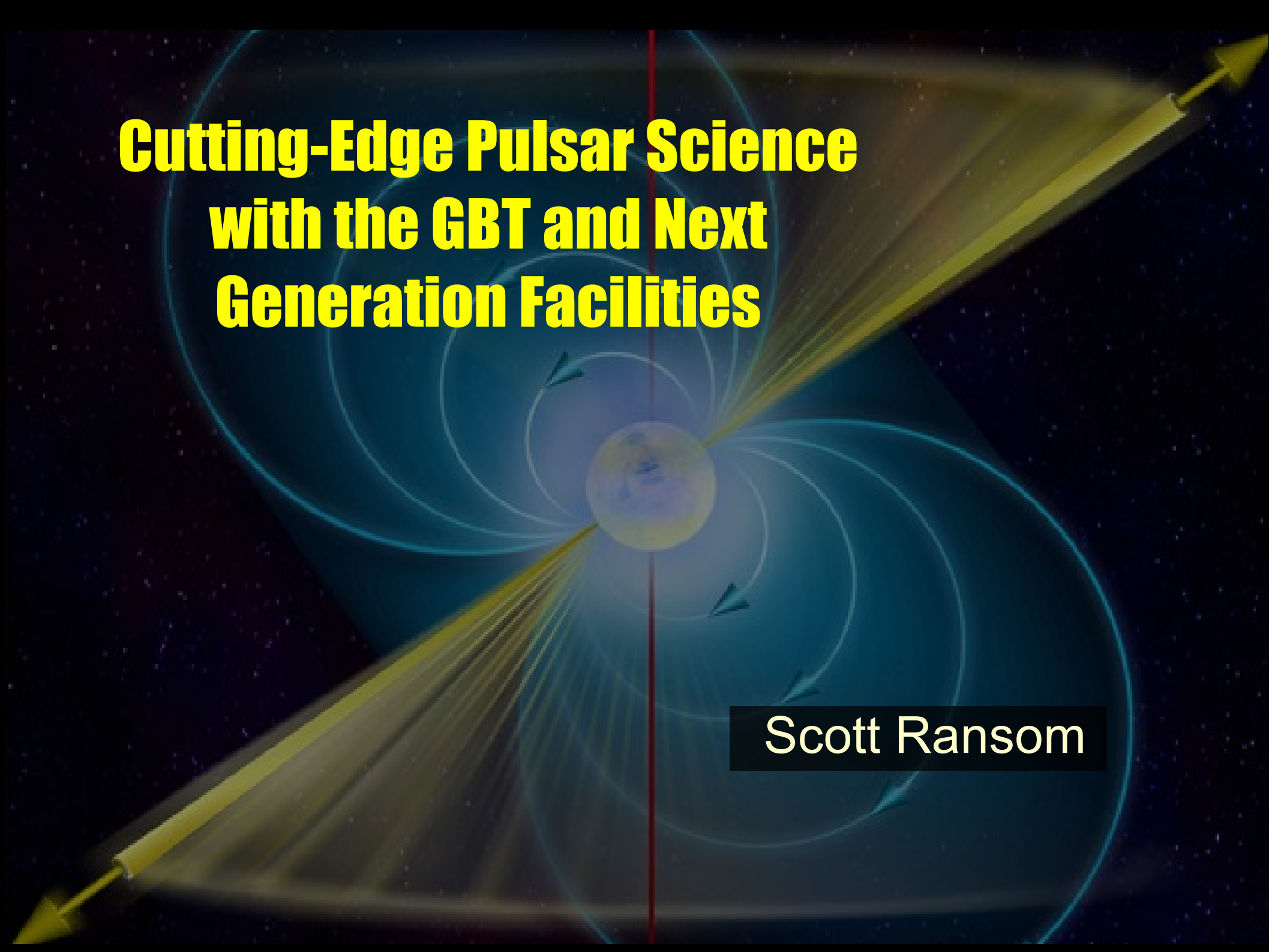
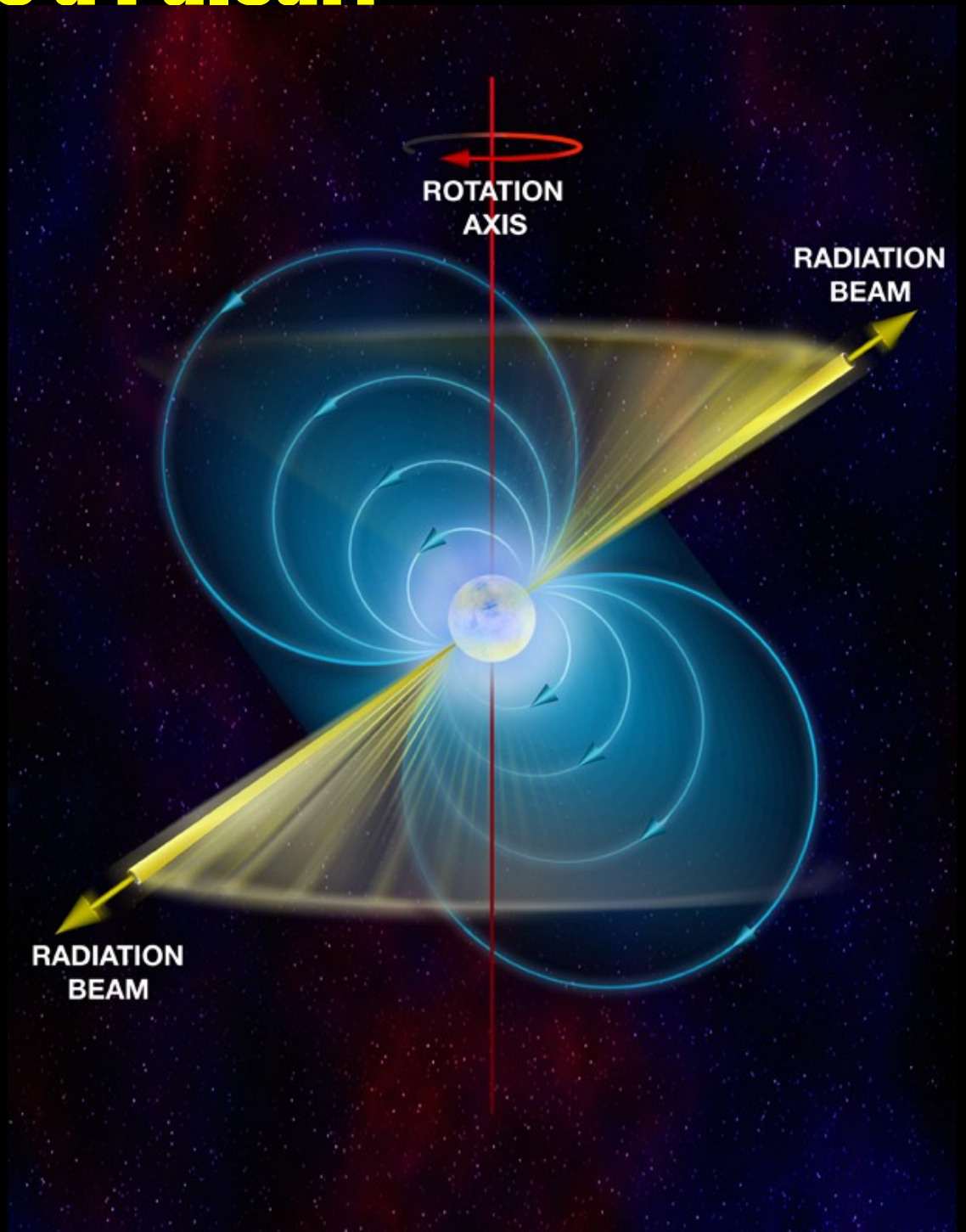

Cutting-Edge Pulsar Science with the GBT and Next Generation Facilities
Scott Ransom

