The European Pulsar Timing Array

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Outline

- Quick Intro to

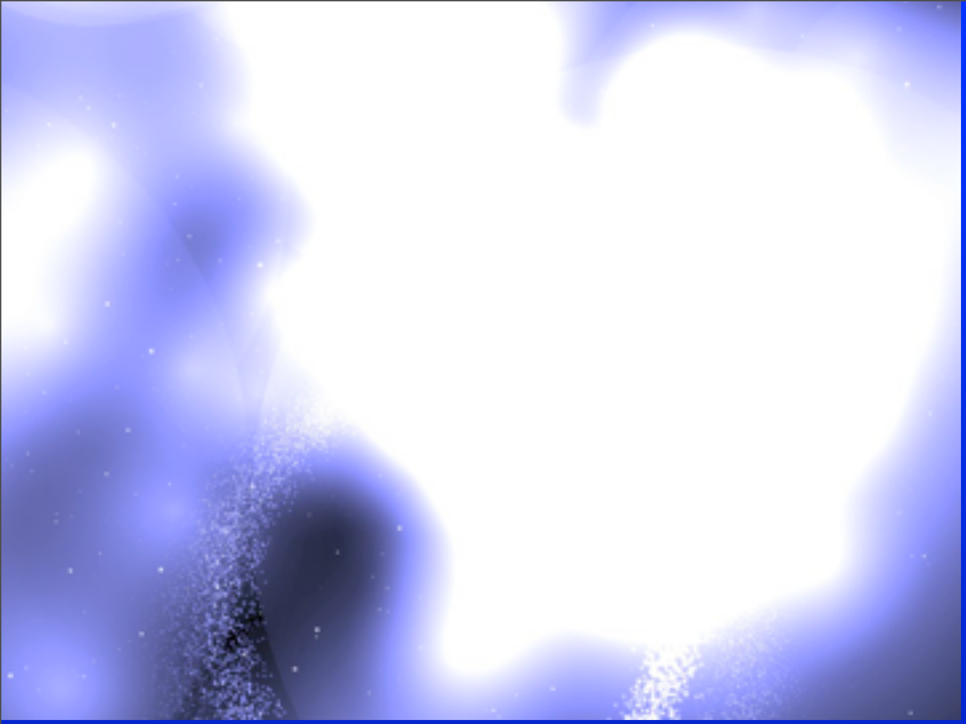
  Pulsar Timing & GW* Detection

- Timing Precision
  - Large European Array for Pulsars (LEAP)
- The ISM and Pulsar Spectra
  - Ultra-Broadband Receiver (UBB)
  - LOFAR
- Summary

* GW = Gravitational Wave

Introduction: Pulsar Timing

Courtesy Andrew Jameson (Swinburne)



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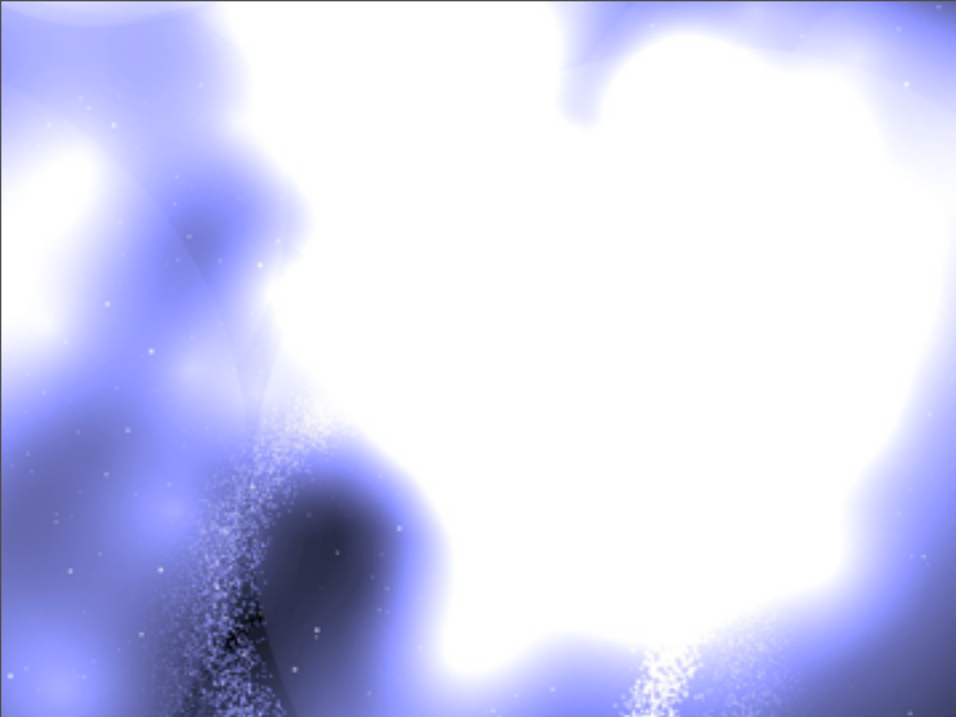

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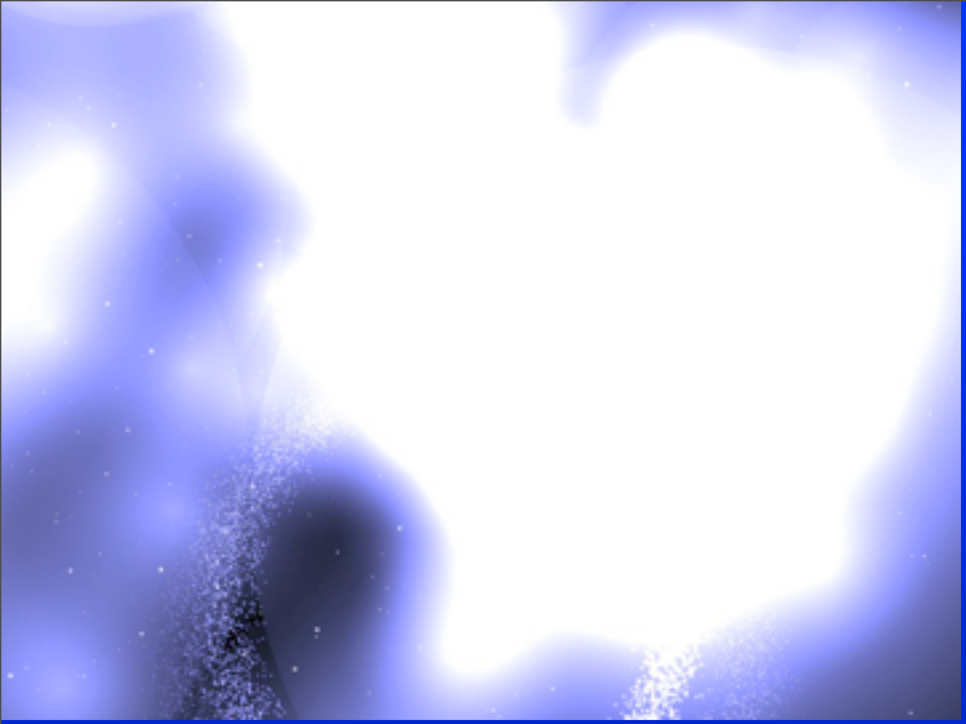
Introduction: Pulsar Timing

$$T_{\rm th} = \nu t + \frac{1}{2}\dot{\nu}t^2 + D\frac{\int_0^d n_e dl}{f^2} - \frac{1}{c}\left(\vec{r}\cdot\hat{s}\right) + \frac{V_{\rm T}^2 t^2}{2cd} - \frac{\left(\vec{r}\times\hat{s}\right)^2}{2cd} + \ldots$$



