International Centre for Radio Astronomy Research

HI Surveys with the Rebaselined SKA

Martin Meyer

with thanks to Oosterloo, Staveley-Smith, Popping, Robotham, Driver, Jarvis, HI SWG

Curtin University

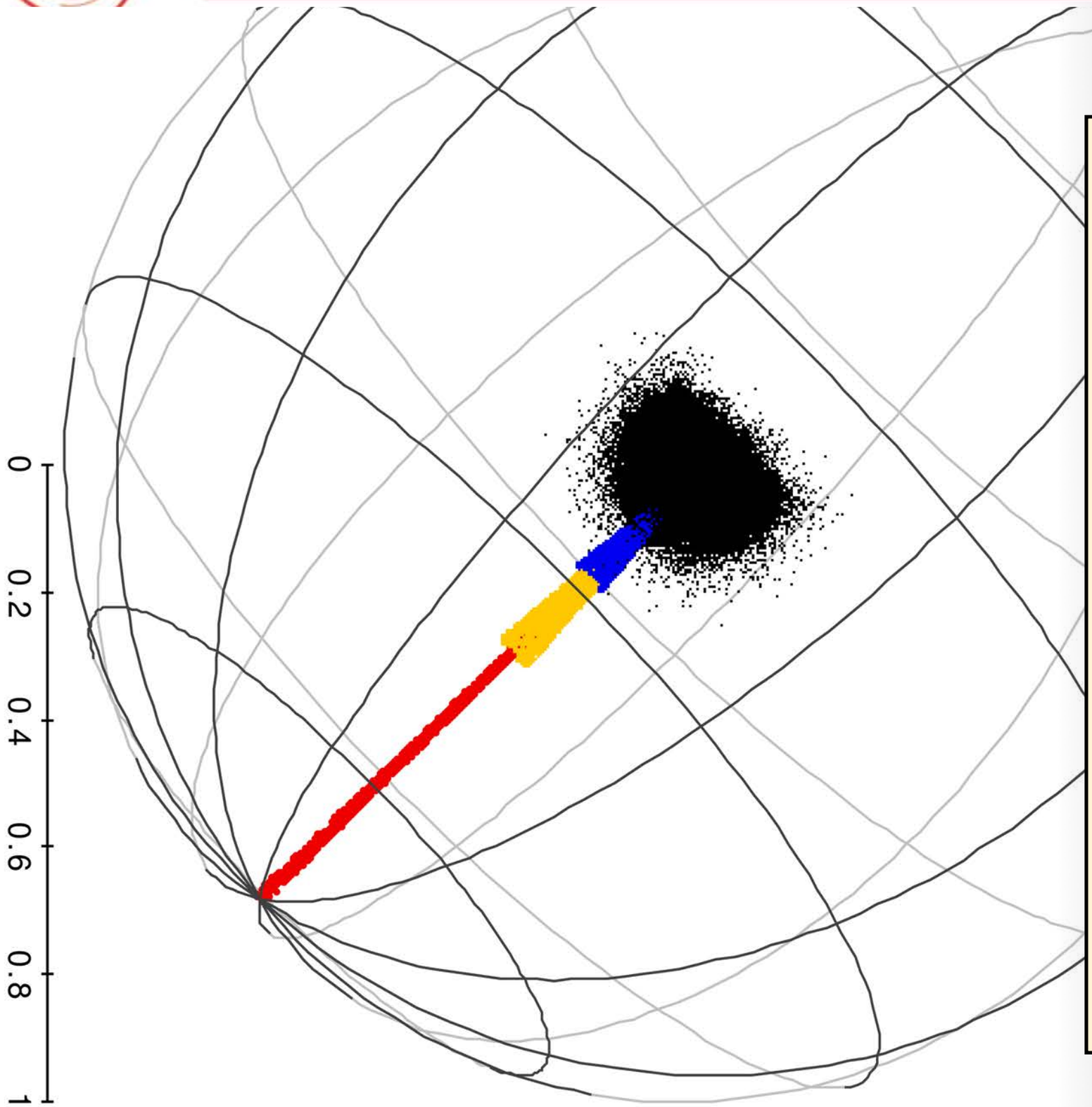
The University of Western Australia

SKA1 HI Surveys

Key Goal: survey ~M_{HI}* to z~0.8 *with high spatial resolution*
➔ detailed studies of environment, interactions, mergers, gas fuelling

Science Goal	SWG	Objective	SWG Rank
1	*CD/EoR*	Physics of the early universe IGM - I. Imaging	1/3
2	*CD/EoR*	Physics of the early universe IGM - II. Power spectrum	2/3
4	*Pulsars*	Reveal pulsar population and MSPs for gravity tests and Gravitational Wave detection	1/3
5	*Pulsars*	High precision timing for testing gravity and GW detection	1/3
13	*HI*	Resolved HI kinematics and morphology of ~10^10 M_sol mass galaxies out to z~0.8	1/5
14	*HI*	High spatial resolution studies of the ISM in the nearby Universe.	2/5
15	*HI*	Multi-resolution mapping studies of the ISM in our Galaxy	3/5
18	*Transients*	Solve missing baryon problem at z~2 and determine the Dark Energy Equation of State	=1/4
22	*Cradle of Life*	Map dust grain growth in the terrestrial planet forming zones at a distance of 100 pc	1/5
27	*Magnetism*	The resolved all-Sky characterisation of the interstellar and intergalactic magnetic fields	1/5
32	*Cosmology*	Constraints on primordial non-Gaussianity and tests of gravity on super-horizon scales.	1/5
33	*Cosmology*	Angular correlation functions to probe non-Gaussianity and the matter dipole	2/5
37 + 38	*Continuum*	Star formation history of the Universe (SFHU) – I+II. Non-thermal & Thermal processes	1+2/8

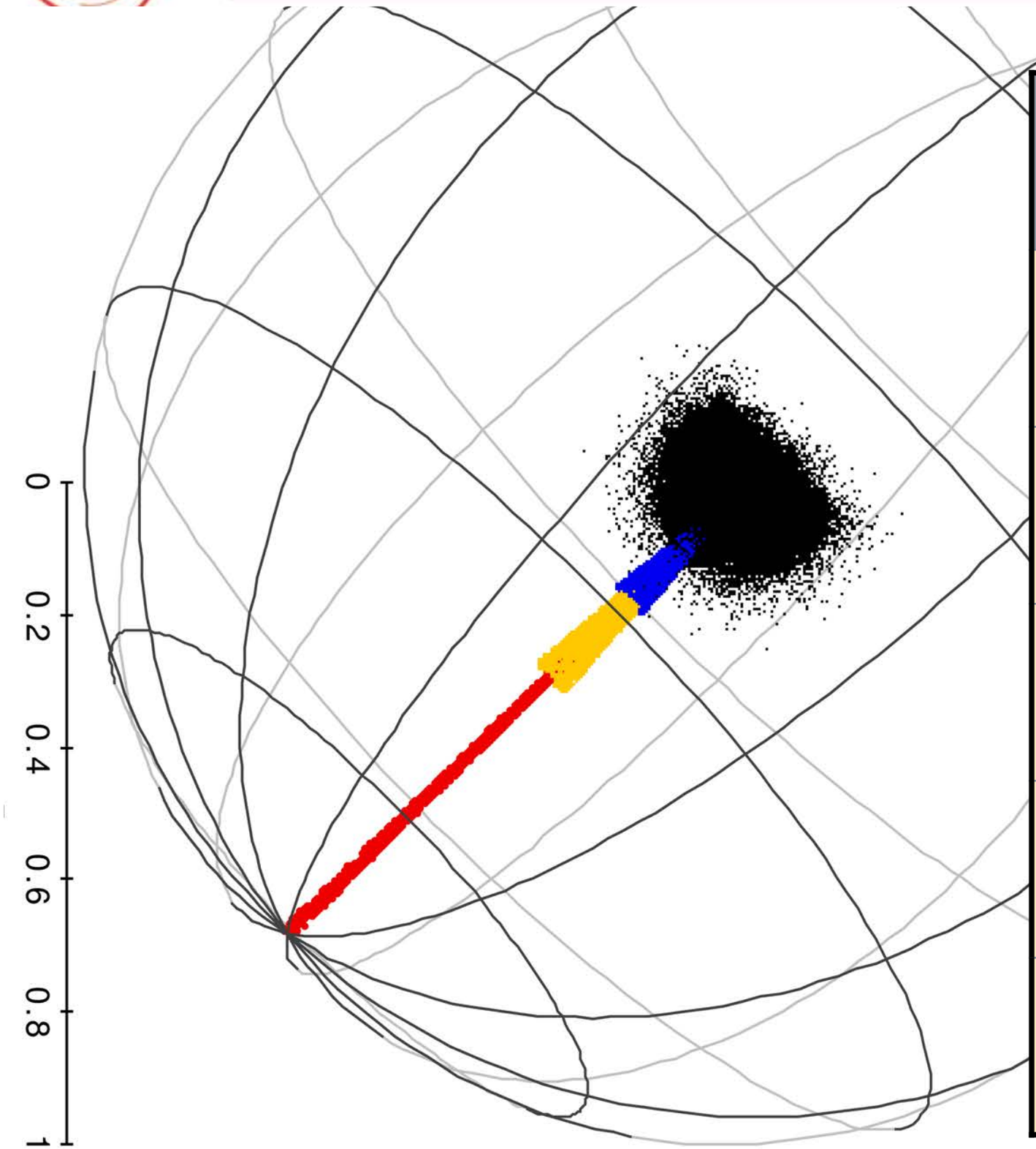
Pathfinder HI Surveys



Blind HI Surveys:

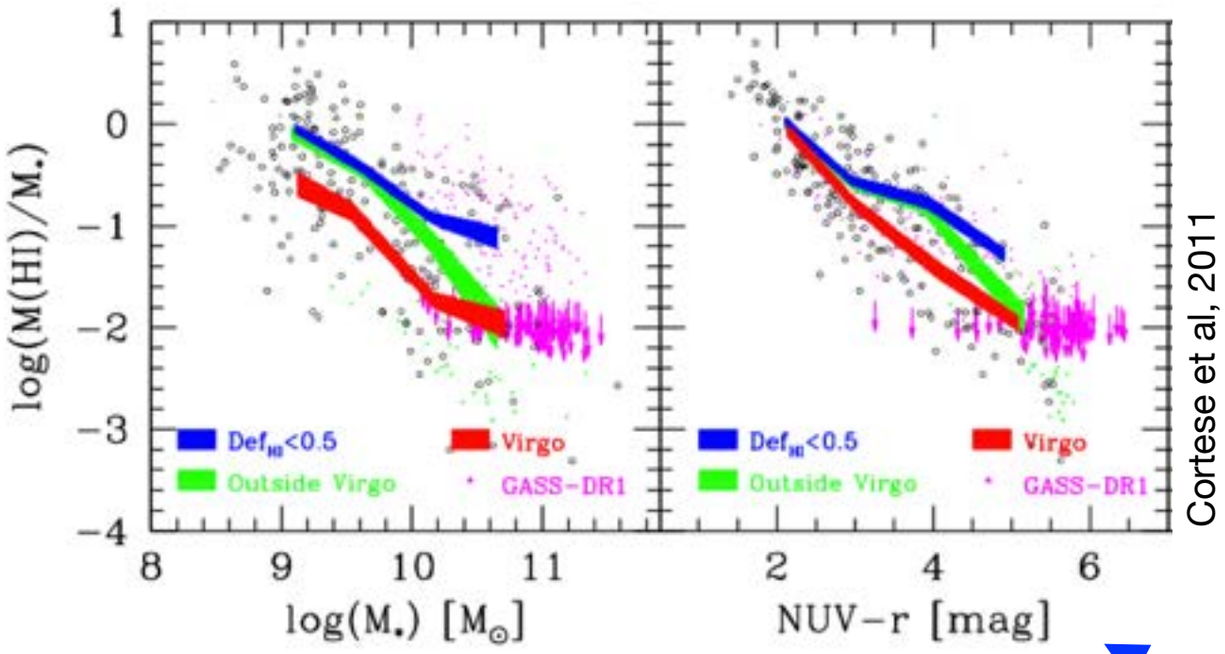
- **WALLABY (ASKAP)** + WNSHS (APERTIF):
  - 600k galaxies, all-sky
- CHILES (VLA):
  - 300 galaxies, 0.25 deg^2
- **DINGO (ASKAP)**:
  - **DEEP**: 50k gals, 150 deg^2
  - **UDEEP**: 50k gals, 60 deg^2
- **LADUMA (MeerKAT)**:
  - 10k galaxies, 1+ deg^2

Pathfinder HI Surveys: Resolution



Survey	Resolution	Redshift	Sources
HIPASS/ ALFALFA	3-15 arcmin	$z < 0.06$	**unresolved**
WALLABY/ WNSHS	15-30 arcsec	$z < 0.26$	**low-z resolved (~slightly)**
DINGO	30-40 arcsec	$z < 0.43$	**unresolved**
CHILES	5-10 arcsec	$z < 0.4$	**resolves galaxies $z \lesssim 0.3$**
LADUMA	8-16	$z < 1.2$	**mostly unresolved**

