AGN Feedback & Obscured Star Formation

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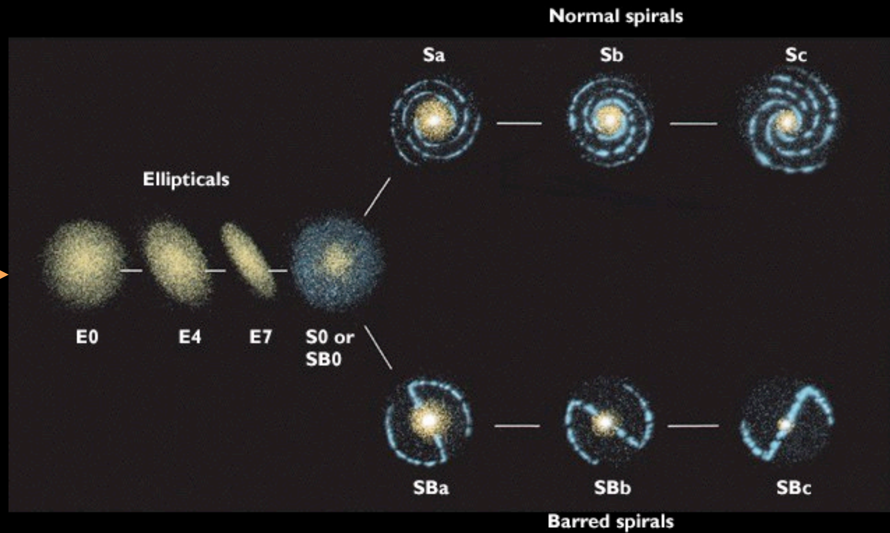
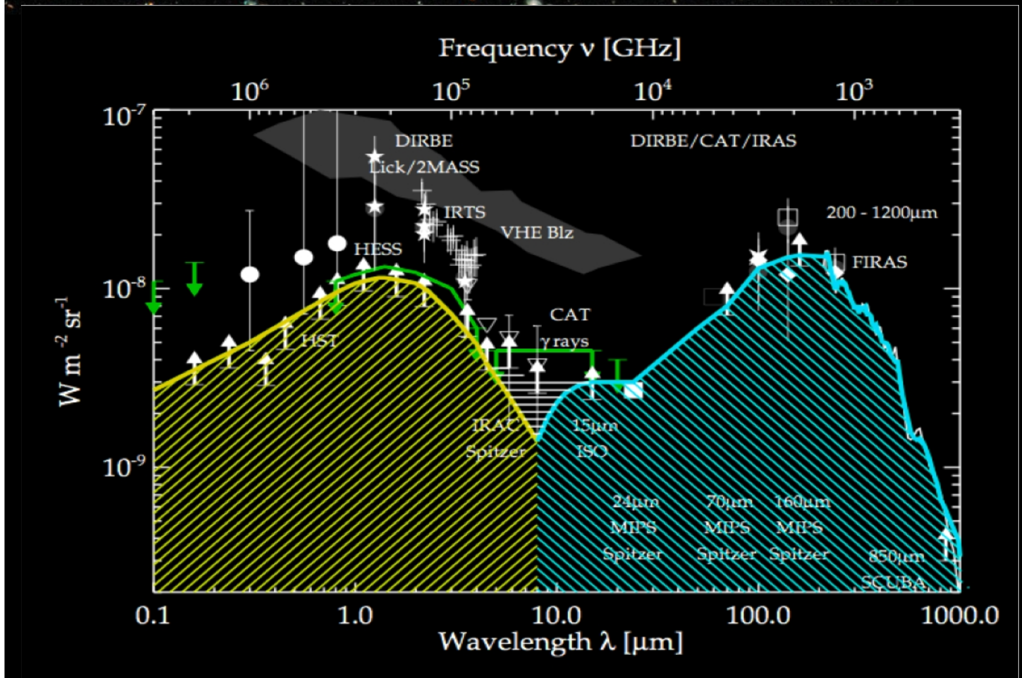
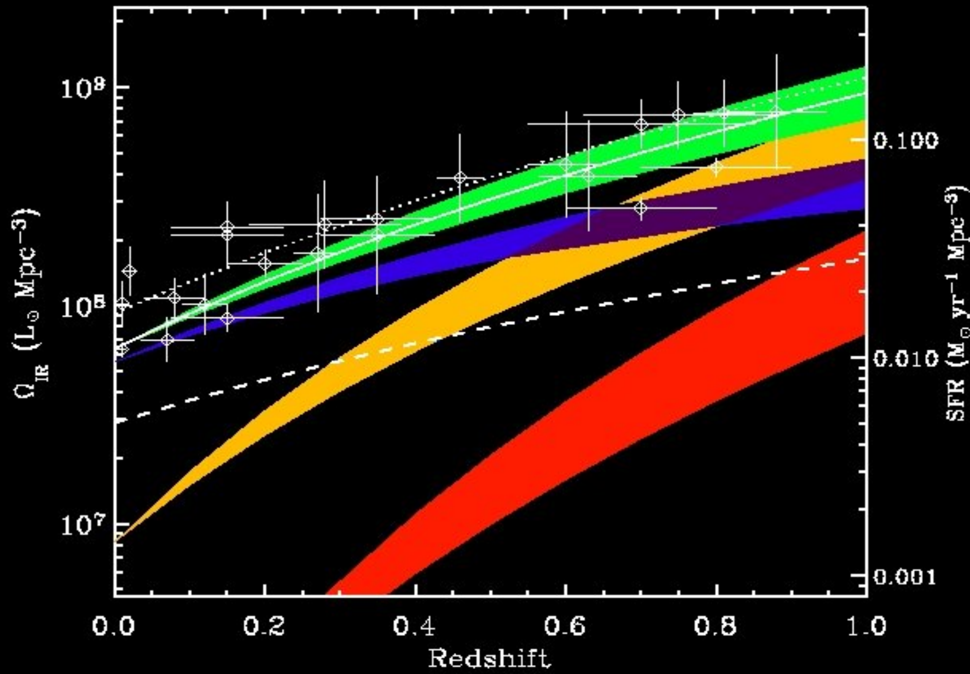
"Through The Infrared Looking Glass"
Pasadena, October 2011