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Introduction: Pulsar Timing

Basic Method:

Actual Pulse TOA*

— Theoretical Model

= Timing Residual

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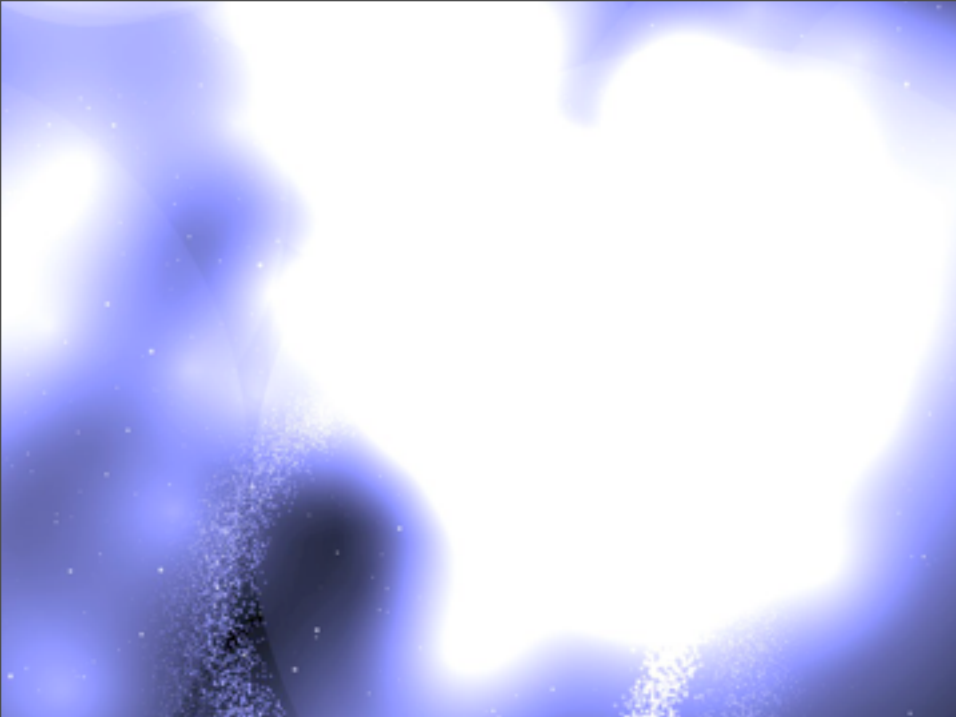
* TOA = Time-of-Arrival



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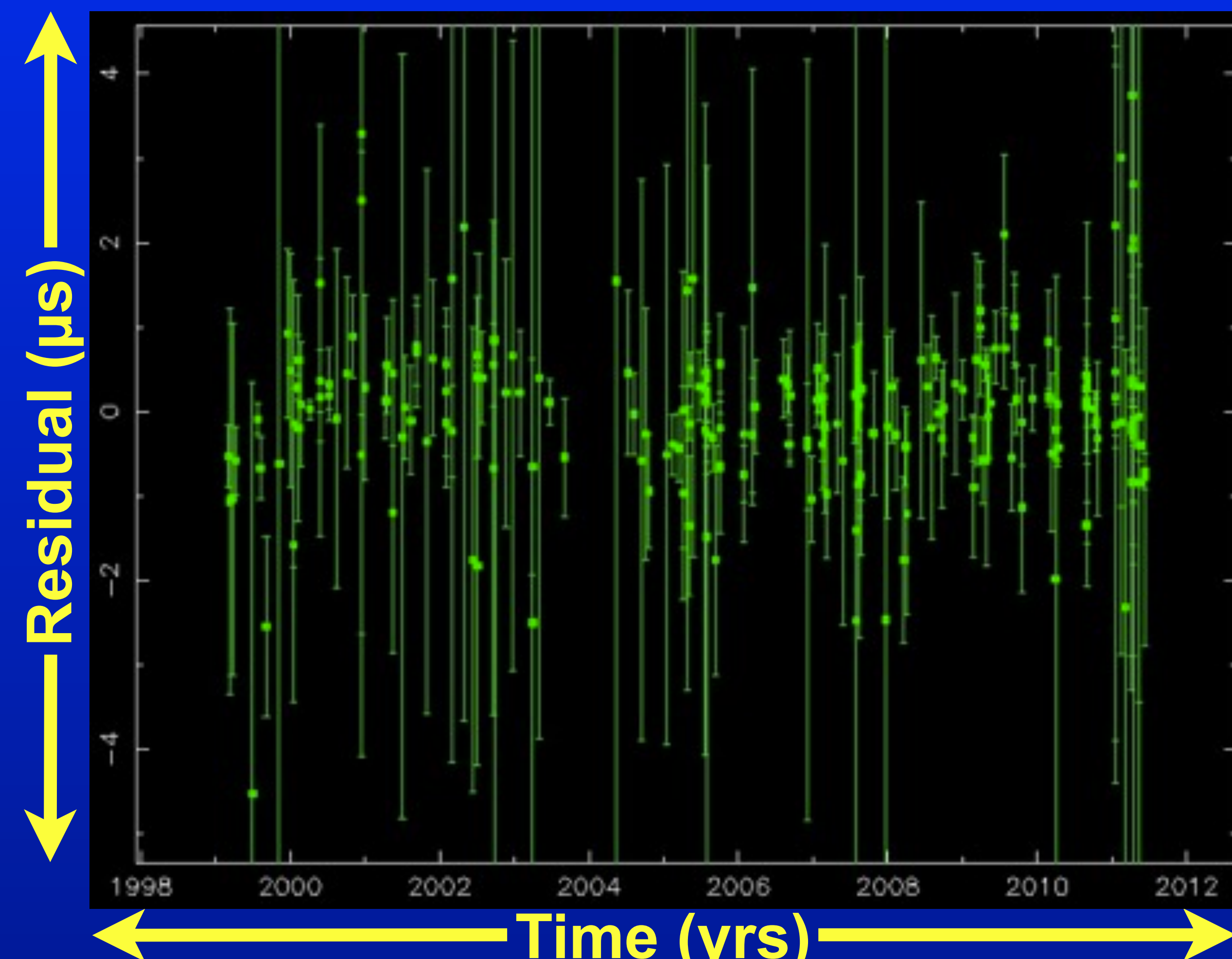

