APERTIF

HI imaging surveys

Marc Verheijen
+ Apertif team

university of groningen / Kapteyn Astronomical Institute

NOVA NWO DAGAL Detailed Anatomy of GALaxies

A P E R T I F

HI imaging surveys

- Apertif specs & performance
- HI science ‘requirements’
- prospects from existing blind surveys
- HI survey definition
- forthcoming activities

university of groningen / Kapteyn Astronomical Institute

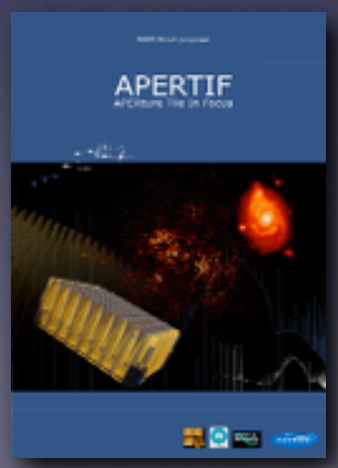
NOVA NWO DAGAL Detailed Anatomy of GALaxies

APERTIF a grand proposal

WSRT upgrade - SKA pathfinder

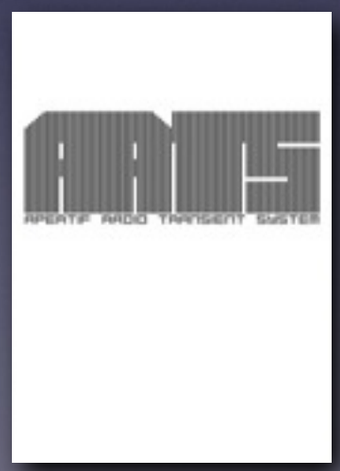
After 45 years of service,
transform the WSRT into
an efficient 21cm survey facility
using phased-array technology.

Winning community support + 3 NWO/NOVA investment grants
+ 3 ERC grants + 2 NWO grants:



2006 5 M€

2008 2.5 M€



2013 1.3 M€

- HIstoryNU - van der Hulst, 2.5 M€
- RadioLife - Morganti, 2.5 M€
- ALERT - van Leeuwen, 2 M€
- TOP - Oosterloo, 0.7 M€
- VICI - Verheijen, 1.5 M€

APERTIF

timeline

2006 : *Apertif* grant (PAF development & construction)
2007 : Digestif PAF prototype in RT5
2008 : *Apropos* grant (correlator, pipeline, archive)
2009 : Preliminary Design Review
2010 : - Call for Expressions-of-Interest
- workshop with EoI teams
2012 : workshop with EoI teams
2013 : - *ARTS* grants (pulsar/transient backend)
- start refurbishment of dishes
Oct 2014 : Critical Design Review
Jun 2015 : 'Go' for APERTIF-10 roll-out
Jul 2015 : Call for participation, Draft Survey program

Specifications

Array of Vivaldi antennas fully samples the focal plane.

		APERTIF	WSRT
# antennas/dish		121	1
# primary beams		37	1
field-of-view	[deg^2]	8	0.3
freq. range	[GHz]	1.13−1.75	0.12−8.7
T_{sys}	[K]	70	30
aperture efficiency		75%	55%
bandwidth	[MHz]	300	160
# channels		24576	1024
# dishes		12	14 (13)

<u>APERTIF Resolution :</u>

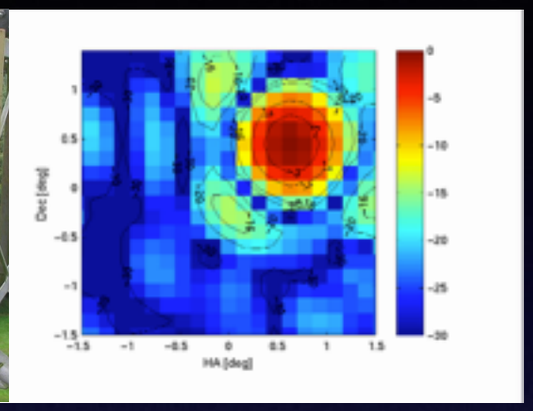
$\Theta = (1+Z)^2 \times 15 \times 15/\sin(\delta)$ arcsec^2 (10kpc @ D=150 Mpc)

R = (1+Z) x 5.2 km/s (after Hanning smoothing)

APERTIF increases survey speed of WSRT 15−30x

APERTIF specifications & performance

121 Vivaldi antennas



PAF : 37 'compound' beams - 8 deg^2 FoV
12x25m-dishes, Θ=15"x15"/sin(δ)
1130−1730 MHz, 300 MHz bandwidth
24,576 channels, R=5.2 km/s, full pol.

Some bad luck :

RFI : digital TV , airplanes
→ pre-/post-LNA filters
→ $T_{sys} \lesssim 70K$ (25% increase)

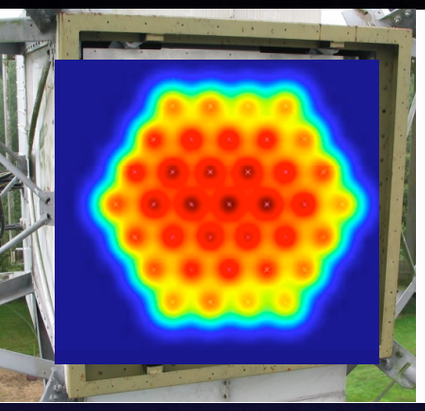
Lots of good news :

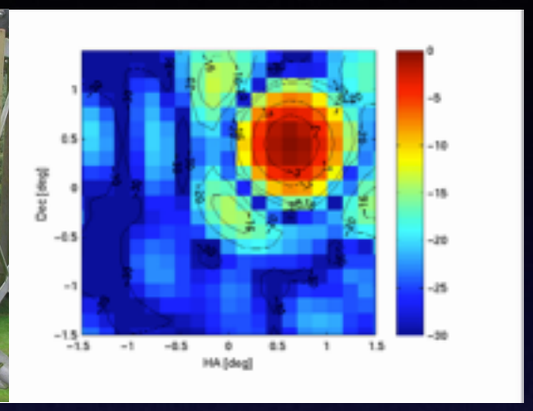
- standing waves eliminated
- 75% aperture efficiency
- 8 deg^2 confirmed
- beam & pol. stability OK

	(A	FoV	BW	SS
Apertif	1	1	1	1
ASKAP	0.62	3.7	1	2.5
MeerKAT	23	0.096	1.7	3.8
JVLA	11	0.028	0.77	0.23

APERTIF specifications & performance

121 Vivaldi antennas





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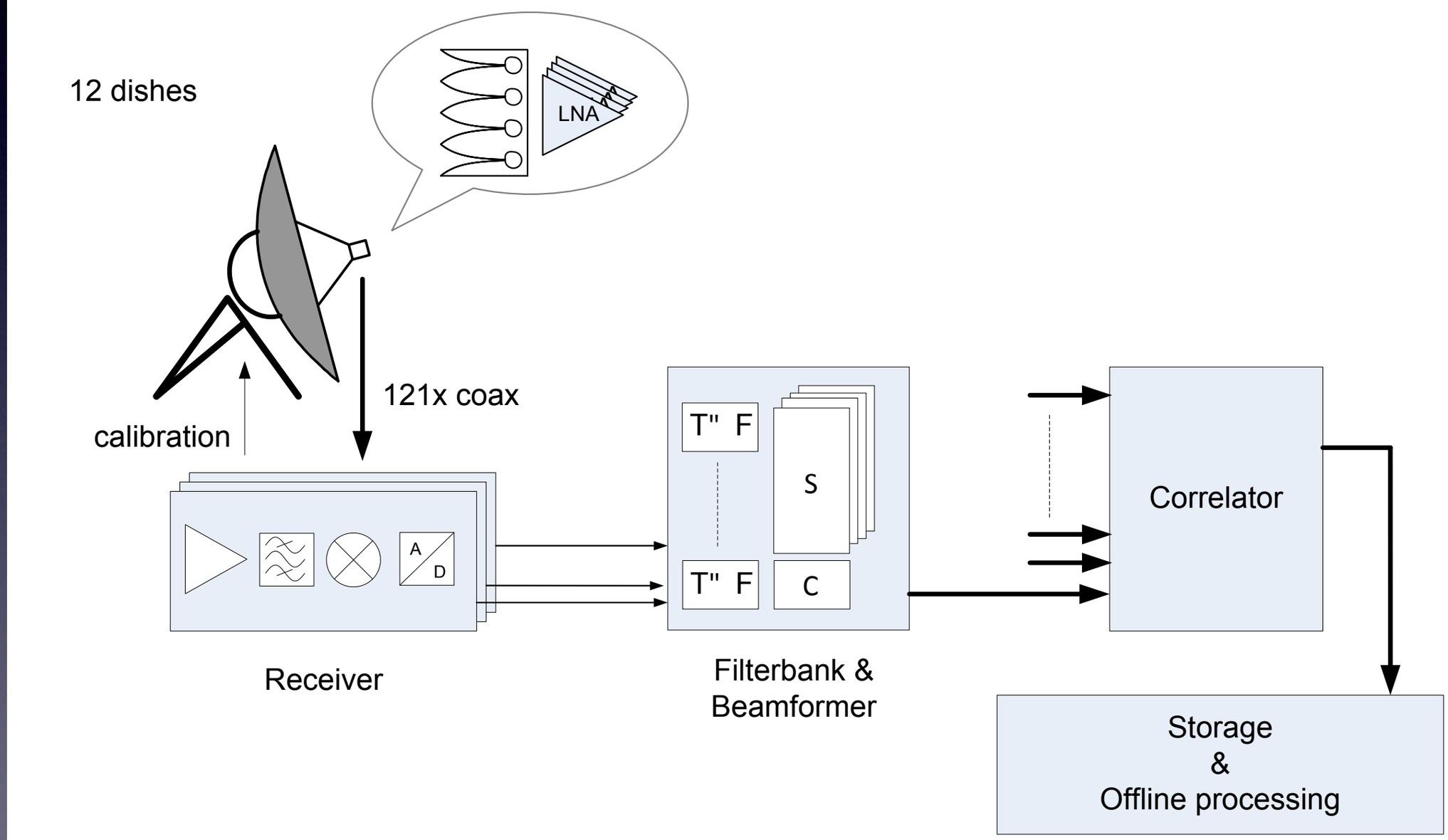
hardware developments