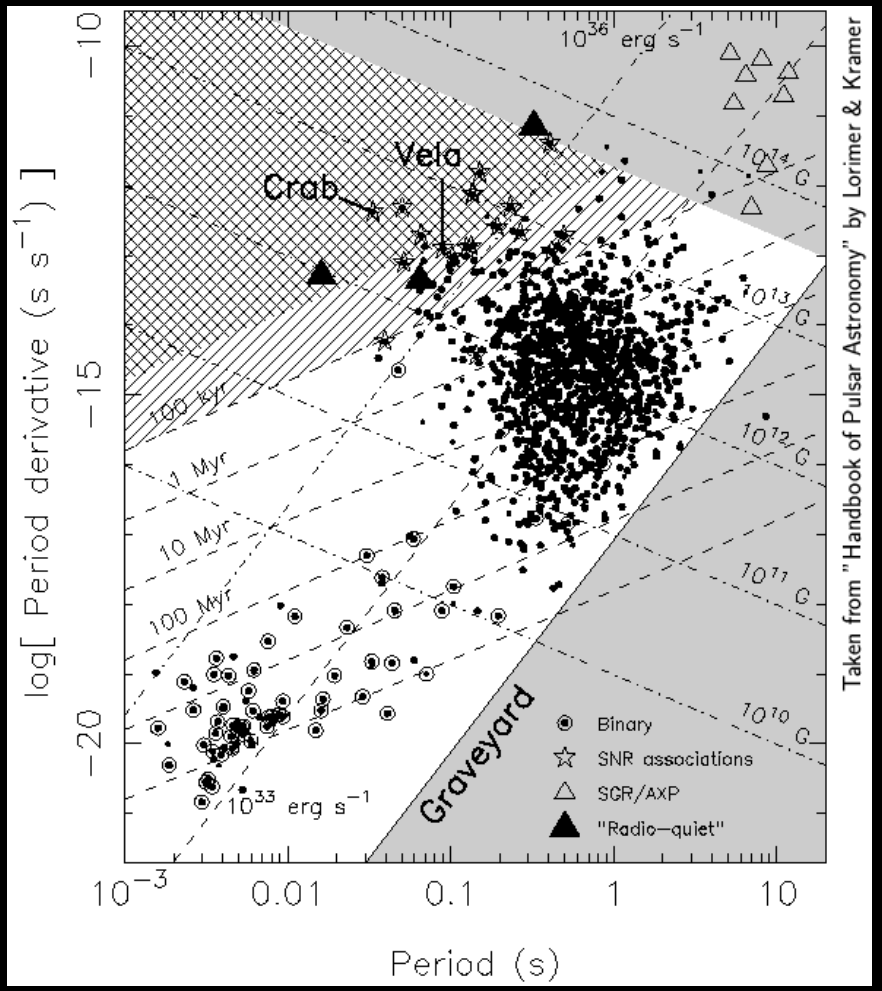
What's a Pulsar?

- Rotating Neutron Star!
- Size of city:
  - R ~ 10-20 km
- Mass greater than Sun:
  - M ~ 1.4 M_{sun}
- Strong Magnetic Fields:
  - B ~ 10^{8}-10^{14} Gauss
- Pulses are from a "**lighthouse**" type effect
- "Spin-down" power up to 10,000 times more than the Sun's total output!



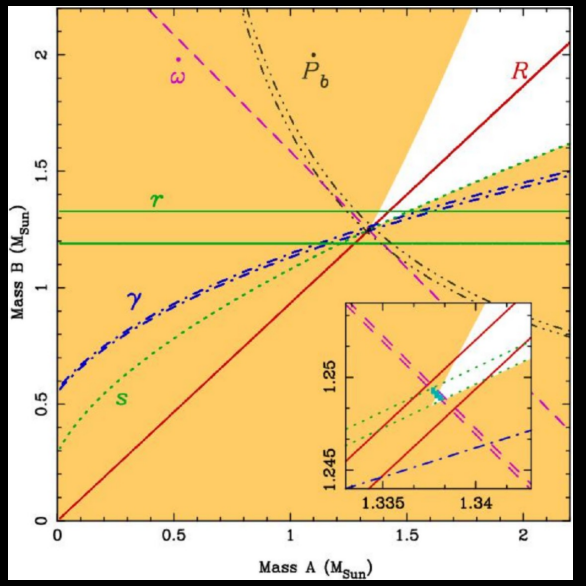
Last 10 yrs: A Pulsar Renaissance

- Low-noise, wide BW, receivers from 1-2 GHz
  - Can see much deeper into the Galaxy (i.e. volume)
  - Greatly reduced scattering and/or smearing
- Better telescope systems
  - Parkes Multibeam system
  - Arecibo upgrade
  - GBT
- Much better pulsar backends
  - Faster sampling
  - Better frequency resolution
- Improved computational resources



Key Science with Pulsars

- Strong Field GR Tests:
  - PSRs around Sgr A* would be best (10-15 GHz)
  - Stellar-mass BH-PSR system(s) (400 MHz - 3 GHz)

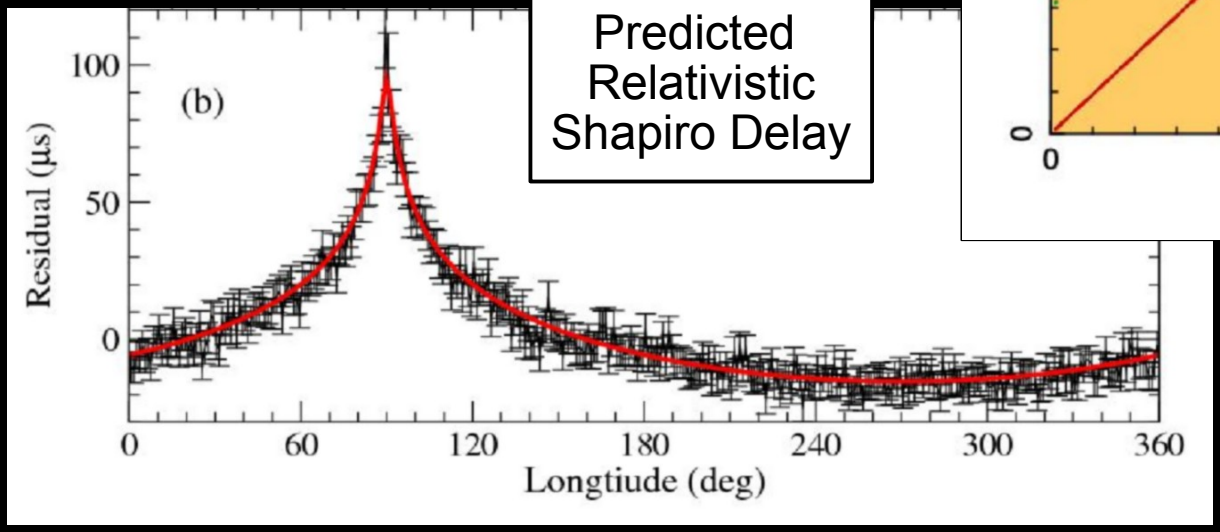


The Double Pulsar J0737-3039

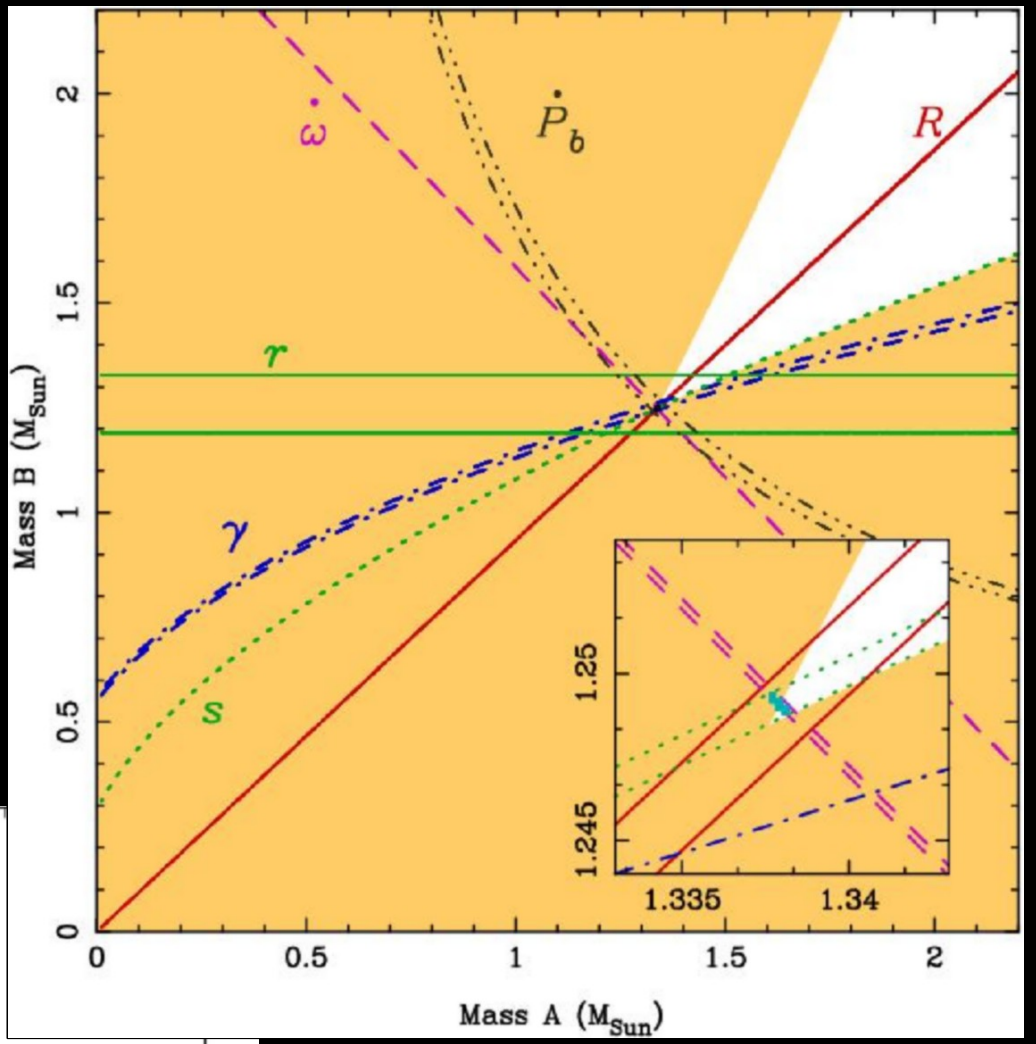
GBT provides the best timing precision for this system

