# The Large European Array for Pulsars

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# Outline

- LEAP project overview
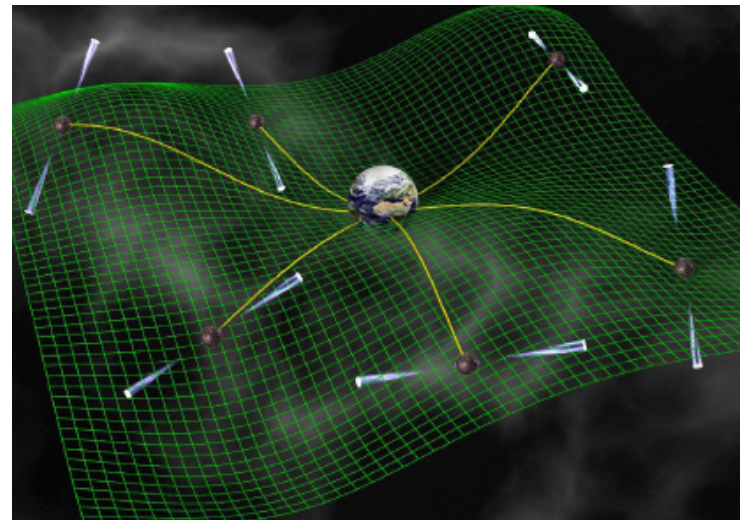- LEAP project implementation at SRT
- LEAP first results

# Pulsar Timing Arrays for GW detection

Pulsar Timing Arrays (PTAs) use millisecond pulsars (MSPs) and Earth as test masses.

GWs affect the space-time between Earth and pulsars, introducing offsets in pulsar times-of-arrival (TOAs).

▸ PTAs sensitive to nHz GWs from supermassive BH binaries and cosmic strings

▸ PTAs monitor timing residuals of MSPs over 10-30 years

▸ Detection achieved by studying correlation of residuals between different pulsars

# International Pulsar Timing Array (IPTA)



NANOGrav

EPTA

PPTA

Green Bank, West Virginia

Westerbork, The Netherlands

Effelsberg, Germany

Pune, India

Arecibo, Puerto Rico

Cheshire, United Kingdom

Nancay, France

Sardinia, Italy

Parkes, Australia

Under Construction

# European Pulsar Timing Array (EPTA)

▸ 100m Effelsberg Telescope (Germany)

▸ 94m–equivalent Nancay Radio Telescope (France)

▸ 94m–equivalent WSRT (Netherlands)

▸ 76m Lovell Telescope (UK)

▸ 64m Sardinia Radio Telescope (Italy)

# LEAP project overview

- Goal: coherently add pulsar observations from the five 100m-class European telescopes to increase aperture and TOA accuracy

- Combine telescopes to form a tied array and create a single telescope with the equivalent size of a 200 m dish

- Comparable in aperture to the illuminated Arecibo dish, but able to cover – 30 < dec < 90

# Phased Array Telescope

In a "tied array telescope", signals from different telescopes are corrected for differences in time delay, then added in phase
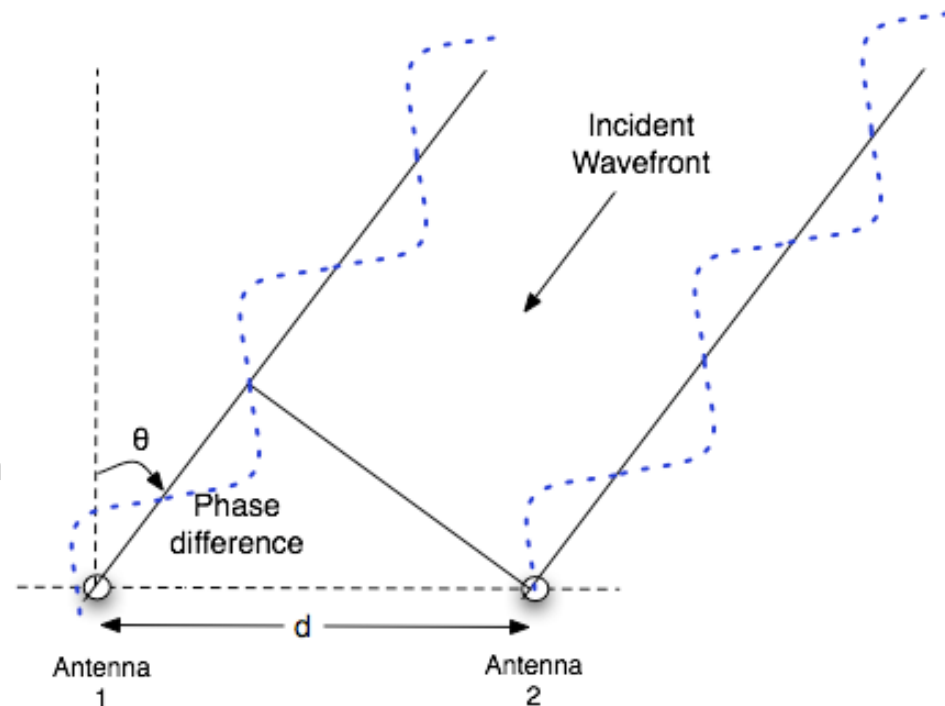
Time delays are due to:
•Differences in geometry
•Observatory clocks
•Instruments (cable length)
•Atmospheric conditions