top level block diagram

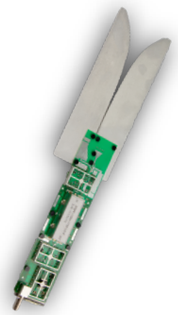


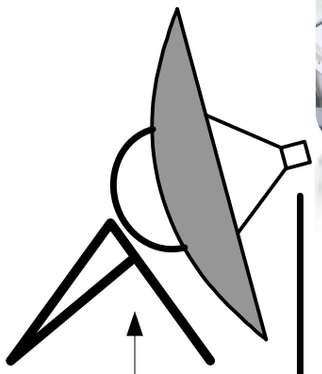
APERTIF

hardware developments

top level block diagram

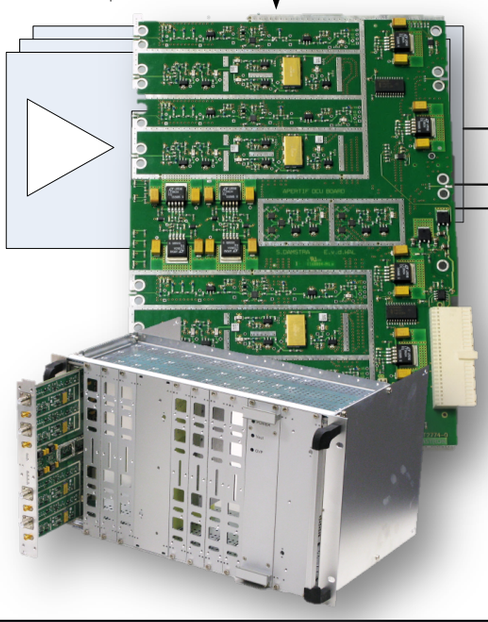
12 dishes

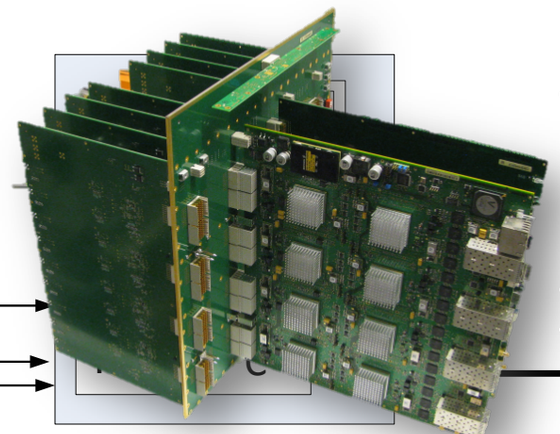




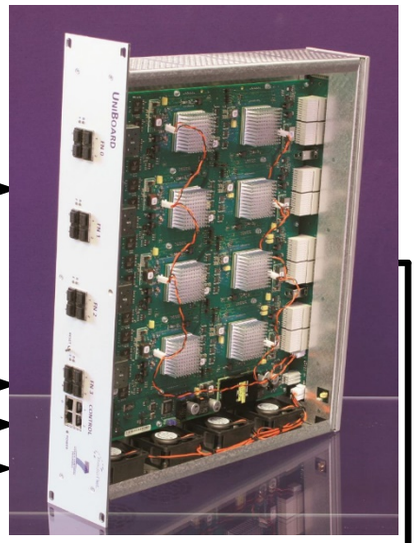
121x coax

calibration





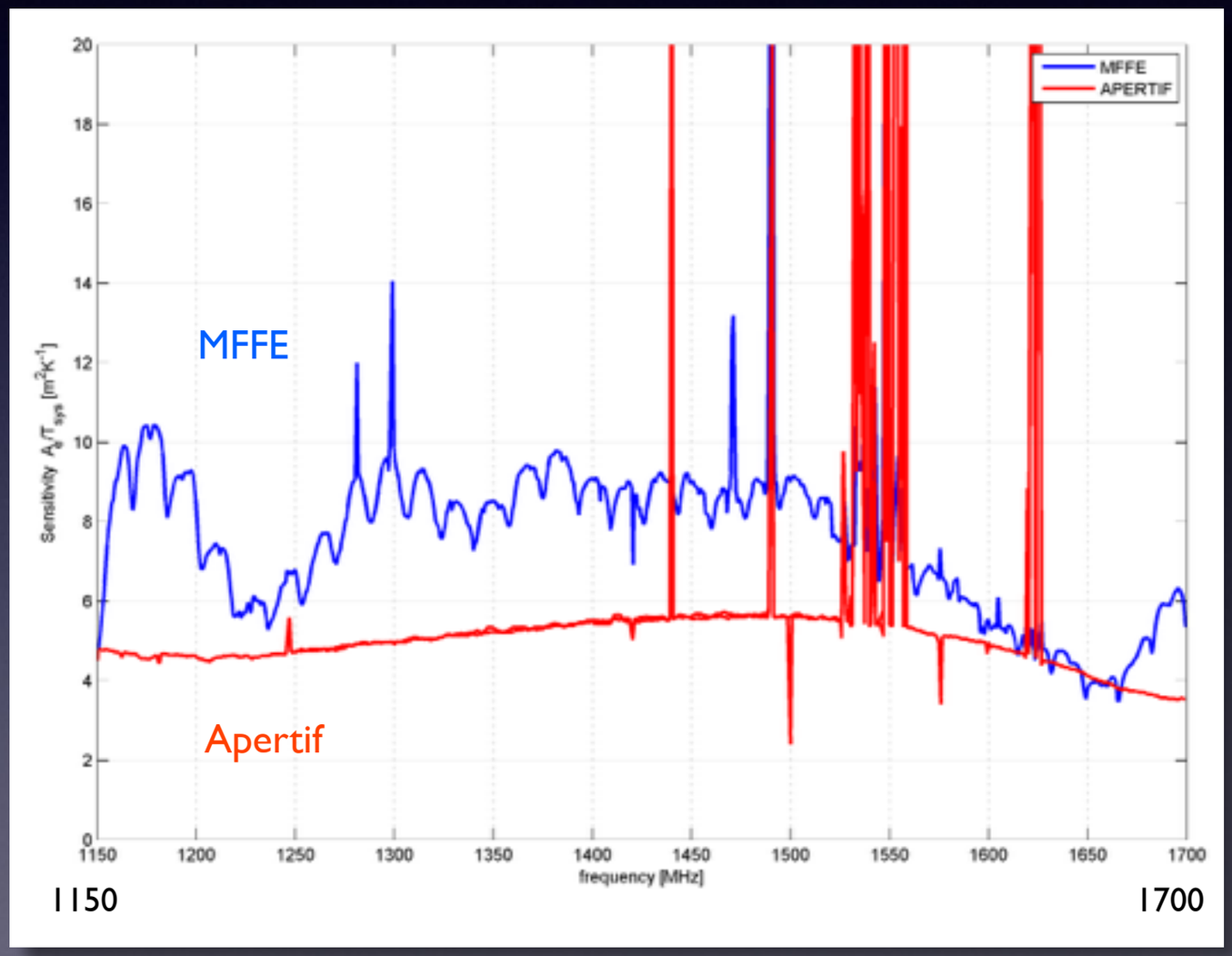
Filterbank &
Beamformer



Storage
&
Offline processing

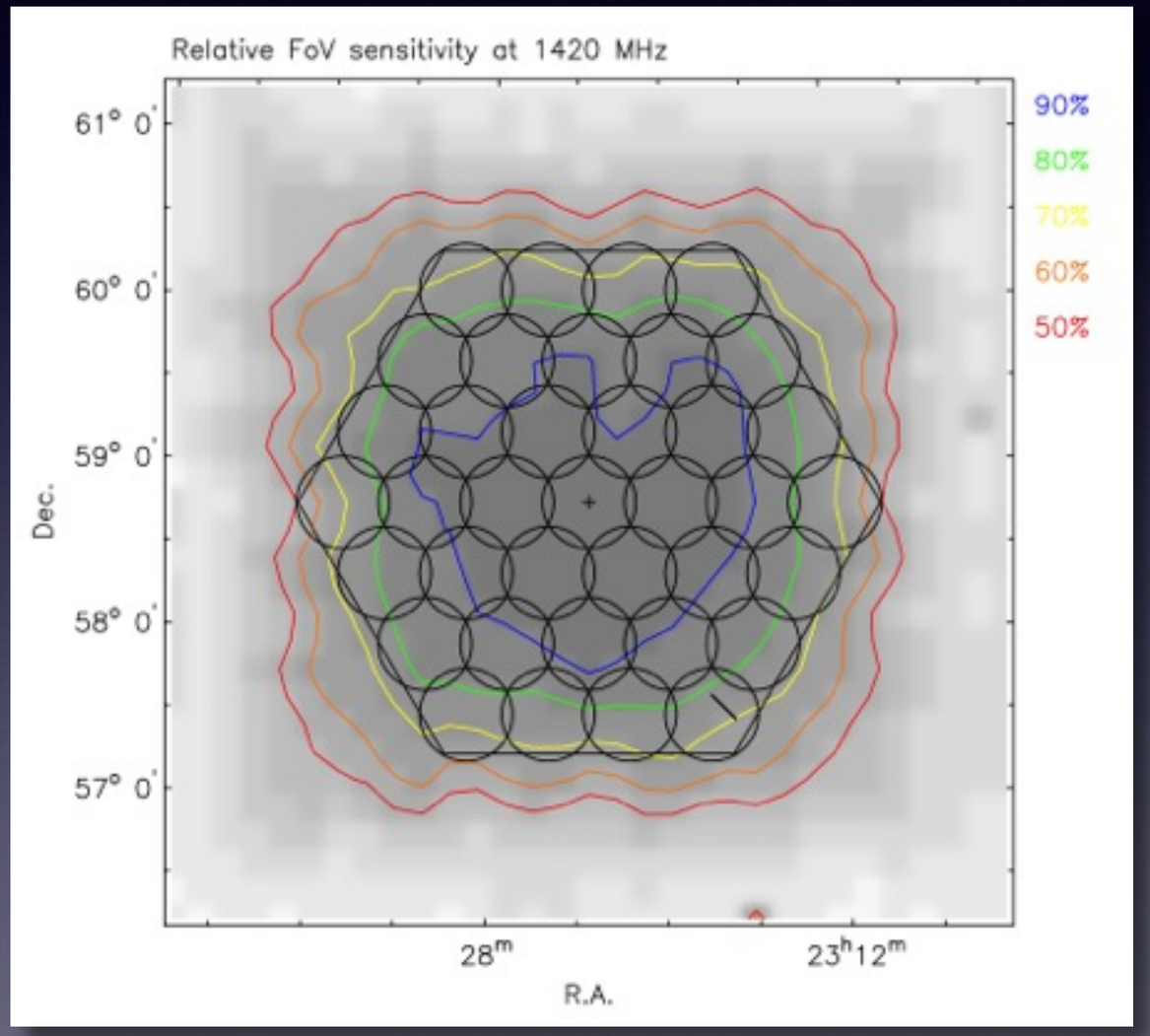
on-sky performance

A_{eff}/T_{sys}



1150 1700

Relative FoV sensitivity



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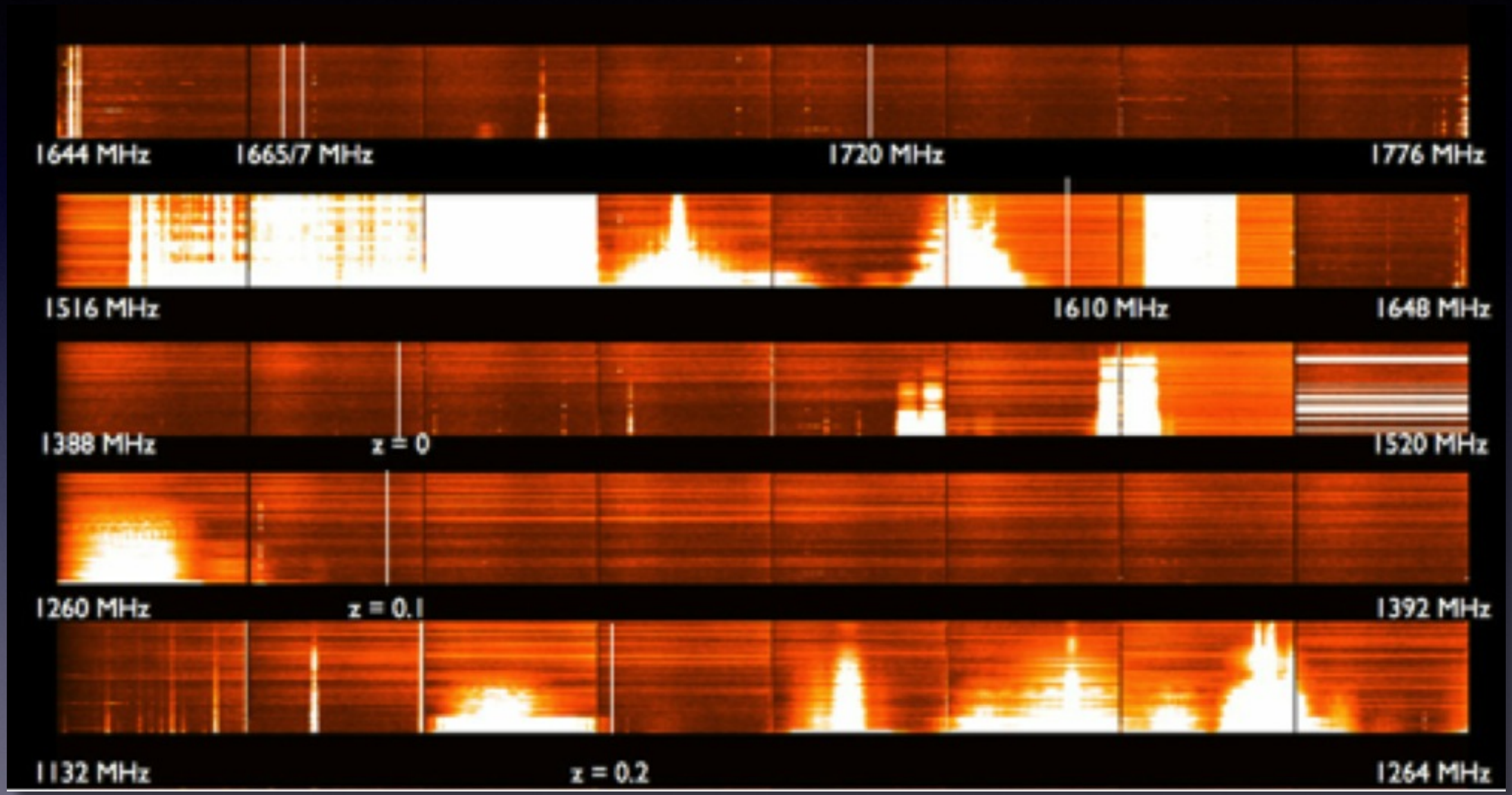
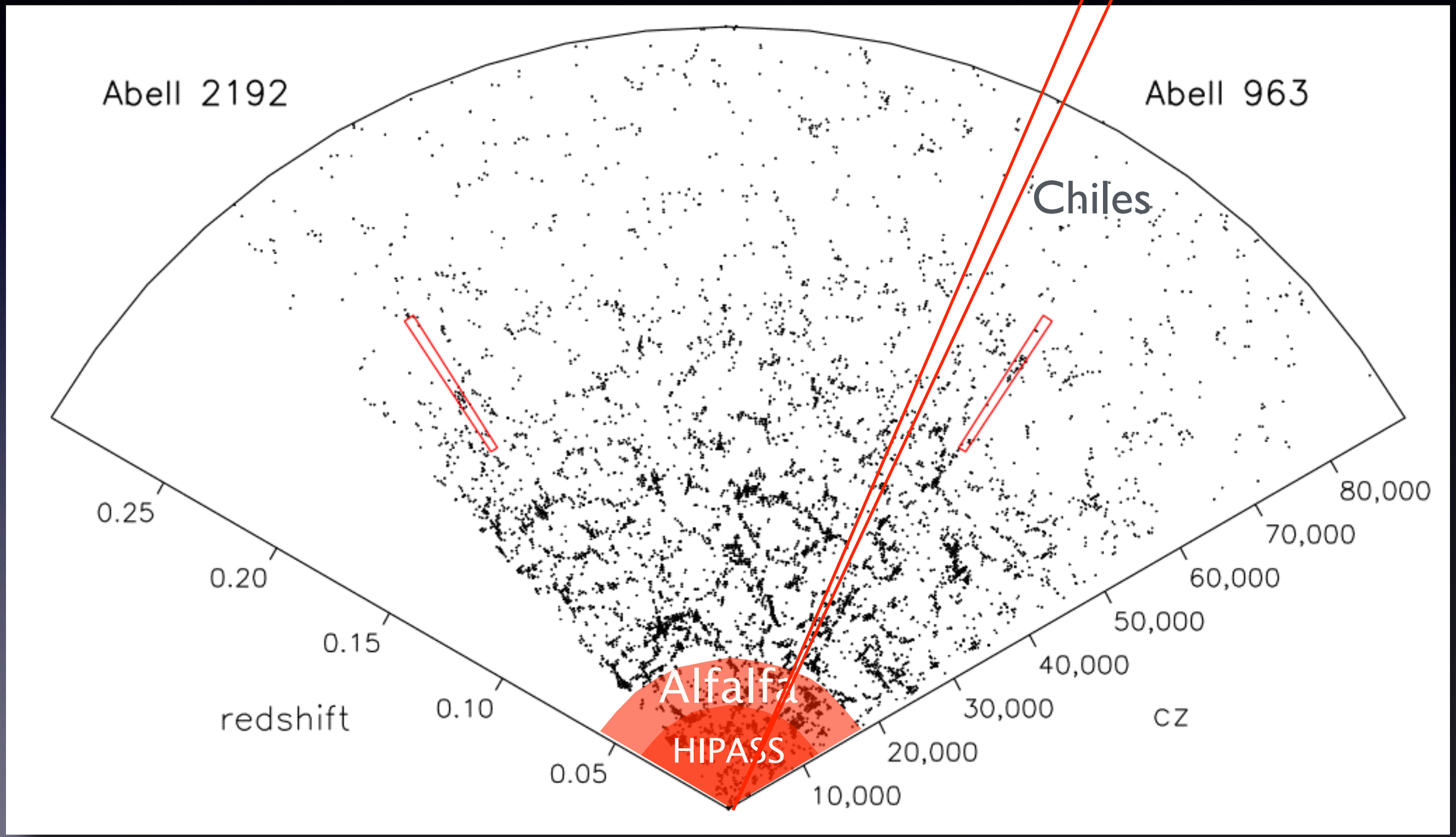
Radio Frequency Interference



