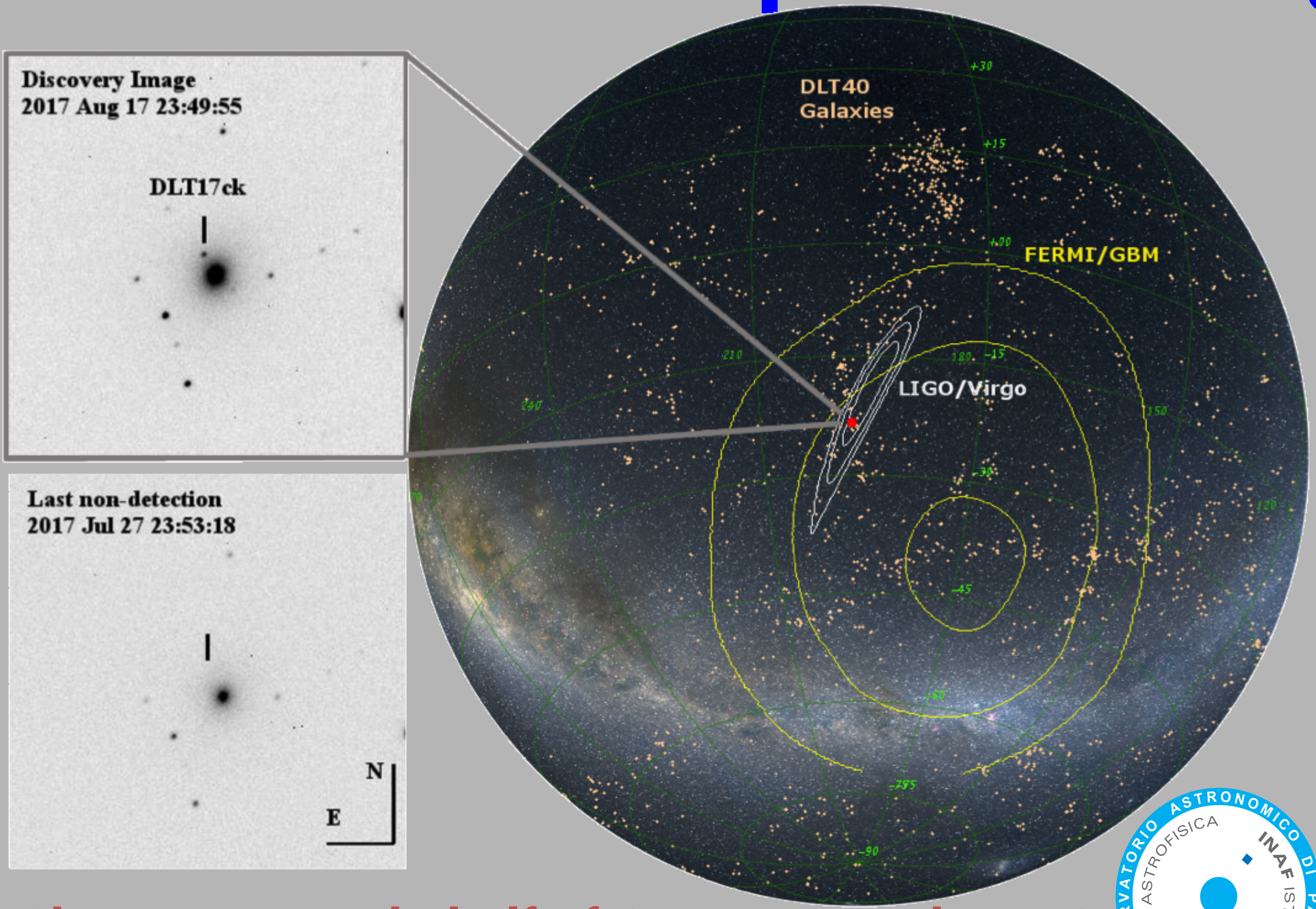
Gravitational wave electromagnetic counterpart searching



Sheng Yang on behalf of GRAWITA and DLT40

INAF-observatory of Padova
UNIPD-Department of Astronomy
UC Davis-Department of Physics

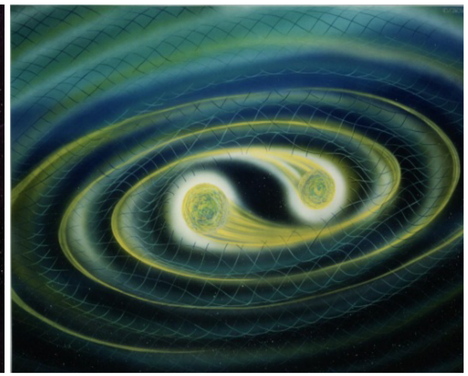
2/3/2018 @ GRASS inPadova

Why EM follow-up are interesting?

- Precise (arcsec) sky localization – e.g. link to EM event
- Energetics – e.g. EM emission (beamed and isotropic)
- Host galaxy – e.g. Redshift, Environment (stellar populations, dynamics..) where the EM counterparts are generated and evolve
- Nucleosynthesis of elements
- Cosmology
- Fundamental physics – e.g. speed of photons and gravitational waves (GW)
- Constraint models of GW+EM emitters

ASTROPHYSICAL SOURCES emitting transient GW signals detectable by LIGO and Virgo (10-1000 Hz)

Coalescence of binary system of neutron stars (NS) and/or stellar-mass black-hole (BH) $10^{-2} M_{\odot} c^2$



Range

197 Mpc for BNS
410 Mpc for NS–BH
968 Mpc for BBH

Rate

SOURCE	$\dot{N}_{low}$	$\dot{N}_{re}$	$\dot{N}_{high}$	$\dot{N}_{max}$
NS-NS	0.4	40	400	1000
NS-BH	0.2	10	300	
BH-BH	0.4	20	1000	

Abadie et al. 2010

For CC SN: uncertain GW waveforms

Range

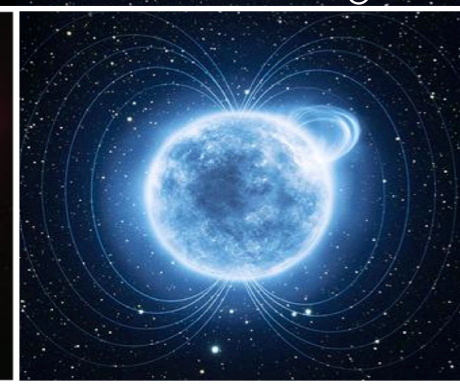
GW: Milky Way   Ott et al. 2012
Optimistic models: few Mpc Fryer&New 2011

Rate

~2 per century in Milky way   Li 2011
Cappellaro 1999
2 per year within 20 Mpc   Li 2011

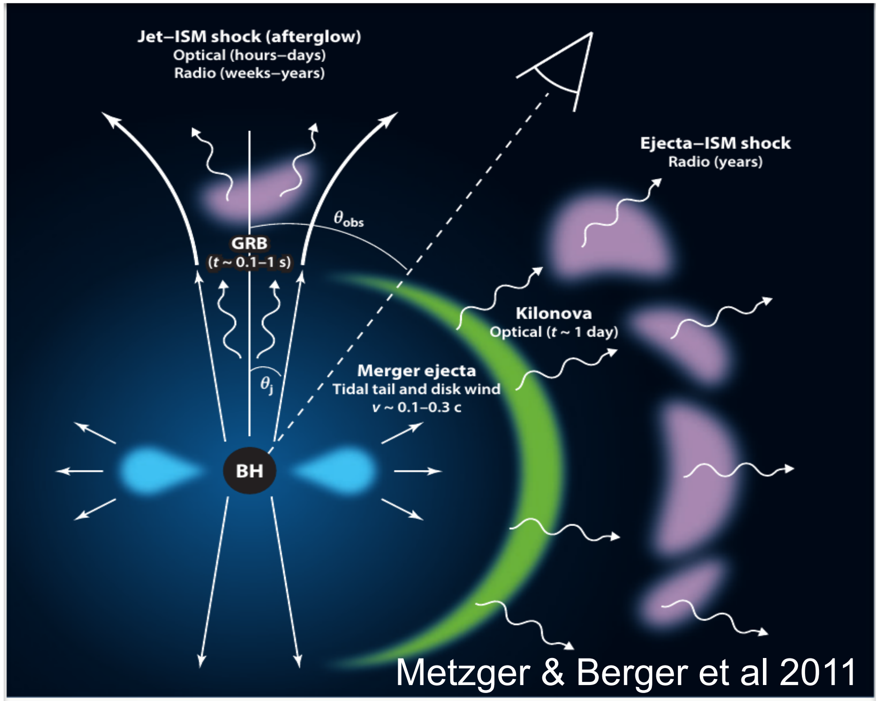
Core-collapse supernova 10^{-8}~10^{-5} $M_{\odot} c^2$

Isolated NSs instabilties 10^{-16}~10^{-5} $M_{\odot} c^2$



EM emission

BNS/NS-BH

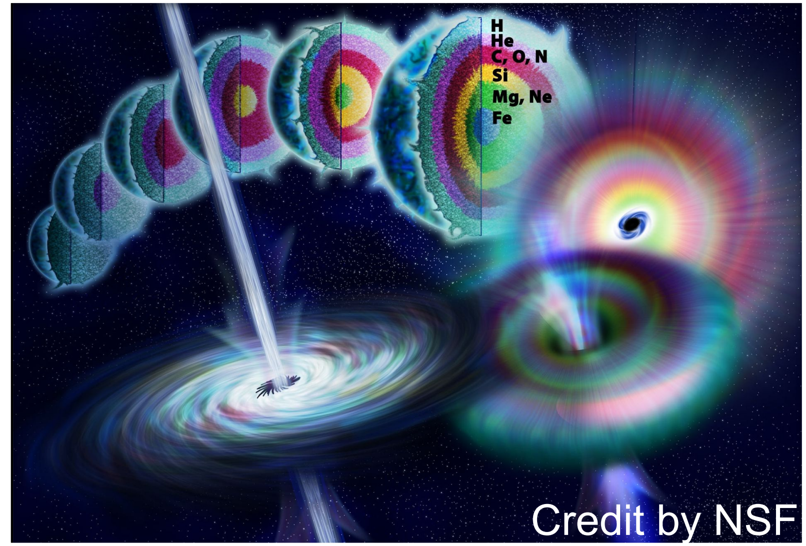


Metzger & Berger et al 2011

anisotropic
- sGRB(gamma)
- afterglow(X, optical)

isotropic
- afterglow(radio)
- kilonova(optical,IR)

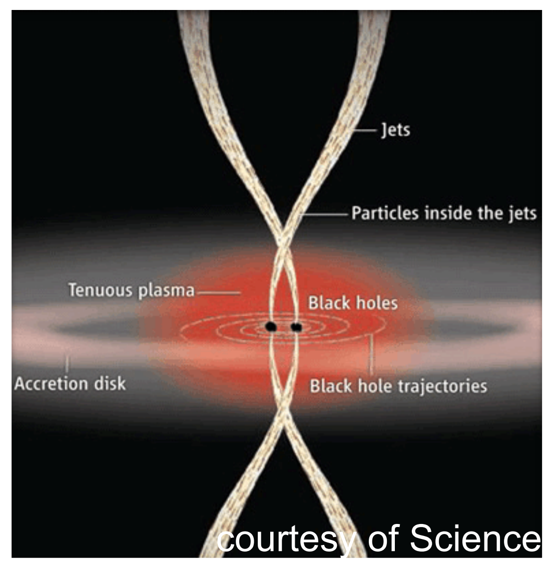
CC SN



Credit by NSF

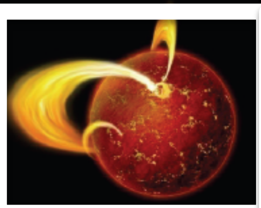
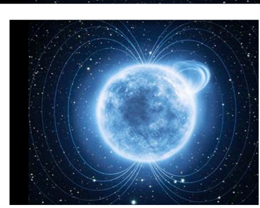
IGRB
X,UV:
 minutes-days
optical:
 weeks-months
radio:
 years

BBH emission?



