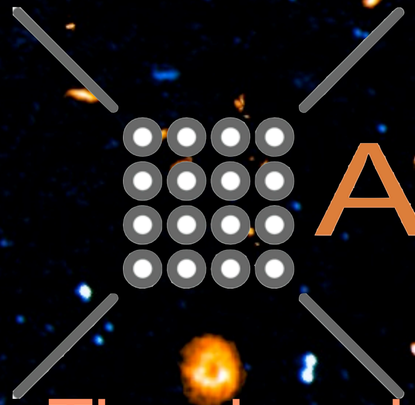


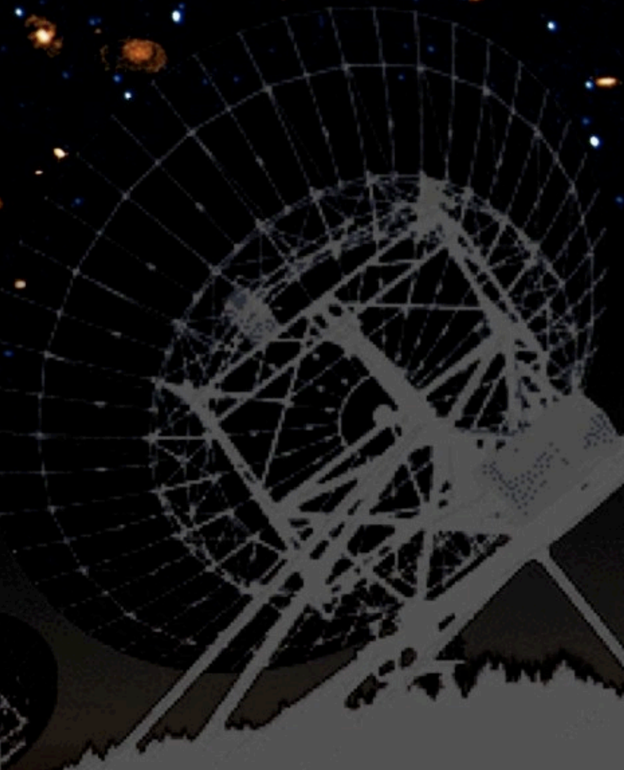
APERTIF

The phased-array feed system for the WSRT

Thijs van der Hulst
Kapteyn Astronomical Institute, University of Groningen, NL

&

Tom Oosterloo, Wim van Cappellen, Laurens Bakker
Netherlands Institute for Radio Astronomy, Dwingeloo, NL
Marc Verheijen
Kapteyn Astronomical Institute, University of Groningen, NL



ASTRON
Netherlands Institute for Radio Astronomy

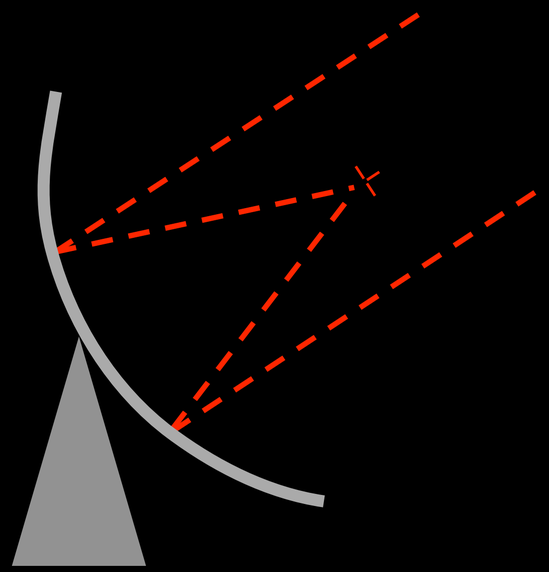
ASTRON is part of the Netherlands Organisation for Scientific Research (NWO)

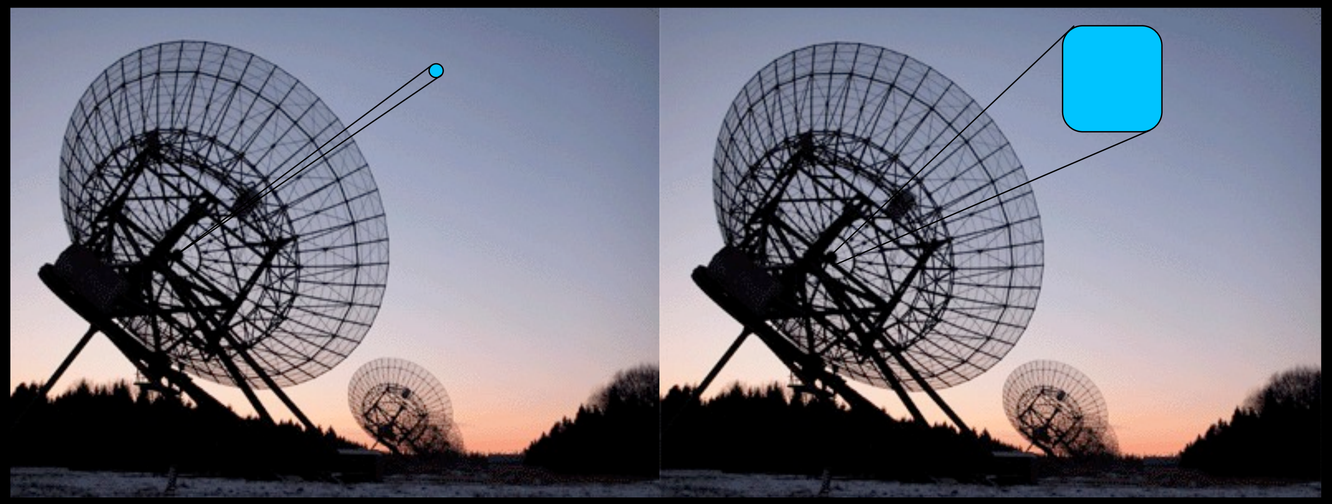
university of groningen

APERTIF: turn the WSRT into a survey instrument

APERTIF
APERture Tile In Focus

Small field of view of current radio telescopes is a major limitation.
Observing large survey areas with good sensitivity takes too much time





Replace single-pixel detector with array of detectors.
Turn single dish into a camera

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APERTIF
APERture Tile In Focus

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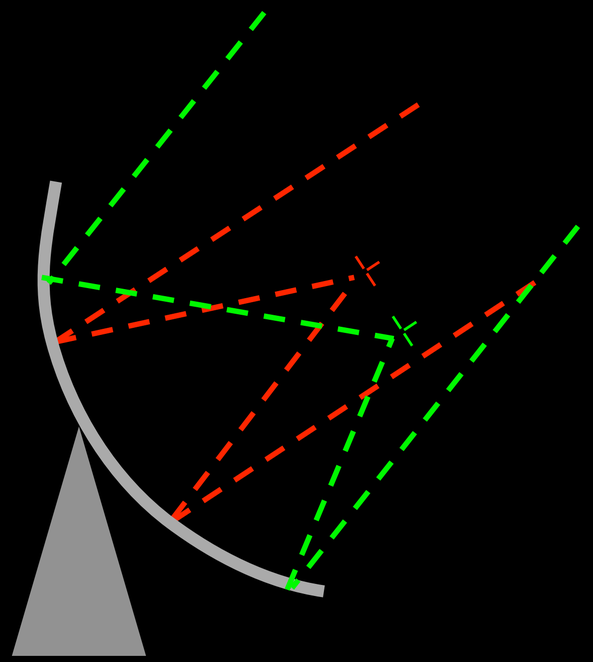
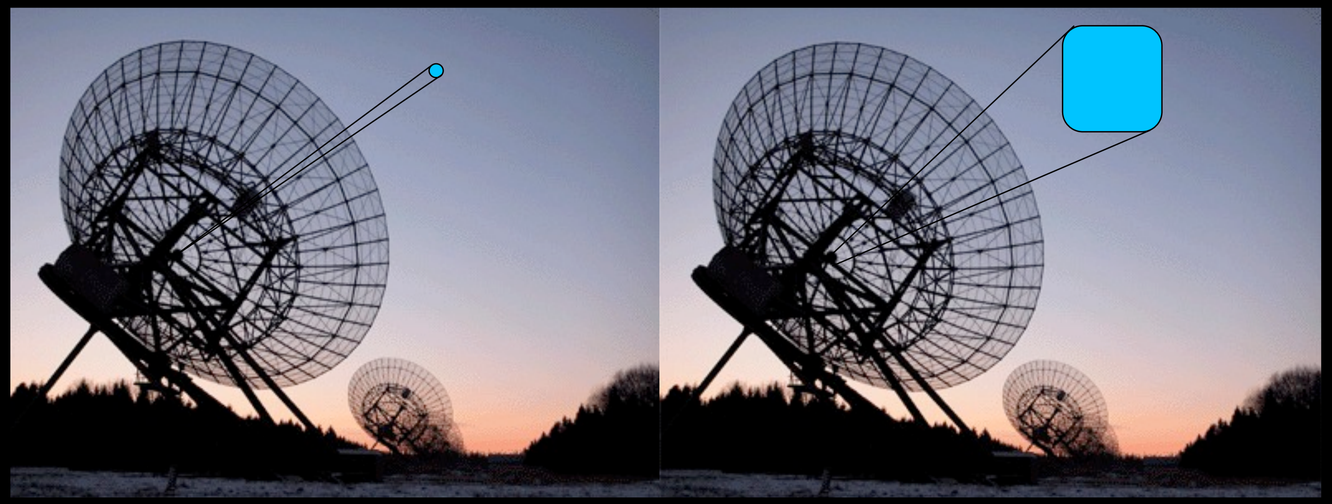




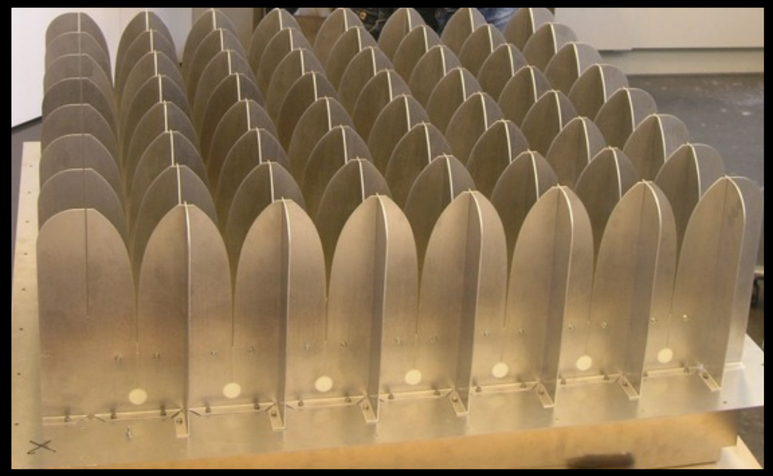
Replace single-pixel detector with array of detectors.
Turn single dish into a camera

Apertif: APERture Tile In Focus

APERTIF
APERture Tile In Focus

Array of densely packed Vivaldi receptors in each WSRT dish to **fully sample focal plane**

Apertif	WSRT
121 elements (2 pol)	1 (2 pol)
37 beams on the sky	1
FoV 8 deg²	**0.3 deg²**
Range ν: 1000 – 1750 MHz	117 – 8650 MHz
T_{sys} < 55 K	30 K
Aperture efficiency 75%	55%
Bandwidth 300 MHz	160 MHz
16384 channels	1024 channels
12 dishes	14 (13) dishes



Recycle of lot of LOFAR software (pipeline & archive)

Survey speed increases by factor 20-40 - similar to ASKAP.
Can do in a day what now takes a month

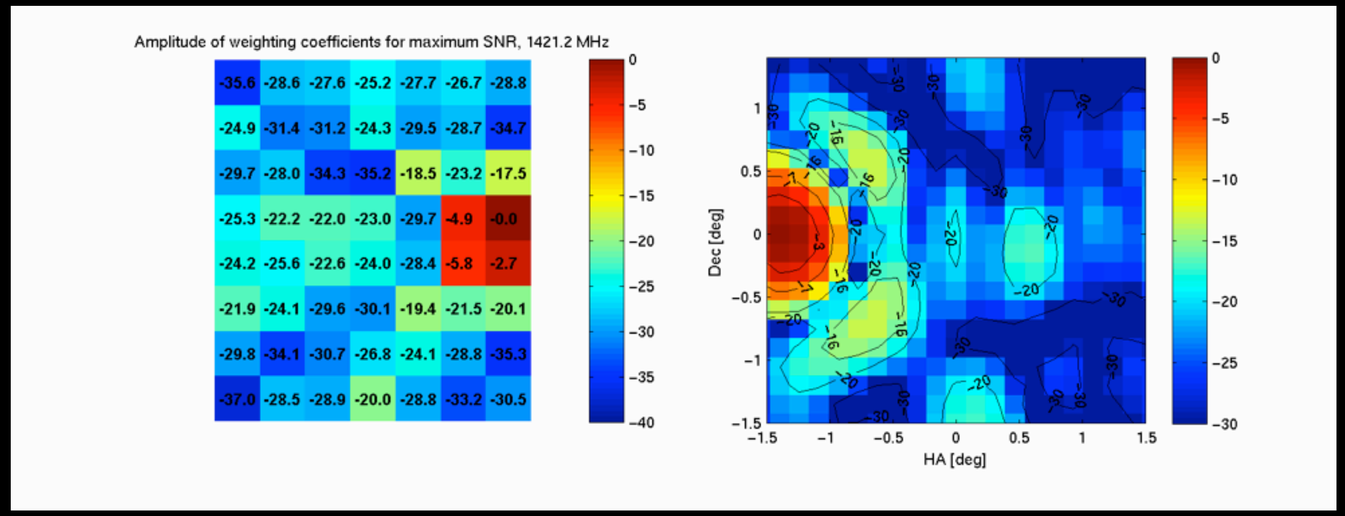
Use optimised beams

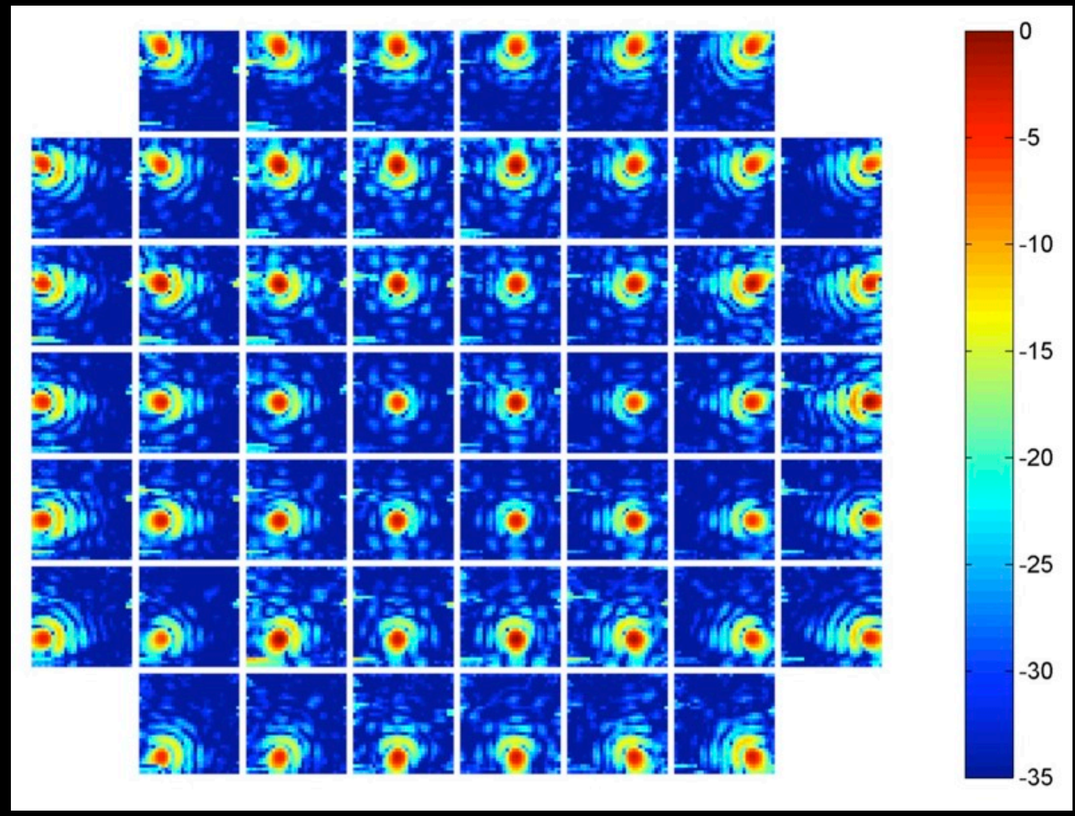
APERTIF
APERture Tile In Focus

Each element sees a different part of the sky (it's a camera...).
But: not use elements beams directly, but make many *optimised* beams,
using weighted sum of all element beams.

