Status of LOFAR Pulsar Observing Modes and Pipelines Jason Hessels (ASTRON / UvA)

+LOFAR Pulsar Working Group



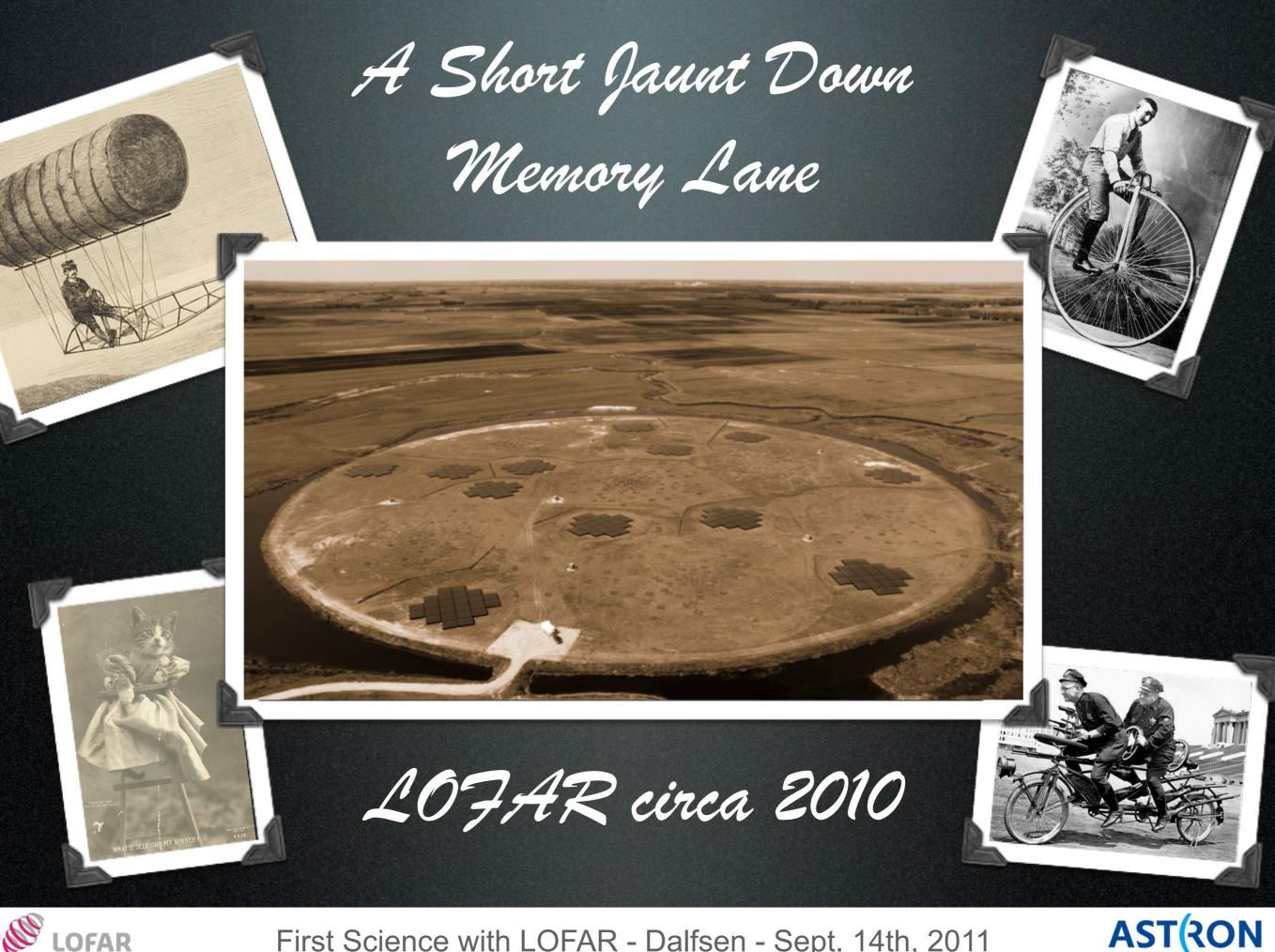


Status of LOFA Pulsar Observing Modes Pipelines Jason Housels (ASTRON / UVA)

