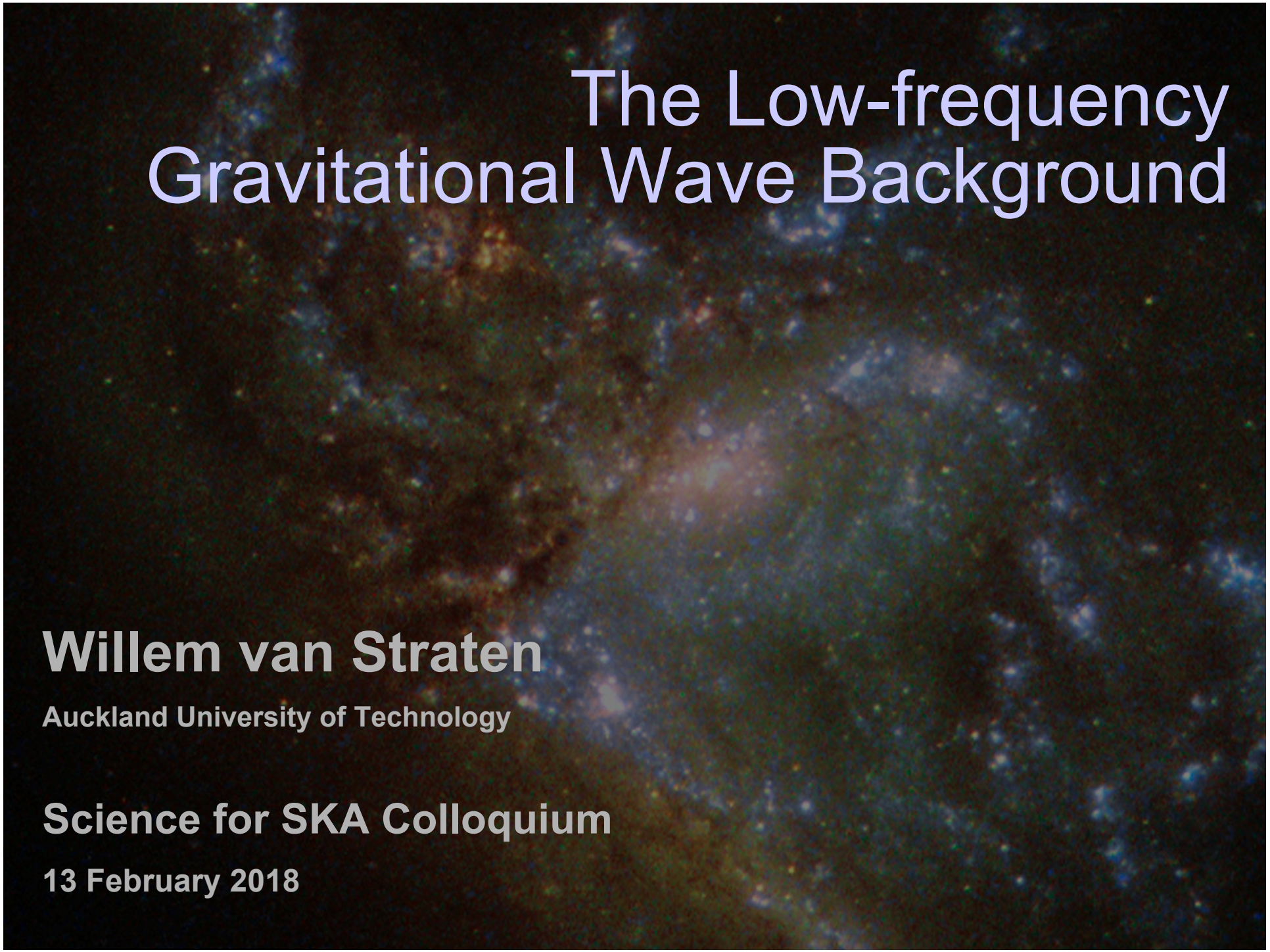


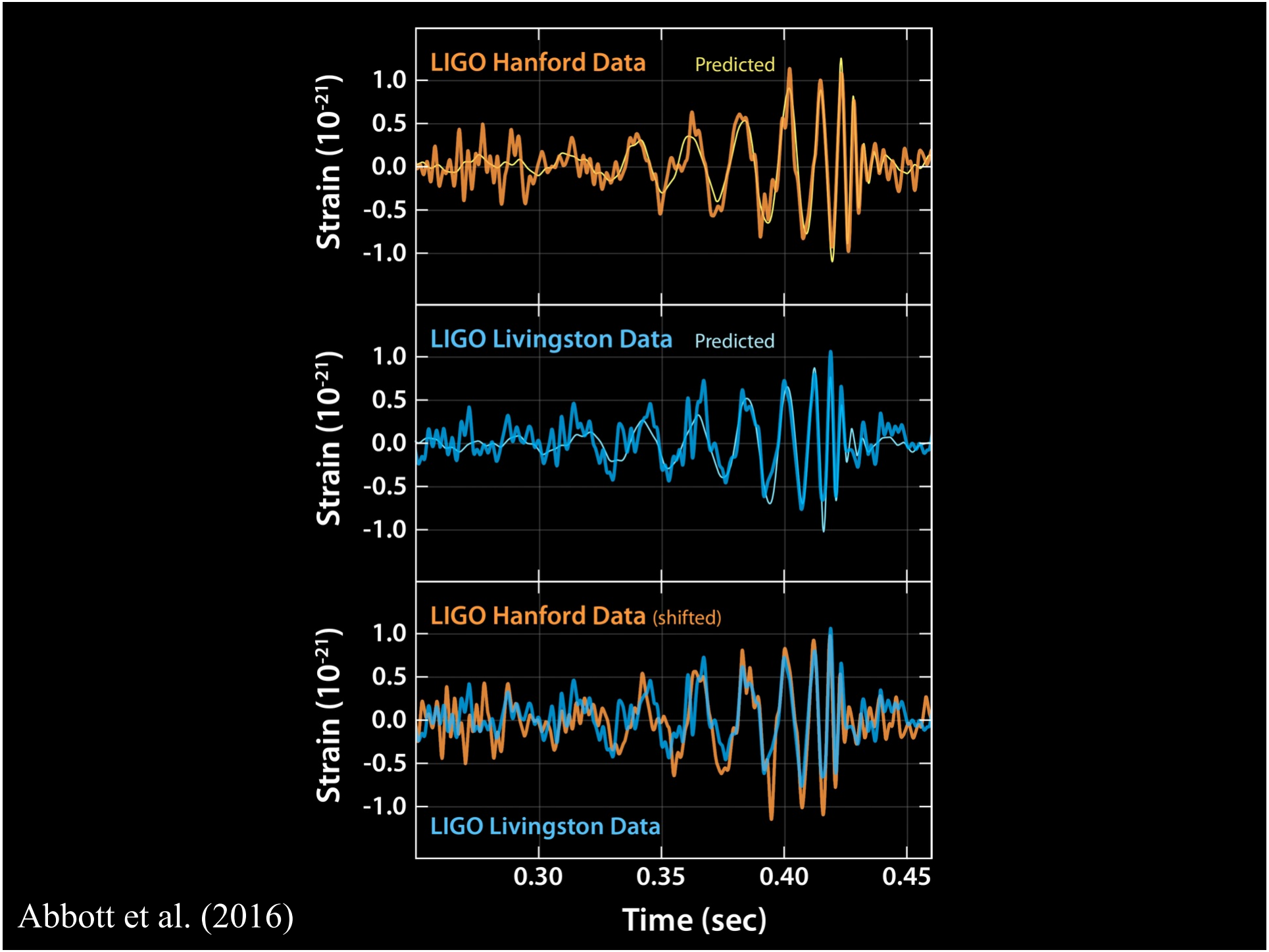
The Low-frequency Gravitational Wave Background

