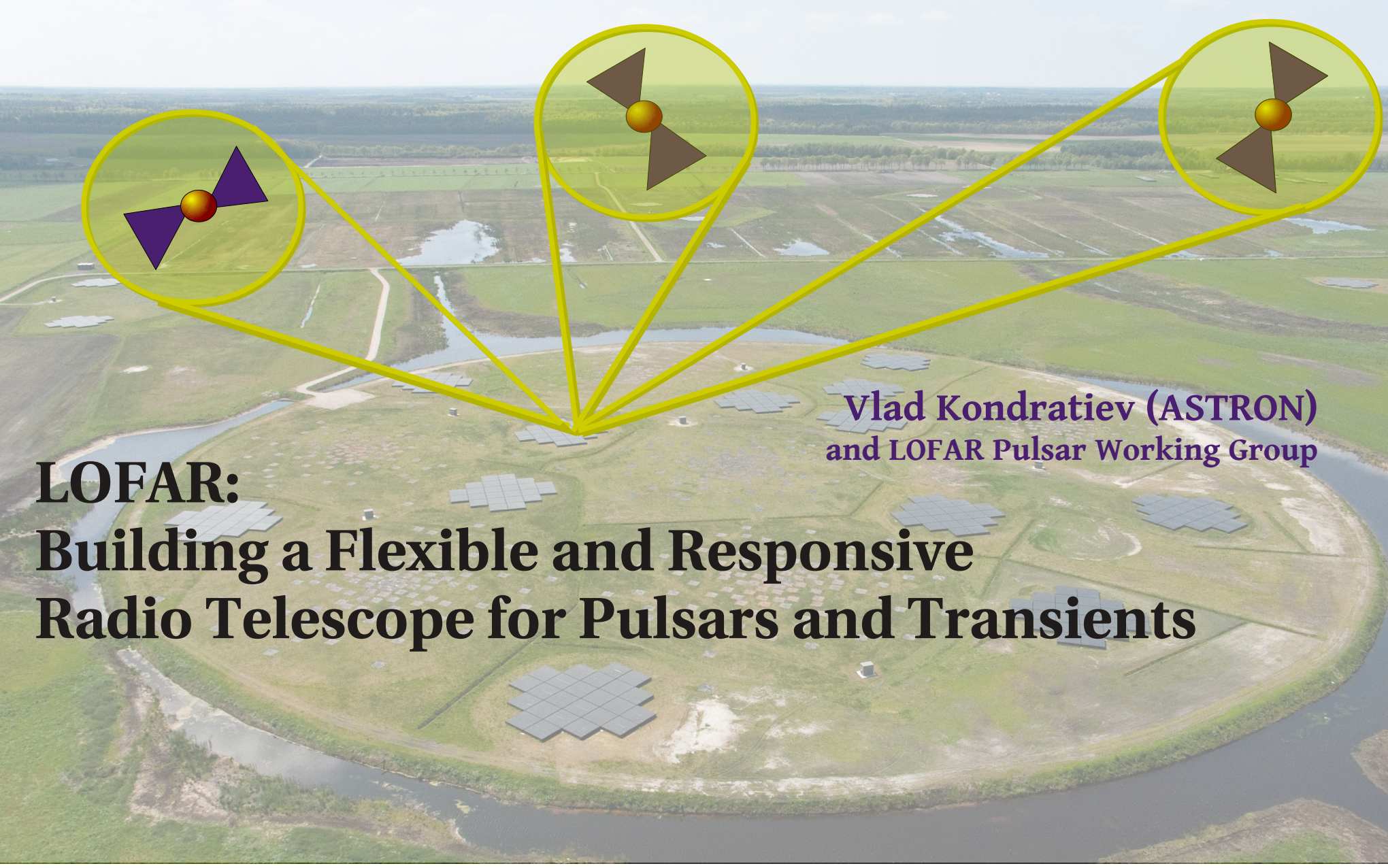


Vlad Kondratiev (ASTRON)
and LOFAR Pulsar Working Group

LOFAR: Building a Flexible and Responsive Radio Telescope for Pulsars and Transients

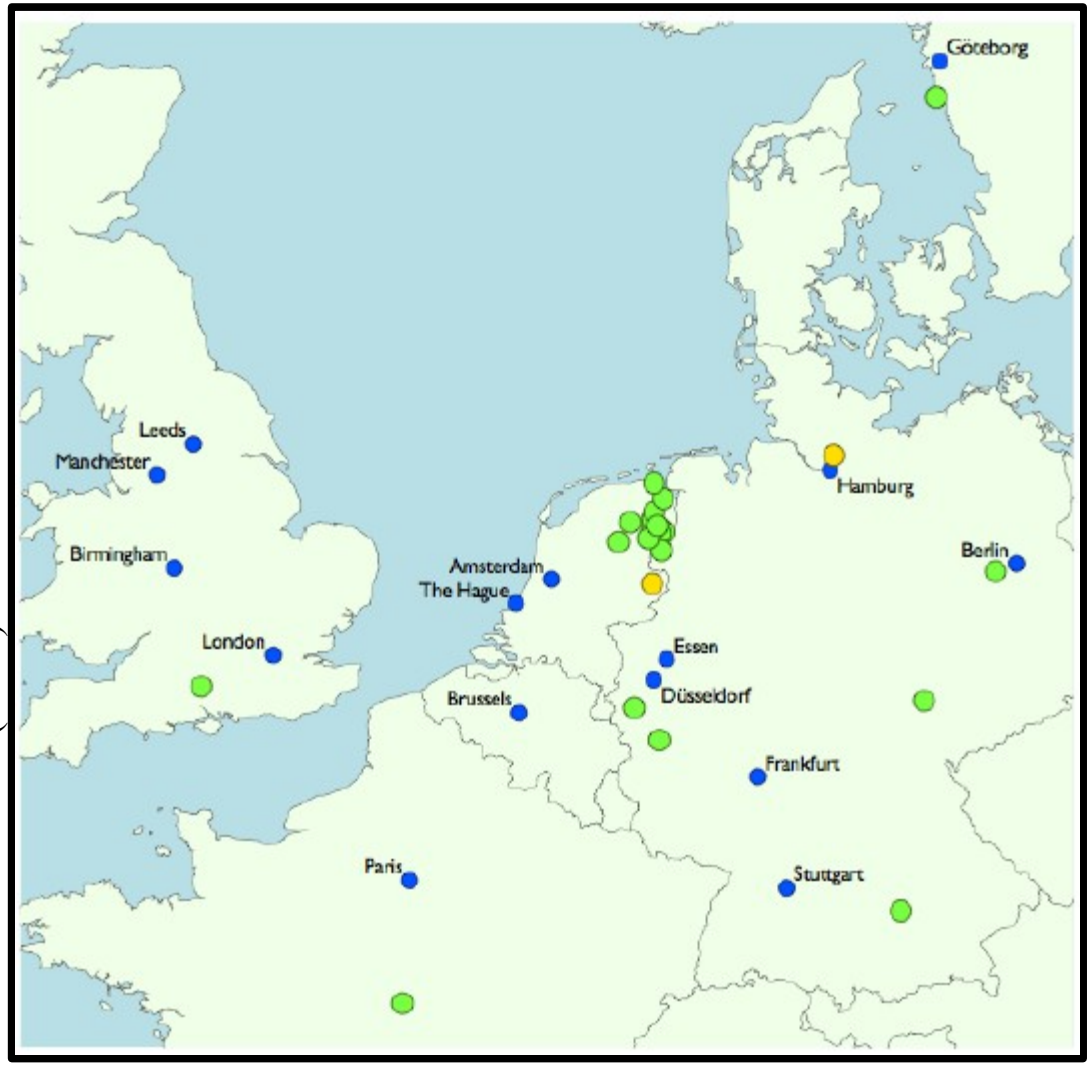
LOFAR Pulsar Working Group

Jason Hessels (co-lead)	*ASTRON/Universiteit van Amsterdam*
Ben Stappers (co-lead)	*University of Manchester*
Anya Bilous	*Radbound Universiteit Nijmegen*
Thijs Coenen	*Universiteit van Amsterdam*
Sally Cooper	*University of Manchester*
Heino Falcke	*Radbound Universiteit Nijmegen*
Jean-Mathias Grießmeier	*LPC2E/CNRS/Université d'Orléans*
Tom Hassall	*University of Southampton*
Aris Karastergiou	*University of Oxford*
Evan Keane	*MPI für Radioastronomie*
Vlad Kondratiev	*ASTRON*
Michael Kramer	*MPI für Radioastronomie*
Masaya Kuniyoshi	*MPI für Radioastronomie*
Joeri van Leeuwen	*ASTRON/Universiteit van Amsterdam*
Aris Noutsos	*MPI für Radioastronomie*
Maura Pilia	*ASTRON*
Maciej Serylak	*LPC2E/CNRS*
Charlotte Sobey	*MPI für Radioastronomie*
Sander ter Veen	*Radbound Universiteit Nijmegen*
Joris Verbiest	*MPI für Radioastronomie*
Patrick Weltevrede	*University of Manchester*
Kimon Zagkouris	*University of Oxford*

Outline:

- ✔ LOFAR – where and whats
- ✔ Observing capabilities
- ✔ Towards aperture arrays (paving the road to SKA)
- ✔ LOFAR and timing

LOFAR across Europe



van Haarlem et al. (2013)

40 Dutch

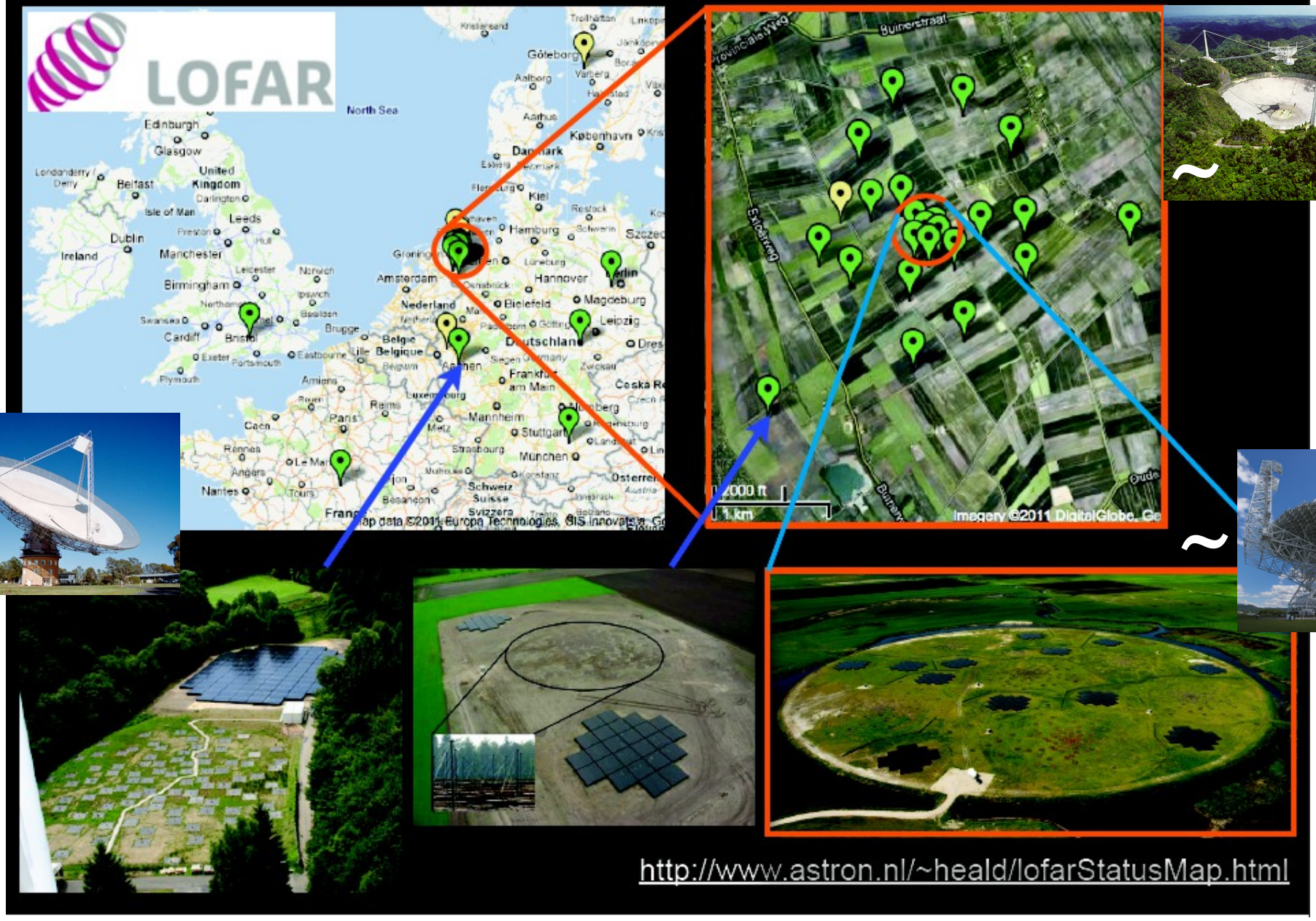
+

9 Intl. Stations

LOFAR in NL

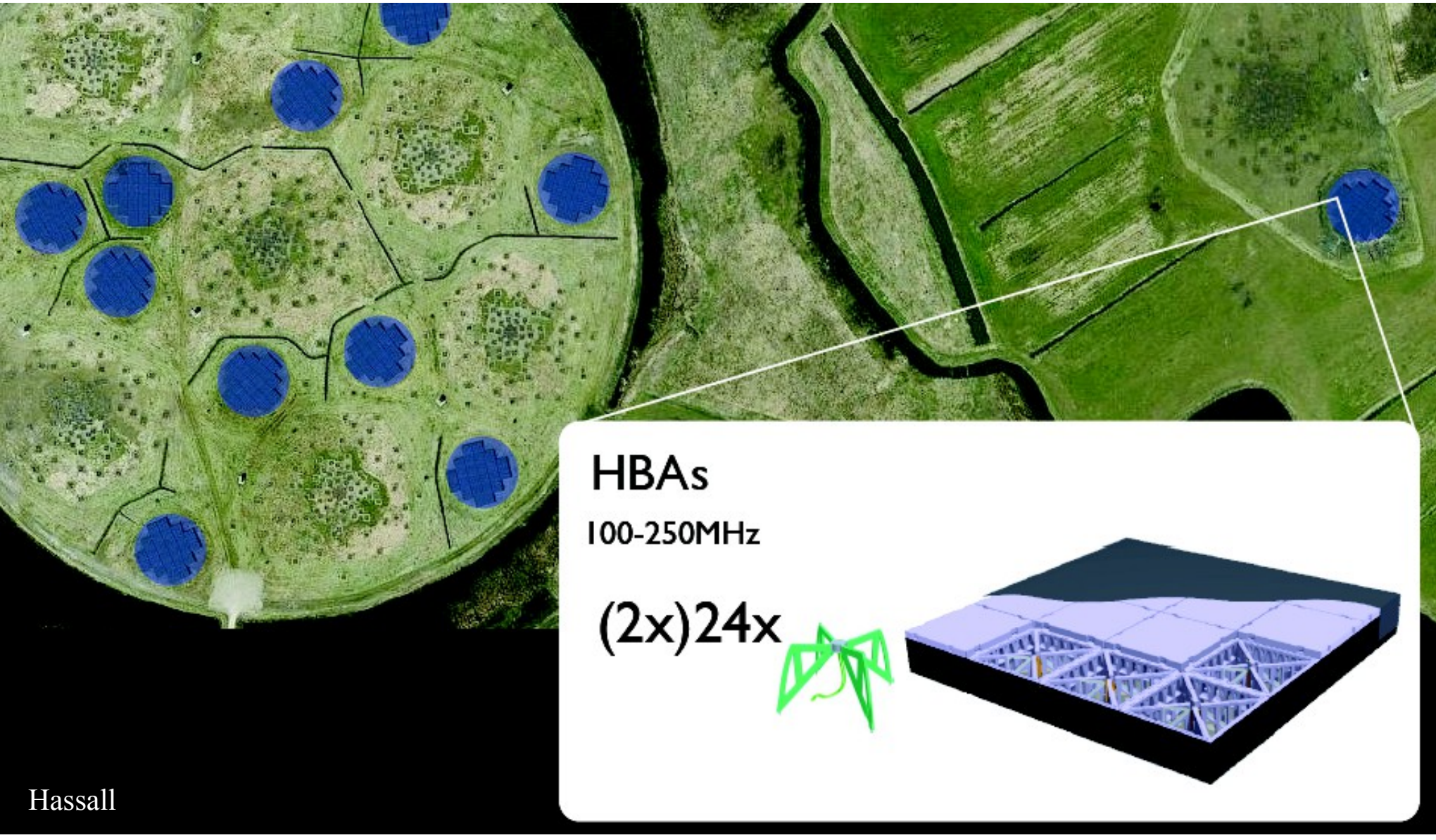
van Haarlem et al. (2013)

