Probing glitches in the SKA era

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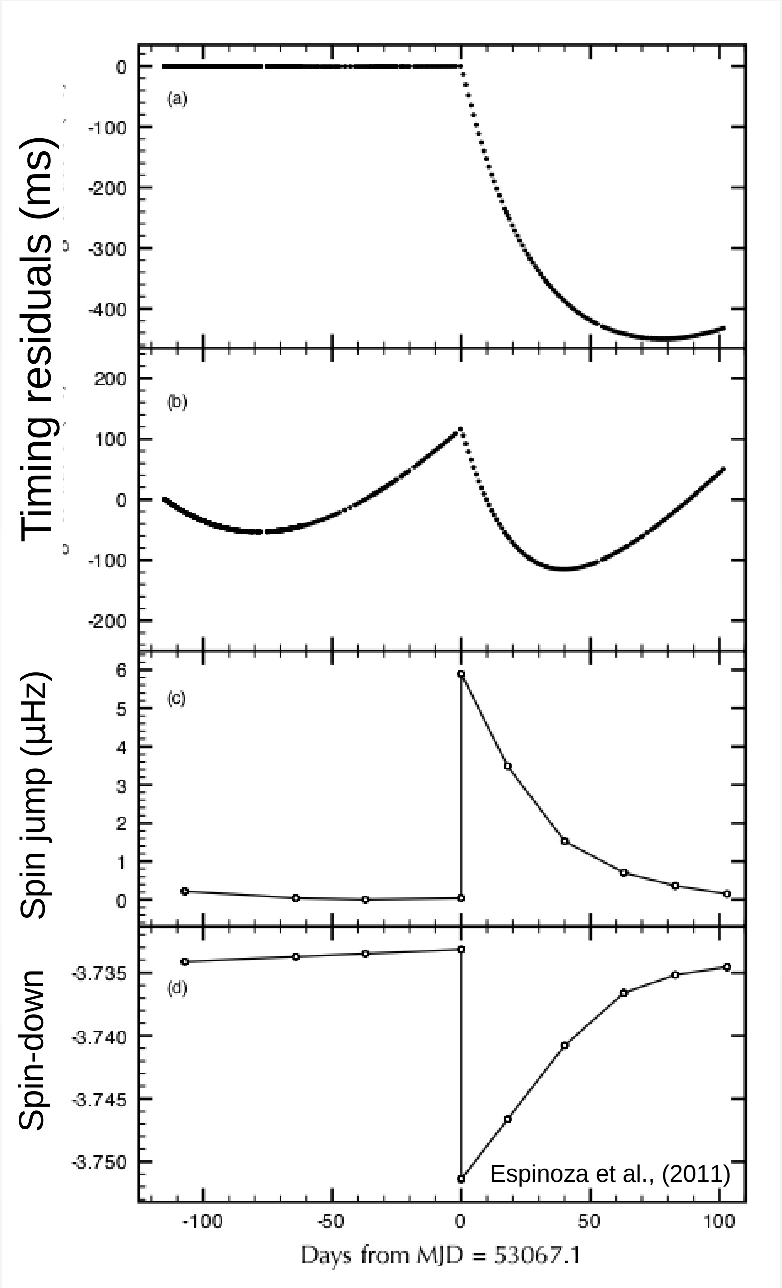
Outline

- Some background
  - Glitches – effects on pulsar timing
  - The Jodrell Bank timing programme
  - Crab and Vela – case studies
  - Factors affecting measurement
- Next generation telescopes
  - SKA1-MID
  - SKA1-LOW
  - Other instruments
- Future possibilities

Glitches in pulsar timing

- **A sudden increase in rotation frequency (few ppm)**
- **Rise in frequency typically unresolvable**
- **Some pulsars recover pre-glitch rotation rate but most do not**

  Often accompanied by a change in spin-down
- **Rare/non-periodic**
- **Typically more common in young pulsars**



Introduction

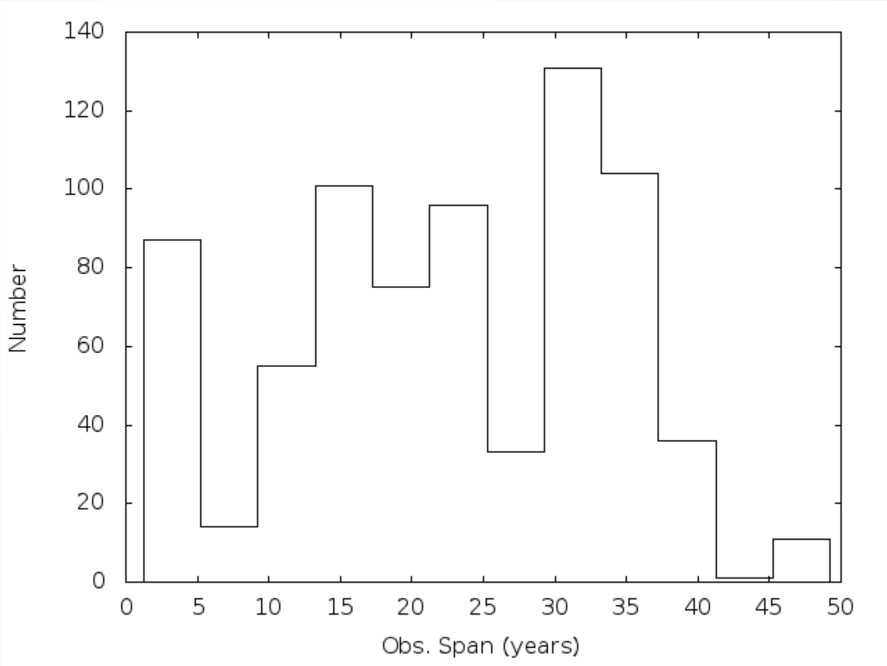
Background

SKA+

Discussion

The Jodrell Bank Timing database

- Monitoring rotation of more than 800 pulsars (inc ~100 MSPs)
- More than 400 with >10 years of rotational history
- Cadence ranges from daily to monthly
- Totalling more than 8000 years of rotational history
- Have >45 years of Crab rotational history
- Allows detailed study of timing irregularities



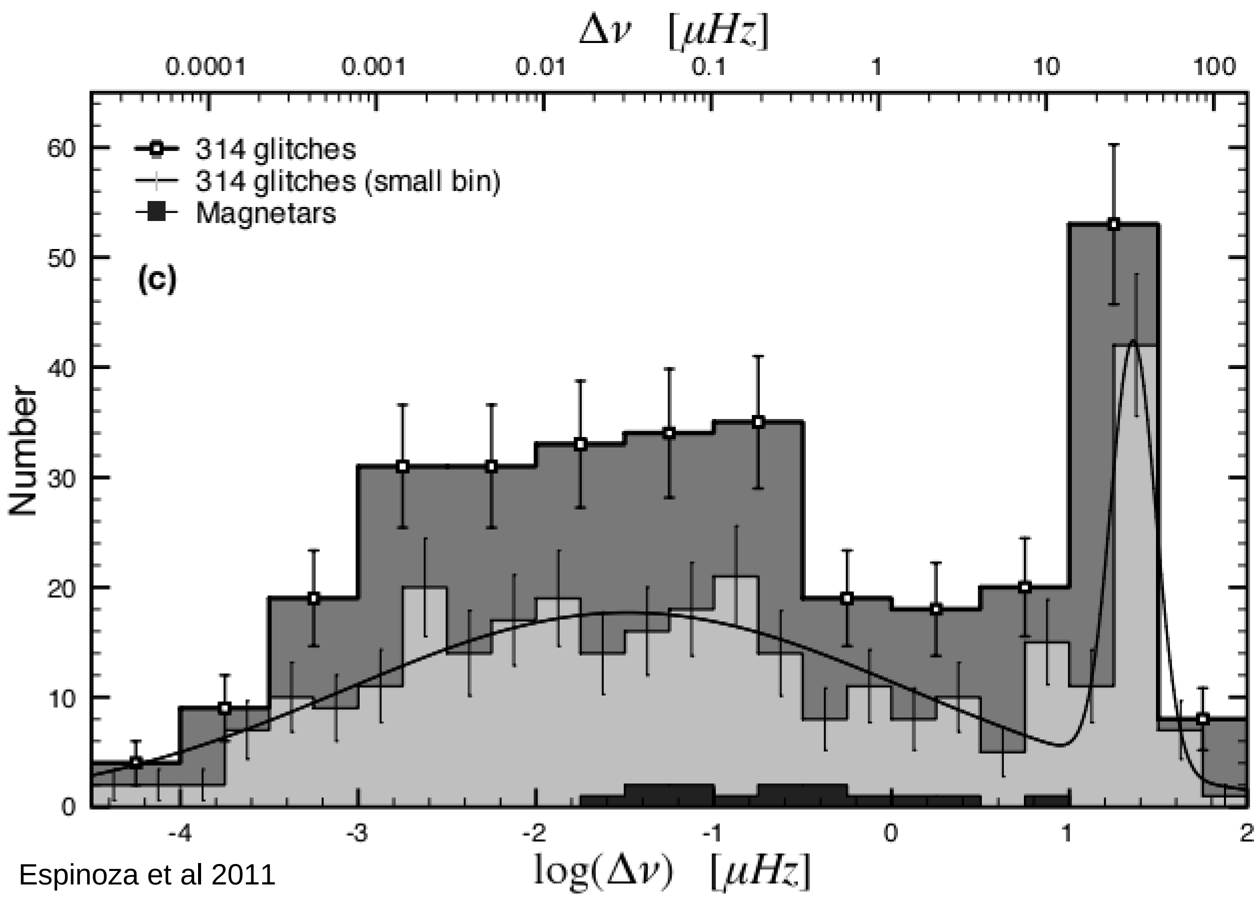
Introduction

Background

SKA+

Discussion

The Jodrell Bank Glitch catalogue

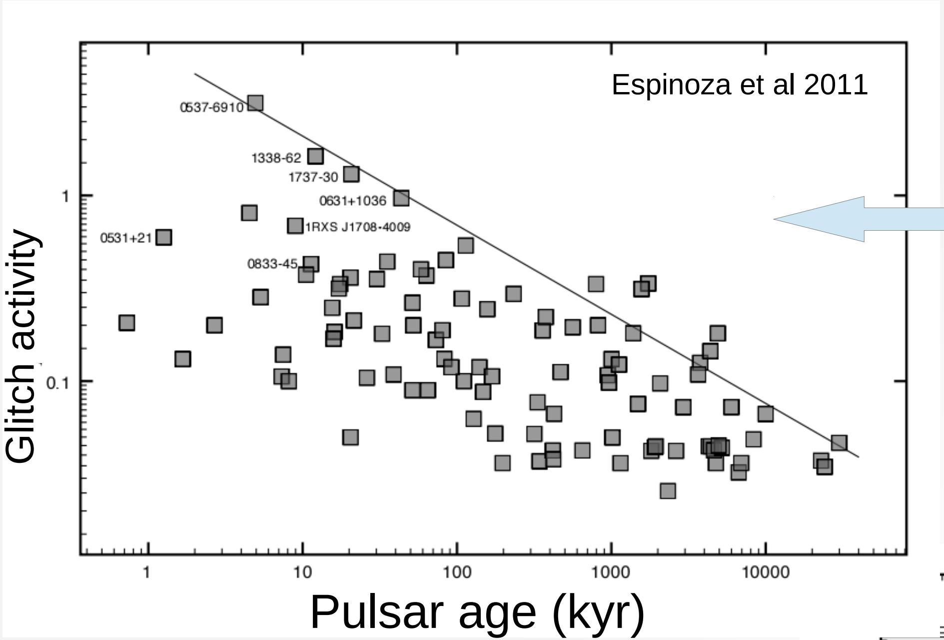


Espinoza et al 2011

- 493 glitches in 176 pulsars (~ 100 new, unpublished)