6(!) post-Keplerian orbital terms give neutron star masses and strong-field tests of general relativity to 0.05% accuracy

Timing may eventually allow measurement of the neutron star moment of inertia



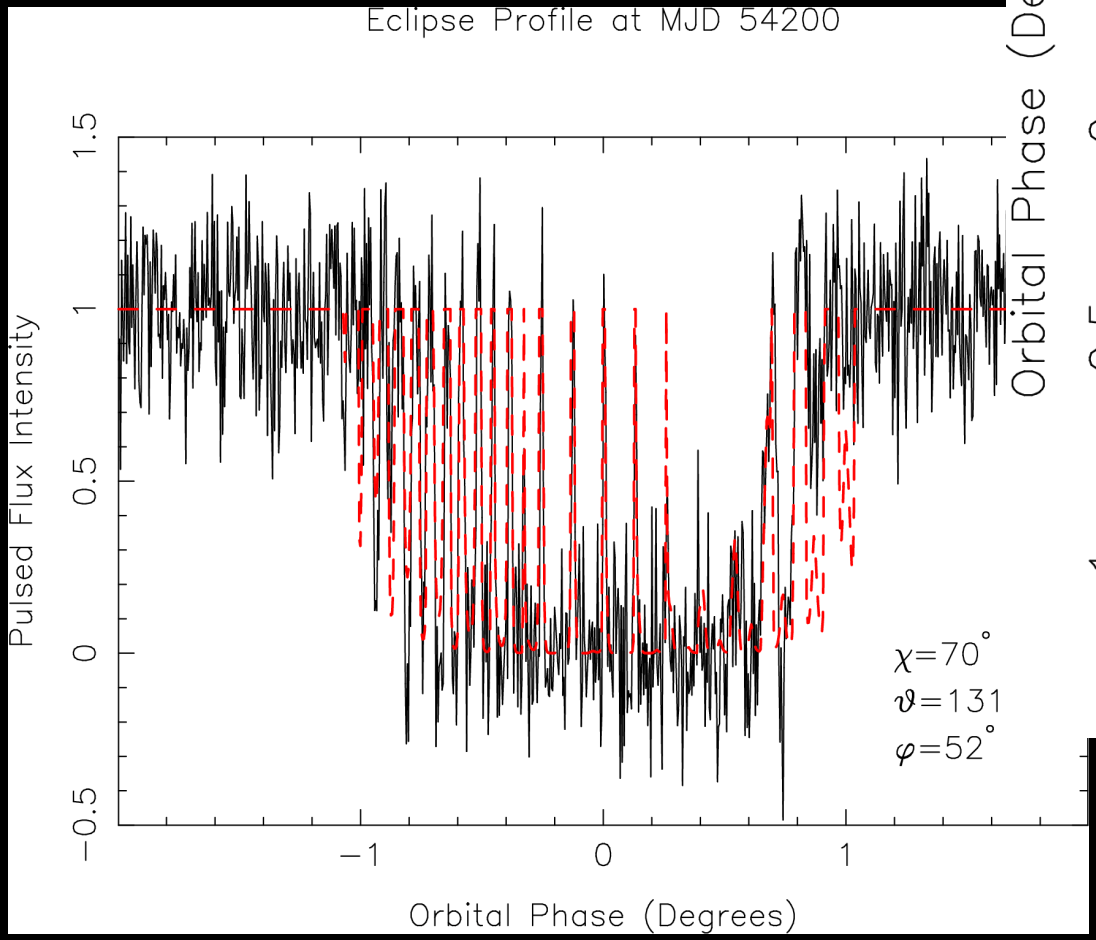
Measured vs Predicted Relativistic Shapiro Delay

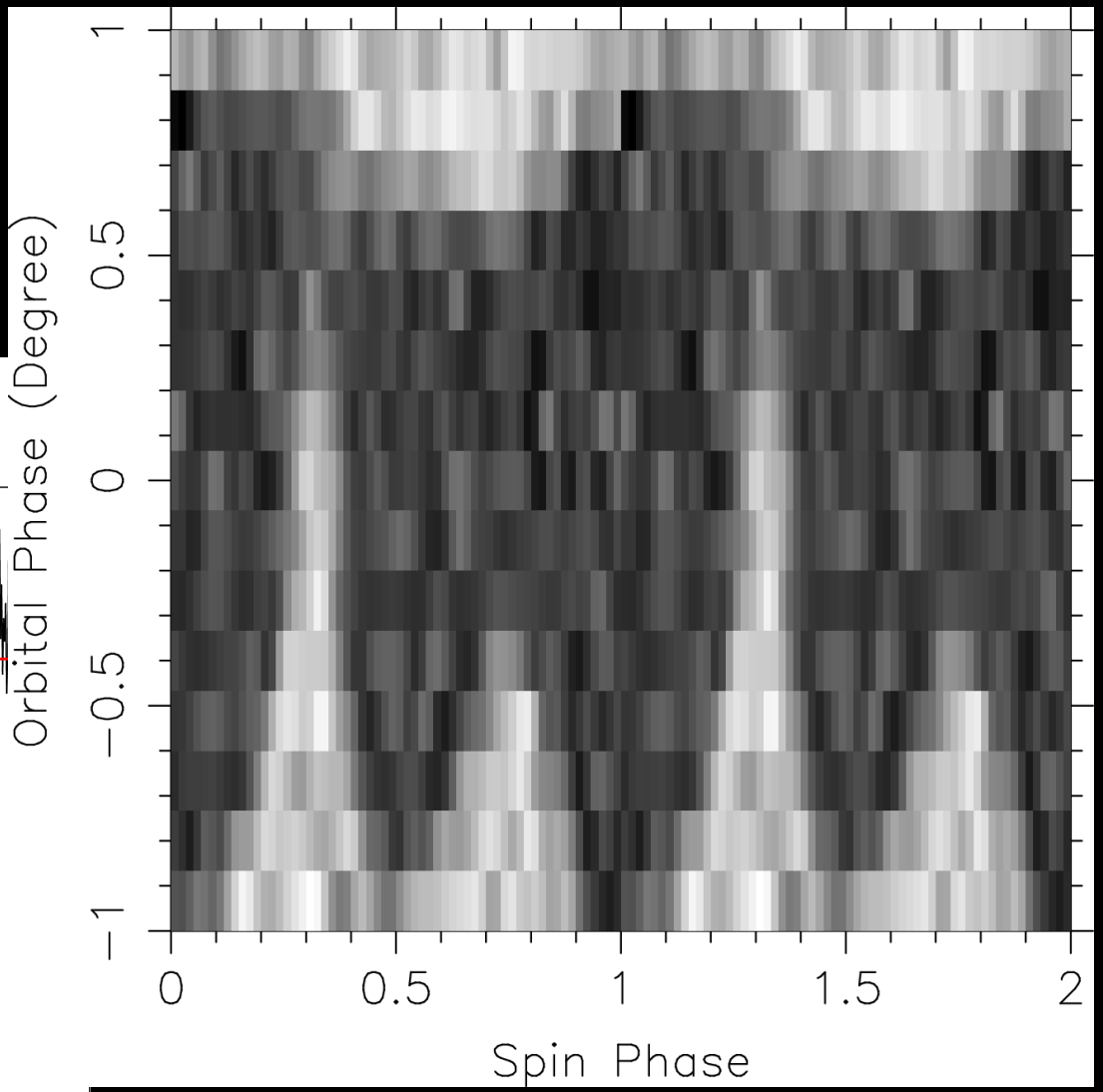


Kramer et al., 2006, *Science*, 314, 97

Relativistic Spin Precession of PSR B

The ~30sec eclipses of PSR A by PSR B are caused by a plasma effect in Pulsar B's dipolar magnetosphere (Lyutikov & Thompson 2005)



