# The Death of Galaxies: Evolution Through the Post-Starburst Phase

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#### Identifying Transitioning Galaxies

Why?

- Study transition from star-forming to quiescence ("quenching")
  - How/When/Where does transition occur? What is the role of feedback processes? Interplay between stars, interstellar medium, central black hole?
- Dramatic conditions as galactic center transitions
  - Increased accretion of stars into central black hole



- Why do galaxies stop forming stars? For "fast mode", merger-triggered starburst  $\rightarrow$  ?
  - Gas used up in star formation?
  - Gas ejected or removed from galaxy?
  - Gas dispersed within galaxy?
  - Starvation?

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• Gas heated? Turbulence? Other?

Processes imprinted on post-starburst galaxies







#### Testing Grounds: Post-Starburst Galaxies





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



Observations:

- 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)







French+ 2015, SF and ETG data from: Young+ 2011, Saintonge+ 2011 Decker French (U. Arizona)



ALMA Cycle 3 Observations





### Molecular gas vs. star-formation rate

surface densities



Kennicutt-Schmidt plot

SB/SF data from Kennicutt (1998)

## Why do galaxies stop forming stars?

- Gas used up in star formation?
- $\rightarrow$ No, large molecular gas reservoirs • Gas ejected or removed from galaxy?
- ->No, large molecular gas reservoirs • Gas dispersed within galaxy? ->KS offset observed, need spatial info
- Starvation?  $\rightarrow$  No, large molecular gas reservoirs
- Gas heated? Turbulence? Other? ? Something else must happen to the gas

How do these galaxies evolve to the red sequence? Need subsequent episodes of star-formation or AGN feeding



- Growing evidence AGN activity peaks \*after\* post-starburst phase
  - Black hole accretion rate in starbursts/post-starbursts (Wild + 2010)
  - Post-starbursts vs. post-starburst quasars (Cales+ 2015)
  - Post-starbursts vs. "transiting" post-starbursts (Yesuf+ 2014)
  - Seyfert/LINER host galaxies in intermediate age galaxies (Schawinski+ 2007,2009)

#### Starburst



Post-Starburst t = 200-600 Myr



AGN feeding





Major Merger Decker French (U. Arizona) Ages of Post-Starbursts with molecular gas consistent with delay in AGN feeding



Quiescence

- Growing evidence AGN activity peaks \*after\* post-starburst phase
  - Black hole accretion rate in starbursts/post-starbursts (Wild + 2010)
  - Post-starbursts vs. post-starburst quasars (Cales+ 2015)
  - Post-starbursts vs. "transiting" post-starbursts (Yesuf+ 2014)
  - Seyfert/LINER host galaxies in intermediate age galaxies (Schawinski + 2007,2009)
  - Molecular gas reservoirs persist 200-600 Myr post-starburst
  - Also in younger post-starbursts (Rowlands<br/>+2015) & shocked post-starbursts (Alatalo<br/>+2016)
- Recent starburst/major merger  $\rightarrow$  accretion of stars by central black hole



#### Tidal Disruption Events:

- Stars which travel closer than the tidal radius of a black hole are disrupted
- If this occurs outside the event horizon (if  $\rm M_{BH} < 10^{-8}$  Msol), observable flare



French+ 2016



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French+ 2016

- Growing evidence AGN activity peaks \*after\* post-starburst phase (Wild + 2010, Cales+ 2015, Yesuf+ 2014, Schawinski+ 2007, 2009), molecular gas persisting 200-600 Myr post-starburst
- Recent starburst/major merger  $\rightarrow$  accretion of stars by central black hole
  - Rate ~ few x  $10^{-3}$  per galaxy per year in post-starbursts
  - Debris from these events  $\rightarrow$  can deposit energy to gas near galactic center (Guillochon+ 2016)

#### Lessons Learned from Transitioning Galaxies

1. Molecular gas can remain post-burst Star formation can end without completely removing/ consuming/starving the molecular gas reservoir

Subsequent episodes of SF/ AGN feeding must occur

2. AGN activity can be delayed 200-600 Myr after the starburst ends

3. Accretion of stars by the central black hole peaks after a starburst/merger

