PULSAR TIMING ARRAYS:

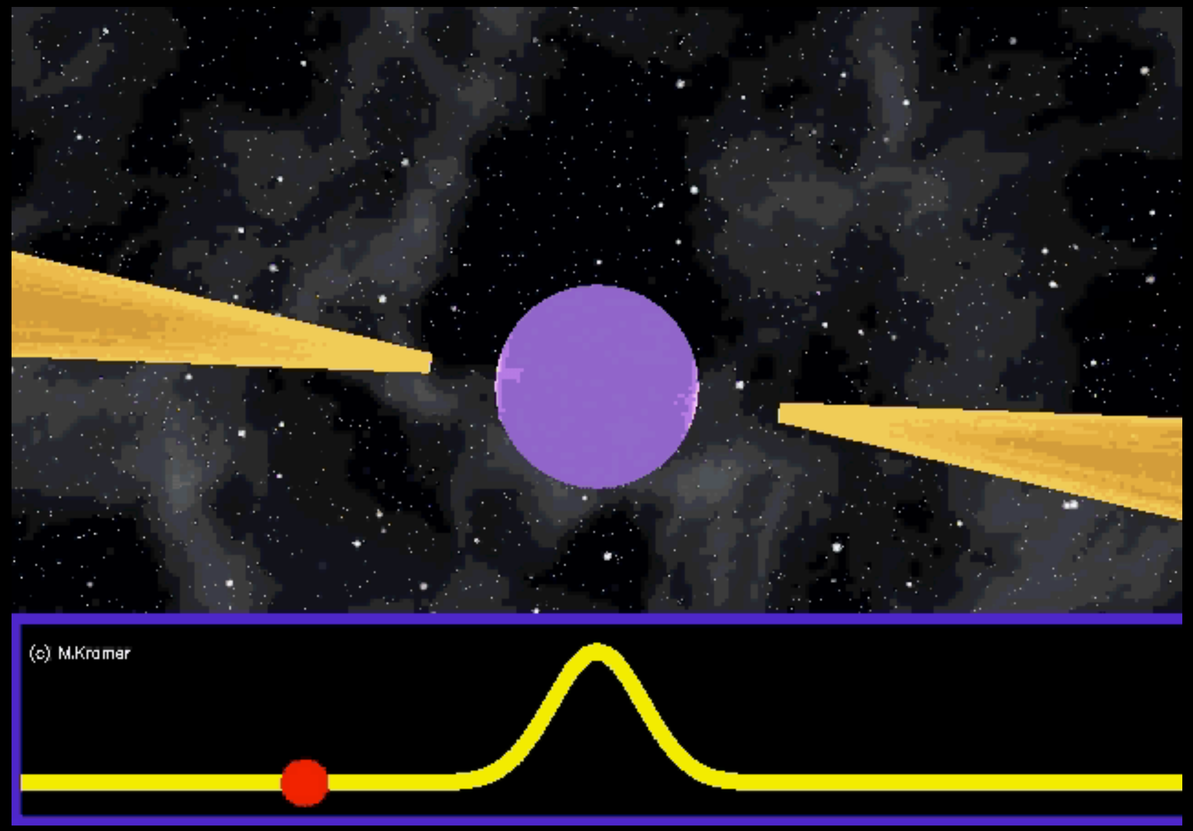
THE NEXT WINDOW ON THE GRAVITATIONAL-WAVE UNIVERSE

CHIARA MINGARELLI

Flatiron Research Fellow,

Co-Chair, International Pulsar Timing Array Gravitational-Wave Working Group

Think Big. Think the Size of the Milky Way.



- Pulsars are excellent clocks
- Gravitational waves change the distance between Earth and pulsars
- Supermassive black hole binaries emit gravitational waves with periods of decades
- Need to time pulsars for decades
- This is a galactic-scale gravitational-wave detector

DETWEILER 1979; HELLINGS & DOWNS 1983

REVIEWS: LOMMEN 2015, BURKE-SPOLAOR 2015

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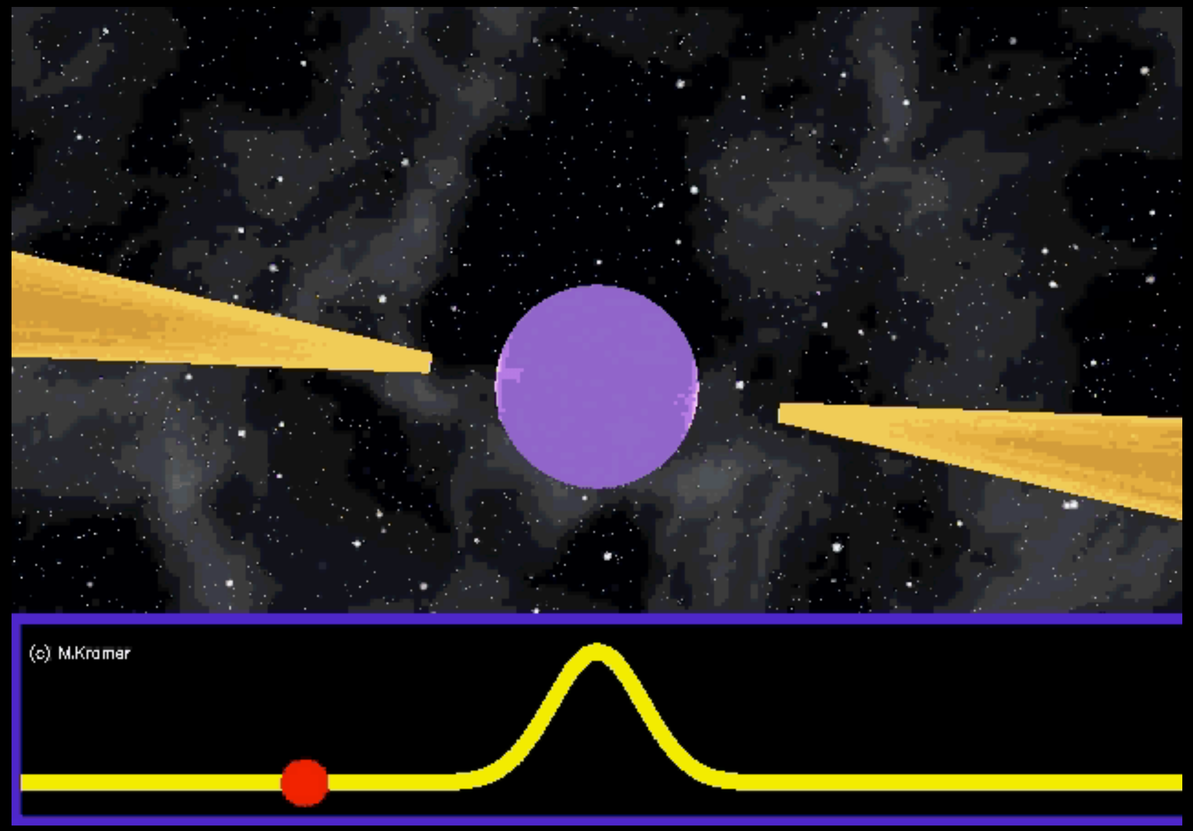