The Assembly History of Galaxies







Difficulties

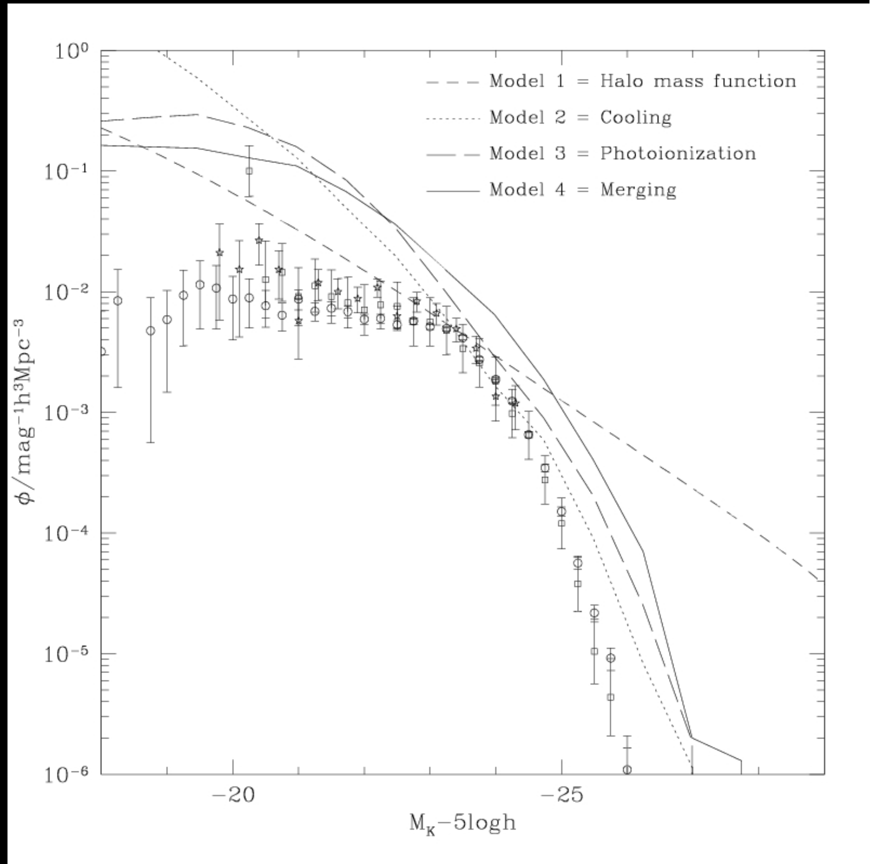
Early models struggled to explain observations

Low-z & high-z galaxy mass functions are hard to fit simultaneously

High-z IR-luminous galaxies are more numerous than predicted

SMBHs are observed to be less massive than predicted

There are fewer cooling flows in clusters than predicted



The local K band Luminosity Function, and early attempts to model it (Benson et al 2003)

