Aperture Arrays for Pulsars

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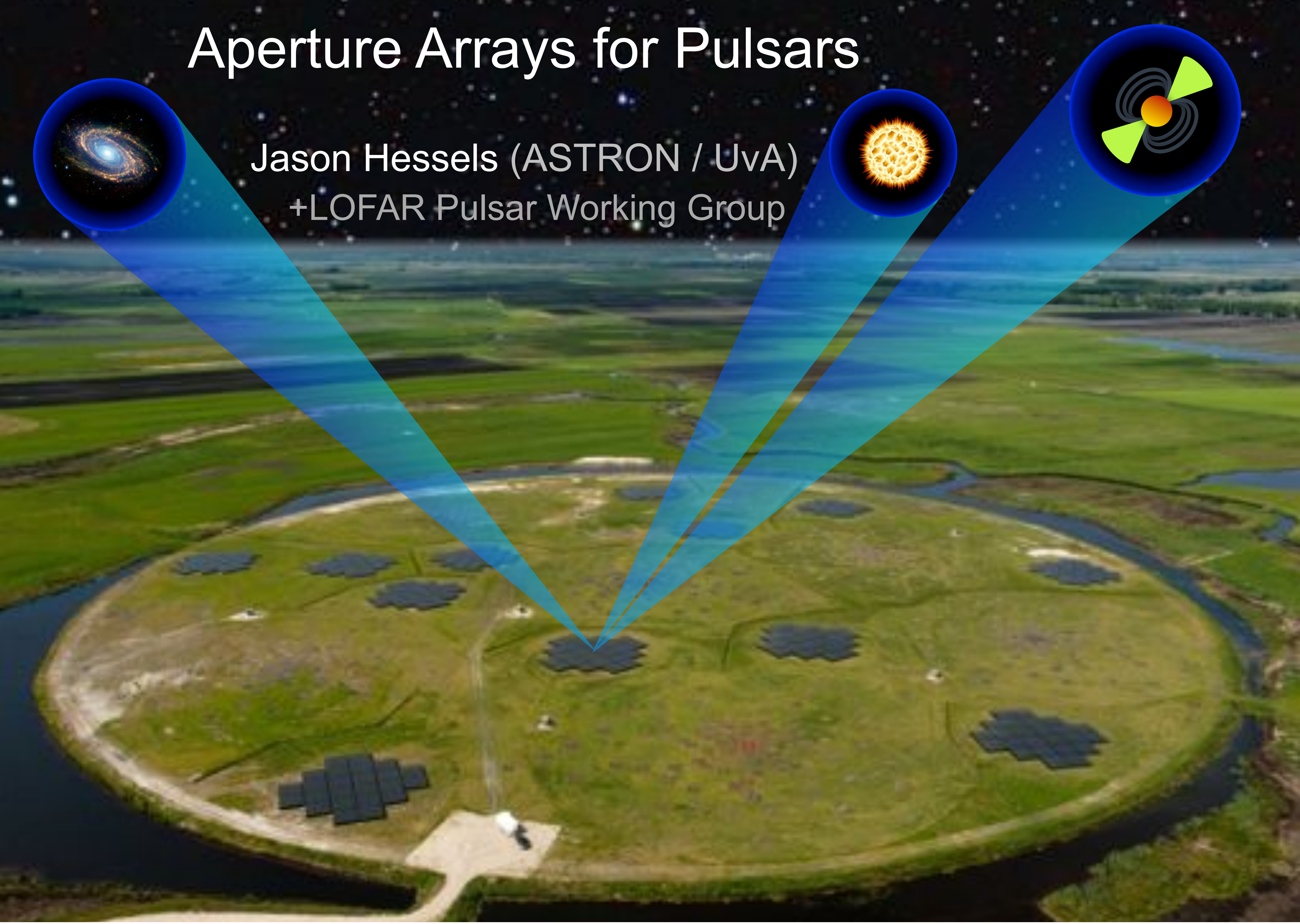
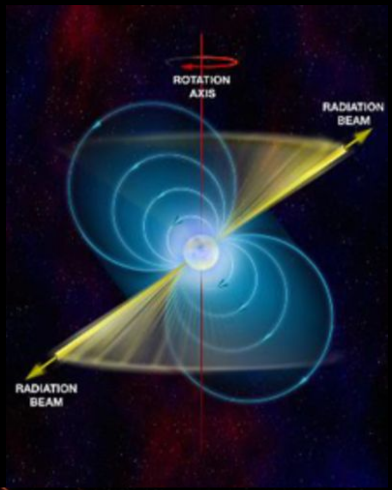
+LOFAR Pulsar Working Group



Pulsar Science with AAs



- Pulsar surveys at mid to high Galactic latitudes (0.5-1.4GHz is the sweet spot for this, but AA-low would also be very powerful).

- Pulsar timing and monitoring (e.g. glitches, gravitational waves).

- Wide-band studies of the pulsar emission mechanism.

- Searches for intermittent pulsars, rotating radio transients, and extra-galactic fast transients (large FoV x T factor).

AA for Pulsars

Technical Requirements

- A/Tsys is critical for these weak (S1400 < 0.1mJy) sources.

- Large FoV: surveys and monitoring of multiple sources.

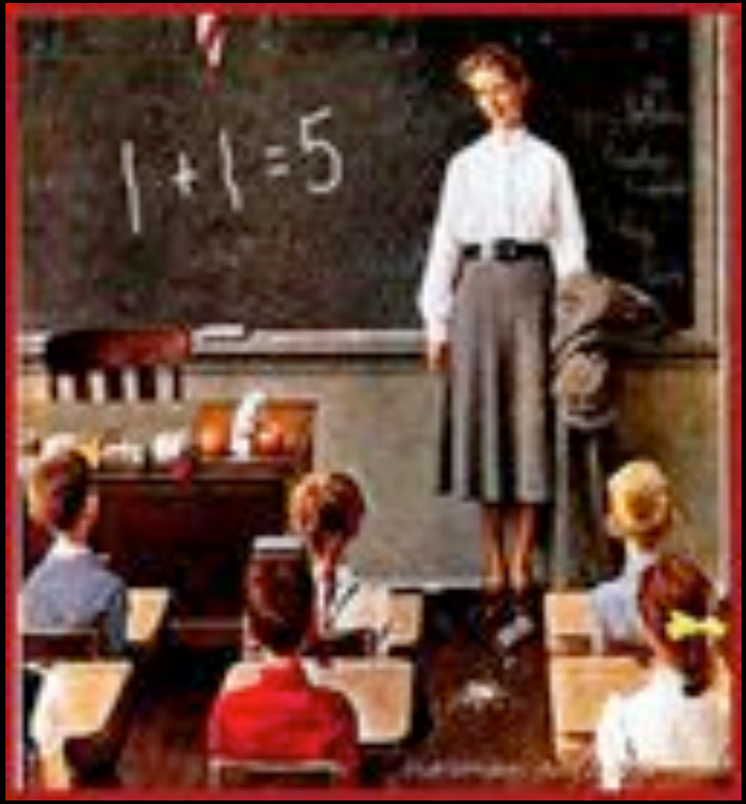
- Multiple, independent FoVs for anti-coincidence (e.g. RFI rejection in a survey), calibration, and to get more time on sources that aren't sensitivity limited.

- Sub-arrays for even larger FoV, frequency coverage, and monitoring more sources simultaneously.

- *Potential* for very short slew time.

AA for Pulsars

The Drawbacks

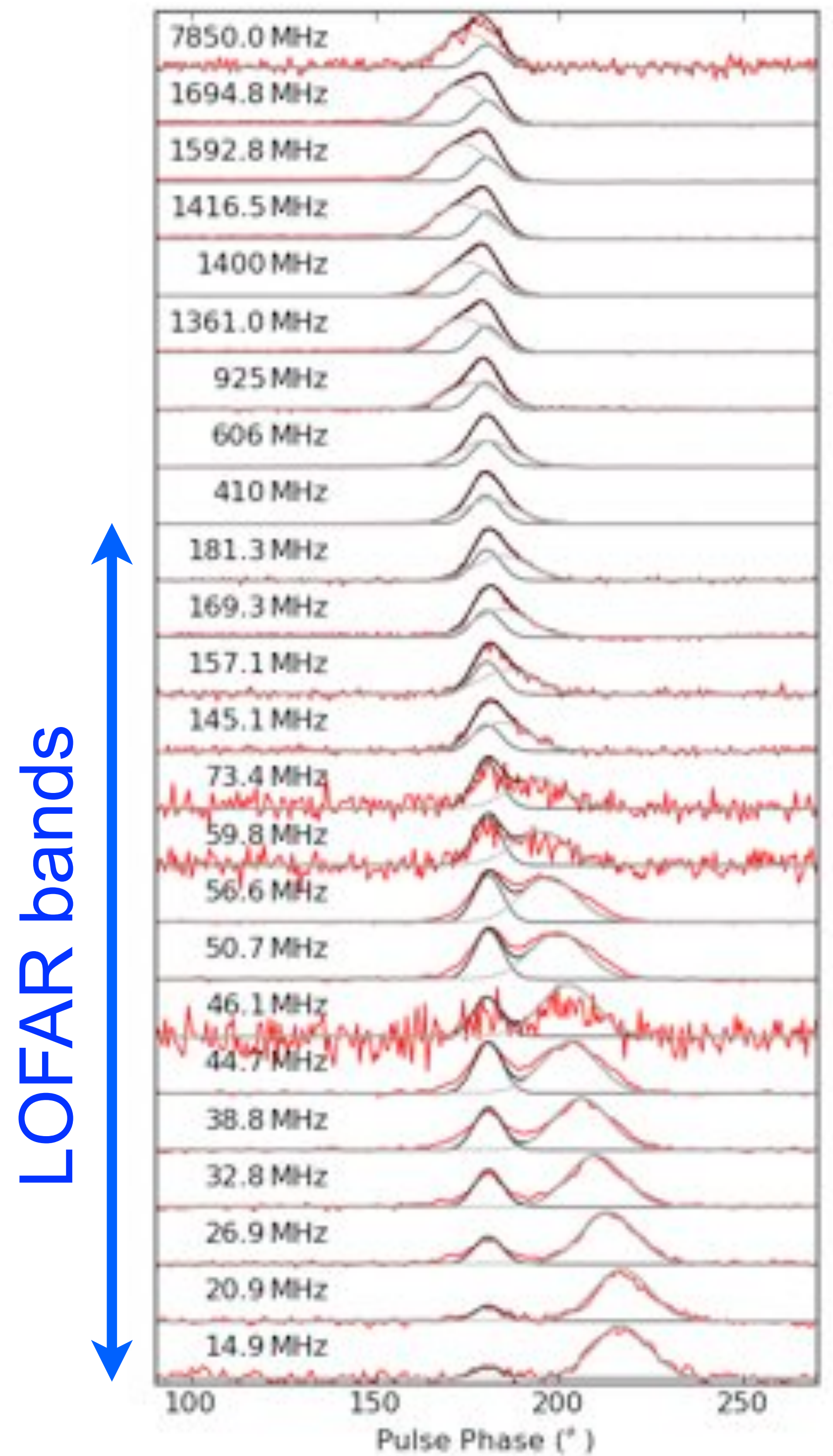


- Large N number of stations and elements means some part of the collecting area is always broken.
- Need to know what’s broken.
- Beam-formed modes require online RFI removal.
- Can’t do correct these problems post-facto.

