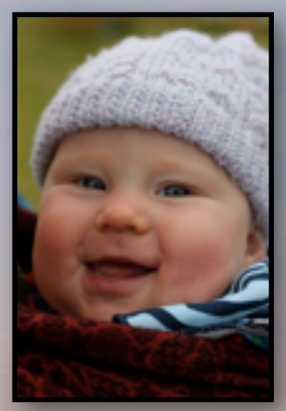
The incidence of AGN in post-starburst galaxies at ~~1<z<2~~ z~0

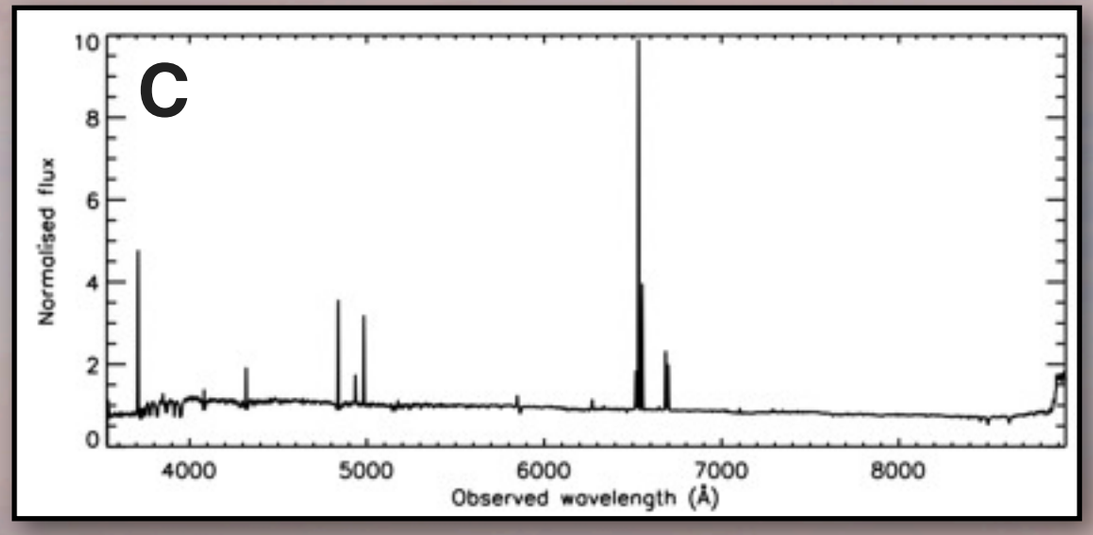


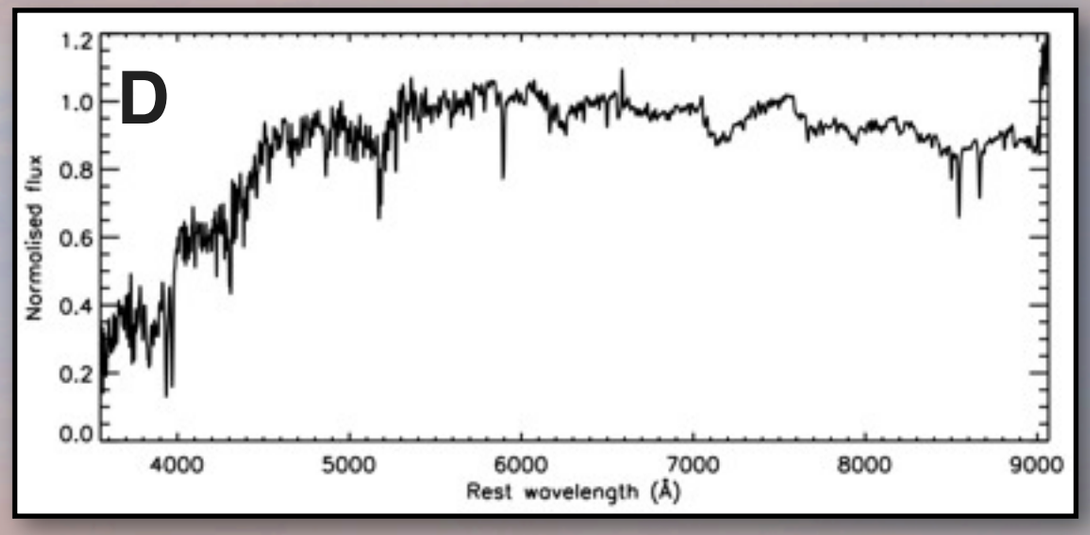
Vivienne Wild

University of St Andrews, UK

Galaxy bimodality

Vivienne Wild



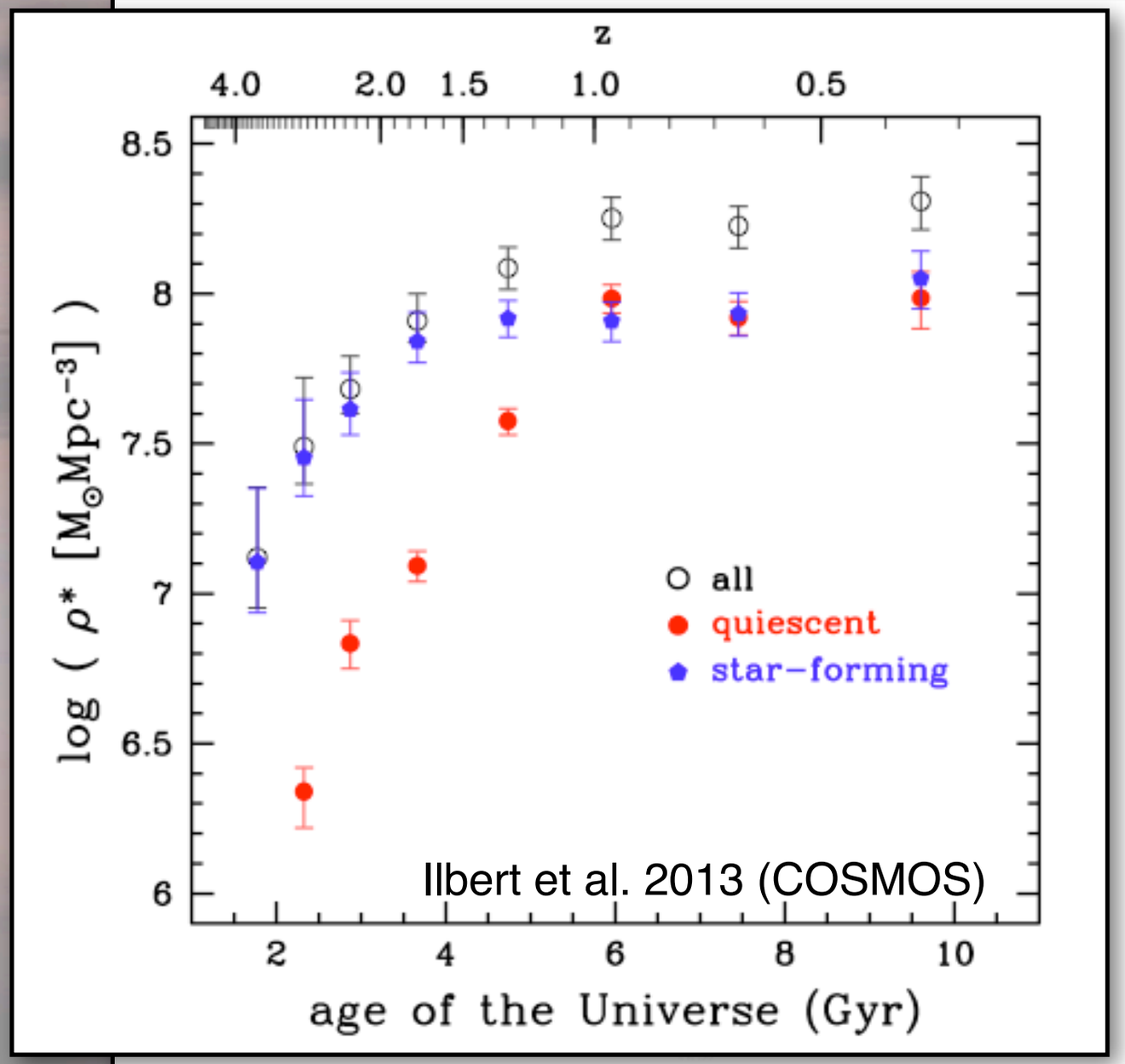


Why is Galaxy A spiral, while Galaxy B is elliptical?
Why is Galaxy C forming stars, while Galaxy D has stopped?
Why does A=C and B=D in general?

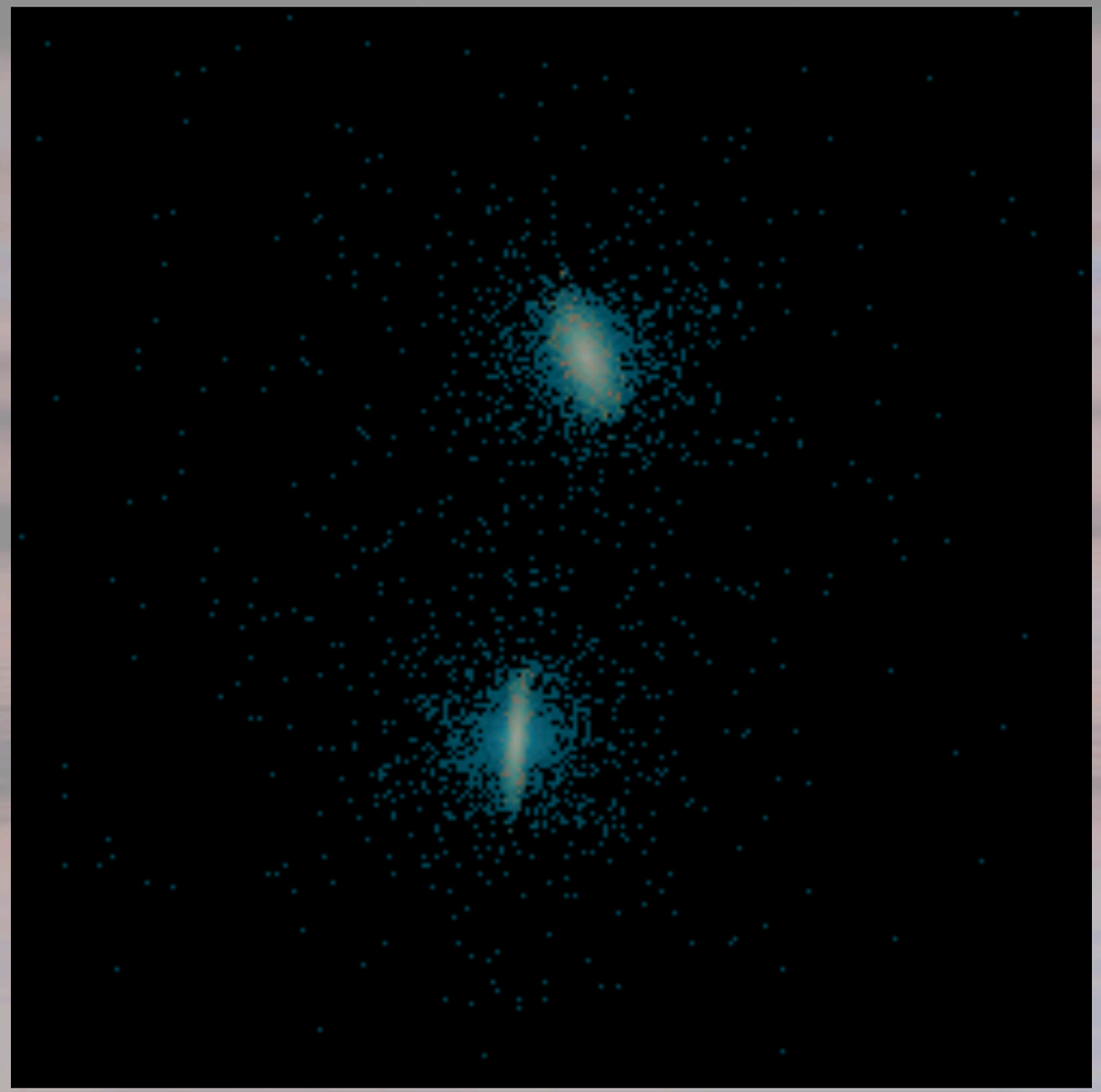
Evolution of galaxy bimodality

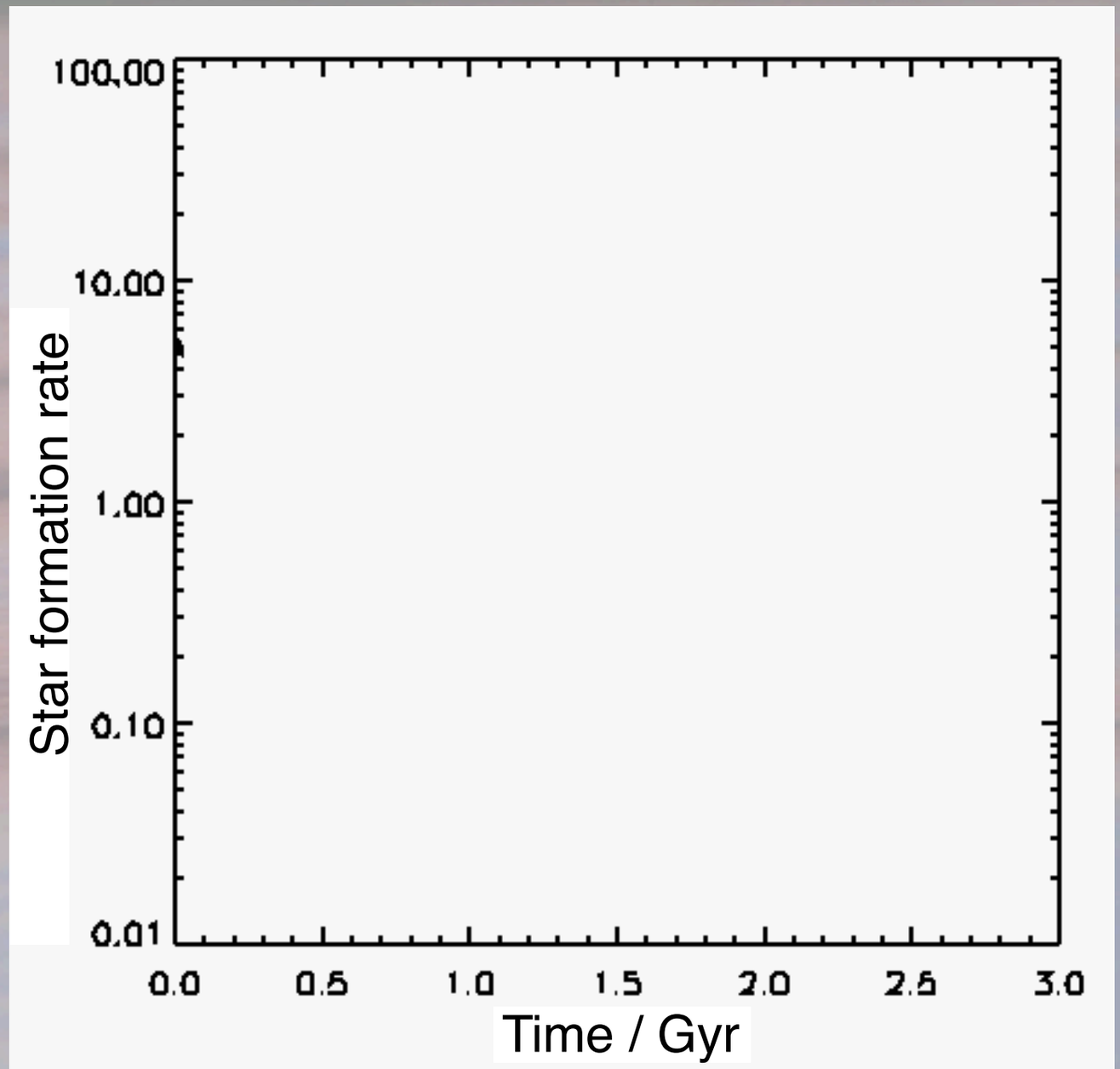
Vivienne Wild

Muzzin et al. 2014 (COSMOS/UltraVISTA)



Spectral Energy Distribution (SED) **bimodality**





Why are (gas-rich) galaxy mergers interesting?

1) quench star formation
2) make ellipticals from disks
3) fuel for growing SMBHs
4) outflows and feedback

Wild, Walcher, Johansson et al. 2009

Overview

Vivienne Wild

(1) Post-starburst galaxies as a transition population

- Observing an evolutionary sequence from starburst to quiescent
- Post-starburst = post-merger?
- Post-starburst => red-sequence galaxy?