Willem van Straten

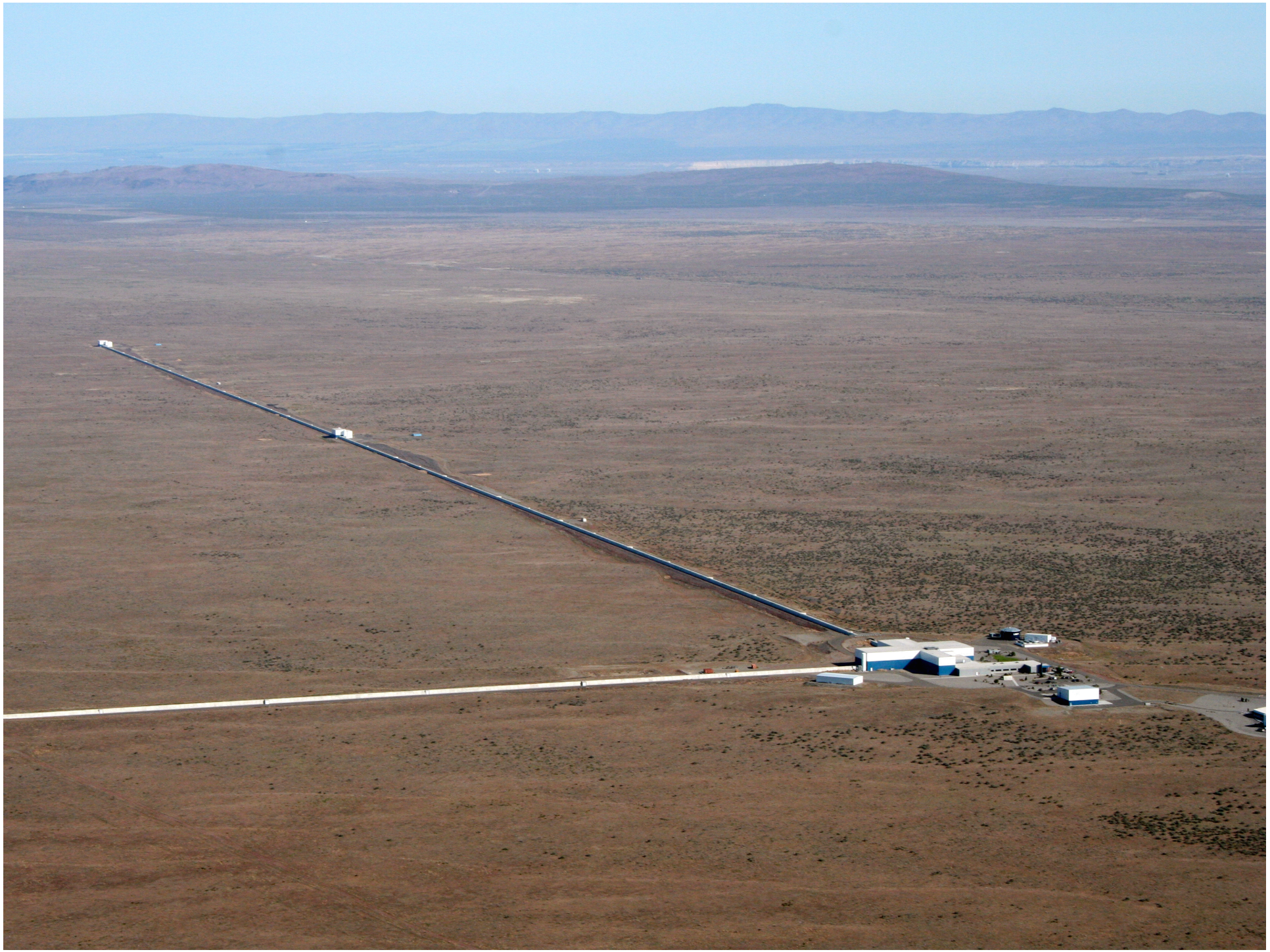
Auckland University of Technology

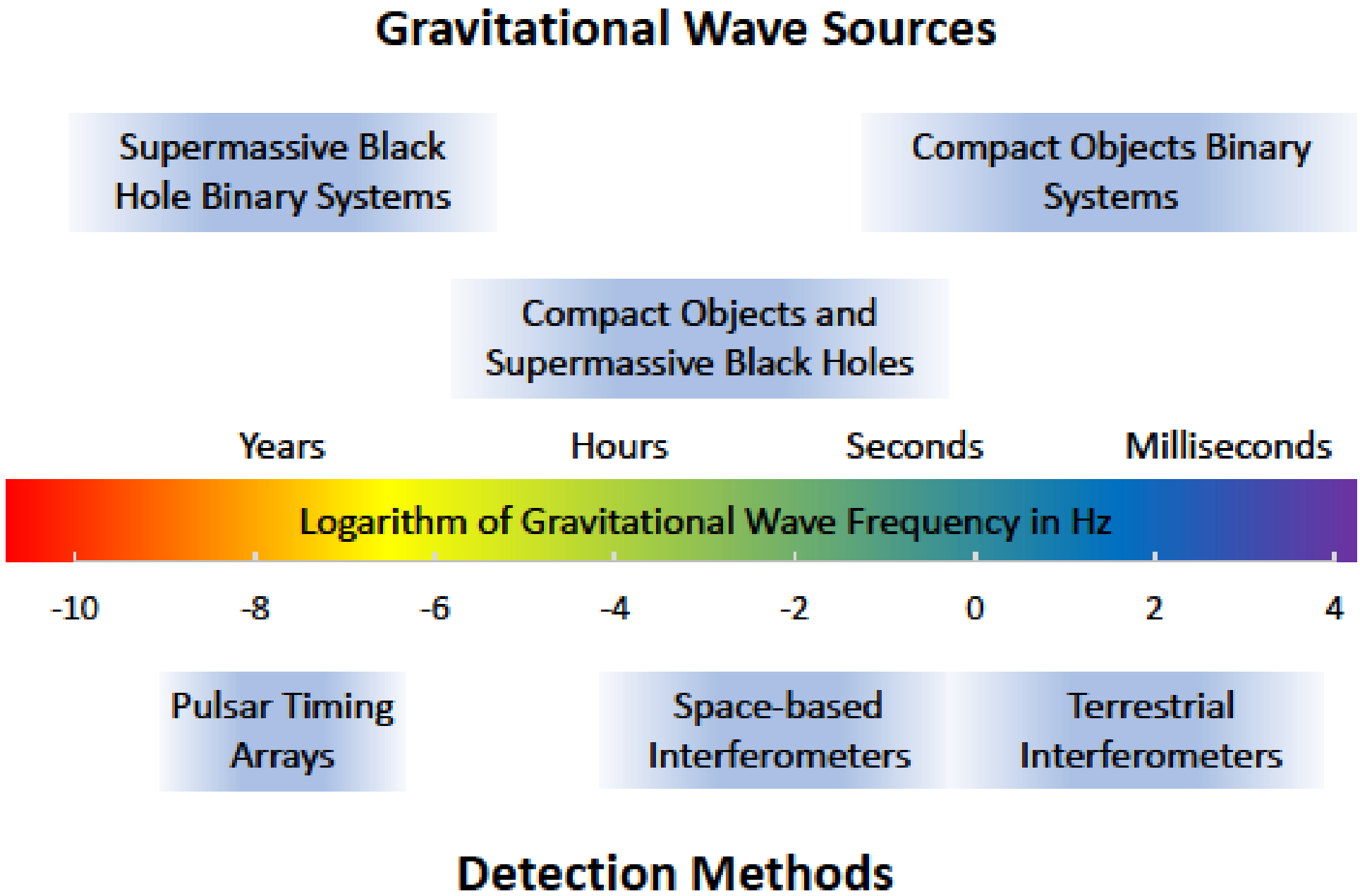
