



*Strange gamma-ray bursts registered as  
LIGO/Virgo counterparts*

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# Outline

- Binary Black Hole Merger: no EM counterparts
- BNS: case of GW 170817 / GRB 170817A
- What is strange?
  - Huge error box localization area
  - OT in the nearby galaxies
  - Odd GRB prompt emission
  - Absence of an Afterglow
  - Kilonova
- BNS: other cases: S190425z
- How to search for prompt emission?

# Binary Black Hole Merger (BBH)

- no EM counterparts in 10 BBHs of O1-O2
- no EM counterparts in 24 BBH candidates of O3

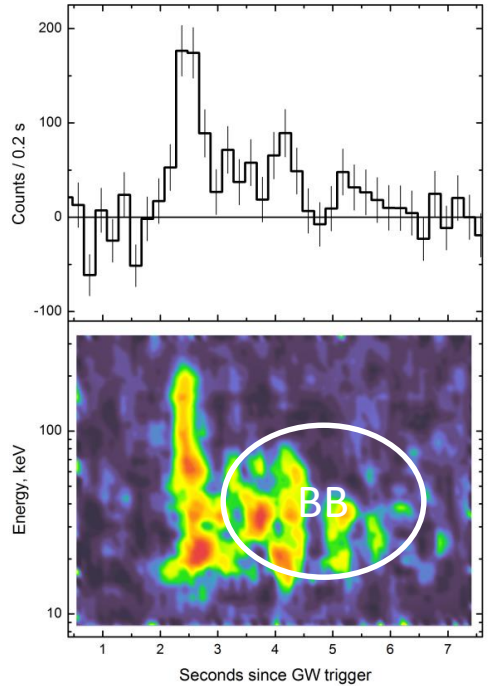
=> This is not strange

# Binary Neutron Star Merger (BNS)

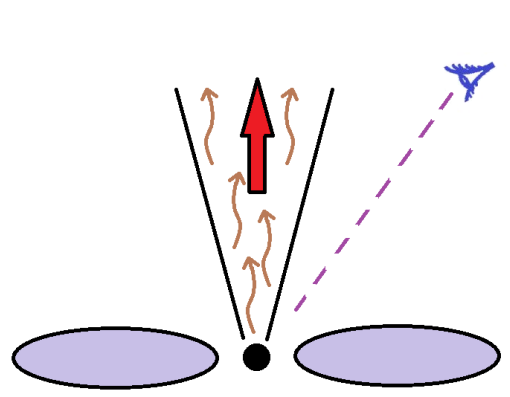
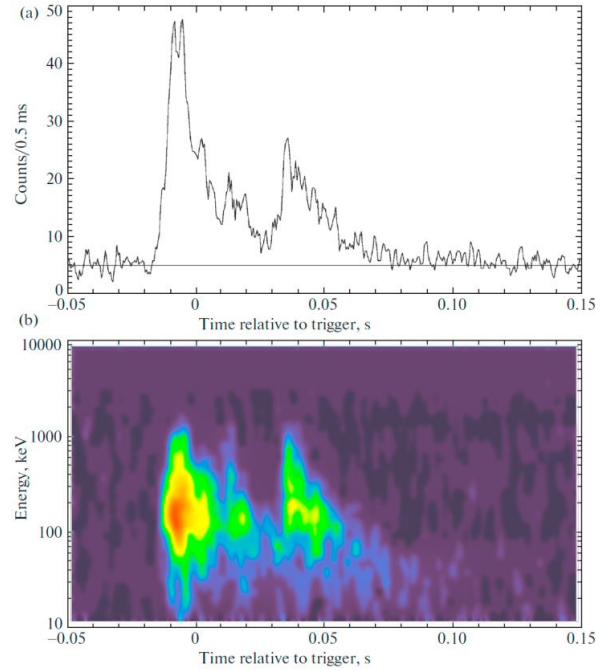
- BNS O2: GW 170817 / GRB 170817A / AT2017gfo
- BNS: 2 candidates in O3
- NS-BH: 2 candidates in O3

# GW 170817/ GRB 170817A / AT2017gfo

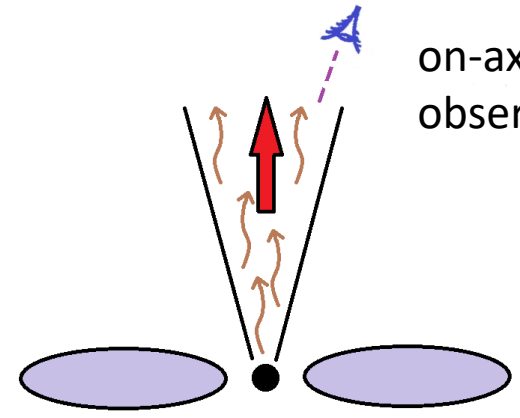
## GRB170817/GW170817



## "typical" short GRB



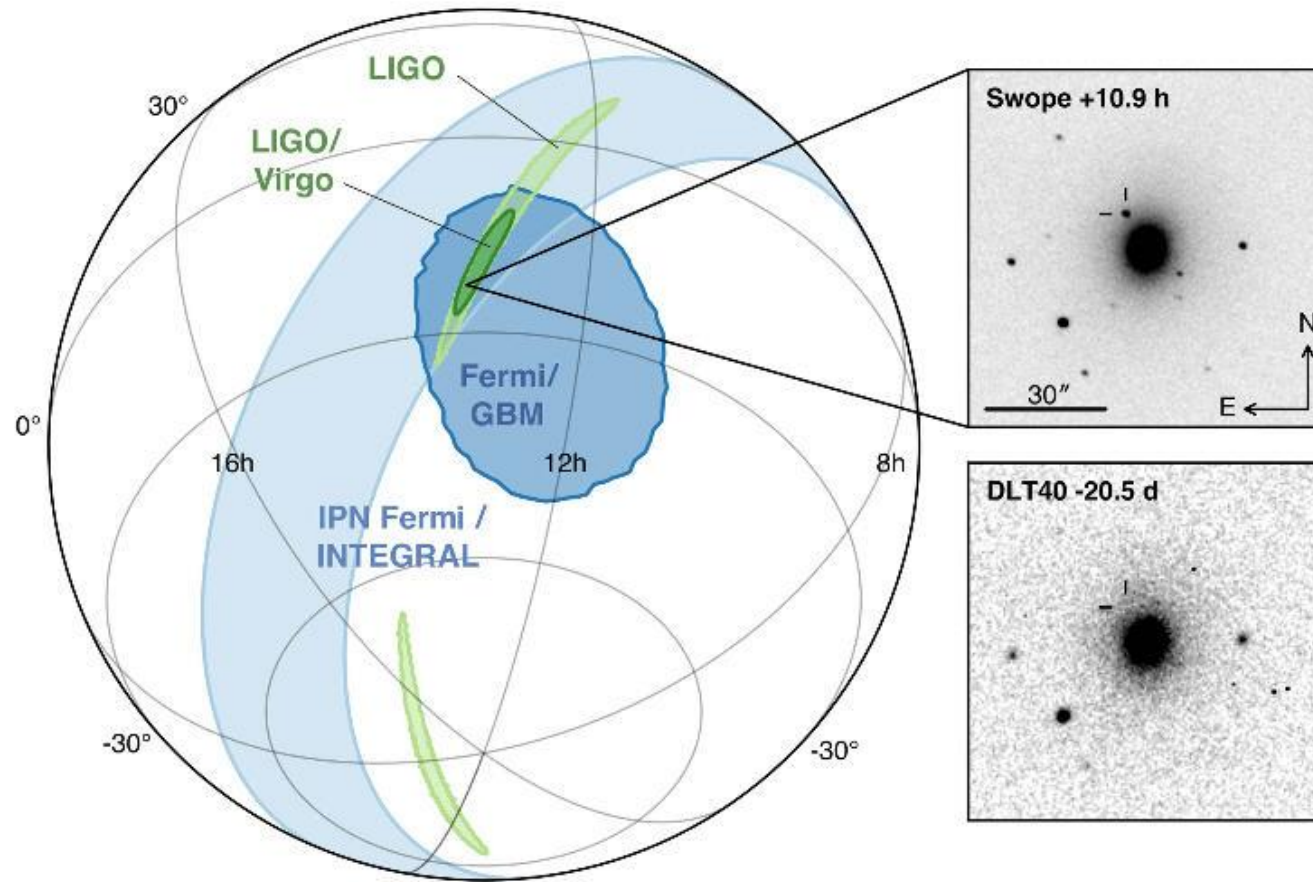
off-axis of  
cone solid  
angle of  $\Omega$



on-axis  
observer

# Localization of GW 170817/ GRB 170817A / AT2017gfo

## Not a huge but large!



Aug 17 23:33 UT  
(tc+10.87 hr) – Swope  
(Las Campanas, Чили)

