Gravitational Waves optical follow-up @VST

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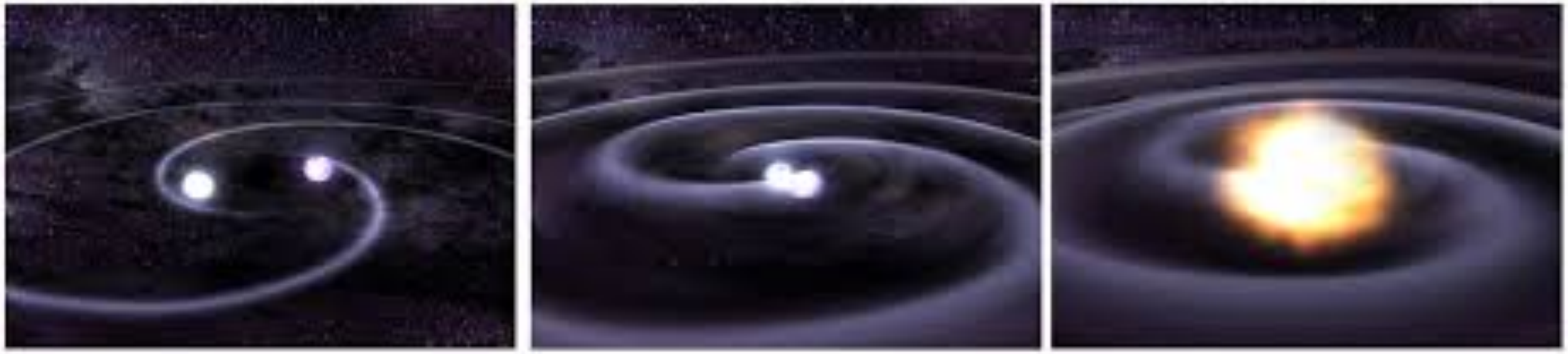
& the GraWita team

THESEUS Workshop INAF-Capodimonte 5-6 October 2017

GW-EM symbiotic probes



GW

EM

Environment, energy

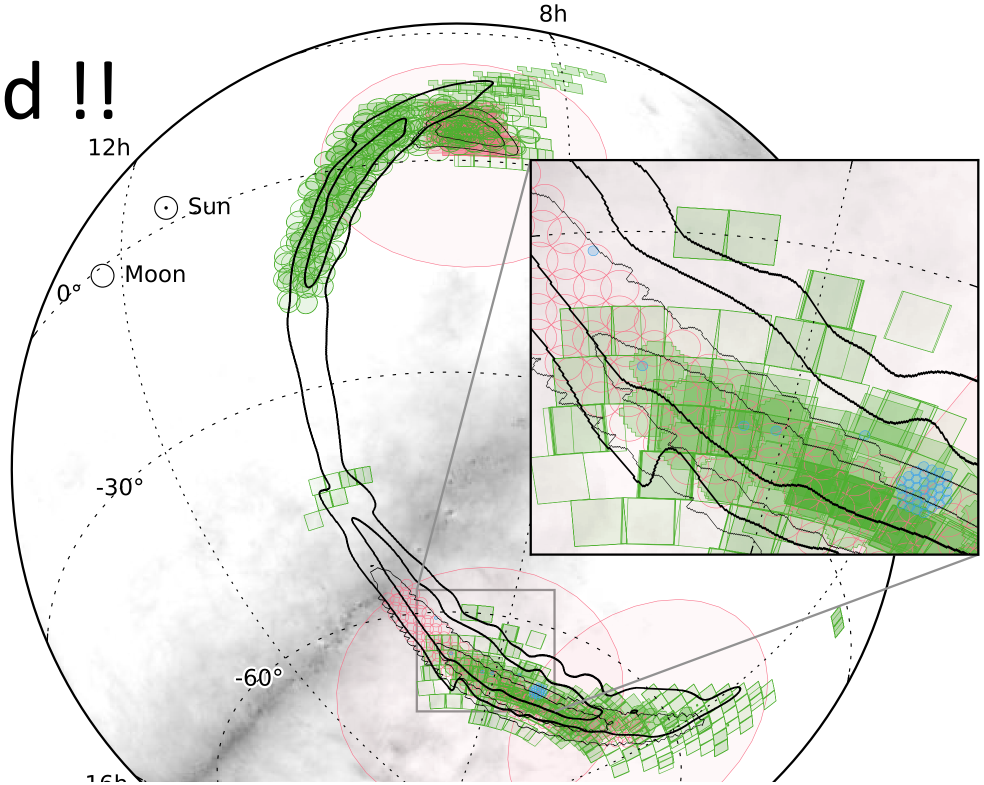
Dynamics, mass, spin

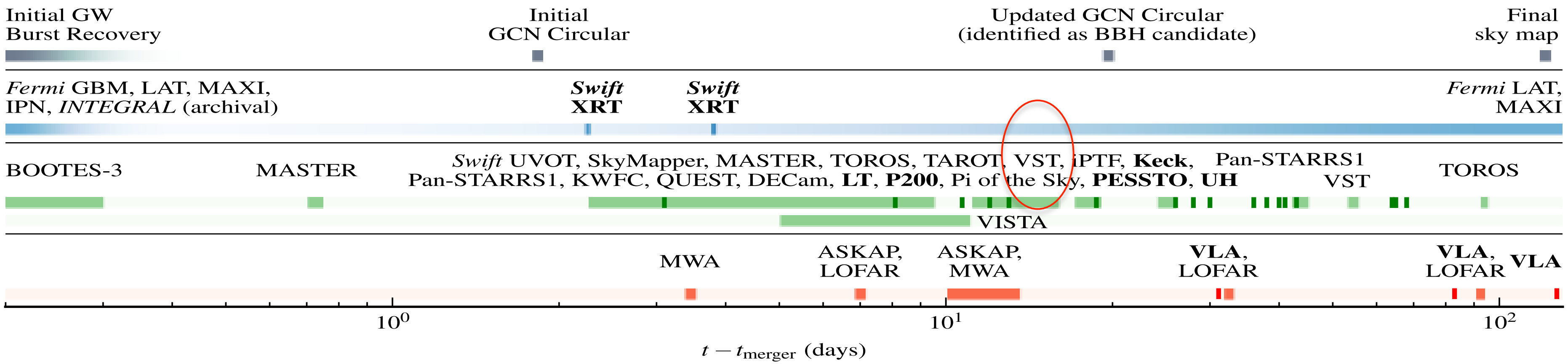
GW150414 EM sky coverage

24 observatories involved !!

