Mock Quasar Catalog at z~0.5 using Horizon-Run 4

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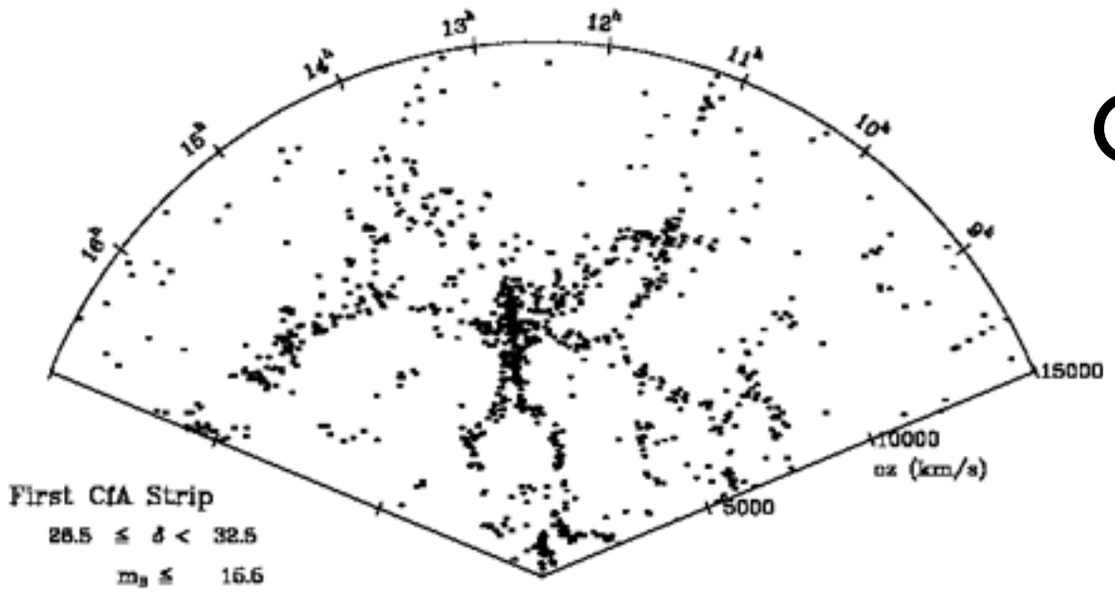
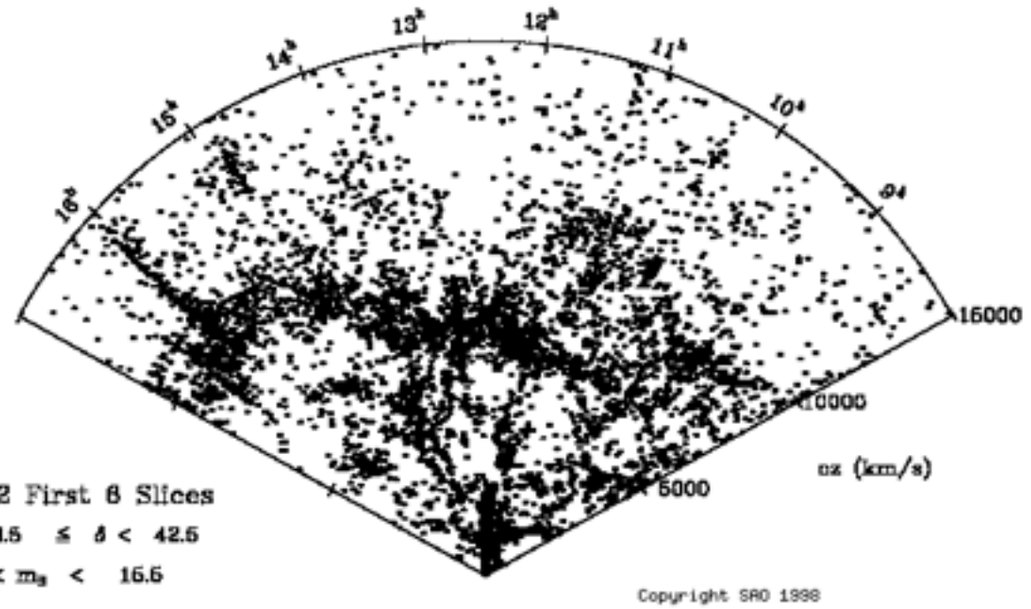
Large-scale structures

