Post-starburst galaxies from z=0-1: new clues to the formation of the red sequence

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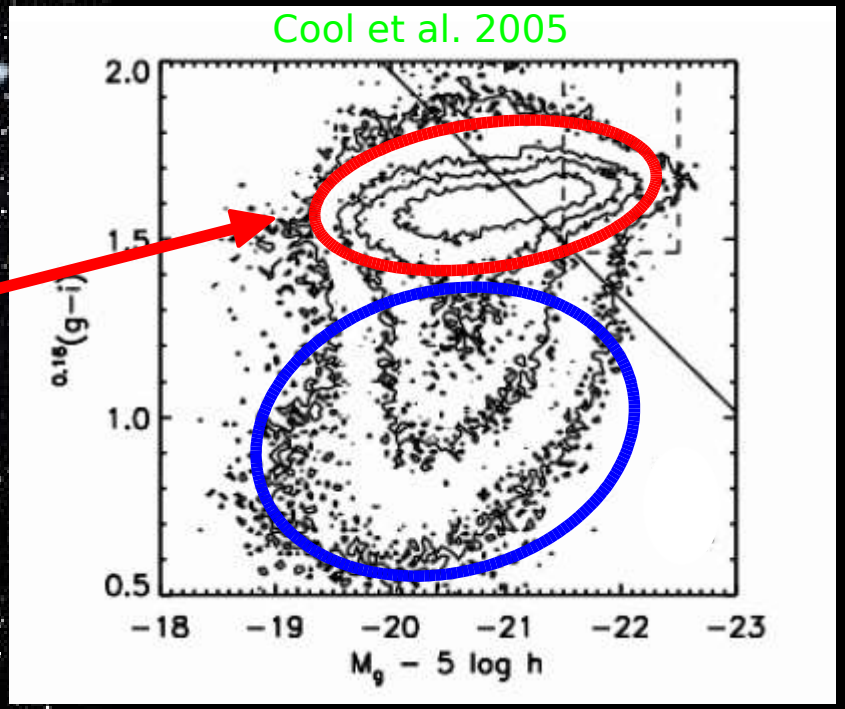
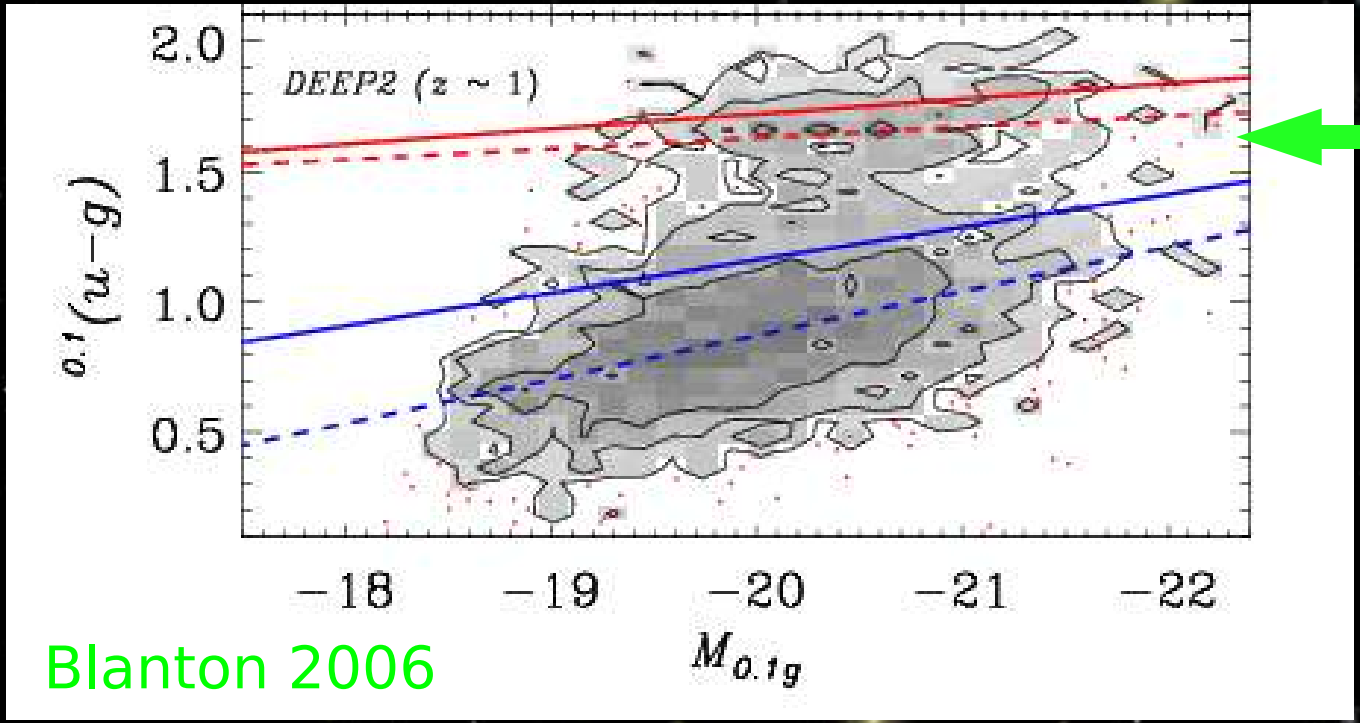
Post-starburst galaxies: The Missing Link?

Early types occupy a narrow 'red sequence' in the color-magnitude diagram



Blue galaxies must become red galaxies very quickly to preserve the color gap



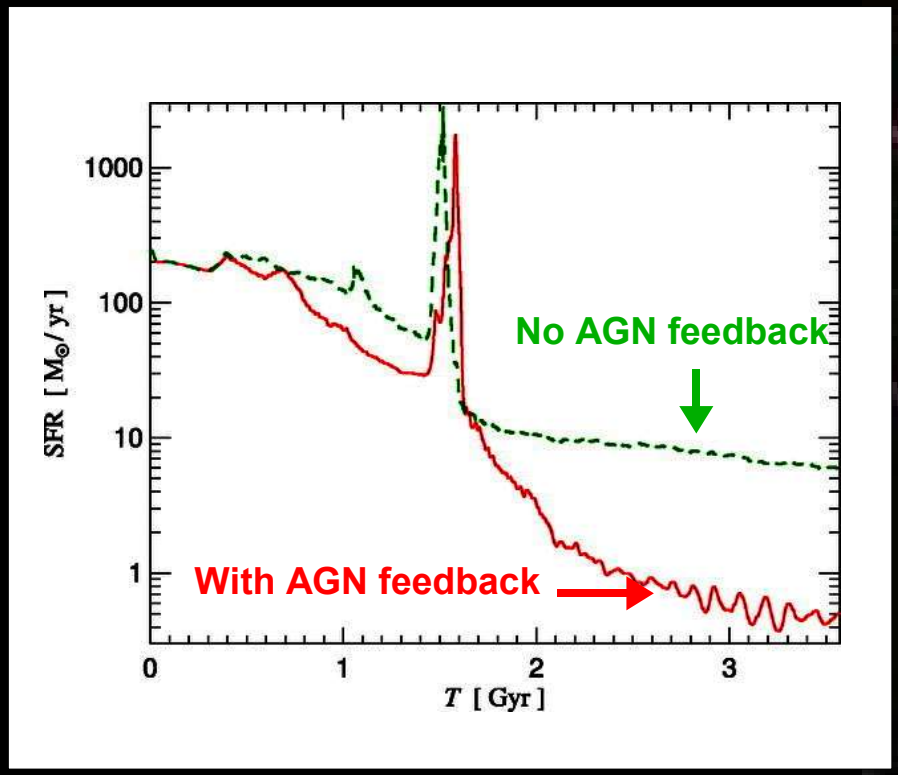
Bell et al. 2004, Faber et al. 2005

Suggested Evolutionary Scenario

(Sanders 1988, 2004)

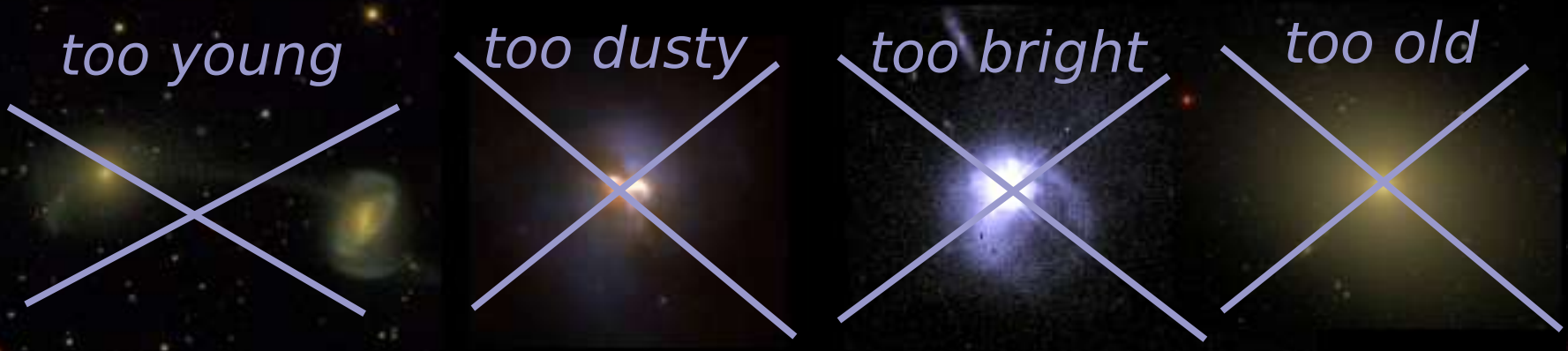
Merger of gas-rich disks → Ultra-Luminous Infrared Galaxy → Quasar → Massive Elliptical

To make star formation turn off more quickly models have invoked feedback from AGN ...



Springel et al. 2005

To test models we need to observe galaxies near the peak of their star formation and black hole accretion



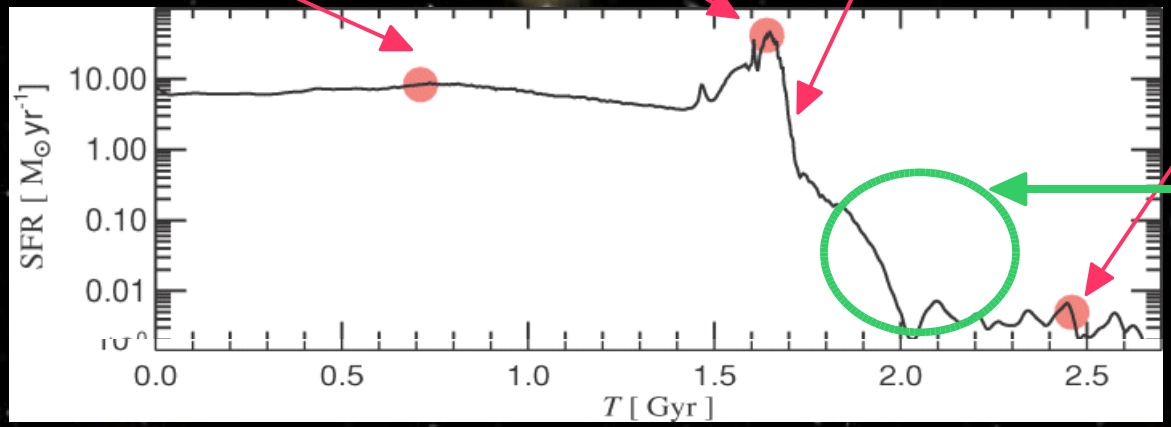
Merger of gas-rich disks

ULIRG

Quasar

Massive Early-type

SFR

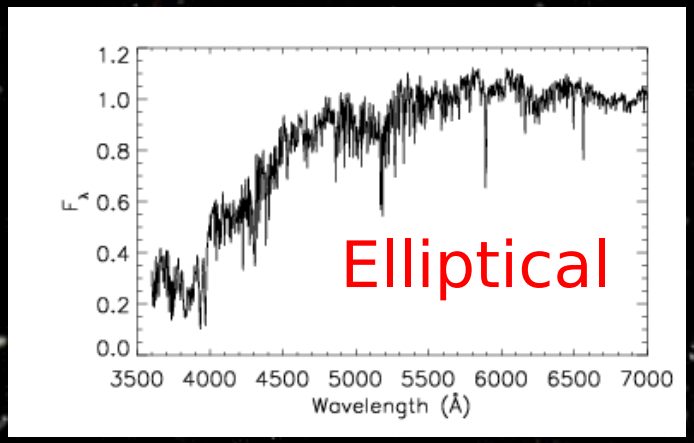


time since merger began (Gyr)

Post-starburst Galaxy

just right!

