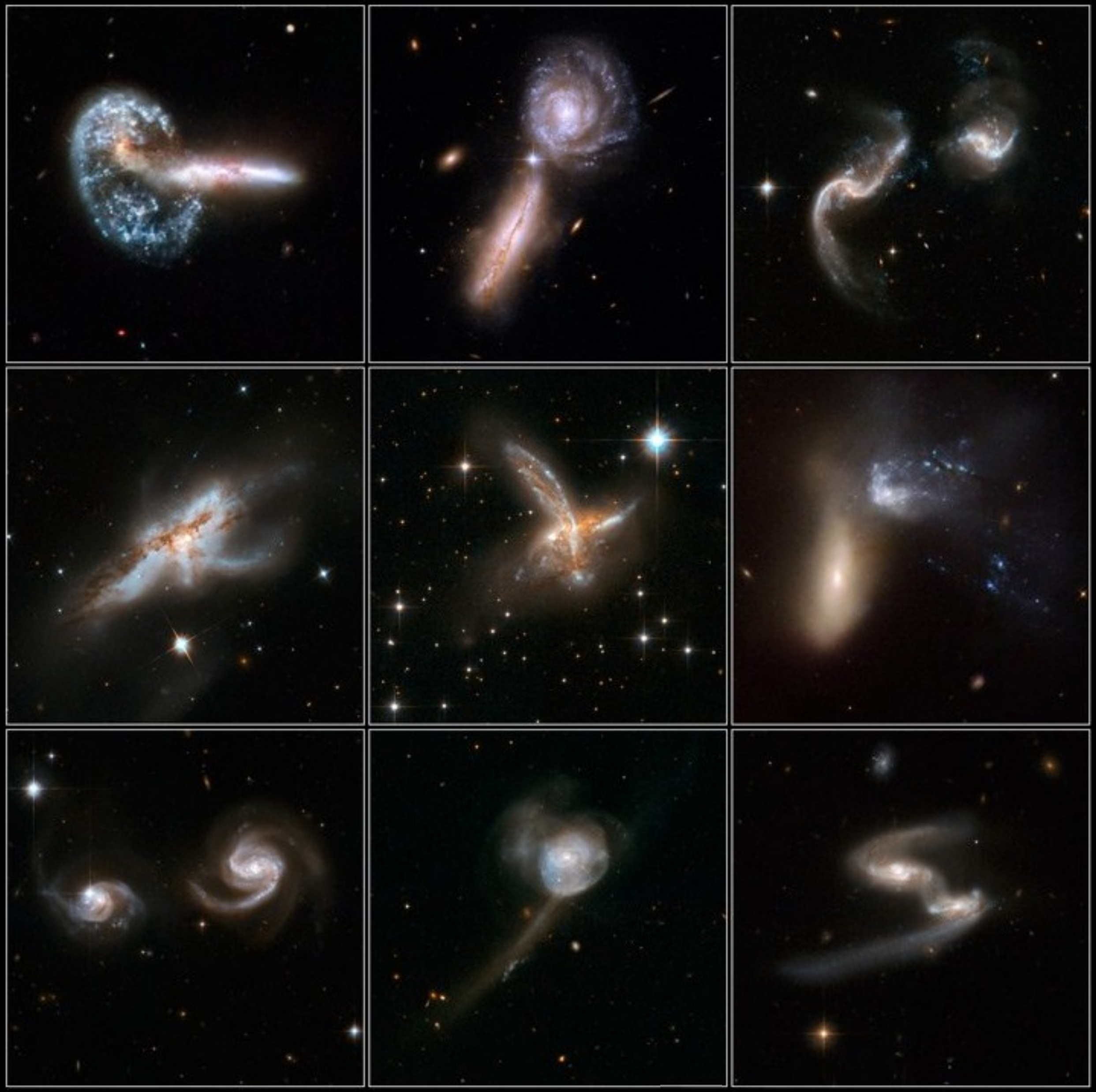
Do Galaxy Mergers Trigger AGN?



Hai Fu

University of Iowa
Physics & Astronomy

Sep 24, 2019

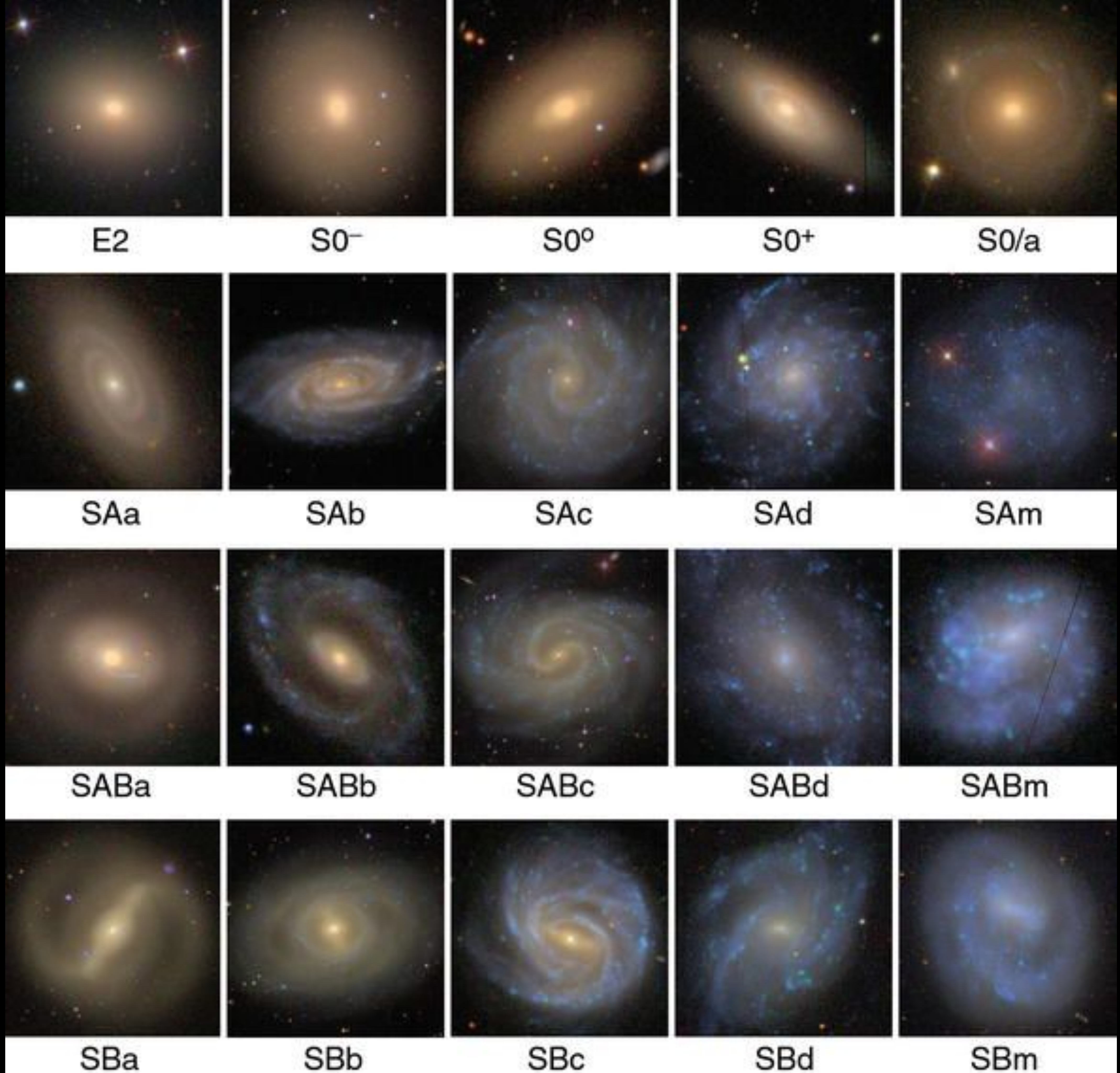

in 7 billion years

Coming next ...

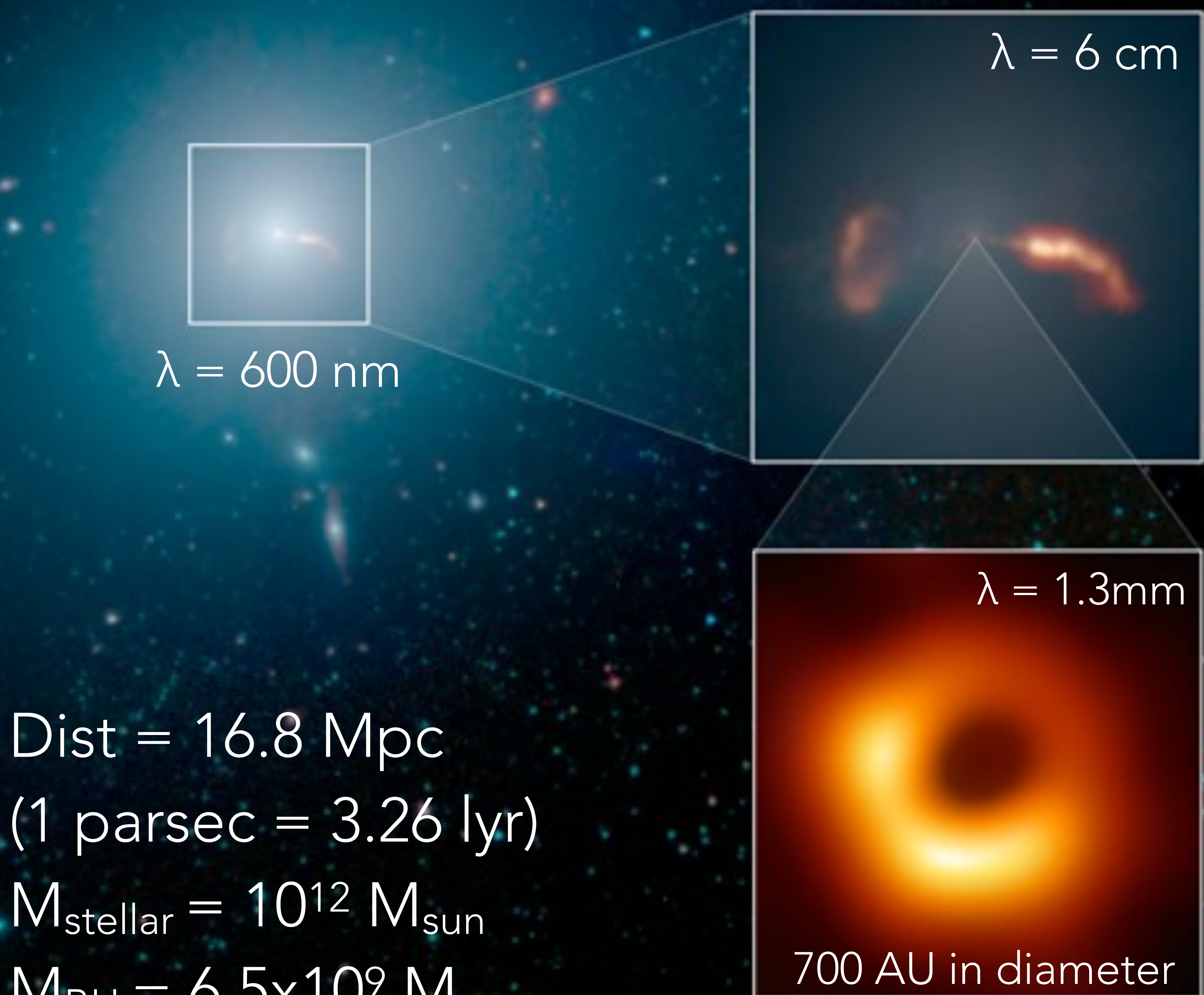
- What are active galactic nuclei (AGN)?
- How are AGN triggered? Black holes need to be fed with "food".
- What do we observe in the nearby universe with SDSS/MaNGA?
- Do observations agree with expectations from simulations?

A Zoo of Galaxies

various shapes of normal galaxies



A Small Fraction of Galaxies Host Active Galactic Nuclei (AGN)



Accreting SMBHs as the powering source was first suggested for quasars by Hoyle et al (1964), Lynden-Bell (1969)

Dist = 16.8 Mpc

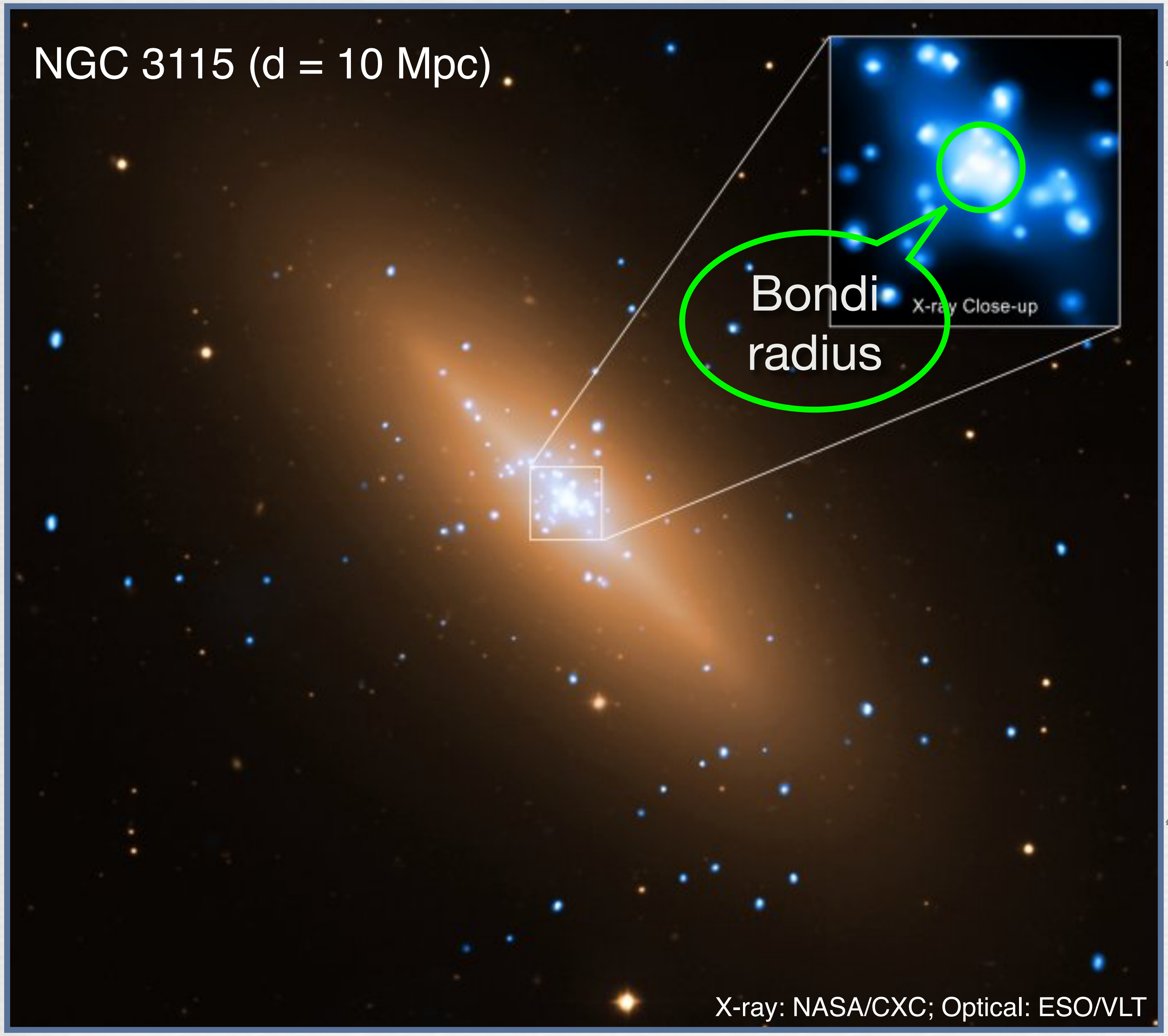
(1 parsec = 3.26 lyr)

