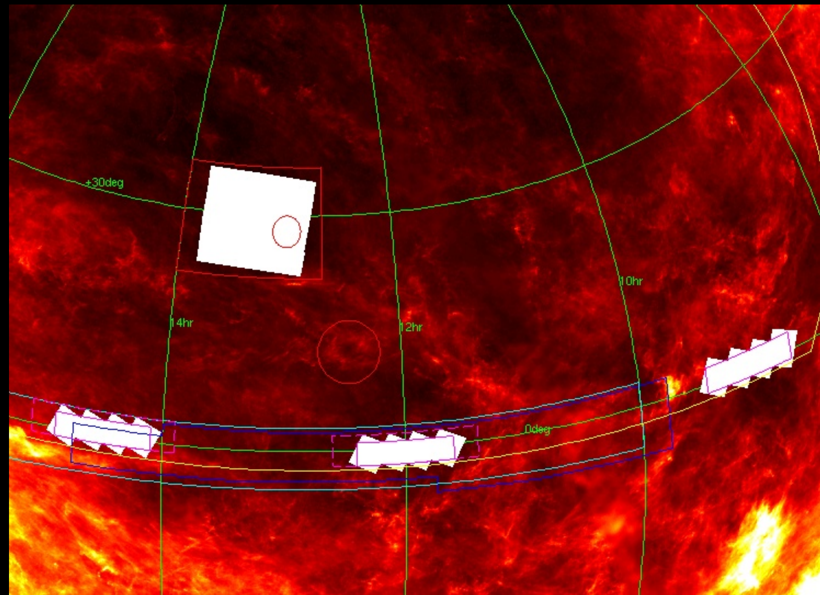
The evolution of star formation and galaxy morphology revealed by the deepest and shallowest Herschel surveys

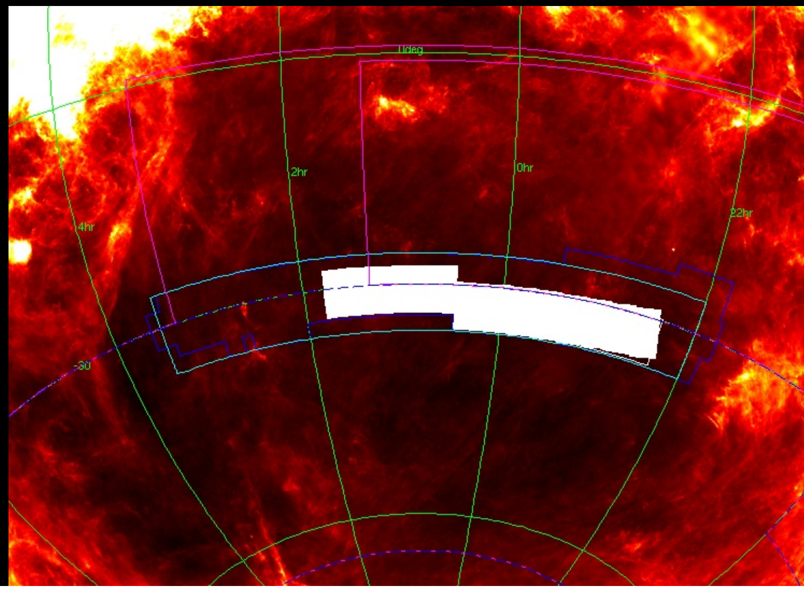
Steve Eales (Cardiff University) and the H-ATLAS and GAMA teams

The Herschel ATLAS

North



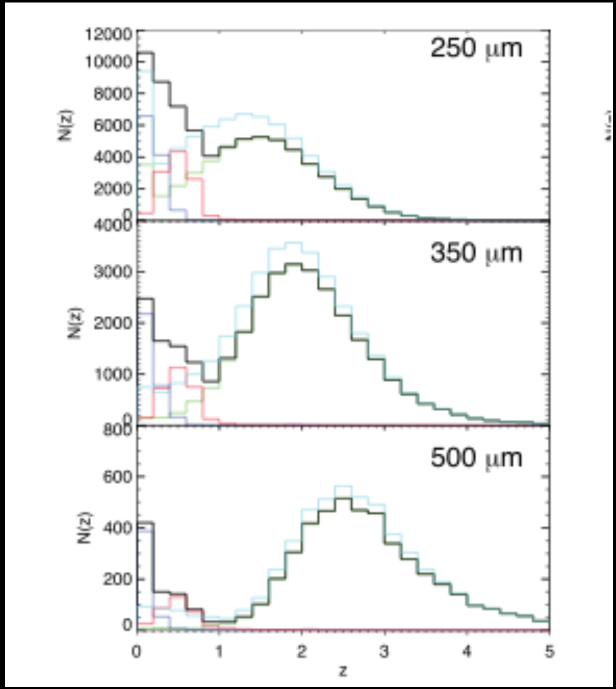
South



- The widest area extragalactic survey with Herschel (~ 550 sq deg)
- Covers 5 bands with PACs and SPIRE (100, 160, 250, 350, 500 μm)
- Five fields: North Galactic Pole (150 deg^2), South Galactic Pole (250 deg^2), and three fields (50 deg^2 each) coincident with the field surveyed in the deep spectroscopic survey of the Galaxy and Mass Assembly (GAMA) project
- Detects half a million sources
- Data Release for the GAMA fields (images, source catalogues and catalogues of optical counterparts) will occur in 2015, with the data release for the NGP and SGP six months later (h-atlas.org)

