International Centre for Radio Astronomy Research

Galaxy And Mass Assembly (GAMA)

- What is GAMA
- GAMA v SDSS/BOSS etc
- Early science results
- Lessons learnt

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The GAMA Team

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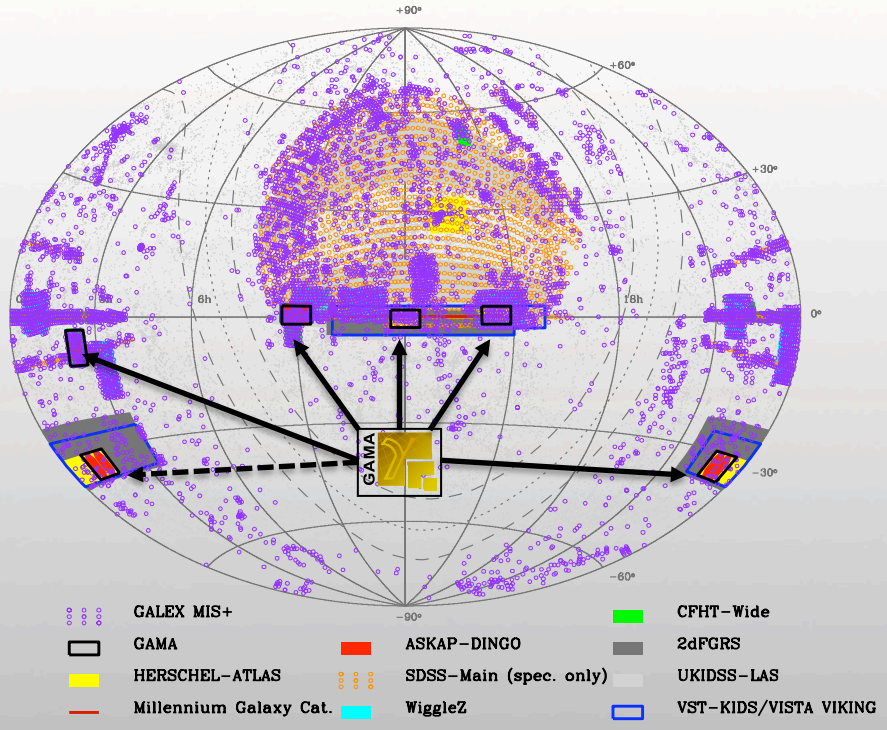
GALEX-GAMA	Barry Madore
	Mark Seibert
DINGO	Lister Staveley-Smith
VISTA-VIKING	Will Sutherland
UKIDSS	Steve Warren

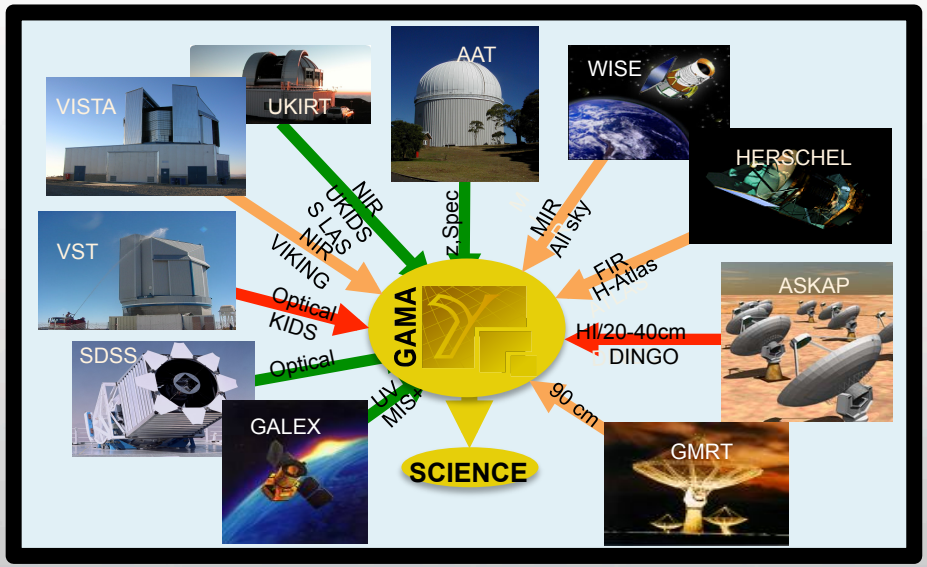
GROUND–BASED FACILITIES:
AAT, Siding Springs
SDSS, Apache Point
VST, Paranal
UKIRT, Mauna Kea
VISTA, Paranal
GMRT, Pune
ASKAP, WA

SPACE MISSIONS
Herschel, L2
GALEX, Earth Orbit
WISE, Earth Orbit

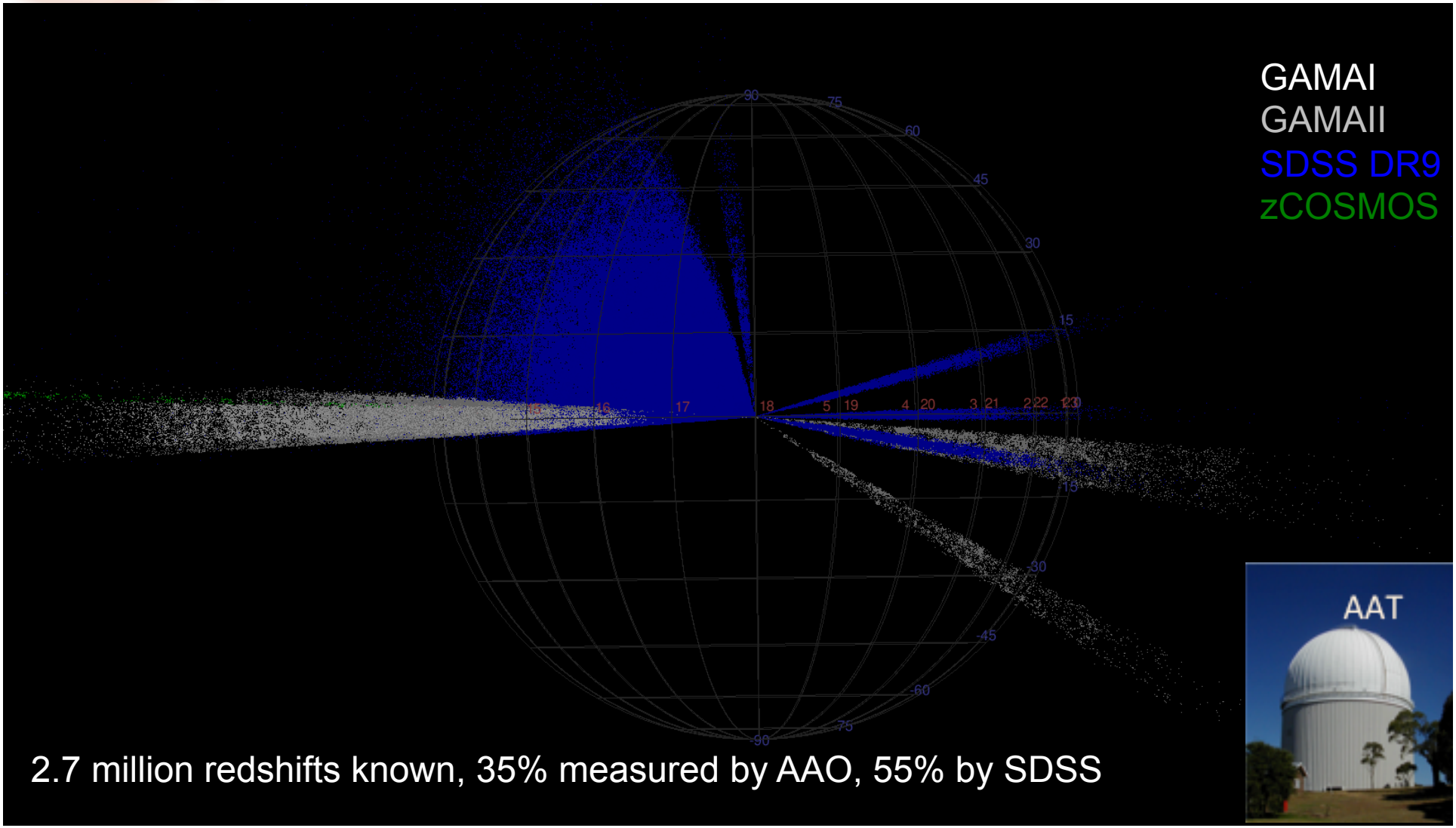
What is GAMA

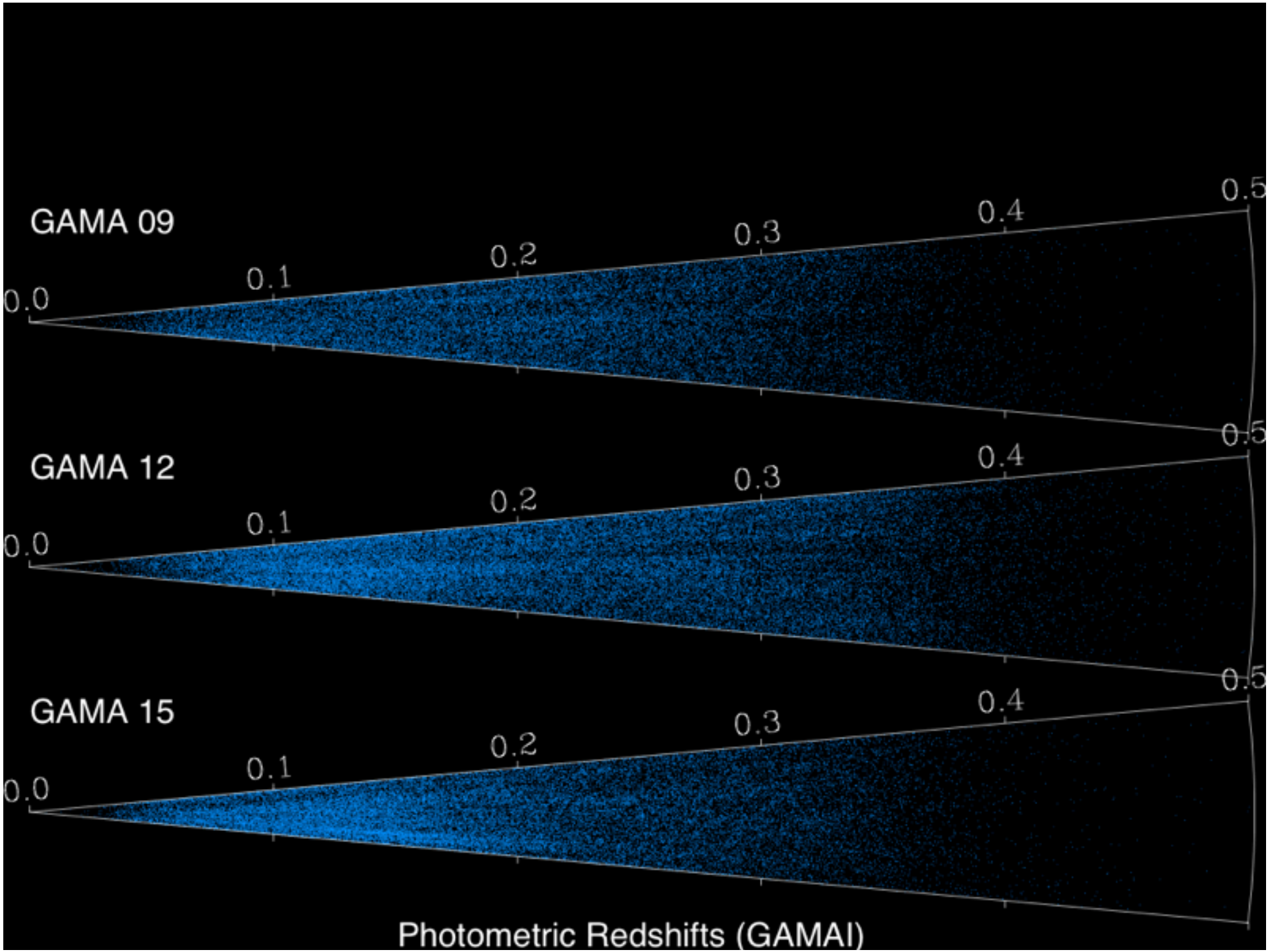
1. A spectroscopic survey on the Anglo-Australian Telescope
   i. 380,000 galaxies in five (or six) 60sq deg regions (200 nights)
   ii. r<19.8 mag (selected from SDSS DR6), no pre-selection
   iii. Fully sampled (~7 passes to resolve pairs, multiples, groups etc)
   iv. 3000-9000A at 3-5A res. for good SFR, Z, and BPT diagnostics





Without redshifts science is very limited:
GAMA is currently the 3rd largest
z-survey: SDSS, BOSS, GAMA,
2dFGRS, (LEGAS?), WiggleZ




GAMA 09
0.0
0.1
0.2
0.3
0.4
0.5
GAMA 12
0.0
0.1
0.2
0.3
0.4
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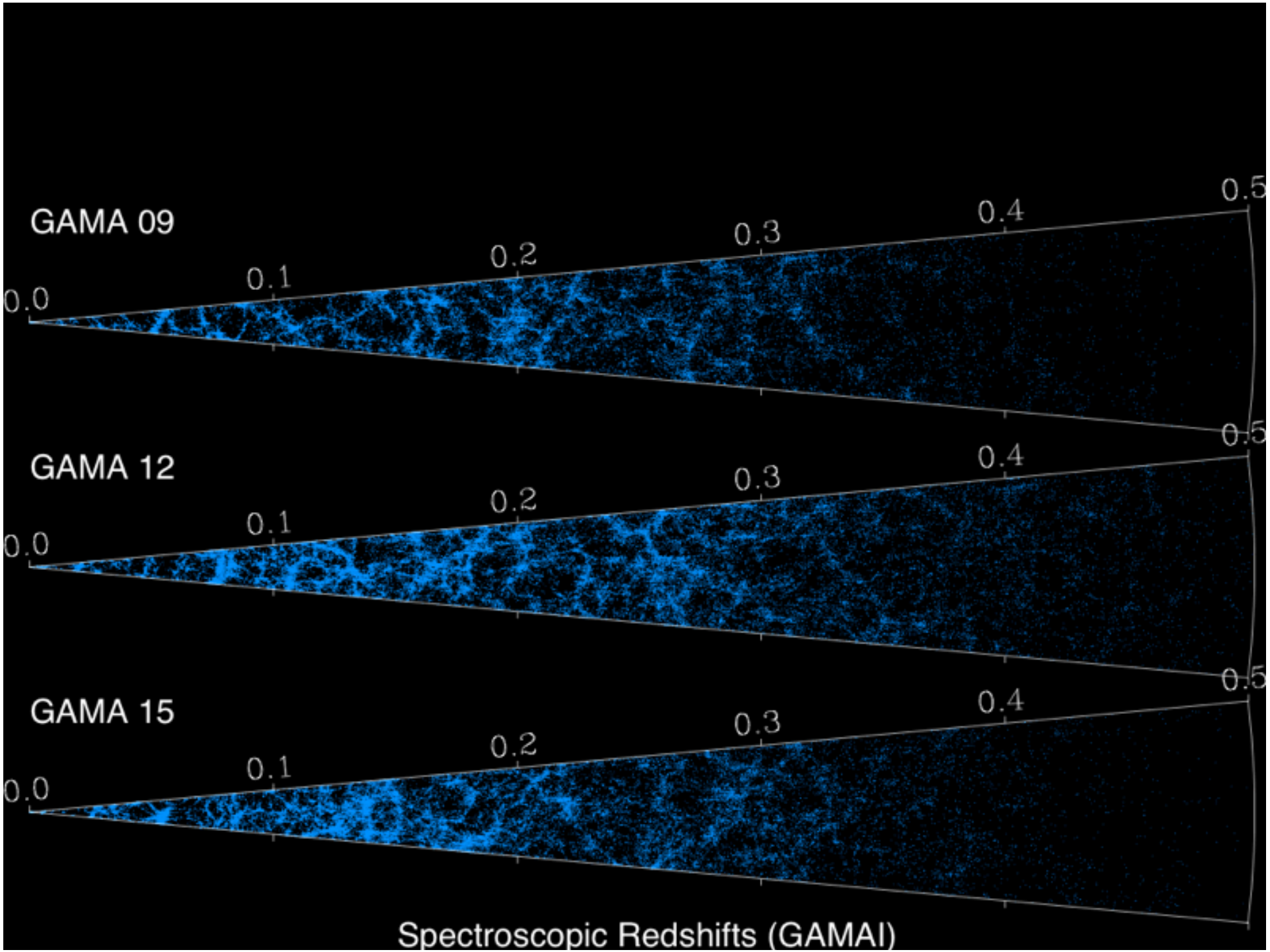
GAMA 15
0.0
0.1
0.2
0.3
0.4
0.5
Photometric Redshifts (GAMAI)


GAMA 09
0.0
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0.2
0.3
0.4
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GAMA 12
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0.1
0.2
0.3
0.4
0.5
GAMA 15
0.0
0.1
0.2
0.3
0.4
0.5
Spectroscopic Redshifts (GAMAI)

What is GAMA

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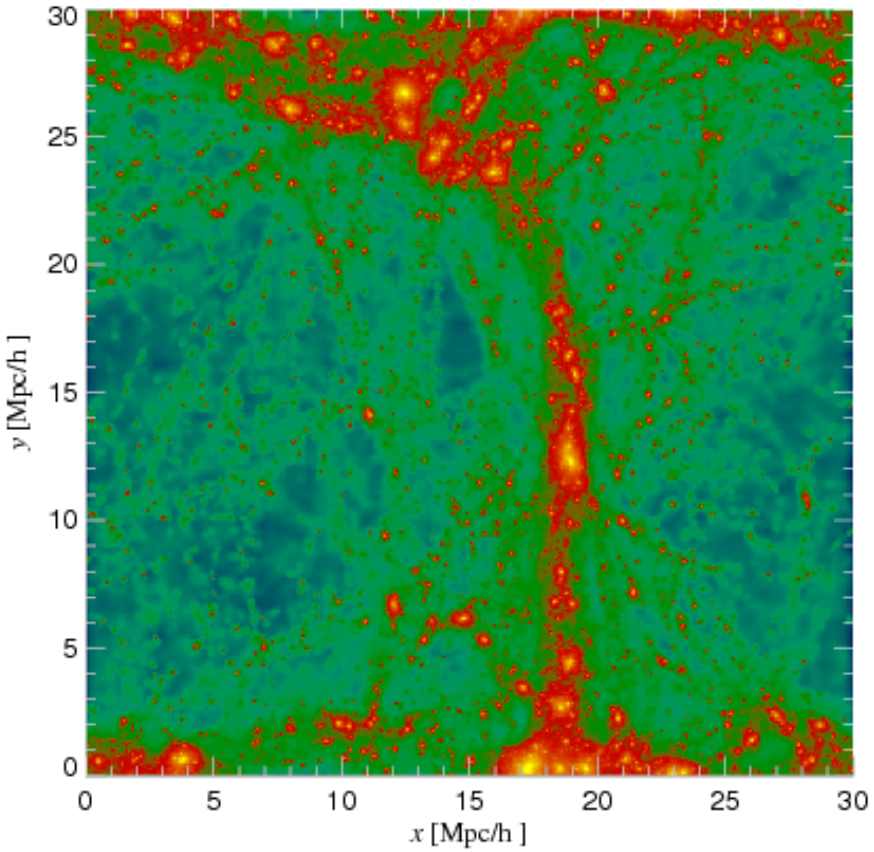
   iv. 3000-9000A at 3-5A res. for good SFR, Z, and BPT diagnostics

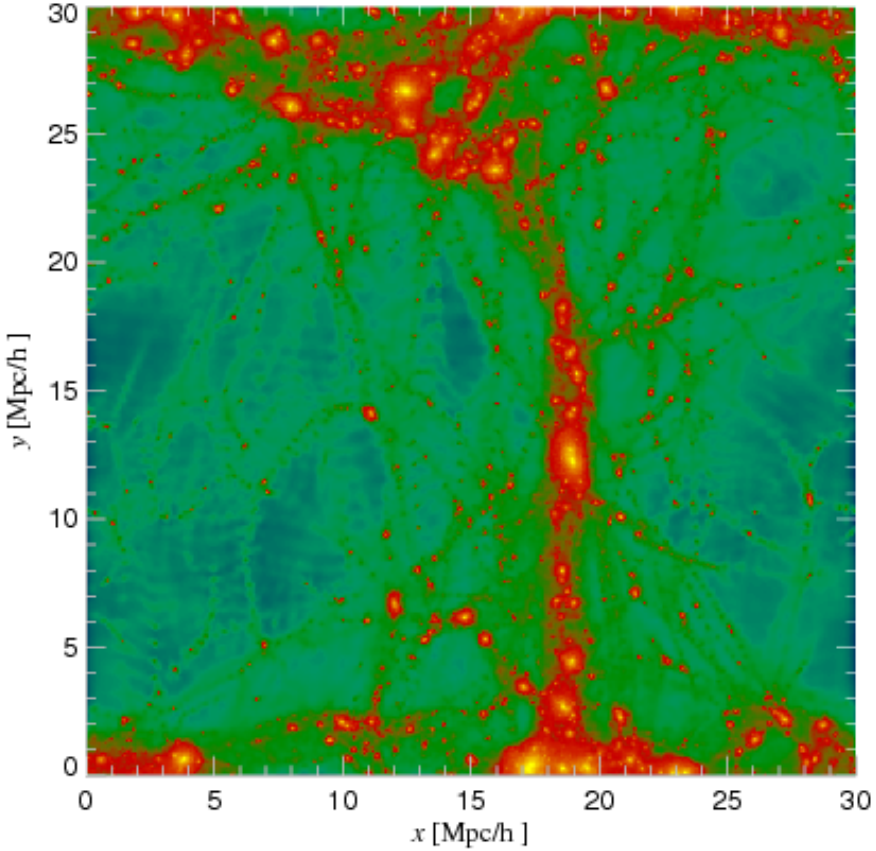
+

1. Key science goals
   i. Testing dark matter:
      - Halo mass function
      - Galaxy v halo merger rates
      - Star-formation efficiency (feedback)
   ii. Structure on 1kpc to 100Mpc scales (bulges → filaments)
   iii. Energy and mass budgets (stars, gas and dust)
   iv. Galaxy evolution over most recent 3Gyr baseline

