Convergence of Deep Learning and Large Scale Computing: A Paradigm Shift for Multi-Messenger Astrophysics

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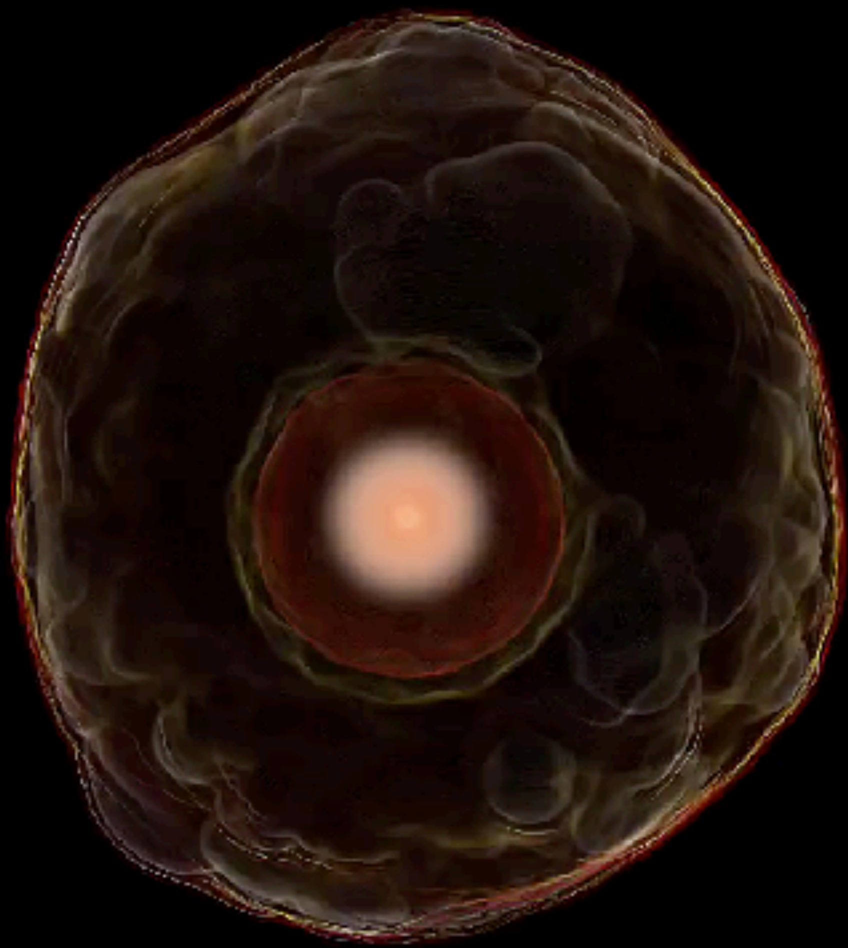
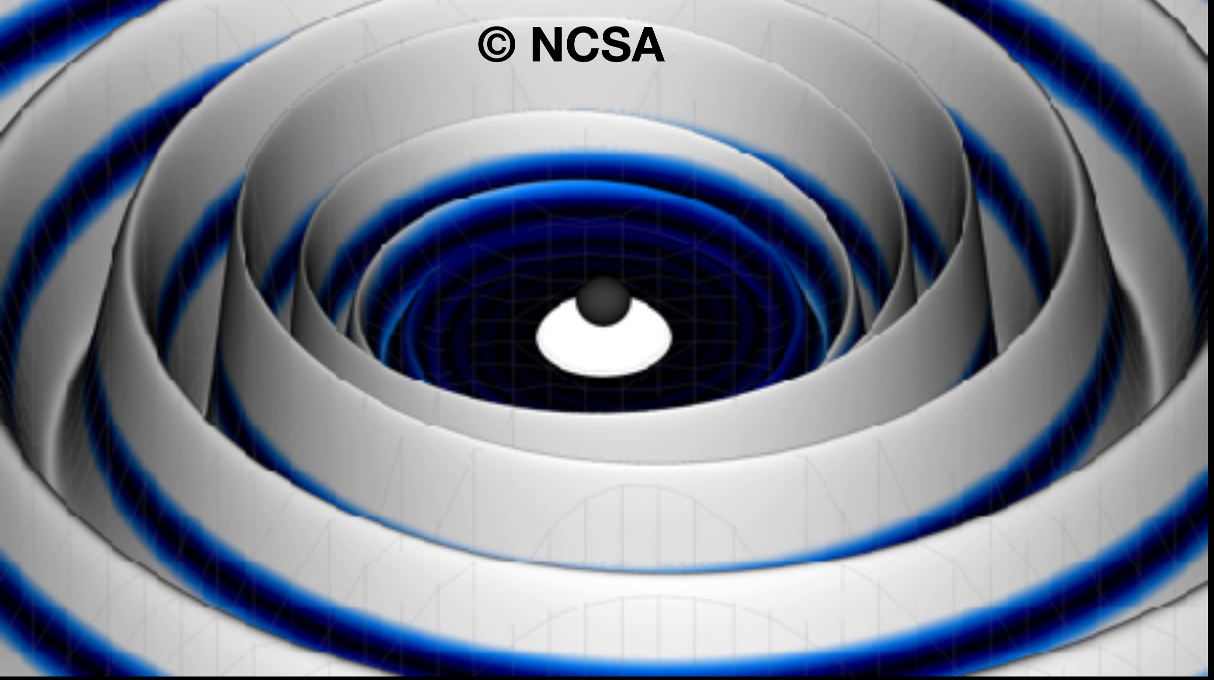
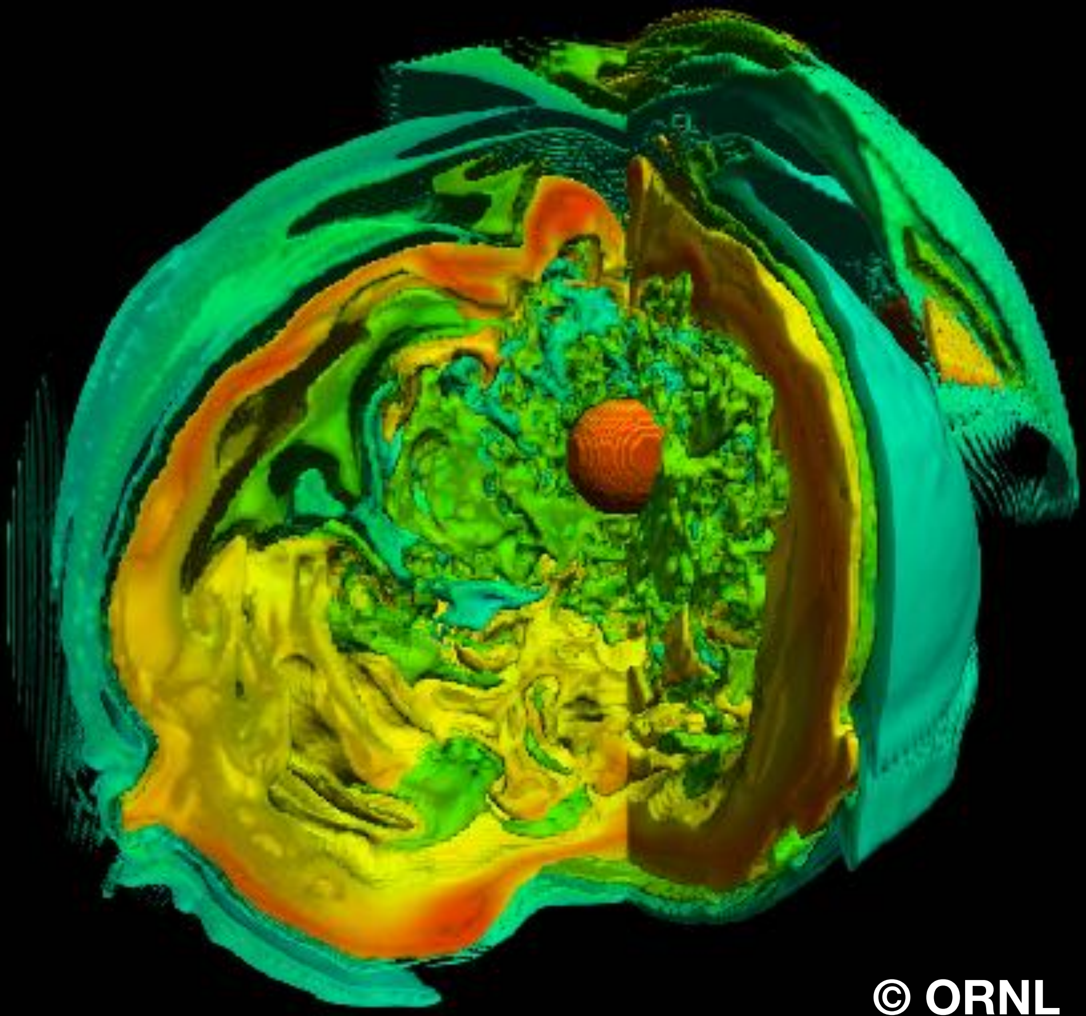
March 5th 2019





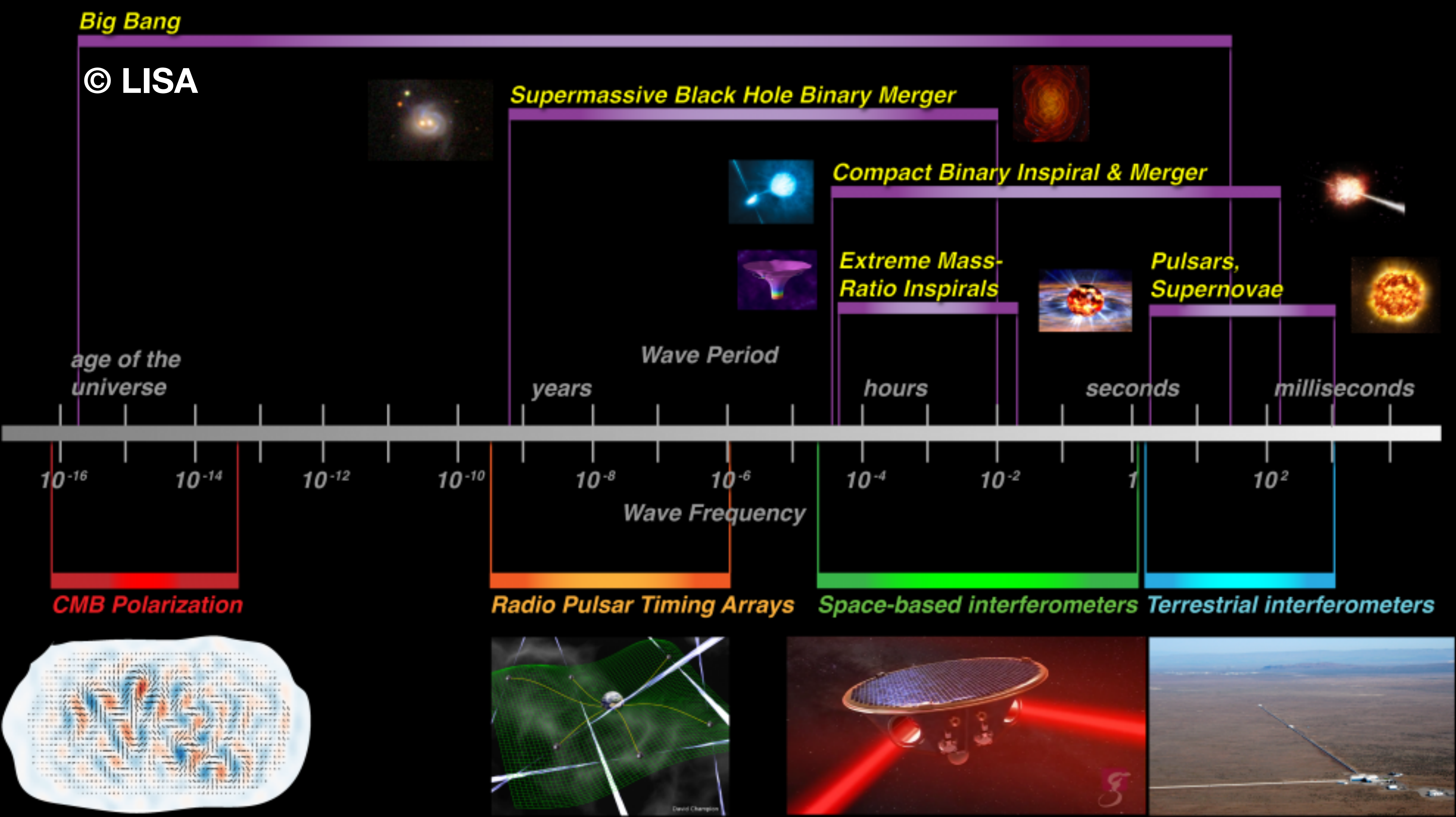
Listen to the Dark Sector of the Universe