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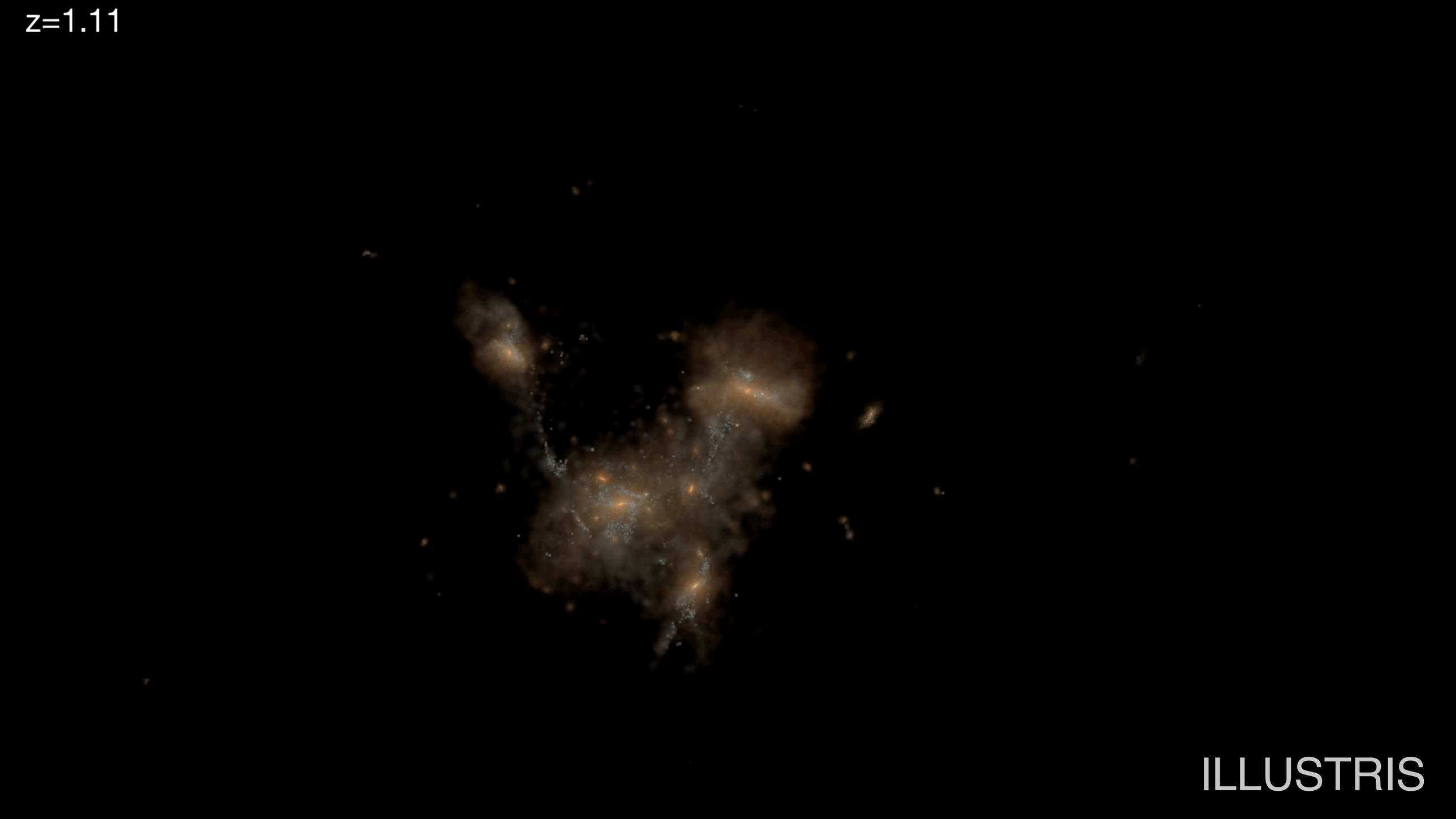
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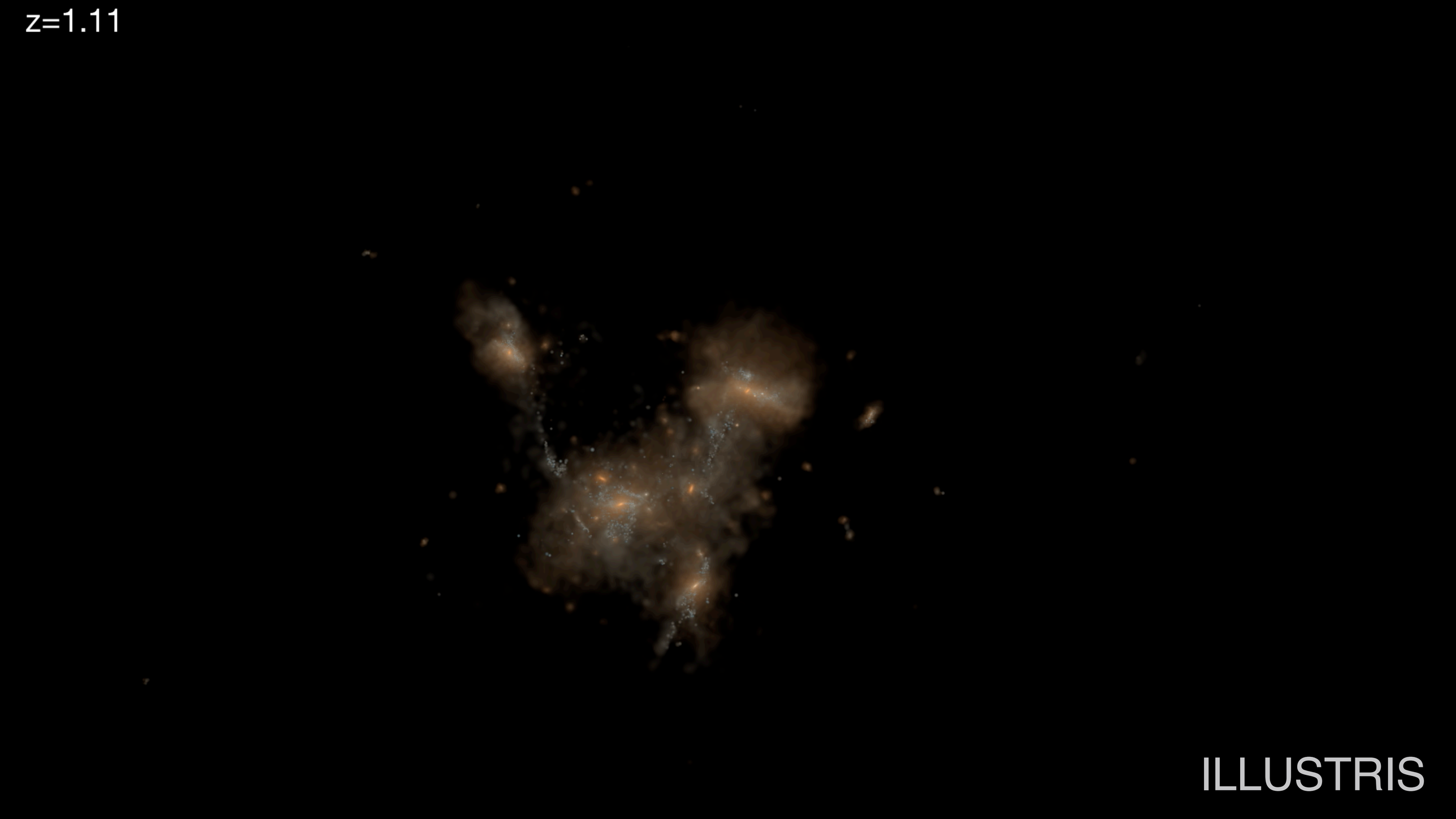
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ANIMATION FROM JOHN ROWE ANIMATION/
AUSTRALIA TELESCOPE NATIONAL FACILITY, CSIRO

