Something Old, Something New, Something Borrowed , Something Blue

Multi-wavelength Spectroscopic Surveys in the (pre-)SKA Era

Luke Davies

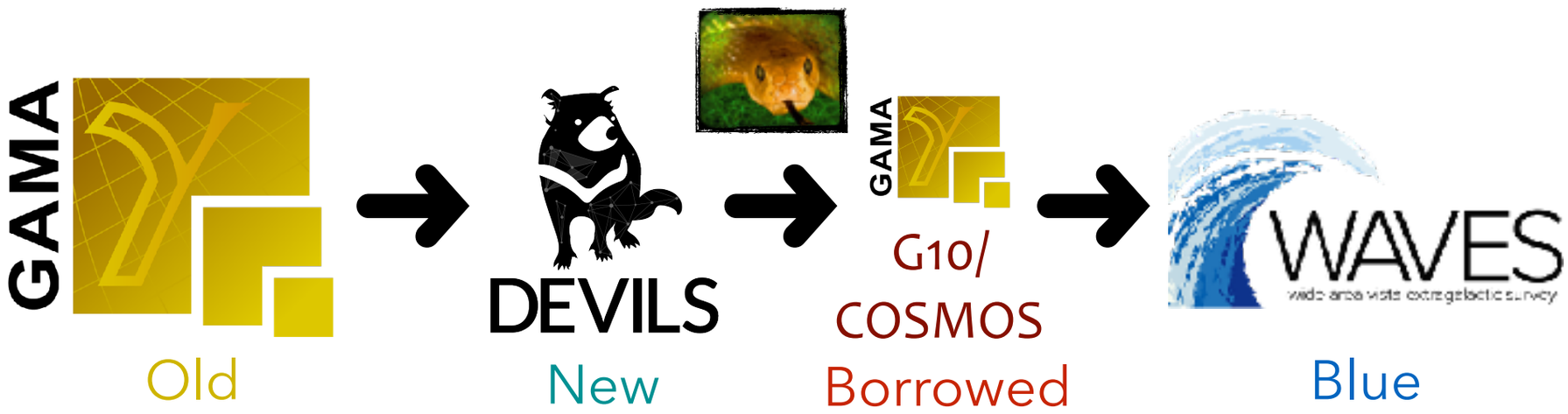
GAMA, G10 lead, DEVILS PI, WAVES PS

Old, New, Borrowed, Blue

- The SKA and precursors will produce produce a wealth of radio data, over the southern sky.

- To maximise the science potential of this data we require auxiliary multi-wavelength and spectroscopic observations

  - Australia is leading the world multi-wavelength spectroscopic galaxy evolution surveys:

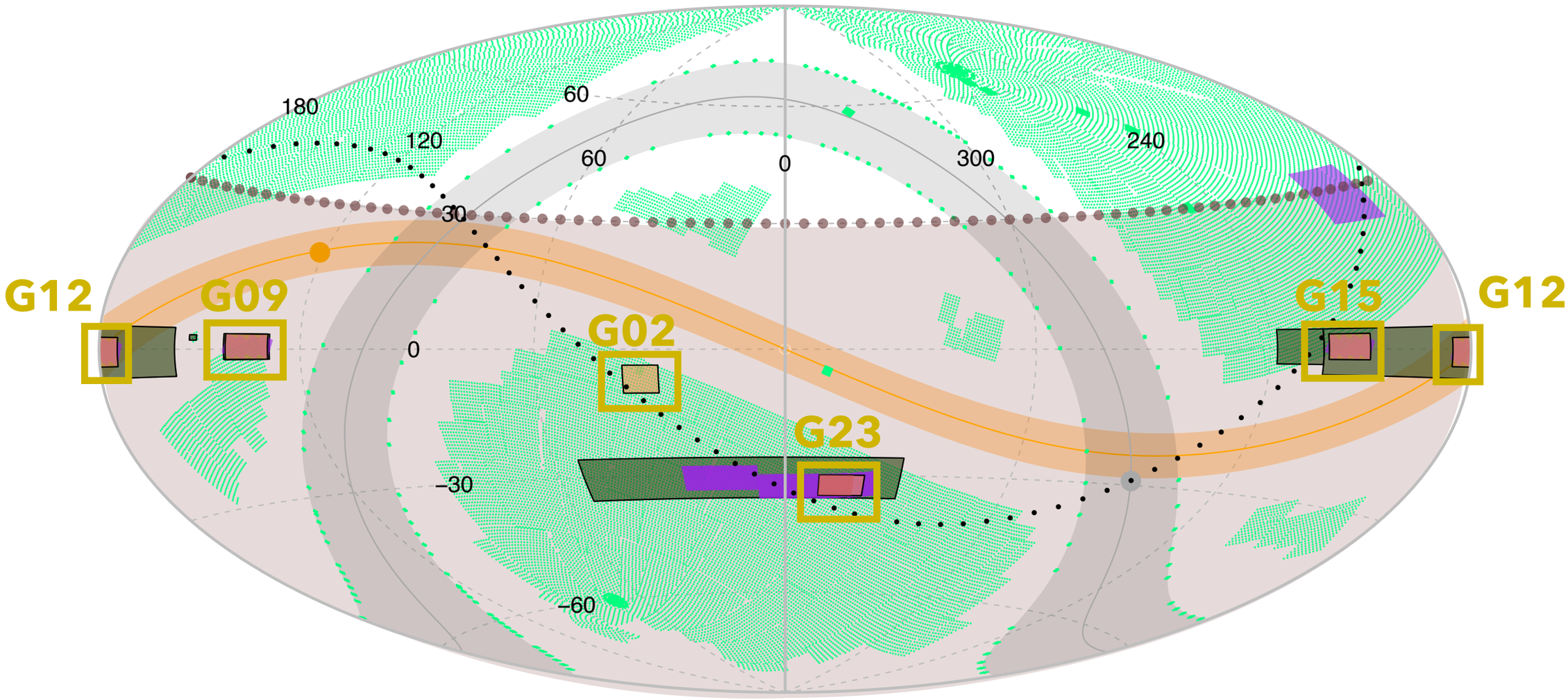


(note, I am going to focus on synergy with these deep small ➜ medium area projects c.f. Taipan, WISE, LSST, eROSITA… for full hemisphere)

Galaxy And Mass Assembly Survey

- ~300,000 galaxies with spectroscopic redshifts
- r-mag < 19.8 to >98% completeness
- Covering ~286deg^2 over 3 equatorial and 2 southern Field
- Extensive multi-wavelength coverage on 21-bands and derived properties (stellar mass, SFR, bulge-disc decomposition, morphology,….)
- Robust group and pair catalogue for environmental metrics

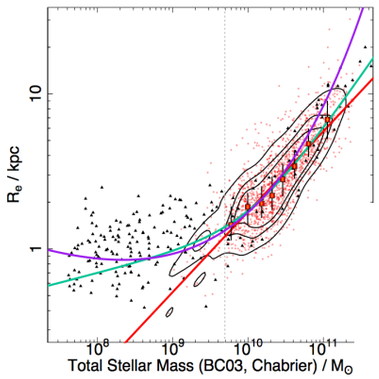
Galaxy And Mass Assembly Survey



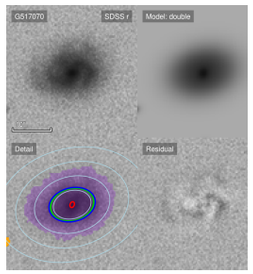
www.astromap.icrar.org

Galaxy And Mass Assembly Survey

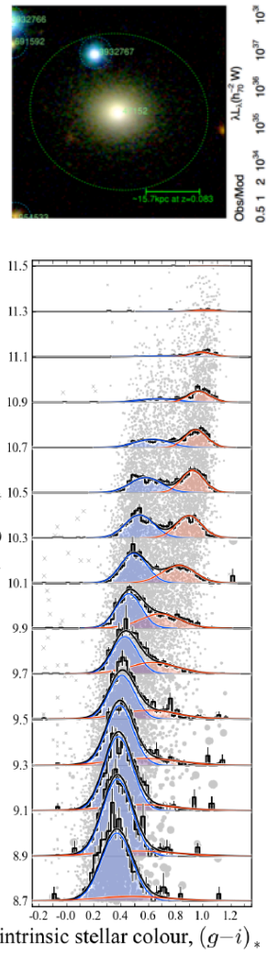
- Tonnes of GAMA data description and science papers - Driver et al (2013,2015), Hopkins et al (2013), Liske et al (2015)….



