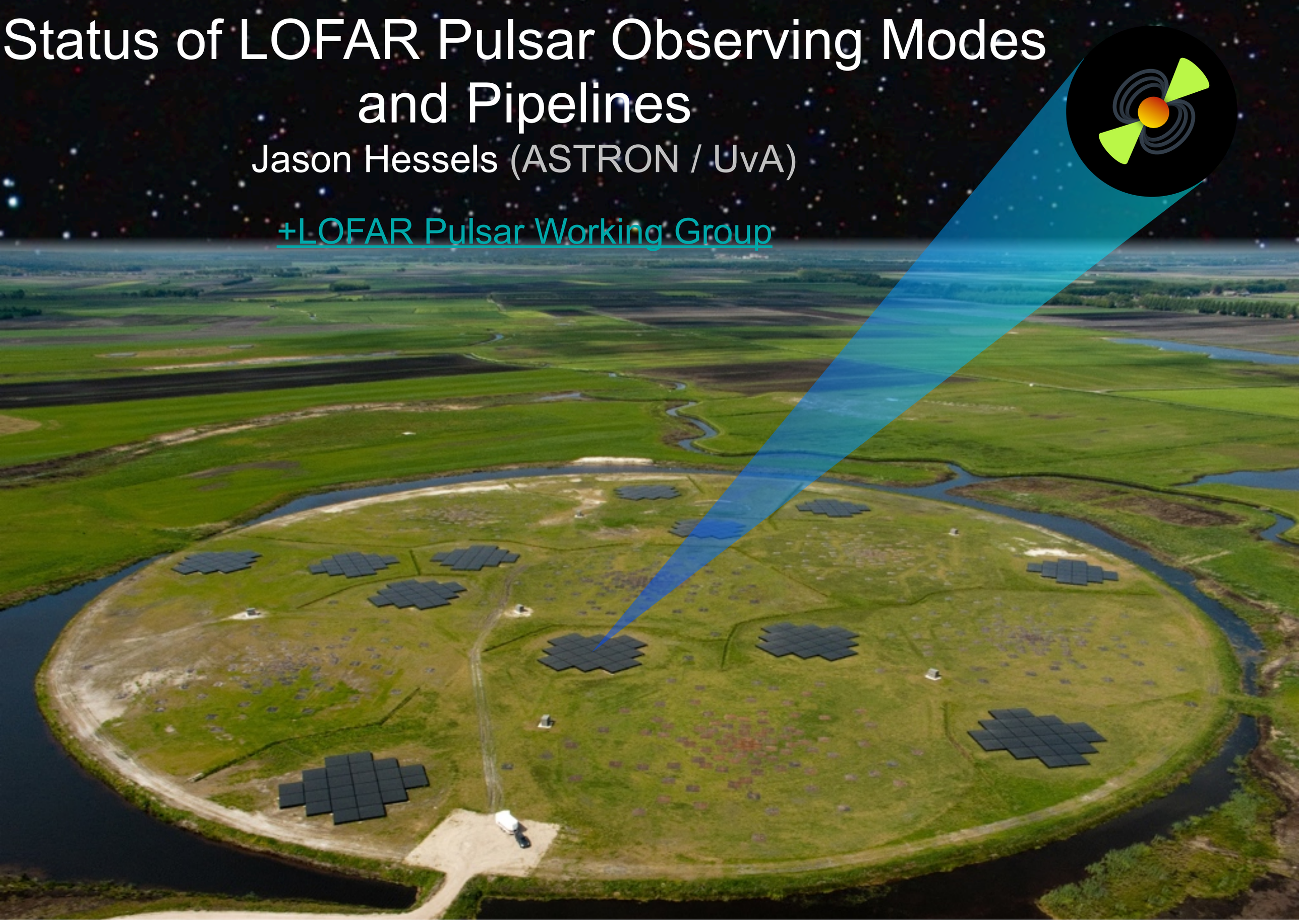
Status of LOFAR Pulsar Observing Modes and Pipelines

Jason Hessels (ASTRON / UvA)

+LOFAR Pulsar Working Group



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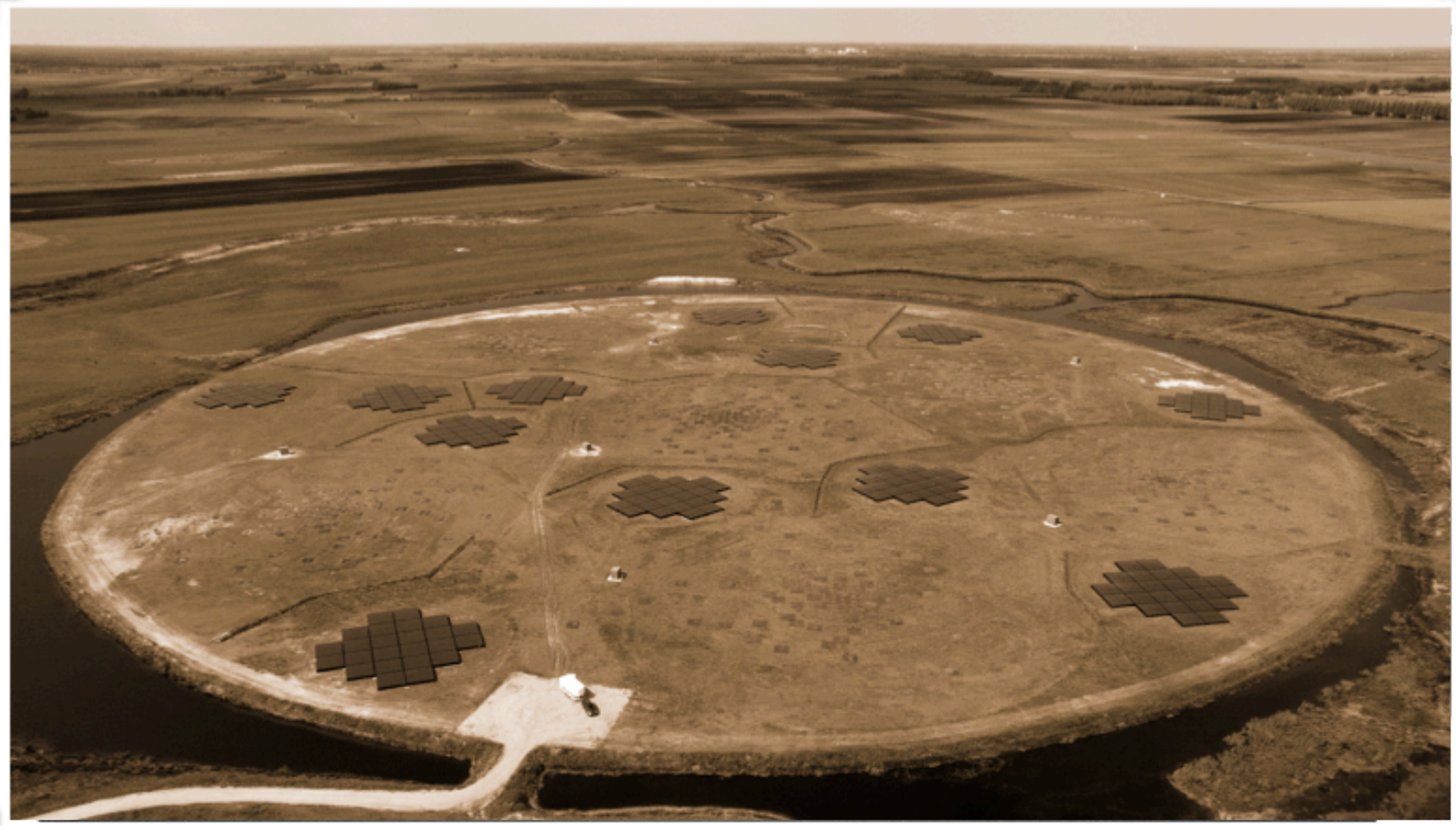
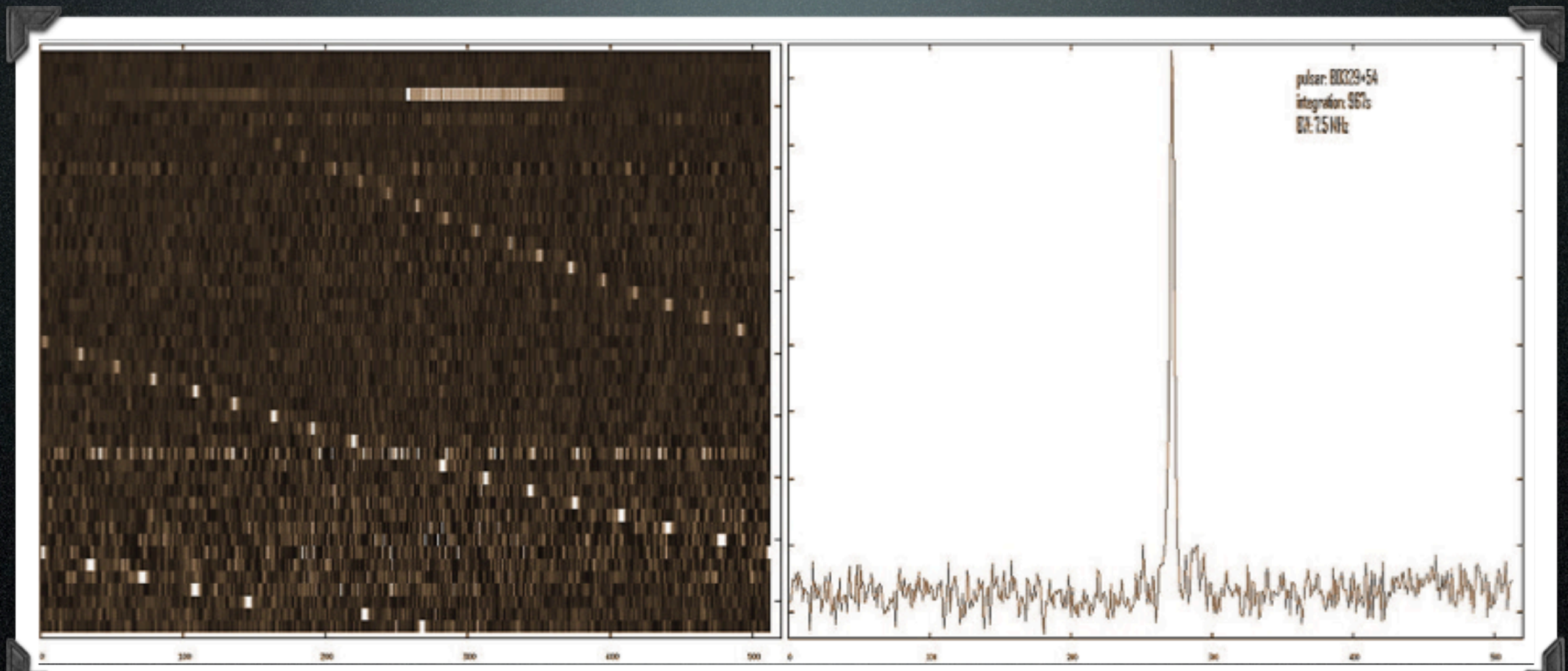
A Short Jaunt Down Memory Lane



LOFAR circa 2010

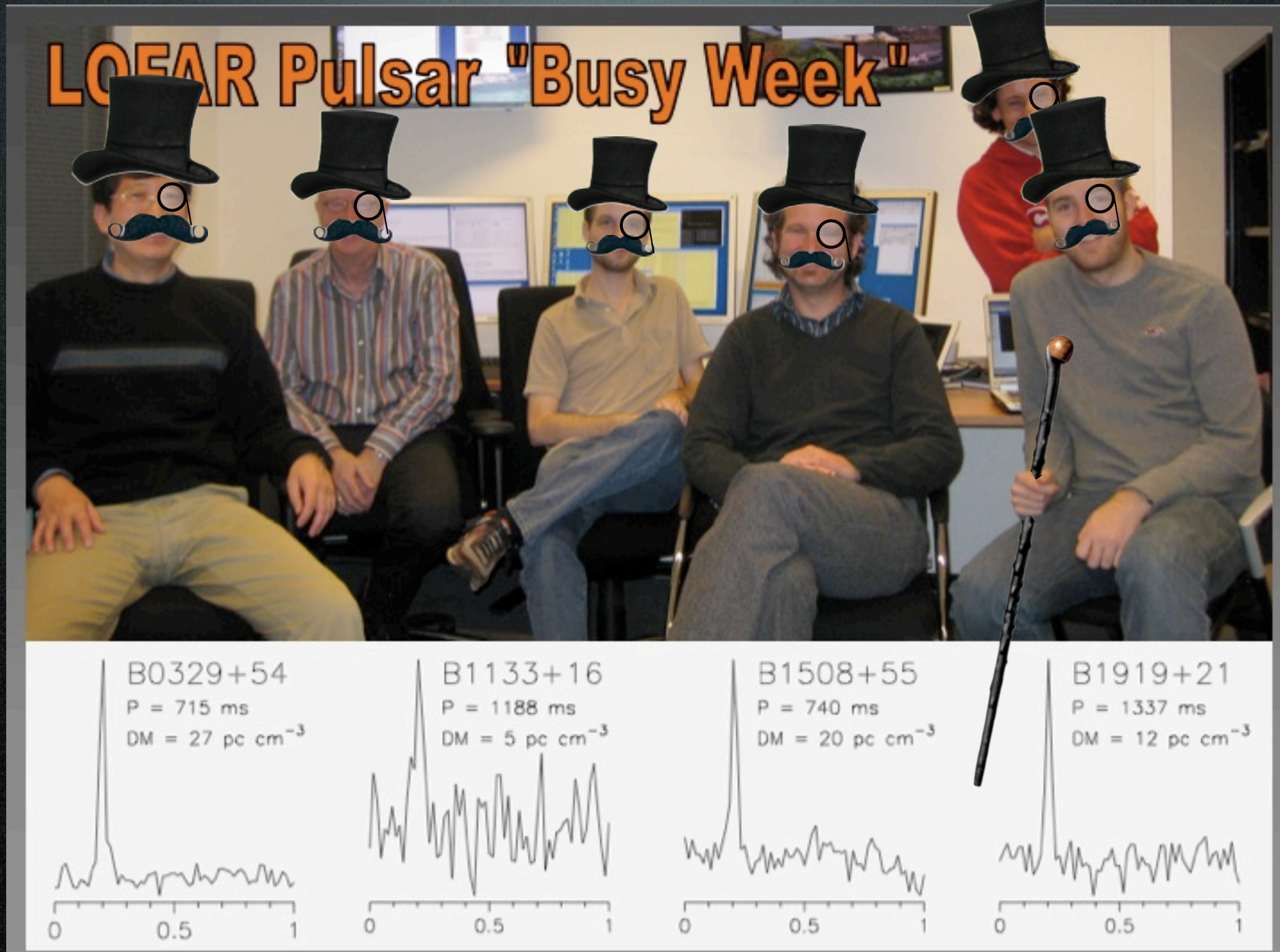
Pulsars with LOFAR...
...it all started June 14th, 2007