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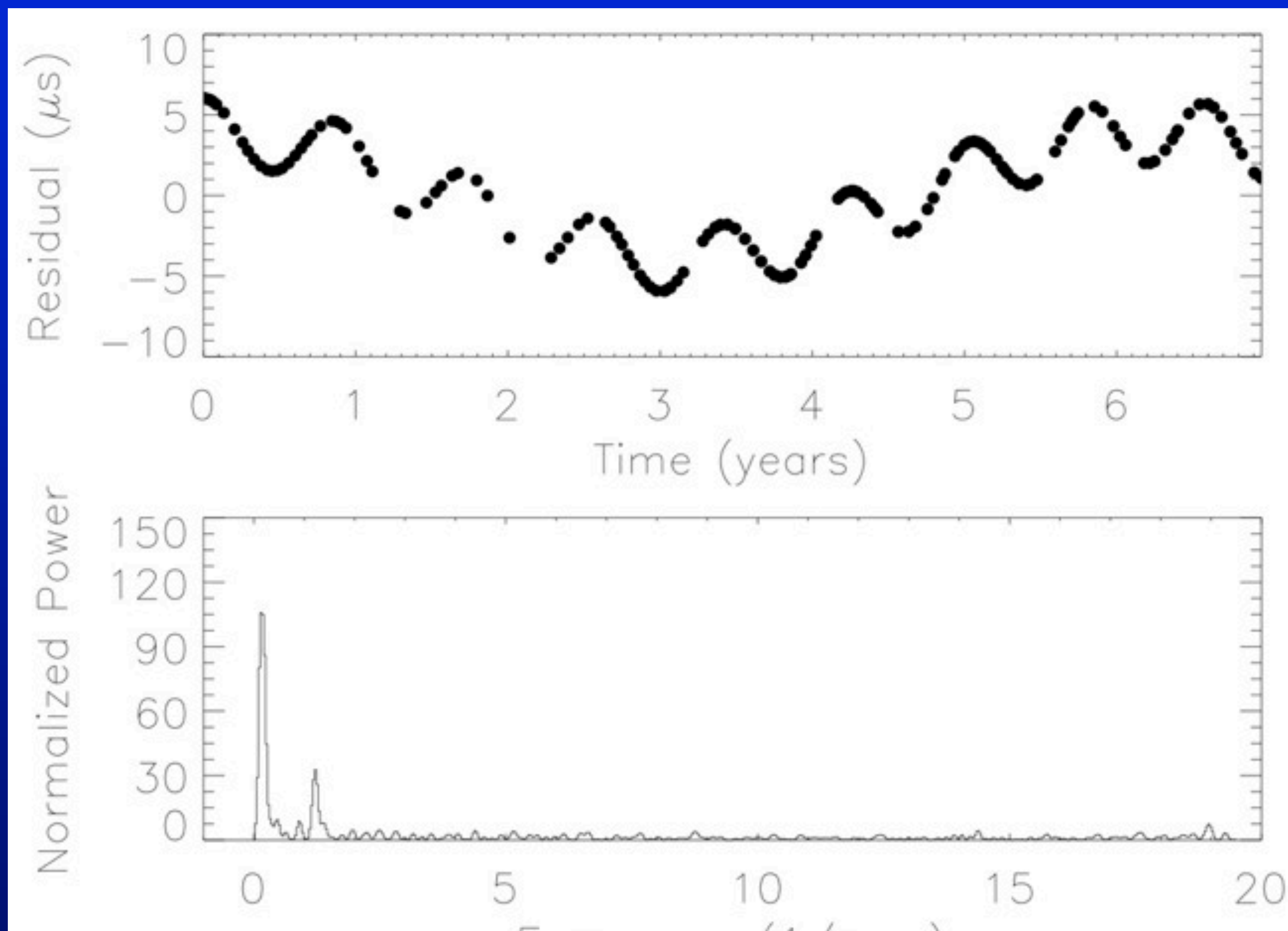
What GWs Look Like

Orbital Motion in the Radio Galaxy 3C 66B: Evidence for a Supermassive Black Hole Binary
Hiroshi Sudou, *et al.*
Science **300**, 1263 (2003);
DOI: 10.1126/science.1082817



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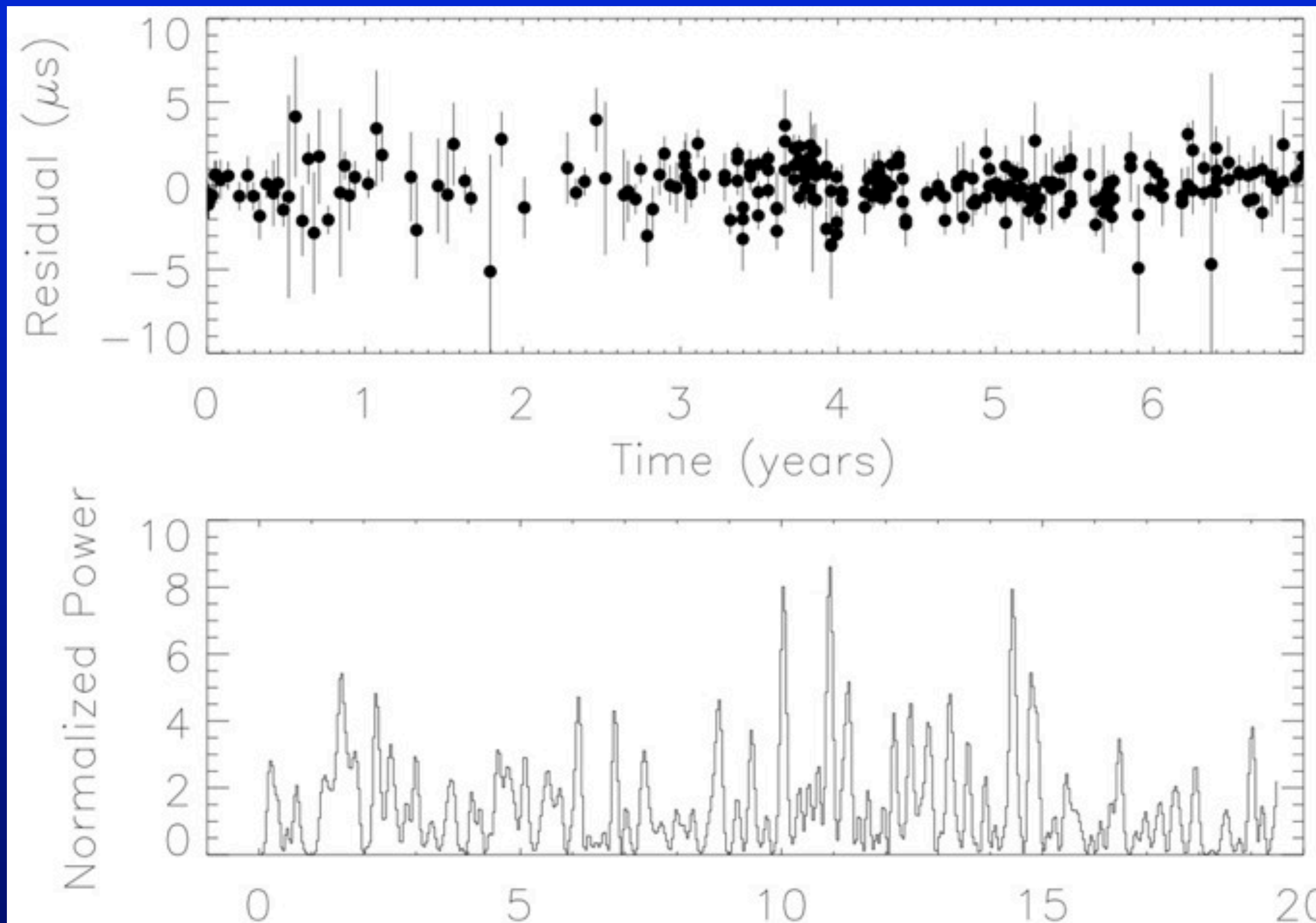