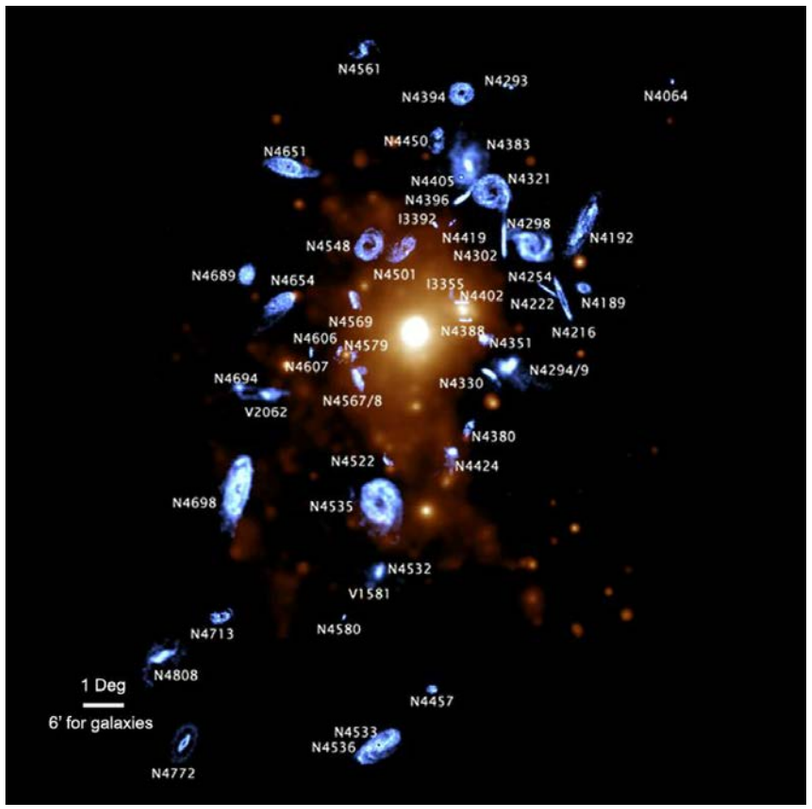
Pathfinder HI Surveys: Resolution



Cortese et al, 2011

unresolved

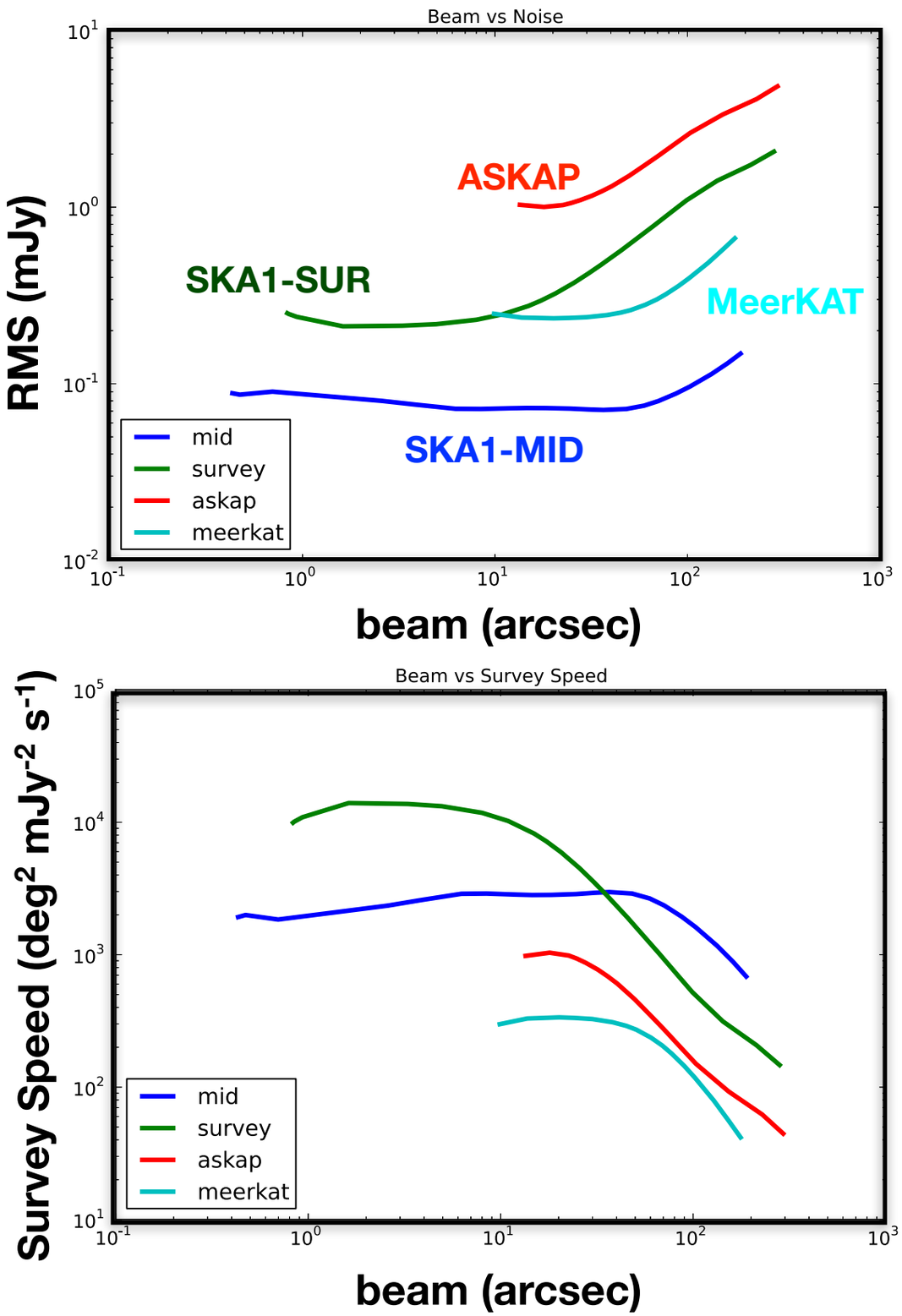
resolved

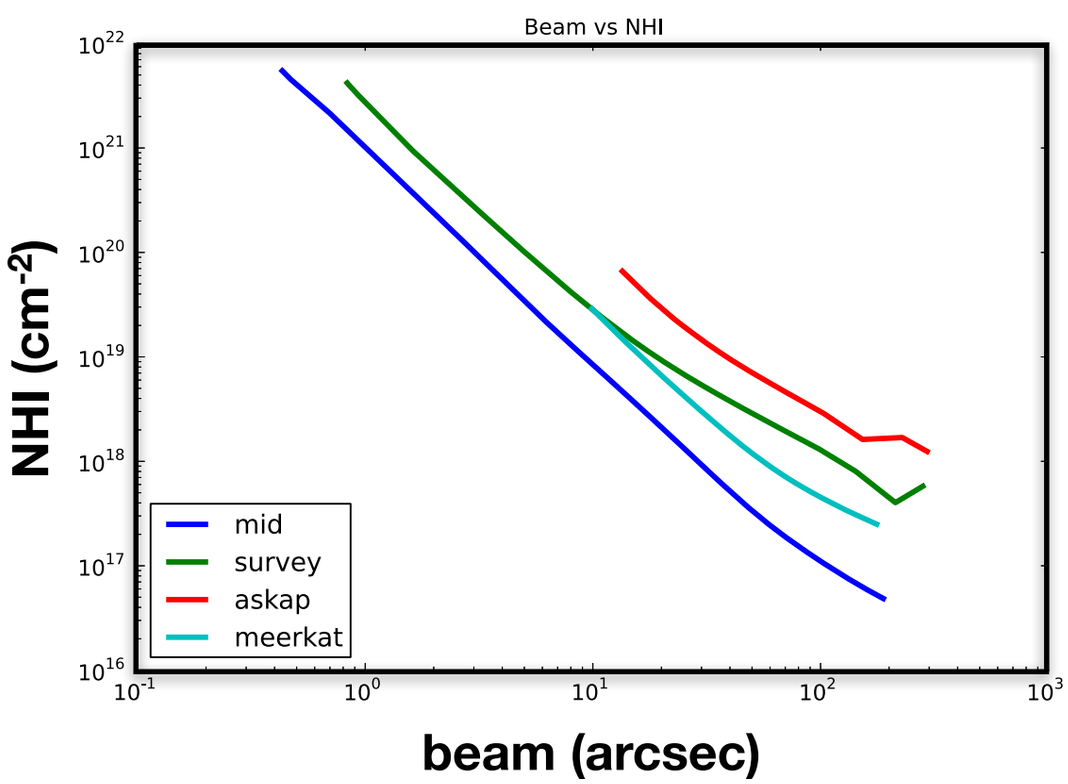


Chung et al, 2009

Survey	Resolution	Redshift	Sources
HIPASS/ ALFALFA	3-15 arcmin	$z < 0.06$	**unresolved**
WALLABY/ WNSHS	15-30 arcsec	$z < 0.26$	**low-z resolved (~slightly)**
DINGO	30-40 arcsec	$z < 0.43$	**unresolved**
CHILES	5-10 arcsec	$z < 0.4$	**resolves galaxies $z \lesssim 0.3$**
LADUMA	8-16	$z < 1.2$	**mostly unresolved**