One Solution - AGN Feedback

Radiation **AND/OR** Matter

Heat ISM gas

Heat IGM gas

Expel ISM gas

Inhibit IGM gas accretion

Secondary effects

Condense all that into

Quasar Mode

Brief

Intense

Radiation from accretion disk

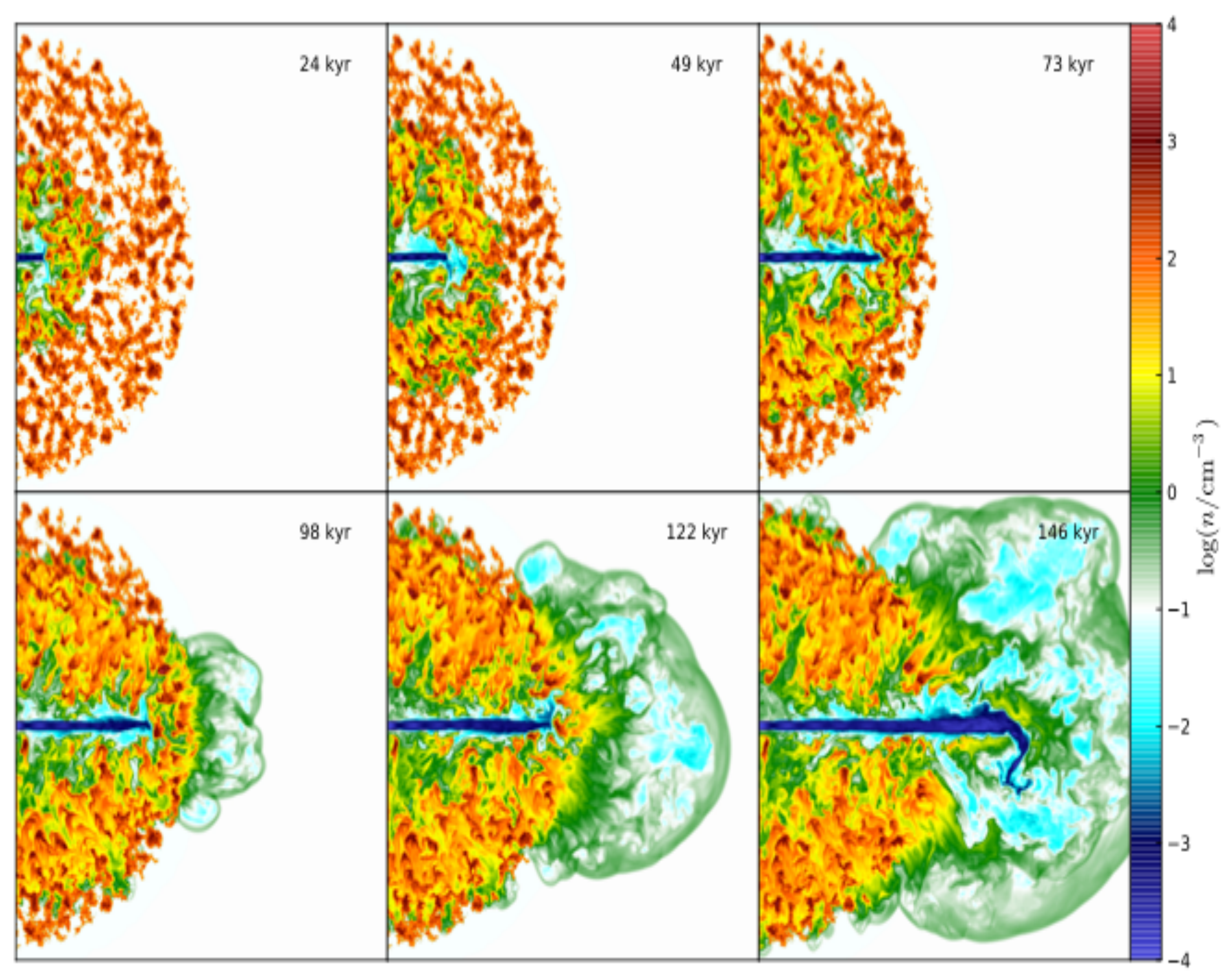
Radio mode

Longer

Less intense

Radio jet

Example I: An AGN powered Jet



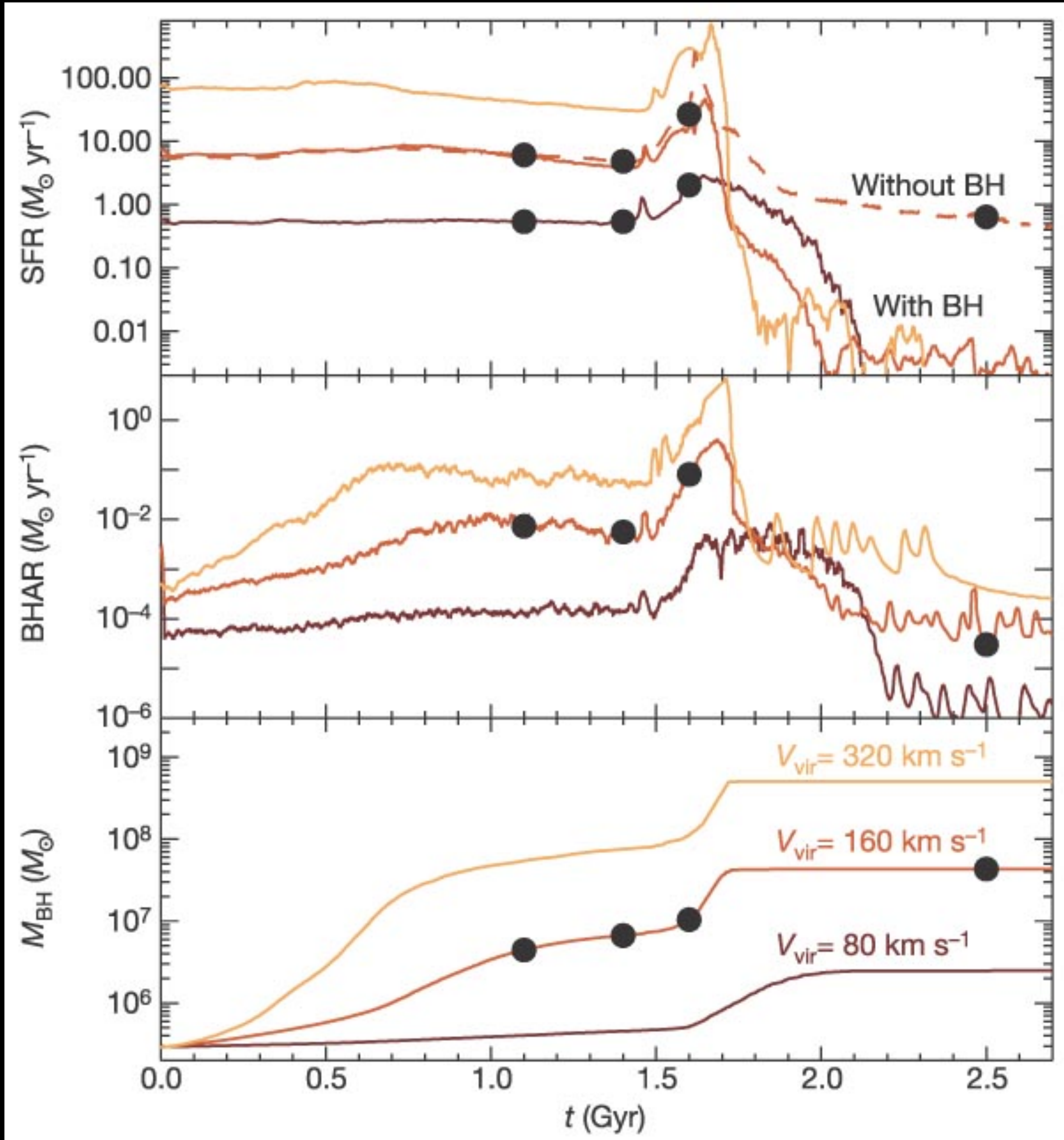
Wagner & Bicknell 2011

- high pressure bubble driven into ISM
- Relativistic jet disperses dense gas and so inhibits star formation
- <200,000 year timescales

Example II: 'Quasar' feedback in a merger

Di Matteo et al 2005

- Couple some fraction of the QSO luminosity to kinetic energy injected into ISM
- Inhibits peak starburst luminosity
- Turns off star formation early



Observing Feedback

Cannot be seen `in the act', timescales are too long

- Infer from the relic properties of quiescent galaxies

- Look for evidence that an outflow has the required properties

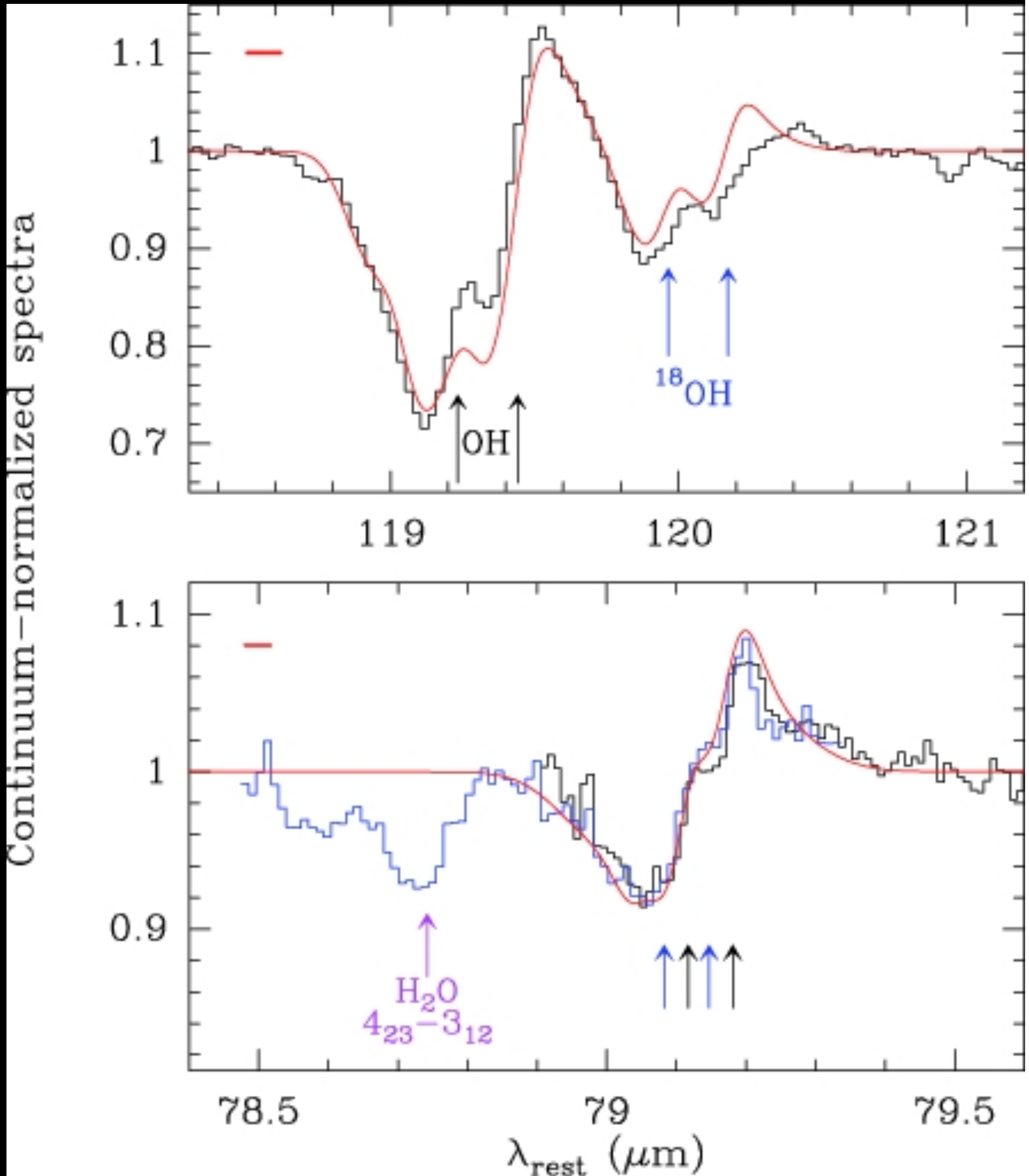
- Show that an existing outflow may have caused a relic effect

