Post-Starburst Galaxies: Tracers of Galaxy Evolution and the Unlikely Hosts of Tidal Disruption Events

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Why do galaxies stop forming stars?

Standard View (e.g. Hopkins+ 2006)

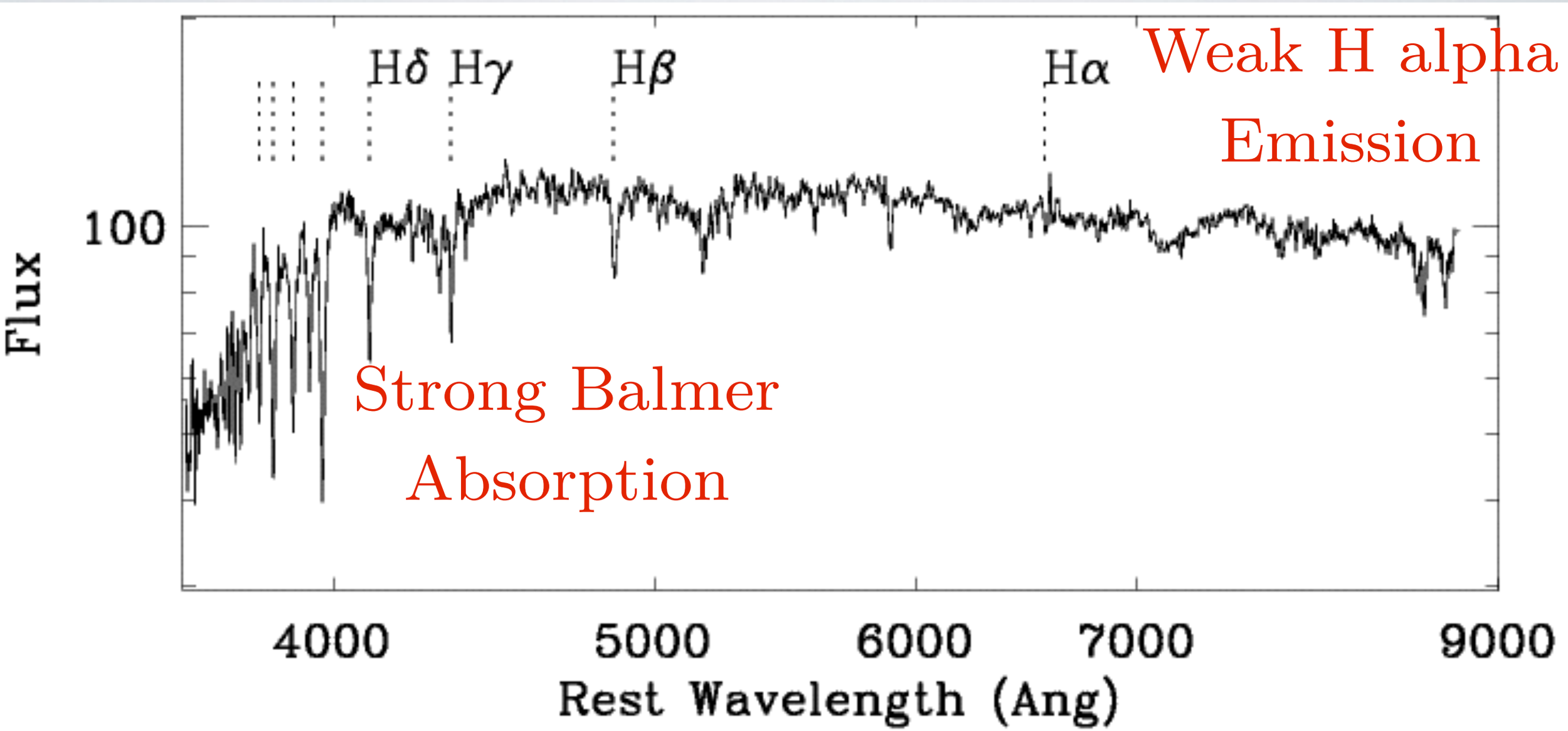
- Galaxy-galaxy merger
- Gas driven to center
- Fuels starburst
- Fuels AGN
- AGN/SF feedback expels remaining gas

Processes Imprinted on Post-Starbursts

Hopkins model predicts:

Post-Starburst, galaxies should have no remaining gas

Testing Grounds: Post-Starburst Galaxies



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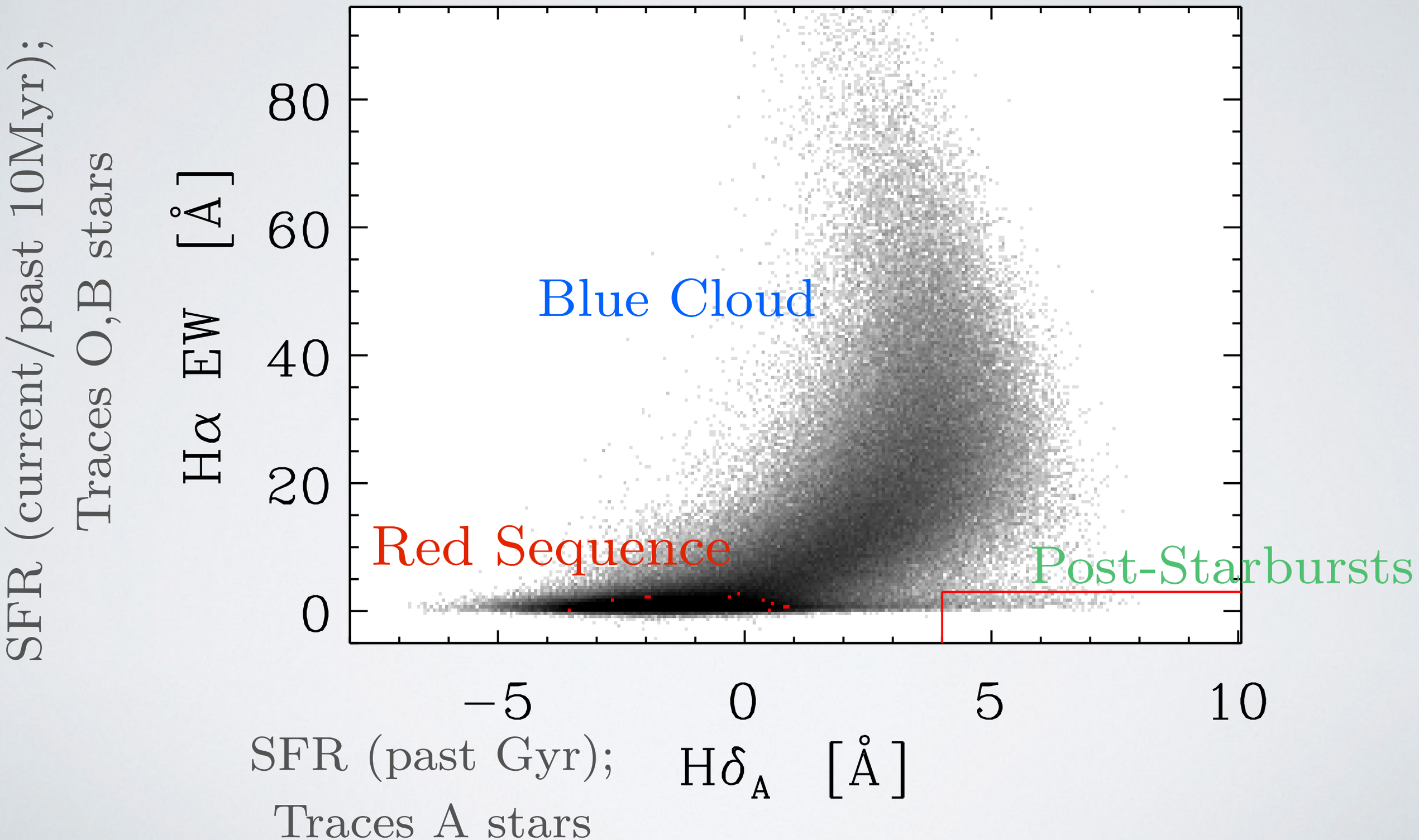


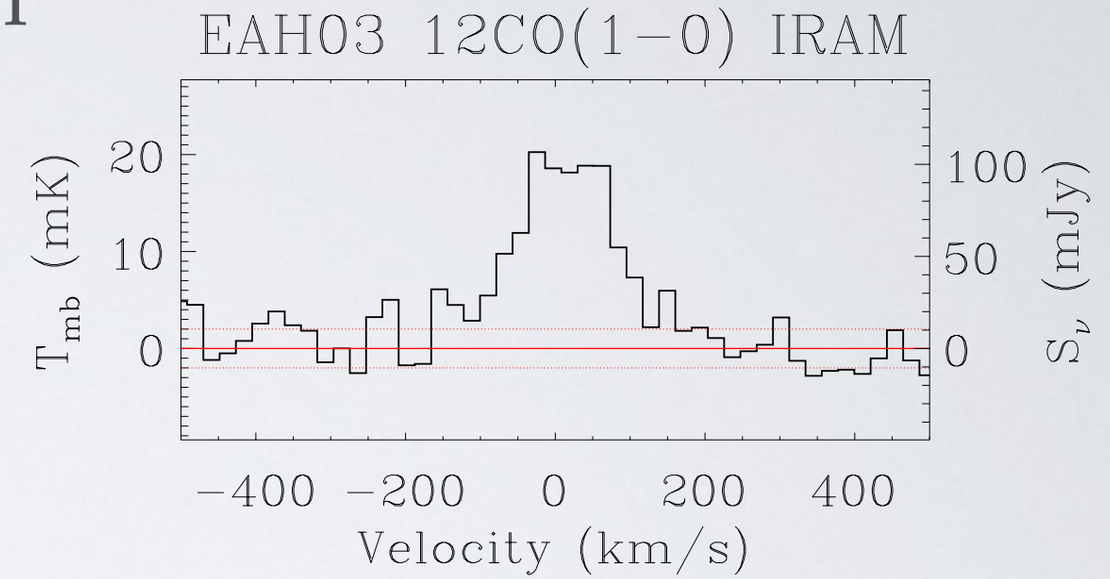
Why do galaxies stop forming stars?

- Gas used up in star formation?
- Gas ejected or removed from galaxy?
  - AGN feedback?
  - SF feedback?
- Gas dispersed within galaxy?
- Starvation?
- Gas heated?
- Morphological quenching? Other?

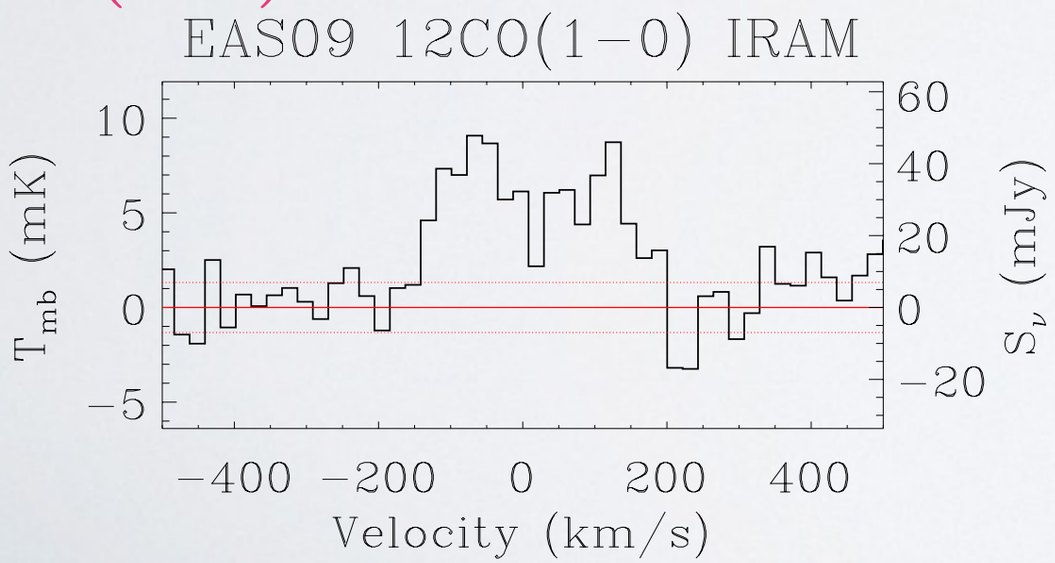
Test: Observe Molecular Gas, CO (1-0) and (2-1) using IRAM 30m and SMT 10m for 32 post-starburst galaxies

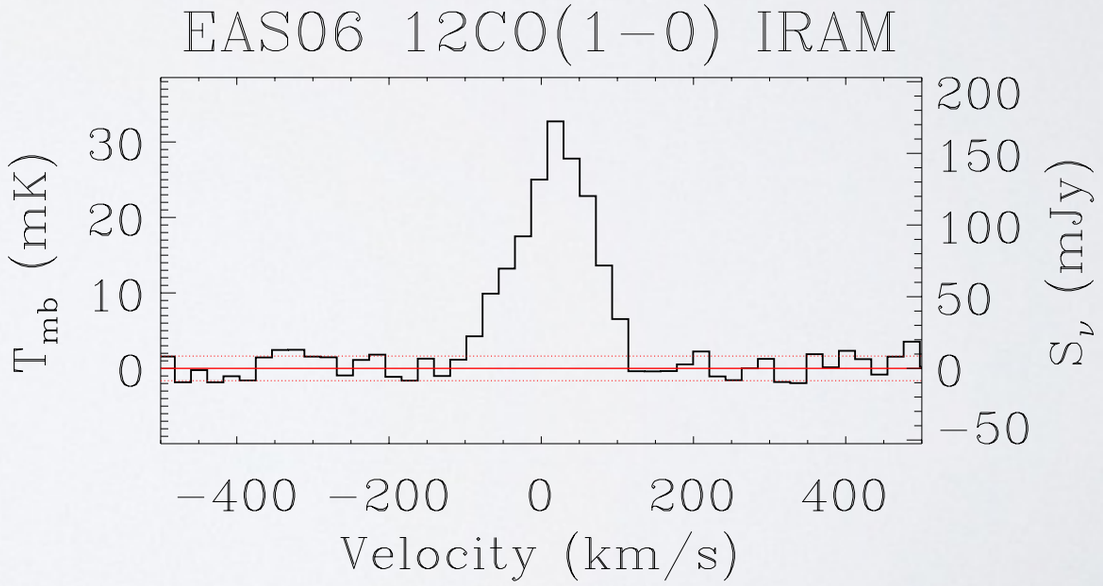
Detection of Molecular Gas

- 32 galaxies with IRAM 30m in CO (1-0) and CO (2-1)
- 13 galaxies with SMT 10m in CO (2-1)

