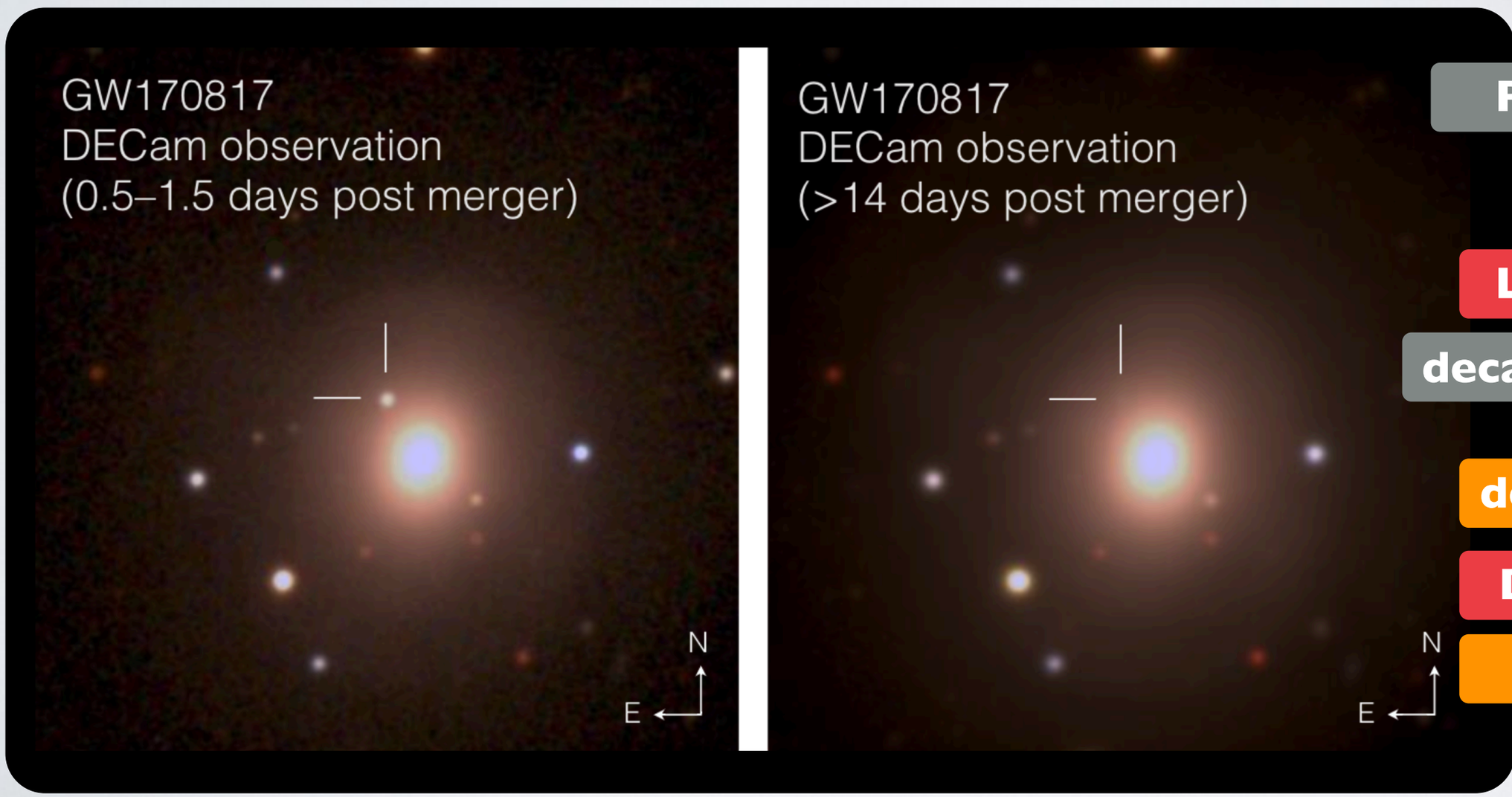
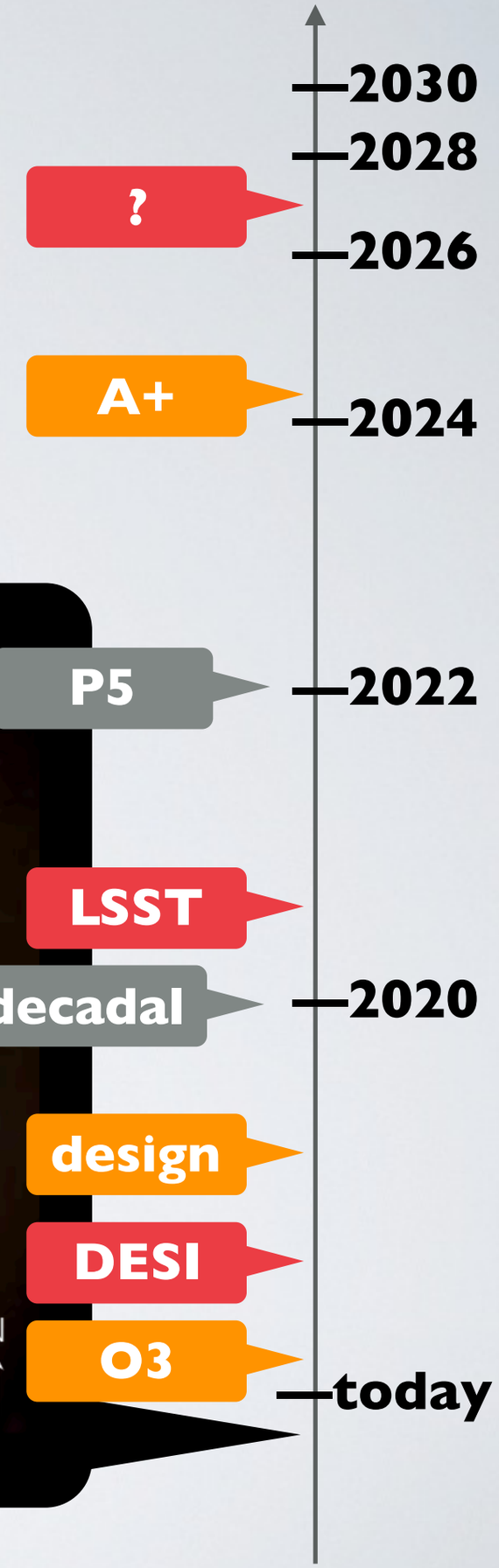
MULTI–MESSENGER ASTRONOMY WITH DECAM

Dillon Brout

on behalf of Marcelle Soares-Santos and DES-GW





GW+EM OPPORTUNITIES

Astrophysics

- **First observations of NS-NS**, NS-BH mergers
- **Evolution of binary systems and their environment**
- **Origin of r-process elements in the Universe**
- **Neutron Star equation of state**
- Potential for discovery of new astrophysical phenomena
- BBH Emission?