http://www.astron.nl/~heald/lofarStatusMap.html

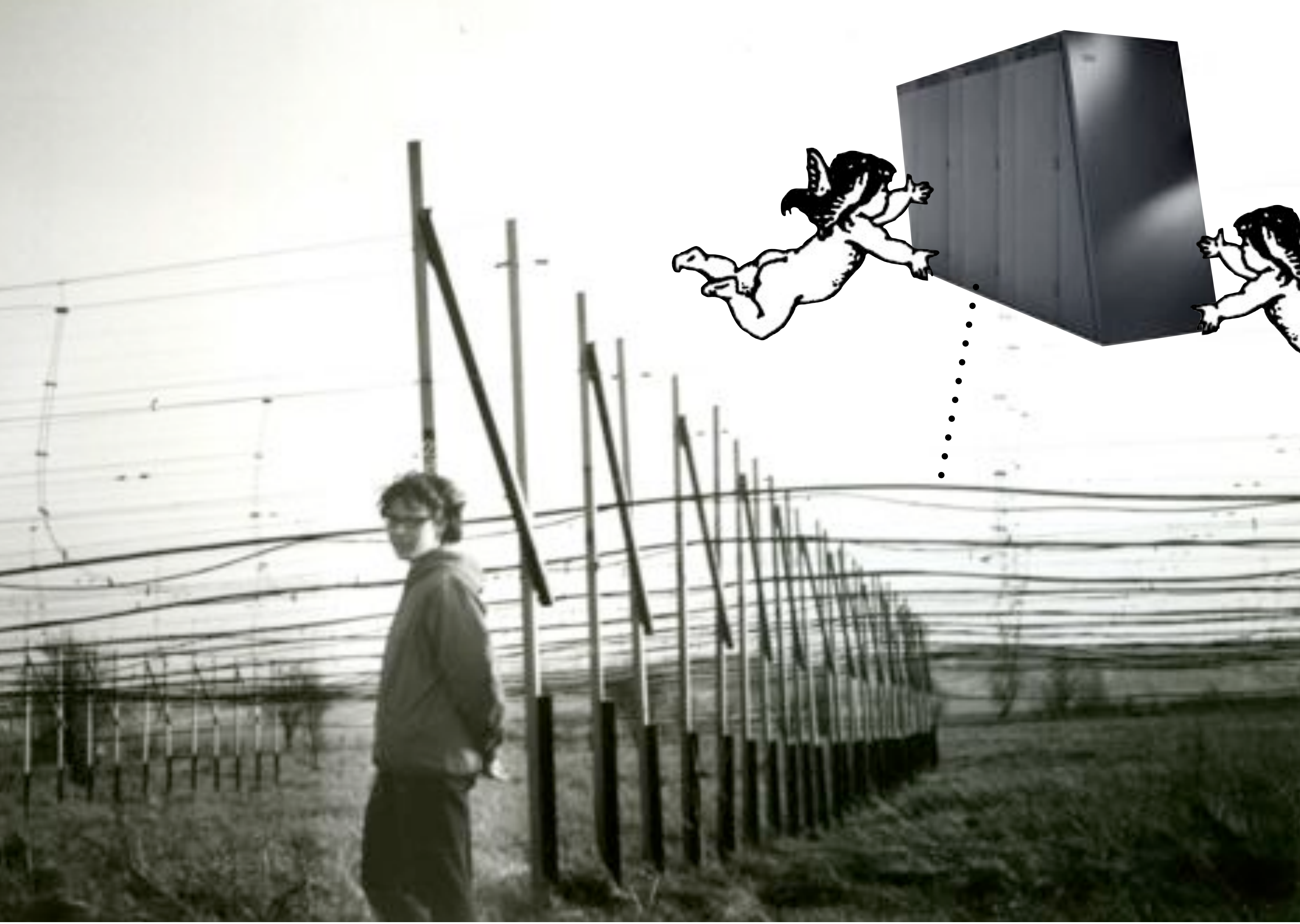
B0809+74

Fitting Pulse Profile Evolution



- Two Gaussians with frequency dependent amplitudes, widths, and separation.
- Simultaneous, so no DM variation.
- Nice demonstration of sub-arraying and single-station use.

Hassall et al., submitted



Flexible Beam-forming

(sparse aperture array)

Credit: van Leeuwen

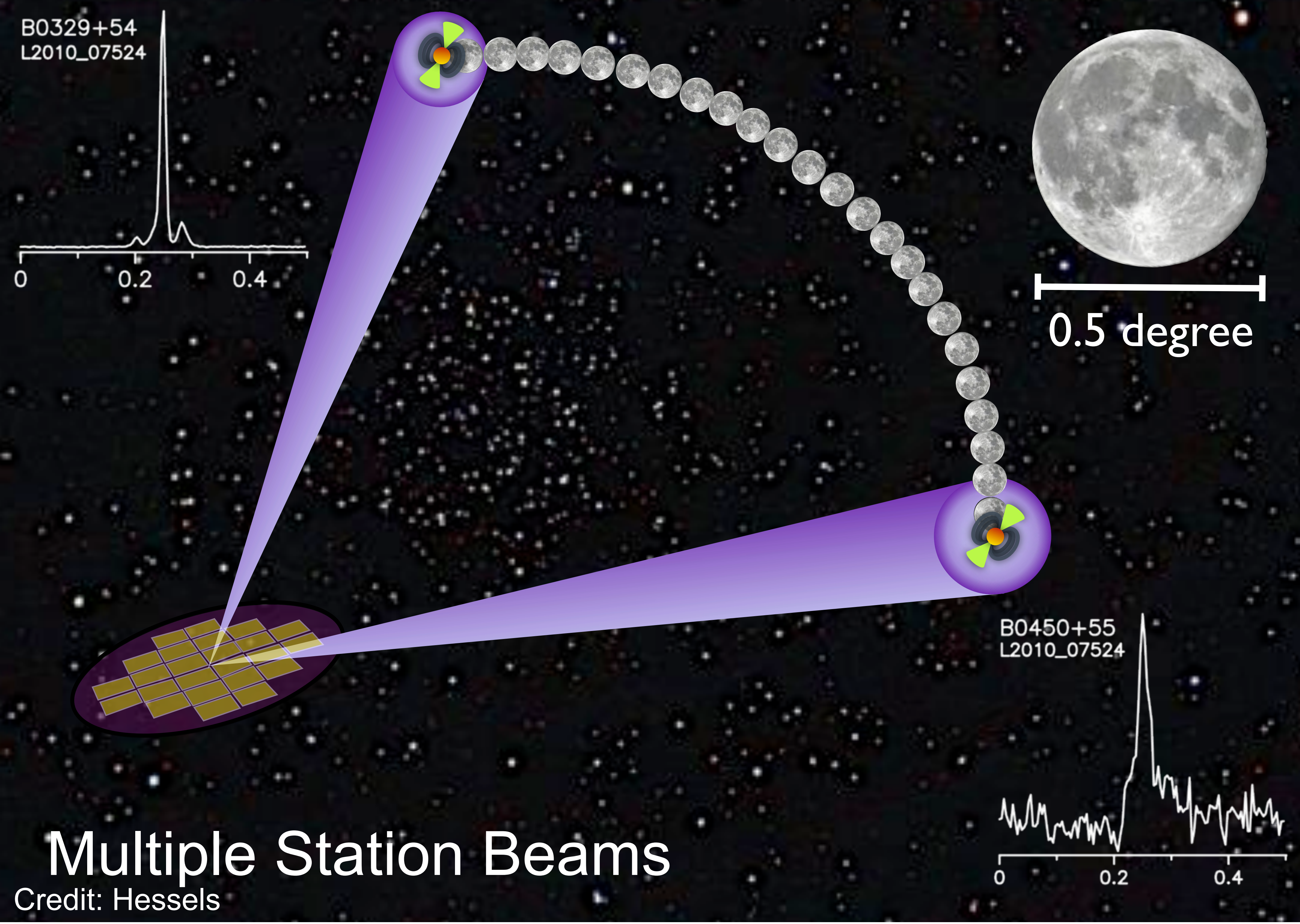
Element beam | Stations beam(s) | Tied-array beam(s)

This is driving the development of beam-formed modes, of which tens of different sub-modes are possible

Beam-formed modes ...there are many possible.

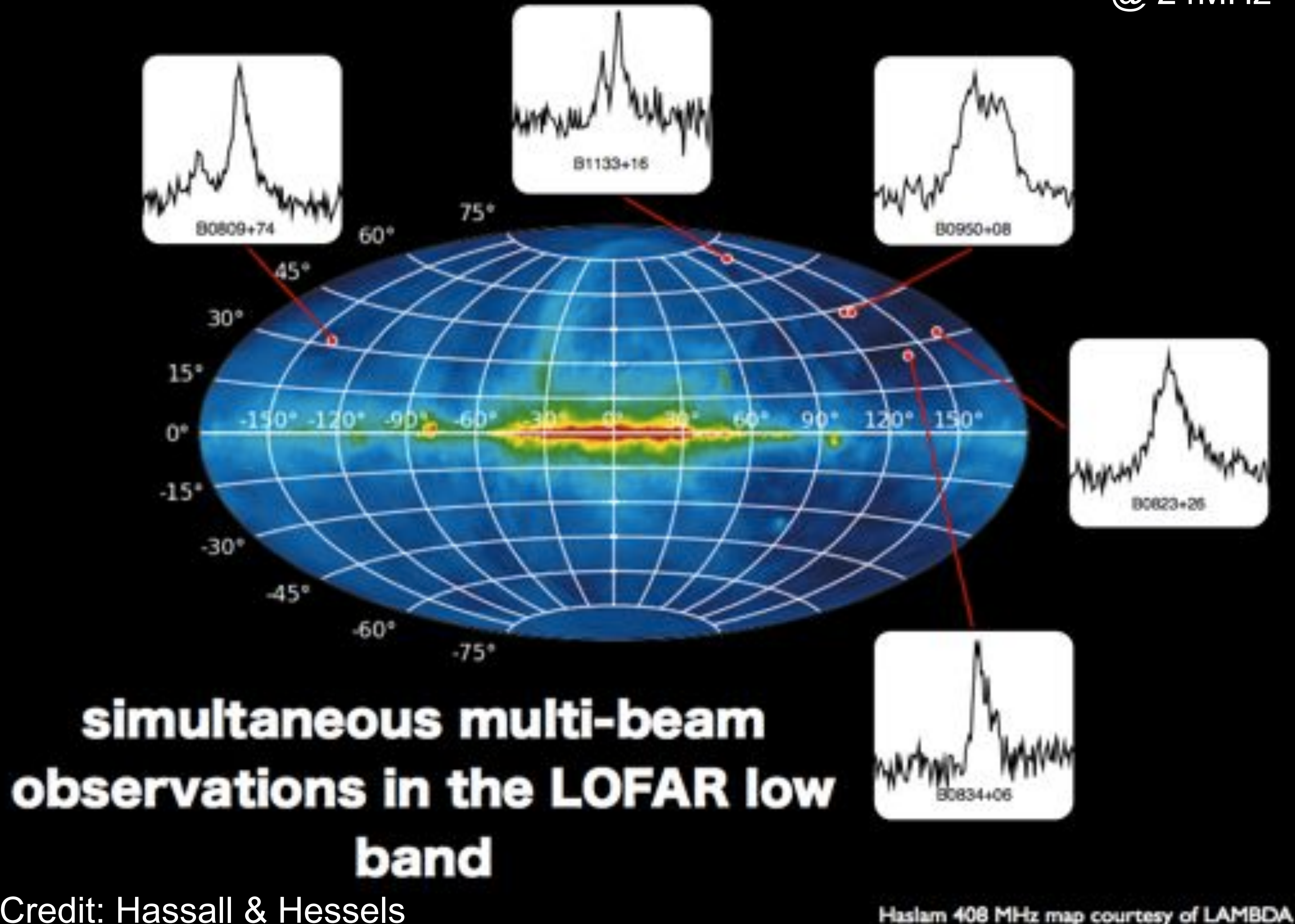
Mode	Description	Data Rate	FoV (sq. deg.)	Res. (deg.)	Sens. (norm.)
Incoherent (par. imaging)	Stations added without proper phase correction.	2-250 GB/hr	2,5	2	6,0
Tied-array	Stations add... prope...			0,03	36,0
Single Station	For p... tim... s... requ...	...B/hr	12,5	2	1,0
Superstation	Interesting balance of sensitivity and FoV.	Up to 23TB/hr	9,0	0,2	12,0
Fly's Eye	Maximize total FoV for bright transient survey.	Up to 8TB/hr	450	2	1,0

