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HI imaging surveys

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NCRA • TIFR

ASTRON

NWO

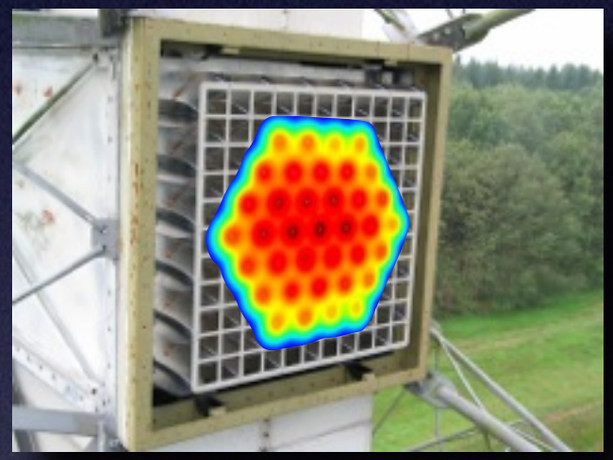
10th PHISCC, Pune, 6-8 Feb 2017

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.



	APERTIF	MFFE
# antennas/dish	121	2
# 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)

$(A_{eff}/T_{sys})^2_{\ MFFE-14} = 4x\ (A_{eff}/T_{sys})^2_{Apertif-12}$

<u>APERTIF Resolution :</u>

$\Theta = (1+Z)^2 x\ 15" x 15"/\sin(\delta)$

(10kpc @ D=150 Mpc)

$R = (1+Z) \times 2.6$ km/s

APERTIF increases survey speed of WSRT 20x

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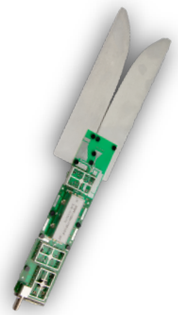
hardware developments

a fully reconstructed signal chain

12 dishes



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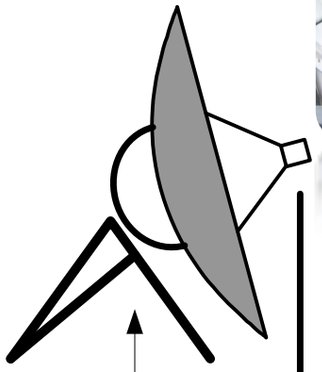
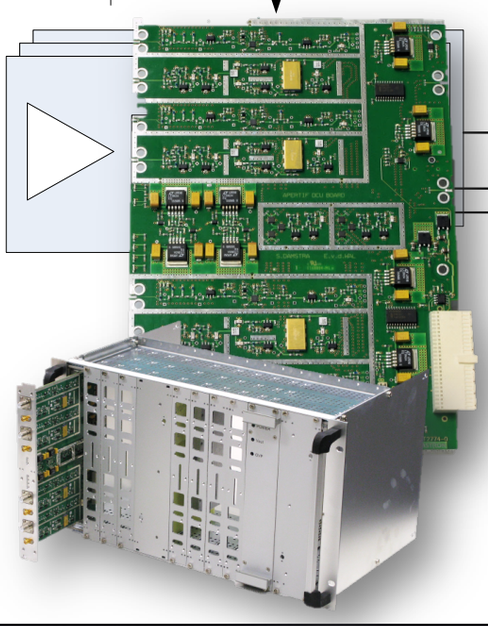
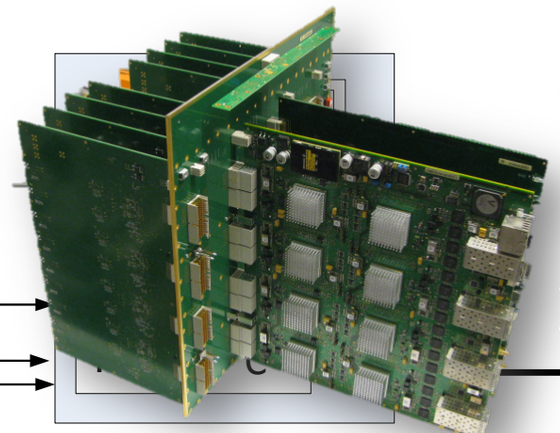