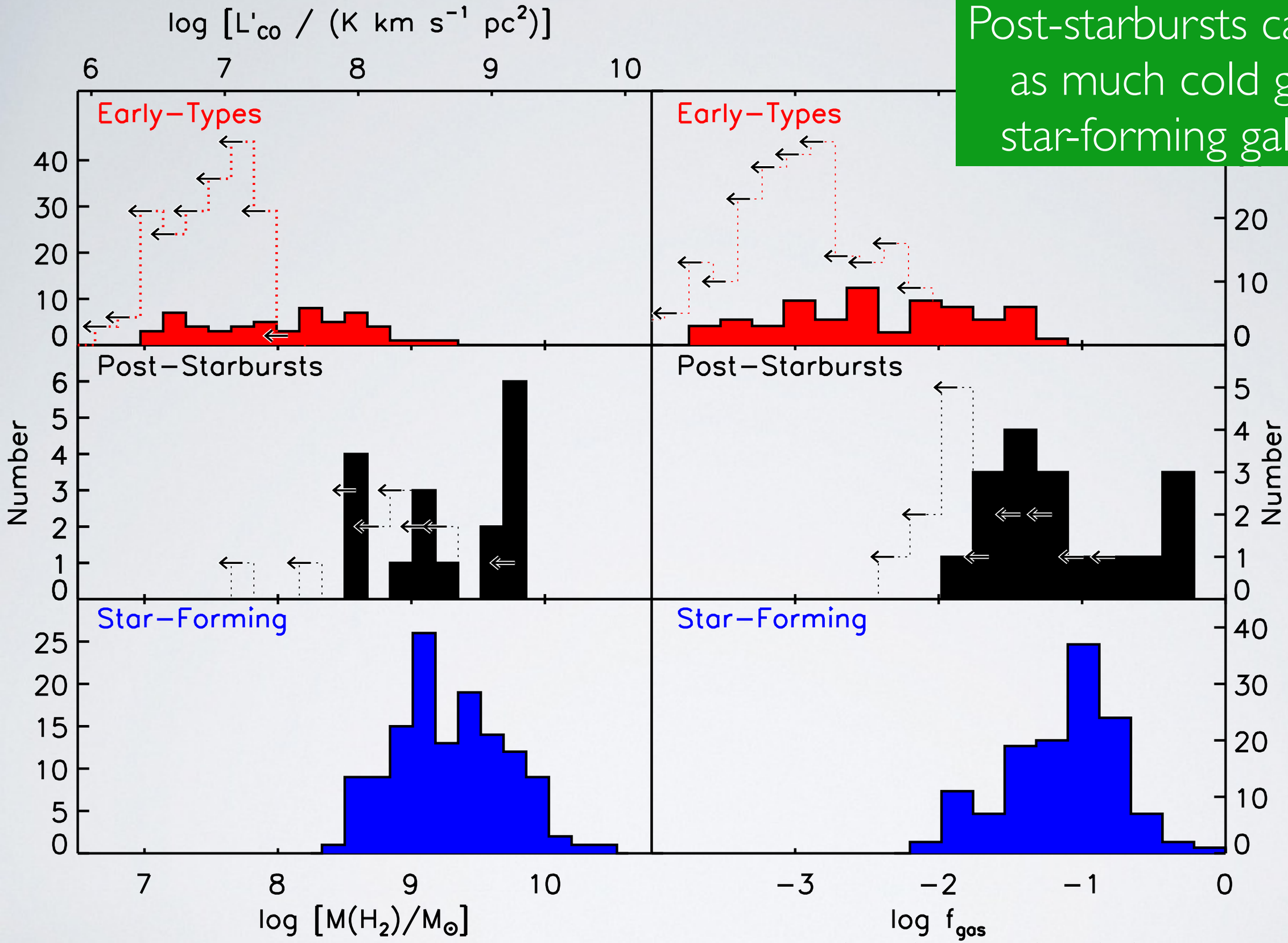


- Detect 17/32 galaxies in CO (1-0)





Post-starbursts can have as much cold gas as star-forming galaxies!



f(gas)= M(H2)/M★

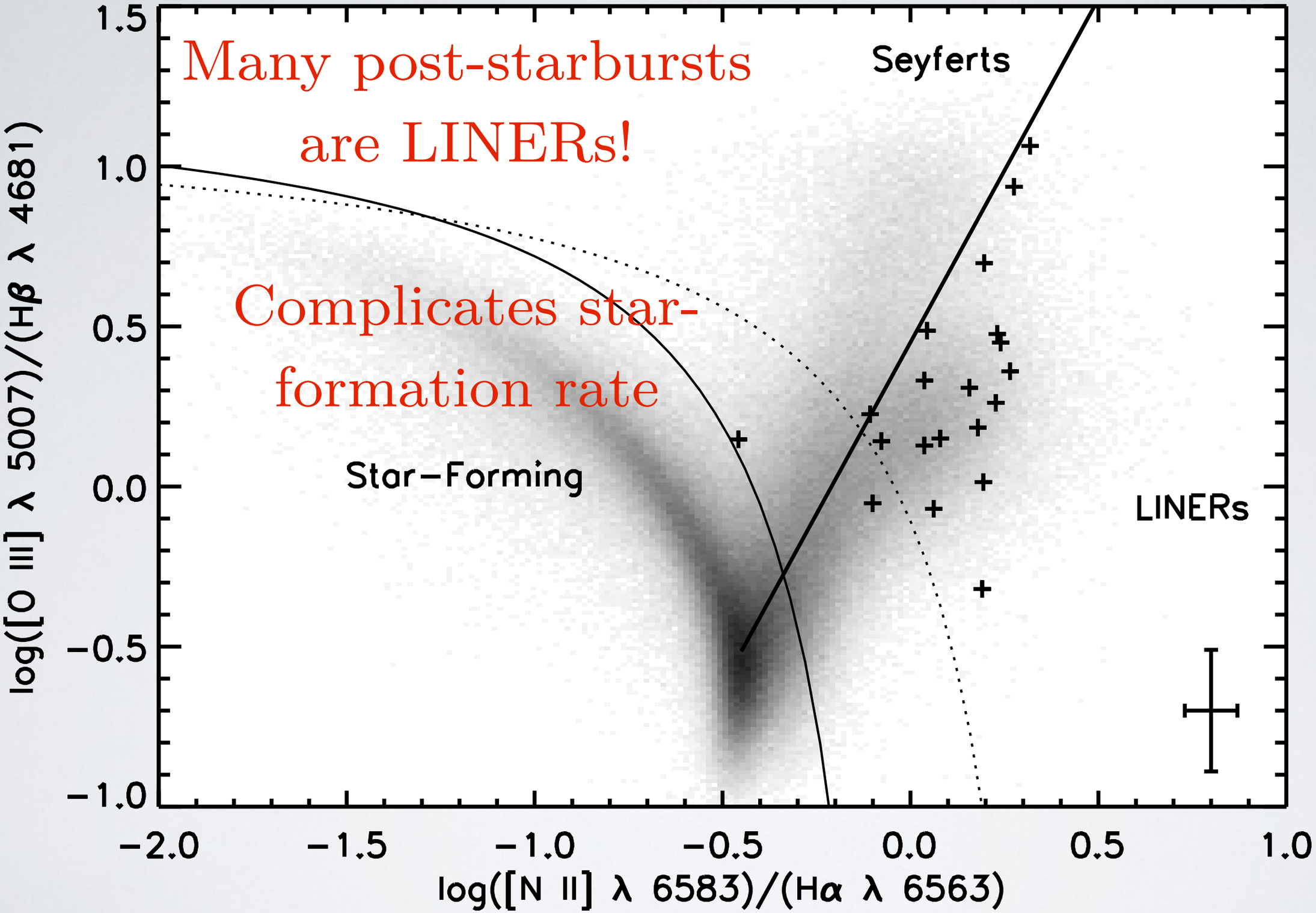
French+ 2015, SF and ETG data from: Young+ 2011, Saintonge+ 2011

Compare to Star Formation Rates

- But:
- Need short timescale indicator (<<100 Myr)
- Contribution from LINER

Many post-starbursts are LINERs!

Complicates star-formation rate

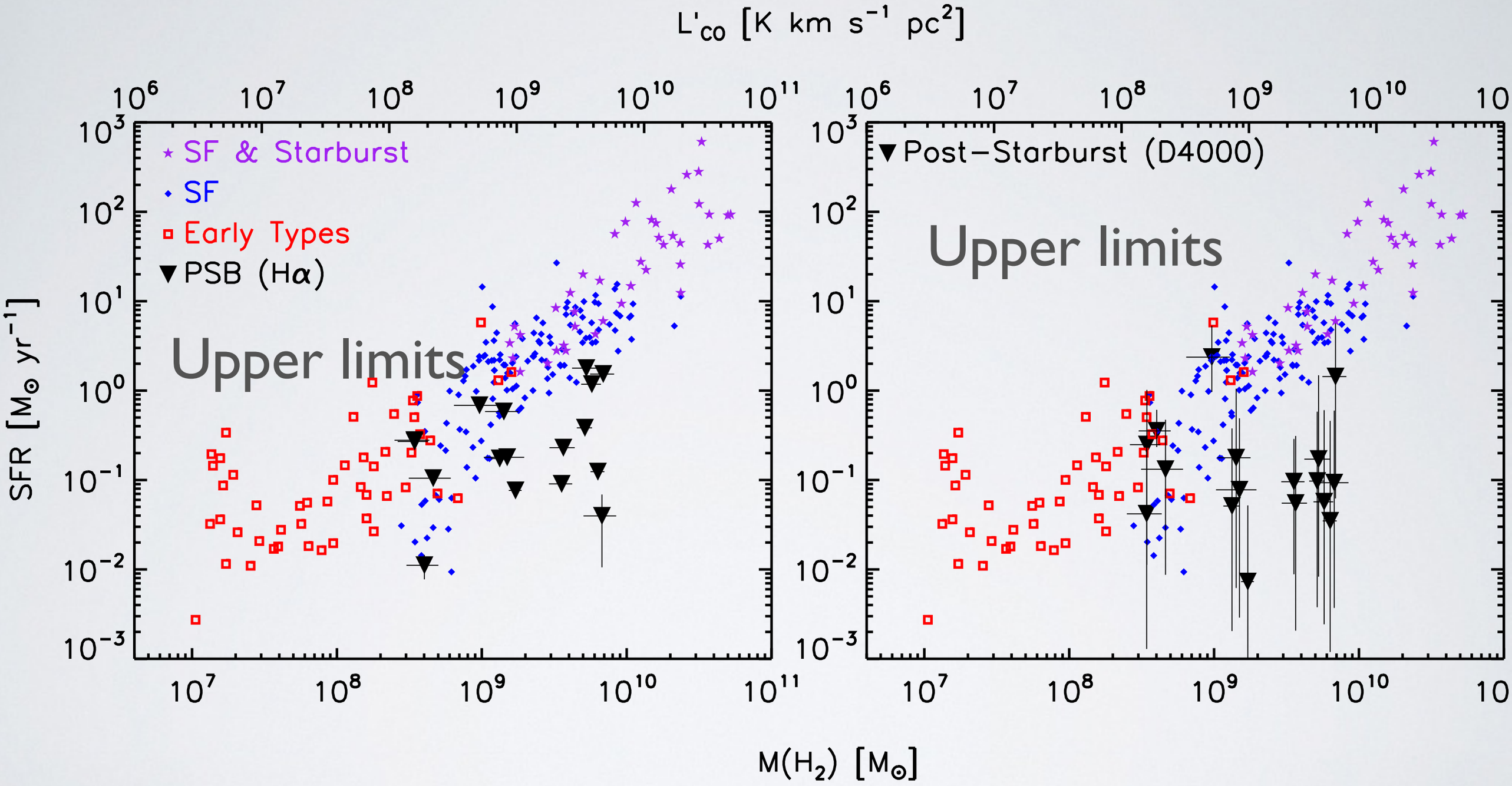


French+ 2015

Star-Formation-Rates

- H alpha (from SDSS) → Upper limit on SFR
  - Corrected for dust extinction, stellar continuum, fiber aperture but best estimate
  - But: contribution from LINER
- D(4000Å) break (from SDSS) → Upper limit on SFR
  - Used to avoid AGN contribution
  - But: affected by recent starburst
- 1.4GHz luminosity (from VLA FIRST) → Upper limit on SFR
  - Finds un-obscured SF
  - But: contribution from LINER- significant, with large scatter
- IR luminosities → Upper limit on SFR
  - large contribution from A stellar heating

Star-Formation-Rate vs. M(H2)



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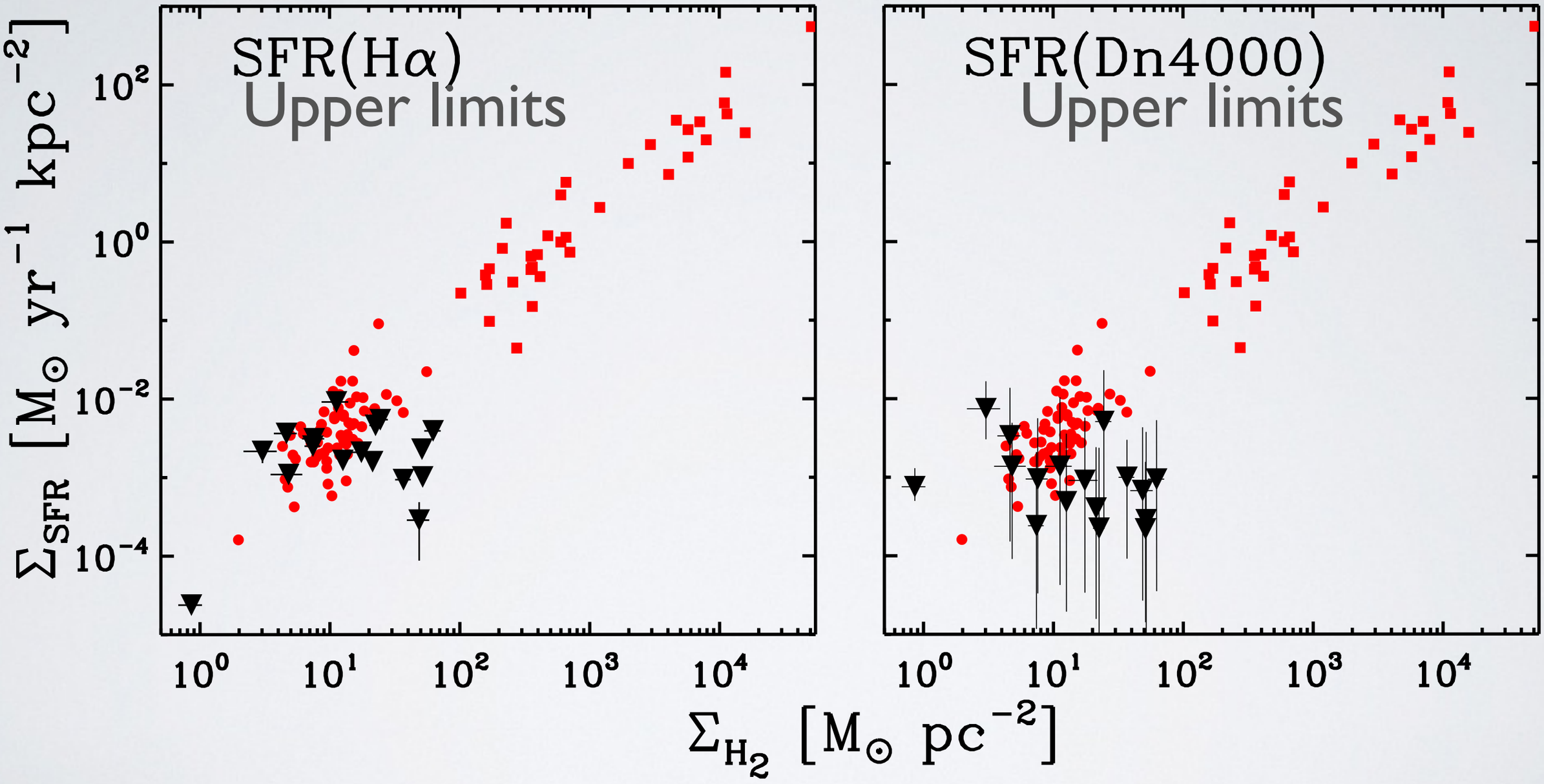
Molecular gas vs. star-formation rate surface densities



