Black Hole Growth in Mergers: Predictions from Simulations

Laura Blecha

with July Thomas, Mohammad Sayeb, Megan Newsome, Giraldo Pino, Luke Kelley, Mike Koss, Michael Katz, Davide Gerosa, Shane Larson, Michael Kesden, the BASS collaboration, and the Illustris & TNG collaborations

BASS Workshop
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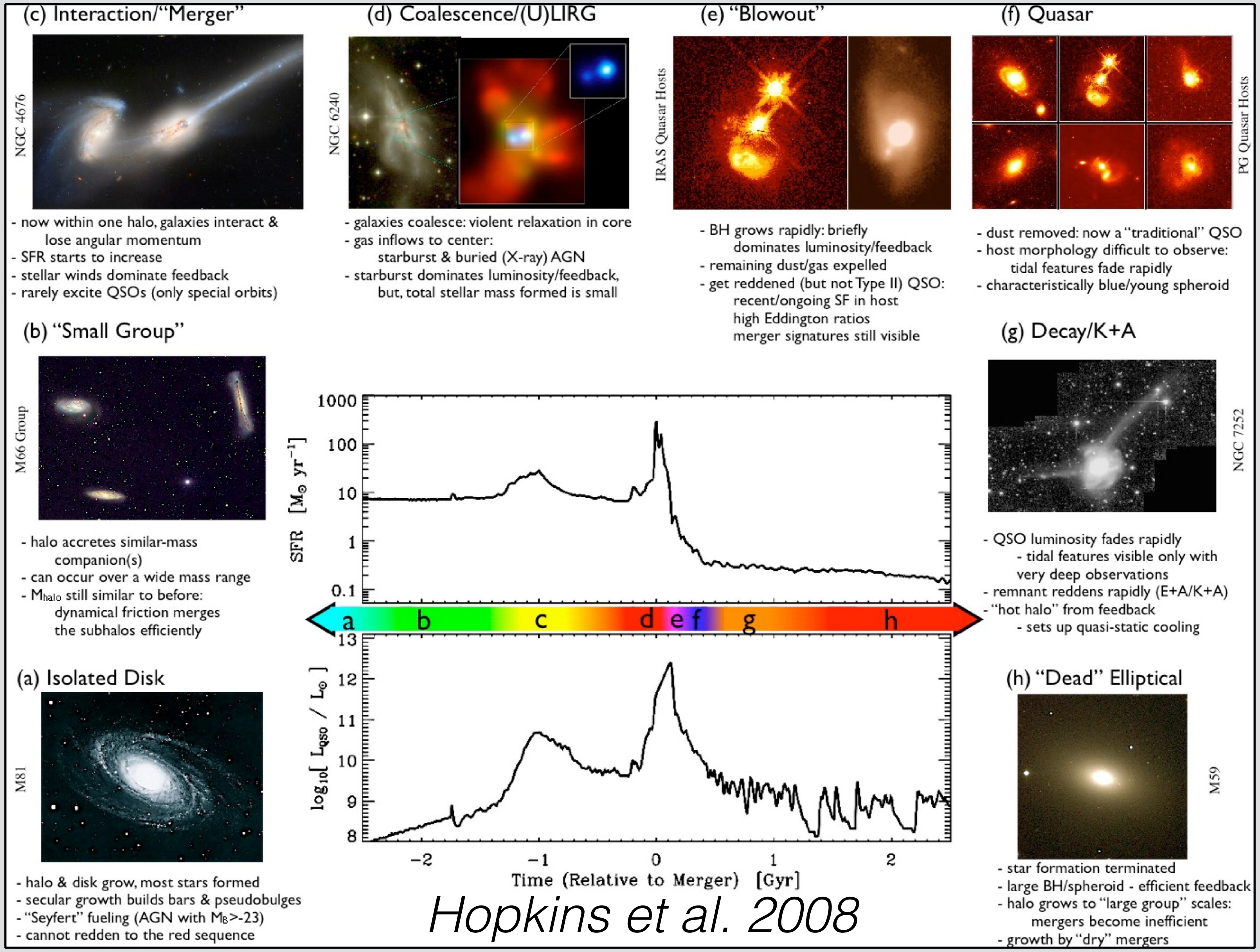
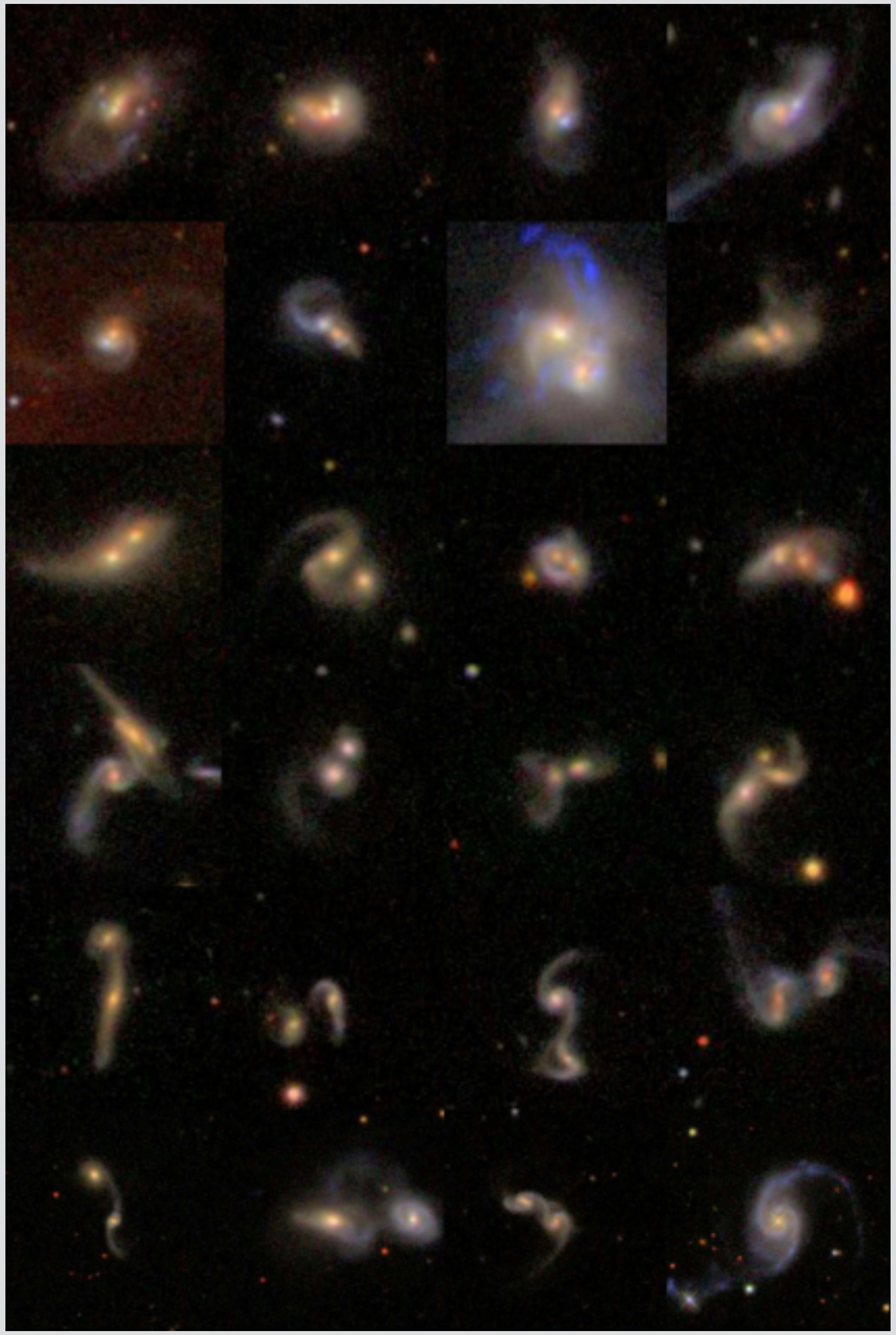
SMBH/galaxy co-evolution:
the merger-driven paradigm



Hopkins et al. 2008

- Simultaneous growth of galaxy bulges and SMBHs
- (Self-)regulation of growth via stellar and AGN ***feedback***
- Formation of ***SMBH pairs, mergers and recoils***

The elusive merger/AGN connection

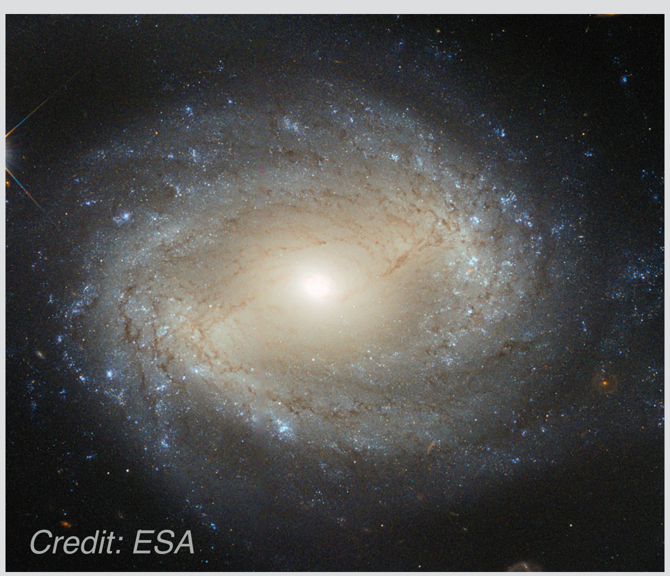


(Liu et al. 2011)

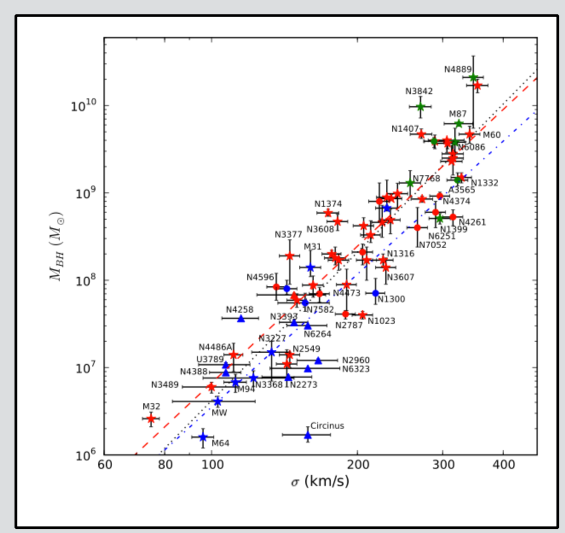
- **Most AGN are not found in major mergers** (ex: ~4% of SDSS AGN)
- **Not all (major) mergers trigger AGN**
- Many surveys find **lack of connection** between mergers & AGN *(e.g., Cisternas et al. 2011, Kocevski et al. 2012, Simmons et al. 2012, Villforth et al. 2014, Rosario et al. 2015)*
- Major mergers *do* appear to trigger the most luminous AGN —> **critical (dominant?) mode of BH growth**
- Selection effects are critically important, esp. **merger stage, AGN luminosity, obscuration, & redshift**

The merger-driven paradigm: where does it apply?

~~What triggers most AGN?~~

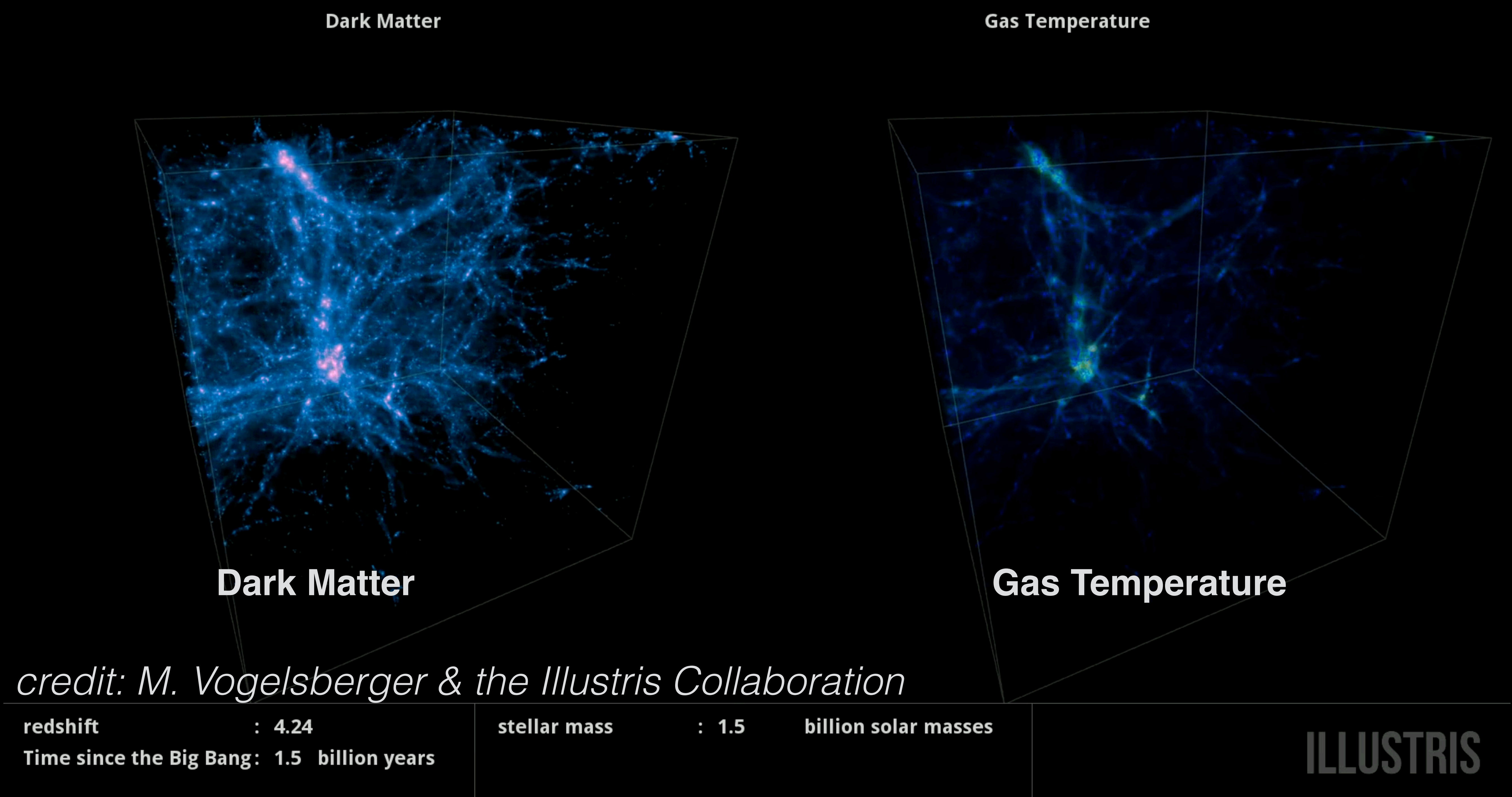


How did massive SMBHs (and stellar bulges) get their mass?



—> must consider selection effects

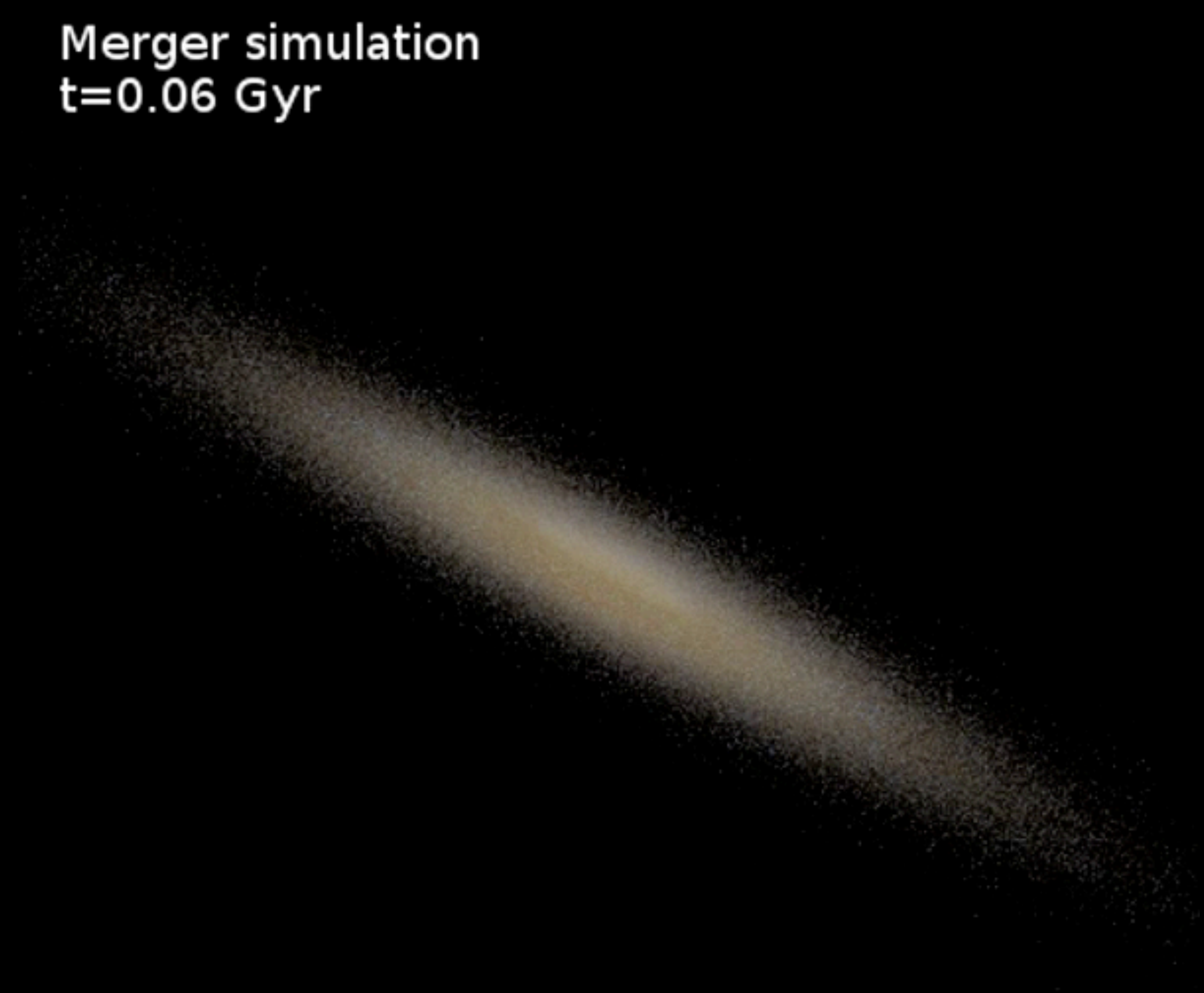
Modeling BH & galaxy evolution
in the Illustris cosmological simulations