Cold versus Warm Dark Matter

Cold and warm dark matter simulations of the underlying dark matter distribution
by Chris Power@ICRAR



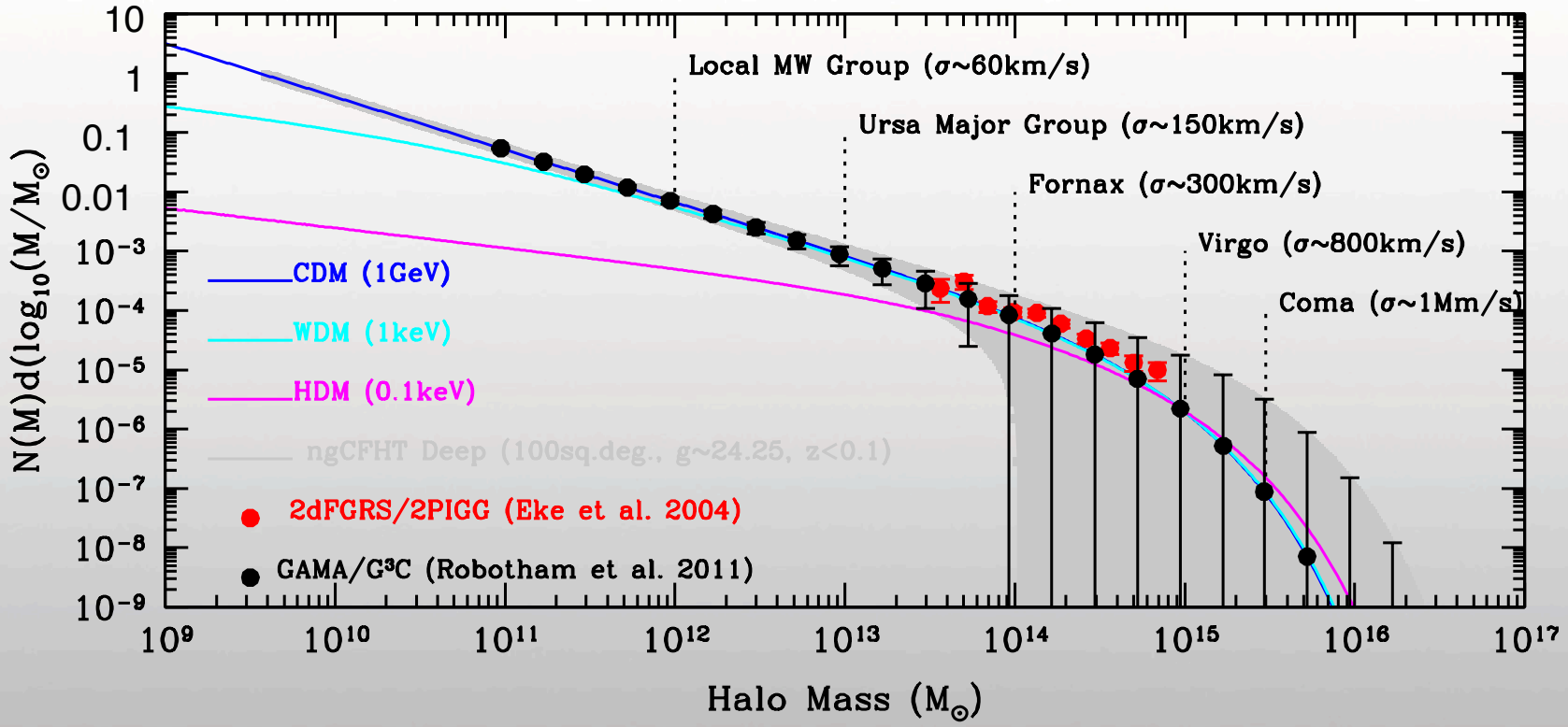


Cold versus Warm Dark Matter

Two clear differences between CDM and WDM:

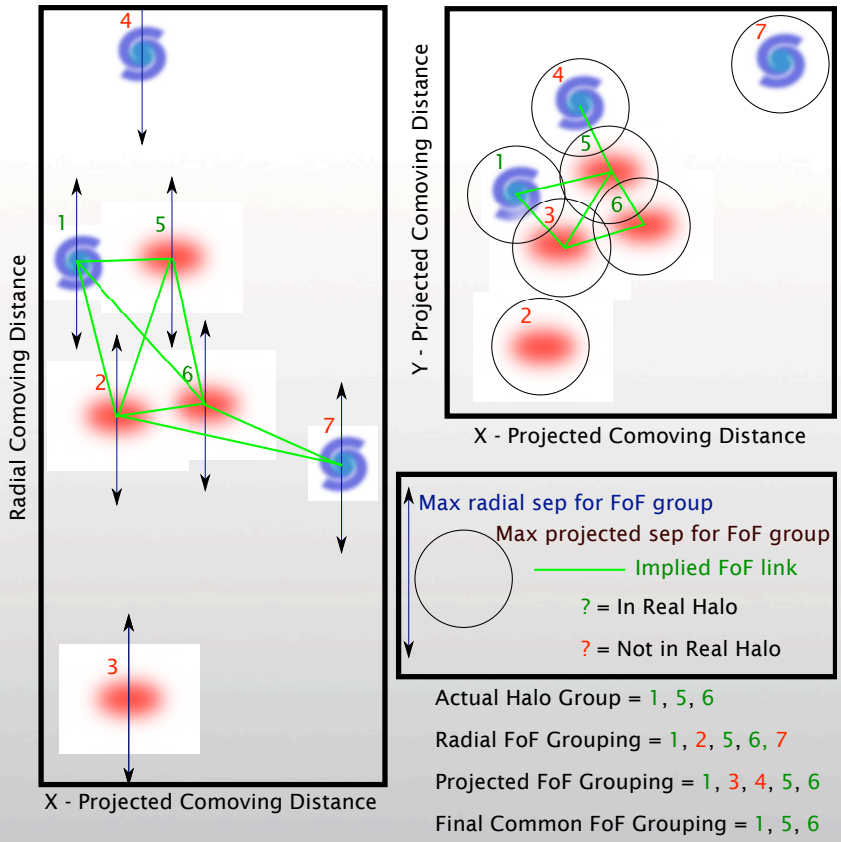
- space density of low mass halos
- galaxy binary pair fraction

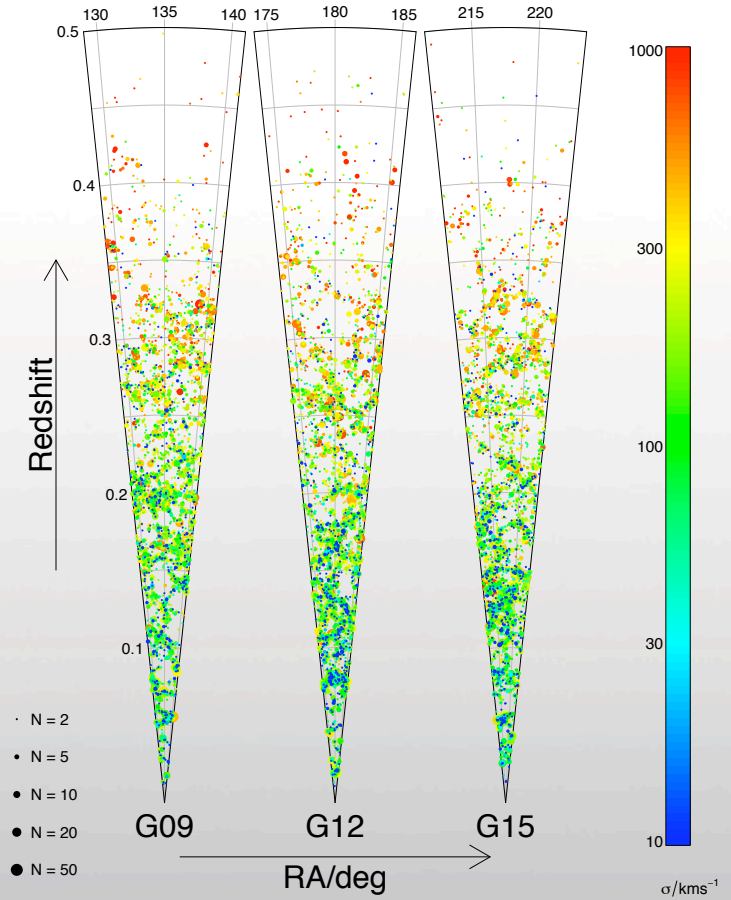
will measure both with GAMA (full sampling absolutely critical)



GAMA group catalogue
1600 N>5, 20,000 N>2

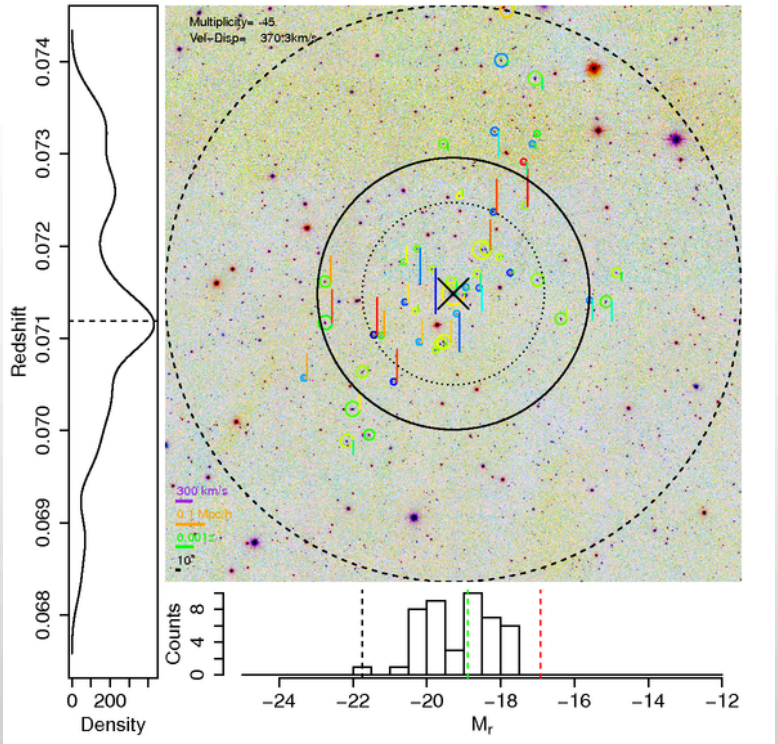
Robotham et al (2011)

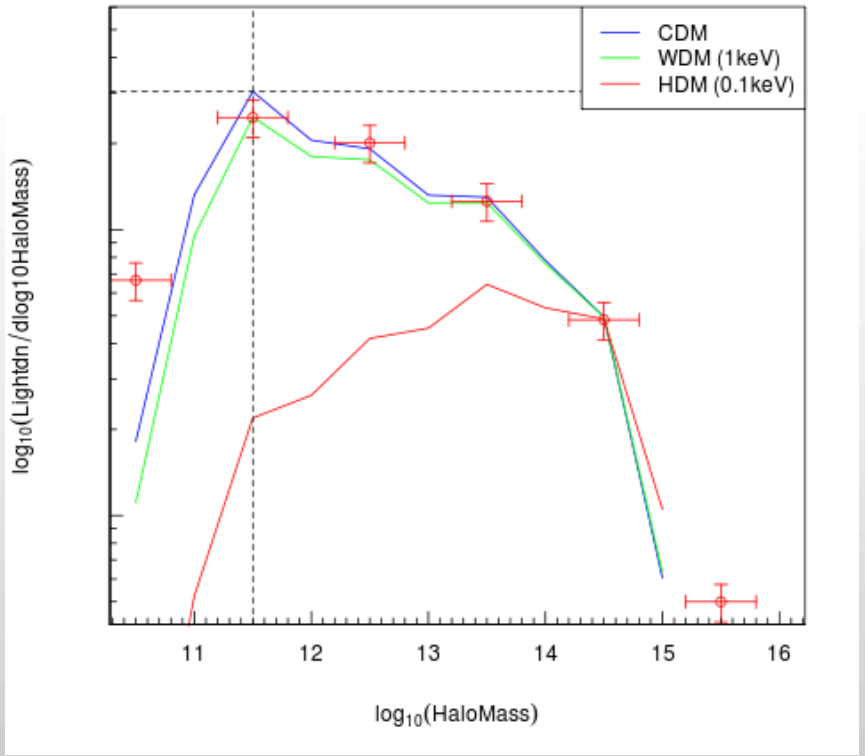




Preliminary look (20% of final dataset)

1600 N>5, 20,000 N>2





Local Group Analogues

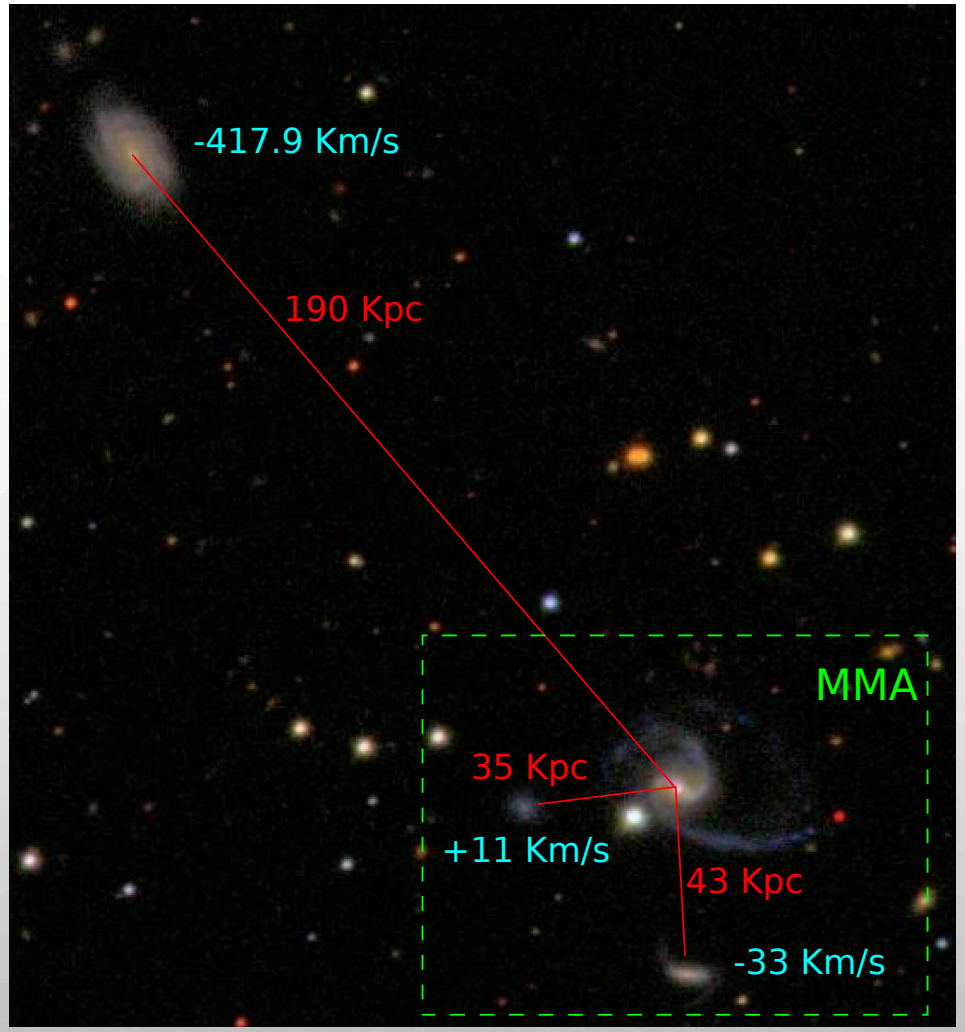
12 groups found in GAMA with
- MW mass dominants
- LG halo mass
- Magellanic mass companions

Follow-up at all λ's to address typicality of MW/LG system

SF currently anomalously low

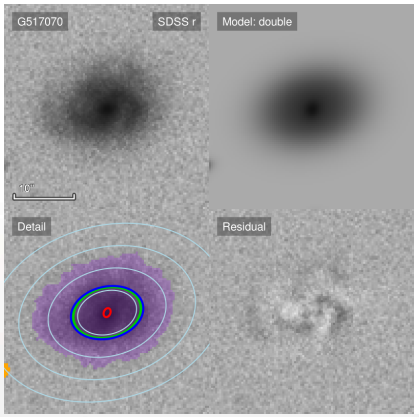
Need larger survey to improve stats.

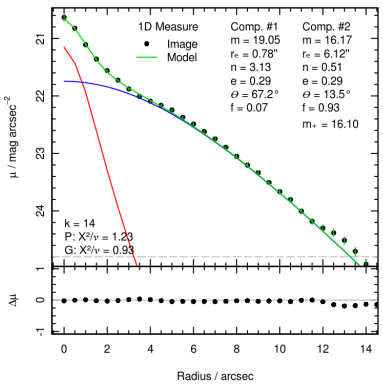
Robotham et al (2011, 2012, 2013)



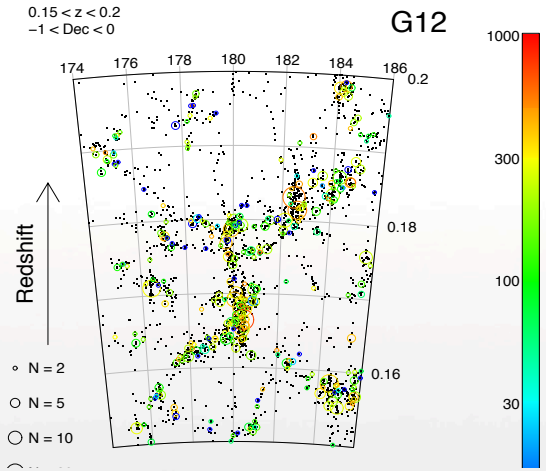
Structure on 1kpc to 100Mpc scales

Galaxy Decomposition (1-20kpc)

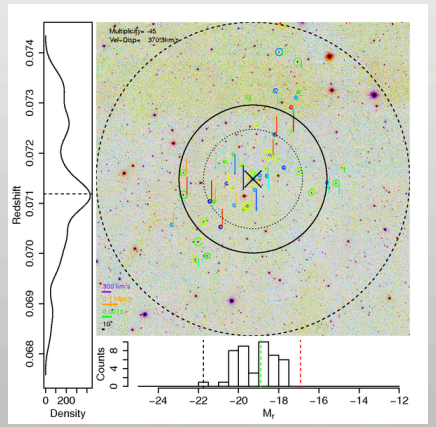


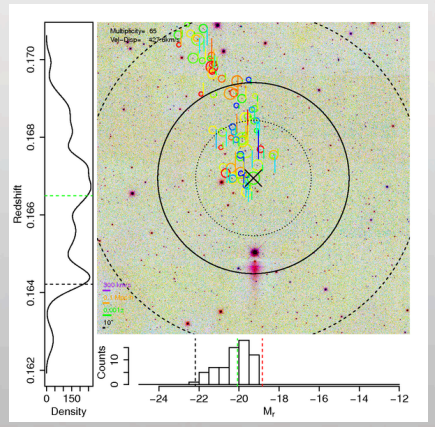


Superclusters (1-10Mpc)

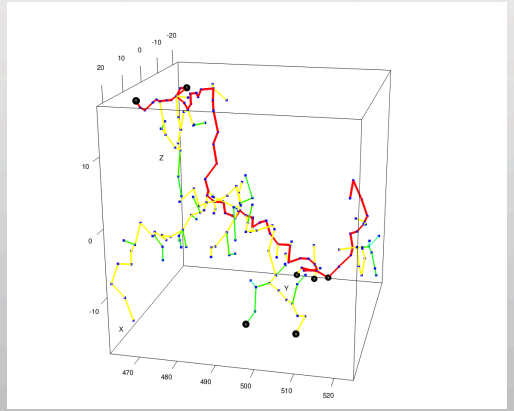


Groups (100kpc-1Mpc)

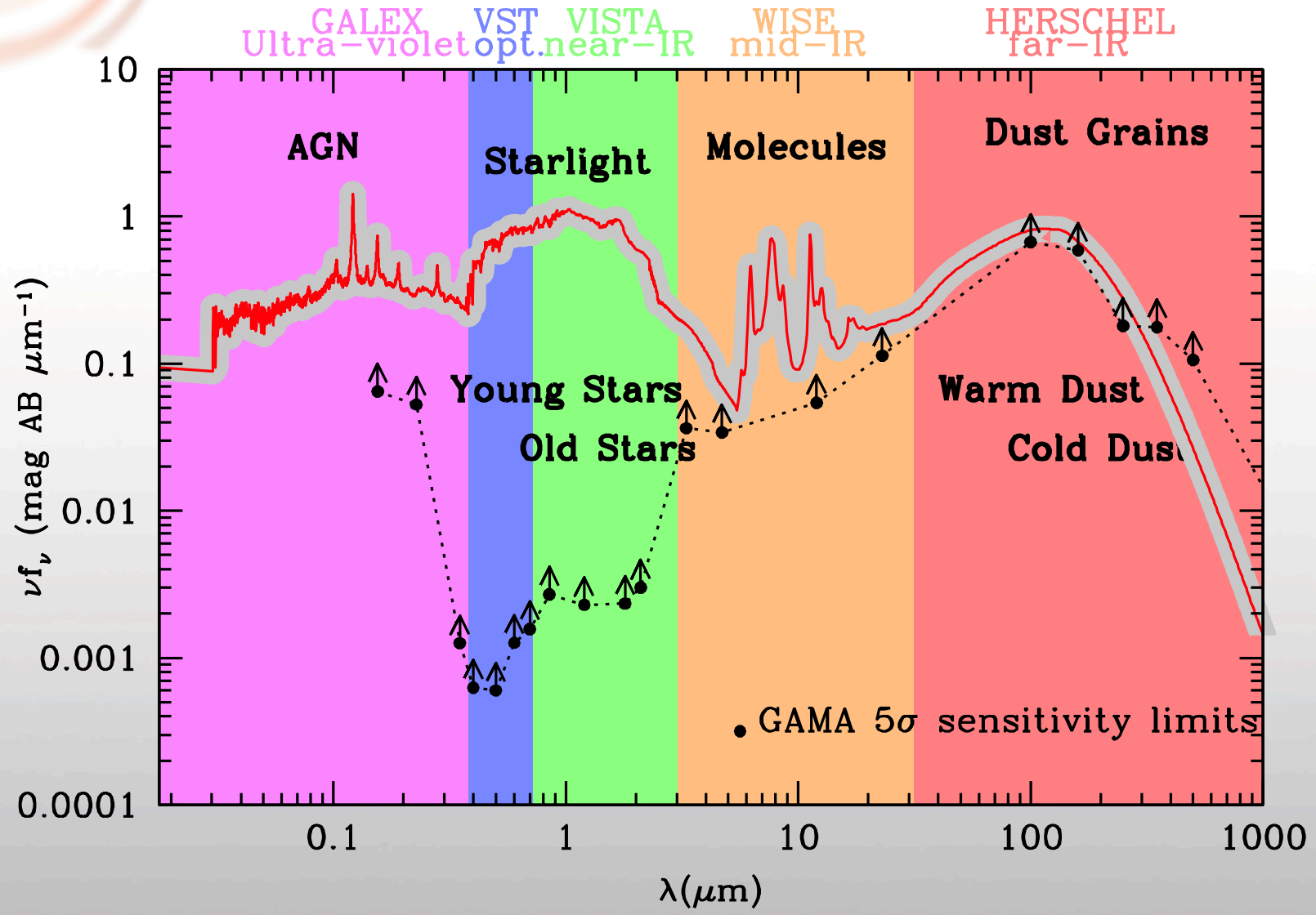




Filaments (10-100Mpc)