Kennicutt-Schmidt plot

French+ 2015, SF/SB data from Kennicutt 1998

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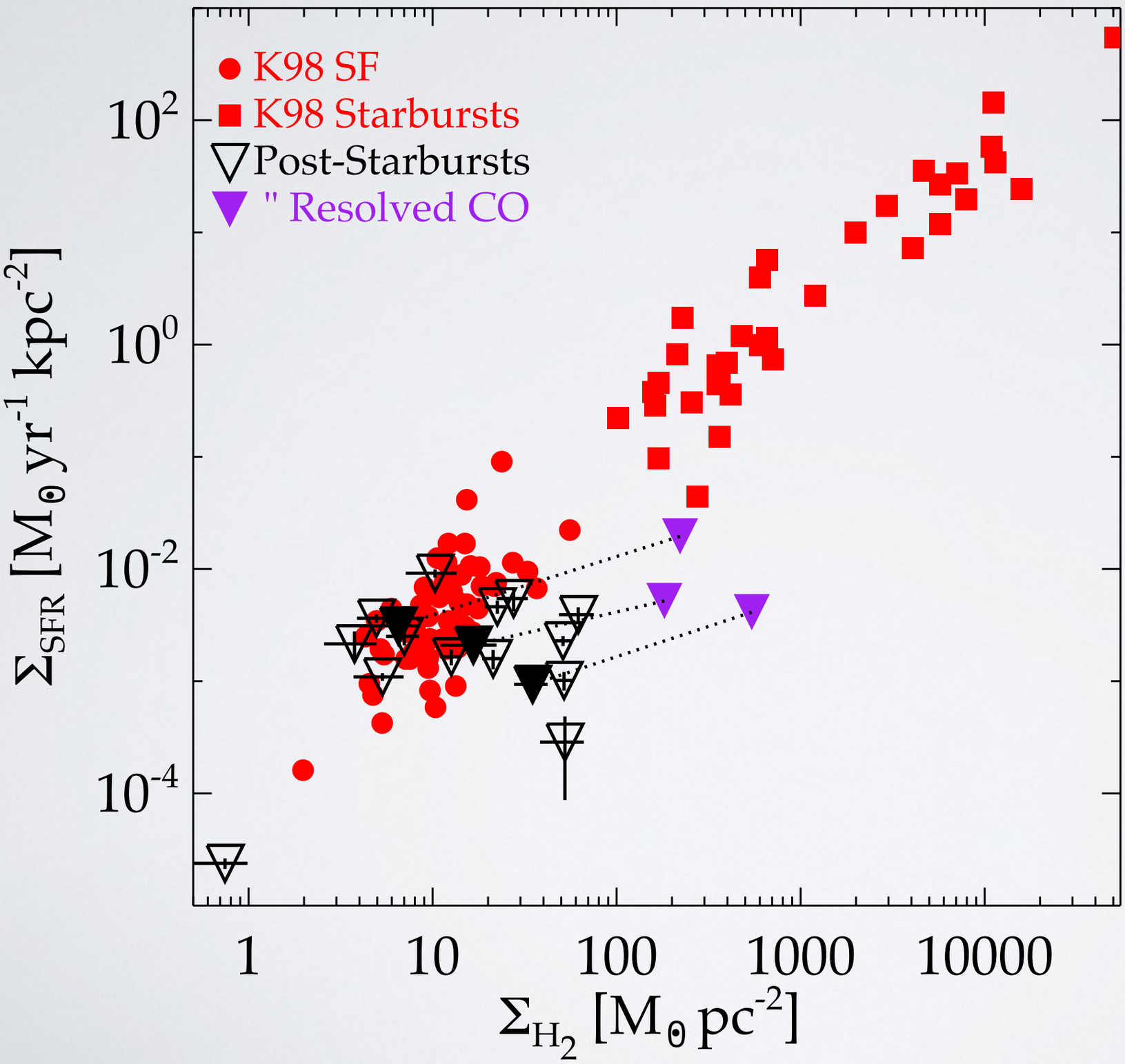

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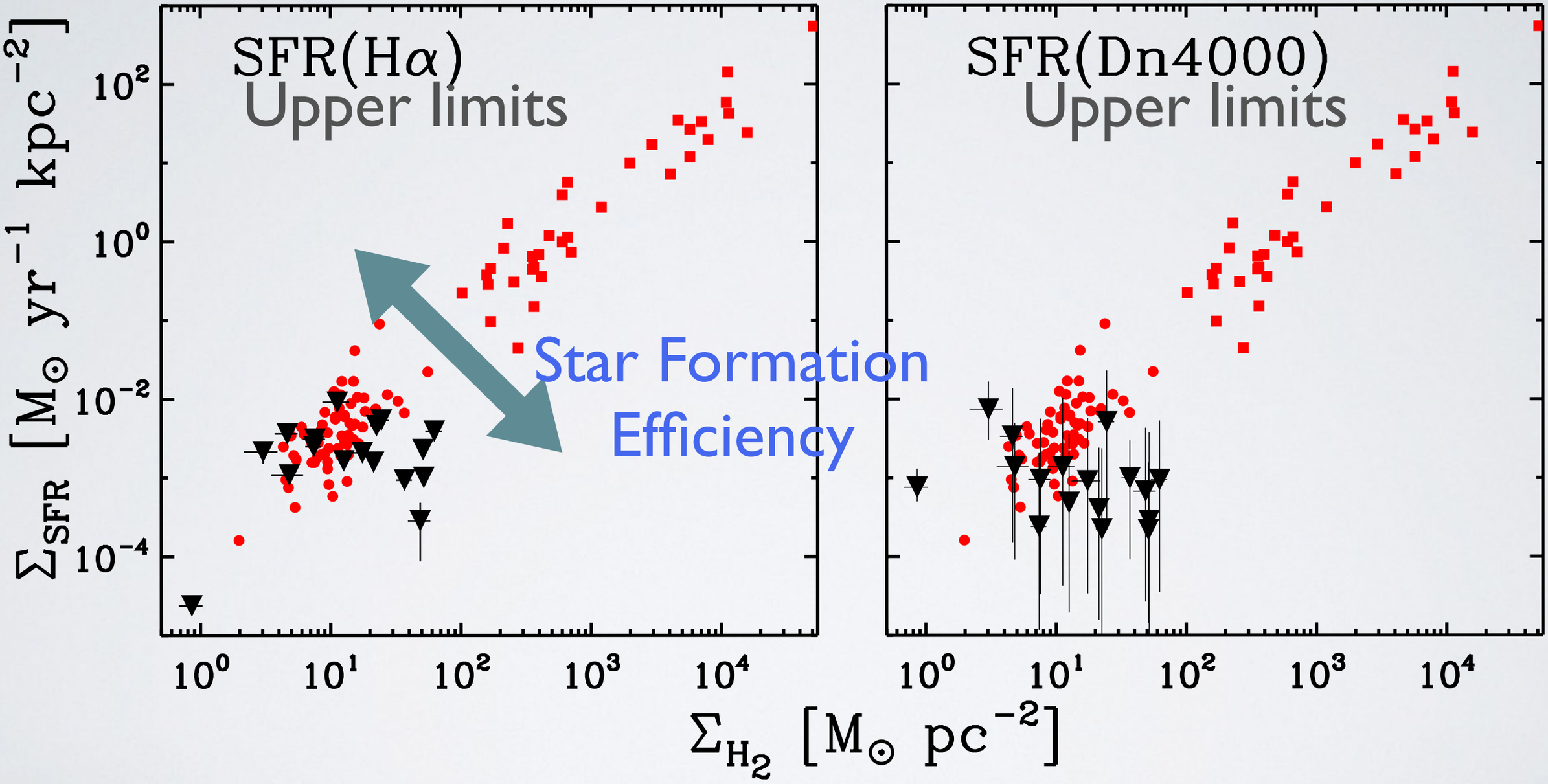

Kennicutt-Schmidt plot

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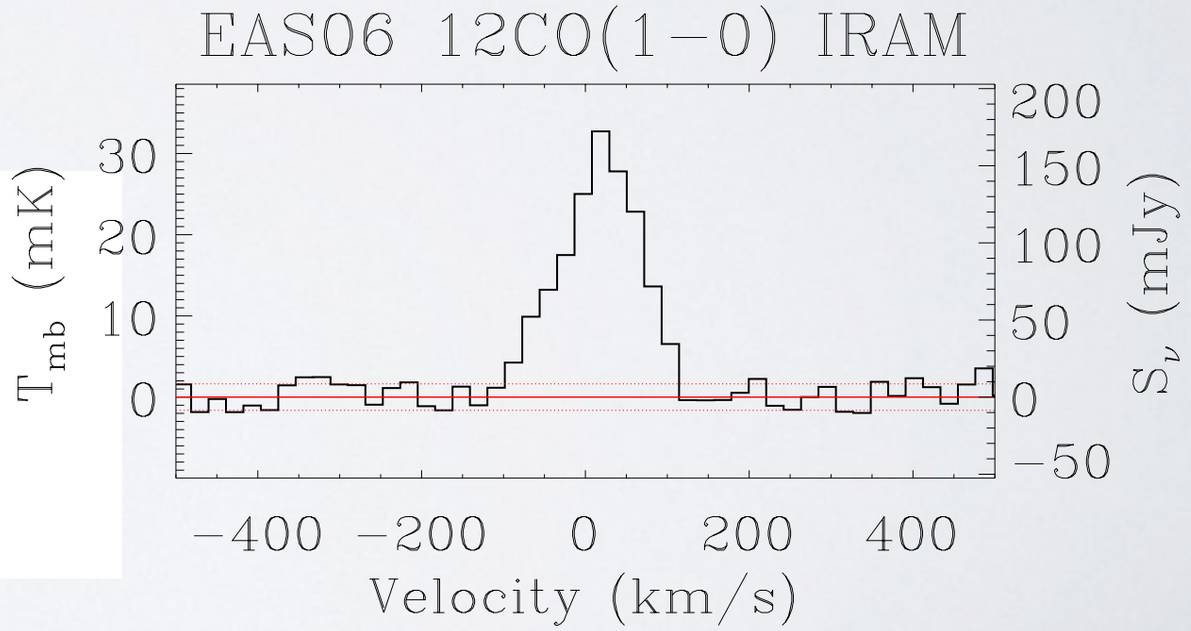
Why are post-starbursts offset?

- CO-to-H2 conversion factor α_{CO}

- α_{CO} =4 for Milky Way, α_{CO} =0.8 for ULIRGs

  - Temp (T), and velocity dispersion (sigma) higher, even though H_2 density also higher

$$\alpha_{CO} \propto \frac{N(H_2)}{I_{CO}} \propto \frac{N(H_2)}{T \times \sigma}$$



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- CO-to-H2 conversion factor α_{CO}
  - ULIRG type value can provide consistency, but: t(post-burst) > t(dyn)
- Stellar component not enough to lower α_{CO}

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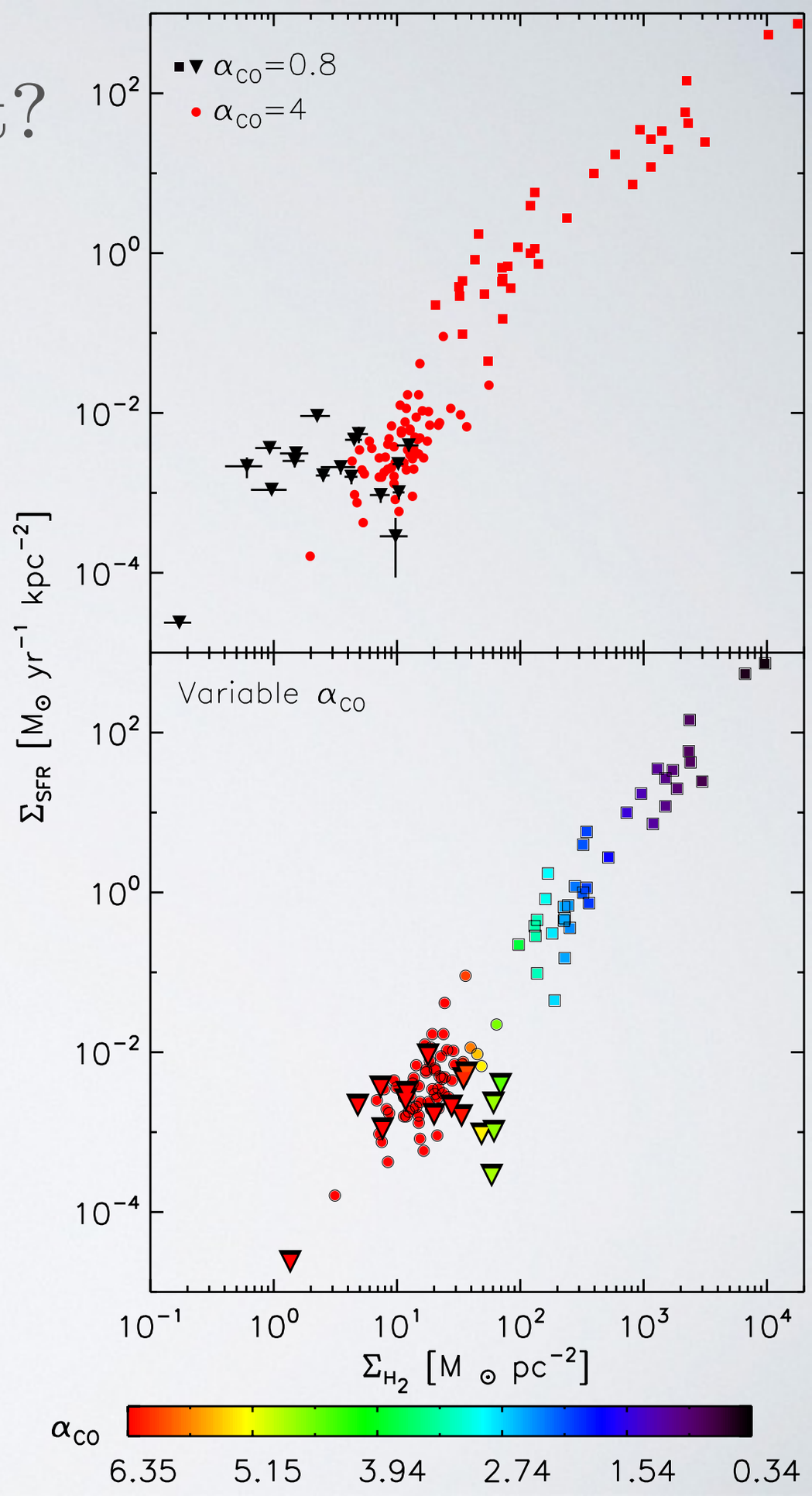

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  - But, distribution of SF regions largely unconstrained

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  - But, distribution of SF regions largely unconstrained
- Lowered star-formation efficiency? Bottom-heavy initial mass function?

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- Gas dispersed within galaxy?
  →KS offset observed, need spatial info
- Starvation? →No, large molecular gas reservoirs
- Gas heated?
  ? Something else must happen to the gas
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Next Steps

Something else must happen to the gas

- Denser gas tracers
- HCN

KS offset observed, need spatial info

- Resolved CO emission
- H alpha mapping to observe current SF

Study of dust, PAH properties using Spitzer, Herschel data:
Smercina, Smith et al (in prep)

Why do galaxies stop forming stars?

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What role do these play, when and where?

