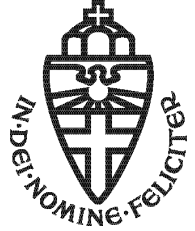


# ***LOFAR Science Workshop 2015 - Summary***



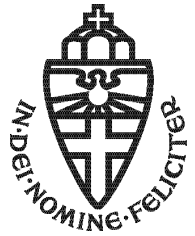
Radboud University Nijmegen

***Heino Falcke***

*(Chair of the ILT Board)*

*Radboud University Nijmegen*

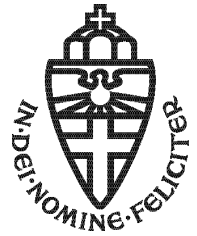
*ASTRON, Dwingeloo*



# Science Output

- Refereed commissioning papers (2014 → 2015)
  - 15 → 27 (→ 524 cites)
  - Top Cited:
    - van Haarlem 2013 (LOFAR): 53 → 174 cites
    - Stappers 2011 (pulsars): 67 → 90 cites
    - Hermsen et al. 2013 (psr mode switch): 37 cites
  - High Impact: 1x Science (Hermsen) + 1x Nature??
- Papers mentioning LOFAR:
  - 747 → 852 papers with 4869 → 6242 cites
  - Top 10: 8xEOR, 1xSRV, 1xCR (all promises)

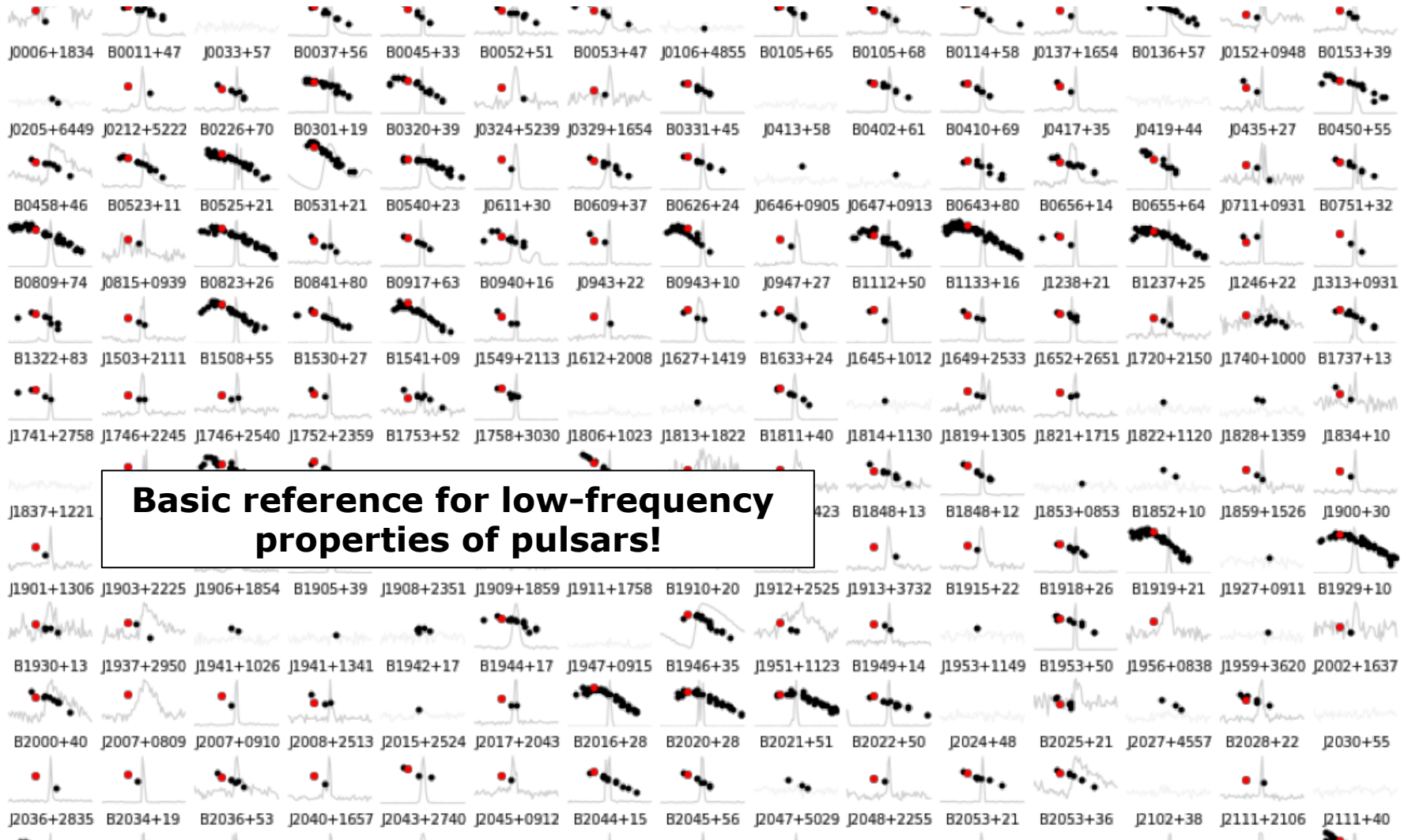
# LOFAR Top 10 (commissioning) papers



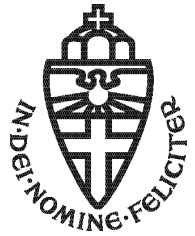
Radboud University Nijmegen

- van Haarlem, M. P., and 200 colleagues 2013. LOFAR: The LOw-Frequency Array. *Astronomy and Astrophysics* 556, A2. **(174 cit.)**
- Stappers, B. W., and 93 colleagues 2011. Observing pulsars and fast transients with LOFAR. *Astronomy and Astrophysics* 530, A80. **(90 cit.)**
- Hermsen, W., and 88 colleagues 2013. Synchronous X-ray and Radio Mode Switches: A Rapid Global Transformation of the Pulsar Magnetosphere. *Science* 339, 436. **(39 cit)**
- Yatawatta, S., and 88 colleagues 2013. Initial deep LOFAR observations of epoch of reionization windows. I. The north celestial pole. *Astronomy and Astrophysics* 550, A136.
- van Weeren, R. J., and 84 colleagues 2012. First LOFAR observations at very low frequencies of cluster-scale non-thermal emission: the case of Abell 2256. *Astronomy and Astrophysics* 543, A43.
- Hassall, T.E., and 93 colleagues 2012. Wide-band simultaneous observations of pulsars: disentangling dispersion measure and profile variations. *Astronomy and Astrophysics* 543, A66.
- de Gasperin, F., and 94 colleagues 2012. M 87 at metre wavelengths: the LOFAR picture. *Astronomy and Astrophysics* 547, A56.
- Offringa, A. R., and 95 colleagues 2013. The LOFAR radio environment. *Astronomy and Astrophysics* 549, A11.
- Sotomayor-Beltran, C., and 79 colleagues 2013. Calibrating high-precision Faraday rotation measurements for LOFAR and the next generation of low-frequency radio telescopes. *Astronomy and Astrophysics* 552, A58.
- Schellart, P., and 104 colleagues 2013. Detecting cosmic rays with the LOFAR radio telescope. *Astronomy and Astrophysics* 560, A98.

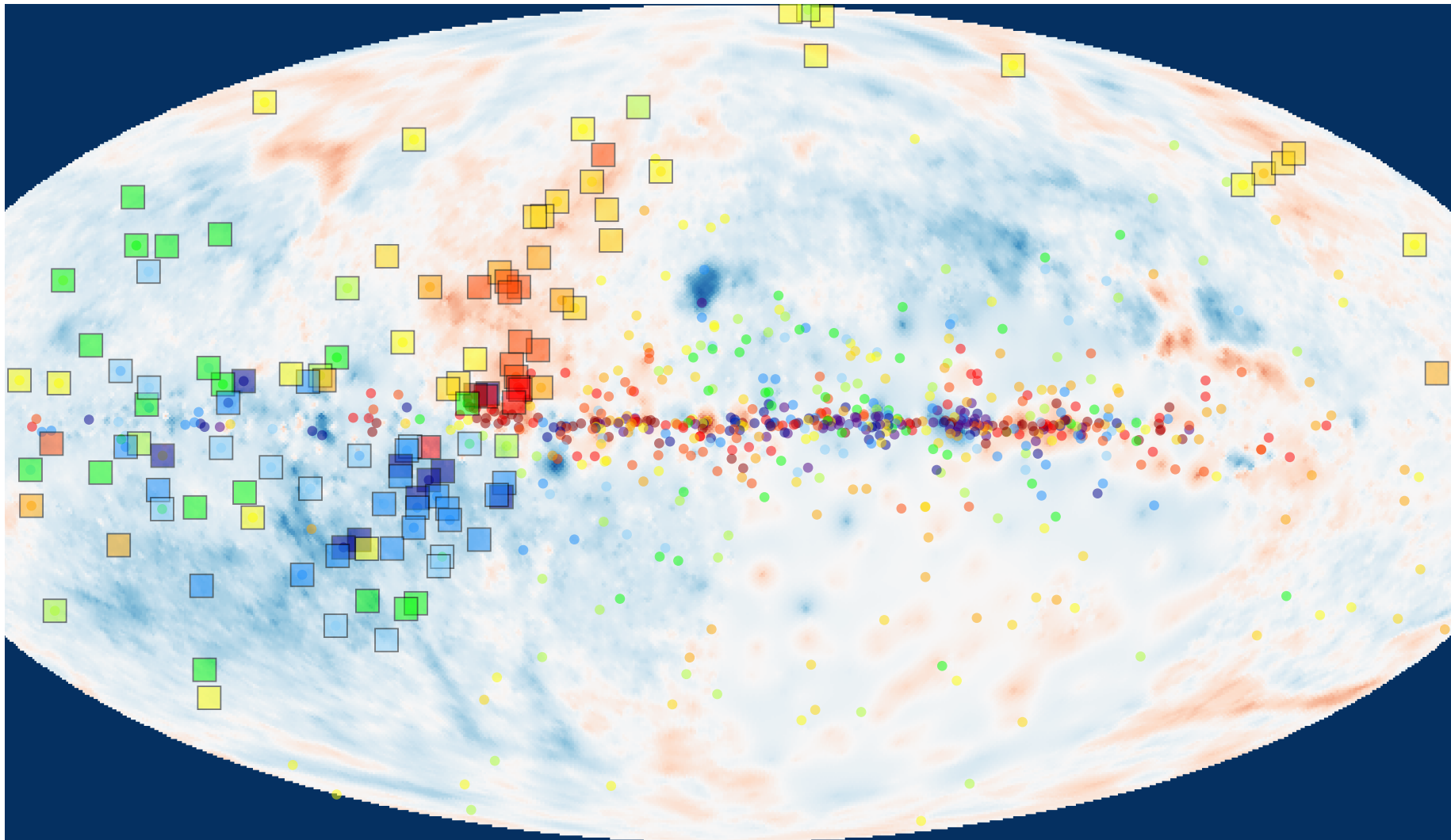
# Pulsar Census



# *Pulsar Census: Galactic B-Field*



Radboud University Nijmegen



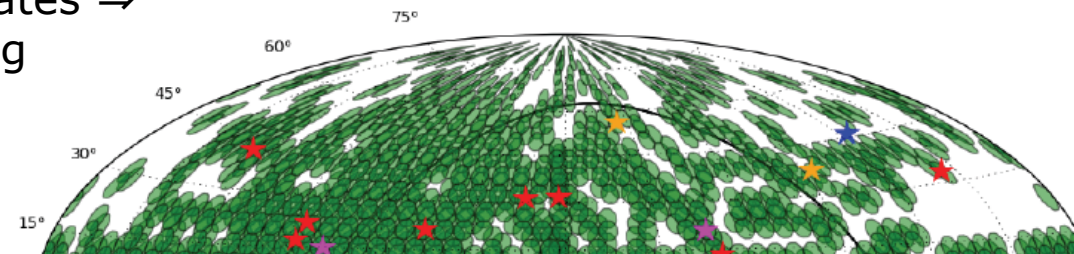
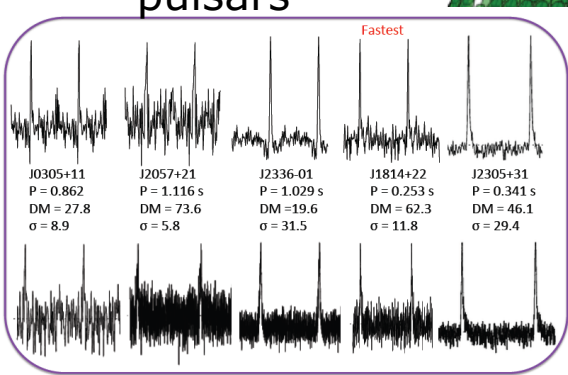
Charlotte Sobey