APERTIF

The promise of Apertif

10^5 HI detections , 10^4 resolved HI disks



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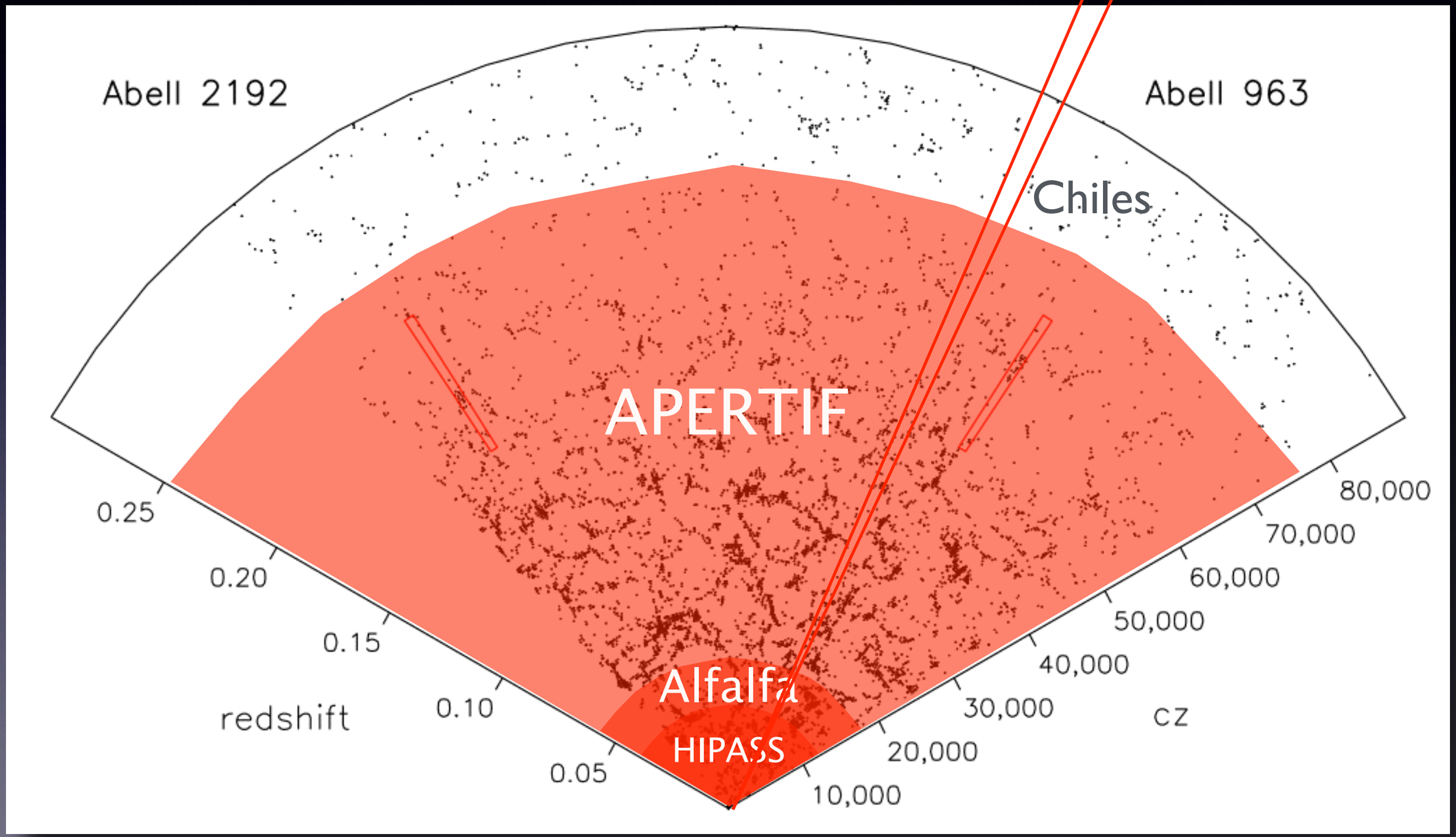
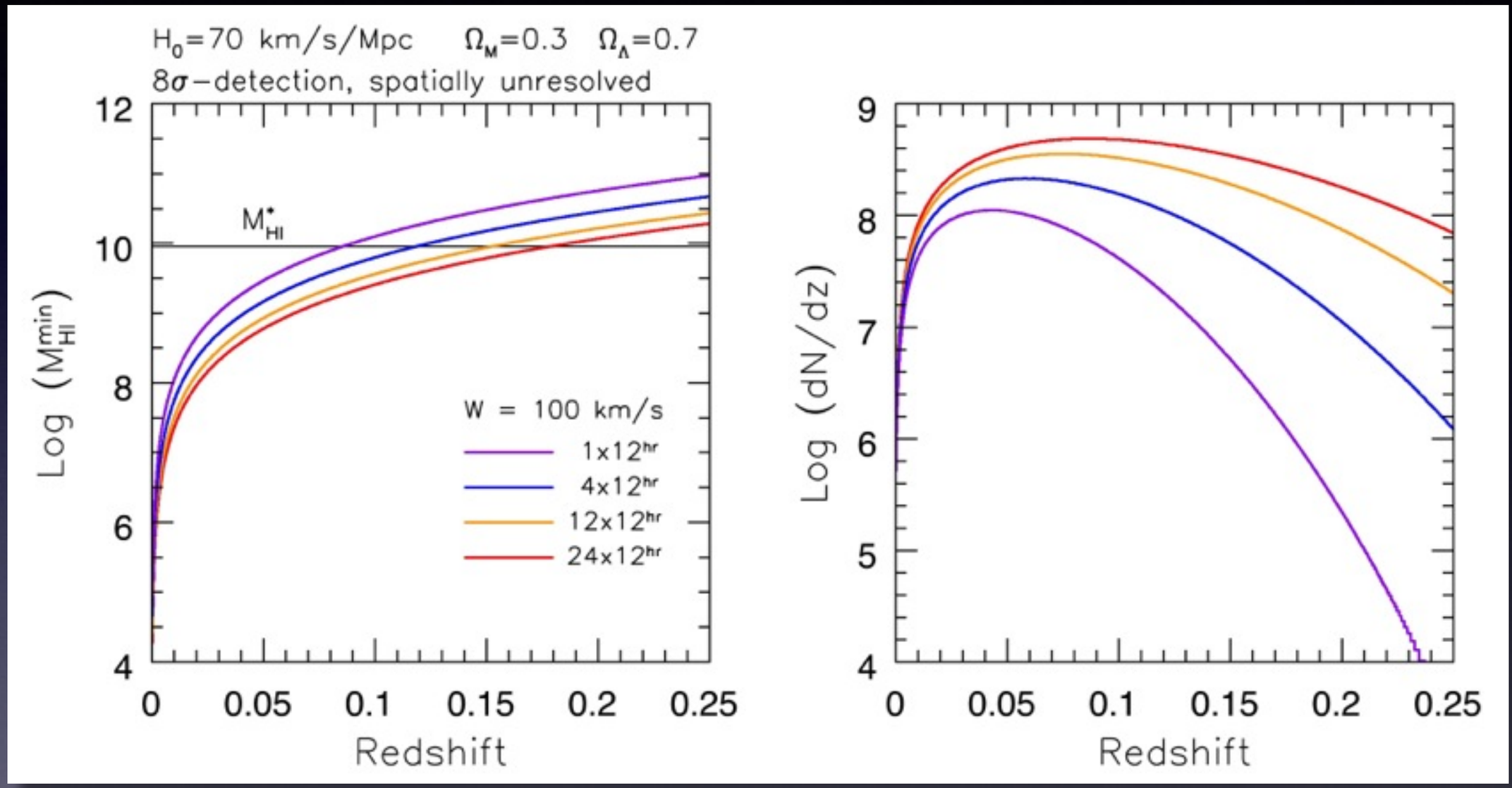


HI mass limits & detection rates

Based on Alfalfa HIMF

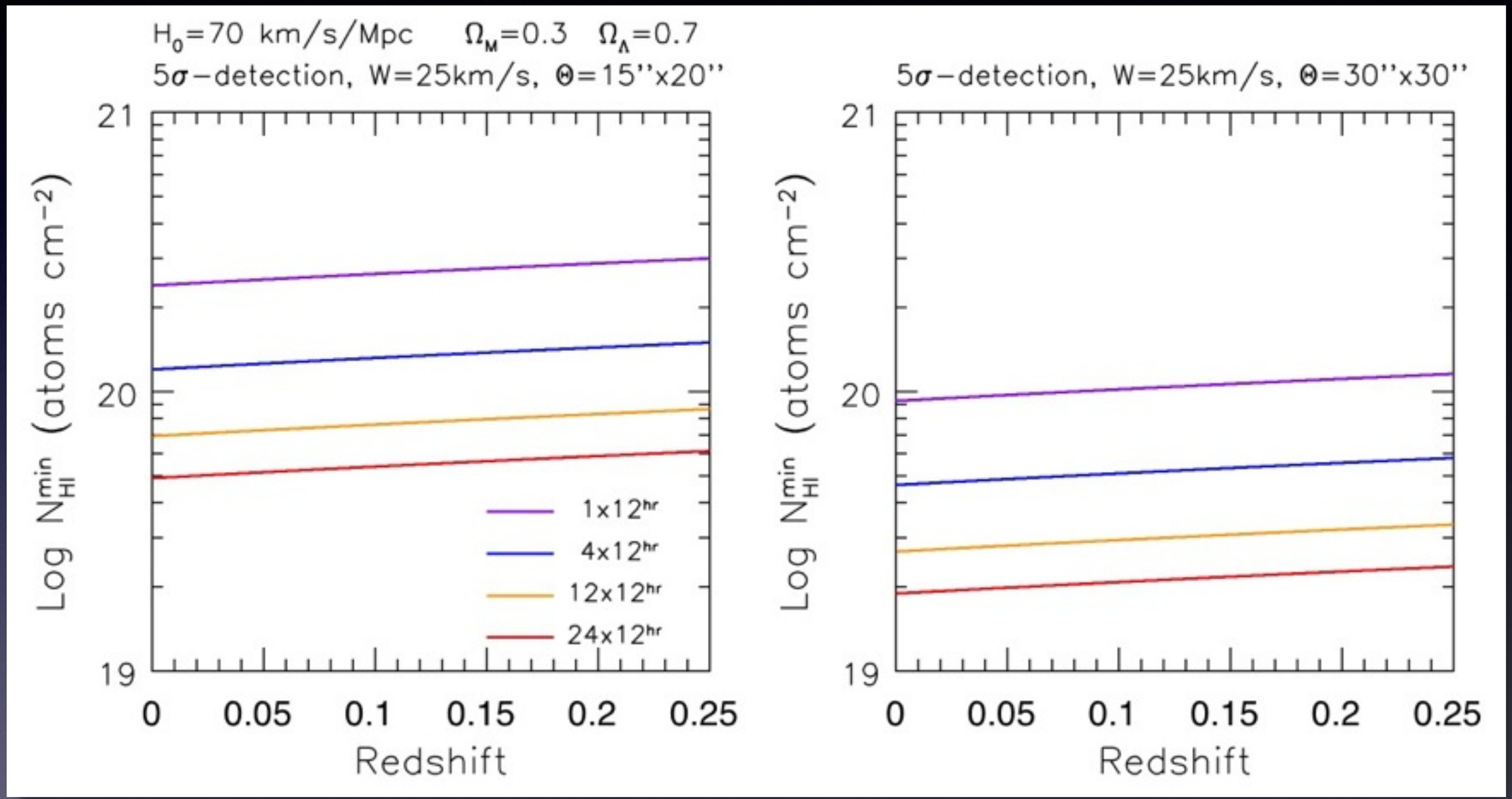


$1x12^{hr}$: M^*_{HI} at z=0.08, $1x10^{11}$ M_{sun} at z=0.25

$12x12^{hr}$: M^*_{HI} at z=0.16, $3x10^{10}$ M_{sun} at z=0.25

HI column density limits

5σ, W=25 km/s

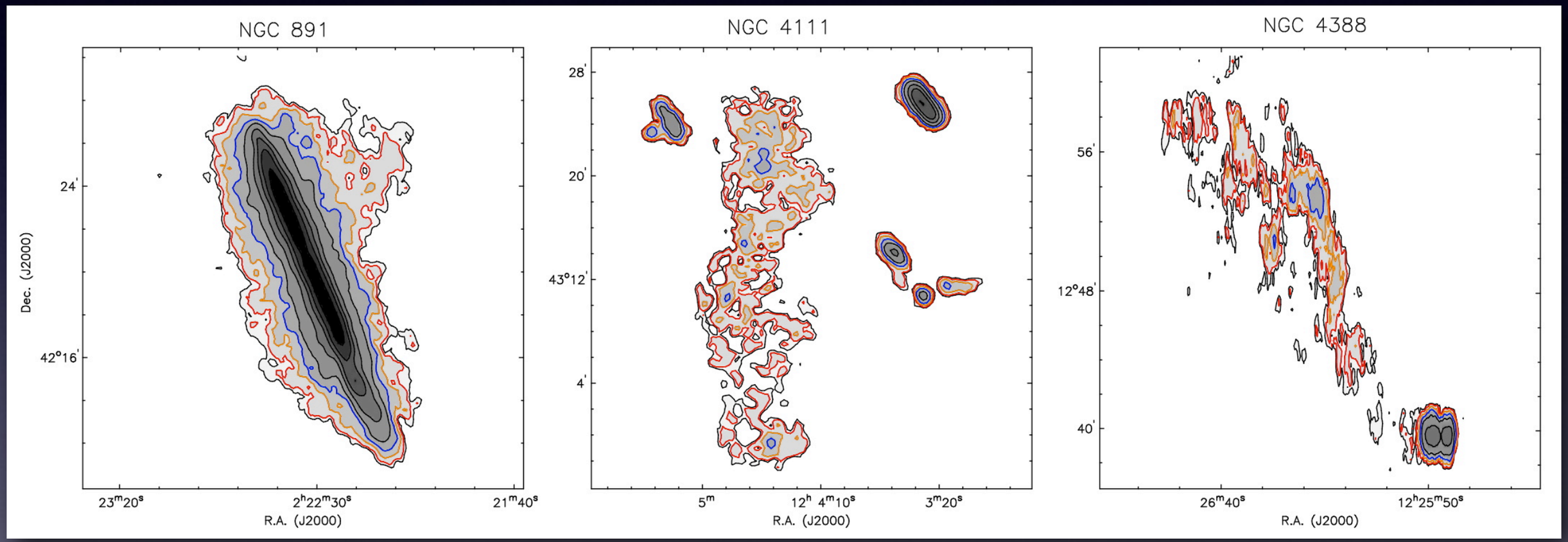


Note: smoothing to half the angular resolution reduces the survey volume at a particular linear resolution by a factor 8 .

Column density limit : $N_{HI}<5x10^{19}$

Accretion, depletion and removal of gas

extra-planar gas | tidal stripping | ram-pressure stripping



Fraternali et al

Oosterloo et al

Verheijen et al

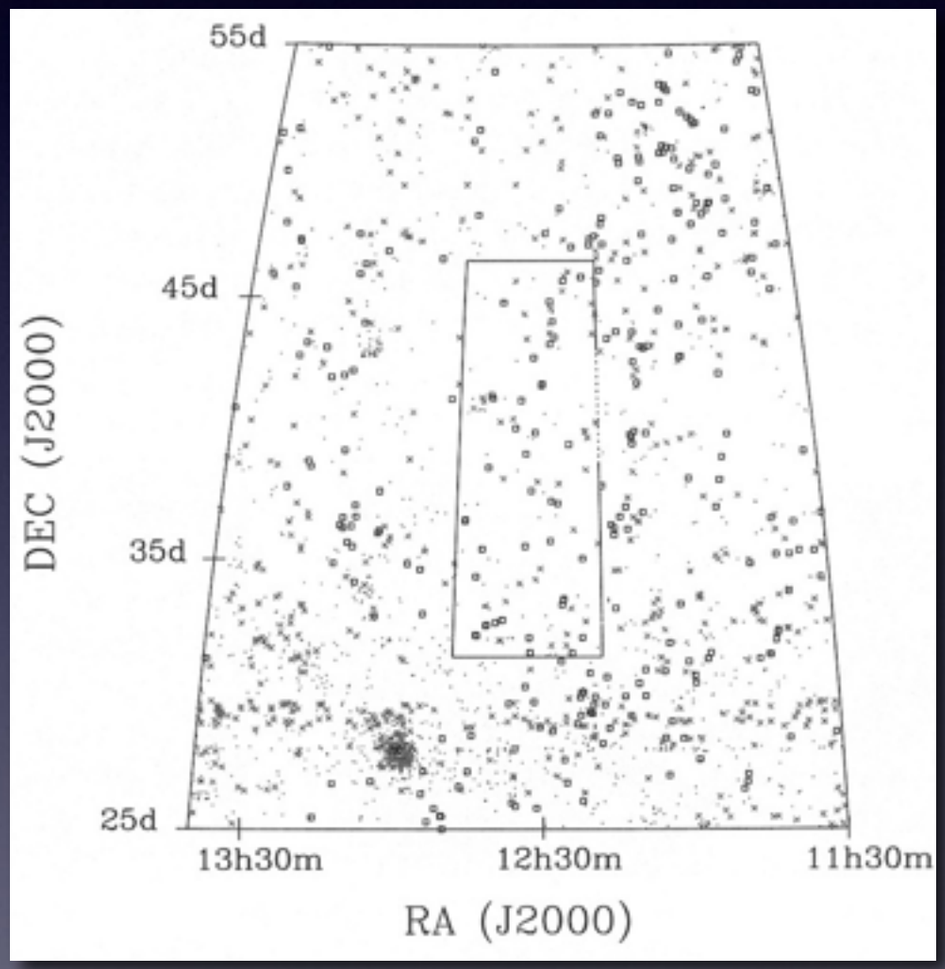
$2x10^{19}$ (atoms/cm^2)
$5x10^{19}$ (atoms/cm^2)
$10x10^{19}$ (atoms/cm^2)

Gas disks are responsive to environmental influences and reveal processes not easily observed otherwise.

