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Netherlands Organisation for Scientific Research

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# *A high-speed, wide-angle radio camera for LOFAR*

*Sotiris Sanidas*

Anton Pannekoek Institute for Astronomy, University of Amsterdam

June 29, 2015

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# *Outline*

- The LOFAR telescope
- The LOTAAS survey
- DRAGNET

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# *Involved WG*

DRAGNET (ASTRON/A'dam)
Jason Hessels (PI)
Vlad Kondratiev
Cees Bassa
Alexander van Amesfoort
Daniele Michilli
Sotiris Sanidas

ARTEMIS (Oxford)
Aris Karastergiou
Wes Armour
Chris Williams
Jayanth Chennanmangalam

LOFAR PWG
Jason Hessels (co-lead)
Ben Stappers (co-lead)
Joeri van Leeuwen
Aris Karastergiou
Vlad Kondratiev
Thijs Coenen
Sally Cooper
Daniele Michilli
Aris Noutsos
Kimon Zagkouris
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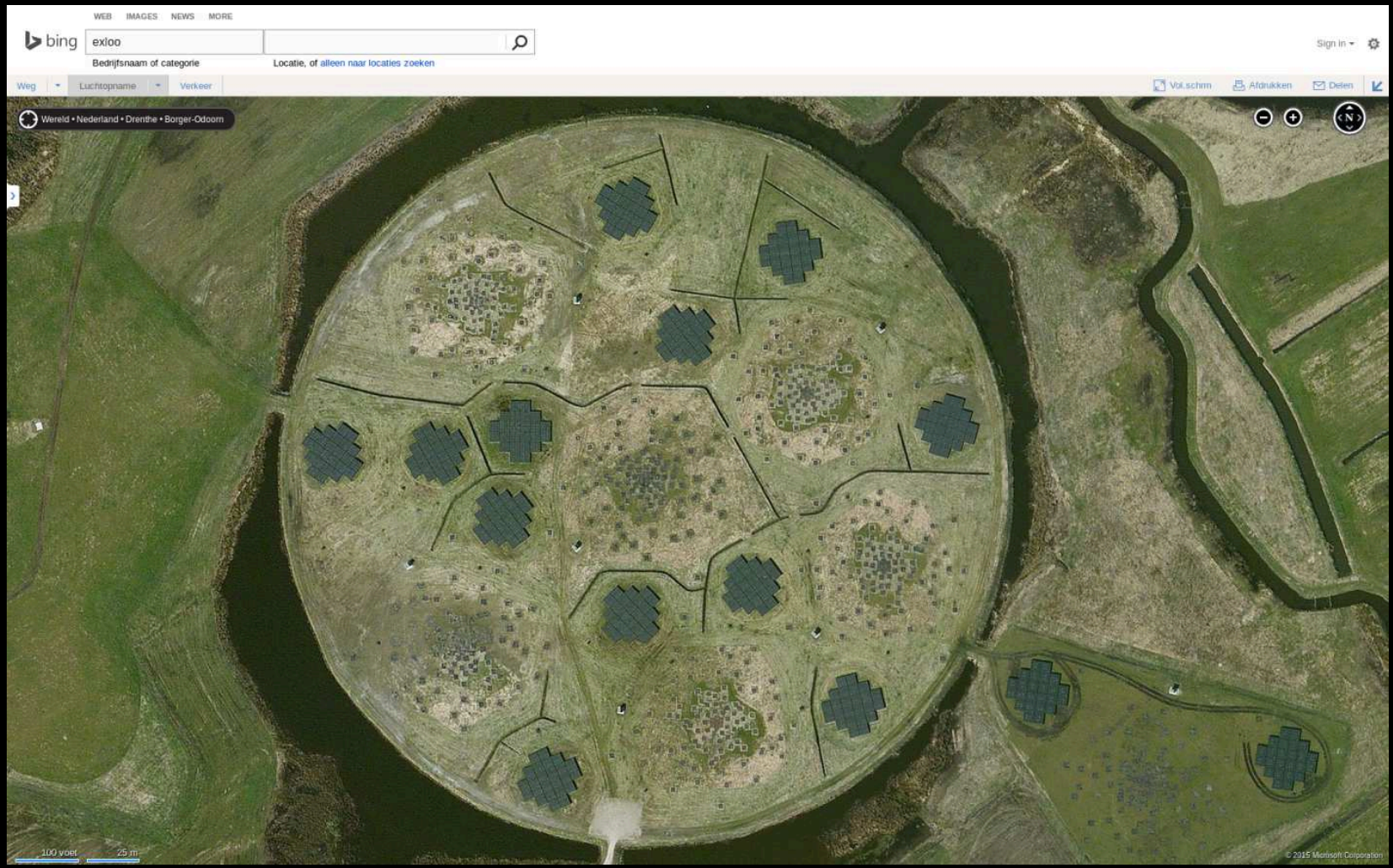
# The LOFAR telescope



