# Developing a pulsar-based time standard

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CSIRO ASTRONOMY AND SPACE SCIENCE
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# Time scales

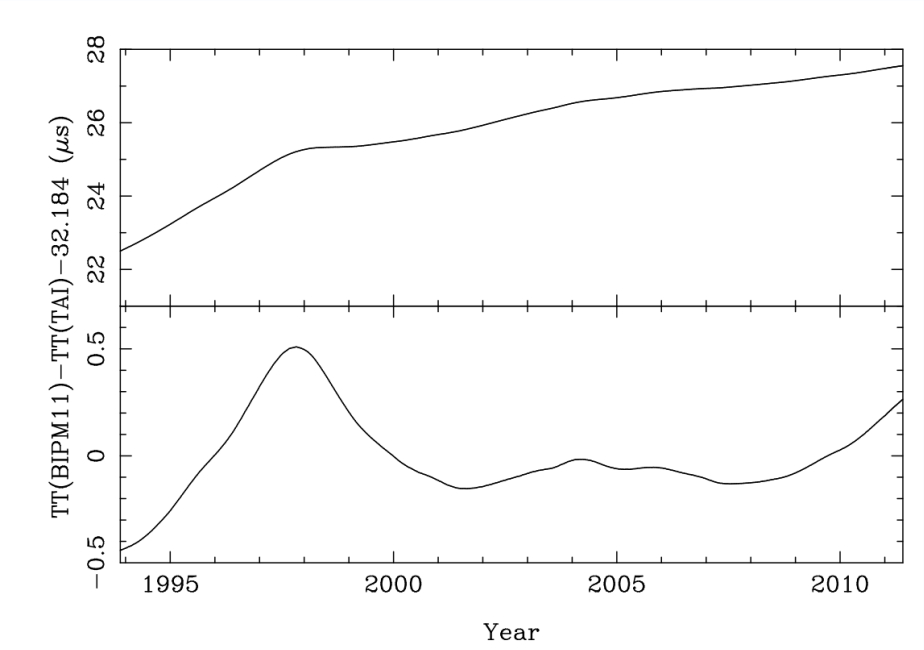
Atomic frequency standards and clocks are the basis of terrestrial time keeping.

Local timescales are combined to form International Atomic Time (TAI)

TAI is the basis for Terrestrial Time (TT) formed by referencing individual clocks to the Earth's geoid.

TT(TAI) is Terrestrial Time as realised by TAI (never revised)

TT(BIPMYY) is Terrestrial Time updated regularly



# Pulsars

Pulsars are rapidly rotating neutron stars

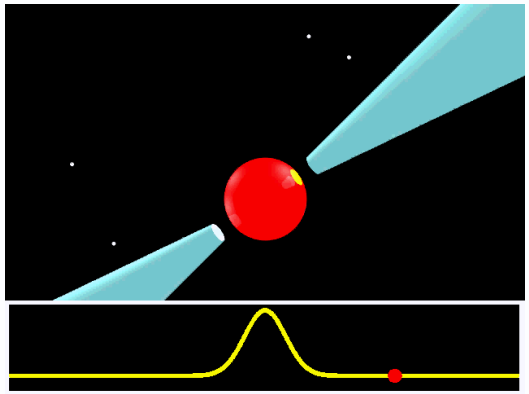
Formed during supernovae as massive stars “die”.

~2000 known

Massive flywheels in space => incredibly stable rotators

Get a flash of radio emission every time the pulsar rotates => like a lighthouse in space

P = 0.0023230904667610 +/- 0.0000000000000001 s



▪Credit: Michael Kramer (MPIfR)

# Using the pulsars to develop an Ensemble Pulsar Scale

Analogous to Echelle Atomique Libre (EAL), can use the stable rotation of pulsars to form an Ensemble Pulsar Scale

The Ensemble Pulsar Scale is not an absolute timescale and must be "steered" to a reference timescale which conforms to the SI.

Relies on forming timing residuals for each pulsar with respect to a reference timescale, TT(TAI), and removing a quadratic polynomial.

Fluctuations in the reference timescale with respect to the Ensemble Pulsar Scale can be identified and used to "correct" that realisation of TT, thereby realising a new pulsar-based timescale.

- See works such as Guinot & Petit (1991), Petit & Tavella (1996), Rodin (2008), Rodin & Chen (2011), Hobbs et al. (2012) …

# Simple way to think about this timescale

We can predict the arrival time of a pulse at our telescope assuming the pulsar's position, rotational parameters and the Earth's motion.  We can compare with the actual time to see how well we did.