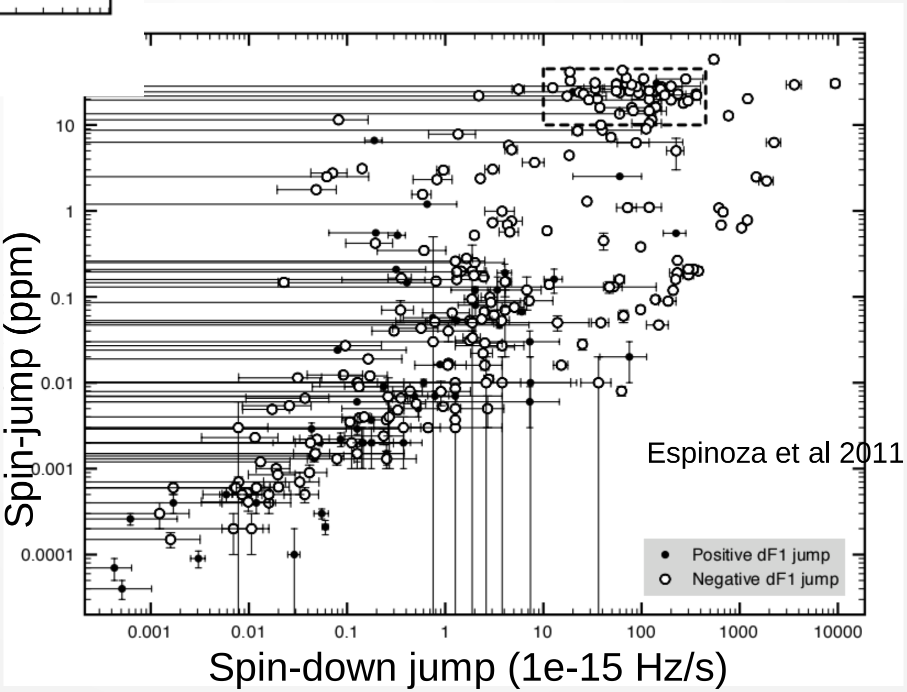
http://www.jb.man.ac.uk/~pulsar/glitches/gTable.html

The Jodrell Bank Glitch catalogue



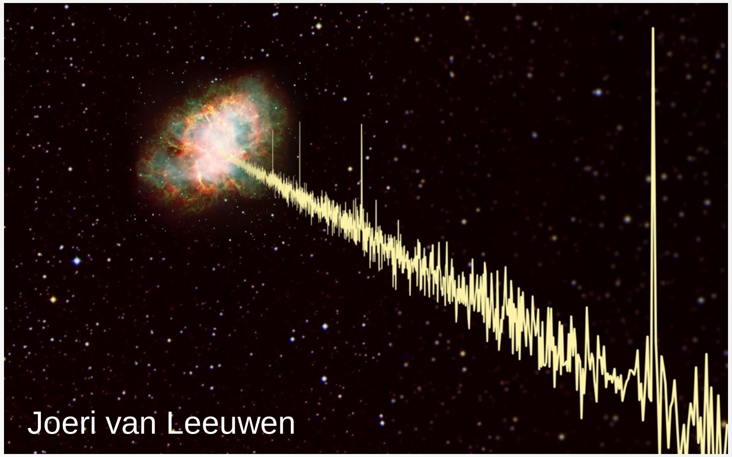
Glitch activity reduces as pulsars age

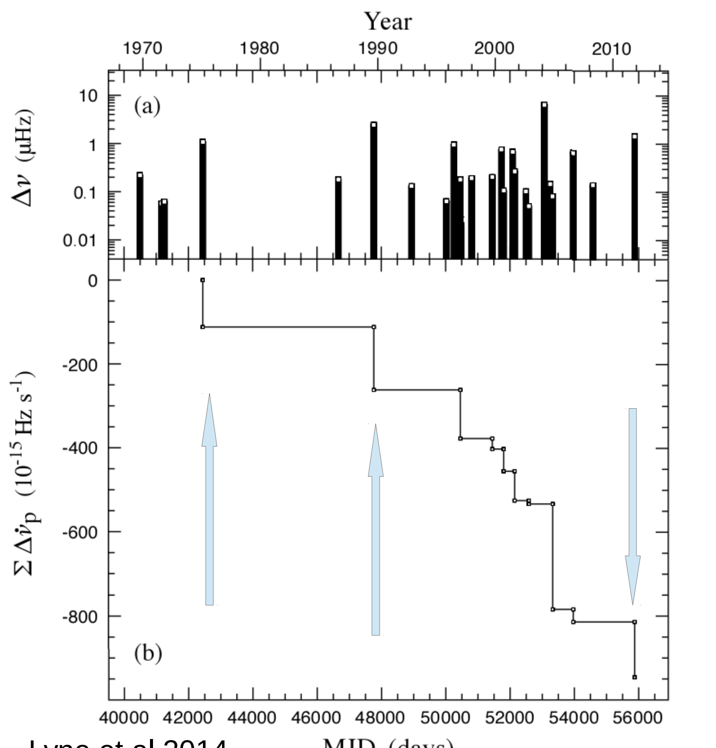
In general, F0 and F1 jump sizes are correlated



The Crab Pulsar

- Spin frequency, 30 Hz
- Monitored at JBO since 1968, daily since 1984
- Total of 45 years of rotation (11,000 TOAs)
- 24 glitches observed since 1968

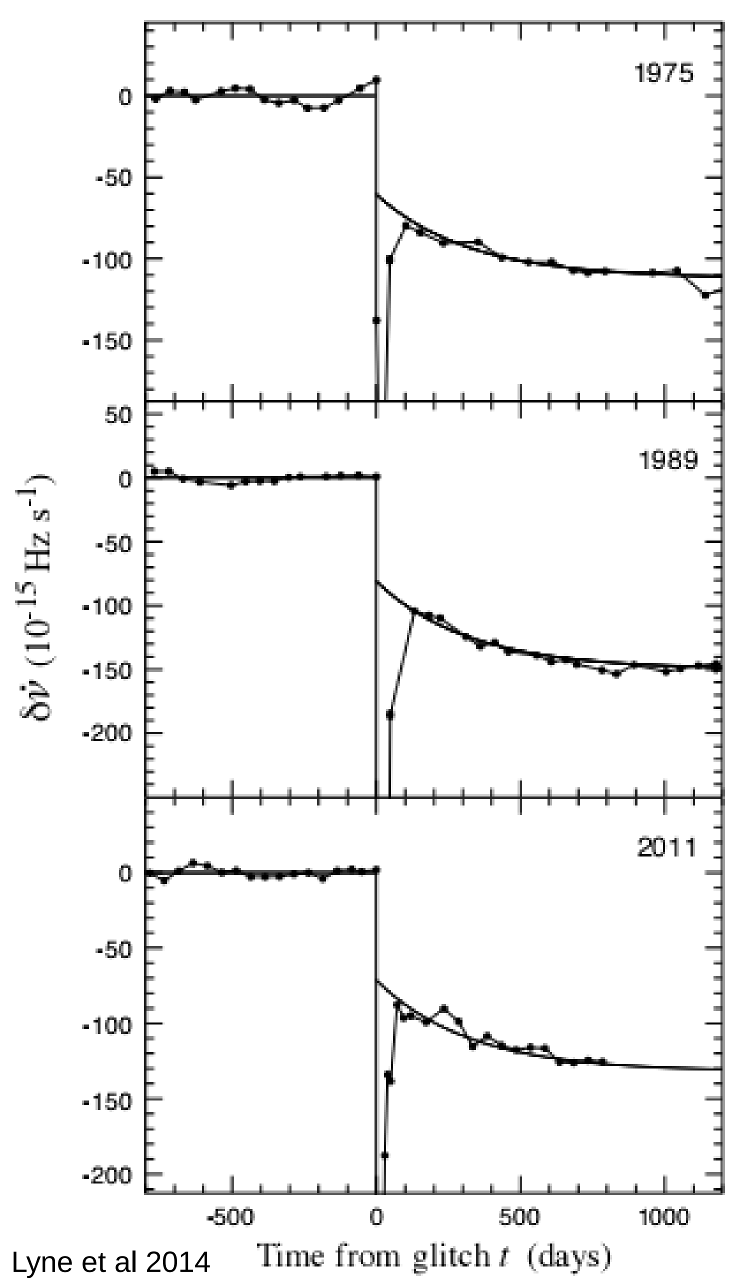

Joeri van Leeuwen



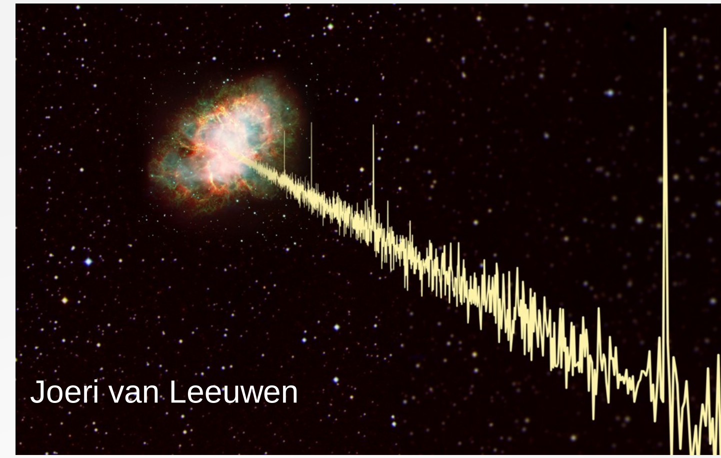
Lyne et al 2014

- $10^{-9} < \Delta\nu < 10^{-7}$ Hz
- Spin *nearly* recovers within ~20 days
- Spin-down recovers over much longer timescales
- Long term glitch impact difficult to study due to subsequent glitches