Flexible to match different science goals!

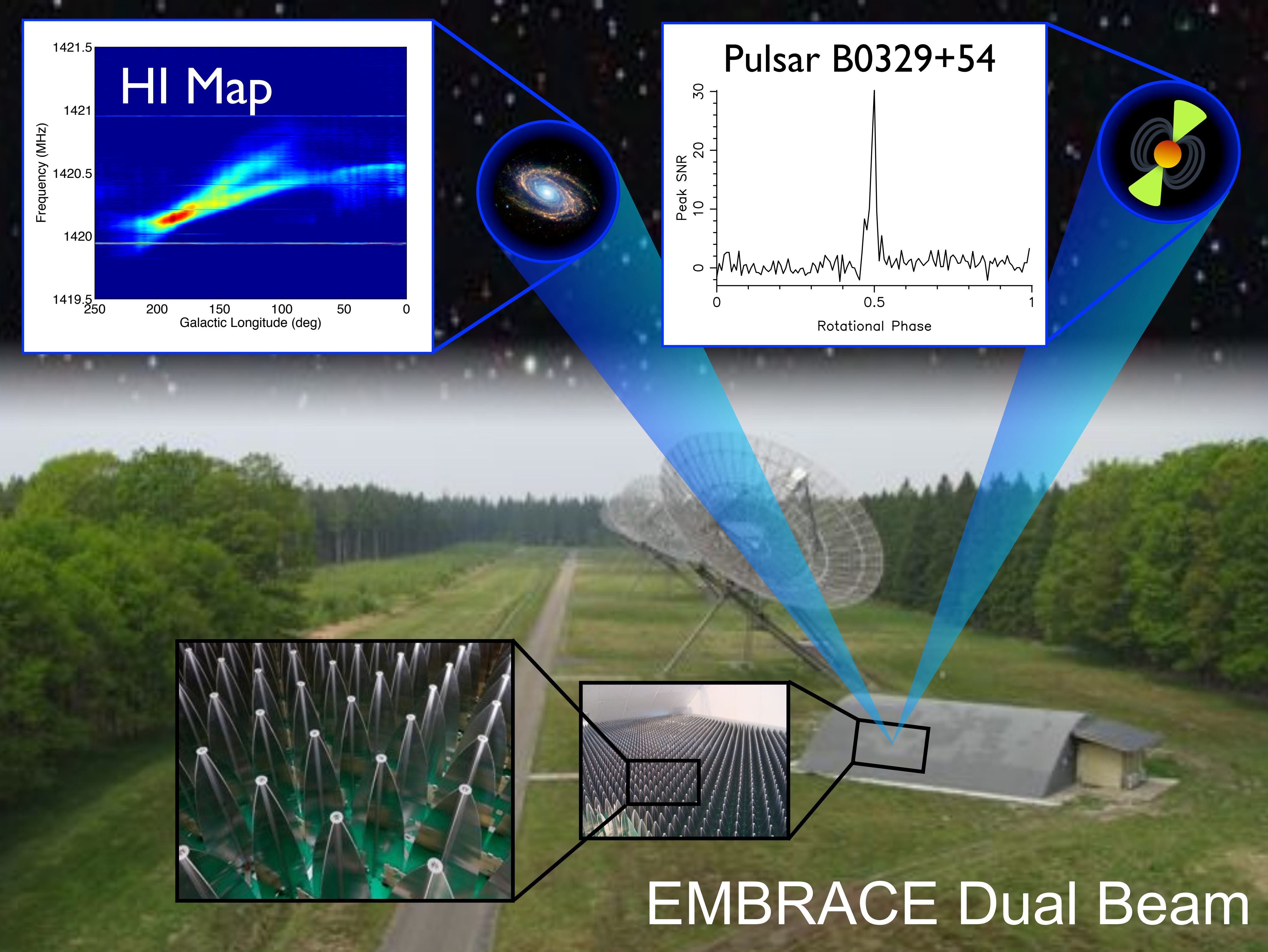

B0329+54
L2010_07524
0
0.2
0.4
0.5 degree
B0450+55
L2010_07524
0
0.2
0.4
Multiple Station Beams
Credit: Hessels

Multiple, widely separated FoVs

@ 24MHz



Credit: Hassall & Hessels


HI Map
1421.5
1421
1420.5
1420
1419.5
Frequency (MHz)
250
200
150
100
50
0
Galactic Longitude (deg)
Pulsar B0329+54
Peak SNR
0
10
20
30
0
0.5
1
Rotational Phase
EMBRACE Dual Beam

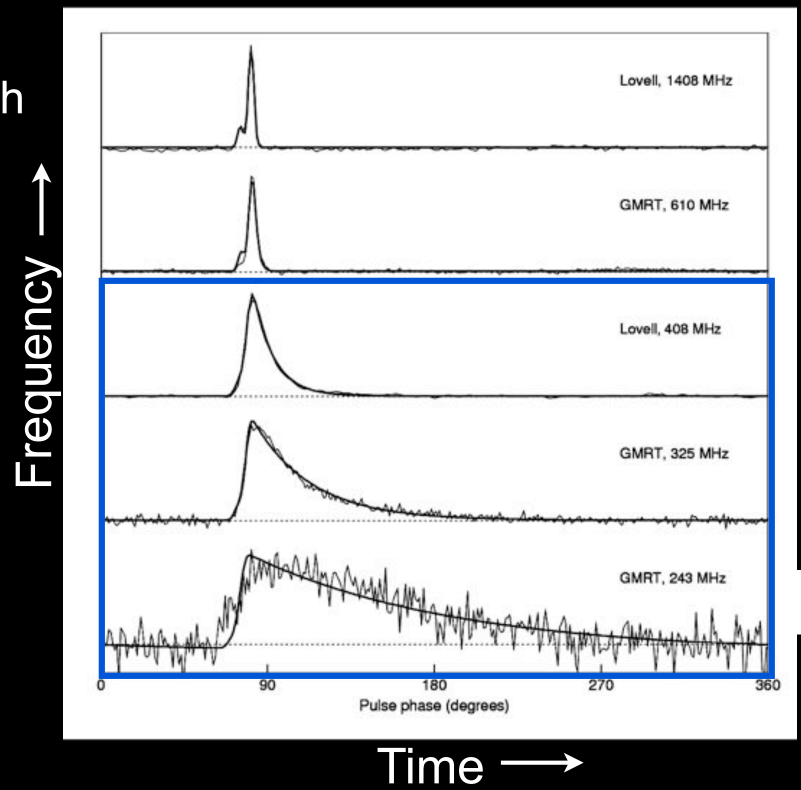
Propagation effects in the ionized interstellar medium

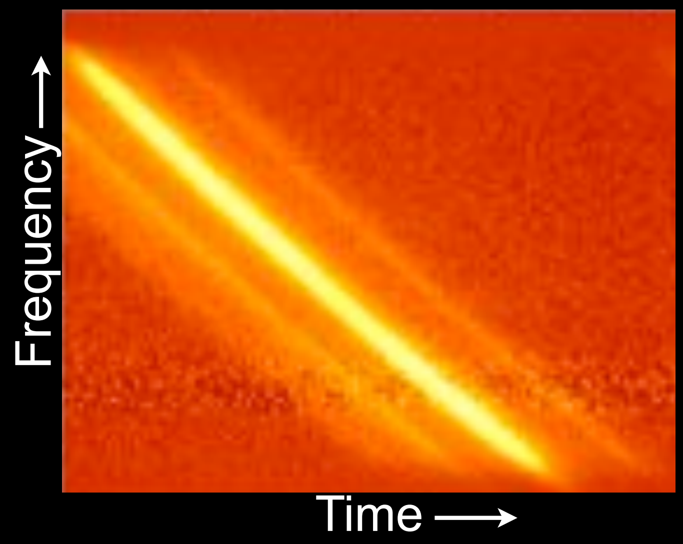
$$I(t) = g_r g_d S(t) * h_{\rm DM}(t) * h_d(t) * h_{\rm Rx}(t) + N(t)$$