19 orders of magnitude in frequency space
+ neutrino search IceCube/ Antares (+/- 500s)

LVC-EM, APJL,826,1 L13,2016
Antares,IceCube, LVC, Phys. Rev. D**93** 122010,2016



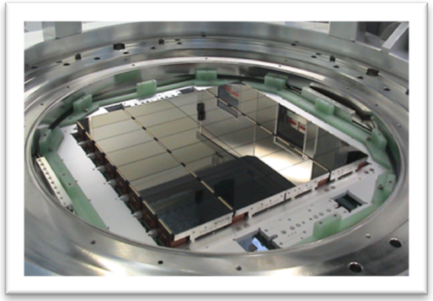


VST in a nutshell

Located on Paranal Chile

In operation since October 2011

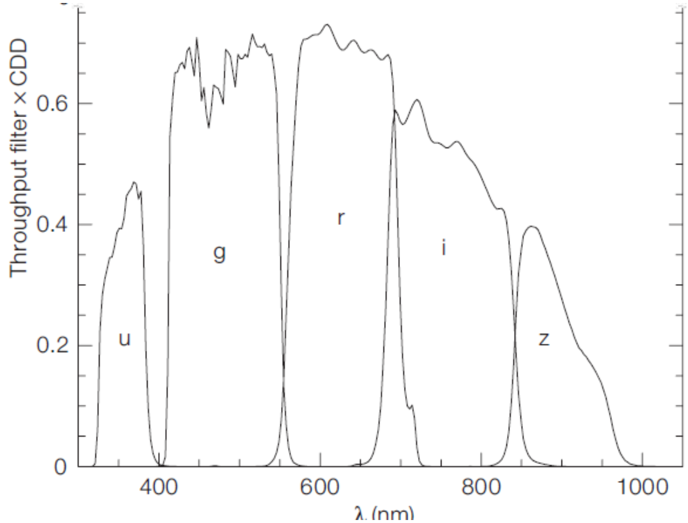
- Primary mirror: 2.6m
- 1.46 deg corrected FoV (∅)
- 80% EE in 0.4″



Camera OmegaCam

- 268 Mpixel 1°x1° FoV
- 0.21 arcsec/pixel
- 32 scientific CCDs + 4 outer CCDs

5 SDSS filters



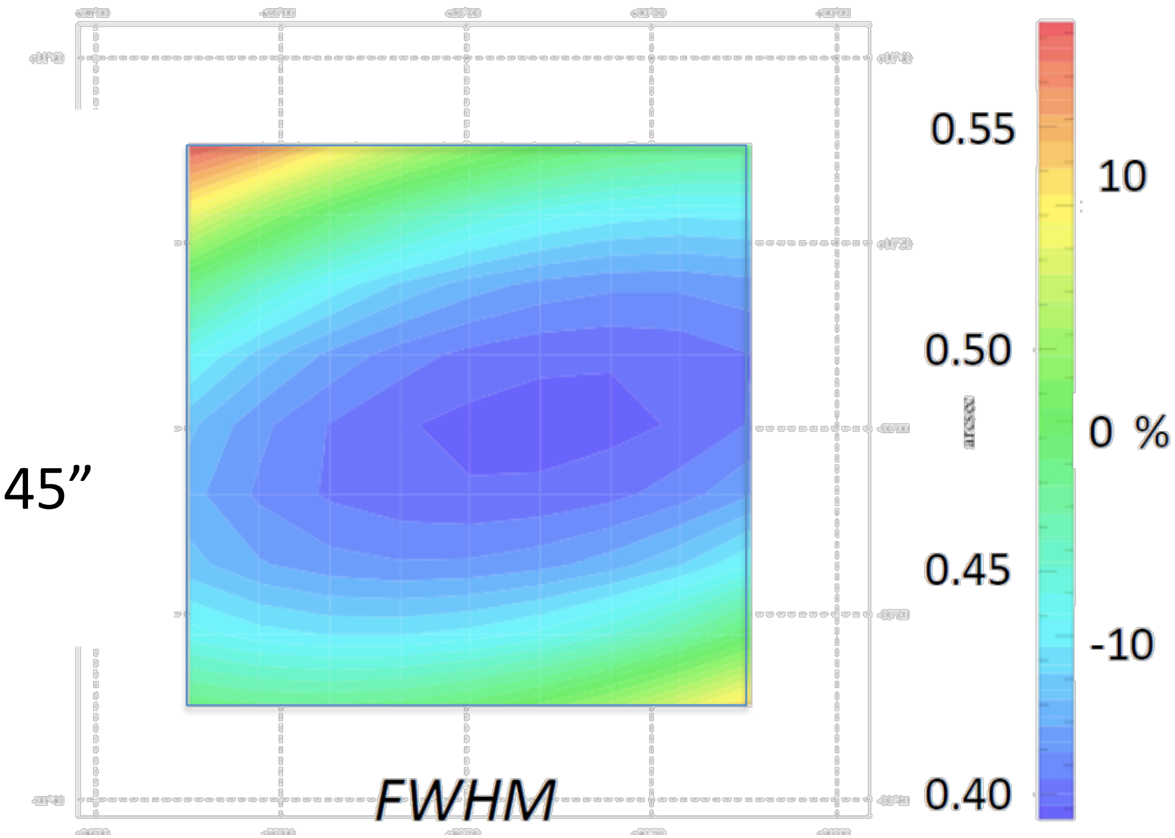
Founds, design and construction @Osservatorio di Capodimonte

VST performances: FWHM

VST regularly delivers images down to 0.5'' FWHM uniformly over the whole field, with small ellipticities

i-band

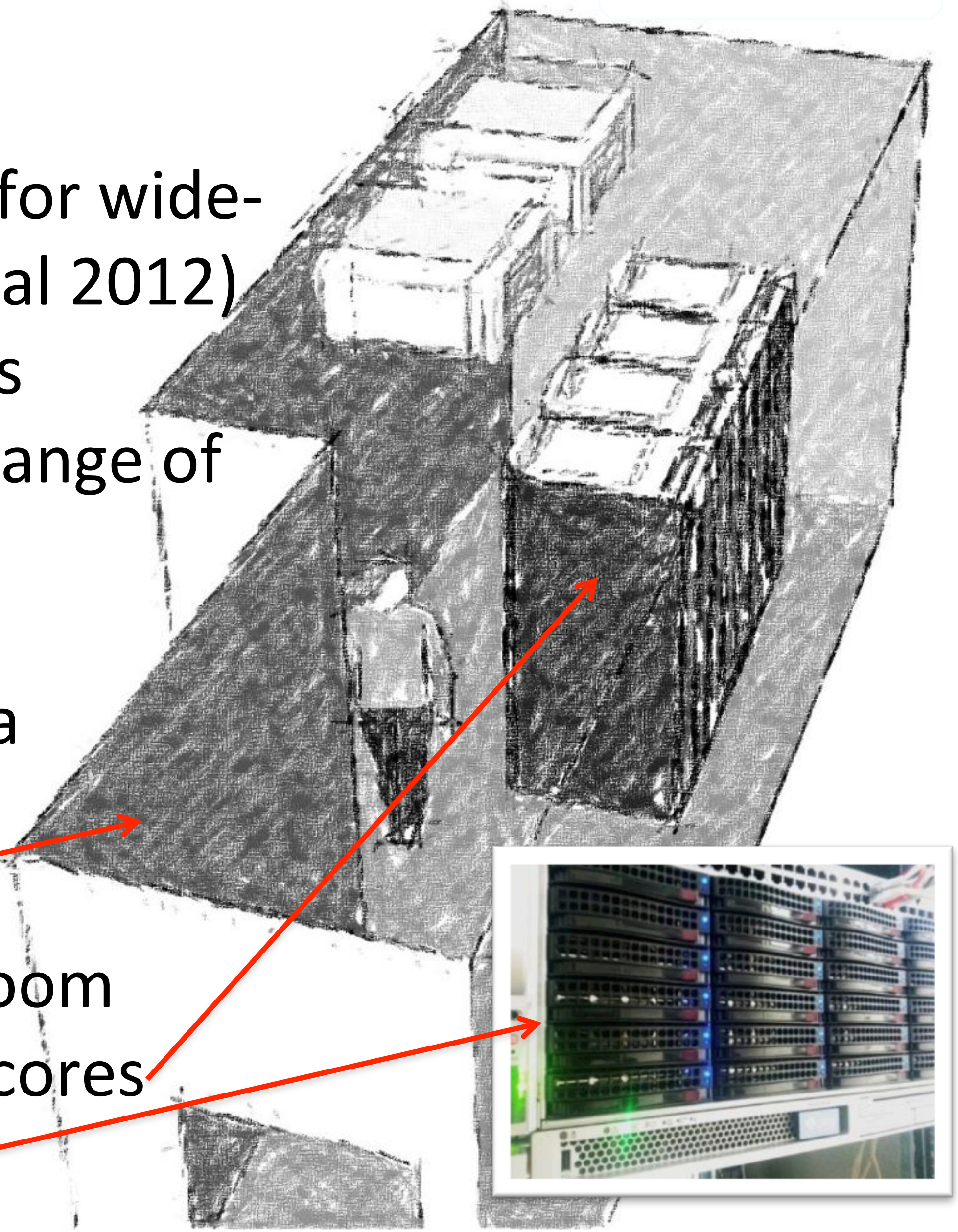
Median FWHM =0.45"



