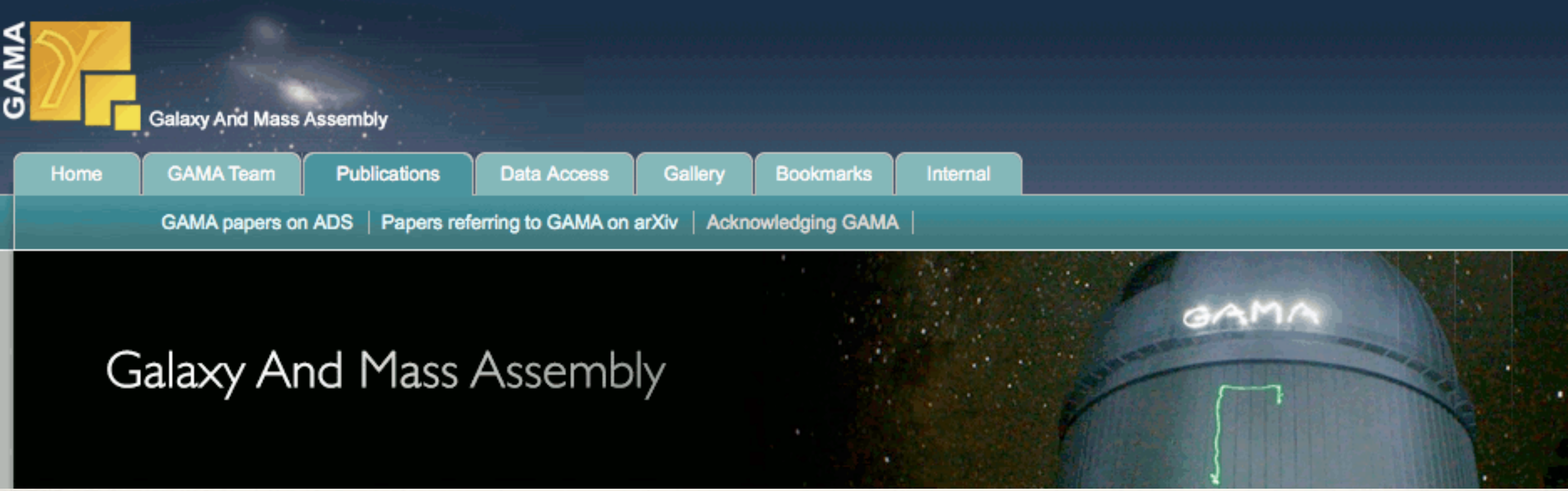


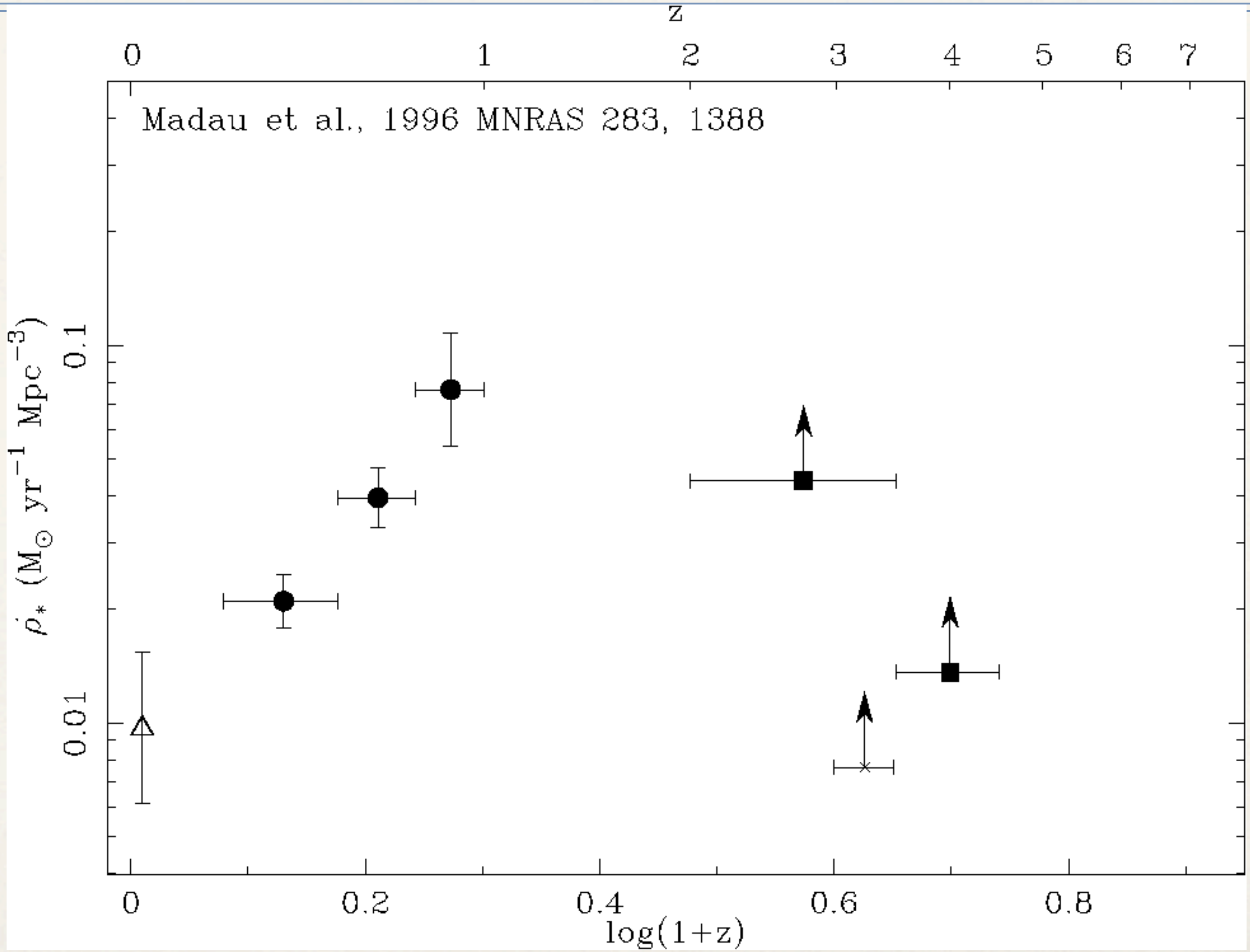
Measuring star formation in galaxies and its evolution

Andrew Hopkins
Australian Astronomical Observatory

Australian Government
Department of Industry
Innovation, Science, Research
and Tertiary Education

AAO

Evolution of Star Formation



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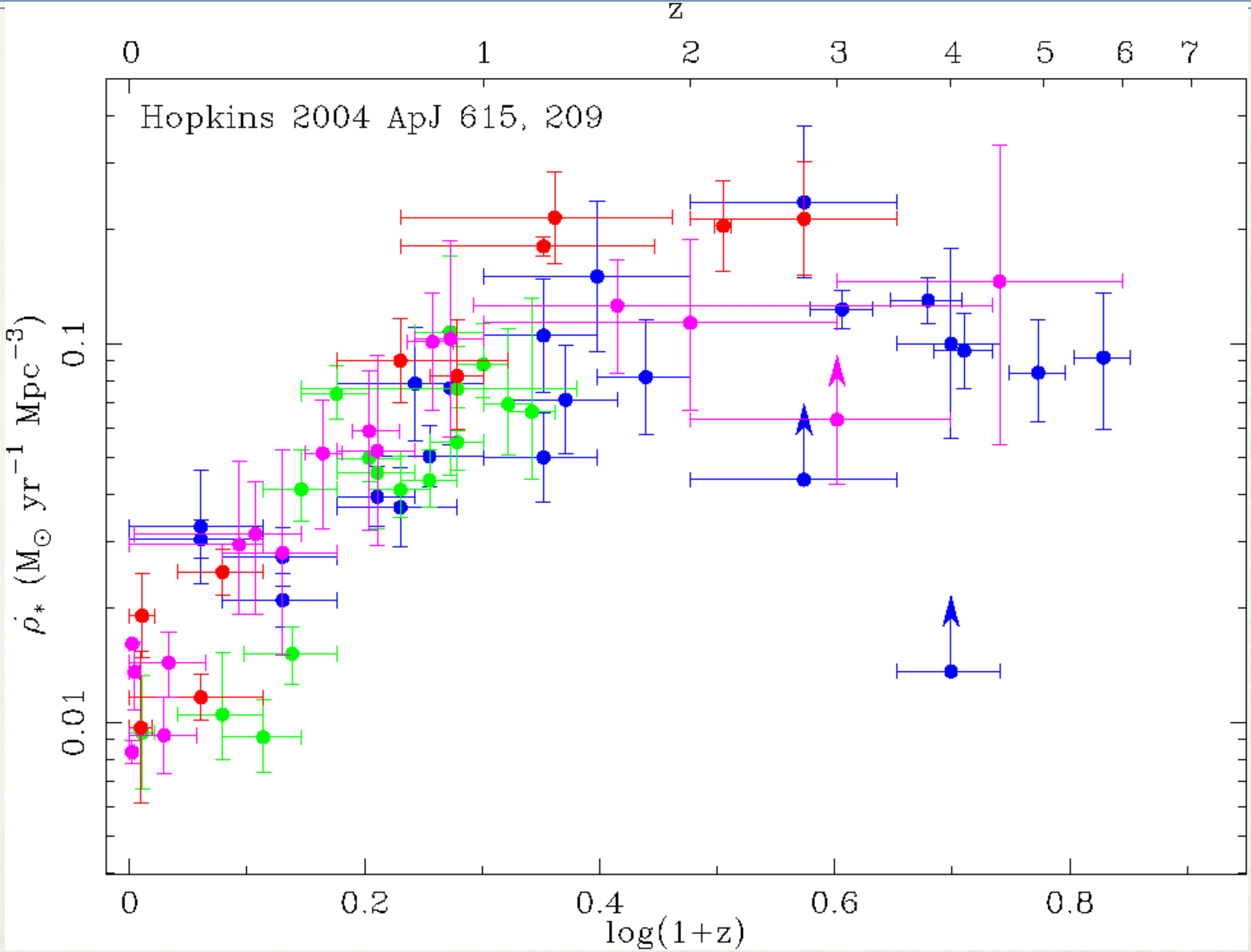

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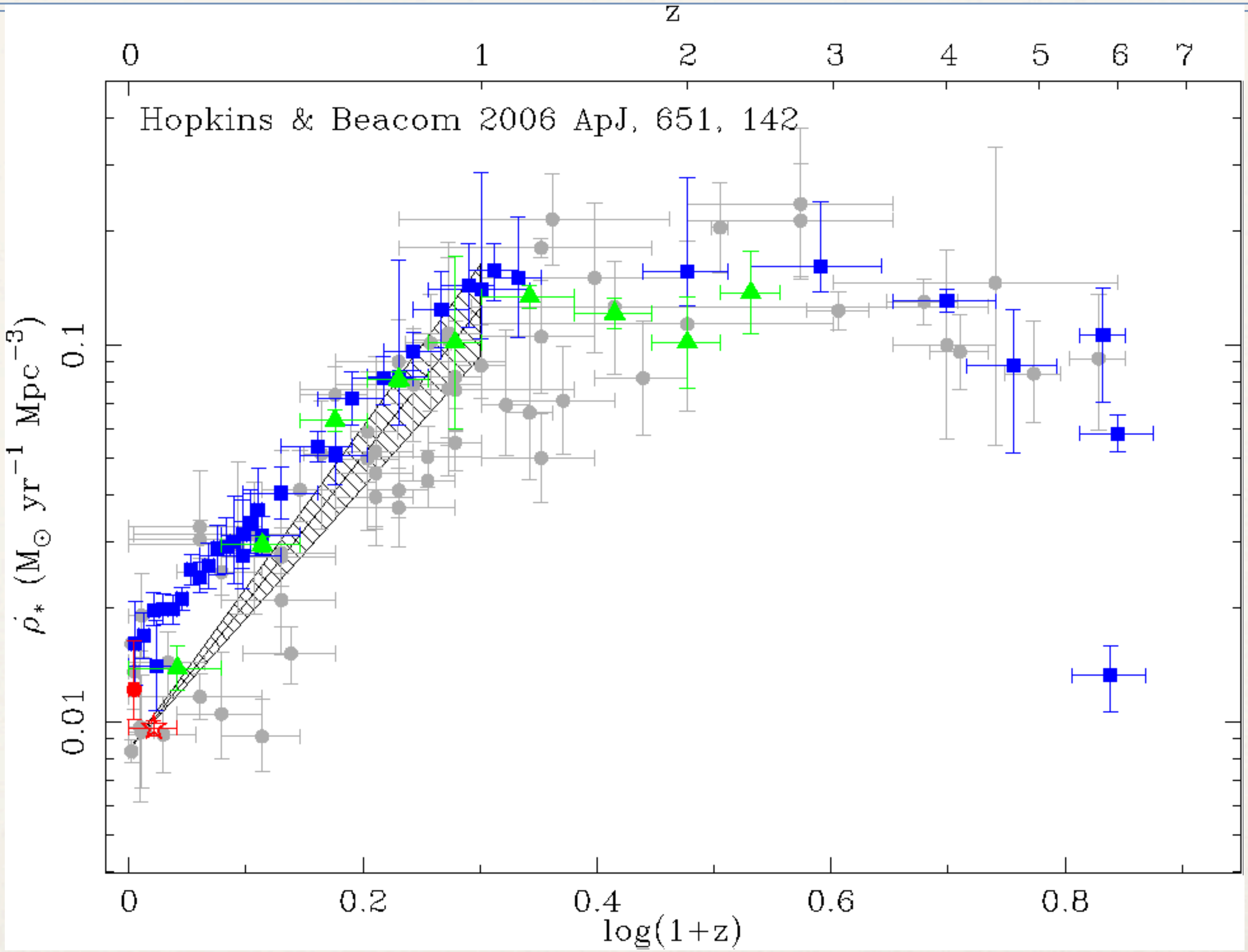