24 Core + 16 Remote Stations

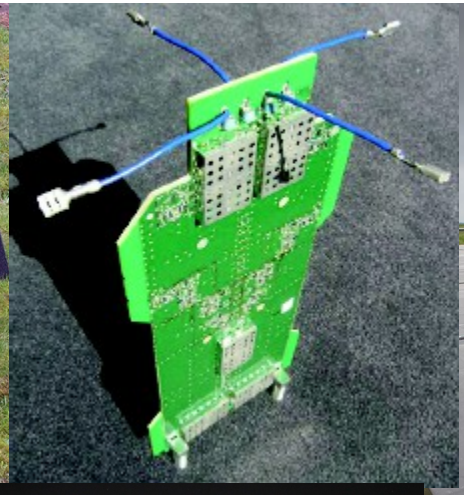

LOFAR
North Sea
Edinburgh
Glasgow
Belfast
United Kingdom
Dublin
Ireland
Manchester
Leeds
Birmingham
Cardiff
Bristol
Amsterdam
Nederland
Belgique
Hamburg
Hannover
Berlin
Bielefeld
Magdeburg
Leipzig
Deutschland
Frankfurt am Main
Mannheim
Stuttgart
München
Paris
Schweiz
Suisse
Imagery ©2011 DigitalGlobe, Ge
http://www.astron.nl/~heald/lofarStatusMap.html