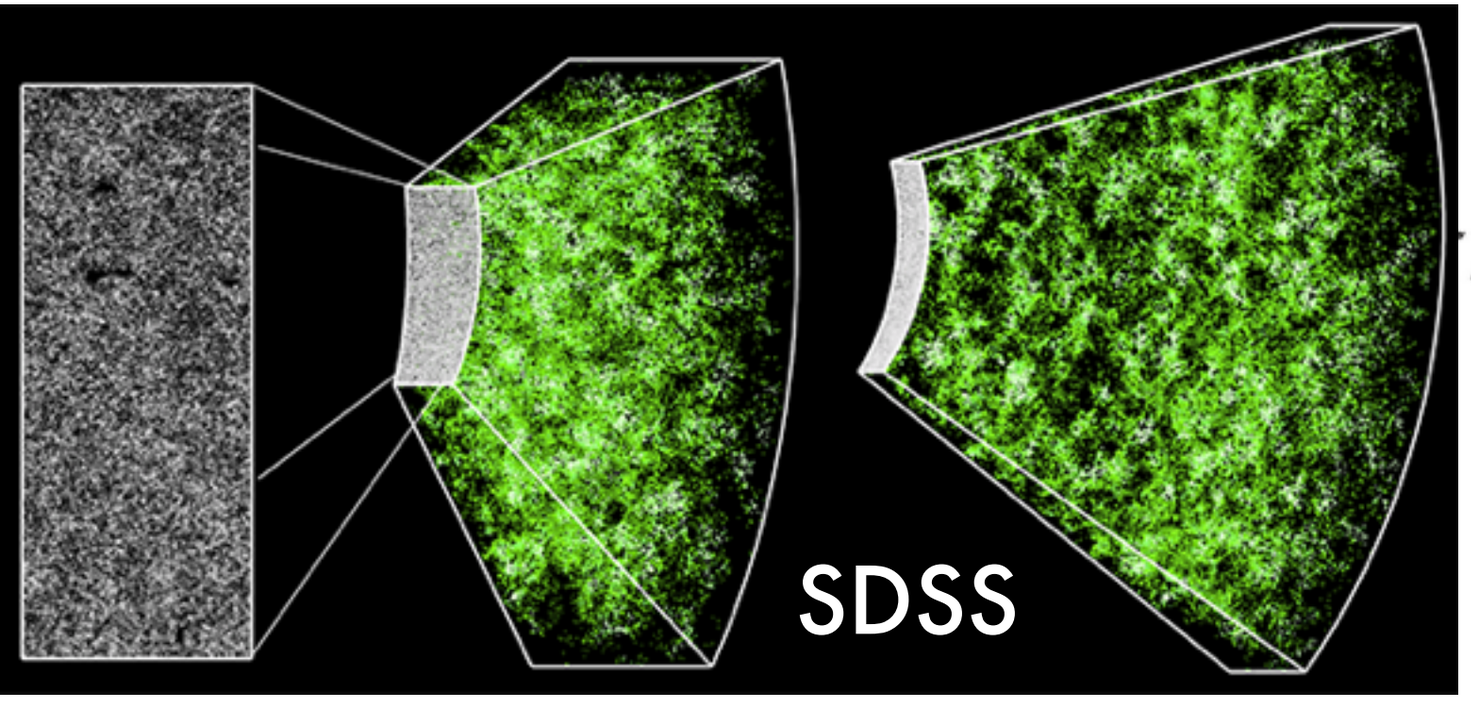
- Large-Scale Structures (LSS)
  - Of dark matter halos
- Traceable by bright and ubiquitous objects
  - Luminous Red Galaxies (LRG)
  - Quasars