Scattering: multi-path propagation

Dispersion: freq. dependent arrival time

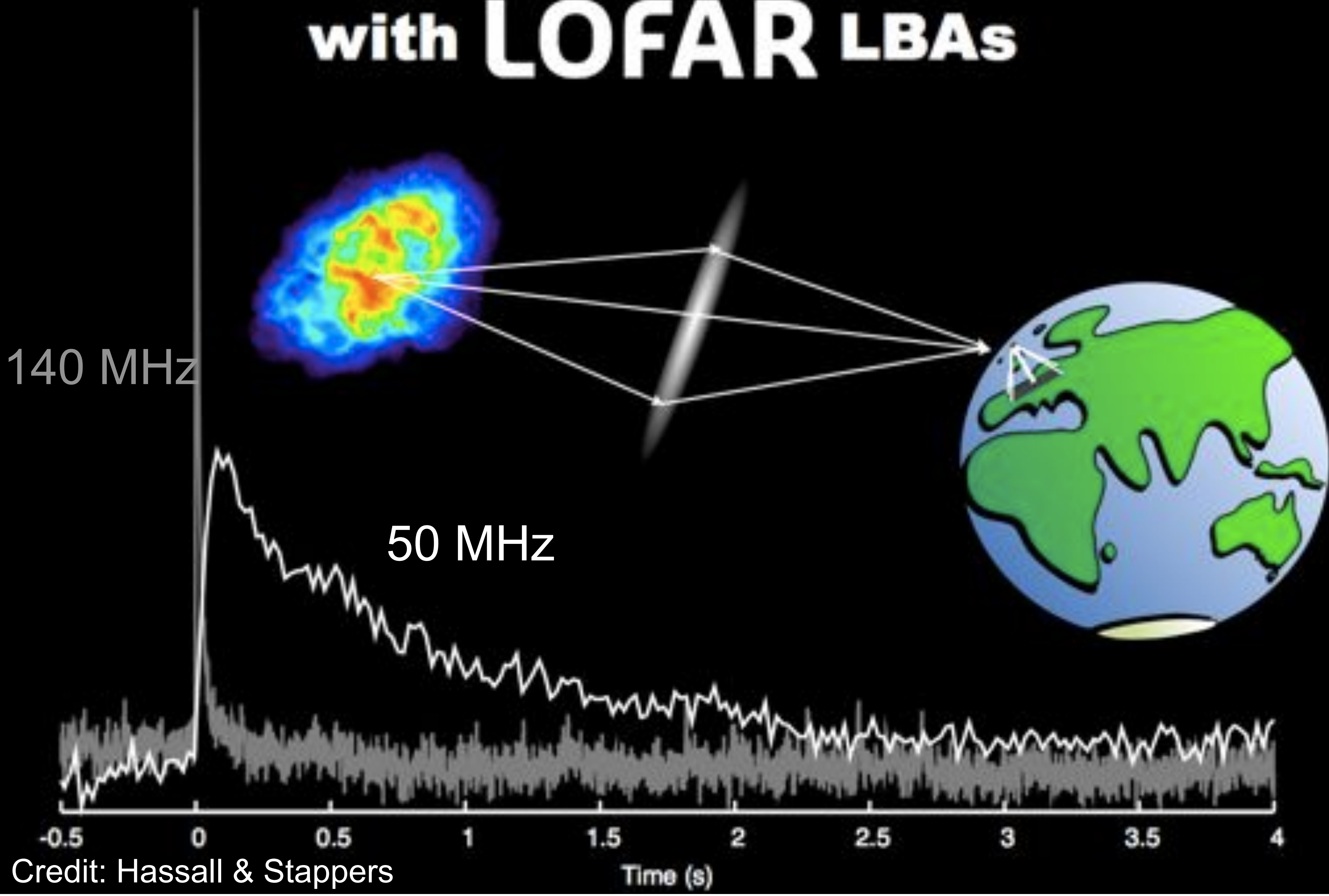
Scintillation: const./dest. interference





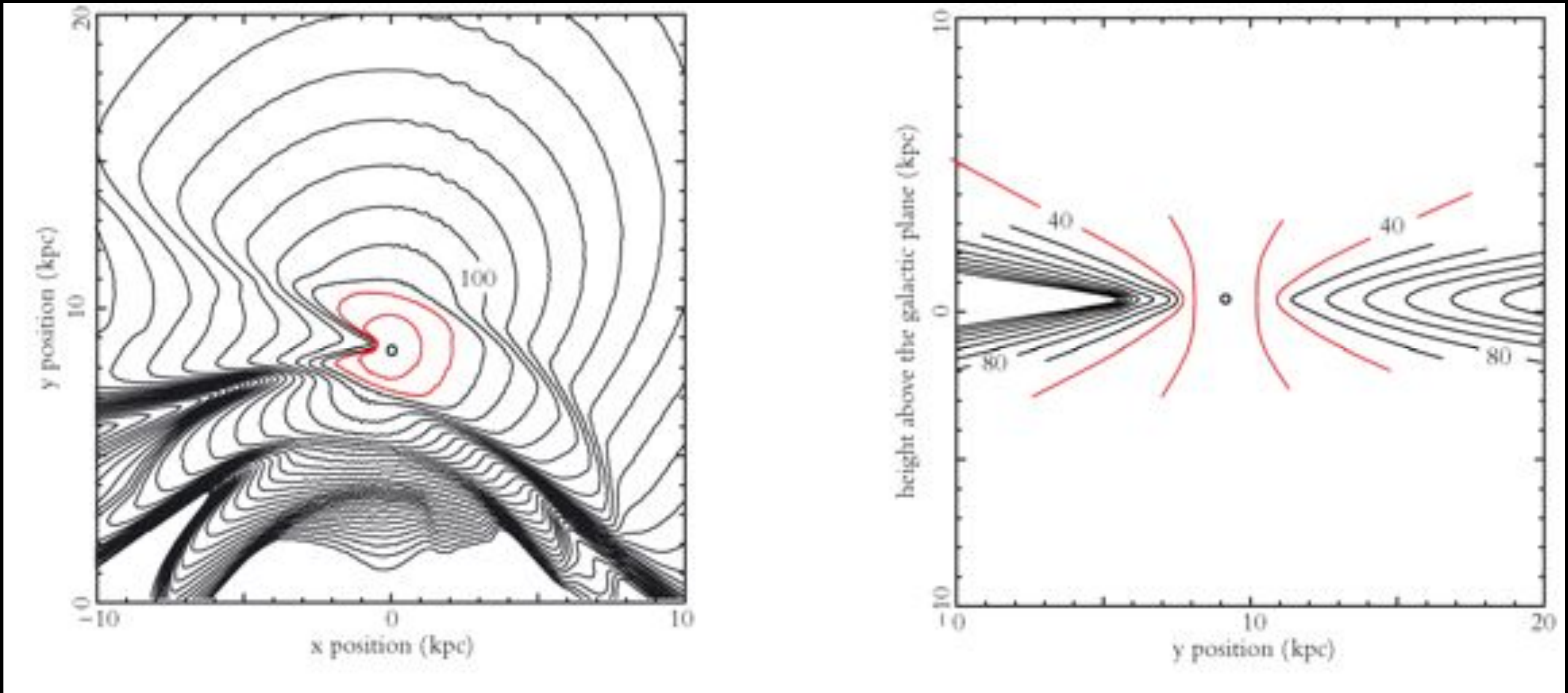
Not pure evil: show that the signal is astronomical and can be used to study the ISM

Detection of Crab Giant Pulses with LOFAR LBAs



Credit: Hassall & Stappers

Pulsar/Fast Transient Survey
the case for higher frequencies

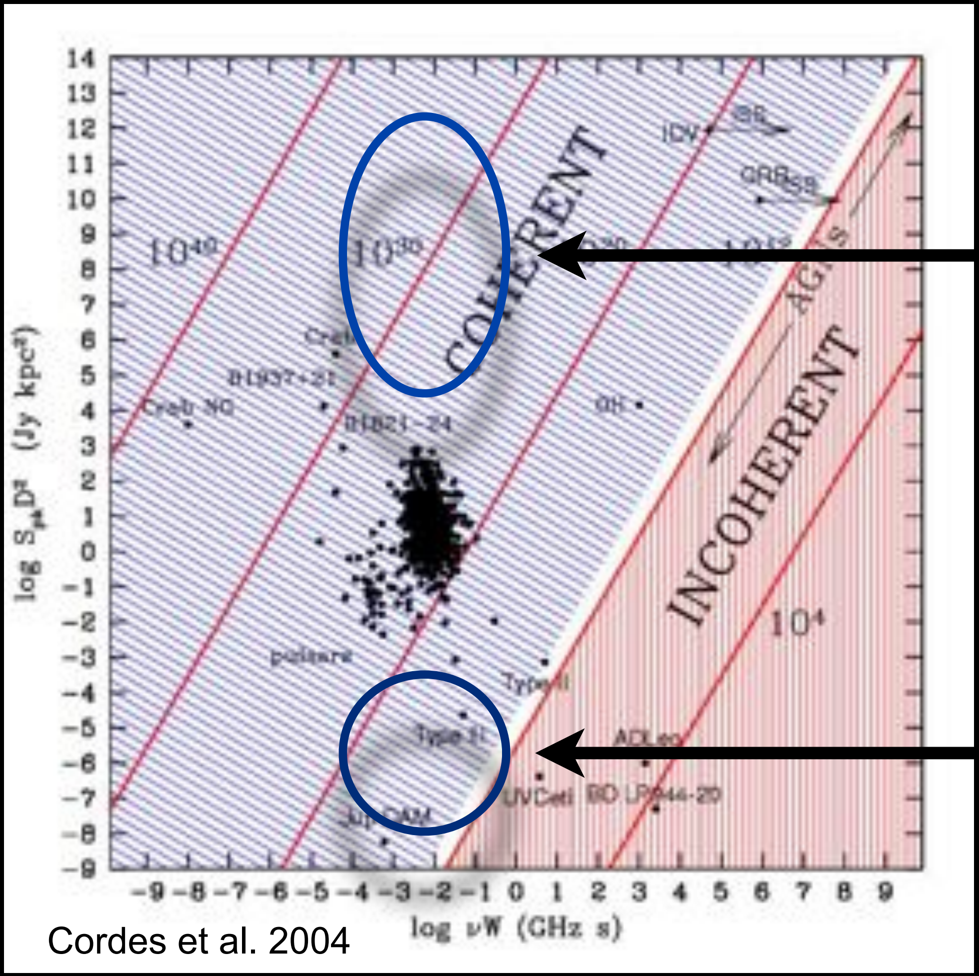


Credit: van Leeuwen

At ~100 MHz, one is limited to d < 2kpc for millisecond bursts in Galaxy.

SKA pulsar surveys would benefit from any system operating > 300MHz

Transient Parameter Space



Large FoV for rare, bright events

Large instantaneous sensitivity for weak source classes

Survey for sources in the known area of parameter space, but maintain good sensitivity for serendipitous discoveries.

On-going LOFAR Pilot Pulsar Surveys

- Incoherent beam(s): large FoV
- Tied-array beam(s): high sensitivity
- Online coherent dedispersion: highest time resolution, e.g. for millisecond pulsars.