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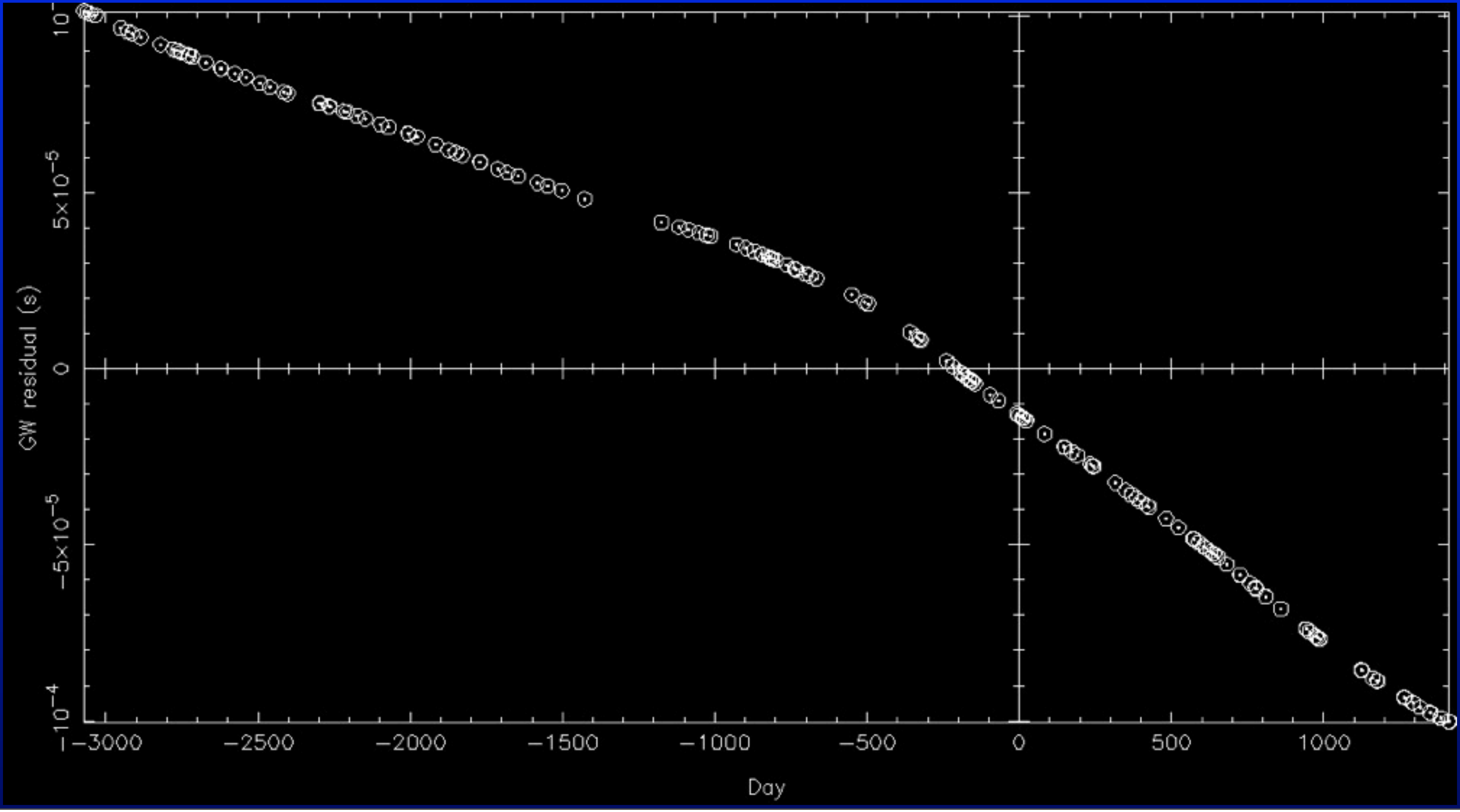
What GWs Look Like

- More likely to see a *background* of GWs.
- This would have a steep, red spectrum.