credit: M. Vogelsberger & the Illustris Collaboration

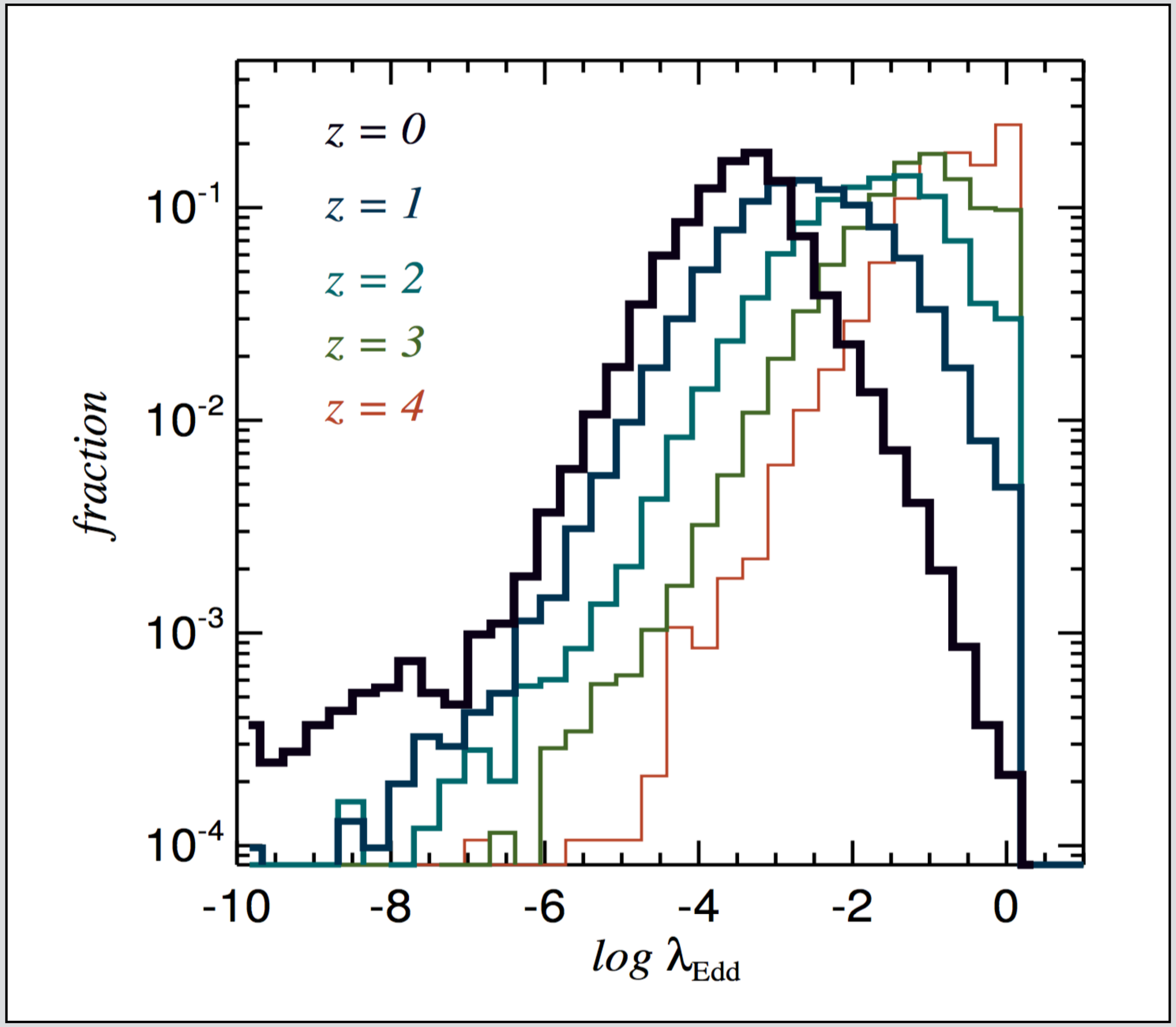
Modeling BH & galaxy evolution

with isolated merger simulations + dust radiative transfer



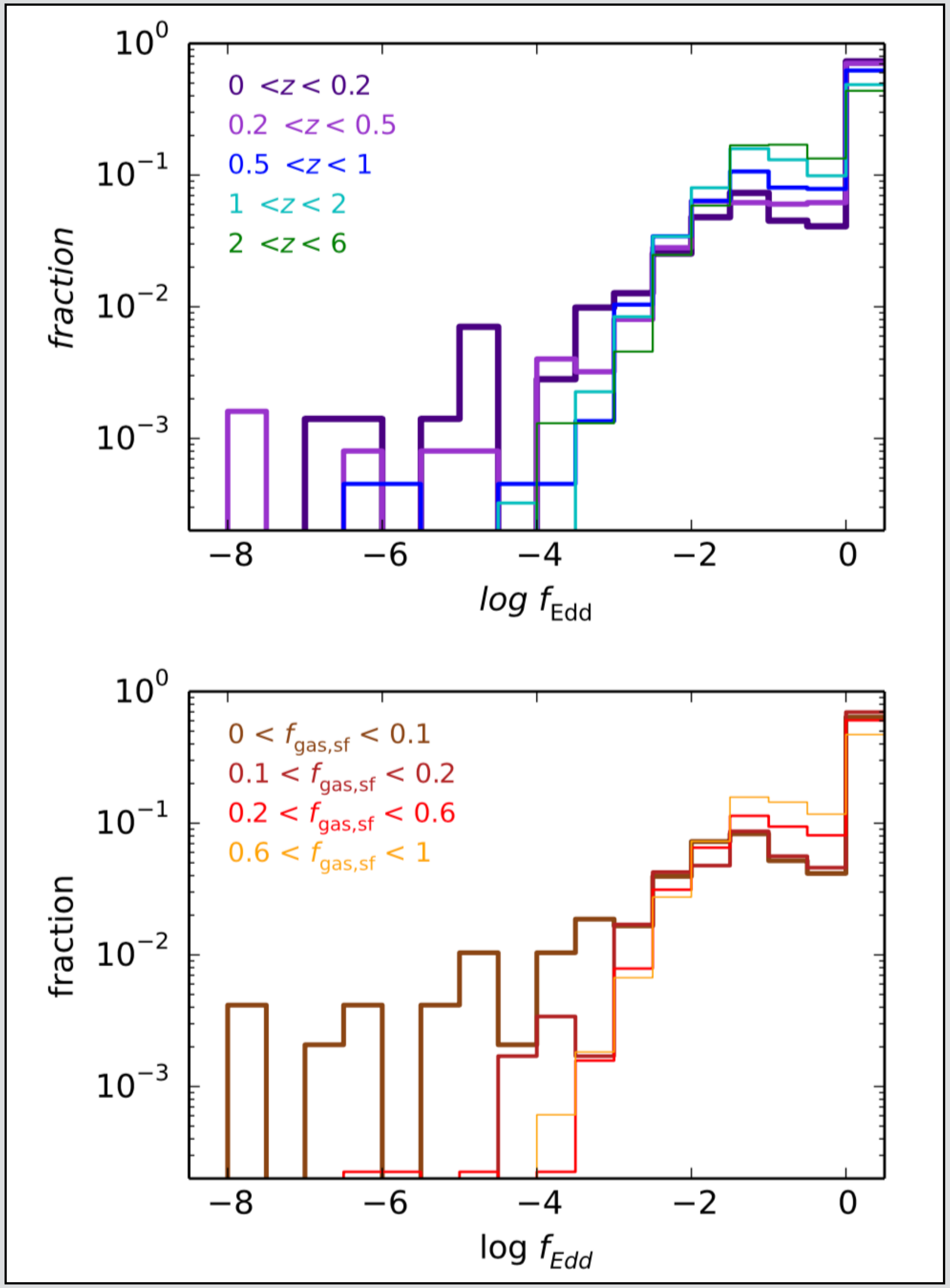
BH accretion in Illustris

All BHs



Sijacki et al 2014

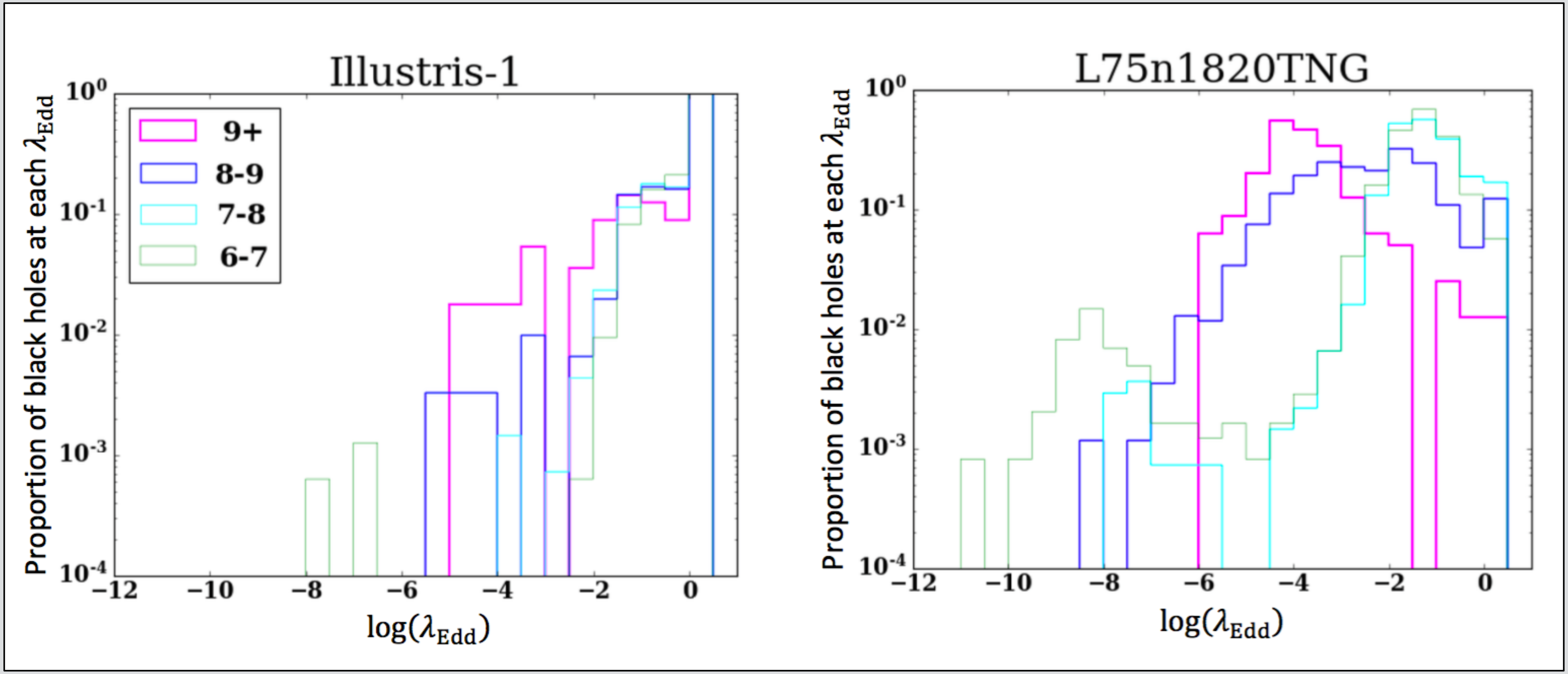
Merging BHs



Blecha et al 2016

Accretion rates of merging BHs in Illustris vs TNG

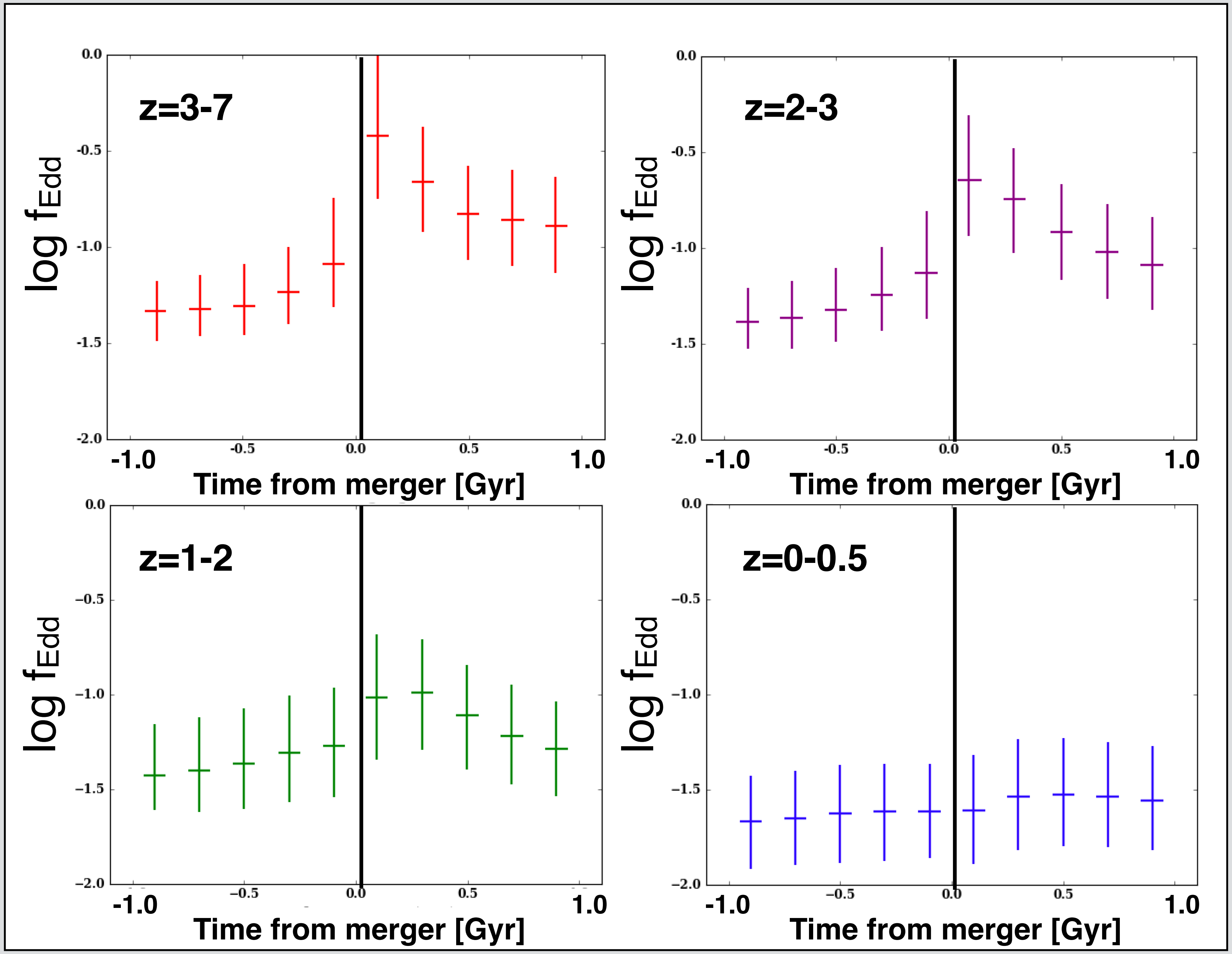
Thomas et al. in prep.



Use observations to constrain feedback models?

