APERTIF

- Apertif tech & specs
- Science topics
- Survey planning
- Commissioning results
- Preparatory science projects

Marc Verheijen

Kapteyn Institute / NCRA

+ entire Apertif Team

university of groningen / Kapteyn Astronomical Institute

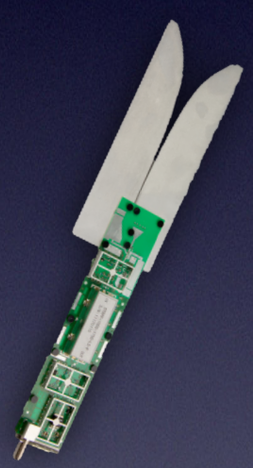
ASTRON

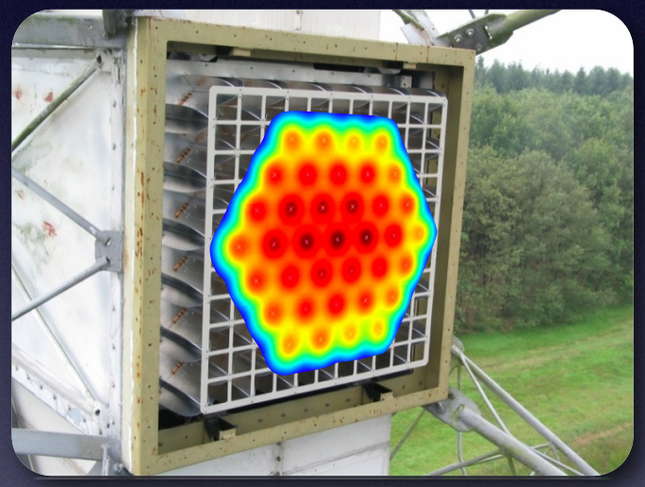
NWO

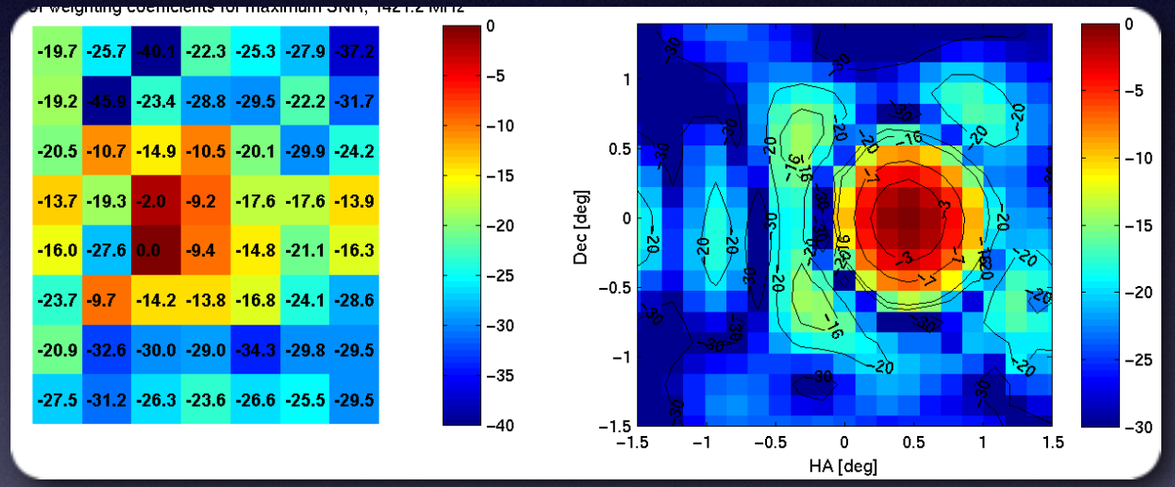
NOVA

New technology & specifications

Transform the WSRT into
an efficient 21cm ***survey facility***
using phased-array technology.







receivers : 2 → 121
primary beams : 1 → 40
Field-of-view : 0.28 → 5.6 [deg²]
Bandwidth : 8x20 → 300 [MHz]

Resolution (z=0):

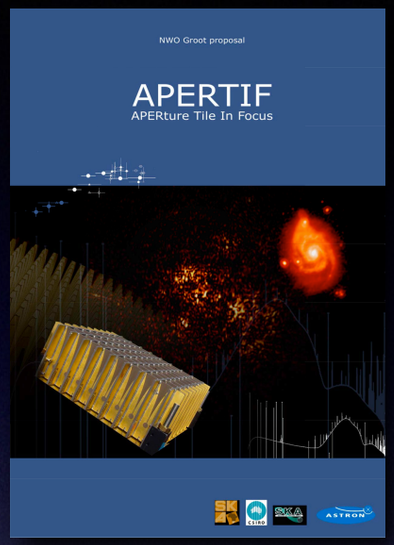
Θ = 15”x15”/sin(decl.)
R = 2.6 [km/s]
Redshift range : 0–0.257 for HI

Survey speed increase : ~48x for line , ~18x for continuum

5.2 TB/12hr

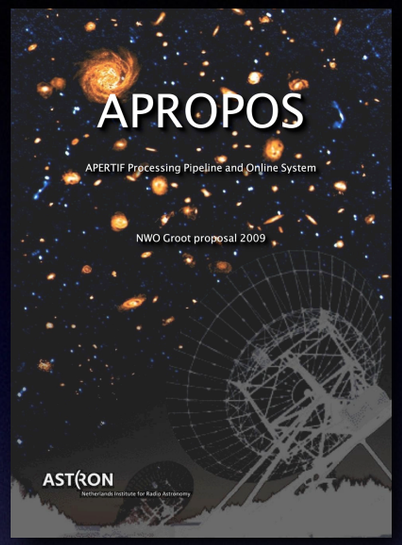
Science topics

2006



Braun & Verheijen

2010



Oosterloo & Verheijen

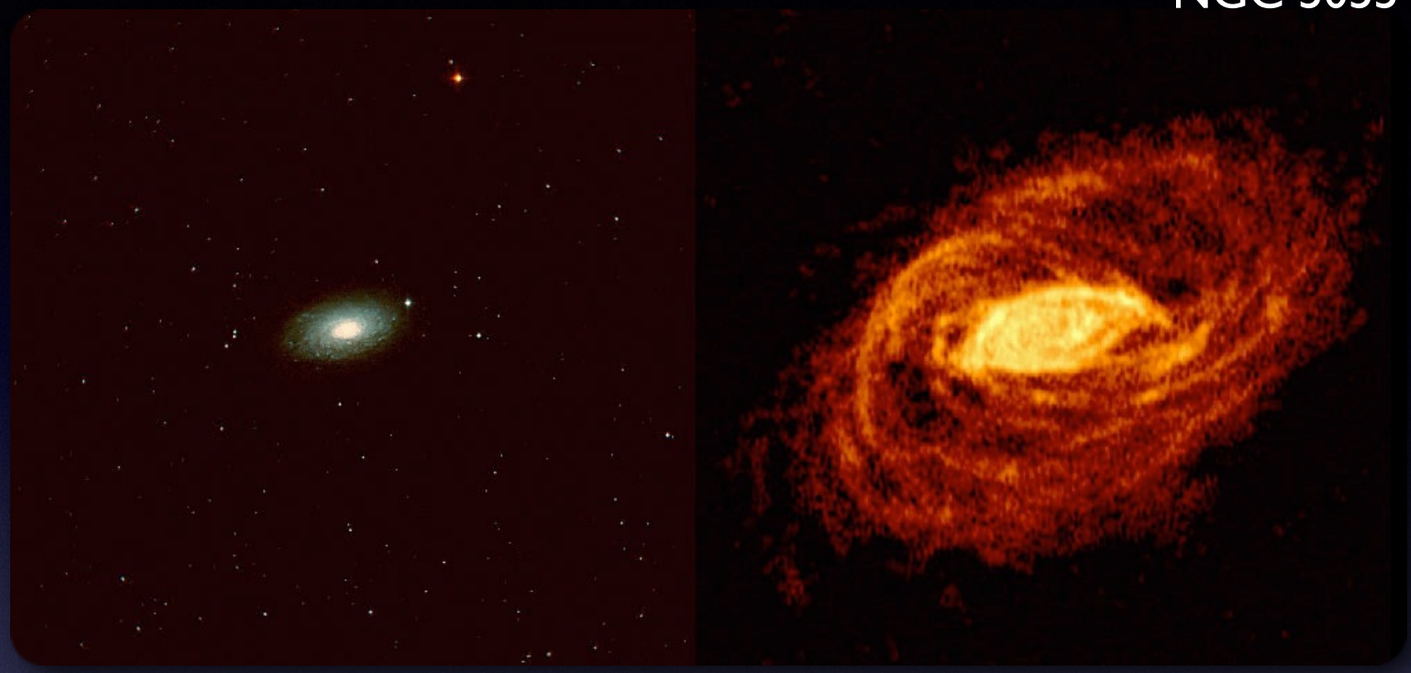
- 21-cm neutral Hydrogen studies
- 1.4-GHz radio continuum studies
- Polarisation studies
- Pulsars and fast transients
- The variable radio sky

Grant-supported science projects with Apertif:

HIstoryNU - The HI story of the Nearby Universe (van der Hulst)
HIperEdge - HI perspective on Environment-Driven Galaxy Evolution (Verheijen)
HuDaGa - The Search for the Smallest Galaxies (Oosterloo)
SHARP - Search for HI absorption with Apertif (Morganti)
HIgal - Galaxy HI kinematics and outer-disk morphologies (de Blok)
ALERT - Apertif Legacy Exploration of the Radio Transient Sky (van Leeuwen)

See **www.apertif.nl** for concise project descriptions.

21-cm neutral Hydrogen studies



HI disks of galaxies are

- fuel for star formation
- spatially extended
- kinematically cold
- collissional

→ sensitive tracers of
astrophysical processes that govern galaxy evolution:

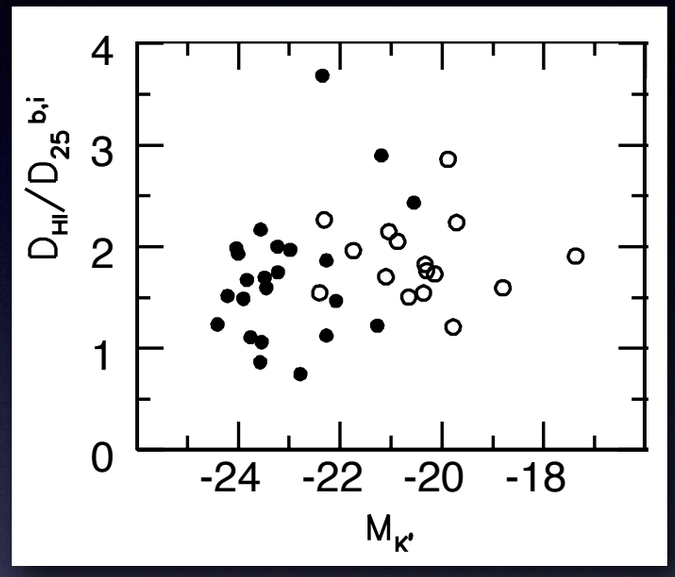
- galaxy internal structure, kinematics and dynamics
- gas accretion, consumption and removal
- star-formation triggering and quenching
- interactions with the local and global environments

APERTIF

21-cm neutral Hydrogen studies

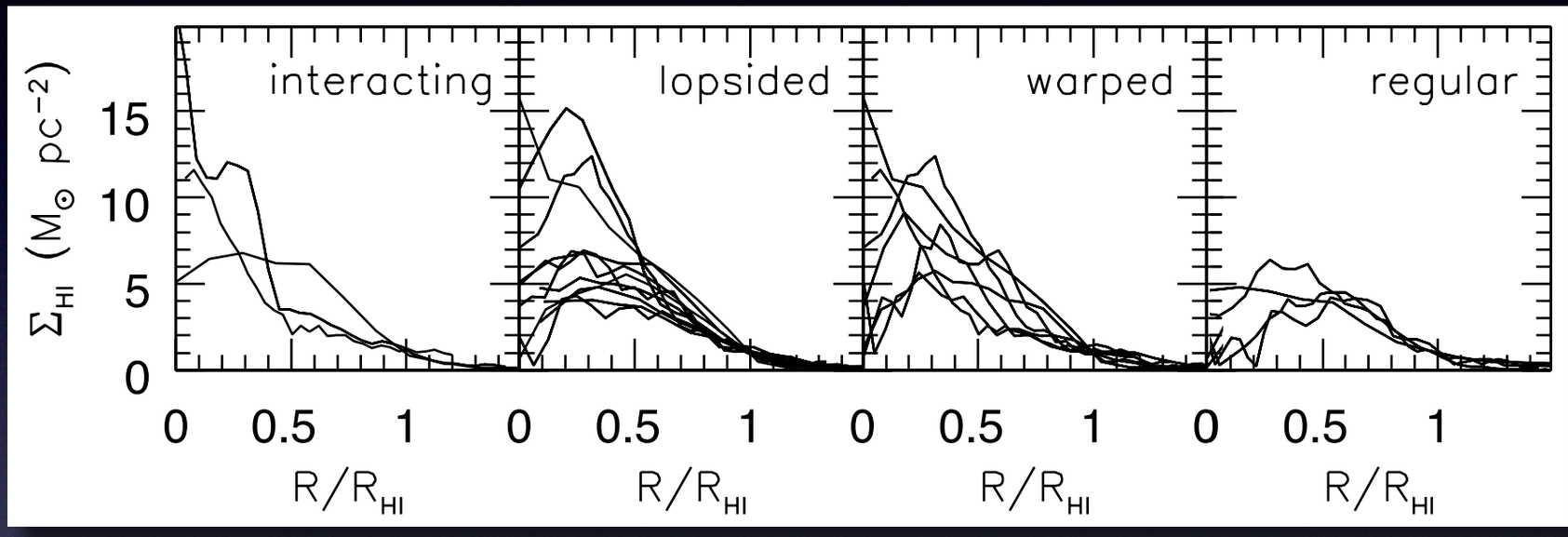
Internal structure and kinematics

HI / optical diameters



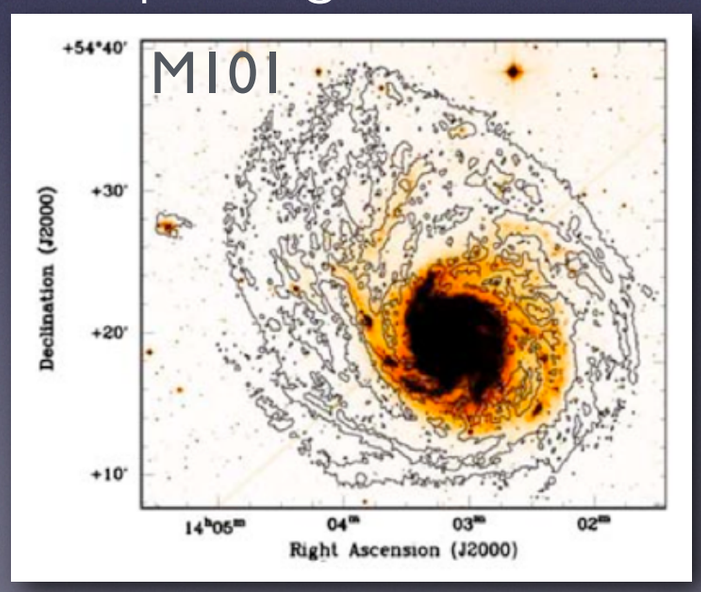
Ursa Major volume

HI radial column-density profiles

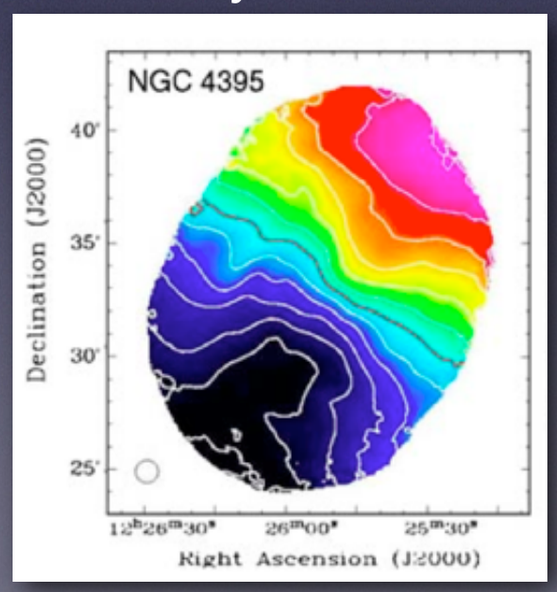


Verheijen & Sancisi 2001

morphological & kinematical asymmetries

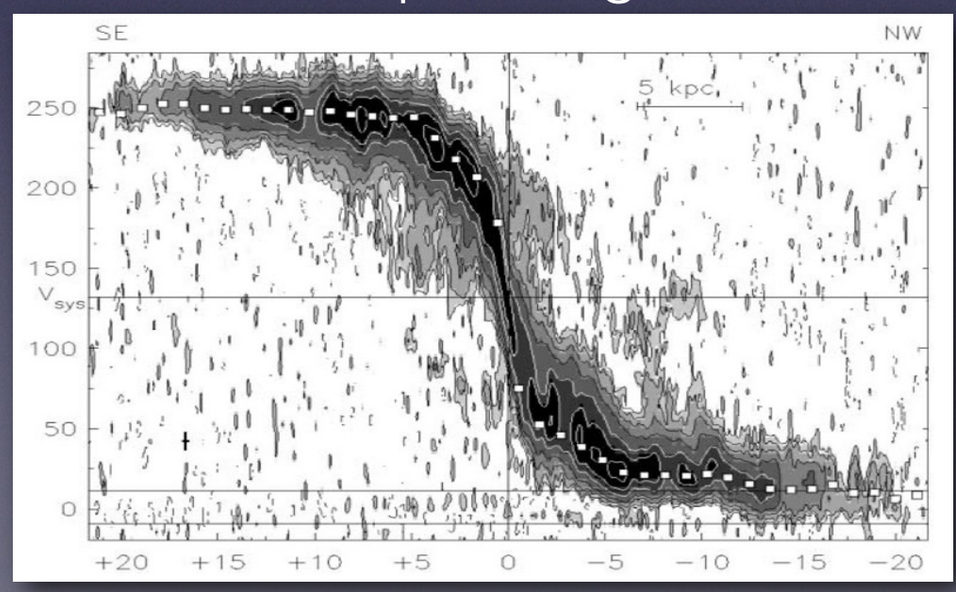


Kamphuis 1993



Heald & Oosterloo 2008

Extraplanar gas

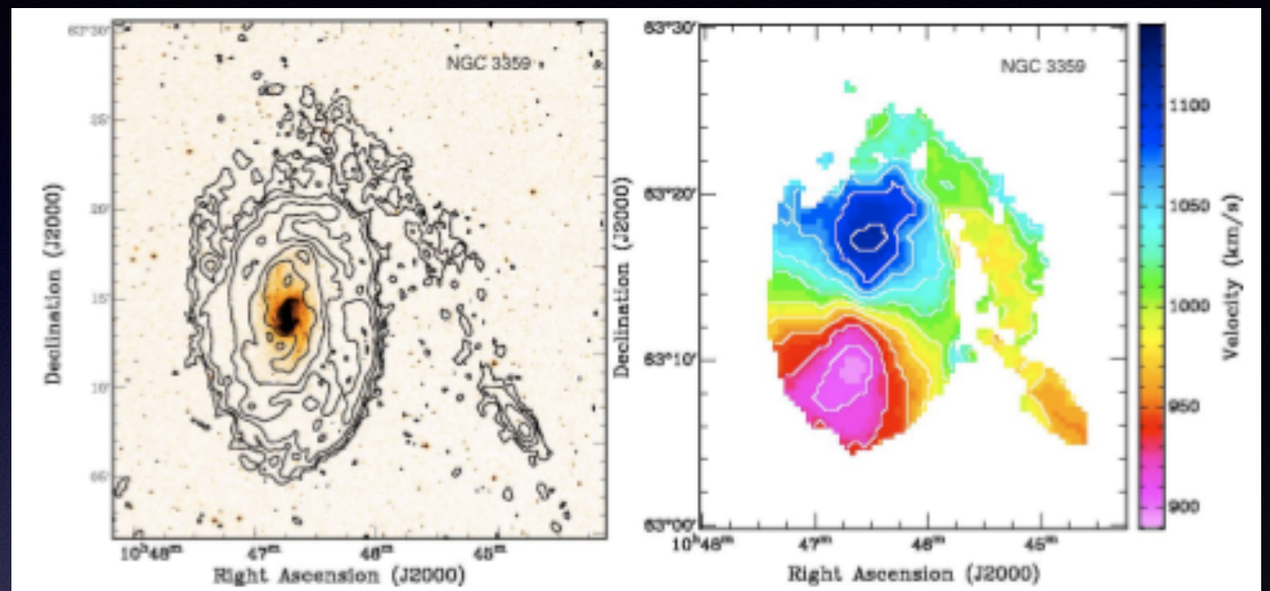


Fraternali+ 2001

21-cm neutral Hydrogen studies

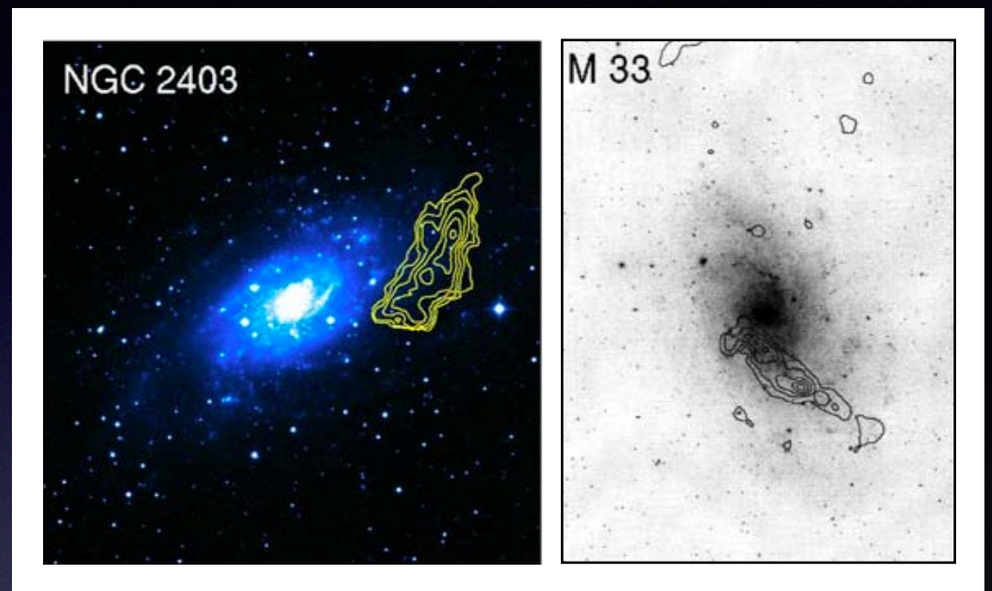
gas accretion, consumption and removal

minor mergers?