Listen to and observe cosmic mergers

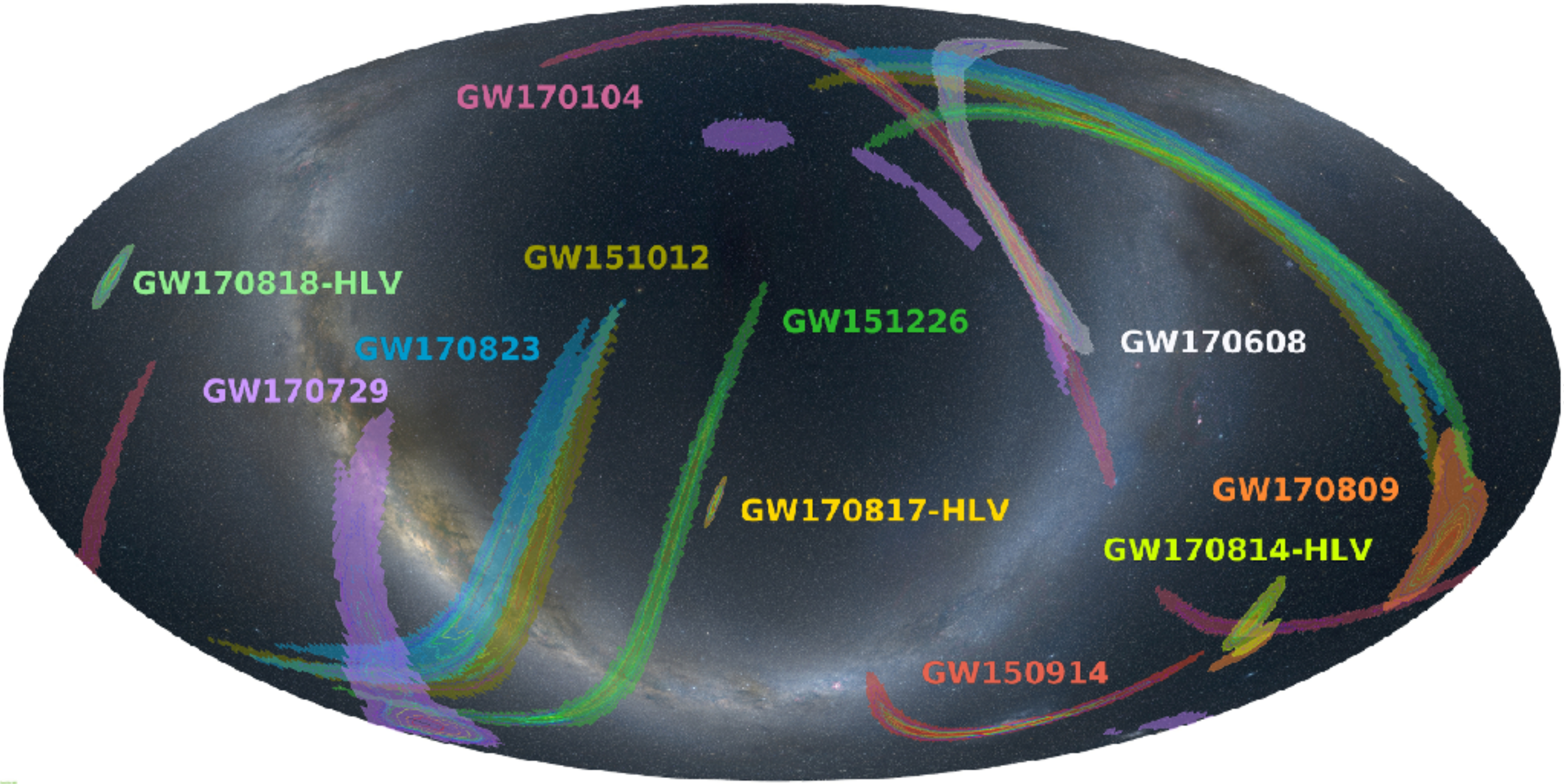


Listen to, observe and feel cosmic explosions in the nearby Universe

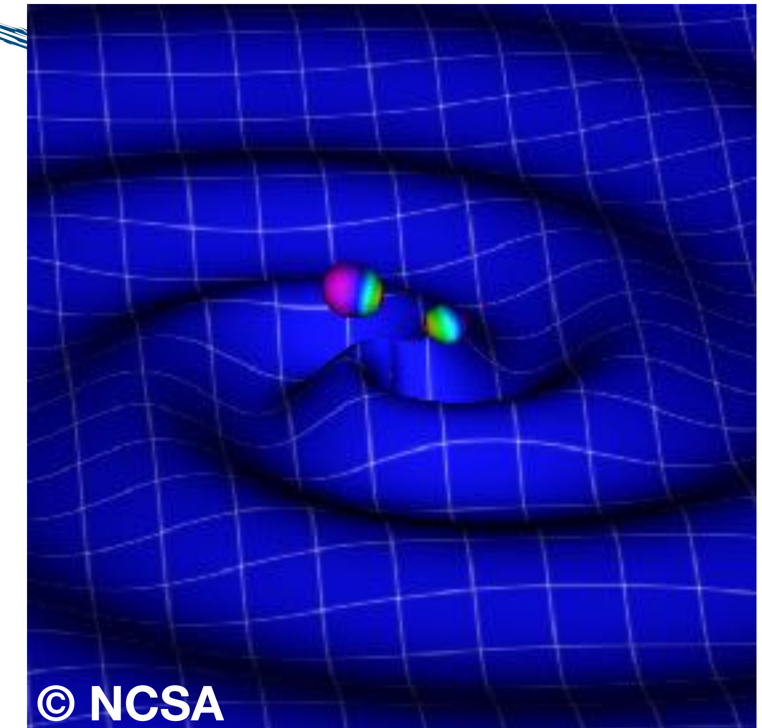
Gravitational Wave Astronomy



Gravitational Wave Discovery: An All-Sky Survey



Models and simulations



Discovery

Produce high quality gravitational wave data

Search for and find signals

Interpret observations

Implications for stellar evolution, astrophysics and cosmology

Repeat

Observations

Theory

$G_{\mu\nu} = 8\pi T_{\mu\nu}$

Sources: black hole and neutron star collisions, supernovae, oscillating neutron stars….