Post-starburst are similar to classic E+A's



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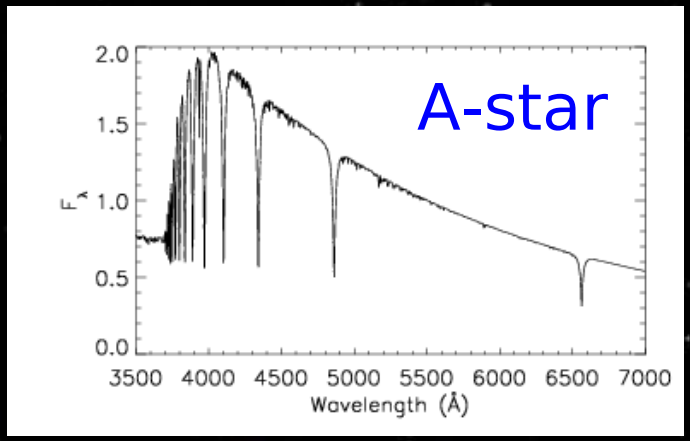

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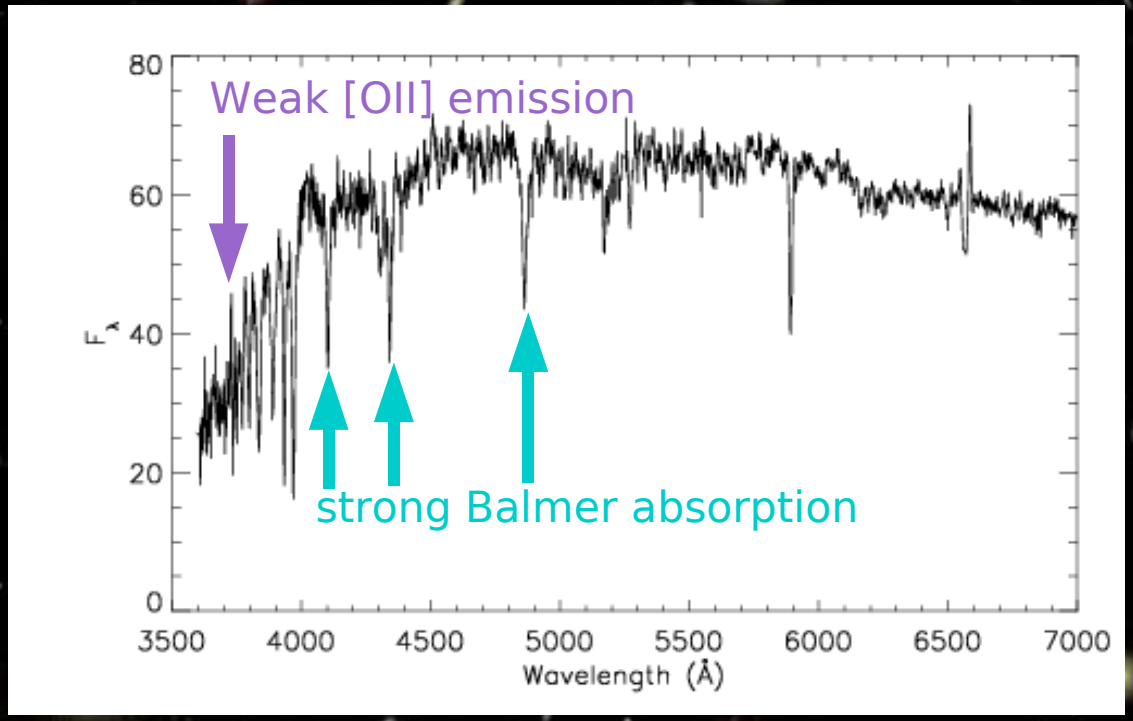


E+A Galaxy
(Dressler 1980)

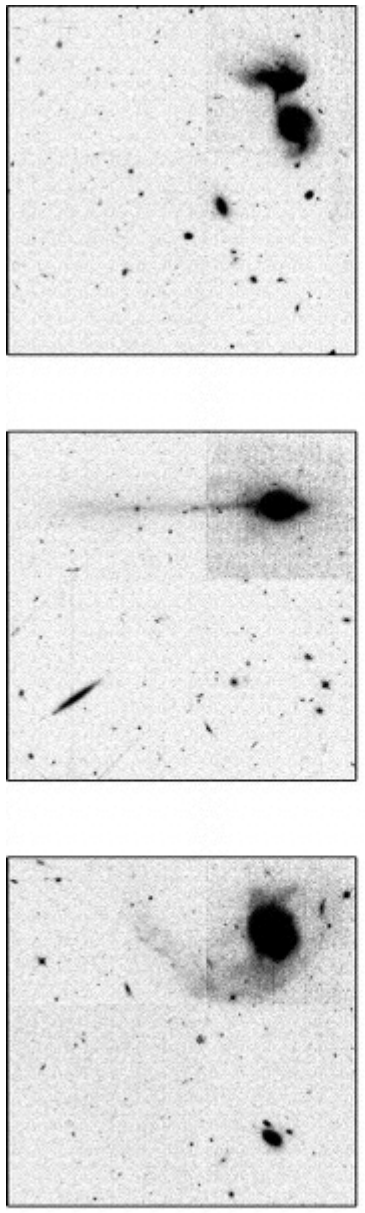
Local E+A's

- bulge-dominated morphologies, but with tidal features suggestive of late-stage mergers (Yang et al. 2004)

- most are in groups (Zabludoff et al 1996)

- kinematics similar to early-types (Norton 2001)

- they are rare: **0.2 – 6% of local galaxies!** (Zabludoff et al. 1996; Poggianti et al. 1999; Balogh et al. 2000; Goto et al. 2002)



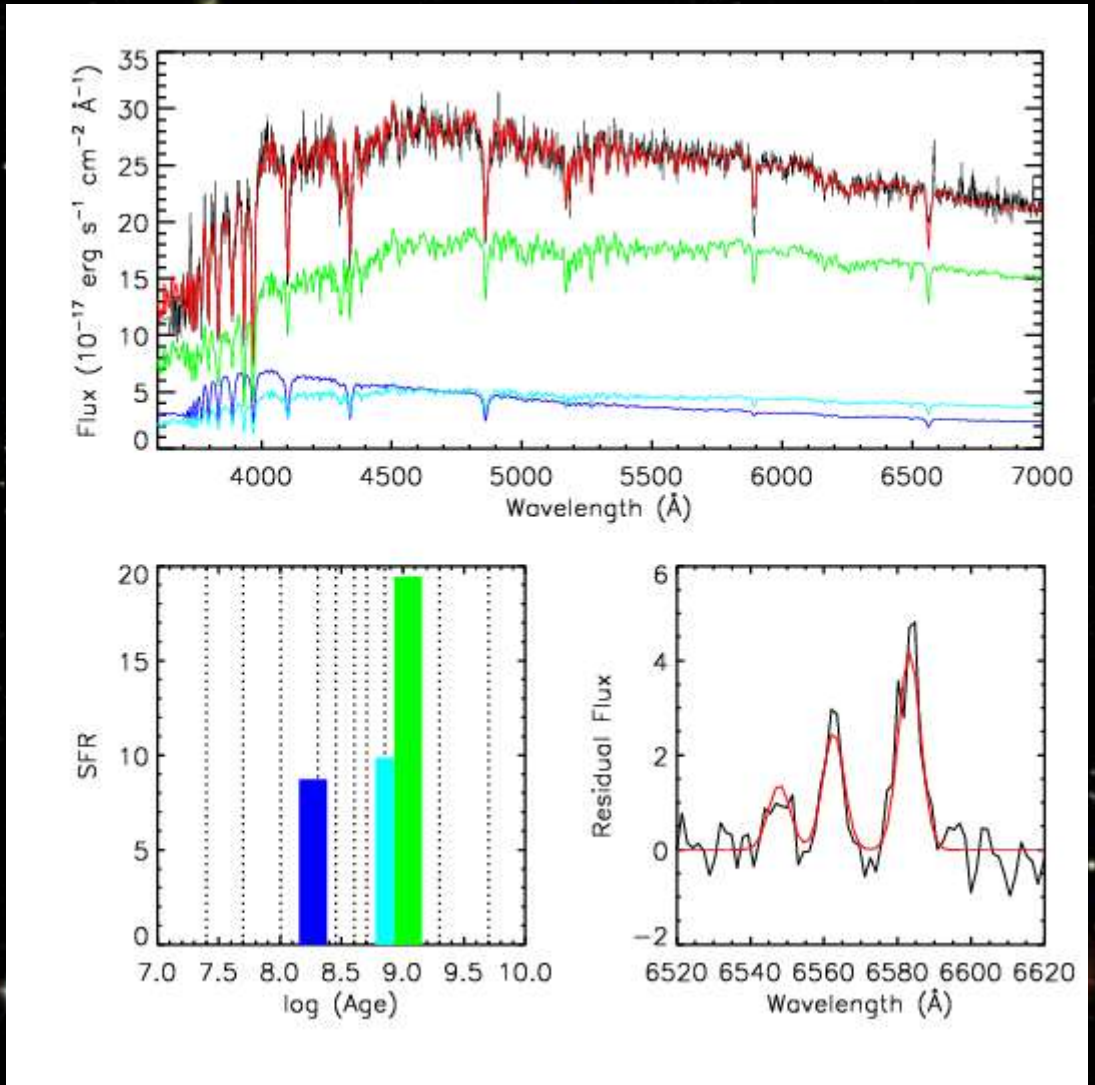
Yang et al. 2004

We perform an automated search on 520,082 galaxy spectra in the SDSS

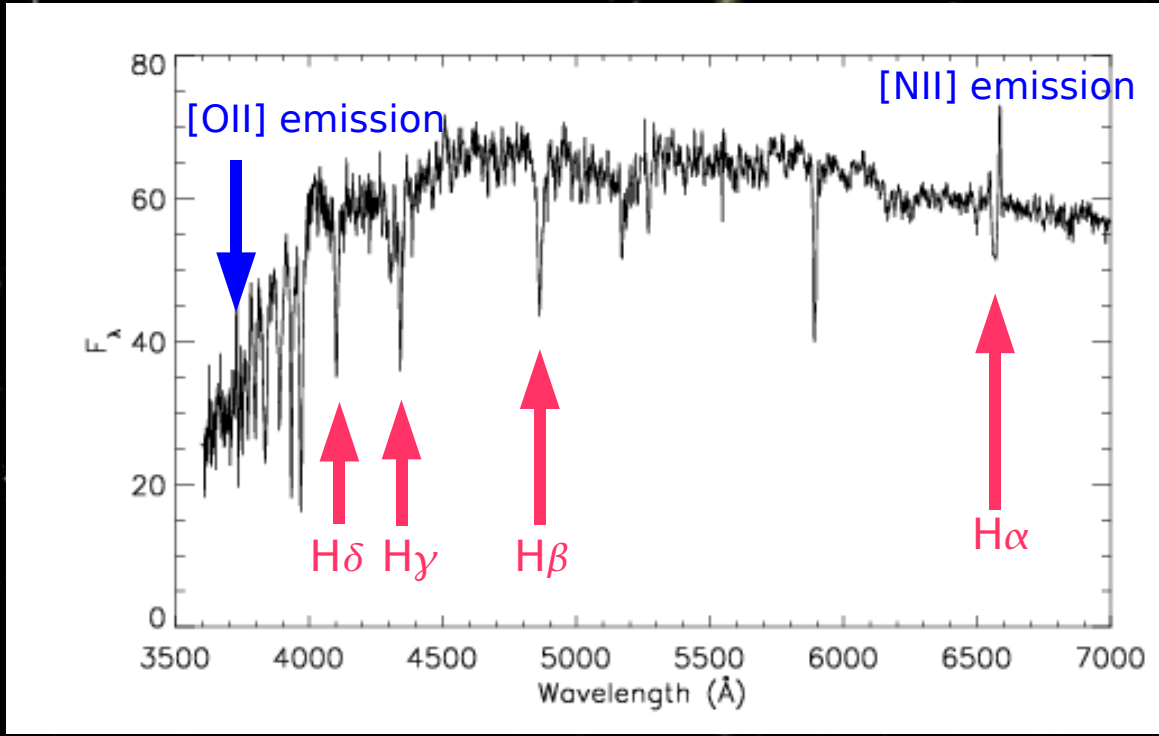
Fit continuum with Bruzual & Charlot 2003 stellar population models