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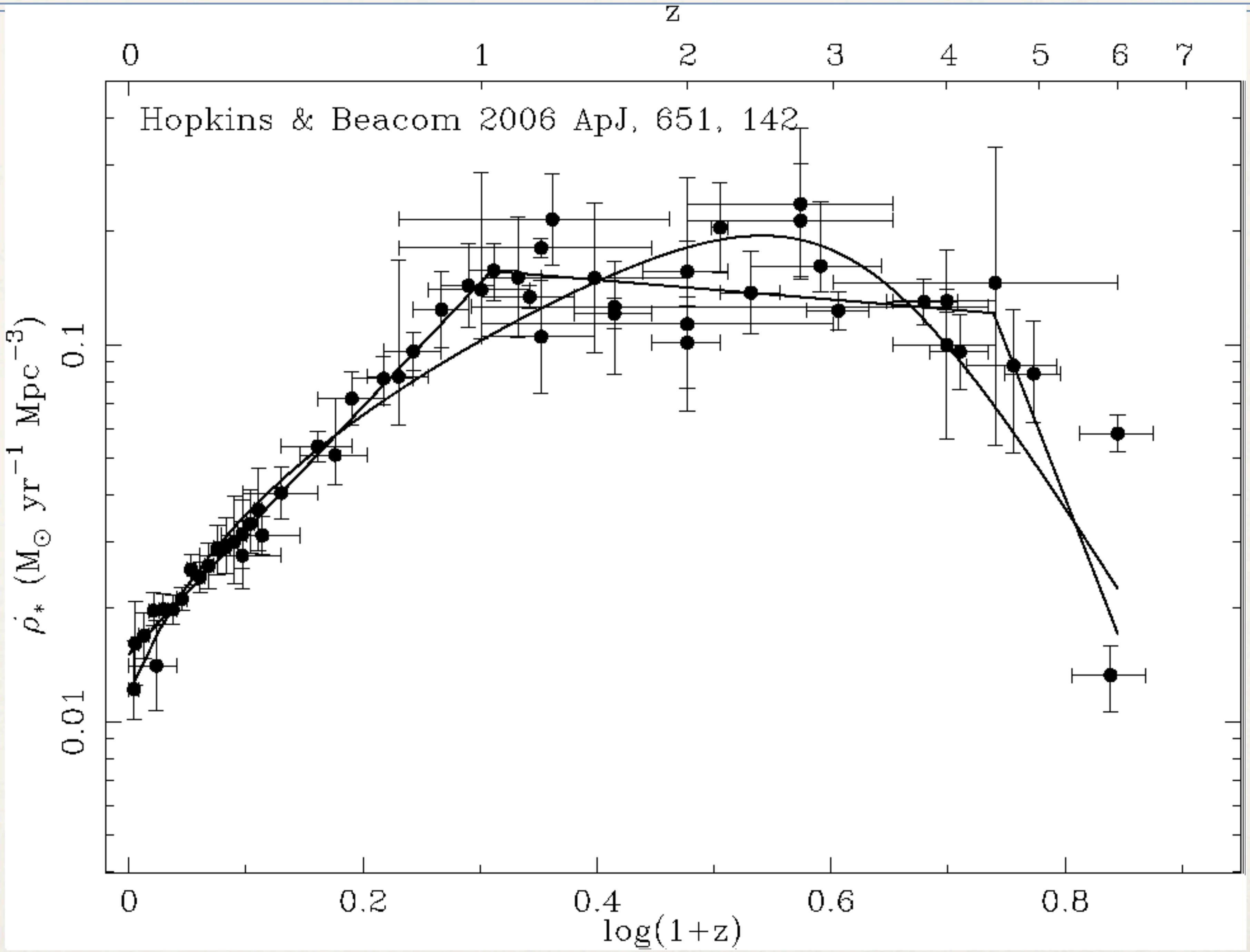

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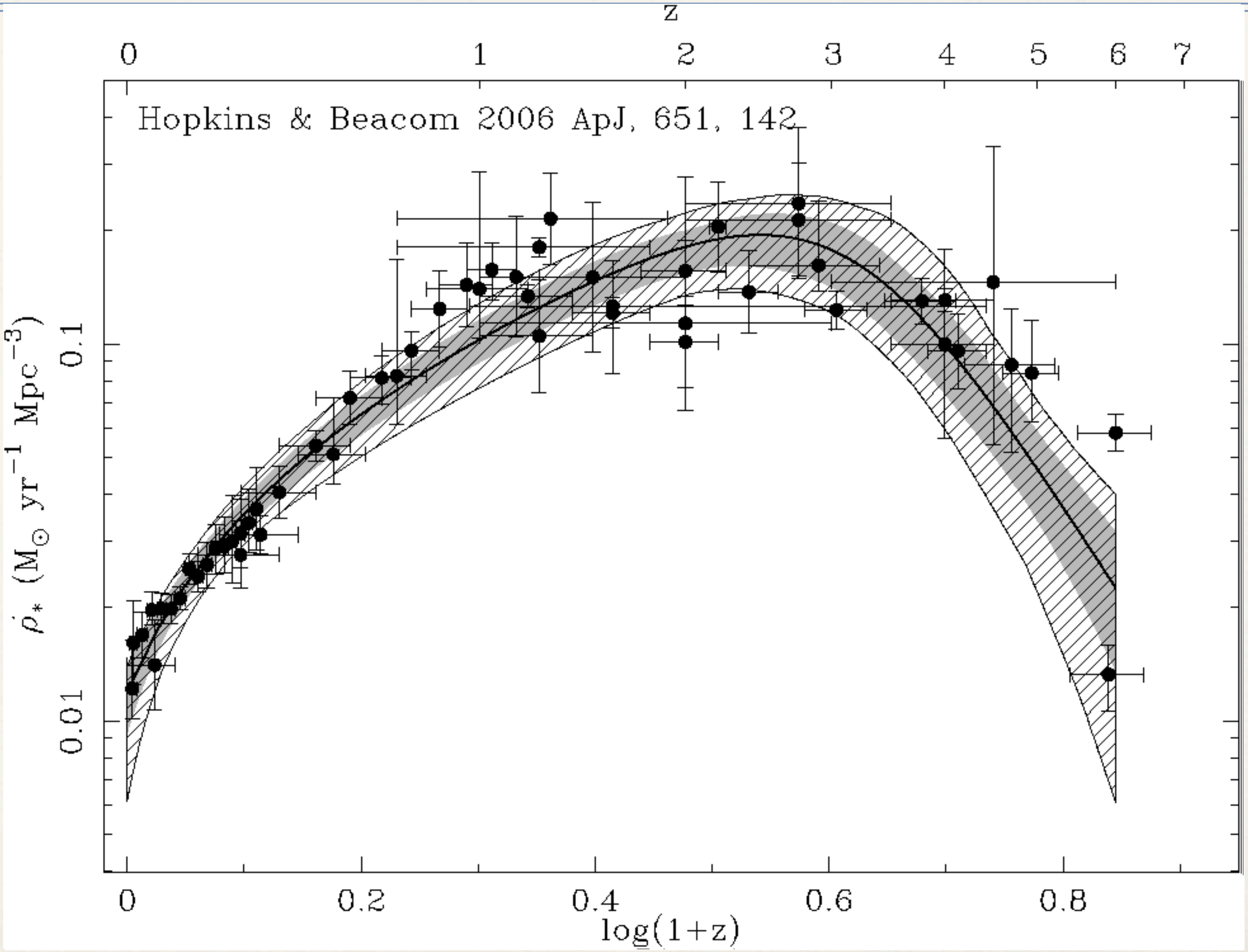

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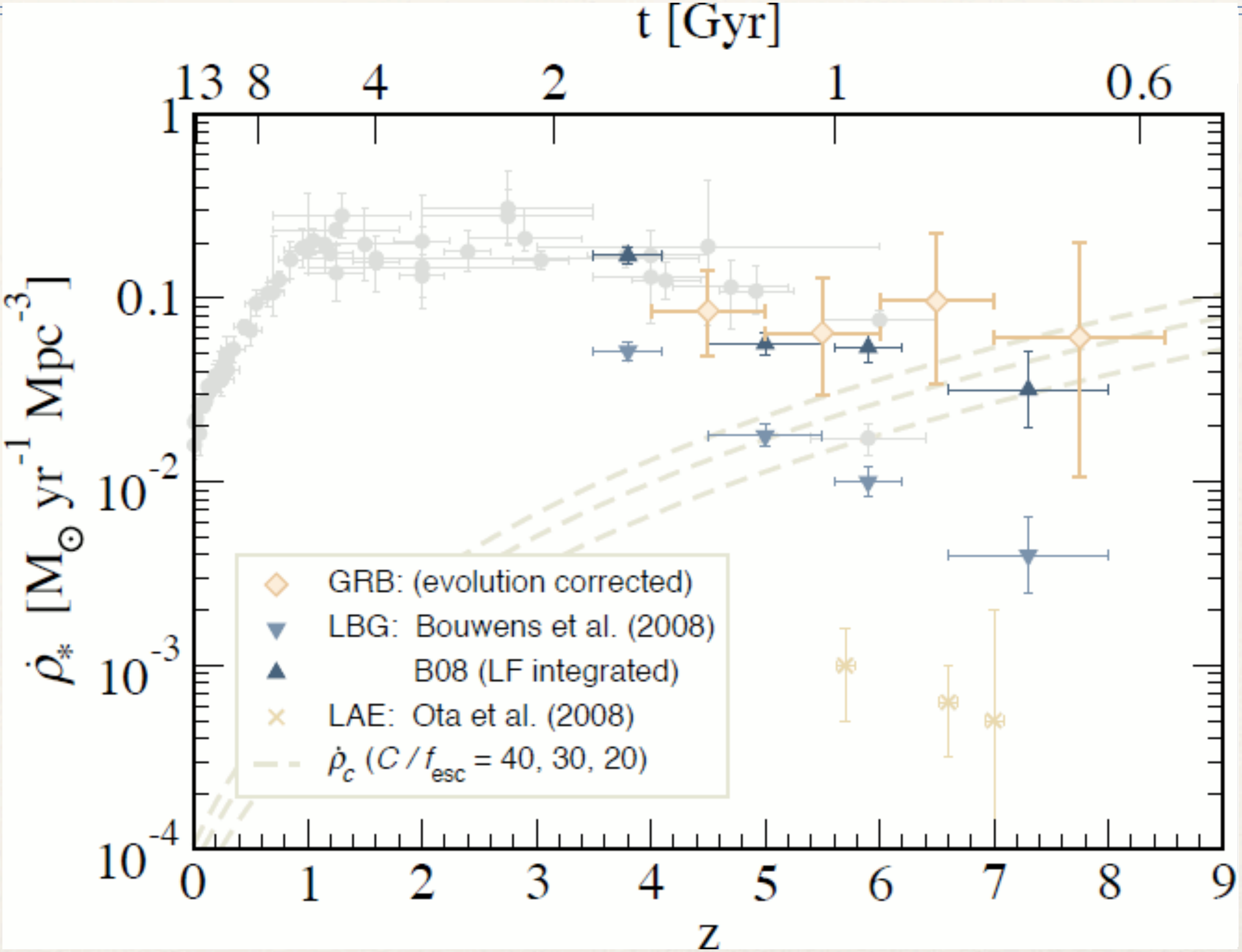
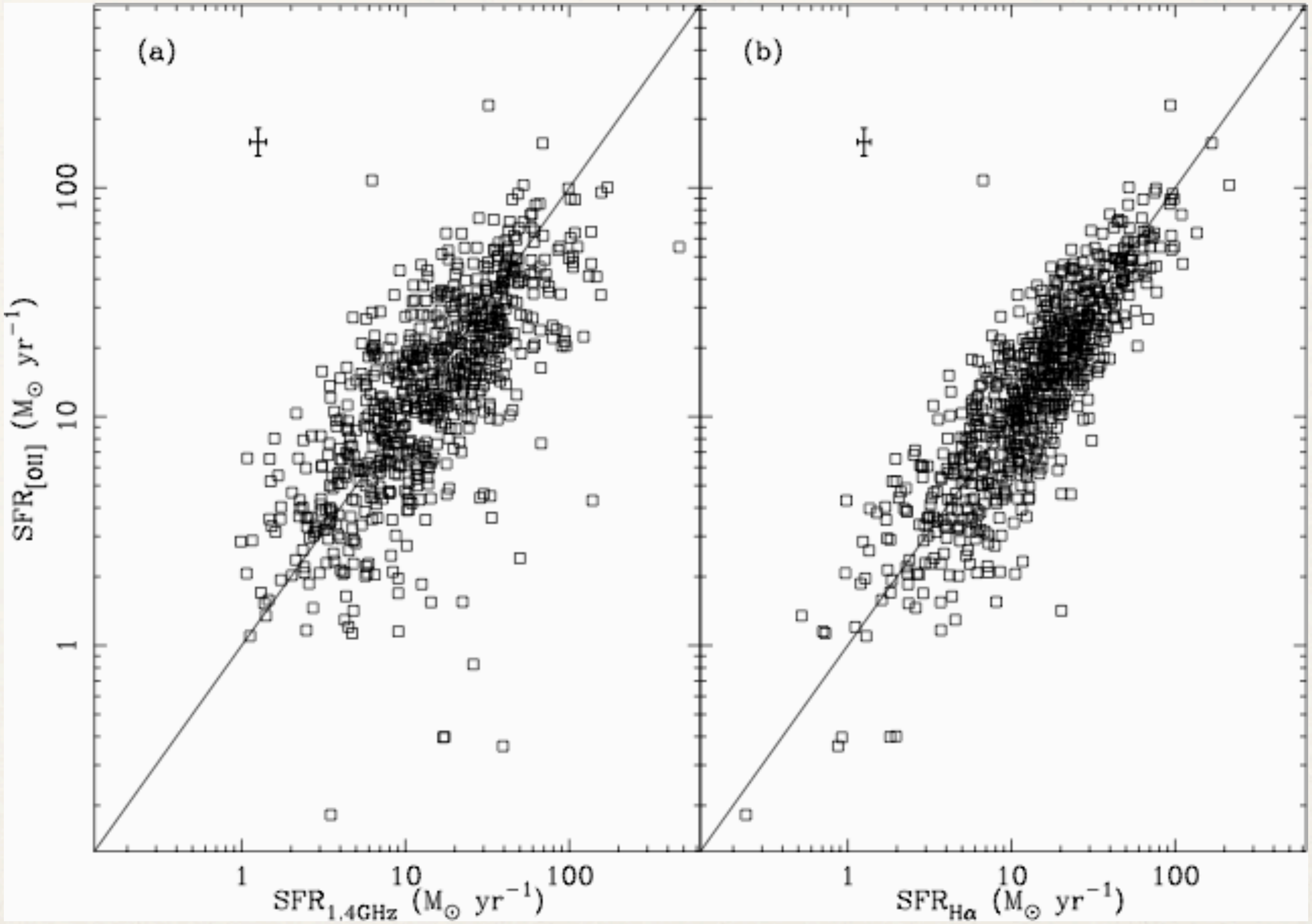


Kistler et al, 2009, ApJ, 705, L104

Star formation tracers

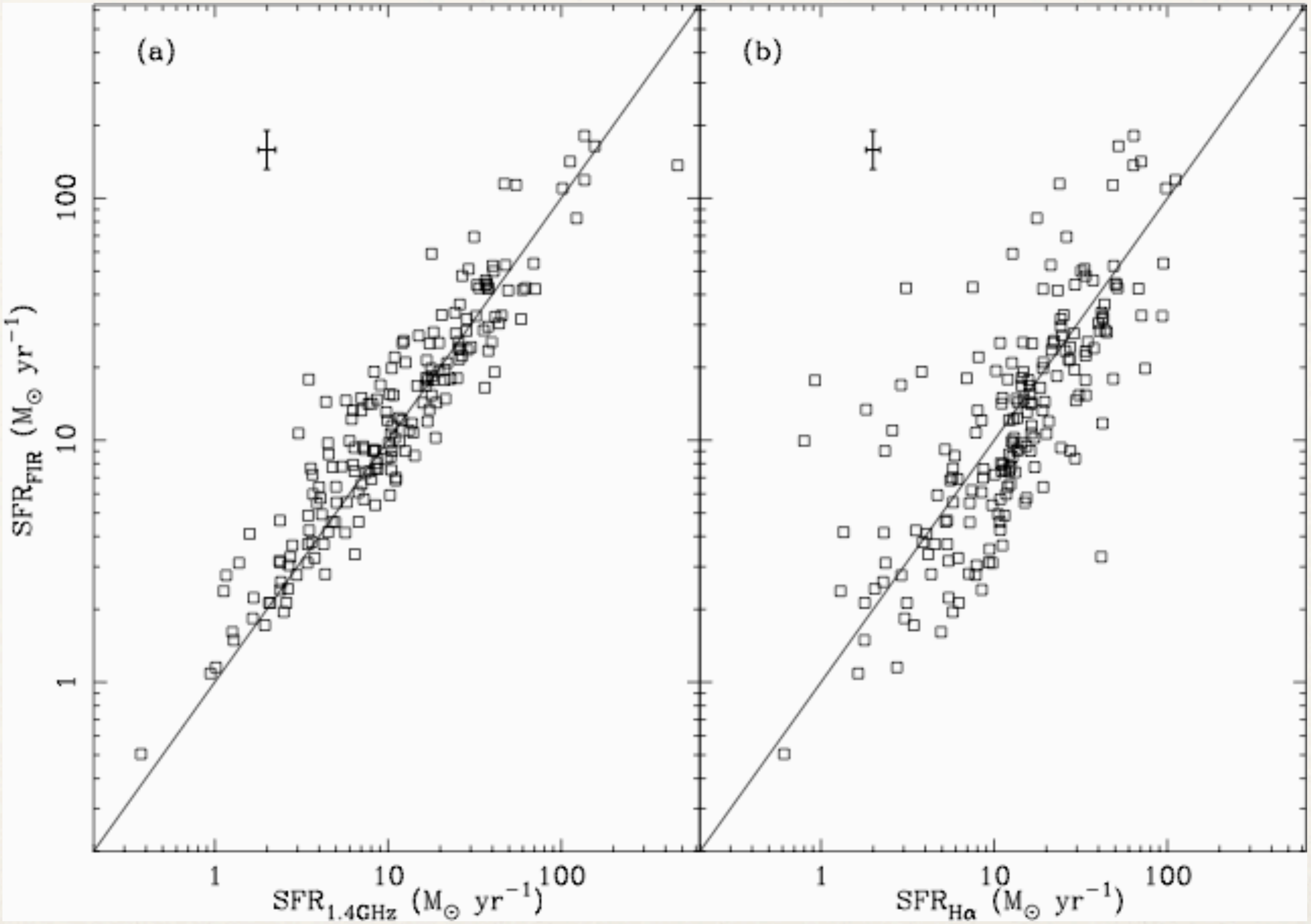
- Pretty much everything!
- Some handle on massive stellar population, either direct or indirect.
- Photometric: UV, u-band, mid-IR, far-IR, radio, X-ray.
- Spectroscopic: Hydrogen recombination lines, Balmer Hα especially, but also Hβ, Paschen lines in NIR, Lyα for high-*z*, and forbidden lines, primarily [OII], but also [OIII].
- Other: GRB rate, broad-band (optical) luminosity density plus SFH models.