(2) Timing the starburst-AGN connection

- Using stellar populations as a convenient clock

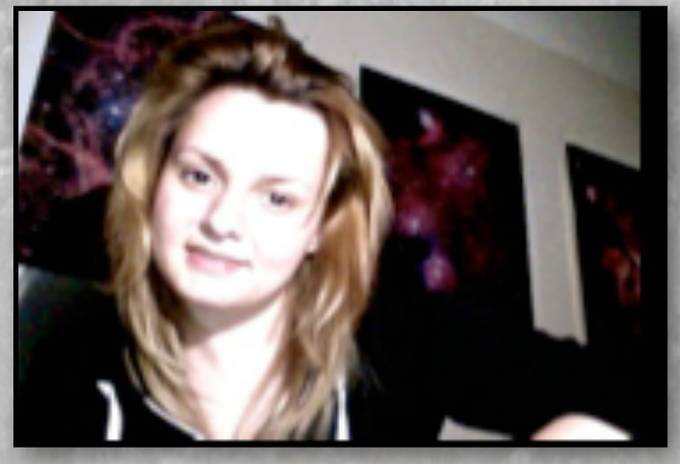
(3) Timing the starburst-AGN connection at high-z

- Finding PSBs in broad-band photometric surveys

(1) Post-starburst galaxies as a transitional population

Kate Rowlands

Rowlands et al. 2015



Milena Pawlik

See Pawlik, 2014, Astronomy & Geophysics, Volume 55, Issue 6

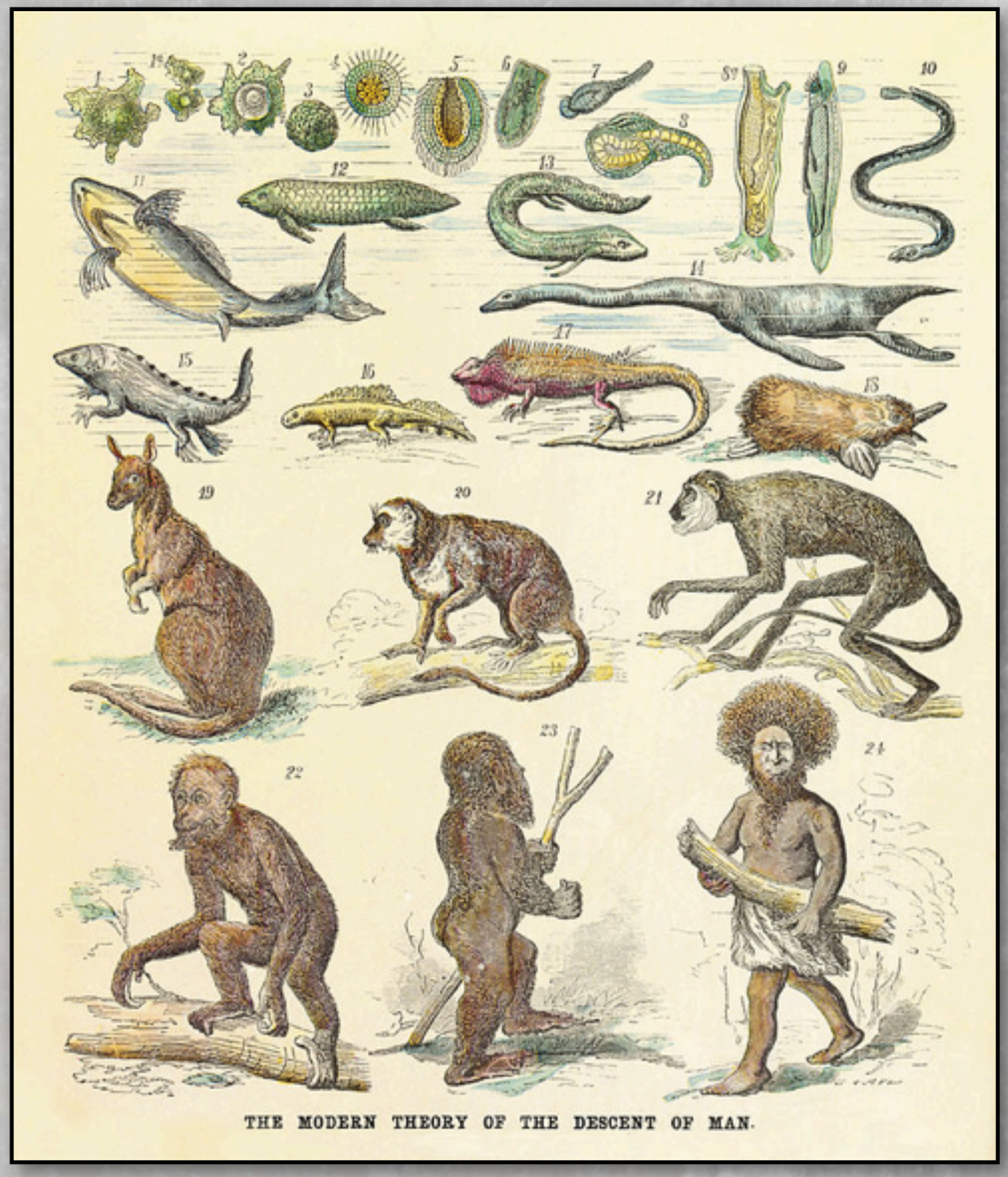
University of St Andrews

Jakob Walcher, Peter Johansson, Nicole Nesvadba, Bruce Sibthorpe, Angela Mortier, Matt Lehnert, Elisabeta da Cunha

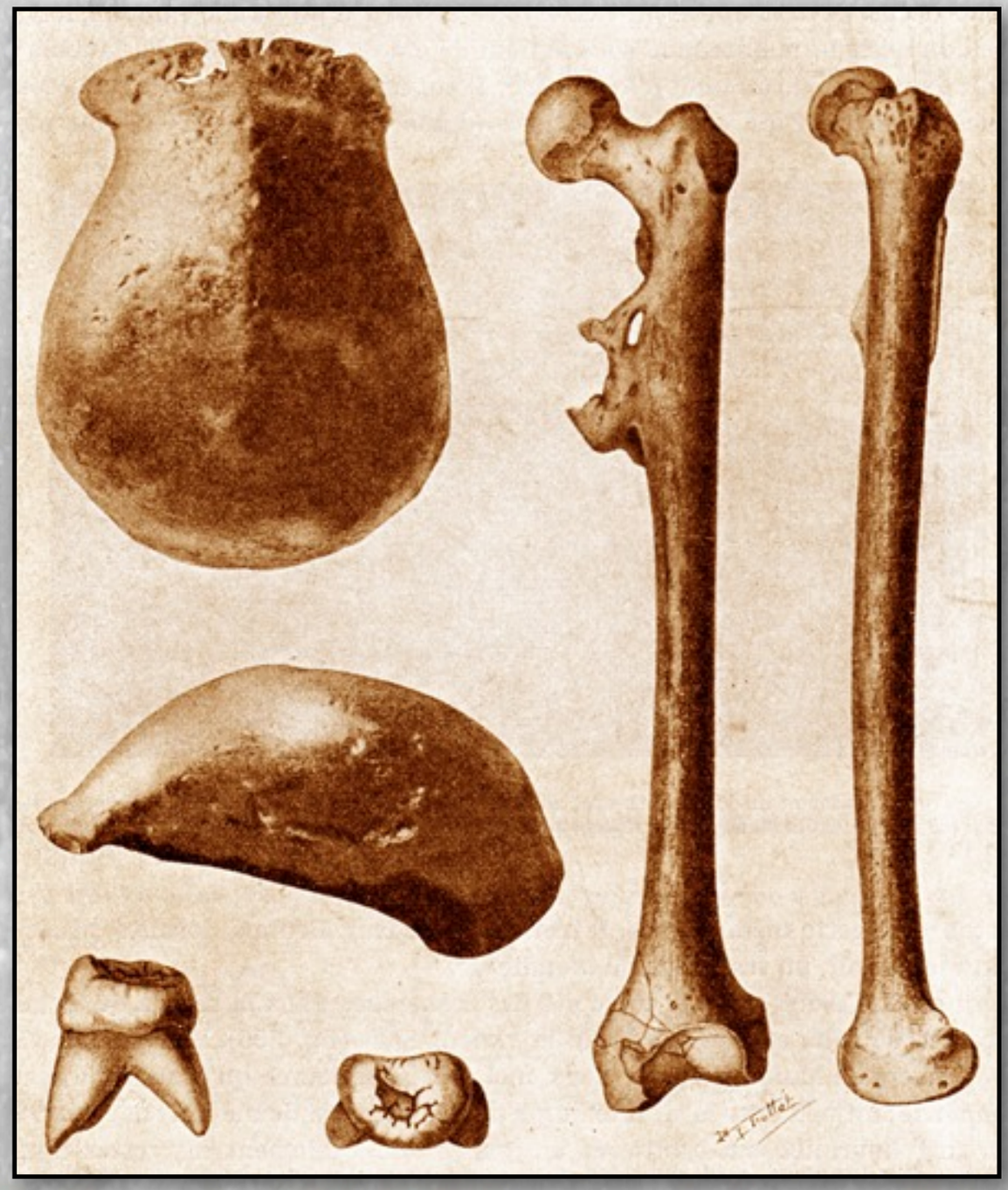
SEDMorph erc

"Missing links"