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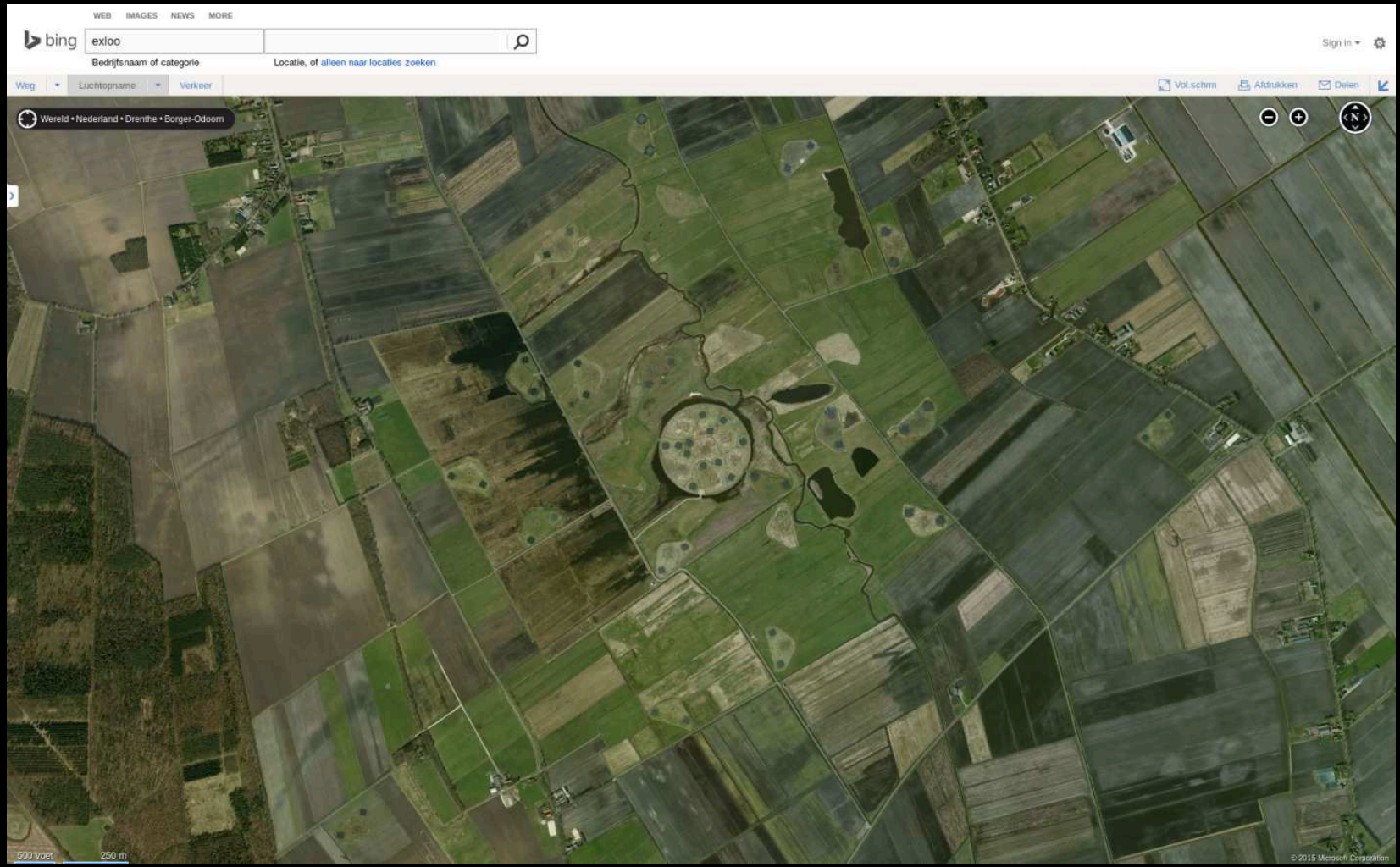
# The LOFAR telescope



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# The International LOFAR telescope


- 24 Dutch core stations
- 16 Dutch remote stations
- 8 International stations (+3 in Poland, end 2015)