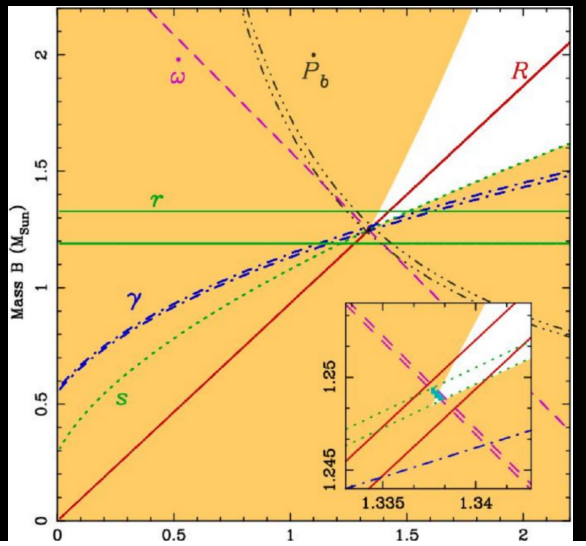


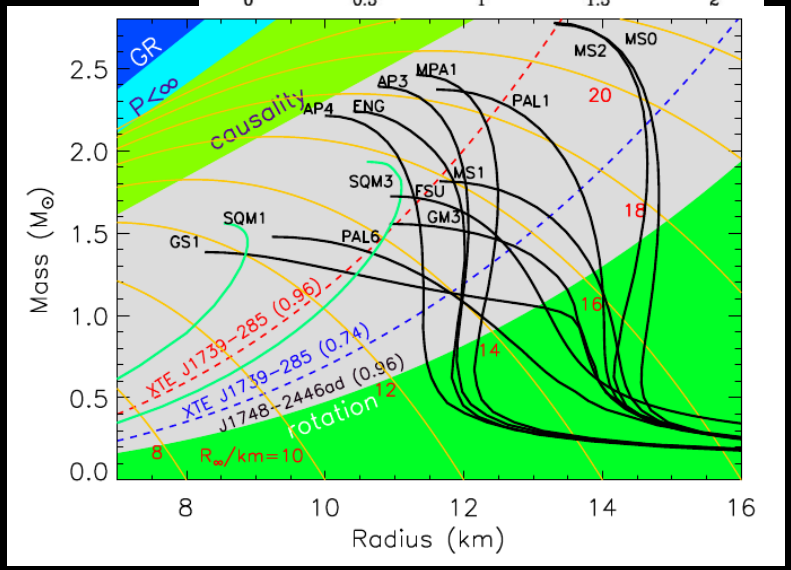
Measured precession rate is consistent with GR to ~12%
This is a brand new GR test.

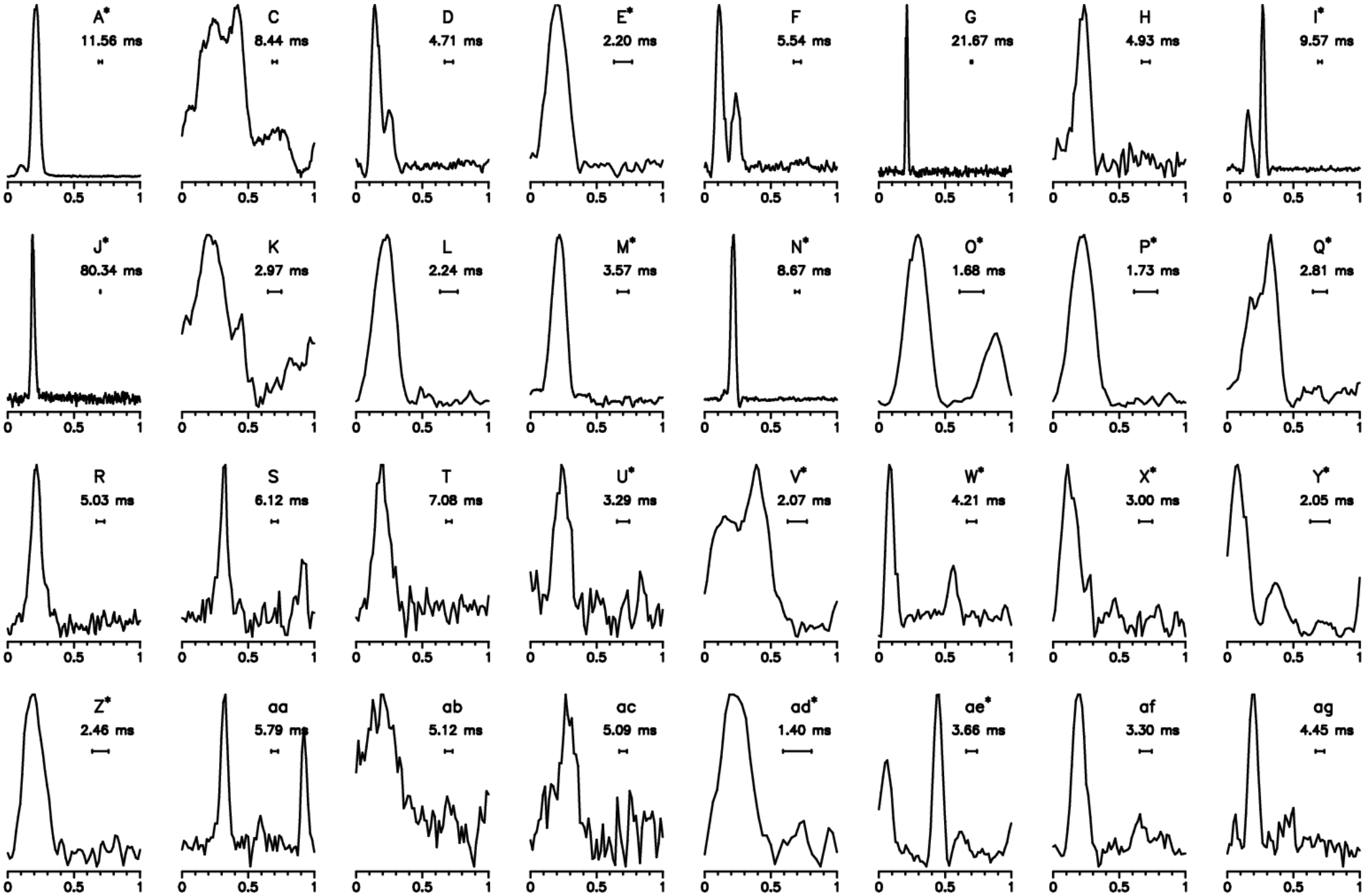
Breton et al. 2008, submitted to *Science*

Key Science with Pulsars

- Strong Field GR Tests:
  - PSRs around Sgr A* would be best (10-15 GHz)
  - Stellar-mass BH-PSR system(s) (400 MHz - 3 GHz)
- Equation of State of Matter at Supra-Nuclear Density
  - Masses of many MSPs