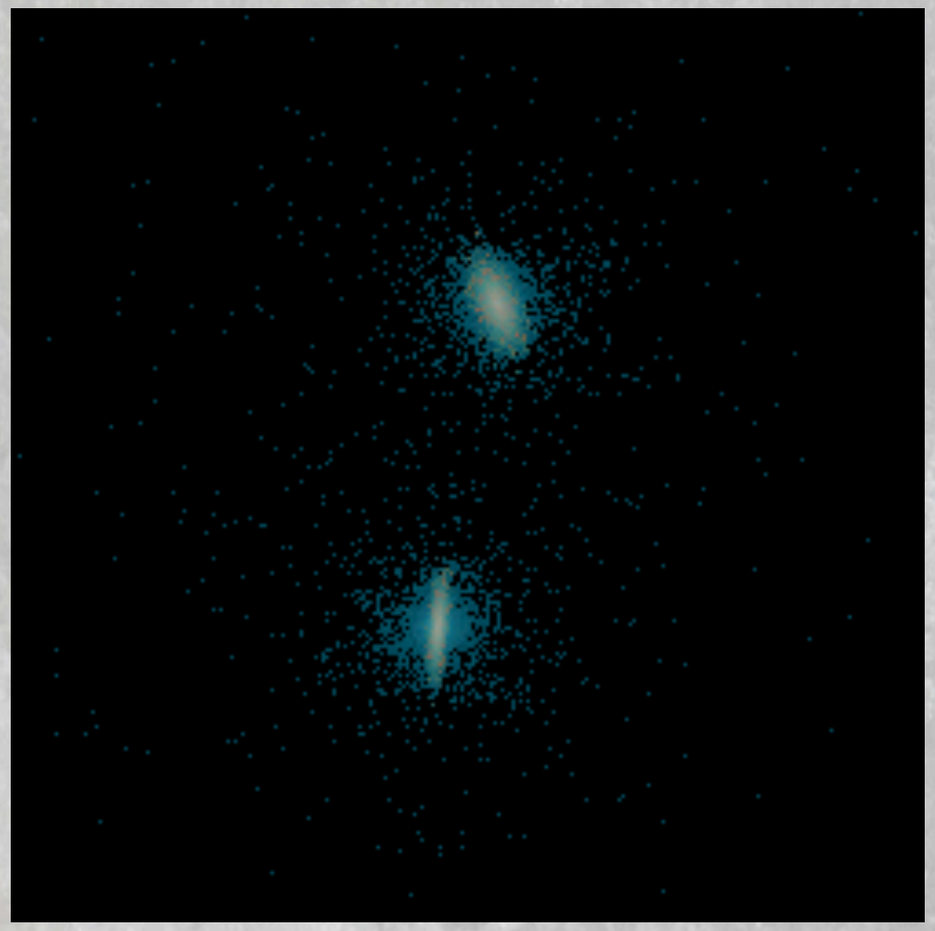
Vivienne Wild

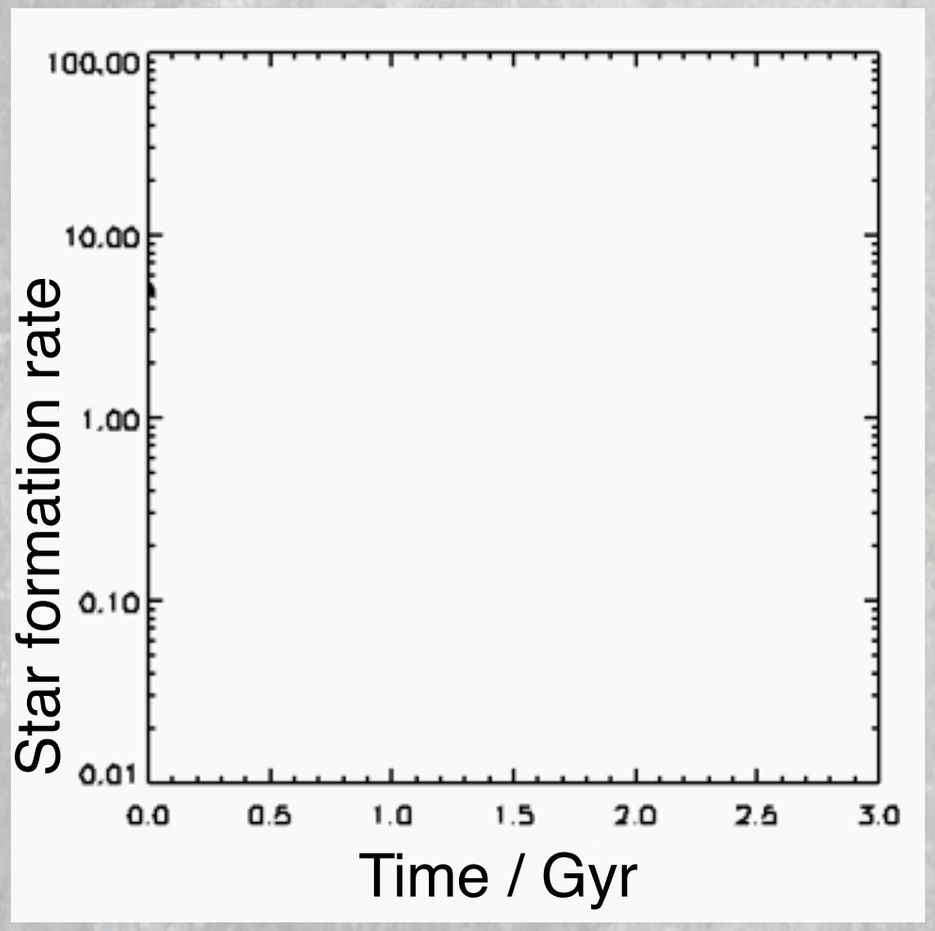


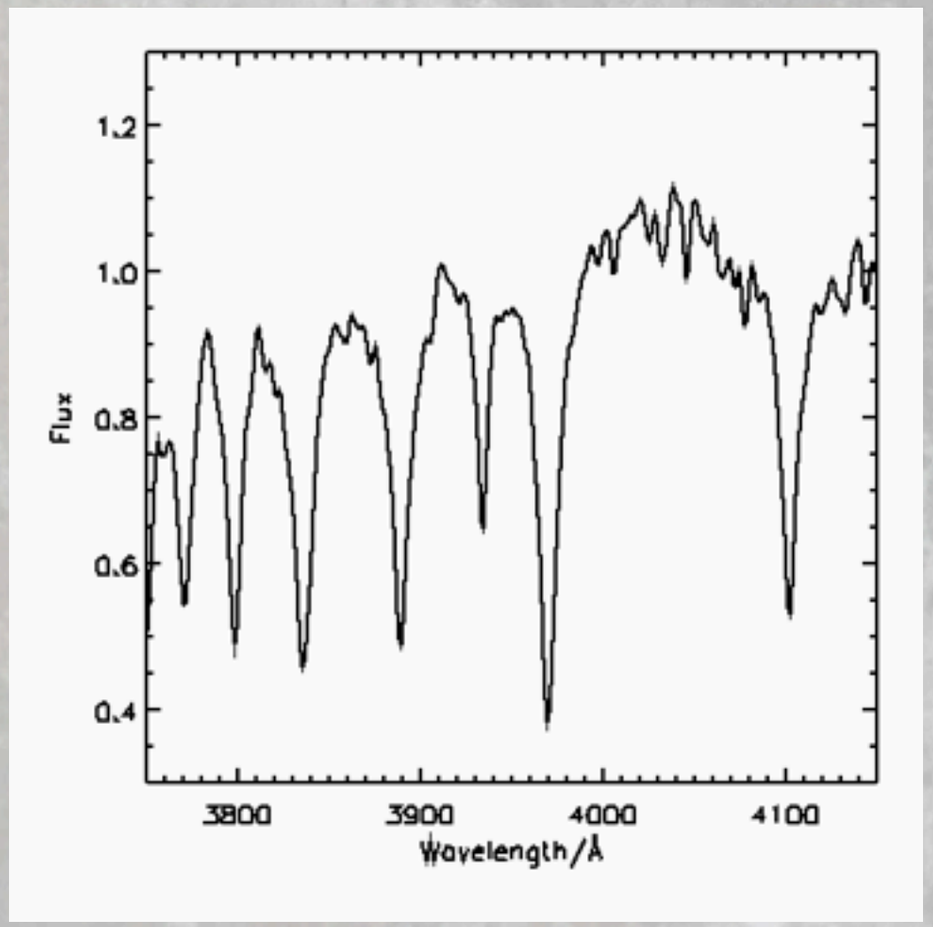
Wikipedia: Transitional fossils

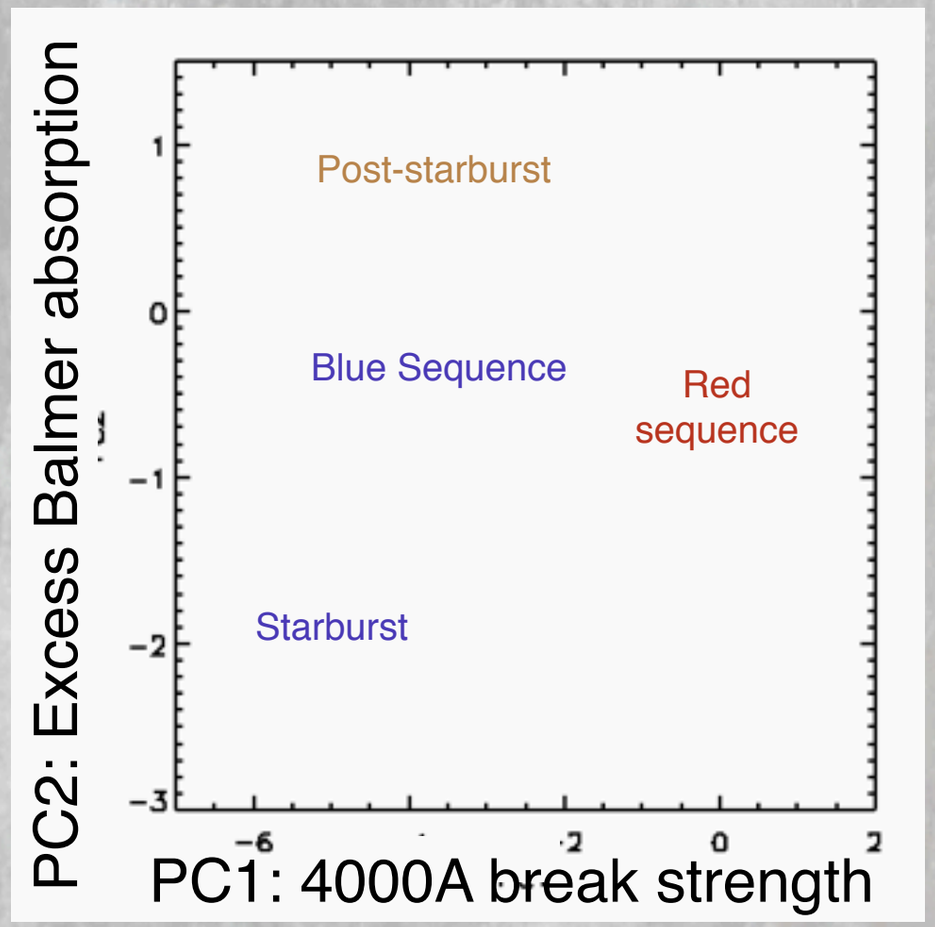


The Java man: A transitional fossil









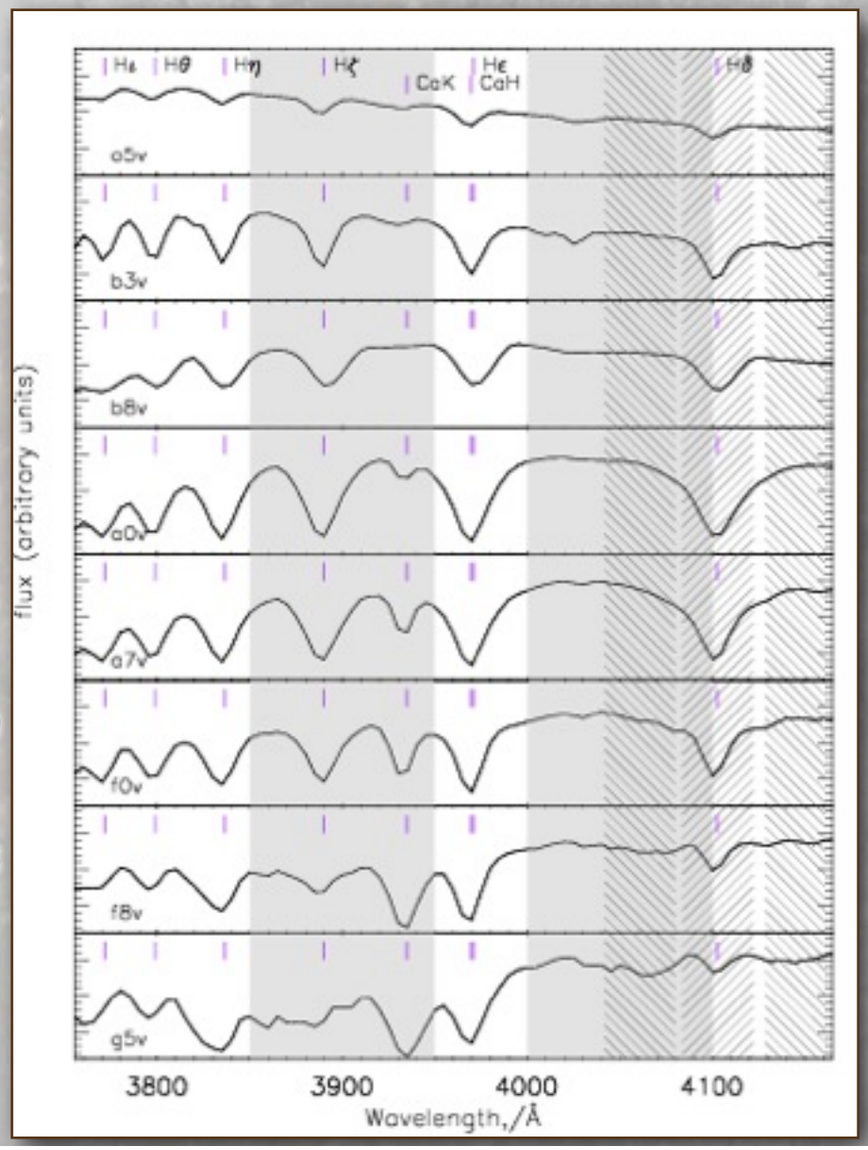
Wild, Walcher, Johansson et al. 2009

Starburst → post-starburst → quiescent

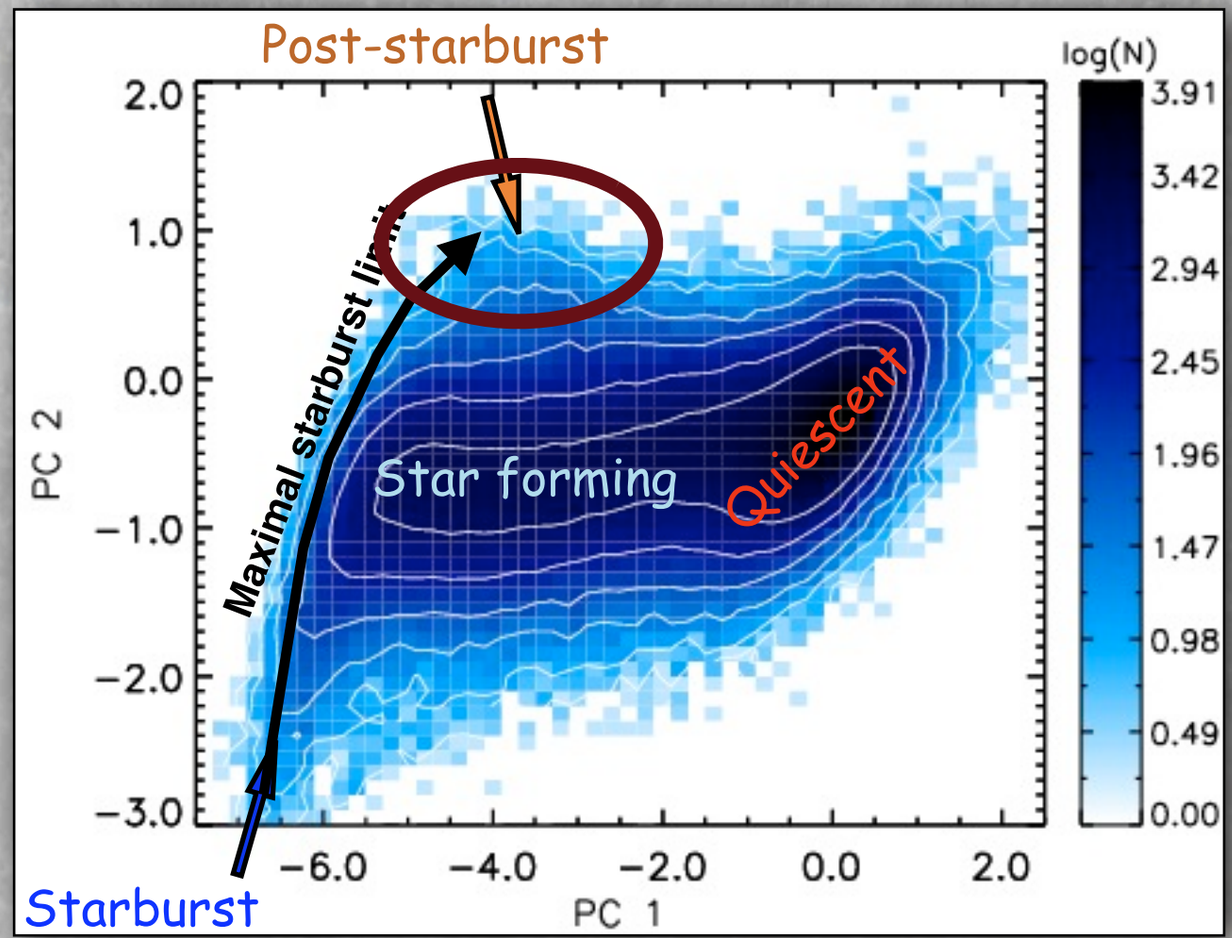
Vivienne Wild

- ✦ Parameterise shape of optical spectrum of galaxies using spectral indices
- ✦ Plot distribution of indices for a *complete sample* of galaxies (e.g. mass limited)
- ✦ Edges of distribution provide additional information on properties of *population*

Stellar spectra around 4000A



Stronger Balmer lines



Increasing 4000A break
(decreasing SSFR)

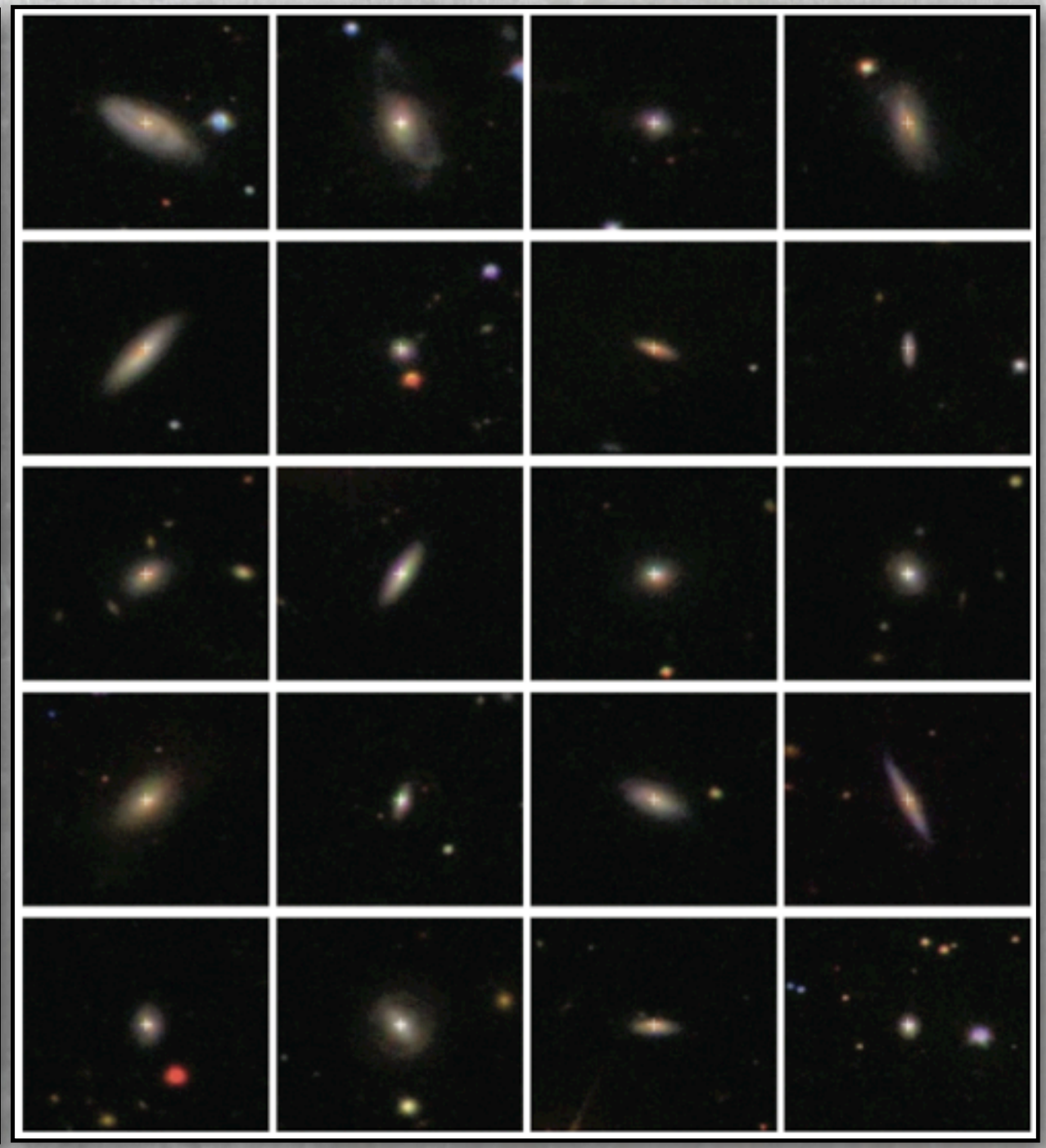
SDSS DR7
galaxies

Post-starburst ↔ Post-merger ?