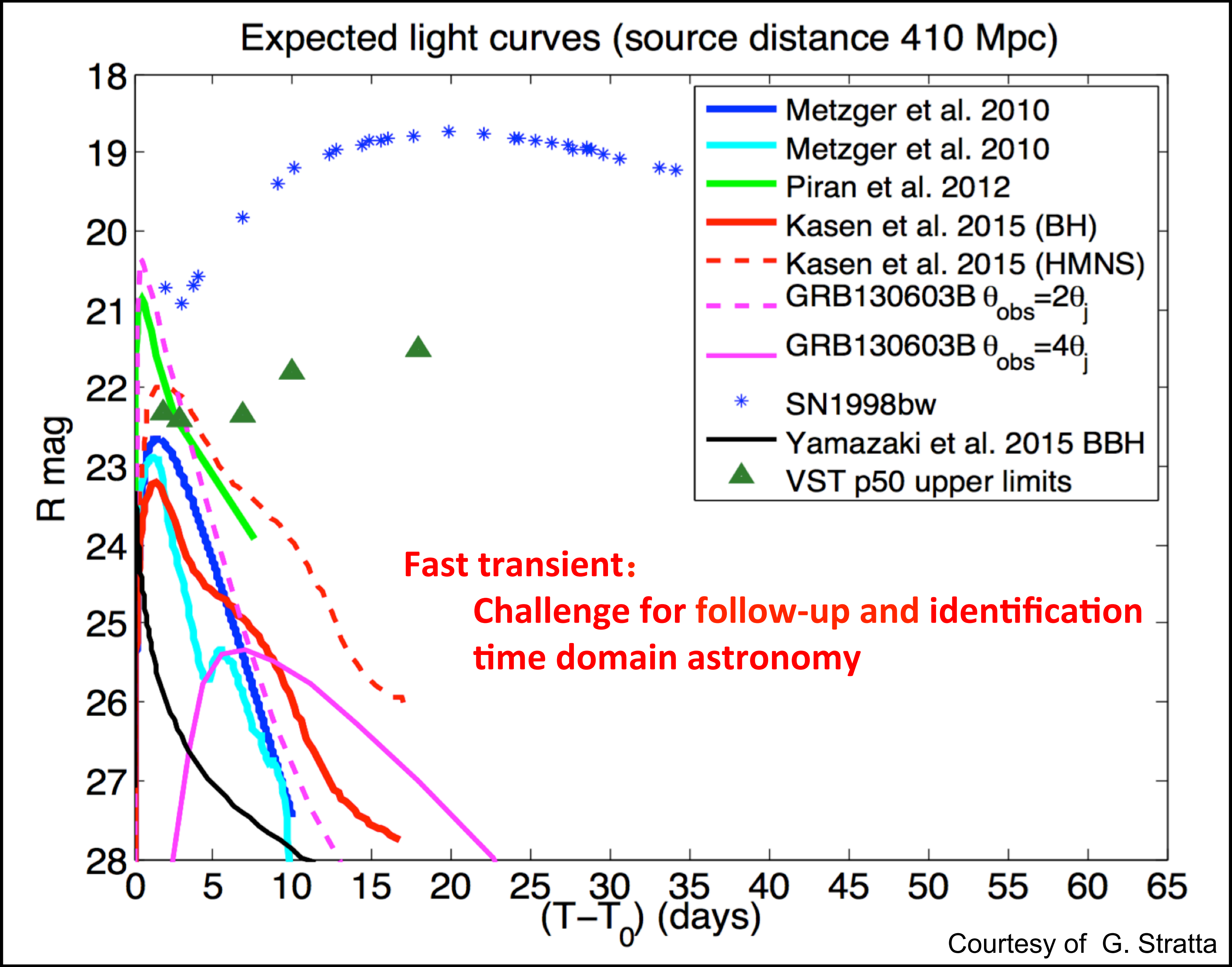
courtesy of Science

Isolated NS instabilities

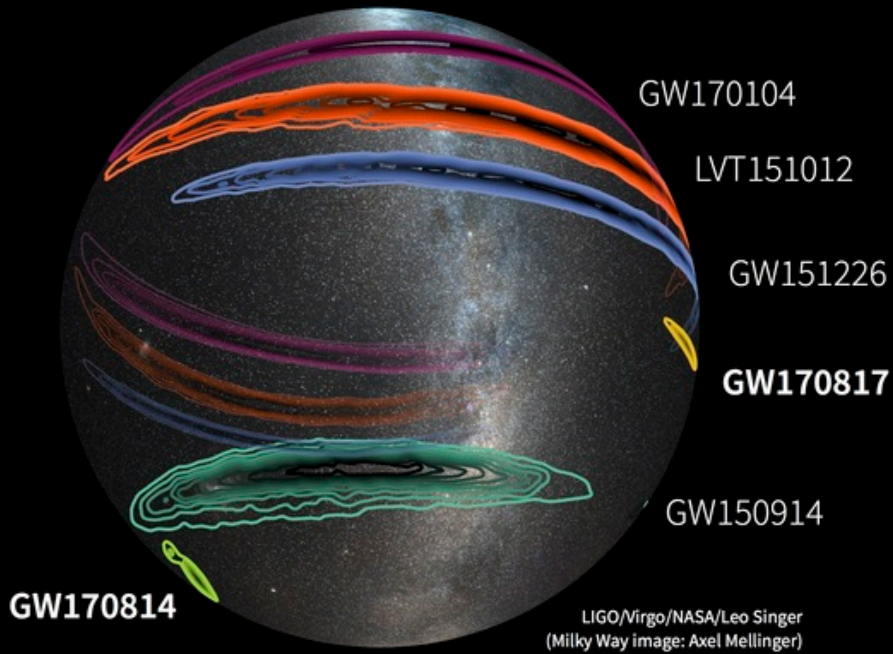



gamma
X
radio

Expected optical light curves from BNS



EM follow-up: 'Seek needle in a haystack'



~100-1000 square degrees(H+L)

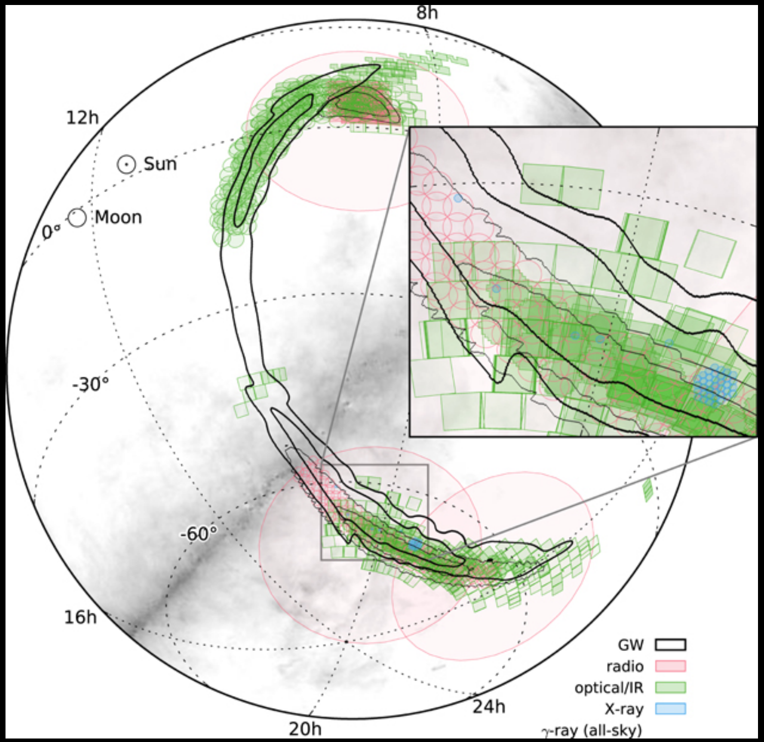
~10 square degrees(H+L+V)

Future? LIGO-India, KAGRA…
triangle localization

Optical GW follow-up: fast, wide, deep.

1. 'blind search strategy': wide-field tilling search on high probability GW region
   e.g. **GRAWITA**

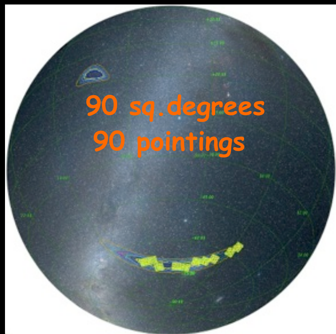
2. 'targeting search strategy': pointed search of selected galaxies in high probability GW region
   e.g. **DLT40**



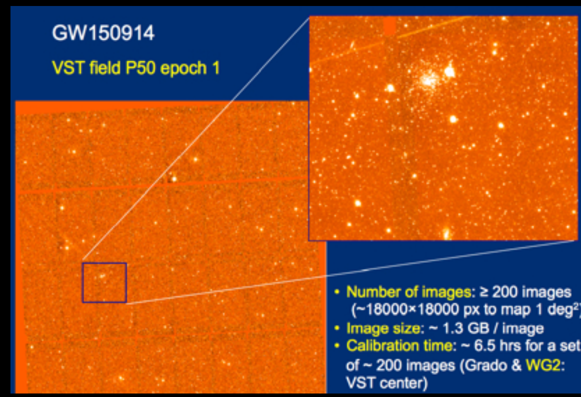
EM follow-up for GW150914
Abbott B.P., et al. 2016