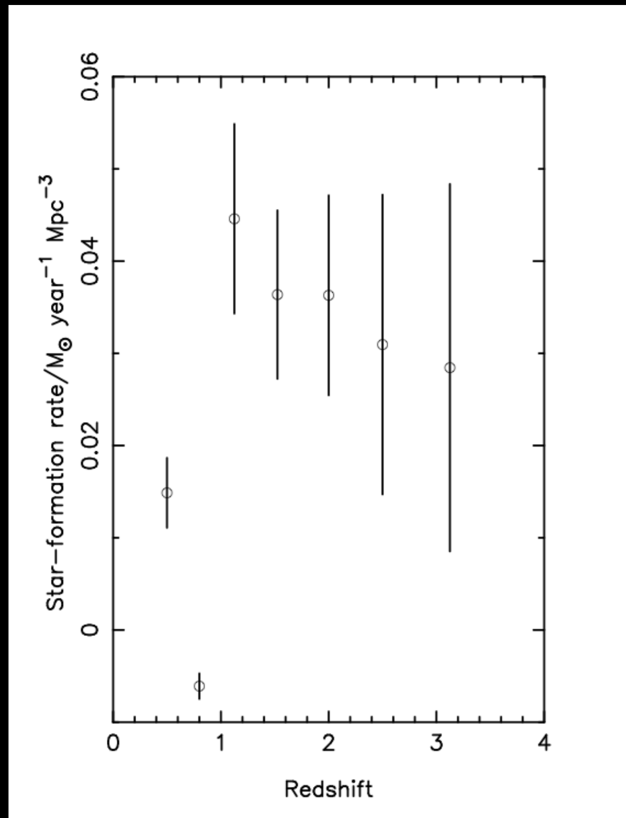
Key Science Themes

1. Local Universe Survey (to complement the SDSS/ 2dFGRS by providing estimates of ISM mass and star formation obscured by dust)
2. Synergies with Planck
3. The Herschel Lens Survey
4. AGN and rare objects
5. Large scale structure and High-z galaxies
6. Galactic star and planet formation



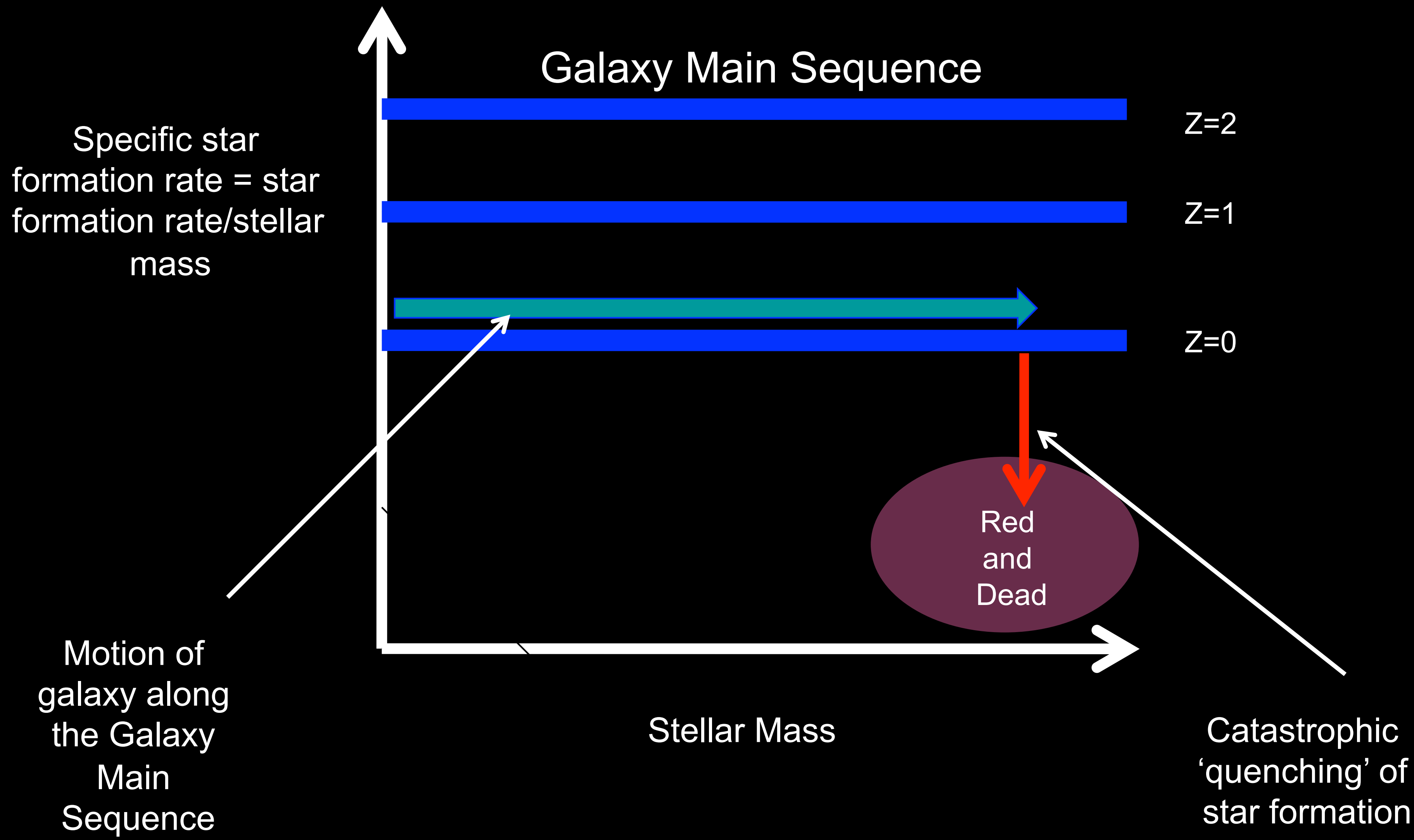
Why the Last Four Billion Years is Interesting

The star-formation rate in the galaxy population was greatest at z>1, but it was changing most quickly at z<1.