# LOFAR Pulsar Survey

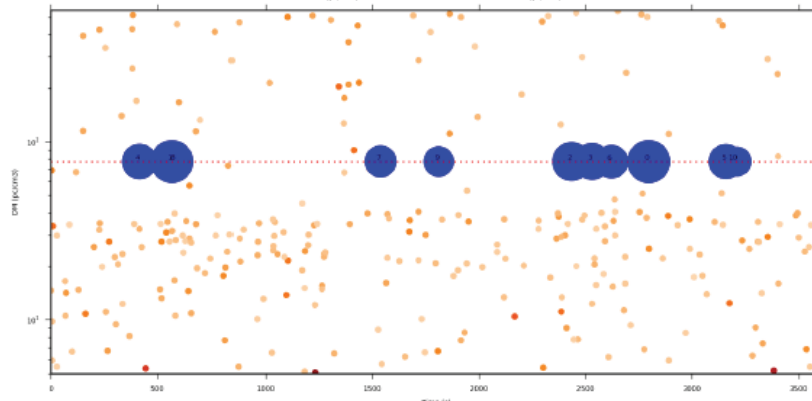
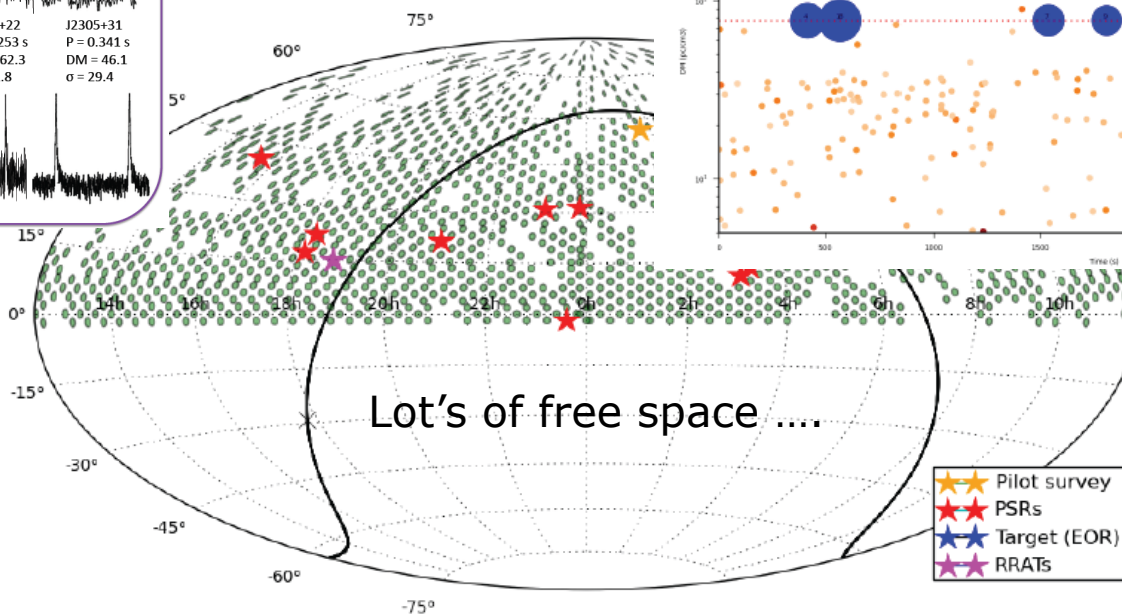
Radboud University Nijmegen

5 Million candidates  $\Rightarrow$   
machine learning

15 new  
pulsars



including  
2 RRATs



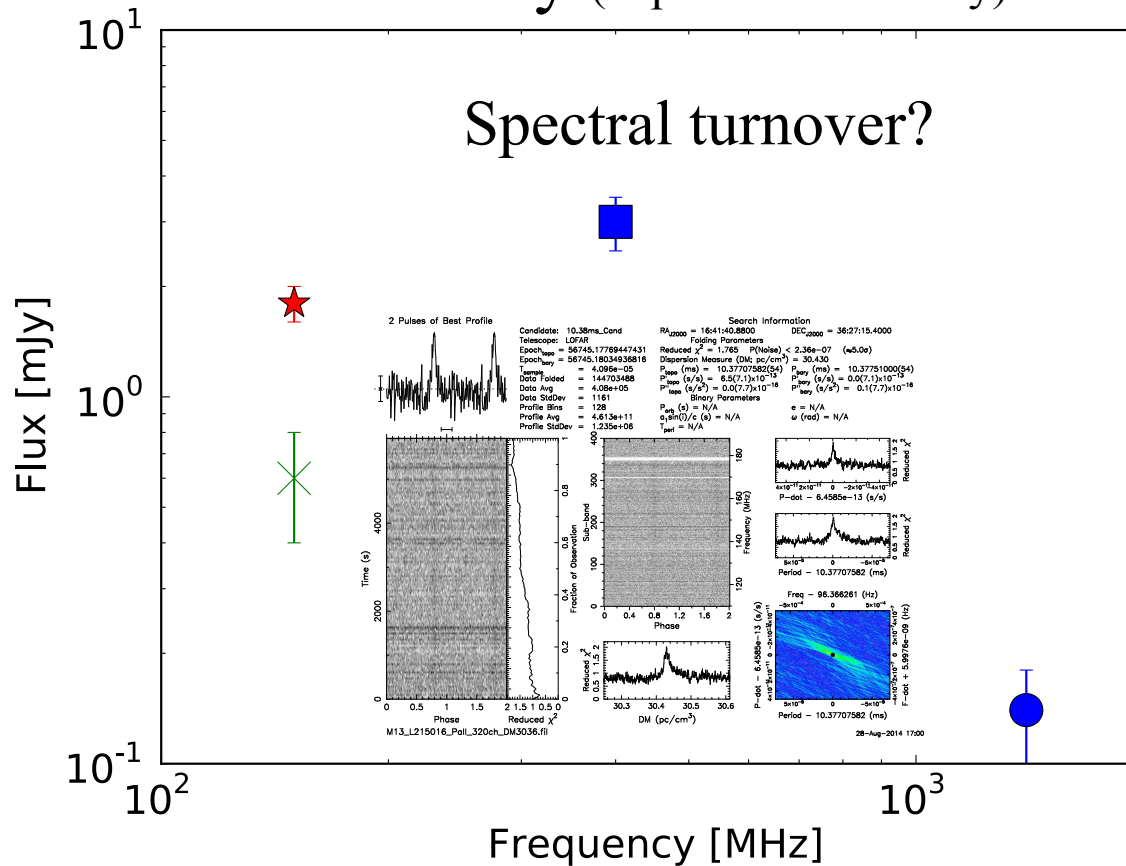
- ★ Pilot survey
- ★ PSRs
- ★ Target (EOR)
- ★ RRATs

# Globular Cluster Pulsars: Detection of M13A – turnover?



Radboud University Nijmegen

1.8 mJy (expected 12-18 mJy)

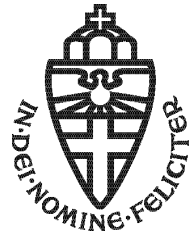


- Hessels et al. '07
- Kulkarni et al. '91
- ✕ LOFAR measured
- ★ LOFAR corrected

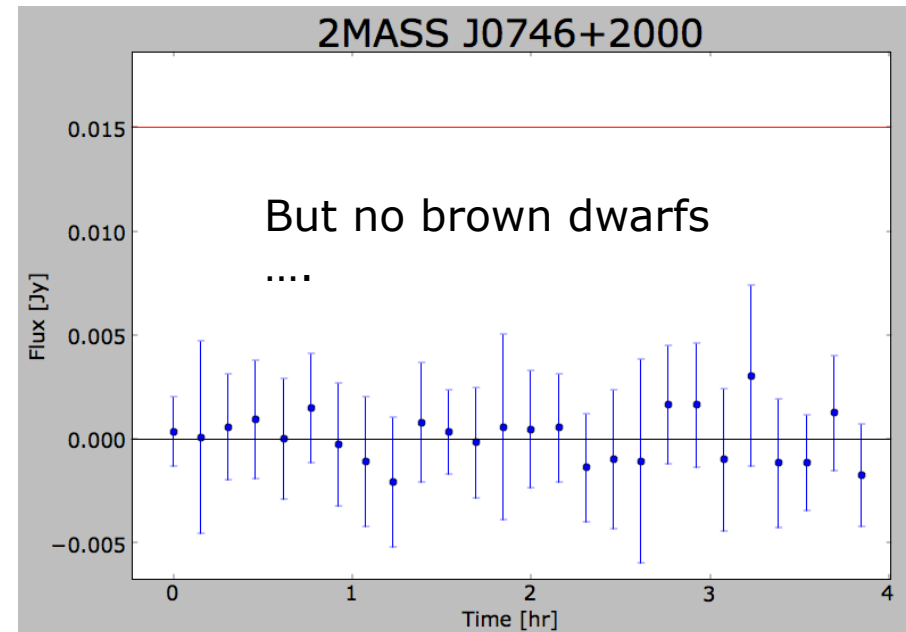
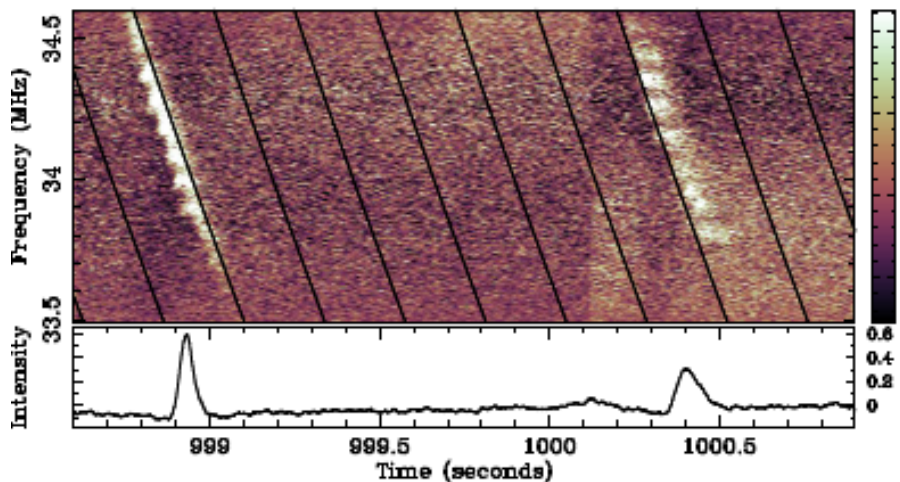
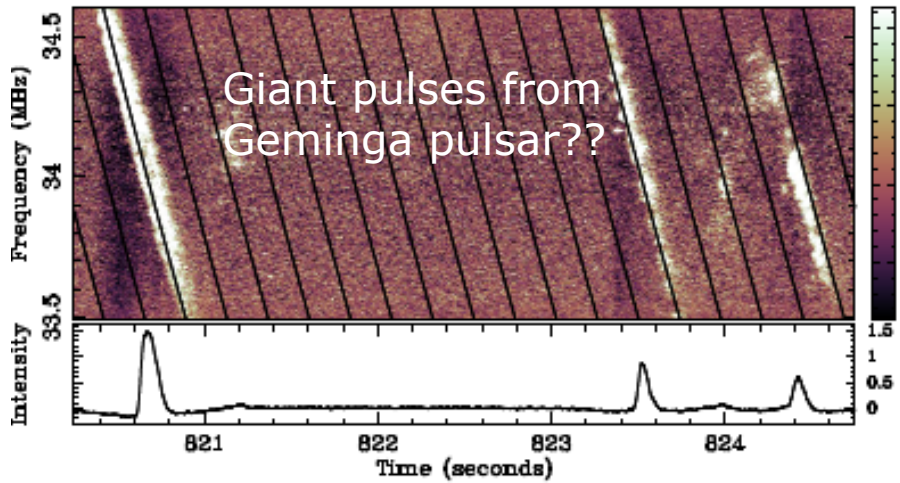
Where are the others?  
Can we trust our fluxes?