+LOFAR Pulsar Working Group

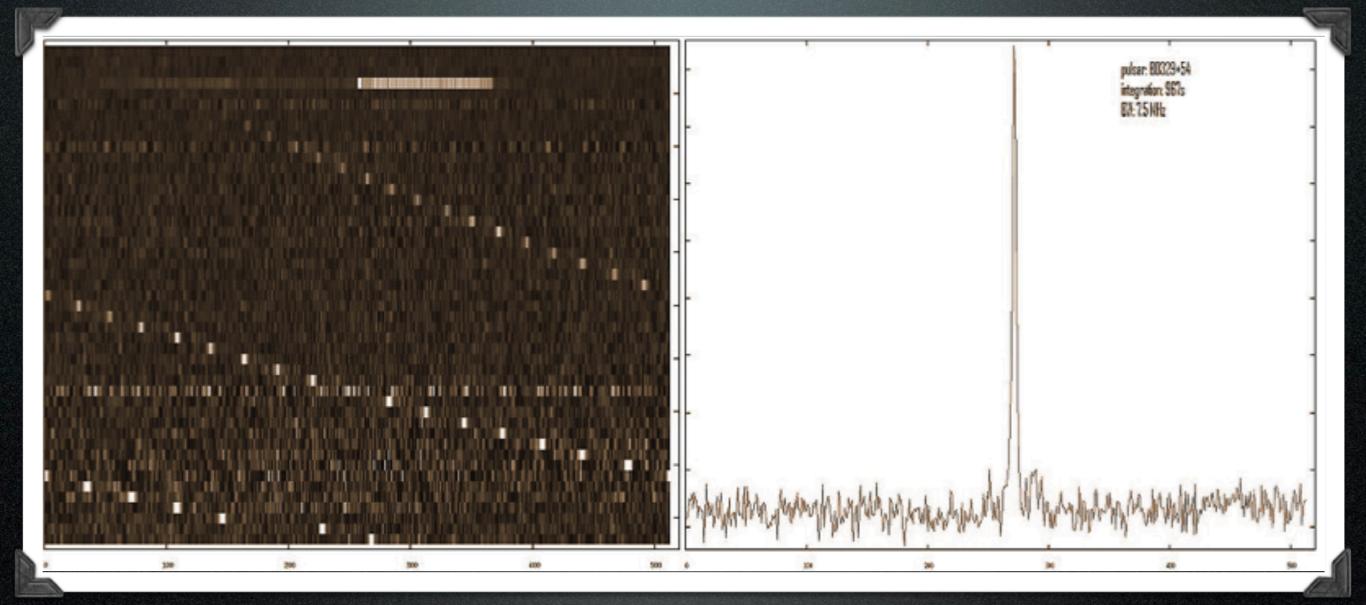






LOFAR

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

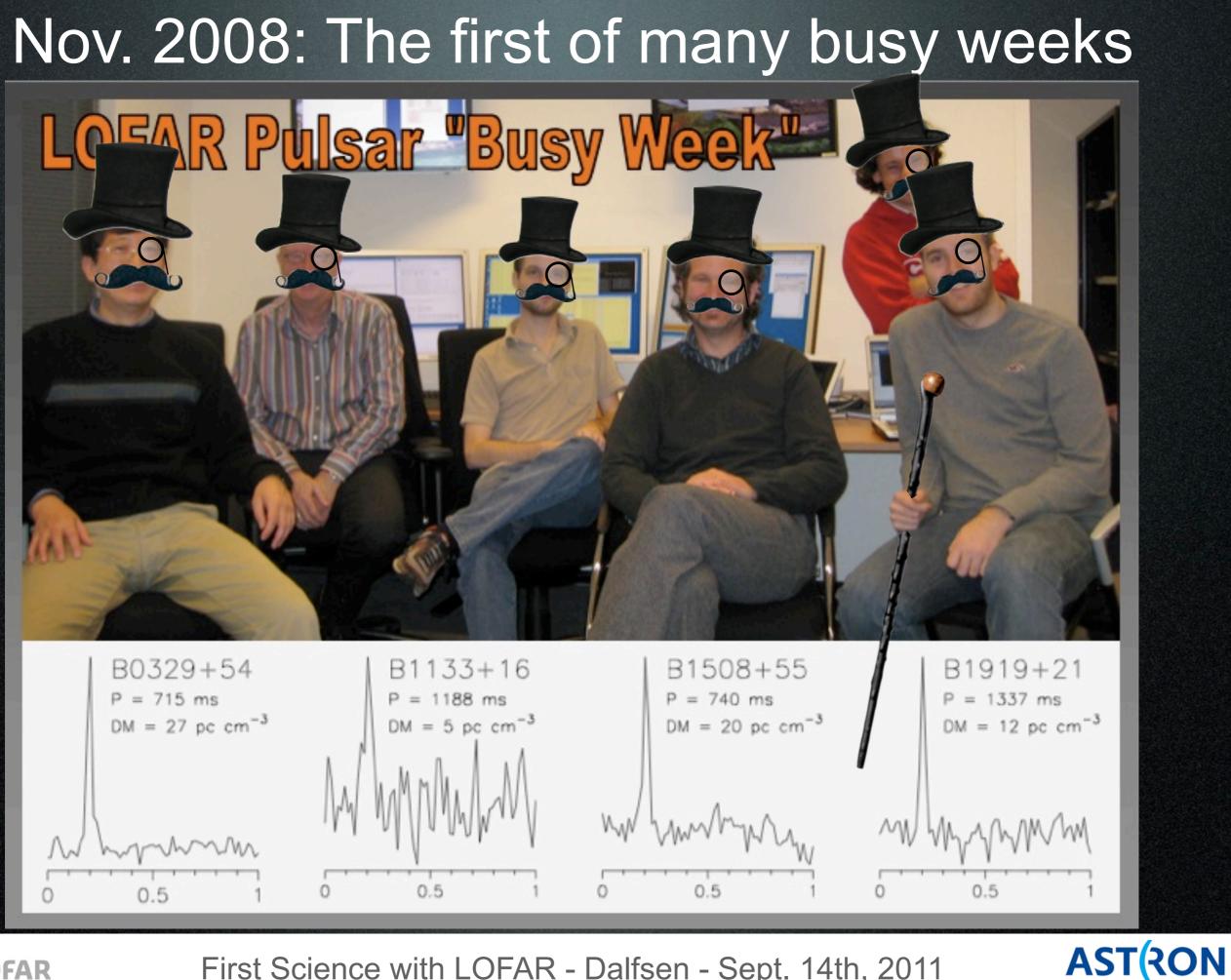


Credit: Karuppusamy & Stappers

CS1 Pulsar First Light

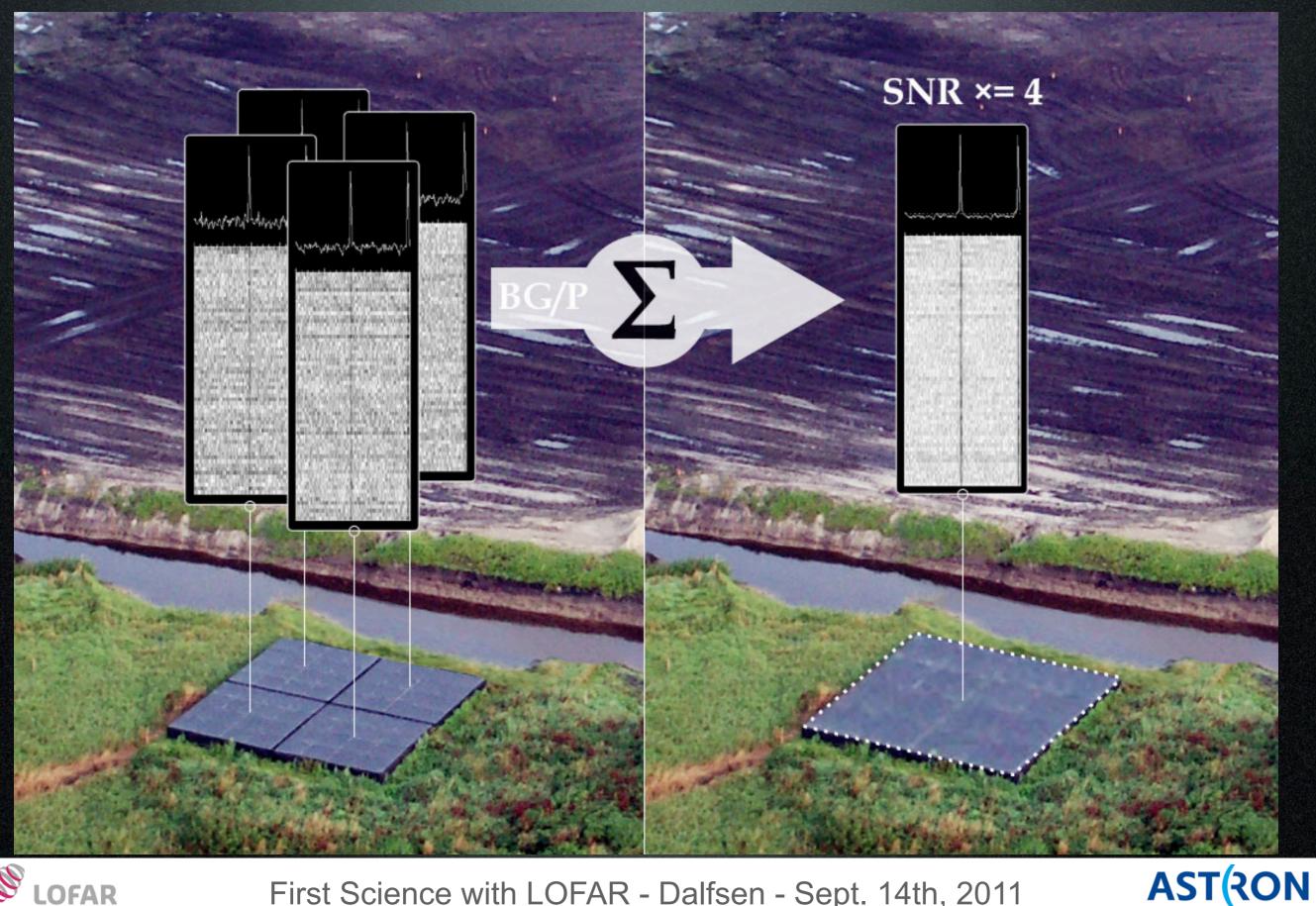






LOFAR

Tied-array beams with a whopping 4 tiles!