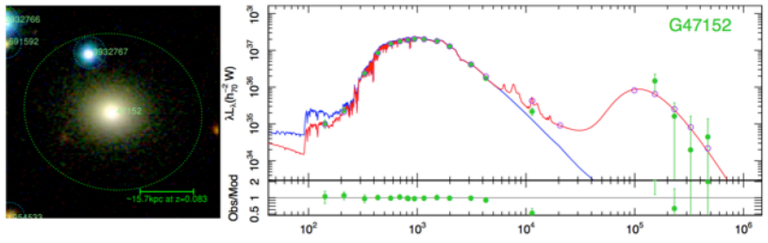
Mass-size relation



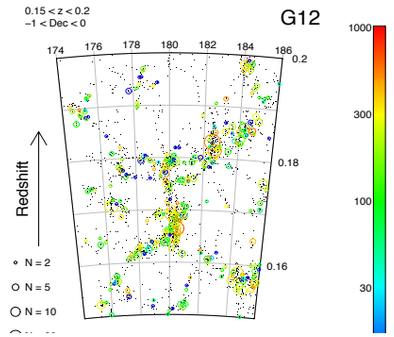
Bulge-disc decomposition



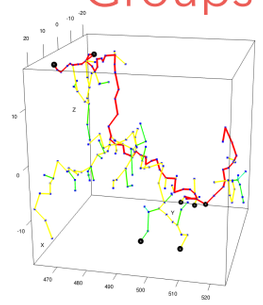
Galaxy Bimodality



SED modelling

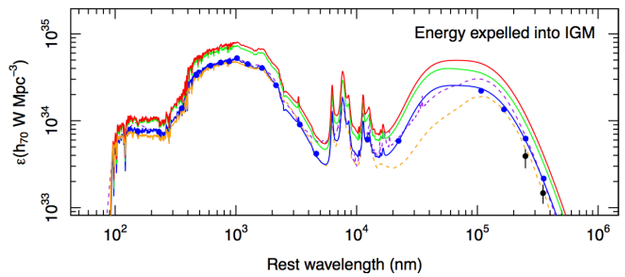


Groups

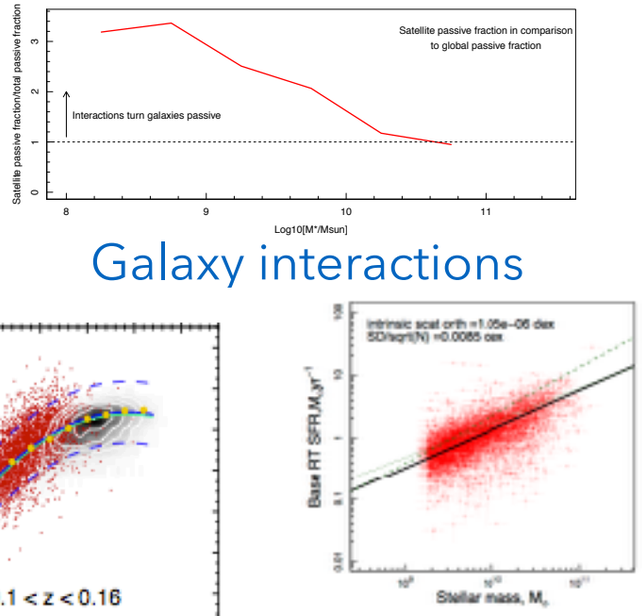


LSS

Mass-metallicity relation

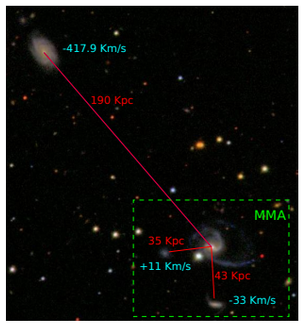


Cosmic SED

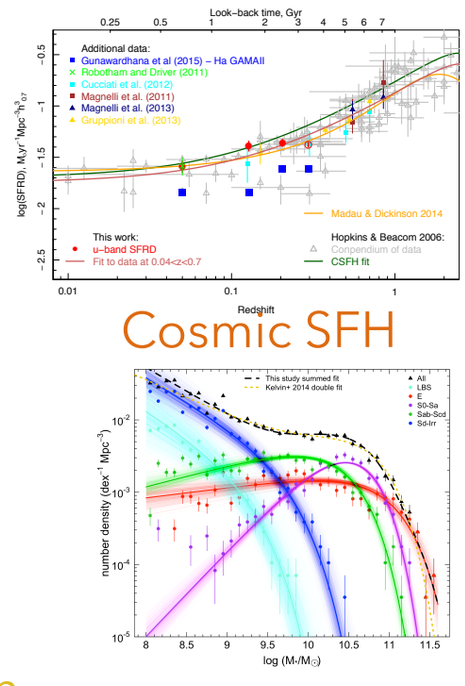


Galaxy interactions

SFR-M* Relation

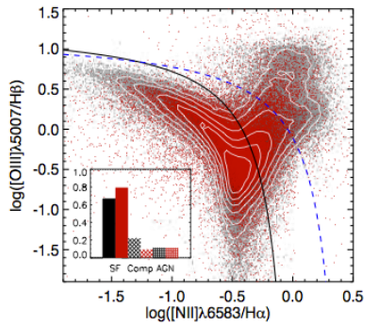


Local Group Analogues



Cosmic SFH

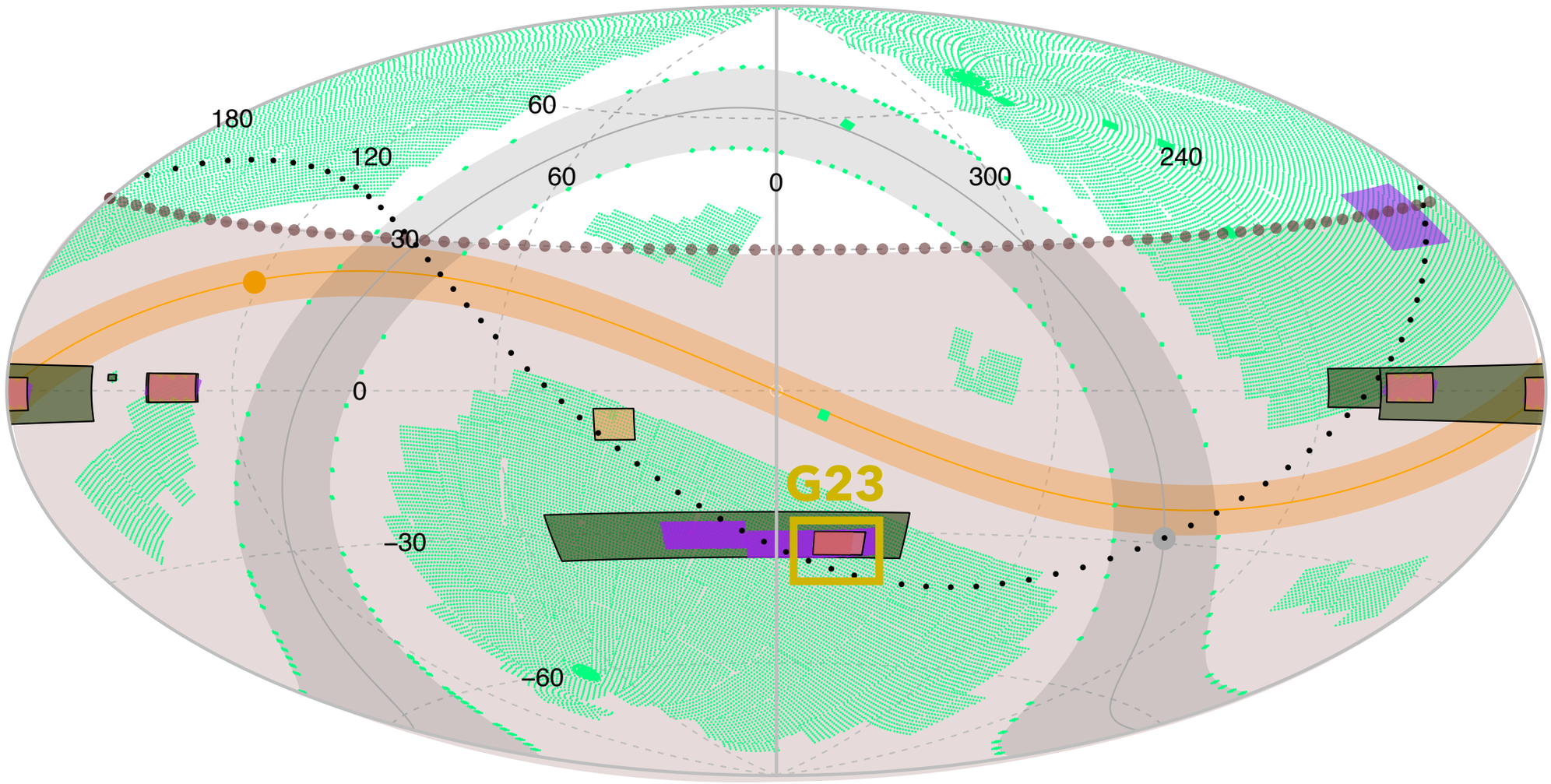
Stellar Mass function



AGN

http://www.gama-survey.org

Galaxy And Mass Assembly Survey



www.astromap.icrar.org

GAMA 23h Field

- The G23 field is rapidly becoming one of the most well studied fields in the southern sky:

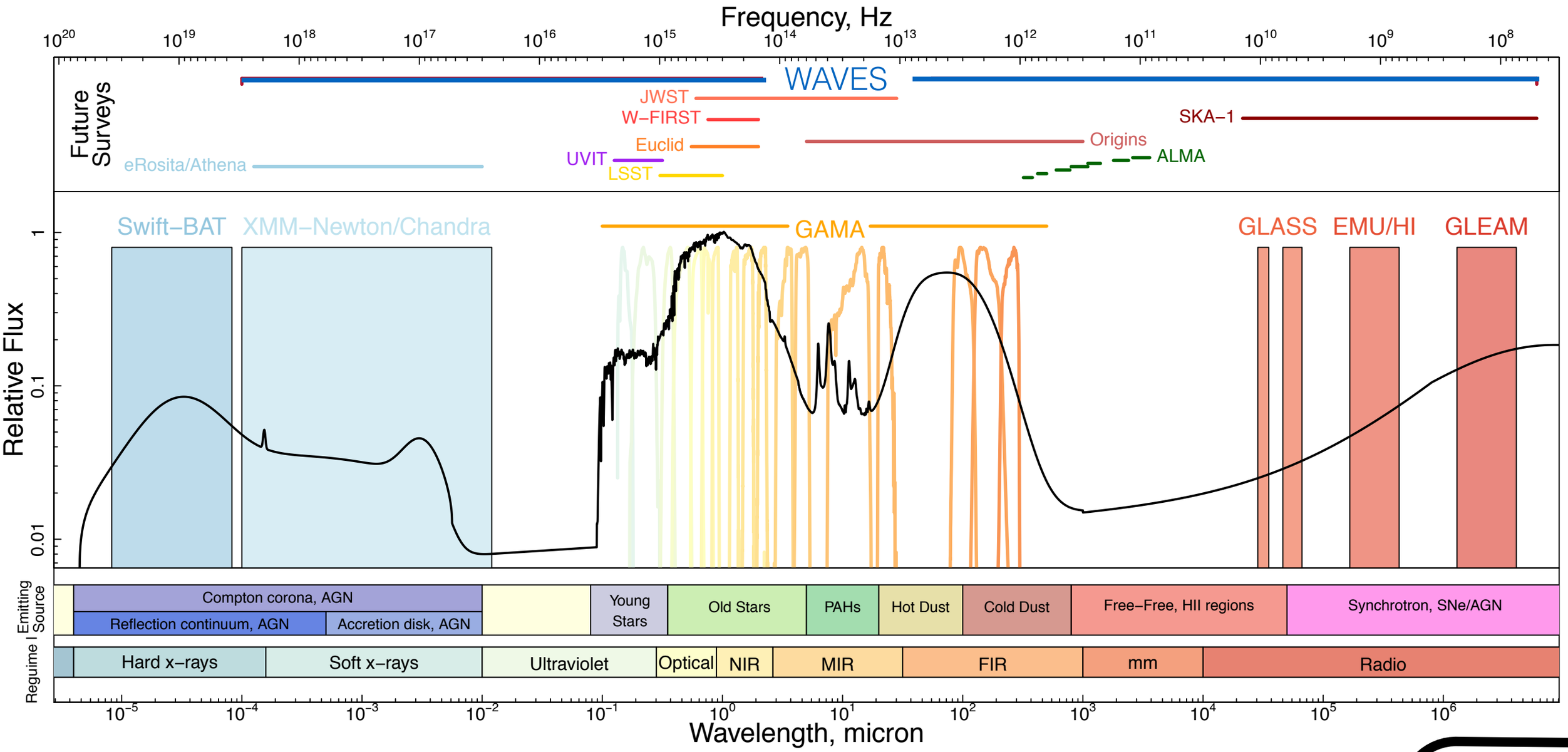
	Existing:	Ongoing:	Future:
X-ray			eROSITA (proposed early targeting)
UV	Deep GALEX		UVIT?
Optical	KiDS		LSST
NIR	VIKING	SHARKS (deeper Ks band)	Euclid (Legacy Program)
MIR	WISE		
FIR	H-ATLAS		
Radio Cont		GLASS/EMU-ES /GLEAM	EMU/GLEAM-X
Radio HI			DINGO
High-res			Euclid/W-FIRST
Spectra	r<19.8 (>98% complete)		z<21.5 (>98% complete)

GAMA

WAVES

GAMA 23h Field

- G23 multi-wavelength coverage:

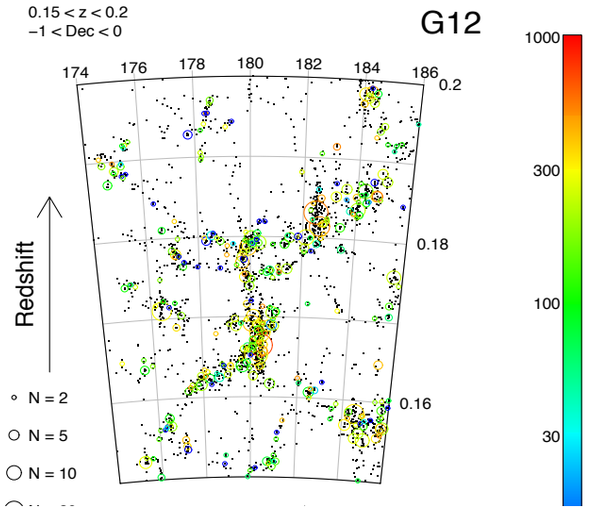


GAMA 23h Field

Davies et al - GAMA +FIRST
Parcy et al - GAMA/WiggleZ +FIRST

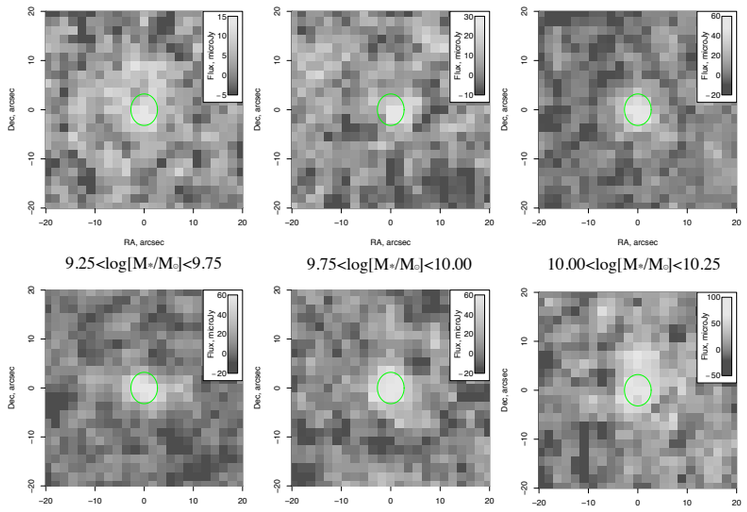
- Groups and pairs for environment effects:

Robotham et al (2012)



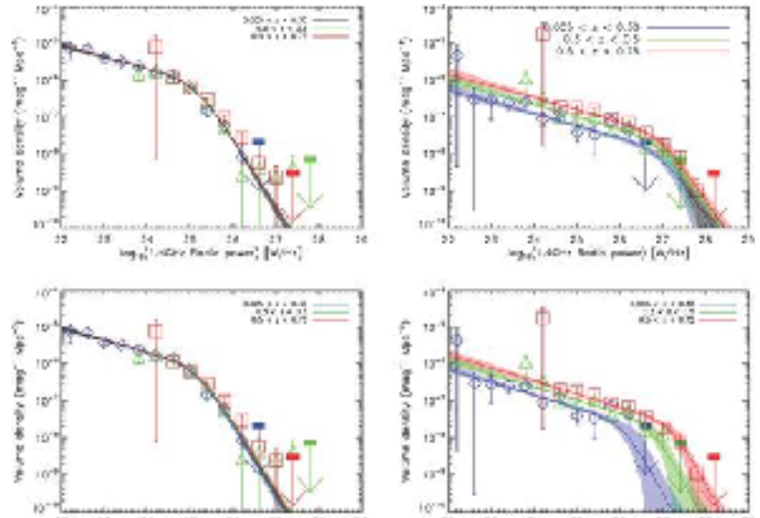
- Large stellar mass selected samples for stacking:

Davies et al (2017)



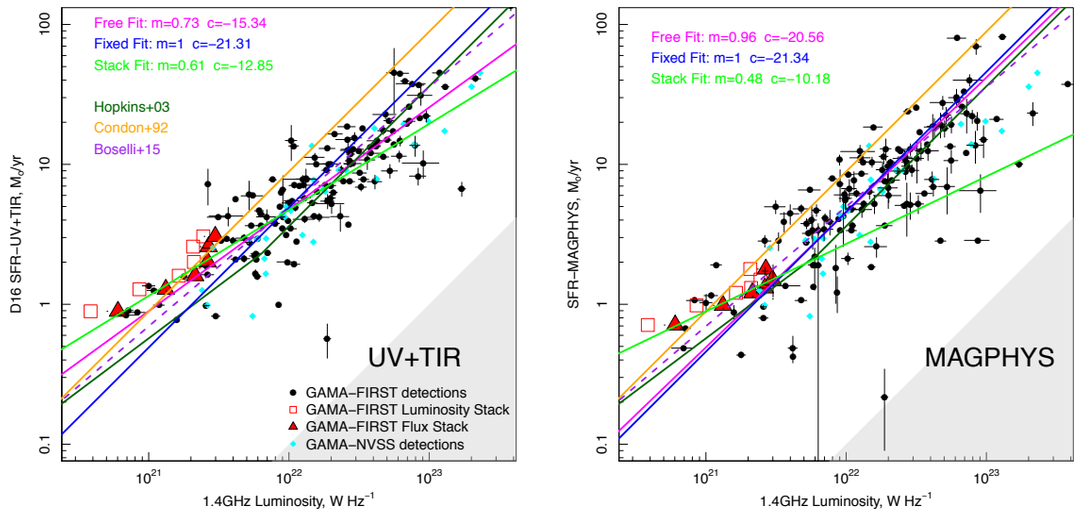
- 1.4GHz Luminosity function evolution

Parcy et al (2016)



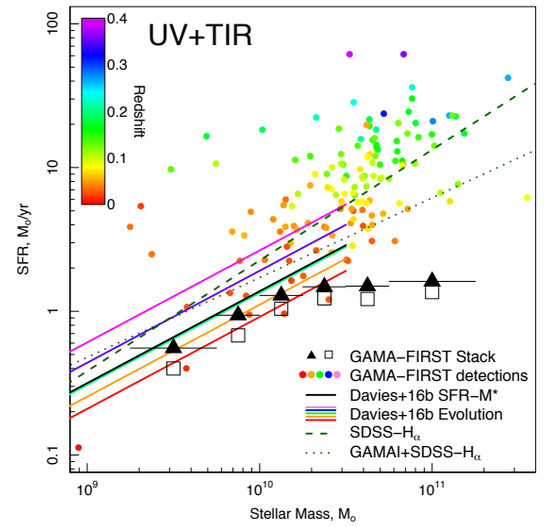
- Multiple SFR diagnostics for comparison to radio continuum (SF timescales):

Davies et al (2017)



- Stellar/Dust masses + HI for baryonic mass function, radio SFR-M* relation:

Davies et al (2017)



Going Further Than GAMA

Survey such as…..

… have provided a wealth of information about the galaxies and structure in the local Universe.

In order to go beyond this we can either:

- Probe out to higher redshifts and explore the formation of the fundamental relation observed by GAMA and SDSS

- Probe to fainter limits to extend the relations of observed by GAMA and SDSS to lower stellar and halo masses

Going To High-z

Many of the fundamental trends observed by SDSS/GAMA, such as…..

- Fundamental galaxy scaling realtions (SMF, SFR-M*, M*-M_{HI}…)
- Environmental trends (morphology-density, SFR-density,…)
- Distribution of DM halos (Halo Mass Function, merger rates…)

…. were forged at z>0.3

We have (somewhat) robustly parametrised these relations at z~0:

There is also currently a large focus on determining these relations at high-z (z>1):

GAMA

SDSS

WAVES Wide

ZFOURGE Fourstar Galaxy Evolution Survey

COSMOS

Prime Focus Spectrograph SJMIRe

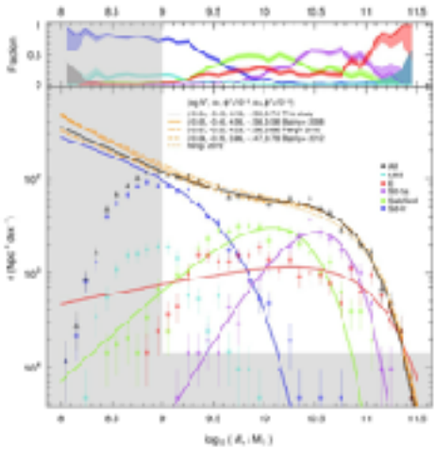
Maunakea Spectroscopic Explorer

However there is a paucity of well sampled, complete and statistically robust surveys at intermediate redshift. (0.3<z<1)

Going To High-z

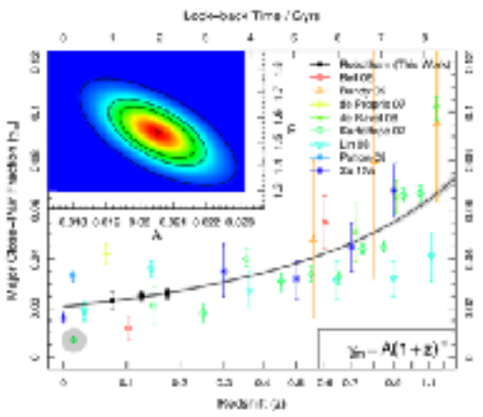
This is a key epoch in the formation of these fundamental relations:

Moffet et al.



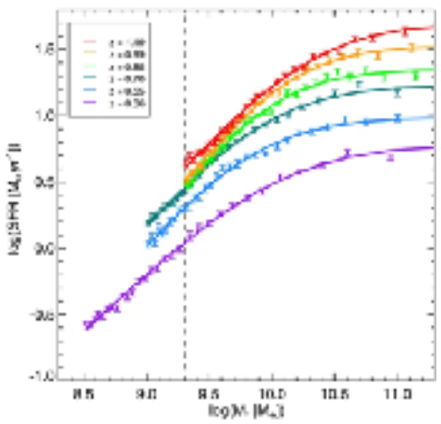
Various components of SMF assembled

Robtoham et al.



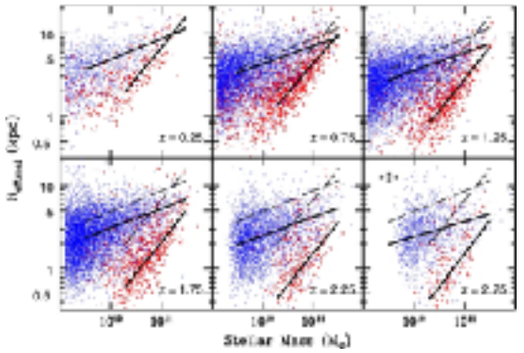
Major merger rates evolve dramatically

Lee et al.



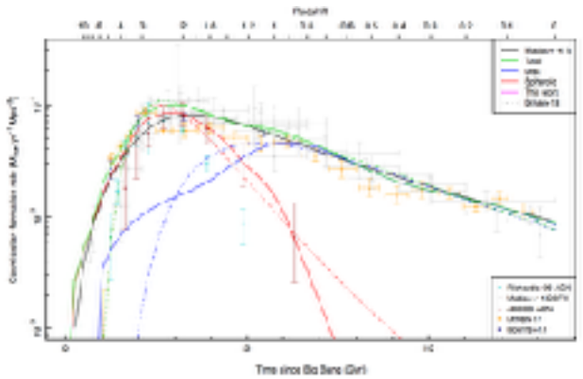
The SF-MS evolves in slope and normalisation

van der Wel et al.
+ Lange et al



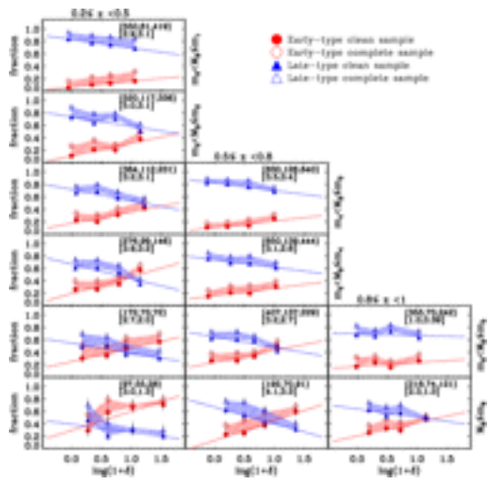
Size-mass relation evolves

Andrews et al.



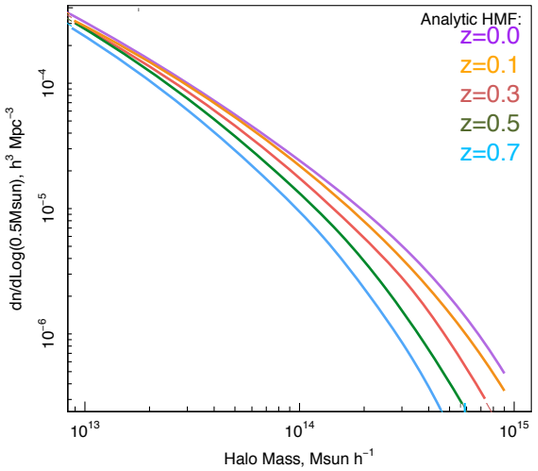
Disc growth begins to dominate over spheroid growth

Tasca et al.



