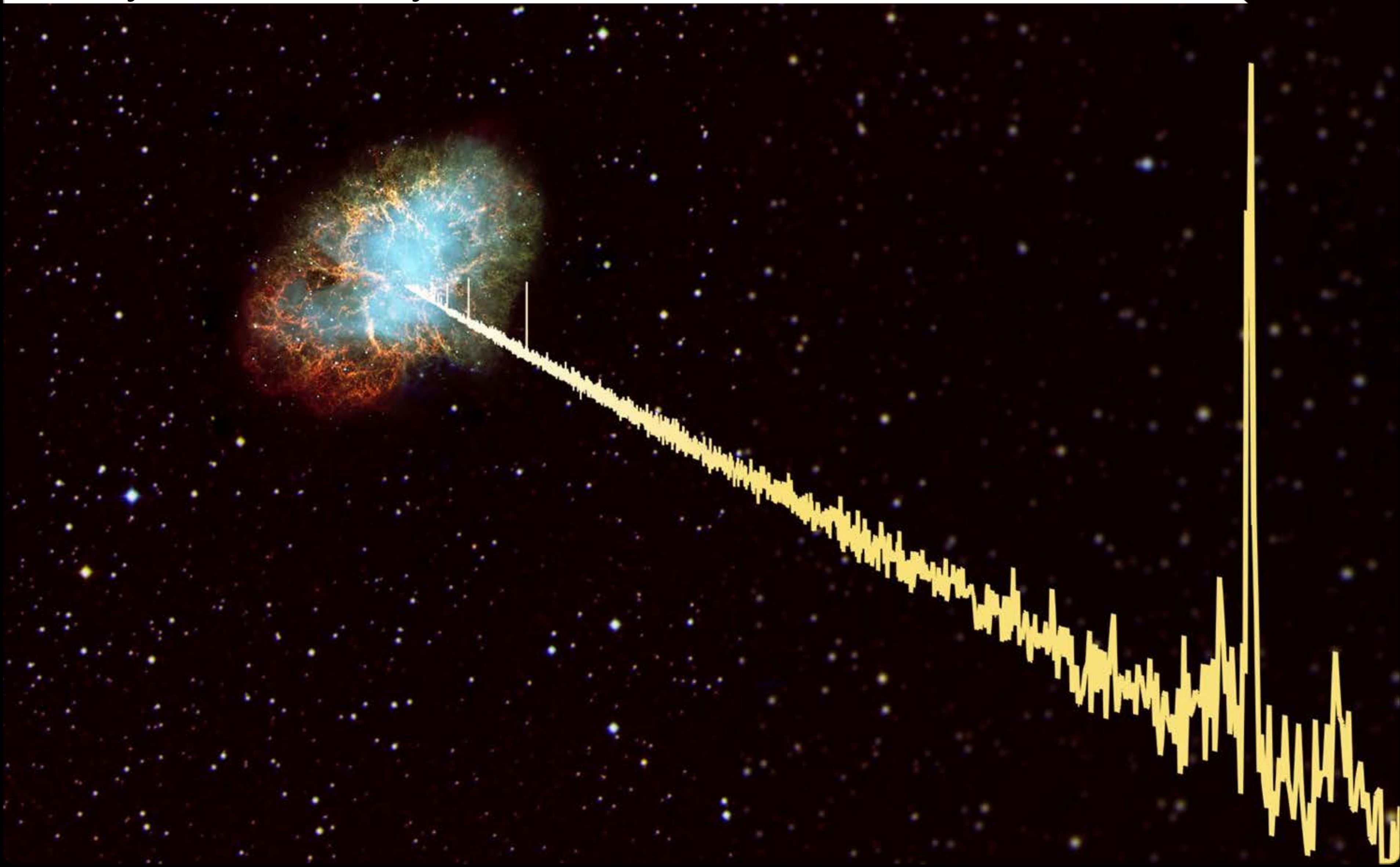
Joeri van Leeuwen

The dynamic radio sky: Pulsars and Transients



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The dynamic radio sky: Pulsars and Transients

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The dynamic radio sky: Pulsars and Transients

SKA2-MID (AA, PAF)