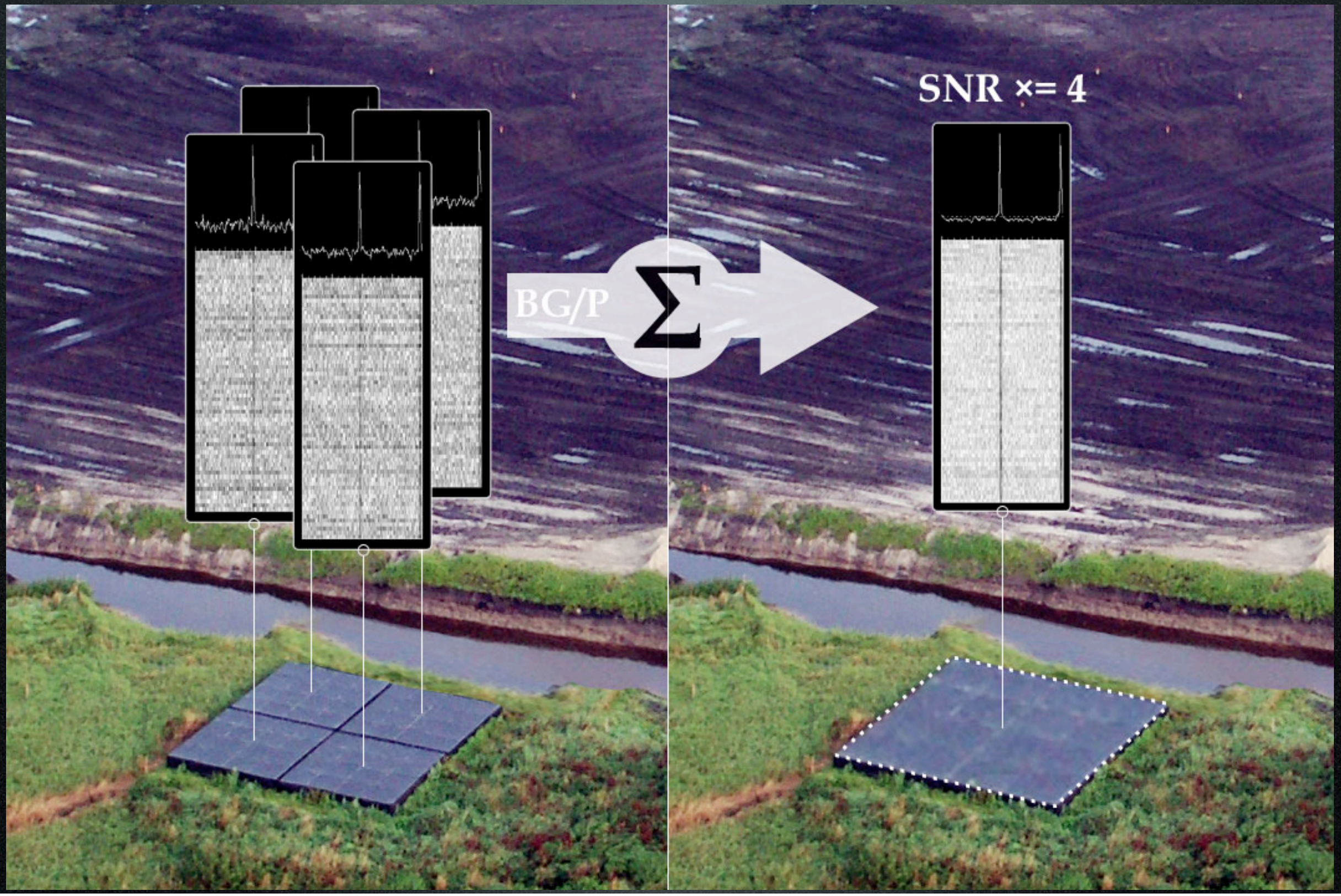
Credit: Karuppusamy & Stappers

CS1 Pulsar First Light

Nov. 2008: The first of many busy weeks



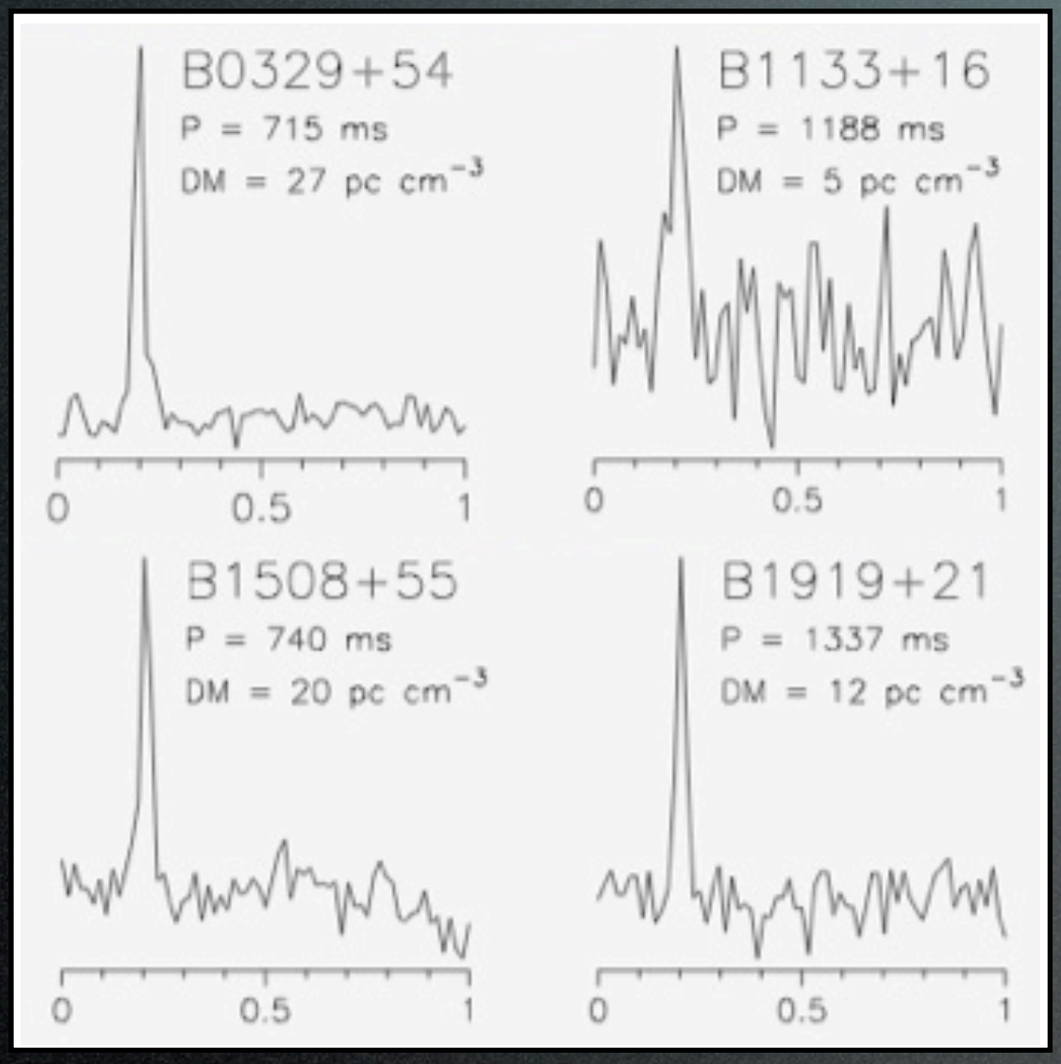
Tied-array beams with a whopping 4 tiles!



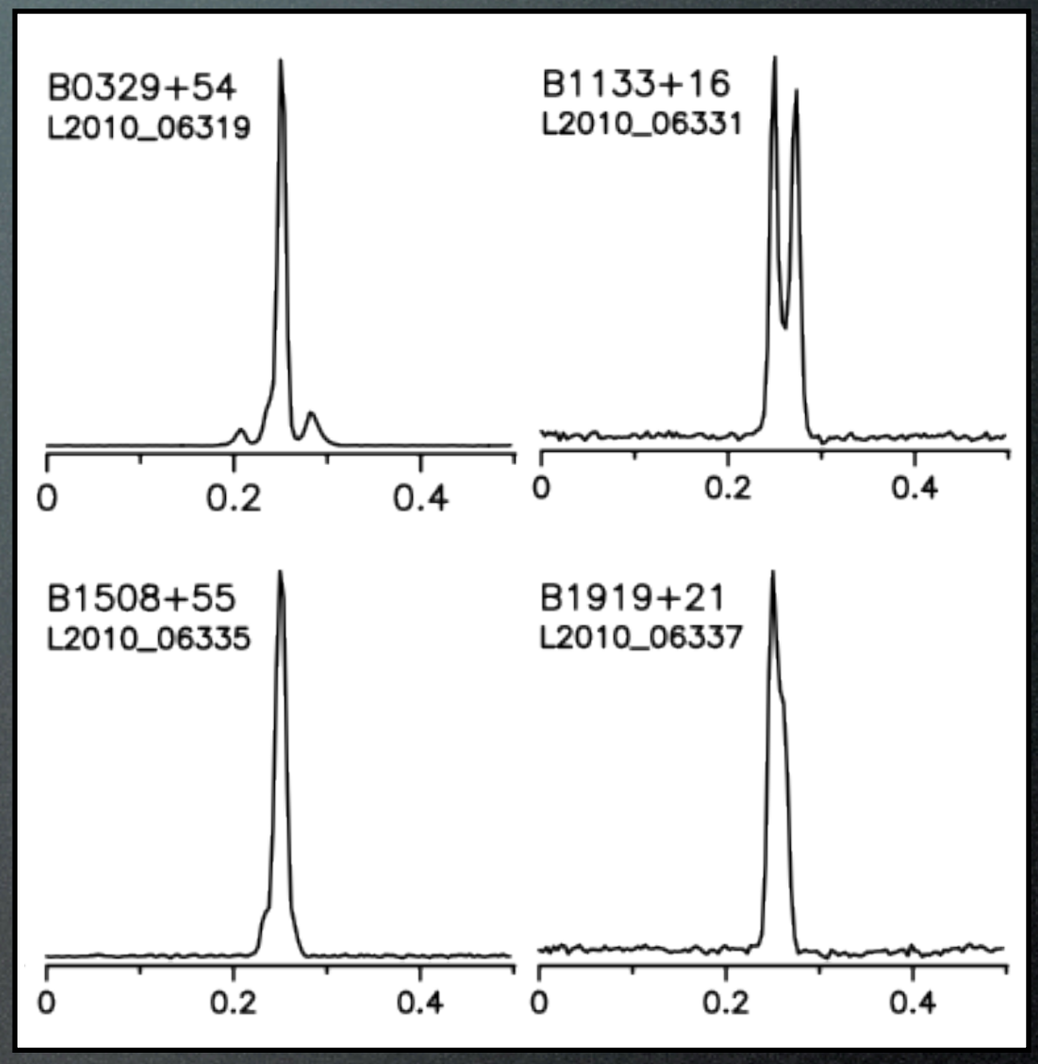
But things progressed quickly

Credit: van Leeuwen

What a difference a year and a half can make...