$M_{stellar} = 10^{12}\ M_{sun}$

$M_{BH} = 6.5 \times 10^{9}\ M_{sun}$

The EHT Collaboration 2019

Feeding SMBHs is difficult because of their tiny sphere of influence



Shcherbakov et al. 2014

- BH sphere of influence, the Bondi radius (1952):

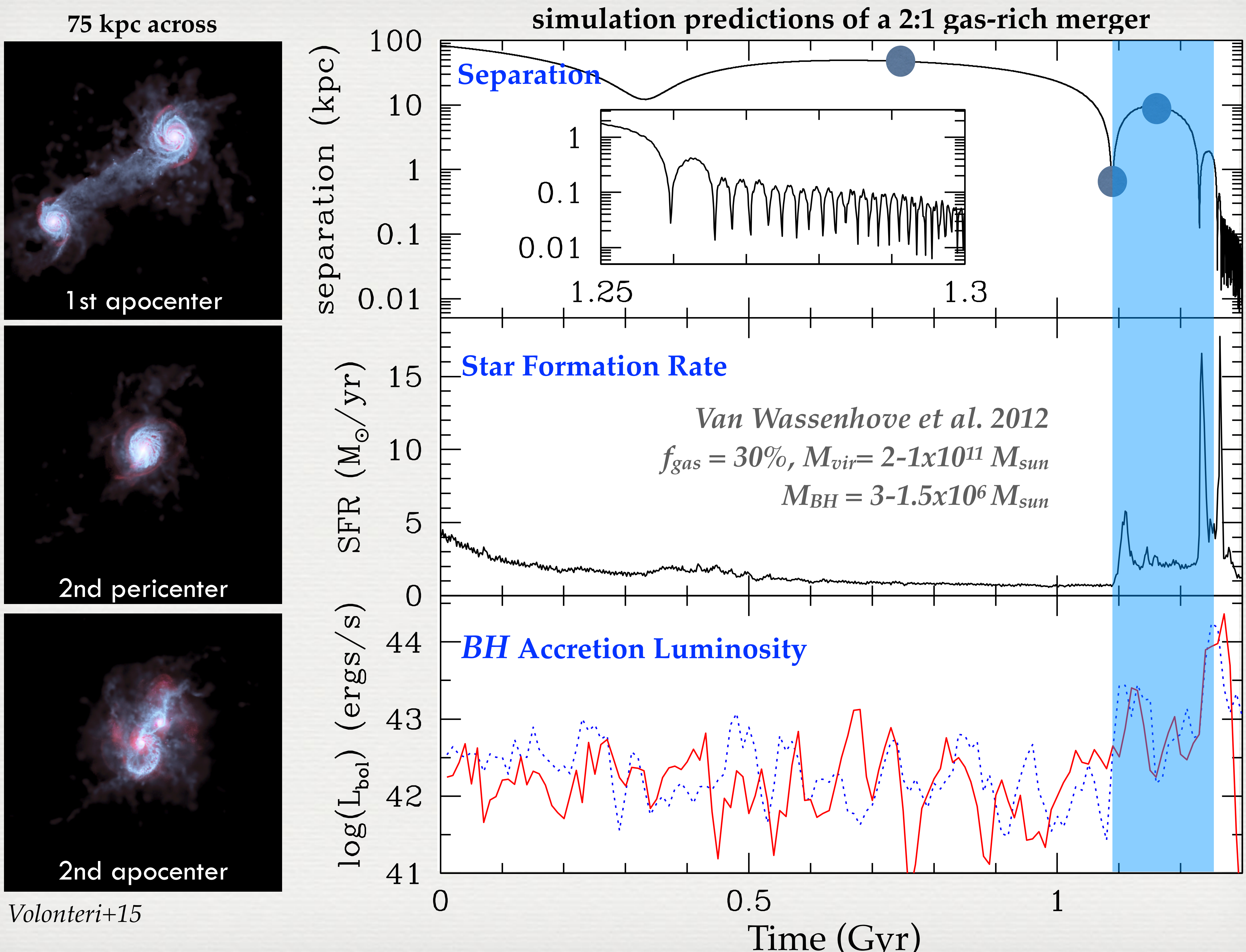
$$R_\mathrm{B} = \frac{2GM_\bullet}{c_s^2}$$
$$\simeq 17\,\mathrm{pc}\left(\frac{M_\bullet}{10^8\,M_\odot}\right)\left(\frac{0.5\ \mathrm{keV}}{kT}\right)$$

- Angular momentum

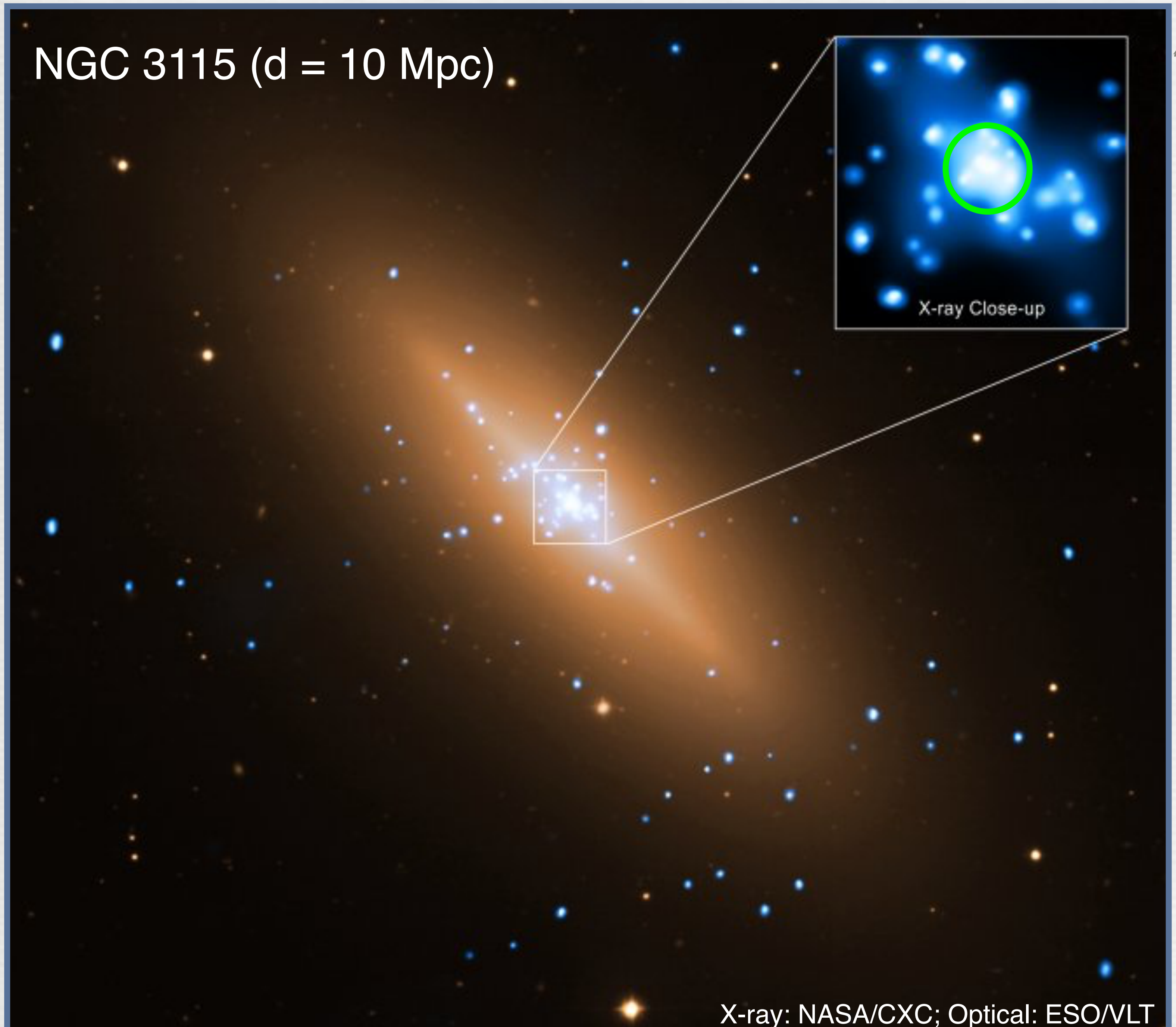
$$\mathbf{L} = \mathbf{r} \times \mathbf{p}$$

tidally-induced stellar bars can drive rapid gas inflows

How to efficiently remove the angular momentum of the gas?


75 kpc across
1st apocenter
2nd pericenter
2nd apocenter
Volonteri+15
simulation predictions of a 2:1 gas-rich merger
Separation
separation (kpc)
100
10
1
0.1
0.01
1.25
1.3
Star Formation Rate
SFR ($M_\odot$/yr)
15
10
5
0
Van Wassenhove et al. 2012
f_{gas} = 30%, M_{vir}= 2-1x10^{11} M_{sun}
M_{BH} = 3-1.5x10^{6} M_{sun}
BH Accretion Luminosity
log(L_{bol}) (ergs/s)
44
43
42
41
0
0.5
1
Time (Gyr)

Caveat #1:
BH Feeding Zone Barely Resolved

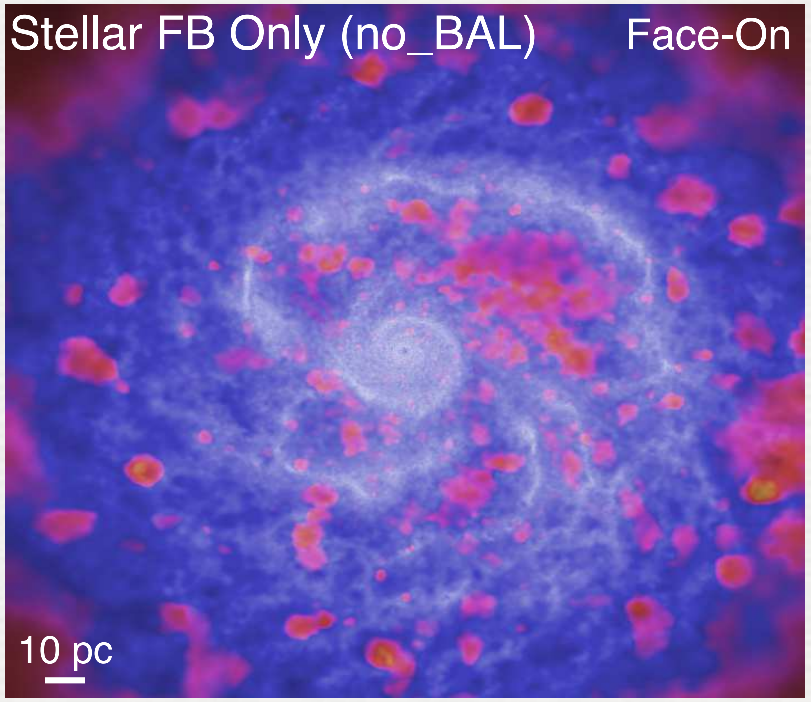


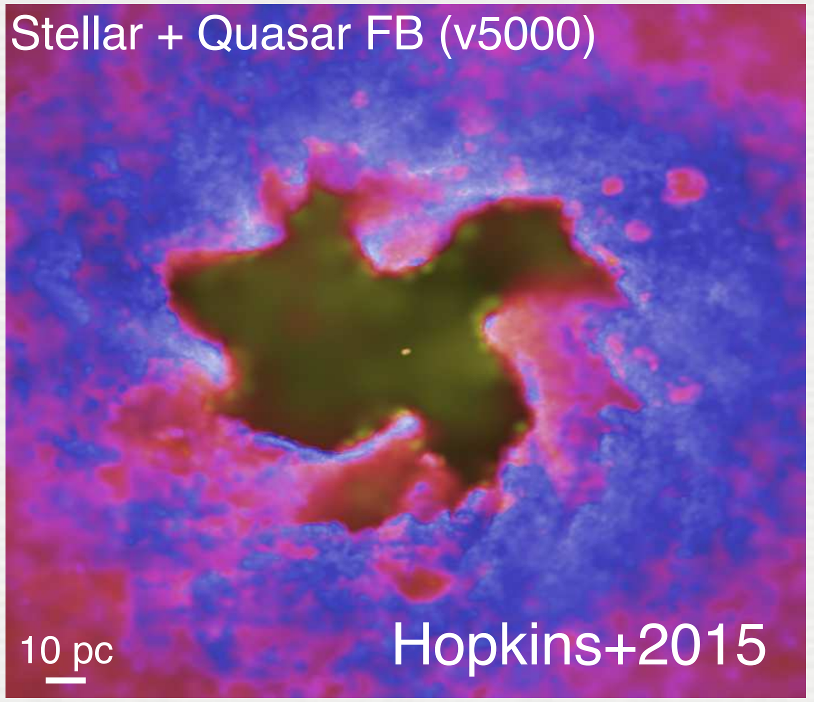
Shcherbakov et al. 2014

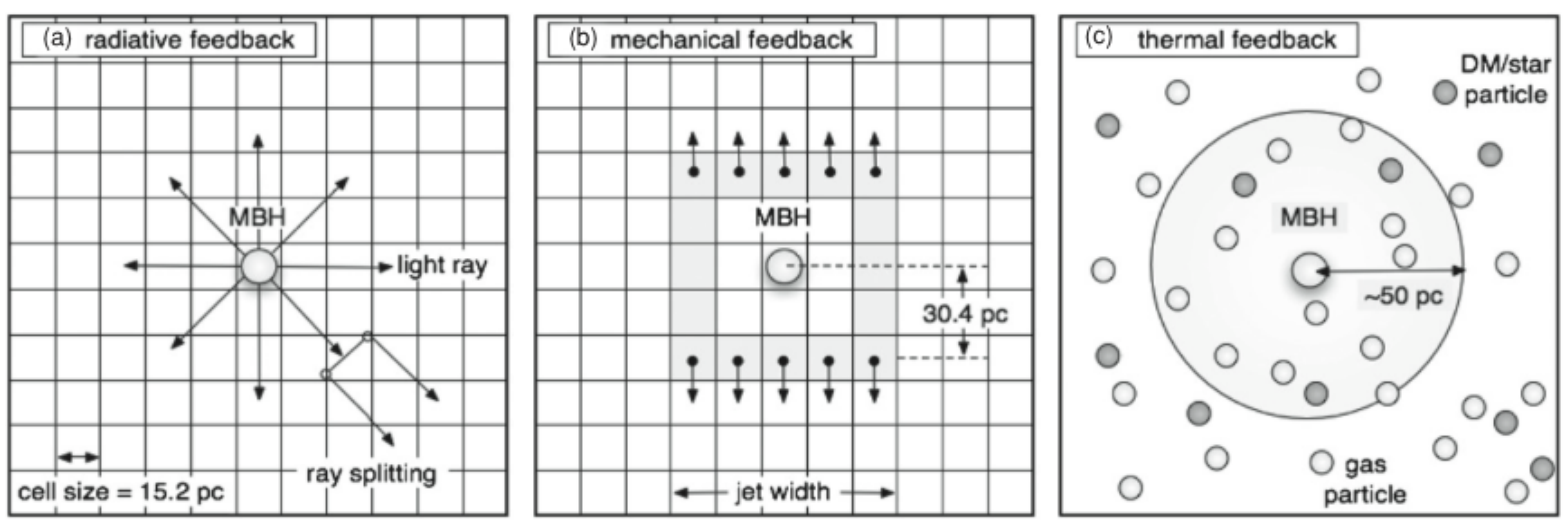
- Typical resolution is ~10 pc in simulations. The black hole's sphere of influence is barely resolved.

$$R_{\rm B} = \frac{2GM_\bullet}{c_s^2}$$
$$\simeq 17\,{\rm pc}\left(\frac{M_\bullet}{10^8\,M_\odot}\right)\left(\frac{0.5\ {\rm keV}}{kT}\right)$$