1. Pulsars
2. Fast Radio Bursts
3. Gravitational Waves

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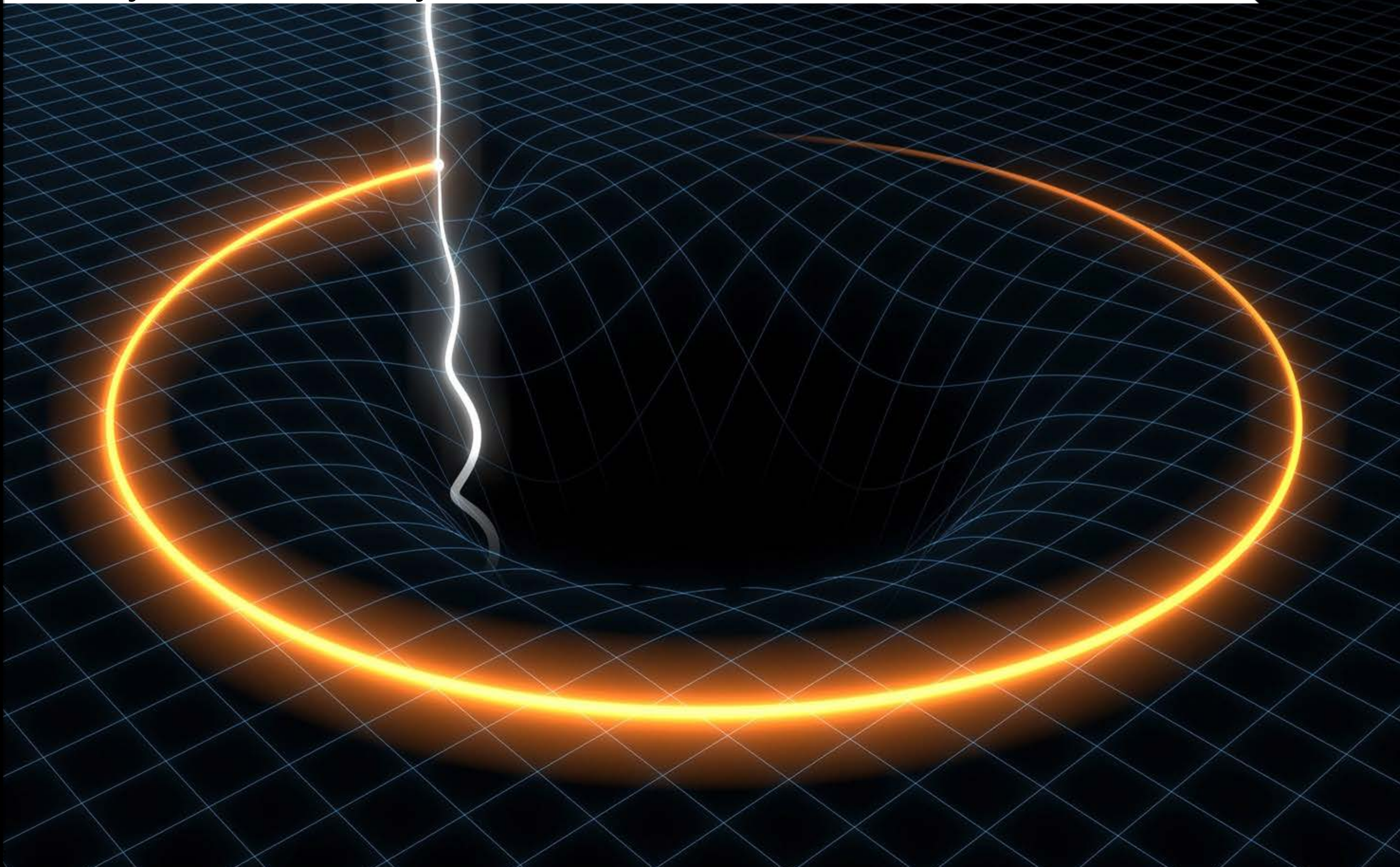
The dynamic radio sky: Pulsars and Transients



SKA2-MID (AA, PAF, WBSPF)

Assuming

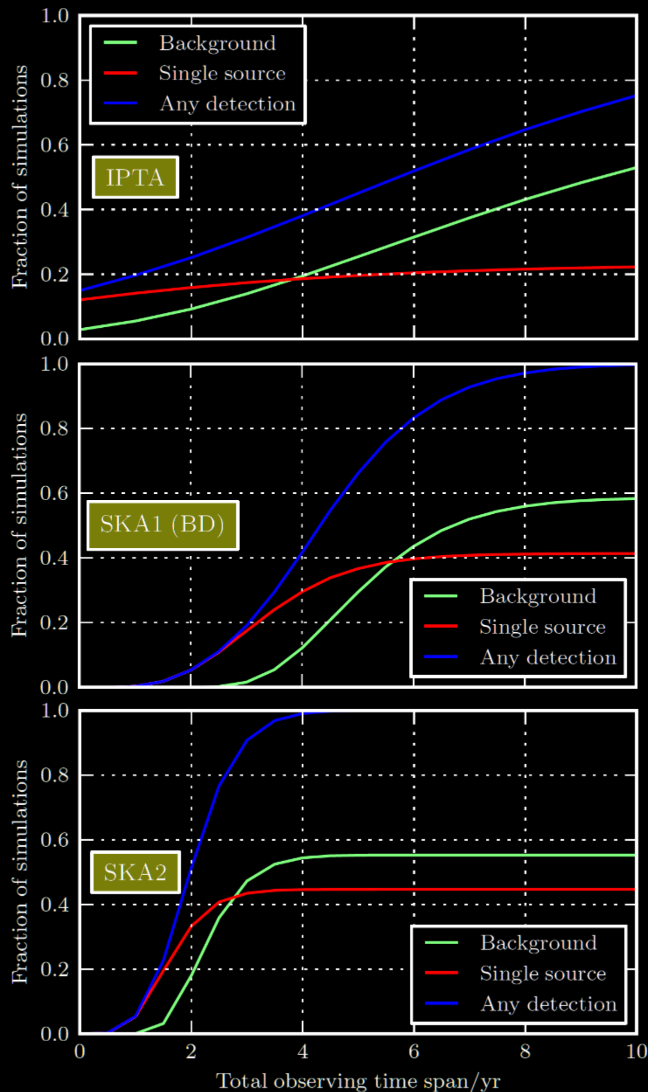
1. $A/T = 10{,}000\ m^2/K$ ($A = 300{,}000\ m^2$; $T_{rec} = 30\ K$)
2. Frequency = ~300-1500 MHz
3. Bandwidth = 0.5 GHz

SKA2-MID (AA) pulsar science: Pulsar Timing

Pulsar Timing Arrays:

First direct-GW PTA detection: SKA1/IPTA

Increased sensitivity of SKA2-MID(AA)/(DISH) SMBH gravitational wave astronomy will become a reality, study detailed properties of GWs.

