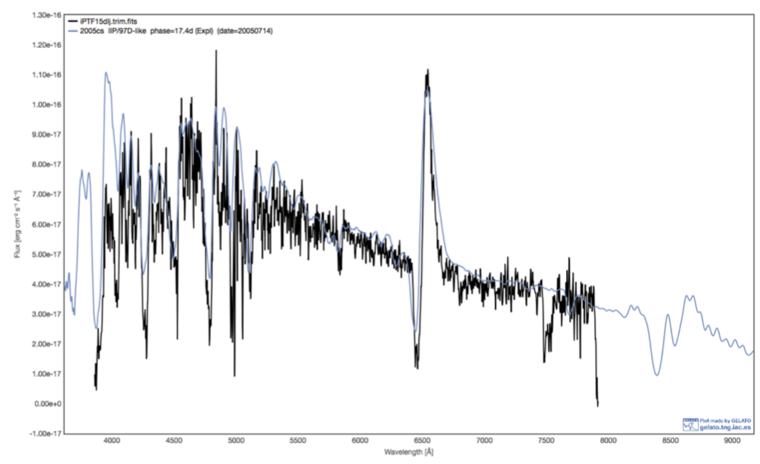


Figure 3: TNG spectrum of iPTF15dlj of 29 October 2015 (black) and best match with SN 2005cs (blue), using GELATO (Harutyunyan et al. 2008, A&A, 488, 383).

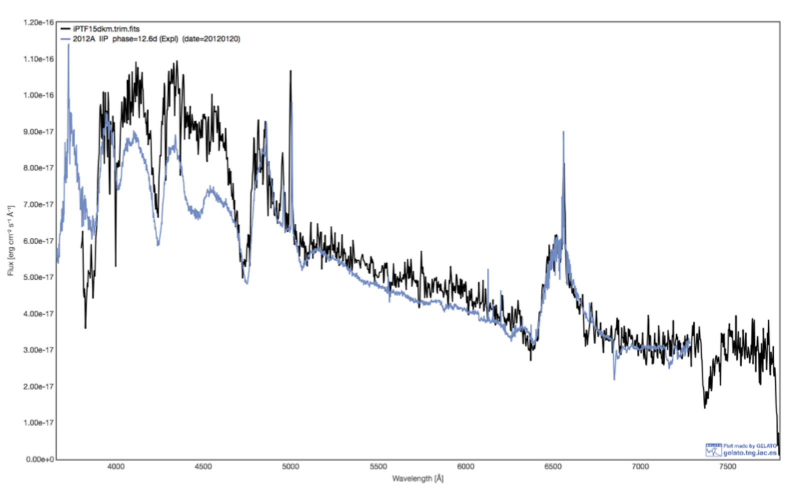


Figure 2: TNG spectrum of iPTF15dkm of 29 October 2015 (black) and best match with SN 2012A (blue), using GELATO (Harutyunyan et al. 2008, A&A, 488, 383).

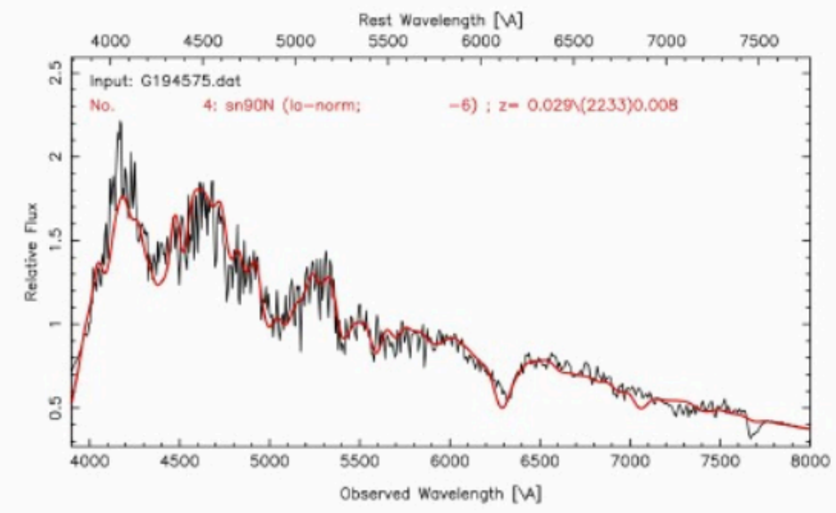


Figure 1: TNG spectrum of LSQ15bjb of 26 October 2015 (black) compared with that of SN 1990N (red), six days before *B*-band maximum light.