- Observe outflows and star formation together and see if their properties are consistent with affecting each other

Example: Emptying a galaxy of fuel

Fischer et al 2010

- Massive molecular outflow seen in OH-
- ~1400km s^{-1}, several 10^7 solar masses
- Mass/velocity implies removing all fuel for further star formation in <1Gyr



Our Work – FeLoBAL QSOs

FeLoBAL QSOs have the following properties:

- Broad, deep absorption lines in the rest-frame UV
- Always reddened, and often IR-luminous (`ULIRG' level)
- Sometimes host intense starbursts

AGN-driven outflows and (sometimes) high star formation rates *in the same objects*

Approach:

- 31 FeLoBAL QSOs at $0.8<z<1.8$
- Optical spectroscopy (usually SDSS) to constrain outflow properties
- Optical to infrared photometry (2MASS/UKIDSS+WISE+Spitzer) to constrain AGN & starburst IR luminosities

Compare outflow strengths with the infrared luminosities to assess the role of outfows in terminating star formation

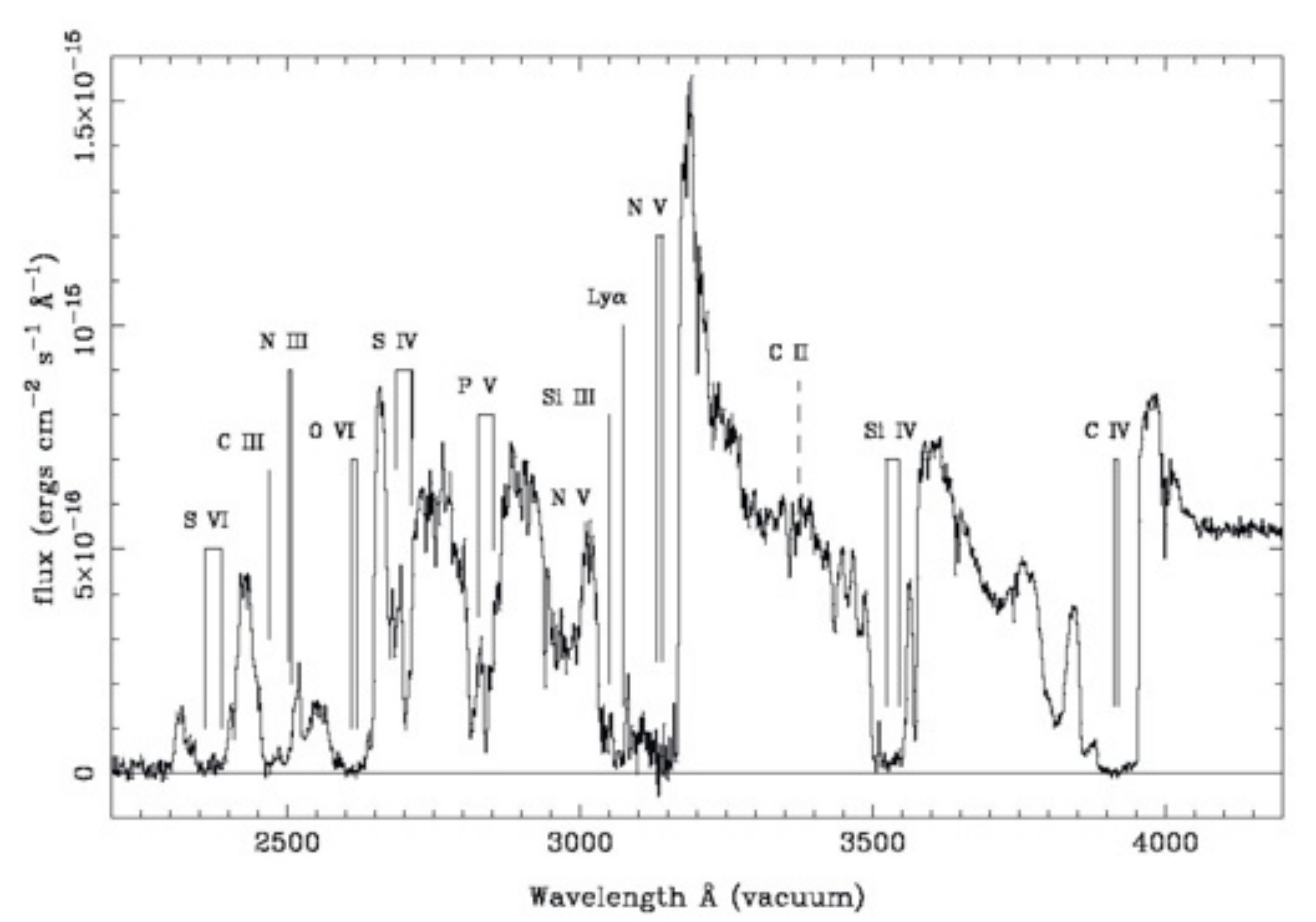
Outflow strengths

Optical spectra are mostly low S/N SDSS spectra

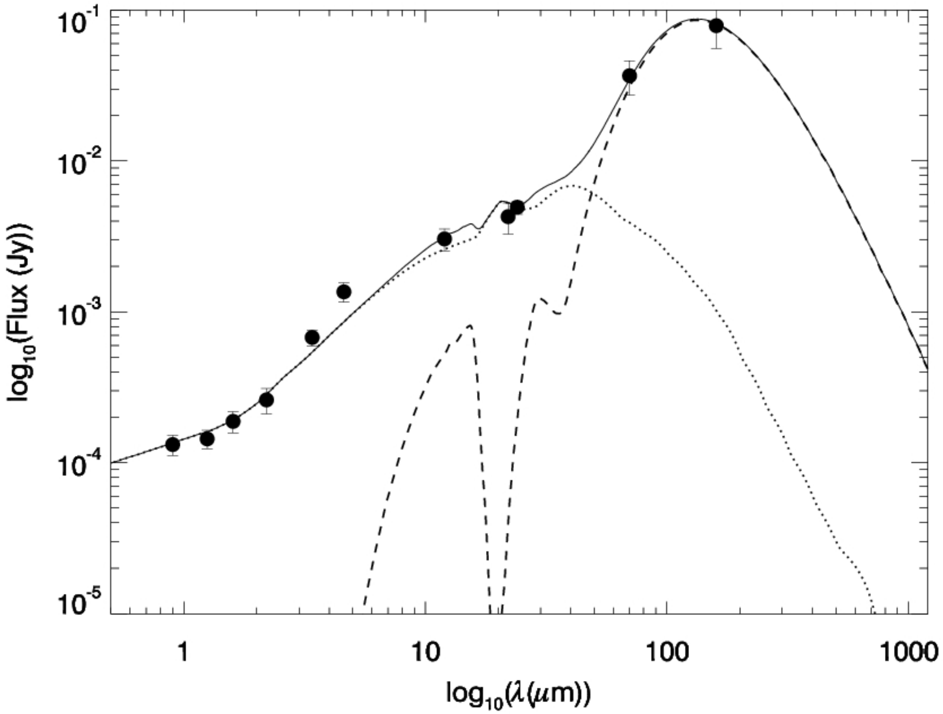
Impossible to quantify KE injected into the ISM