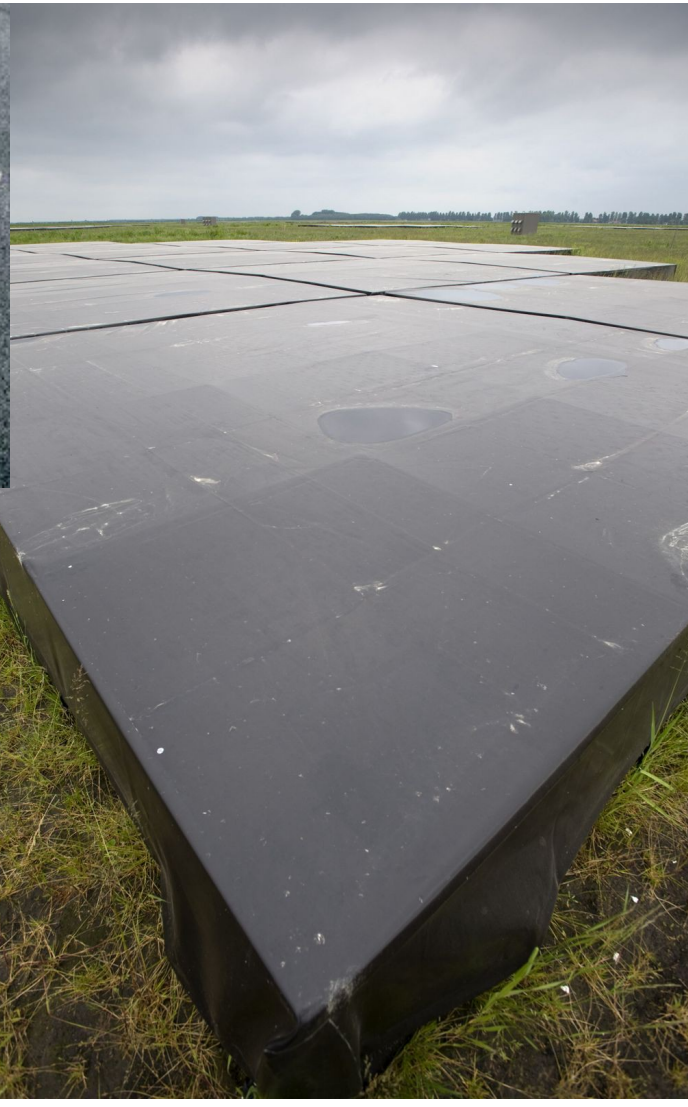
Hassall

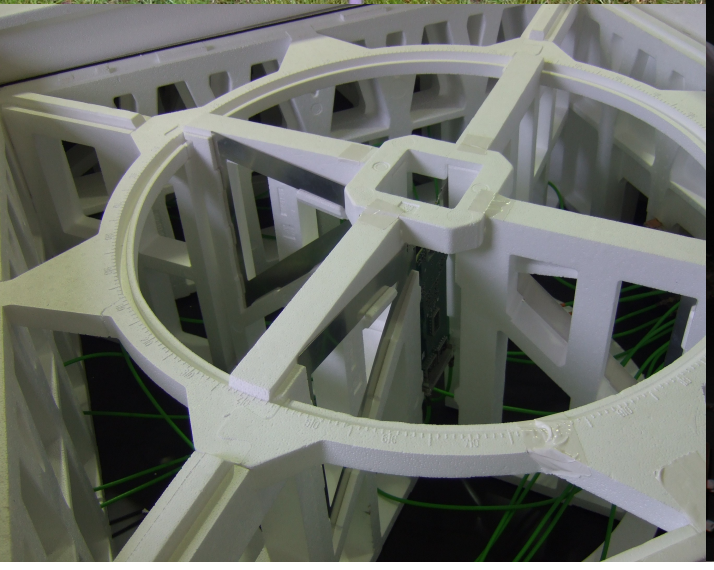
Hassall

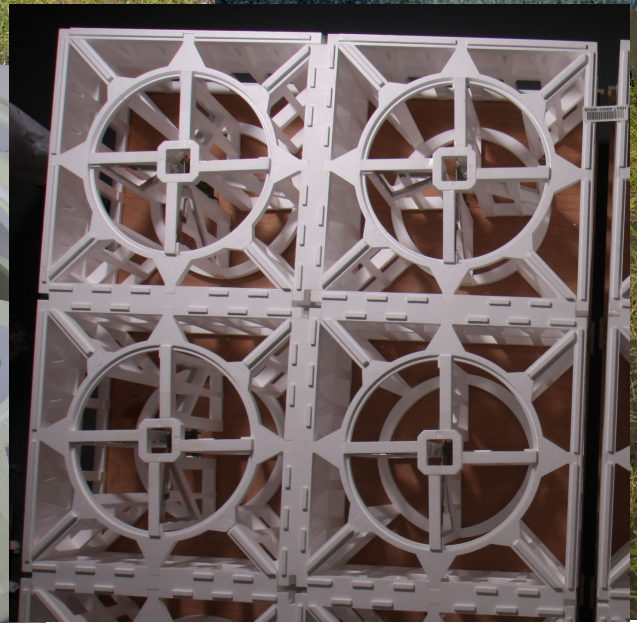

HBAs
100-250MHz
(2x)24x
Hassall

High Band Antenna

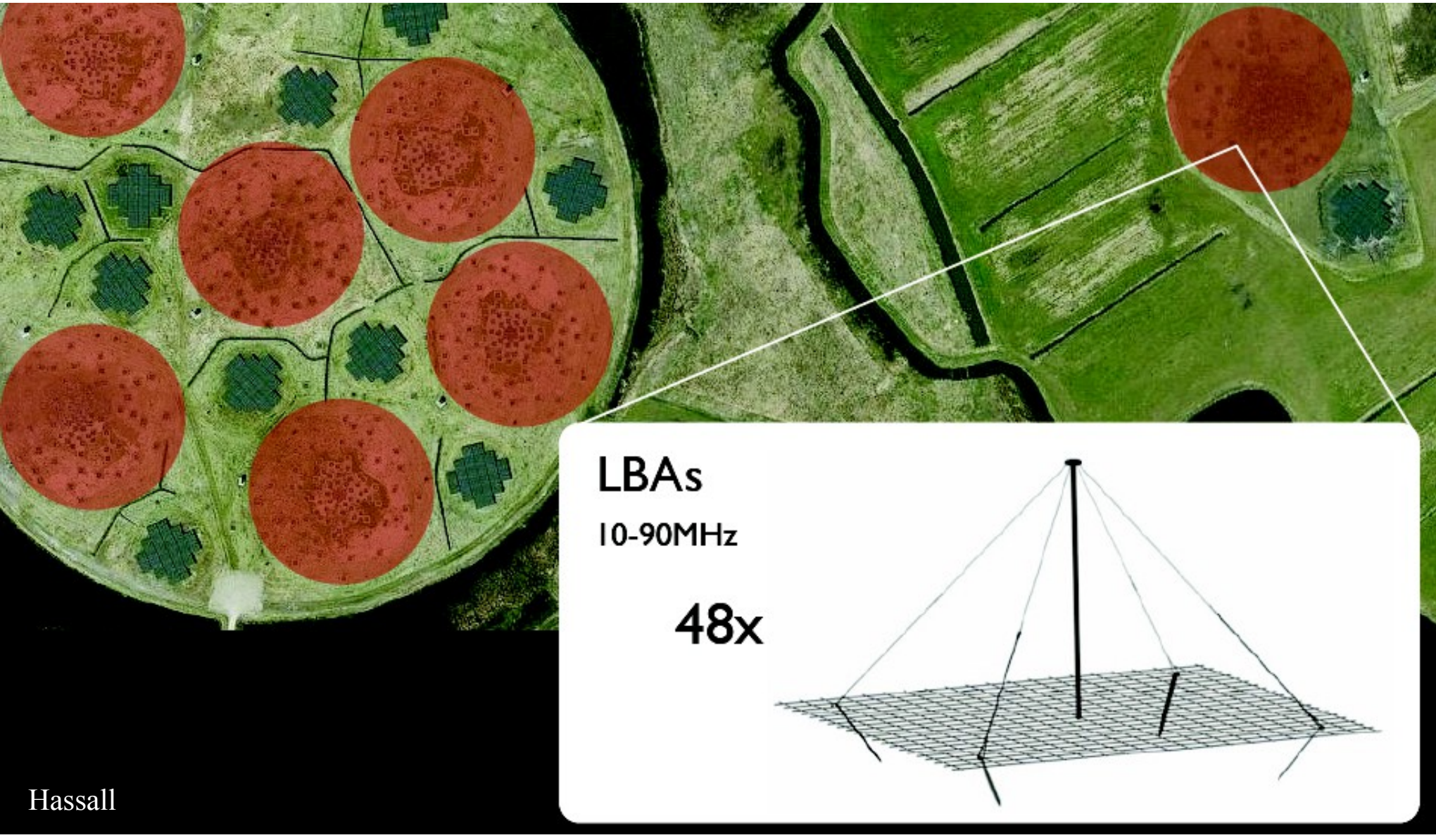






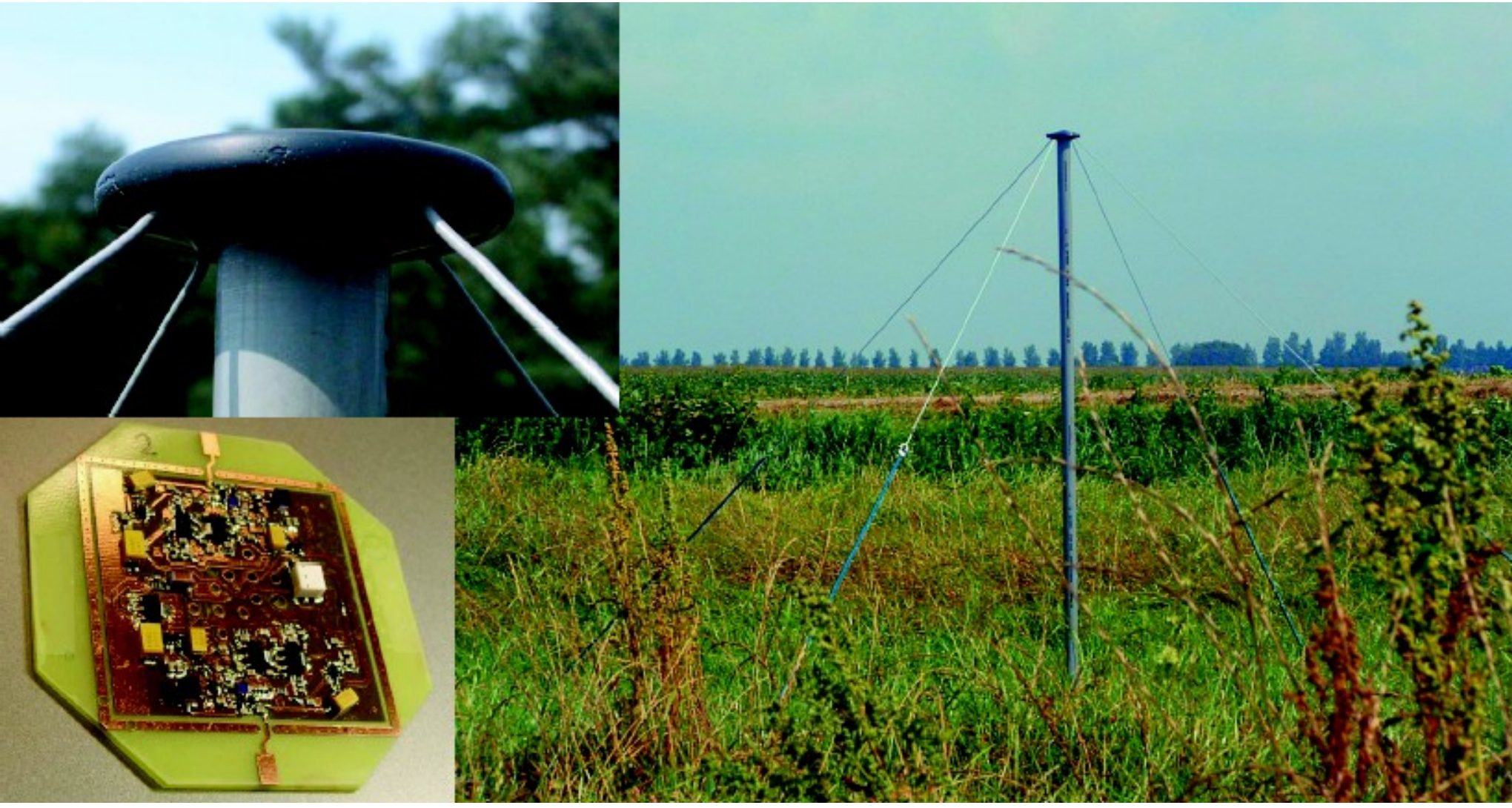


LOFAR

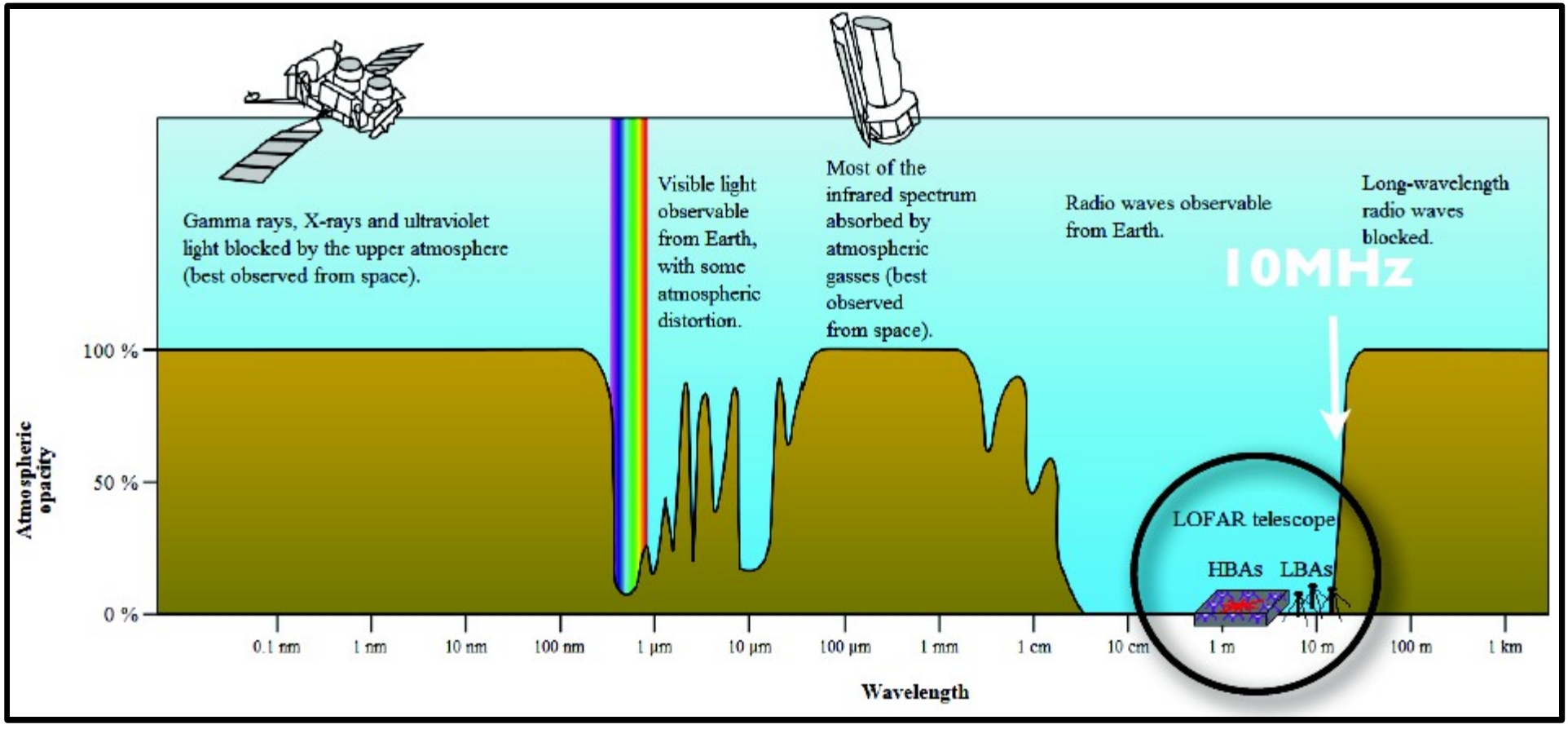


Low Band Antenna

LOFAR



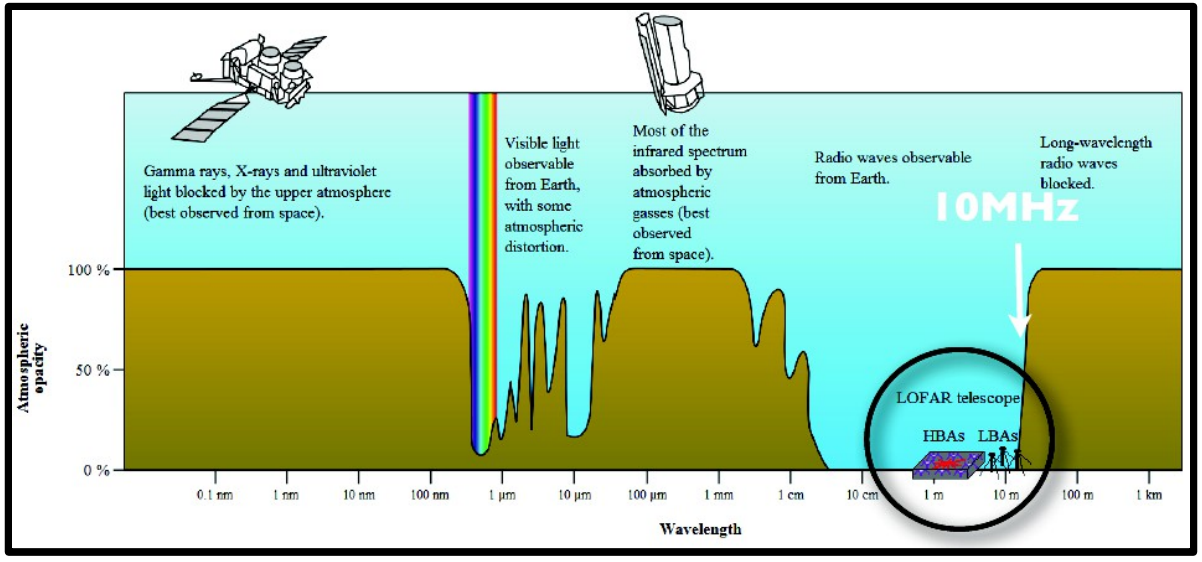
LOFAR in EM

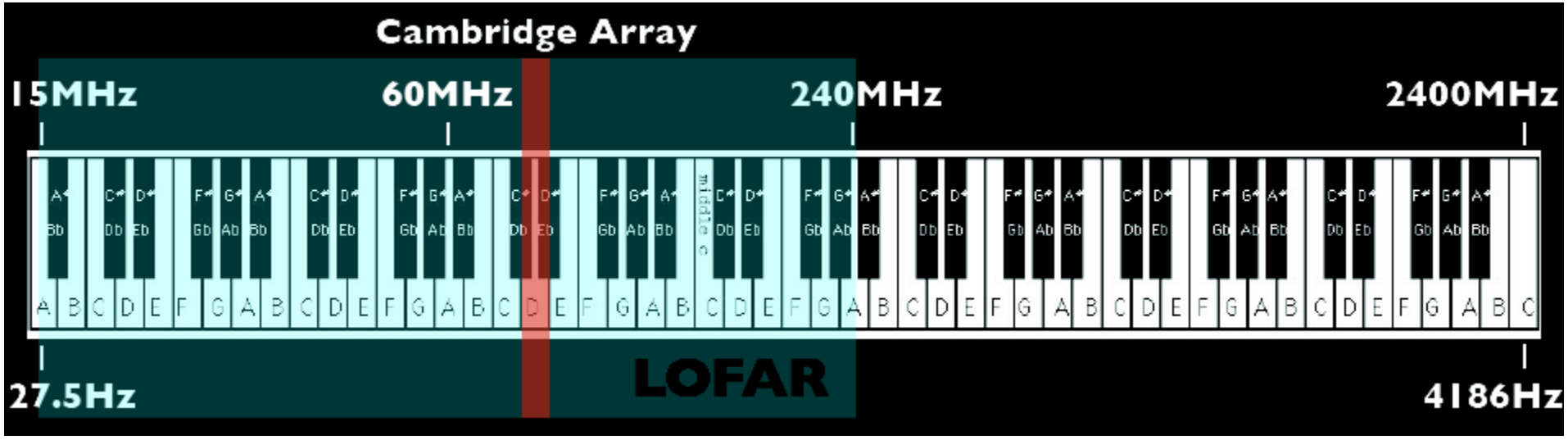


Hessels

Covers the 4 lowest octaves of the radio window

LOFAR's Enormous Frequency Range





Hessels

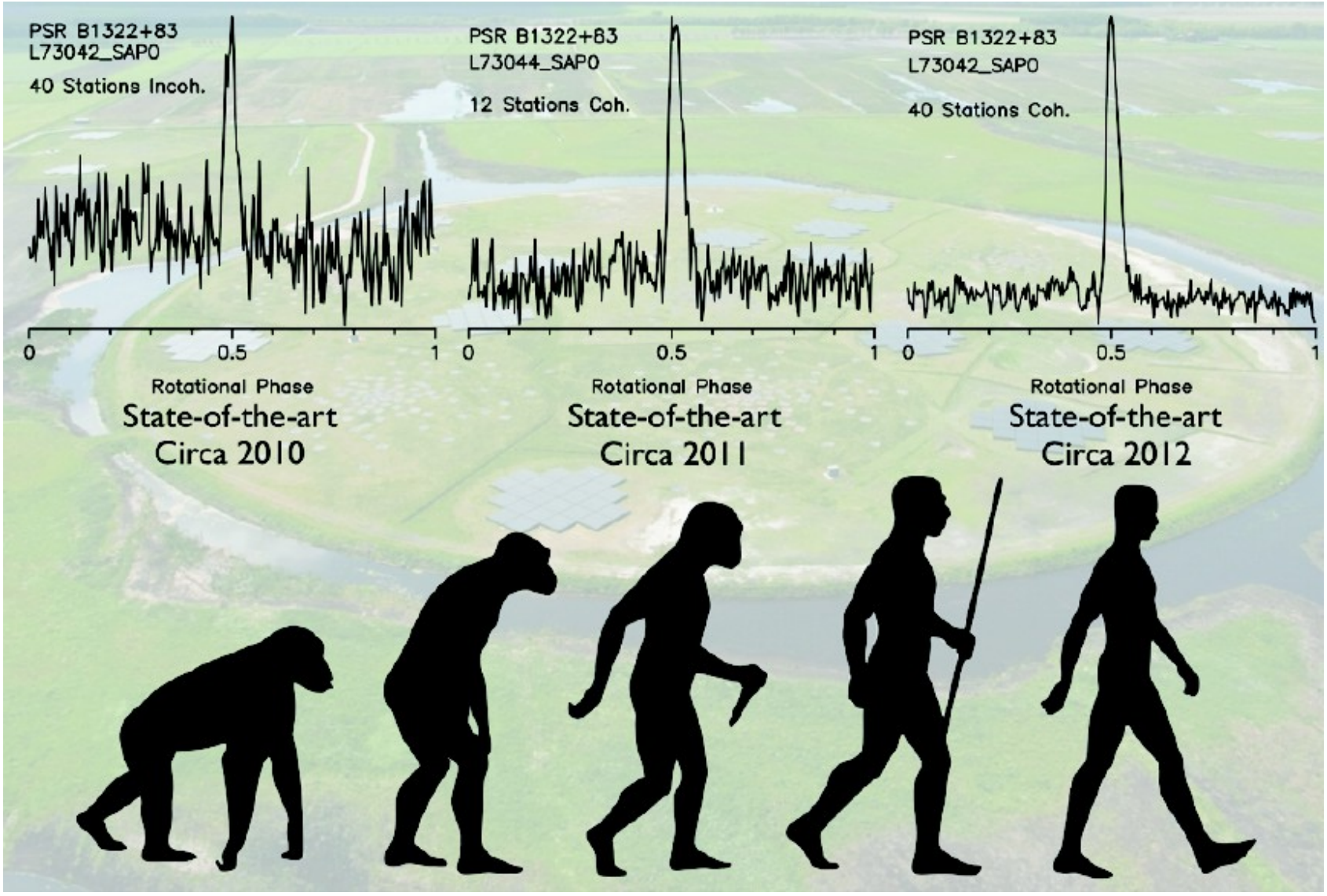
Flexible Beam-forming

(sparse aperture array)

