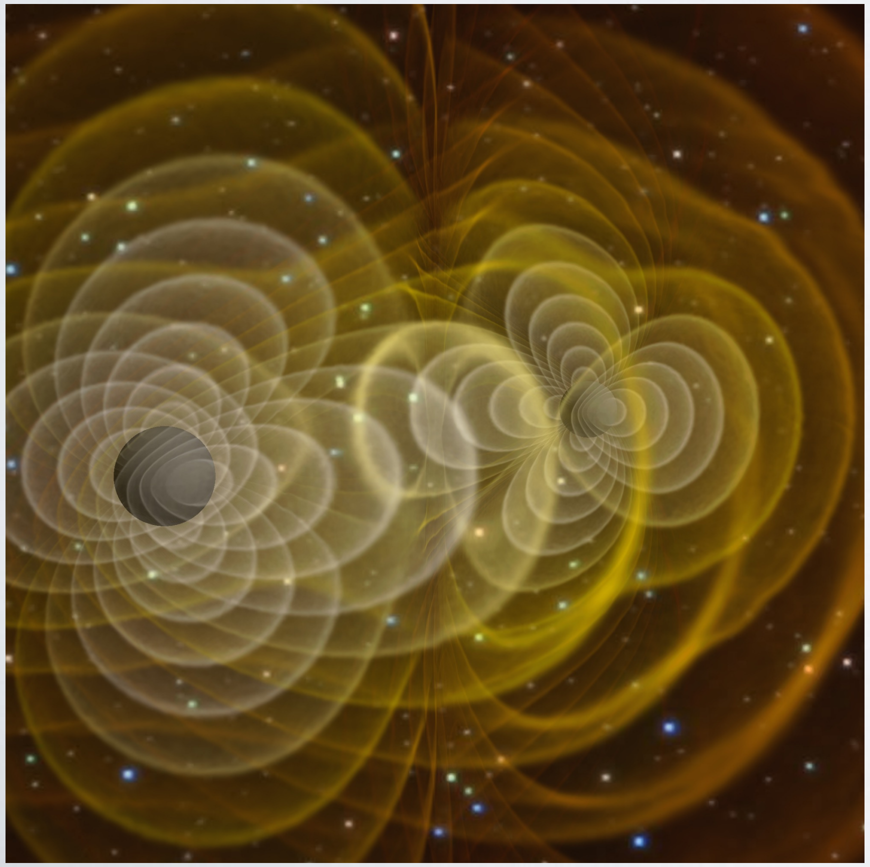
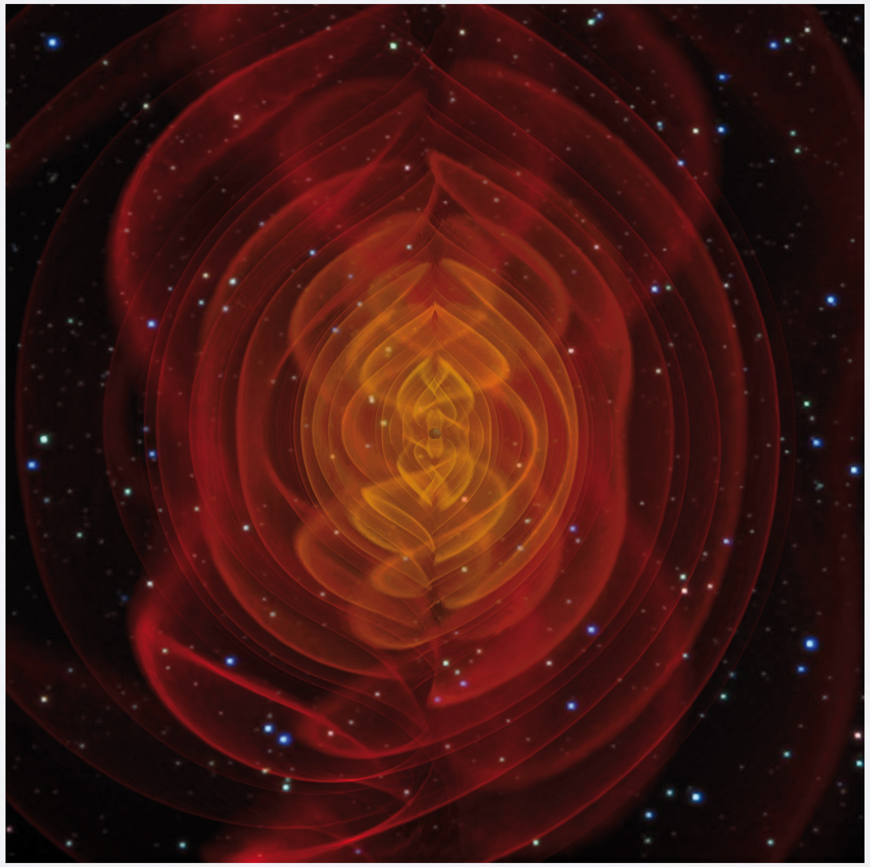
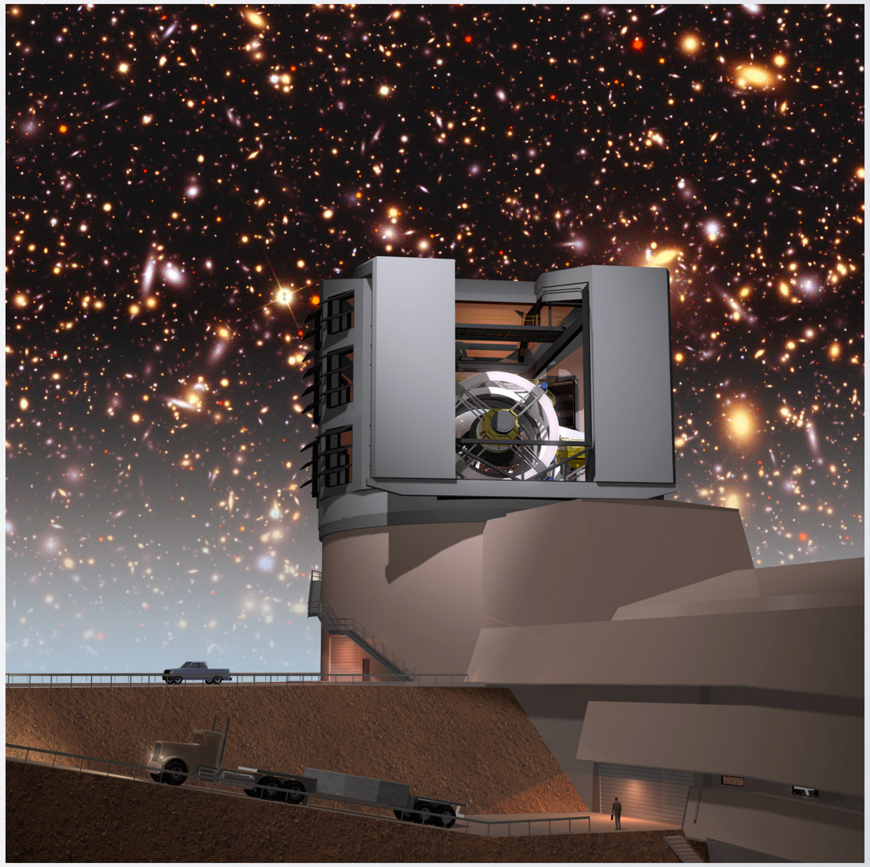
COSMOLOGY WITH GRAVITATIONAL WAVES IN FUTURE COSMIC SURVEYS