→ measure stellar absorption & nebular emission lines

→ use stellar & nebular lines to define a class of post-starburst galaxies



Traditionally post-starburst (E+A's) are selected using cuts on Balmer absorption and [OII] emission

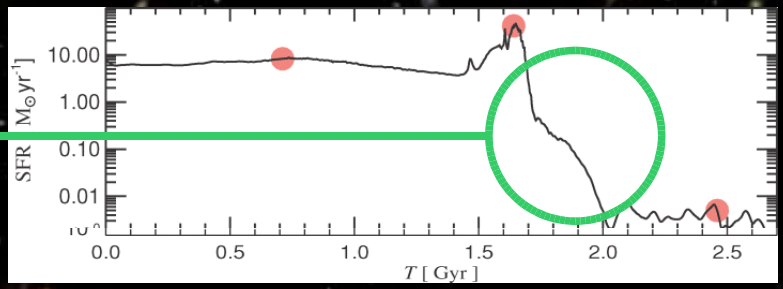


Zabludoff et al. 1996:

$(H\beta + H\gamma + H\delta)/3 > 5.5$

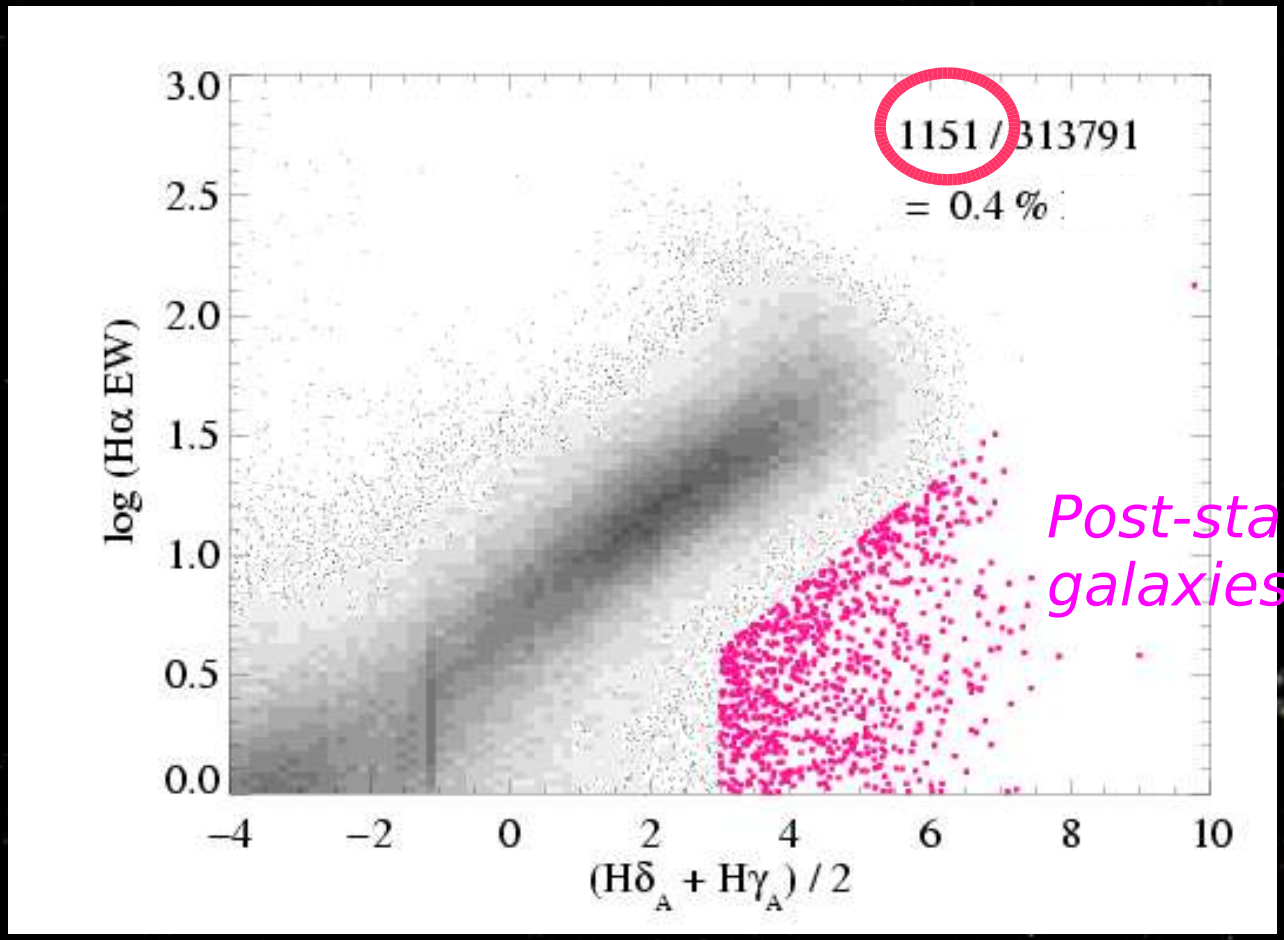
[OII] EW < 2.5 Å

We wish to select galaxies where SFR is still in the *process* of shutting off



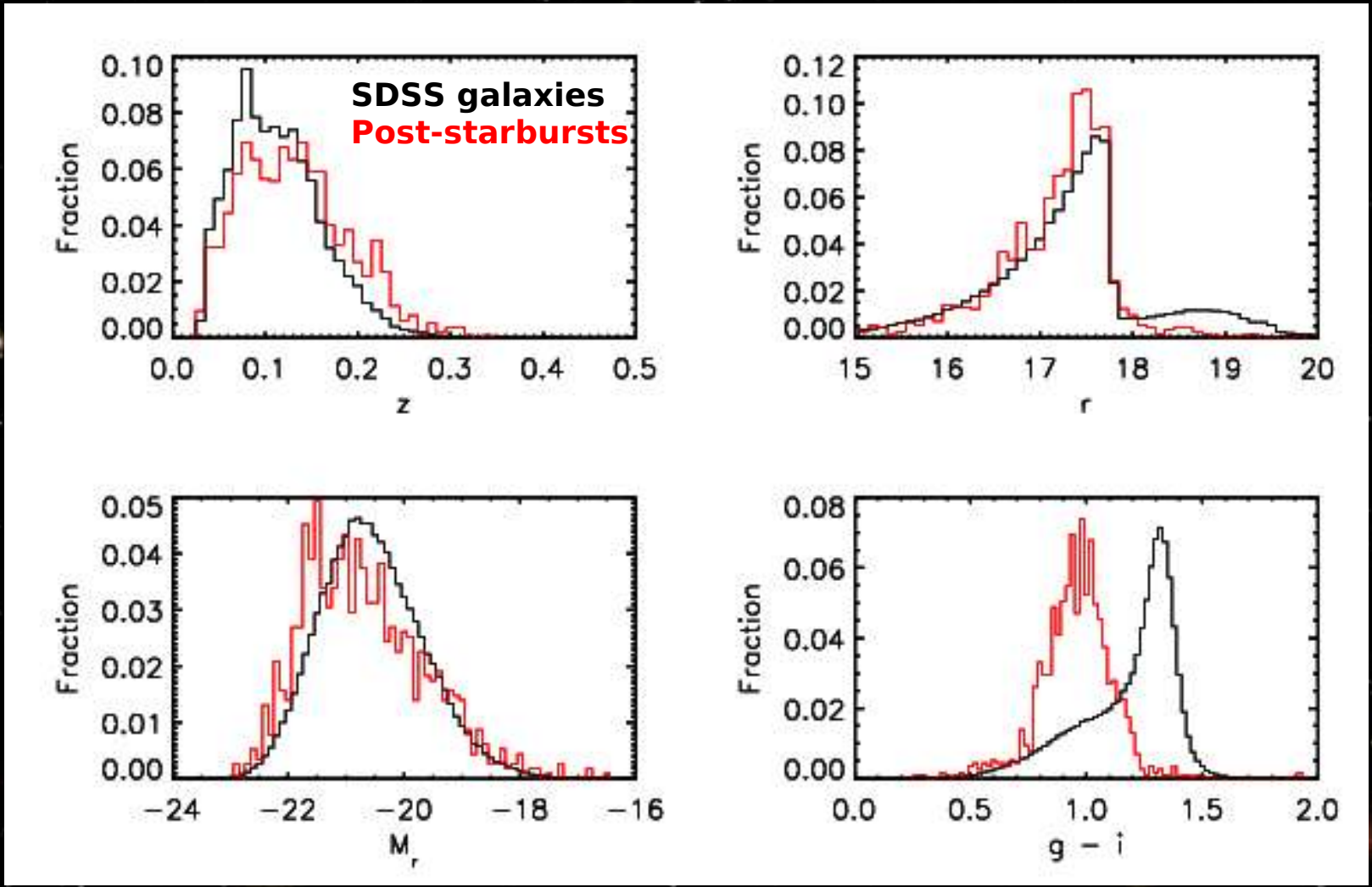
A new way to select Post-starbursts

Hα *emission* traces SF in last 10 Myr

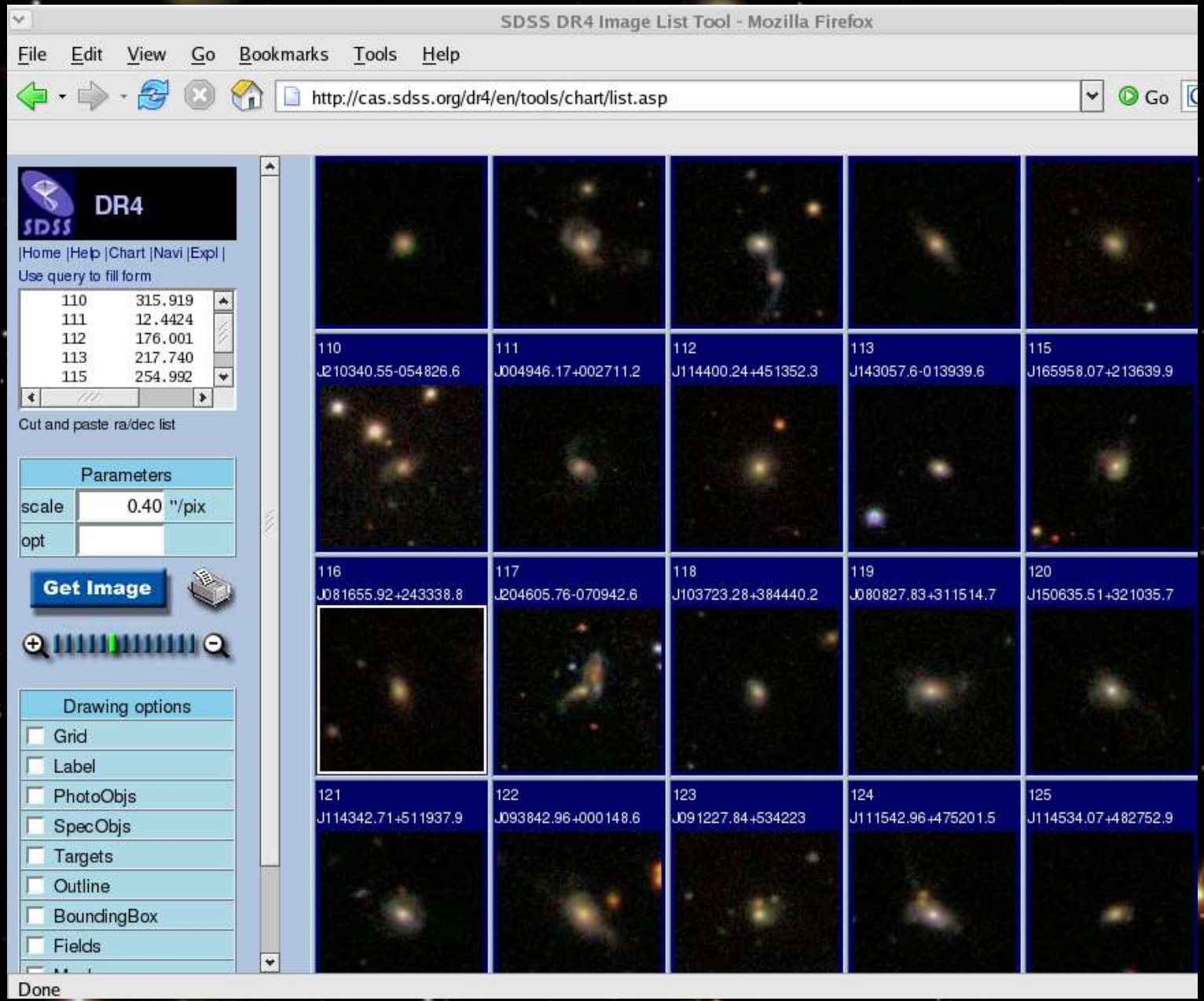


Balmer *absorption* traces SF 0.5 – 1.5 Gyr ago

The post-starburst sample is similar to parent SDSS sample, but has bluer colors