*LOFAR serves as an important pathfinder for SKA-Low*

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# LOFAR Antennas

LBA (300E)
Frequency coverage:
$10 - 90\,\mathrm{MHz}$
$(30 - 80)\,\mathrm{MHz}$

HBA tile-16 elements (3.5k E)
Frequency coverage:
$120 - 240\,\mathrm{MHz}$

Large coverage (many sq. deg.) - Ideal for surveys

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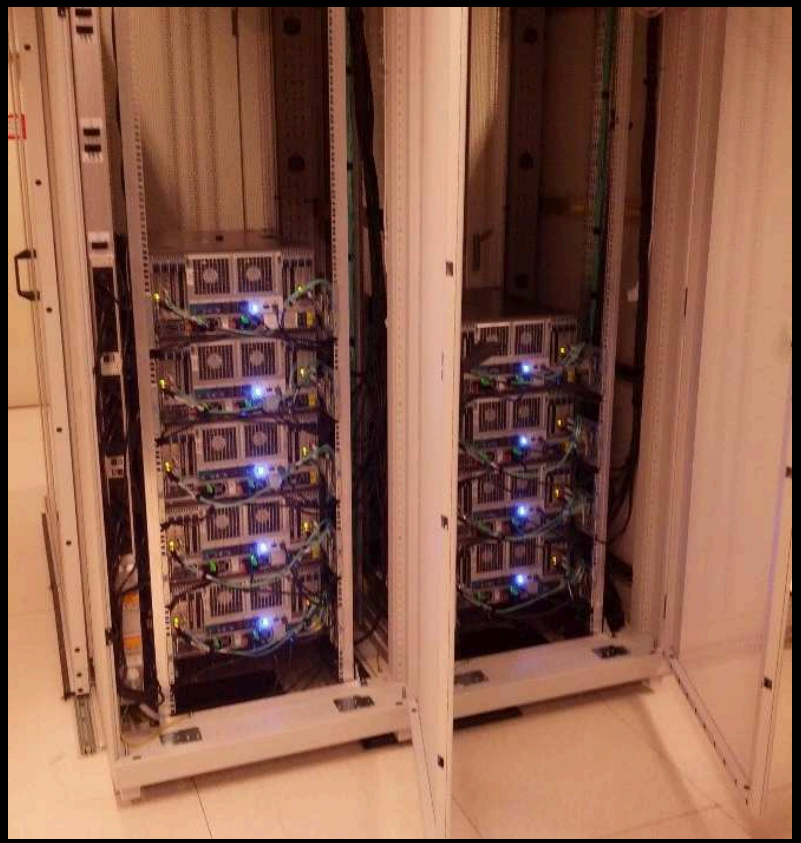
# STELLA/COBALT

CPU-based correlator/beamformer
BlueGene/P



CPU/GPU-based correlator/beamformer
NVIDIA TESLA K10

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# The LOTAAS survey

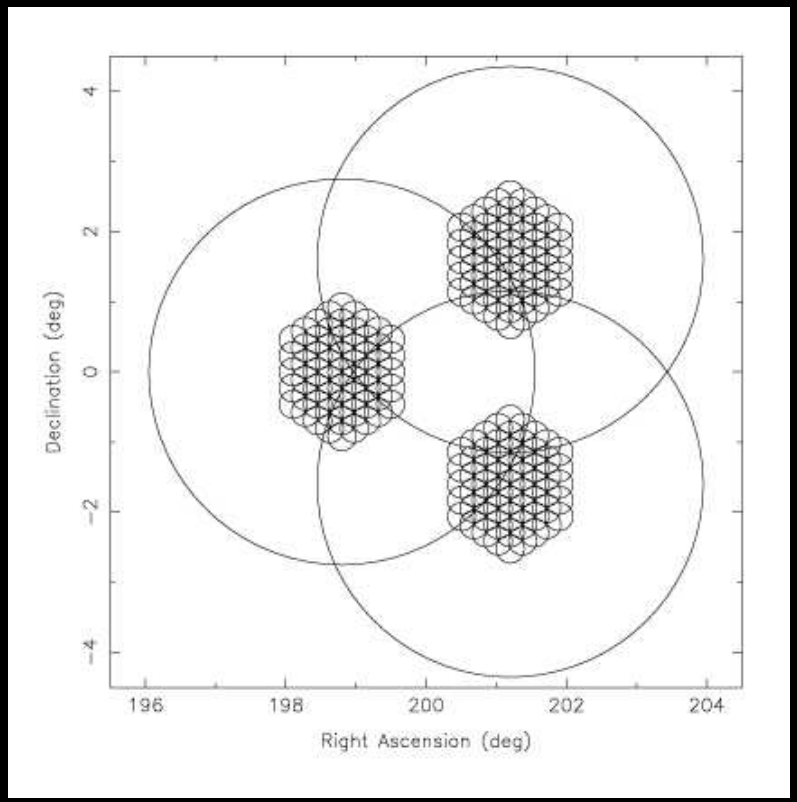
## *LOFAR Tied-Array All-sky Survey*

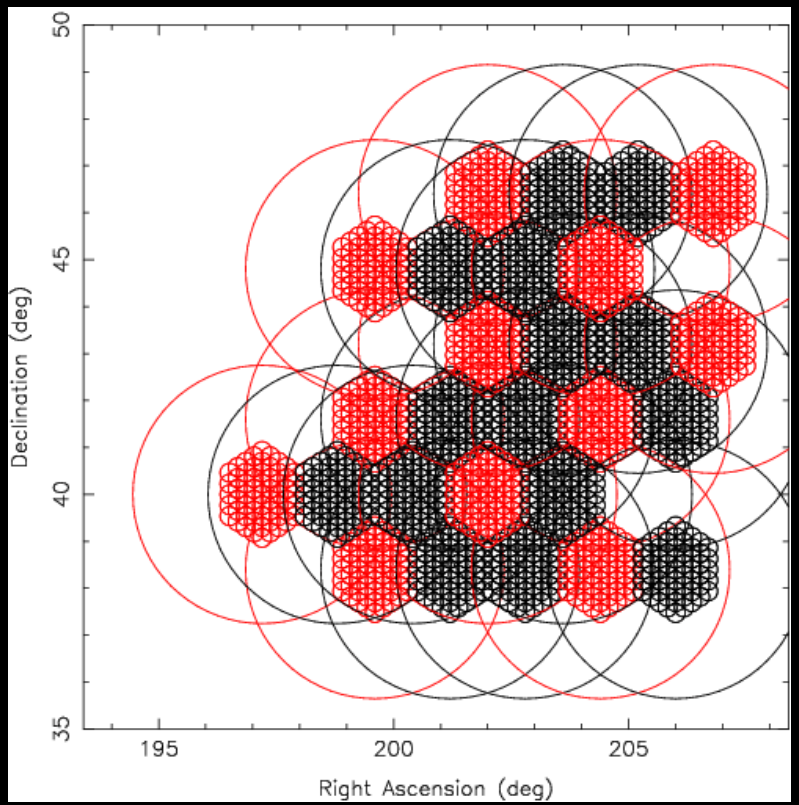
- Survey for pulsars, RRATs and bursts
- 12 HBA substations from superterp
- 3 sub-array pointings (SAP) incoherent beams (30 sq. deg.)
- 183 tied-array beams
  61 per SAP (9 sq. deg.)
- 12 tied-array beams “free” (targeting known sources)
- $32\,\mathrm{MHz}$ BW, $119 - 151\,\mathrm{MHz}$
- 1hr integration, $493\,\mu s$ sampling
- 35 Gbps, 16TB/pointing
- Sensitive to MSPs up to DM $50\,\mathrm{pc\,cm^{-3}}$