Energy budget



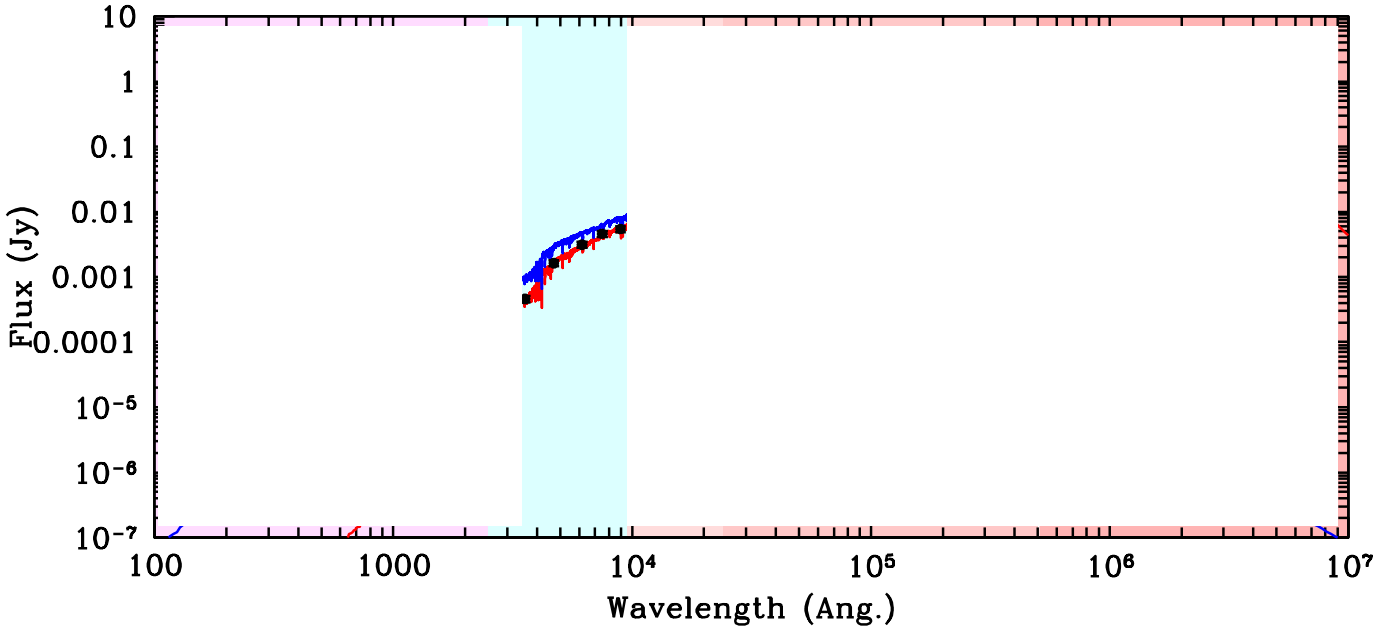
GAMA & SDSS

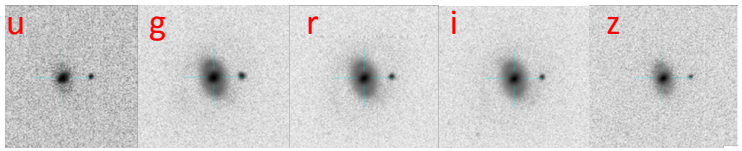
Table 1: GAMA and SDSS survey parameters

Parameter	GAMA	SDSS
Galaxy redshifts	400k	700k
Sky coverage (deg^2)	400	~8000
Spectral resolution (Å)	4.6	3.3
Spectral range (Å)	3700—8800	3900—9100
Spec. r limit (mag)	19.8	17.6
M^* z limit	0.27	0.11
M^* volume ($h^{-3}Mpc^3$)	1.0×10^7	2.6×10^7
Imaging bands	21 27	5
Spatial resolution ($''$)	0.7	1.5
λ range (μm)	0.15-10^6	0.3-0.9
Data volume	200Tb–1Pb	60 Tb

GAMA: Building on SDSS

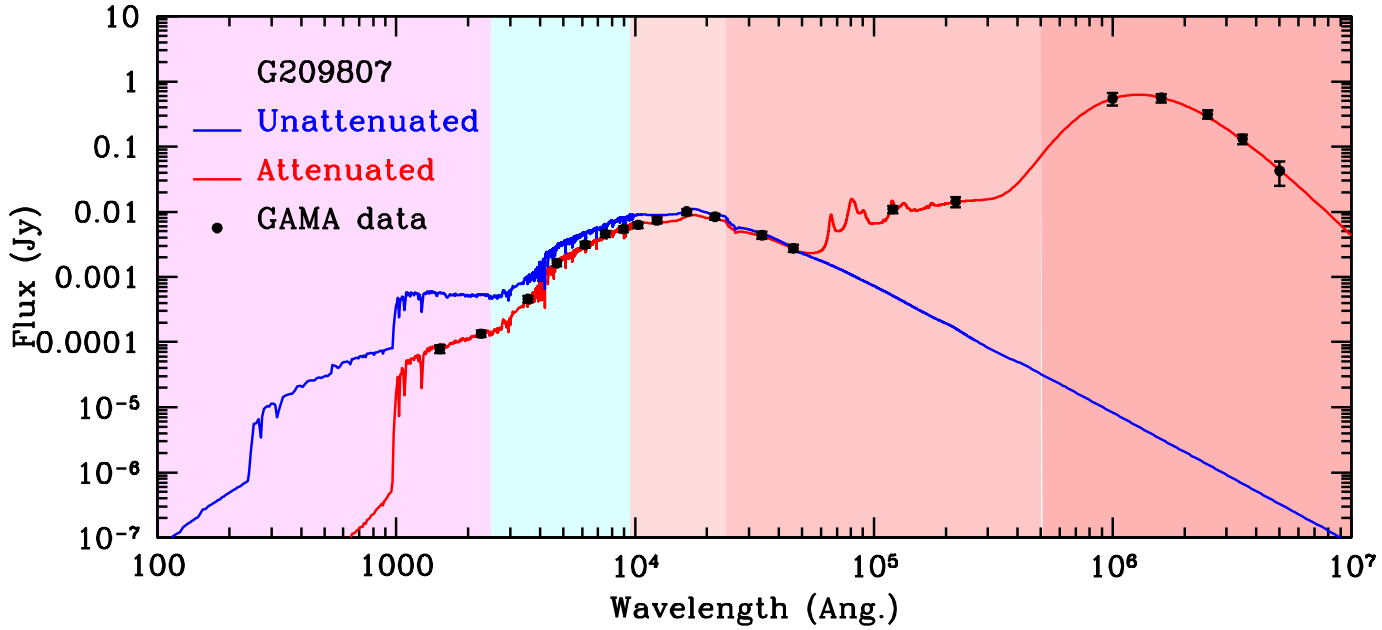
GAMA input catalogue based on SDSS DR6
Spectroscopic density is x15 that of GAMA Main Survey

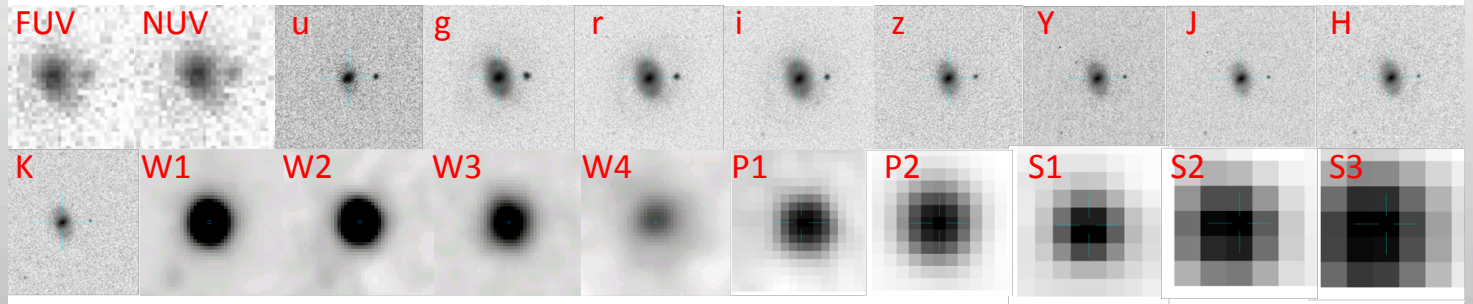




GAMA: Building on SDSS

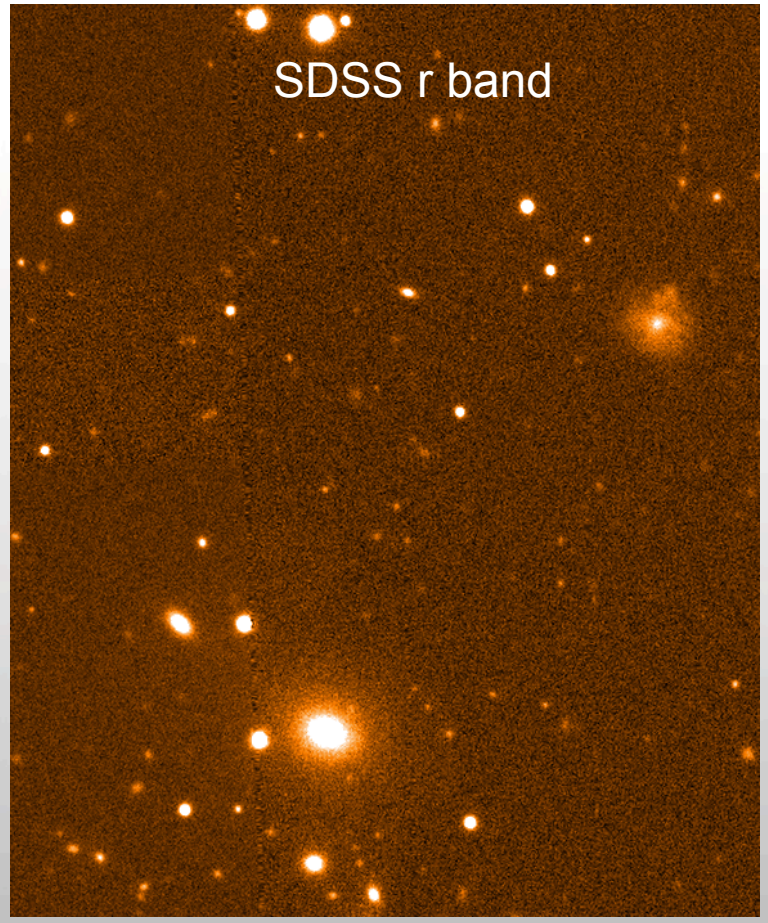
ugriz → 21 band photometry + Radio (HI+20cm-1m)

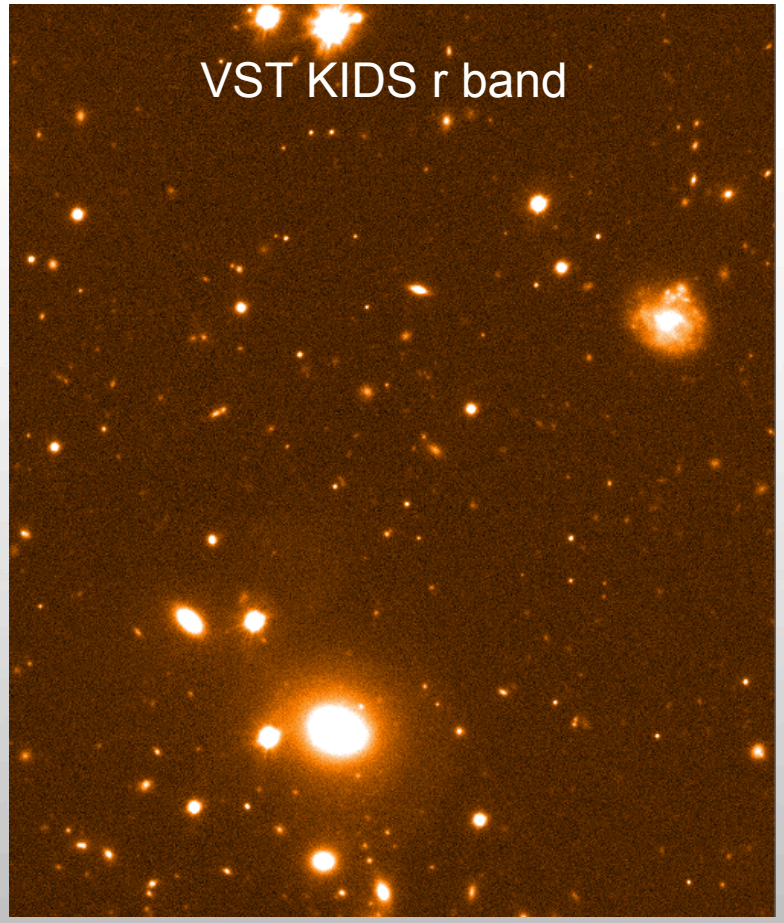




GAMA: Building on SDSS

Imaging resolution & depth
1.5” → 0.7”, r ~22 → r~24





SDSS Database

Opt/near-IR imaging

Stellar Mass

UV

Optical spectra

AGN

Unif.

Winds

SFR

σ

Age

Metal.

GANDALF

3000 papers
50000 citations
and growing

The Ultimate Galaxy Database

VST/VISTA

Opt/near-IR imaging

Stellar Mass

Nucleus

Bar

GALFIT

CAS

Bulge Mass

Disc Mass

Sersic index

Colour

Scalelength

SMBH mass

Trunc. rad

GALEX

UV

AAT

Optical spectra

AGN

SFR

Unif.

Winds

σ

Age

Metal.

GANDALF

GMRT/ASKAP

Radio

Cont.

90cm

20cm

HI

AGN v SFR

HI Mass

W_{21}

Dynamical Mass

HERSCHEL

Far-IR

Popescu & Tuffs

Dust Mass

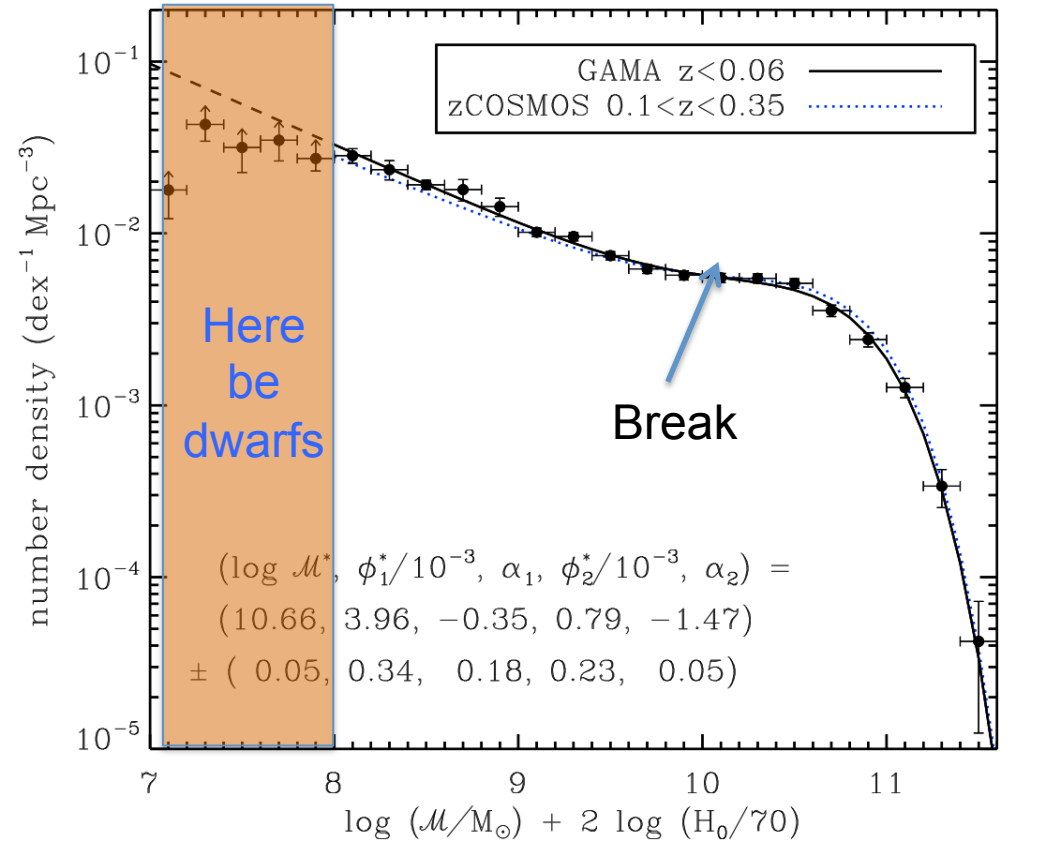
Dust Geom.

Attenuation

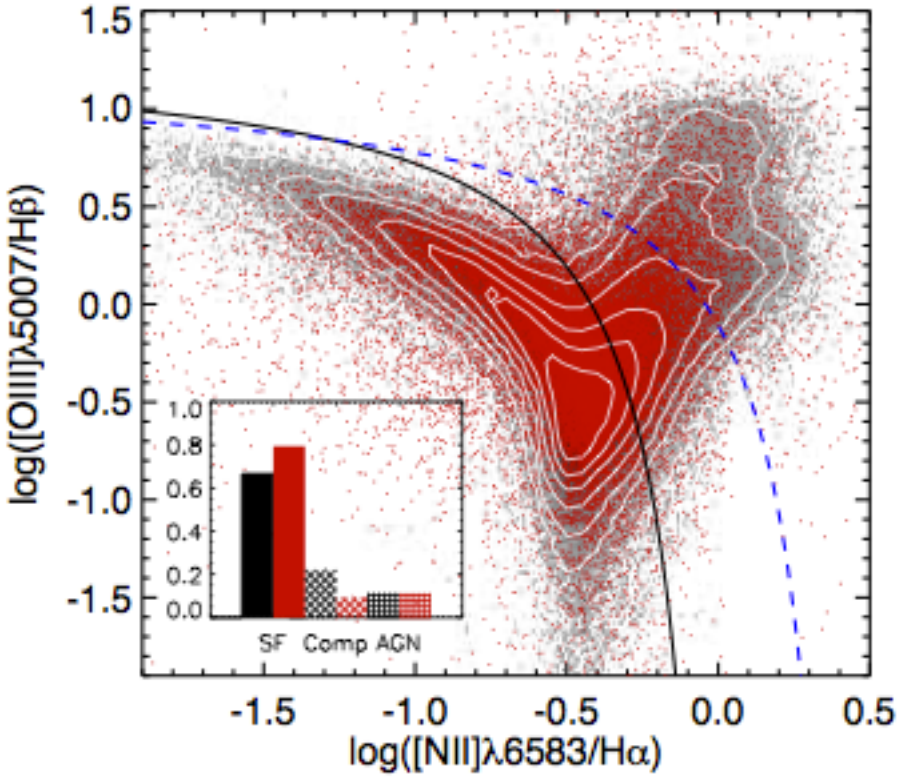
Galaxy Stellar Mass Function

Baldry et al (2011)