But things progressed quickly

Pulsar/Planet Busy Week VI



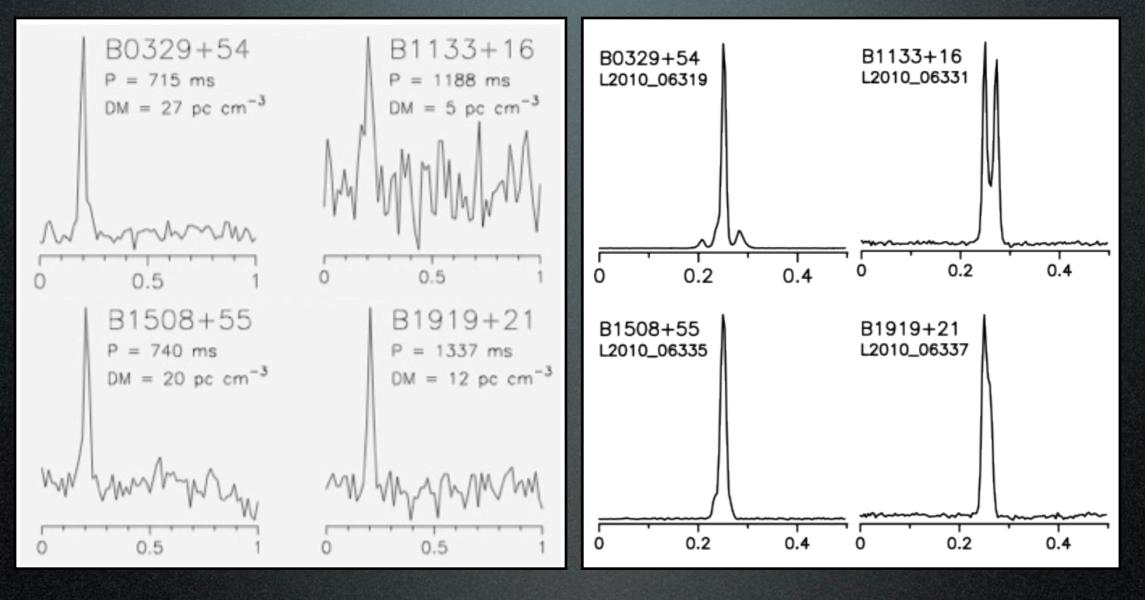
Dec 7-11, 2009

Credit: van Leeuwen





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

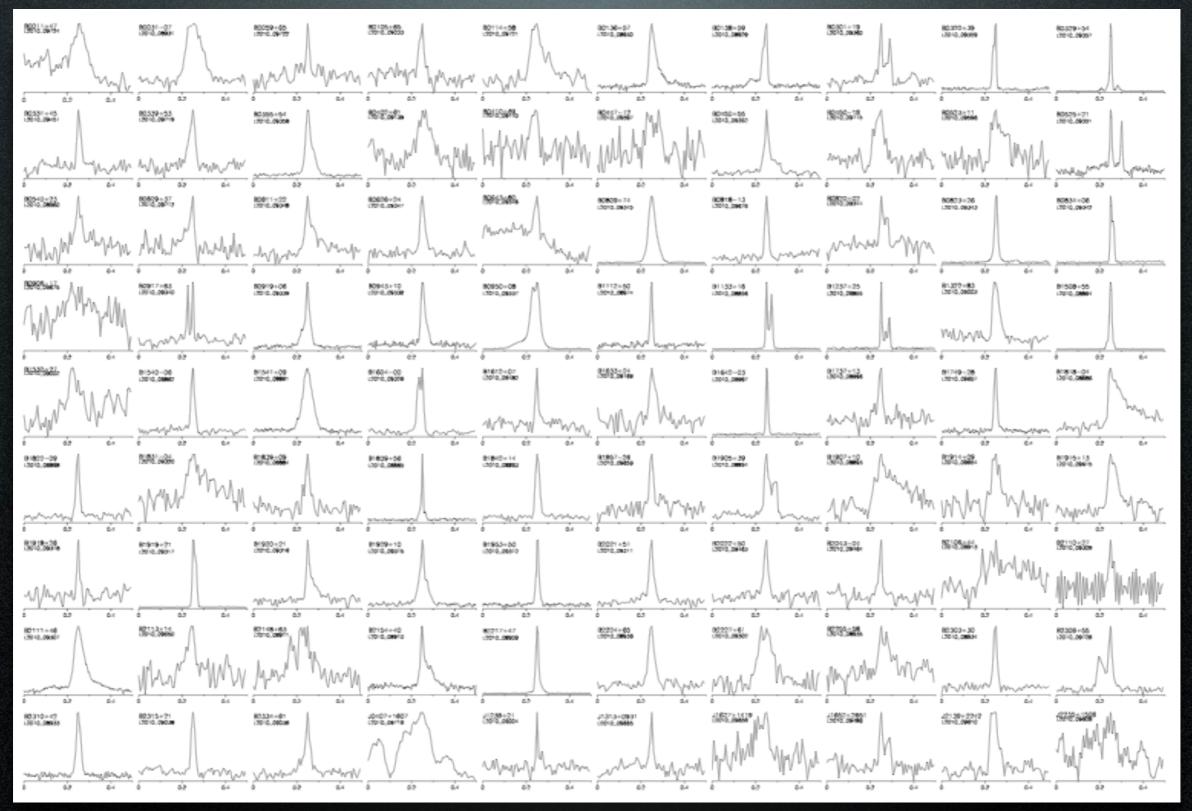


One HBA tile PBW #1 Nov. 2008 Multiple Stations PBW #7 Mar. 2010

AST(RON



Automation: 100+ Pulsars Detected with LOFAR



Credit: Hessels

LOFAR



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

AST(RON



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	



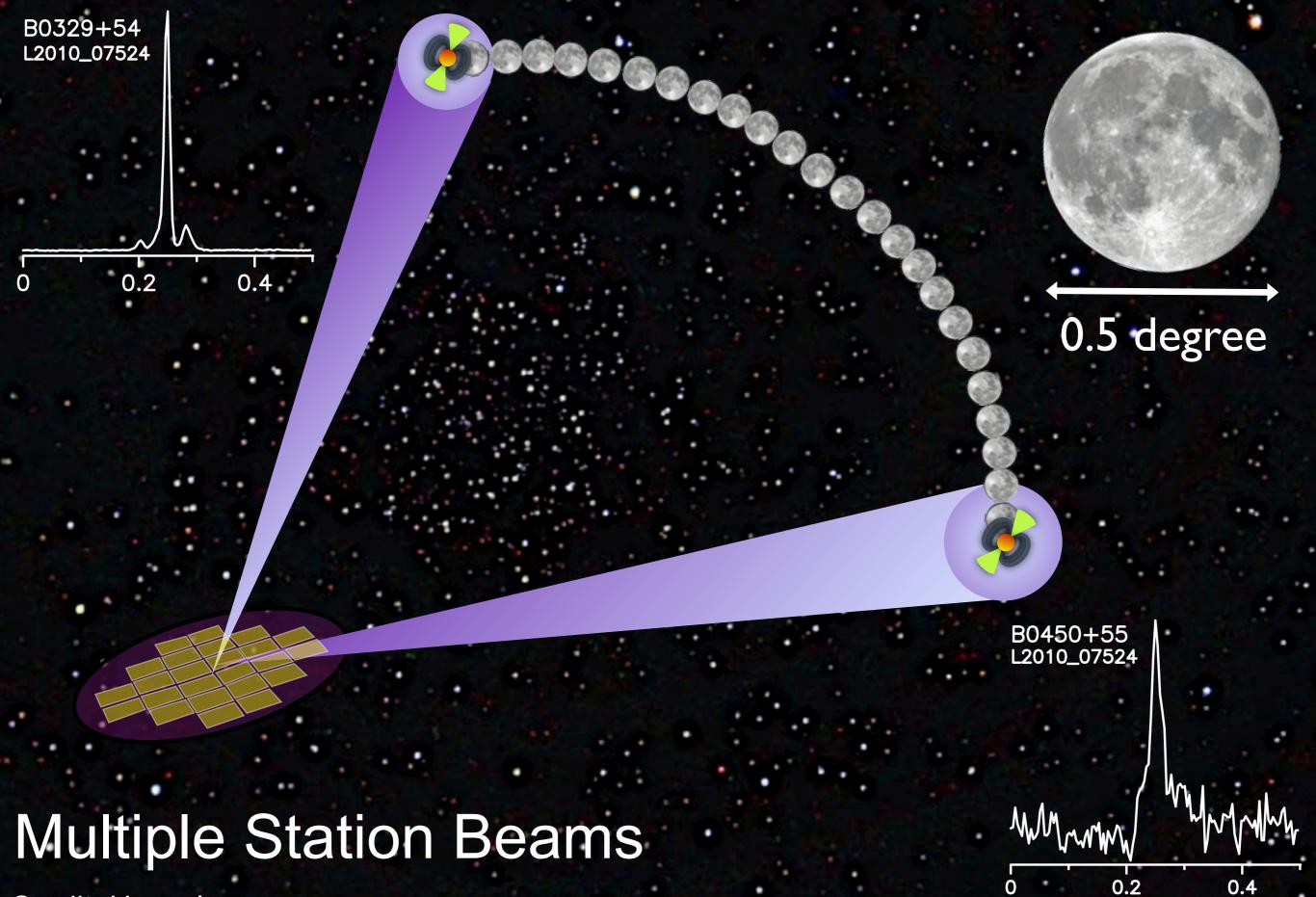


Beam-formed modes ...there are many possible.

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 addupton			0,03	36,0
Single Station	For p tim s requ		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