Star formation tracers: SDSS



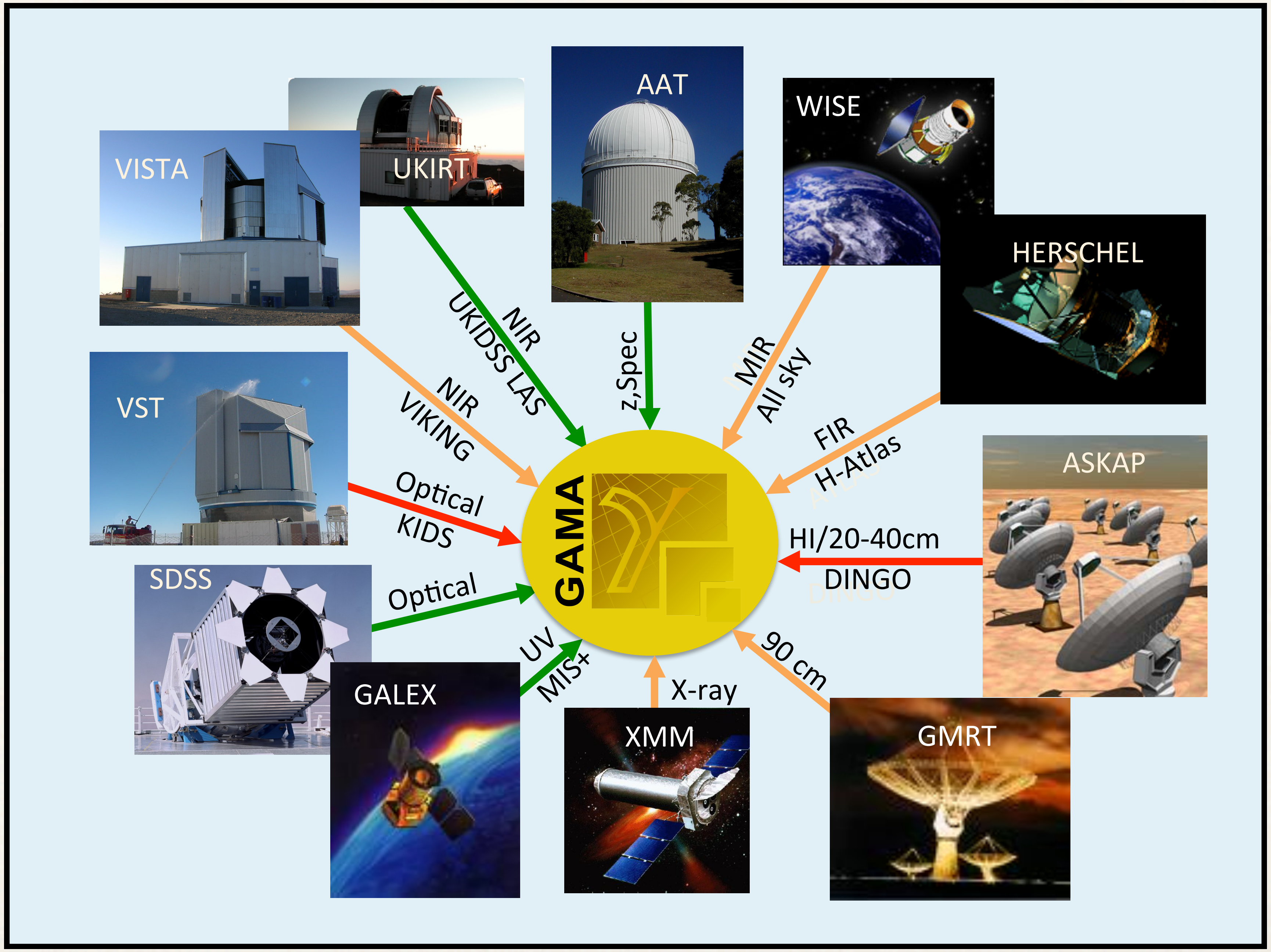
Hopkins et al 2003, ApJ, 599, 971

Star formation tracers: SDSS



Hopkins et al 2003, ApJ, 599, 971

GAMA

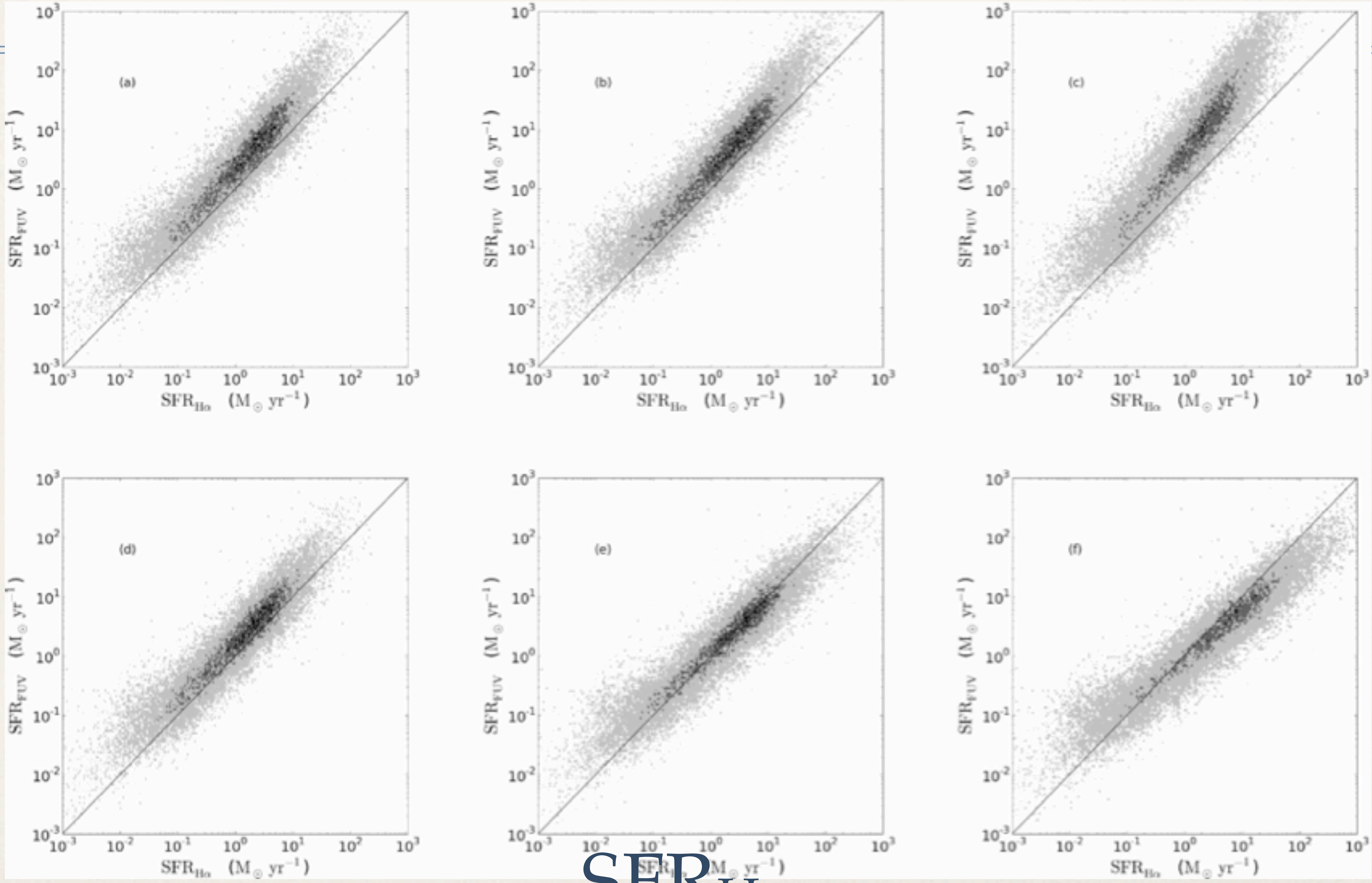


Driver et al 2009, A&G, 50, 5.12; Driver et al 2011, MNRAS, 413, 971

GAMA Key Science

* A measurement of the dark matter halo mass function of groups and clusters using group velocity dispersion measurements.
* A comprehensive determination of the galaxy stellar mass function to Magellanic Cloud masses to constrain baryonic feedback processes.
* A direct measurement of the recent galaxy merger rates as a function of mass, mass ratio, local environment and galaxy type.