Sander ter Veen

# Fast transients



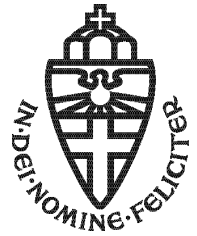
Radboud University Nijmegen




Emilio Enriquez




# The LOFAR Toolbox



Radboud University Nijmegen



## Main Telescopes + People



### XMM-Newton

**Wim Hermsen (SRON/UvA)**  
**Lucien Kuiper (SRON)**  
**Sandro Mereghetti (IASF)**

### LWA


**Kevin Stovall (UNM)**

### LOFAR (international)


**Jason Hessels (ASTRON/UvA)**  
**Stefan Oslowski (U. Bielefeld)**  
**Maciej Serylak (UWC)**

### Arecibo

**Joanna Rankin (U. Vermont)**  
**Andrea Possenti (OAC)**



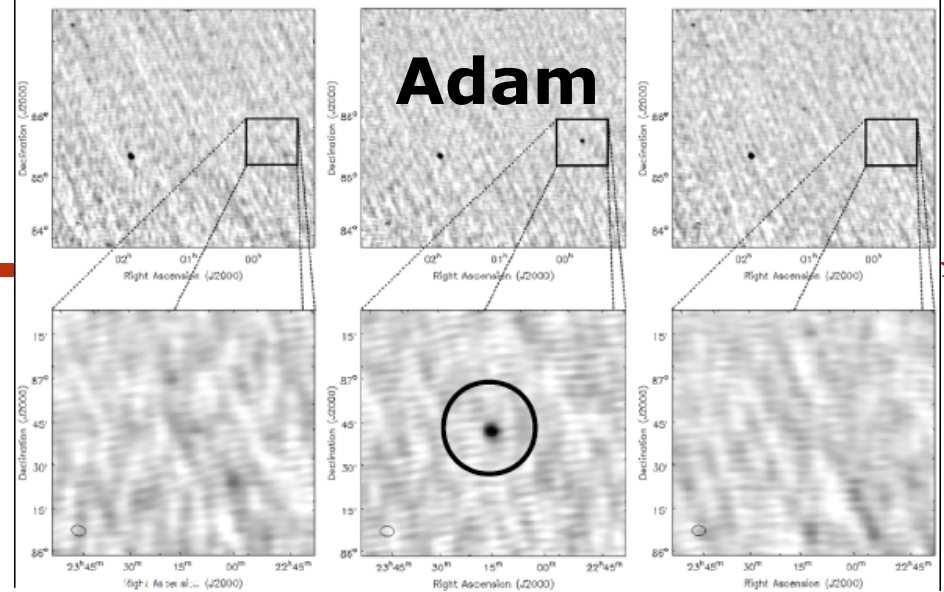
**“Some science  
just takes time”**



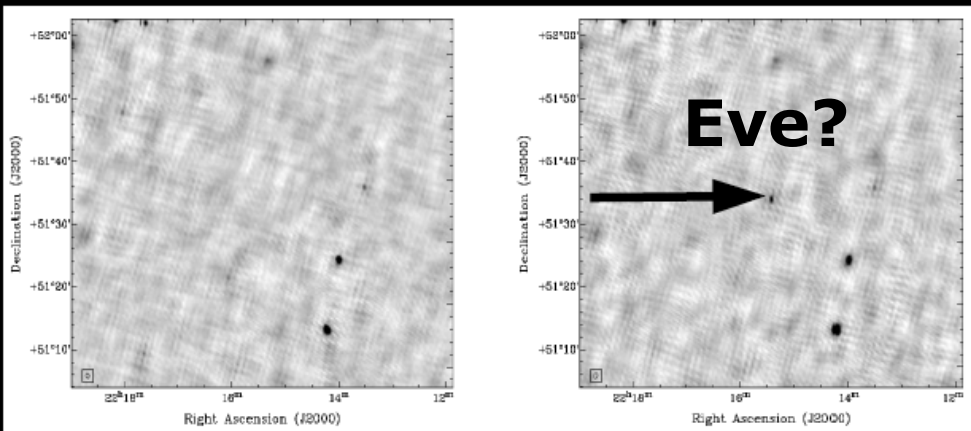
Jason Hessels

# Transients

But, what's next?

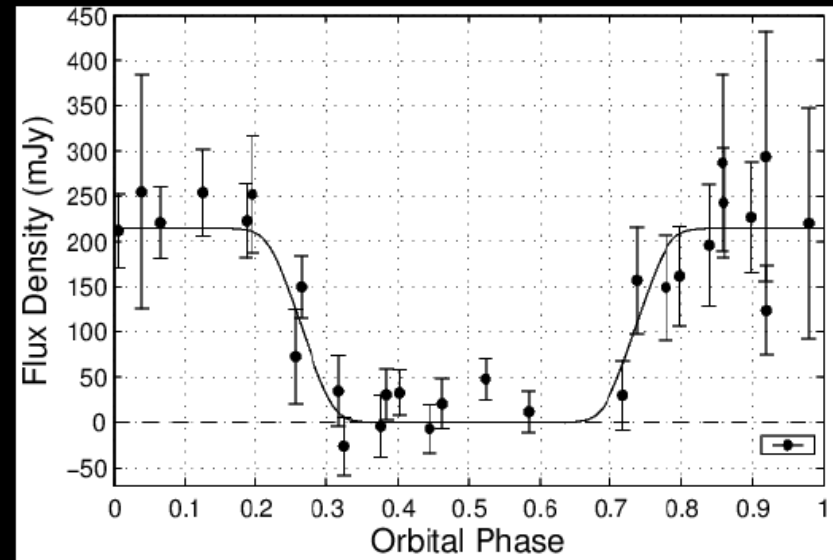


124 MHz observations



2013 February 10

2014 January 15



Full RSM dataset (e.g. 28 x 11 min images)  
→ eclipses observed

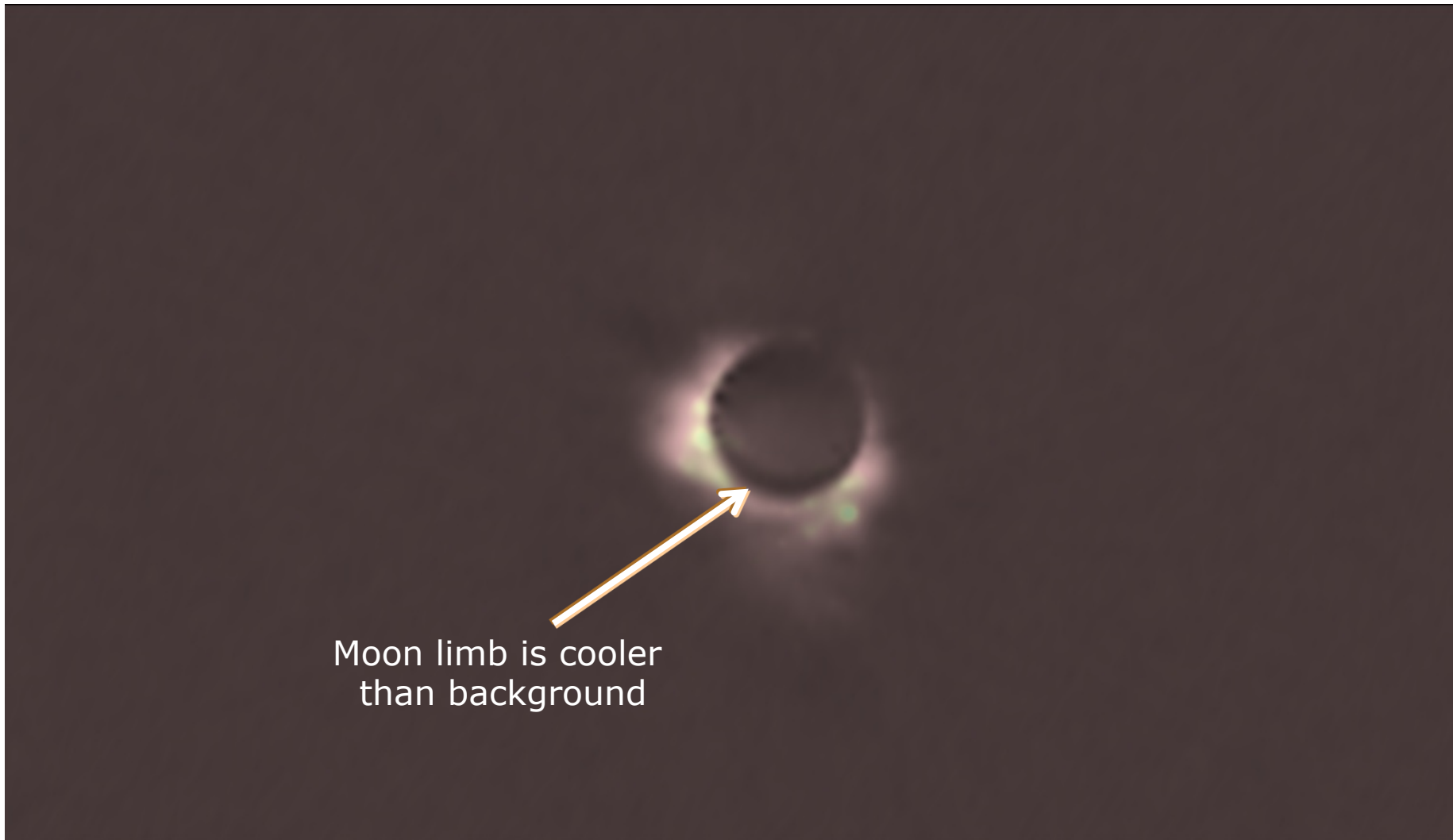
Dario Carbone, Assen – 02/06/2015

Dario Carbone

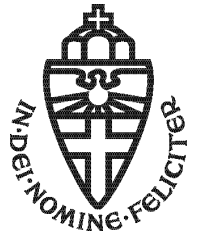
# *Solar Eclipse Imaging*



Radboud University Nijmegen



Moon limb is cooler  
than background



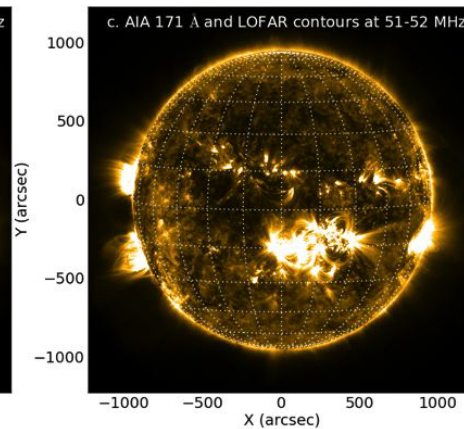
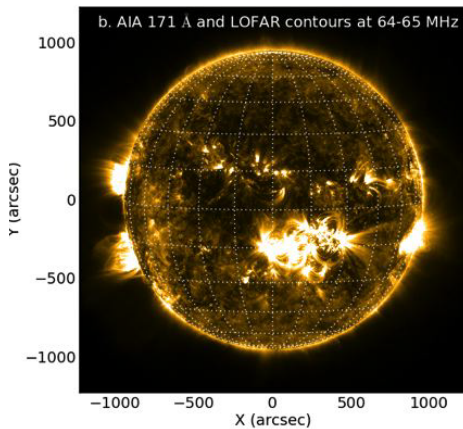
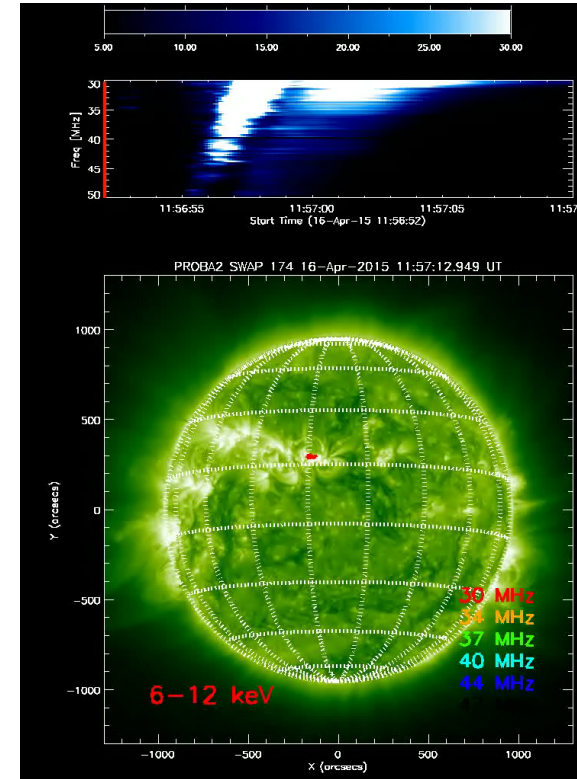
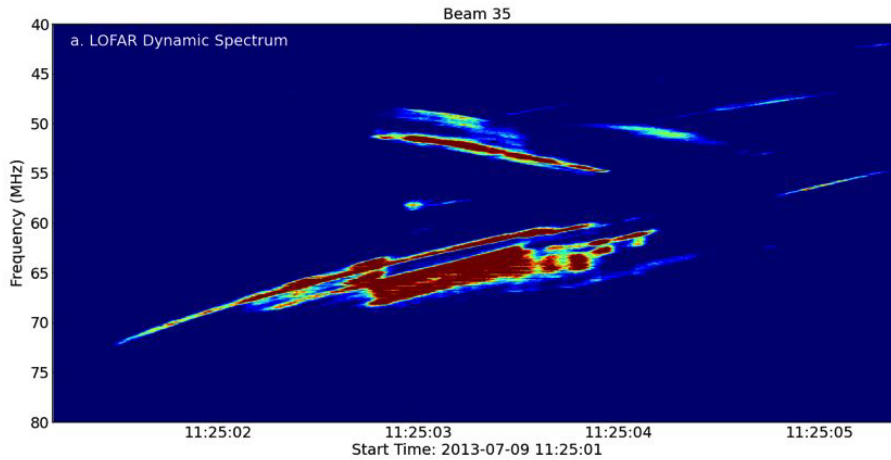
# *The Sun is bright*

Radboud University Nijmegen

A blurry image of a solar eclipse, showing a bright, glowing ring of light against a dark background.