See Coenen et al. 2014 for more info

# The LOTAAS survey

222 beams per survey pointing!
A unique stepping stone for SKA-Low surveys

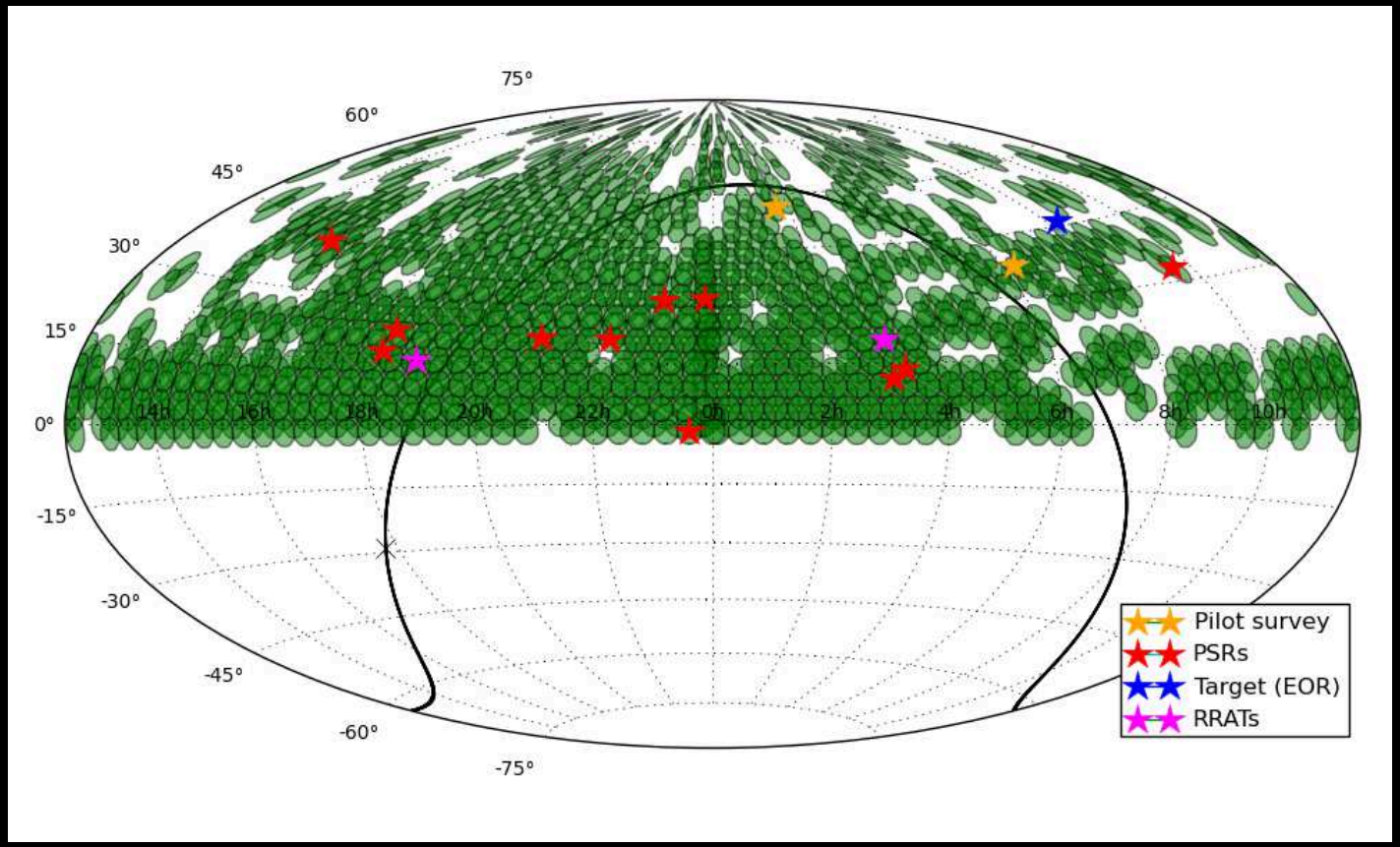



Coherent beams x4 more sensitive than incoherent beams → deeper search

# The LOTAAS survey

Coverage up to 15th June 2015




- 1st pass: 435/651 pointings completed
- 1st pass will cover the whole northern hemisphere with incoherent beams