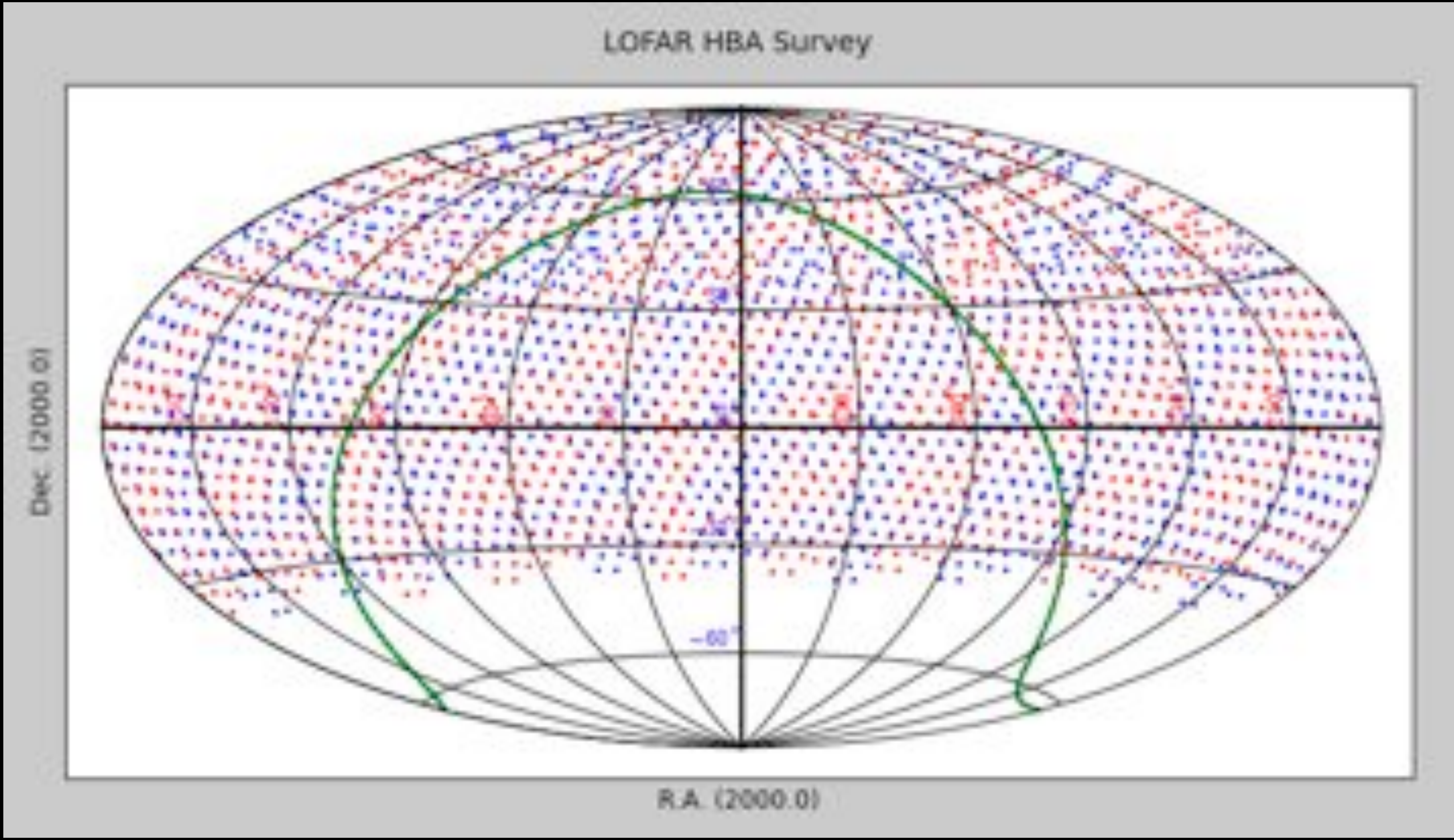
Important input for Phase I SKA pulsar surveys

LOFAR Pilot Pulsar Survey (LPPS)

- Incoherent beams - all avail. (~20) stations
- 7 beams of 7 MHz each and 0.65ms samp.
- 57 minutes per pointing (82GB)
- ~167 sq. deg. total FoV per pointing
- ~250 pointings taken during Christmas 2010
- Data being processed on "Hydra" at the University of Manchester.

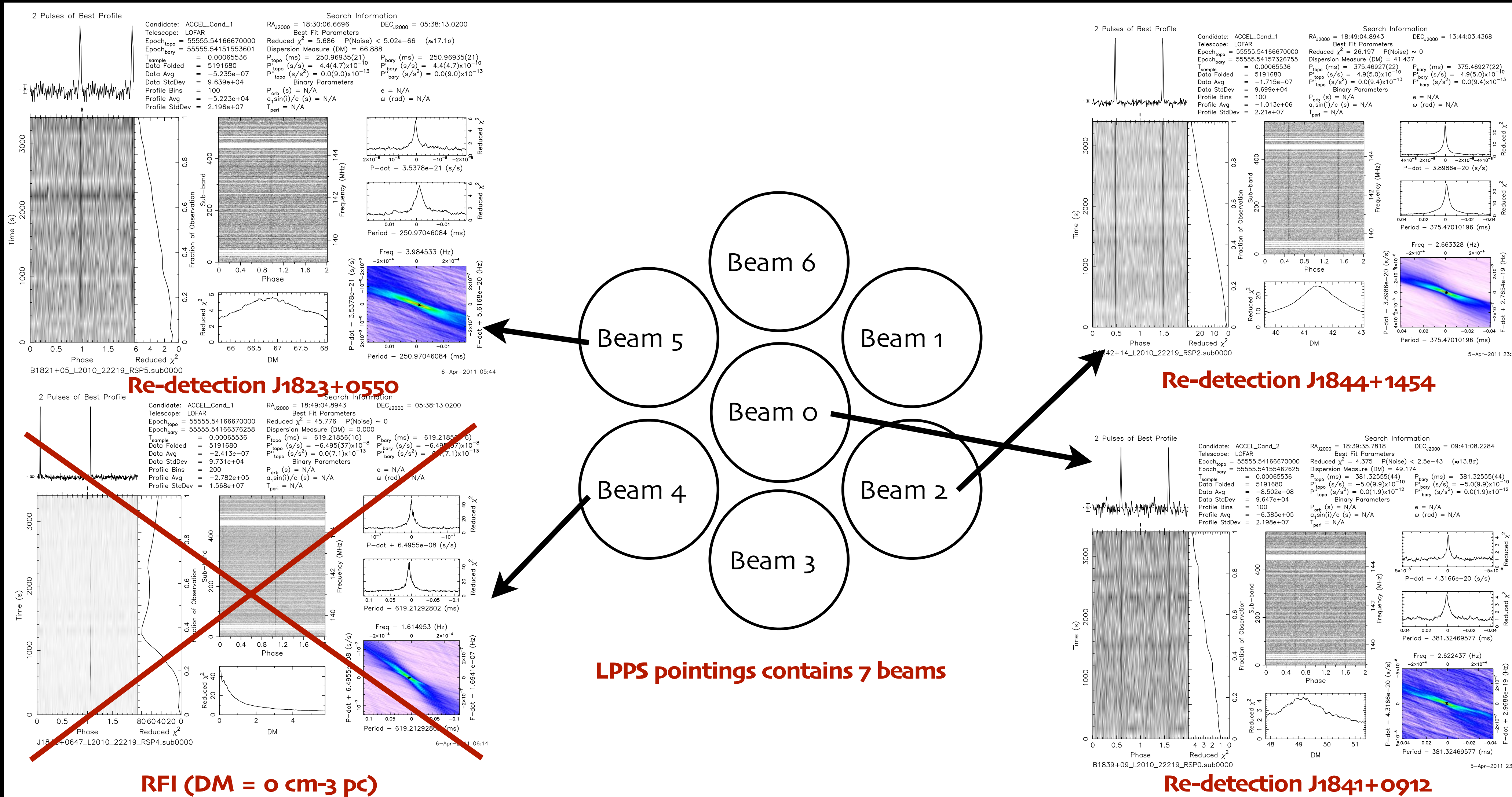
SKA could use a similar mode to find pulsars <u>fast</u>

LOFAR Pilot Pulsar Survey (LPPS)



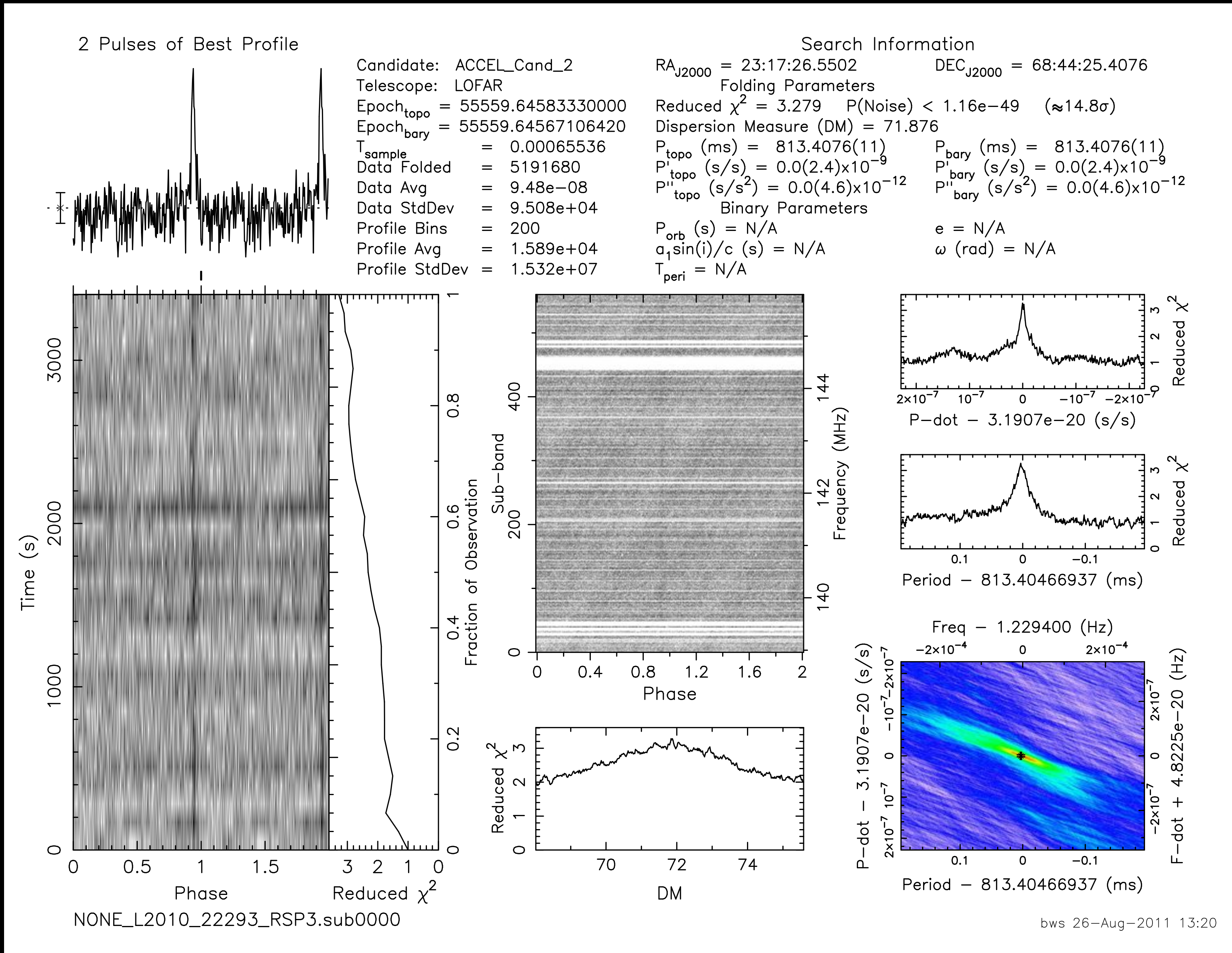
Only ~400 7-beam pointings > -35 deg DEC

LOFAR Pilot Pulsar Survey (LPPS)



Courtesy: Thijs Coenen

Independent Discovery of PSR J2317+68!