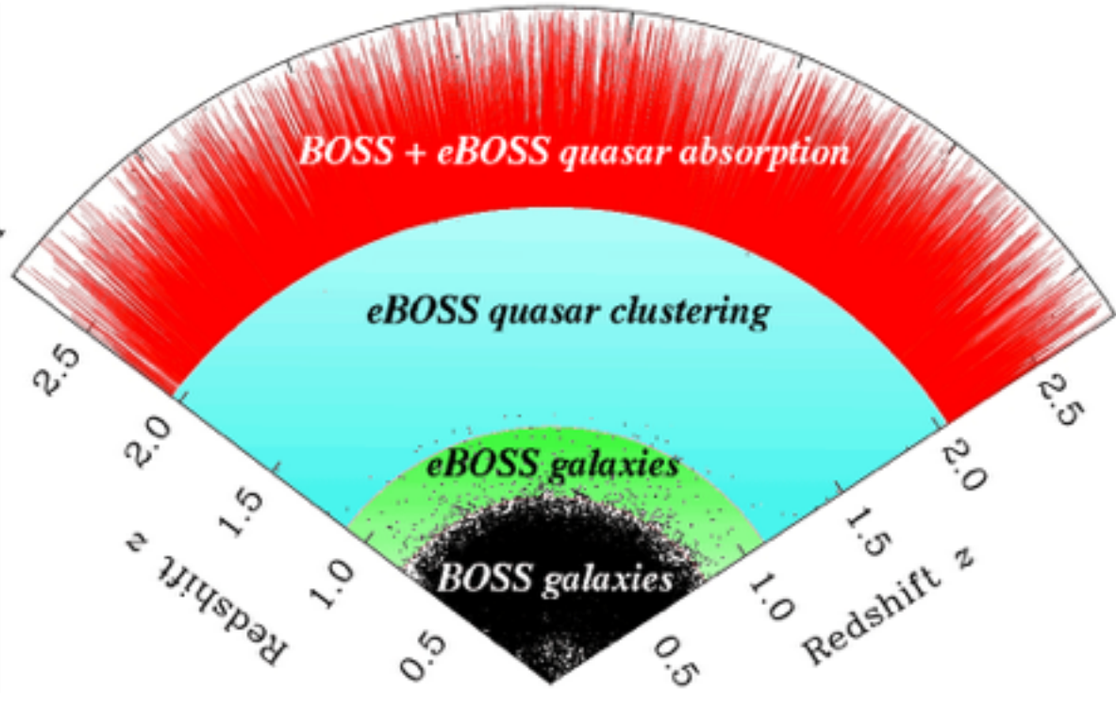
Probes of LSS in observations

CfA









Comparison with theory

- It is important to compare/test LSS found in observations with theoretical expectations to interpret/apply the observational results correctly.

- **(observations)** Gott et al. (2005), Geller & Huchra (1989), Clowes et al. (2012), Horvath et al. (2013), …

- **(tests with simulations)** Park (1990), Park et al. (2012), Einasto et al. (2011, 2014), Park, Song, et al. (2015), …

- We are building larger and larger volume in observation, so we need larger cosmological simulations with galaxies (quasars).

Galaxies & quasars in cosmological simulations

- Full/direct treatment of baryonic components in cosmological simulations that include hydrodynamics
  - e.g. EAGLE (100Mpc), Horizon-AGN (100h^{-1}Mpc), Illustris (106.5h^{-1}Mpc)
- Indirect treatment using Semi-Analytic Models (SAMs), Halo Occupation Distribution (HOD), etc

Computationally cheap,
so implementable for large-volume simulations!