The star-formation history of the Universe calculated from the stellar mass functions for the COSMOS field (Ilbert et al. 2013) by Eales et al. (2014).

The Paradigm

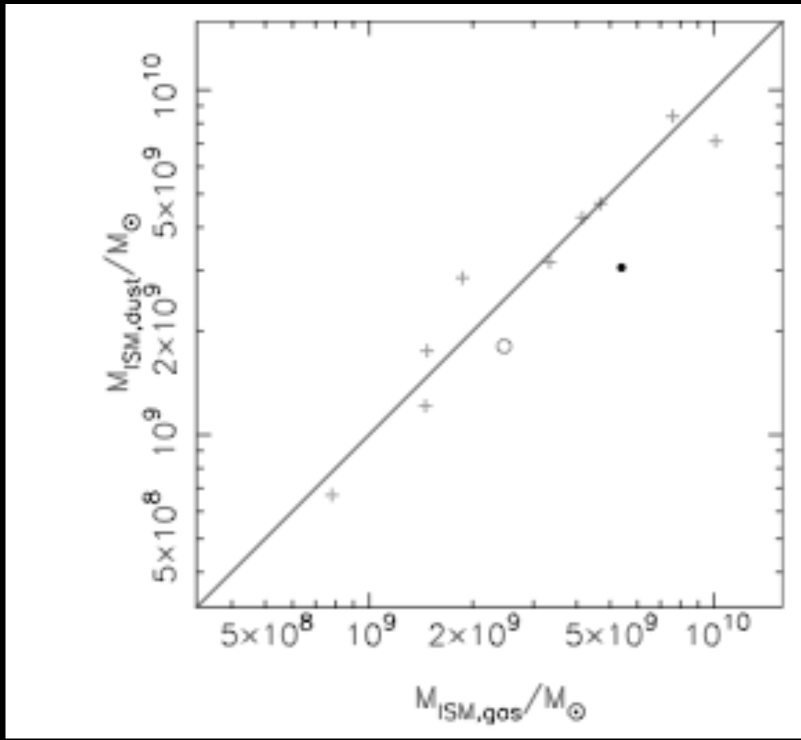


Observations of Galaxy Evolution from 0<z<0.4

- 13343 H-ATLAS galaxies at 0 < z < 0.4, including 3547 with z<0.1 (94% spectroscopic redshifts)

- We have used the MAGPHYS galaxy model (Da Cunha et al. 2008) and the spectral energy distributions of each galaxy from the UV (GALEX) to the far-infrared (Herschel) to estimate the star-formation rates, dust masses, and stellar masses of each galaxy.

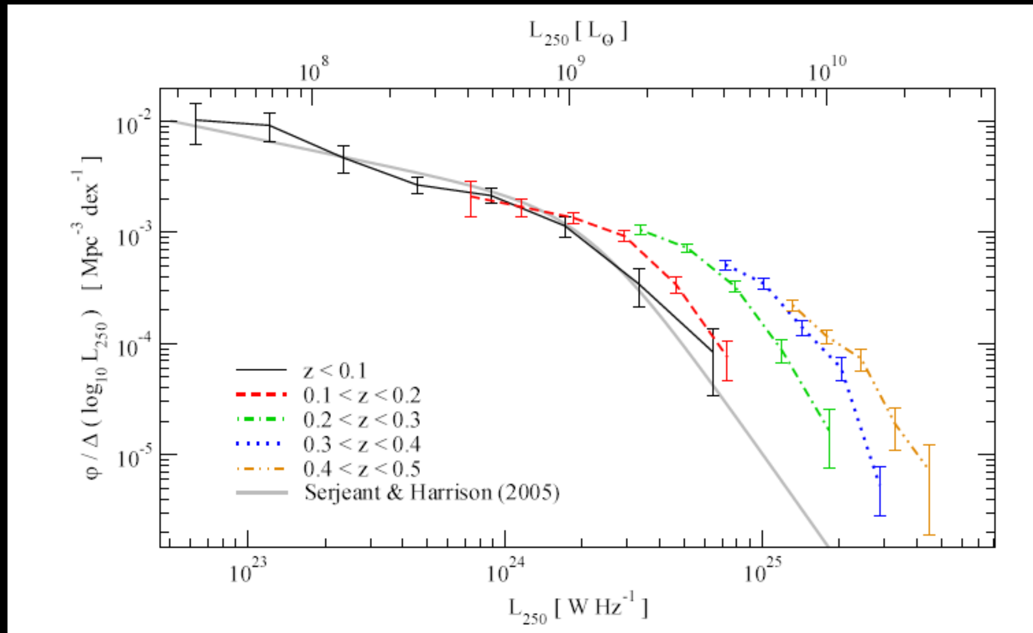
- We use the dust mass to trace the total mass of the ISM in each galaxy (Eales et al. 2012; Scoville et al. 2014).