Cosmology

- **Standard sirens** (the GW-equivalent of standard candles)*

Physics of space-time

- Time of flight experiments (including neutrinos)
- Tests of General Relativity

***Speaker's favorite!**

PROSPECTS FOR OBSERVING

***Binary neutron star merger** rate density=1E-6 Mpc^{-3} yr^{-1}

***30-30 M⊙ binary black hole merger** rate density=2E-8 Mpc^{-3} yr^{-1}

	Average redshift	Redshift encloses 90% of events	# of Events
2018+ HLV O3	**0.03 / 0.28**	**0.04 / 0.45**	**5 / 80**
2020+ HLV Design	**0.05 / 0.48**	**0.07 / 0.77**	**40 / 500**
2024+ HLVJI Design	**0.06 / 0.60**	**0.09 / 0.96**	**80 / 900**

Chen & Holz (2016)

GW+EM CHALLENGES

All-sky effort covering large regions of interest

- Ideally we would have capability to pursue all targets
- Need a global network of resources (north and south)
- Search areas: 60-200 deg^2 , Mag = -16 or fainter

PROSPECTS FOR OBSERVING

90% confidence level localization

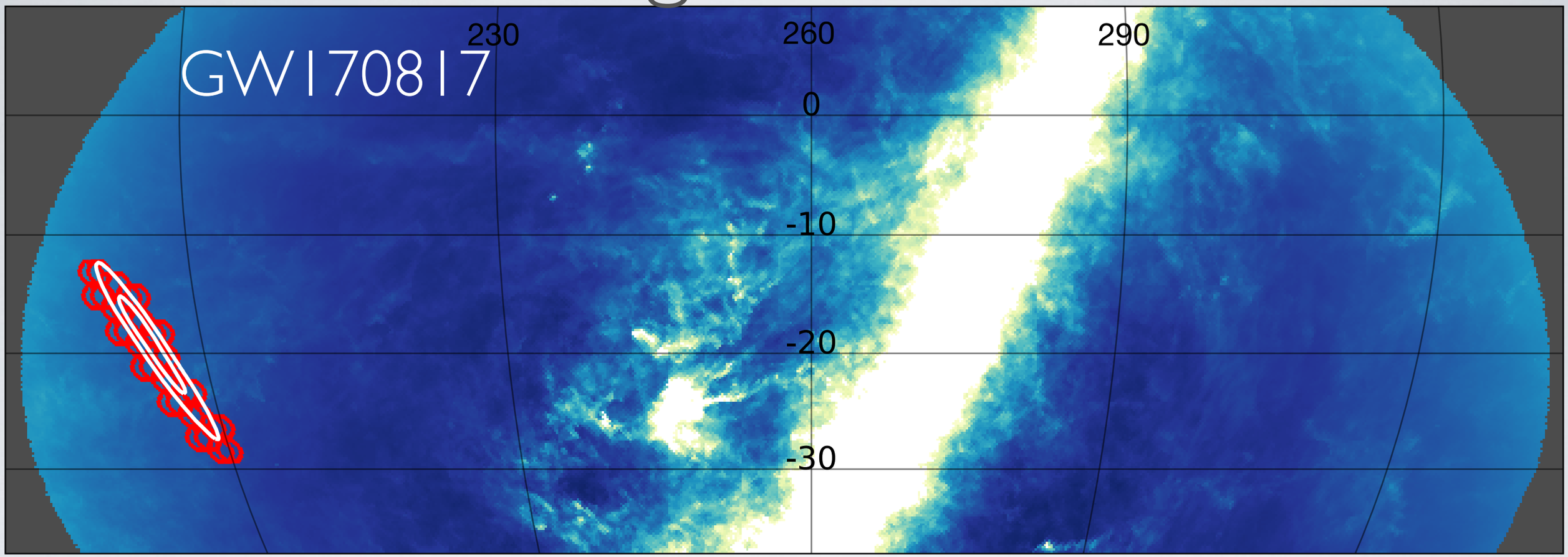
	Sky Area (deg^2)	Volume (Mpc^3)
2018+ HLV O3	**20 / 250**	**9k / 60M**
2019+ HLV Design	**10 / 200**	**20k / 200M**
2024+ HLVJI Design	**3 / 65**	**13k / 100M**

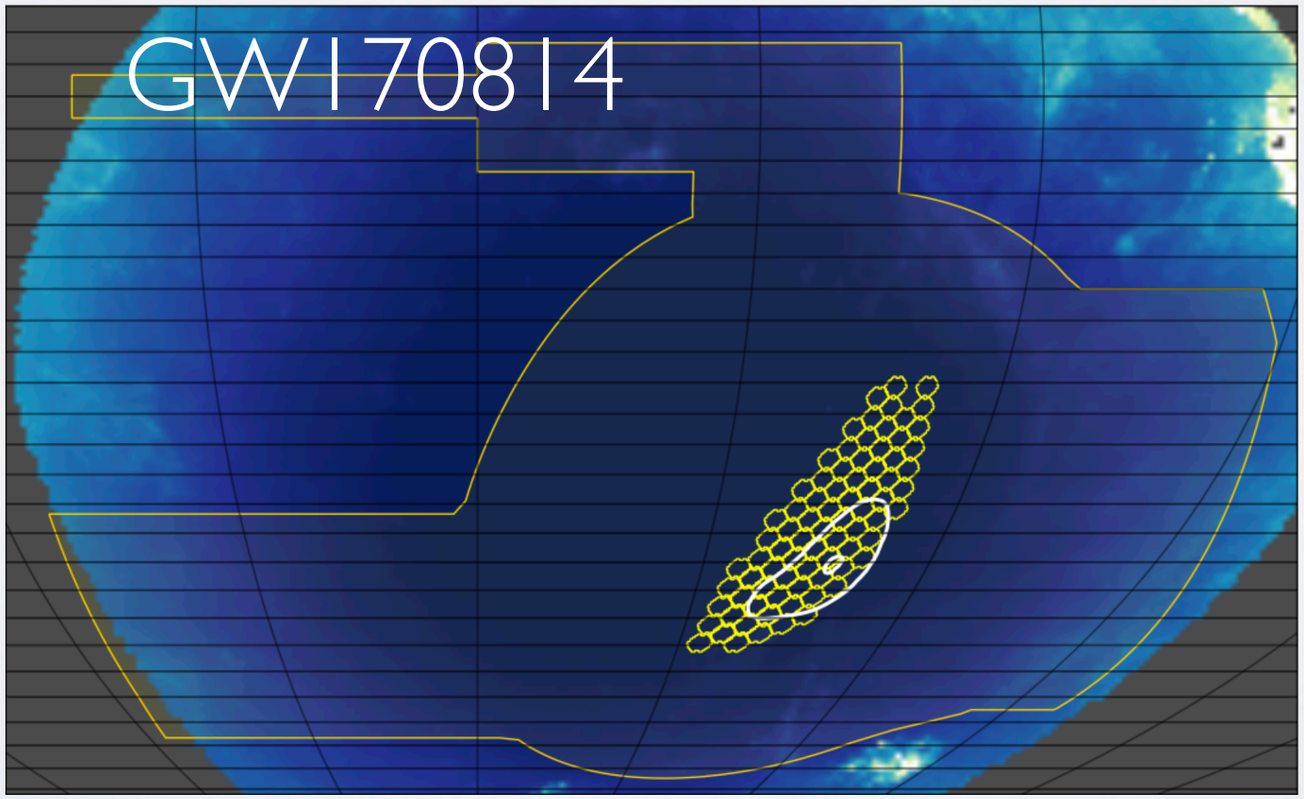
Chen & Holz (2016)