MW SFR: FUV vs Hα

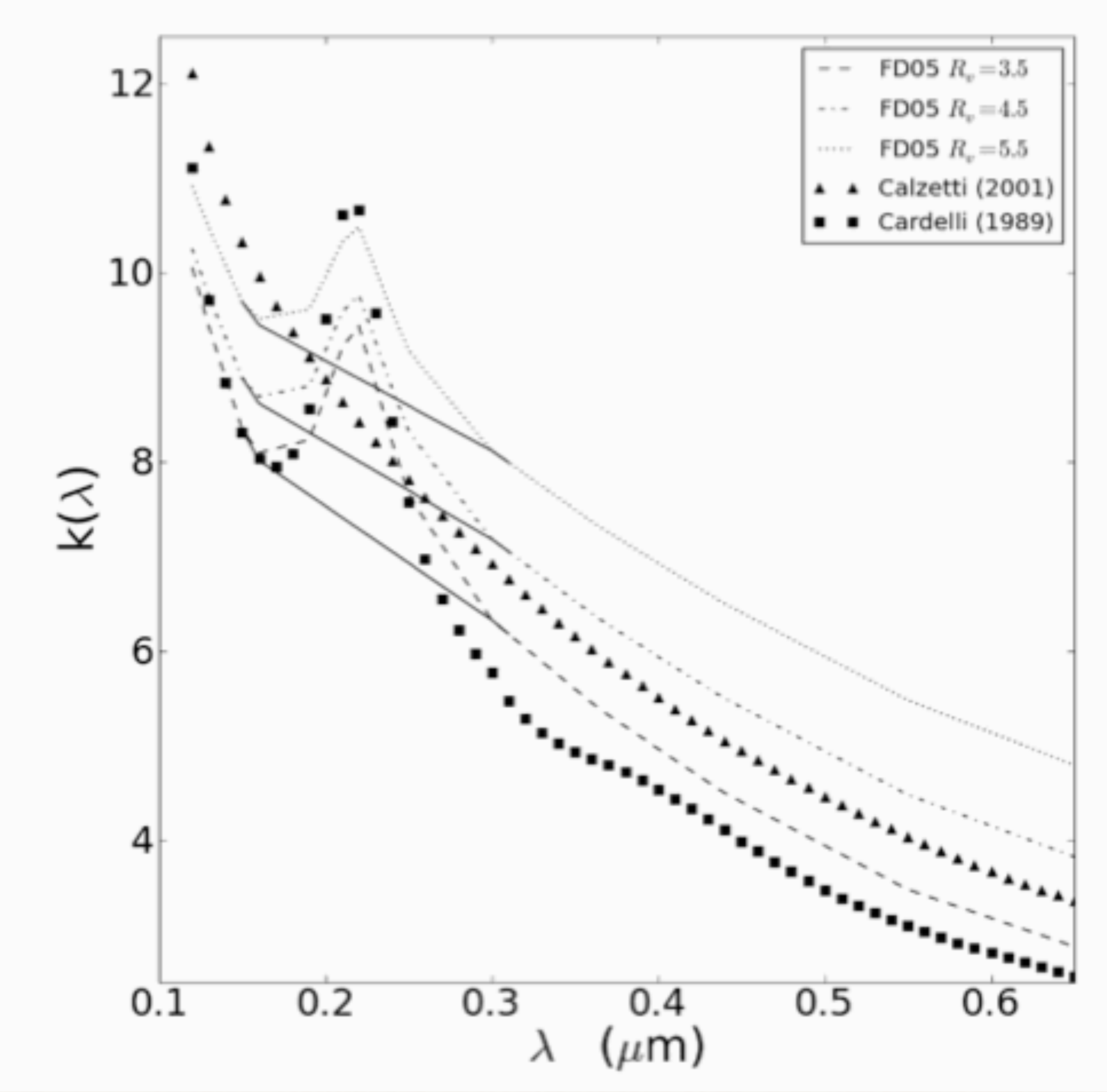


SFR_{FUV}

$SFR_{H\alpha}$

Wijesinghe et al, 2011, MNRAS, 410, 2291

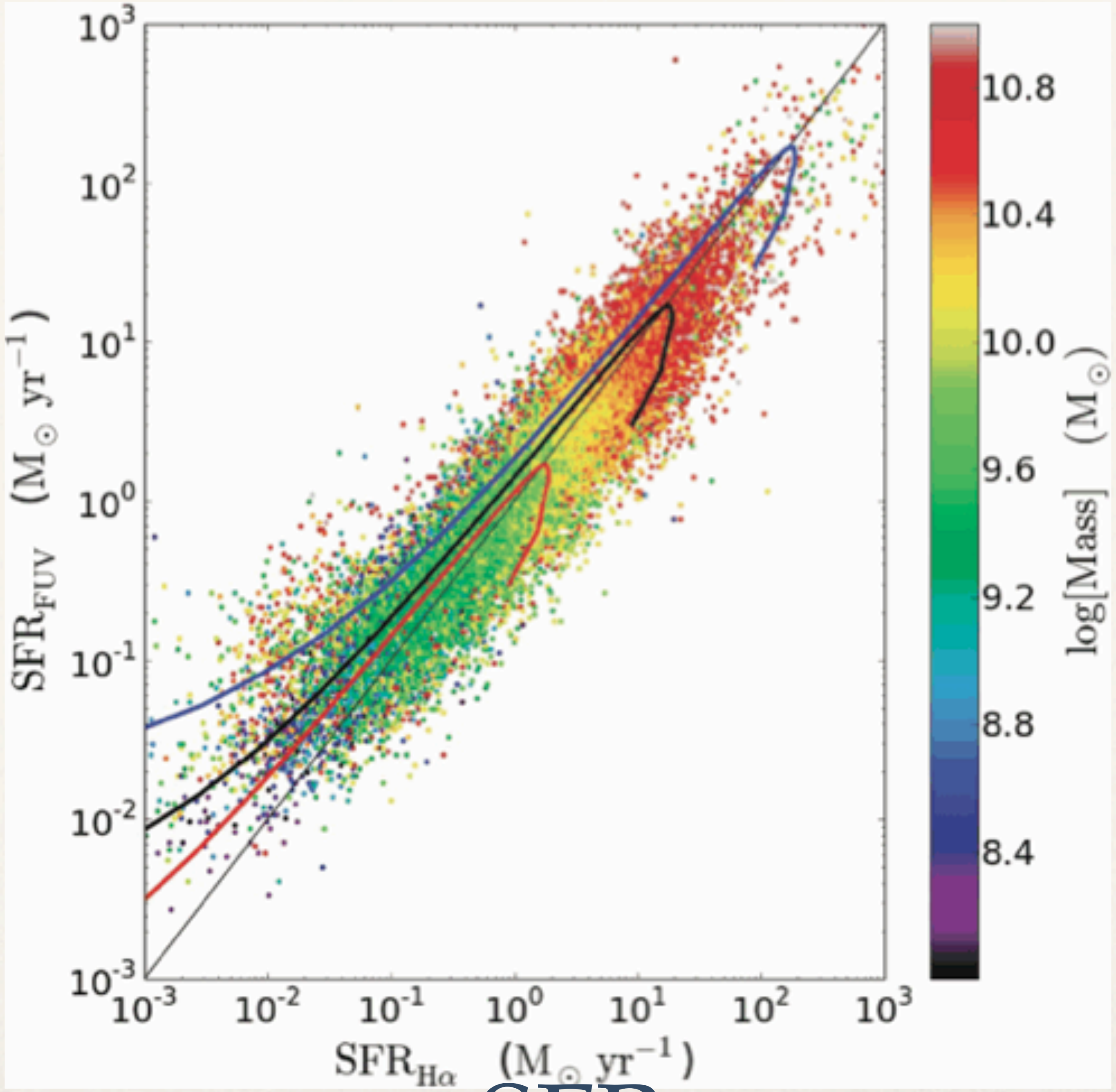
Obscuration curves



Wijesinghe et al, 2011, MNRAS, 410, 2291

FUV vs Hα

SFR_{FUV}

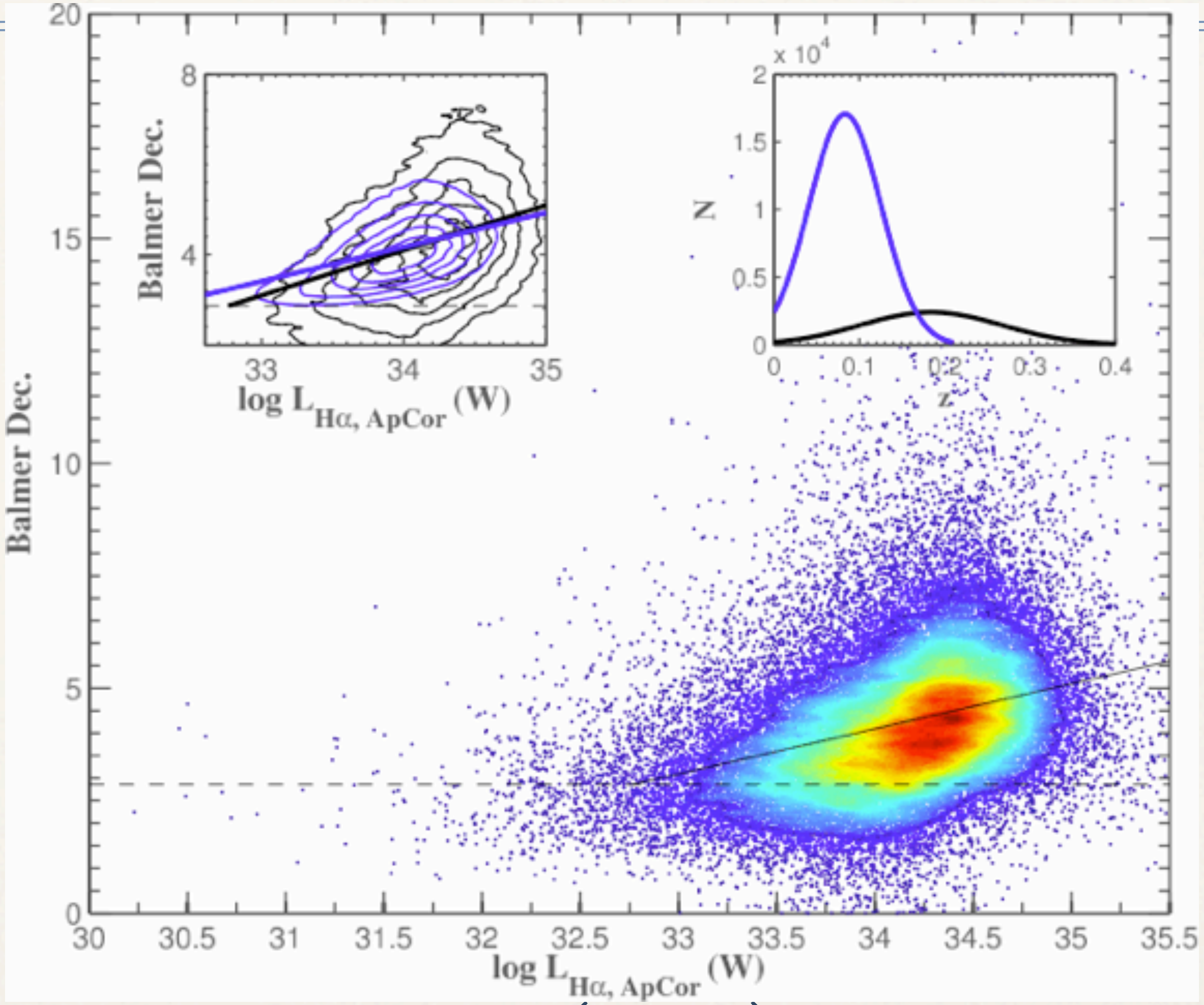


$SFR_{H\alpha}$

Wijesinghe et al, 2011, MNRAS, 410, 2291

Luminosity-dependent obscuration

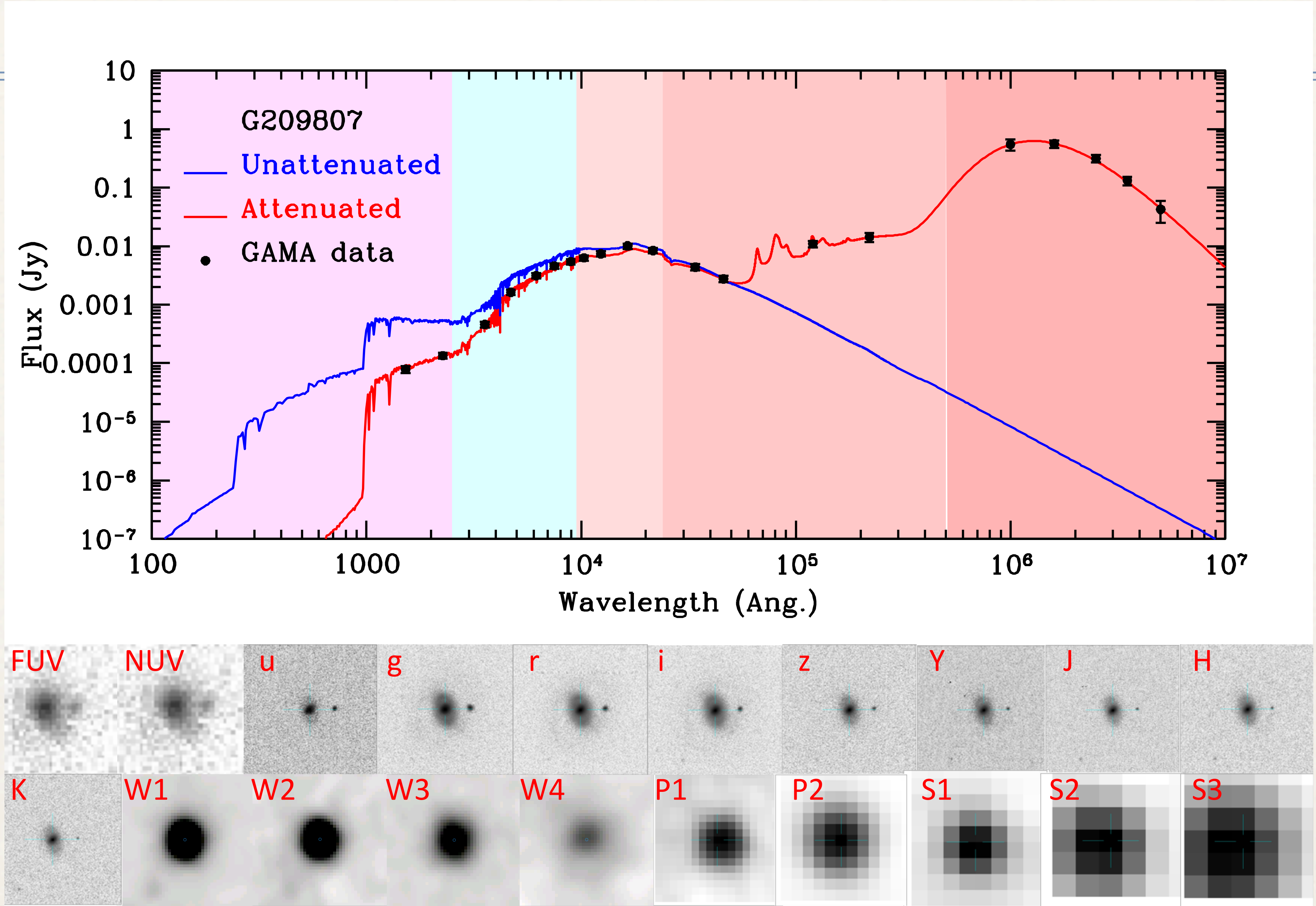
Balmer decrement



log($L_{H\alpha}$)

Gunawardhana et al, 2012, MNRAS (submitted).

SED fitting

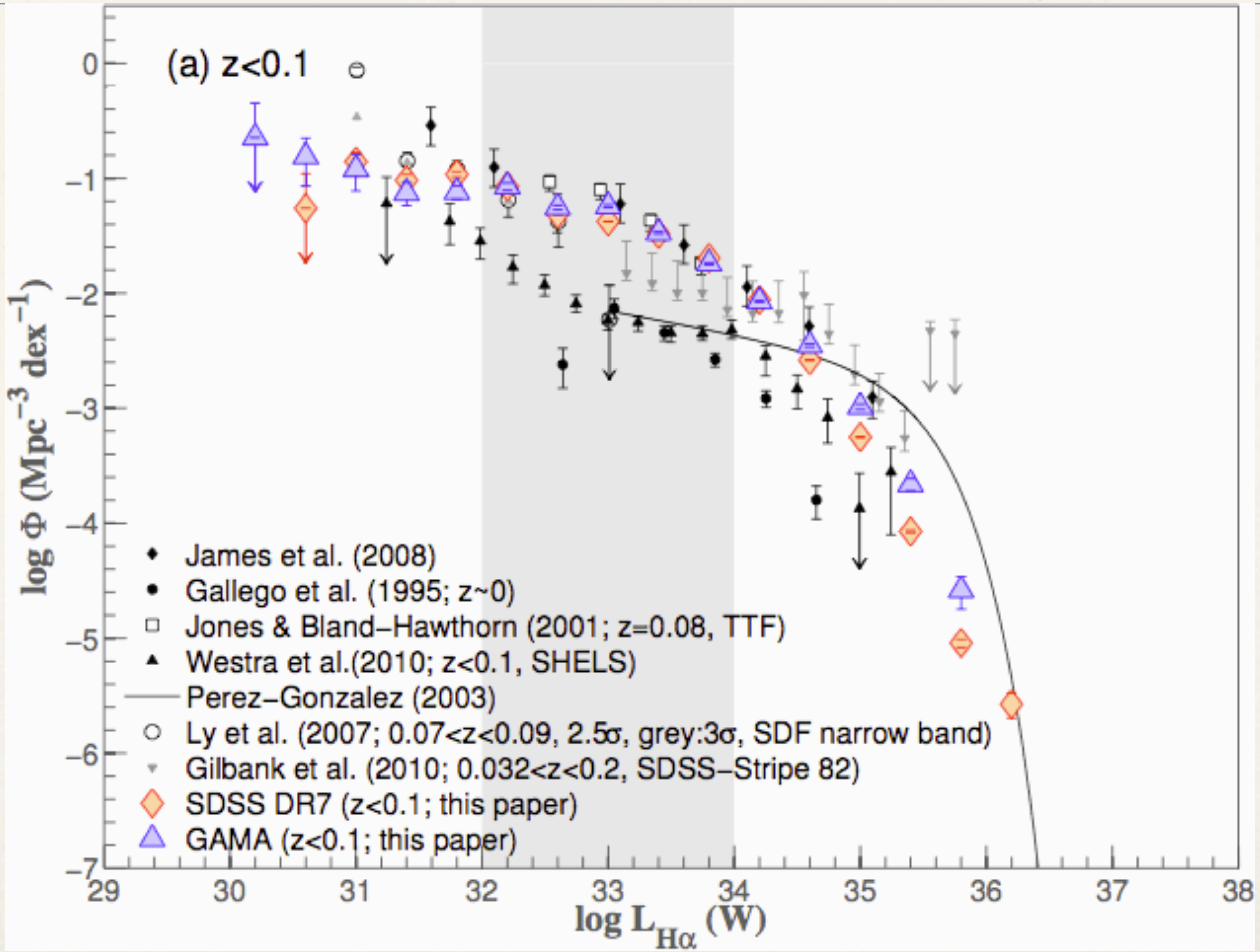


SED fitting using MAGPHYS from Da Cunha et al. (arXiv:1111.3961)

http://www.iap.fr/magphys

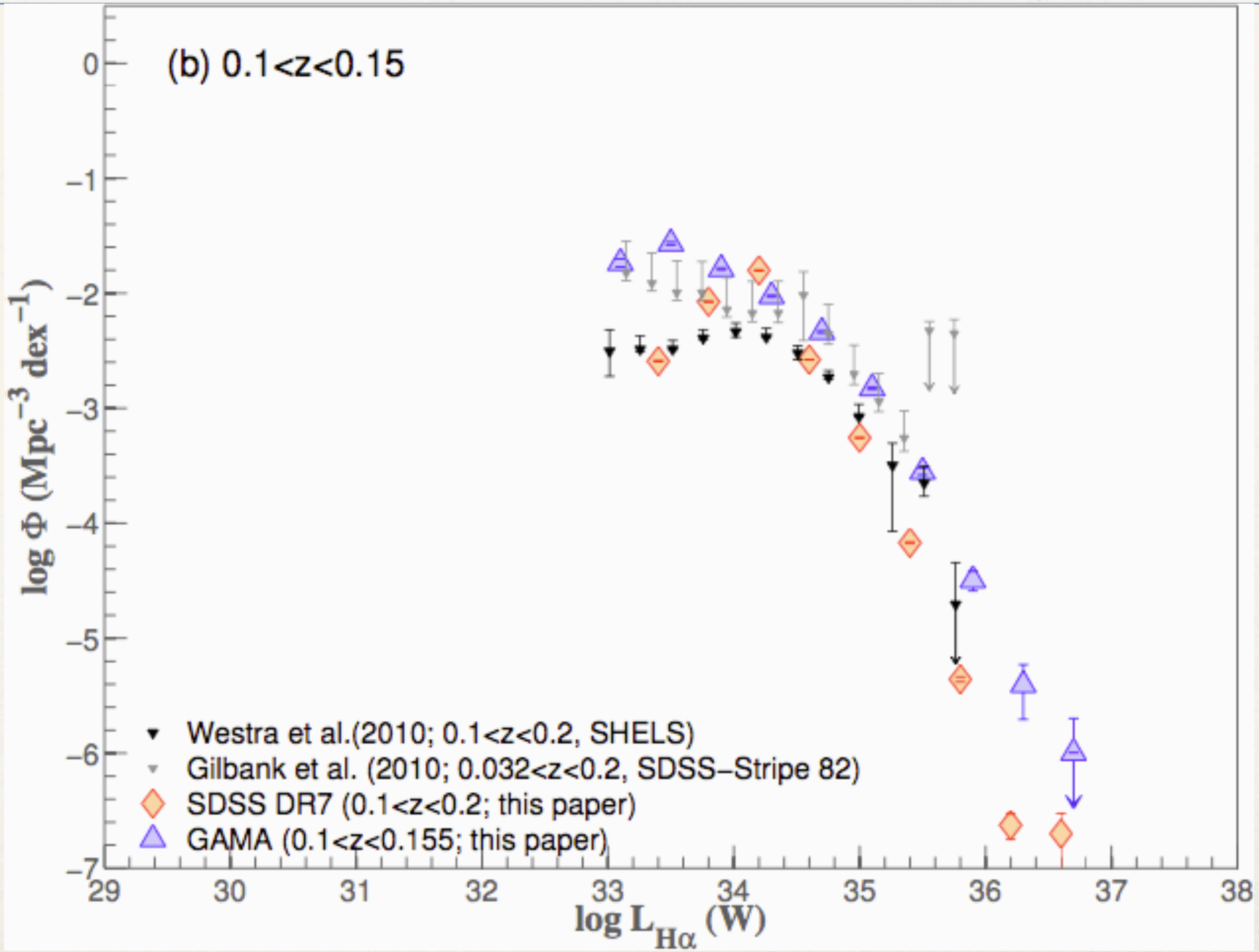
Driver et al, (in prep)