Eales et al. 2012, ApJ, 761, 168

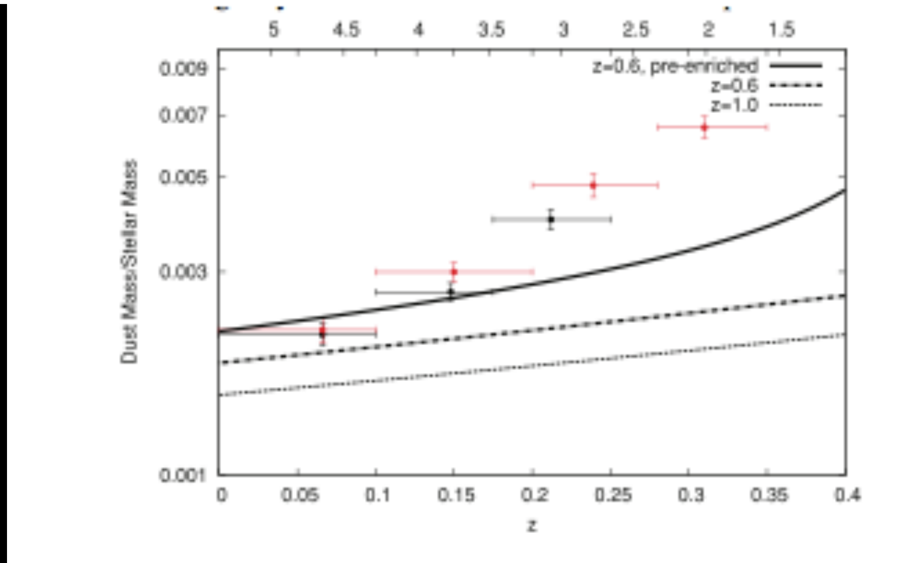
Rapid Recent Cosmic Evolution

In the luminosity function



Dye et al, 2010,A&A, 518,L10

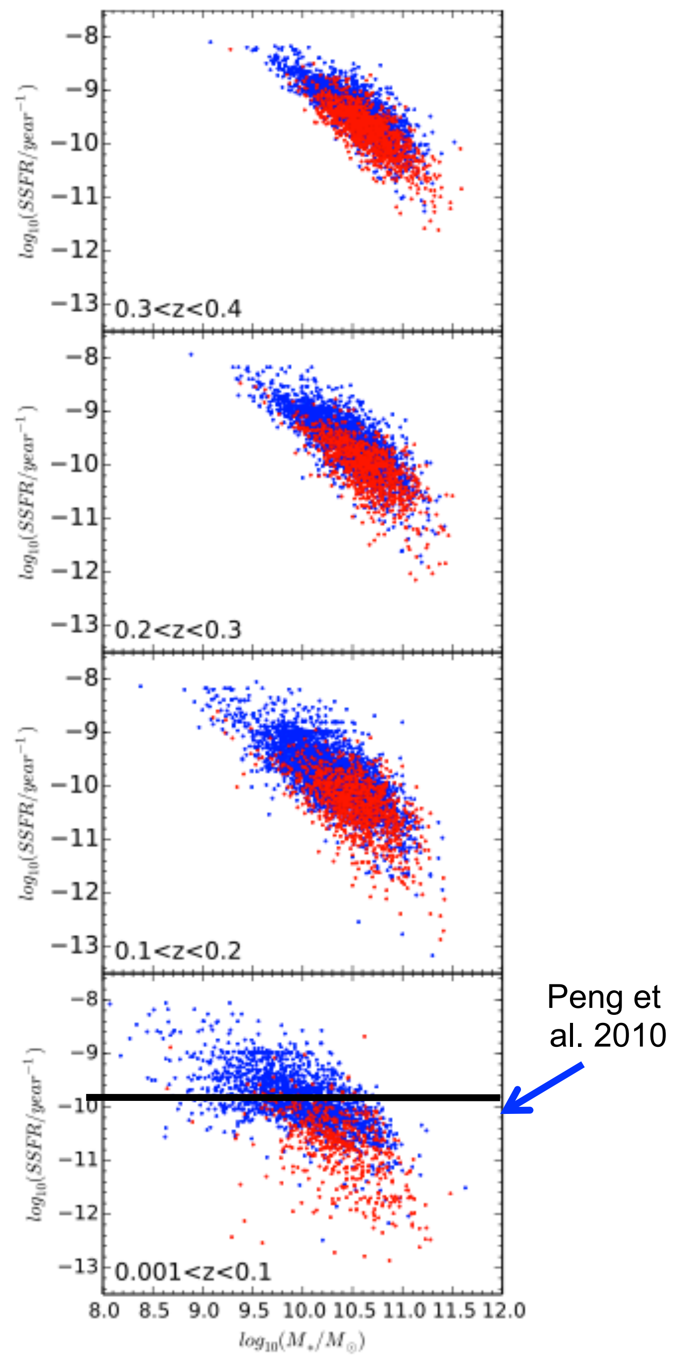
And in the dust masses



Dunne et al. 2011 MNRAS. 417, 1510

A Steep Galaxy Main Sequence

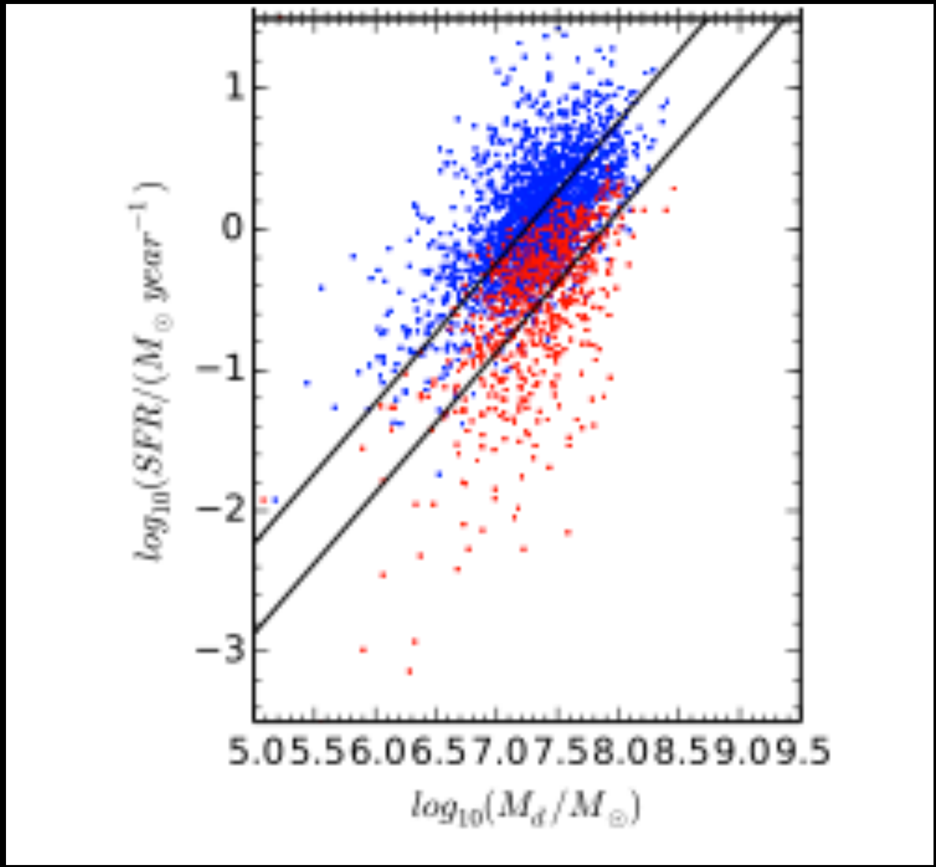
• The H-ATLAS galaxy main sequence is much steeper than that derived from most optical surveys
• 20-30% of H-ATLAS galaxies are optically-red galaxies optical surveys would have missed
• These galaxies have old stellar populations, but contain large reservoirs of ISM and are still forming stars.



Eales et al. 2014