VST Data Center @OACN

- ***SW***
  - VST-Tube
    in house dev. pipeline for wide-field images (Grado et al 2012)
  - Support 18 VST surveys
  - tailored on very wide range of science goals
  - > 40 papers based on VST-Tube reduced data

- ***HW***
  - Dedicated computer room
  - beowulf cluster ~ 300 cores
  - ~ 1 PB data storage



STANO –vST opticAl follow-up of gravitatioNAl waves In the framework of GraWita

Two companion programs on GTO time (in reward of telescope and camera construction):

- On ***VST-GTO***: PI A. Grado
- On ***OmegaCam-GTO***: E. Cappellaro

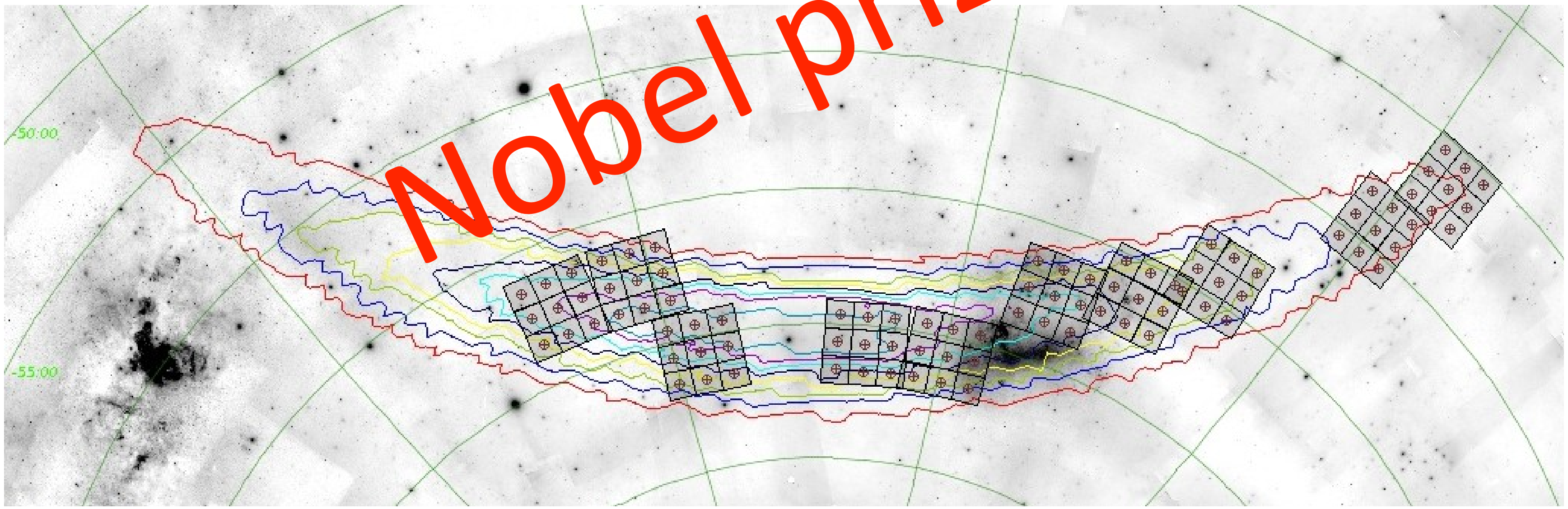
We start with a negotiation with ESO to have the VST in ToO mode.

Since P95 ToO and follow-up programs.

Up to now allocated 240h on these surveys

First event GW150914

Nobel prize!!



Blocks of 3x3 deg^2

2x40 s dithered images

90 deg^2 in 6 epochs (over 2 months)

29% of the localization probability for cWB sky map enclosed

10% considering the LALinference sky map (shared with observers on 2016 January 13)

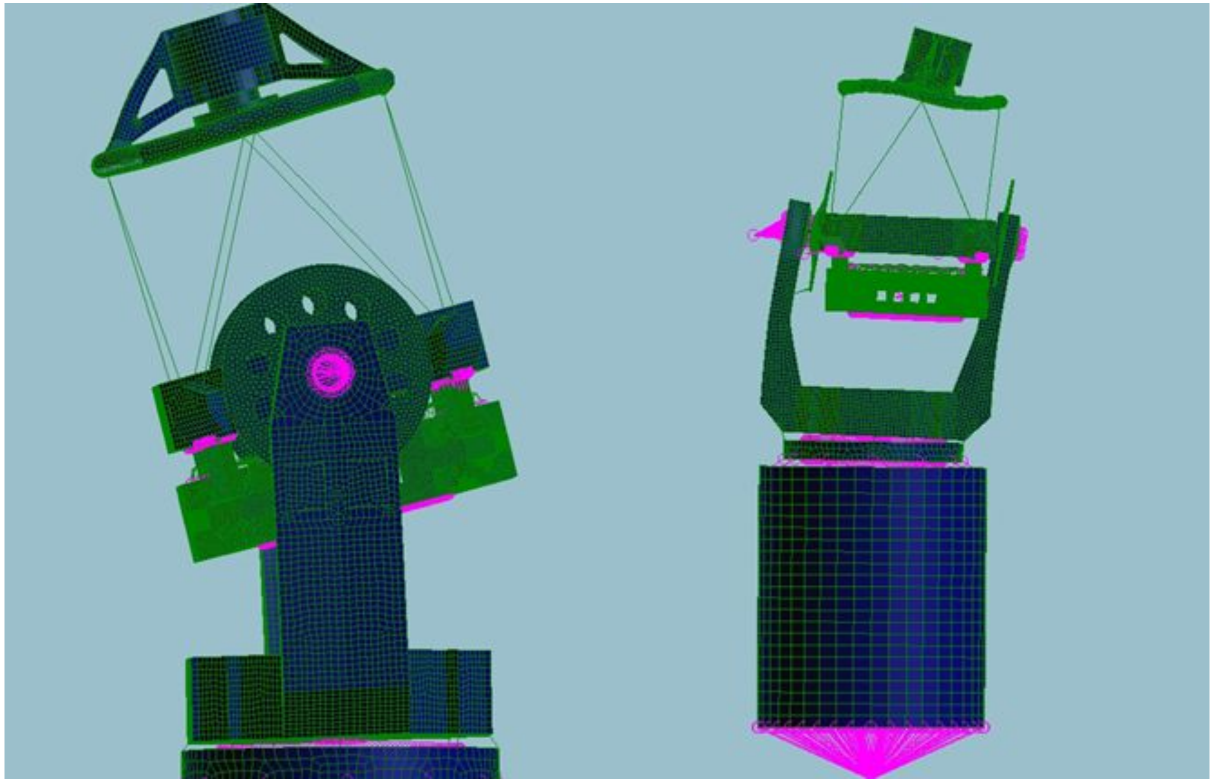
cWB sky location: red 90% enclosed probaility