The environmental density relations reverse

Murray et al

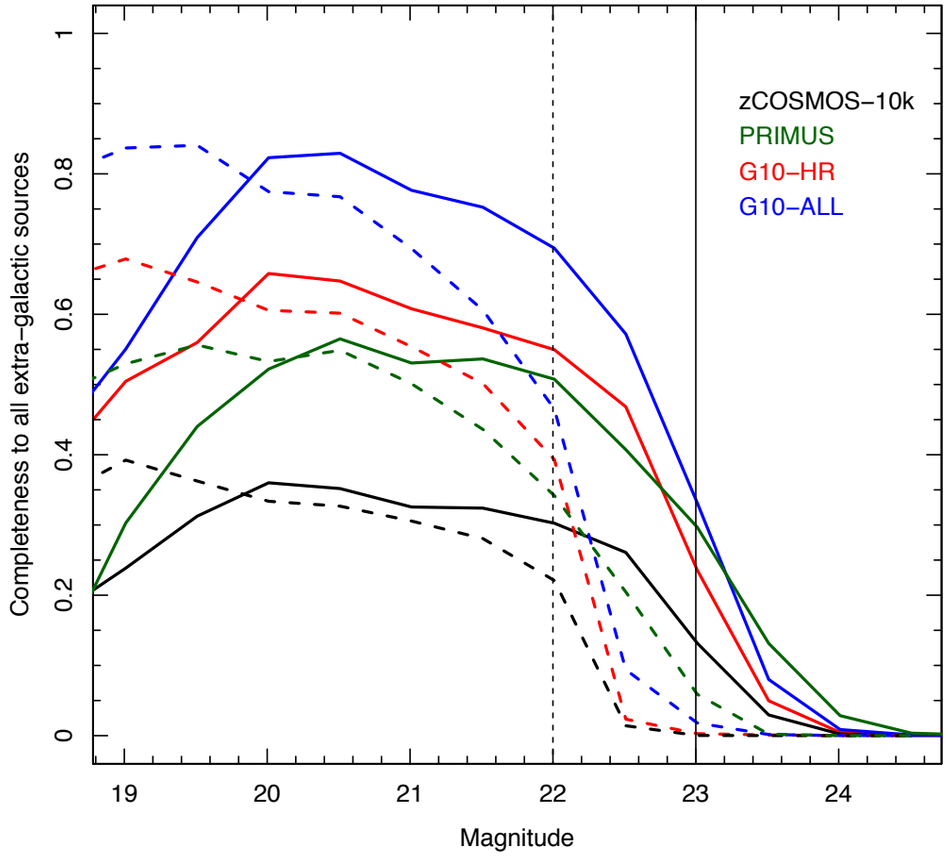


ΛCDM predicts a strong evolution of the high mass HMF

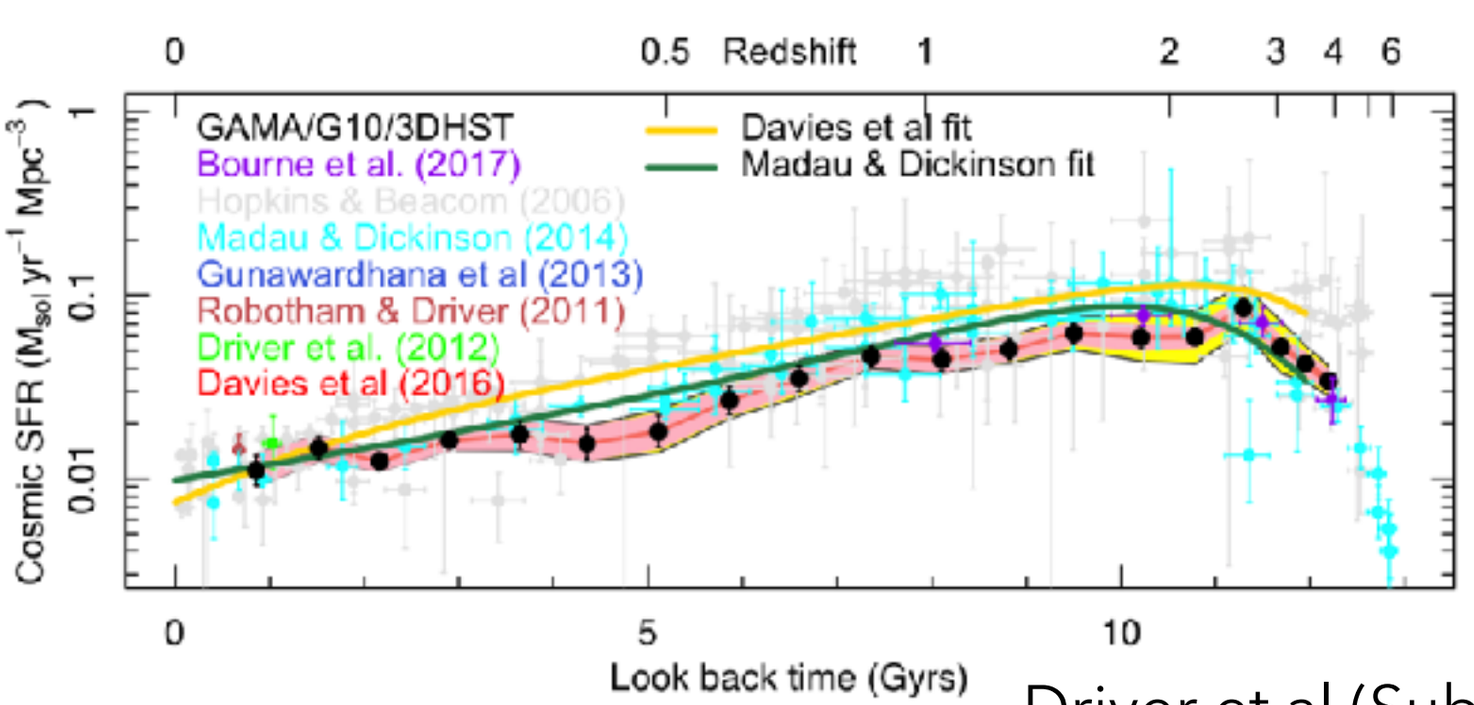
…. also this is the epoch where the next generation of HI/continuum surveys will probe (EMU, LADUMA, MIGHTEE, DINGO…. SKA)

"Borrowing" Redshifts

- The initial stages of our expansion to higher-z came from a re-analysis and curation of spectra in the COSMOS region (Davies et al. 2015) - mainly zCOSMOS
- We then also performed GAMA-like photometric analysis (Stephens et al. 2016) and MAGPHYS SED fitting on the sample (Driver et al MNRAS submitted)



Davies et al (2015)



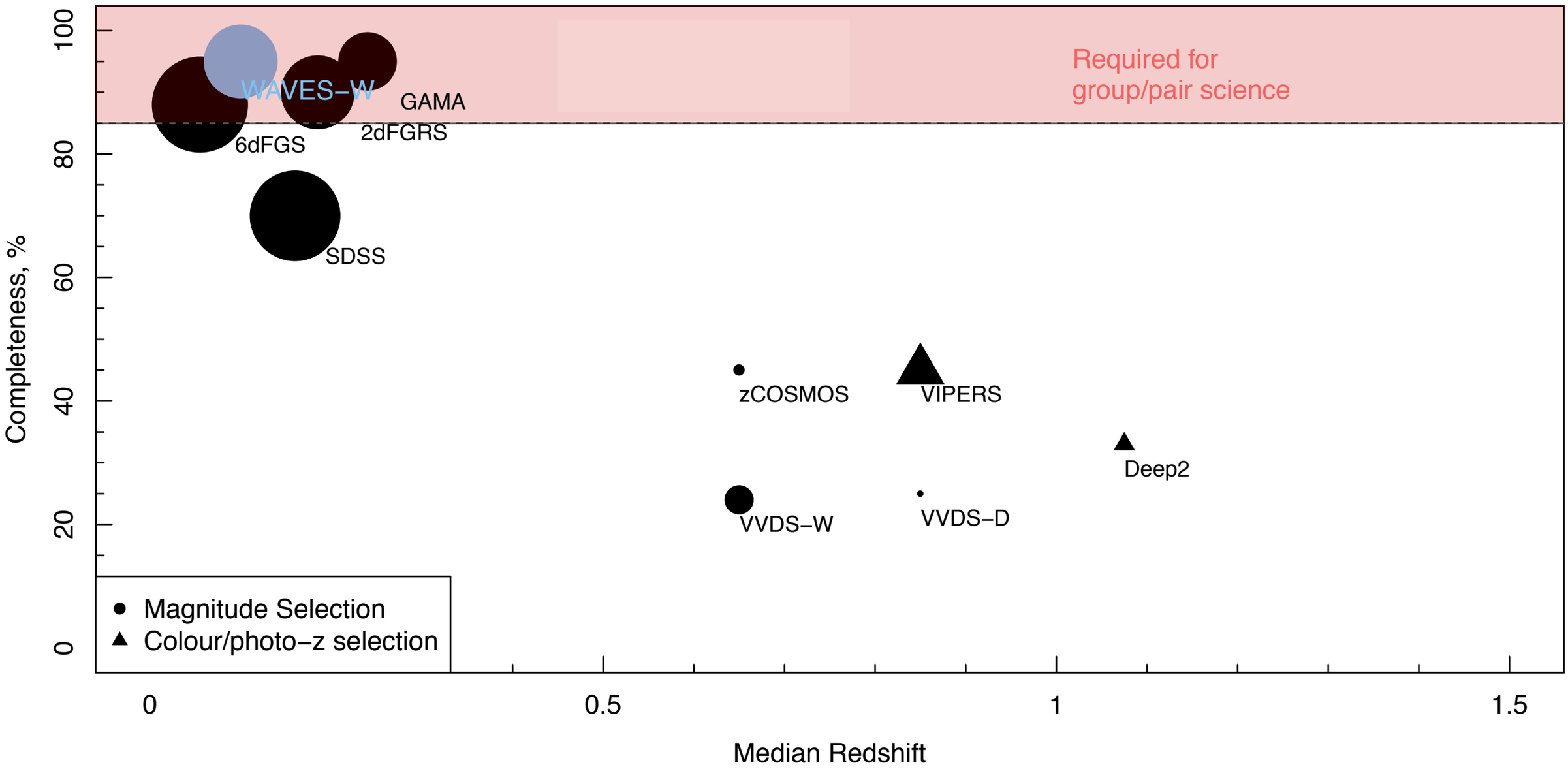
Driver et al (Sub)

G10/ COSMOS

- ~16,000 galaxies with spectroscopic redshifts
- i-mag < 22 to ~50% completeness
- Covering ~2deg^2 in COSMOS
- New photometric catalogue from 38 band photometry from LambdaR
- Full MAGPHYS runs of all galaxies for derived properties
- Covers CHILES region

Going To High-z

However, in order to perform the majority of GAMA-like science we require fully sampled populations (Groups/Pairs/Stellar Mass complete samples):