Kennicutt-Schmidt Relation

The star-formation efficiency is less for the optically red galaxies



Comparison with Theory

- We have compared our results with the analytic models of Lilly et al. (2013) and Peng and Maiolino (2014). These assume that the star-formation rate is proportional to the mass of the ISM and that the rate of accretion of gas is proportional to the rate of increase of the mass of the dark-matter halo.
- The models predict a flat Galaxy Main Sequence rather than the steep one we observe.
- We see much stronger evolution at low redshift than the models predict.

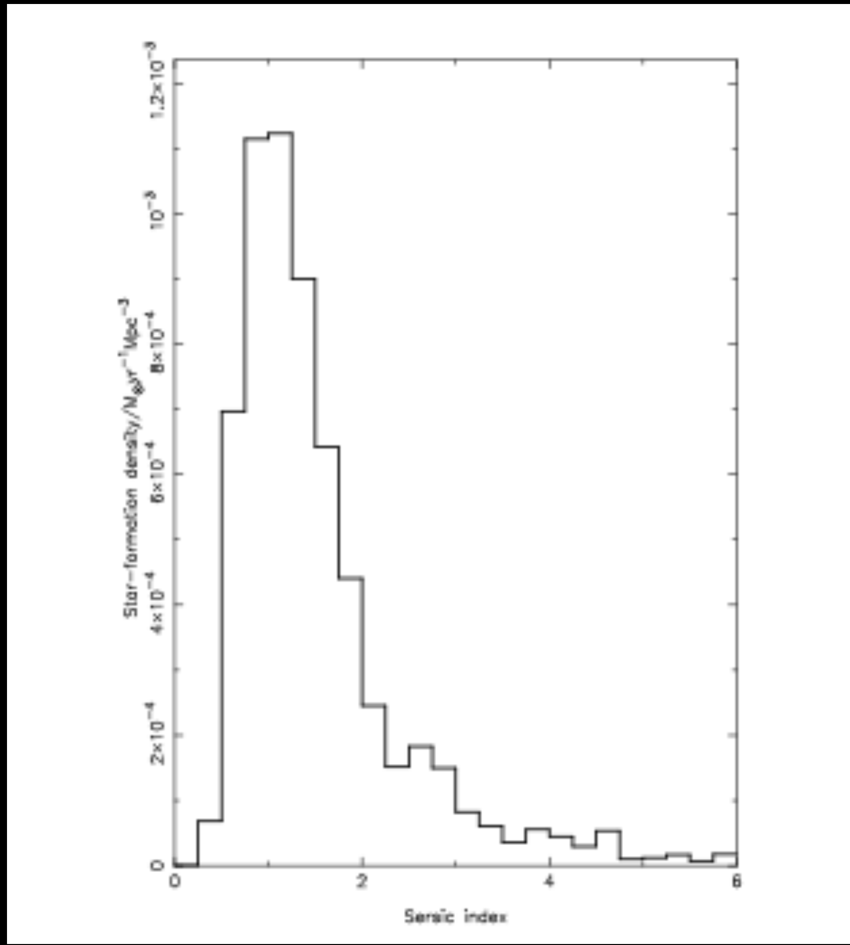
Two Types of ‘Quenching’