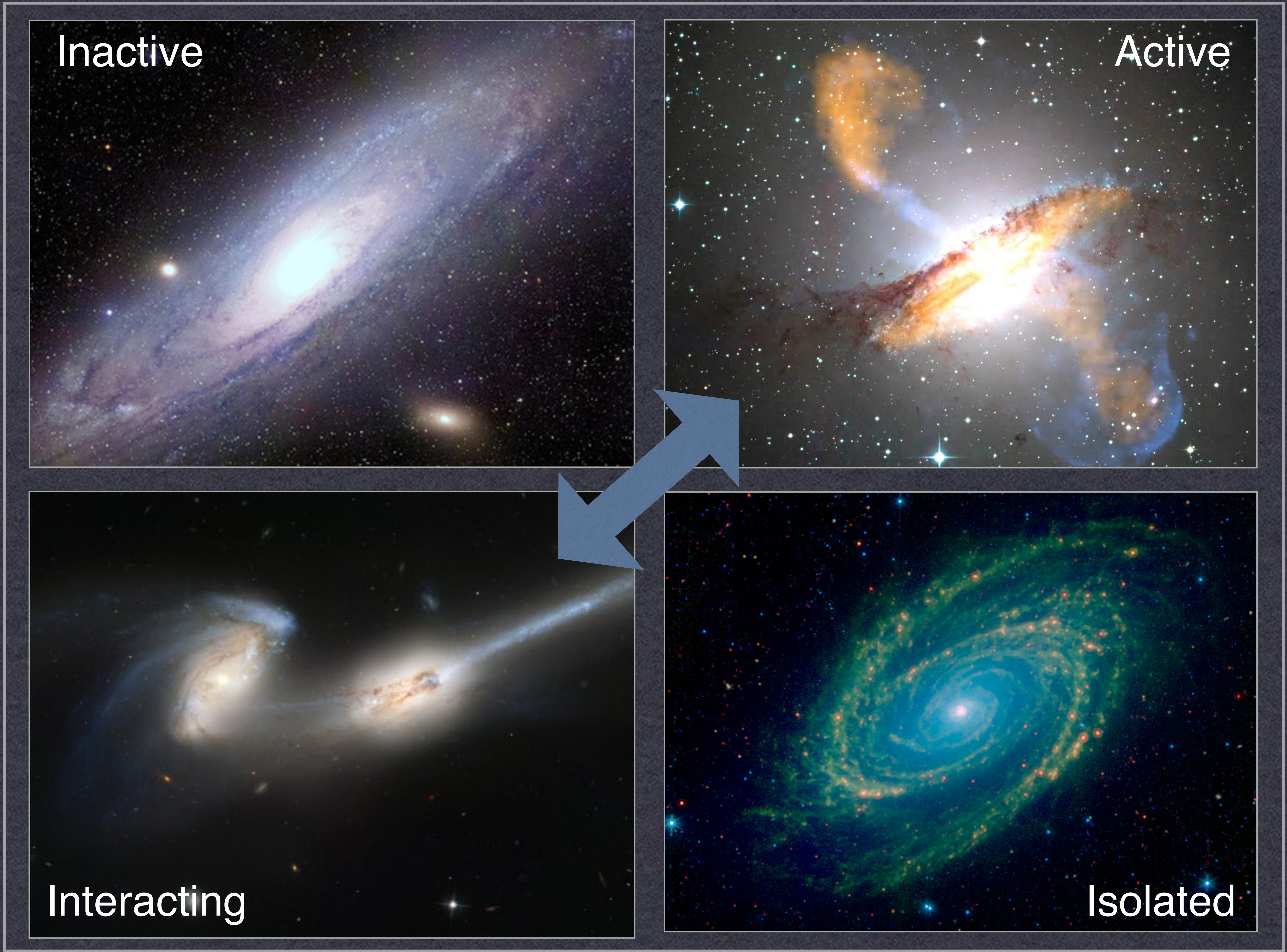
Caveat #2:
Uncertain self-regulation mechanisms



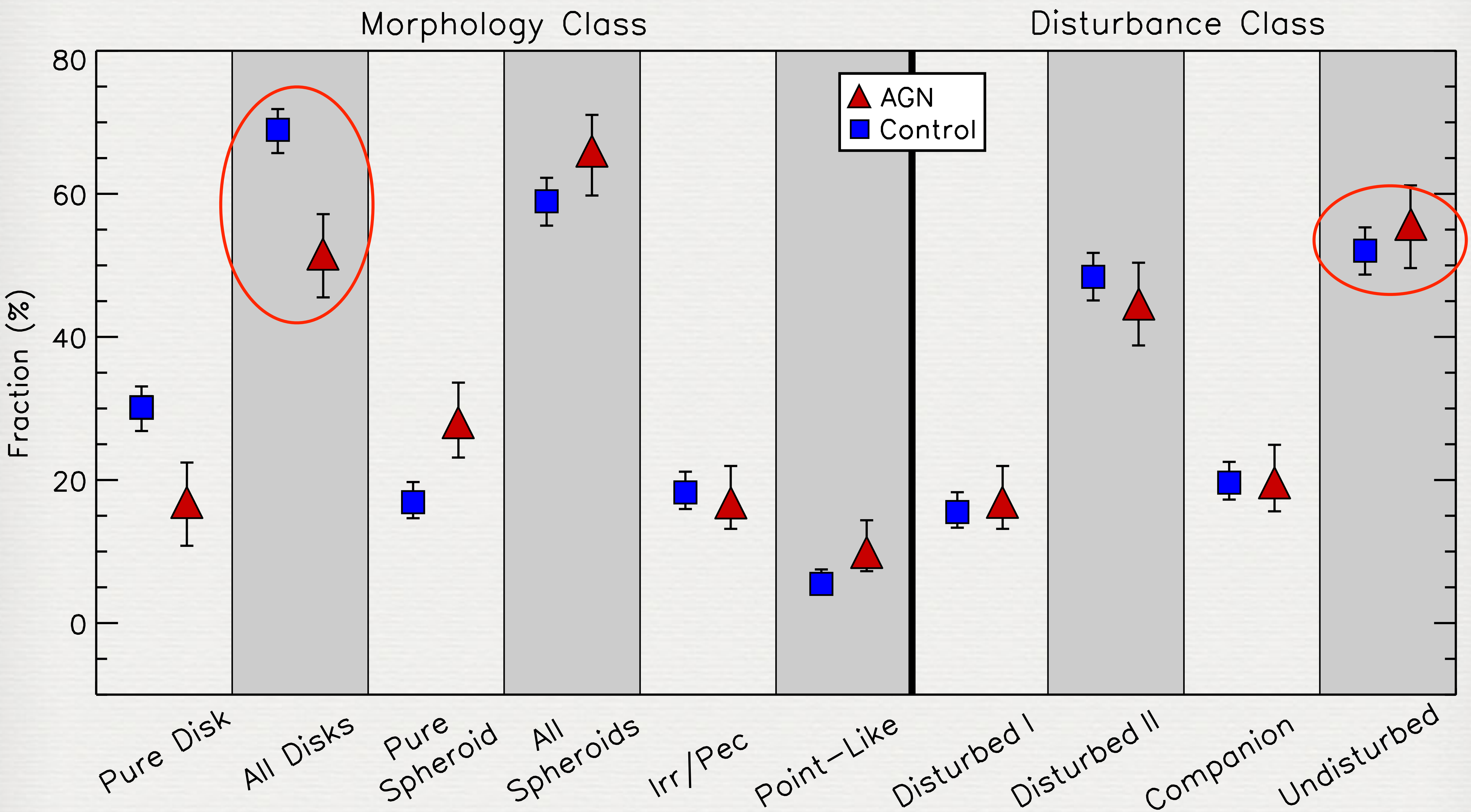




Kim+11

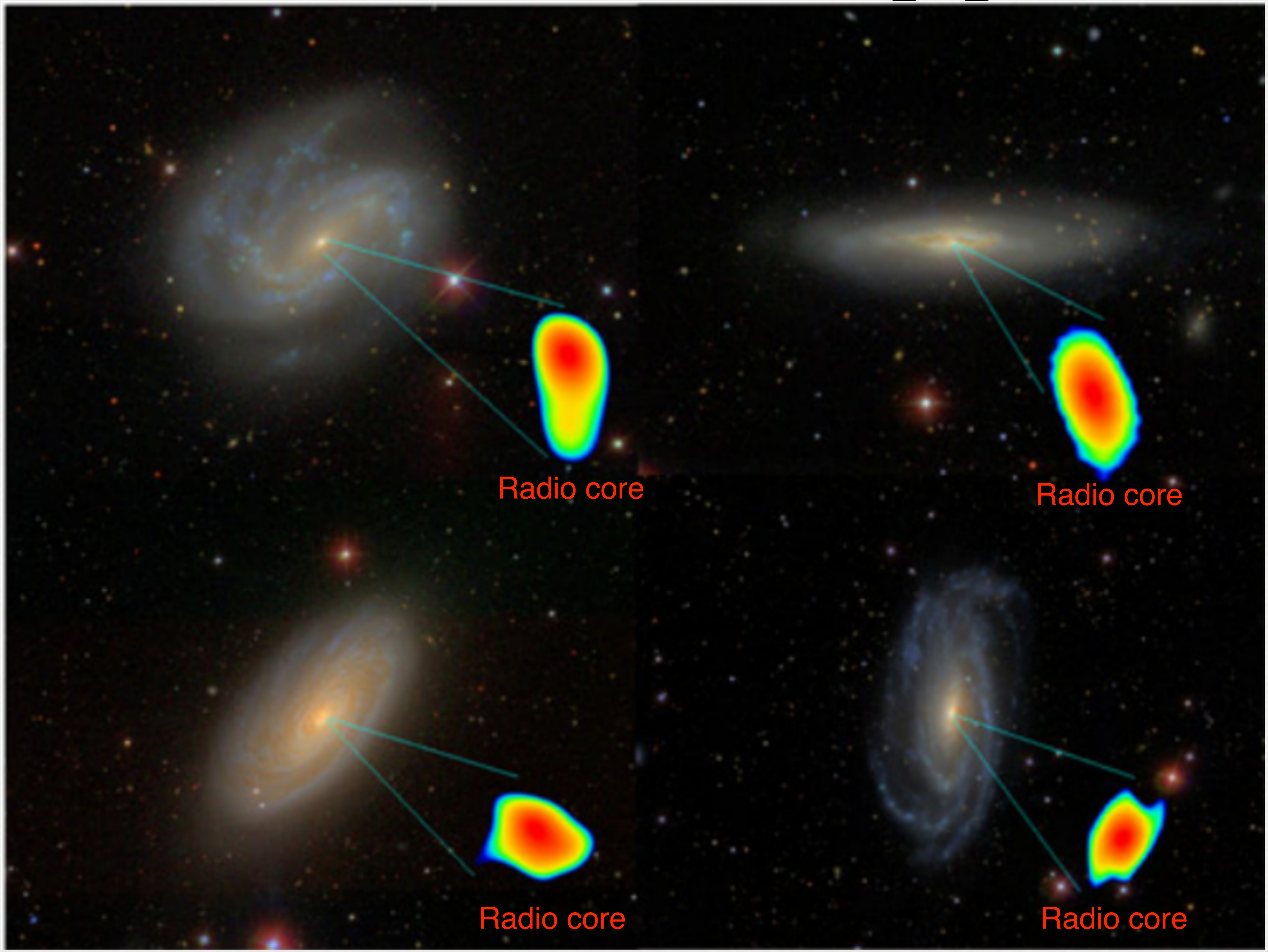

Inactive
Active
Interacting
Isolated

AGN show similar galaxy morphologies as non-AGN



X-ray-selected AGN at 1.5 < z < 2.5 (Kocevski+12)

The stochastic feeding baseline:
AGN in non-interacting galaxies



Giroletti & Panessa 2010

AGN Triggering Mechanisms: Merger-Driven vs. Stochastic Feeding

- Simulations indicate merger is important
- An observational test will require
  - a spectroscopic galaxy survey that have:
    - an interacting sample: close galaxy pairs
    - a non-interacting control sample
    - and quantifiable selection biases
  - counting AGN in both pair sample and control sample and correcting for sample biases
  - a comparison between observed and expected AGN volume densities in close galaxy pairs