- Gas dispersed within galaxy?
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AGN Feedback in Post-Starburst Galaxies

- Growing evidence AGN activity peaks *after* post-starburst phase
  - Post-starbursts vs. post-starburst quasars (Cales+ 2015)
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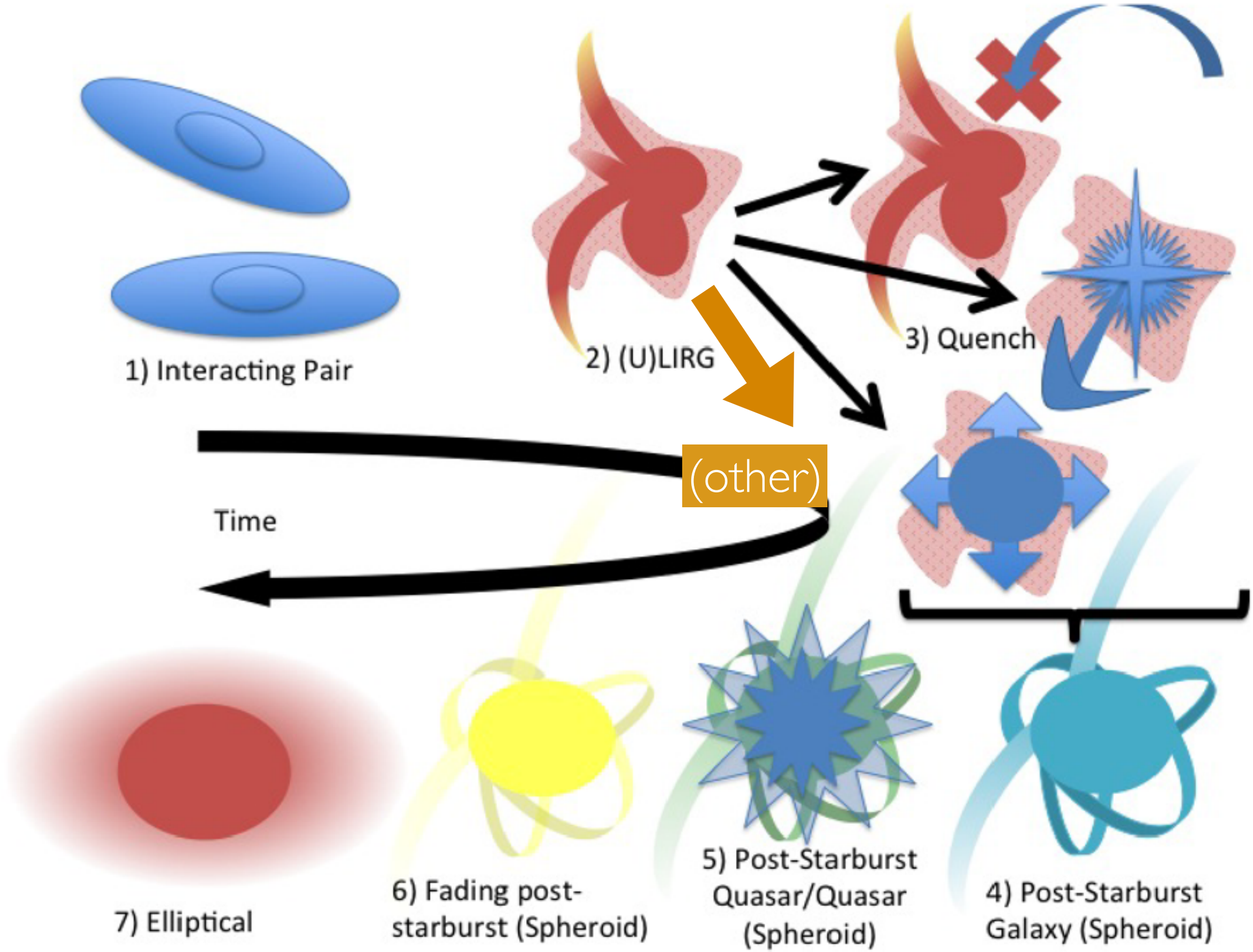
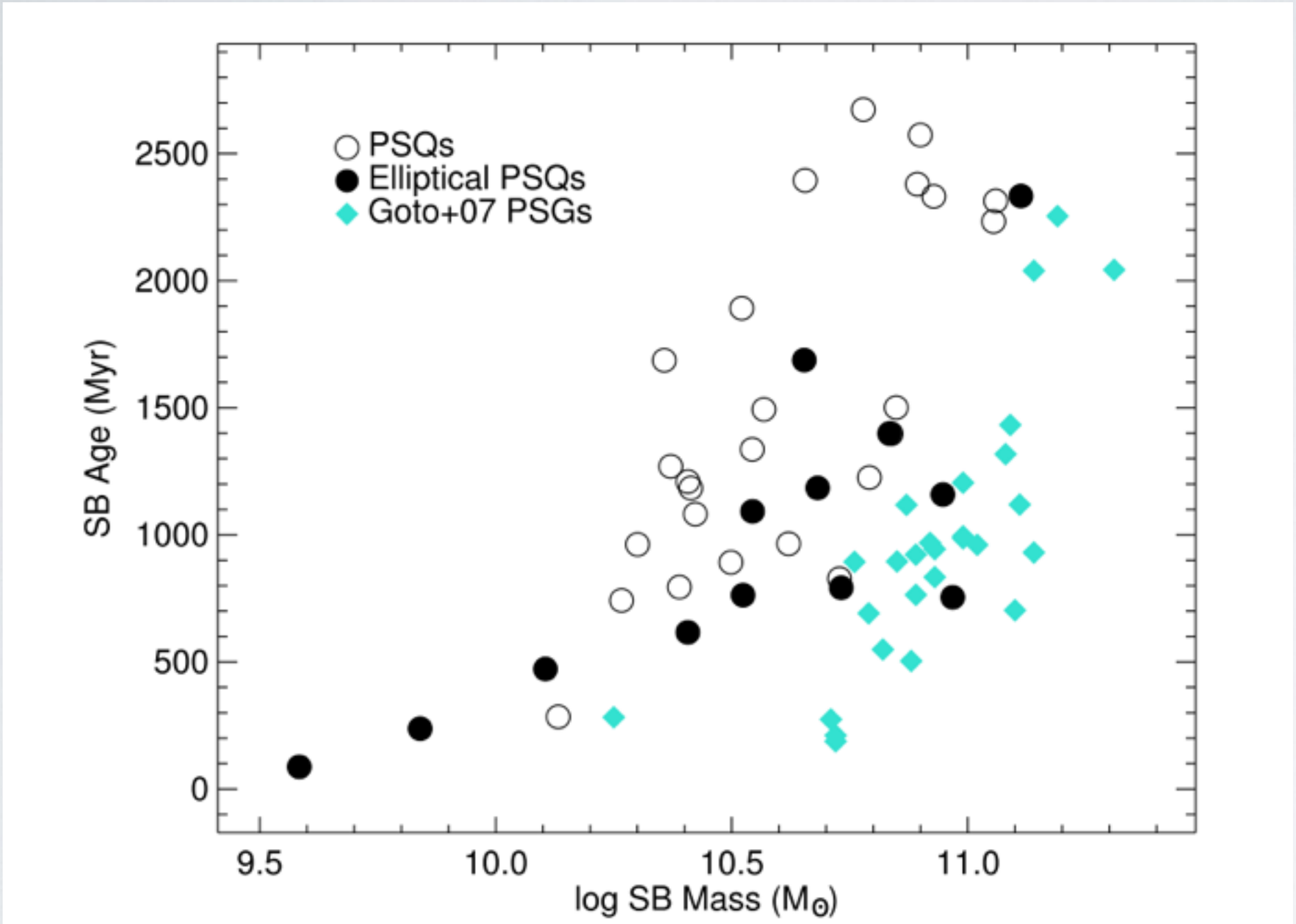
  - Seyfert/LINER host galaxies in intermediate age galaxies (Schawinski + 2007,2009)


1) Interacting Pair
2) (U)LIRG
3) Quench
(other)
Time
7) Elliptical
6) Fading post-starburst (Spheroid)
5) Post-Starburst Quasar/Quasar (Spheroid)
4) Post-Starburst Galaxy (Spheroid)

Cales+ 2015

AGN Feedback in Post-Starburst Galaxies



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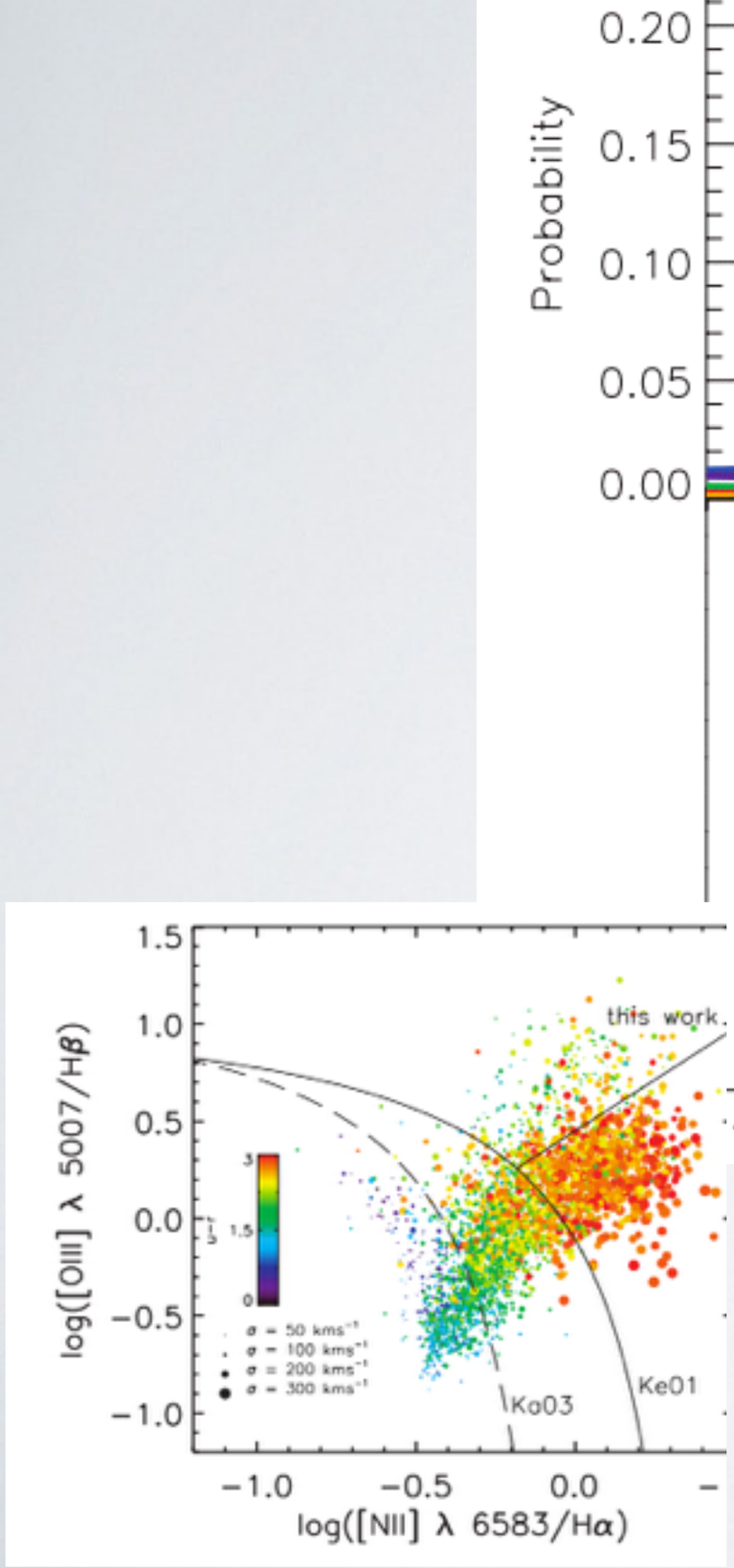
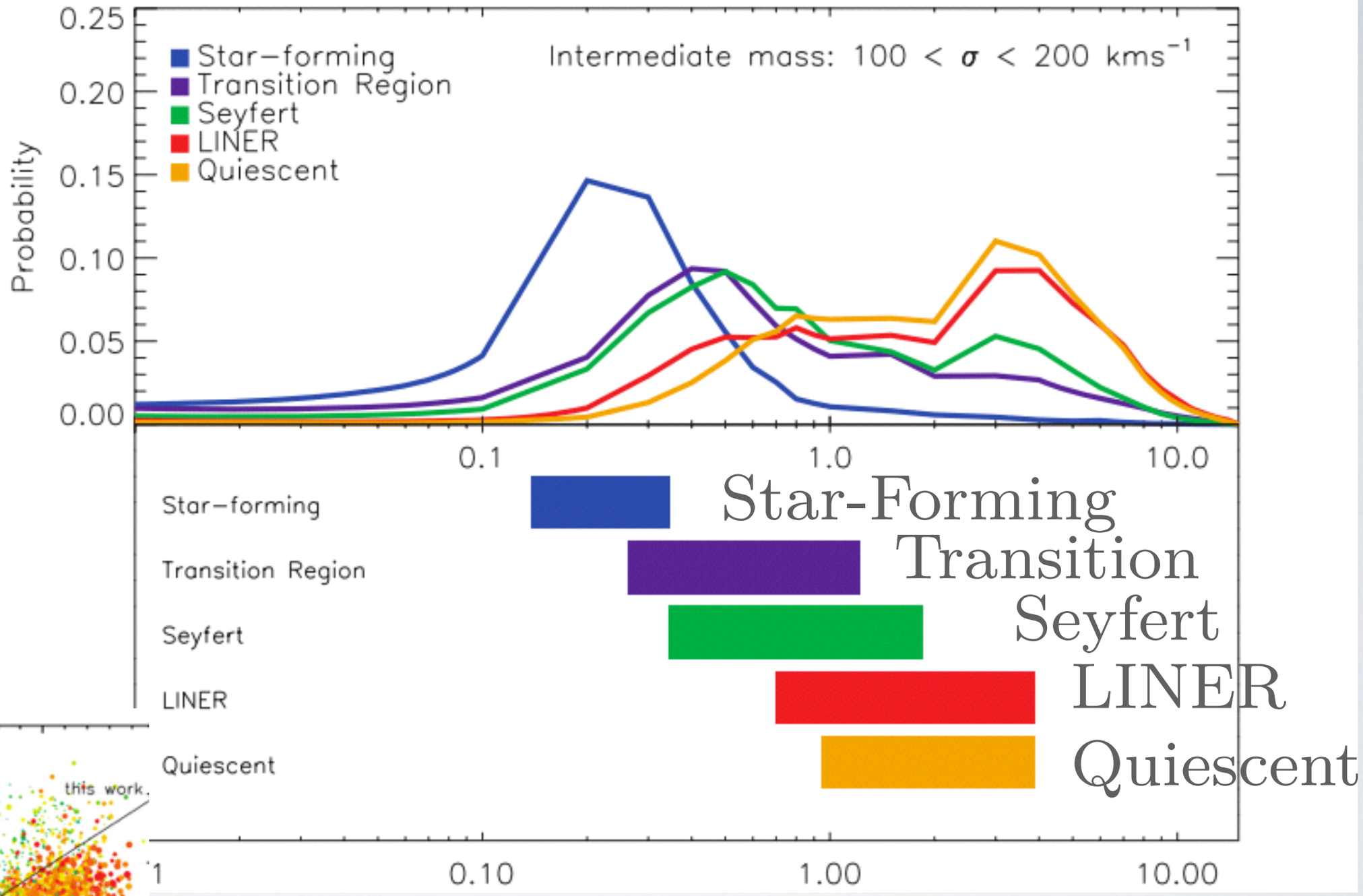
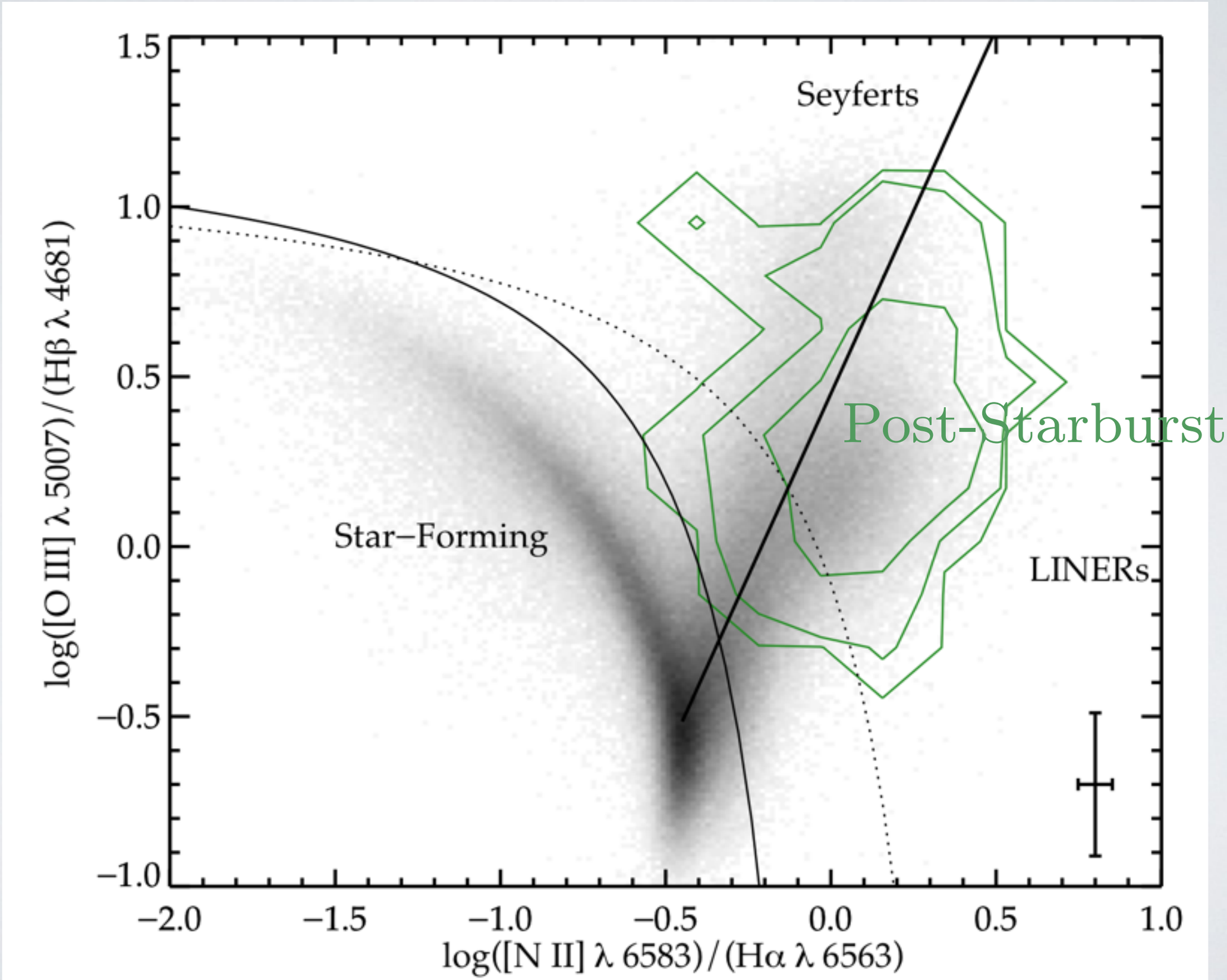