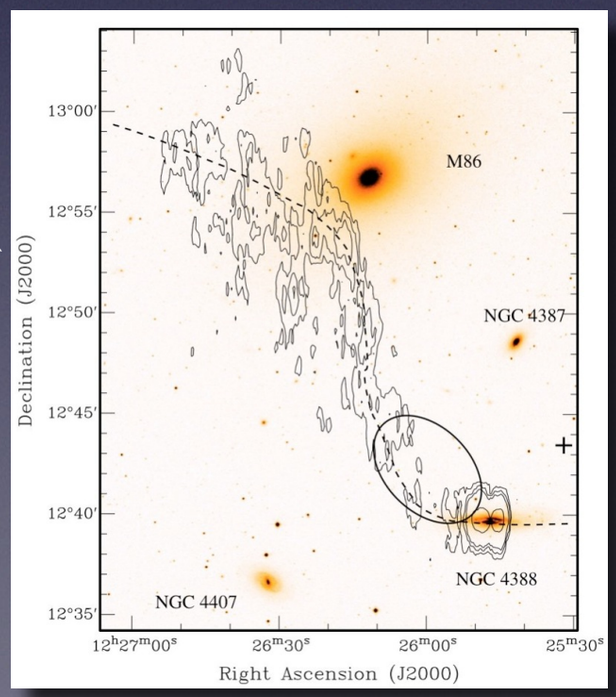
Sancisi+ 2008

cold accretion?



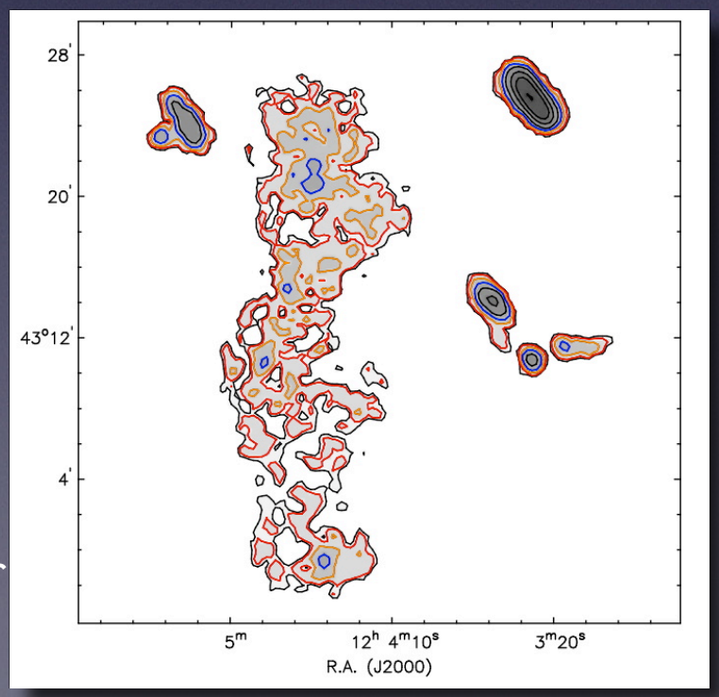
Oosterloo+ 2007

ram-pressure stripping



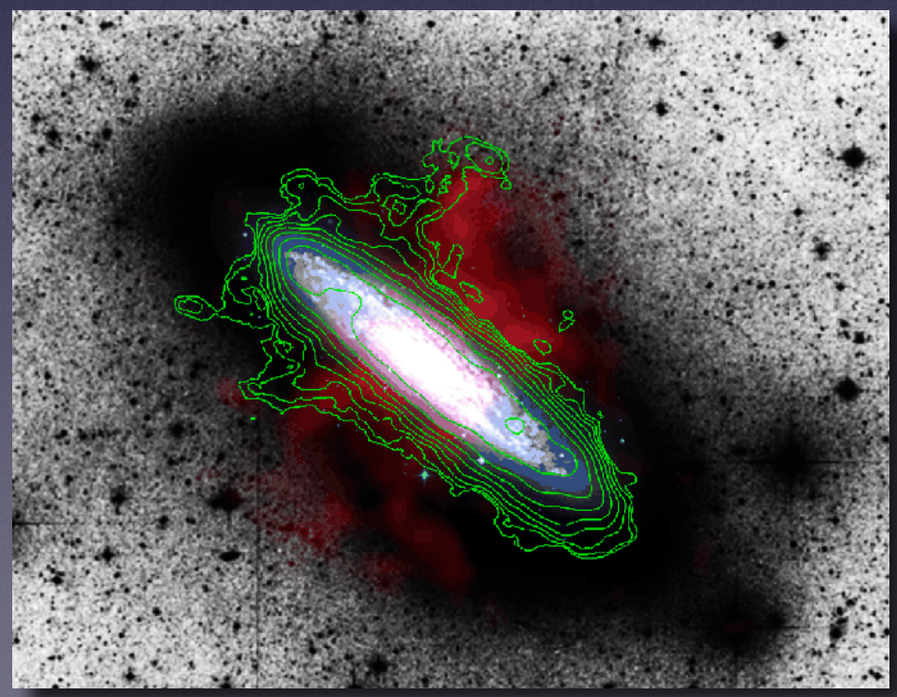
Oosterloo & van Gorkom, 2005

tidal stripping



Verheijen+ 2001

stellar feedback

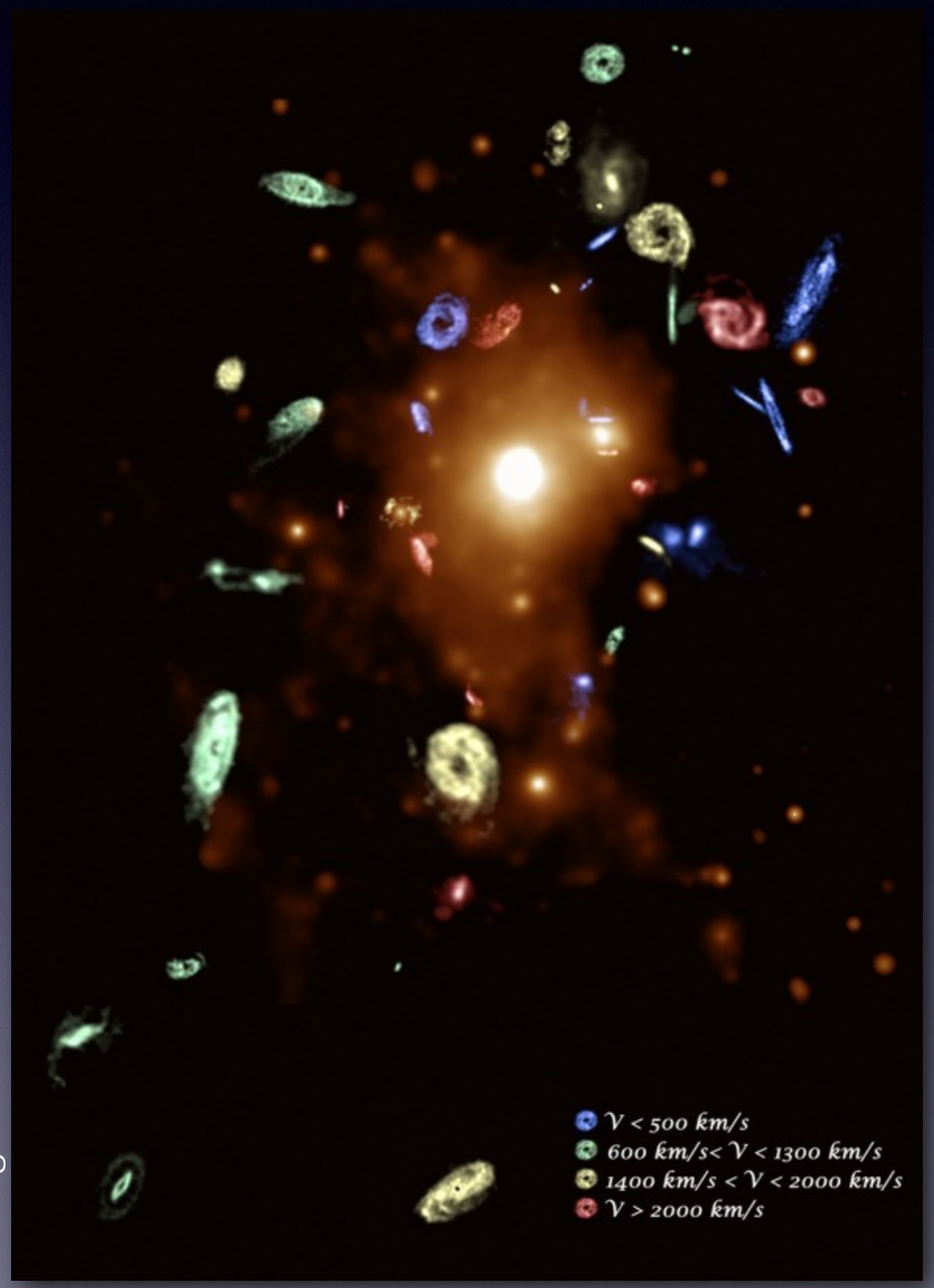


Boomsma+ 2007

21-cm neutral Hydrogen studies

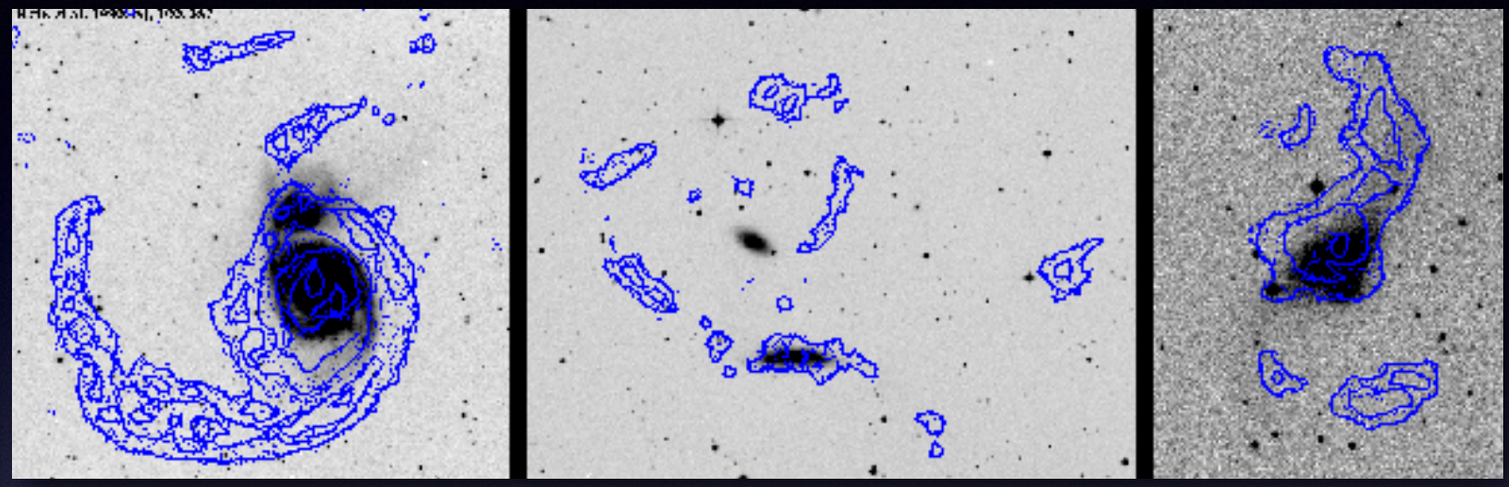
interactions with the local and global environments

VIVA - HI disks in the Virgo cluster



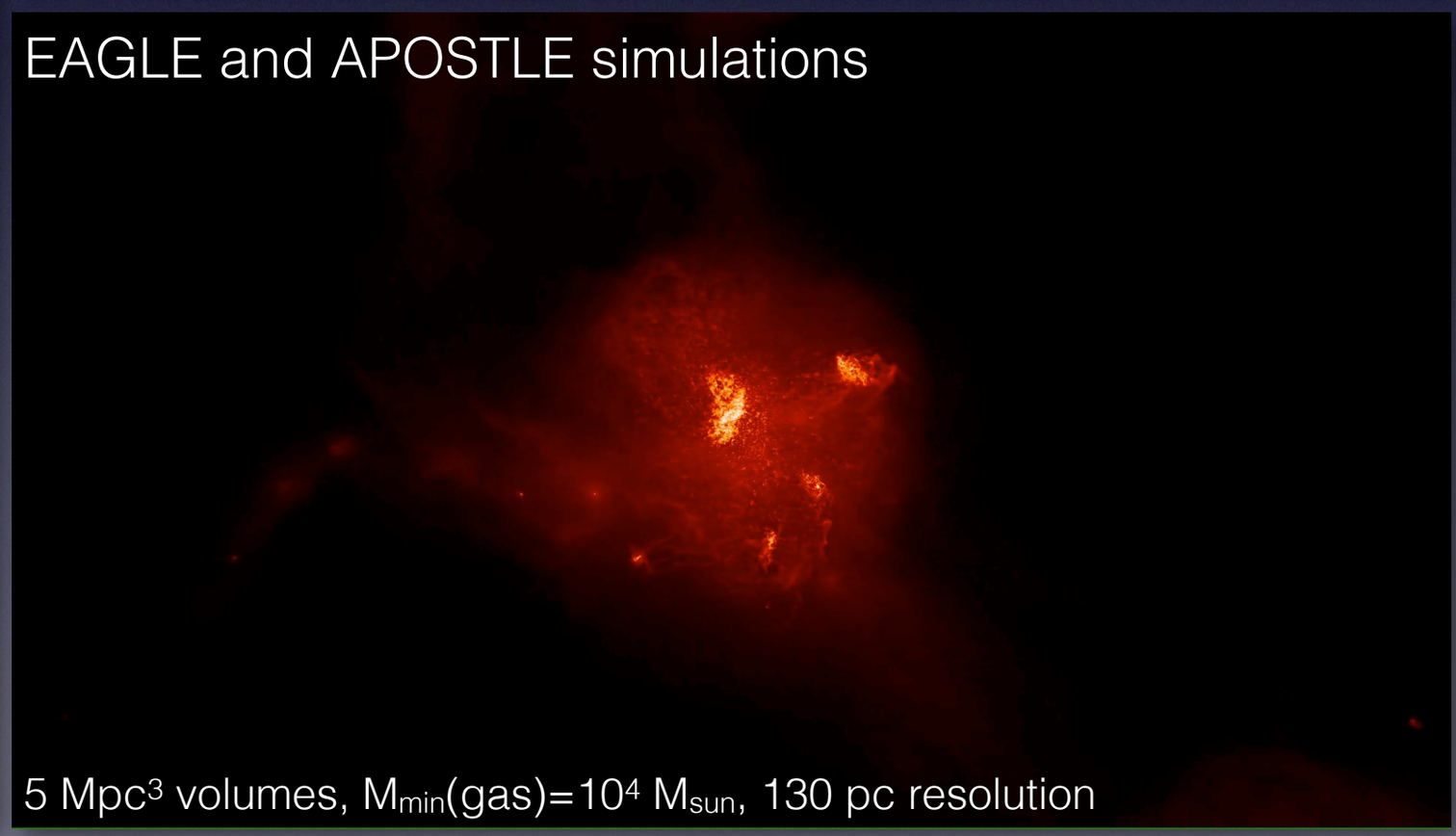
Chung+ 2009

An HI rogues gallery



Hibbard+ 2001

EAGLE and APOSTLE simulations



Courtesy of Kyle Oman

Surveys : anecdotal evidence → robust statistics

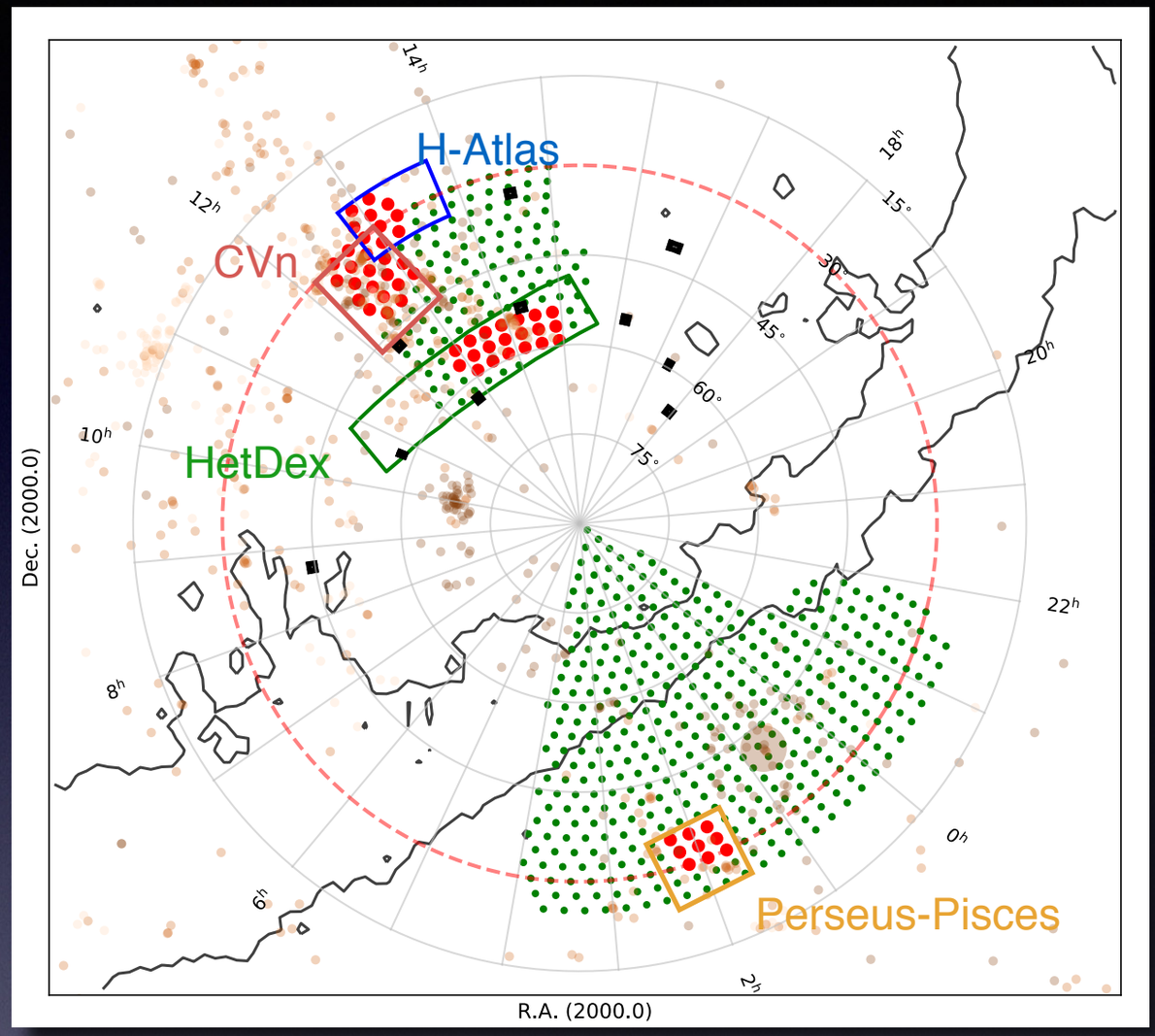
Imaging surveys

- a phased, minimum 4-year survey plan
- a single observing mode
- θ=15”and 30” resolution
- 1430 -1130 [MHz] or 0<z<0.257 for HI
- Rms = 0.65 [mJy/beam] over 20 [km/s] at θ=15” after 1x12^{hr}

