Continuum and HI surveys working together

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ASTRON

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Plan for this talk

- HI science with SKA1: the opportunities
- the types of surveys the HI science needs, and why
- potential for commensal surveys
- how to make our wedding cake

The problem

~ 5000 hr per year available on both Mid and Low for ALL surveys combined

⇨ of the order of 1000 hr per year specifically for HI work (or for continuum, or …)

current plans could fill a multiple of that!!!!

If we design surveys such that they serve many purposes, we can gain a lot.

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

Table 2. List of highest priority SKA1 science objectives, grouped by SWG, but otherwise in arbitrary order.

The opportunities

SKA1 Mid (single pointing) will be

~20-50x faster than JVLA
- CHILES (1000 hr EVLA) in <50 hrs
- 1 THINGS galaxy in 1 hr

~10-20x faster than MeerKat
- Laduma (5000 hr MeerKat)~ few hundred hr
- Monghoose galaxy in 10-20 hr

~100x faster WSRT
- Halogas in 1 hr

all with better uv coverage and/or resolution.


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Founded by B.A. Gould 1849

THINGS

The HI Nearby Galaxy Survey

Papers reprinted from The Astronomical Journal Volume 136, Number 6, 2008 December

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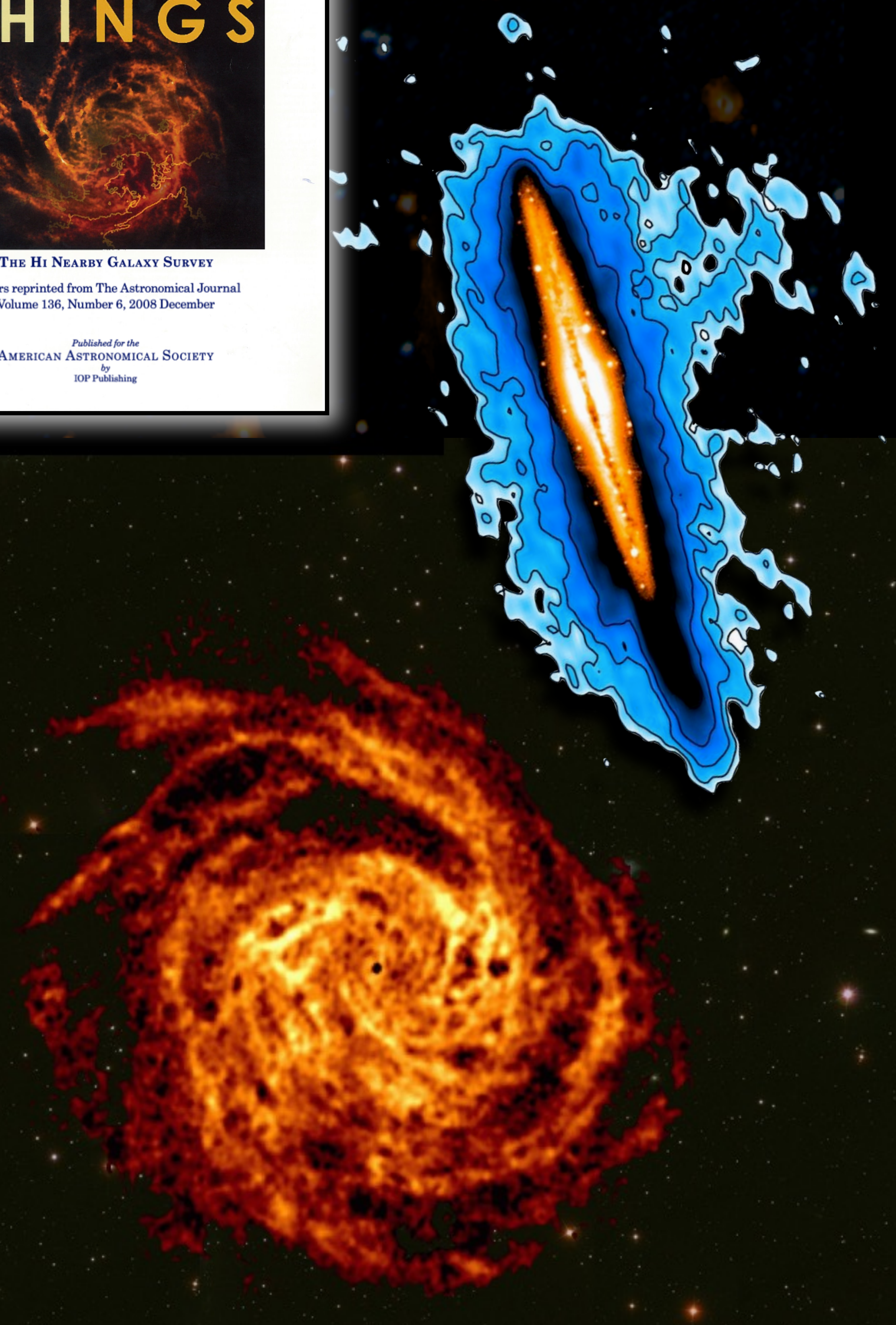