Science for SKA Colloquium

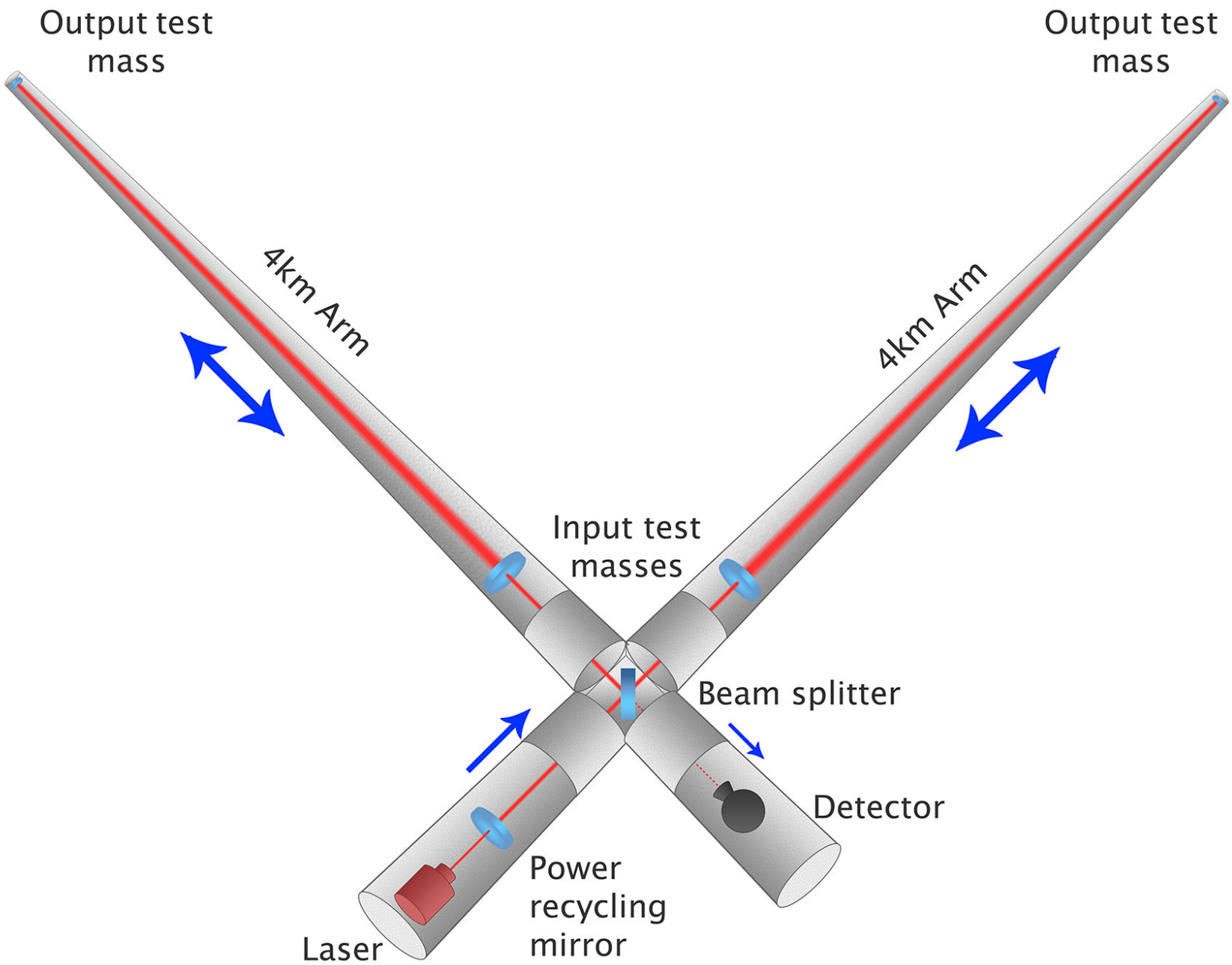
13 February 2018

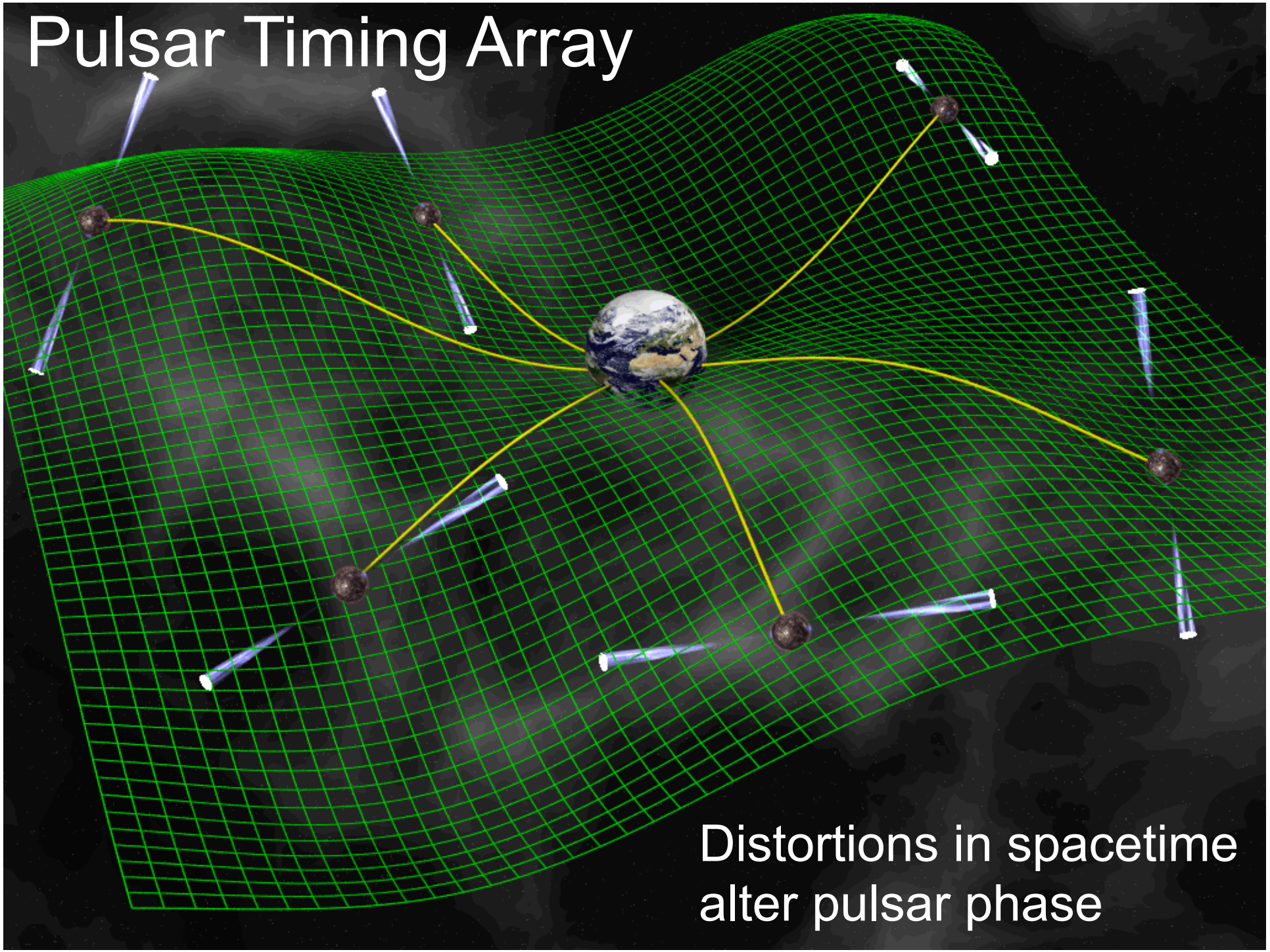


Abbott et al. (2016)