SAM & HOD

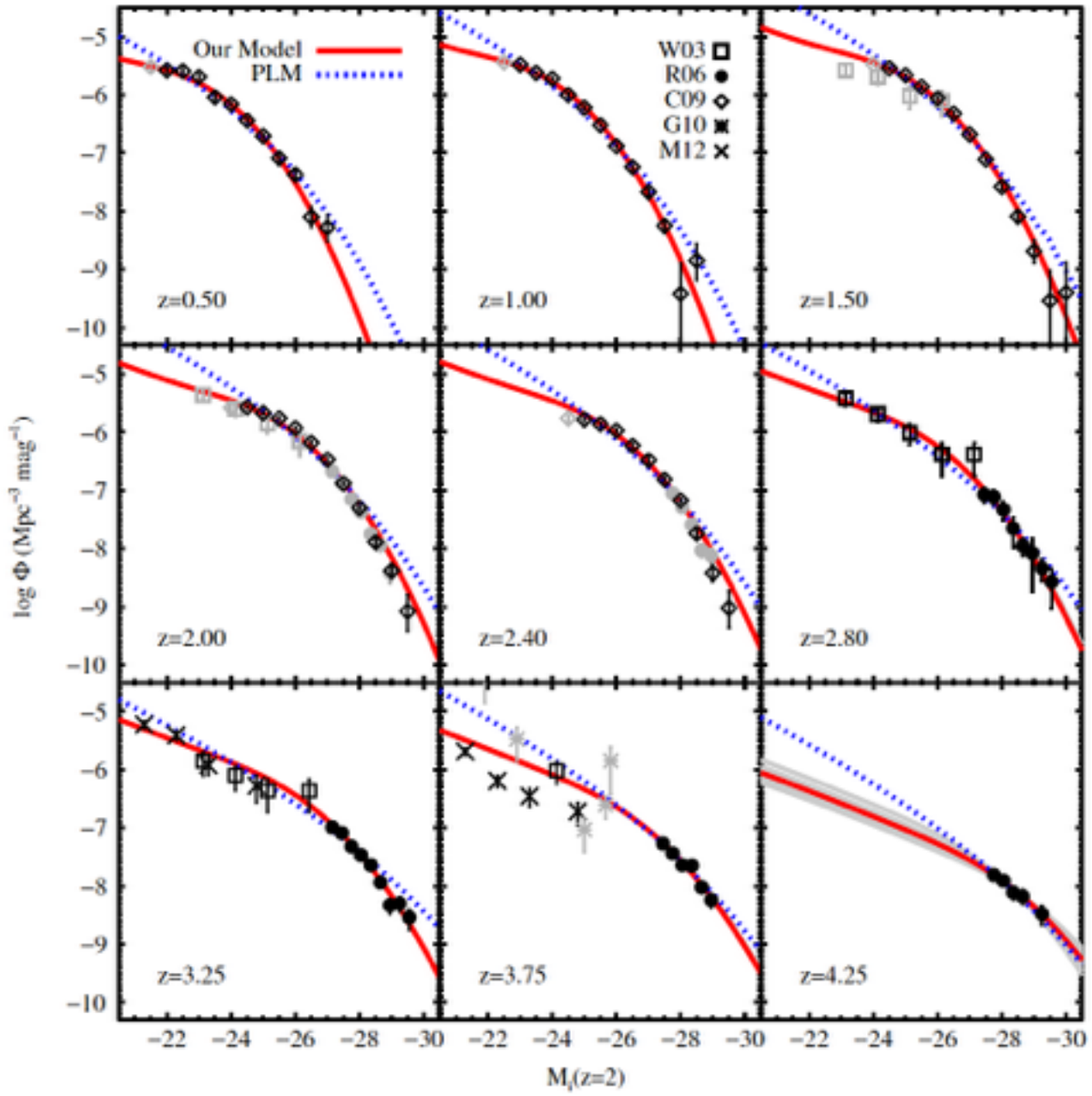
- While SAM considers physical processes of galaxy formation and evolution, HOD takes statistical approaches.

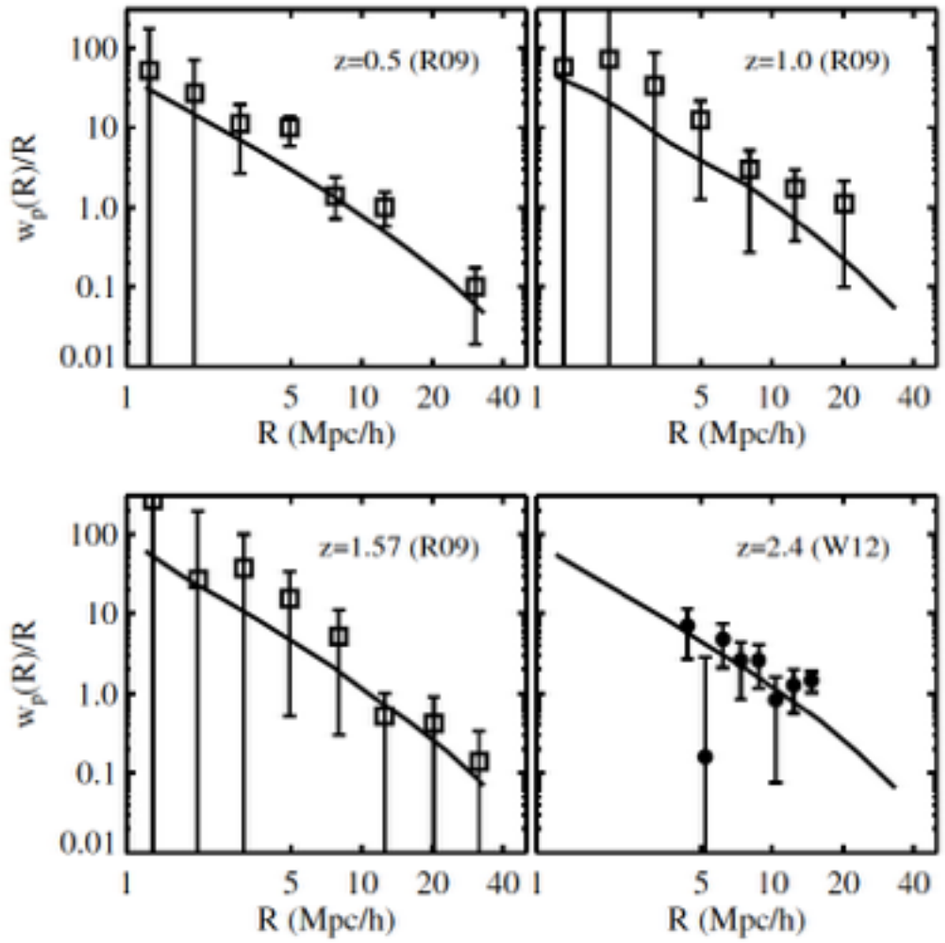
- Therefore, while SAM generates a galaxy population evolving self-consistently across cosmic time, HOD provides an accurate reproduction of galactic content of haloes at a given epoch.