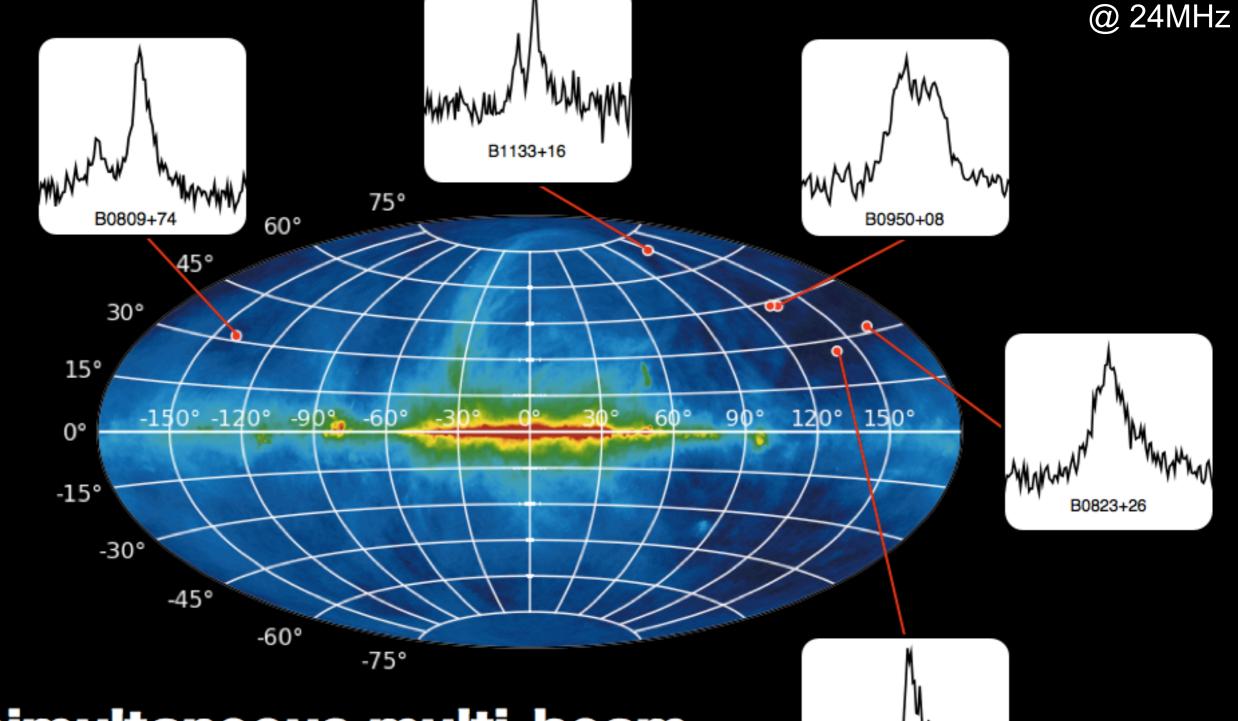


Credit: Hessels

LOFAR

First Science with LOFAR - Dalfsen - Sept. 14th, 2011

AST(RON



simultaneous multi-beam observations in the LOFAR low band

Credit: Hassall & Hessels

LOFAR

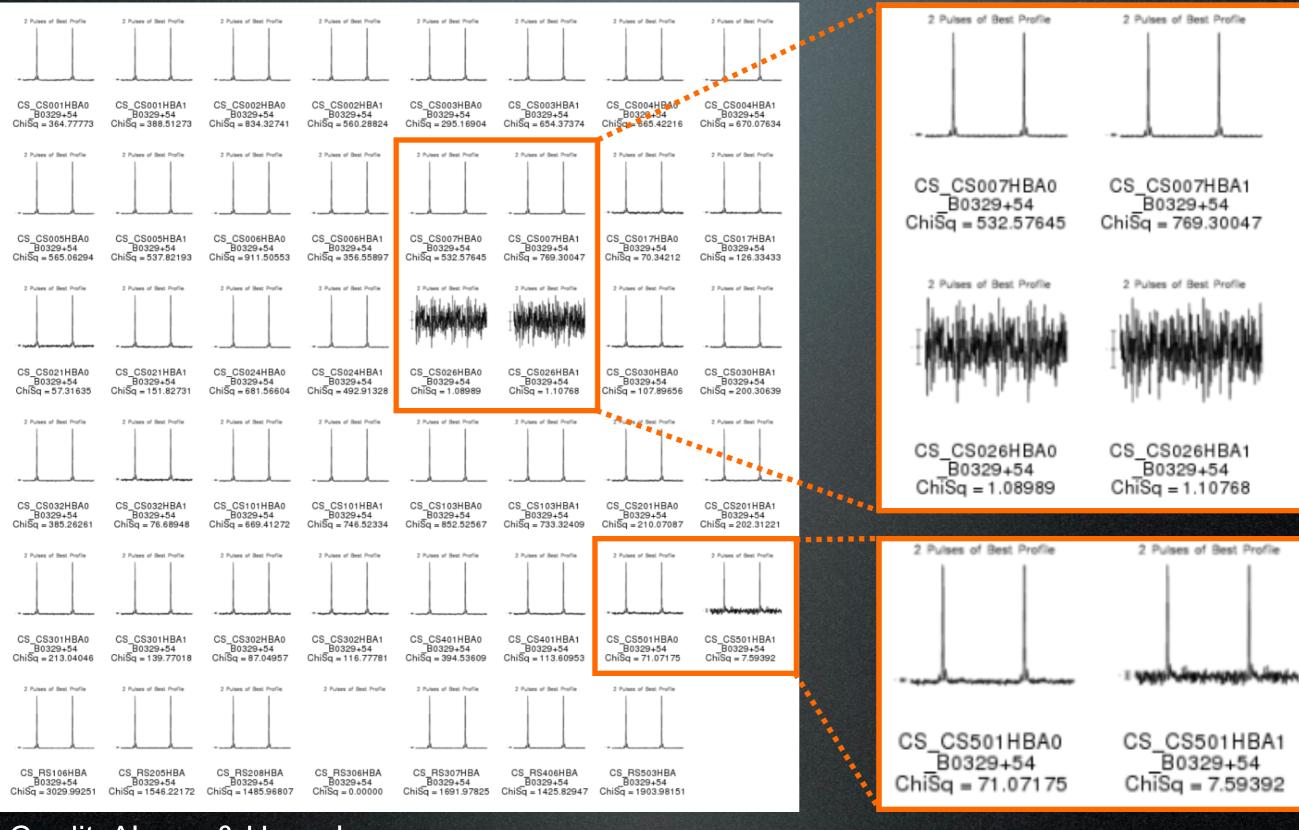
Haslam 408 MHz map courtesy of LAMBDA

AST(RON

WA-MAA

hummun

Fly's Eye Observation with 47 HBA stations

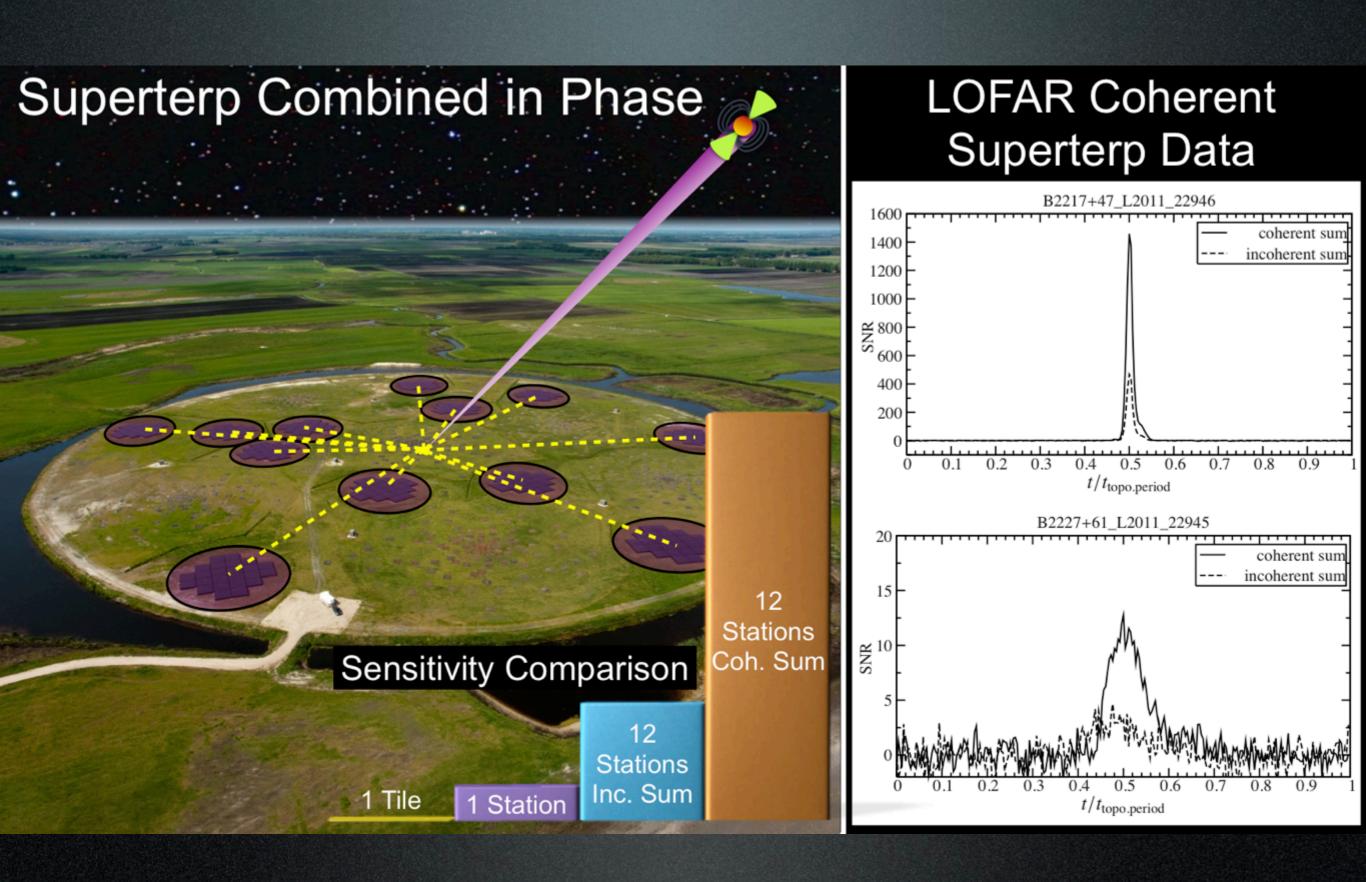


Credit: Alexov & Hessels

LOFAR

First Science with LOFAR - Dalfsen - Sept. 14th, 2011