Aug 17 23:50 UT – DLT40  
(Cerro Tololo, Чили)

Aug 17 23:55 UT – VISTA  
(ESO, Чили)

Aug 17 23:59 UT –  
MASTER-OAFA (SAAO,  
ЮАР)

Aug 18 00:15 UT – Las  
Cumbres Observatory  
(Cerro Tololo, Чили)

Aug 18 00:42 UT –  
DECam (Cerro Tololo, Чили)

# What is strange (I)?

- On-axis probability is  $\sim \Omega/2\pi \sim 1/400$
- All of BNS merger within several year will be visible off-axis
- Absence or suppressed an Afterglow
- Kilonova for which we do not know properties
- Not typical, off-axis “short” GRB (mimicking faint long duration GRB)

# What is strange (II)?

- look for a needle in a haystack, i.e. OT in a huge LIGO/Virgo error localization region
  - It looks like 20 years ago we were looking the OT in BATSE error box, or even worse
- W/o gamma-detection (and localization) we hardly can recognize promptly OT corresponding to the BNS (or NS-BH) merger



# What is strange (III)?

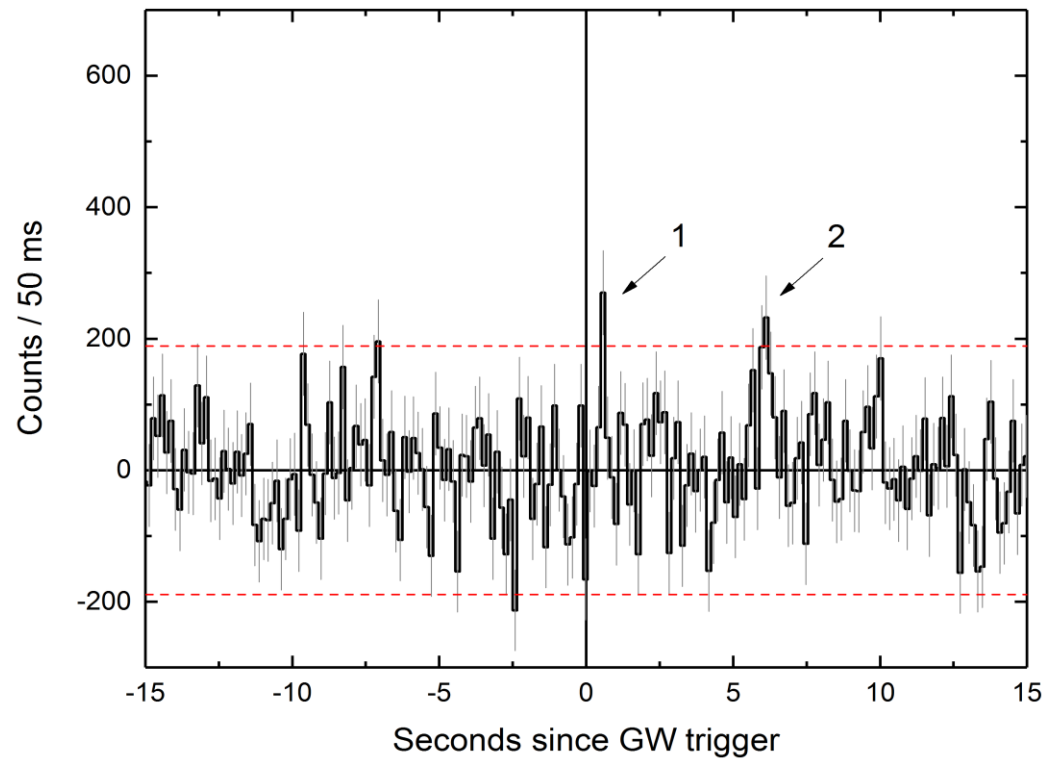
- The longer we observe GRBs, the closer sources of GRB we see

# Binary Neutron Star Merger (BNS)

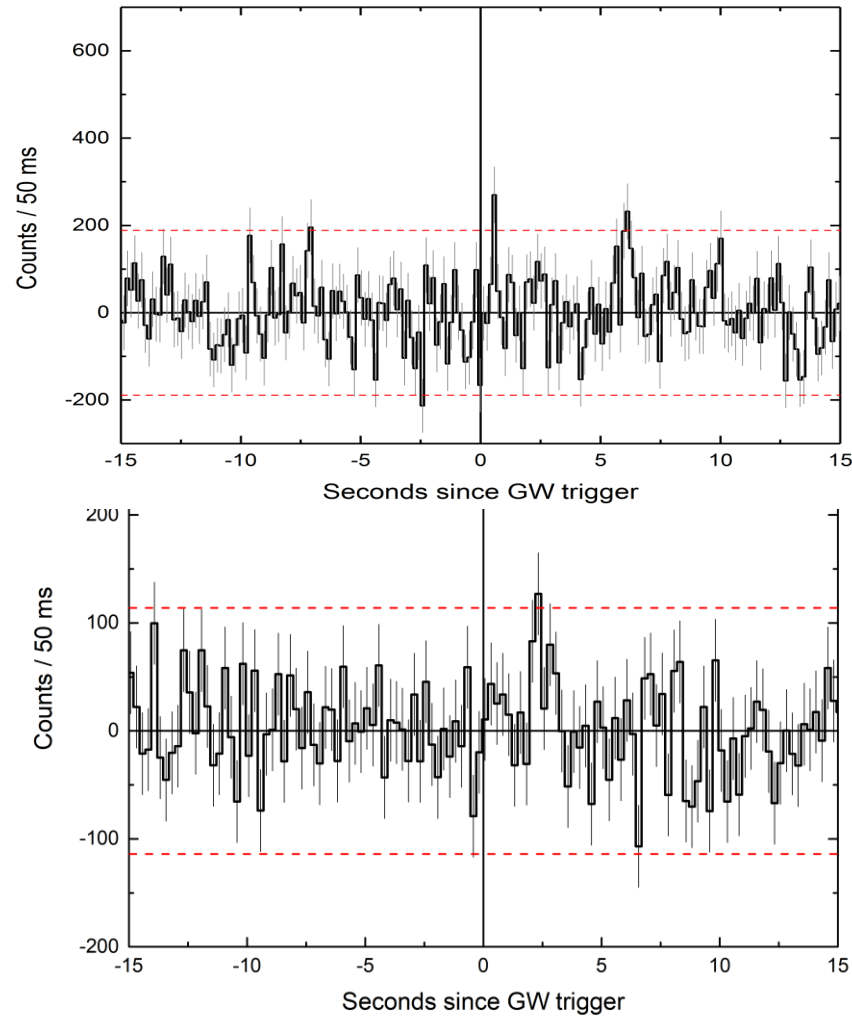
- BNS: 2 candidates in O3
- NS-BH: 2 candidate in O3