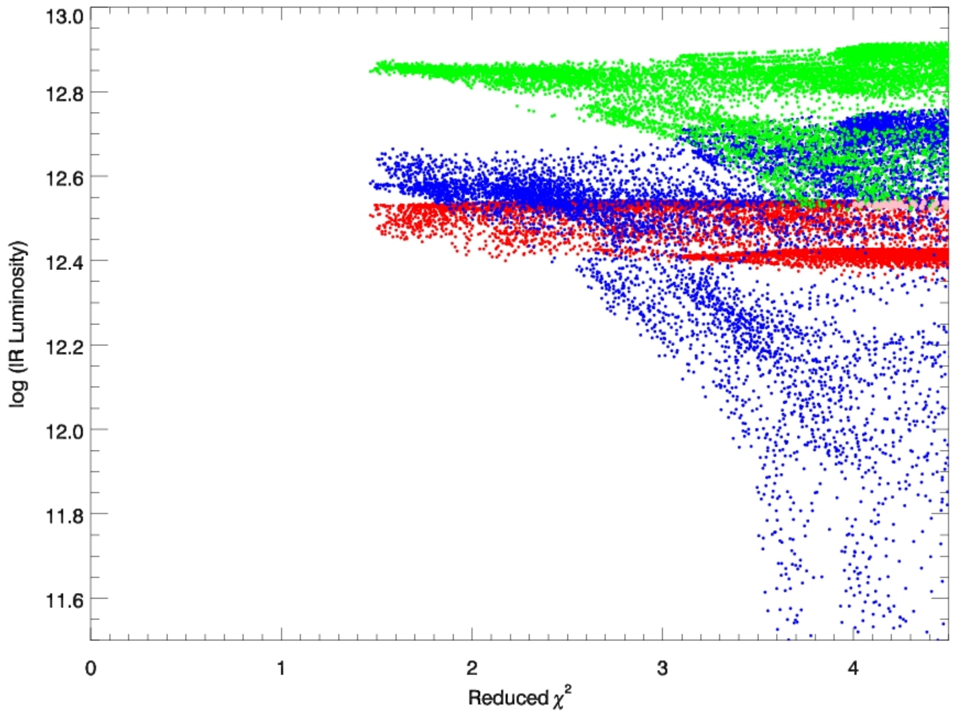
So, take one species (MgII) and measure the `BALnicity Index' (the velocity range over which the absorption exceeds 10% of the continuum level)

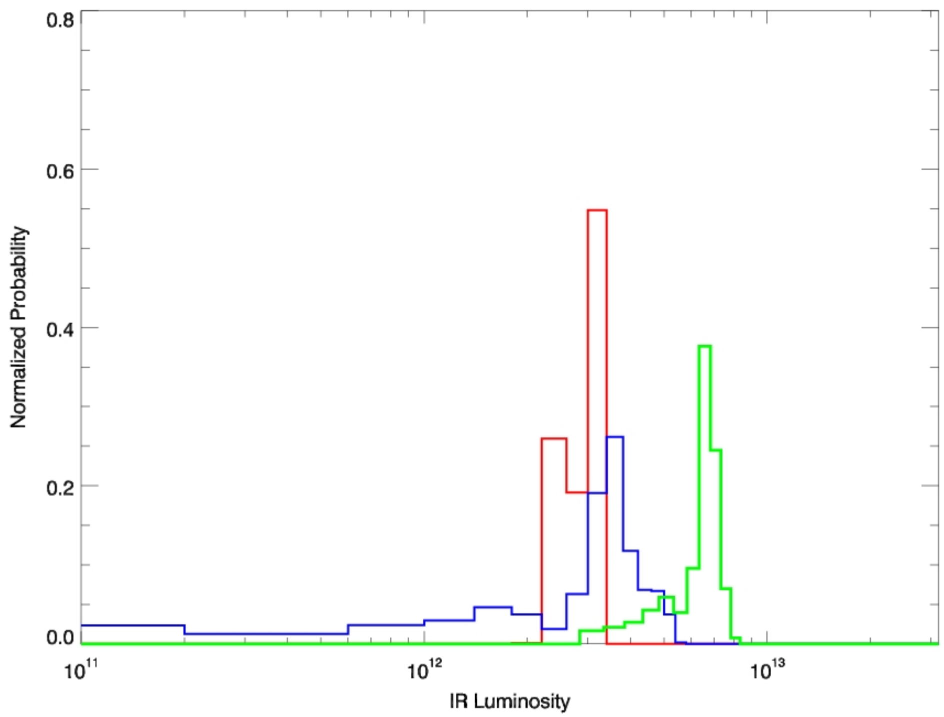
Even then, derived strengths are sensitive to the choice of continuum