***Binary neutron star merger**

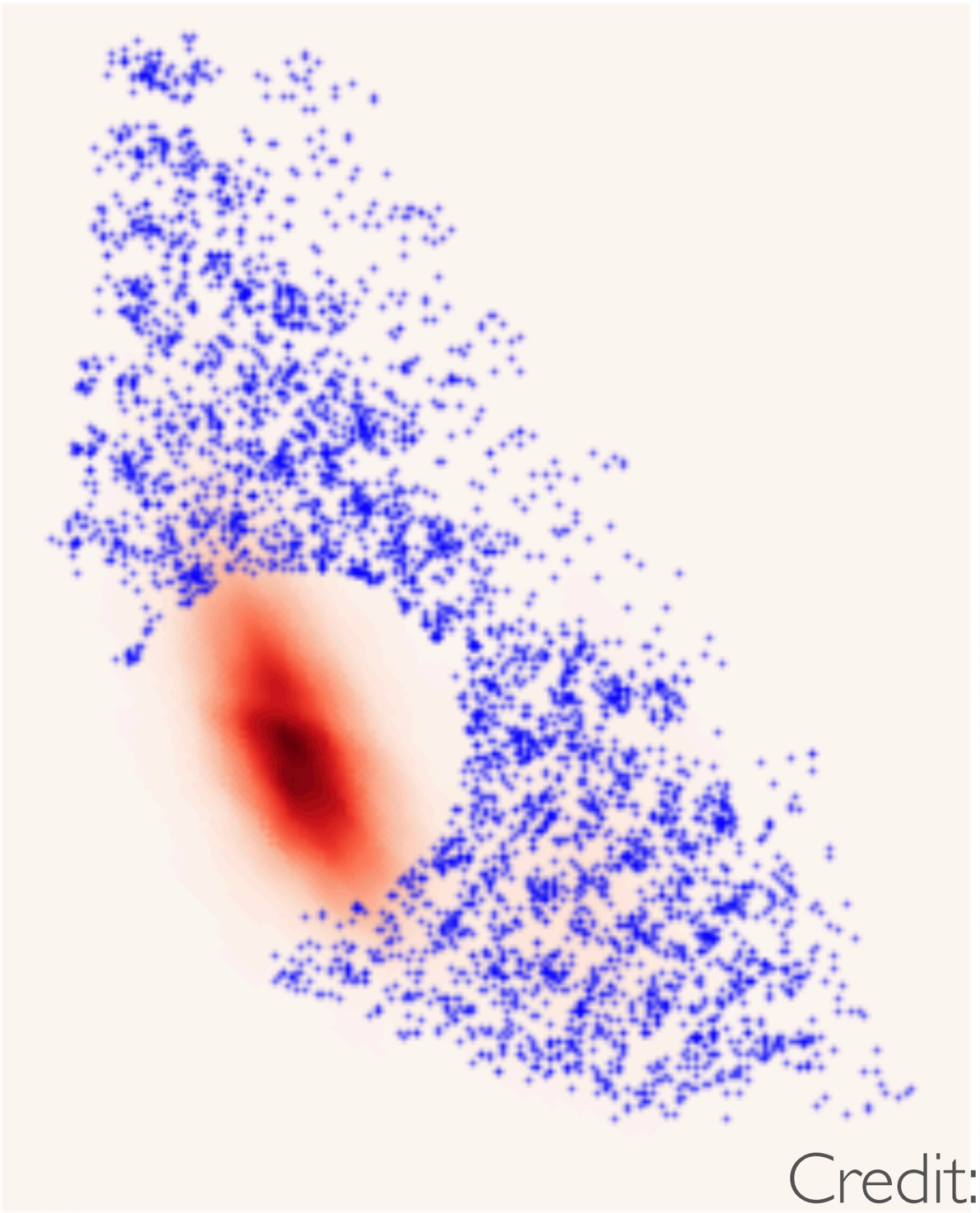
***30-30 M⊙ binary black hole merger**

August 2017





BBH SEARCH



Credit: Zoheyr Doctor

GW+EM CHALLENGES

All-sky effort covering large regions of interest

- Ideally we would have capability to pursue all targets
- Need a global network of resources (north and south)
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Targets of opportunity with external triggers

- Triggers are provided by the GW observatories
- Coordination needed between different communities

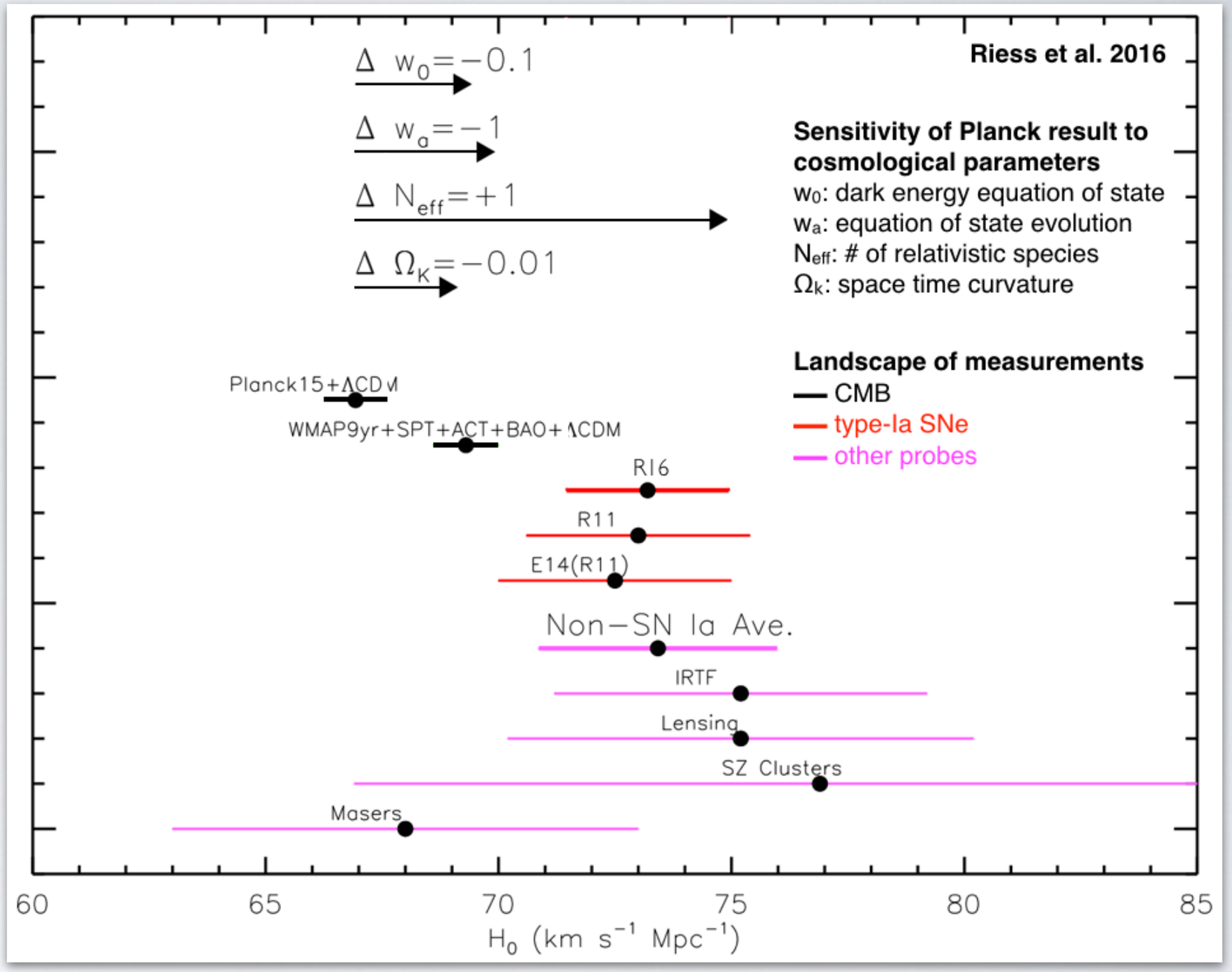
Rapid development in this emerging field