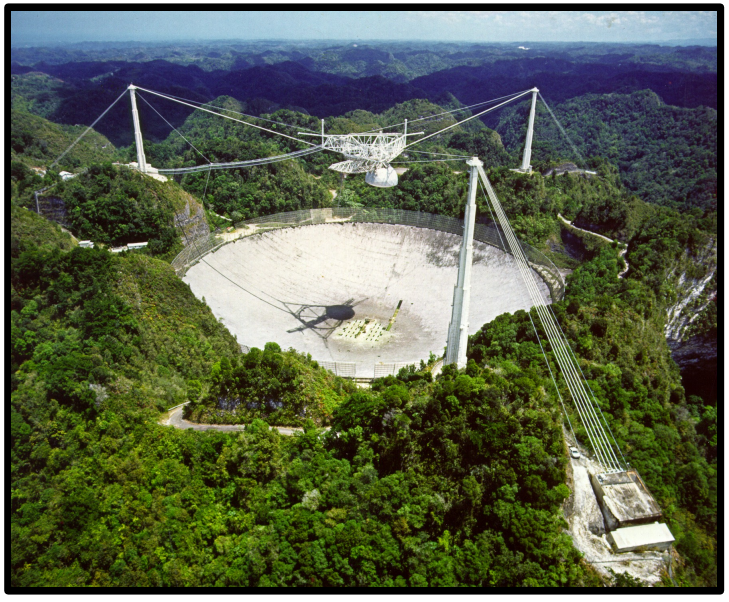
van Leeuwen

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

Evolution of LOFAR's sensitivity



Hessels



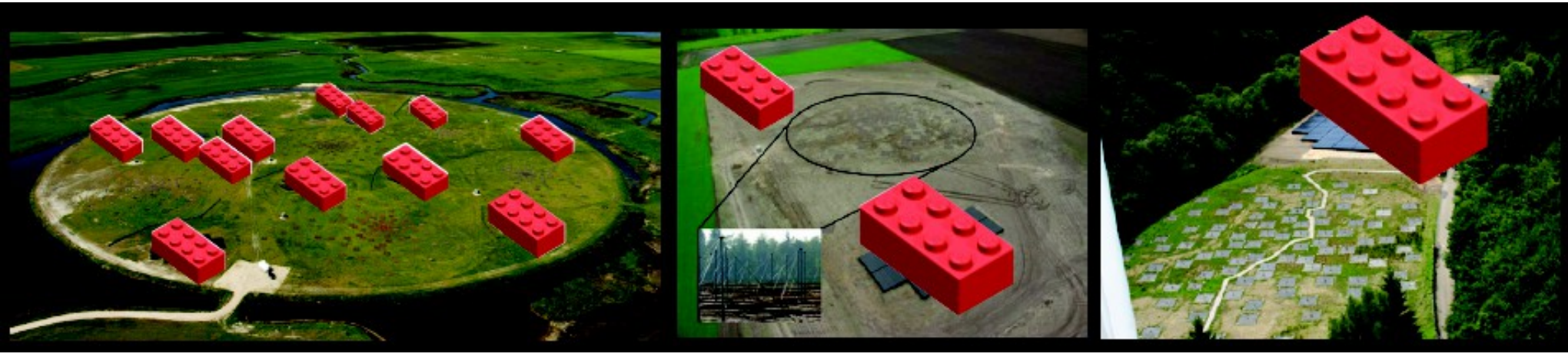
Arecibo

$\neq$

LOFAR

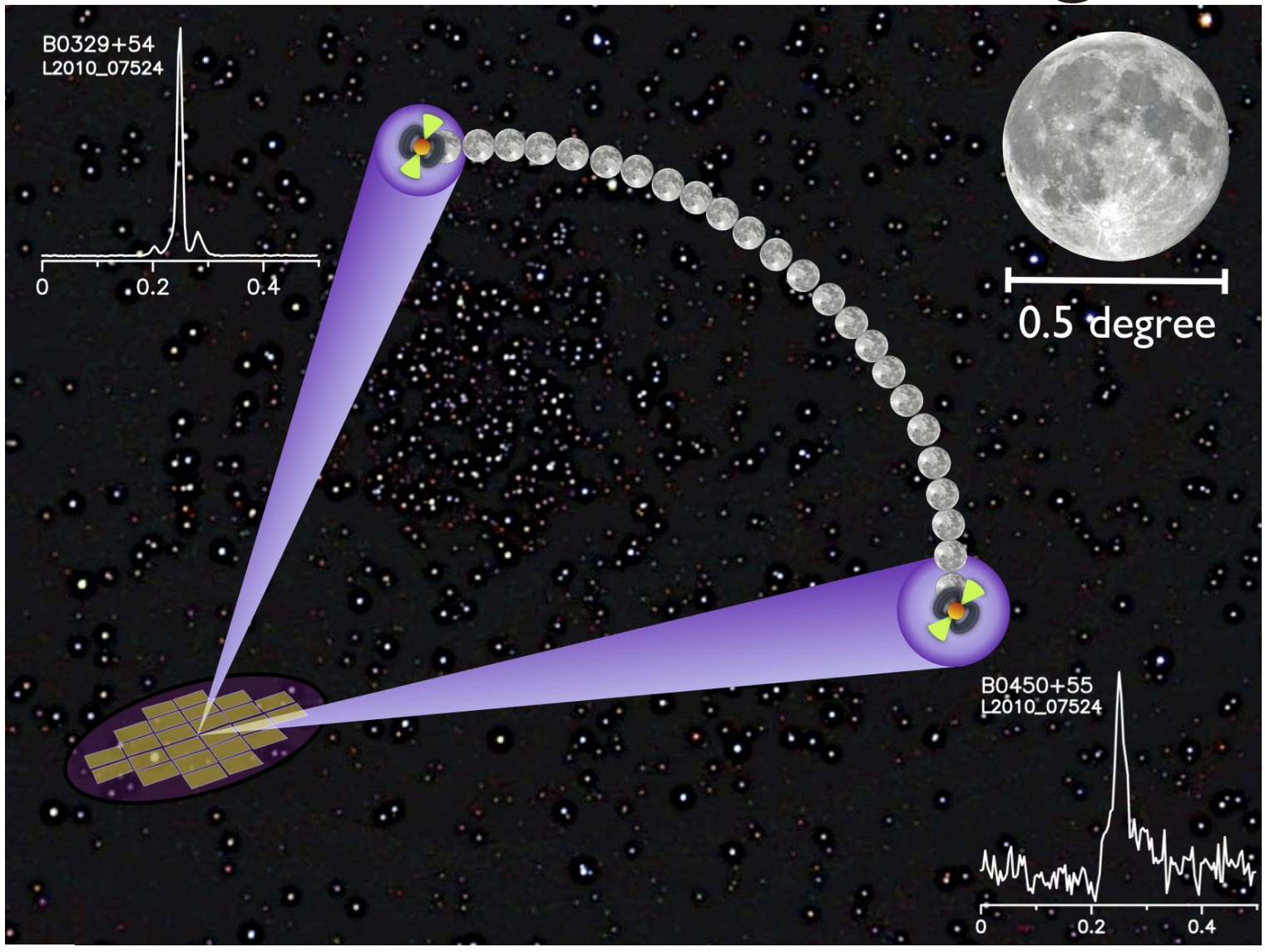
Sub-arraying
(customize your own telescope)

Hessels



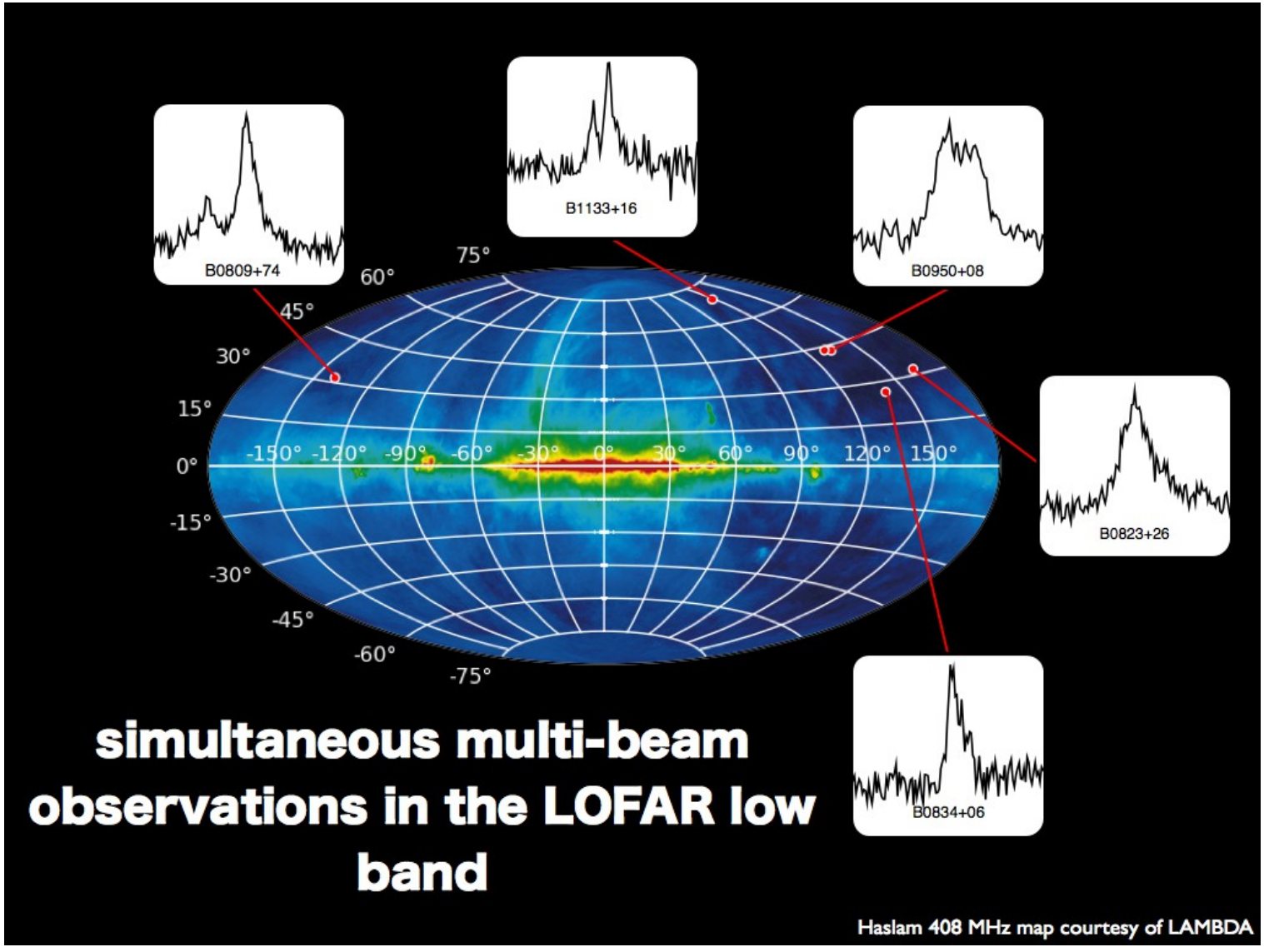
24	16	9
Dutch Core Stations	Dutch Remote Stations	International Stations

