Science with Weave's IFUs

galaxy structure, dynamics and evolution

-

synergies with Apertif and LOFAR

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Scott Trager

+ Weave science teams

university of groningen

Kapteyn Astronomical Institute

NOVA

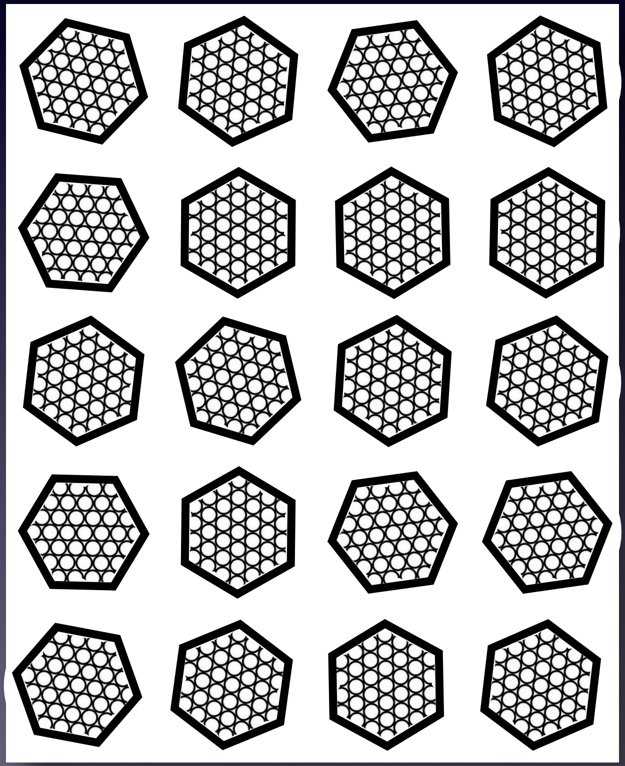
NWO

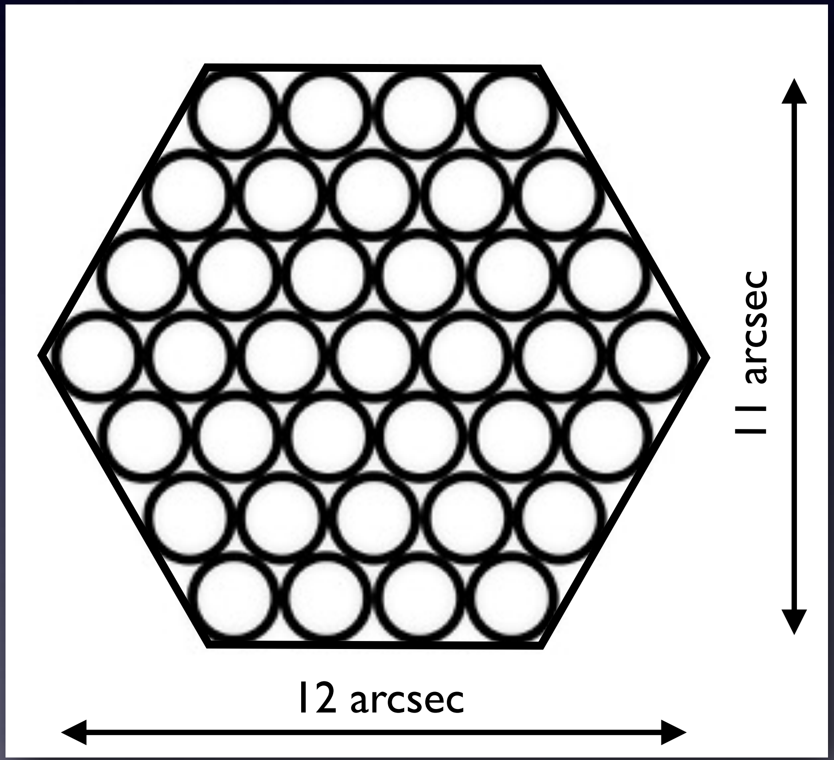
DAGAL Detailed Anatomy of GALaxies

Weave mini-IFUs (mIFU)

20 mini IFUs
>1' separation

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



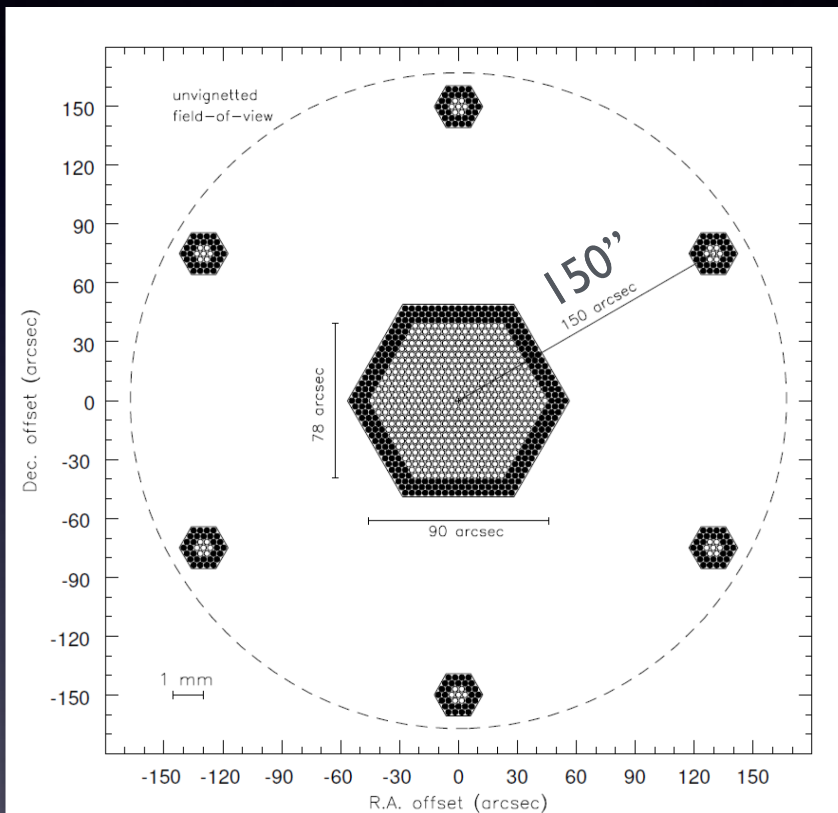


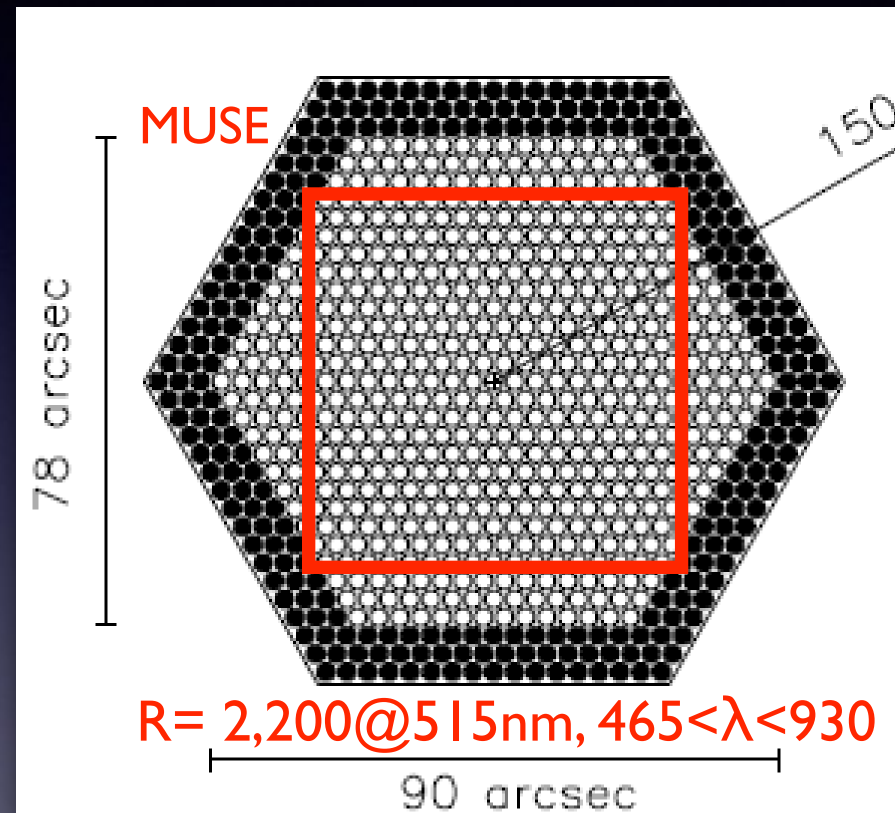
11"x12" FoV

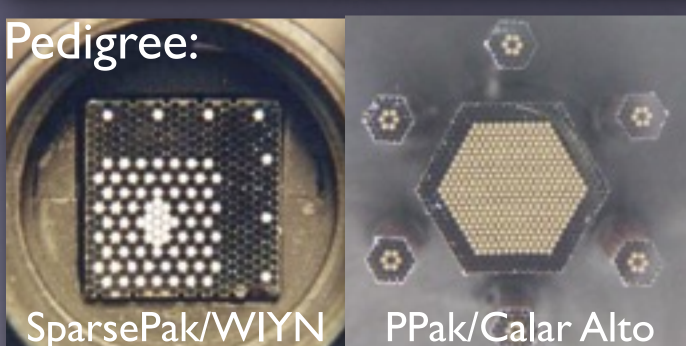
Same λ-range as LIFU but 2x better spectral resolution.

Weave Large IFU   (LIFU)

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







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

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

Theme 1: Weave - Clusters

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

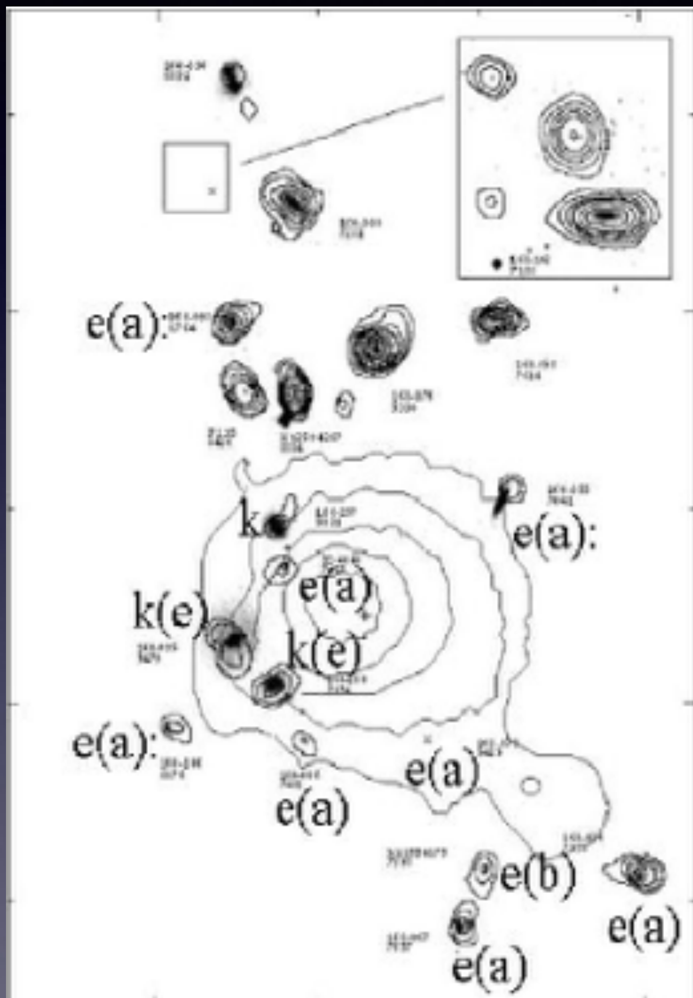
Which mechanisms dominate the transition from field to cluster galaxies?
Where and how does star formation stop?
Is there a mass/environmental dependence in pre-processing of galaxies?
How does the ISM respond to starvation/harassment/stripping?
How does the environment affect AGN activity and feedback?

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?

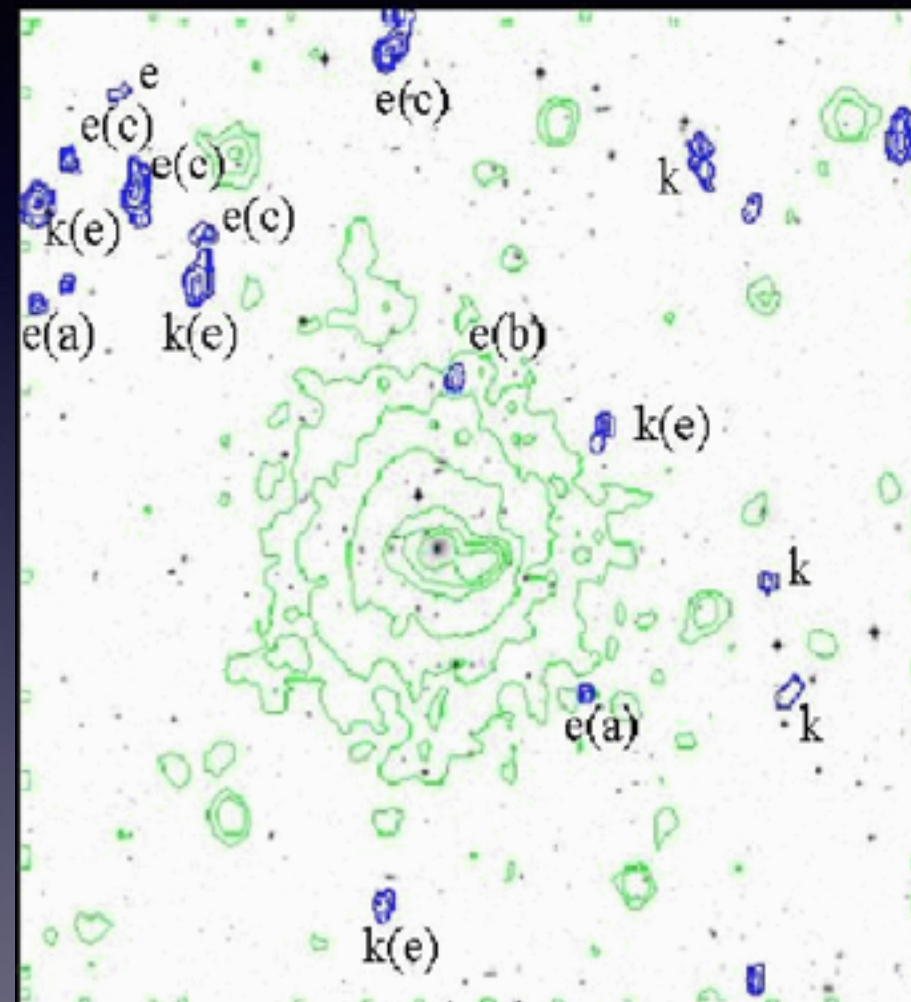
The infall regime : HI, ICM, SFR, SP relations

Coma Z=0.02



Bravo-Alfaro+ 01

Abell 2670 Z=0.08



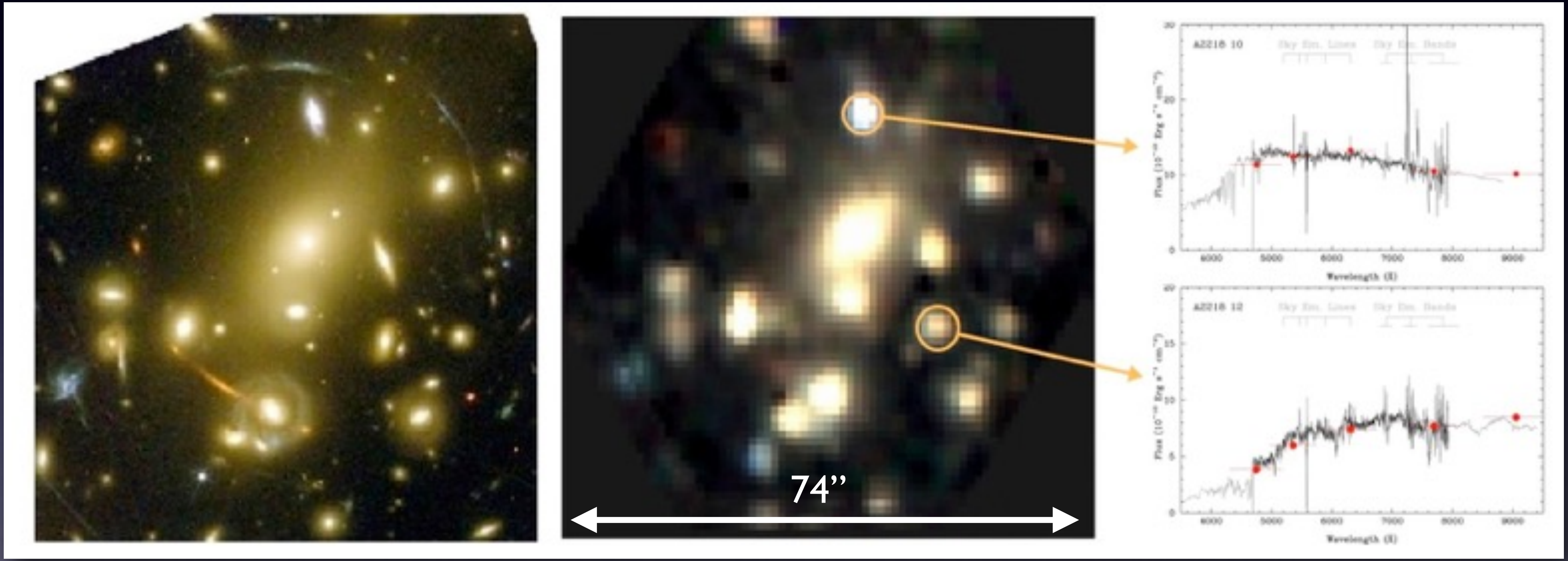
Poggianti & van Gorkom, 01

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

HST PPak galaxy spectra



With 6 hours of PPak:

Sanchez et al (2007)

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

Theme 2 : Weave - Apertif

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)

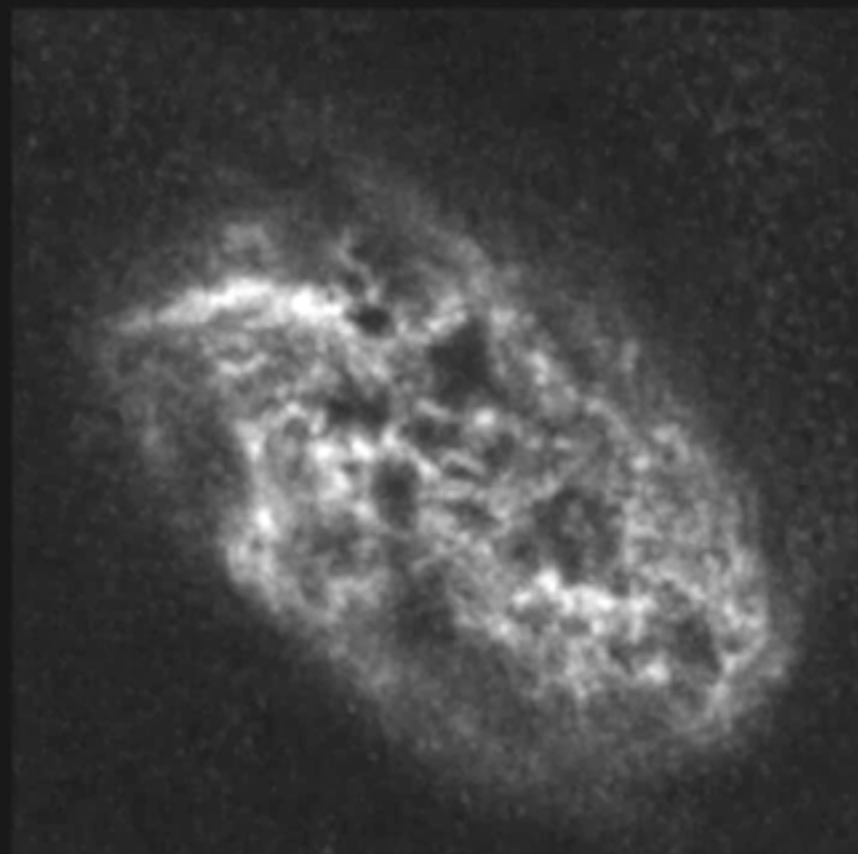
- Stellar kinematics in gas-dominated Lower Surface Brightness galaxies
- Galaxies at higher redshifts using Asymmetric Drift

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

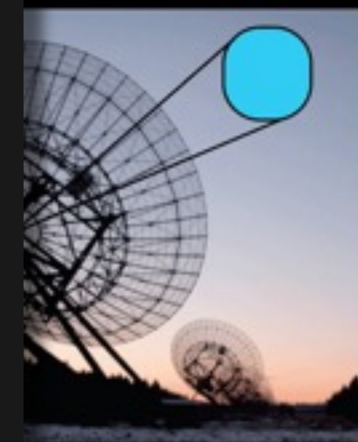
Westerbork upgrade

DDO 81



THINGS:VLA-BCD

De Blok et al (2008)



ctrograph

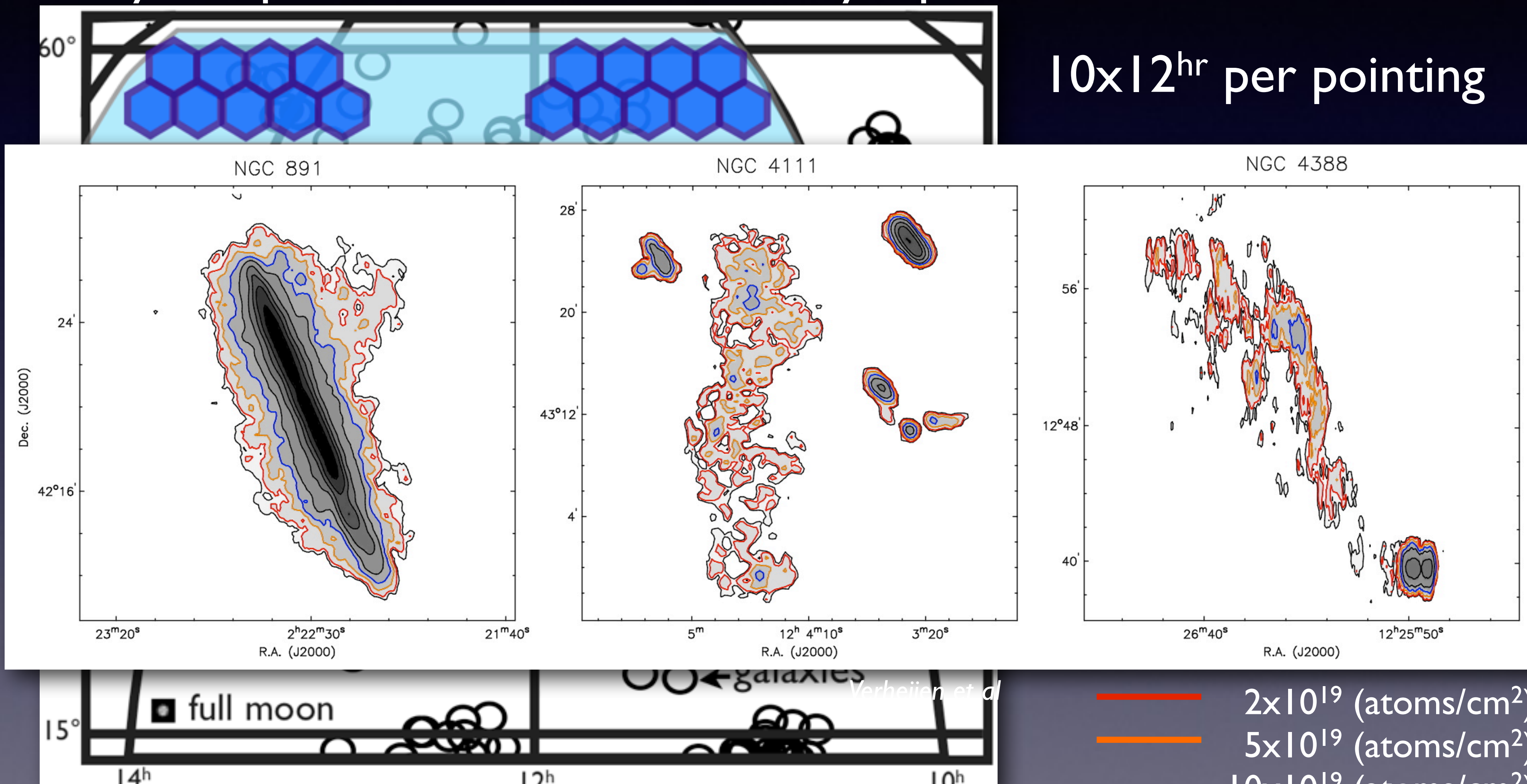
(HI z<0.25)

(R≈75,000)

medium-deep survey

APERTIF

likely footprint : based on community input



Fraternali et al

Verheijen et al

Oosterloo et al

10×12^{hr} per pointing

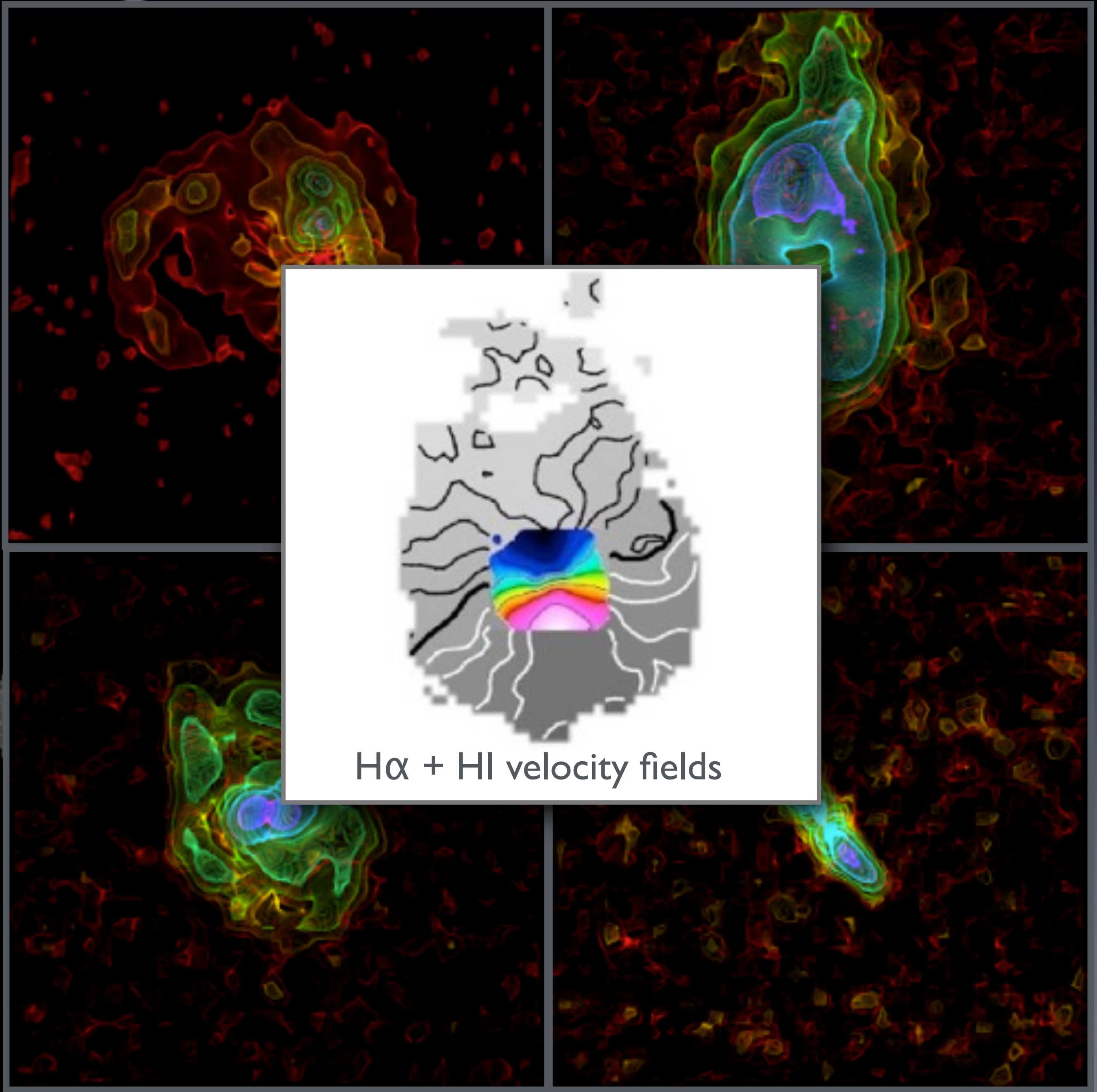
2×10^{19} (atoms/cm^2)

5×10^{19} (atoms/cm^2)

10×10^{19} (atoms/cm^2)

+ Perseus-Pisces supercluster

(includes ~100 Abell clusters)



WSRT mosaic
35 pointings, 1×12^{hr}
1717 channels

1346-1409 MHz
Θ = 16”x23”
$\Delta V \approx$ 16 km/s
σ = 0.6 mJy/bm

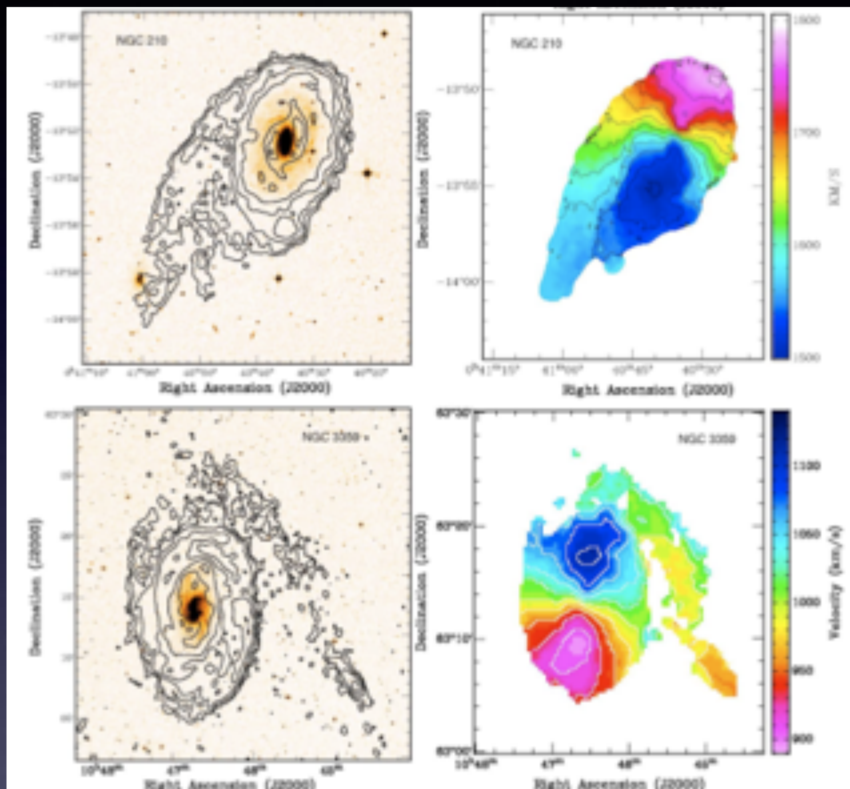
includes 3C129

200+ HI detections

Gas & Galaxy Evolution

APERTIF

Sancisi+ 2008



Fueling the Blue Cloud

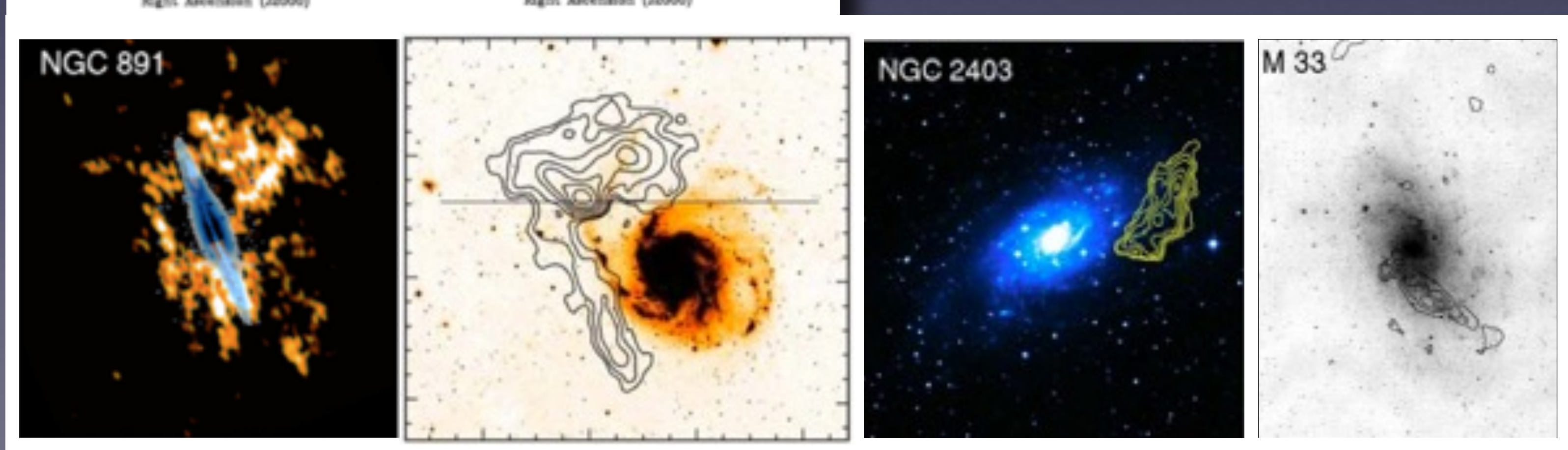
sustaining star formation

-

building up stellar mass

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

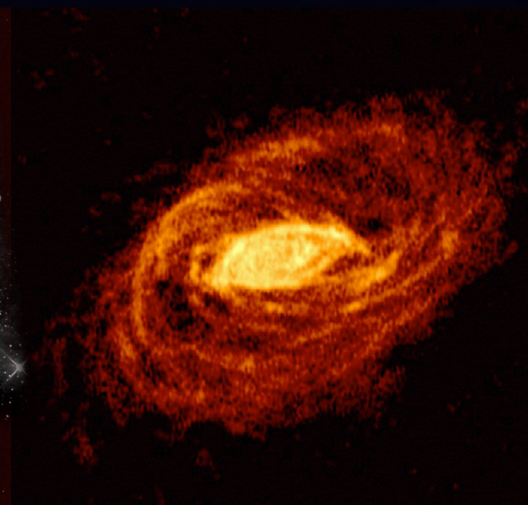
Oosterloo+ 2007



Warps and stellar streams - is there a link?