- Optimal program must be flexible to adapt to new inputs
- Uncertainties on rates, emission models, etc. are still large

COSMOLOGY MOTIVATION

Growing discrepancy between local and CMB-based measurements of the current rate of expansion: **systematic effects, or new physics?**

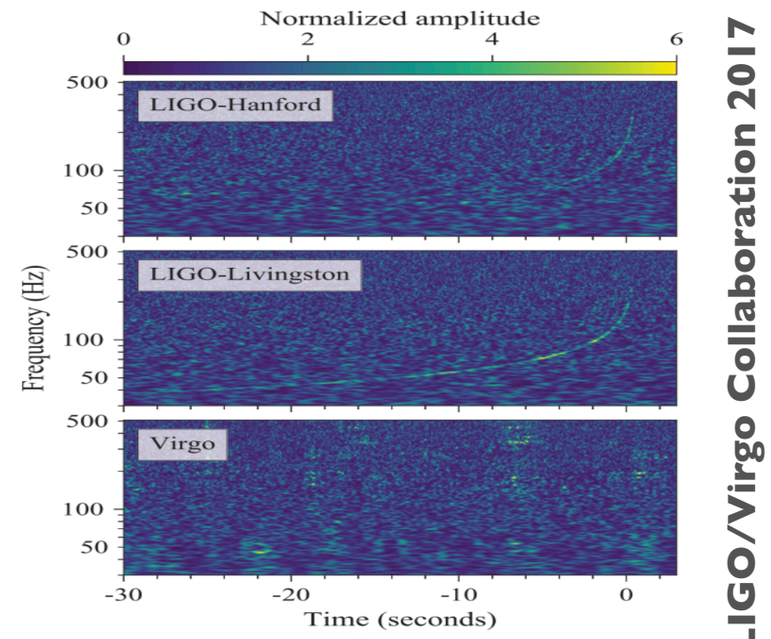
A new, independent, measurement will be most helpful here!



$$H \equiv \dot{a}/a \ , \text{ where } a = 1/(1+z)$$
$$H(z) = H_0 \cdot f(z; \Omega_m, \Omega_k, \Omega_{DE}, w_0, w_a)$$