AST(RON

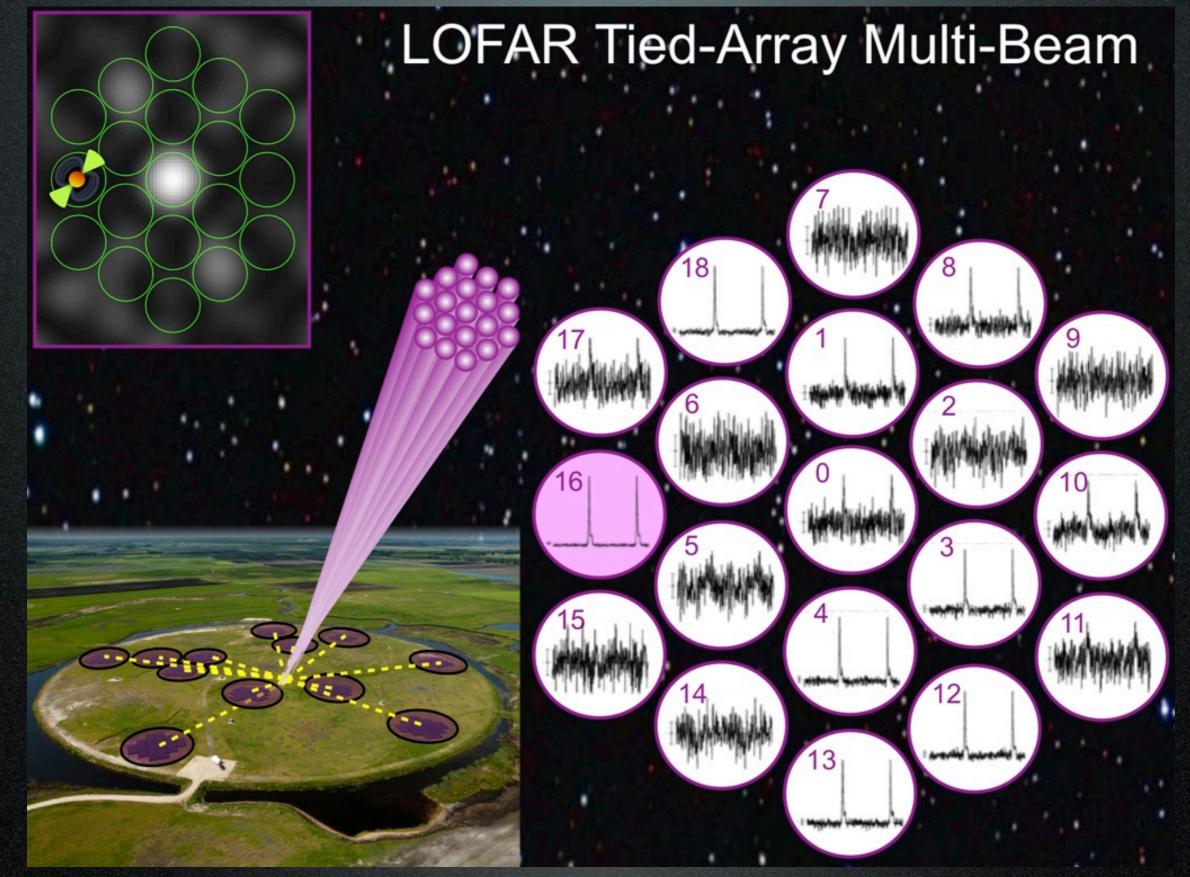


Credit: Hessels & Griessmeier

LOFAR

First Science with LOFAR - Dalfsen - Sept. 14th, 2011

AST(RON



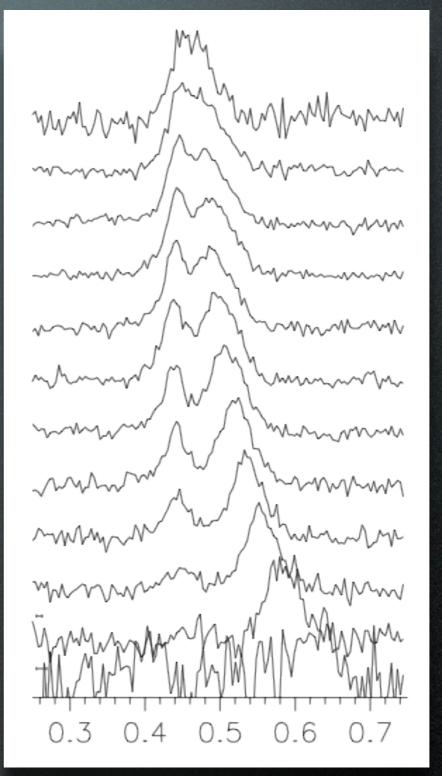
See Mol & Romein 2011 for multi-beam tied-array benchmarking results Credit: Hessels, Stappers & Scaife

LOFAR



Pulsar Detection < 30MHz

Freg: 38.768 MHz BW: 47.656 Length: 3600.000 S/N: 194.235 8 3 25 50 2 Frequency (MHz) 40 15 Index ĝ 2 ιĊ 20 0.2 0 0.4 0.60.8 Pulse Phase