- Shallow Northern-sky Survey (SNS ●)
  3000 deg^2, 1x12^{hr} per pointing
  N(HI)$_{4\sigma}$ = 2.5x10^{20} [cm^{-2}] at θ=15”

- Medium-Deep Survey (MDS ●)
  300 deg^2, 10x12^{hr} per pointing
  N(HI)$_{3\sigma}$ = 5x10^{19} [cm^{-2}] at θ=15”

- Selected LOFAR fields (■)
  4x12^{hr} per pointing
  confusion limited in continuum



MDS footprint

Yr 1: Perseus-Pisces supercluster
Yr 2: HetDex area
Yr 3: H-Atlas field (incl Coma cluster)
Yr 4: CVn and the super galactic plane

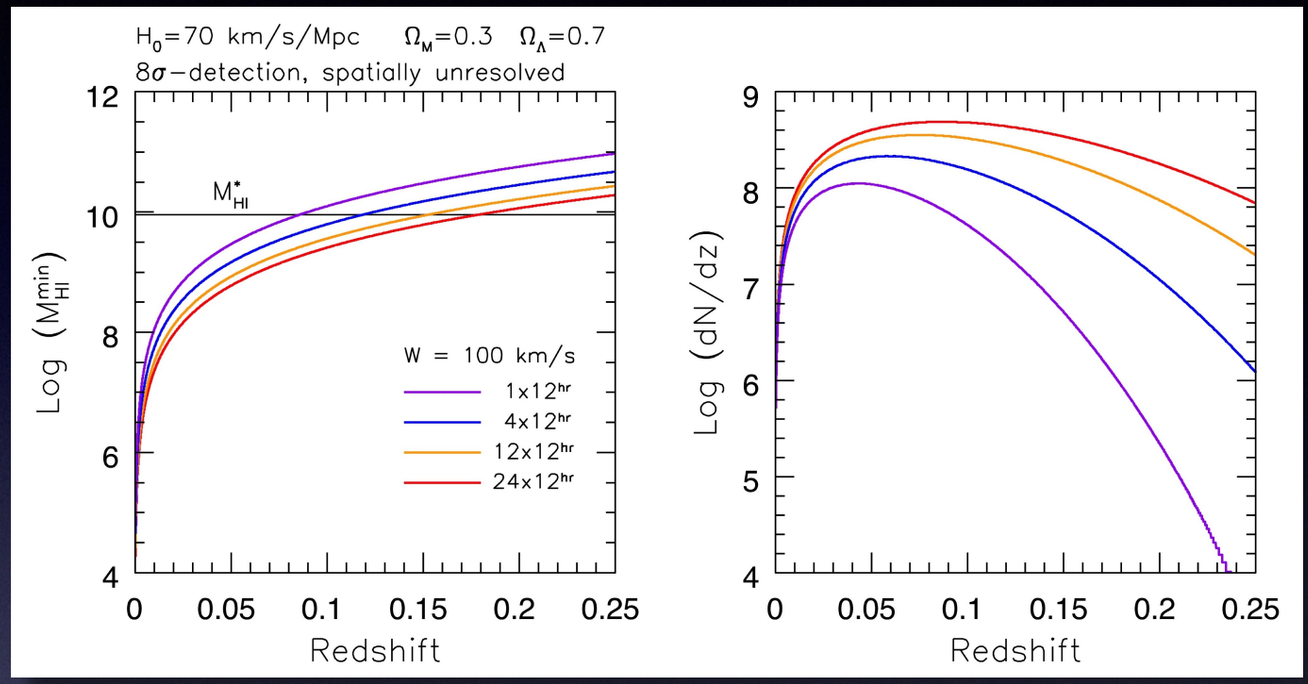
(Exact pointing grid TBD)

Apertif surveys

Imaging surveys:

10^5 HI detections
10^4 spatially resolved HI disks
10^7 continuum sources
tens of intervening HI absorbers
hundreds of associated HI absorbers

Expectations



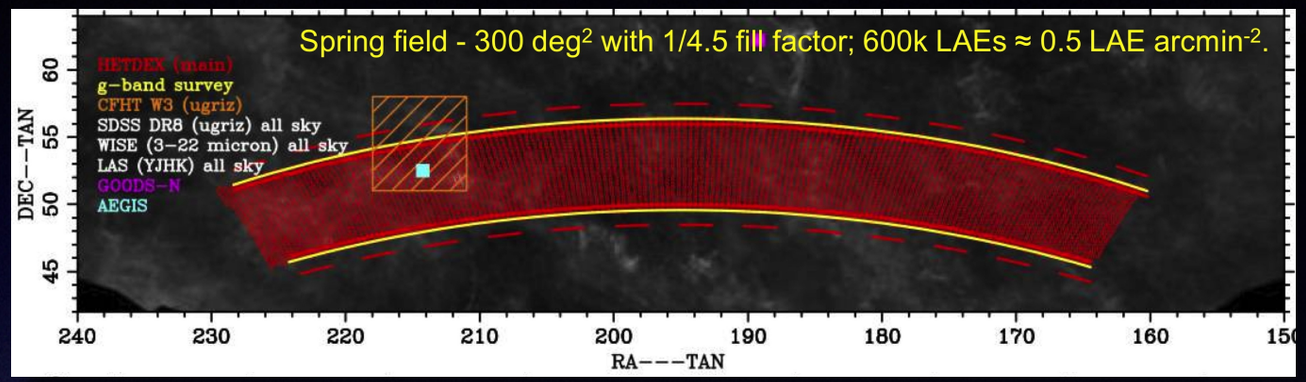
Time-domain surveys:

Finding (binary) Milli-Second Pulsars
Doubling the number of known pulsars
Obtain statistics and localisation of Fast Radio Bursts
Detection uploaded to live catalog : **frbcat.org**

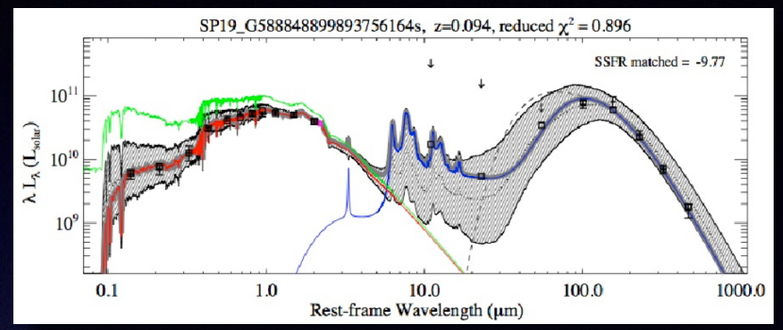
frbpoppy

Ancillary data and survey synergies

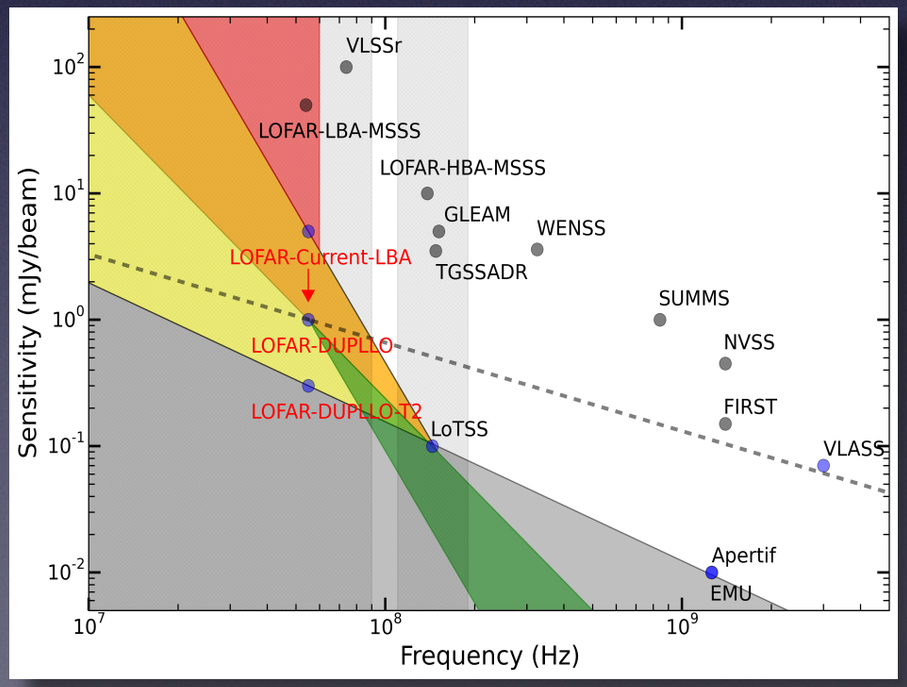
10^5 [OII] redshifts in HetDex field - HI stacking



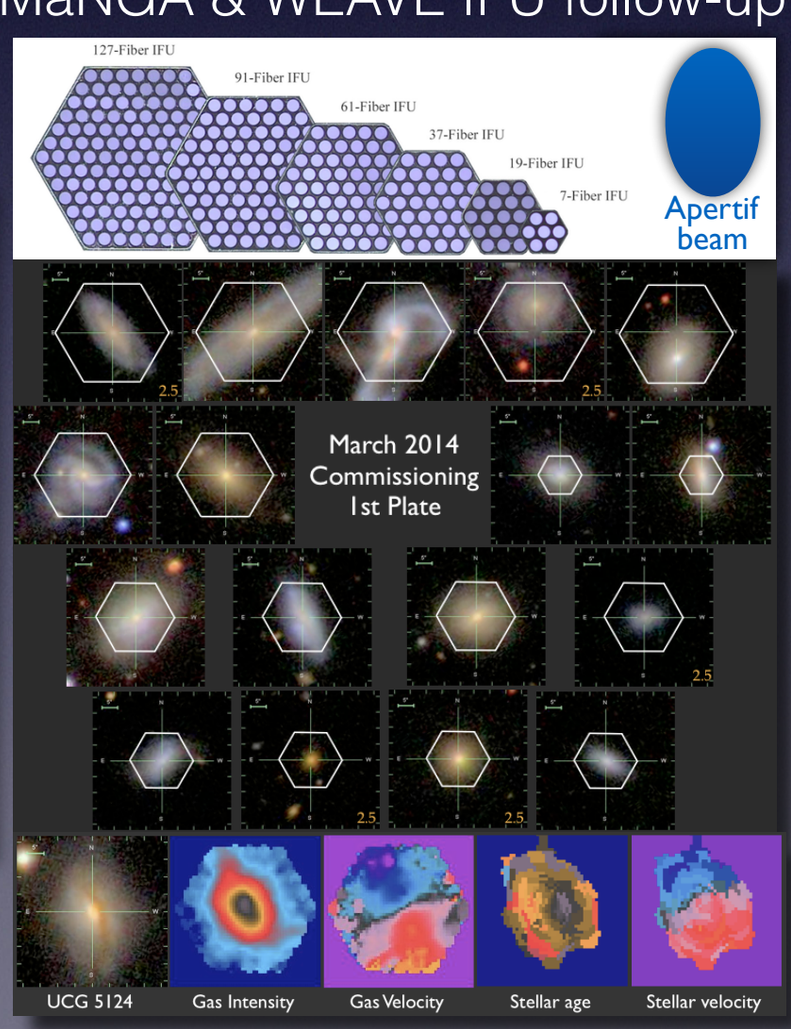
Full SED reconstruction for H-Atlas sources

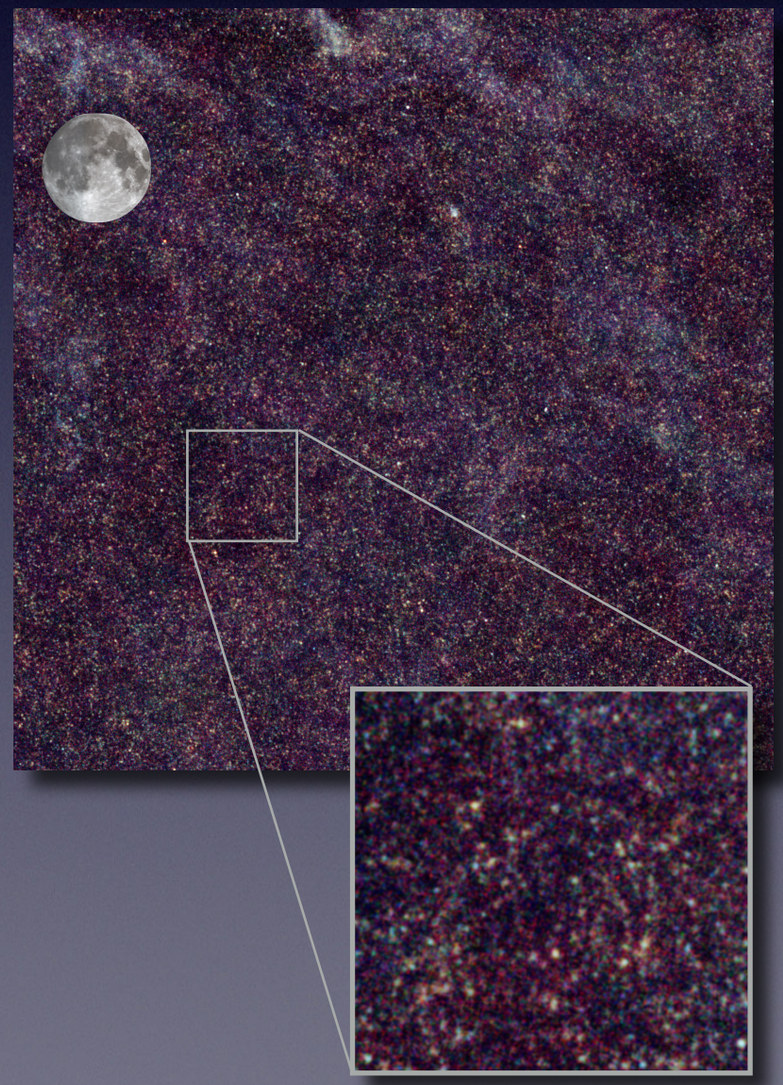


Apertif and LOFAR see the same star-forming galaxies



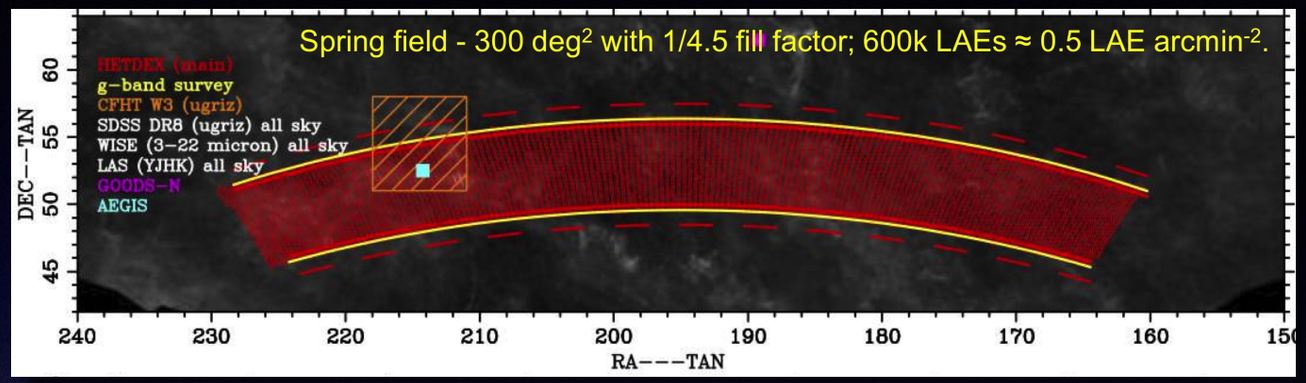
MaNGA & WEAVE IFU follow-up



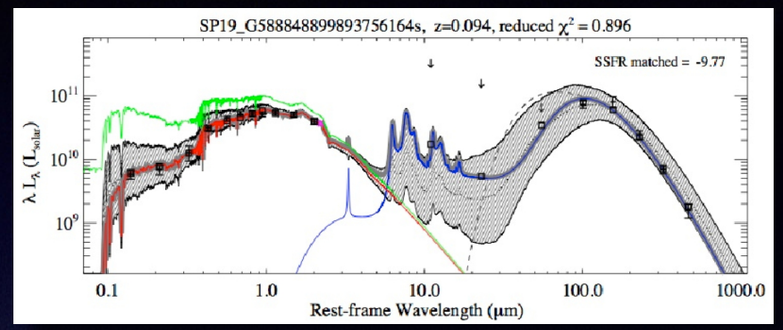


Ancillary data and survey synergies

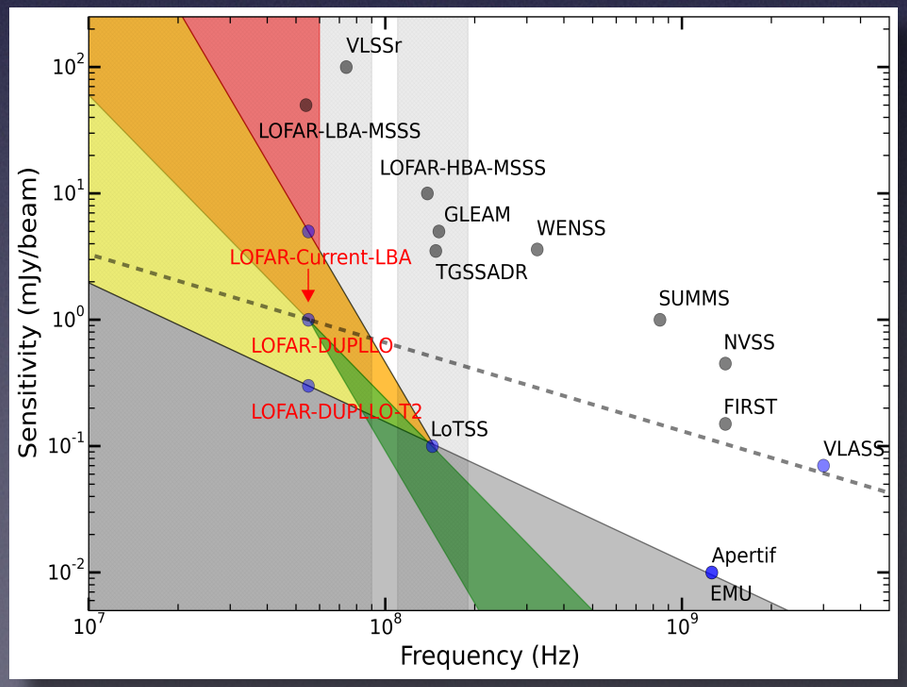
10^5 [OII] redshifts in HetDex field - HI stacking