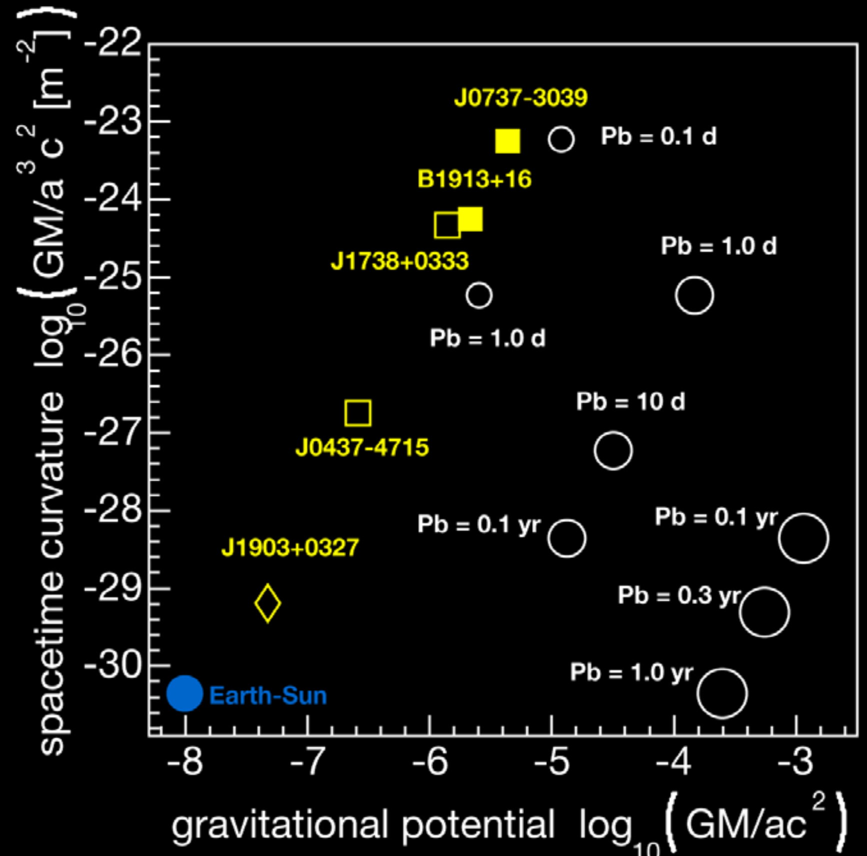


Janssen et al. 2015

SKA2-MID (AA) pulsar science: Pulsar Timing

Testing Gravity:

Simulations for SKA2-MID (AA) predict sub-us timing variance for Double Pulsar -- allows highly precise measurements of "higher-order Post-Newtonian" parameters.



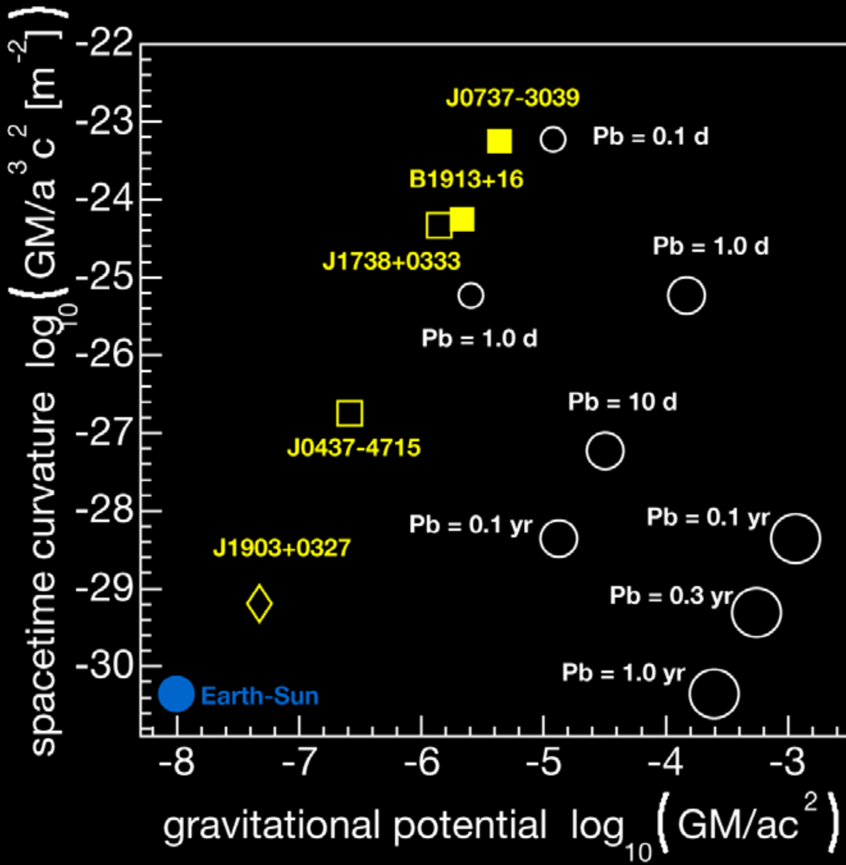
Shao, Stairs et al. 2015

SKA2-MID(AA) pulsar science: Pulsar Timing

Testing Gravity:

The SKA2 survey FoV and sensitivity can help find pulsar – black hole (PSR-BH) binaries.