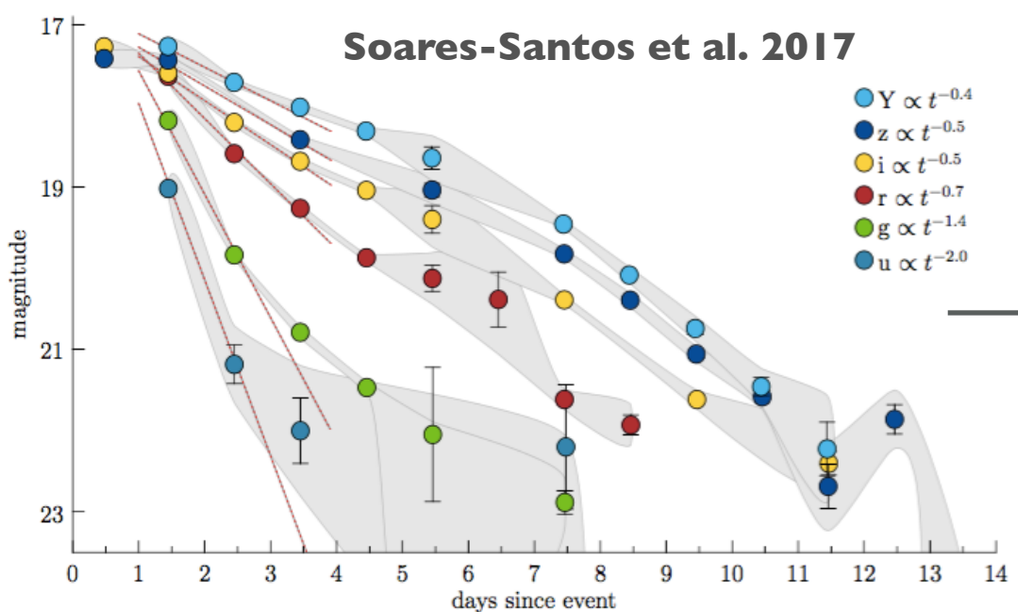
GW170817: FIRST OBSERVATION

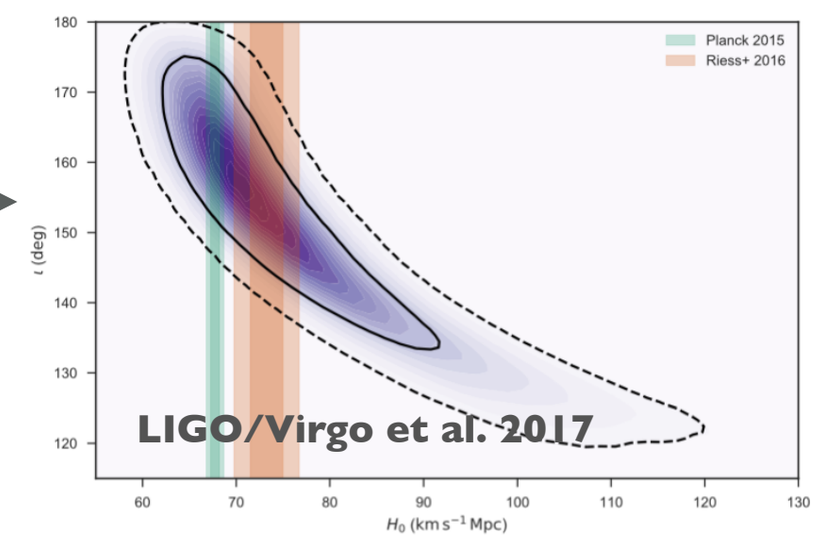
LIGO/Virgo



LIGO/Virgo Collaboration 2017

DES/DECaM

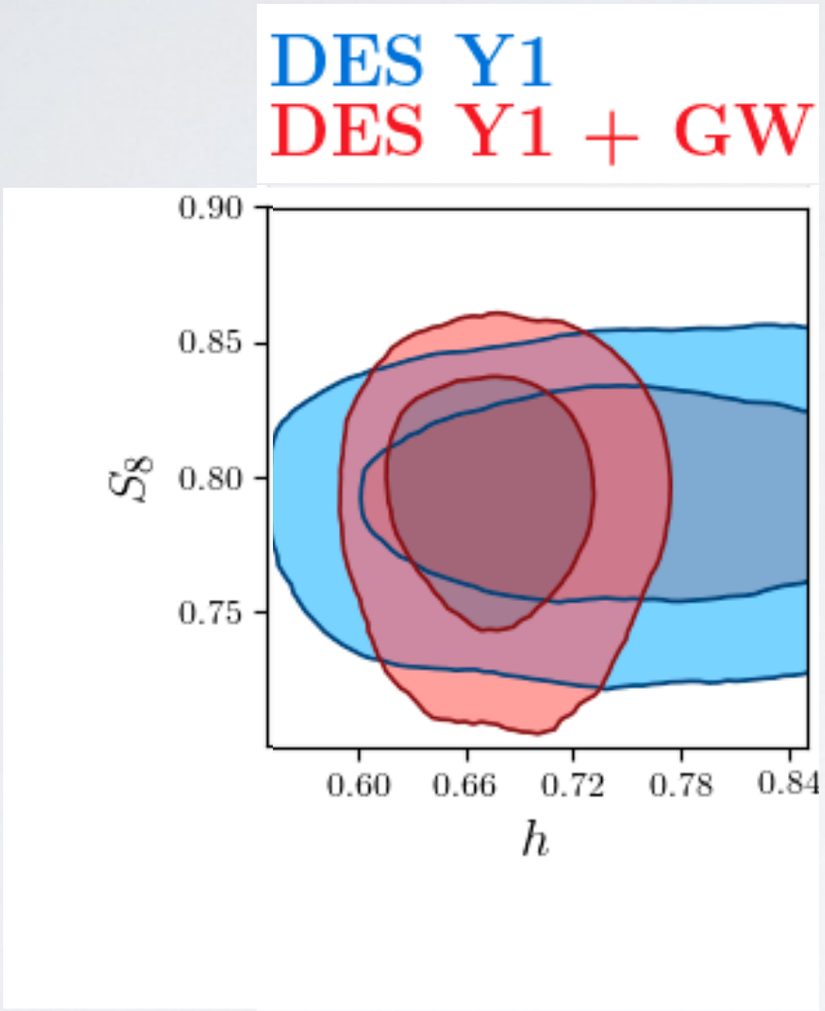




PROJECTIONS: SHORT TERM

PRELIMINARY

GW O3 mock data



(Soares-Santos, Pereira & Garcia)

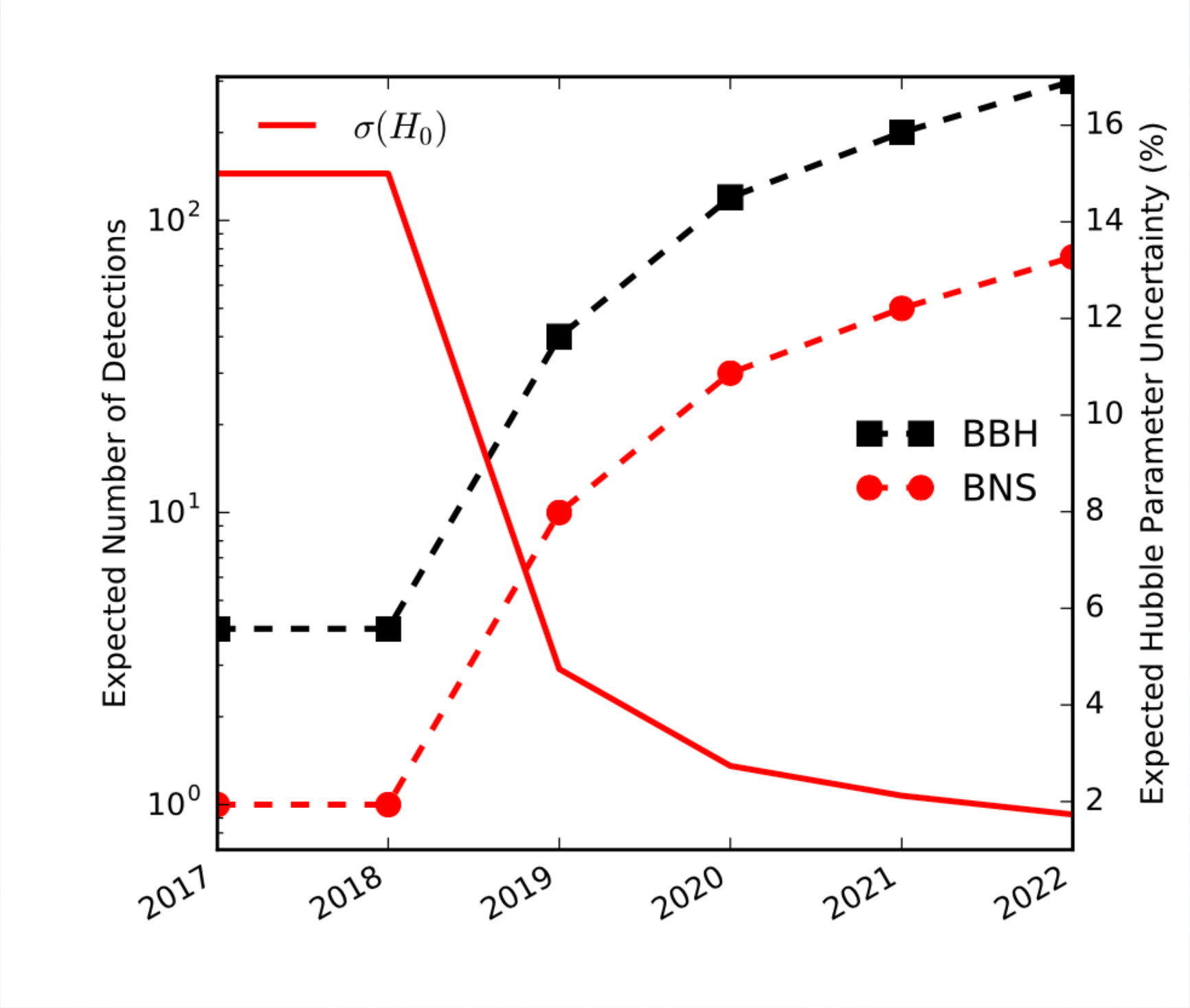
Assumptions:

8 events in 2018-2019 run.