Optimise for:

- Optimum S/N
- Low instrumental polarisation
- Low sidelobe level



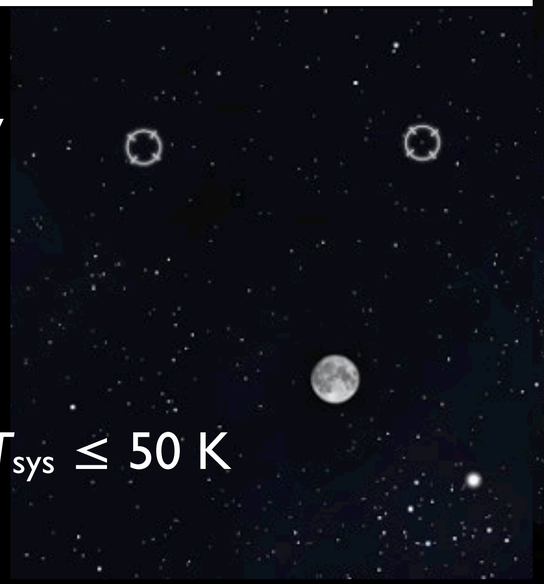


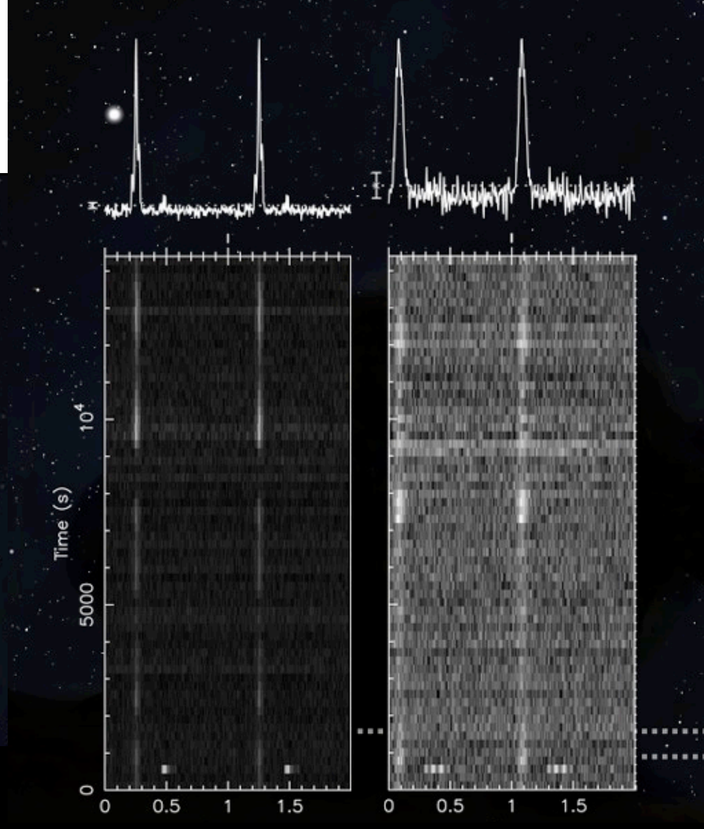
Element beams are ugly, but compound beams are very well behaved

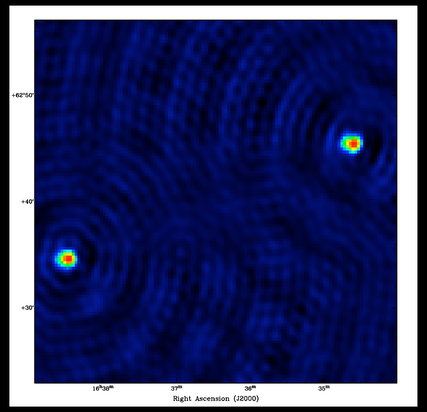
Since 2008: prototype(s) PAF in WSRT dish: Digestif

- LOFAR real time beamformer;
  Connected with part of WSRT for real time interferometry

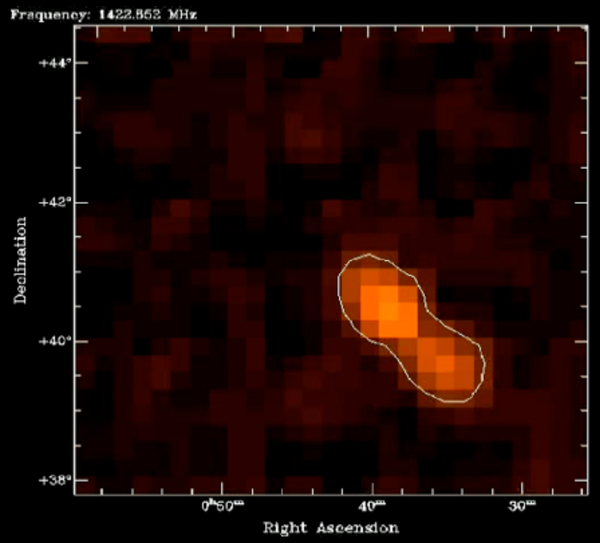
- Digestif has demonstrated:
  - Aperture efficiency of 75%
  - Current T_{sys} = 61 K (45 K as AA), final Apertif will have $T_{sys} \leq 50$ K
  - *A/T* of Apertif will be ≥0.8 times that of WSRT
  - Achieved *effective* field of view of 8 degree^2
  - Eliminated standing waves (and understand why…)
  - Interferometry with WSRT
  - Dual-beam pulsar detection
  - Beam stability OK
  - Polarisation OK
    (like WSRT or better)



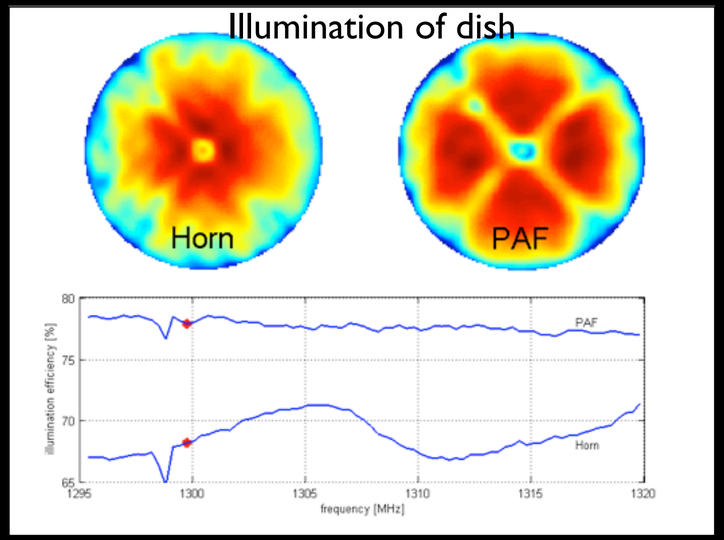




Interferometry on 3C343 & 3C343.1



single dish M31; 4 pointings covering 40 deg^2



HI in M33 - single pointing with real-time beamforming

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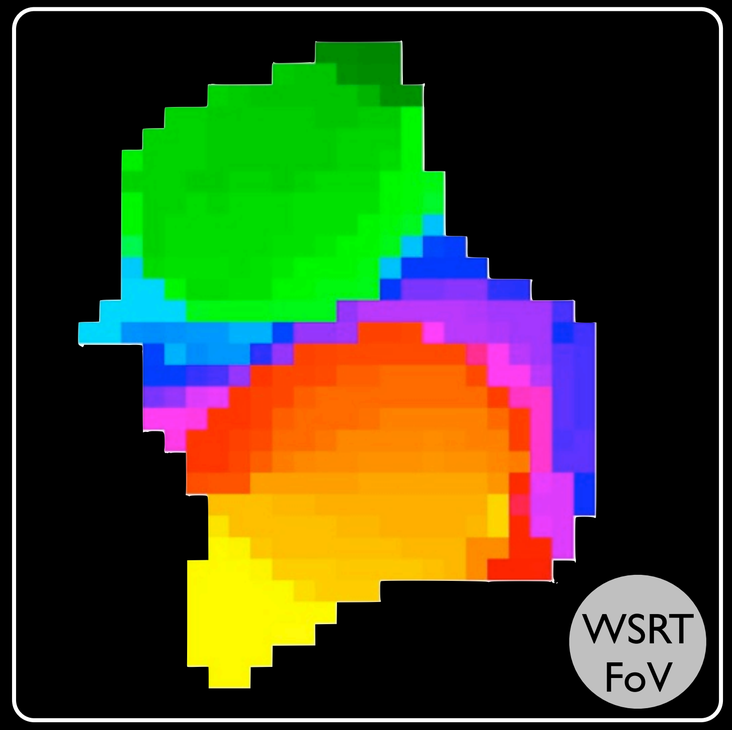
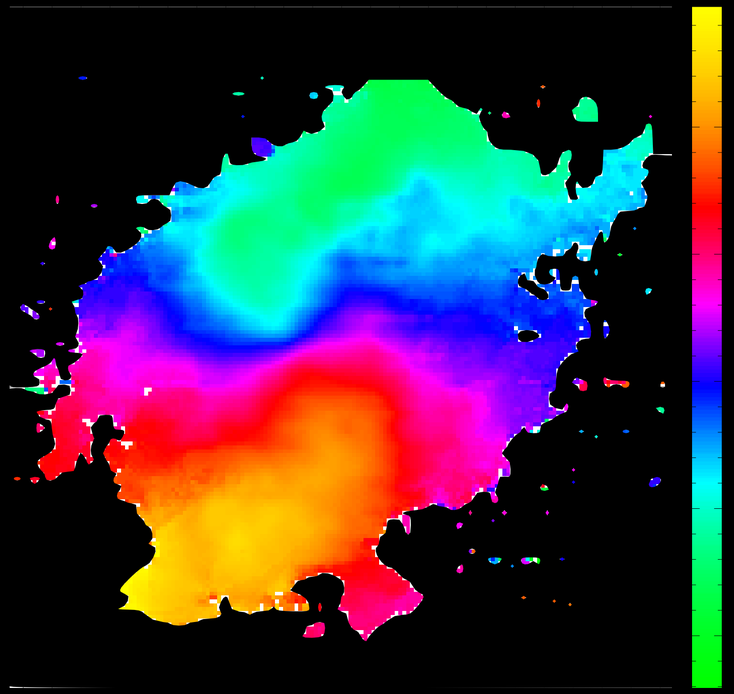
APERture Tile In Focus

HI in M33 with Digestif



Apertif



Arecibo
(Putman+ 2009)

Low noise amplifier

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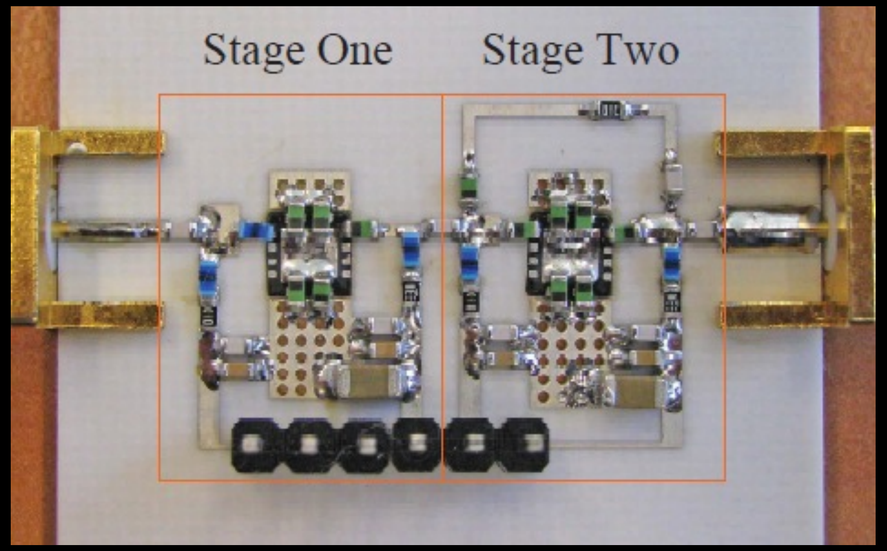
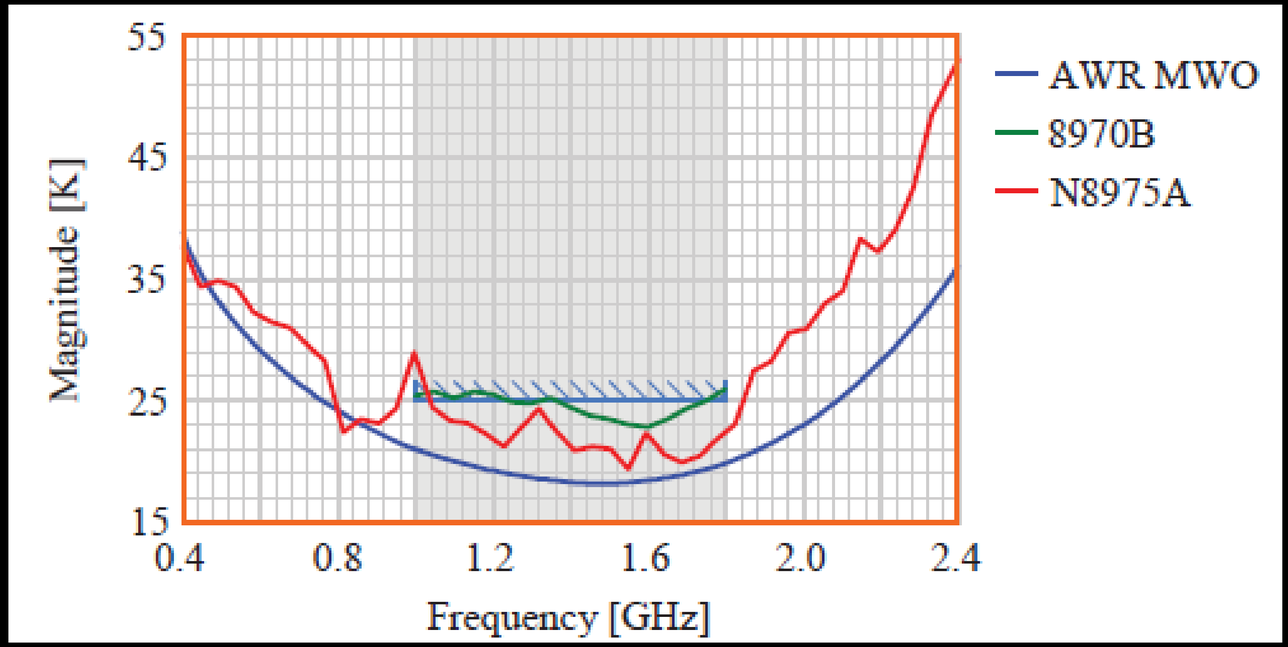
- First LNA fulfilling APERTIF requirements has been built and measured