NGC 5055

R. Jay GaBany



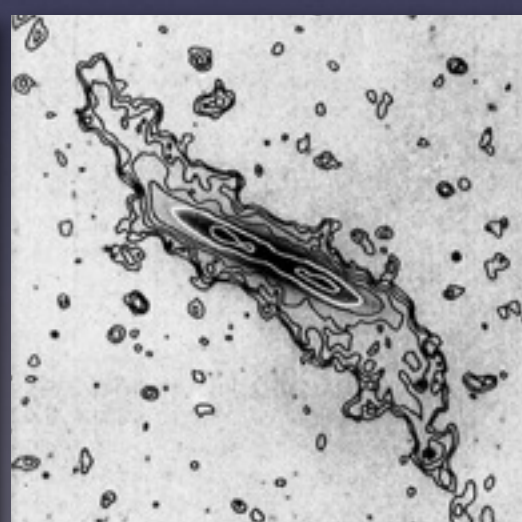
Battaglia+ 05

NGC 5907

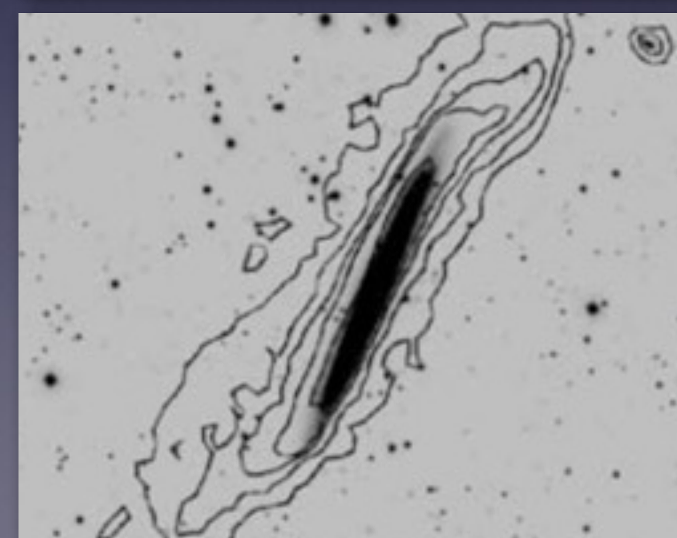
R. Jay GaBany

NGC 4013

R. Jay GaBany



Bottema 95



Shang+ 98

No gas associated with the streams.

