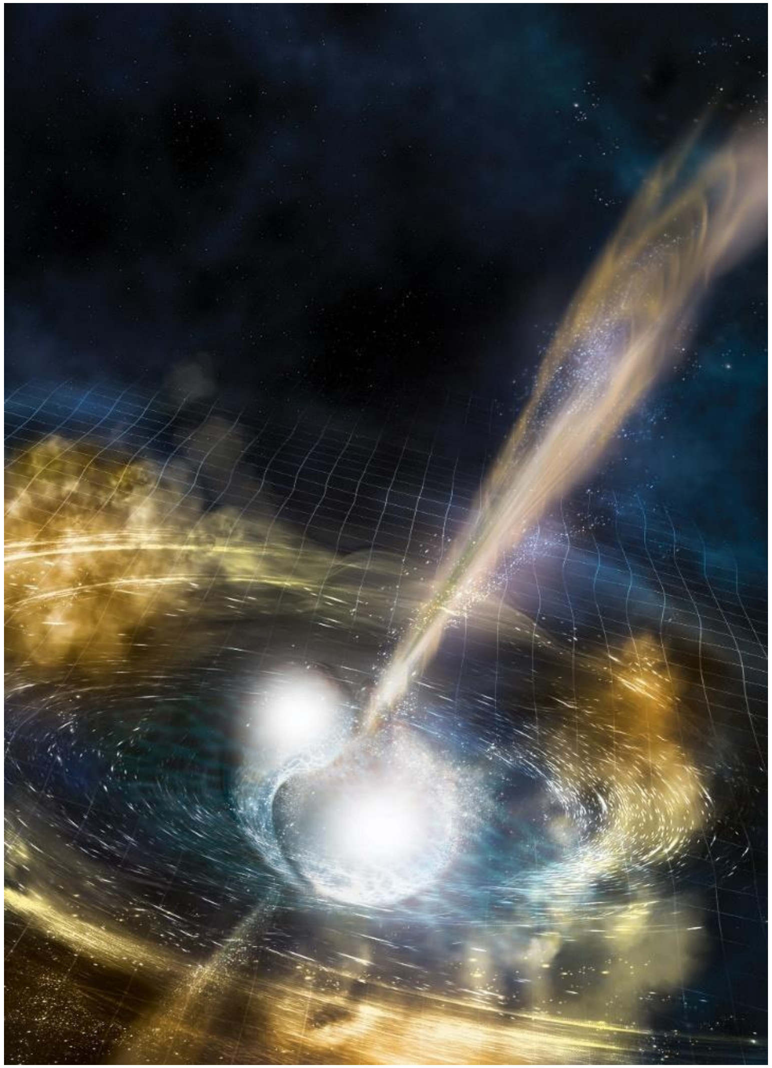
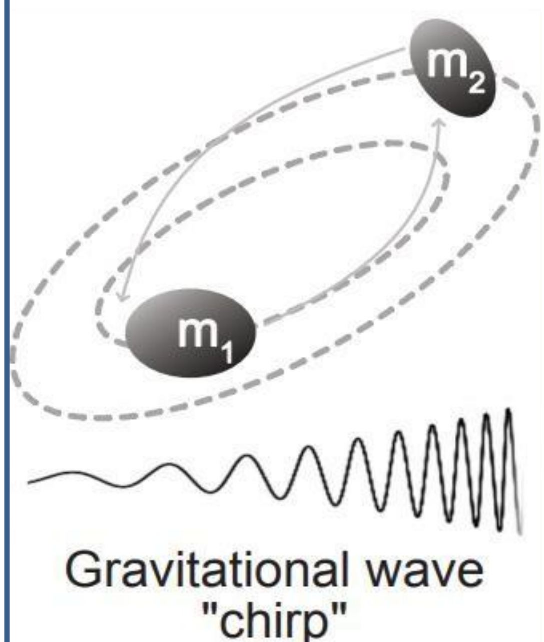


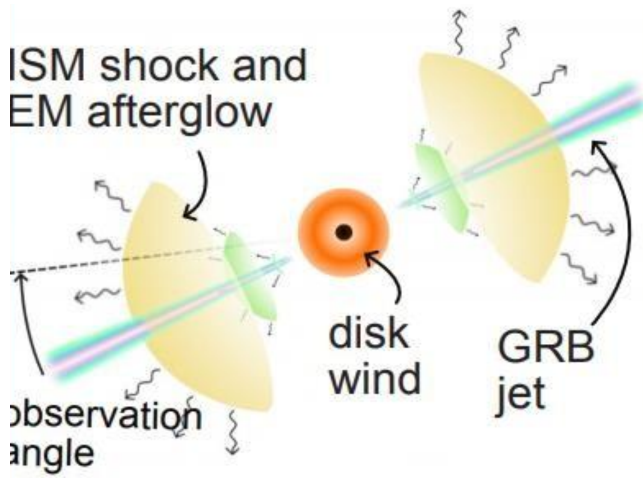
Enabling multi-messenger cosmology with the LIGO-Virgo alert system

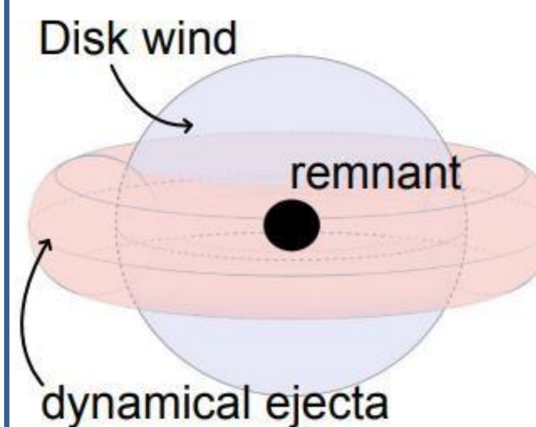
S. Antier (CNRS/APC - CNES)
antier@apc.in2p3.fr

Coupling the **messengers** of compact objects coalescences

Merger Event → Gamma Ray Burst → Kilonovae



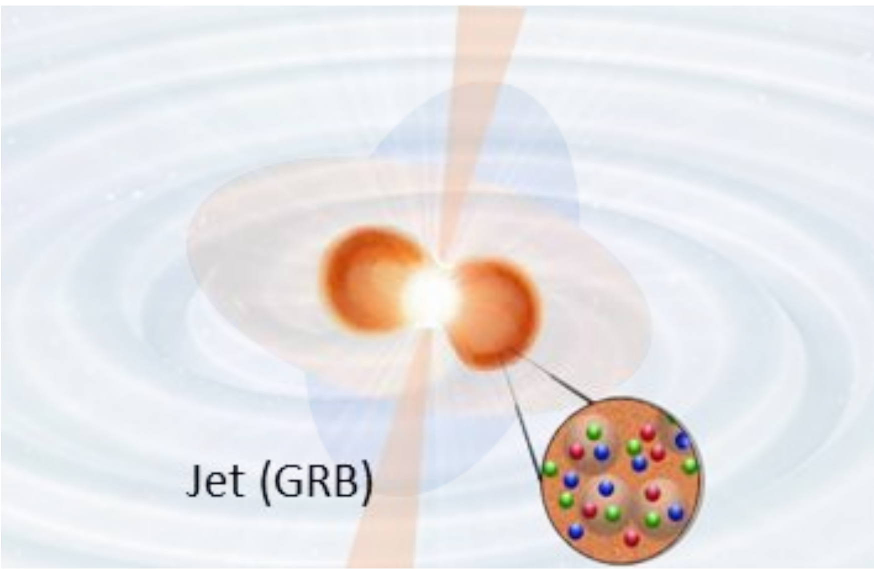




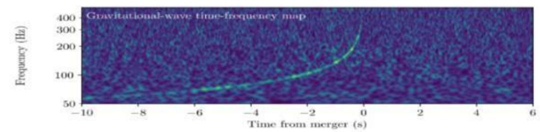
GW170817 – The only example

Matter behavior in extreme conditions ?