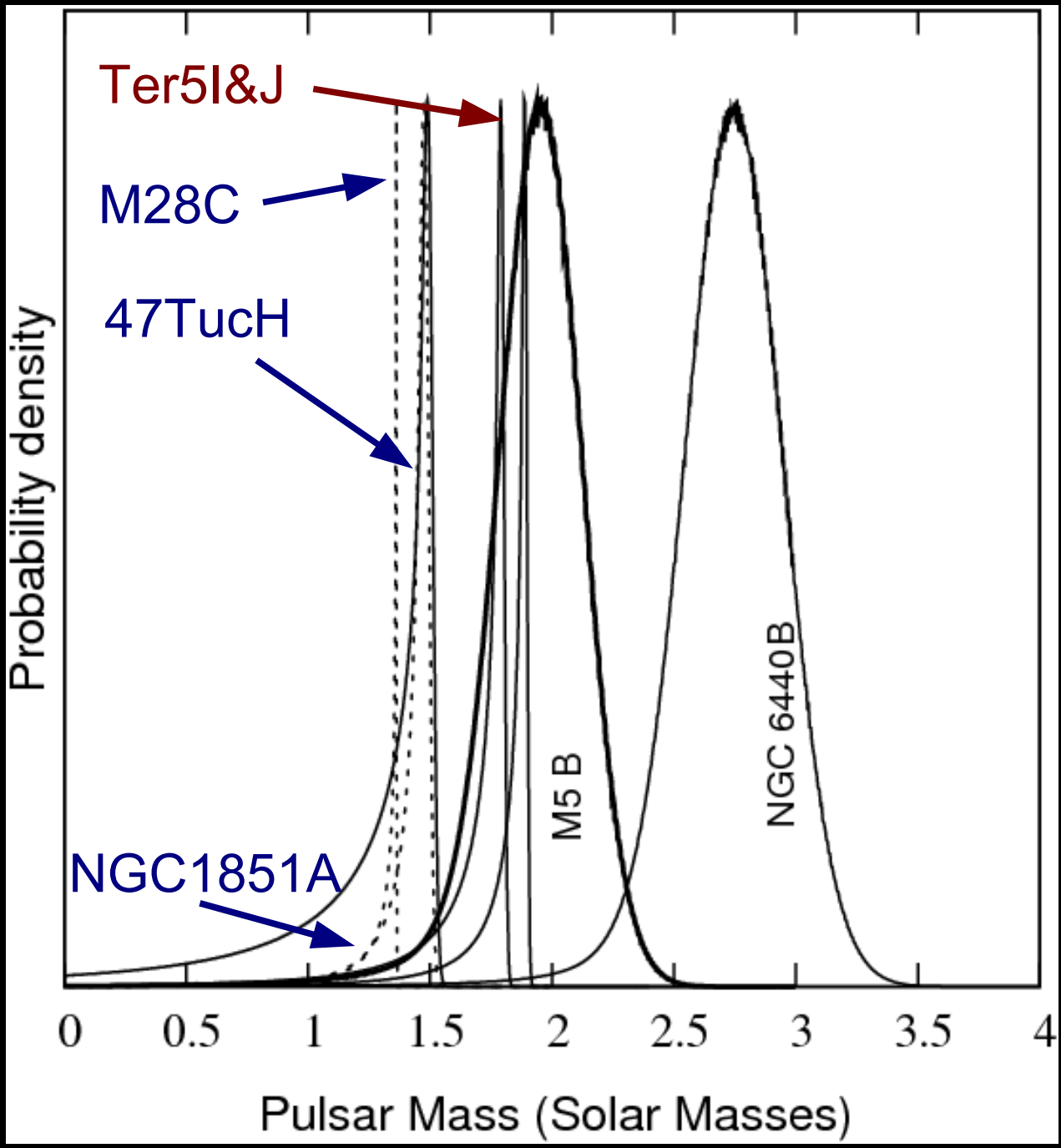


33 MSPs in Globular Cluster Terzan 5!

(First 21 reported in Ransom et al., 2005, *Science*, 307, 892)

At least 4 GC eccentric binaries appear massive

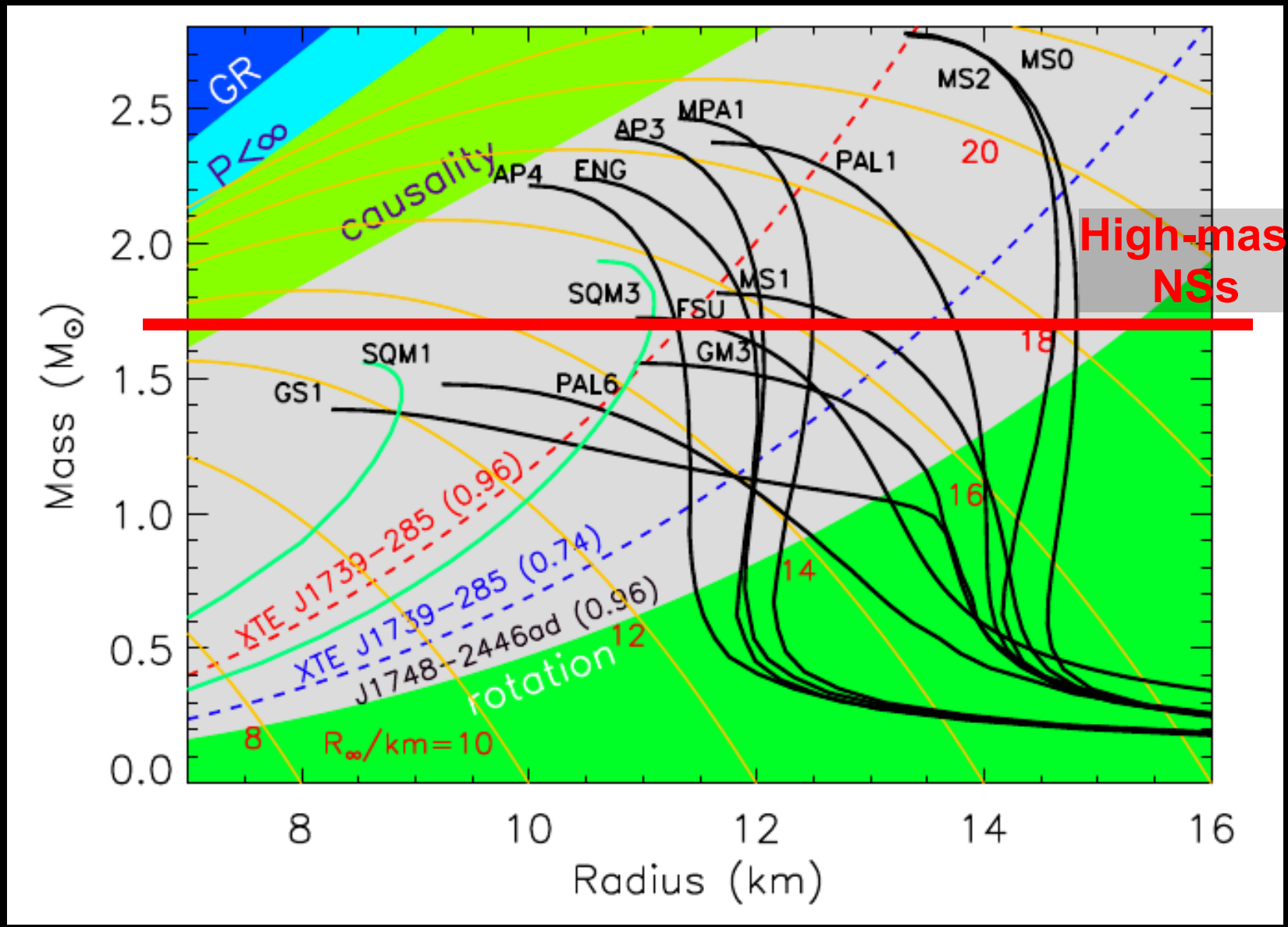
Total system masses are determined by measuring the relativistic advance of periastron of the eccentric orbits.



Freire et al. 2008

Neutron Star Equations of State:

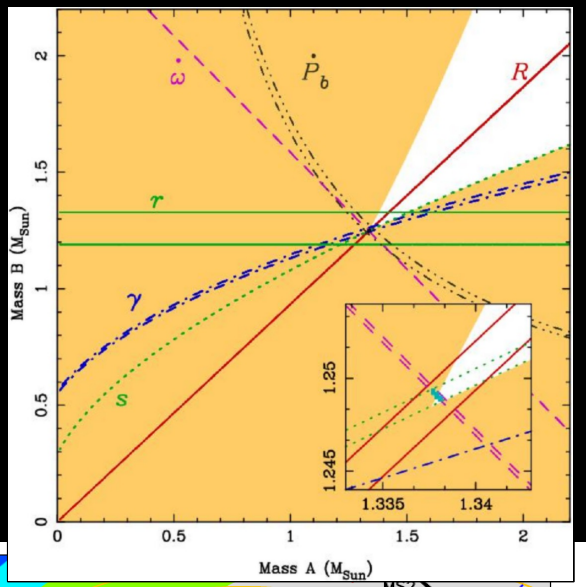
Understanding matter at supra-nuclear densities.