EXAMPLE OF GRAWITA RESPONSE

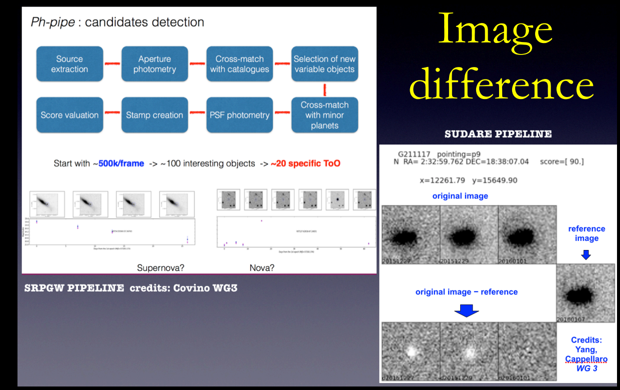
1. Tiling



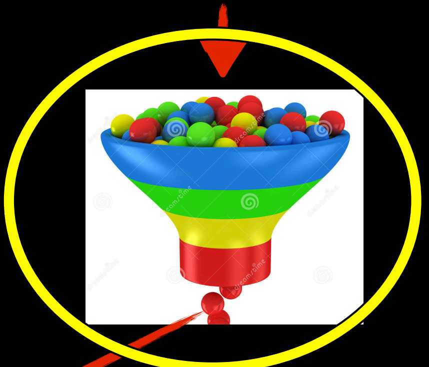
2. Observations



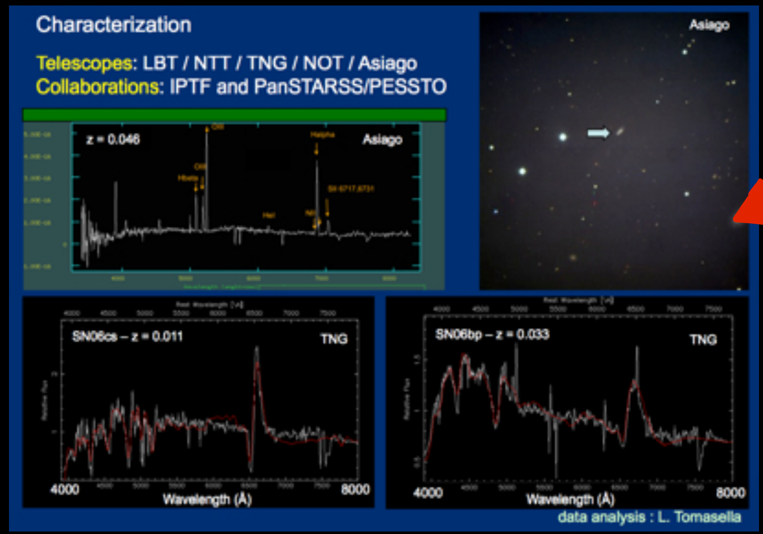
3. Search



See Grado talk for more details



4. Characterization and follow-up



1. Ranking algorithm for hotpants and sextractor parameters
2. Machine learning for image and light curve

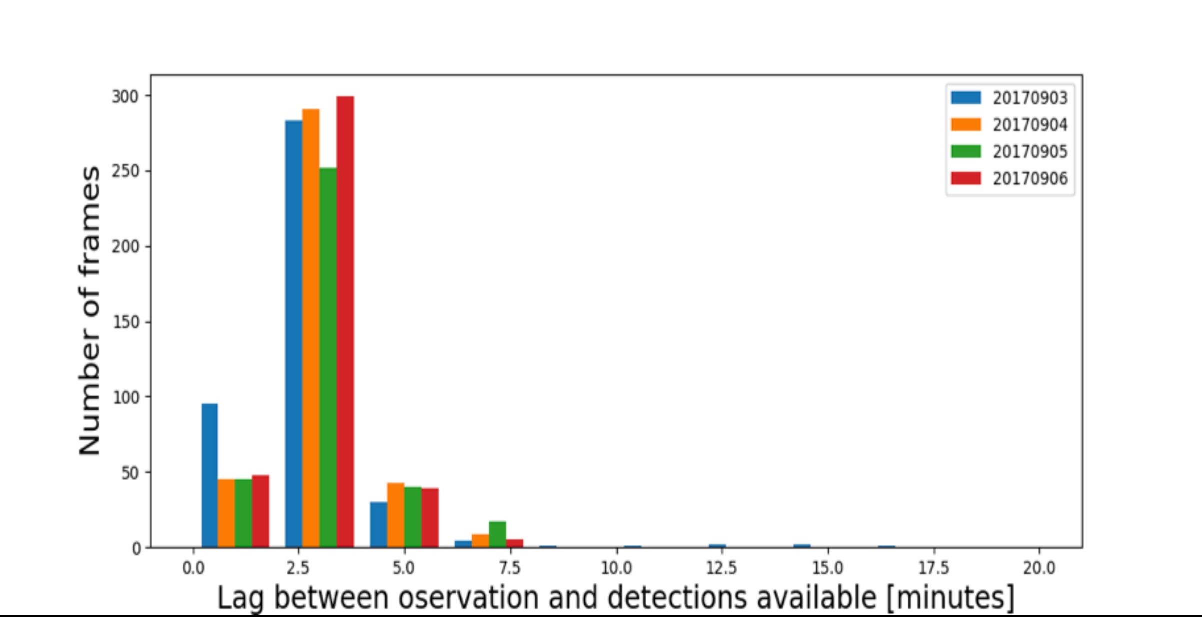
Distance Less Than 40 Mpc = DLT40

SN search

'DLT40 normal run':

- Prompt 5(search) + LCOGT/FLOYDS···(spectroscopy)

1. Aim: Search for SNe in nearby galaxies with 1 day cadence, which is the time when we can learn the most on the physics of the explosion
2. Fast, well designed for GW, GRB, neutrino··· follow-up. Follow LIGO trigger from O2 period



1. 0.4m telescope with 10*10 arcmin FoV in Chile
2. 0.4m in Australia

Automatically pipeline

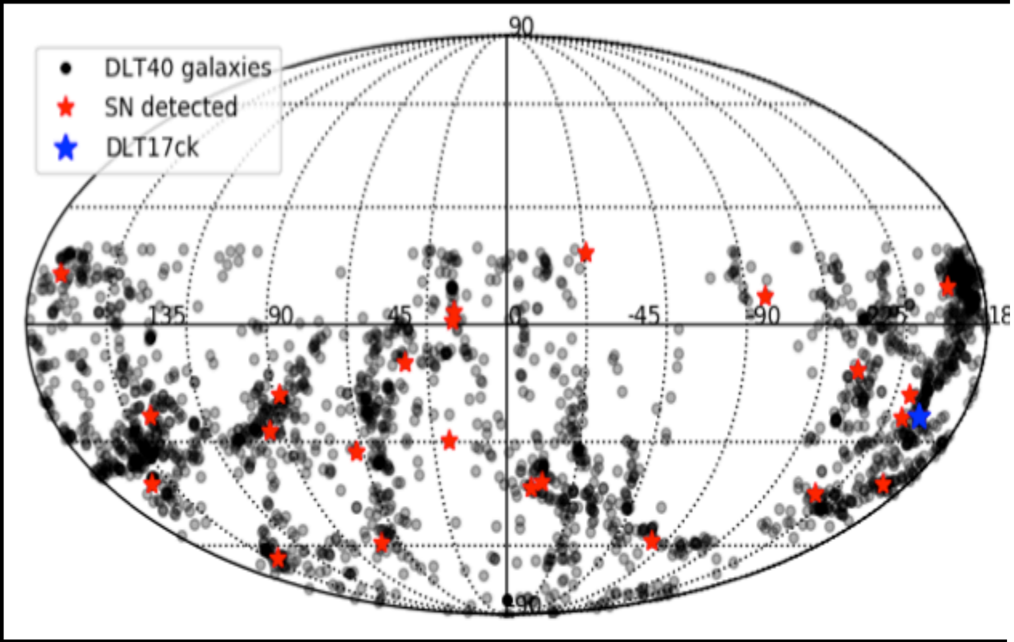
Decrease Delay time between explosion and data collected

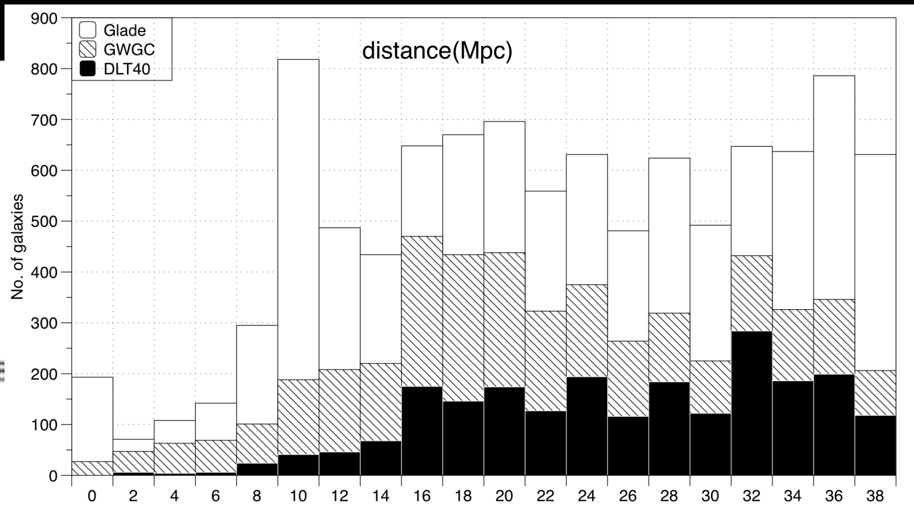
Distance Less Than 40 Mpc = DLT40

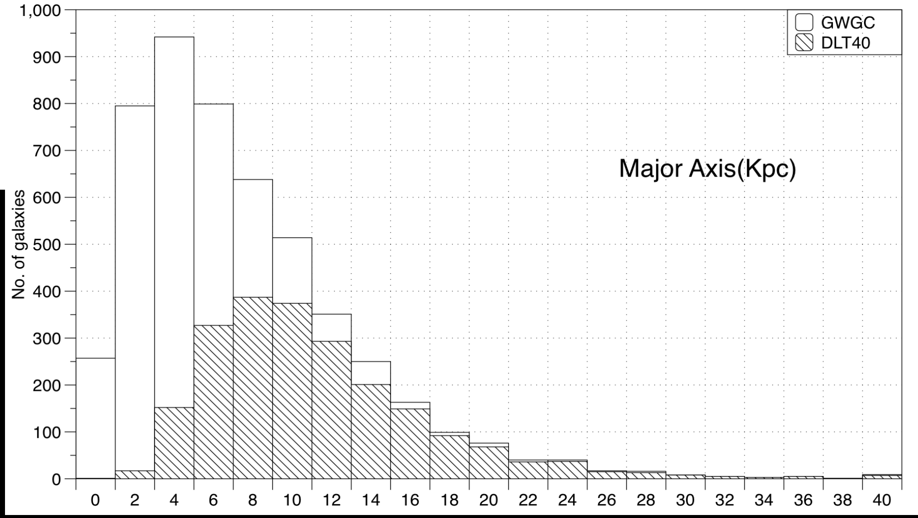
SN search

'DLT40 normal run':

- Prompt 5(search) + LCO/FLOYDS···(spectroscopy)
- 400-600 galaxy every night, ~2000 in total (sub-catalogue from GWGC)







Galaxy samples construction:

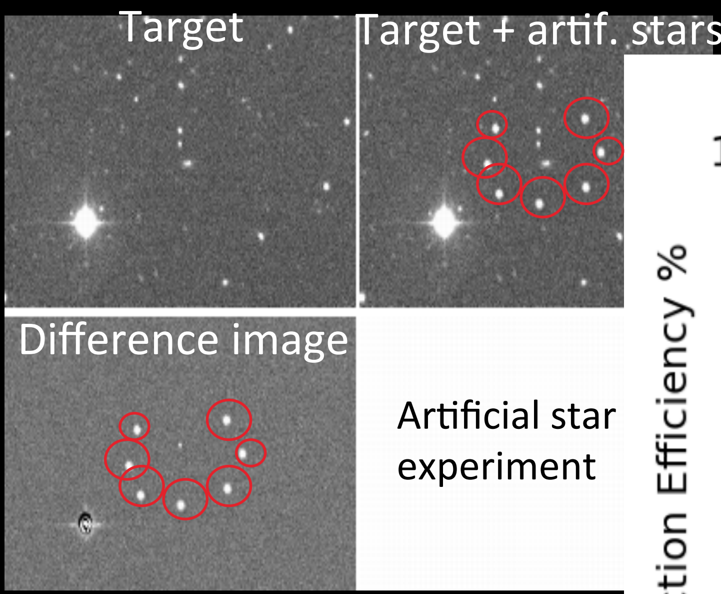
1. rec. velocity < 3000 km/s
2. MB < −18 mag
3. E_MW(B−V) < 0.5 mag

Distance Less Than 40 Mpc = DLT40

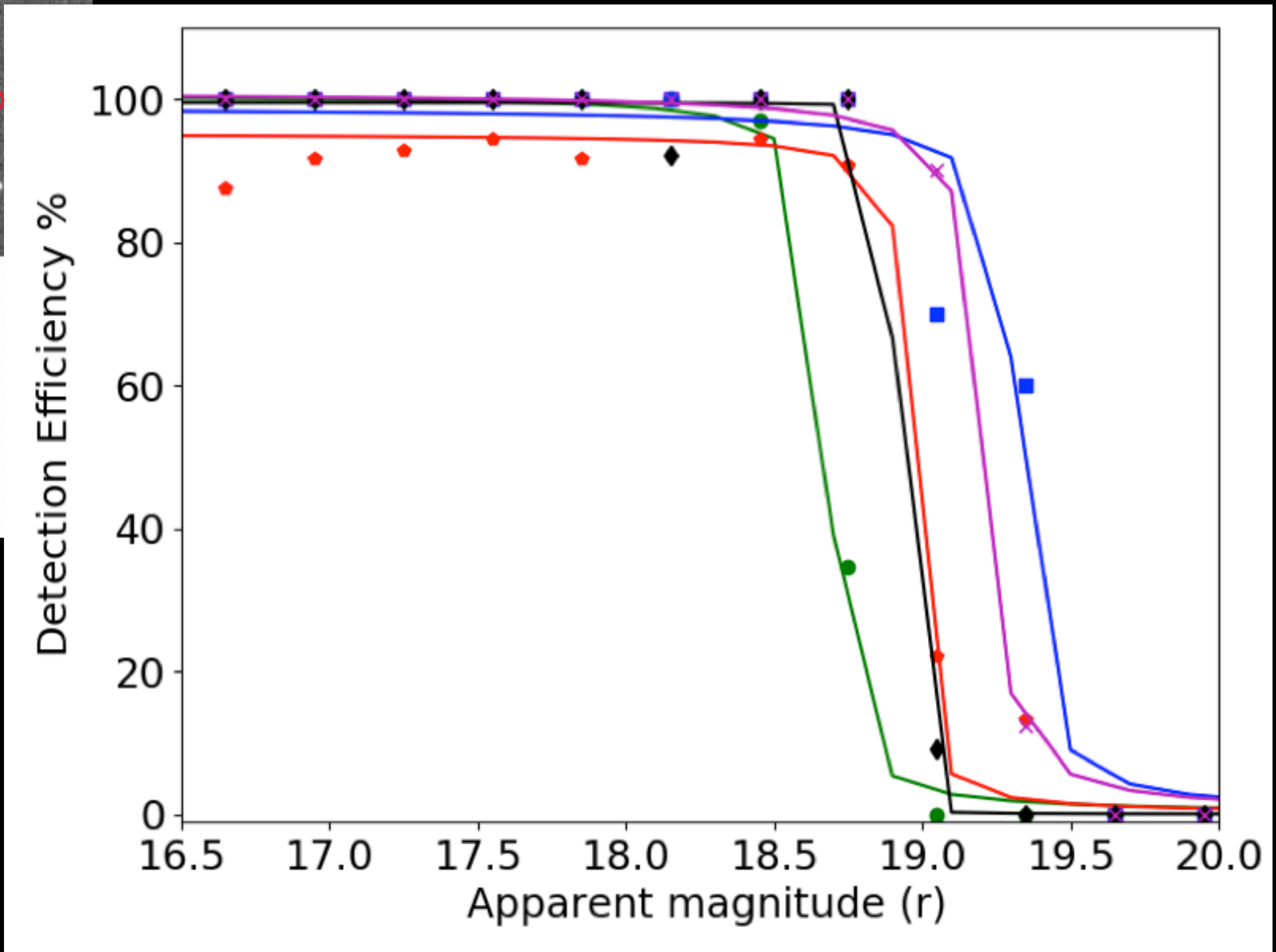
SN search

'DLT40 normal run':

- Prompt 5(search) + LCO/FLOYDS···(spectroscopy)
- 400-600 galaxy every night, ~2000 in total (sub-catalogue from GWGC)
- Reach to r=19 mag on average



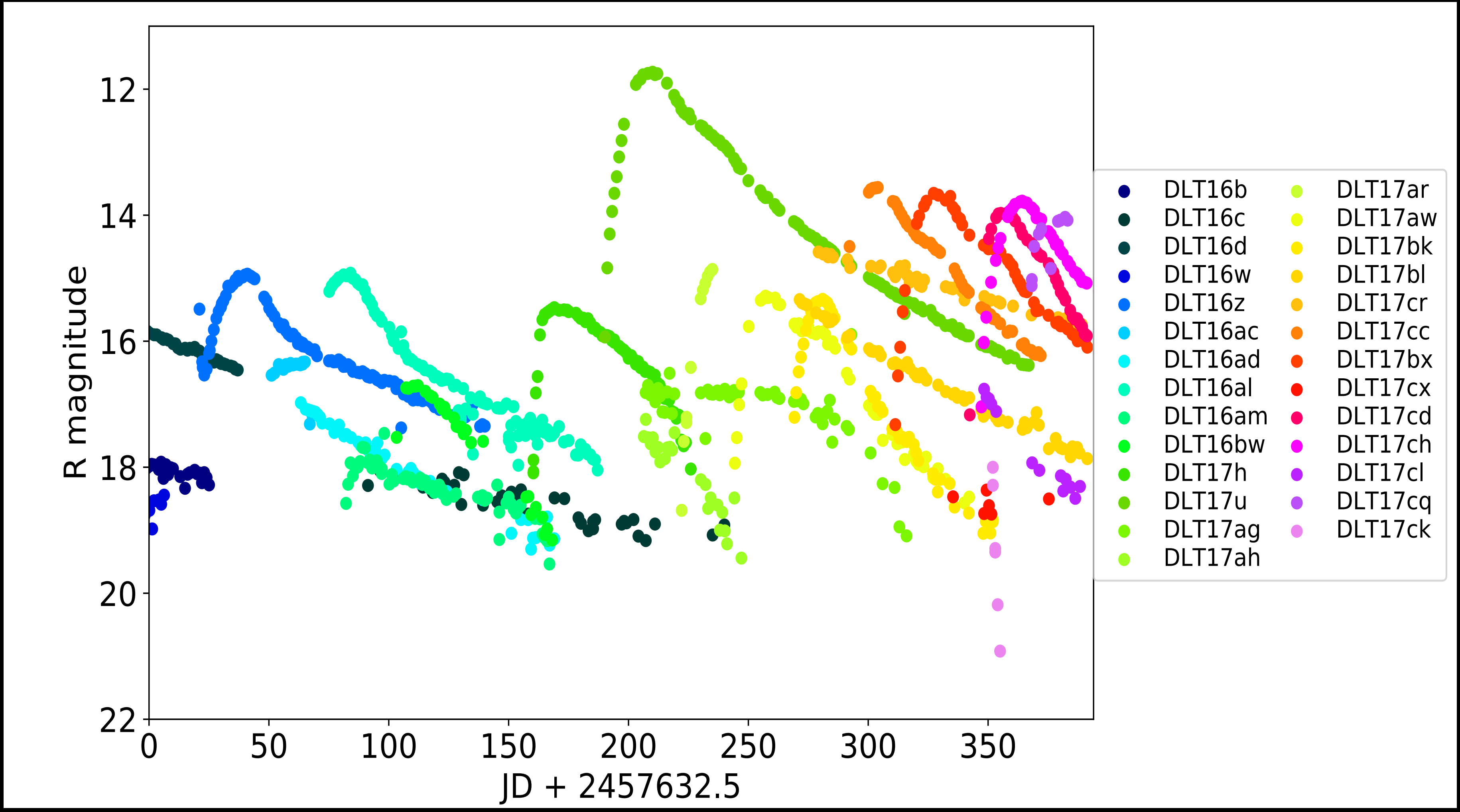
$DE = N_{detect}/N_{inject}$



Distance Less Than 40 Mpc = DLT40 SN search

'DLT40 normal run':

- Prompt 5(search) + LCO/FLOYDS···(spectroscopy)
- 400-600 galaxy every night, ~2000 in total (sub-catalogue from GWGC)
- Reach to r=19 mag on average
- ~30 nearby SN in the last 2 years