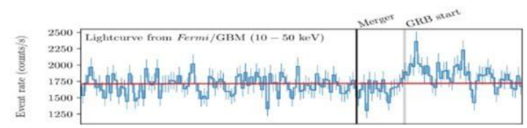
Uncertainties in the Equation of State of Utra-dense matter



GW170817

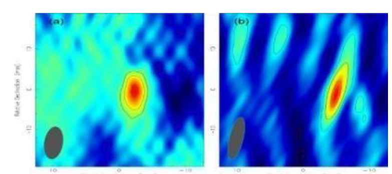


Gravitational waves



Gamma-ray Burst

Kilonova



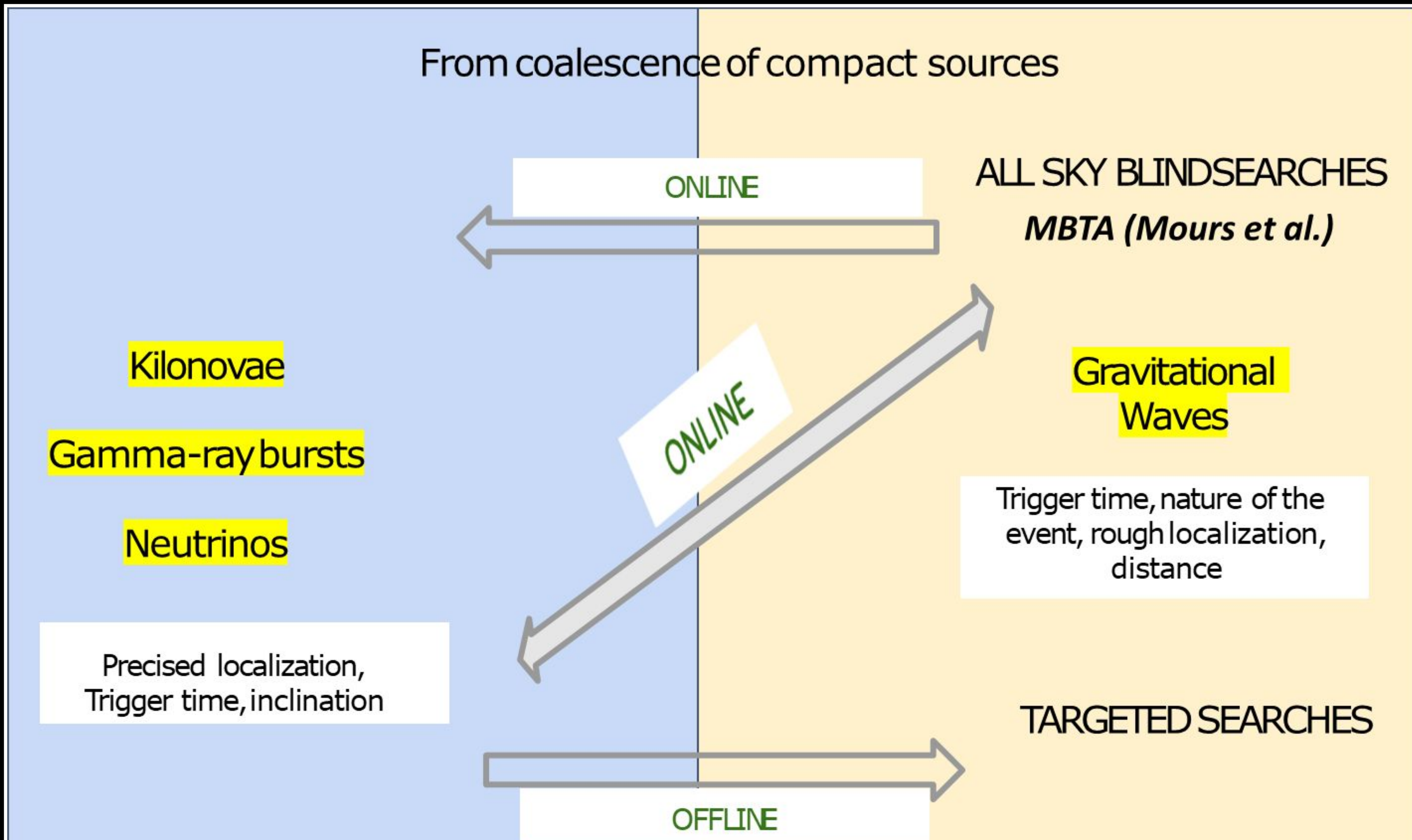
Afterglow

How are produced ejected matter in compact collision ?