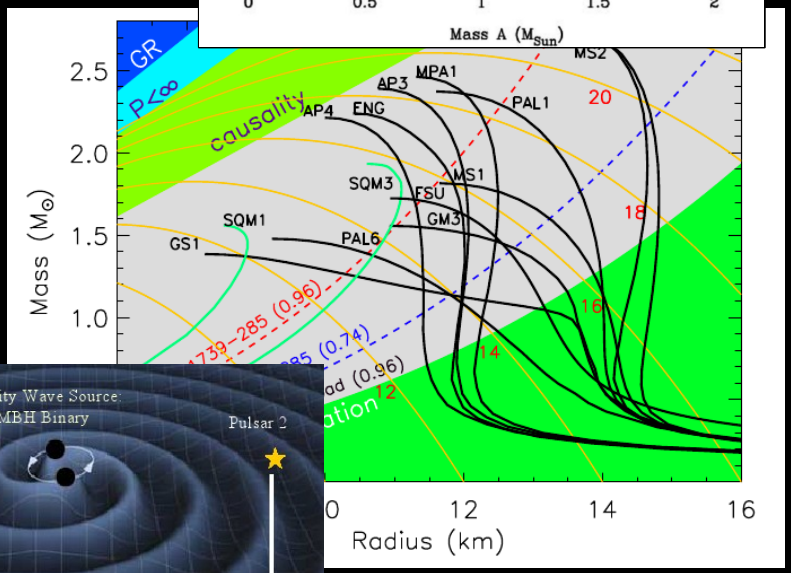


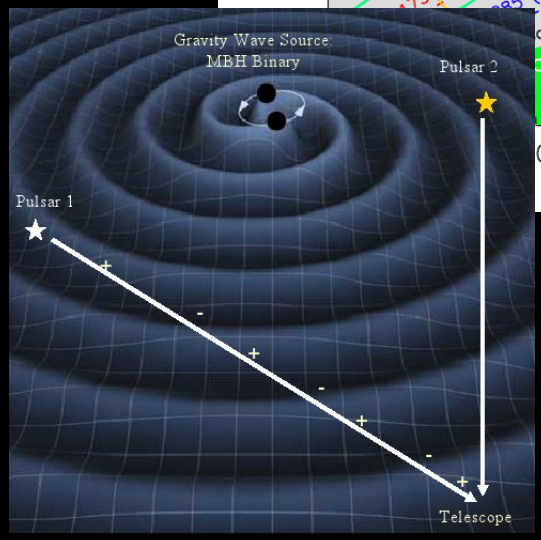
Adapted from Lattimer and Prakash 2007, *Physics Reports*

Key Science with Pulsars

- Strong Field GR Tests:
  - PSRs around Sgr A* would be best (10-15 GHz)
  - Stellar-mass BH-PSR system(s) (400 MHz - 3 GHz)
- Equation of State of Matter at Supra-Nuclear Density
  - Masses of many MSPs
- Direct detection of nanoHz Gravitational Waves
  - Need both new MSPs, more sensitivity, and reduction in systematics







High-precision MSP Timing for Gravitational Wave Detection

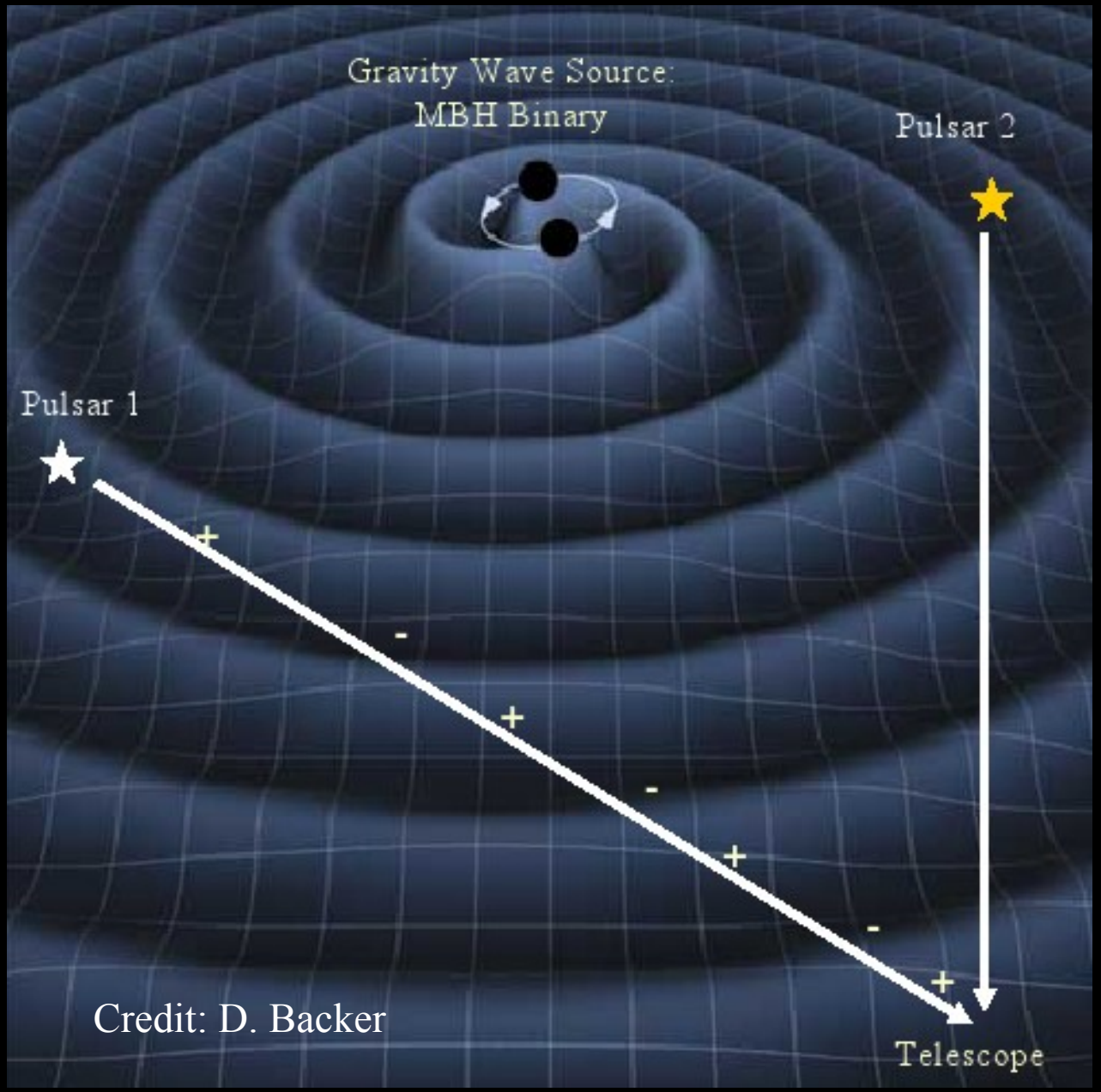
e.g. Detweiler, 1979
Hellings & Downs, 1983

The best timing MSPs (~100-500 ns RMS) can be used to search for a stochastic nHz gravitational wave background

Sensitivity comparable and complementary to Adv. LIGO and LISA!

Need best MSPs and instrumentation.

NANOGrav, PPTA, EPTA



High-precision MSP Timing for Gravitational Wave Detection

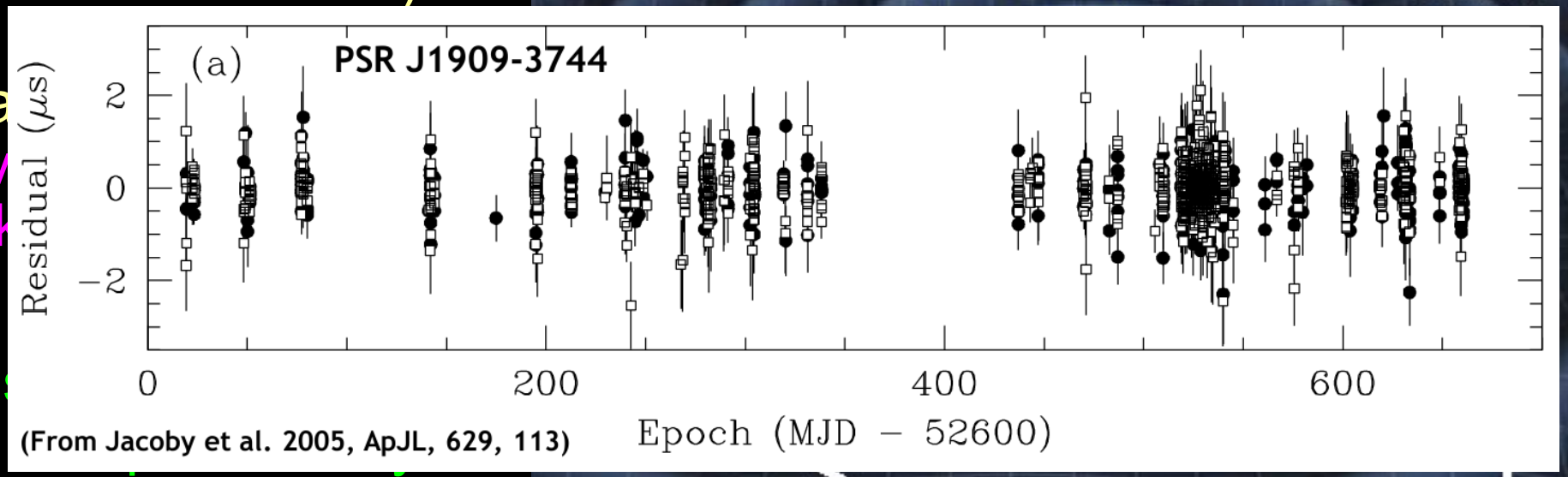
e.g. Detweiler, 1979
Hellings & Downs, 1983

The best timing MSPs (~100-500 ns RMS) can
for a
grav
back

Sens
and
Adv. LIGO and LISA!