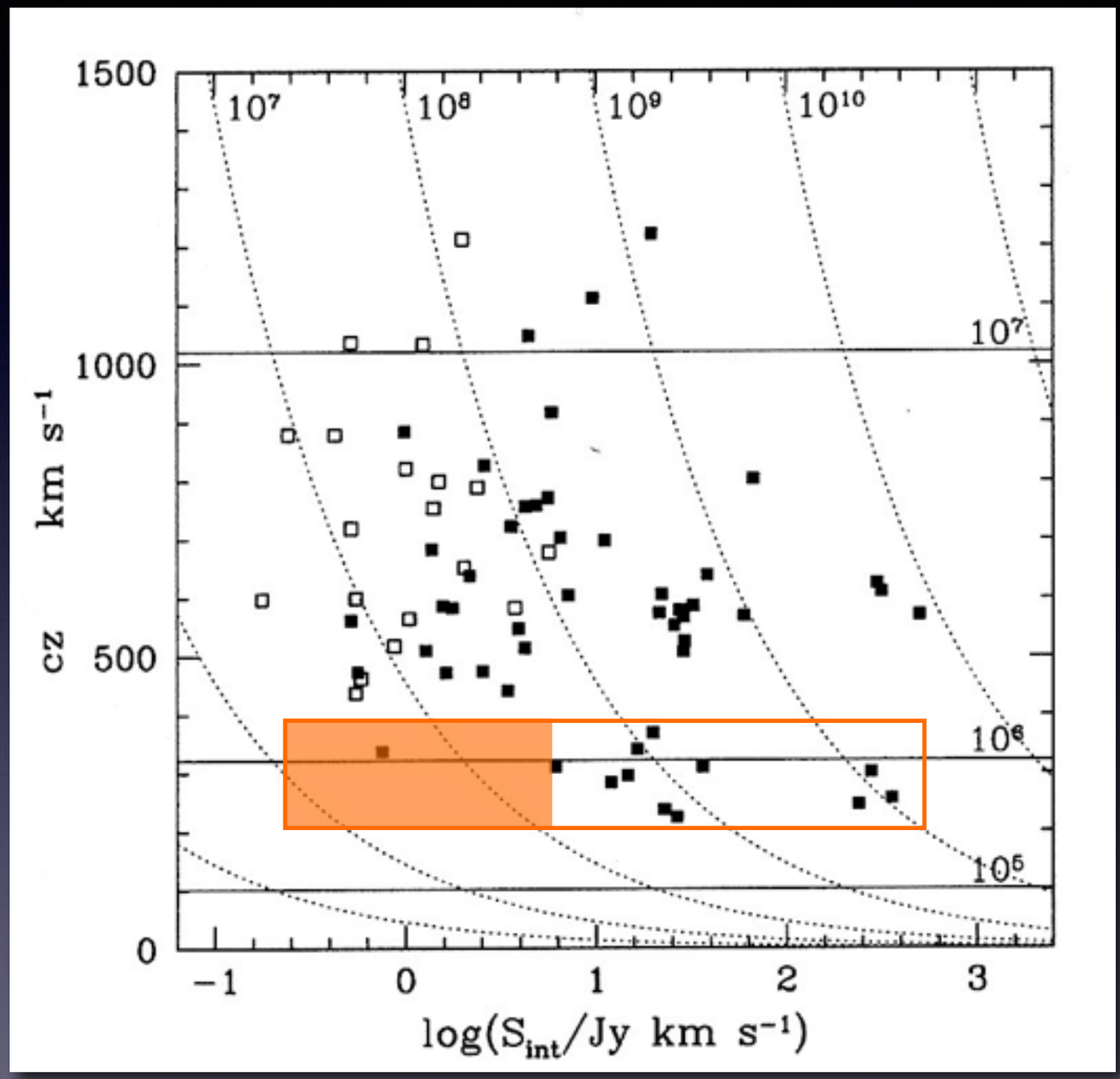
HI mass limits

APERTIF

Blind WSRT Survey of CVn
86 deg^2 , 1372 pointings
60x12 hrs, 80 min/pointing



Kovač et al (2007)

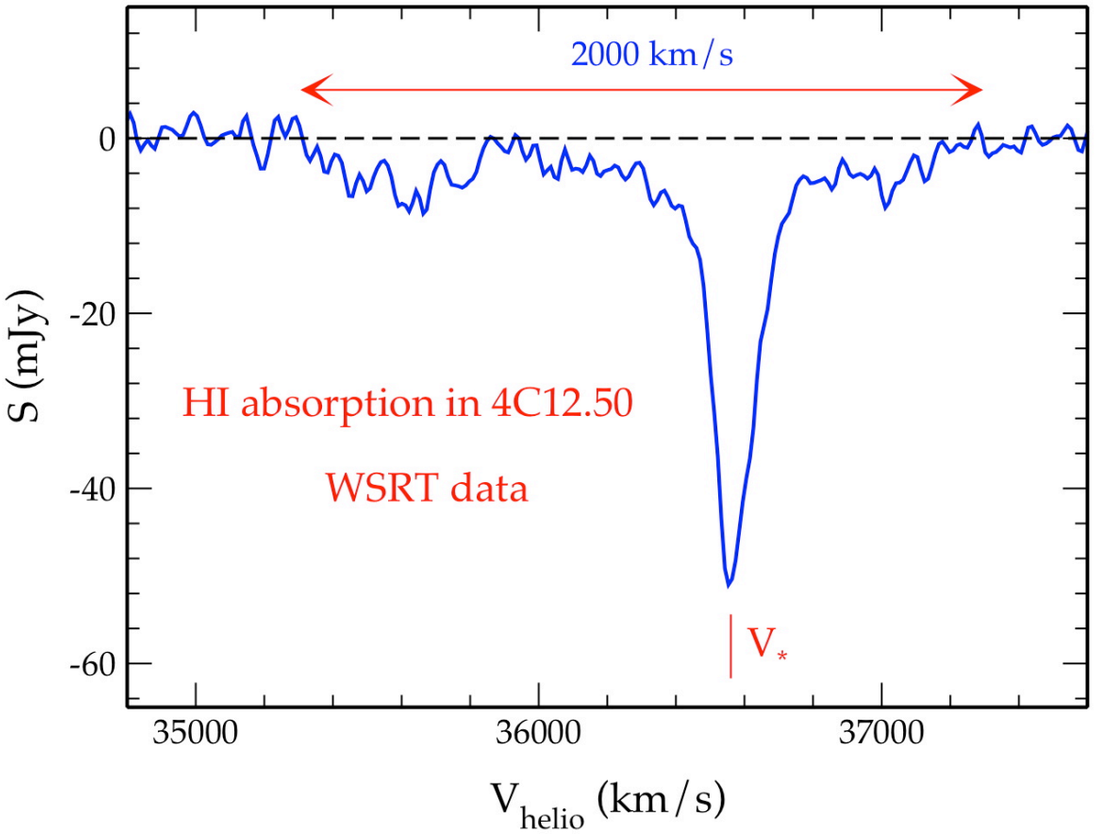


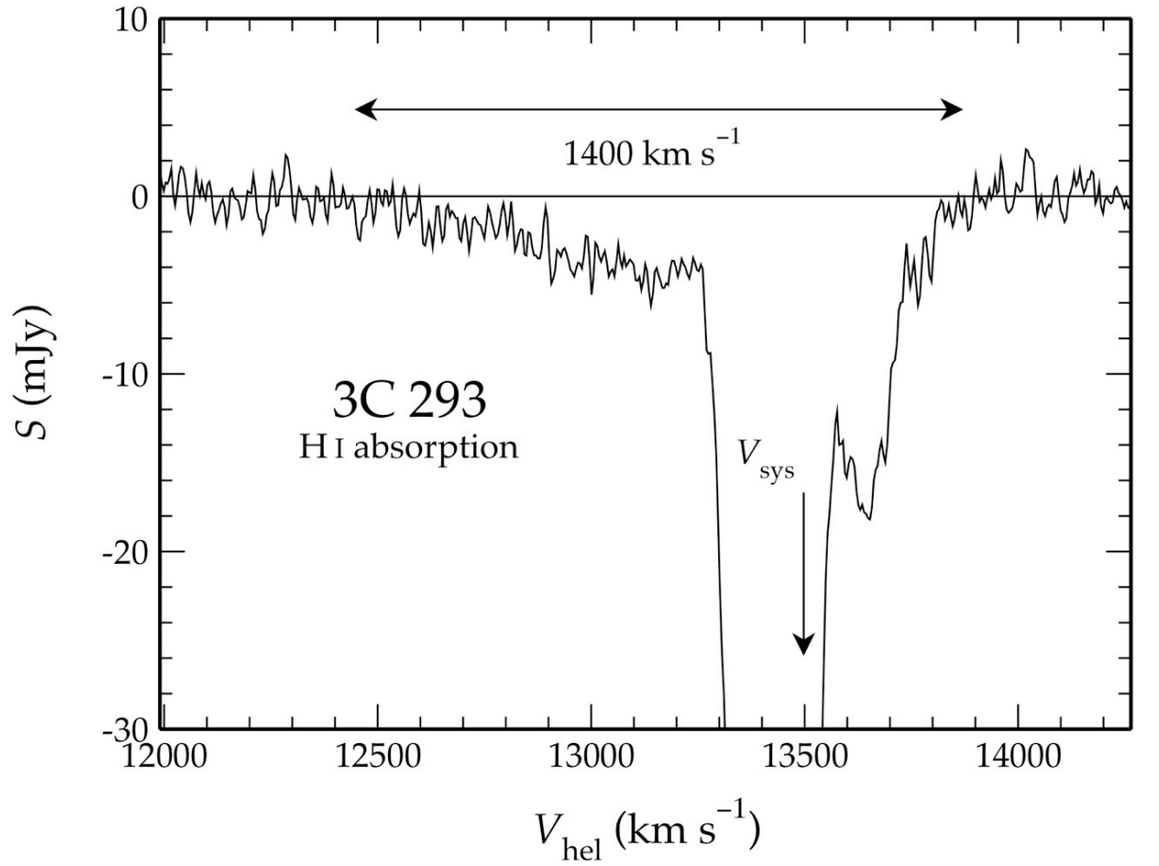
Kovač et al (2007)

Where are these low HI-mass dwarfs?

APERTIF will efficiently survey local volumes to greater depth.

Broad HI absorption



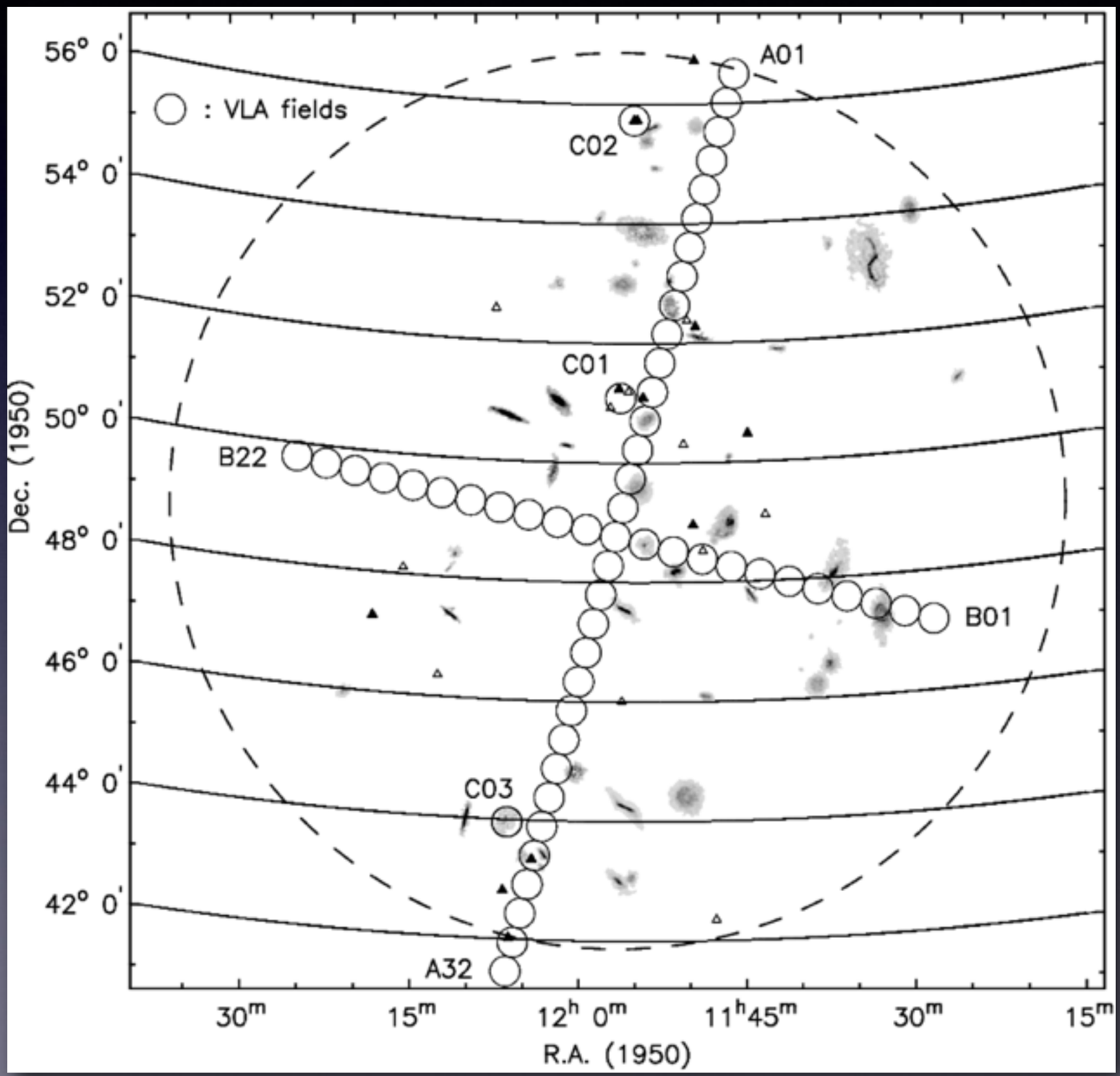


Morganti et al

Requires a stable bandpass.

A blind HI imaging survey of Ursa Major

APERTIF



VLA-D
54 pointings

1414-1417 MHz
Θ = 45”
ΔV ≈ 8 km/s
σ = 0.8 mJy/bm

$M_{HI,\,min} = 2 \times 10^7\ M_{sun}$

See poster by
Eva Busekool

A blind HI imaging survey of Ursa Major

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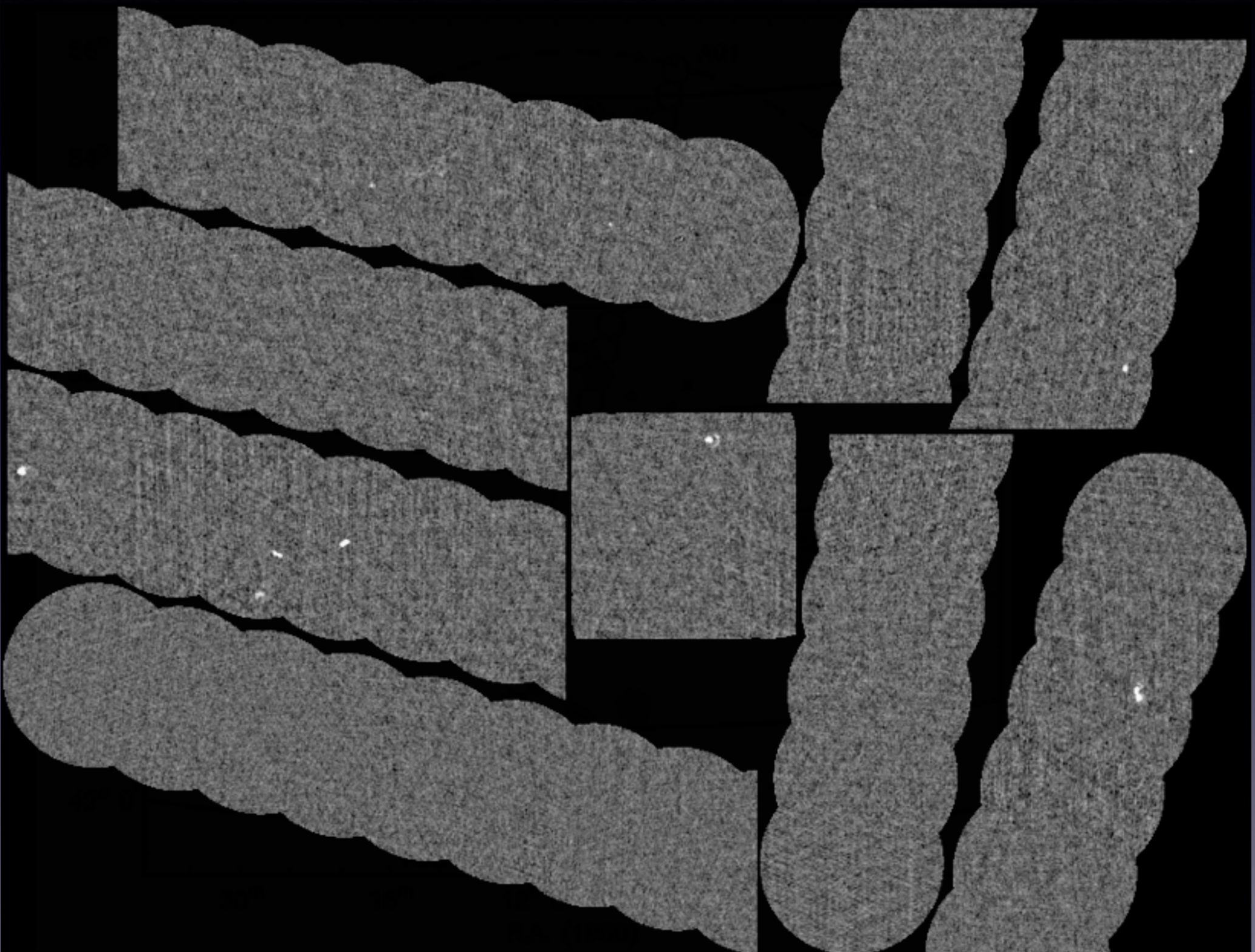