The GAMA Hα Luminosity Function



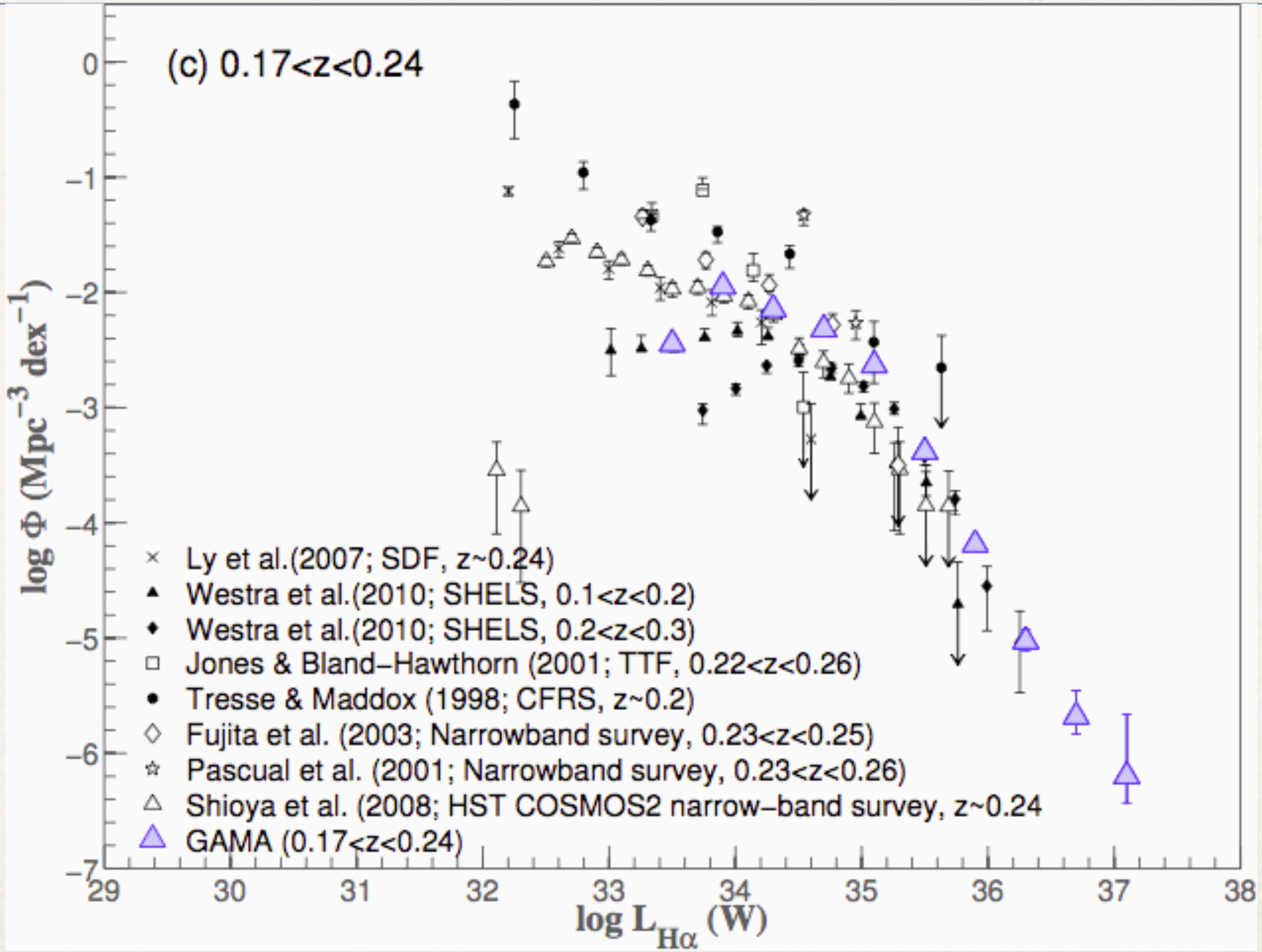
Gunawardhana et al., 2012, MNRAS (submitted)

The GAMA Hα Luminosity Function



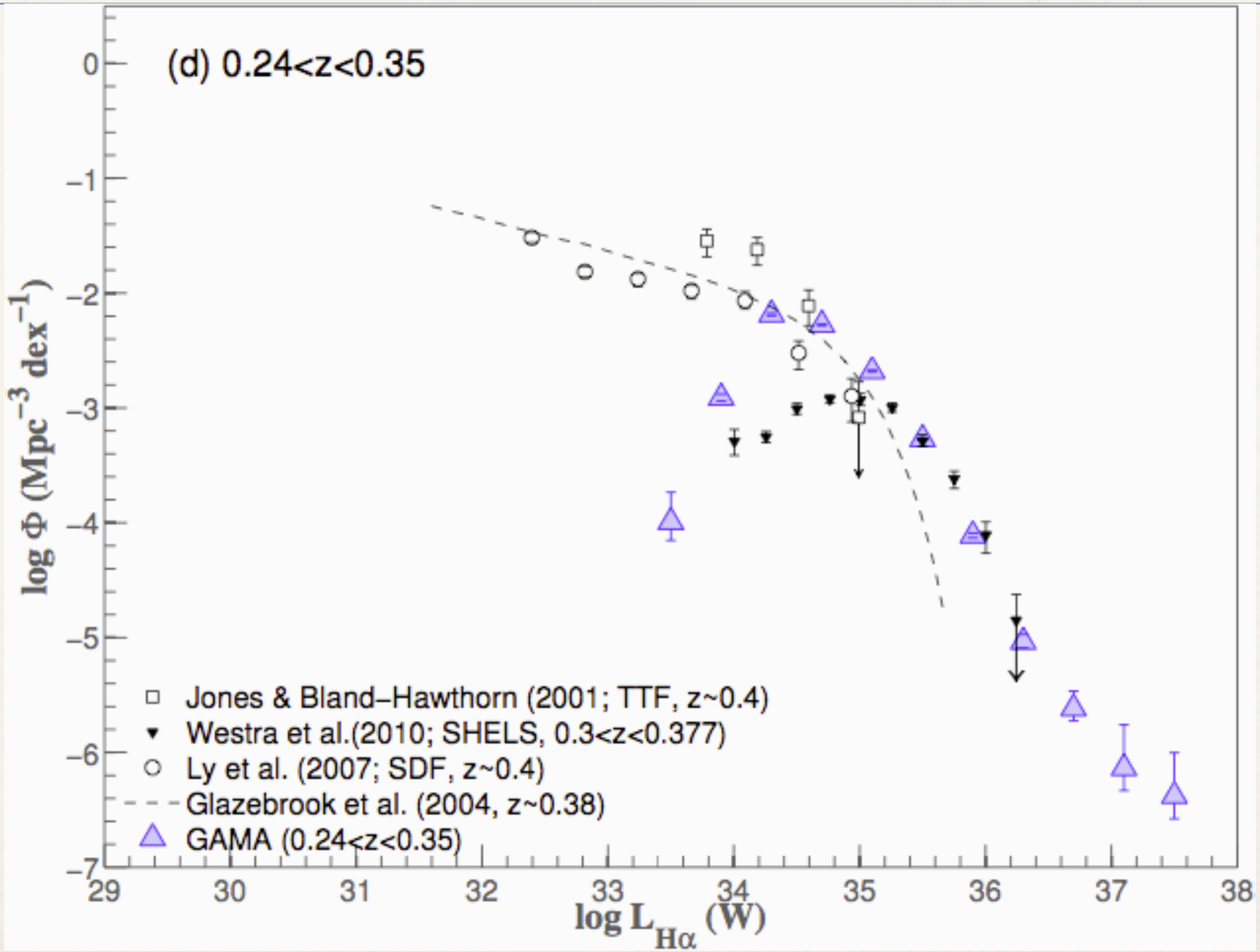
Gunawardhana et al., 2012, MNRAS (submitted)

The GAMA Hα Luminosity Function



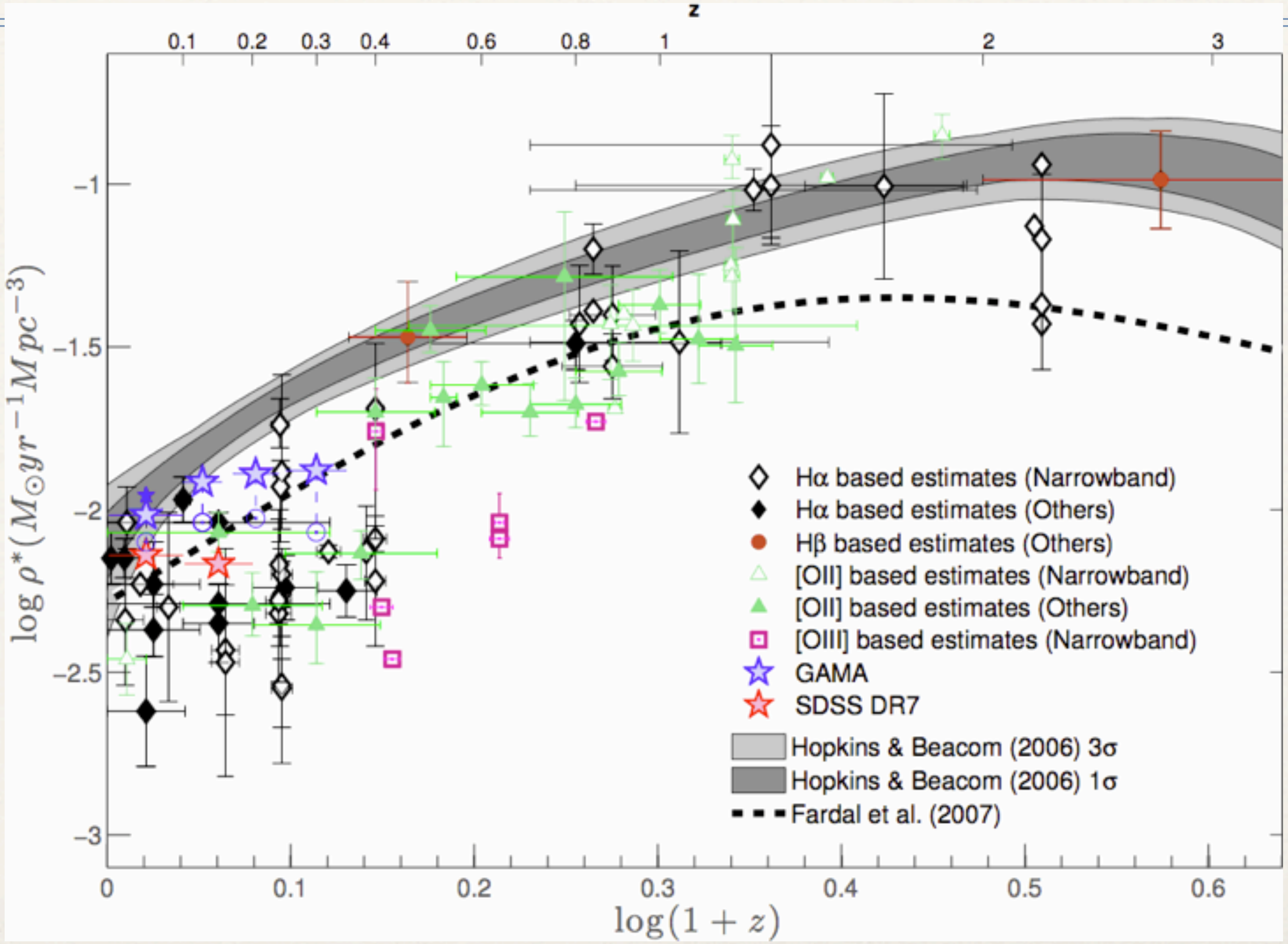
Gunawardhana et al., 2012, MNRAS (submitted)