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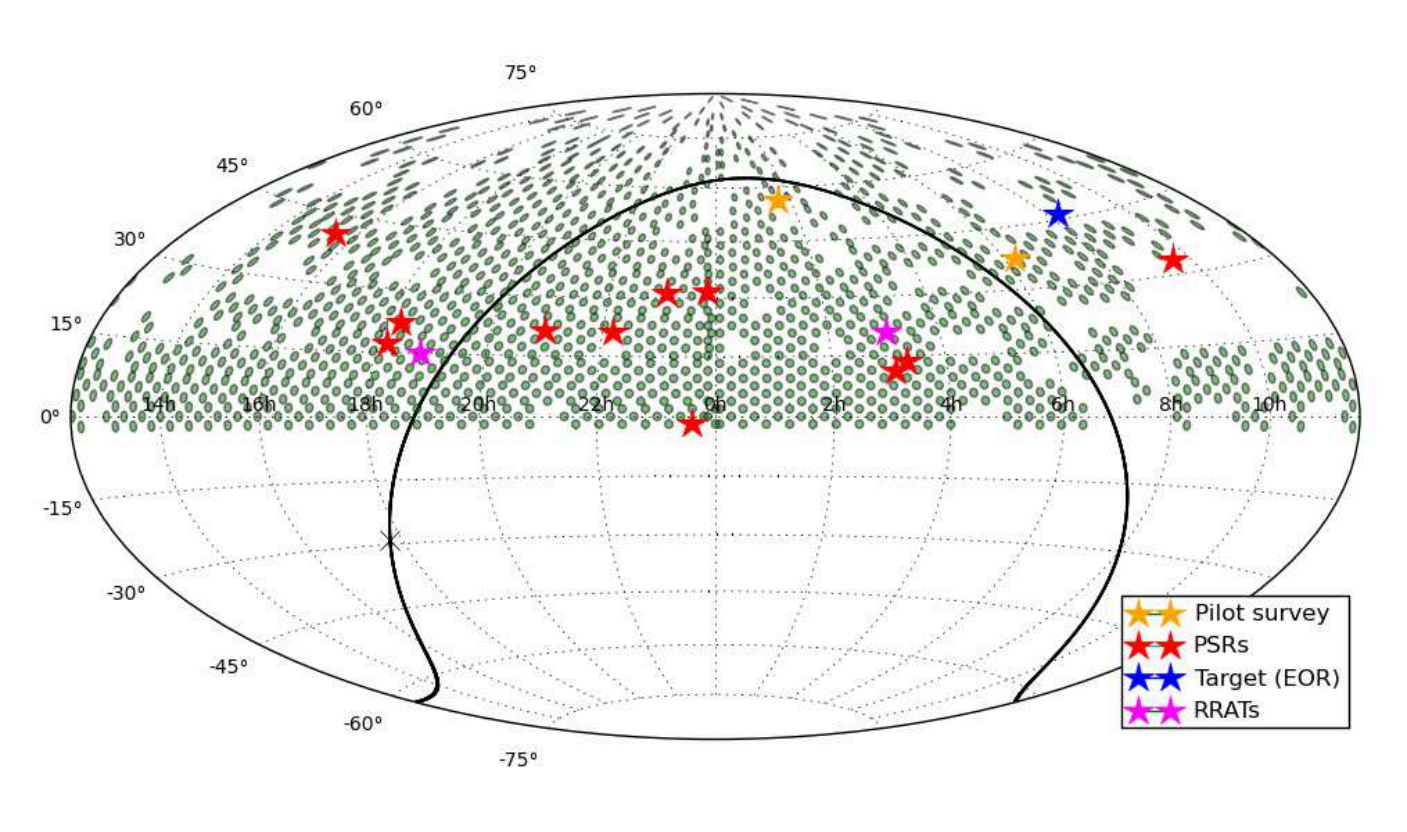
# The LOTAAS survey

Coverage up to 15th June 2015




- 3 passes needed to cover the northern hemisphere with coherent beams.
- 1953 pointings in total