Vivienne Wild

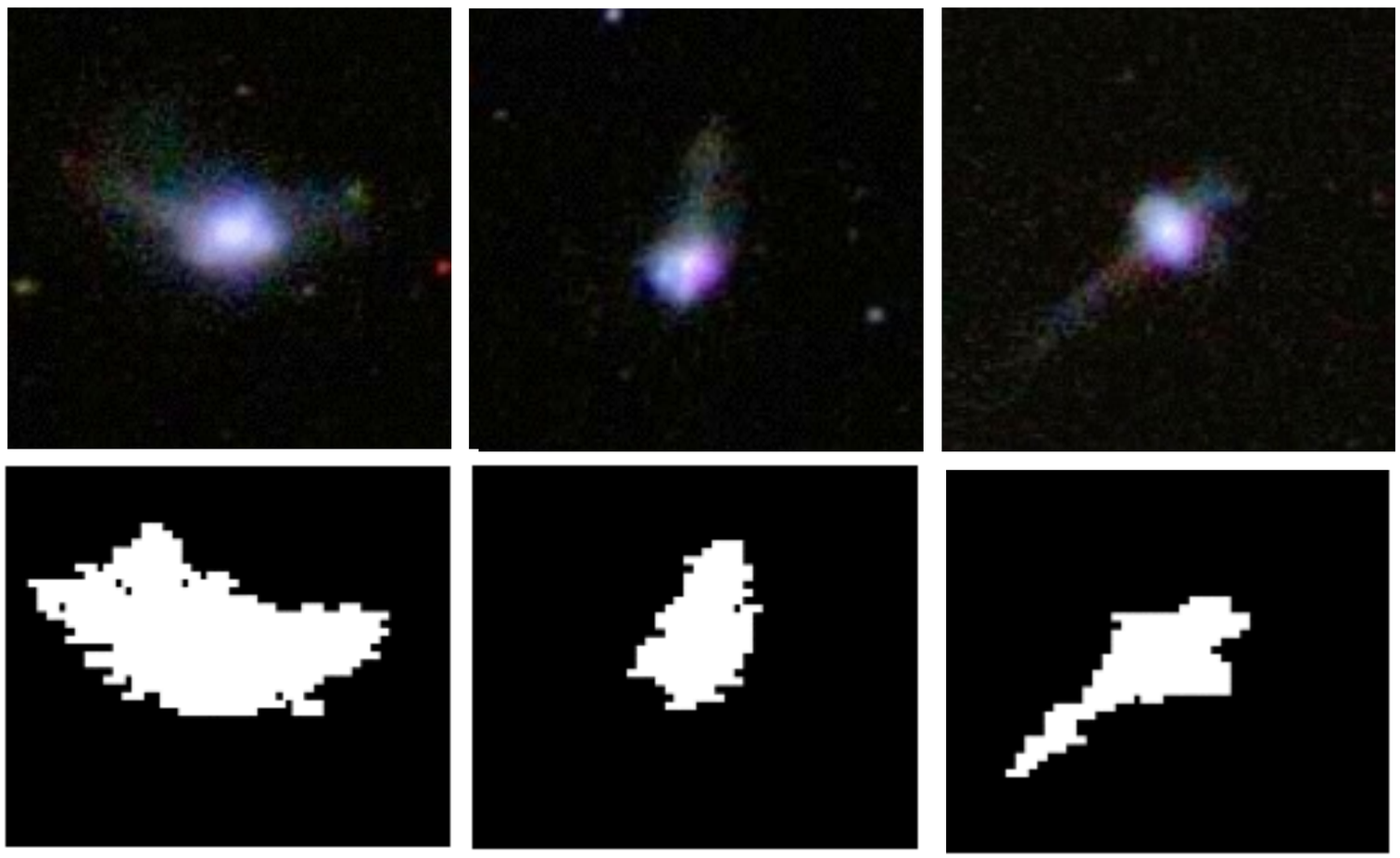
~10 Myr

~600 Myr



Probing the outskirts of galaxies

‘Shape’ asymmetry



$$A = \frac{\sum_{i,j} |I(i,j) - I_{180}(i,j)|}{\sum_{i,j} I(i,j)}$$

Remove the flux dependance completely!

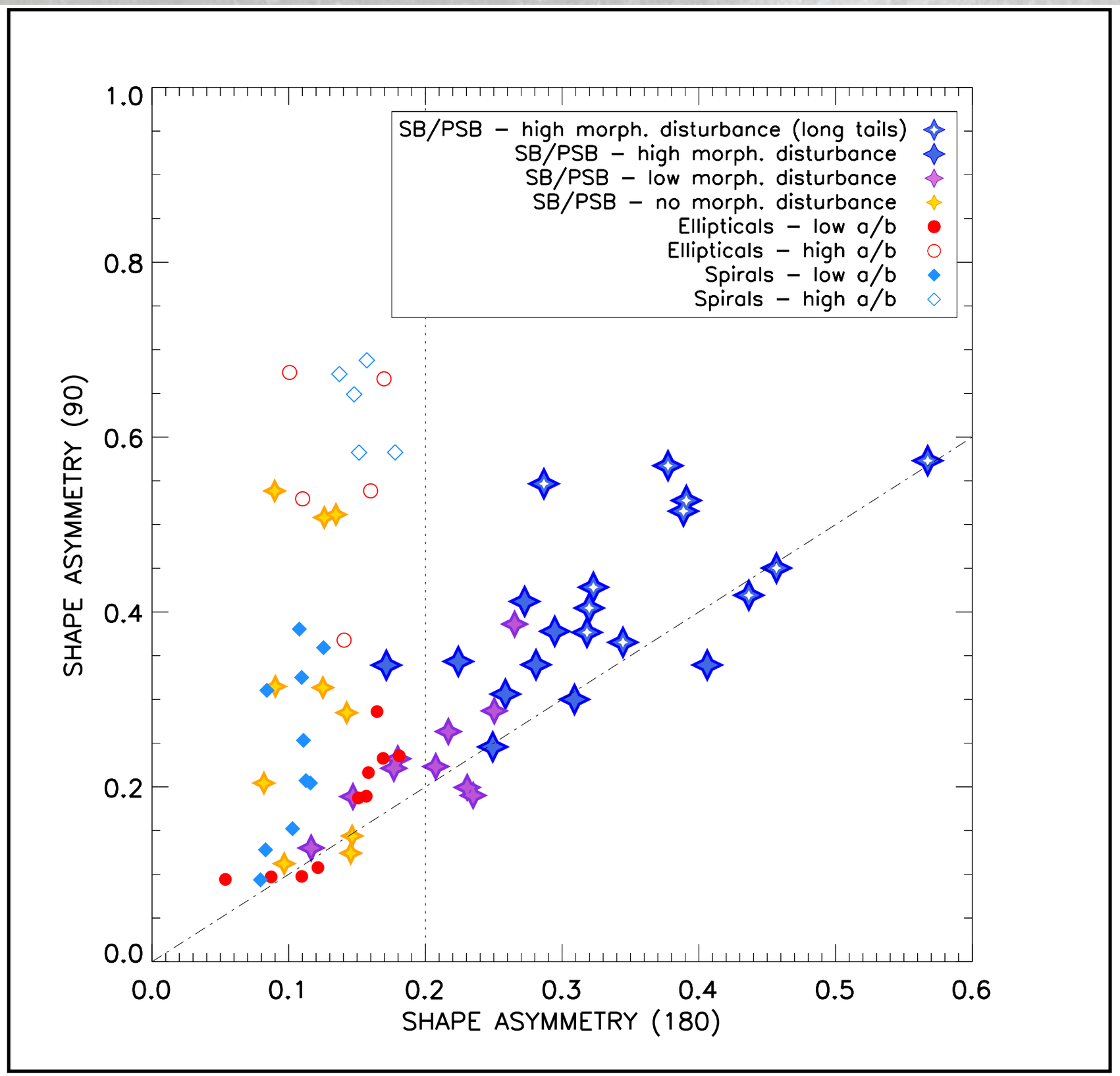
Measure the asymmetry of the binary image of the galaxy detection mask.

Pawlik, VW et al. in prep

mp84@st-andrews.ac.uk

Automated identification of post-mergers

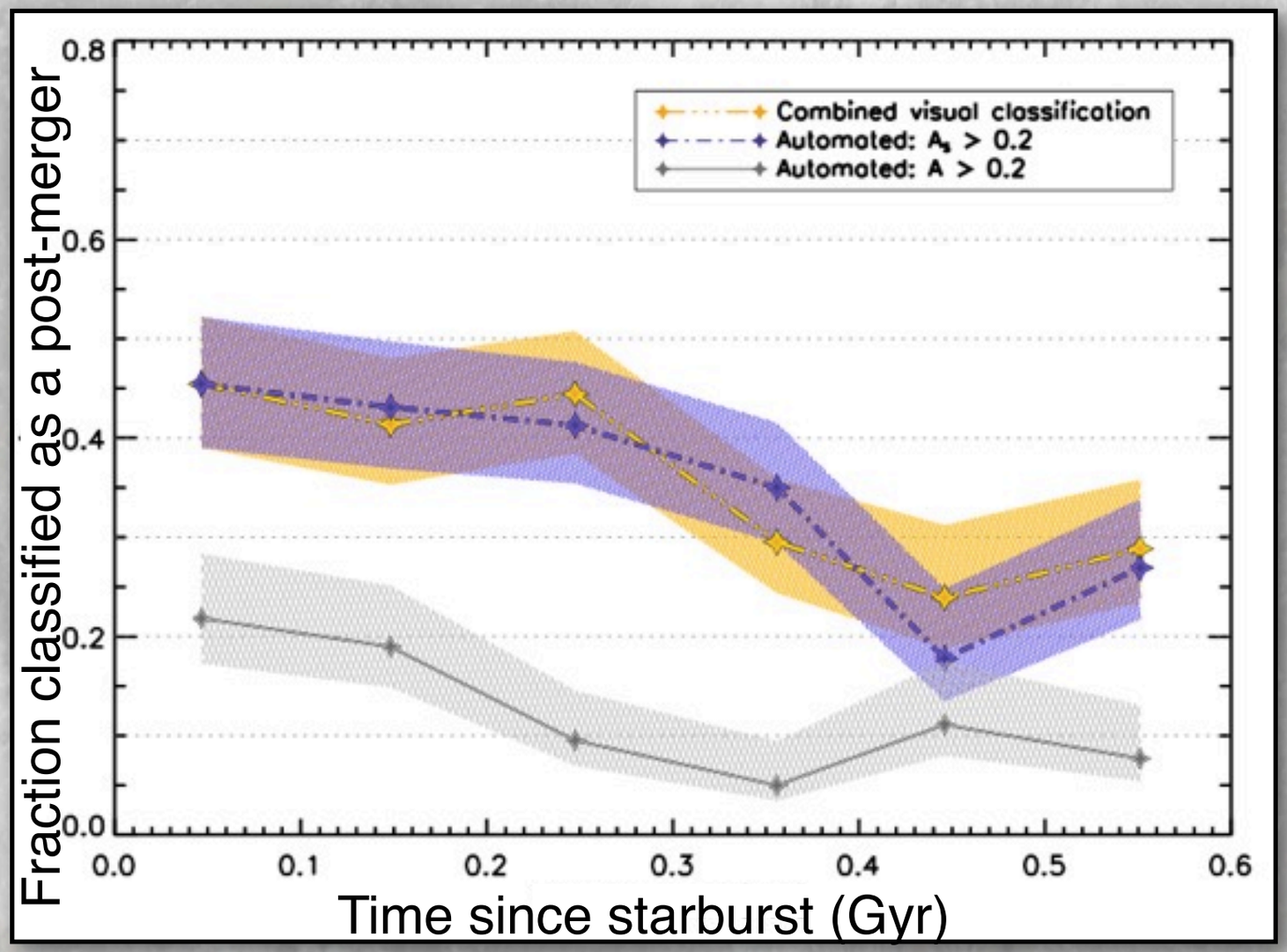
Vivienne Wild



Pawlik, VW et al. in prep

Post-starburst = post-merger

Vivienne Wild

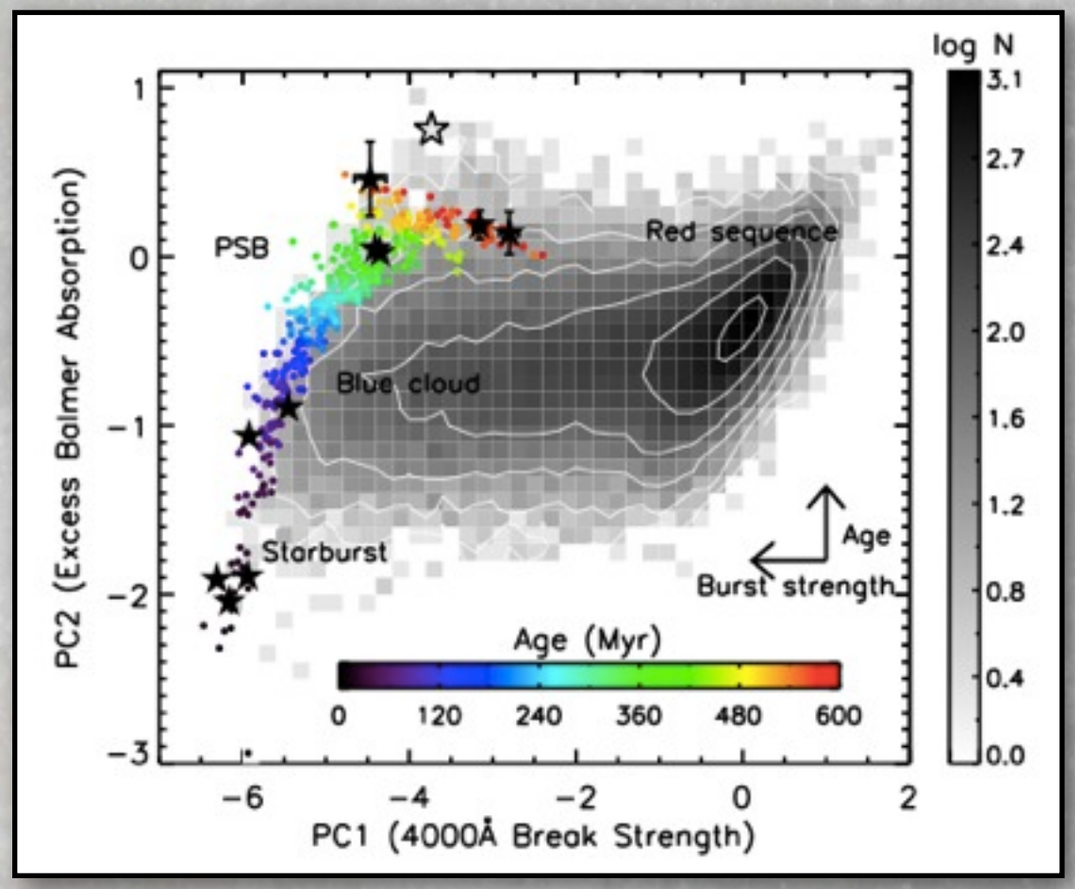


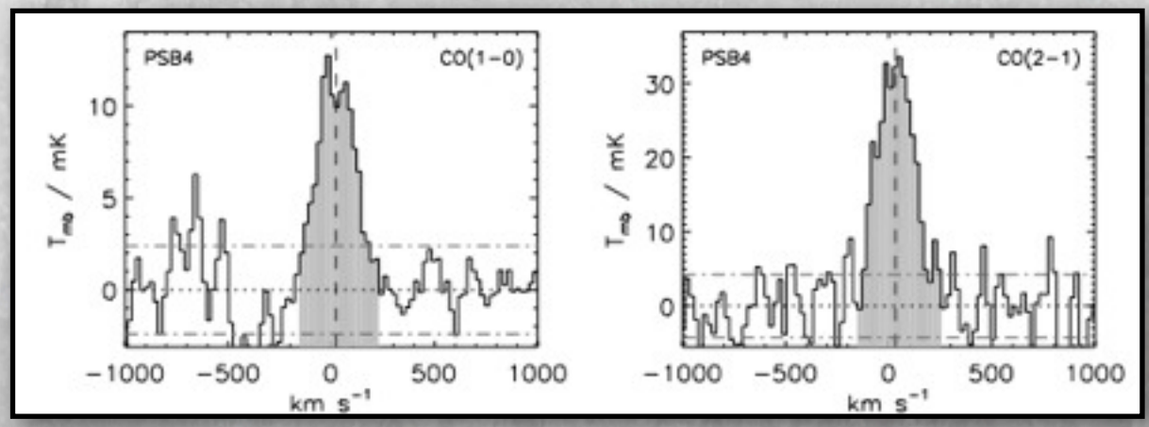
- ★ ~50% of young PSBs have merger remnant features, even at low-z
  - Declining to ~30% by 600Myr after the starburst
- ★ Is this consistent with ~100% triggering by mergers?
  - When orientation, gas fraction etc. taken into account?
  - Work-In-progress: compare with merger simulations

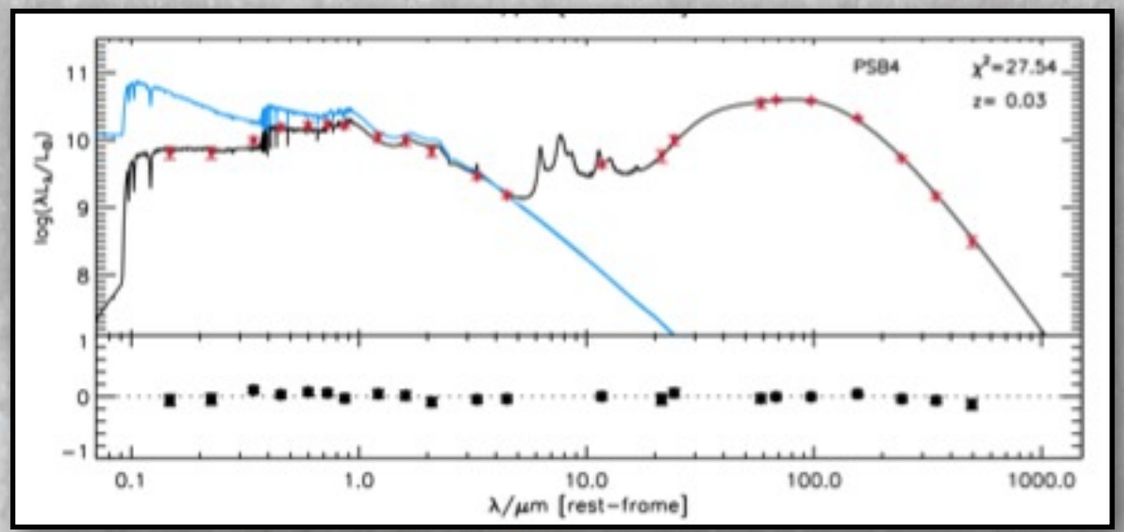
Pawlik, VW et al. in prep

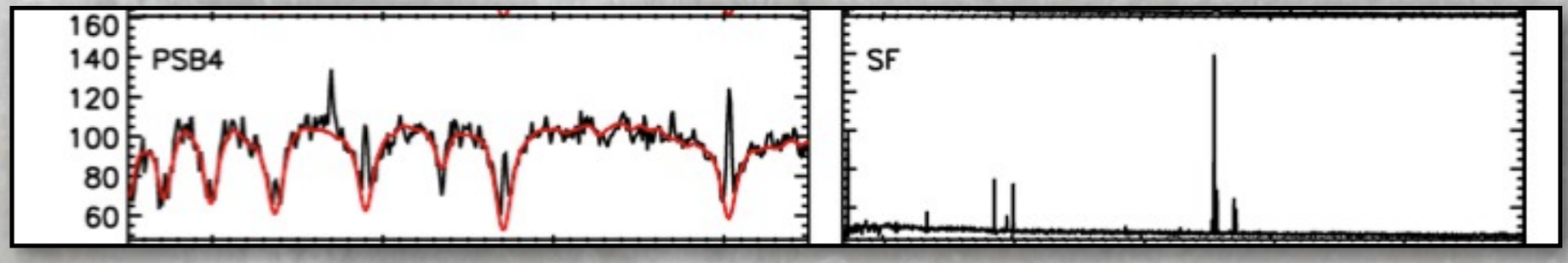
Post-starburst => red-sequence galaxies?