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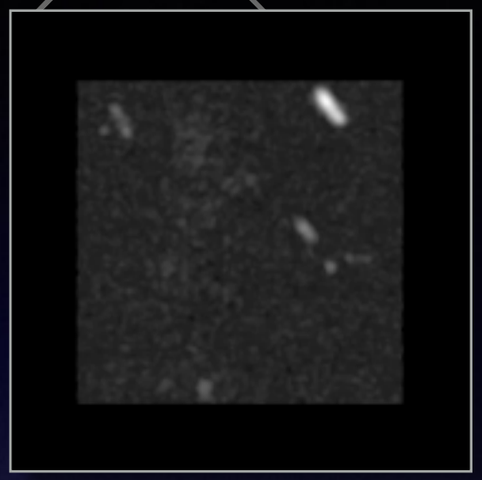
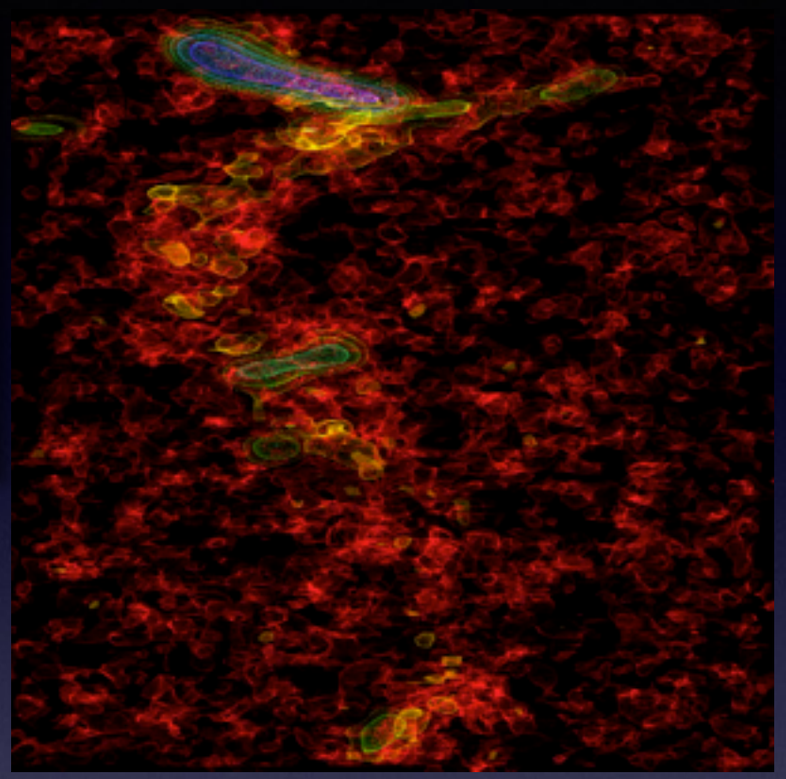
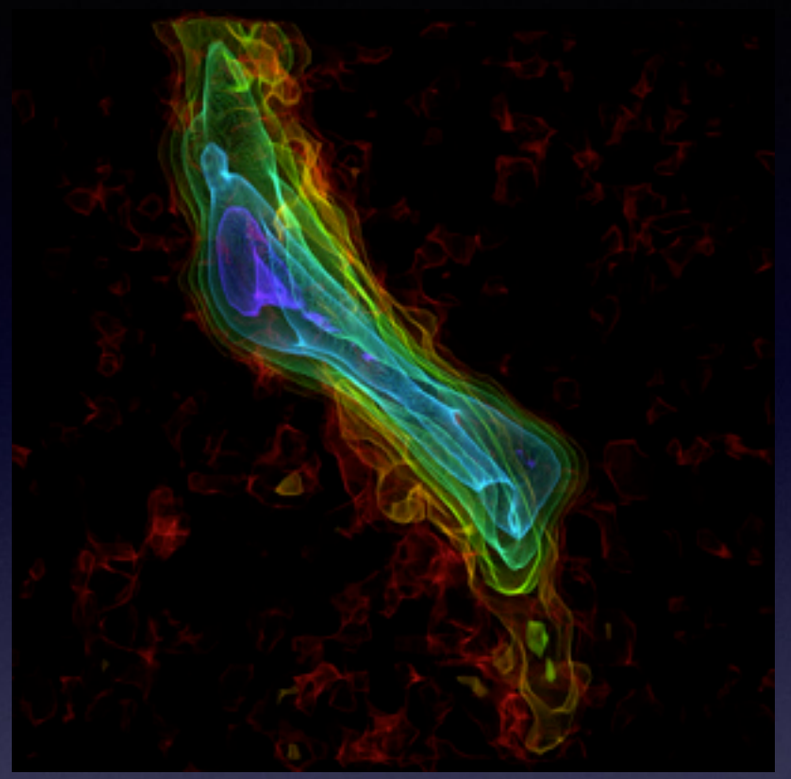
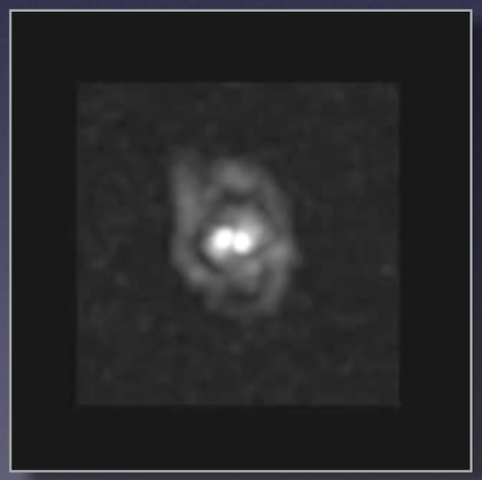
APERTIF

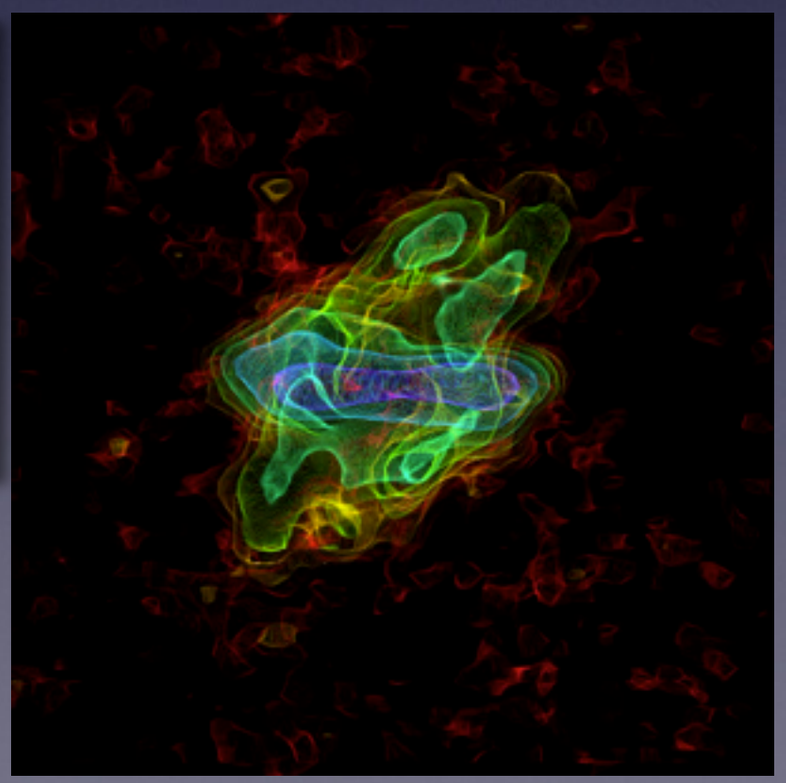
Detecting & characterizing 3D structures

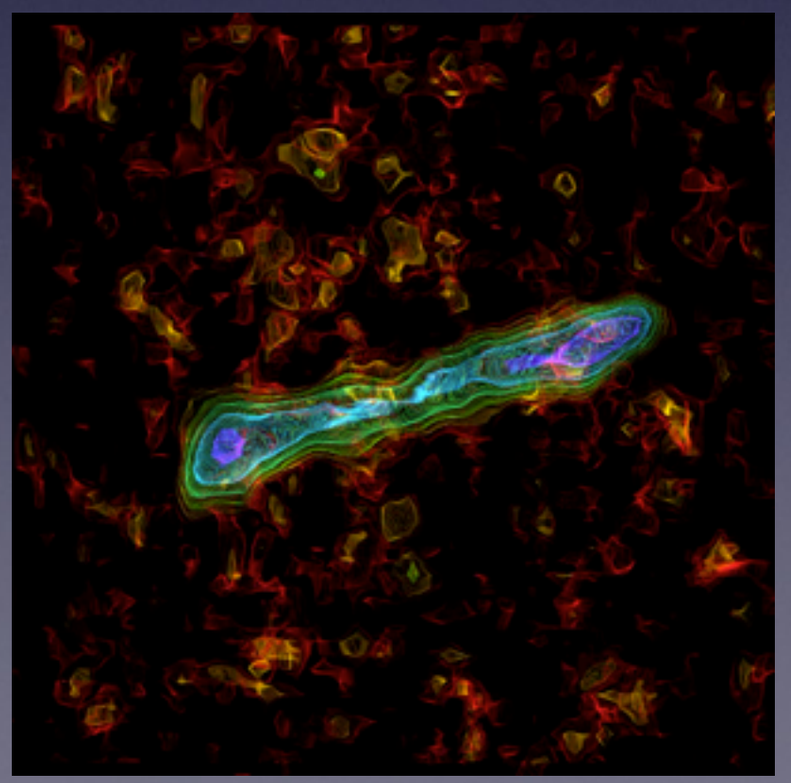








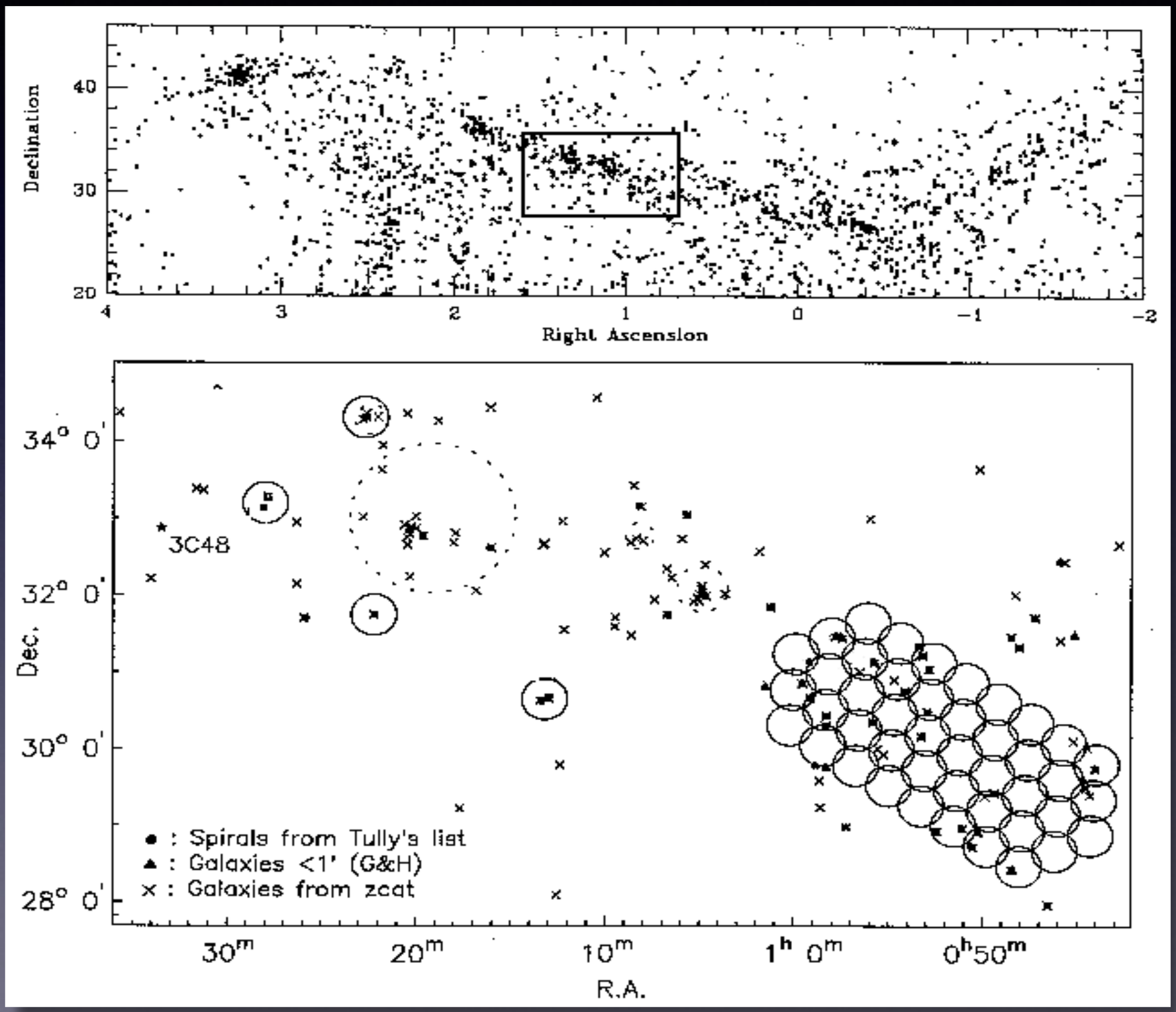




Visualization by
Davide Punzo
Kapteyn Institute

A blind HI imaging survey of Perseus-Pisces

APERTIF



VLA-C mosaic
44 pointings
117 channels

1395-1408 MHz
Θ = 15”
ΔV ≈ 20 km/s
σ = 0.8 mJy/bm

$M_{HI,\,min} = 5 \times 10^8\ M_{sun}$

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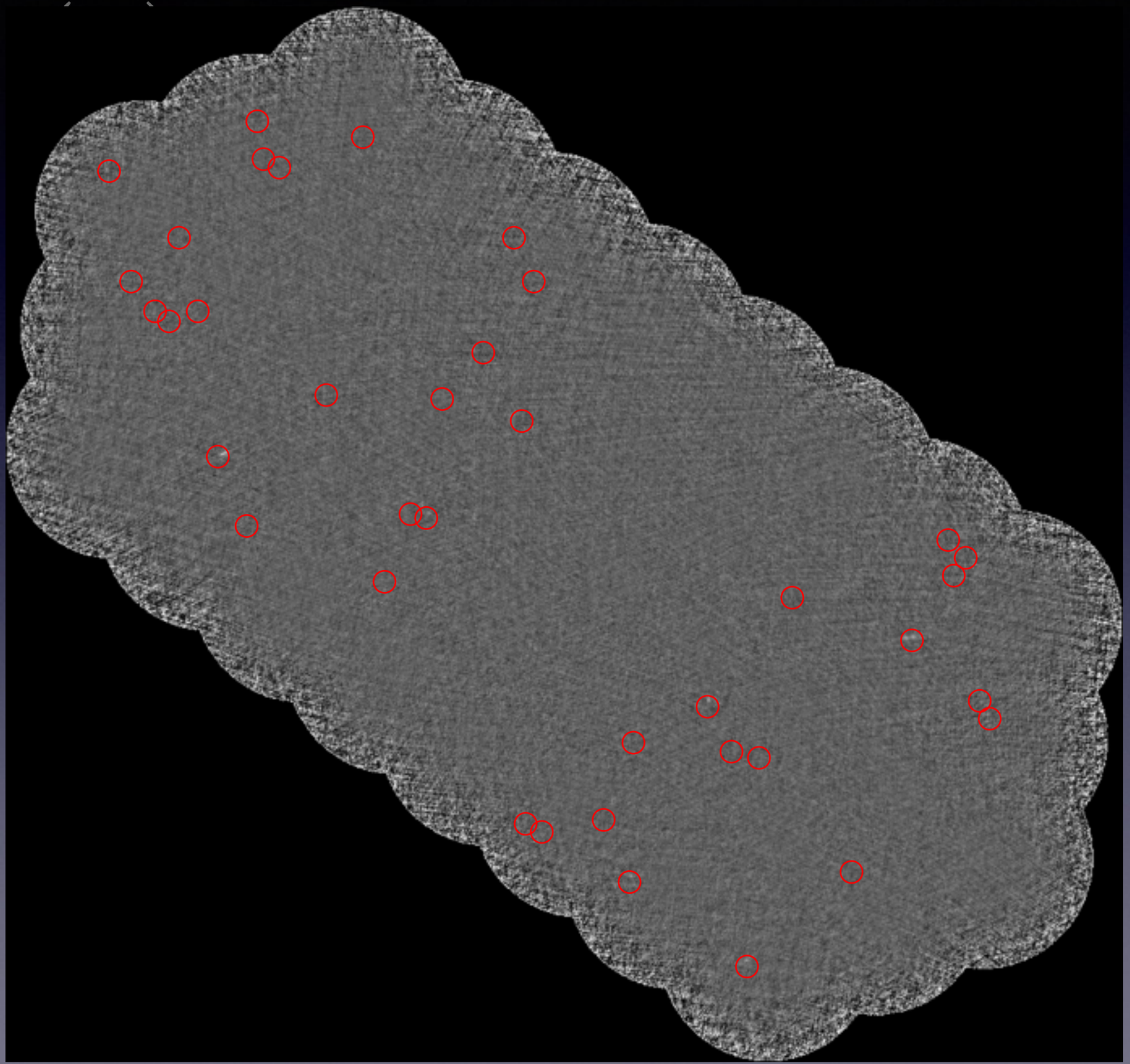

