The WSRT focal plane array system Apertif

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

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

APERTIF (NL) & ASKAP (AUS)
Apertif: APERture Tile In Focus

Upgrade to Westerbork Synthesis Radio Telescope

Array of ~120 densely packed receptors in each WSRT dish. Full sampling of the focal plane.

Phased Array Feed: combine signals from all elements to simultaneously form 30-40 optimised beams on sky, covering 8 degree$^2$ with uniform sensitivity

300 MHz bandwidth with 4 km/s resolution. Covering L band: 1000 - 1700 MHz

Sensitivity (A/T) of WSRT is ~2 that of ASKAP, Field-of-view is ~¼ ASKAP. Survey Speeds the same.

~10 times more efficient for surveys than EVLA,
~5 times more efficient than ALFALFA
Prototype to study beamforming, performance, etc
Leading to final design of Apertif FPA

Recycle Lofar ITS hardware

Stand alone, record realtime signals for later processing in software

144 elements

Noisy LNA ($T_{sys} = 70$ K)

Can integrate for 6.7 sec...

Processing can take up to 40 minutes…
Compound beams

Tile FoV with many separate compound beams, using weighted sum of all elements for each compound beam, optimising for:

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

Same colourscale

Element beams are ugly, but compound beams are very well behaved
- Achieved aperture efficiency of 75% (compared to 55% of “old” WSRT)
- $T_{\text{sys}}$ of prototype 70K Apertif will have 50-55 K (uncooled LNA) (compare with 30 K of WSRT)
- $A/T$ of Apertif will be $\sim$0.8 times that of WSRT
- Smooth variation of sensitivity over sky
- Have achieved field of view of 9 degree$^2$ with 25-m dish (compare with 0.3 degree$^2$ of WSRT)
First synthesis image of compound beam in array

- Synthesis image made with 3 Digestif-WSRT baselines

Correlating WSRT dishes with compound beam

3C343 and 3C343.1
Latest: 2\textsuperscript{nd} prototype FPA (october)

Measurement on sky (3C 147)

- Measured $T_{sys}/\eta = 91$ K, $T_{sys} \sim 68$ K
- Excellent agreement between simulated and measured sensitivity
- On planned path to $T_{sys}=55$ K

In Spring '10, this FPA will go to the GMRT
Exciting times ahead for H I work

- **Large field-of-view and large bandwidth.**
  given its collecting area, the spatial resolution of WSRT is near optimum for deep surveys of neutral hydrogen (H I)

- **Current: ALFALFA** with $\sim$10000 galaxies with 3 arcmin resolution. In total, we know about H I in few $\times$ 10$^4$ galaxies, a few 100 above $z = 0.1$, mostly single-dish

- **Future: combination of ASKAP and Apertif** will give all-sky database with HI cubes of $>10^5$ galaxies out to $z = 0.4$, most above $z = 0.1$, with $\sim$20 arcsec resolution.

- 10$^7$ continuum sources as H I absorption candidates

- OH Megamaser survey out to $z = 0.67$

WSRT detection of HI in a galaxy at $z = 0.21$ (Verheijen)
The SFR density is a factor 10 higher at $z = 1$. Cosmic HI density does not track SFR. Galaxies have short gas consumption timescales. What is the gas cycle in galaxies? How does this depend on environment, mass, type, redshift?

In a cosmological context, we do not understand the connection between gas content and star formation.

Have to go to “high” redshifts.
Not only at high z

• What happens when galaxies get too small to form stars?
• Interface galaxies - IGM
• Cosmic Web (only 10-20% of the baryons are in galaxies!!!)

Need deep surveys of the Local Volume for galaxies as small as possible. Problem: need enough volume for good statistics

Can see a few $10^5 \, M_\odot$ only out to 10 Mpc, so need to observe large area on sky (> 1000 deg$^2$) to detect sufficient number of sources

Properties likely strongly dependent on environment

With Apertif we may start to see “failed” galaxies

Leo T: $M_{\text{HI}} = 3 \times 10^5 \, M_\odot$
90% of baryons in cold gas.

Statistics only known for objects with $M_{\text{HI}} > \text{few} \times 10^6 \, M_\odot$

This is also an important consideration for SKA!!
Combine with continuum survey

- Continuum images of deep H I observations will have noise of ~5 $\mu$Jy beam$^{-1}$, will be confusion limited in Stokes I (but not in Stokes Q, U, V!!!)
- Continuum survey ~50 times deeper than NVSS
- Such a survey will give a ~$10^7$ detections

Apertif & Lofar complementary
Galactic Magnetic field

Galactic B poorly known but is essential in most processes in the interstellar medium

Measure rotation measure against many extragalactic sources so one can reconstruct Galactic magnetic field (“The Rotation-Measure Grid”)

Will allow to determine detailed structure Galactic magnetic field

Russ Taylor et al
Pulsars & Transients

On northern sky, important for timing experiments (now most pulsars are Australian…)

Galactic census of pulsars
Search for pulsars in globular clusters, many expected.
Probe stellar evolution
Rare objects, e.g. MSP-Black Hole binary

Lofar will find 1000 nearby pulsars,
Apertif 1500 more distant ones
Radio flare in nearby star (last week...)
Status

- Have working prototype Phased-Array Feed in one WSRT dish. Have demonstrated required performance.
- Passed Preliminary Design Review in August 2009
- Final Design ready in 2011
- Operational in 2012

- Soon: call to join science teams. If interested: oosterloo@astron.nl