Morphology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111 J004946.17+002711.2
112 J114400.24+451352.3
113 J143057.6-013939.6
115 J165958.07+213639.9
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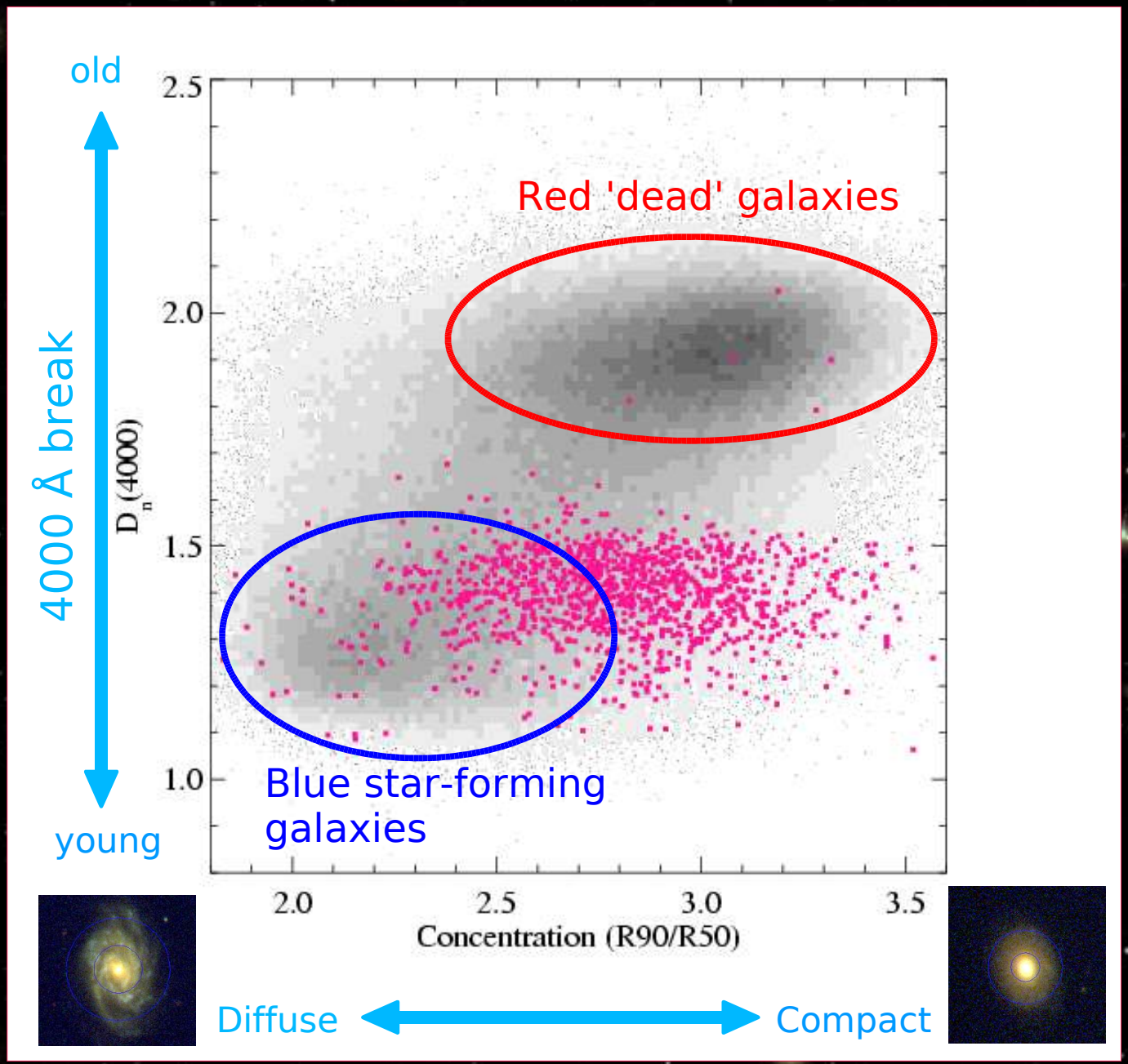
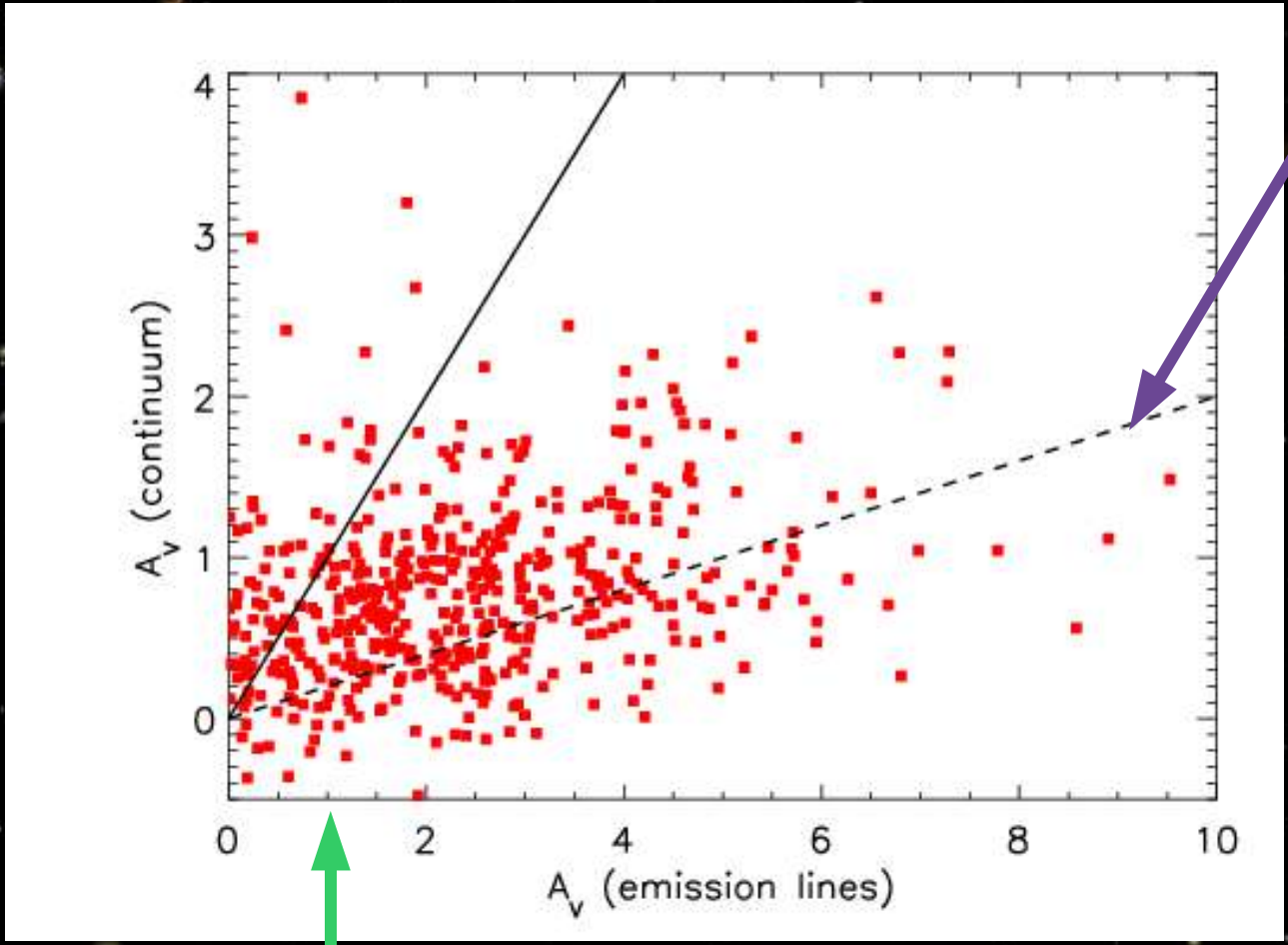
118 J103723.28+384440.2
119 J080827.83+311514.7
120 J150635.51+321035.7
121 J114342.71+511937.9
122 J093842.96+000148.6
123 J091227.84+534223
124 J111542.96+475201.5
125 J114534.07+482752.9
Done

Morphology

Post-bursts are more compact than typical star forming galaxies

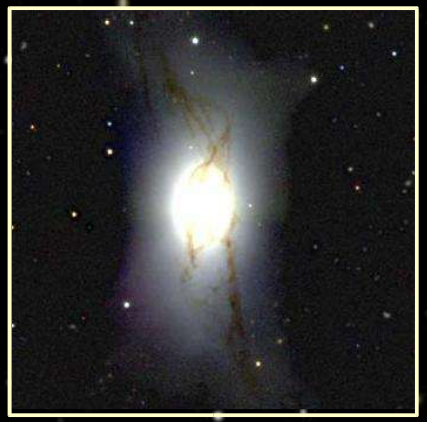


Dust content



stars experience ~20% of the attenuation of the gas

Lots of patchy dust!



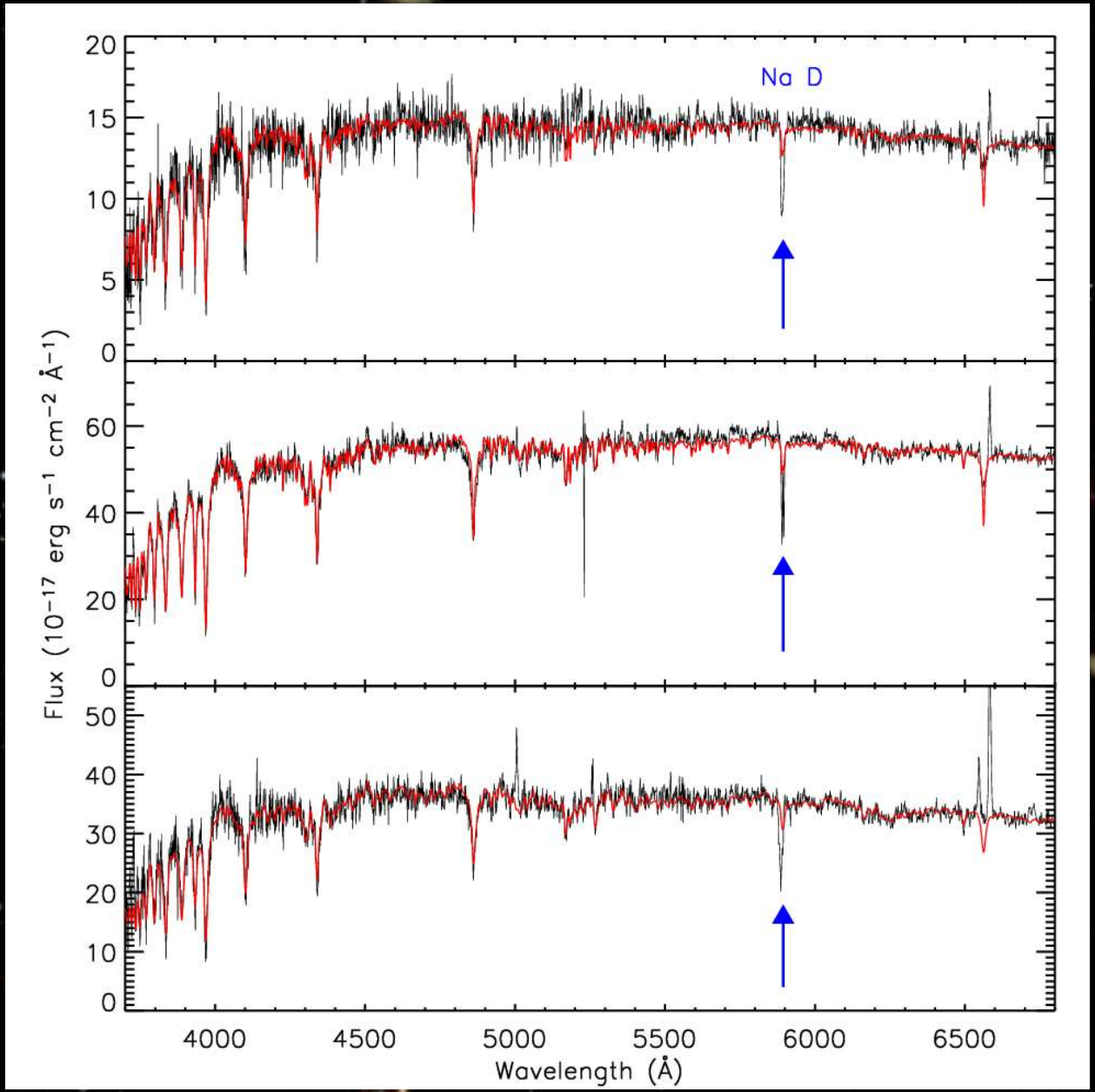
Median for actively star-forming galaxies