Discovery of even single PSR-BH system opens study of BH physics with great precision, including possible tests of the “cosmic censorship conjecture” and the “no-hair theorem”.



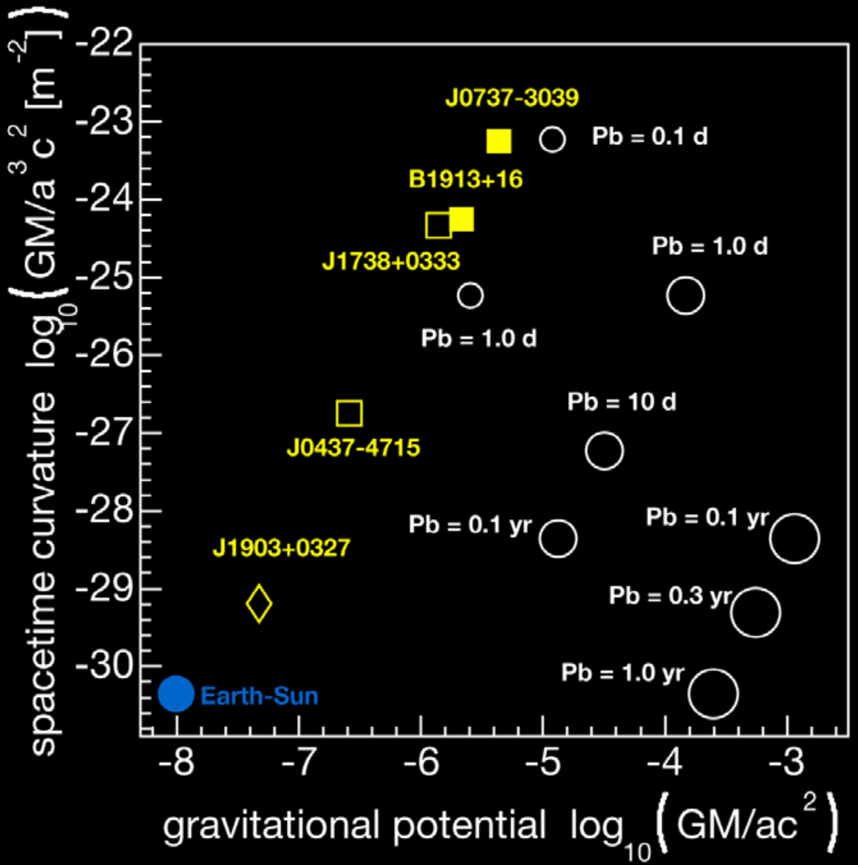
Shao, Stairs et al. 2015

SKA2-MID(AA) pulsar science: Pulsar Timing

Testing Gravity:

The SKA2 "Galactic Census" will discover ~200 double neutron stars (Keane et al. 2015).

Some will have orbits that allows for measurement of "spin-orbit coupling", or "frame-dragging" effect.



