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APERTIF
APERture Tile In Focus

Phased Array Feeds

a new lease of life for the Westerbork Radio Telescope

Wim van Cappellen

2018 CWTe Research Retreat

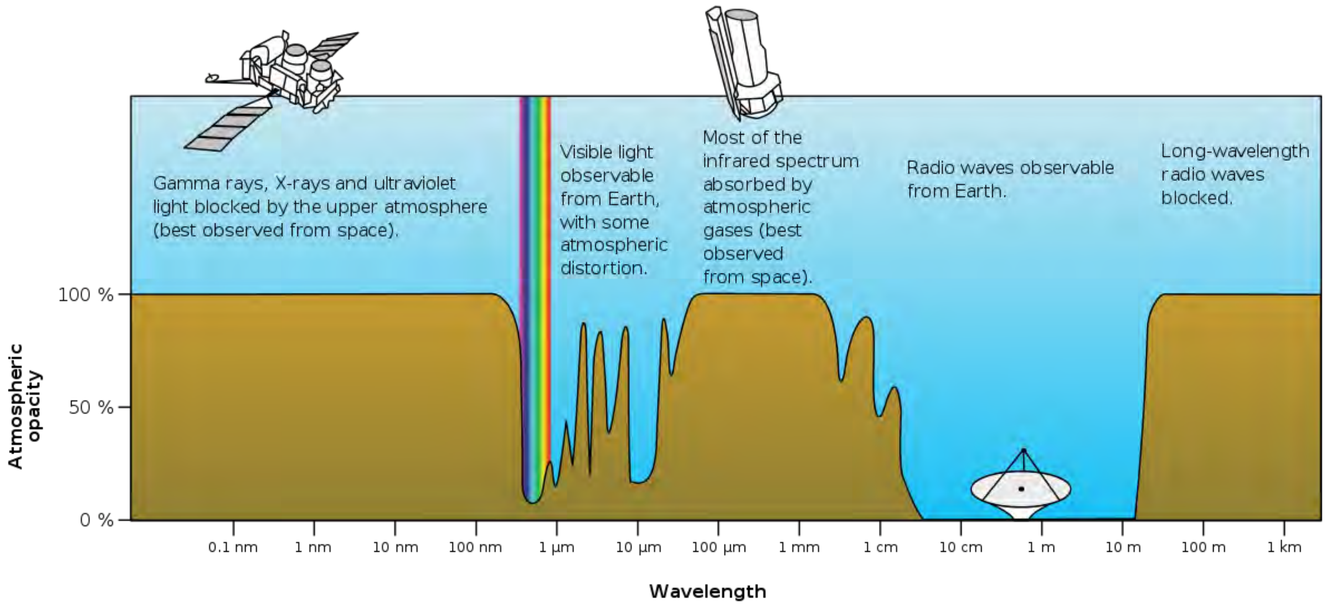
“Making Discoveries in Radio Astronomy Happen”

ASTRON Dwingeloo, Drenthe

itute for Radio Astronomy

Radio Astronomy

- Determine the intensity and polarization state of the radio waves emitted by celestial objects
- Wide frequency range
  - Observing frequency corresponds to how the Universe looked like a certain time ago.
  - Few protected bands



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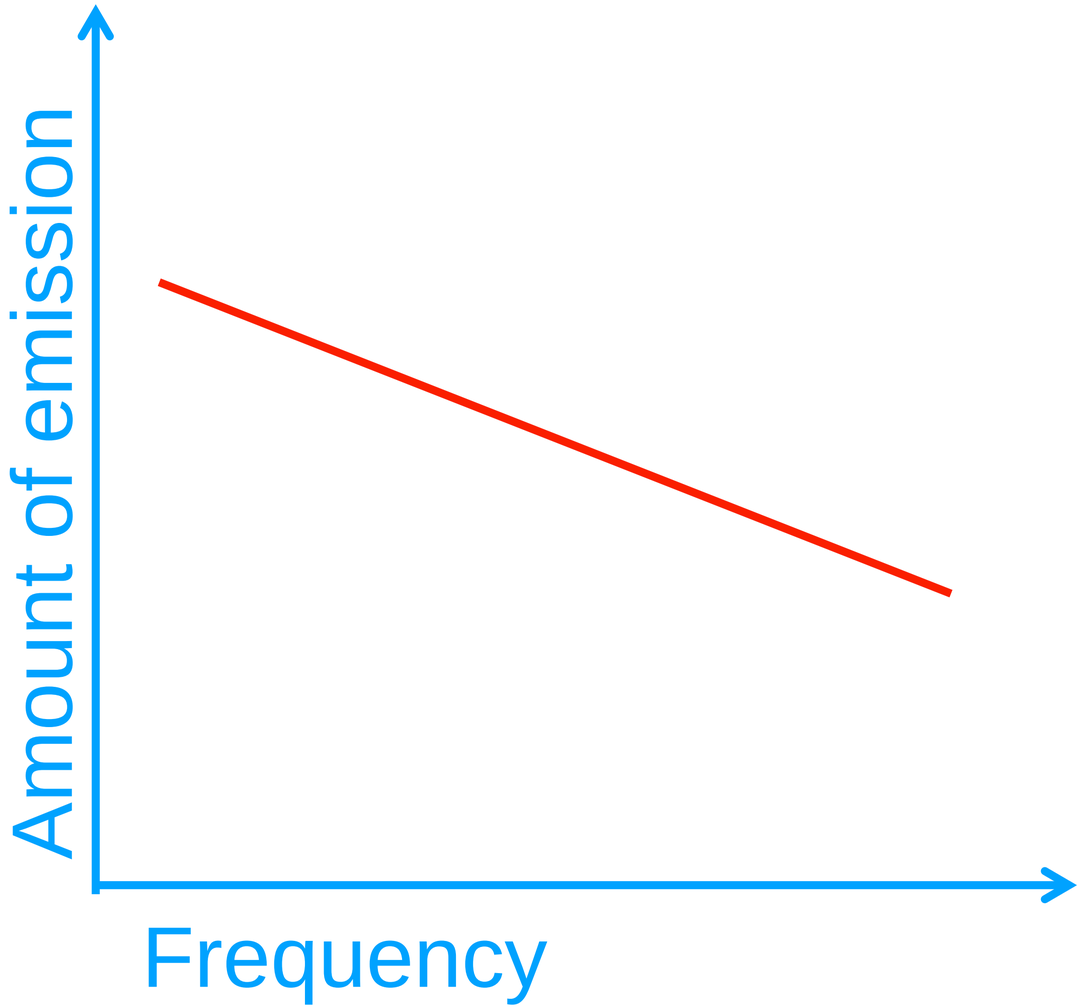
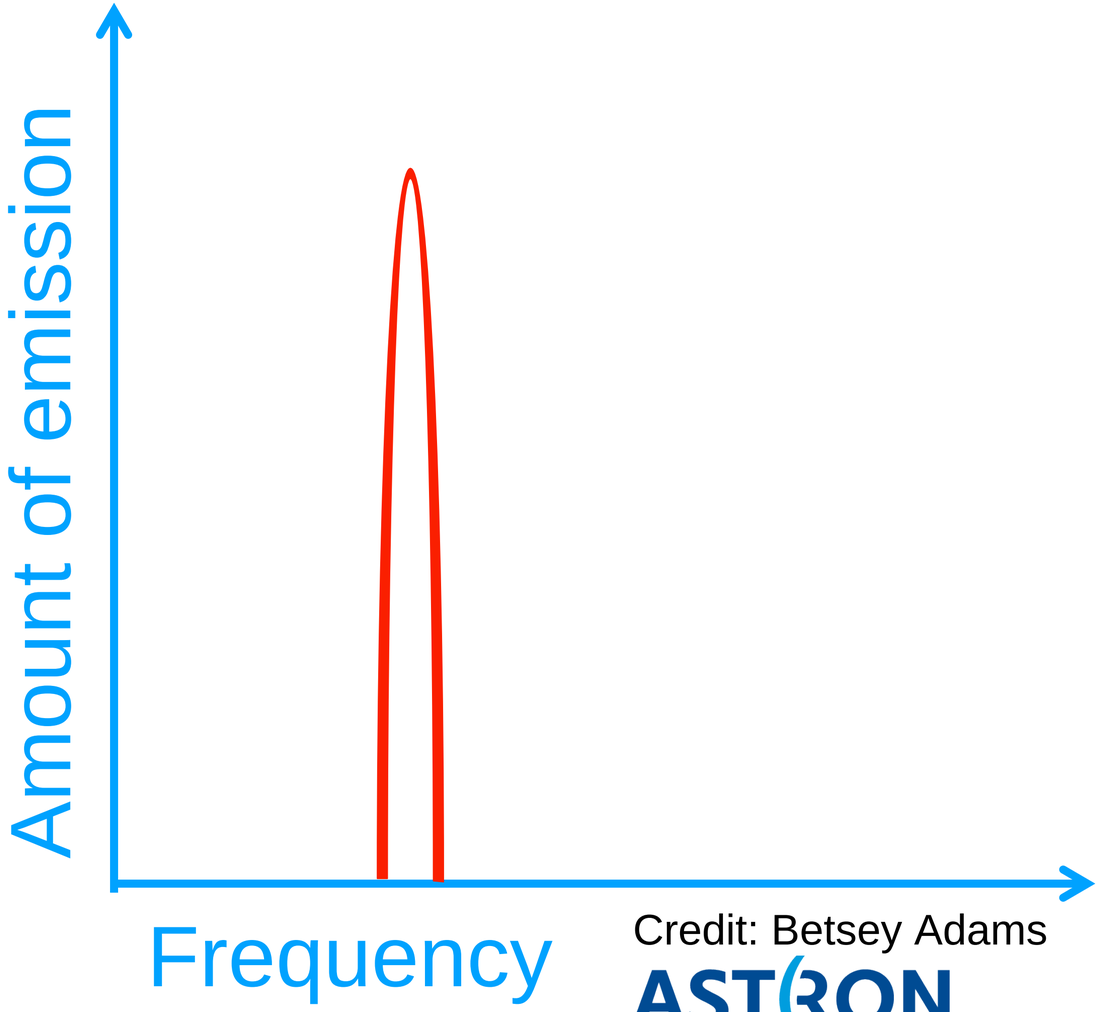
Radio continuum vs. HI spectral line