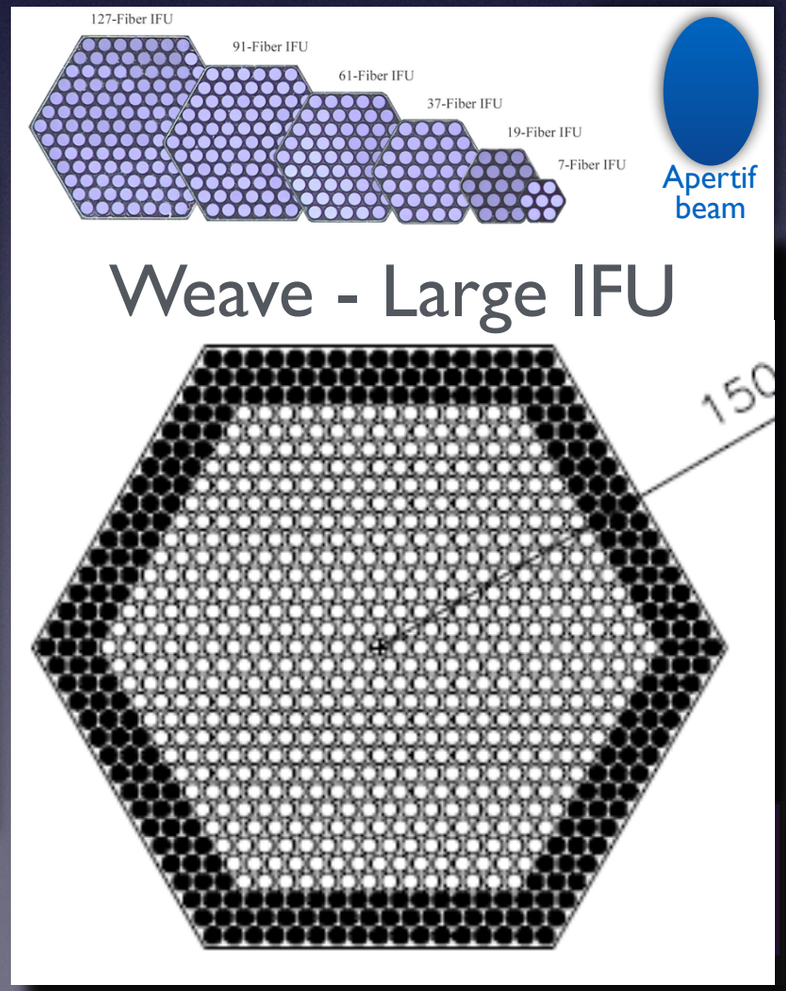
Full SED reconstruction for H-Atlas sources

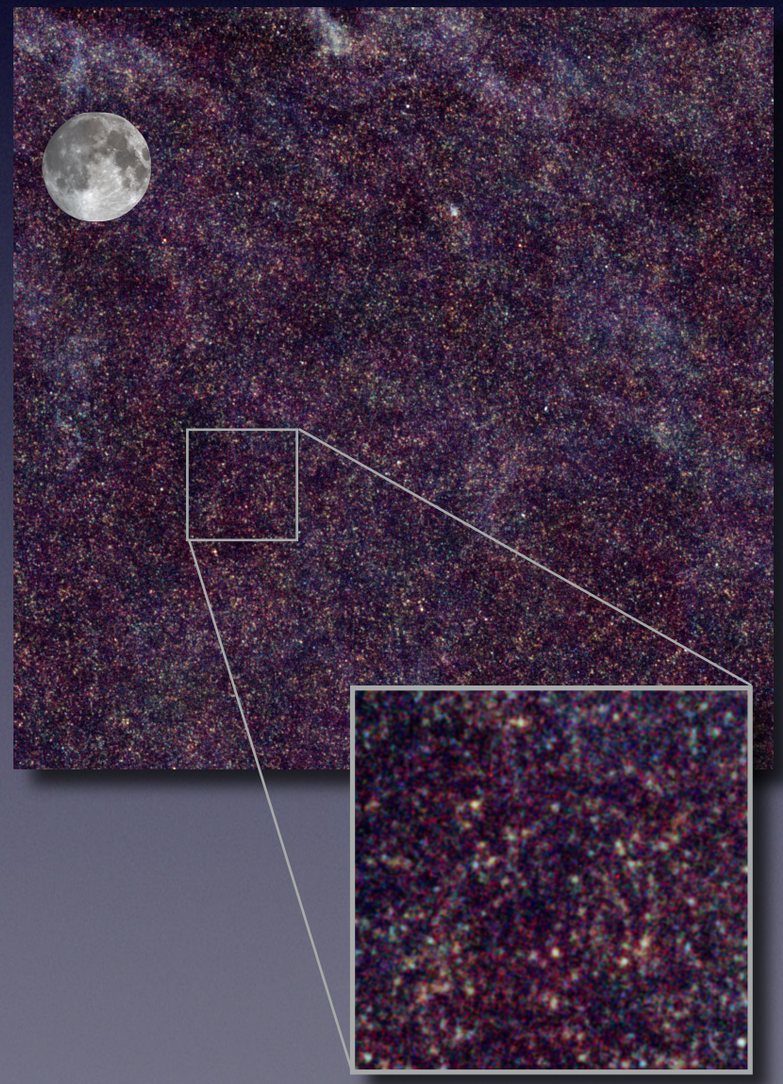


Apertif and LOFAR see the same star-forming galaxies



MaNGA & WEAVE IFU follow-up





Commissioning results

APERTIF

Betsey Adams
Björn Adebahr
Erwin de Blok
Helga Dénes
Tammo Jan Dijkema
Kelley Hess
Thijs van der Hulst
Alexander Kutkin
Anqi Li
Danielle Lucero
Filippo Maccagni
Raffaella Morganti
Vanessa Moss
Tom Oosterloo
D.J. Pisano
Anastasia Ponomareva
Robert Schulz
MV
Joris Verstappen

Achievements:

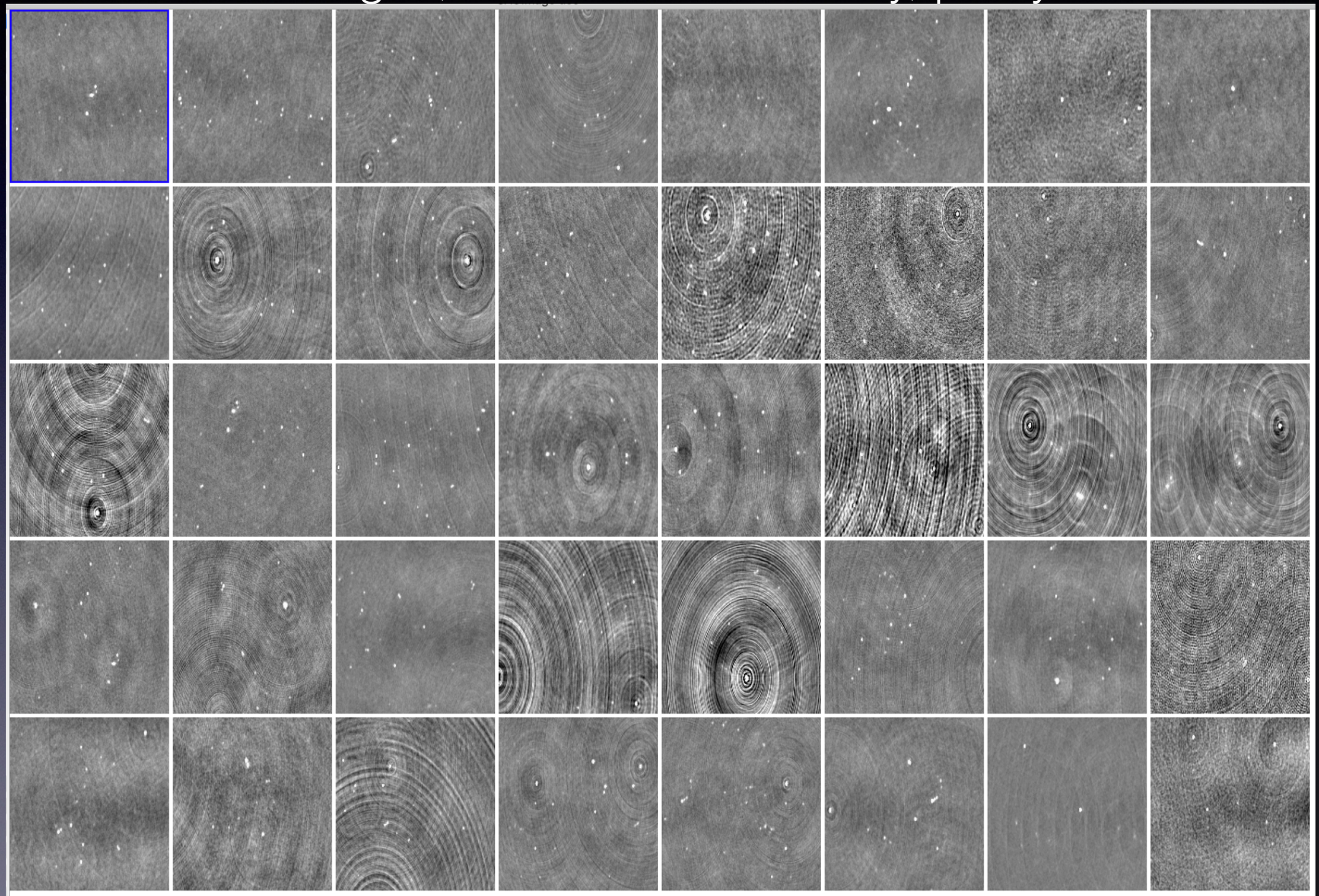
- ✓ 12 dishes equipped with PAF
- ✓ 1,452 receivers, 40 compound beams
- ✓ 300 MHz, 384x64=24,576 channels
- ✓ Full polarisation
- ✓ Updated pointing model
- ✓ Improved LNA beam weights
- ✓ New FIR for channelisation
- ✓ Functional, long-term, public archive

Challenges:

- – Strong Direction Dependent Effects
- – Sub-band aliasing
- – No real-time beam stabilisation
- – Polarisation calibration missing
- – Unknown primary beam shapes
- – Beam-to-beam bandpass variations

Commissioning results

40 Stokes-I images, cross-calibrated only, partly cleaned



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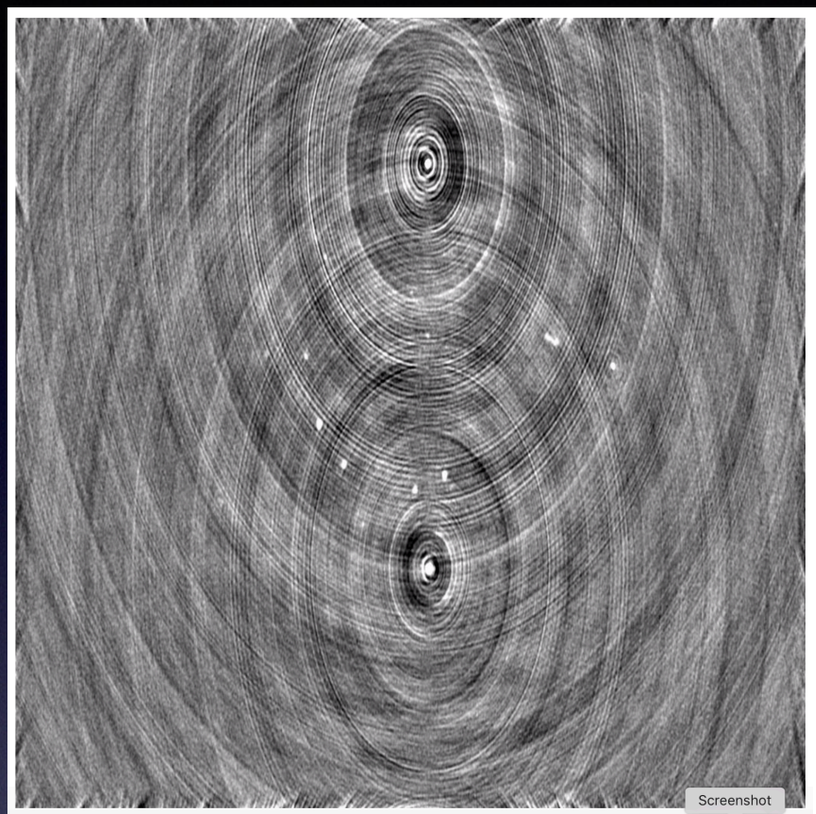
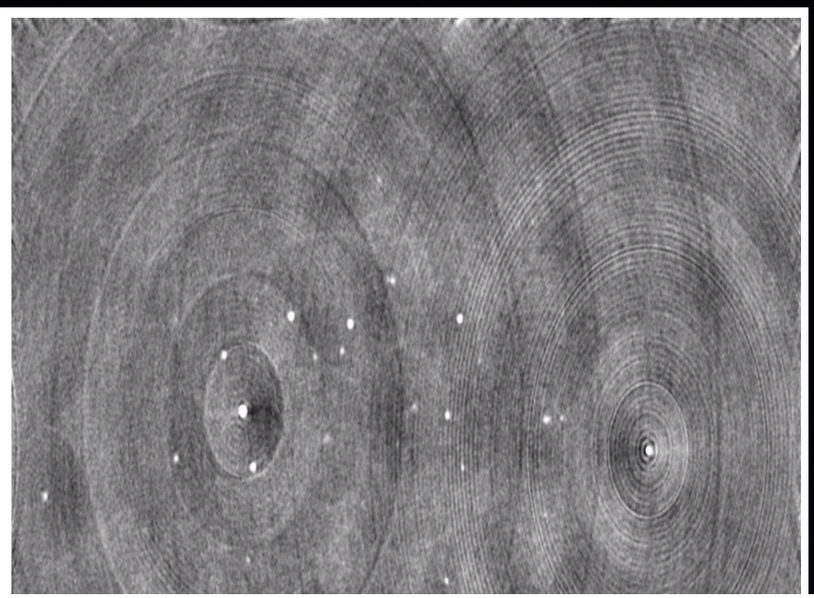


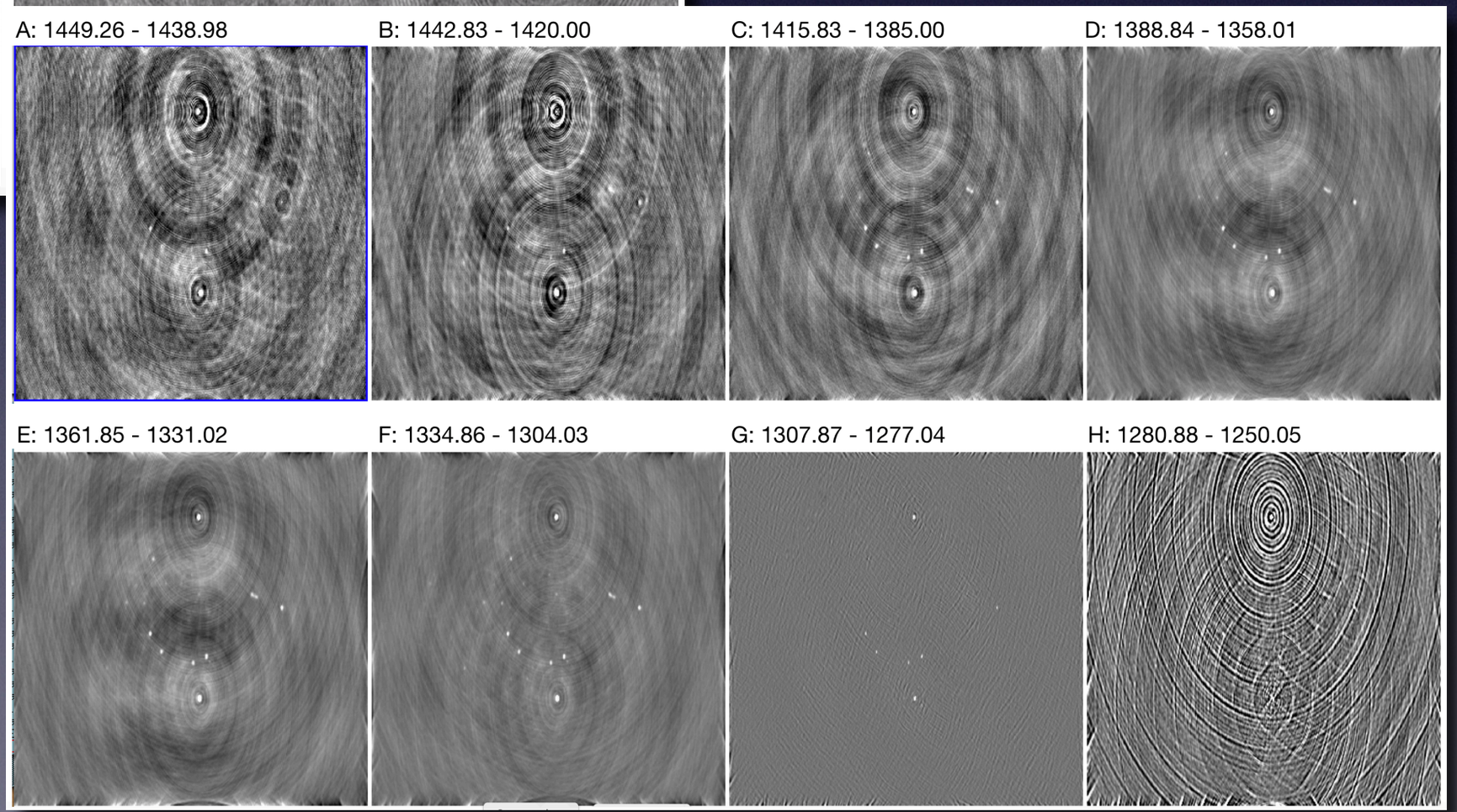


Strong Direction-Dependent Effects

- Phase error only
- Mirrored in pointing center

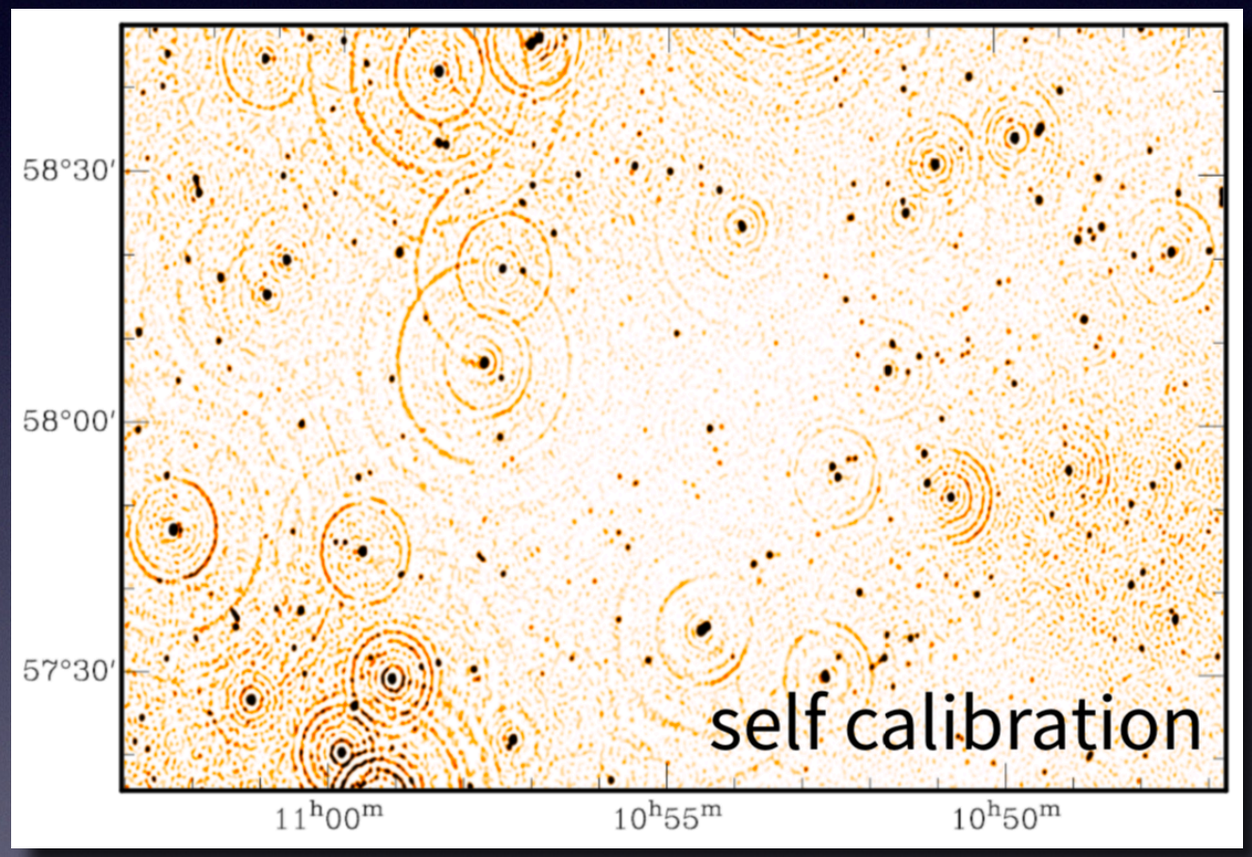
All 121 LNA signals contribute to all compound beams…