# LVC BNS: S190425z

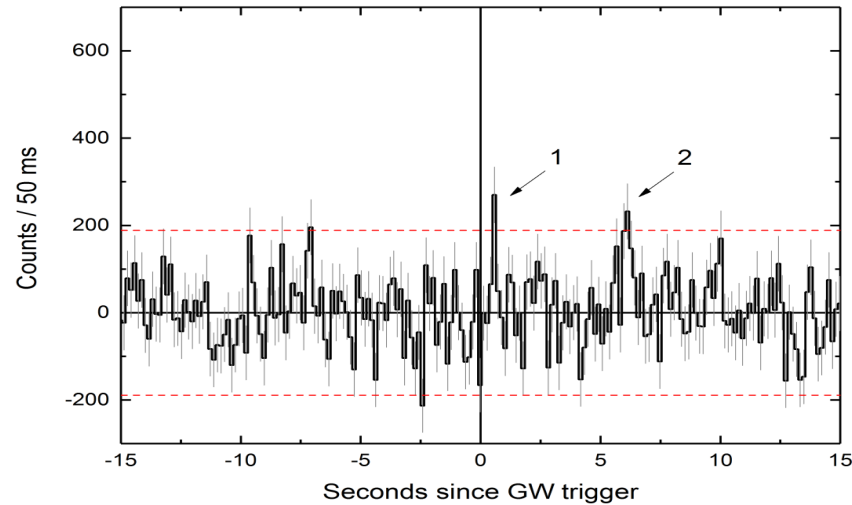
## SPI-ACS/INTEGRAL



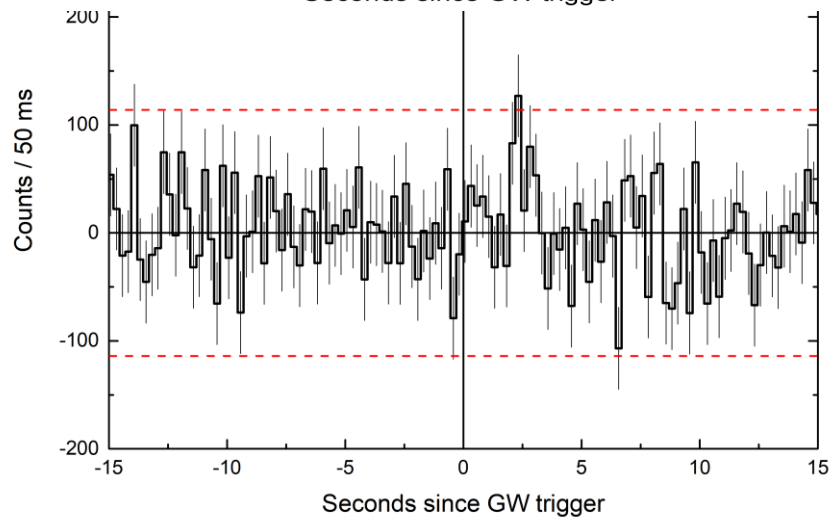
# SPI-ACS/INTEGRAL find two differences



# SPI-ACS/INTEGRAL find two differences



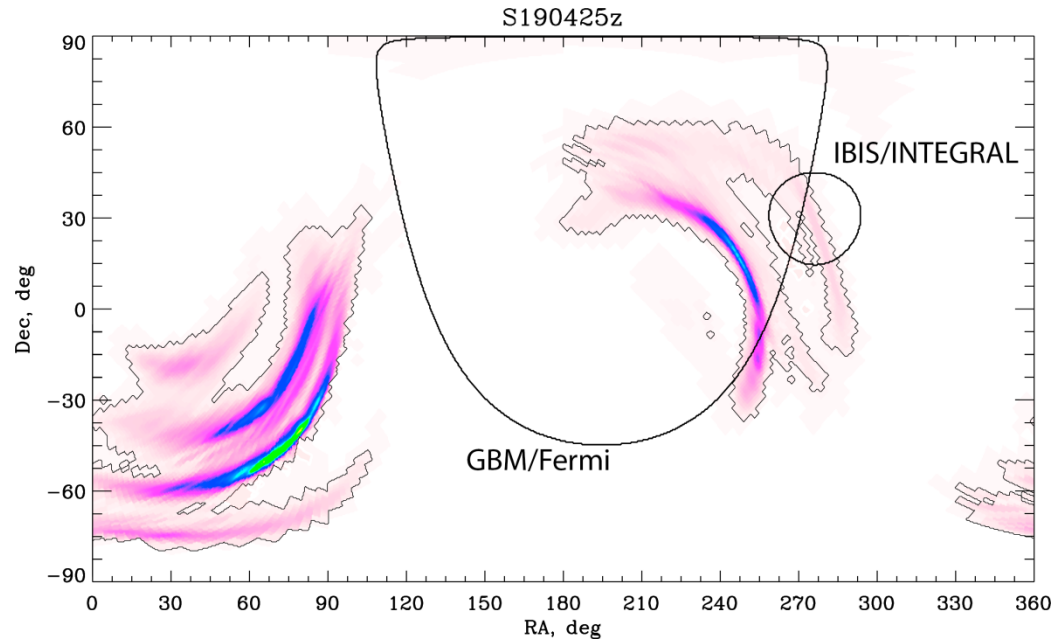
S190425z



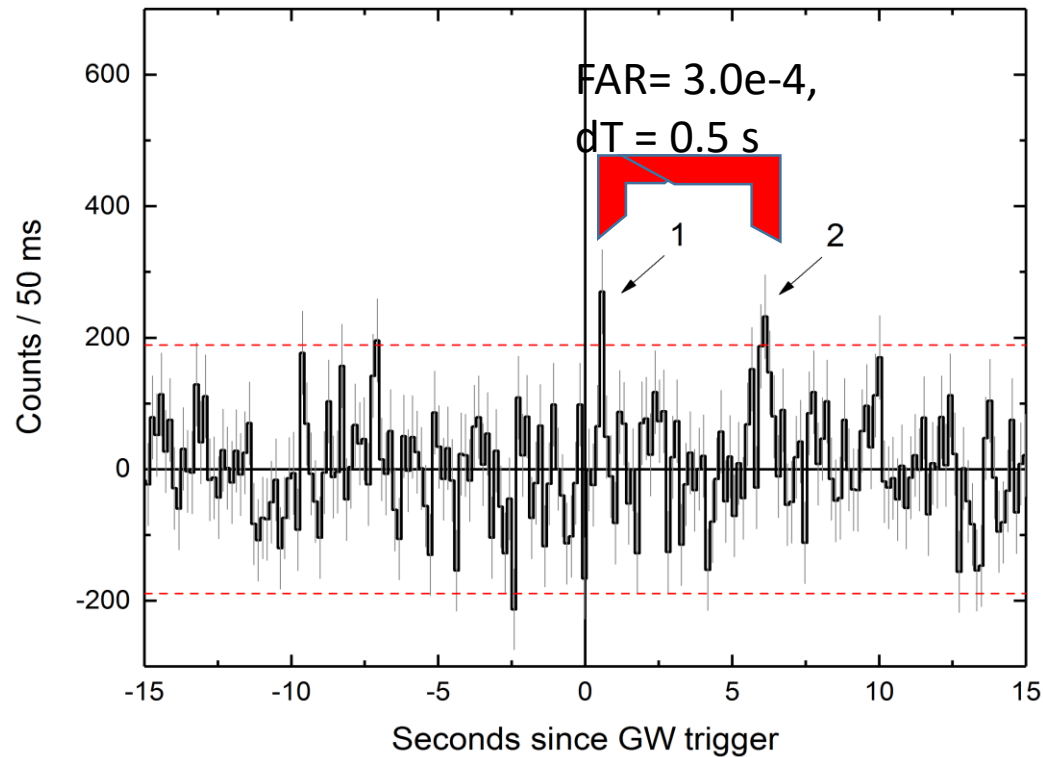
GRB 170817A

# LVC BNS: S190425z

LIGO/Virgo localization, GBM/Fermi Earth shadow



LVC BNS: S190425z  
SPI-ACS/INTEGRAL,  
FAR, chance probability =  $5e-4$



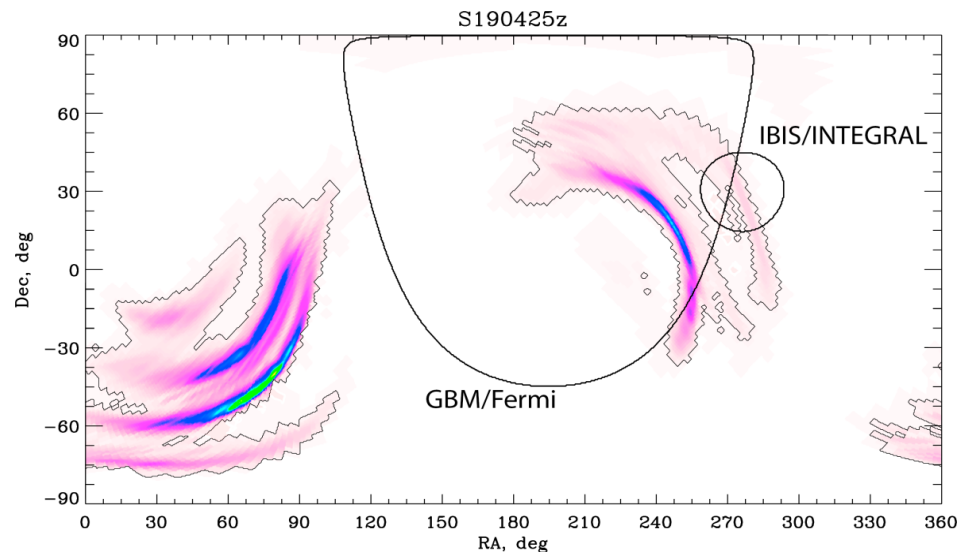
# Conclusions

- Most of BNS merger within next several year will be registered off-axis
- We believe that SPI-ACS detected prompt emission (GRB) at the level of 4sigma (chance probability of  $5e-4$ ) of LIGO/Virgo S190425z
- If confirmed it is 2<sup>nd</sup> EM counterpart detected from LIGO/Virgo BNS merger
- Assuming distance to the S190425z source (160 Mpc) the intensity ( $\sim E_{iso}$ ) of the GRB is  $6e47$  ergs
- No spectral information is available –(
- The GBM non detection is due to Earth occultation