Vivienne Wild





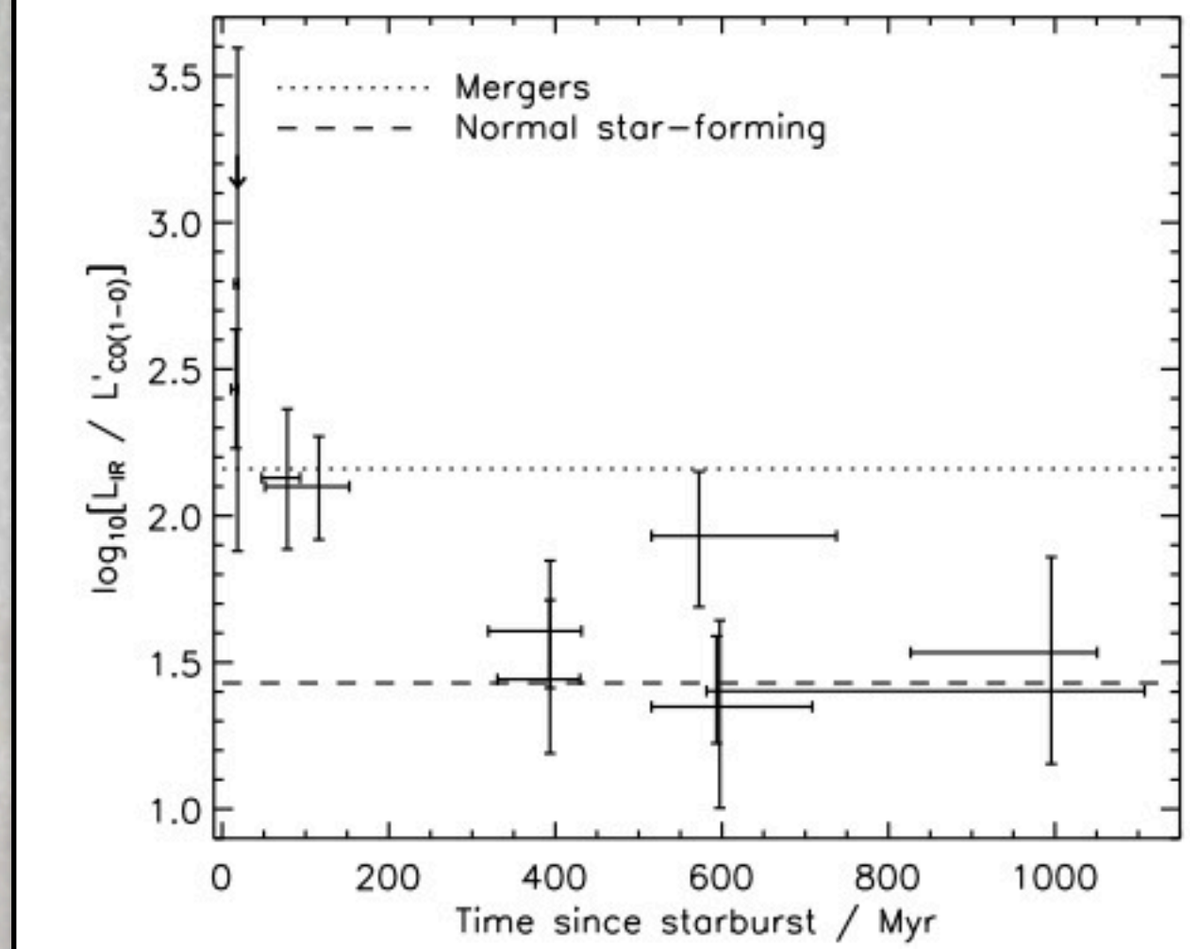


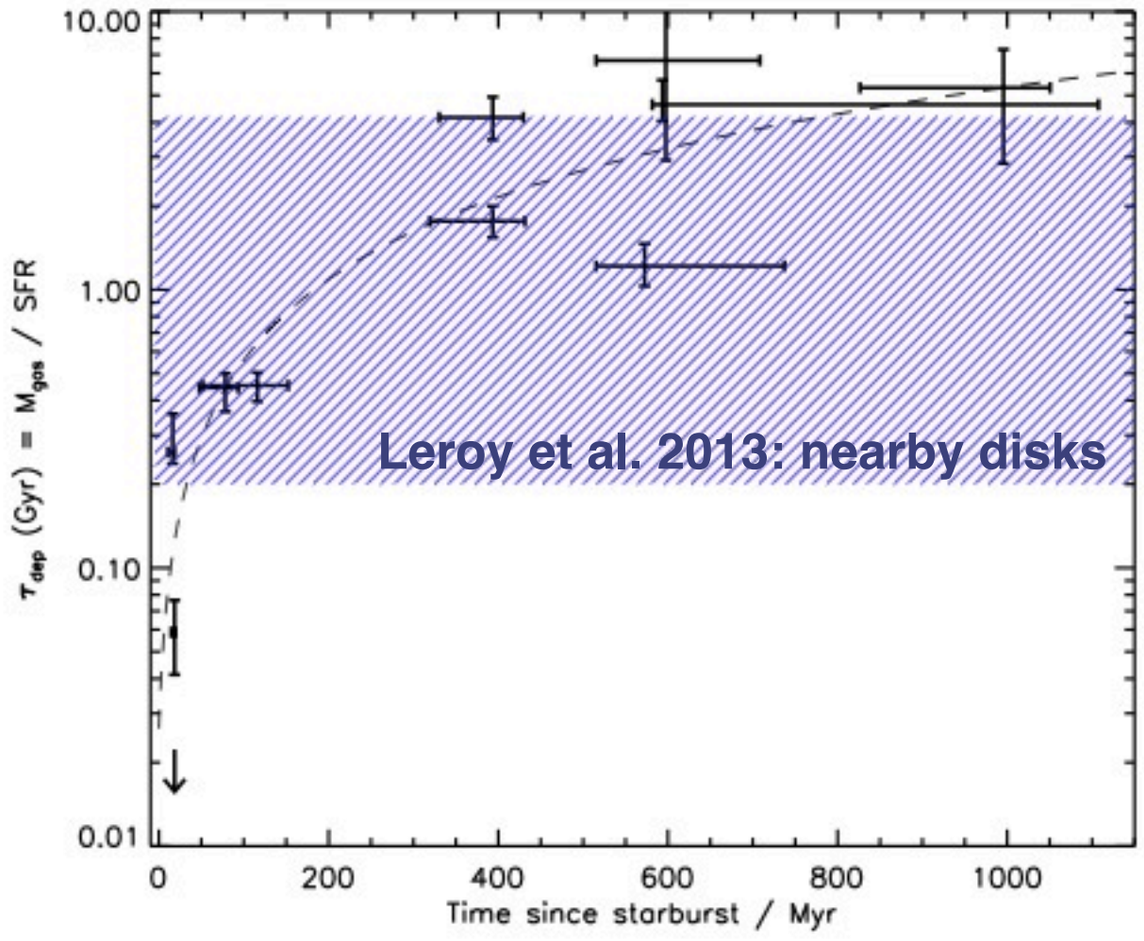


- ★ IRAM 30m CO(2-1) and CO(1-0)
- ★ Herschel PACS + SPIRE

Not the red-sequence as we know it....

Vivienne Wild





- ★ Steady decrease in the star-formation efficiency, molecular gas and SFR surface density, and effective dust temperature
- ★ Efficiency declines from starburst galaxies to normal star-forming galaxies.
- ★ PSBs still have gas, even ~1Gyr following starburst (see also Zwaan et al. 2013 for HI)

Post-starburst galaxies as a transitional population

Vivienne Wild

★ Post-starbursts galaxies: galaxies which have undergone an unsustained star formation episode and are now shutting down their star formation

★ Easily identified in (moderate quality) spectroscopic surveys by their strong Balmer absorption lines and distinctive spectral shape

- Stellar population modelling can distinguish post-starburst from passively “quenched” galaxies

★ At low-z, a large fraction (all?) are caused by a merger event, although the tidal features are difficult to detect >500Myr after the event.

★ At low-z, they still have significant cold gas contents, suggesting that multiple events are needed to form a red-sequence galaxy

- **But today’s red sequence was formed at z>1 where the properties of galaxies were very different...**

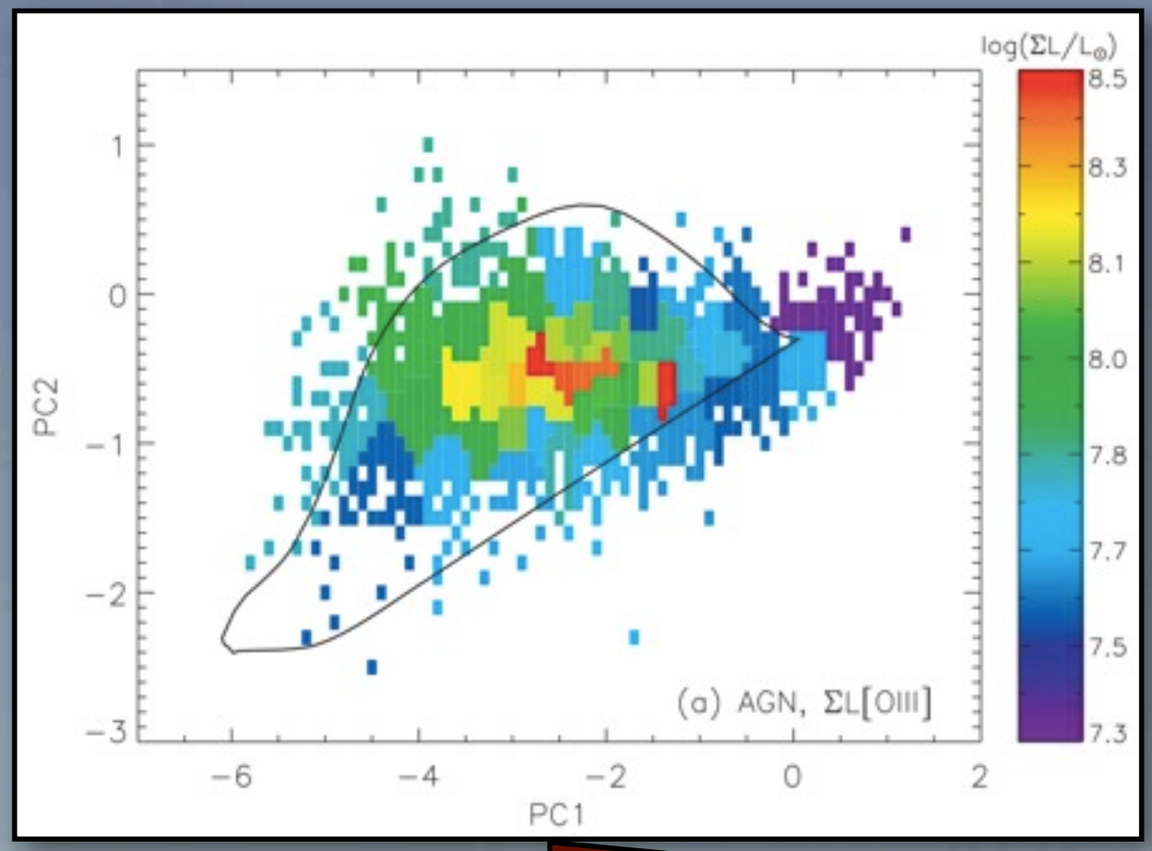
(2) Timing the starburst-AGN connection

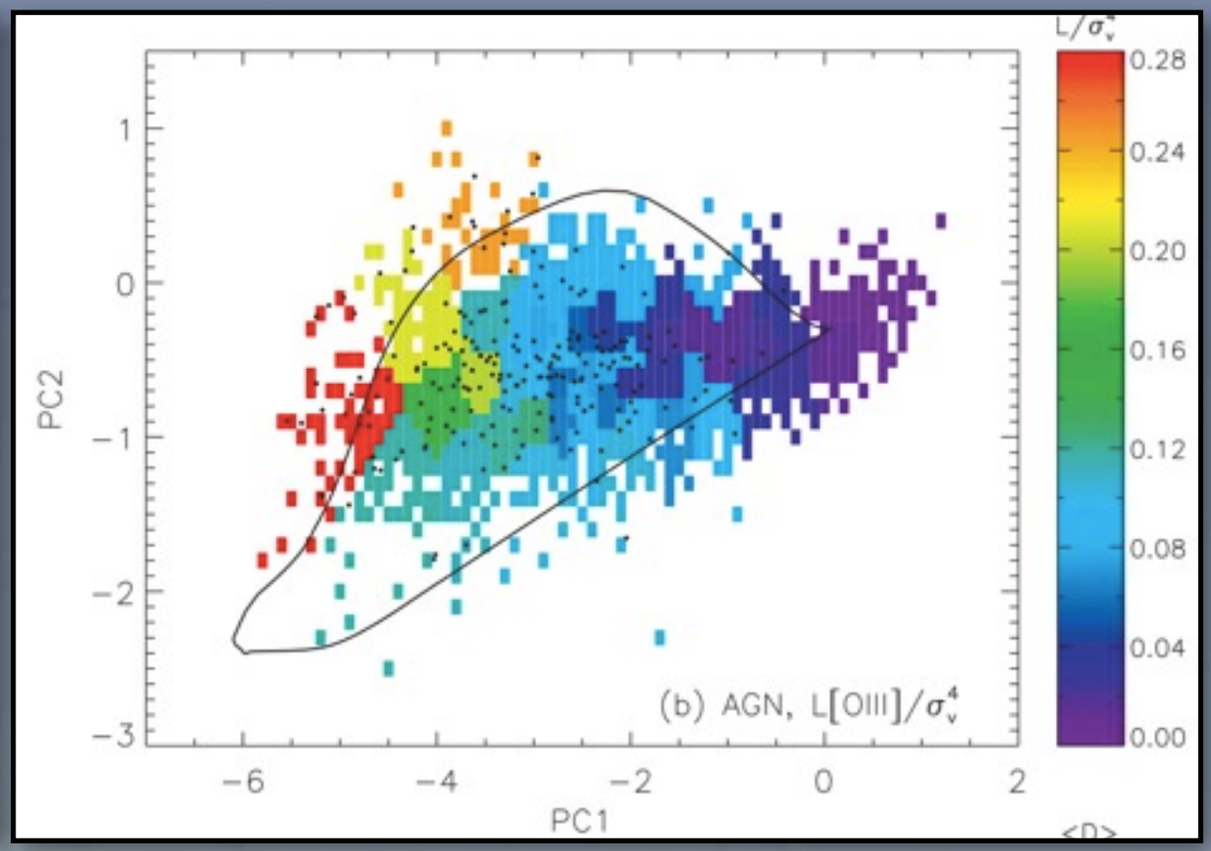
Tim Heckman, Stephane Charlot, Guinevere Kauffmann

Where is most local black hole growth happening?