Total time delay needs to be known
to a fraction of a wavelength
(21 cm = 0. 7 ns)



Advantages
•Large aperture will improve TOA accuracy
•Ability to time weaker pulsars
•Calibration of instrumental delays between telescopes
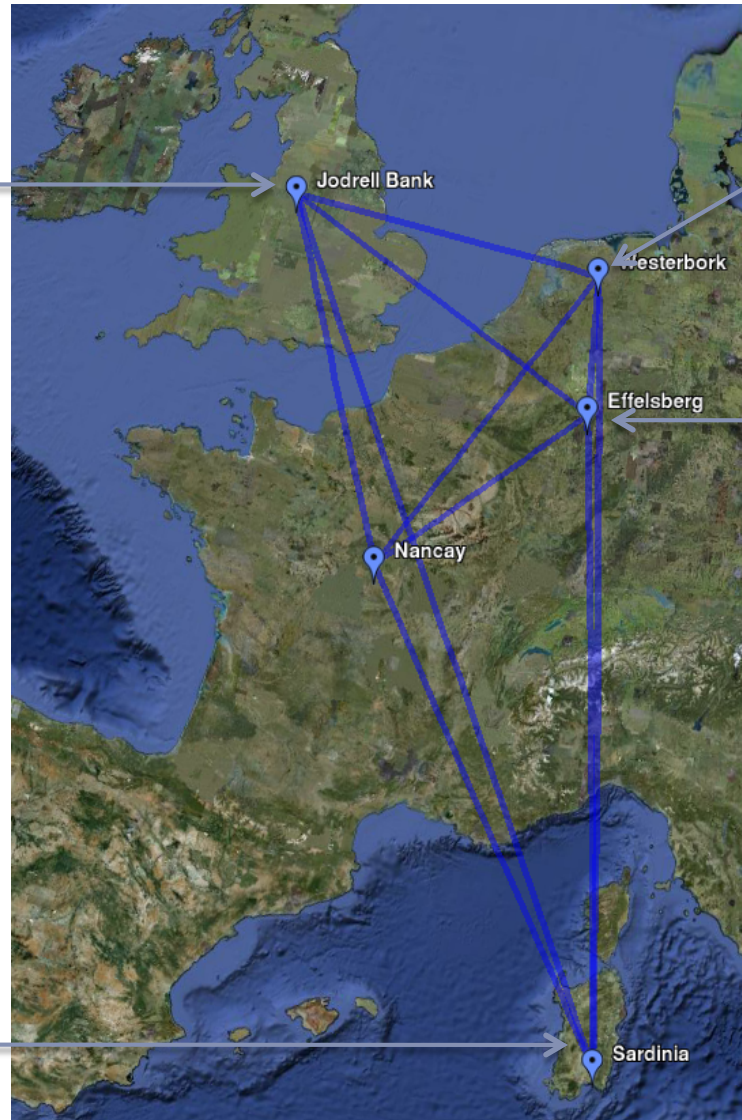
# LEAP team



Ben Stappers
James McKee
(Mark Purver)

Gemma Janssen
Cees Bassa
Roy Smits
Sotiris Sanidas

Michael Kramer
Ramesh Karuppusamy
Kuo Liu
Weiwei Zhu

+ help at observatories
+ SRT Astrophysical
  Validation Team

Delphine Perrodin

CHINA: KJ Lee

# LEAP observations

▸ Monthly 25-hr sessions

▸ 20-30 millisecond pulsars

▸ Simultaneous with all 5 EPTA telescopes

▸ Observe pulsars and phase calibrators

▸ 8 x 16 =128 MHz of bandwidth at L-band

▸ Baseband data (raw voltages) recorded on disk, corresponding to ~ 40 TB of data at each telescope!

▸ Disks are shipped to Jodrell Bank for correlating

▸ Precursor to SKA science!