  David Smith, postdoc from Stellenbosch, SA

  To do: design for manufacturing





Design for manufacturing

APERTIF
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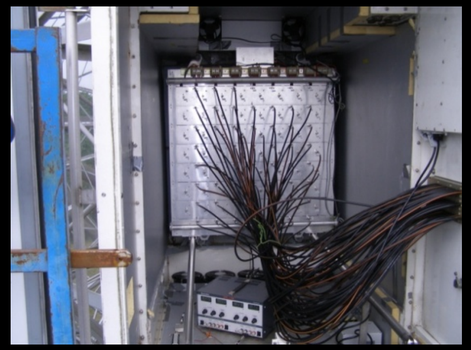
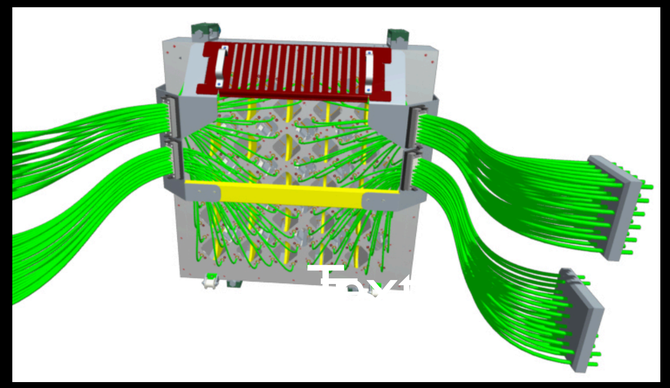
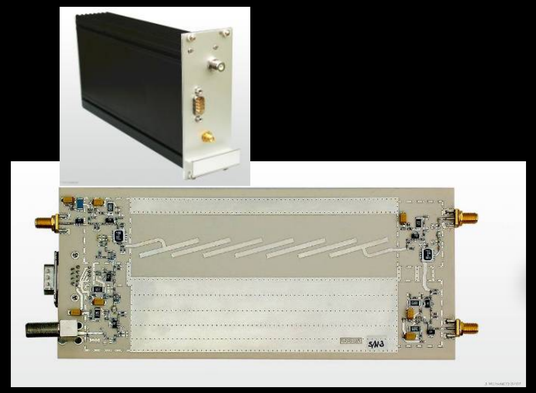
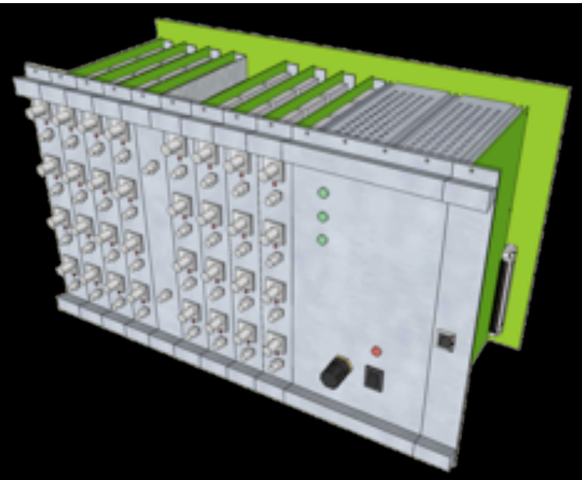
- Prototypes demonstrated functionality
- To design for easy production and maintenance









Avoid small component values (e.g. no 0.5 pF C's)

Squeezing the last Kelvin

Fine-tuning gain to final cable lengths

Test points on pcb

Include monitoring and control

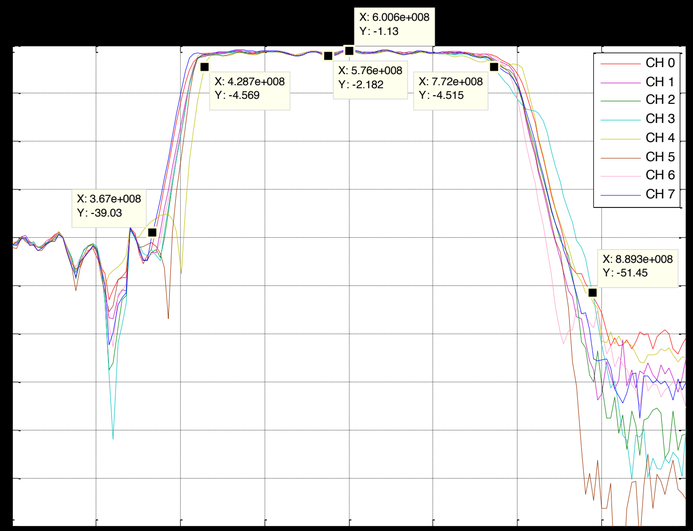
From LOFAR IF to APERTIF IF

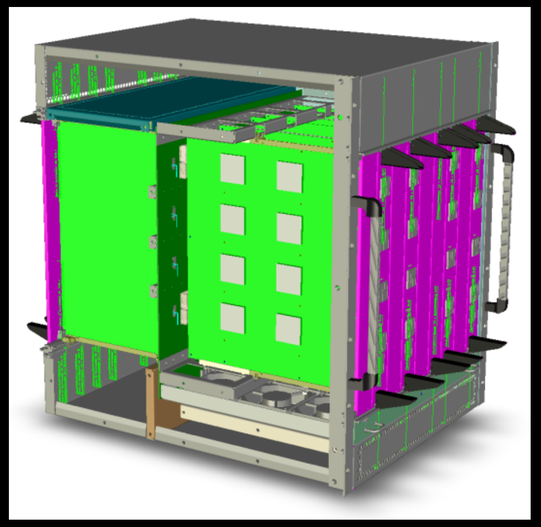
Higher level of integration

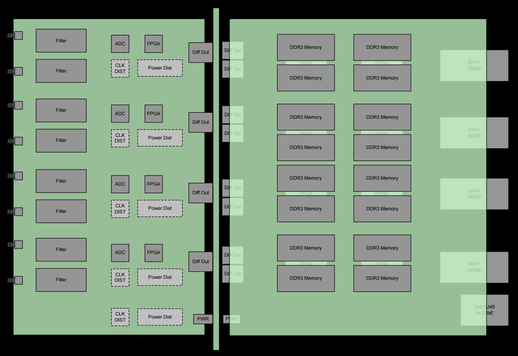
Slide-on instead of screw connectors

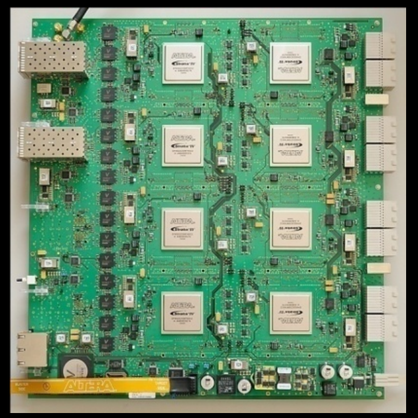
ADC and Digital Beamforming Subrack

- Link to ADC and UniBoard is up & running
- Full subrack ordered and ready end 2011 (ADCs, backplane, clock, UniBoards)









Planning

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- 2011 Site preparation (fibre to all dishes)
- 2012 Hardware procurement, production and testing
- 2013 Begin PAF installation

RFI at Westerbork

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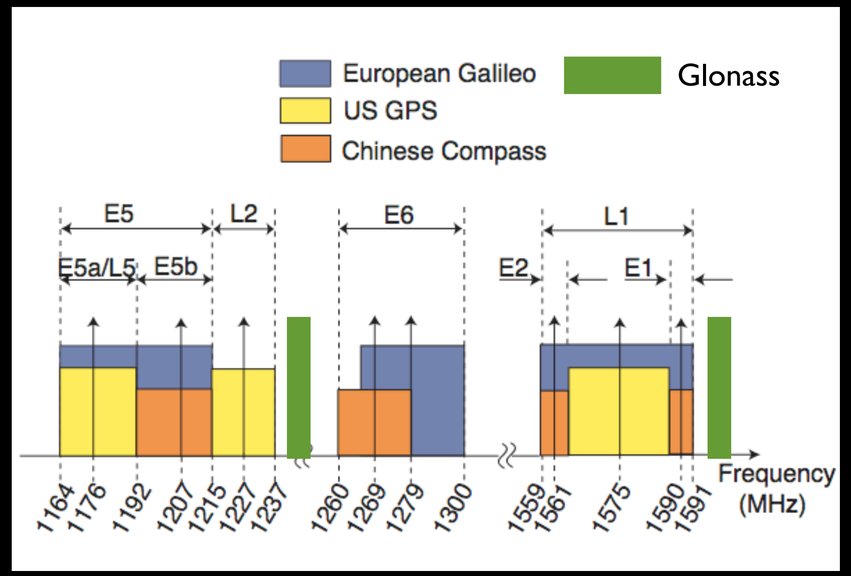
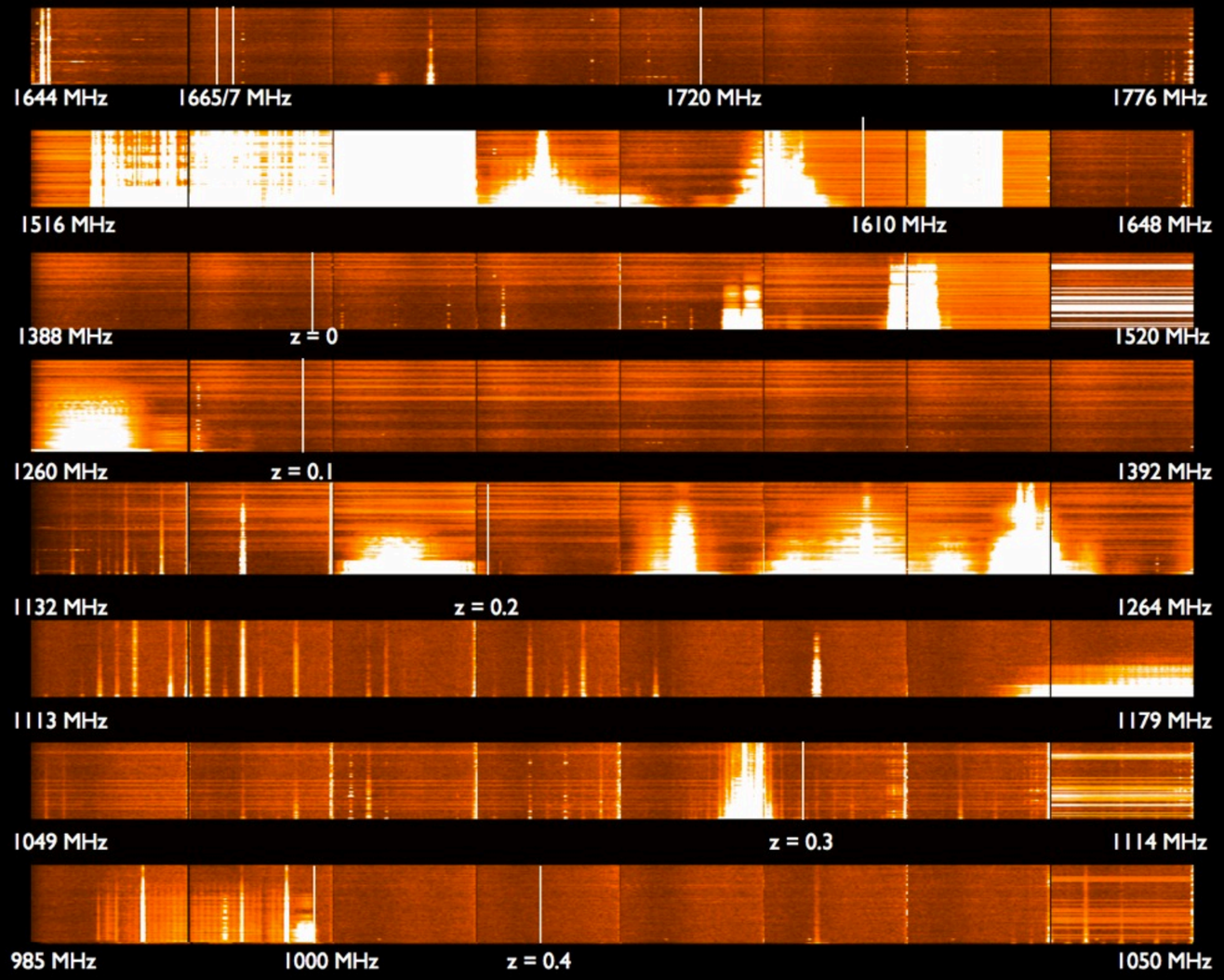
Are monitoring RFI in Apertif band

RFI is going to have strong impact on science:

- HI work at z = 0.1 - 0.2.
- RM synthesis, continuum

same will be true for ASKAP, MeerKat, EVLA, SKA





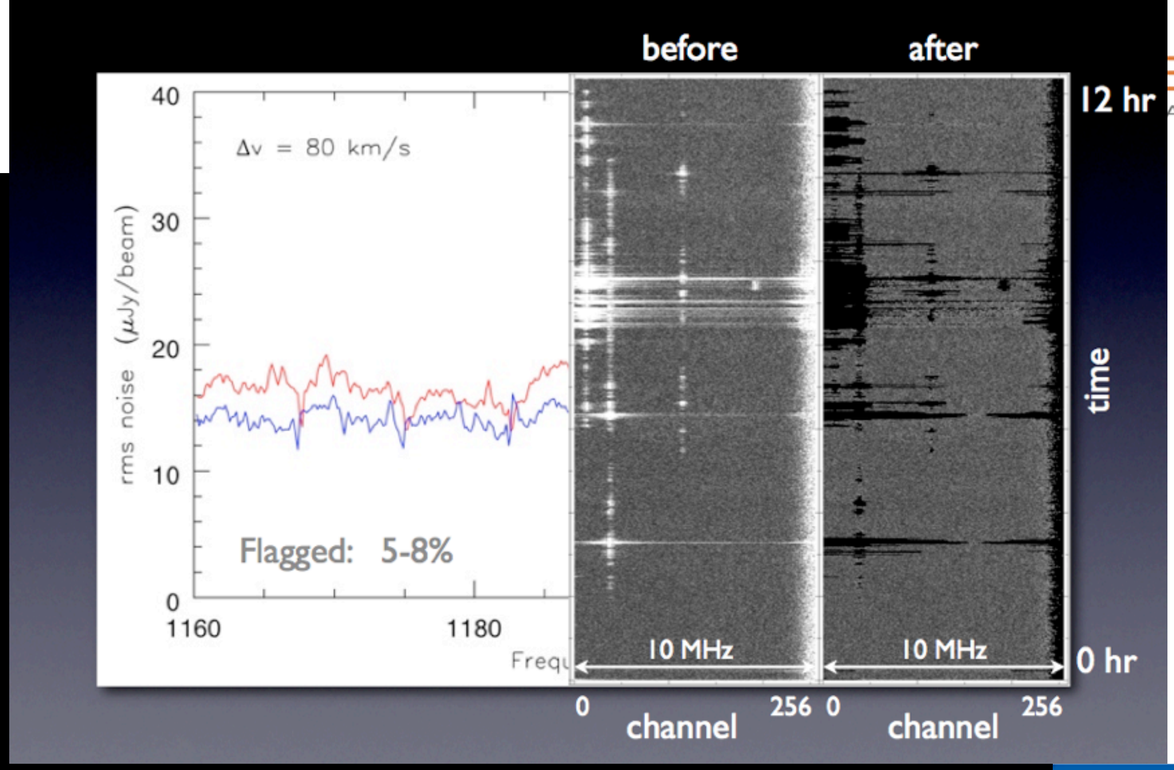
- Below 1150 MHz: air traffic
- 1612 MHz is (just) OK.