**Solar eclipse March 2015**  
**International LOFAR Telescope**

# Happy Sunshine Movies



Frequency-dependent size and location of type III bursts

S-Bursts: Sun disguising as Jupiter

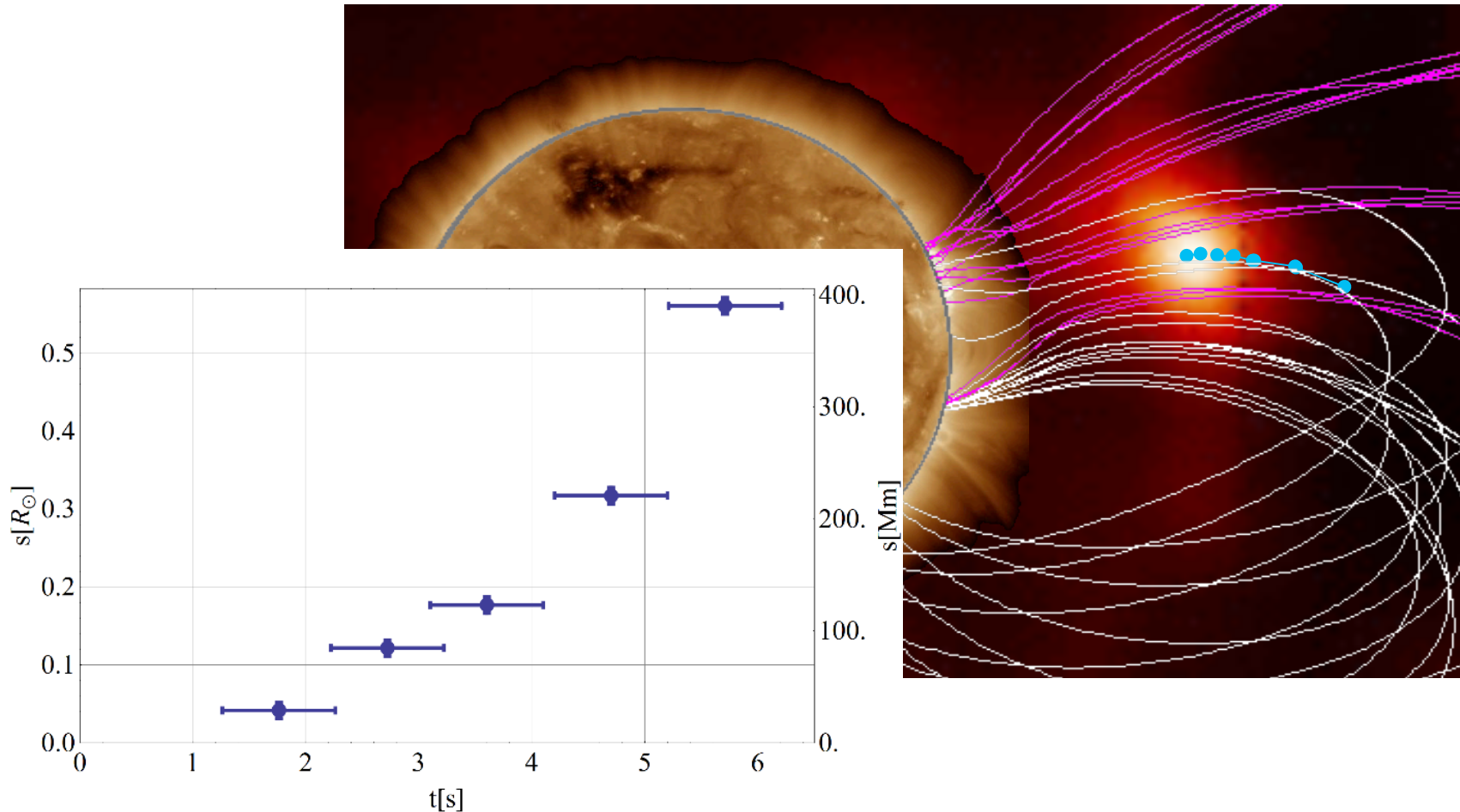
Diana Morosan

Hamish Reid

# Happy Sunshine Movies

Radboud University Nijmegen

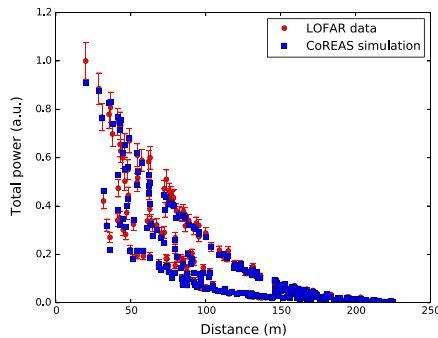
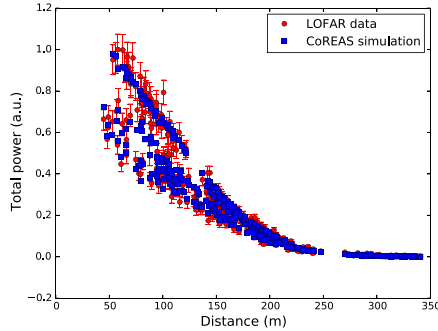
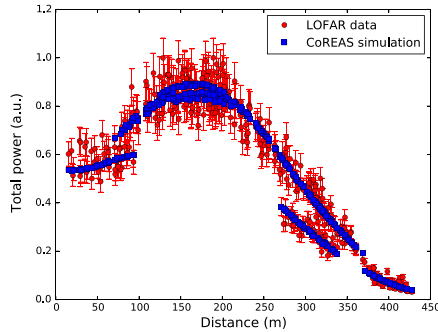
Turning Images into physics: Velocity and velocity distribution of electrons.



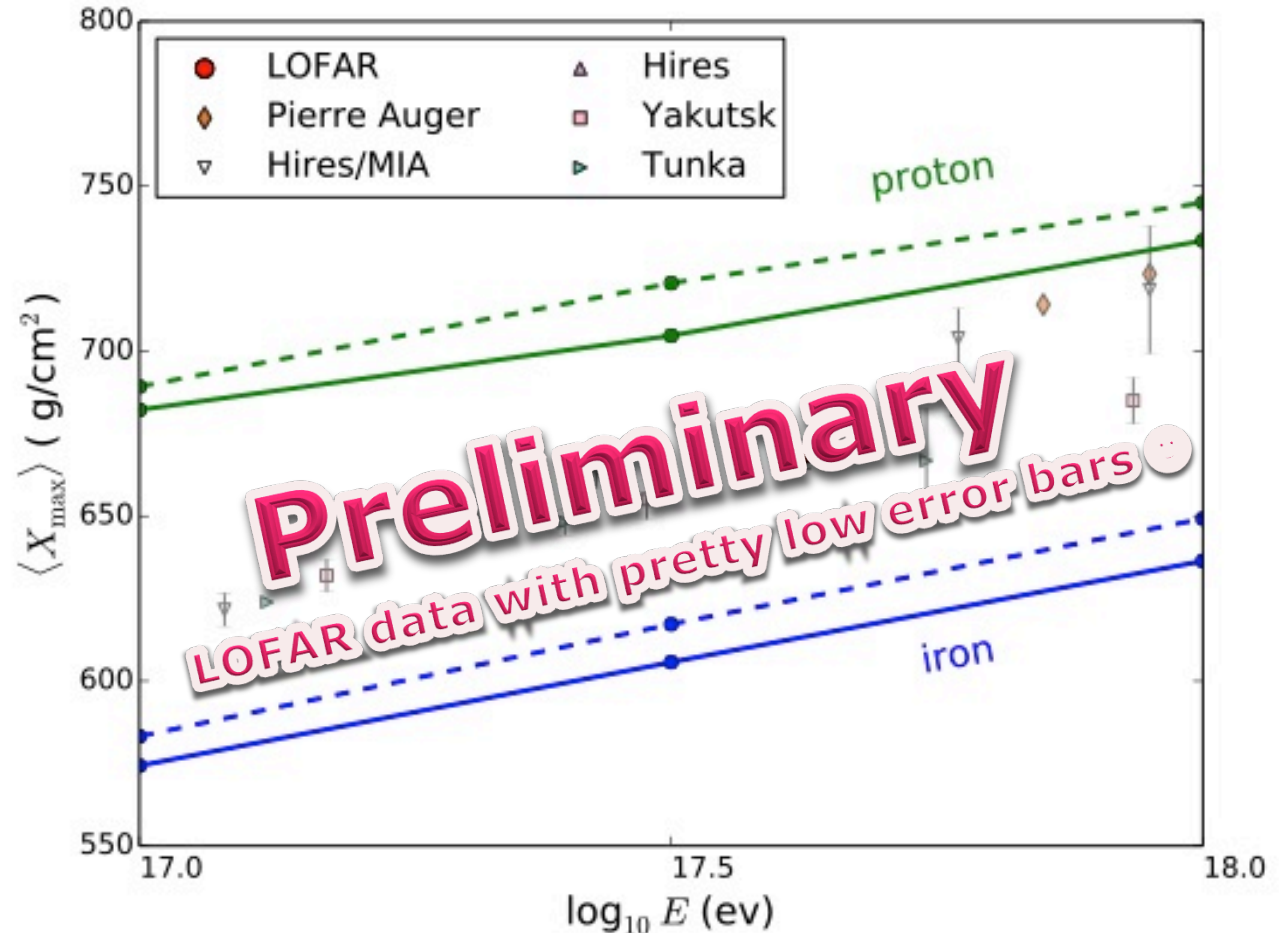
# Cosmic Ray Precision Composition Measurements



Radboud University Nijmegen

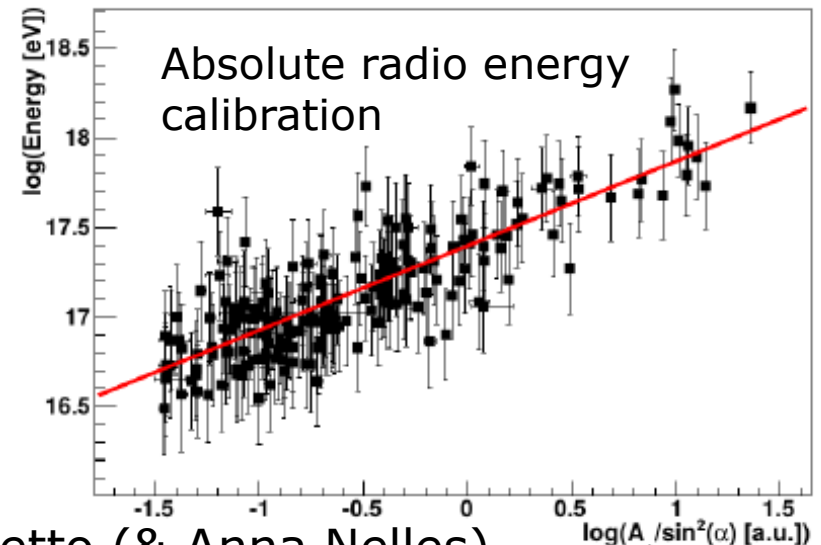
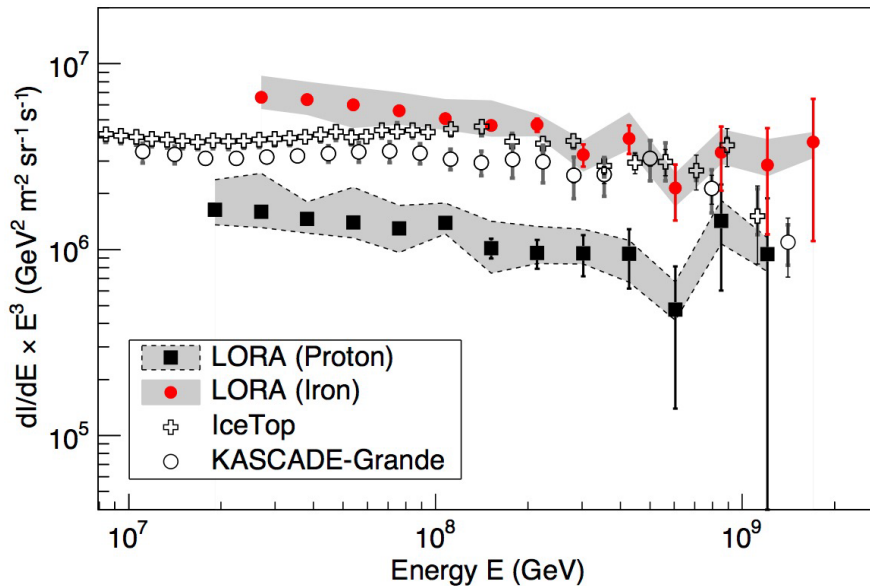
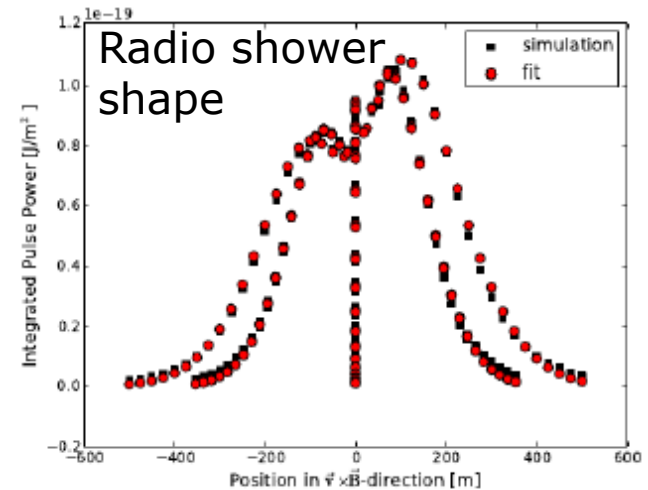


Most precise and probably most accurate CR composition measurements



Jörg Hörandel

# Cosmic Ray measurements





# Lightning & CRs: Astroparticlegeophysics



Radboud University Nijmegen

P. Schellart et al. (PRL 114, 165001)

P. Schellart et al. (PRL 114, 165001)

Distance along  $\hat{e}_v \times \hat{B}$  [m]

**LOFAR in New York Times**

Stars' Rays May Help Measure Thunderstorms

Scientists measure electric fields in thunderclouds with instruments aboard airplanes and weather balloons, but during violent conditions these methods can be difficult, even dangerous. Now researchers may have found a better way to measure these fields: the cosmic rays that originate from exploding stars.