The Crab Pulsar



Lyne et al 2014



- Two component dF1
- Instantaneous component
- ~320 day exponential recovery

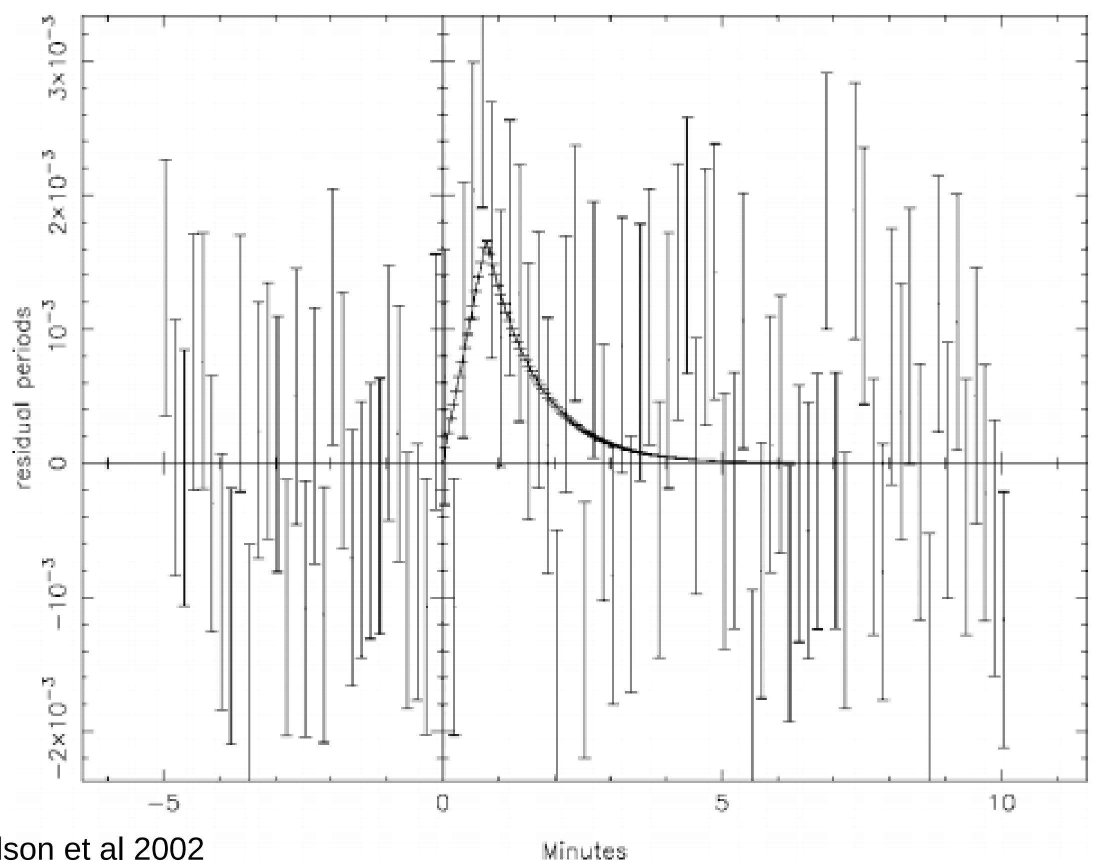
$$\delta\dot{\nu} = \begin{cases} 0 & \text{if } t < 0 \\ \Delta\dot{\nu}_{\rm p} \times (0.46 \times \exp(-t/320) - 1.0) & \text{if } t > 0, \end{cases}$$

Only possible due to very high cadence, sensitive monitoring!

The Vela Pulsar

- Introduction
- Background
- SKA+
- Discussion

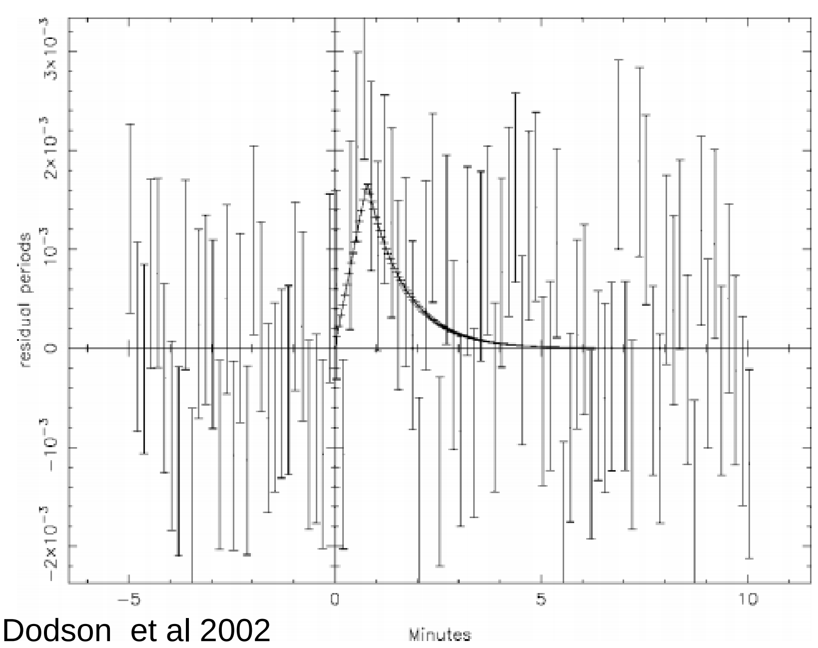
- Spin frequency 11 Hz, young
- Glitches typically every 3 years (few ppm)
- Daily monitoring at HARTRAO/Hobart since the 1980s
- Nearly completely recovers spin over several weeks
- Spin-down recovers over longer term
- Resolved the spin-up in 1996 large glitch



Dodson et al 2002

The Vela Pulsar

- Spin frequency 11 Hz, young
- Glitches typically every 3 years (few ppm)
- Daily monitoring at HARTRAO/Hobart since the 1980s
- Nearly completely recovers spin over several weeks
- Post-glitch spin-down has longer term features



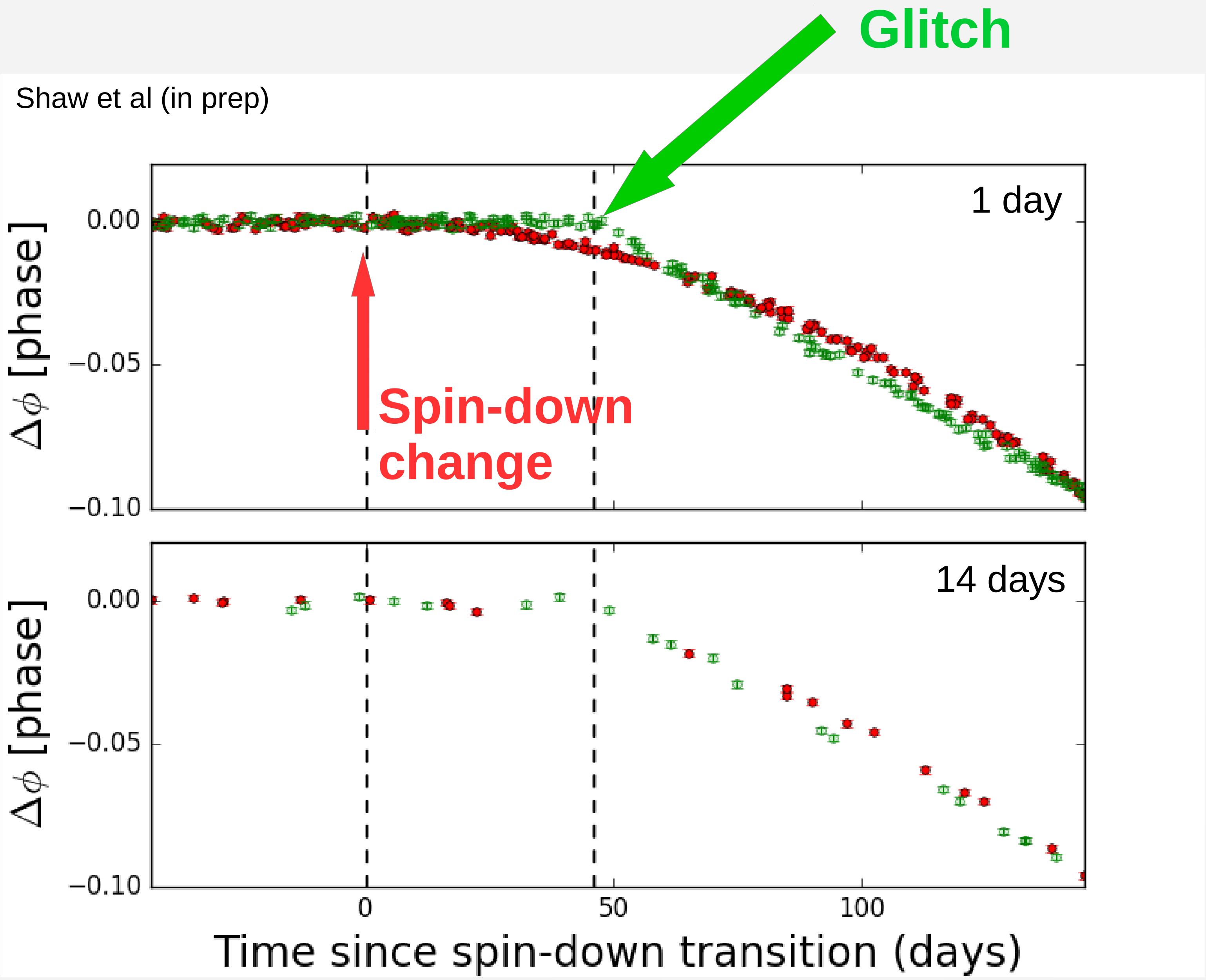
Dodson et al 2002

- Frequent monitoring has resolved the spin-up in 1996 large glitch
- Also resolved 4 distinct decay timescales (1 min – 20 days)
- **BUT not all pulsars have dedicated telescopes!**

Key parameters

- **Glitch detection/measurement is affected by:**
  - Cadence
  - Telescope sensitivity/glitch size
  - Dwell time
- Cadence allows:
  - (Earlier) detection
  - High time resolution of recovery
- Sensitivity allows:
  - More precise measurement of glitch parameters
- Longer dwell time:
  - Better S/N
  - Profile stability (implications for time resolution)
- What‘s more important? Glitches themselves or their parameter space? => Has implications for how we proceed.