Starburst/AGN Luminosities







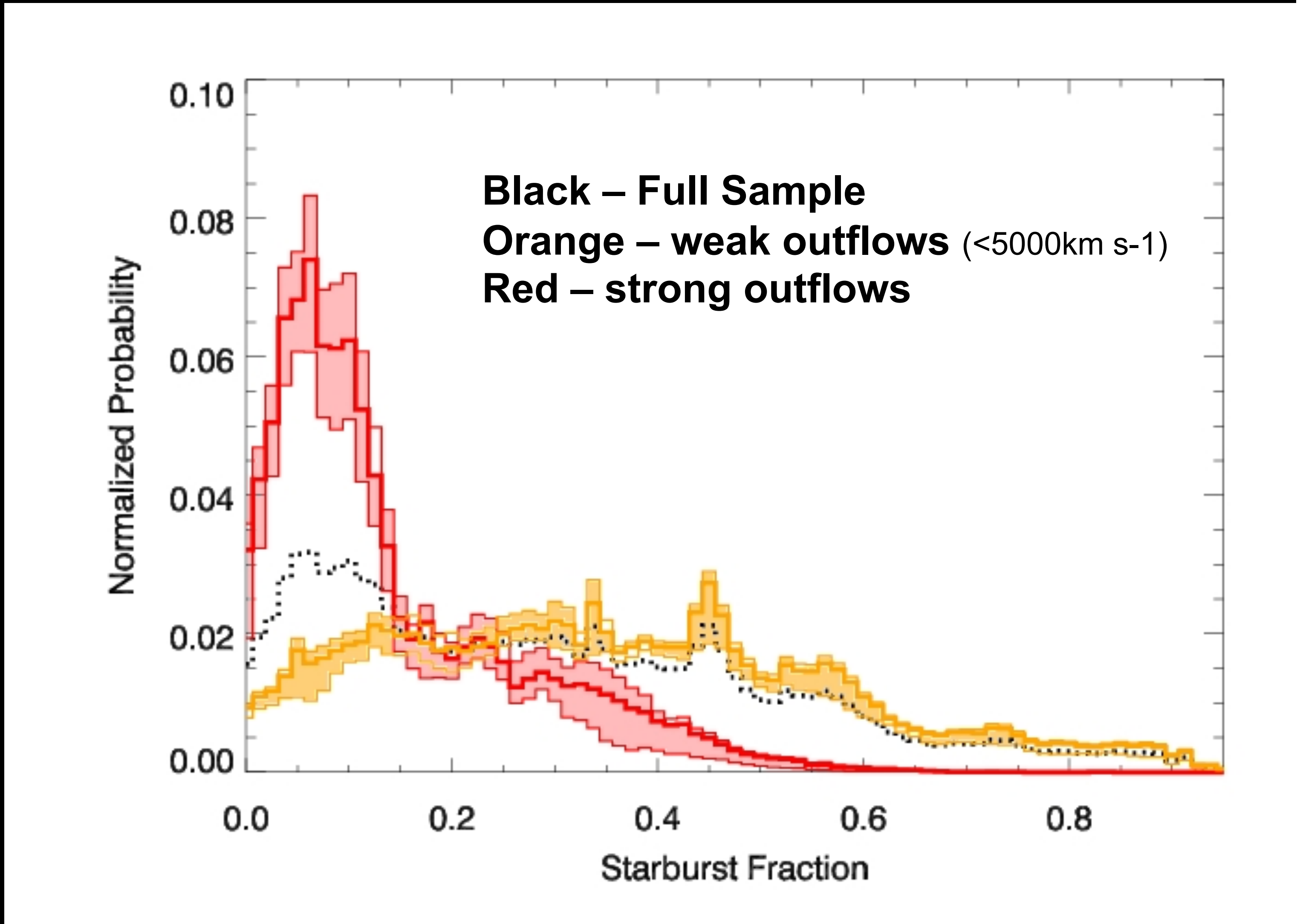
Farrah et al 2011, ApJ submitted

Starburst Contribution – by Outflow Strength

All Objects:
$P(F_{Sb}>0.25)$: 51% +/- 5%
$P(F_{Sb}>0.50)$: 18% +/- 2%

Weak Outflows:
$P(F_{Sb}>0.25)$: 63% +/- 4%
$P(F_{Sb}>0.50)$: 24% +/- 3%

Strong Outflows:
$P(F_{Sb}>0.25)$: 18% +/- 5%
$P(F_{Sb}>0.50)$: <2%



Weak Outflows means a greater chance of seeing a large starburst contribution than strong outflows

What could cause this?

There are five possible causes:

1 – The AGN-driven outflow inhibits star formation

2 – The star formation inhibits the AGN-driven outflow

3 – Observation bias: strong starbursts cause Mg II troughs to *appear* weak

4 – Selection bias: QSOs with strong Mg II absorption and strong starbursts drop out of the SDSS QSO selection

5 - The outflow strength correlates with the *Infrared* luminosity of the AGN, with no effect on the starburst

Feedback!

Not likely?