NCSA Gravity Group

Astronomy

Physics

NCSA

Blue Waters XSEDE

Innovative Systems Lab

DES and LSST

SPIN and REU

Coordinated Science Lab

Computer Science

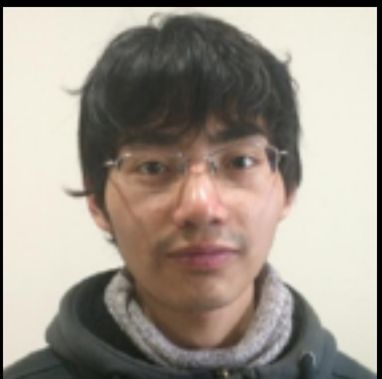
Statistics and Mathematics

Electrical and Computing Engineering


CAUTION
ILLINOIS



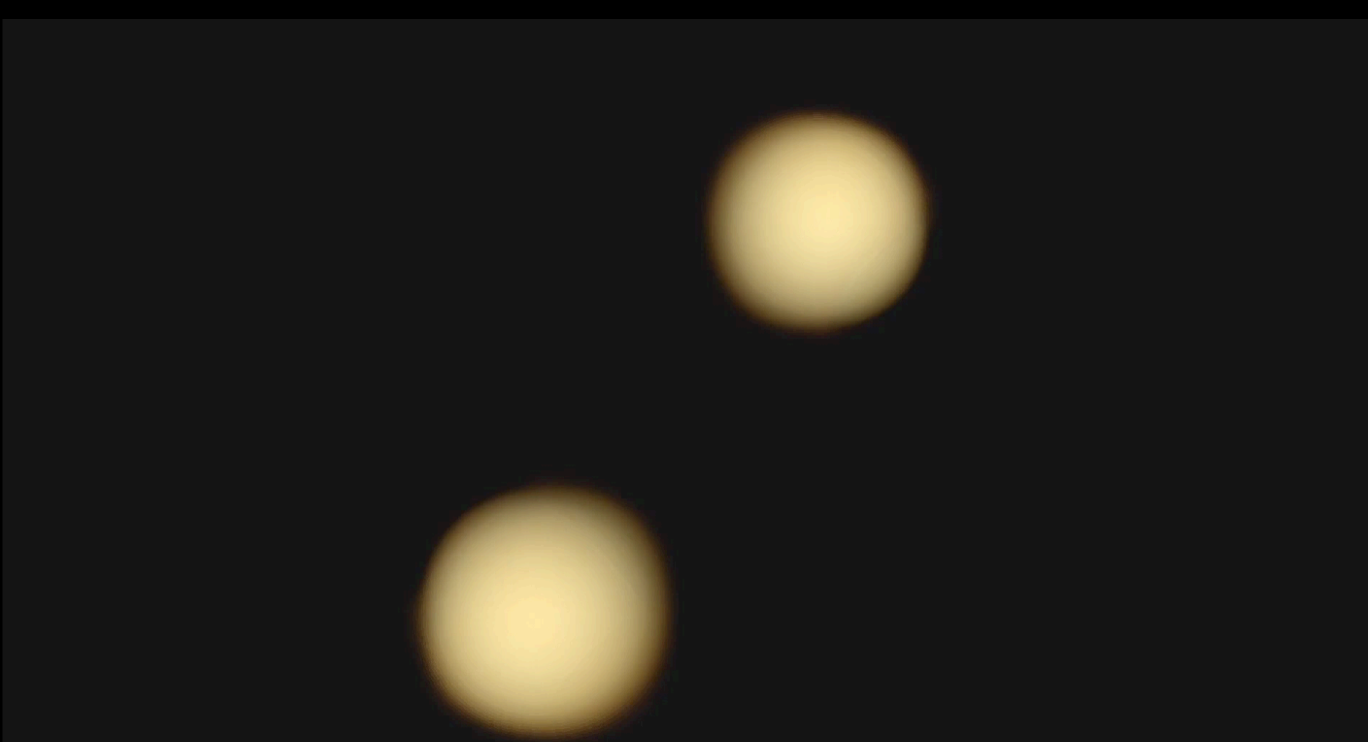


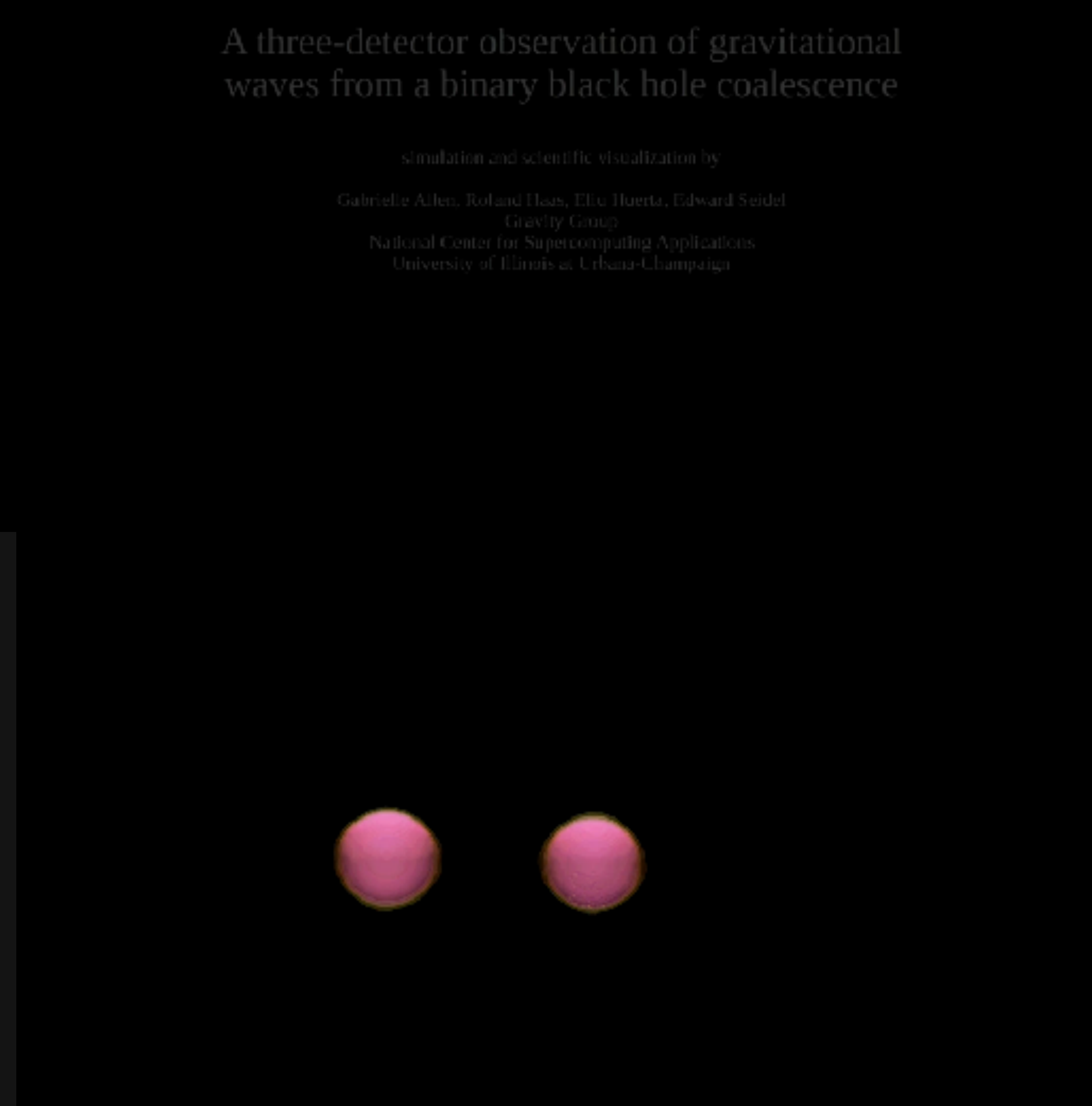






Numerical Relativity at NCSA



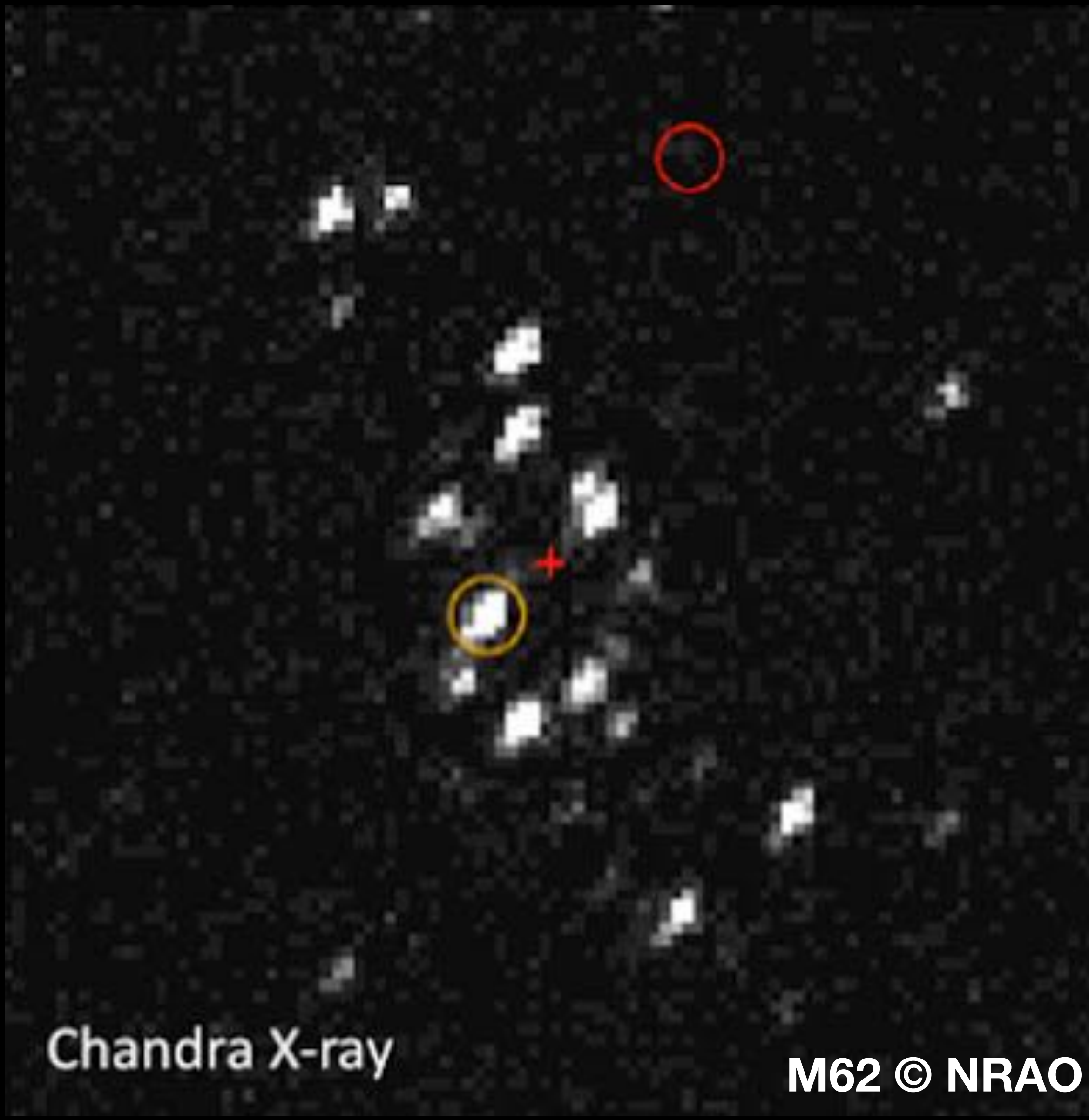


Numerical Relativity at NCSA

Huerta et al, arXiv:1901.07038

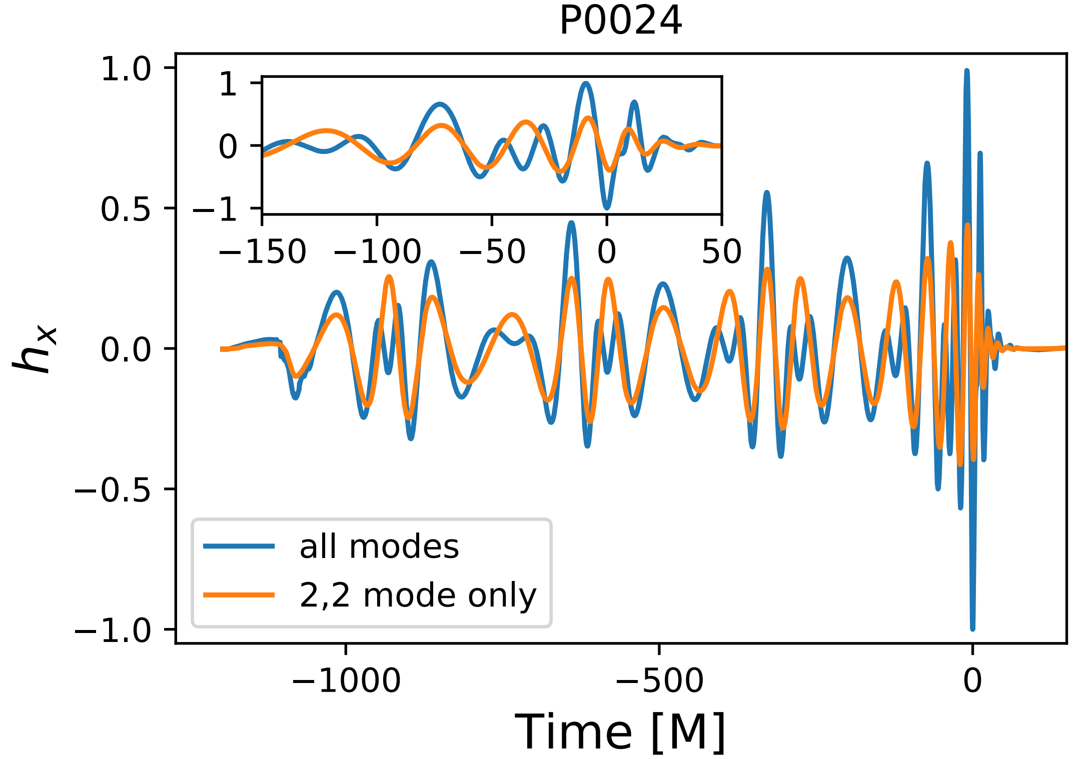
Gravitational Wave Astronomy

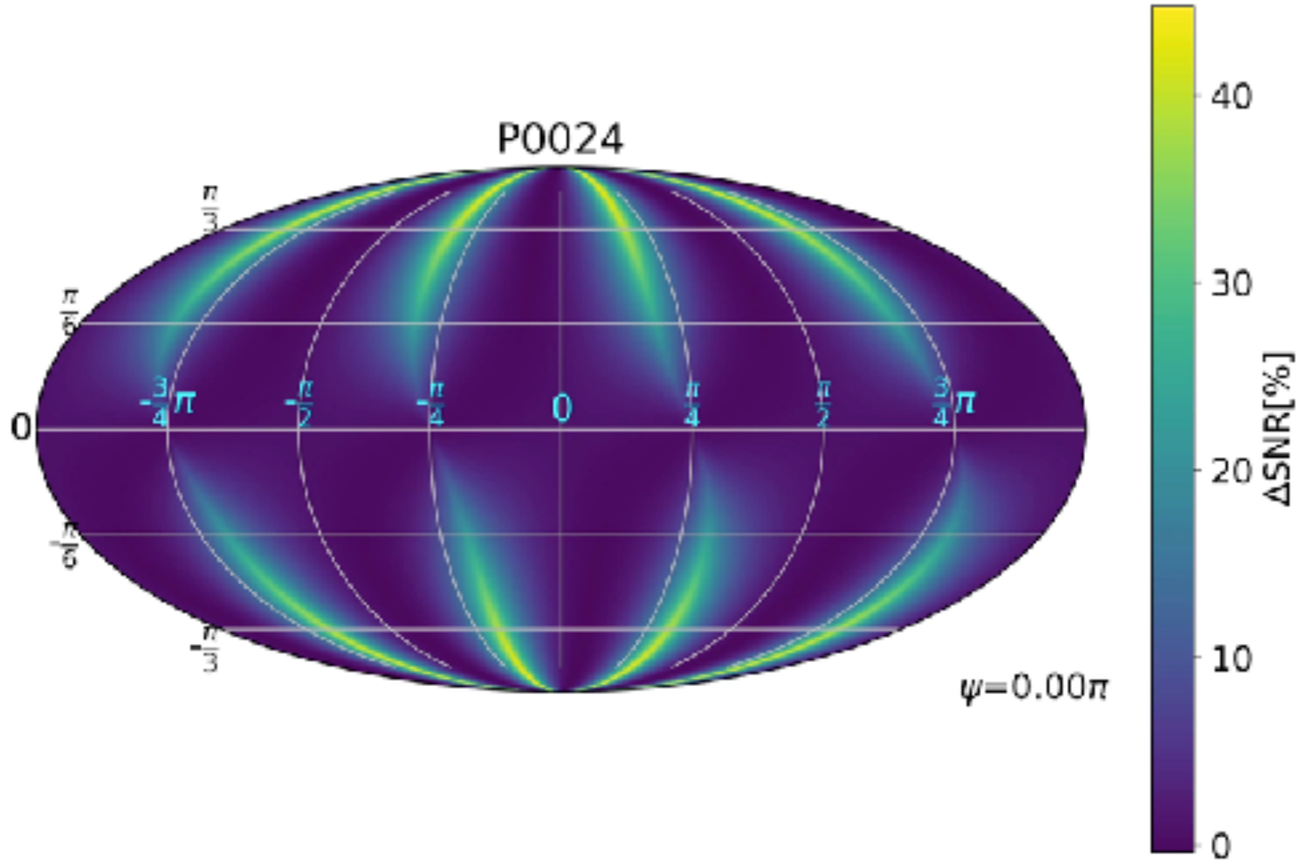
- Dynamical assembly of black hole and neutron star binaries in dense stellar environments
- Use gravitational waves to probe the existence of these sources
- Can we actually detect these signals with available algorithms?
- What can we learn from the observation of dynamically assembled compact binaries?