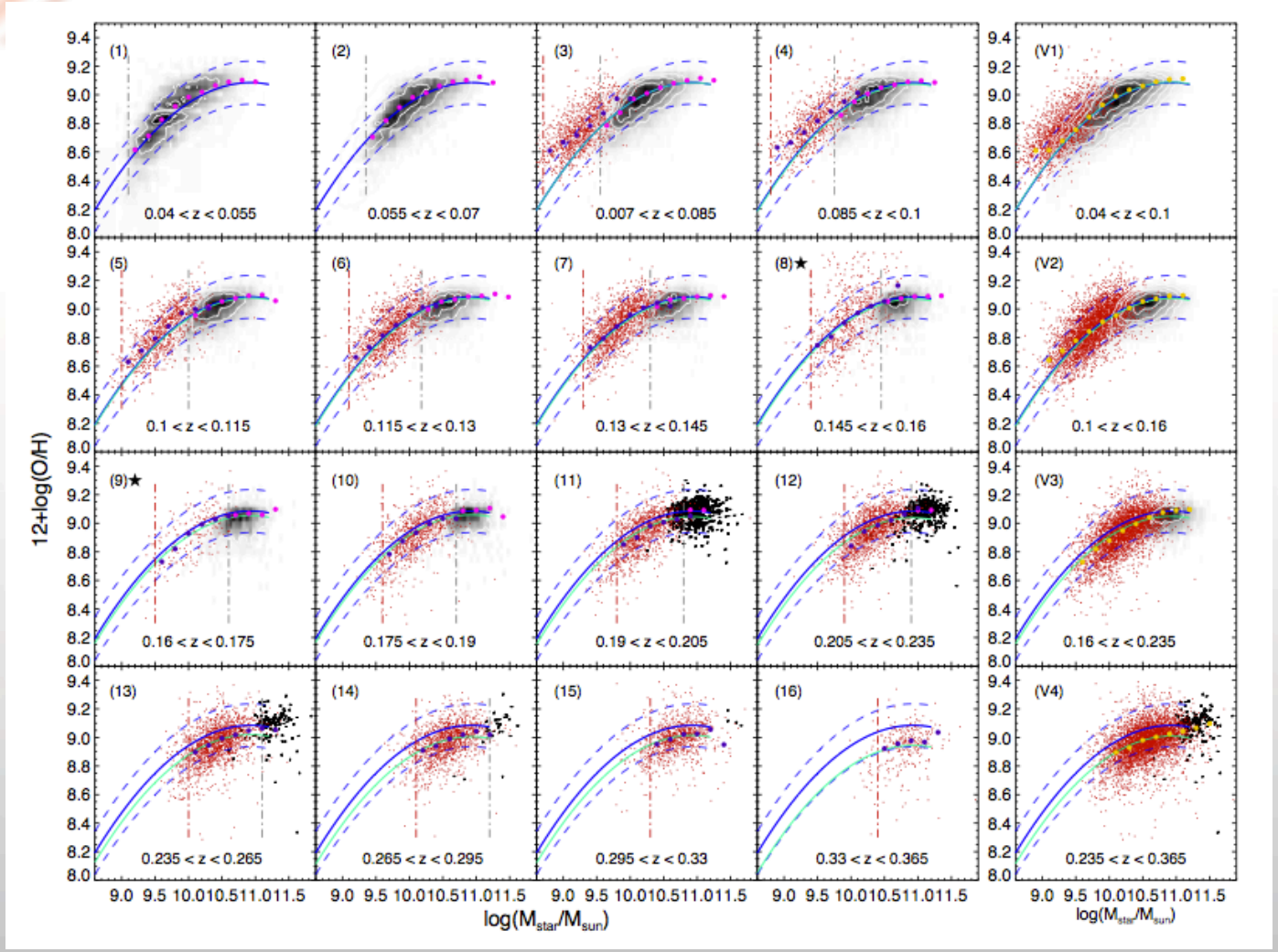
Clear upturn seen



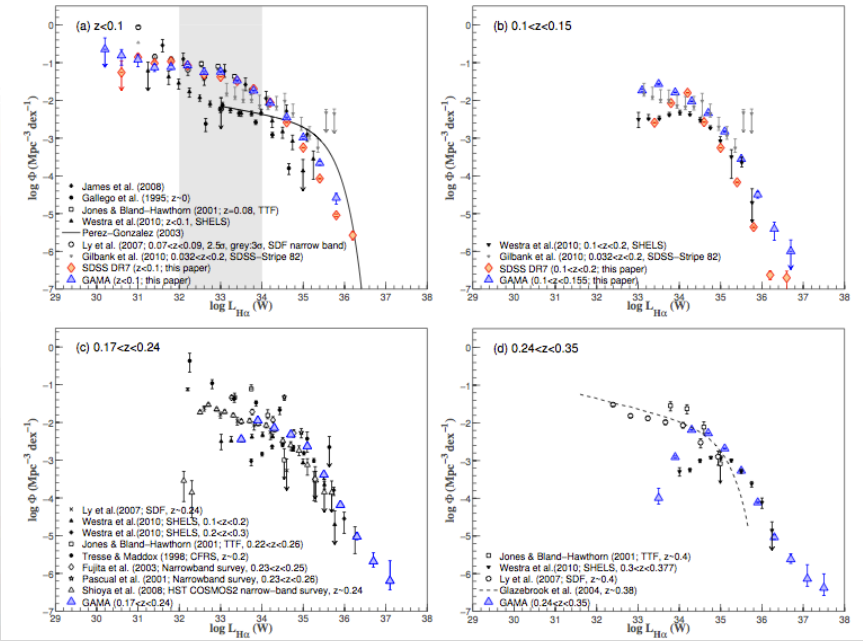
AGN via BPT

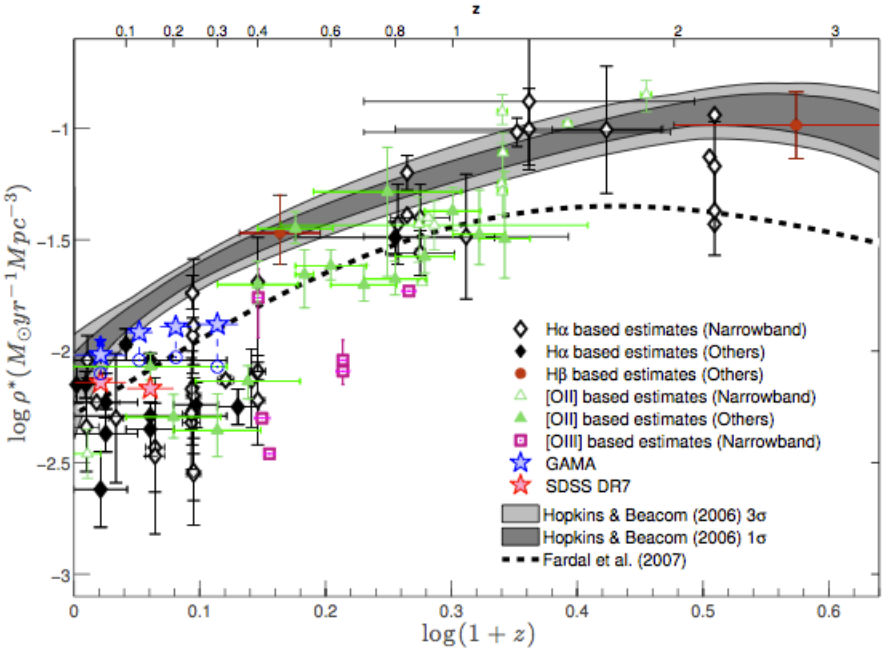

1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
log([OIII]λ5007/Hβ)
1.0
0.8
0.6
0.4
0.2
0.0
SF
Comp
AGN
-1.5
-1.0
-0.5
0.0
0.5
log([NII]λ6583/Hα)

Mass-metallicity relation

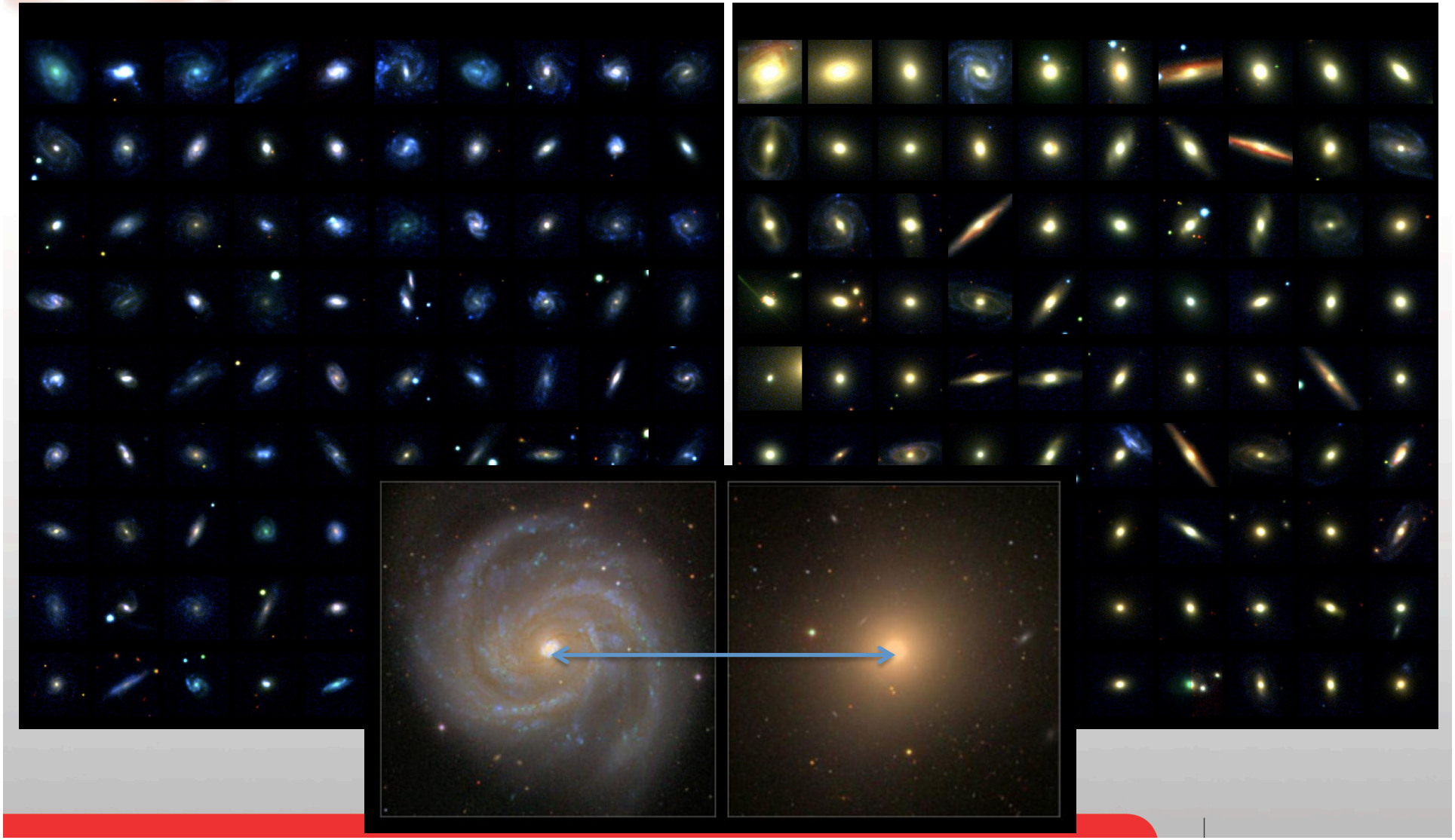


Hα Luminosity Function

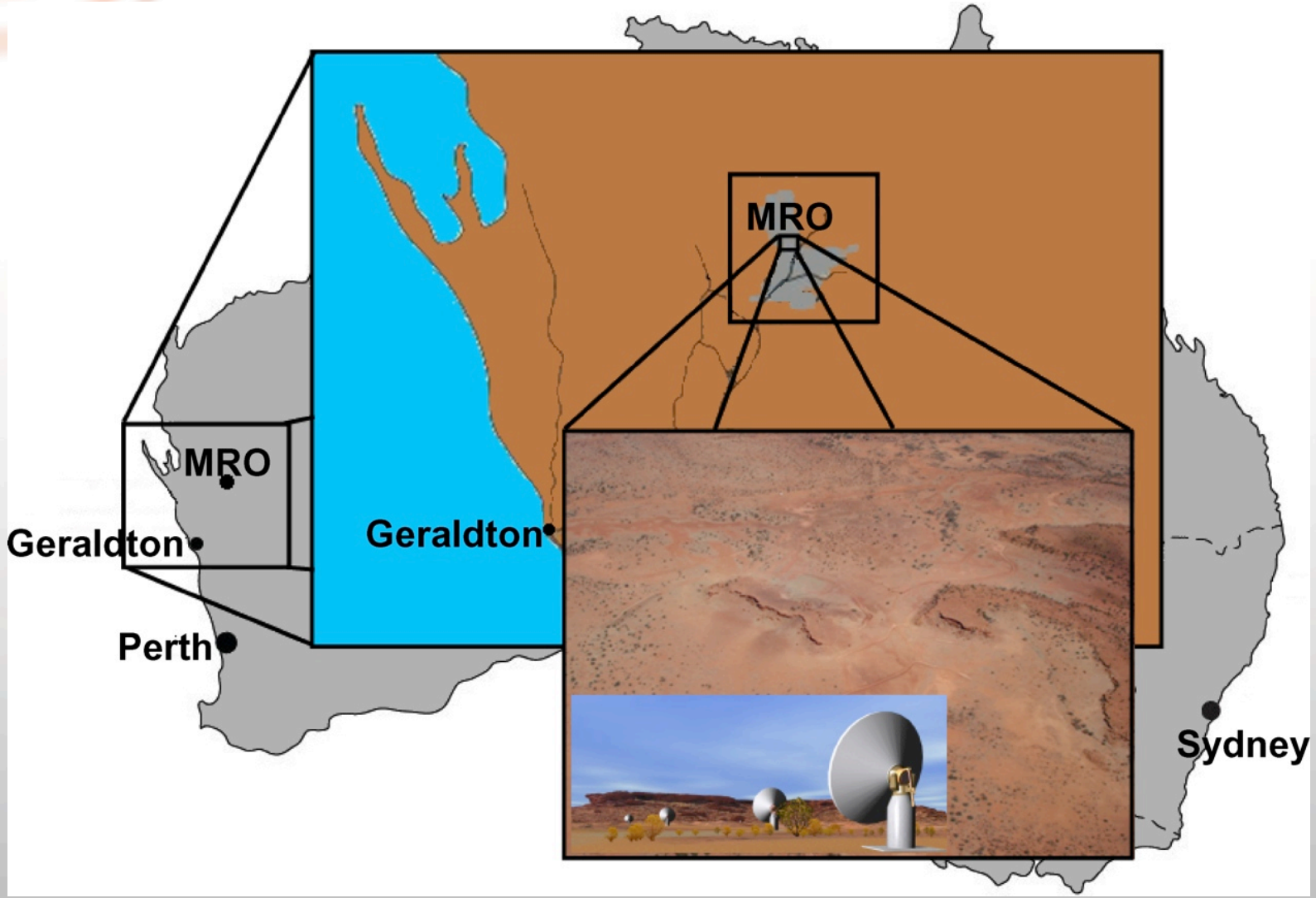


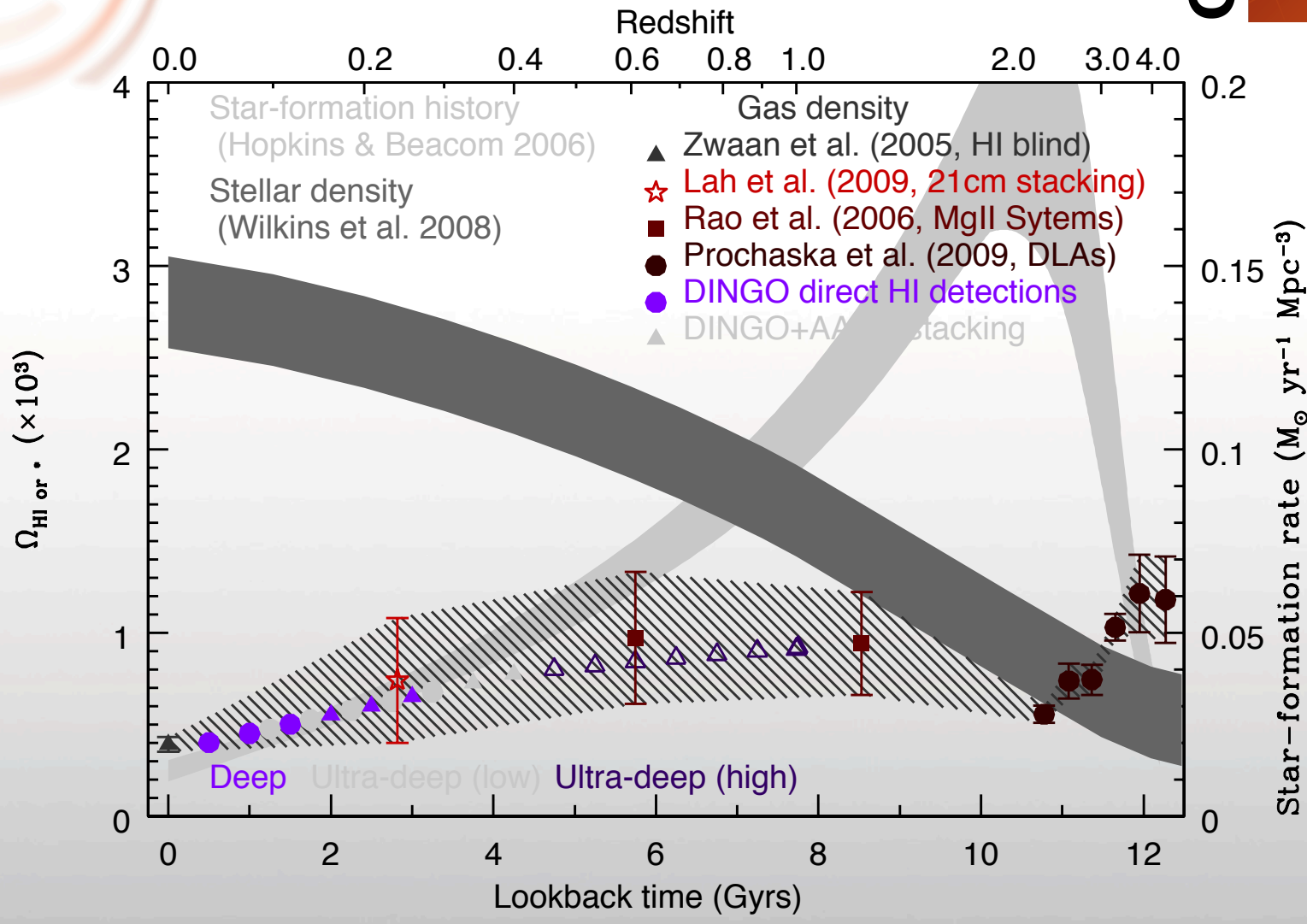


Galaxy bimodality or duality?

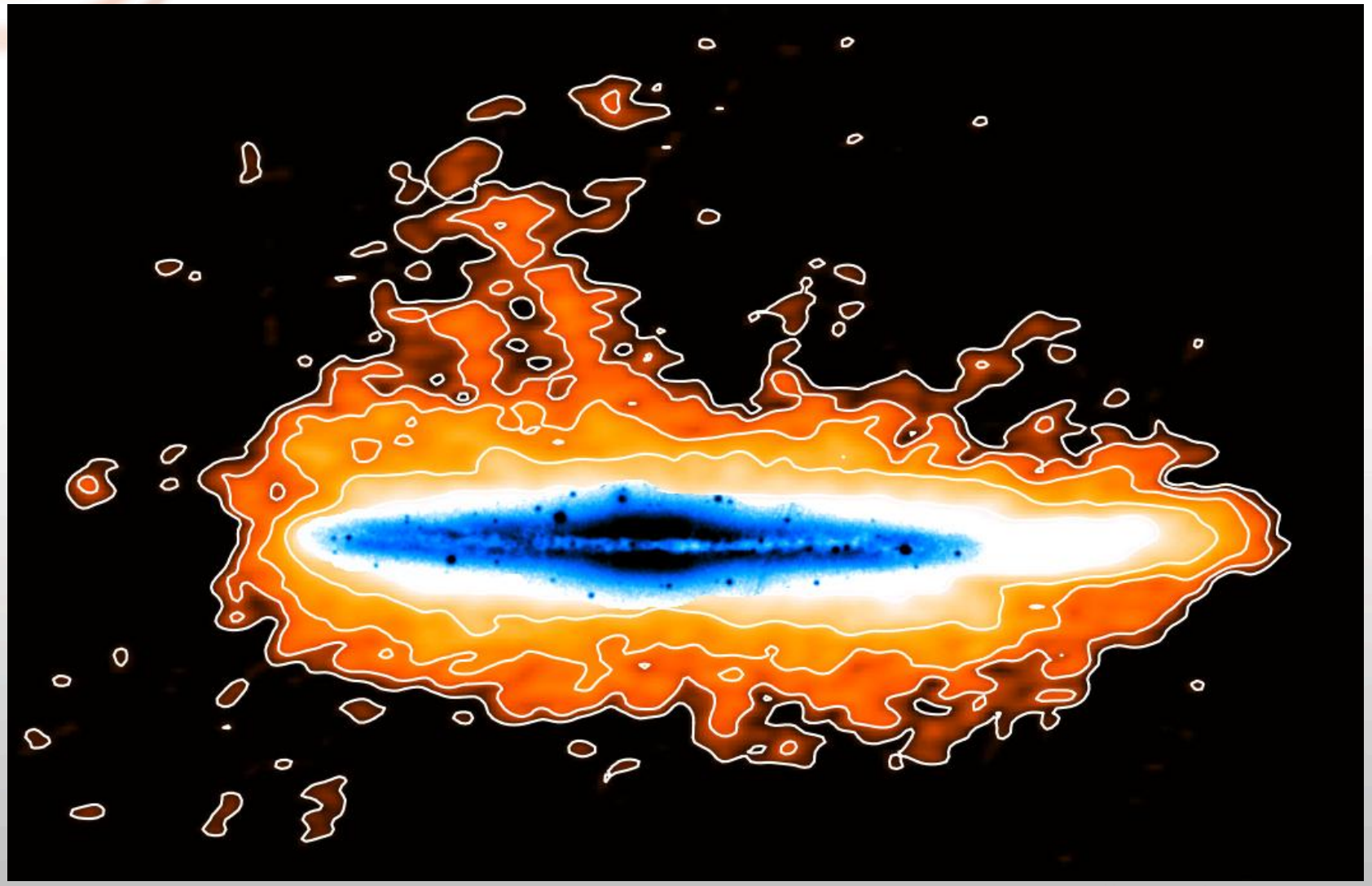


ASKAP (Australian Square Kilometer Array Pathfinder)
A$150 million investment to construct unique radio facility to study gas in galaxies




Redshift
0.0
0.2
0.4
0.6
0.8
1.0
2.0
3.0
4.0
Star-formation history
(Hopkins & Beacom 2006)
Stellar density
(Wilkins et al. 2008)
Gas density
Zwaan et al. (2005, HI blind)
Lah et al. (2009, 21cm stacking)
Rao et al. (2006, MgII Sytems)
Prochaska et al. (2009, DLAs)
DINGO direct HI detections
DINGO+AA
stacking
Deep
Ultra-deep (low)
Ultra-deep (high)
$\Omega_{HI\ or\ \bullet}$ ($\times 10^3$)
Star−formation rate ($M_\odot$ yr^{-1} Mpc^{-3})
Lookback time (Gyrs)
0
1
2
3
4
0.05
0.1
0.15
0.2
6
8
10
12