Gravitational Wave Sources
Supermassive Black Hole Binary Systems
Compact Objects Binary Systems
Compact Objects and Supermassive Black Holes
Years
Hours
Seconds
Milliseconds
Logarithm of Gravitational Wave Frequency in Hz
-10
-8
-6
-4
-2
0
2
4
Pulsar Timing Arrays
Space-based Interferometers
Terrestrial Interferometers
Detection Methods


Output test mass
Output test mass
4km Arm
4km Arm
Input test masses
Beam splitter
Detector
Power recycling mirror
Laser


Pulsar Timing Array
Distortions in spacetime
alter pulsar phase

Pulsar Timing Arrays

- PPTA: Parkes Pulsar Timing Array
- NANOGrav: North American Nanohertz Observatory
- EPTA: European Pulsar Timing Array
- IPTA: International Pulsar Timing Array
  - consortium of consortia (2008)

Gravitational Wave Detection

- Sazhin (1978) and Detweiler (1979)
  - single pulsar-Earth baseline
  - single SMBH binary system
- Hellings & Downs (1983)
  - quadrupolar correlations between pulsars
  - stochastic background of gravitational waves

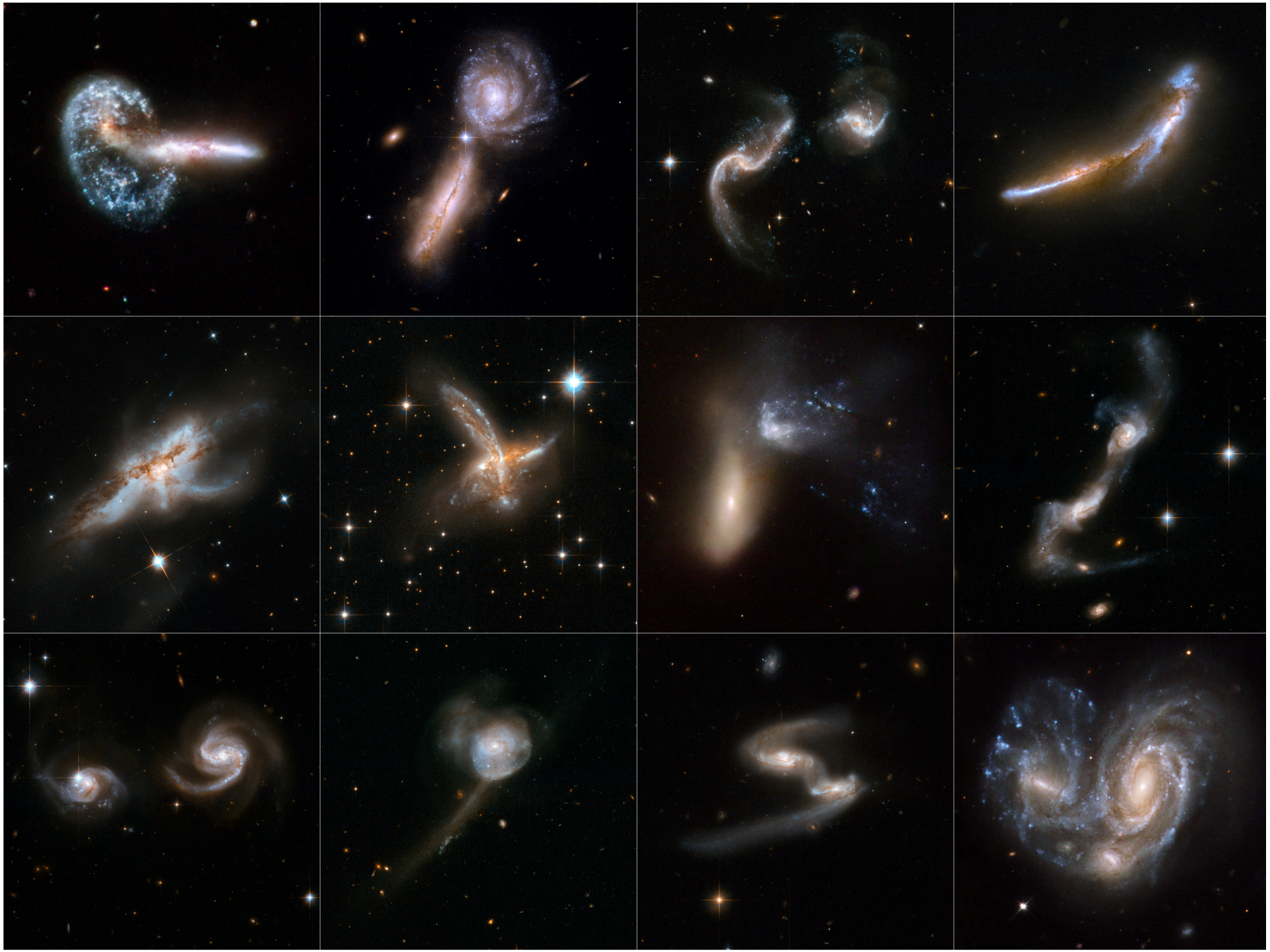
Gravitational Wave Detection

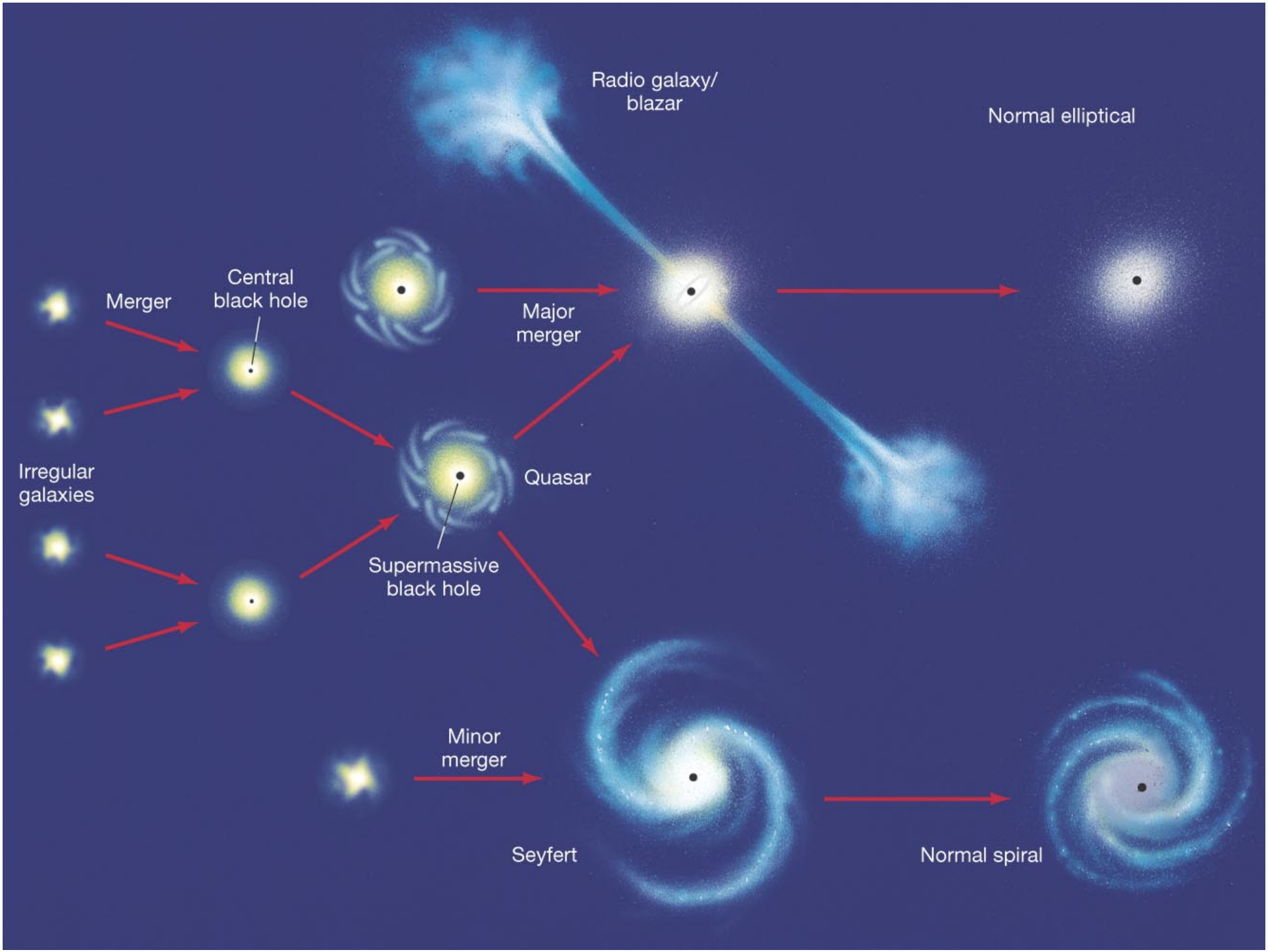
… is challenging

in the pulsar timing array regime:

Amplitude ~ 10 nanoseconds
Period ~ 10 years

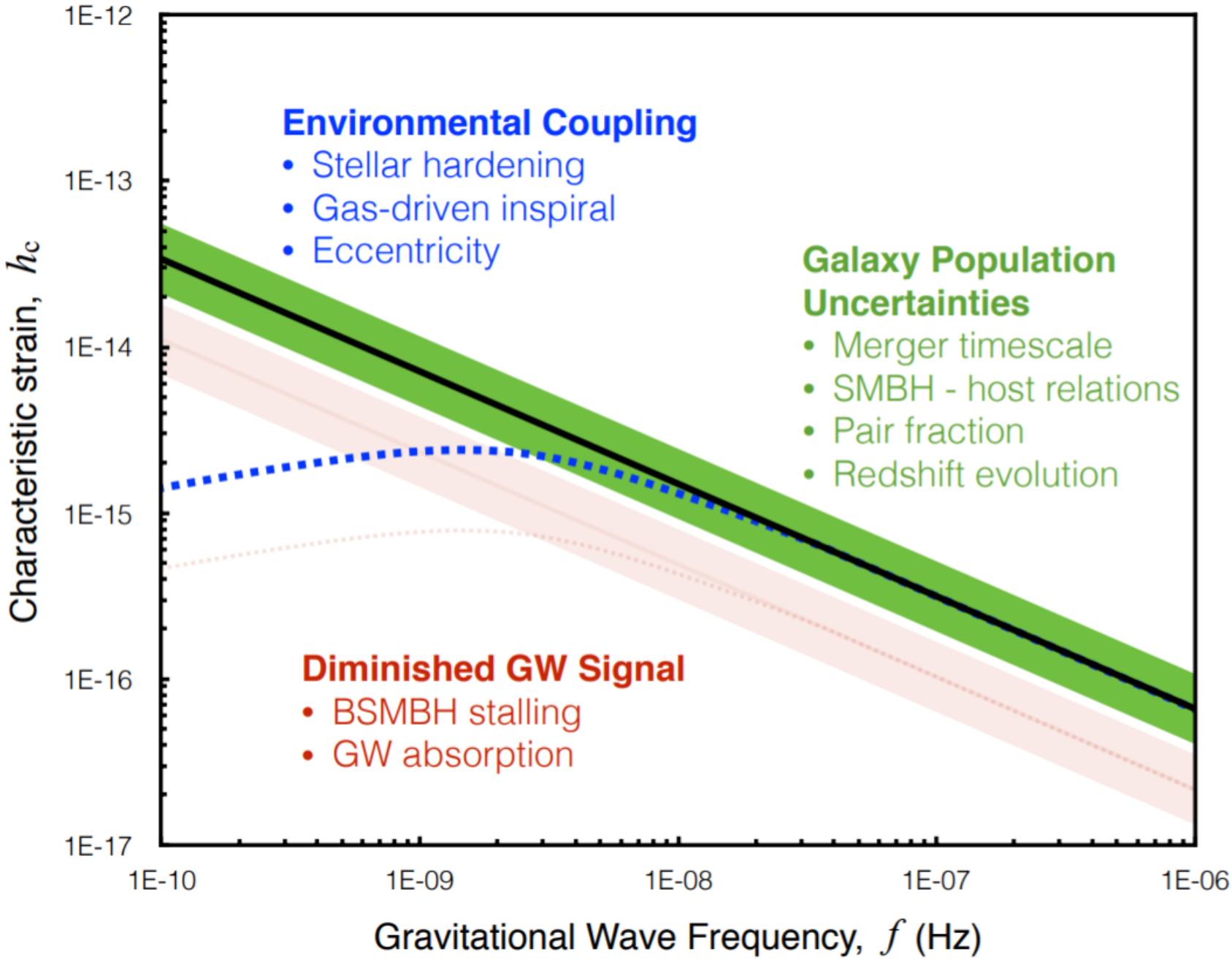
… why bother?