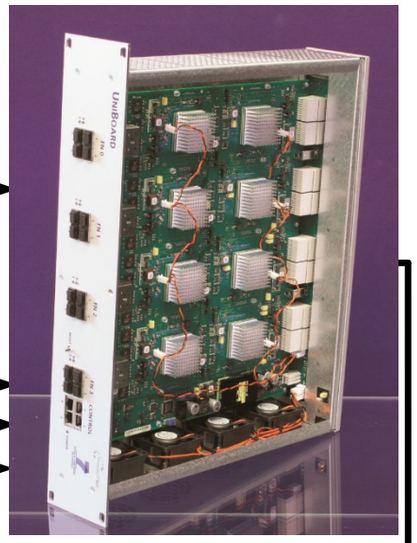
calibration

121x coax





Filterbank &
Beamformer

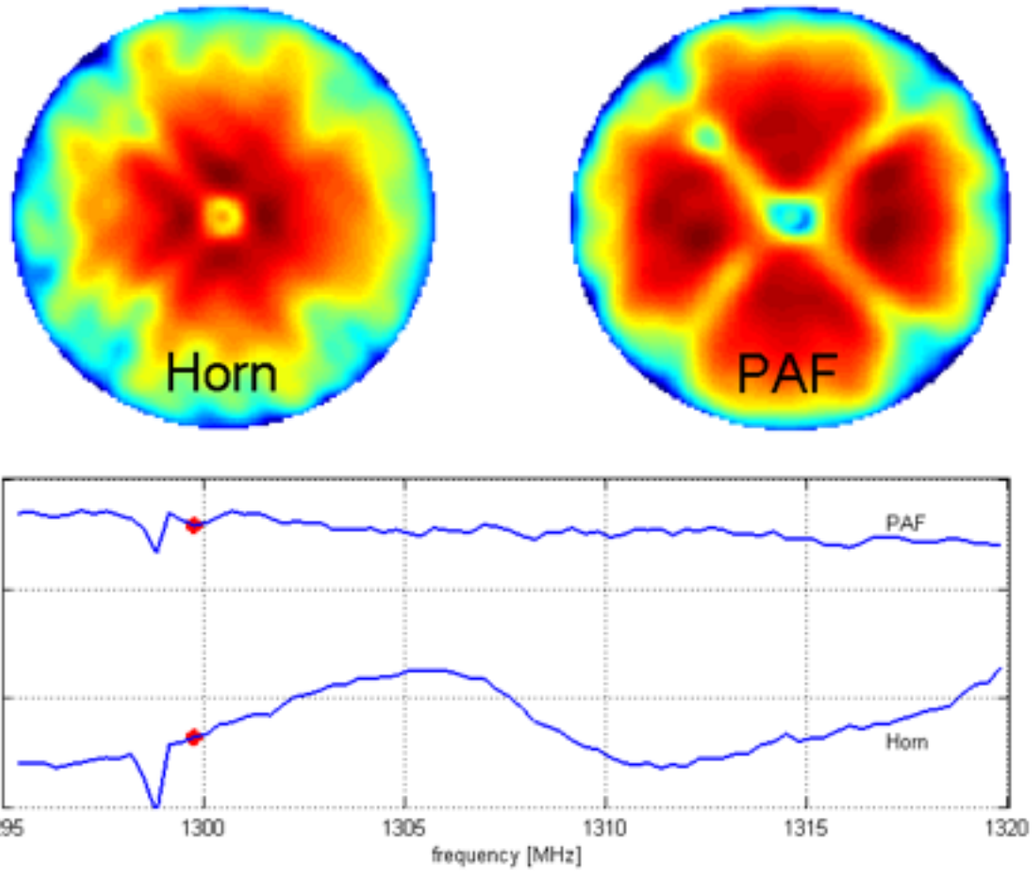


Storage
&
Offline processing

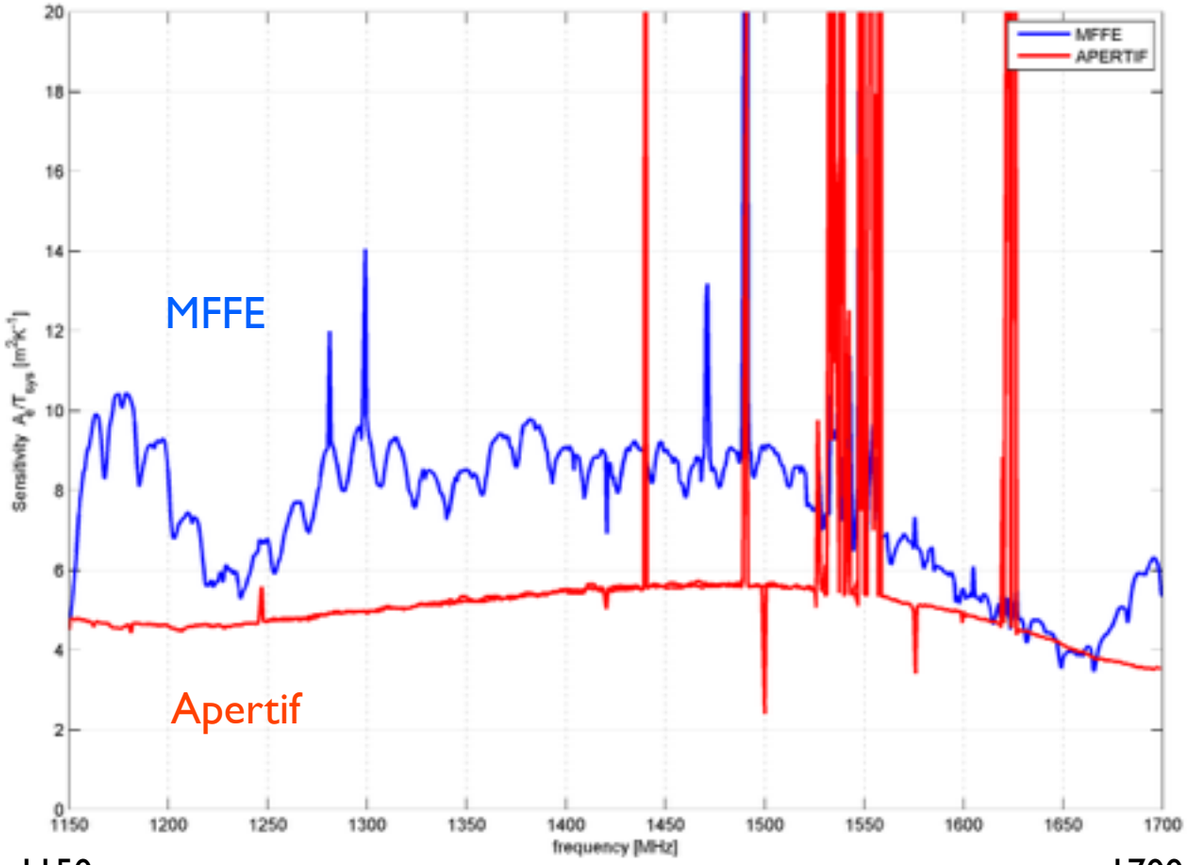
~2.9 TB/12hr

on-sky performance

Holography



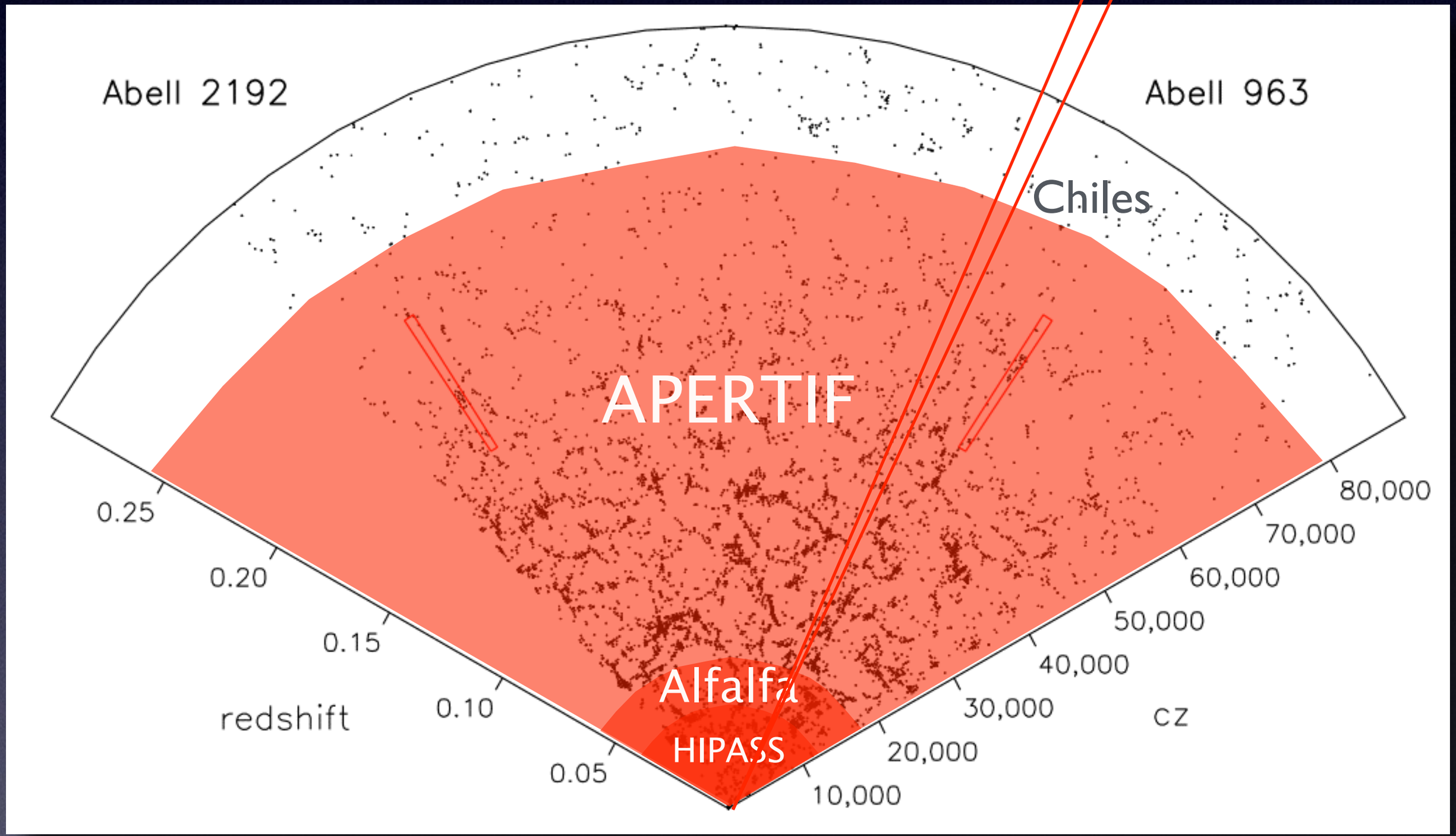
A_{eff}/T_{sys}



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

The promise of Apertif

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



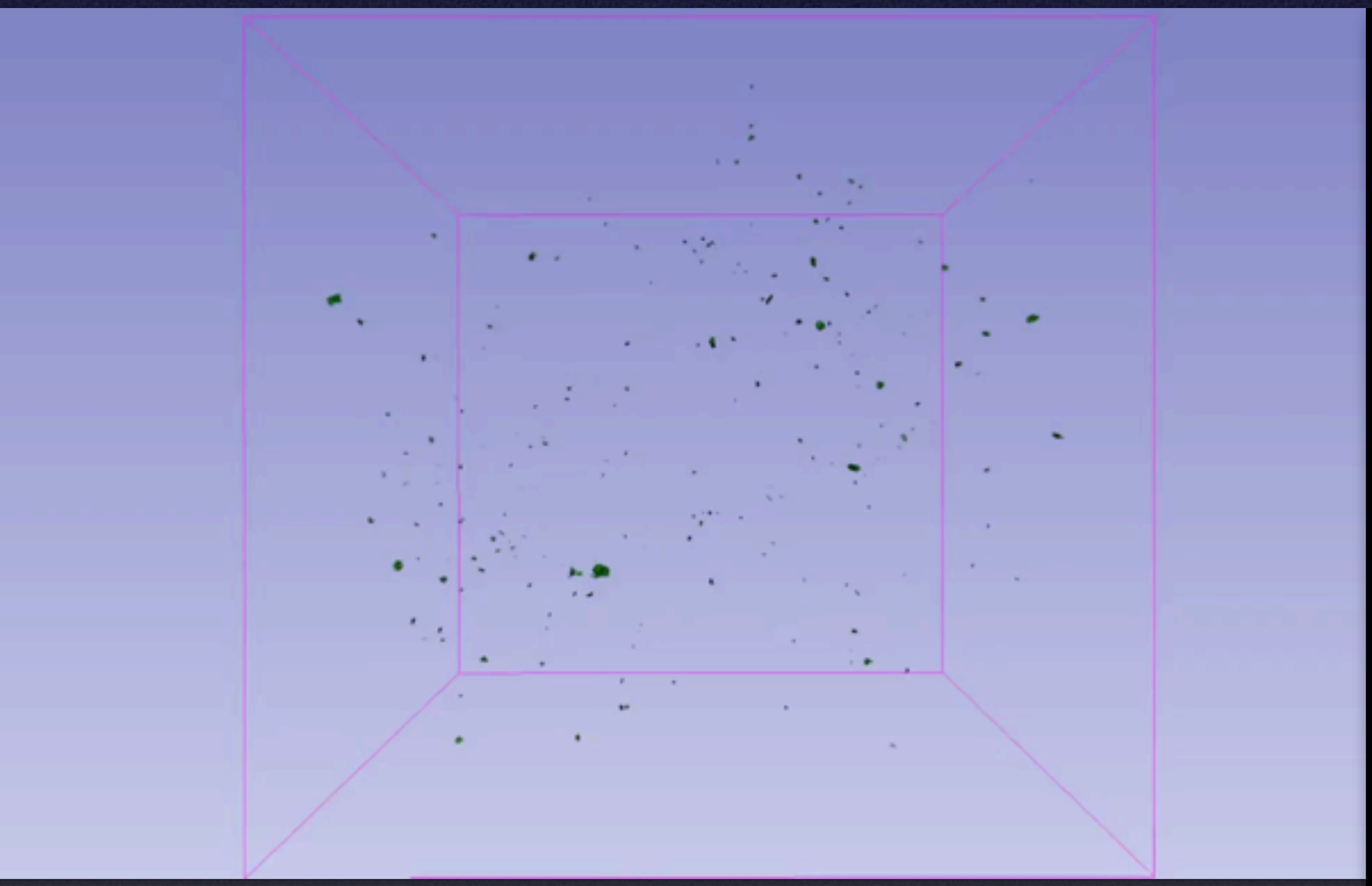
The promise of Apertif

training cubes

Perseus-Pisces - ZoA

$Z = 0.008-0.055$

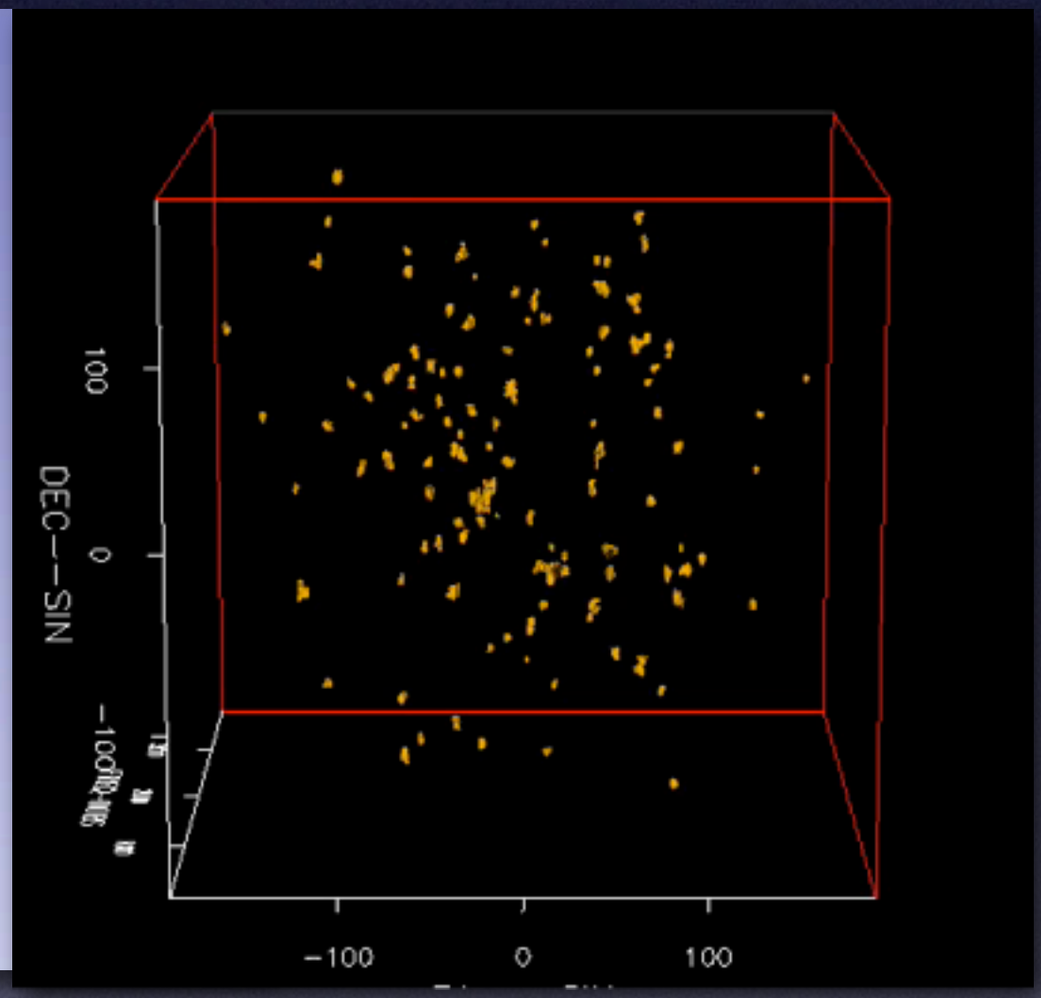
$D_L = 35-237$ Mpc



Budhies

$Z = 0.164-0.224$

$D_L = 790-1120$ Mpc



Mpati Ramatsoku, Davide Punzo

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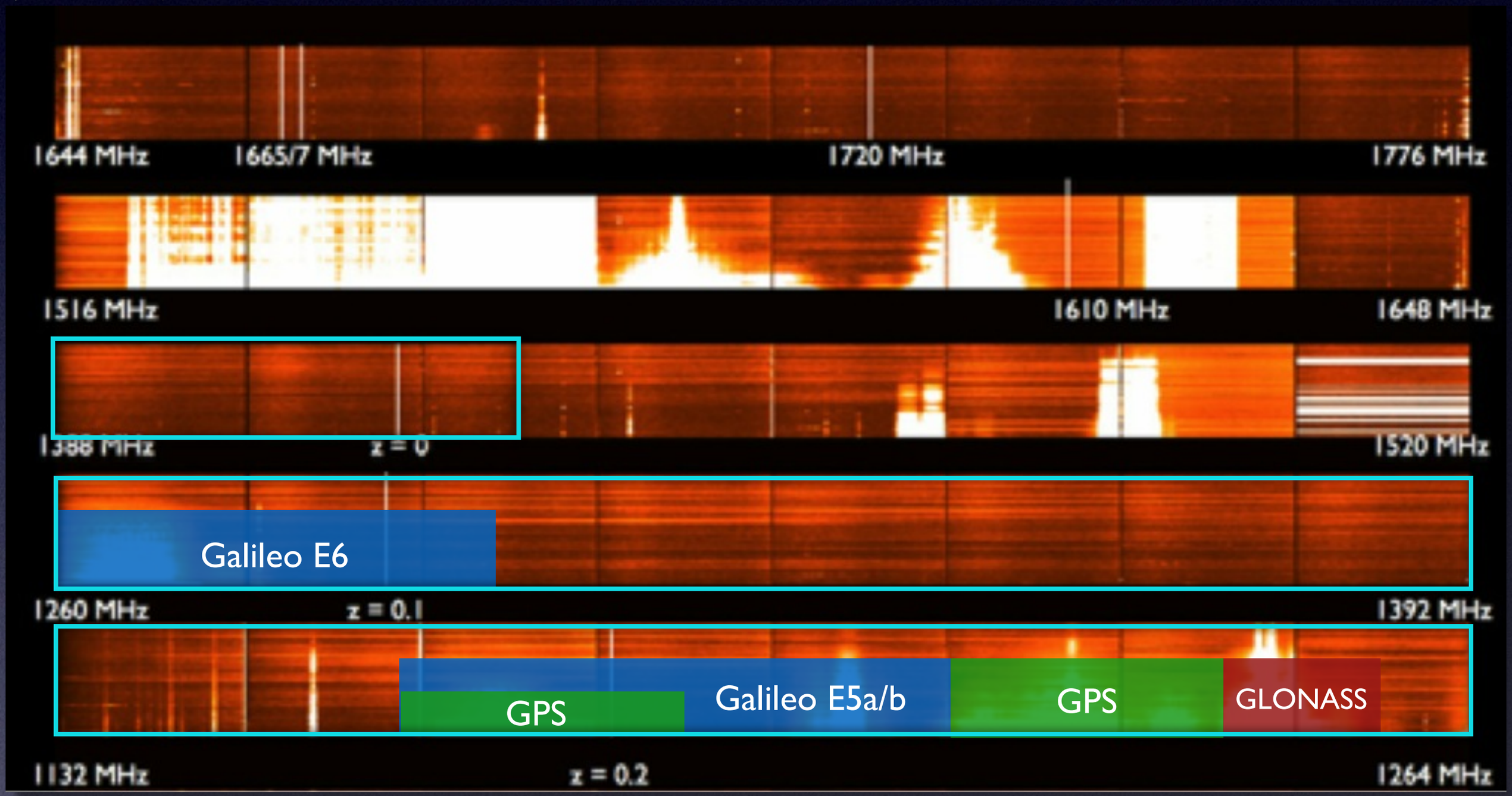
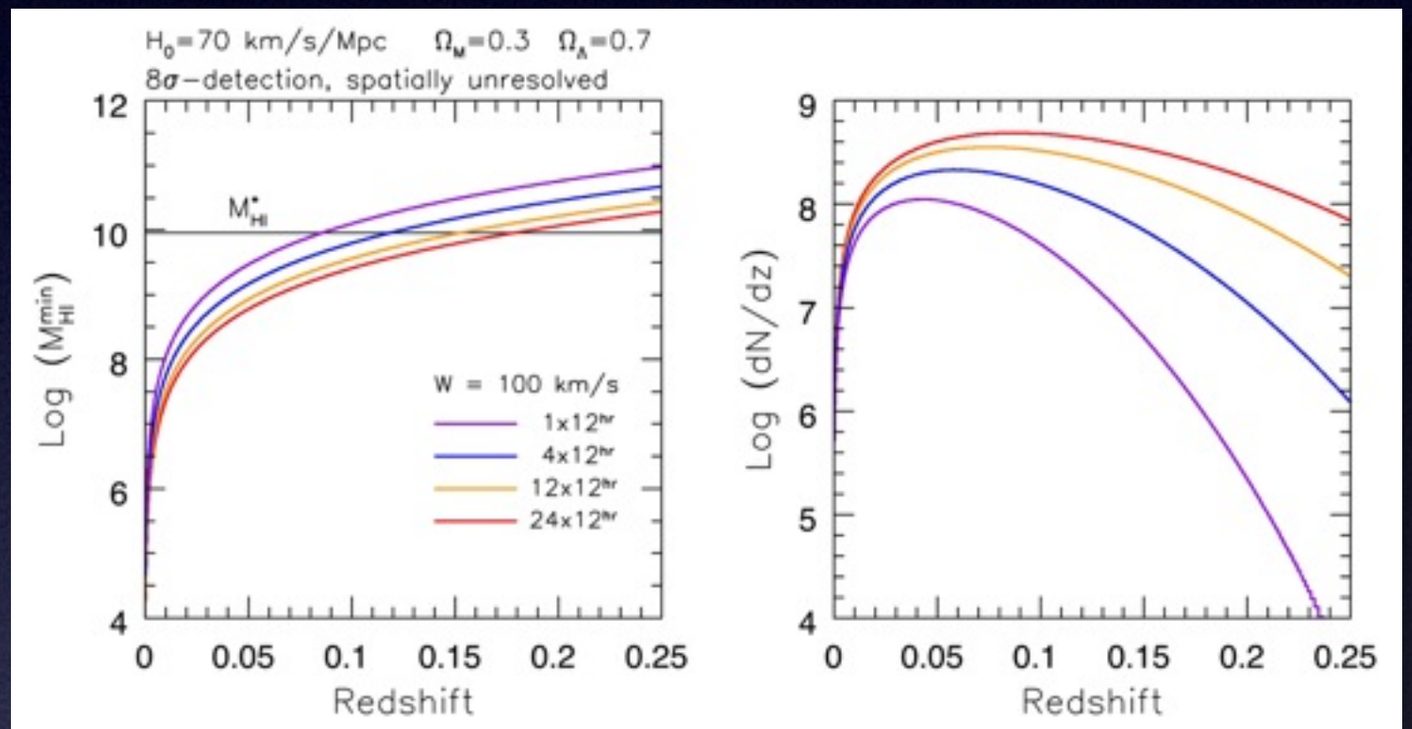
Radio Frequency Interference



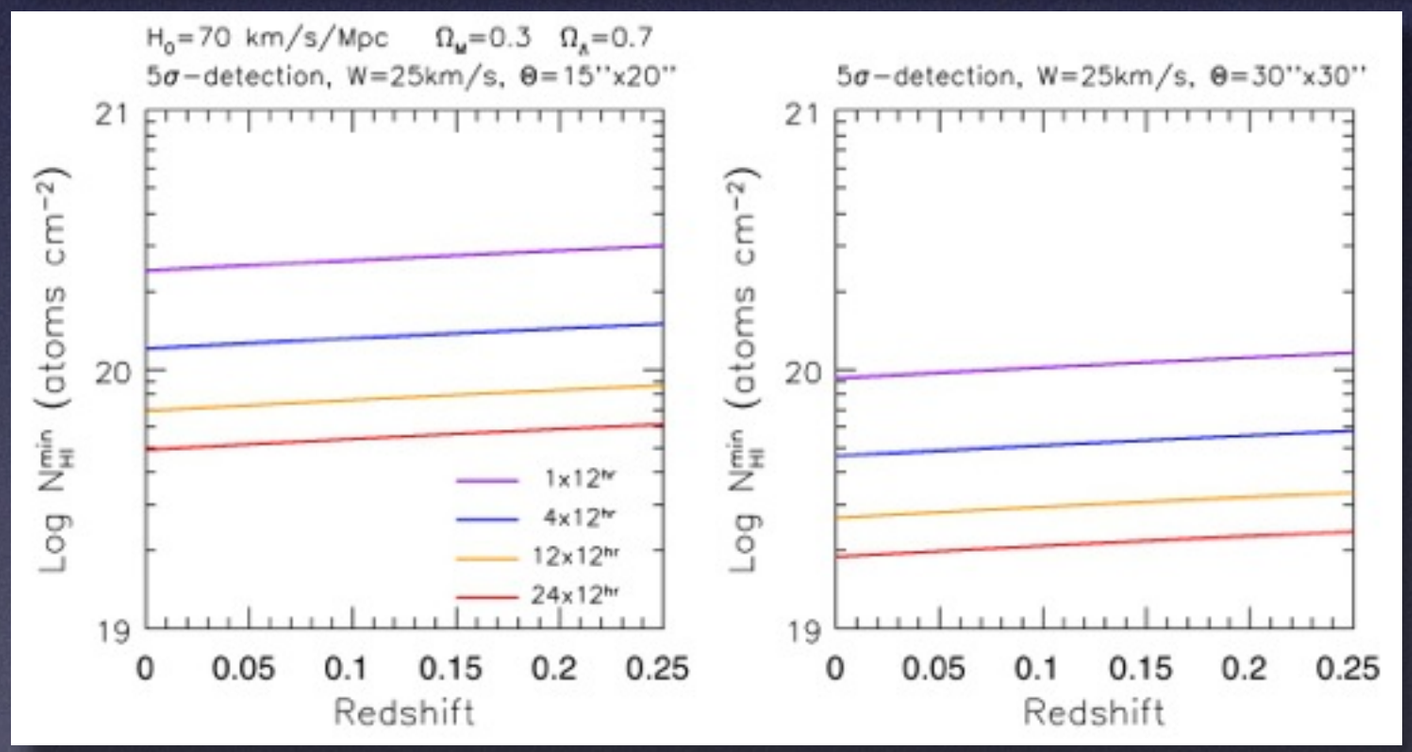
HI mass & column density limits

Based on Alfalfa HIMF

HI mass limits



HI column density limits



Imaging surveys: 1430−1130 MHz

$1x12^{hr}$: 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

Expectation:

- 10^5 HI detections
- 10^4 resolved galaxies
- 10^7 continuum sources

Note:
smoothing to Θ=30" reduces survey volume at fixed linear resolution by a factor 8 .

Inventory of community interest

Based on input from the community:

- shallow northern-sky survey (SNS)
- medium-deep survey (MDS)
- pulsar/transients survey (PTS)