Credit: Betsey Adams

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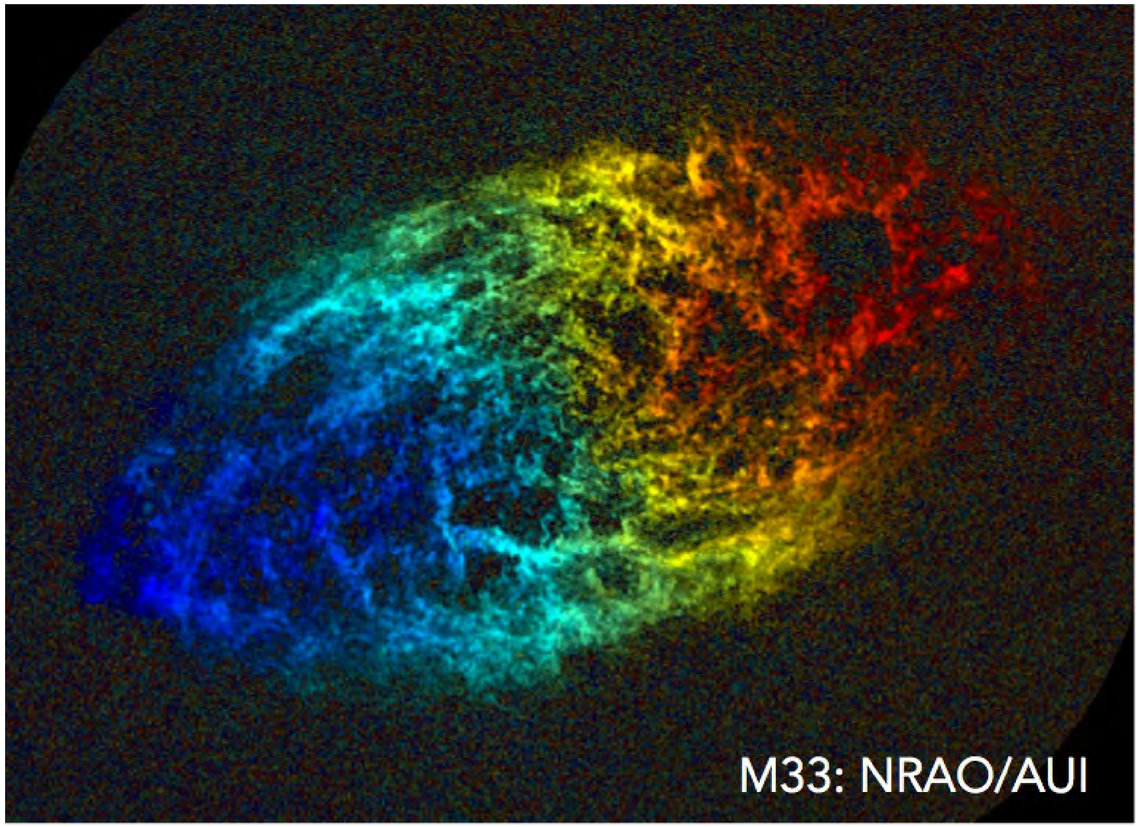
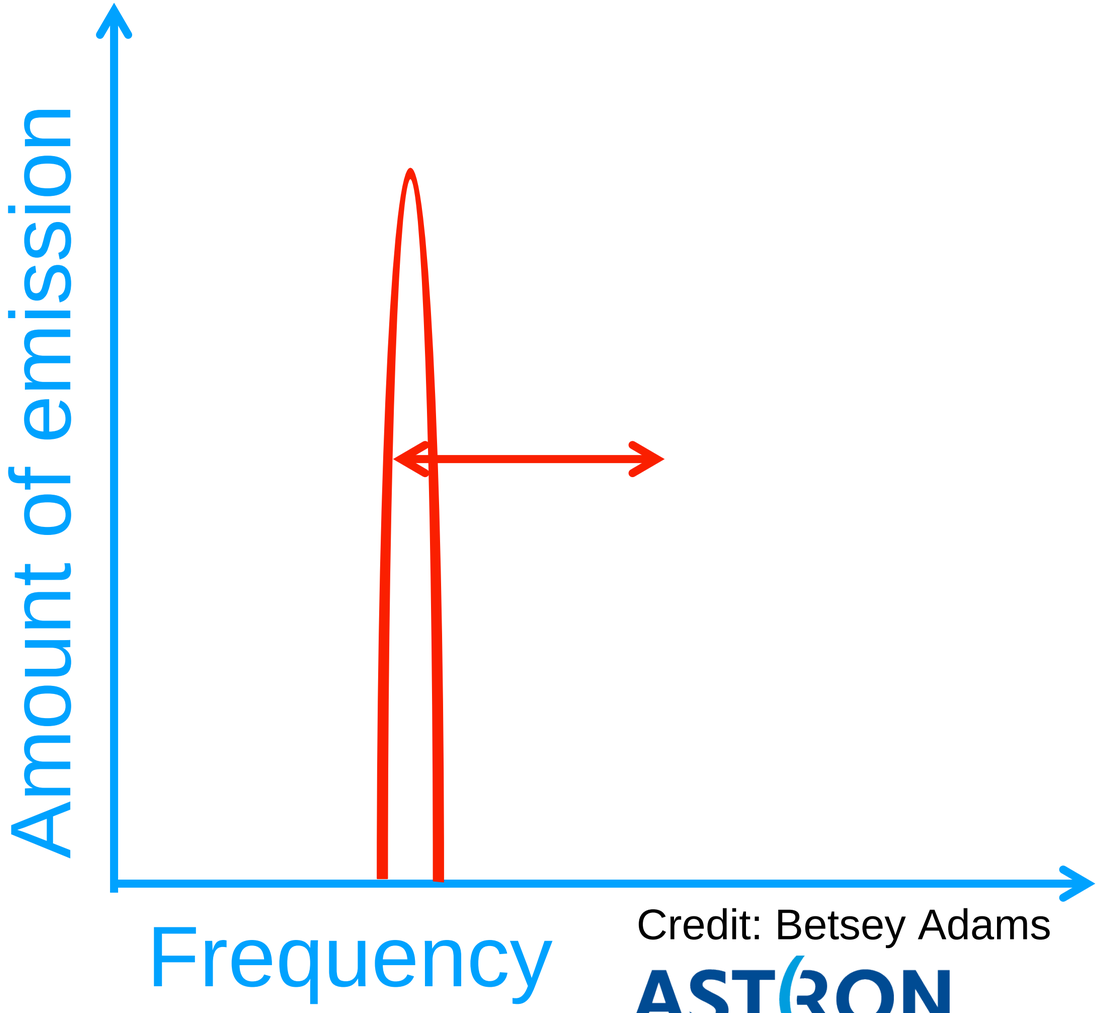
The power of the HI spectral line





Credit: Betsey Adams

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Gas: Raw material for stars

Credit: Betsey Adams

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Gas: Raw material for stars

Credit: Betsey Adams

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Radio Continuum: Tracing star formation