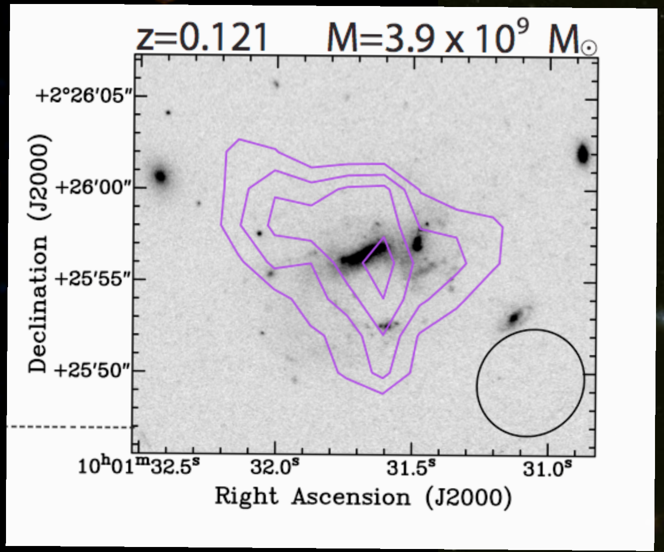

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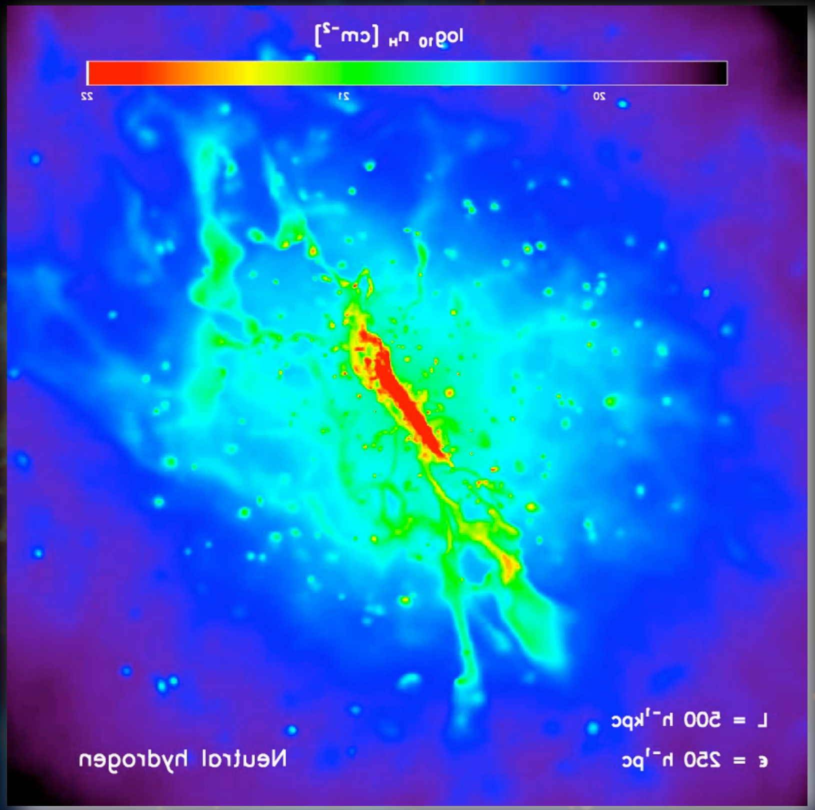
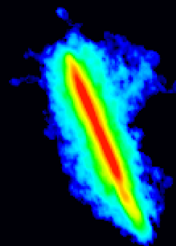
- large surveys: **HI and galaxy evolution**

  Resolved studies of HI in and around galaxies out to z ~ 0.8, i.e. from Now to ~7 Gyr ago.
  Current state: the large HI surveys are single dish and limited to z ~ 0
  Pathfinders will go to ‘higher’ redshift but will not resolve galaxies.

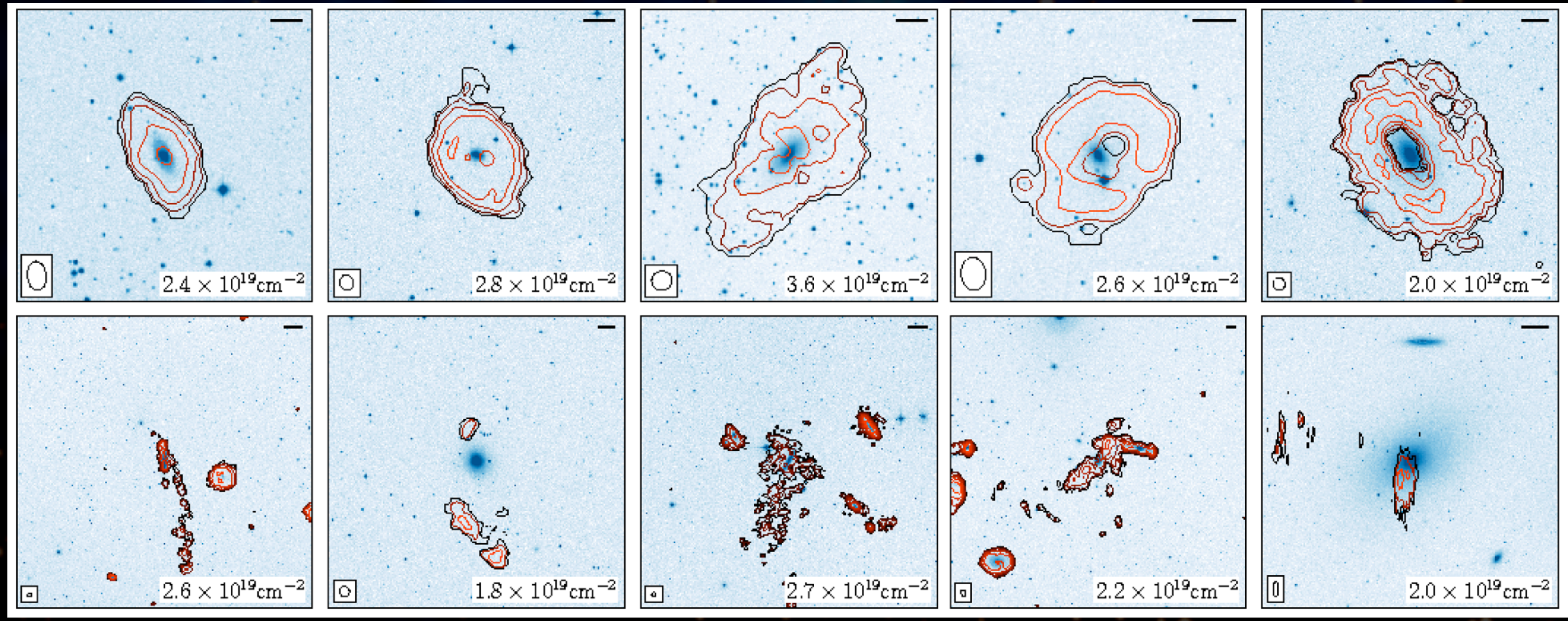




- explore the low column density,
  the HI interface with the IGM.
  Understand how galaxies acquire and lose their gas

- Unresolved statistical studies
  (emission & absorption) beyond 7 Gyr

- Will provide, for large part of the life span of the Universe, information about cold-gas in galaxies and their environment which can be used with multi-wavelength studies of galaxy evolution.



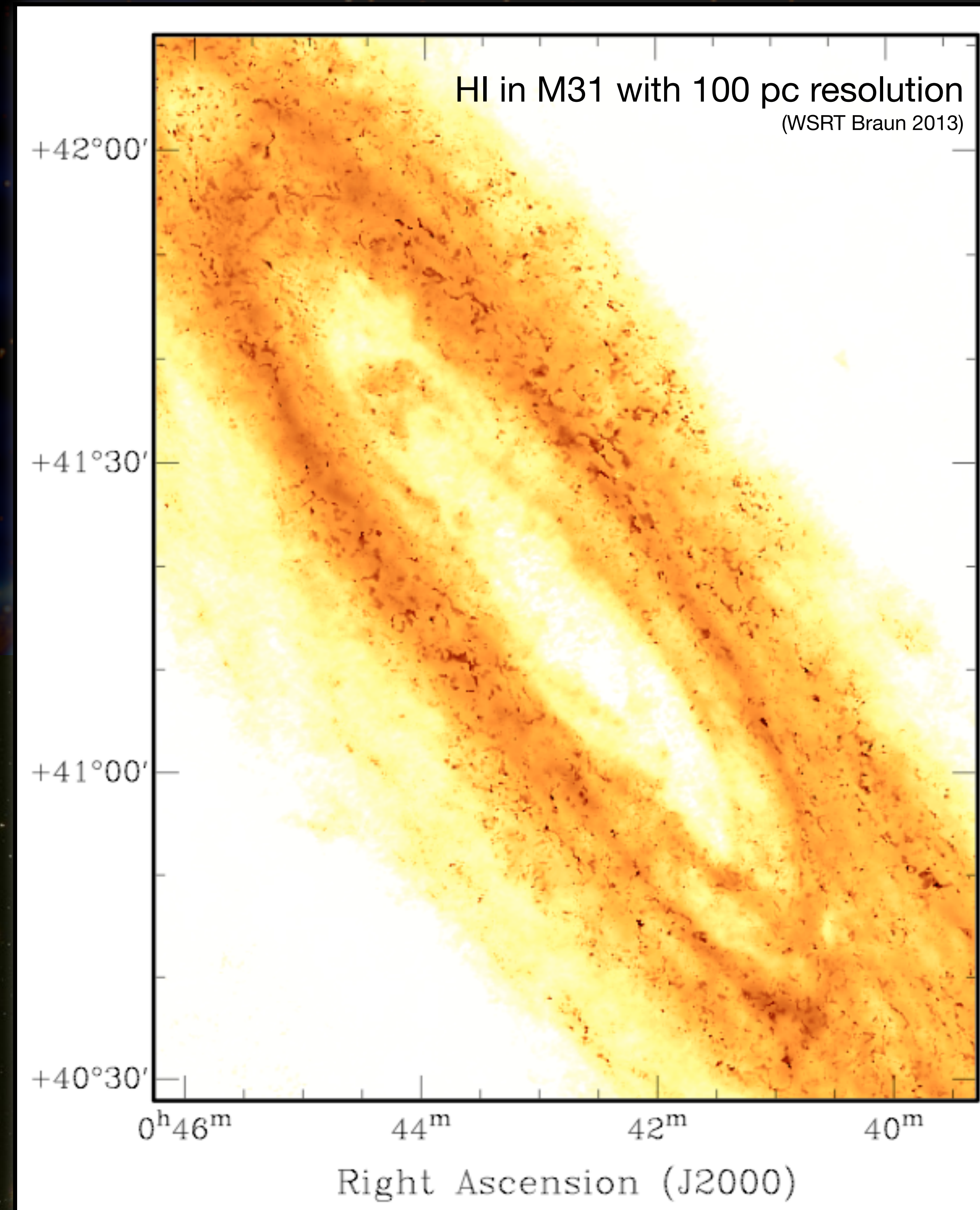
HI rich early-type galaxies in
low-and high density field