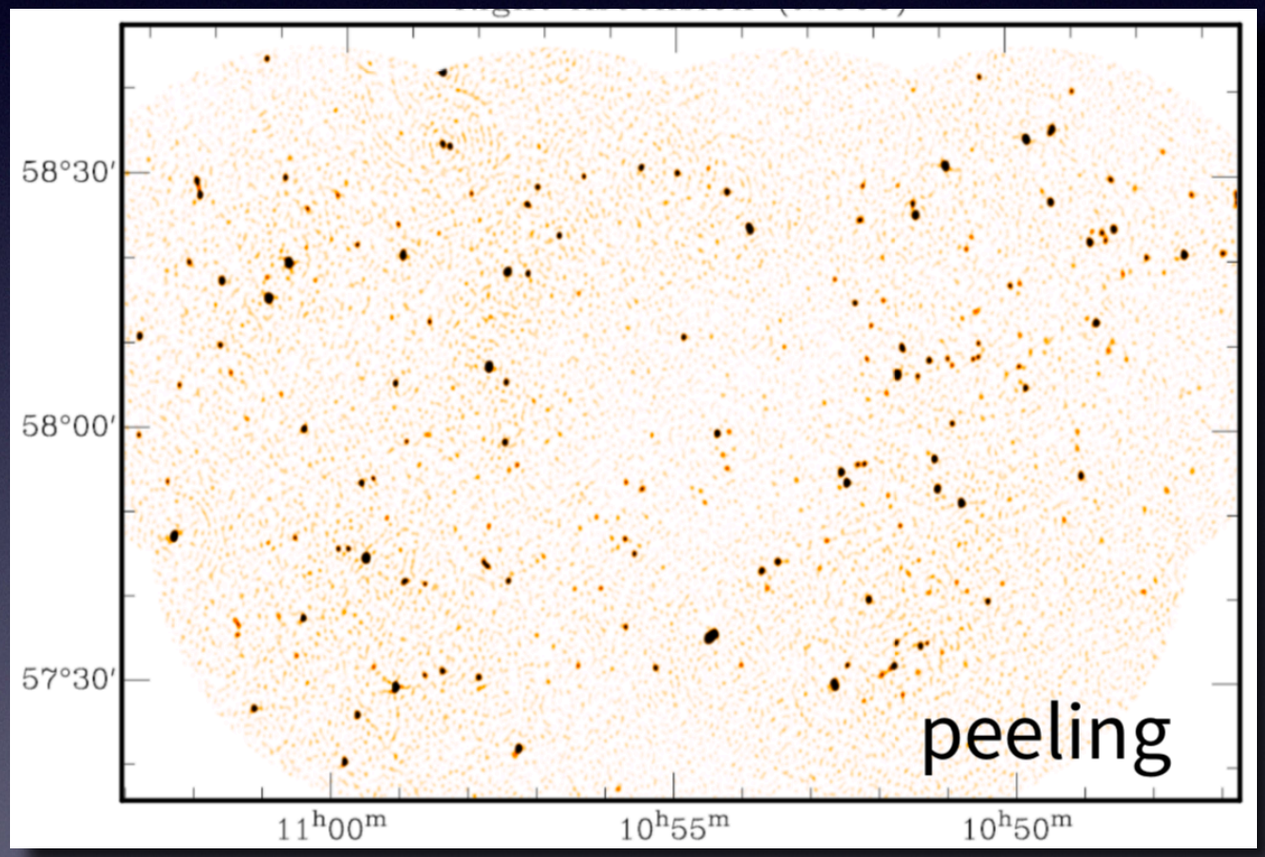
Frequency dependent



Commissioning results

Peeling removes the DDE's,
but only at the position of continuum sources
at great (prohibitive) computational expense.





T. Oosterloo

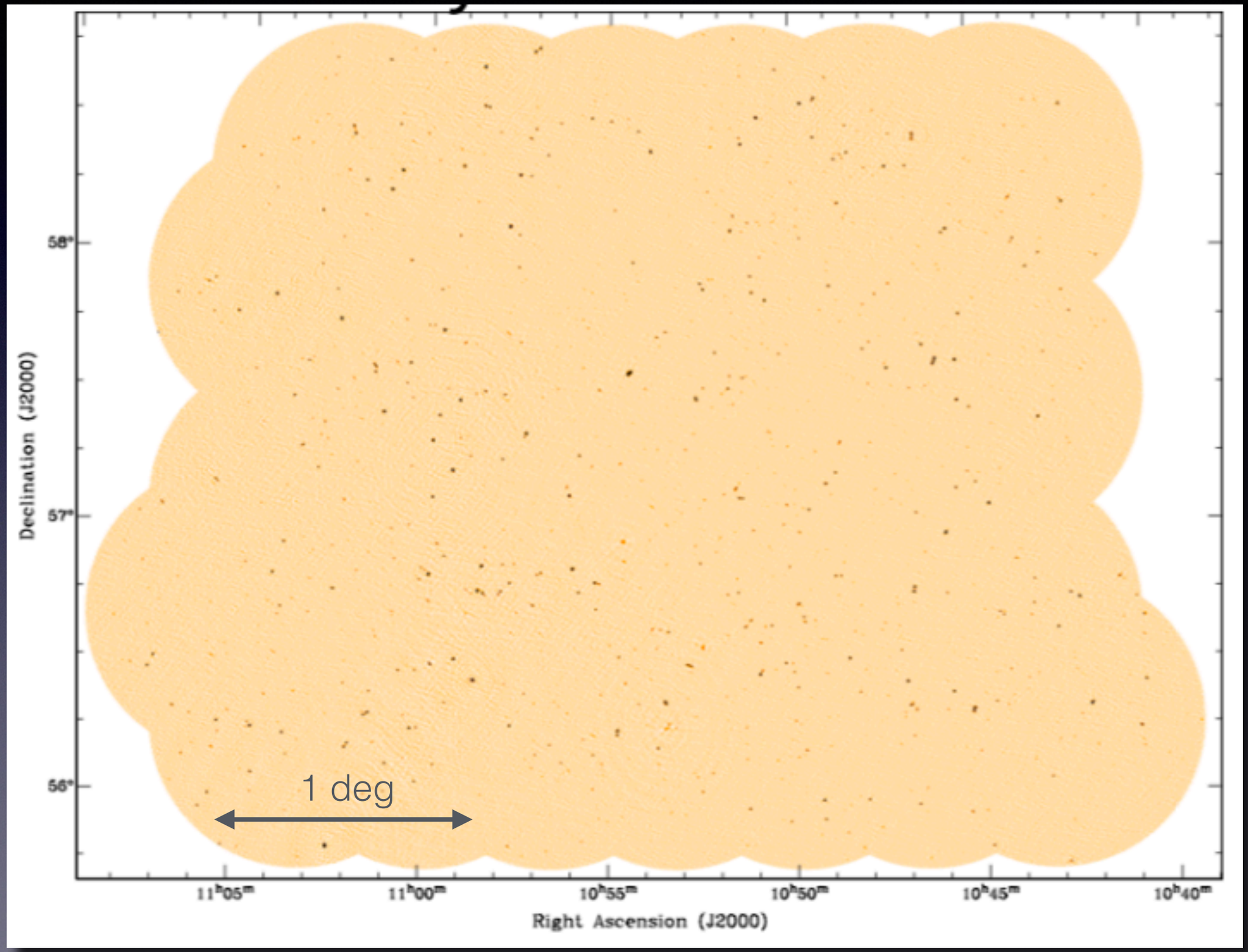
DDE's vary on angular scales of arcminutes.

Likely solution: real-time 'flat-fielding' of LNA's in PAF.

Commissioning results

single-pointing continuum mosaic

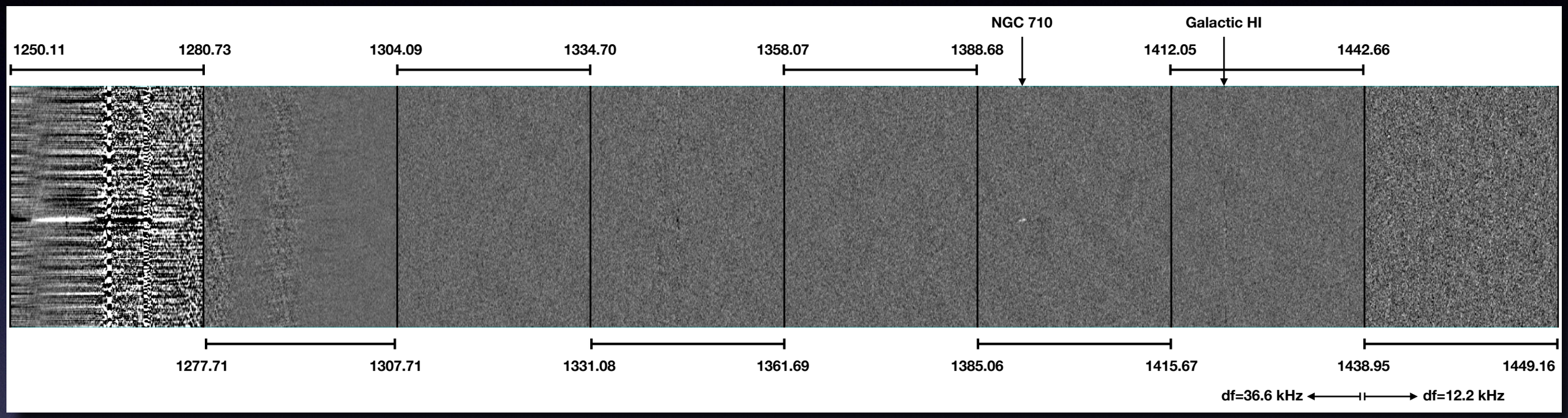
- 38 beams
- 150 MHz
- 50-100 μJy
- XX-only
- peeled

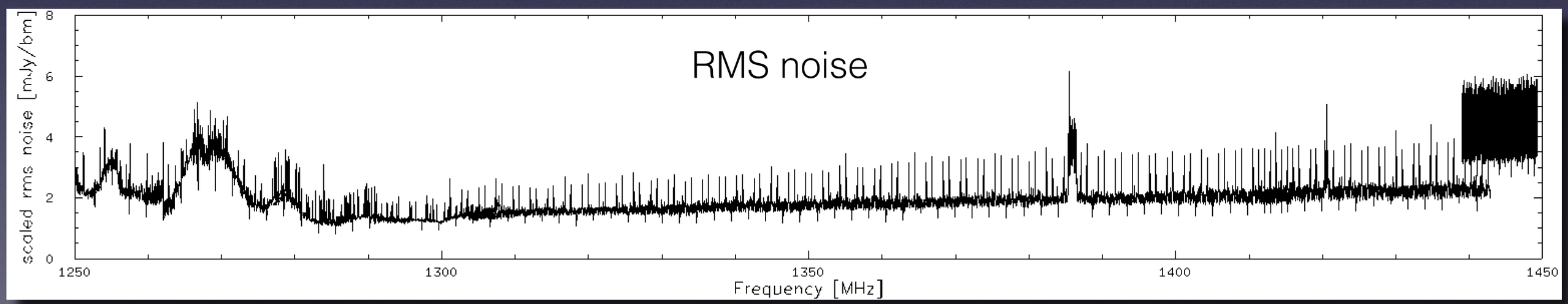


T. Oosterloo

Commissioning results

Freq-Dec slices through continuum-subtracted line cubes





1250 1350 1450

Frequency [MHz]