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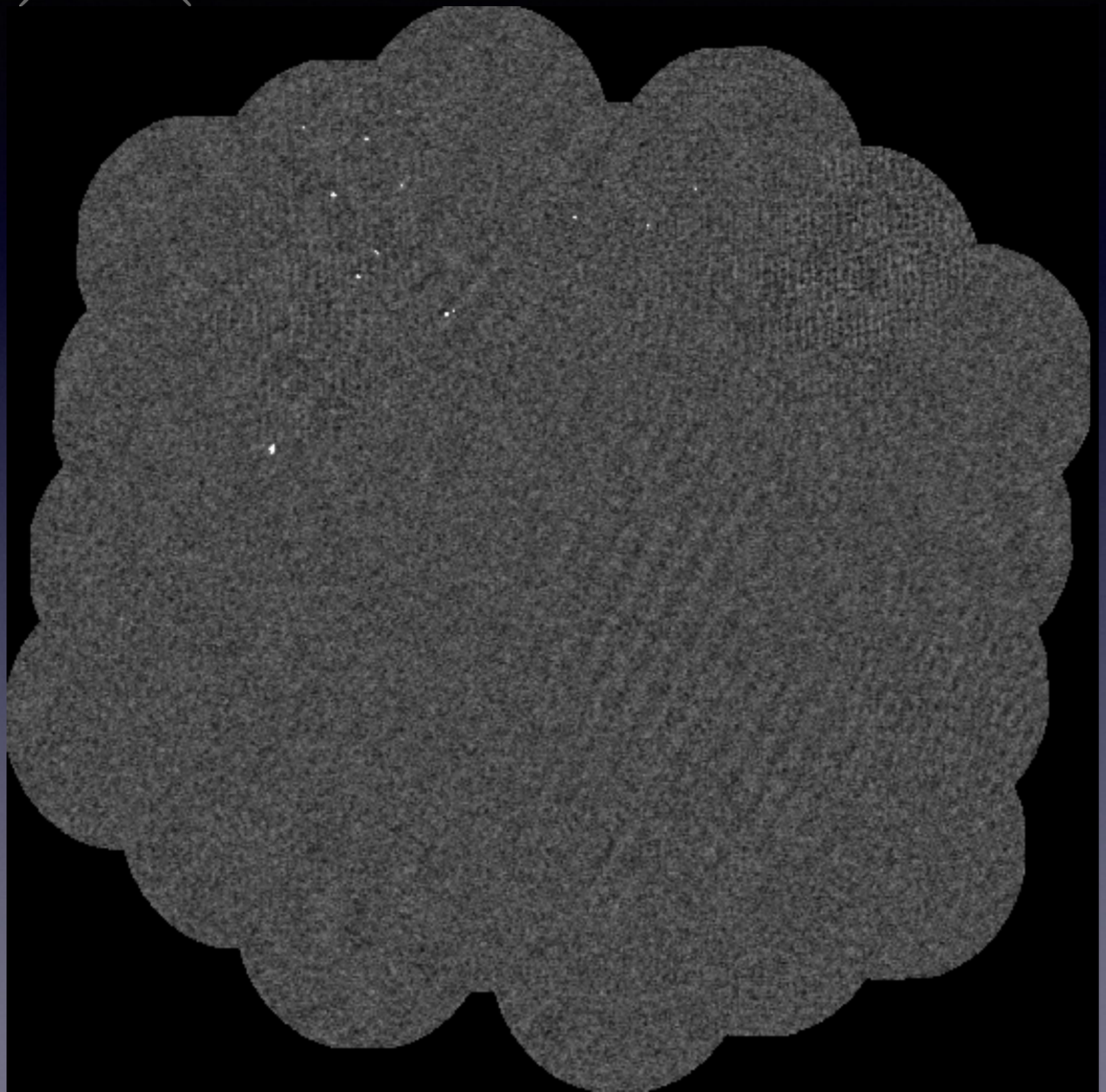
A blind HI imaging survey of Perseus-Pisces in the Zone-of-Avoidance

APERTIF

Rendering by Davide Punzo (Kapteyn Institute)



WSRT mosaic
35 pointings, 1x12^{hr}
1717 channels

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

includes 3C129

200+ HI detections

PhD: Mpati Ramatsoku
Renee Kraan-Korteweg
Gyula Jozsa ++

A blind HI imaging survey of Perseus-Pisces in the Zone-of-Avoidance

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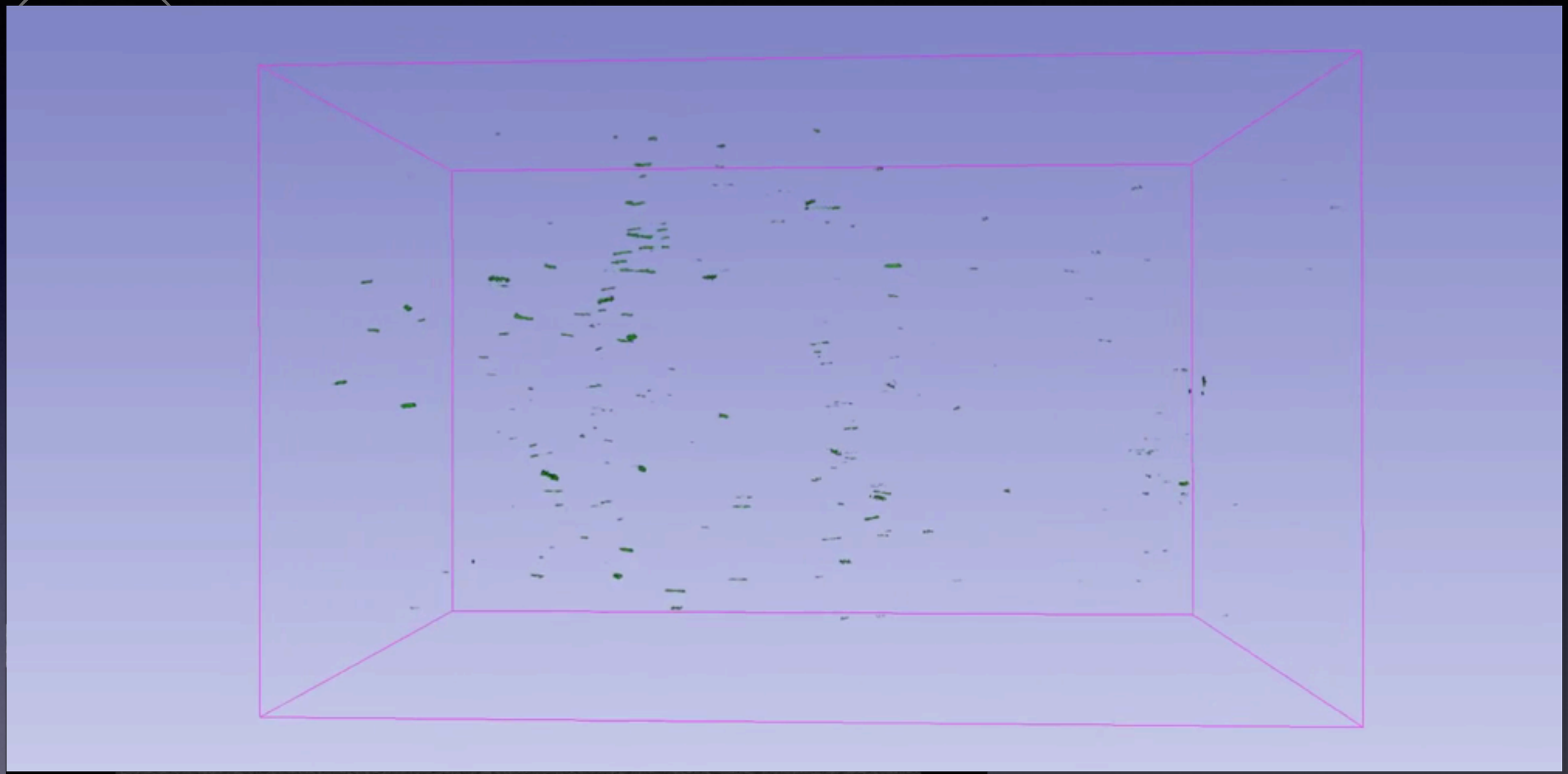
Rendering by Davide Punzo (Kapteyn Institute)



PhD: Mpati Ramatsoku

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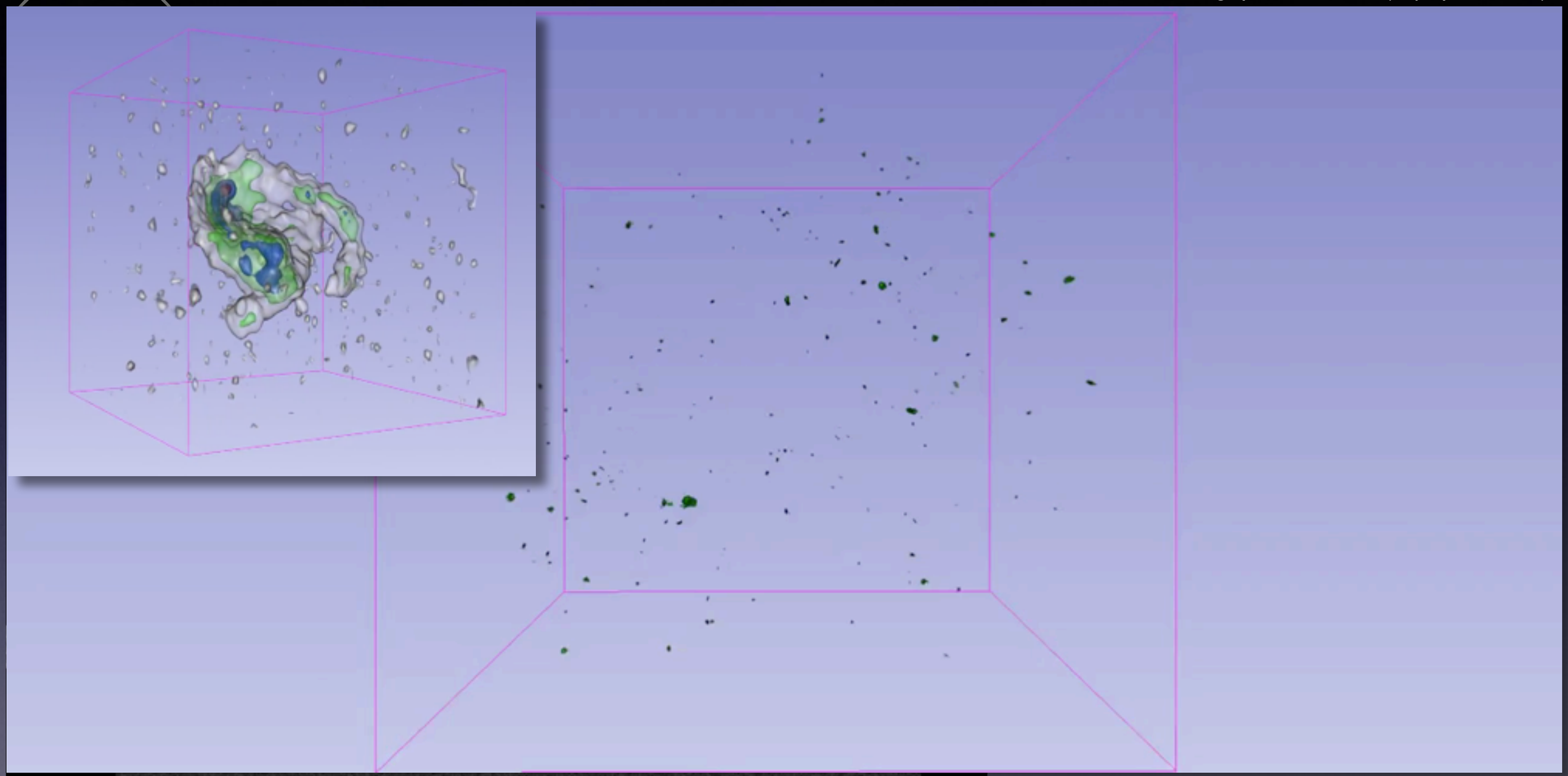
Gyula Jozsa ++

LocalGas, Dwingeloo, 4 Sept 2015

APERTIF

A blind HI imaging survey of Perseus-Pisces in the Zone-of-Avoidance

Rendering by Davide Punzo (Kapteyn Institute)



PhD: Mpati Ramatsoku

Renee Kraan-Korteweg

Gyula Jozsa ++

LocalGas, Dwingeloo, 4 Sept 2015

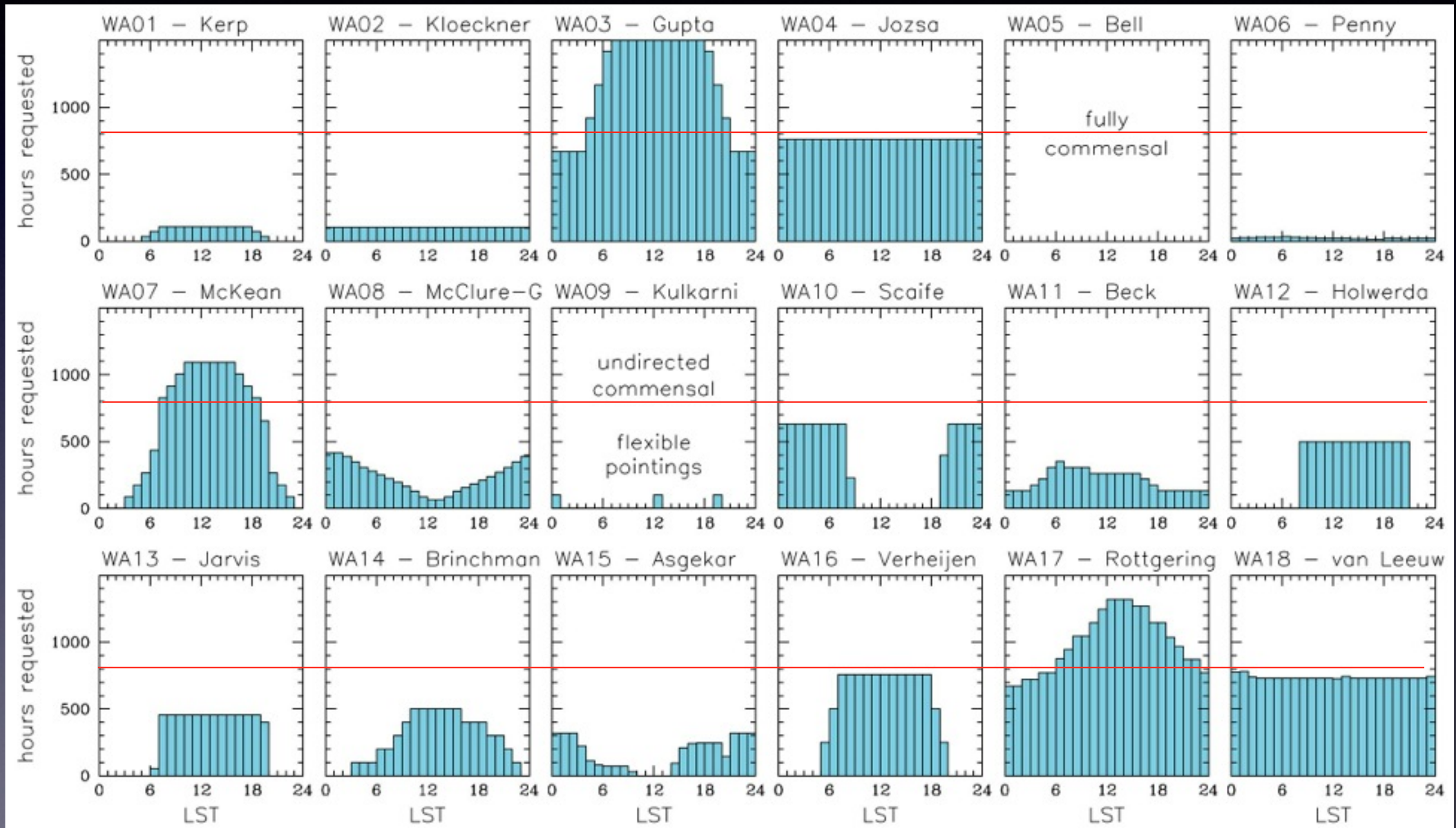
Apertif draft surveys

Guiding principles:

- public, legacy-type surveys
  based on ideas from 18 Expressions-of-Interest++
- collaborate, compromise, consolidate
- be ambitious yet realistic
- simplicity
  few observing modes, fixed pointing grid
- staged delivery of data and science
- maximum ancillary data availability
- community involvement & commitment

APERTIF

20 years of Apertif survey time required…



APERTIF consolidated Apertif surveys

Based on community input via EoI's:

- shallow wide-area survey
- medium-deep survey
- pulsar search survey
- Galactic plane survey
- commensal transients search survey

Realistic: 4-year survey period (2017−2020), 15% DD time,
75% observing efficiency, ¼ of time dedicated to a survey

→ 6600^{hr} = **550×12^{hr} per survey**

Ambitious: 8-year survey period until 2024 (SKA-1 is ready 😀)

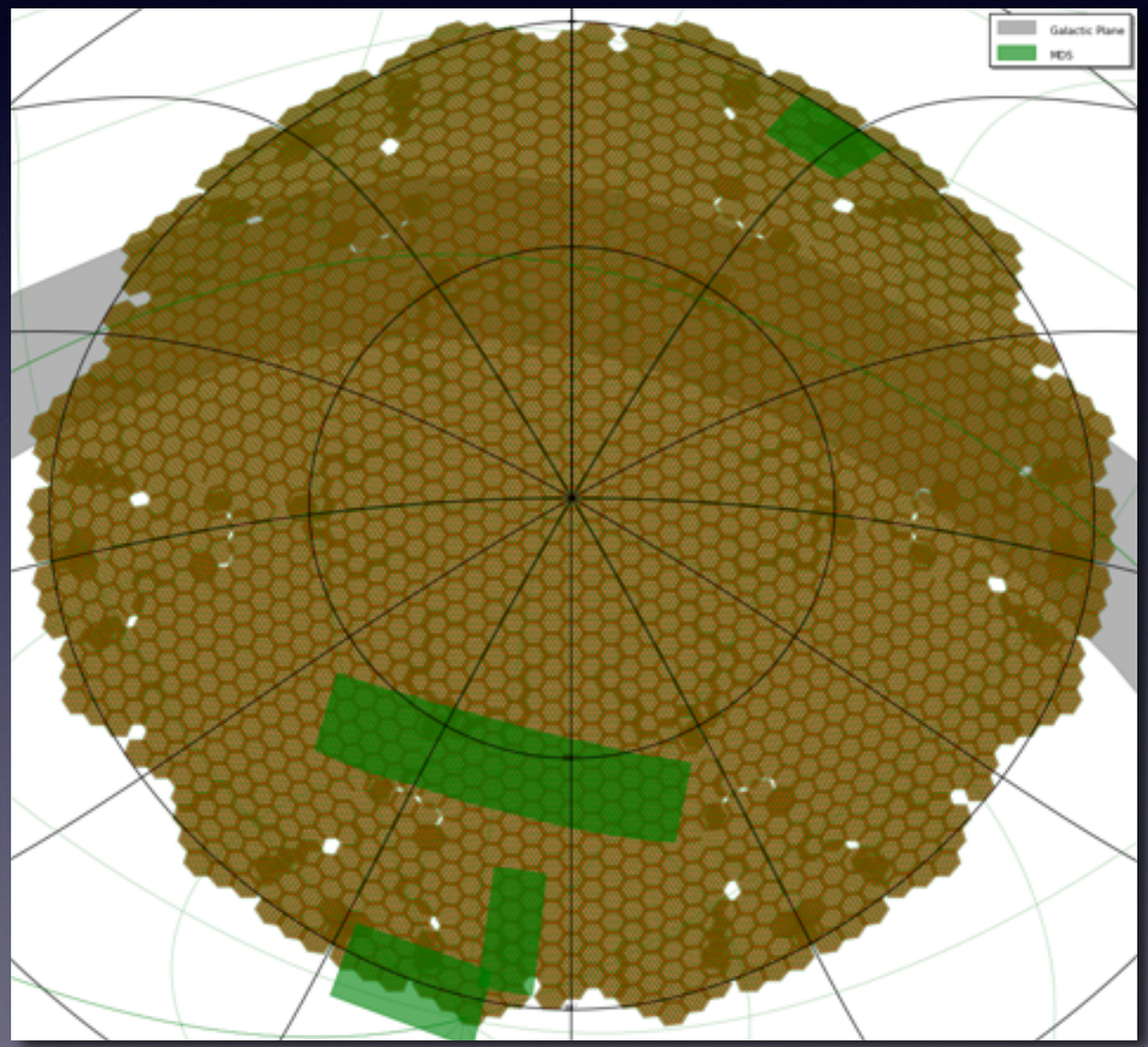
shallow wide-area survey

Survey the northern sky at δ>+27°

(requires ~1600 pointings,
or 20.000^{hr} if 12^{hr}/pointing…)

Observables of interest:

- HI redshifts, line widths, gas masses and kinematics
- HI absorption statistics and properties
- radio continuum sources (LOFAR counterparts)
- OH mega-masers
- rotation measure grid
- fast radio transients



shallow wide-area survey

Science of interest:

- HIMF, velocity function, (B)TF relation, angular momentum
- Large scale structure, spin alignments, cosmic flows
- AGN outflows/feedback
- star formation vs AGN (spectral index of LOFAR sources)
- starbursts and (major) merger rates
- the Galactic magnetic field
- extreme physics and rare objects
- + …

APERTIF

medium-deep survey

Survey 500 deg^2 at $N_{HI} \lesssim 5 \times 10^{19}$ with 15”x20”x25km/s resolution.

(requires ~60 pointings or 8.640^{hr} if 12x12^{hr}/pointing…)

Survey area is required to minimize cosmic variance.

Observables of interest:

- all shallow-survey observables but 5x deeper
- low N_{HI} structures in outer disks, filaments, tails
- slow transients (~12 epochs)
- polarized extended continuum
- RRL’s in external galaxies
- M^*_{HI} at z=0.2

medium-deep survey

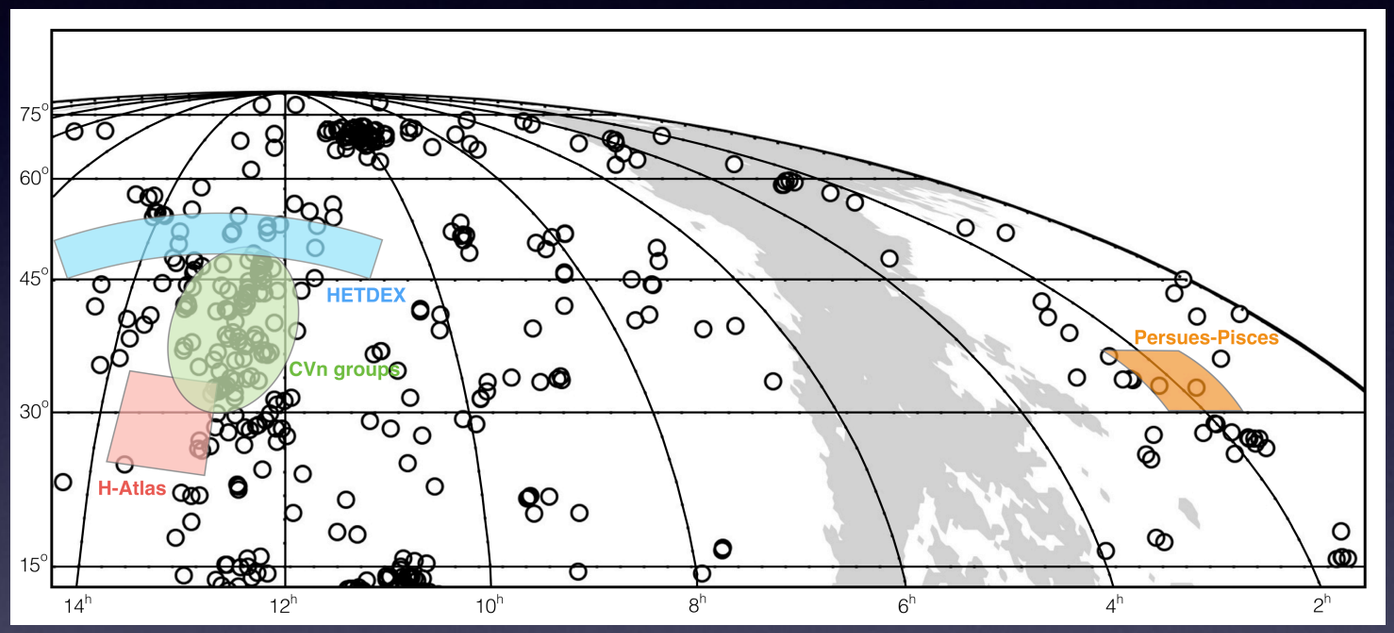
Science of interest:

- low-mass end of the HIMF at $<10^6$ $M_\odot$
- properties of the ISM and resolved SF in external galaxies
- gas accretion and minor merger rates
- environmental influence on gas in/around galaxies
- extra-planar gas, warps, streaming motions
- Ω_{HI} at $z=0.2$
- faint continuum sources (viz-a-viz LOFAR)
- magnetic fields in external galaxies
- radio halos in galaxy clusters
- the variable radio sky (in concert with Palomar Transient Factory)

medium-deep survey

Four areas comprise footprint of medium-deep survey, maximising use of existing ancillary data.

sky areas of interest



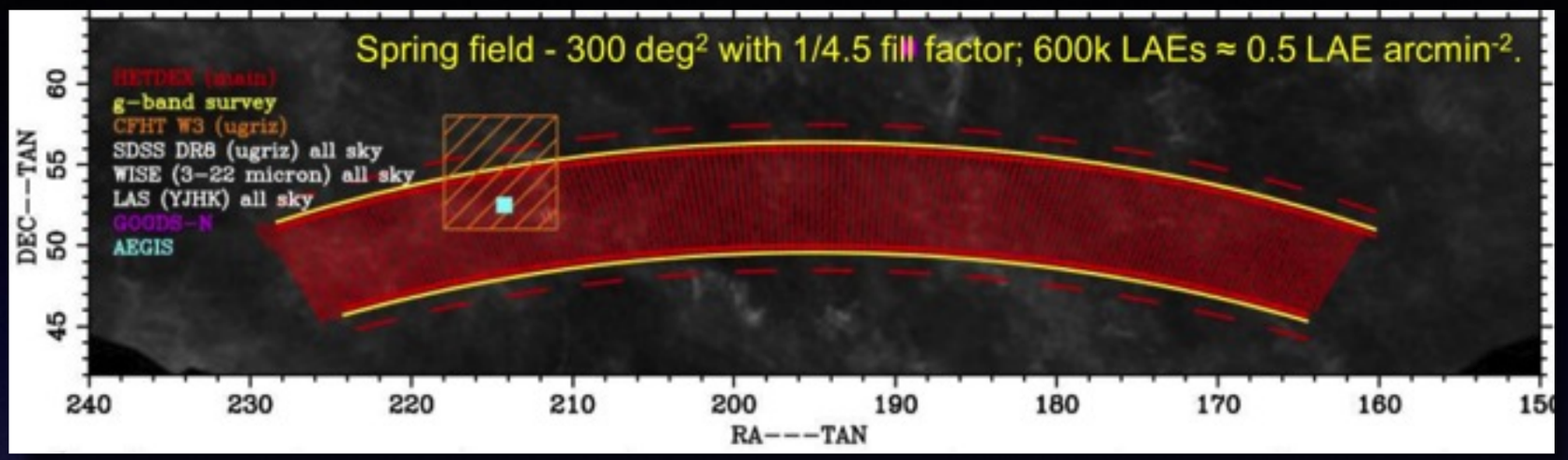
- The HETDEX survey area
  ~10^5 optical redshifts, stacking
- CVn group of galaxies
  low-mass end of HIMF
- Herschel-Atlas Northern Field - SF, gas & galaxy evolution, Coma cluster
- The Perseus-Pisces supercluster - environmental effects, magnetic fields

Spring fields are in SDSS with coordinated overlap with MaNGA and HetDex, delivering resolved information on Stellar Pops, ISM, kinematics, metallicities etc.