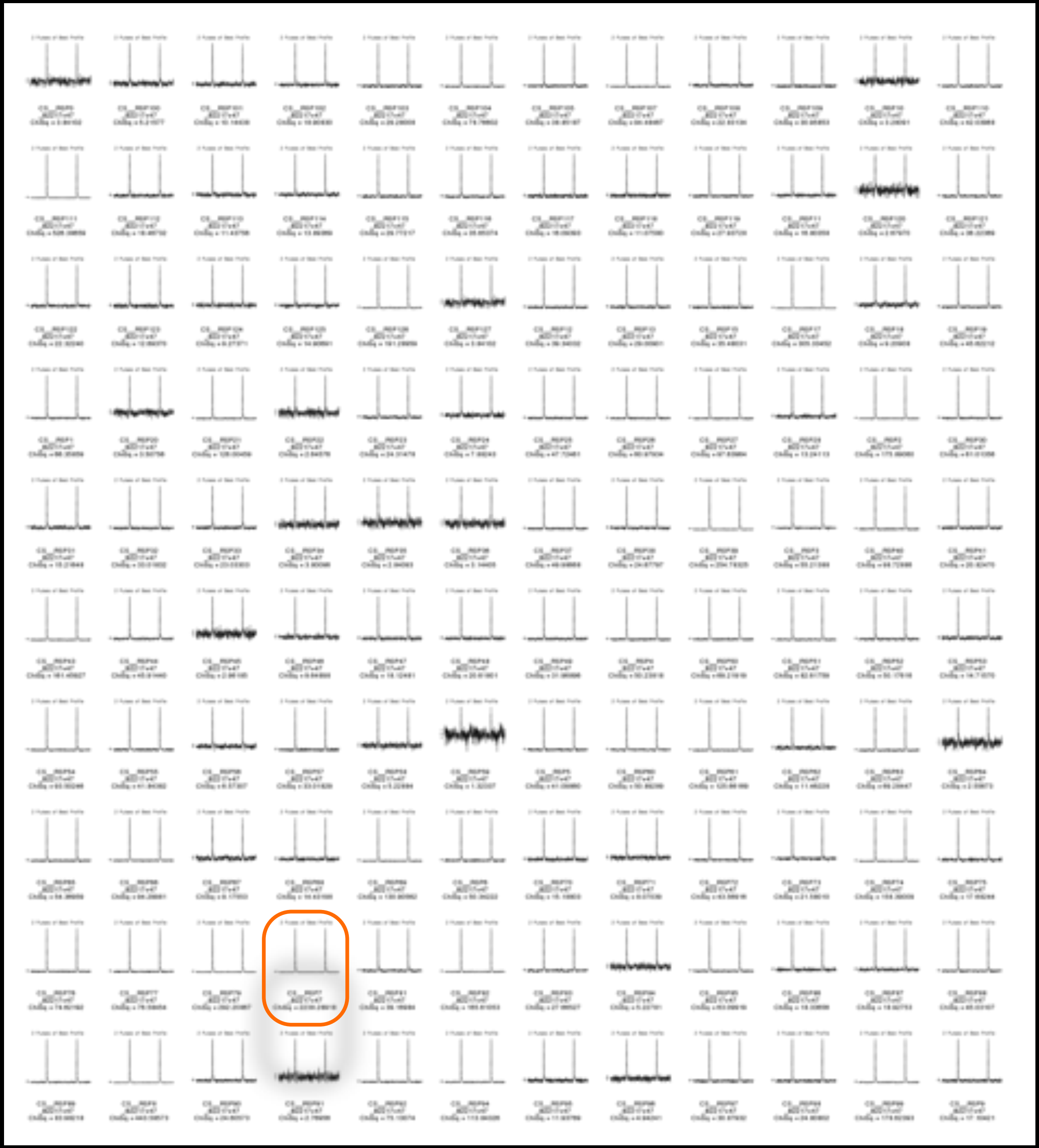
Credit: Green, Hassall & Stappers

LOFAR Tied-Array Survey (LOTAS)

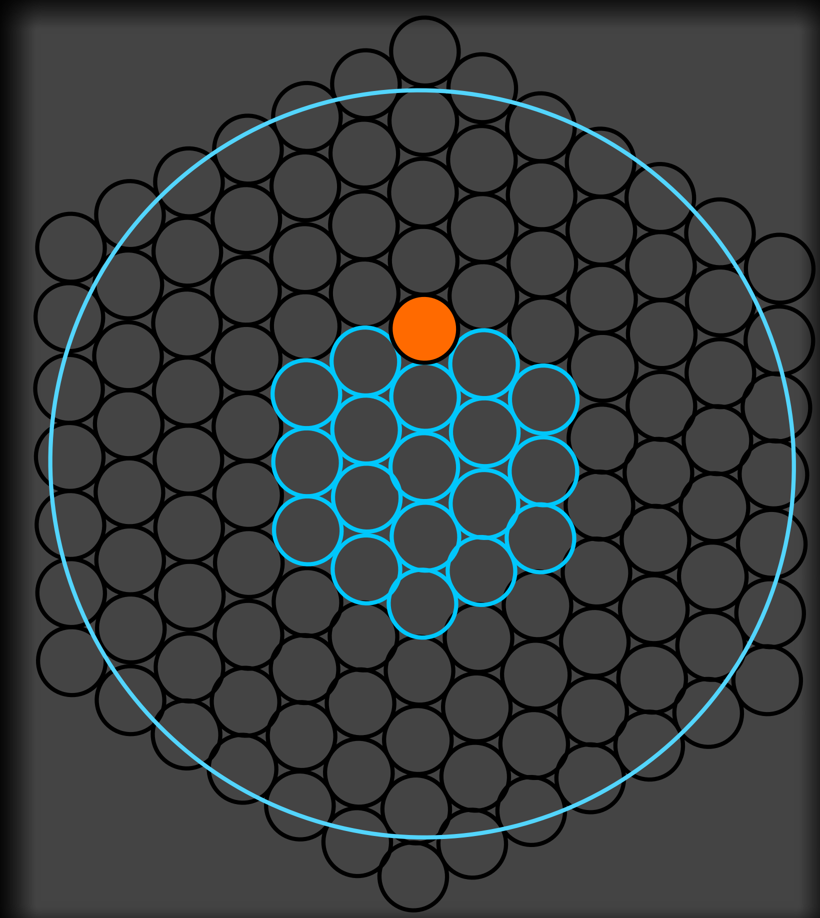
- Tied-array (coherent) beams (Superterp)
- 19 beams with full 48MHz and 1.3ms samp.
- 17 minutes per pointing (246GB)
- ~3.7 sq. deg. FoV per pointing
- ~200 pointings taken from May 11-15th
- Increase in sensitivity ~10 x LPPS
- Less affected by RFI?

SKA could use a similar mode for a deep all-sky pulsar survey

LOFAR 127-beam Tied-Array!!



Shifted 1 deg south

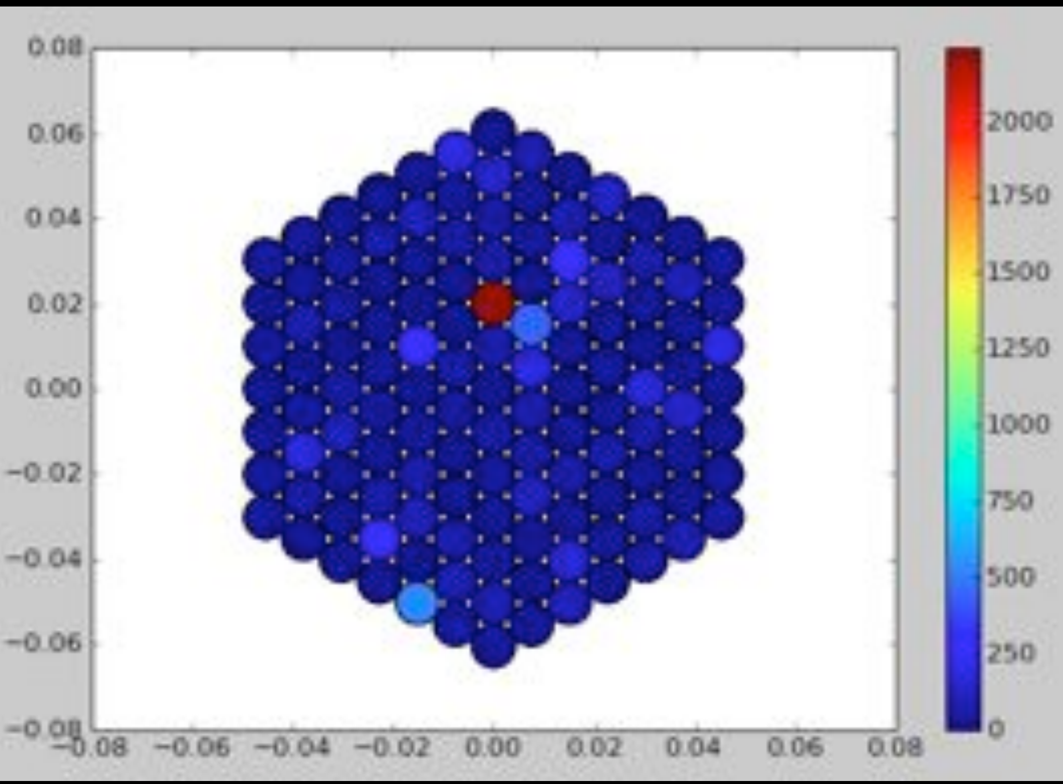


Pulsar is 10x brighter in the correct beam (beam 7)!