Currently: 300 [MHz] available

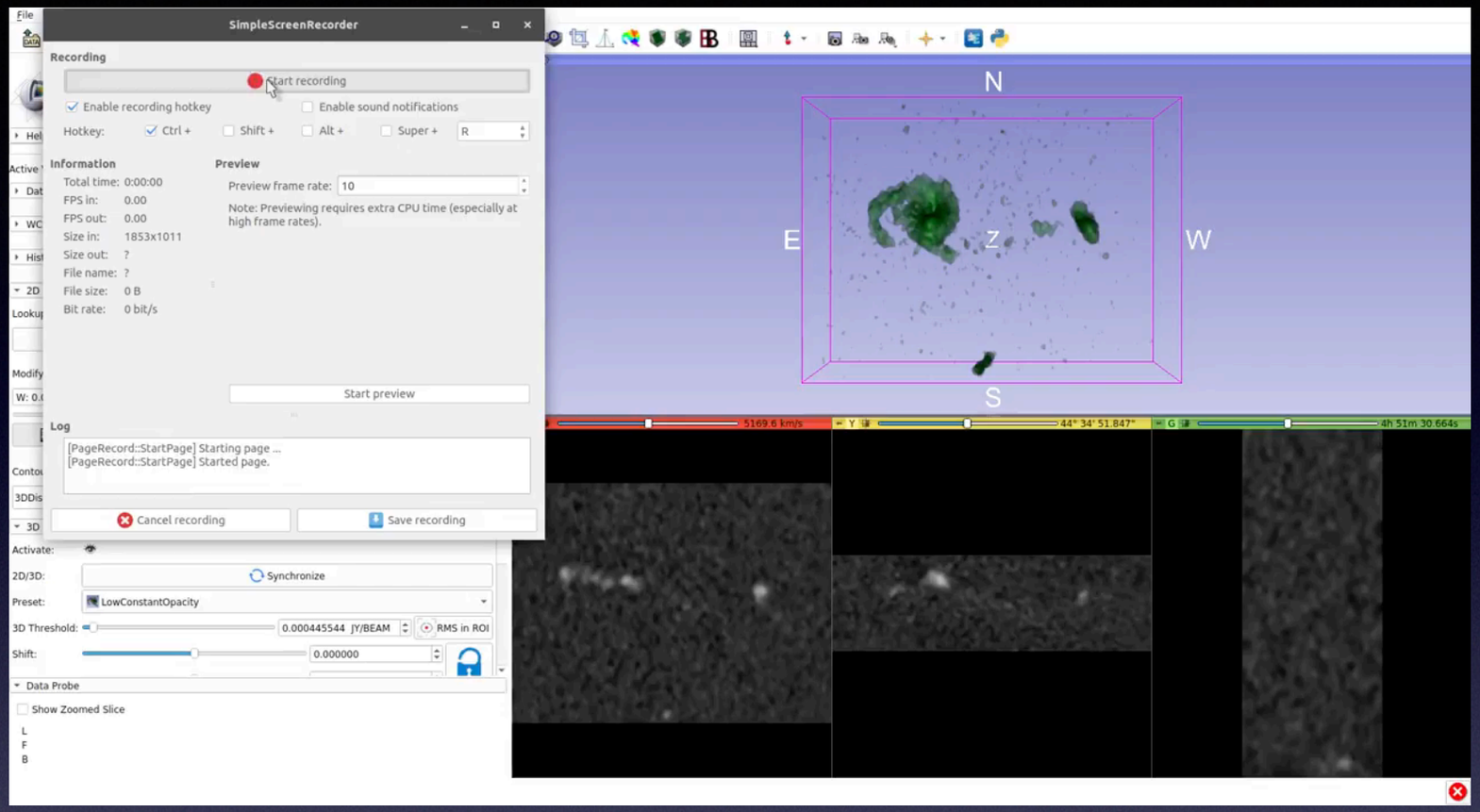
Visualisation

APERTIF

Davide Punzo

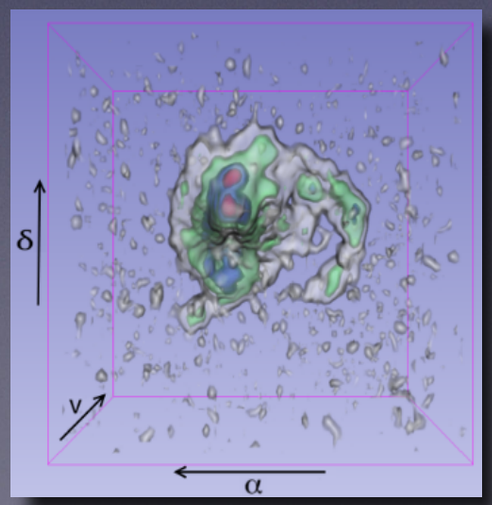
Slicer Astro

Open source
well documented

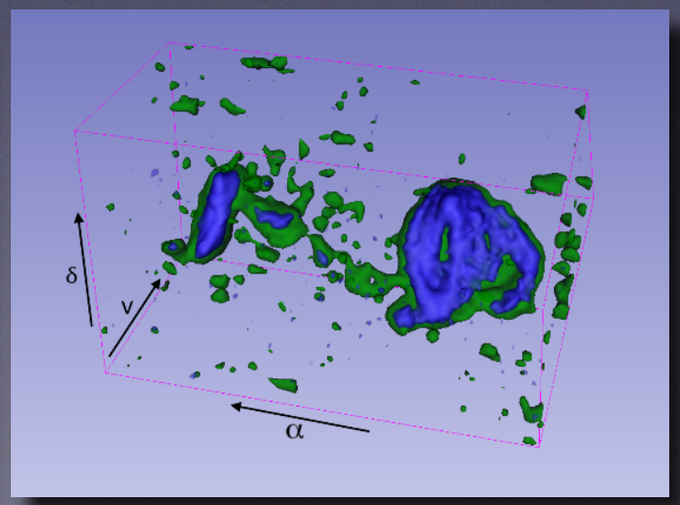


https://github.com/Punzo/SlicerAstro

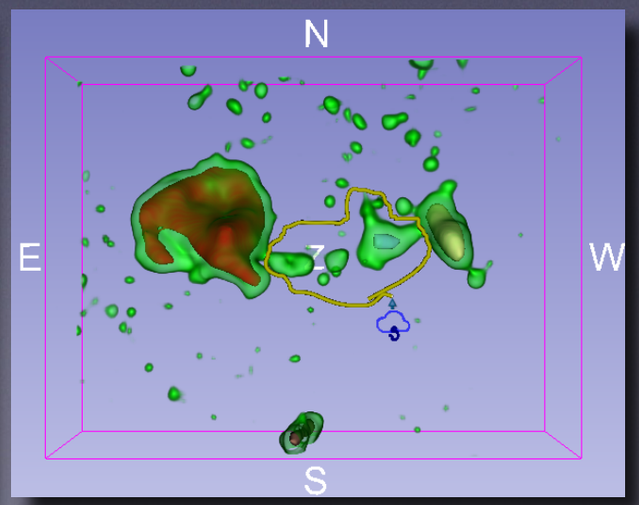
3D interactive visualisation



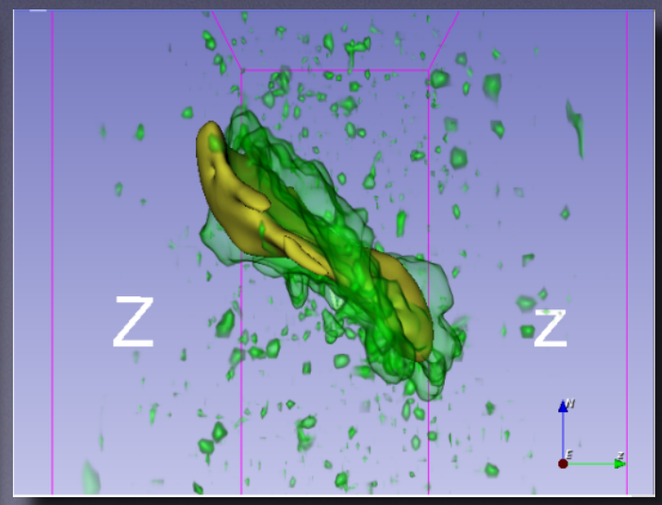
Filtering and adaptive smoothing



Interactive 3D volume selection

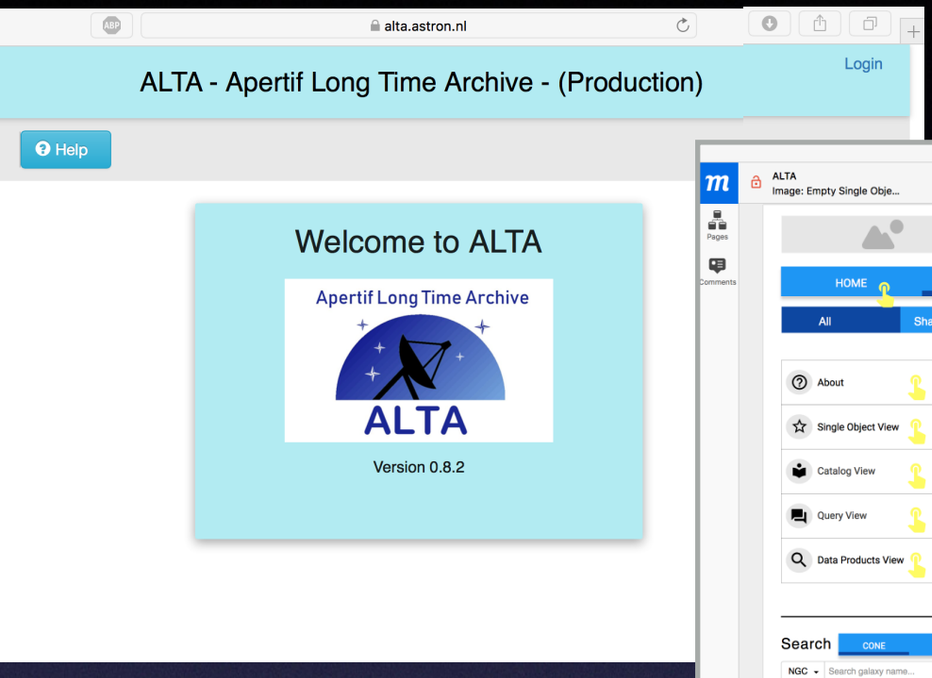


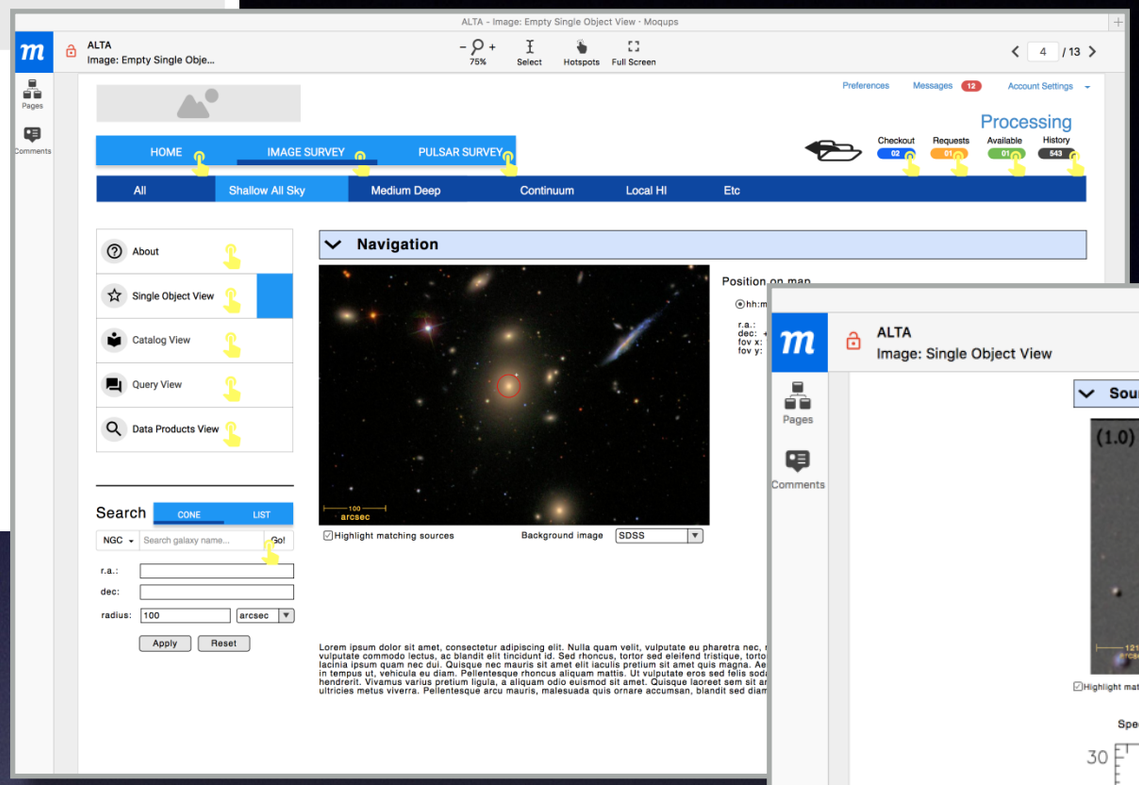
Full 3D modelling and analysis

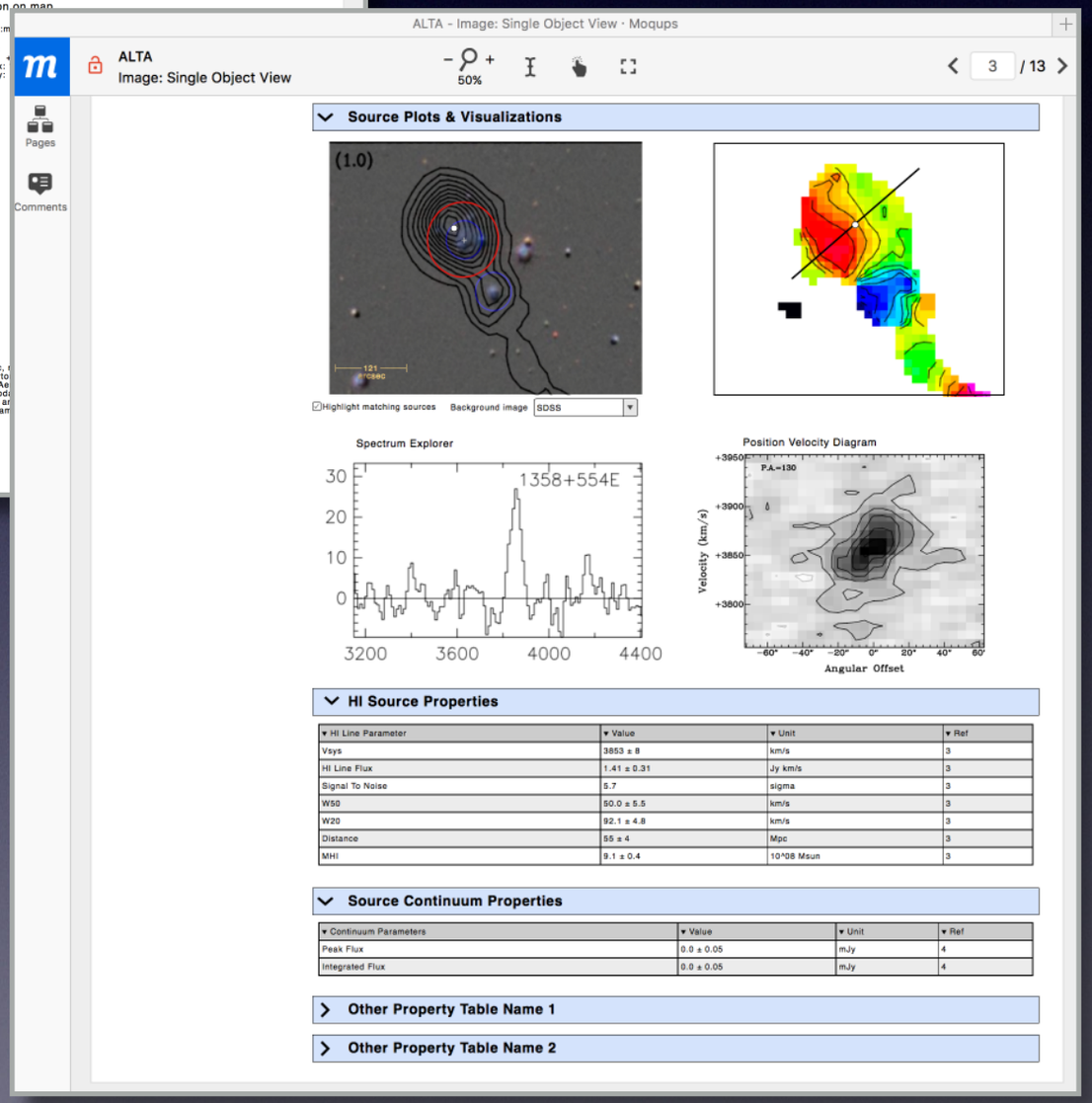


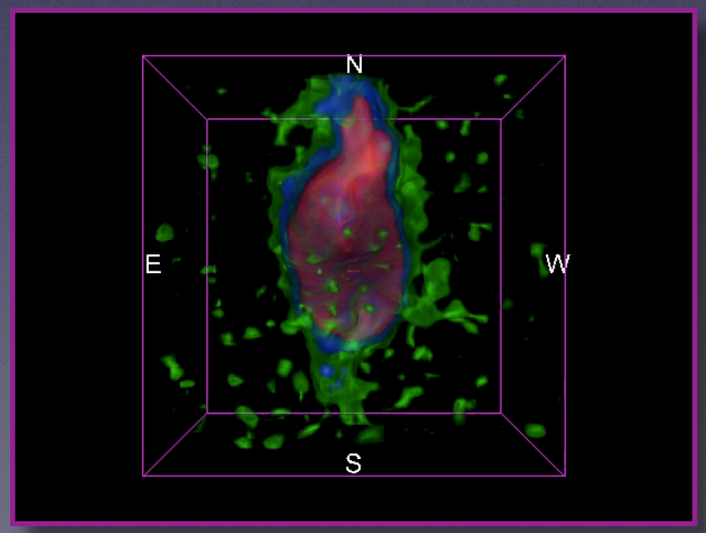
Apertif Long-Term Archive - ALTA

www.alta.astron.nl









Data goes public shortly after quality assessment.

- Catalogs
- Continuum maps
- Cubelets
- Moment maps

UNDER DEVELOPMENT

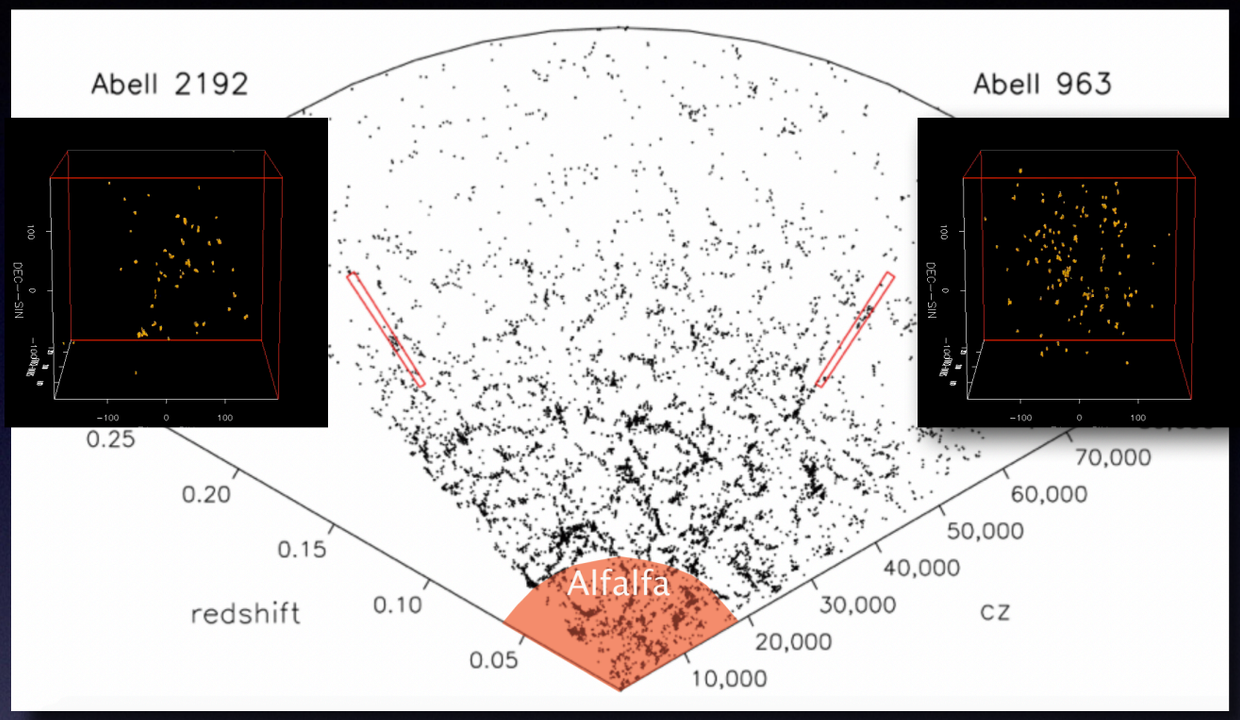
WORK IN PROGRESS

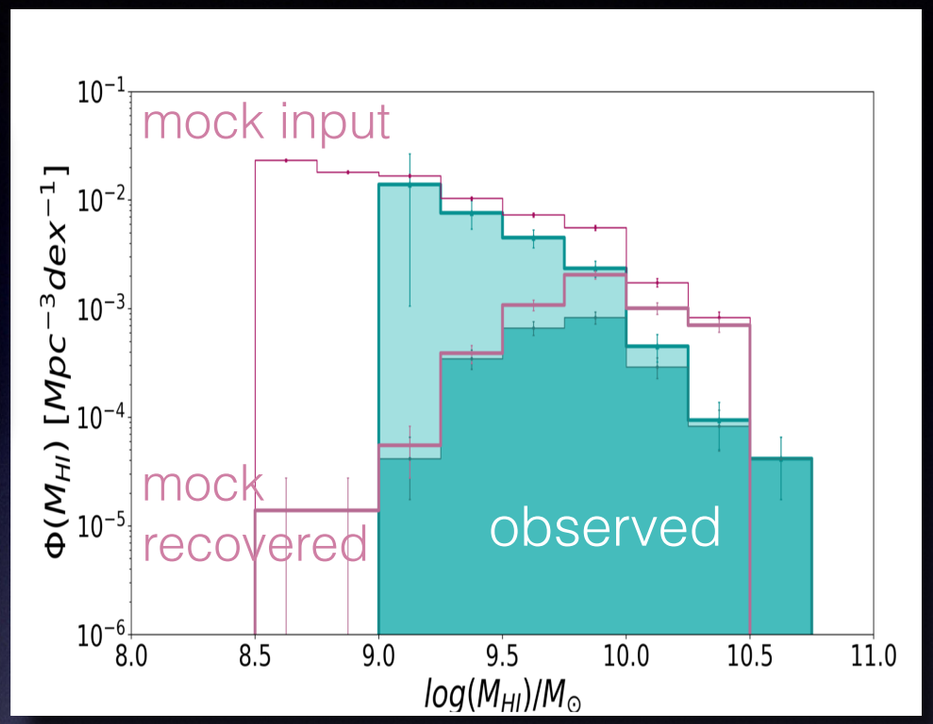
The HI Mass Function and Ω_{HI} at z=0.2