Marcelle Soares-Santos
Fermilab

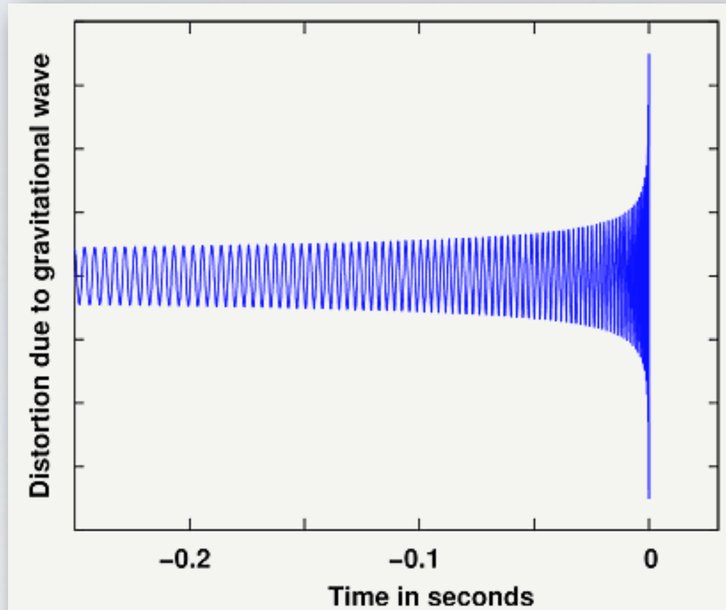
Cosmic Visions Workshop ◆ Nov 10, 2015



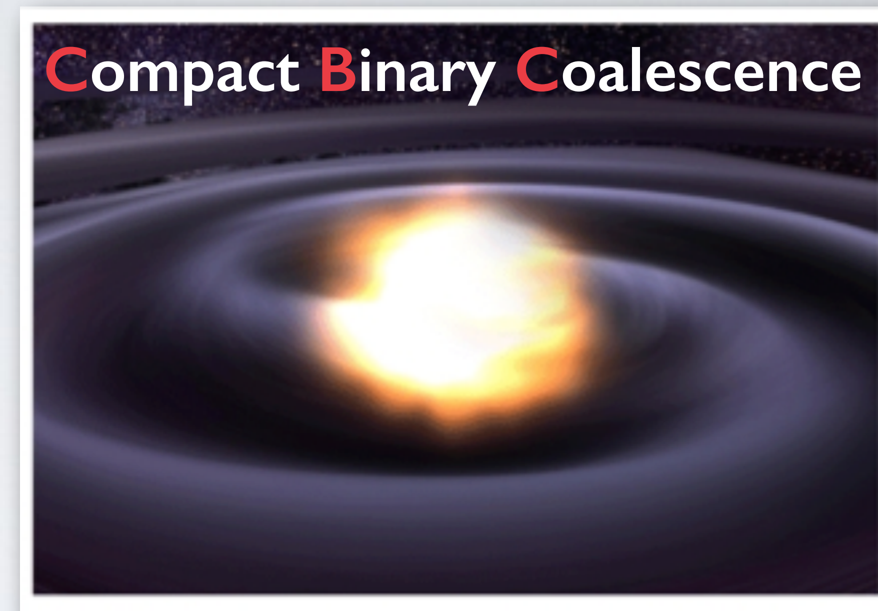




STANDARD SIRENS

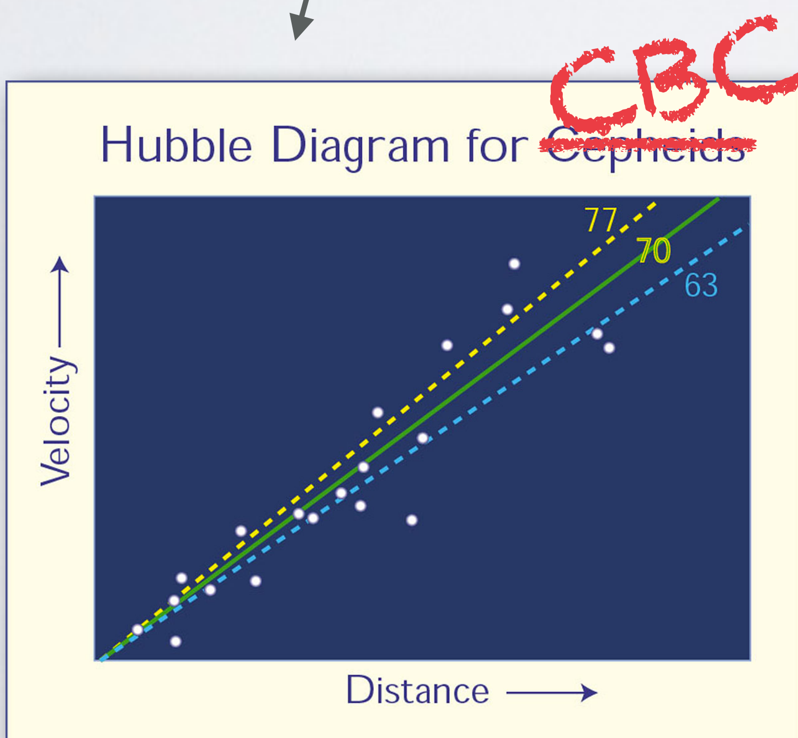