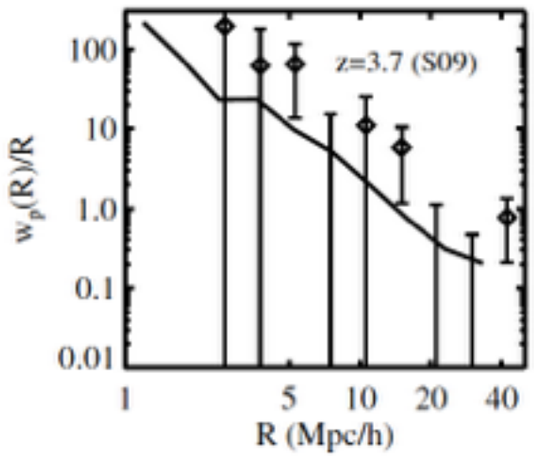
- **Our goal - to populate quasars in DMHs with an approach of more physically-motivated HOD**

A previous study

- Conroy & White (2013)







A physically-motivated quasar HOD

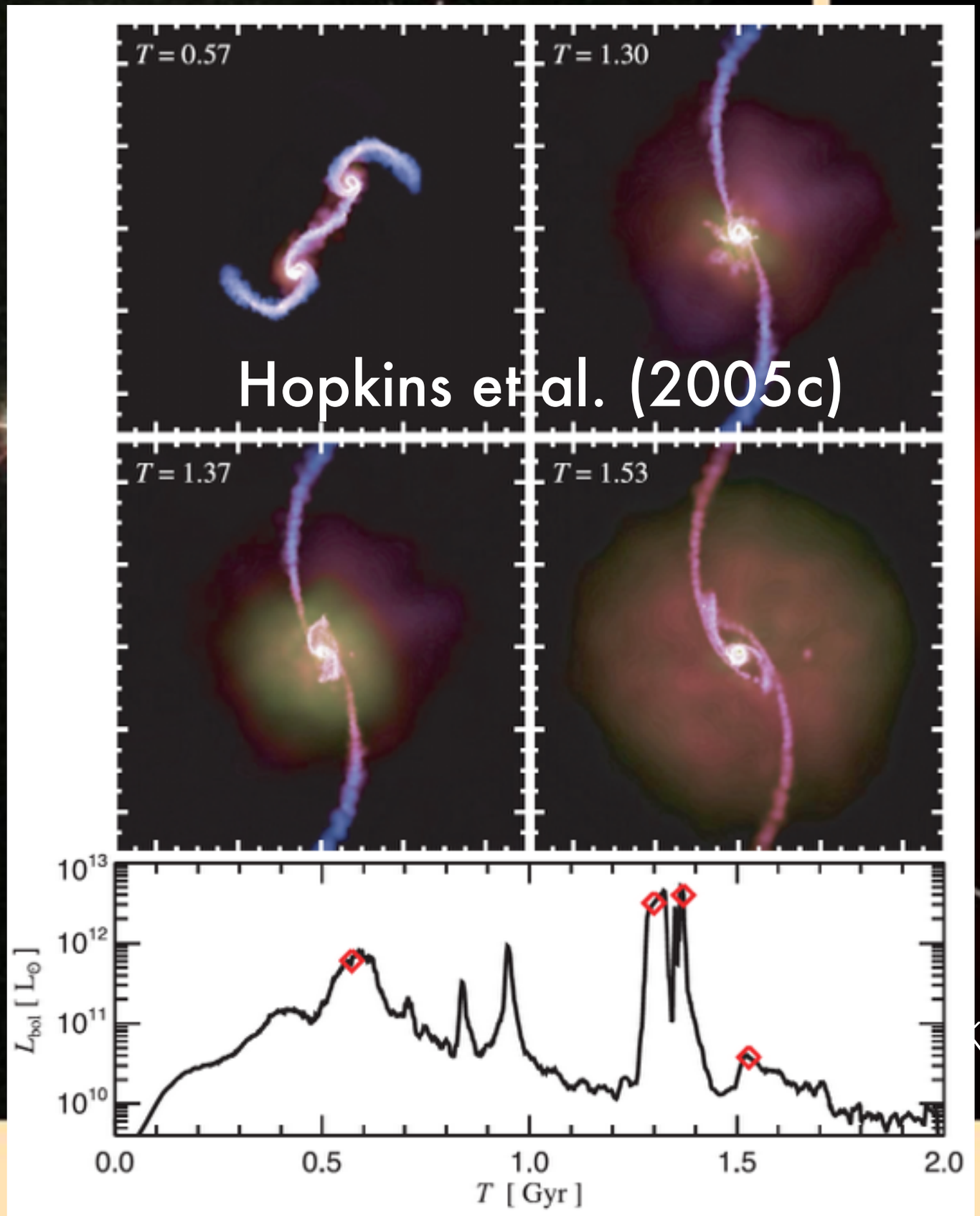
- **Gas-rich major merger** as the quasar triggering mechanism