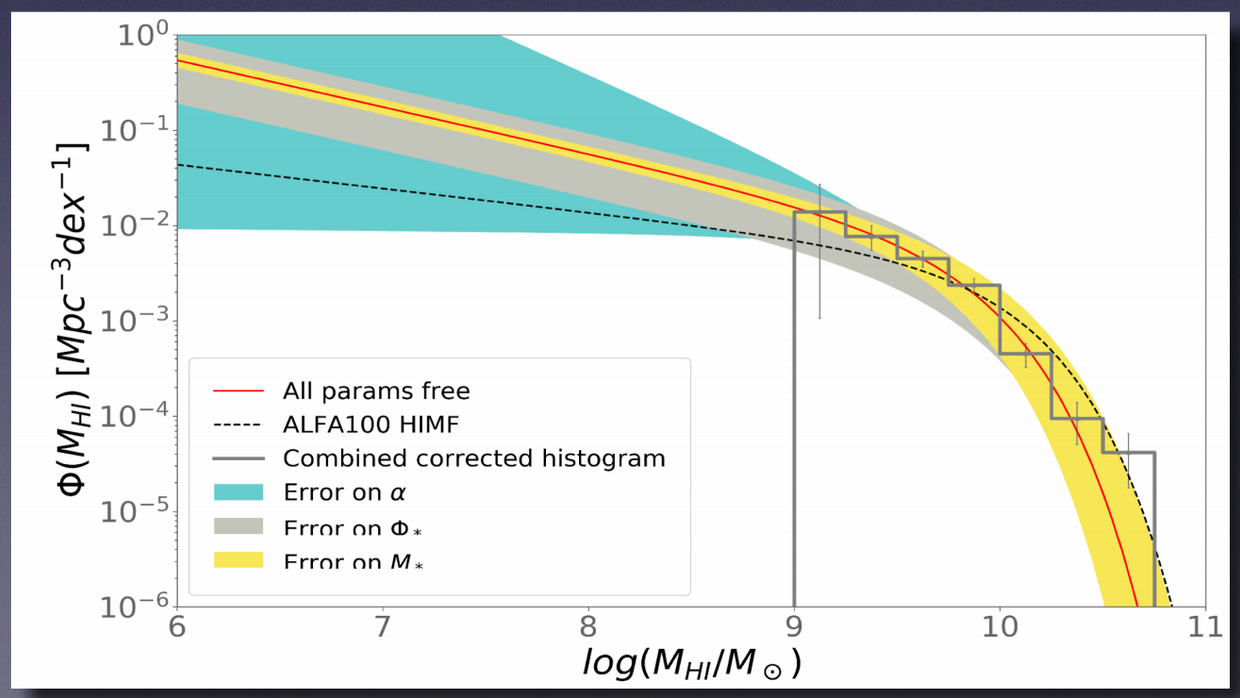
preparatory science project

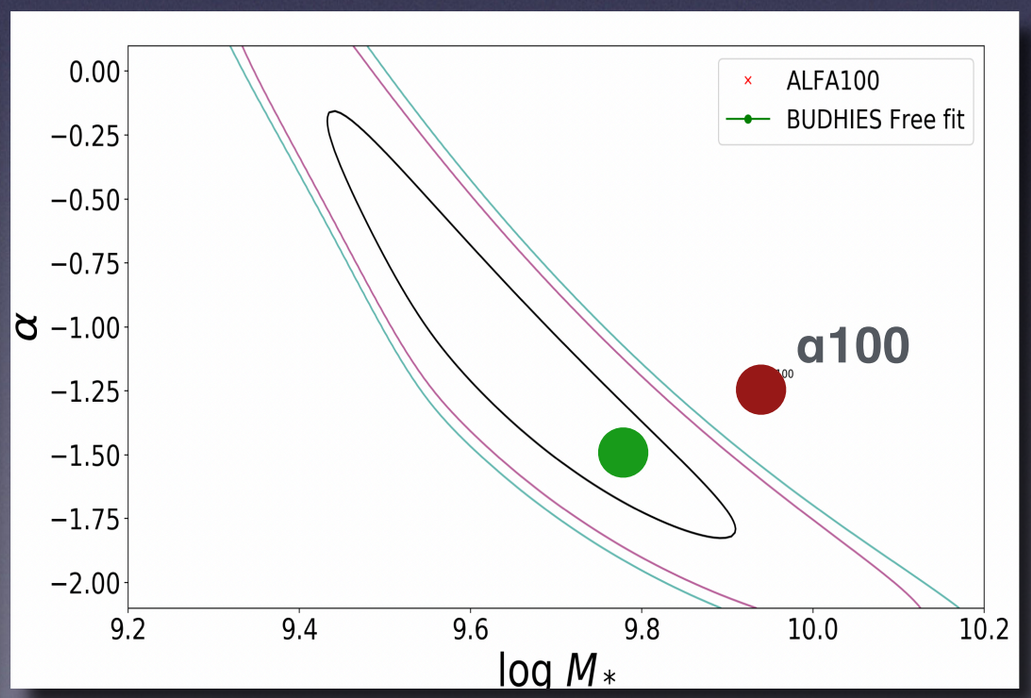
from 160 blind, direct HI detections

Avanti Gogate









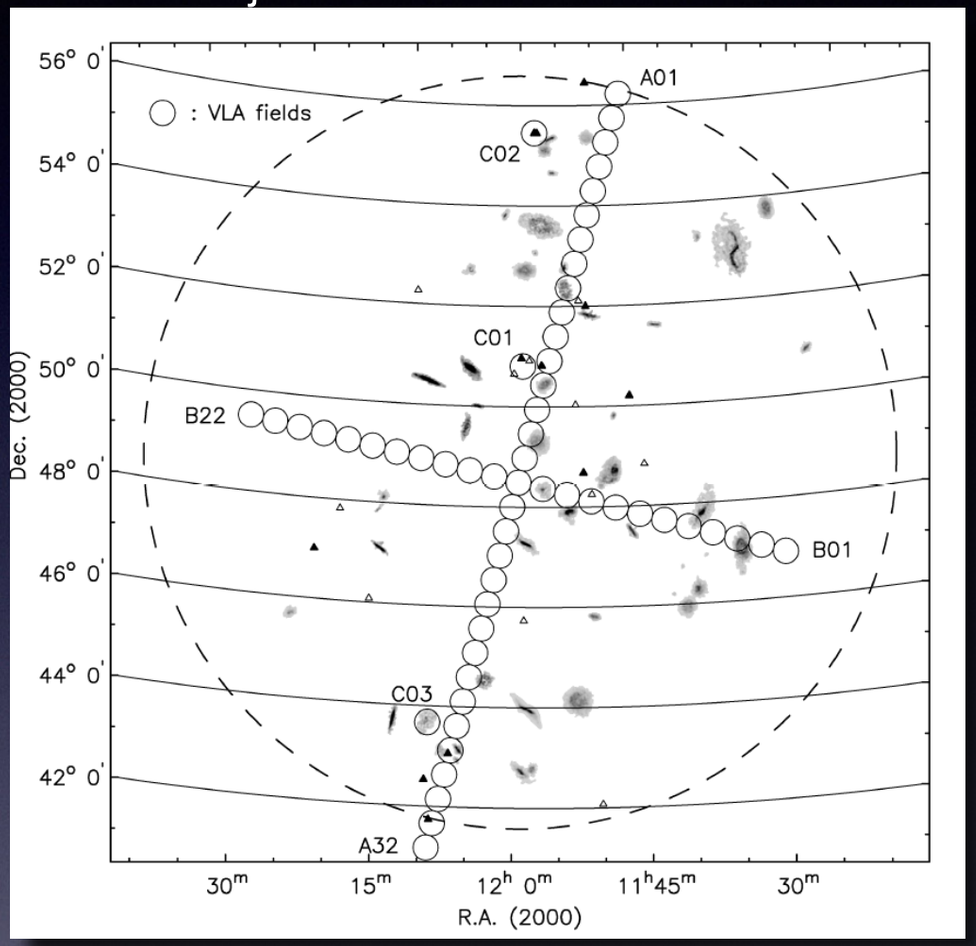
HI morphologies & environment

UNDER DEVELOPMENT
WORK IN PROGRESS

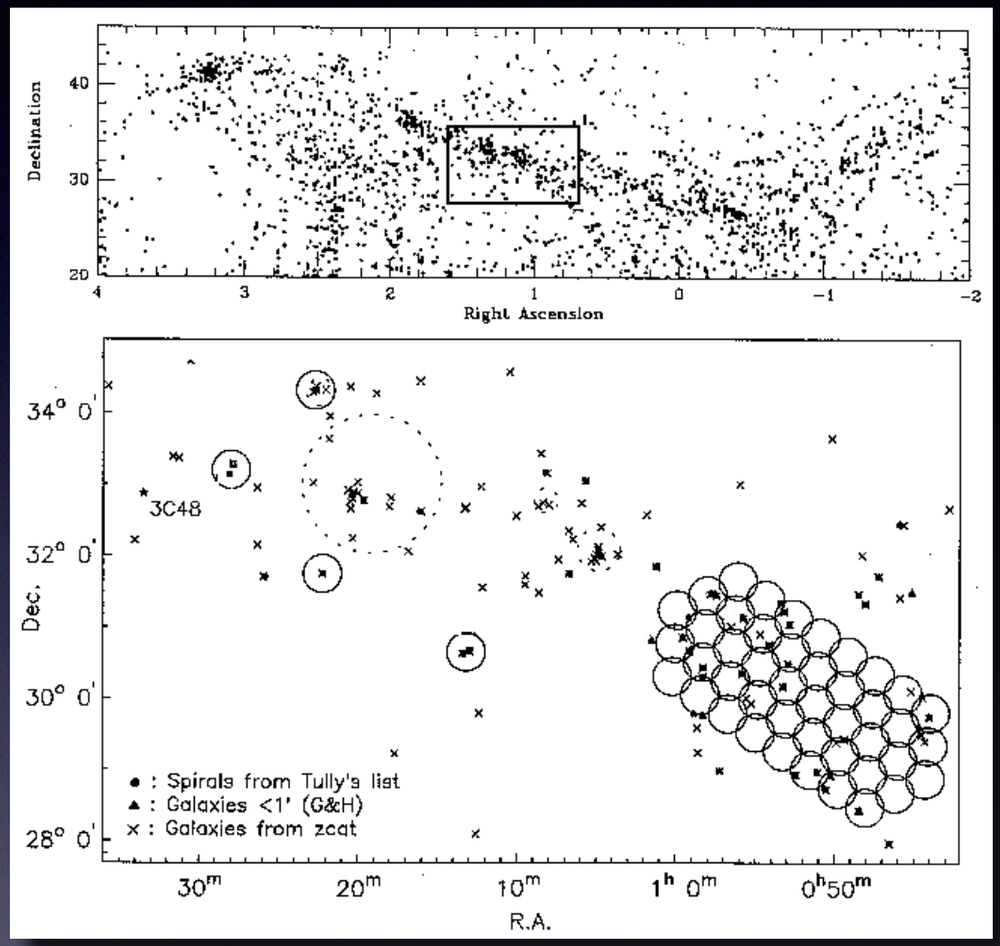
preparatory science project

Pooja Bilimogga

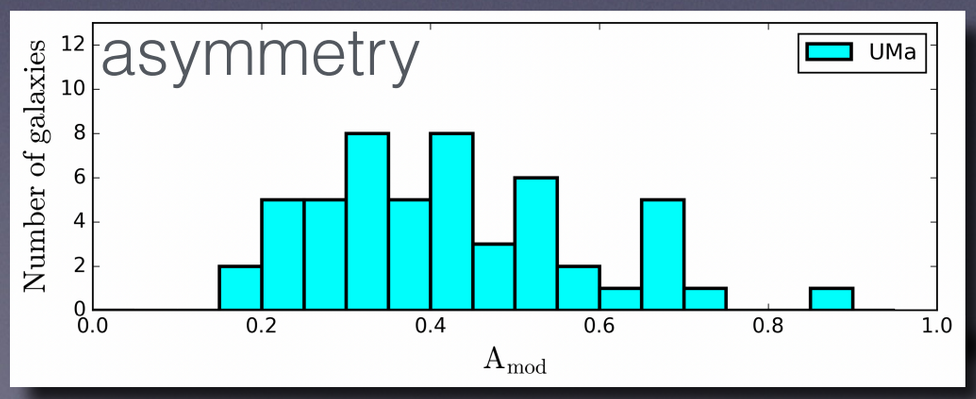
Ursa Major: WSRT + VLA-D

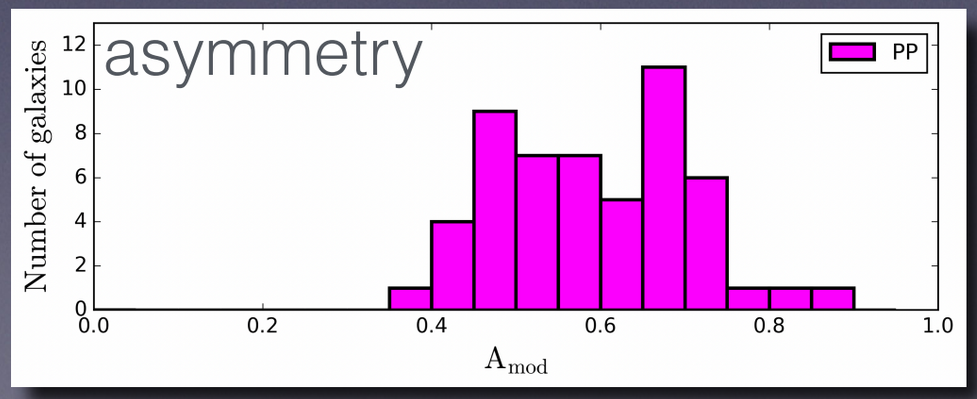


Perseus-Pisces: VLA-C



Source finding & characterisation





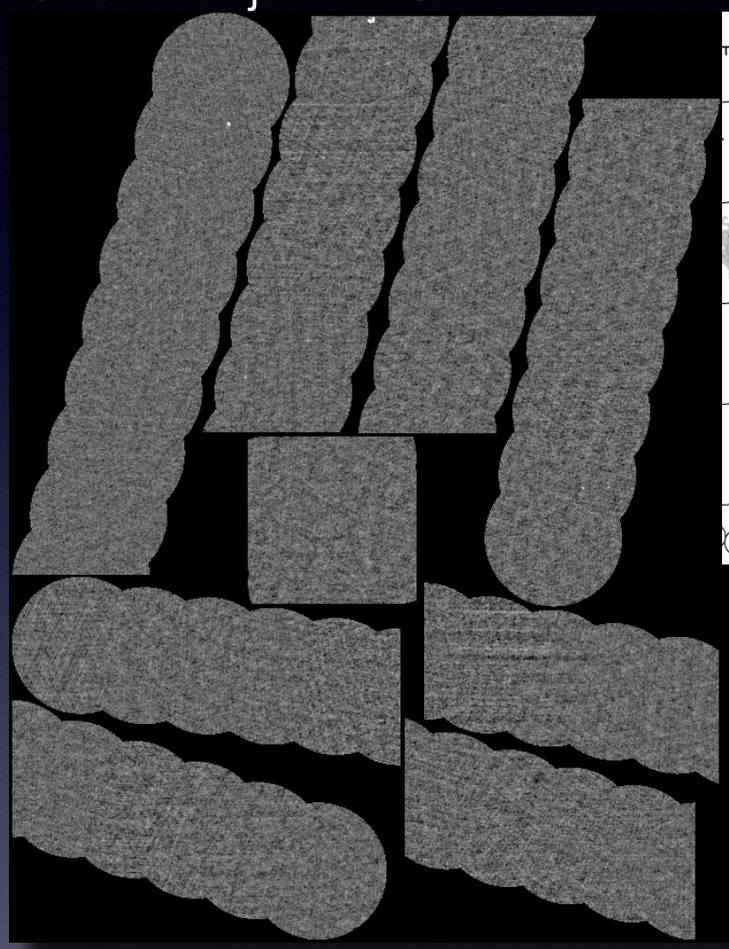
Environmental dependence of HI disk asymmetry?

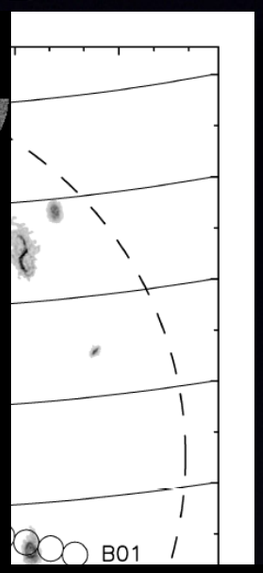
HI morphologies & environment

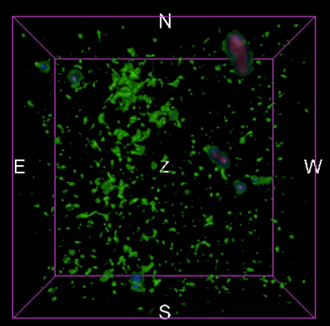
preparatory science project

Pooja Bilimogga

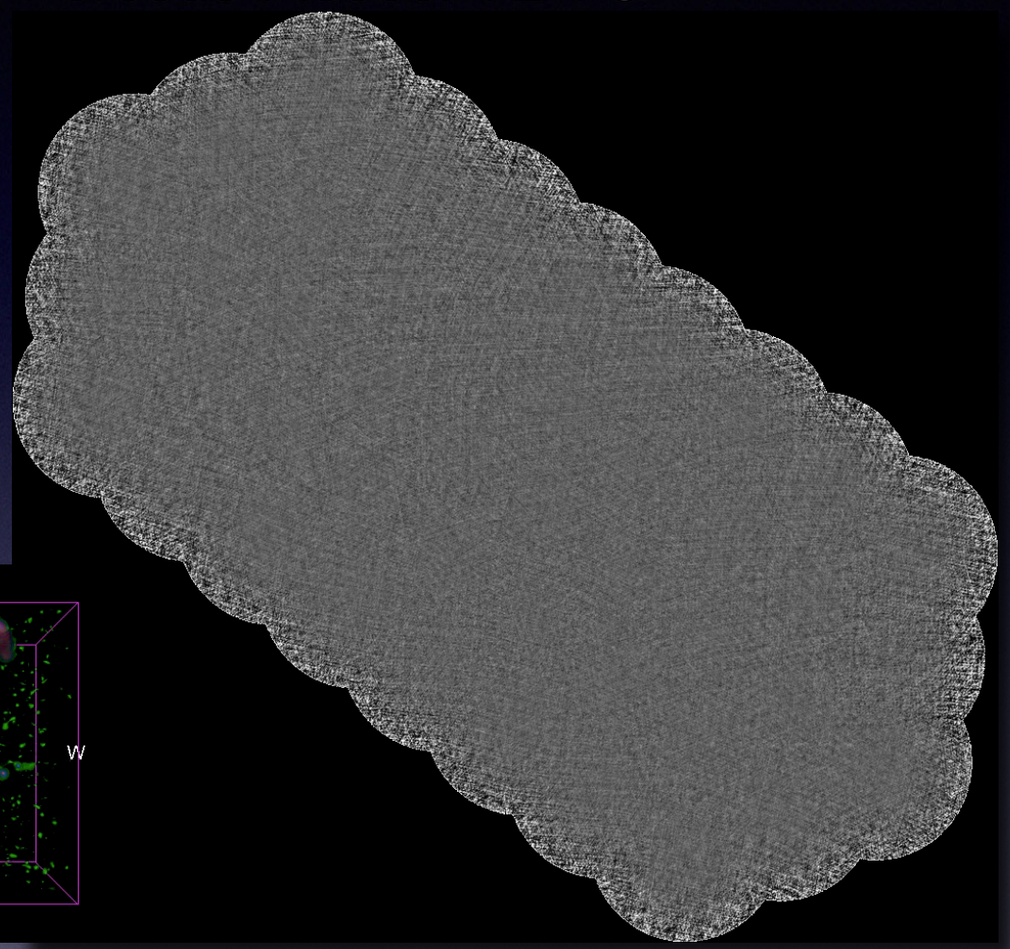
Ursa Major: WSRT + VLA-D



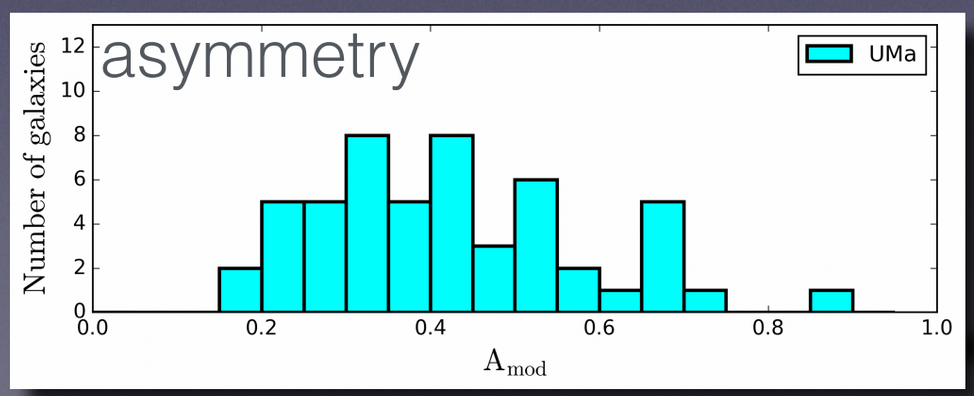


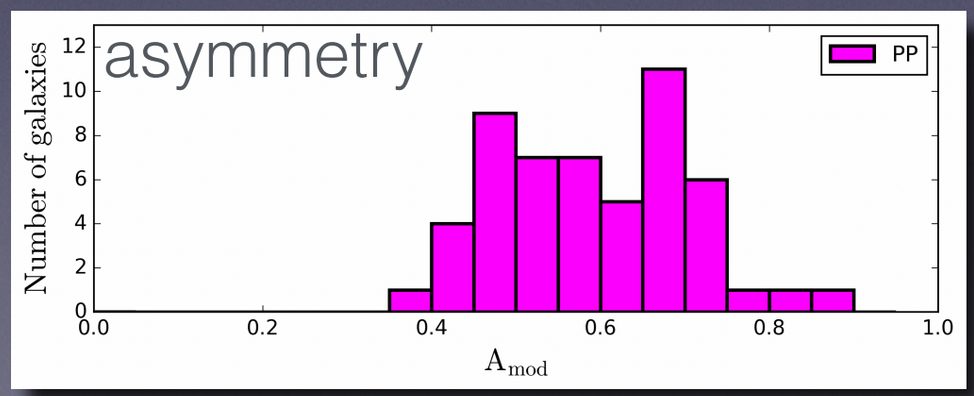


Perseus-Pisces: VLA-C



Source finding & characterisation





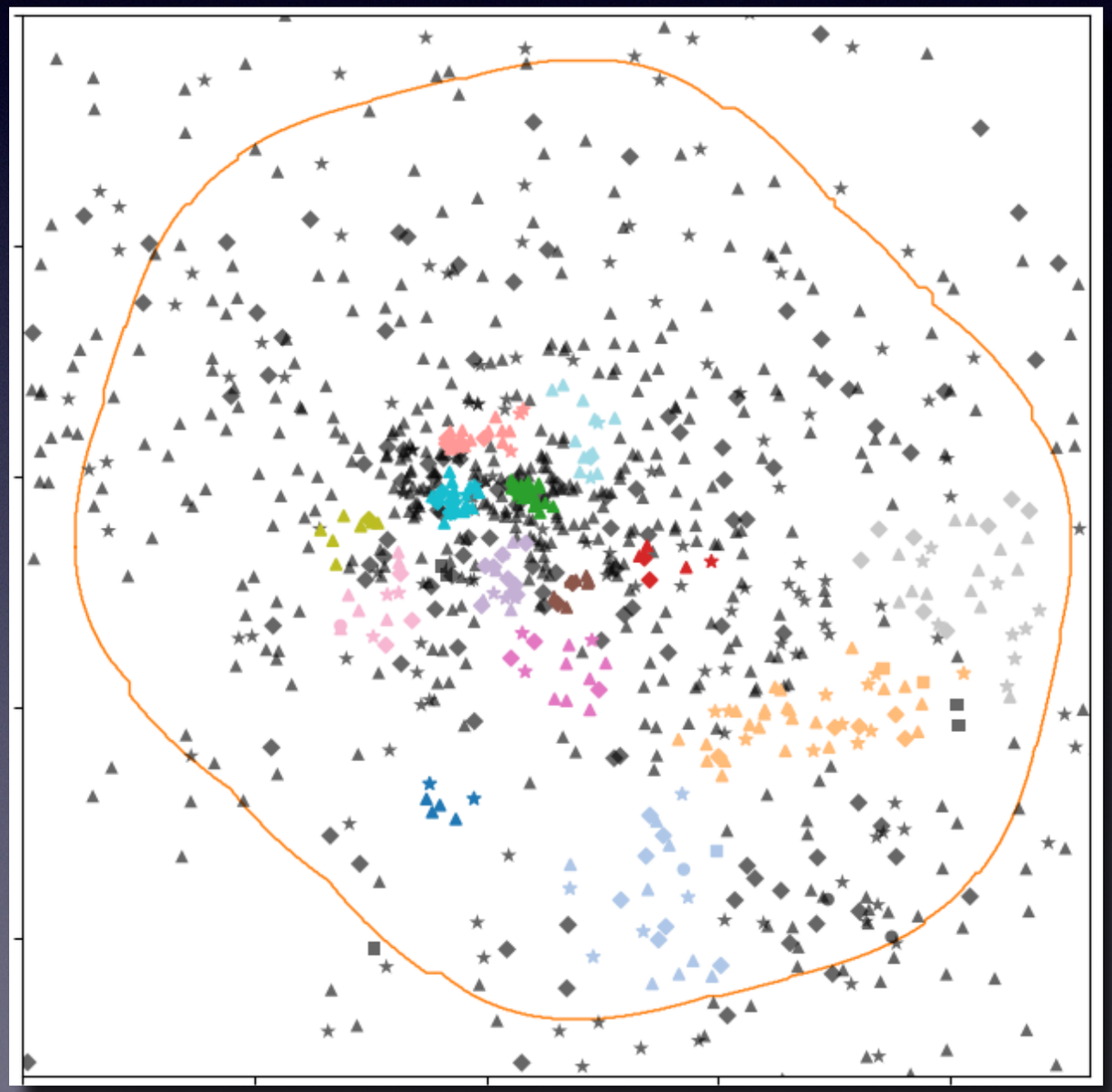
Environmental dependence of HI disk asymmetry?