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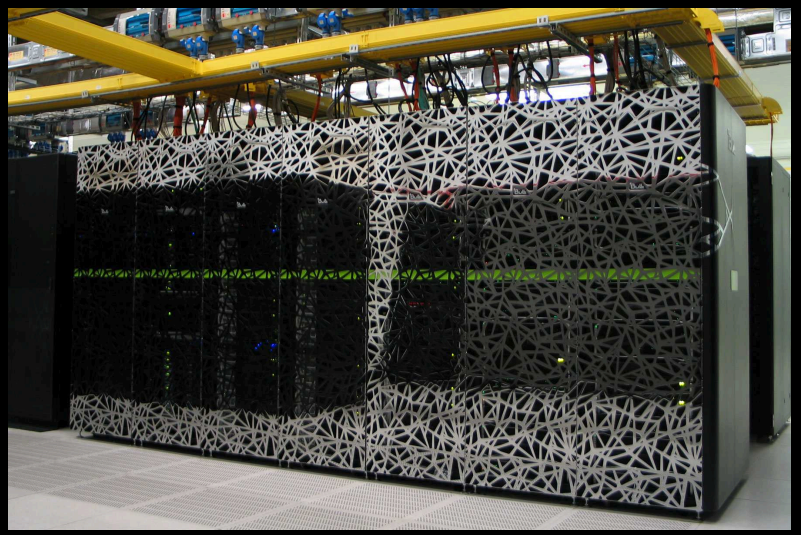
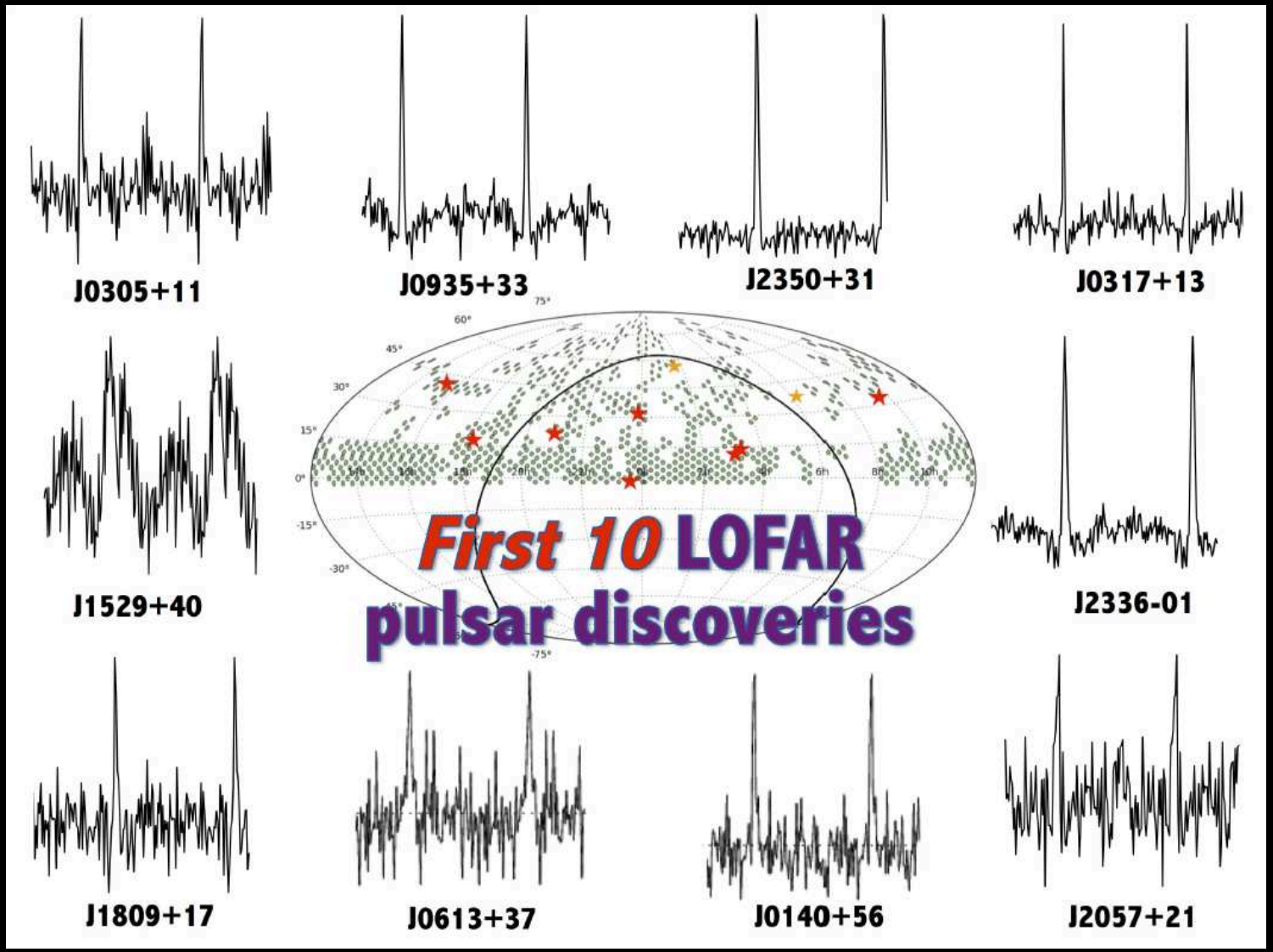
# The LOTAAS survey - Processing

- 1st year observations processed at Manchester
- Since Dec 2013 - Cartesius (Dutch National supercomputer) 500 nodes (24 cores, 64GB RAM)
- 10 million CPU hours granted
- ∼3 hours processing/beam on a 24-core node
- ∼40 million candidates expected
- ∼20000 candidates per pointing
- Machine learning classifier implemented (Lyon et al. 2015) ∼500 candidates per pointing