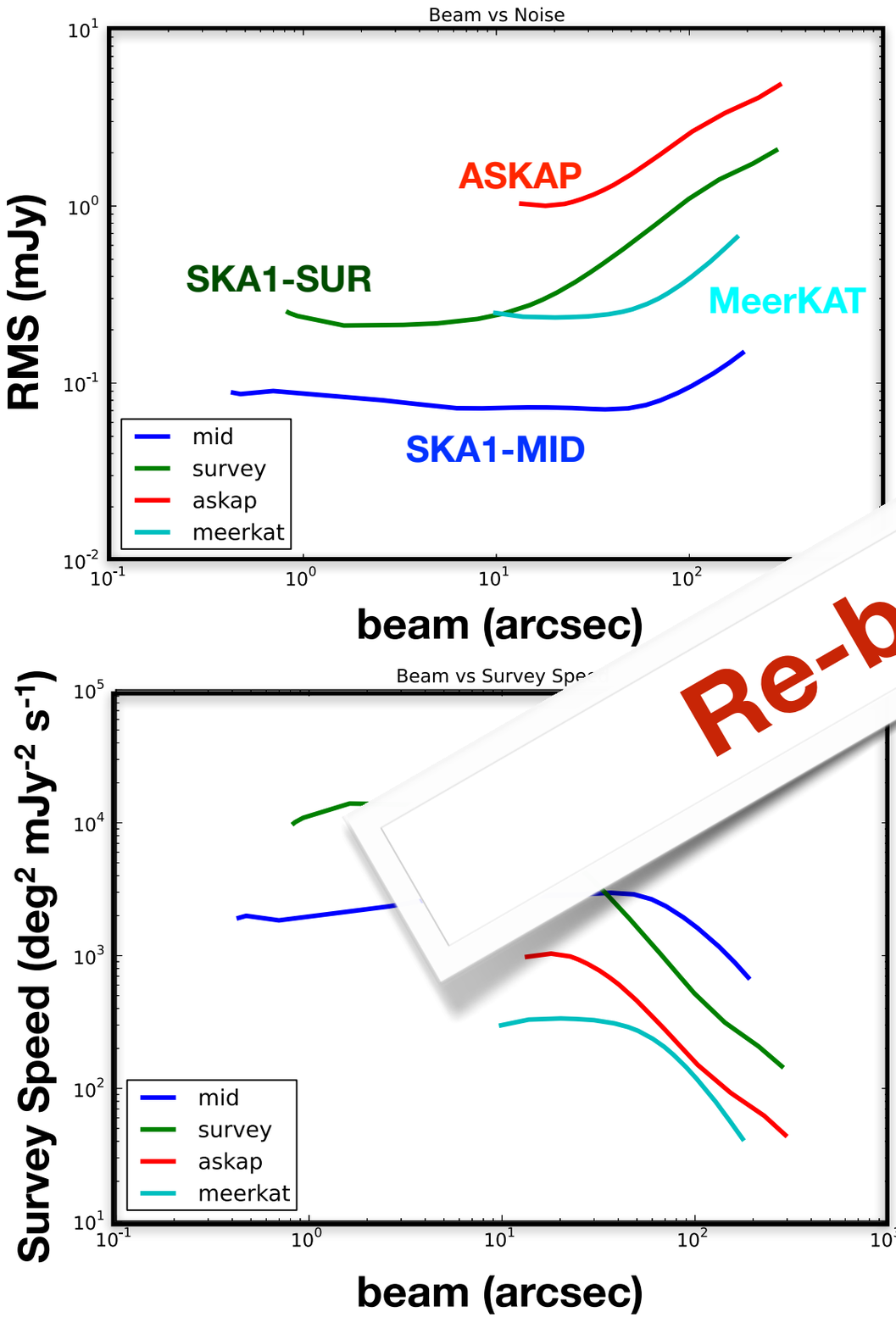
SKA1 Capabilities

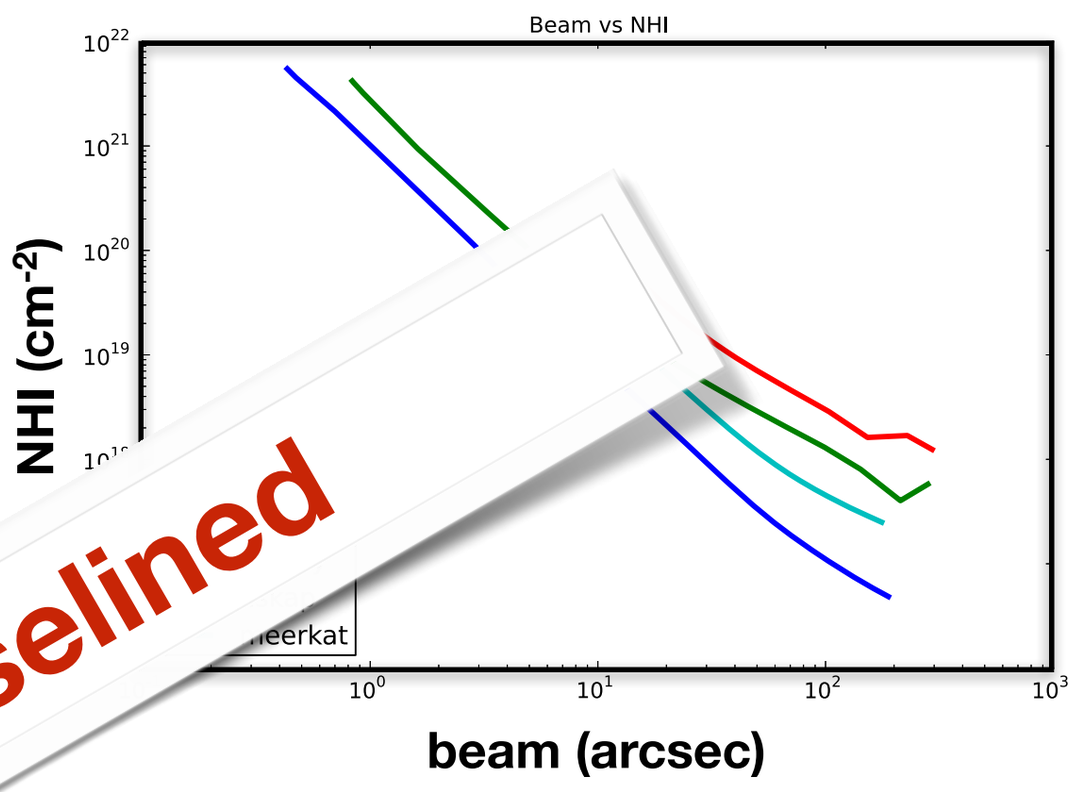




- Popping, Meyer, et al., 2015, The IGM, PoS(AASKA), 132

SKA1 Capabilities





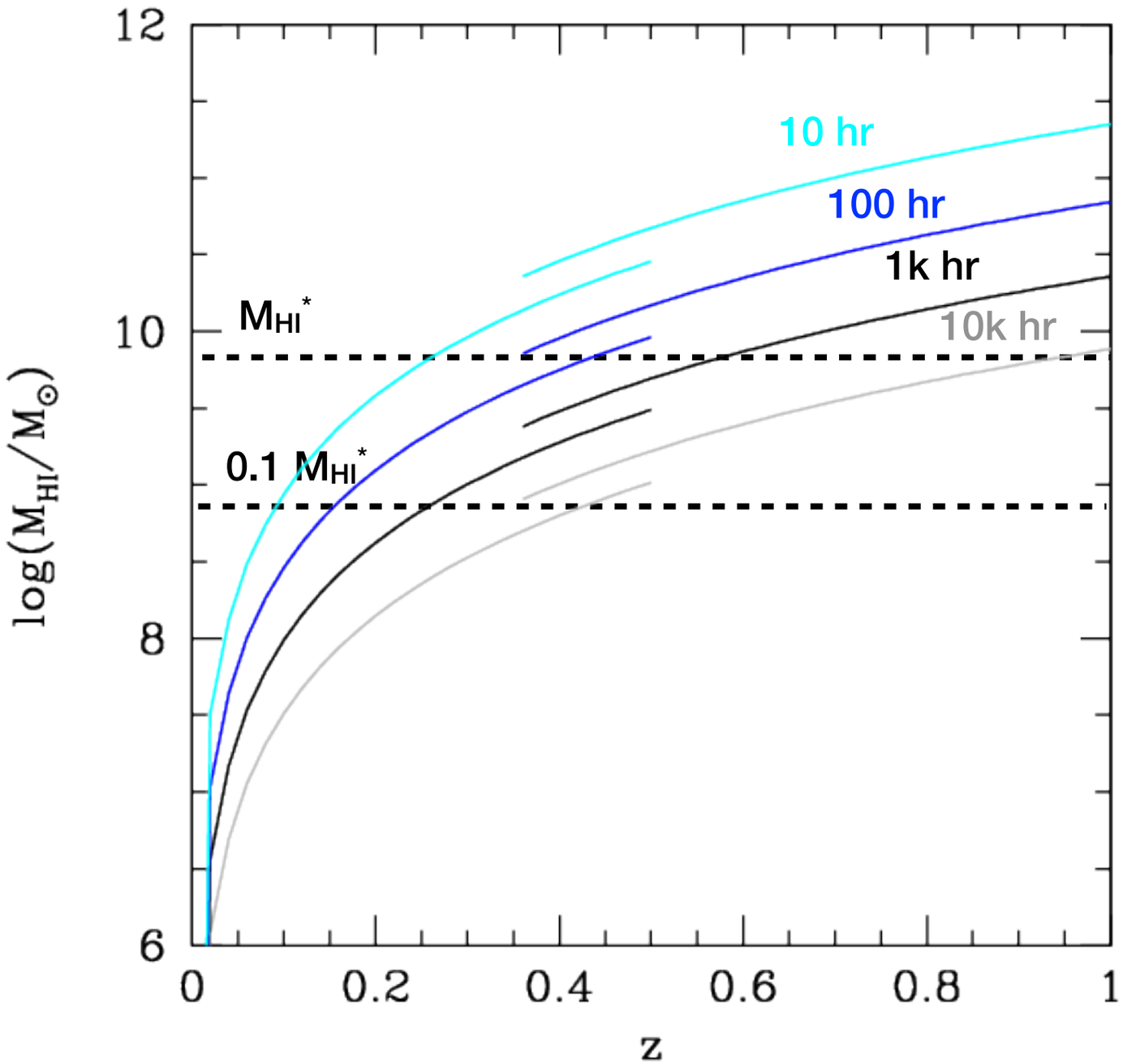
Re-baselined

- Popping, Meyer, et al., 2015, The IGM, PoS(AASKA), 132

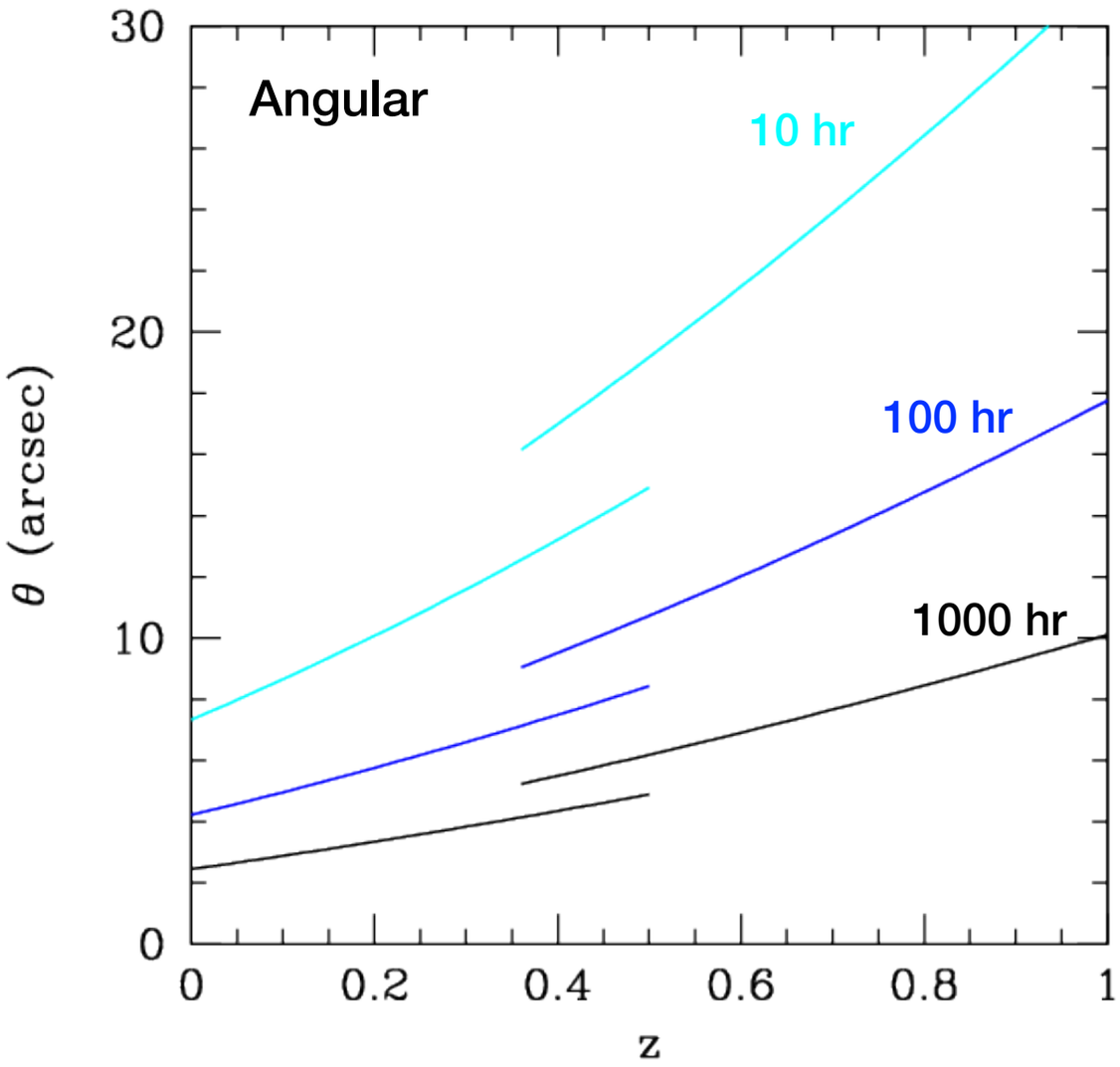
SKA1 Surveys: Pt. Source Sensitivity

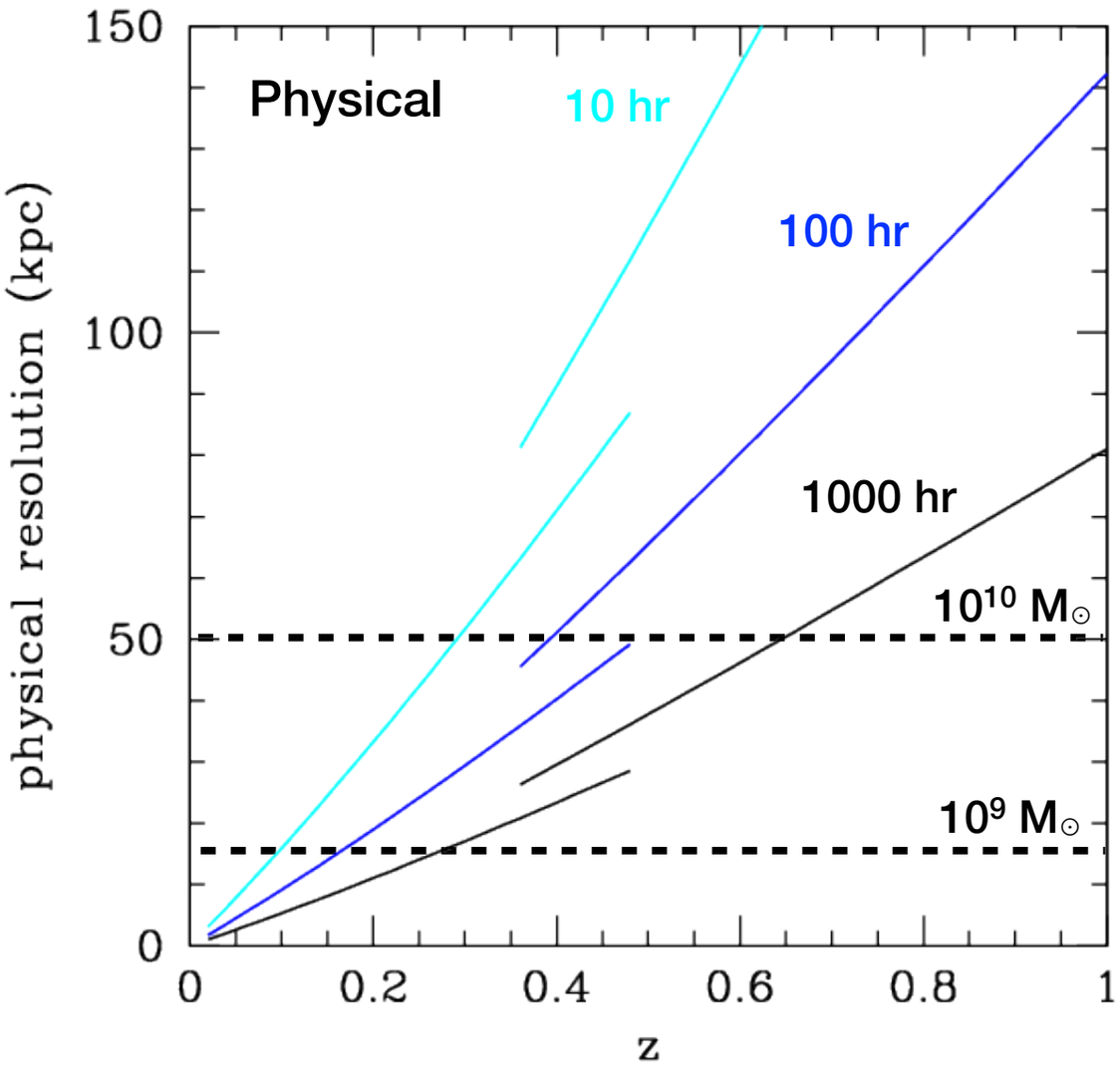
Highlights

- Option: pusher deeper in single pointing
- Option: carry out CHILES/ LADUMA type studies over larger areas
- Issues: band 1/2 frequency divide; band 1 performance; band 1 delivery timescale
- Would ideally shift band 2: 950-1760 → 770-1430 MHz



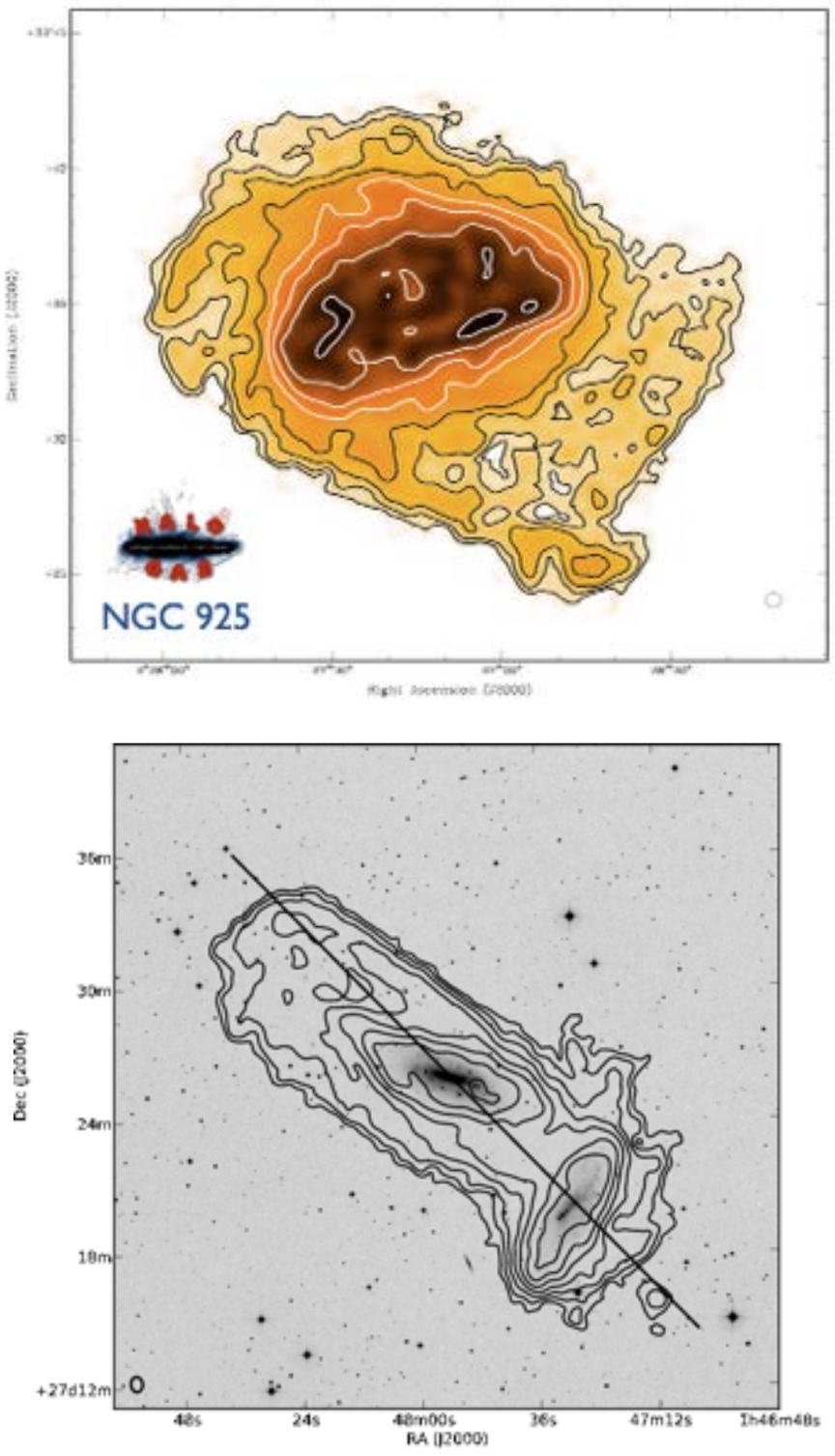
SKA1 Surveys: Resolution @ 10^{20} cm^{-2}

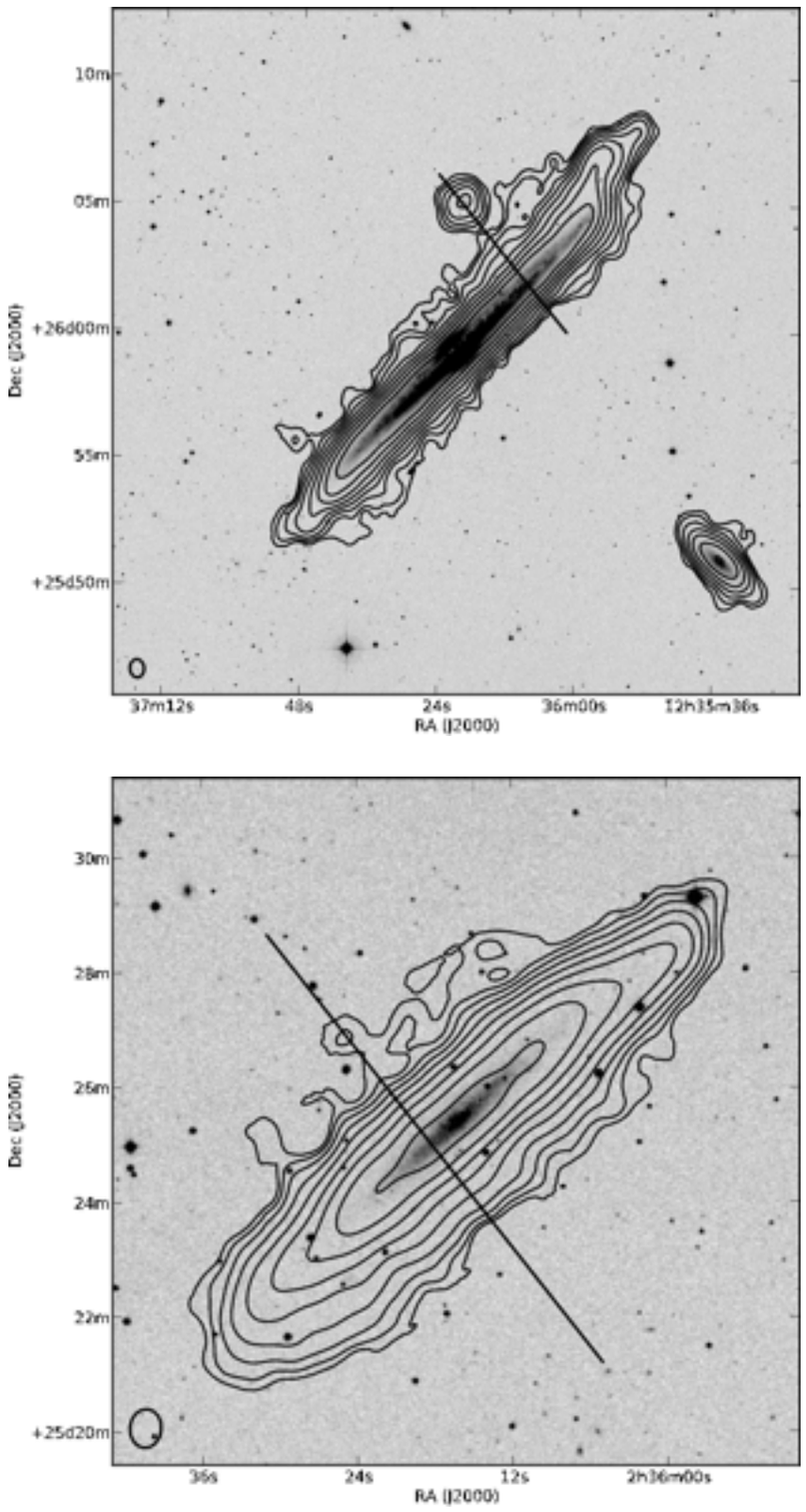




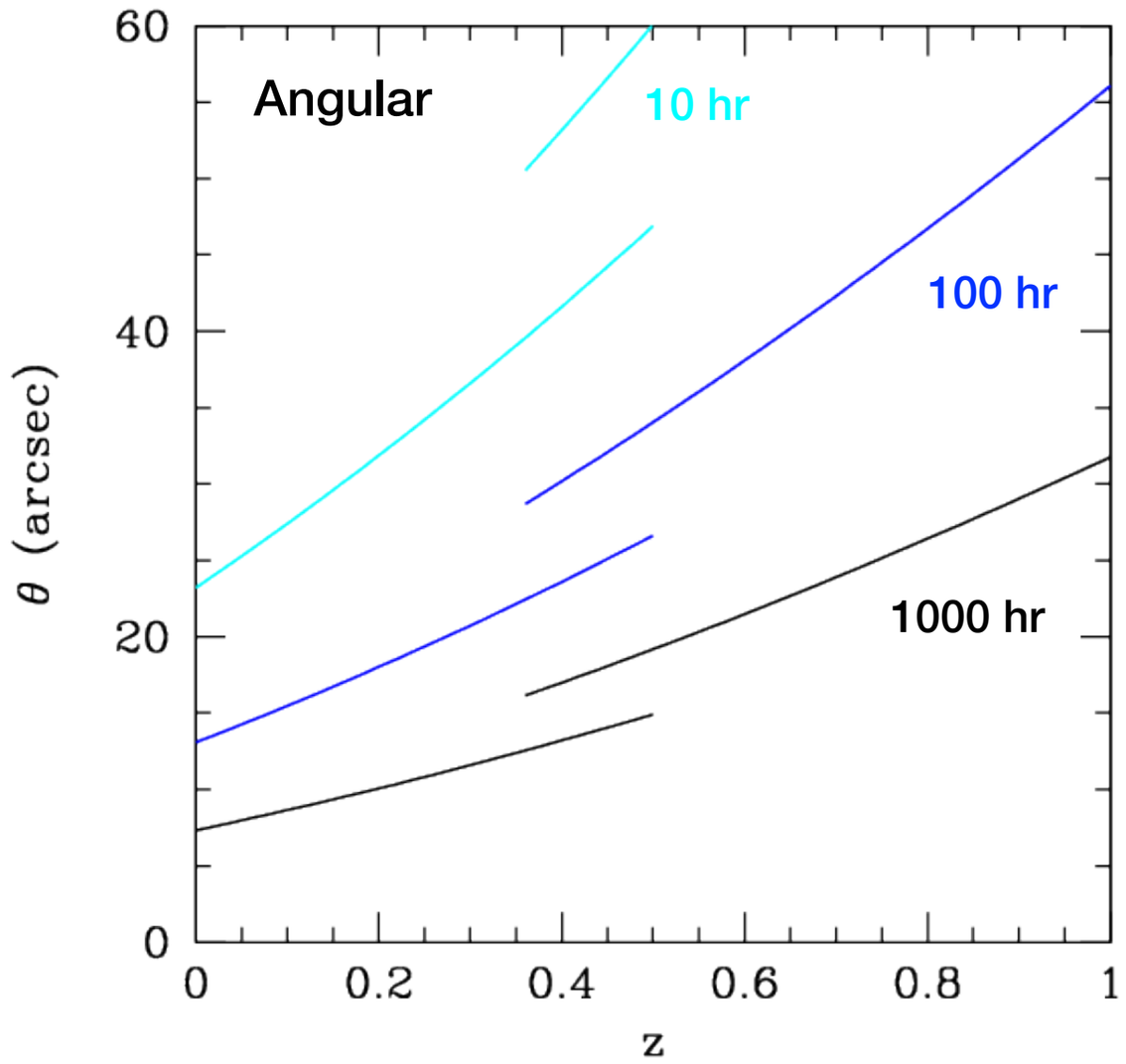
- possible to <u>resolve</u> many galaxies over large redshift range
- understand role of local environment
- carry out detailed studies of galaxy kinematics & angular momentum
- high resolution studies of ISM in nearby galaxies (~100 pc)