Mergers trigger *luminous* AGN
(especially at high redshift)

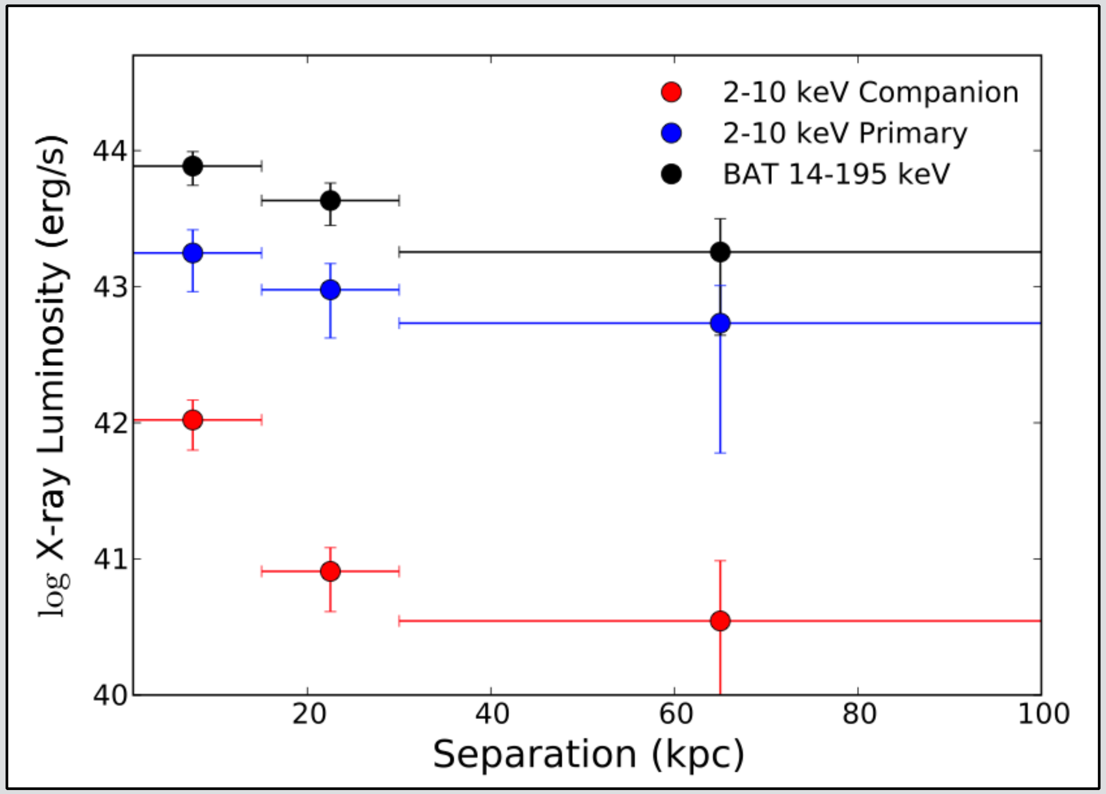
Edd ratio evolution during mergers in IllustrisTNG



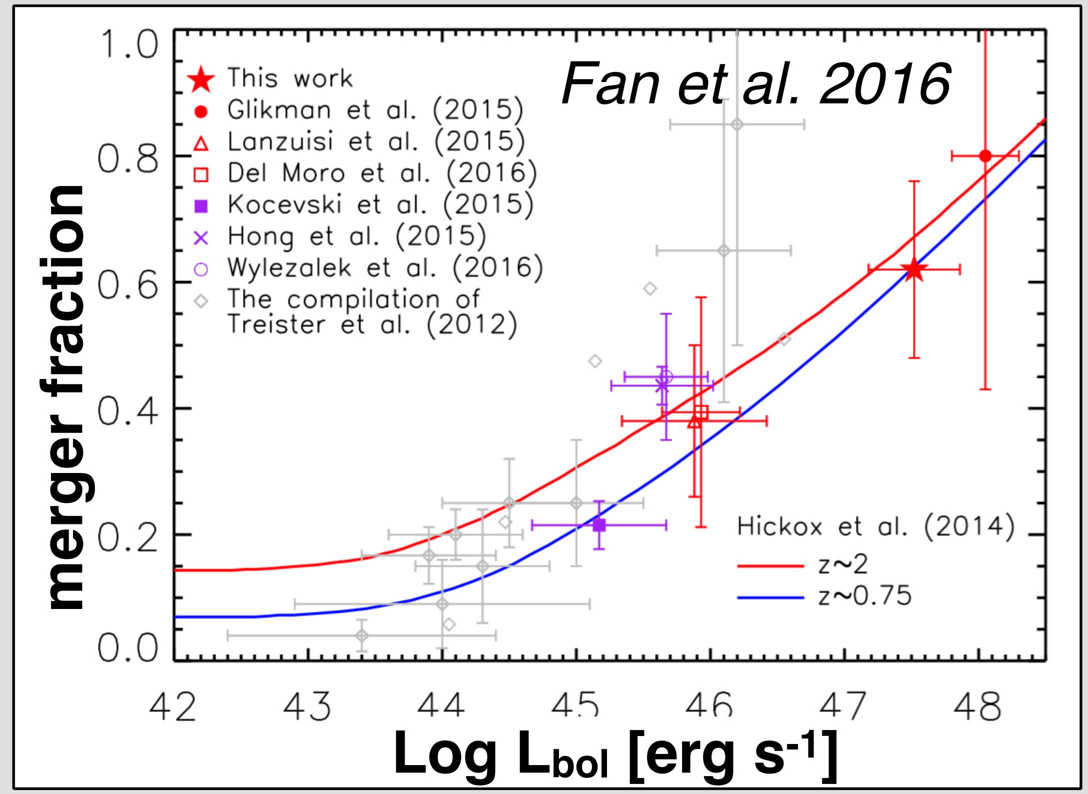
Empirical fEdd & Lbol measurements: bridge gap b/t sims &observations

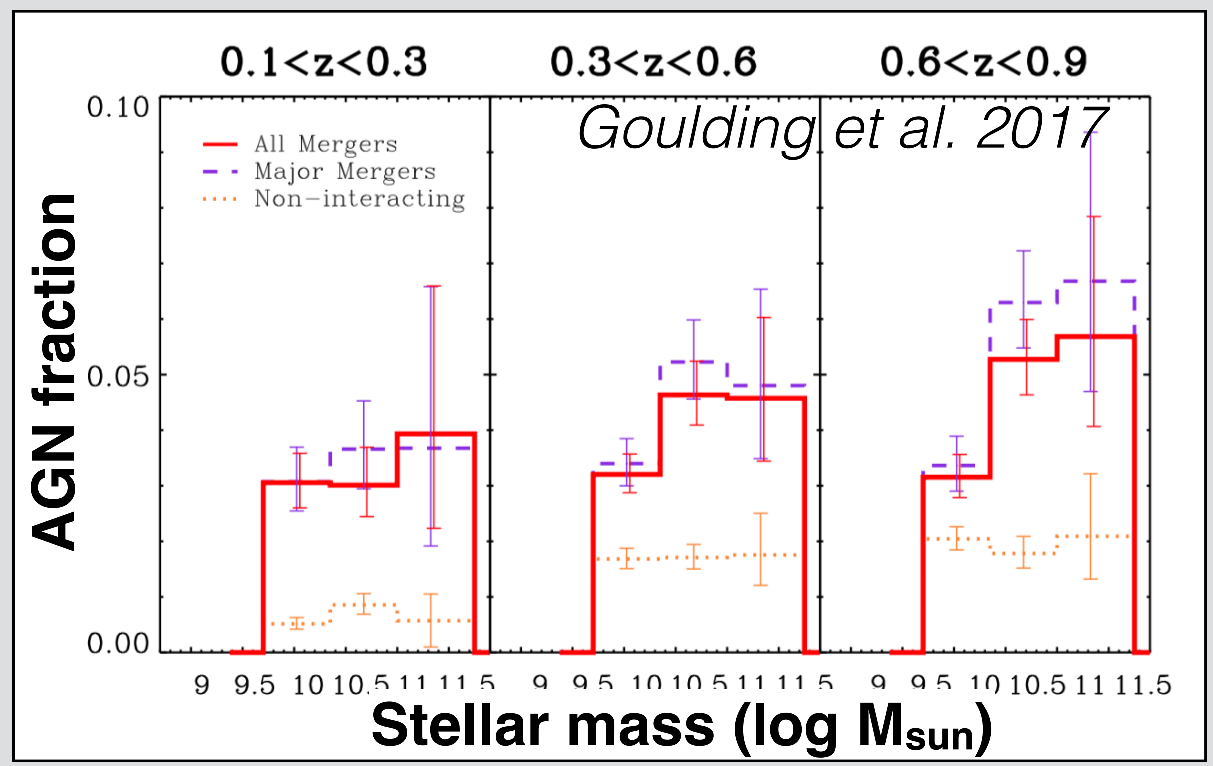
Thomas et al. in prep.

(Late-stage) mergers trigger *luminous* AGN

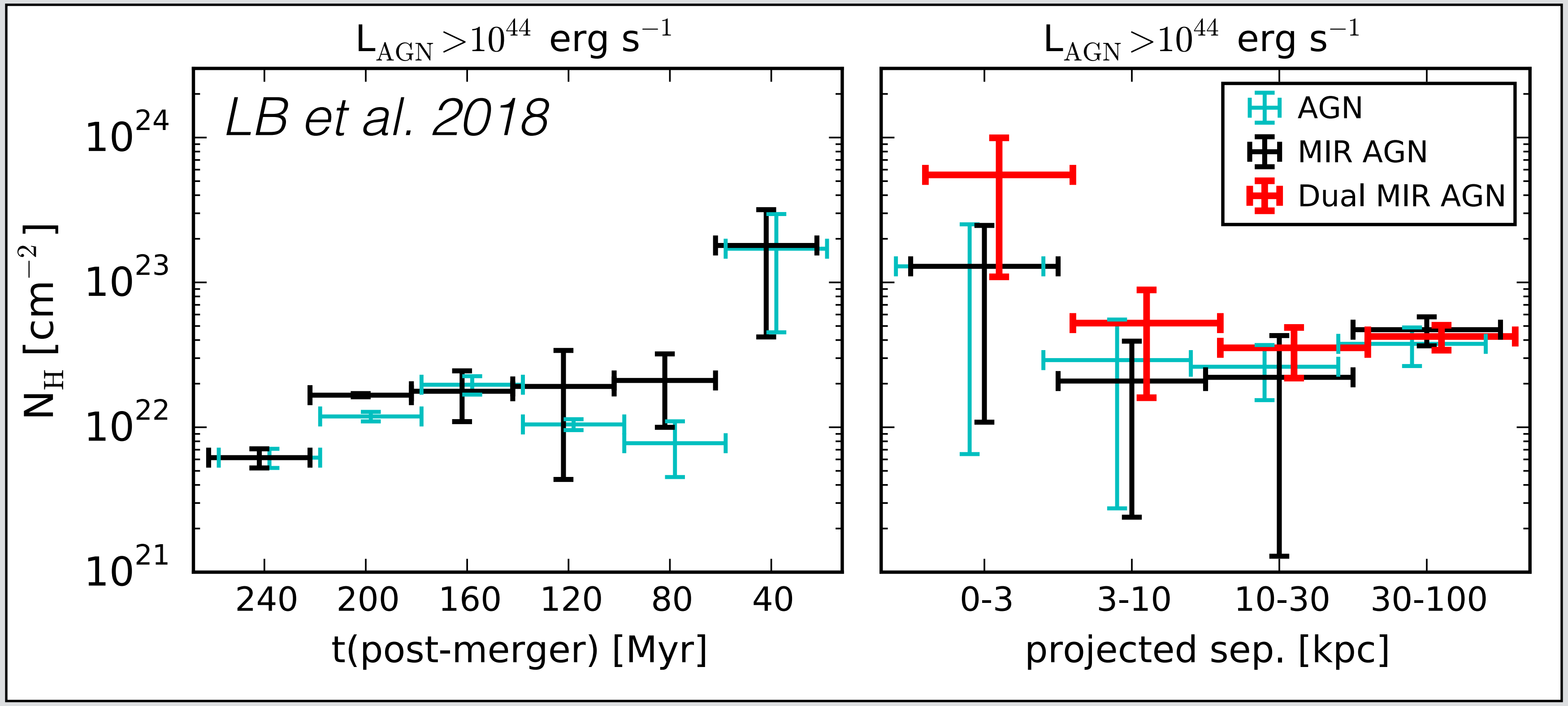


Koss et al. 2012

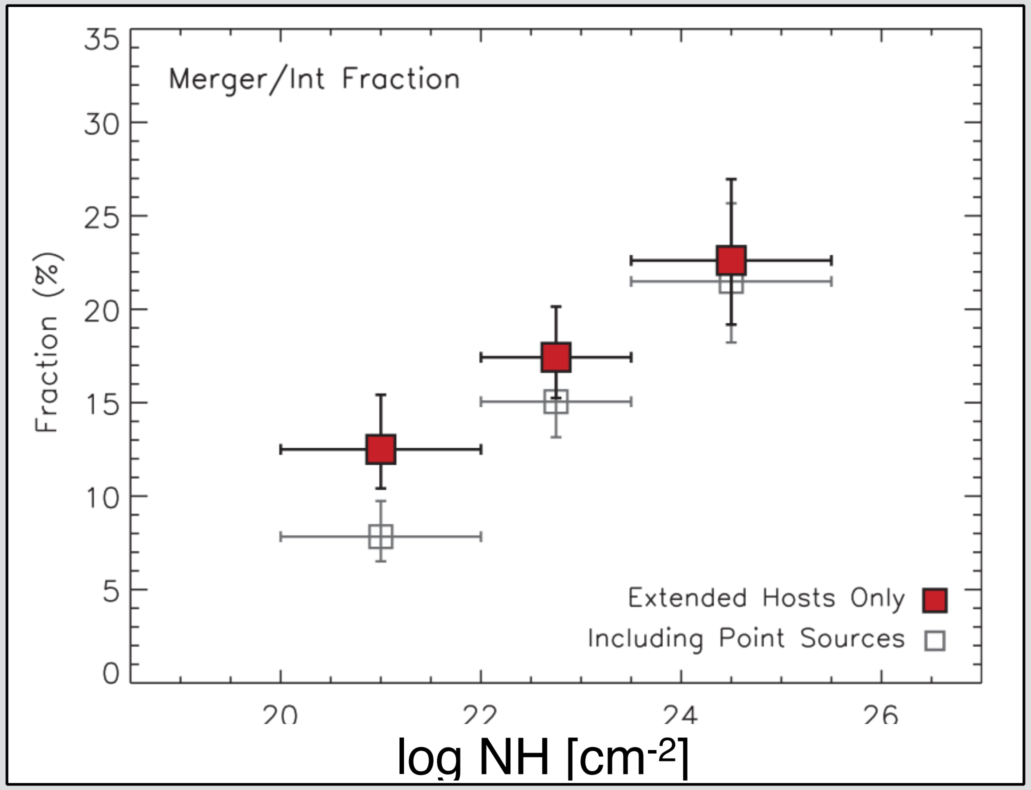




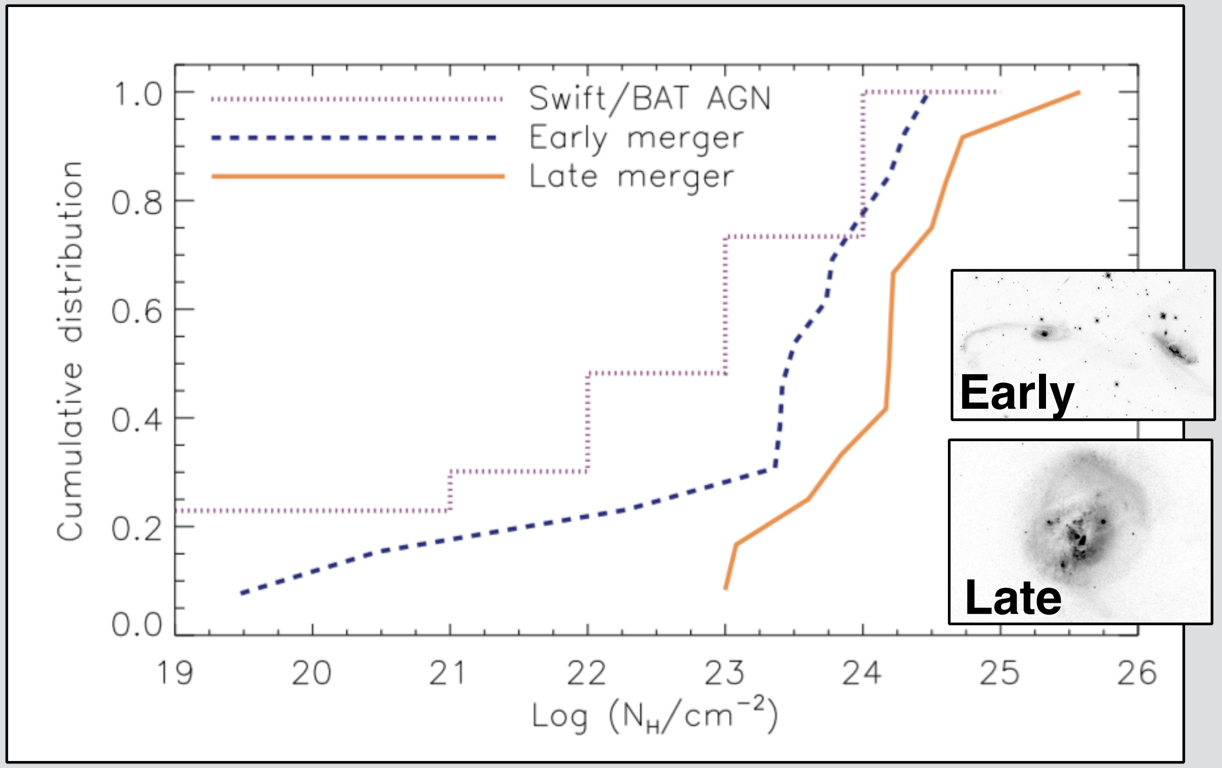
(Late-stage) mergers trigger obscured, luminous AGN