Optical and radio image of NGC891

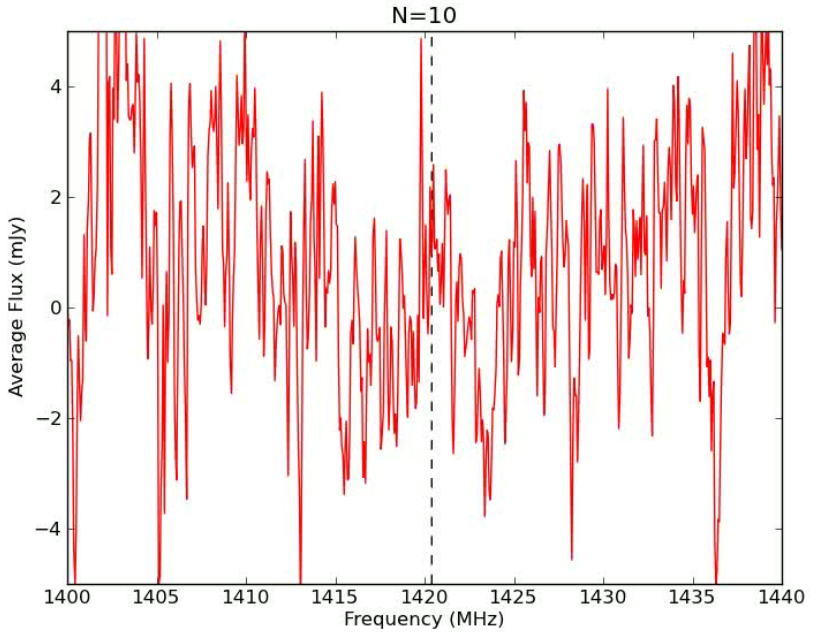


Cosmic HI

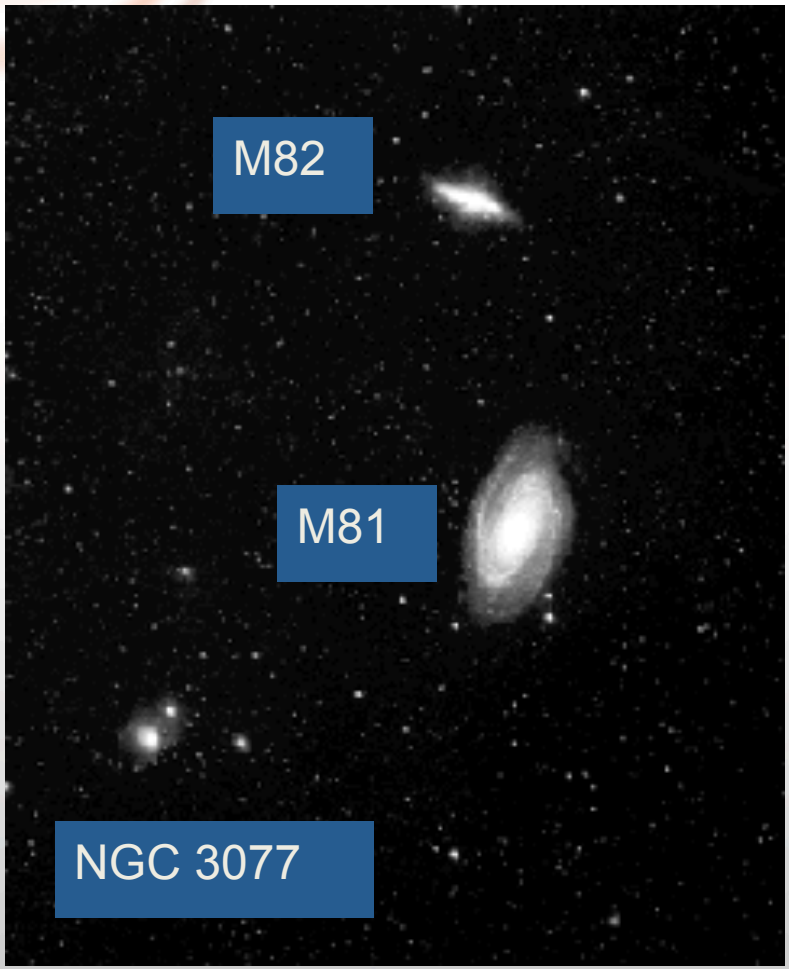
Stack HI cubes at locations of known z's

ASKAP WALLABY
- 75% of sky
- HI to z<0.26
- 600,000 detections expected
- HI, dynamical masses, rot. curves

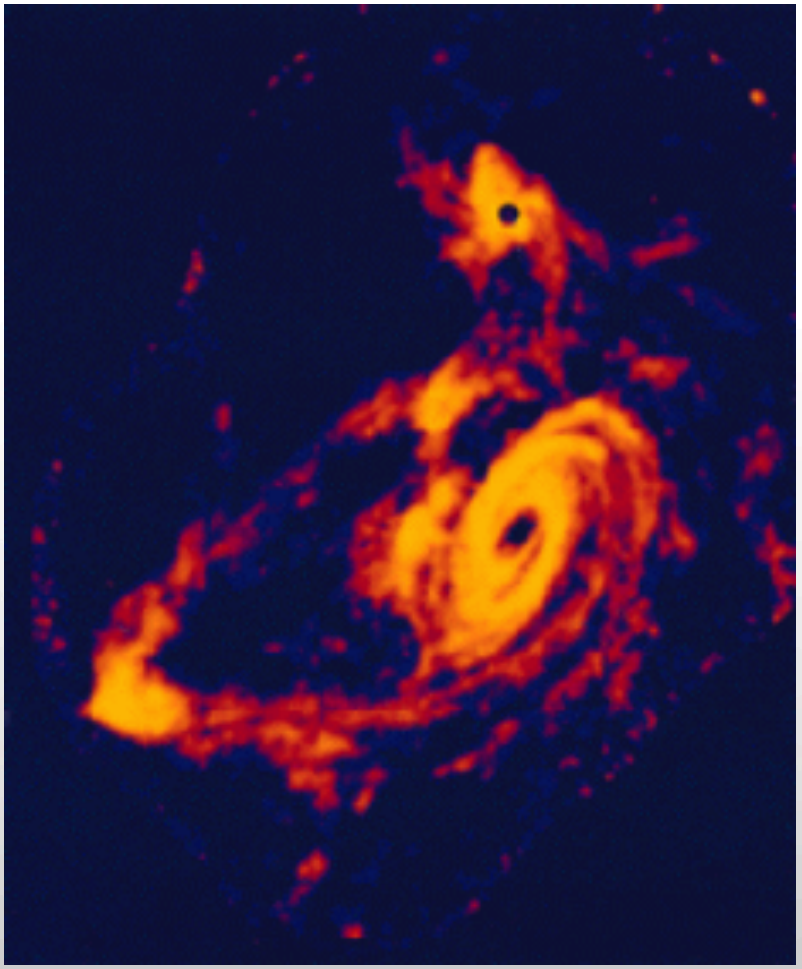
ASKAP DINGO
- 8x30sq deg fields
- 2 deep, 6 ultradeep z<0.46
- HI stacking to measure cosmic HI
- Study of gas, dust, and stars v galaxy type, SFR, Z, halo mass



How to combine data which emerges from fundamentally different regions and processes?



Optical data (stars)



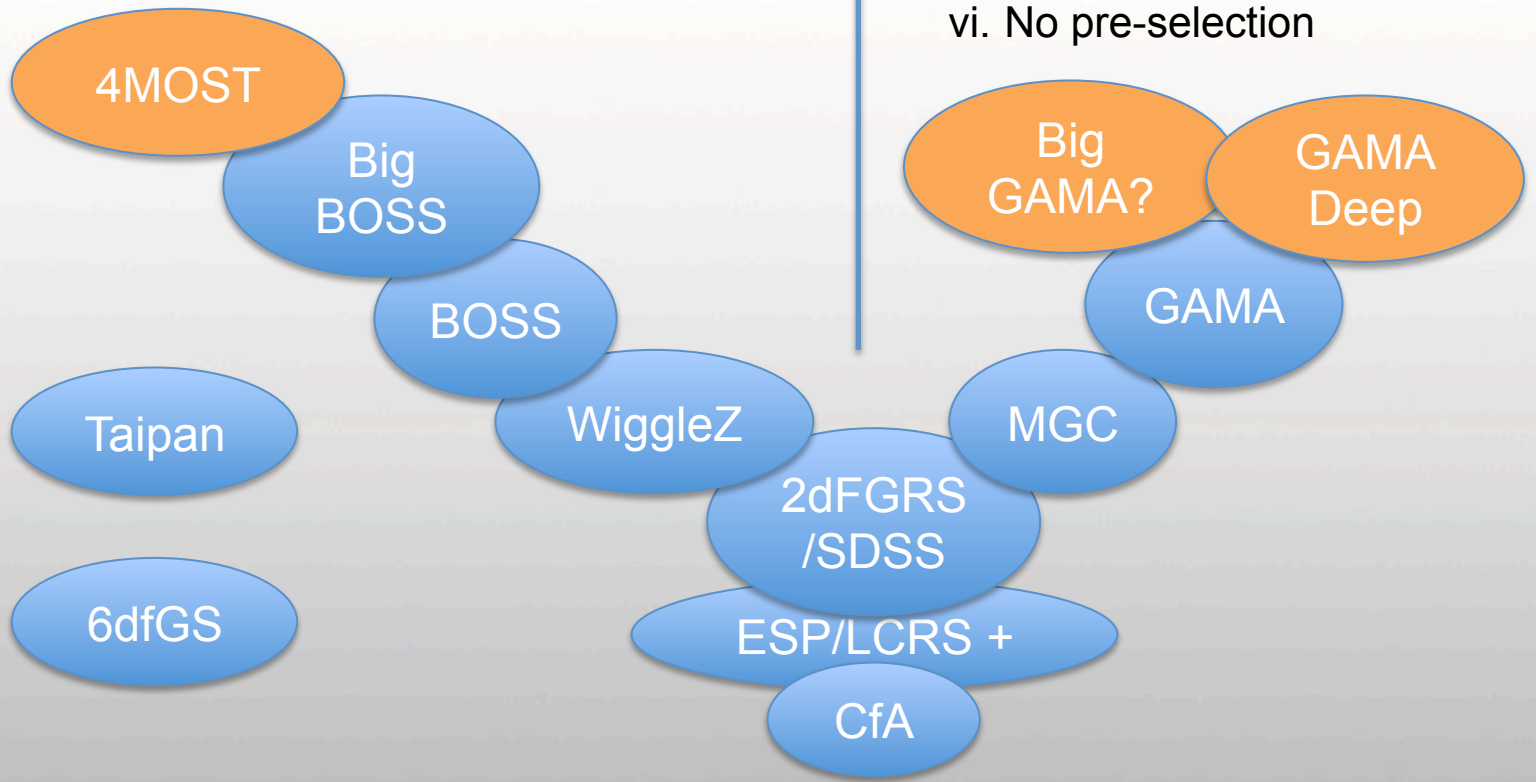
Radio data (hydrogen)

Cosmology Survey v Galaxy Survey

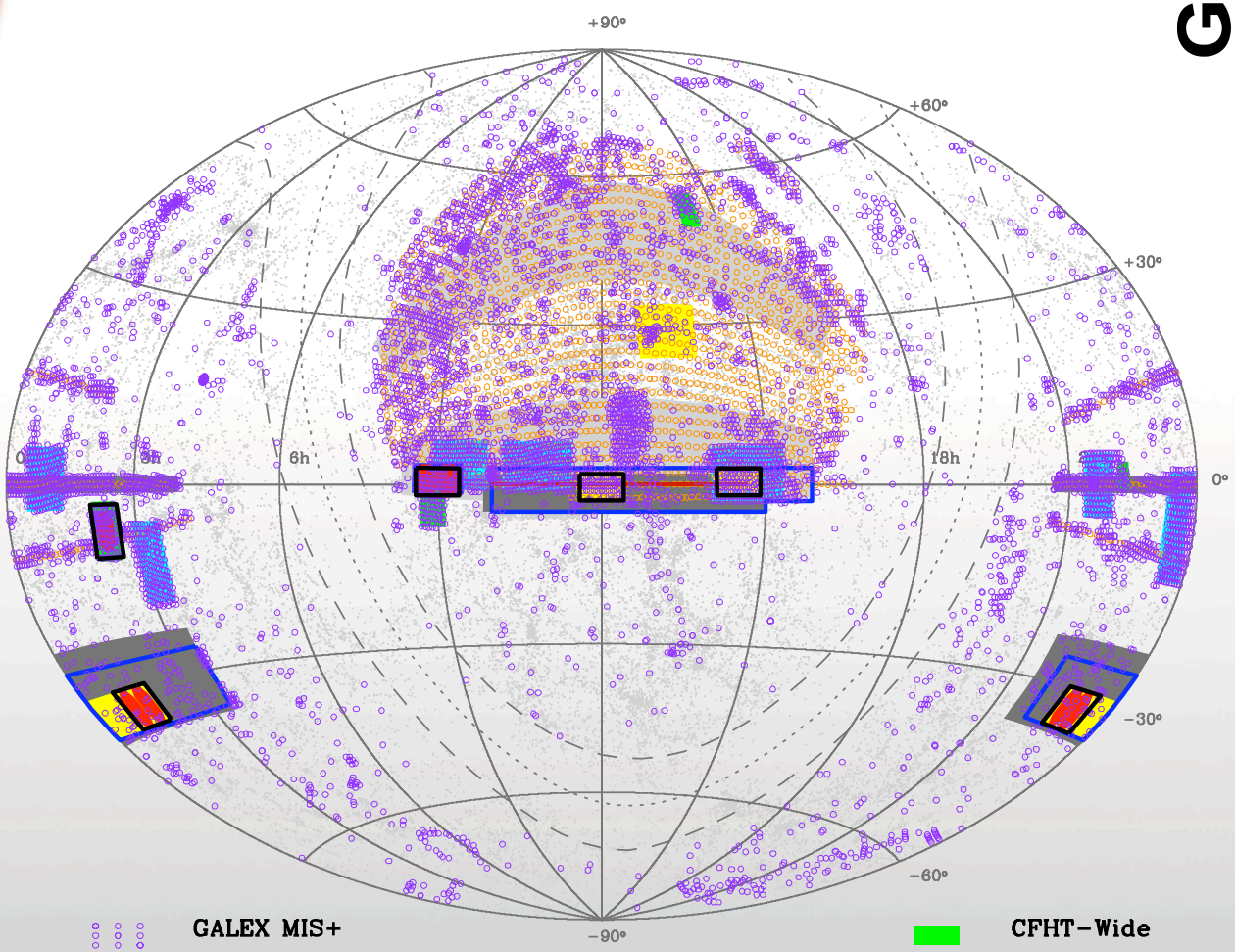
1. Optimal cosmology 4MOST survey
   i. Low fidelity
   ii. All sky
   iii. Sparse sampled
   iv. Stand alone
   v. Colour pre-selection

1. Optimal galaxy 4MOST survey
   i. High fidelity (low mass)
   ii. ~100-500 sq deg
   iii. Fully sampled (groups)
   iv. Multi-wavelength overlap (dust,stars,gas)
   v. High spatial resolution (kpc resolution)
   vi. No pre-selection

VVDS/ DEEP



Where to go


+90°
+60°
+30°
0°
−30°
−60°
−90°
0h
6h
18h
GALEX MIS+
GAMA
HERSCHEL−ATLAS
Millennium Galaxy Cat.
ASKAP−DINGO
SDSS−Main (spec. only)
WiggleZ
CFHT−Wide
2dFGRS
UKIDSS−LAS
VST−KIDS/VISTA VIKING

GAMA Wide & GAMA Deep

f.o.v. 4.5 sq. deg, 1600 fibres, R~5000

1. GAMA Wide
    i. r<19.8 mag
    ii. 190sq. deg (Hatlas)
    iii. fully-sampled
    iv. 1000 gals/sq. deg
    v. 190k galaxies
    vi. 22h < RA < 2h

~63 fields, 2 passes, 3x20mins

~18 dedicated nights required

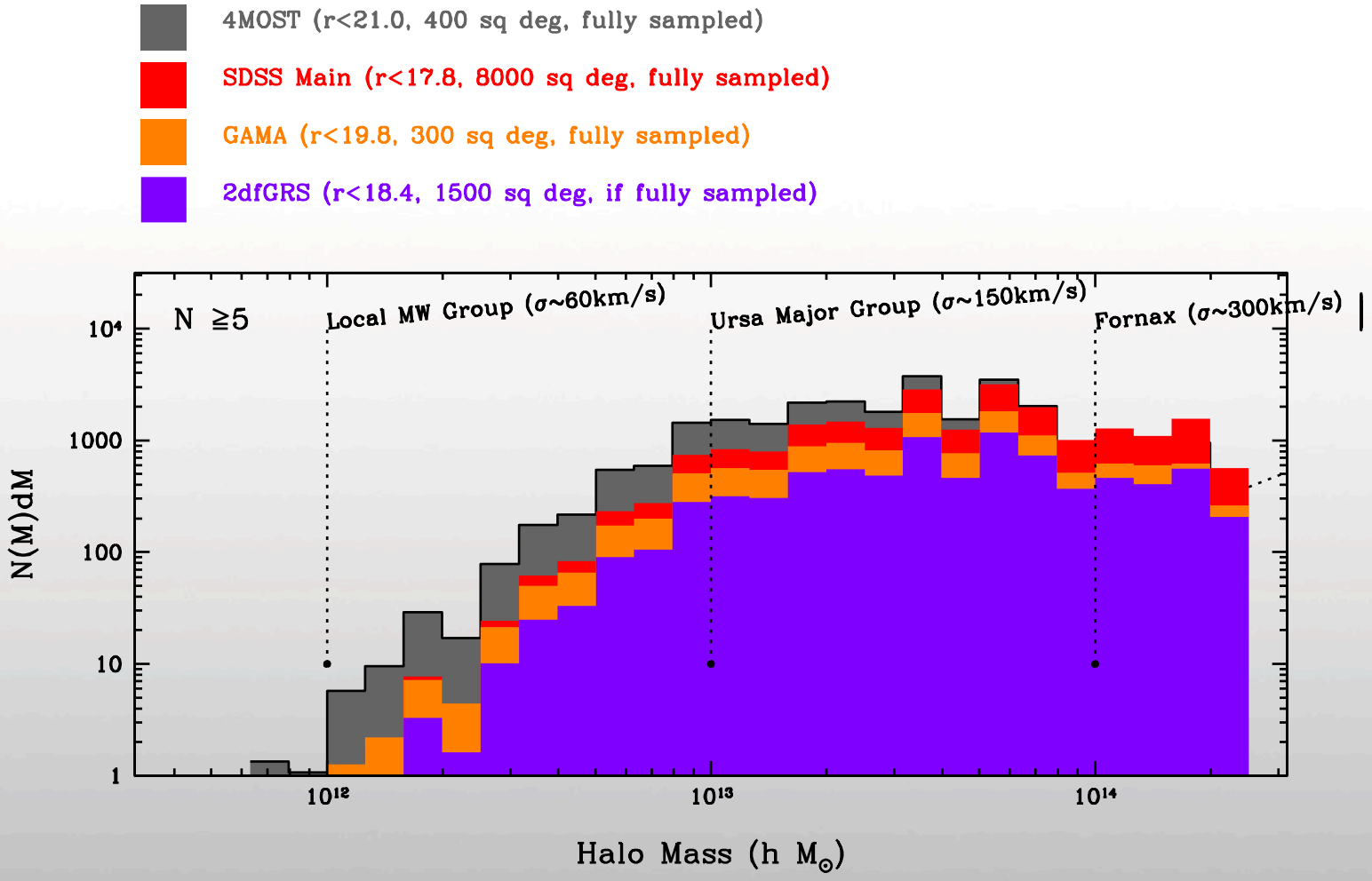
1. GAMA Deep
    i. r<21mag
    ii. 100sq. deg (400 sq deg)
    iii. fully-sampled
    iv. +1500 objects per sq. deg
    v. 150k galaxies
    vi. 22h and 2h

~33 fields, 2 passes, 6x20mins

~17 dedicated nights required

Complete survey of Herschel Atlas sky region to r<21mag
GAMA deep & wide: 86 dedicated nights, 790k galaxies+380k from GAMA over 400 sq deg of sky

Group expectation (rough)



GAMA Wide & GAMA Deep

f.o.v. 4.5 sq. deg, 1600 fibres, R~5000

1. Key survey design features:
   i. High pair/group fidelity – multiple passes
   ii. High redshift completeness – unbiased faint-end studies
   iii. Unbiased – no pre-selection beyond star-galaxy
   iv. High dynamic mass range – wide AND deep
   v. Galaxy group studies to 100s of Local Group mass halos
   vi. Galaxy constituents (AGN, gas, dust and stars) –multi-λ
   vii. Galaxy components (bulge, bar, disc) – 1kpc resolution
   viii. GALEX+VST+VISTA+WISE+HERSCHEL+ASKAP from outset