Credit: Betsey Adams

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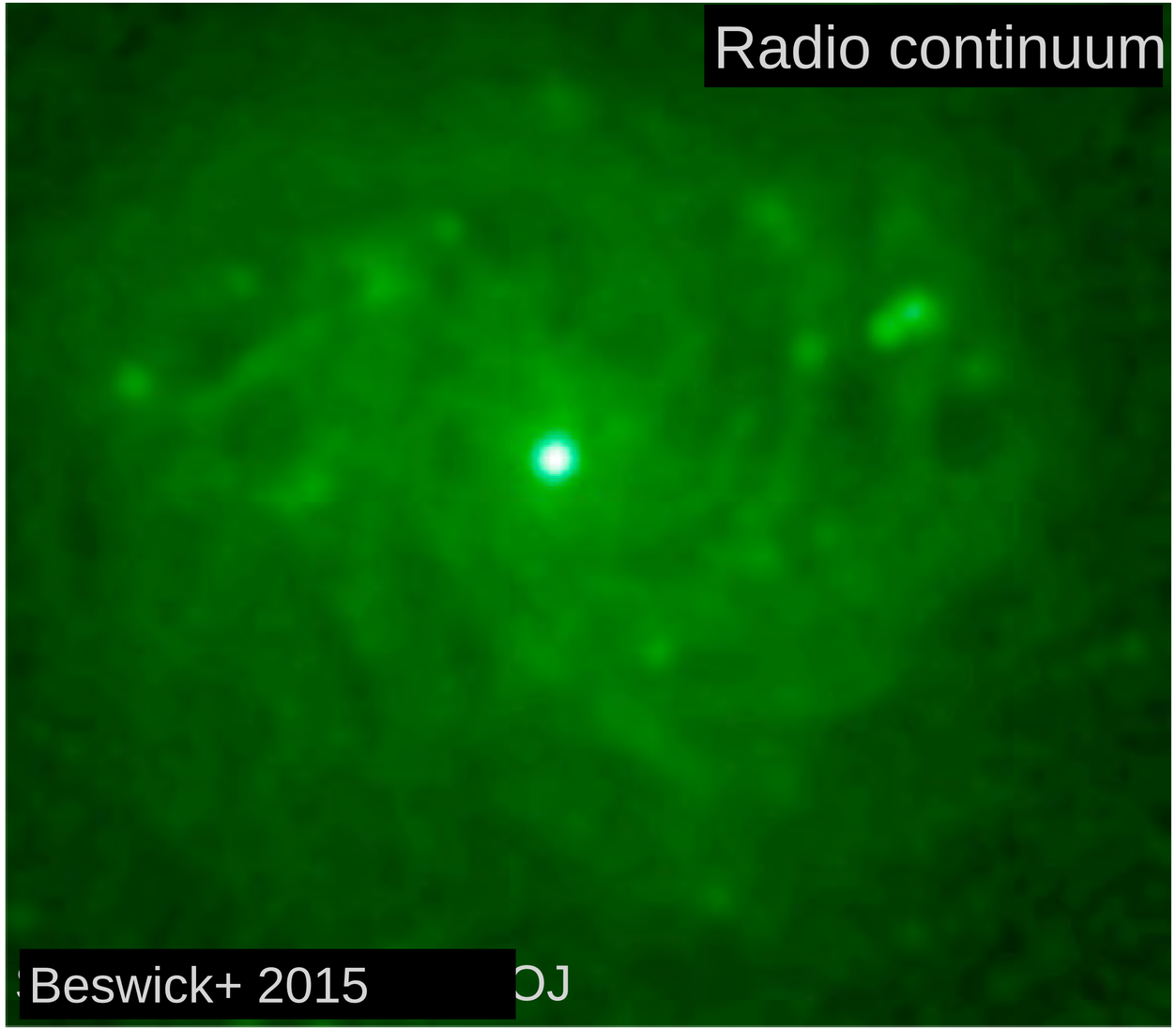
Radio Continuum: Tracing star formation



Credit: Betsey Adams

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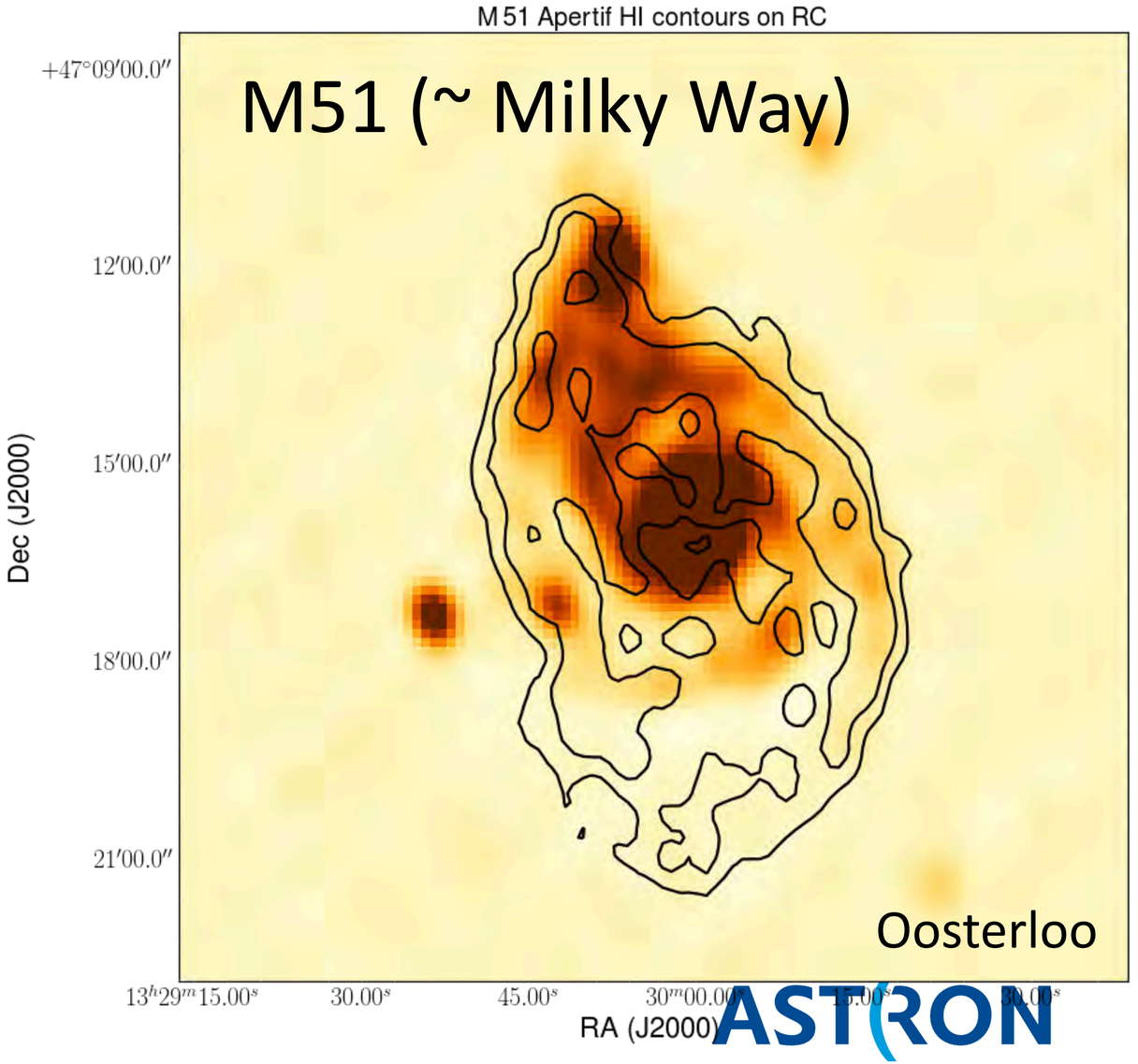
Connecting gas and star formation

- Total HI map (contours) overlaid on radio continuum (color scale)
- How is gas connected to star formation?



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Connecting gas and star formation

- Survey science. Need to observe large area’s of the sky instead of 1 galaxy in great detail