Our time measurement is made with respect to a realisation of TT.

If the pulse seems to arrive early or late then there could be a problem with our realisation of TT or the pulsar itself could be unstable.

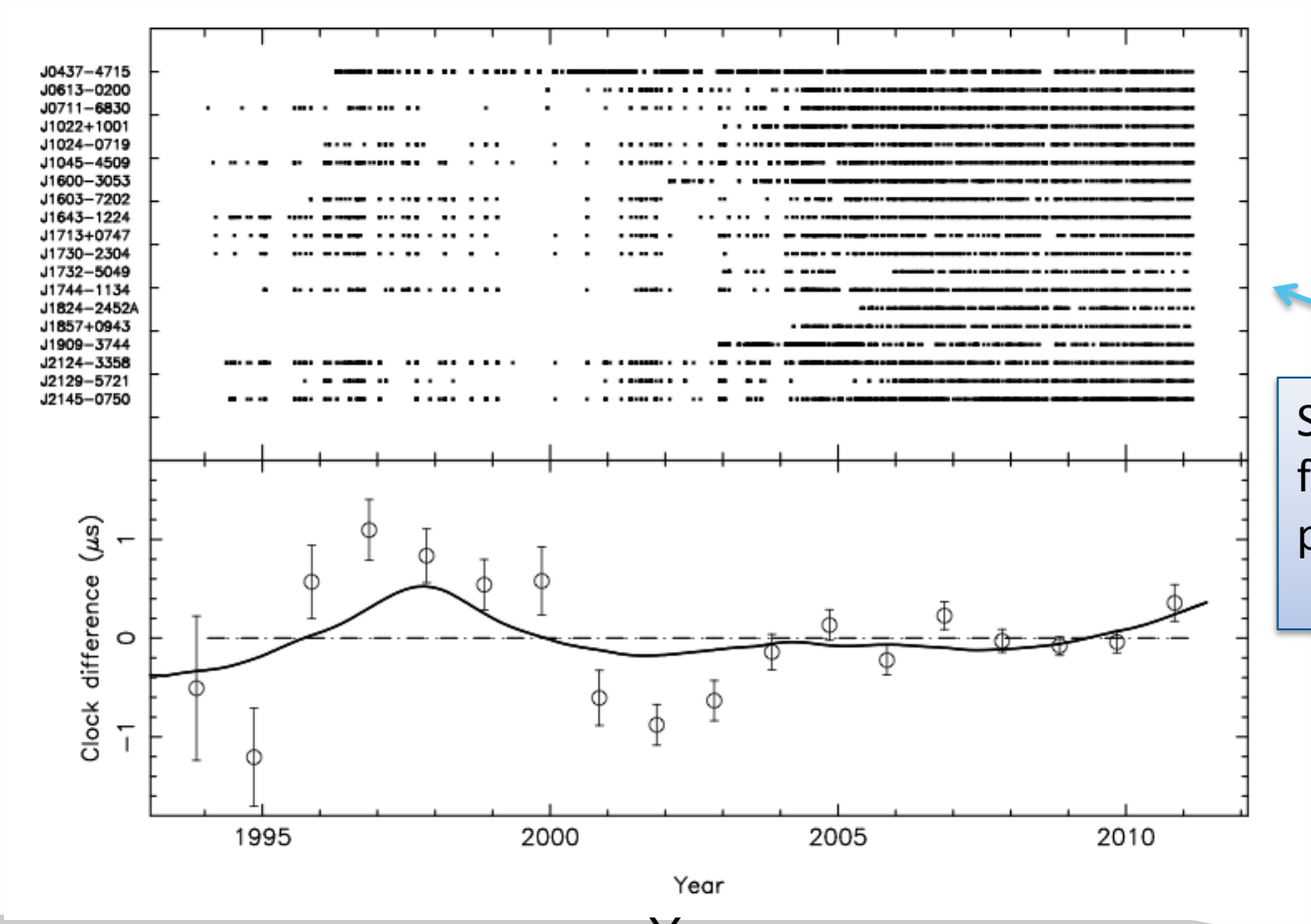
If we see all pulsars showing the same effect then we can improve the realisation of TT from the pulsar observations.

# The Parkes Pulsar Timing Array project

- Main goal is to direct gravitational waves using observations of pulsars with the Parkes radio telescope
- The Parkes observatory is situated in Australia
- We have been observing ~20 pulsars every 2-3 weeks since 2005
- Have earlier observations (less well sampled) of many of these pulsars.