Distance Less Than 40 Mpc = DLT40

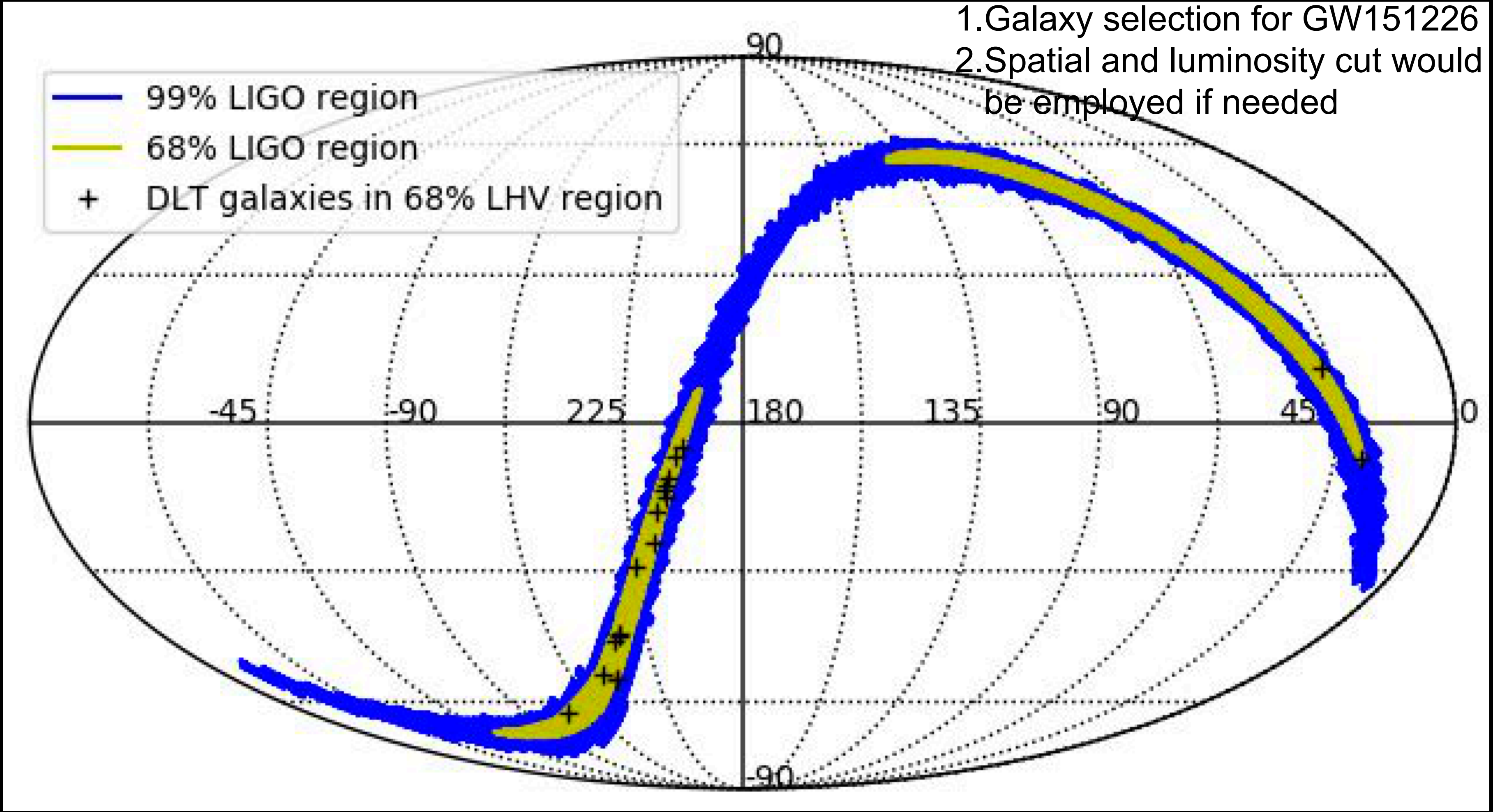
GW follow-up

'DLT40 GW run':

- Prompt 5(search) + LCO/FLOYDS···(spectroscopy)
- 400-600 galaxy every night, ~2000 in total (sub-catalogue from GWGC)
- Reach to r=19 mag on average
- ~30 nearby SN in the last 2 years
- high priority would be given to LIGO galaxies if any

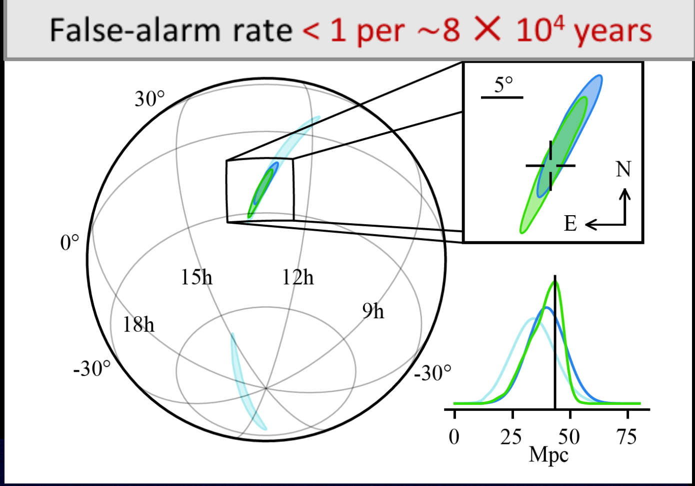
1.Galaxy selection for GW151226

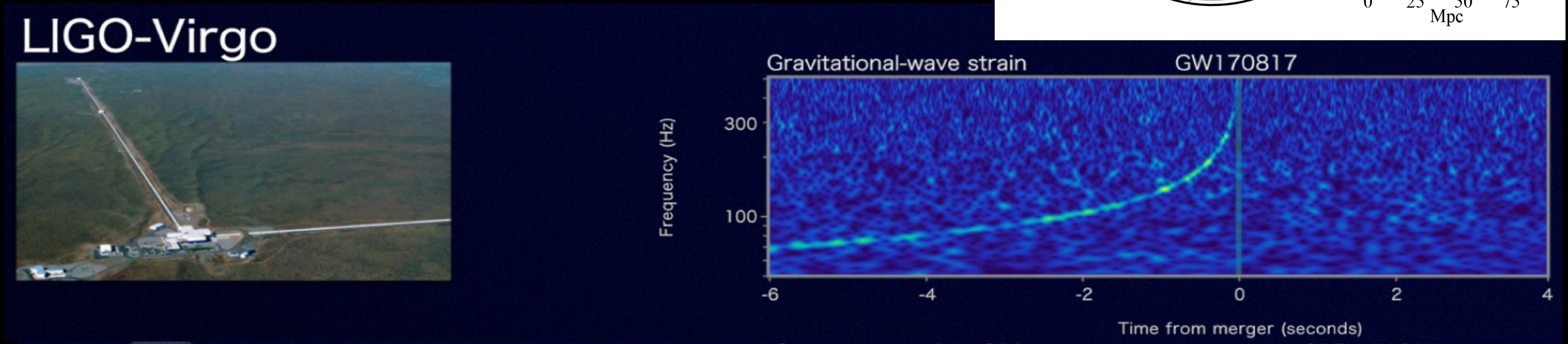
2.Spatial and luminosity cut would be employed if needed

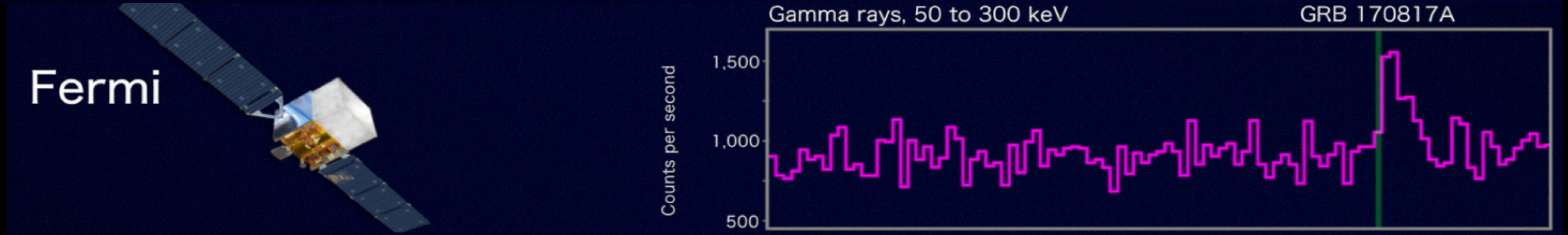


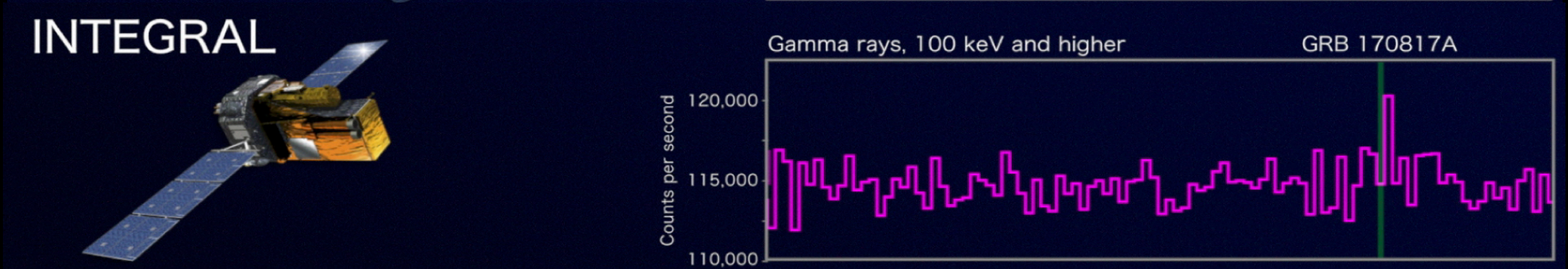
BNS at 40 Mpc !!