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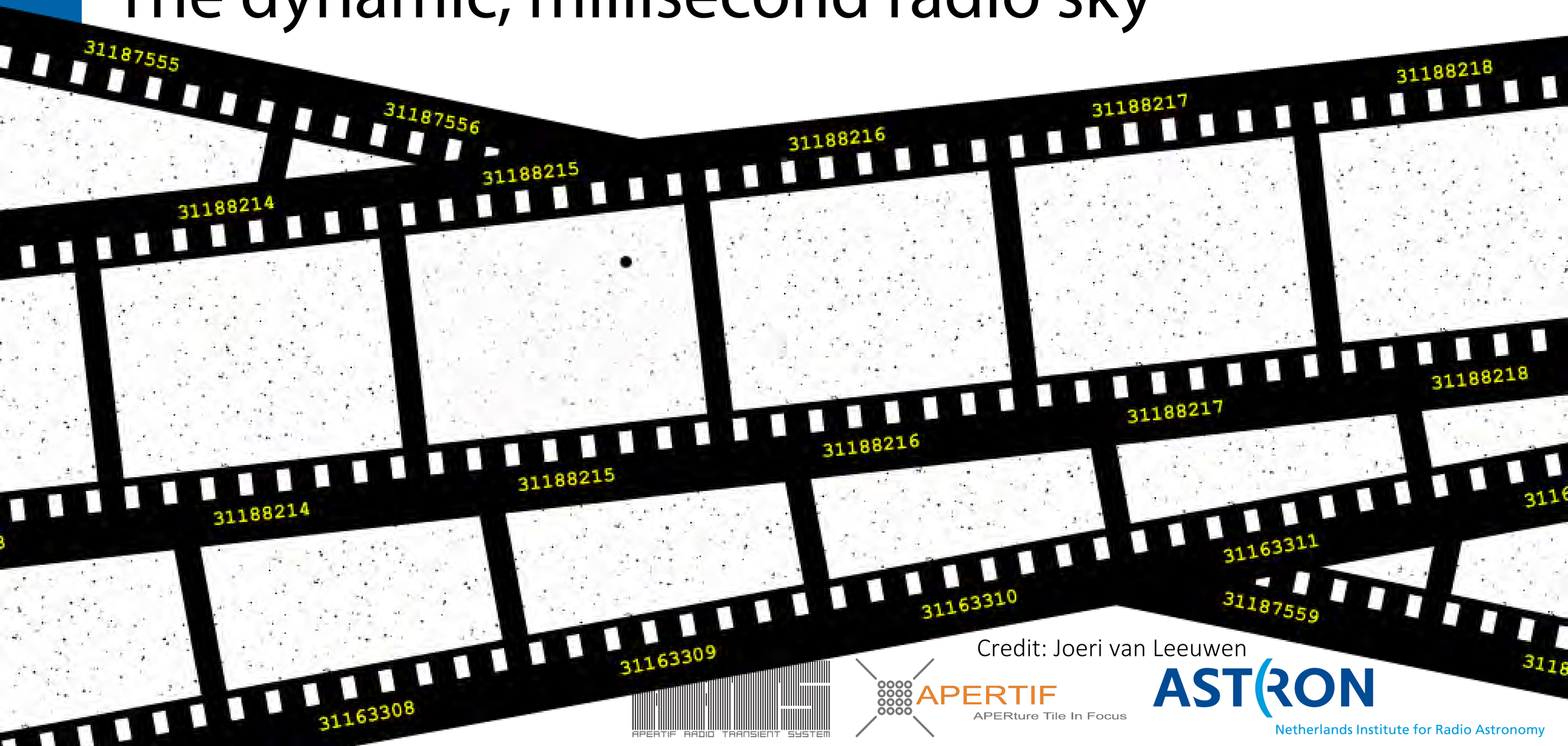
The dynamic, millisecond radio sky



Credit: Joeri van Leeuwen

APERTIF RADIO TRANSIENT SYSTEM

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Radio telescope - Wikipedia
en.wikipedia.org

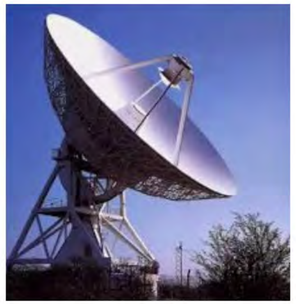
Radio telescope - Wikipedia
en.wikipedia.org

Radio telescope - Simple English ...
simple.wikipedia.org

Radio telescope - Wikipedia
en.wikipedia.org

CSIRO Parkes Radio Telescope - Gold Tr…
goldtrails.com.au

What are Radio Telescopes? - Nationa…
public.nrao.edu



functions of radio telescopes ...
quora.com

How does a radio telescope work? - YouTube
youtube.com

Government-funded radio telescopes fall ...
sen.com

synchronise radio telescopes ...
news.aarnet.edu.au

About Parkes radio telescope - CSIRO
csiro.au

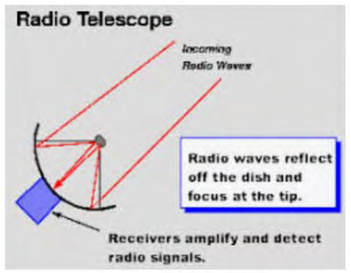
Arecibo Observatory: Watching f…
space.com

Jodrell Bank Centre for Ast…
jb.man.ac.uk

Iconic Arecibo radio telescope saved by ...
sciencemag.org

Largest Active Radio Telescope ...
wmfe.org

NRAL - VLBI: Image Gallery - R…
jb.man.ac.uk



What are Radio Telescopes? - Nation…
public.nrao.edu

MIT Haystack Observatory…
haystack.mit.edu

Visit Parkes CSIRO Radio Telescope
atnf.csiro.au

- We need more sensitivity AND field of view

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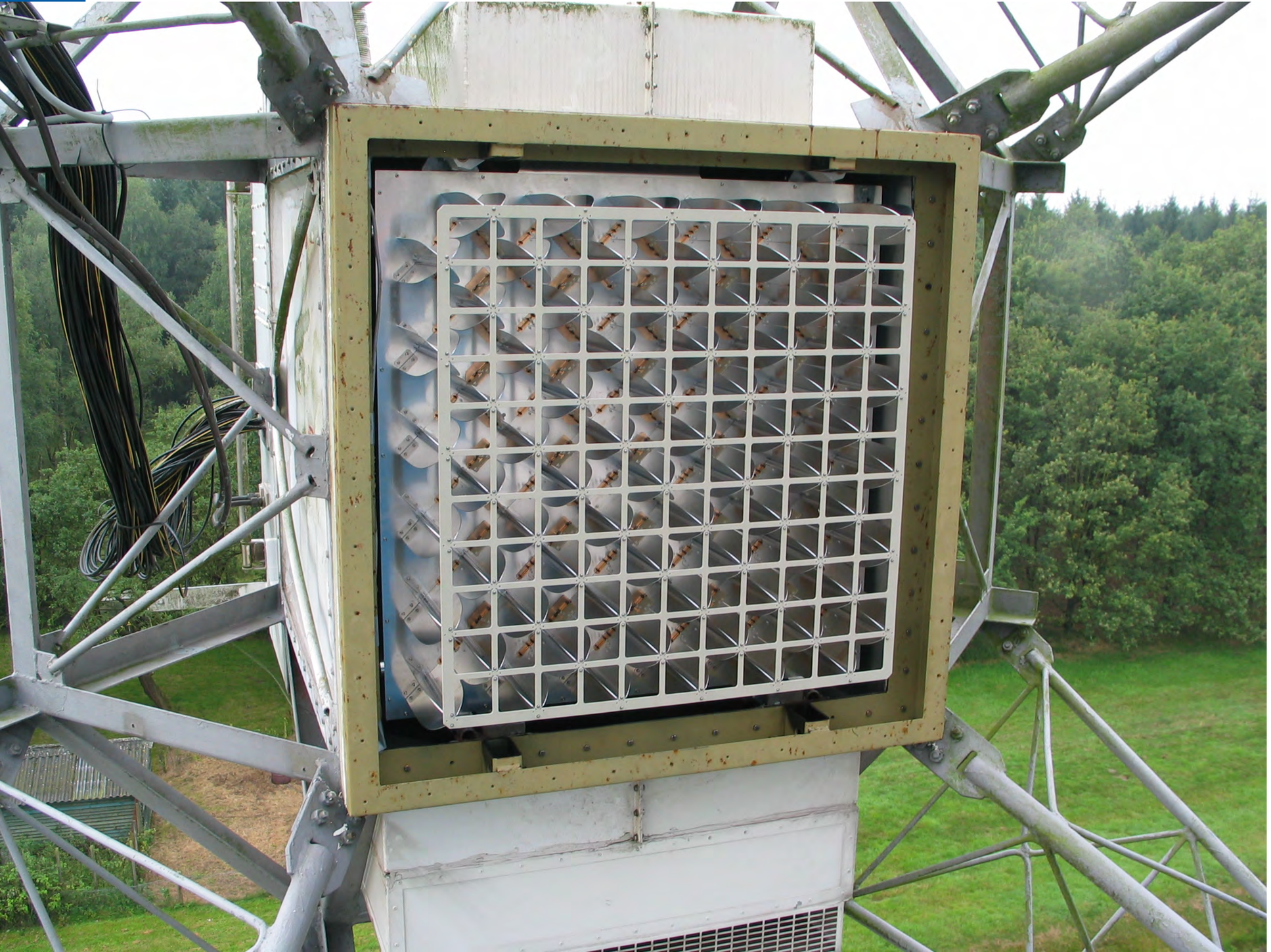
Most important discoveries in astronomy result from technical innovation [Harwit, 1981]

Array antennas!