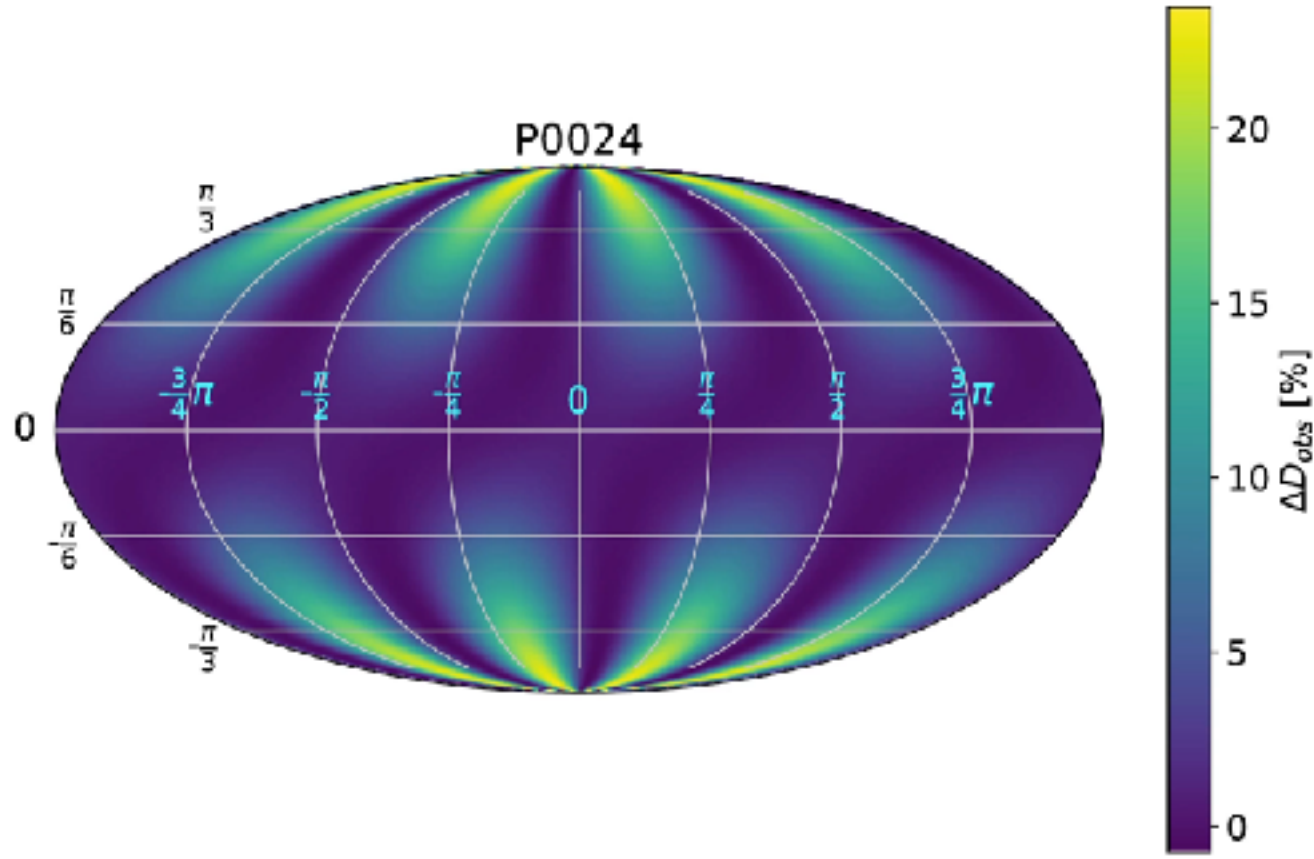


Gravitational Wave Astronomy

Rebei, Huerta, Wang, *et al.*, arXiv:1807.09787 To appear in *Phys. Rev.* D



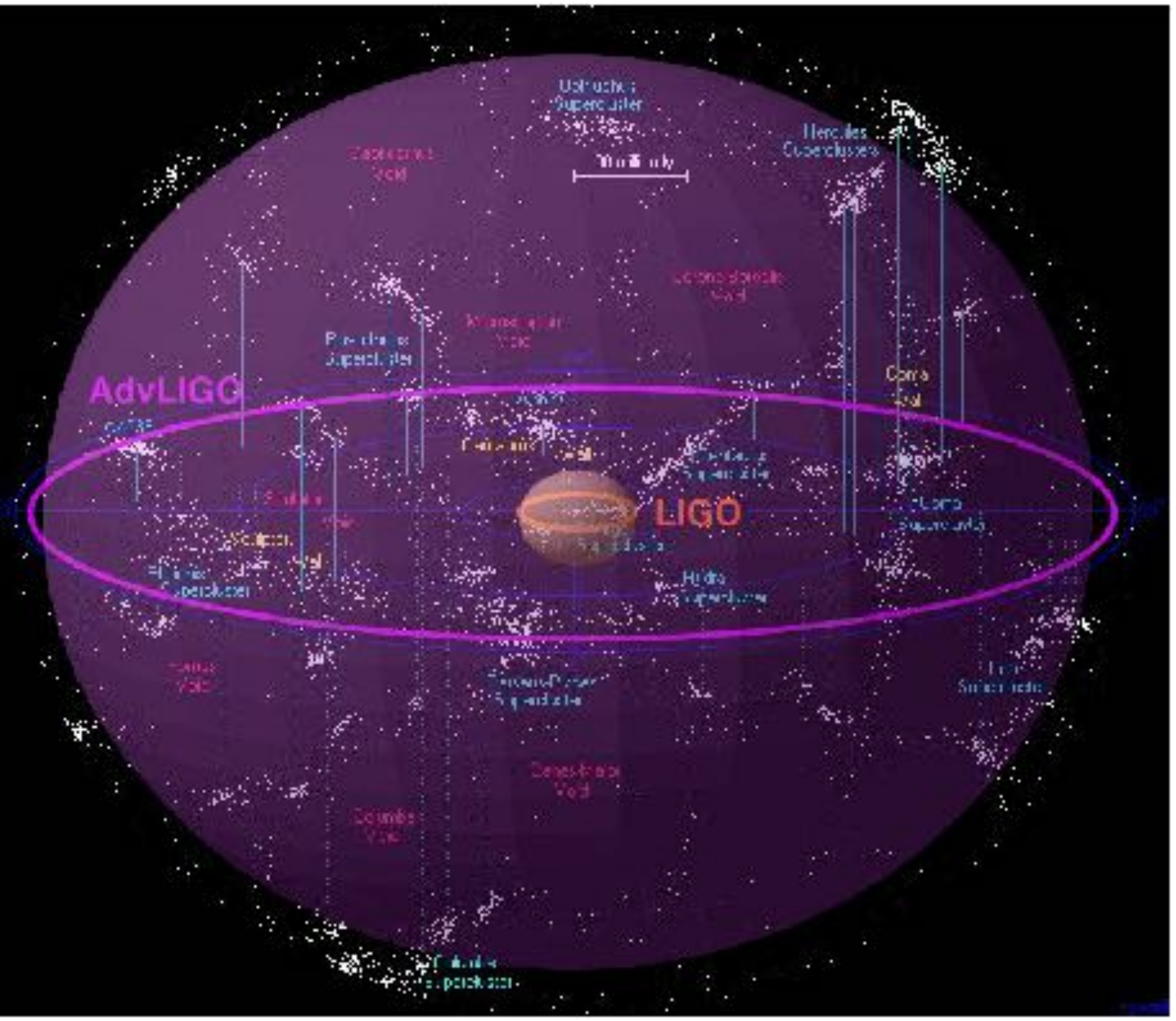




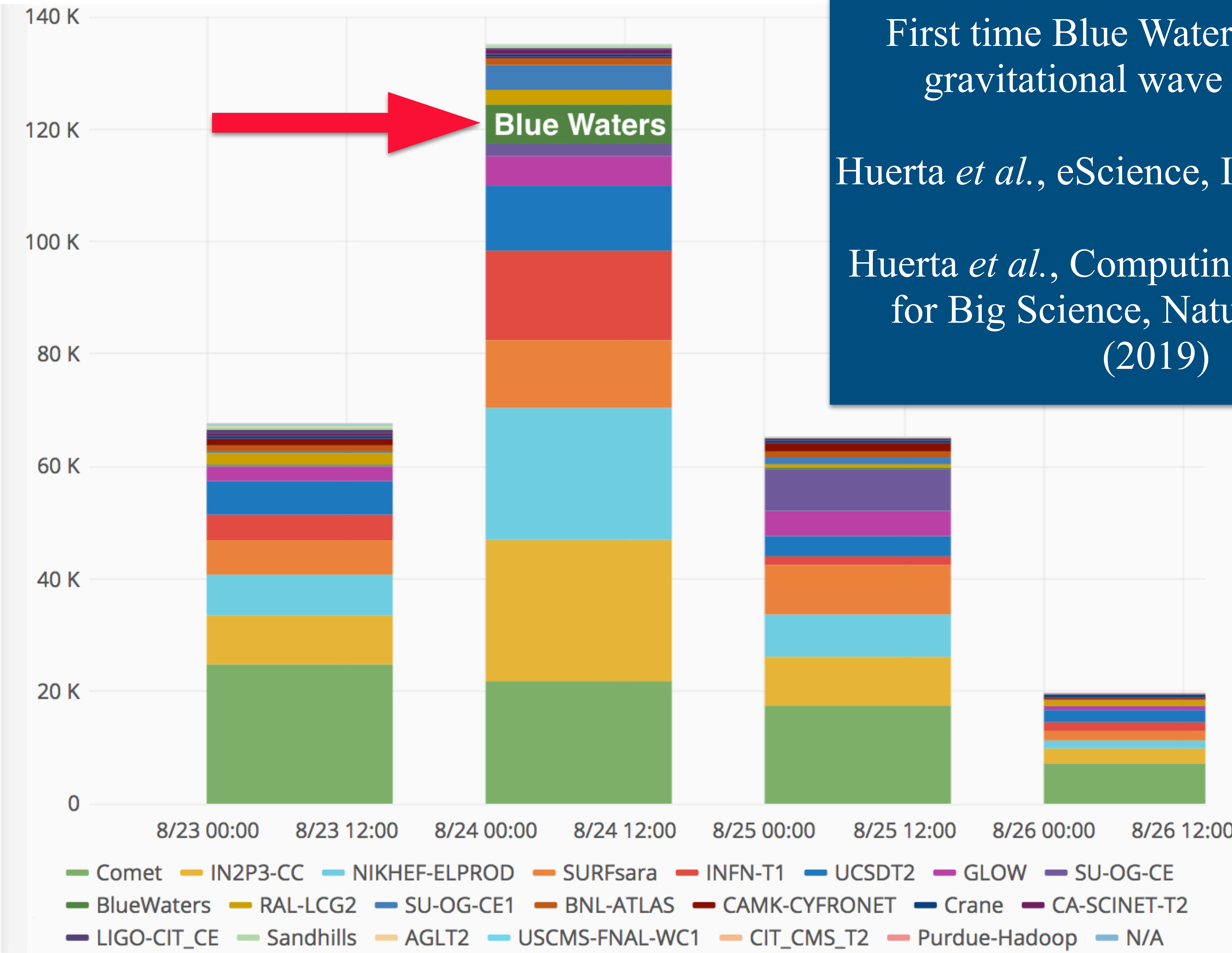
Sources, Signals and *Searches*

Number of observations increases with the detectors' sensitivity

Localization improves with a global detector network



Gravitational Wave Data Science at Illinois



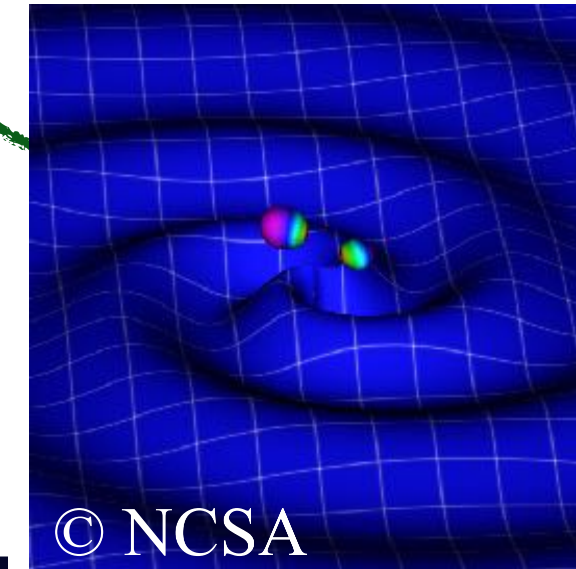
First time Blue Waters is used for gravitational wave discovery

Huerta *et al.*, eScience, IEEE 47 (2017)