- **ISM in nearby galaxies, the Milky Way and the Magellanic Clouds**

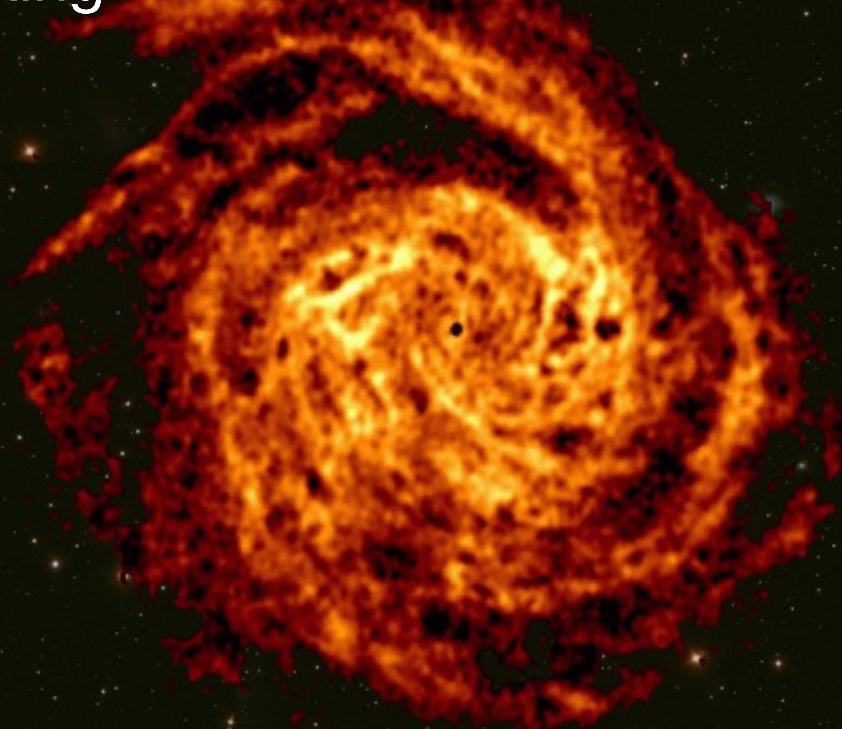
  at high-spatial resolution (< 500 pc) to study the physics of the ISM and star formation, below scales where statistical relations (KS-law) break down and simulations cannot (yet) go. Detailed view of the gas cycle in the MW (emission and absorption)

  Work at few arcsec resolution in targeted nearby galaxies

- The synergy with ALMA for this kind of work is very exciting



SKA1 out to 10 Mpc



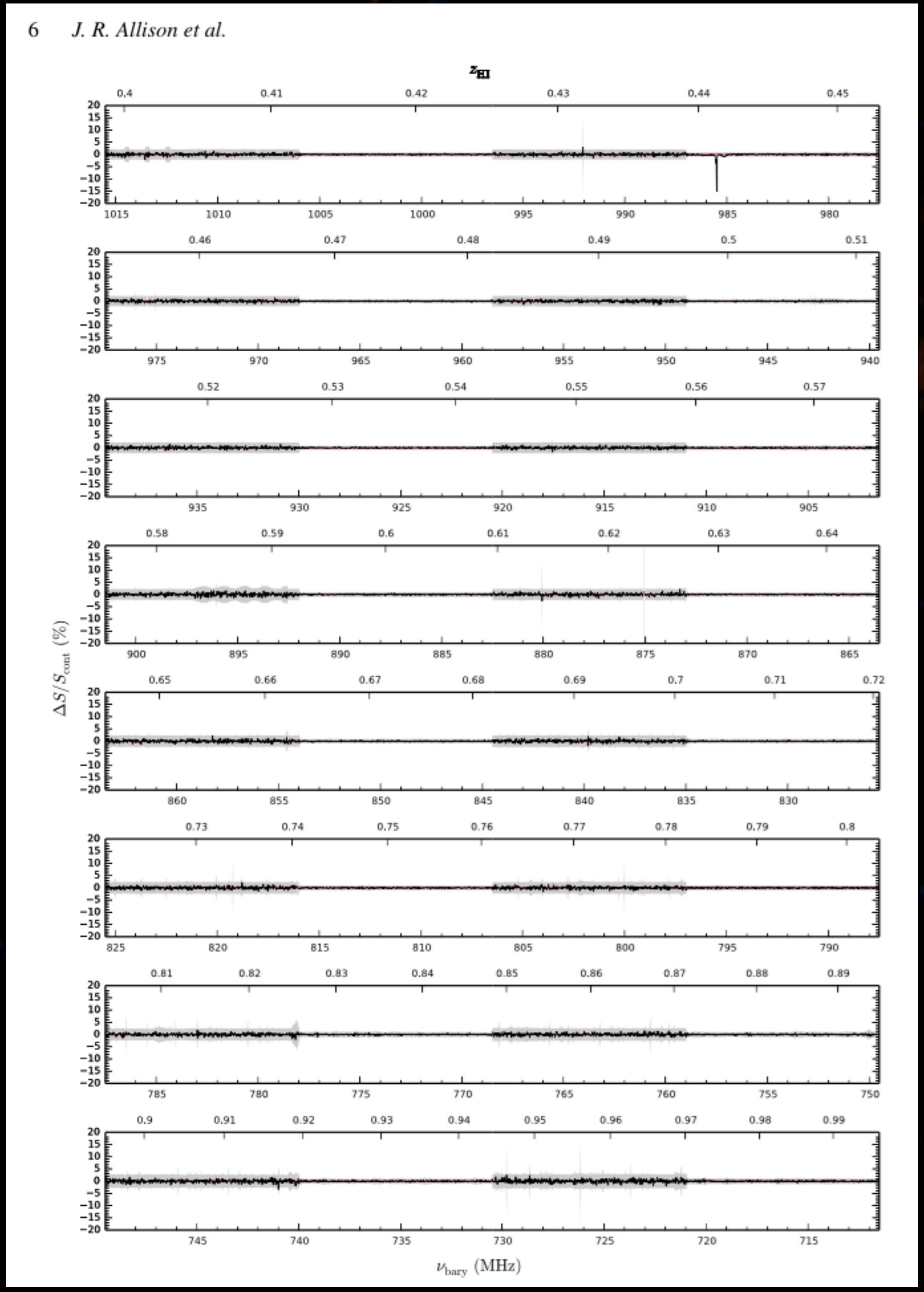
pre-SKA1

N6946 (Boomsma+ 2005)