The GAMA Hα Luminosity Function



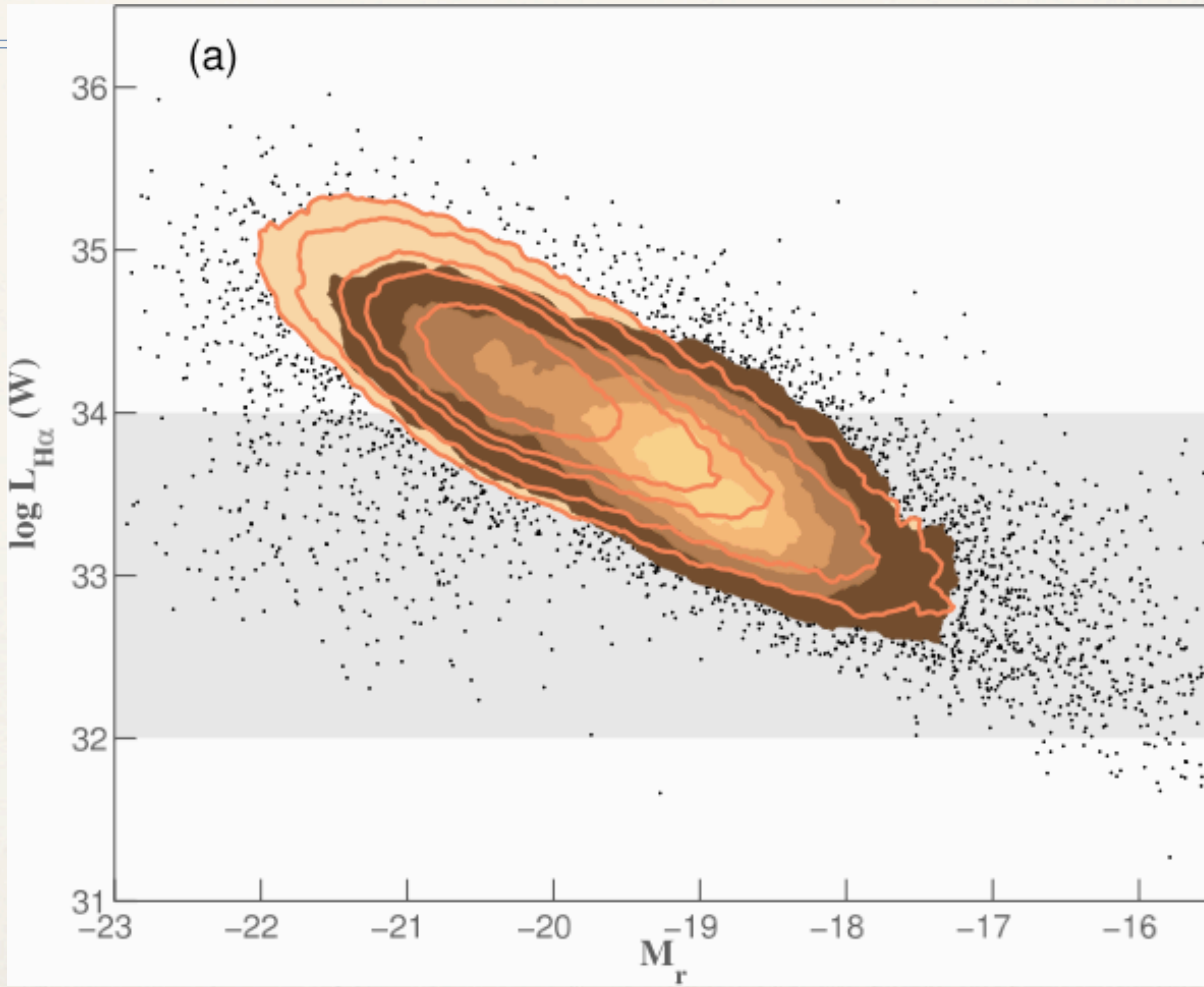
Gunawardhana et al., 2012, MNRAS (submitted)

Cosmic SFR density



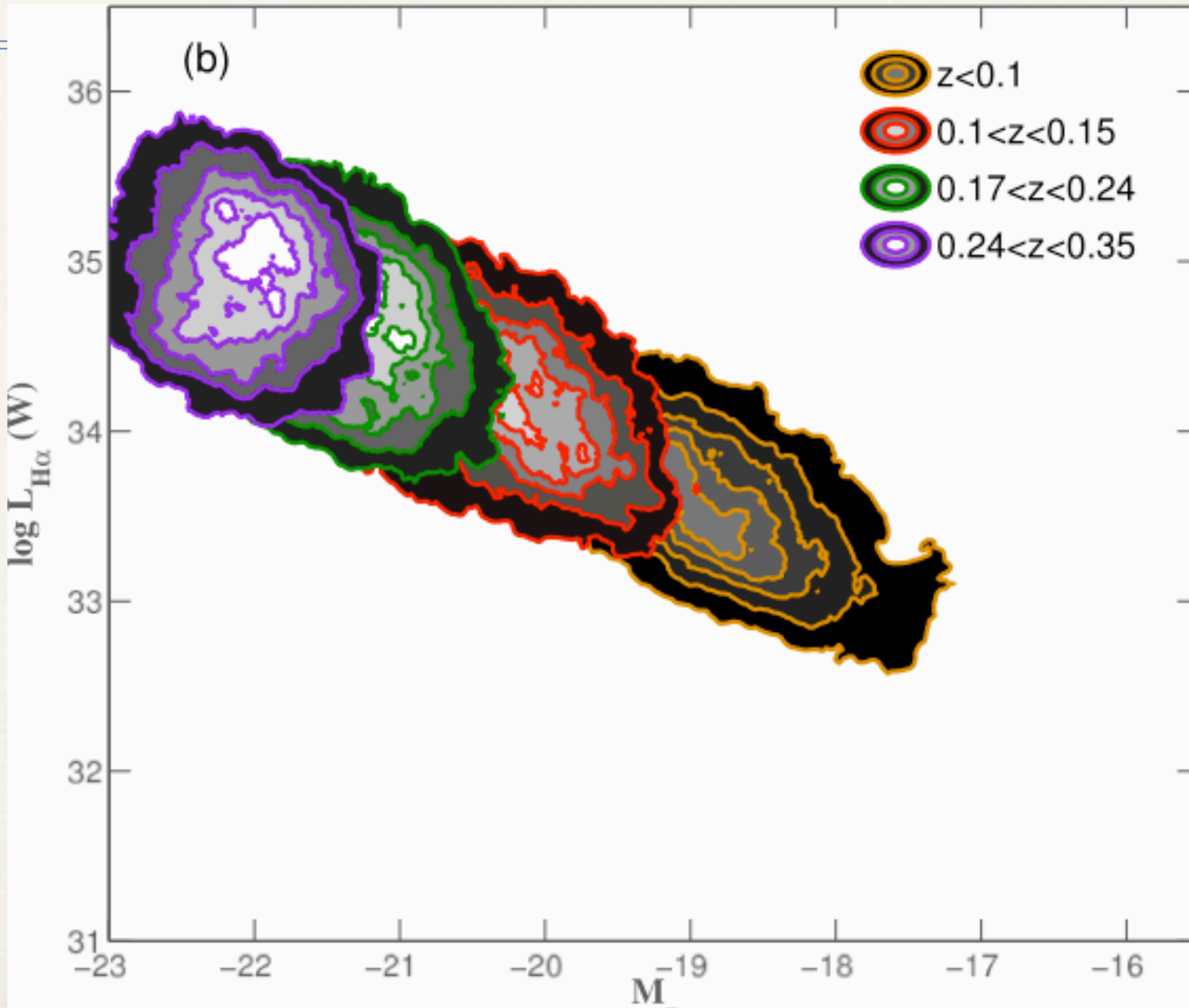
Gunawardhana et al., 2012, MNRAS (submitted)

Bivariate Hα-M_r luminosity distribution



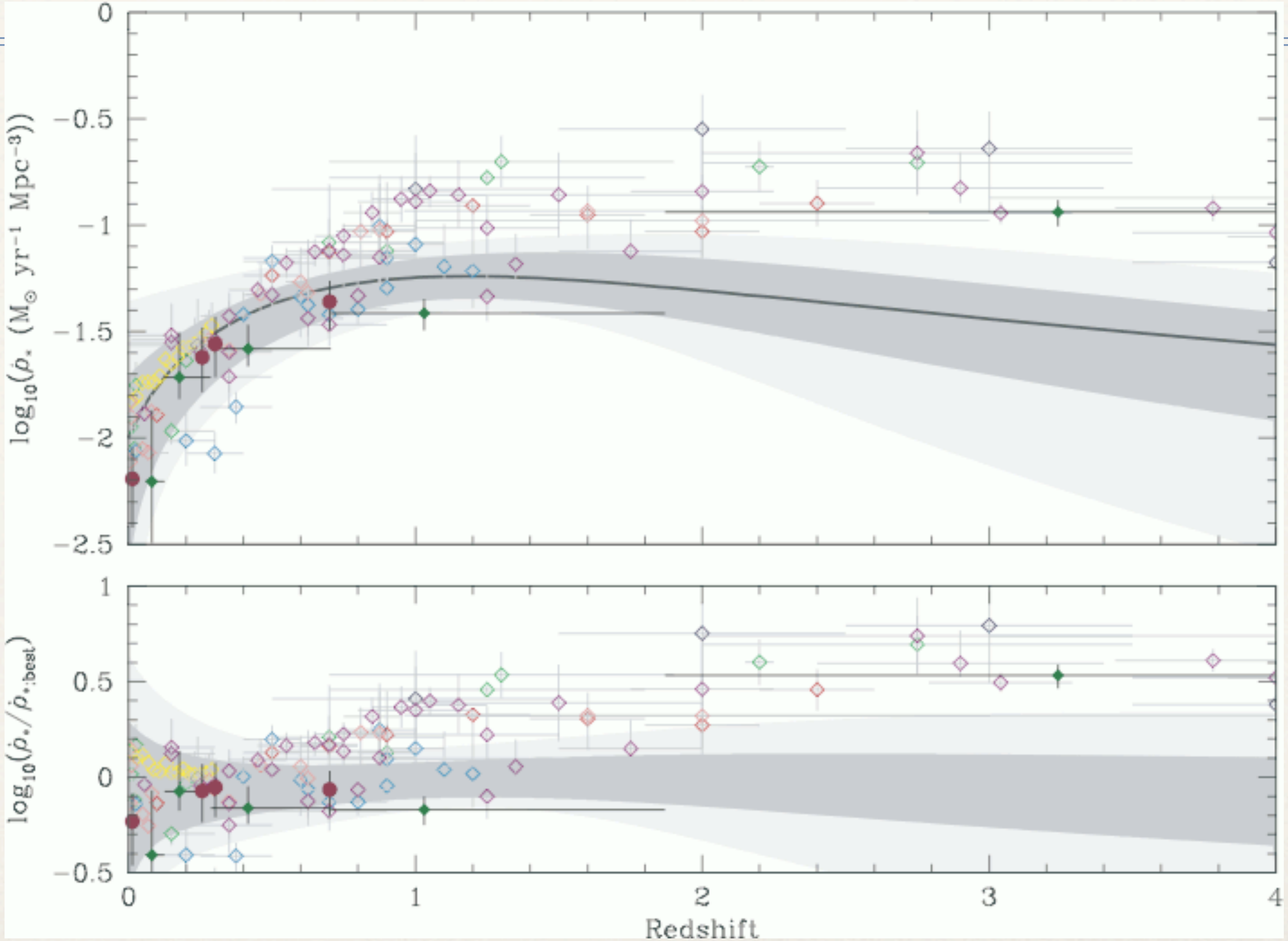
Gunawardhana et al., 2012, MNRAS (submitted)

Bivariate Hα-M_r luminosity distribution



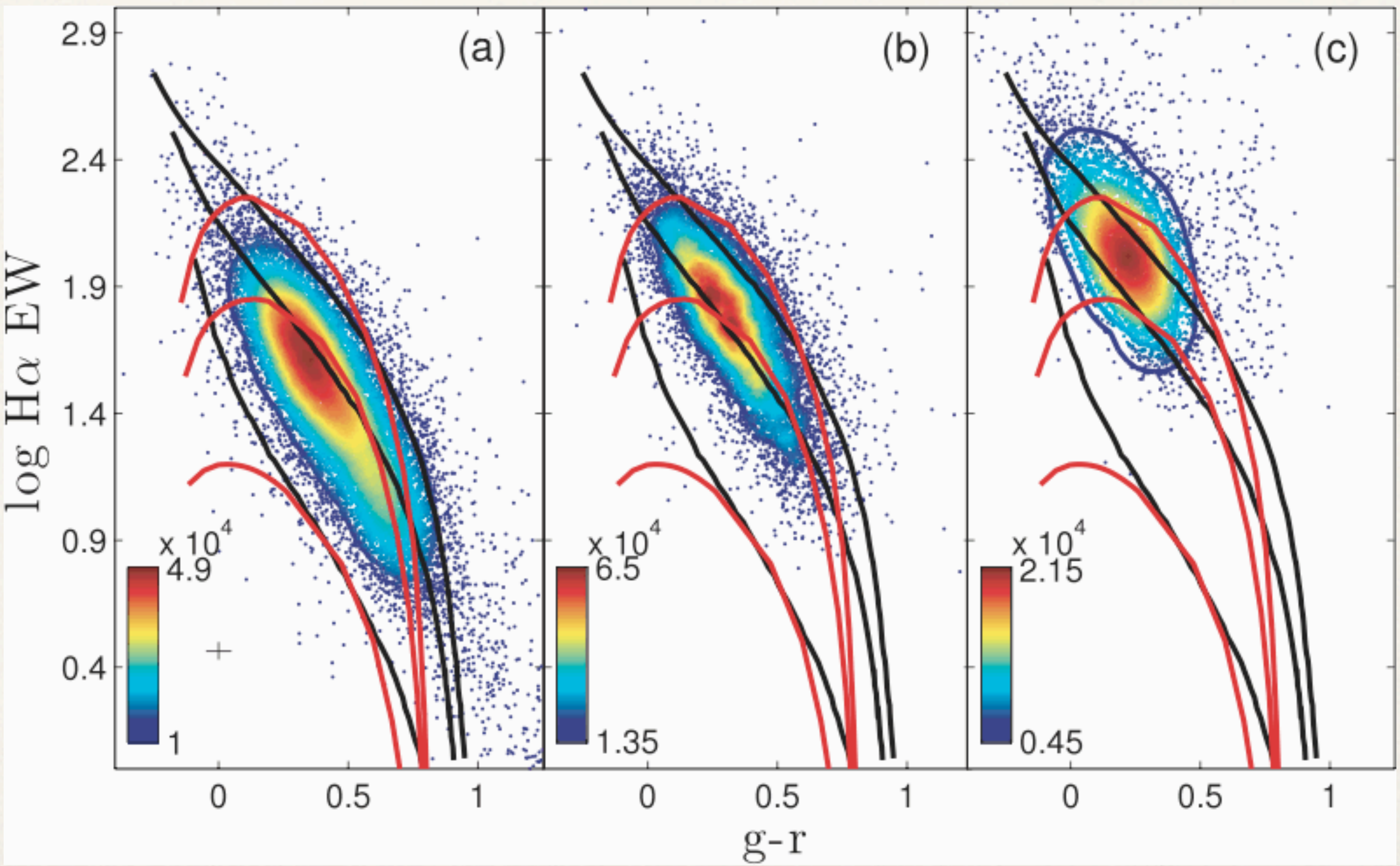
Gunawardhana et al., 2012, MNRAS (submitted)

Evolution of the stellar initial mass function?