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



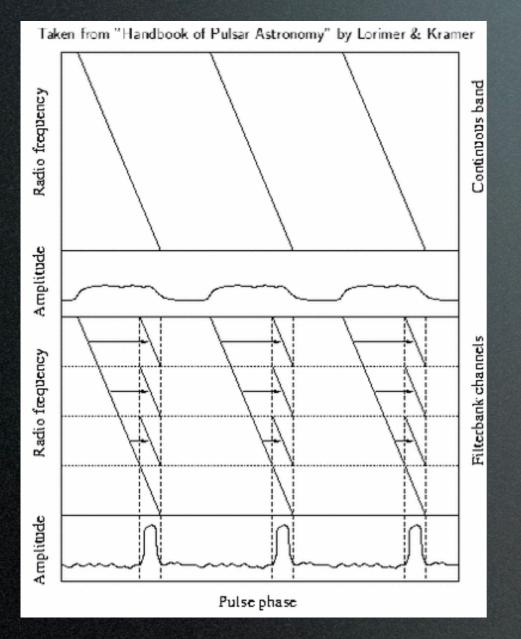
63 MHz Observing Frequency

2

-



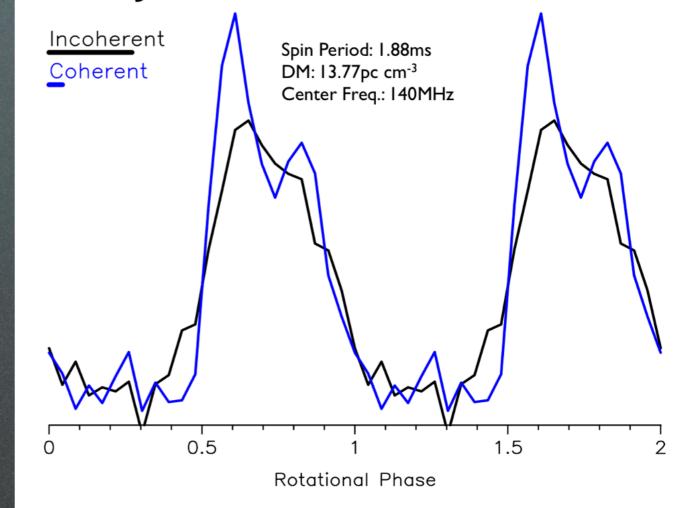
Coherent dedispersion



Incoherent dedispersion

Shift frequency channels in time

PSR J0034-0534 with LOFAR



Coherent dedispersion Apply inverse filter to raw voltages

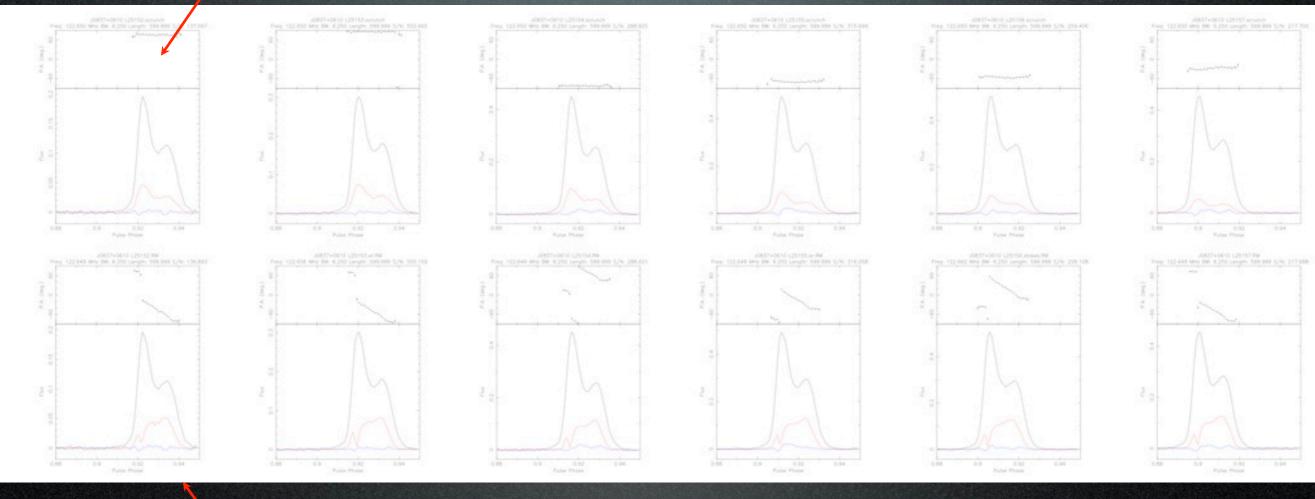
Credit: Romein, Hessels, Mol

LOFAR



Polarimetry of PSR B0834+06

RM = 0



 $HA = -1 \qquad HA = 0$

= 0

HA = +1 HA = +2

HA = +3

AST(RON

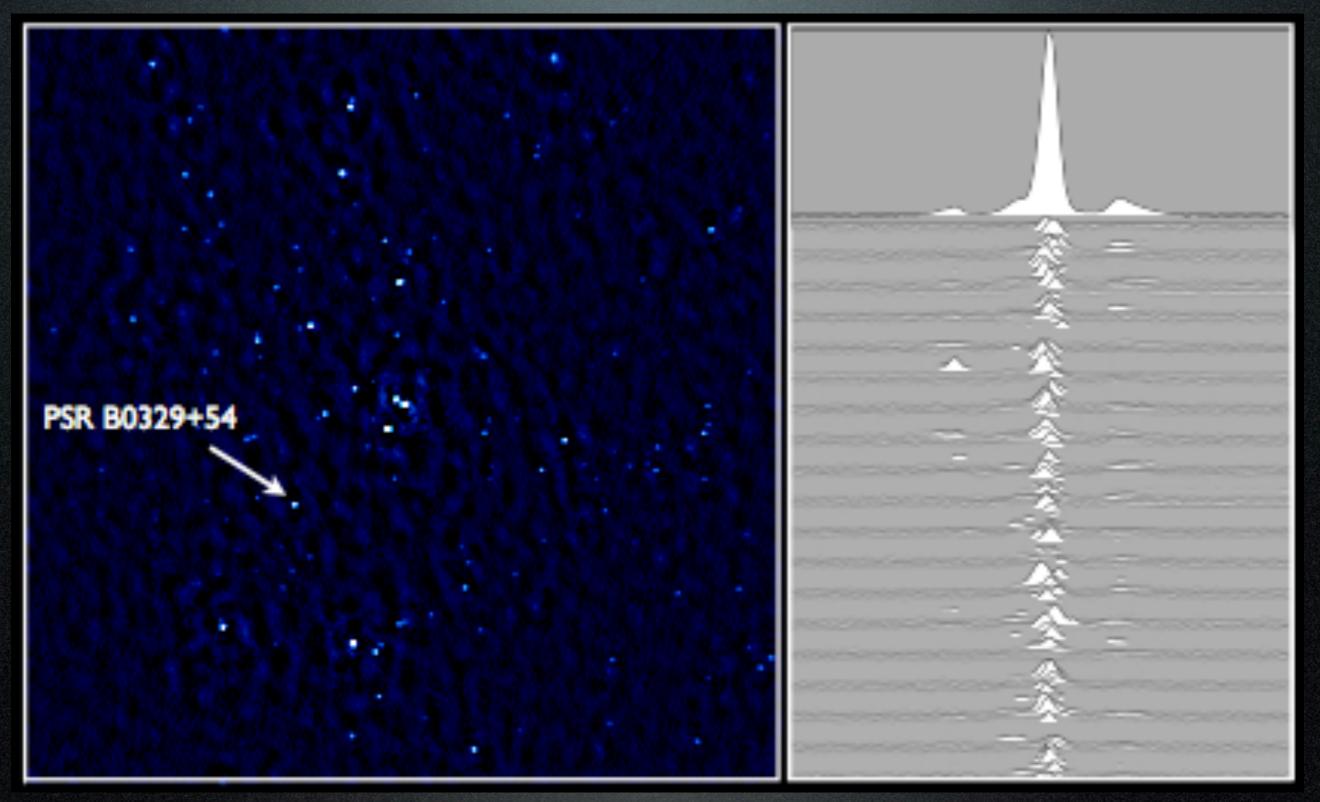
RM ~ 27

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

Credit: Sobey & Noutsos

LOFAR

Simultaneous Imaging + Pulsar Observations



Credit: Alexov, Heald & Hessels





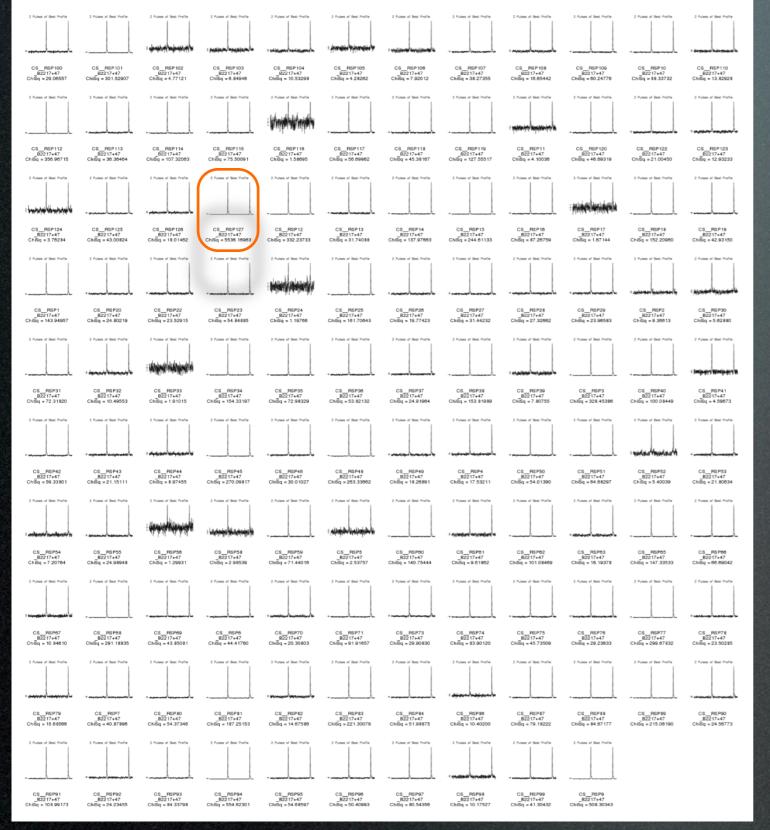
What's working

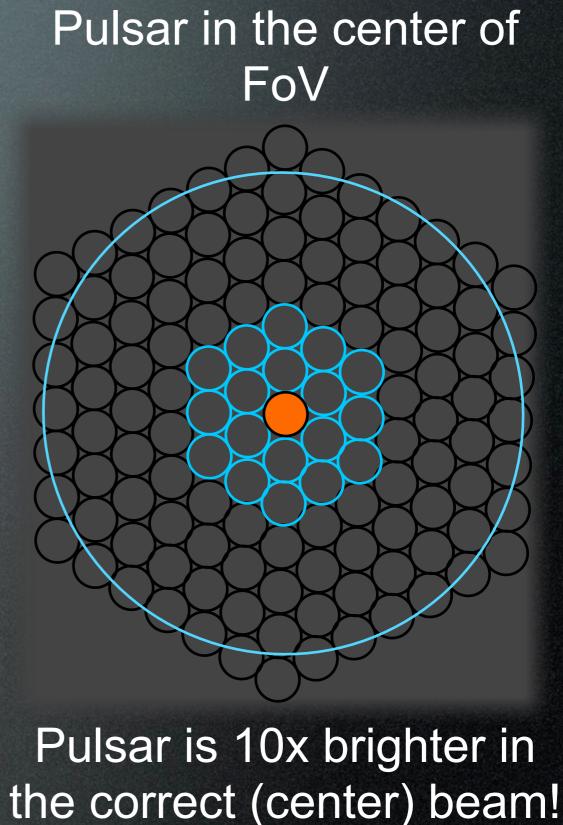
Incoherent Stokes: in principal with all stations.
Coherent Stokes (tied-array): only for Superterp. >100 beams possible!
Fly's Eye: in principal with all stations.
Online coherent dedispersion (one DM).
"Voltage"/Stokes I/Stokes IQUV output.





>100 beam Tied-Array!!