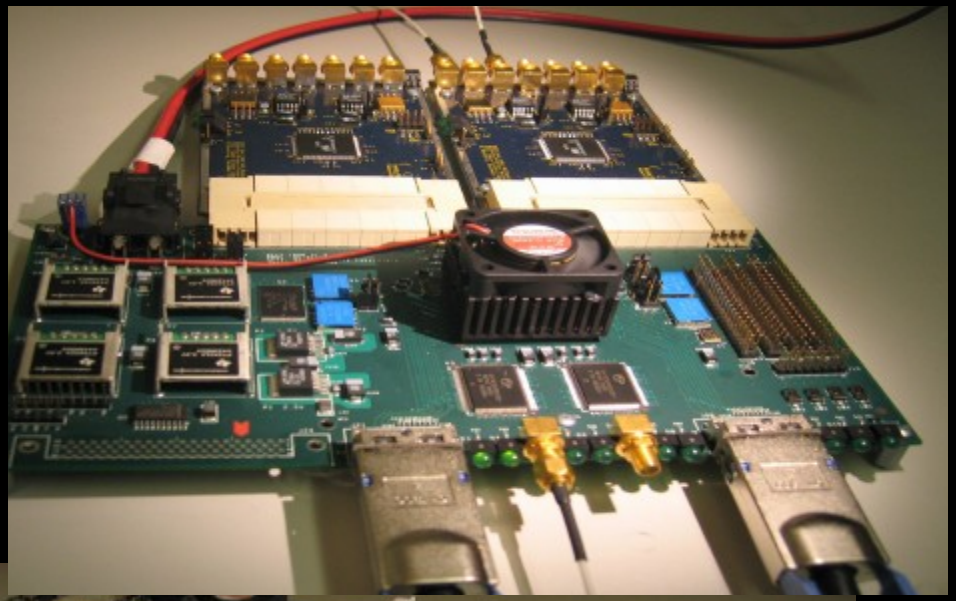
Need best MSPs and instrumentation.

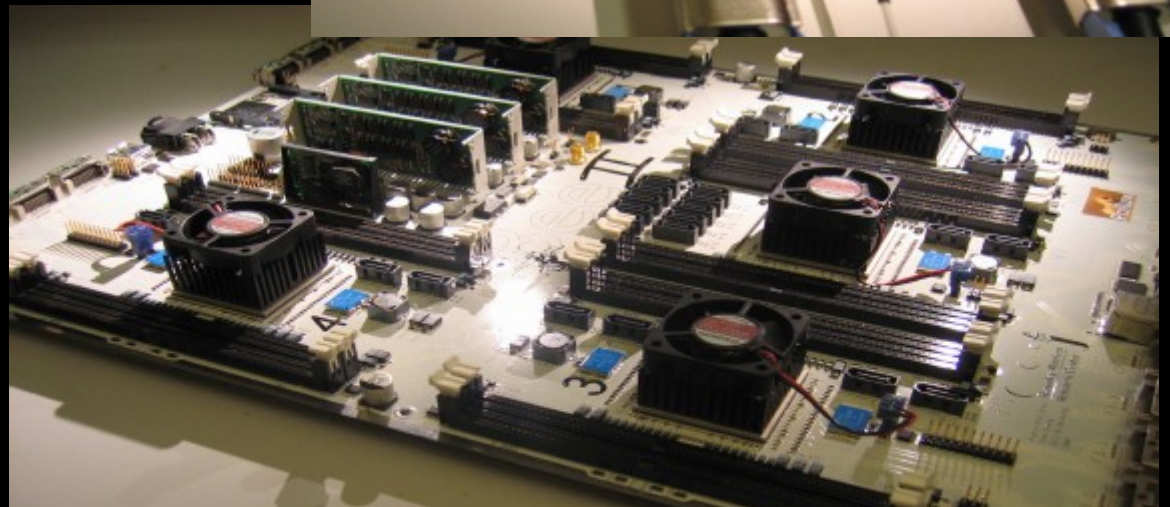
NANOGrav, PPTA, EPTA



New Instrumentation: GUPPI

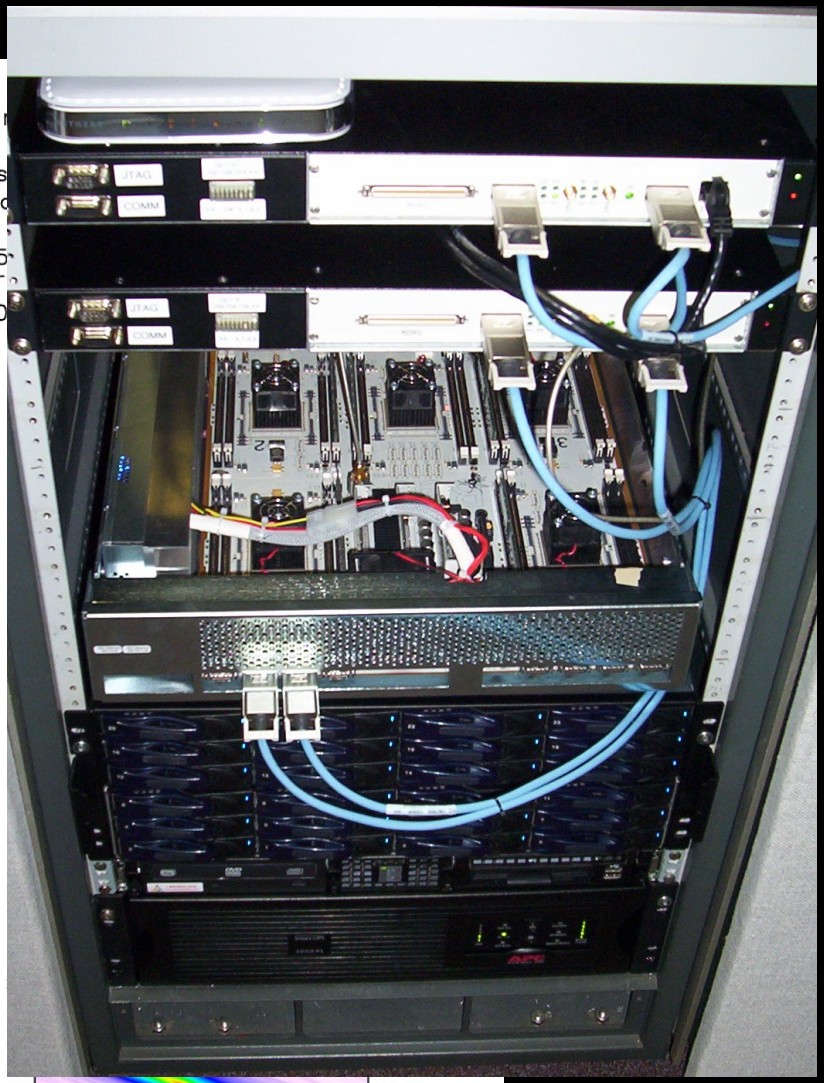
- GreenBank Ultimate Pulsar Processing Instrument
- Based on Berkeley Wireless Research Center hardware (BEE2, iBOB) and CASPER tools
- 8-bit sampling
- 800MHz BW
- 4096 Channels
- Full Stokes
- Facility instrument





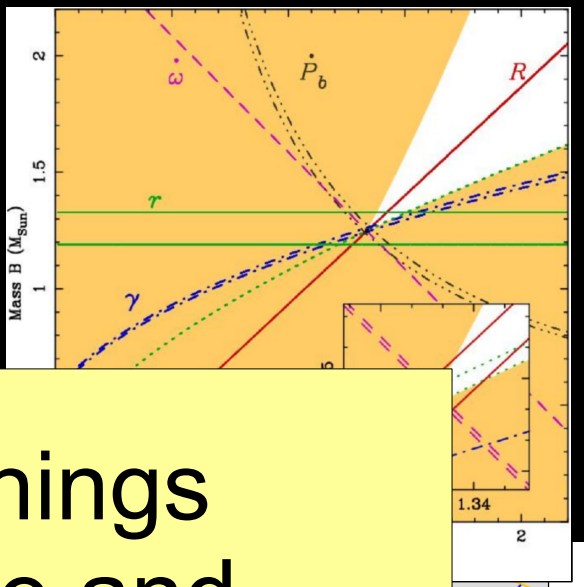
And eventually, wideband coherent dedispersion...