Uncertainty of the central object

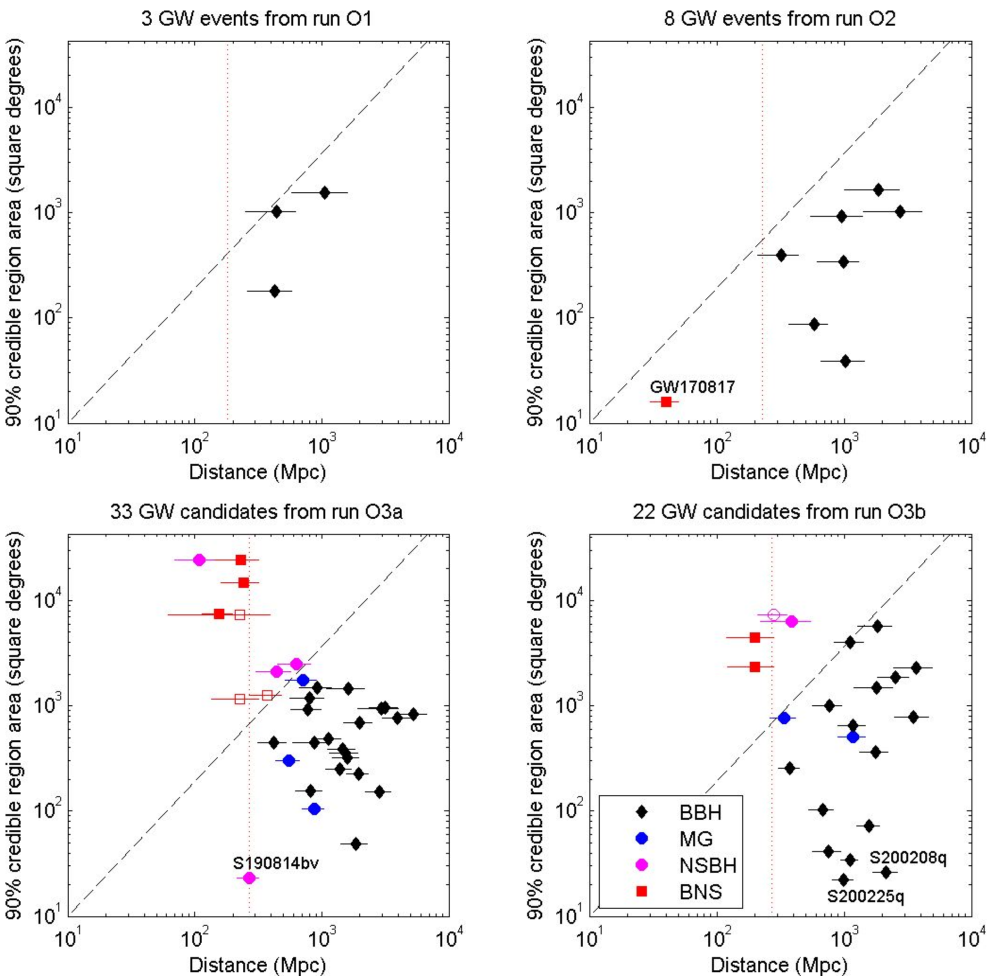
Mechanisms for the jet emission

LIGO-Virgo Alert System



Enabling multi-messenger discoveries with

Alert statistics O1, O2 and O3



Antier et al., GRANDMA O3, 2020

Fom april 2019 to march 2020
~ 330 days

80 +1 alerts with 56+1 “still alive”
24 retractations (30 % retracted)

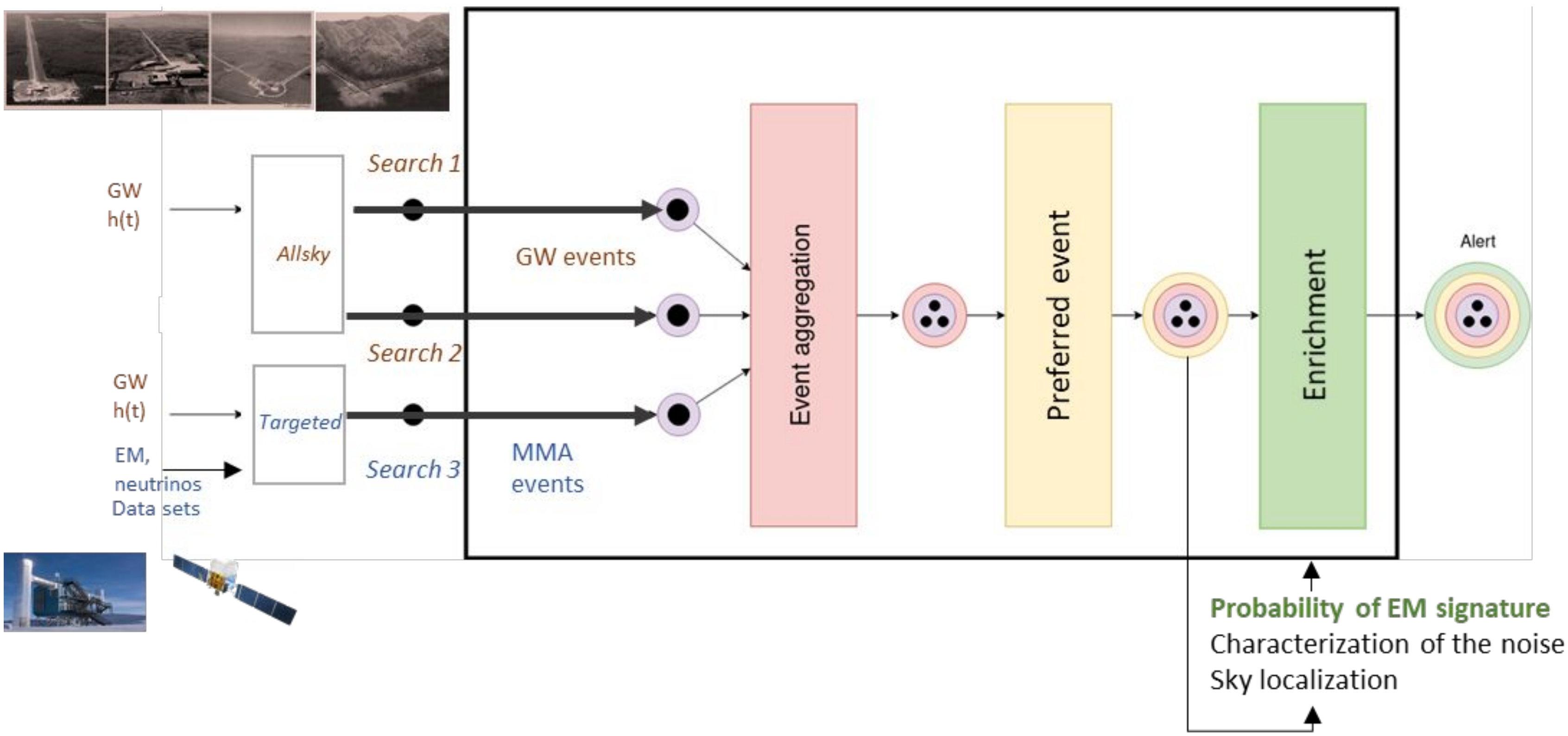
A traffic of alerts 4 times bigger than O2

41 alerts with updated sky localization areas
(73% of the total of the alerts)

52 of the alerts with P (Terres) < 50 %

8 BNS candidates
6 NS-BH candidates
5 Mass-Gap candidates
36 BBH candidates
1 burst candidate
1 LIGO/Virgo - GBM-190816

Toward O4 - The LIGO-Virgo alert system



O4 ~ 1 alert per day

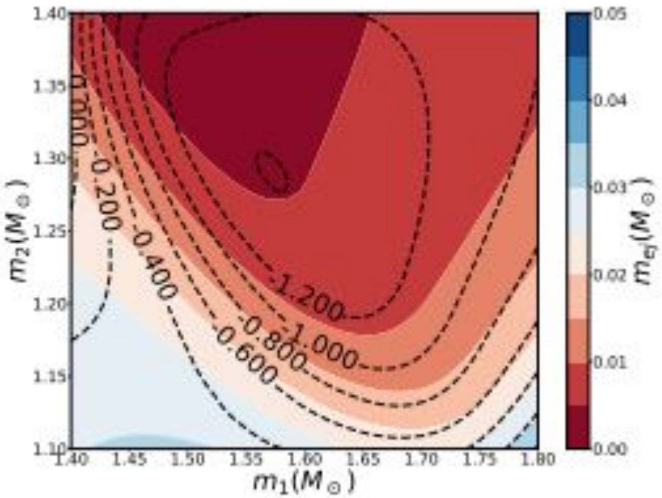
Work in progress in the alert system

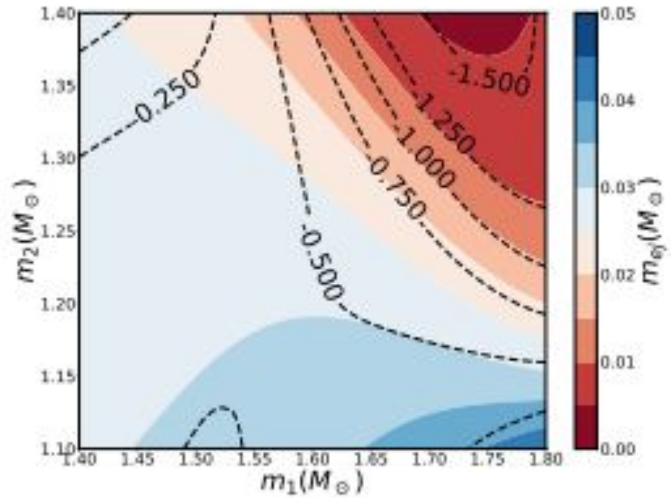
I am the key contact for Virgo-CNRS node

- *Integrate the* KAGRA *detector*
- *Reduce the latency of the alert (< 5 min)*
- *Provide early-warning alert before the merger time*
- *Integrate new observatories* (Km3NET, SVOM)
- *Reduce the flow of false positive alerts (purity ~ 90 %)*
- *Provide updates with full paramters estimation within a day*
- *Provide from an update to another, how informations has changed*
- *Work on visibility and clearness*

Predicted mass ejecta and HasEjecta on alerts
Stachie et al.