GW170817: **2017/08/17 UT:12:41:04.445710**
GRB170817a: **~2 sec later**



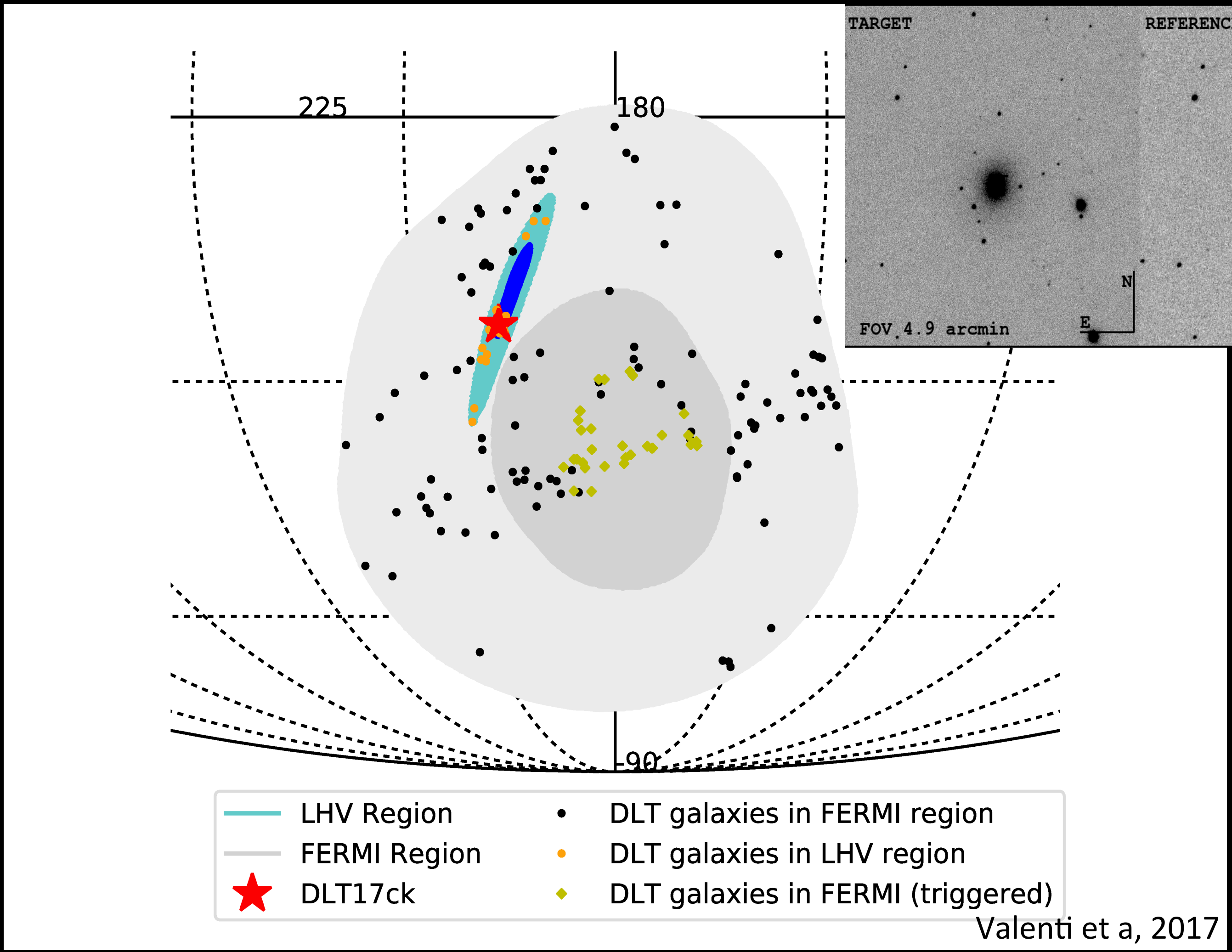


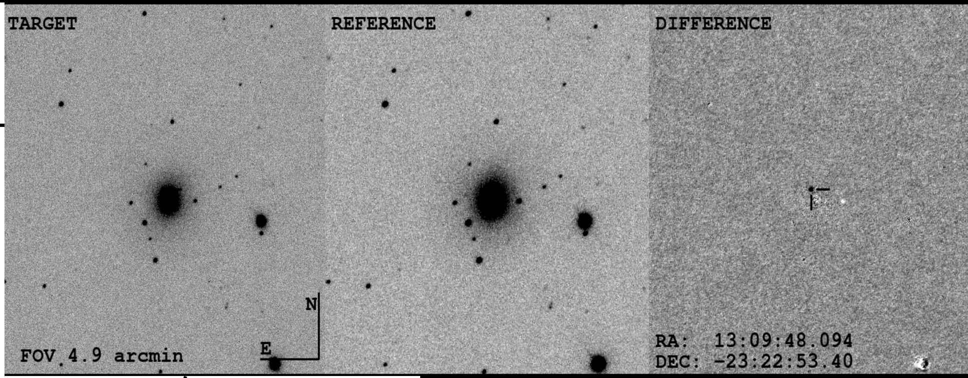




BNS at 40 Mpc !!

GW170817: 2017/08/17 UT:12:41:04.445710
GRB170817a: ~2 sec later
2017fgo/sss17a/DLT17ck: ~11 hours later, optical kilonova in NGC4993





Valenti et a, 2017

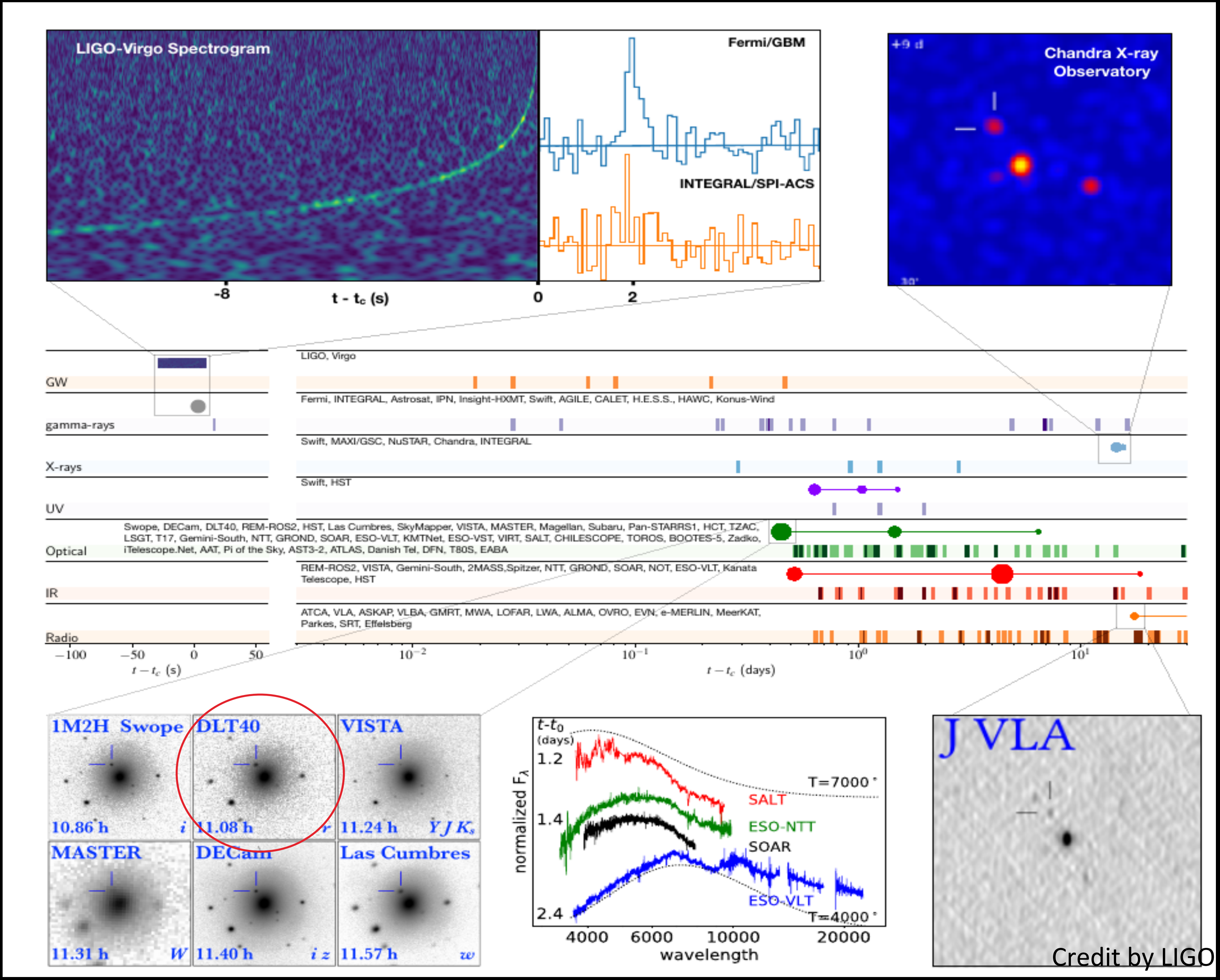
DLT17ck

On 2017 August 17 23:49:55 UT (11.08 hours after GW170817)

RA=13:09:48.09,DEC=-23:22:53.4.6, 5.37W, 8.60S arcsec offset from NGC 4993

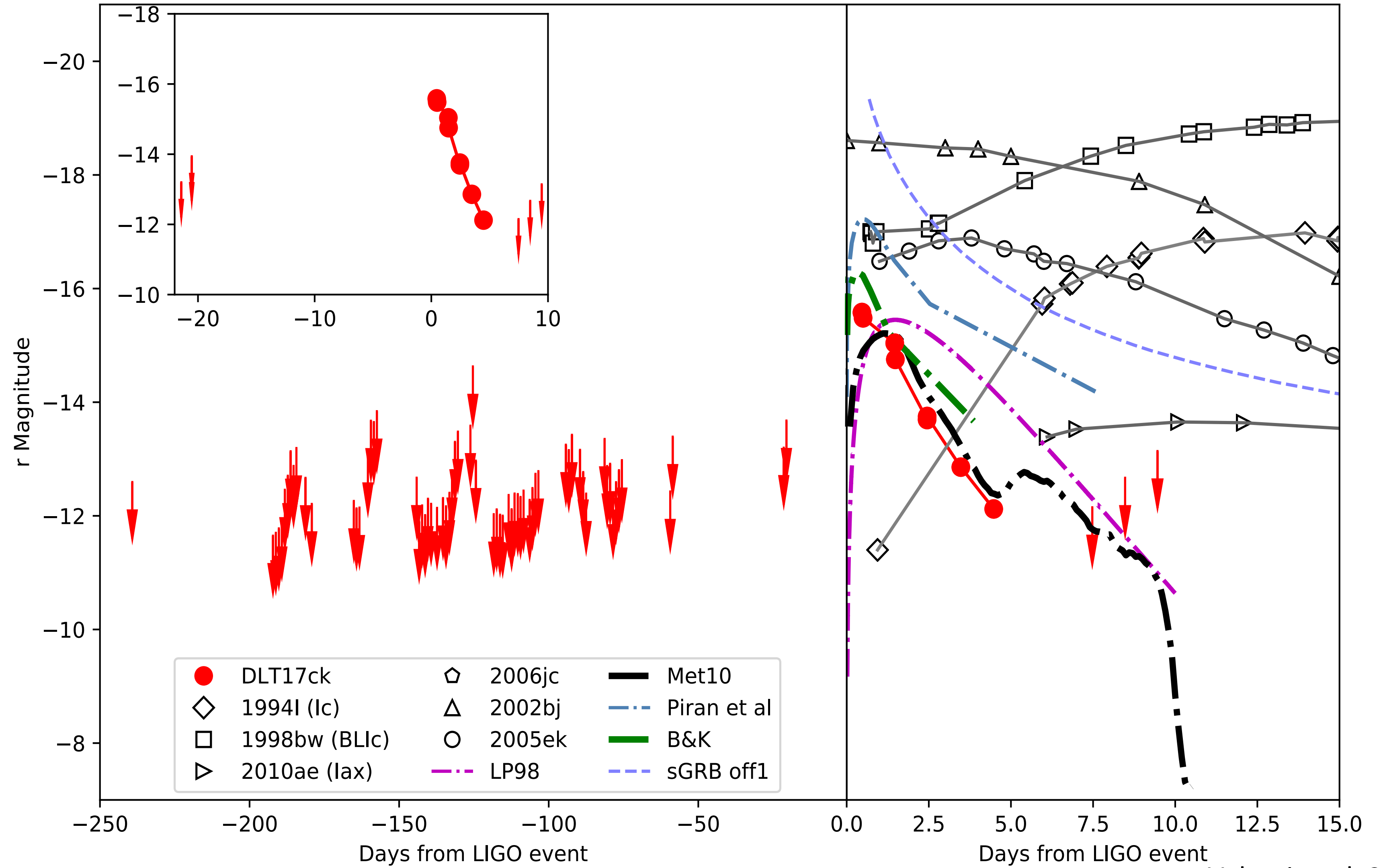
Multi-messenger astronomy has truly begun !