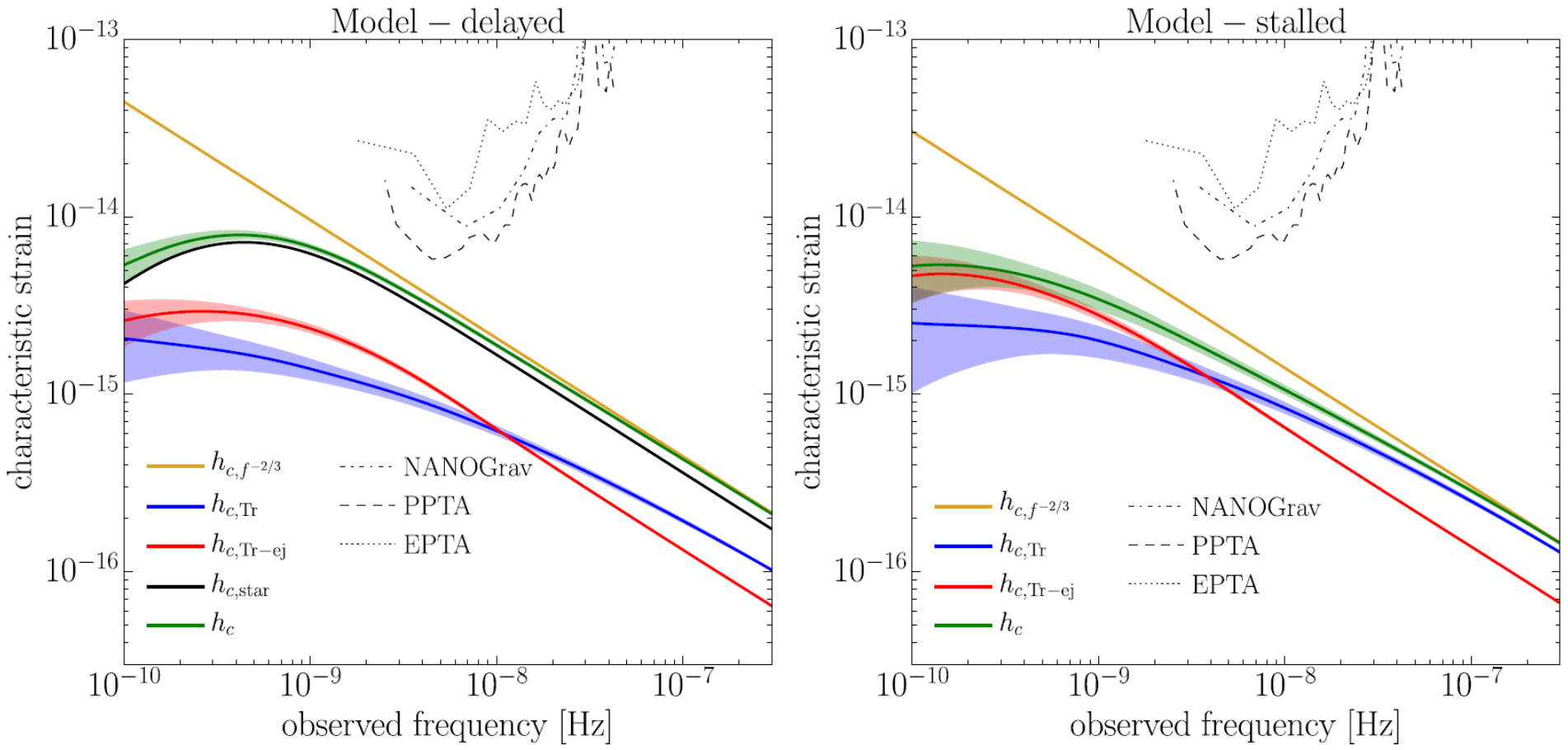

Radio galaxy/
blazar
Normal elliptical
Merger
Central
black hole
Major
merger
Irregular
galaxies
Quasar
Supermassive
black hole
Minor
merger
Seyfert
Normal spiral

Regimes of Energy Loss

- Dynamical friction (stars and/or gas)
  - effective down to ~parsec
  - ($M\downarrow\mathrm{cloud}$ too small and $v\downarrow\mathrm{BH}$ too high)
- Binary hardening
  - ejecting stars via 3-body interactions
  - effective until no more stars to eject
- Gravitational wave emission
  - kicks in ~ 1 – 10 milliparsecs



Burke-Spolaor (2015)



Bonetti et al. (2018)

Gravitational Wave Detection is Challenging

- Pulsar intrinsic
  - Stochastic impulsive emission (white noise)
  - Spin irregularity (red noise)
- Interstellar medium
  - Variations in electron density along line of sight (red)
  - Multipath propagation (scattering)
- Within solar system
  - Errors in the solar system ephemeris (dipolar)
  - Errors in the definition of time on Earth (monopolar)