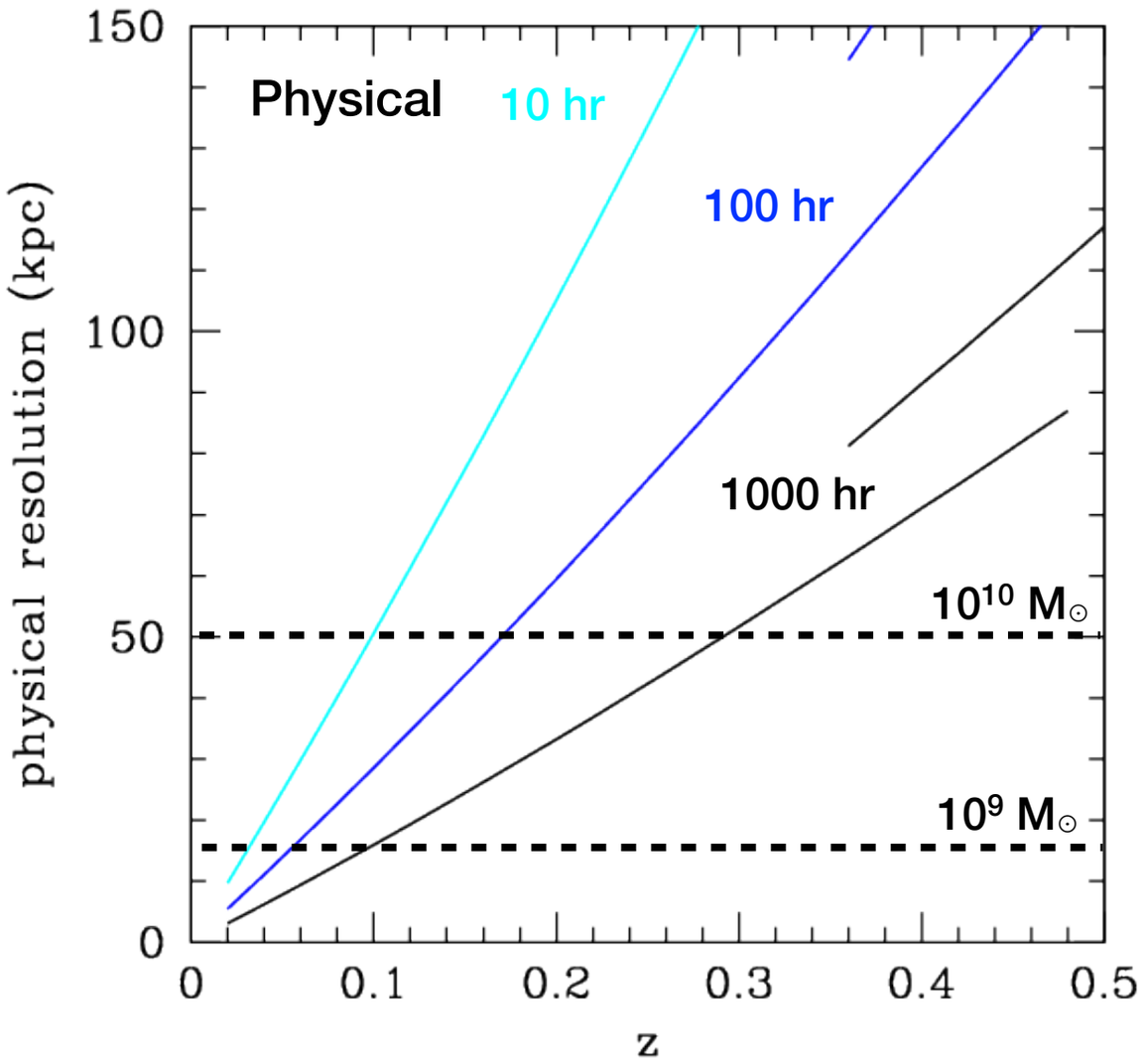
SKA1 Surveys: Resolution @ 10^{19} cm^{-2}





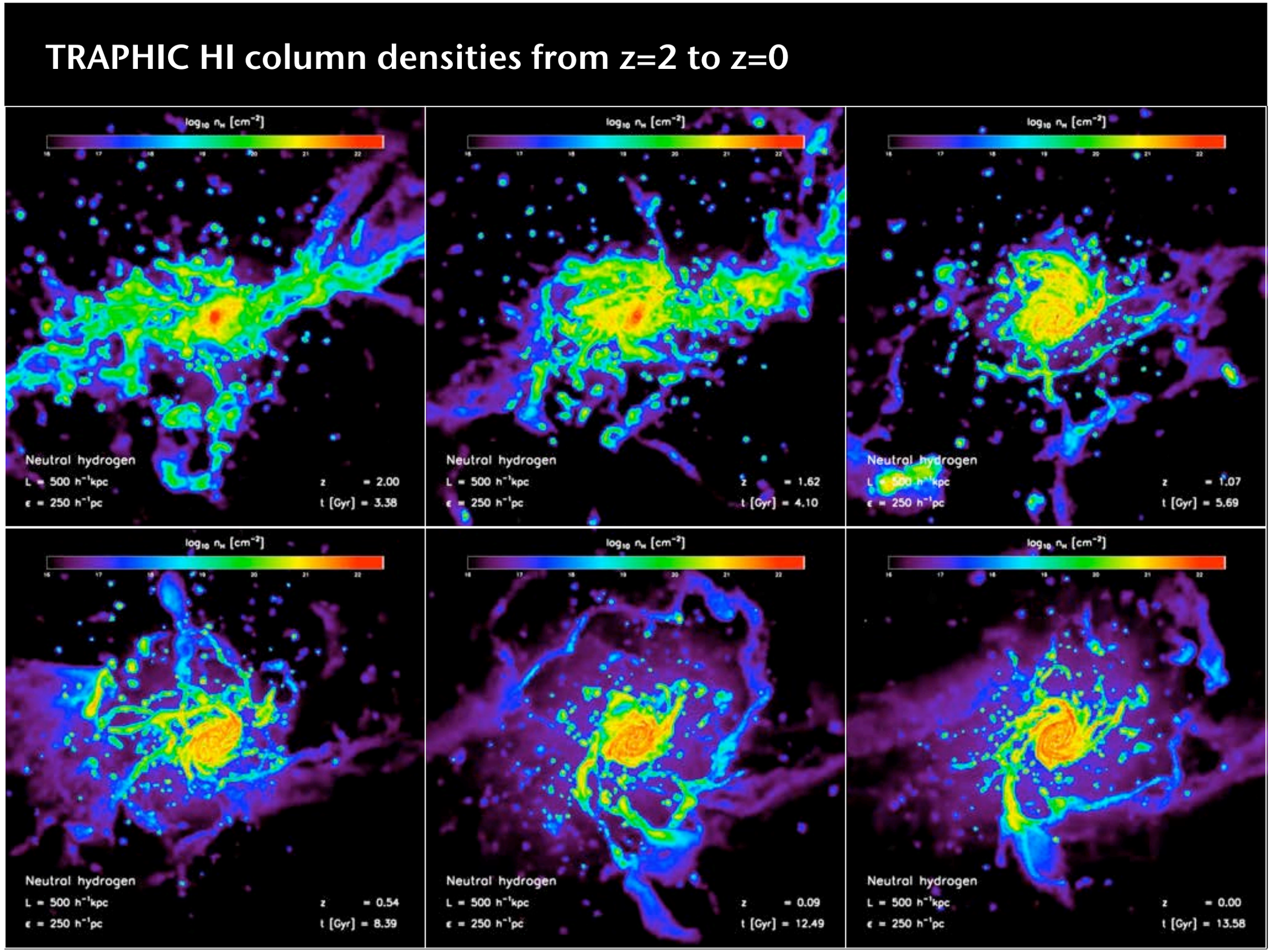
SKA1 Surveys: Resolution @ 10^{19} cm^{-2}



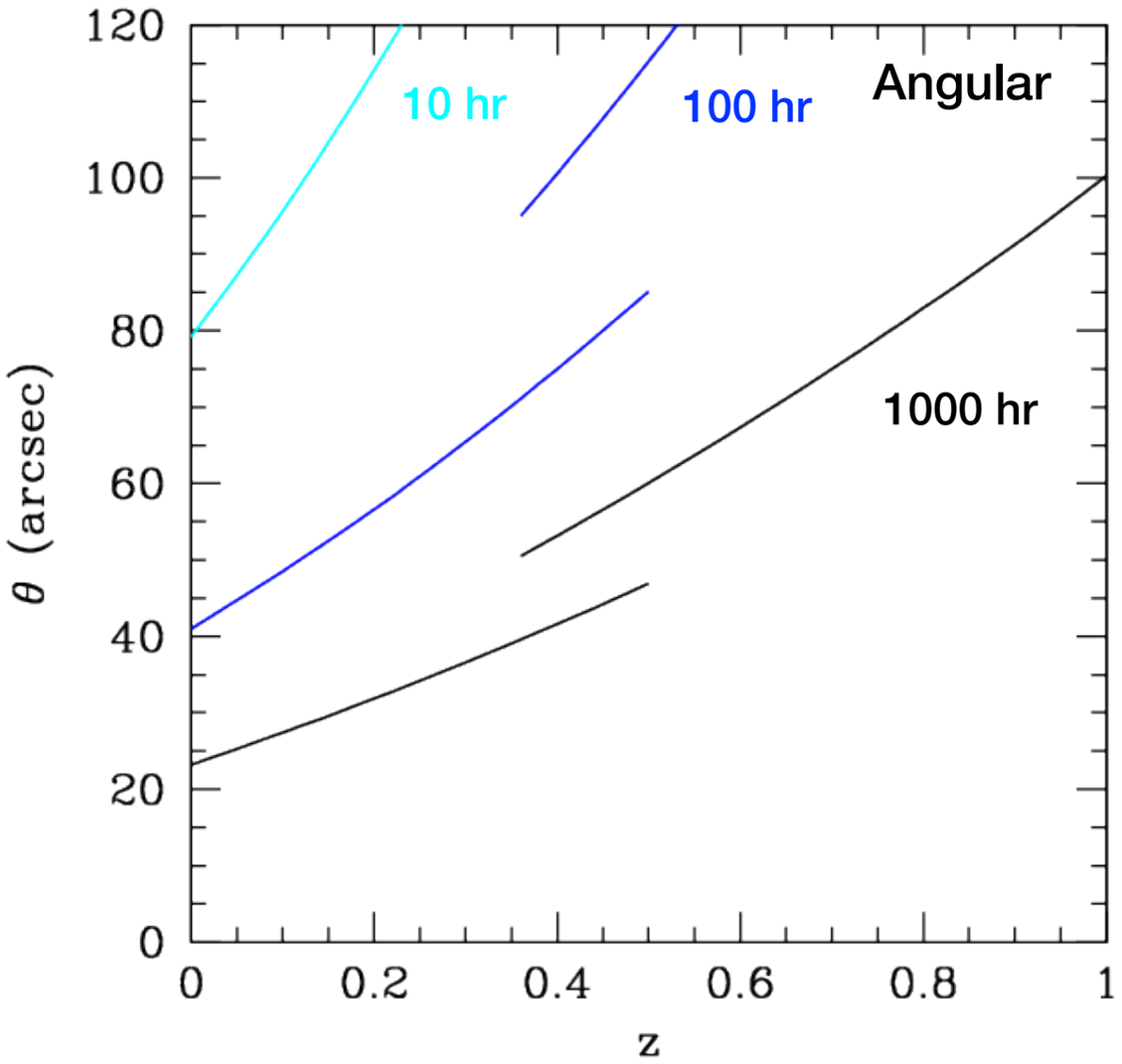


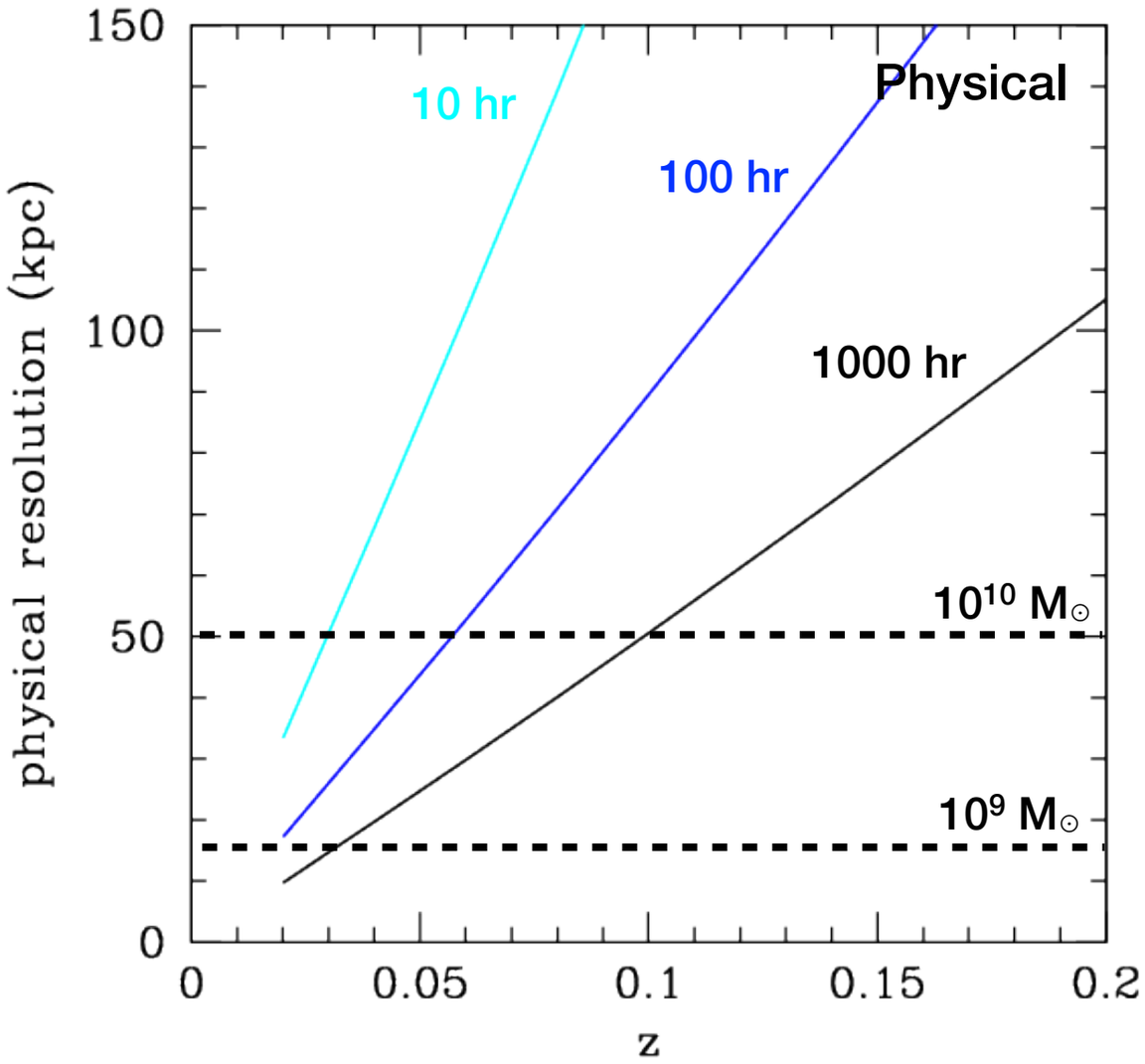
- HALOGAS type studies beyond local Universe
- environment/accretion

SKA1 Surveys: Resolution @ 10^{18} cm^{-2}



SKA1 Surveys: Resolution @ 10^{18} cm^{-2}



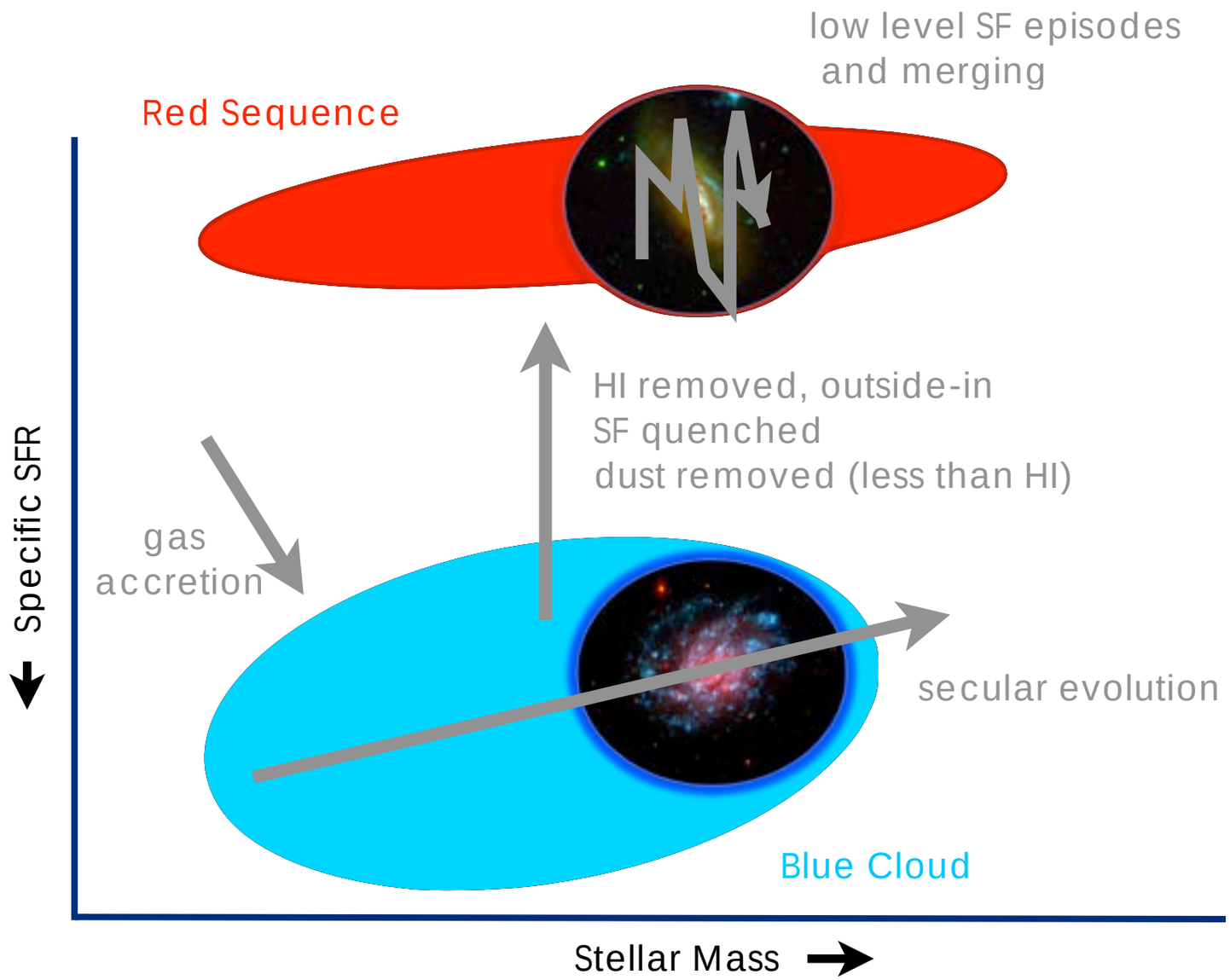


- New studies of the disk-halo-IGM interface

Need Multi-λ

HI + multi-λ essential for understanding the evolution of galaxies

- different baryonic states: gas (atomic/molecular/ ionised), stars, dust
- environment: group properties (membership/ multiplicity/halo mass/ central-satellite), accretion, outflow
- feedback: AGN, stars
- galaxy dynamics: gas, stars, halo