Neutral Gas:

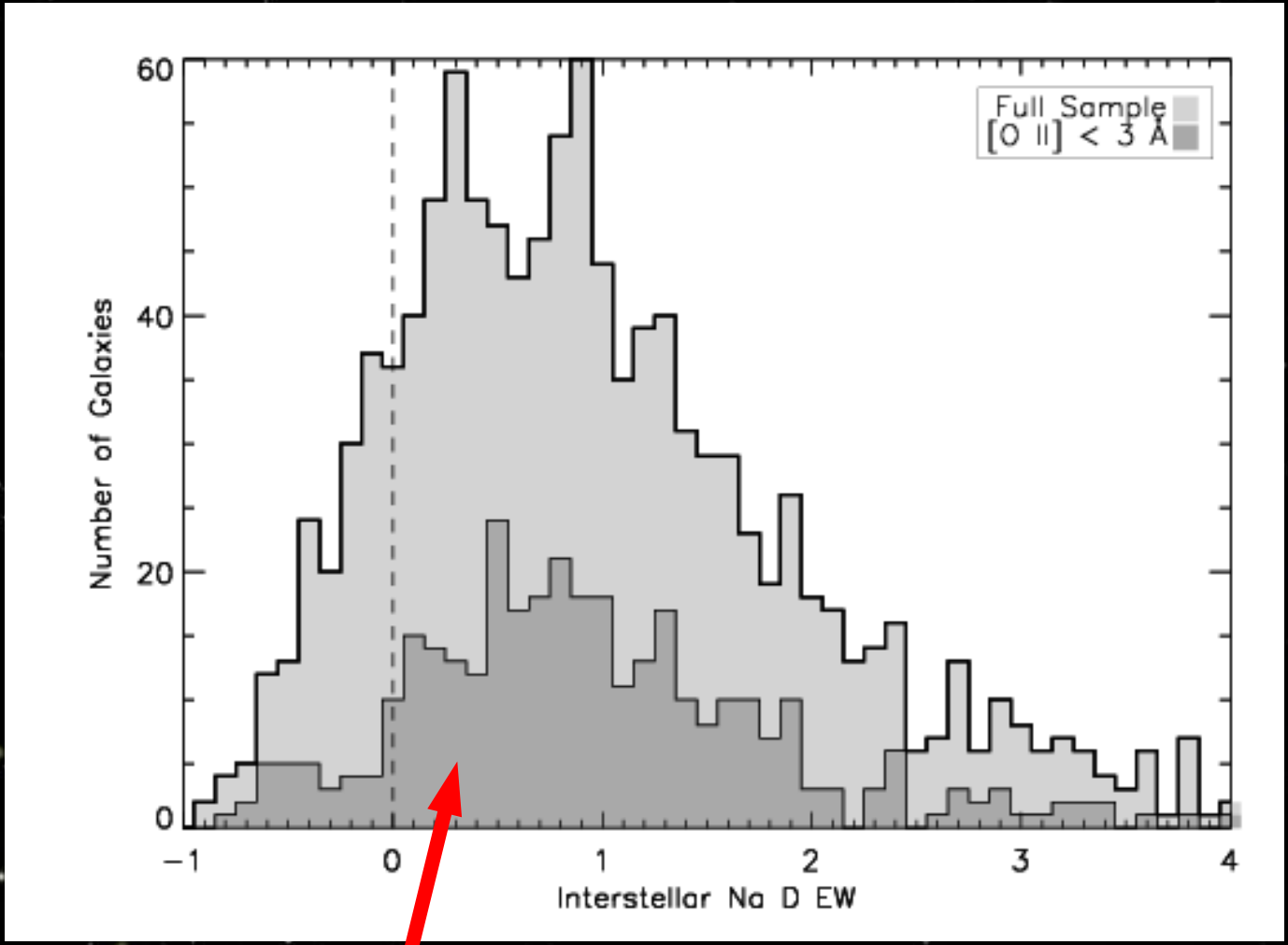
Na I “D” interstellar absorption line λλ5890, 5896

Ionization potential < 13.6 EV, so *good tracer of cool neutral medium*

Also found in stars, so good continuum subtraction is needed

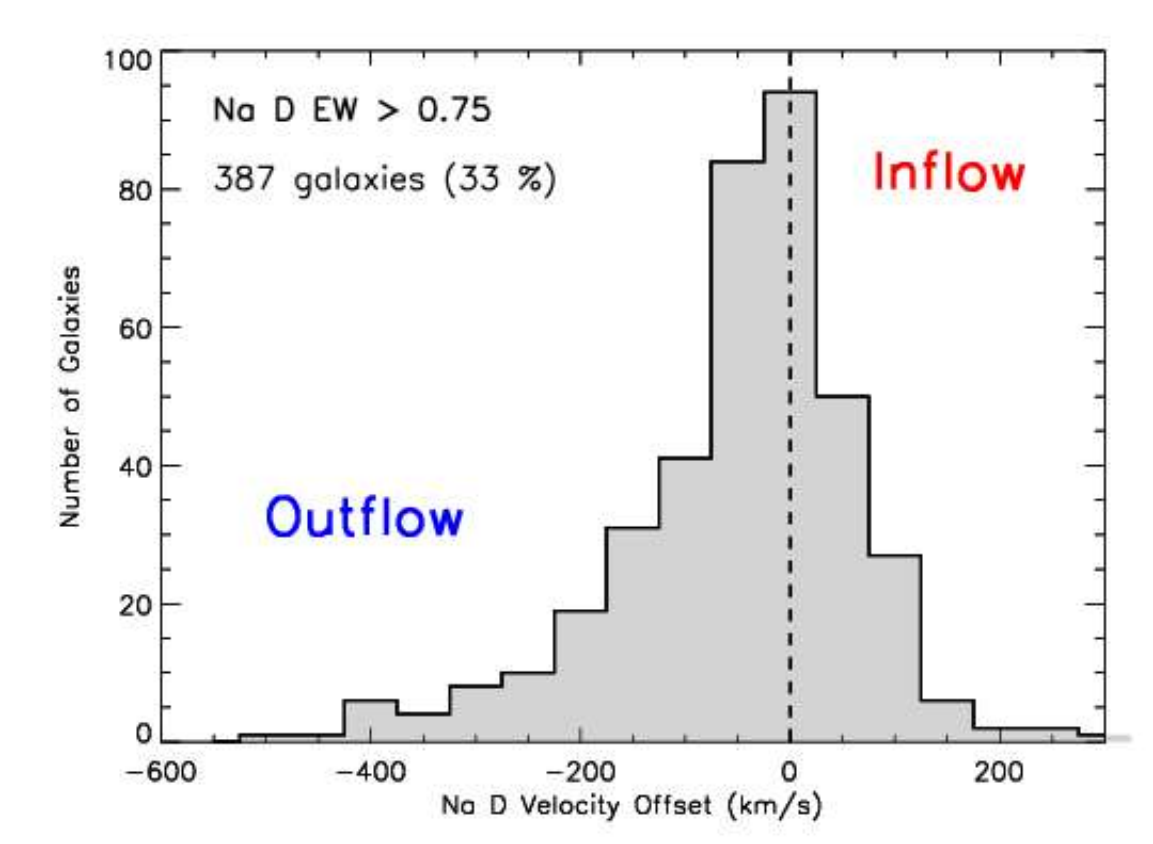


Cold gas is present in most galaxies , even when there is little on-going star formation!



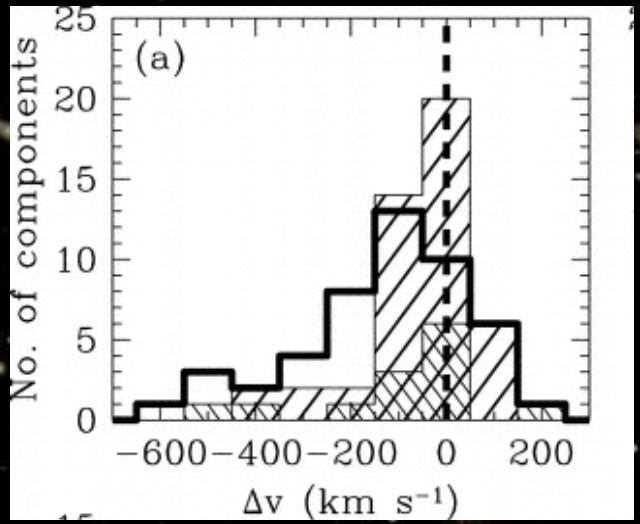
Classic E+A galaxies (little/no SF)

Gas Kinematics



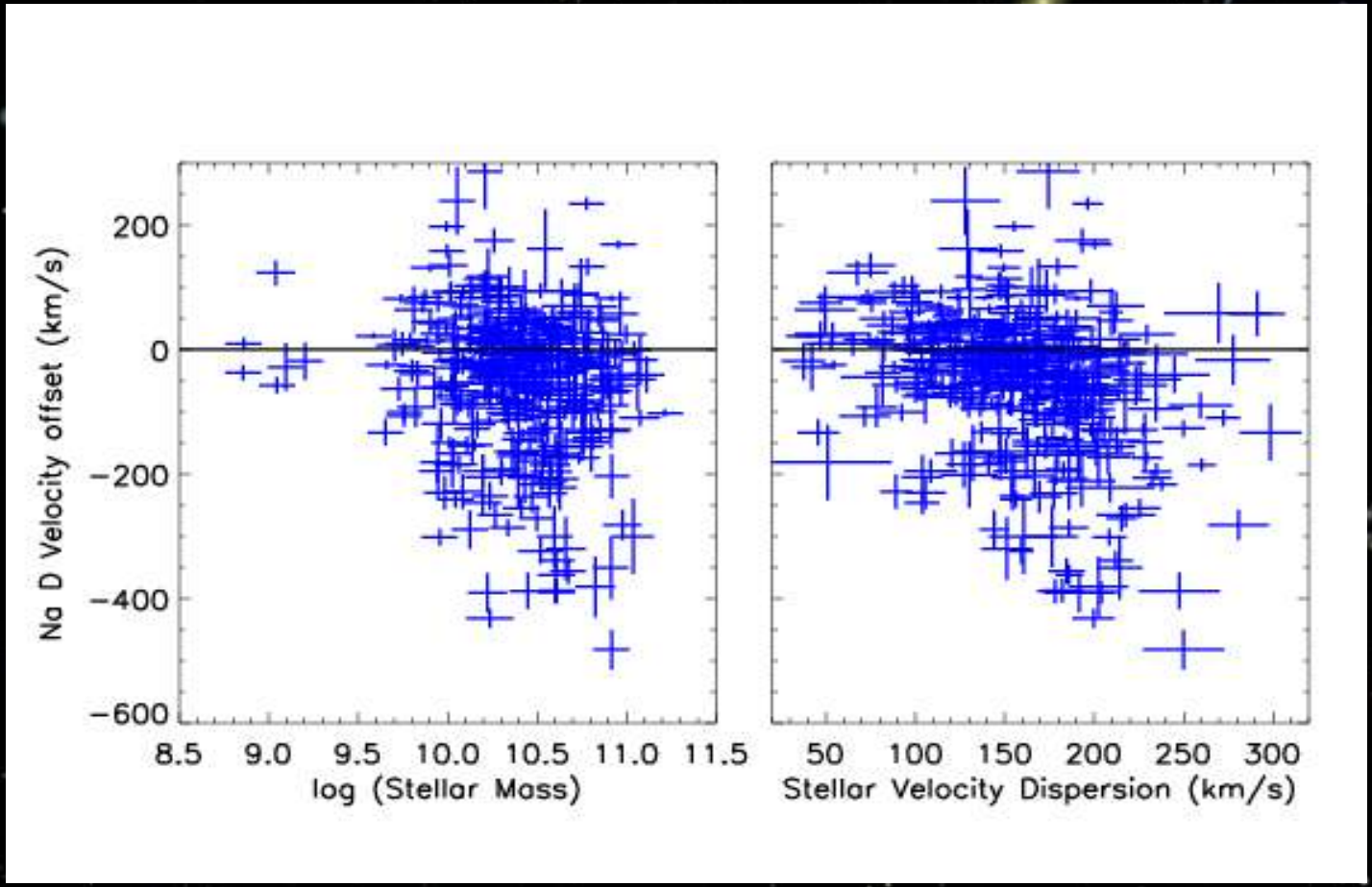
Outflows are common! 40% of galaxies with strong Na D have v < -50 km/s