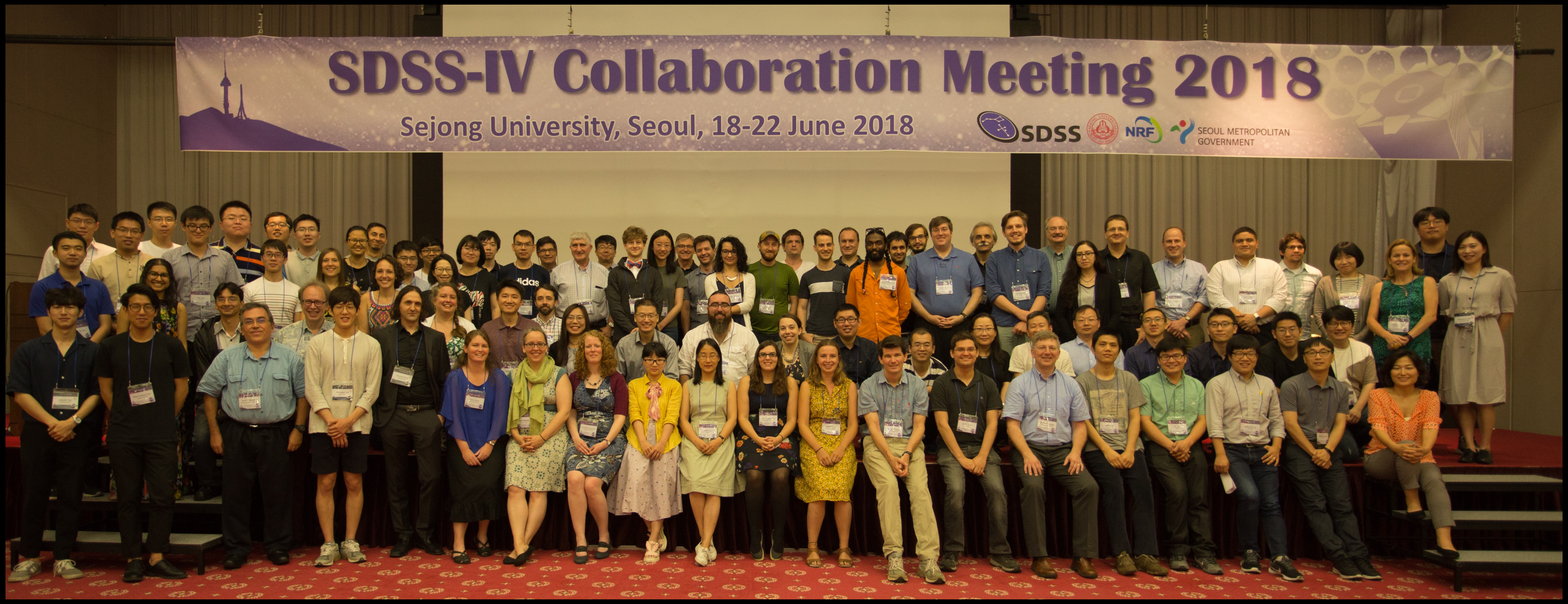
Galaxy Mergers in MaNGA

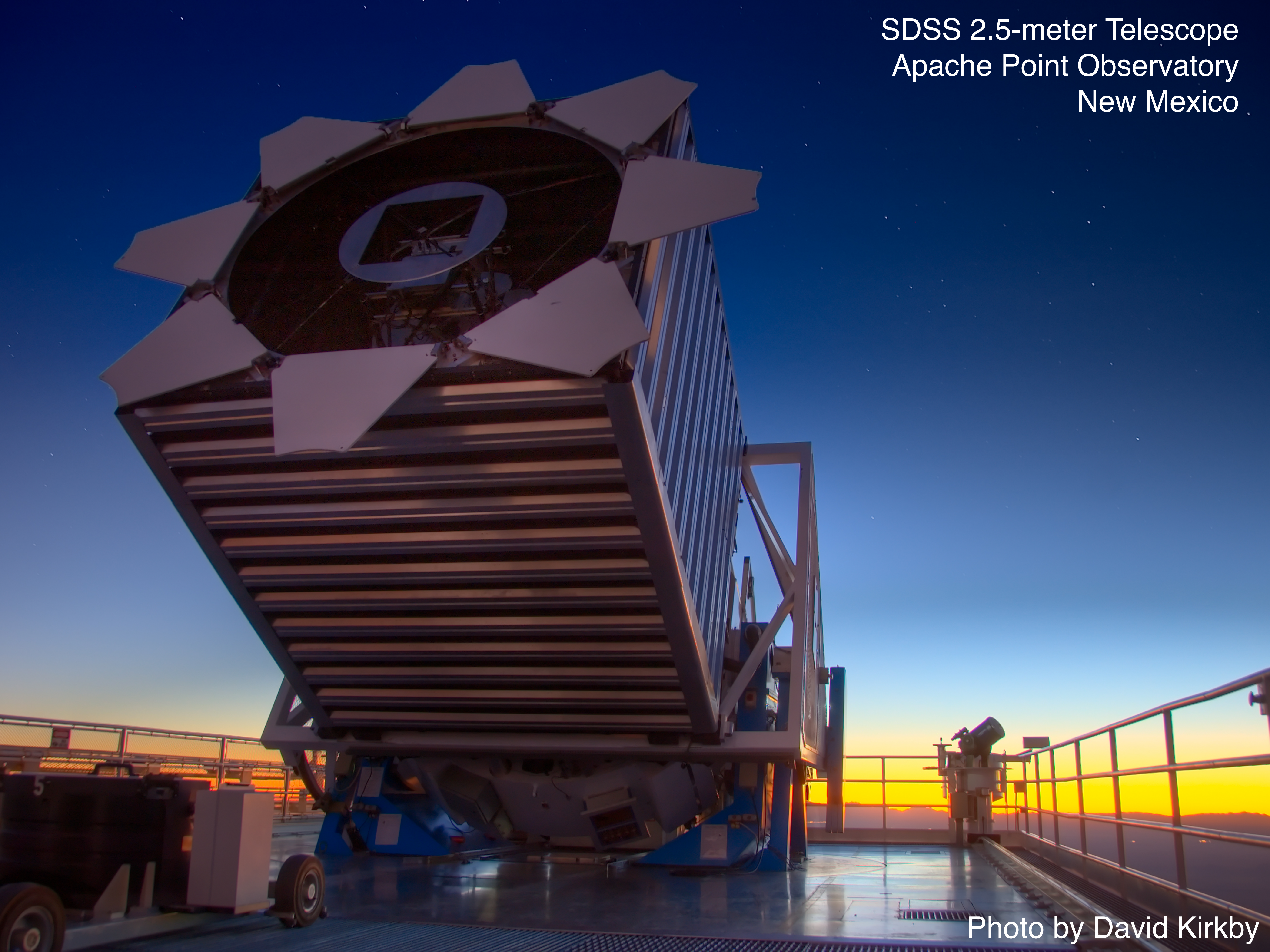
Fu, Steffen, Gross, et al. (2018) ApJ 856 93 (Paper I - AGN activity)
Steffen, Fu, et al. (2019) in prep. (Paper II - Star Formation & Metallicity)

Josh Steffen (UI grad)

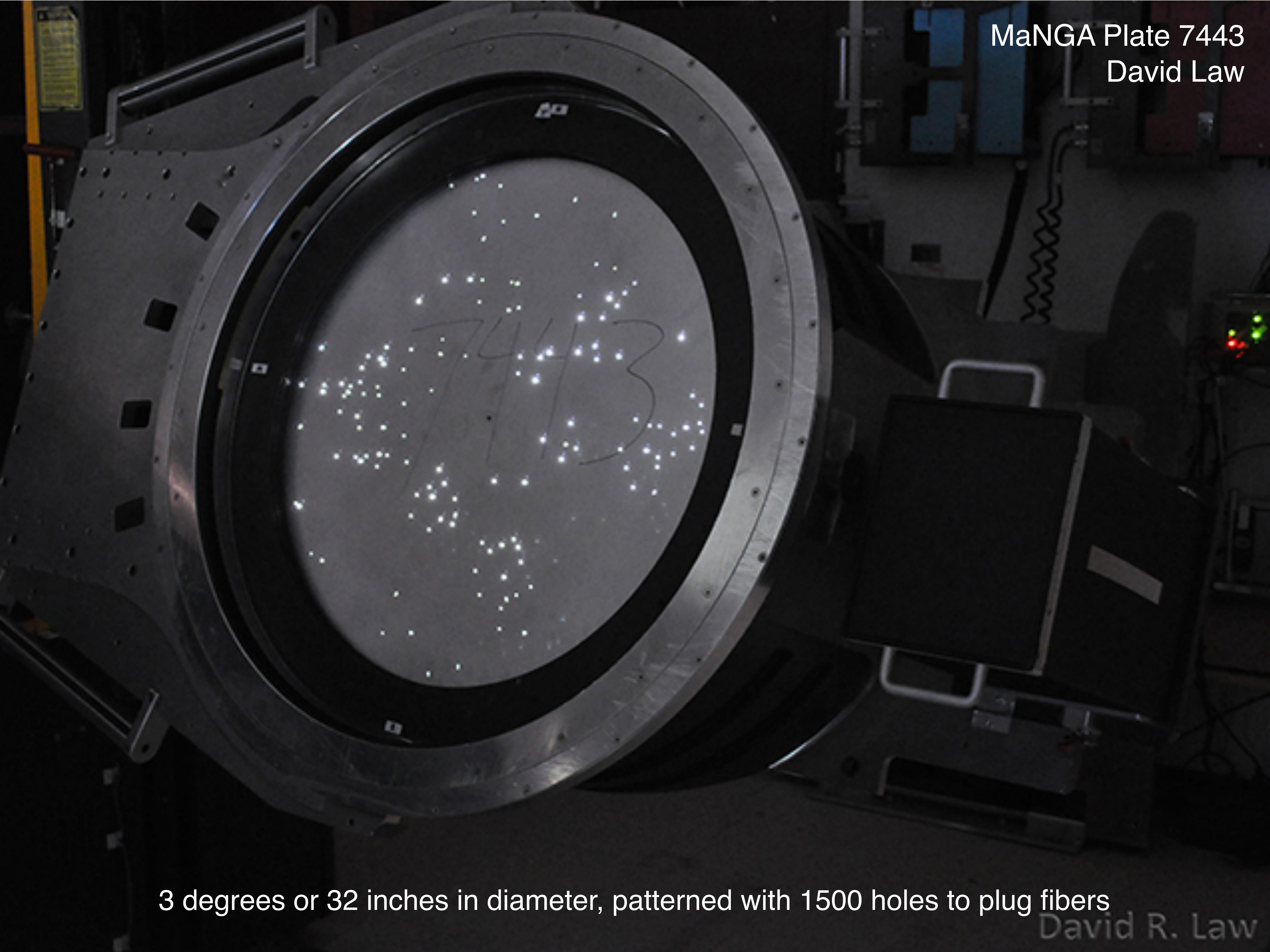
Arran Gross (UI grad)

Jacob Isbell (UI UG, now at MPIA)




SDSS 2.5-meter Telescope
Apache Point Observatory
New Mexico
Photo by David Kirkby