EOS1





EOS2

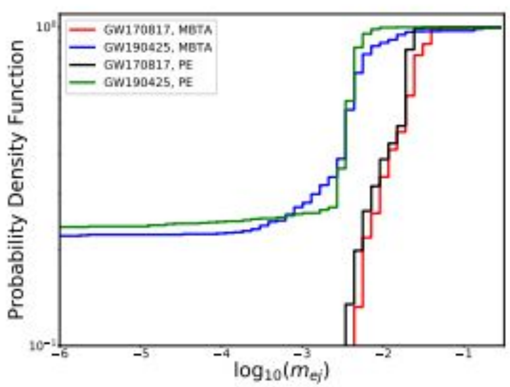
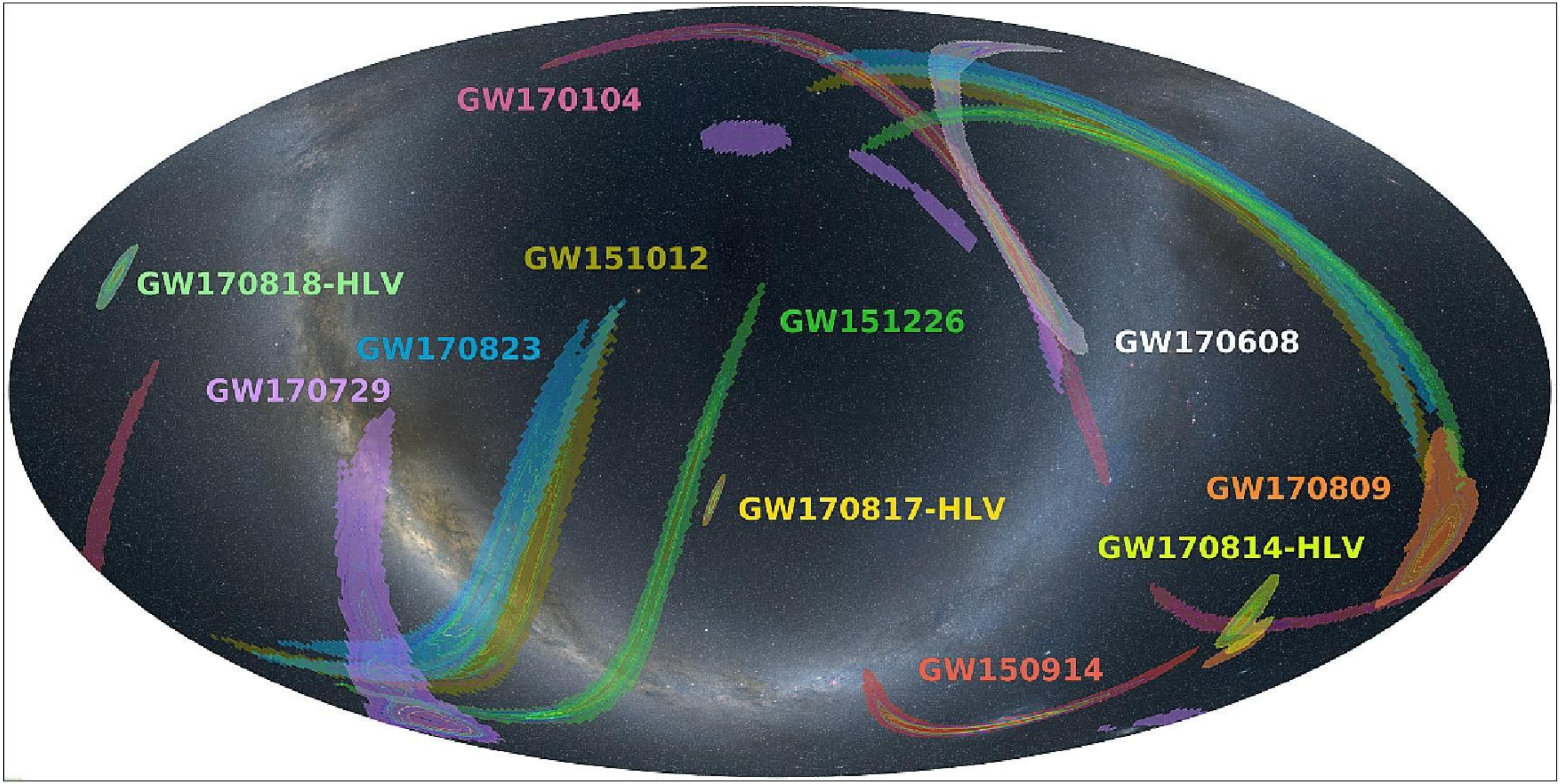


Figure 7. Cumulative distribution function of the ejected mass m_{ej} for the following GW triggers: GW170817, GW190425. There are both the low-latency results (the input data is represented by the MBTA weighted templates) and the PE results (the input data is represented by the offline PE (Veitch et al. 2015) posteriors).

Event	HasRemnant	MBTA HasEjecta	PE HasEjecta
GW170817	100%	100%	100%
GW190425	> 99%	80%	77%
GW190814	< 1%	0%	0%

Localizations



P-A Duverne, Singer et al.
https://git.ligo.org/lscsoft/lalsuite-archive/blob/5fc7b8eede53e3aee325dd16f0916e5d77636510/lalinference/python/lalinference/bayestar/sky_map.py

Once the alert is received

Lots of observations are running

Everyone is looking at the same region of the search
area to find the counterpart of GW events