Na D kinematics similar to Rupke et al. 2005 LIRGS & ULIRGS

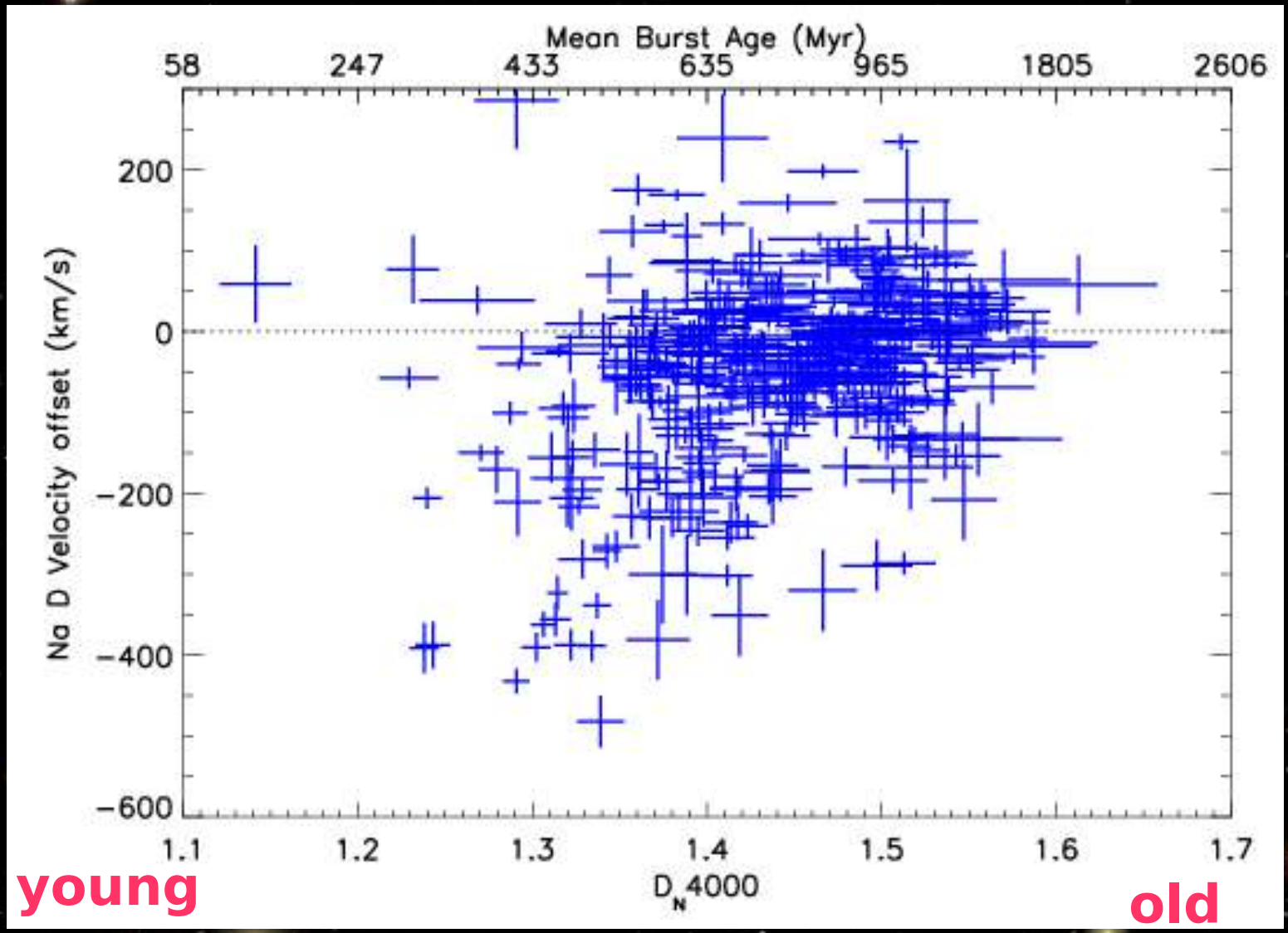



Cold gas in a hot wind?? Yup.
Cold gas is entrained by the hot wind – Hα emission is from the interface regions
M82 Hα + Optical
(Westmoquette et al., 2004)

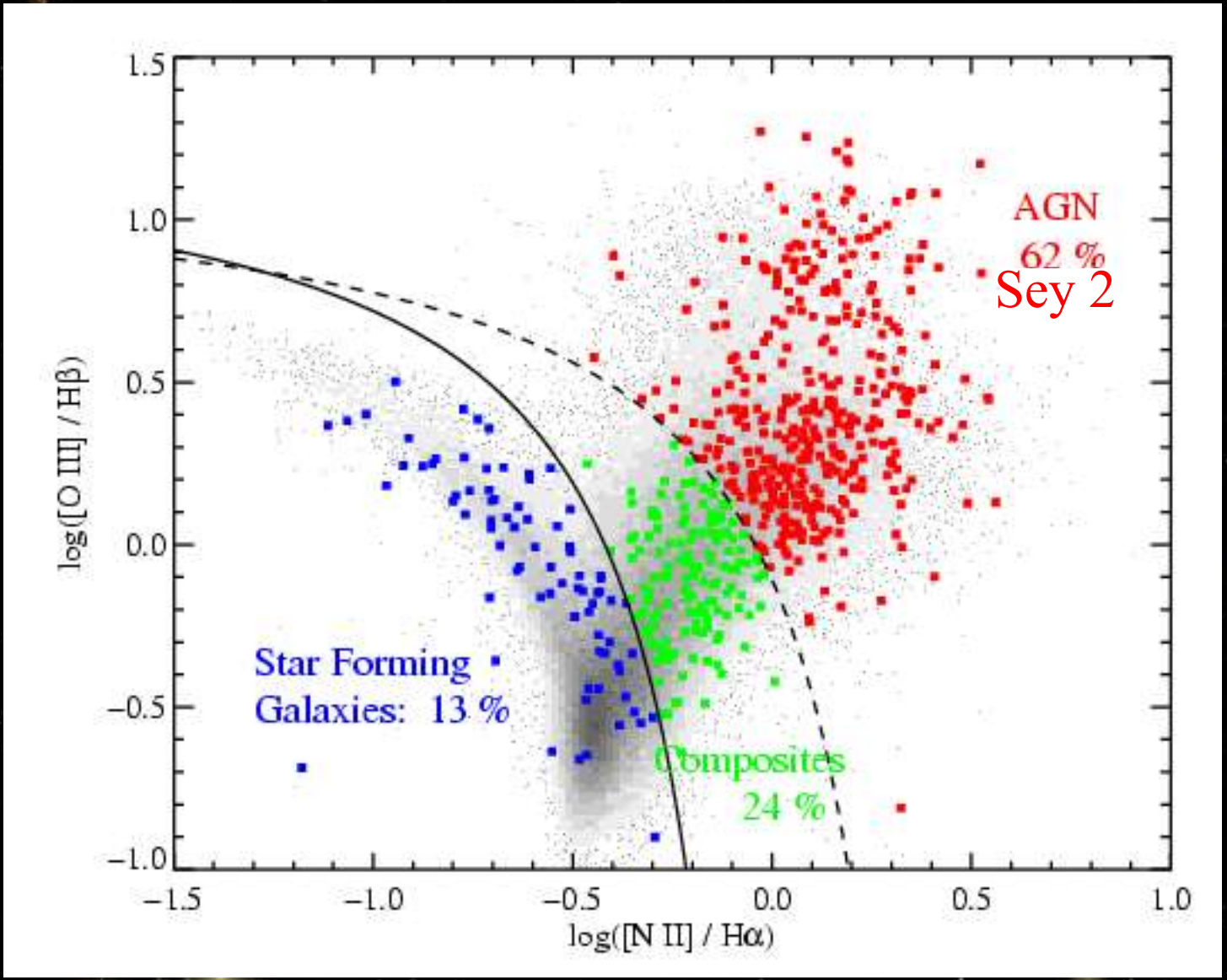
Outflow velocity is correlated with galaxy mass, similar to starbursts (e.g. Martin 2005)



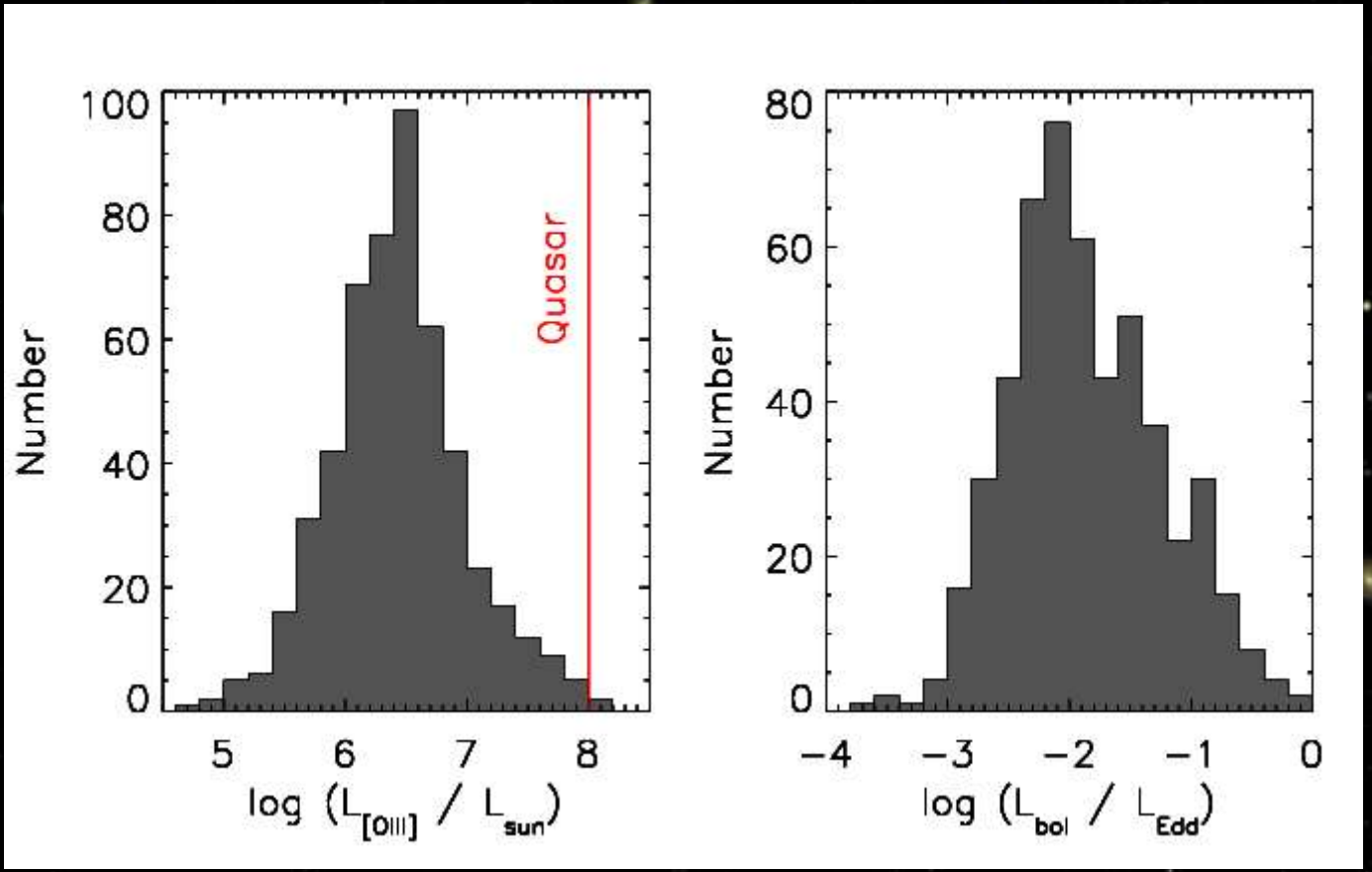
Younger galaxies are more likely to host winds!