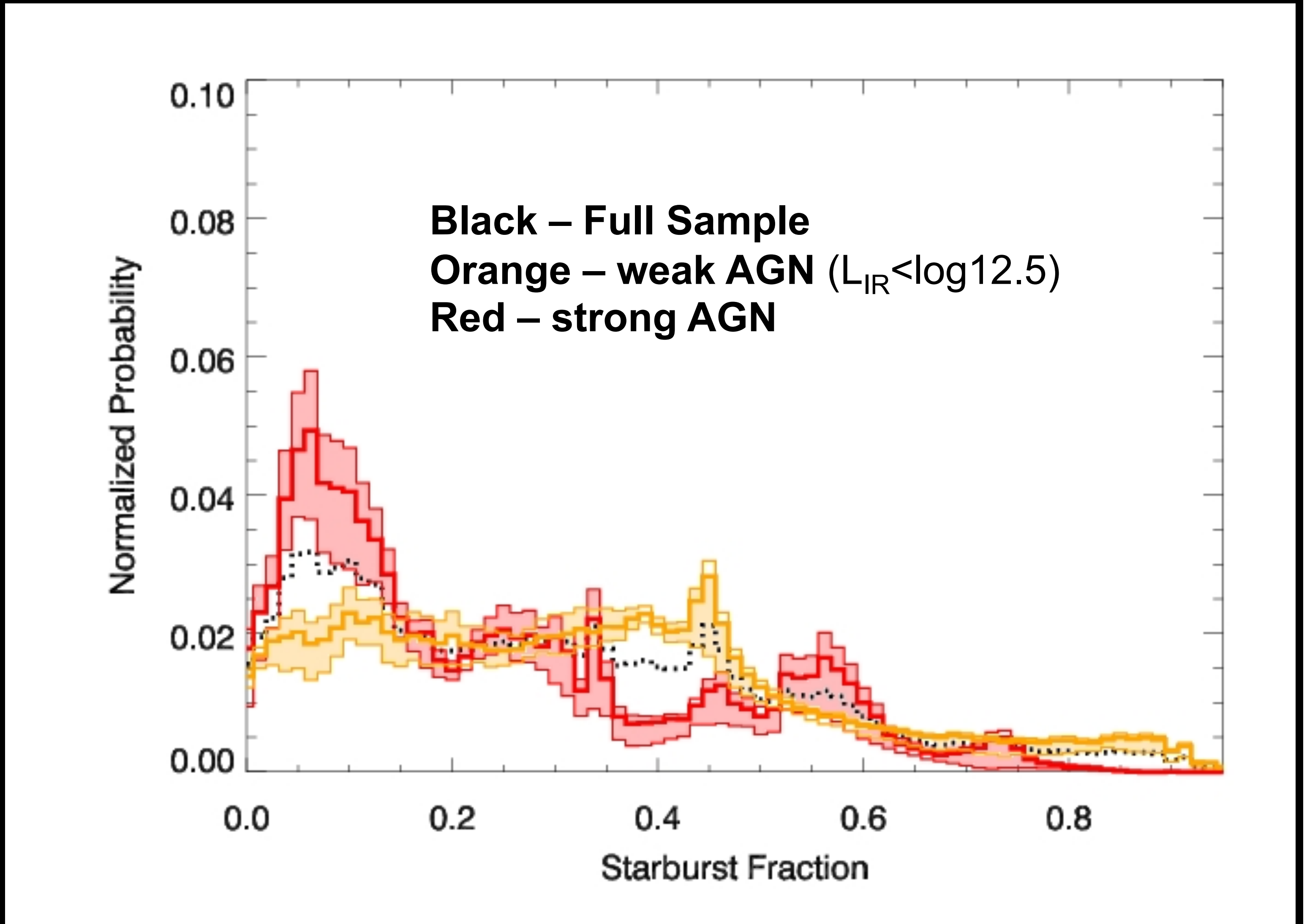
In principle very possible

Starburst Contribution - by AGN luminosity

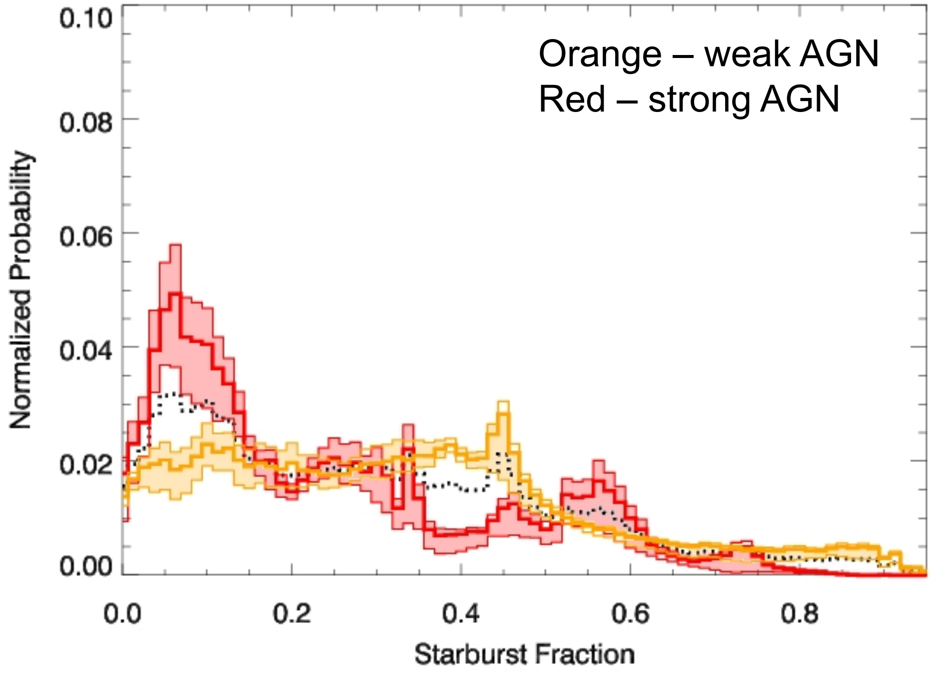
All Objects:
$P(F_{Sb}>0.25)$: 51% +/- 5%
$P(F_{Sb}>0.50)$: 18% +/- 2%

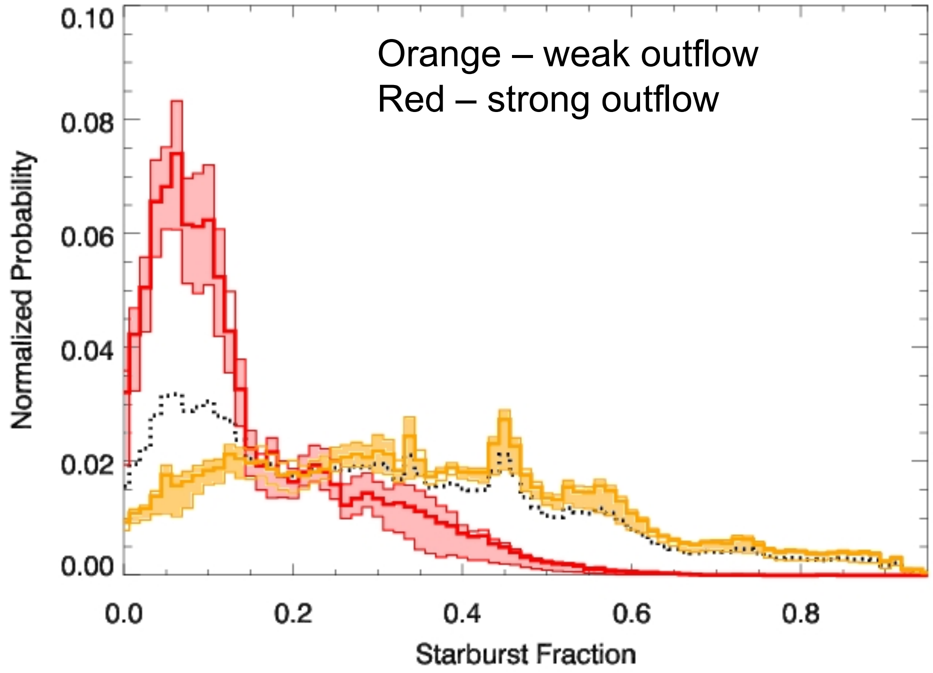
Faint AGN:
$P(F_{Sb}>0.25)$: 59% +/- 5%
$P(F_{Sb}>0.50)$: 13% +/- 2%

Bright AGN:
$P(F_{Sb}>0.25)$: 40% +/- 8%
$P(F_{Sb}>0.50)$: 20% +/- 5%



Weak AGN means at be best a marginally greater (or possibly a lesser) chance of seeing a large starburst contribution than a strong AGN





P(Starburst) > 25%

Weak Outflows: 63% +/- 4%
Strong Outflows: 18% +/- 5%
Big Difference

Weak AGN: 59% +/- 5%
Strong AGN: 40% +/- 8%
Marginal Difference

P(Starburst) > 50%

Weak Outflows: 24% +/- 3%
Strong Outflows: <2%
Big Difference

Weak AGN: 14% +/- 4%
Strong AGN: 20% +/- 5%
No Difference (& opposite!)