- Galactic plane survey (GPS)
- commensal transients search survey

<u>Nominal</u> : 4-year survey period (2017–2021), 15% DD time (?),
10% maintenance, 75% efficiency, ⅓ of time to a survey

→ 6700^{hr} = **550×12^{hr} per survey**

<u>Extended</u> : full northern-sky survey (10,000 deg^2)

Apertif Survey Design

Guiding principles:

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

Apertif Survey Plan

Three imaging and one pulsar/transients surveys :

- Shallow (1x12^{hr}), large-area (~3000 deg^2) imaging
  overlap with SDSS, PanStarrs-I, MaNGA, Califa, HetDex, S^{4}G

- Medium-deep (10x12^{hr}), medium-area (~300 deg^2) imaging
  overlap with H-Atlas+Coma, CVn, HetDex, Perseus-Pisces

- Apertif-LOFAR (4x12^{hr}, ~10 fields of 10 deg^2) imaging

- Wide-field pulsar and transients survey (3^{hr}, 15.000 deg^2)
  triggers LOFAR for accurate FRB positions

Surveys to be conducted by the community

Apertif Survey Team

Erwin de Blok - *HIgal* : rotation curves and galaxy edges

Thijs van der Hulst - *HIstoryNU* : The HI story of the Nearby Universe

Kelley Hess, Manolis Papastergis, Davide Punzo, Nadine Giese

Joeri van Leeuwen - *ARTS* : Apertif Radio Transients Survey

Raffaella Morganti - *SHARP* : Search for HI absorption with Apertif

Bjorn Adebahr, Filippo Maccagni

Tom Oosterloo - *HuDaGa* : The search for the smallest galaxies

Betsey Aams, Antonino Marasco

Marc Verheijen - *HIperEdge* : HI perspective on Env. Driven Gal. Evol.