- It is usually assumed that there must be some catastrophic quenching process that converts a star-forming galaxy into a ‘red dead galaxy’
- There must be other processes that explain the variation in galaxy properties along the Main Sequence and, in particular, the production of the ‘red but not dead’ galaxies at its end.

Star Formation in the Universe Today

- The GAMA team has measured the structures of galaxies in their survey by fitting a Sersic function
- The Sersic index is 1 for a pure disk, 4 for a pure spheroid
- We have used H-ATLAS to estimate the star-formation density in the Universe today as function of Sersic index
- Star-formation in the Universe today occurs in disk-dominated galaxies

Star formation density



Sersic Index

Cosmic Calorimetry

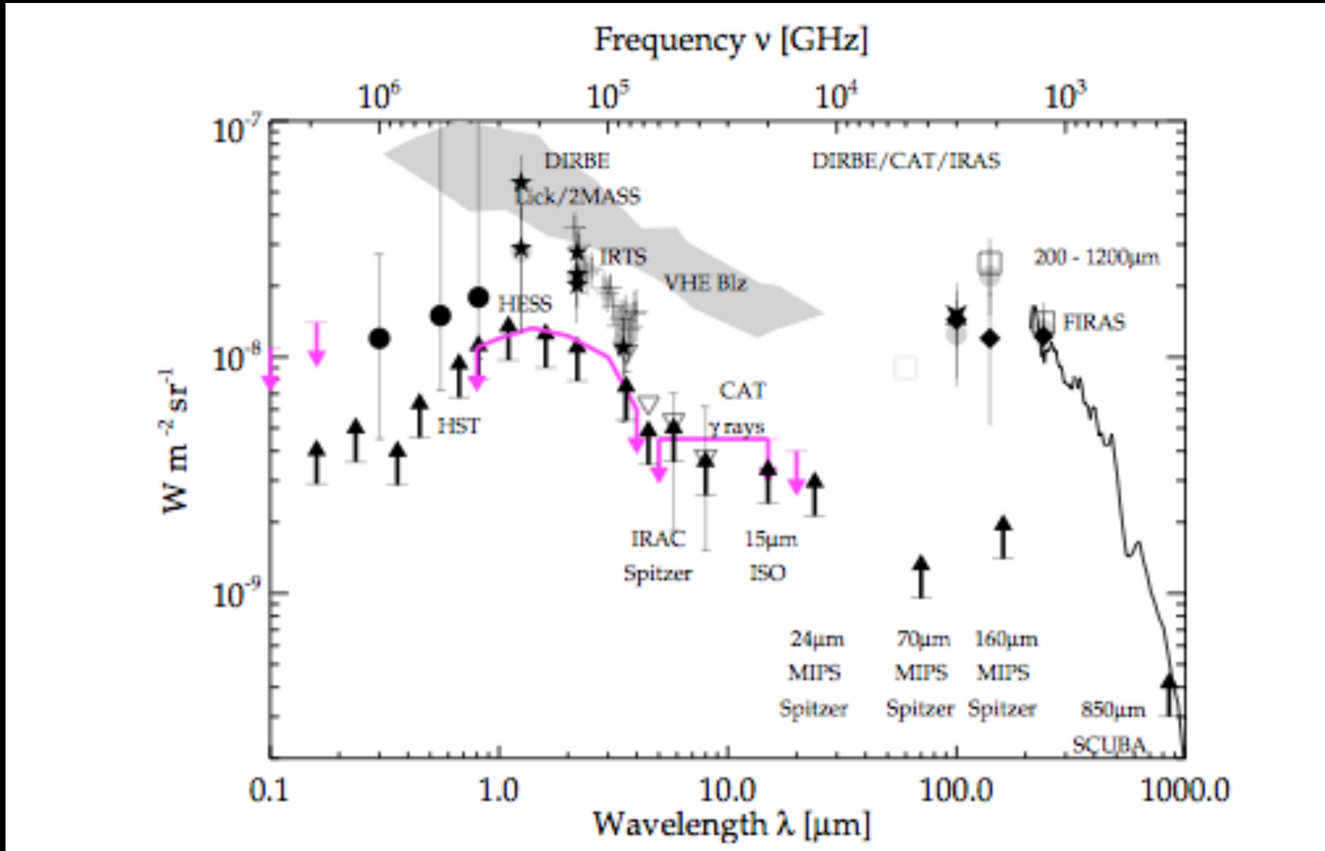
The accumulated products of nuclear fusion in the stars producing the background