Based on observing radiatively driven outflows and obscured star formation in the same objects and comparing their properties, we propose:

Radiatively driven outflows from an AGN can act to dramatically curtail star formation in the host galaxy

The magnitude of this effect is (probably) NOT strongly related to the IR luminosity of the AGN

Future Work

Higher quality optical spectra – **Compare results from different species, construct quantitative outflow models, BAL variability?**

Far-infrared data – **Factor of 2-3 increase in accuracy on starburst luminosities, sensitivity to fainter starbursts.**

High resolution imaging – **Are the hosts interacting? How big are they? Smaller hosts = more effective feedback (since the outflow doesn't have to work as hard)?**

Different infrared models – **Explore sensitivity of results to choice of templates.**

Expand to LoBALs/increase sample size

Search for emerging radio jets

Conclusions

Models and observations of galaxy assembly with redshift face differences that are irreconcilable without invoking one or more `exotic' solutions

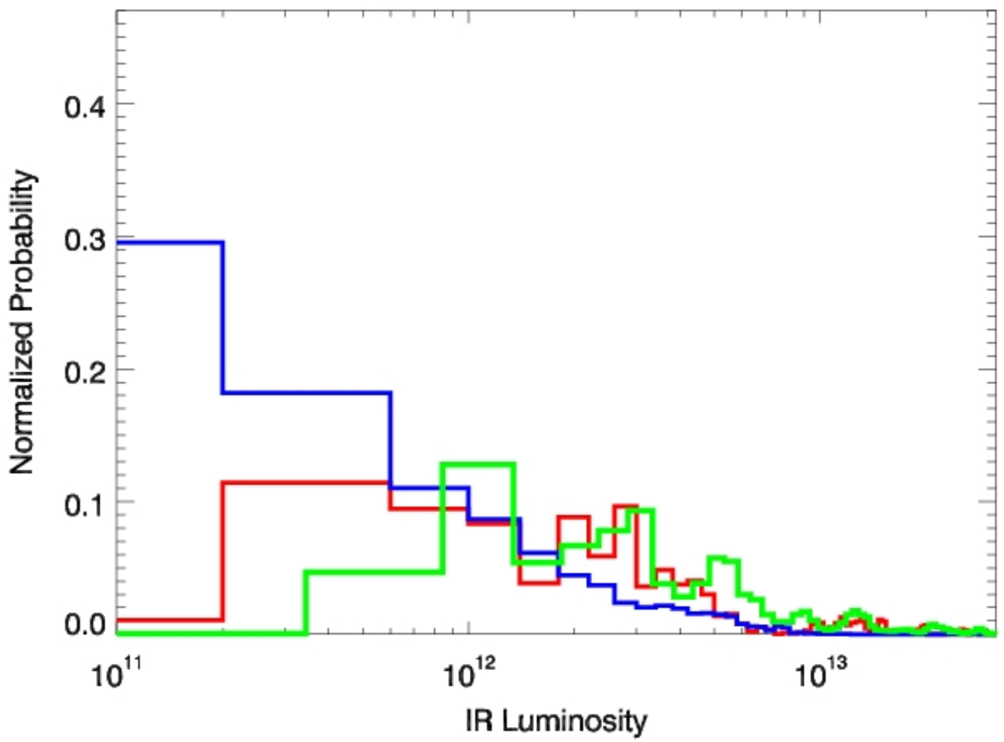
One of these solutions is AGN feedback, which involves a luminous AGN acting to drastically curtail star formation in the host galaxy, and empty it of fuel

Observational evidence for such feedback is difficult to obtain, and usually indirect

We have shown that starburst luminosity and AGN-driven wind strength anticorrelate in reddened, dusty QSOs, and that this anticorrelation is probably not driven by changes in the IR-luminosity of the AGN

This is good, though not conclusive evidence that radiatively driven outflows act to curtail star formation in their host galaxies

Summed PDFs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Normalized Probability
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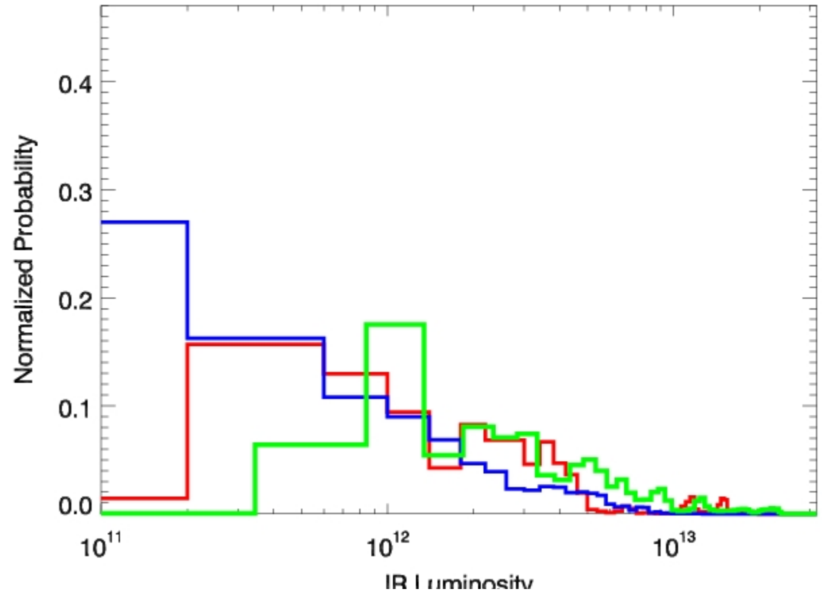
IR Luminosity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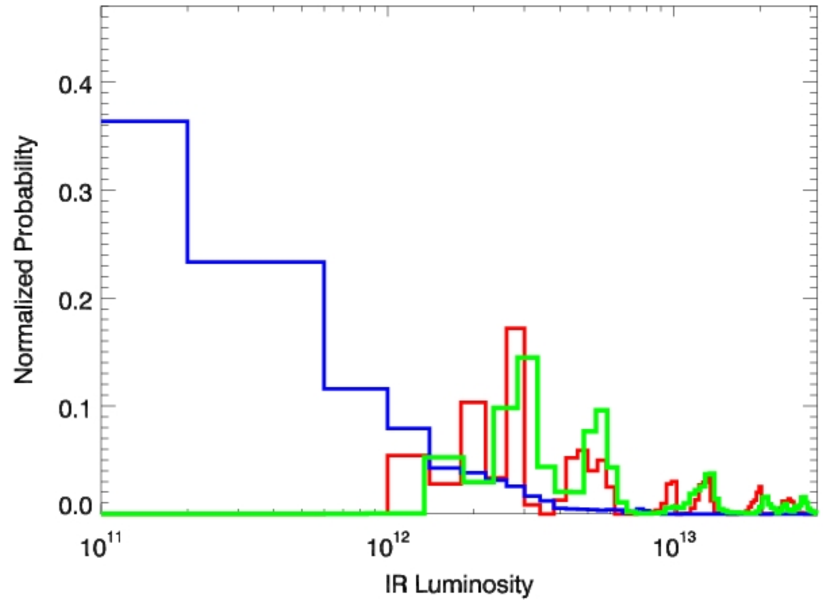
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0.3
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0.0
Normalized Probability
10^{11}
10^{12}
10^{13}
IR Luminosity

Example II: An obscured, line-driven outflow

Spoon et al 2009/Norris et al 2011

- Mid-IR fine structure lines reveal kinematics not seen in the optical

- Local ULIRGs show velocity offsets in different [Ne] lines

- Offsets and widths imply an energetic, radiatively driven outflow

- Can `trace' development of the outflow by looking at which lines show asymmetries

- Combine with radio interferometry to witness the birth of a jet?