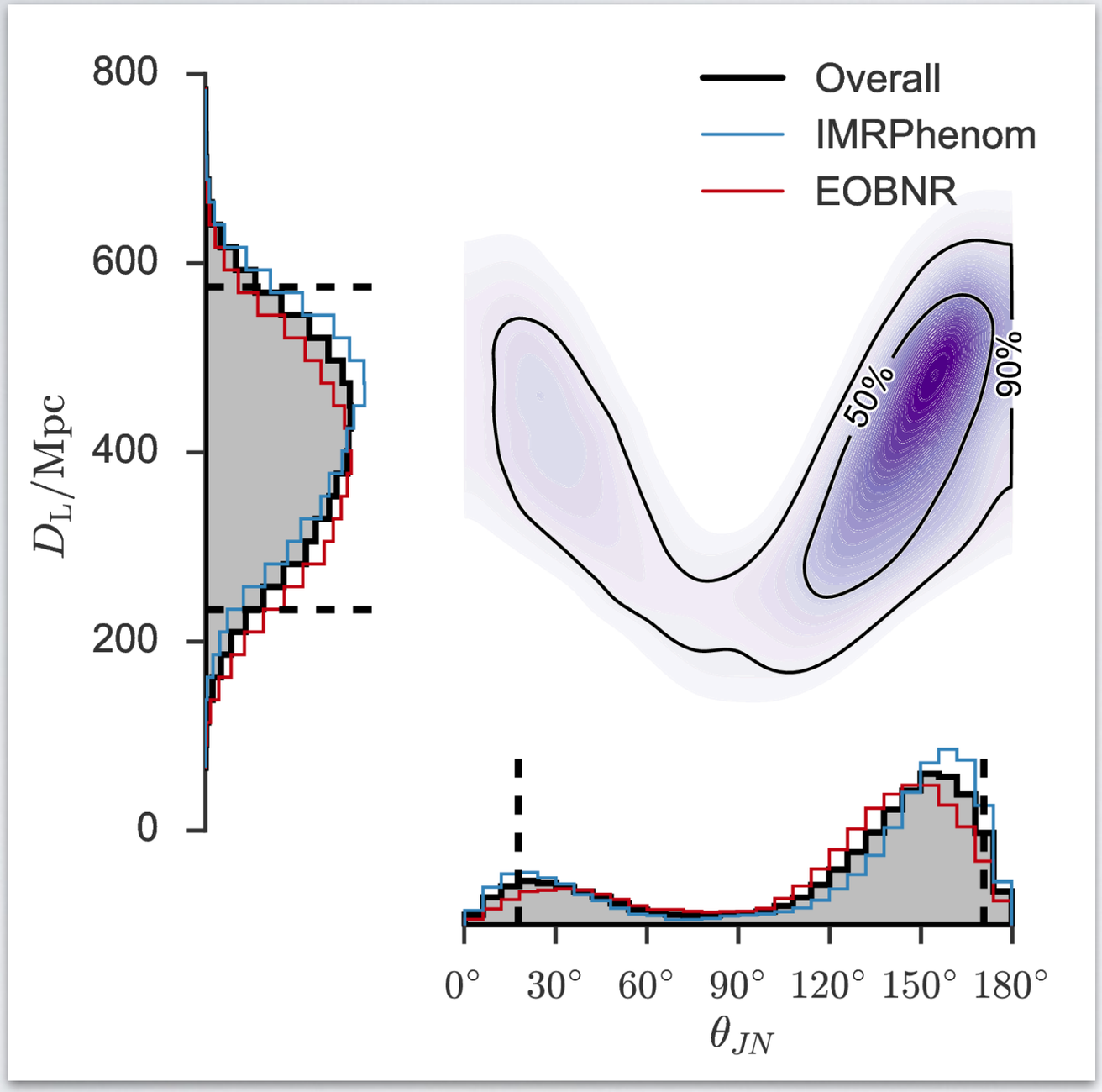
25% uncertainties in distance.

300 km/s uncertainties from peculiar velocities.

5 YR PROJECTIONS



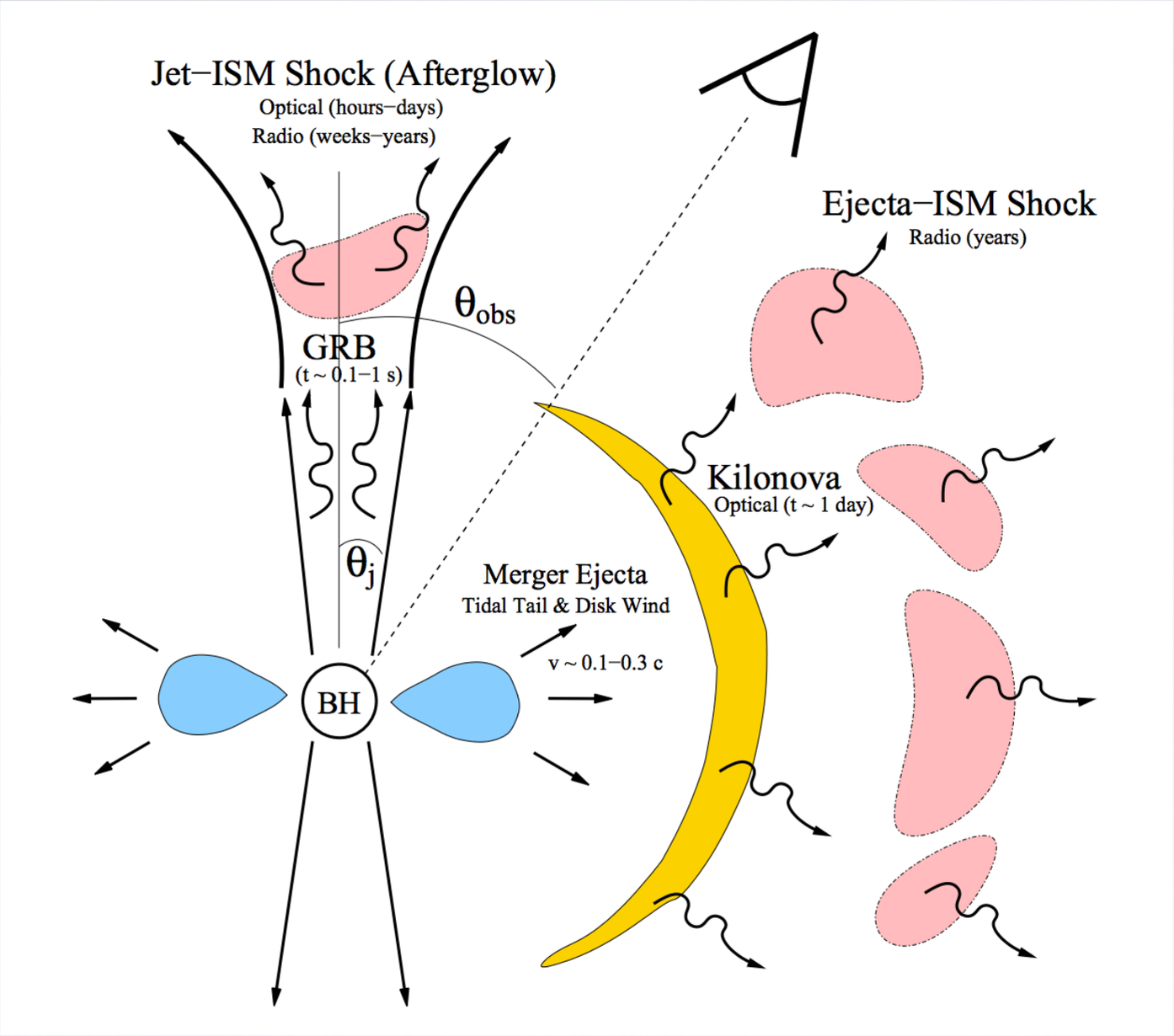
INCLINATION AND DISTANCE



Degeneracy between inclination angle and distance is a major source of uncertainty in cosmological parameters.

Example: GW150914

MERGER MODELS



Metzger & Berger 2011

Maybe modeling of the EM signal can help break the inclination-angle distance degeneracy.

This is one of many good reasons to study the astrophysics of these systems.