Cadence


Glitch
Shaw et al (in prep)
Spin-down change
1 day
14 days
Δφ [phase]
0.00
−0.05
−0.10
0
50
100
Time since spin-down transition (days)

Key parameters

- **Glitch detection/measurement is affected by:**
  - Cadence
  - Telescope sensitivity/glitch size
  - Dwell time

- Cadence allows:
  - (Earlier) detection
  - High time resolution of recovery

- Sensitivity allows:
  - More precise measurement of glitch parameters
  - Detection of smaller glitches

- Longer dwell time:
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- What‘s more important? Glitches themselves or their parameter space? => Has implications for how we proceed.

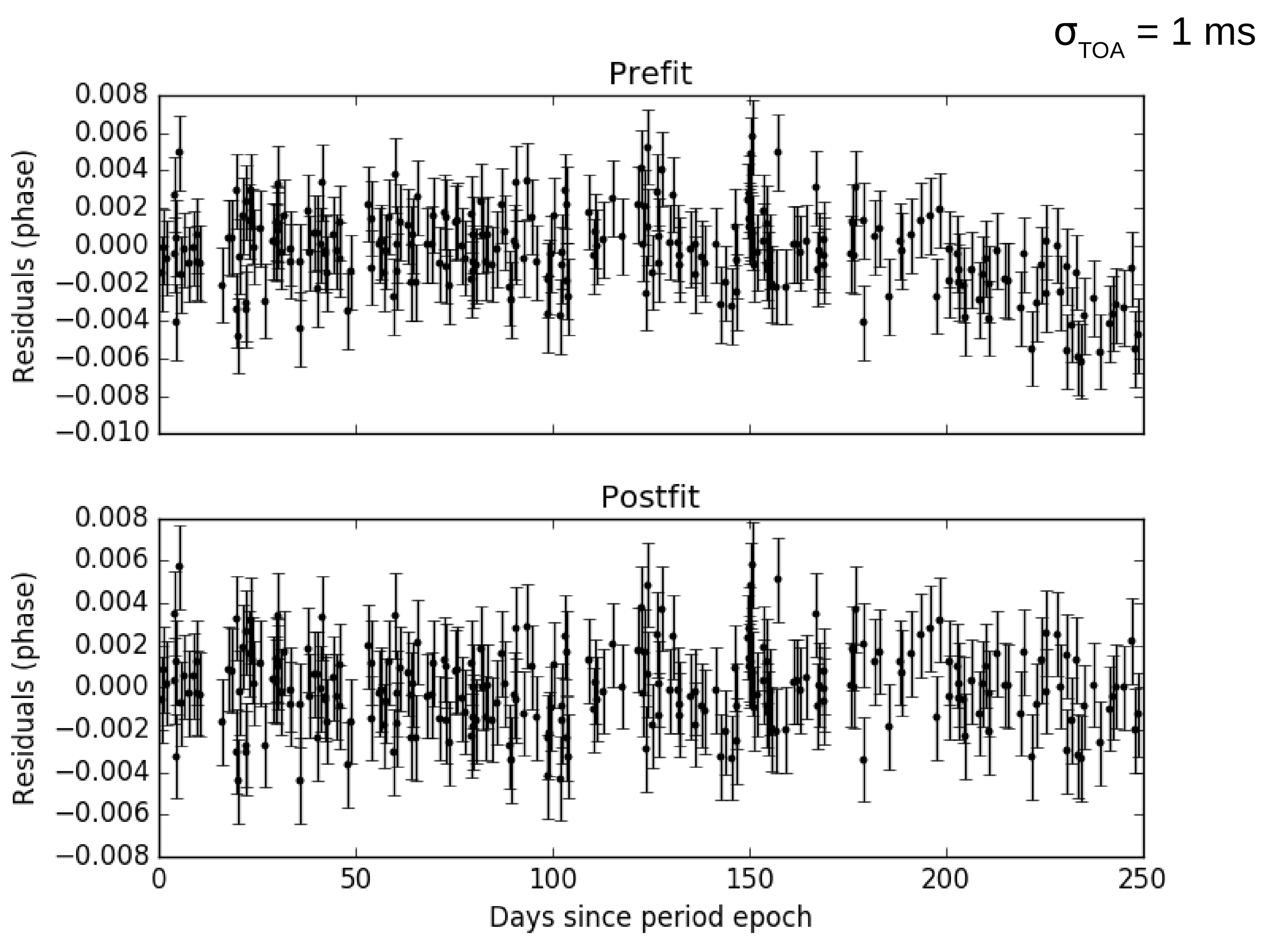
Introduction

Background

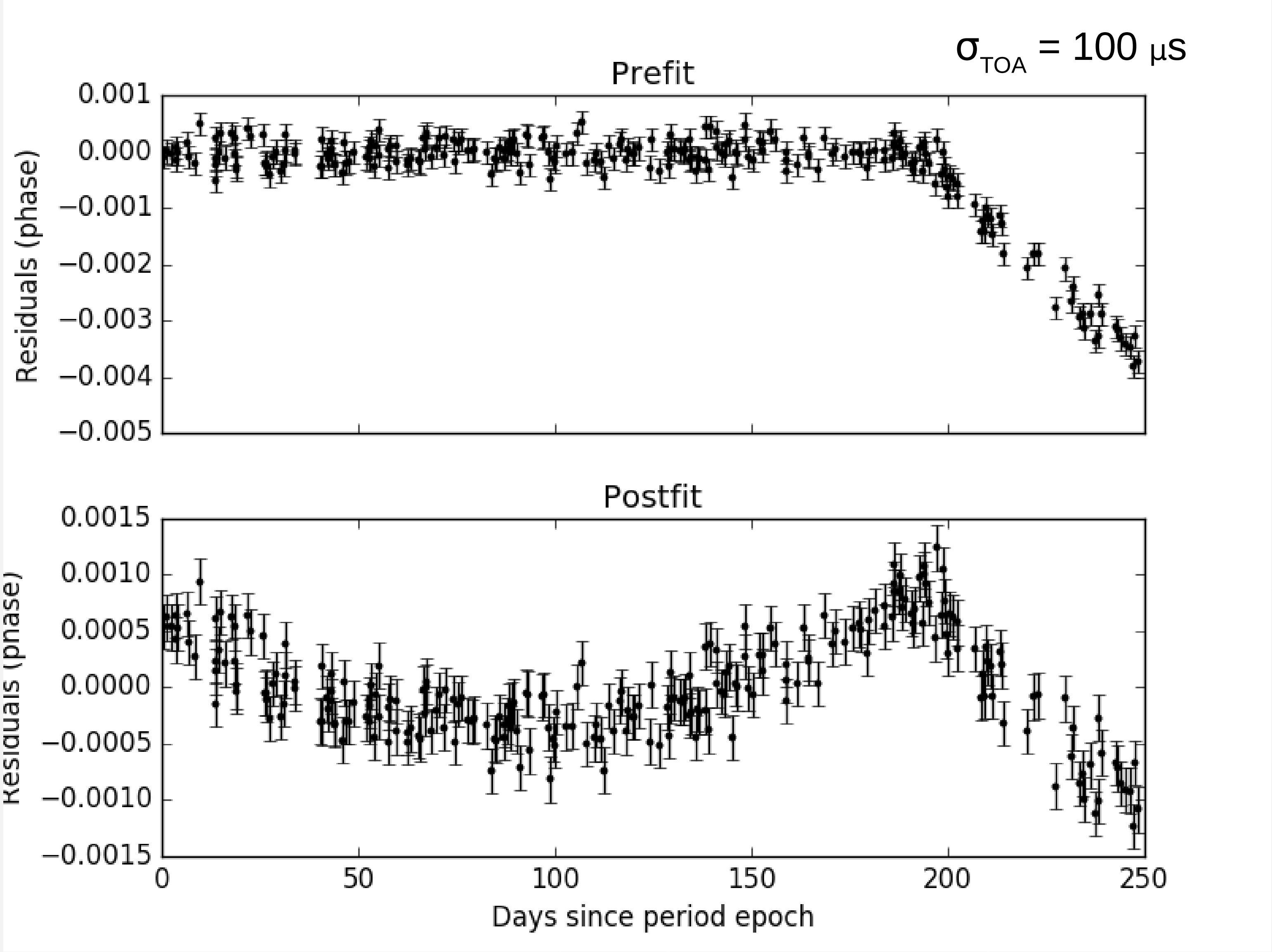
SKA+

Discussion

Sensitivity



Sensitivity



Introduction

Background

SKA+

Discussion

Key parameters

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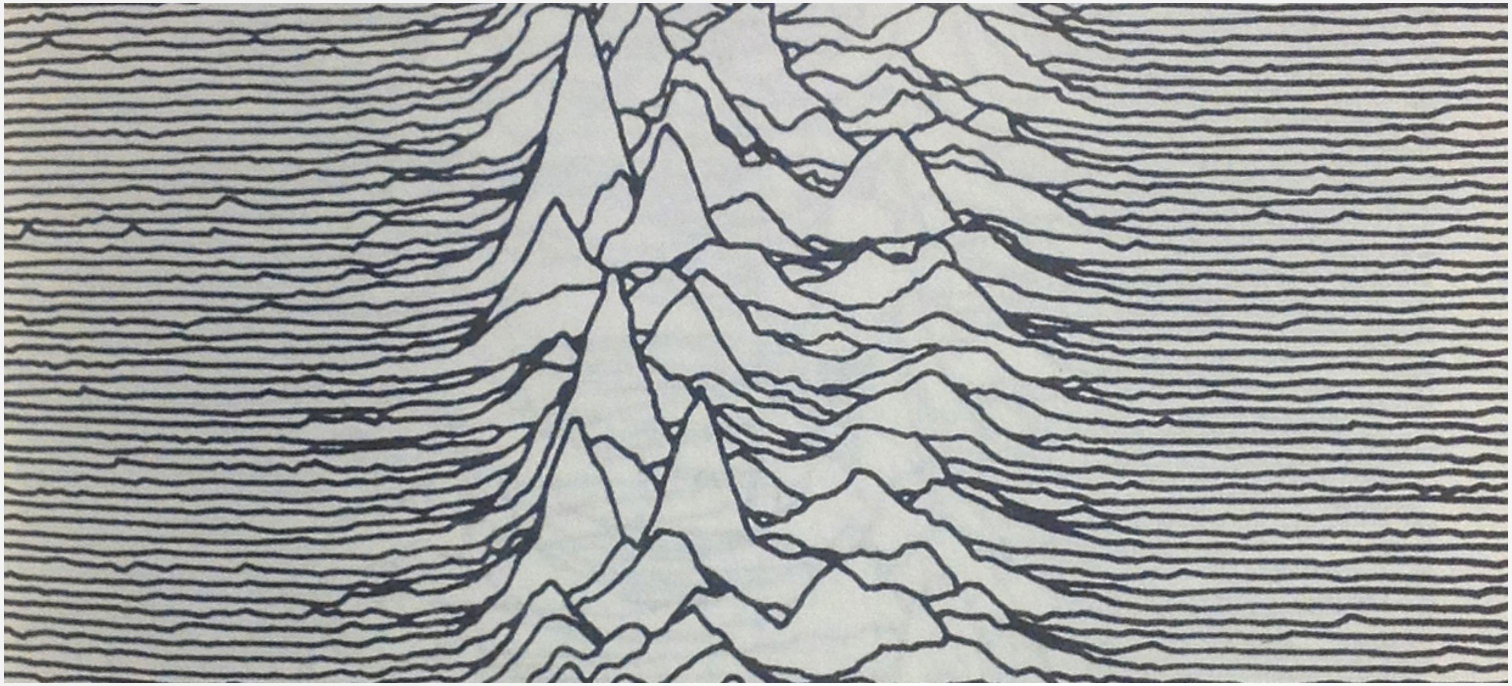
Introduction

Background

SKA+

Discussion

Dwell time



- Pulses are not consecutively stable
- Even for brightest sources, need long enough dwell time to form stable profile
- This sets a fundamental limit, per pulsar, on the glitch resolution timescale

The SKA (+)

Nominal SKA cadence for routine timing = 2 weeks

10x better sensitivity – great for smaller glitches!

BUT

- Not good enough if we want to understand glitch recovery
- Other programmes can already do better
- **So what else can we do with new facilities?**

- What‘s more important? Glitches themselves or their parameter space? => Has implications for how we proceed.

SKA1-MID

- ~ 190 15 m dishes
- 0.35 – 14 Ghz
- 15x Lovell sensitivity
- Wide FOV (30 deg^2)

SKA1-MID

POSSIBILITIES

- **Wide FOV allows:**
  - Access to many pulsars simultaneously
- **We could:**
  - Piggyback on others' observations
  - Pros: High cadence obs of many sources
  - Cons: No choice of target/dwell time. No immediate follow up if something interesting happens