# Conclusions (continued)

- One need to refine properties of northern OT candidades in looking optical counterpart of the S190425z





# GW history (short)

- Gravitational waves were first predicted by Einstein's [general theory of relativity](#) in 1916.
- Their existence was indirectly confirmed when observations of the binary pulsar [PSR 1913+16](#) in 1974 showed an orbital decay which matched Einstein's predictions of energy loss by gravitational radiation.
- The [Nobel Prize](#) in Physics 1993 was awarded to [Hulse](#) and [Taylor](#) for the discovery.

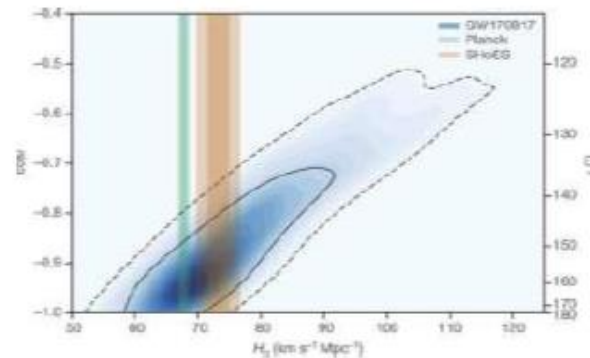
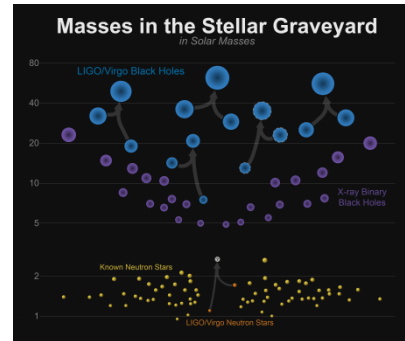
# More GW history (recent)

- The 2017 [Nobel Prize in Physics](#) was awarded to Rainer Weiss, Barry Barish and Kip Thorne "for decisive contributions to the LIGO detector and the observation of gravitational waves"

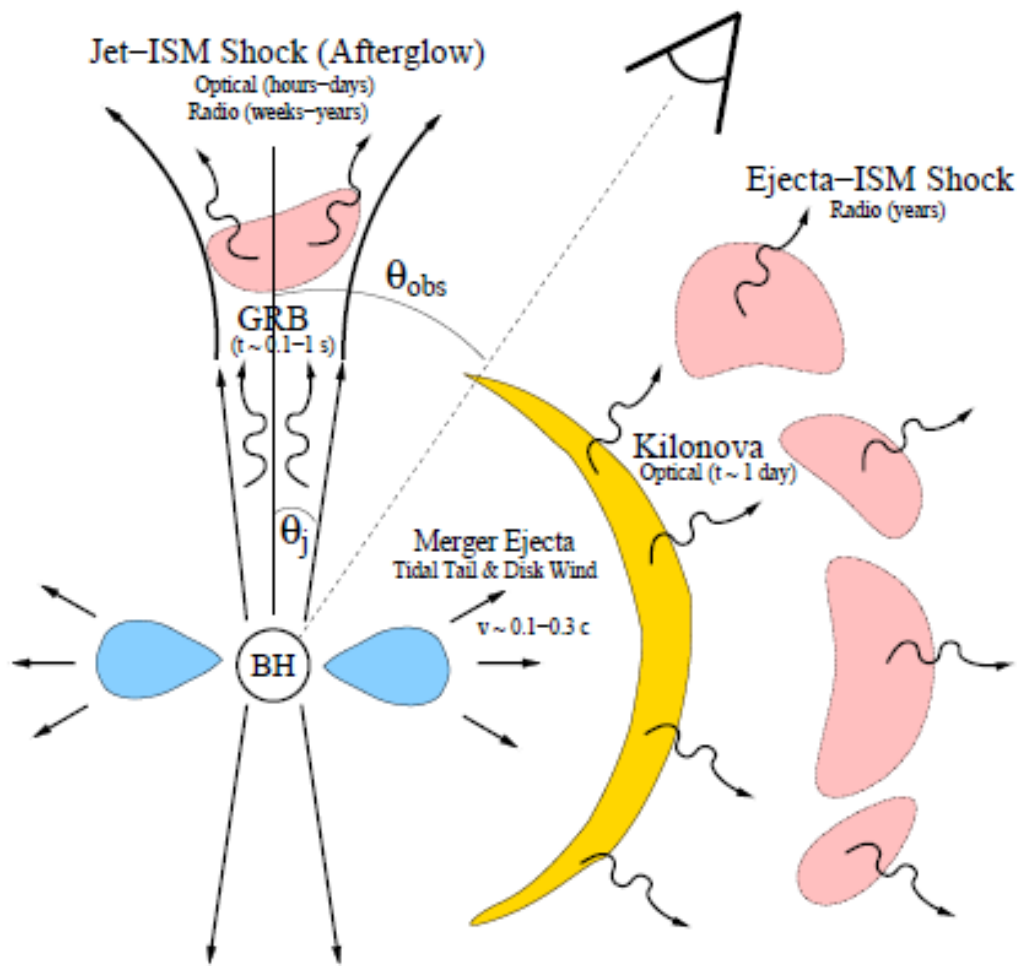
... за решающий вклад в создание детектора LIGO и наблюдение гравитационных волн...