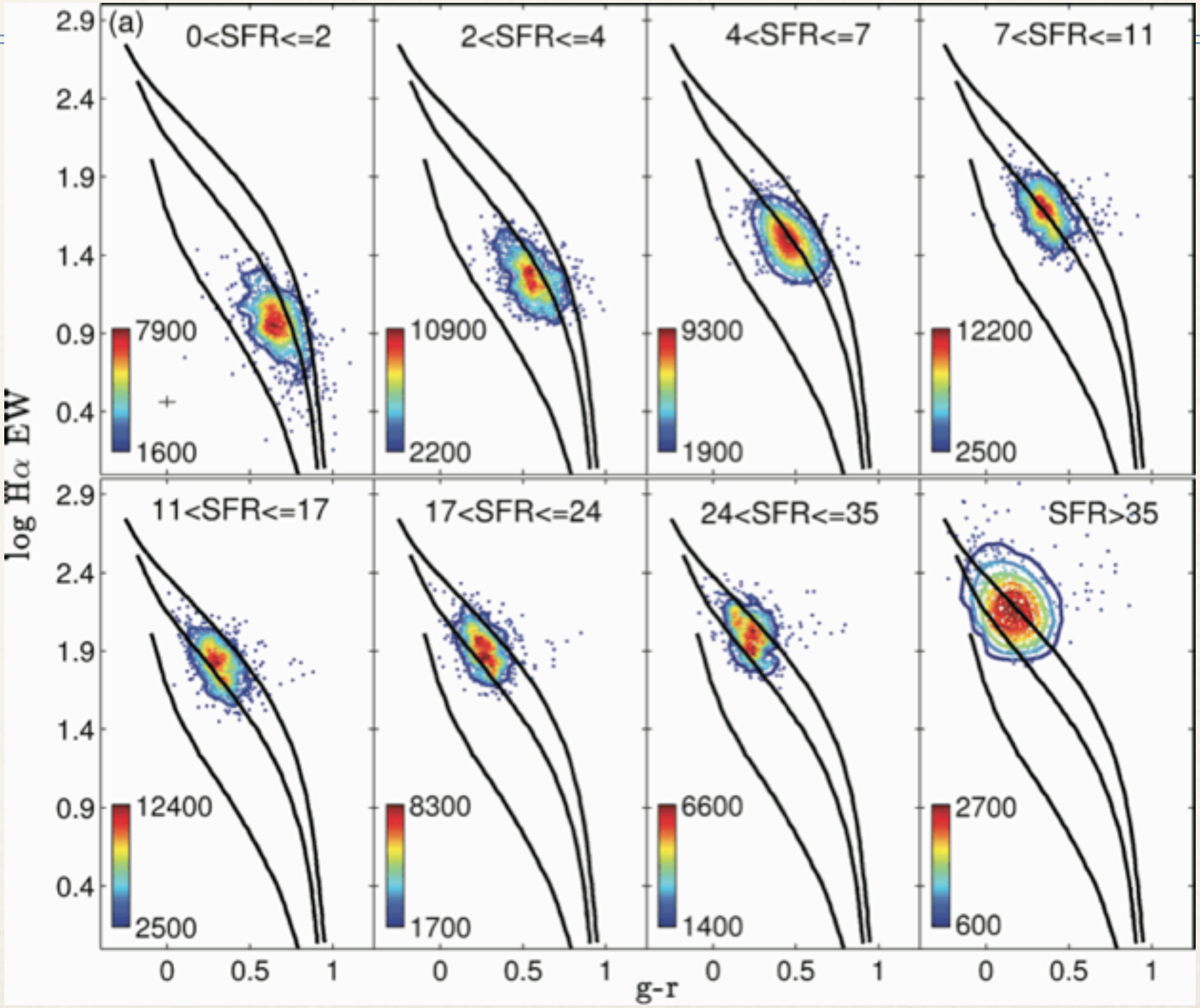
Wilkins et al., 2008, MNRAS, 385, 687

Initial mass function variations?



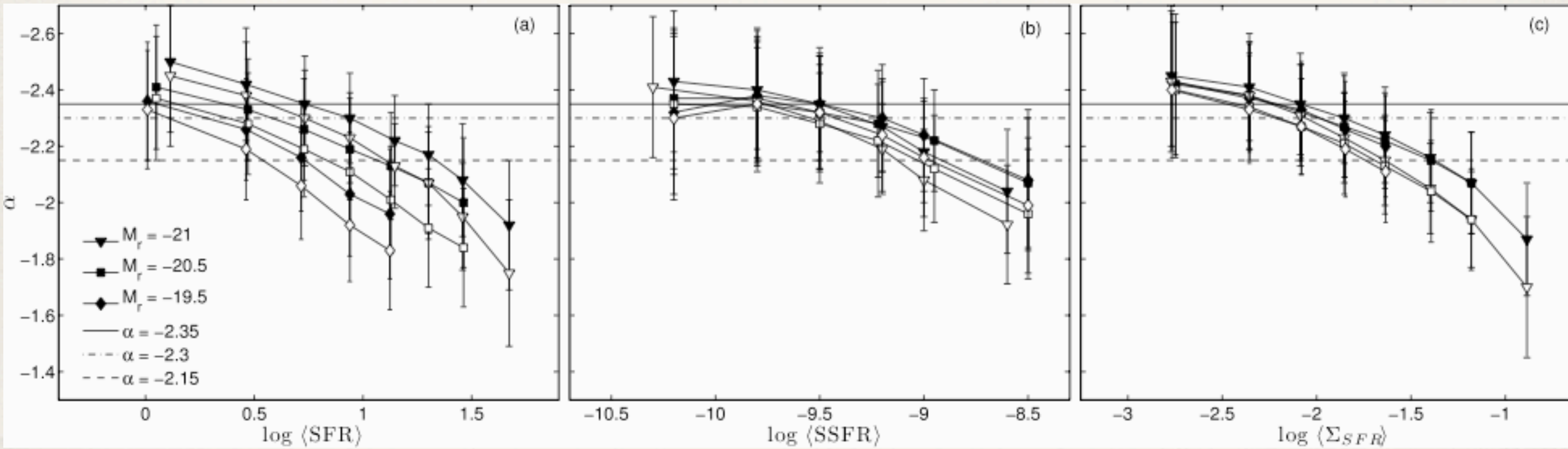
Gunawardhana et al., 2011, MNRAS, 415, 1647

Initial mass function variations?



Gunawardhana et al., 2011, MNRAS, 415, 1647

Initial mass function variations?



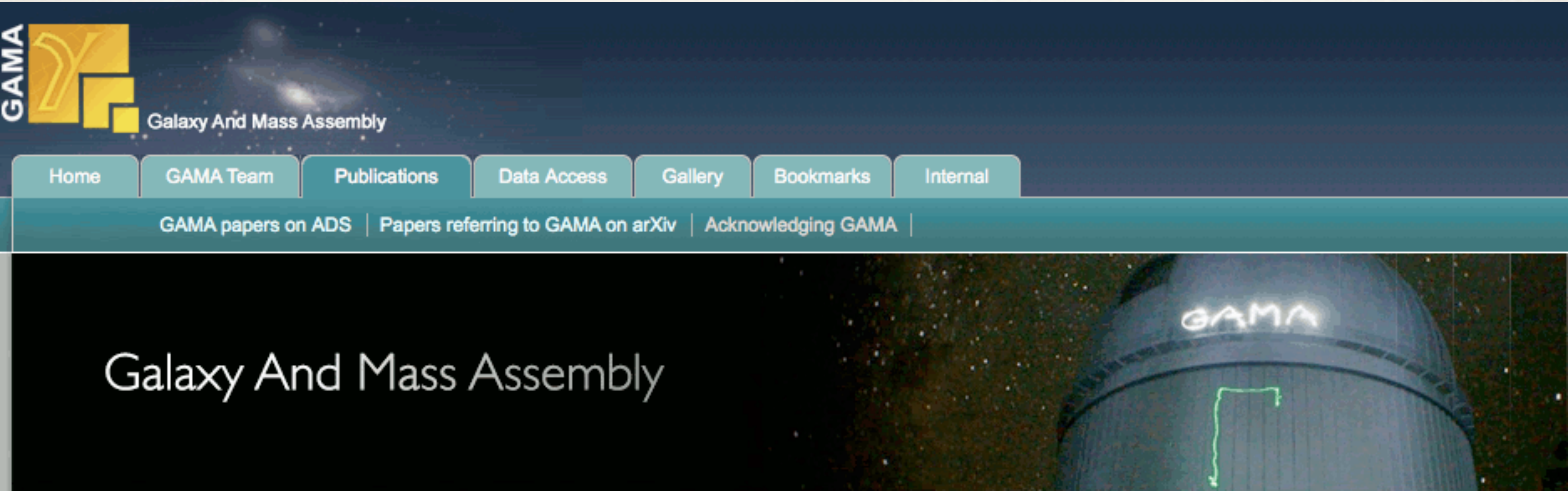
Gunawardhana et al., 2011, MNRAS, 415, 1647

Conclusions

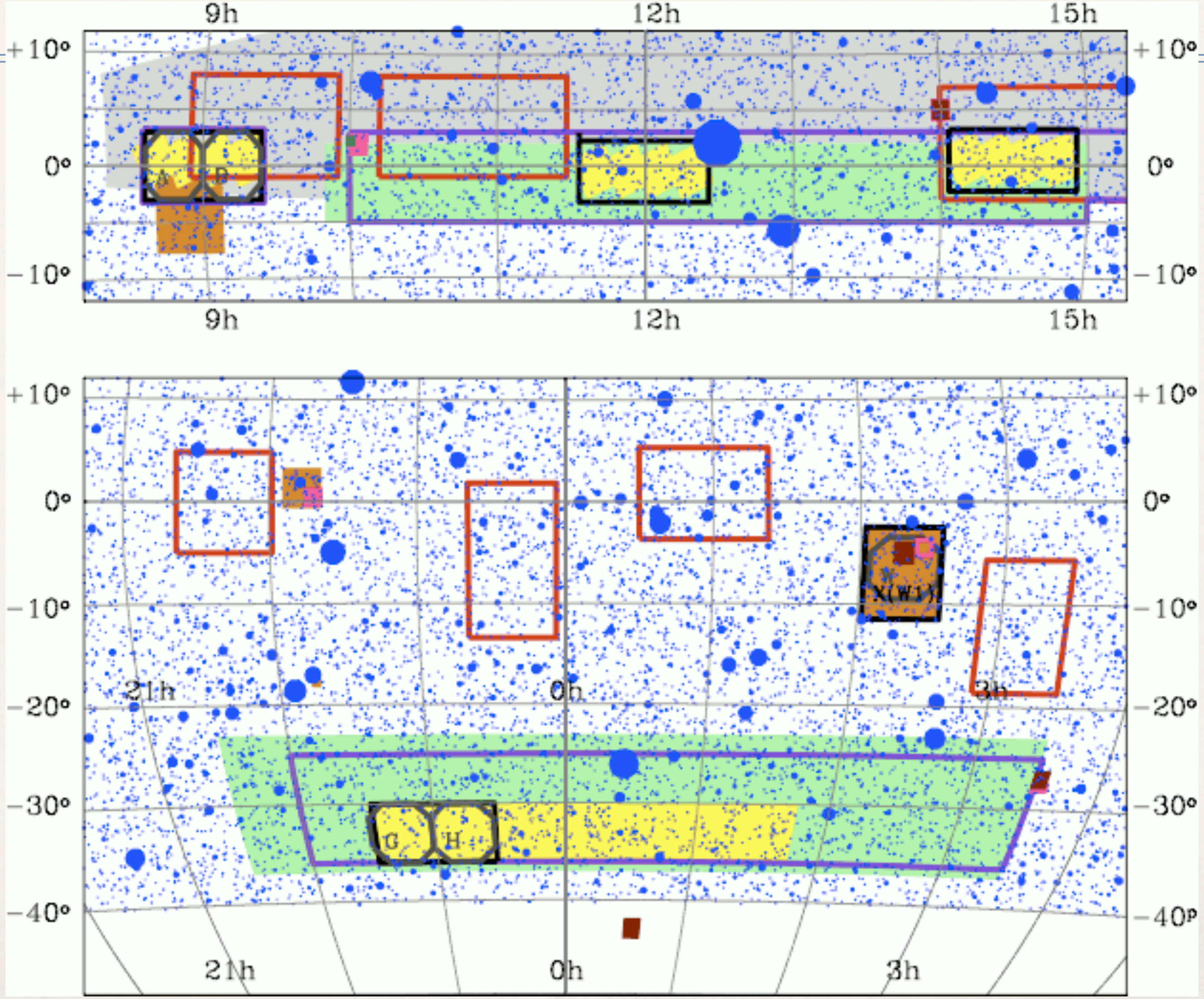
- SED modelling is likely to be the most robust approach to accurately estimating global SFRs for galaxies, but: (1) need to have a good stellar evolution template library; and (2) need to worry about obscuration and IMFs.
- Sensitive radio (SKA!) and FIR observations may ultimately turn out to be the most reliable, simple approach, but: (1) needs careful calibration; and (2) need to worry about AGN "contamination".
- Star formation in galaxies follows a Saunders (or two-power law) distribution, **not** a Schechter function.
- The Hα luminosity function from GAMA and SDSS confirms this for the first time, making Hα finally consistent with other wavelength estimators of SFR.

GAMA DR2

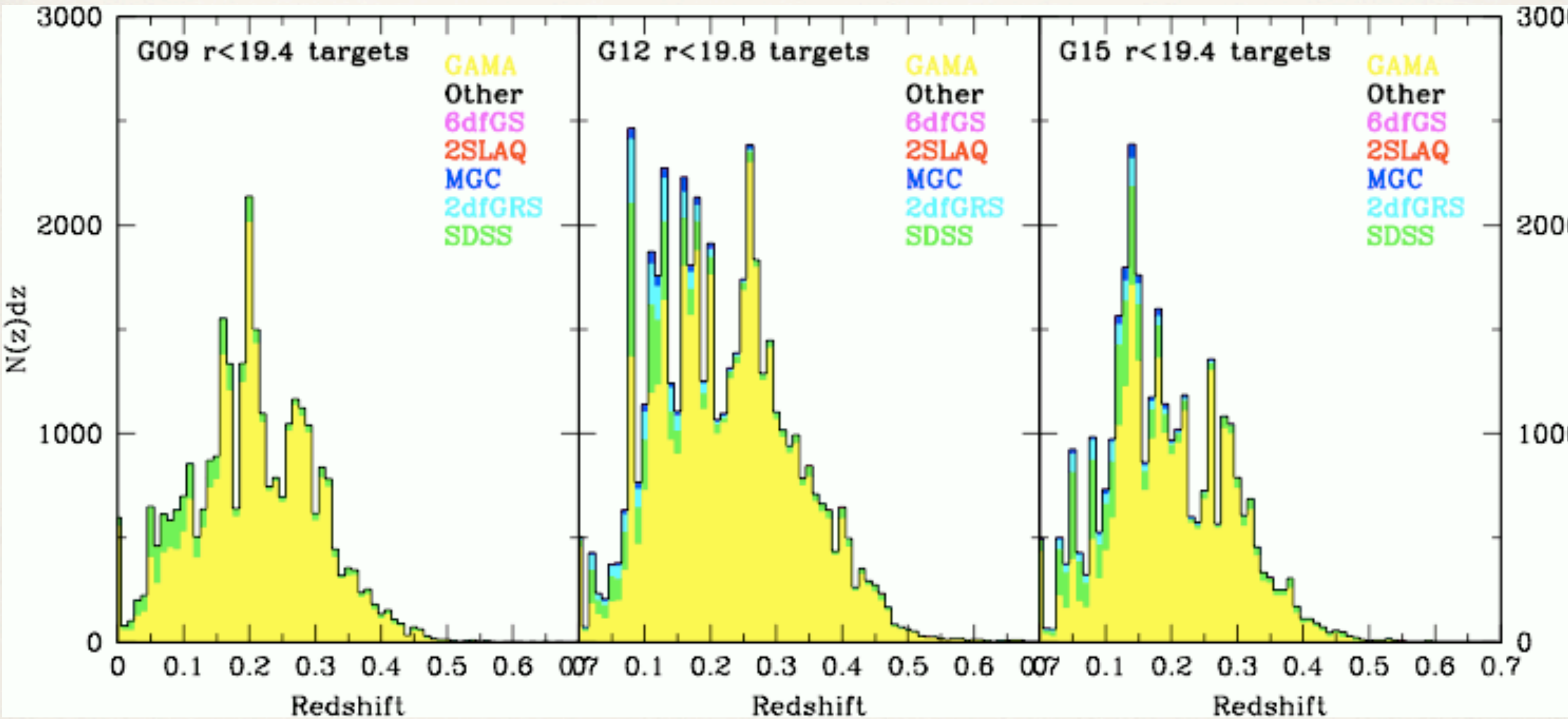
- **http://www.gama-survey.org/**
- The second GAMA public data release is scheduled for October 2012. Data release will include not only flux-calibrated spectra and redshifts, but derived products such as improved photometry, stellar masses, emission line measures and SFRs, group catalogue and membership, and more.