GW
Gamma
X
UV
Optical
IR
Radio



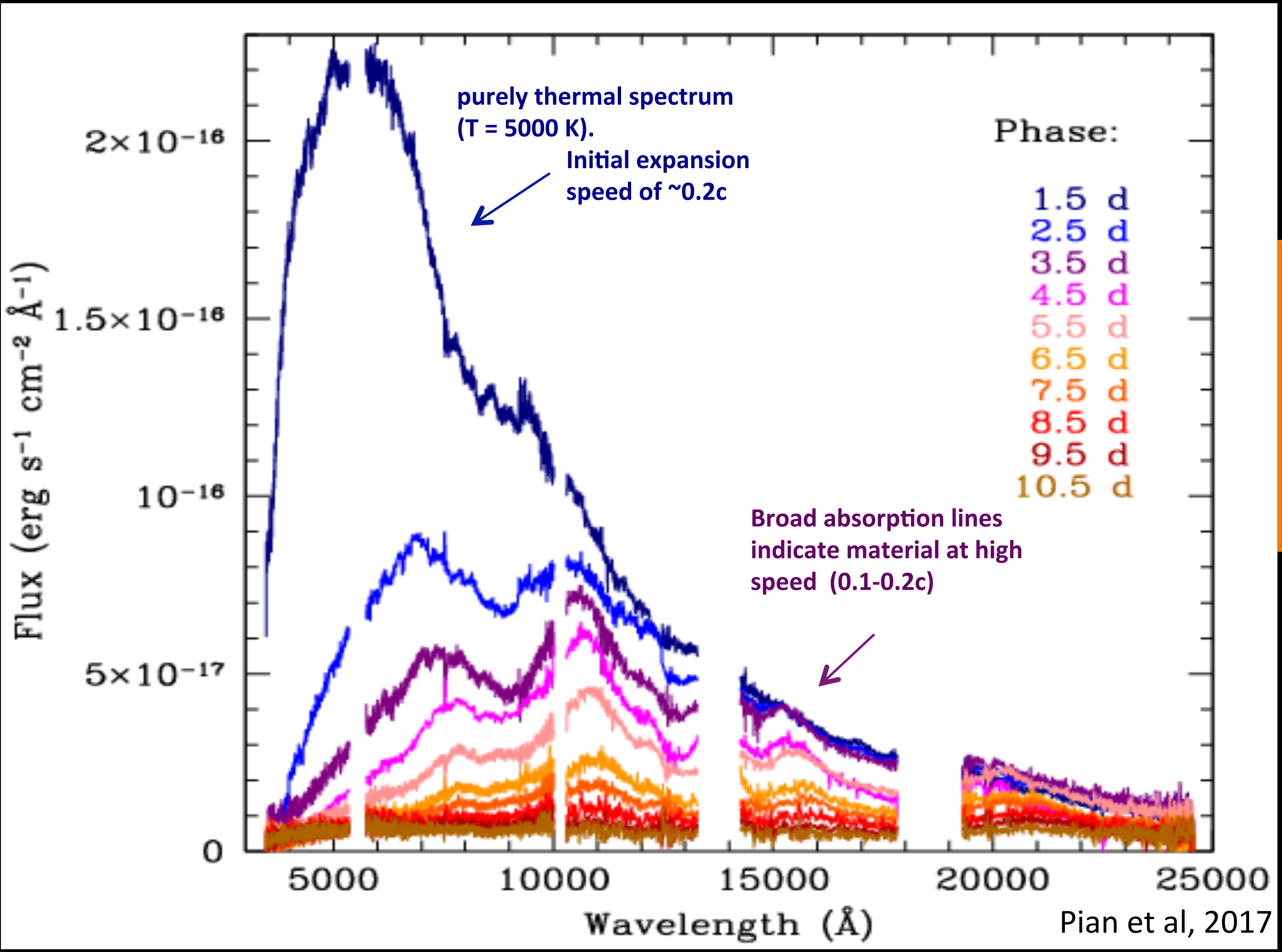
DLT17ck light curve

DLT17ck lc is comparable to the fast kilonova model.
Cooling down fast.



Valenti et al, 2017

Kilonova identification - GRAWITA spectrum



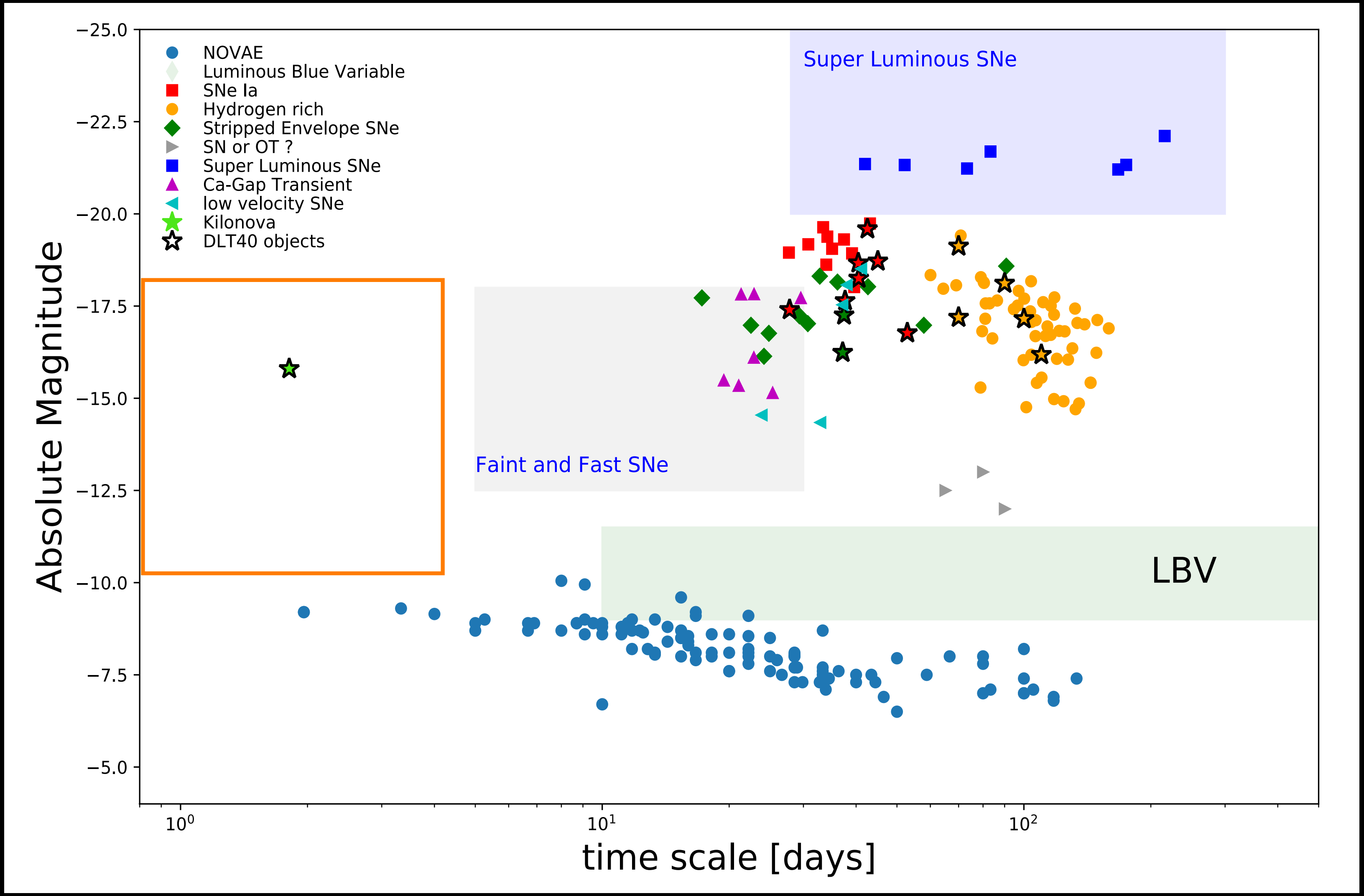
Pian et al, 2017

These data revealed signatures of the **radioactive decay of *r*-process nucleosynthesis** providing the **first spectral identification of the kilonova emission**