AST(RON

Credit: Alexov & Hessels

C

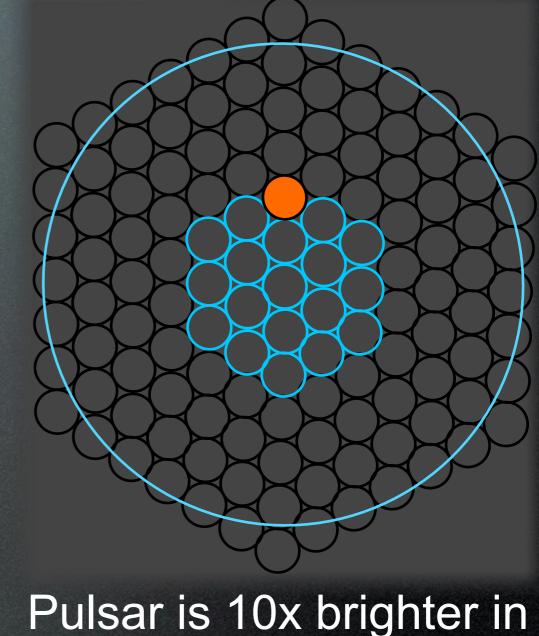
LOFAR

Data <12 hours old!!!

Data <12 hours old!!! >100 beam Tied-Array!!

2 Puters of Boot Profile	2 Puters of Dect Profile	2 Puises of Best Profile	2 Pulses of Best Profile	2 Pulses of Best Profile	2 Pulses of Best Profile	2 Pulses of Bost Profile	2 Puters of Best Profile	2 Pulses of Best Profile	2 Puters of Best Profile	2 Puters of Best Profile	2 Pulses of Best Purifie
CSRSP0 _B2217+47 ChiSq = 3.84102	CSRSP100 B2217+47 ChiSq = 5.21577	CSRSP101 _B2217+47 ChiSq = 10.14438	C5R5P102 _B2217+47 Chi5q = 18.90830	CSRSP103 _B2217+47 ChiSq = 29.29008	CSRSP104 B2217+47 Chil5q = 78.76602	CSRSP105 B2217+47 Chil5q = 38.85187	CSRSP107 _B2217+47 ChiSq = 94.48467	CSRSP108 _B2217+47 Chi5q = 22.83134	CSRSP109 _B2217+47 ChiSq = 30.95853	CSRSP10 _B2217+47 ChiSq = 3.28091	CSRSP110 _B2217+47 ChiSq = 42.03968
2 Putses of Best Profile	2 Pulses of Best Profile	2 Pulses of Best Profile	2 Pulses of Best Profile	2 Pulses of Best Profile	2 Pulses of Best Profile	2 Pulses of Best Profile	2 Pulses of Best Profile	2 Pulses of Best Profile	2 Pulses of Best Profile	2 Pulses of Best, Pulse	2 Pulses of Best Profile
CS_RSP111 	CSRSP112 _B2217+47 ChiEq = 18.46732	CS_RSP113 _B2217+47 ChiSq = 11.43756	CS_RSP114 _B2217+47 ChiSq = 13.89399	CSRSP115 _B2217+47 ChiEq = 29.77217	CSRSP116 _B2217+47 ChiEq = 35.65374	CS_RSP117 _B2217+47 ChiSq = 16.09393	CSRSP118 _B2217+47 ChiSq = 11.07580	CSRSP119 _B2217+47 Chil5q = 27.93728	CS_RSP11 _B2217+47 Chiling = 18.80358	CS_RSP120 _B2217+47 ChiSq = 2.87970	CSRSP121 _B2217+47 Chil5q = 36.22369
2 Putses of Best Profile	2 Pulses of Best Profile	2 Puters of Best Profile	2 Pulses of Best Profile	2 Pulses of Best Profile	2 Pulses of Best Profile	2 Pulses of Best Profile	2 Putes of Best Profile	2 Pulses of Best Profile	2 Puters of Best Profile	2 Puters of Best Profile	2 Pulses of Best Profile
CS_RSP122	CS_RSP123	CS_RSP124	CS_RSP125	CS_RSP126	CS_RSP 127	CS_RSP12	CS_RSP13	CS_RSP15	CS_RSP17	CS_RSP18	CS_RSP19
	B2217+47 Chi8q = 12.09370	B2217+47 ChiSq = 9.27371	B2217+47 ChiSq = 14.90891	_B2217+47 Chi5q = 191.28959 2 Putes of Best Profile	B2217+47 ChiSq = 3.84102	B2217+47 ChiSq = 39.34032	B2217+47 ChiSq = 29.00901	B2217447 Chi5q = 35.48031	B2217+47 Chil5q = 305.33452 2 Pulses of Best Profile	CSRSP18 B2217+47 ChiSq = 9.20908	B2217+47 Chil5q = 45.82212 2 Putes of Best Profile
	· : (1)144 1446-2013144 1446-2		: ::::::::::::::::::::::::::::::::::::								
CSRSP1 _B2217+47 Chil5q = 66.35859	CSRSP20 _B2217+47 ChiSq = 3.50756	CS_RSP21 _B2217+47 ChiSq = 125.00459	CSR\$P22 _B2217+47 ChiSq = 2.64576	CSRSP23 _B2217+47 Chi5q = 24.31478	CSRSP24 _B2217+47 ChiSq = 7.88243	CSR\$P25 _B2217+47 ChiSq = 47.72461	CS_RSP26 _B2217+47 ChiSq = 60.97934	CSRSP27 _B2217+47 Chi5q = 97.63964	CSRSP28 B2217+47 ChiSq = 13.24113	CSRSP2 _82217+47 Chil5q = 175.89080	CS_RSP30 _B2217+47 ChiSq = 61.01356
2 Pulses of Best Profile	2 Pulses of Best Profile	2 Pulses of Best Profile	2 Pulses of Best Profile	2 Pulses of Best Profile	2 Pulses of Best Profile	2 Pulses of Best Profile	2 Pulses of Best Profile	2 Pulses of Best Profile	2 Pulses of Best Profile	2 Pulses of Best Profile	2 Pulses of Best Profile
			: હેમનાં પ્રમંત્રદેવનાં પ્રમંત્ર	-	: many fanimany fani						·
CSRSP31 _B2217+47 ChiSq = 15.21648	CSRSP32 _B2217+47 ChiSq = 33.01832	CSR6P33 _B2217+47 ChiSq = 23.03303	CSRSP34 _B2217+47 ChiSq = 3.80096	CSRSP35 _B2217+47 Chi5q = 2.84093	CSRSP36 _B2217+47 Chil5q = 3.14405	CSRSP37 _B2217+47 ChiSq = 49.98668	CSRSP38 _B2217+47 ChiSq = 24.67797	CSRSP39 _B2217+47 Chil5q = 254.78325	CSRSP3 B2217+47 ChiSq = 55.21388	CSRSP40 _B2217+47 Chi5q = 98.72886	CSRSP41 _B2217+47 Chi5q = 20.82470
2 Pulses of Best Profile	2 Pulses of Best Profile	2 Pulses of Best Profile	2 Pulses of Best Profile	2 Pulses of Best Profile	2 Pulses of Best Profile	2 Pulses of Best Profile	2 Pulses of Best Profile	2 Pulses of Best Profile	2 Pulses of Best Profile	2 Pulses of Best Profile	2 Pulses of Best Profile
CSRSP43 _B2217+47 ChiSq = 161.45927	CSRSP44 _B2217+47 ChiSq = 45.91440	CSRSP45 B2217+47 ChiSq = 2.96185	CSRSP46 _B2217+47 ChiSq = 9.64898	CSRSP47 B2217+47 ChiSq = 18.12481	CSRSP48 B2217+47 ChiSq = 20.61801	CSRSP49 B2217+47 ChiSq = 31.96898	CSRSP4 B2217+47 ChiSq = 50.23818	CSRSP50 B2217+47 Chil5q = 69.21919	CS_RSP51 Chilling = 82.61759	CSRSP52 	CSRSP53 B2217+47 Chil5q = 14.71570
2 Puters of Best Profile	2 Pulses of Best Profile	2 Pulses of Best Profile	2 Pulses of Best Profile	2 Puters of Best Profile	2 Puisses of Best Purity	2 Pulses of Best Profile	2 Puters of Best Profile	2 Pulses of Best Profile	2 Pulses of Best Profile	2 Pulses of Best Profile	2 Pulses of Best Profile
CS_RSP54	CS_RSP55	CS_RSP56	cs_RSP57	: 444 at 144 at 144	CS_RSP59	CS_RSP5	CS_RSP60	CS_RSP61	CS_RSP62	CS_RSP63	5_RSP04
B2217+47 B2217+47 ChiSq = 93.50246	B2217+47 ChiSq = 41.84382		B2217+47 Chil5q = 33.01829	B2217+47 Chi5q = 5.22884		B2217+47 Chilling = 41.09880	B2217+47 Chi8q = 50.89289				_B2217+47 Chil5q = 2.55673
CSRSP65 _B2217+47 Chil5q = 54.36959	CSRSP66 _B2217+47 Chi5q = 94.29981	CSRSP67 _B2217+47 Chi5q = 9.17553	CS_RSP68 _B2217+47 Chi5q = 14.43198	CSRSP69 _B2217+47 ChiSq = 130.90562	CS_RSP6 _B2217+47 Chi5q = 50.34222	CS_RSP70 _B2217+47 Chi5q = 15.18803	CSRSP71 _B2217+47 ChiSq = 8.07039	CS_RSP72 _B2217+47 Chi5q = 43.56916	CS_RSP73 _B2217+47 Chi5q = 21.58010	CS_RSP74 _B2217+47 ChiSq = 158.39009	CS_RSP75 _B2217+47 ChiSq = 17.88244
2 Pulses of Best Profile	2 Pulses of Best Profile	2 Pulses of Best Profile	2 Pulses of Best Profile	2 Pulses of Best Profile	2 Pulses of Best Profile	2 Pulses of Best Profile	2 Puters of Best Profile	2 Puters of Best Profile	2 Putes of Best Profile	2 Pulses of Best Profile	2 Pulses of Best Profile
CS_RSP76 _B2217+47	CSRSP77 _B2217+47	CS_RSP79 _B2217+47	CS_RSP7 _B2217+47	CS_RSP#1 _B2217+47	CSRSPR2 B2217+47	CS_RSP83 _B2217+47	CS_RSP84 B2217+47	CS_RSP85 _B2217+47	CS_RSP86 _B2217+47	CS_RSP87 _B2217+47	CS_RSP88 _B2217+47
Chilling = 74.82192	ChiBq = 78.58454	Chil5q = 292.20887	ChiSq = 2238.28918	ChiSq = 39.10984	Chil5q = 185.81053	Chil5q = 27.88527	Chil5q = 5.22781	2 Pulses of Best Profile	2 Puters of Best Profile	2 Pulses of Best Profile	Chil5q = 45.03107
			= andoriyasoniandoriyasoni	-			I yayah kesali yayah kesali				T Aning Service and
CS_RSP99 _B2217+47 ChiSq = 83.98218	CSRSP8 _B2217+47 ChiSq = 443.58573	CS_RSP90 _B2217+47 ChiSq = 24.80573	CS_RSP91 _B2217+47 ChiSq = 2.76958	CSRSP92 _B2217+47 Chi5q = 75.13074	CSRSP94 _B2217+47 Chil5q = 113.84326	CS_RSP95 _B2217+47 ChiSq = 11.93789	CS_RSP98 _B2217+47 ChiSq = 4.94241	CSRSP97 _B2217+47 ChiSq = 30.87932	CSRSP98 _B2217+47 ChiSq = 24.80802	CS_RSP99 _B2217+47 Chi5q = 178.82393	CS_RSP9 _B2217+47 ChiSq = 17.10421