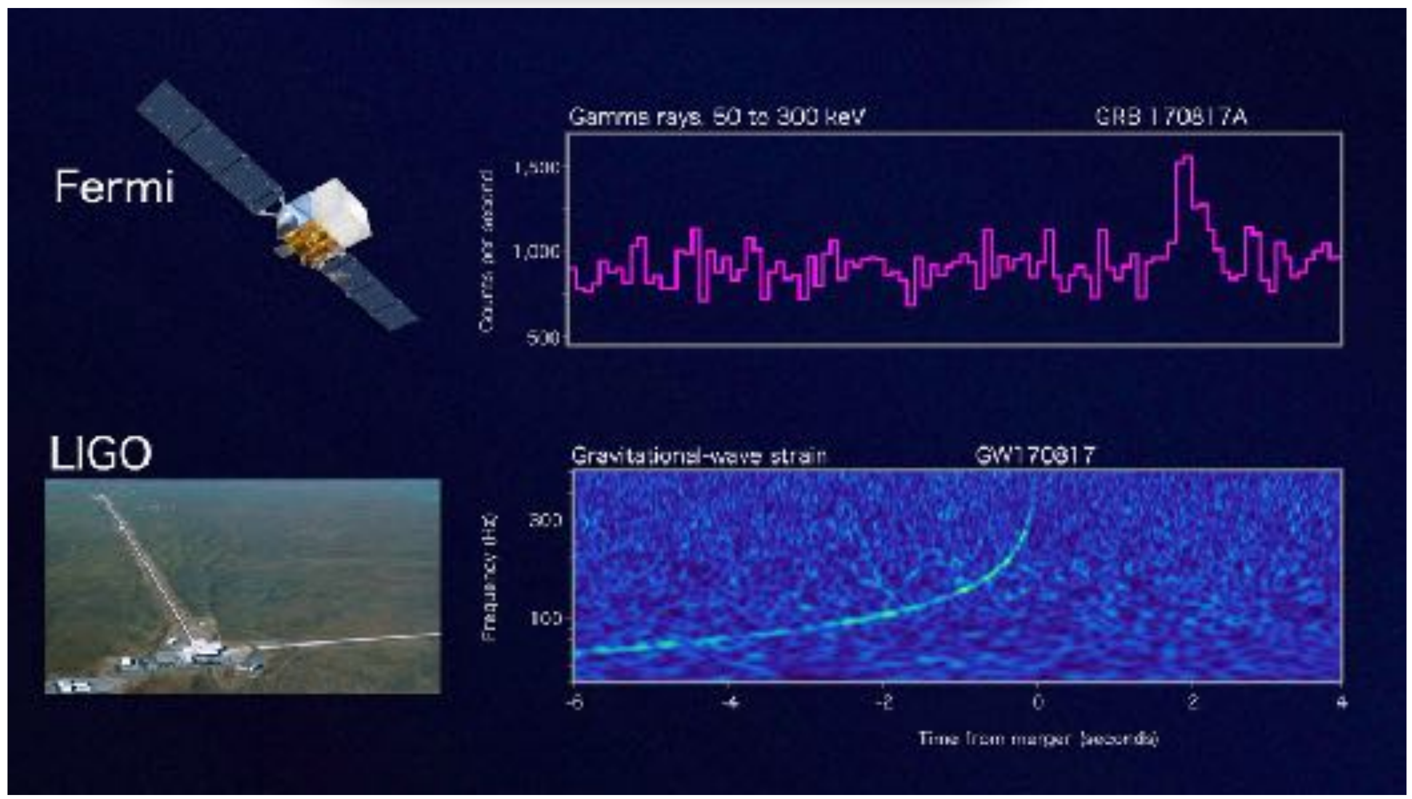
Huerta *et al.*, Computing and Software for Big Science, Nature Springer (2019)

Models and simulations

Scientific Discovery



Observations



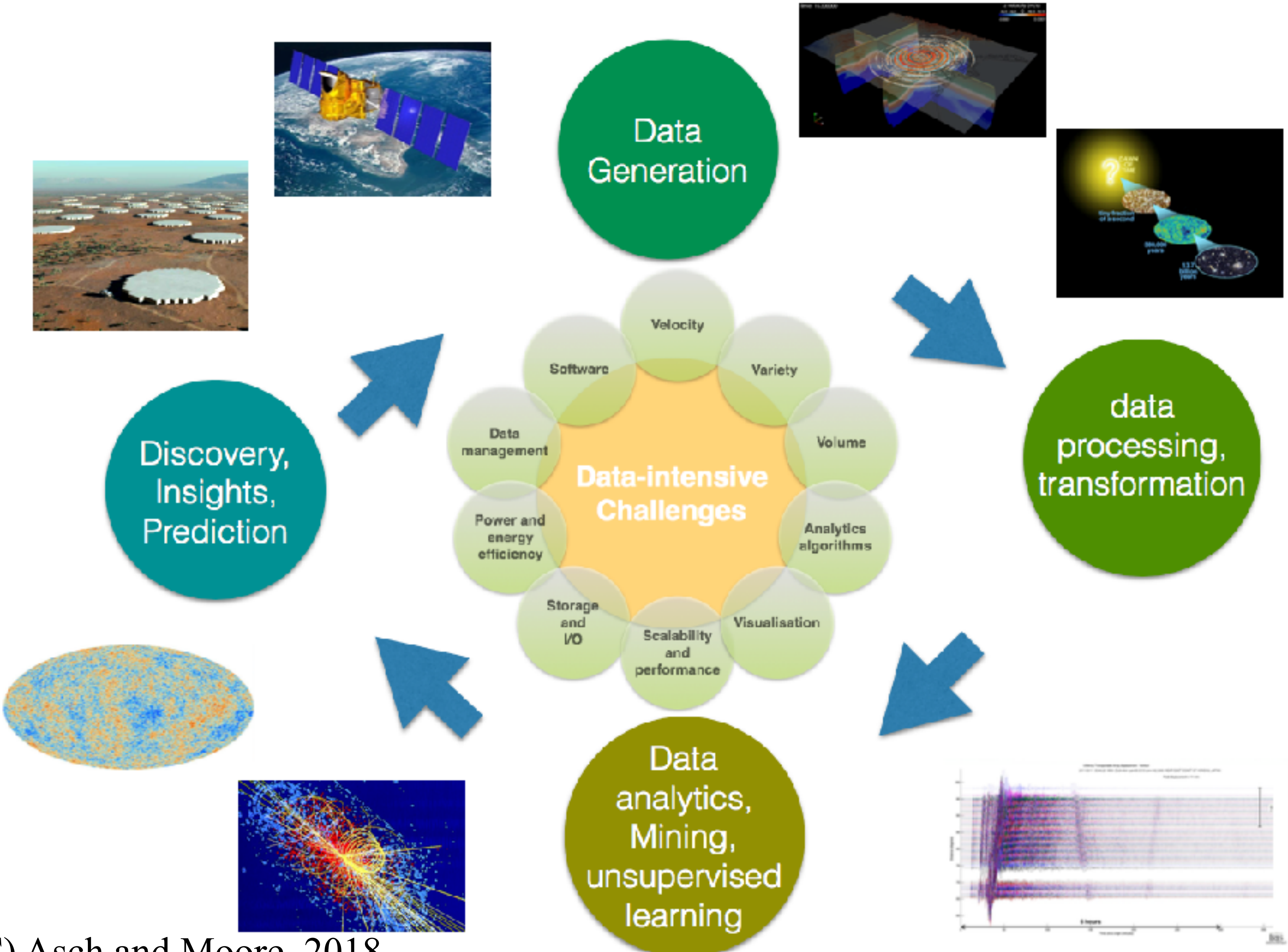
Theory

$$G_{\mu\nu} = 8\pi T_{\mu\nu}$$

Routine: black hole and neutron star collisions

Future: supernovae, oscillating neutron stars….

Data-driven Discovery in the Community



Multi-Messenger Astronomy has taken off!

Swift transition from "first detection era" to discovery at scale

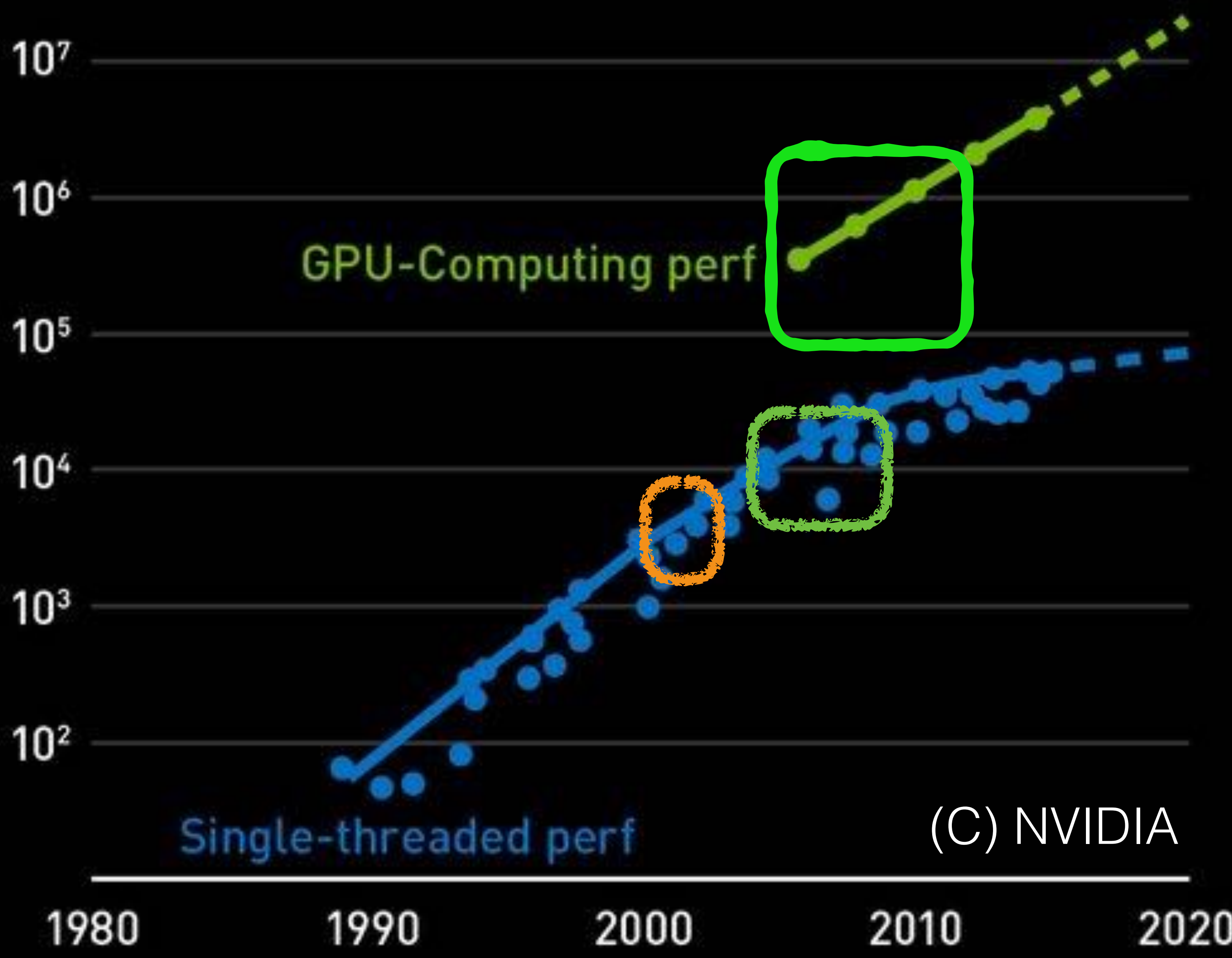
Binary black holes observations are now routine!

Several Multi-Messenger observations will take place in LIGO-Virgo-Kagra third observing run

Pressing need to change existing paradigm to maximize discovery

On disruptive changes and data revolutions

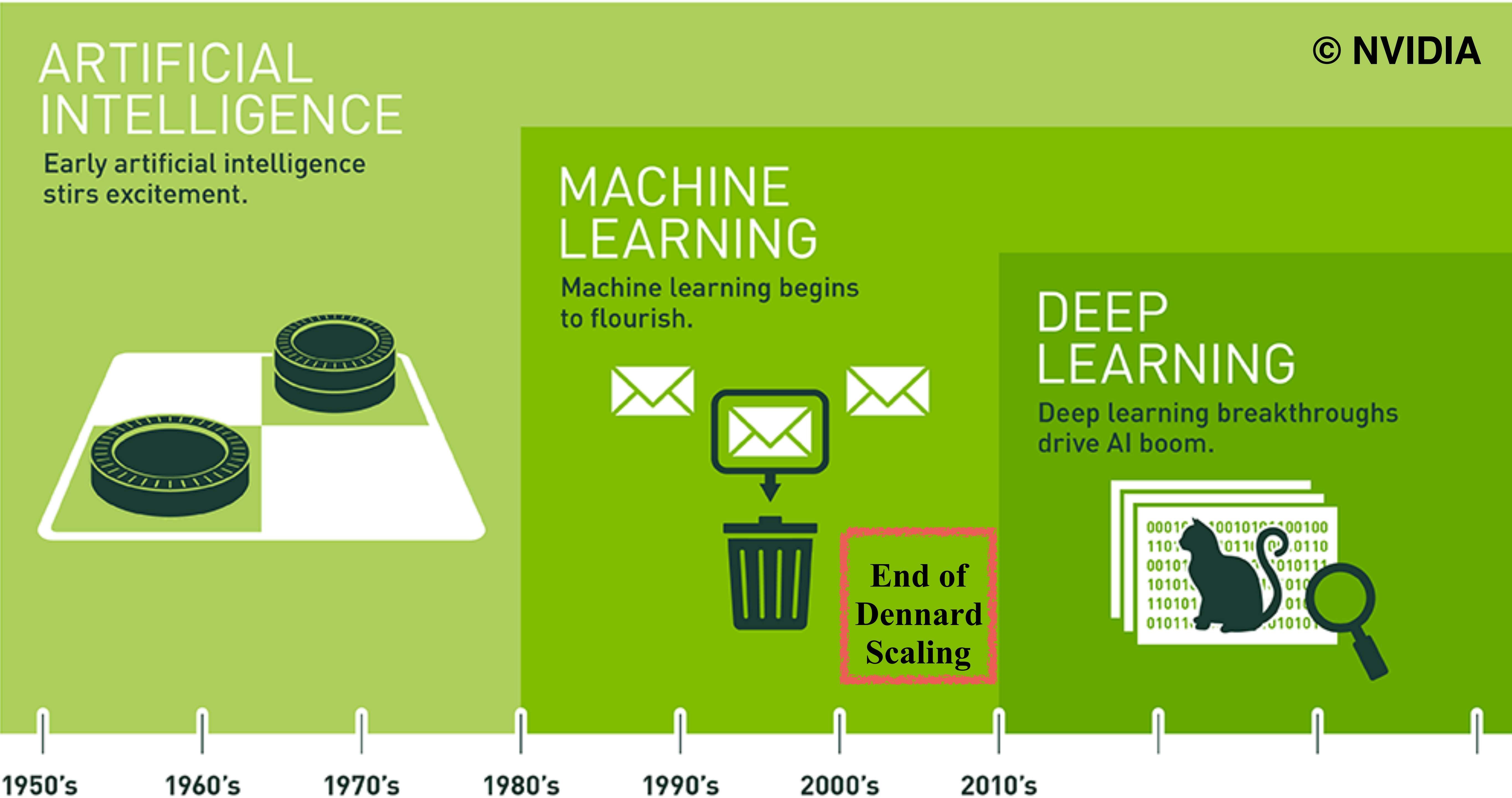
HPC and Big Data Revolution Coexist
Roadmap for Convergence