When cosmic rays strike the atmosphere, they create a shower of high-energy particles. Researchers in the Netherlands measured the particles generated by these showers and found that they varied markedly during fair weather and thunderstorms. The differences may provide an effective way to estimate the electric field in a thunderhead.

Monitoring a cloud's electric field is important because it helps define the power of a thunderstorm, said Heino Falcke, an astrophysicist at Radboud University and one of the study's authors.

"Only the electric field is strong enough to do this," he said. "Dr. Falcke said this is like measuring the horsepower of a car or the mass of a truck."

Dr. Falcke and his colleagues took their measurements using the LOFAR radio telescope in the Netherlands and published their findings in the Journal Physical Review Letters.

SINDYA N. BHANOO

**A Mission's Crash**

A four-year orbit by a NASA craft has uncovered several surprises about Mercury.

By KENNETH CHANG

NASA's Messenger spacecraft, in orbit around Mercury the past four years, will come to an abrupt end on Thursday. Messenger's path will intersect with the surface of the planet. The impact of the 1,000-pound spacecraft at 5,750 miles per hour is expected to gouge a crater some 50 feet wide.

That will bring to a close a mission that has painted an unexpected portrait of Mercury, once thought a boring rock not much different from Earth's moon. Mercury, the smallest planet in our solar system, is only slightly larger than the moon, although it has more drastic temperature swings — 800 degrees Fahrenheit during the day, minus 300 degrees at night.

"It's really been exciting to see a planet unfold, a planet that is one of our neighbors," said Sean C. Solomon, the principal investigator for the mission. "Almost every aspect of Mercury has had its share of surprises."

Messenger — a shortening of Mercury Surface, Space Environment, Geochemistry and Ranging — discovered that Mercury shrank slightly as it cooled over billions of years; mapped ancient lava flows; found enigmatic shallow depressions and brightened and brightest spots; and confirmed the presence of ice in perpetually dark craters near the poles.

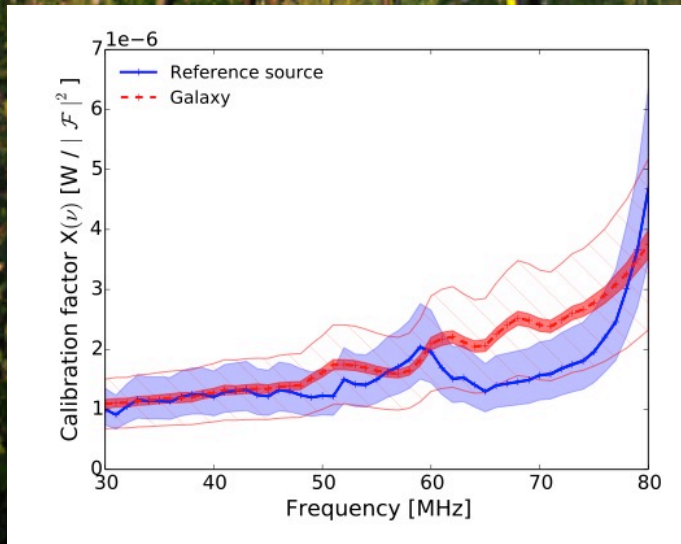
The water ice, perhaps a billion tons, was not a complete surprise. Radio telescope observations from Earth had hinted at something reflective, and the shadowed craters are extremely cold. Beyond confirming the