Morphologically selected early-type galaxies
Schawinski+ 2007

AGN Feedback in Post-Starburst Galaxies



LINER-like Emission

- LINER = Low Ionization Nuclear Emission Region
- Low luminosity AGN?
- Post-AGB Stars
- Merger shocks

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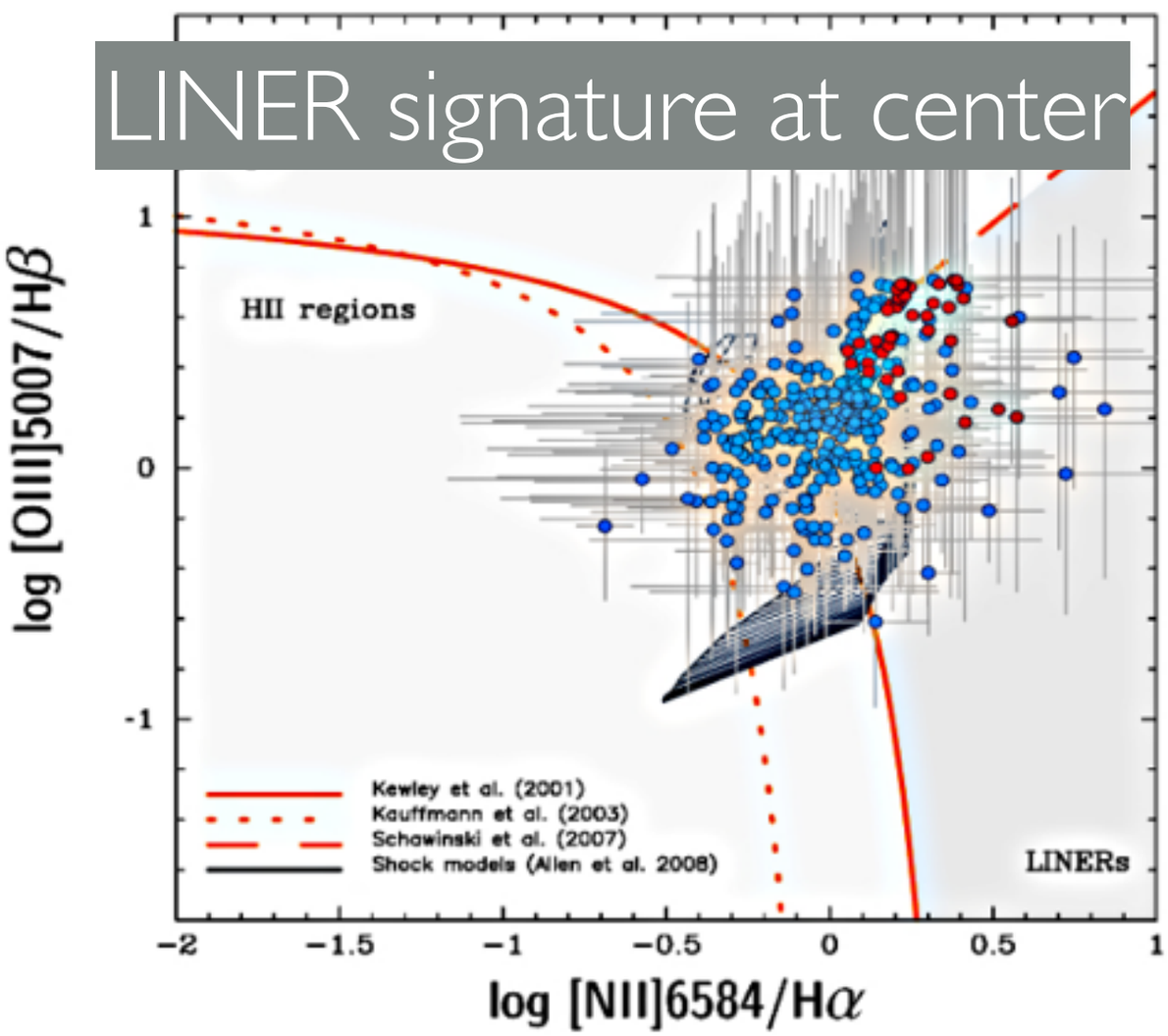
CALIFA IFU data: Early-type galaxies

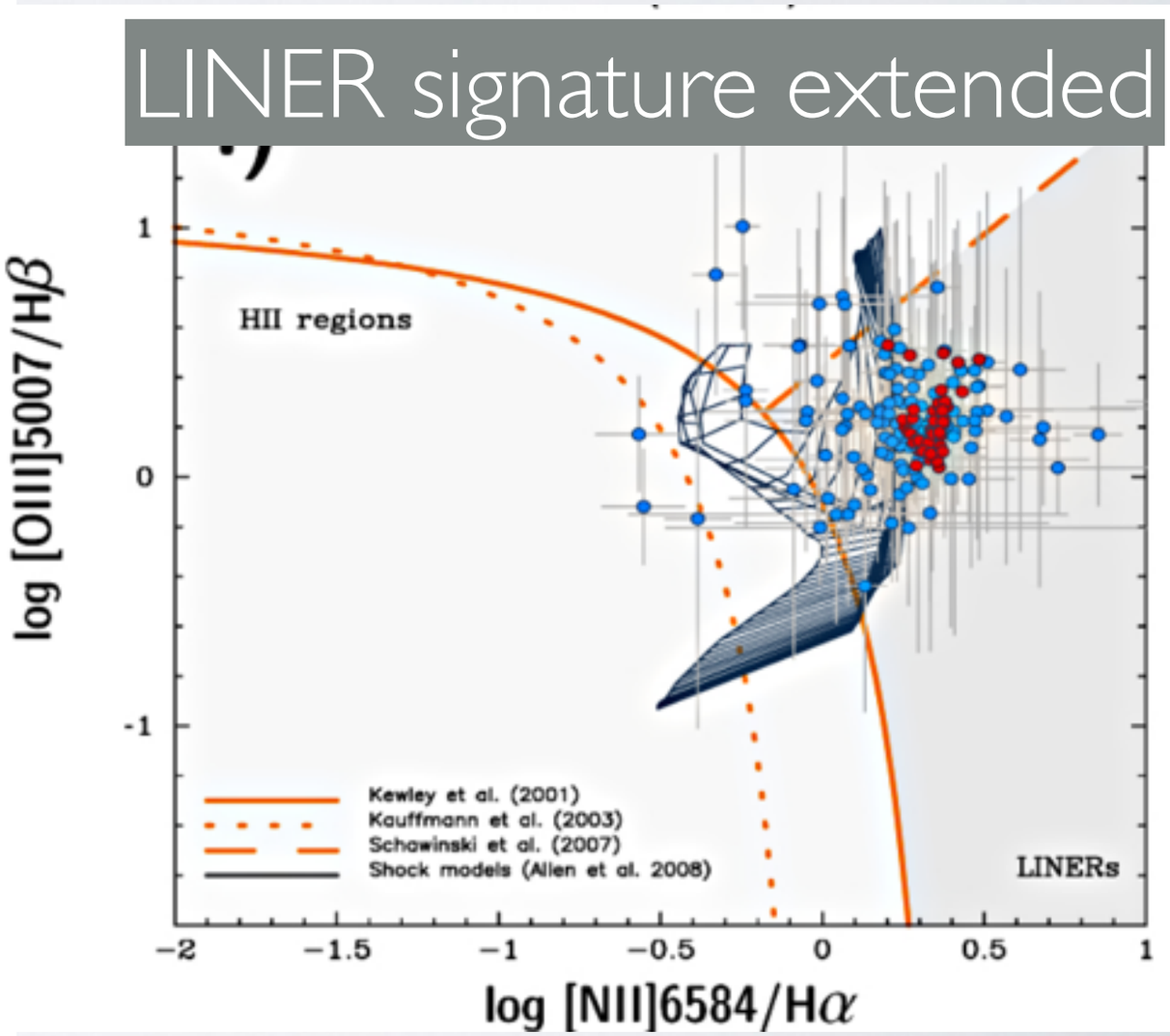
Gomes+ 2016

Extended Center

LINER signature at center



LINER signature extended



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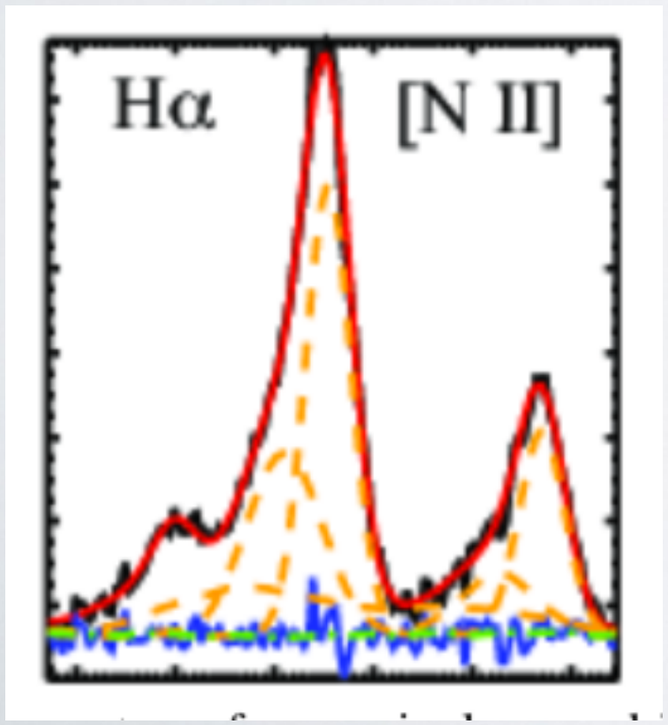
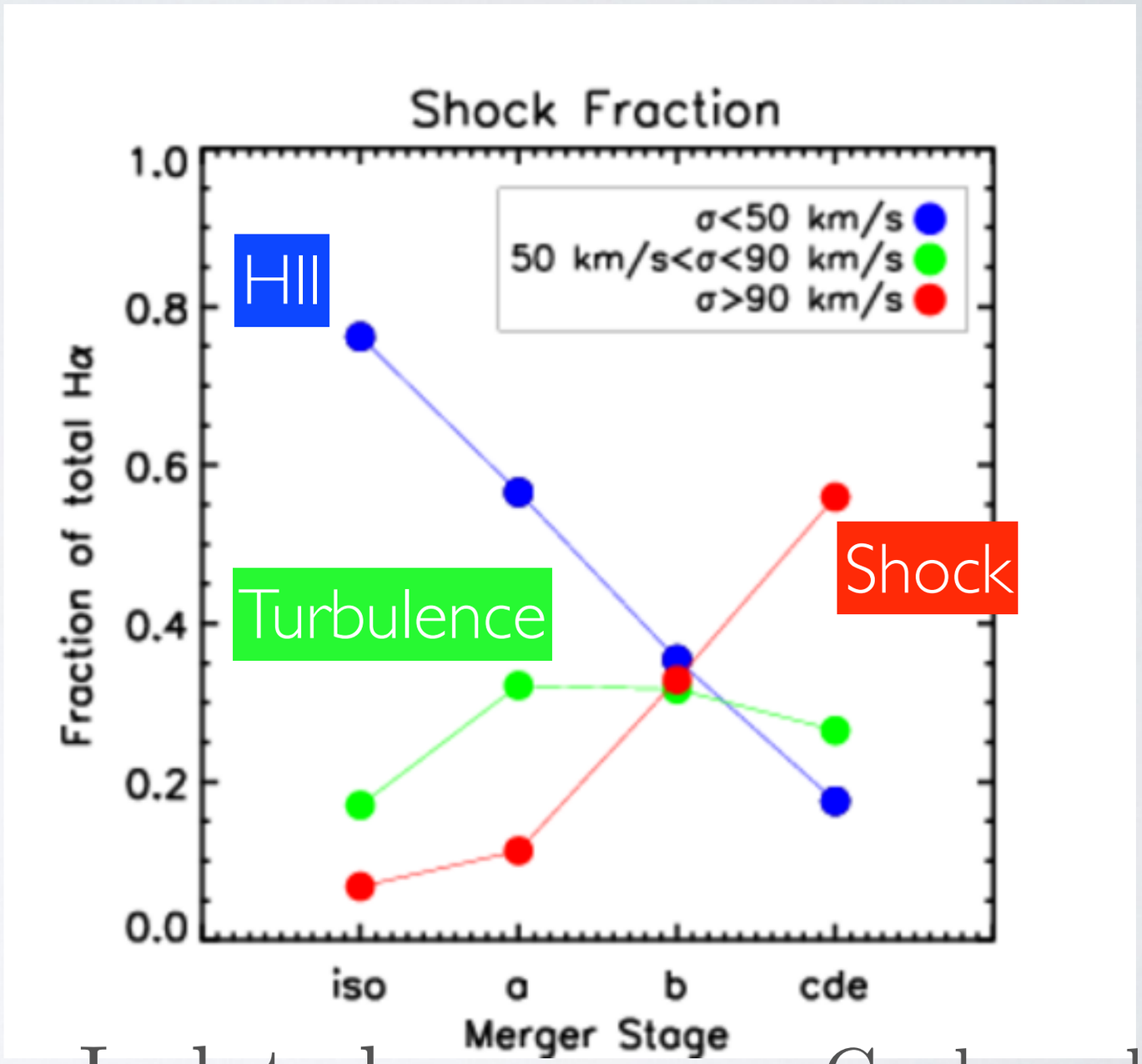
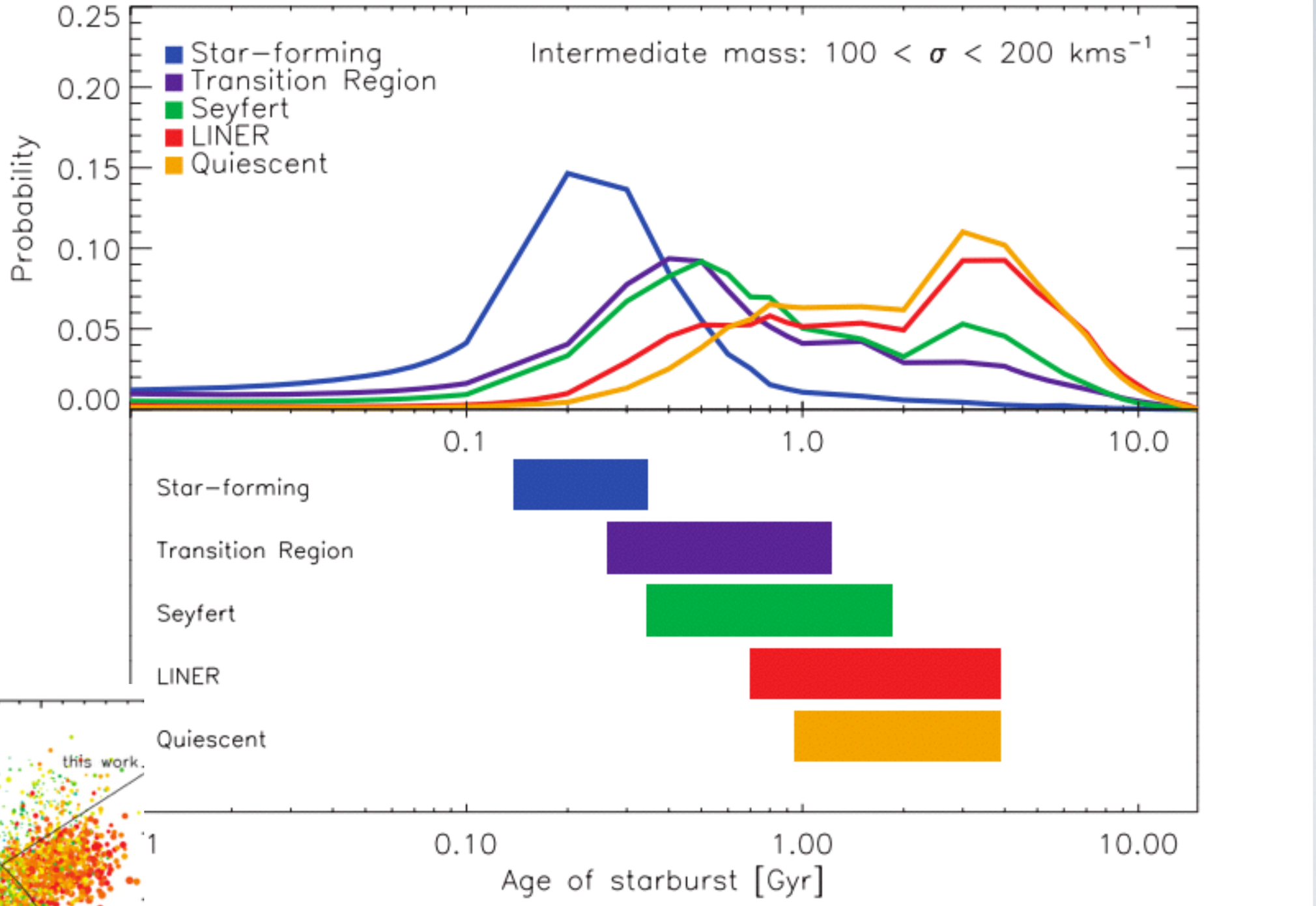
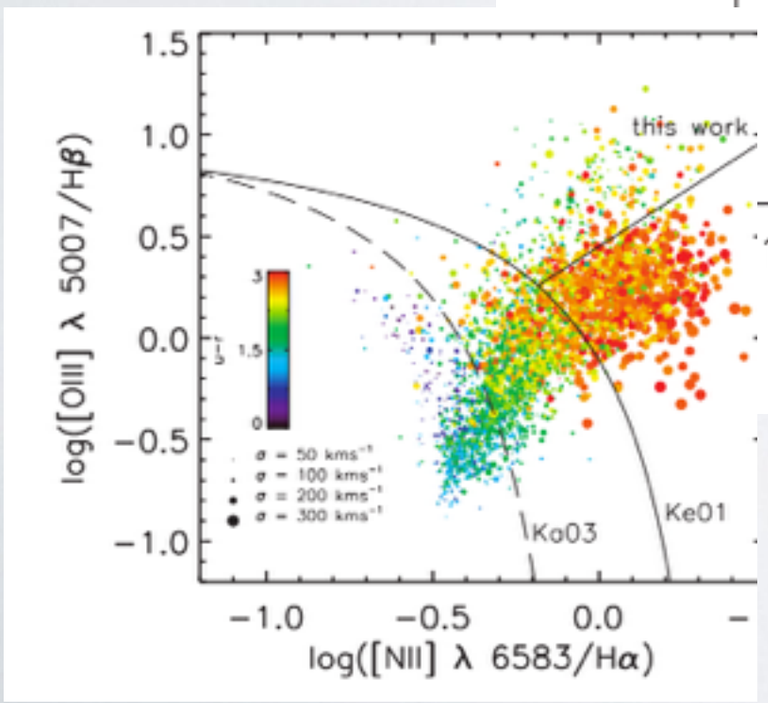
Rich+ 2015