# Compact binaries merging tests Universe and physics (some main results after a few LIGO/Virgo detections)

- No gap in mass of BHs
- Speed of GW (= c)
- Hubble constant
- Model of short GRB (suggested by Paczyński)



# GW Counterparts in ElectroMagnetic range



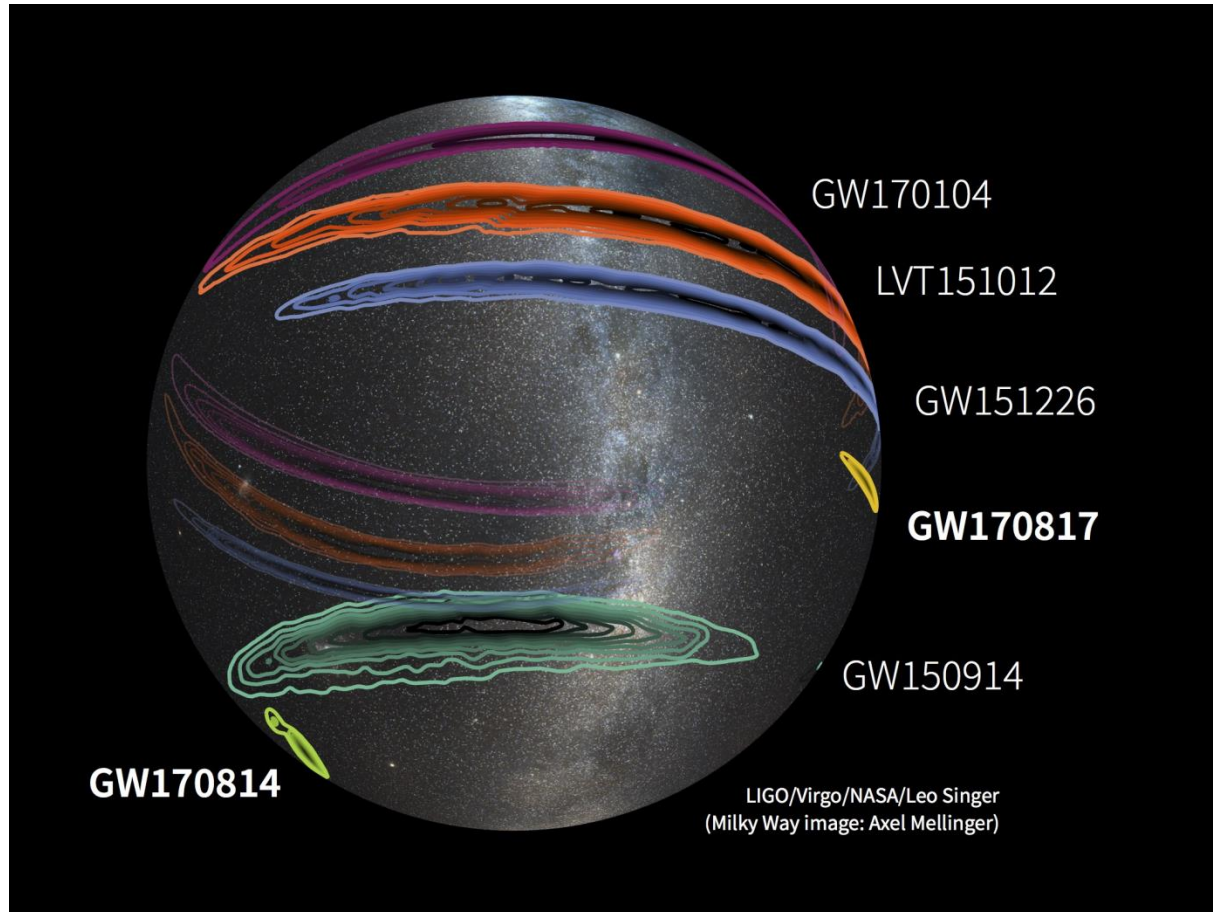
*Гамма-всплеск*

*Послесвечение гамма-всплеска*

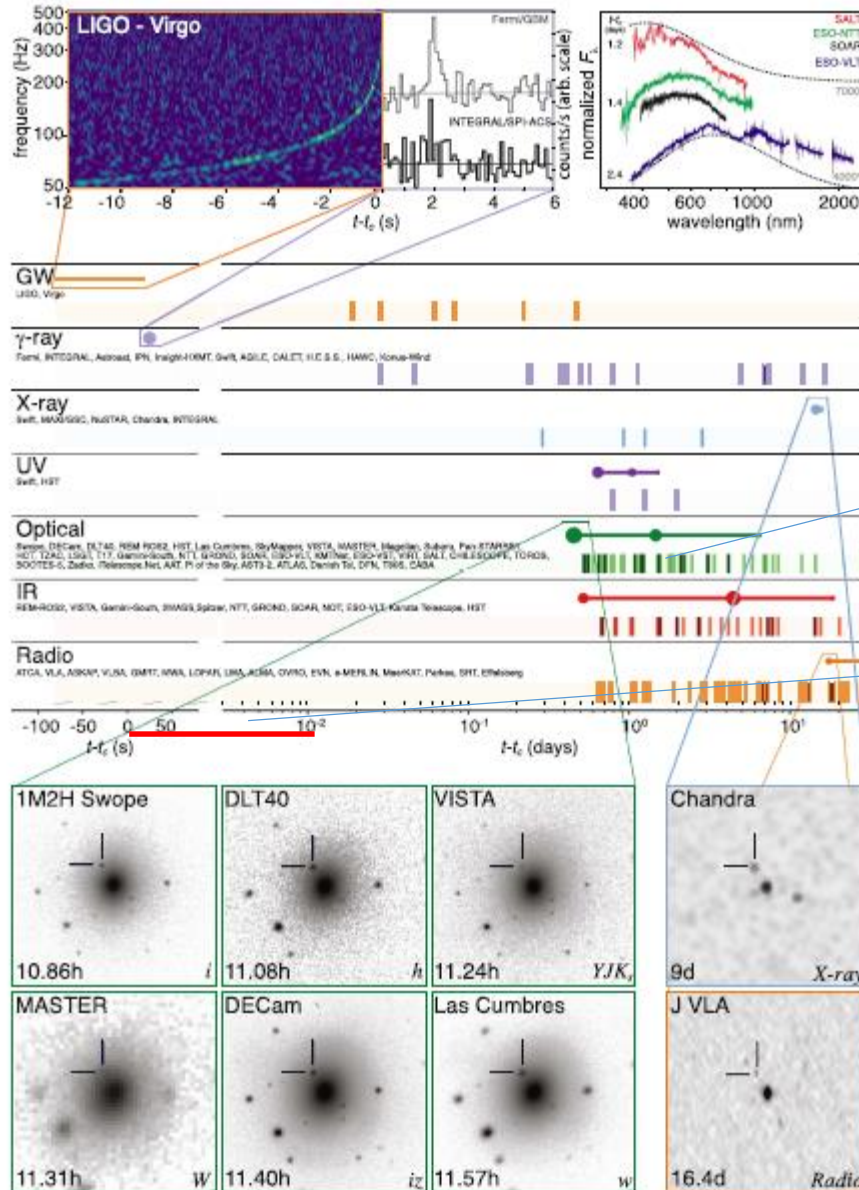
*Килоновая –аналог SN*

# Merging Binary Systems

## LIGO/Virgo events maps



GW170817 and GRB 170817A