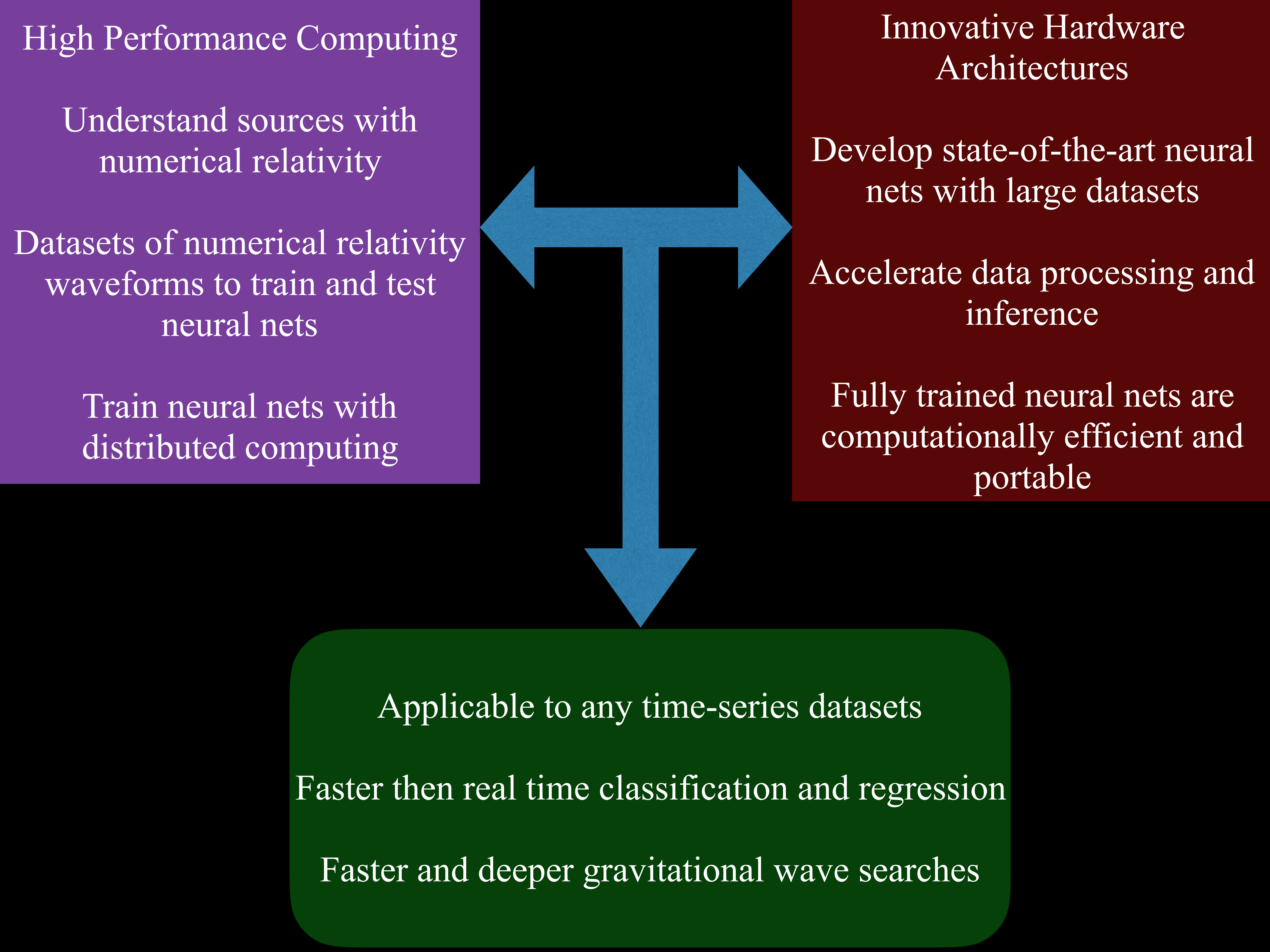


2012
Boom of interest in infrastructure and tools for big data analytics in cloud computing environments

2015
US Presidential Strategic Initiative: convergence of big data and HPC ecosystem

Deep Learning
From optimism to breakthroughs in technology and science




High Performance Computing
Understand sources with numerical relativity
Datasets of numerical relativity waveforms to train and test neural nets
Train neural nets with distributed computing
Innovative Hardware Architectures
Develop state-of-the-art neural nets with large datasets
Accelerate data processing and inference
Fully trained neural nets are computationally efficient and portable
Applicable to any time-series datasets
Faster then real time classification and regression
Faster and deeper gravitational wave searches

ACM Award, 1st place

ACM Award Worldwide, 3rd place

2019 HPCwire Award, Best AI Application

Sociological Implications

Daniel George now a Research Scientist at Google X

From pioneering work to production scale applications

First application of deep learning to detect and characterize a 4-D signal manifold with 1+ trillion templates
Shen, Huerta and Zhao

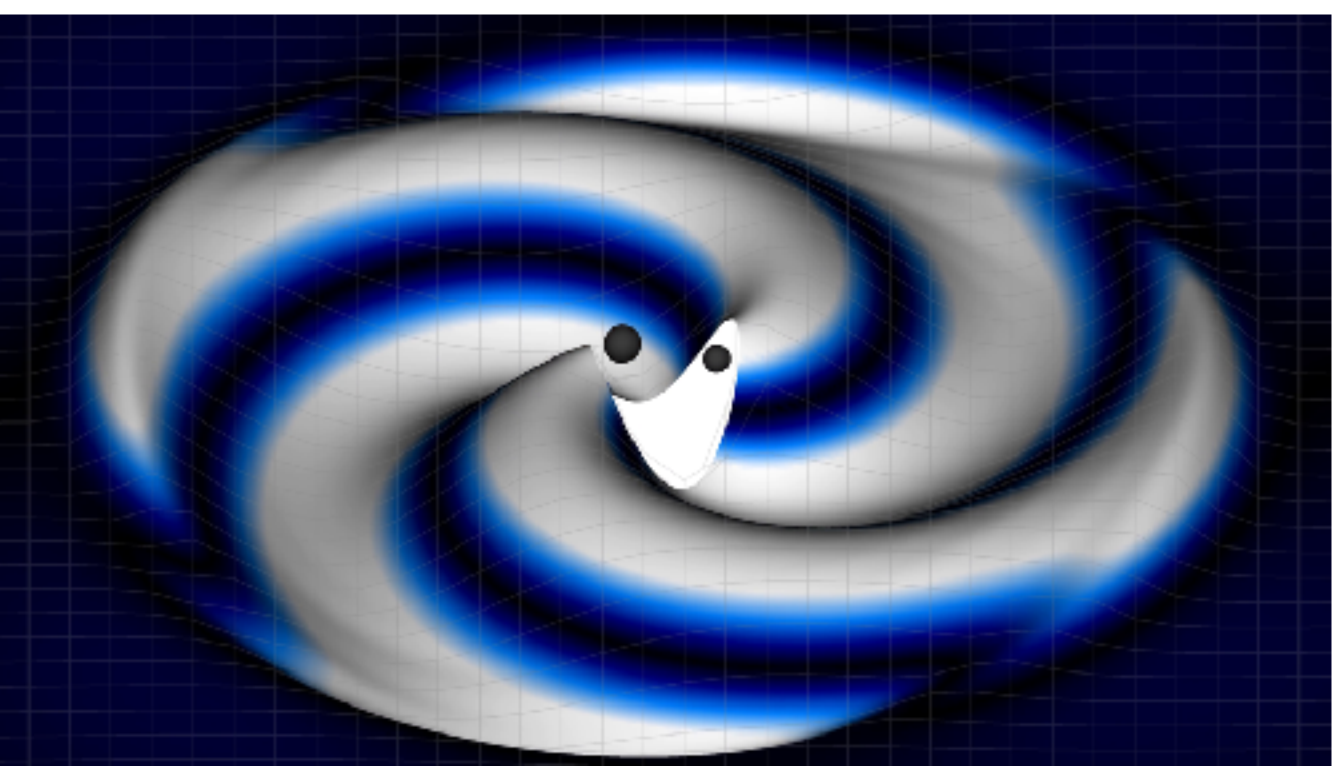
End-to-end analysis: from detection to tests of general relativity

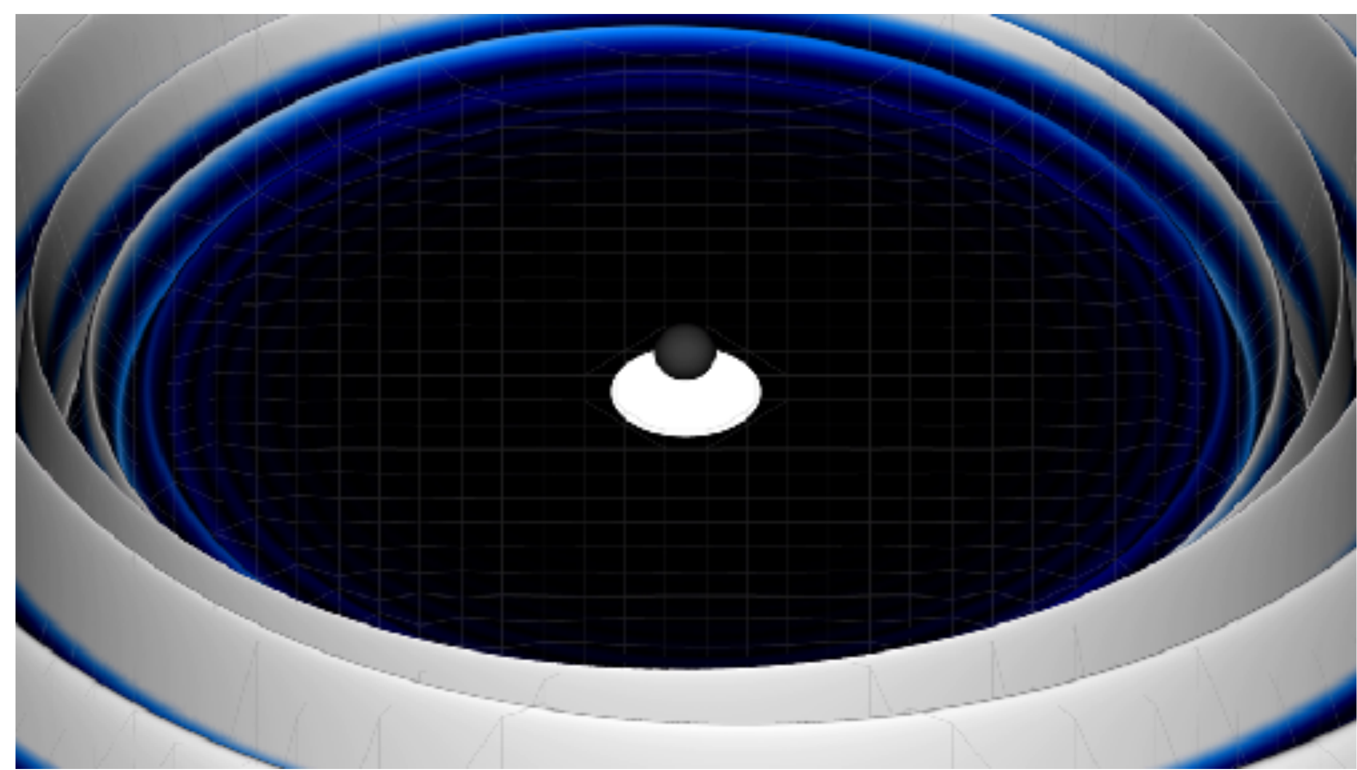
Parameter estimation studies are now endowed with a solid statistical backbone

From pioneering work to production scale applications

Shen, Huerta and Zhao. To hit arXiv this week!