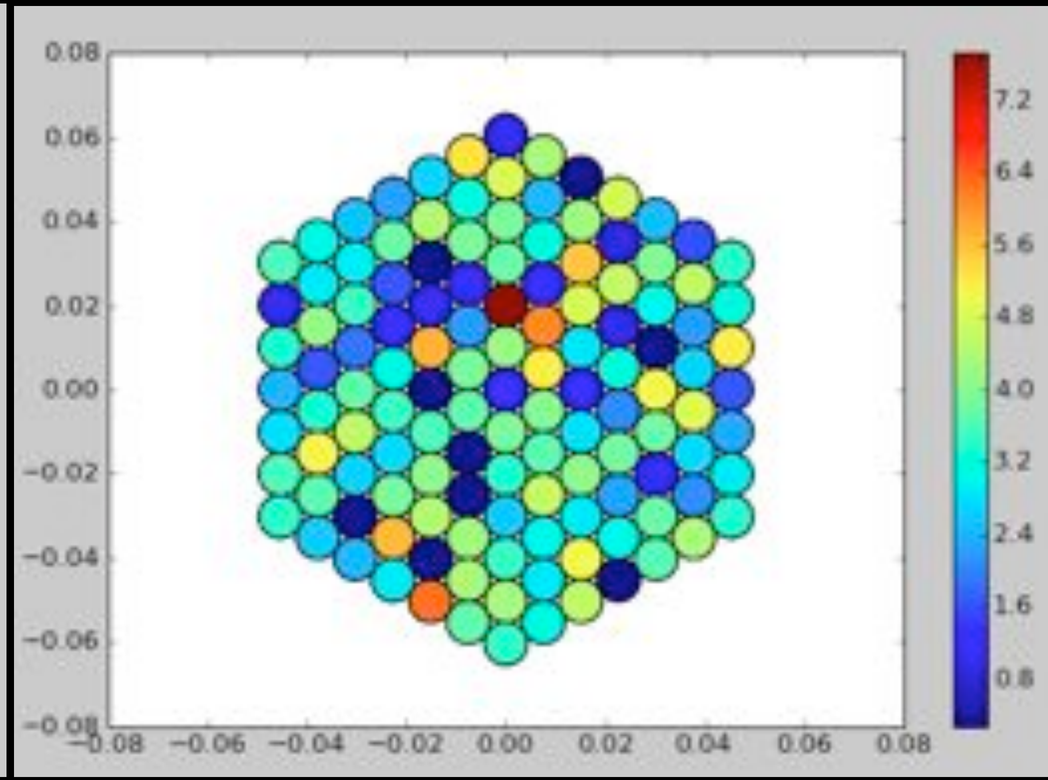
Credit: Alexov & Hessels

LOFAR 127-beam Tied-Array!!