GRAWITA O1 SUMMARY

The **experience matured** with GRBs/SNe was very fruitful for the first GW follow-ups

- No EM detection in O1…..but we got results from “secondary science”!!

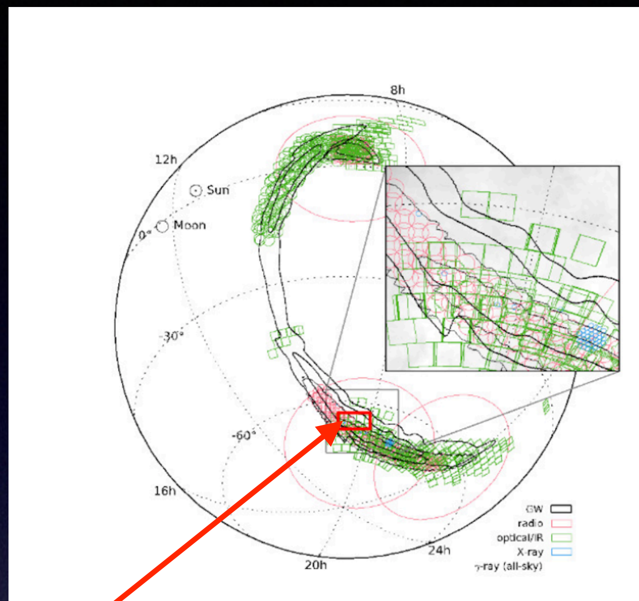
- We are working on the follow-up of candidates of the O2 run. We improved pipelines for better selections proposals for ToO -- we are waiting for NS-NS or NS-BH!

- Main goal is to detect the **EM of GW signals**, but even if we won’t….

- Characterisation of the **transient Universe:**

new transients, FRBs, novae, orphan GRBs, SNe
preparatory studies for LSST and future facilities at all wavelengths

GW EM counterpart research — WHAT'S NEXT?