@devilsurvey

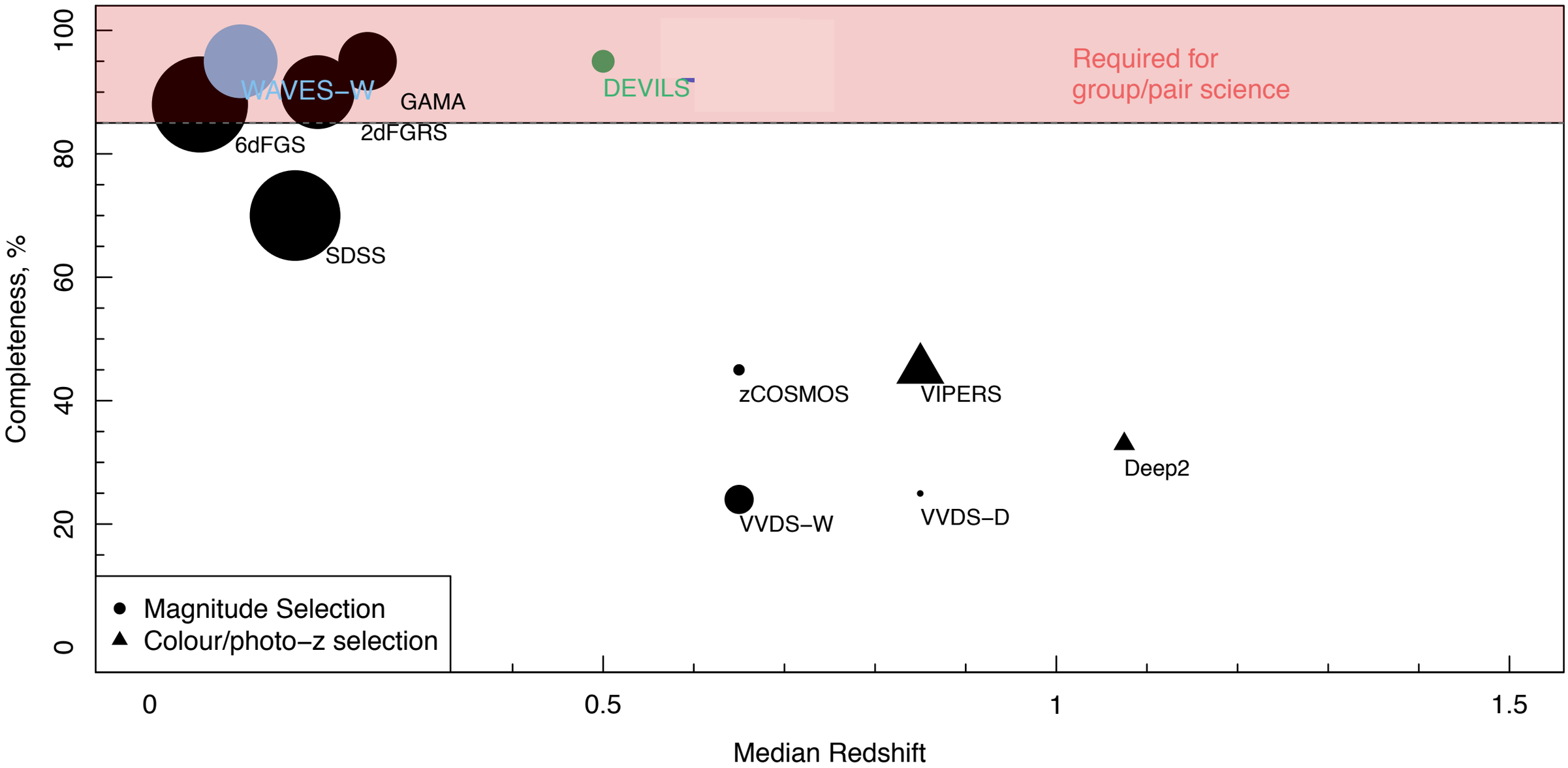
DEVILS

DEEP EXTRAGALACTIC VISIBLE LEGACY SURVEY

- Upcoming Large Program survey of ~60,000 galaxies with spectroscopic redshifts
  - Y-mag < 21.2 to >95% completeness
  - Covering ~6deg^2 in COSMOS, ECDFS, and XMM-LSS
- Extensive multi-wavelength coverage and derived properties (stellar mass, SFR, bulge-disc decomposition, morphology,….)
- Robust group and pair catalogue for environmental metrics
  - Covers CHILES, LADUMA, MIGHTEE, EMU-ES regions

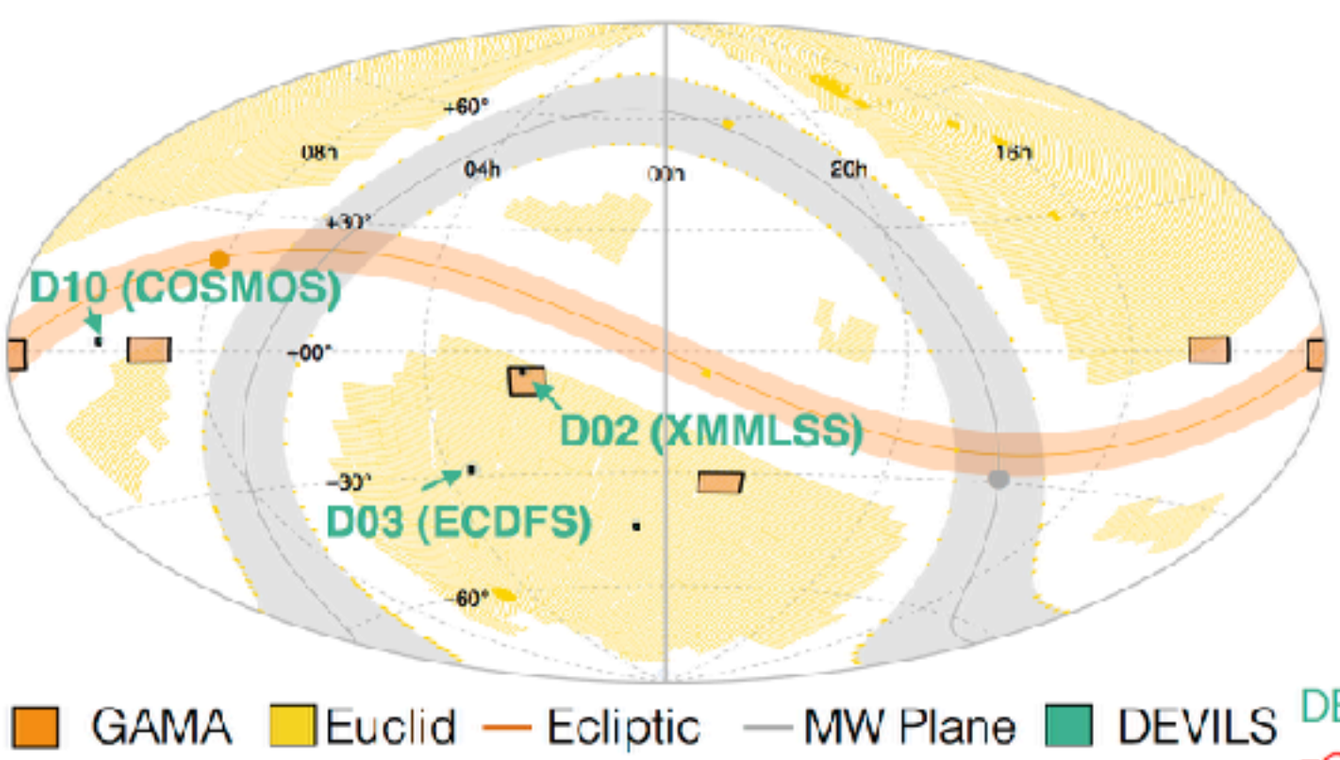
Deep Extragalactic VIsible Legacy Survey

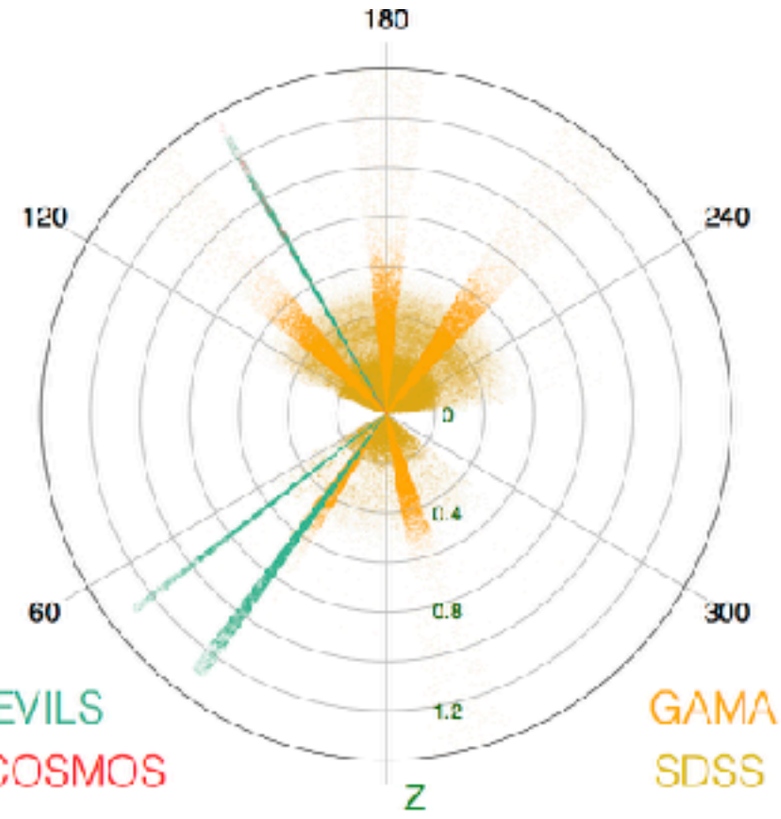
- DEVILS will perform GAMA-like science out to z~1:



Deep Extragalactic VIsible Legacy Survey

- DEVILS will target field with extensive existing or upcoming multi-wavelength and spectroscopic data
- Will piggy-back off exisiting spectra to reach >95% with minimal observing time (OzDES, zCOSMOS…)





- LSST deep-drill fields, VIDEO, SPLASH, XMM, MeerKat, EMU-ES….

DEVILS Science

- Formation the environmental trends we observe at z~0
- Formation the fundamental relations, such as the SMF
- Evolution of bulge, disk, bar and spiral arm components.
- Parameterisation of the late time evolution of the HMF predicted by ΛCDM

DEVILS field covered in deep HI (CHILES, LADUMA, MIGHTEE) and radio continuum (MIGHTEE, COSMOS-VLA, CHILESConPol, EMU-ES).

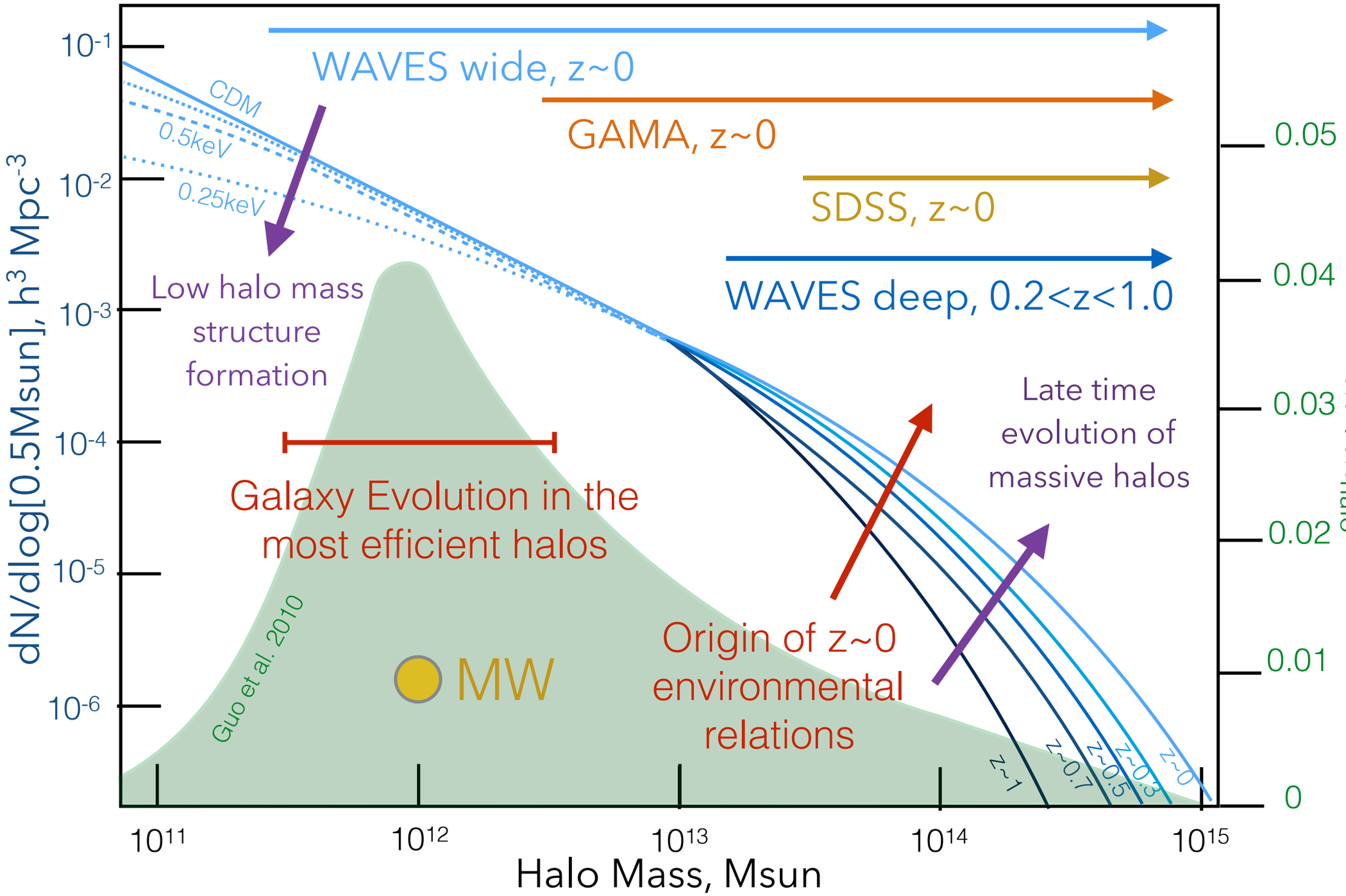
Redshifts for stacking, environmental metrics, SFR diagnostics…. Environmental effect on HI and robust constraints on gas and continuum emission in simulations. Also compiling extensive multi-wavelength database