▸

# Implementation of LEAP at SRT



- Using ROACH backend
- 8-node cluster installed in Feb 2014 for the recording of full LEAP band

  (8 x 16 MHz = 128 MHz)

# LEAP storage cluster (April 2014)

LEAP storage at SRT (96 TB) installed in April 2014. Able to store the ~40 TB of LEAP data each month

# LEAP: progress at SRT

▶ ROACH backend installed at site in July 2013. First LEAP observation with one sub-band

▶ Participating in full-bandwidth monthly LEAP runs since March 2014 for 20 pulsars

▶ Automated data acquisition for LEAP runs

▶ Copying data to storage and shipping to Manchester

▶ Incorporated SRT in LEAP correlation software

▶ Fringes first obtained with WSRT in May 2014

▶ Since October 2014: monthly correlating of 5-telescope data at Jodrell Bank

▶ Quality of SRT data limited by RFI (military radars, RFI caused by antenna, broadband RFI)

▶

# LEAP results: Coherence



Pulsar profiles for J1022+1001

# LEAP results: Coherence



Coherent addition of J1022+1001
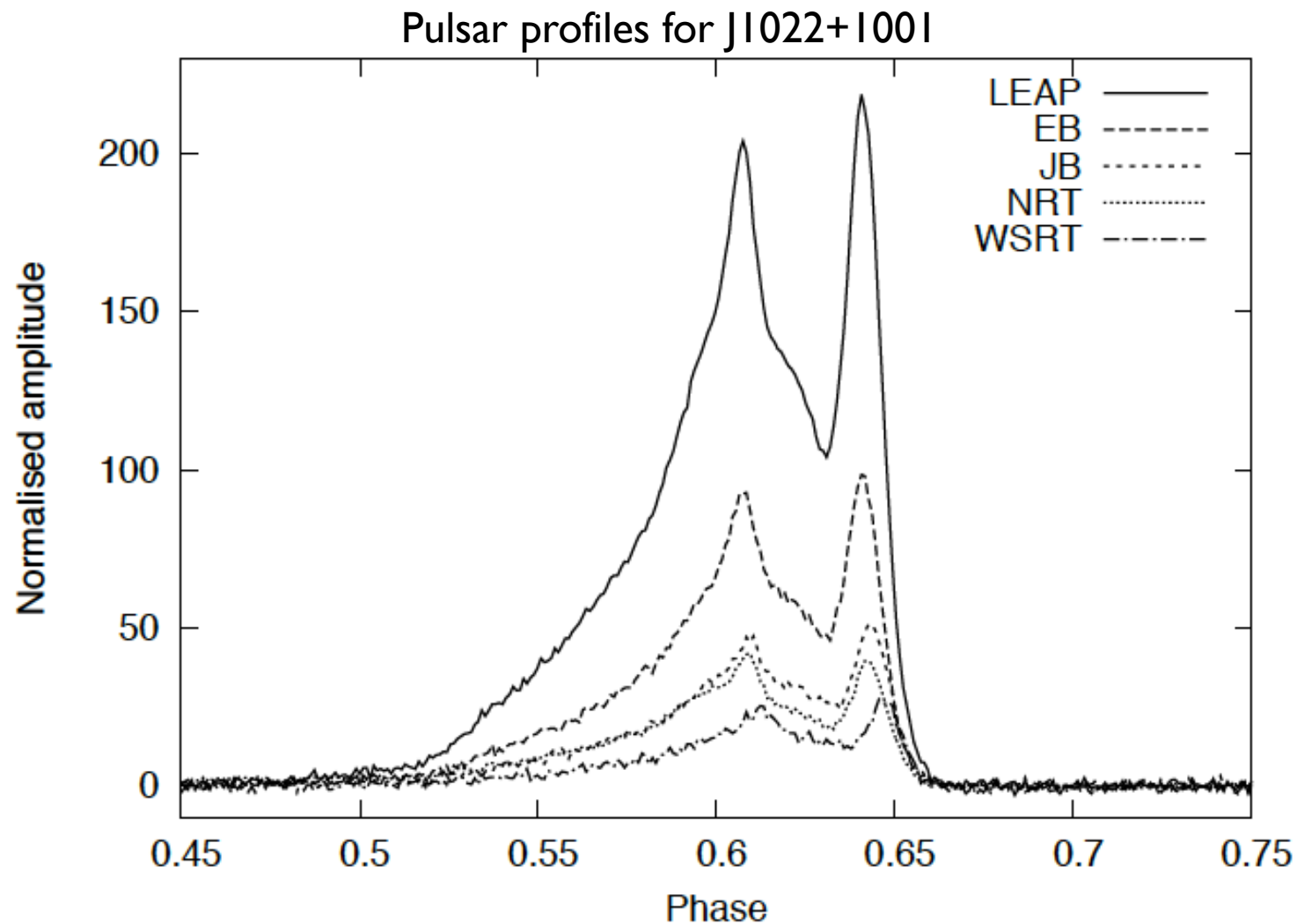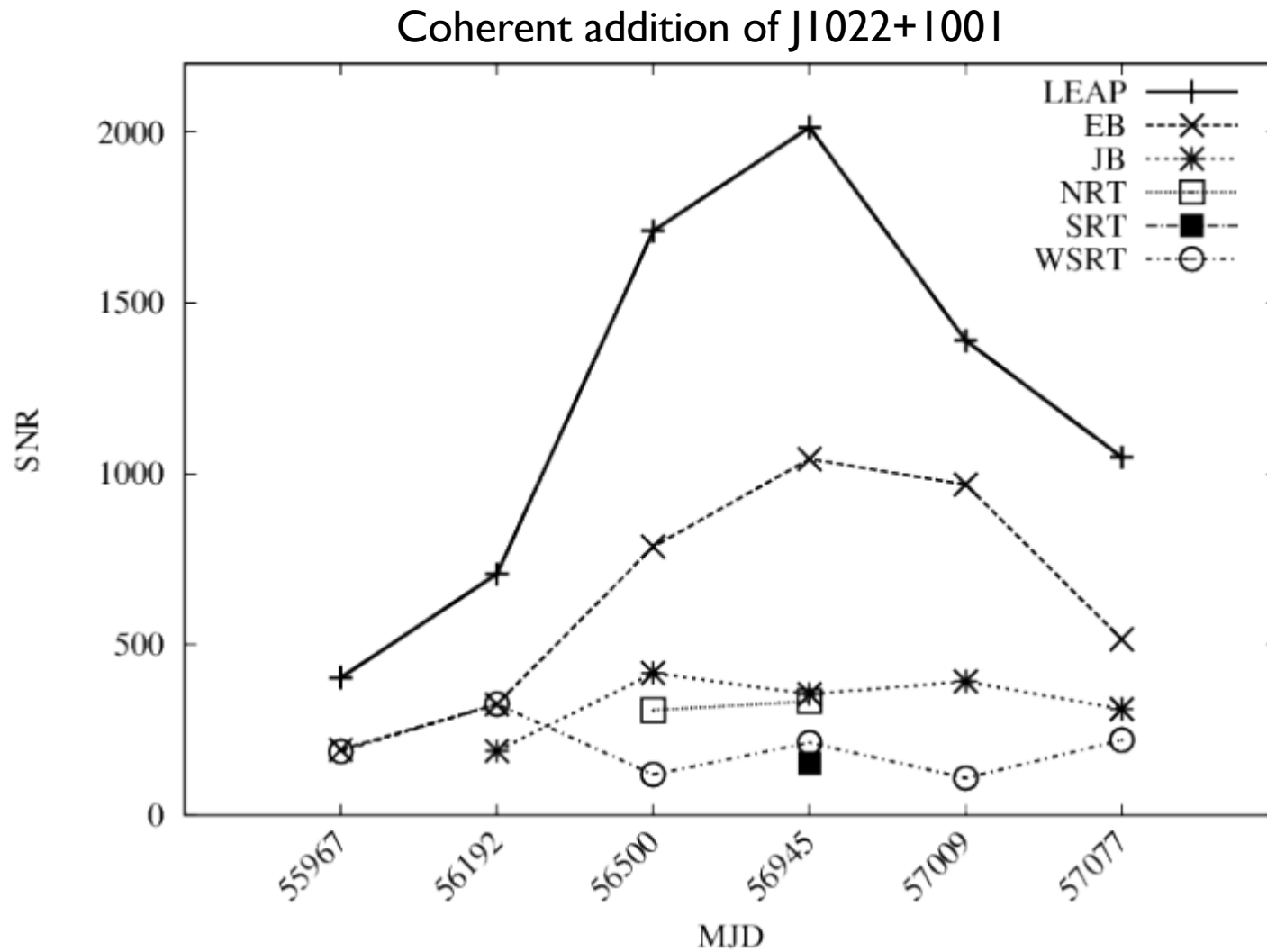
# LEAP updates

- Data acquisition hardware and software in place at all telescopes (including SRT)
- All five telescopes are fully participating in monthly LEAP sessions
- LEAP reduction pipeline up-to-date
- Data reduction: now on a month-to-month basis
- Reducing backlog of existing data in parallel

- Science obtained from the data that have already been reduced
- Expecting to submit 6 papers this year!

# Future of LEAP at SRT?