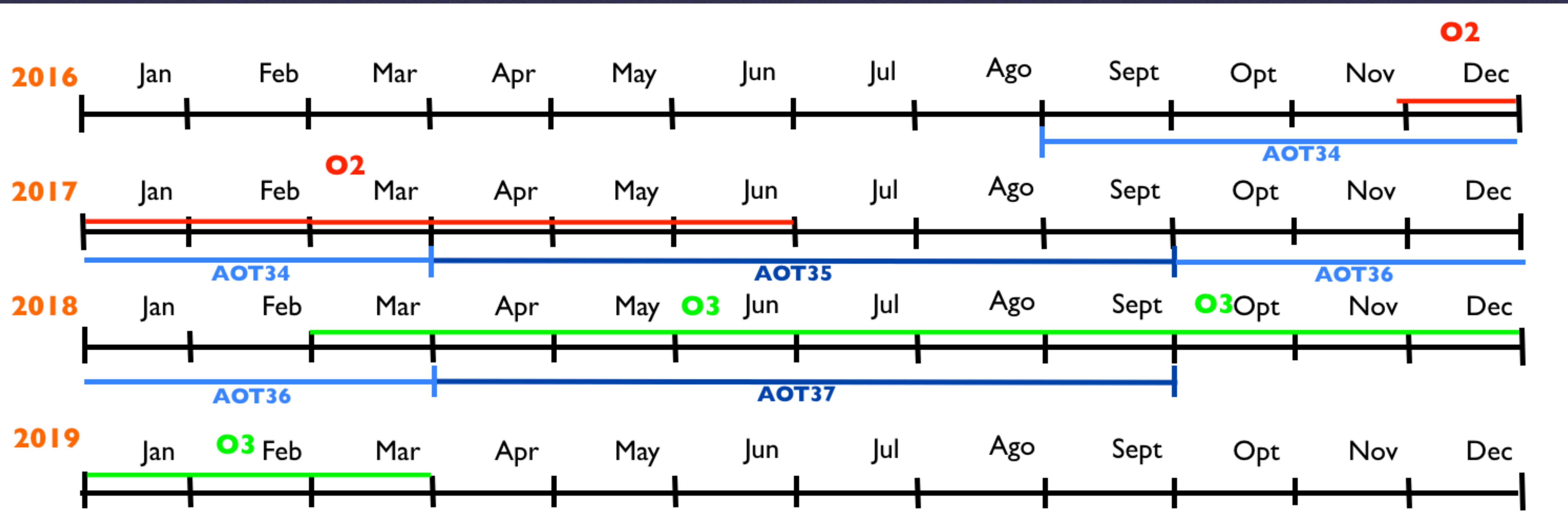


PAST TNG GW PROGRAMS:

AOT30: (Palazzi) NO overlap with LVC
AOT31: (Palazzi) NO overlap with LVC
AOT32: (Piranomonte) overlap with O1 (70% of the allocated hrs)
AOT33: (Piranomonte) NO overlap with LVC

if Virgo was on line during GW150914...

AOT34-AOT37: Large program (Piranomonte) 10% already used



LVC during O2 - O3 — TNG EM Strategy

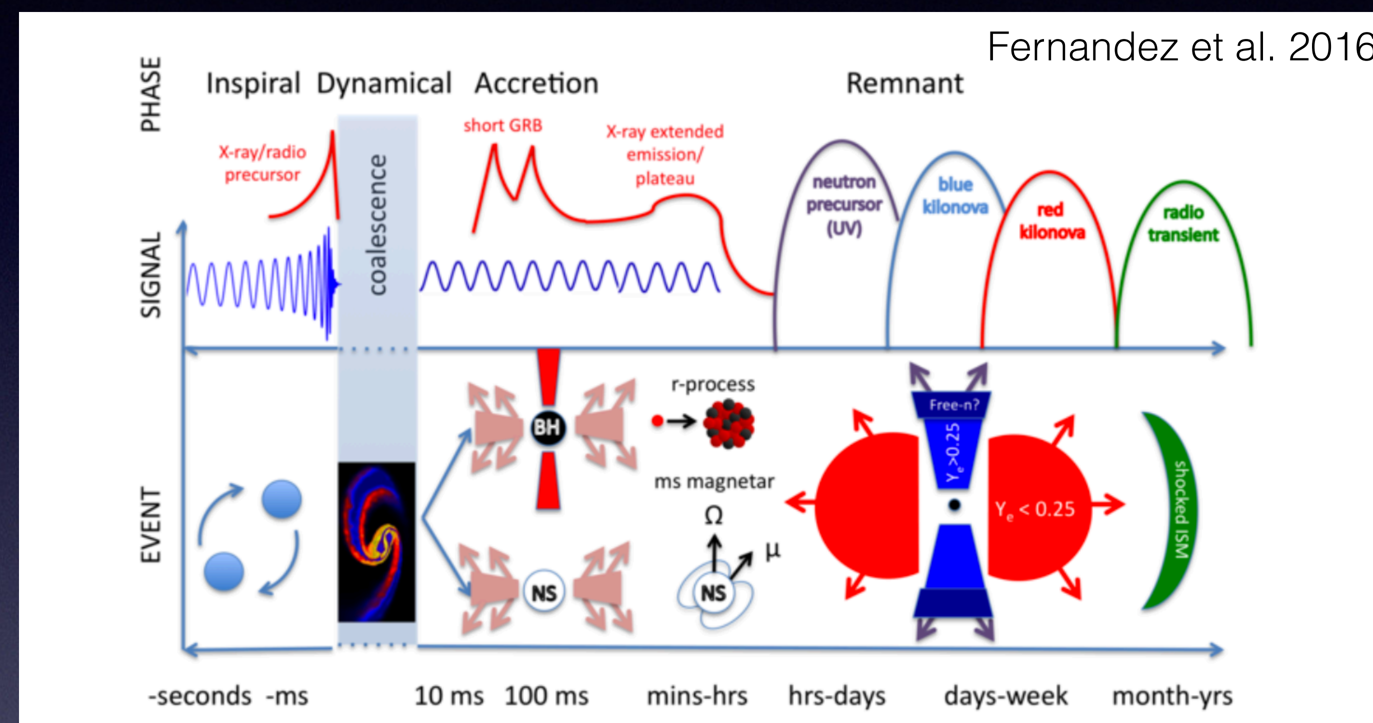
INFO FROM LVC: event time, localization, system type (CO binary or burst), for CO binary distance and presence of NS