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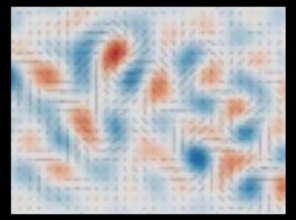
The Spectrum of Gravitational-Wave Astronomy

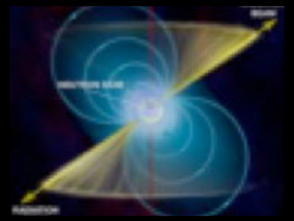
All three experiments measure changes in light travel times between objects due to GWs.

Cosmic Microwave Background



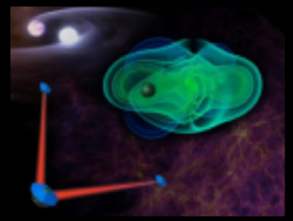
- PRIMORDIAL GRAVITATIONAL WAVES

Pulsar Timing Arrays



- SUPERMASSIVE BLACK HOLE BINARIES AND MERGERS
- PRIMORDIAL GRAVITATIONAL WAVES

Space-based Interferometers



- STELLAR MASS COMPACT BINARIES
- SUPERMASSIVE BLACK HOLE MERGERS

Ground-based Interferometers

- NEUTRON STAR MERGERS
- BLACK HOLE MERGERS

SMBHBs:
Millions of years in band

h

10^{-5}

10^{-10}

10^{-15}

10^{-20}

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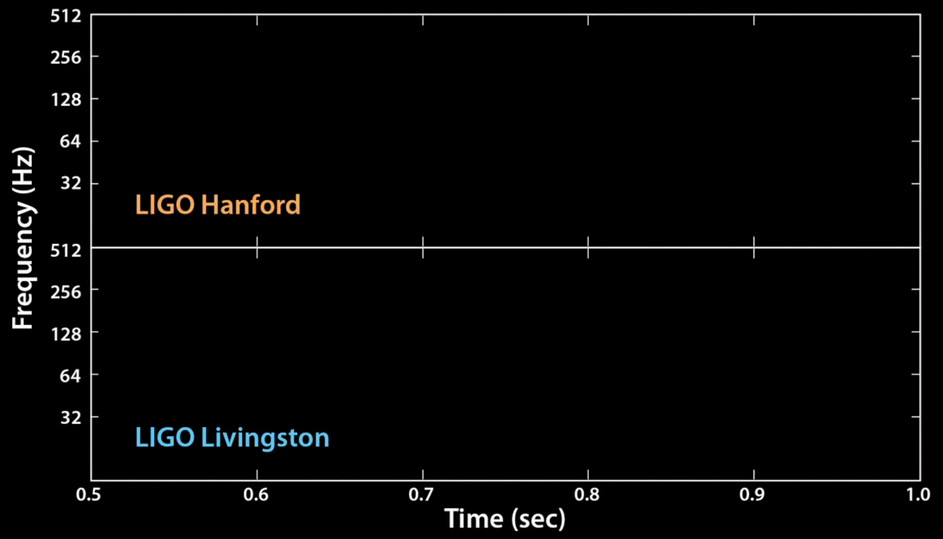
10^{-16} 10^{-8} 10^{-4} 10^{2}

Frequency (Hz)



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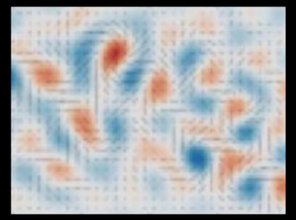

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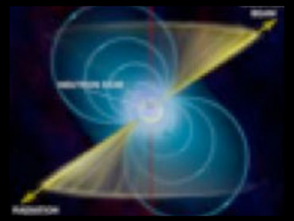

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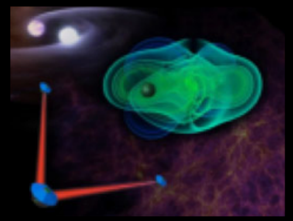

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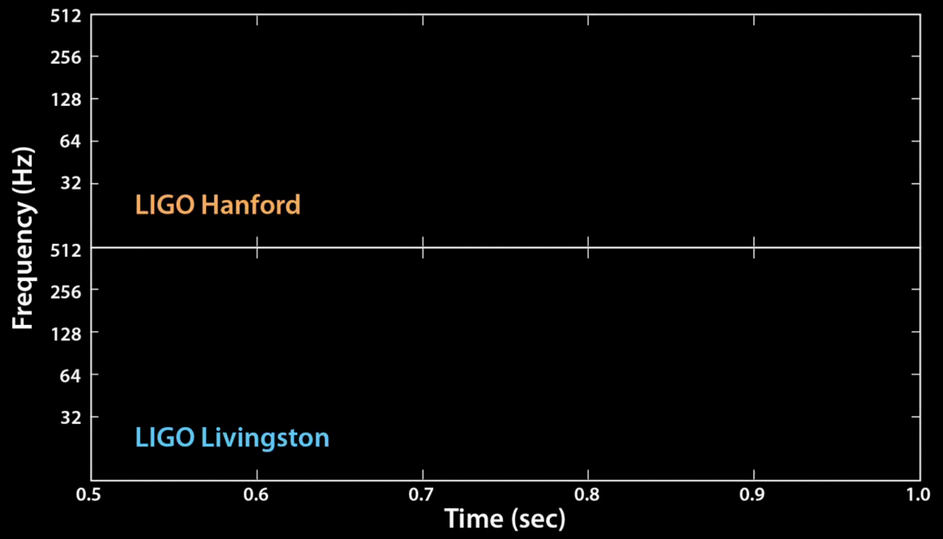