Cooling down very fast

See Cappellaro talk for more details

DLT17ck is unique, first kilonova

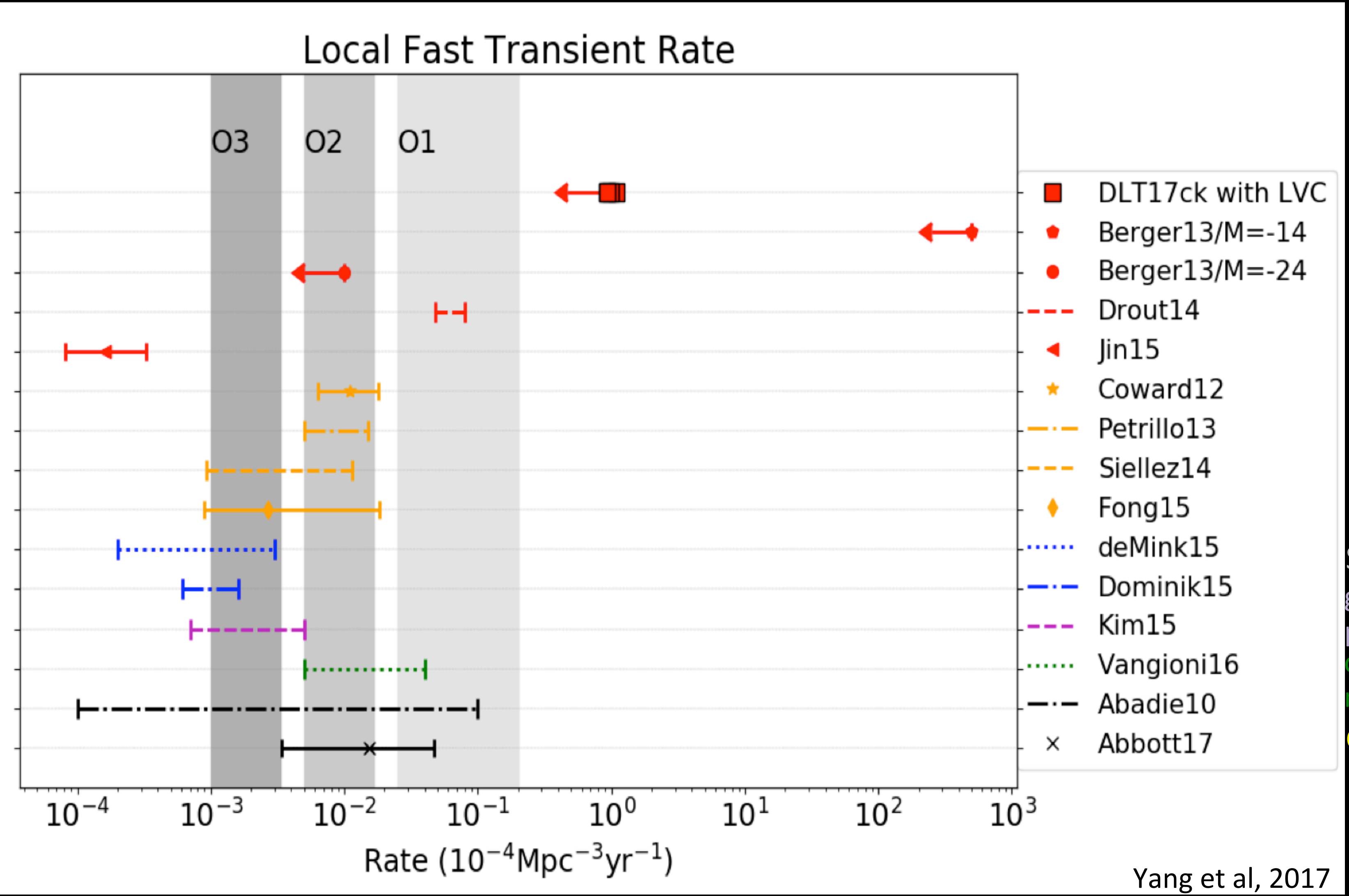


1.Identification: cadence

daily cadence search & multi-messenger search

2.Rate: time

Rate estimation



BNS rate

fast optical transients

short GRB

Stellar evolution

galactic pulsar population

cosmic nucleosynthesis

GW

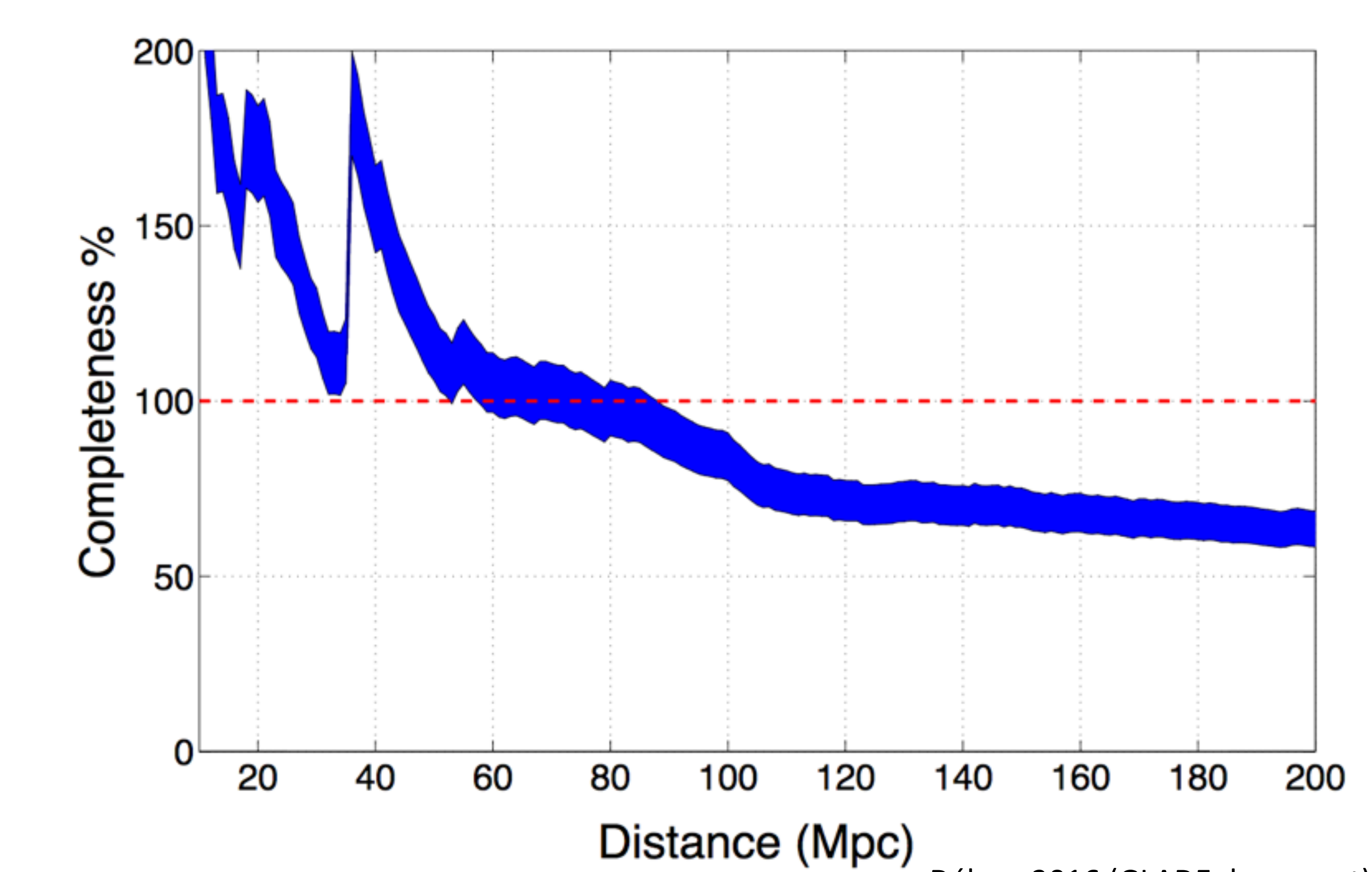
Detecting a kilonova with a survey like DLT40 (independently on the LIGO trigger) will take ~18.4 years!

Future − pointed search

Success of the pointed search and small telescopes, but future?

Galaxy catalogue incompleteness

GLADE: the best public galaxy catalogue



Dálya+ 2016 (GLADE document)

Complete up to 73 Mpc

Future − EM in LIGO O3

- BNS? NS-BH?
- galactic SN?
- BBH?

DLT40	exptime	limit magnitude	Number of galaxies	Distance
O2	45s	19	400-600	70 Mpc
O3	100s	19.5	230	85 Mpc

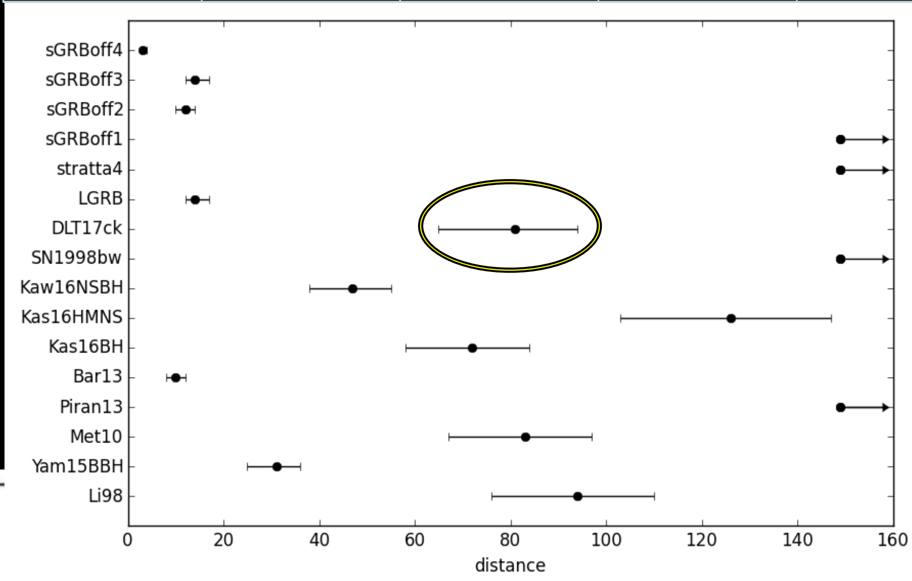
'pointed': Nearby bright transient

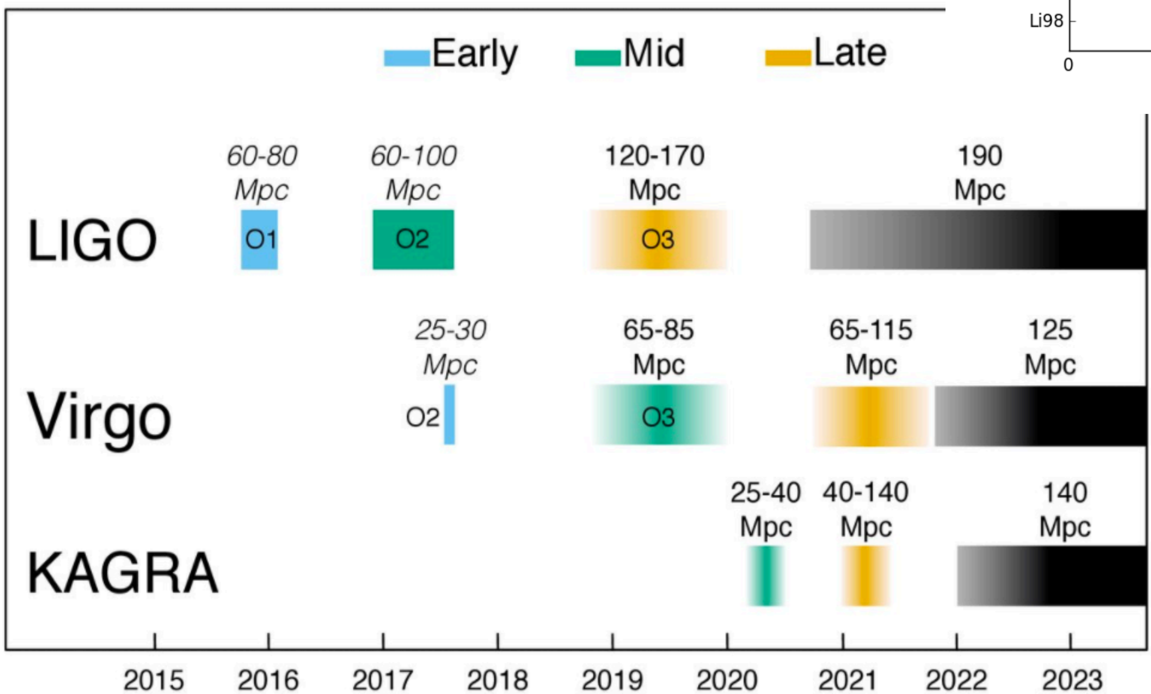
Pro:

high cadence

Con:

1. Galaxy completeness
2. Distance limited





'tiling': distant faint transient

Pro:

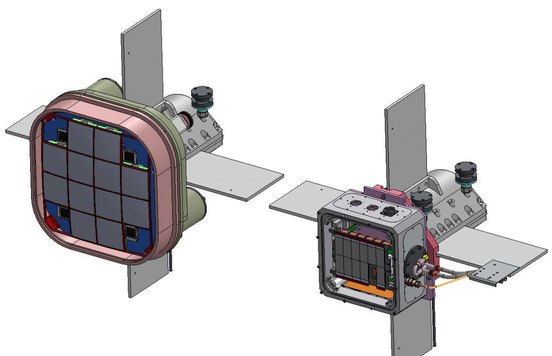
go further

Con:

1. time consumed for image processing
2. real/bogus candidate classification

Future – prepare for multi-messenger era & big data astronomy era

1. Multi-messenger search: GW, neutrino…
2. Multi-wavelength search: GRB, FRB…
3. Fast identification: machine learning - scikit-learn/tensorflow
4. Test facility:
   Asiago Schmidt telescope/PROMPT/REM



ZTF (46 deg.^{2}) *i*PTF (7.2deg.^{2})

LSST - 15TB data/night


Thanks for attention!