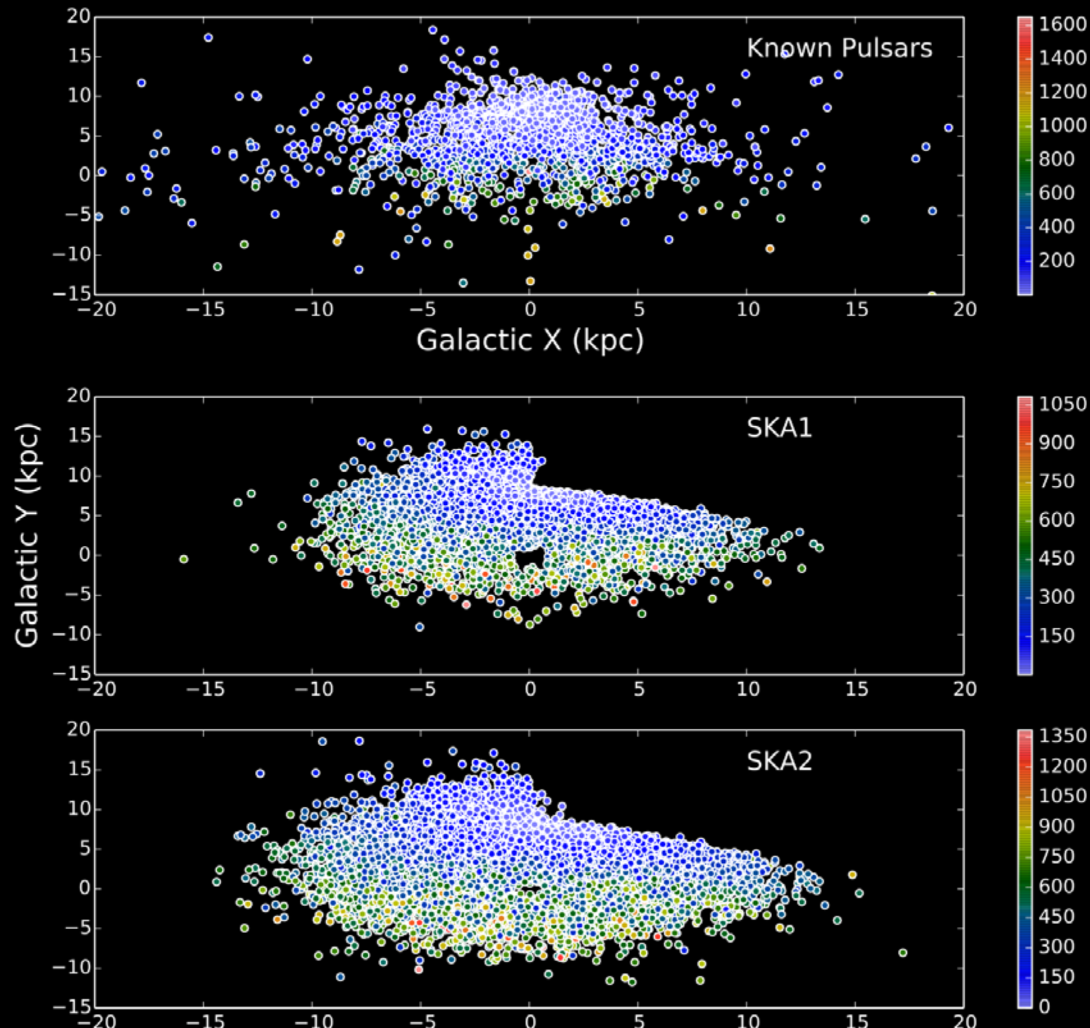
Shao, Stairs et al. 2015

SKA2-MID (AA/PAF) pulsar science: Surveys

Simulations show a pulsar survey with a SKA-MID (AA) at 750 MHz would detect around 27,000 normal pulsars and 3000 MSPs (Keane, .. vL., et al. 2015)

In some regions of the sky this corresponds *to detecting the entire population of pulsars* that are beamed in our direction.

SKA2-MID (AA) pulsar science: Surveys



Keane, .., vL, et al. 2015

SKA2-MID (AA) pulsar science: Follow-up Timing

Telescope with "front-end beams" (dish beams, analog/digital station beams, etc.) small enough to fully sample with "back-end beams" (e.g. tied-array beams)?

Then follow-up timing of a successful survey takes about as long as survey itself.

This is where large FoV has huge benefit, *without* high back-end costs. Ability to make even e.g. 100 TABs anywhere in > 100 sq. deg. would create high-speed bulk timing machine.

→ This is the part that creates 95% of the survey science value

SKA2-MID (AA) pulsar science: Processing

Processing is done to make Tied Array Beams (TABs) and next search these.

LOFAR: 200 TABs
Apertif: 500 TABs
SKA1: 750 TABs
SKA2: 10,000 TABs

Known Knowns & Known Unknowns

Time-domain - bursty and generally coherent

- Pulsars: Magnetar bursts, Transitional XRBs, Giant Pulses, RRATs
- Fast Radio Bursts
- Bursty emission from exoplanet-star systems, brown dwarfs

Image domain - incoherent synchrotron or thermal

- X-ray binaries
- Tidal Disruption Events
- Novae & Flare stars
- Intra-day variable quasars/Extreme Scattering Events
- System mergers/gravitational wave events

A number of the following slides were adapted from J-P Macquart's presentation at *3rd MIDPREP and AAMID Workshop* (2016).

Extraordinary FRB properties

ASTRON

Bright Fluences up to ~10 Jy ms

~30 events, from Parkes, Arecibo, GBT, UTMOST, ASKAP (Bannister et al. 2017)

Distant Extremely high dispersion measures, above Galactic plane (375-2000 pc/cm^3)

FRB 121102 now associated with star-forming dwarf system at ~0.8 Gpc.

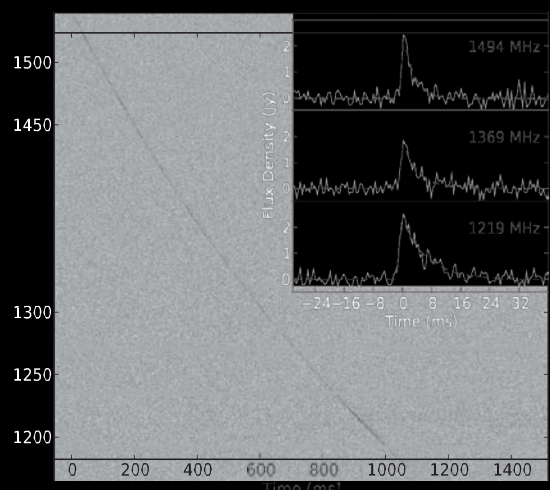
Common Inferred event rate ~ 2-5 x10^3 sky^{-1} day^{-1}

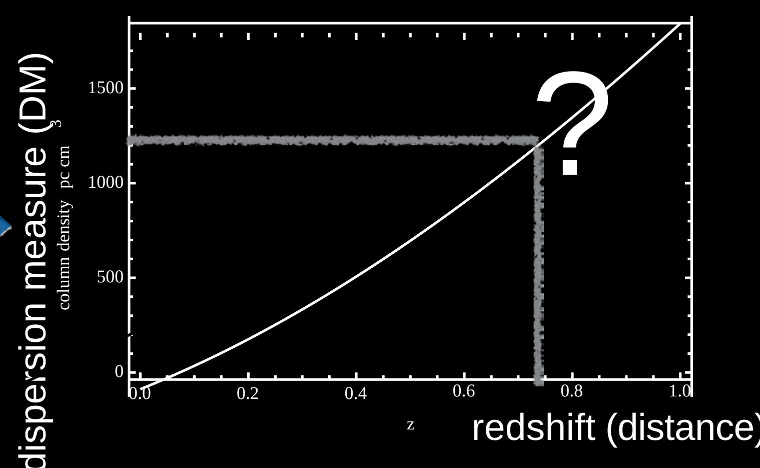
Scattered At least 4 exhibit temporal smearing of order several milliseconds (much larger than expected due to scattering in the Milky Way)