New Avenue to Explore the Universe

Galaxy mergers: how they universe works

Each galaxy hosts a supermassive black hole: merge via gravitational waves

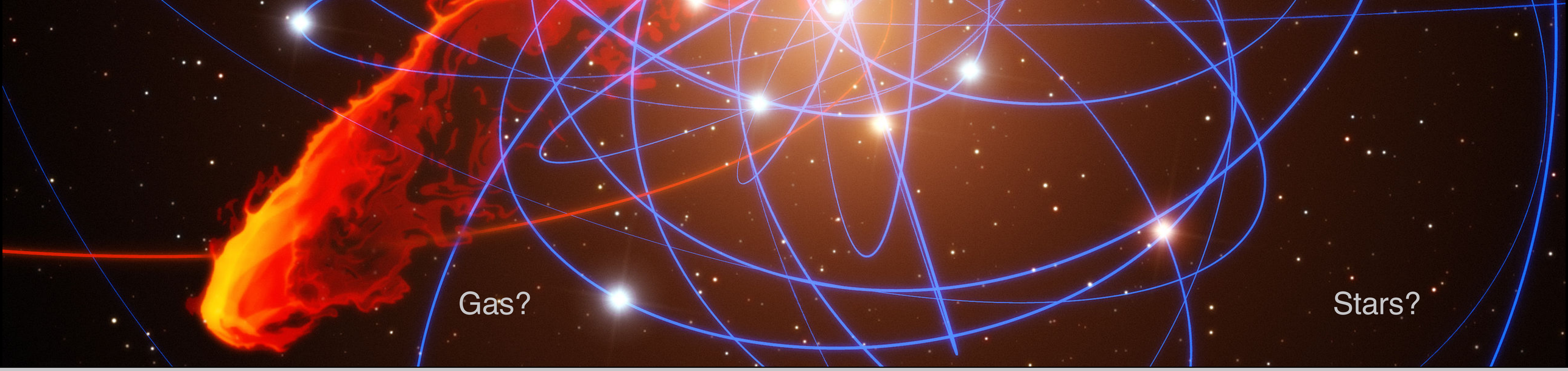
Gravitational waves: important in cosmology, galaxy evolution and fundamental physics

Information not accessible by any other means

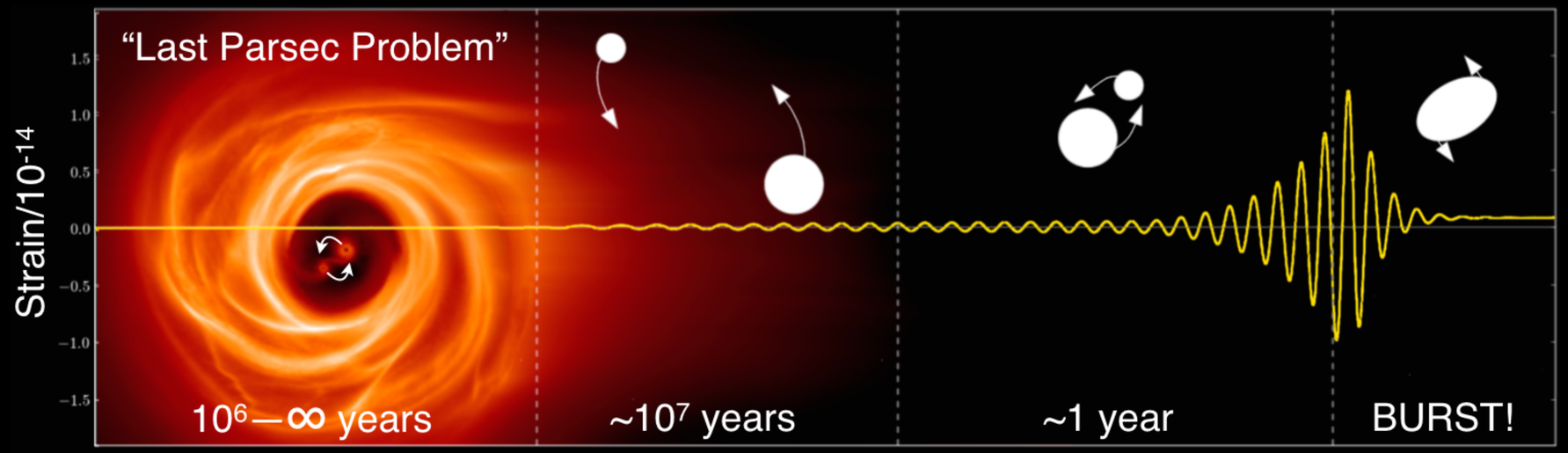
What's New with PTAs?

- Datasets are now long enough and of sufficient quality to make a detection.
- At this point, non-detections matter — can tell us about how supermassive black holes merge, galaxy evolution.
- Time to detection is anchored in underlying black hole astrophysics.

Arzoumanian et. al. 2016, 2018; Verbiest et al. 2016;
Lentati et al. 2015; Taylor et al. 2016



How Do Supermassive Black Holes Merge?



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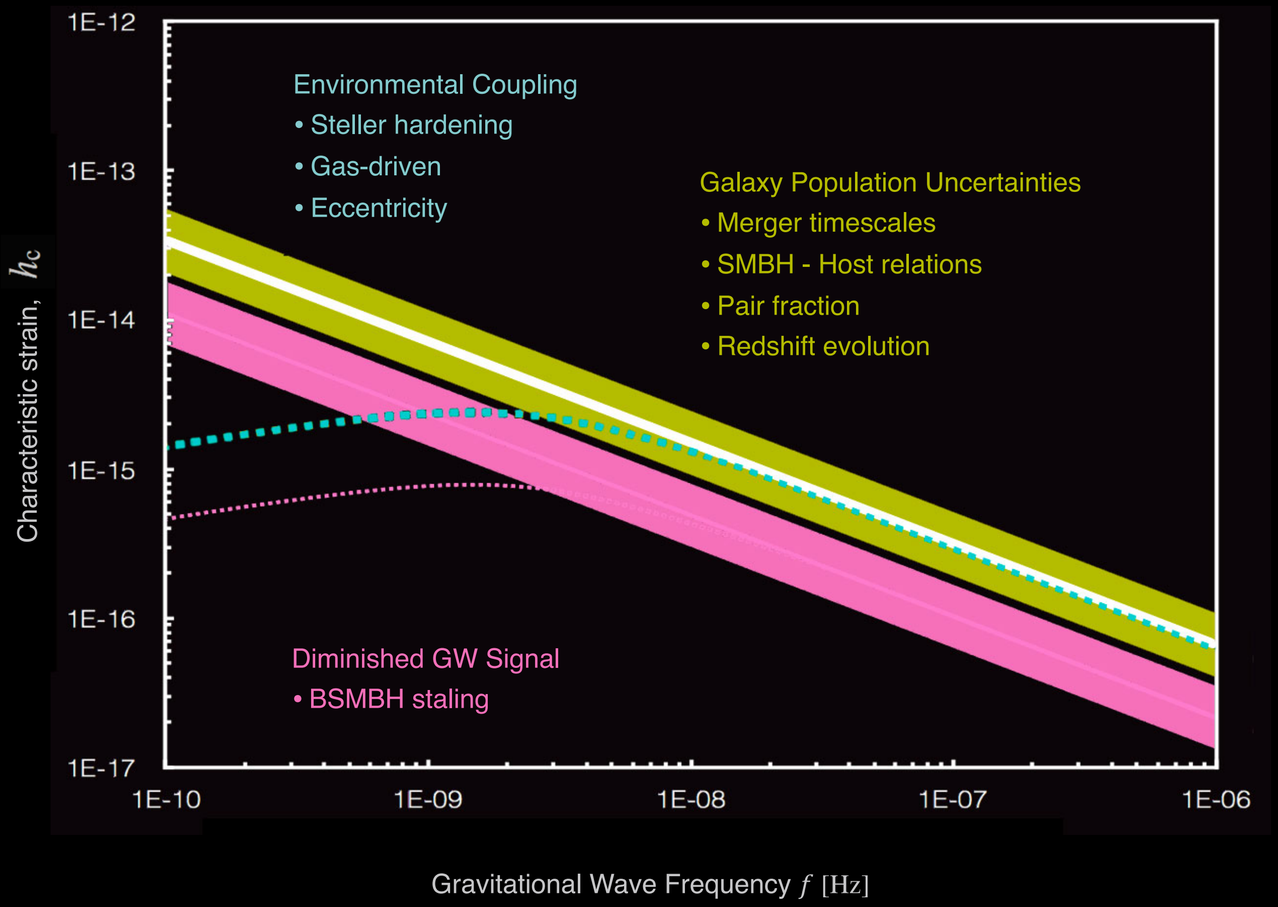