GW

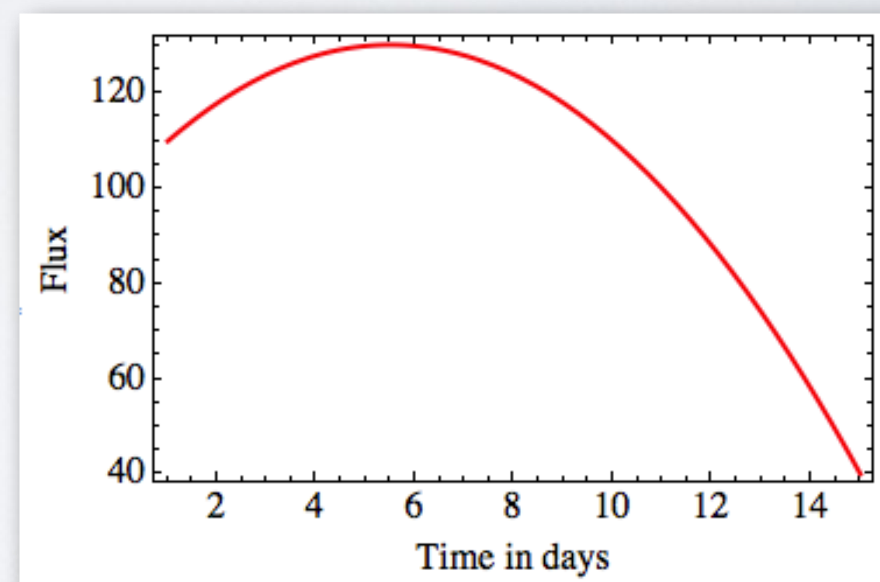


distance

EM



redshift



GW "DIRECT" DETECTION

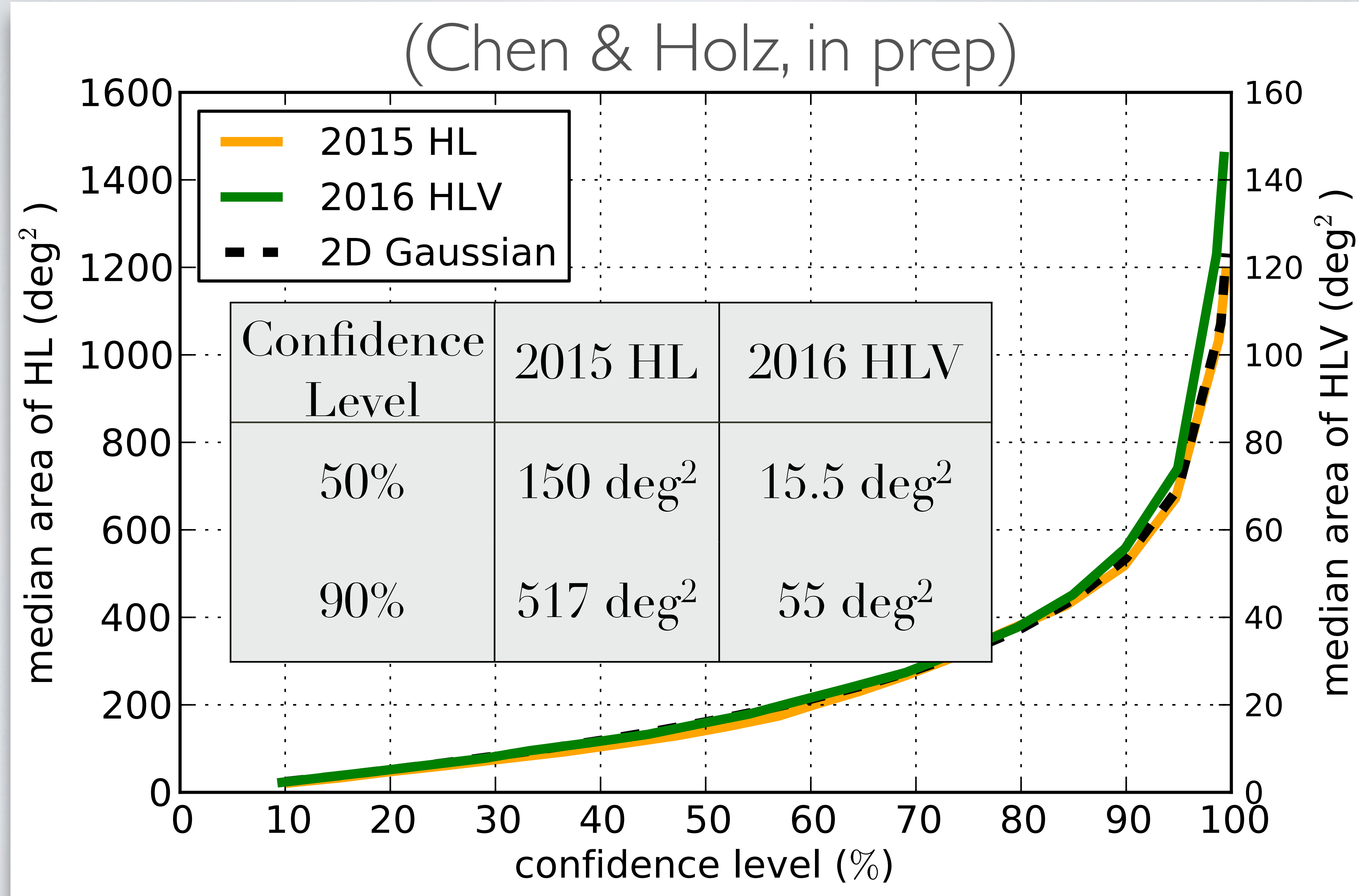
LIGO Livingston, LIGO Hanford, and Virgo