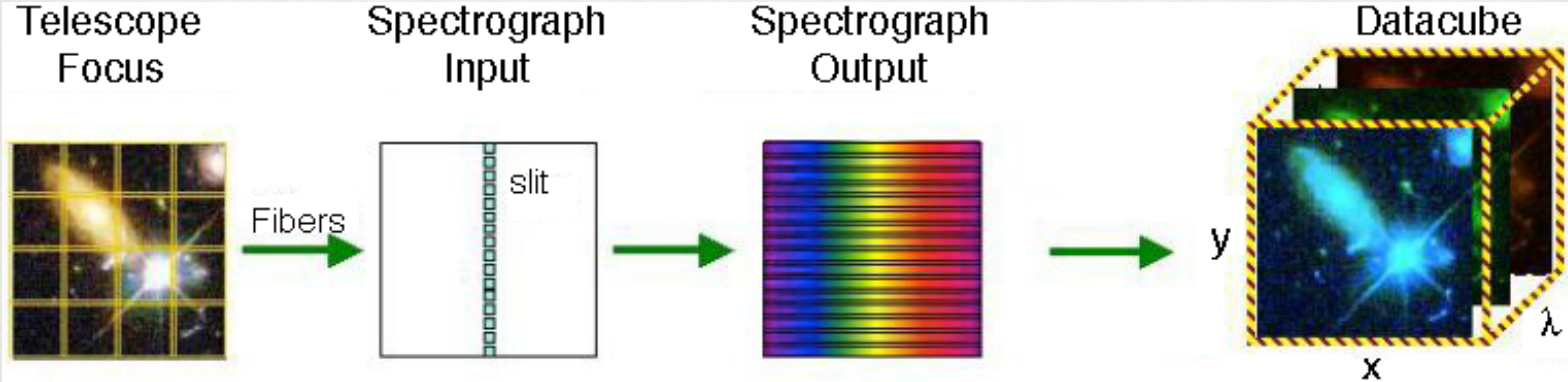
MaNGA Plate 7443
David Law

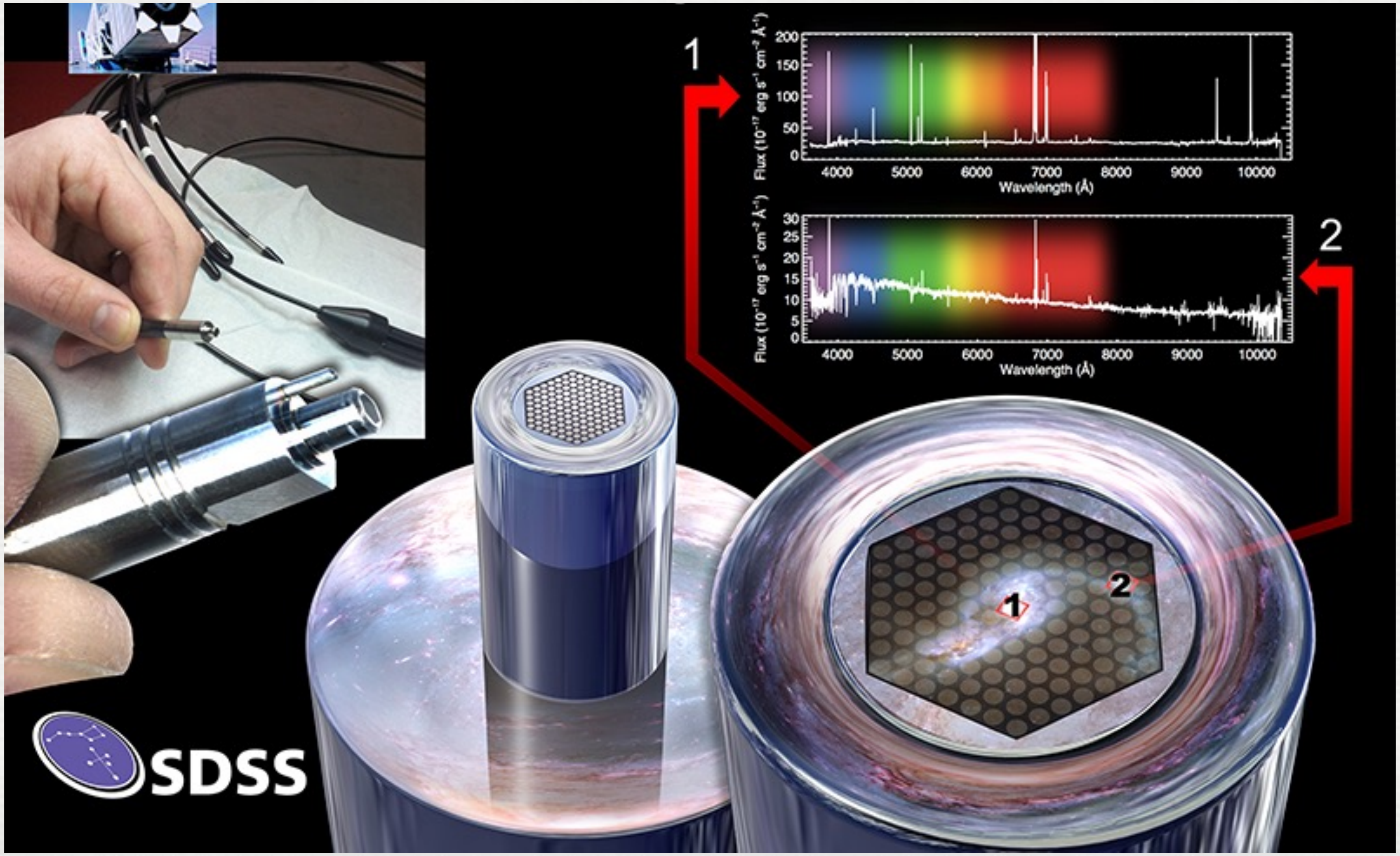


3 degrees or 32 inches in diameter, patterned with 1500 holes to plug fibers

Anne-Marie Weijmans
plugging fibers into plate

MaNGA Integral-Field Spectroscopy

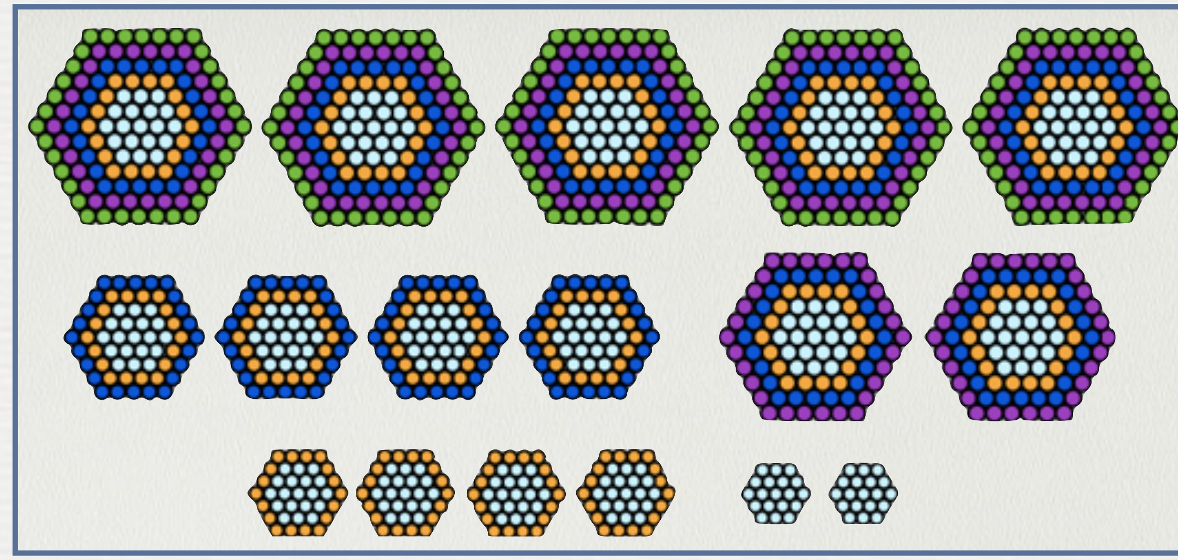




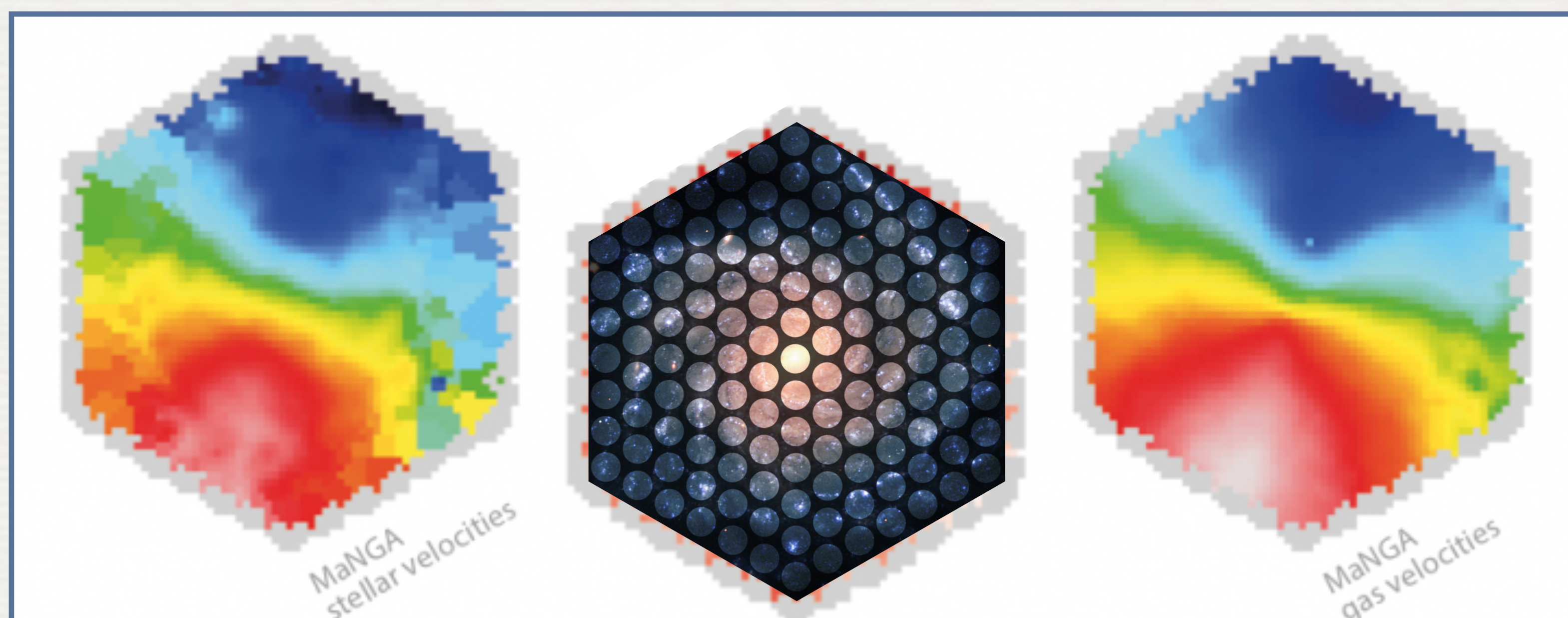
SDSS-IV MaNGA: Mapping Nearby Galaxies at APO

- Fall 2014 to Spring 2020

Bundy+15

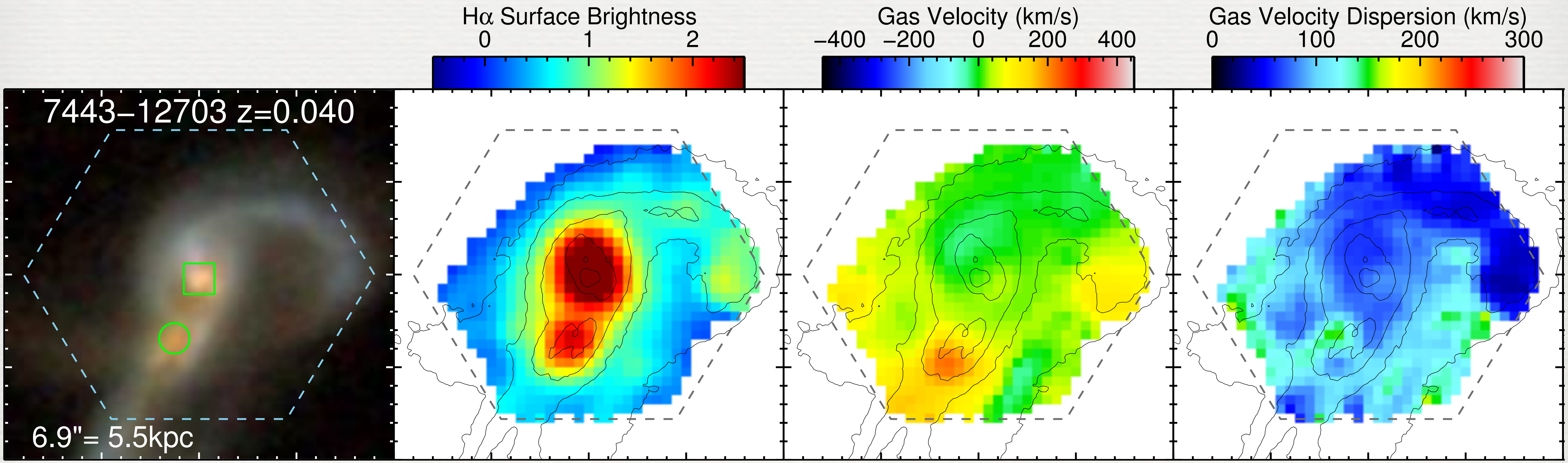


- 17 science IFUs per plate: 5/2/4/4/2 of 127/91/61/37/19-fibers (2″-diameter fibers)

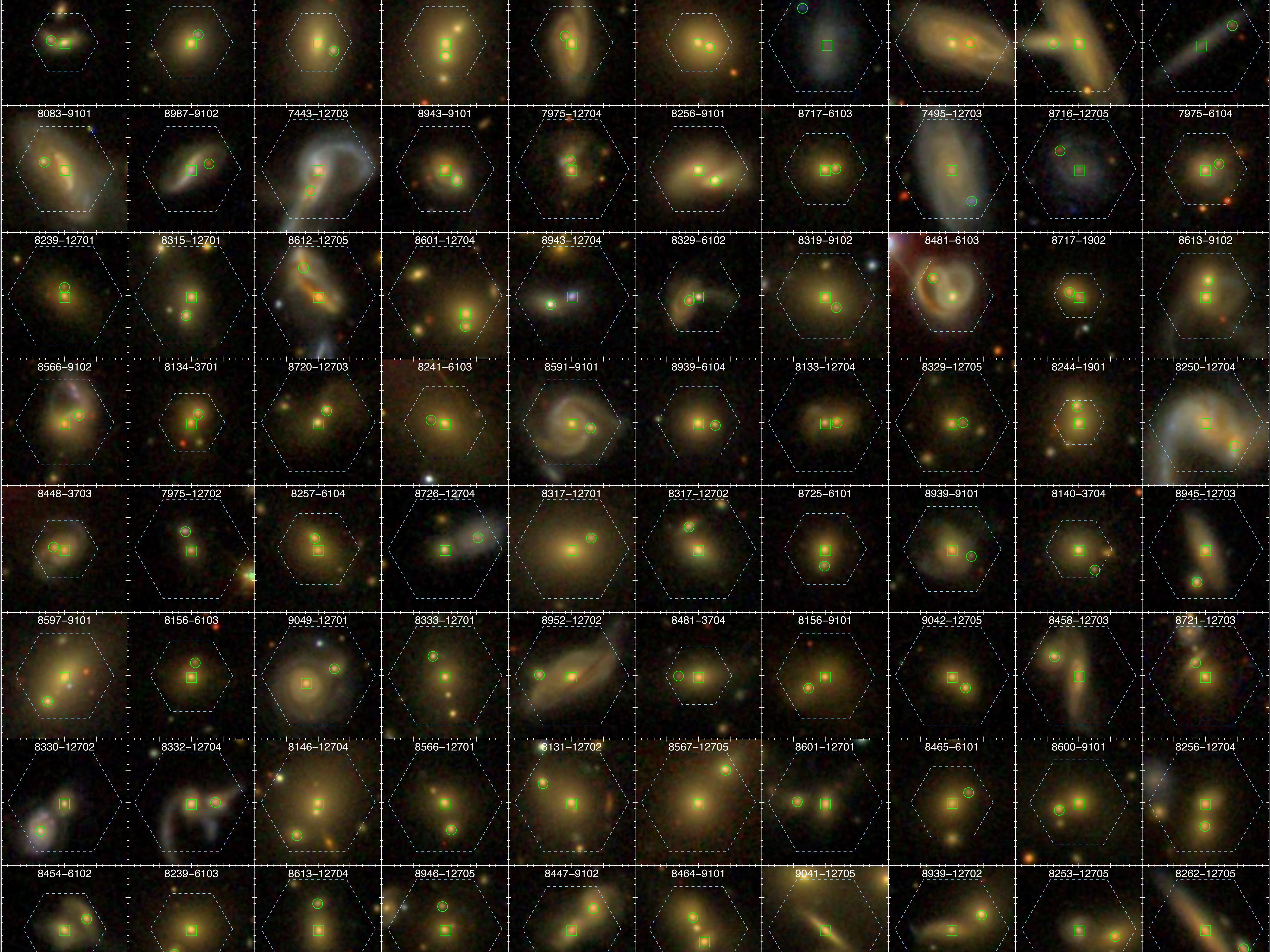


- **10,000 galaxies at 0.01 < z < 0.15 (2,772 in DR14) (6,142 in DR16)**
- R ~ 2000
  Exptime ~ 3 hours

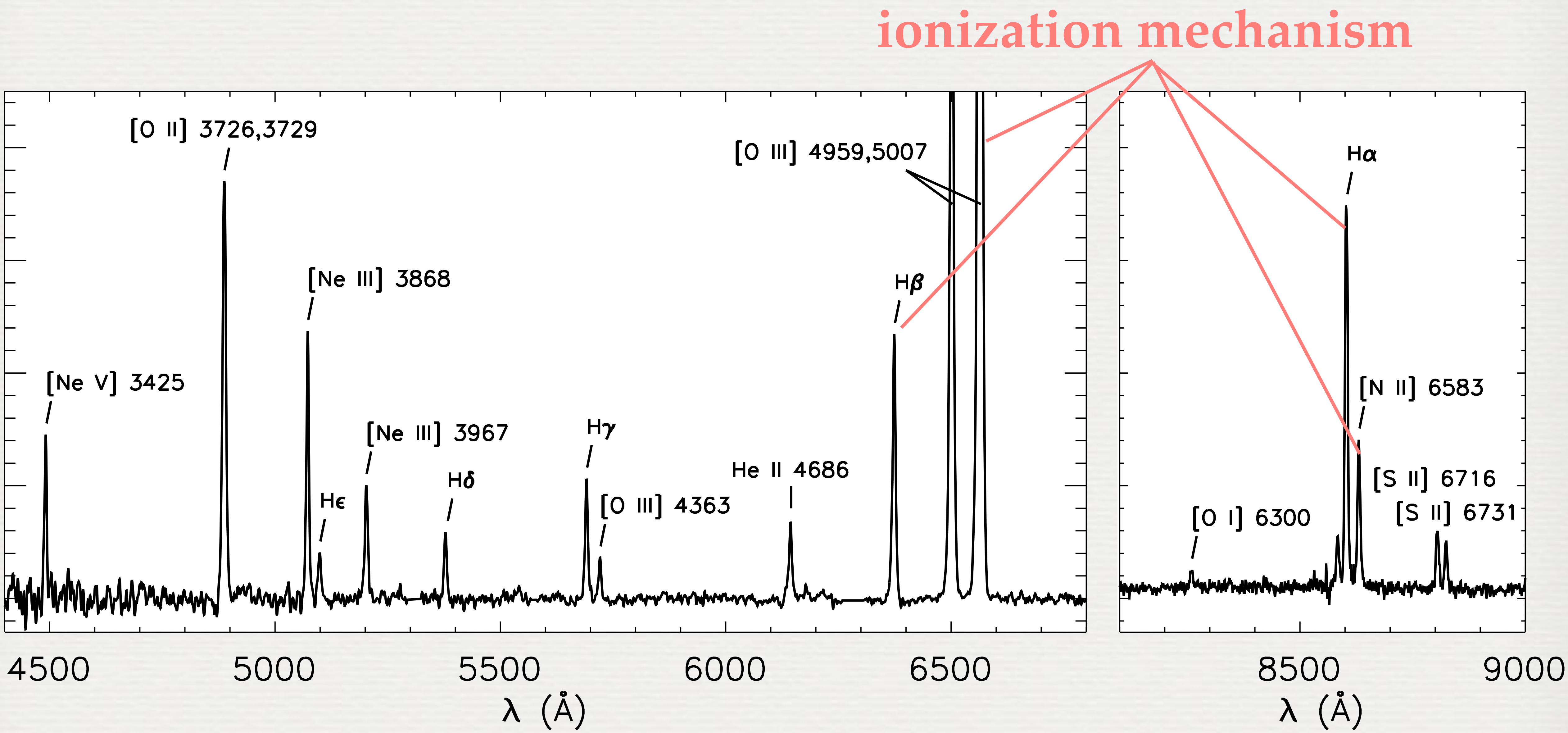
1. Selection of pairs that are fully covered by single IFUs



- DR14 Main Galaxy Sample: 2,618 unique datacubes
- 105 kinematic pairs in the final sample (~4%):
  - $M_1/M_2 < 10{:}1$, $dV < 600$ km/s, 1 kpc < Sep < 30 kpc


8083–9101
8987–9102
7443–12703
8943–9101
7975–12704
8256–9101
8717–6103
7495–12703
8716–12705
7975–6104
8239–12701
8315–12701
8612–12705
8601–12704
8943–12704
8329–6102
8319–9102
8481–6103
8717–1902
8613–9102
8566–9102
8134–3701
8720–12703
8241–6103
8591–9101
8939–6104
8133–12704
8329–12705
8244–1901
8250–12704
8448–3703
7975–12702
8257–6104
8726–12704
8317–12701
8317–12702
8725–6101
8939–9101
8140–3704
8945–12703
8597–9101
8156–6103
9049–12701
8333–12701
8952–12702
8481–3704
8156–9101
9042–12705
8458–12703
8721–12703
8330–12702
8332–12704
8146–12704
8566–12701
8131–12702
8567–12705
8601–12701
8465–6101
8600–9101
8256–12704
8454–6102
8239–6103
8613–12704
8946–12705
8447–9102
8464–9101
9041–12705
8939–12702
8253–12705
8262–12705