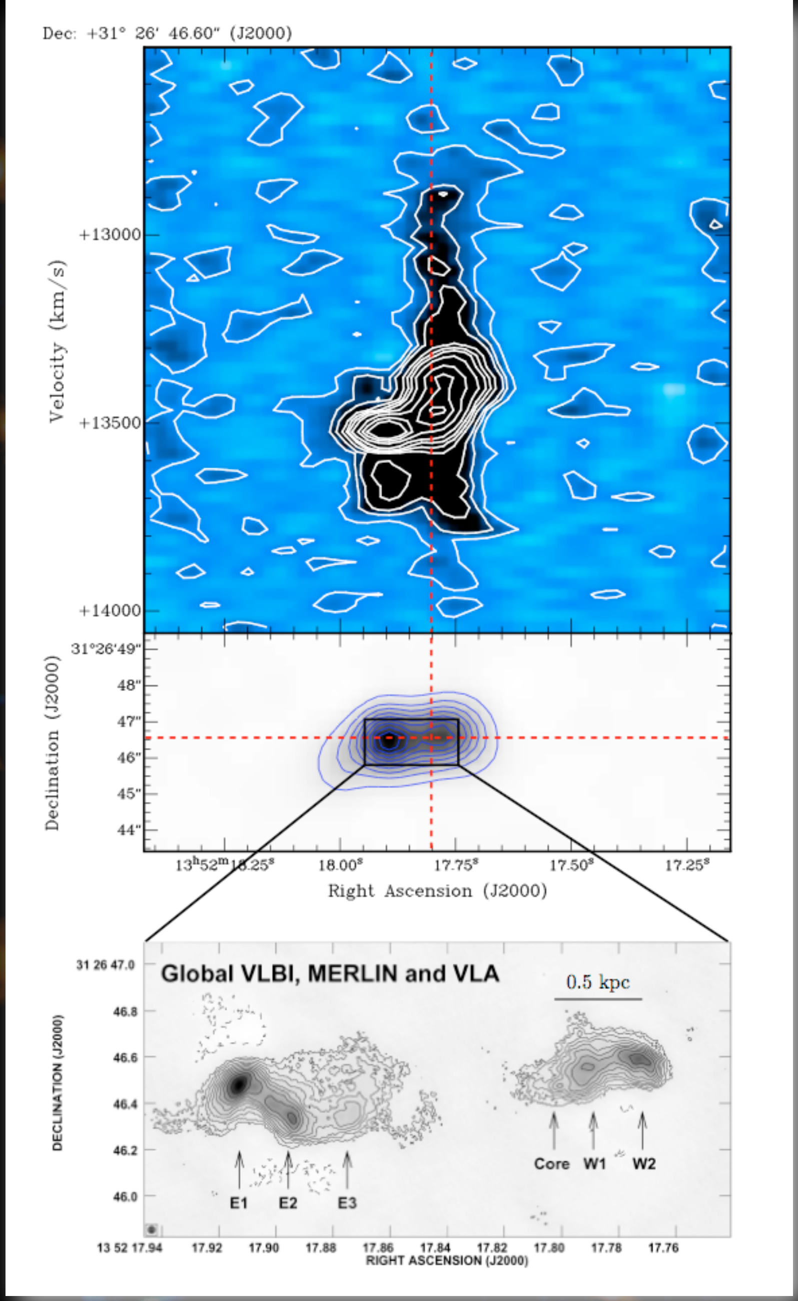
HI absorption in and in between galaxies

- Role of AGN feedback in galaxy evolution
- Evolution of cold ISM

Progress possible by:
- higher spatial resolution: locate where the outflow is occurring,
- explore to the highest redshifts for the first time
  so large surveys have to be done in Band 1 and with SKA1-Low



HI absorption at z = 0.44
ASKAP, Allison+ 2015



AGN driven outflow of HI in 3C293

Mahony+ 2014

What drives the survey parameters?

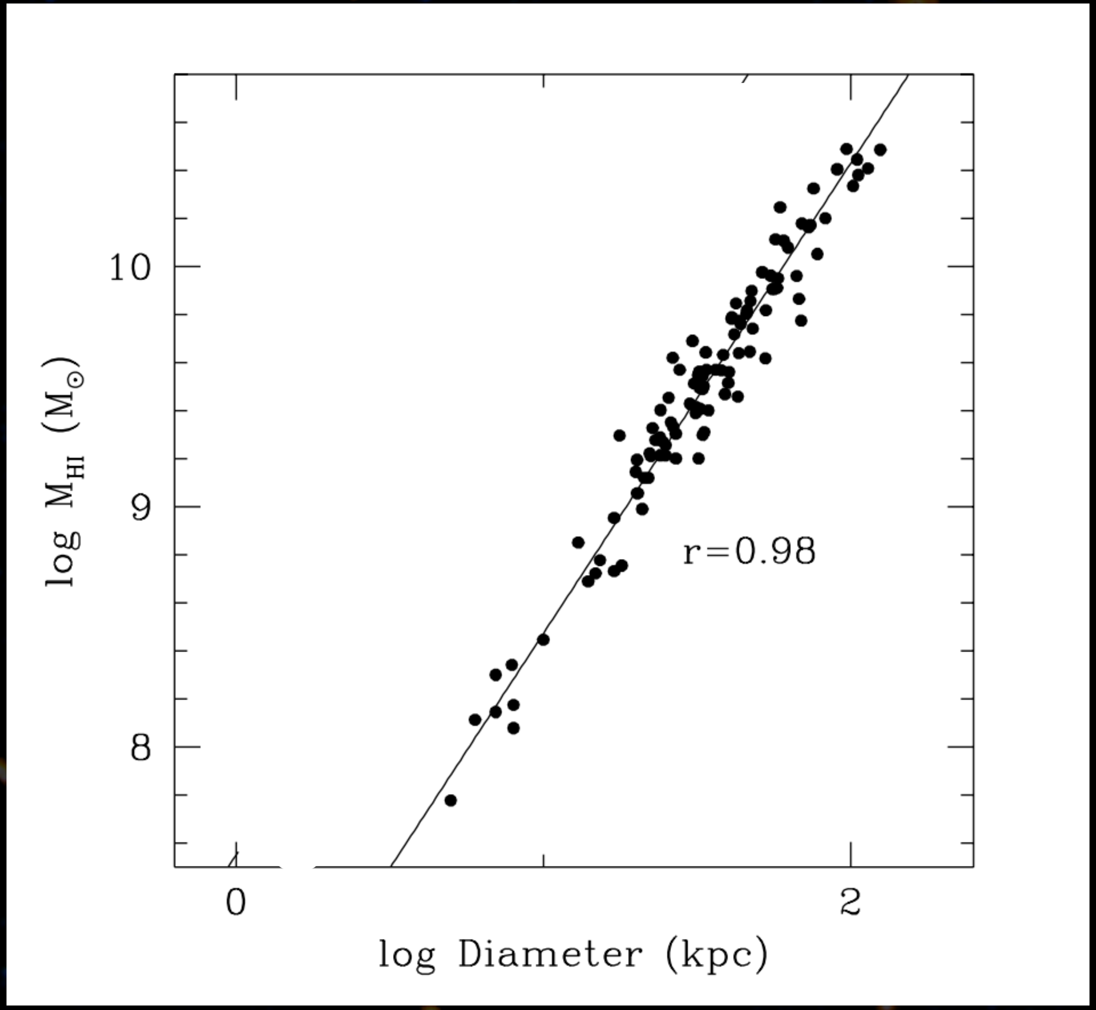
Much of HI science is about column density sensitivity