  - Treister et al. (2012)

  “… to reach the highest AGN luminosities a major merger appears to be required.”

  - NGC 6240 and Hopkins et al. (2005c)

  - Hopkins et al. (2008)



Hopkins et al. (2005c)

Komossa & G. Hasinger (MPE) et al. (CXC, NASA)

Chandra X-ray

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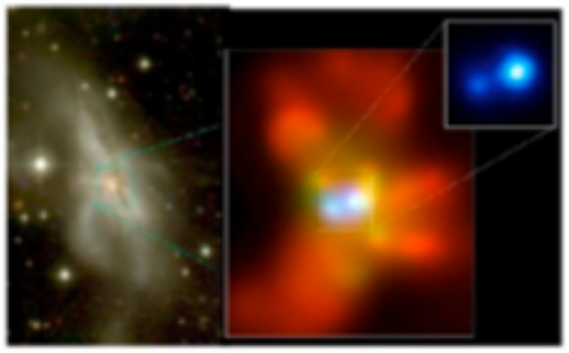
(c) Interaction/"Merger"

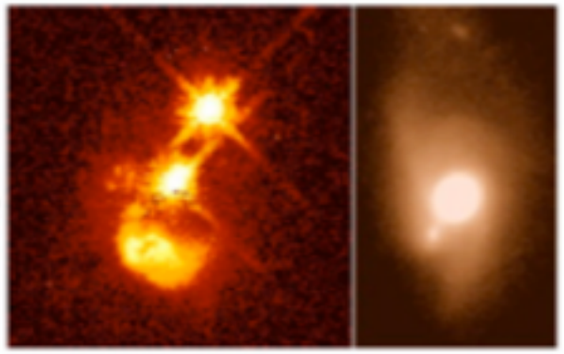
- now within one halo, galaxies interact & lose angular momentum
- SFR starts to increase
- stellar winds dominate feedback
- rarely excite QSOs (only special orbits)

(d) Coalescence/(U)LIRG



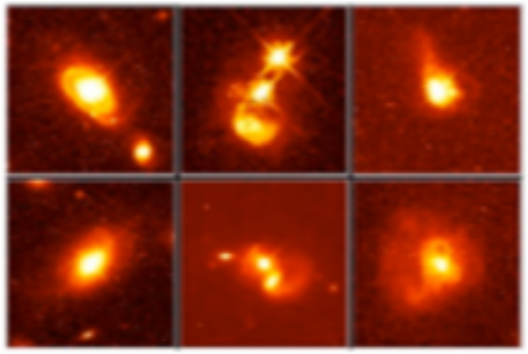
- galaxies coalesce: violent relaxation in core
- gas inflows to center: starburst & buried (X-ray) AGN
- starburst dominates luminosity/feedback, but, total stellar mass formed is small

(e) "Blowout"



- BH grows rapidly: briefly dominates luminosity/feedback
- remaining dust/gas expelled
- get reddened (but not Type II) QSO: recent/ongoing SF in host high Eddington ratios merger signatures still visible