LOFAR Multi-beaming



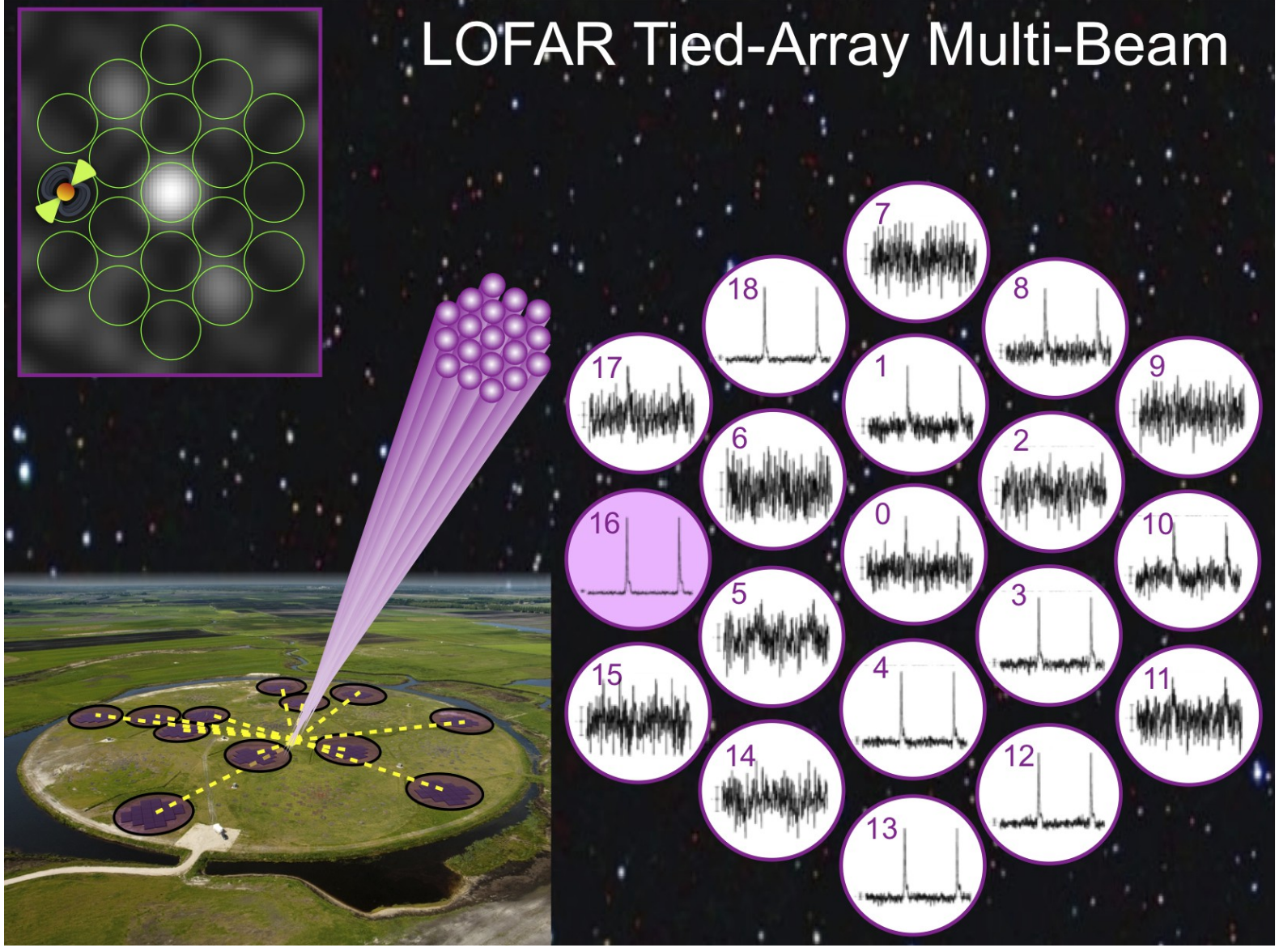
Hessels

Multiple, widely separated FOVs



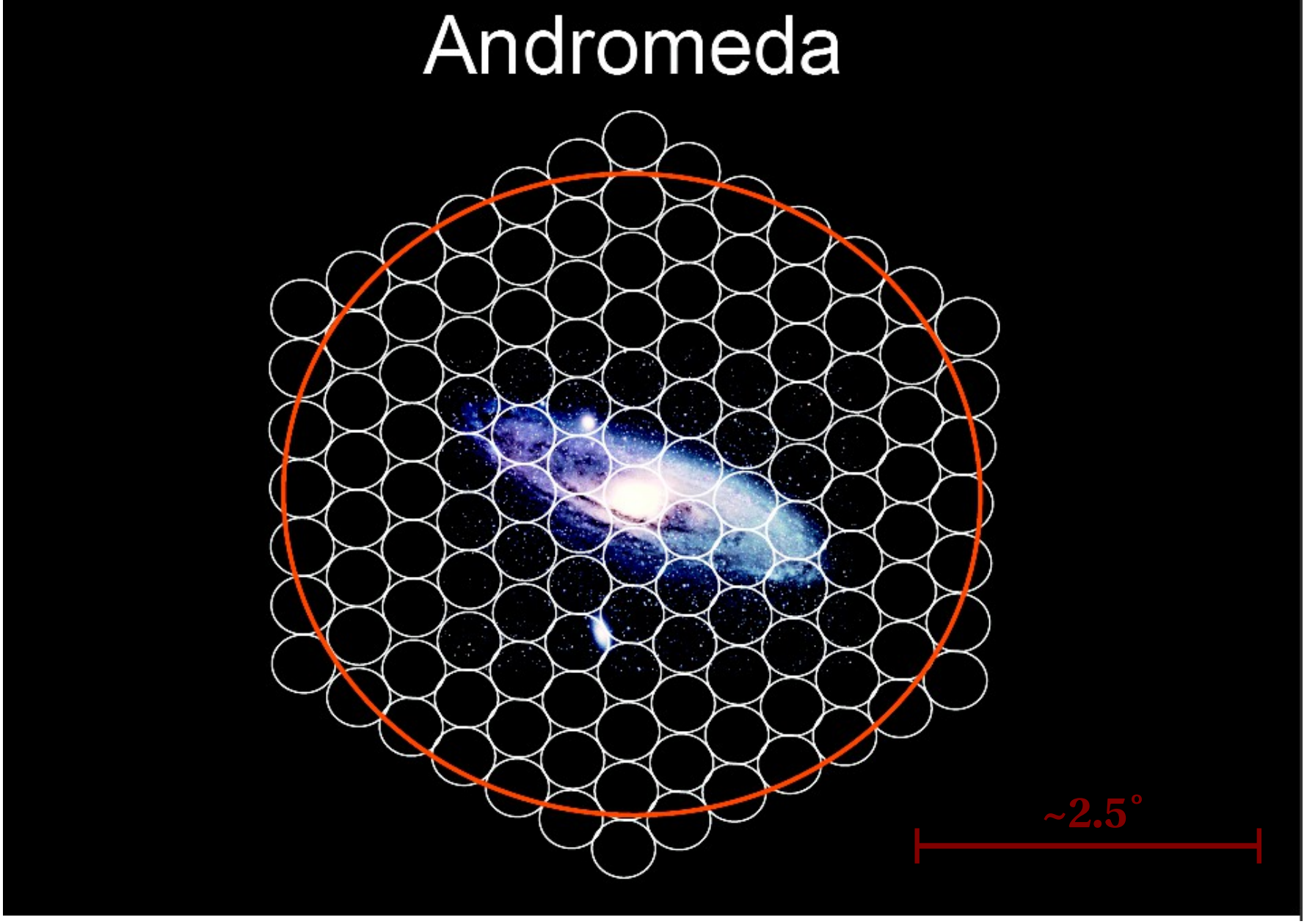
@28MHz
BW=8MHz

Hassall
Hessels
Stappers

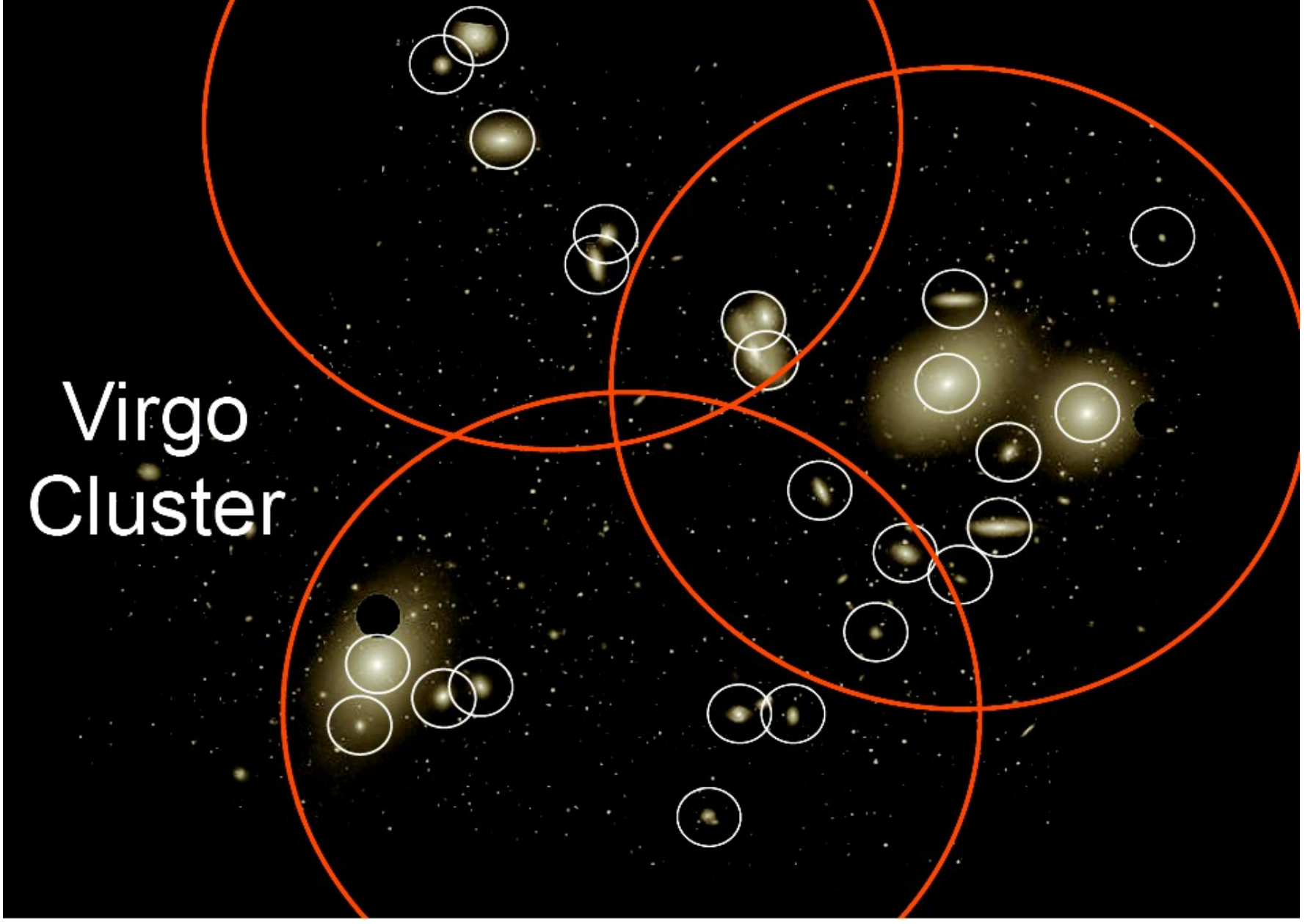


Hessels
Stappers
Scaife

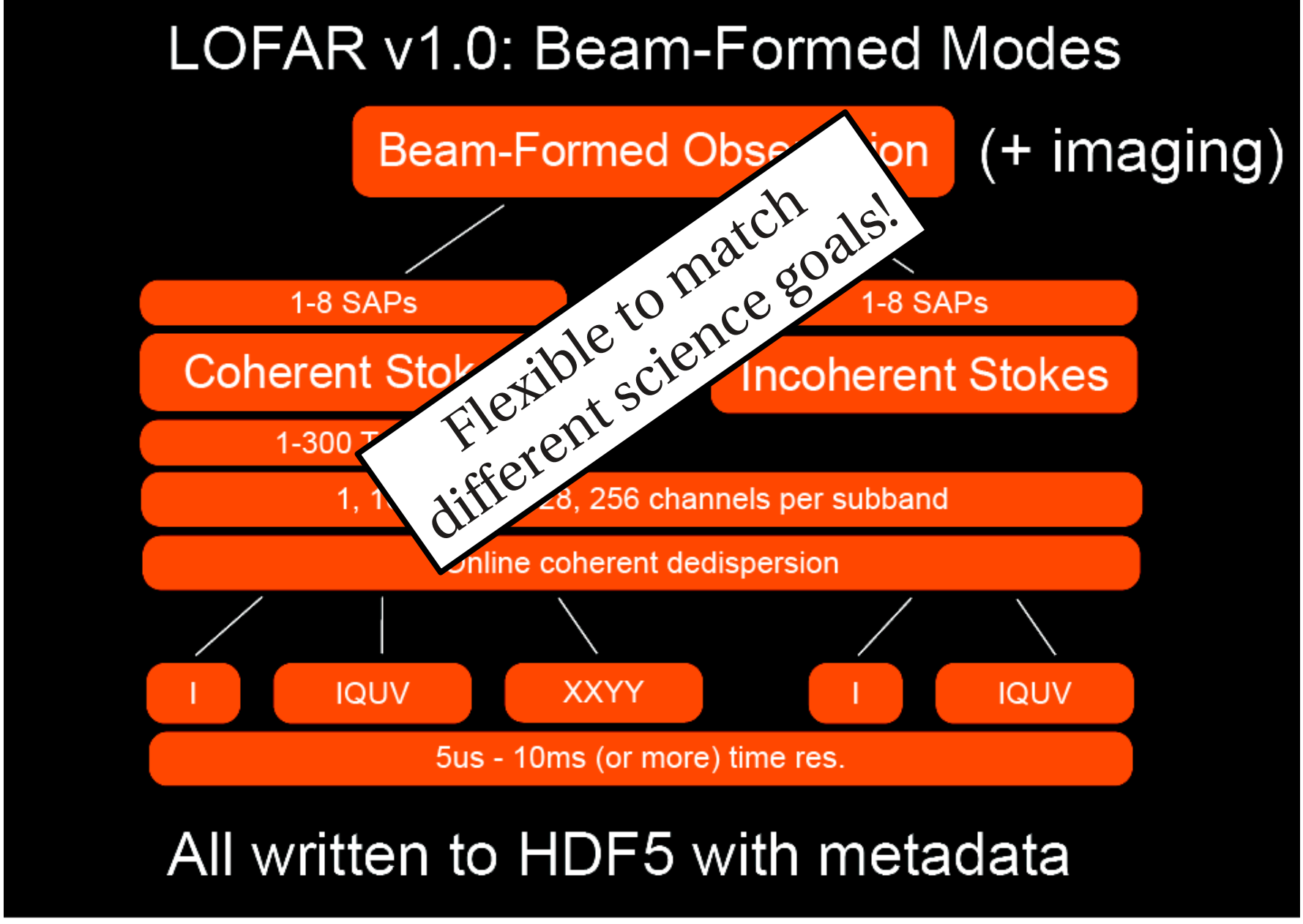
See Mol & Romein 2011 for multi-beam tied-array benchmarking results



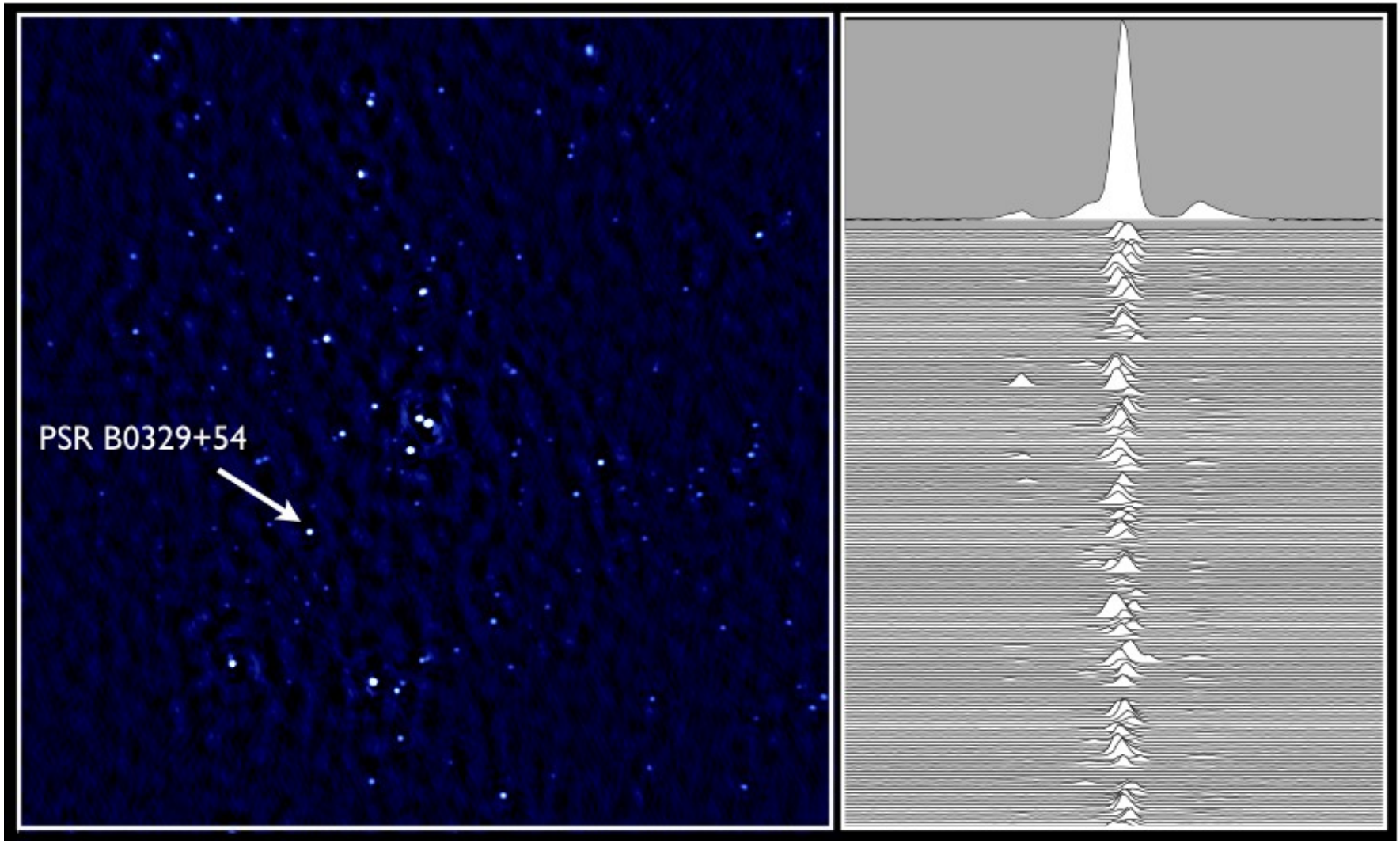
Hessels



Hessels


LOFAR v1.0: Beam-Formed Modes
Beam-Formed Obse ion
(+ imaging)
1-8 SAPs
1-8 SAPs
Coherent Stok
Incoherent Stokes
1-300 T
1, 1 28, 256 channels per subband
Online coherent dedispersion
I
IQUV
XXYY
I
IQUV
5us - 10ms (or more) time res.
Flexible to match different science goals!
All written to HDF5 with metadata

Simultaneous Imaging + Pulsar observations



Heald
Alexov
Hessels

Stappers et al. 2011, A&A, 530, 80

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]

LOFAR Reference Paper Online!