Slide after JP Macquart 2016

Fast transients as cosmological probes

We can
* directly detect every single baryon along the line of sight!
* use the DM-redshift relation as a cosmic ruler
* measure turbulence on sub 10^8m scales at distances of ~1Gpc
* probe IGM physics: primordial magnetic field & energy deposition



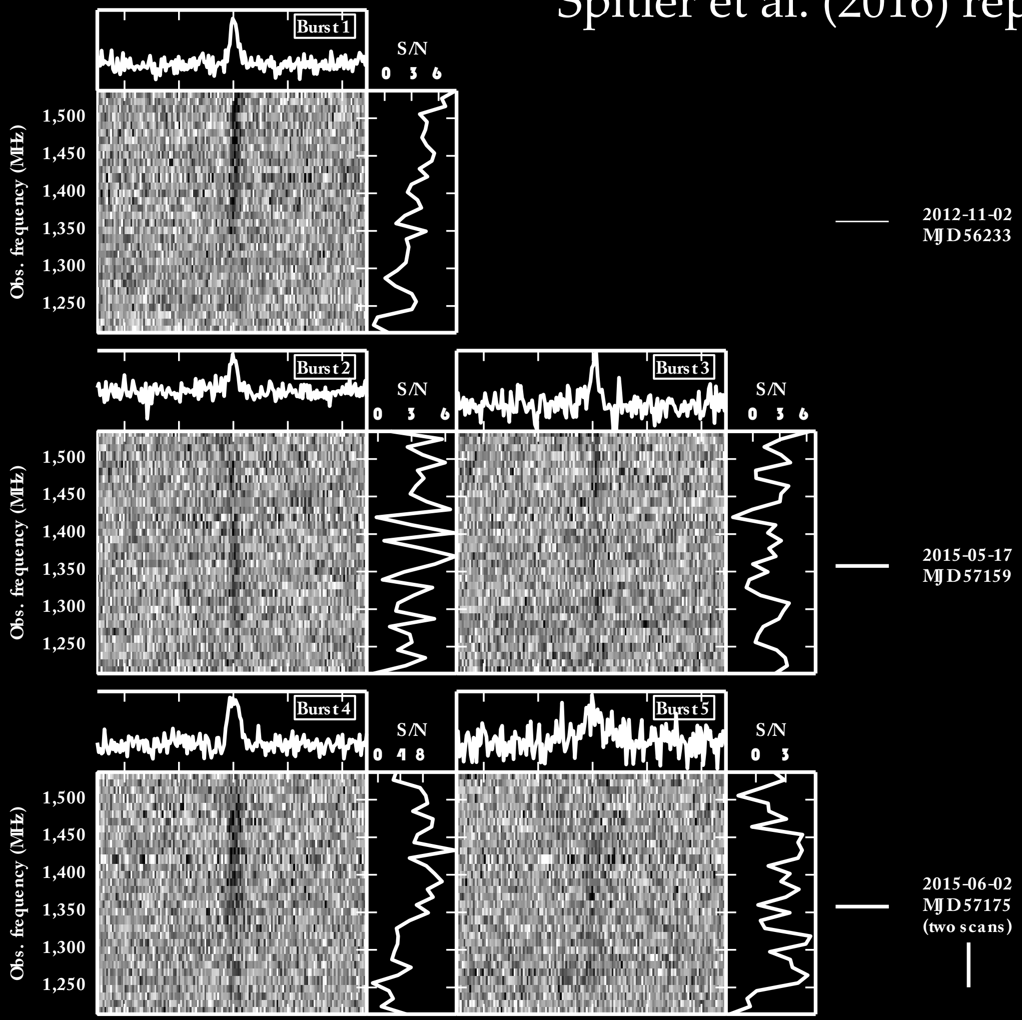


see Macquart et al. & Fender et al. in the SKA Science book

Slide after JP Macquart 2016

Are FRBs Cosmological?