Isolated Wide Pairs Close Pairs Coalesced





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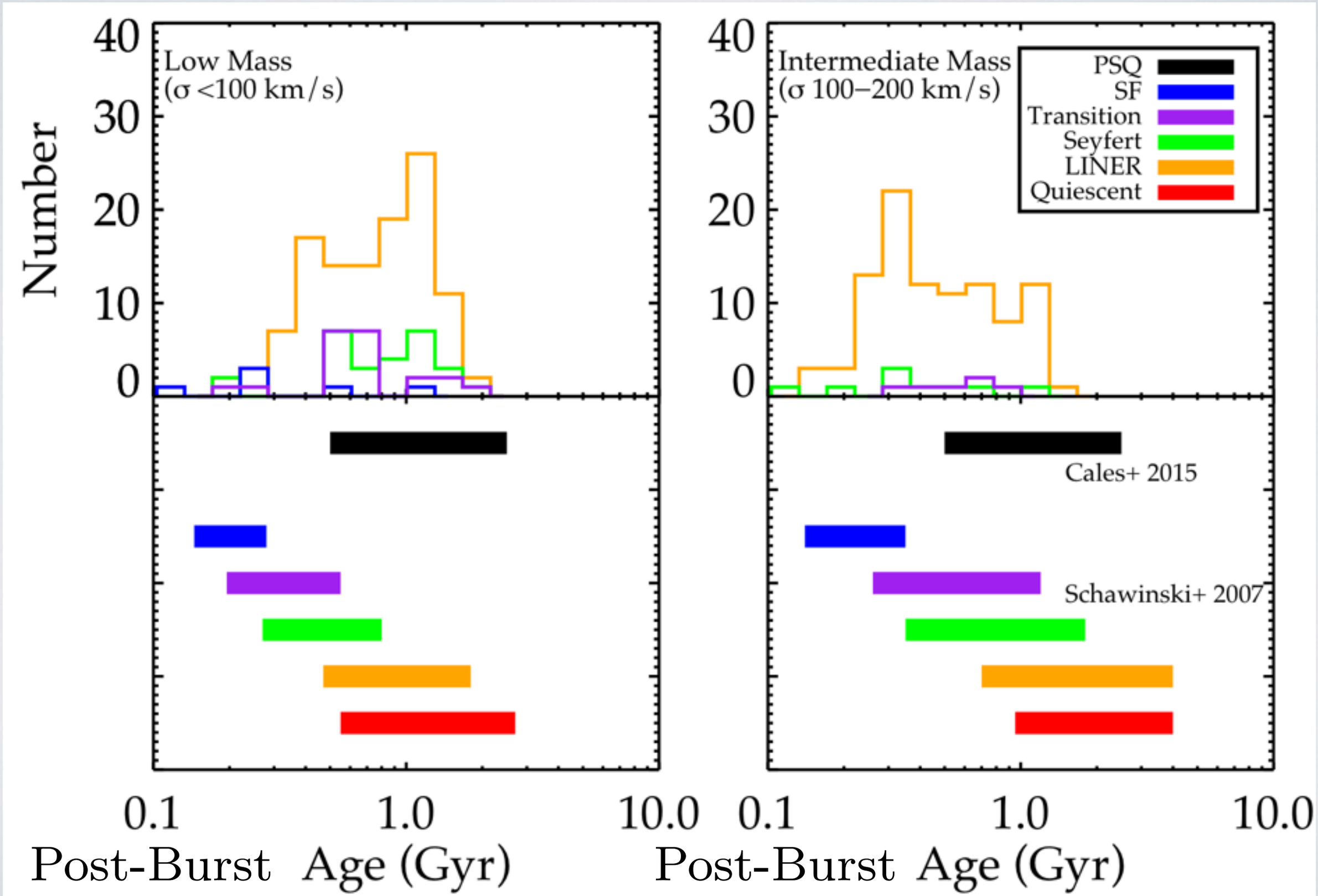
AGN Feedback in Post-Starburst Galaxies



AGN Feedback in Post-Starburst Galaxies

- Growing evidence AGN activity peaks *after* post-starburst phase
  - Post-starbursts vs. post-starburst quasars (Cales+ 2015)
  - Post-starbursts vs. “transiting” post-starbursts (Yesuf+ 2014)
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Post-Starbursts *younger* than post-starburst quasars

No evidence for Seyfert -> LINER sequence within post-starburst phase

AGN Feedback in Post-Starburst Galaxies

- Difficulties:
  - Identifying true progenitor sequence
  - Disentangle emission from SF, AGN,
    - shocks, p-AGB stars...
    - H delta absorption line filling
- Work with Hassen Yesuf (UCSC) on gas properties of TPSBs
- Significant gas reservoirs also observed in:
  - Starbursting -> post-starburst sequence (Rowlands+ 2015)
  - Shocked post-starbursts (Alatalo+ 2016)

Why do galaxies stop forming stars?

- Gas used up in star formation?
  →No, large molecular gas reservoirs
- Gas ejected or removed from galaxy?
  →No, large molecular gas reservoirs
  - AGN feedback? → May act after PSB phase
    - SF feedback? → May act in $M_\star$ <10^10.5 $M_\odot$ galaxies
- Gas dispersed within galaxy?
  →KS offset observed, need spatial info
- Starvation? →No, large molecular gas reservoirs
- Gas heated?
  ? Something else must happen to the gas
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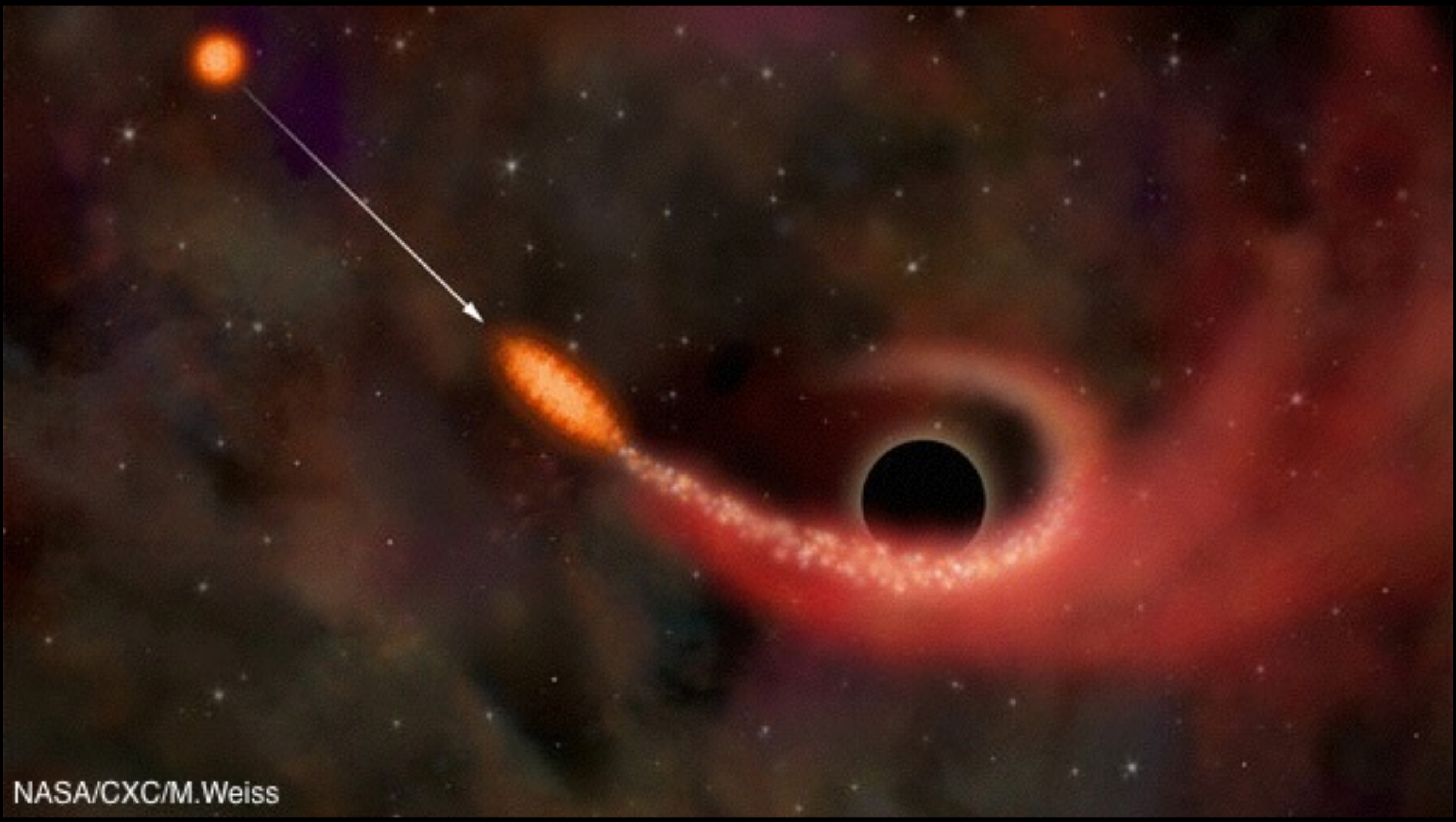
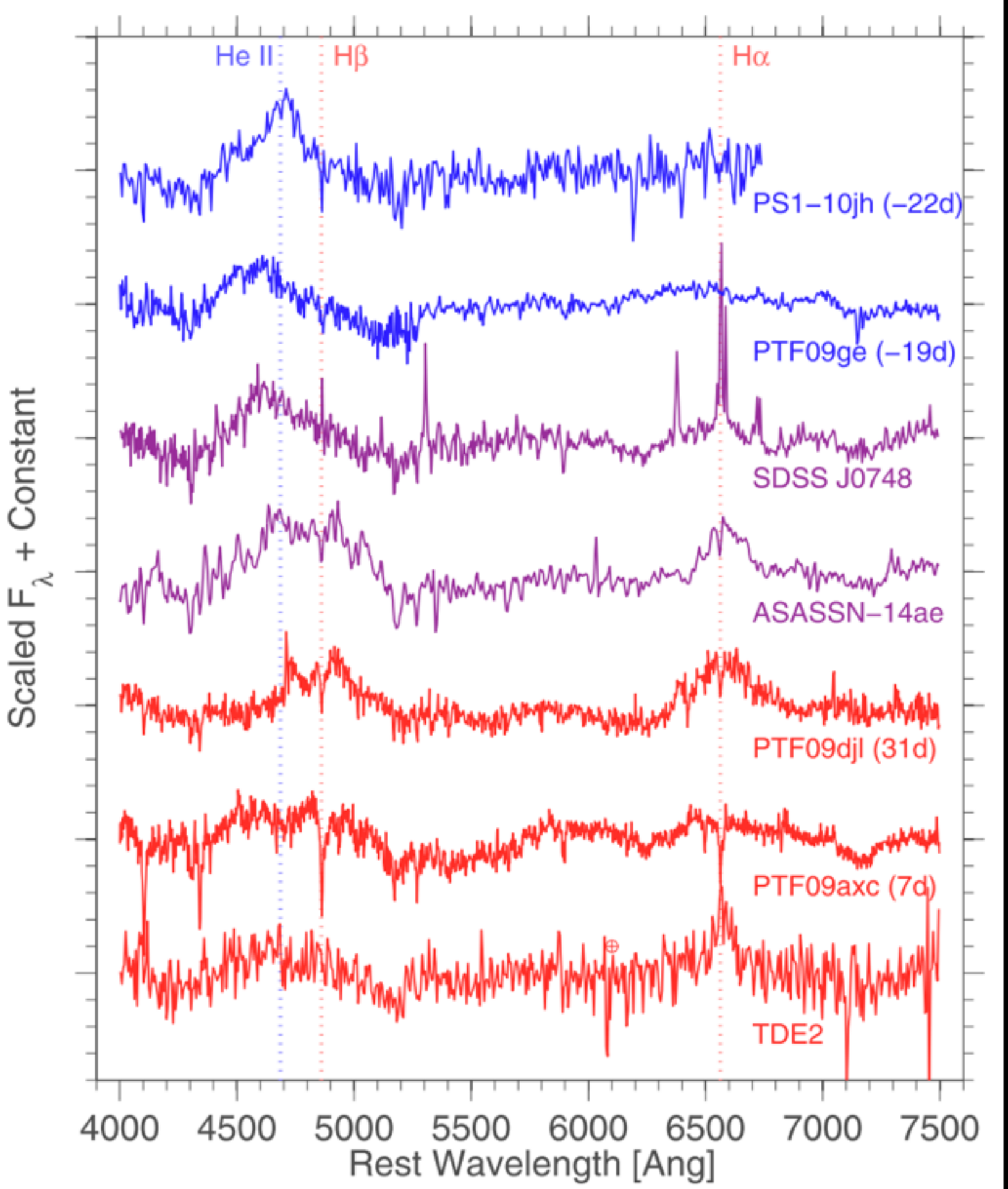
Can we study the SMBH outside of its active AGN phase?