Onsala
Birr
Dutch stations
Norderstedt
Chilbolton
LOFAR Core (NL)
Potsdam
Baldy
Borówiec
Jülich
Effelsberg
Tautenburg
Łazy
Unterweilenbach
Nançay


LOFAR



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Specifications

Frequency range	1130 – 1750 MHz
Instantaneous bandwidth	300 MHz
Channel bandwidth	12 kHz
Polarization	Dual linear
Reflectors	12 x 25m
Baselines	36 to 2412 m
System temperature	70 K
Aperture efficiency	75%
Simultaneous beams	37 dual pol
Field of view	8 deg^2
“Survey speed increase”	17x

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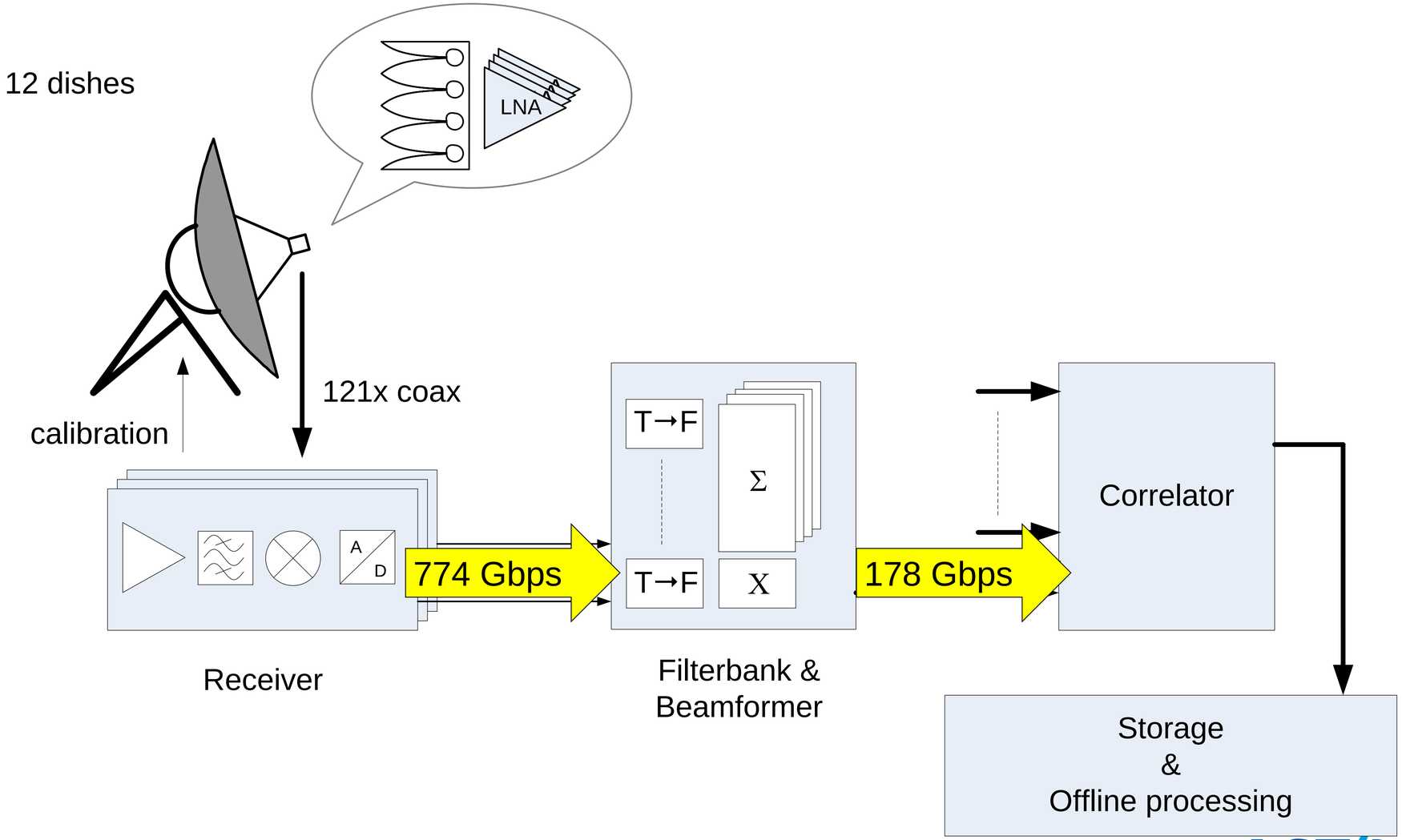
Top level block diagram



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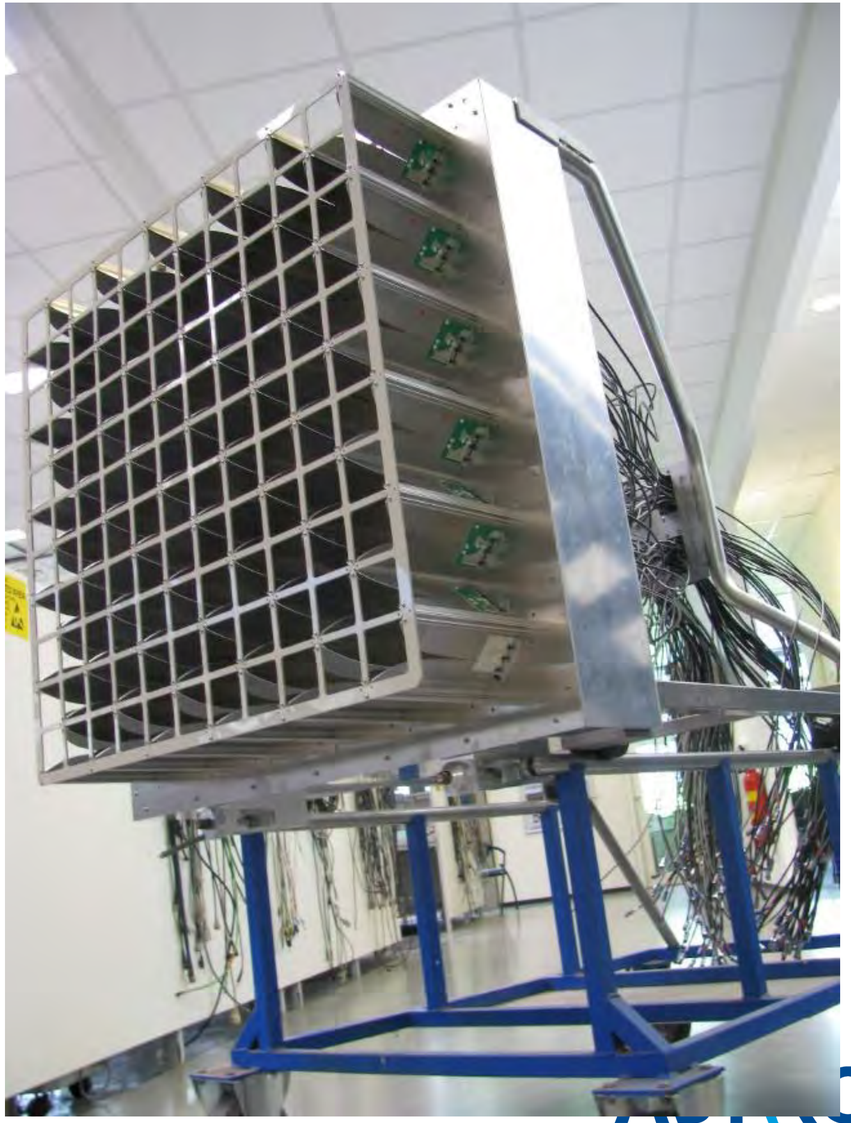
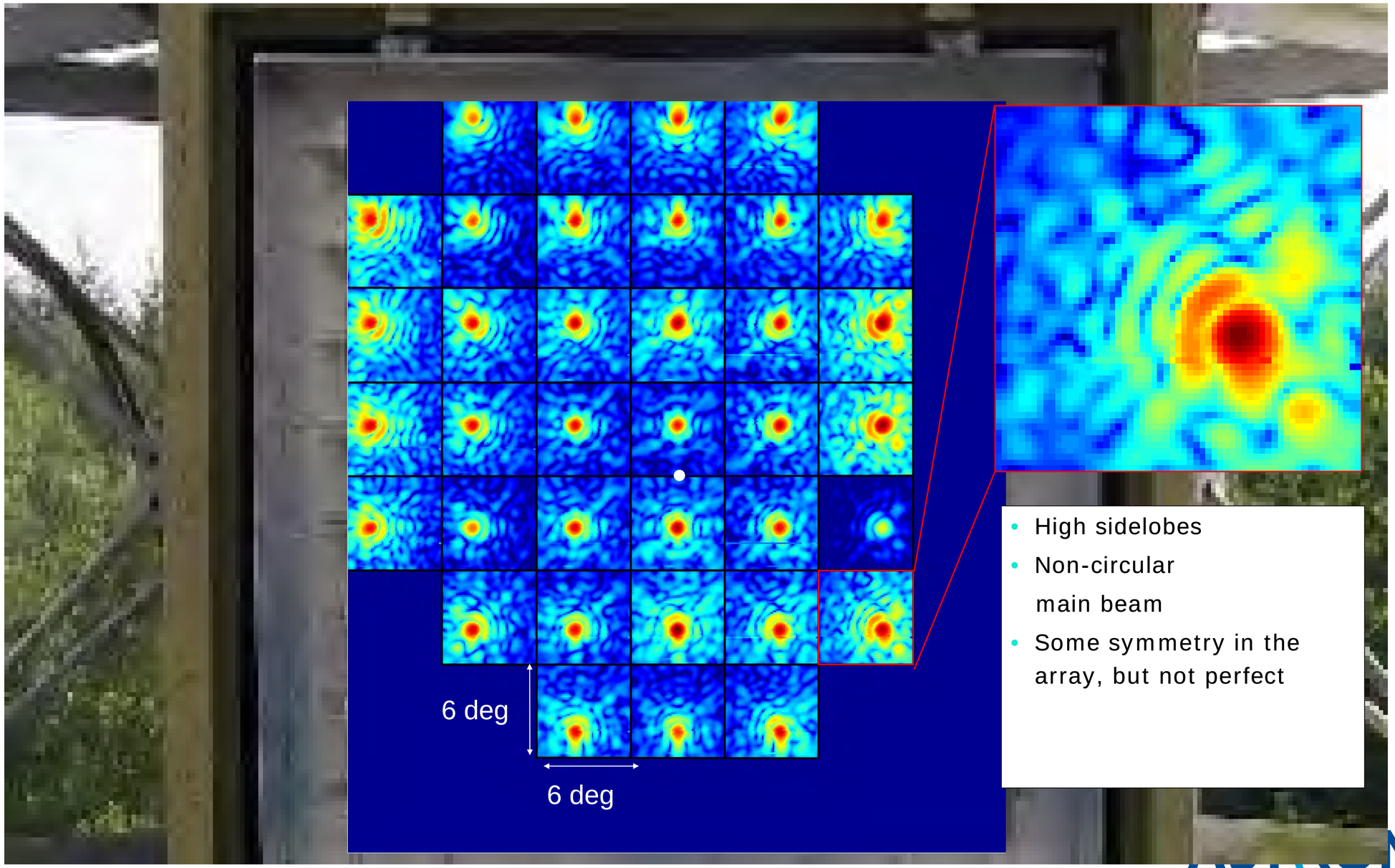
Feed array