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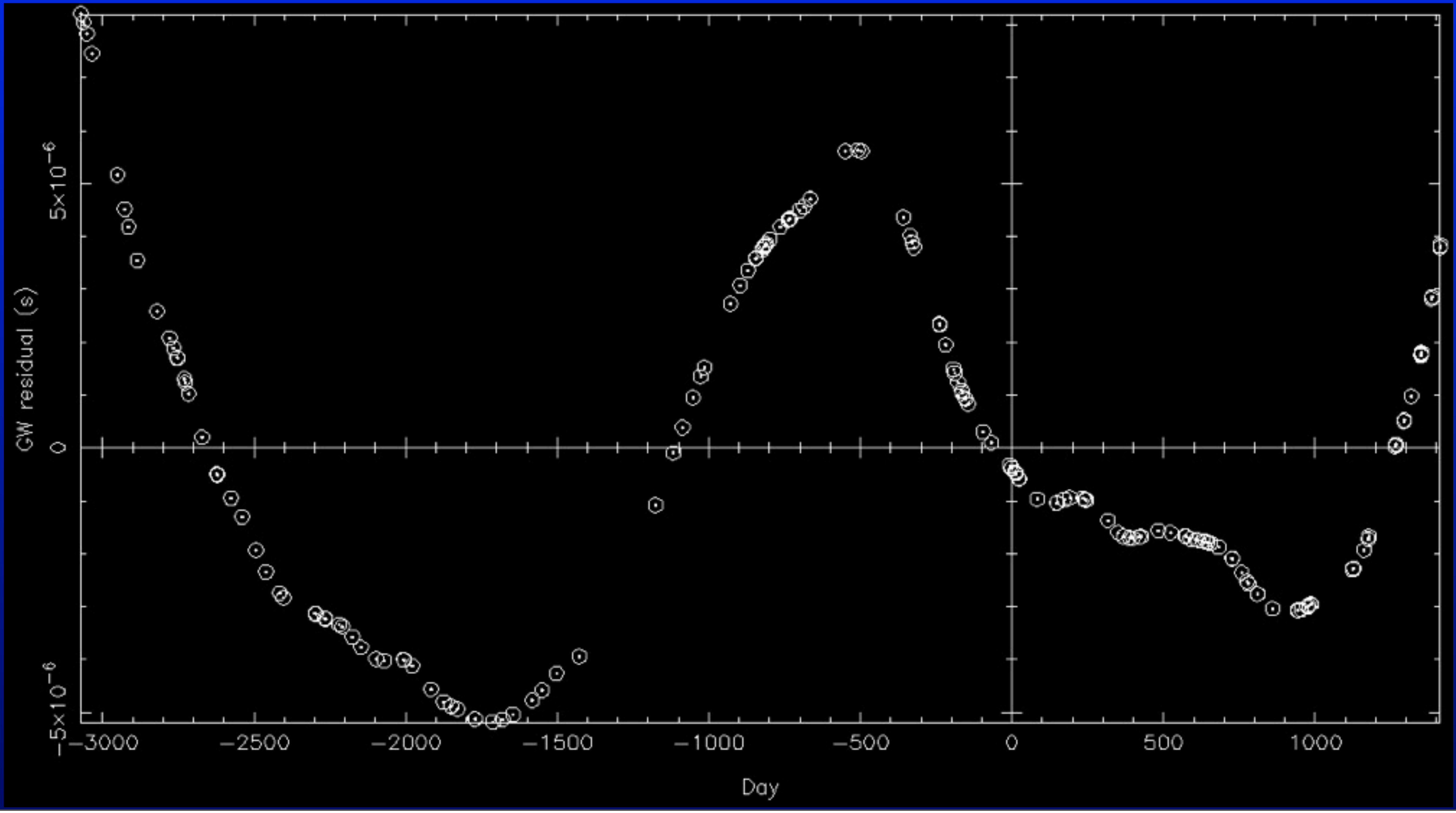

International PTA (IPTA)

Figure courtesy of Brian Burt, Franklin & Marshall

The GW Spectrum

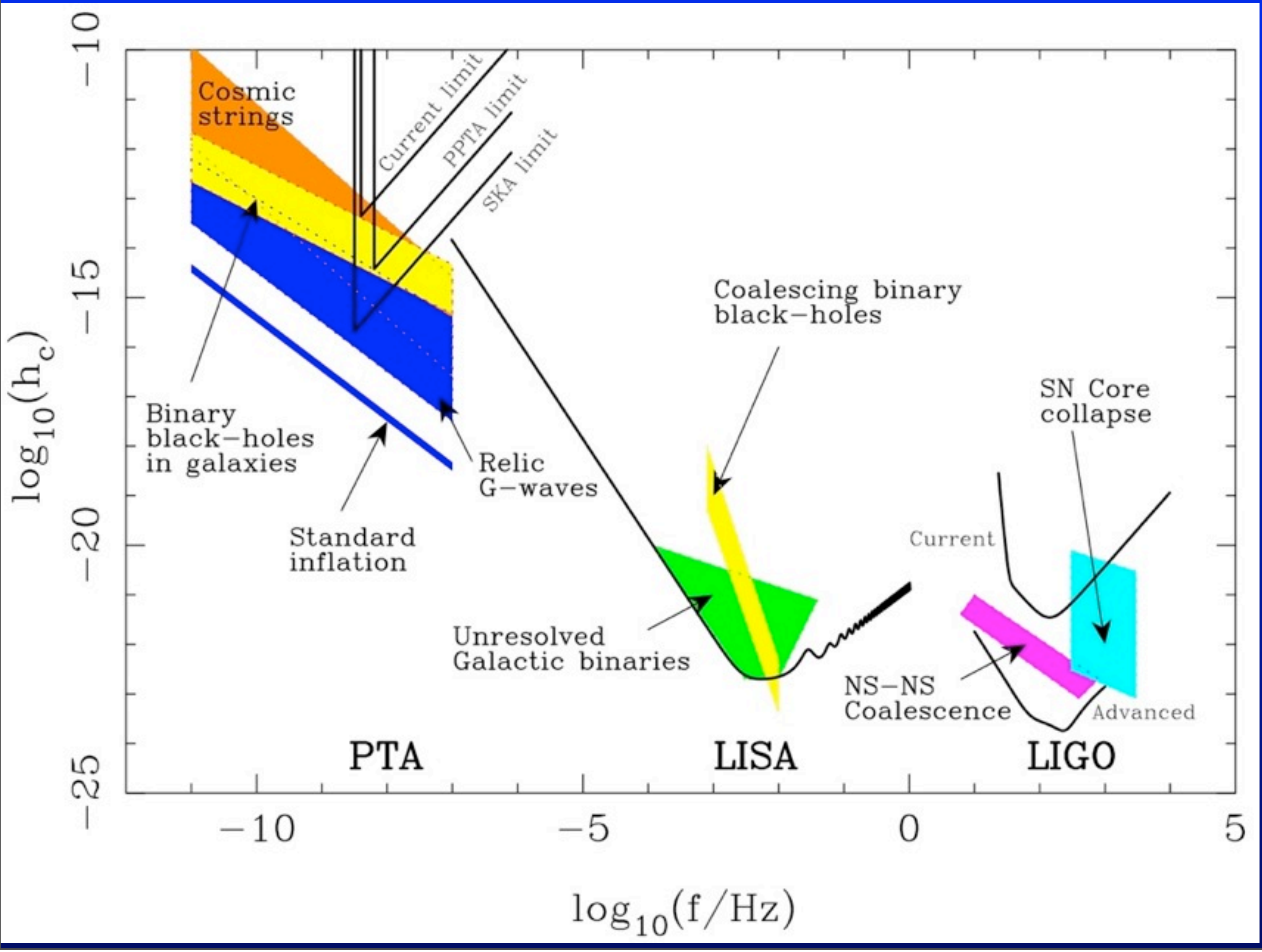

Figure courtesy George Hobbs (ATNF)