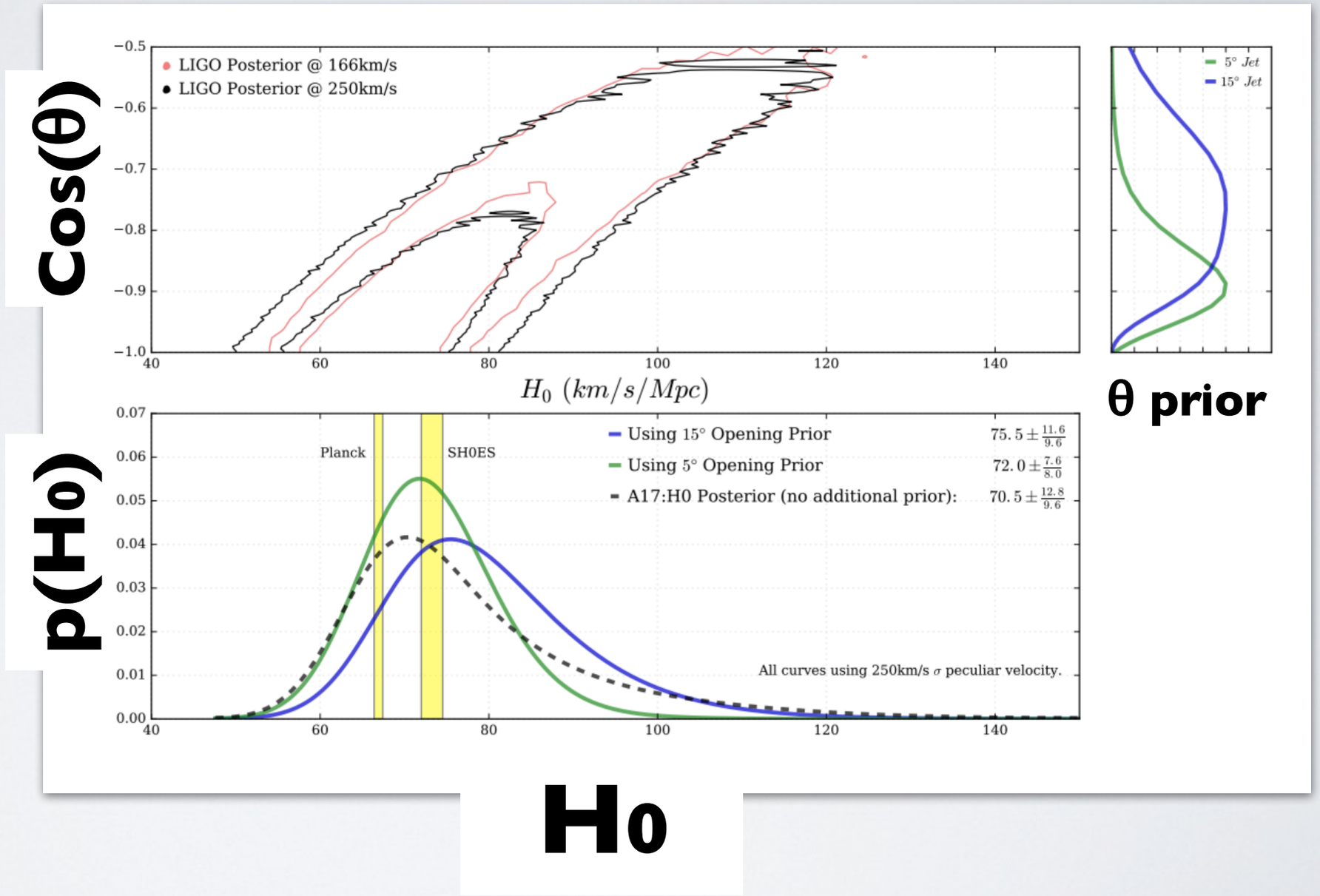
HUBBLE PARAMETER RESULTS

We can improve the Hubble parameter measurements significantly if we can put a prior on the inclination angle of the angle.

The X-ray data modeling indicates that we have an off-axis jet with an opening angle of ~15 deg and an off axis angle ~25-50 deg.

This results in an Hubble parameter measurement that is **slightly more consistent with the local measurements than with the CMB**.

Guidorzi, Margutti, Brout et al. 2017 (arXiv:1710.06426)



Lessons learned from GW170817

Improving cosmology measurements:

1) at d < 80 Mpc we need improved **peculiar velocity maps**
2) at d > 80 Mpc, **sources are fainter** and there is **probability of host galaxy confusion**
3) at all distances, **constraining the inclination is very helpful**

Constraining the inclination: three possibilities

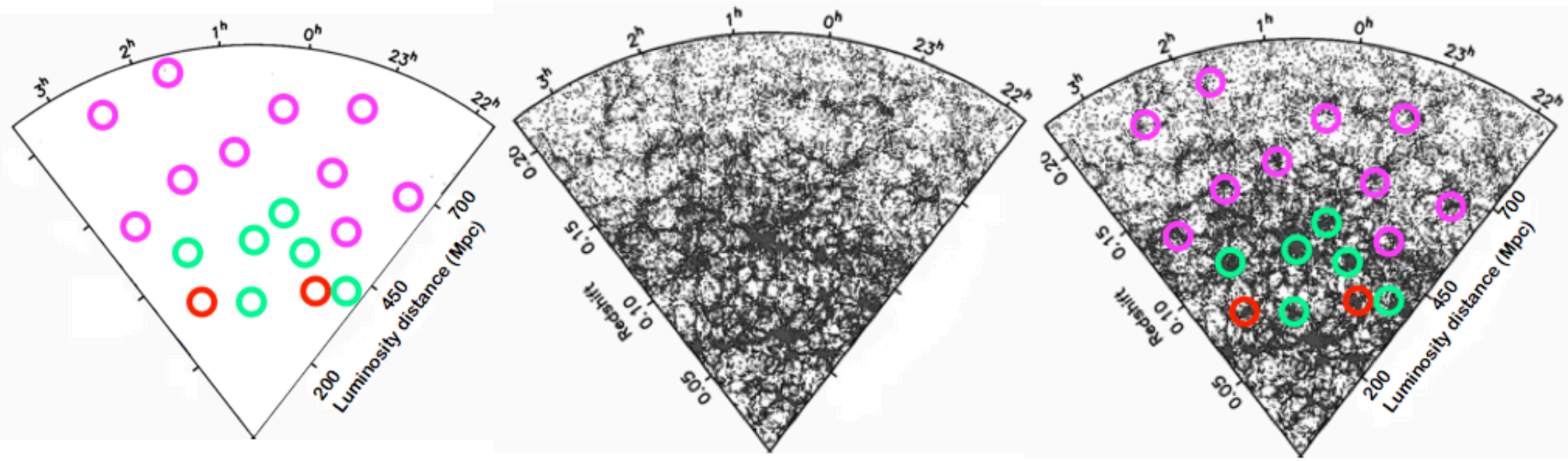
1) GW polarization measurements (improves with larger GW detector network)
2) radio & x-ray modeling of the jet (hard to achieve for large samples)
3) optical, infrared modeling of the ejecta shell (our best option if it works; worth trying)

Optical light curves and inclination (or, what is behind door no. 3)

* Edge-on mergers are expected to result in red kilonovae
* Face-on mergers are, in contrast, expected to be bluer and brighter
* We can explore this feature: use optical, NIR data to model the ejecta
* We need to include this information in the cosmology likelihood analysis
* Polarization of the optical signal might be helpful too

… but we can use dark sirens for cosmology too!

