Science with Weave’s IFUs

galaxy structure, dynamics and evolution

- synergies with Apertif and LOFAR

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+ Weave science teams
Weave mini-IFUs (mIFU)

- 20 mini IFUs
- >1’ separation

- 37 science fibres, no dedicated sky fibres
- 1.3” cores (85 μm), 46% filling factor

- Same λ-range as LIFU but 2x better spectral resolution.

- 11”x12” FoV
Weave Large IFU (LIFU)

547 science fibres, 6x7 sky fibres
2.6” cores (170 μm), 54% filling factor

Pedigree:
SparsePak/WIYN  PPak/Calar Alto

Low-res: R = 2,500  blue: 366<λ<606
            red : 579<λ<959

High-res: R = 10,000  blue: 404<λ<465 or 473<λ<545
              red : 595<λ<685

MOS meeting, 2-6 Mar 2015 - La Palma
The effect of environment on galaxy structure and evolution

**Topic 1:** Tracing the evolution of dwarf galaxies in clusters

→ talk by Alfonso & Aguerri after coffee

**Topic 2:** The infall regime

- Which mechanisms dominate the transition from field to cluster galaxies?
- Where and how does star formation stop?
- Is there a mass/environmental dependence in pre-processing of galaxies?
- How does the ISM respond to starvation/harassment/stripping?
- How does the environment affect AGN activity and feedback?

**Topic 3:** The evolution of cluster galaxies at $z<0.5$

- How do stellar populations of cluster galaxies evolve with redshift?
- What is the origin of archaeological downsizing?
- What is the nature of the blue Butcher-Oemler galaxies?
- Do the internal kinematics of cluster galaxies evolve over time?
How does the infall process affect the internal kinematics and distribution of ISM and stellar population parameters?
Evolution of galaxies in clusters

Abell 2218 (z≈0.2) : crowded-field spectroscopy

With 6 hours of PPK:

- redshifts for 48 galaxies
- absorption line strengths for 12 galaxies
- stellar population parameters for 30 galaxies with $V \leq 21.7$

Sanchez et al (2007)
Synergy with Apertif surveys: An HI-selected perspective

Topic 1: The nature of galaxy bimodality
- Fueling the Blue Cloud and the recycling of gas - detailed SF histories
- Star formation quenching mechanisms - gas content and stellar populations

Topic 2: The mass distribution in disc galaxies (Bershady’s talk yesterday)
- Stellar kinematics in gas-dominated Lower Surface Brightness galaxies
- Galaxies at higher redshifts using Asymmetric Drift

Topic 3: Secular evolution of galaxies:
- Determine the stability of discs
- Characterise the stellar velocity dispersion ellipsoid
- Measure higher orders of the LOSVD
- Determine pattern speeds
- Differentiate the kinematics of distinct stellar populations
Westerbork upgrade

An 8 deg $^{2}$ 21-cm Integral Field Spectrograph

SKA technology pathfinder

THINGS: VLA-BCD

DDO 81

medium-deep survey

likely footprint: based on community input

10\times12^{\text{hr}} \text{ per pointing}

+ Perseus-Pisces supercluster
(includes \sim 100 Abell clusters)

\text{10}^{6}\text{ continuum sources}
\text{10}^{5}\text{ detections}
\text{10}^{4}\text{ resolved HI disks}

2\times10^{19} \text{ (atoms/cm}^2\text{)}
5\times10^{19} \text{ (atoms/cm}^2\text{)}
10\times10^{19} \text{ (atoms/cm}^2\text{)}

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WSRT mosaic
35 pointings, 1x12 hr
1717 channels

1346-1409 MHz
Θ = 16" x 23"
ΔV ≈ 16 km/s
σ = 0.6 mJy/bm

includes 3C129

200+ HI detections
**Gas & Galaxy Evolution**

Fueling the Blue Cloud
sustaining star formation
- building up stellar mass

How do the ISM and SF/AGN activity respond to (minor) mergers and/or cold accretion?

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*Oosterloo+ 2007*  

*Sanctisi+ 2008*
Gas & Galaxy Evolution

Warps and stellar streams - is there a link?

No gas associated with the streams.

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SF quenching: How do galaxies lose/deplete their gas?