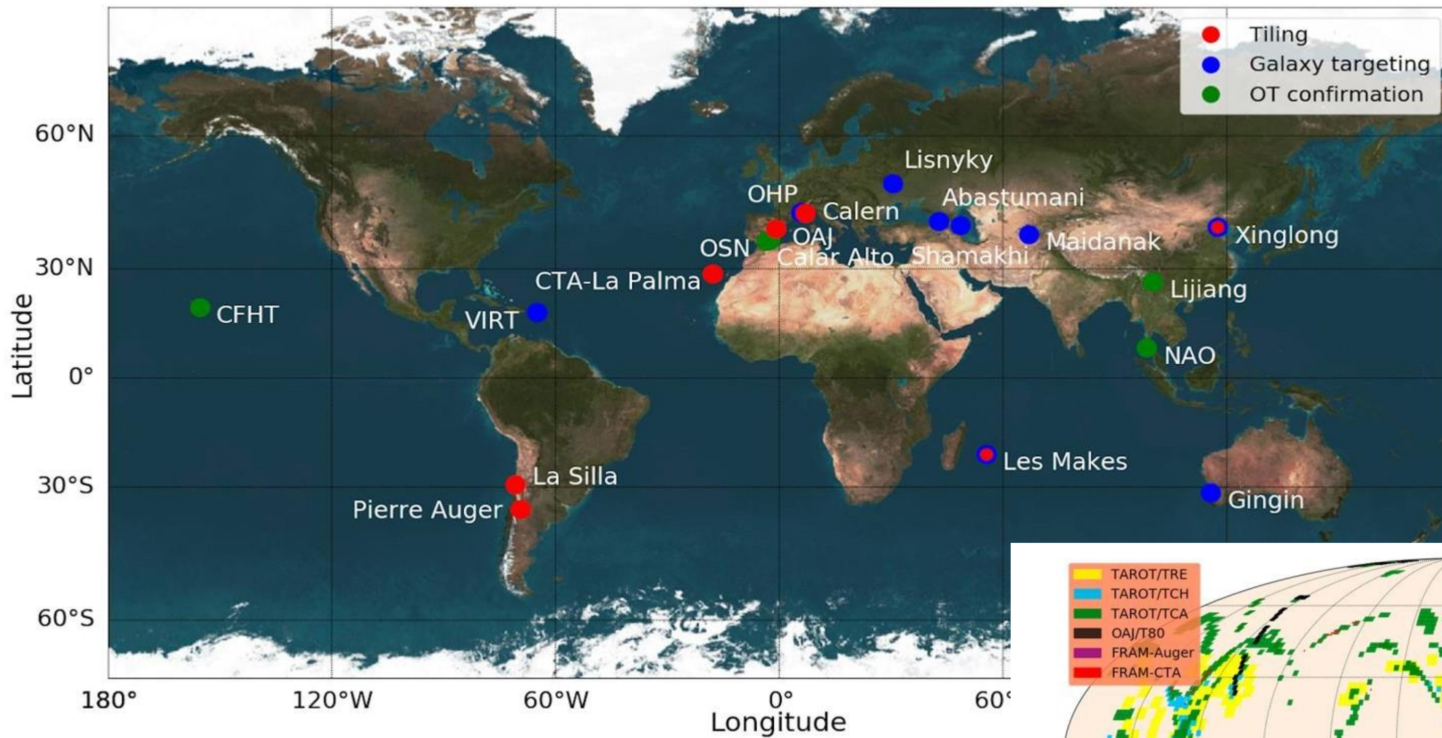
Our proposition - Coordination

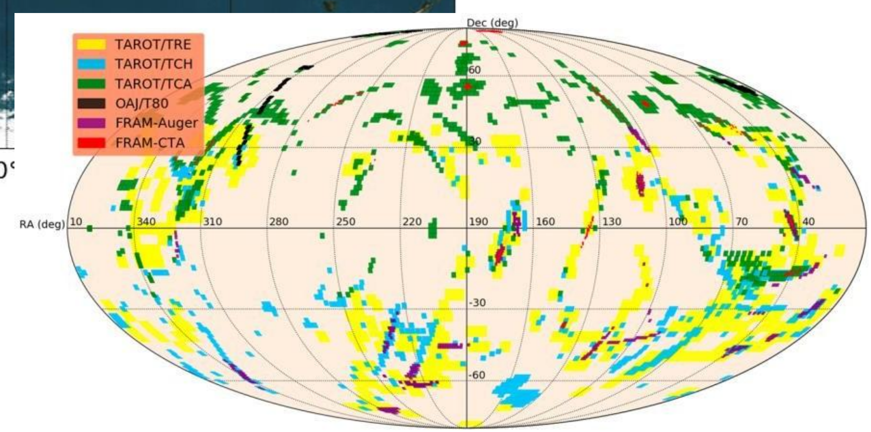
When the sun never rises

PI-Sarah Antier

20 observatories - ToO time guaranteed

CNRS/- APC - IAP - LAL - OCA - IRAP – LAM - IPHC



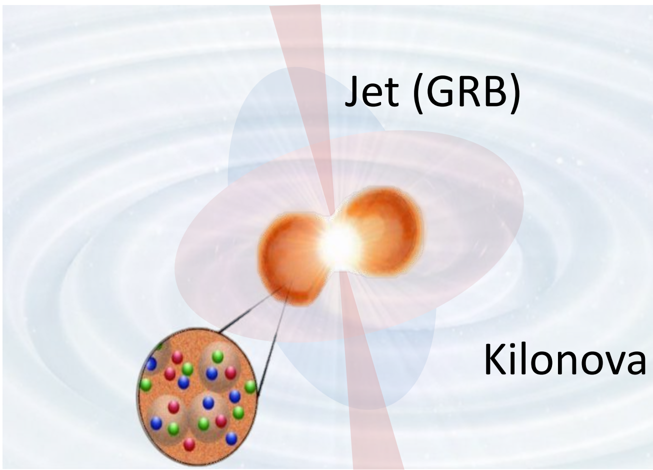


O3b and global summary of O3: **GRANDMA Observations of Advanced LIGO's and Advanced Virgo's Third Observational Campaign** O3a and presentation of the collaboration: **The first six months of the Advanced LIGO's and Advanced Virgo's third observing run with GRANDMA**, 2020, MNRAS, 492, 3904