LIGO: arXiv:1304.0670

	Epoch	Estimated Run Duration	$E_{GW} = 10^{-2} M_{\odot} c^2$ Burst Range (Mpc) LIGO	Virgo	BNS Range (Mpc) LIGO	Virgo	Number of BNS Detections	% BNS Localized within $5\,\mathrm{deg}^2$	$20\,\mathrm{deg}^2$
aLigo	2015	3 months	40 – 60	–	40 – 80	–	0.0004 – 3	–	–
aLigo	2016–17	6 months	60 – 75	20 – 40	80 – 120	20 – 60	0.006 – 20	2	5 – 12
aVirgo + aLigo	2017–18	9 months	75 – 90	40 – 50	120 – 170	60 – 85	0.04 – 100	1 – 2	10 – 12
aVirgo + aLigo	2019+	(per year)	105	40 – 80	200	65 – 130	0.2 – 200	3 – 8	8 – 28
	2022+ (India)	(per year)	105	80	200	130	0.4 – 400	17	48

Advanced GW detectors projected timetable.

MEDIAN LOCALIZATION AREA



Confidence Level	2015 HL	2016 HLV
50%	150 deg^2	15.5 deg^2
90%	517 deg^2	55 deg^2

POSSIBLE COUNTERPARTS

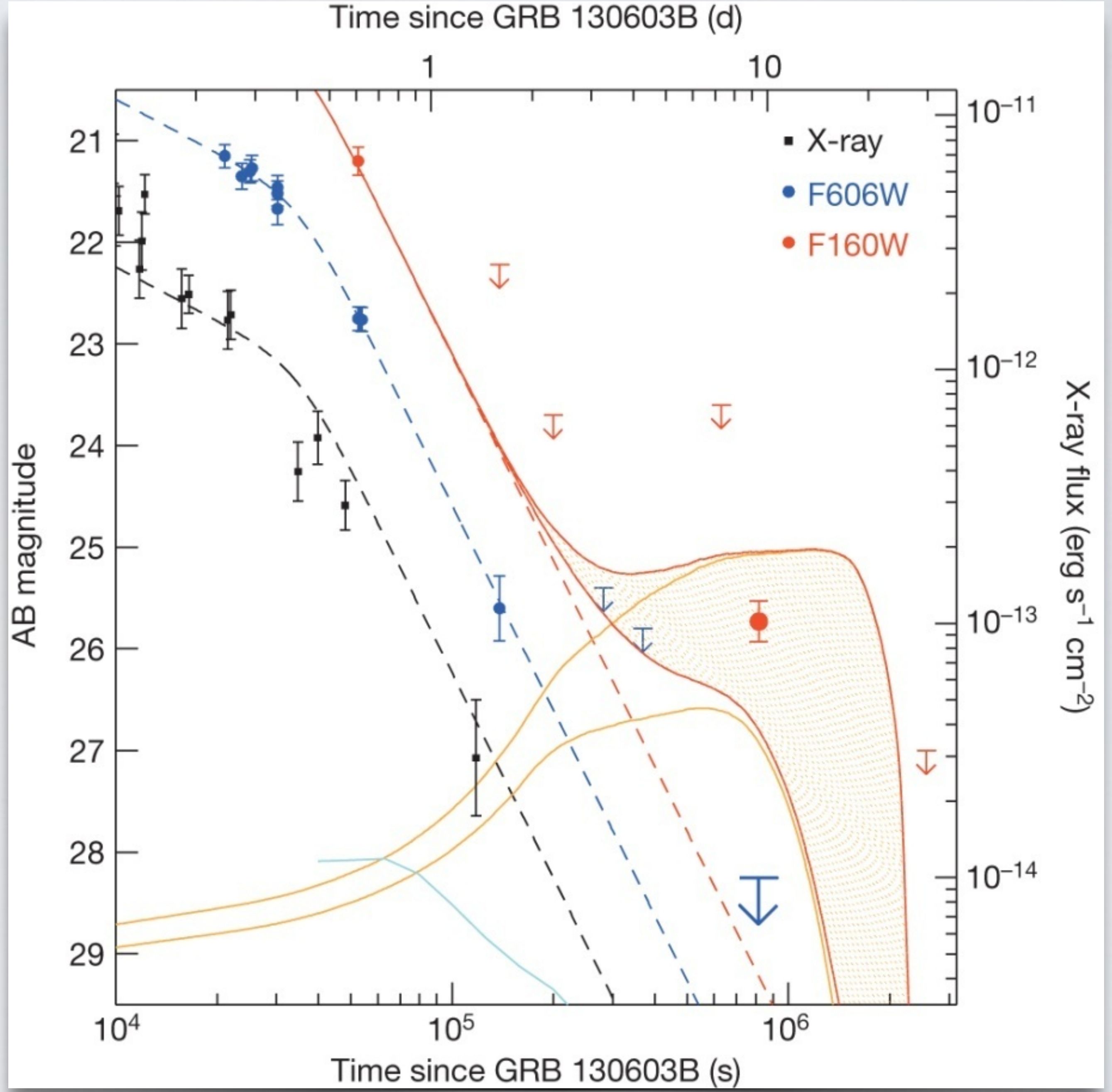
short GRB
(+ afterglow)