Nuclear Activity: 86 % are AGN!



Most galaxies display weak AGN activity



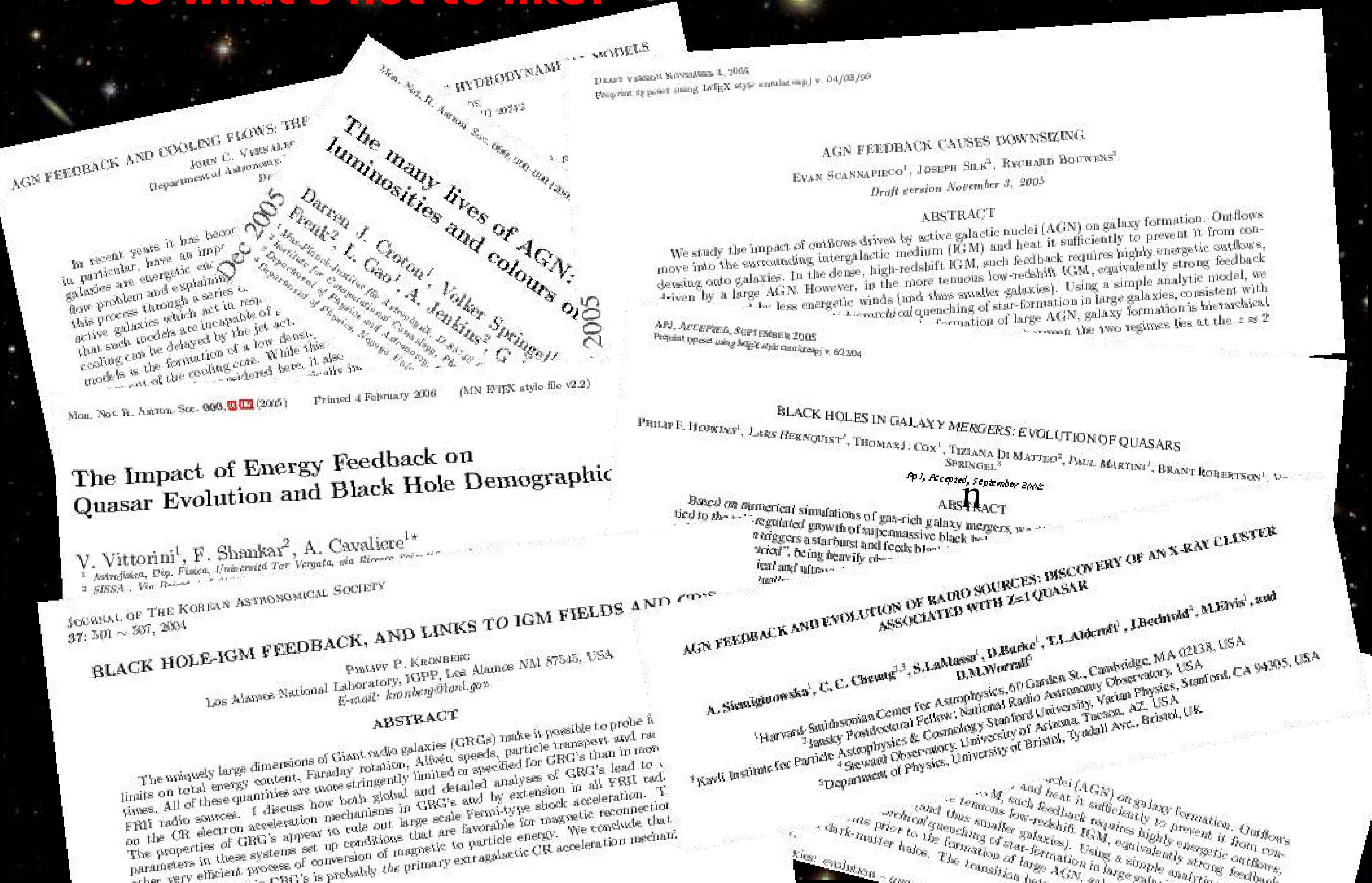
AGN luminosity

AGN activity state

Post-burst galaxy properties:

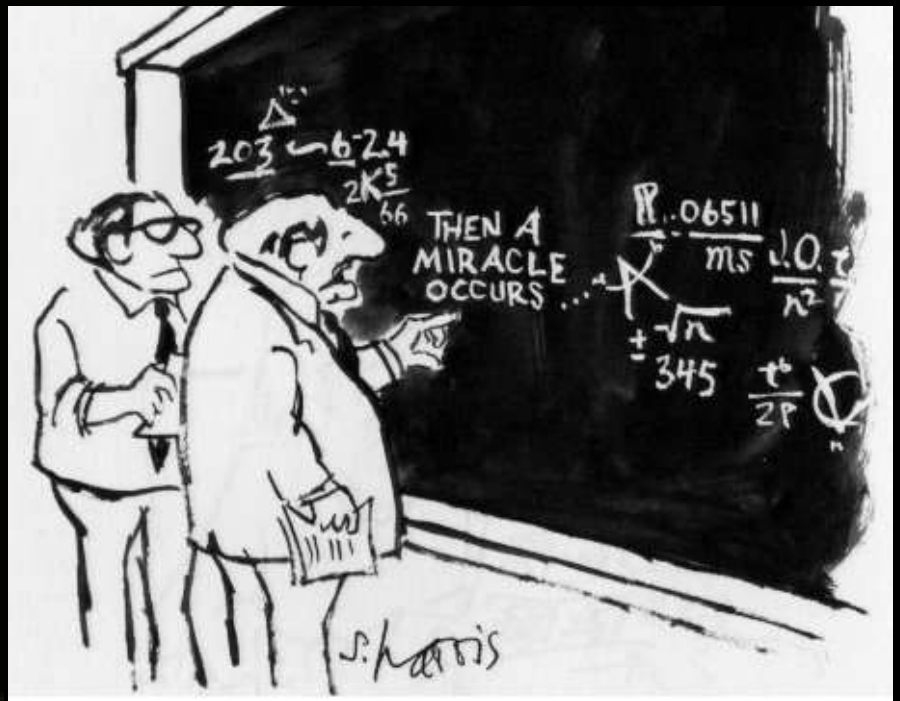
- Late-stage mergers
- centrally concentrated
- lots of patchy dust
- neutral gas present even when little/no SF
- outflows in young systems
- most are low luminosity AGN

AGN feedback seems to solve a lot of probelms, so what's not to like?



We don't know how AGN feedback works

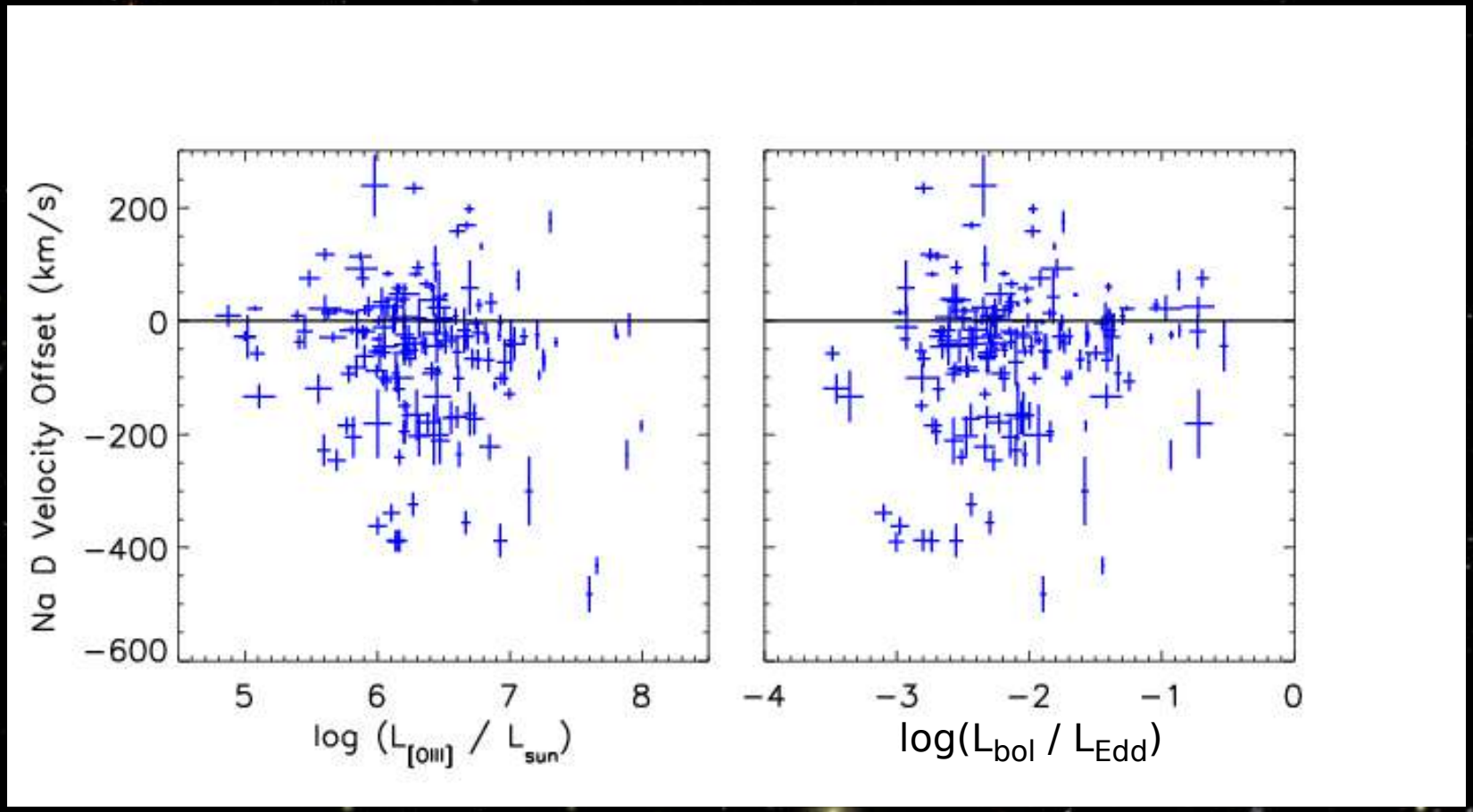
$\dot{E}_{feed} = 0.005\ \dot{M}c^2$



"I think you should be more explicit here in step two."

How does accretion energy become KE, and how is it transported to kpc scales?

Are winds linked to AGN activity?