http://arxiv.org/abs/1305.3550

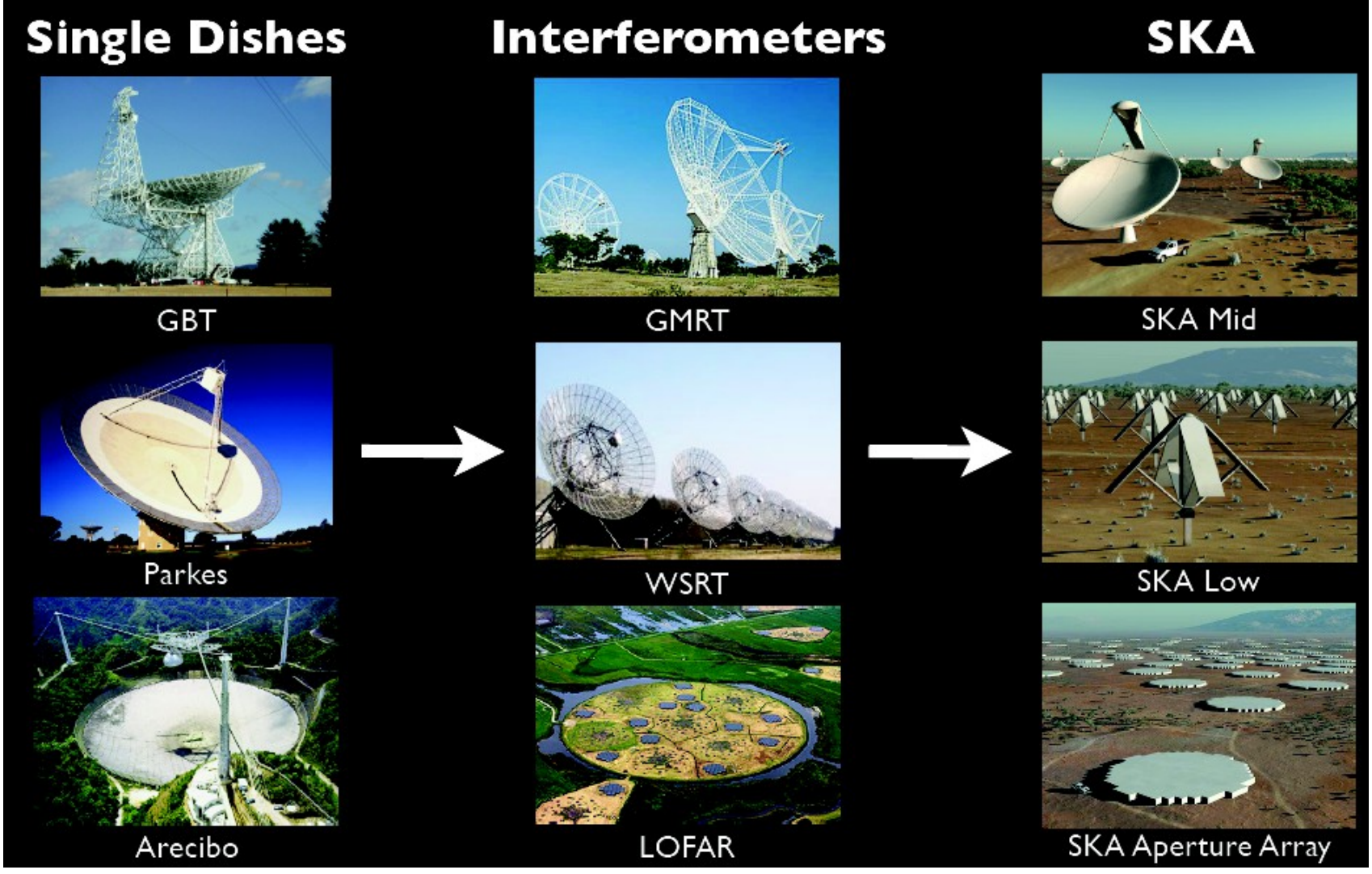
LOFAR: The LOw-Frequency ARray

M. P. van Haarlem, M. W. Wise, A. W. Gunst, G. Heald, J. P. McKean, J. W. T. Hessels, A. G. de Bruyn, R. Nijboer, J. Swinbank, R. Fallows, M. Brentjens, A. Nelles, R. Beck, H. Falcke, R. Fender, J. Hörandel, L. V. E. Koopmans G. Mann, G. Miley, H. Röttgering, B. W. Stappers, R. A. M. J. Wijers, S. Zaroubi, M. van den Akker, A. Alexov, J. Anderson, K. Anderson, A. van Ardenne, M. Arts, A. Asgekar, I. M. Avruch, F. Batejat, L. Bähren, M. E. Bell, M. R. Bell, I. van Bemmel, P. Bennema, M. J. Bentum, G. Bernardi, P. Best, L. Bîrzan, A. Bonafede, A.-J. Boonstra, R. Braun, J. Bregman, F. Breitling, R. H. van de Brink, J. Broderick, P. C. Broekema, W. N. Brouw, M. Brüggen, H. R. Butcher, W. van Cappellen, B. Ciardi, T. Coenen, J. Conway, A. Coolen, A. Corstanje, S. Damstra, et al. (139 additional authors not shown)

(Submitted on 15 May 2013)

LOFAR, the LOw-Frequency ARray, is a new-generation radio interferometer constructed in the north of the Netherlands and across europe. Utilizing a novel phased-array design, LOFAR covers the largely unexplored low-frequency range from 10-240 MHz and provides a number of unique observing capabilities. Spreading out from a core located near the village of Exloo in the northeast of the Netherlands, a total of 40 LOFAR stations are nearing completion. A further five stations have been deployed throughout Germany, and one station has been built in each of France, Sweden, and the UK. Digital beam-forming techniques make the LOFAR system agile and allow for rapid repointing of the telescope as well as the potential for multiple simultaneous observations. With its dense core array and long interferometric baselines, LOFAR achieves unparalleled sensitivity and angular resolution in the low-frequency radio regime. The LOFAR facilities are jointly operated by the International LOFAR Telescope (ILT) foundation, as an observatory open to the global astronomical community. LOFAR is one of the first radio observatories to feature automated processing pipelines to deliver fully calibrated science products to its user community. LOFAR's new capabilities, techniques and modus operandi make it an important pathfinder for the Square Kilometre Array (SKA). We give an overview of the LOFAR instrument, its major hardware and software components, and the core science objectives that have driven its design. In addition, we present a selection of new results from the commissioning phase of this new radio observatory.

Radio Pulsar Searches

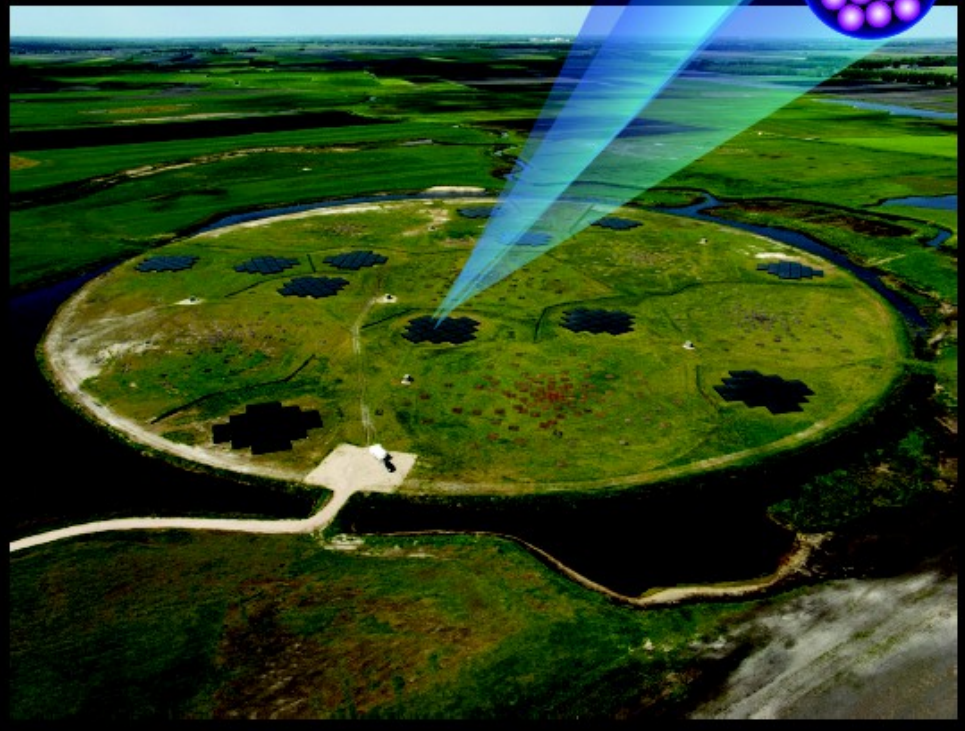


Hessels

LOFAR Pulsar Surveys

Great field-of-view
Great sensitivity

219 coh. beams
3 incoh. beams



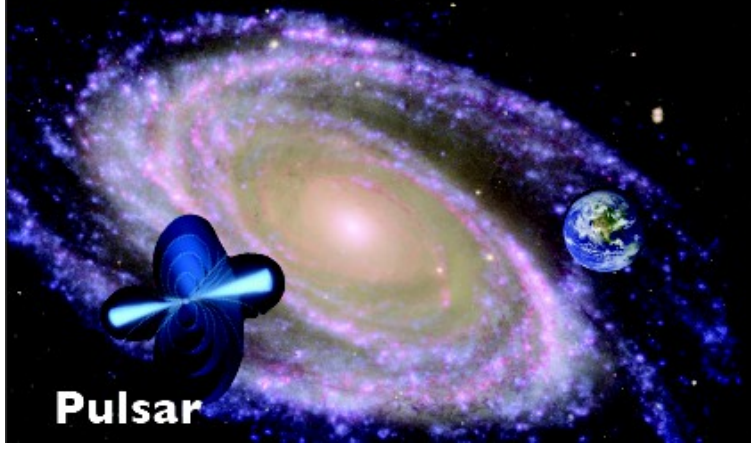
LOTAAS

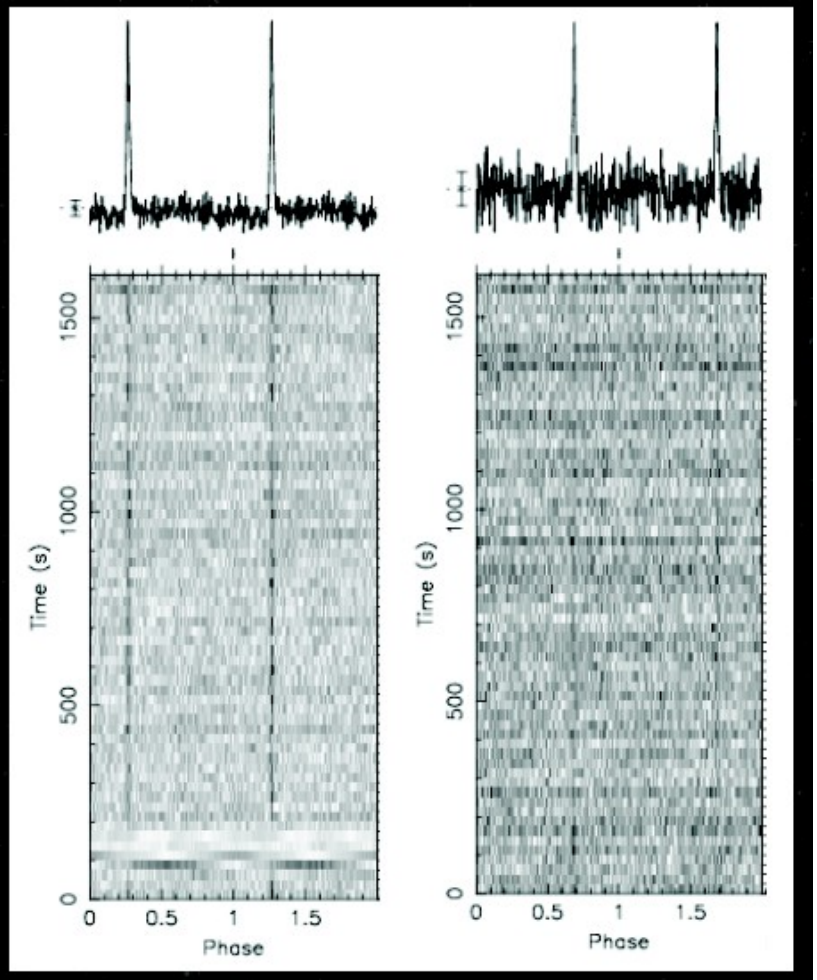
Hessels

First LOFAR Pulsar Discoveries

Expect 1/100 sq. deg.

Thijs Coenen PhD Thesis (U. Amsterdam)

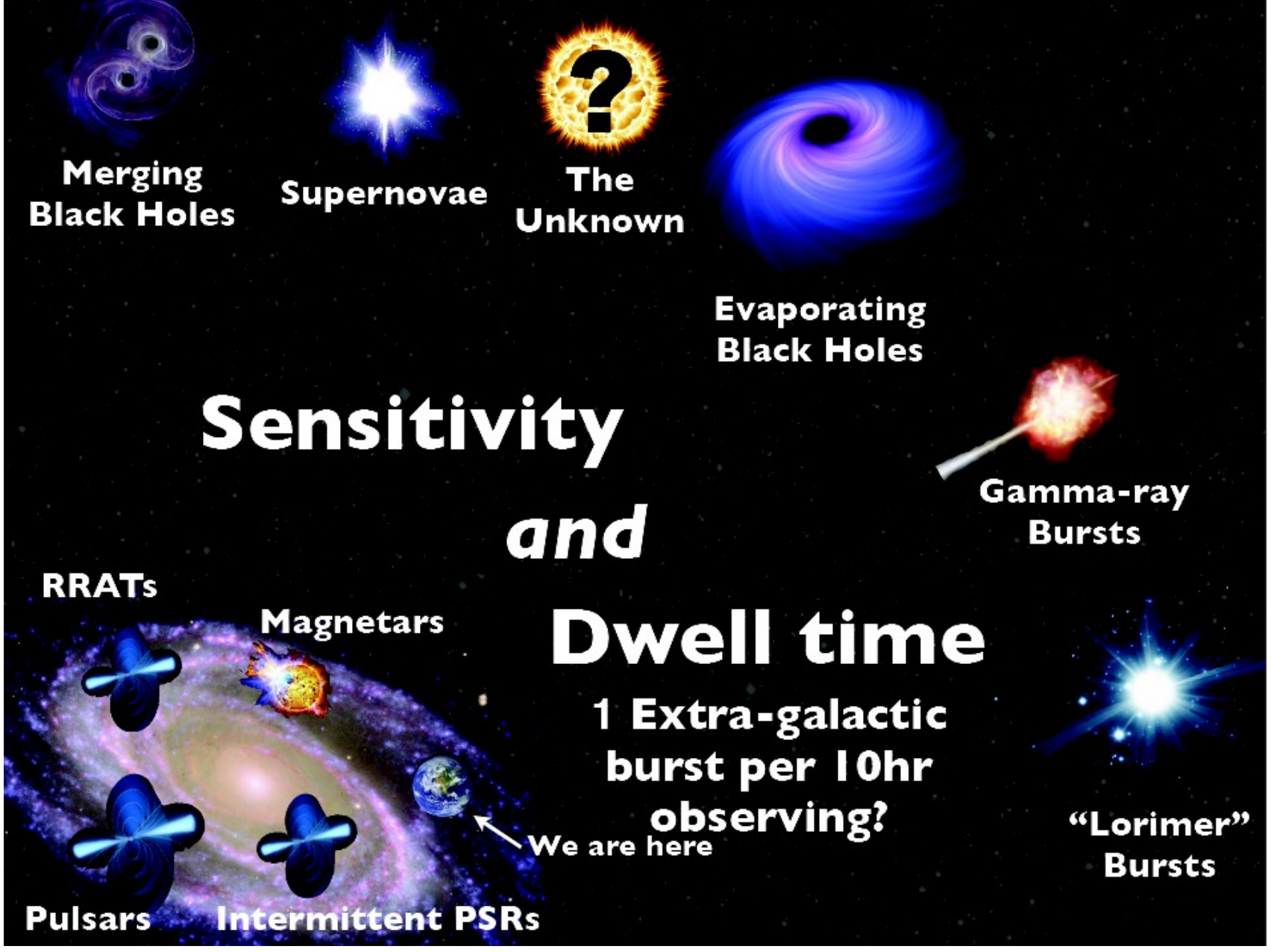




Period = 1.8 sec **Period = 0.6 sec**

DM = 102 pc cm^{-3} **DM = 19 pc cm^{-3}**

Hessels


Merging Black Holes
Supernovae
The Unknown
Evaporating Black Holes
Sensitivity
and
Dwell time
Gamma-ray Bursts
RRATs
Magnetars
1 Extra-galactic burst per 10hr observing?
We are here
"Lorimer" Bursts
Pulsars
Intermittent PSRs

Hessels

Fast radio transient factories

Parkes

0.6 sq. deg.