HI mass is strongly correlated with galaxy area

$$M_{\rm HI} = 10^{6.5-6.7}\, D_1^2$$

all (spiral) galaxies have the ‘same average column density’
and
‘galaxies of a given HI mass have the same size’

Higher sensitivity means you can better resolve galaxies,
or resolve them out to larger distances



Broeils & Rhee 1997

Resolution is the key aspect for HI science with SKA1

Trade-off between survey parameters like area and depth per pointing is between
how many galaxies I can resolve in what detail, out to which redshift

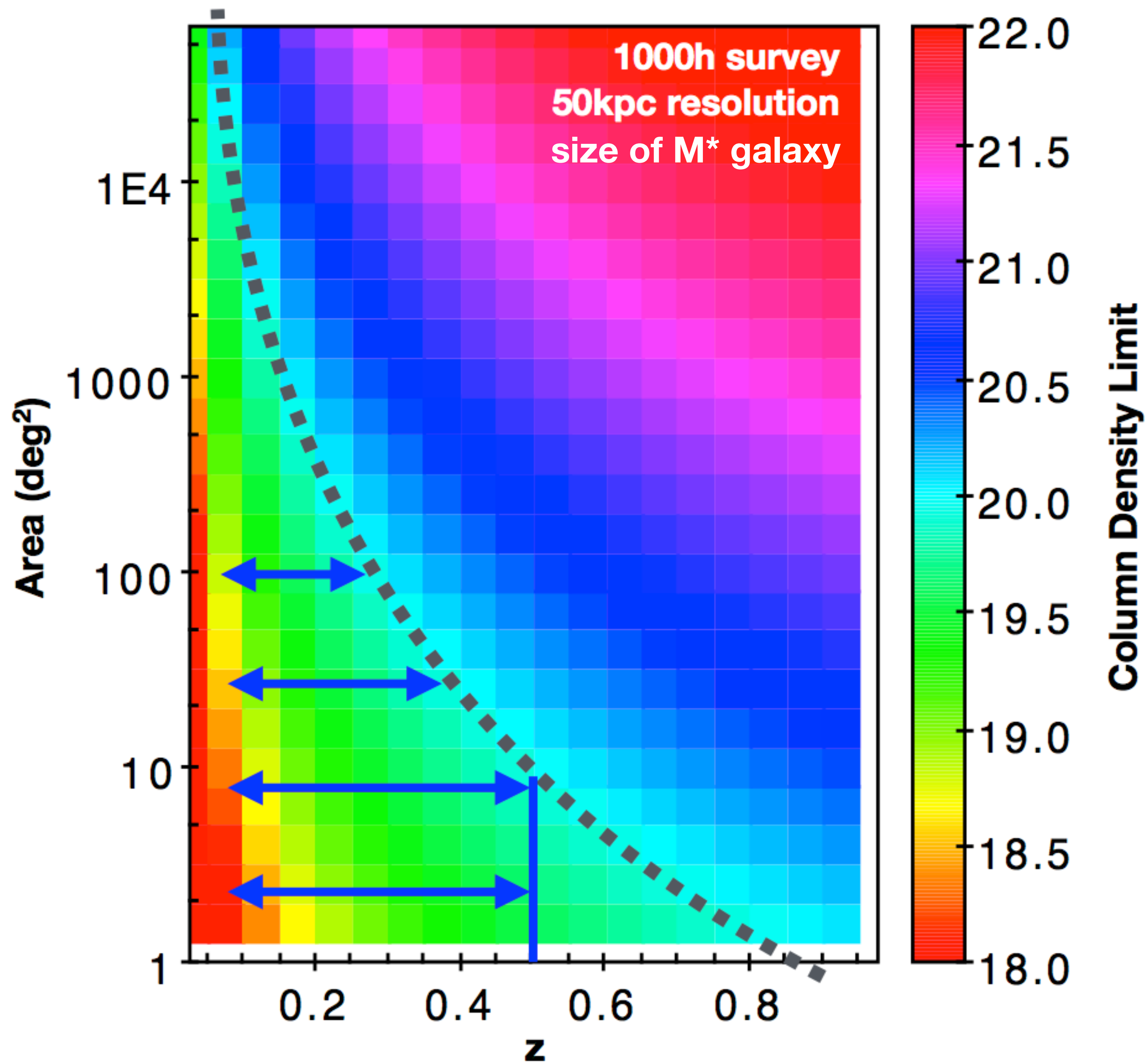
How to choose survey parameters?

Requirements

- Want to observe HI down to at least galactic scales
- SKA observation time is limited (~1000h KSPs)
- Time+beam+z+area sets column density limit
- Need $n_{HI} > 10^{20}$

Preferred Surveys

- **band 2: ~10→100 deg²**



Similar plot for Band 1: only single pointing is interesting

this is our current thinking

Survey	Area (deg²)	Freq MHz	HI Resolution	<z> (z_{lim})	T (hrs)
Medium wide	400	950-1420	10"	0.1 (0.3)	2000
Medium deep	20	950-1420	5"	0.2 (0.5)	2000
Deep	1 pointing	600-1050	2"	0.5 (1)	3000
Targeted ISM	30 targets	1400-1420	3"-30"	0.002 (0.01)	3000
Targeted Accretion	30 targets	1400-1420	30"-1'	0.002 (0.01)	3000
Galaxy/MS	500	1418-1422	10"-1'	0 (0)	4.500
Galaxy Abs	(5000)	1418-1422	2"	0 (0)	(10.000)
Absorption	1000+	350-1050	2"	1 (3)	1,000+
	1000	200-350	10"	4 (6)	1.000