Vivienne Wild

Stronger Balmer lines





Increasing 4000A break
(decreasing SSFR)

★ $z < 0.07$, galaxies with bulges

- 40% blue sequence bulges ⇒ > 60% of BH growth
- **4% (post)-starburst bulges ⇒ 10-20% of BH growth**
- 56% quiescent bulges ⇒ 10% of BH growth
- The most actively accreting BHs occur in wide range of bulges

Most BH accretion occurs in ordinary star-forming galaxies, but strong (post-) starburst galaxies are more likely to host a rapidly accreting AGN

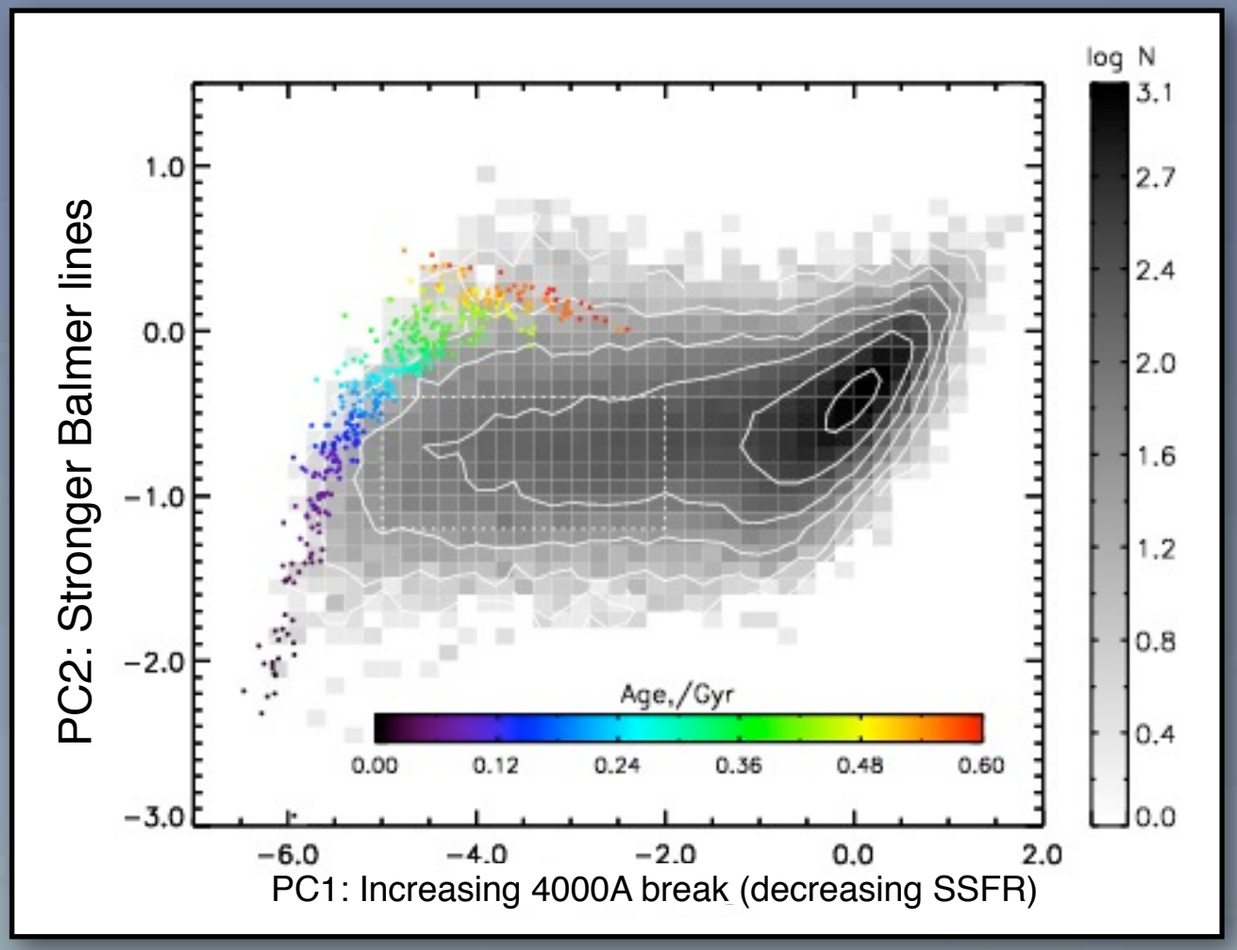
Wild et al. 2007; See also Kauffmann et al. 2003

A starburst → post-starburst sequence

Vivienne Wild

Stellar continuum + population locus → age of the starburst

Narrow emission lines → BHAR



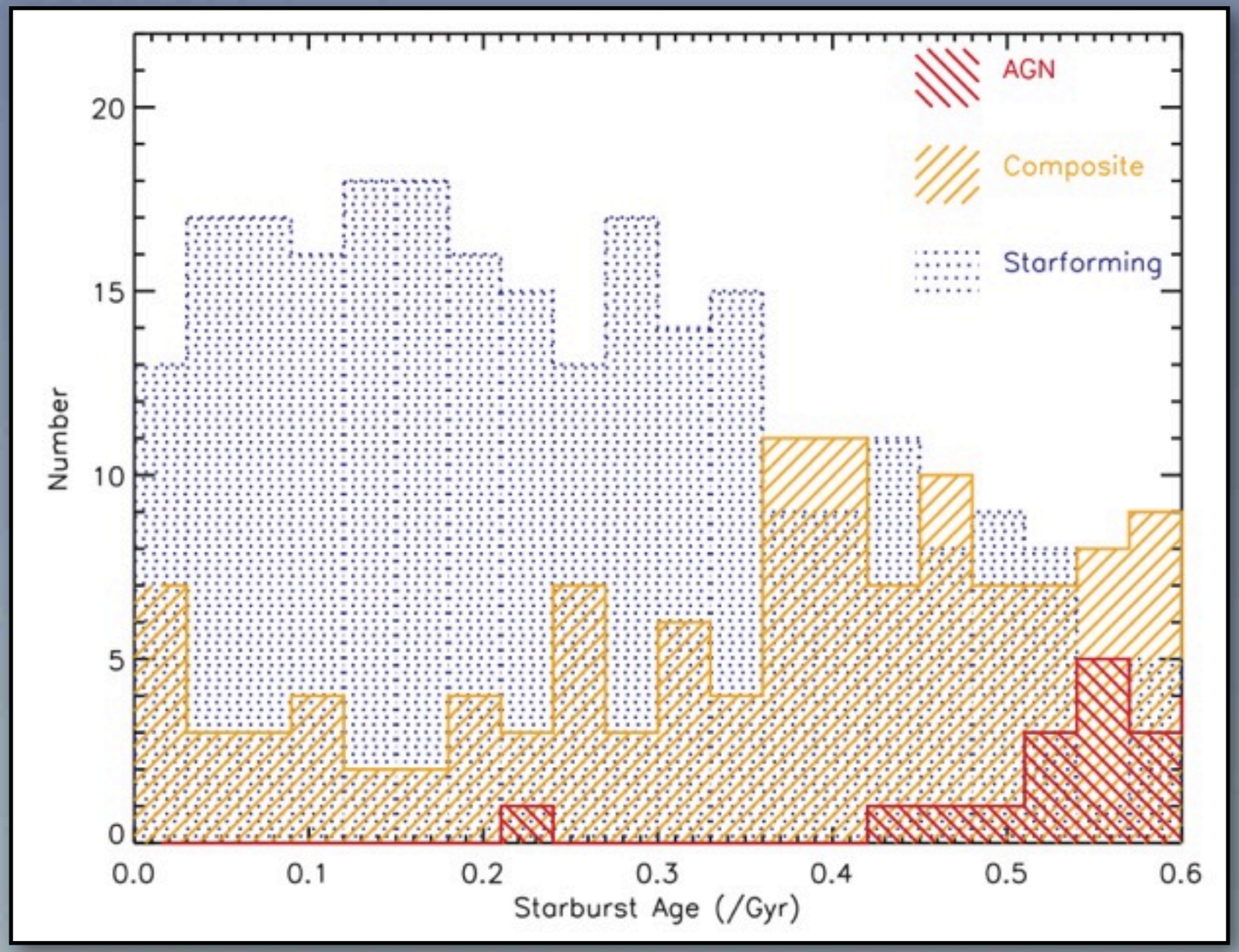
★ 400 strongest starburst to post-starburst bulge-galaxies in local Universe

- $0.01 < z < 0.07$ (3” SDSS fibre => 0.6 - 4 kpc diameter)
- Stellar surface mass density > 3×10^8 $M_\odot$ /kpc^2 (where majority of $L[OIII]_{AGN}$ originates)
- **Complete sample** to 600Myr: constant number per unit starburst age
- Starburst stellar mass fractions ~10-20% (continuum fits and Ha luminosities agree)

Wild et al. 2010, MNRAS

The appearance of narrow line AGN

Vivienne Wild



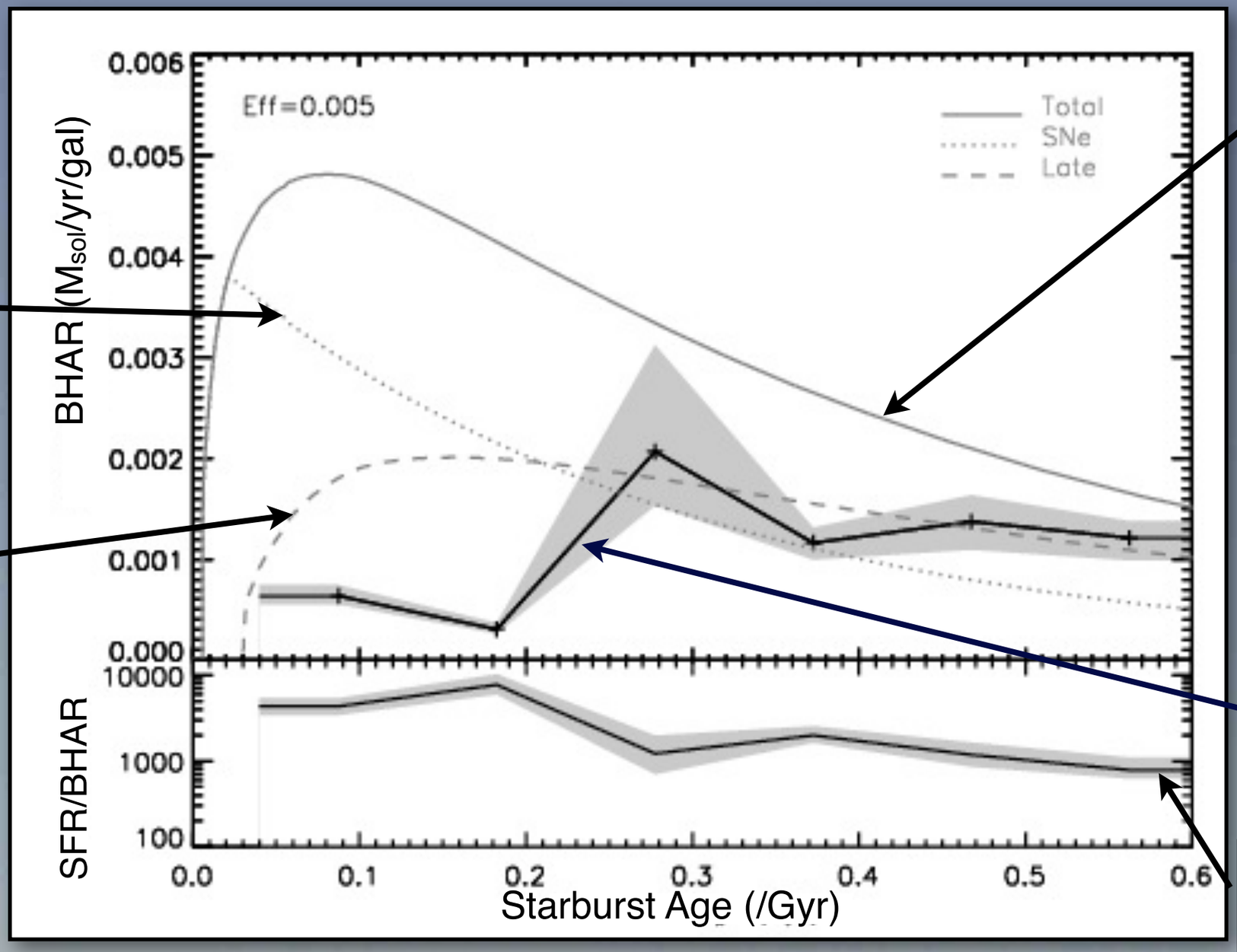
- ★ “Pure” AGN only appear once star formation has fully decayed
- ★ Deficit of any AGN in young starbursts.

Timing the AGN accretion

Vivienne Wild

First 200Myr dominated by **fast** ejecta from high mass stars (SNe,O/B)

After 50Myr first appearance of **slow** stellar ejecta from low-mass stars



Mass loss rate from stars in starburst τ_{exp} =0.3Gyr

Black Hole starts to accrete after **~200Myr**.

Consistent with M-σ relation after ~10Gyr

★ Accretion commences when fast ejecta have decayed

- **Feedback from fast stellar ejecta prevents accretion??**

★ Accretion efficiency: ~1% of low mass stellar ejecta

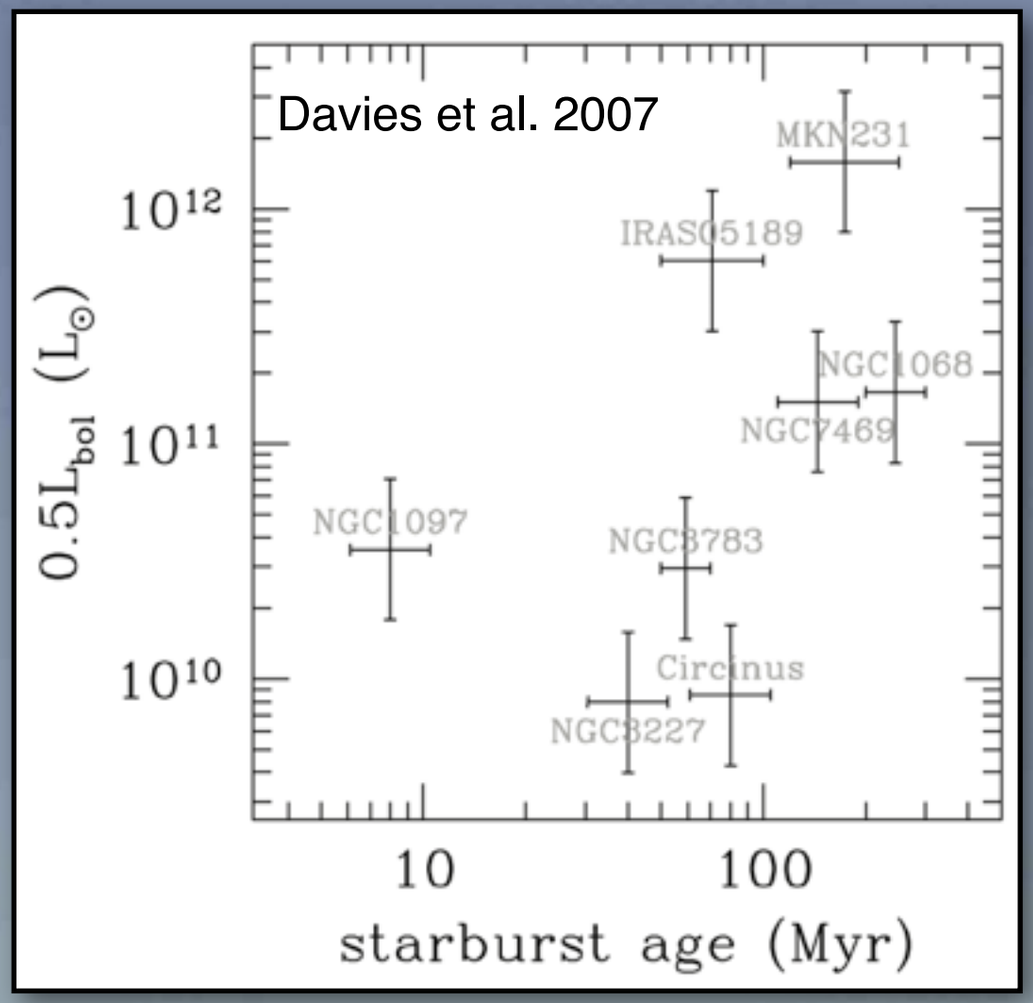
- (see also Ciotti & Ostriker 07; Kauffmann & Heckman 09)