# The LOTAAS survey - Results



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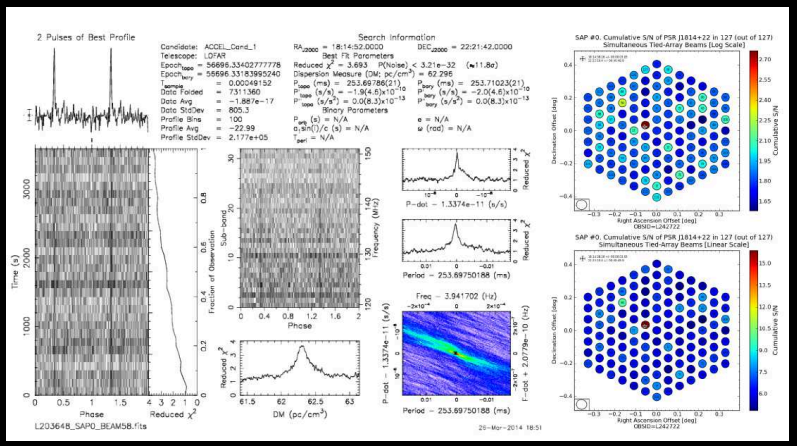
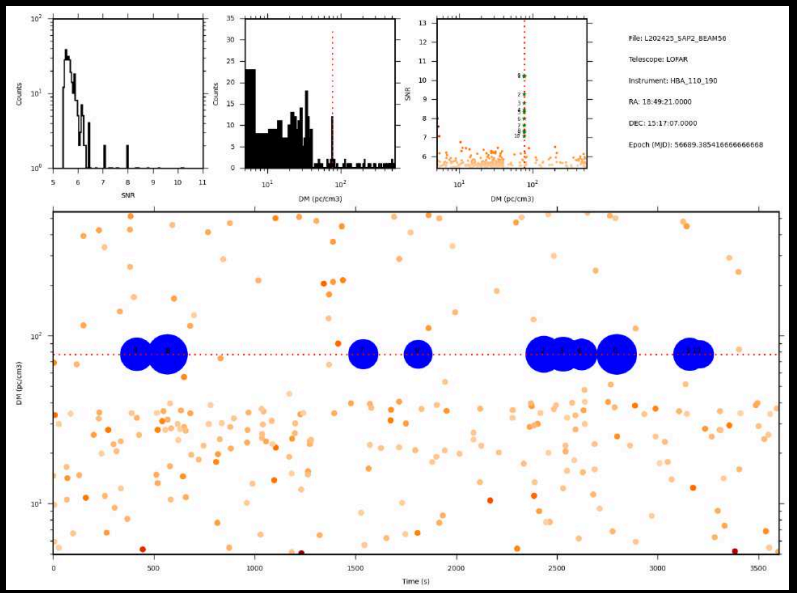
# The LOTAAS survey - Results

- Discoveries webpage: *www.astron.nl/lotaas*
- 10 new pulsars from periodicity searches (Sally Cooper)
- 2 new RRATs from single pulse searches (Daniele Michilli)
- 2 new pulsars from pilot survey (Thijs Coenen)
- 1 new pulsar from targeted search (Vlad Kondratiev)
- 2 new pulsars last week (Cooper, S.S.)
- Only ∼330 pointings processed (Cartesius failure)



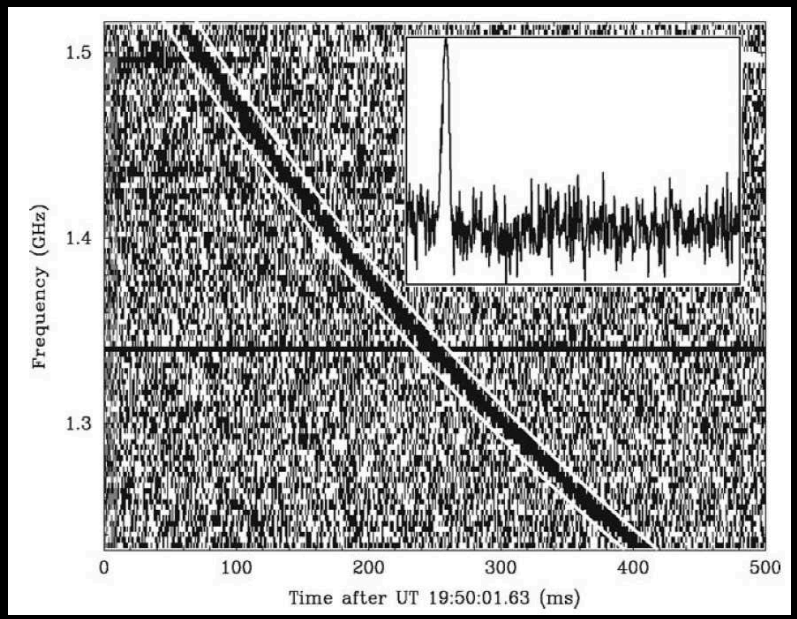




More to come!!!