  - Would need some automated "interesting event" detector to trigger follow up at other facilities

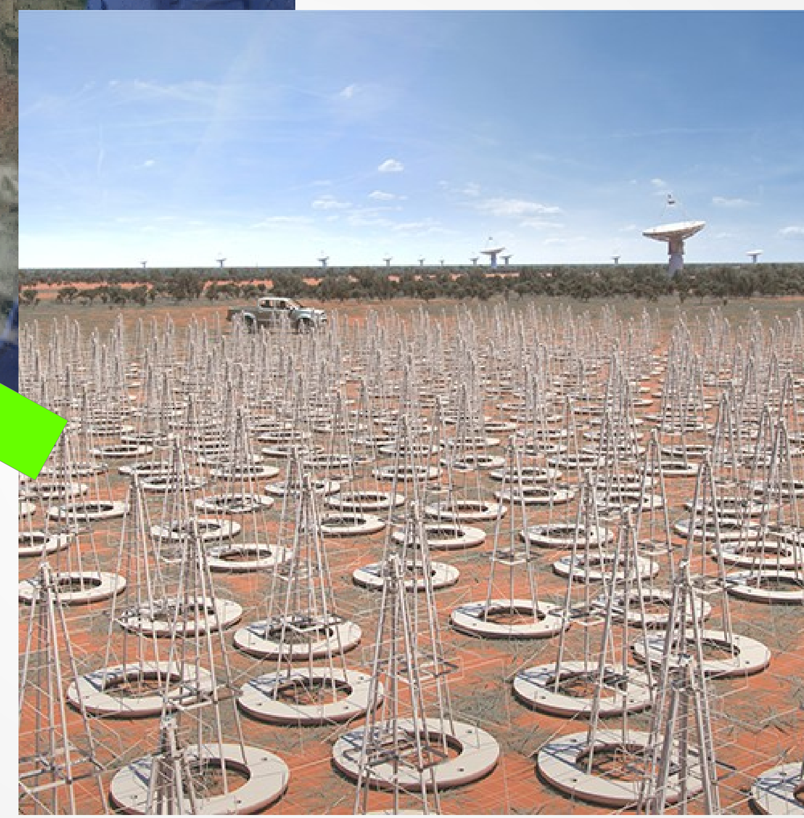
SKA1-MID

POSSIBILITIES

- **Wide FOV allows:**
  - Access to many pulsars simultaneously
- **We could:**
  - Split the array into a number of subarrays
  - Pros:
    - Can monitor a large number of sources, potentially identifying more glitches
  - Cons:
    - Sensitivity may be compromised.
    - Possibly only useful for sufficiently bright/stable sources
    - Less sensitive to smaller glitches

Introduction
Background
The SKA+
Discussion

SKA1-LOW



- ~130k antennae over 500 stations
- 50 – 350 Mhz
- 25% better resolution than LOFAR
- 8x LOFAR sensitivity

SKA1-LOW

POSSIBILITIES

- **Wide field of view**
  - Can see a large fraction of the sky
  - Large number of tied-array beams
- **Subarraying**
  - Up to 16 sub-arrays
  - TAB possiblities

- **We could:**
- Form large number of TABs and/or split the array in to sub-arrays
- Pros: High cadence – better sampling of glitch epoch.
  Observe many pulsars simultaneously – wider sample of glitches
- Cons: Lower sensitivity – more difficult to probe recovery, less sensitive
  to smaller glitches

Introduction

Background

The SKA+

Discussion

SKA1-LOW

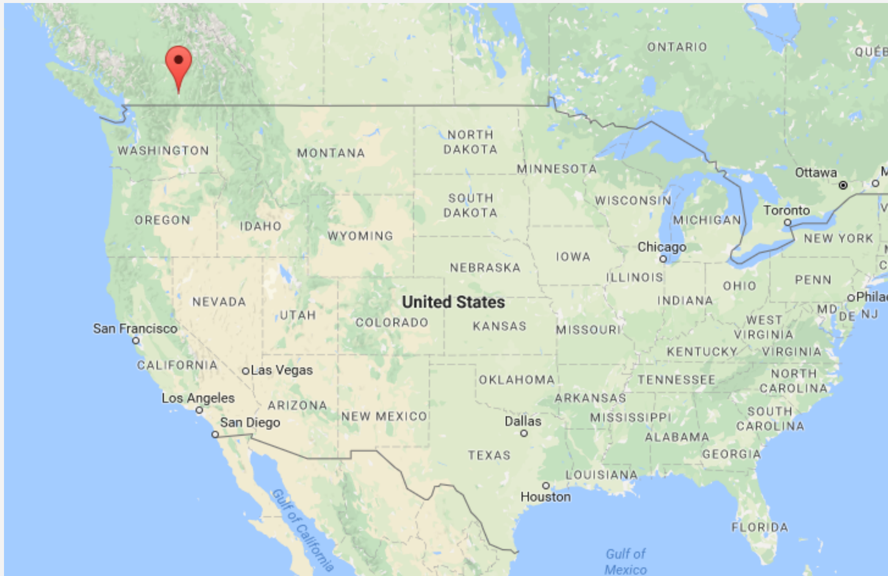
POSSIBILITIES

- **Wide field of view**
  - Can see a large fraction of the sky
  - Large number of tied-array beams
- **Subarraying**
  - Up to 16 sub-arrays
  - TAB possiblities

- **We could:**
- Dedicate time to monitoring selected sources only
- Pros: Can be highly sensitive to recovery
- Cons/issues: Still need sufficient cadence to catch glitch ASAP (triggering?)
  Open to selection effects – glitch population less well sampled

CHIME

Canadian Hydrogen Intensity Mapping Experiment

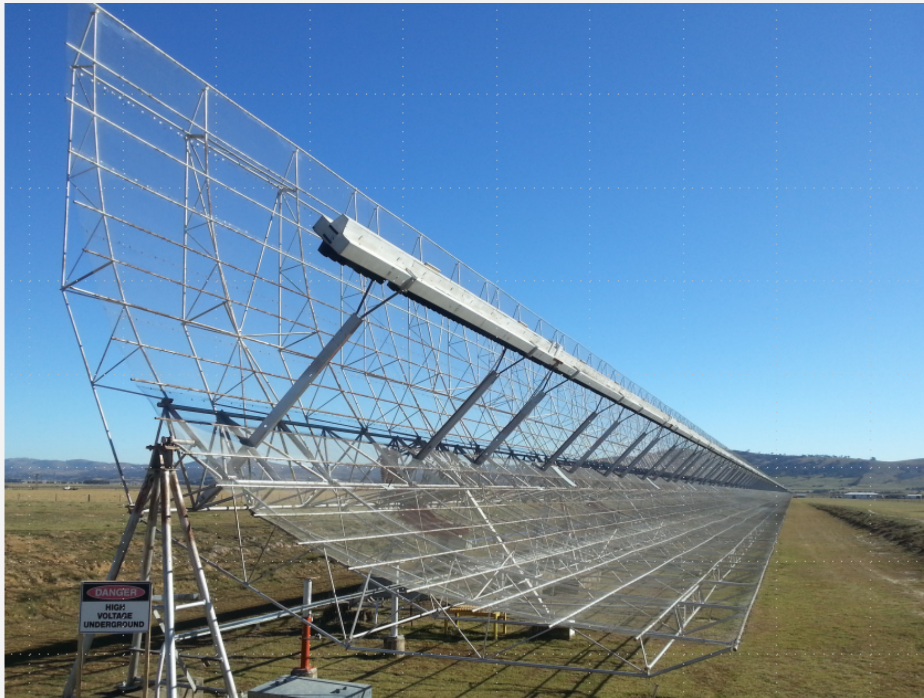


- Can see all Northern pulsars for 5-10 minutes per day
- Only steerable in declination

- Better constraints on glitch epochs
- S/N limited – transit time dec dependent
- No possibiliy of rapid follow up – can we trigger elsewhere?