EVENT NAME	$m_1[M_\odot]$		$m_2[M_\odot]$		a_f		ω_R		ω_I	
GW150914	37.46	[4.13| 0.06]	30.80	[0.43|-1.65]	0.689	[0.037| 0.17]	0.5362	[0.0127|-0.20]	0.0798	[0.0011| 0.16]
GW151012	23.89	[0.35| 1.65]	17.34	[0.56| 1.44]	0.653	[0.009| 0.25]	0.5214	[0.0030| 0.15]	0.0810	[0.0003|-0.15]
GW151226	17.60	[2.01| 0.87]	14.14	[2.85| 0.73]	0.646	[0.006| 1.53]	0.5188	[0.0021| 1.51]	0.0812	[0.0001|-1.60]
GW170104	36.45	[1.54|-0.76]	21.83	[3.54|-0.56]	0.661	[0.080|-0.84]	0.5185	[0.0306|-0.48]	0.0816	[0.0029| 0.57]
GW170608	13.96	[1.13| 1.10]	11.96	[1.07| 1.56]	0.697	[0.025|-1.28]	0.5278	[0.0154|-0.95]	0.0809	[0.0011|-0.67]
GW170729	48.61	[1.58|-1.61]	37.69	[1.82|-0.28]	0.694	[0.019|-0.47]	0.5102	[0.0107|-0.50]	0.0812	[0.0019|-0.16]
GW170809	31.01	[3.29| 0.60]	22.42	[4.56| 1.85]	0.698	[0.034|-1.23]	0.5428	[0.0163|-1.15]	0.0779	[0.0016|-1.05]
GW170814	35.07	[1.75| 0.84]	21.50	[0.52| 0.99]	0.718	[0.010|-1.89]	0.5377	[0.0108|-1.38]	0.0794	[0.0003| 1.76]
GW170818	40.05	[1.29|-1.57]	24.08	[0.93|-1.33]	0.656	[0.015| 0.73]	0.5129	[0.0043| 1.21]	0.0816	[0.0005|-1.02]
GW170823	39.56	[1.75|-1.44]	30.14	[0.53|-1.68]	0.740	[0.002|-1.76]	0.5510	[0.0007|-1.74]	0.0782	[0.0001| 1.75]





Gravitational Wave Cosmology

Gravitational waves can enable standard-siren measurements of the Hubble constant

No electromagnetic counterpart needed

Gravitational Wave Cosmology

Gravitational wa

enable st

measurem

Hubble c

No electromagnetic
counterpart needed

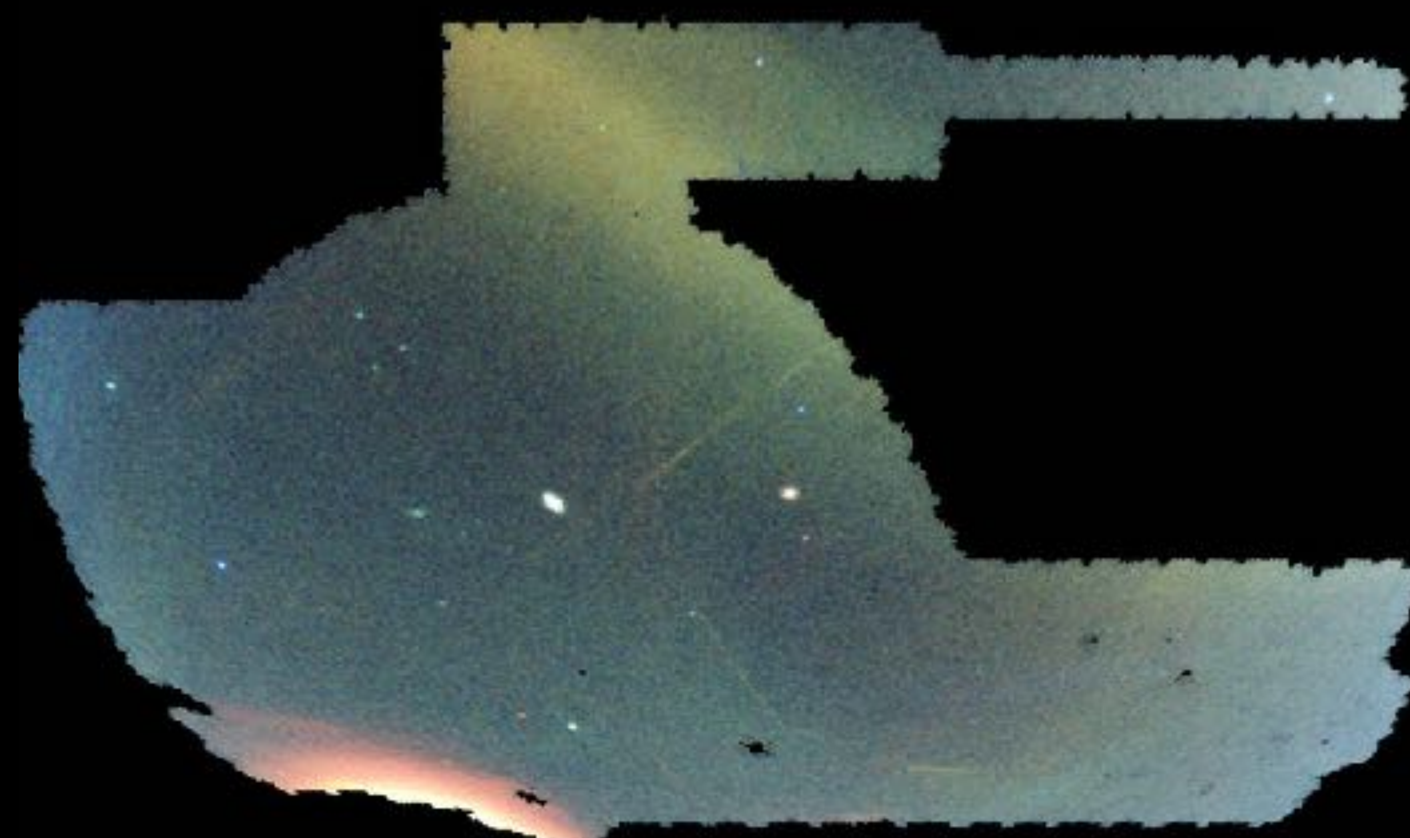
We need galaxy catalogs

DES provides ideal case study

Deep Learning for DES data science

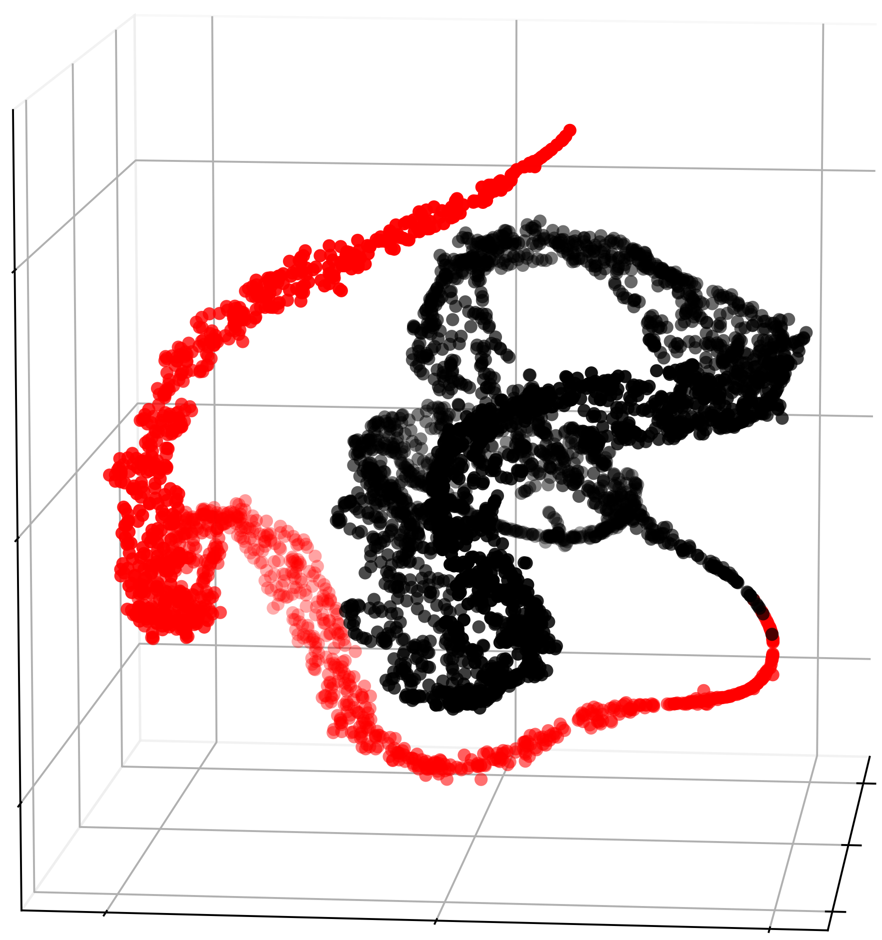
From the citizen science revolution using the Sloan Digital Sky Survey…

… to large scale discovery using unlabeled images in the Dark Energy Survey using deep learning



Deep Learning for DES data science

Khan, Huerta, Wang and Gruendl,
arXiv:1812.02183
To appear in Physics Letters B



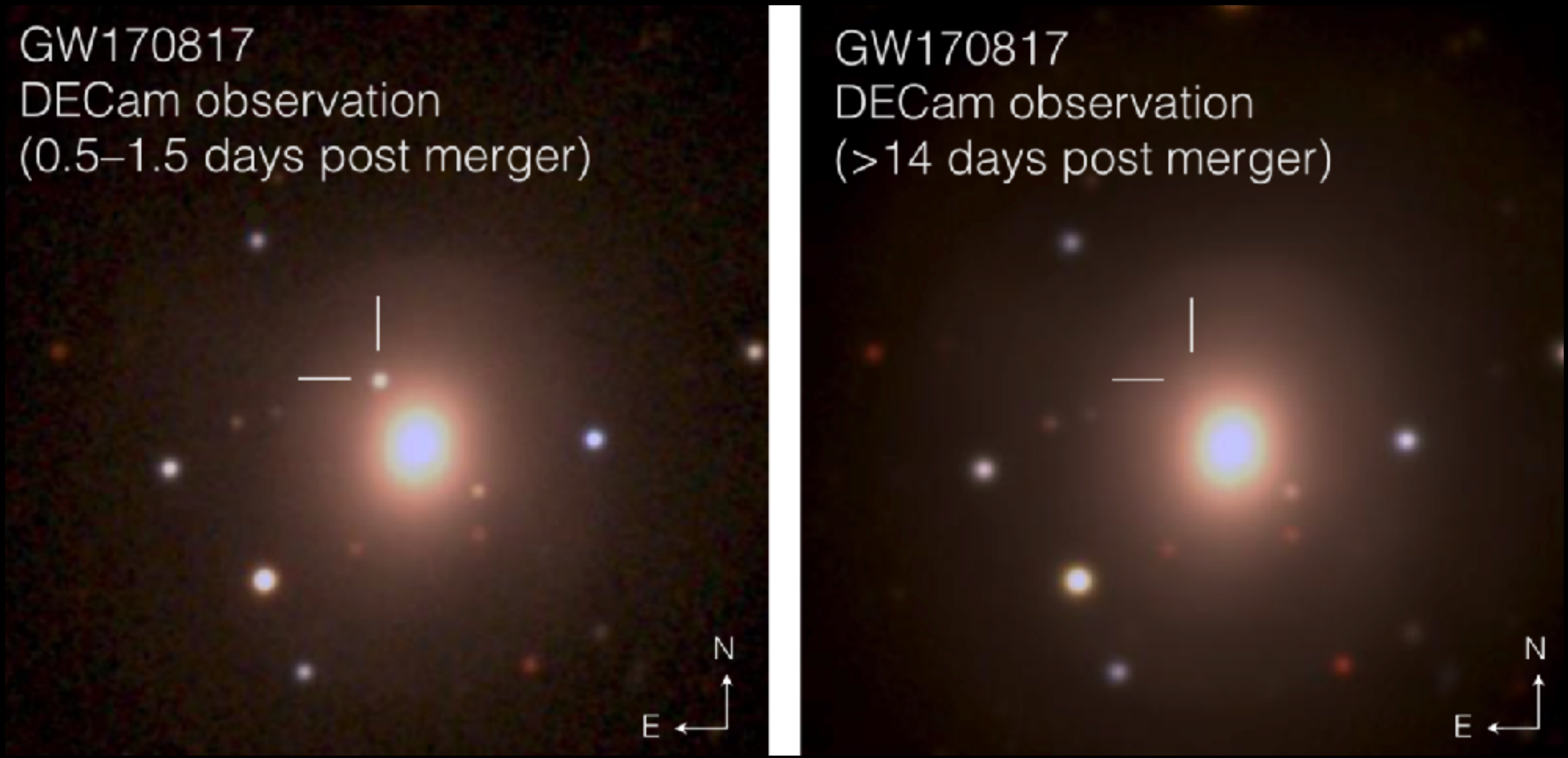
10k+ raw, unlabeled galaxy images from DES clustered according to morphology using RGB filters