Kocevski et al. 2015



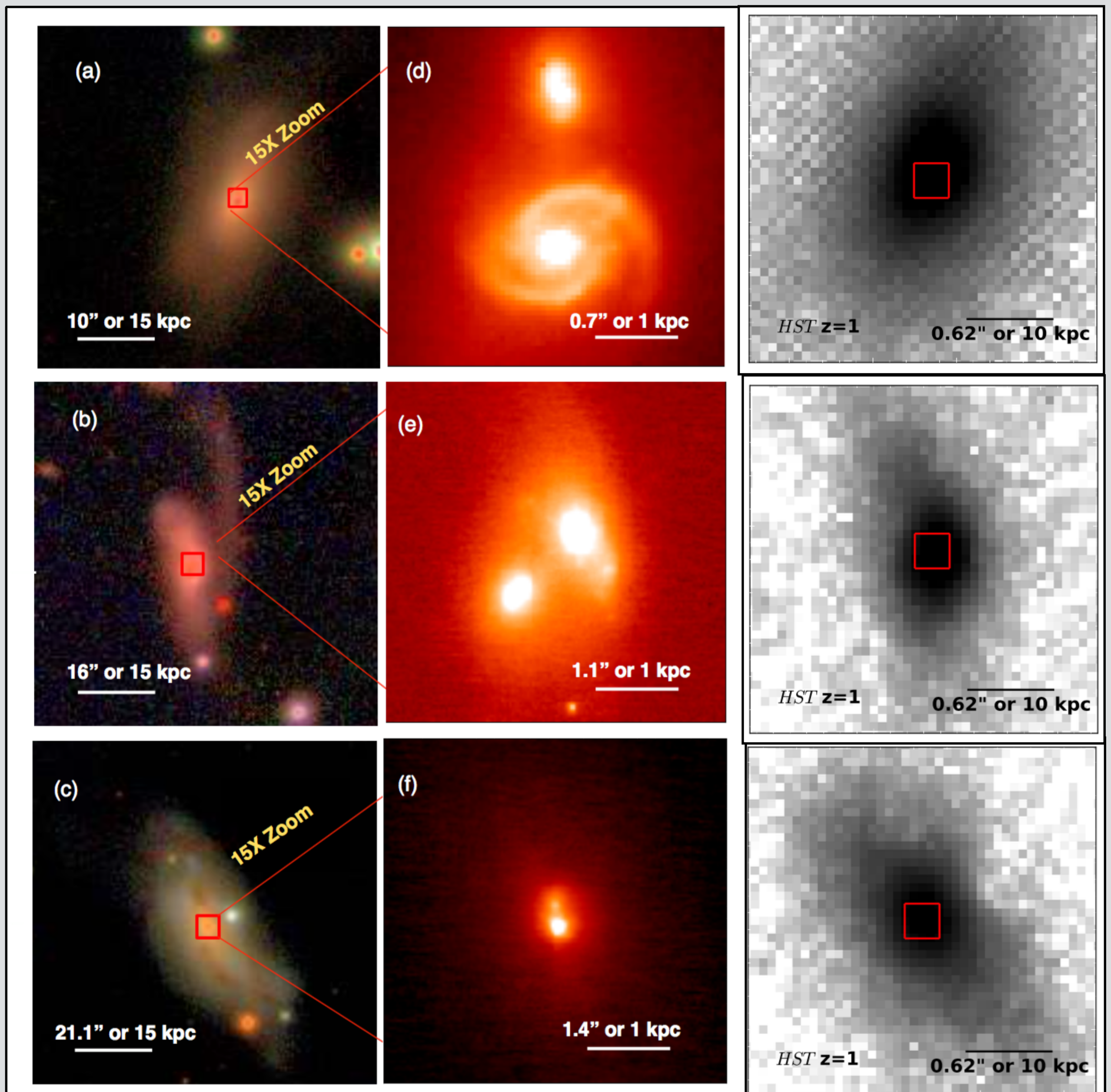
Ricci et al. 2017a

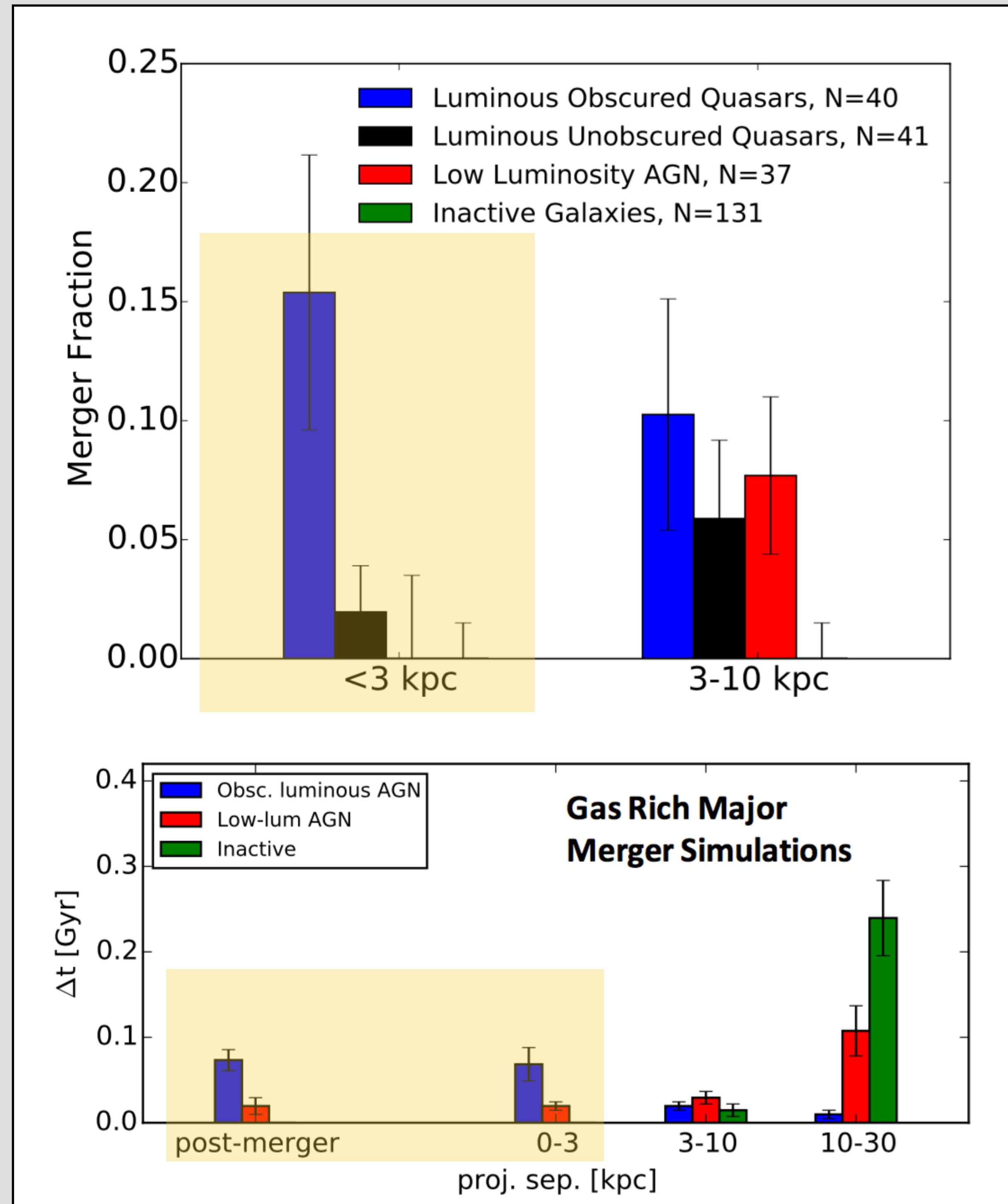


(Late-stage) mergers trigger obscured, luminous AGN

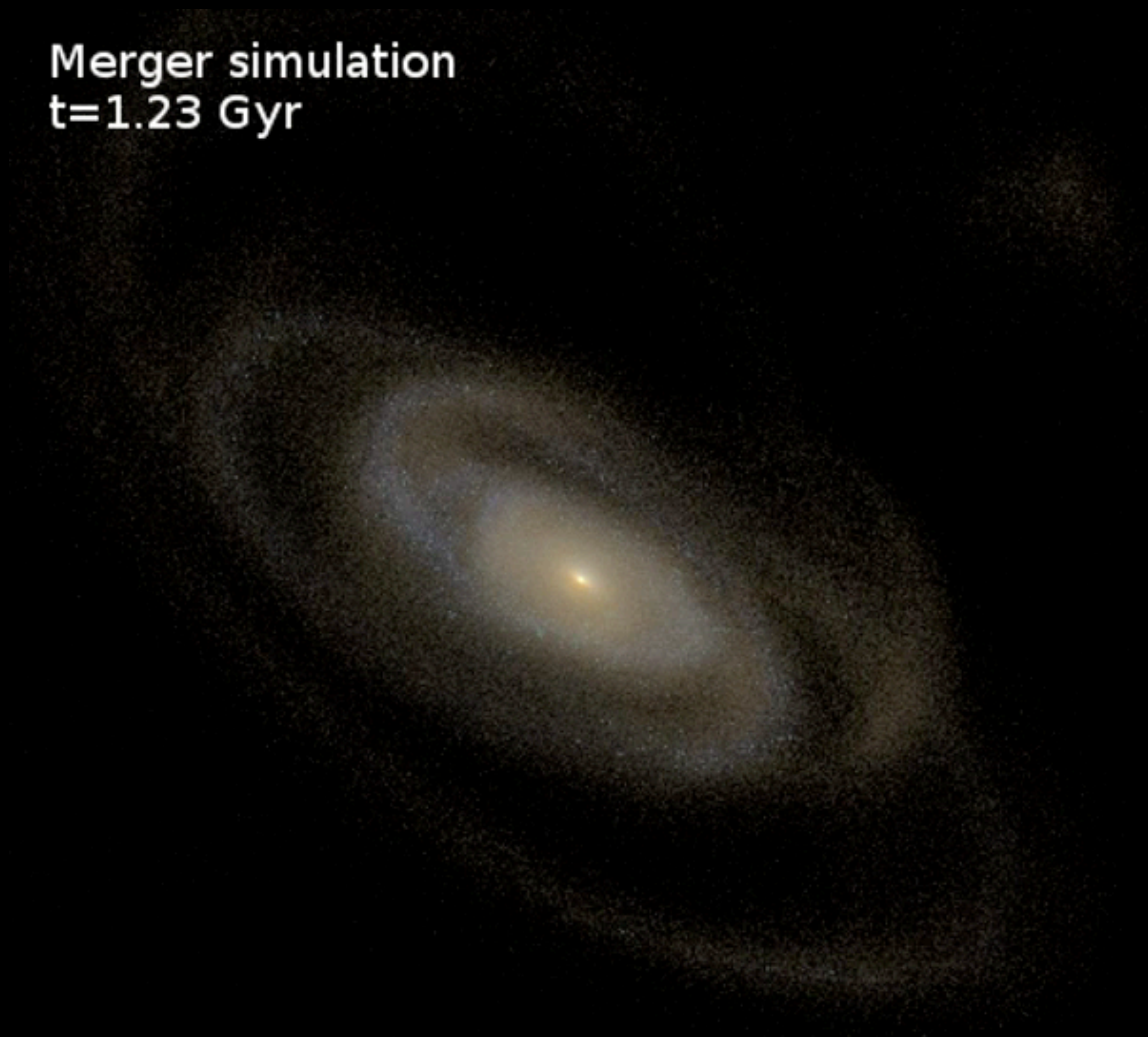
Follow-up of Swift-BAT AGN:

SDSS/Kitt | Keck AO | mock HST @ z=1

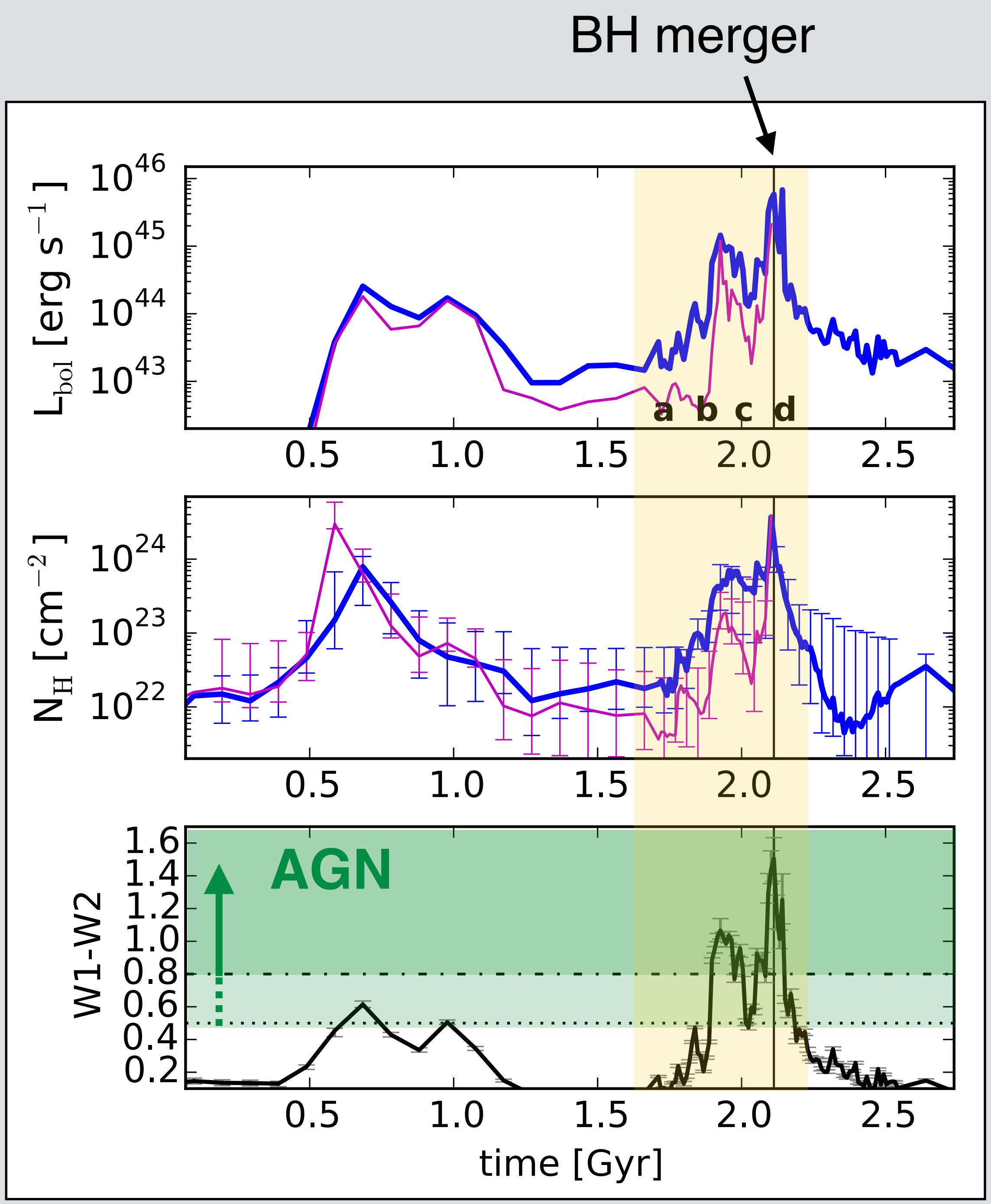




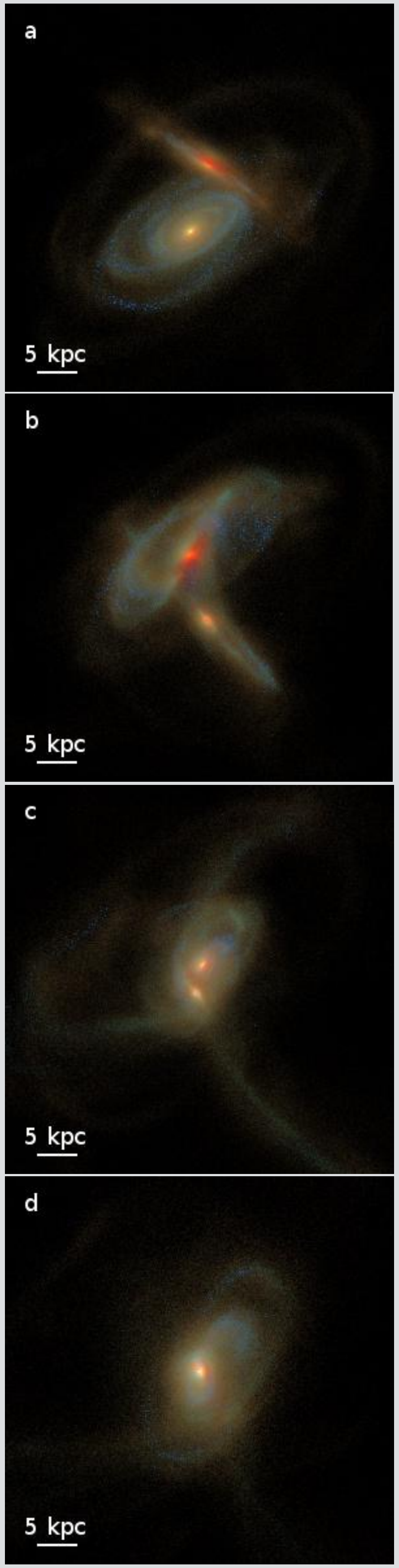
Koss, LB et al. 2018 in review

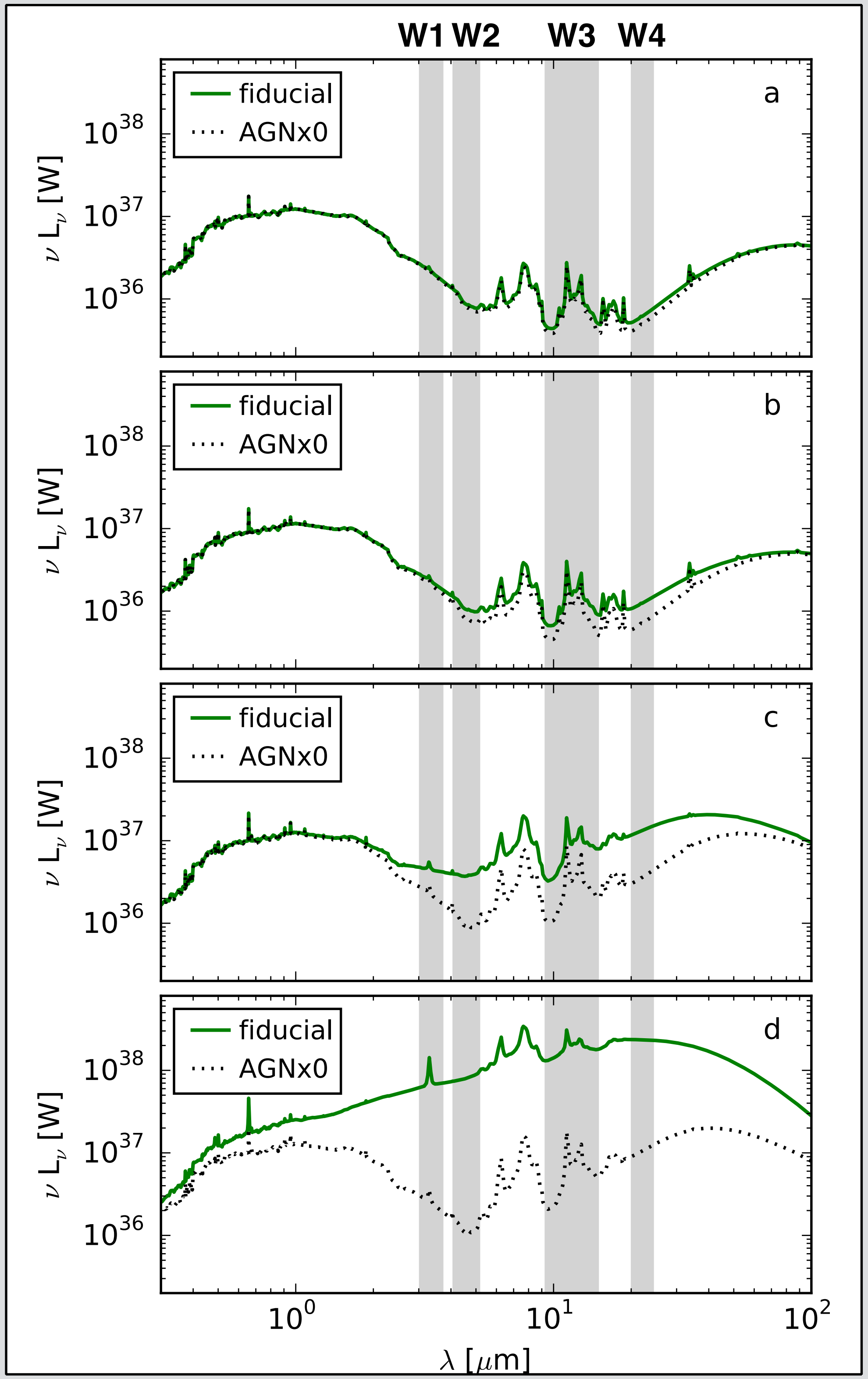

Merger simulation
t=1.23 Gyr

(Late-stage) mergers trigger obscured, luminous AGN

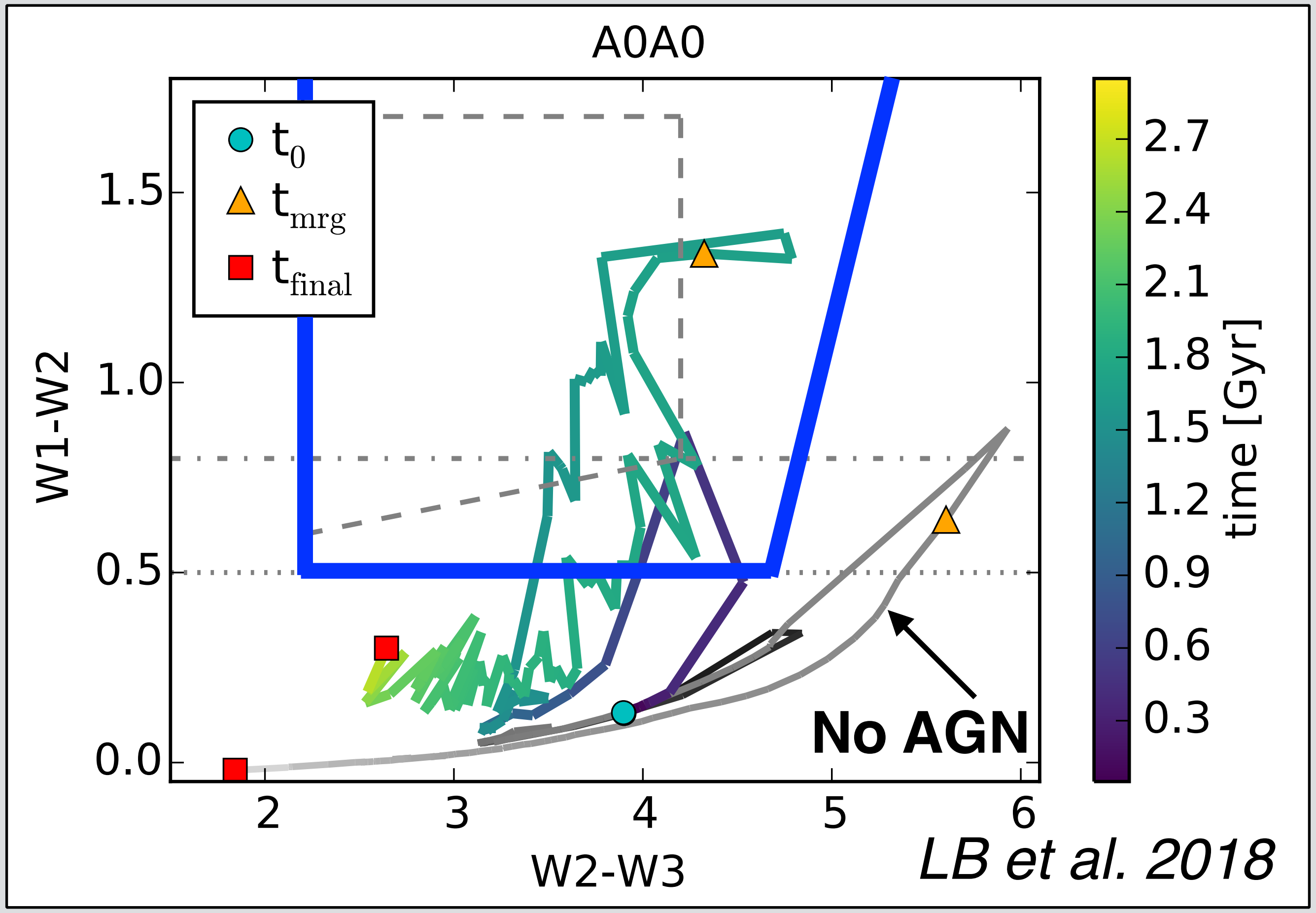


LB et al. 2018



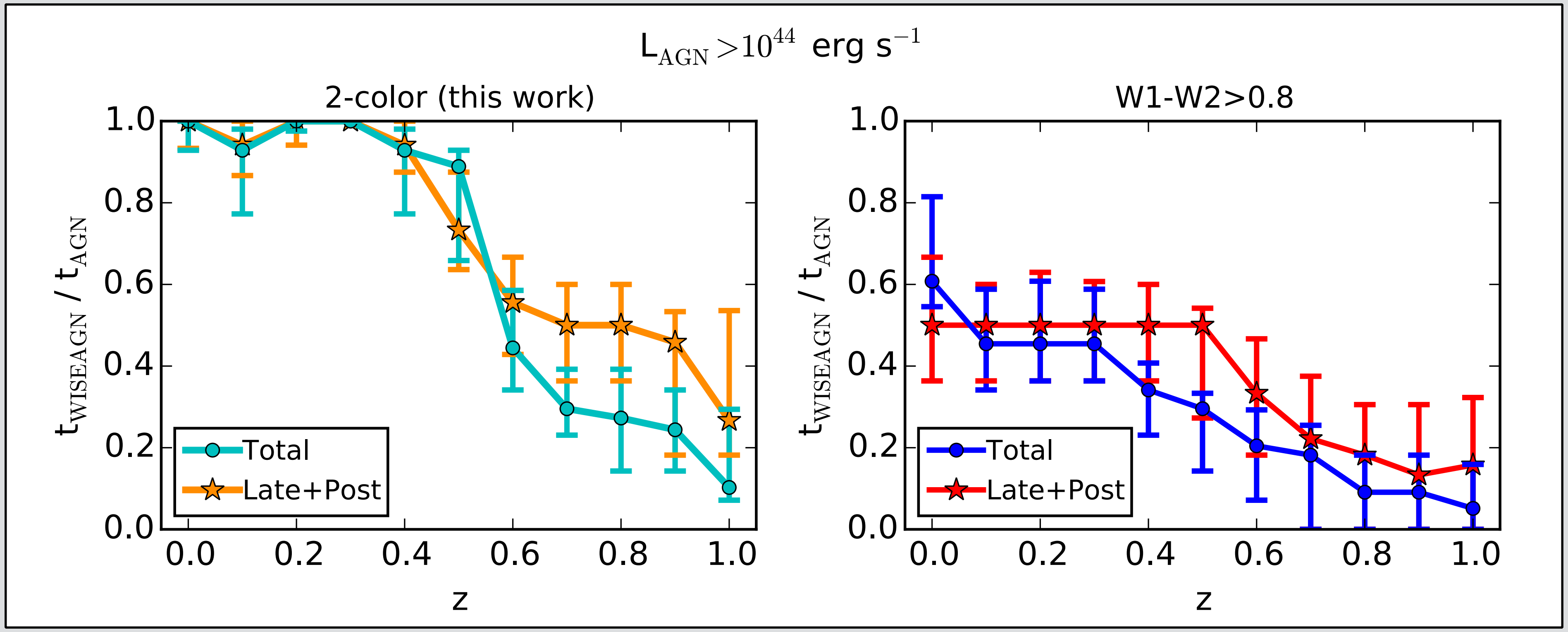


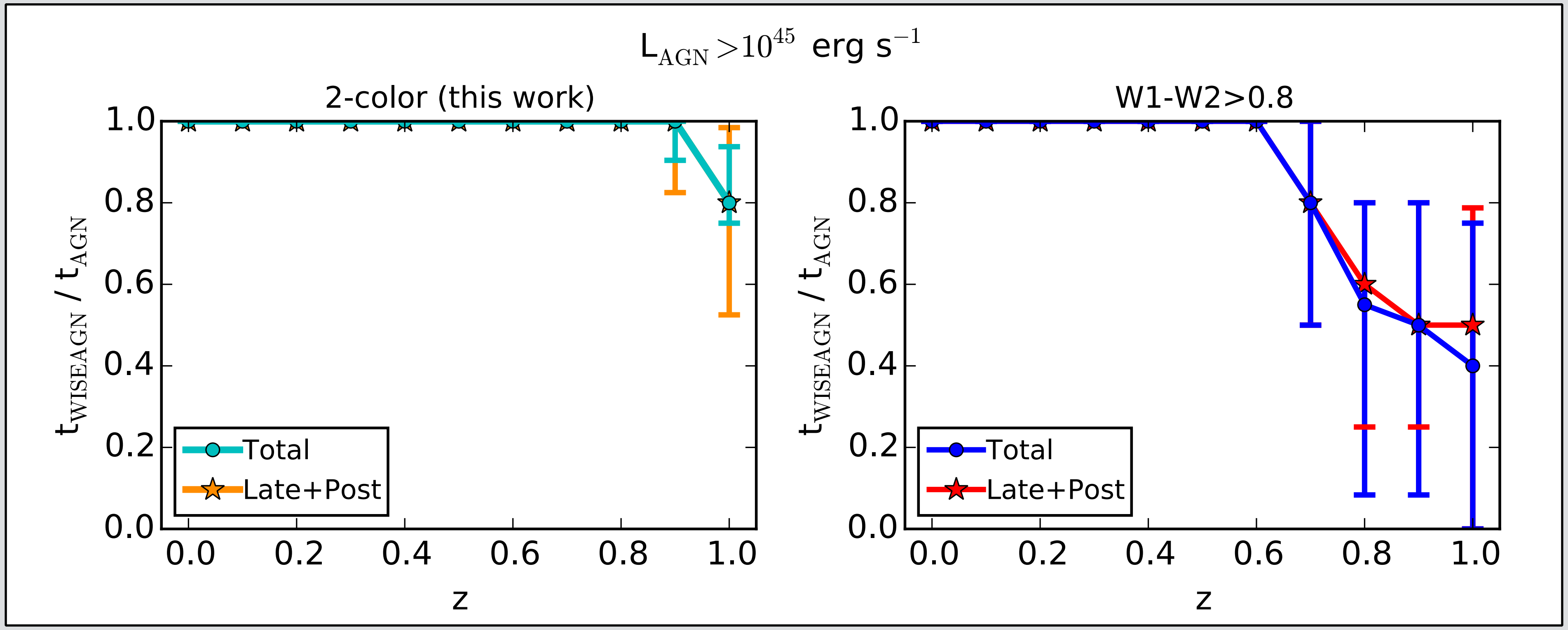
Mid-IR AGN completeness & reliability



- Virtually all luminous quasars are selected via mid-IR colors
- Nearly 1/2 of moderate-luminosity AGN missed with common selection criteria
- More lenient cuts: much higher completeness (for $z < 0.5$), and v. high reliability (for $z < 1$)
- **In mergers, starbursts with red mid-IR colors is accompanied by an AGN —> no "true" contamination by SF**

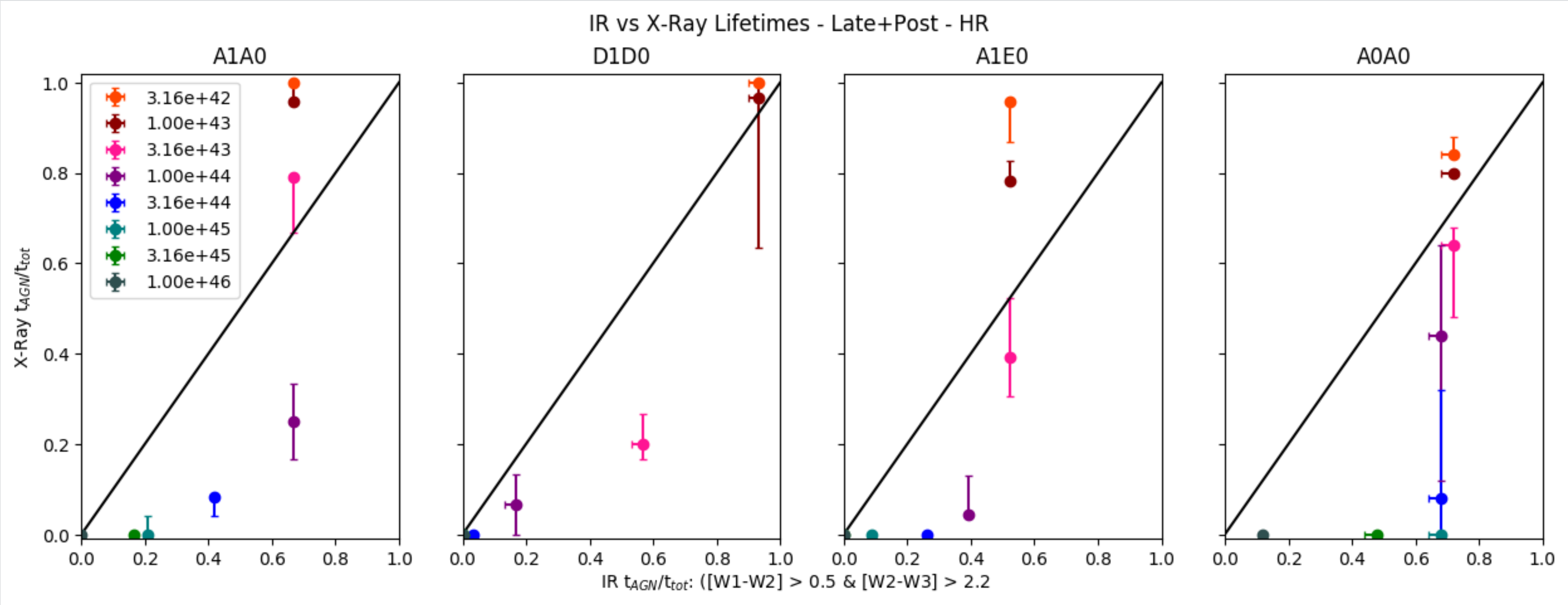
Redshift evolution of WISE mid-IR color in mergers