The extragalactic background radiation

$$\int_0^\infty B_\nu d\nu = \int_0^{t_H} \frac{0.007\rho c^3}{4\pi(1+z)} dt$$

- For a universal IMF, the average density of the stellar population today produced by star-formation at a redshift z is proportional to the contribution of that stellar population to the background radiation multiplied by (1+z)
- If we knew the structures of a fair sample of the galaxies making up the background radiation, we could determine what kinds of galaxies have contributed most of the stars

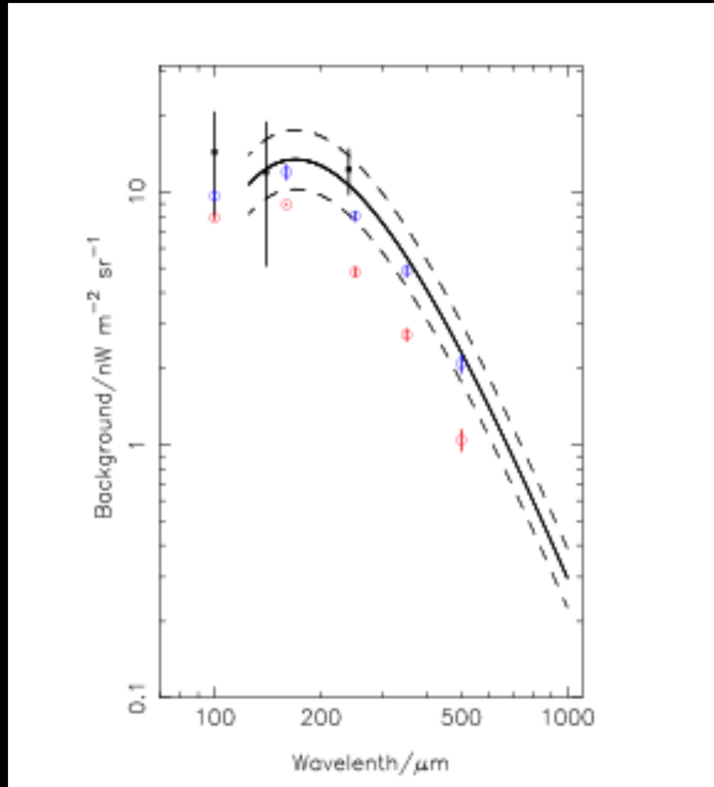
Extragalactic Background Radiation



- One peak in the far infrared
- One in the optical/near infrared

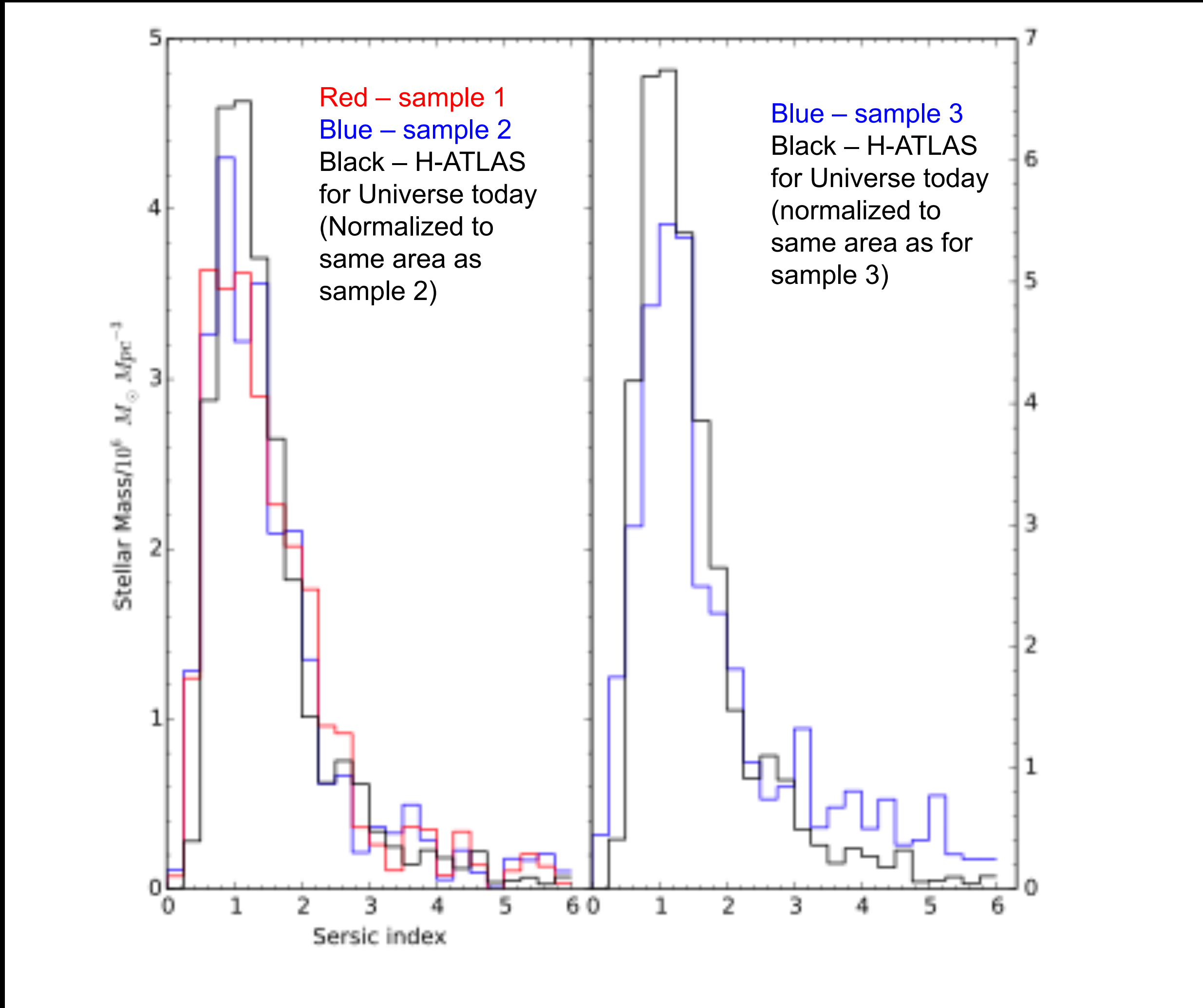
Samples of the background radiation

- 527 sources detected by the Herschel GOODS survey in GOODS-South – sample 1
- 1557 sources detected by Spitzer at 24 μm in GOODS-South – sample 2
- 8488 sources detected by the CANDELS HST survey at 1.6 μm in GOODS-South – sample 3
- Sersic indices measured by CANDELS team



Sample 2 contributes 90% of the far-infrared background. If there is no diffuse optical/near-IR background, sample 3 contributes 94% of that background

Star formation over all time



If disk-dominated galaxies have Sersic indices betweem 0 and 2.5, 80% of stars must have formed in disk-dominated systems

Which came first – early-types or late-types?

- The GAMA team (Kelvin et al. 2014, MNRAS, 444, 1647) have used eye-ball classification to estimate that 34% of the stellar mass today is in ellipticals and 37% is in S0-Sa → 71% of the stellar mass today is in early-types