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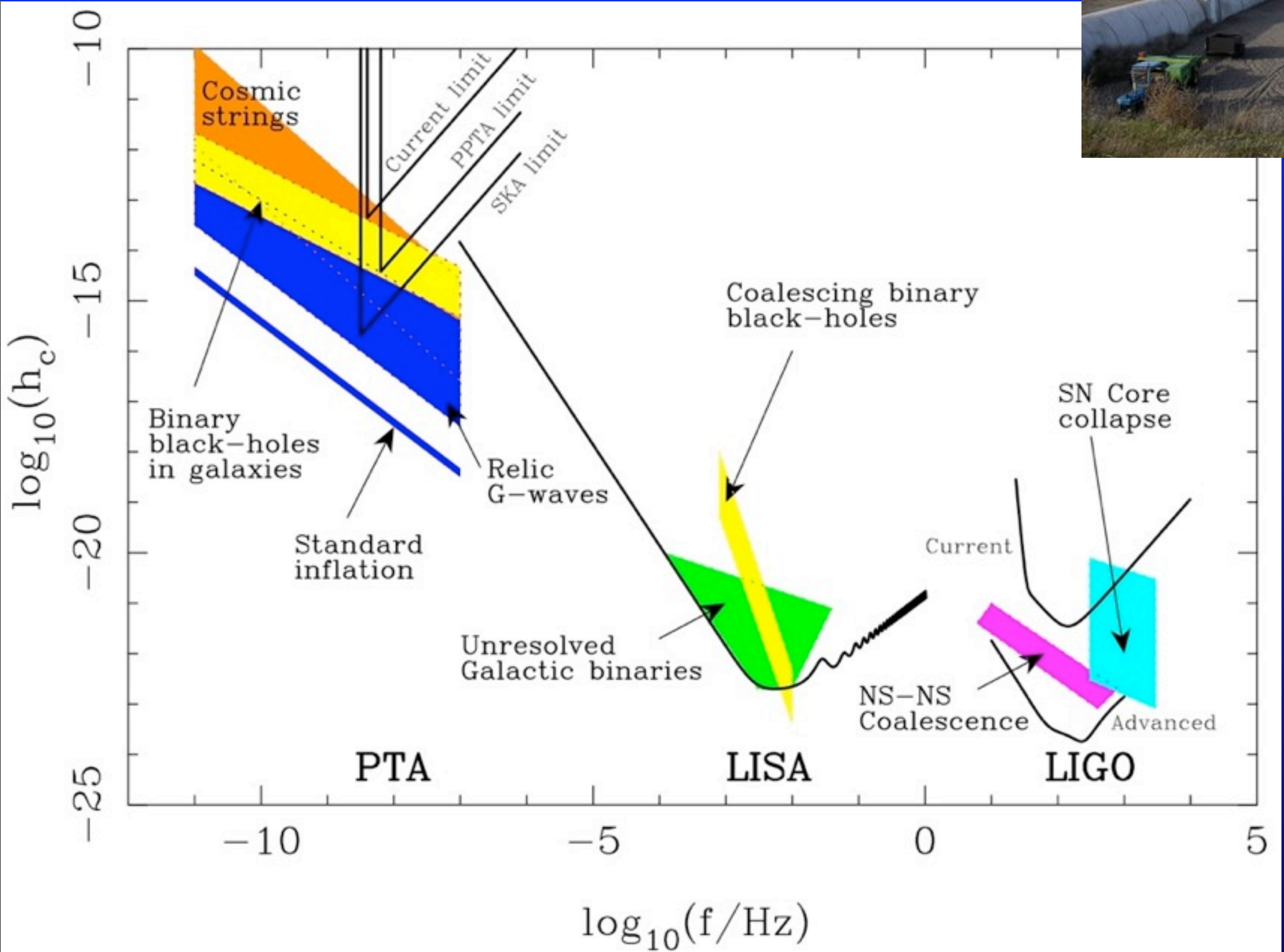

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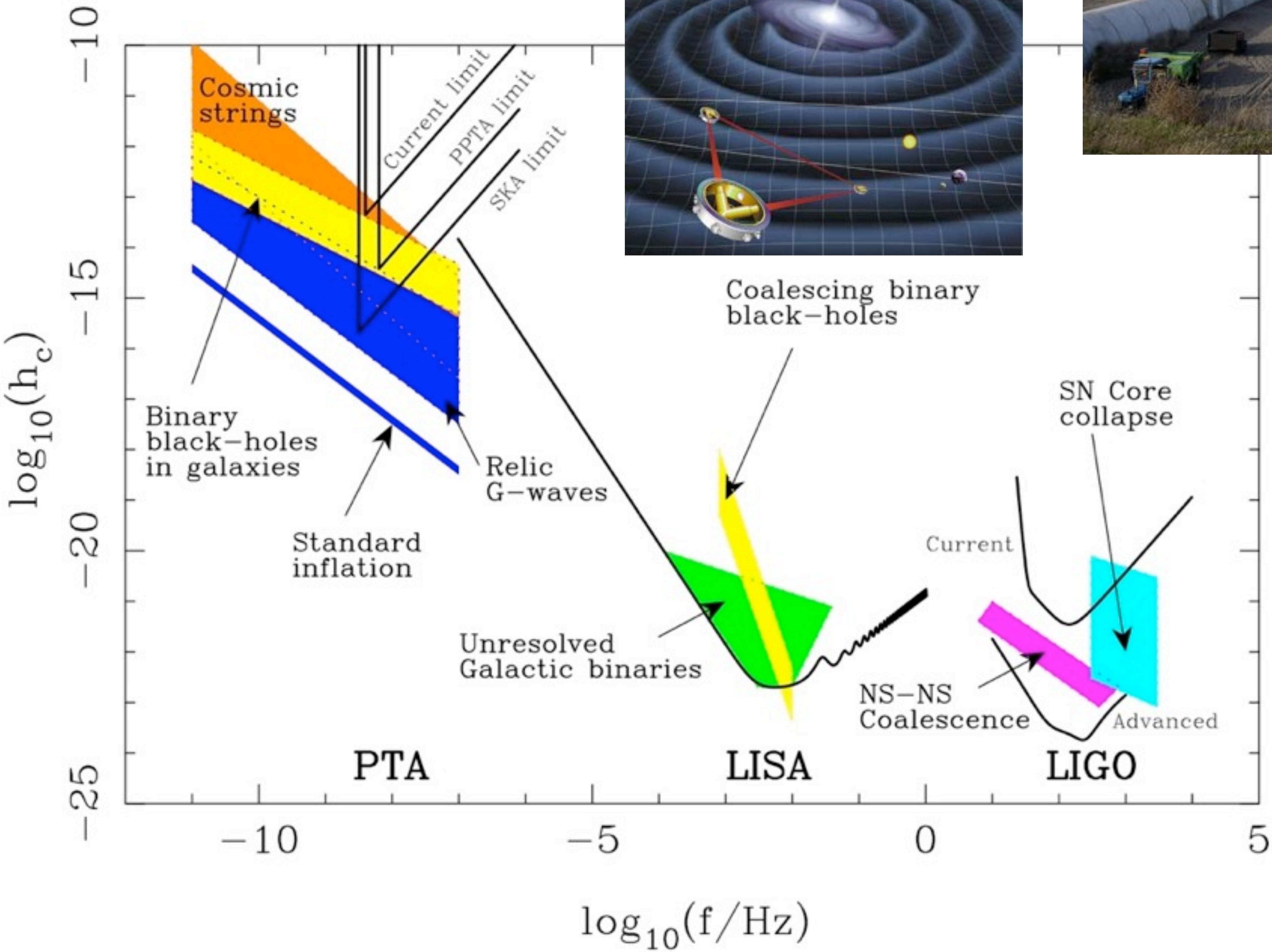