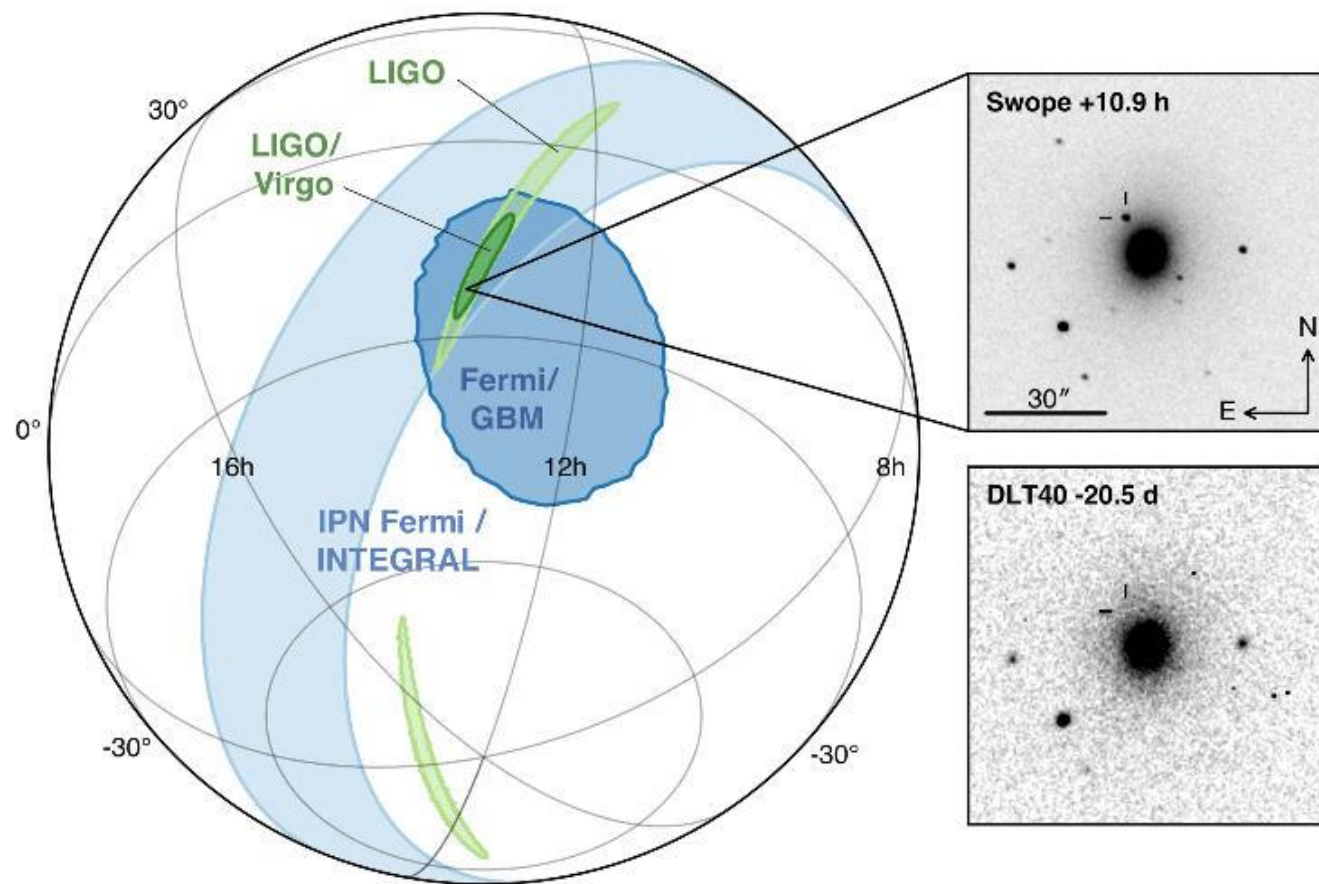


RC-1000 (IKI)

BSA/110MHz (Pushino)



# Локализация источника GW170817 на небесной сфере



Aug 17 23:33 UT  
(tc+10.87 hr) – Swope  
(Las Campanas, Чили)

Aug 17 23:50 UT – DLT40  
(Cerro Tololo, Чили)

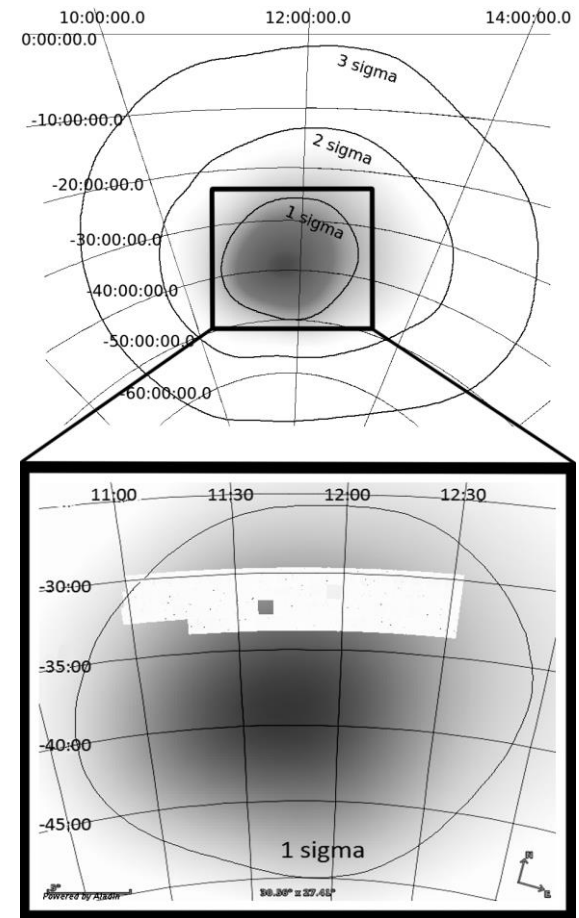
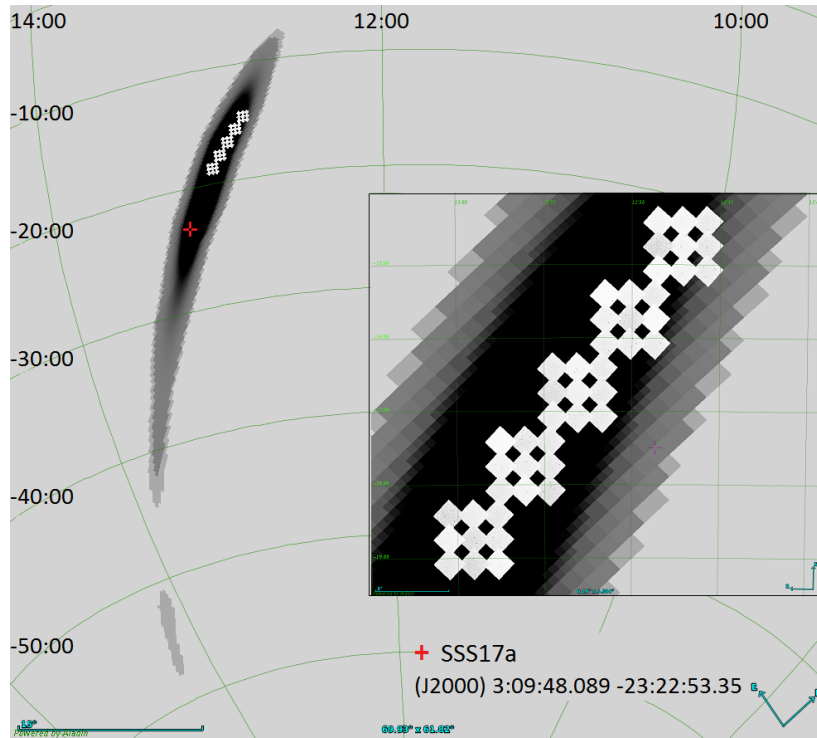
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DECam (Cerro Tololo, Чили)

# First day GRB170817A search for OT



CHILESCOPE, RC-1000 (left), RC-500 (right)