Gain ~40 dB

LNA T_{min} = 0.24 dL

Skyworks SKY67151





- High sidelobes
- Non-circular main beam
- Some symmetry in the array, but not perfect

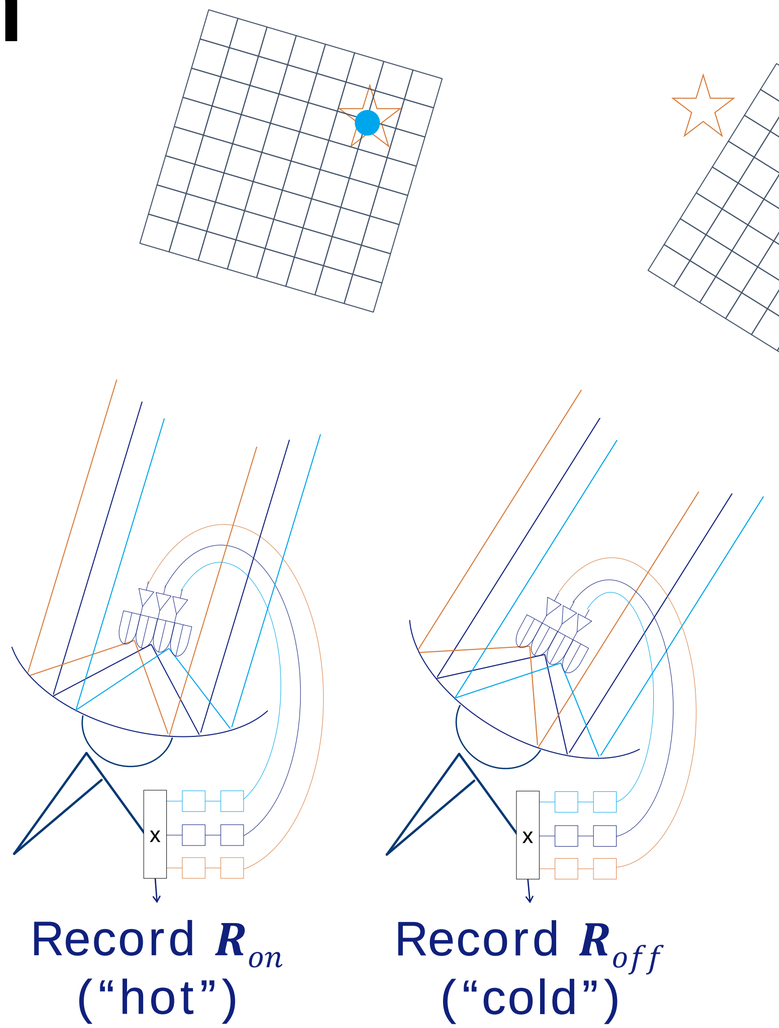
Beamformer weights

- Maximise signal
- Minimise noise
- In the presence of spillover, mutual coupling, a very complex reflector…

Weight Determination

- Hot-Cold method, per beam:
  1. Point dishes to hot and cold position
  2. Measure correlation matrices
  3. Determine weights

- “max-snr” algorithm
- Select weights that maximizes sensitivity



Credit: Boudewijn Hut

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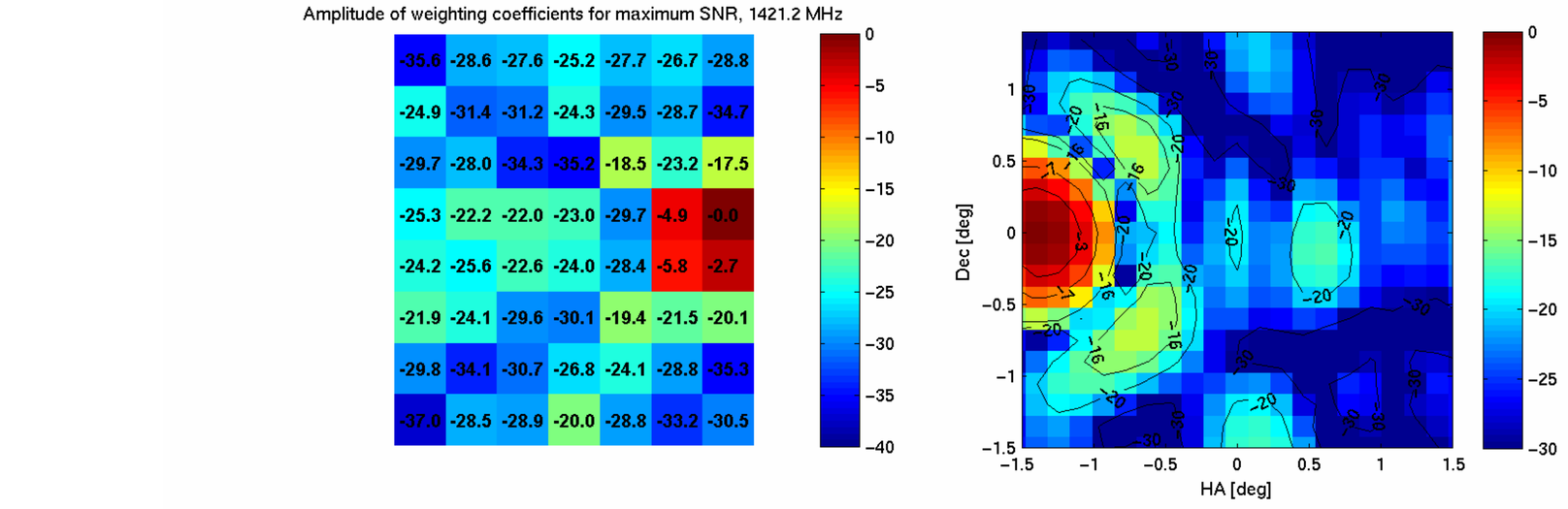
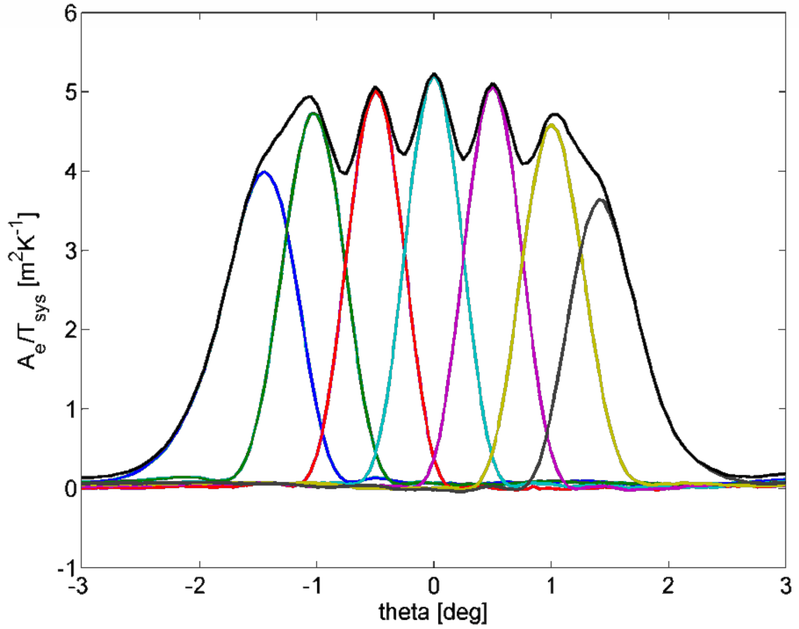
Compound beam patterns