Danielle Lucero	- HI in early-types	
Anastasia Ponomareva	- Tully-Fisher, mass models	(\w K.C. Freeman)
NN postdoc	- observing simulations	
Avanti Gogate	- local environment, groups	
Pooja Bilimogga	- global environment, cosmic web	
Julia Healy	- stacking, HIMF, Ω_{HI}	(\w S.L. Blyth)
Mpati Ramatsoku	- ZoA pilot study	(\w R.C. Kraan-Korteweg)
NN PhD student	- galaxy cluster outskirts	(\w B.M. Poggianti)

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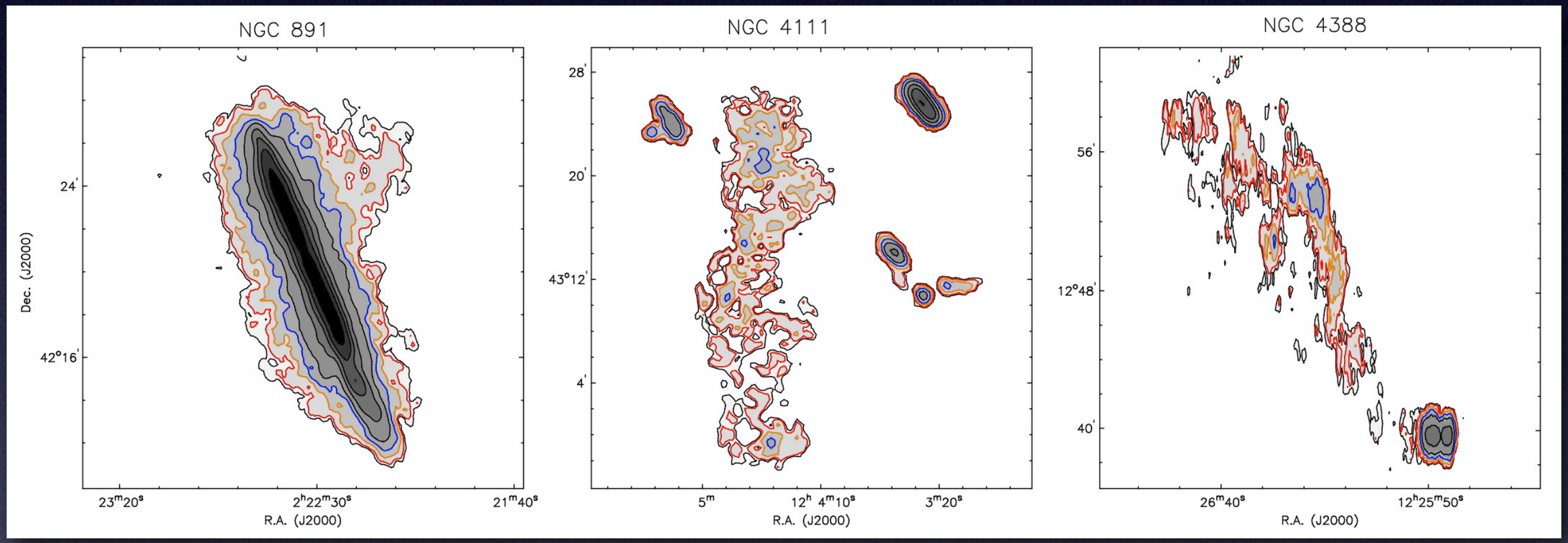
Science requirement : $N_{HI}^{min} \approx 5x10^{19}$

Accretion, depletion and removal of gas

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



Fraternali et al

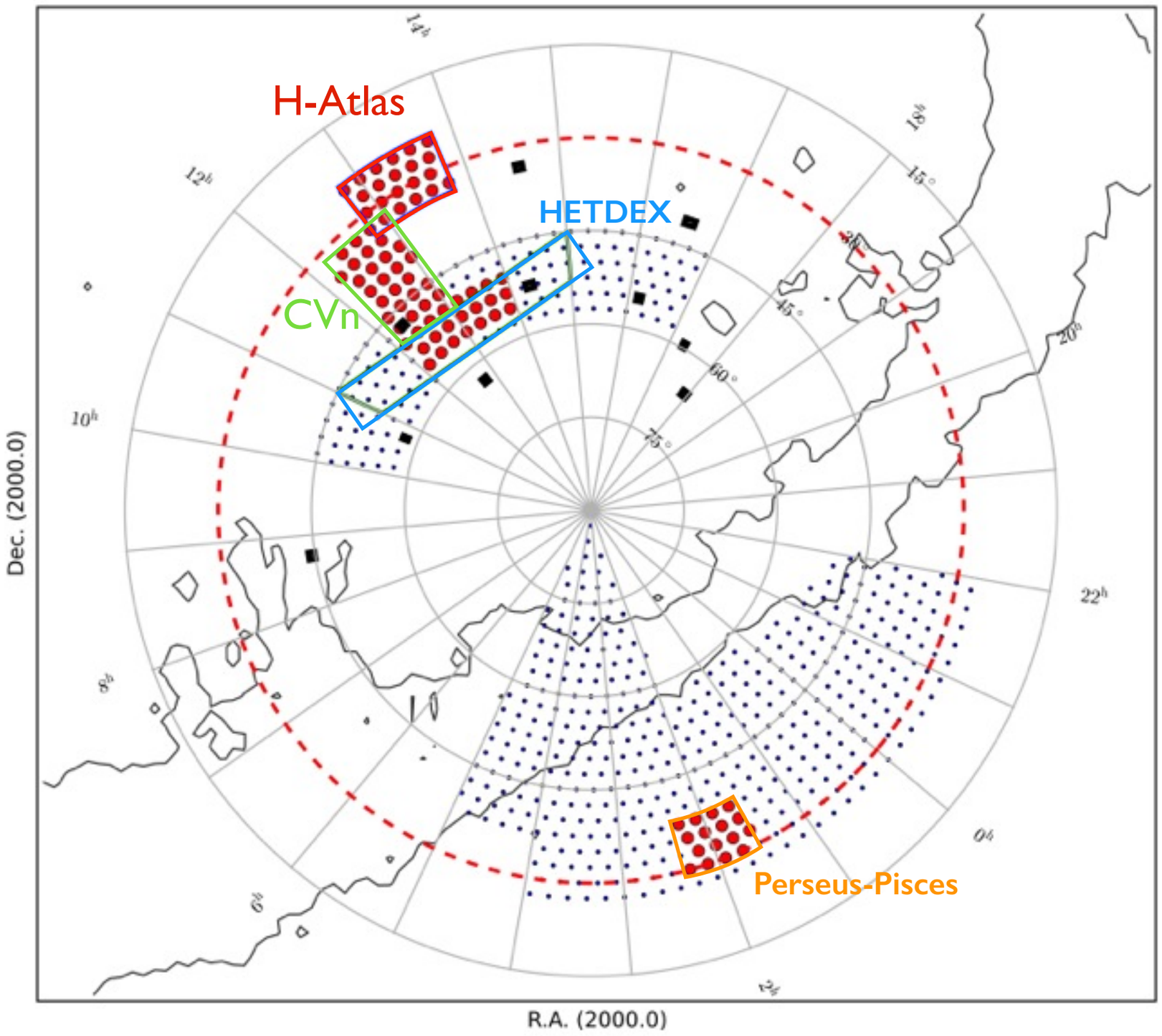
Verheijen et al

Oosterloo 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.

Apertif Survey Plan



- Shallow Northern Survey
- Medium-Deep Survey
- LOFAR fields

SNS: 3,000 deg^2
1x12^{hr}/pointing

MDS: 300 deg^2
10x12^{hr}/pointing

PTS: 15,000 deg^2
3^{hr}/pointing

10 LOFAR fields:
4x12^{hr}/pointing

Pointing grid and survey boundary details to be determined.

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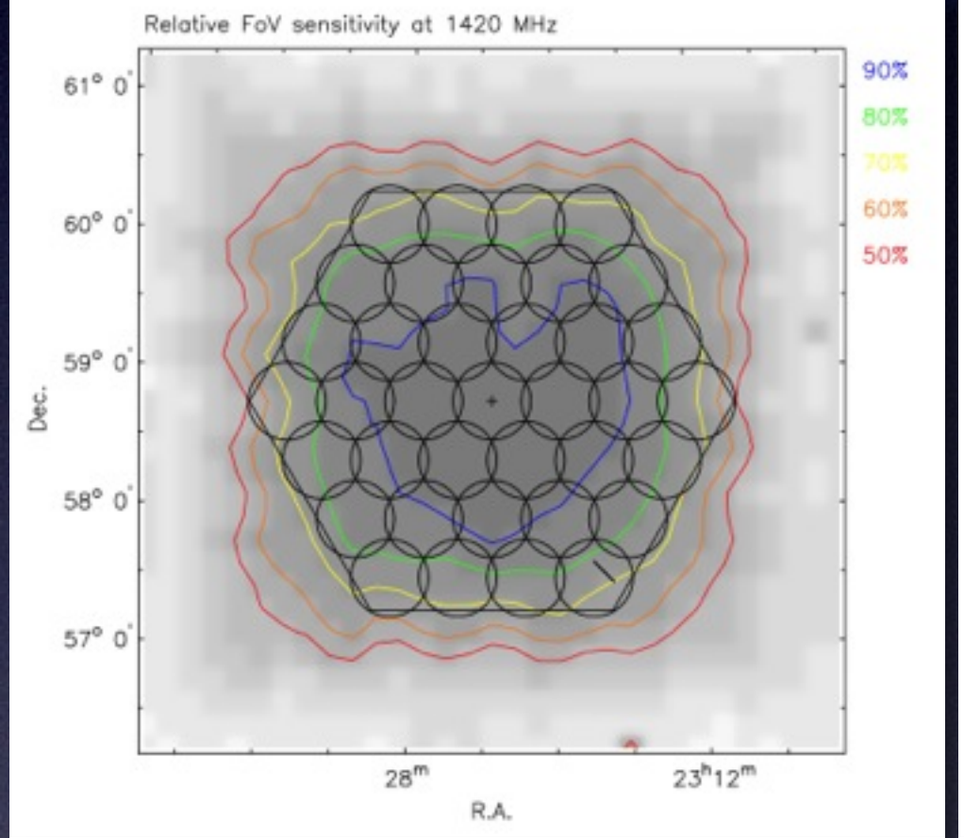
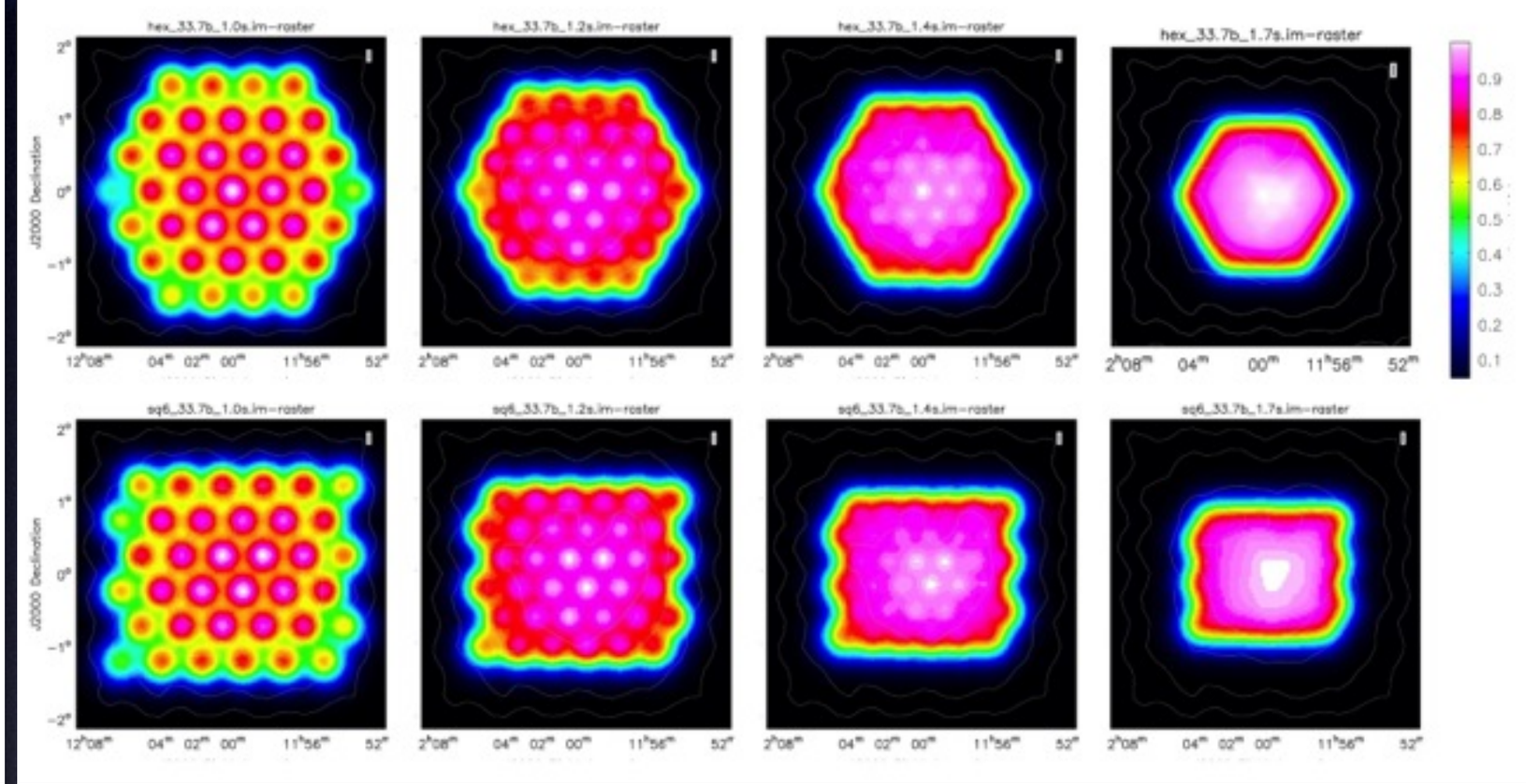
beam packings