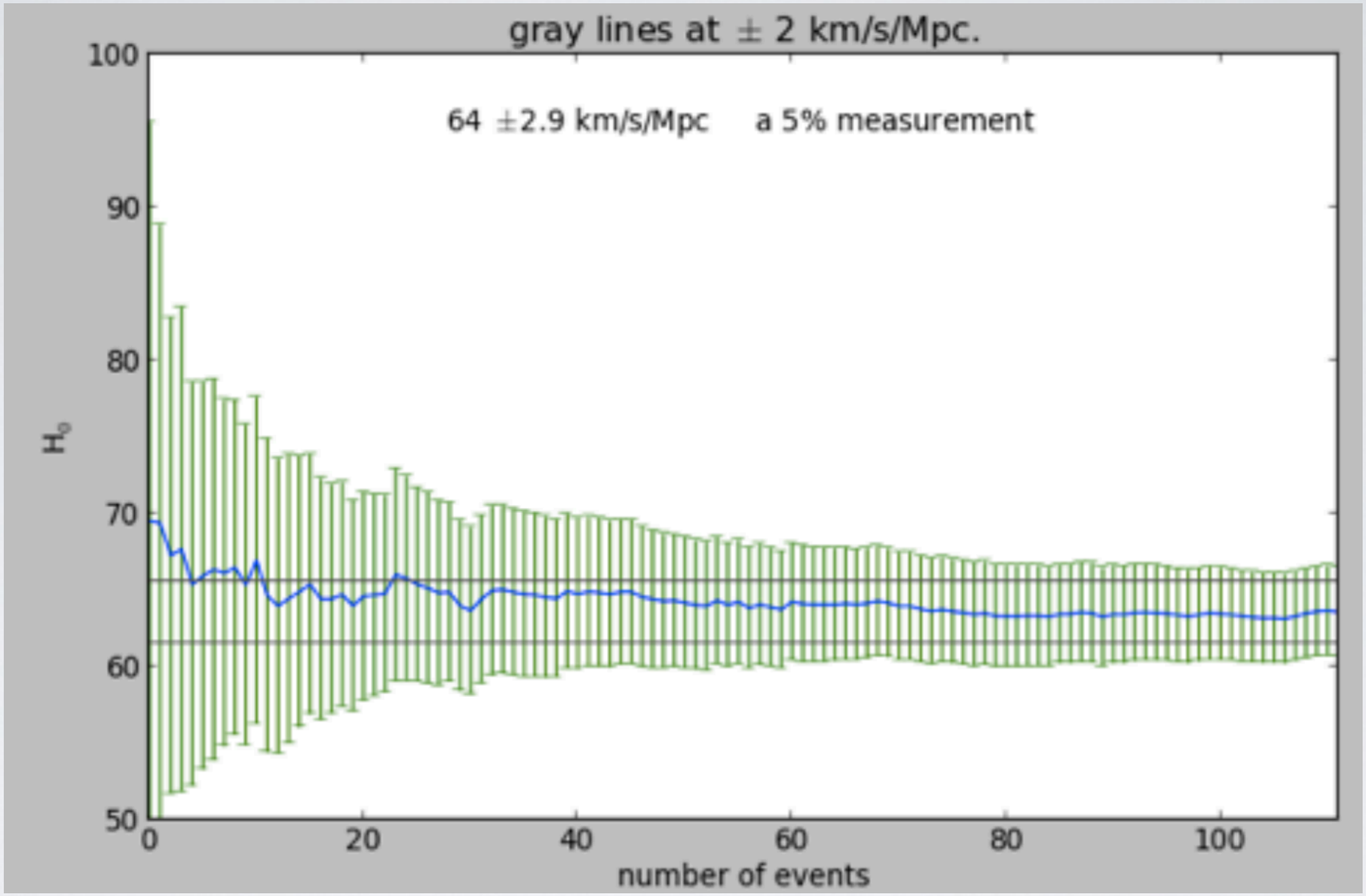
Cross-correlation between large samples of BBH from aLIGO and galaxy samples of the cosmological surveys



BBH-based cosmological measurement is analogous, and complementary to BAO measurements.

DARK SIRENS

Preliminary



(Annis, Brout & Soares-Santos)

PROGRAM ELEMENTS

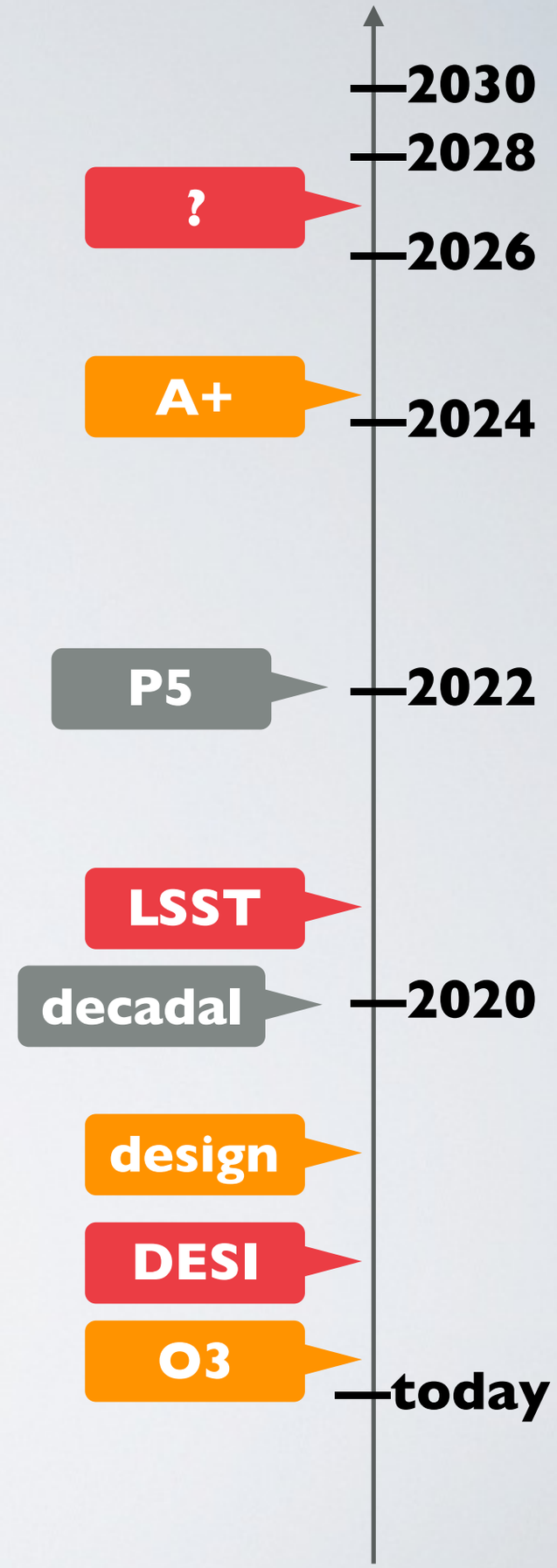
DECam will be a great search & discovery machine for EM counterparts of GW events in the southern sky.

LSST and several existing camera-telescope systems are capable to complement the DECam program.

Spectroscopy capability is needed, for candidate classification, astrophysical modeling, and cosmology.

DESI could provide spectra for dark siren analyses, but **new** spectroscopic facilities in the south are key.

Above all, coordination is needed a) between exiting, planned and new efforts b) with the community.



These are exciting times for **Multi-Messenger Astronomy** with **Gravitational Waves**.

DES image including the potential hosts of neutron star mergers yet to be observed.

DECam participated on the discovery of the first neutron star merger with an associated electromagnetic counterpart, **inaugurating the GW era of multi-messenger astronomy**, and **blazing a new trail for cosmology**. Now we have the opportunity to help shape the future of this emerging new field.