2. AGN Identification



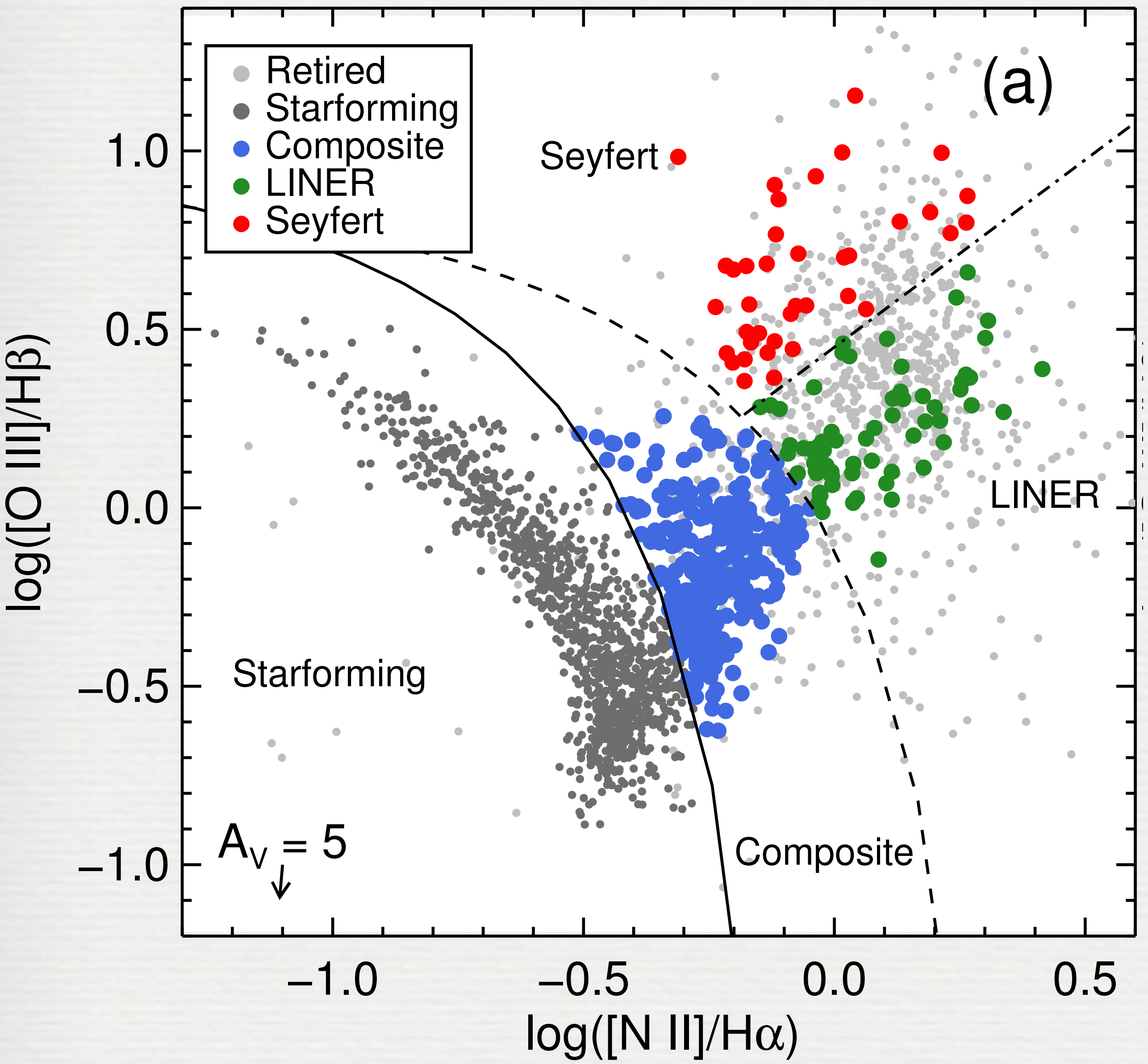
A Spectrum of a Narrow-Line AGN (continuum removed)

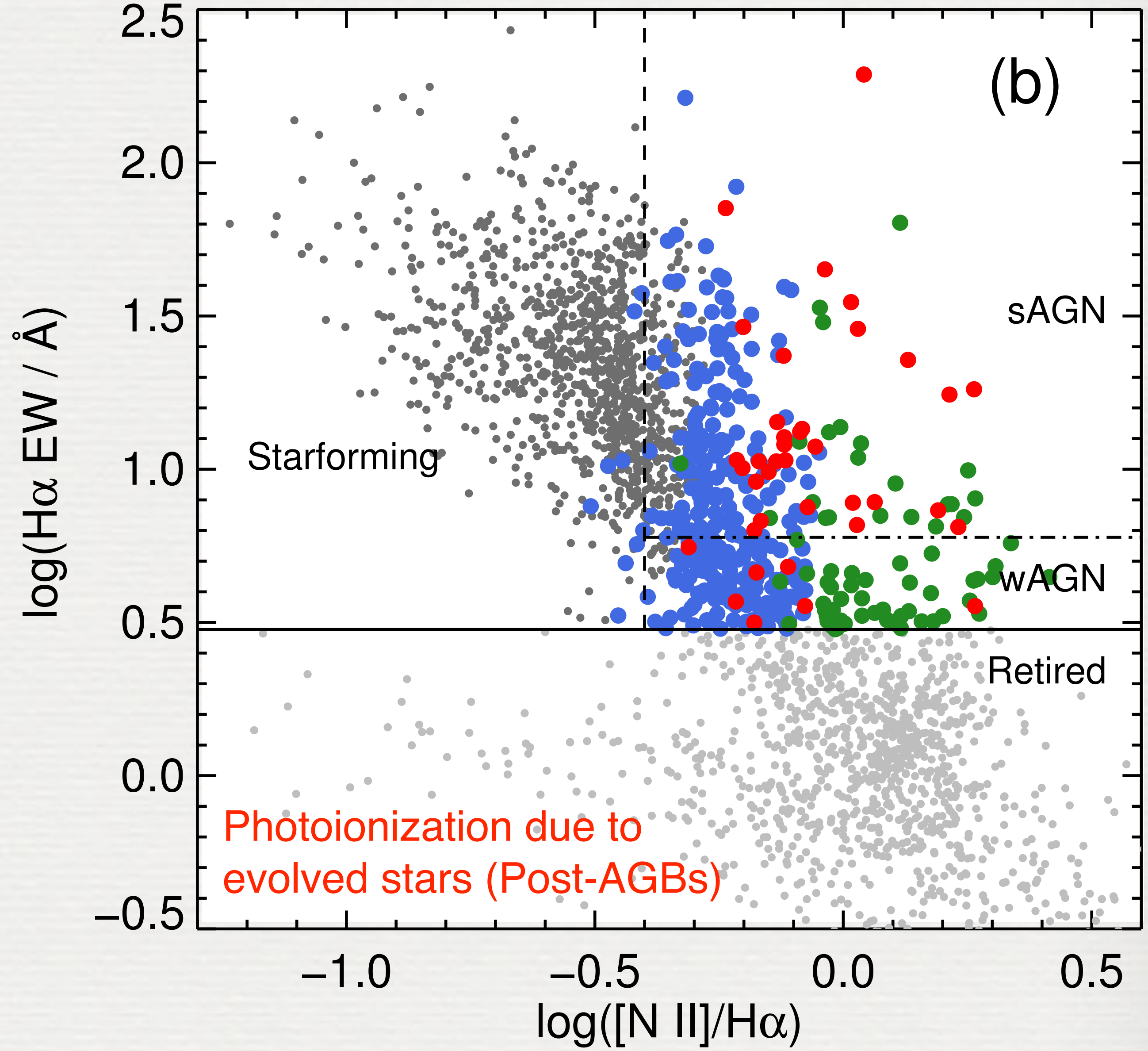
Fu & Stockton (2006)

Emission-line Classification: BPT + WHAN diagrams

- The AGN branch includes Seyferts, LINERs, and Composites

  Based on nuclear spectra extracted with **2.6 kpc**-diameter apertures

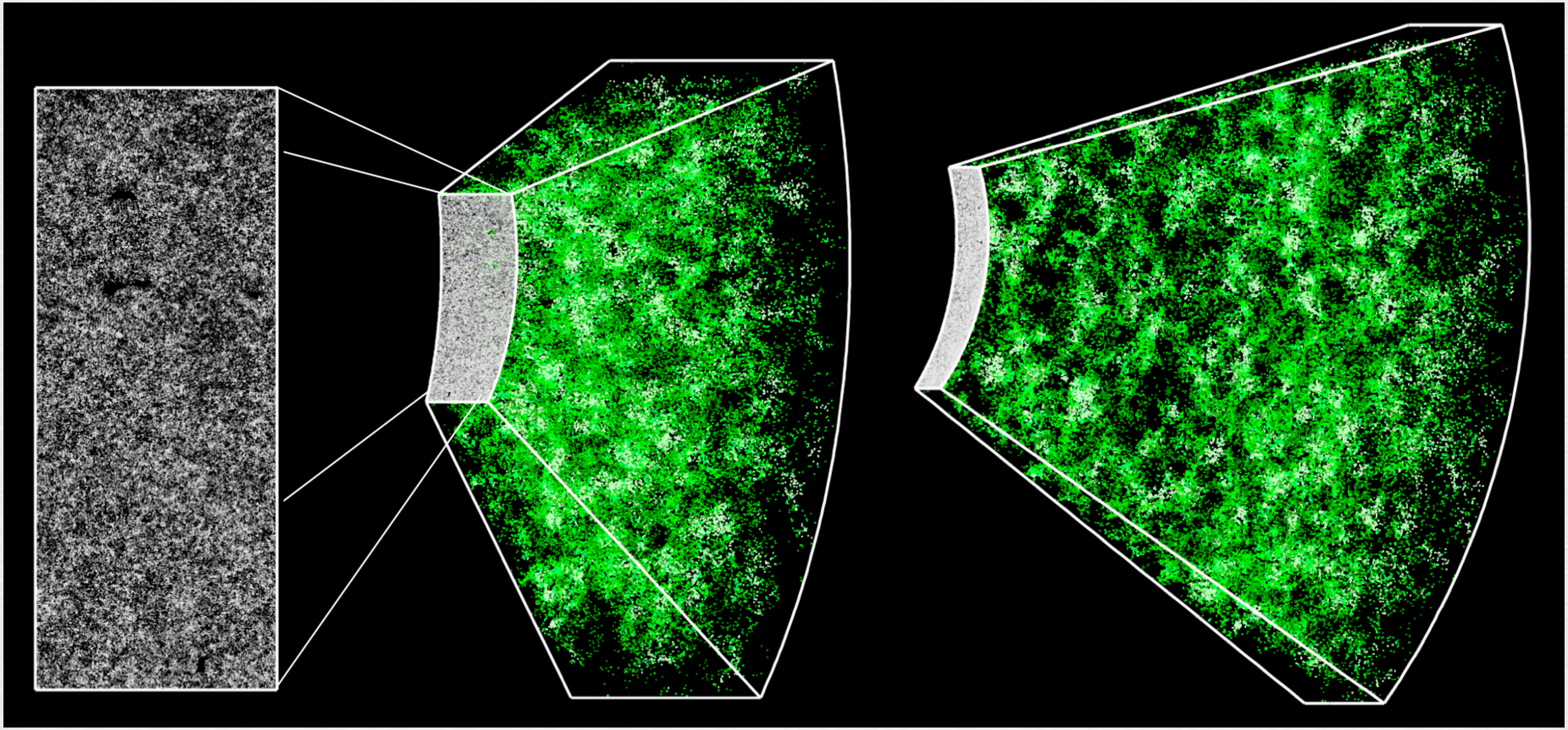




Fu et al. (2018)

3. Correcting for MaNGA Sample Biases

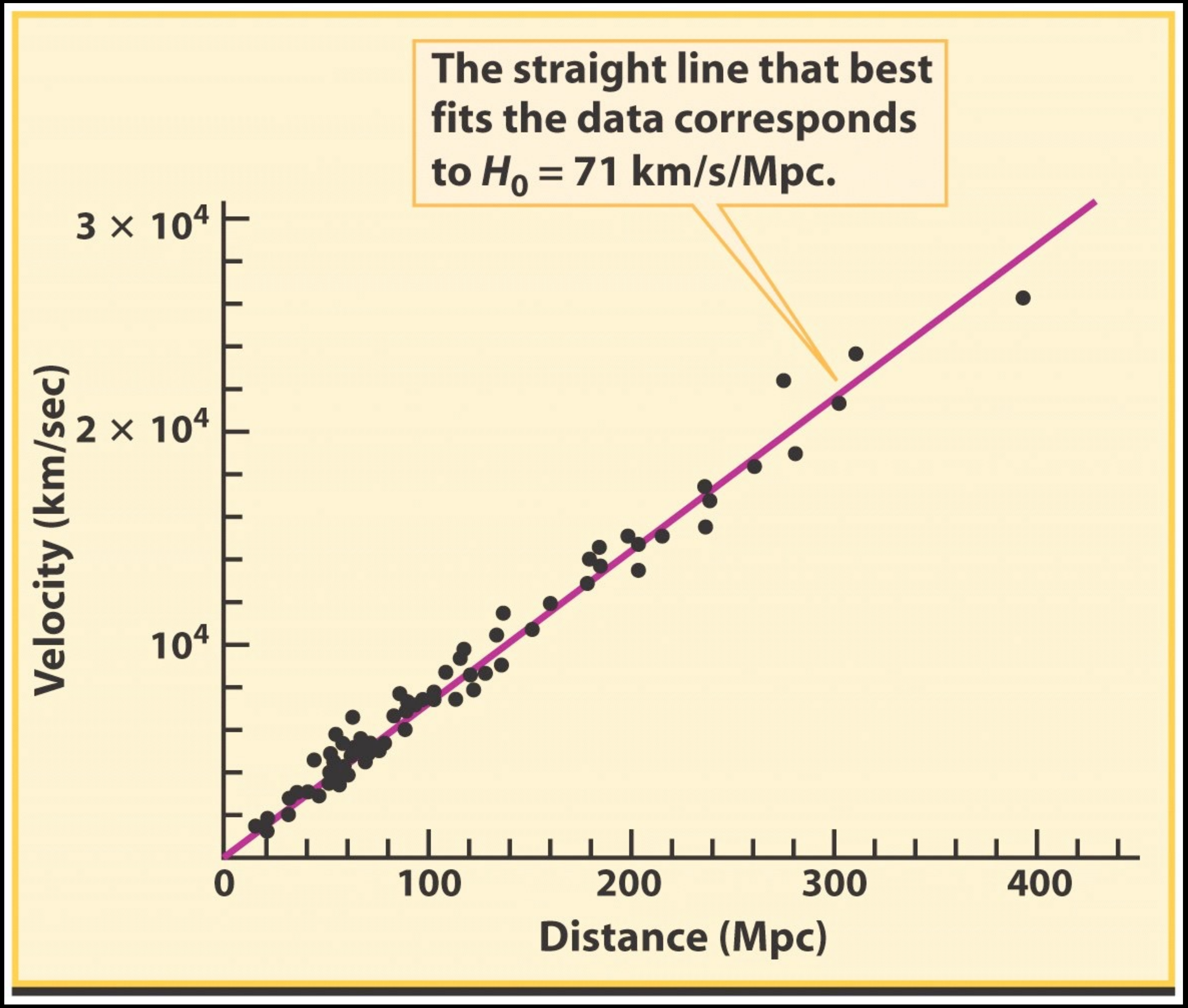
A Volume-Limited Sample of Galaxies



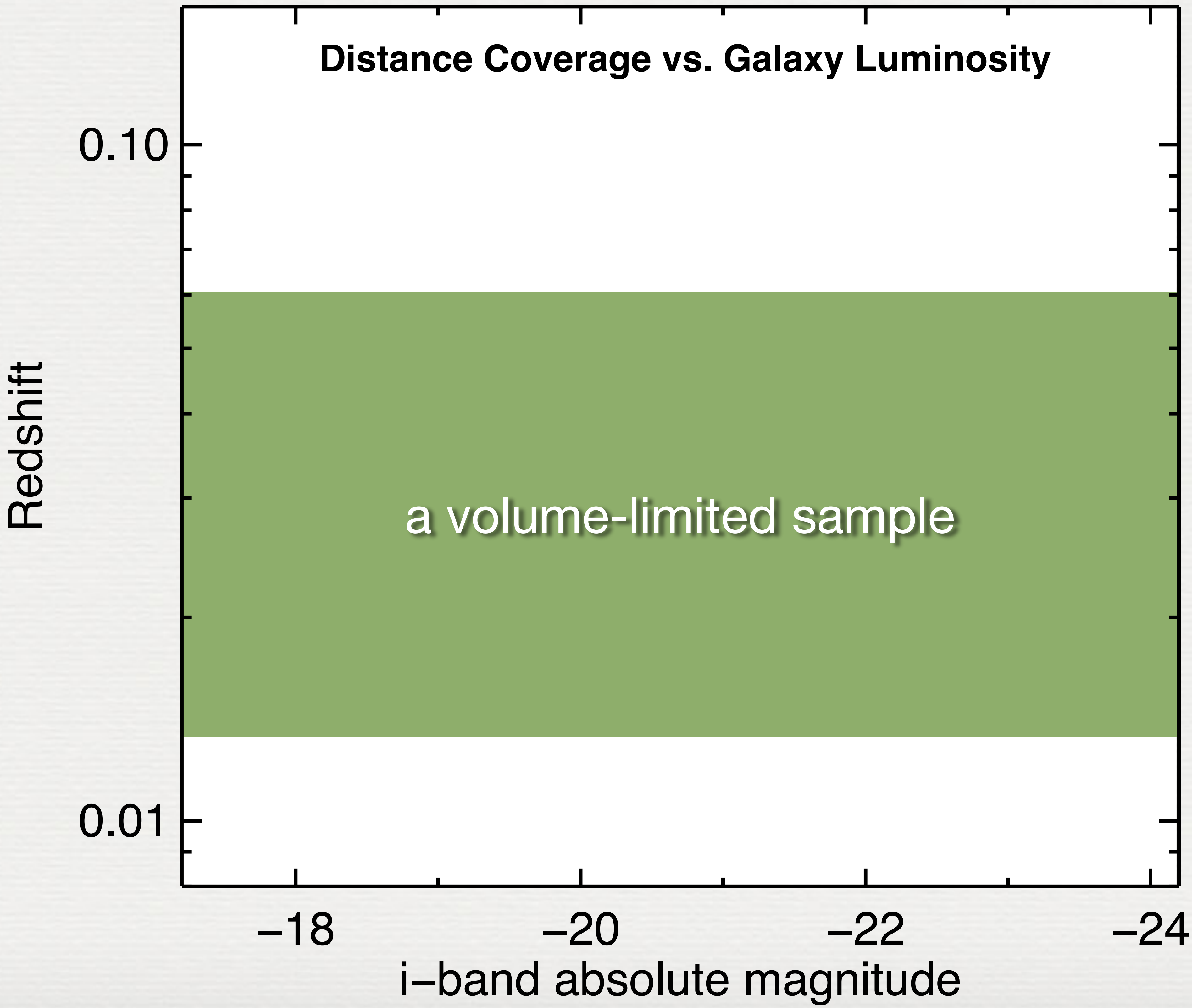
"The history of astronomy is a history of receding horizons"