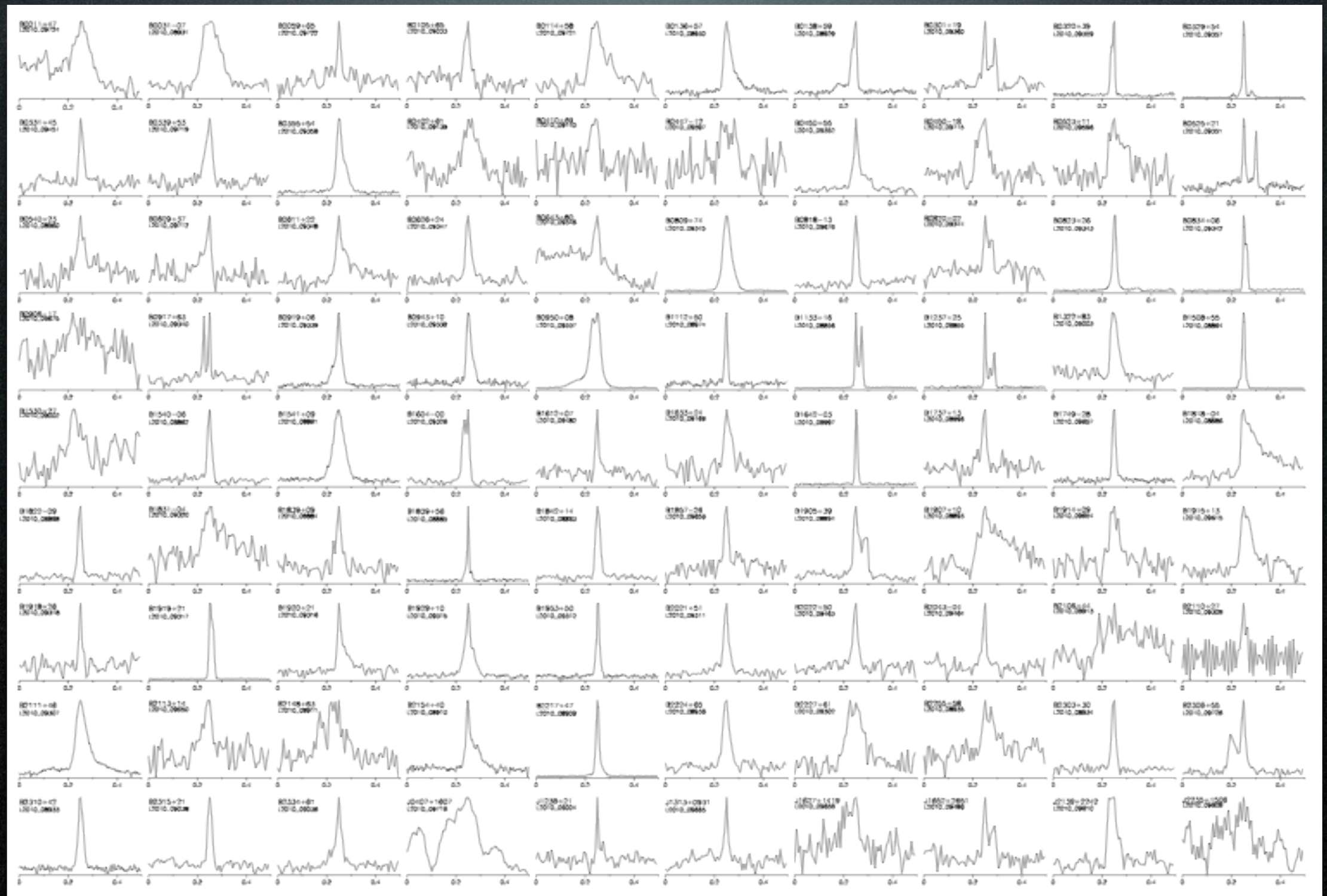


One HBA tile
PBW #1
Nov. 2008



Multiple Stations
PBW #7
Mar. 2010

Automation: 100+ Pulsars Detected with LOFAR



Credit: Hessels

Flexible Beam-forming

(sparse aperture array)

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	12,5	2	6,0
Tied-array	Stations added properly in phase.	Up to 23TB/hr	0,2	0,03	36,0
Single Station	For projects with high time, but lower sensitivity requirements.	2-250 GB/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

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

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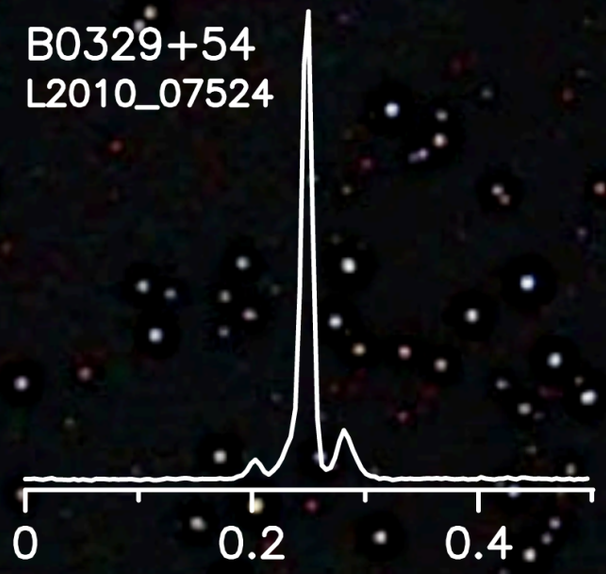
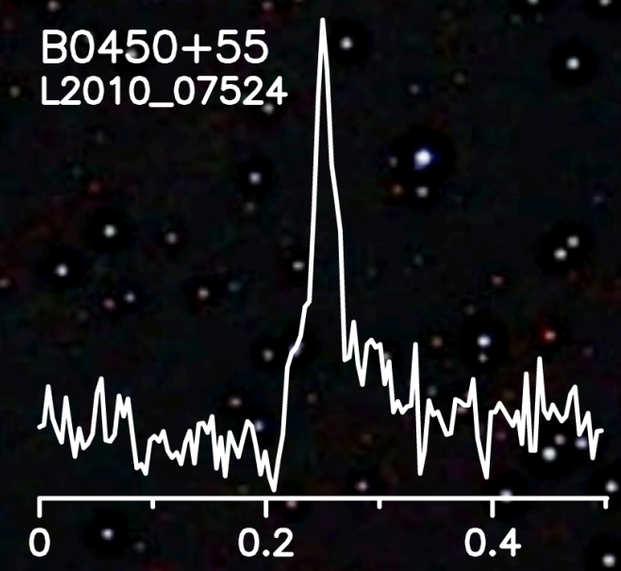


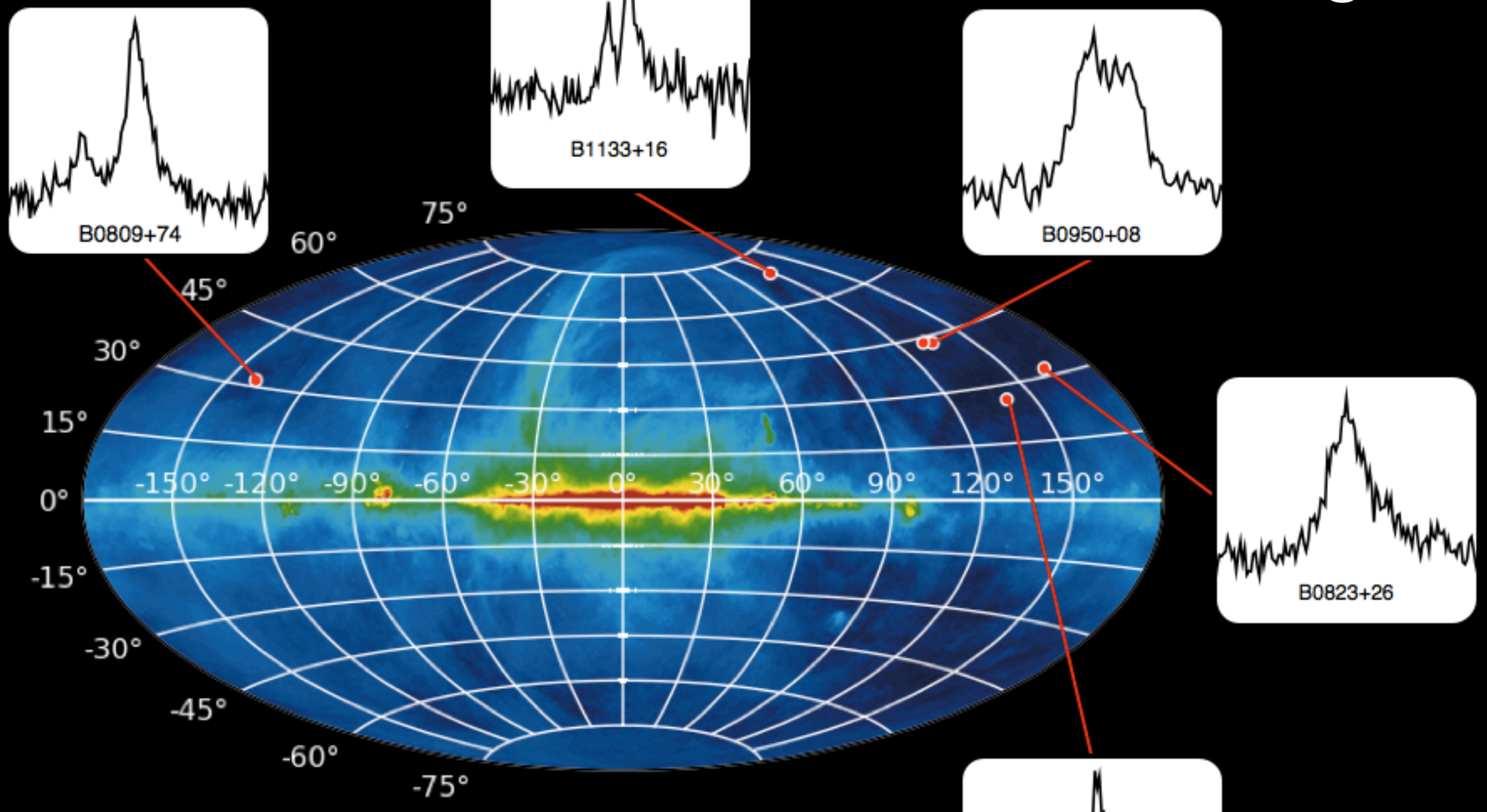
0.5 degree



Multiple Station Beams

Credit: Hessels

@ 24MHz

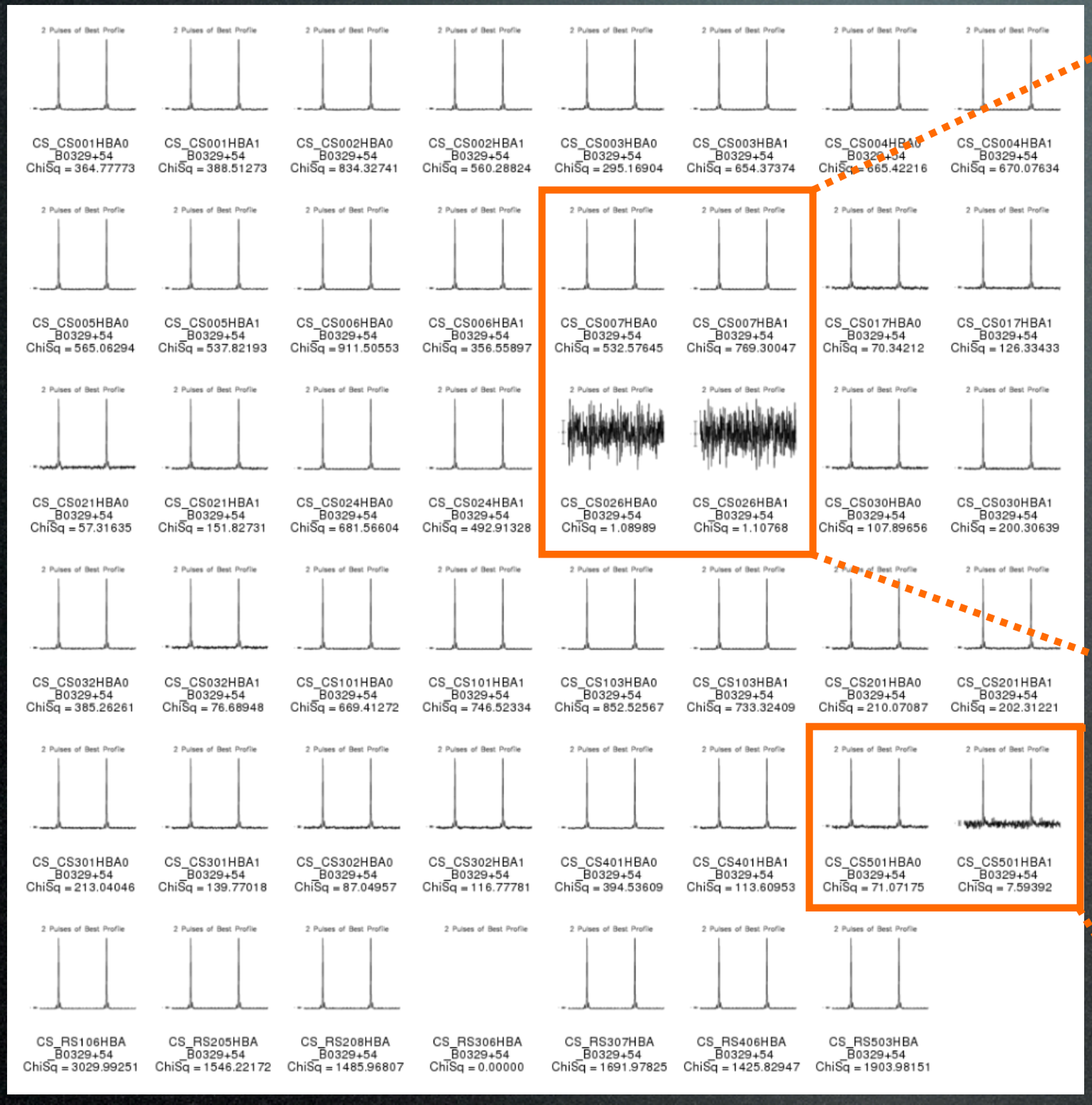


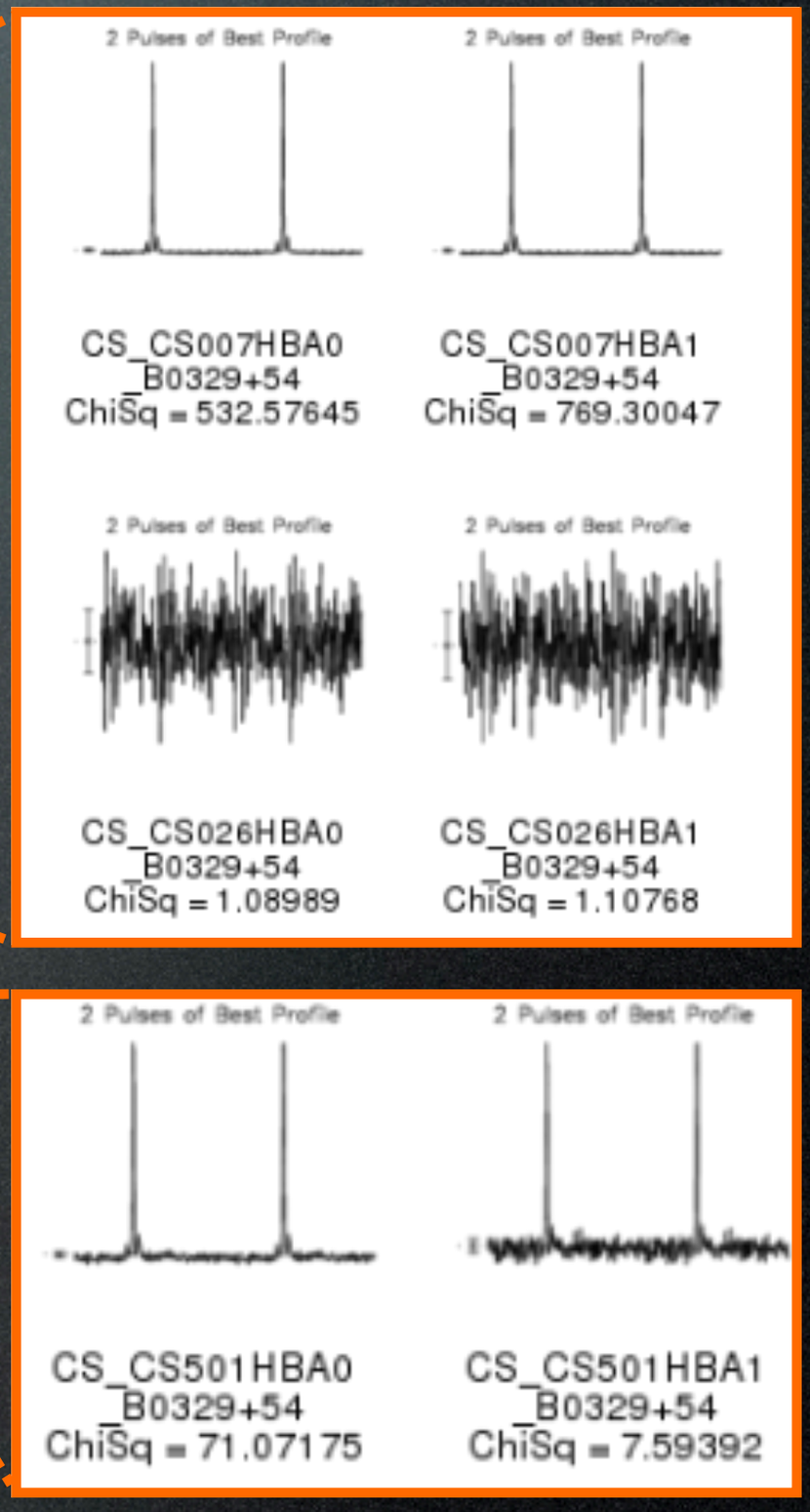
simultaneous multi-beam observations in the LOFAR low band