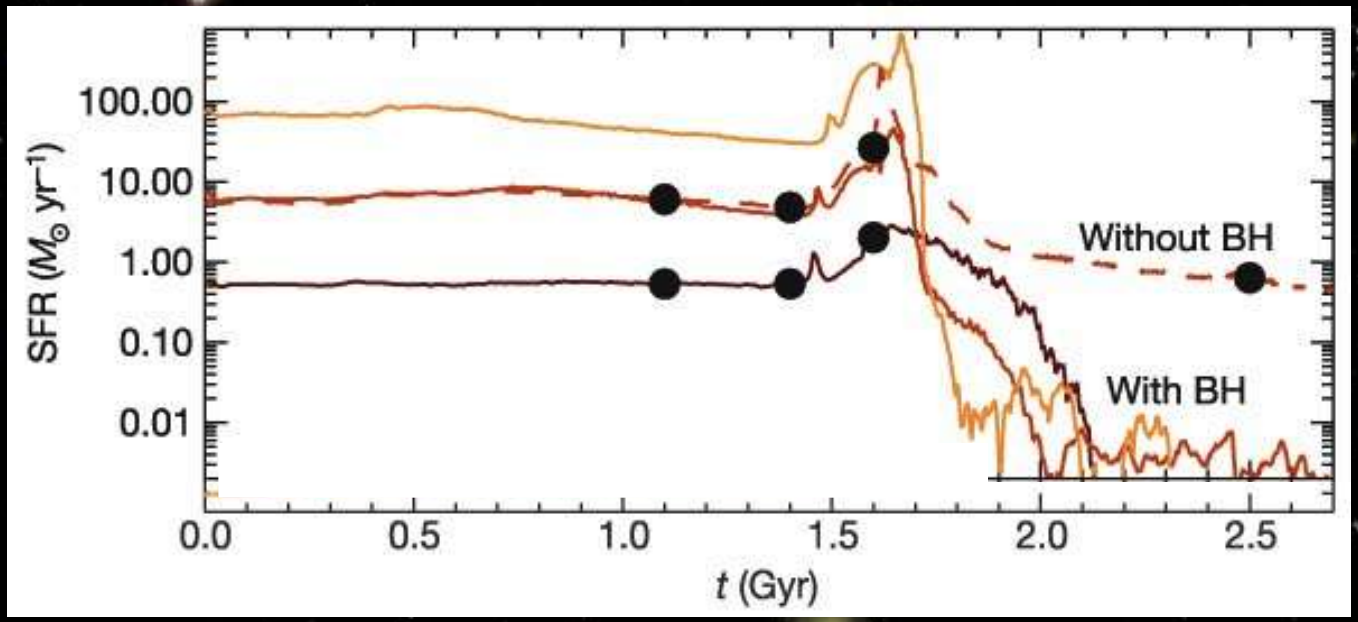


AGN luminosity

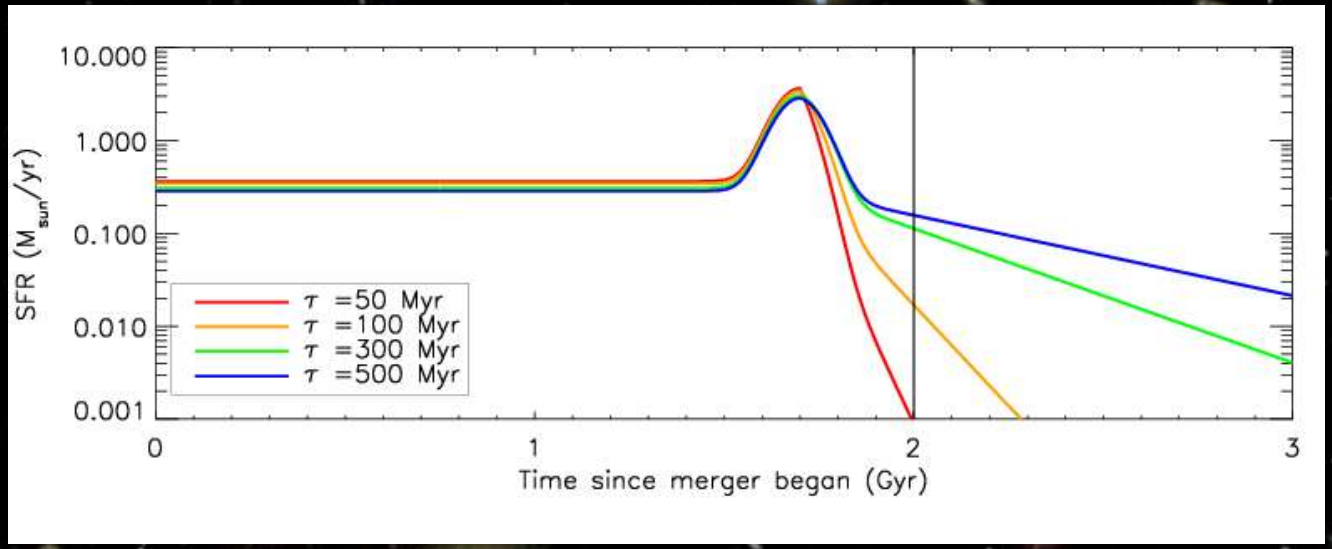
AGN activity state

Not really ...

Testing AGN feedback models:



Models make quantitative predictions about the effect AGN feedback on the evolution of the starburst

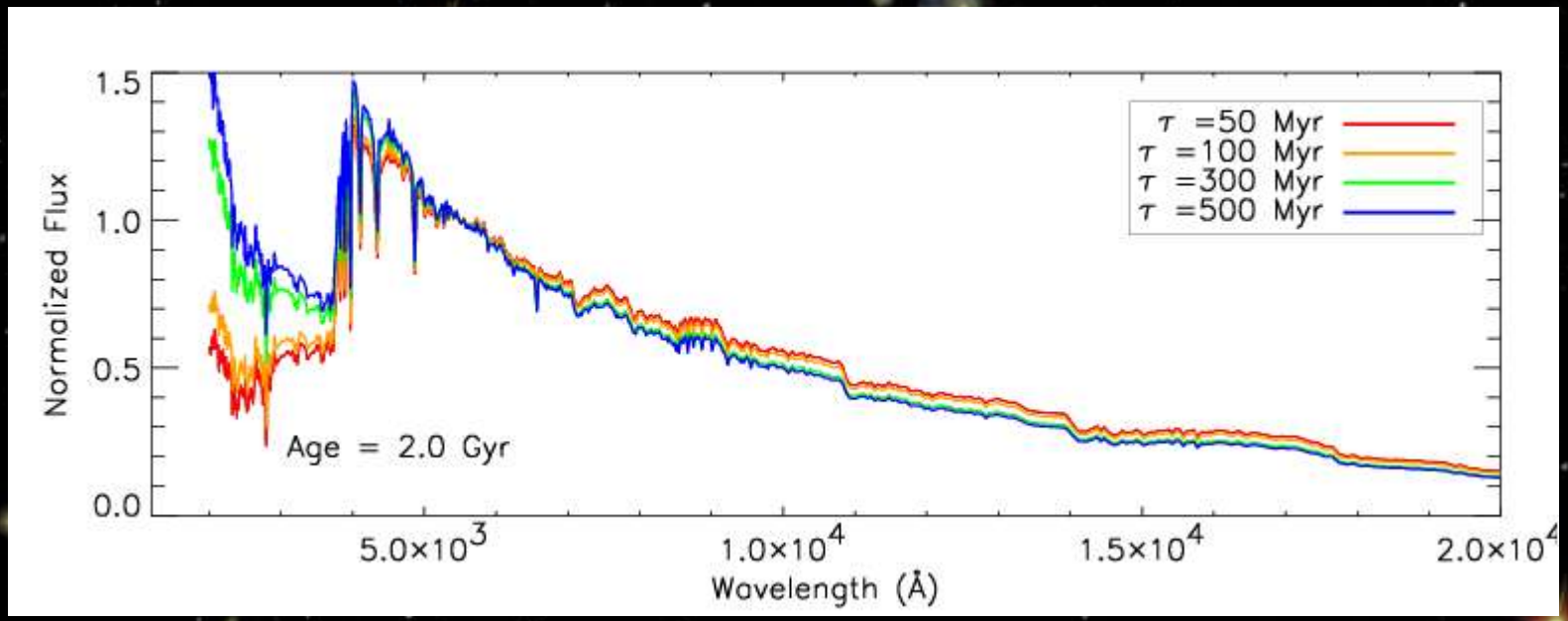


Can we measure starburst timescales?

Maybe ...

Model Parameters

- age
- τ (burst decay time)
- reddening
- fraction of young/old stars
- mass of young stars (normalization)



Broad wavelength coverage needed to break degeneracies!

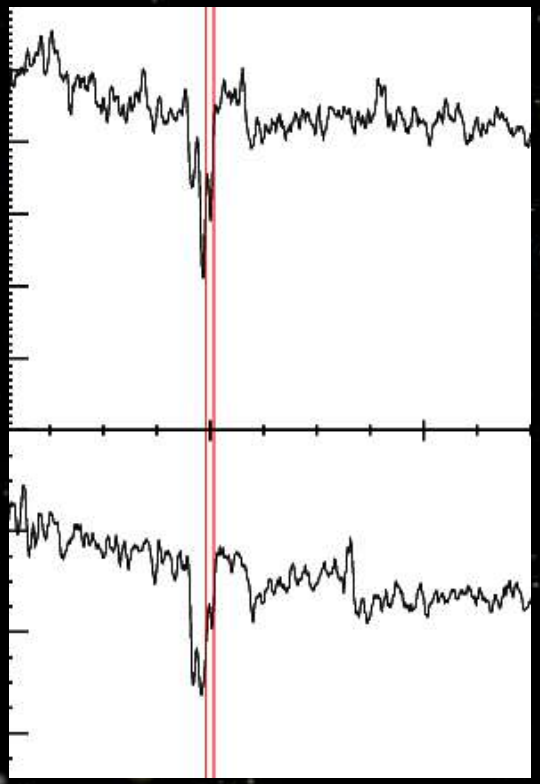
Conclusions

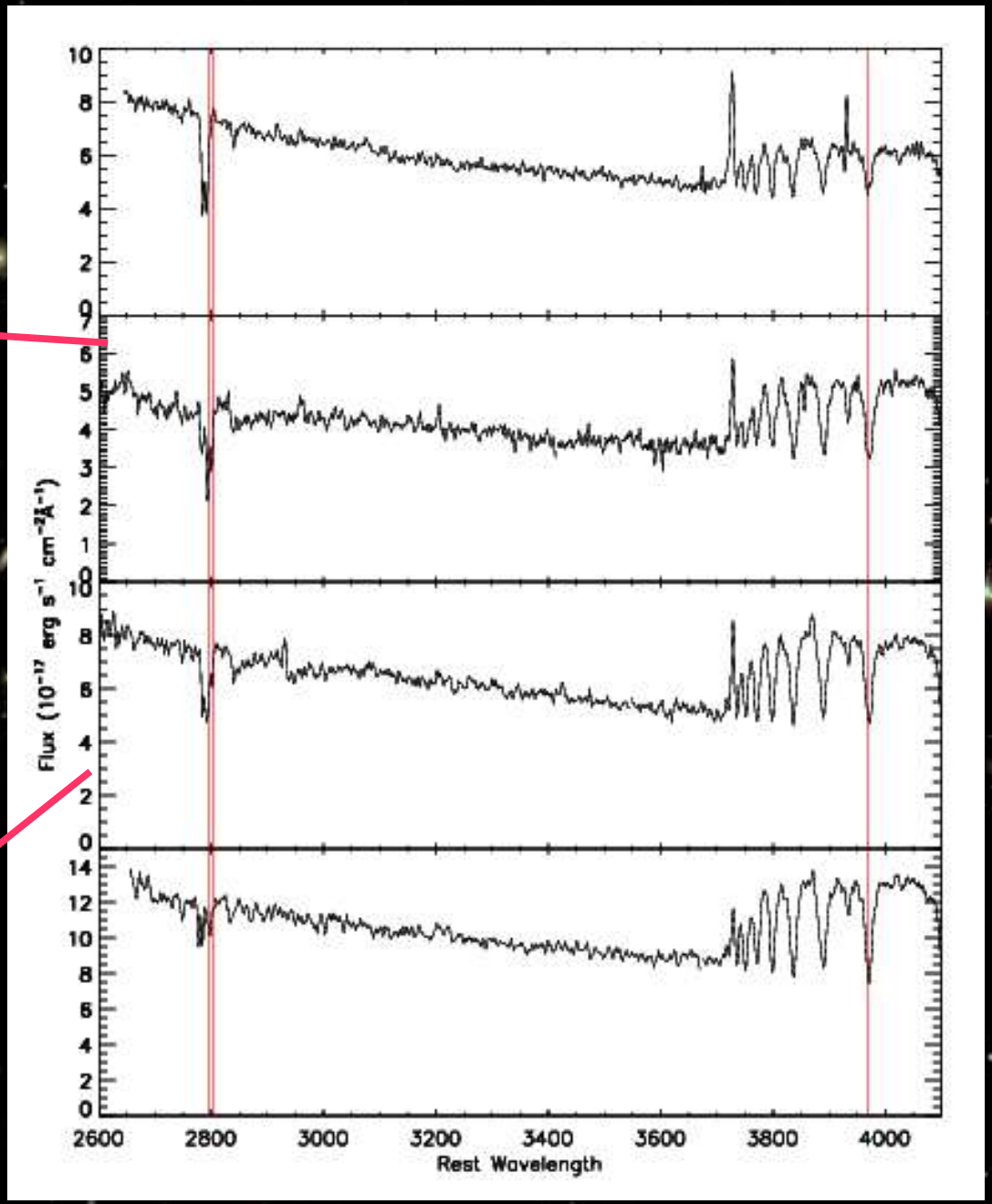
There is compelling observational evidence that post-starburst galaxies are Early types in transition

- patchy dust, weak (faded?) AGN, and winds!

If we succeed in modeling the recent star formation in these galaxies, we can provide quantitative tests of AGN feedback models

Post-starbursts at z~1





Mg II 2800 blueshifted by 1000-2000 km/s!