# Calibration of LOFAR

Radboud University Nijmegen

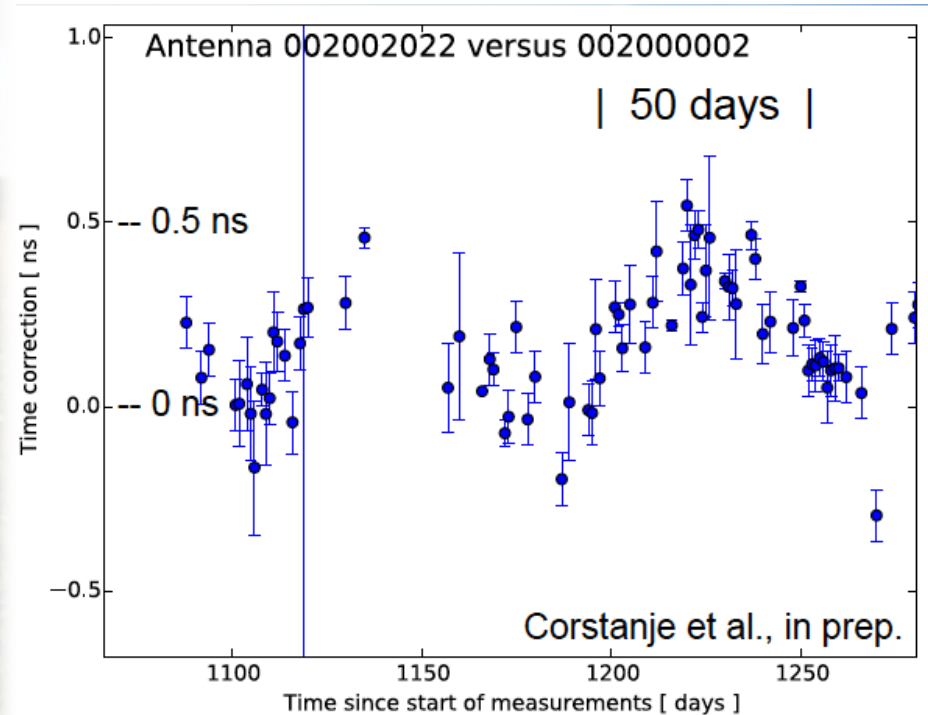


Absolute Flux



Jörg Hörandel

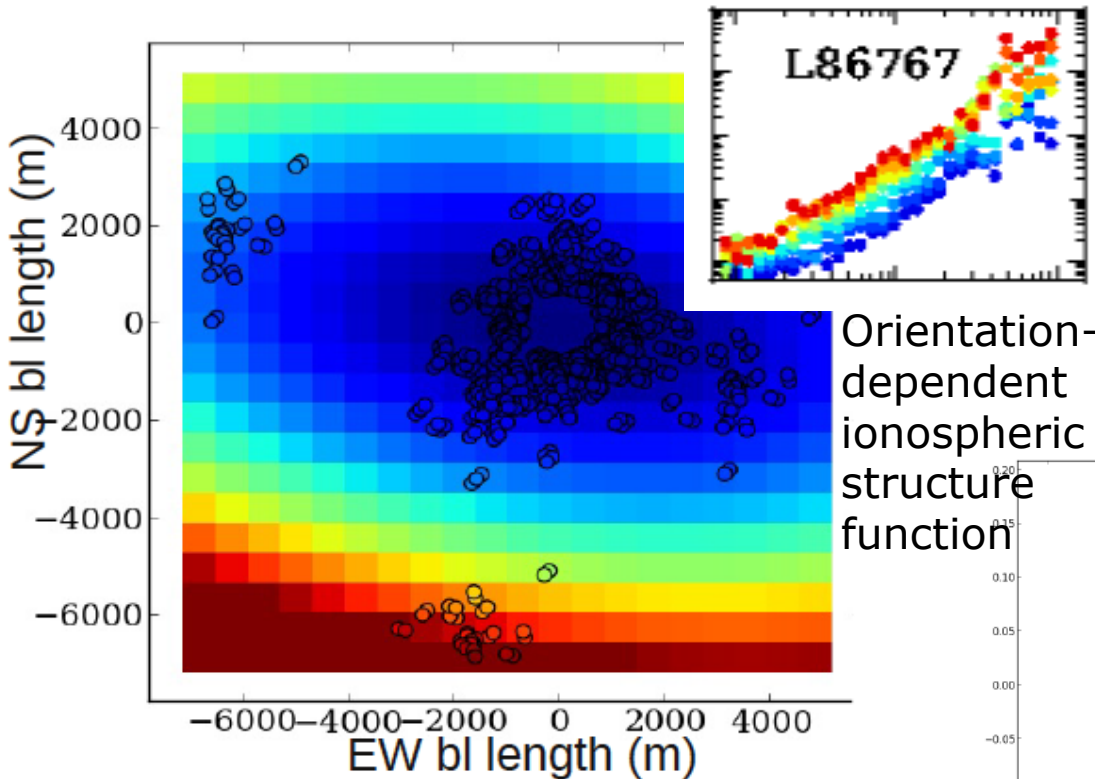
## Timing



Arthur Corstanje

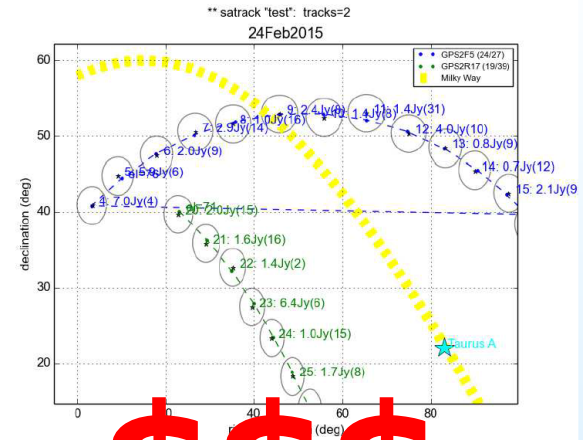
# Dissecting the Ionosphere

Radboud University Nijmegen

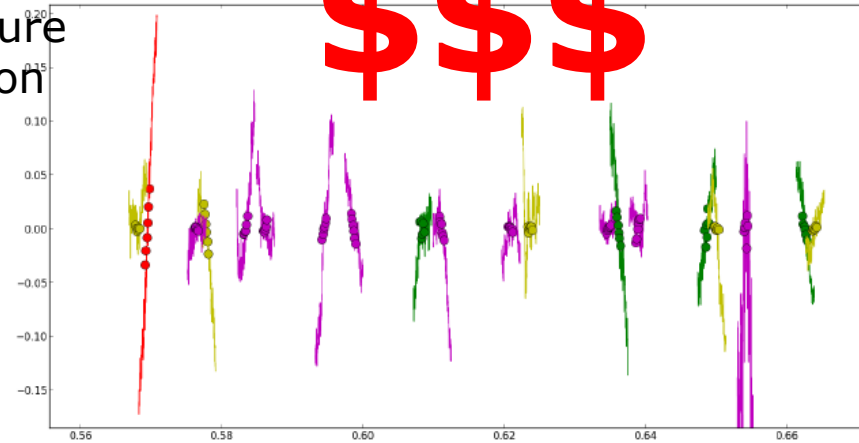


Orientation-dependent ionospheric structure function

2D Structure of Ionosphere aligned with geomagnetic field  
Maaïke Mevius



\$\$\$

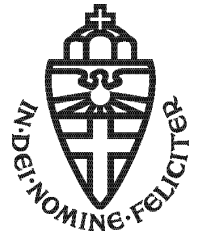


Improving Galileo GPS with LOFAR?  
Bas van der Tol

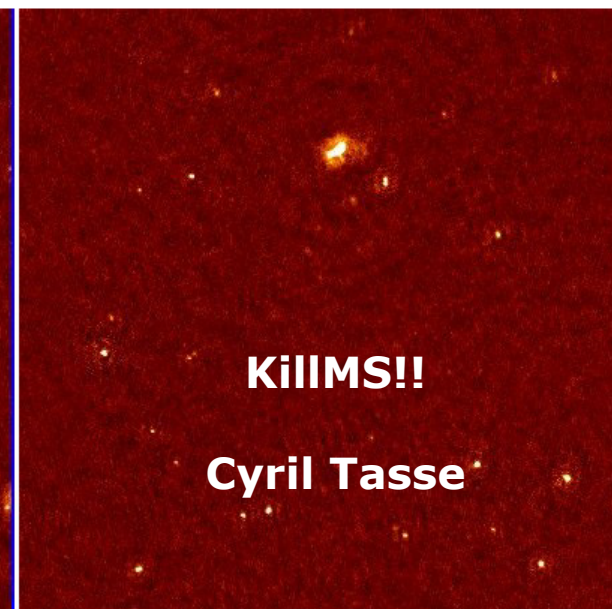
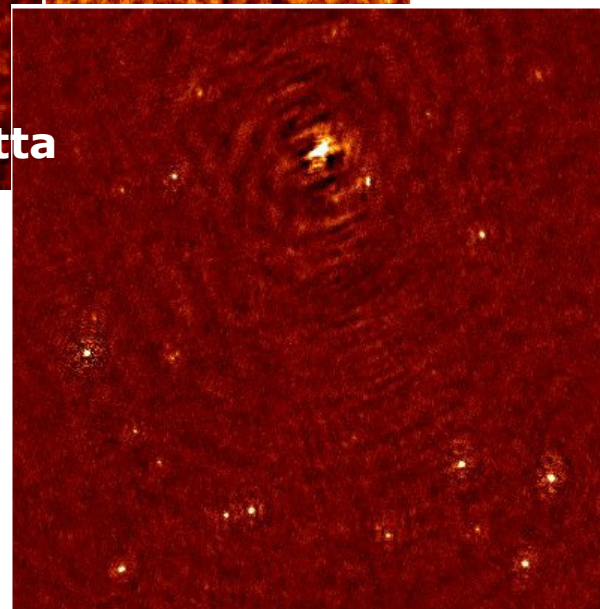
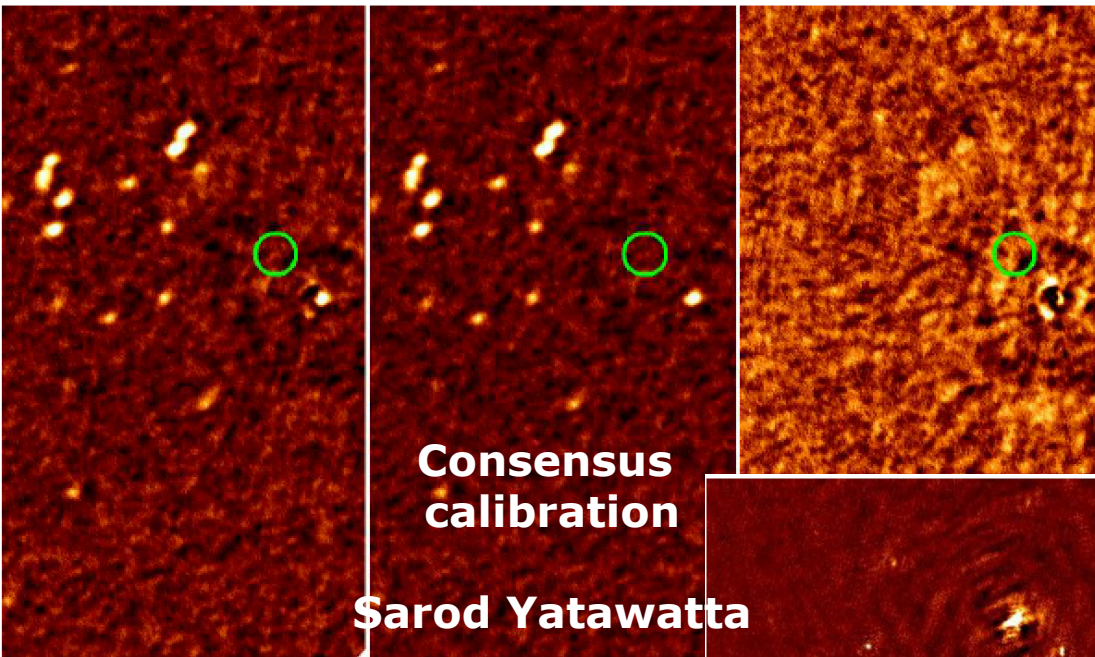
See also Richard Fallows' Christmas present

# WOW Imaging

*Wonders of Widefield Imaging*



Radboud University Nijmegen



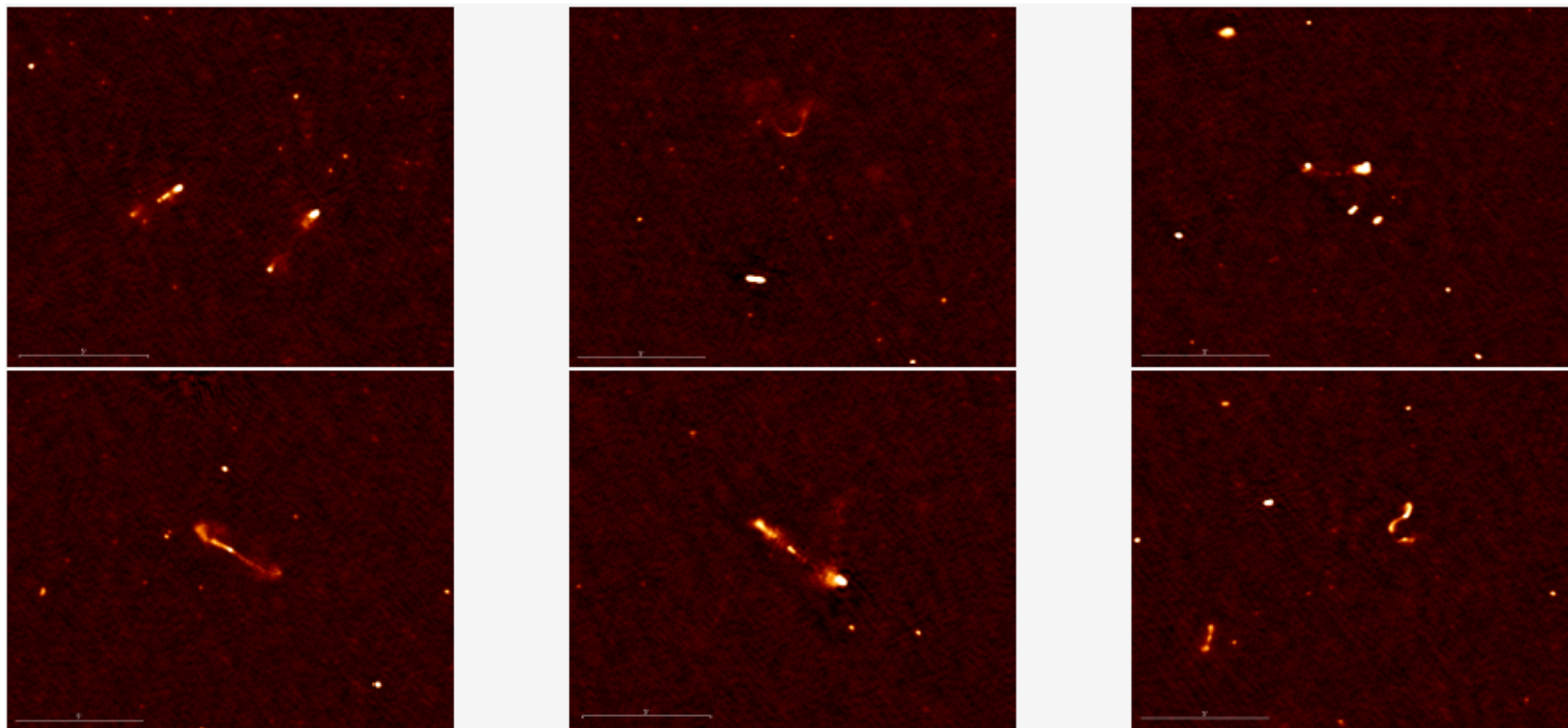
**KillMS!!**

**Cyril Tasse**

# WOW Imaging Facet Calibration



Radboud University Nijmegen



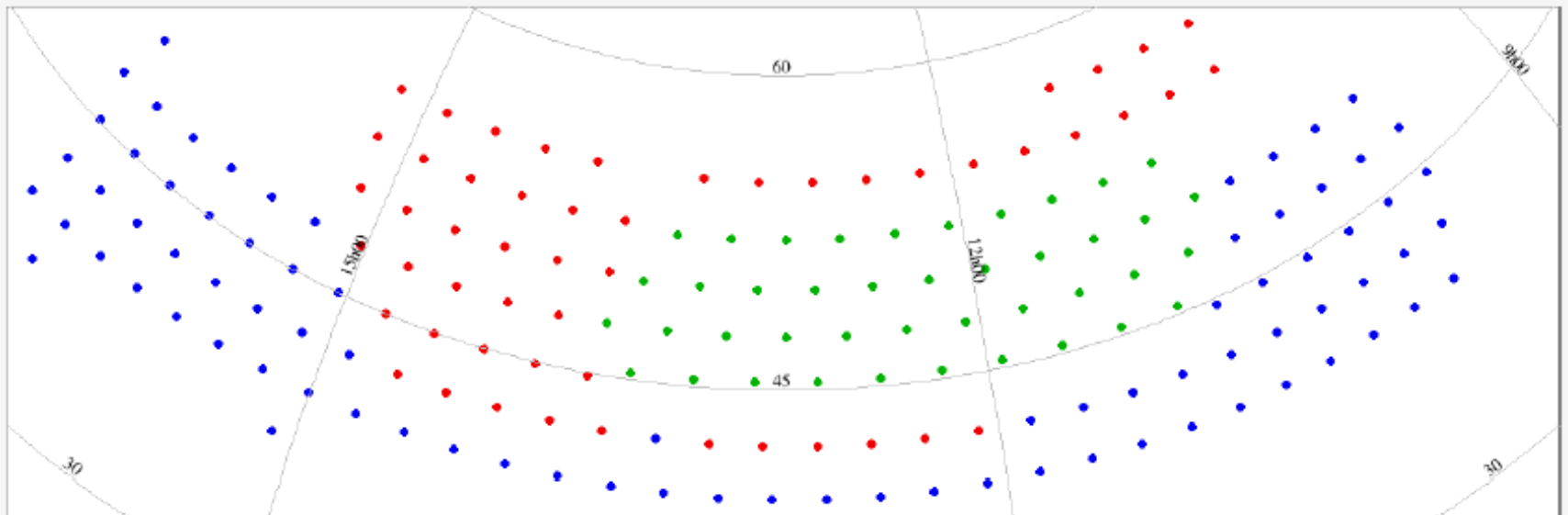
120 $\mu$ Jy and 5x7arcsec resolution.

Timothy Shimhwel (Wendy Williams) -> Apply to deep survey  
Sarrvesh S. Sridhar - > NGC 5775

# *Continuum Survey possible*

Radboud University Nijmegen

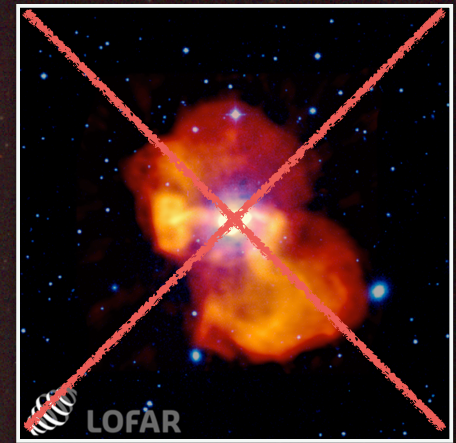
- $\approx 100 \times 8$  hr pointings have been observed and 80 are scheduled.
- 48 MHz bandwidth (from 120 MHz to 168 MHz) towards each pointing
- Always using core and remote stations (40 m to 120 km) in HBA-dual-inner mode and  $\approx 50\%$  of the time also using the international stations.