Credit: Hassall & Hessels

Haslam 408 MHz map courtesy of LAMBDA

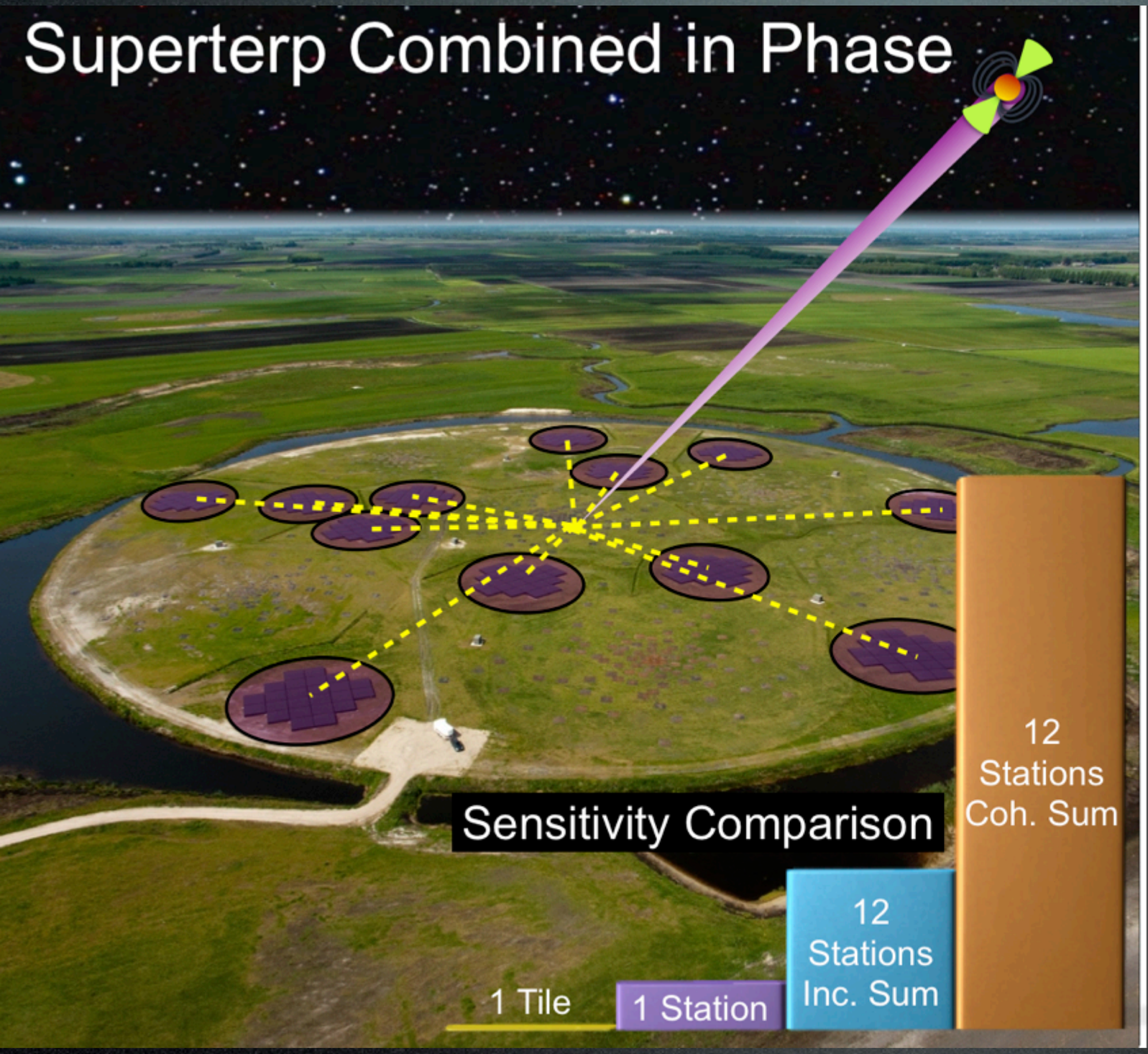
Fly's Eye Observation with 47 HBA stations