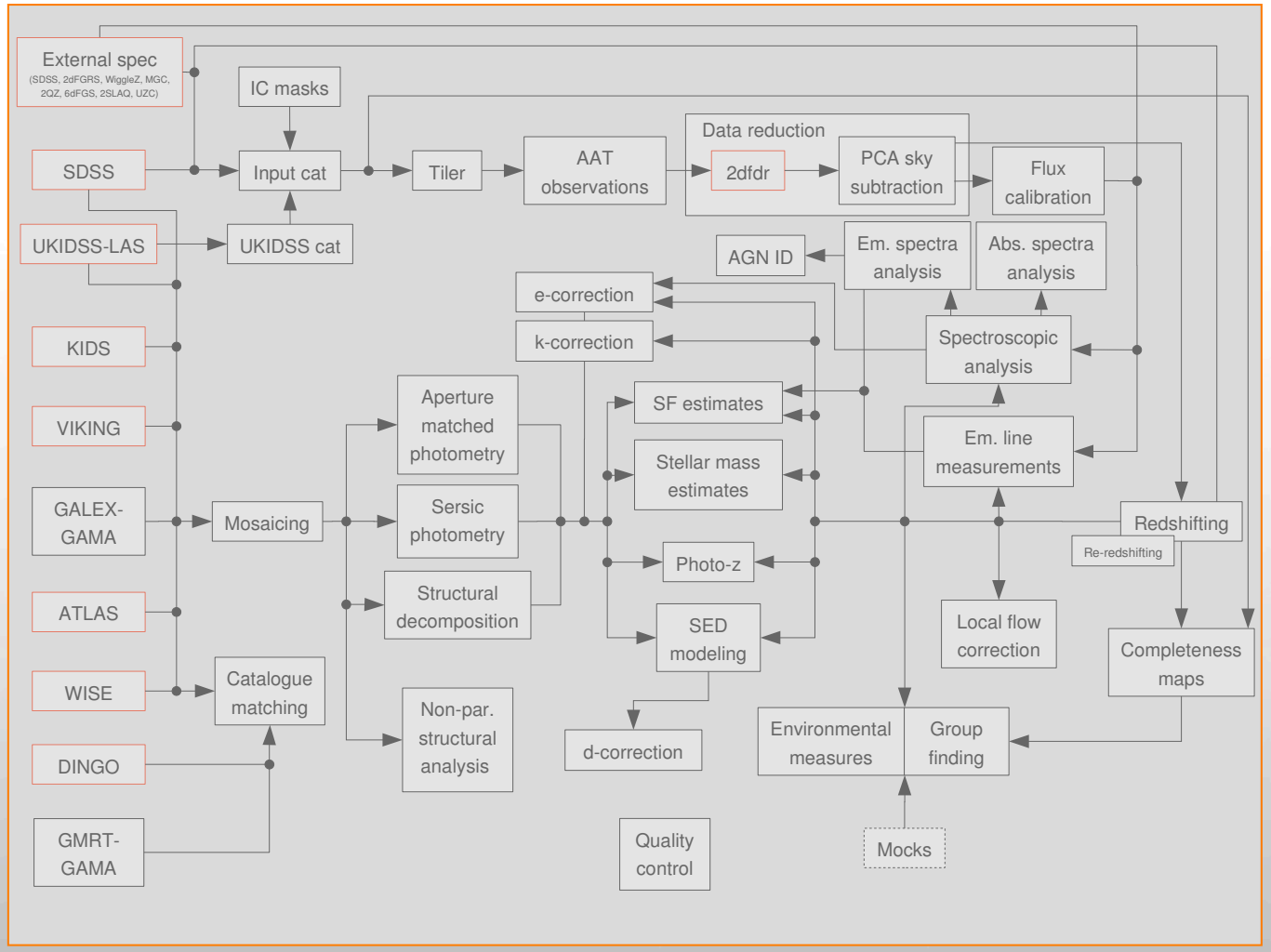
Complete survey of Herschel Atlas sky region to r<21mag
GAMA deep & wide: 86 dedicated nights, 790k galaxies+380k from GAMA over 400 sq deg of sky

Lessons learnt

1. Massive software task, serious software funding required, start early
2. Dataset is only as good as the data interface, more non-science funding needed
3. At every automated step 20% of your output will be rubbish, these build-up quickly!
4. 90% of your time will be spent on QC
5. A few people do a lot, most do nothing, project depends on finding these few people
6. Progress better when effort is localised/centralised
7. The right tiling strategy vital (don't get tied up in knots)

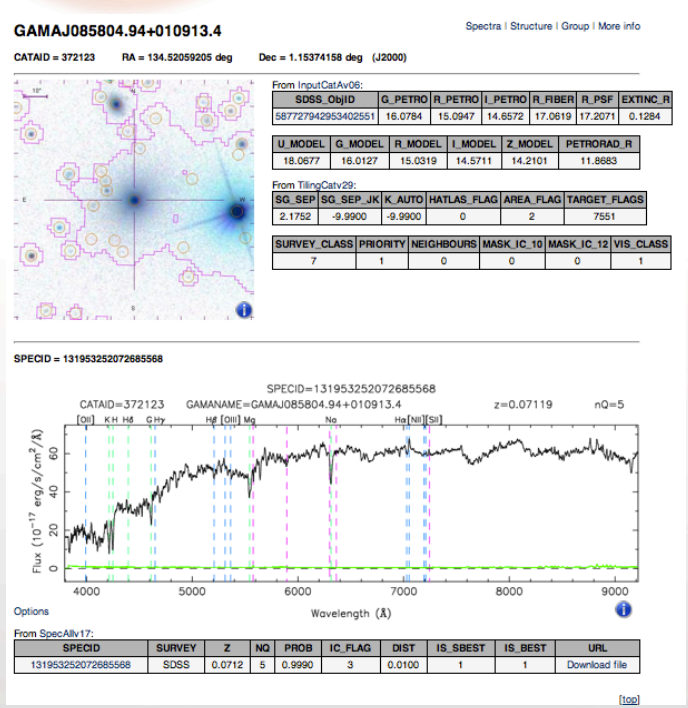
GAMA pipeline

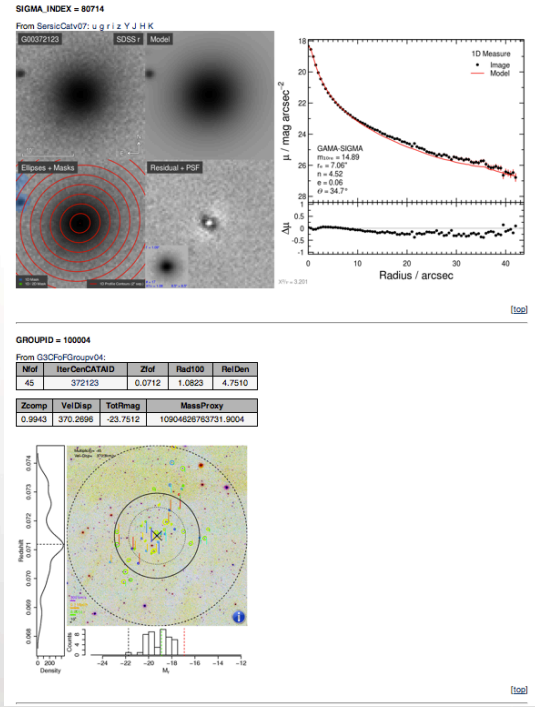
Budget: $0

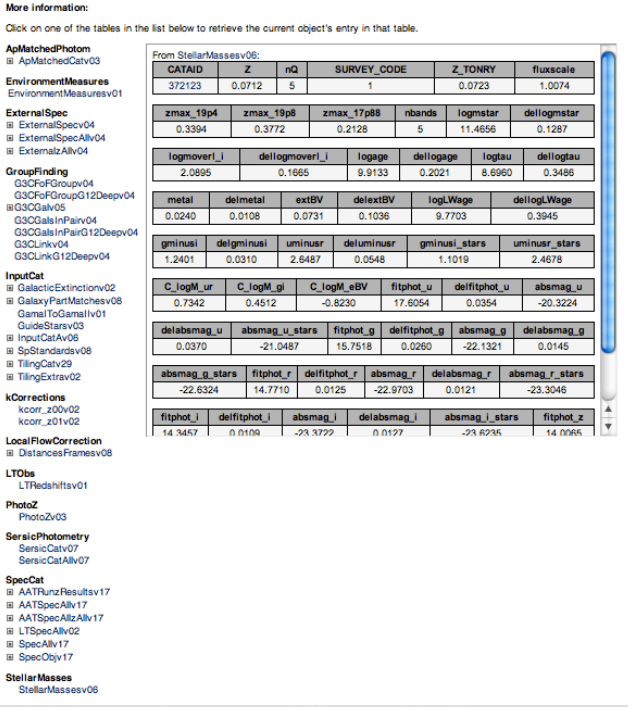


GAMA Database

Budget: $0.00







Single object viewer (above)
SQL Query Builder

Multi-object viewer
Multi-band cutout tool

SQL query tool
Colour stamp generator

Your database is only as good as its usability but don't expect anyone to fund it!

GAMA Data Release 2 (Jan 2013, AAS LongBeach)

All redshifts in G15 to r<19.4mag (Liske et al in prep)
All redshifts in G09 & G12 to r<19.0mag
GAMA Groups (Robotham et al 2011)
Stellar Masses (Taylor et al 2011)
9 band Sersic profiles (Kelvin et al 2011)
ugrizYJHK matched aperture photometry (Hill et al 2011)
GALEX Photometry (Seibert et al in prep)
Spectroscopic line indicees (Hopkins et al submitted)
SDSS and UKIRT LAS SWARPs (Hill et al 2011)

Sponsors

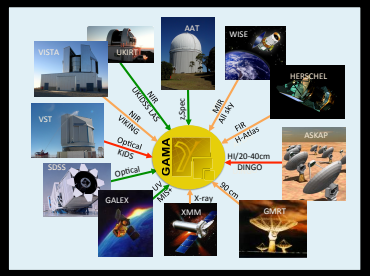
SUPA Physics Scotland
University of St Andrews
ICRAR International Centre for Radio Astronomy Research
Australian Government Department of Industry Innovation, Science, Research and Tertiary Education
AAO

Funding Agency Support

Science & Technology Facilities Council
Australian Government Australian Research Council
erc European Research Council Established by the European Commission
THE ROYAL SOCIETY

GAMA Team

60 researchers (including 15 PhD students) across 20 institutions

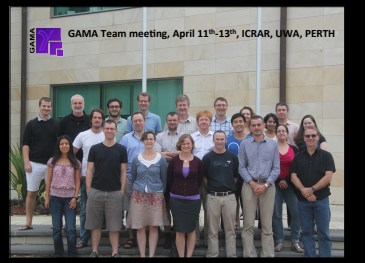


Progress

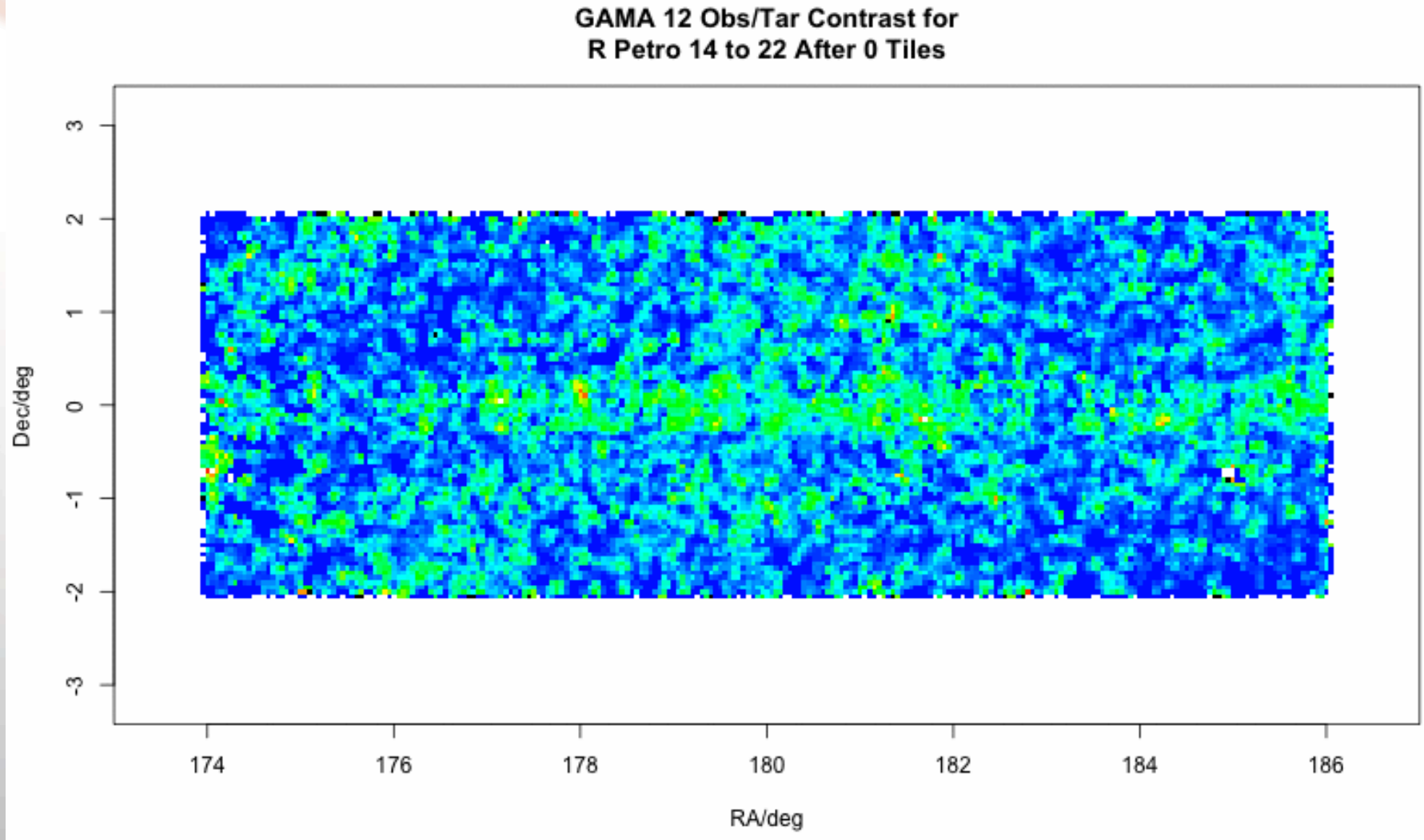
40+ publications (50% HAtlas led)
120 papers in progress (50% led by non GAMA-team members)

http://www.gama-survey.org/

gama@gama-survey.org



GAMA Tiling

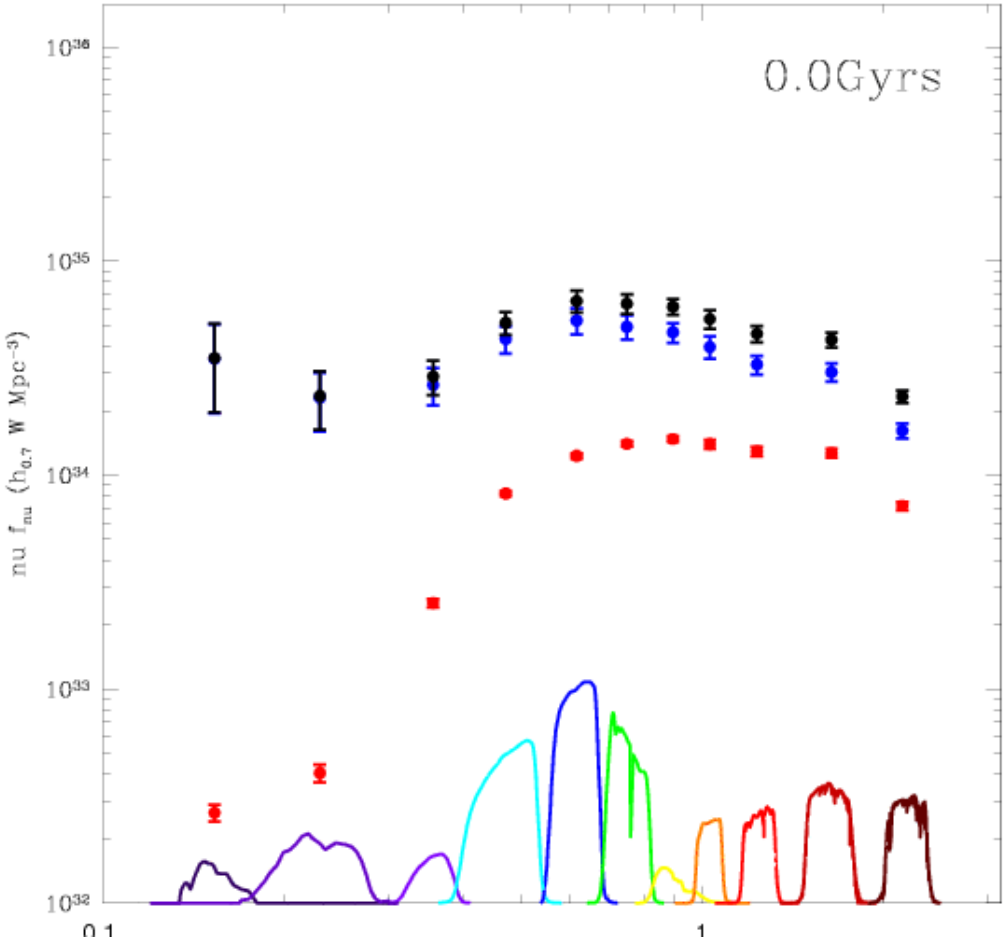

GAMA 12 Obs/Tar Contrast for
R Petro 14 to 22 After 0 Tiles
Dec/deg
3
2
1
0
-1
-2
-3
174
176
178
180
182
184
186
RA/deg

Modeling the energy output of the nearby Universe

Zero-free parameter model based on two axioms

Agreement implies axioms provide an acceptable model:

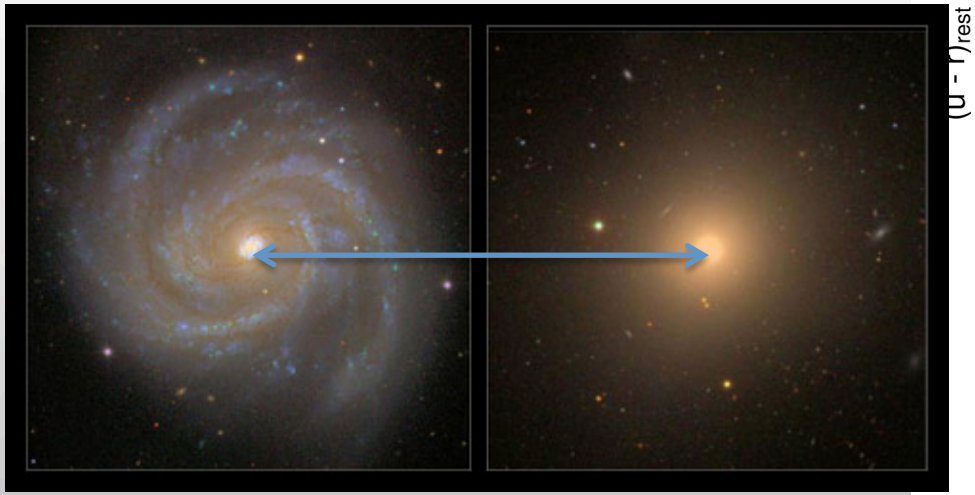
- Spheroid formation follows AGN
- Spheroid dominates early CSFH
- Baldry & Glazebrook (2003) IMF
- Linear metalicity evolution
- CSFH (Hopkins & Beacom 2003)
- AGN Activity (Richards et al 2005)

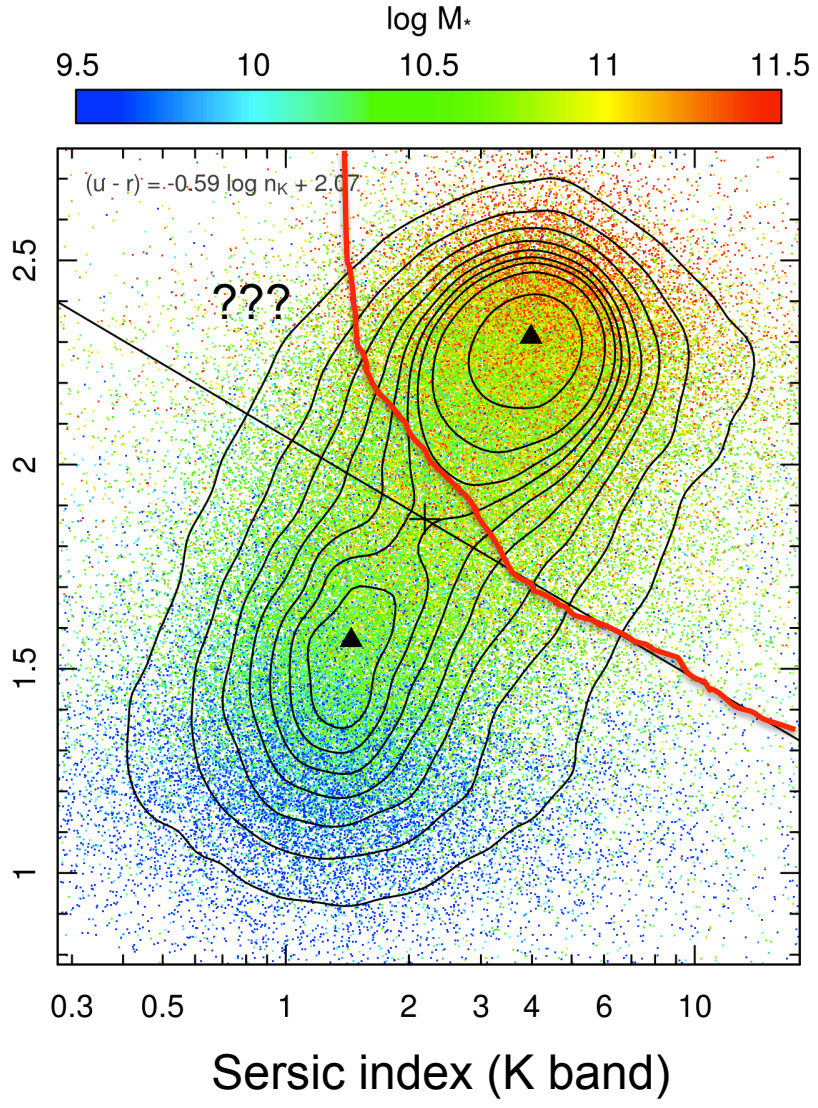


Joint structure colour cut

Kelvin et al (2011)

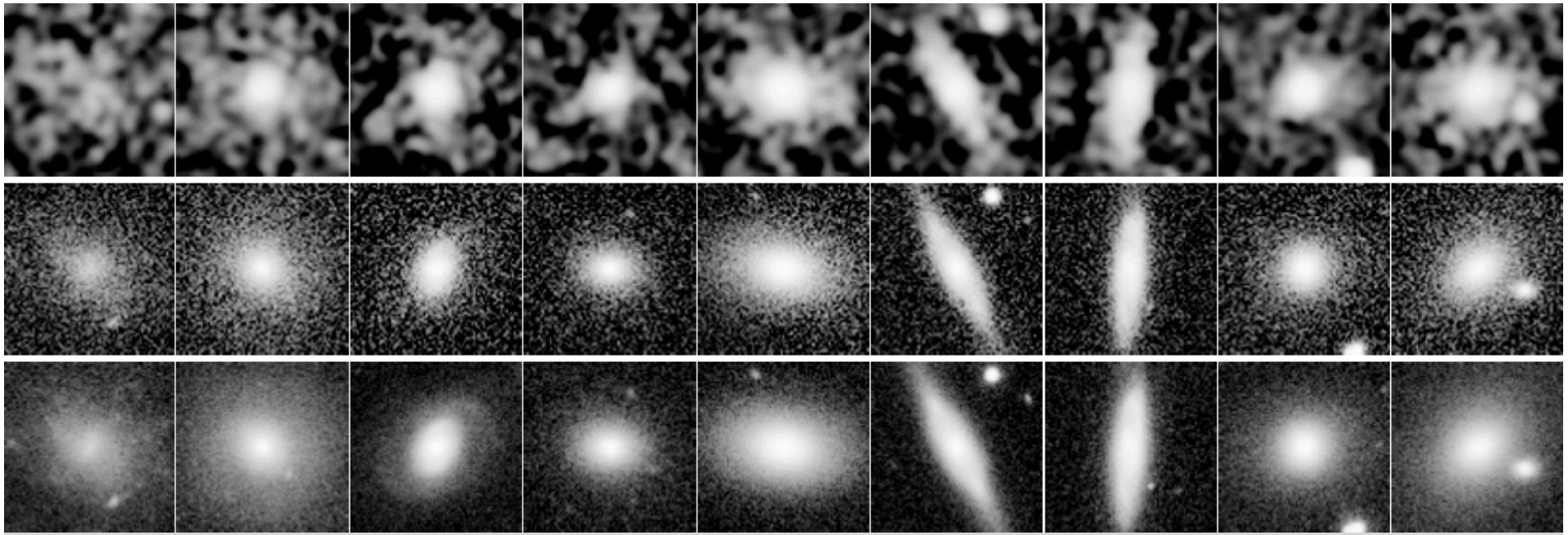
Bimodality or duality ?