Ancillary data - HetDex

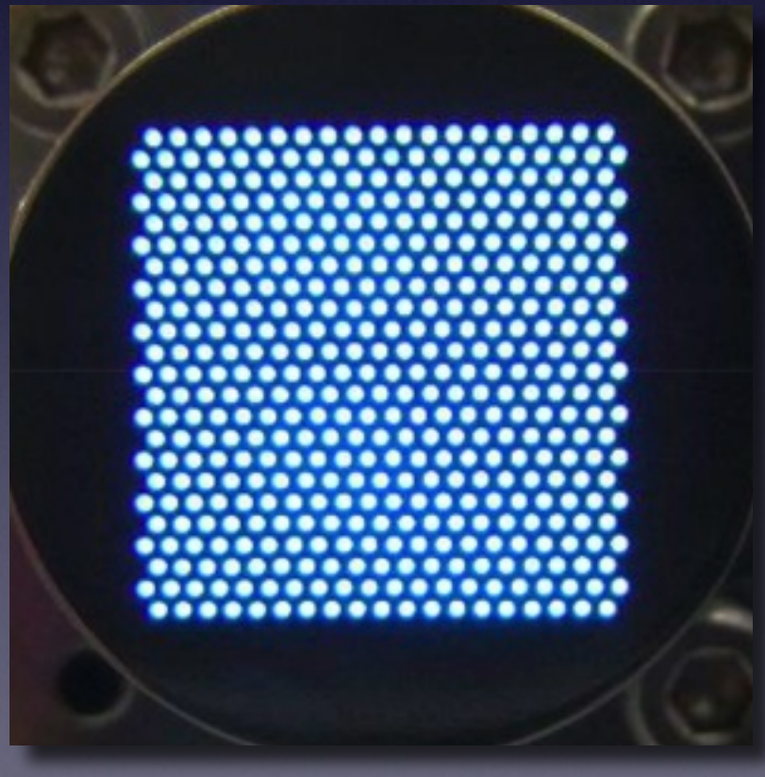
A *blind* IFU survey using VIRUS on HET

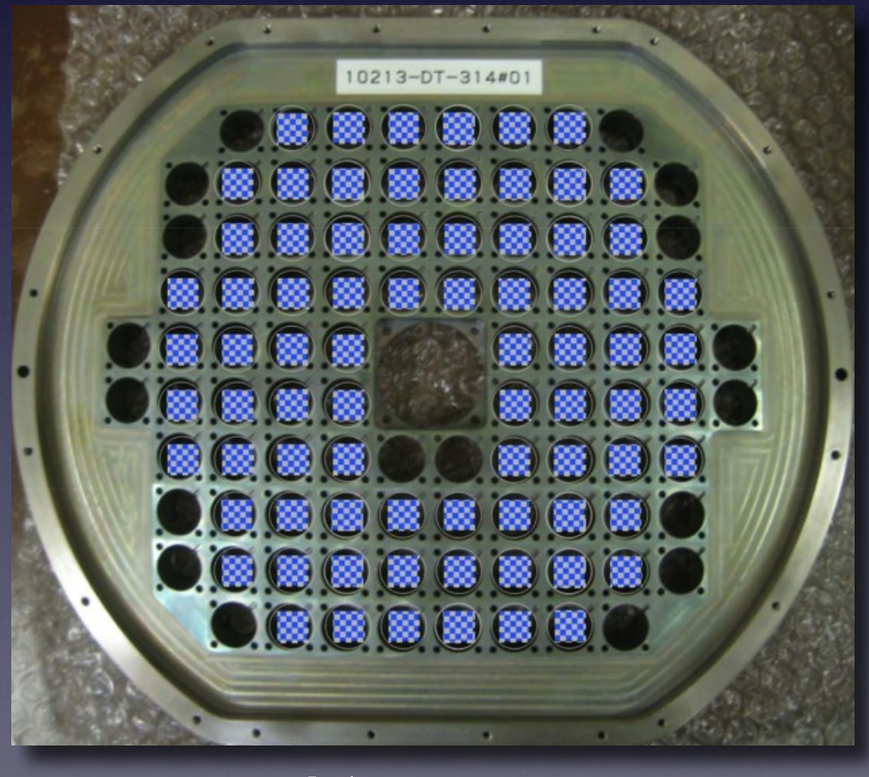
22% fill factor over 300 deg^2



- 1.5" fibers
- 448 fibers/IFU, 78 IFUs
- 350-550 nm

  Ly-α : Z=1.9−3.5
  [OII] : Z= 0−0.48
  Hβ : Z= 0−0.13
  [OIII] : Z= 0−0.10
- R=700





16 arcmin

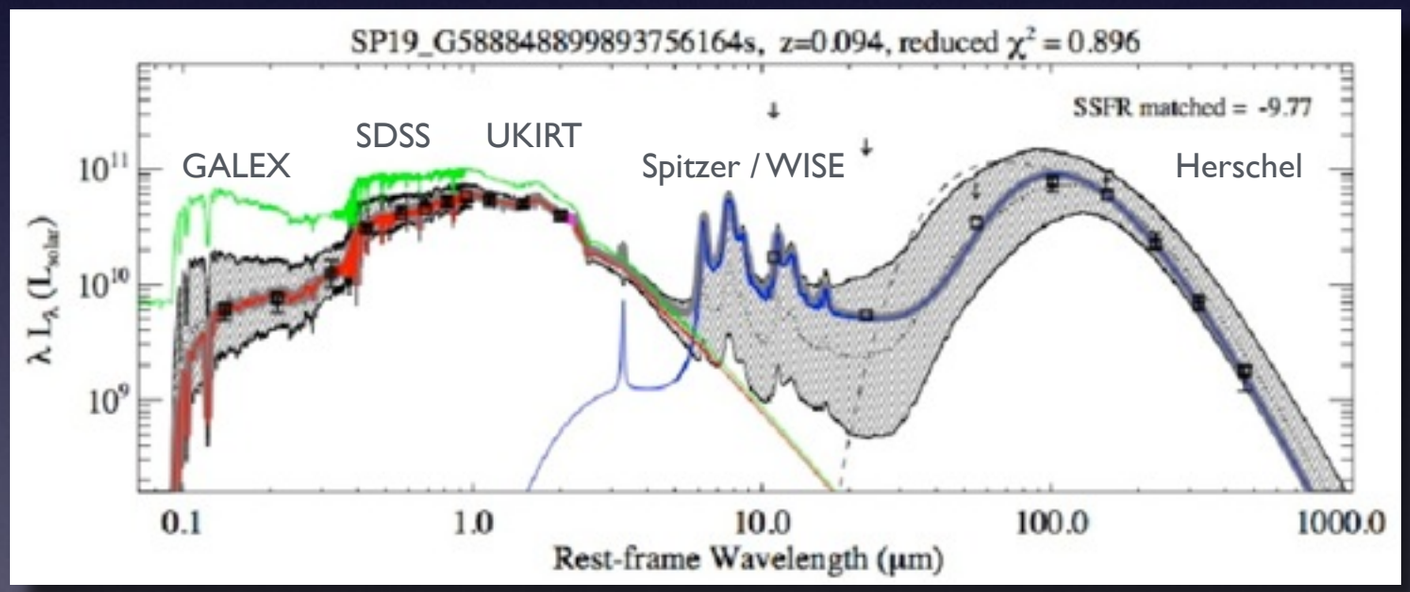
⋈ 50" spacing

~10^5 [OII] redshifts in Apertif bandwidth (Z≲0.25)

Ancillary data - H-Atlas

Blind Herschel PACS/SPIRE imaging of North Galactic Pole region (~150 deg^2)

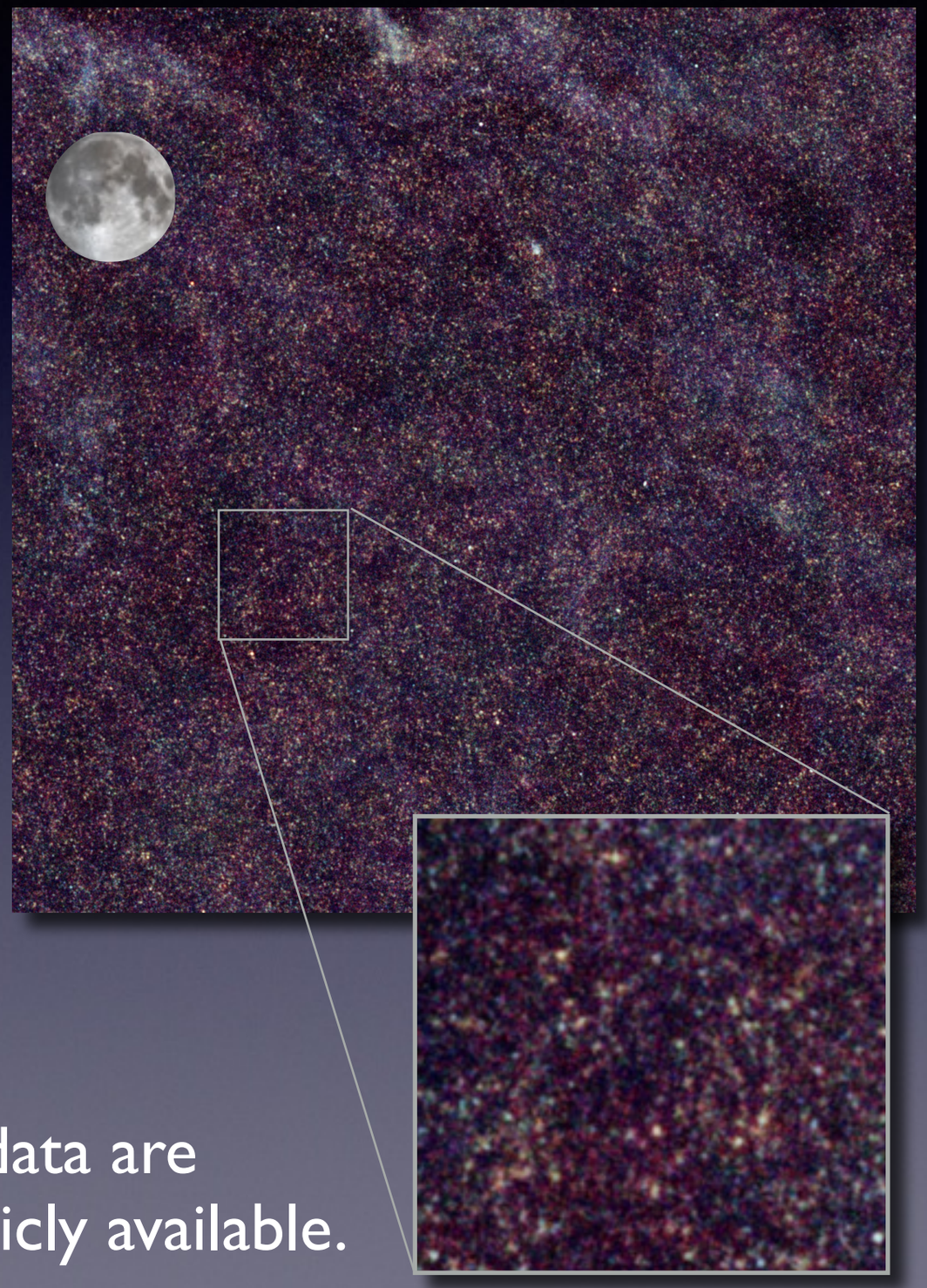
PACS: 110, 170 μm ~500 sources/deg^2
SPIRE: 250, 350, 500 μm Θ=18" at 250 μm



Complete SED reconstruction:

- Total energy output
- Star Formation Rates
- Dust masses and temperatures

1/12th of NGP field, including Coma

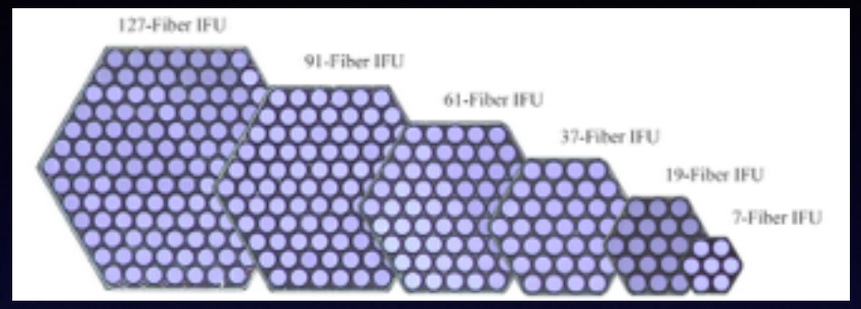


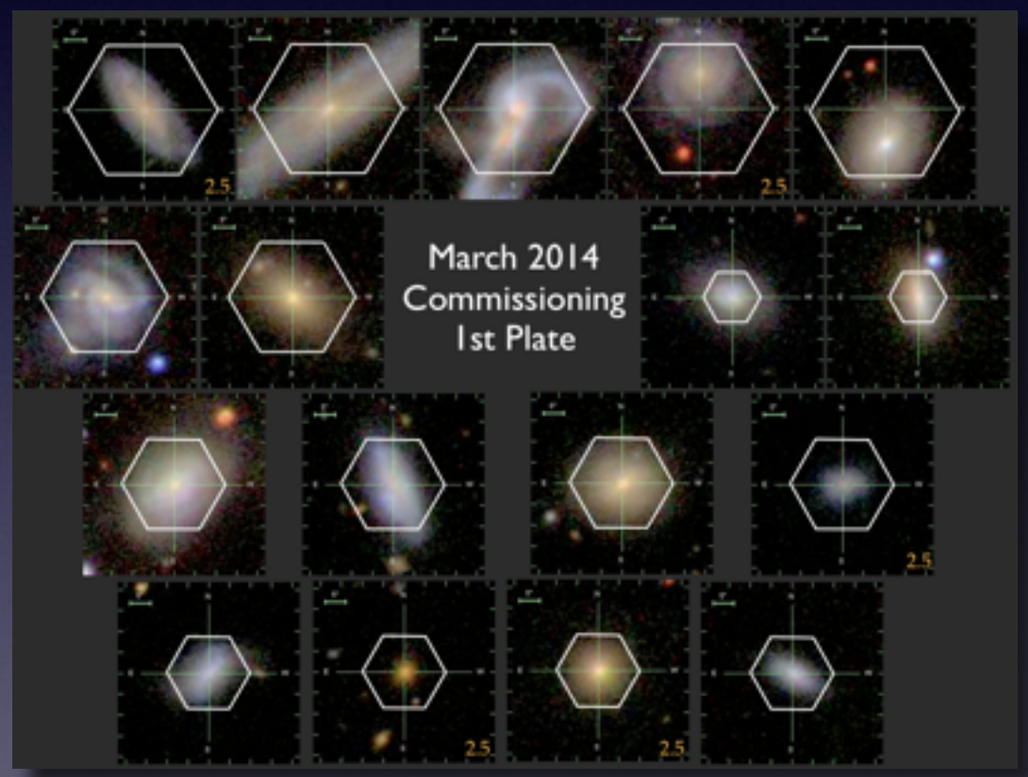
All data are publicly available.

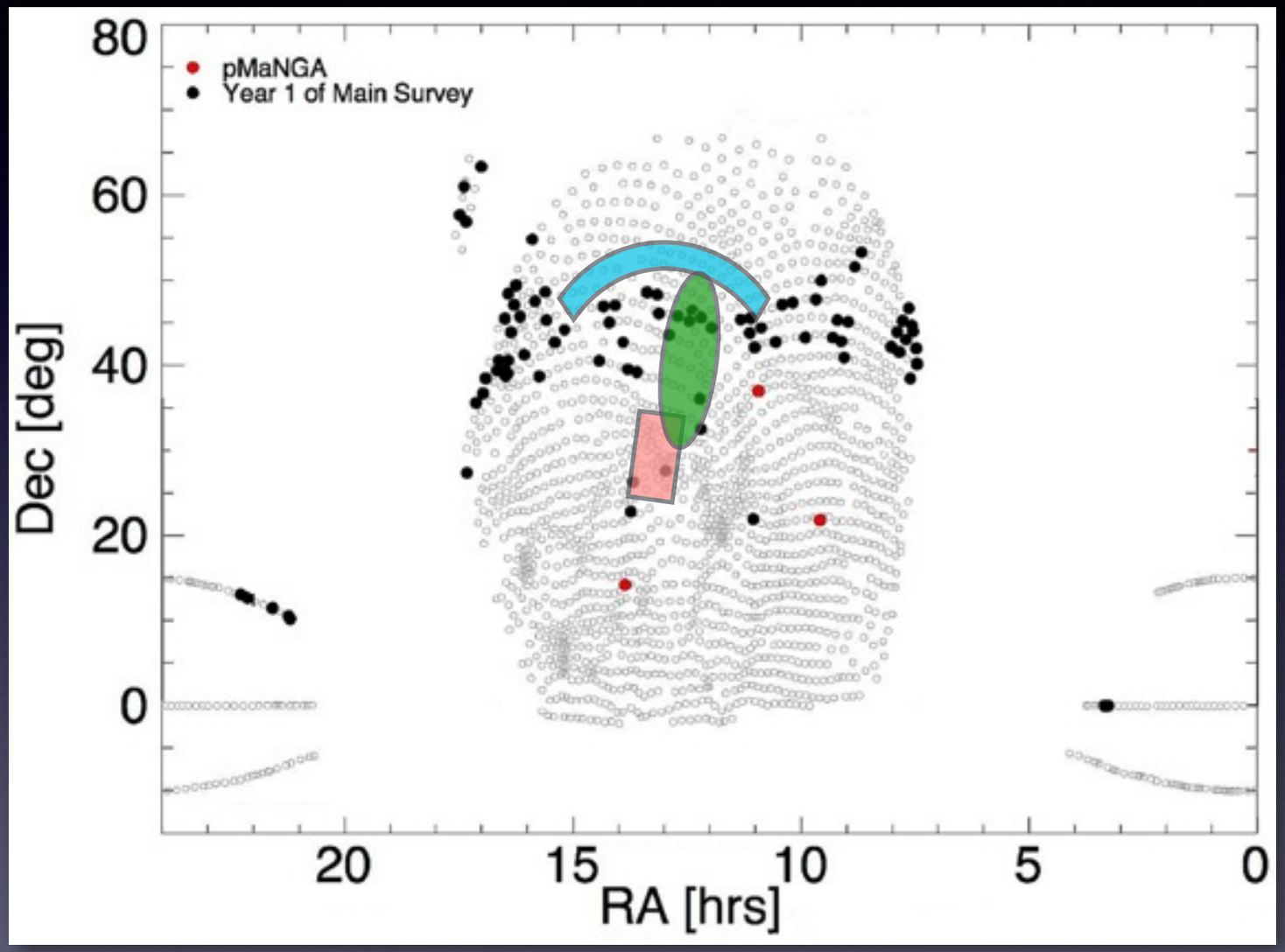
Ancillary data - MaNGA

APERTIF

A SDSS-IV multi-IFU survey of 10^4 nearby galaxies at z≈0.03







- 2” fibers
- 17 IFU’s per 7 deg^2 field
- 12”−32” FoV per IFU
- 360-1000 nm
- R=2000

forthcoming activities

late 2015 : Apertif-6 roll-out & performance tests

early 2016 : roll-out of remaining 6 PAFs, full correlator shake-down, commissioning, science verification ramp-up of science teams

late 2016 : Early Science programs

early 2017 : Start of surveys