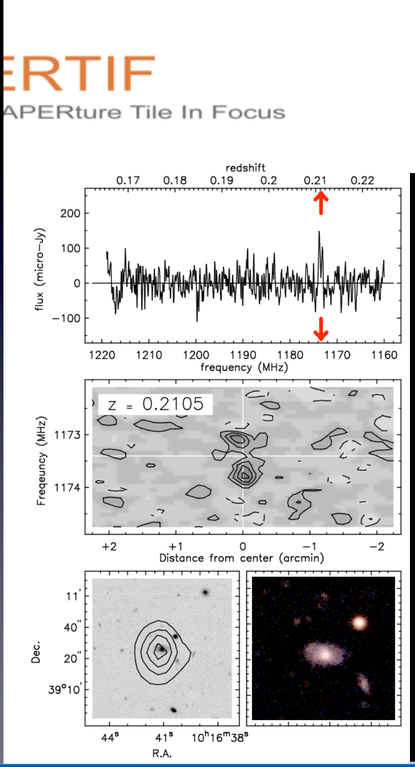
RFI

Survey teams should consider

impact on their science

- HI:
  - OK up to z = 0.1
  - between z = 0.1 and 0.2: strong RFI from GPS, Glonass. 10-20% lost
    Galileo system will make things worse
  - above z = 0.25 RFI from air traffic. 25% lost??? better at night?
- Strong RFI 1500 - 1630 MHz; 1612 MHz is OK.
  GPS, Glonass, Iridium mobile satellite transmissions

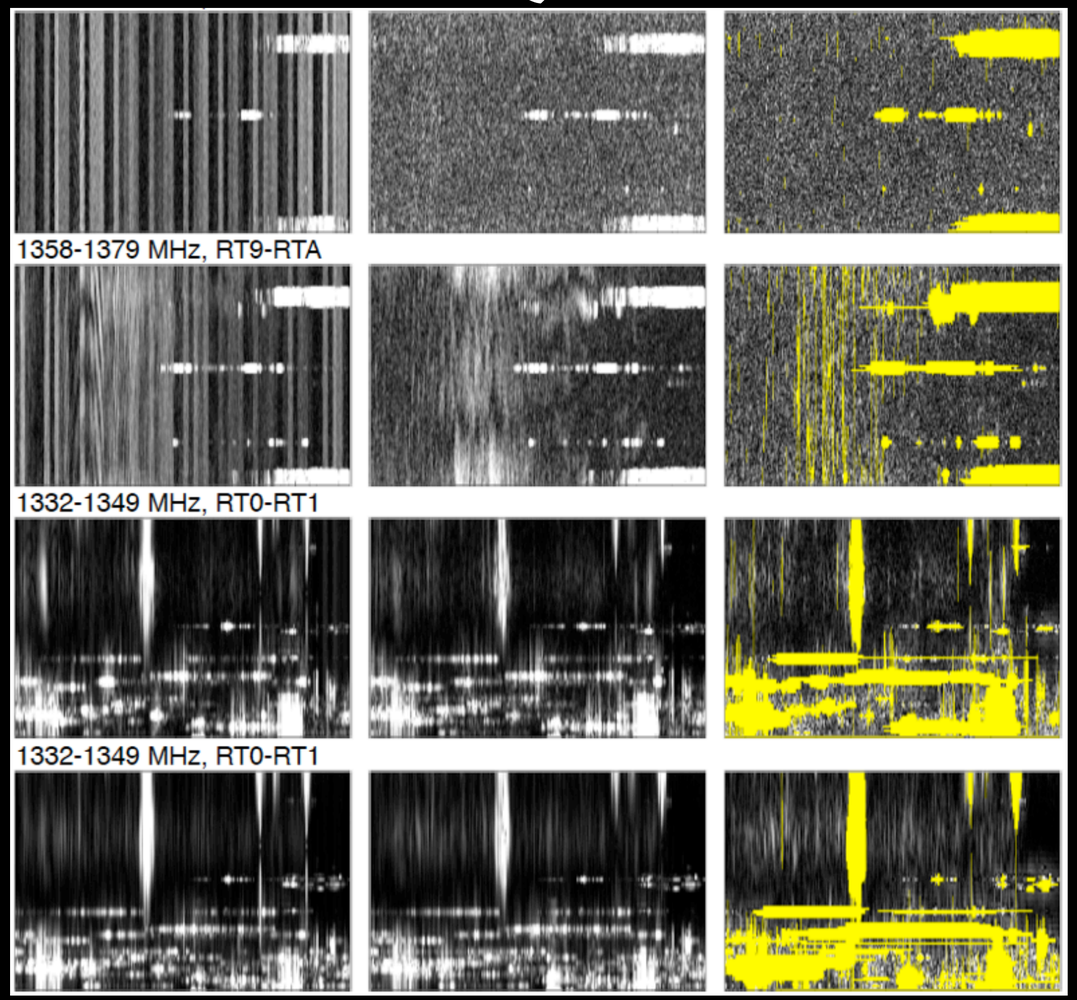




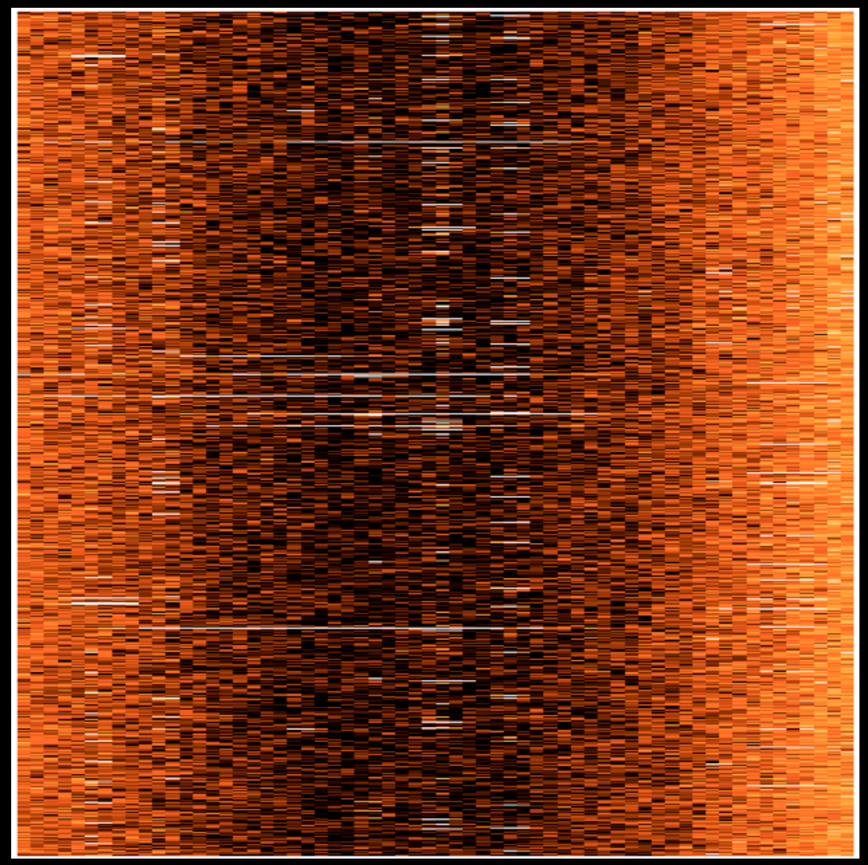
RFI

APERTIF
APERture Tile In Focus

- LOFAR flagger works pretty well on sharp RFI
- work to be done for broad RFI

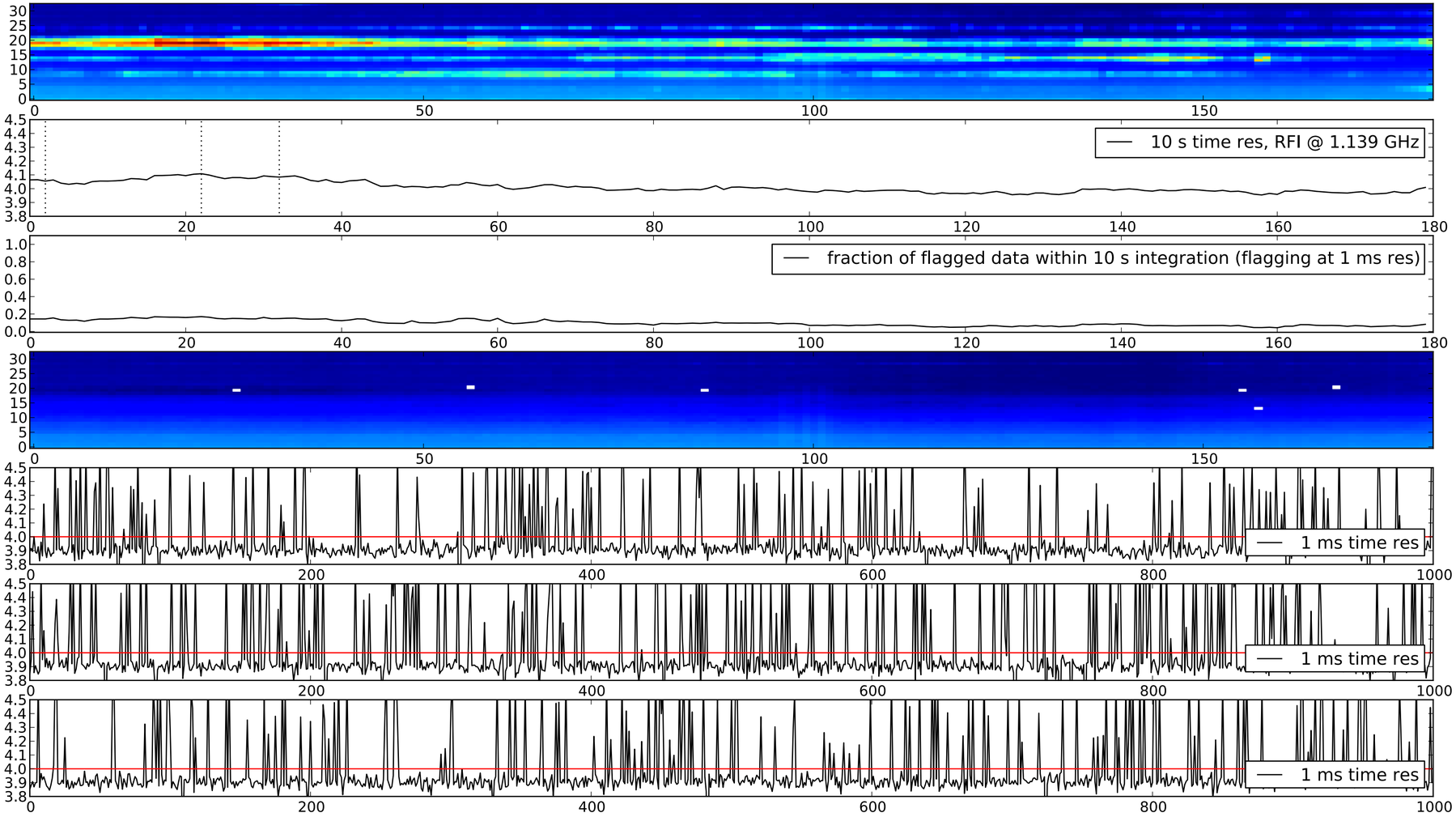


- below 1150 MHz: air traffic.
- msec burst with lot of empty space.
- Flag before correlation ??