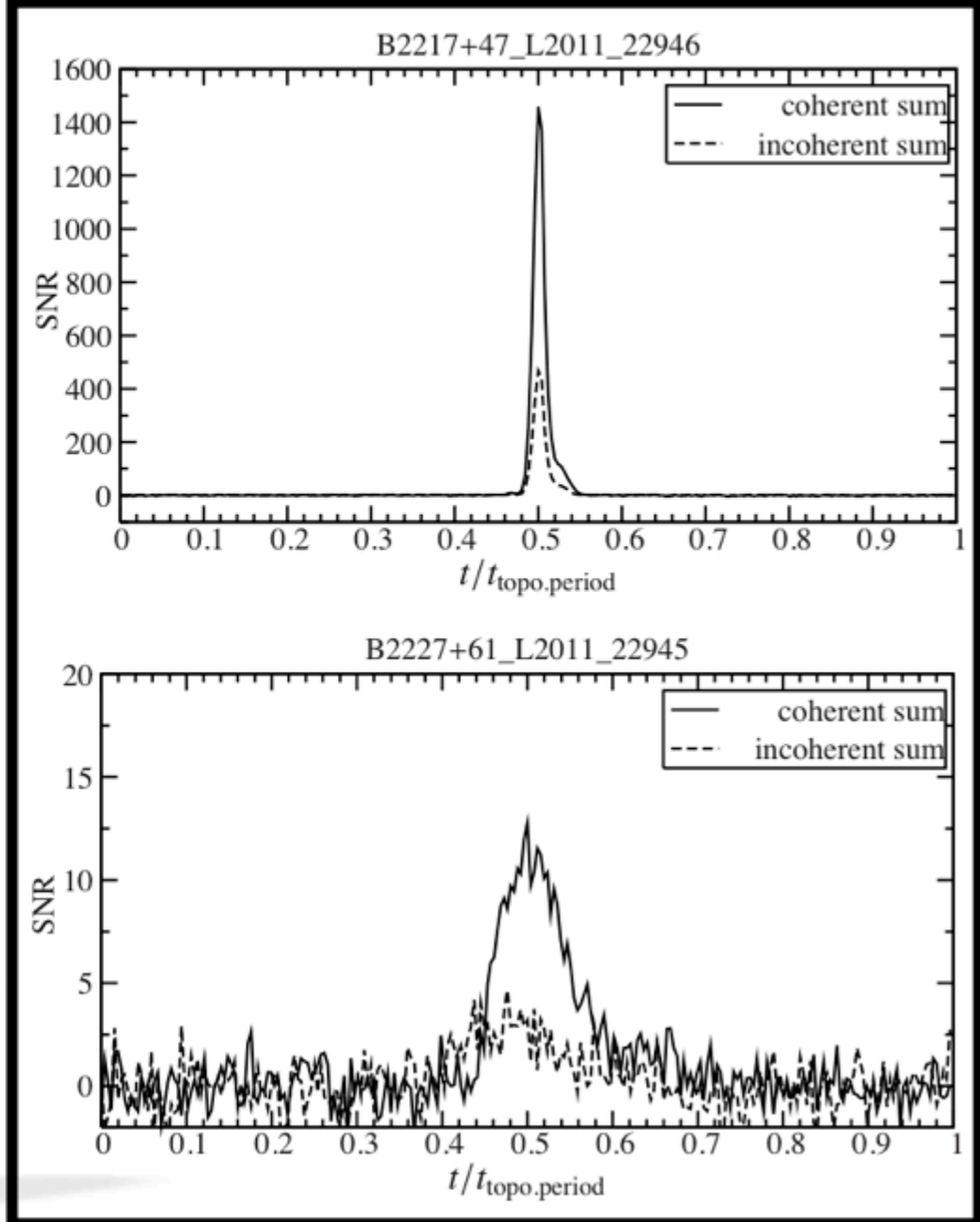


Credit: Alexov & Hessels

Superterp Combined in Phase

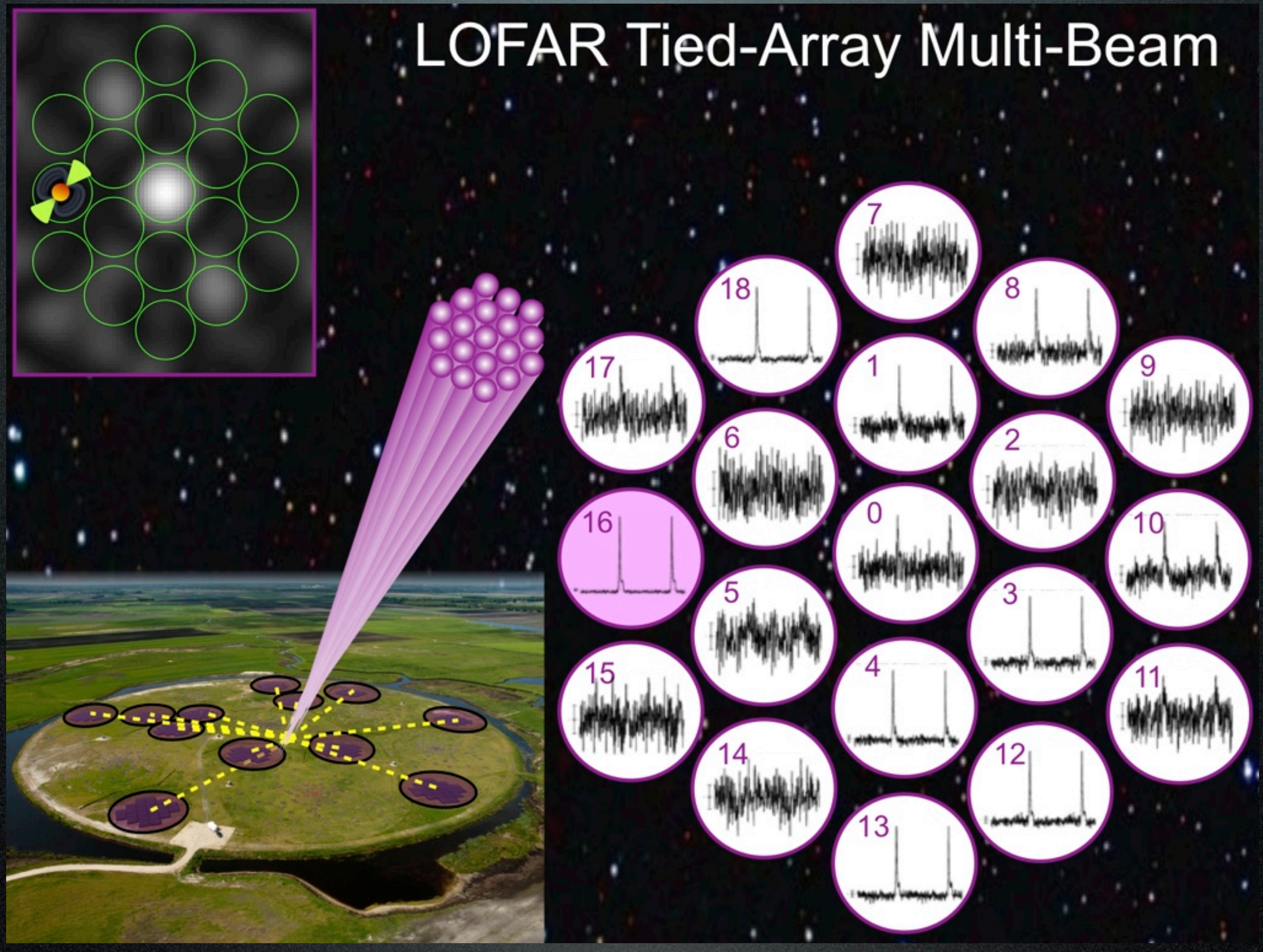


LOFAR Coherent Superterp Data



Credit: Hessels & Griessmeier

LOFAR Tied-Array Multi-Beam

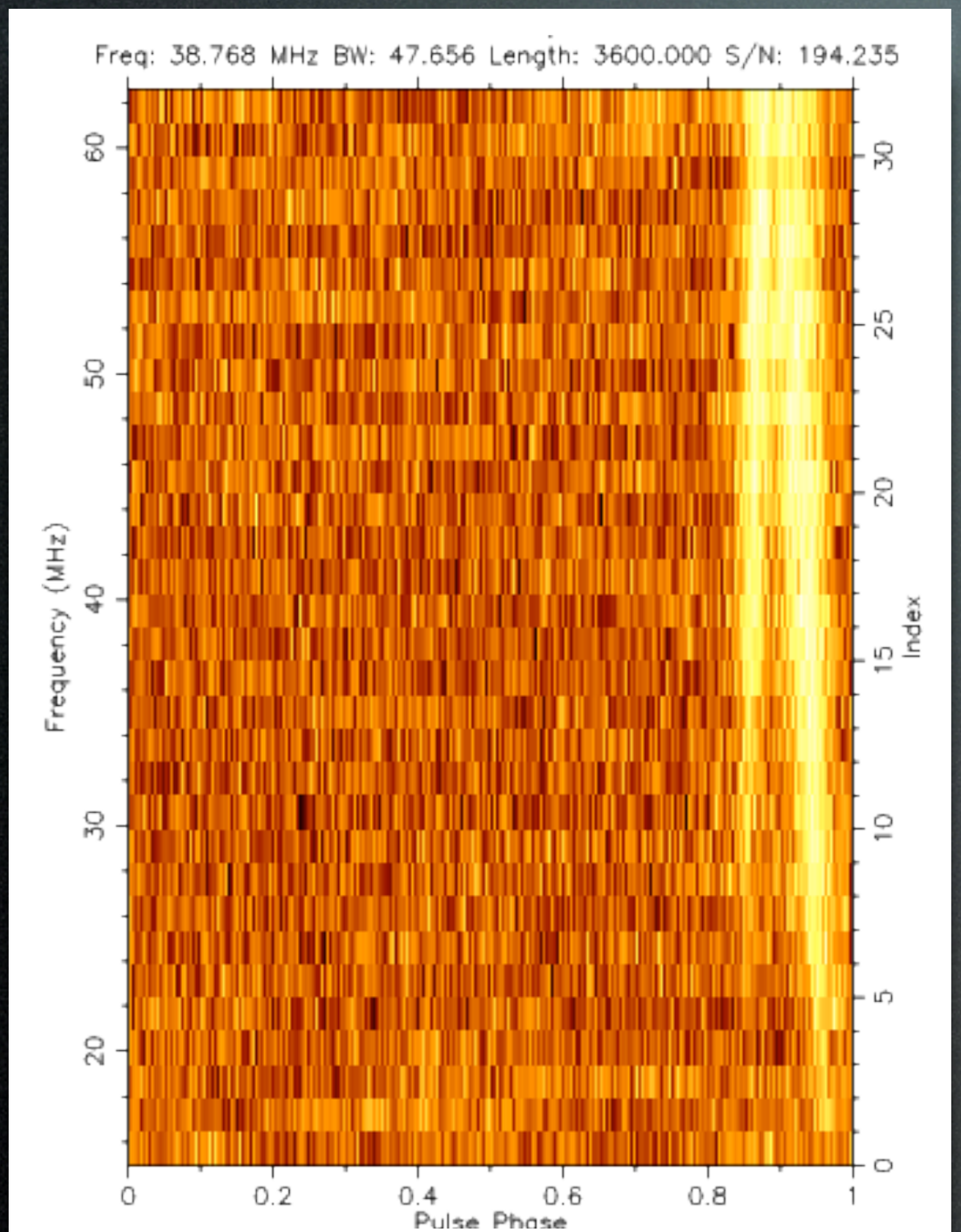


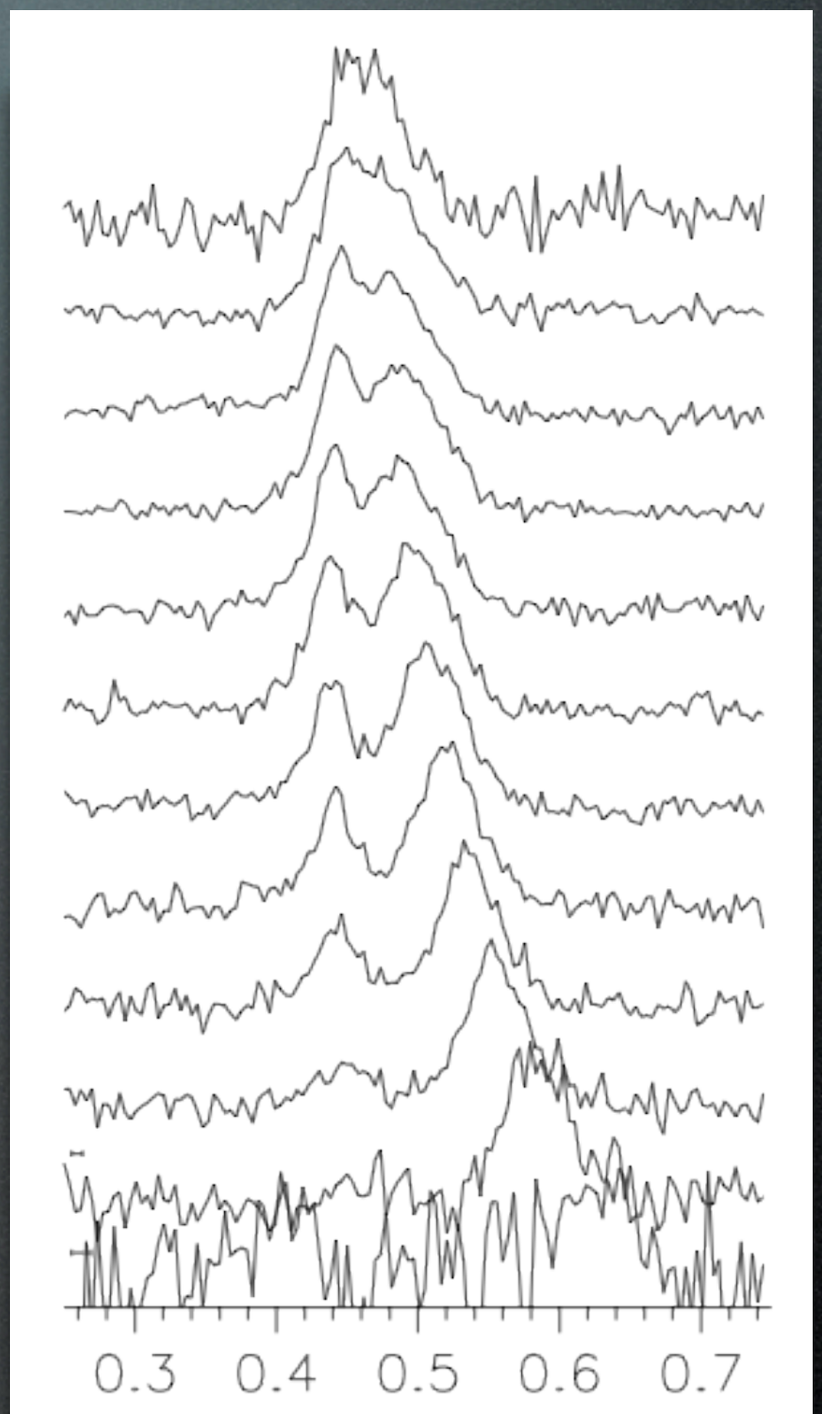
See Mol & Romein 2011 for multi-beam tied-array benchmarking results