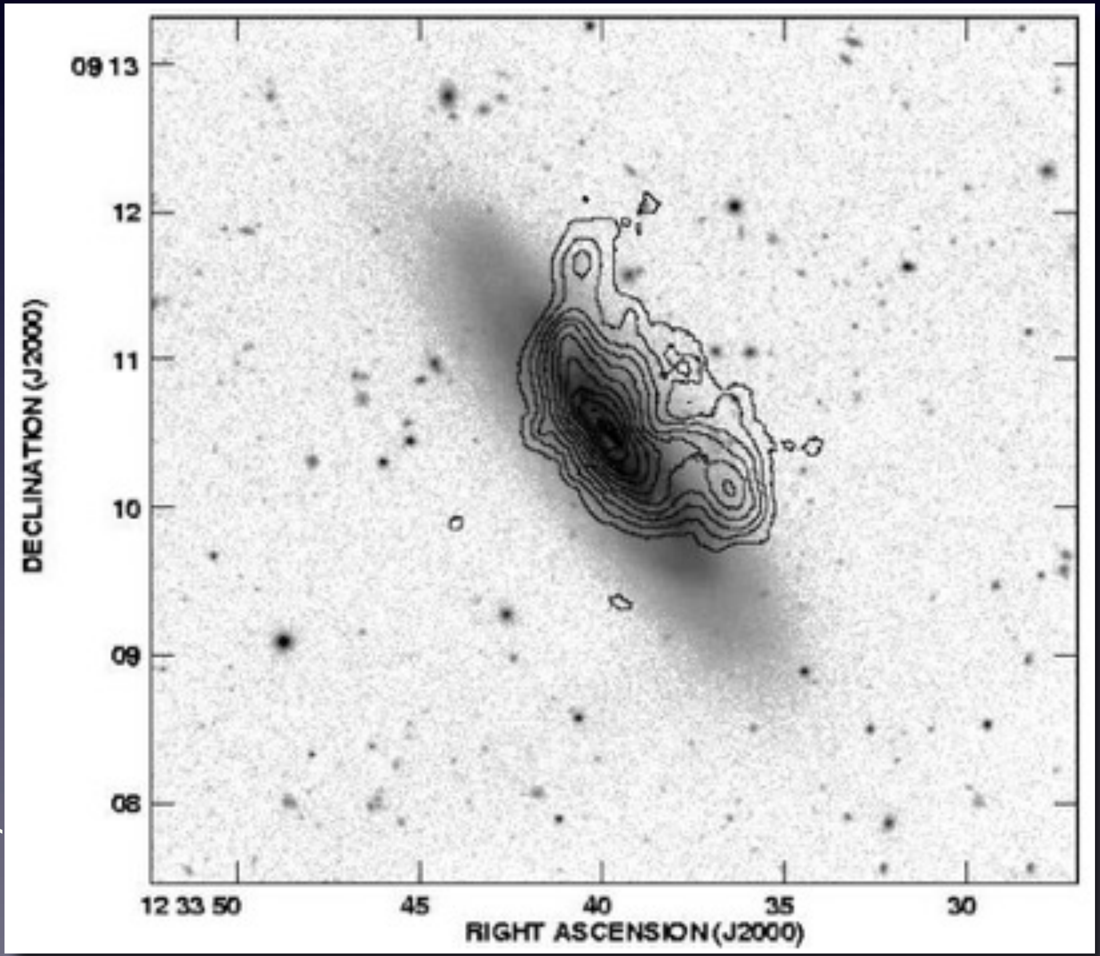
Gas & Galaxy Evolution

APERTIF

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

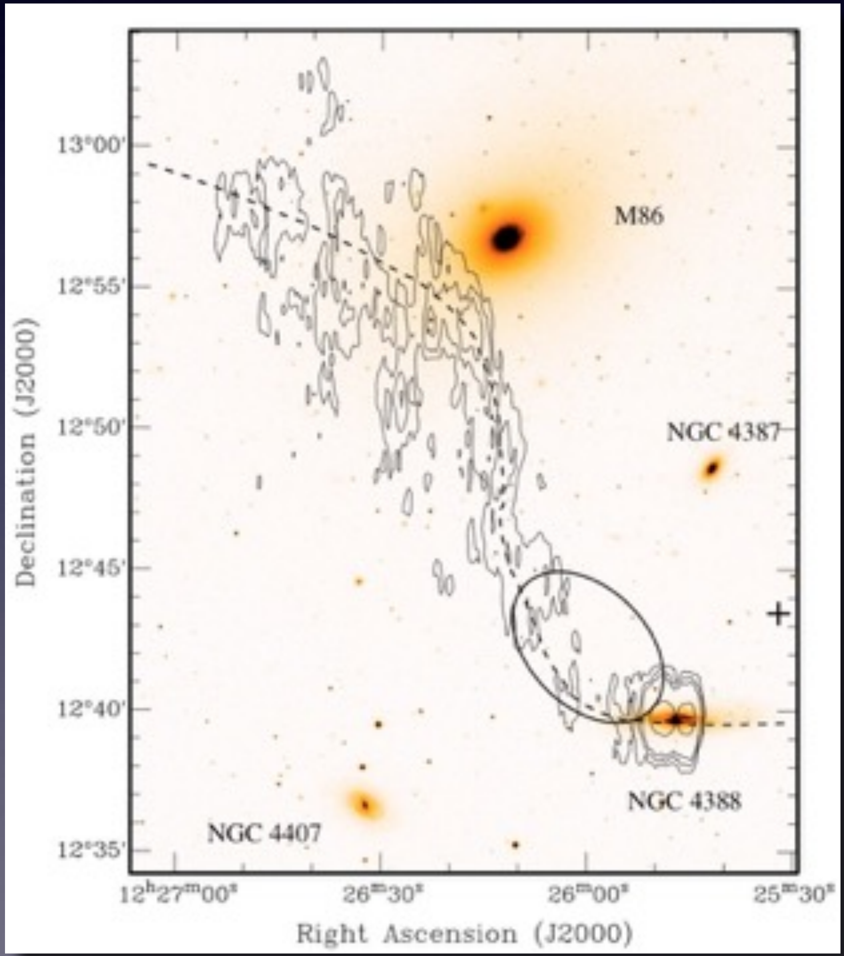
ram-pressure stripping in action

NGC 4522



Kenney+ 2004

NGC 4388

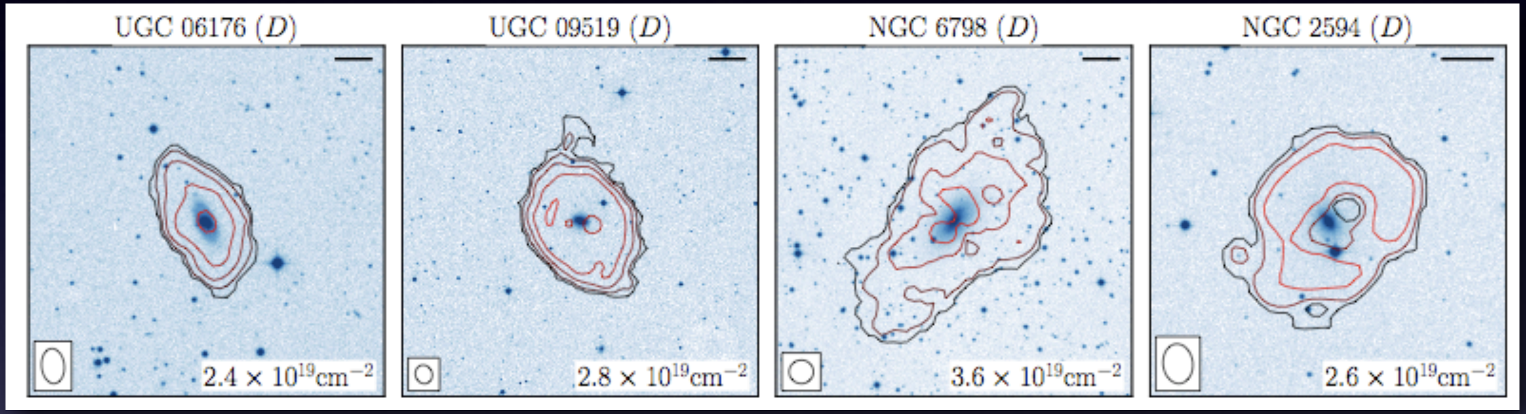


Oosterloo & van Gorkom, 2005

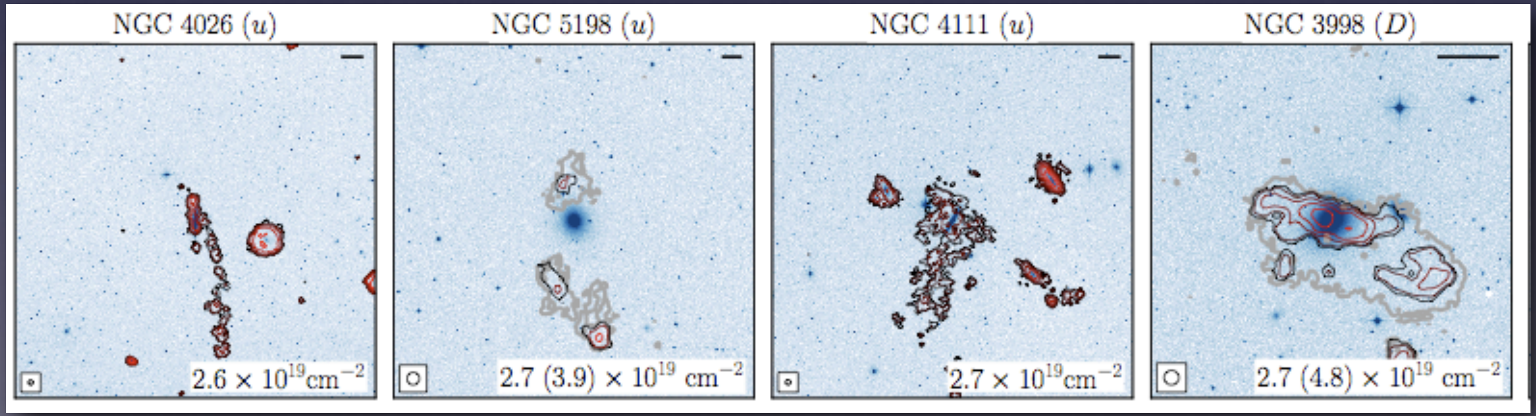
Gas & Galaxy Evolution

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

Lower density regions: extended & regular HI disks



Higher density regions: clumpy & unstructured



Serra+ 2011

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

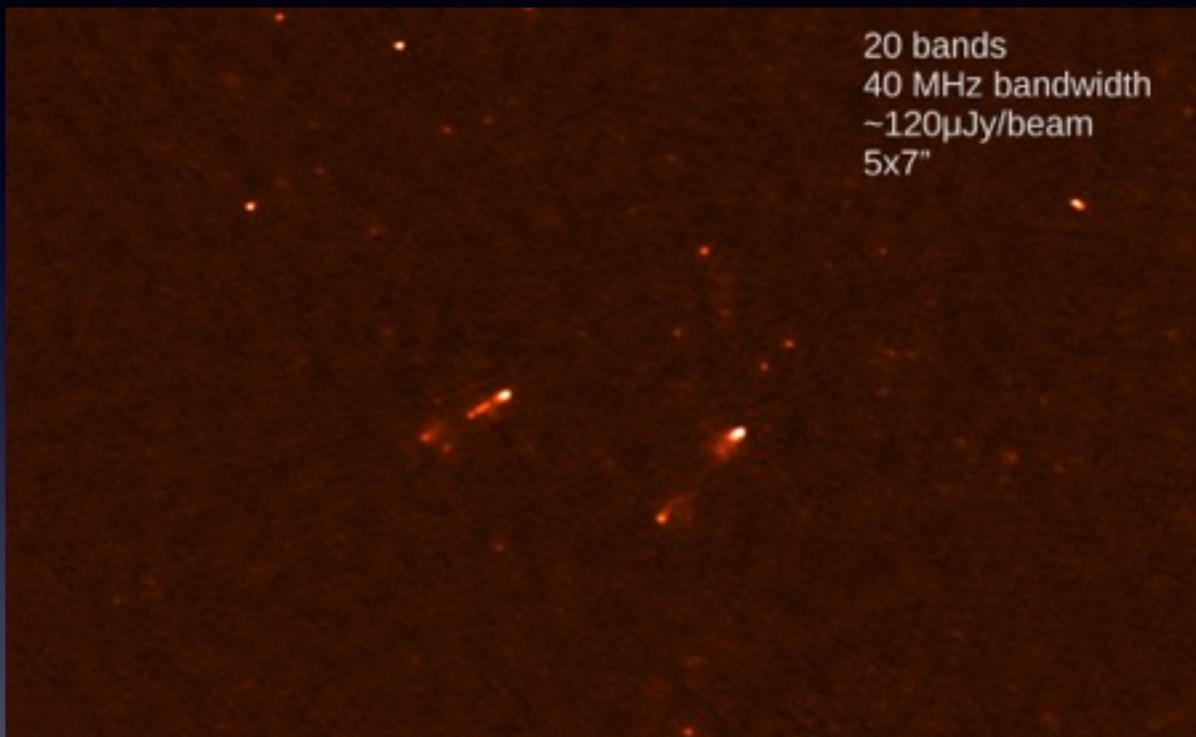
international stations

LBA : 10−90 MHz

HBA : 110−270 MHz → HI at Z=4−12 : Epoch of Reionisation

recent results

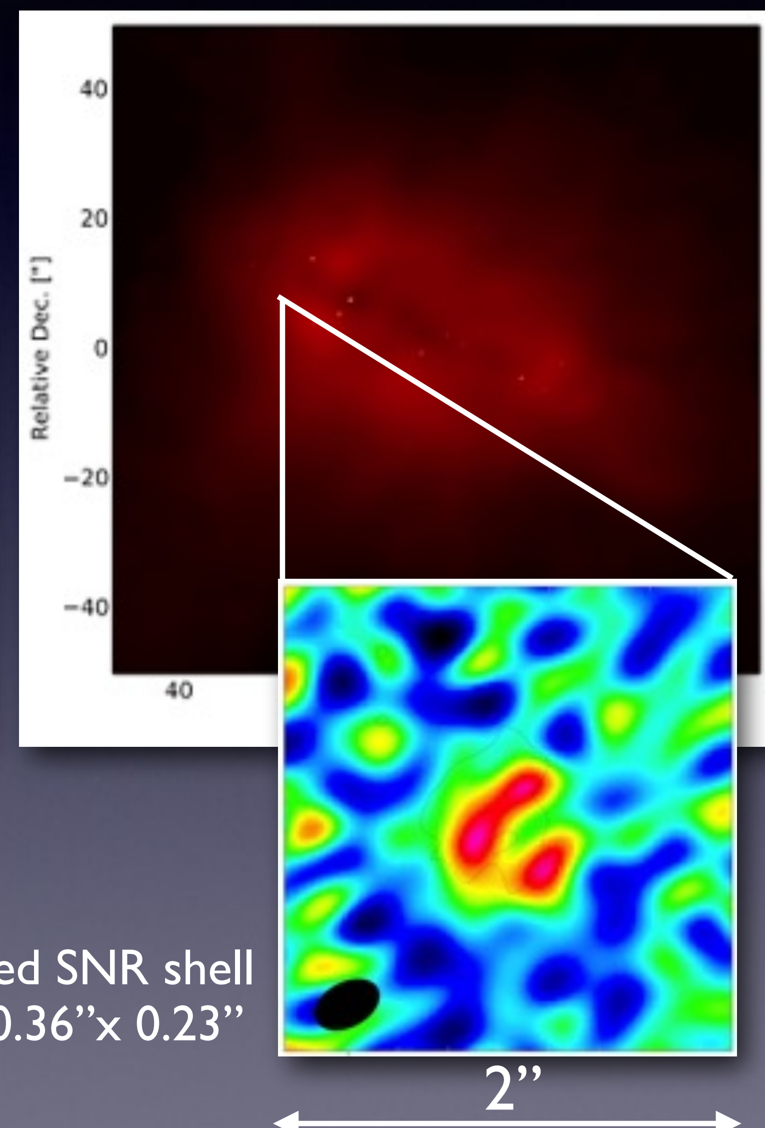
LOFAR HBA deep Bootes field



Courtesy: Wendy Williams (Leiden)

An unbiased view on
star formation
& AGN activity

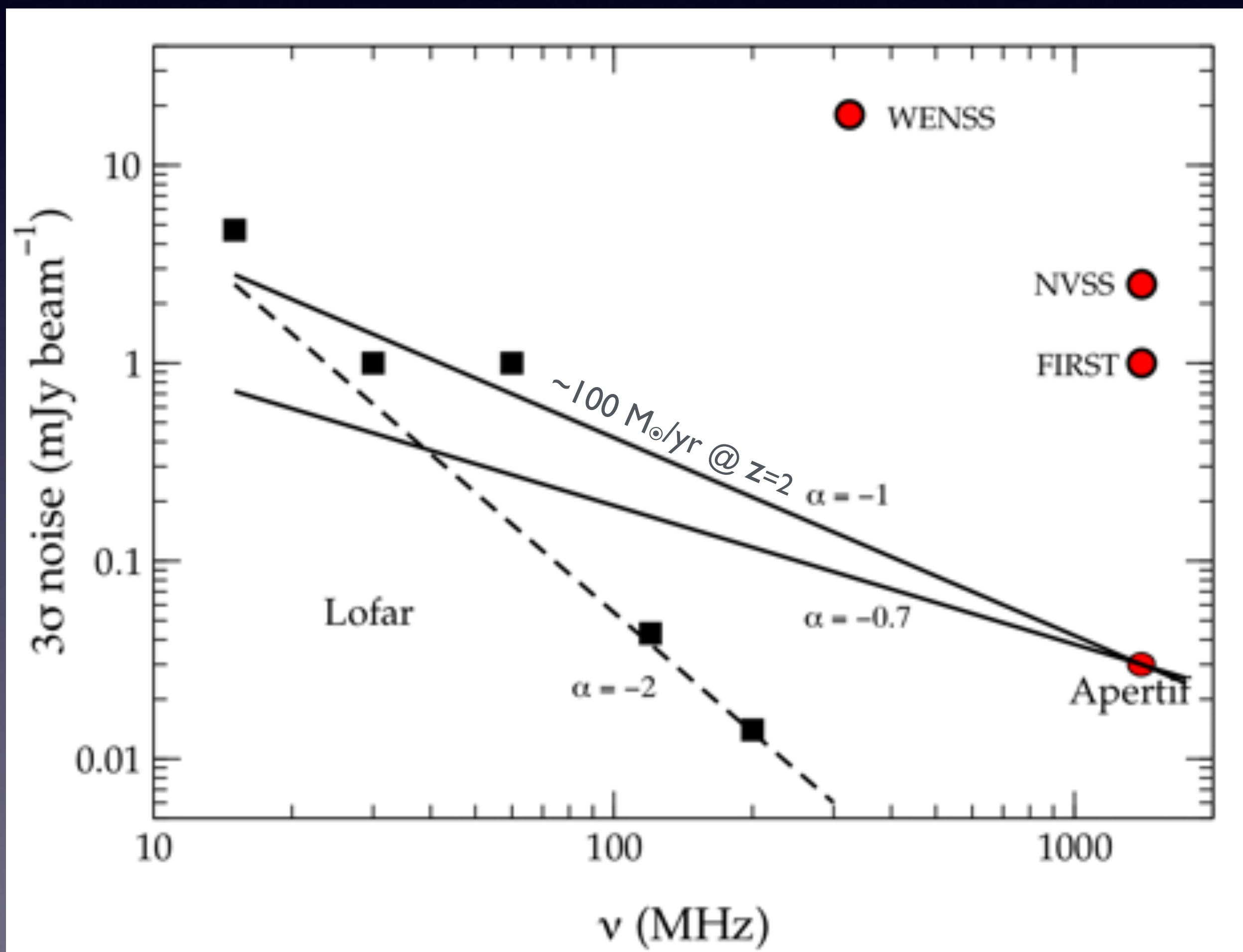
M82 at 154 MHz



Resolved SNR shell
beam: 0.36”x 0.23”

Varenius et al (2015)

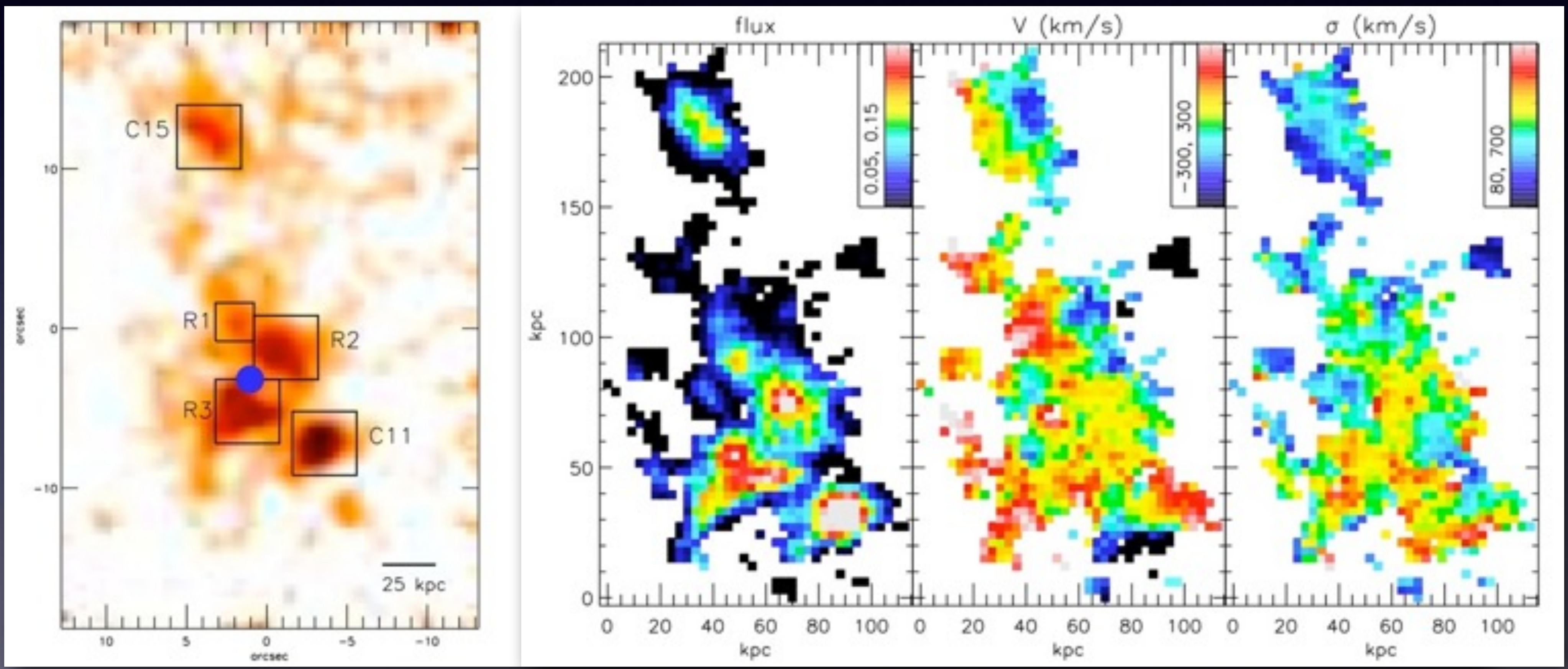
LOFAR & Apertif will see the same population of SF galaxies



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

Higher angular resolution of LOFAR reveals morphology of SF sites.

Lyman-α emission from proto cluster at z=3.09



Weijmans et al (2010)

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

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 deg^2 FoV by forming 37 'compound' beams.
- Frequency range : 1000 - 1750 MHz (z<0.4 , 0.6 for HI, OH)
- Instantaneous bandwidth : 300 MHz, 16384 chans, full stokes
- Resolution : $\Theta = (1+z)^2 \times 13\times13/\sin(\delta)$ arcsec^2 (10kpc @ D=150 Mpc)
  $R = (1+z) \times 7.7$ km/s (after Hanning smoothing)
- Line sensitivity : ~0.8 x current WSRT (~1 mJy bm^{-1}/chan/12^{hr})

Community interest

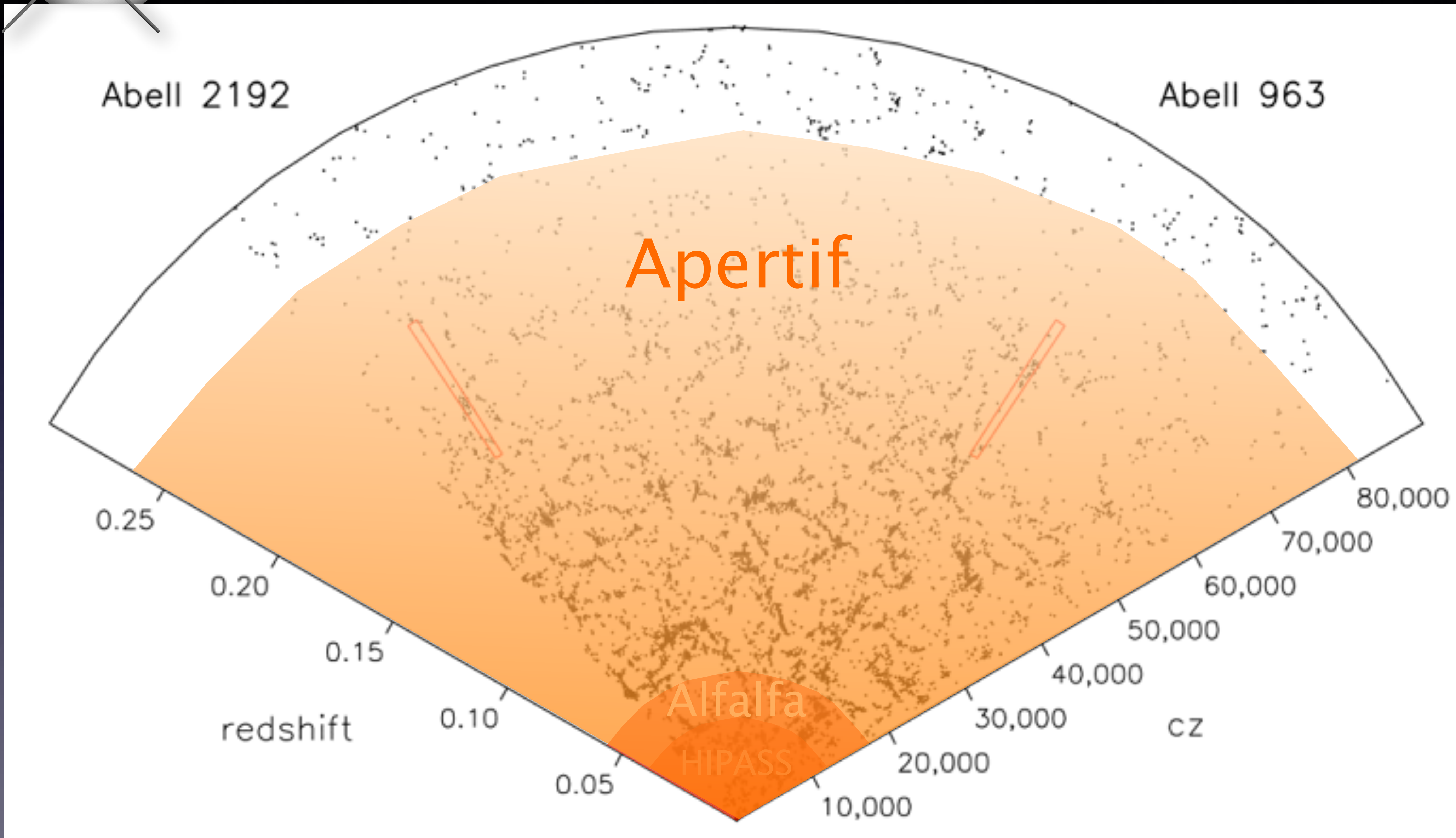
- July 2010 : Call for Expressions of Interest
- 18 EoIs received, requesting a total of 20 years
- November 2010 : Apertif Survey Coordination workshop
- 2011 : roll-out & commissioning plan
  Time line and involvement of sciene teams under consideration.

Call for Survey Proposals is pending ...