Relative FoV sensitivity



Relative Compound Beam sensitivity



Kelley Hess

FoV vs noise uniformity

‘Electronic vignetting’ :

8.0 deg^2 → ~40% spatial noise variations

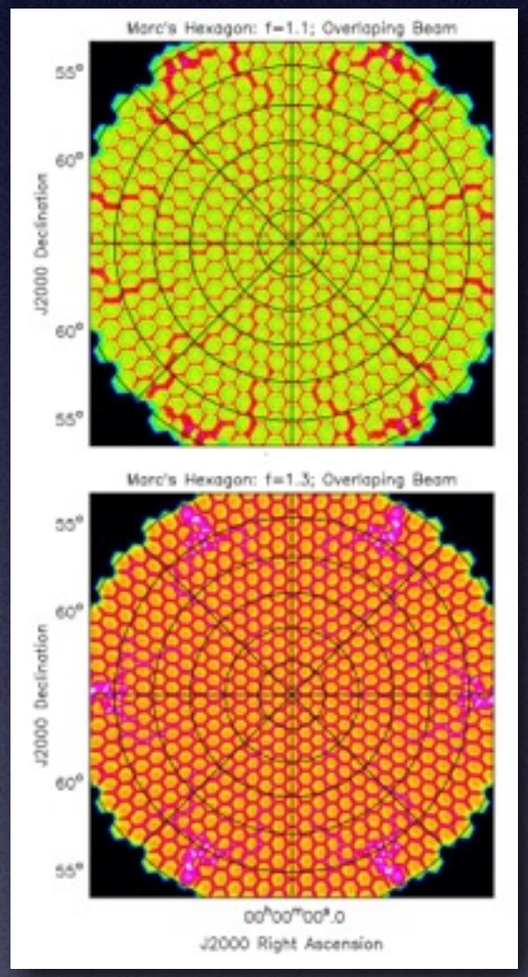
5.6 deg^2 → ~15% spatial noise variations

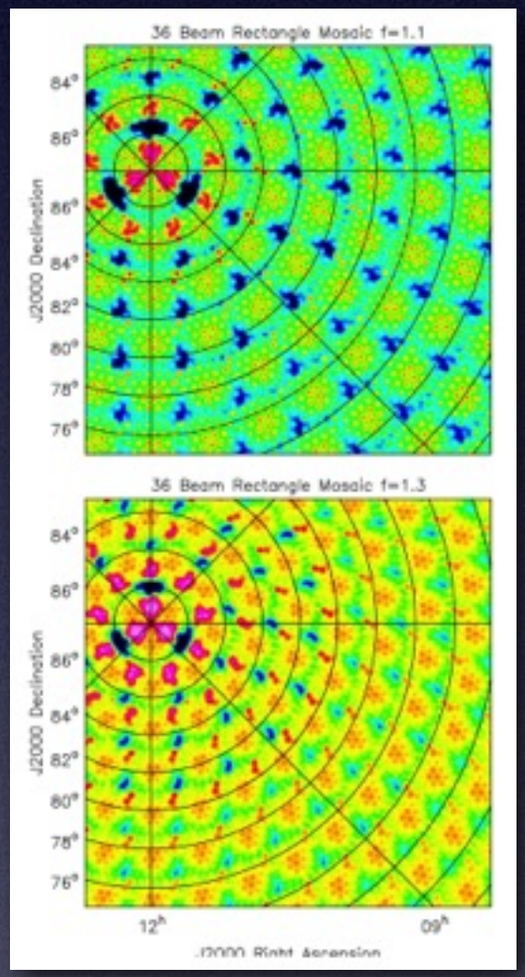
Pointing grids & survey uniformity

noise variations

Hexagonal
higher decl.

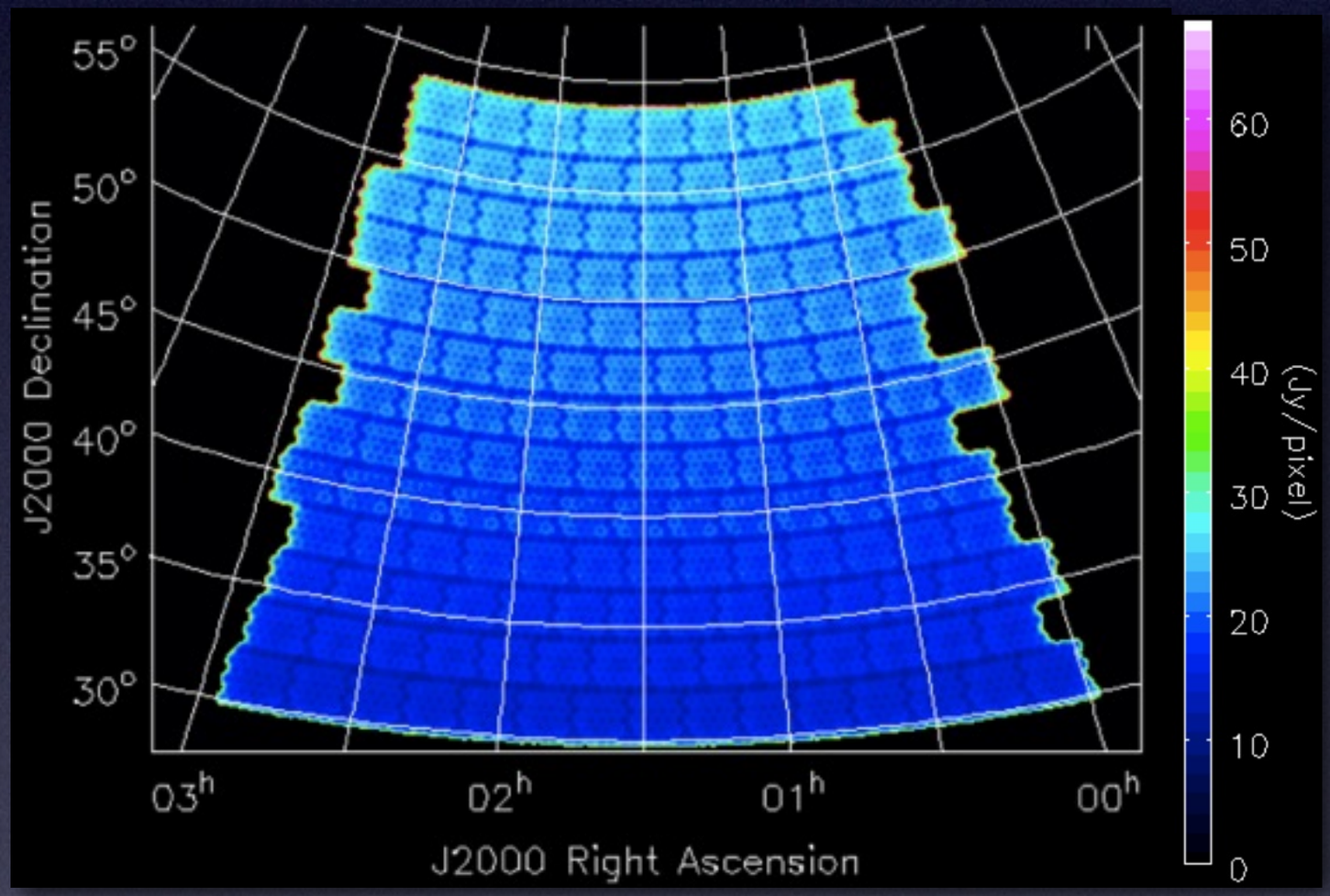
Rectangular
lower decl.





N_{HI} variations

Note: $\theta = 15'' \times (15/\sin\delta)''$



Kelley Hess

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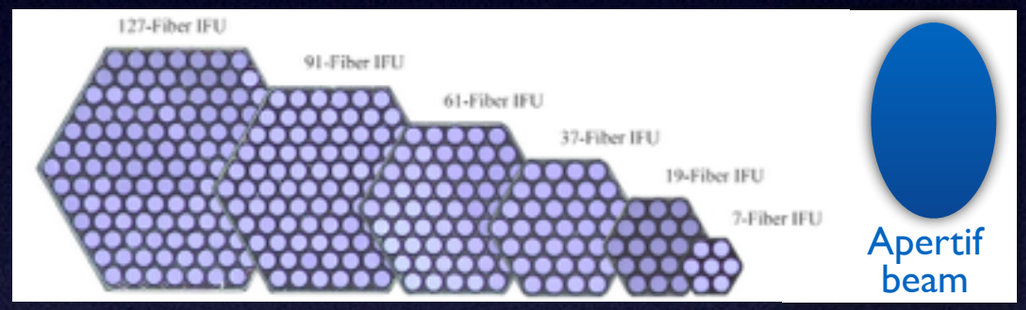
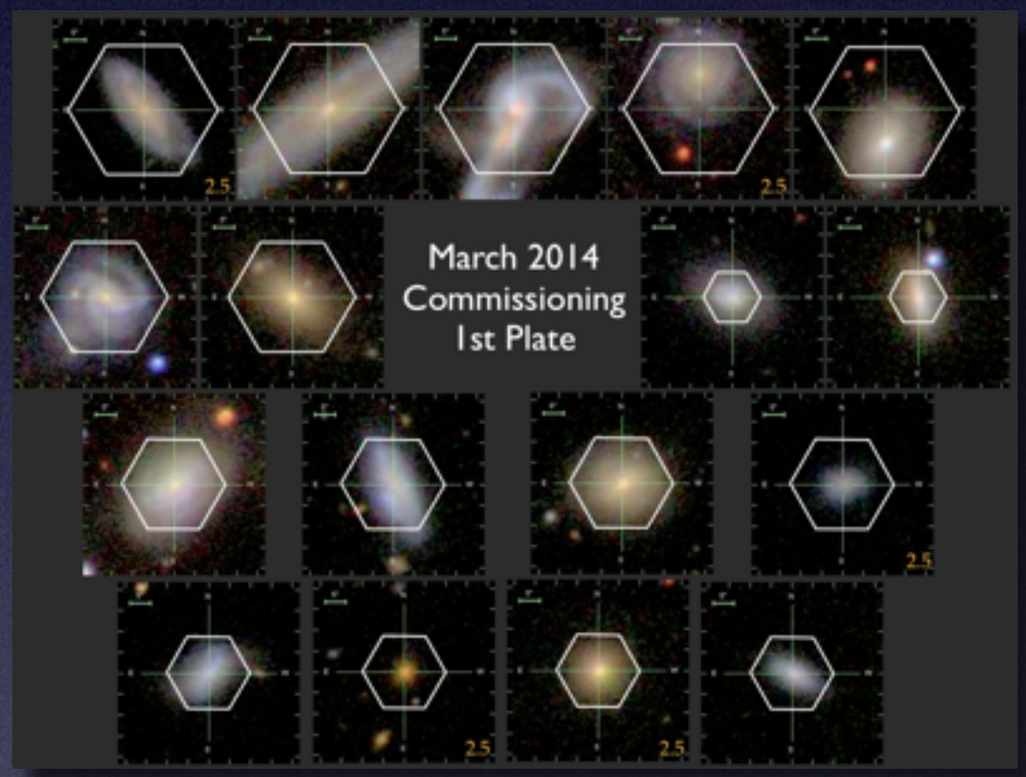
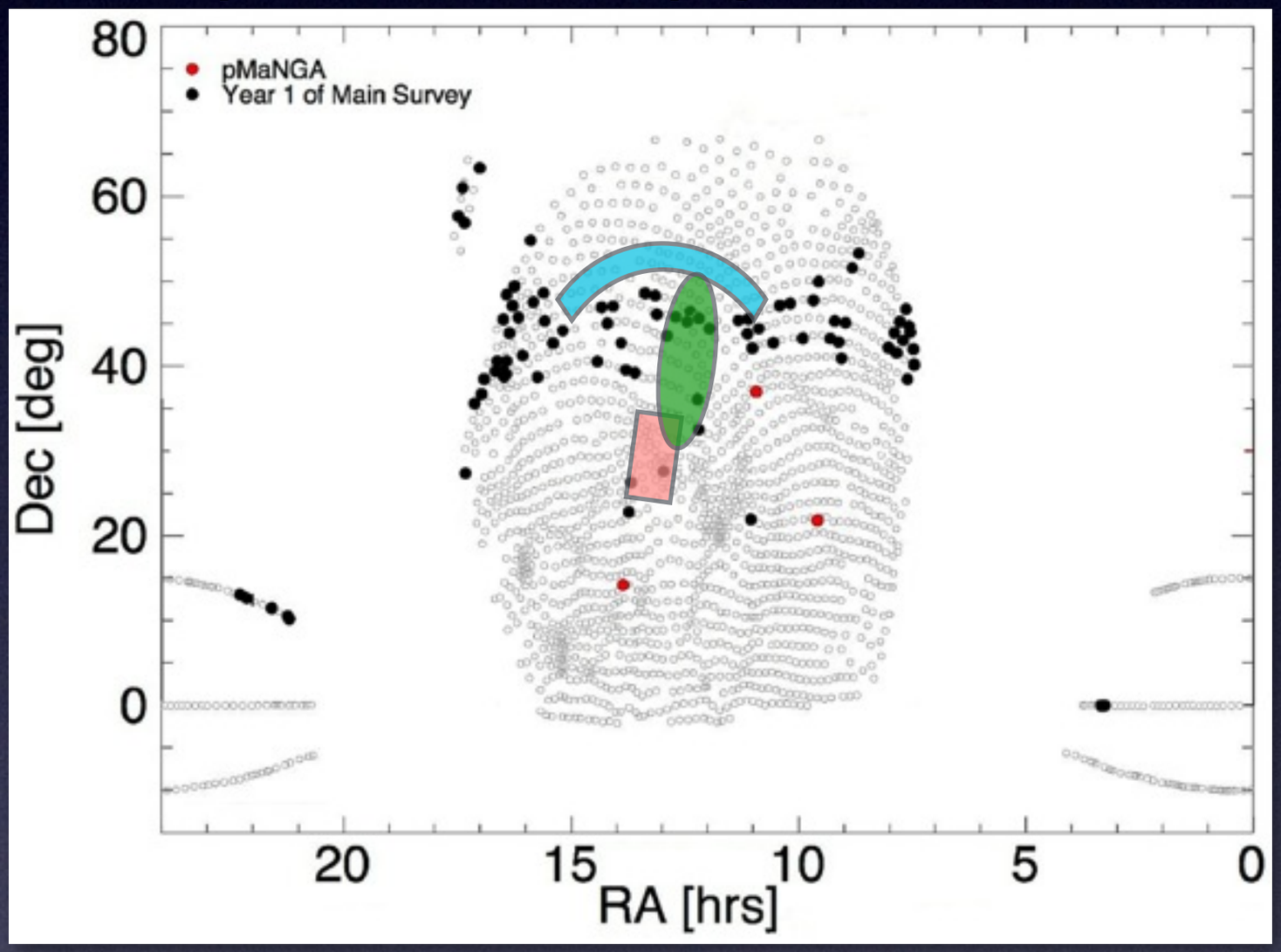
Synergy - MaNGA & Weave