Tidal Disruption Events





Continuum Subtracted TDE spectra (Arcavi+ 2014)

Feature Broad H, He lines

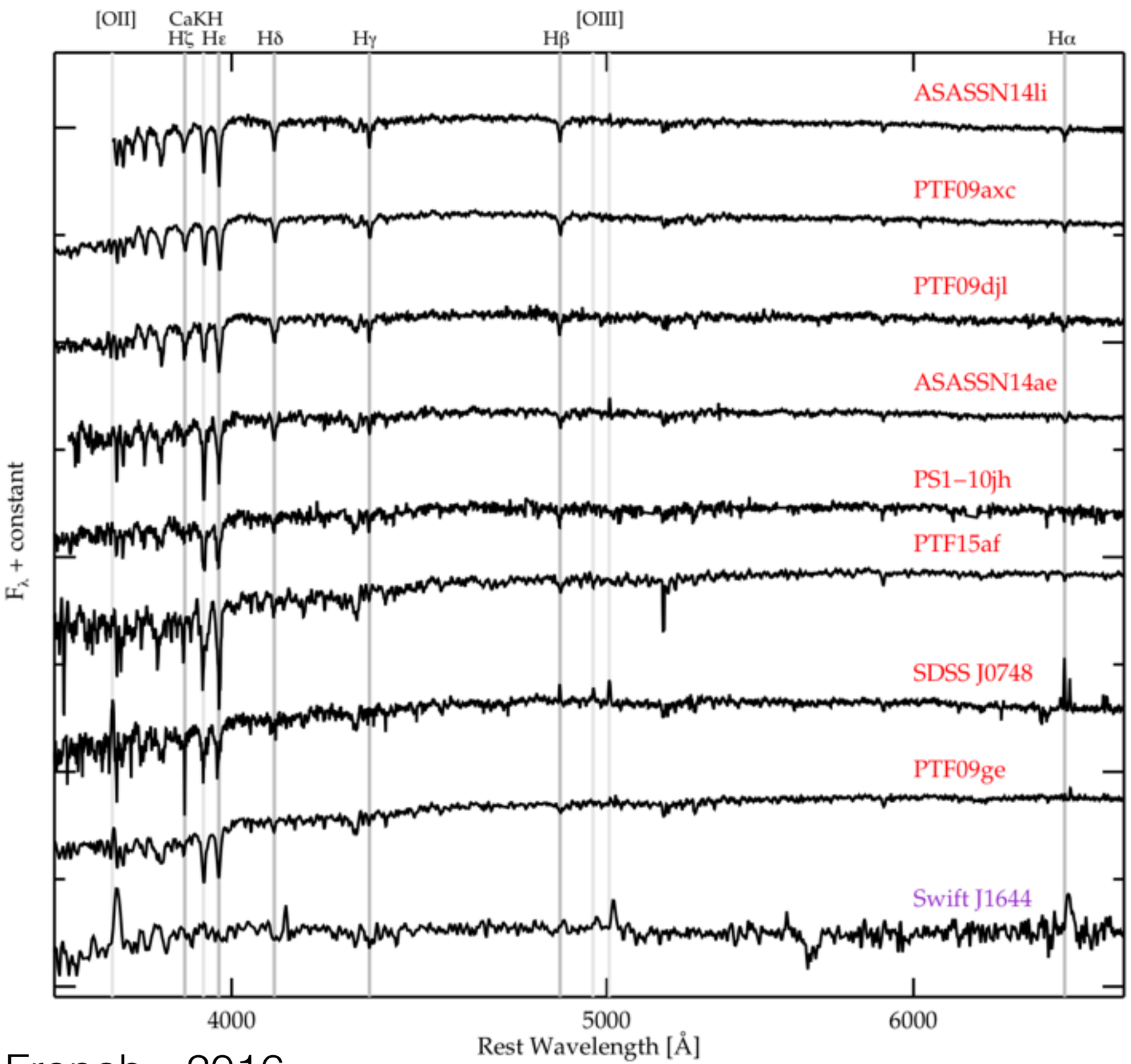
Efficient selection using PTF, ASASSN, PS, etc.

But...

TDE rates 10x lower than predicted

What is the source of the observed emission?

Unusual host galaxies?



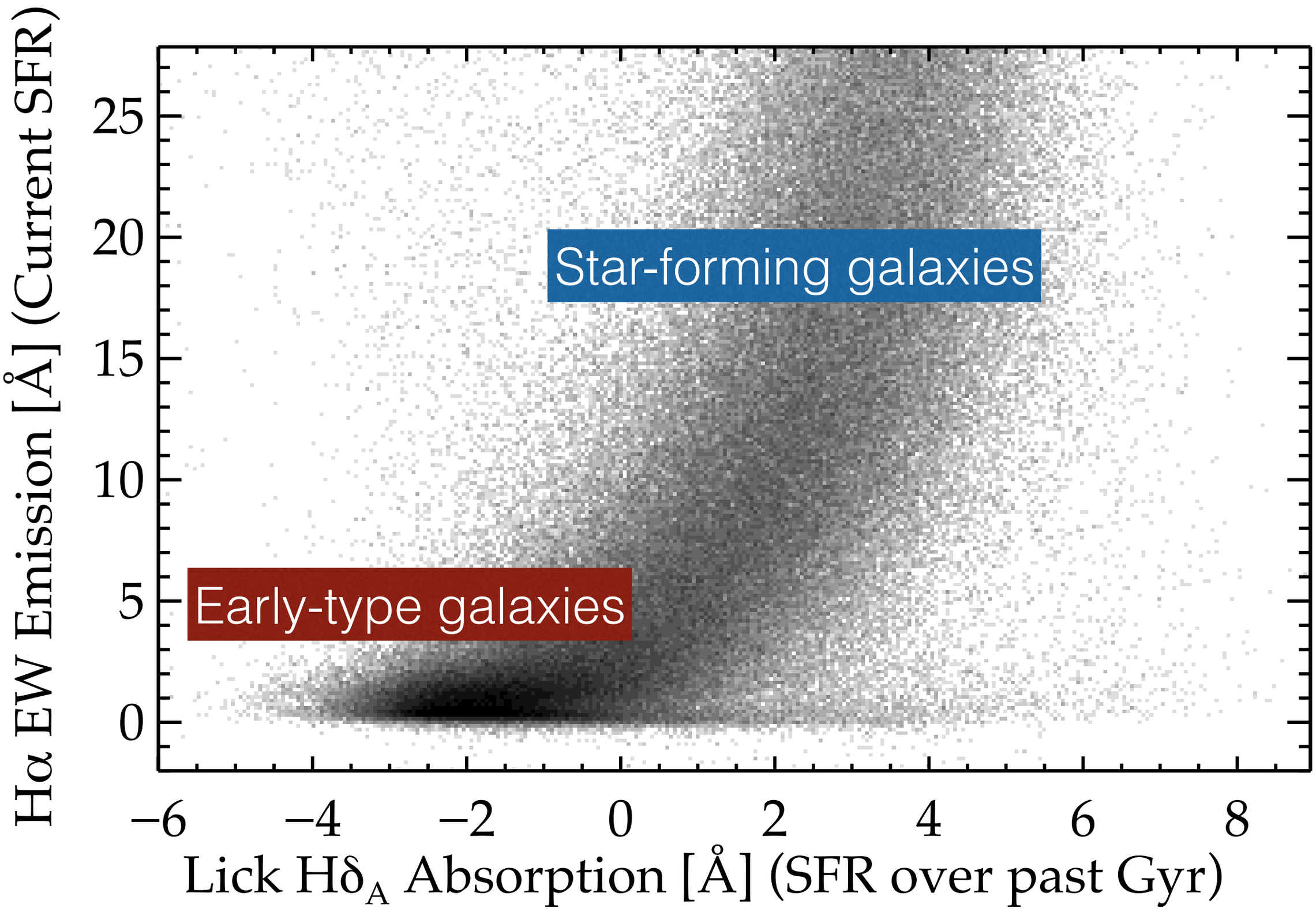
French+ 2016

Host Galaxy Spectra

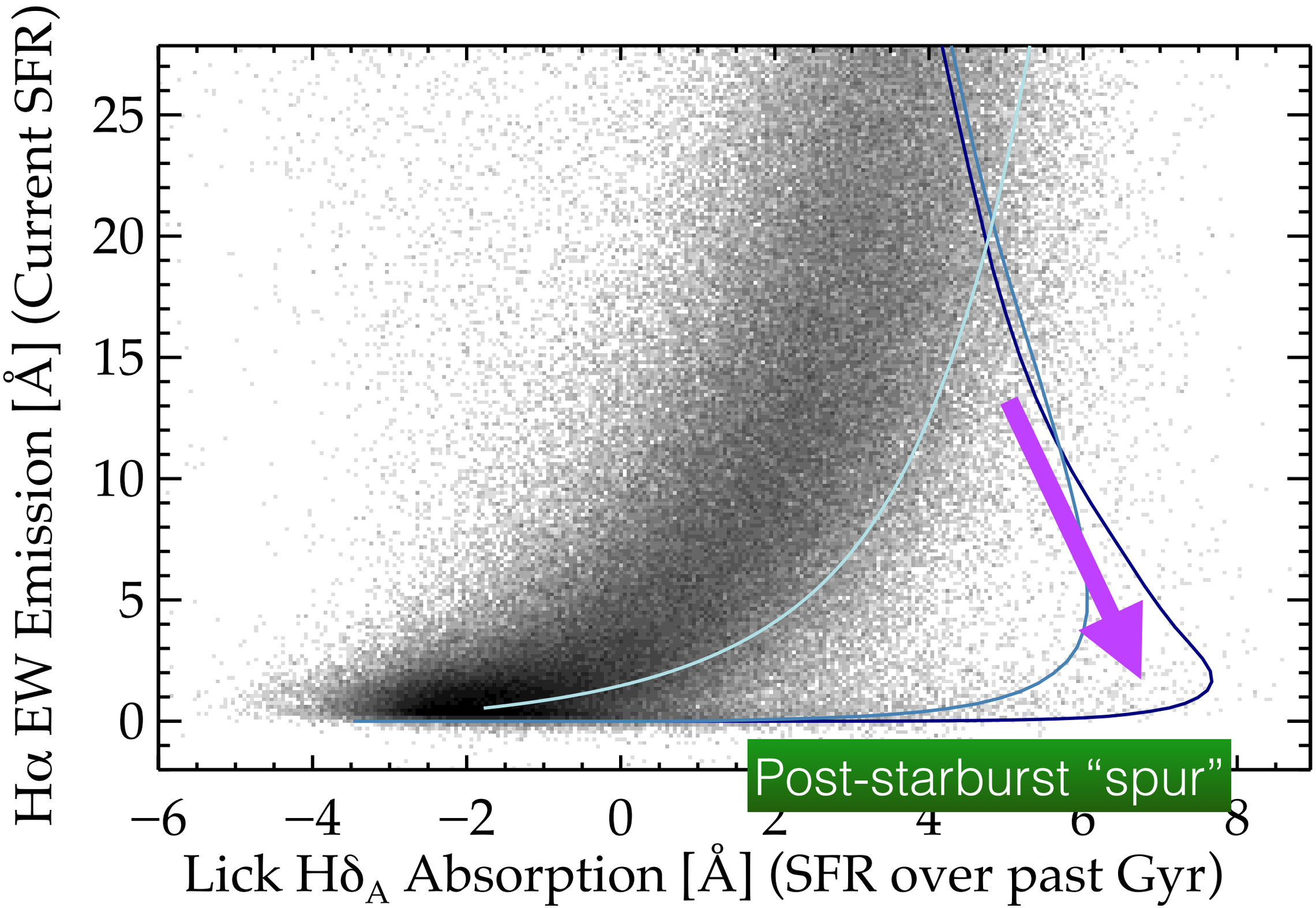
Only one star-forming galaxy

Strong Balmer absorption

Look to host galaxies for clues to TDE rate


Star-forming galaxies
Early-type galaxies
Hα EW Emission [Å] (Current SFR)
25
20
15
10
5
0
−6
−4
−2
0
2
4
6
8
Lick HδA Absorption [Å] (SFR over past Gyr)

French+ 2016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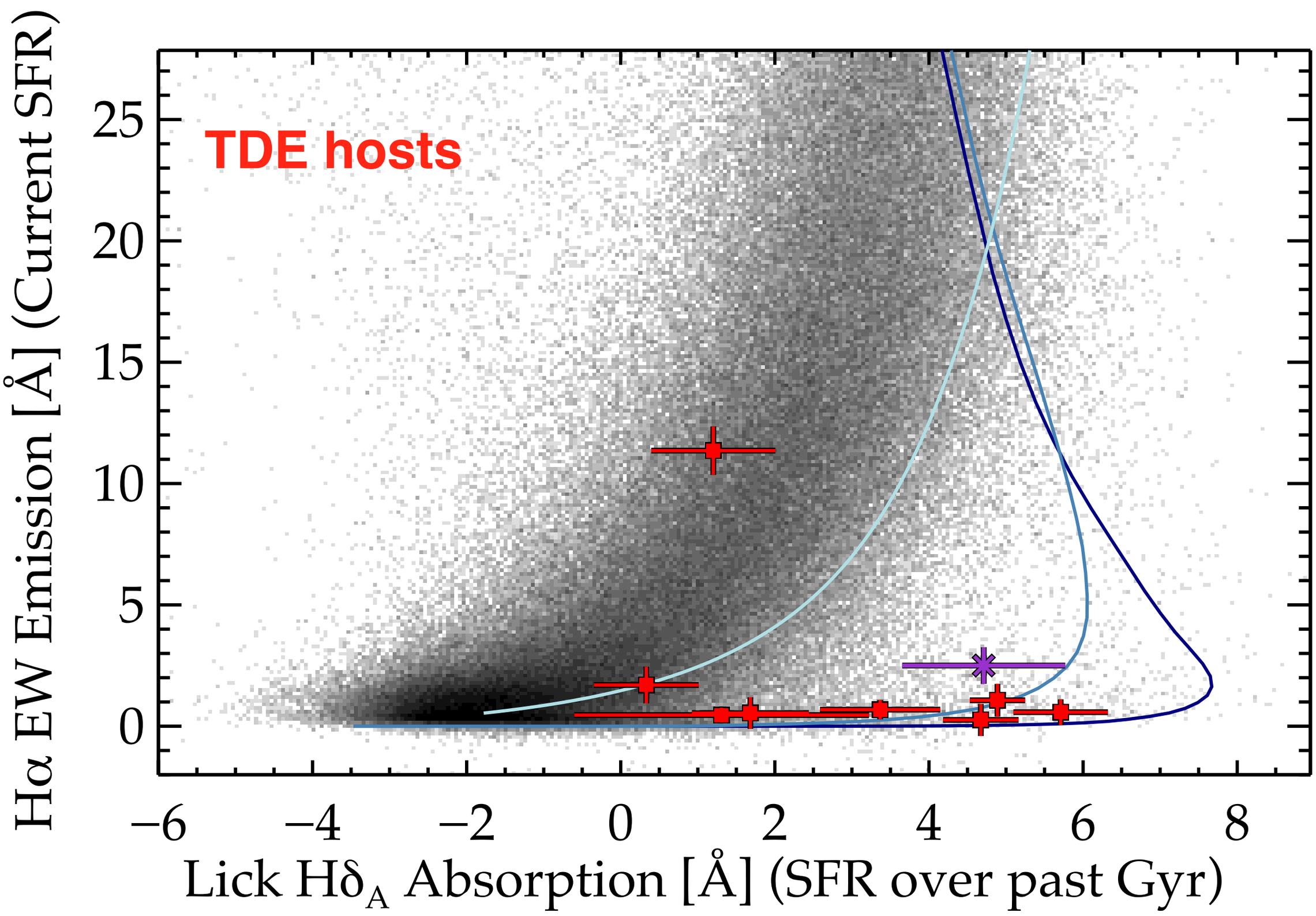
Post-starburst “spur”