Result from Stockholm meeting

Updated from Staveley-Smith & Oosterloo, 2015, PoS, AASKA14, 167

Survey	Area (deg^2)	Freq MHz	T (hrs)	Magnetism	Cosmology/ EoR	Continuum
Medium wide	400	950-1420	2000		1000 sq deg 5000 hours weak lensing	similar strategy
Medium deep	20	950-1420	2000	100 deg2 tracing cosmic web, smilar depth		similar strategy
Deep	1 pointing	600-1050	3000	compatible; magn. plans wider		useful only if in band 1
Targeted	30 targets	1400-1420	3000	good match in sample, res and depth		
Targeted (Accr)	(30 targets)	1400-1420	(3000)	fully commensal with ISM Accretion		
Galaxy/MS	500	1418-1422	4500	commensal with Galaxy + Magn WG to get optimum 1200 deg2 and 11500 hours		
Galaxy Abs	(5000)	1418-1422	(10000)	fully commensal with “Galaxy/MS”, continuum, magnetism		
Absorption	1000+	350-1050	1,000+	all sky, optimum commensality if band 1		
	1000	200-350	1.000		fully commensal 5000 deg2 absorption survey	

Stockholm summary

and commensal with medium-wide HI band 2

Very good potential overlap in survey parameters

‘all-sky’ should be done in Band 1, not Band 2 (also should consider RFI)

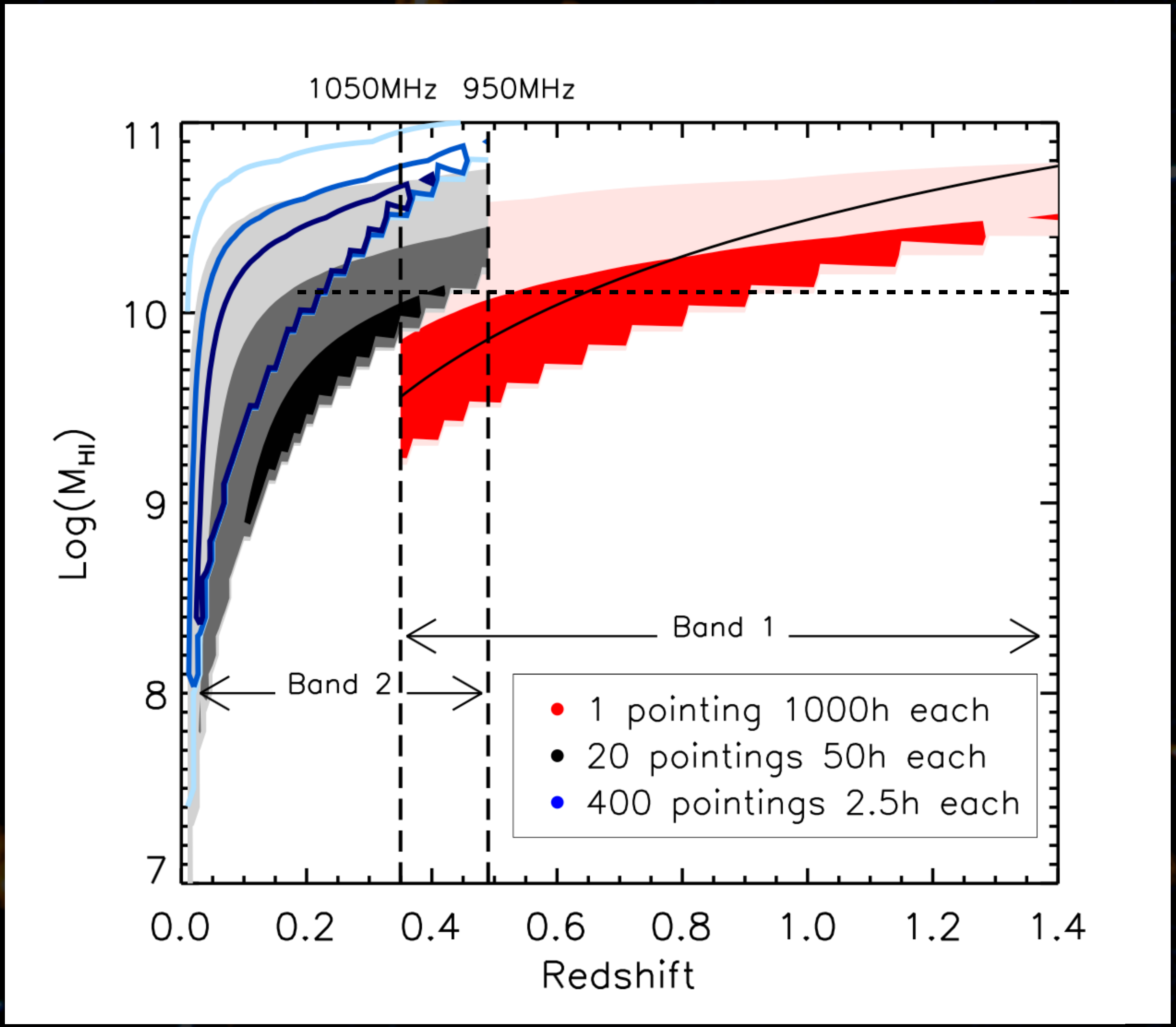
Should engage in common studies to refine this

How to make a wedding cake?

Use Natasha's recipe!!!!

What is the optimum combination of shallow, medium-deep and deep HI surveys?