Timothy Shimwell (Survey KSP)

# WOW Imaging

*Wonders of Widefield Imaging*



**M87 at Low-Band!!!!**

**Francesco de Gasperin**

Virgo A

LOFAR LBA (46 MHz)

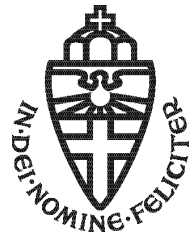
rms: 30 mJy/b

beam: 16" x 17"

dyn range: 7500

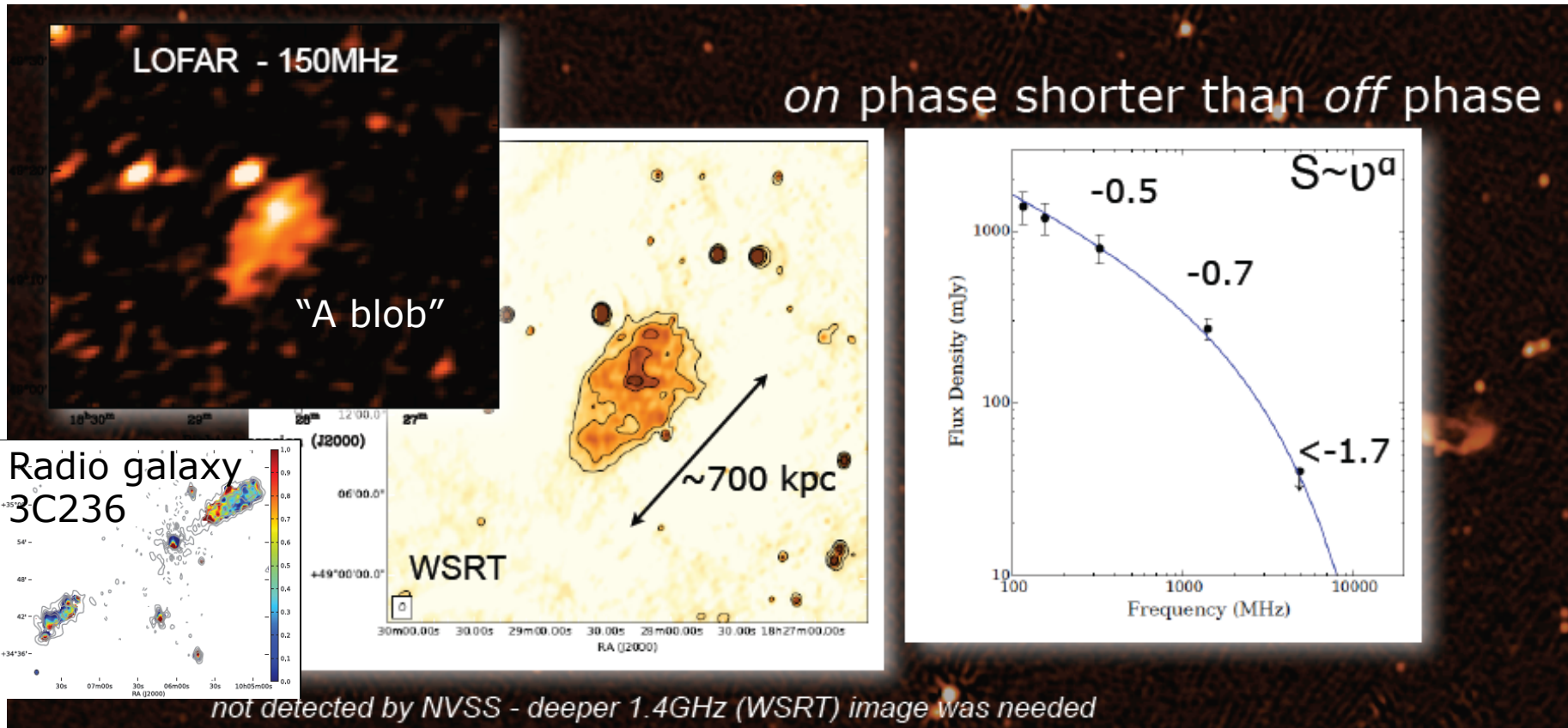
Expected flux: 3120 Jy  
Measured flux: 3004 Jy

# Picking out interesting sources – blobby universe



Radboud University Nijmegen

Structure and spectral index info adds a lot of new information facilitated by LOFAR

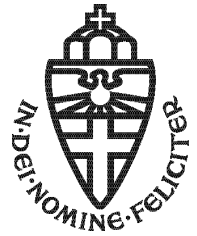


Raffaella Morganti, Marisa Brienza,  
Aleksandar Shulevski

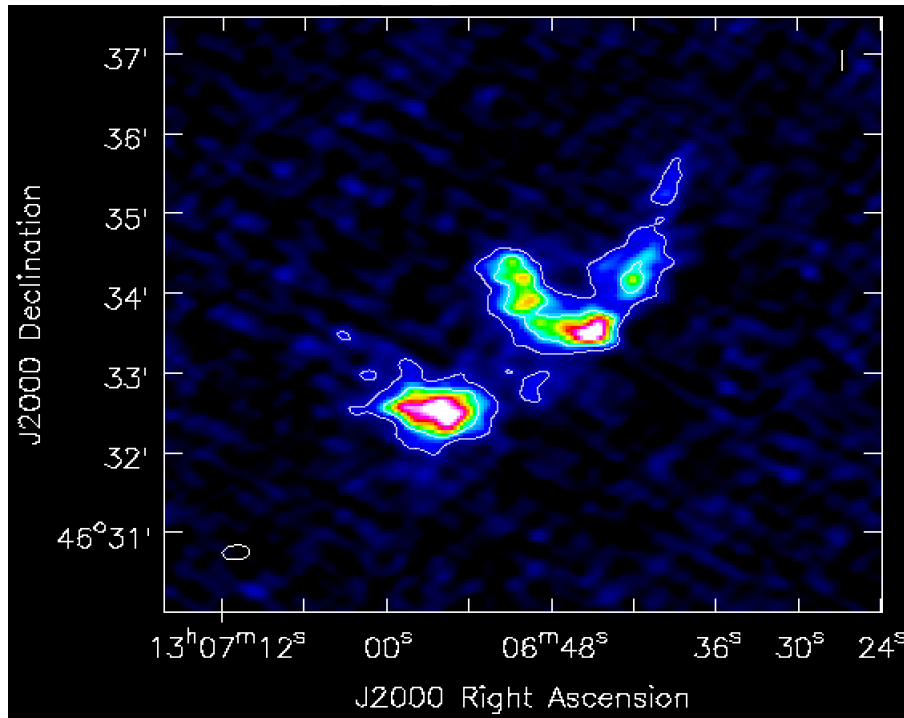
"LOFAR getting so deep, that you need  
very deep high-frequency follow-up!"