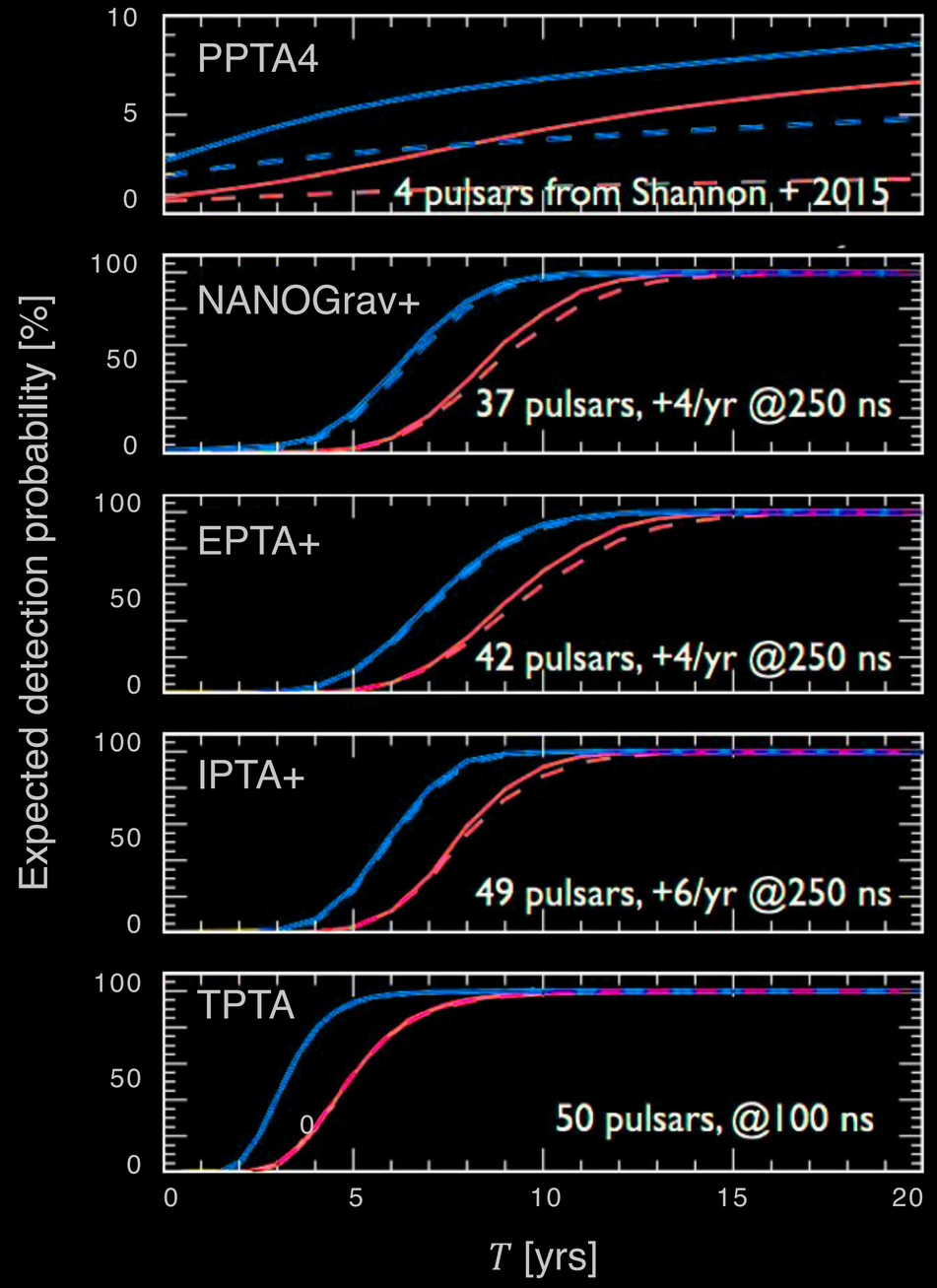
S. BURKE-SPOLAOR 2015

- Cosmic merger history of supermassive black holes forms a gravitational-wave background
- Shape informs us of final parsec solutions
- No gravitational waves = how does the universe work?
- Constrained for the first time in 2016

The NANOGrav nine-year data set: Limits on the isotropic stochastic gravitational wave background

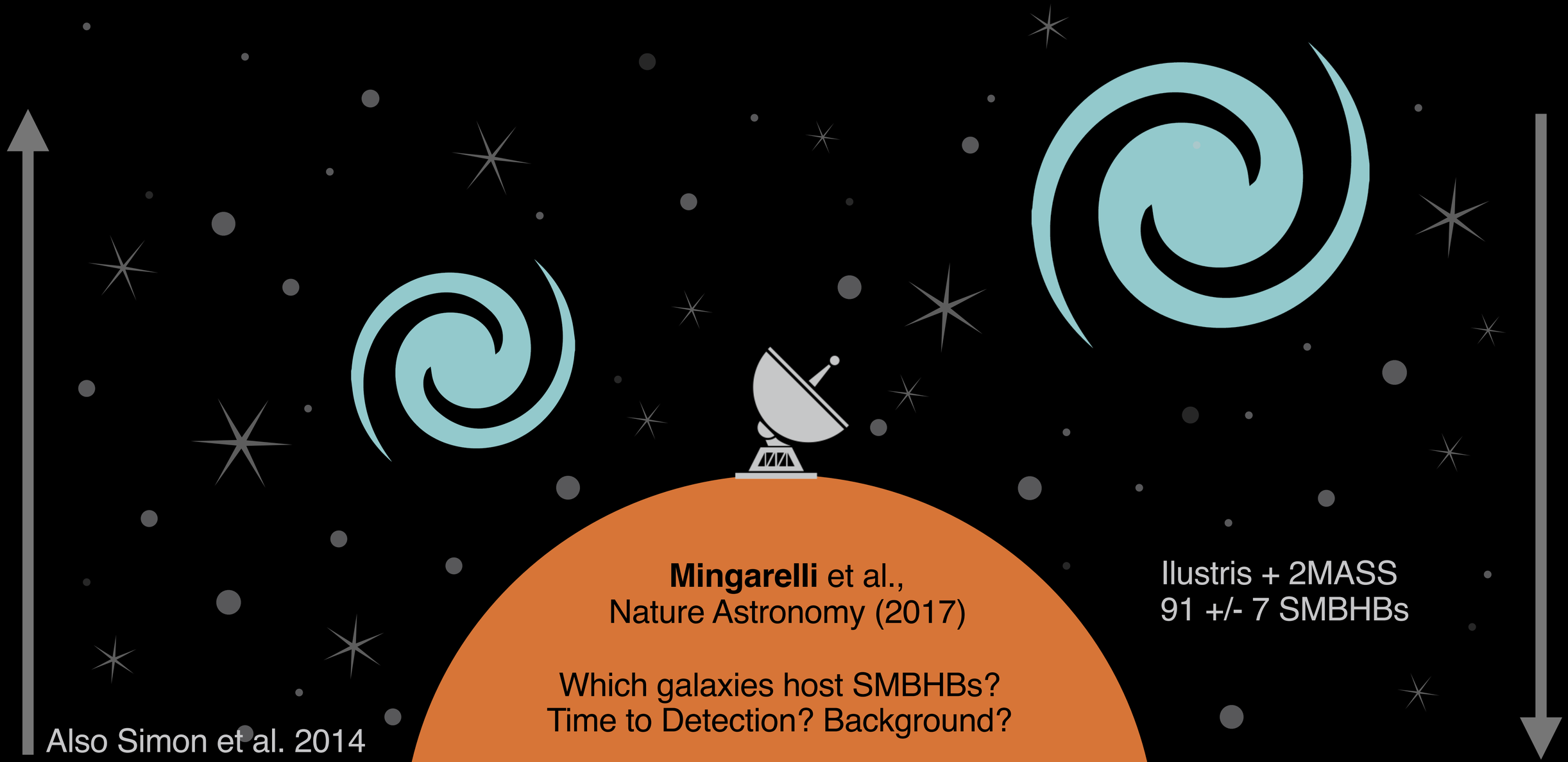
Time to Detection of Gravitational-wave Background?