given a total observing time

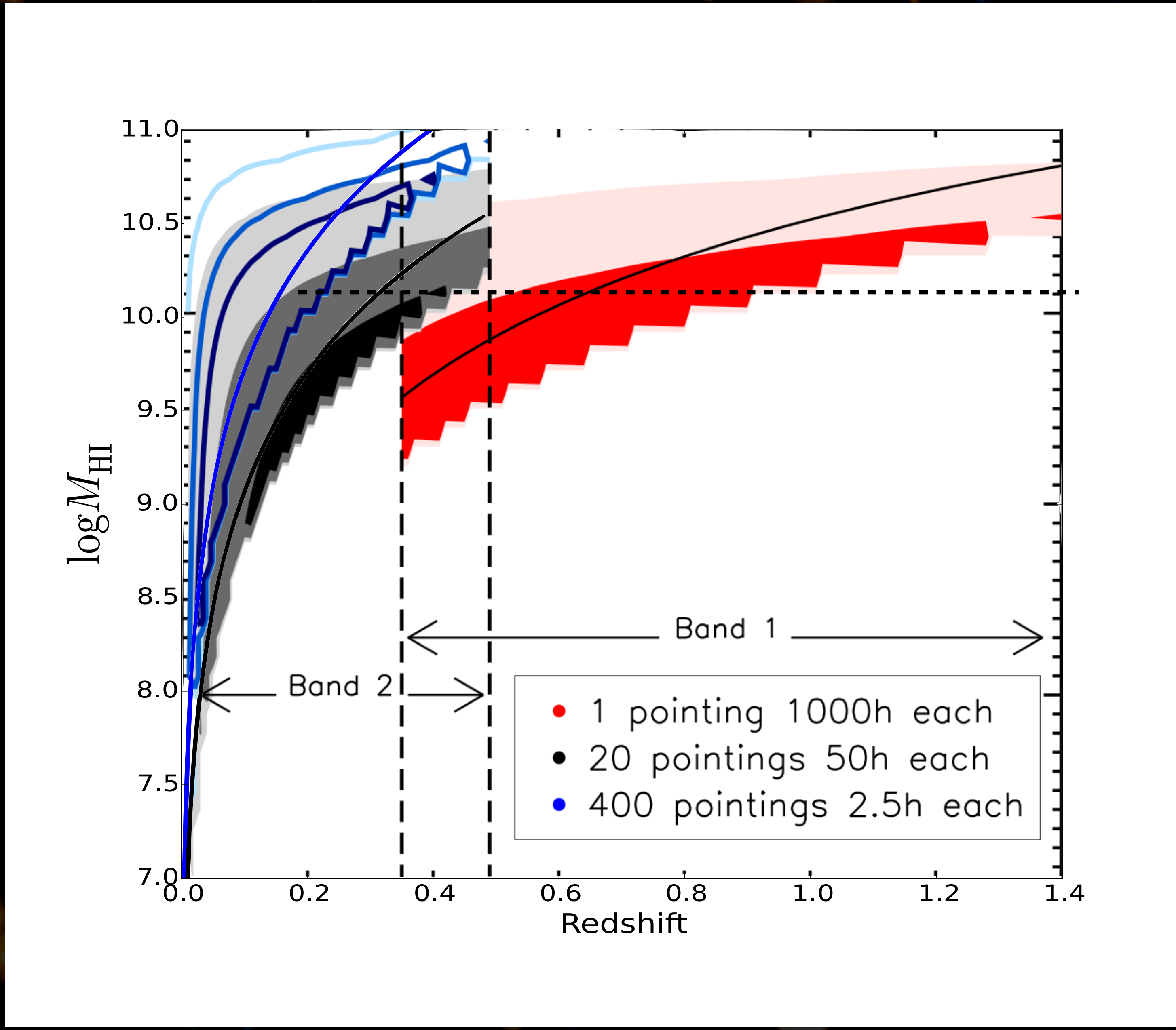


Look at combined coverage of z - M_{HI} plane and find optimum combination by varying survey parameters

What is the optimum combination of shallow, medium-deep and deep HI surveys?

given a total observing time

also considering that one would like to resolve objects



parameter space that is unique to large-area shallow survey for HI emission at low redshift is relatively limited.
Would give ‘deep’ view of local Universe but not worth to do the whole sky

Shallow survey over very large area (>1000 deg^2) in Band 2 is not on our priority list.
Much better to do in Band 1: HI absorption out to large redshift.

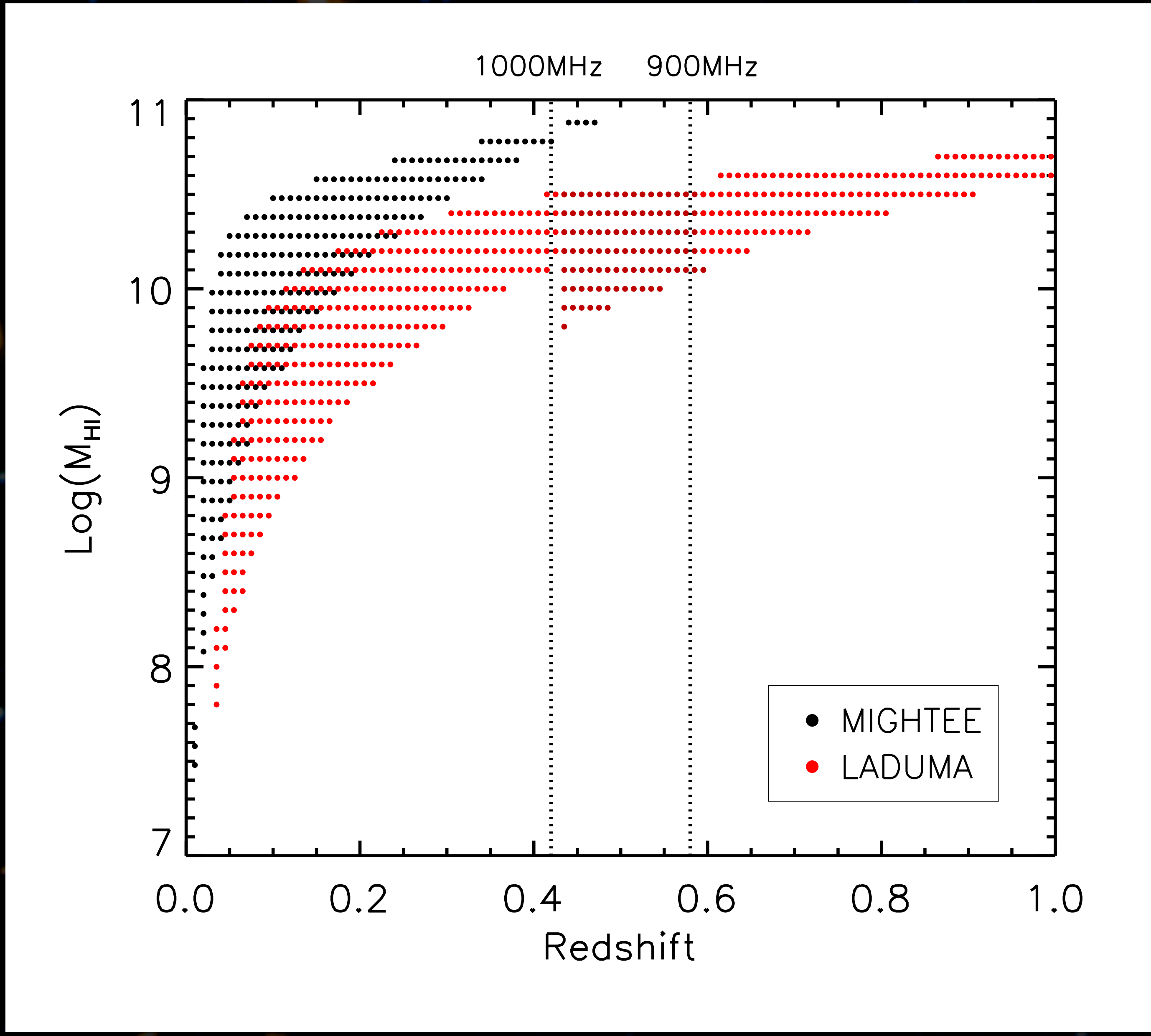
How things can work out well

Continuum survey Mightee
and HI survey Laduma on MeerKat

complement each other very well for HI!!!