2-10 keV X-ray vs MIR AGN lifetimes

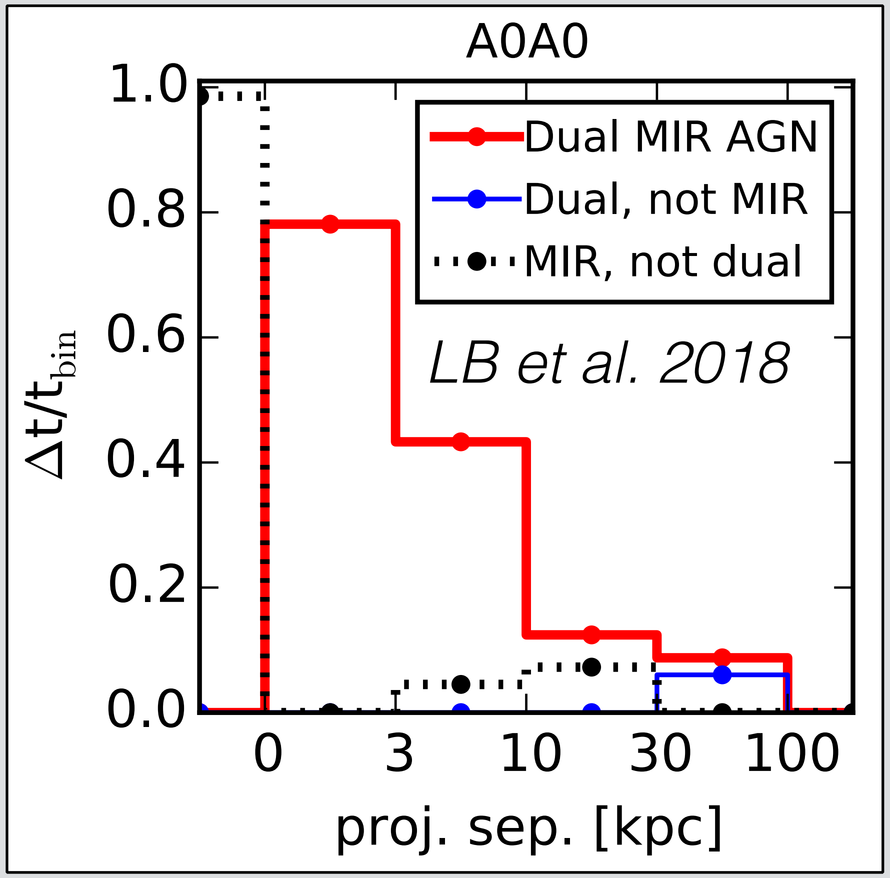
Newsome et al. in prep



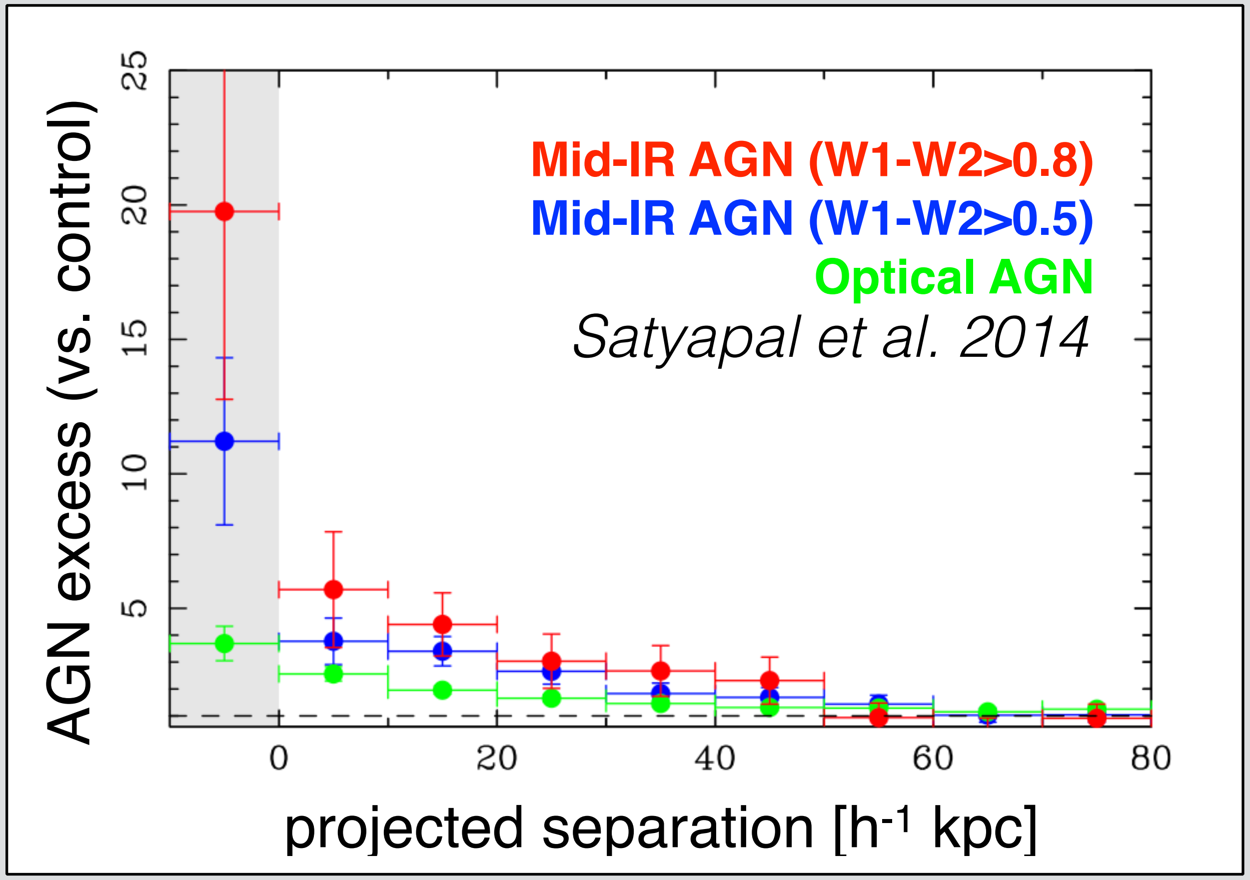
Next steps: compare different sub-grid torus models (incl. evolution-dependent?), compare with observations

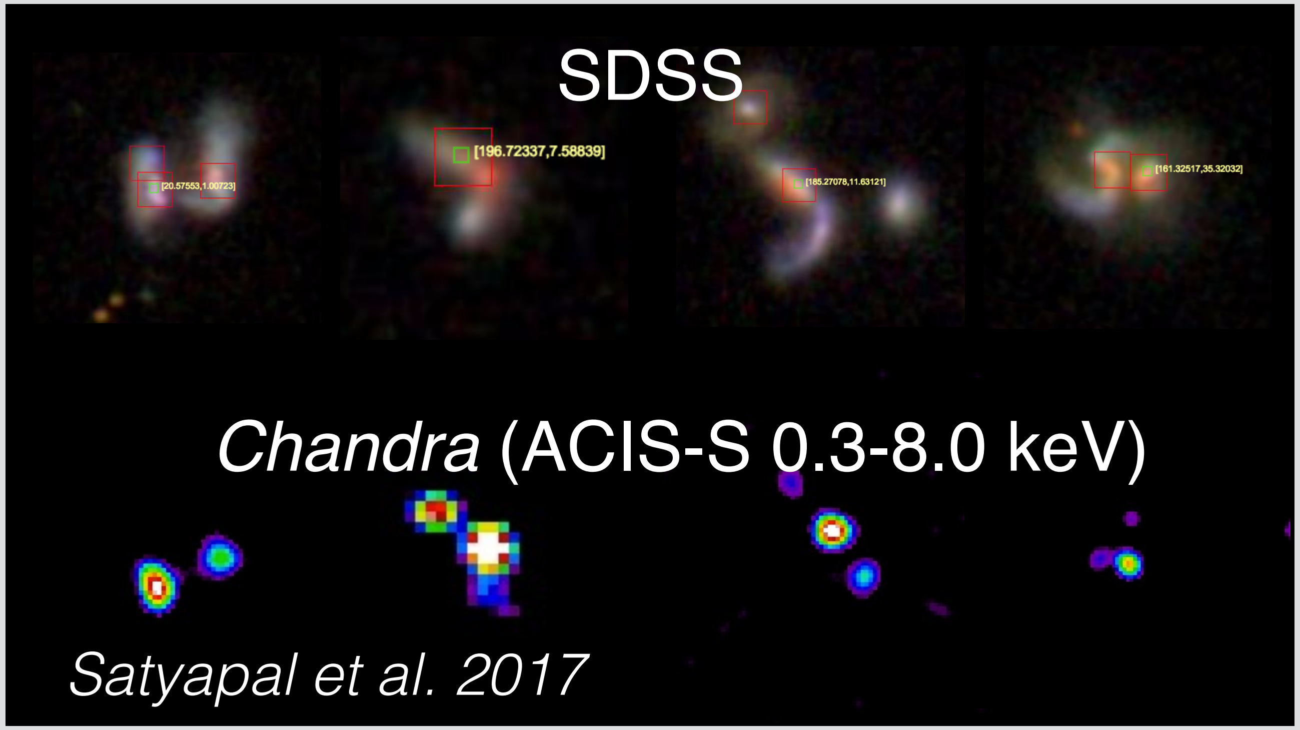
Uncovering dual nuclei in mid-IR selected AGN

Simulated *WISE* **dual** AGN:



Candidate *WISE* **dual** AGN:





SMBH binary evolution

kpc

10^{2}

10^{1}

10^{0}

10^{-1}

10^{-2}

10^{-3}

10^{-4}

10^{-5}

10^{-6}

Galaxy inspiral phase

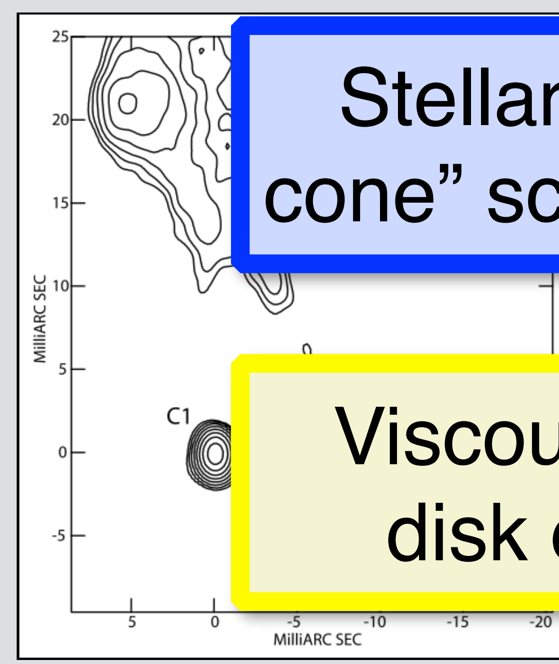
Dual SMBH inspiral phase

Bound SMBH *binary* phase

GW-dominated phase

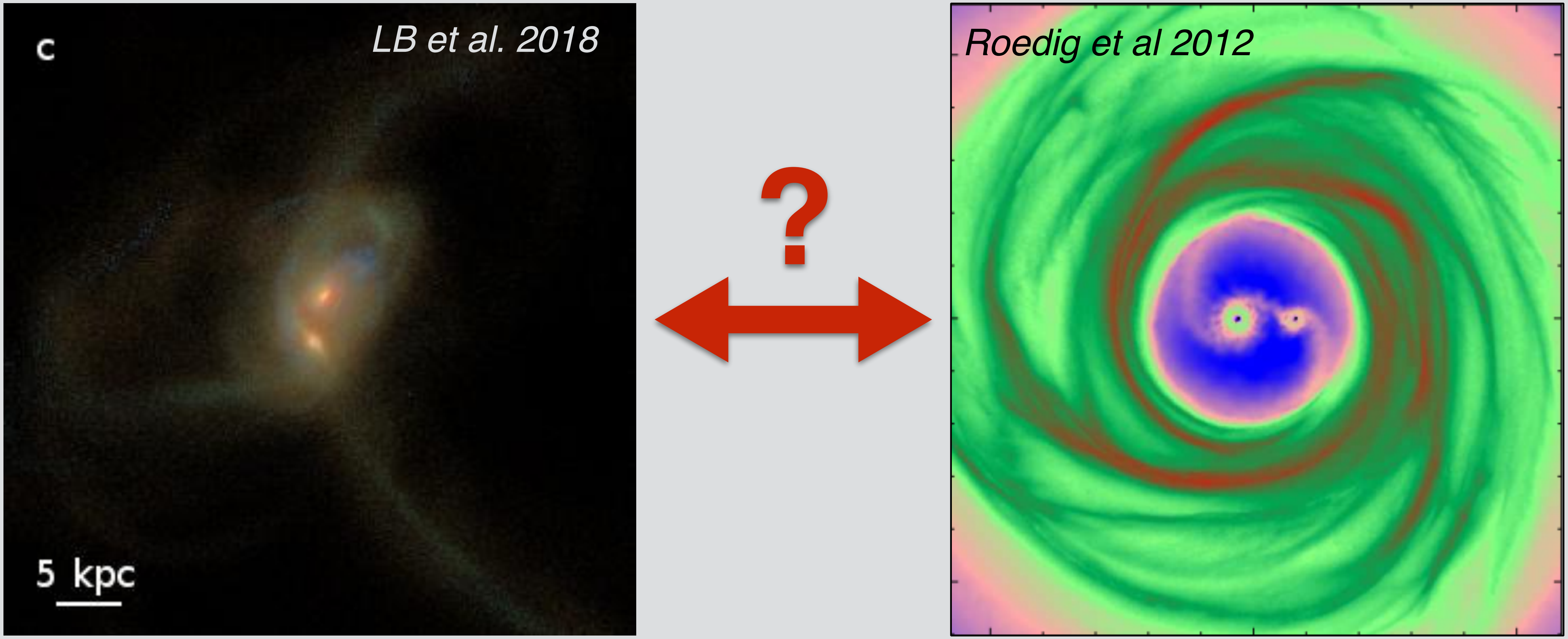
Dynamical Friction

Stellar “loss cone” scattering



Viscous gas disk drag

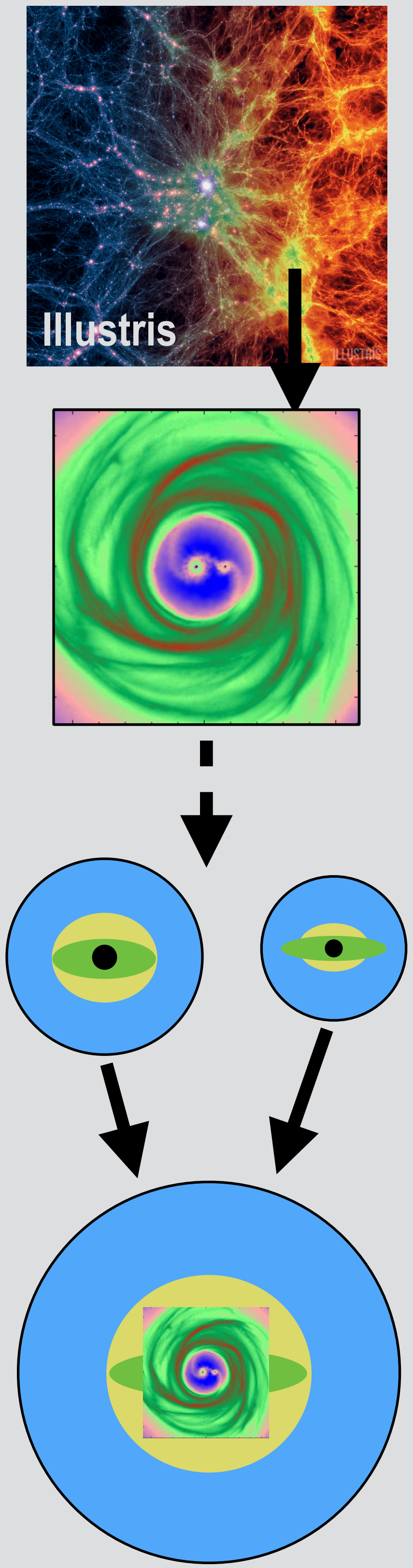
What happens in the BH binary phase?



Open questions:

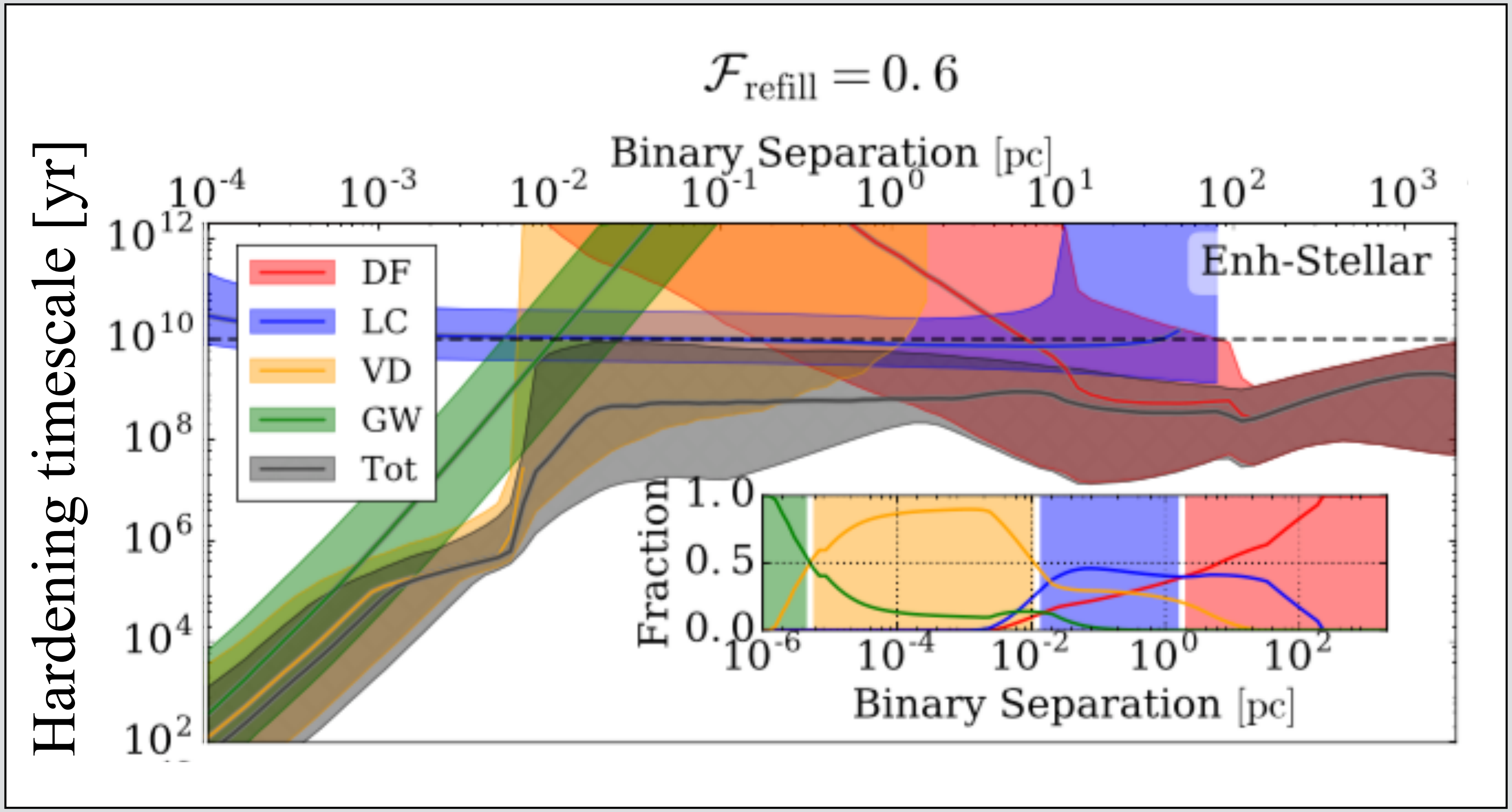
- How long do SMBHBs take to inspiral & merge? *do* they merge?
- Do they accrete through all/some of that phase or not? If so, how can we find their signatures?