–EDWIN HUBBLE

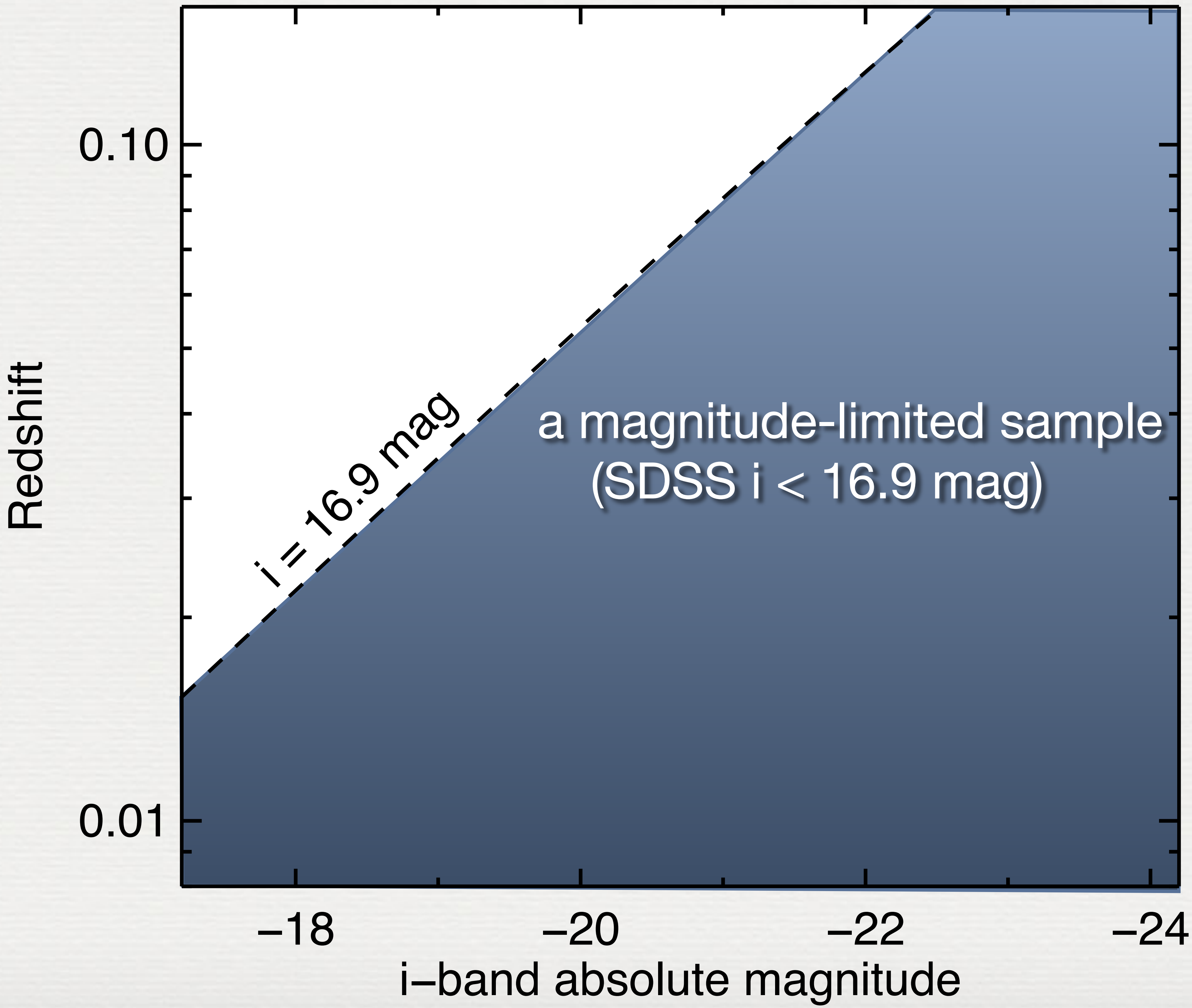
Distance = $c\, z\, H_0$, where z is the **redshift**



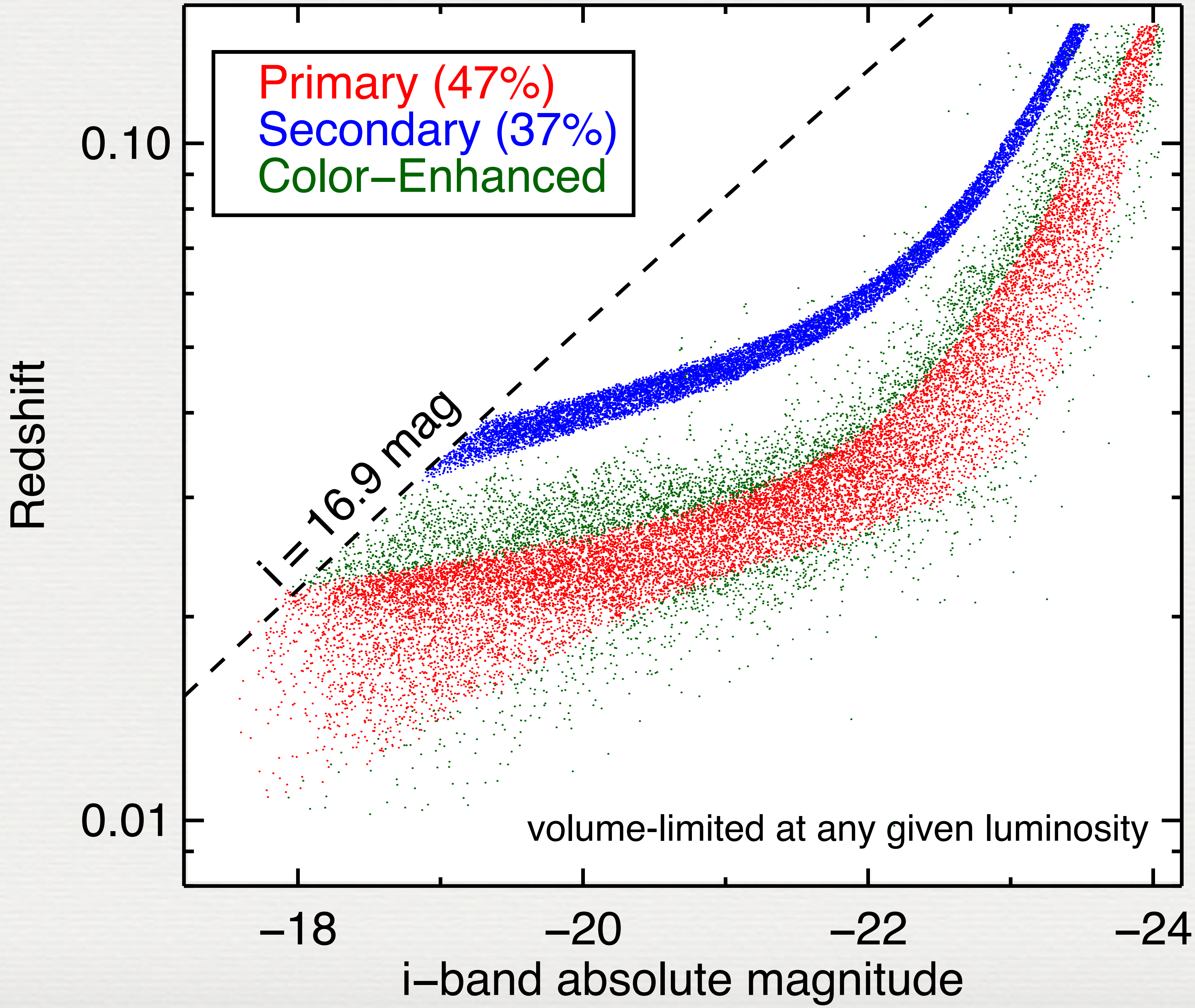
A volume-limited sample



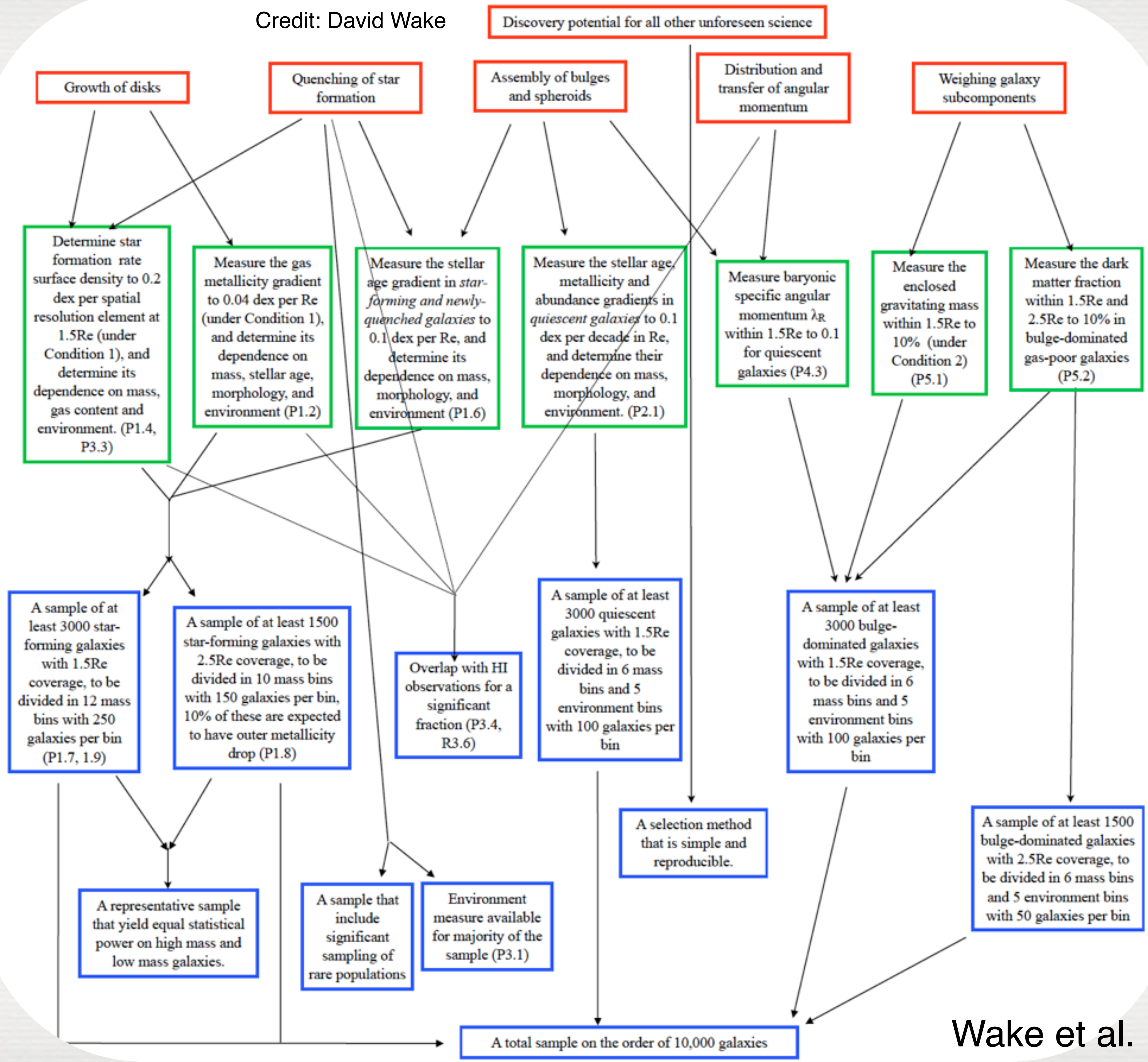
A flux-limited sample



The MaNGA sample:
survey volume varies with luminosity



MaNGA Science Drivers



Wake et al. (2017)

Correcting a MaNGA sample to a volume-limited one

The volume density of a galaxy population can be estimated from an observed sample as:

$$n(\mathcal{M}_{\min}, \mathcal{M}_{\max}) \simeq \sum_{j=1}^{N_{\mathrm{obs}}} W_j / 10^6 \ \mathrm{Mpc}^3$$

where the dimensionless weight (W_j) is calculated for each galaxy as:

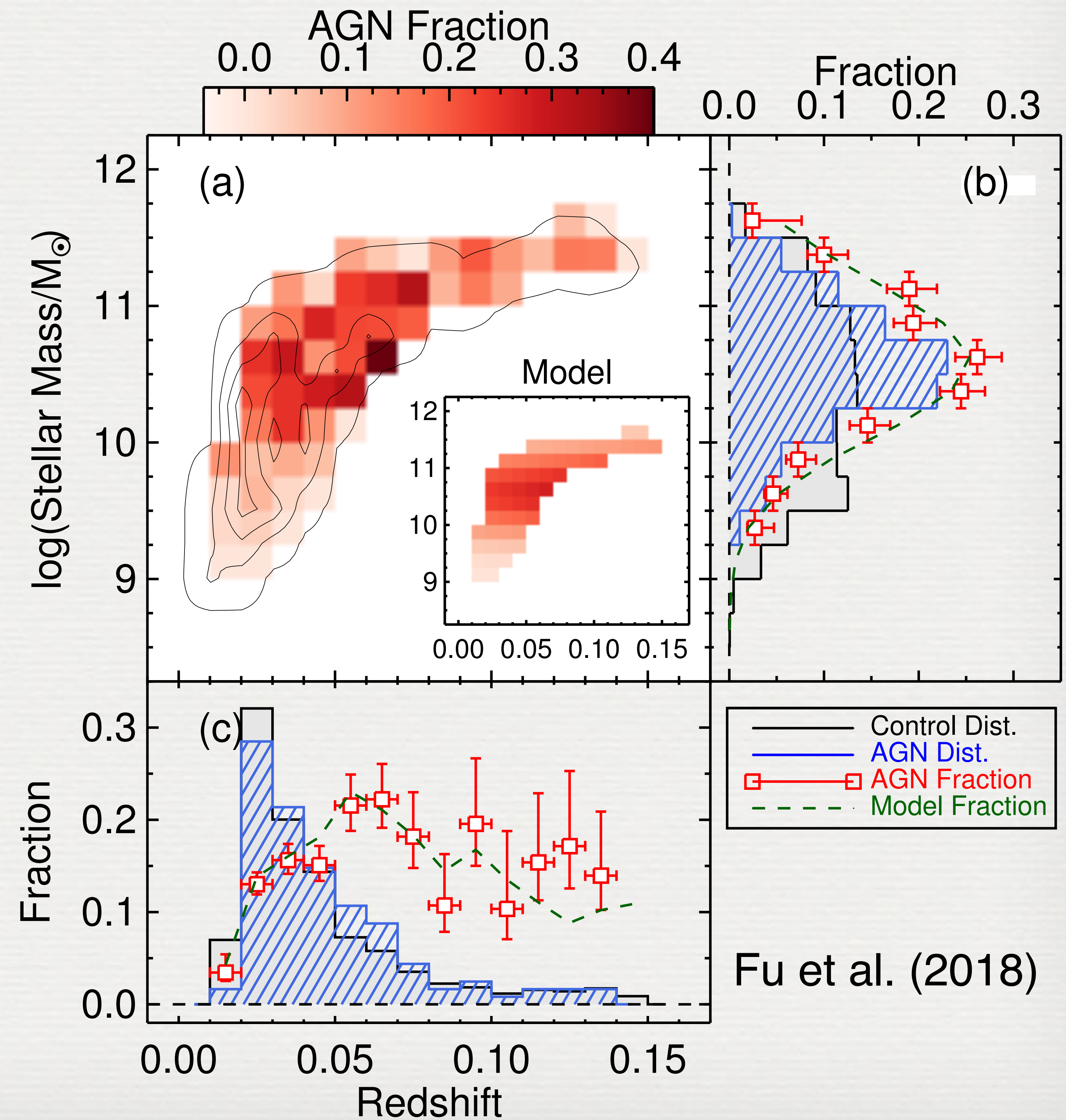
$$W_j \equiv \frac{N_{\mathrm{tiled}}}{N_{\mathrm{obs}}} \frac{10^6 \ \mathrm{Mpc}^3}{V_{\mathrm{tiled}}[z_{\min}(\mathcal{M}_j), z_{\max}(\mathcal{M}_j)]}$$

so instead of **counting the number of galaxies**, we shall sum their **M_i-dependent volume-density weights**.