Once EM counterpart is found

Multi-physics

Multi-physics framework



GW / EM facilities

Chemical evolution
R-process

Global astrophysical modeling

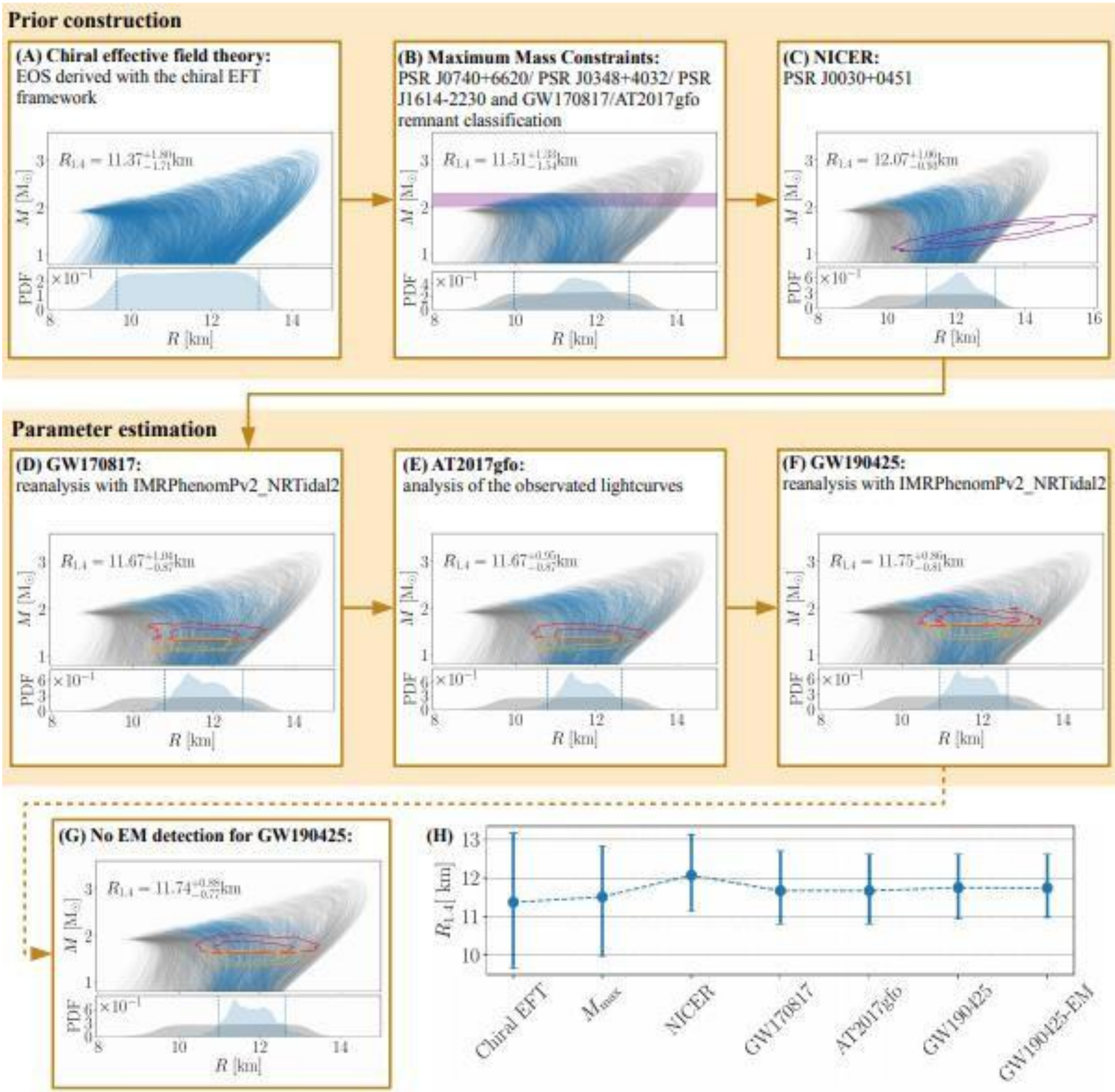
GW modeling

Neutron stars mergers

Nuclear Physics
Theory of dense matter

Cosmology

The multi-messenger framework

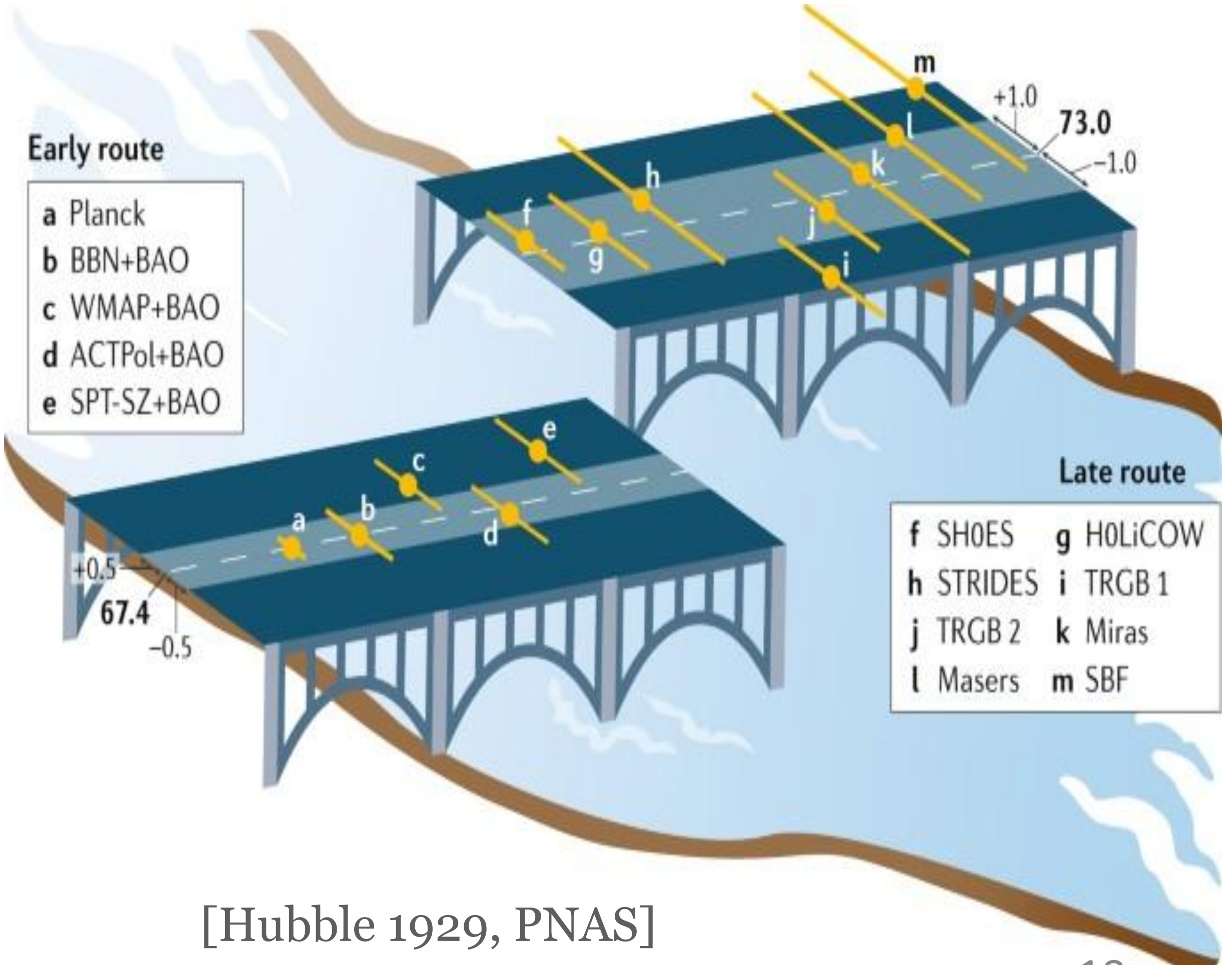


Dietrich T et al., New Constraints on the Supranuclear Equation of State and the Hubble Constant from Nuclear Physics – MMA