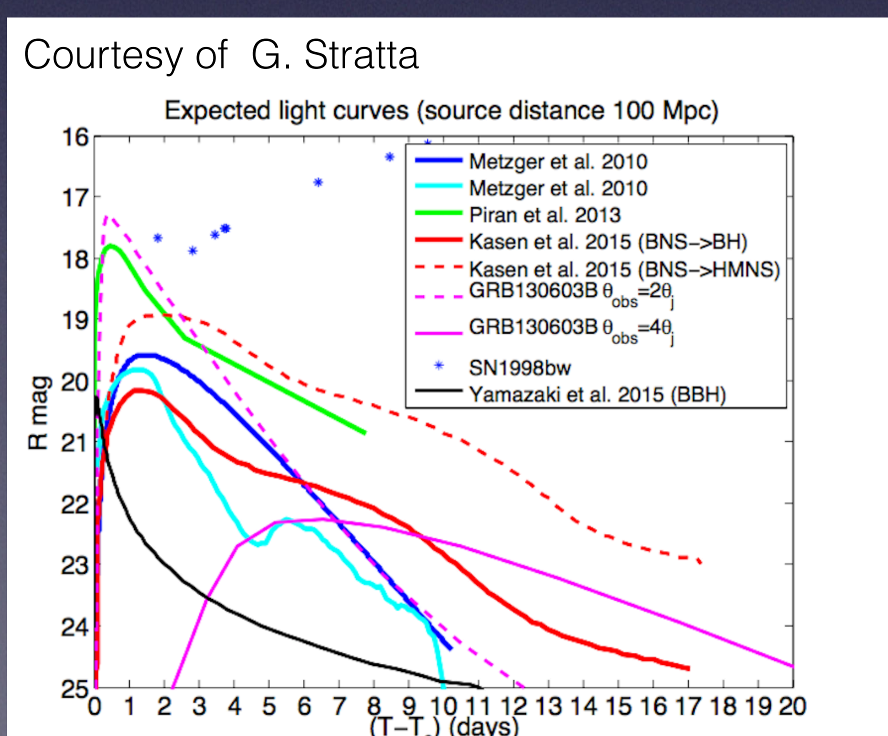
Threshold alert --> FAR < 1/month

O2 --> 6 triggers + astrophysical sources
O3 --> 9 triggers + astrophysical sources

Astrophysical sources rate:
NS-NS rate: 40/yr
BH-NS rate: 10/yr
BH-BH rate: 20/yr **Abadie et al. 2010**

For each trigger --> tens-hundreds of candidate counterparts to characterize!!





DOLORES and NICS @TNG

- execute ToO as soon as EM candidate counterparts for a GW source will be available from other observatories worldwide or from space satellites
- light curves and broad-band colors
- spectra of our and other collaborations top candidates (about 35 per semester)

LVC during O2 - O3 — TNG EM Strategy

LRS/NICS imaging will be performed:

1) to search for the optical/NIR counterpart of a GW source only when its position is known with an accuracy better (e.g. detection of a X-ray counterpart) than the LRS/NICS camera FOV;

2) to monitor the light curve of the candidate counterparts detected by us or by other telescopes. Follow-up imaging (case 2) can be planned ahead, thus it can be considered as a soft ToO. If case 1 applies, we will perform R and H band imaging (with total t_{expo} of 300s and 1200s, respectively).