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



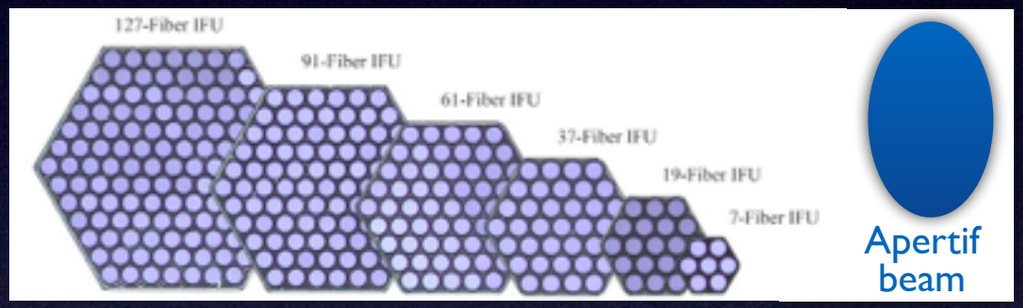




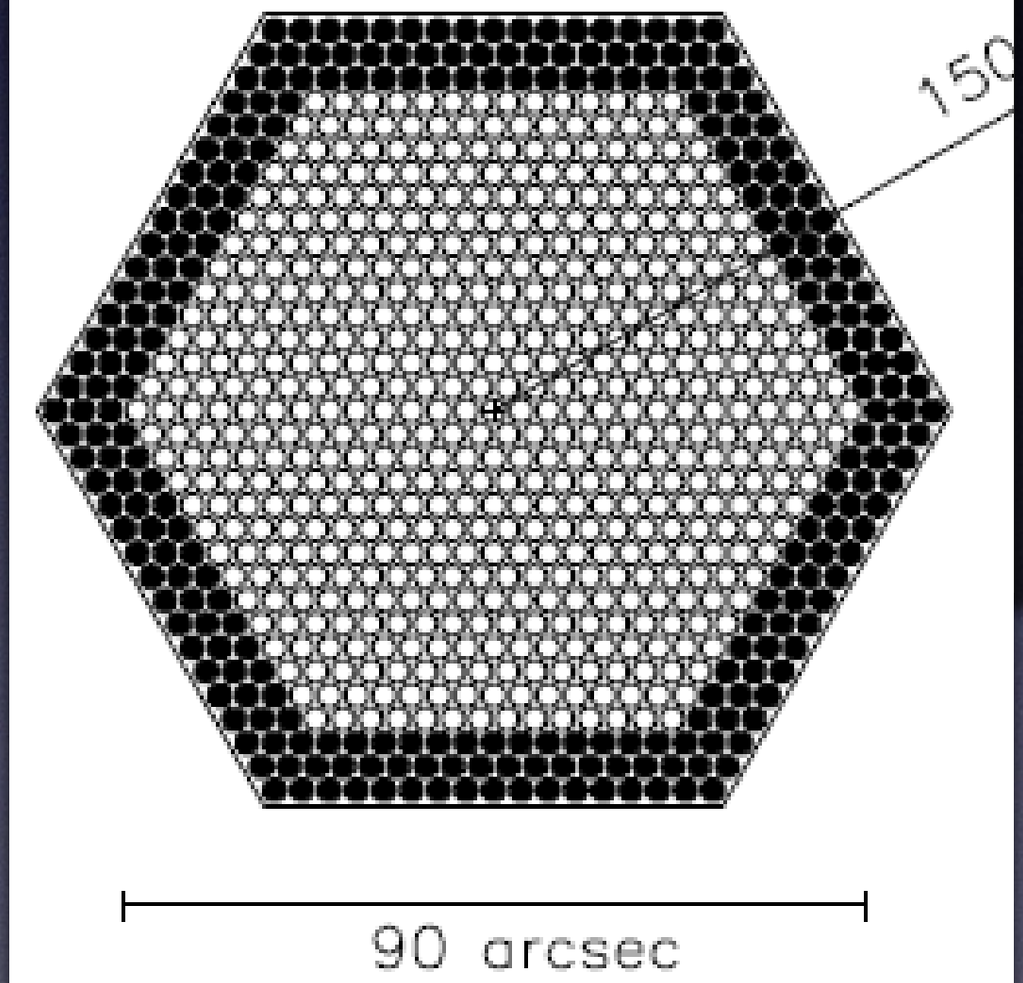
- 2” fibers
- 17 IFU’s per 7 deg^2 field
- 12”−32” FoV per IFU
- 360-1000 nm
- R=2000