Credit: Hessels, Stappers & Scaife

Pulsar Detection < 30MHz

15 - 63 MHz Observing Frequency





72-78 MHz

66-72 MHz

60-66 MHz

54-60 MHz

48-54 MHz

42-48 MHz

36-42 MHz

30-36 MHz

28-34 MHz

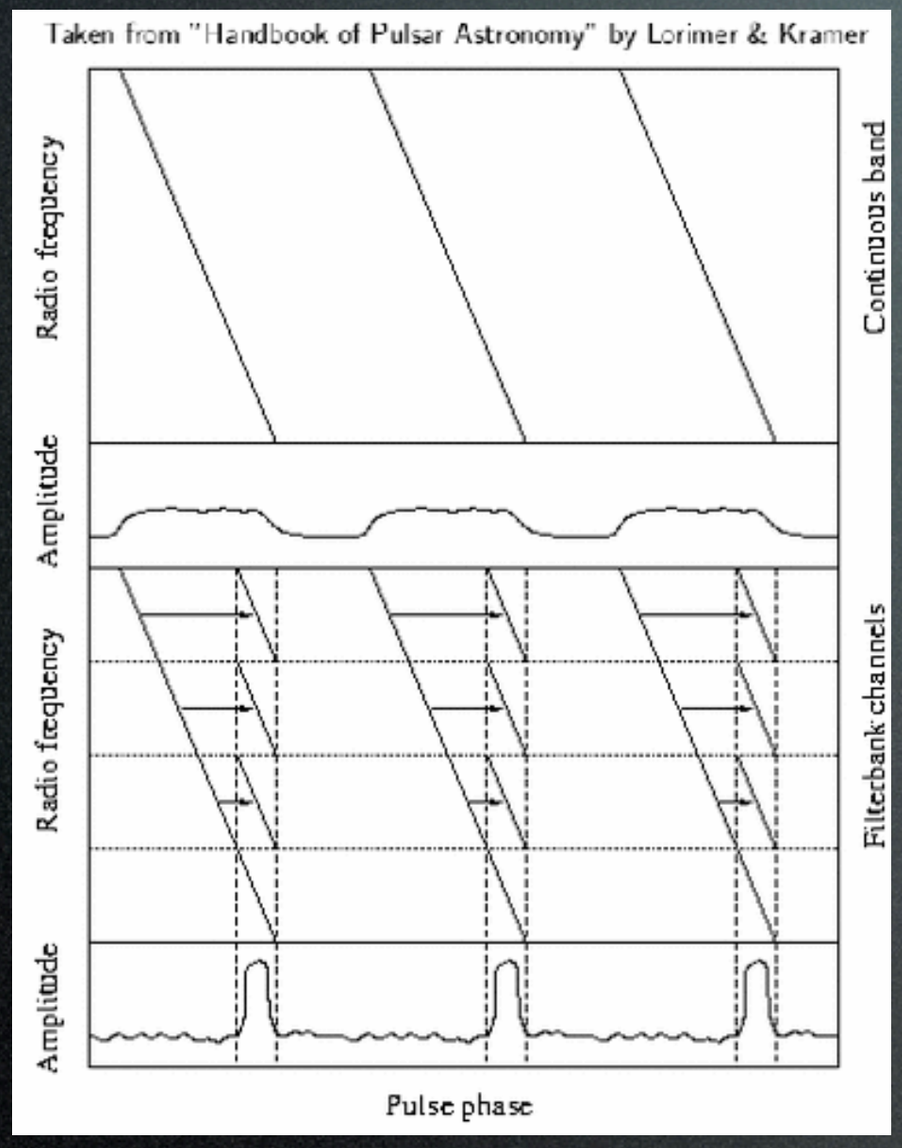
22-28 MHz

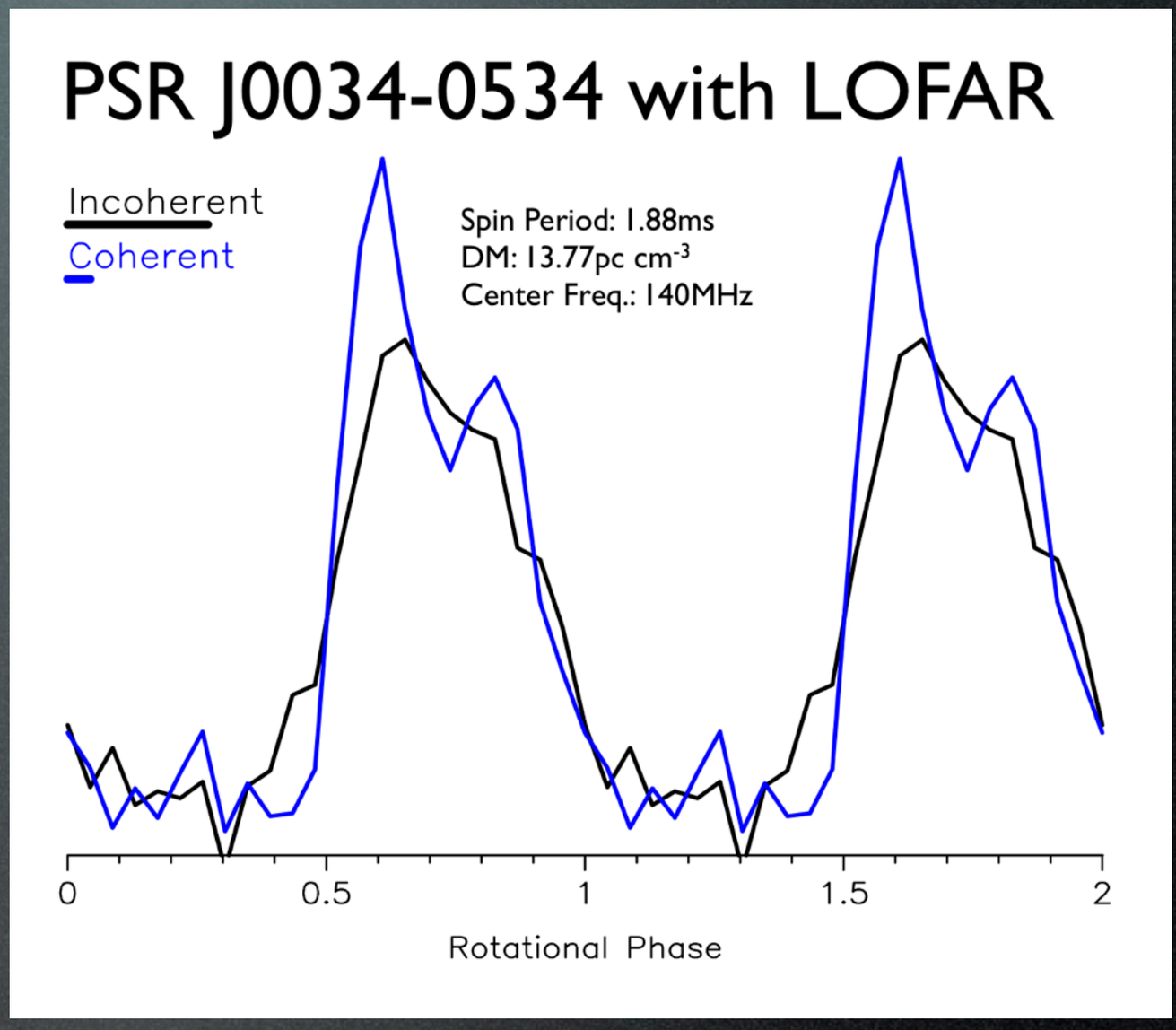
16-22 MHz

10-16 MHz

Credit: Kondratiev

Coherent dedispersion





Incoherent dedispersion

Shift frequency channels in time

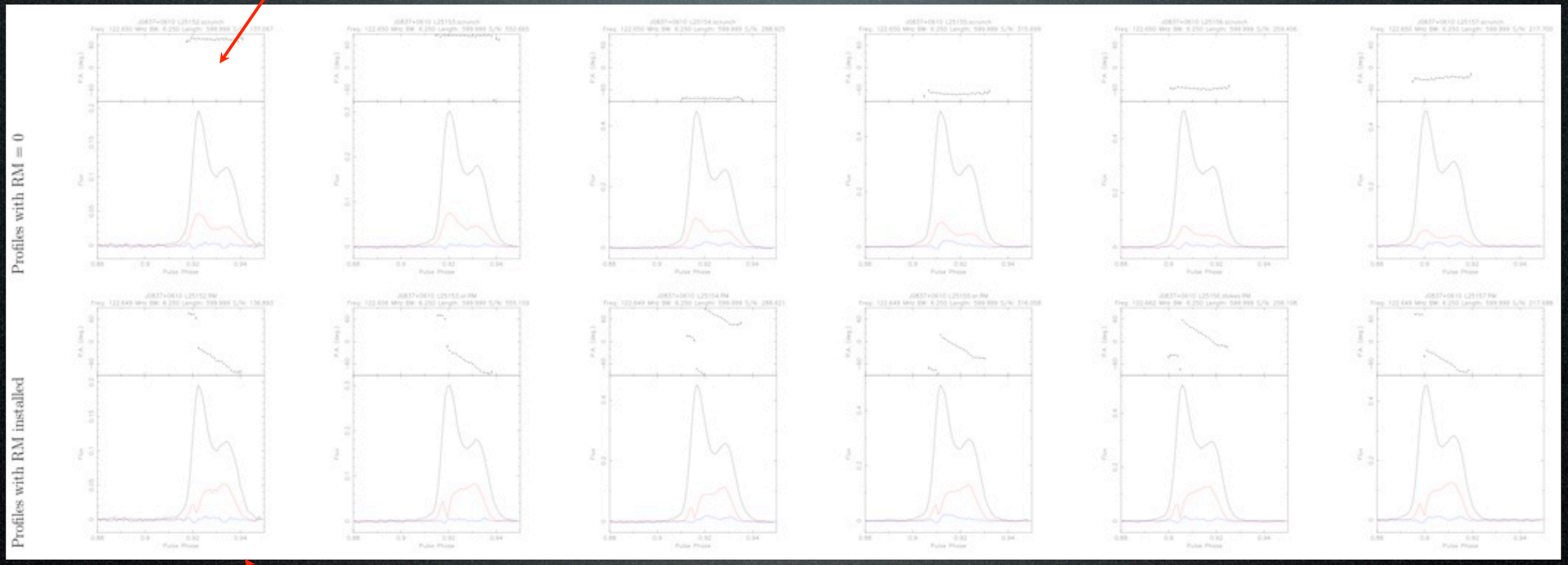
Coherent dedispersion

Apply inverse filter to raw voltages

Credit: Romein, Hessels, Mol

Polarimetry of PSR B0834+06

RM = 0



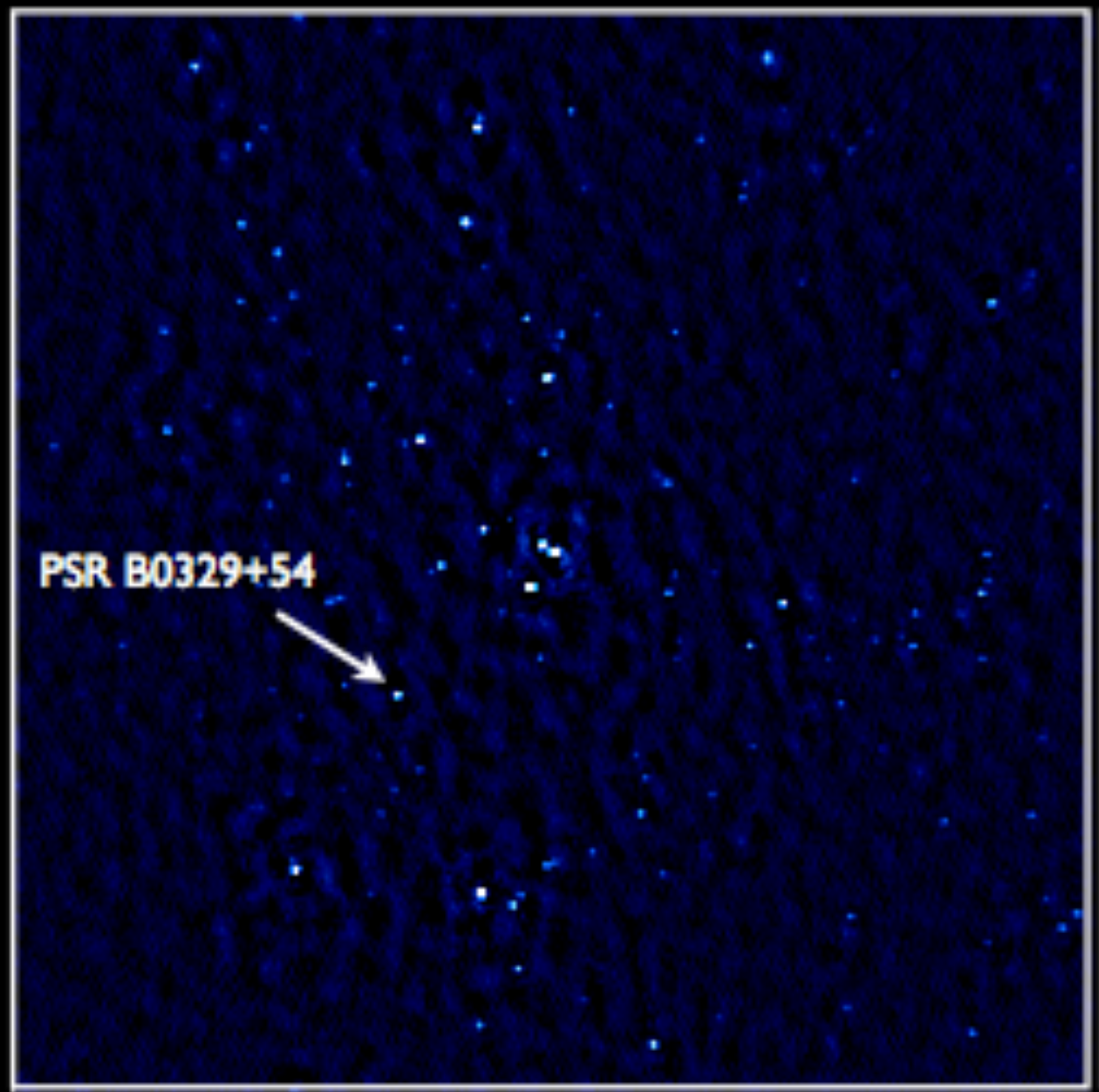
HA = -2 HA = -1 HA = 0 HA = +1 HA = +2 HA = +3

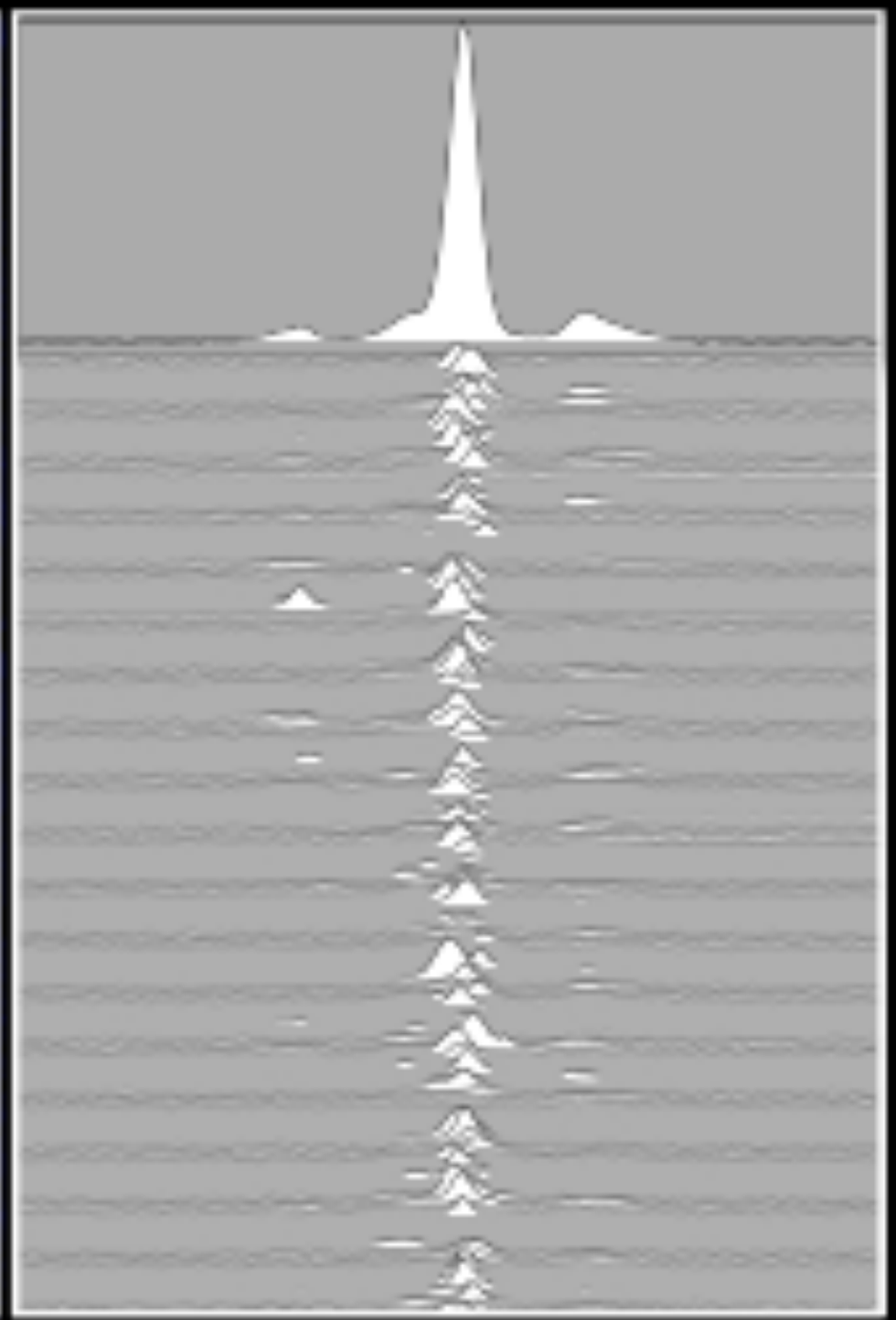
RM ~ 27

- Polarization profile is very stable as a function of hour angle
- Calibration errors on the order of ~5-10%?

Credit: Sobey & Noutsos

Simultaneous Imaging + Pulsar Observations





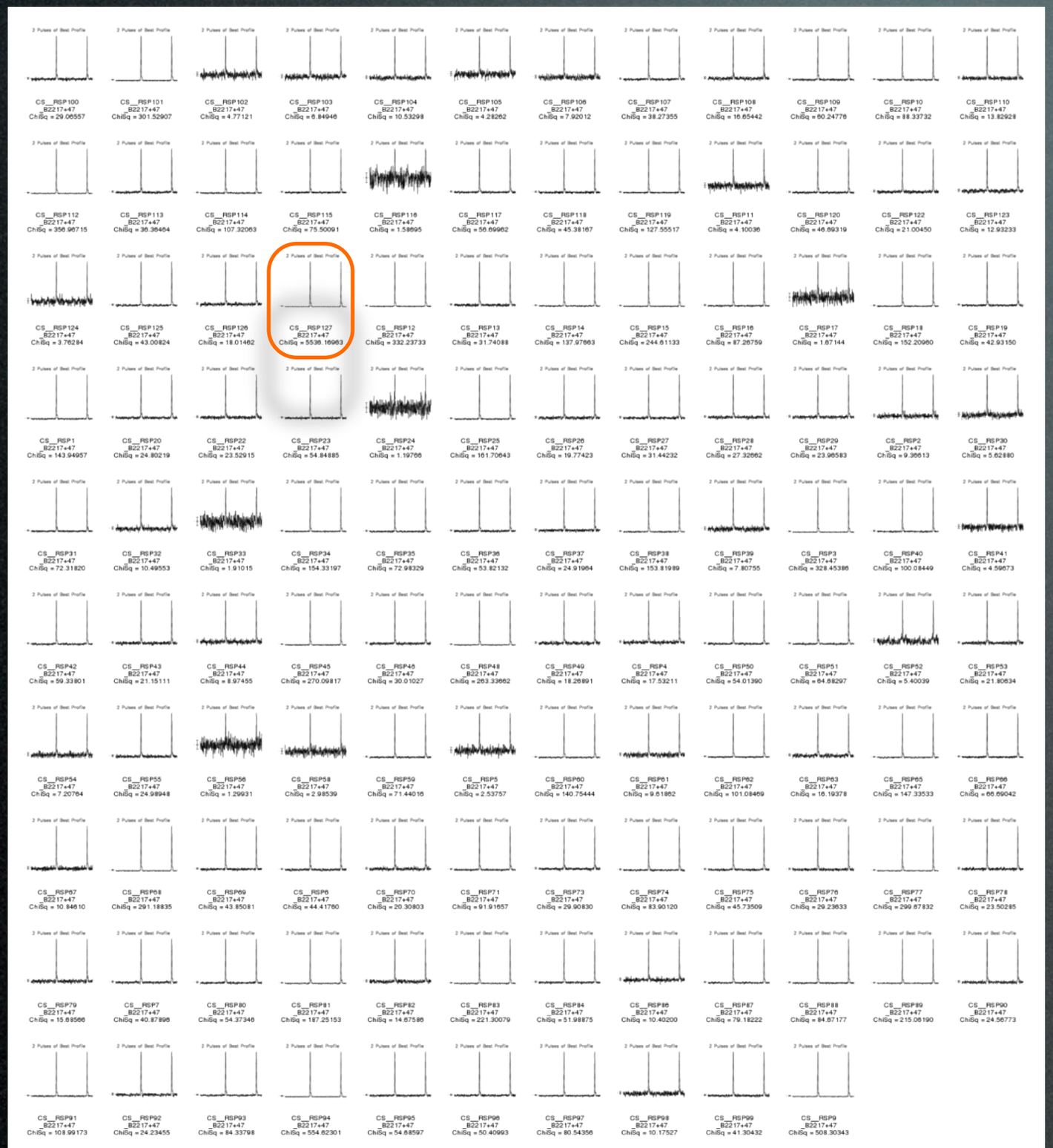
Credit: Alexov, Heald & Hessels

What's working

- Incoherent Stokes: in principal with all stations.
- Coherent Stokes (tied-array): only for Superterp. >100 beams possible!
- Fly's Eye: in principal with all stations.
- Online coherent dedispersion (one DM).
- "Voltage"/Stokes I/Stokes IQUV output.