3) If a transient is detected, either by comparison with the (S)DSS/2MASS or between subsequent images and it has R ≤ 21.5 or H ≤ 20, then we will take **LRS spectroscopy**. Once we have secured the spectroscopic observations of the candidate or if its magnitude is fainter than the above limits we will acquire multi-band optical (BV RI) and NIR (H) photometry over 3 epochs to follow the behavior of its flux, on a time scale that will depend on the source brightness.

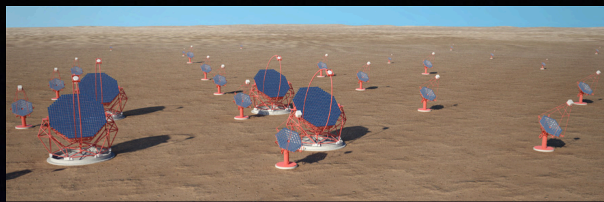
***

We plan to follow-up a range of **20 candidates with DOLORES and 15 candidates with NICS** (depending on their magnitude) for each semester.

Grawita + TNG from 2017 to…??

- prepare to Virgo Impact
- Thanks to the distance+progenitor indication the optical/IR follow-up will be much more efficient
- agreement with other groups
- TNG with DOLORES and NICS capabilities make it a competitive instrument to identify reliable counterparts among candidates localized with arc-second precision by wide-field of view surveys.

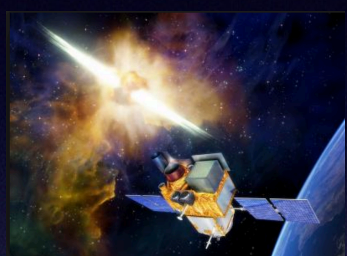
We are only at the dawn of the multi-messenger era!