Figure courtesy George Hobbs (ATNF)

TOA Precision

Big, Sensitive Telescope (duh)

Long Observations,
Wide Bandwidth

Fast, Bright Pulsar

$$\sigma_{\rm TOA} \propto \frac{T_{\rm sys}}{A_{\rm eff}} \times \frac{1}{\sqrt{T_{\rm obs}\Delta\nu}} \times \frac{P\delta^{3/2}}{S_{\rm PSR}}$$

Important Note:

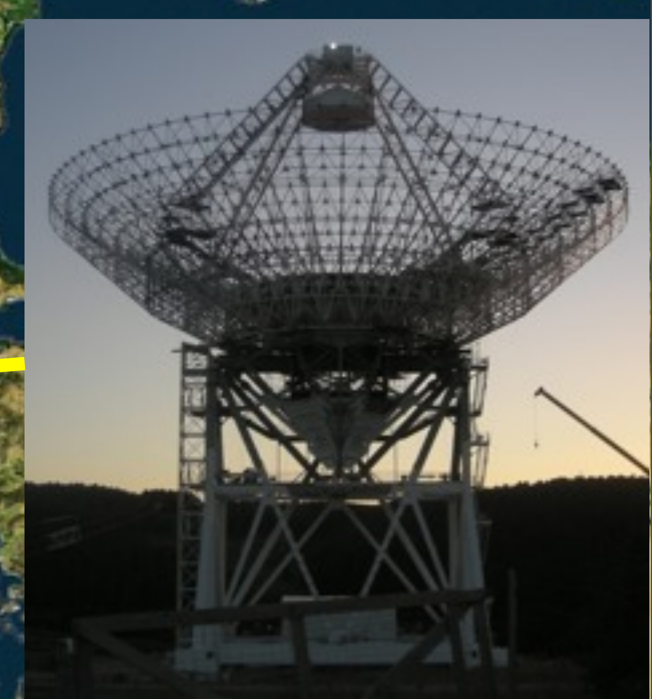
$$S_{\rm PSR} \propto \nu^{\alpha}$$

with $\alpha \approx -1.6 < 0$

Large European Array for Pulsars (LEAP)

- Coherent combination of 5 major European telescopes (at 20cm)

➡ 4% SKA



Timing Precision

- Dominated by TOA precision (σ_{TOA})

- However, increasing corruptions from:
  - ISM
  - Instrumental stability
  - Intrinsic Pulsar Stability
  - ...

Optimal Timing Frequency?

- **Spectral Index**

  ↓

  Low Frequencies

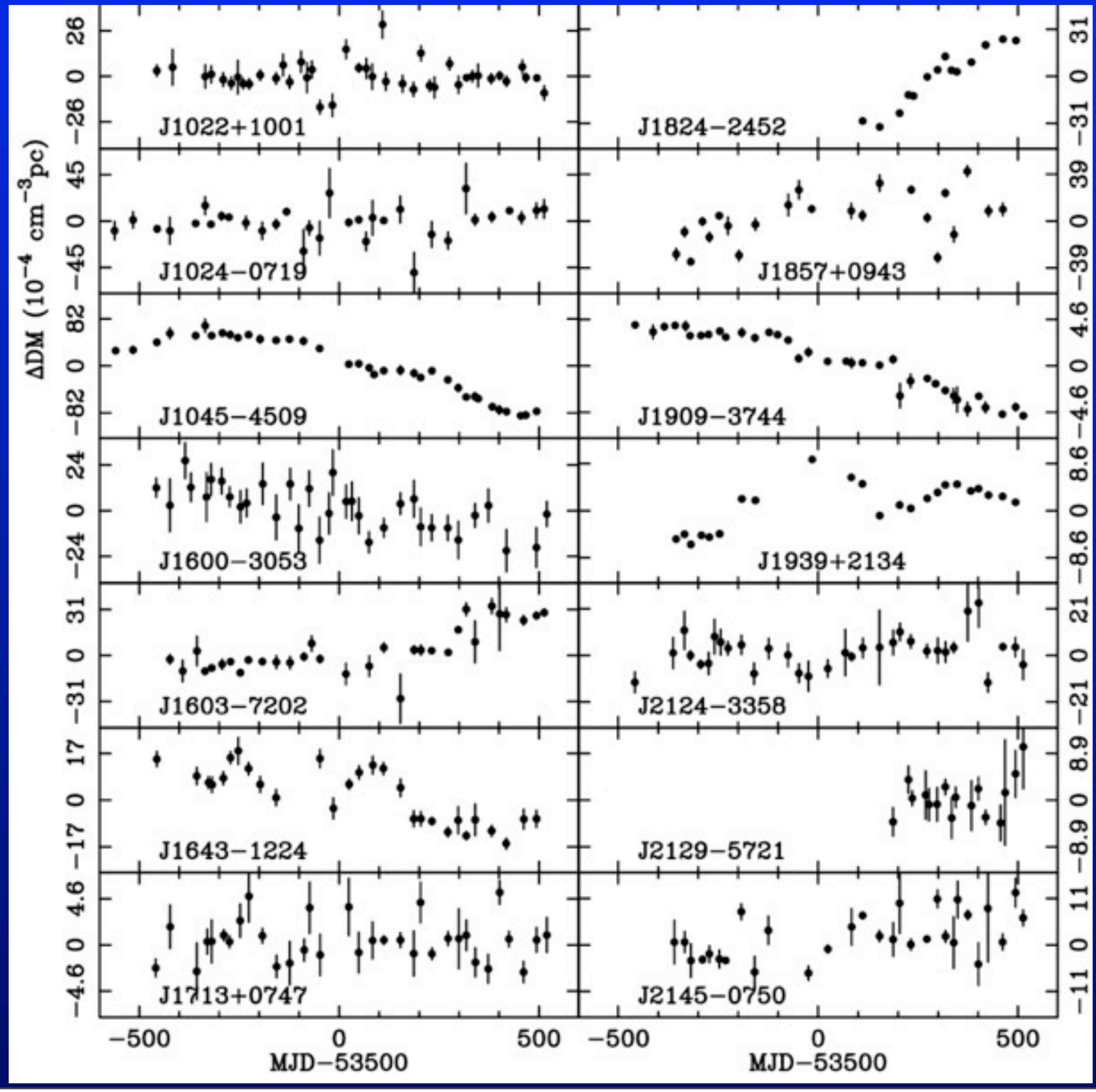
- **Variable ISM Effects**

$$\Delta t \approx 4.15 \times 10^6 \text{ ms} \frac{\text{DM}}{f_1^{-2} - f_2^{-2}}$$