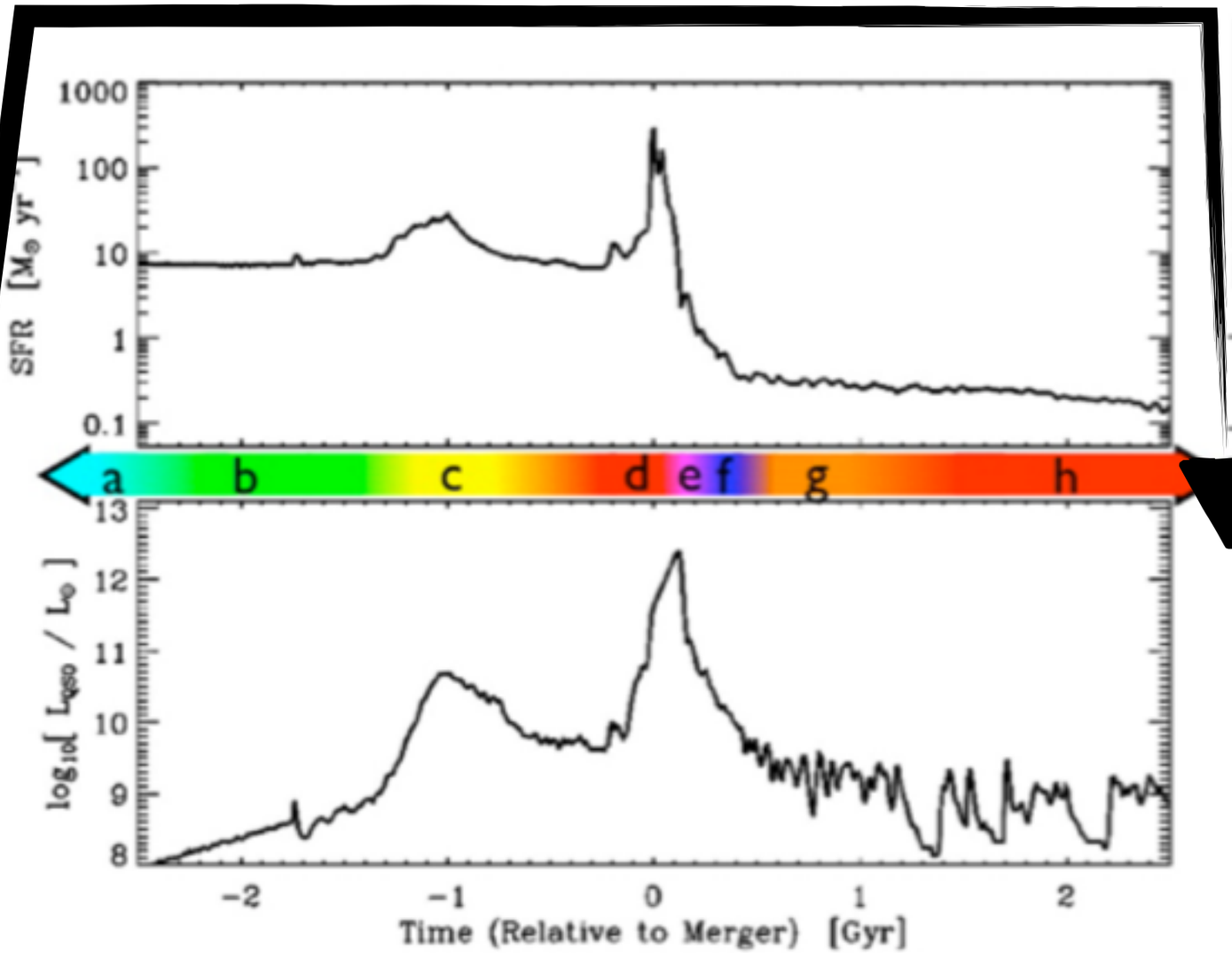
(f) Quasar



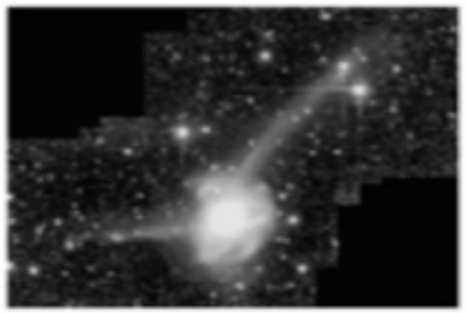
- dust removed: now a "traditional" QSO
- host morphology difficult to observe: tidal features fade rapidly
- characteristically blue/young spheroid

(b) "Small Group"

- halo accretes similar-mass companion(s)
- can occur over a wide mass range
- M_{halo} still similar to before: dynamical friction merges the subhalos efficiently