Scientific diversity

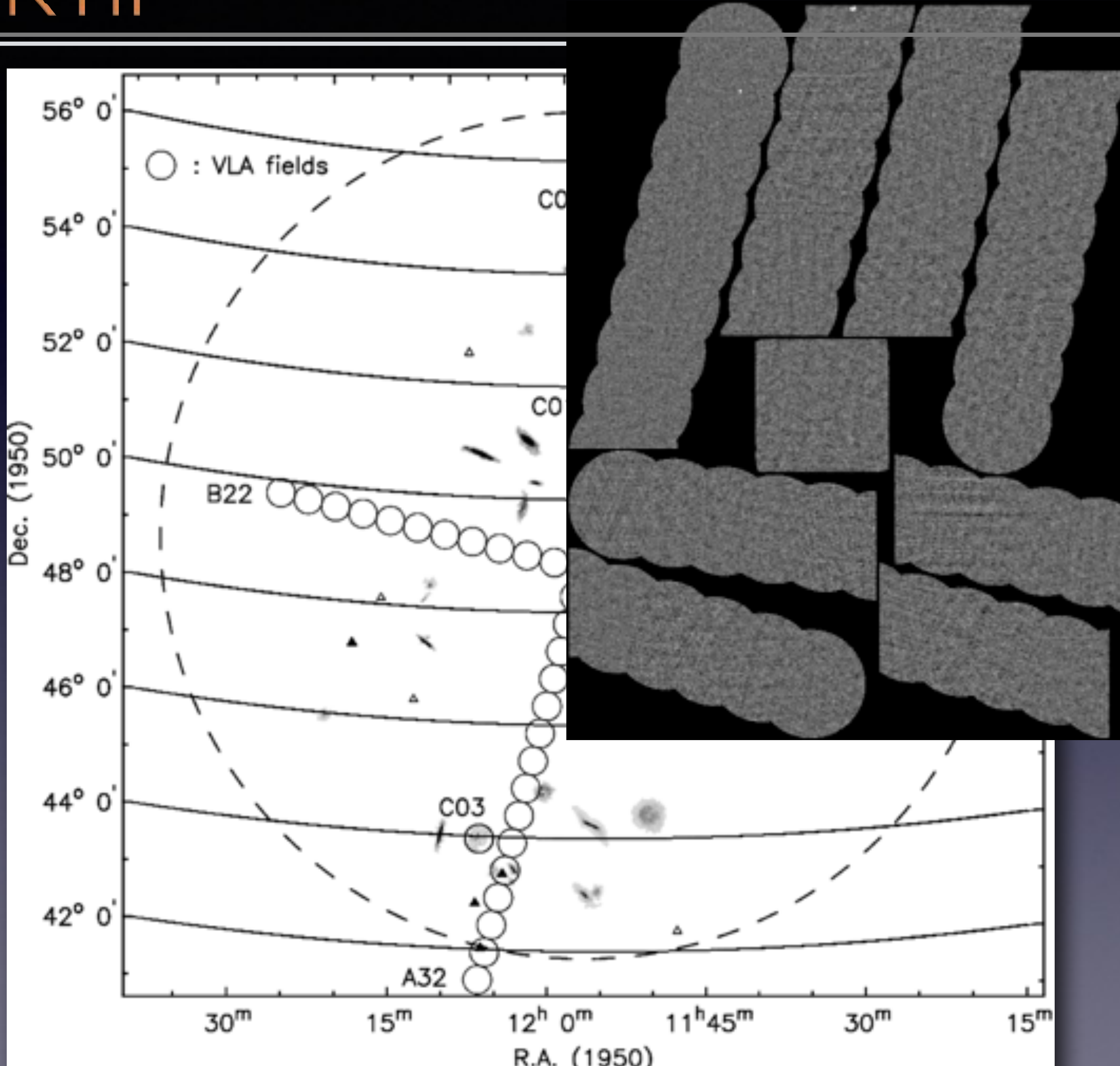
- Radio continuum surveys - Synergy with LOFAR
- Neutral hydrogen surveys - emission & absorption
  from the smallest to the most distant galaxies
- Pulsar searches
- Magnetic fields in the Milky Way and other galaxies
- (extra)galactic OH (mega-)masers
- Radio Recombination Lines
- Variables and Transient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

APERTIF

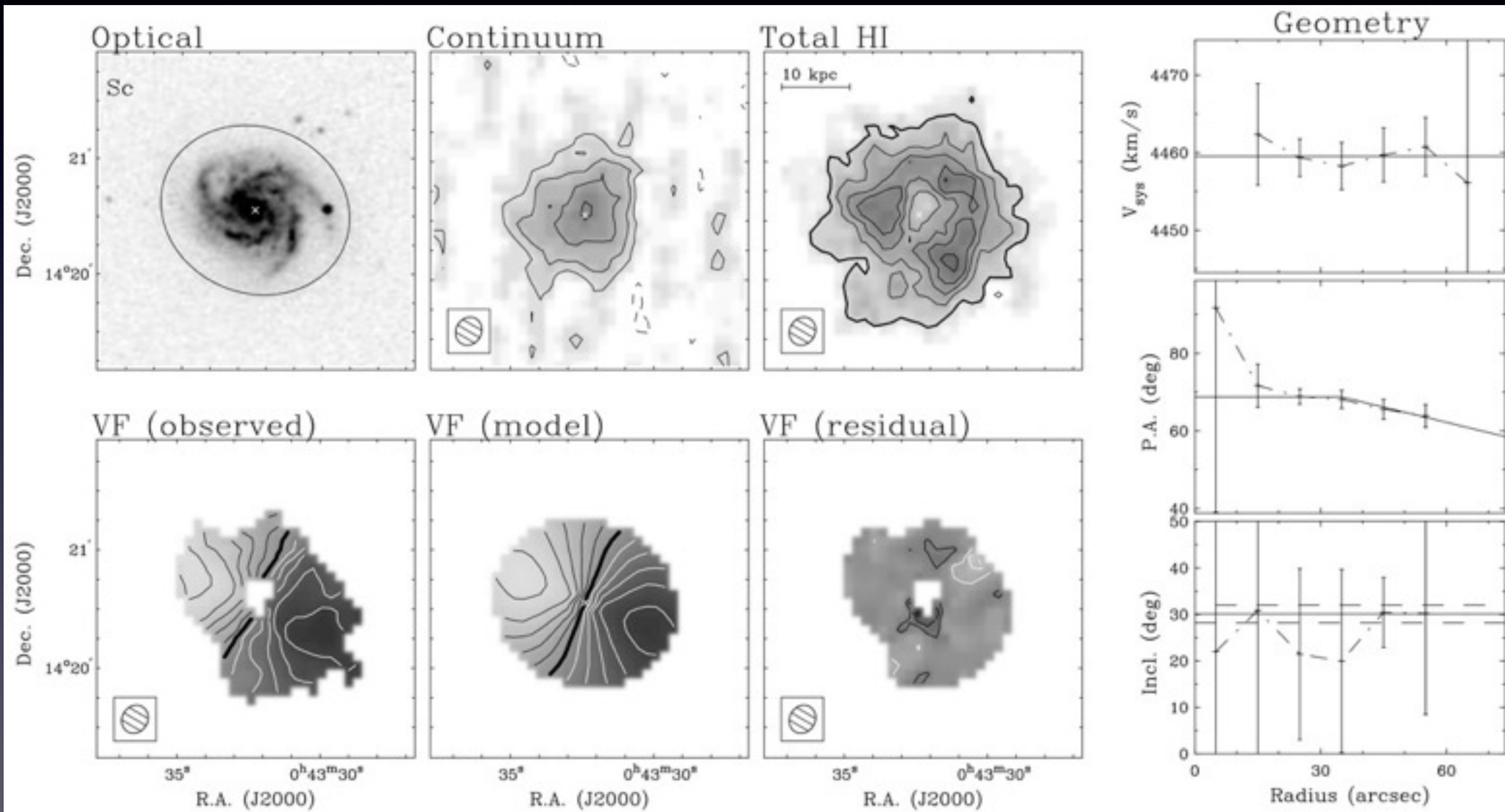


SDSS redshift slice

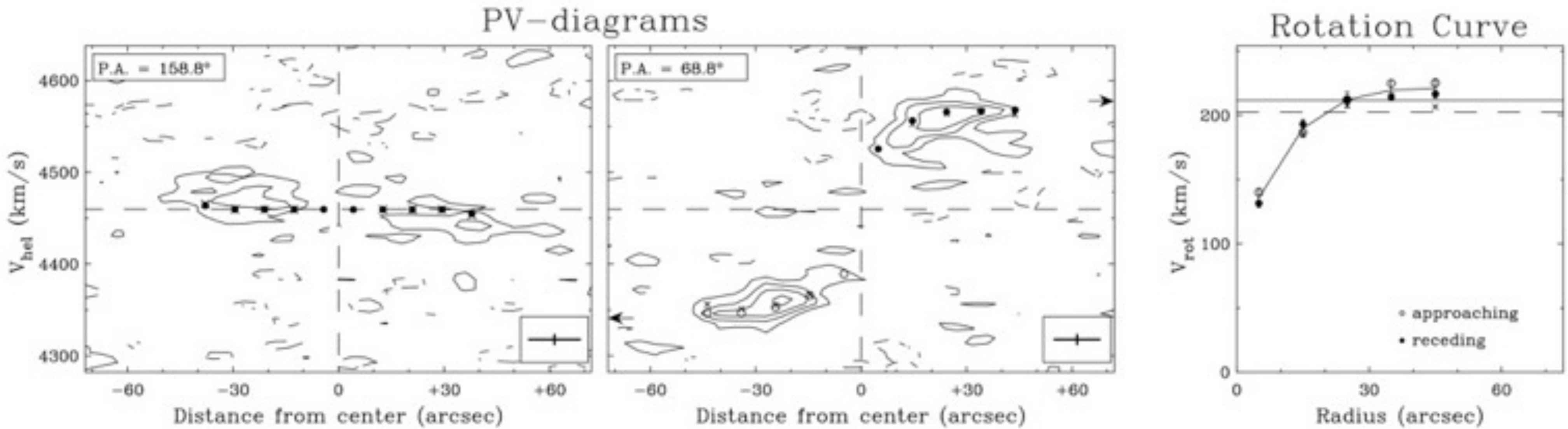
example of Apertif data product

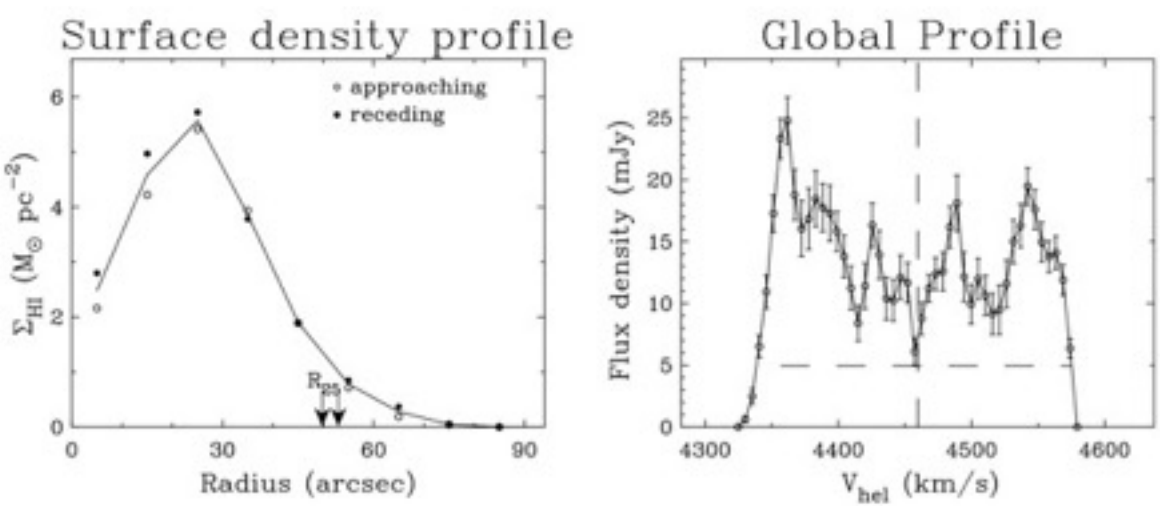


APERTIF


Optical
Sc
Continuum
Total HI
10 kpc
Geometry
VF (observed)
VF (model)
VF (residual)
Dec. (J2000)
21'
14°20'
35s
0h43m30s
R.A. (J2000)
Vsys (km/s)
4470
4460
4450
P.A. (deg)
80
60
40
Incl. (deg)
50
40
30
20
10
0
0
30
60
Radius (arcsec)

HI imaging data products





Atlas Table – UGC00463

Geometry:		**Contour levels:**	
RA	00:43:32.39 (J2000)	σ_{cont}	0.34 (mJy/beam)
Dec	14:20:33.20 (J2000)	σ_{pvd}	0.54 (mJy/beam)
V_{sys}	4459.5±0.5 (km/s)	VF (obs)	V_{sys} ± n×20 (km/s)
PA	68.8°±1.5°	VF (mod)	V_{sys} ± n×20 (km/s)
i_{TF}	30.1°±1.9°	VF (res)	±n×10 (km/s)
Flux & Densities:		**Velocity, Size & Resolution:**	
S_{21cm}	37.2±3.7 (mJy)	W_{20}	236.7 km/s
$S_{HI,max}$	24.8 (mJy)	R_{HI}	53 arcsec
$S_{HI}dv$	3.2±0.2 (Jy km/s)	Beam	14.7"×12.9"
$\Sigma_{HI,max}$	5.57 ($M_\odot$ pc^{-2})	Vel.Res	10.5 km/s

APERTIF

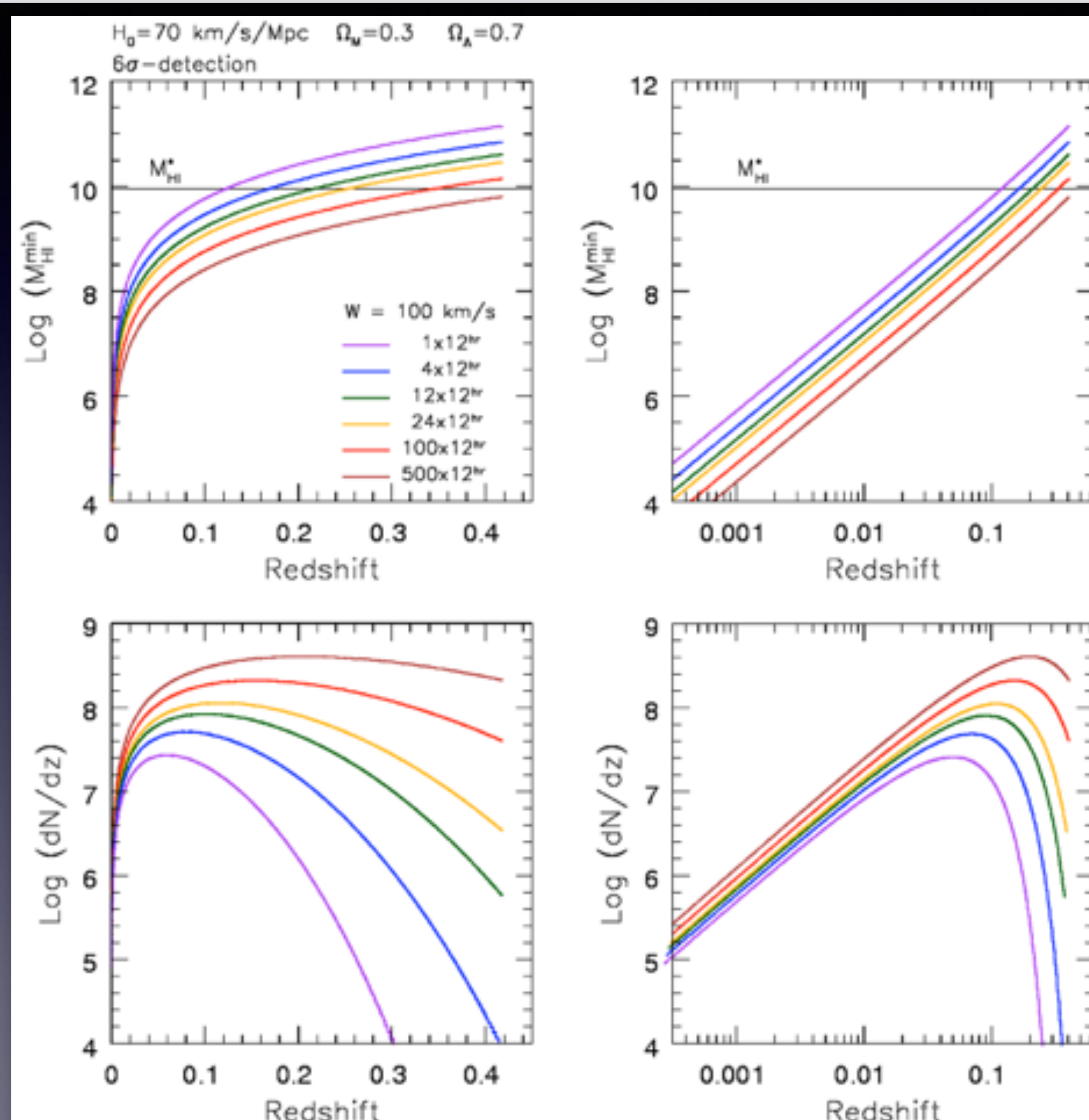
HI mass limits

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

Column density limit :

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

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

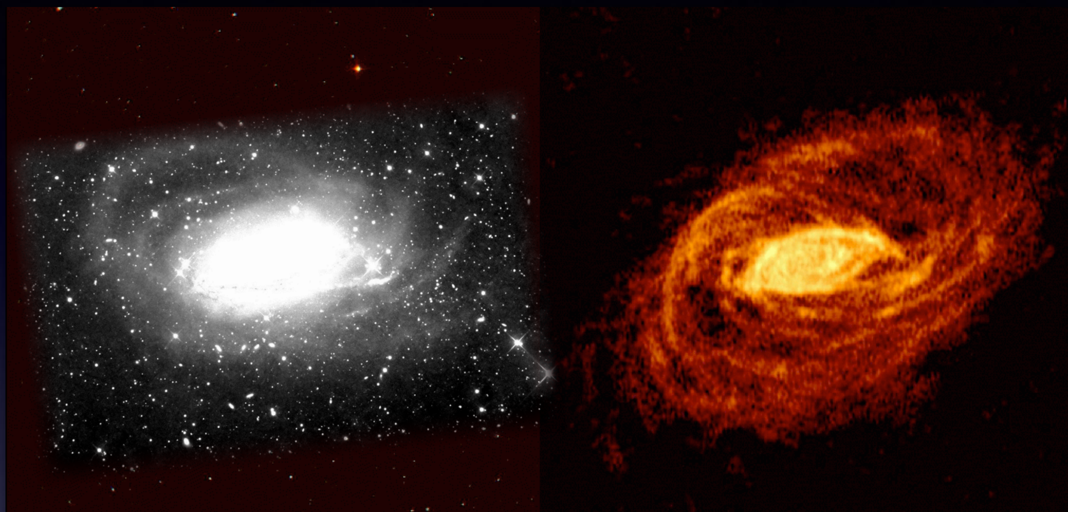


HI science topics

- 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.
  - $\Omega_{HI}(z)$, gas fractions vs mass, role of gas in downsizing...