This is by to some extent by accident (…)
but ‘luck is the residue of design’

We should make this analysis for
combined continuum and HI surveys



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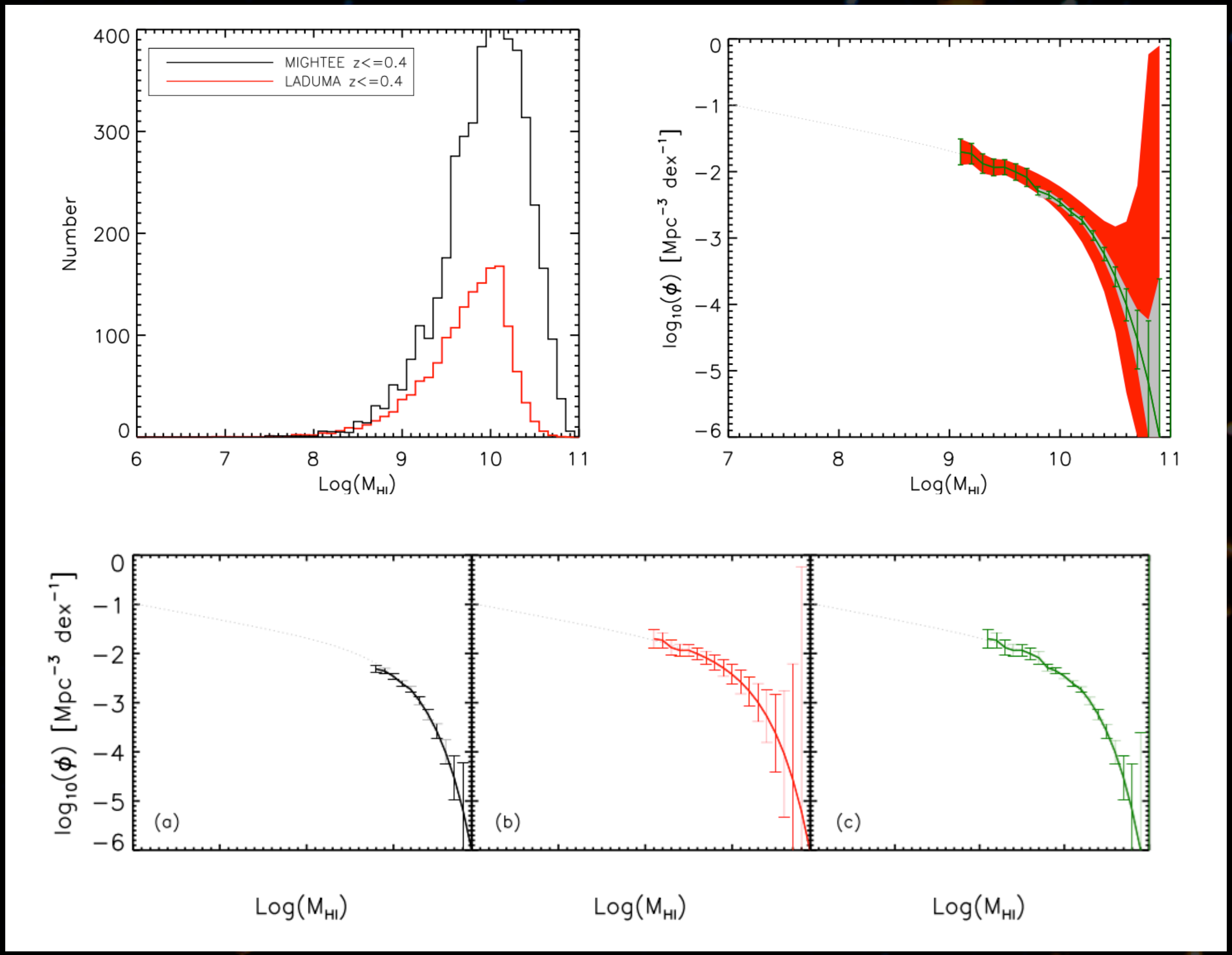

Combined HI mass function of Mightee and Laduma illustrates the value of commensal surveys

Conclusion

~ 5000 hr per year available on both Mid and Low for ALL surveys combined

⇨ perhaps 1000 hr per year specifically for HI work (or for continuum, or …)

Very significant potential for commensal surveys (i.e. > 1000 hr/year)
shallow (if Band 1), medium wide, medium deep and deep (if Band 1), targeted, MW

Should engage in joint studies to refine this

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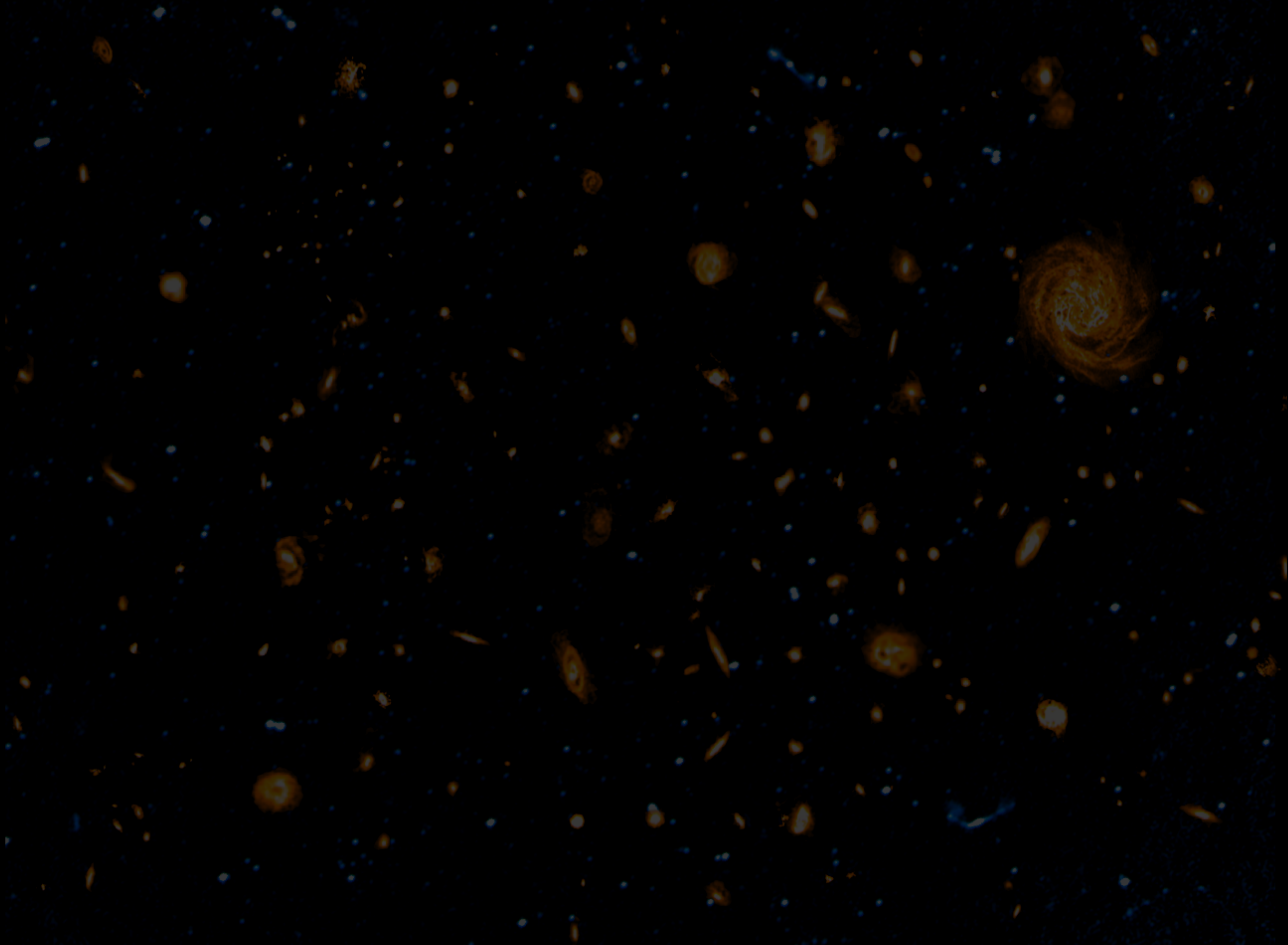

RFI in the Karoo