- What if Supermassive Black Holes stall?
  blue line = no stalling, red line = 90% stalling
- First “hint” likely in next 2-3 years, faster with international collaboration
- No detection? Revisit galaxy evolution models, black hole masses, fundamental physics



TAYLOR, VALLISNERI, ELLIS,
MINGARELLI,
VAN HAASTEREN, LAZIO, APJL (2016)

Resolvable Supermassive Black Holes



Mingarelli et al.,
Nature Astronomy (2017)

Which galaxies host SMBHBs?
Time to Detection? Background?

Ilustris + 2MASS
91 +/- 7 SMBHBs

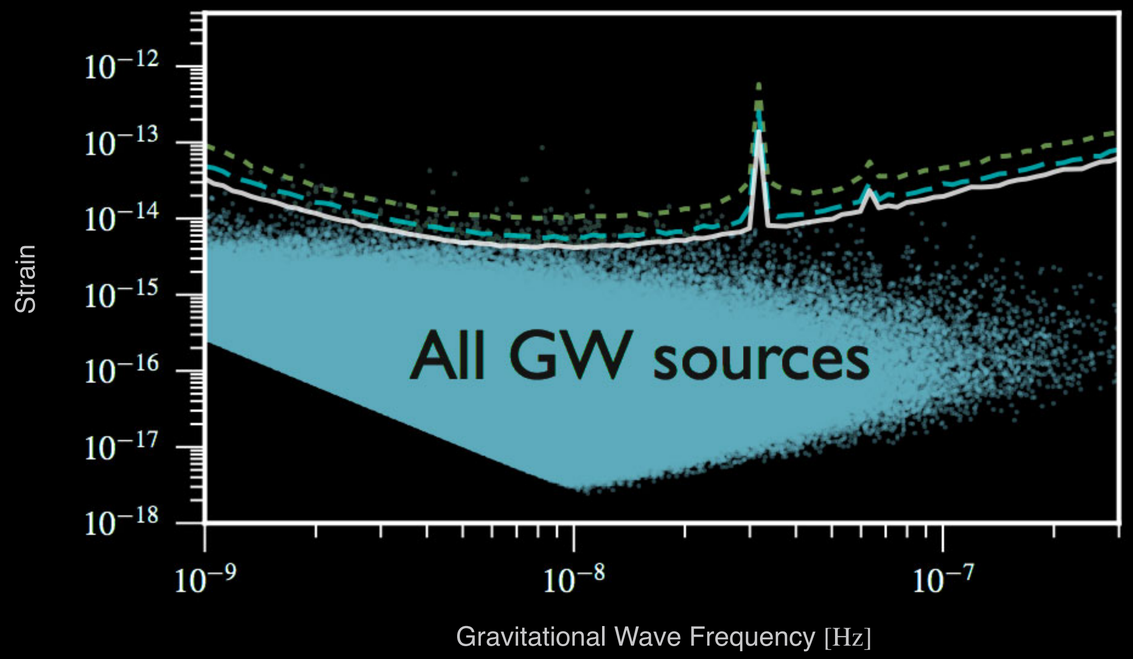