Pointings obtained with GWsky (Greco et al. in preparation)

GW150914

First observations: 23h after the alert (GCN 18336 Brocato et al.) (the first "big" high resolution telescope to cover the area)

Illapel (200Km from Paranal) earthquake in Chile September 16 at 19:54 Chilean Time Mw=8.3! (observations started 7 h later)

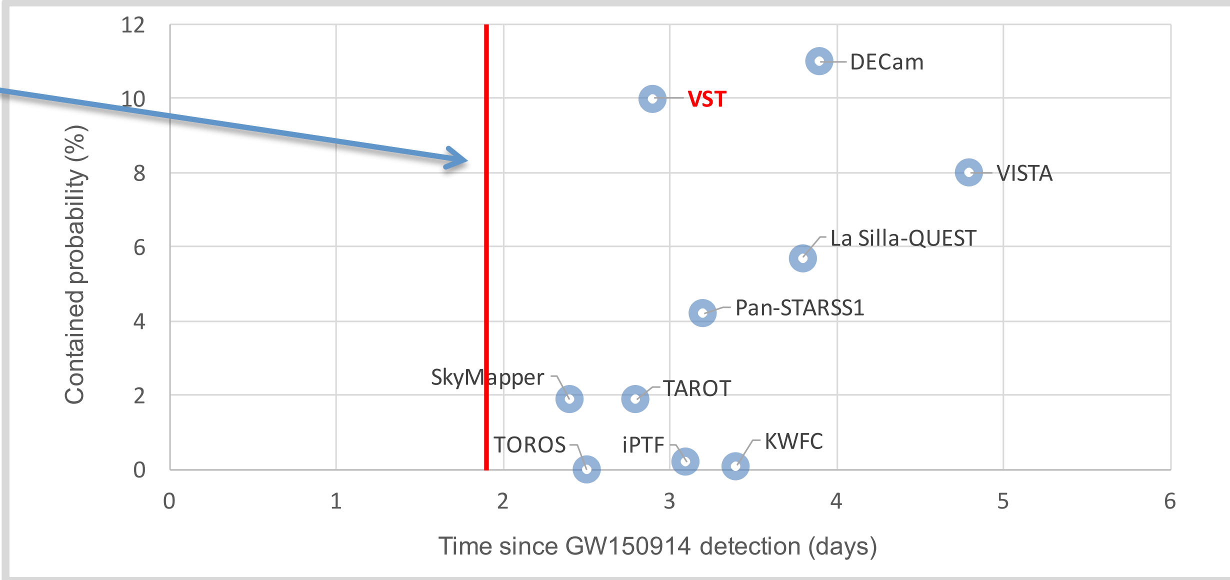


Courtesy: Francesco Perrotta

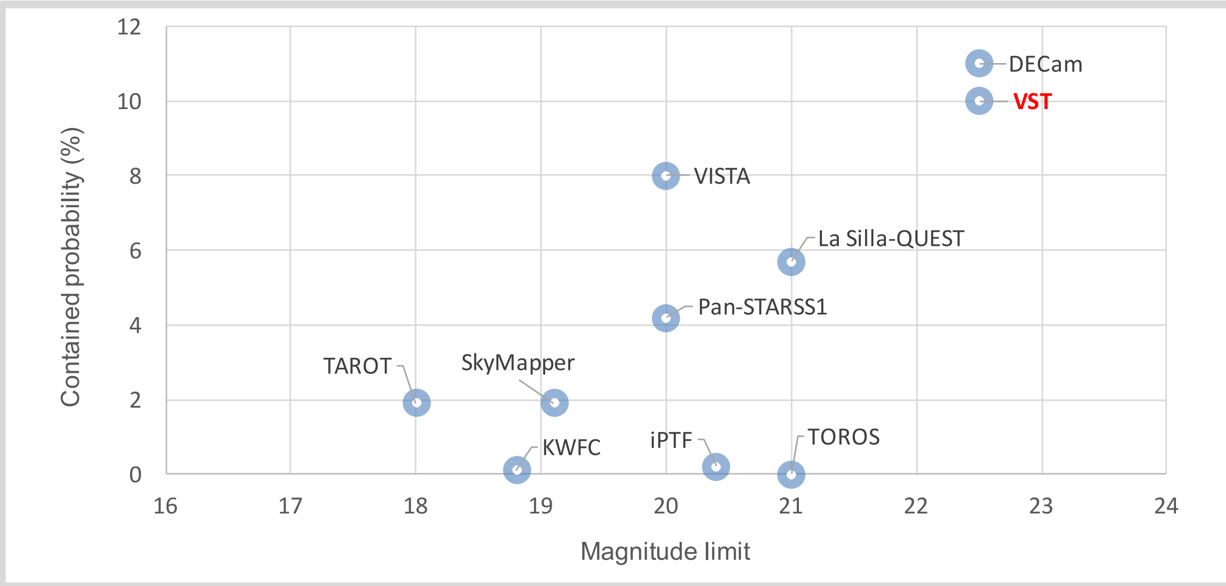
VST survey performance

LVC alert

Contained probability vs Time response

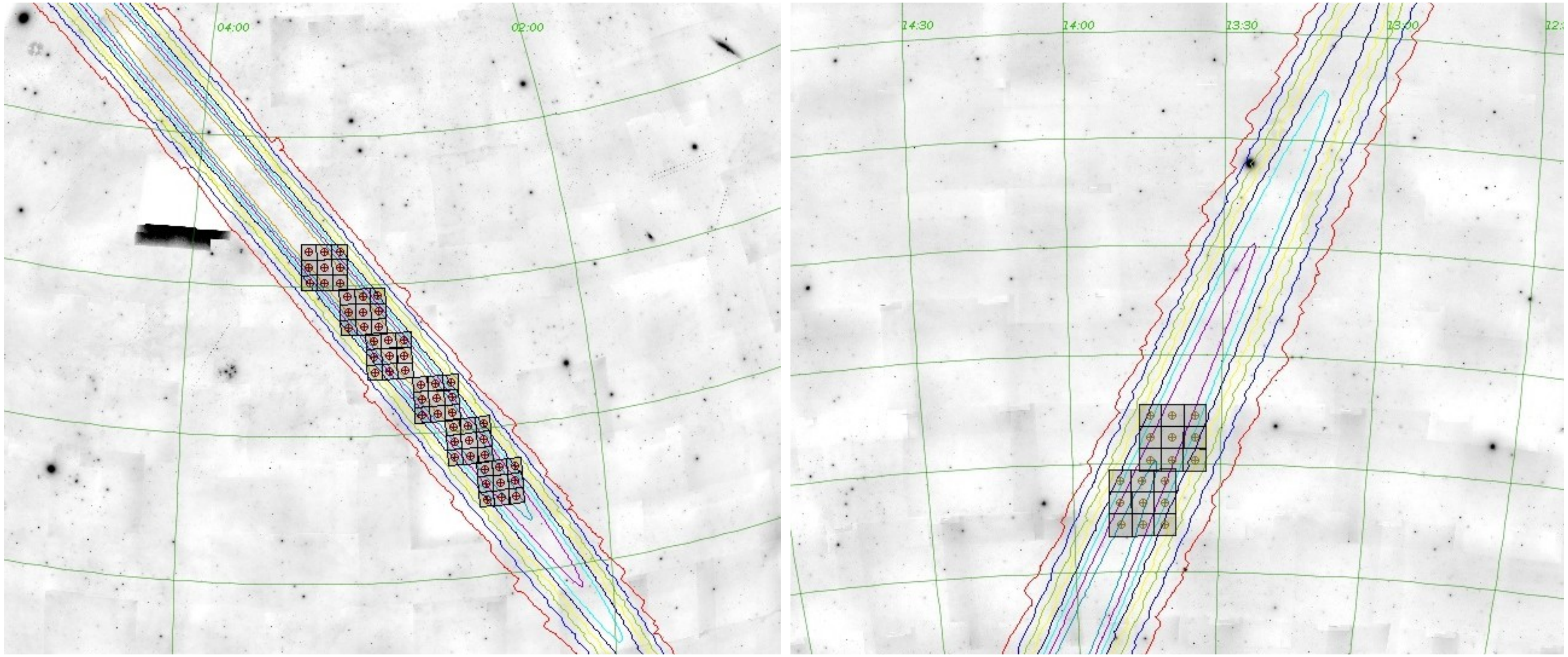


Contained probability vs limiting magnitude



Data from Abbott et al 2016

Second event GW151226



72 deg^2 in 6 epochs

First obs 7.6 hours after the alert and 1.9 days after the merger event (GCN Grado et al. 2015).