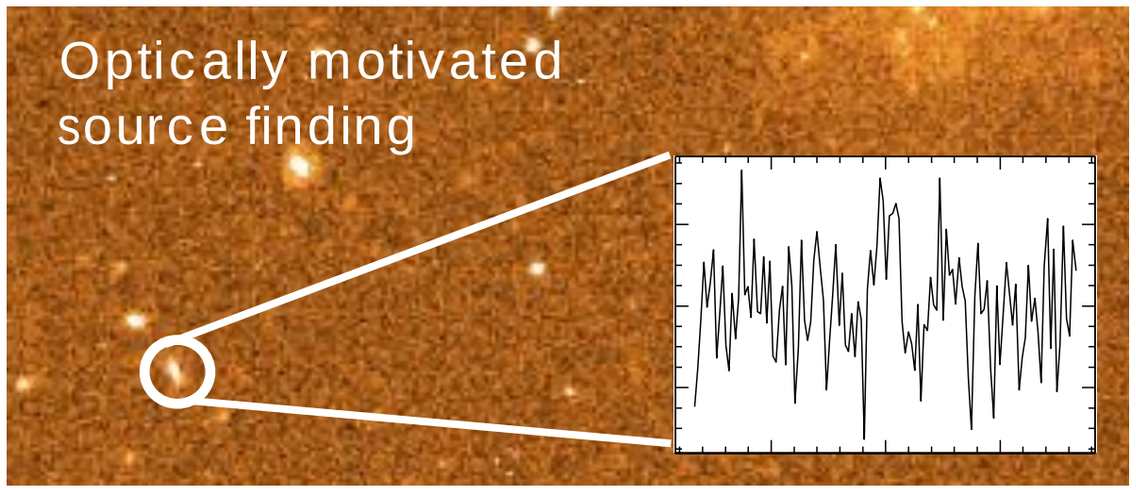


adapted from Catinella, Cortese

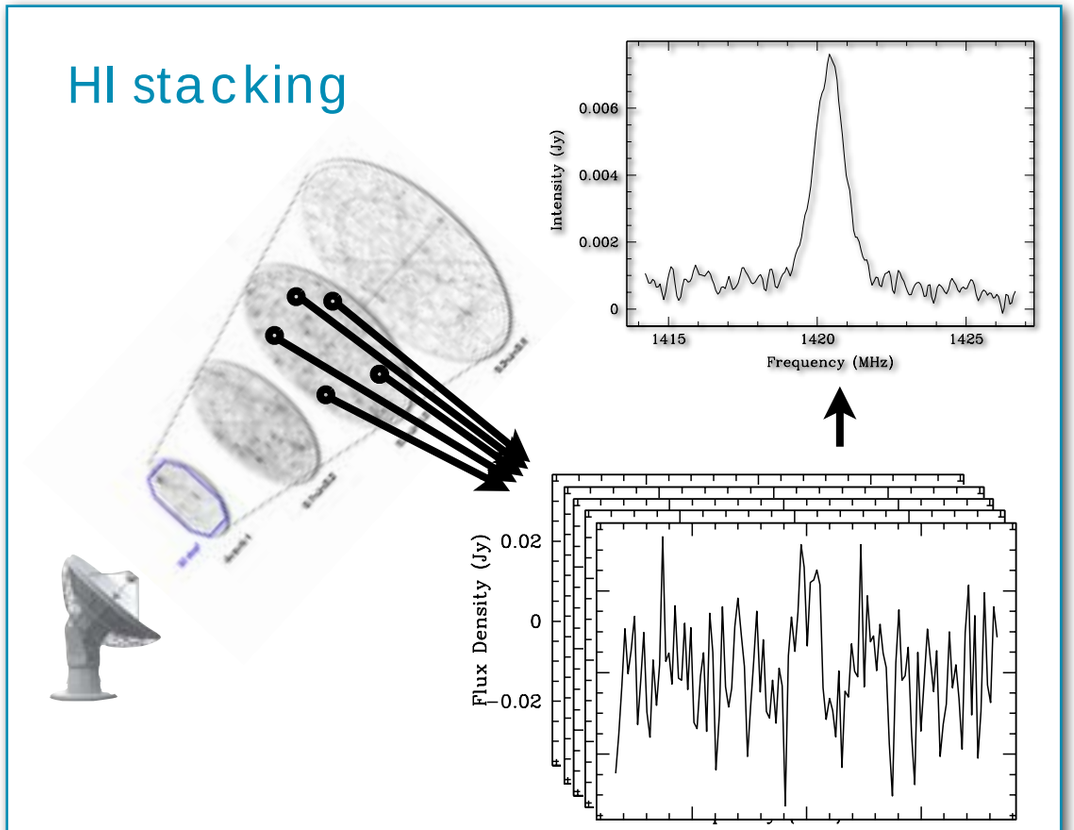
Need Multi-λ: Methods

Improved ability to find and measure HI content through optically motivated methods

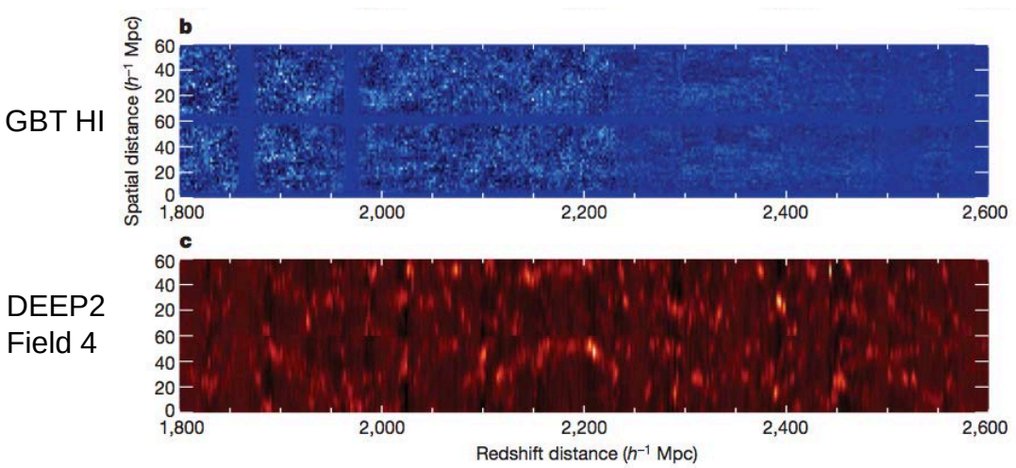
Optically motivated source finding

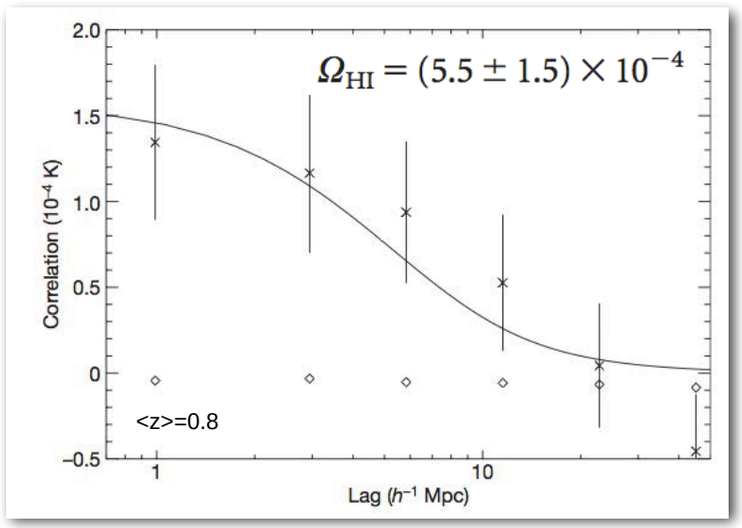


HI stacking



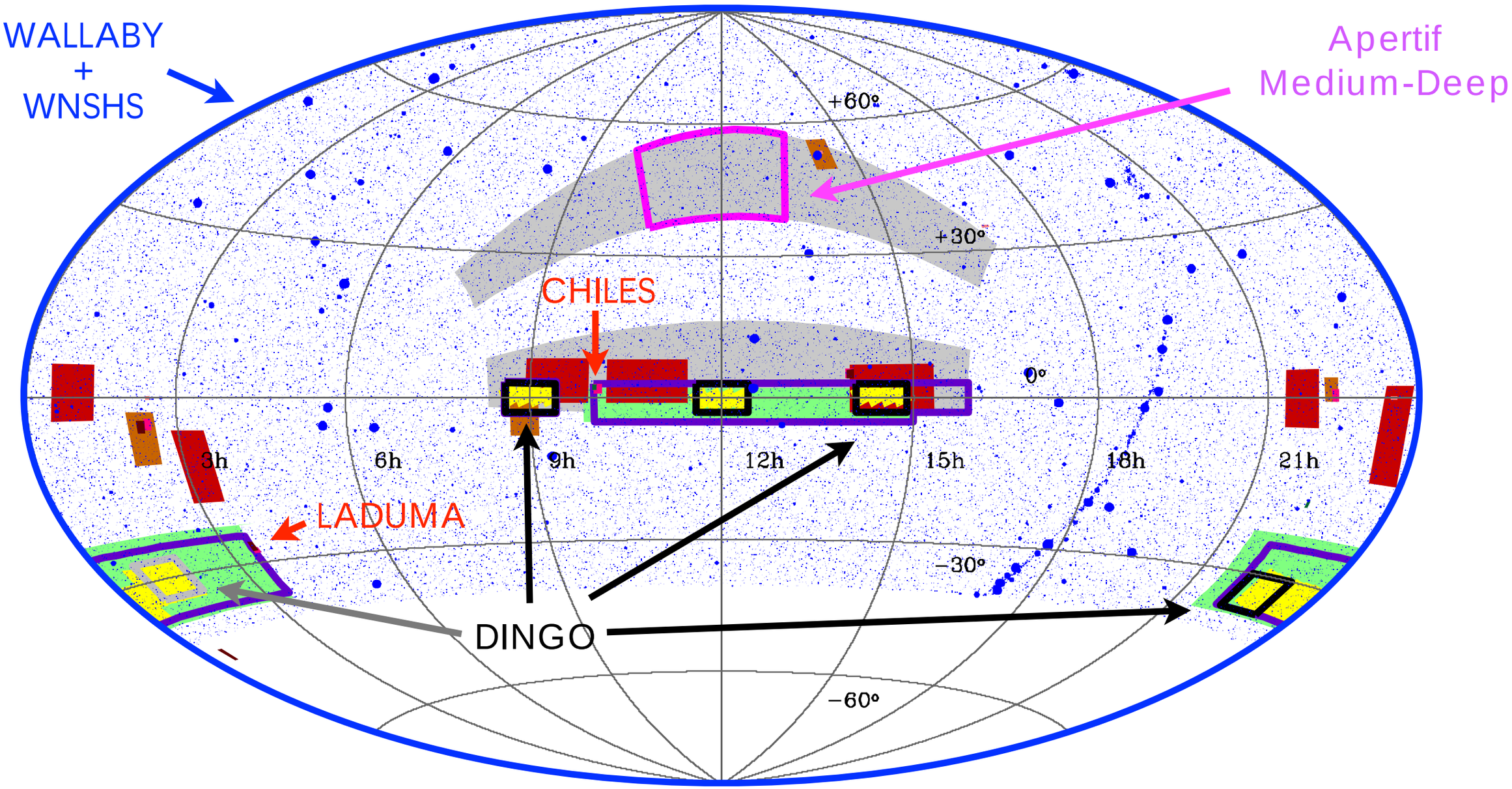
Intensity mapping





Chang et al, 2010

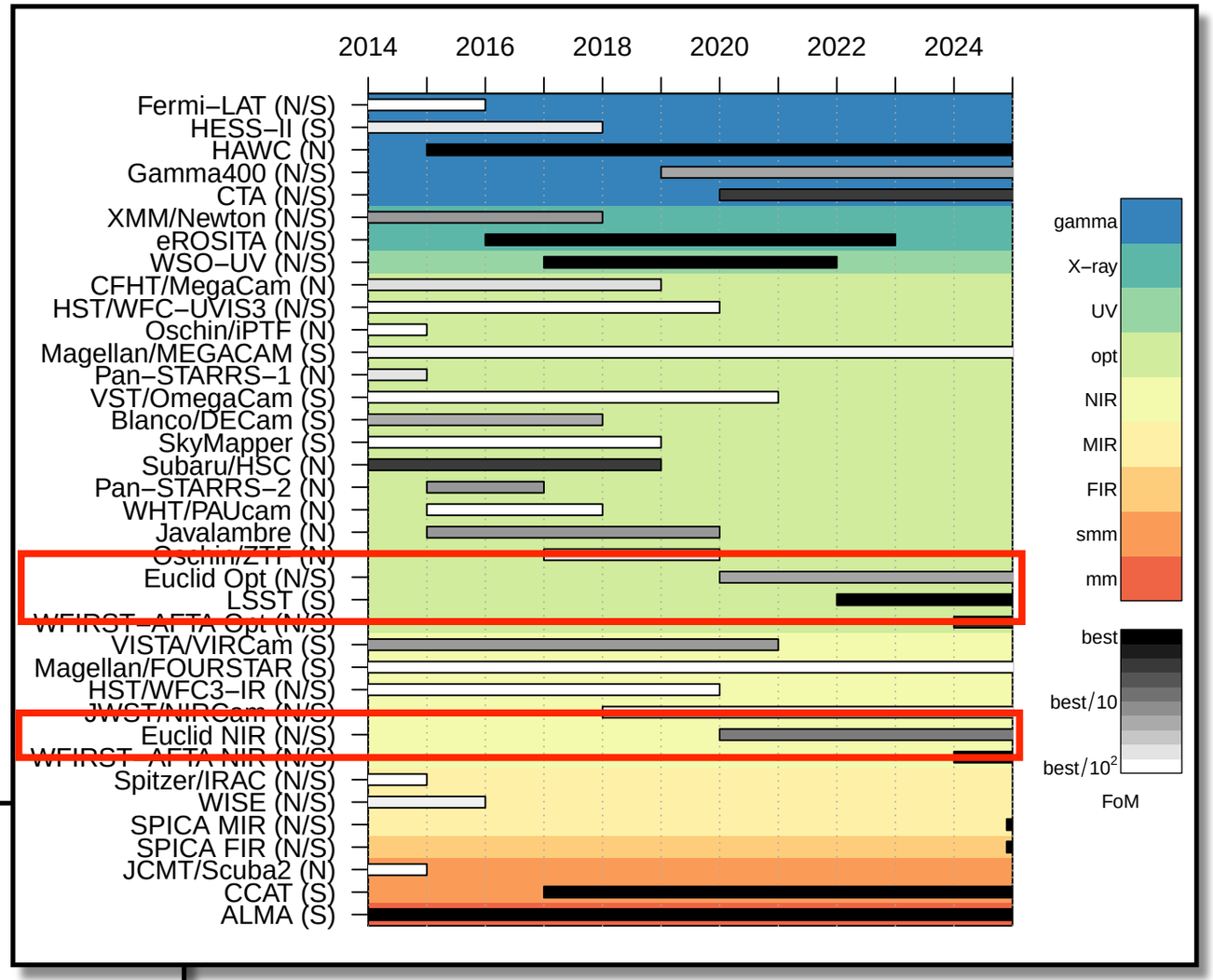
Multi-λ Data for HI Pathfinders



Multi-λ for the SKA

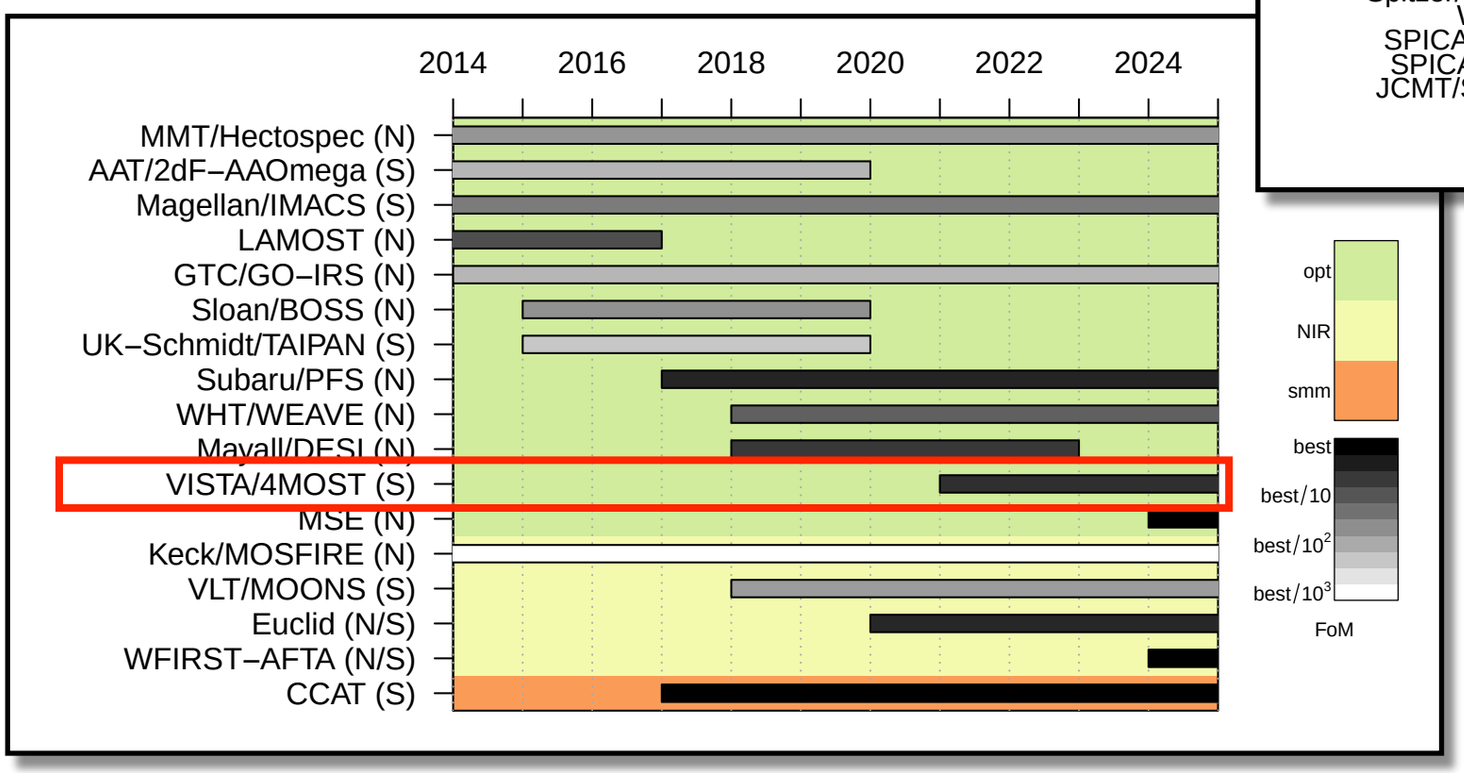
"Connecting the Baryons"
Meyer, Robotham, et al., 2015,
SKA science chapter