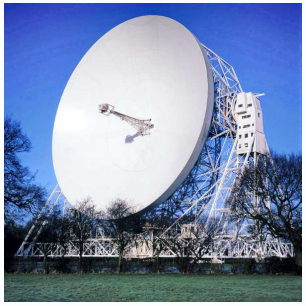
# The result from the PPTA project (in 2012)

The *PPTA* paper discusses lots of tests of the algorithm. Here we just show the result.

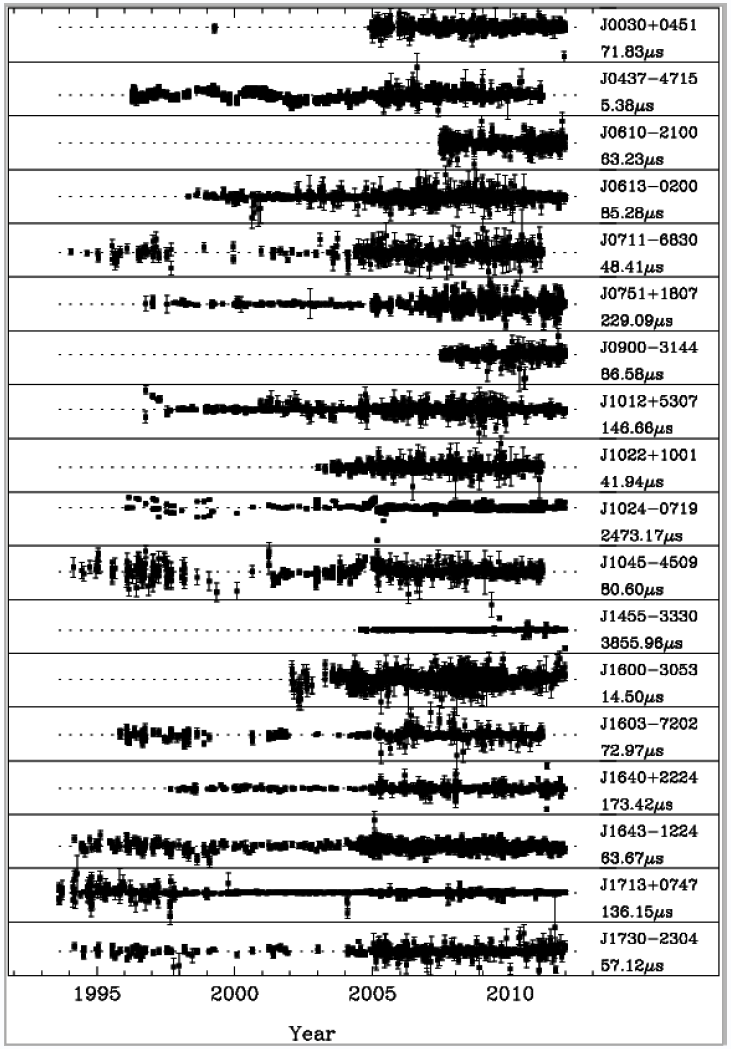


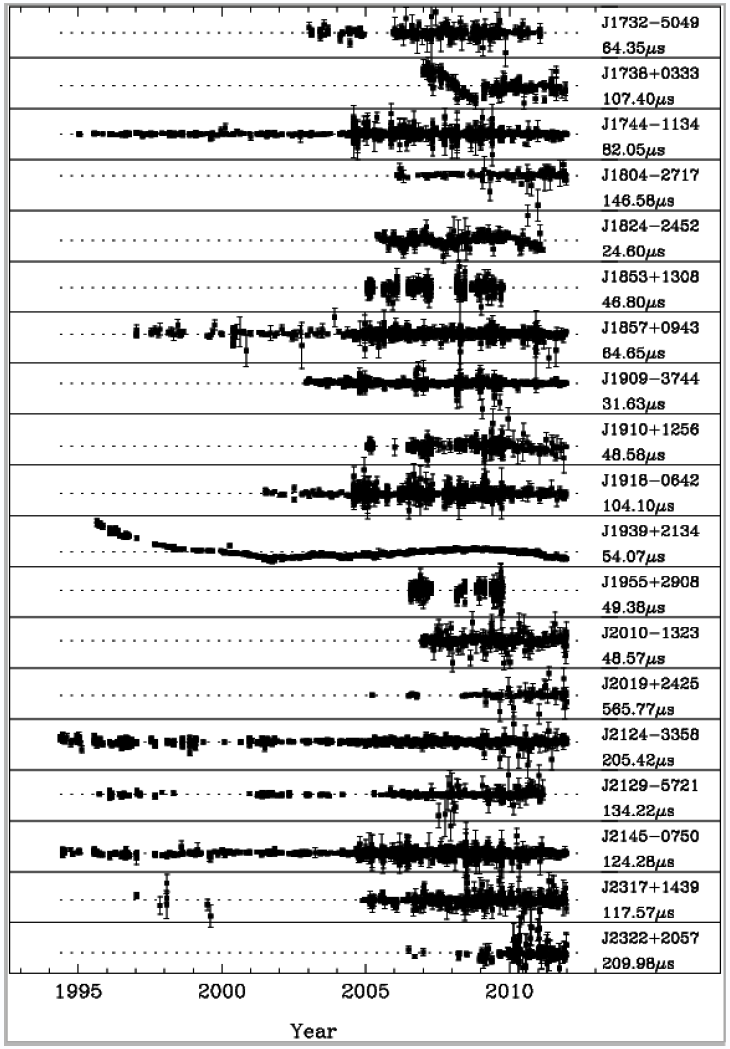

Sampling for different pulsars

# International Pulsar Timing Array




# The current IPTA data sets



# Too many pulsars …

Have 37 pulsars