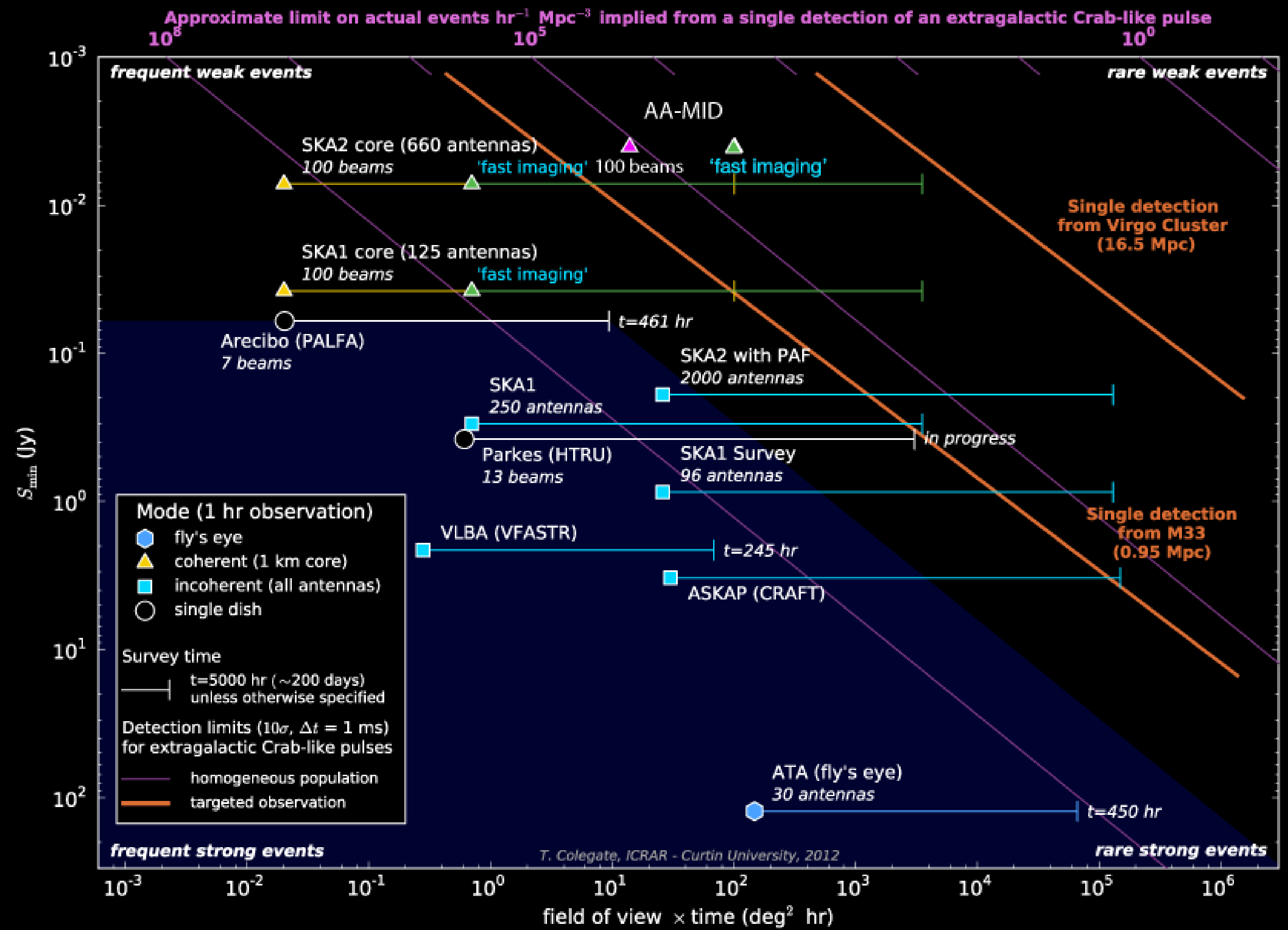
Spitler et al. (2016) report a *repeating* FRB!



- Spectrum is all over the place
- Localised to low-metallicity dwarf galaxy
- Favors super-giant pulses from a young neutron star
- Are there two populations of FRB?

Tendulkar et al. (2017), Chatterjee et al. (2017), Marcote et al. (2017), Bassa et al. (2017)

SKA2-MID (AA / PAF) : excellent transients machine

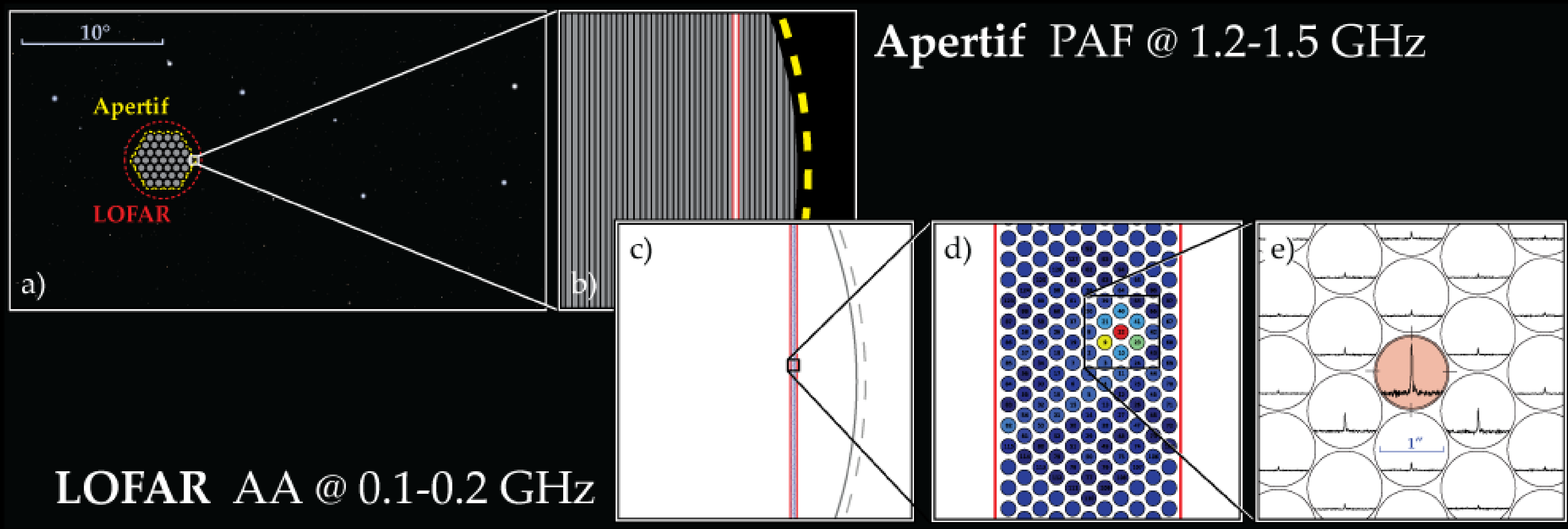


Courtesy of T. Colegate

Localising non-repeating FRBs? ARTS @ Apertif

Apertif Radio Transient System (ARTS):