kilonova
(+ blue kinematic precursor)

radio afterglow

neutrinos

Tanvir et al. Nature (2013)



KILONOVA MODELS

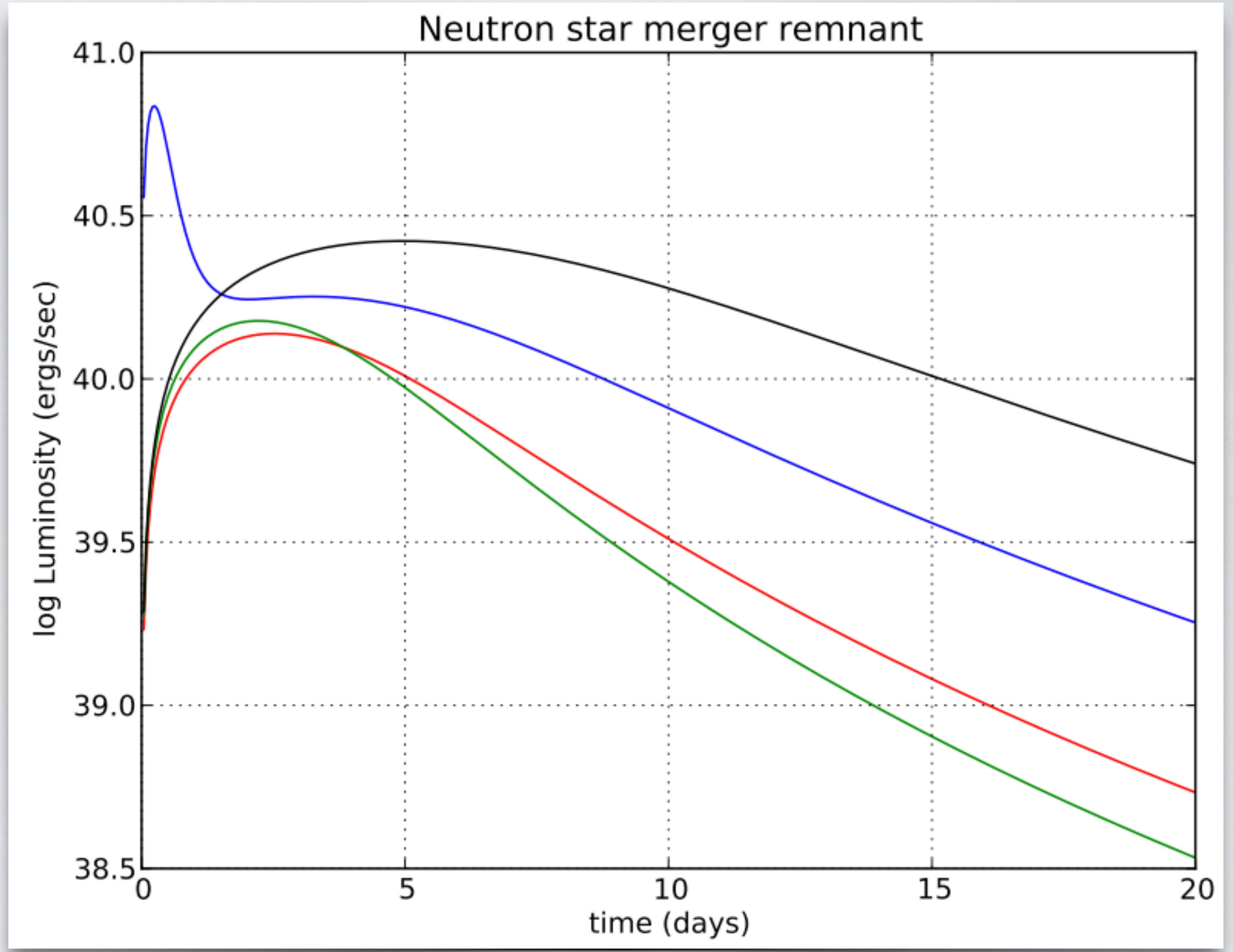
(Annis et al, in prep)

Semi-analytic models tuned with simulations (Annis et al., in prep). Based on Grossman et al 2014.

Optical transient: "kilonova"

The red curve peaks at absolute mag *M* = -*11* in i-band.

Very red transient: i-z ~ 0.8 in all cases except for blue flash.