Weighted 2D pattern





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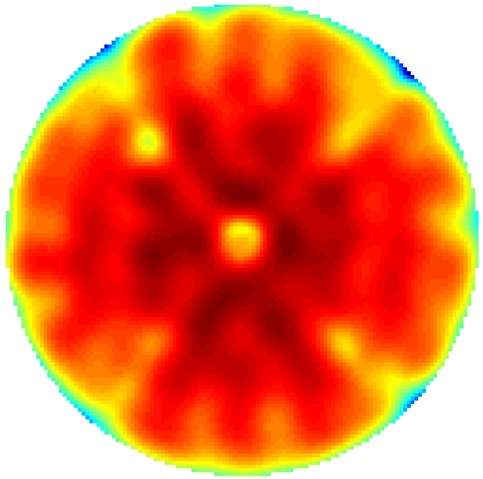
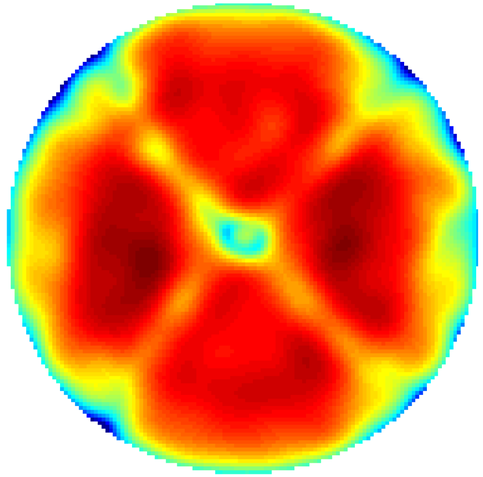
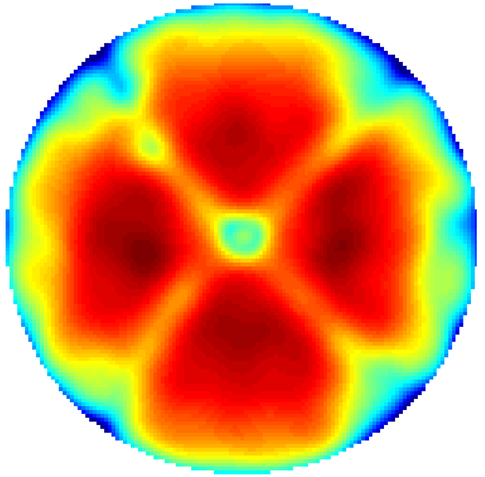


Single Element



CFM
(Max Ae)

η_{ill} ~ 79%

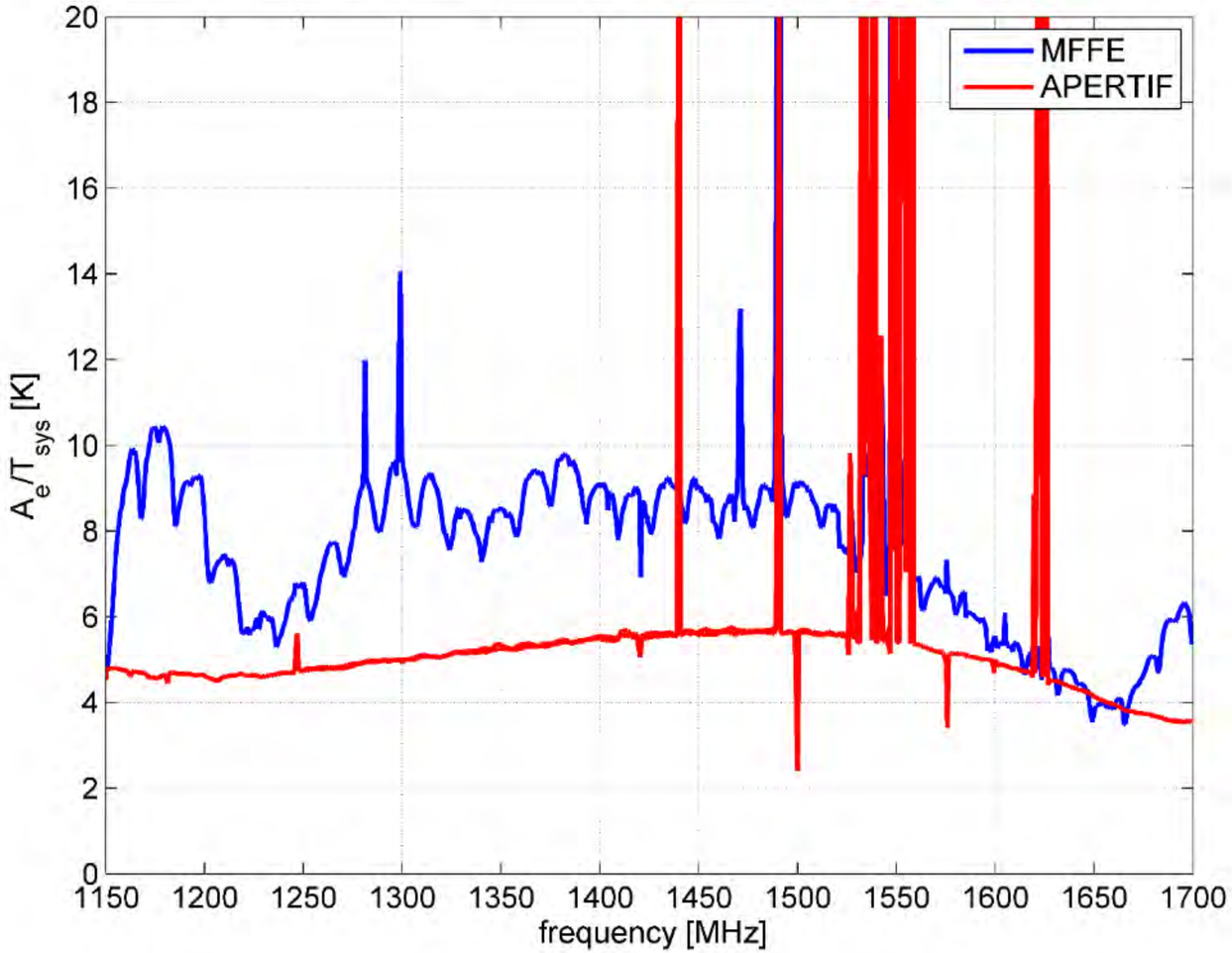


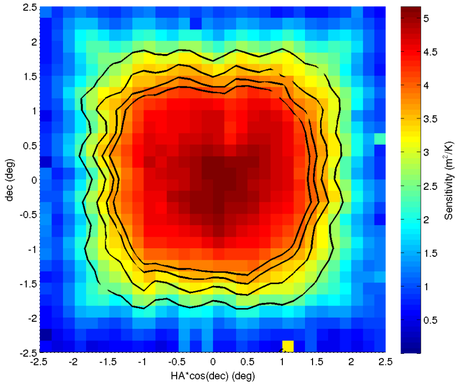
Max SNR

η_{ill} ~ 76%

PAF vs horn single-dish sensitivity

- Lower, but MUCH smoother (good for calibration)





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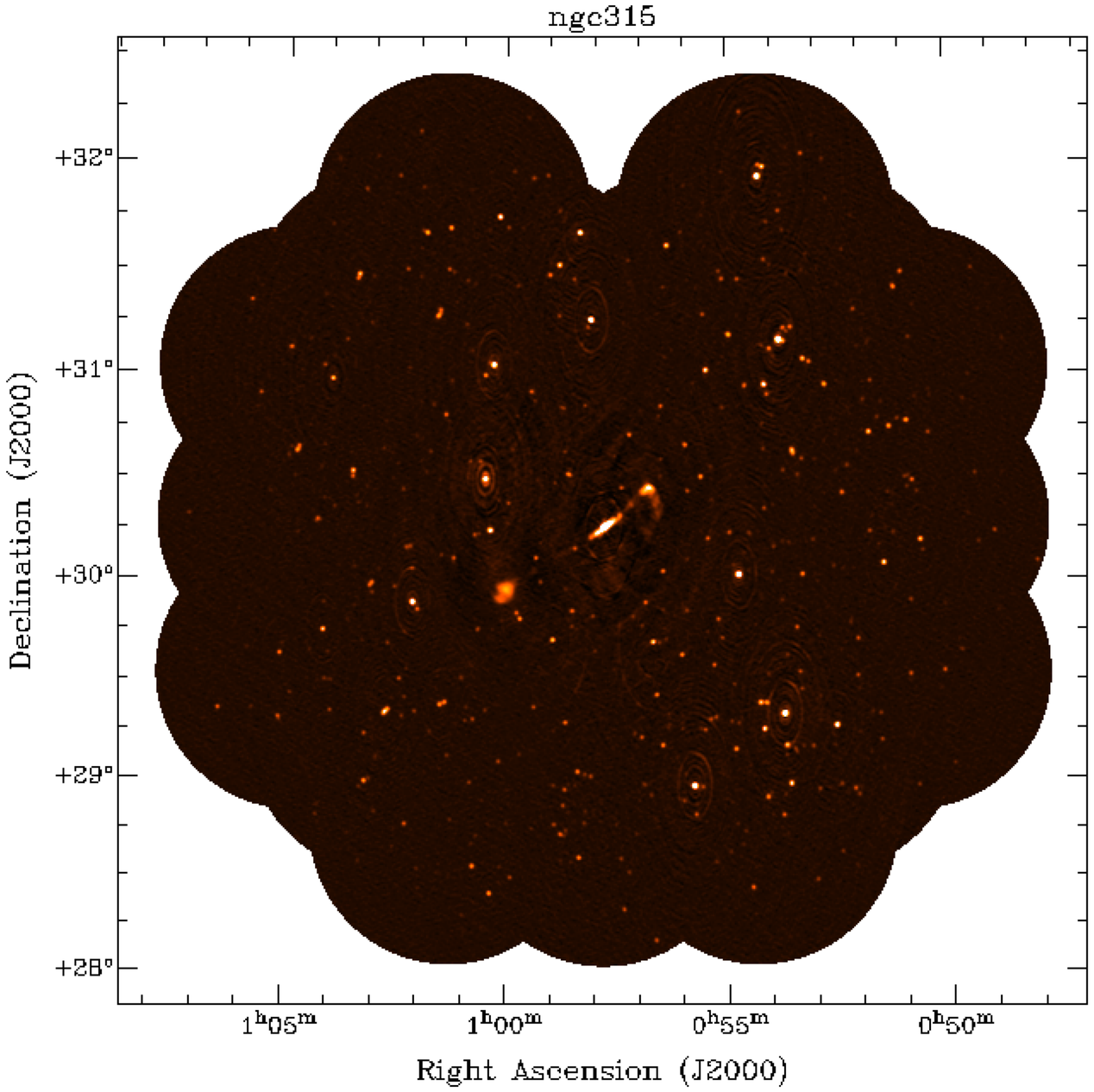
NGC 315 continuum mosaic