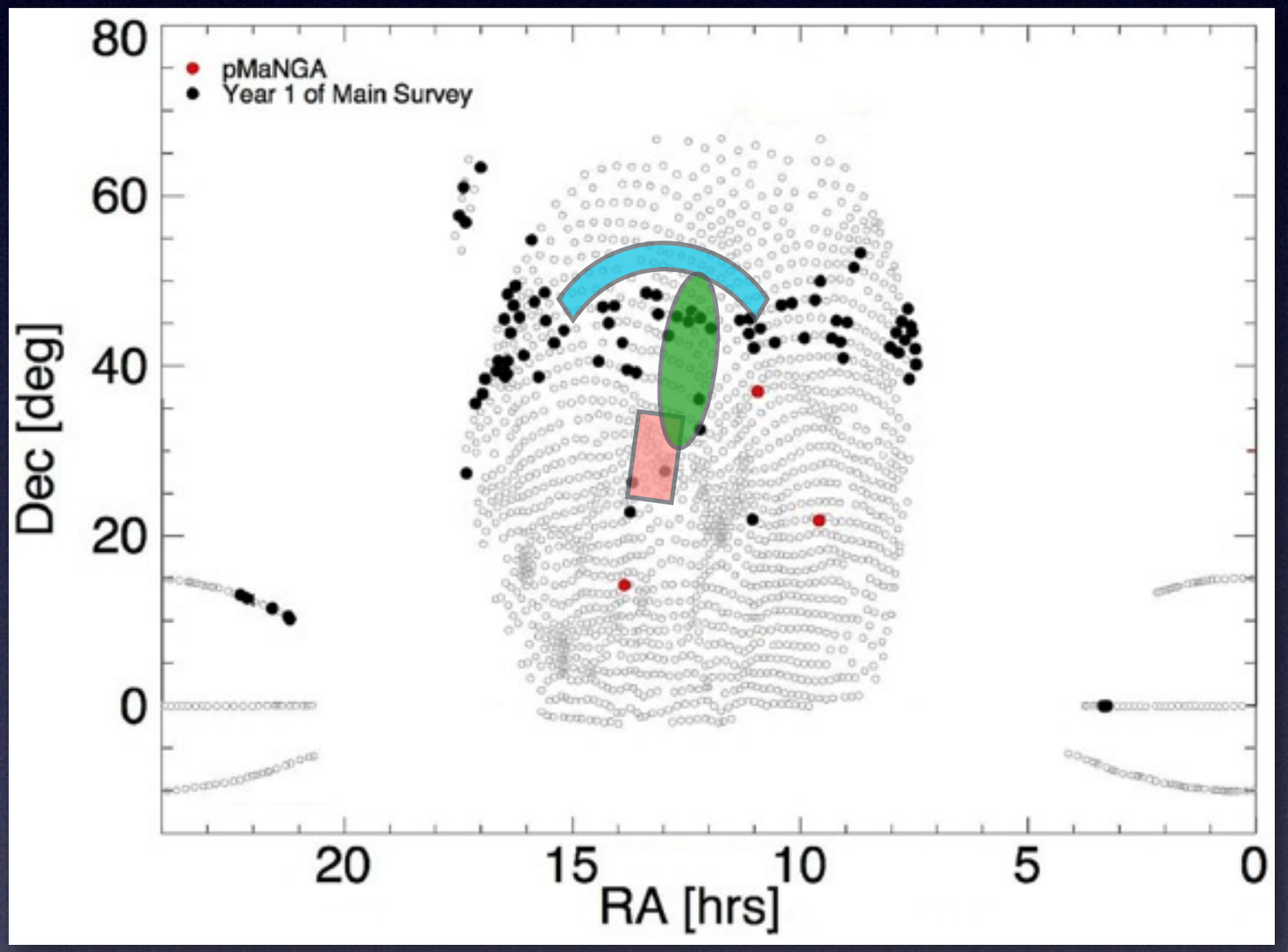
Synergy - MaNGA & Weave

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



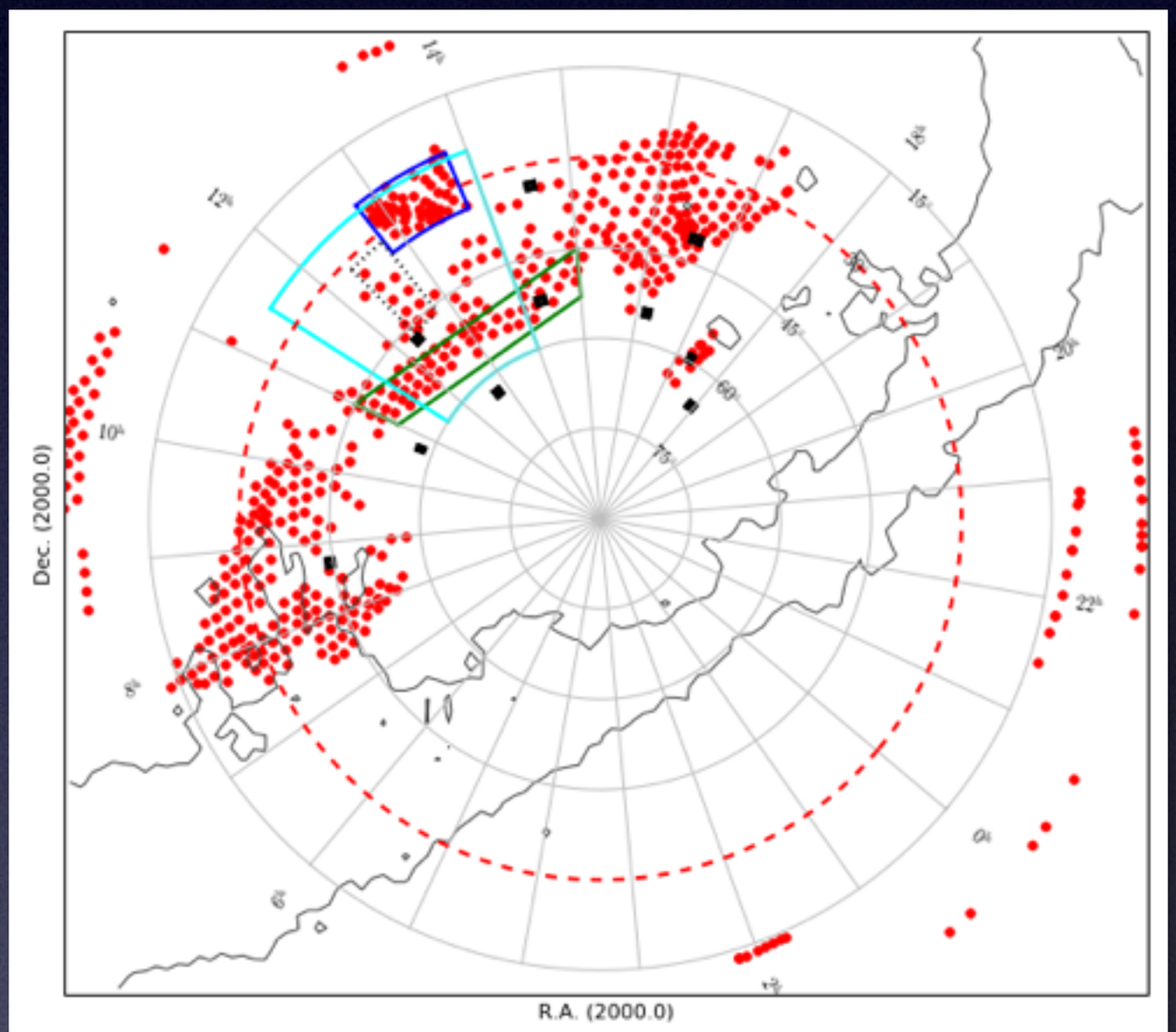
Weave - Large IFU



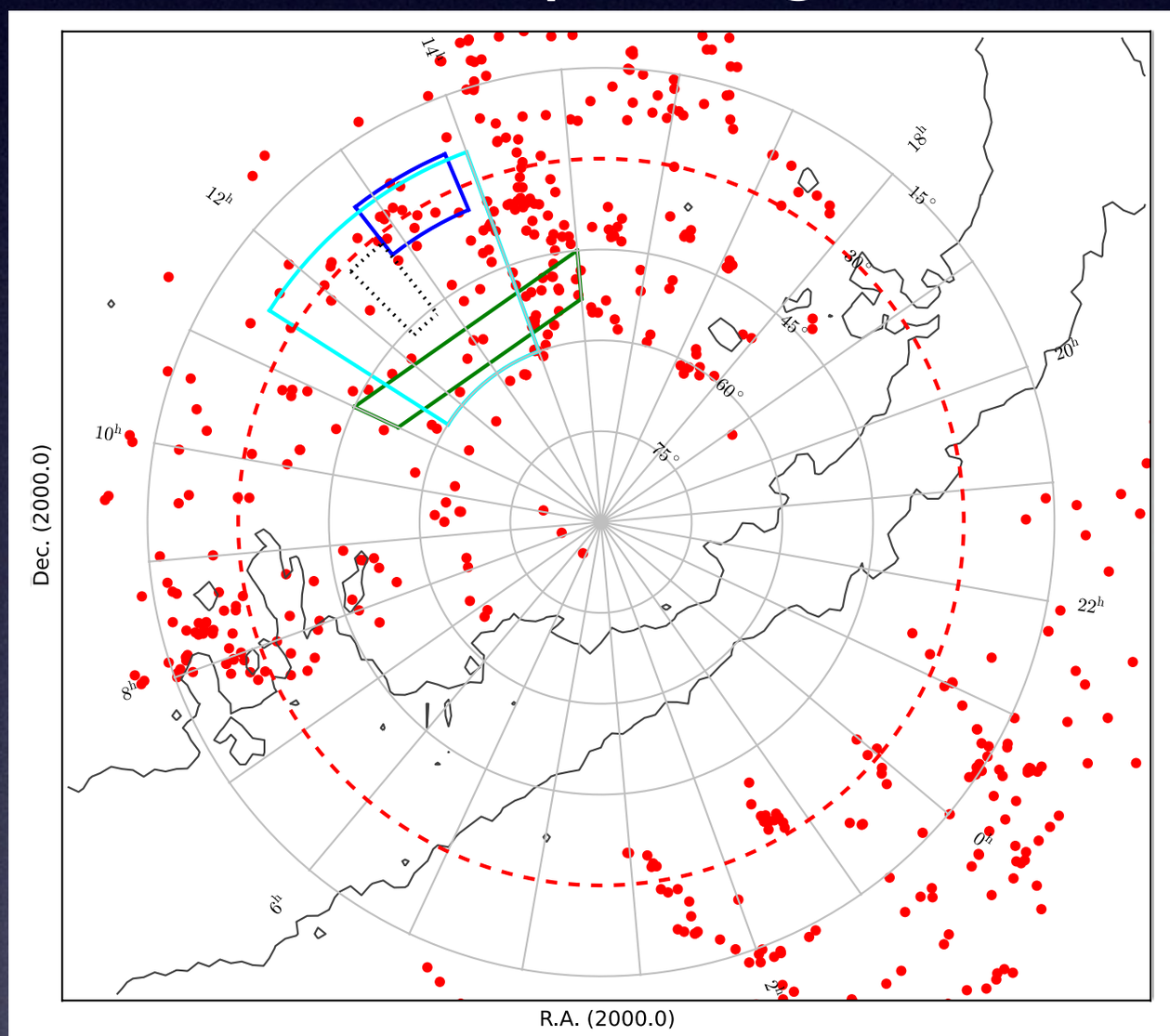


Apertif Survey Plan

MaNGA fields



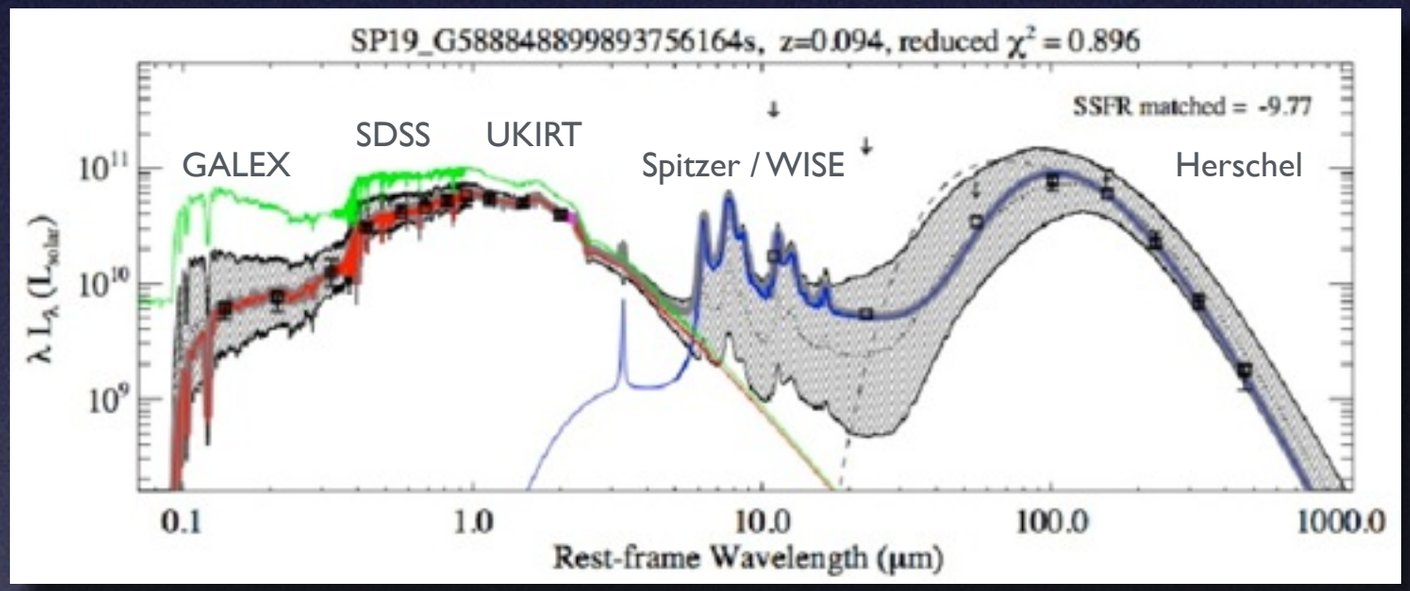
Califa pointings



Synergy - Herschel-Atlas

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

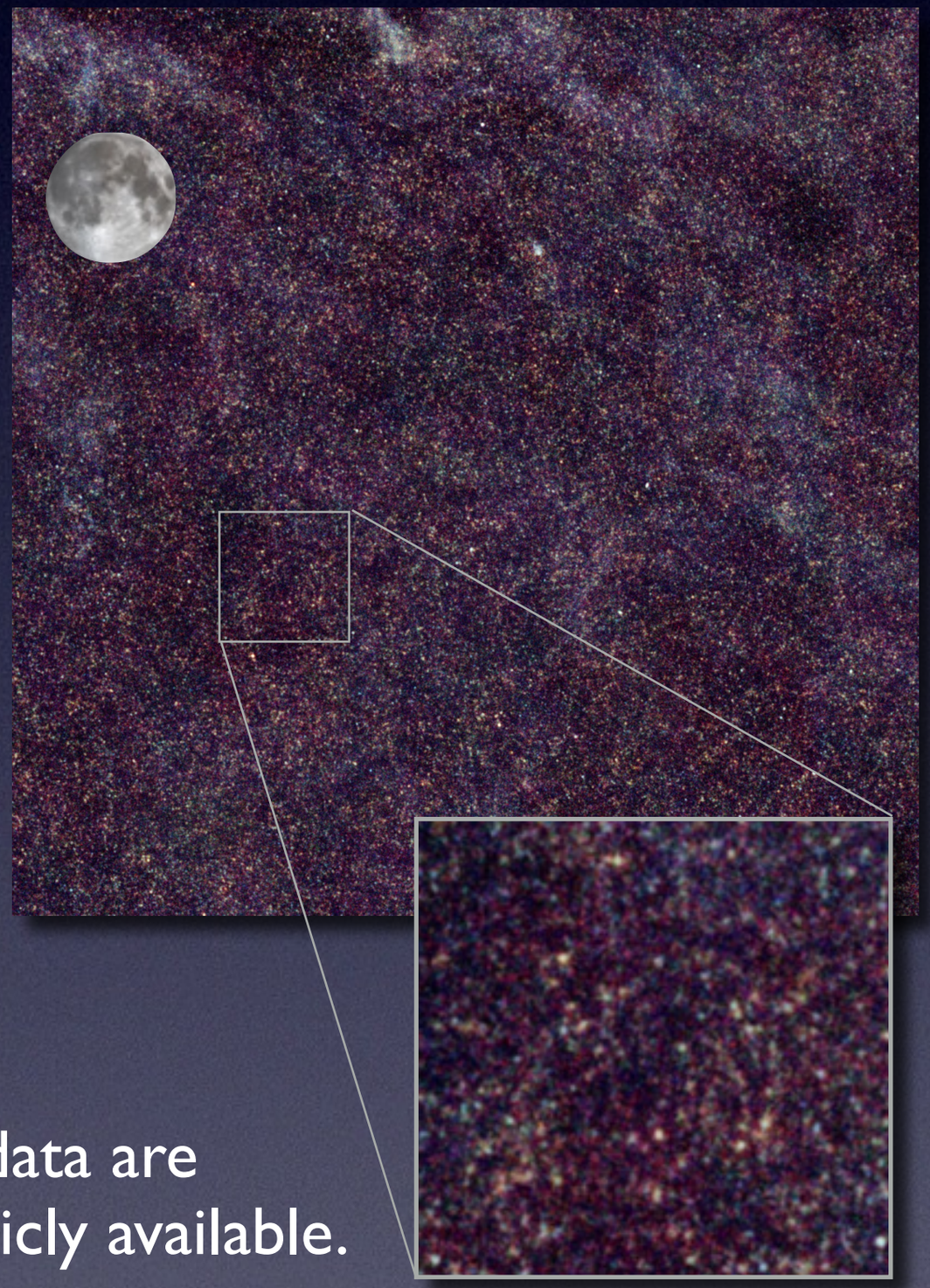
PACS: 110, 170 μm ~500 sources/deg^2
SPIRE: 250, 350, 500 μm Θ=18" at 250 μm



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.