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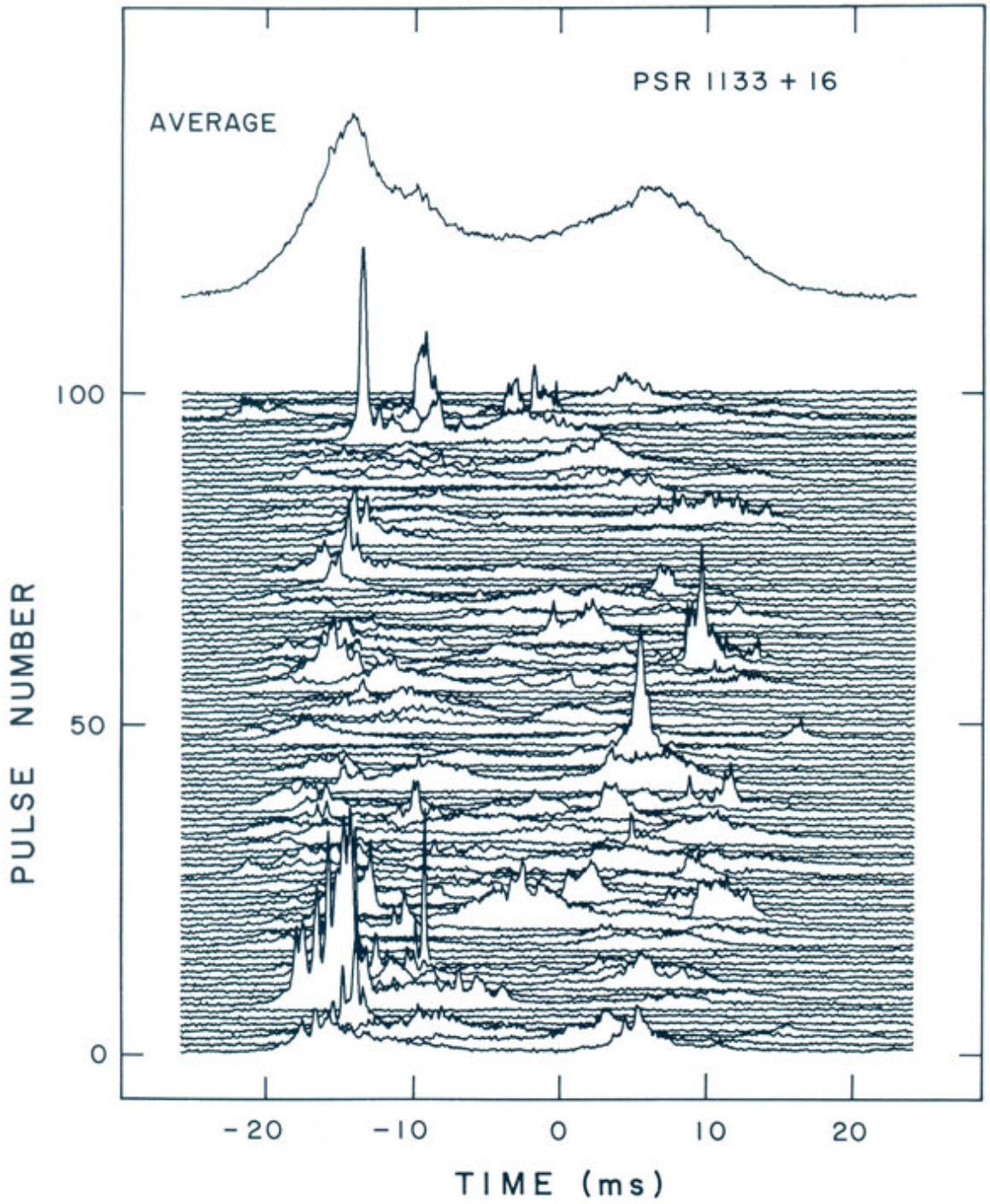