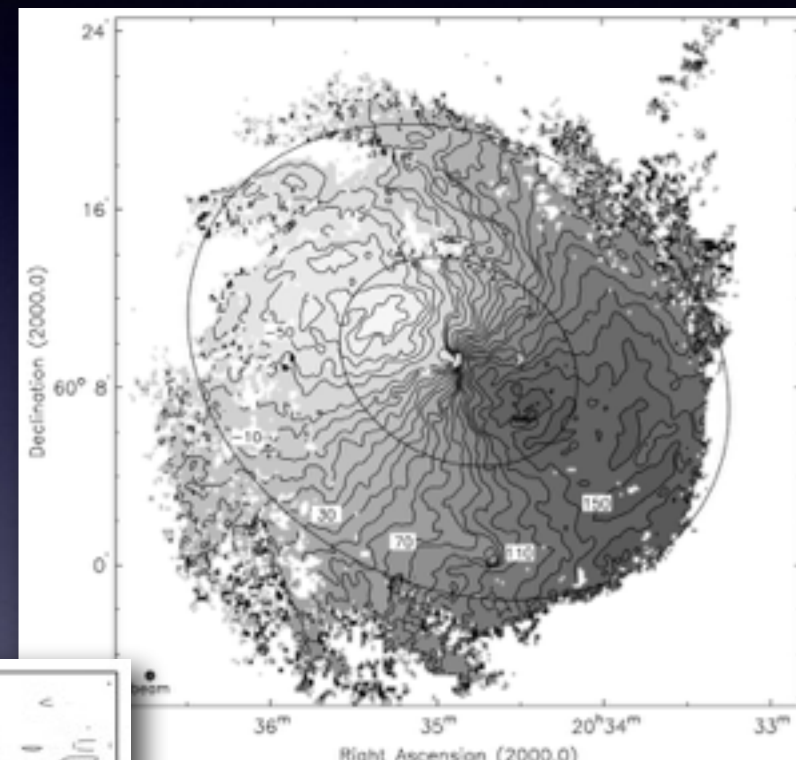
Galaxy structure and kinematics

What causes excessive streaming motions?

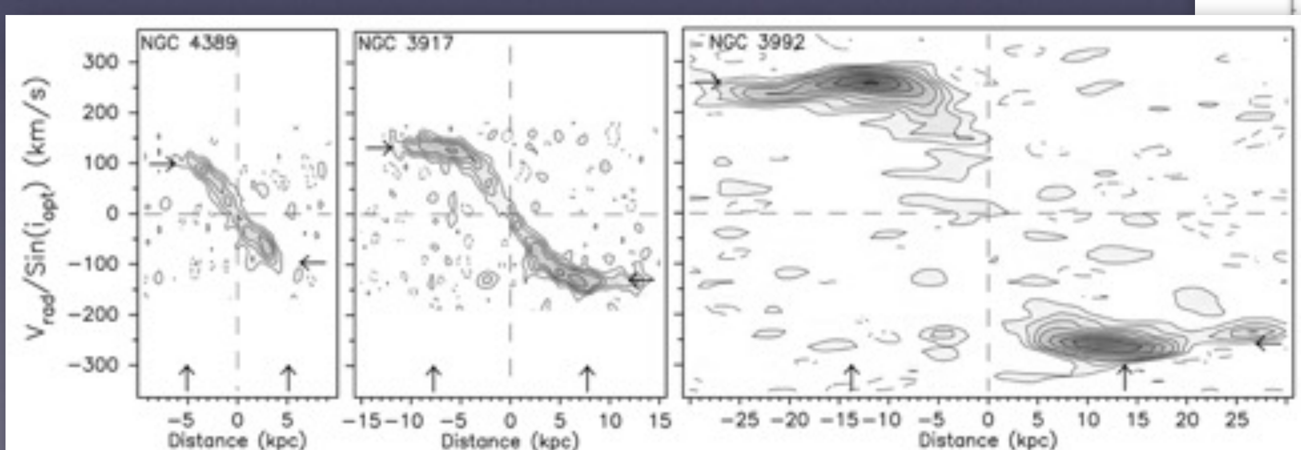


Battaglia et al 2005

Is there a correlation between warps and stellar streams?



Boomsma et al



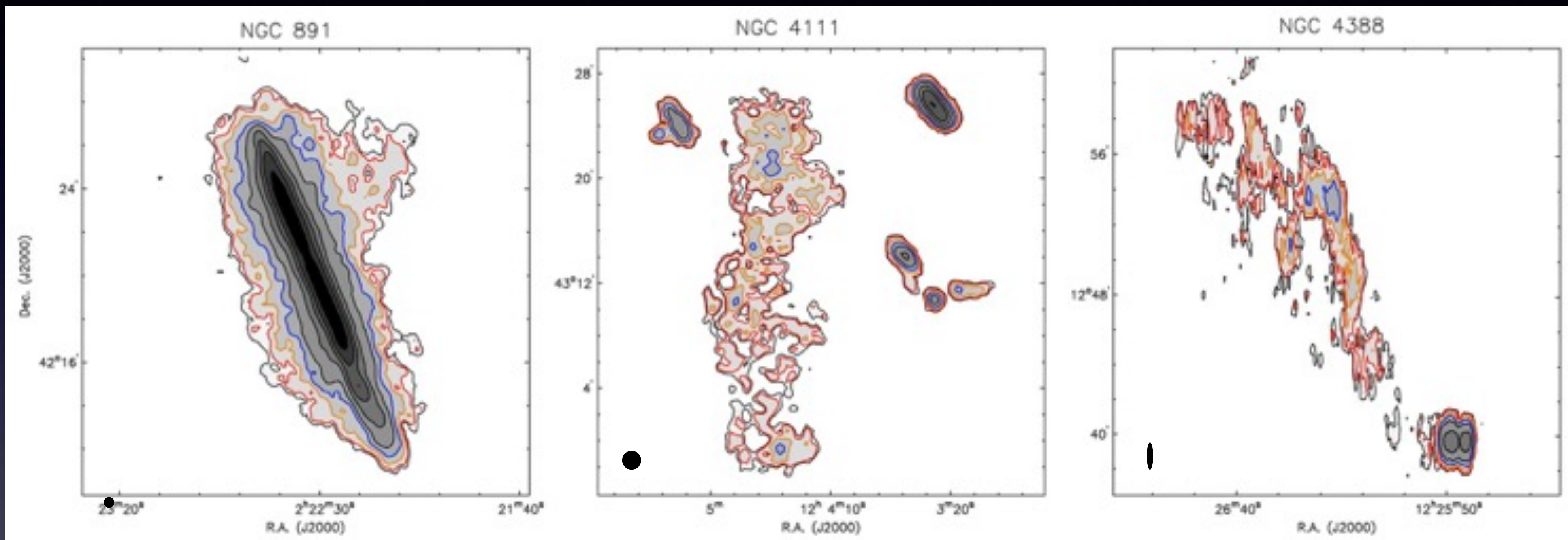
Verheijen

Do rotation curve shapes depend on galaxy environment?

APERTIF

beam = 30”x30” | beam = 45”x45” | beam = 18”x90”

Fraternali et al



Oosterloo et al

Verheijen et al

2x10^{19} (atoms/cm^2)
5x10^{19} (atoms/cm^2)
10x10^{19} (atoms/cm^2)

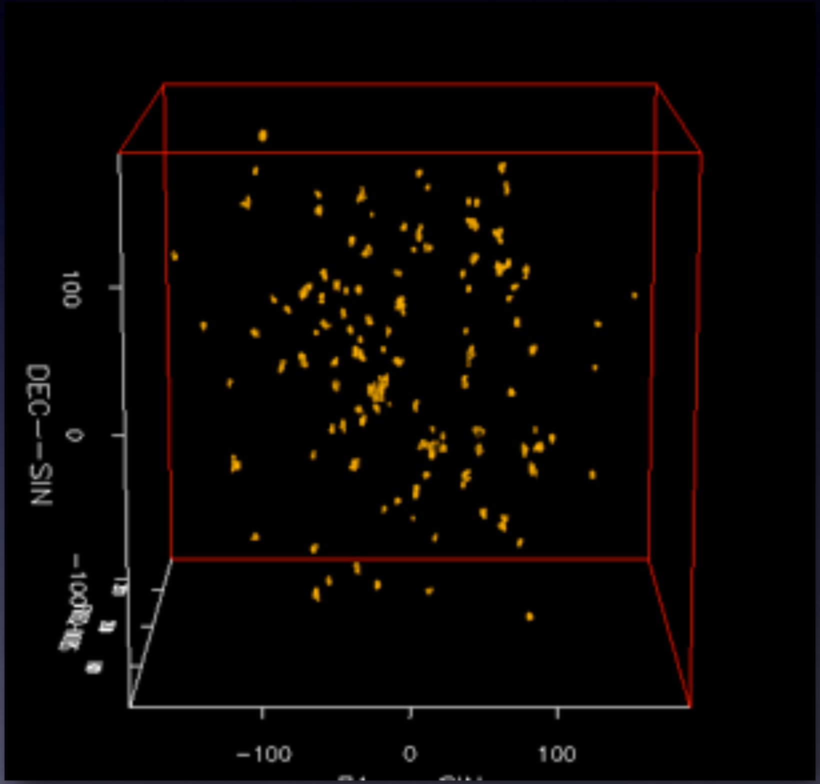
Map and measure these filaments
in various evironments at different redshifts.

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

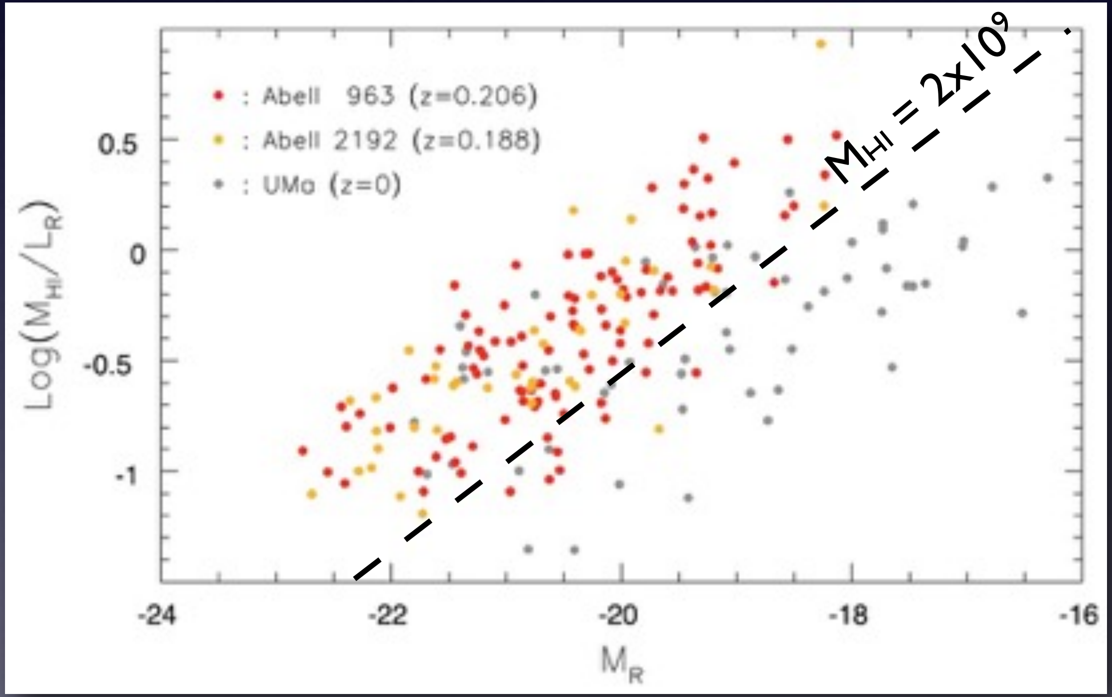
Which gas accretion/depletion mechanisms dominate where?

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?

Shallow HI surveys

- Józsa : WNSHS - Westerbork Northern Sky HI Survey.

  - $\delta > +27°$, $Z = 0 - 0.26$, 6^{hr} - 12^{hr} per pointing

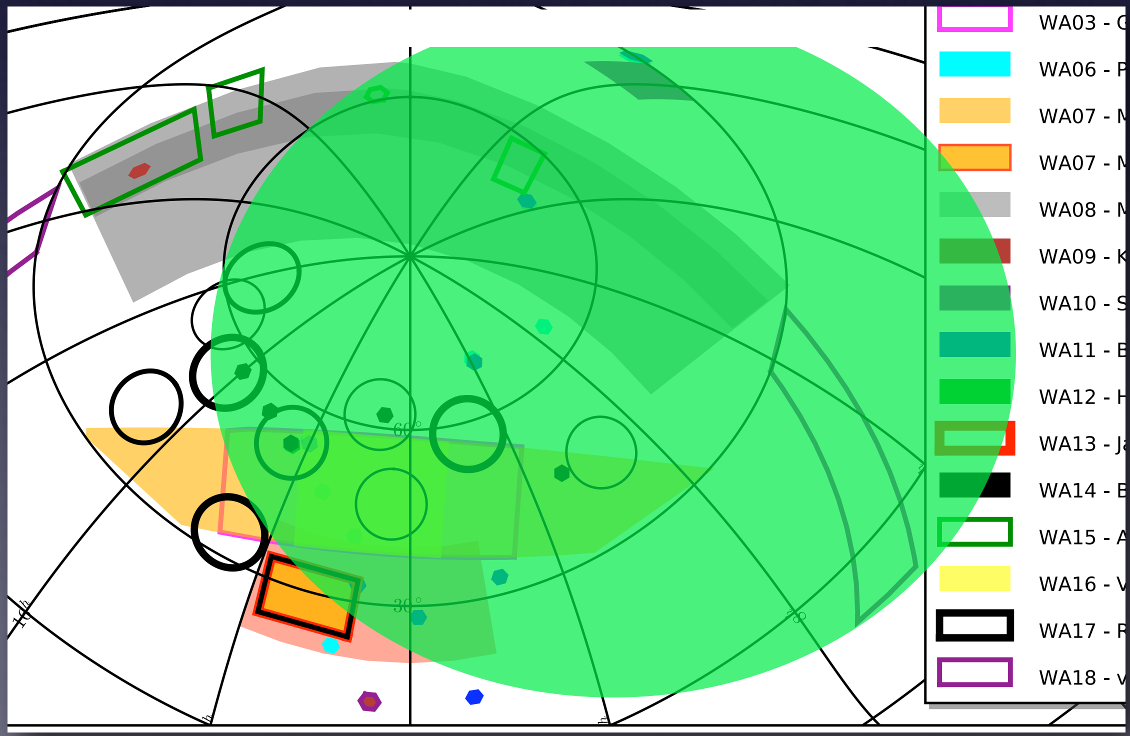
  Expect $\sim 10^5$ HI detections over 10.000 deg^2

  ➙ 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 4π of the sky in concert with the Wallaby survey.

proposed Apertif survey footprints



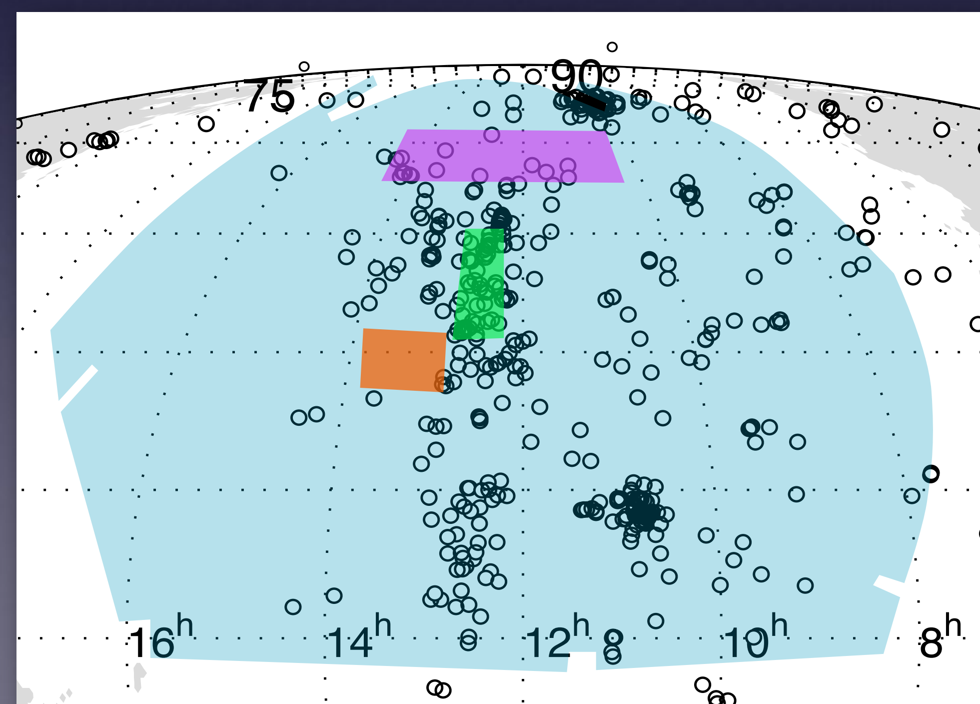
Medium-deep HI surveys

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

1) HI mass function down to $2x10^5$ M_{sun},

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.