CTA 2021


Athena - 2028

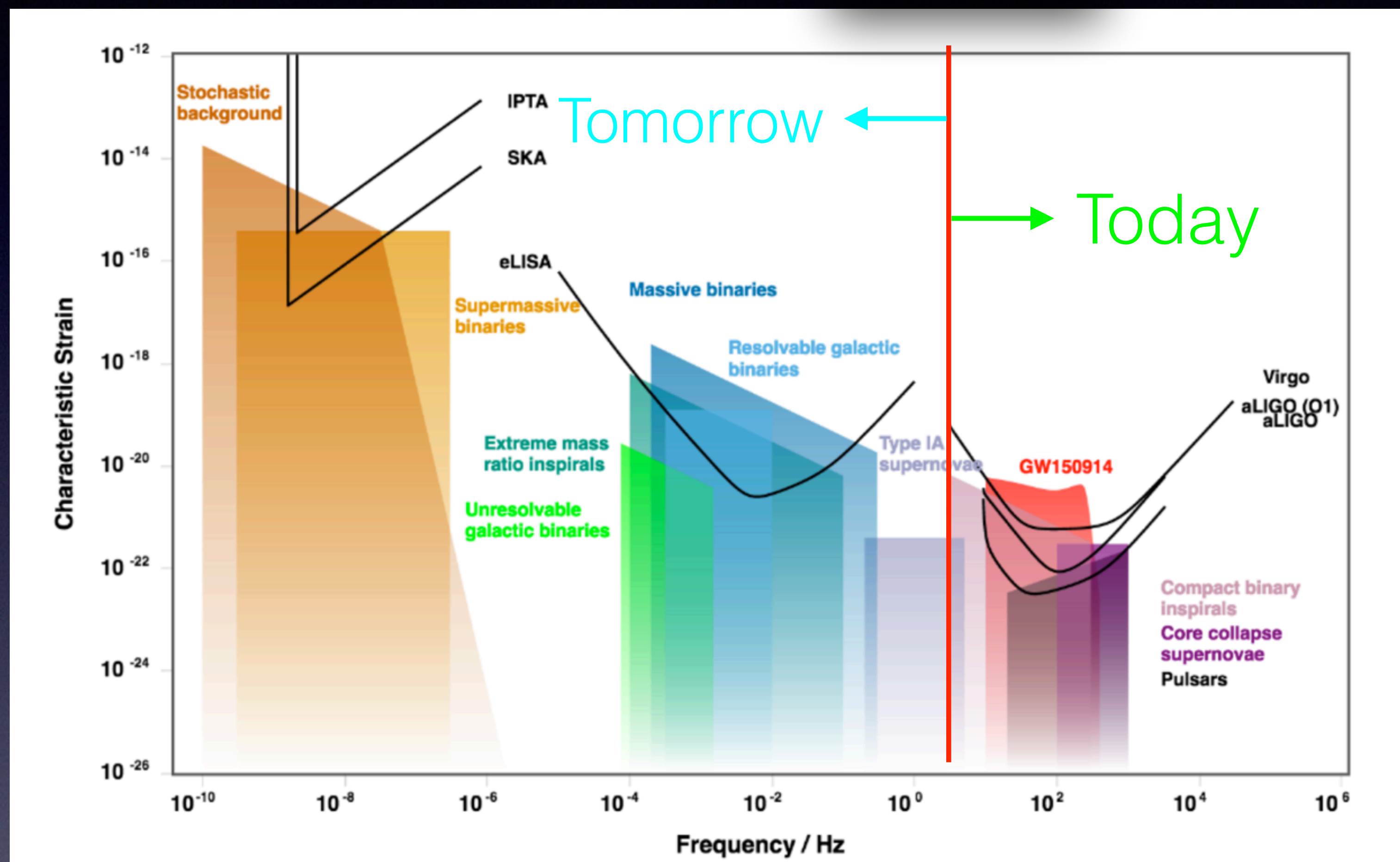

TNG


VLT - 1998-2000

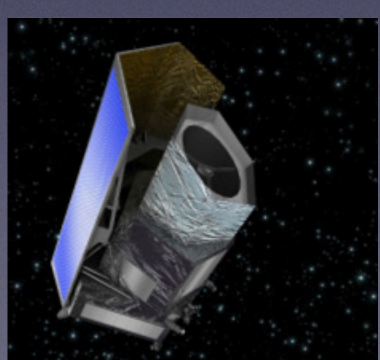

SVOM 2021


LBT


SKA 2025

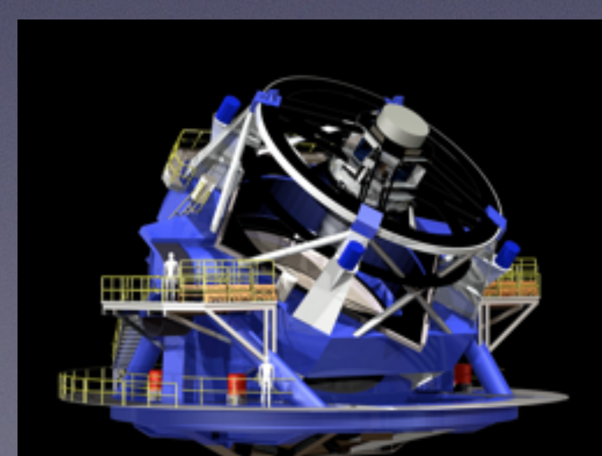



EELT - 2024

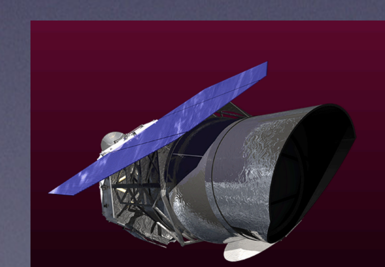

EUCLID - 2020

ESA M5


ALMA - 2013

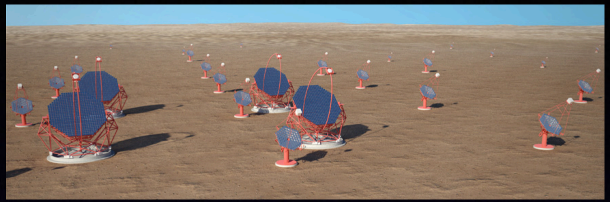

LSST - 2023


JWST - 2018


WFIRST - 2020

THANKS!