https://asgr.shinyapps.io/ganttshiny



Imaging Survey Facilities

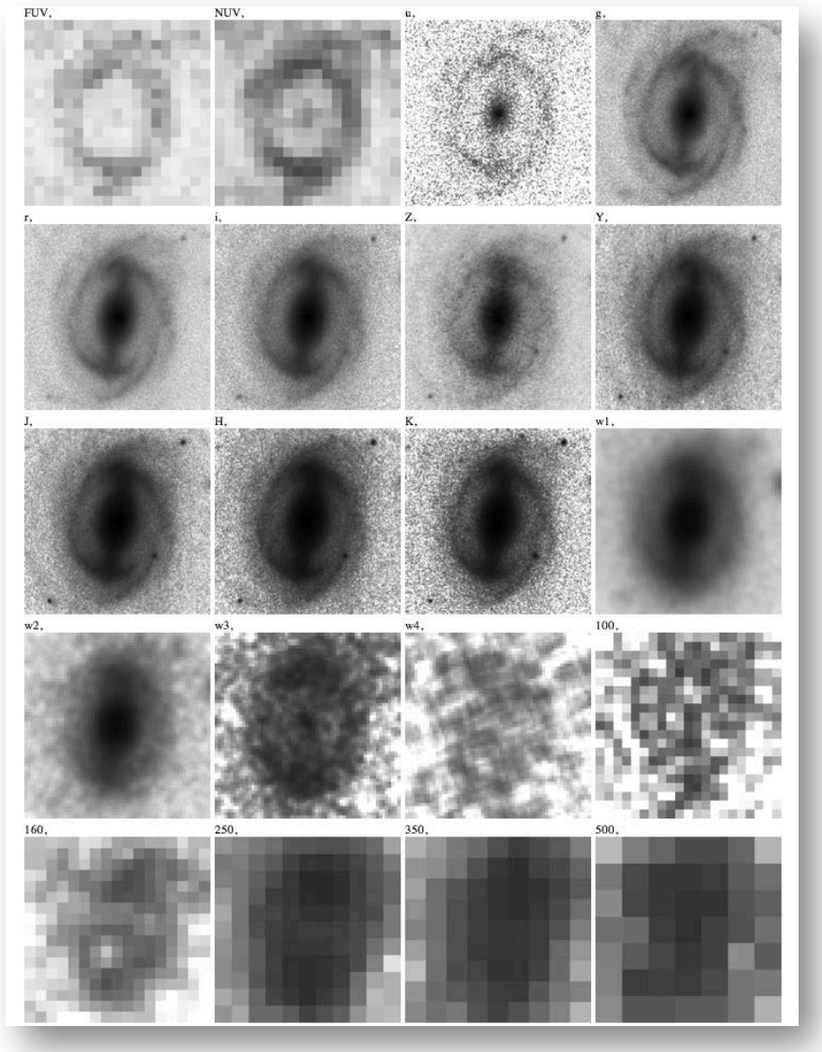
Spectroscopic Survey Facilities

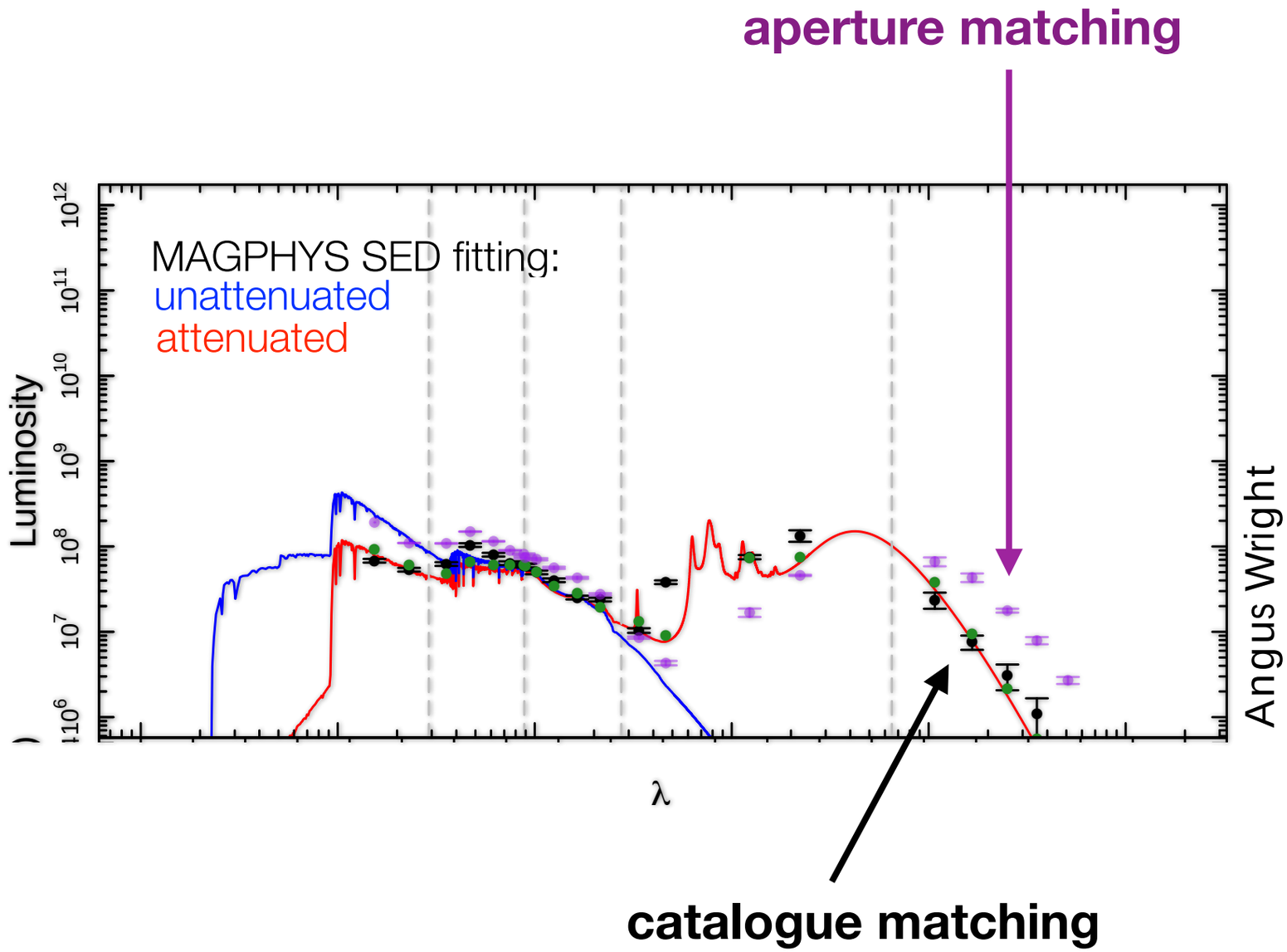


GAMA / DINGO Multi-λ

Panchromatic photometry

LAMBDAR software addresses: mismatched PSFs (convolved r-band apertures), deblend, deconfuse





GAMA / DINGO Multi-λ

Mass:

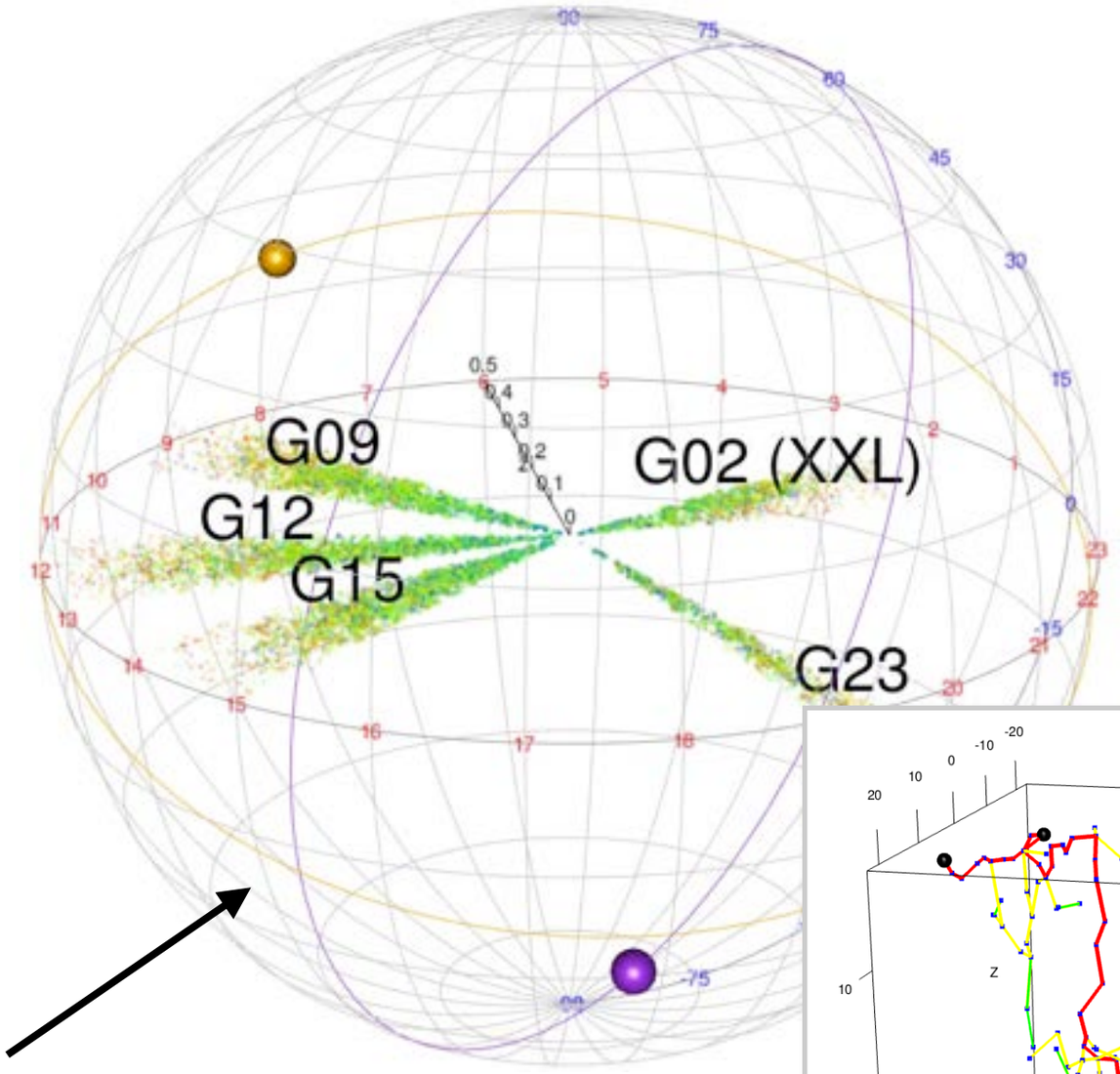
- GSMF (Baldry et al)
- GSMF by type (Kelvin et al)
- SMBH MF (Andrews et al)
- DUST MF (Dunne et al)
- DM HMF (Robotham et al)

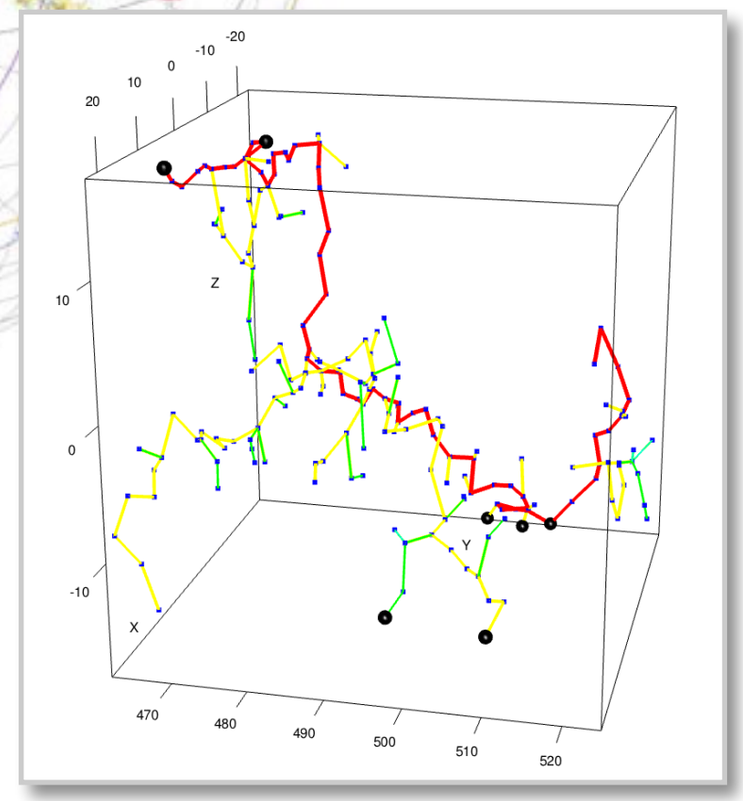
Energy:

- CSED (Driver et al)
- CSFH (Gunawardhana et al)

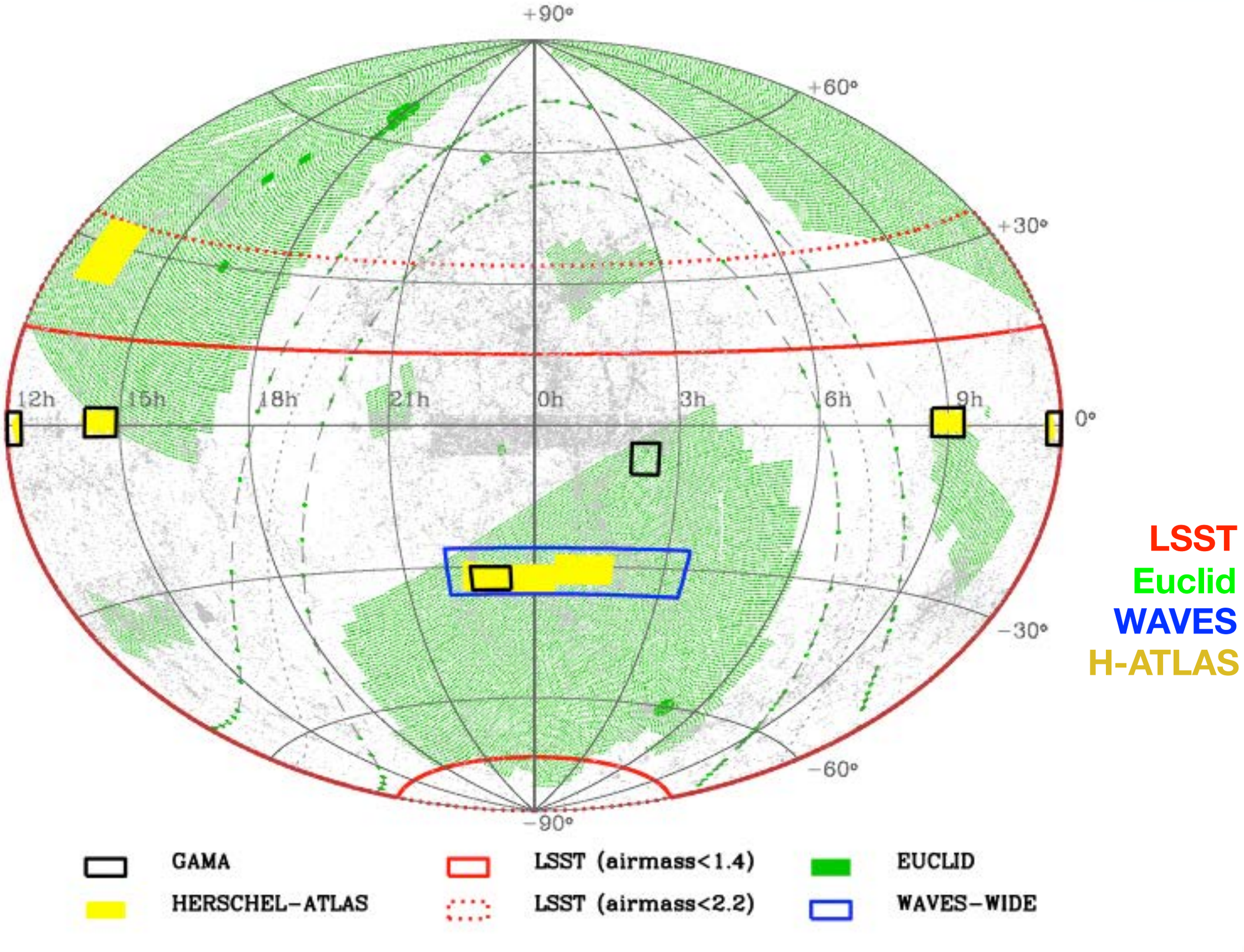
Structure:

- Mass-size relations (Lange et al)
- Groups (Robotham et al)
- Filaments (Alpaslan et al)
- Tendrils (Alpaslan et al)
- Pairs (Robotham et al)
- Bulge-disc decomp (Lange et al, Haussler et al)





WAVES / LSST / Euclid



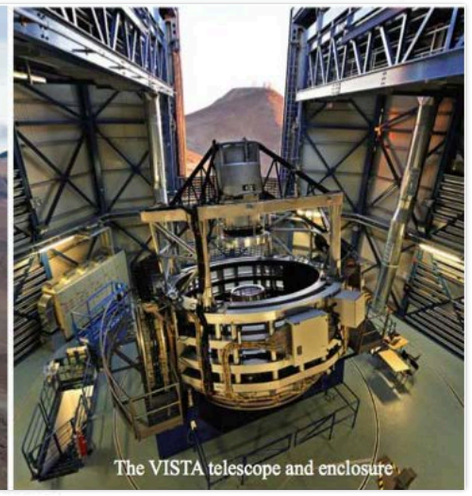
WAVES

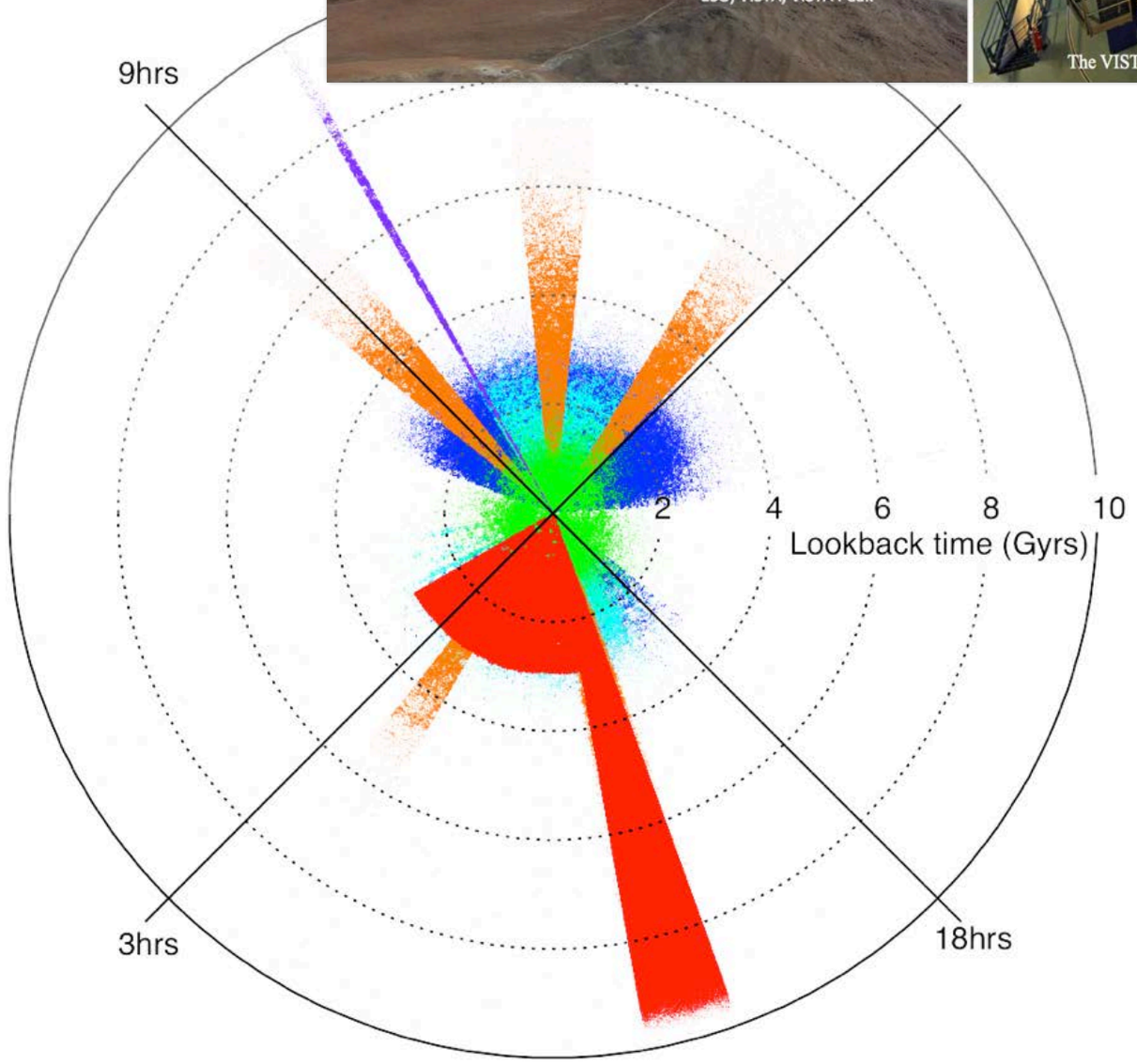
WAVES-WIDE

- 750 deg^2 to $r_{AB} < 22$ mag + photo-z (< 0.2) pre-selection
- ~0.9m galaxies will give 85k DM halos 10^{11}–10^{12} $M_\odot$

WAVES-DEEP

- 100 deg^2 to $r_{AB} < 22$ mag
- ~1.2m galaxies to z~1
- detection of ~50k DM haloes (to 10^{12} $M_\odot$)

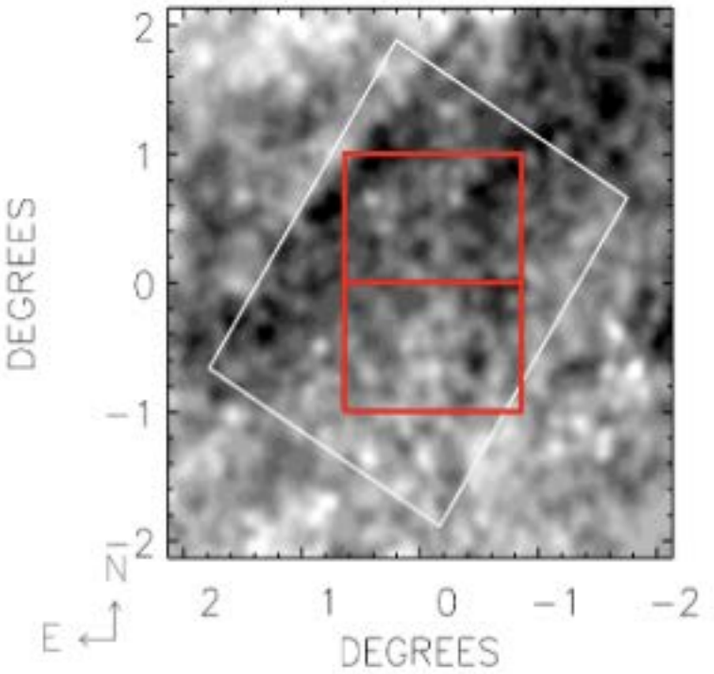




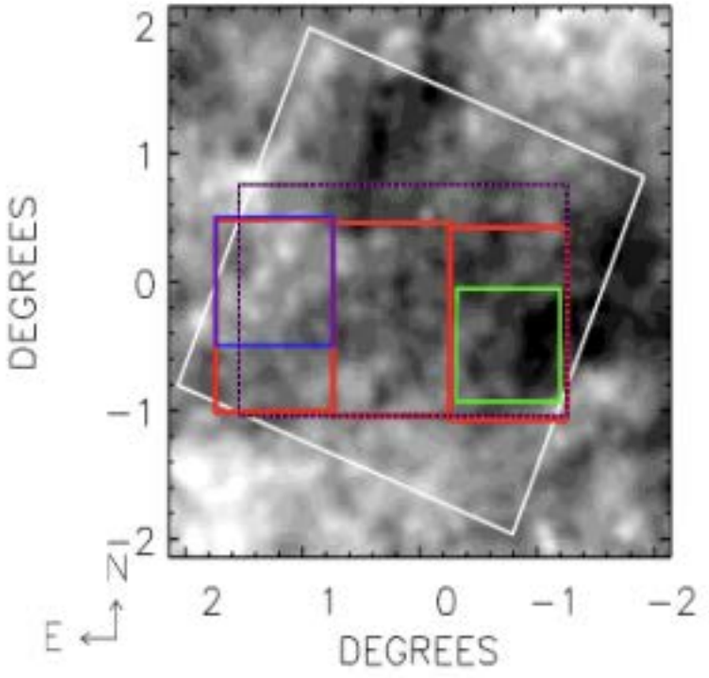
| 6dfGRS | SDSS DR9 | 2dFGRS | GAMA | zCOSMOS | WAVES |

Additional Ultra-Deep Fields

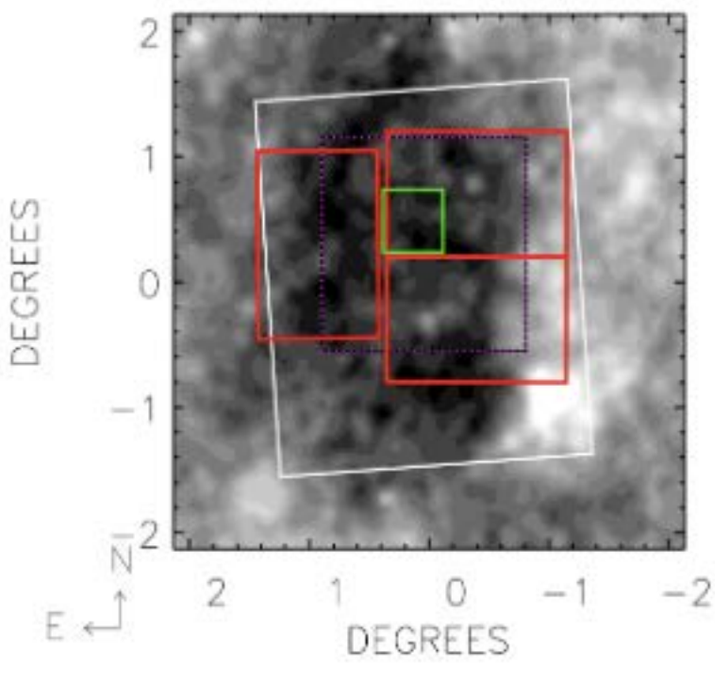
Elais-S1



XMM-LSS



ECDFS



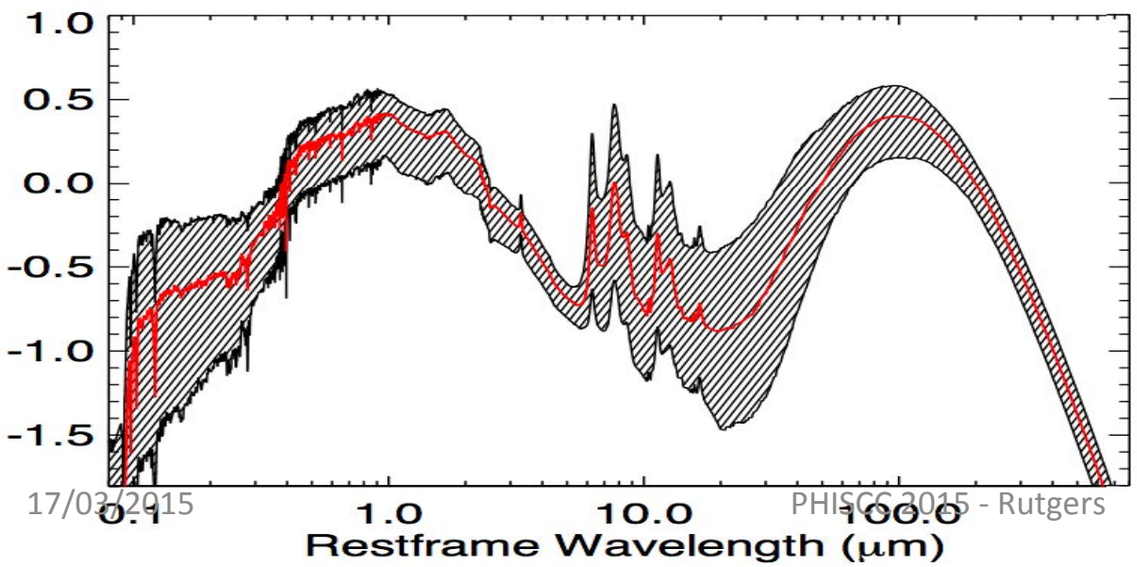
Filter	Time (per source)	Time (full survey)	5σ AB	5σ Vega	UKIDSS-DXS	Seeing	Moon
Z	17.5 hours	456 hours	25.7	25.2	-	0.8	D
Y	6.7 hours	175 hours	24.6	24.0	-	0.8	G
J	8.0 hours	209 hours	24.5	23.7	22.3	0.8	G
H	8.0 hours	221 hours	24.0	22.7	22	0.8	B
K_s	6.7 hours	180 hours	23.5	21.7	20.8	0.8	B

VISTA-VIDEO, PI: Jarvis

Additional Ultra-Deep Fields

"Typical" multi-wavelength coverage over southern deep fields

- Heterogeneous X-ray data from Chandra/XMM (eROSITA soon)
- GALEX: FUV + NUV to AB ~24 (~6arcsec resolution)
- VST-VOICE + DES + HSC + LSST: ugriz to mAB ~26-27 (<1arcsec resolution)
- UltaVISTA/VIDEO: (Z)YJHKs mAB = 25.7, 25.6, 24.5, 24.0, 23.5 (<0.9arcsec resolution)
- SERVS/DeepDrill: Spitzer 3.6 & 4.5um to 2uJy (~2arcsec resolution)
- SWIRE IRAC 5.8 & 8.0um to ~30uJy (~3-4arcsec resolution)
- MIPS 24/70/160um to 0.3,20.100mJy (~10,25,50 arcsec resolution)
- Herschel-HerMES 110,160,250,350,500um to 31.5,60.2,12.7,10.5,15.2mJy (7,10,18,25,35arcsec resolution)
- JVLA/MeerKAT "continuum" imaging 1-4GHz (~1-8arcsec resolution)



SED fits using the energy-balance models of da Cunha et al. 2008

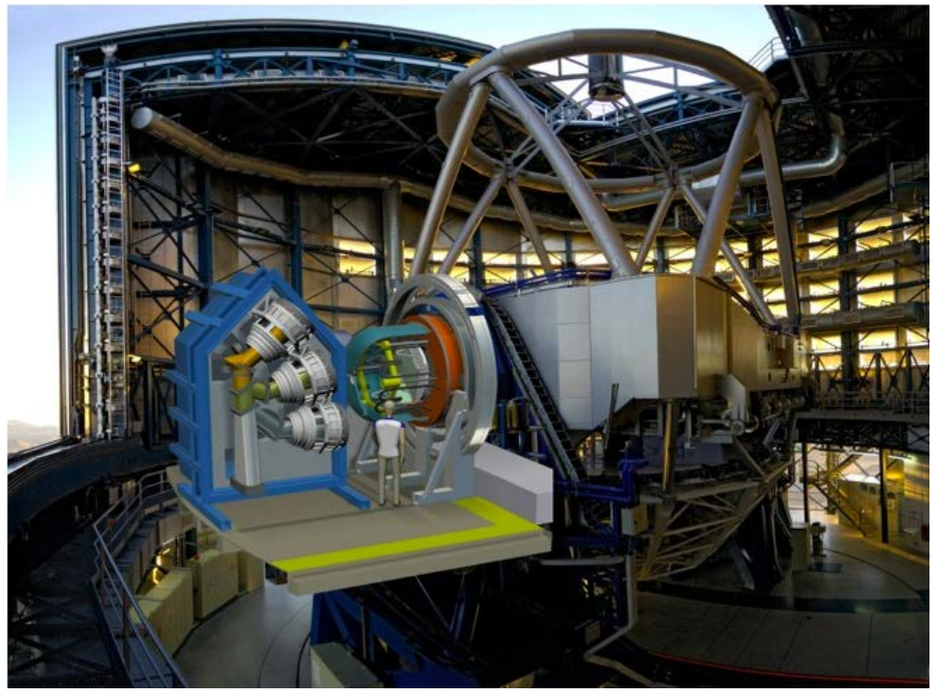
From Smith et al. 2012

Slide credit: Jarvis

Additional Ultra-Deep Fields

Issue: spectroscopy needs improving!