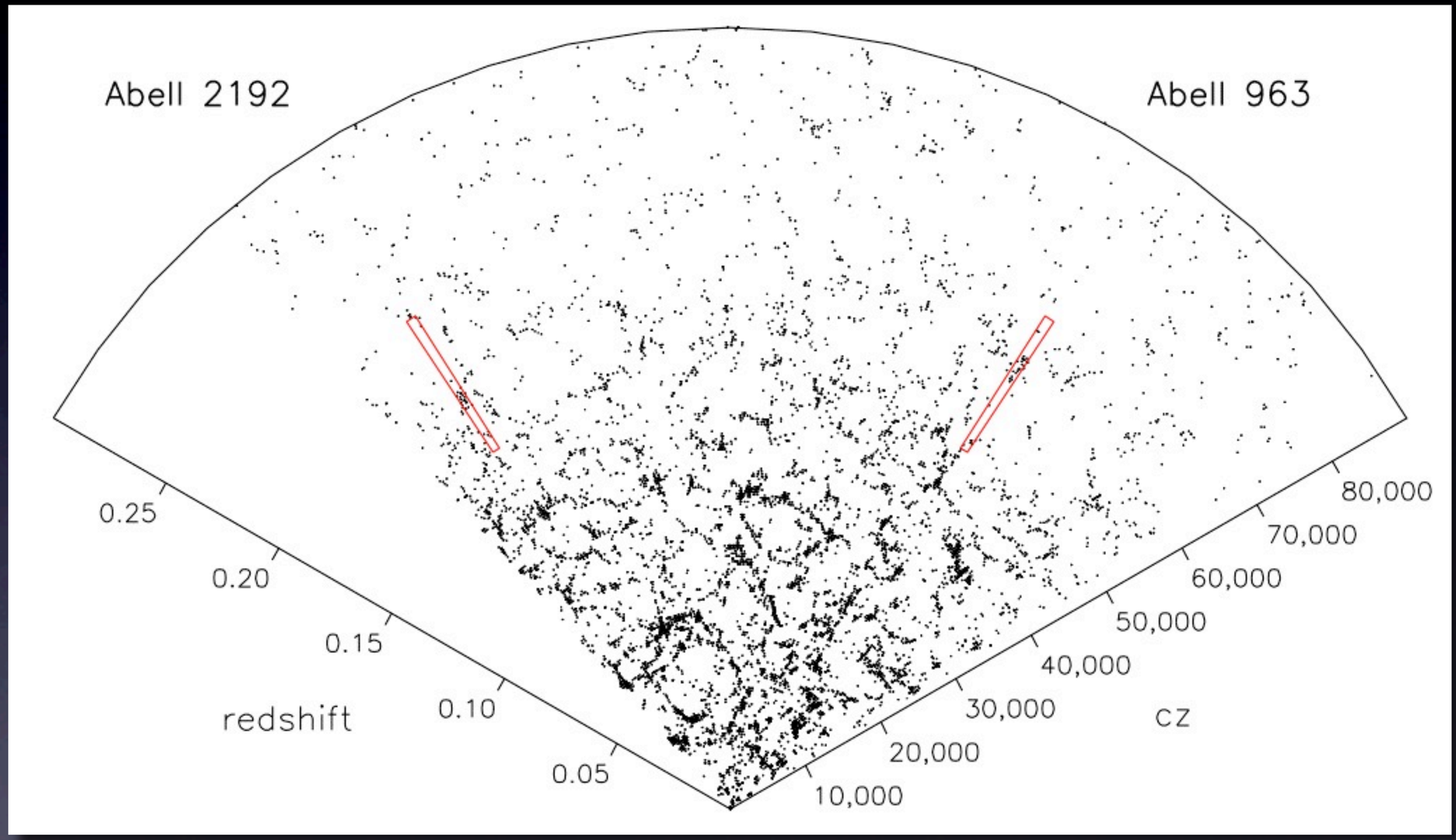


Flagging at high time resolution

APERTIF
APERture Tile In Focus

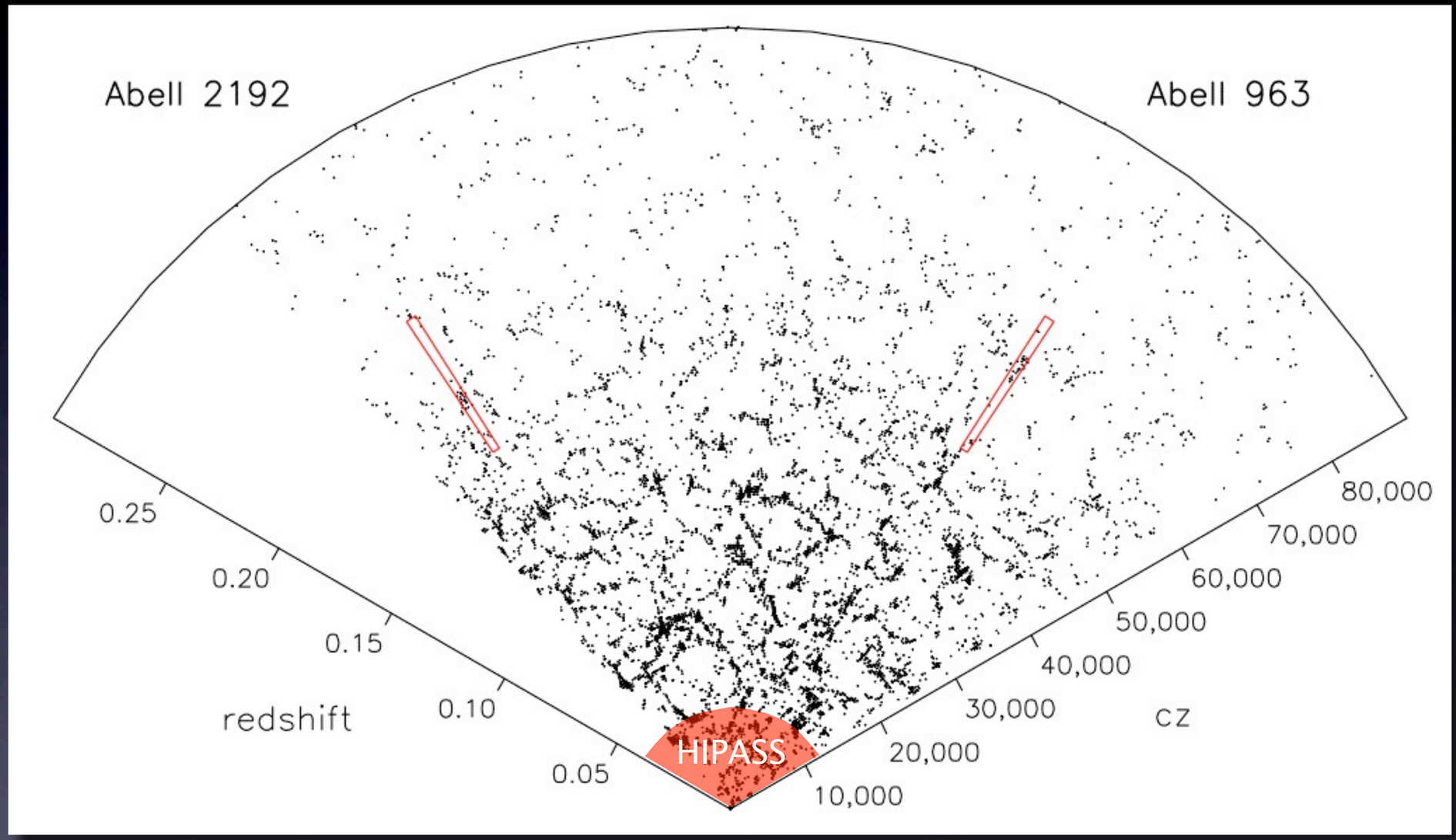


The promise of Apertif



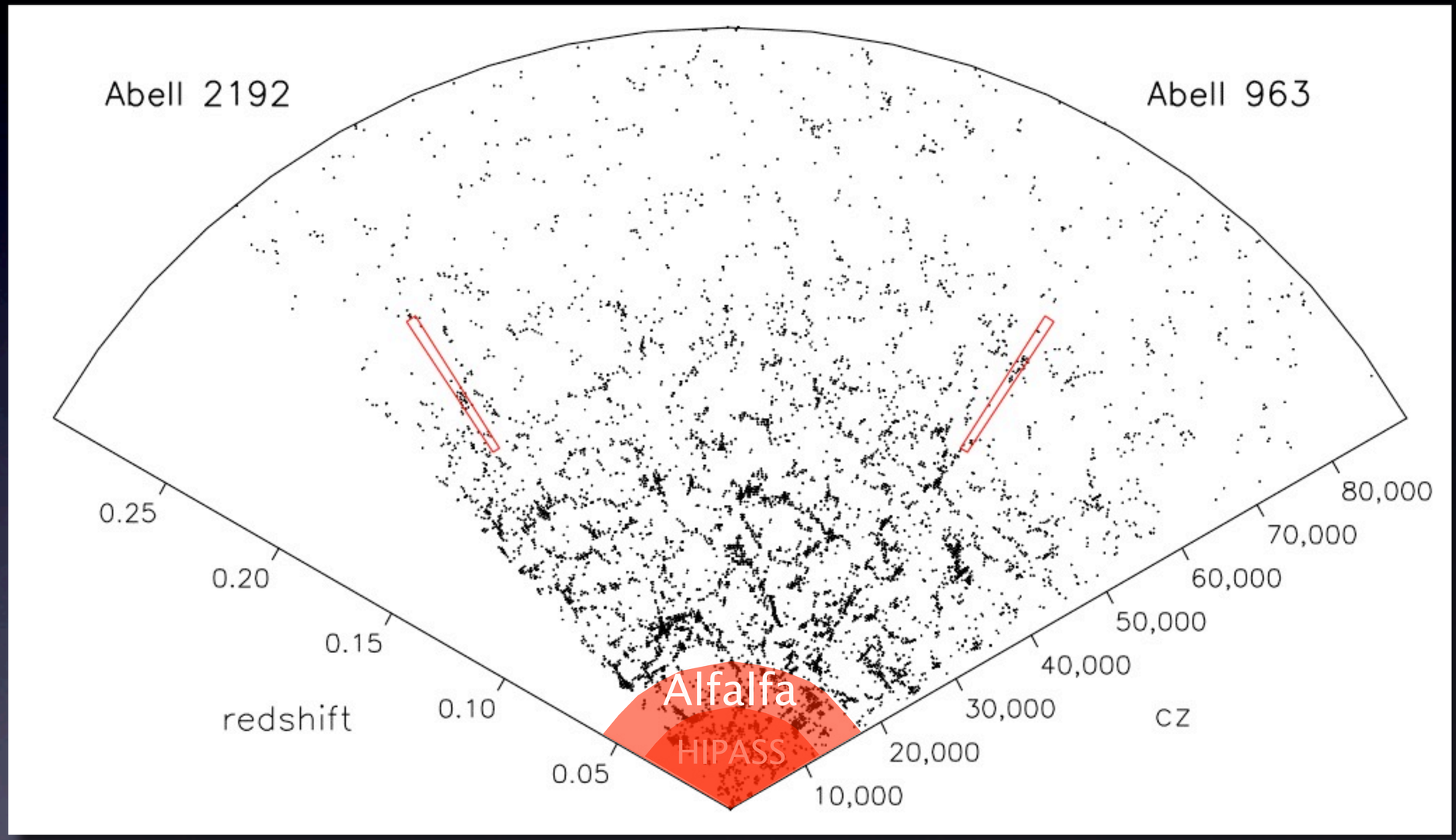
SDSS redshift slice

The promise of Apertif



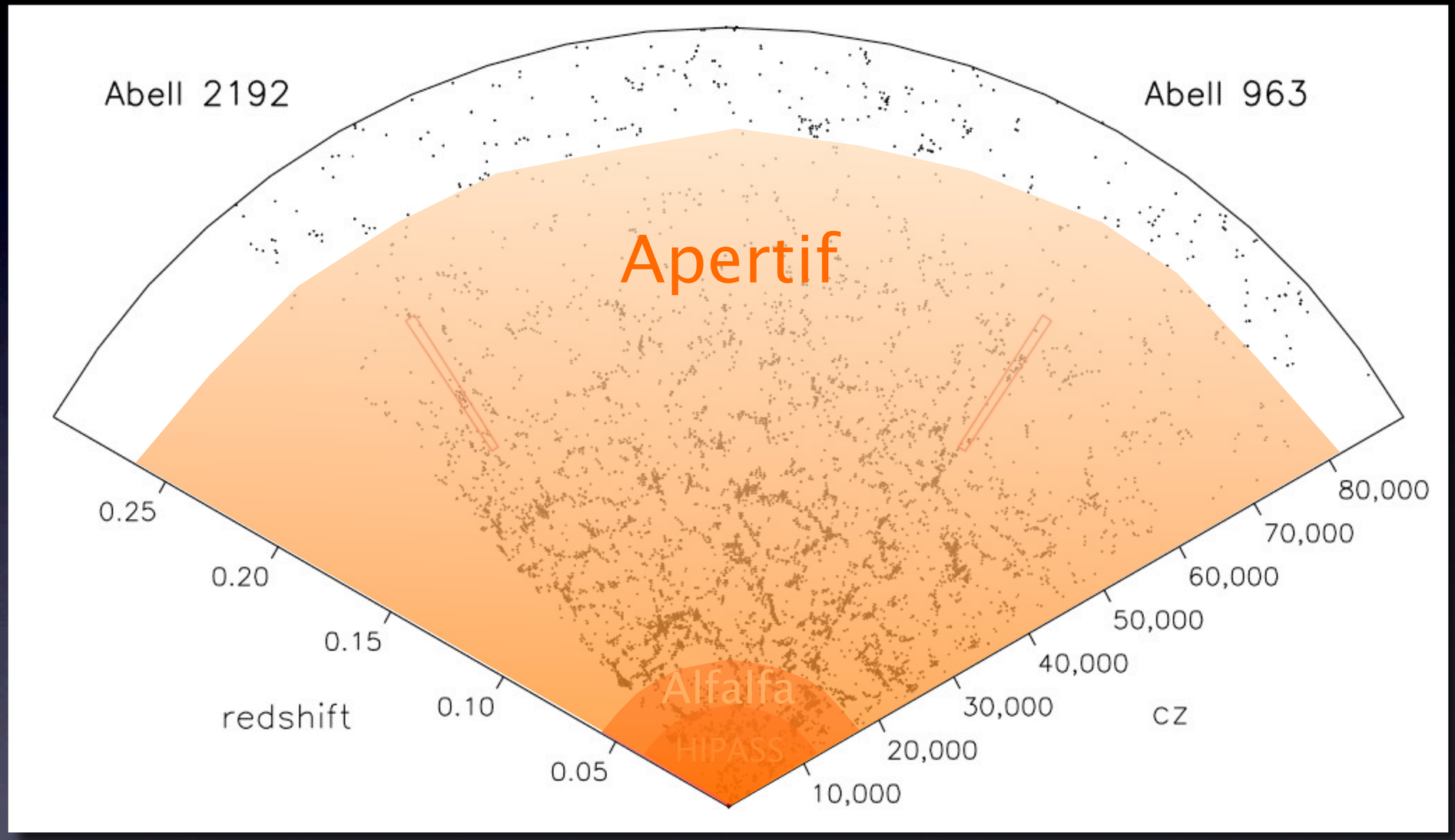
SDSS redshift slice

The promise of Apertif



SDSS redshift slice

The promise of Apertif



SDSS redshift slice

Apertif Expressions of Interest

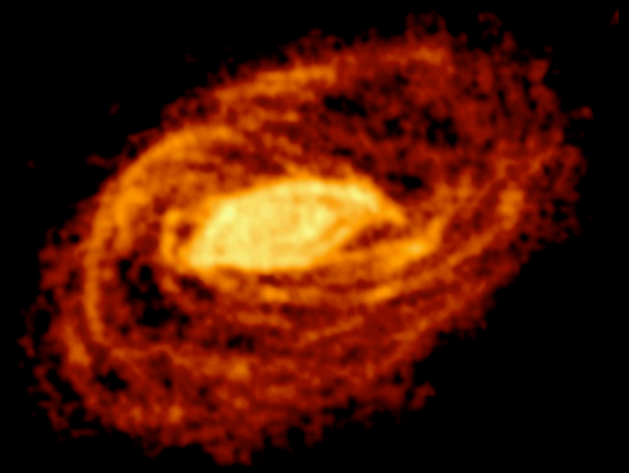
APERTIF
APERture Tile In Focus

- Sep 2010: deadline for Expressions of Interest
  - to get an idea who is interested
  - and for what, how much, what is needed
  - how important are commensal surveys?
- 'Classical' way of assigning observing time does not optimise output of Apertif.

- Many projects can, in principle, use the same data
- Data public very soon after completing observations
- Legacy value very very important:

"Half of these achievements were among the original "design goals" of the SDSS,
but the other half were either entirely unanticipated or not expected to be nearly as exciting
or powerful as they turned out to be."

(from SDSS webpages)



Apertif Expressions of Interest

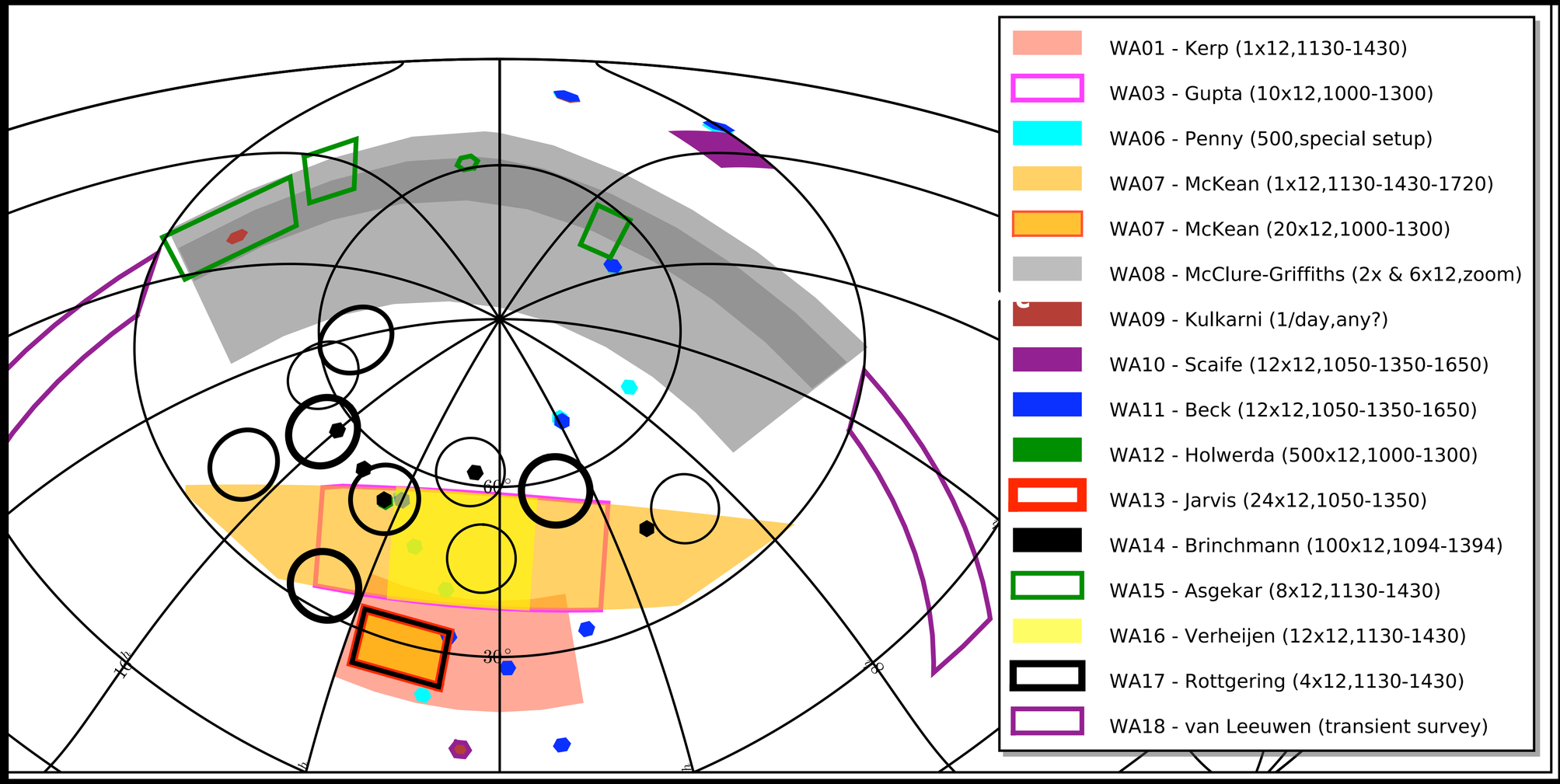
APERTIF
APERture Tile In Focus

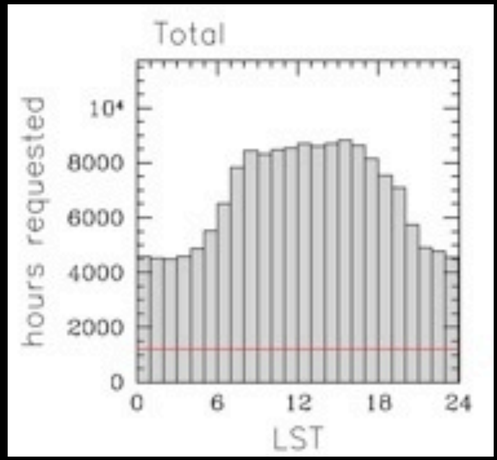
- Sep 2010: 18 EoIs submitted
  - 8 x NL, 4 x UK, 2 x Germany, 1 x AUS, 1 x ZA, 1 x USA, 1 x Ireland
- Proposed science very similar to that of ASKAP surveys, except for LOFAR connections & SETI
  - HI surveys: shallow - medium - ultra deep; Galactic & extragalactic; emission & absorption
  - continuum: all sky - magnetic fields in MW, nearby galaxies & in clusters
    Strong synergy with LOFAR
  - Pulsar & transient searches
  - Galactic radio recombination lines
  - OH masers (Galactic & extragalactic)
- If all surveys were to be done separately: > 20 years of Apertif observing time (600 years WSRT!!!)
  - challenge: can we combine very different science goals into a small number of observing strategies?