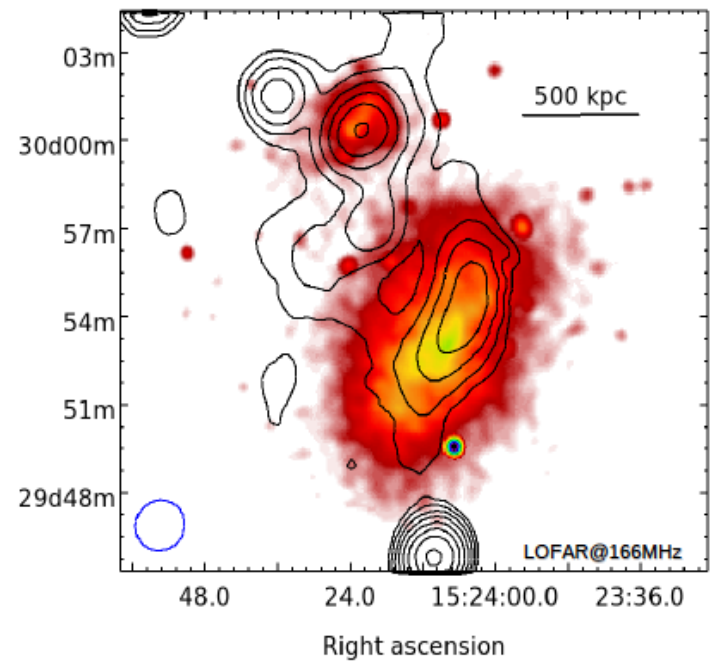
# A cluster of clusters



Radboud University Nijmegen



AA1682  
Alex Clarke

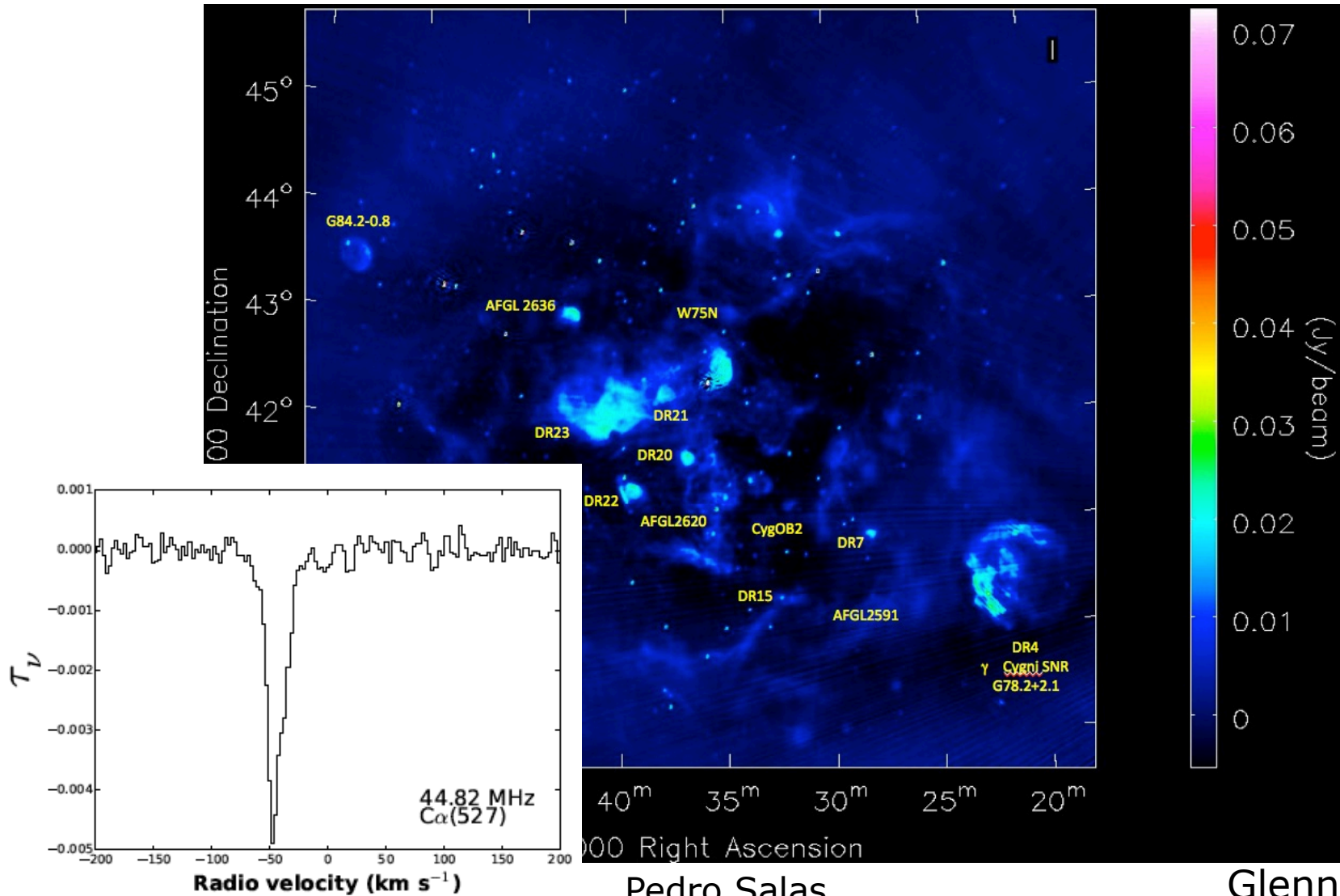


A2069  
Alexander Drabent

# Galactic WOW Imaging Bonanza



Radboud University Nijmegen

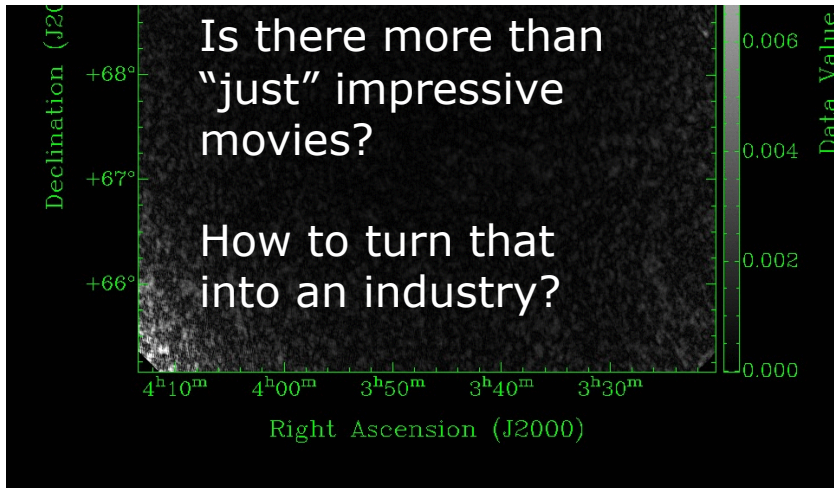
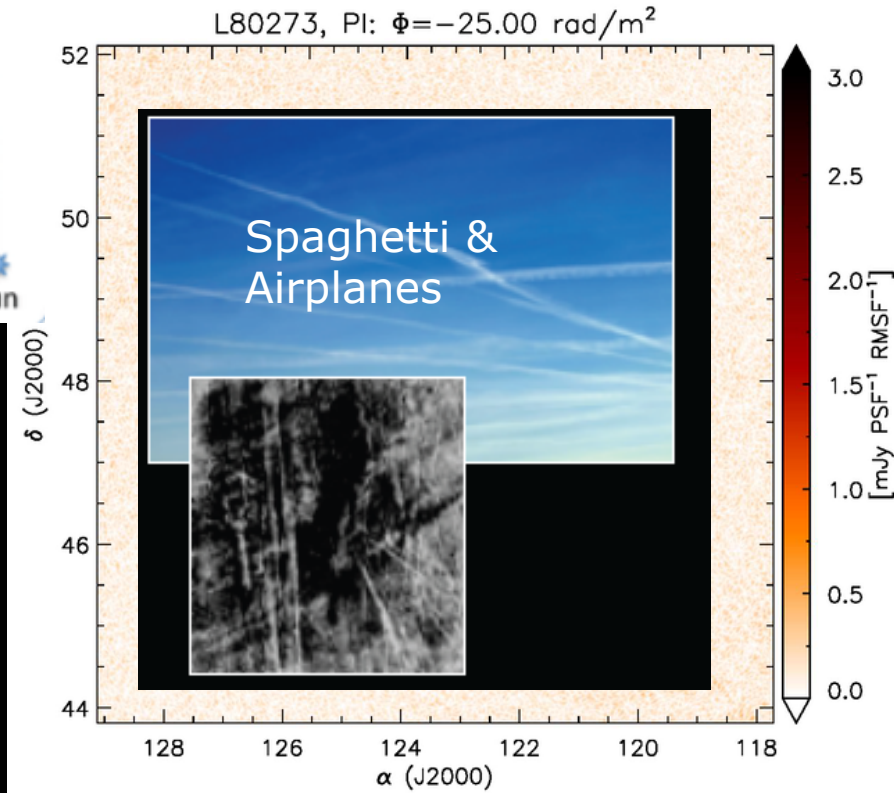
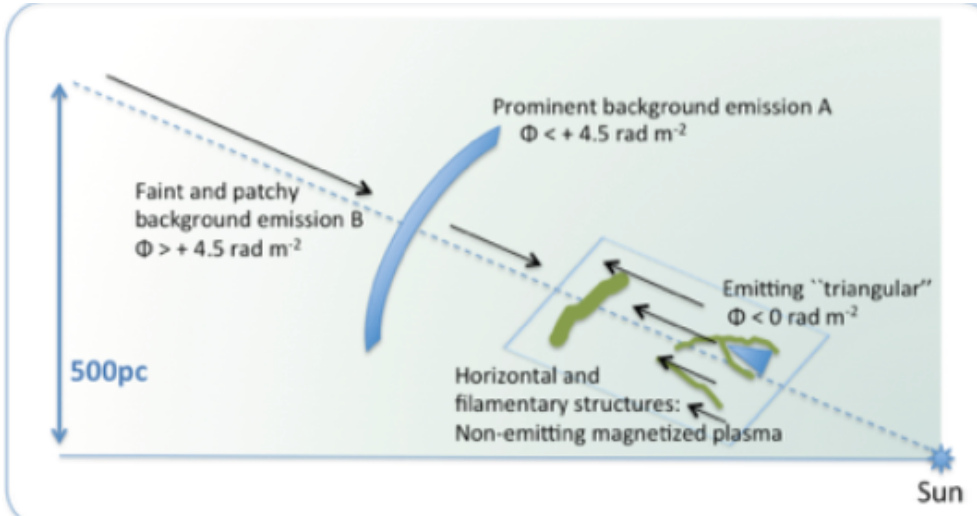


Pedro Salas

Glenn White

# Galactic WOW Foregrounds

Radboud University Nijmegen



Is there more than "just" impressive movies?

How to turn that into an industry?

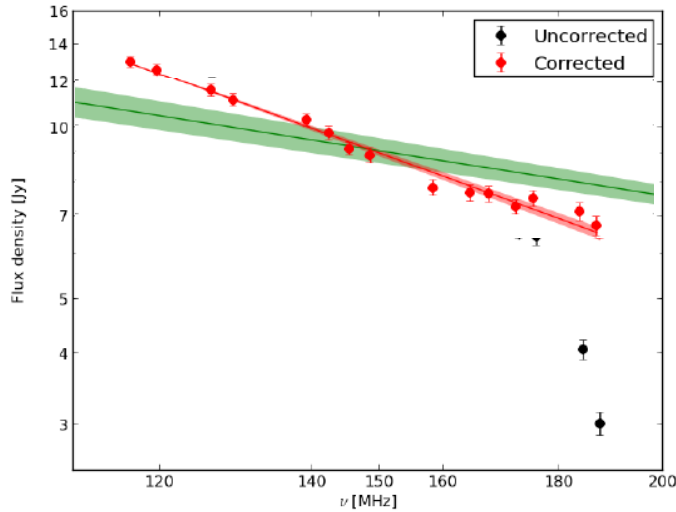
Cameron van Eck

Vibor Jelić

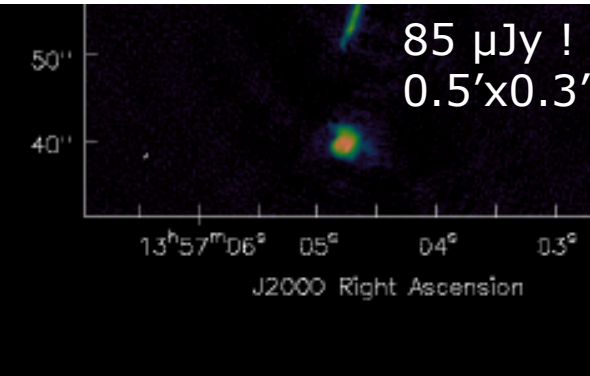
# Long Baselines becoming more common place



Radboud University Nijmegen

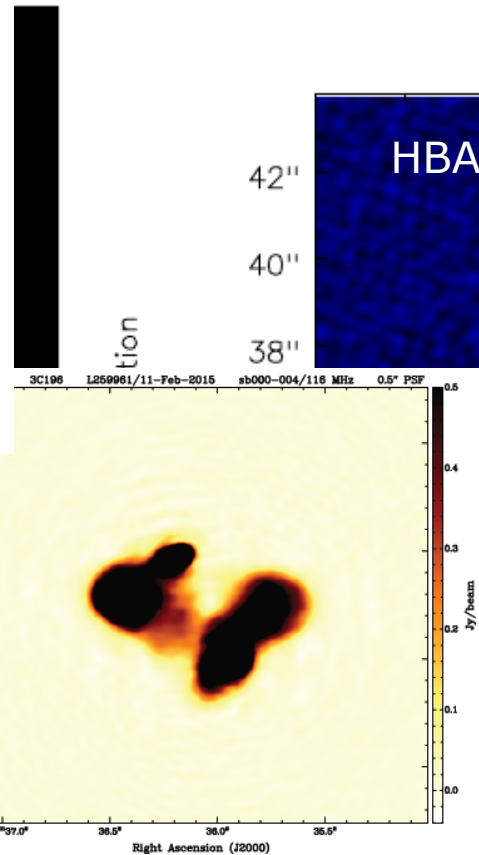


J2000 Declination

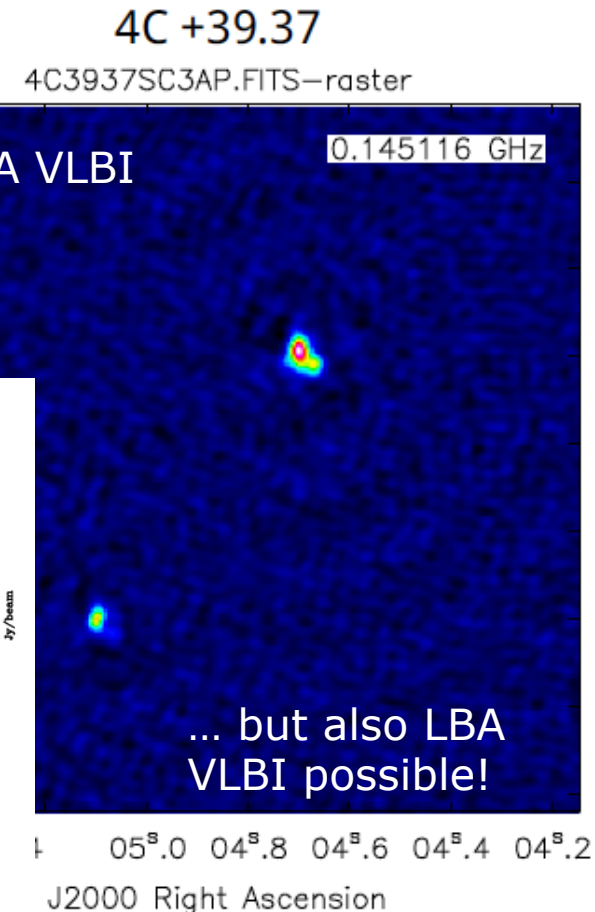


LOFAR 150 MHz

Javier Moldon



EOR can use long baselines as well!  
Ger de Bruyn

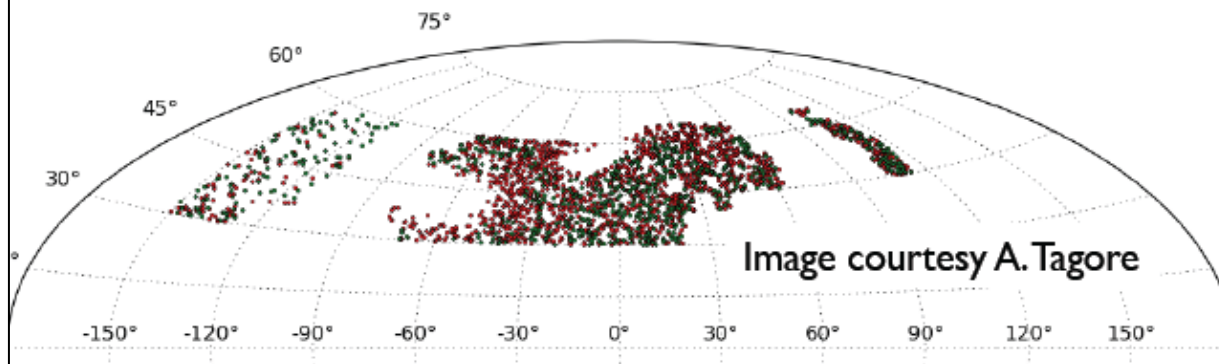


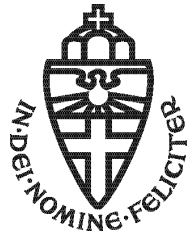
Leah Morabito

# Long Baselines

Long Baselines will become bread & butter science soon – any surprises expected?

- 31 hours (>7,000 sources) observed, about half reduced
  - Big thanks to RO+Michiel: much manual work!
  - Detection rate >30%
  - Data has been affected by incorrect BBS parset which reduced sensitivity (now fixed)

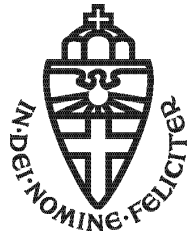




# Meeting flavor

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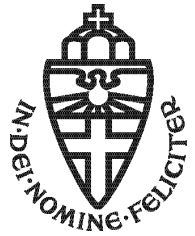
- Refreshingly “boring”: people discuss **published** papers!!
- Family meeting with remarkably little dirty laundry but a lot of hard and successful efforts to make LOFAR work!!
- Occasionally smiling PostDocs and PhD students ...
- Evolutionary phases of LOFAR Science meetings:
  - Fantastic promises (2002 - 2011)
  - Nothing works – complete frustration (2012)
  - frantic experimentation (2013)
  - some victories & unpublished world records (2014)
  - normal science programs (like ALMA ...) (2015)
  - fundamental discoveries (unlike any other tel) ...



# What to expect?

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- High-profile papers, unique LOFAR science (2015+)
  - CR lightning paper (Phys. Rev. Lett.)
  - CR composition paper & Solar KSP paper in “negotiations” with high-profile journal
  - First MSSS papers (→ reprocessing)
  - First EOR upper limit
  - A Fast Radio Burst with LOFAR ... ?
  - Interesting new pulsar, new transients, deep survey object?
- Deep understanding on how to do radio astronomy today
  - SKA will never work if LOFAR doesn't work (but we will make it work!)
  - SKA will never work if it doesn't learn from LOFAR (will they?)



# *Work to be done*

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- Major progress in imaging, incorporate extreme/facet peeling in standard processing (and other options seem promising too!)
- Flux-calibration, beams shape, in-band spectral index, phasing stability
- Rapid response: TBB modes & real-time triggers, real-time transients, piggybacking incoherent beam searches
- Fix-up some remaining long-baseline issues.

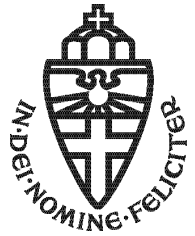


# LOFAR 2.0



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- Develop a vision – start thinking and discussing now!
  - Make LBA more useful, more signal paths, improved/more antennas, parallel observing with HBAs
  - More LOFAR stations in core and a few to fill gap at 100 km range
  - Long baselines and LBA will remain a very unique selling point of LOFAR
  - ...?



# Conclusion

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- LOFAR is about to start for real only now! The top of the hill is in sight.
- Big thanks to all who have made this possible over the years!
- Still, we need to finish the job - looking forward to new discoveries in 2016!