Wide Area VISTA Extragalactic Survey

@wavessurvey

- Upcoming survey of 2M galaxies with spectroscopic redshifts
- Wide - Z-mag<21.5 & z_{photo}<0.2 | Deep - Z-mag<21.5 to >95% completeness
- Wide - ~1350deg^2 of KiDS/VIKING | Deep ~100deg^2 in G23 & ?
- Extensive multi-wavelength coverage and derived properties (stellar mass, SFR, bulge-disc decomposition, morphology,….)
- Robust group and pair catalogue for environmental metrics
- Wide -~1350deg^2 of WALLABY/EMU | Deep - aligned with DINGO

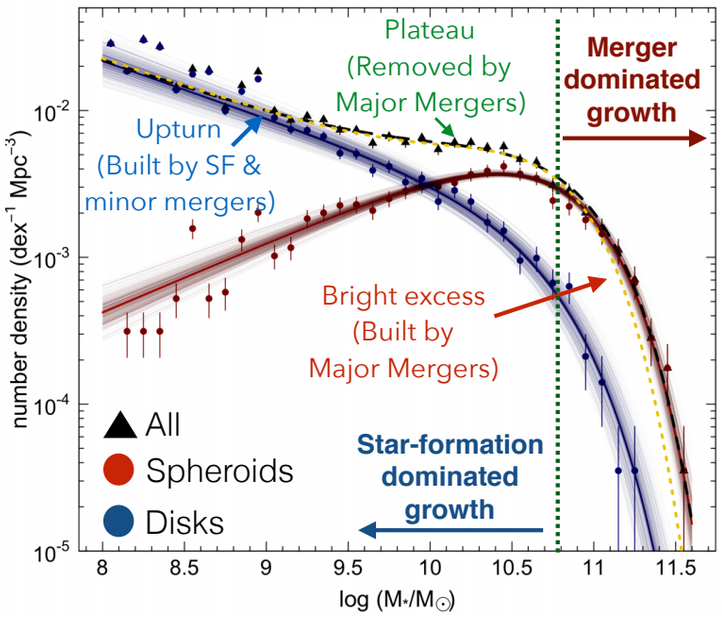
WAVES Science: Groups



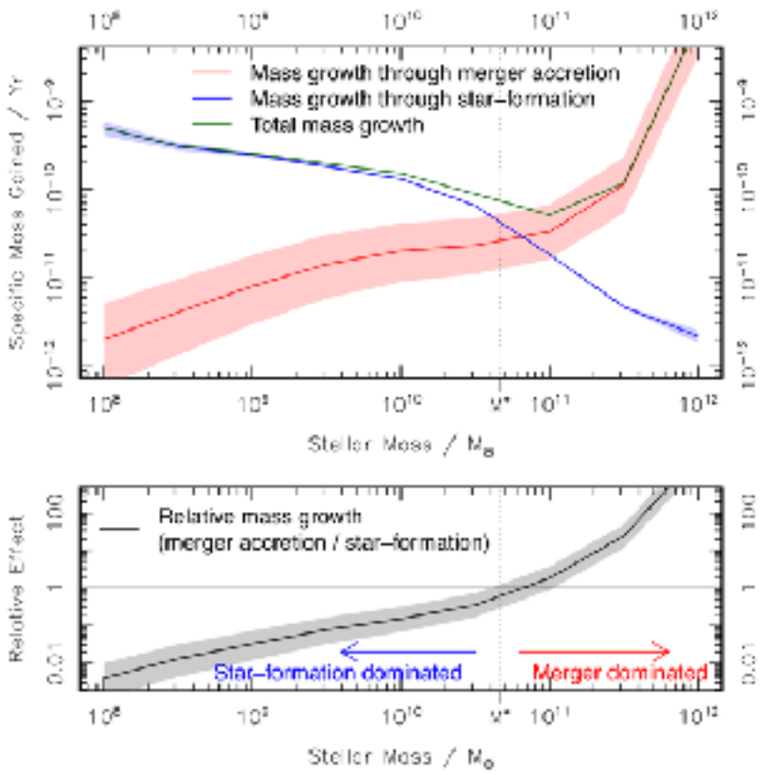
Analytic Function exactly predicts GAMA Halo Mass Function at z~0 (Robotham et al in prep)

WAVES Science: Formation Of Fundamental Relations

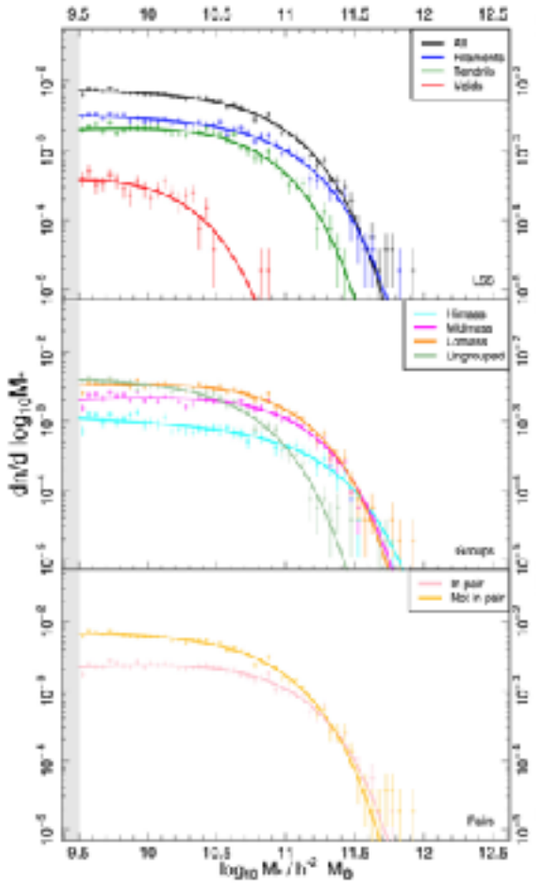
- Combining local environment with galaxy properties to probe the genesis of fundamental relations:



Contribution of morphological types to z~0 SMF (Moffett el al.)



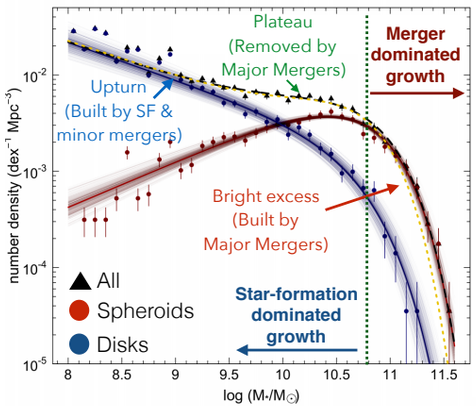
Contribution of mergers and SF in shaping the z~0 SMF (Robotham et al.)



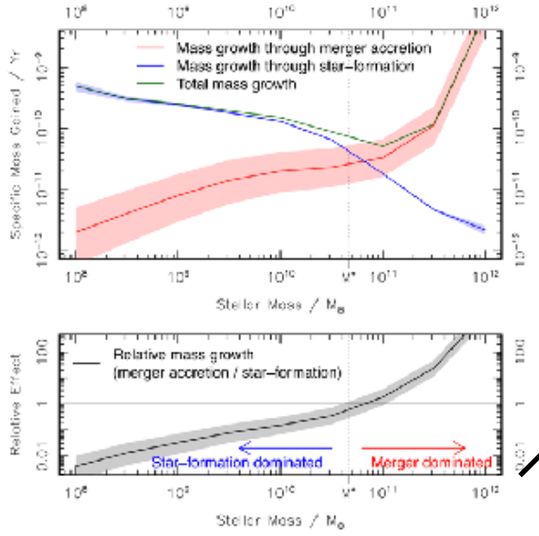
Contribution of environment in shaping the z~0 SMF (Alpaslan et al.)

WAVES Science: Formation Of Fundamental Relations

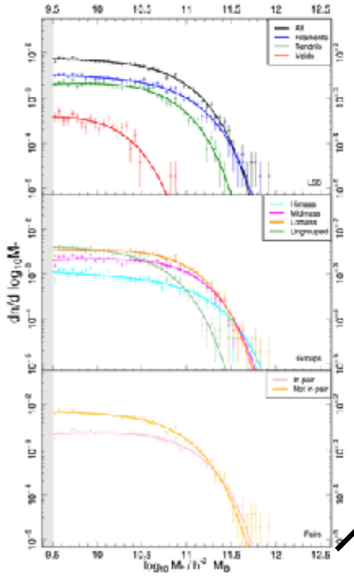
- With WAVES-deep we can add a 'time' axis to these relations:



Z



Z



Z

- How does the distribution of different morphological types and components evolve since z~1?
- How do they shape the SMF at each epoch?
- How does this combine to form the z~0 SMF?

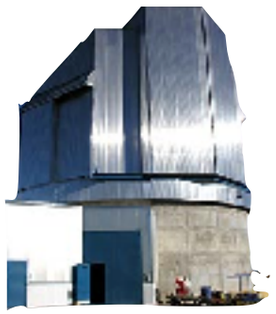
- How does the relative contribution of mergers and SF to mass growth evolve?
- At any given epoch how are they changing the shape of the SMF?
- Can we combine the observed merger and SF-driven mass growth to produce the z~0 SMF?

- How is environment driving mass growth at each epoch?
- How does this produce the morphology-density relation?
- How do environmental effects over the las 8Gyr shape the z~0 SMF?

Formation of z~0 SMF!