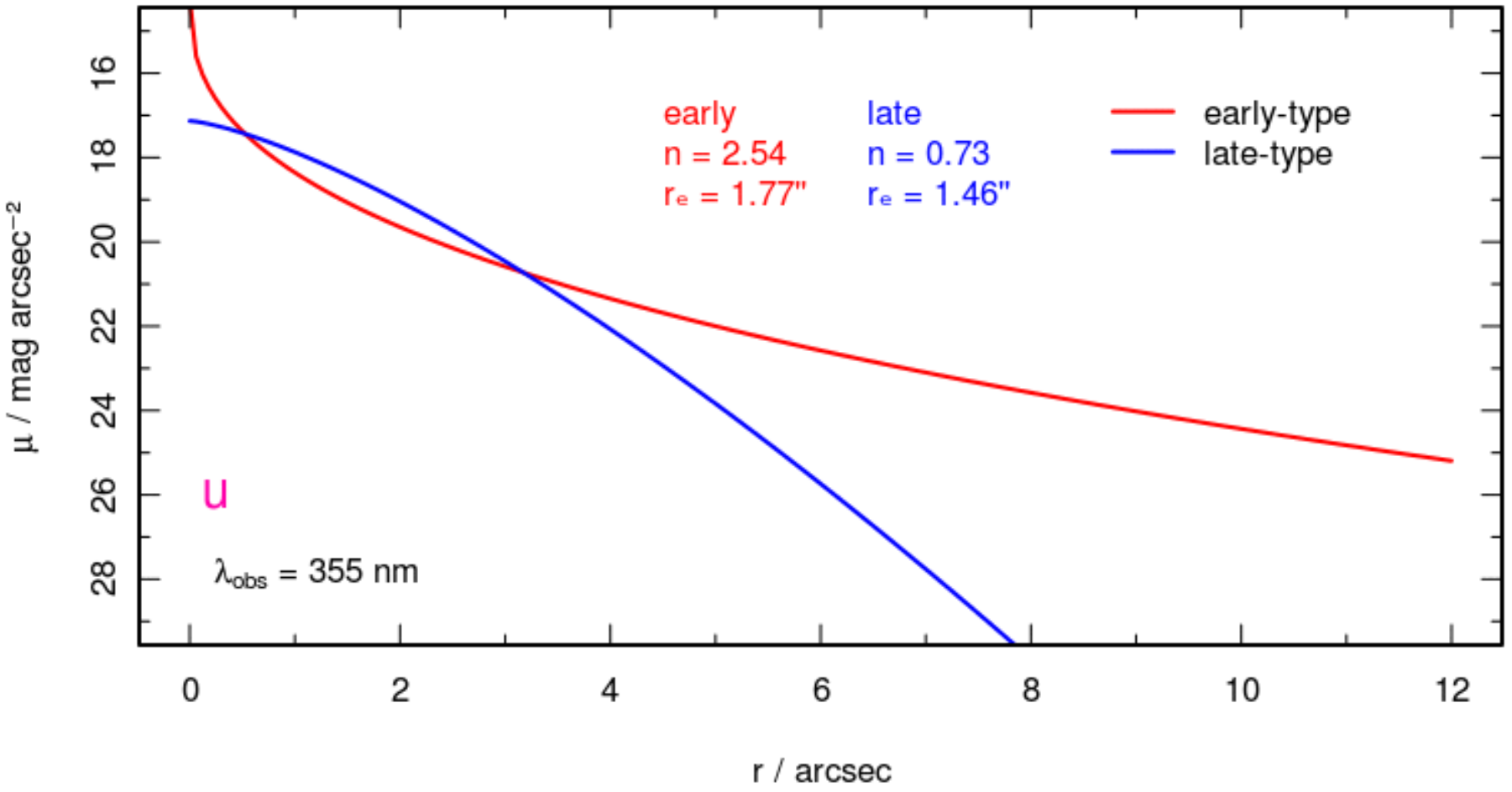


GAMA: Building on 2MASS

2MASS → UKIDSS LAS → VISTA VIKING

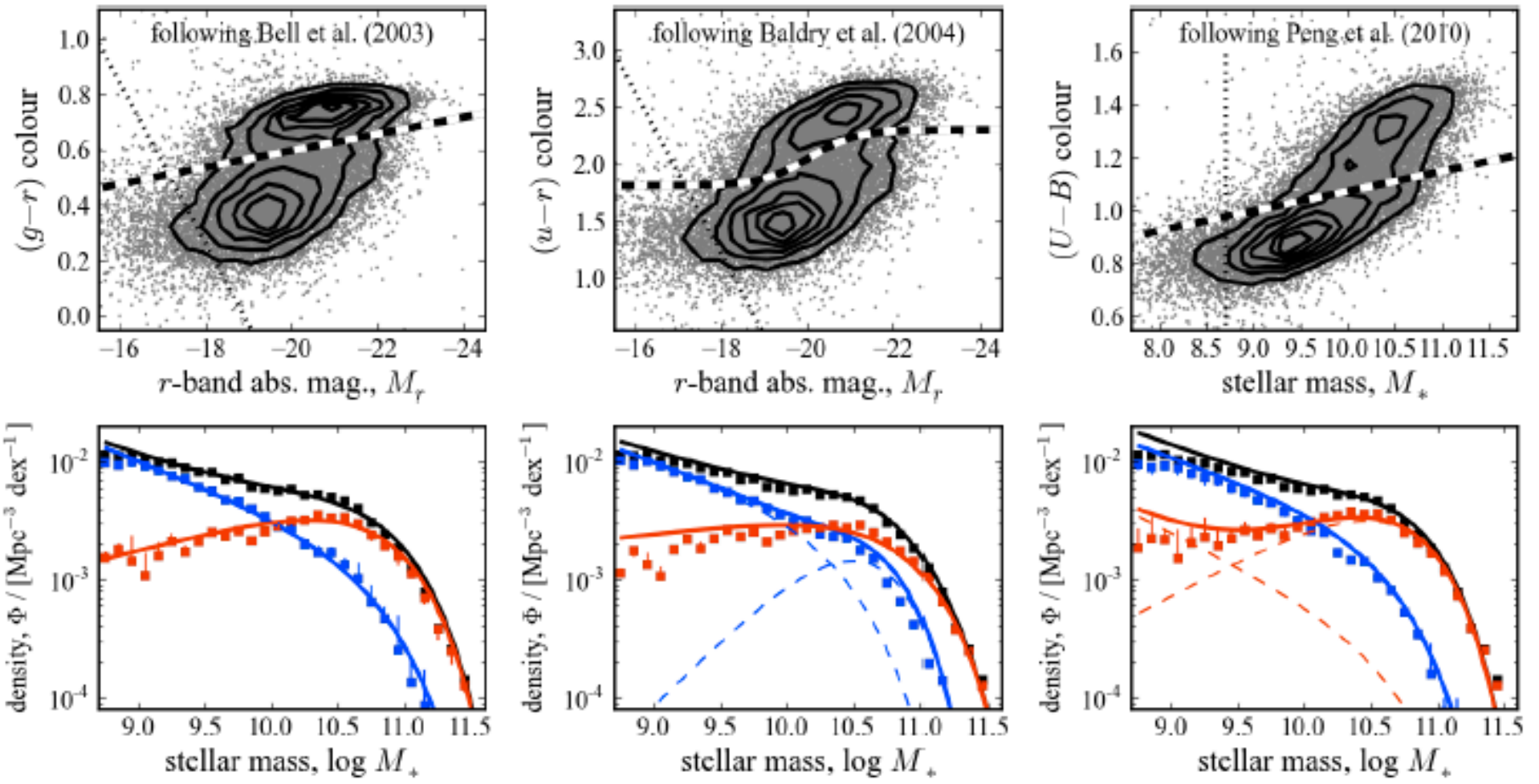


Mean galaxy profile v λ

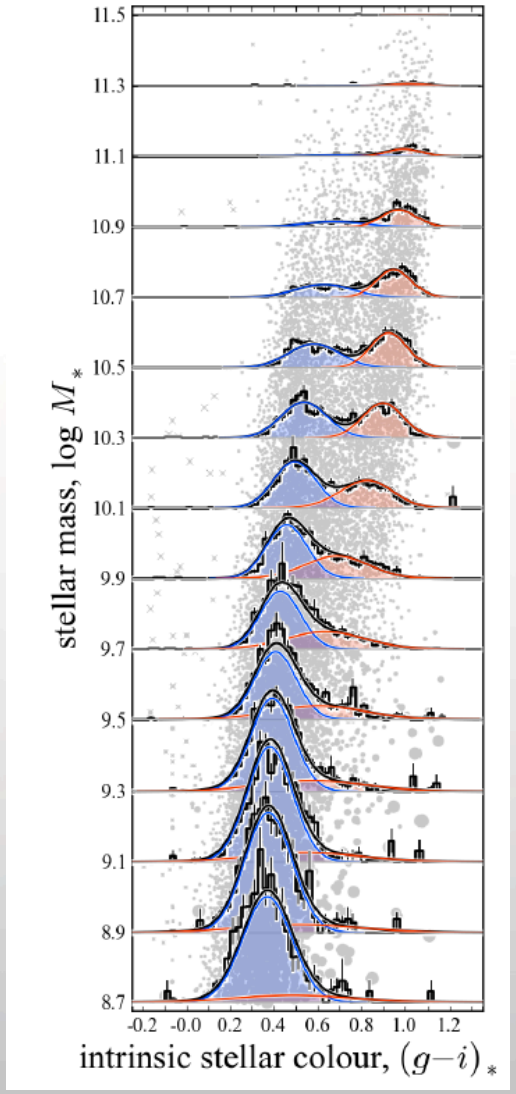


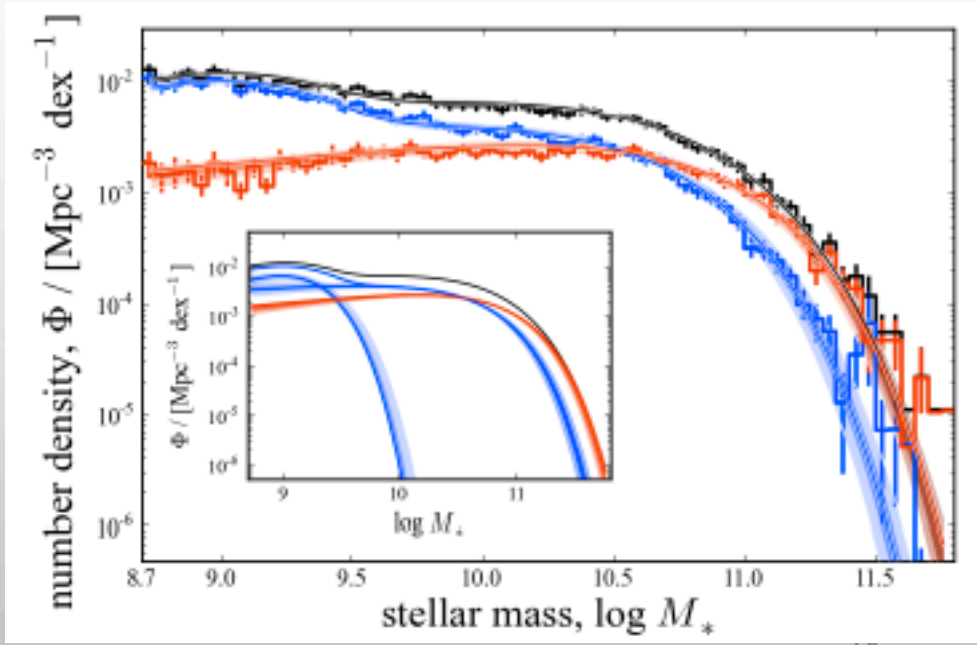
Local group analogues

Galaxy Bimodality

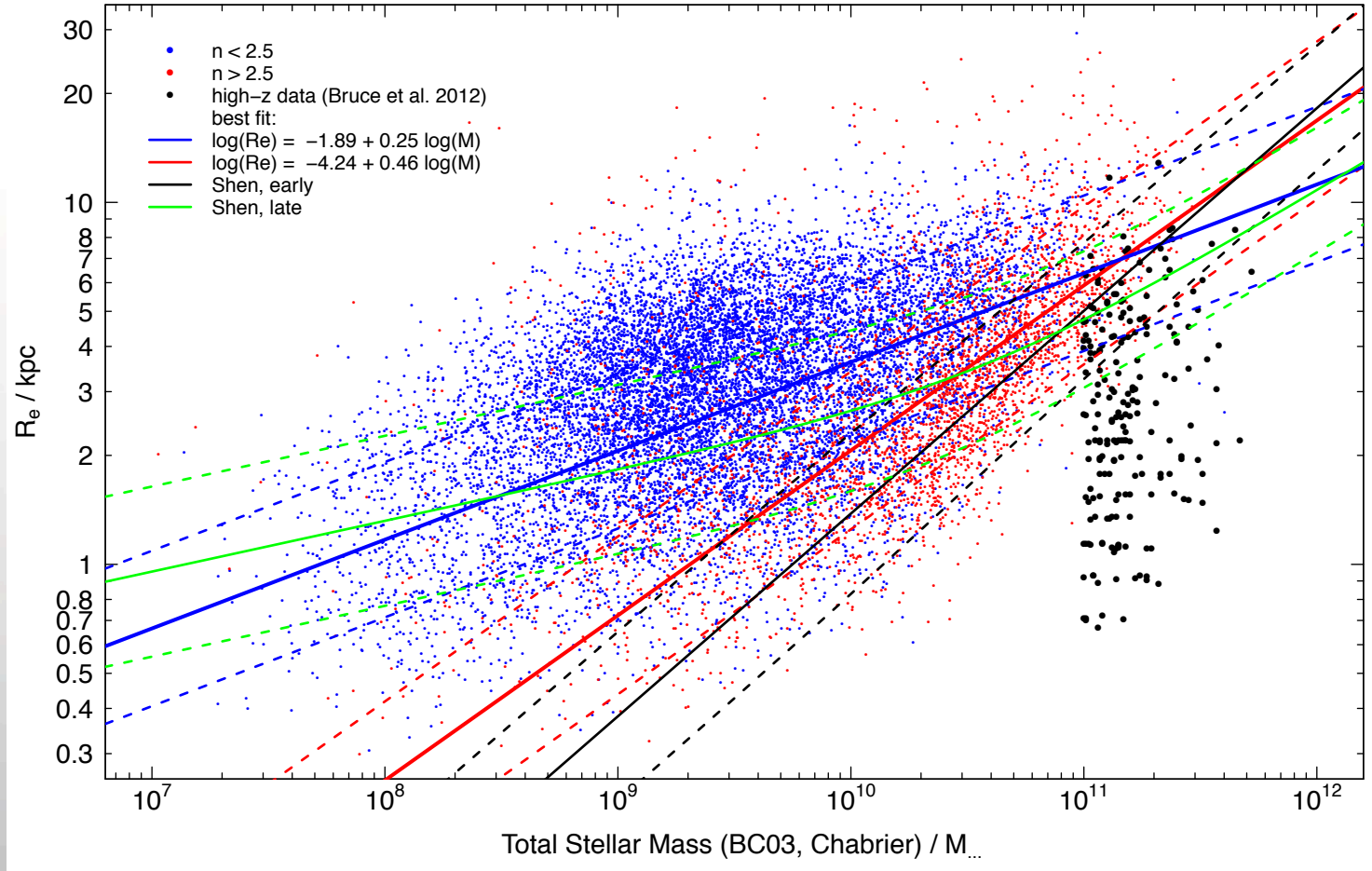


Galaxy Bimodality





The stellar mass-size relation of galaxies



Building leading galaxy databases to study the mass and energy evolution of the Universe

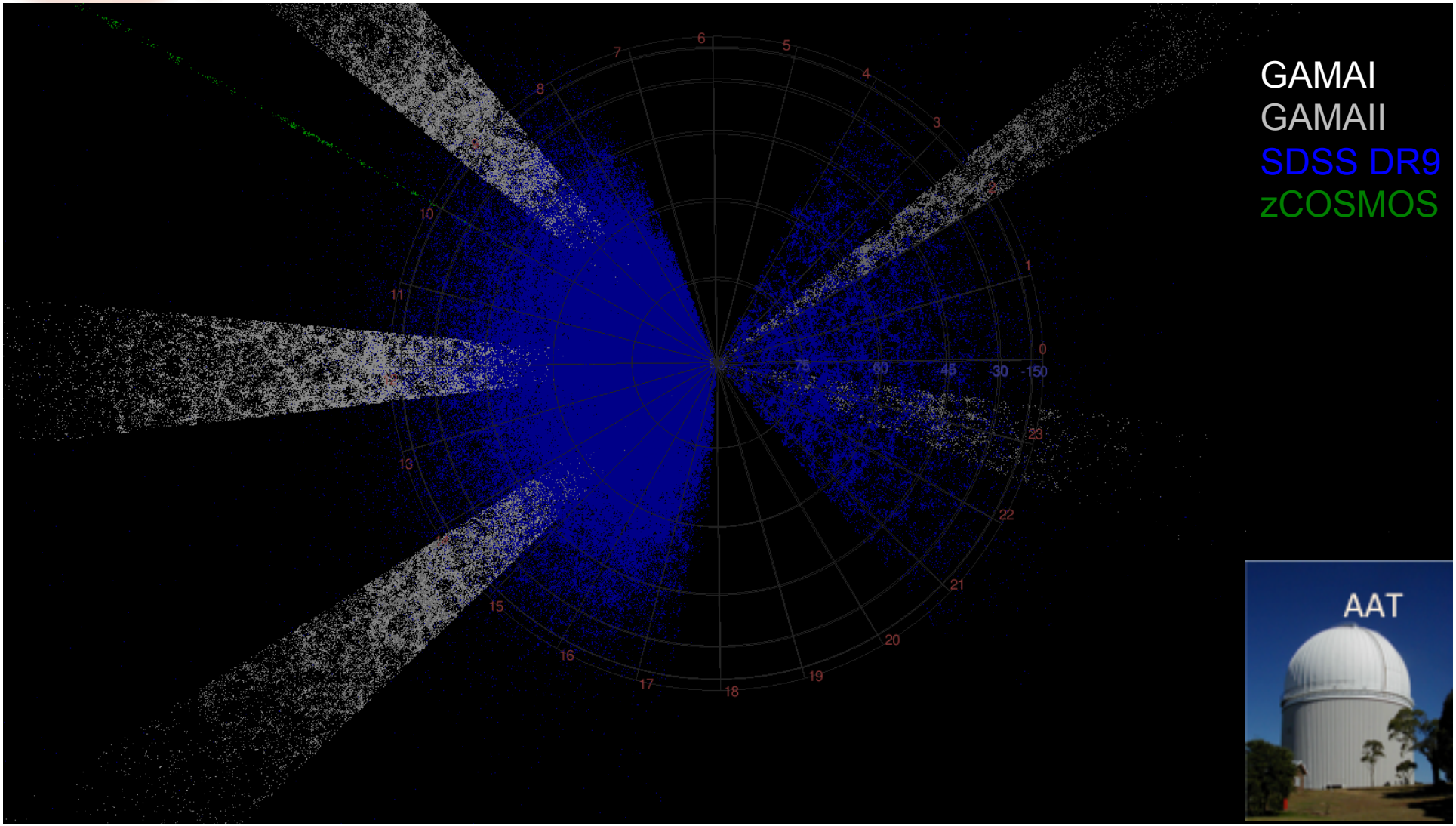
What is GAMA

1. A spectroscopic survey on the Anglo-Australian Telescope
   i. 380,000 galaxies in five 60sq deg regions
   ii. r<19.8 mag (selected from SDSS DR6), no pre-selection
   iii. Fully sampled (~7 passes to resolve pairs, triplets, groups)
   iv. 3000-9000A at 3-5A resolution