↓

High Frequencies

You et al. (MNRAS, 2007)

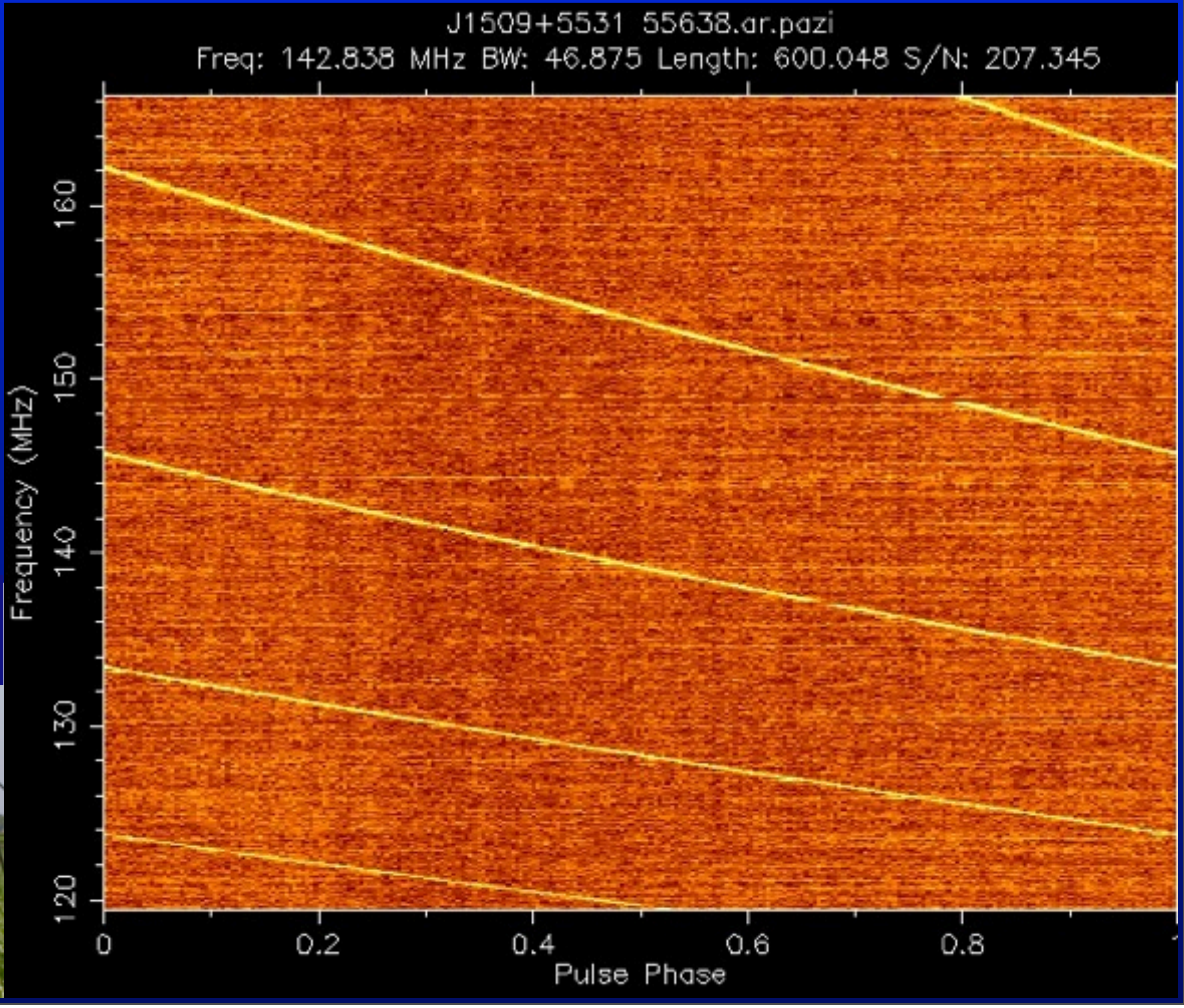


LOFAR & ISM Effects

- **Low-f observations:**
  - are *very* sensitive to DM variations
  - *may* be used to correct higher-f data

- **Challenges?**
  - RFI
  - Ionosphere
  - Sample volume (scattering disk)

Stay Tuned...



Ultra-Broadband Receiver

- 600 MHz to 3 GHz continuous & cooled (<49K)
- No IF but specially developed sampler boards feeding into ROACHs (Casper)
- M€ 1.8 ERC grant to Paulo Freire (MPIfR)
- Feed design by Sandy Weinreb (JPL)
- Feed being cut; commissioning early 2012
- Similar feeds considered for
  Lovell (UK),
  Parkes (Aus),
  GBT (USA)

Instantaneous Multi-frequency Observing:
- Scintillation
- Pulse profile evolution
- Frequency-dependent effects
- High sensitivity

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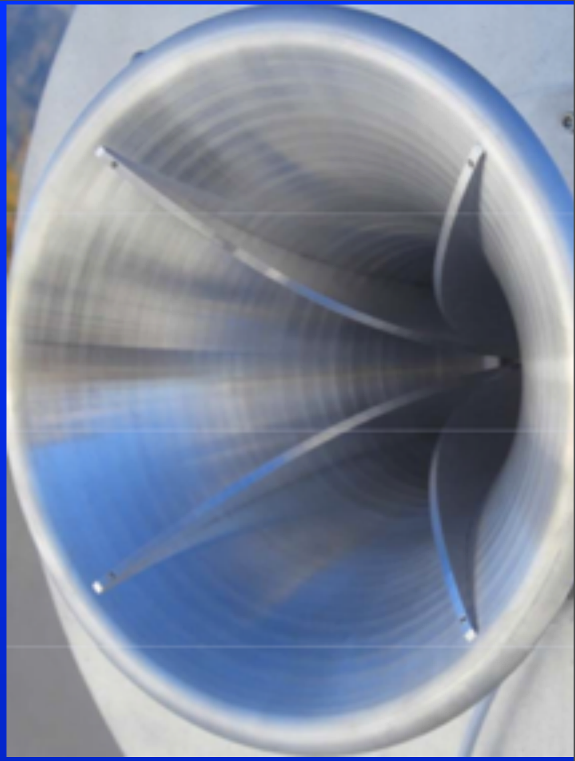
Picture: Weinreb (Caltech/JPL)



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Summary

- **Aperture Arrays *may* be *crucial* to correct ISM variations in higher-frequency timing data**

- **LOFAR and Ultra-Broadband receivers will demonstrate the use of low-f observations for timing array work**