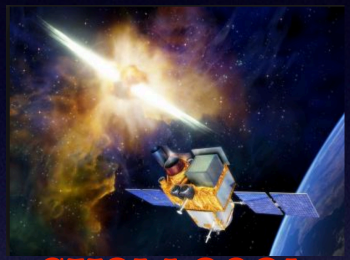
We are only at the dawn of the multi-messenger era!

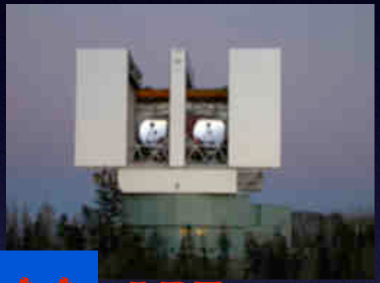

CTA 2021

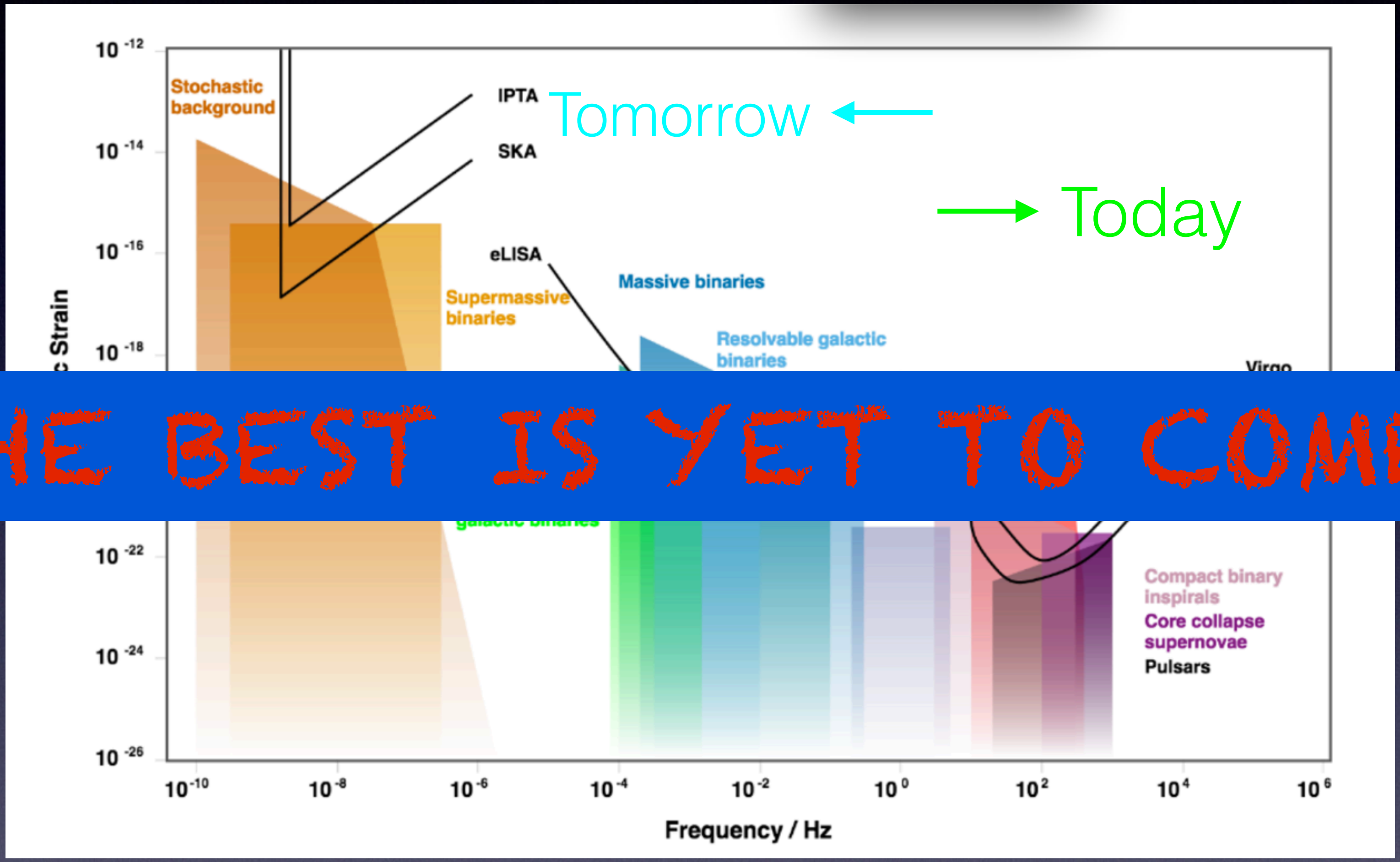

Athena - 2028


TNG


VLT - 1998-2000

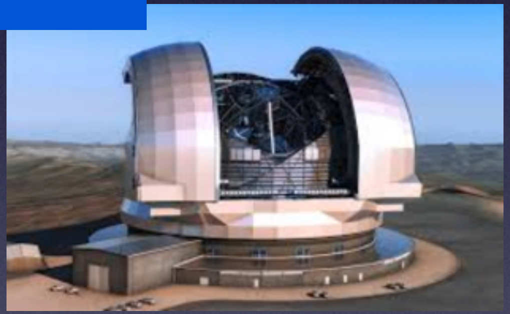

SVOM 2021