9% of the initial BAYESTAR sky map and 7% of the LALinference sky map

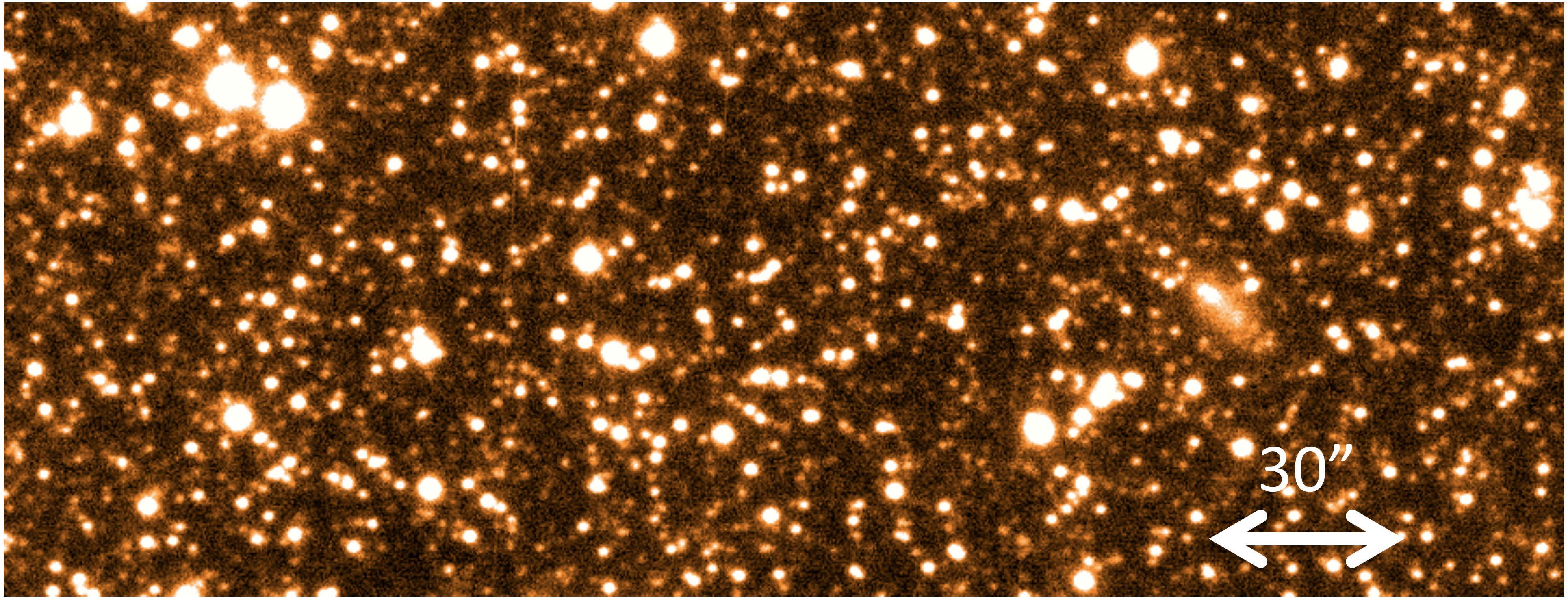
EM counterpart search: a very tough task

Find ONE transient in the GW box error. For the first two events 90% enclosed prob. ~ 200-1000 deg^2

- 10-50 SN
- > 100 AGN
- Thousand of variable stars
- Thousand of asteroids

Very tough task

If you are lucky ……



In 1 deg^2 ~ 300k sources !!

Transient search

Two complementary pipeline for transients search

- ***diff-pipe*** images differences (Cappellaro et al 2015) (PRO: deeper, for crowded fields, source embedded in extended objects; CON: slow, more sensible to images defects)
- ***phot-pipe*** comparison among epochs in catalog space (PRO: fast; CON: shallower, missing transients in extended sources…)