Modeling BH binary inspiral timescales

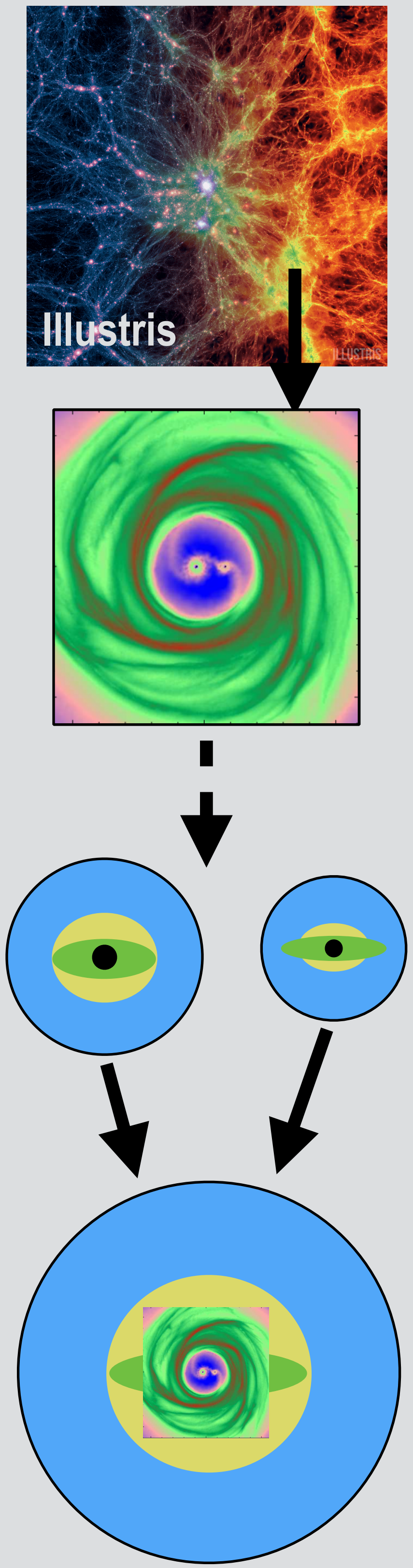


DF: Dynamical Friction
LC: “Loss-Cone” Stellar Scattering
VD: Viscous Disk drag
GW: Gravitational wave emission

Kelley, LB, & Hernquist 2017a



Modeling BH binary inspiral timescales



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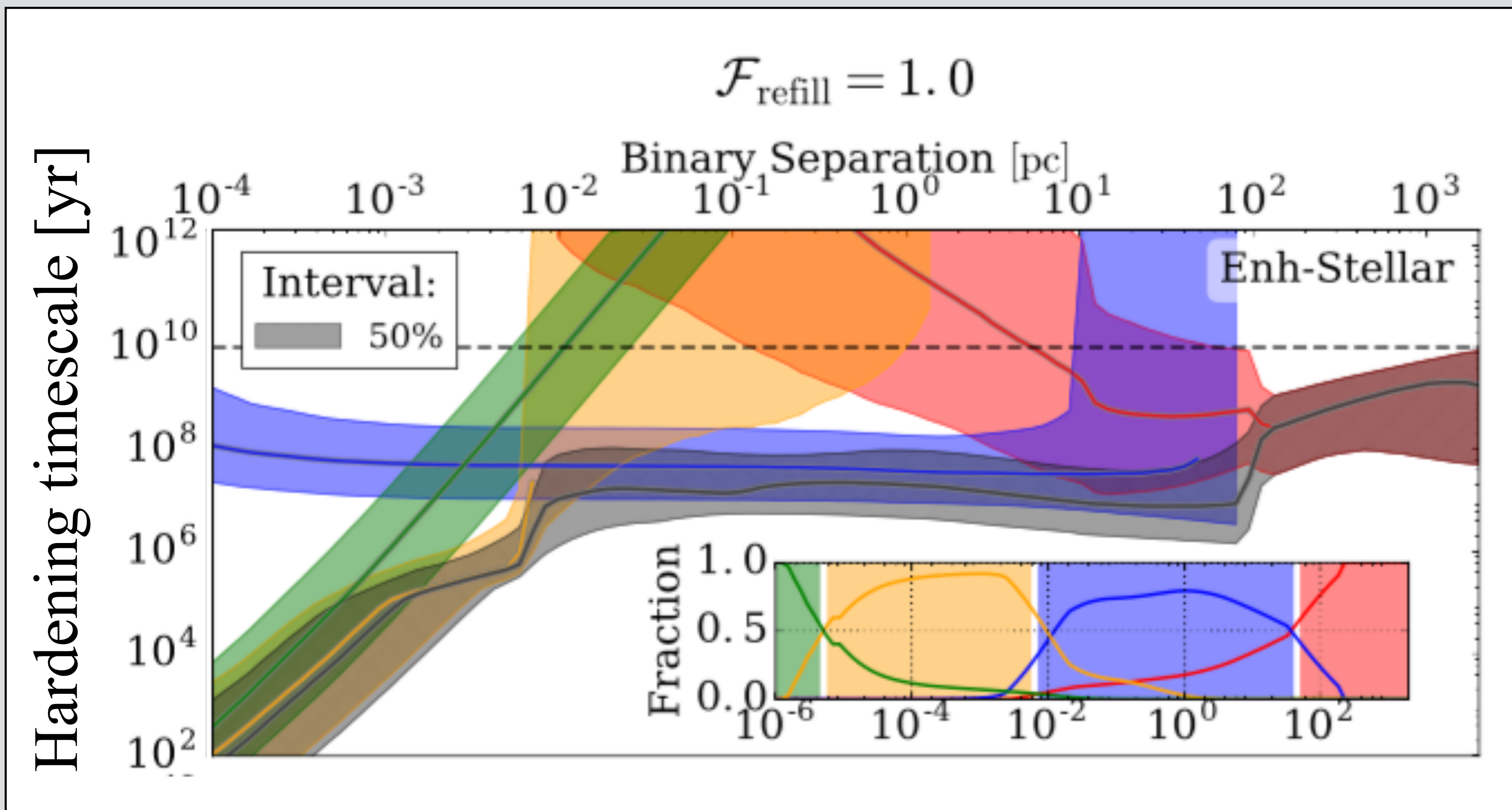
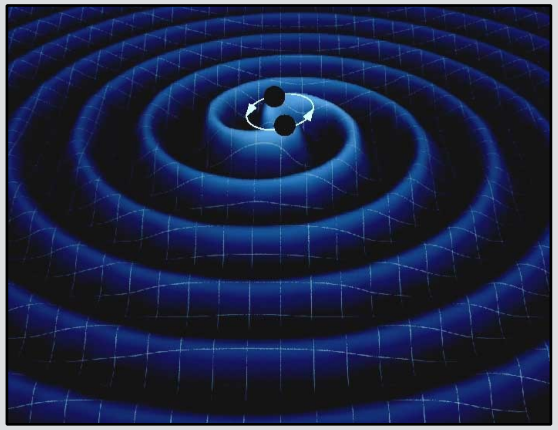
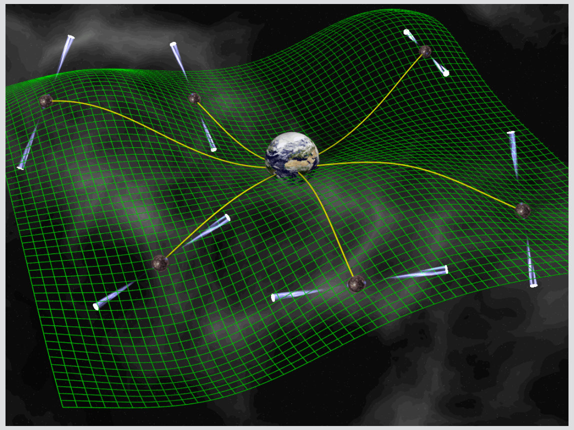
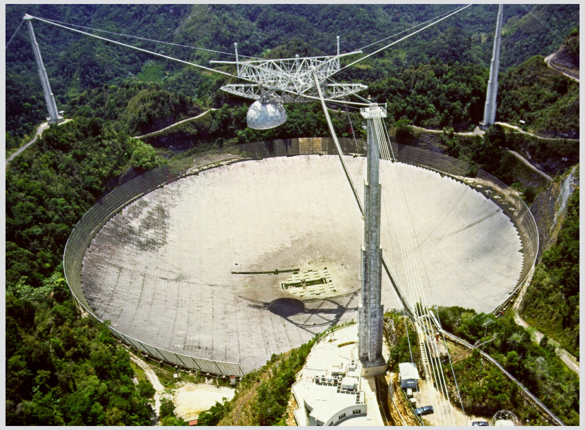


nHz GW background & BH coalescing fraction

Detecting GWs with Pulsar Timing Arrays:

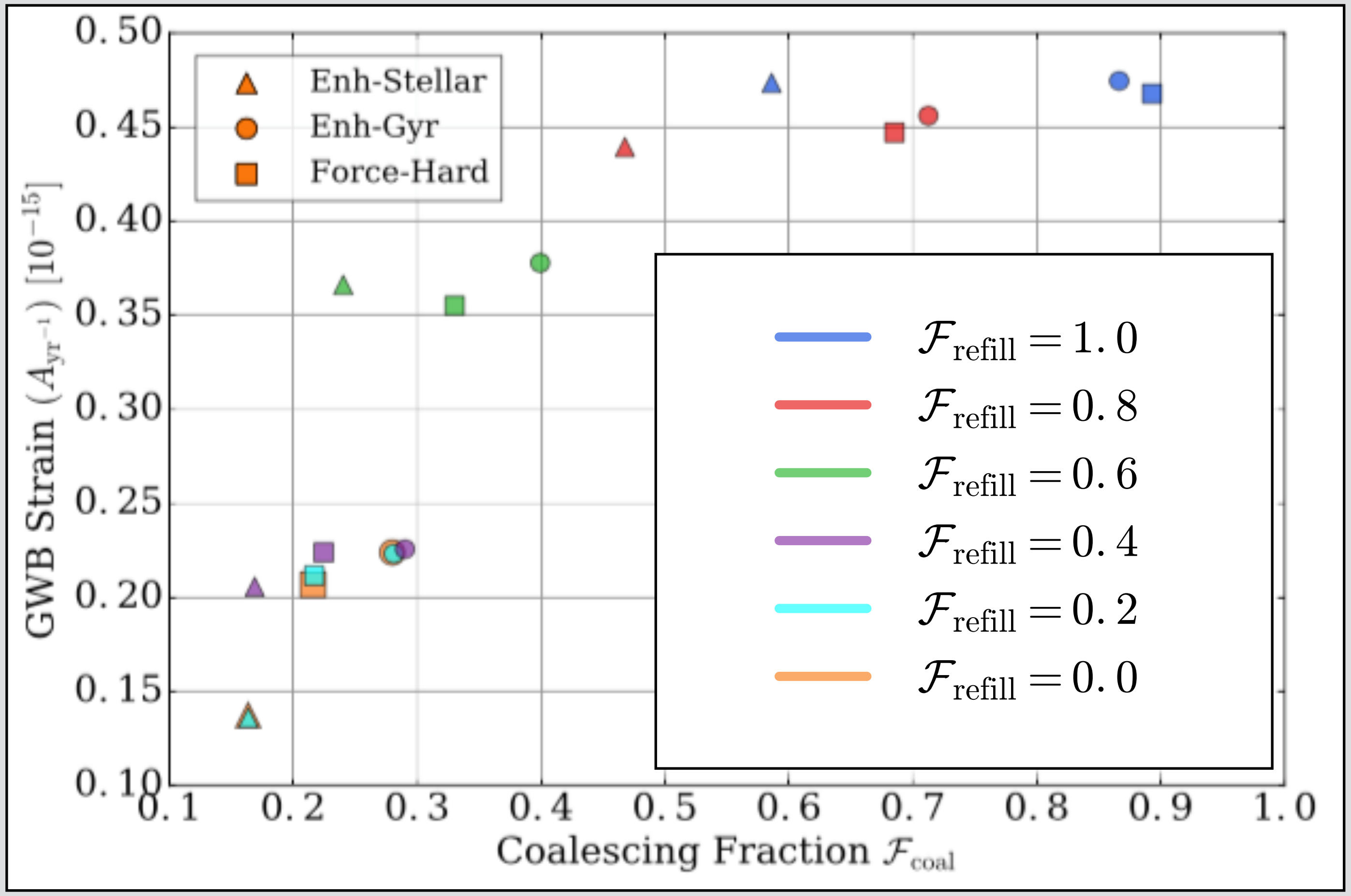






Kelley, LB, & Hernquist 2017a

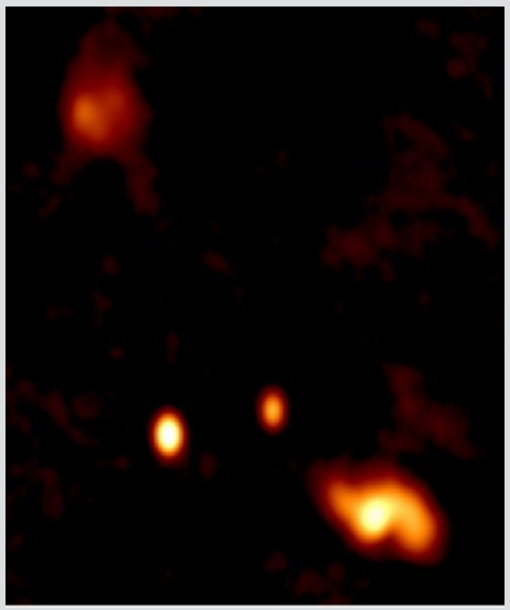
- **GWB strain amplitude** depends weakly on host galaxy
- Pulsar timing arrays: **95% detection probability** of GWB in <10yr *(Kelley, LB et al 2017b)*
- **Coalescing fraction** varies widely; long lifetimes common
  - Important for **LISA** merger rates
  - **need EM constraints** on BHs in mergers!



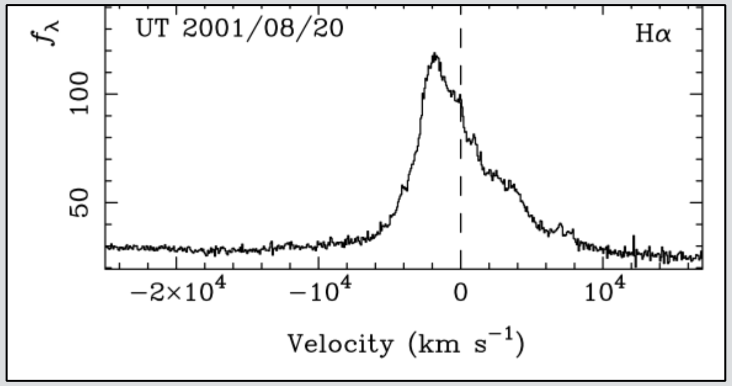
GW + EM constraints on SMBH binaries

parsec-scale binary

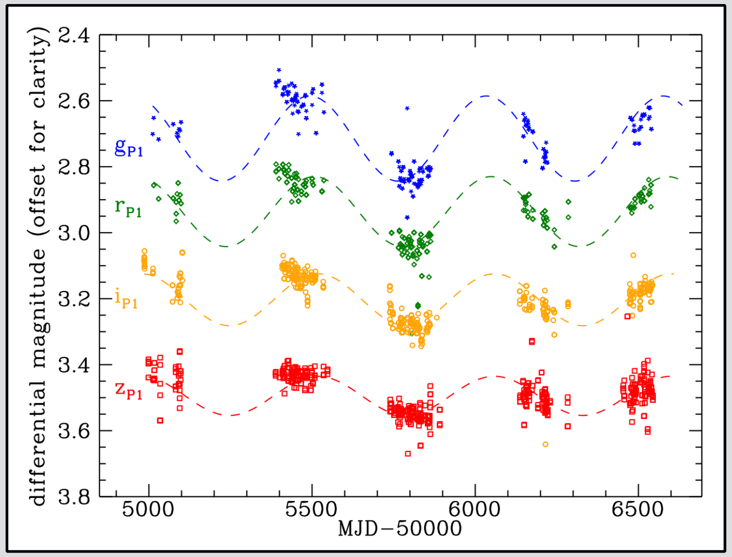
milliparsec-scale binary candidates



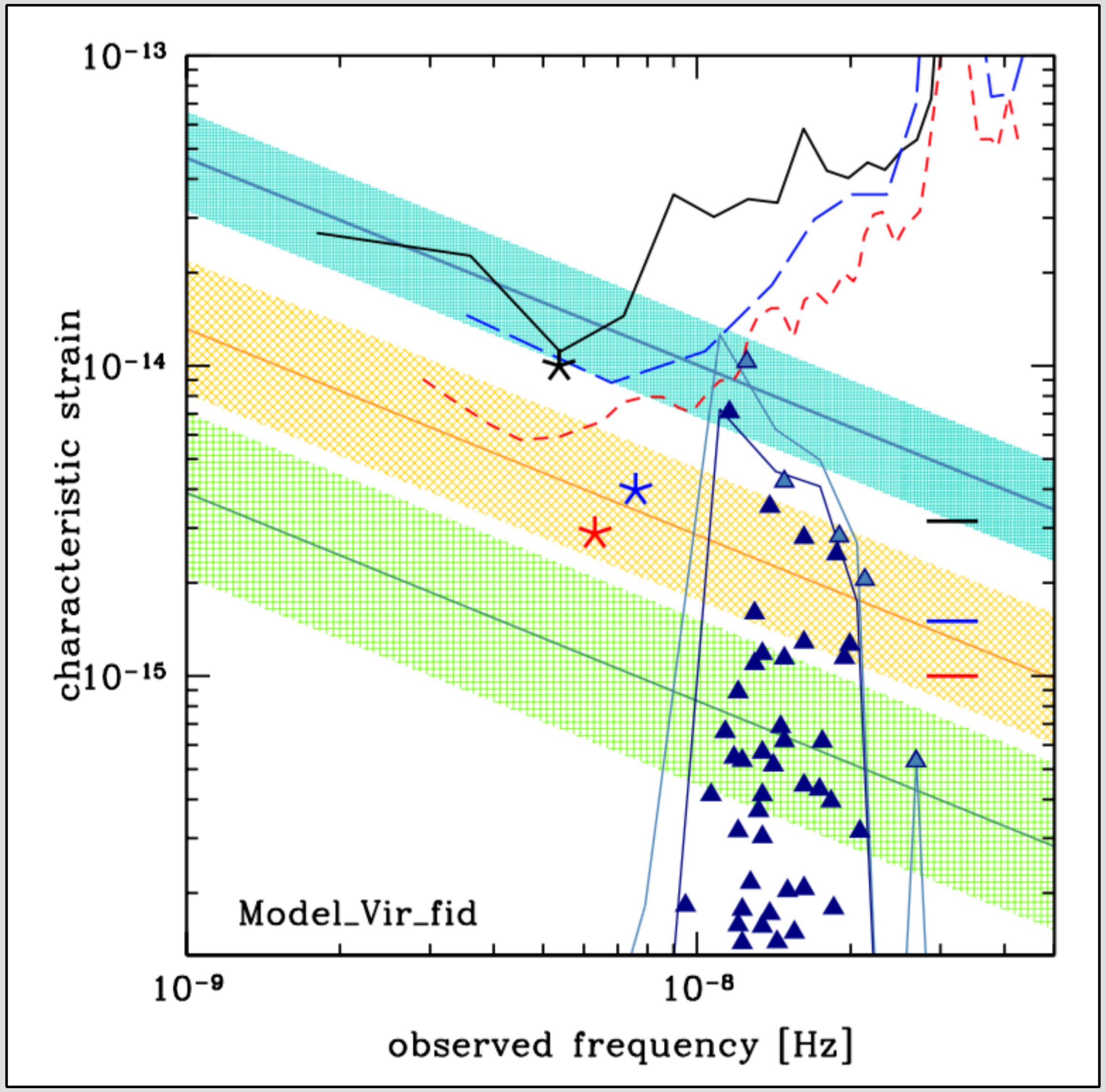
Rodriguez et al. 2006 (See also: Burke-Spolaor 2011)