NGC 4522: ram-pressure stripping in action

NGC 4388

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Atlas$^{3D}$: HI imaging of 166 early-types (1/3 HI detected)

Lower density regions: extended & regular HI disks

Higher density regions: clumpy & unstructured

Different formation histories? Different stellar kinematics? Different stellar population and ISM parameters?
Theme 3: Weave - LOFAR

Synergy with LOFAR: the faint radio source population

**Topic 1: The star formation history of the universe**
- Optical redshifts for faint and dusty SF galaxies
- Velocity dispersions and metallicities

**Topic 2: Accretion and AGN driven feedback**
- Explore all aspects of AGN activity and evolution
- Obtain a complete census of black hole accretion
- Understand the decline in radio-mode AGN space density
- Test models of AGN-galaxy co-evolution

**Topic 3: Probing the Epoch of Reionization**
- A LOFAR-guided search for Lyα emitters
central core

international stations

LBA : 10–90 MHz
HBA : 110–270 MHz → HI at Z=4–12 : Epoch of Reionisation
recent results

LOFAR HBA deep Bootes field

M82 at 154 MHz

Resolved SNR shell beam: 0.36" x 0.23"

2"

An unbiased view on star formation & AGN activity

Courtesy: Wendy Williams (Leiden)


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LOFAR & Apertif will see the same population of SF galaxies

Radio spectral index differentiates between SF galaxies, AGNs and radio relics.

Higher angular resolution of LOFAR reveals morphology of SF sites.
Lyman-\(\alpha\) emission from proto cluster at \(z=3.09\)

Push this to the EoR @ \(Z=6\) (853nm)

Weijmans et al (2010)
Concluding remarks

Understanding galaxy structure & evolution with Weave:

Exploit strength wrt Califa, MaNGA, SAMI:

- Largest Field-of-View (80”x90” for LIFU)
- High etendue (LSB spectroscopy)
- Highest spectral resolution (R=10,000)
- Synergy with Apertif and LOFAR (northern hemisphere)
- Surveys tailored to answer specific questions?
Big Questions:
cosmic SFH growth of stellar mass
first galaxies and EoR
galaxy assembly & origin of Hubble sequence
gas & metals recycling
SMBH growth
role of feedback processes SN & AGN?
IMF universal?

Survey SFR to higher z and fainter levels: LOFAR
Specifications

- 12x25m, 3 km EW-array
- 8 deg² FoV by forming 37 ‘compound’ beams.
- Frequency range: 1000 - 1750 MHz \((Z<0.4, 0.6 \text{ for HI, OH})\)
- Instantaneous bandwidth: 300 MHz, 16384 chans, full stokes
- Resolution: \(\Theta = (1+Z)^2 \times 13 \times 13 / \sin(\delta)\) arcsec² \((10 \text{kpc @ D=150 Mpc})\) (after Hanning smoothing)
- Line sensitivity: \(~0.8 \times \text{current WSRT}\) \((\sim 1 \text{ mJy bm}^{-1}/\text{chan}/12^{hr})\)
Community interest

- July 2010: Call for Expressions of Interest
- 18 EoIs received, requesting a total of 20 years
- November 2010: Apertif Survey Coordination workshop
- 2011: roll-out & commissioning plan
  Time line and involvement of science teams under consideration.

Call for Survey Proposals is pending ...
Scientific diversity

- Radio continuum surveys - Synergy with LOFAR
- Neutral hydrogen surveys - emission & absorption from the smallest to the most distant galaxies
- Pulsar searches
- Magnetic fields in the Milky Way and other galaxies
- (extra)galactic OH (mega-)masers
- Radio Recombination Lines
- Variables and Transient sources
- Search for Extra-Terrestrial Intelligence
SDSS redshift slice

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example of Apertif data product
HI imaging data products

**PV-diagrams**

- **Rotation Curve**
  - **Radius (arcsec)**
  - **V_{rot} (km/s)**

**Surface density profile**

- **Global Profile**
- **Atlas Table - UGC00463**
  - **Geometry**
  - **Contour levels**
  - **Flux & Densities**
  - **Velocity, Size & Resolution**
HI mass limits

- 100 km/s line width
- 6σ detection
- spatially unresolved
- optimal velocity smoothing
- based on $z=0$ HIMF

Column density limit:

$N(\text{HI}) = 5.4 \times 10^{19} \, (\text{cm}^{-2})$

($T_{\text{int}}=12 \times 12^{\text{hr}}, S/N=5, \Theta=13'' \times 15'', \Delta V=15 \, \text{km/s}$)
HI science topics

• Galactic and galaxy structure & kinematics.
  - the ISM, warps, lopsidedness, rotation curves, angular momentum, non-circular motions...

• Accretion and depletion of gas onto galaxies.
  - minor mergers, cold accretion, ram-pressure stripping, outflows and feedback...

• Formation of galaxies and large scale structure.
  - HIMF, major mergers, spin alignments, void population, cosmic web, TF distances...