Current state-of-the-art

100x

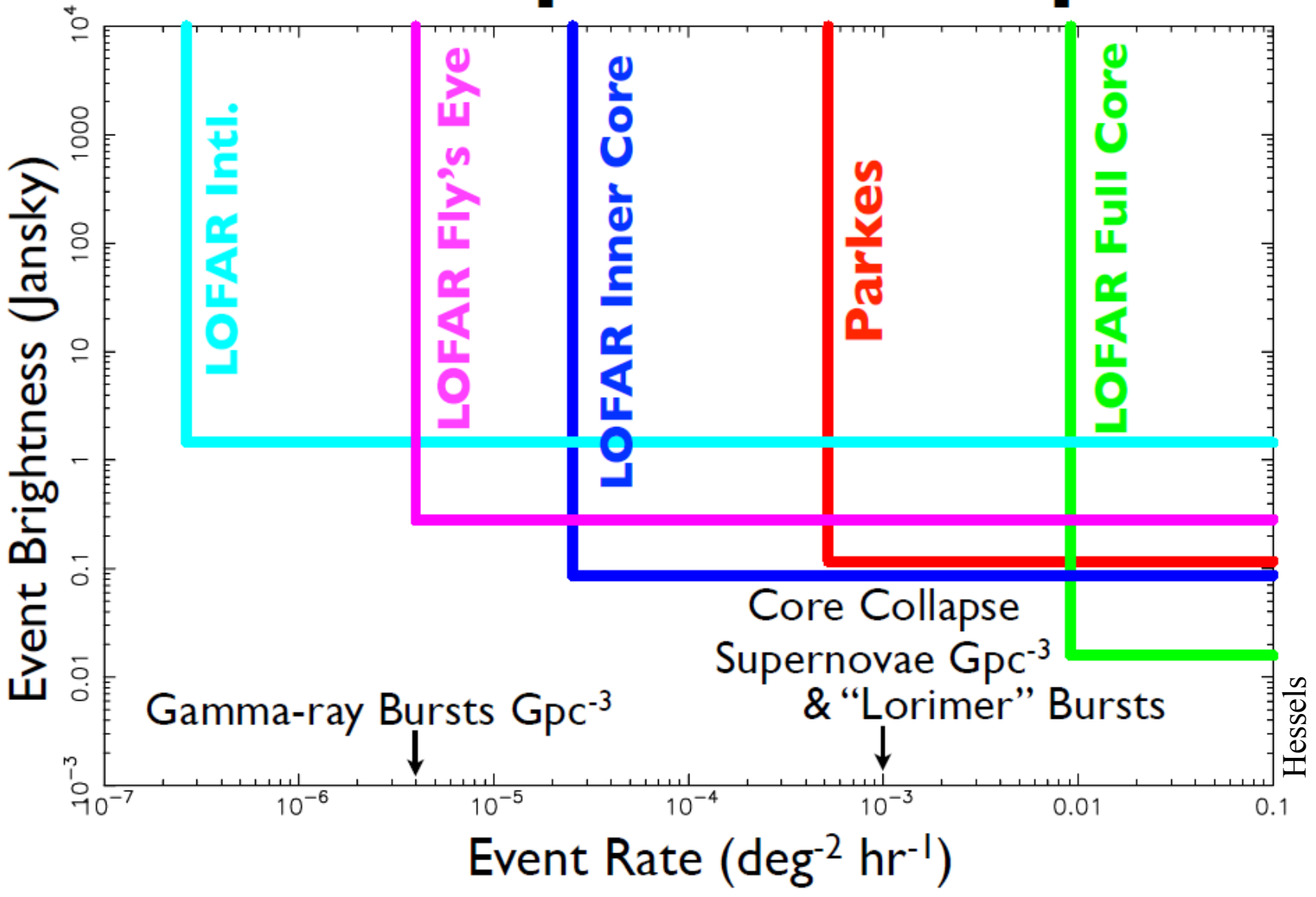
LOFAR

Field-of-view

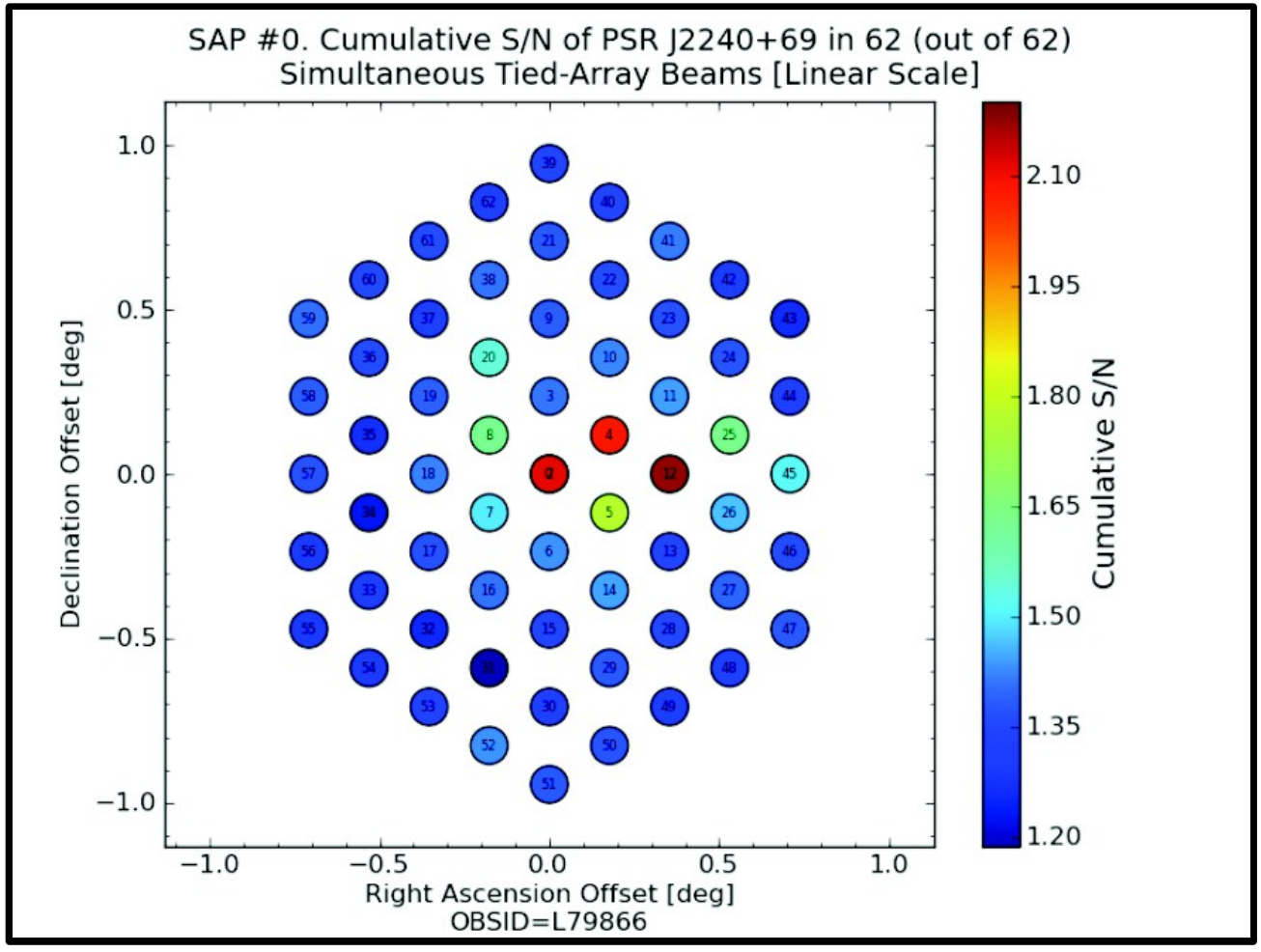
60 sq. deg.

Hessels

Uncharted parameter space



Localizing LOTAAS Sources



Hessels

and also *localize* transients

Towards the SKA

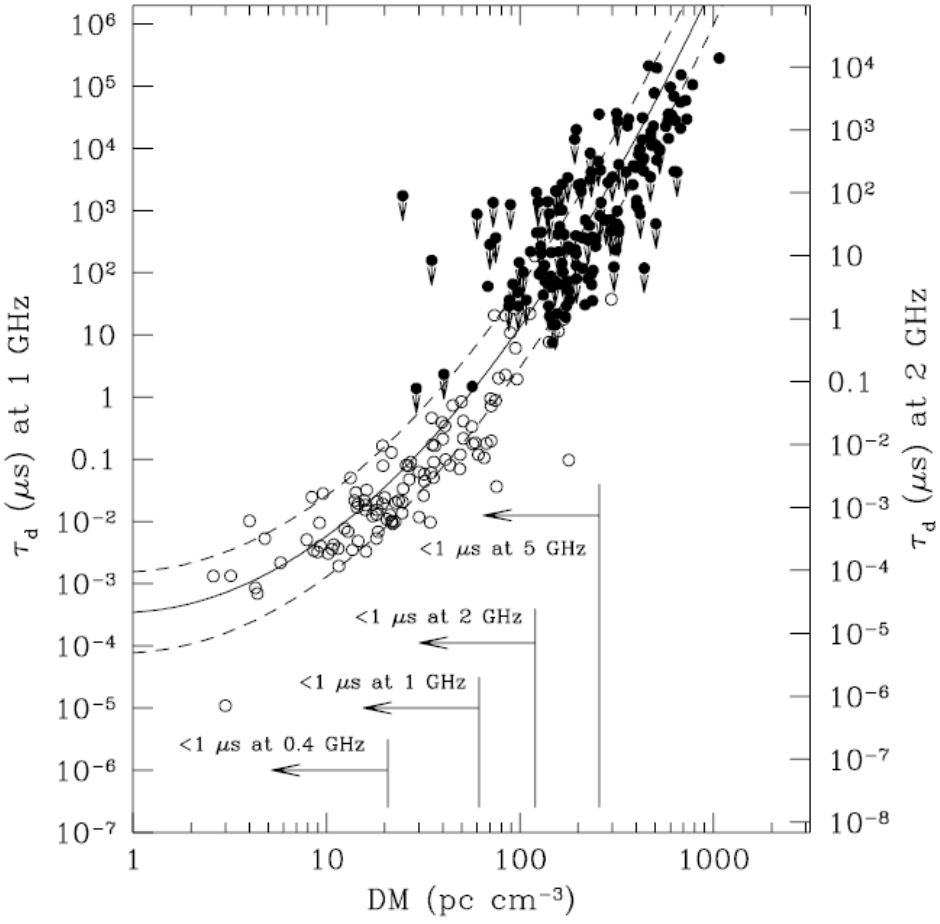
- ✔ SKA will ultimately find all ~20,000 MSPs in the Galaxy, revealing even more exotic systems (e.g., sub-MSP, MSP-BH).

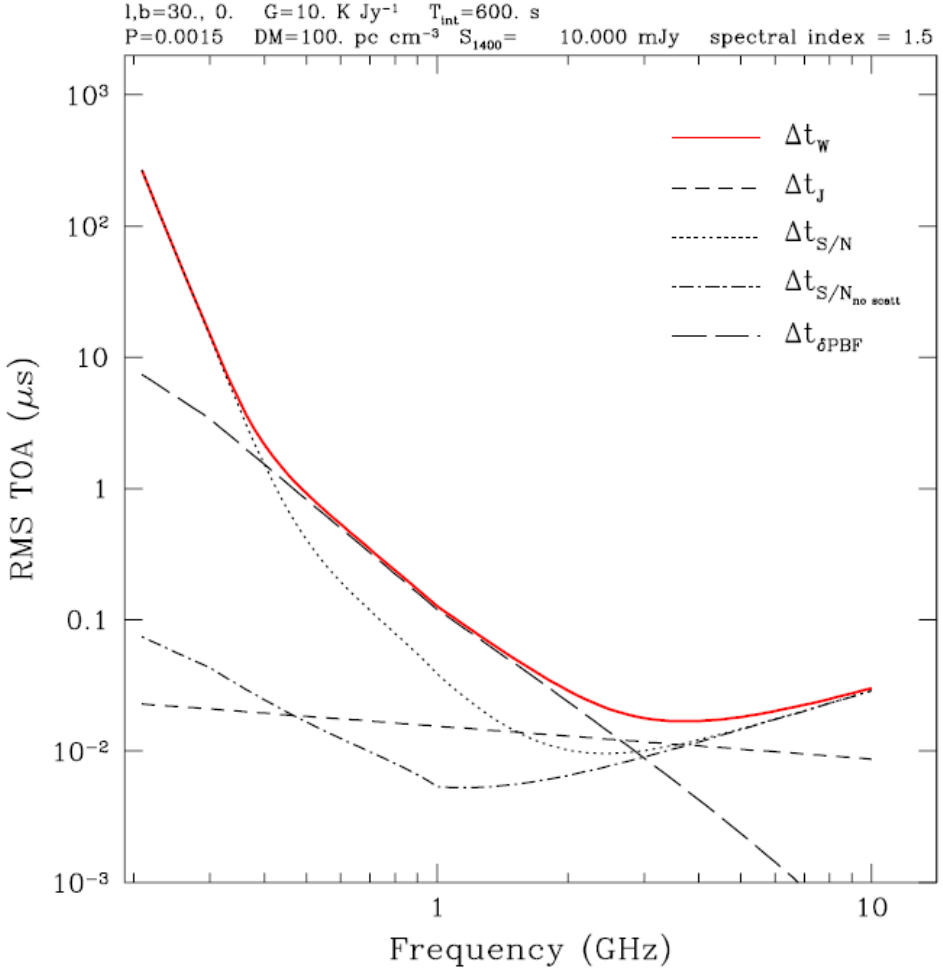
- ✔ Need fo sub-arraying: logistics of timing thousands of sources and achieving the best timing precision.