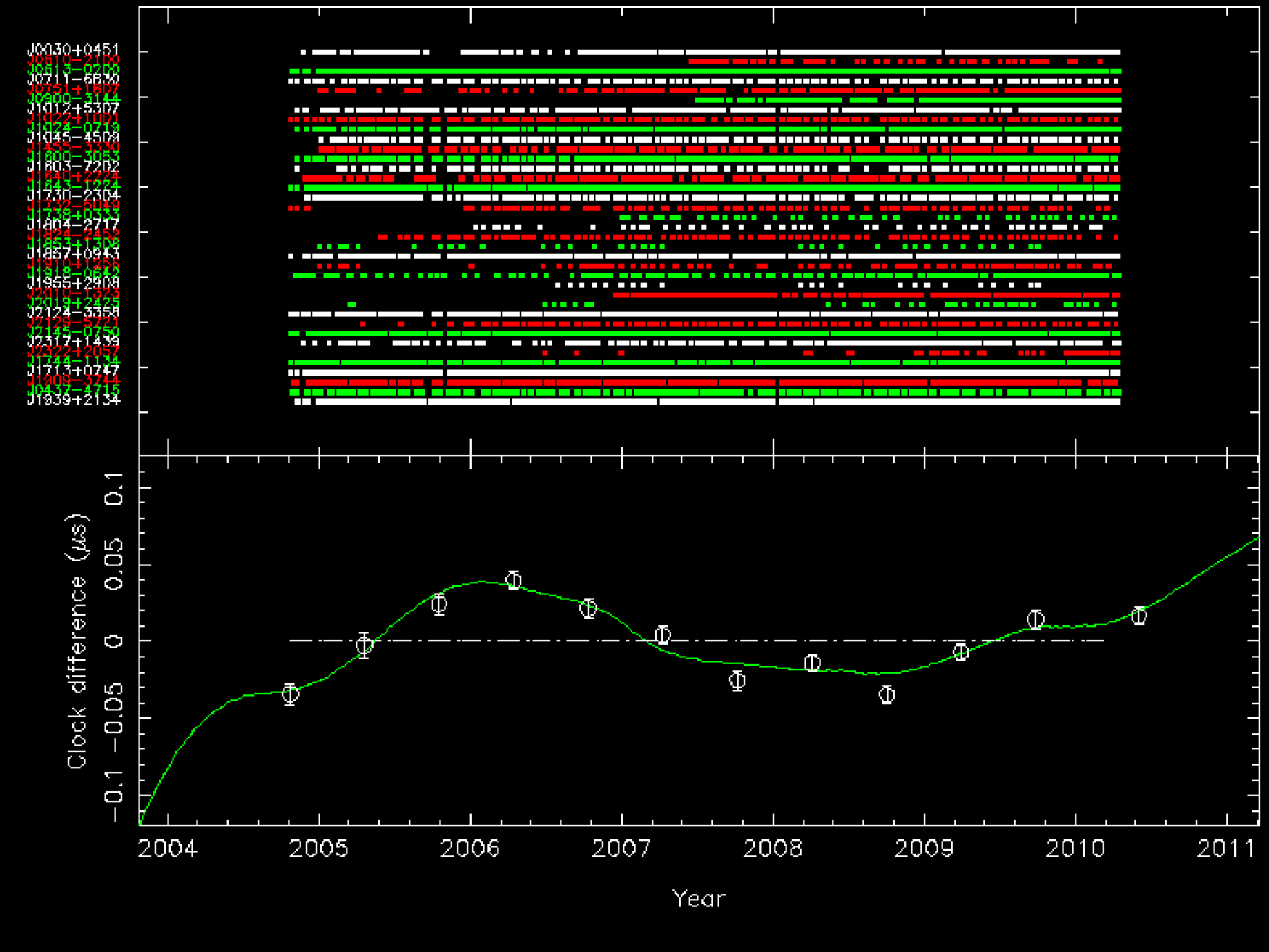
Have a huge number of observations

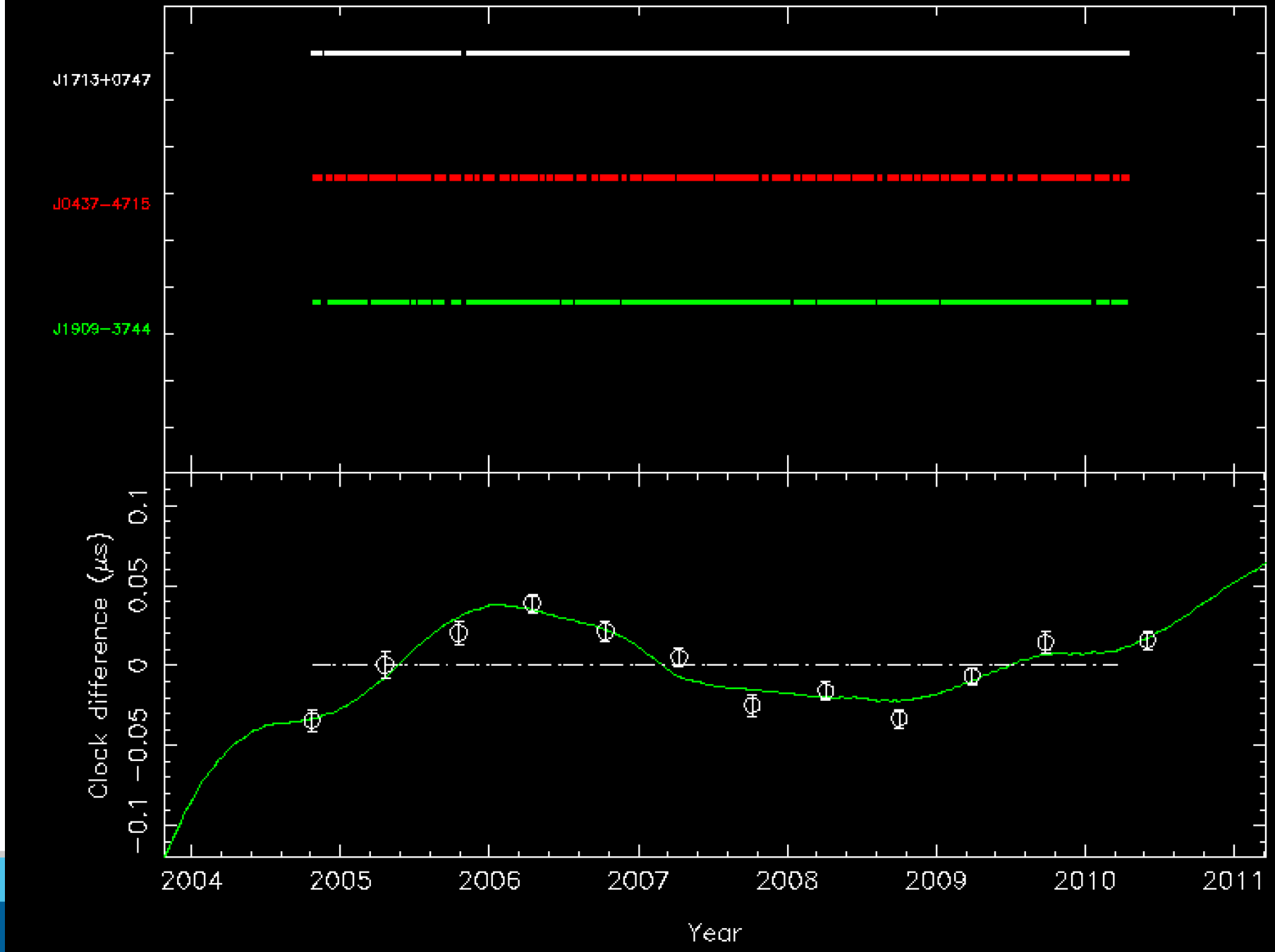
Algorithm relies on manipulating Nobs x Nobs array