Red: Equal mass NS-NS merger
Green: Unequal mass NS-NS merger
Black: NS-BH merger
Blue: Neutron-driven wind (blue flash)

DESGW PROGRAM CONCEPT

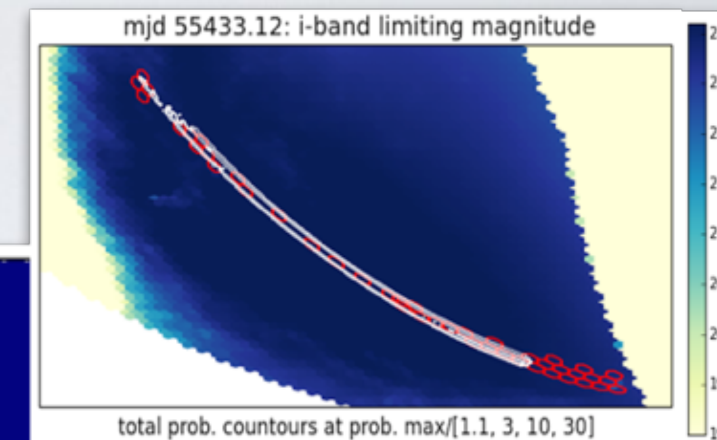
GW trigger

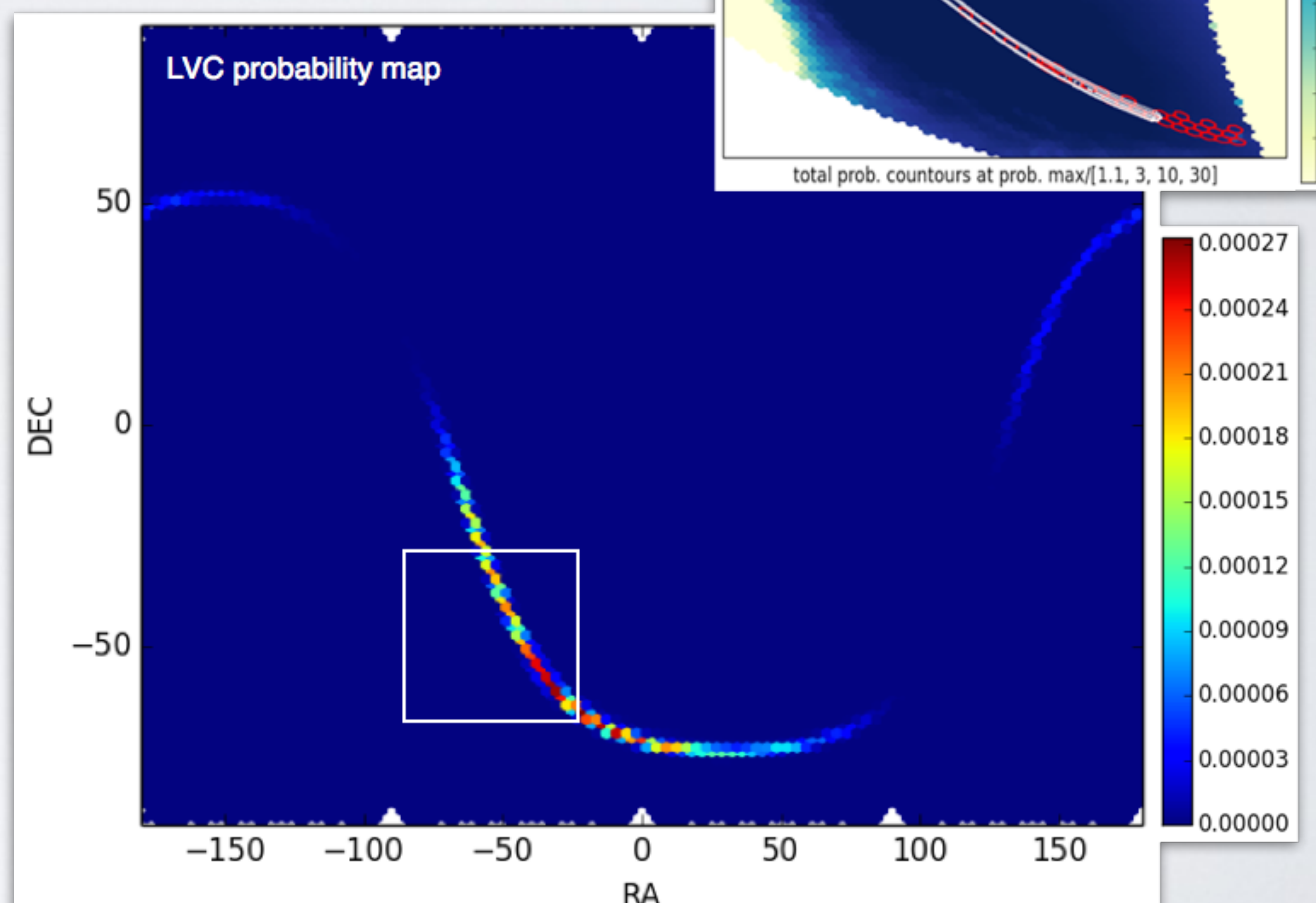
time stamp
sky region
distance

DECam/DES search system

build template image
schedule observations
take new images
perform image subtraction
detect, model counterpart

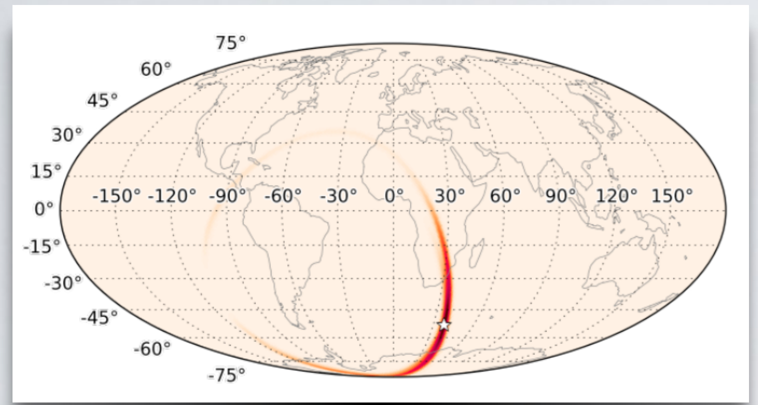
Simulated Event
ID: M184051
Distance: 69 Mpc
Abs mag: -11 at peak (i-band)
No. of DECam hexes: 44
Total detection probability: 18%