Apertif expressions of interest

APERTIF
APERture Tile In Focus

Survey Footprints

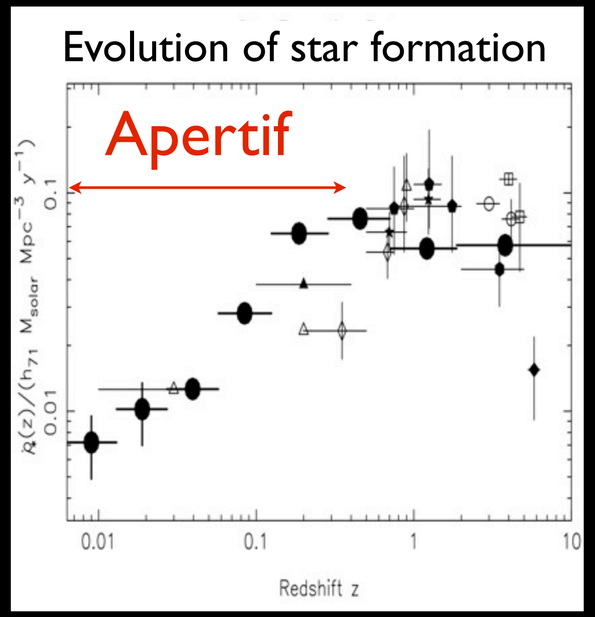




Exciting times ahead for HI

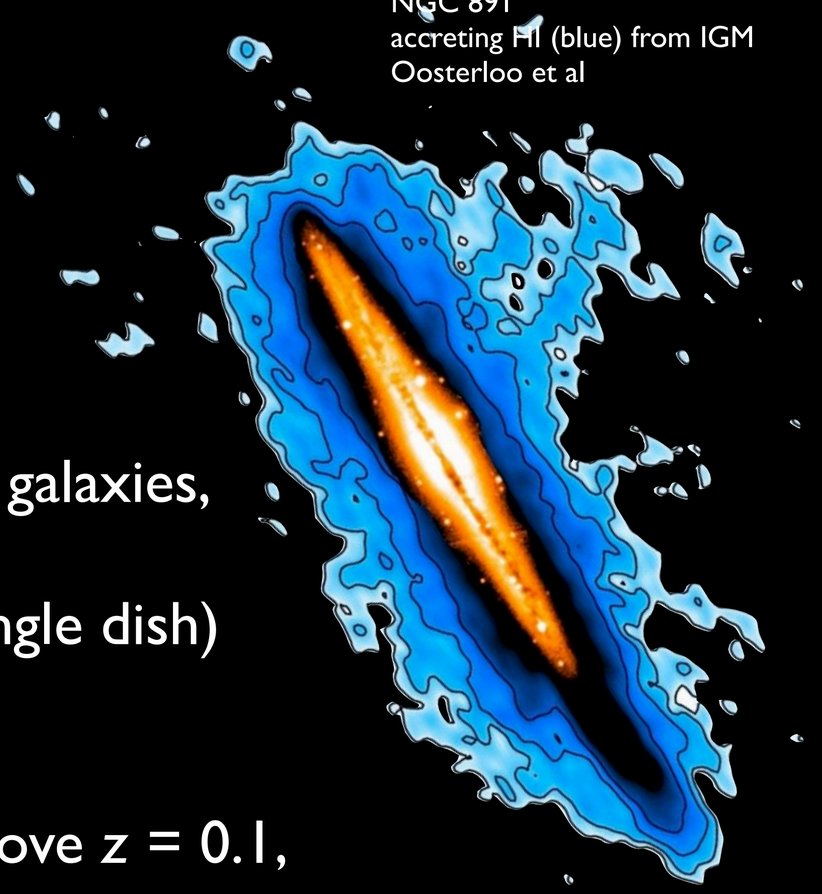
APERTIF
APERture Tile In Focus

- Most stars from 'cold' gas accreted from IGM
- Decline in star formation due to declining accretion rates?



Heavens et al.

- Currently we know about the H I in ~10^4 galaxies,
  ~100 galaxies detected above z = 0.1,
  almost all with 3-15 arcmin resolution (single dish)
- Future: ~10^6 galaxies,
  out to z ~ 0.4, most detections will be above z = 0.1,
  with 20 arcsec resolution.
- We can directly observe the role of HI in the evolution of galaxies.

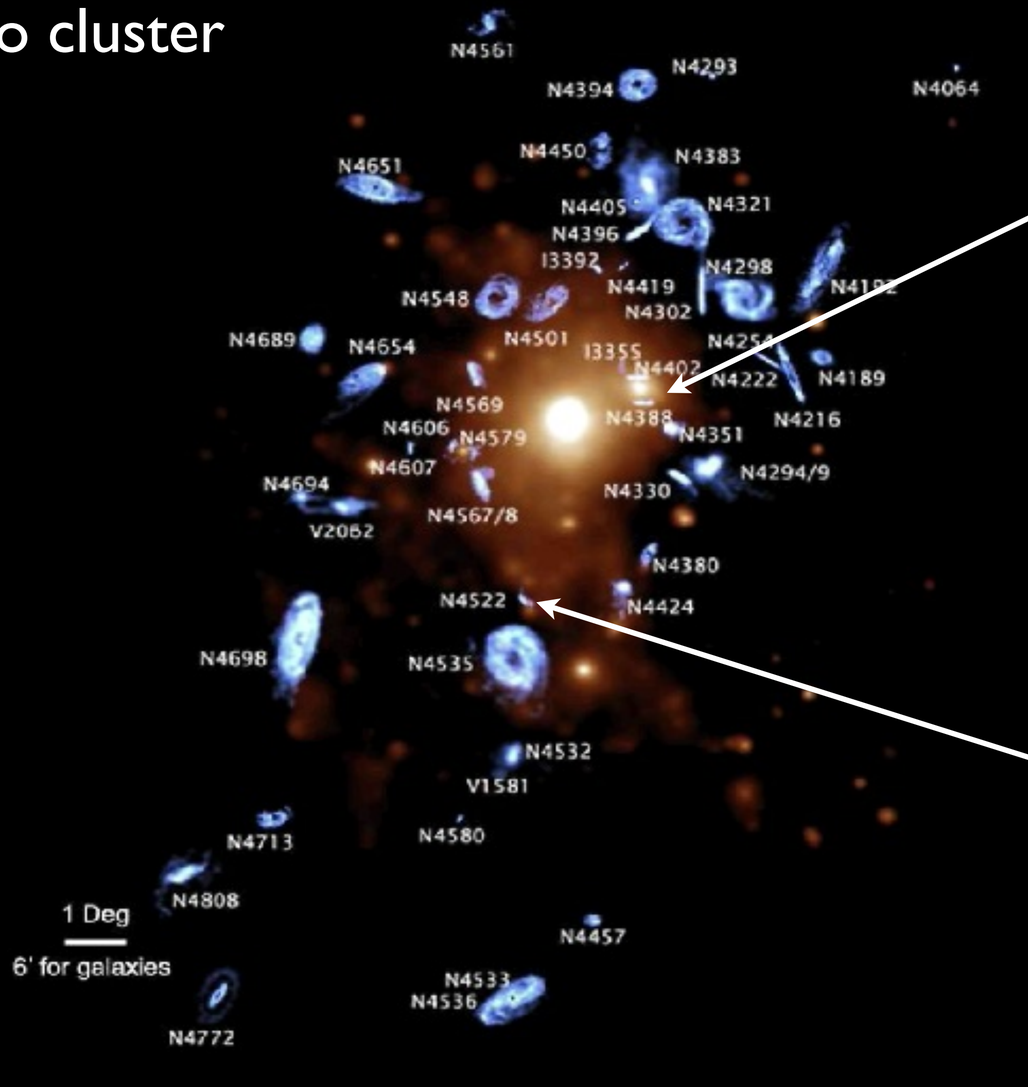


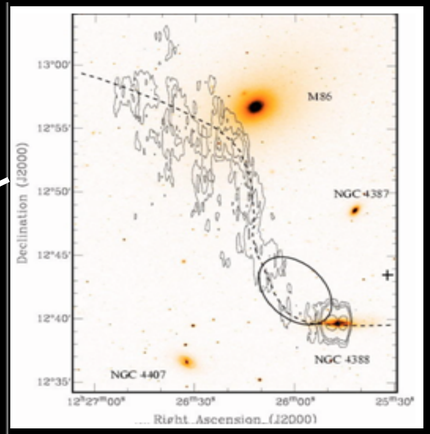
NGC 891
accreting HI (blue) from IGM
Oosterloo et al

Galaxy harassment in dense environments: stripping

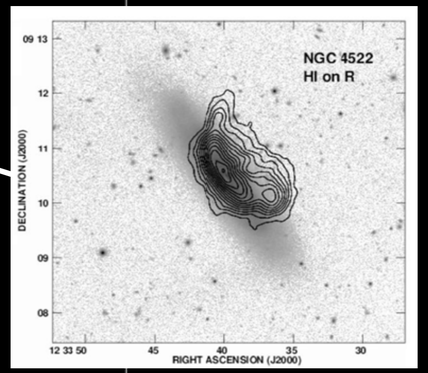
APERTIF
APERture Tile In Focus

Virgo cluster





NGC 4388



NGC 4522

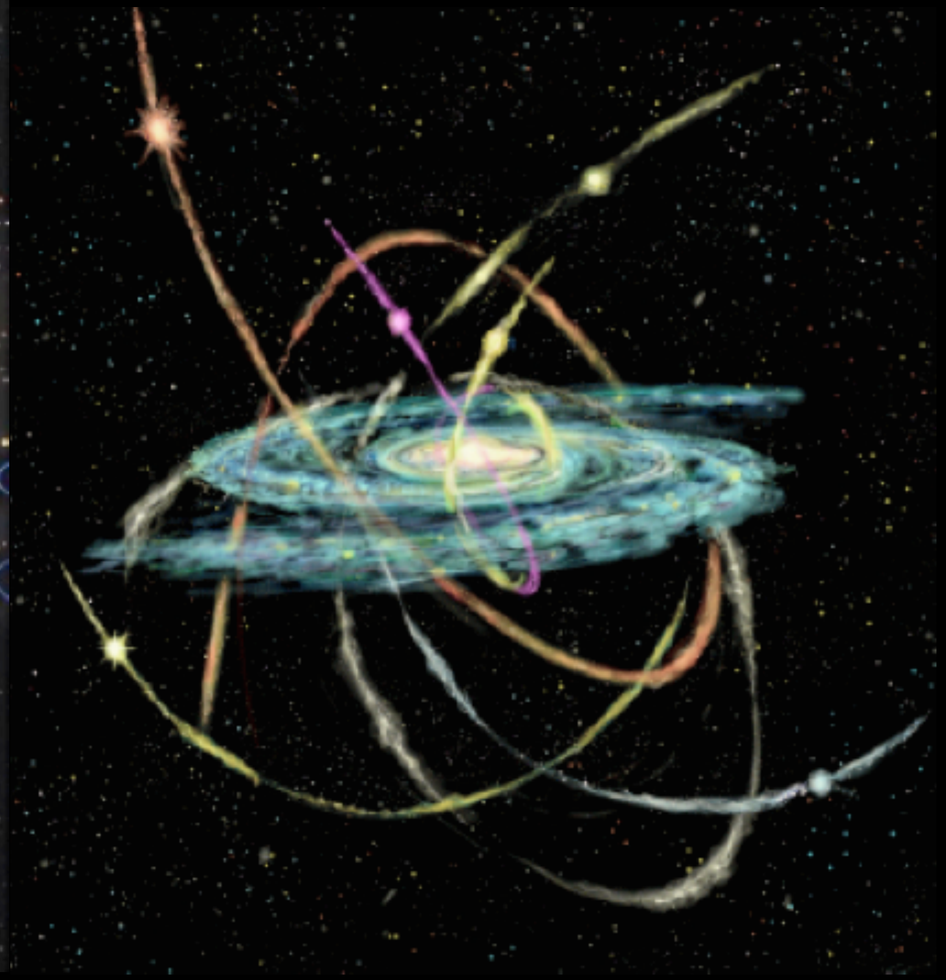
VIVA: Chung et al. 2009, AJ 138, 1741

Building galaxies through accretion of satellites

APERTIF
APERture Tile In Focus

- NGC 5907

Artist impression of satellite capture (F. Gomez, PhD thesis)