- But if 80% of the stellar mass formed in late-types, morphological transformation must have happened after most of the stars had formed

Summary

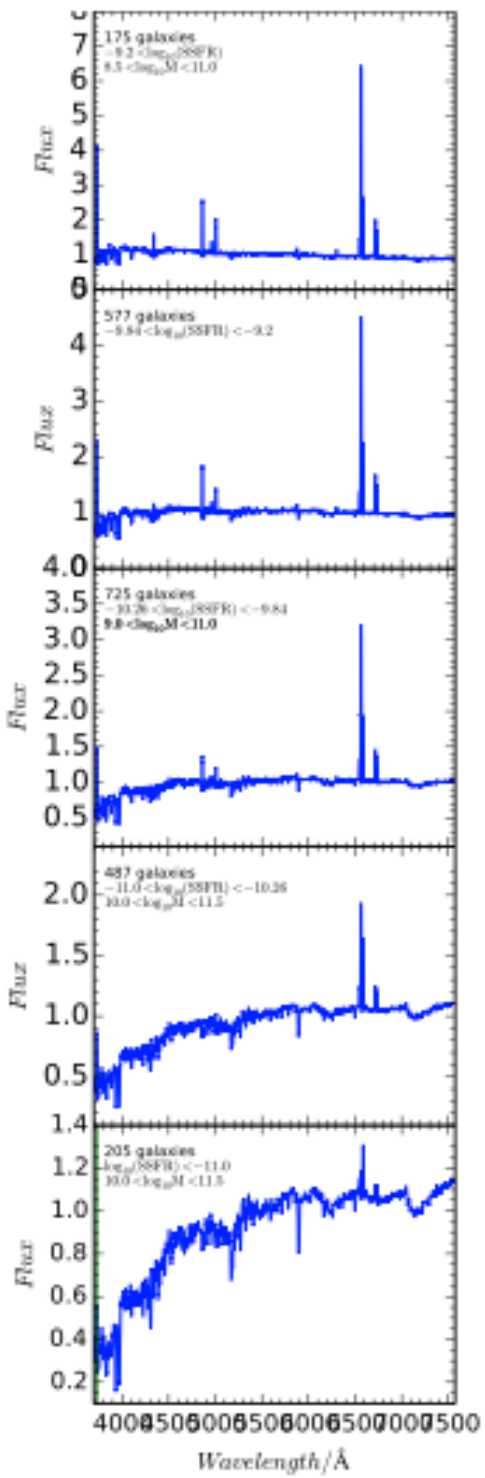
- Rapid cosmic evolution from $0<z<0.4$, inconsistent with recent models
- Very steep Galaxy Main Sequence, with a population of old red galaxies at the bottom, which are generally missed by optical surveys but which still contain large gas reservoirs and are still forming stars
- Steady change in galaxy properties along the Galaxy Main Sequence (from top to bottom, a weak increase in environmental density, a moderate increase in the dominance of the bulge, a strong increase in the fraction of the far-infrared emission that is produced in the diffuse ISM)
- There must be a process apart from quenching that explains the gradual change in properties along the Main Sequence and the production of the ‘red but not dead’ galaxies at the bottom
- 80% of all the stars ever formed were formed in disks
- To explain the present dominance of early-type galaxies, their morphologies must have formed after most of the stars in them had formed.

H-ATLAS/GAMA

Old or Dusty?

The stacked spectra of hundreds of galaxies show that the optically-red galaxies have old stellar populations

Decreasing specific star-formation rate



Variation along the Main Sequence

- Weak variation with environment
- Moderate dependence on morphology – the optically-red galaxies are more dominated by bulges
- Strong dependence on the fraction of the far-infrared emission emitted by the diffuse ISM