Results for GW150914 event

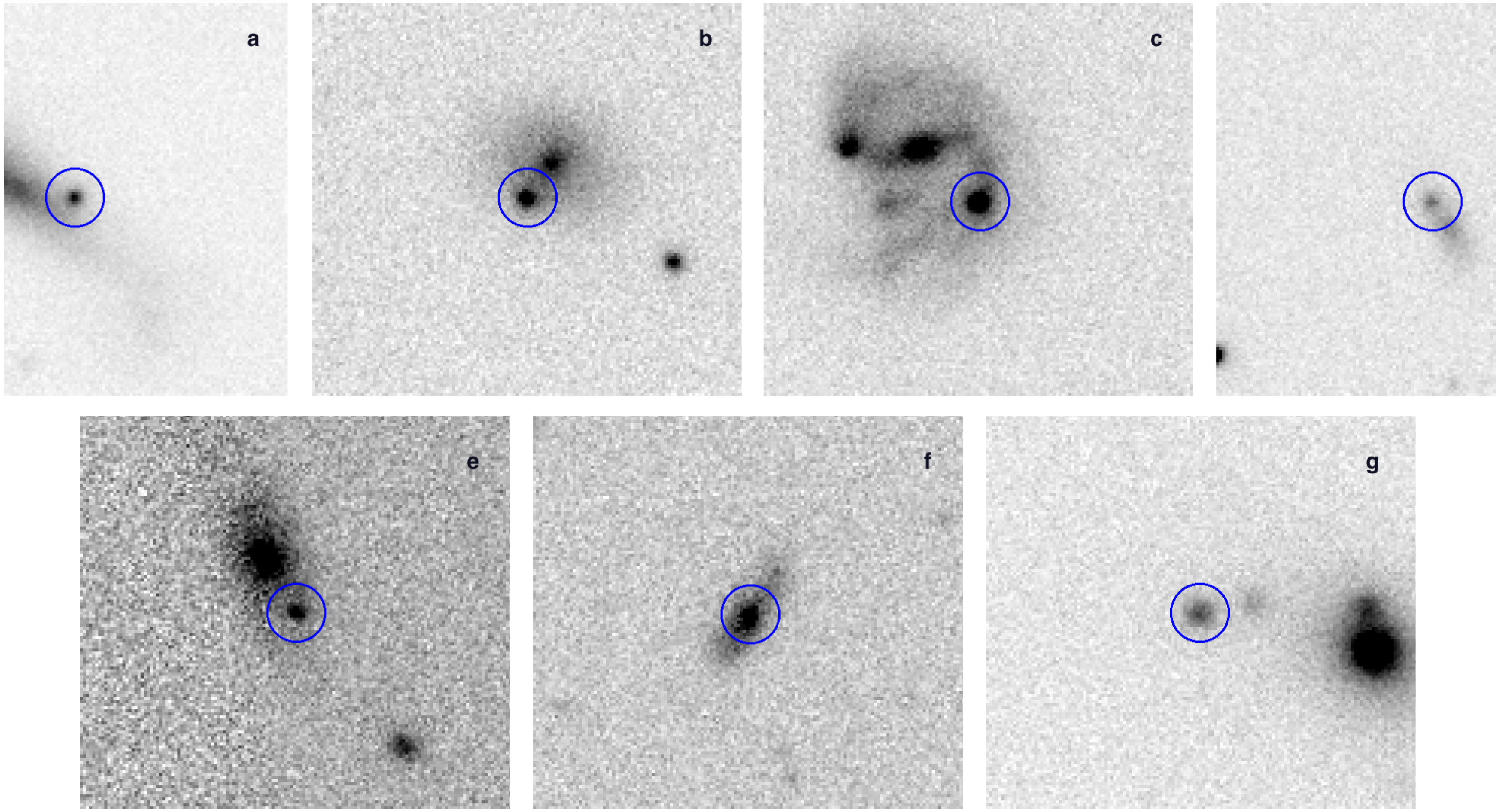
	Diff-pipe	Phot-pipe
Initial number of sources in all epochs	9,000,000	9,000,000
Initial # of candidates	170,000	54,239
Total # of transients	8,000	939
# known variables	6722	
# of known SN in the field/detected	4/4	
# new SN candidates	7	

Brocato et al. submitted

Evident spurious and known variables already removed

VSTJ57.77559-59.13990 SN Ib/c candidate possibly associated with Fermi-GBM GRB 150827A

SN candidates in the GW150914 VST follow-up



Results for GW151226 event

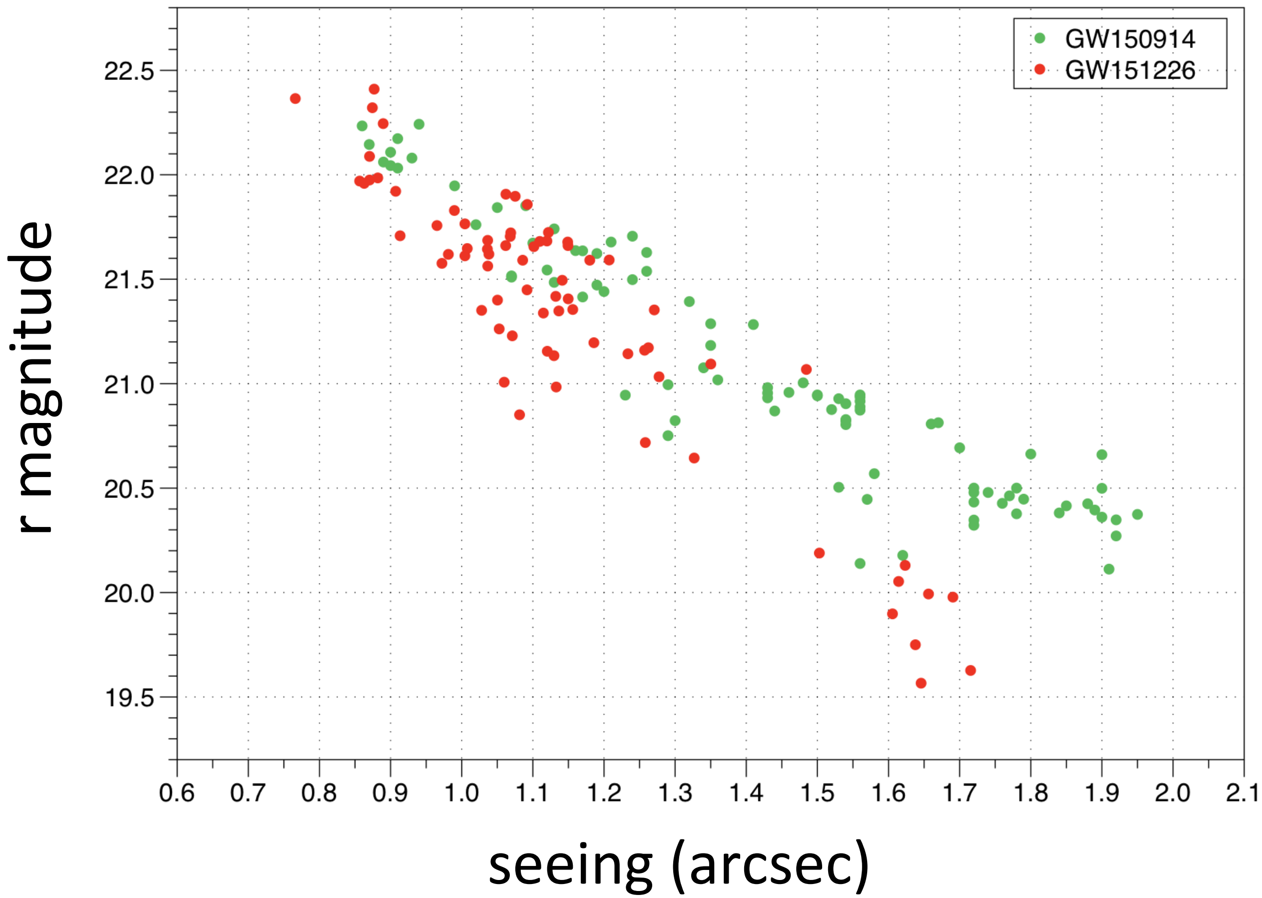
	Diff-pipe	Phot-pipe
Initial number of sources in all epochs	~ 900,000	~ 900,000
initial # of candidates	6,310	4500
total # of transients	3,127	305
# known variables	54	
# minor planets (within 10")	3670	
# of known SN in the field/detected	54/17	
# new SN candidates	4	