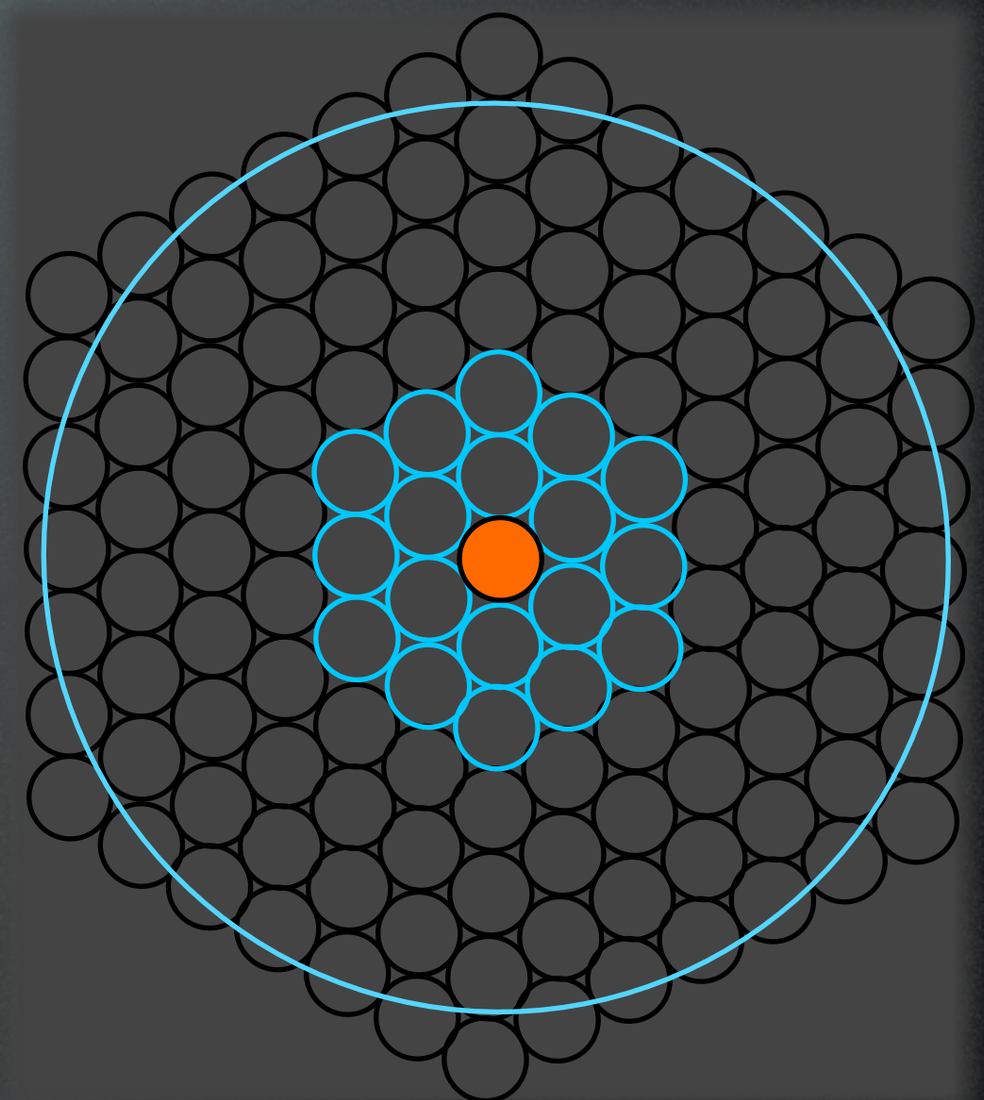
Data <12 hours old!!!

>100 beam Tied-Array!!



Credit: Alexov & Hessels

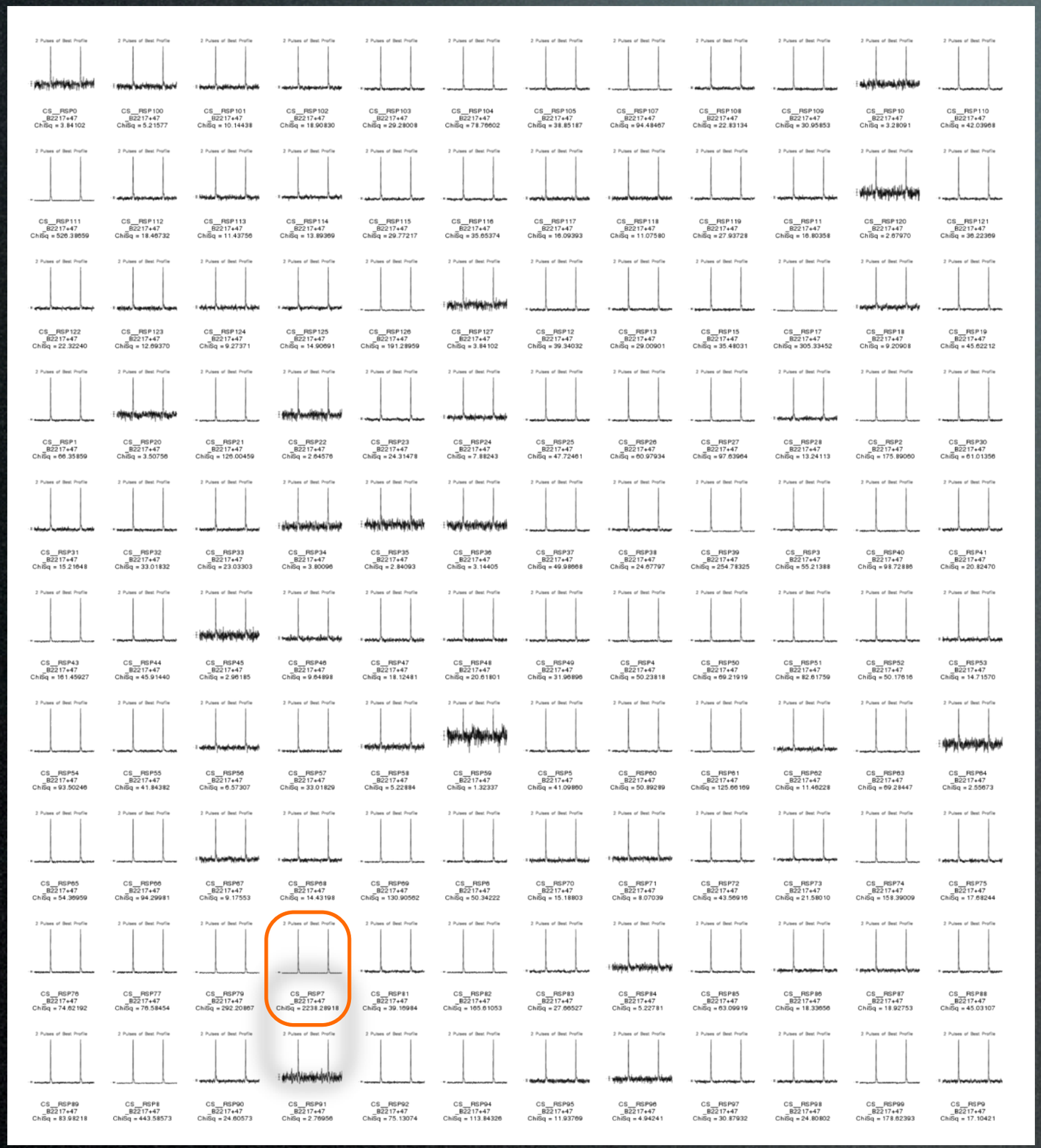
Pulsar in the center of FoV



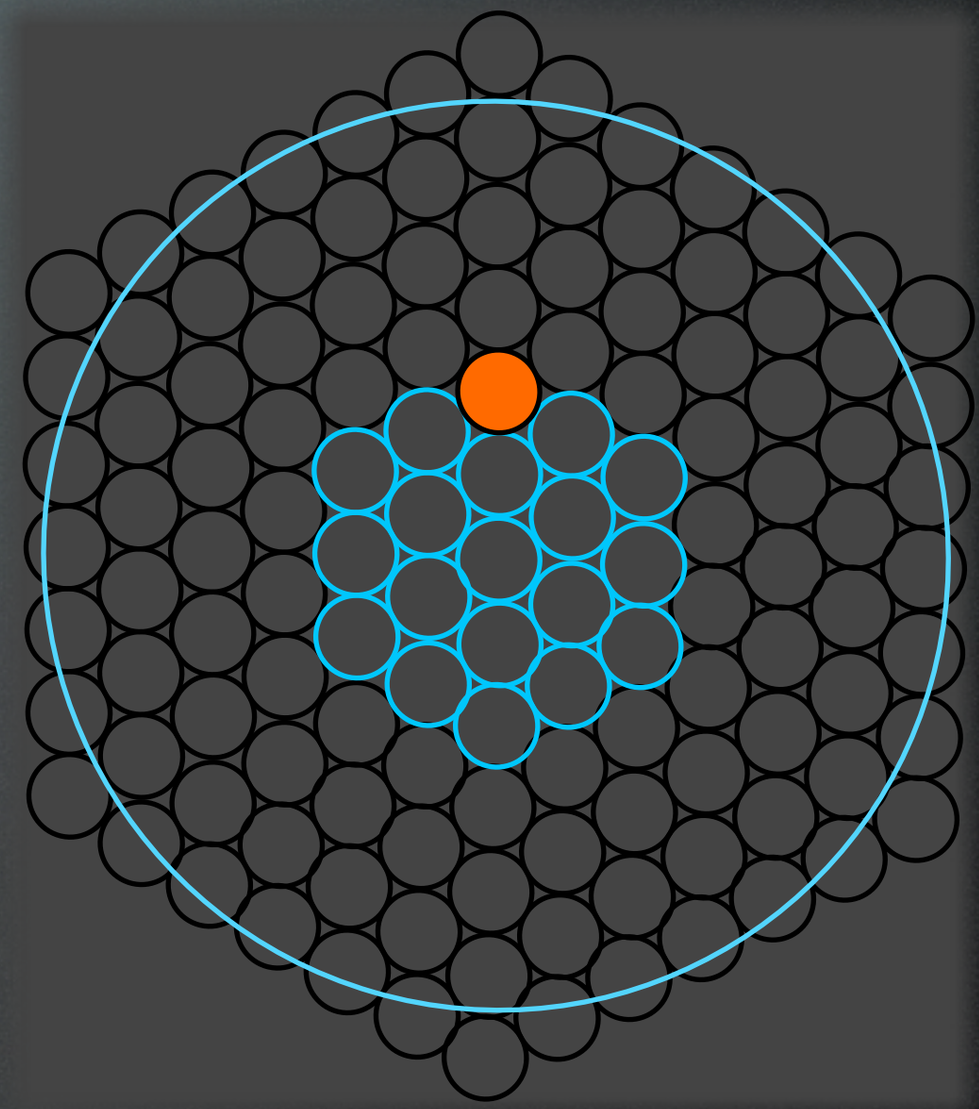
Pulsar is 10x brighter in the correct (center) beam!

Data <12 hours old!!!

>100 beam Tied-Array!!