1. Improved single pulse search algorithm (D. Michilli)
2. Optimization of LOTAAS pipeline for Cartesius (S.S.)

# *Fast Radio Bursts*

The Lorimer burst




- Extragalactic origin
  extremely high DM
- Bright (Lorimer burst 30Jsky!)
- Millisecond duration
- *Uknown source*
- $\sim$ 11 detected so far
- Rate estimates poor, but even $10000$ per day per sky have been suggested!
- All at $1.4\,\mathrm{GHz}$

Lorimer et al. 2007
Keane et al. 2012
Thornton et al. 2013
Spitler et al. 2014

What happens at low frequencies?
$\rightarrow$ A real-time, all sky monitor is needed

# *DRAGNET*


ERC starting grant to Jason Hessels (2.1M Euro)

Scientific Objectives:

- Design, build and commission a dedicated GPU cluster
- Real time searching for FRBs and RRATs
- Accelerate LOTAAS survey processing
- Observing/Timing of all pulsars visible to LOFAR
- Commensal observing with any LOFAR observation

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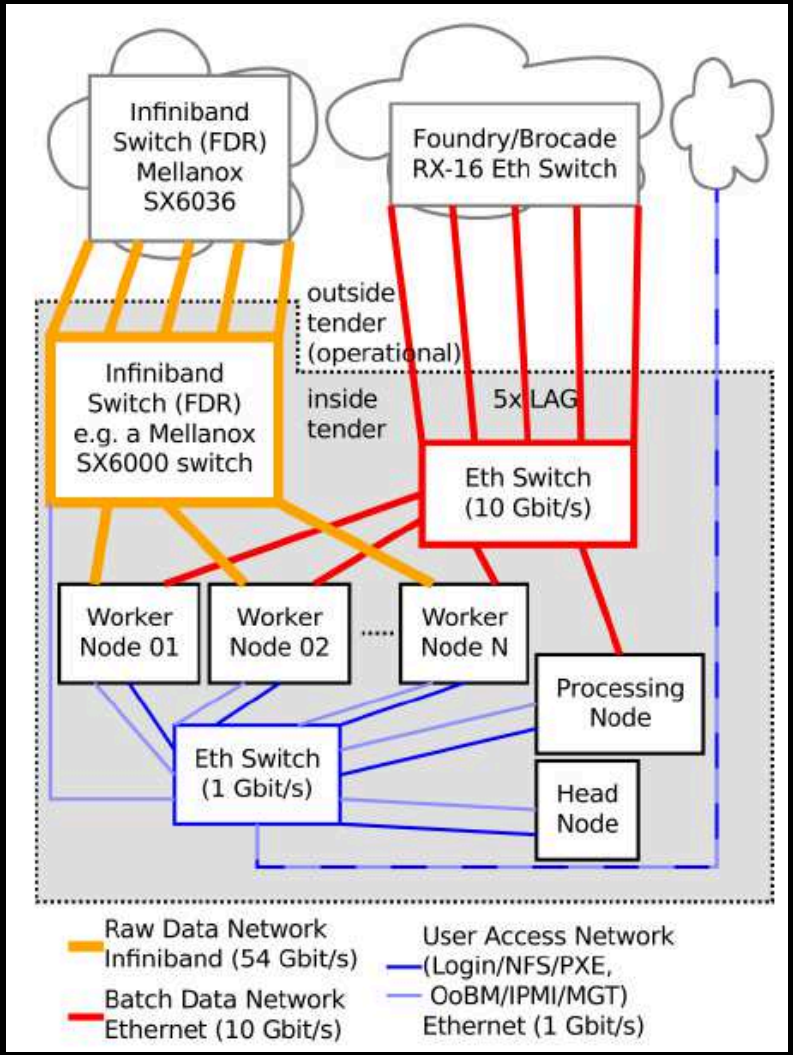
# DRAGNET - backend

DRAGNET requirements

- Acquiring through European tender
- Fixed budget (~400k Euro)
- Direct infiniband connection to COBALT
- NVIDIA GPUs
- 8GB RAM minimum/GPU
- Minimum 50Gbps total disk throughput
- Minimum 240TB storage



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# DRAGNET - backend

DRAGNET backend:
23 nodes

- 2x Intel Xeon E5-2630v3 (16 cores  2.4GHz)
- 4 Titan X consumer cards (12GB, 3072 cores, ~ 7TFLOPS)
- 128GB DDR4 RAM
- 16TB disk space

1 batch processing node

Overall GPU performance:
~ 600TFLOPS
Total storage:400TB

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# *DRAGNET - pipelines*

**Adapt existing GPU accelerated software to our demands:**

- Incoherent dedispersion/transient searching through ARTEMIS and ASTRO-ACCELERATE (real-time)
- Use dedispersed time series for use with PRESTO *accelsearch*
- Timing of known pulsars through PSRDADA and DSPSR

**Add new features to COBALT beamformer:**

- Reduce datarates/increase time resolution through 32bit to 8 bit conversion
- Better RFI rejection through station flagging before beamforming
- Coherent dedispersion at coarse DM steps to allow searching to higher DMs

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# Conclusions

LOTAAS:

- LOTAAS will be the deepest low-frequency pulsar survey ever done
- 17 pulsars found so far, expected to find about 200
- LOTAAS is a valuable stepping stone towards SKA pulsar surveys

DRAGNET:

- Accelerate/improve LOTAAS searching through a GPU version of the pipeline.
- Piggyback LOFAR observations for real-time transient search
- Timing and monitoring a large amount of pulsars simultaneously (in theory, 92 pulsars *simultaneously* in the northern sky)

Long term:

- Get the raw LOFAR data from the stations and do custom beamforming