French+ 2016


TDE hosts
Hα EW Emission [Å] (Current SFR)
25
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15
10
5
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Lick HδA Absorption [Å] (SFR over past Gyr)

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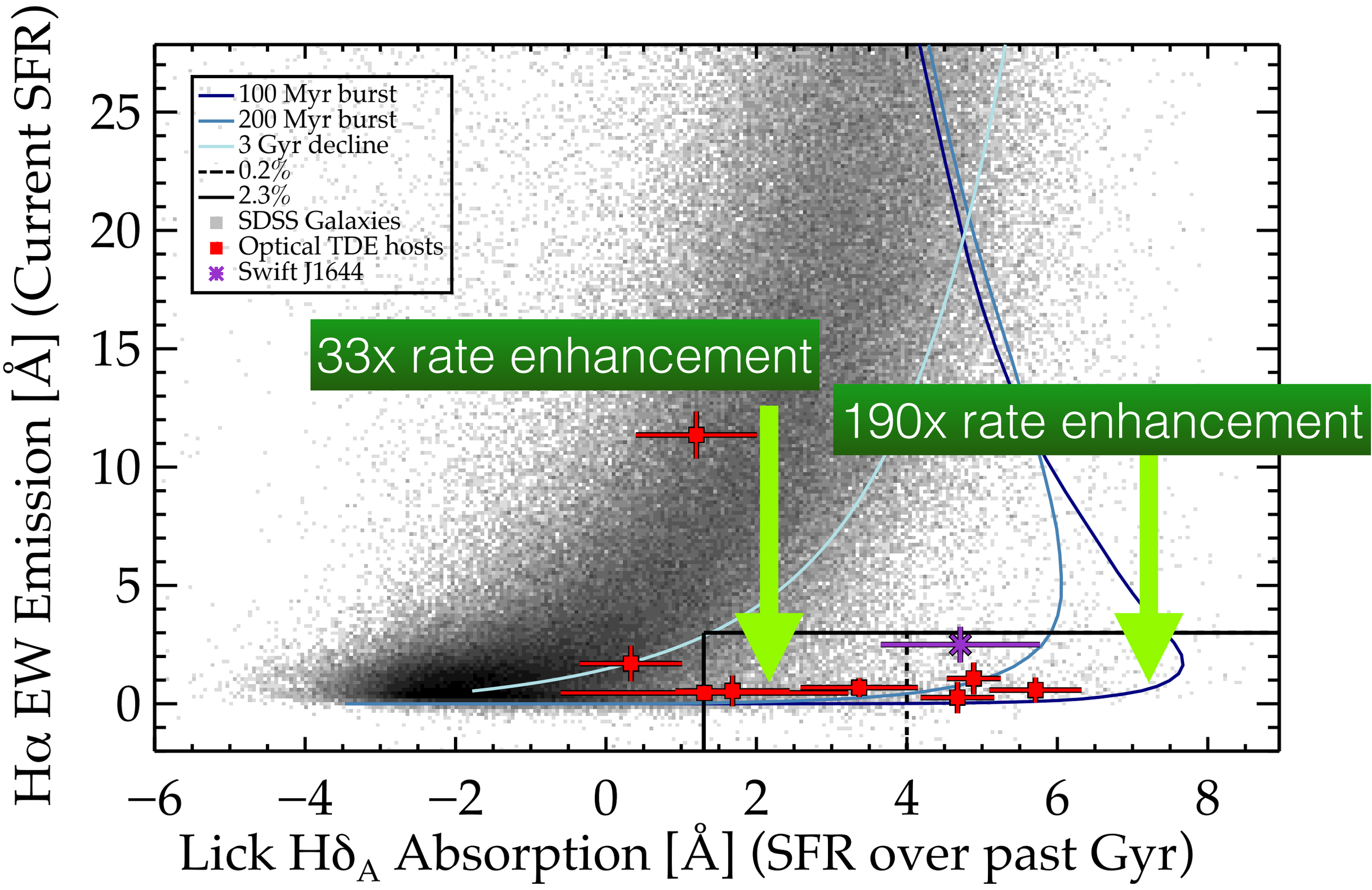
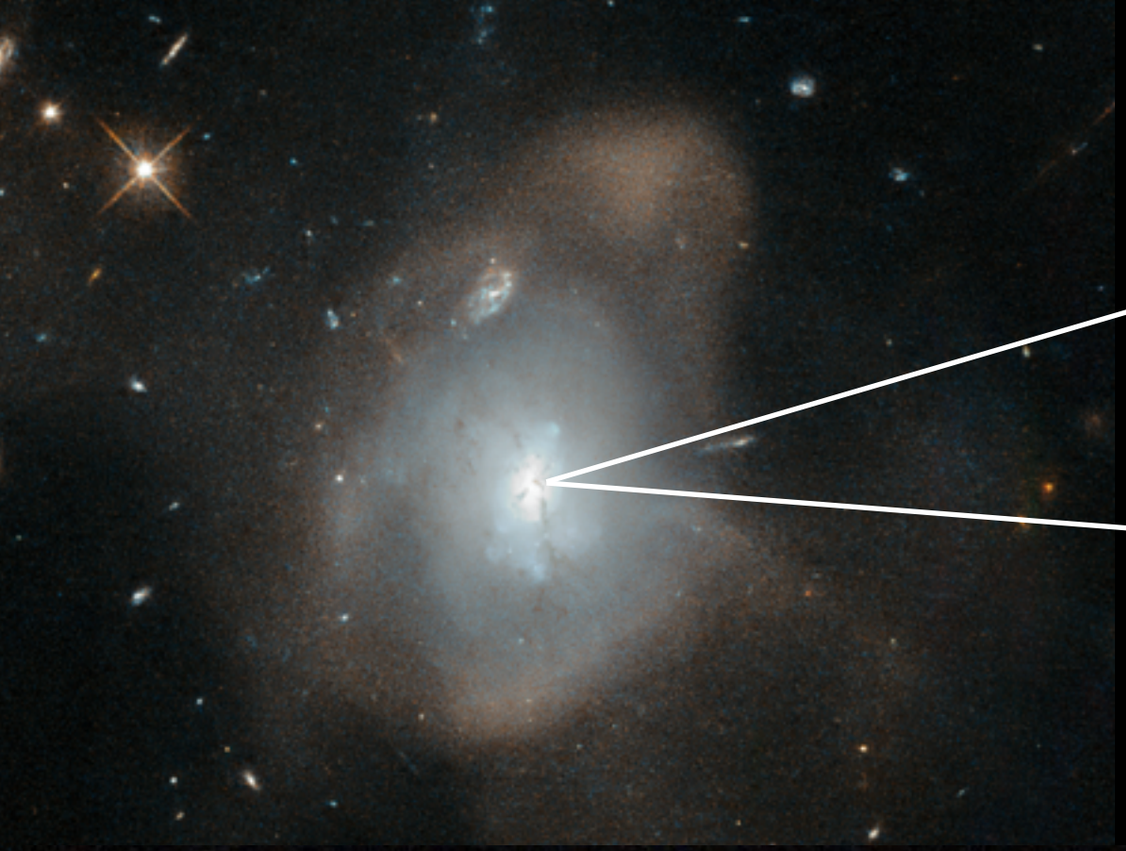
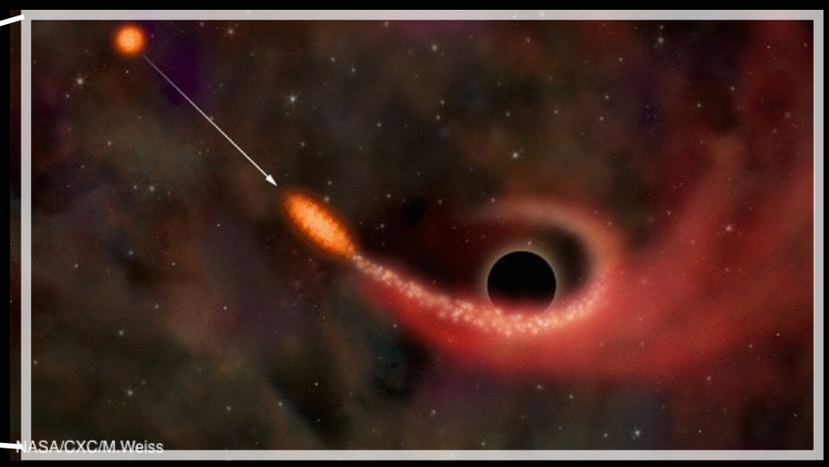

100 Myr burst
200 Myr burst
3 Gyr decline
0.2%
2.3%
SDSS Galaxies
Optical TDE hosts
Swift J1644
33x rate enhancement
190x rate enhancement
Hα EW Emission [Å] (Current SFR)
Lick HδA Absorption [Å] (SFR over past Gyr)
25
20
15
10
5
0
−6
−4
−2
0
2
4
6
8

French+ 2016

TDE Rates

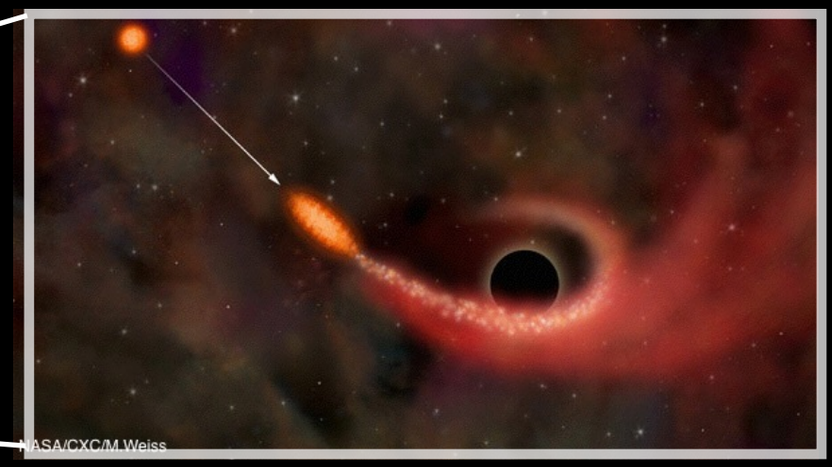
- Theory:
  - few x 10^{-4} per galaxy per year (Stone & Metzger 2016)
- Observed in Post-starburst/ H delta strong
  - 1-3 x 10^{-3} / 2-4 x 10^{-4} per galaxy per year
- Observed in normal galaxies
  - 1-5 x 10^{-6} per galaxy per year





Merger -> starburst:

- BH-BH binary
- High concentration of A stars
- Disturbed central potential
- Evolved stars
- LINER-related?



Plausible, but theory does not predict such a dramatic rate increase

Major mergers

Merger -> starburst:

- BH-BH binary
- High concentration of A stars
- Disturbed central potential
- Evolved stars
- LINER-related?

Minor mergers

~100:1 BH-binary can boost rate, but decay times long

AN ENHANCED RATE OF TIDAL DISRUPTIONS IN THE CENTRALLY OVERDENSE E+A GALAXY NGC 3156

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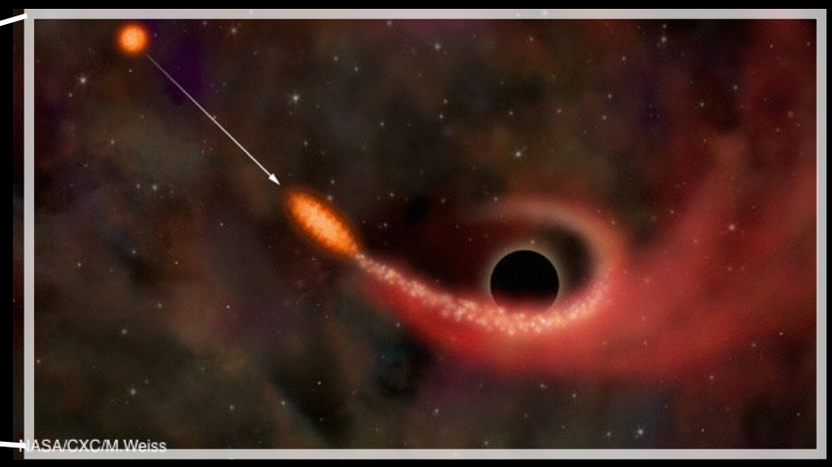
ABSTRACT

Time domain optical surveys have discovered roughly a dozen candidate stellar tidal disruption flares in the last five years, and future surveys like the *Large Synoptic Survey Telescope* will find hundreds to thousands more. These tidal disruption events (TDEs) present an interesting puzzle: a majority of the current TDE sample is hosted by rare post-starburst galaxies, and tens of percent are hosted in even rarer E+A galaxies, which make up $\sim 0.1\%$ of all galaxies in the local universe. E+As are therefore overrepresented among TDE hosts by 1-2 orders of magnitude, a discrepancy unlikely to be accounted for by selection effects. We analyze *HST* photometry of one of the nearest E+A galaxies, NGC 3156, to estimate the rate of stellar tidal disruption produced as two-body relaxation diffuses stars onto orbits in the loss cone of the central supermassive black hole. The rate of TDEs produced by two-body relaxation in NGC 3156 is large when compared to other galaxies with similar black hole mass: $\dot{N}_{\rm TDE} \sim 1 \times 10^{-3}$ yr^{-1}. This suggests that the preference of TDEs for E+A hosts may be due to central stellar overdensities produced in recent starbursts.



Plausible, but theory does not predict such a dramatic rate increase

Major mergers

Merger -> starburst:

- BH-BH binary
- High concentration of A stars
- Disturbed central potential
- Evolved stars
- LINER-related?

Minor mergers

~100:1 BH-binary can boost rate, but decay times long

Possible in at least one case

Predicted to create longer-duration TDE

Future work

Conclusions

- Post-Starburst galaxies, in transition between star-forming and early type
- Molecular gas masses comparable to SF galaxies detected in ~half
- Post-starbursts fall low on molecular gas - star formation rate surface density relation
- Rule out complete gas consumption/expulsion/starvation as end of starburst in this sample
- AGN feedback may operate in the future, after starburst is long ended
- Post-starburst galaxies host disproportionate number of tidal disruption events