(UT)MOST

MOlonglo Synthesis Telescope



- V. Large collecting area (eqiv 150 m dish
- ~8000 individual antennae
- TAB
- Daily monitoring of ~300 pulsars

- Dedicated search programme for glitches
- Similar drawbacks as CHIME
- Probing new area of glitch parameter space

Introduction

Methods

The SKA+

Discussion

High energy connections

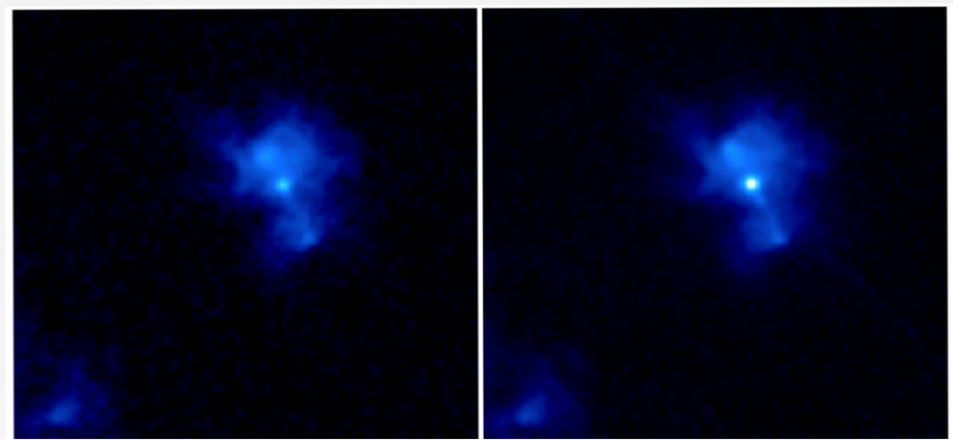
- X-ray outburst – glitch association in PSR J1846-0258

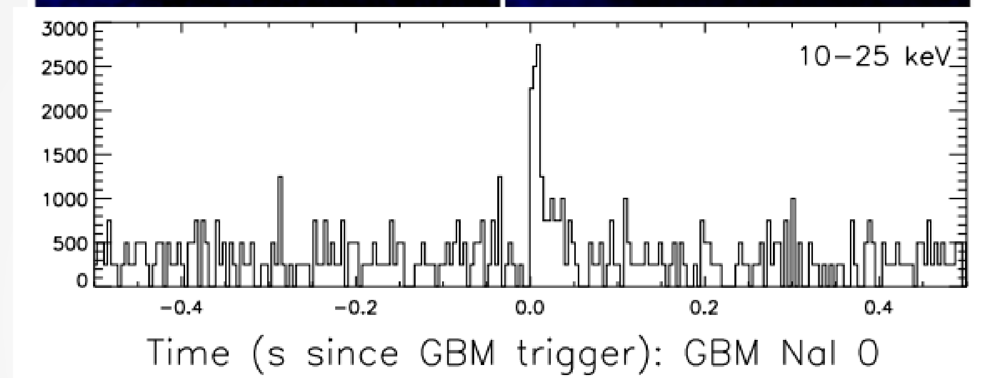
- Current proposal with Kaspi et al to monitor high-B sources for glitches

- Possibly bridge gap between magnetars and RRPs

- Swift BAT caught XRB in PSR J1119-6127

- Coincident glitch observed





- **<u>We could:</u>**

- Use XRBs to trigger radio follow up in slow, high-B RPPs

- Pros: Probe the less well sampled regions of glitch parameter space?

- Cons: Not many pulsars up there[*] – low data rate!

Decision time!
What‘s most important?

No single facility is the solution – observatories need to work together!

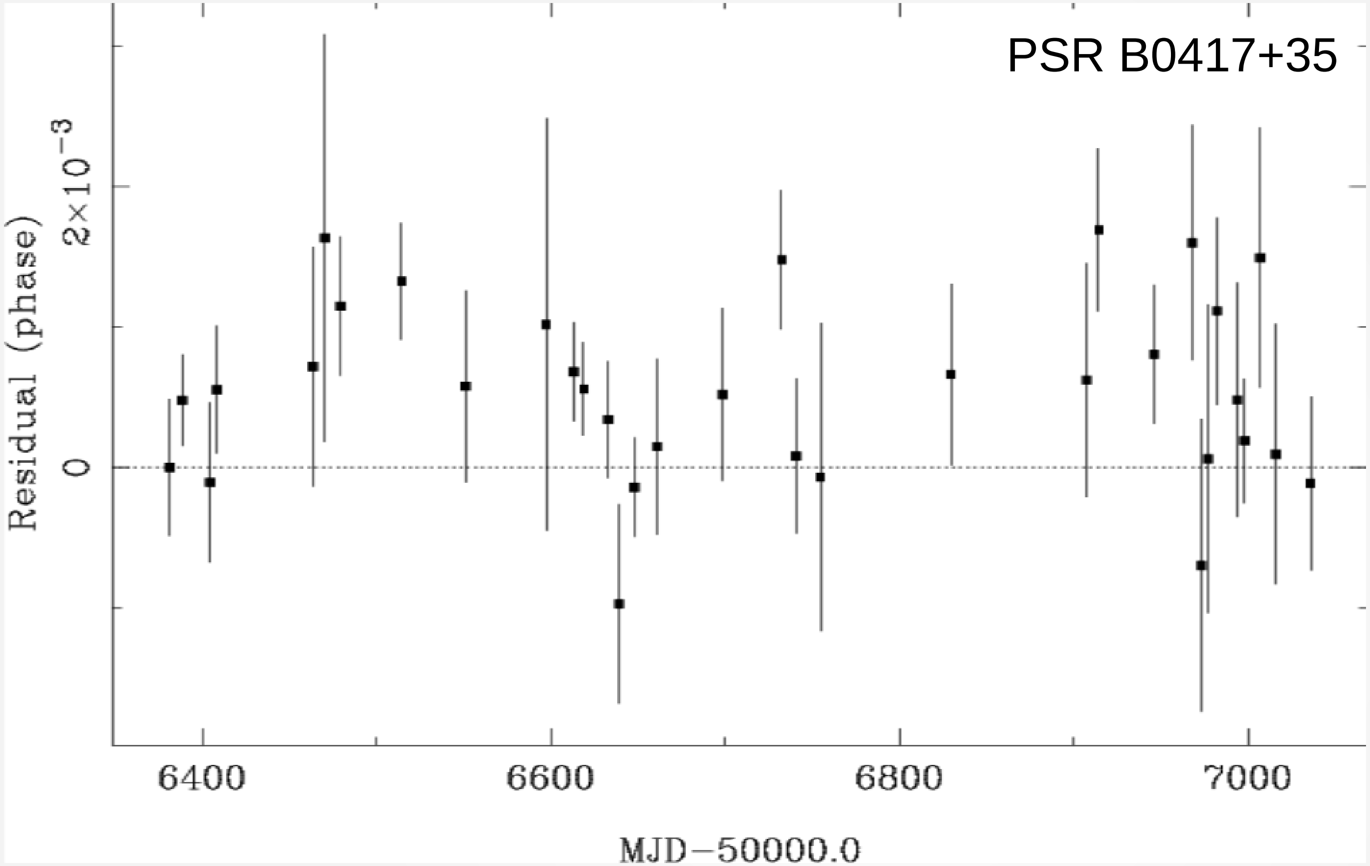
Lots of options but what should we focus on?

- Measuring glitch onsets/recoveries?
  - Monitor a small selection of pulsars with very high cadence
  - Leave routine timing of whole population to piggyback programmes/CHIME/Jodrell etc
  - Add new sources to “glitcher list“ as we find them
- Probing the full glitch parameter space
  - Monitor as many as possible as often and sensitively as we can – CHIME/UTMOST
  - Trigger high cadence follow-up as soon as glitch is seen

How we proceed depends on the answer!

Extra Slides

Finding and measuring glitches



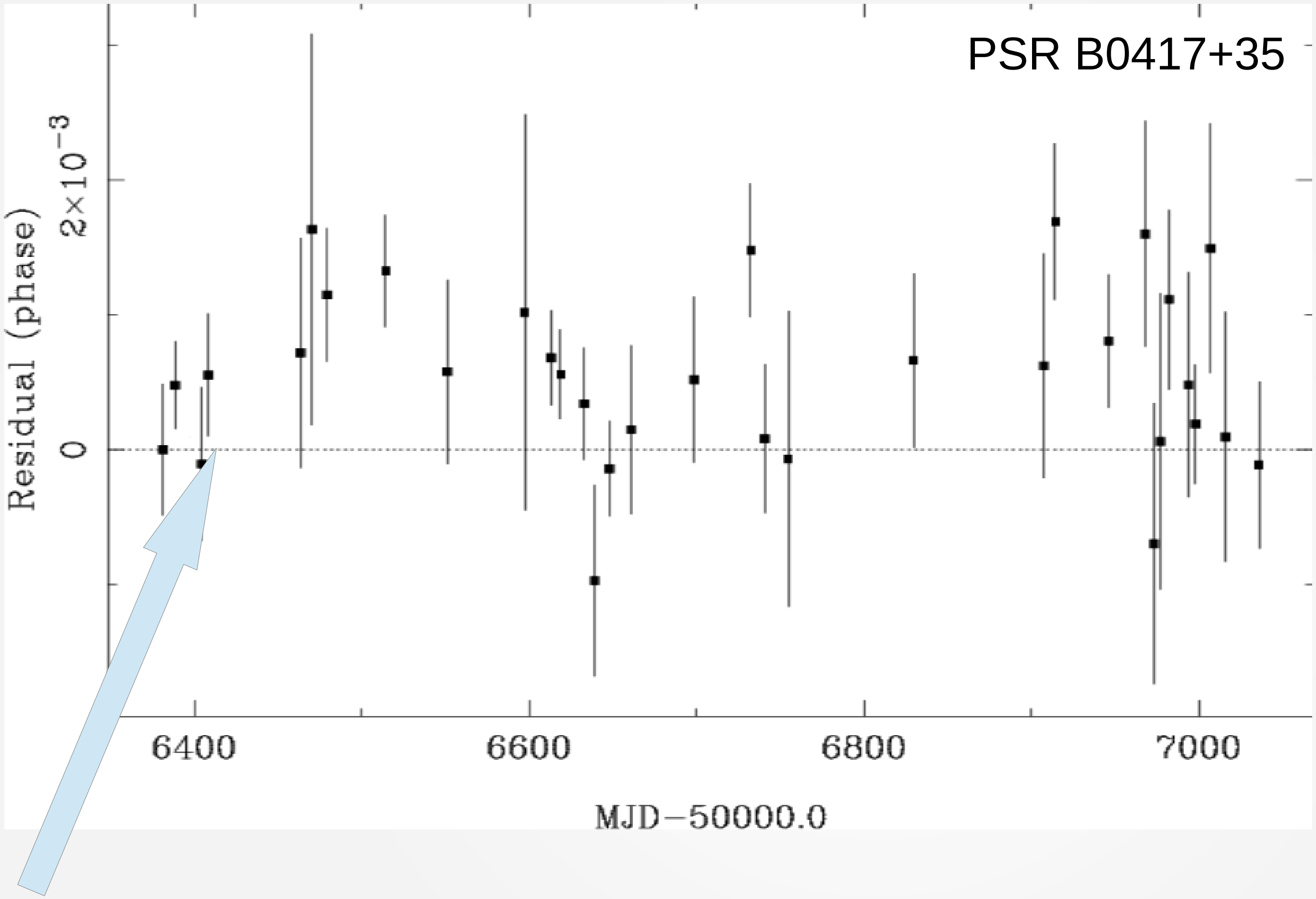
Introduction

Background

SKA+

Discussion

Finding and measuring glitches



Pulses arriving roughly on time (consistent with noise)