Also Simon et al. 2014

e. g. Sesana et al. 2013

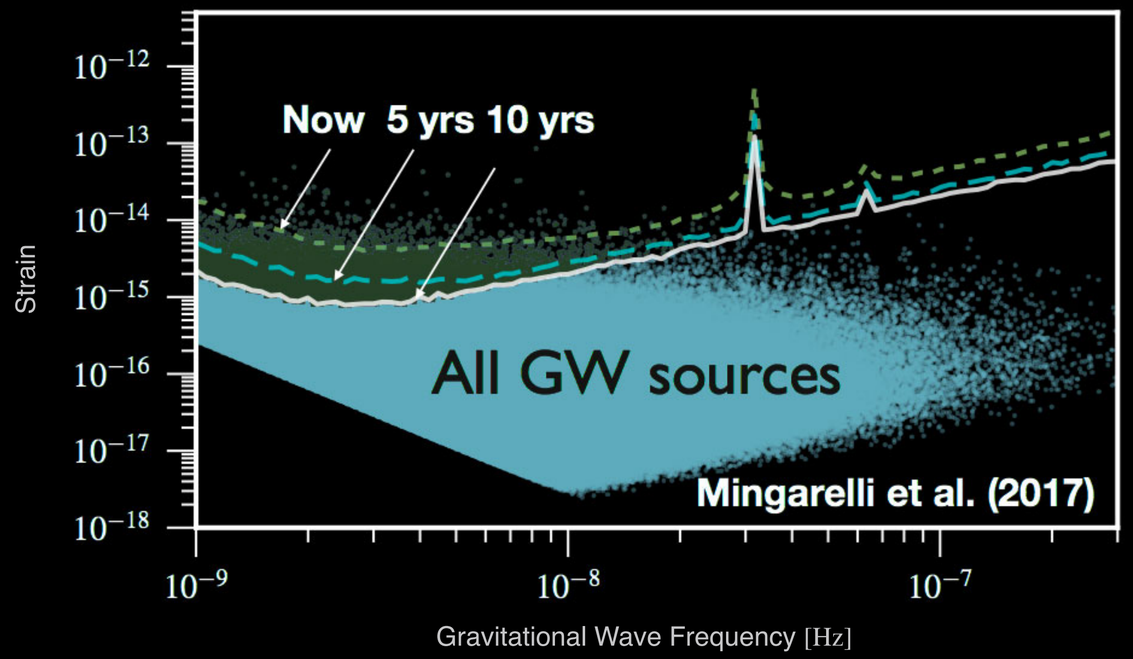
Time to Detection: Single Sources

Detection in < 10 years

Strong Red noise 3σ



White noise 3σ



Factor of 4!
sky location

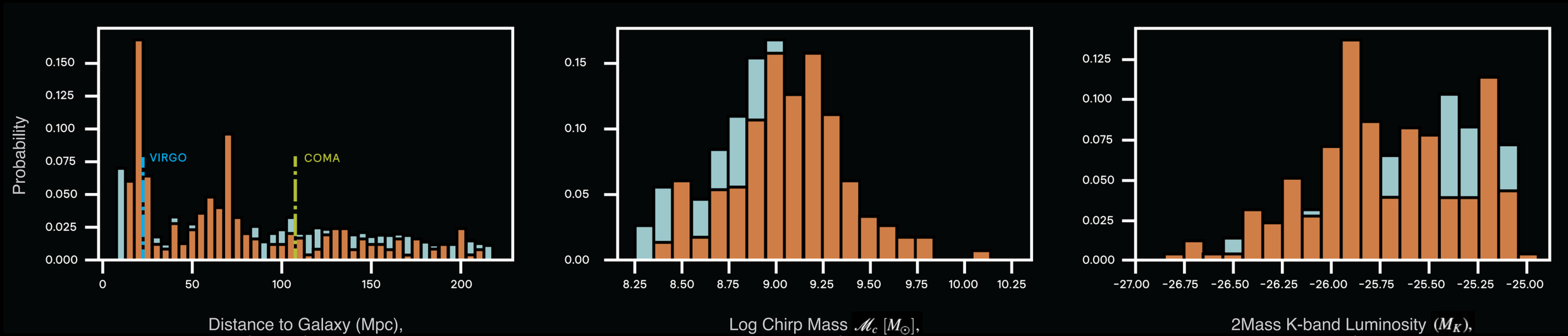
FAP	Now	5 yrs	10 yrs
0.05 (2σ)	8%	96%	100%
3e-3 (3σ)	2%	36%	100%
1e-4 (4σ)	1%	16%	100%

Can have > 1

Clues for EM Counterparts

CLEAN DATA
NOISY DATA

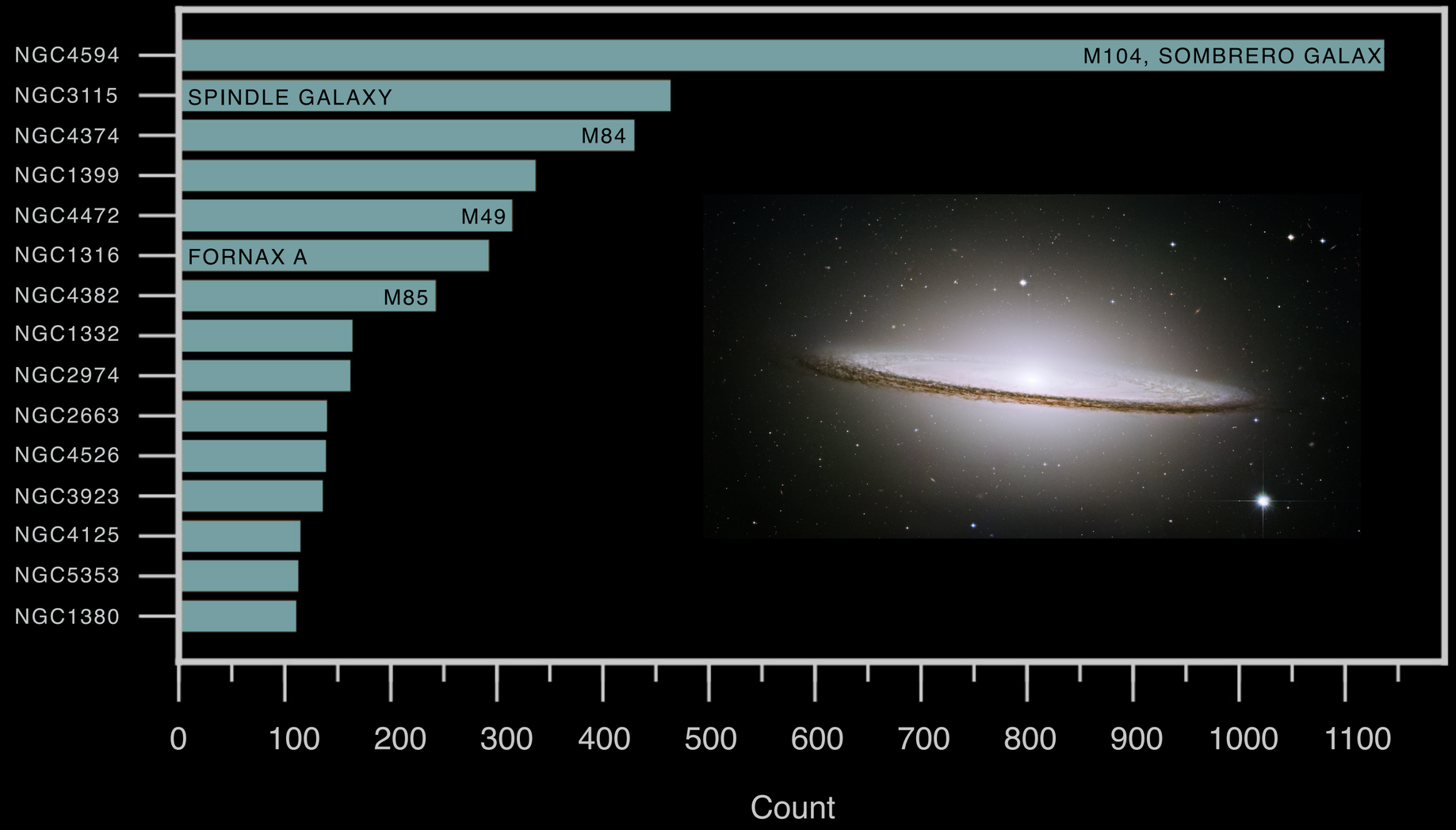
Crucial to identify host galaxies:
Can be many inside error box!



Is there even an EM counterpart?