Real-time Apertif FRB detection & LOFAR TBB localisation



Lessons learned for FRBs

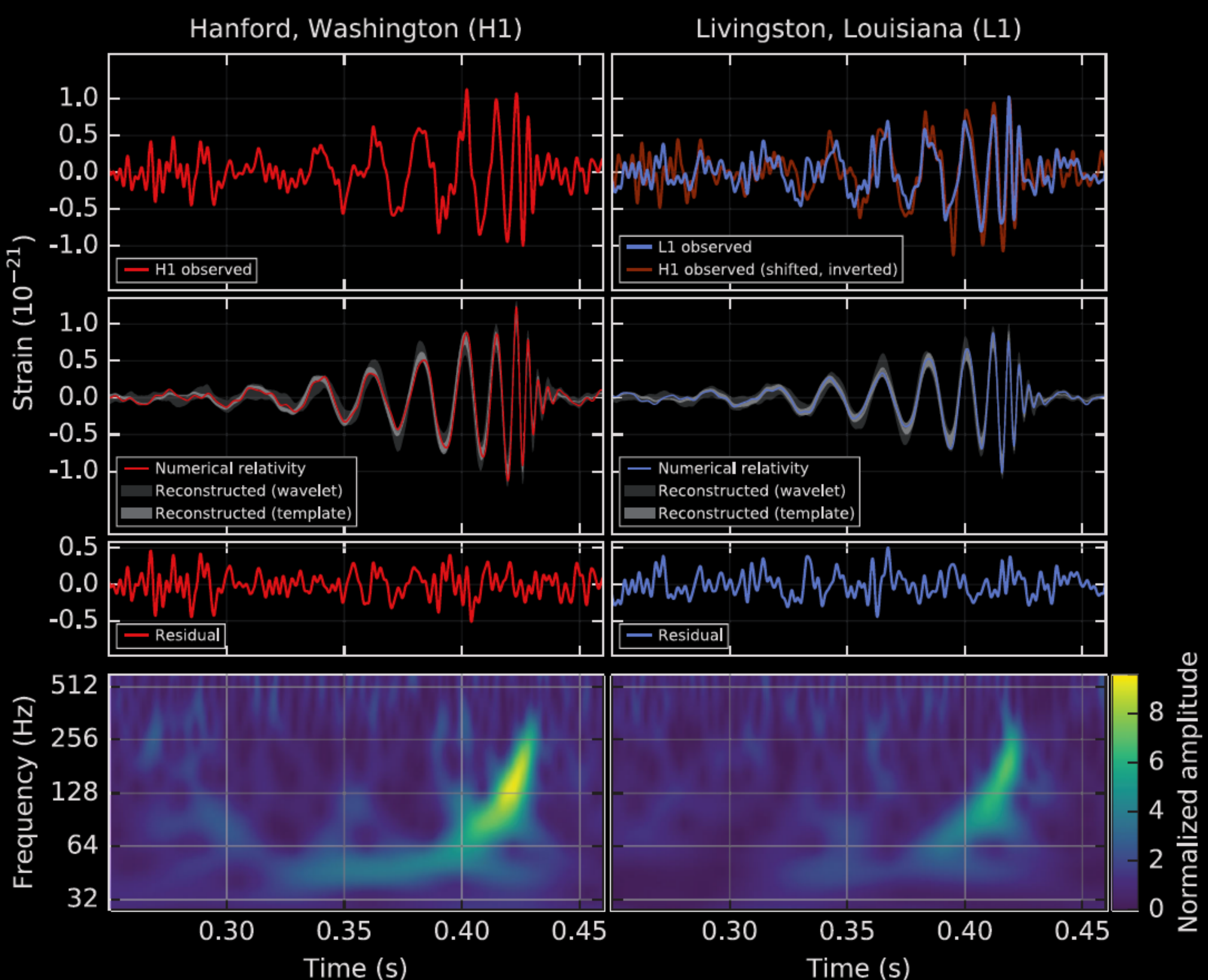
These are bright but highly infrequent events

Now even found in Fly's Eye mode with ASKAP (but not with ATA)

Finding FRBs leans more strongly on FoV than traditional FoV * BW * G^2

Localising FRBs leans on buffer time, primary FoV, and baselines.

Gravitational Wave Events



[Movie]

Where did it come from?

ARTS PAF *Fly's Eye Mode* for Gravitational-wave localisation

[Figure]

But need to physically slew.

Digital pointing + buffer ***much*** more interesting for prompt emission

New science for transients, using AIP

New technologies vastly improve prospects for SKA in:

- Sensitivity & FoV —High redshift FRBs:
  - Probe He (z>2) and H reionization (z>6)
  - Probe w (dark energy equation of state) evolution
- Longer buffering (~ minute)
  - At DM=5000 pc cm^{-3} dispersion is 21s between 1.0 – 0.7 GHz
  - GW-wave triggers have 10s of seconds latency
- Widefield phenomena
  - AIP telescopes can cover entire error region of GWs
  - Prompt emission: AA ; afterglows WBSPF, PAF, AA

Slide partially after JP Macquart 2016

Conclusions

There is a set of excellent pulsar and transient science cases
that is uniquely enabled by
the SKA2-MID (AA/PAF) 's wide field of view.