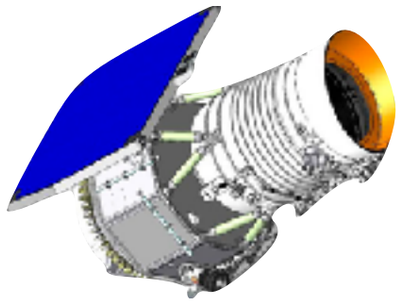
WAVES as a Legacy Resource

JWST

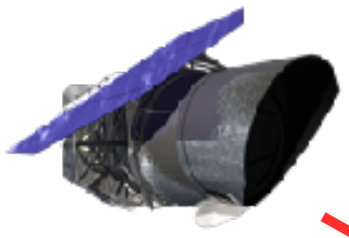


VISTA/VIKING

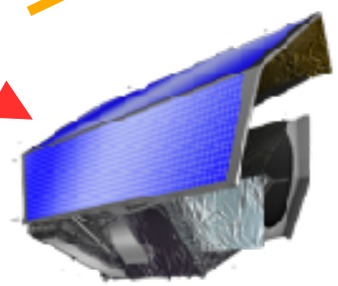
VISTA/4MOST



WISE



W-FIRST



Euclid

NIR

Spec

MIR

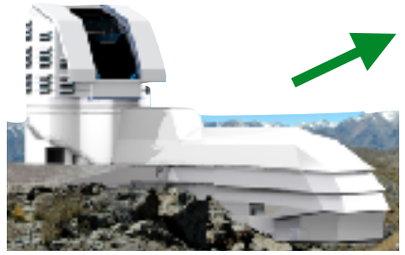
Structure

FIR

Herschel

Optical

HI Cont

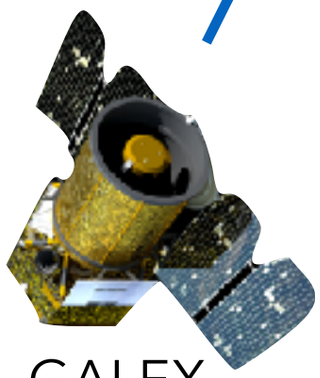


+LSST

VST/KiDS

UV

X-ray



GALEX

eROSITA

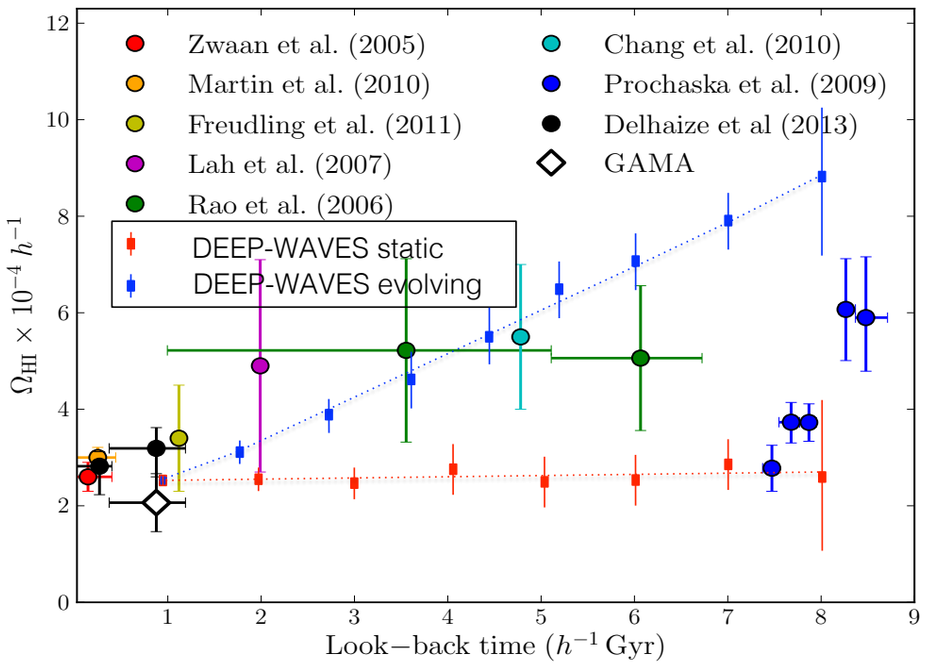
ASKAP/
SKA Phase 1

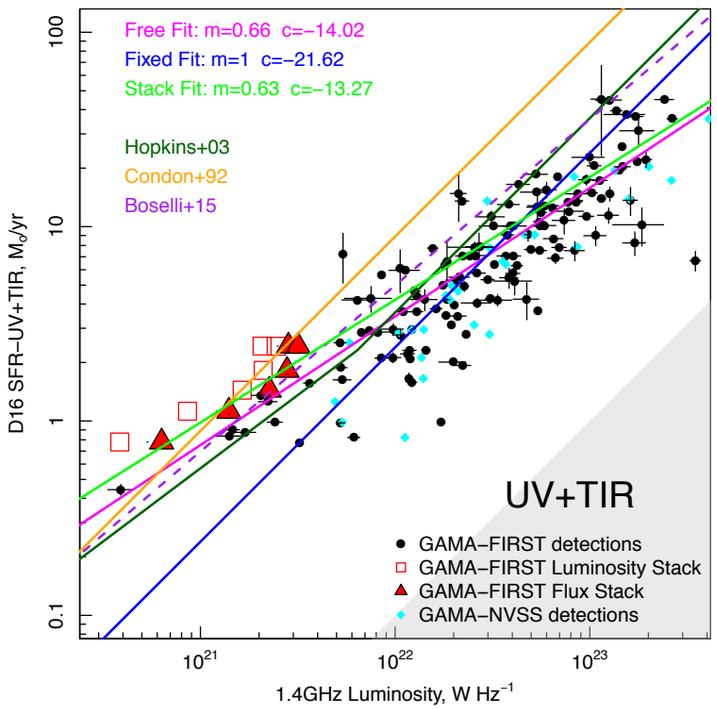
WAVES and SKA-precursors

WAVES-wide - 1Million galaxies in WALLABY/EMU/GLEAM

WAVES-deep - 0.5M galaxies in DINGO-UDeep/EMU-early science/ GLASS region, 0.5M galaxies in DINGO-Deep

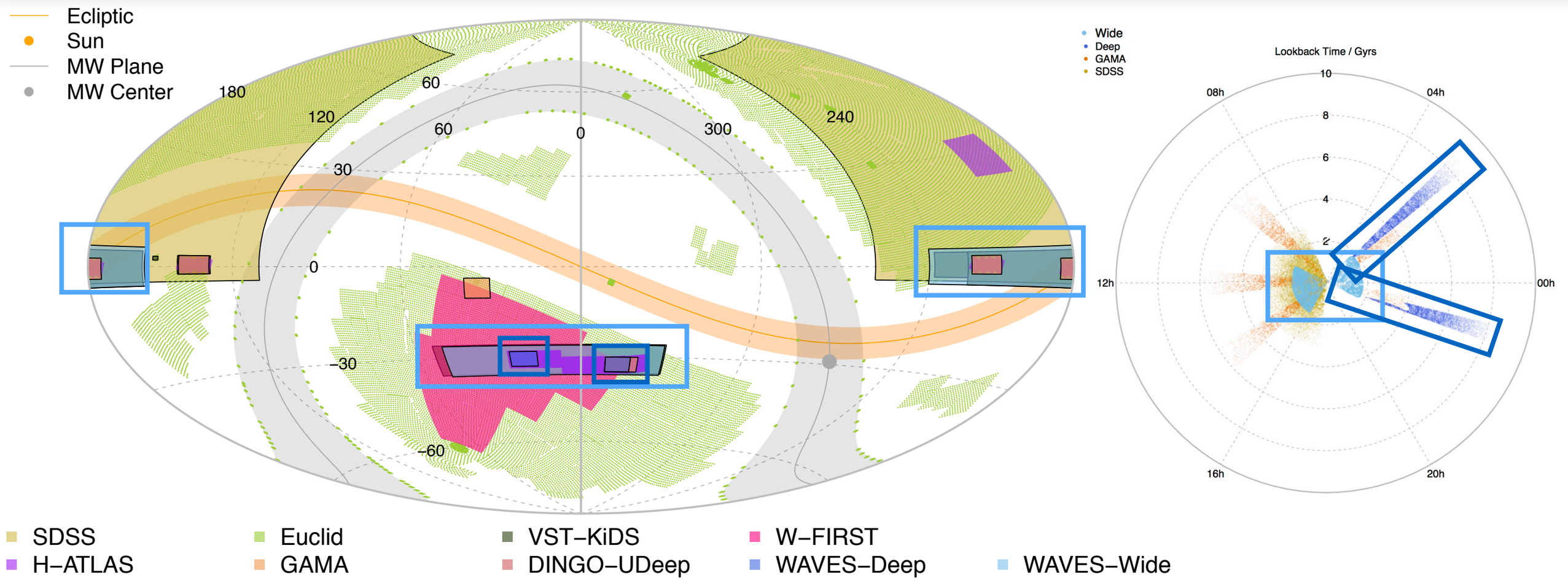
- Pair/Group/Filament/Voids - HI/ Environment Science
- Redshifts with >95% completeness - Stellar mass-selected HI sacking
- Multi-wavelength photometry - Stellar masses, gas fractions, baryonic mass function, HI density, AGN classification….
- Multipule SFR diagnostics - Radio continuum SFRs **- See L. Davies et al 2017**