• Cosmic evolution of gas in galaxies.
  - $\Omega_{\text{HI}}(z)$, gas fractions vs mass, role of gas in downsizing...
Galaxy structure and kinematics

Battaglia et al. 2005

Verheijen

Boomsma et al.

Is there a correlation between warps and stellar streams?

What causes excessive streaming motions?

Do rotation curve shapes depend on galaxy environment?
Map and measure these filaments in various environments at different redshifts.

Non-equilibrium situations allow for lower HI column densities. → enhanced sensitivities are required to detect and map the features.

Which gas accretion/depletion mechanisms dominate where?
Cosmic evolution of gas in galaxies

Abell 963 at $z=0.206$

Are dwarf galaxies at higher redshift relatively more gas-rich?

Are Butcher-Oemler clusters accreting a more gas-rich field population?

\[ M_{\text{HI}} = 2 \times 10^9 \]
Shallow HI surveys

  - $\delta > +27^\circ$, $Z = 0 - 0.26$, $6^{\text{hr}} - 12^{\text{hr}}$ per pointing
  - Expect $\sim 10^5$ HI detections over $10,000$ deg$^2$

$\rightarrow$ tens per WEAVE FoV

Study the HI content, evolution, and the small- and large-scale structure of the nearby Universe and the HI dynamics and star formation of extended galaxies.

Covers full $4\pi$ of the sky in concert with the Wallaby survey.
Medium-deep HI surveys

- Gupta: Blind search for 21-cm absorbers using Apertif
  - 1000 deg$^2$, 10x12$^{\text{hr}}$, Z=0.09–0.40
  - 150 deg$^2$, 24x12$^{\text{hr}}$, Z=0.09–0.40
- Verheijen: A medium-deep blind survey of HI in the local universe
  - 500 deg$^2$, 12x12$^{\text{hr}}$, Z=0–0.26

1) HI mass function down to $2\times10^5$ $M_{\odot}$,

2) Morphologies and kinematics of HI in and around galaxies in different environments,

3) Cosmic evolution of gas in galaxies over the past 3 Gyr.
Deep HI surveys

- Brinchman: DASH - Deep Apertif Survey of HI
  - 5 pointings, 100x12 hr per field, Z=0.02−0.30

To address how galaxies accrete, process and return gas to the intergalactic medium and to understand the fueling of cold gas in very gas-rich galaxies by carrying out a comprehensive characterisation of the HI content of galaxies, and its link to galaxy properties. Taking advantage of HST/COS sightlines.

- Holwerda: WASGOED - Westerbork Apertif Survey of Galaxies Observed at Extreme Distance
  - 1 pointing, 500x12 hr per field, Z=0.09−0.40

To address the HIMF evolution, the Tully-Fisher relation, the HI content of galaxy types and cosmic volumes using both direct line detections and stacked HI line limits. Targeting the Extended Groth Strip.
Radio continuum

Abell 2192

1.4 GHz continuum map
(30’x30’)

σ = 7 μJy/beam
(confusion limited)

SFR ≈ 10 $M_{\text{sun}}$/yr

Apertif & LOFAR will see the same star forming galaxies.
Synergy with WEAVE

Provide a broader astrophysical context for HI detections

**Low-res:** M-IFU $R \approx 5000$, L-IFU $R \approx 2500$

- ionized gas kinematics
- evolutionary state of stellar populations
- ISM & star formation properties
- ..... 

**High-res:** M-IFU $R \approx 20,000$, L -IFU $R \approx 10,000$

- stellar kinematics, disk dynamics (MgI, CaT)
- crowded-field spectroscopy
- ..... 

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CAHA-3.5m / PMAS IFU
16x16 lenslet array, 1" spaxels

ionised gas kinematics

HI detection at z=0.188

[OII] velocity field
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**Kinematics of Low Surface Brightness galaxies**

**Hα+HI rotation curve**

**ionised gas kinematics**

**SparsePak**

*Swaters et al (2003)*
Line ratio maps of the Orion Nebula

PPak mosaic:
- 27 pointings
- 2 sec exposures

Many more emission lines are accessible cf FP imaging.

Sanchez et al (2008)
ISM physical conditions

Continuum subtracted data cube

6308-6818 Angstroms

[OI] 6300
[NII] 6548
Hα 6563
[NIII] 6584
[SII] 6717
[SII] 6731
\[ \lambda = 4975 - 5375 \text{ Å} \quad R \approx 7500 \quad \text{Tint} = 5 - 11 \times 3600 \text{ sec} \]
Stellar kinematics

EW [OIII]

continuum

V sin(i)

σ los stars

σ los gas

V star sin(i)

V gas sin(i)