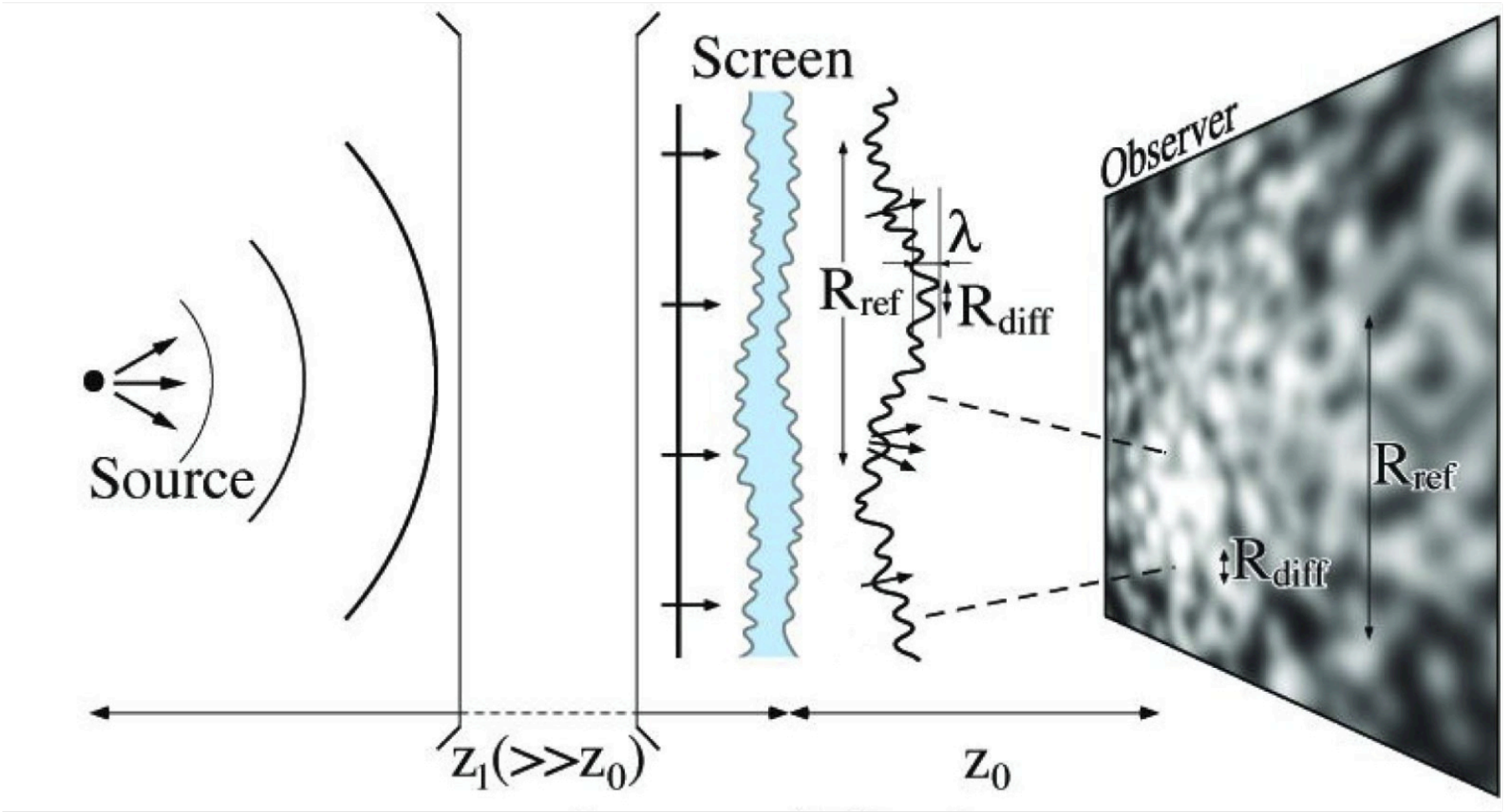
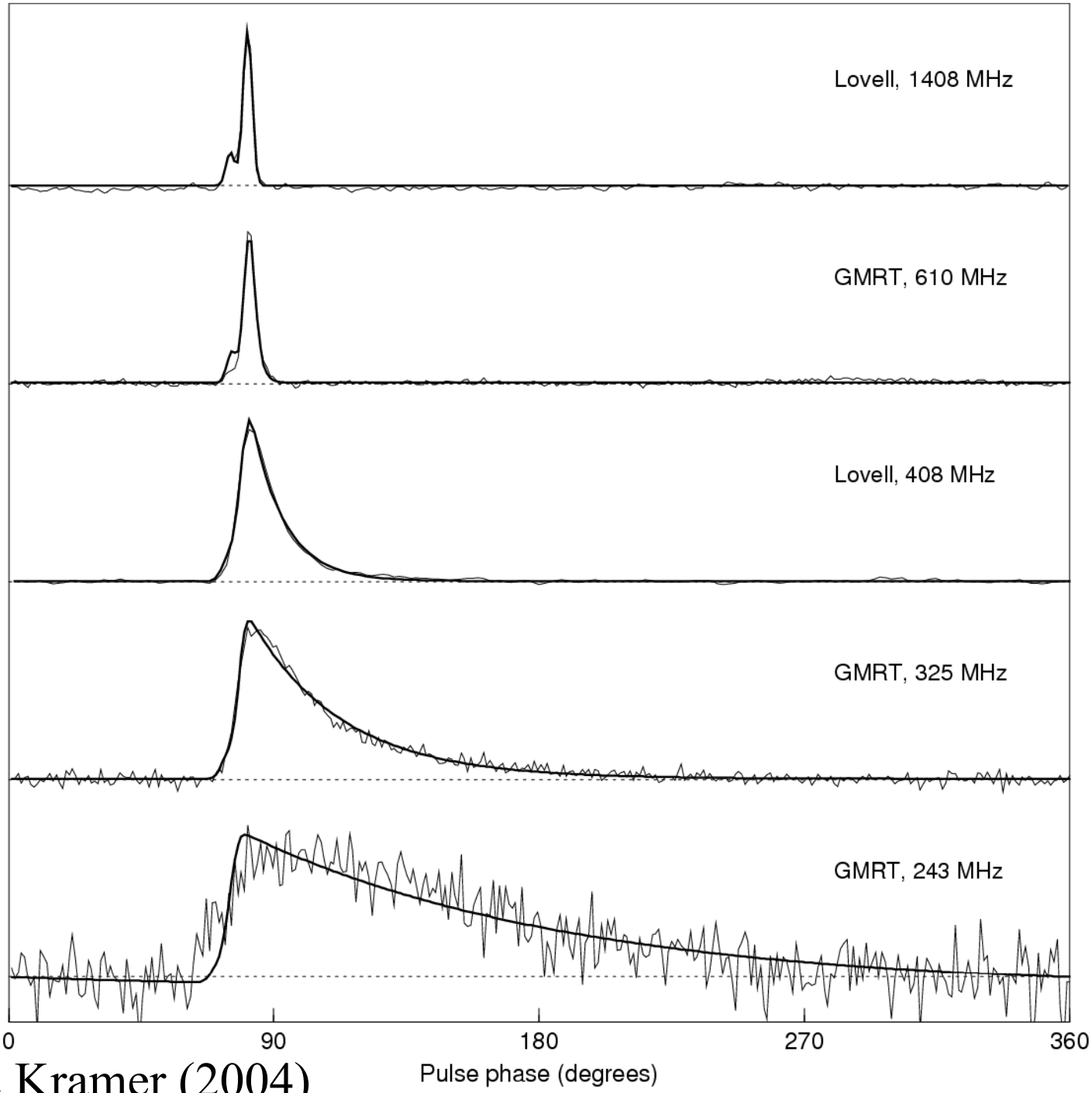
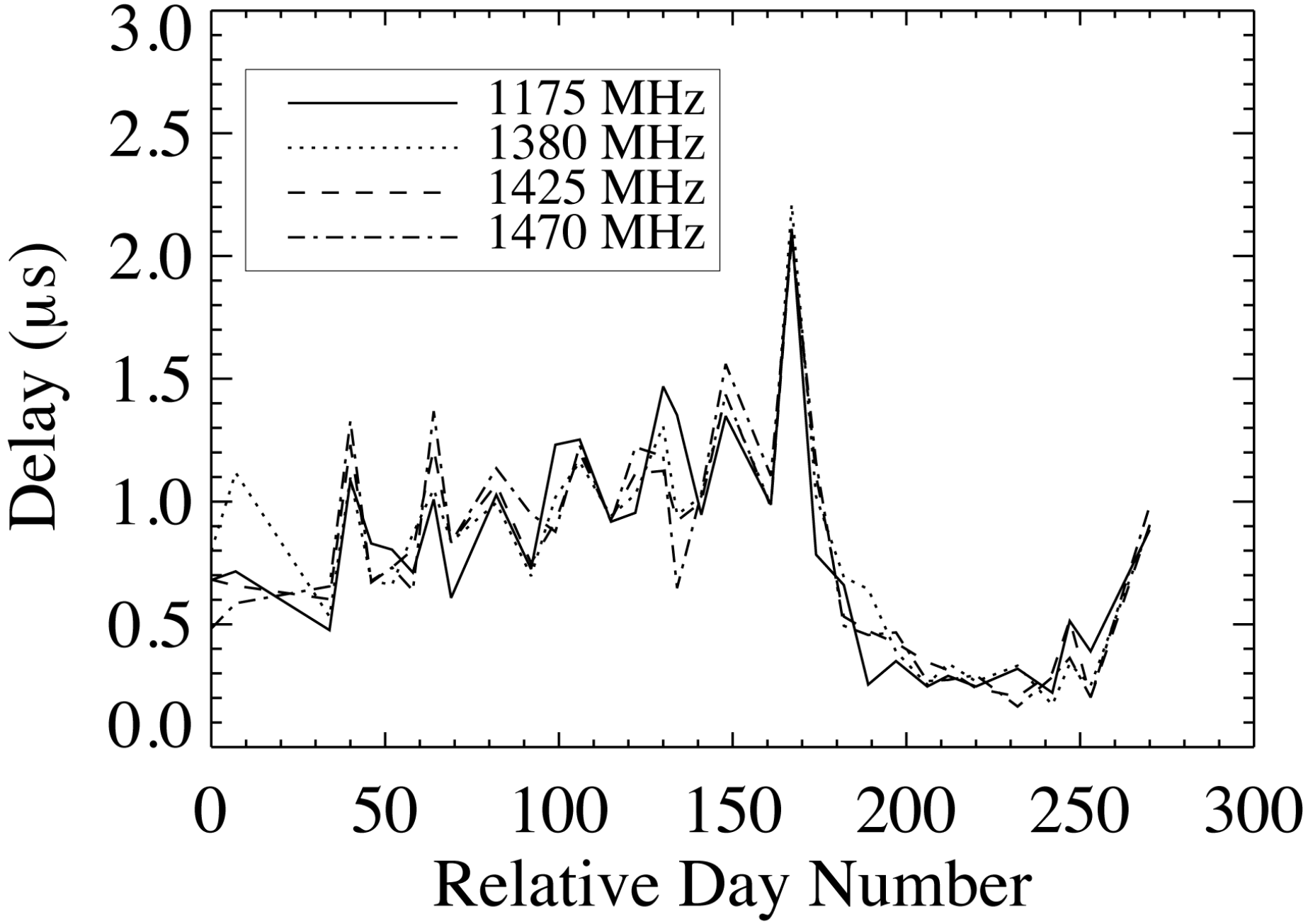