Building galaxies through accretion of satellites

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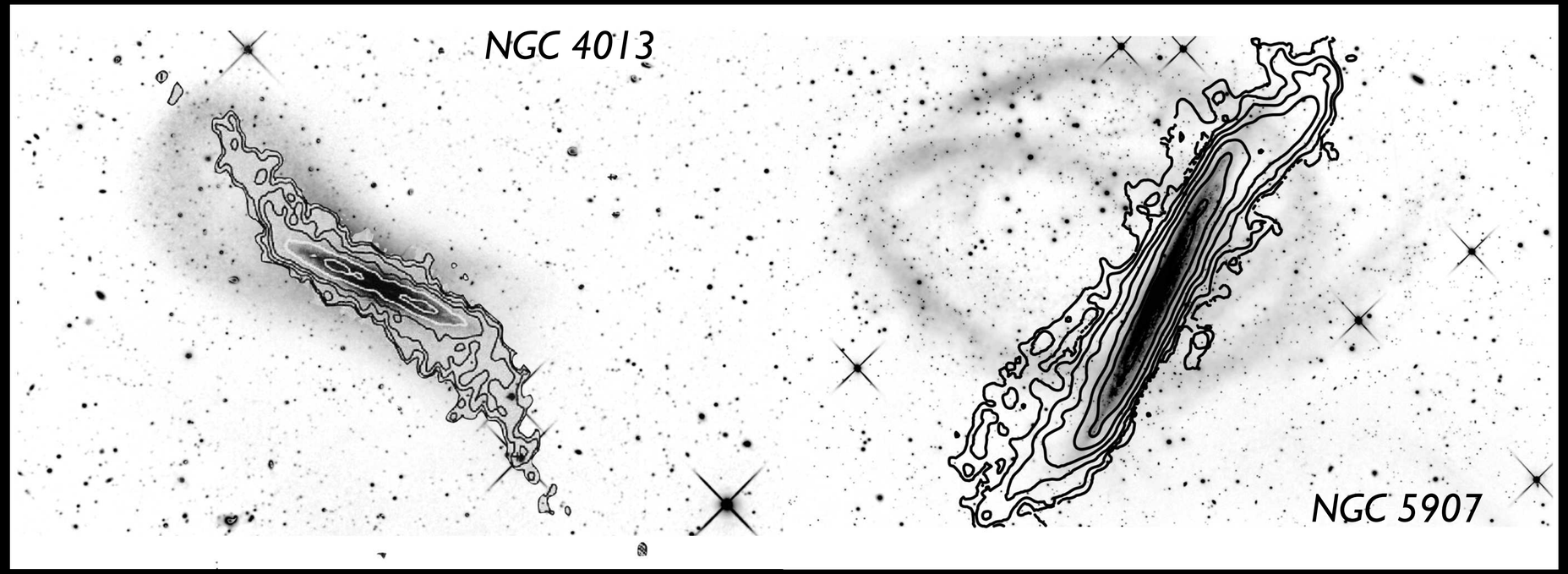

NGC 5033 warped outer disk with structure

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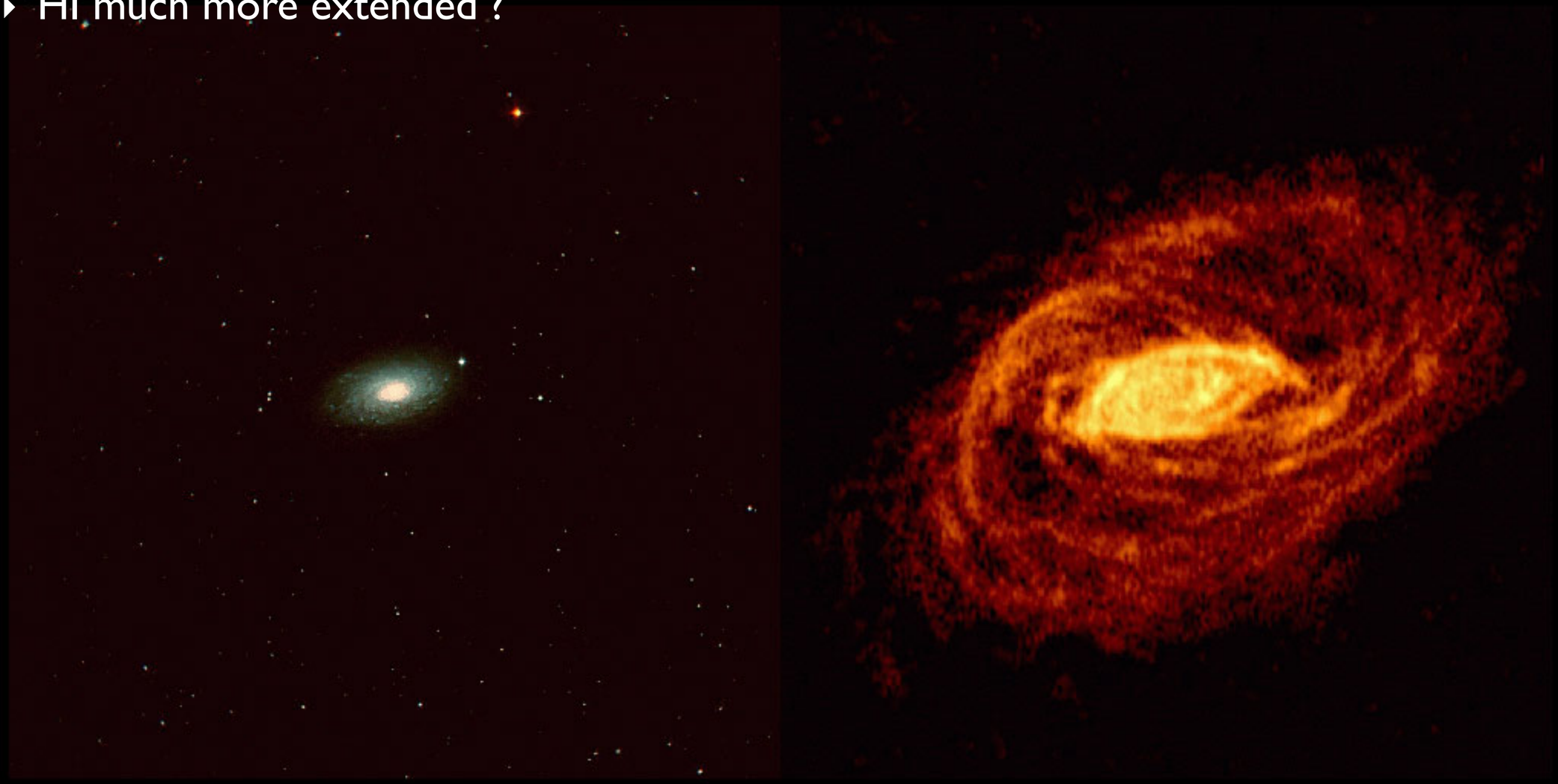
- HI much more extended ?



NGC 5033 warped outer disk with structure

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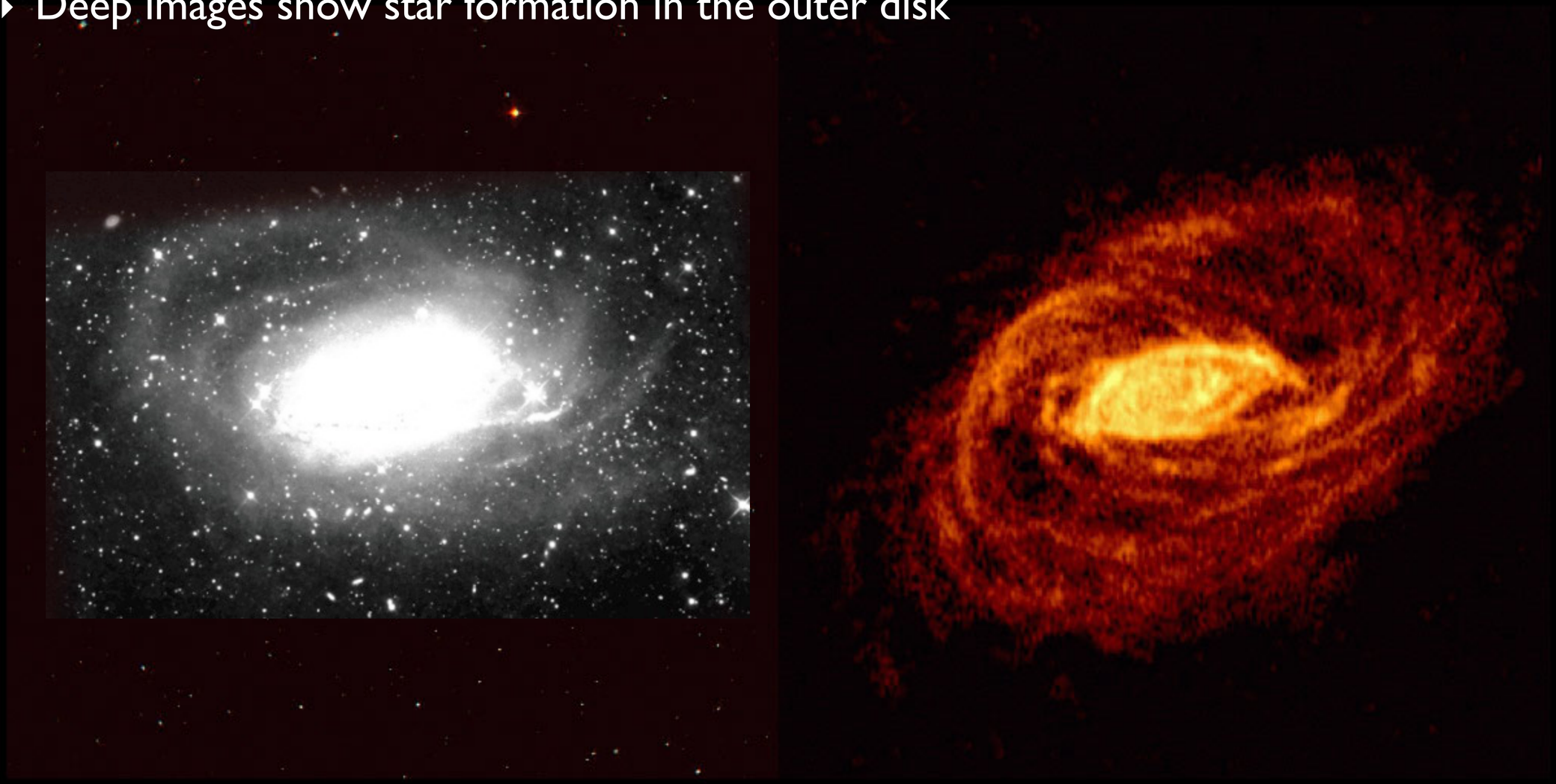
- Deep images show star formation in the outer disk



High resolution cosmological simulations

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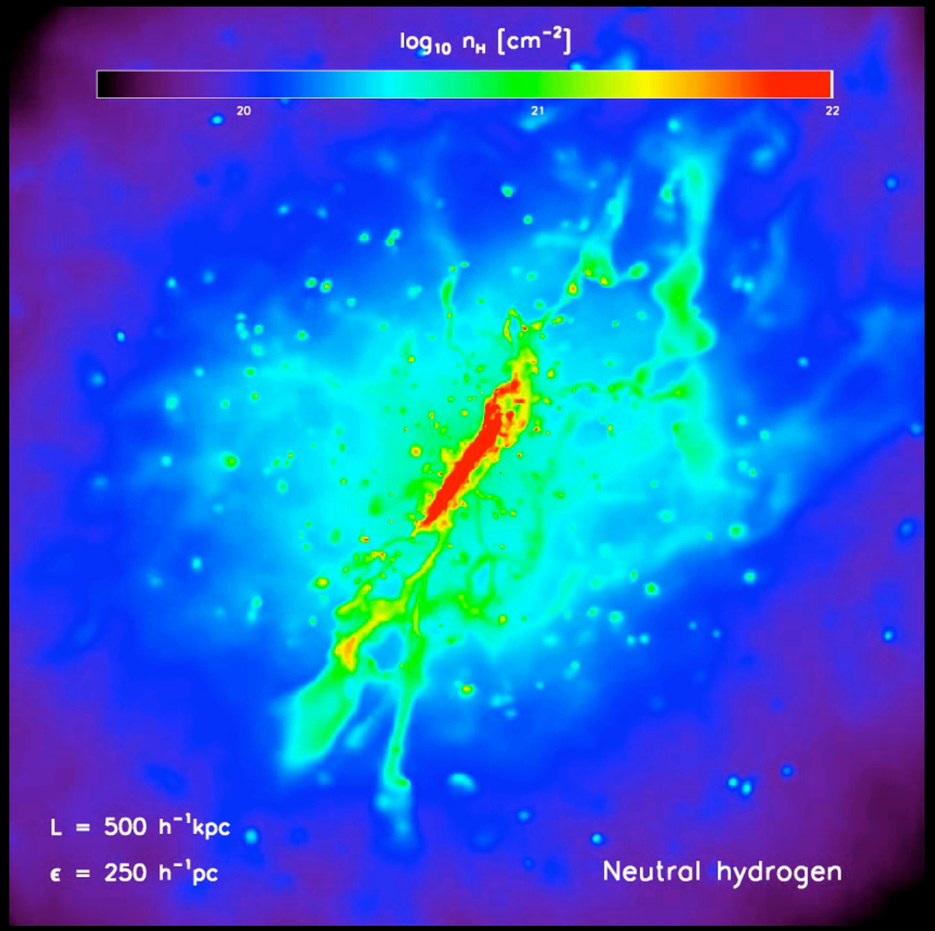
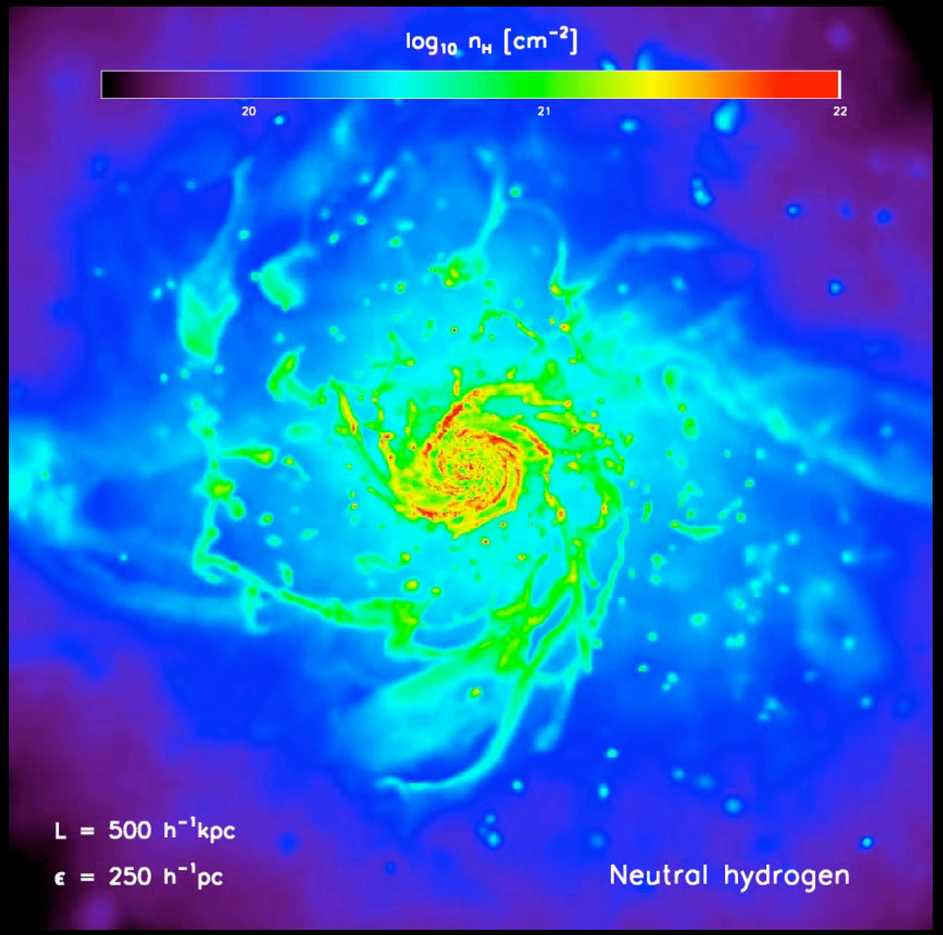
- HI around a MW mass galaxy at z = 0 (edge-on and face-on views)