Reduced completely in Apercal
Lucero+ Apertif imaging team

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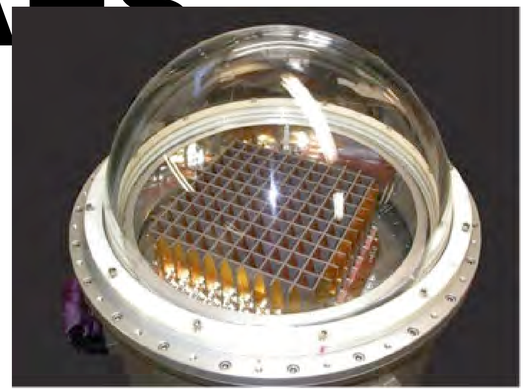
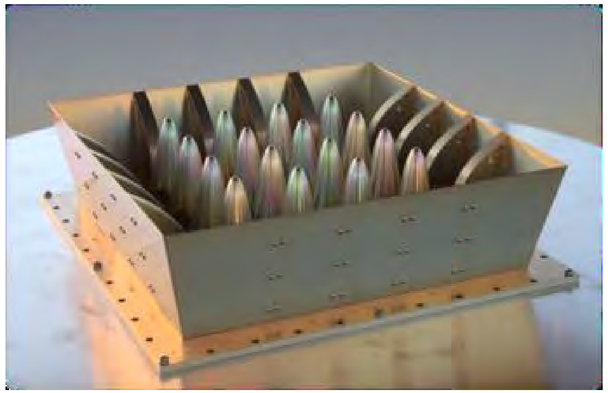
Challenges in astronomy PAFs





- Lowering noise
- Beam forming
- Cost reduction. About 2000 euro per PAF element (room temperature). Integration!!
- Higher frequencies

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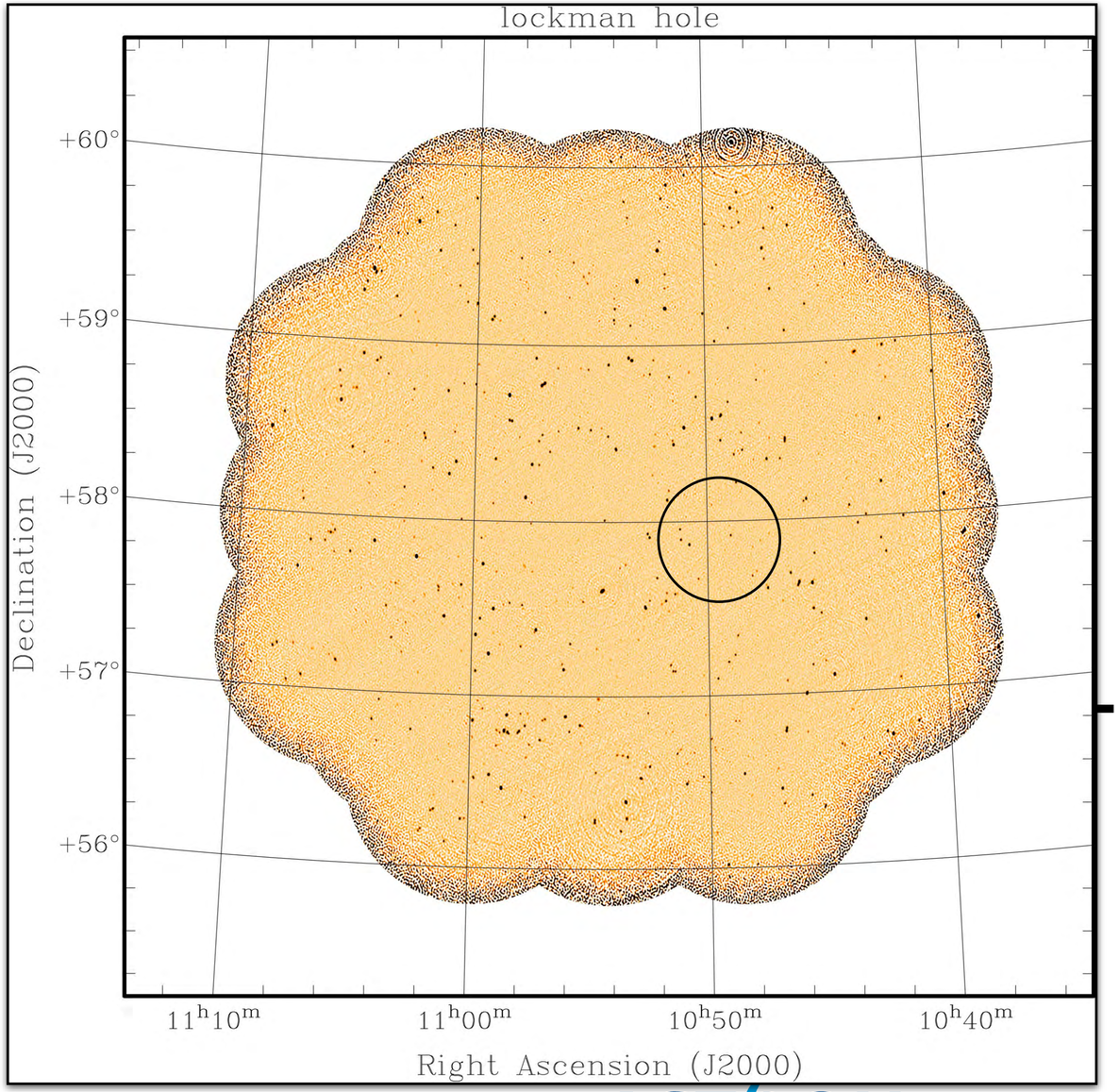
Summarising

- PAFs speeds up how fast we can map the sky by a factor 40!
- We can do in a day what before took a month



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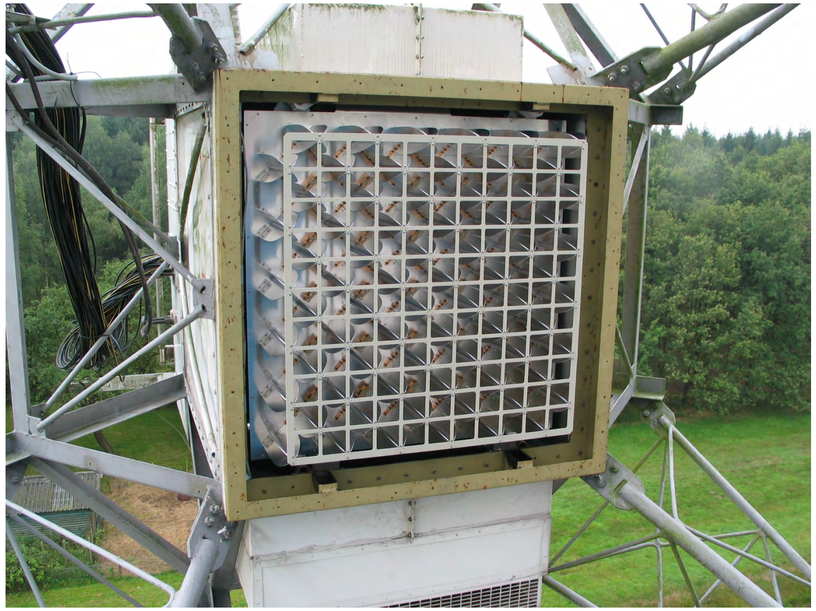
Summarising

- Thanks to Phased Array Feeds, the 50-years old WSRT is (again) state-of-the-art!
- PAF’s are a great upgrade path for existing telescopes
- Astronomy PAF’s are an excellent reference point for developments in wireless applications



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