The Ultimate - Cosmology

The local expansion rate of the Universe

$$H_0 = \frac{\text{Velocity}}{\text{Distance}}$$



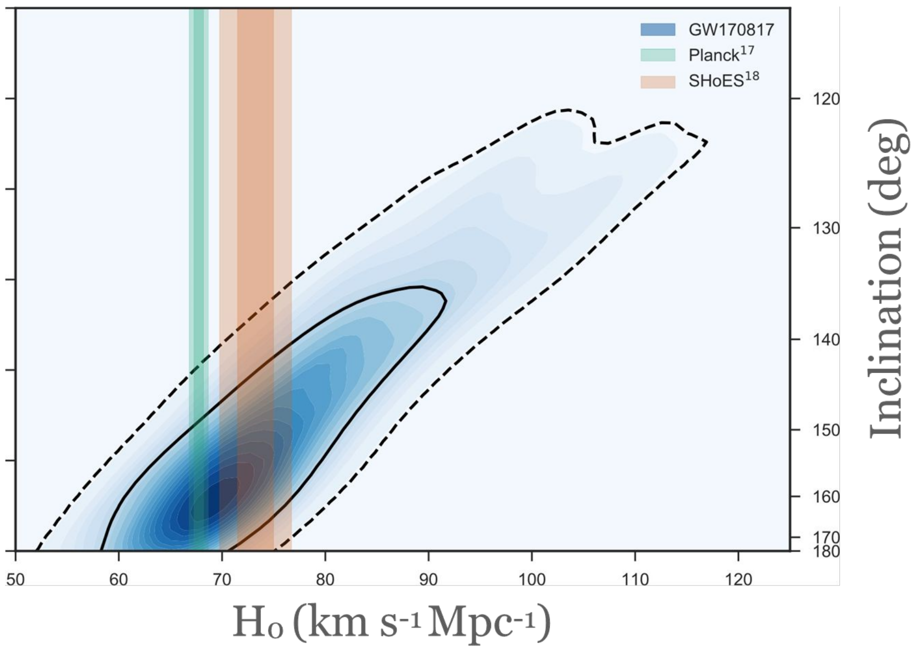
The Hubble tension

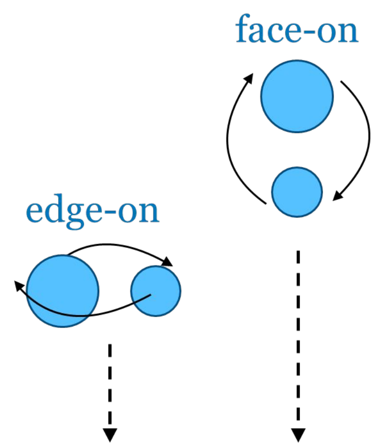
[Hubble 1929, PNAS]

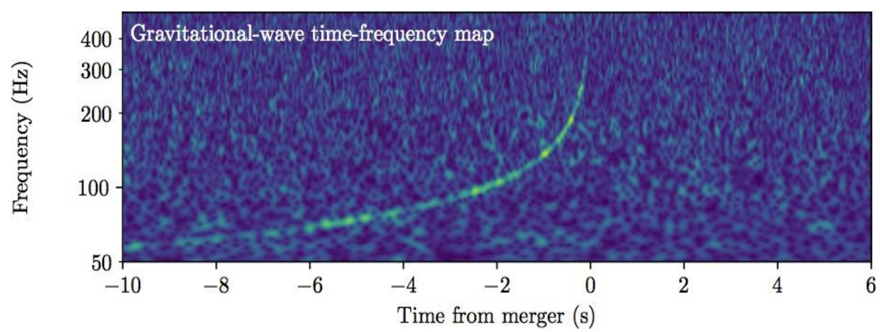
Gravitational Waves as Standard Sirens

[Schutz 1986, Nature; Holz & Hughes 2005, ApJ]

$$H_0 = \frac{\text{Velocity}}{\text{Distance}} = \frac{[\text{speed of light}] \cdot \text{Redshift}}{\text{Distance}}$$

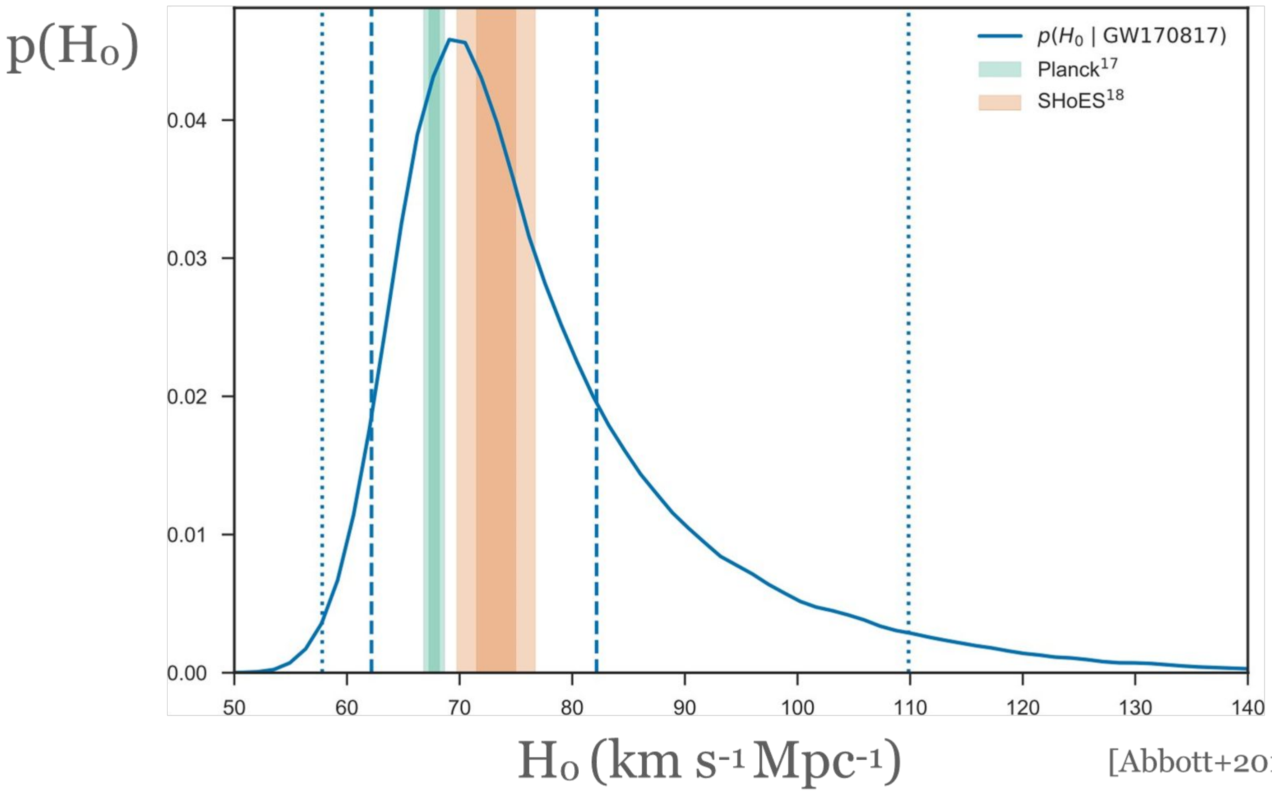






Gravitational Waves as Standard Sirens

[Schutz 1986, Nature; Holz & Hughes 2005, ApJ]