+

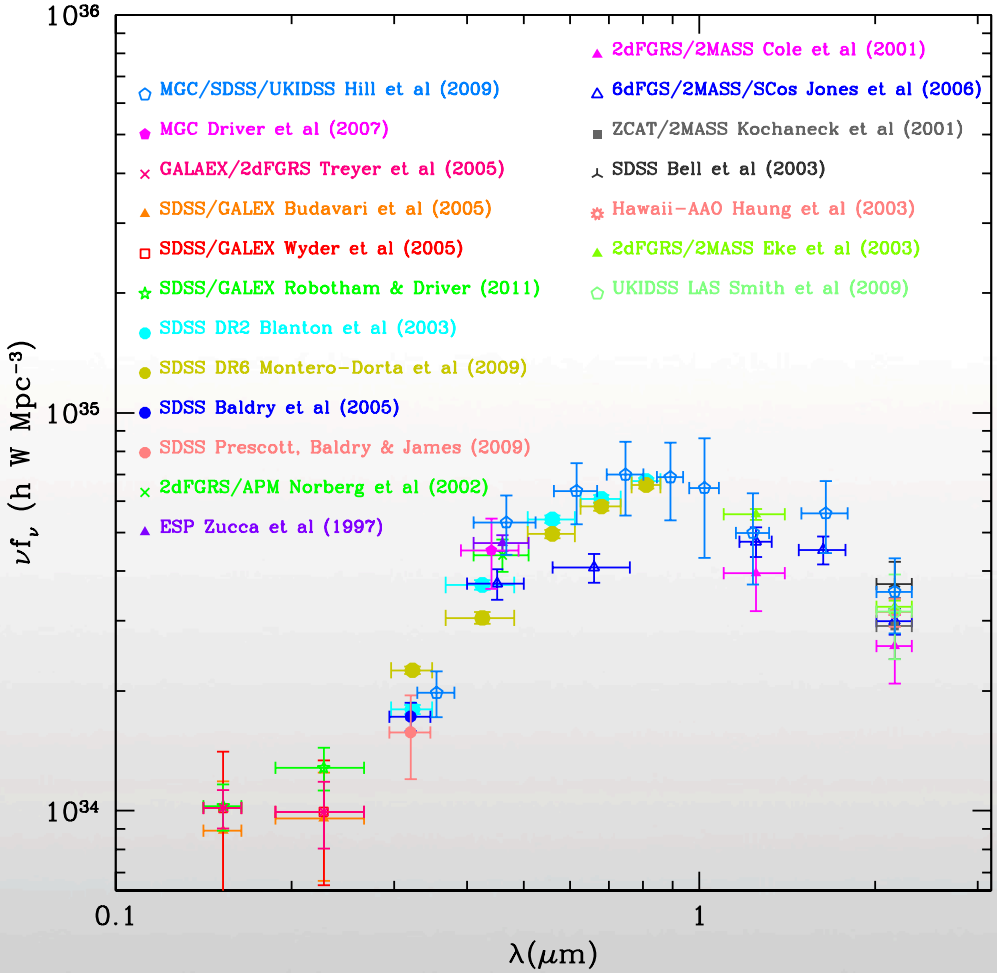
1. Overlapping/supporting imaging from:
   i. GALEX (MIS, GO and Purchased orbits: Madore, Tuffs)
   ii. VST KIDs (ESO Public Survey: Kuijken)
   iii. VISTA VIKING (ESO Public Survey: Edge & Sutherland)
   iv. WISE (NASA Public Survey: Wright)
   v. HERSCHEL-Atlas (Herschel Public Survey: Eales & Dunne)
   vi. ASKAP DINGO (ICRAR-led survey: Meyer)
   vii. GMRT (Hatlas/GAMA follow-up campaign: Jarvis)

Without redshifts science is very limited: GAMA is currently the 3rd largest z survey: SDSS, BOSS, GAMA, 2dFGRS, (LEGAS?), WiggleZ



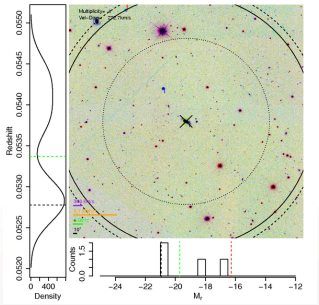
The Cosmic Spectral Energy Distribution (pre-GAMA)

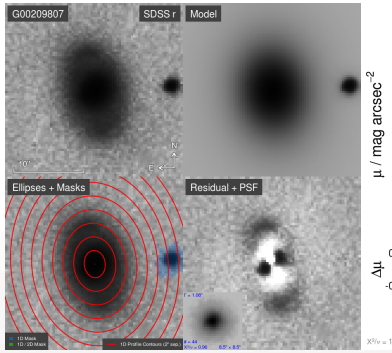
Hill et al (2010)

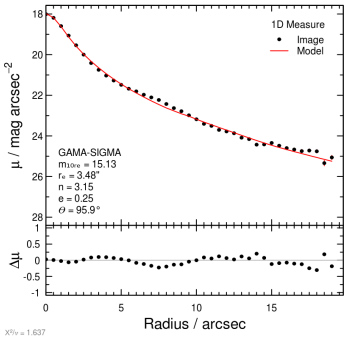


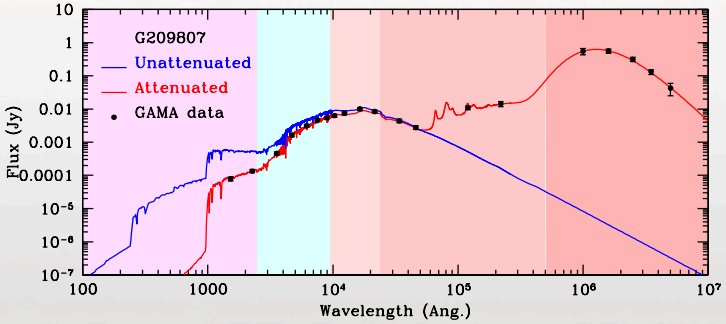
G209807

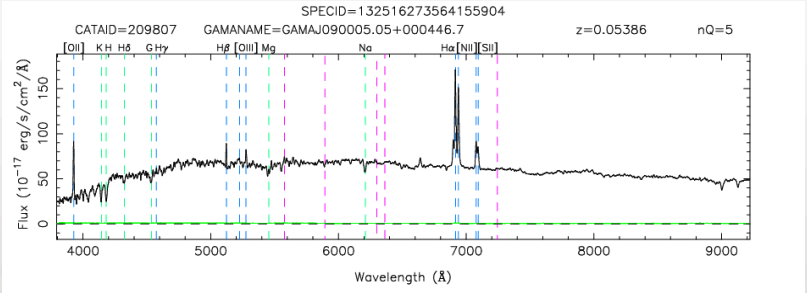
One down 379,999 to go….in reality many data will be upper limits only….deblends…interlopers

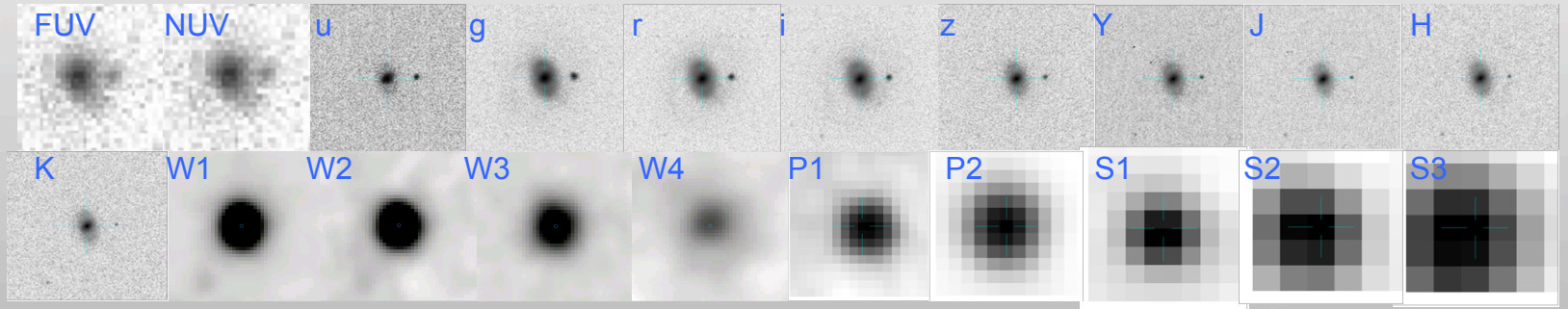


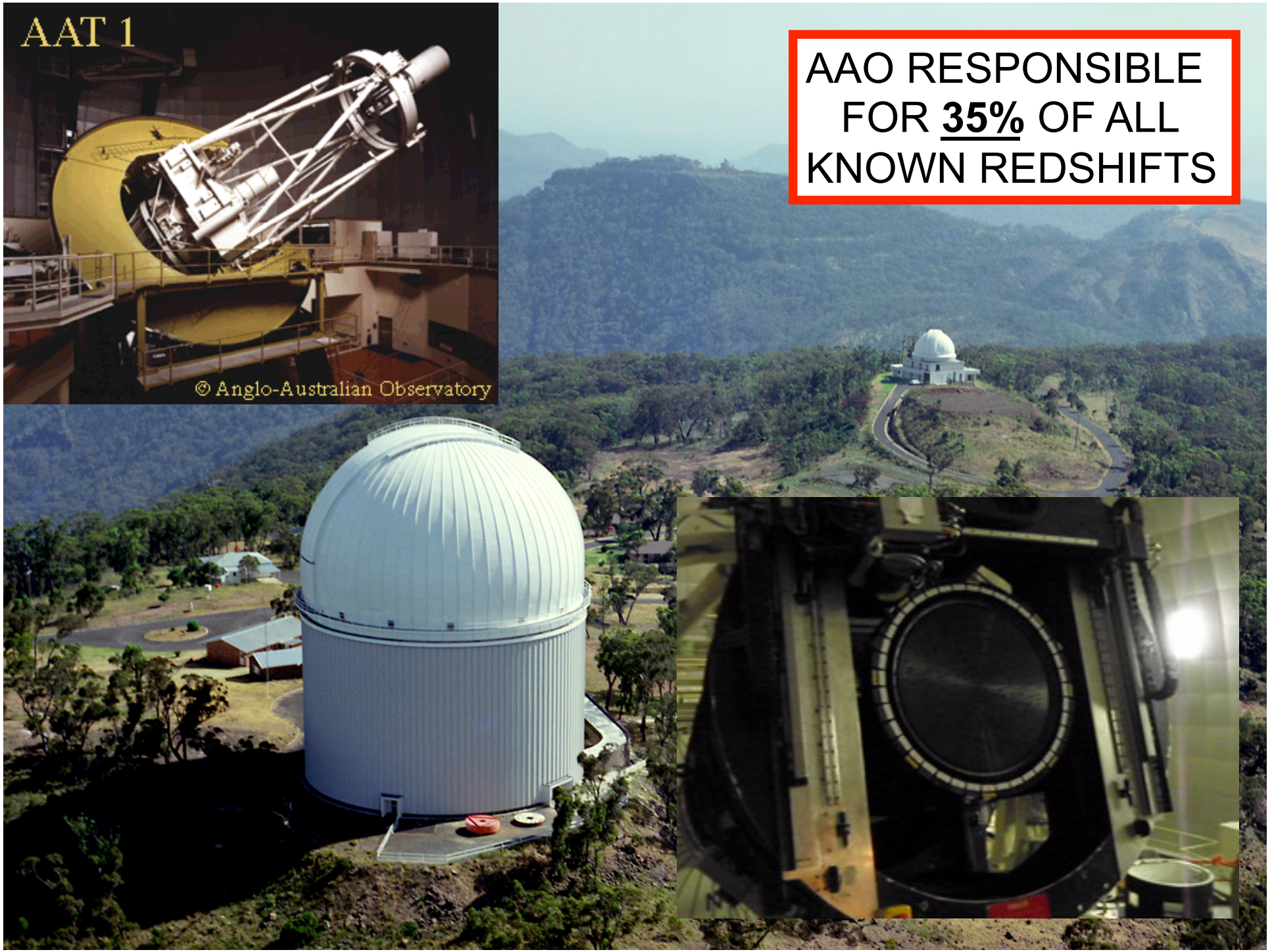










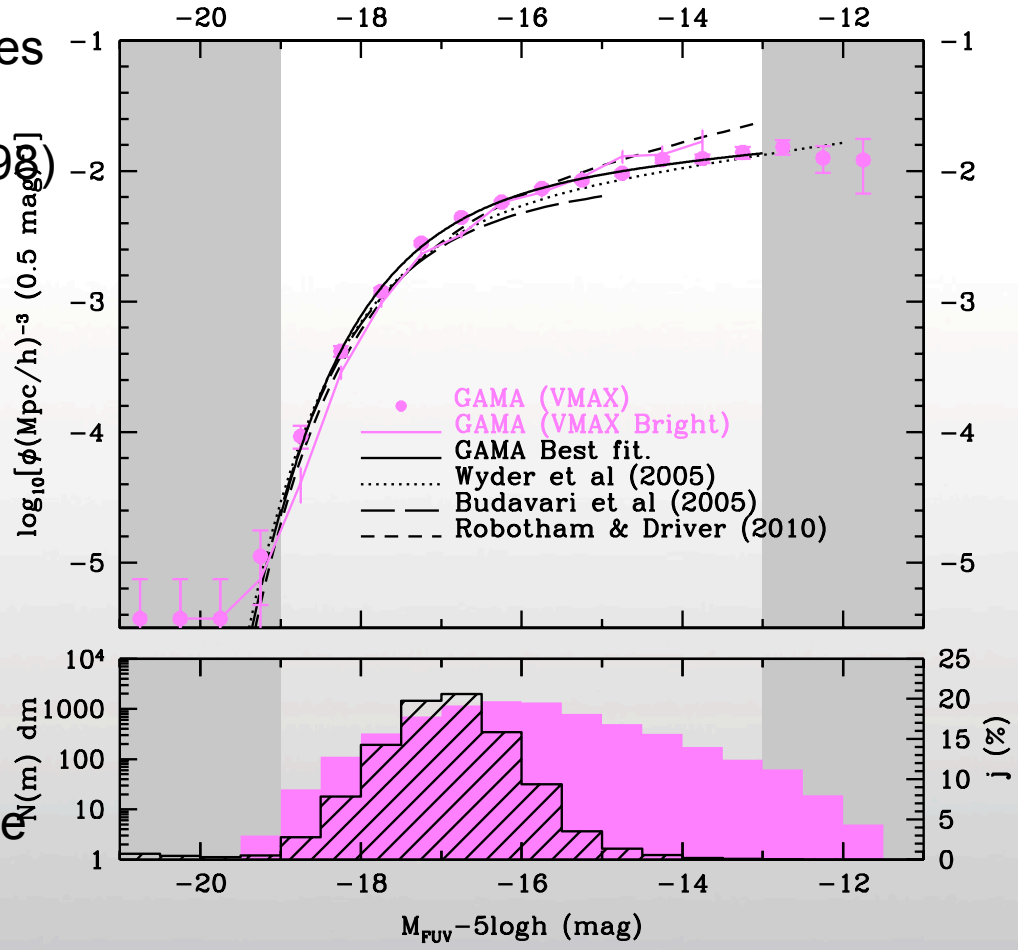

AAT 1
© Anglo-Australian Observatory
AAO RESPONSIBLE FOR 35% OF ALL KNOWN REDSHIFTS

GAMA FUV Luminosity Function and Luminosity Density

FUV LF consistent with previous measures

SFR(hM./yr/Mpc^3) = 0.034 (Kennicutt 1998)
+/- 0.003 Random
+/- 0.009 Dust Correction
+/- 0.002 Cosmic Variance

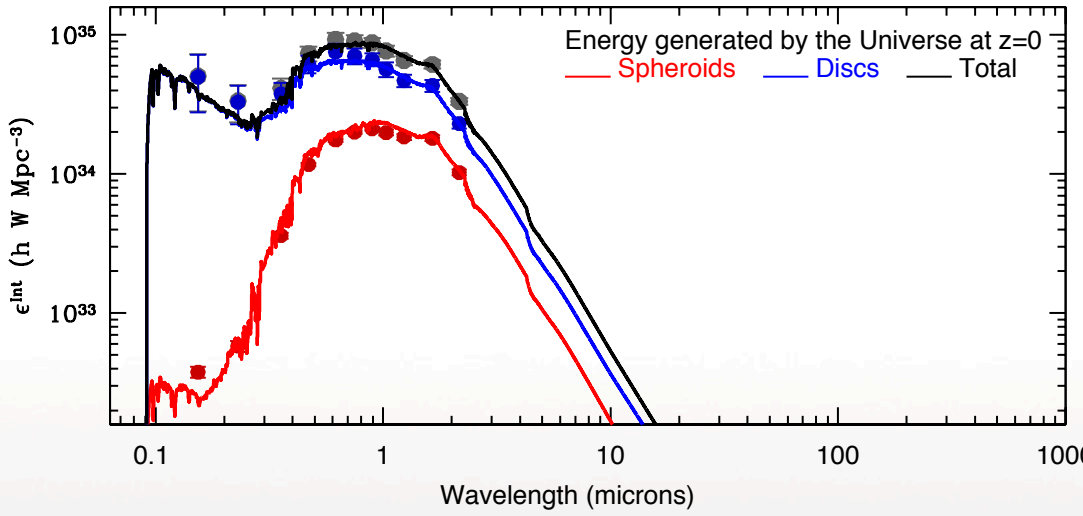
$$\zeta_{\rm Cos.Var.}(\%) = (1.00 - 0.03\sqrt{A/B}) \times (219.7 - 52.4\log_{10}[A.B.291.0] + 3.21(\log_{10}[A.B.291.0])^2) / (\sqrt{N.\frac{C}{291.0}})$$



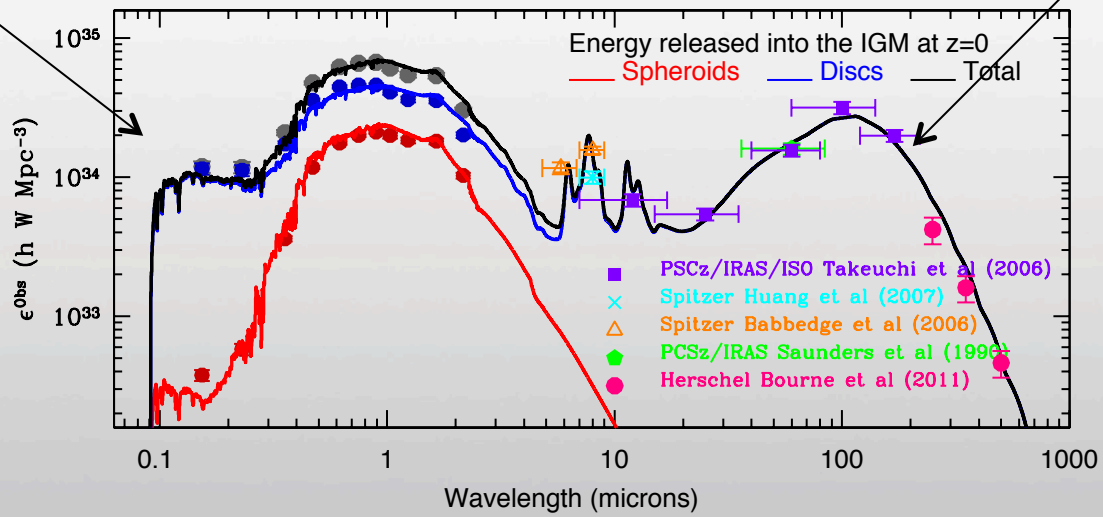
Driver & Robotham (2010), or use online tool at:

http://star-www.st-and.ac.uk/~asgr/cosvar/

The energy density

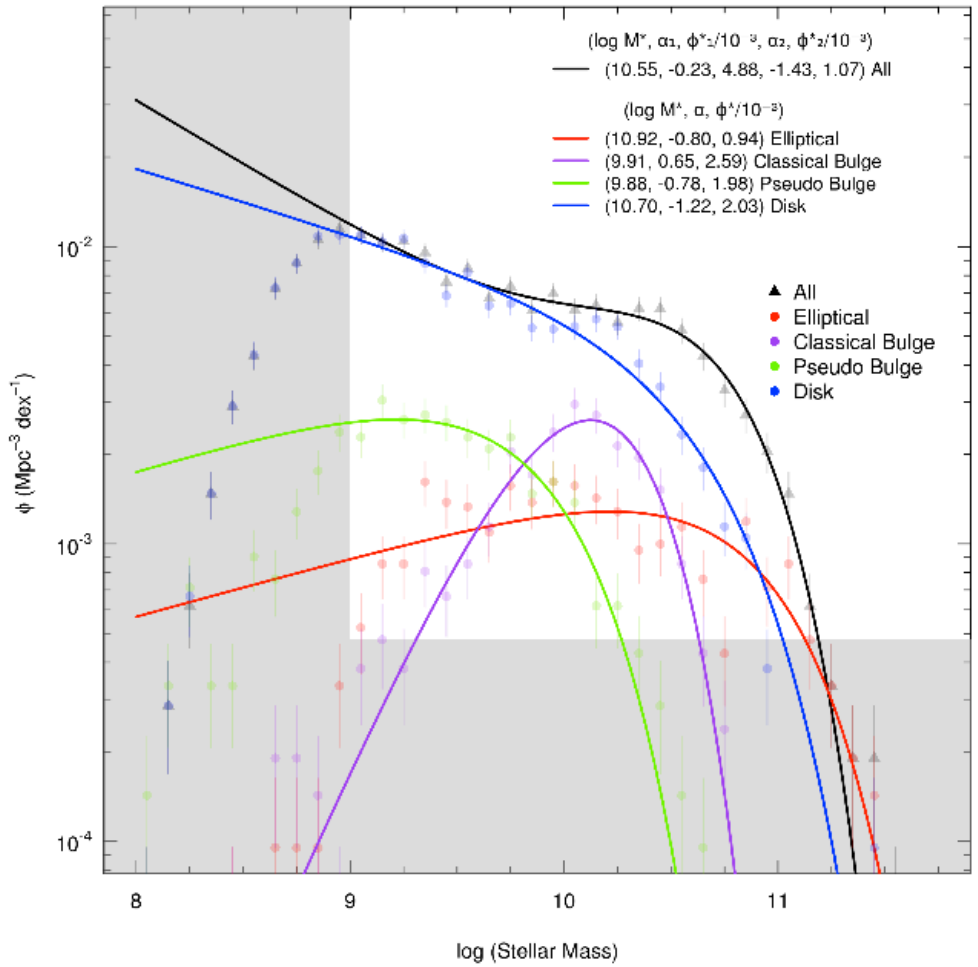


Dust attenuation calculated as per Driver et al 2007 based on Tuffs & Popescu transfer models.



Dale & Helou (2002) model normalised by attenuated light, not fit to data!

Stellar mass in bulges and discs



Breakdown by component:

Elliptical	32%	[Mergers]
Classical bulge	14%	[Mergers]
Pseudo-bulge	6%	[Secular]
Disk	48%	[Infall]