Shifted 1 deg south



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

AST(RON

Credit: Alexov & Hessels

LOFAR

Tile-out Primary Beam with Many "Tied-Array" Beams

Important to regain FoV





What needs work

Online flagging: especially important for incoherent mode.

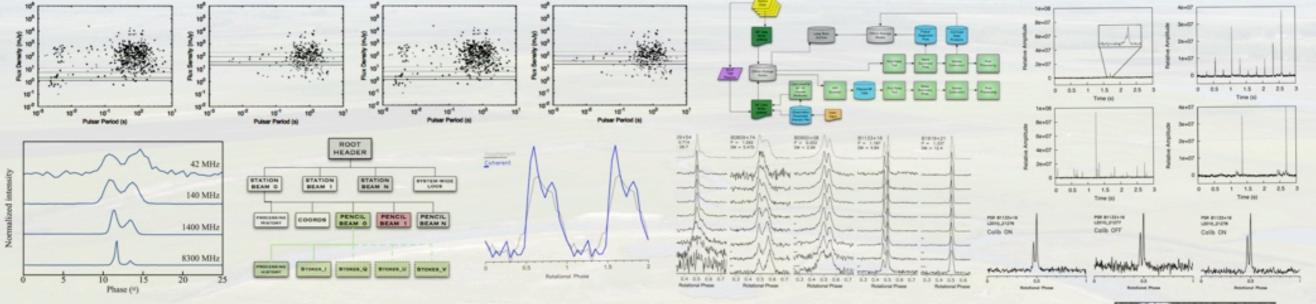
Full-core tied-array: single clock.
Wide-field Fly's Eye: point in different directions.

Simultaneous obs.: e.g. sub-array observations with LBA and HBA.
Data products: move to HDF5 and more upon friendly data products (DAL)

more user-friendly data products (DAL).







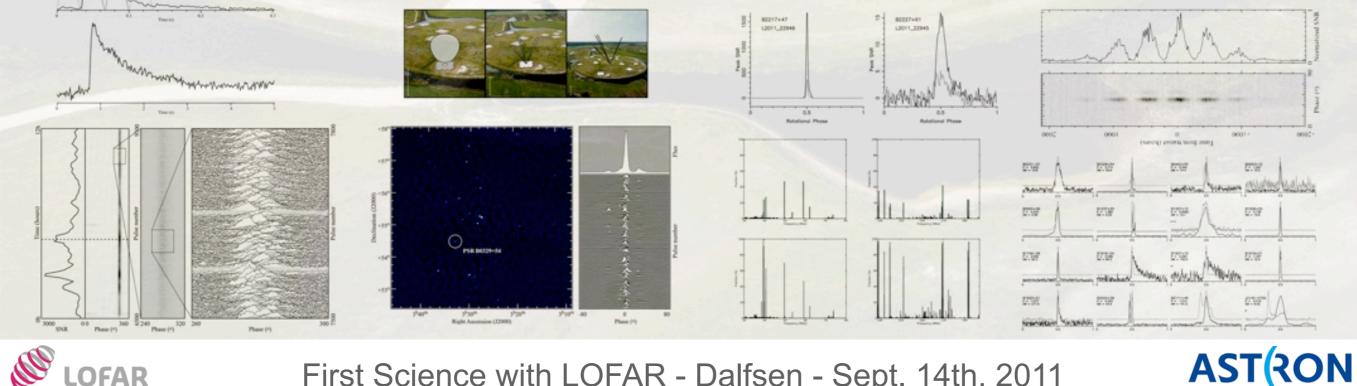
Observing pulsars and fast transients with LOFAR

B. W. Stappers¹, J. W. T. Hessels^{2,3} A. Alexov³, K. Anderson³, T. Coenen³, T. Hassall¹, A. Karastergiou⁴, V. I. Kondratiev², M. Kramer^{5,1}, J. van Leeuwen^{2,3}, J. D. Mol², A. Noutsos⁵, J. W. Romein², P. Weltevrede¹, R. Fender⁶, R. A. M. J. Wijers³, L. Bähren³, M. E. Bell⁶, J. Broderick⁶, E. J. Daw⁸, V. S. Dhillon⁸, J. Eislöffel¹⁹, H. Falcke^{12,2}, J. Griessmeier^{2,22}, C. Law^{24,3}, S. Markoff³ J. C. A. Miller-Jones^{13,3}, B. Scheers³, H. Spreeuw³, J. Swinbank³, S. ter Veen¹² M. W. Wise^{2,3}, O. Wucknitz¹⁷, P. Zarka¹⁶, J. Anderson⁵, A. Asgekar², I. M. Avruch^{2,10}, R. Beck⁵, P. Bennema², M. J. Bentum², P. Best¹⁵, J. Bregman², M. Brentjens², R. H. van de Brink², P. C. Broekema², W. N. Brouw¹⁰, M. Brüggen²¹, A. G. de Bruyn^{2,10}, H. R. Butcher^{2,26}, B. Ciardi⁷, J. Conway¹¹, R.-J. Dettmar²⁰, A. van Duin², J. van Enst², M. Garrett^{2,9}, M. Gerbers², T. Grit², A. Gunst², M. P. van Haarlem², J. P. Hamaker² G. Heald², M. Hoeft¹⁹, H. Holties², A. Horneffer^{5,12}, L. V. E. Koopmans¹⁰ G. Kuper², M. Loose², P. Maat², D. McKay-Bukowski¹⁴, J. P. McKean², G. Miley⁹, R. Morganti^{2,10}, R. Nijboer², J. E. Noordam², M. Norden², H. Olofsson¹¹, M. Pandey-Pommier^{9,25}, A. Polatidis², W. Reich⁵, H. Röttgering⁹, A. Schoenmakers², J. Sluman², O. Smirnov², M. Steinmetz¹⁸, C. G. M. Sterks²³, M. Tagger²², Y. Tang², R. Vermeulen², N. Vermaas², C. Vogt², M. de Vos², S. J. Wijnholds², S. Yatawatta¹⁰,

LOFAR



Delay (s)



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).