Scalable approach to curate datasets, and to construct large-scale galaxy catalogs

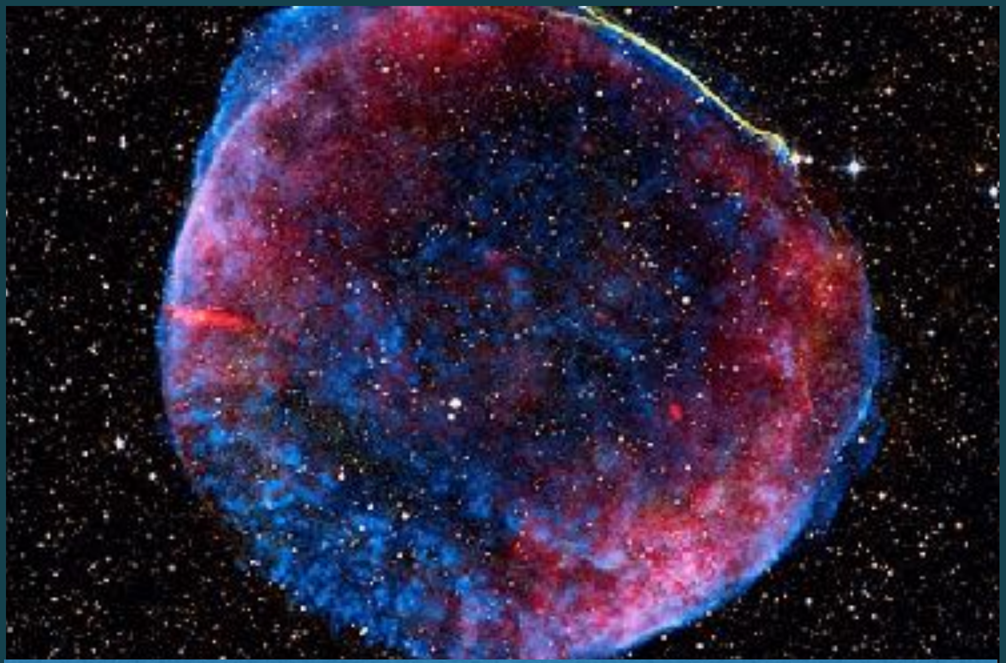
Now consider these anomalies

Post-process images in real-time

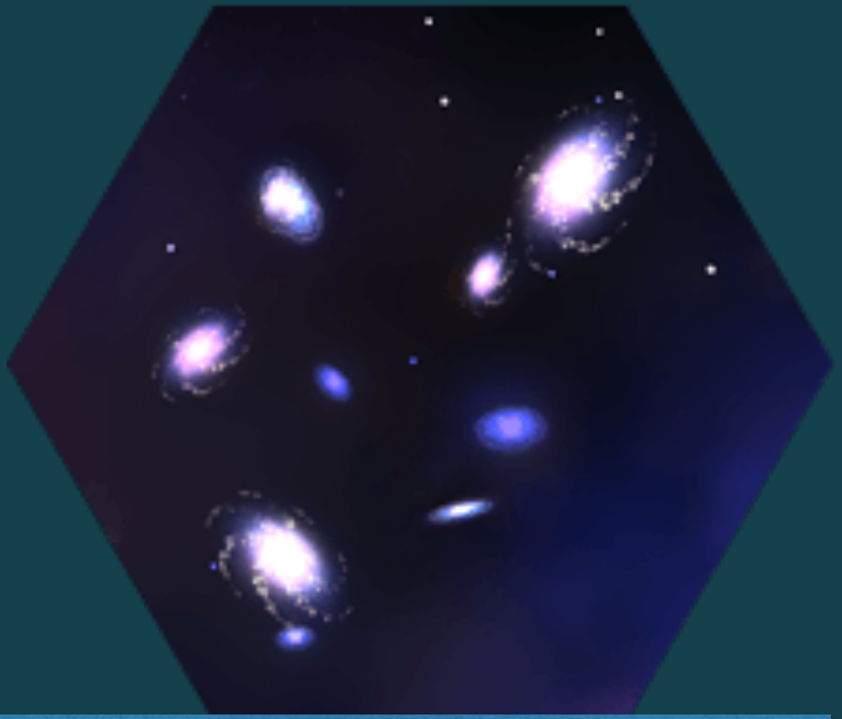
Image subtraction, feature extraction, unsupervised learning



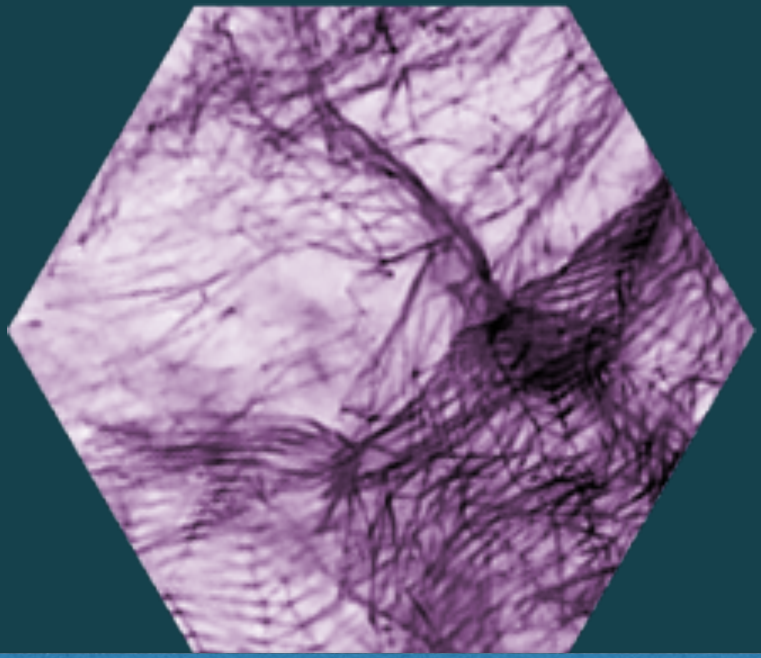
LSST SCIENCE



Observe the transient sky in UHF, prepare for the unexpected!



Galaxy catalogs to unveil effect of dark energy in structure of spacetime



Search for and use weak lenses to find and understand dark matter

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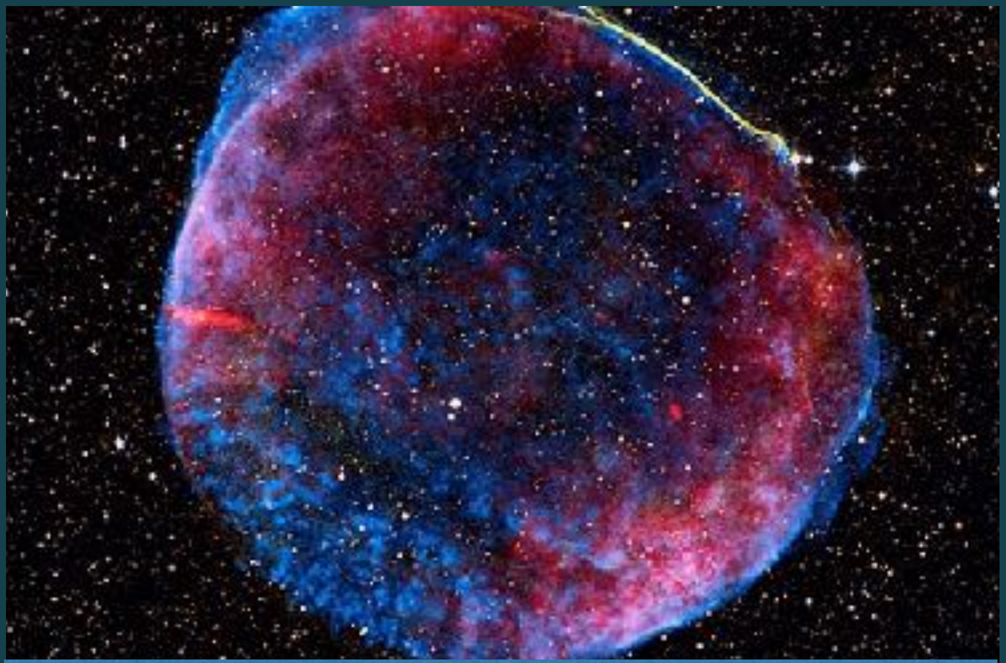

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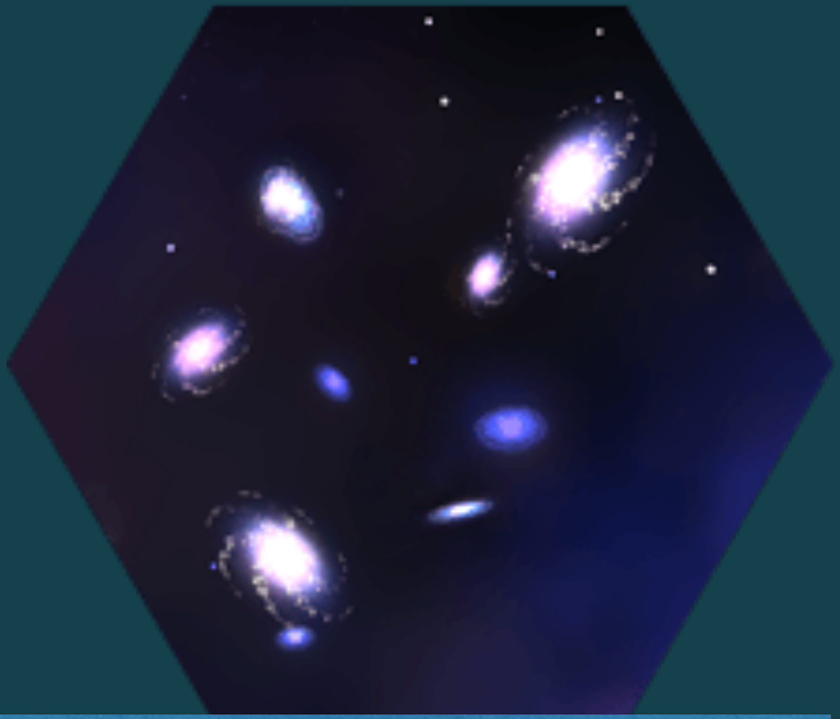

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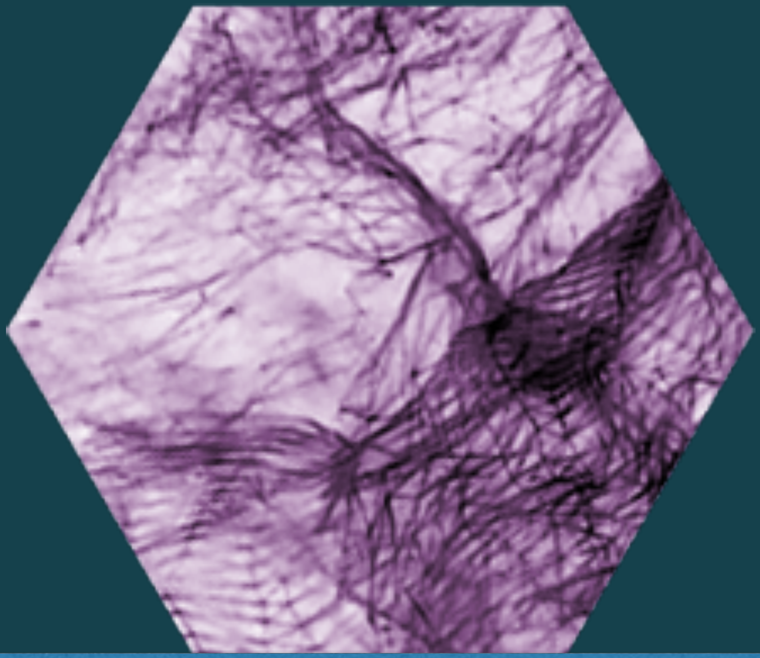

Search for and use weak lenses to find and understand dark matter

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