WAVES: Survey Design

astromap.icrar.org



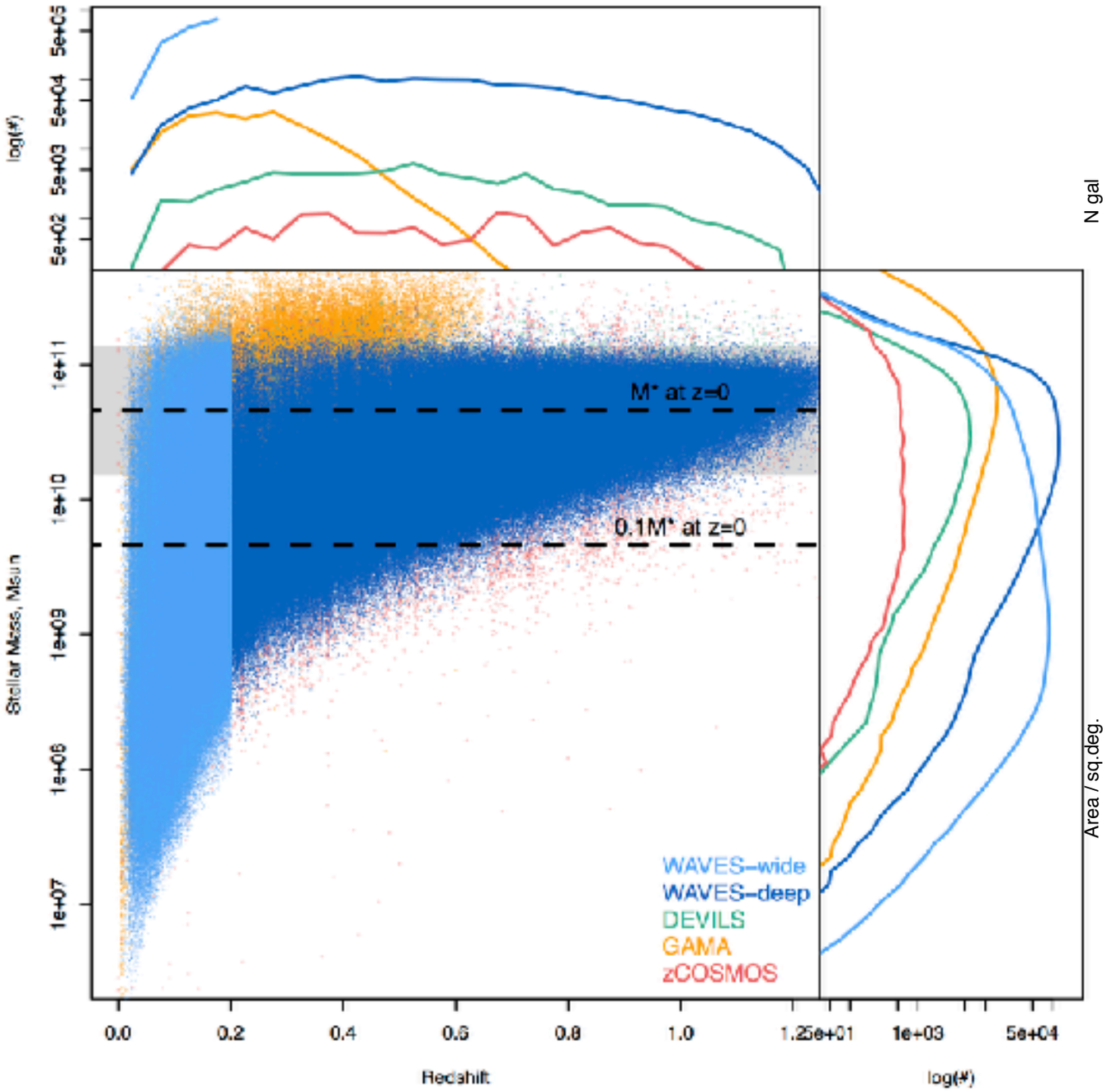
WAVES wide

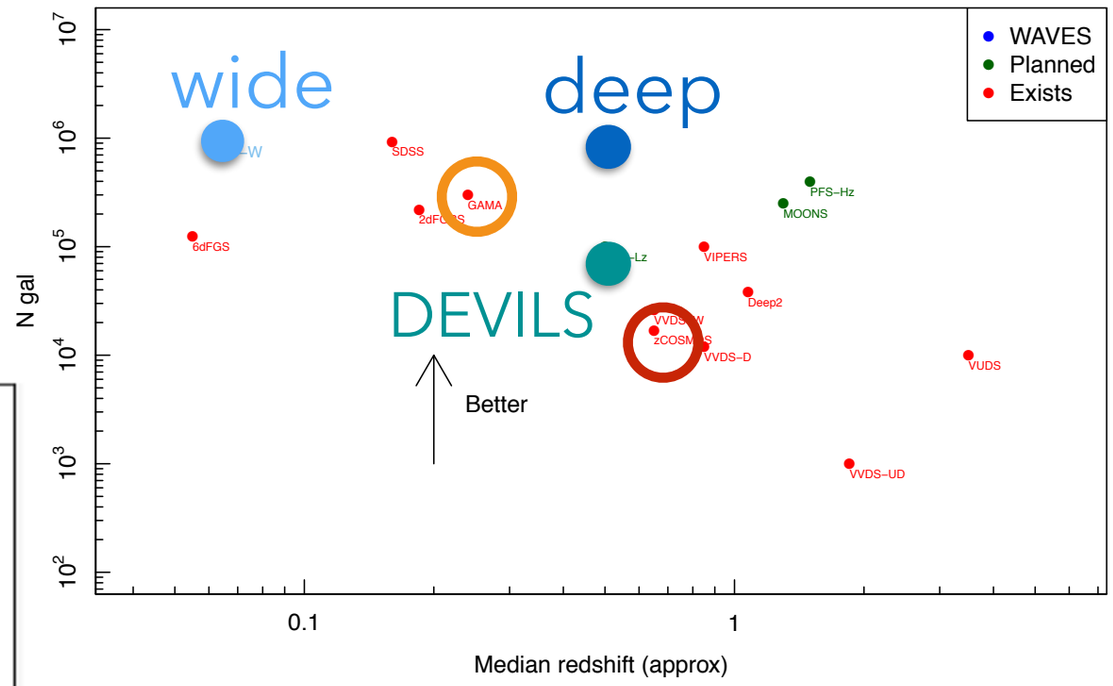
- z<21.5 & photo-z<0.2
- 1350deg^2 KiDS
- ~1M targets, > 95% complete
- Stellar mass to ~$10^6 M_\odot$
- Groups to $10^{10} M_\odot$

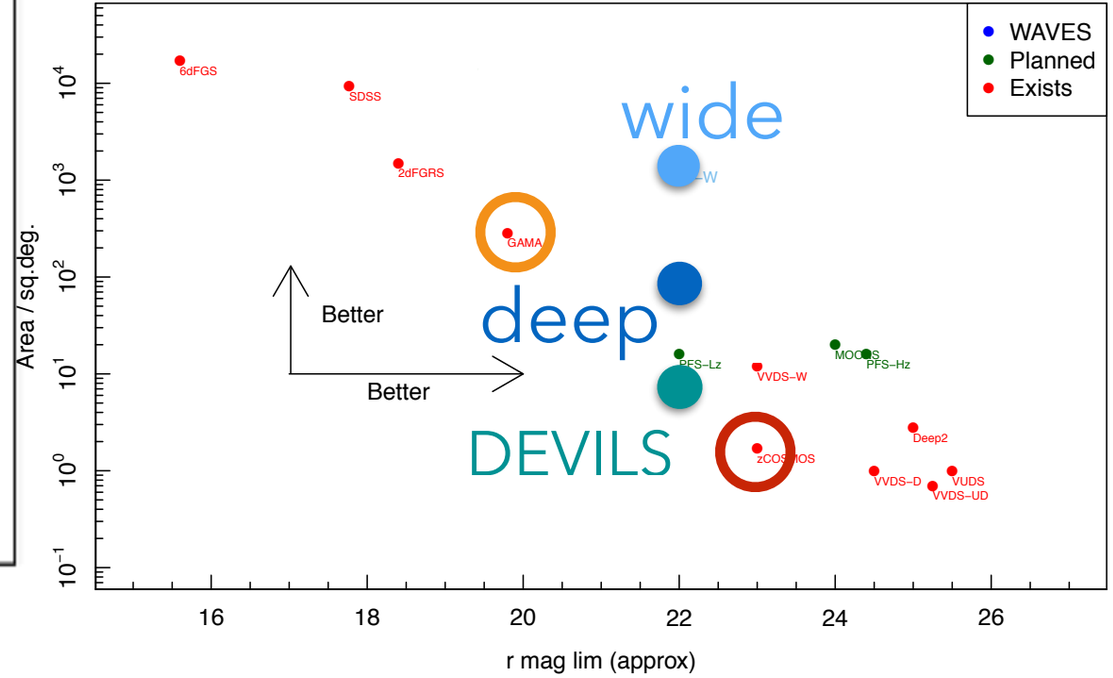
WAVES deep

- z<21.5
- 2x50deg^2 regions
- ~1M targets, > 95%
- GALEX, H-ATLAS, Euclid, DINGO
- Evolution to z~0.8

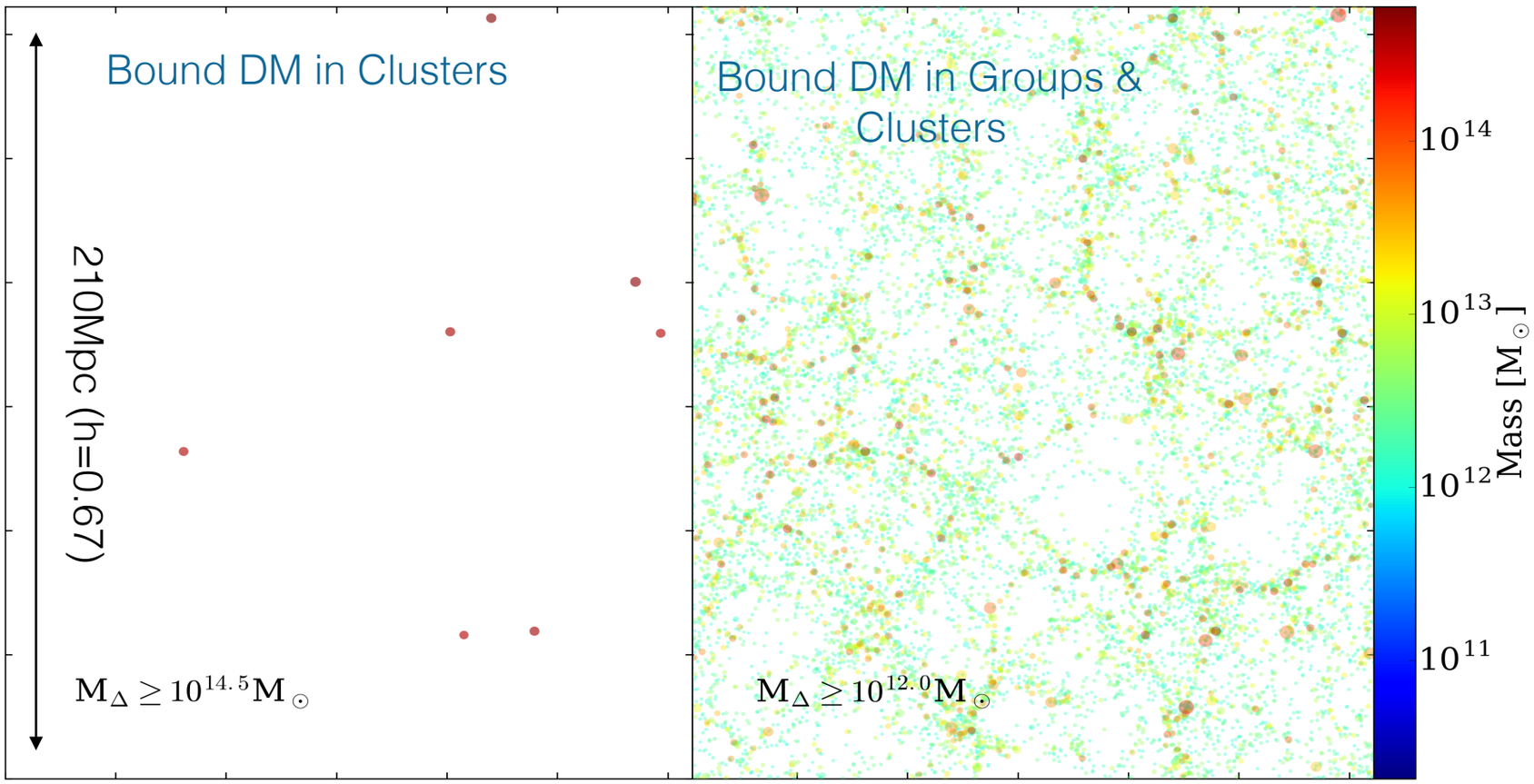
Putting It All Together







Synthetic UniveRses For Surveys (SURFS)



- ~300Mpc box, tiered mass resolution of 130M to ~65Billion particles
- Highest resolution will resolve hosts of stellar mass~$10^8 M_\odot/h$ galaxies

- Orthogonal runs with fixed resolution but ~300Mpc - 2.3Gpc box
- Subset run with hydro and semi-analytics
- Will include x-rays & radio emission from shocks, AGN, SF & x-ray binaries

  - Simulations group led by Chris Power, with: Aaron Robotham, Claudia Lagos, Danail Obreschkow, Pascal Elahi, Charlotte Welker, Guido Munoz-Granda and Rhys Poulton

Meeting

EMU, Wallaby, DINGO, GLASS,
MIGHTEE, LADUMA, CHILES….

GAMA: FINAL DATA RELEASE, LEGACY, AND FUTURE GALAXY EVOLUTION SURVEYS

ICRAR-UWA, 6-11th November

https://www.icrar.org/conferences/gamaworkshop/

Summary

Now!

GAMA

Galaxies: ~300k

Depth: r<19.8

Completenes: 98%

Area: 286deg^2

Redshift: z<0.4

Radio Cont Overlap:

G23: EMU-ES/GLASS

All: EMU/GLEAM

Now!

GAMA G10/COSMOS

Galaxies: ~16k

Depth: i<22

Completenes: 50%

Area: 2deg^2

Redshift: z<1.5

Radio Cont Overlap:

CHILES CON-POL

VLA COSMOS

2017-2020

DEVILS

DEEP EXTRAGALACTIC VISIBLE LEGACY SURVEY

Galaxies: ~60k

Depth: Y<21.1

Completenes: 95%

Area: 6deg^2

Redshift: z<1.0

Radio Cont Overlap:

MIGHTEE

CHILES CON-POL

VLA COSMOS

2021-2026

WAVES

wide area vista extragalactic survey

Galaxies: ~2M

Depth: z<21.5

Completenes: 95%

Area: wide:1350deg^2
deep:100deg^2

Redshift: wide: z<0.2
deep: z<1.2

Radio Cont Overlap:

All: EMU/GLEAM

Deep: GLASS

If you would like to get involved with any of theses surveys come and talk to me! OR luke.j.davies@uwa.edu.au / @astrowelshluke