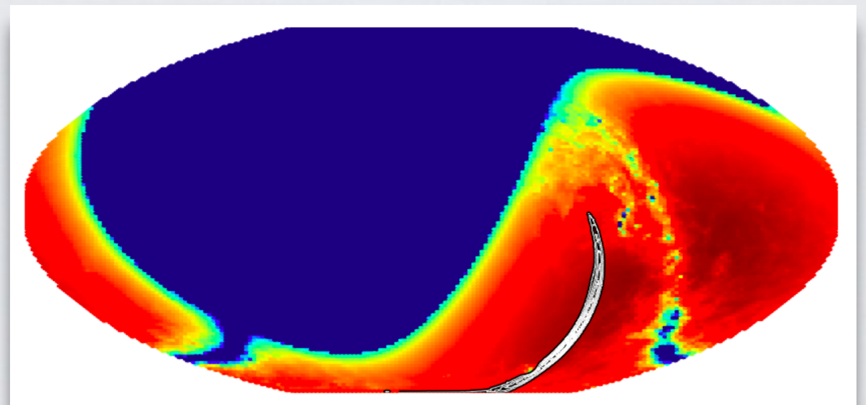


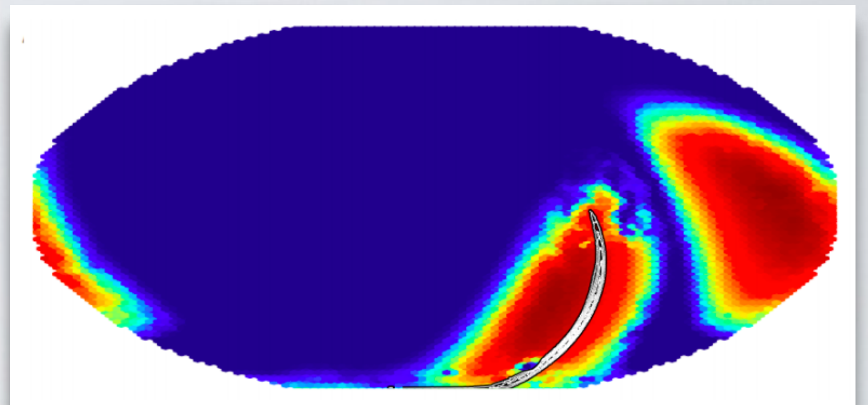


TEST: CTIO DD TIME (FEB 1-3, 2015)

Event # 20823, from 2015 LIGO simulations







LIGO sim event # 20823

Date: 9/19/2010 (moved to 2/1/2015)

Distance: 81 Mpc

Masses: 1.47, 1.38 M_sun

SNR: 13.9

Area: 132 deg^2 @50% c.l.

DECam i-band limiting mag

For 10-sigma point source

3 x 60 second exposures

Moon not included (although we did observe at full moon)

Max mag in this scale: i ~ 23

LIGO contours superimposed

DECam detection probability

For equal mass NSNS merger

Final map is DECam x LIGO probability maps (not shown)

DES default hex schema used
- 38% probability in top 33 hexes (9% in top 7)

LIGO contours superimposed

DESGW PROGRAM GOALS

Near term goal: background rate studies, first searches in 2015

Long term goal: a large scale program for 2016-19 enabling projects beyond DES

- **DECam/DES** — available throughout the LIGO-Virgo ramp up (triggered searches, proof of concept)
- **LSST** — to start in ~2022, will be faster than DECam (untriggered searches, cosmology measurements at low-z)
- **Next Gen. Cosmic Survey?** — could overlap in time with next generation GW detectors (cosmology at high-z)
- **Synergy with future neutrino experiments?** — DUNE and other large neutrino experiments may have enough sensitivity for a joint search (ToF experiment)

PROSPECTS FOR EARLY 2020'S

In the LSST era, after DESGW program is complete:

— GW detectors operating at design sensitivity
— Built experience detecting optical counterparts
— Better estimates of event rates, characteristics
— Ideal time to launch a dedicated program to **measure the Hubble parameter with 1% precision using standard sirens out to z~0.1**

High cadence of LSST will allow us to detect kilonovae w/o a GW trigger, and use that information to search for the GW signals with improved sensitivity.