Have “jumps” between every frequency channel + fits for pulsar parameters => hundreds of fit parameters per pulsar

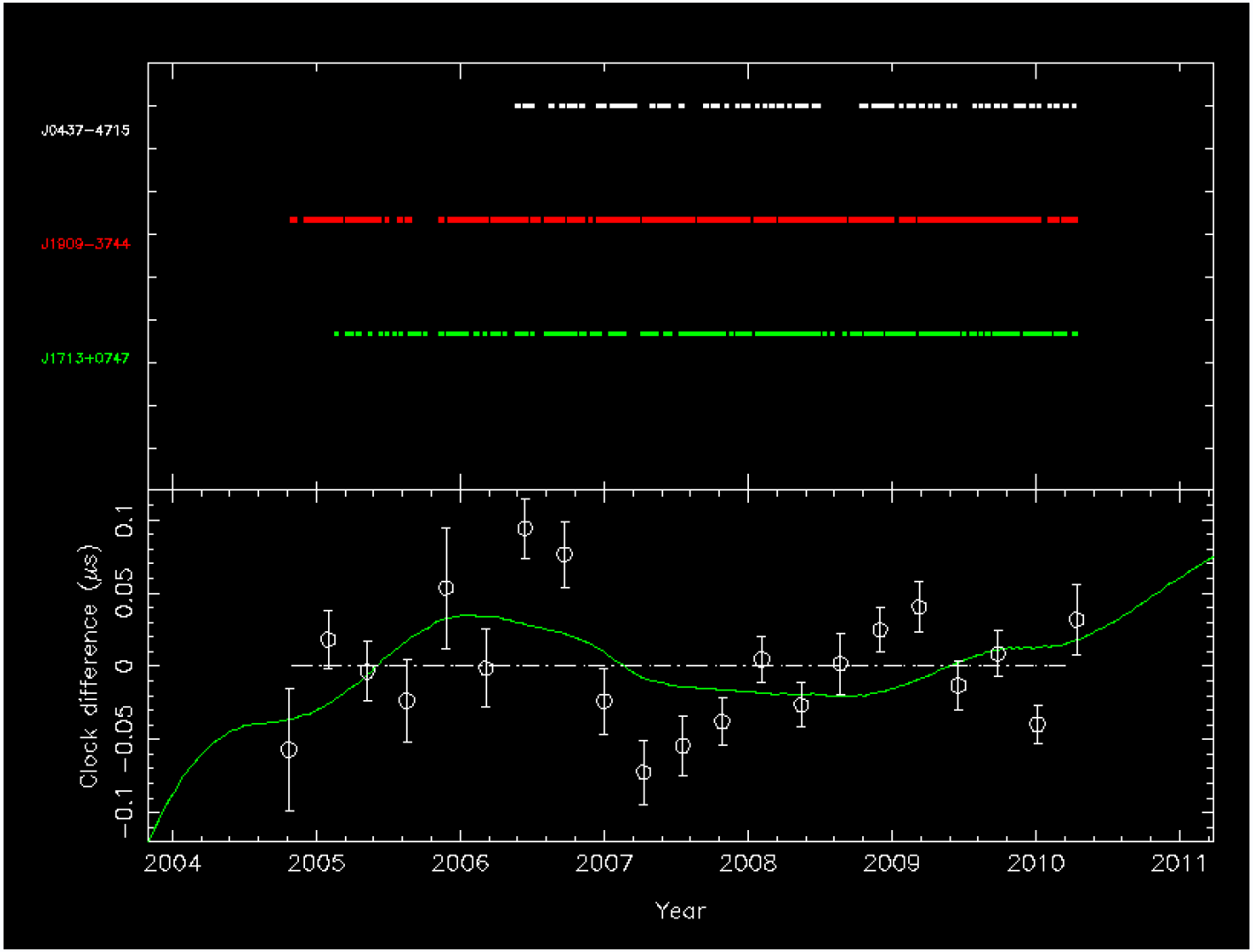
⇒ Algorithm possible, but extremely slow

⇒ Which pulsars will actually contribute to the pulsar time scale?