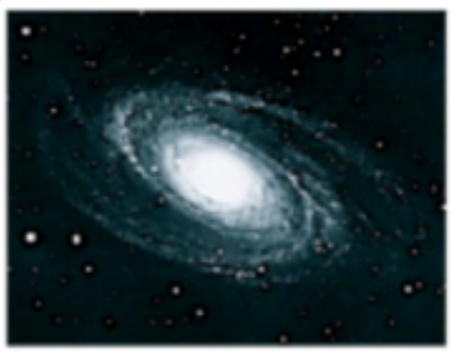


(g) Decay/K+A



- QSO luminosity fades rapidly
  - tidal features visible only with very deep observations
- remnant reddens rapidly (E+A/K+A)
- "hot halo" from feedback
  - sets up quasi-static cooling

(a) Isolated Disk



- halo & disk grow, most stars formed
- secular growth builds bars & pseudobulges
- "Seyfert" fueling (AGN with M_B>-23)
- cannot redden to the red sequence

(h) "Dead" Elliptical

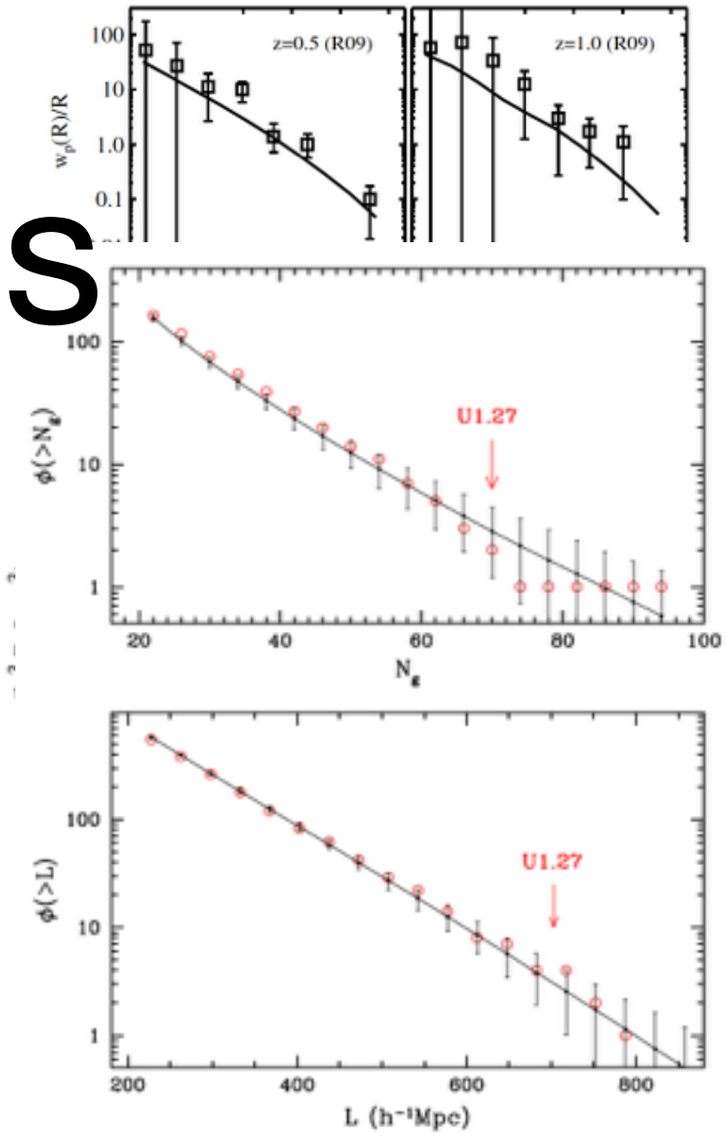
- star formation terminated
- large BH/spheroid - efficient feedback
- halo grows to "large group" scales: mergers become inefficient
- growth by "dry" mergers

Hopkins et al. (2008)

Our model

- Horizon Run 4, a dark matter-only simulation of box size 3150 h^{-1}Mpc
- DMH, its most-bound particle (MBP; corresponding to galaxy; Hong et al. 2016), and DMH's merger tree from HR4
- Select DMHs (or equivalently MBPs) that experience a recent gas-rich major merger from an epoch of interest.
  - free parameters: recent, gas-rich, major merger
  - e.g. <1Gyr (0.1Gyr after merging to be optically observable), no major merger since one's formation, $M_{sat}/M_{cen}<1/3$

Current status



- Comparing large-scale properties of this popu
  those of the SDSS quasars, and by adjusting
  find those that reproduce the observations m

- Large-scale properties to match: 2-point auto/cross correlation functions (many studies from observational side), correlation between large-scale densities of galaxies and quasars (e.g. Song et al. 2016), statistics of large groups (e.g. Einasto et al. 2014, Park, Song et al. 2015)