PROSPECTS FOR MID 2020'S

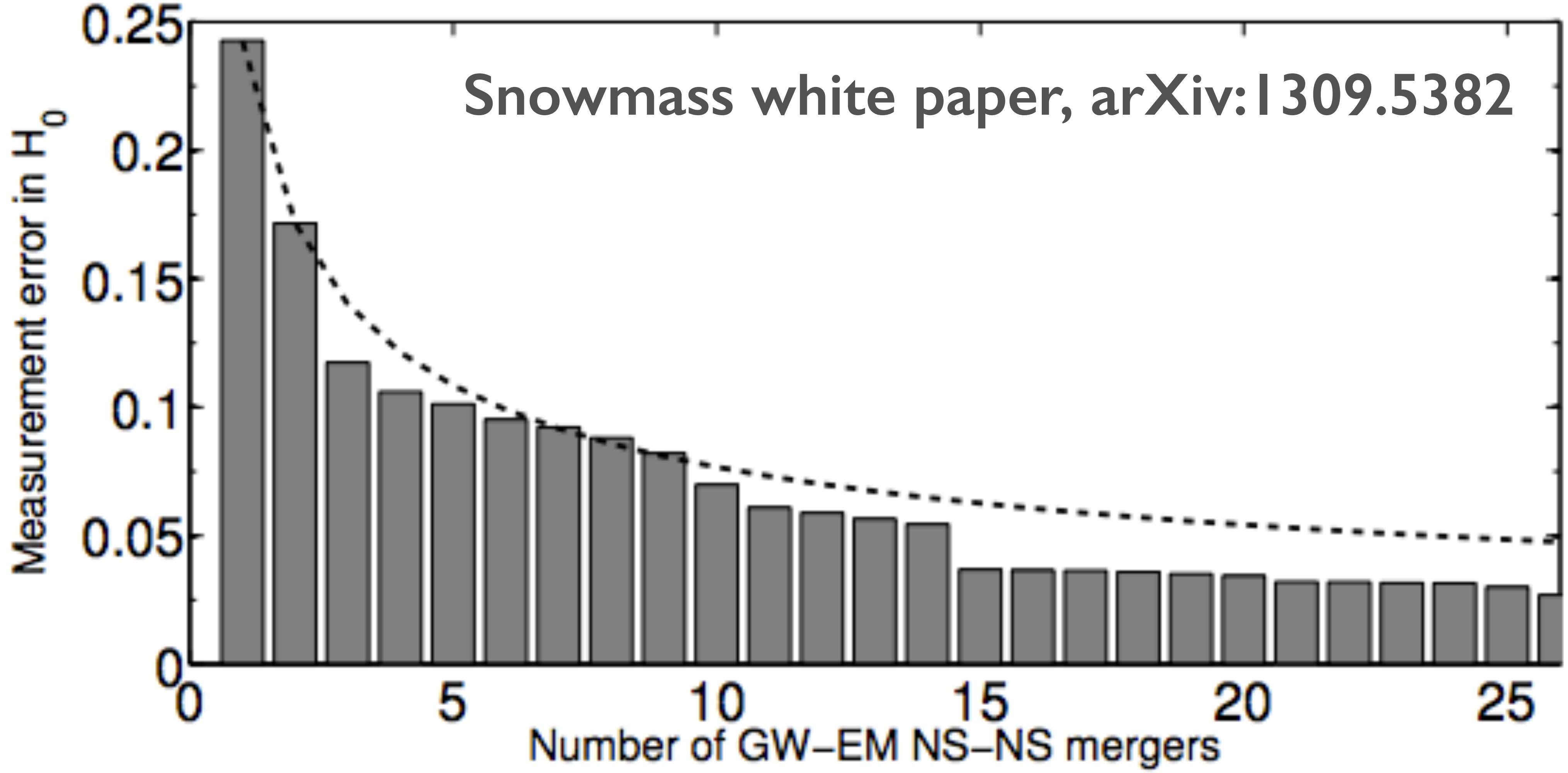


Figure 8: H_0 measurement uncertainty as a function of the number of multi-messenger (GW+EM) double neutron star merger events observed by an advanced LIGO-Virgo network. The dashed line shows Gaussian convergence.

PROSPECTS FOR 2030'S ?

Beyond the LSST era, we can expect that a next generation of cosmic surveys and GW detectors (e.g. LISA) will be operational. **We can imagine extending this program to higher redshifts**.

Projections for LISA (for **BBH*** events)
— **distance errors:**
< 0.5% at z = 1
< 2% at z = 3
—**angular resolution:**
~1 arcmin

*EM signatures for BBH events need to be studied. Kilonovae are not likely.

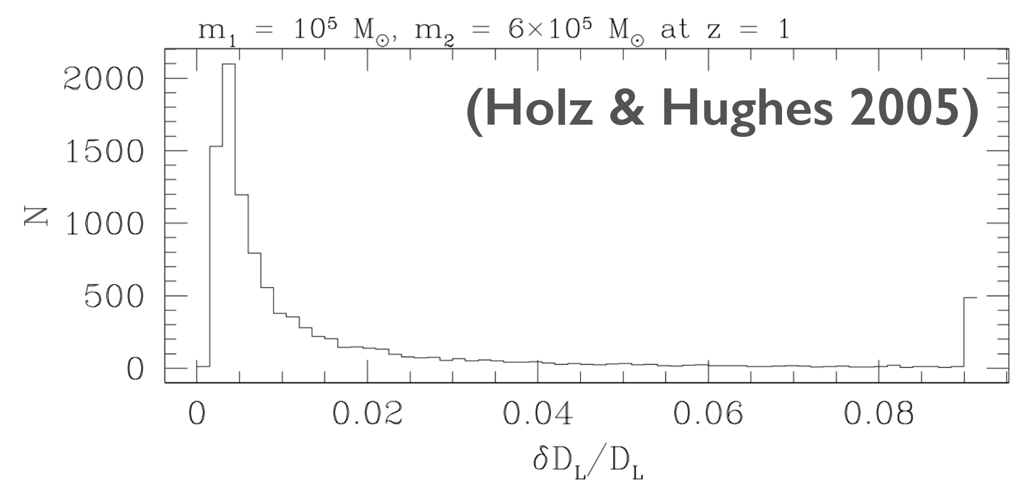


FIG. 5.— Distance errors for BBH measurements at $z = 3$ with $m_1 = 10^5\ M_\odot$, $m_2 = 6\times10^5\ M_\odot$, assuming that an electromagnetic counterpart allows precise sky position determination. The peak error is at $\delta D_L/D_L \sim 0.5\%$, and is almost entirely confined to $\delta D_L/D_L \lesssim 2\%$.

SUMMARY

Advanced GW detectors might offer a new window of opportunity for cosmological measurements, including **measurement of the Hubble parameter with percent-level precision or better**.

This talk describes our ongoing effort towards taking advantage of such opportunity, starting with DESGW. **Prospects for a full fledged program in the LSST era and beyond are encouraging.**