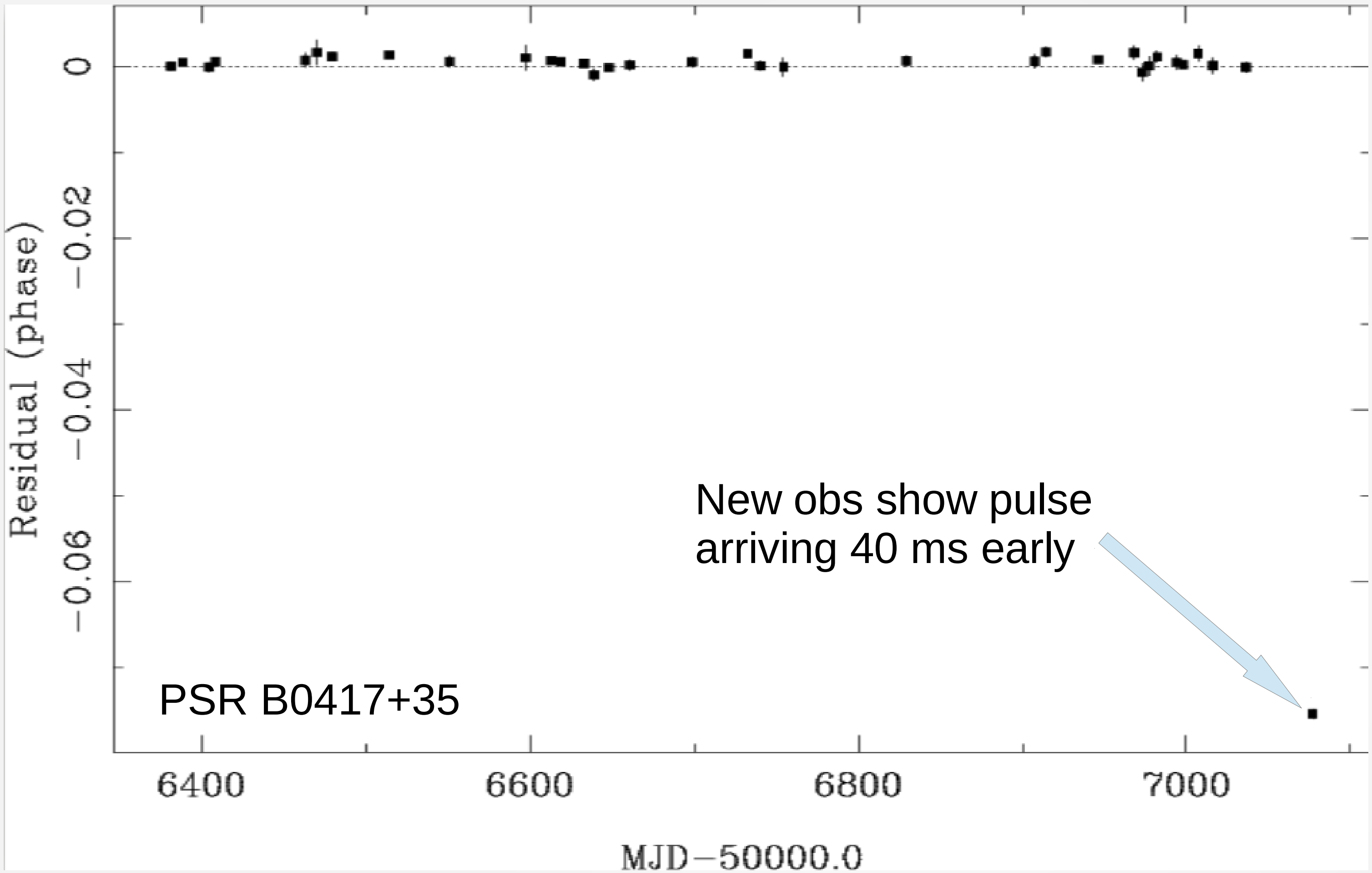
Finding and measuring glitches

Introduction

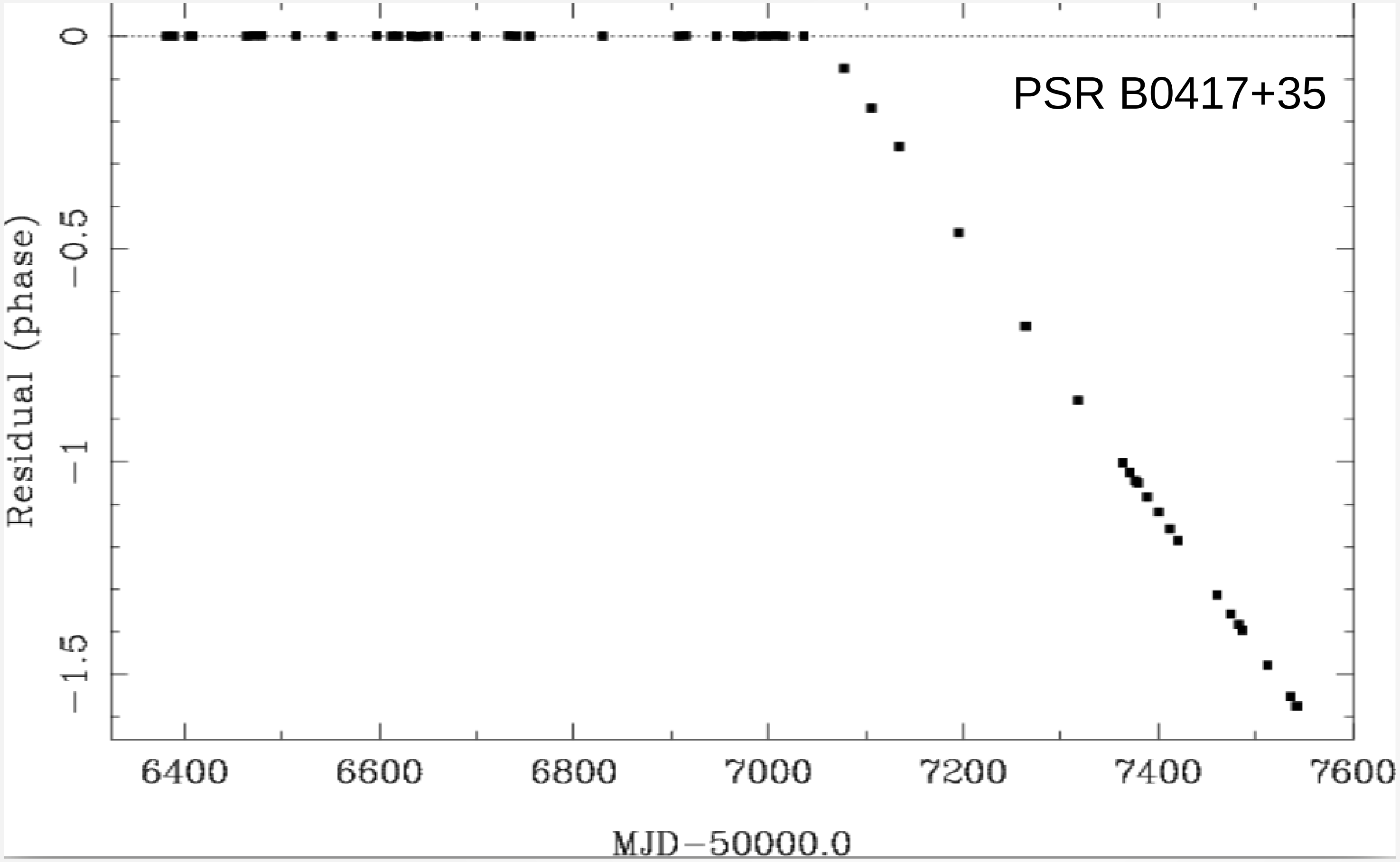
Background

SKA+

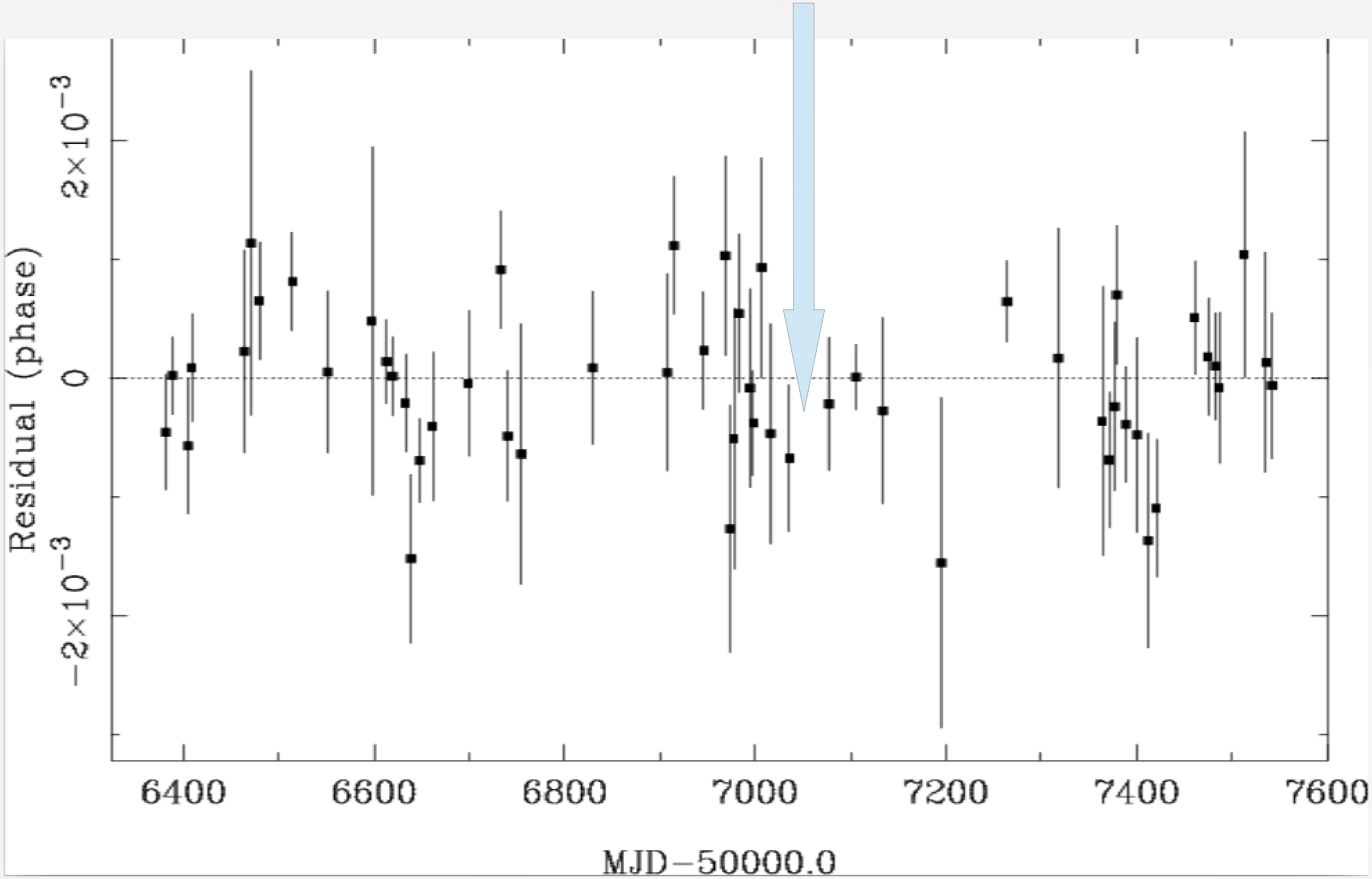
Discussion



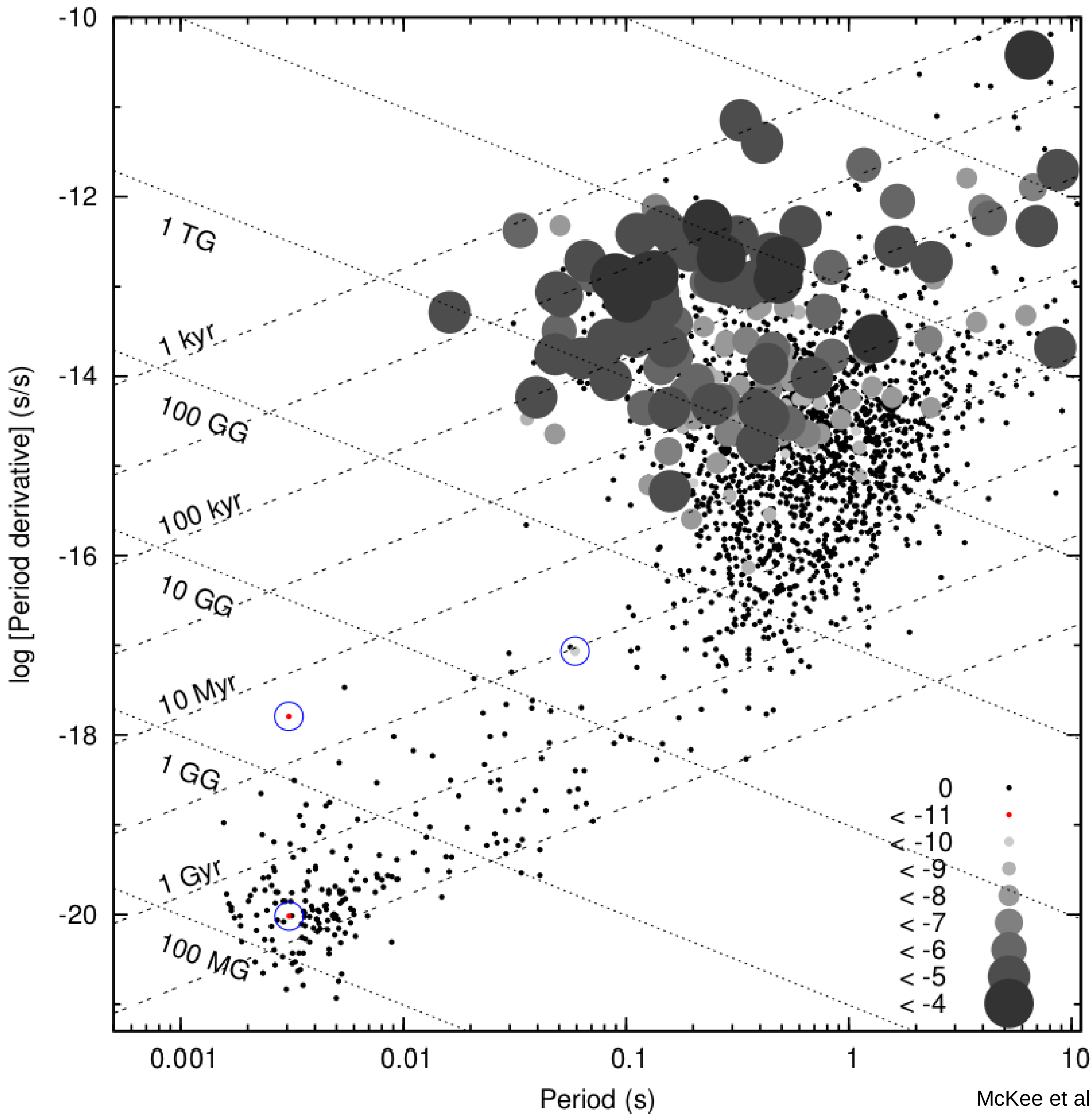
Finding and measuring glitches