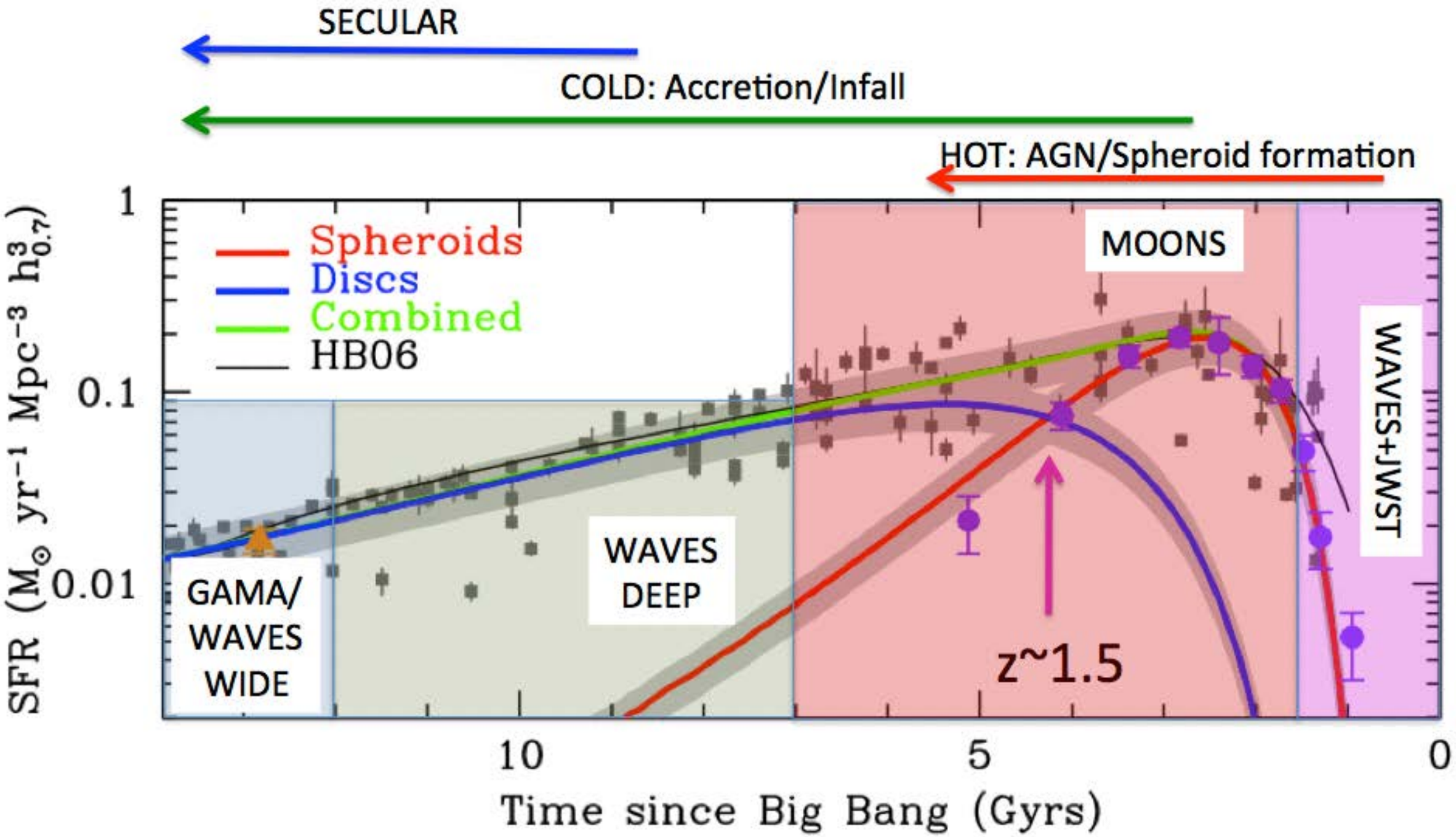
- Spectroscopy in ~1 deg^2 fields often heterogeneous and not ideal for deep HI
- Mainly magnitude limited, sometimes colour selection for high-z



Potential solution: MOONS

Parameter	Specifications
Telescope	VLT
FoV	500 arcmin
Multiplex	1000 (possibility to deploy in pairs)
Close packaging	at least two fibres within 10 arcsec
Sky-projected fibre diameter	1.05 arcsec

WAVES / MOONS



Driver et al., 2013

SKA1 Surveys

Survey	Area (deg	Time (hours)	σ (μJy, 50kHz)	log(N (5σ, 50kHz)	Beam (arcsec)	Band	z	z
Wide	750	2k	226	20	12	**2**	z<0.5	0.17
Deep	100	2k	82	20	6.9	**2**	z<0.5	0.29
UDeep	18	2k	36	20	4.6	**2**	z<0.5	0.44
Single	0.5	2k	11	20	2.5	**1**	z>0.35	0.64

@ 1.4 GHz, rebaselined

SKA1 Surveys

Survey	Area (deg	Time (hours)	σ (μJy, 50kHz)	log(N (5σ, 50kHz)	Beam (arcsec)	Band	z	z
Wide	750	2k	226	20	12	**2**	z<0.5	0.17
Deep	100	2k	82	20	6.9	**2**	z<0.5	0.29
UDeep	18	2k	36	20	4.6	**2**	z<0.5	0.44
Single	0.5	2k	11	20	2.5	**1**	z>0.35	0.64

@ 1.4 GHz, rebaselined

SKA1 Surveys

Survey	Area (deg	Time (hours)	σ (μJy, 50kHz)	log(N (5σ, 50kHz)	Beam (arcsec)	Band	z	z
Wide	750	2k	226	20	12	**2**	z<0.5	0.17
~~**Deep**~~	~~100~~	~~2k~~	~~82~~	~~20~~	~~6.9~~	~~**2**~~	~~z<0.5~~	~~0.29~~
UDeep	18	2k	36	20	4.6	**2**	z<0.5	0.44
Single	0.5	2k	11	20	2.5	**1**	z>0.35	0.64

@ 1.4 GHz, rebaselined

SKA1 Surveys

Survey	Area (deg	Time (hours)	σ (μJy, 50kHz)	log(N (5σ, 50kHz)	Beam (arcsec)	Band	z	z
Wide	750	2k	226	20	12	**2**	z<0.5	0.17
UDeep	18	2k	36	20	4.6	**2**	z<0.5	0.44
Single	0.5	2k	11	20	2.5	**1**	z>0.35	0.64

@ 1.4 GHz, rebaselined

SKA1 Surveys

Survey	Area (deg	Time (hours)	σ (μJy, 50kHz)	log(N (5σ, 50kHz)	Beam (arcsec)	Band	z	z
Wide	750	2k	226	20	12	**2**	z<0.5	0.17
UDeep	18	2k	36	20	4.6	**2**	z<0.5	0.44
Single	0.5	2k	11	20	2.5	**1**	z>0.35	0.64

@ 1.4 GHz, rebaselined

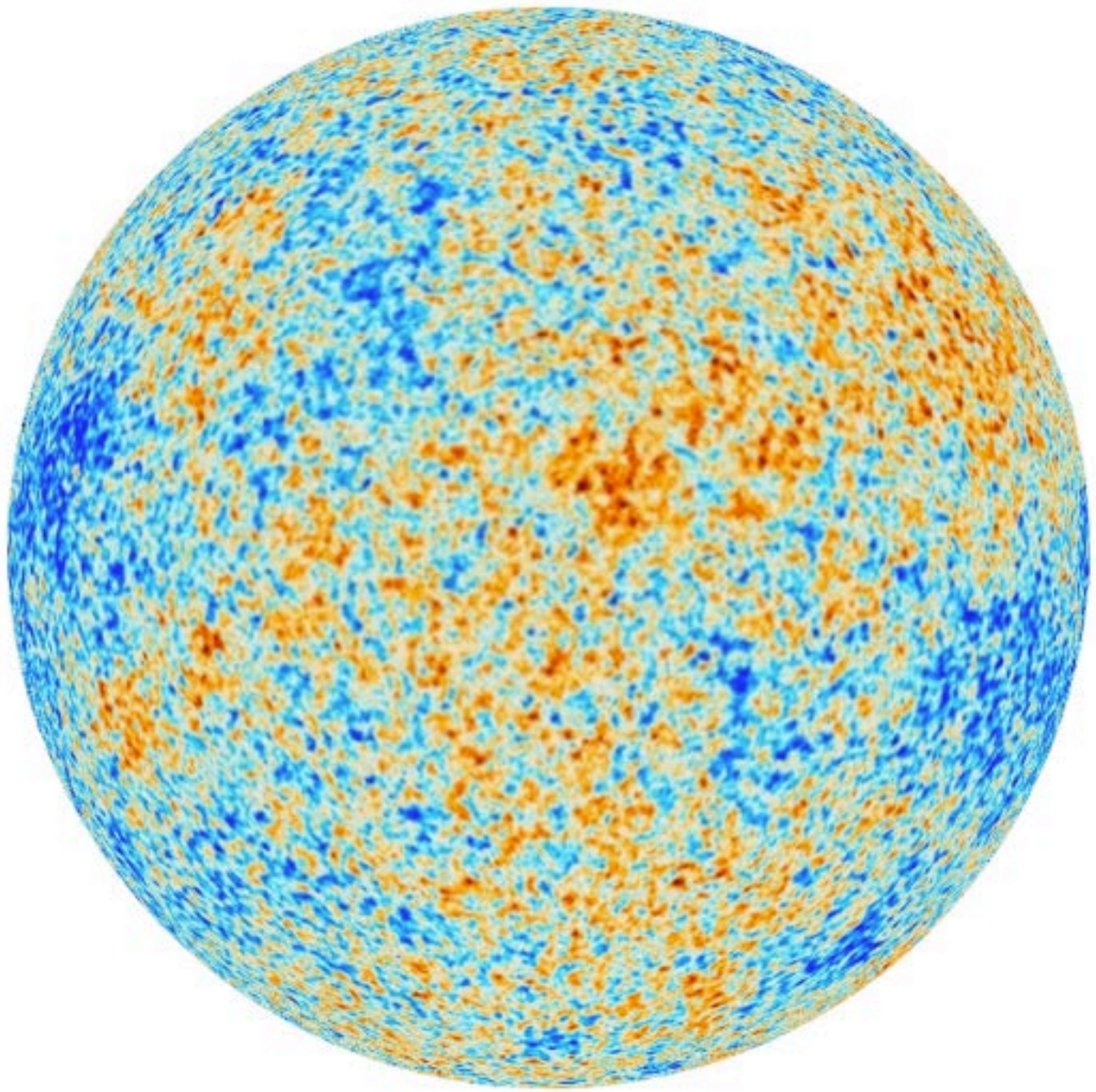
Wide	750	5k	229	20	13.4/30	**ASKAP**	z<0.26	0.17

SKA1 Surveys

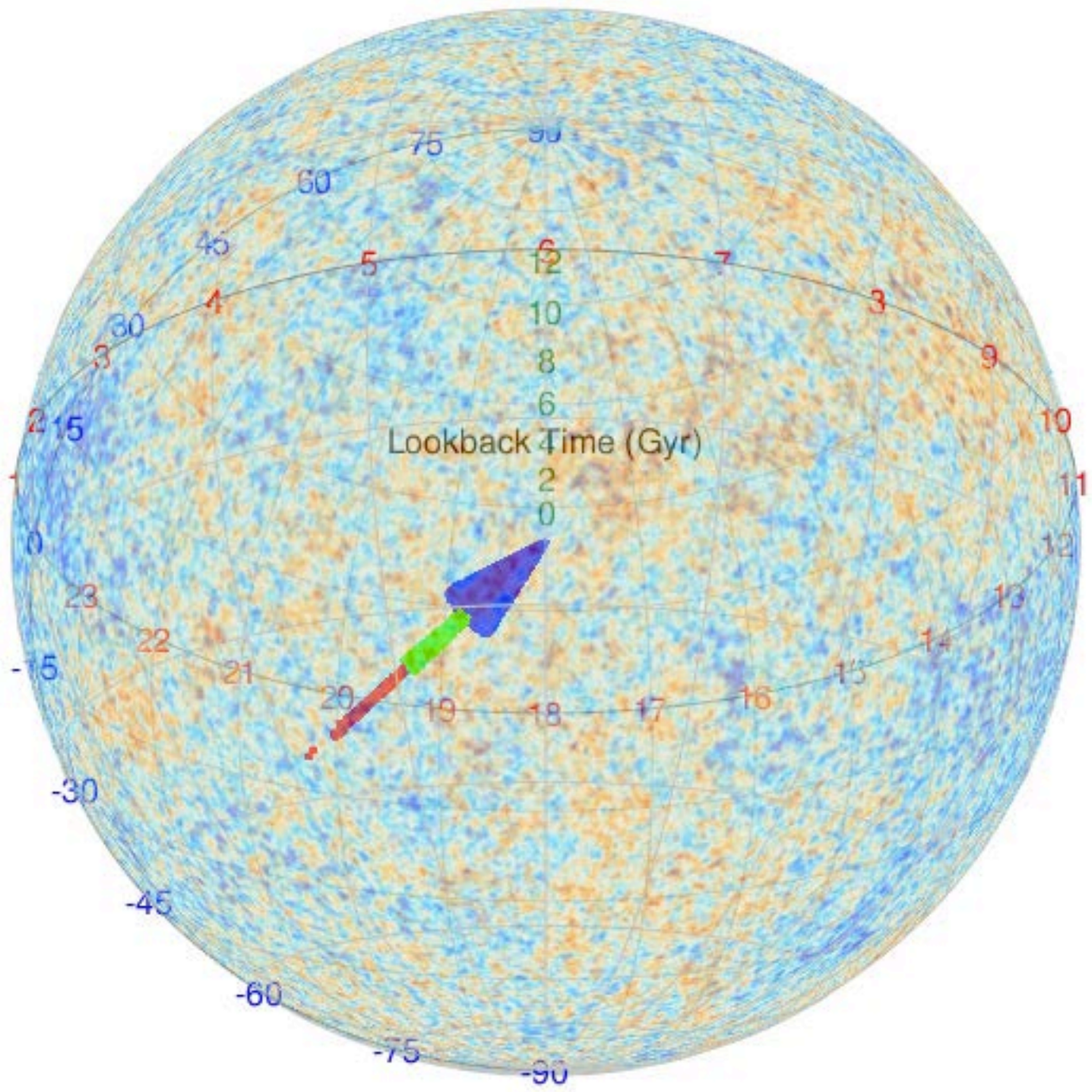
Survey	Area (deg	Time (hours)	σ (μJy, 50kHz)	log(N (5σ, 50kHz)	Beam (arcsec)	Band	z	z
Wide	750	5k	229	20	13.4	**ASKAP**	z<0.26	0.17
UDeep	18	2k	36	20	4.6	**2**	z<0.5	0.44
Single	0.5	2k	11	20	2.5	**1**	z>0.35	0.64

@ 1.4 GHz, rebaselined

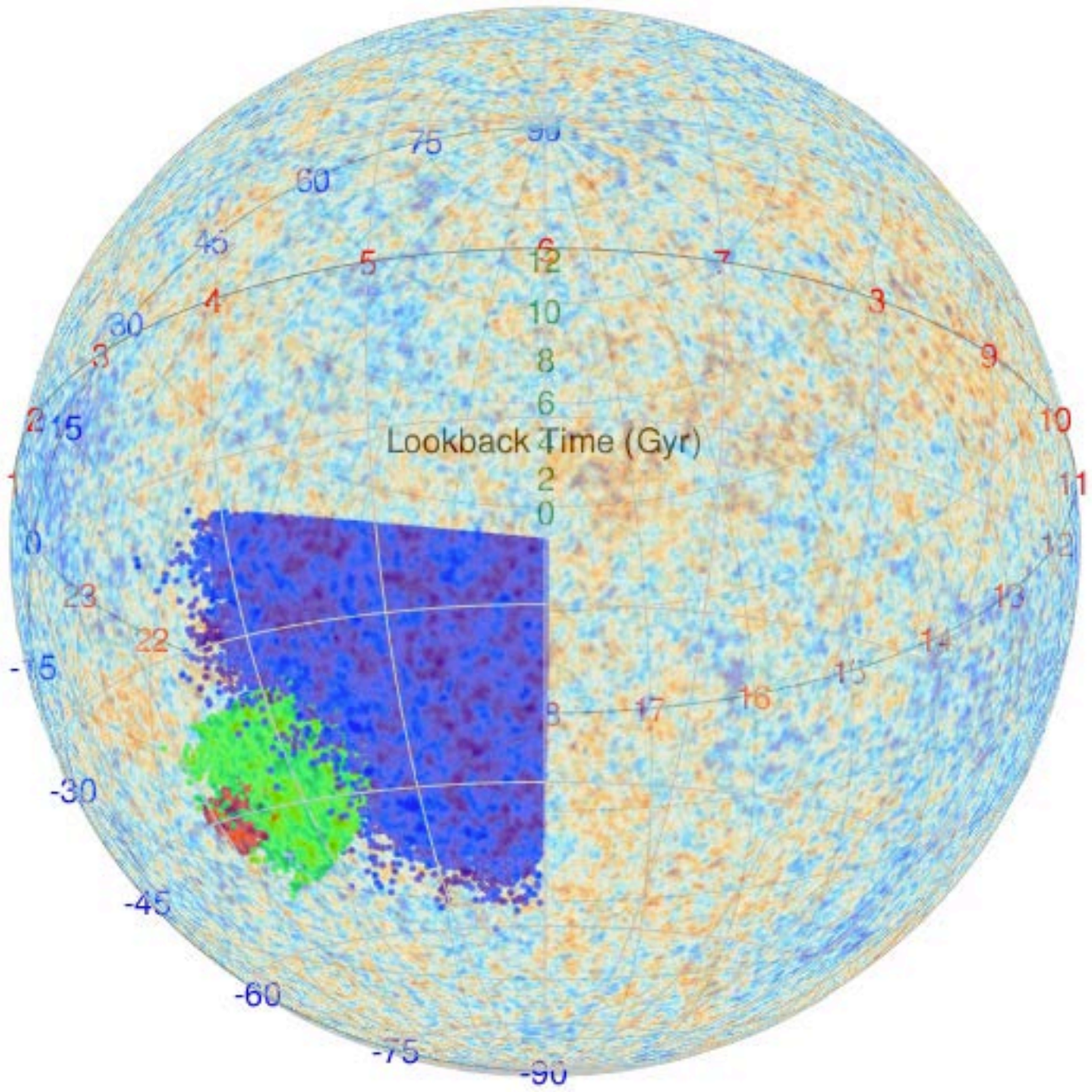
SKA1



SKA1


Lookback Time (Gyr)
12
10
8
6
4
2
0
75
60
45
30
15
0
-15
-30
-45
-60
-75
-90
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23

Full SKA


Lookback Time (Gyr)
12
10
8
6
4
2
0
75
60
45
30
15
0
-15
-30
-45
-60
-75
-90
1
2
3
4
5
6
7
9
10
11
12
13
14
15
16
17
22
23