SKA Low (50 – 600 MHz)

SKA AA (300 – 1500 MHz)

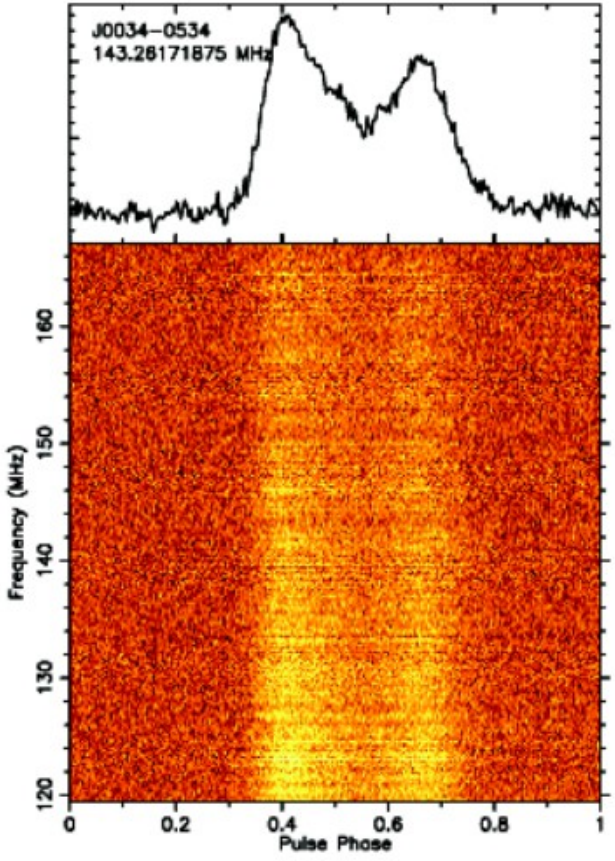
Timing with LOFAR?



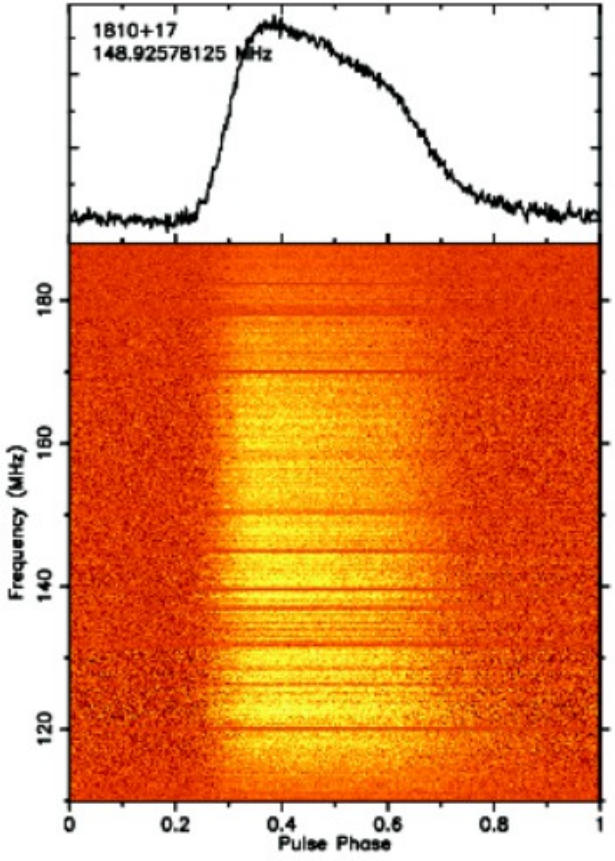


Cordes & Shannon (2010)

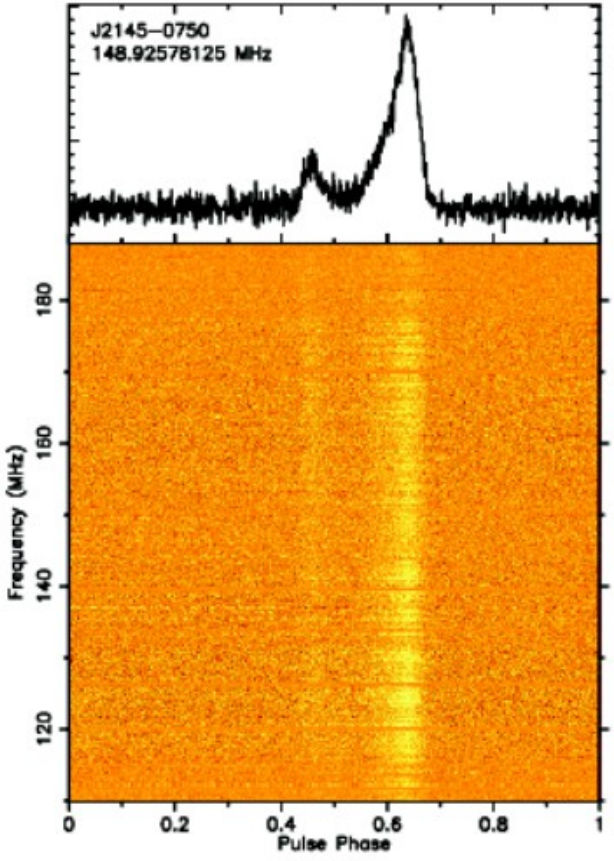
LOFAR MSP Detections (110–190 MHz)



J0034-0534



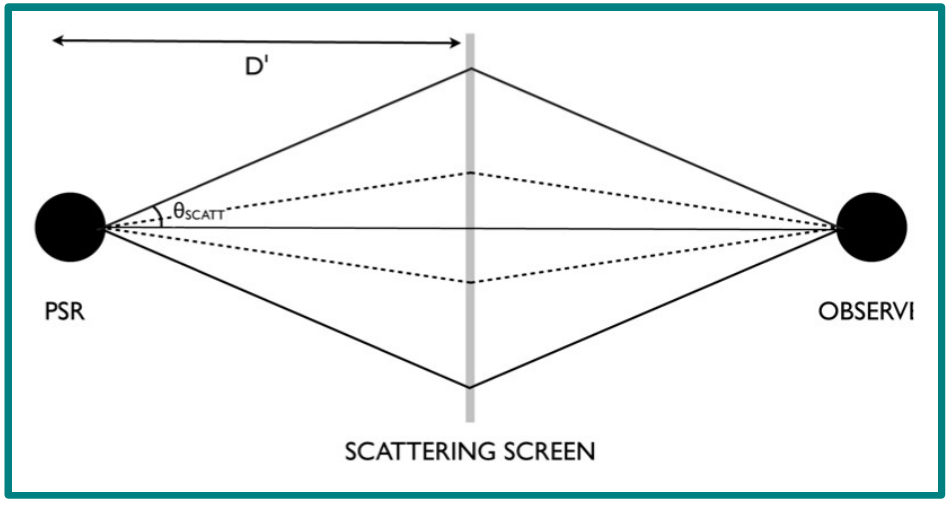
J1810+1744

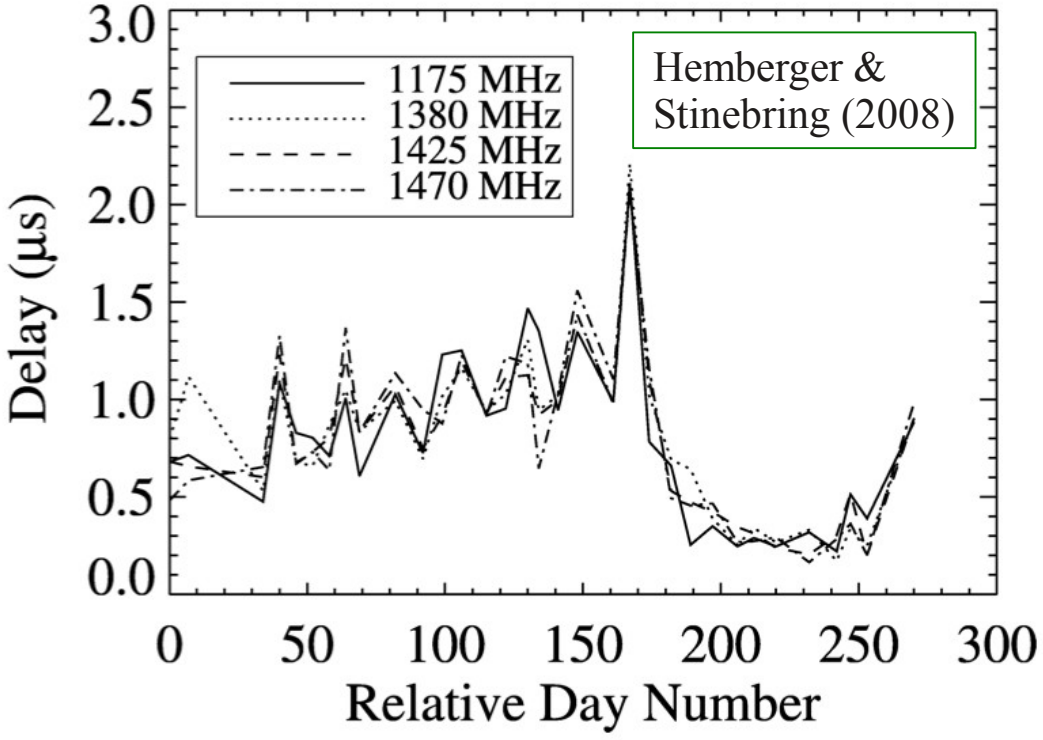


J2145-0750

Verbiest

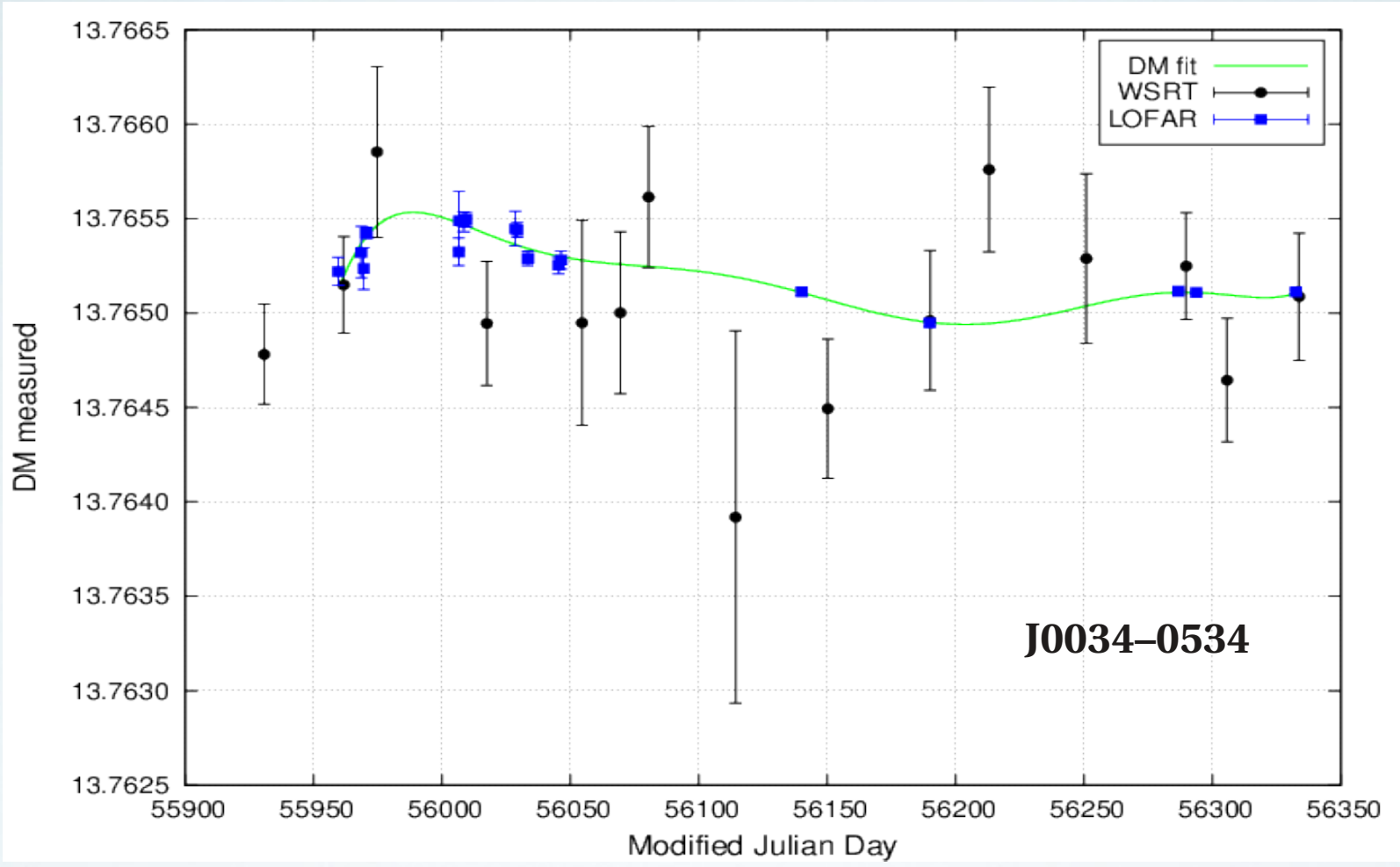
The LOFAR Weather Report





- ✔ 1 μs scatt. at 1400 MHz is 10 ms scatt. at 140 MHz
- ✔ 1 ms scatt. at 140 MHz is 100 ns scatt. at 1400 MHz
- ✔ Do LOFAR DMs/Scatt. agree with those at high-freq?

DM variations



Verbiest

- **Provide LOFAR "ISM Weather" report**
- **Independent DMs to compare with high frequencies**

Summary:

- ✔ LOFAR is revolutionary telescope operating at the very low radio frequencies with great observing capabilities.

- ✔ LOFAR is showing that SKA-Low can be a powerful pulsar/transient survey machine.

- ✔ LOFAR will provide ISM «weather report» for the pulsars' line-of-sights that will improve high-frequency timing.