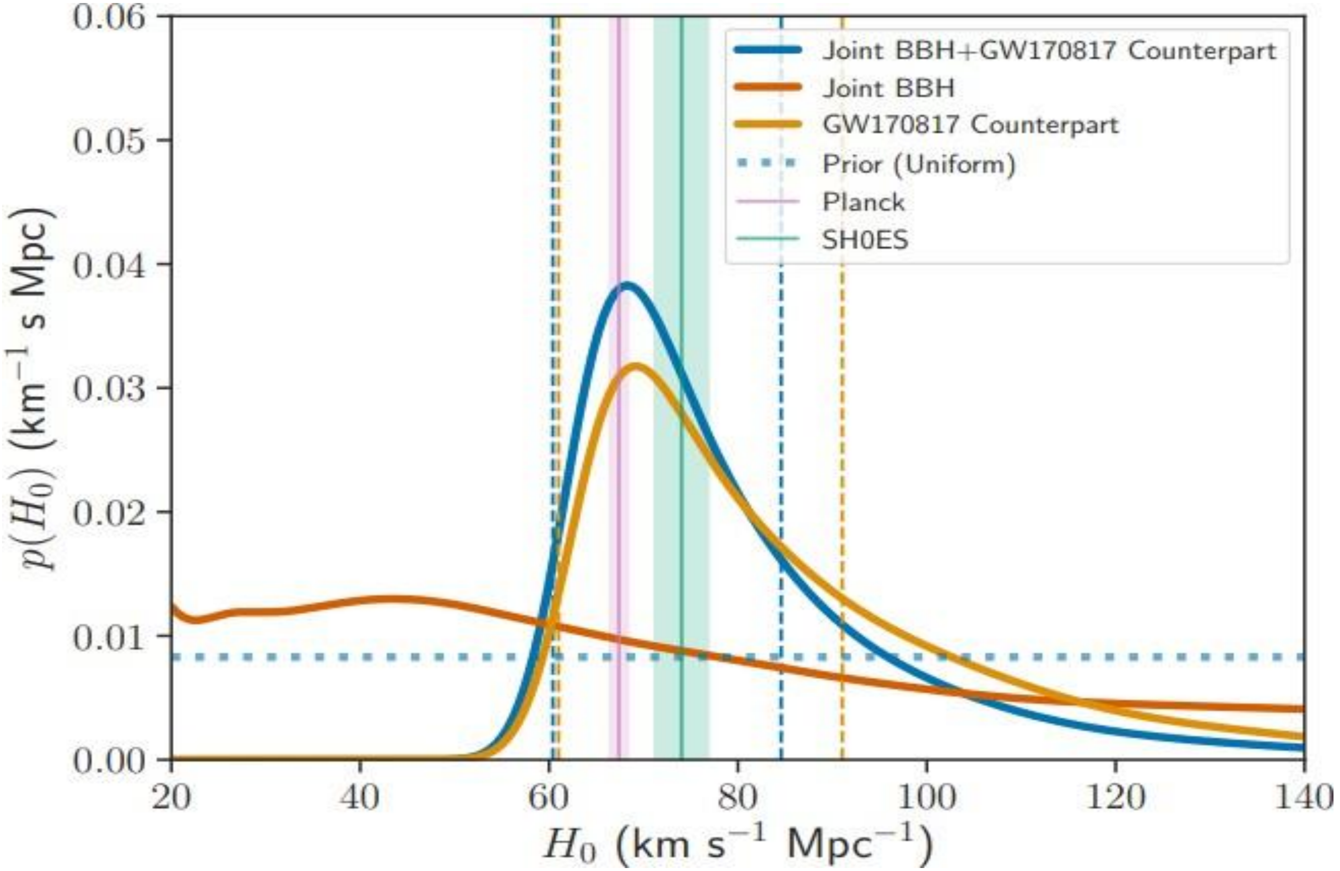


[Abbott+2017, Nature]

$$H_0 = 70.0^{+12.0-8.0}\ \mathrm{km.s^{-1}\ Mpc^{-1}}$$

Gravitational Waves as Standard Sirens

[Schutz 1986, Nature; Holz & Hughes 2005, ApJ]

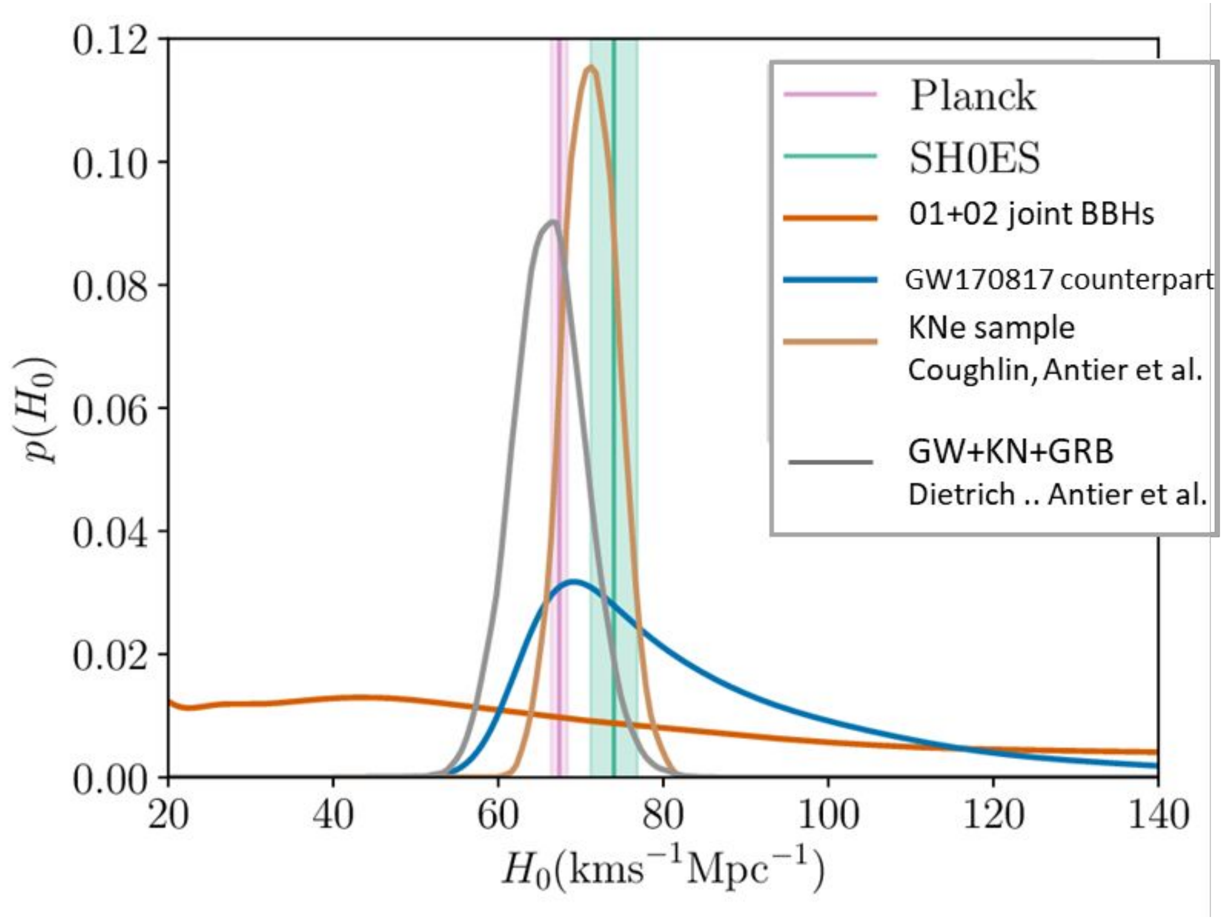


A gravitational-wave measurement of the Hubble constant following the second observing run of Advanced LIGO and Virgo, O2 run, LVC

- Method 1 : GW + KN
- Method 2 : Statistical approchs with BBH (prob loca and catalogs)

Gravitational Waves as Standard Sirens

[Schutz 1986, Nature; Holz & Hughes 2005, ApJ]



- Method 1 : GW + KN + **help the degenary of the distance – inclination**
- Method 2 : Statistical approchs with BBH (prob loca and catalogs)
- **Method 3 : KNe as standard canddles**