APERTIF

Deep HI surveys

- Brinchman : DASH - Deep Apertif Survey of HI

  - 5 pointings, 100×12^{hr} per field, Z=0.02−0.30

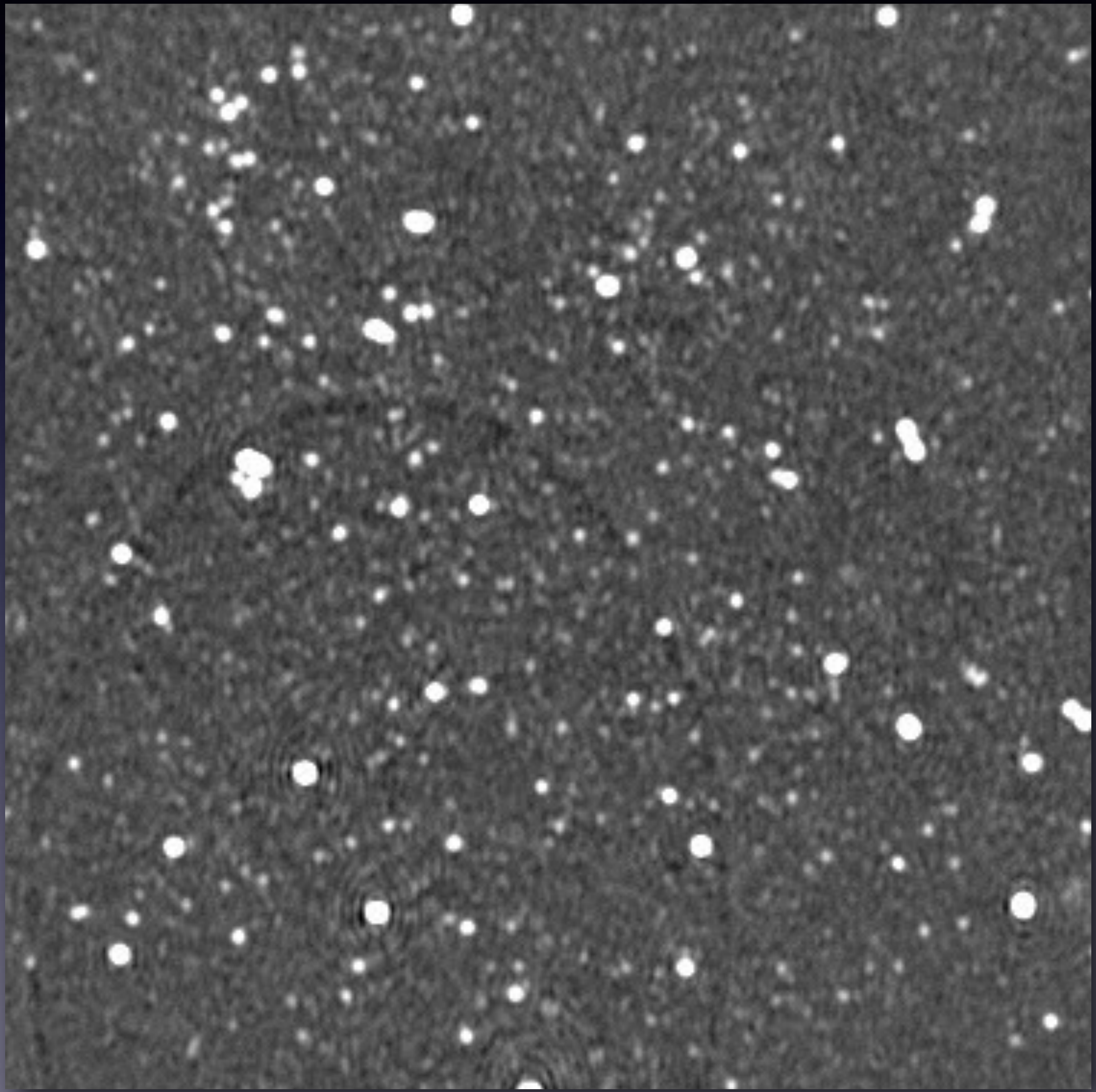
  To address how galaxies accrete, process and return gas to the intergalactic medium and to understand the fueling of cold gas in very gas-rich galaxies by carrying out a comprehensive characterisation of the HI content of galaxies, and its link to galaxy properties. Taking advantage of HST/COS sightlines.

- Holwerda : WASGOED - Westerbork Apertif Survey of Galaxies Observed at Extreme Distance

  - 1 pointing , 500×12^{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_{sun}/yr

Apertif & LOFAR will see the same star forming galaxies.

APERTIF / WEAVE

Synergy with WEAVE

Provide a broader astrophysical context for HI detections

Low-res: M-IFU R≈5000 , L-IFU R≈2500

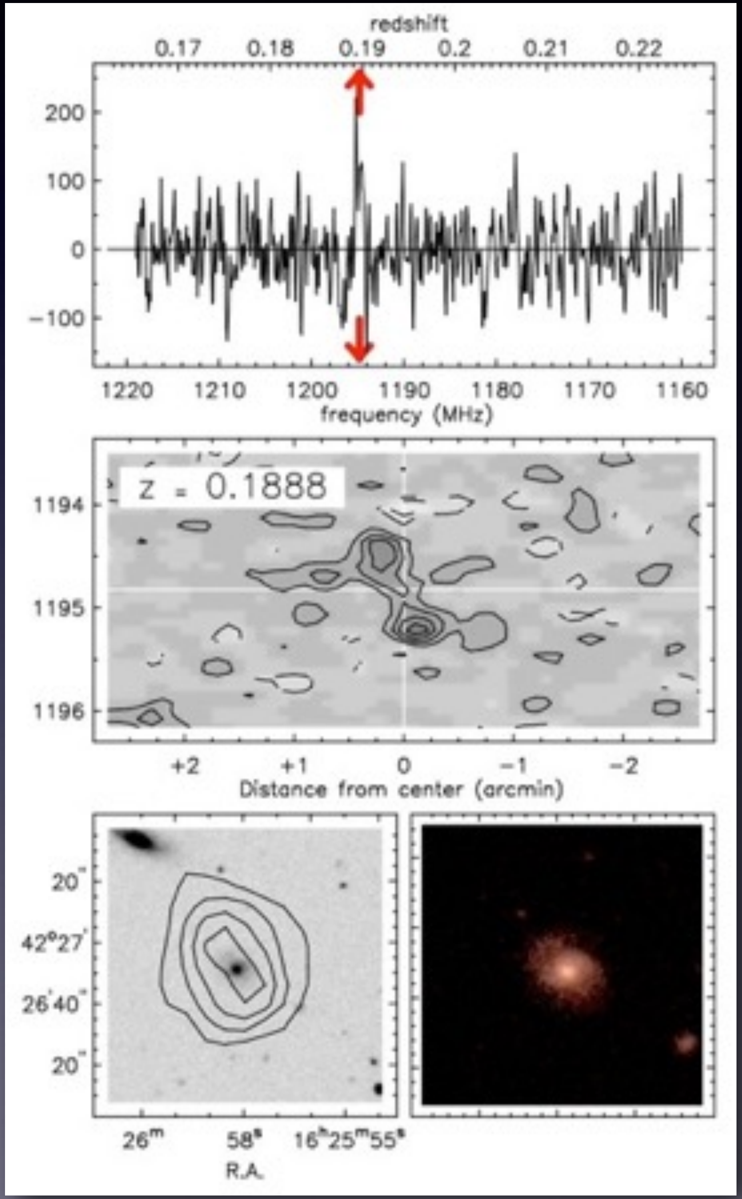
- ionized gas kinematics
- evolutionary state of stellar populations
- ISM & star formation properties
- .....

High-res: M-IFU R≈20.000 , L -IFU R≈10.000

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

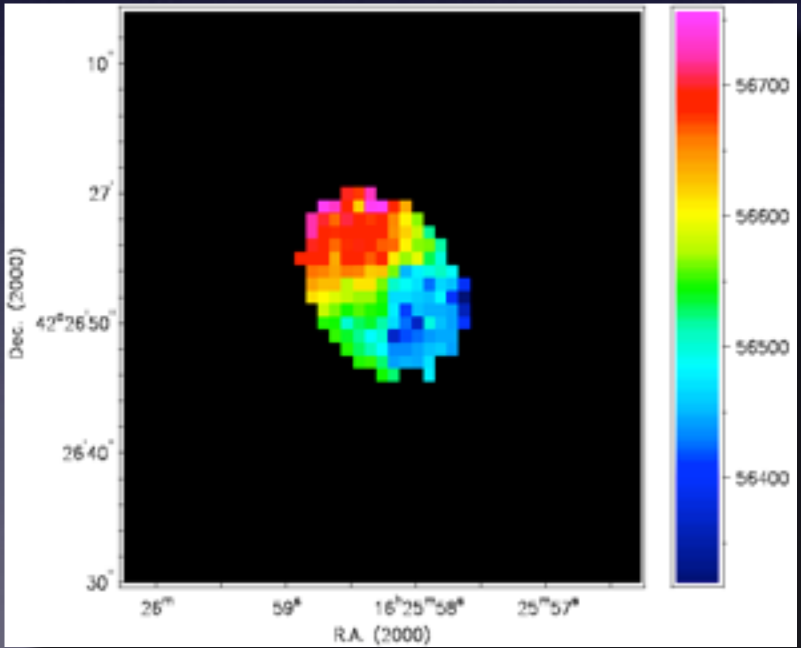
APERTIF / WEAVE

ionised gas kinematics



HI detection at z=0.188

[OII] velocity field



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

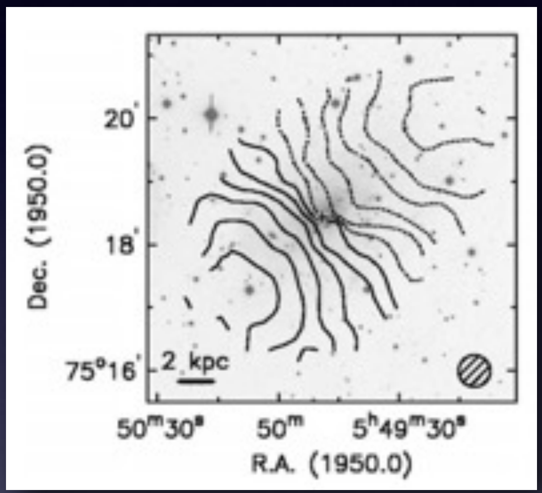
APERTIF / WEAVE

ionised gas kinematics

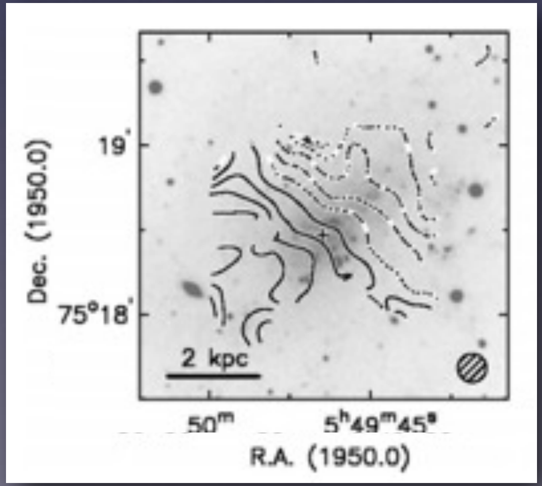
Kinematics of Low Surface Brightness galaxies

Hα+HI rotation curve

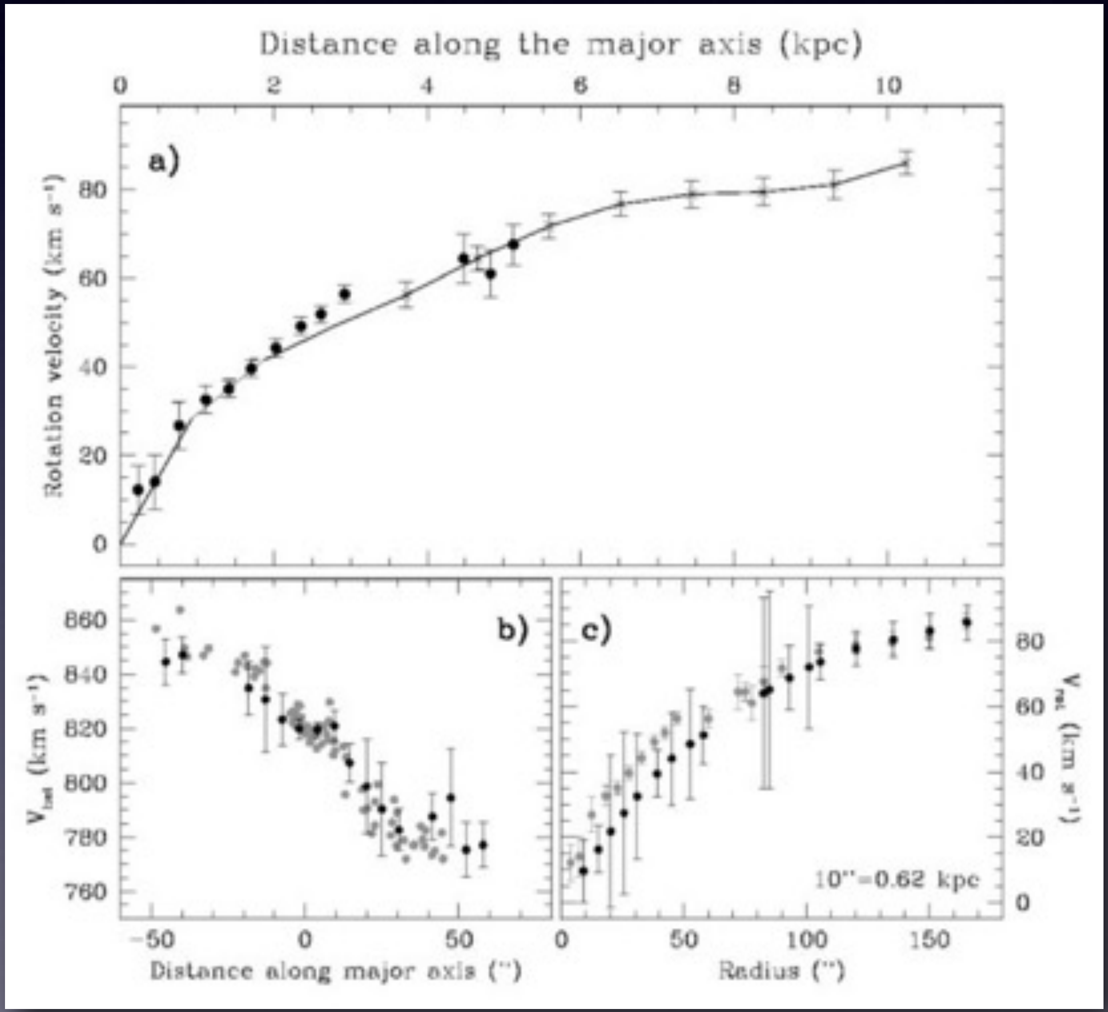
HI



Hα



SparsePak



Swaters et al (2003)