GAMA survey area

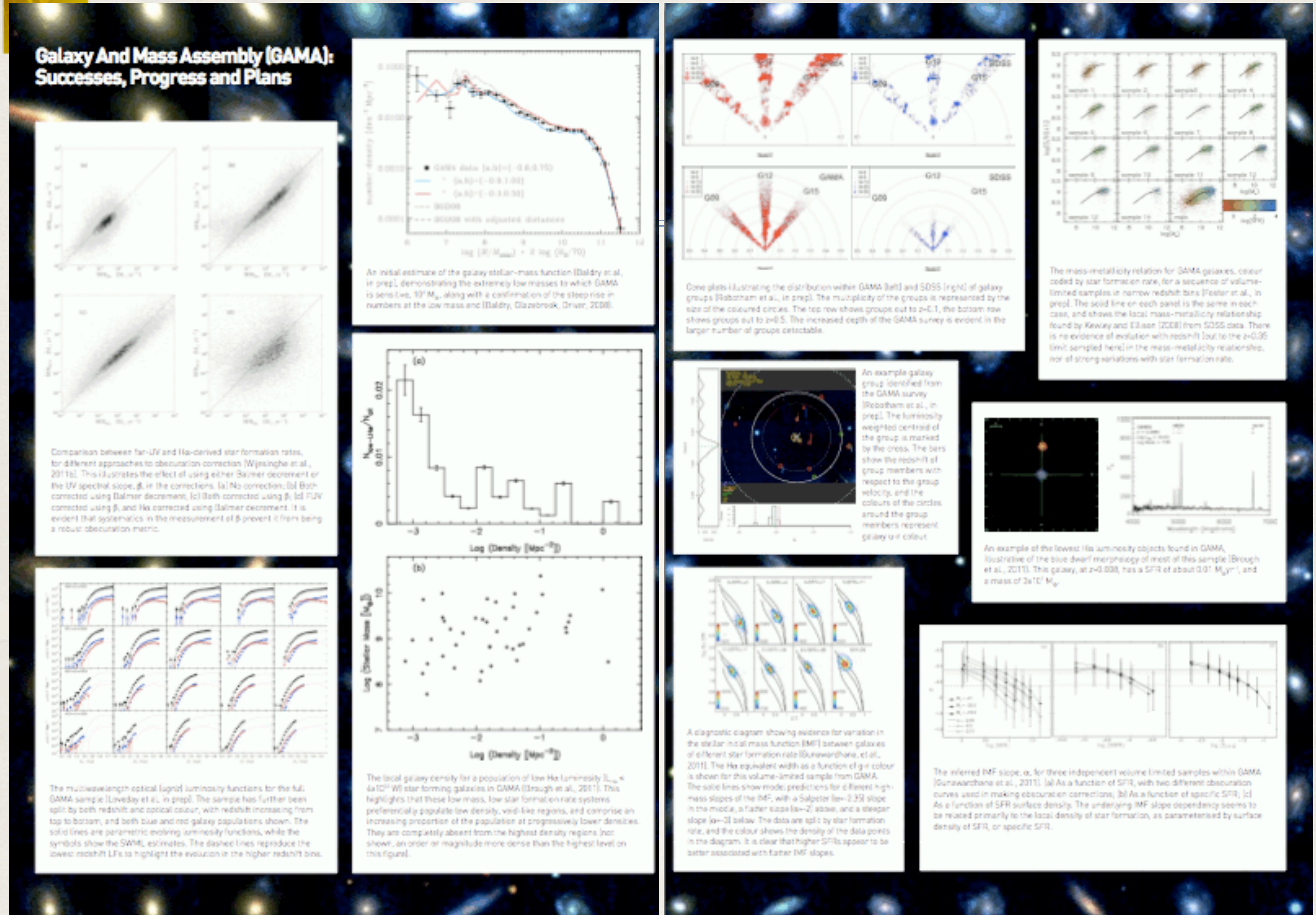


Redshift distribution



Driver et al 2011, MNRAS, 413, 971

GAMA



Galaxy And Mass Assembly (GAMA): Successes, Progress and Plans

Comparison between far-UV and Hα-derived star formation rates, for different approaches to obscuration correction (Wijesinghe et al., 2011b). This illustrates the effect of using either Balmer decrement or the UV spectral slope, β, in the corrections. (a) No correction; (b) Both corrected using Balmer decrement; (c) Both corrected using β; (d) FUV corrected using β, and Hα corrected using Balmer decrement. It is evident that systematics in the measurement of β prevent it from being a robust obscuration metric.

The multiwavelength optical (ugriz) luminosity functions for the full GAMA sample (Loveday et al. in prep). The sample has further been split by both redshift and optical colour, with redshift increasing from top to bottom, and both blue and red galaxy populations shown. The solid lines are parametric evolving luminosity functions, while the symbols show the SWML estimates. The dashed lines reproduce the lowest redshift LFs to highlight the evolution in the higher redshift bins.

An initial estimate of the galaxy stellar-mass function (Baldry et al., in prep), demonstrating the extremely low masses to which GAMA is sensitive, $10^7 M_\odot$, along with a confirmation of the steep rise in numbers at the low mass end (Baldry, Glazebrook, Driver, 2008).

The local galaxy density for a population of low Hα luminosity ($L_{H\alpha} < 4x10^{34}$ W) star forming galaxies in GAMA (Brough et al., 2011). This highlights that these low mass, low star formation rate systems preferentially populate low density, void-like regions, and comprise an increasing proportion of the population at progressively lower densities. They are completely absent from the highest density regions (not shown, an order of magnitude more dense than the highest level on this figure).

Cone plots illustrating the distribution within GAMA (left) and SDSS (right) of galaxy groups (Robotham et al., in prep). The multiplicity of the groups is represented by the size of the coloured circles. The top row shows groups out to z<0.1, the bottom row shows groups out to z<0.5. The increased depth of the GAMA survey is evident in the larger number of groups detectable.

The mass-metallicity relation for GAMA galaxies, colour coded by star formation rate, for a sequence of volume-limited samples in narrow redshift bins (Foster et al., in prep). The solid line on each panel is the same in each case, and shows the local mass-metallicity relationship found by Kewley and Ellison (2008) from SDSS data. There is no evidence of evolution with redshift (out to the z=0.35 limit sampled here) in the mass-metallicity relationship, nor of strong variations with star formation rate.

An example galaxy group identified from the GAMA survey (Robotham et al., in prep). The luminosity weighted centroid of the group is marked by the cross. The bars show the redshift of group members with respect to the group velocity, and the colours of the circles around the group members represent galaxy u-r colour.

An example of the lowest Hα luminosity objects found in GAMA, illustrative of the blue dwarf morphology of most of this sample (Brough et al., 2011). This galaxy, at z=0.008, has a SFR of about 0.01 $M_\odot yr^{-1}$, and a mass of $3x10^7 M_\odot$.

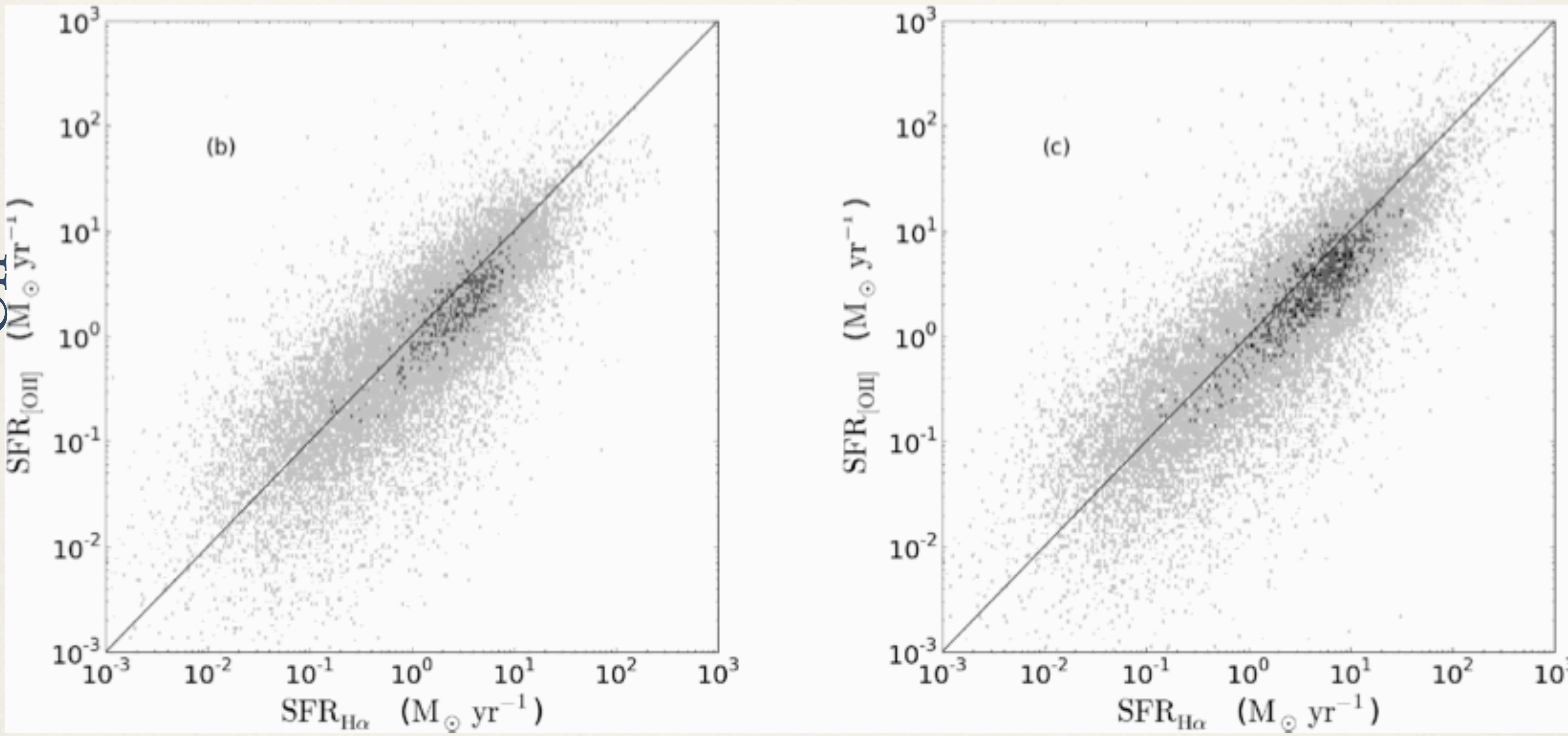
A diagnostic diagram showing evidence for variation in the stellar initial mass function (IMF) between galaxies of different star formation rate (Gunawardhana, et al., 2011). The Hα equivalent width as a function of g-r colour is shown for this volume-limited sample from GAMA. The solid lines show model predictions for different high-mass slopes of the IMF, with a Salpeter (α=-2.35) slope in the middle, a flatter slope (α=-2) above, and a steeper slope (α=-3) below. The data are split by star formation rate, and the colour shows the density of the data points in the diagram. It is clear that higher SFRs appear to be better associated with flatter IMF slopes.

The inferred IMF slope, α, for three independent volume limited samples within GAMA (Gunawardhana et al., 2011). (a) As a function of SFR, with two different obscuration curves used in making obscuration corrections; (b) As a function of specific SFR; (c) As a function of SFR surface density. The underlying IMF slope dependency seems to be related primarily to the local density of star formation, as parameterised by surface density of SFR, or specific SFR.

AAO Observer, Feb 2011, pp16-17

MW SFR: Hα vs [OII]

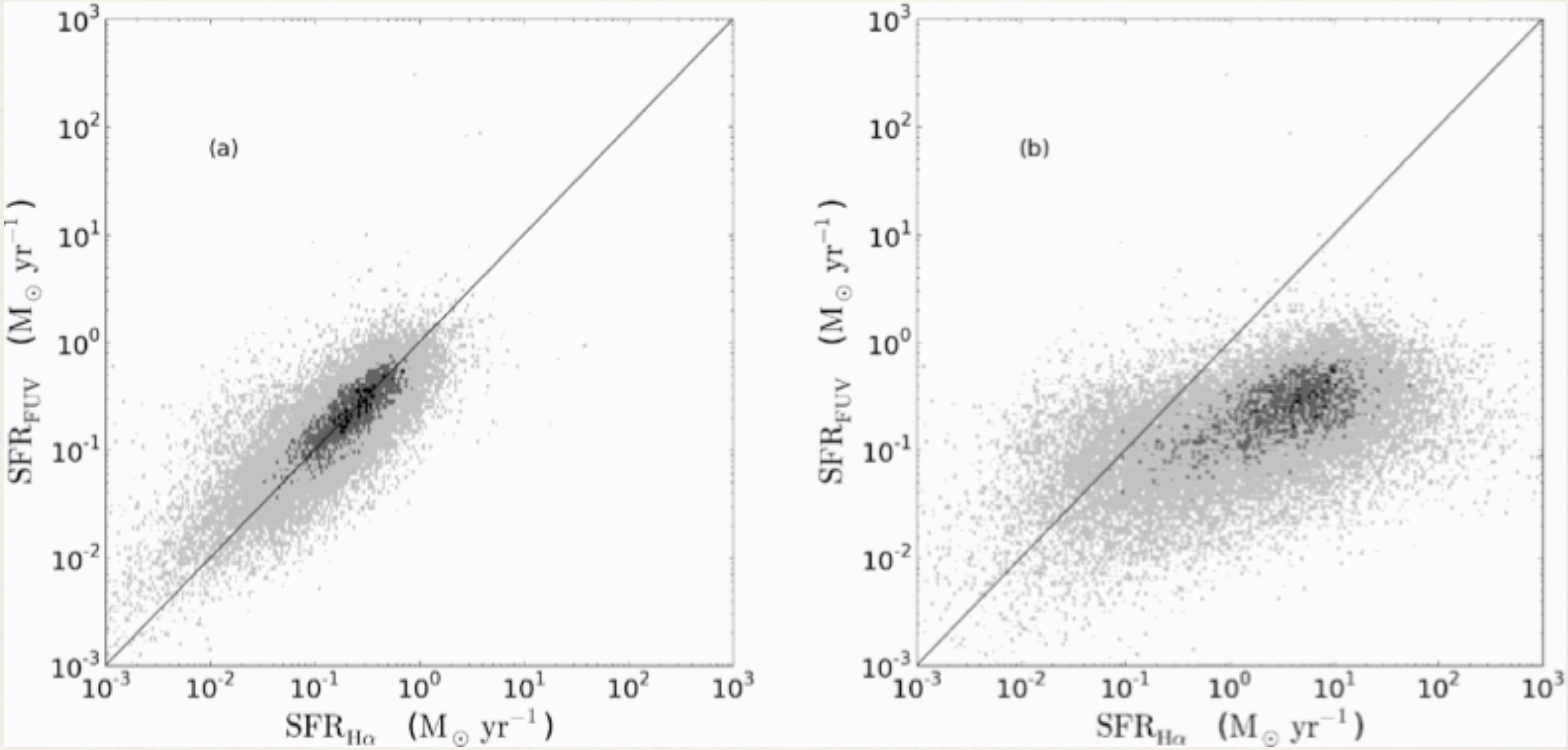
SFR_{OII}



$SFR_{H\alpha}$

Wijesinghe et al, 2011, MNRAS, 410, 2291

MW SFR in GAMA



Wijesinghe et al, 2011, MNRAS, 410, 2291

GAMA Additional Science

- ★ Galaxy evolution: SFR dependence on environment, merger rate, galaxy type/morphology, mass, etc.
- ★ Obscuration, radiation balance between UV/IR, dependence on other galaxy properties, evolution.
- ★ IMF variations?
- ★ Metallicity evolution, dependence on galaxy properties, environment, etc.
- ★ Cluster/group properties, evolution, role in galaxy evolution.
- ★ Relationship between single-fibre galaxy properties and resolved spectroscopic properties from integral-field spectroscopic measurements.
- ★ Stellar/gas inter-relationships (GAMA+DINGO): galaxy fueling/stripping/feedback, etc. Stellar mass function, HI mass function, baryonic mass function.
- ★ AGN evolution, feedback mechanisms, (radio continuum from EMU).
- ★ And much, much more!