Wild et al. 2010

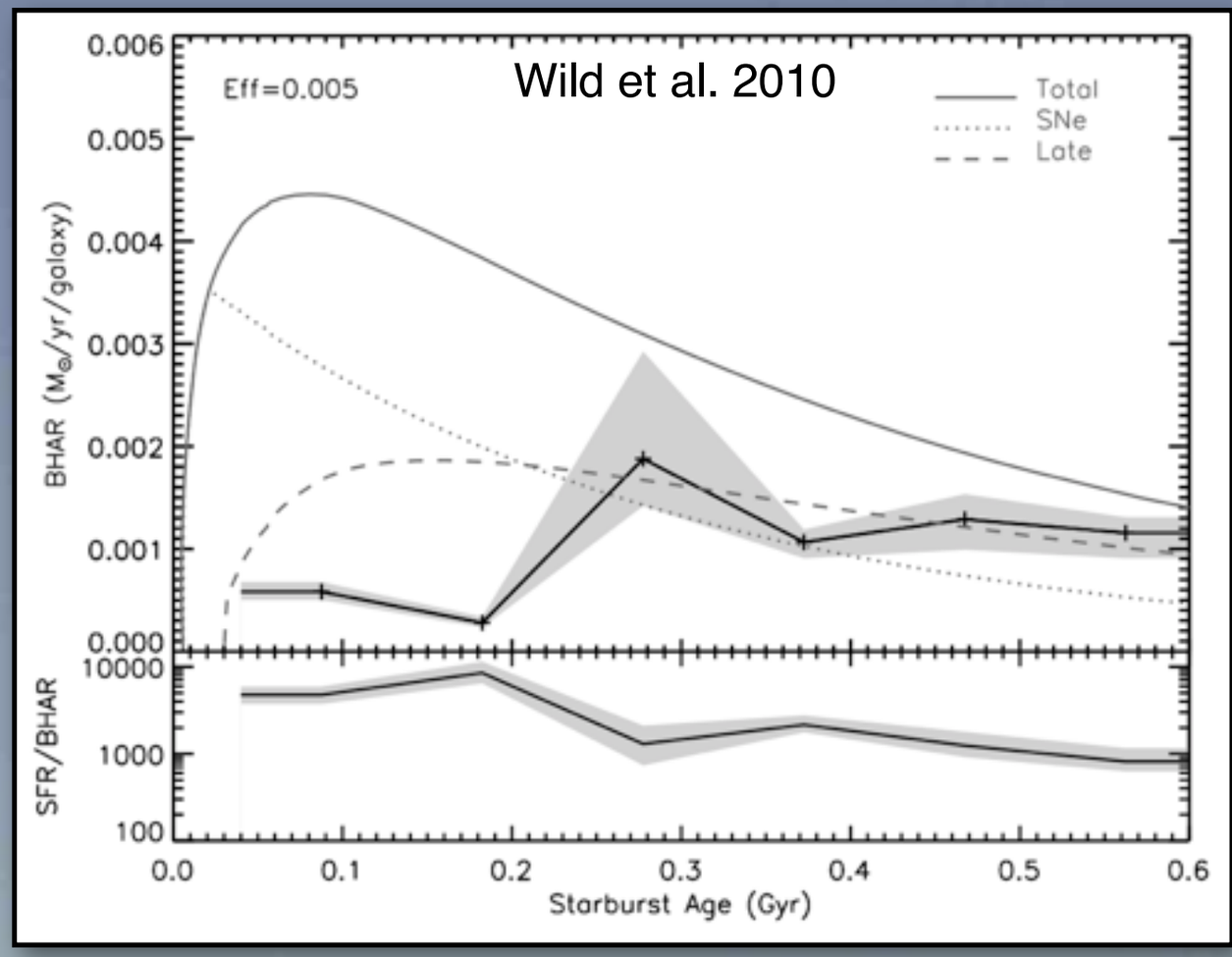
See also Davies + 2004

Timing the AGN accretion

Vivienne Wild



- ★ 8 Local Seyferts observed with SINFONI (NIR AO IFU)
- ★ Age of most recent episode of SF in central 10-100 pc
  - Continuum colours and Brγ emission line EQW vs. stellar population models



- ★ 400 z < 0.07 galaxies with bulges; undergone a recent starburst
  - 1.5” fibre radius = 0.3-2 kpc
  - Fraction of mass formed in burst > 5-10%
- ★ Age of starburst
  - Balmer absorption line strength vs. stellar population models

See also Canalizo & Stockton 2013 for local QSOs

Beware of results that neglect line mixing or impose inappropriate SFHs

Timing the starburst-AGN connection

Vivienne Wild

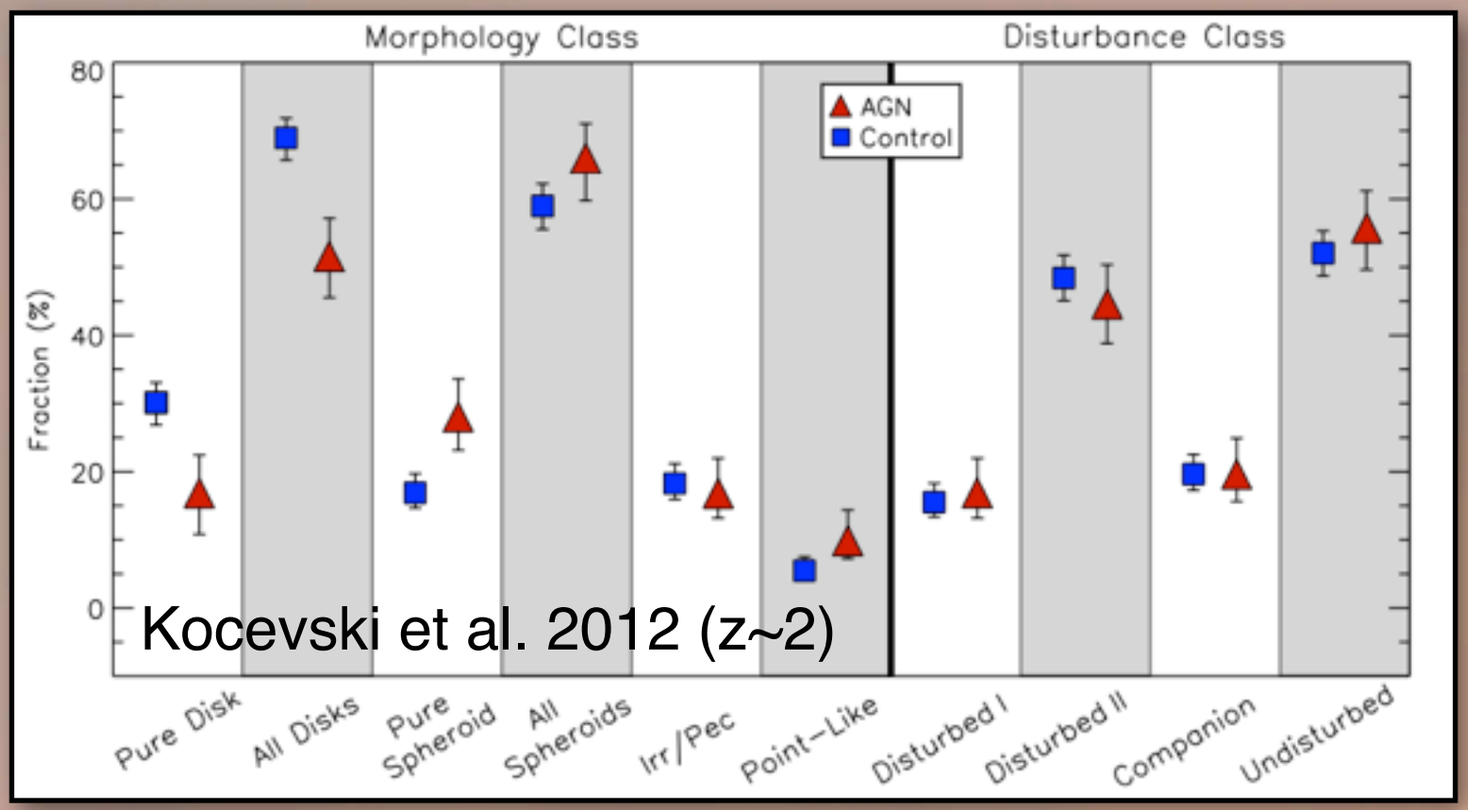
- ★ Observe a correlation between AGN accretion rate and SFR of host
  - Note that correlation ≠ causation
  - Holds for type-2 AGN (Kewley 2006) and Type-1 QSOs at low-z (Scweitzer et al. 2006, Netzer et al. 2007) and high-z (Lutz et al. 2008)
  - See also Netzer 2009, Shi et al. 2009; Shao et al. 2010; Rosario et al. 2012 and many others
- ★ At low-z most BH accretion occurs in ordinary star-forming galaxies
  - see e.g. Kauffmann et al. 2003
- ★ Detailed stellar population analysis shows that strong (post-)starburst galaxies are more likely to host a rapidly accreting AGN
  - see also Yan et al. 2006
- ★ In these single significant burst objects, significant black hole accretion starts ~250Myr following a starburst
  - Fast stellar winds preventing black holes from feeding?
  - Dynamical time delay between starburst and black hole fuelling? (Hopkins 2011)

(3) Timing the starburst-AGN connection at high-z

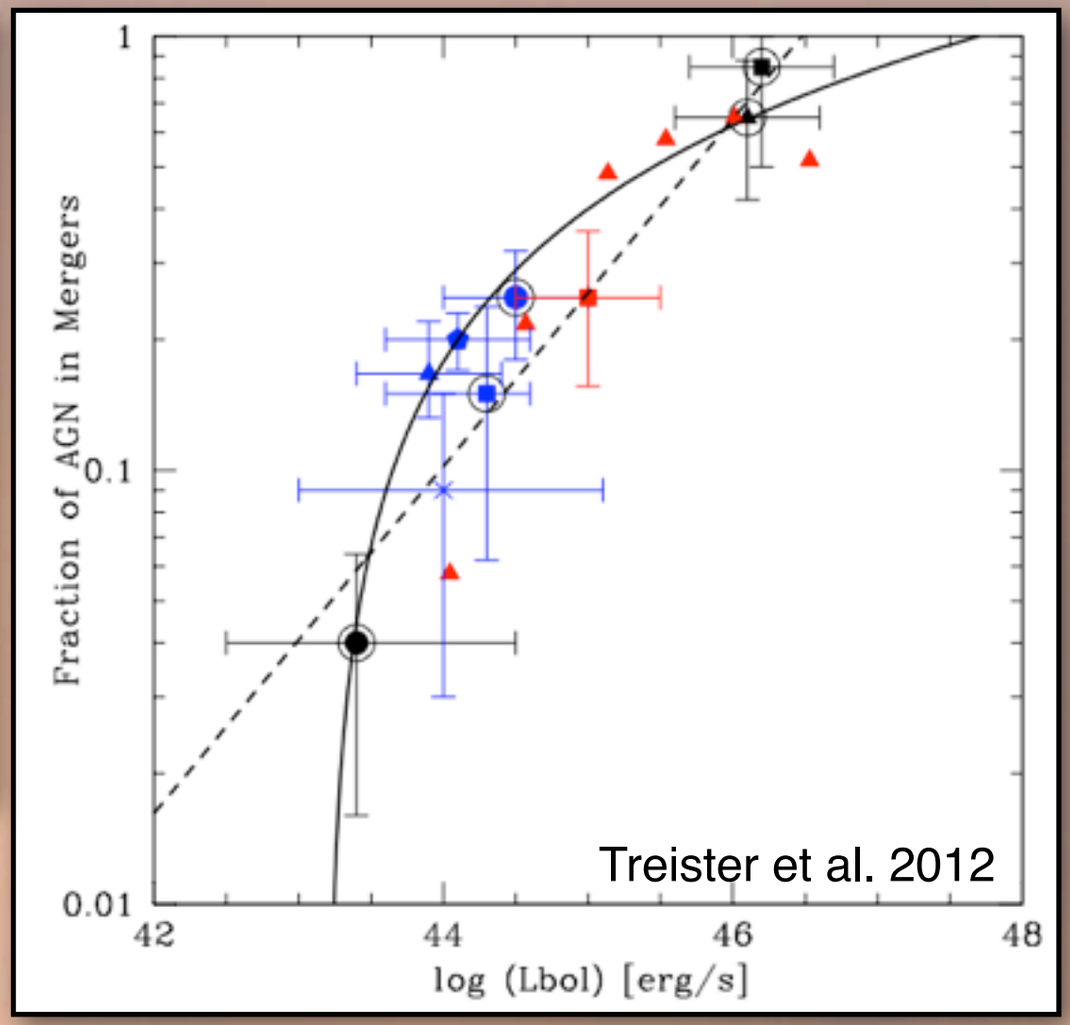
Omar Almaini (Nottingham), Jim Dunlop (Edinburgh),
Chris Simpson (Liverpool)

Mergers as driver of black hole growth?

Vivienne Wild



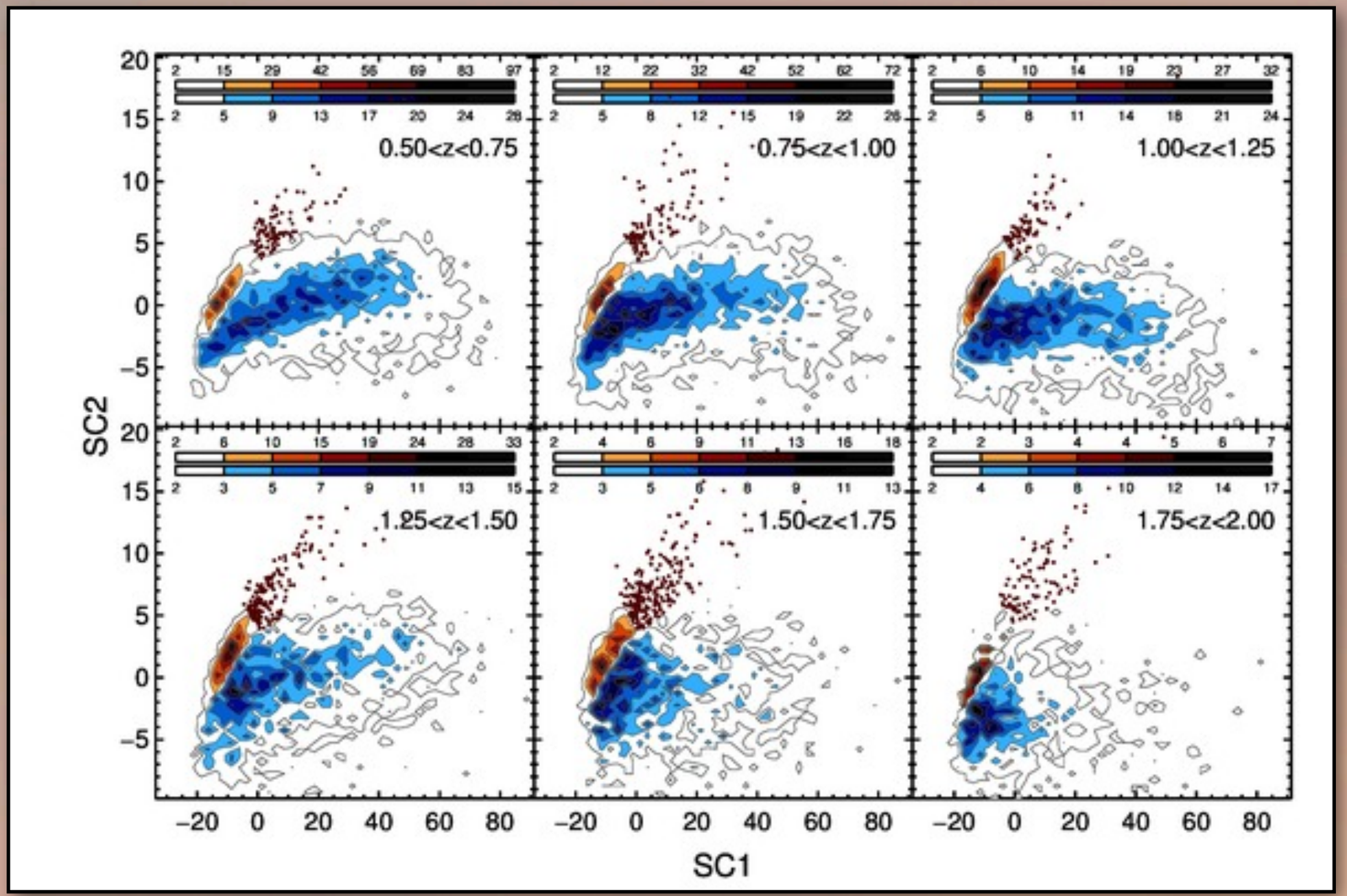
See also Villforth et al. 2014
+ talk on Friday by Patricia/Cristina



- ★ Completely bipolar views in the literature: yes and no
  - Almost certainly a function of AGN luminosity, possibly of mass, or progenitor gas fractions
  - But if there is a time offset, do we really expect to see anything?
- ★ An apparent (induced) correlation between BH growth and mergers?
  1. **Mergers ⇔ star-formation**
  2. **Star formation ⇔ BH growth**

Post-starburst = significant at high-z?