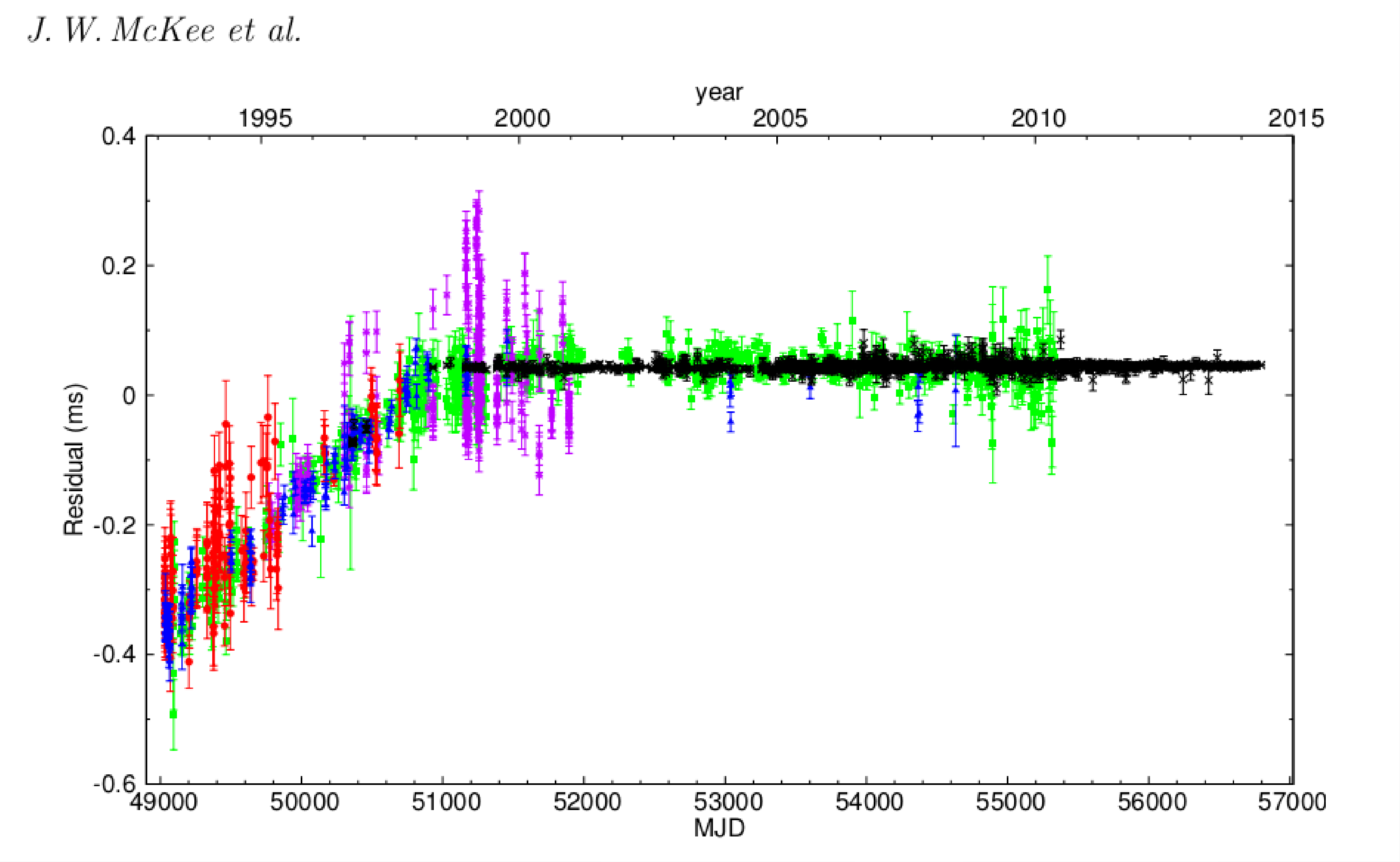
Finding and measuring glitches



Epoch: 57053.6
DF = 25 ppb



McKee et al 2016


J. W. McKee et al.
year
1995
2000
2005
2010
2015
0.4
0.2
0
-0.2
-0.4
-0.6
Residual (ms)
49000
50000
51000
52000
53000
54000
55000
56000
57000
MJD