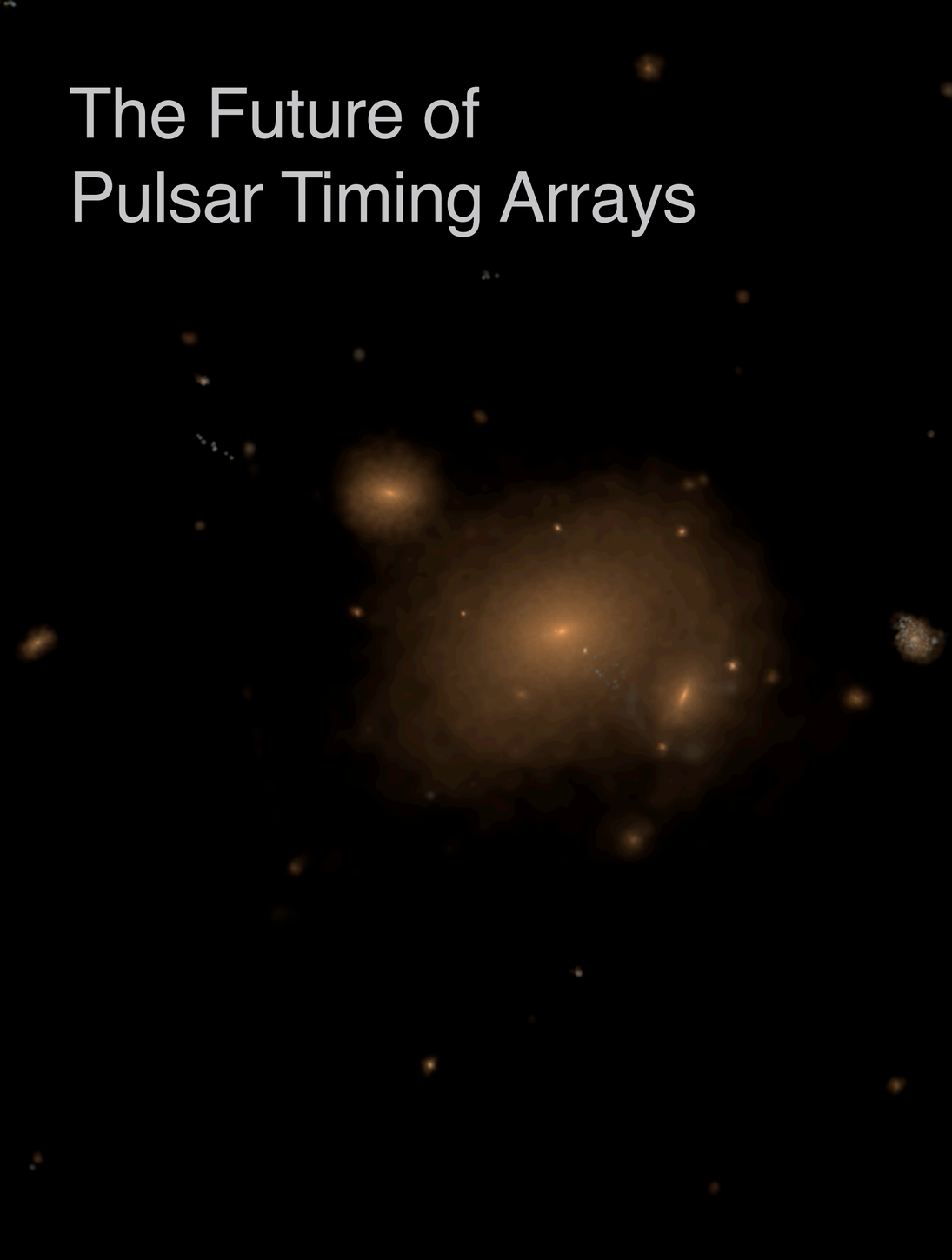
Tang, Haiman, MacFadyen 2018; D'Orazio & Loeb 2017; many others!.

Hit List



Useful for Event Horizon Telescope

The Future of Pulsar Timing Arrays



- Unlock mysteries in galaxy evolution: how do galaxies grow and evolve?
- Measure supermassive black hole masses and spins over cosmic history
- Does gravity work as we expect it to when dealing with supermassive black holes?
- Most optimistic gravitational-wave background models ruled out

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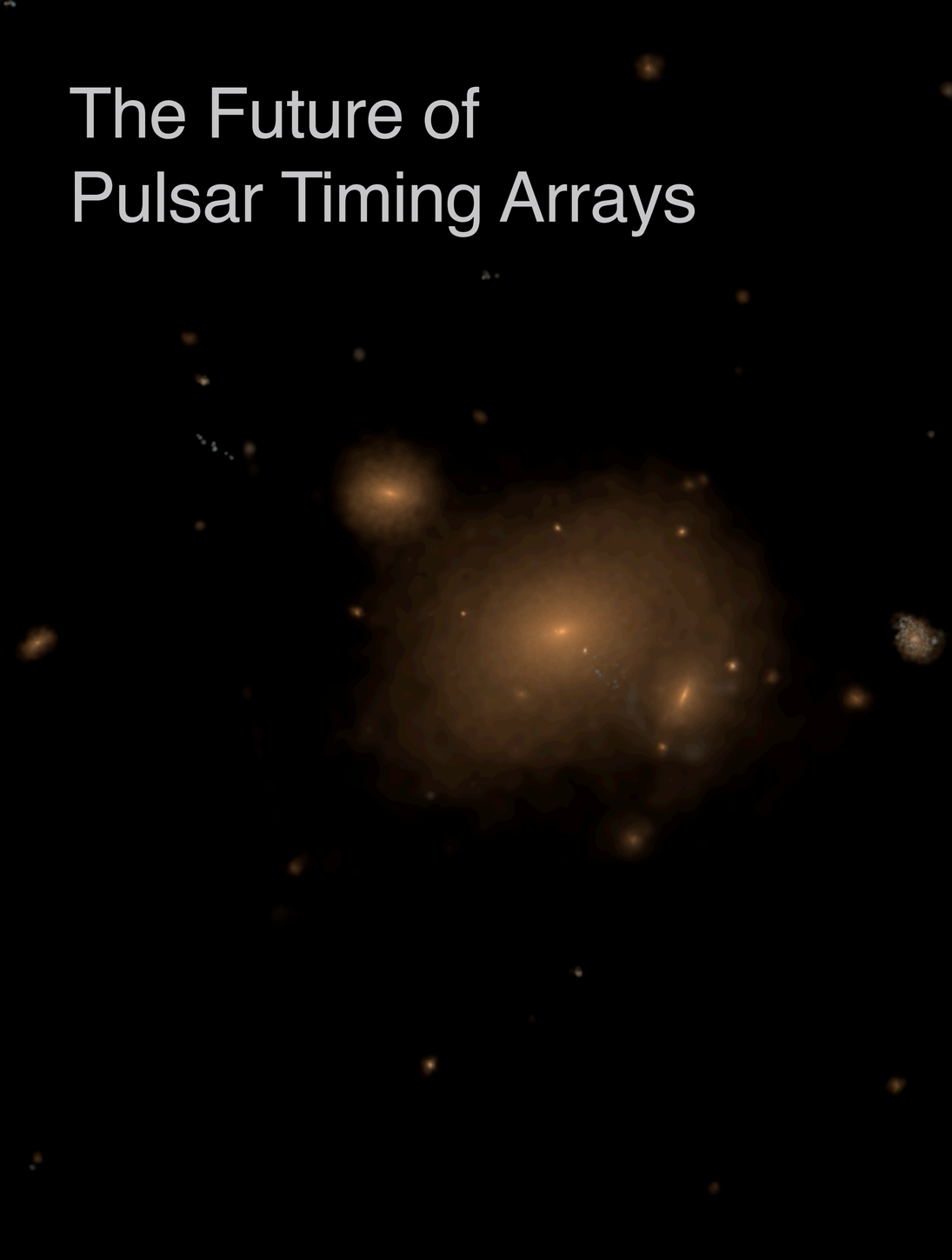

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