HI stacking of Coma substructures

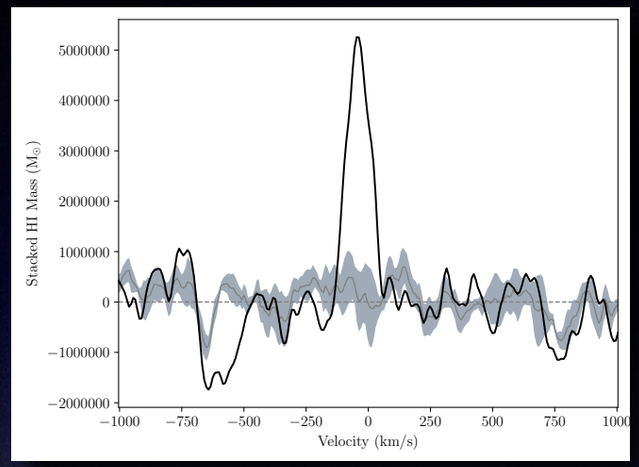
preparatory science project

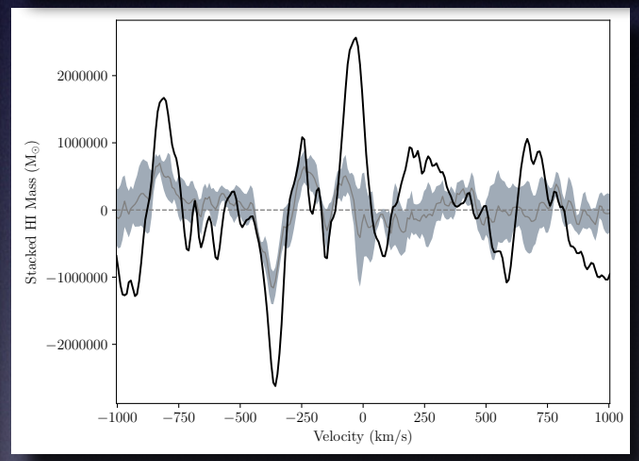
Julia Healy

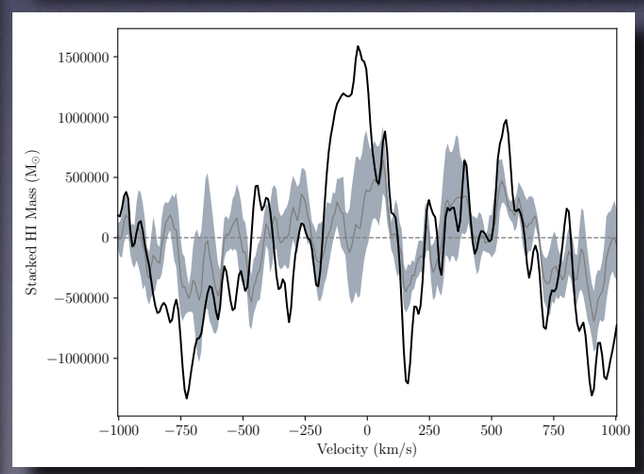
Kinematic substructures in outskirts of Coma cluster.

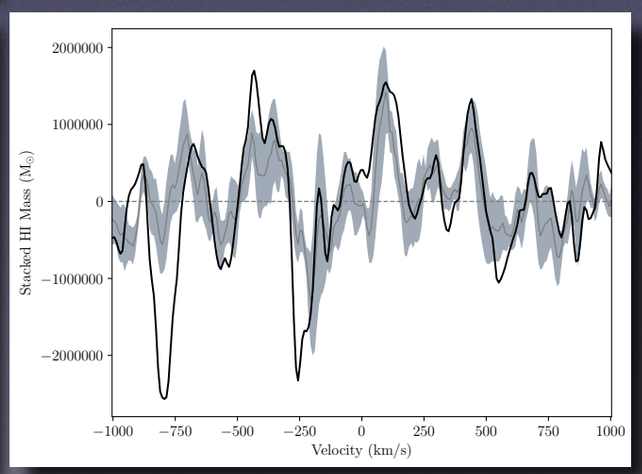


Stacked HI spectra.









Infalling groups have different gas content.

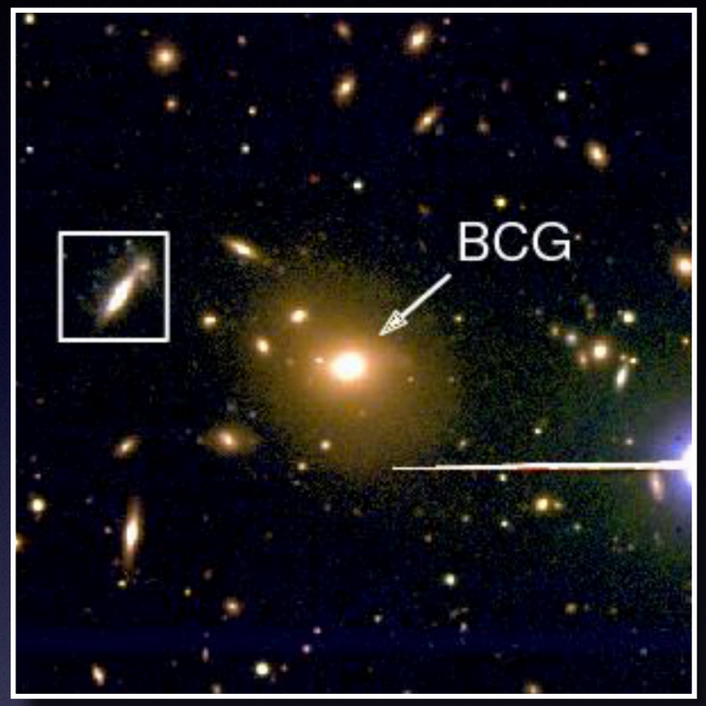
Pre-processing of gas depletion in group environment?

ram-pressure stripping

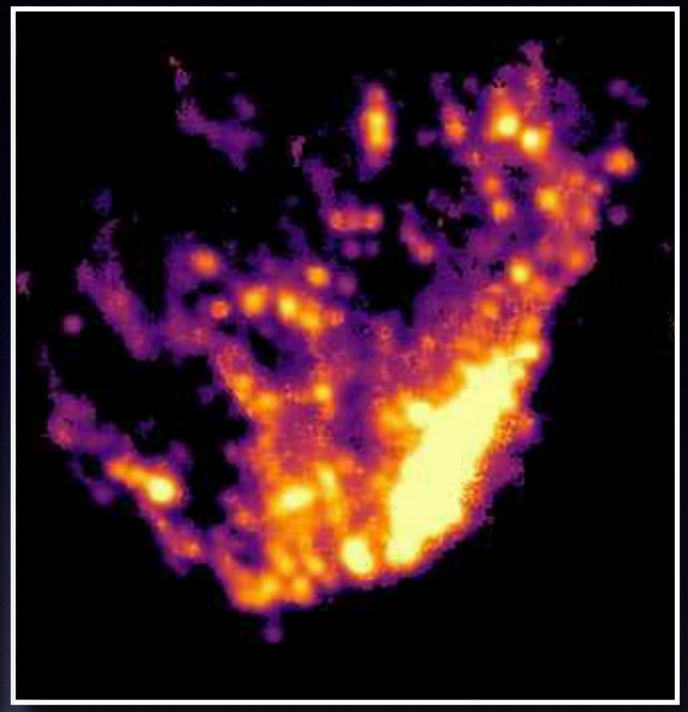
UNDER DEVELOPMENT
WORK IN PROGRESS

preparatory science project

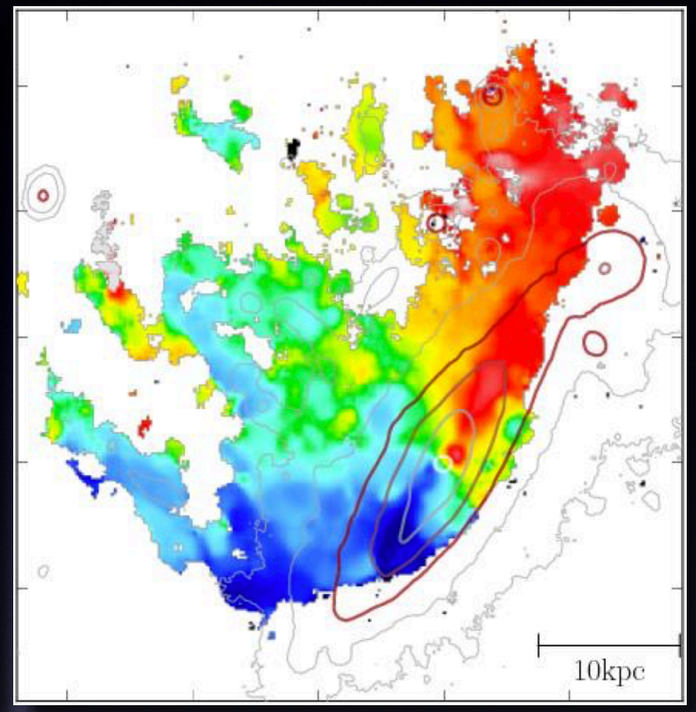
JO204



MUSE

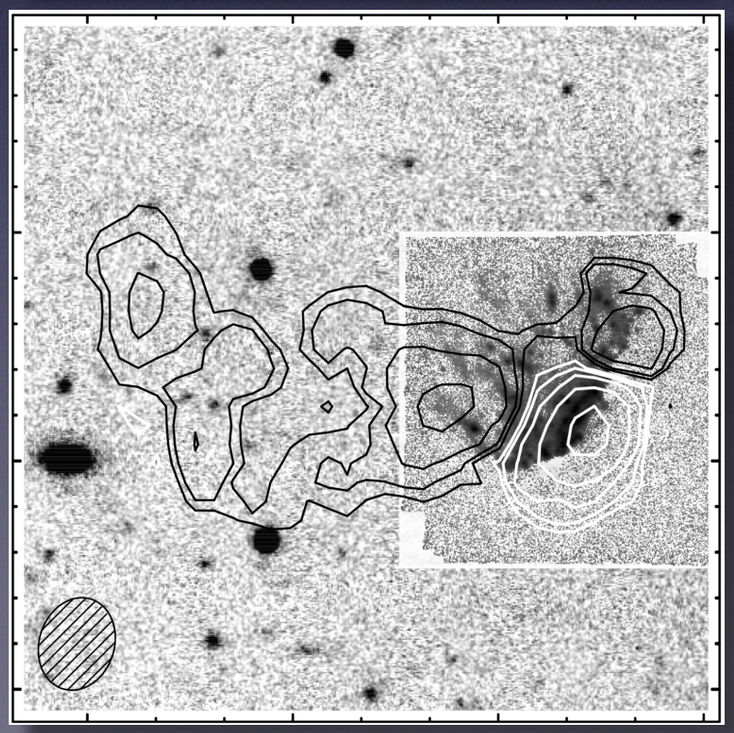


GASP collaboration
Poggianti ++



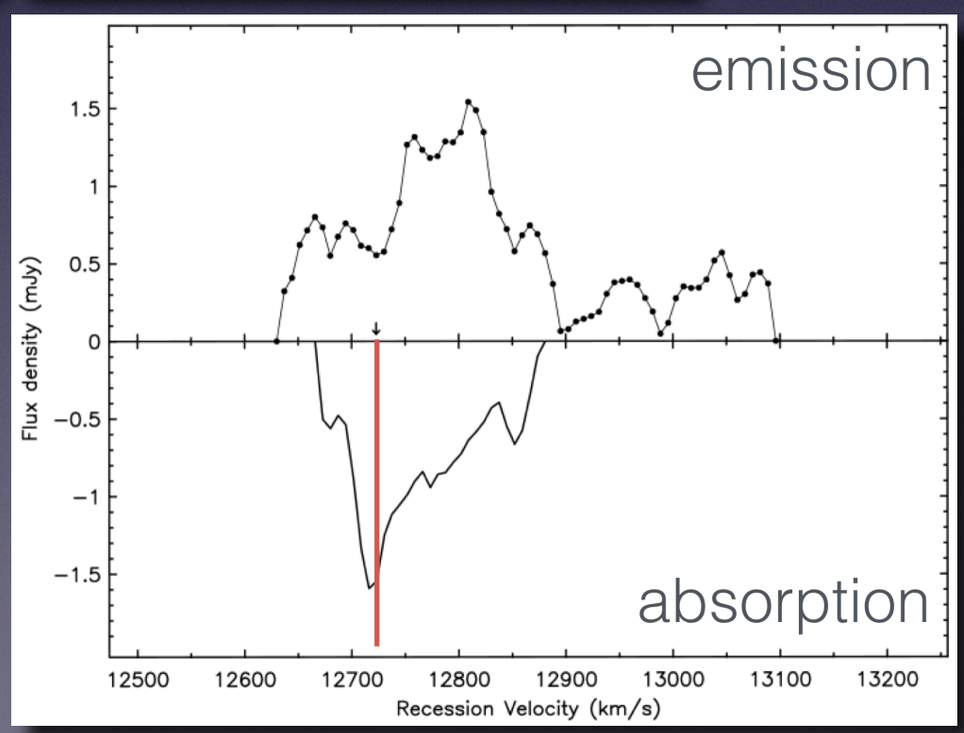
Tirna Deb

Mpati Ramatsoko



ram-pressure induced AGN activity?

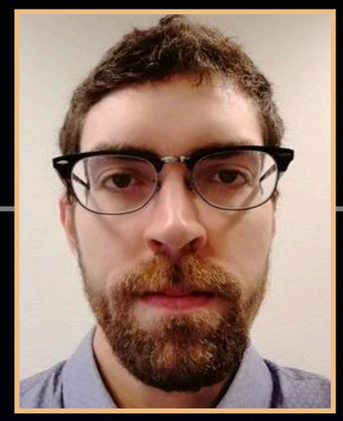
JVLA-C



APERTIF

preparatory science project

Observing simulations



Kyle Oman

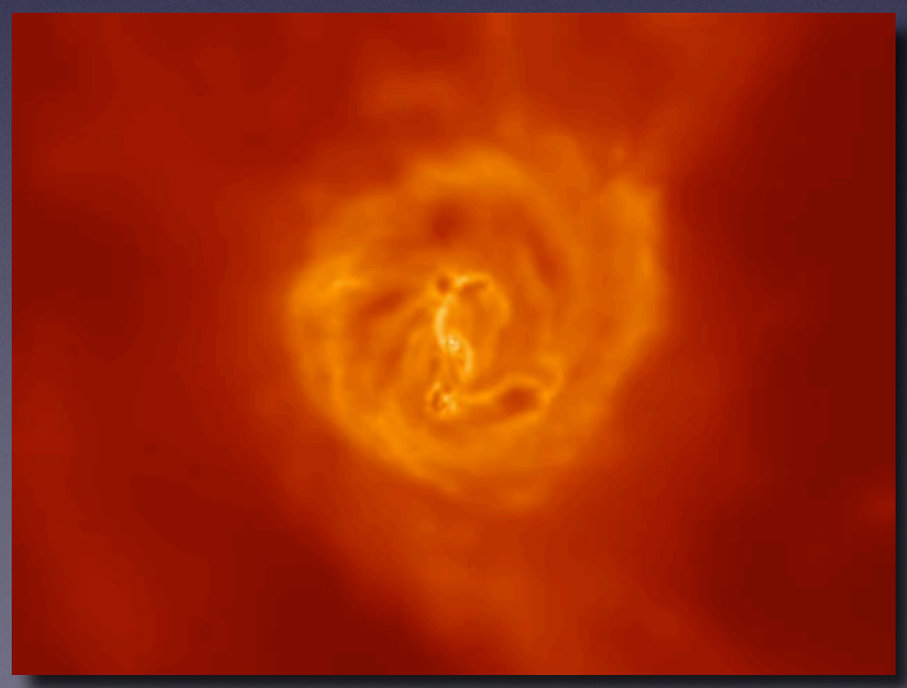
MARTINI
Mock APERTIF-like Radio Telescope Interferometry of the Neutral ISM

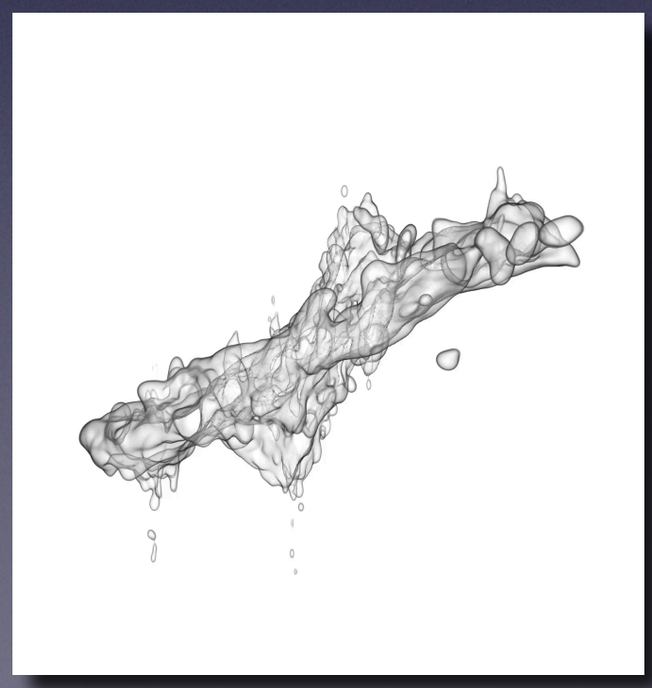
https://github.com/kyleaoman/martini

Configurable resolution, beam, spectral model, instrument, noise model, etc.
Fully documented!

Available for the public EAGLE and Illustris families of simulations.

Support for the TNG web API (https://tinyurl.com/martiniTNGexample)
and soon for the IllustrisTNG JupyterLab. (http://www.tng-project.org/data/lab)





Simulated HI datacube
of a warped EAGLE galaxy,
visualized with SlicerAstro.

koman@astro.rug.nl

APERTIF

Summary

- Apertif development since 2006
- Significant progress in recent weeks
  system capabilities, operations, pipelines
- Development is halted, but system not yet fully functional
  compound beams and bandpass stability
- Currently in system performance verification phase
  science requirements evaluated in April
- Surveys to commence in ~May 2019
- ASTRON does not commit to operations after 2020
  third parties sought to secure 4-year survey