4. Setting the stochastic AGN baseline in close pairs

we need probabilities of stochastic AGN

- $f_{AGN}(M, z)$
- calculated from the AGN fractions in the non-interacting **control sample.**



Fu et al. (2018)

First, the expected volume density of pairs that host at least one AGN can be calculated as:

$$n_{\rm eagn}^{\rm exp} = \sum_{j=1}^{N_{\rm pair}} W_j \; f_{\rm agn}(M_j^p, z_j)$$

Primary as AGN

$$+ \sum_{j=1}^{N_{\rm pair}} W_j \; f_{\rm agn}(M_j^s, z_j)$$

Secondary as AGN

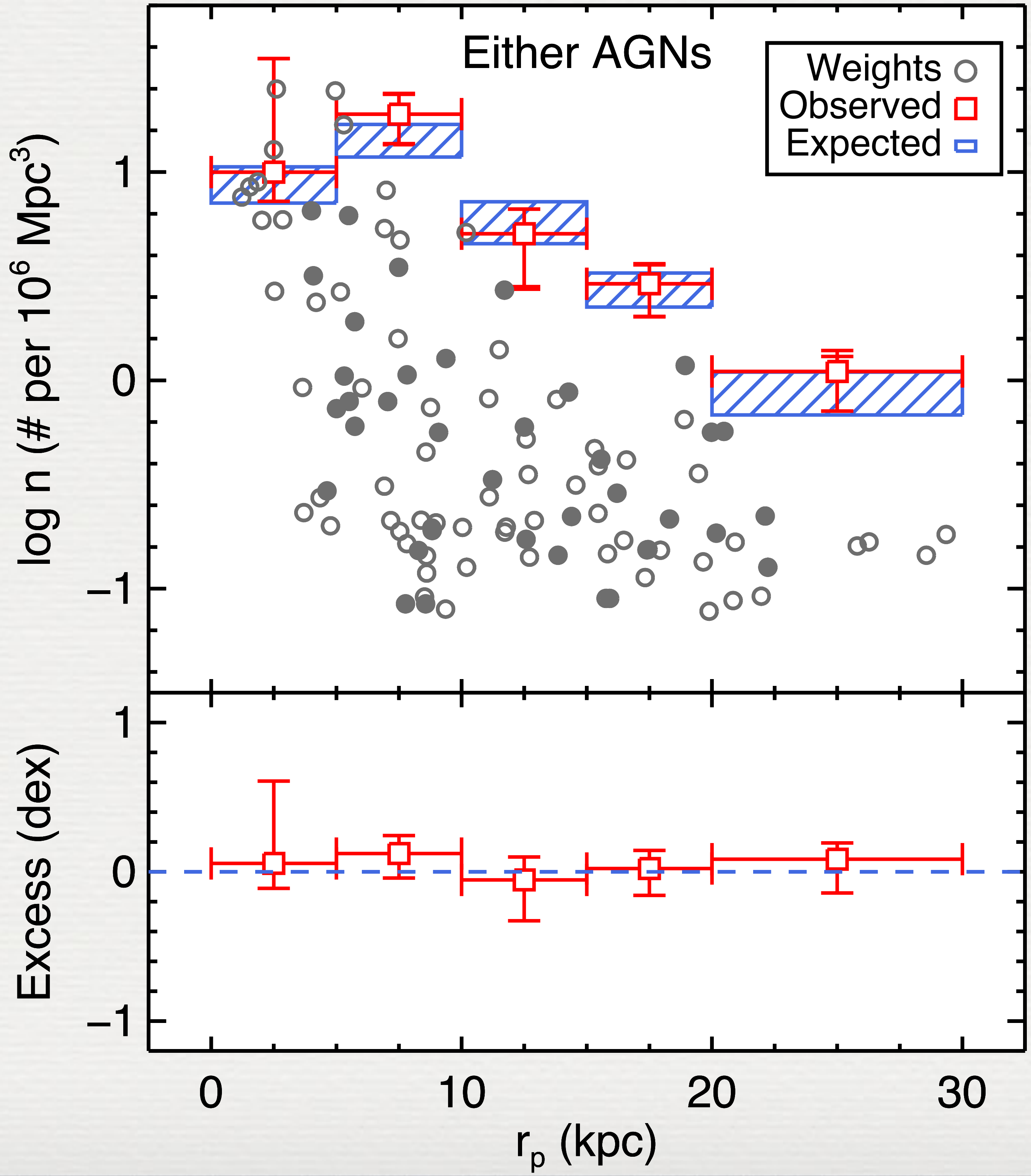
Avoid Double Counting

$$- \sum_{j=1}^{N_{\rm pair}} W_j \; f_{\rm agn}(M_j^p, z_j) \; f_{\rm agn}(M_j^s, z_j)$$

where the stochastic AGN probabilities is from the control sample:

$$f_{\rm AGN}^{\rm mod}(M, z) = 22\% \exp\left[- \left(\frac{\log M/M_{\odot} - 10.6}{2 \times 0.54} \right)^2 \right] (1+z)^4$$

Observed volume densities agree with expectations from random pairing of stochastic AGNs



Secondly, the expected volume density of pairs that host two AGN (i.e., binary AGN) can be calculated as:

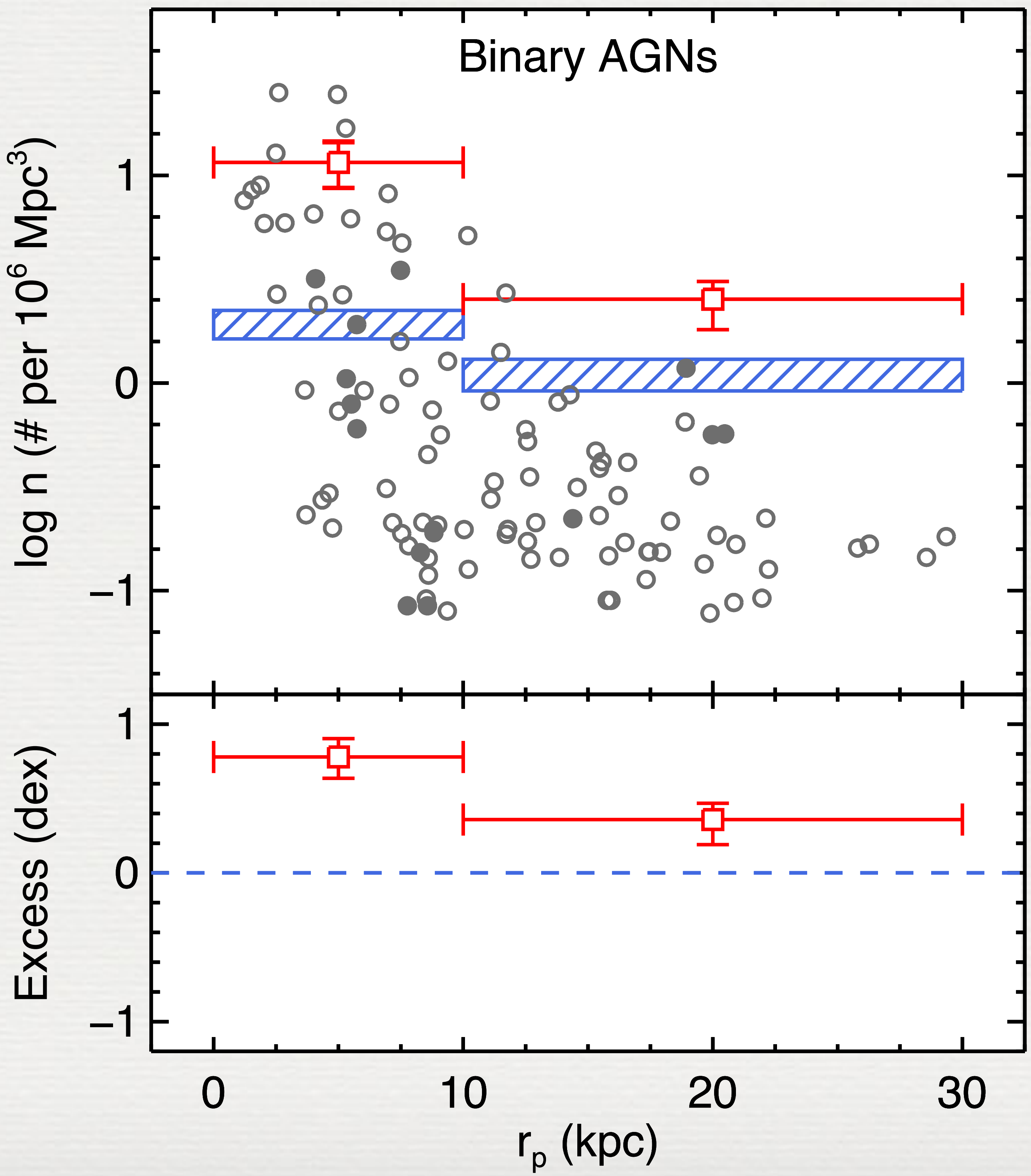
$$n_{\rm bagn}^{\rm exp} = \sum_{j=1}^{N_{\rm pair}} W_j \; f_{\rm agn}(M_j^p, z_j) \; f_{\rm agn}(M_j^s, z_j)$$

Assume Random Pairing of Stochastic AGNs

where the stochastic AGN probabilities is from the control sample:

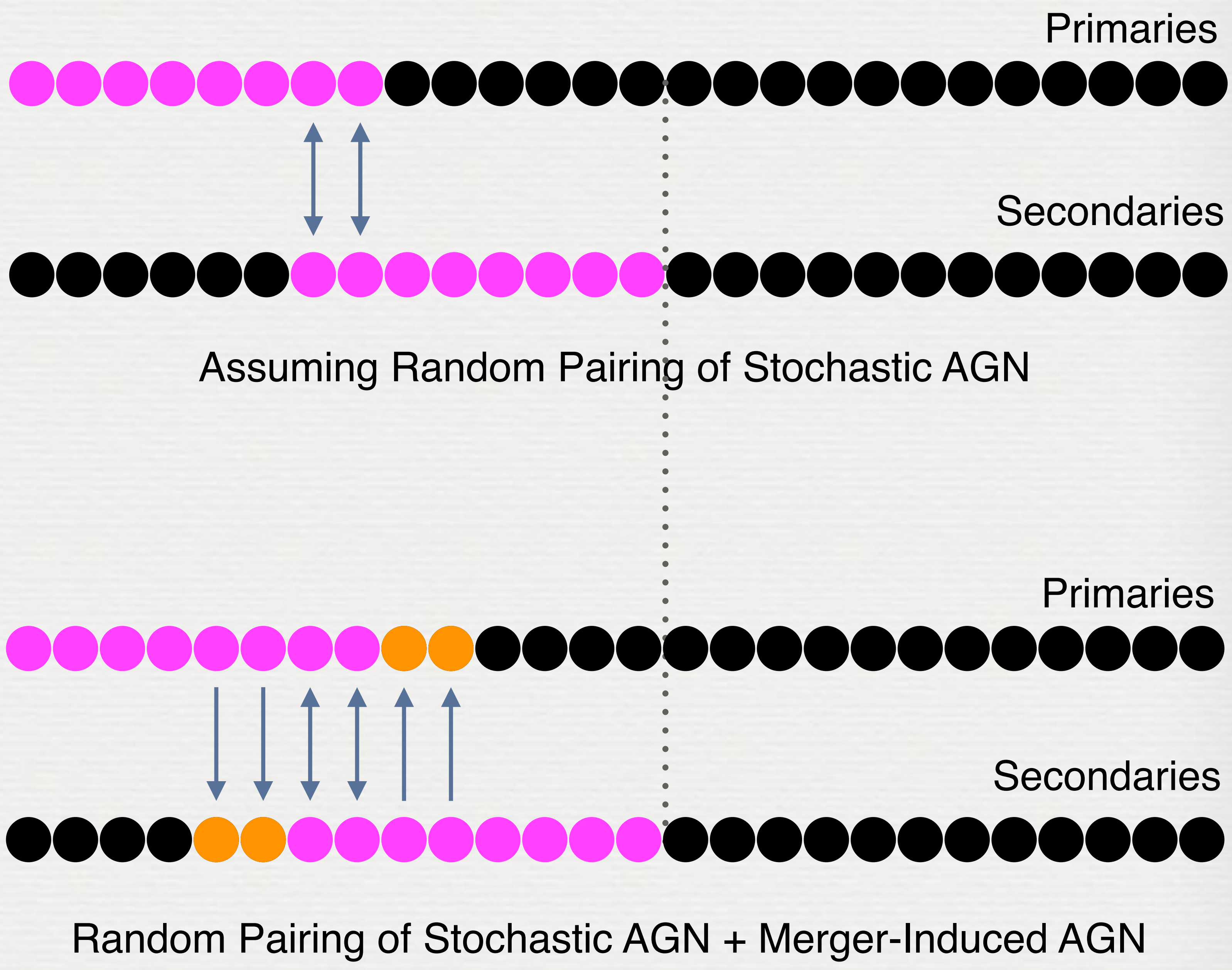
$$f_{\rm AGN}^{\rm mod}(M, z) = 22\% \exp\left[-\left(\frac{\log M/M_\odot - 10.6}{2 \times 0.54}\right)^2\right](1+z)^4$$

The Excess of Binary AGNs



5. Combining the Results

- The vol. density of pairs that host at least one AGN agrees with expectation from stochastic feeding
- However, there is a significant excess of binary AGN



Summary

- The virtual reality of galaxy mergers:

  ✓ tidally induced torques drive inflows, which may trigger BH accretion in both galaxies

  ? sub-grid models for accretion rate and BH feedback

  ? stochastic feeding not properly modeled yet

- The MaNGA reality of galaxy pairs:

  ✓ AGN duty cycle is similar in close pairs as in isolated galaxies; stochastic feeding dominates over merger-driven accretion even among merging galaxies

  ✓ Mergers seem to induce additional AGN, especially at close separations; but one of the AGN has to be triggered by stochastic processes in the first place