PSR 1133 + 16
AVERAGE
100
50
0
PULSE NUMBER
-20
-10
0
10
20
TIME (ms)



Habibi et al. (2011)



Lorimer & Kramer (2004)



Hemberger & Stinebring (2008)

Challenges = Opportunities

- Jitter noise
  - better statistical models of noise
  - e.g. Feasible Generalised Least Squares
- Scattering delays
  - “adaptive optics” via interstellar holography
  - cyclic spectroscopy and phase retrieval

SKA Phase 1

- Pulsar Survey capability
  - SKA1-Mid: ~1400 MSPs
  - SKA1-Low: ~900 MSPs
- ~ 10-fold increase in MSPs
  - more angular separations
  - greater sky coverage
- High-fidelity Pulsar Timing

Journal of Astronomical Instrumentation

Performance of Oversampled Polyphase Filterbank Inversion Via Fourier Transform

I. Morrison*,†,‡, W. van Straten§, J. Bunton⊥, A. Deller†, A. Jameson†
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‡*Curtin Institute of Radio Astronomy, Curtin University, Bentley, Western Australia, Australia. E-mail: ian.morrison@curtin.edu.au*
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⊥*CSIRO Astronomy and Space Science, Marsfield, New South Wales, Australia*

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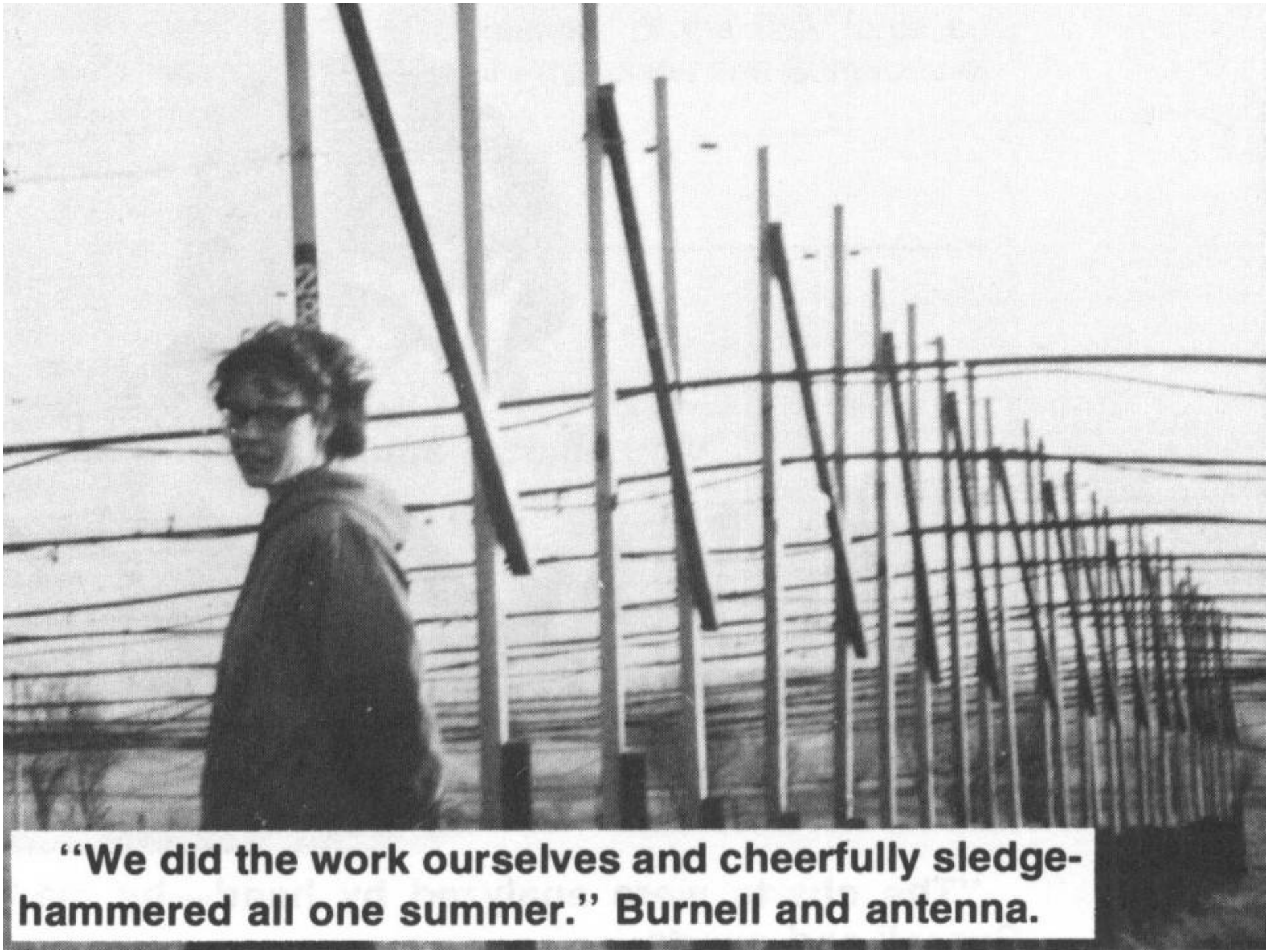
… reports on outcome of theoretical and prototyping effort to reduce cost of SKA

Those who build discover

- Many things learned during design
- and to be learned during construction
- provide deeper insight during operation.



"We did the work ourselves and cheerfully sledge-hammered all one summer." Burnell and antenna.