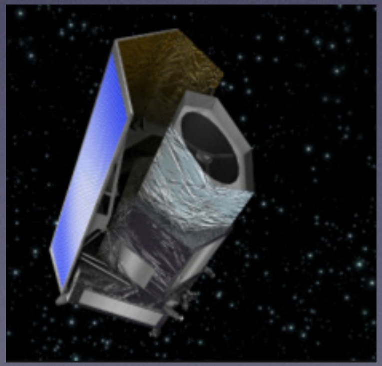

LBT

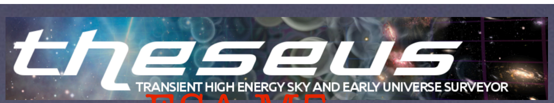


THE BEST IS YET TO COME!!!


SKA 2025

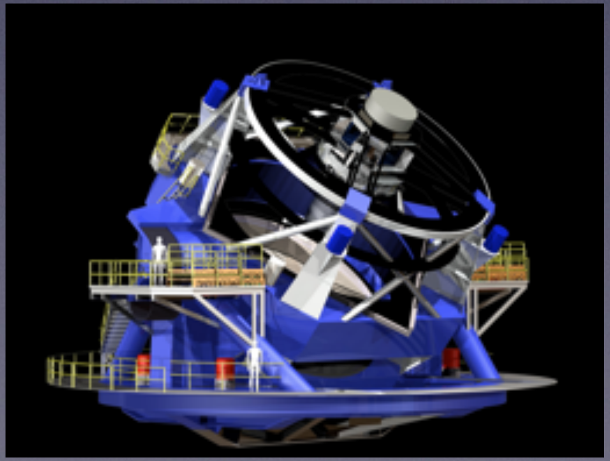

EELT - 2024


EUCLID - 2020

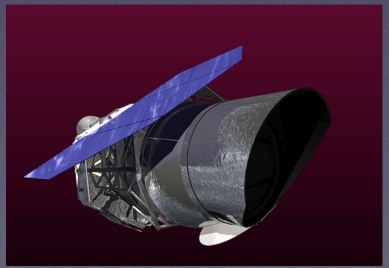


ESA M5


ALMA - 2013


LSST - 2023


JWST - 2018


WFIRST - 2020

THANKS!