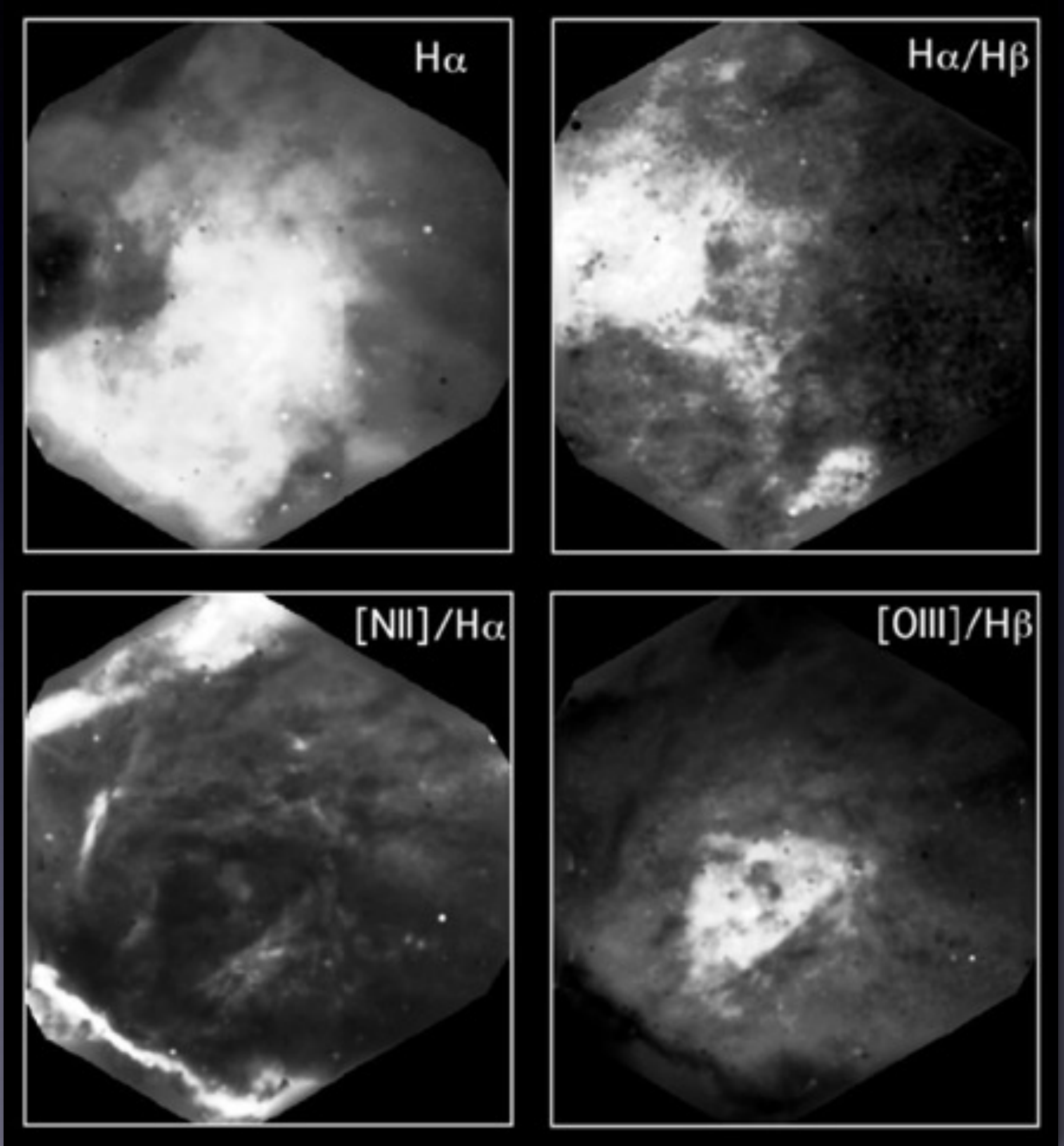
APERTIF / WEAVE

ISM physical conditions

Line ratio maps of the Orion Nebula

PPak mosaic:
- 27 pointings
- 2^{sec} exposures

Many more emission lines are accessible cf FP imaging.

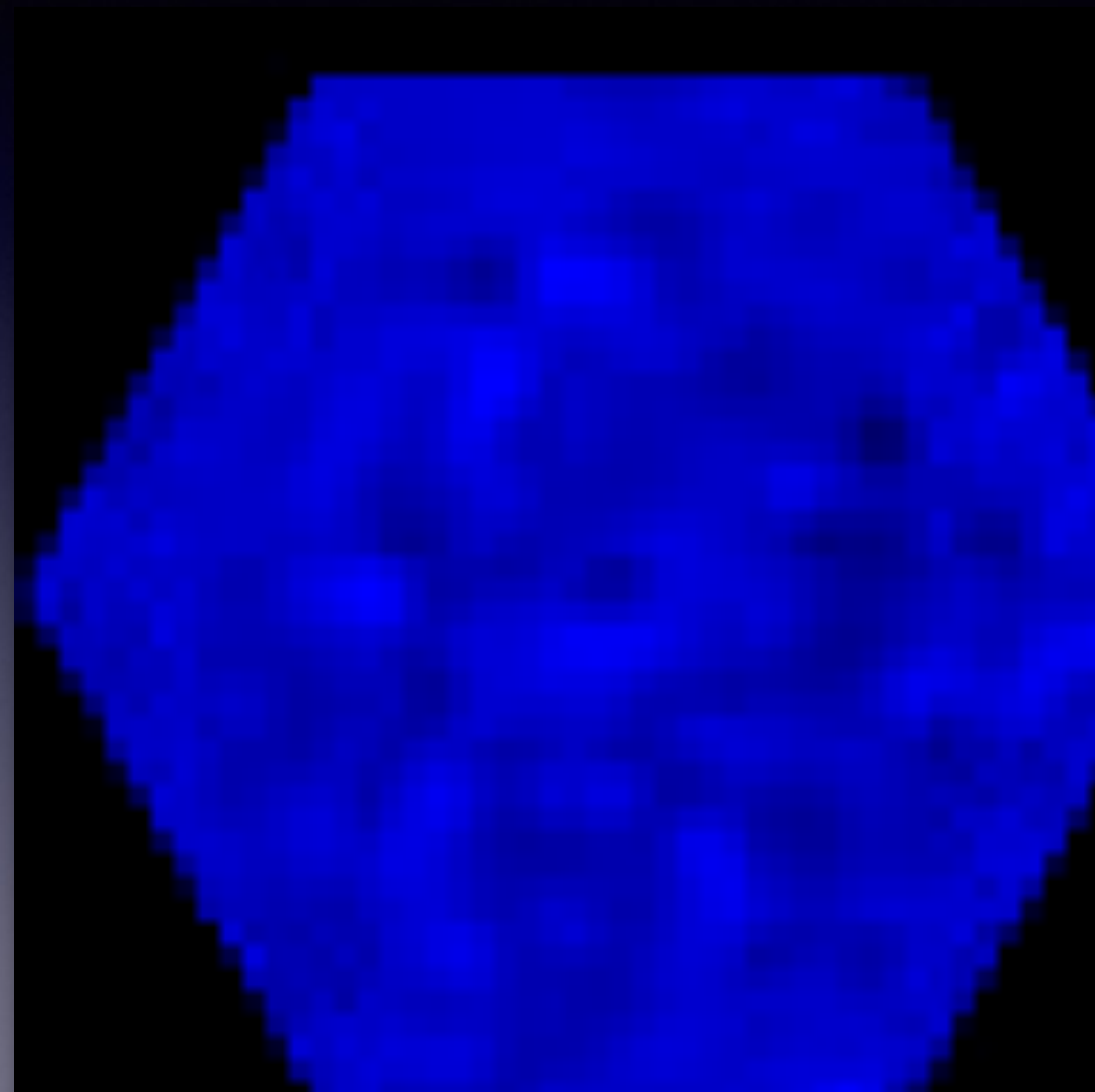


Sanchez et al (2008)

APERTIF / WEAVE

ISM physical conditions

Continuum subtracted data cube

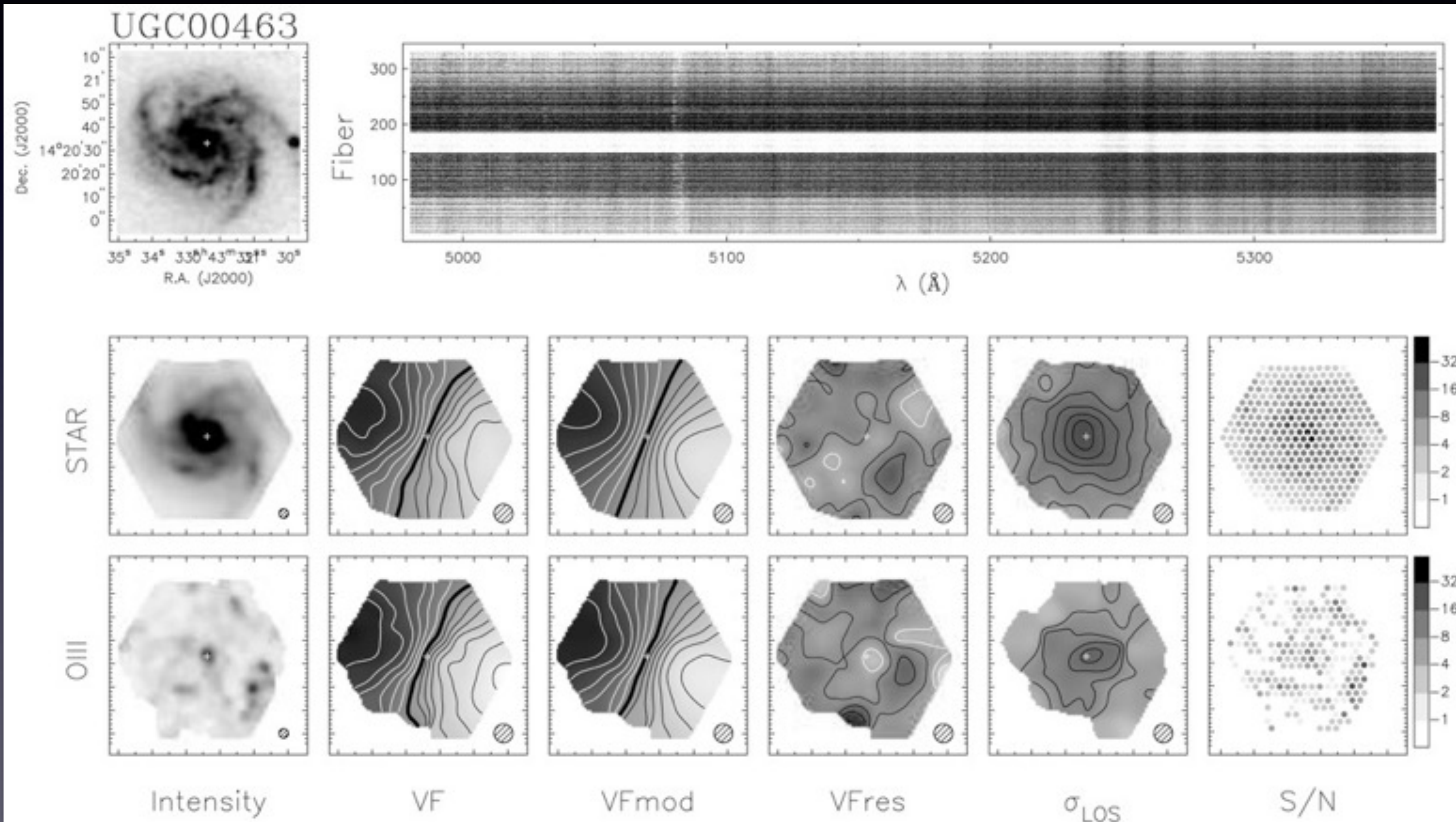


6308-6818 Angstroms

[OI] 6300
[NII] 6548
Hα 6563
[NII] 6584
[SII] 6717
[SII] 6731

APERTIF / WEAVE

λ = 4975−5375 Å R≈7500 Tint = 5−11 x 3600 sec



APERTIF / WEAVE

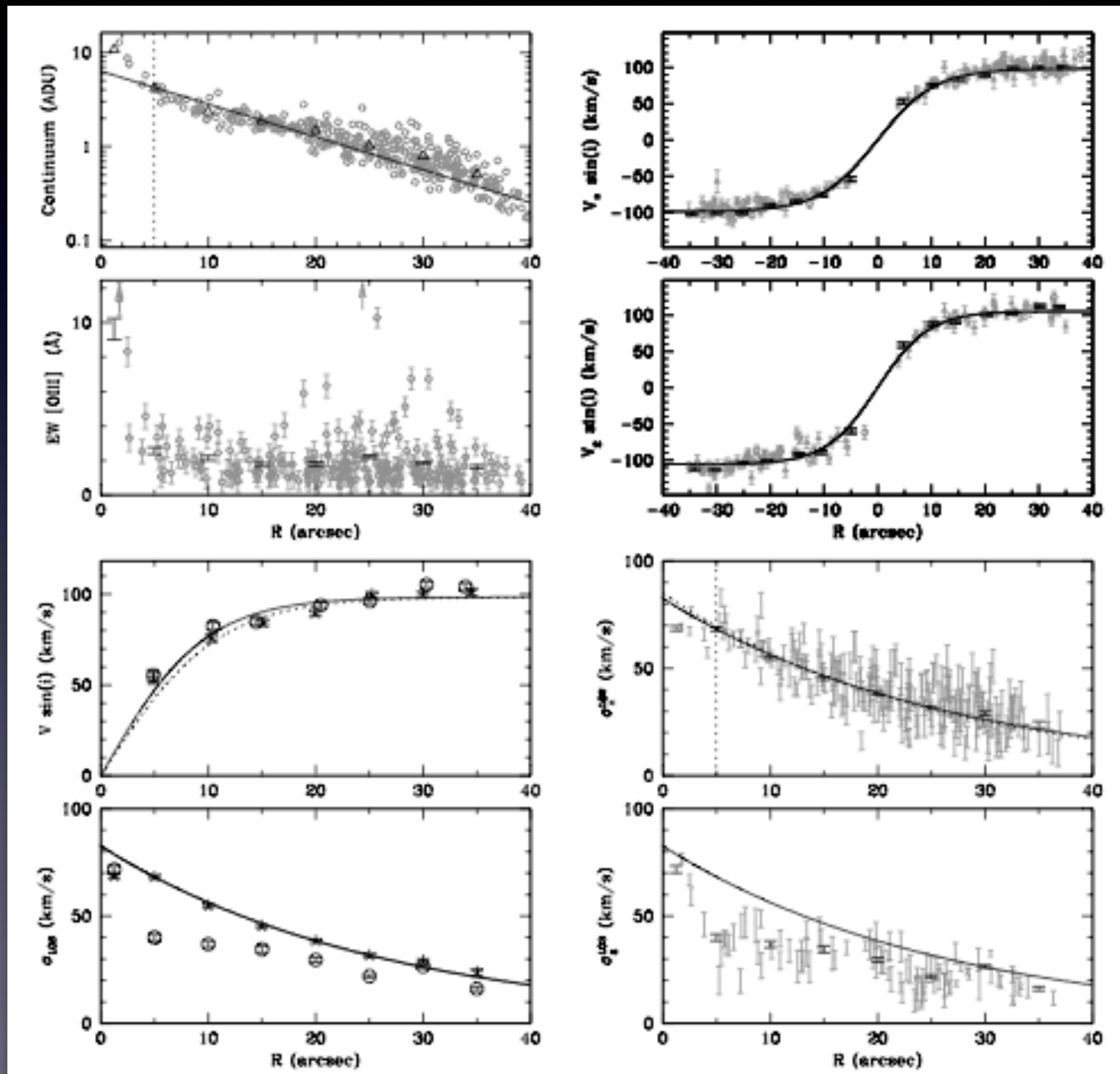
Stellar kinematics

continuum

EW [OIII]

V sin(i)

σ los



V_{star} sin(i)

V_{gas} sin(i)

σ^{los}_{stars}

σ^{los}_{gas}