Synergy - HETDEX

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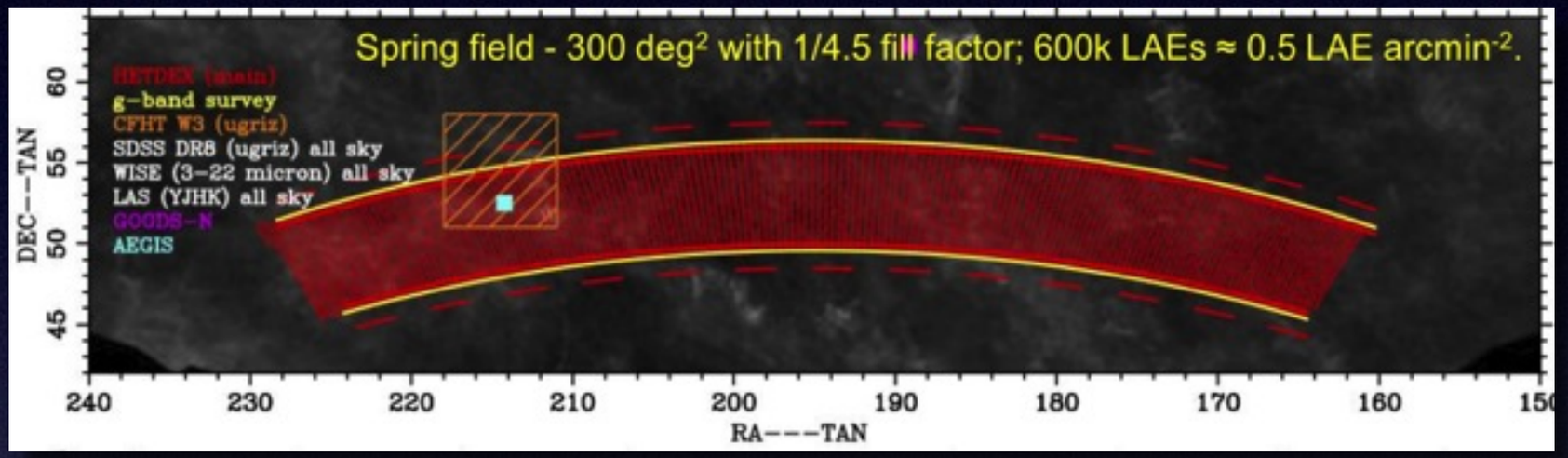
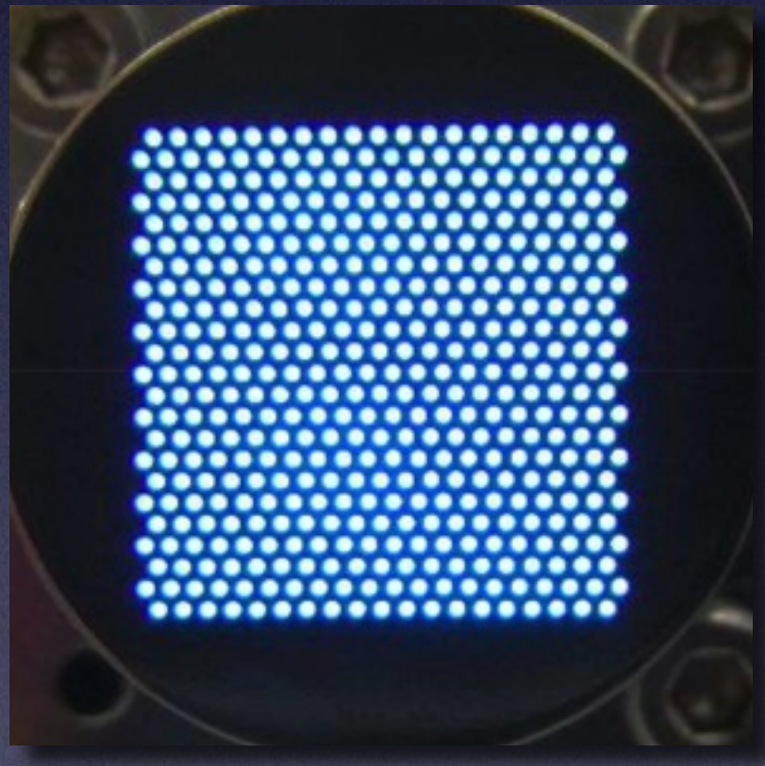
A *blind* IFU survey using VIRUS on HET

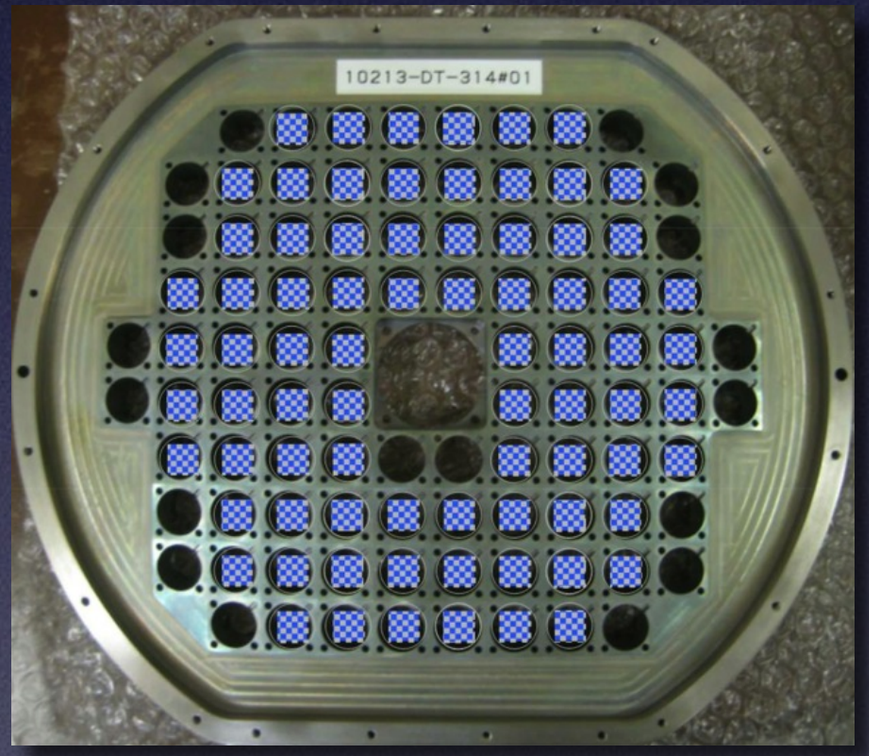
22% fill factor over 300 deg^2



- 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

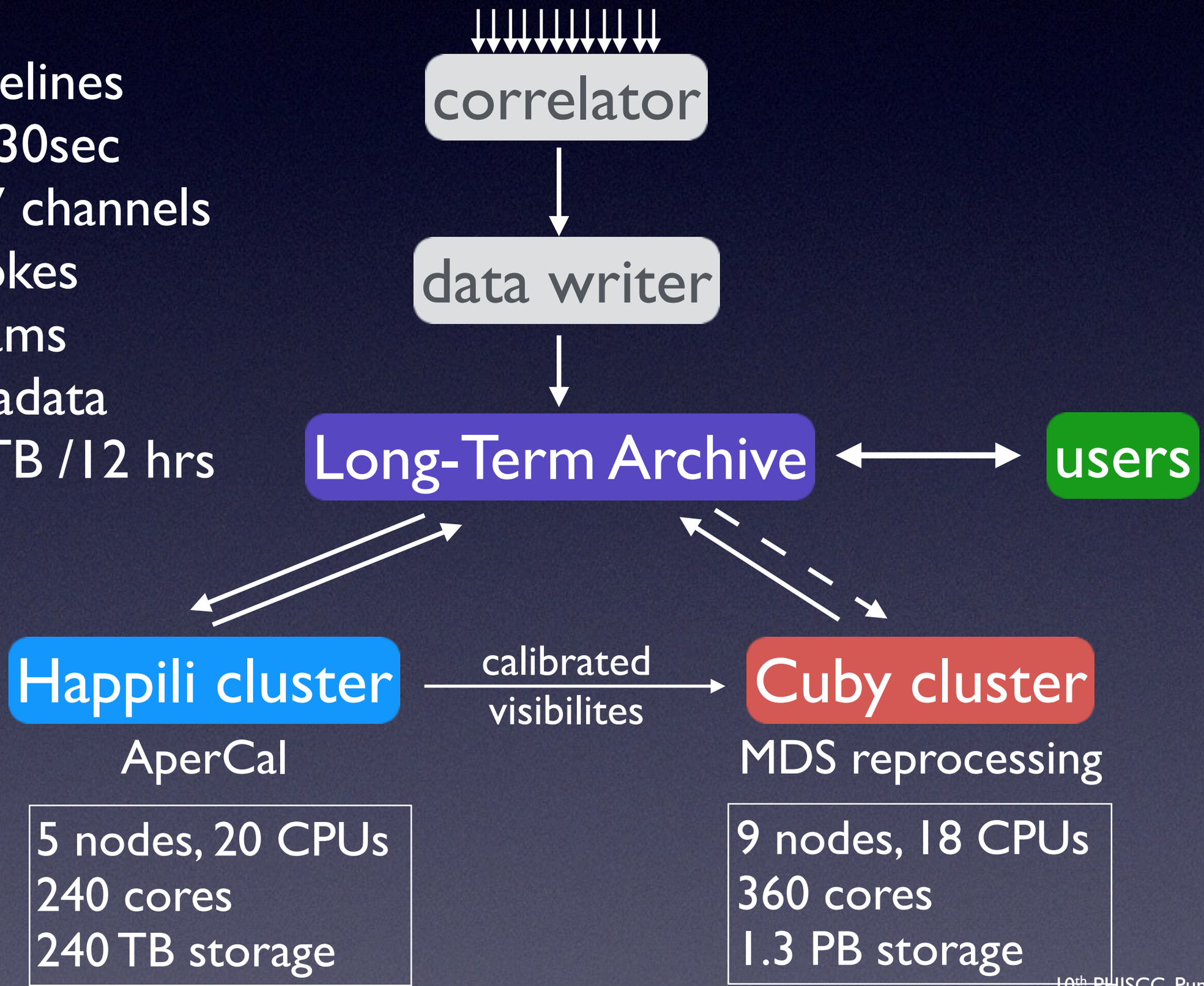
⋈ 50" spacing

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

computing resources

APERTIF

66 baselines
1440x30sec
24,567 channels
full stokes
37 beams
+ metadata
= 2.9 TB /12 hrs



Cuby MDS reprocessing cluster

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Kapteyn intranet

37 data sets
flagged & calibrated
(2.9 TB/12hr)

LTA → portal → switch → cuby 1, cuby 2, cuby 3, cuby 4, cuby 5, cuby 6, cuby 7, cuby 8

Cuby portal: reduce and distribute data:

- drop cross-pol (/2)
- reduce channels (/3 → 7.5 km/s)
- split into 8 spectral windows

→ 37x1.6 GB per compute node

Embarrassingly parallel processing:
continuum subtraction, source finding,
cleaning, mosaicing, analysis pipeline

science data products (catalogues, cubes, maps, profiles,…)

APERTIF

Summary

Imaging mode : 1430−1130 MHz
θ=15” x (15/sinδ)” , R=2.5 km/s
δ>+27°
Full stokes

Shallow Northern-sky Survey :
~3,000 deg^2 , 1x12^{hr} per pointing
$N_{HI}^{min} \approx 2x10^{20}$ (cm^{-2})

Medium-Deep Survey :
~300 deg^2 , 10x12^{hr} per pointing
$N_{HI}^{min} \approx 5x10^{19}$ (cm^{-2})
Selected areas with ancillary data

Public legacy archive, VO-compliant