# Conclusions after O2 (I)

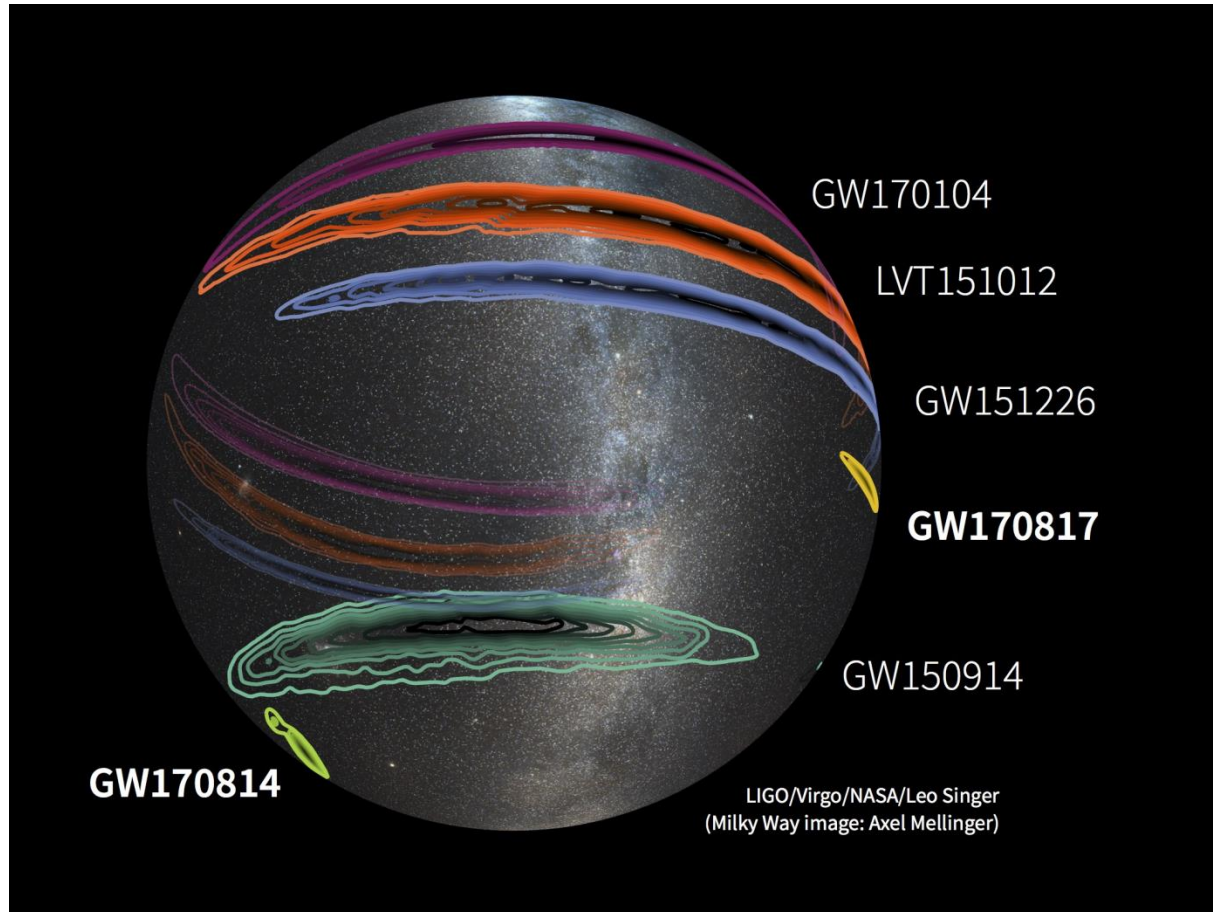
- BH/BH merger: no EM emission is expected/detected
- NS/NS merger: only one observed within 9 months
- Most probably we would observe off-axis GRB from LIGO/Virgo
  - *Underluminous GRB*
  - Cocoon or jet break out with ISOTROPIC emission
  - “Strange” Gamma-ray Burst

# Conclusions after O2 (II)

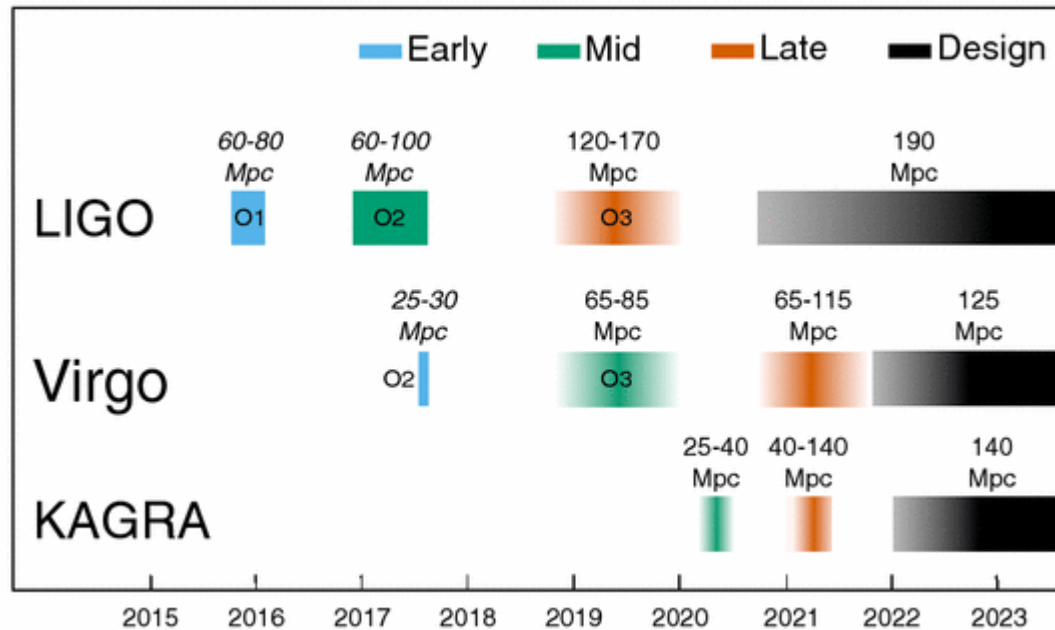
- Evident lessons
  - Worldwide distributions of alert/maps (will be free in O3 run)
  - Widely distributed networked telescope (...)
  - Two different tactic searching for OT (wide FOV vs. narrow FOV = use both!)
  - Searching EM counterpart even for BH/BH events
- Less evident lessons
  - Instruments for optical search in (catalogs of galaxies with distance less than  $D$ , masks of known galaxies?, coronagraph?)
  - Afterglow vs. Kilonova (search for OT in days since trigger)
  - Different temporal filters for gamma-ray data (wavelet)

# Merging Binary Systems

## LIGO/Virgo events maps



# Time schedule of LIGO/Virgo/KAGRO



# Expected number of LIGO sources in 03

source category	full year $\dot{V}T$	$N_d$
BBH / bbh_astrophysical_aligned	$6.8 \times 10^8 \text{ Mpc}^3 \text{ yr}$	$35_{-26}^{+78}$
BNS / bns_mw_like	$3.2 \times 10^6 \text{ Mpc}^3 \text{ yr}$	$4_{-4}^{+9}$
BNS / bns_broad	$7.3 \times 10^6 \text{ Mpc}^3 \text{ yr}$	$9_{-7}^{+19}$
NSBH / nsbh_broad_aligned	$4.9 \times 10^7 \text{ Mpc}^3 \text{ yr}$	$1_{-1}^{+24}$
NSBH / nsbh_broad_isotropic	$5.7 \times 10^7 \text{ Mpc}^3 \text{ yr}$	$1_{-1}^{+28}$

**BBH** rate will **dominate**, possibly by more than an order of magnitude, up to **~few/wk.**, at **least ~few/mo.**

**1-10 BNS**, possibly up to **~1/mo.**

$\dot{V}T$  has **strong mass dependence** but **very mild dependence** on assumed spin distribution

**NSBH:  $N=0$  not ruled out** in any scenario, most give **~50%  $N>0$**

# Expected number of LIGO sources in O3

source category

full year  $\mathcal{VT}$

$N_d$

**BBH** rate will **dominate**, possibly by more than an order of magnitude, up to **~few/wk.**  
**least ~few/mo.**

**1-10 BNS**, possibly up to **~1/mo.**

$\mathcal{VT}$  has **strong mass dependence** but **very mild dependence** on assumed spin distrib