S/N in each beam



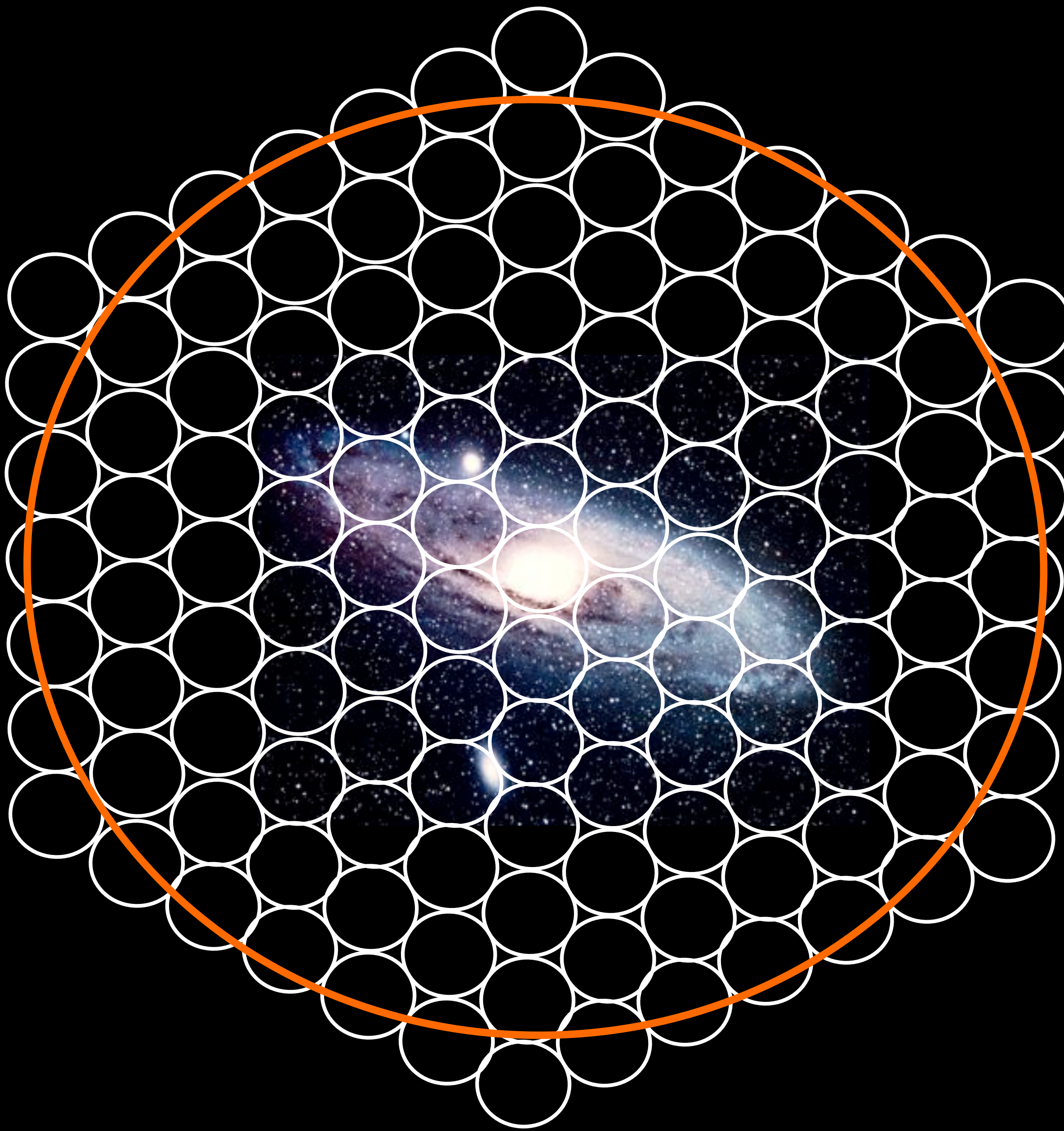
Linear Scaling

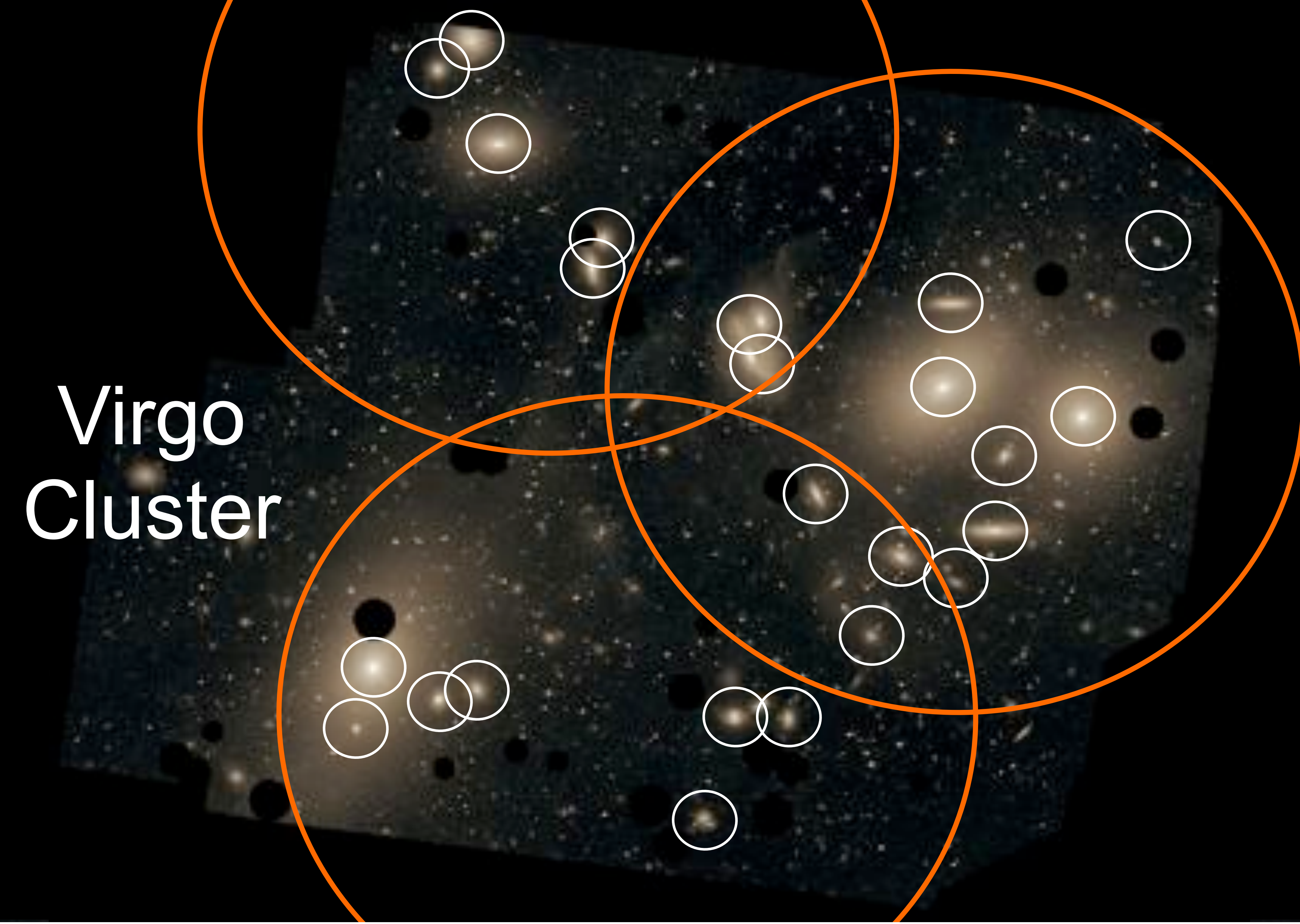


Log Scaling

Credit: Hessels & Alexov

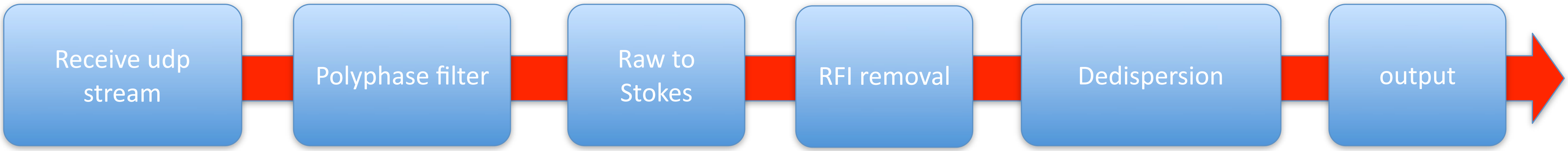
Andromeda



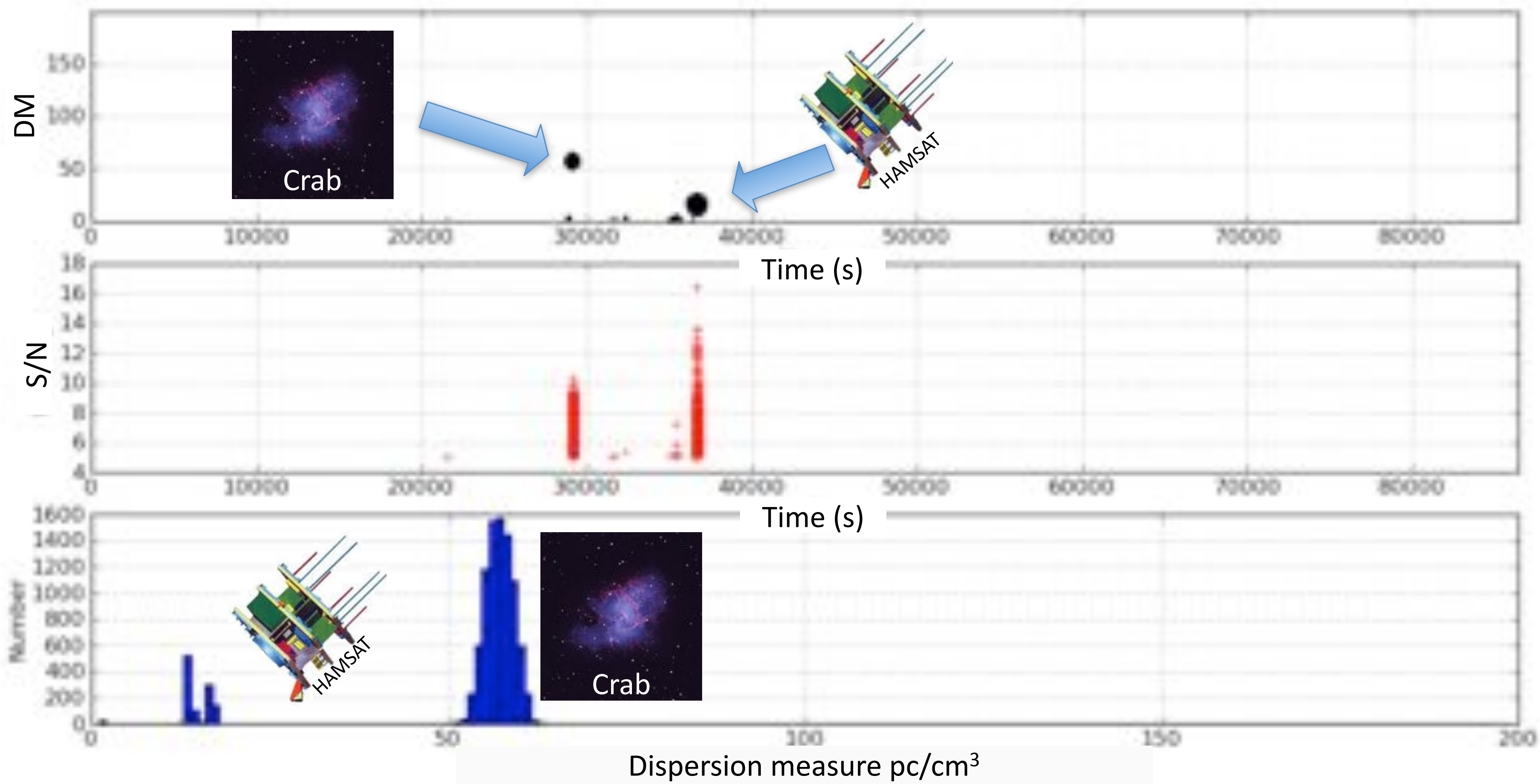

Virgo
Cluster

ARTEMIS

- Working prototype for non-image processing
- Real-time searches for Individual Radio Pulses using CPU/GPU
- Dedispersion over 4000 DMs per beam in real time with GPUs
- Pilot survey 1: 6-8 beams tracking circumpolar targets
- Pilot survey 2: 6 beams fixed on the meridian from 8º to 28º dec



Pipeline diagnostic plot from Pilot survey – daily summary from one of six beams

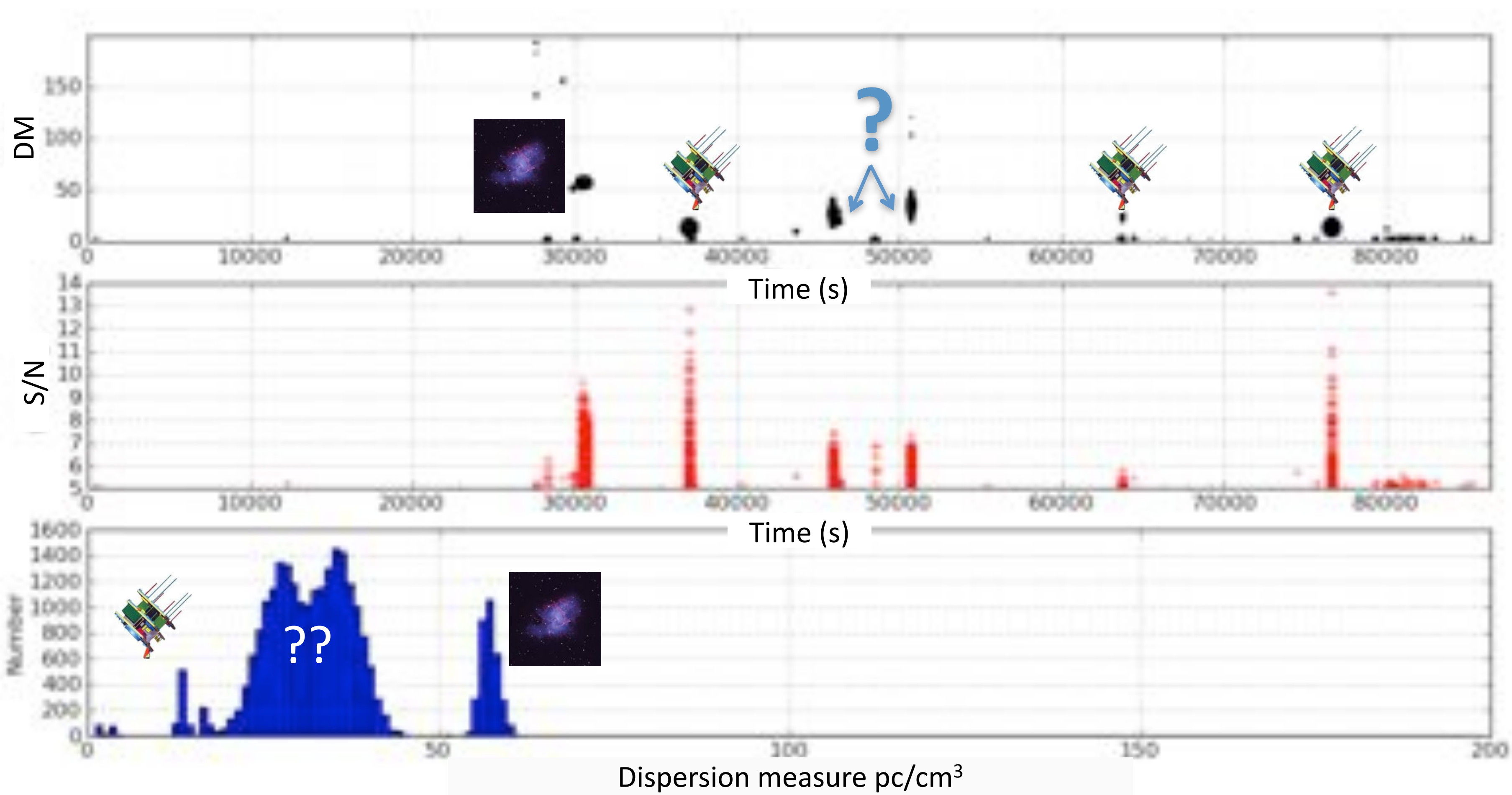


Aris Karastergiou (aris@astro.ox.ac.uk)

- Performed on 800 mbps streams
- Each node has: 12 Xeon CPU cores + 1 NVIDIA M2050 (or GTX)
- DM processing is ~10x better than real time
- RFI rejection performing well in very contaminated environment

Detecting known sources of dispersed pulses including pulsars and frequency swept radio emitters (HAMSAT).

Anticoincidence experiments with Effelsberg + Nancay will reveal nature of enigmatic detections



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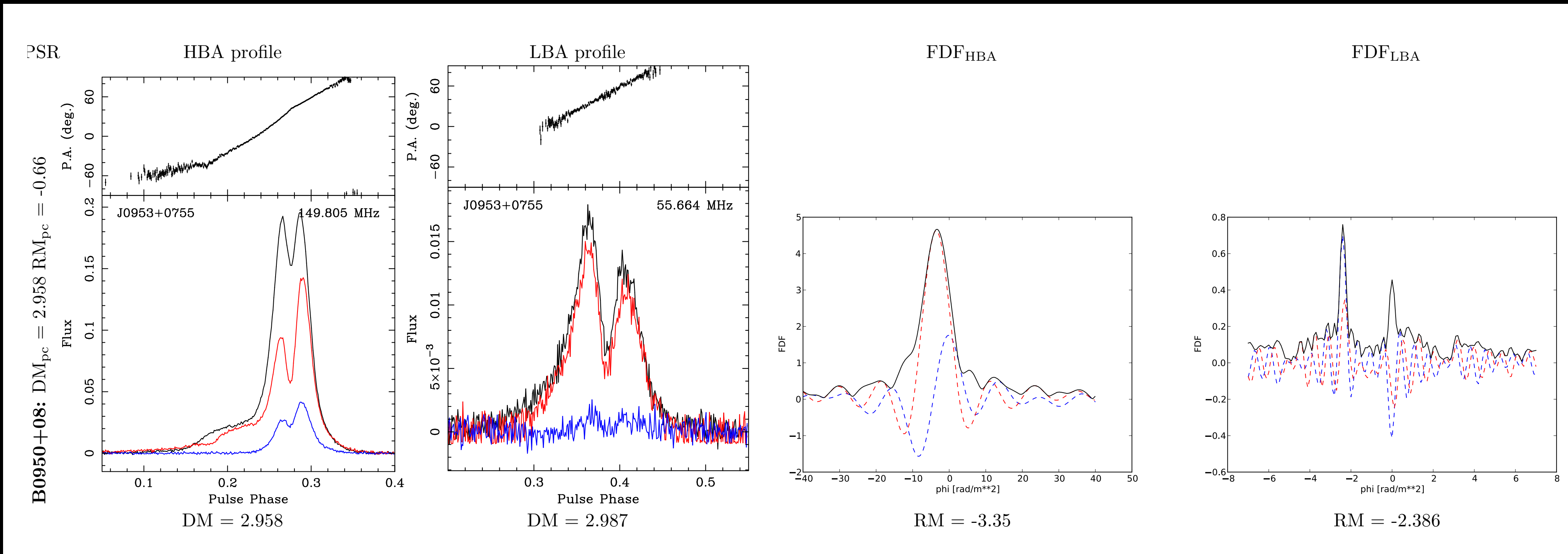
Low-Frequency Polarimetry



Close to the only pulsar polarimetry at < 100MHz

Credit: Sobey

Summary

- We don’t just want bigger telescopes. We also want more flexible telescopes (and “future proofing”).

- LOFAR pilot pulsar surveys are already providing competitive scientific data and are an important input for SKA Phase I.

- Early pulsar science coming from LOFAR’s wide-band coverage from 10-240MHz and polarimetric abilities.