GUPPI: First-light on PSR B1821-24

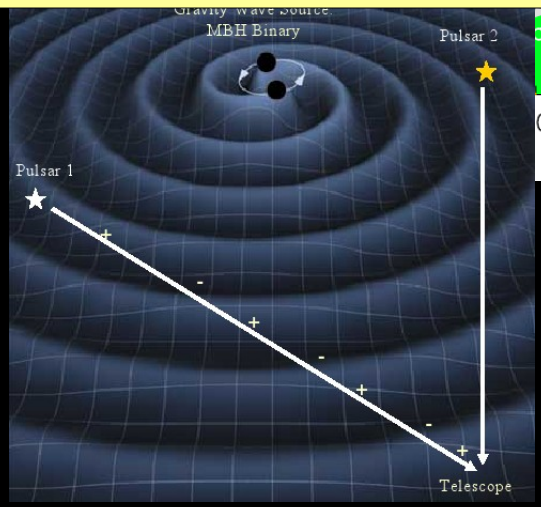


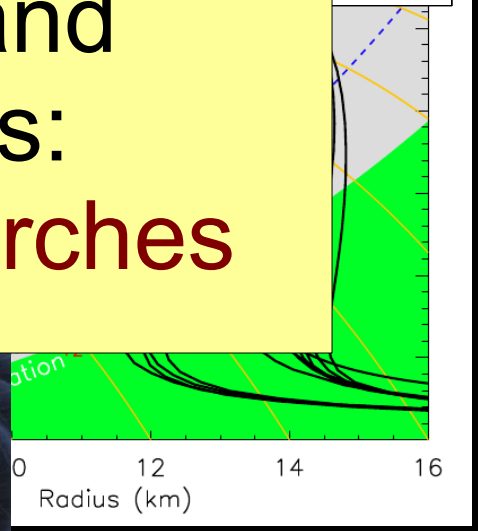
Key Science with Pulsars

- Strong Field GR Tests:
  - PSRs around Sgr A* would be best (10-15 GHz)
  - Stellar-mass BH-PSR (400 MHz - 3 GHz)
- Equation of State of Matter at Supra-Nuclear Densities
  - Masses of many MSPs
- Direct detection of nanoHz Gravitational Waves
  - Need both new MSPs, more sensitivity, and reduction in systematics



All these things require more and better pulsars:
That means Searches





Future Pulsar Observations

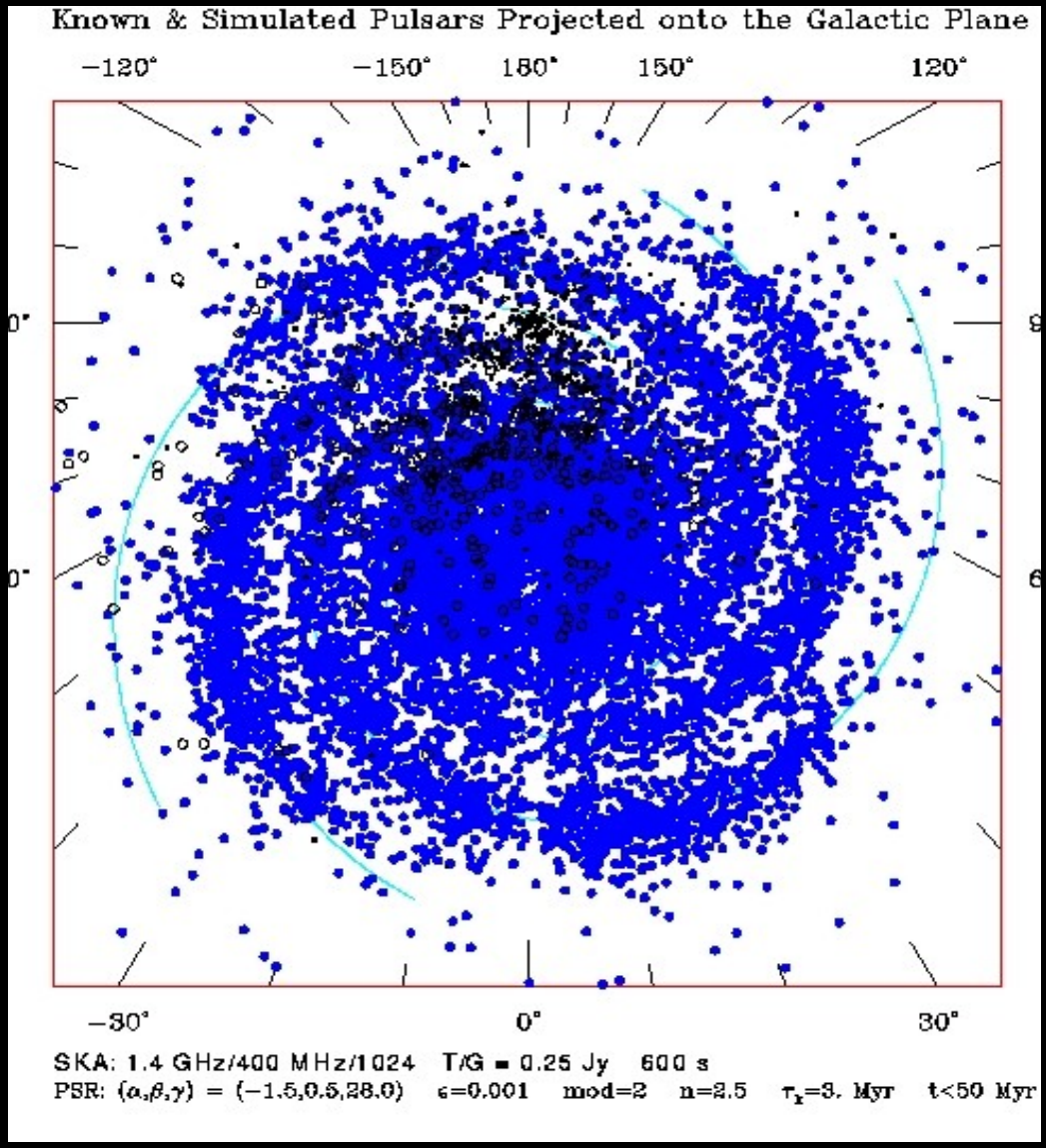
- With good pulsar backends and plentiful computing, pulsar obs are almost completely sensitivity limited:

$$\text{Sensitivity} \propto \frac{T_{\text{sys}}}{G\sqrt{t_{\text{obs}}\,\text{BW}}}$$

- For next "Renaissance" we need collecting area!
- Next sensitivity improvements will come from:
  - MeerKAT: Should be ~GBT in southern hemisphere
    - Searches may be difficult given 80 12m antennas
  - FAST: 2xArecibo in illuminated area
    - How much new (i.e. southern) sky will be visible?

Pulsar Searching with Future Facilities

- Currently ~2,000 pulsars known (~200 MSPs)
  - Only a small fraction ~1% are useful for the science that we want to study
- ~100,000 potentially visible pulsars and RRATs (~20,000 MSPs)
- Most within 30º of Gal Ctr
- Most within 5º of Gal Plane
- SKA has the potential to find 20,000+ pulsars, FAST should find thousands



Simulation by J. Cordes

Some thoughts on PSR searches with FAST

- Multiple beams (10? 30?) will be essential for survey speed
- For periodicities, need integration times >100 sec
- Whole-sky searches will be impossible in short term
- Need to concentrate on where the pulsars are:
  - Galactic plane +/- few degrees latitude (1 – 3 GHz)
  - Mid-galactic latitudes (primarily in south) (0.3 – 1 GHz)
- Beam quality is not important for search – only telescope gain
- Will need good pulsar backends for each beam (e.g. GUPPI)
- Data rates (~40MB/s/beam) and computational demands will be large, but much less than required for SKA!
- All the pulsars will need to be timed! That takes a lot of time...