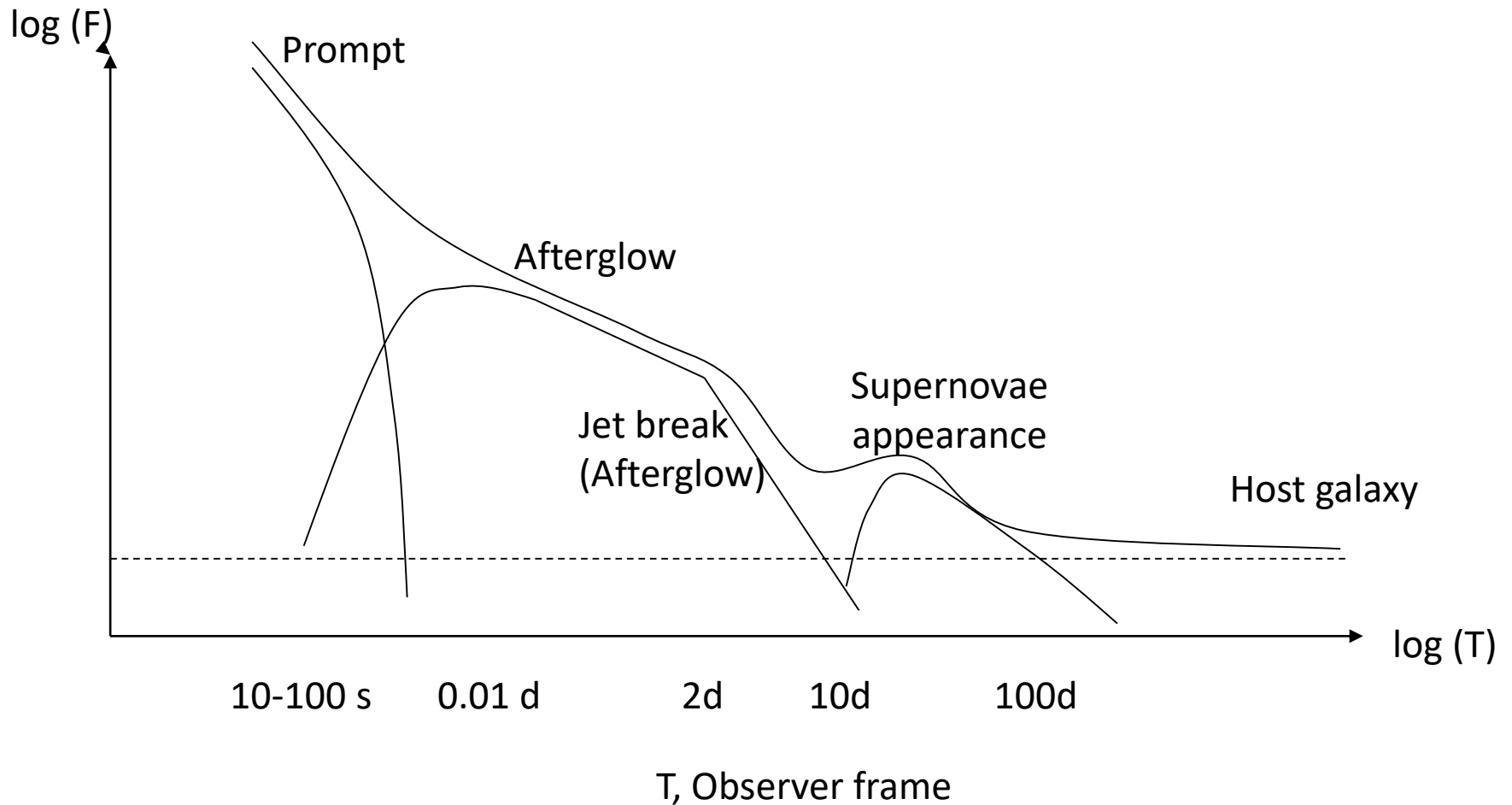
**NSBH: N=0 not ruled out** in any scenario, most give **~50% N>0**

We expect 1–50 **BNS** events over the course of O3. For BNS events, the median localization accuracy of in terms of the 90% credible area will be **120–180 deg<sup>2</sup>**. 12–21% of BNS mergers will be localized to **less than 20 deg<sup>2</sup>**.

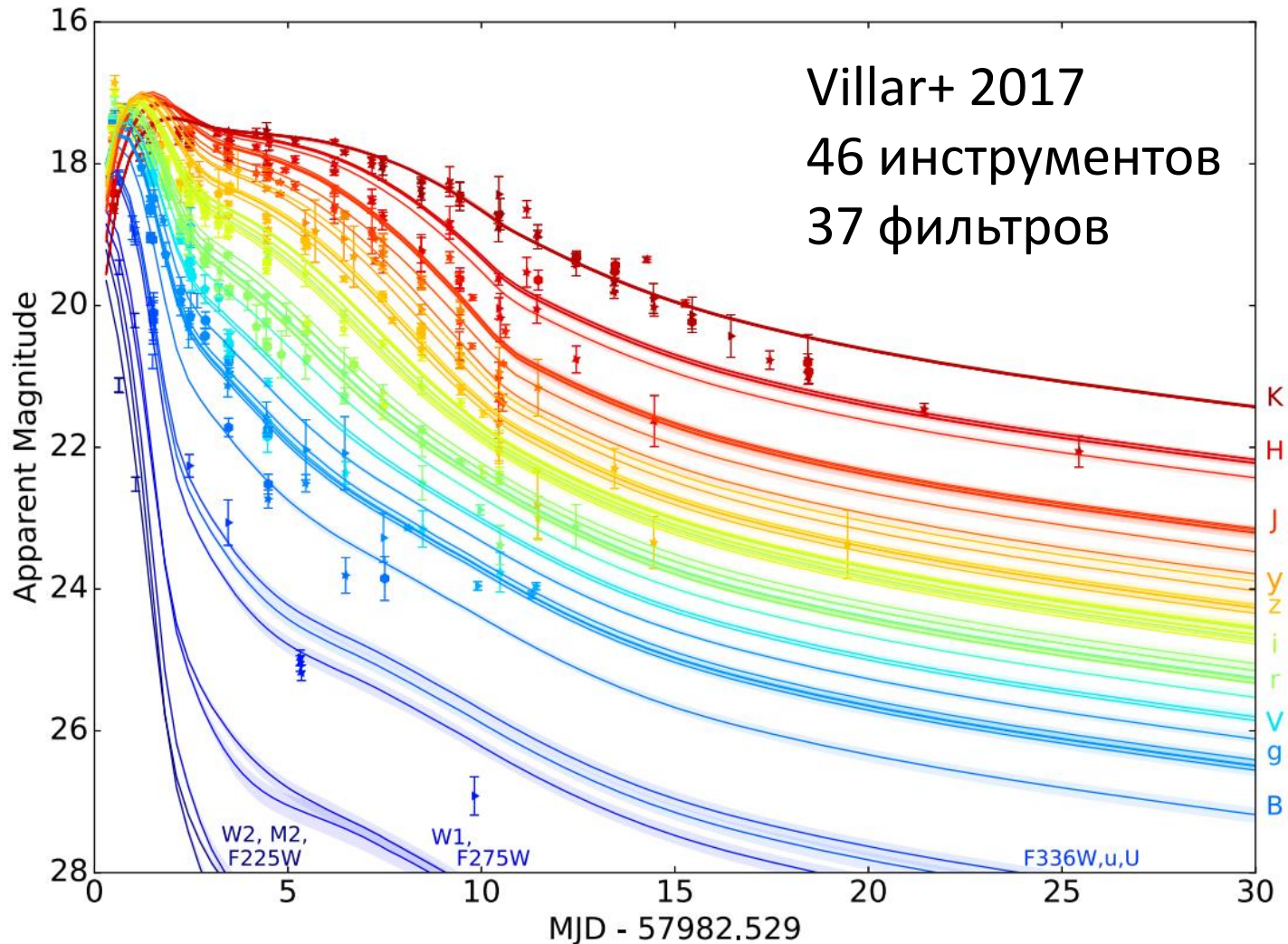


What we should to look for?

# Long (classical) GRB: typical afterglow curve in optic



# Optical counterpart of GW170817 kilonova AT 2017gfo



Tactics for 03 LIGO/Virgo run?

# Tactics for 03 LIGO/Virgo run?

- Mosaic of an LIGO/Virgo localization area
- Follow up of found (by other team) Optical Transient candidates
- Looking only for galaxies with distance less than reported by LIGO/Virgo collaboration

# Importance of software pipeline development for (near-) real time operations

- Data receiving via socket (internet)
- Automatic score based target planning
- Initial data quality reduction
- Calibration
- Frames combining (rendering)
- Astrometry
- Secondary standards for photometry
- Building of Catalog based on rendered frames (coordinates, photometry, quality)
- Transient extraction
  - Cross matching with known catalogs
  - Cross matching with own catalogs of the field
  - Comparison of brightness obtained for different epochs
- Human control of obtained transient candidates
- Alerting scientific community about validated optical transient candidates

# GW 170817 / GRB 170817A