J0030+0451
J0218+2130
J0613+0200
J0711-6830
J0751+1807
J0900-3144
J1012+5307
J1022+1001
J1024-0719
J1045-4509
J1455-3330
J1600-3053
J1603-7202
J1640+2224
J1643-1224
J1730-2304
J1732-5049
J1738+0333
J1804-2717
J1824-2452
J1853+1303
J1857+0943
J1910+1256
J1918-0642
J1955+2908
J2010-1323
J2019+2425
J2124-3358
J2129-5721
J2145-0750
J2317+1439
J2322+2057
J1744-1134
J1713+0747
J1909-3744
J0437-4715
J1939+2134
Clock difference (μs)
0.1
0.05
0
−0.05
−0.1
2004
2005
2006
2007
2008
2009
2010
2011
Year


J1713+0747
J0437−4715
J1909−3744
Clock difference (μs)
−0.1
−0.05
0
0.05
0.1
2004
2005
2006
2007
2008
2009
2010
2011
Year

# My (initial) result with the real IPTA data over short data span

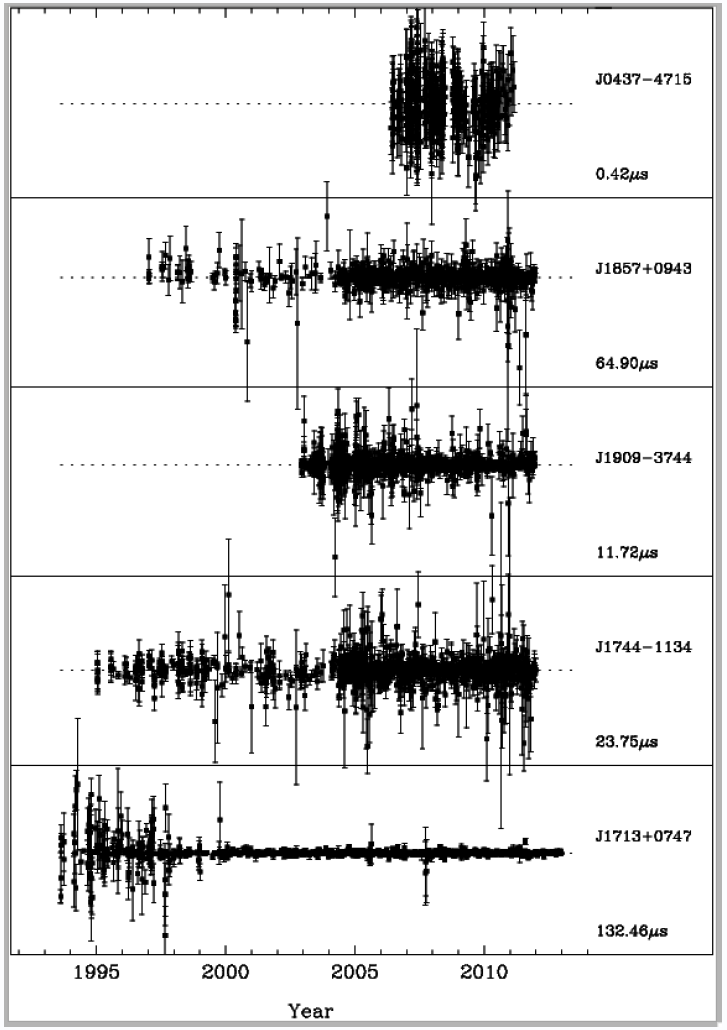


# Using trial IPTA data set that uses long data spans of the “best” pulsars

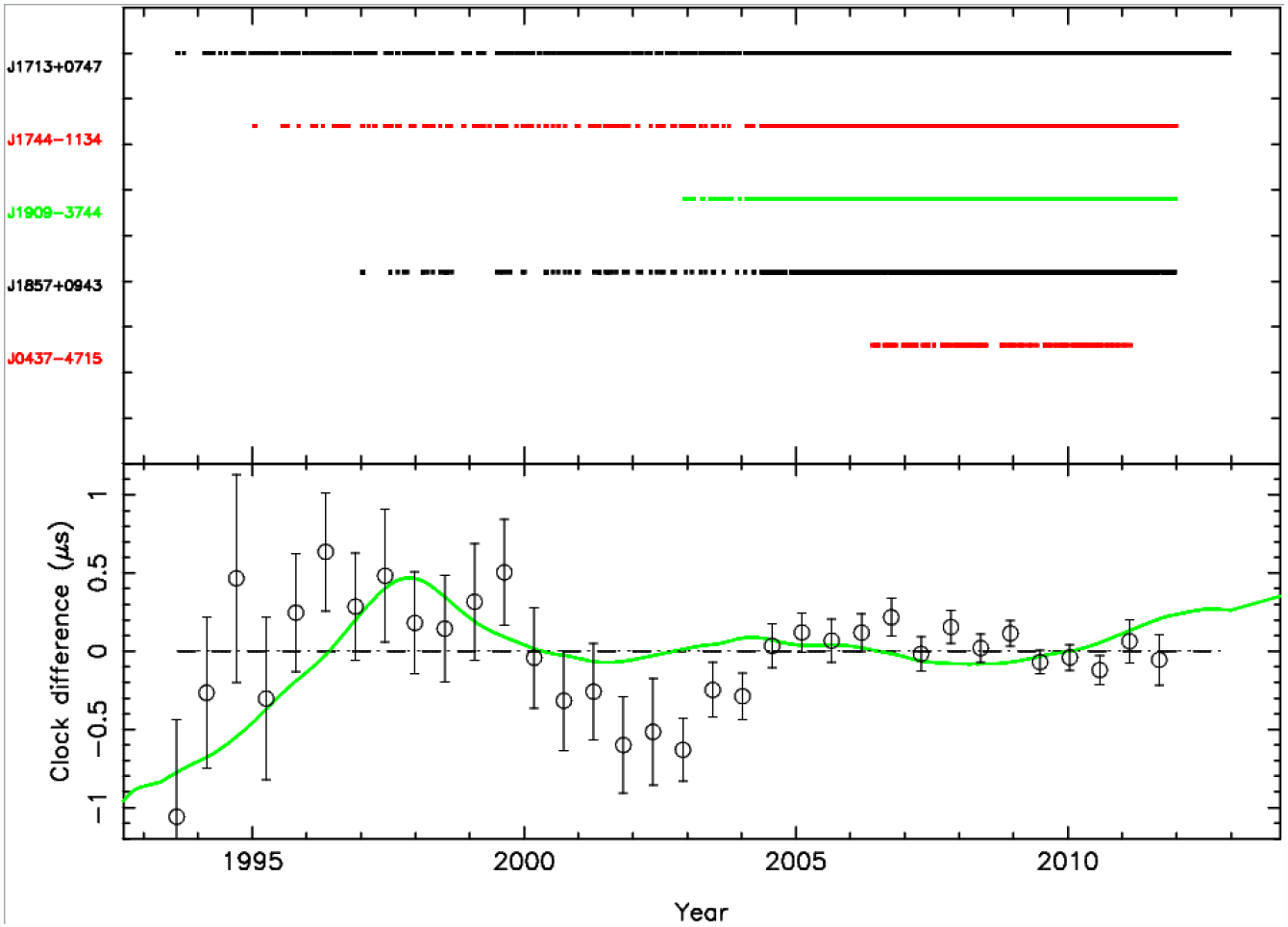
Data from 1995 to 2012

Have red noise models

Only 5 pulsars



# Initial result with longer IPTA data set



# The IAU Working Group

During the Beijing IAU meeting, a working group was set up to study pulsar-based time standards.

To consider how to generate a pulsar-based time scale

To consider the combination of pulsar-based time scales with atomic time scales to provide an independent confirmation of the atomic timescales and to provide the world's most stable timescale

To consider limitations on the stability and accuracy of both pulsar-based and combined atomic-pulsar timescales including time-transfer issues

To consider the means to make both pulsar-based and combined atomic-pulsar timescales publically available

Should have some results … very, very behind schedule …

# Been a bit distracted …

Introduce Edward Du Hobbs, born 7th May 2013

# Let's get started on this again now

Please contact me if you'd like to be involved!

- As an aside
- pulsar astronomers use a Solar System ephemeris (typically DE421, INPOPXX)
- Must convert to TCB
- Must convert observatory coordinates. ITRF->ICRF (using EOP)
- …
- I don't really know if we're "up-to-date"

# Next steps

We have algorithms to develop a pulsar-based timescale

Expect improved timescale using IPTA data within ~1 year (waiting on a final data set)

Have IAU working group to develop our understanding of the timescale

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# Thank you

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