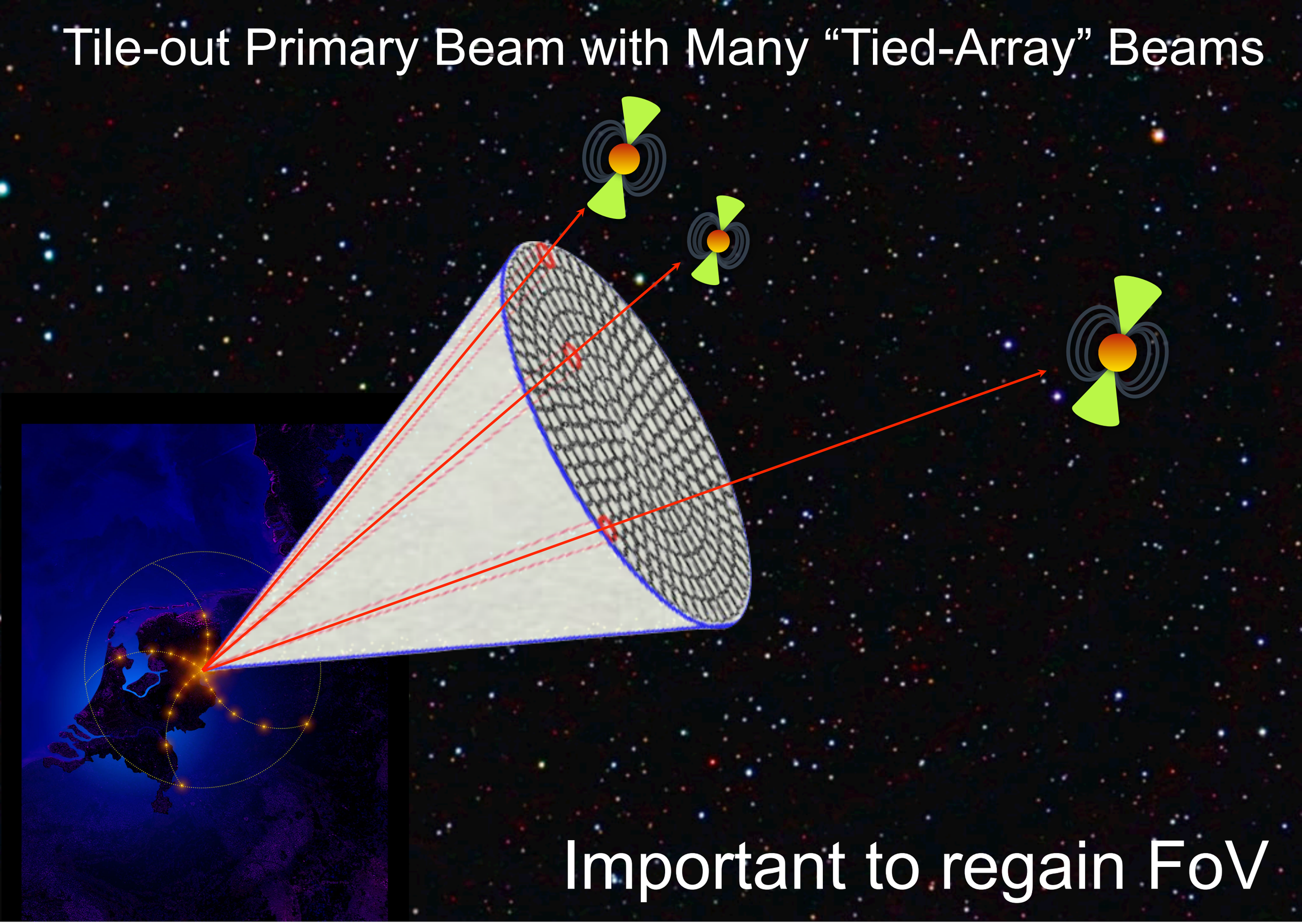
Shifted 1 deg south



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

Credit: Alexov & Hessels

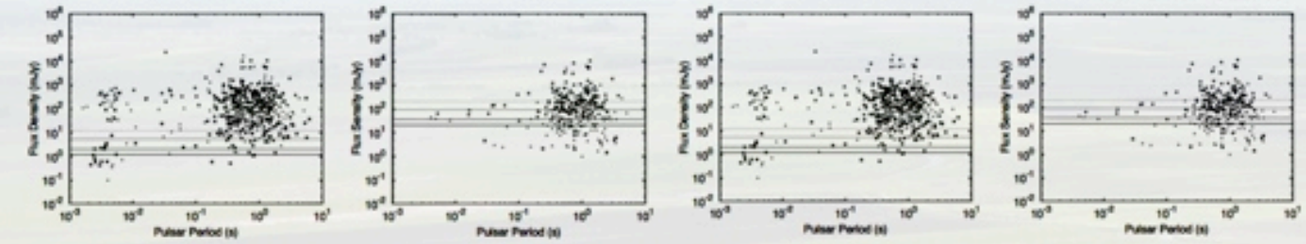
Tile-out Primary Beam with Many “Tied-Array” Beams

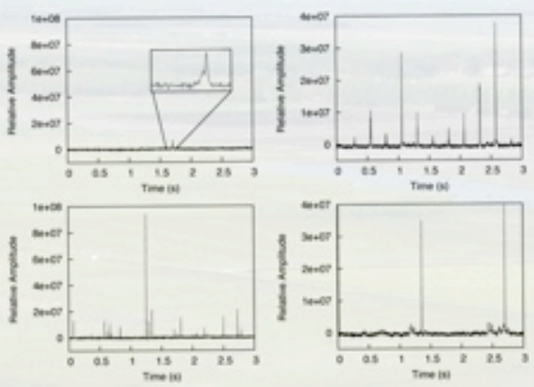


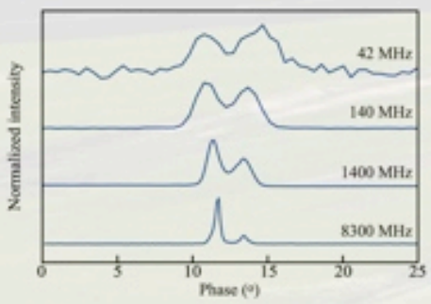
Important to regain FoV

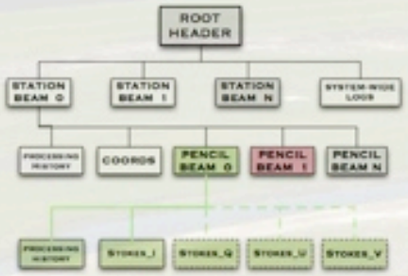
What needs work

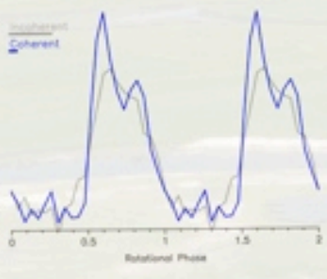
- Online flagging: especially important for incoherent mode.
- Full-core tied-array: single clock.
- Wide-field Fly's Eye: point in different directions.
- Simultaneous obs.: e.g. sub-array observations with LBA and HBA.
- Data products: move to HDF5 and more user-friendly data products (DAL).

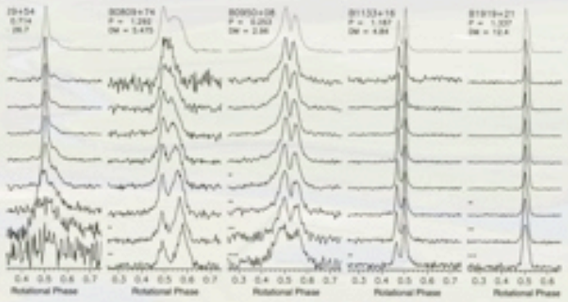


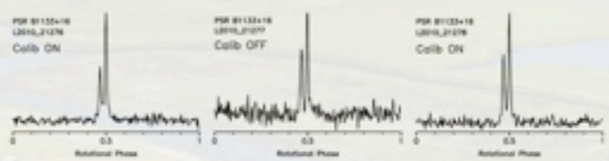






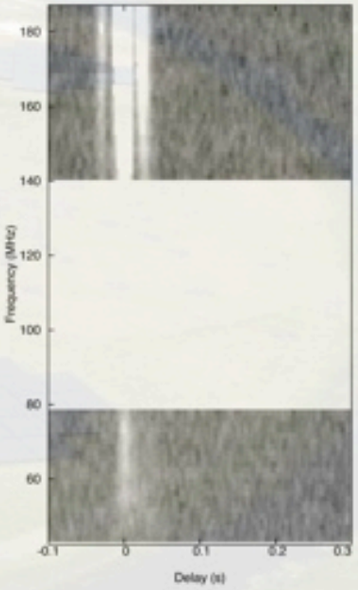


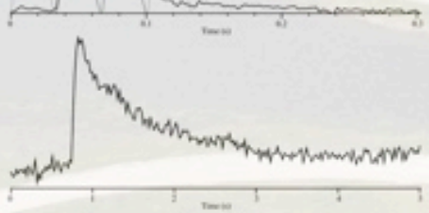


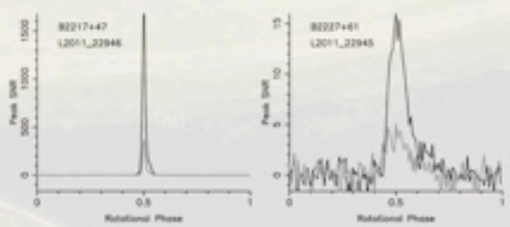


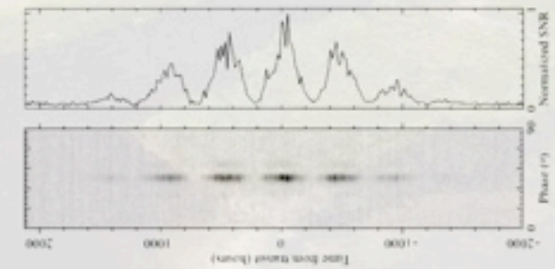
Observing pulsars and fast transients with LOFAR

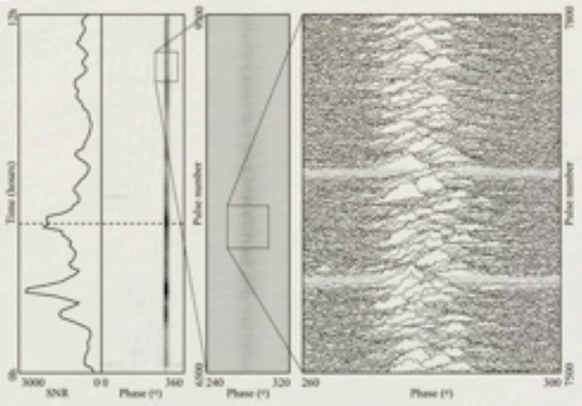
B. W. Stappers[1], J. W. T. Hessels[2,3] A. Alexov[3], K. Anderson[3], T. Coenen[3], T. Hassall[1], A. Karastergiou[4], V. I. Kondratiev[2], M. Kramer[5,1], J. van Leeuwen[2,3], J. D. Mol[2], A. Noutsos[5], J. W. Romein[2], P. Weltevrede[1], R. Fender[6], R. A. M. J. Wijers[3], L. Bähren[3], M. E. Bell[6], J. Broderick[6], E. J. Daw[8], V. S. Dhillon[8], J. Eislöffel[19], H. Falcke[12,2], J. Griessmeier[2,22], C. Law[24,3], S. Markoff[3] J. C. A. Miller-Jones[13,3], B. Scheers[3], H. Spreeuw[3], J. Swinbank[3], S. ter Veen[12] M. W. Wise[2,3], O. Wucknitz[17], P. Zarka[16], J. Anderson[5], A. Asgekar[2], I. M. Avruch[2,10], R. Beck[5], P. Bennema[2], M. J. Bentum[2], P. Best[15], J. Bregman[2], M. Brentjens[2], R. H. van de Brink[2], P. C. Broekema[2], W. N. Brouw[10], M. Brüggen[21], A. G. de Bruyn[2,10], H. R. Butcher[2,26], B. Ciardi[7], J. Conway[11], R.-J. Dettmar[20], A. van Duin[2], J. van Enst[2], M. Garrett[2,9], M. Gerbers[2], T. Grit[2], A. Gunst[2], M. P. van Haarlem[2], J. P. Hamaker[2] G. Heald[2], M. Hoeft[19], H. Holties[2], A. Horneffer[5,12], L. V. E. Koopmans[10], G. Kuper[2], M. Loose[2], P. Maat[2], D. McKay-Bukowski[14], J. P. McKean[2], G. Miley[9], R. Morganti[2,10], R. Nijboer[2], J. E. Noordam[2], M. Norden[2], H. Olofsson[11], M. Pandey-Pommier[9,25], A. Polatidis[2], W. Reich[5], H. Röttgering[9], A. Schoenmakers[2], J. Sluman[2], O. Smirnov[2], M. Steinmetz[18], C. G. M. Sterks[23], M. Tagger[22], Y. Tang[2], R. Vermeulen[2], N. Vermaas[2], C. Vogt[2], M. de Vos[2], S. J. Wijnholds[2], S. Yatawatta[10], and A. Zensus[5]

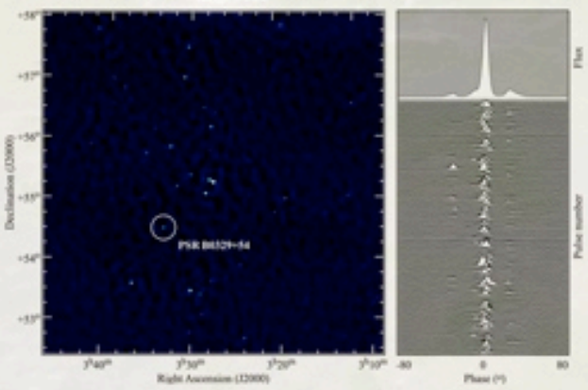


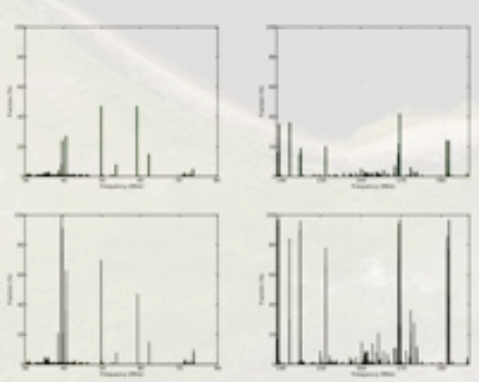


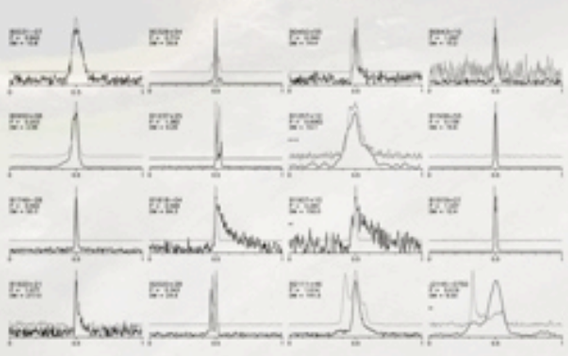












Summary

- The basic “beam-formed” data modes are working robustly.

- Offline pipeline exists to read these data into a number of publicly available pulsar software packages.

- Final steps need to be taken to provide user-friendly data products (e.g. metadata).