Courtesy Joop Schaye and collaborators

Continuum survey: excellent combination with LOFAR

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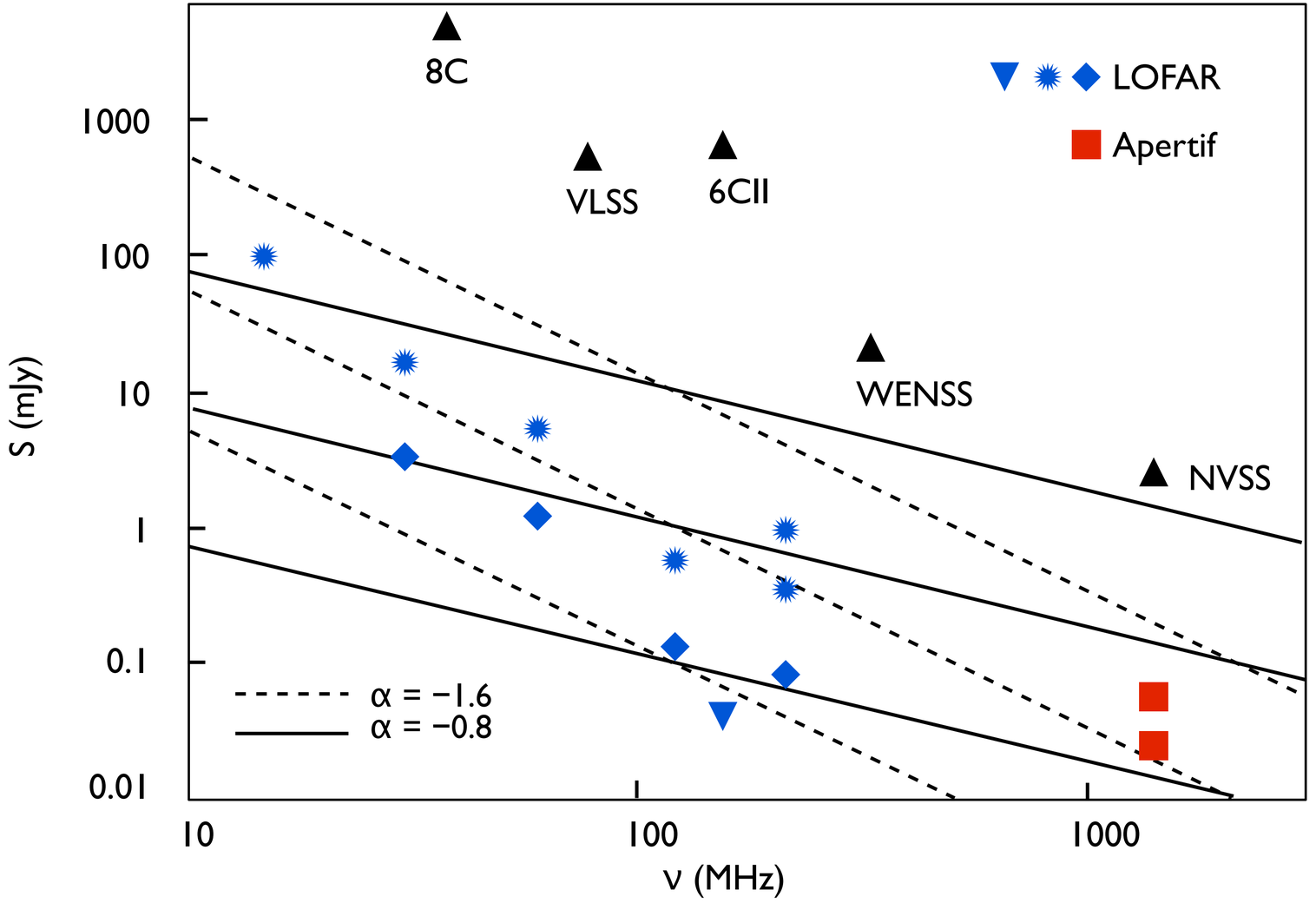
- ~50 times deeper than NVSS
- cover factor 50 in frequency
- ~10^7 detections



Science: transients

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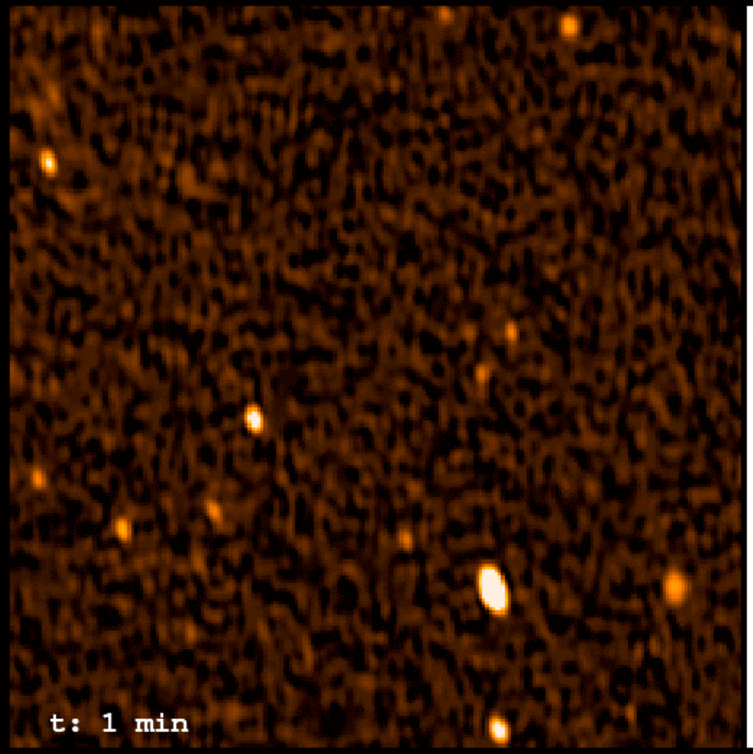
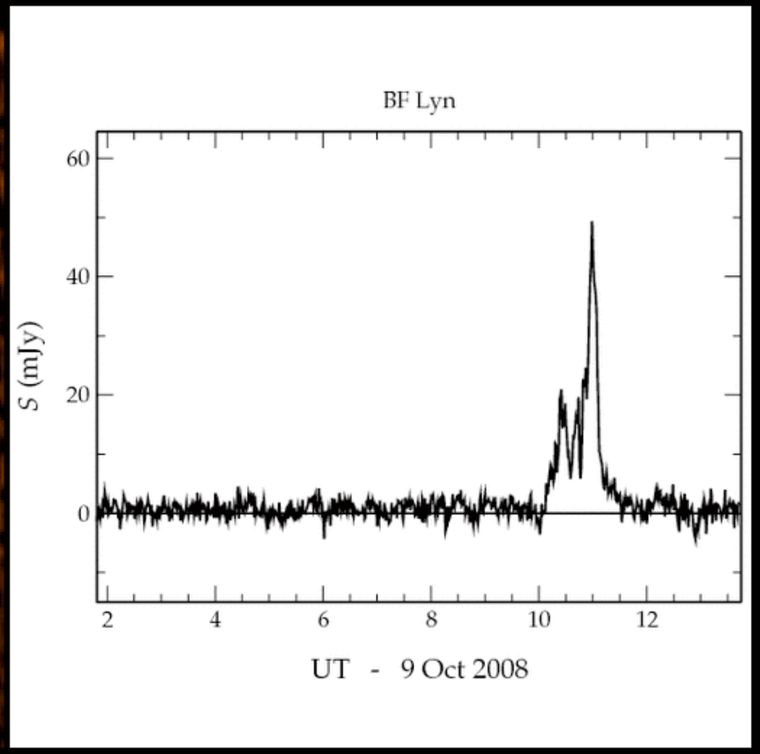
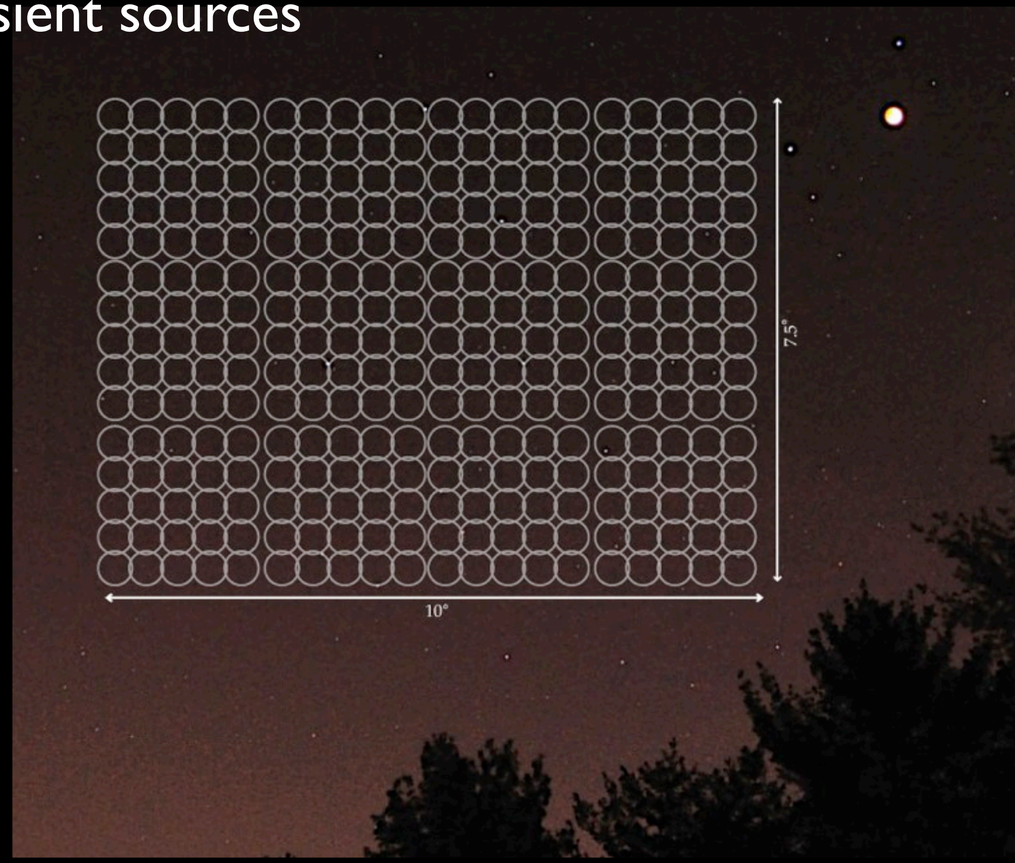
Large FoV: transients!!! Piggy-back with imaging surveys

Or: Fly's eye mode: can cover 100 deg^2 in one observation

Can look at same part of sky (Virgo?) often and search for transient sources







Flare star detected with WSRT

Science & timeline

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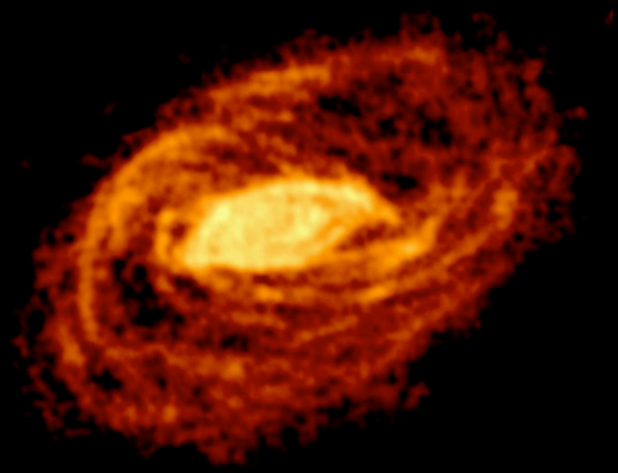
- 2010: expressions of interest; discussions with science teams
- 2012: proposals; definition of surveys
- 2013/14: Apertif will be installed, initially 6 - 8 PAFs;
  Extensive commissioning period with strong involvement of survey teams;
  Early science
- end 2014: Start of Apertif surveys



Summary

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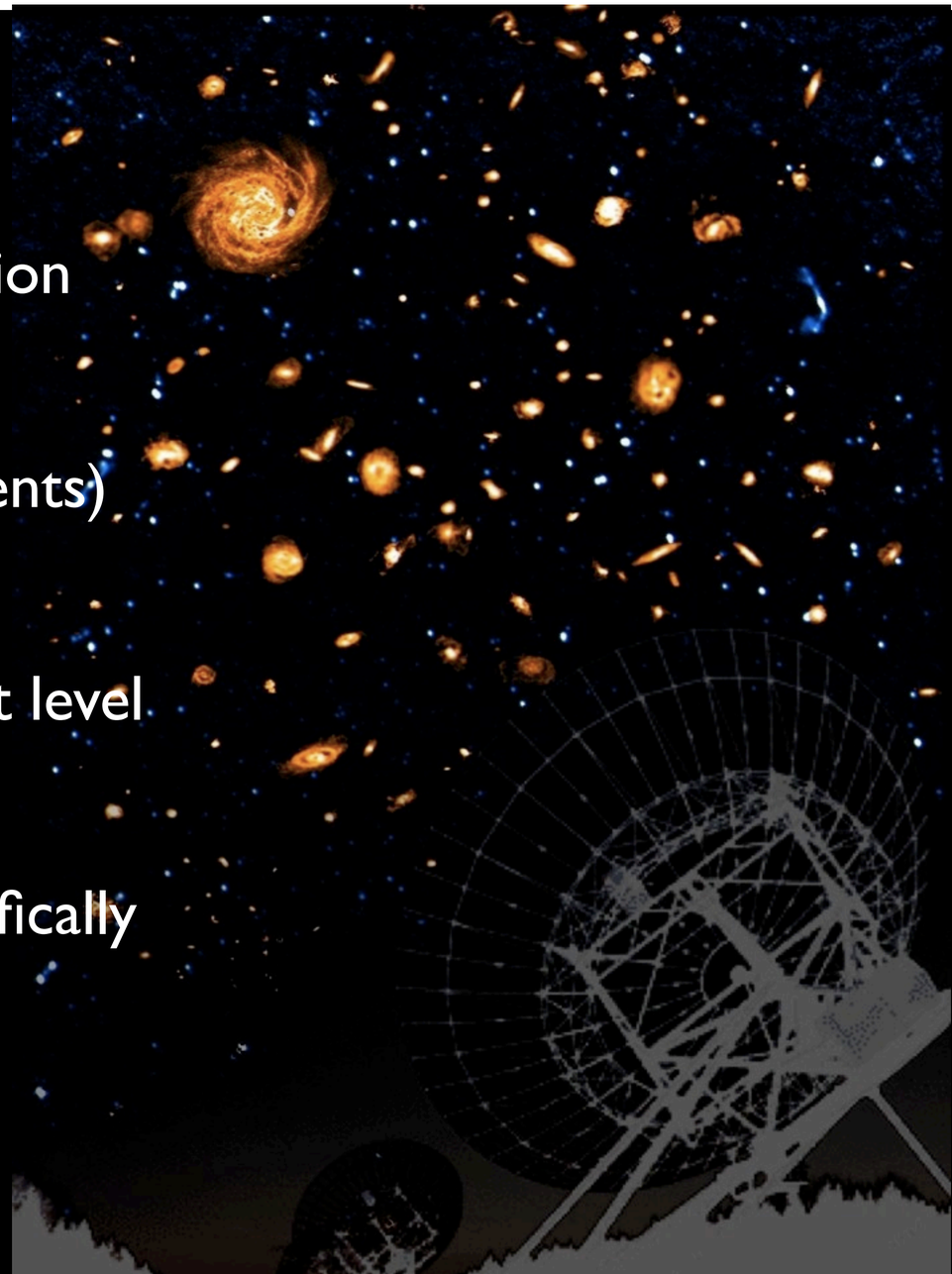
- Digestif has demonstrated the feasibility of PAFs
- Apertif is fully funded and well on its way to implementation
- Very exciting science (line, continuum, polarisation, transients)
- With Apertif radio astronomy will be elevated to the next level
- Apertif (and other pathfinders) are technically and scientifically important steps toward SKA



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Thank you