Brocato et al. submitted

Spurious and known variables already removed

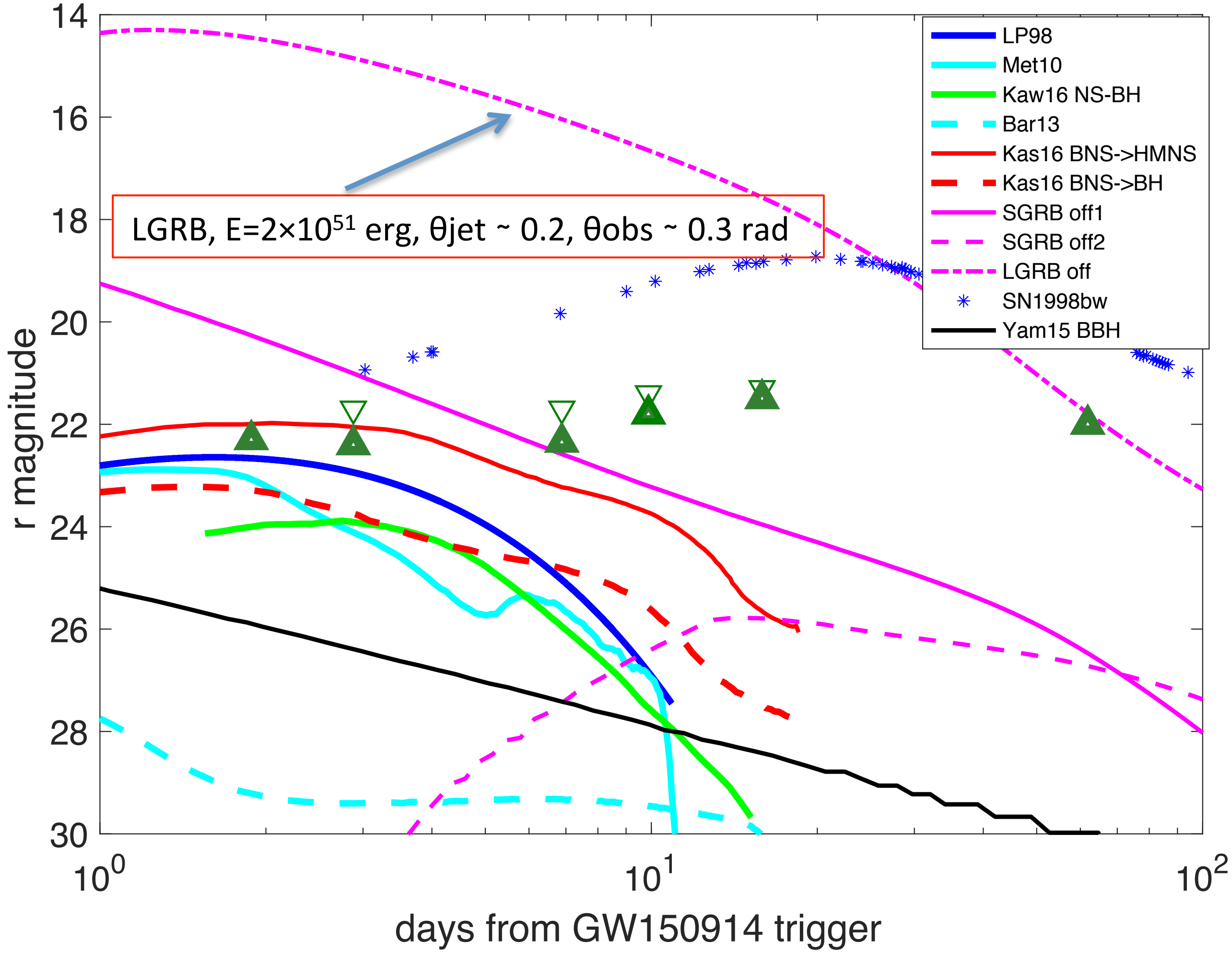
Detection efficiency

Artificial stars experiments



The limiting magnitude for transient detection (DE_{50}) as a function of seeing for the pointings of the two triggers.

Brocato et al. submitted

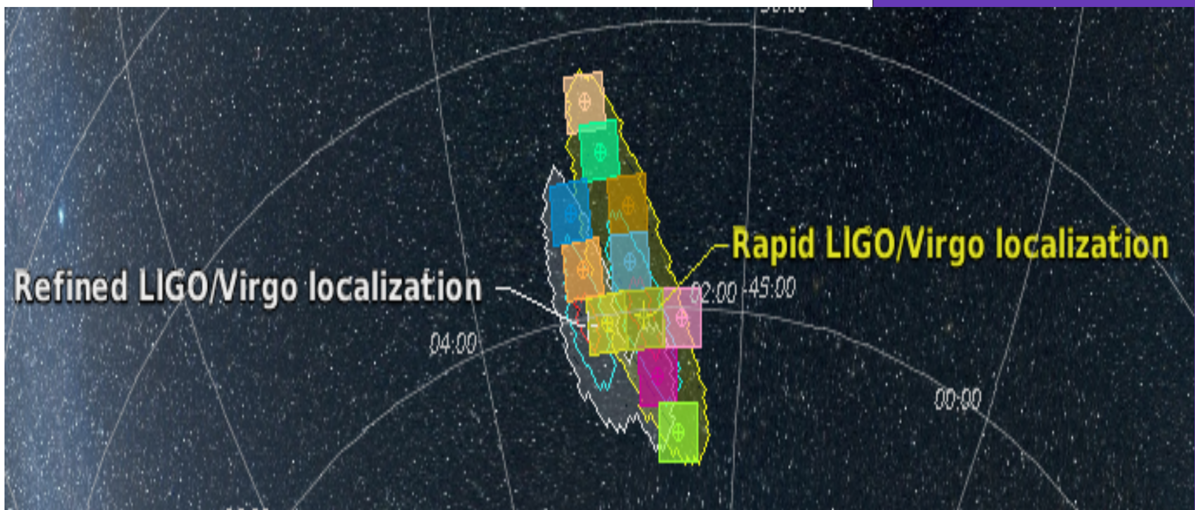


The expected fluxes (r band magnitudes) versus observed time from the GW150914 trigger, assuming several possible electromagnetic GW source emission models at the given distance of 410 Mpc, plotted against the 6 epochs VST observation 5σ limiting magnitude (dark green triangles)