Vivienne Wild

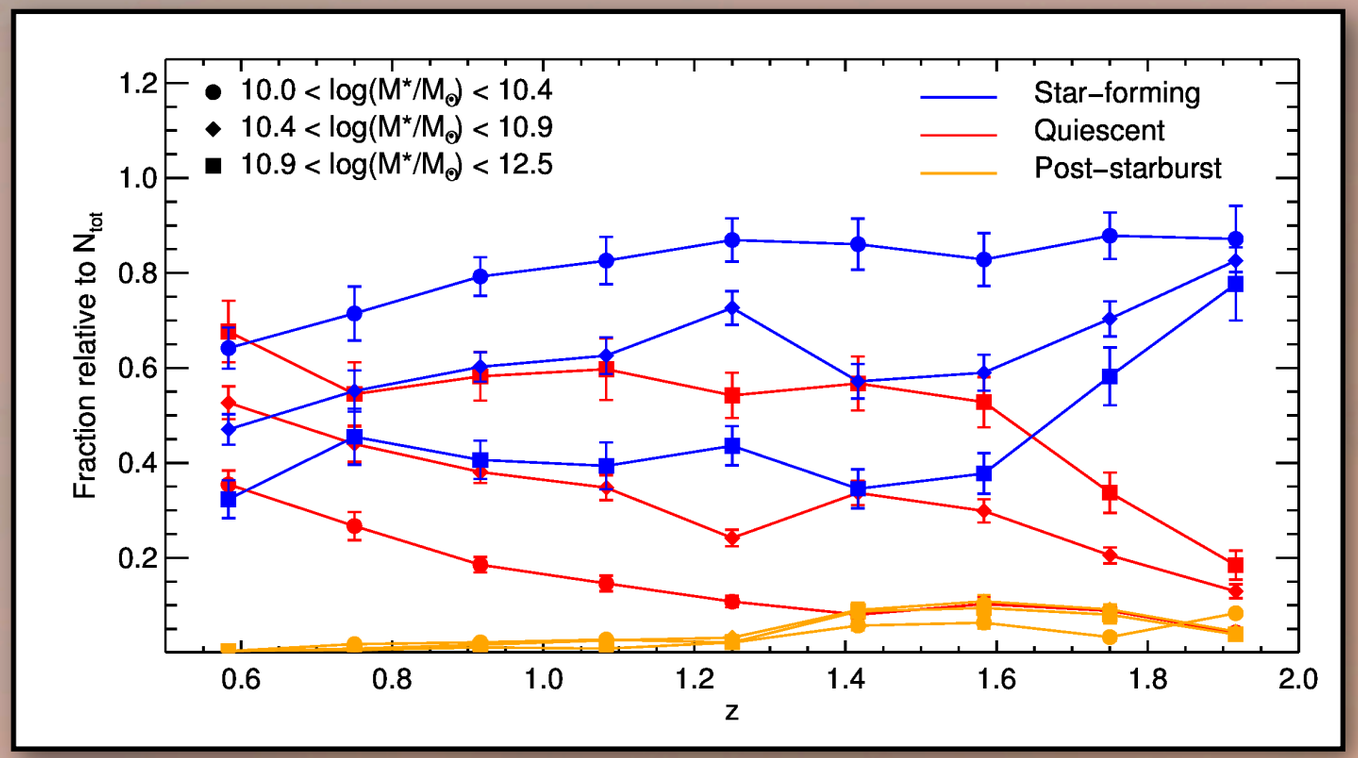


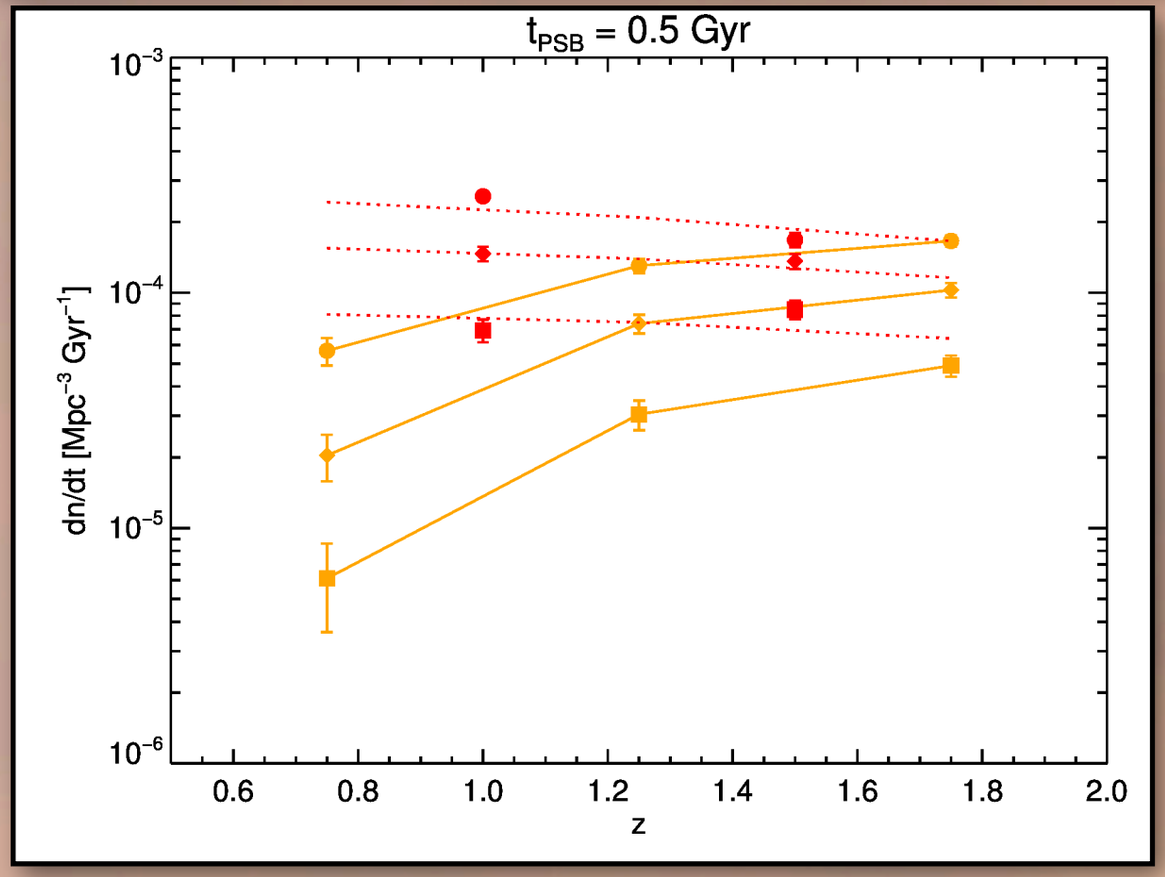
- ★ Finding PSBs at high-z is a challenge
- ★ Here, use multi-band photometry and PCA method to identify them via their spectral shape (Wild et al. 2014)

Wild et al. in prep

Post-starburst = significant at high-z?

Vivienne Wild



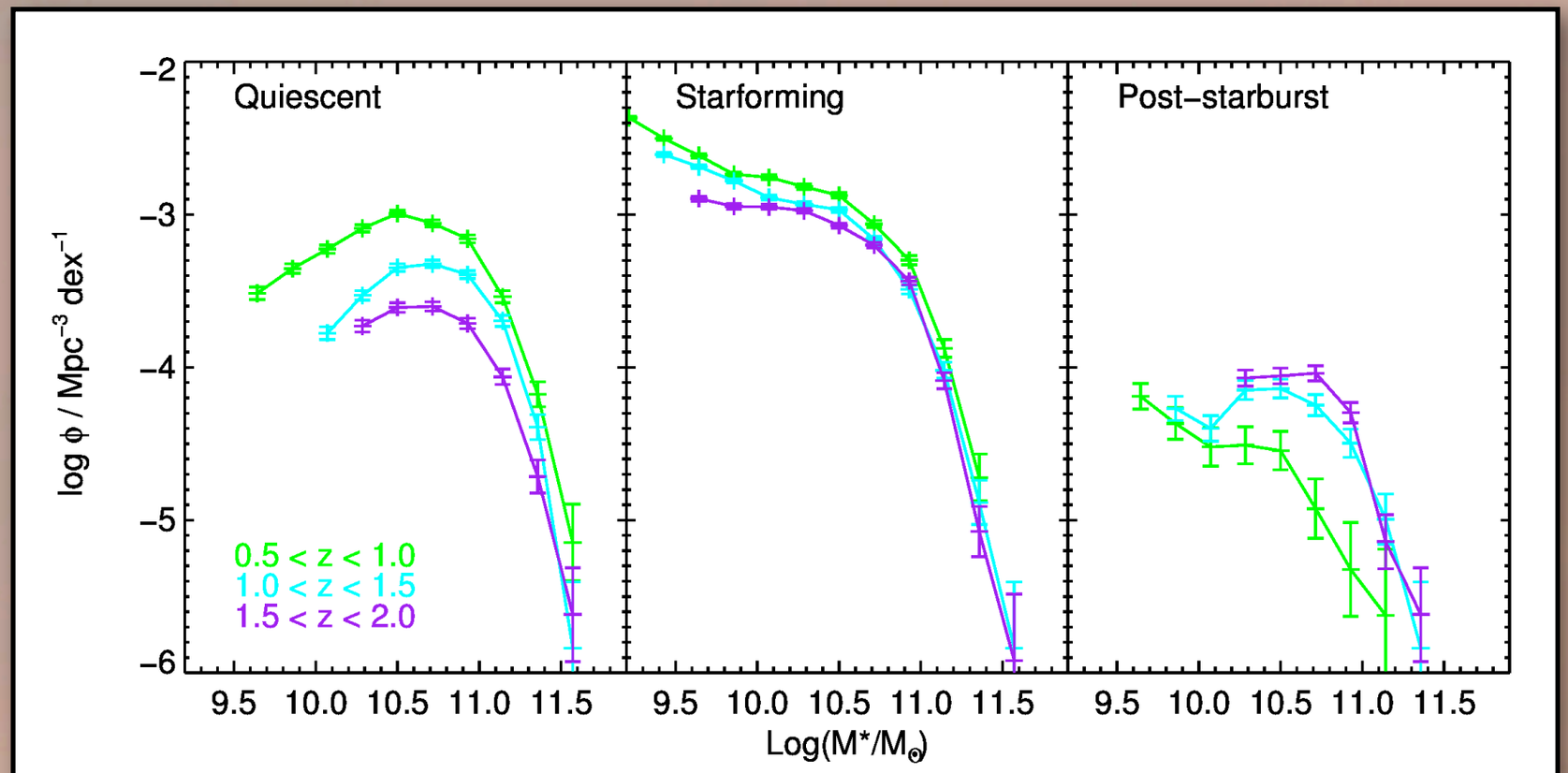


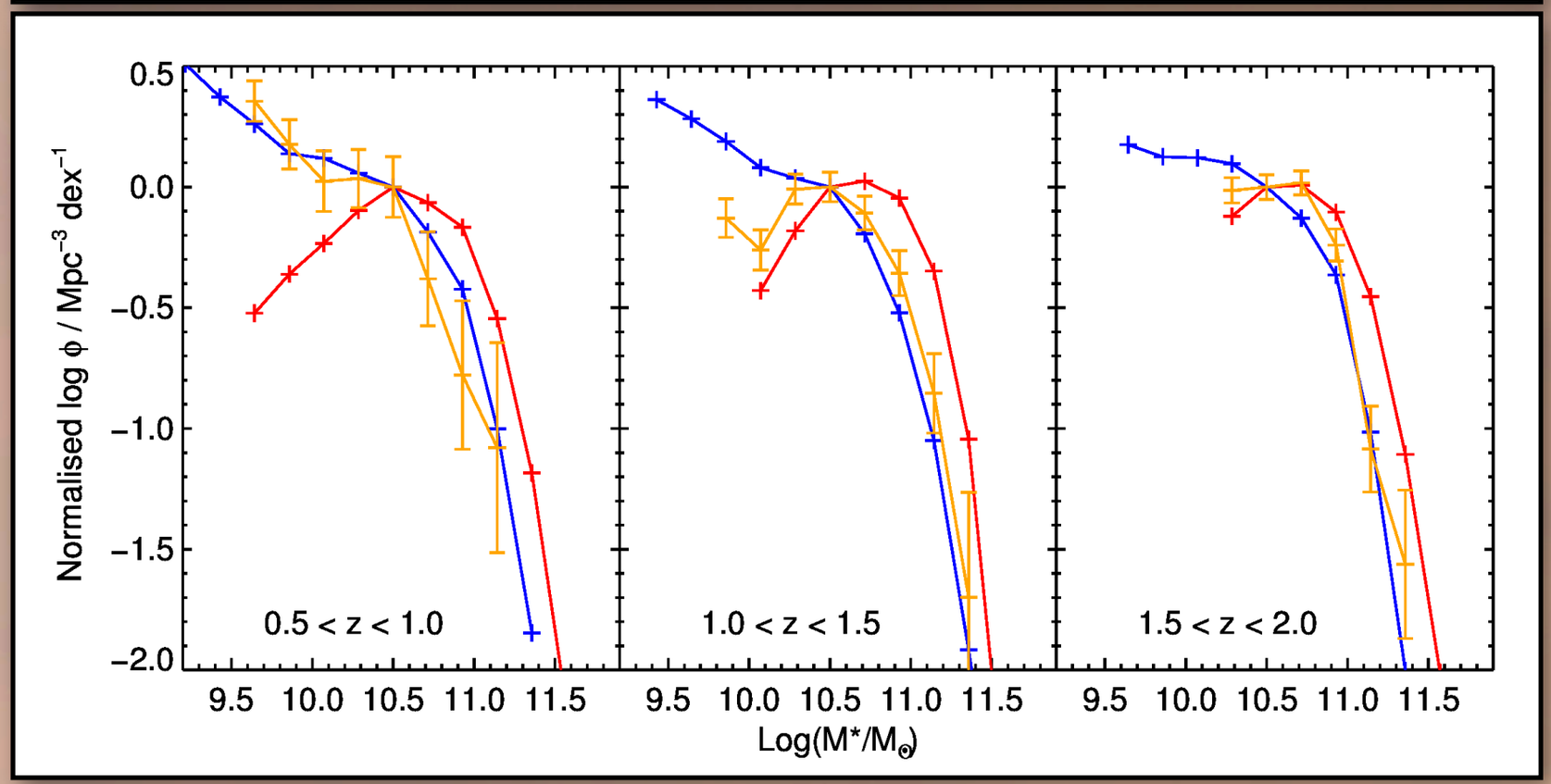
Small in number, but potentially significant contribution to growth in quiescent fraction at z>1

Wild et al. in prep

Stellar mass functions

Vivienne Wild





Two regimes?

z>2

"Formation epoch"

mass function of descendants

z<1

"Merger epoch"

mass function of progenitors

Consistent with being descendants of sub-mm galaxies (Swinbank et al. 2014, Simpson et al. 2014)

Wild et al. in prep

Timing the starburst-AGN connection at high-z

Vivienne Wild

★ The present day red-sequence was formed at high-redshift

- To understand today's galaxy bimodality, need to observe physical processes happening at z>1

★ Now have a method to find post-starburst galaxies at high-redshift

- By characterising the shape of the SED using PCA

★ Post-starburst galaxies are rare but they are "transitional"

- Can contribute significantly to formation of red sequence galaxies.

★ Work in process: are AGN more common in high-z post-starburst galaxies, than other types of host....?

- Using GOODS-S field with deep X-ray and multiband photometry

Summary

Vivienne Wild

- ★ Stellar populations can be used as a clock to time events that occurred in the recent past (< 1Gyr)
  - Note, this is not true for ordinary star-forming galaxies where the recent SFH is unconstrained.
- ★ Post-starburst galaxies are rare, but transitional objects: there are sufficient numbers to account for red sequence growth at z~1-2
- ★ At low-z, their morphologies are consistent with post-mergers. But they still have significant gas supplies.
  - But low-z PSBs are not expected to form the red-sequence as we know it
- ★ At low-z, most BH accretion occurs in ordinary star-forming galaxies. But (post-)starburst galaxies have higher average accretion rates.
- ★ Average BHAR increases significantly 250Myr after a starburst
  - Can only do this for specific case of starburst galaxies. For ordinary star-forming galaxies the precise SFH is unconstrained.
  - Dynamical effect? or fast stellar winds preventing accretion?
- ★ At high-z ... we are working on it!