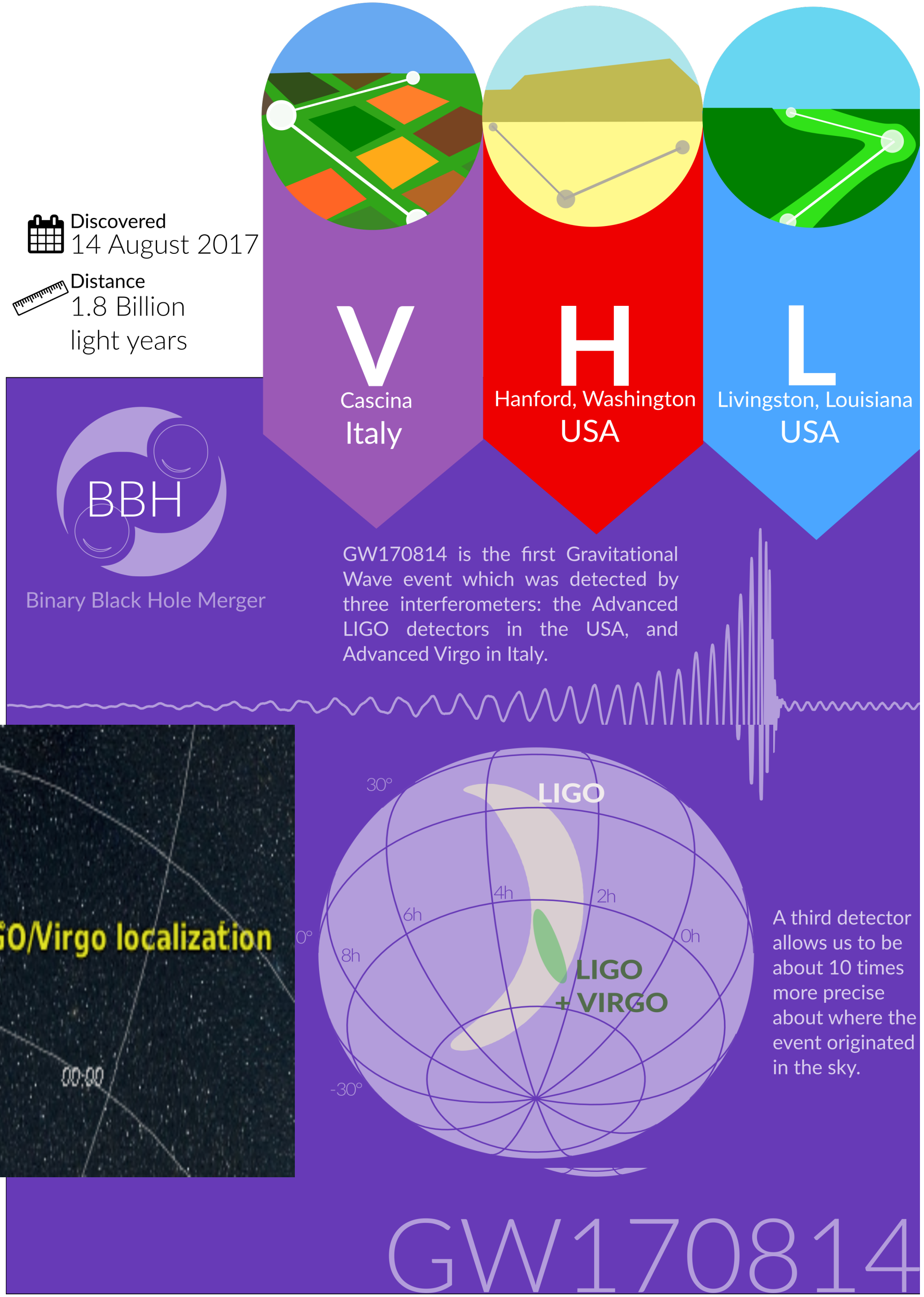
GW170814
the promise of Multi-messenger Astronomy

Abbott et al 2017.

VST was there !!

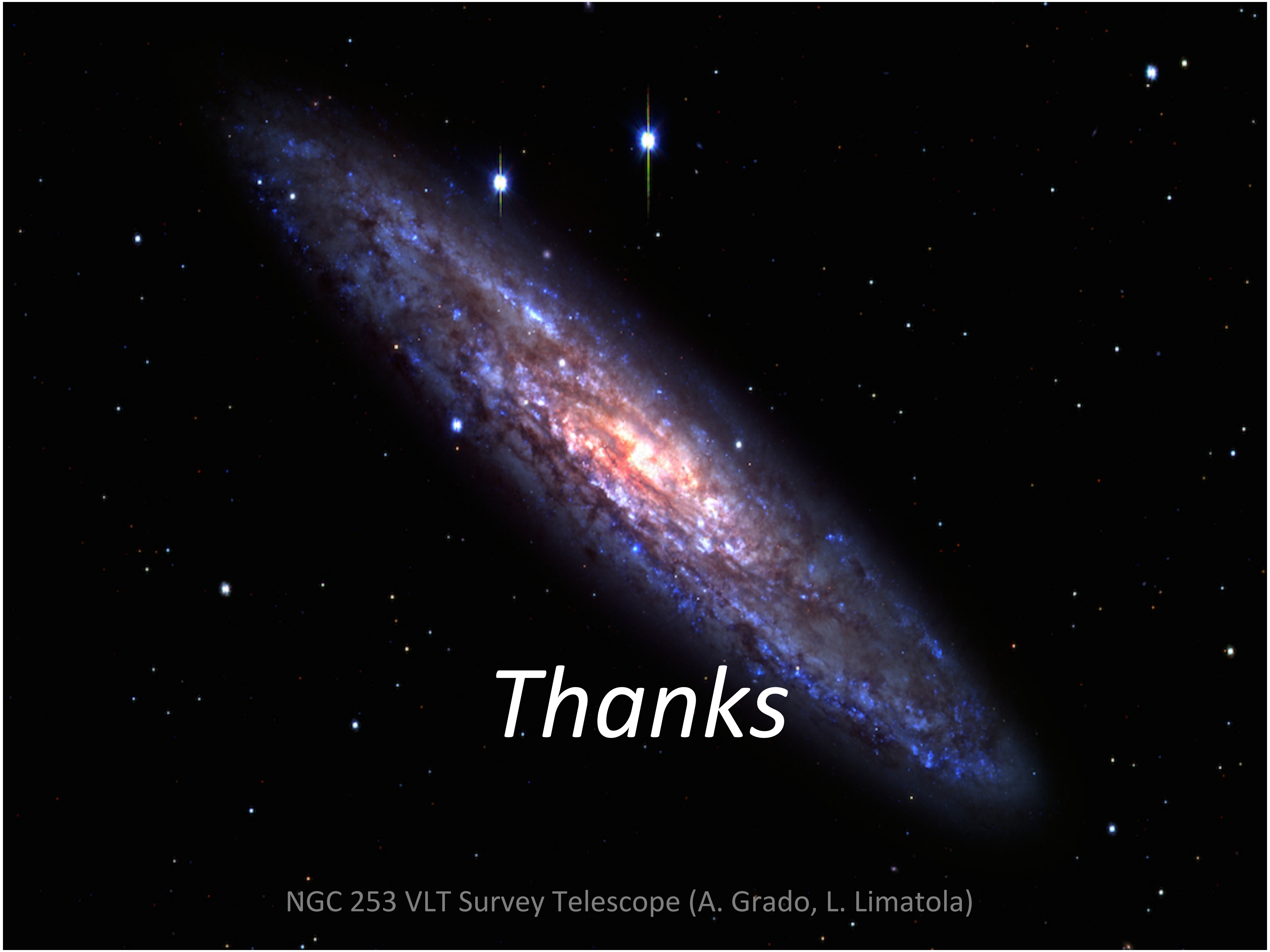


~ 80% of the initial bayestar map



Conclusion

- The multi-messenger Astronomy is becoming reality
- GW optical follow-up has an important role
- For faint transients (detectable with ~ deep surveys) still work needed to shorter the candidates list for further spectroscopic follow-up
- Among the optical observation facilities VST is an important player



NGC 253 VLT Survey Telescope (A. Grado, L. Limatola)