Eracleous et al. 2012



Liu et al. 2015

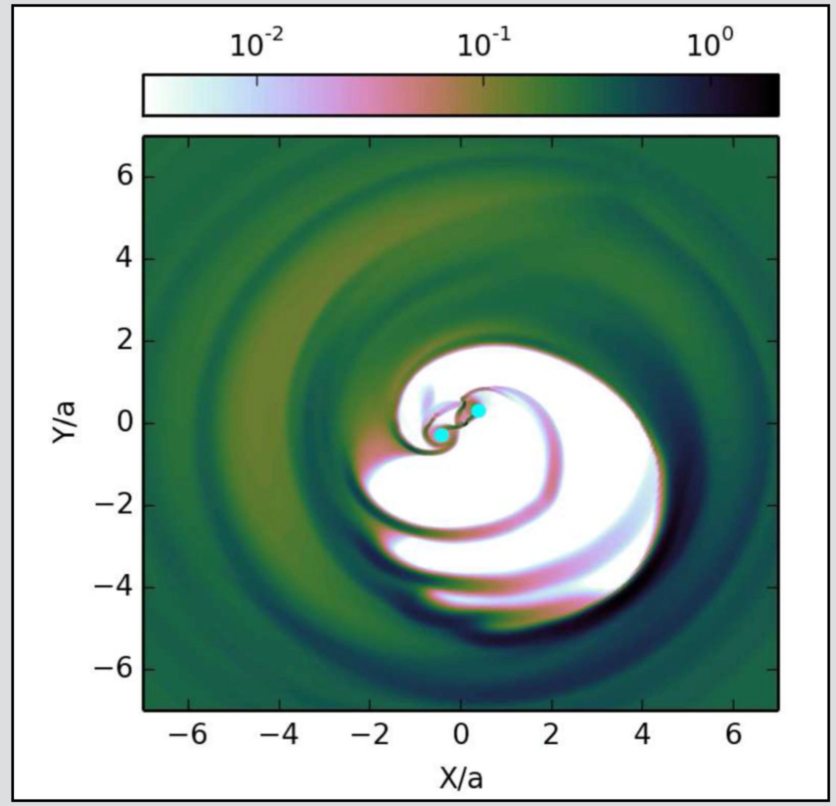


Sesana et al. 2017

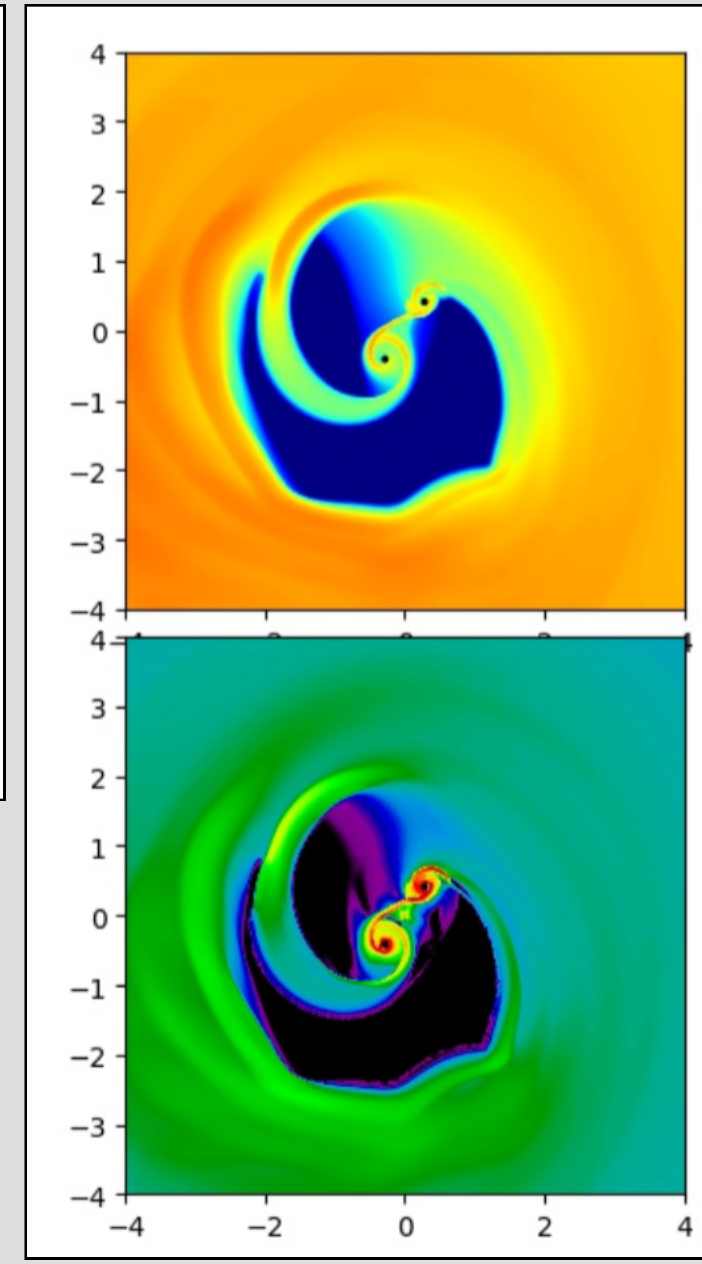
—> future constraints from PTAs + LSST?

EM signatures of SMBH binaries

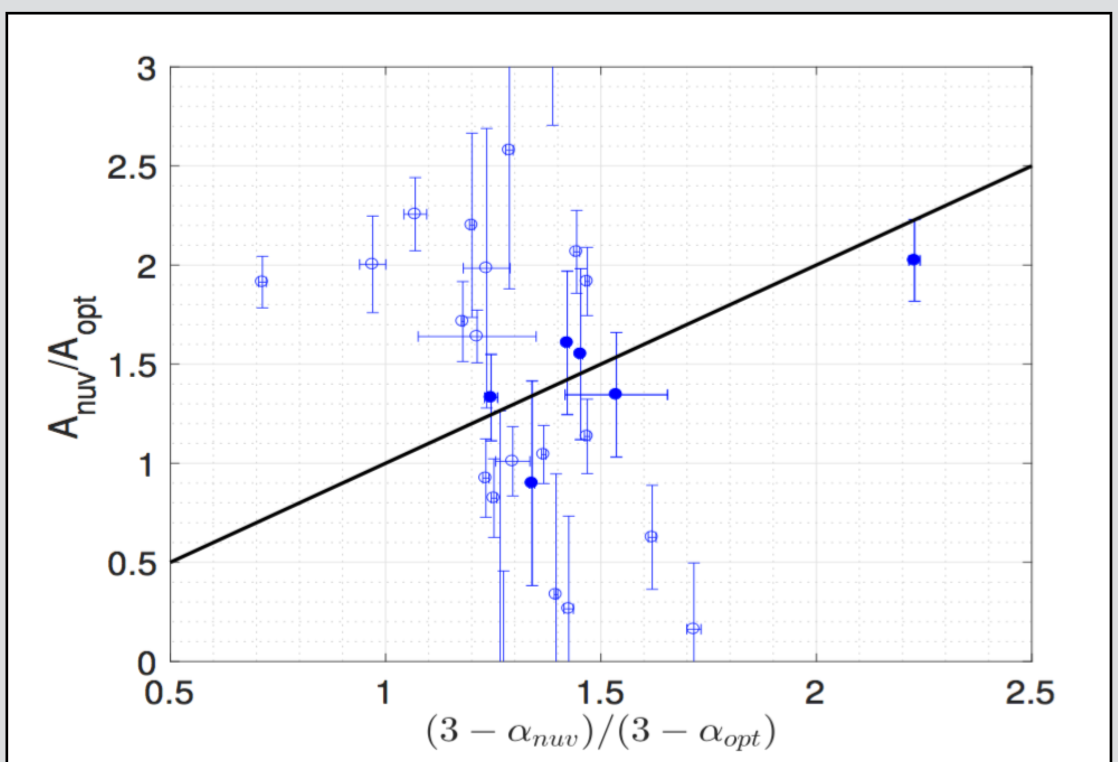
- Relativistic Doppler boost
- Hydrodynamic variability
- Disambiguation of variability?
- Dilution?
- Obscuration?



Farris et al 2015



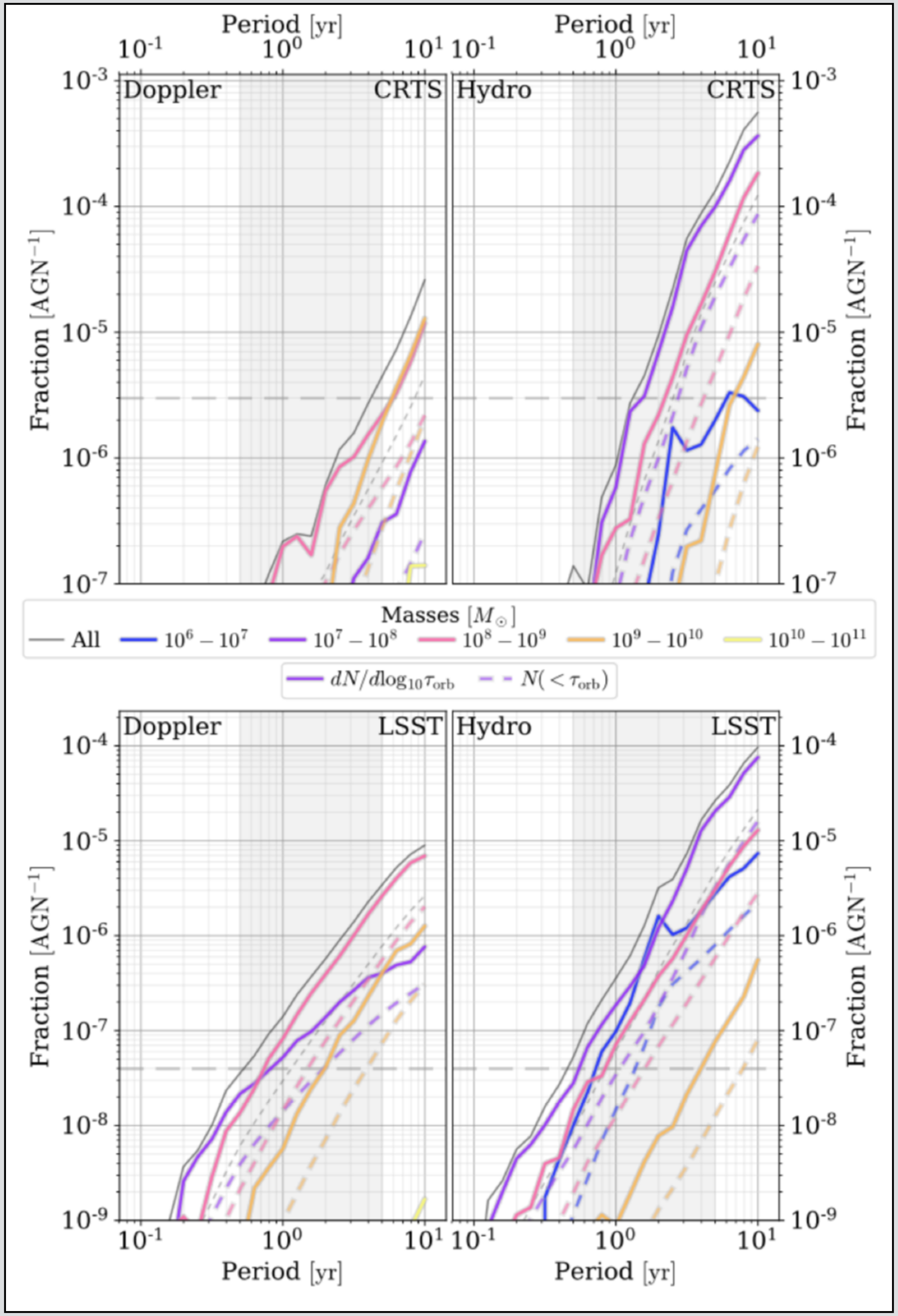
Tang et al 2017



Charisi et al 2018

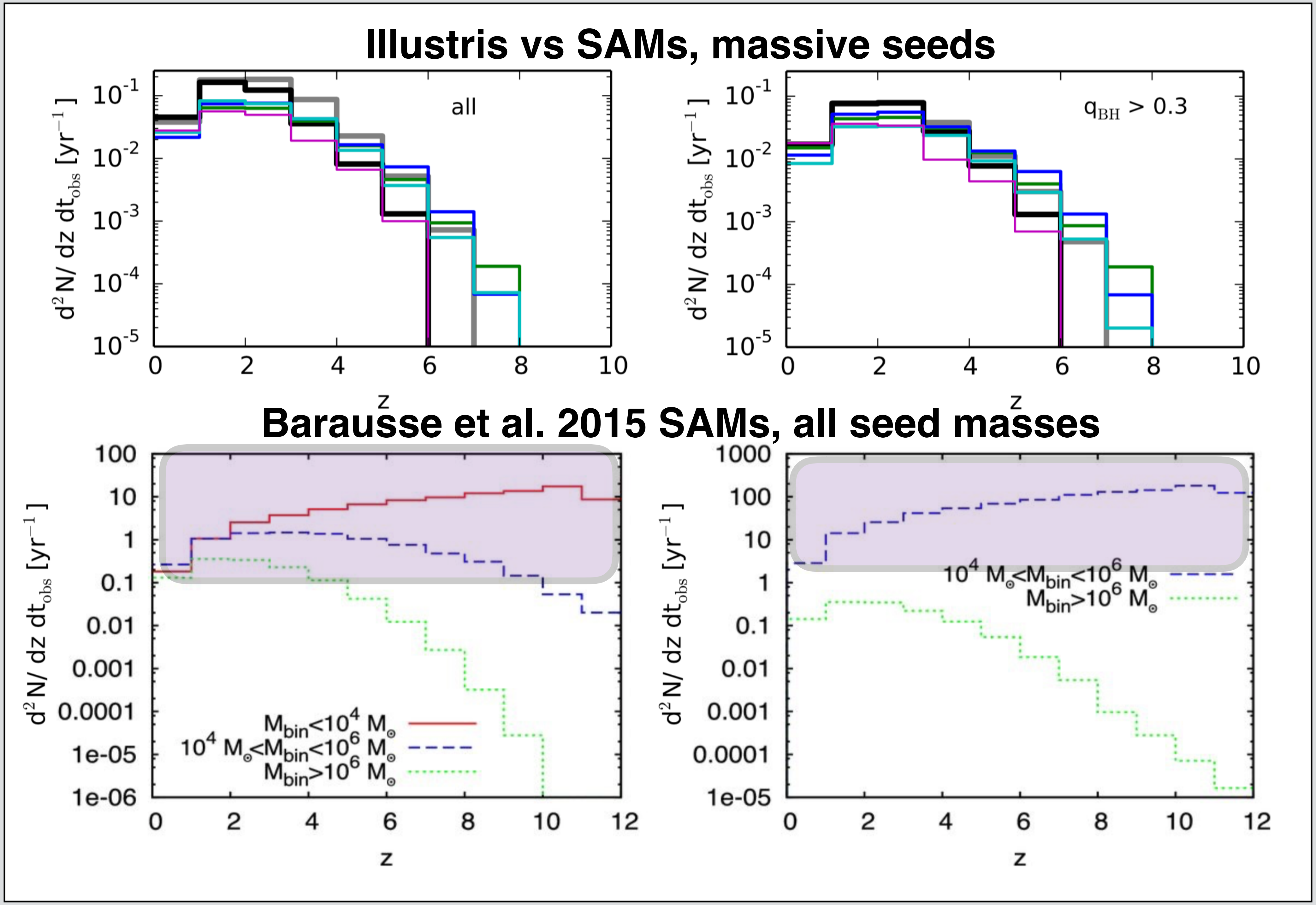
Predictions for detectable EM variability of SMBHBs from Illustris

- Kelley et al 2018 predict ~ 0.2 Doppler and 5 hydrodynamic binaries identifiable in CRTS
- 20 and 100 identifiable in 5-yr LSST



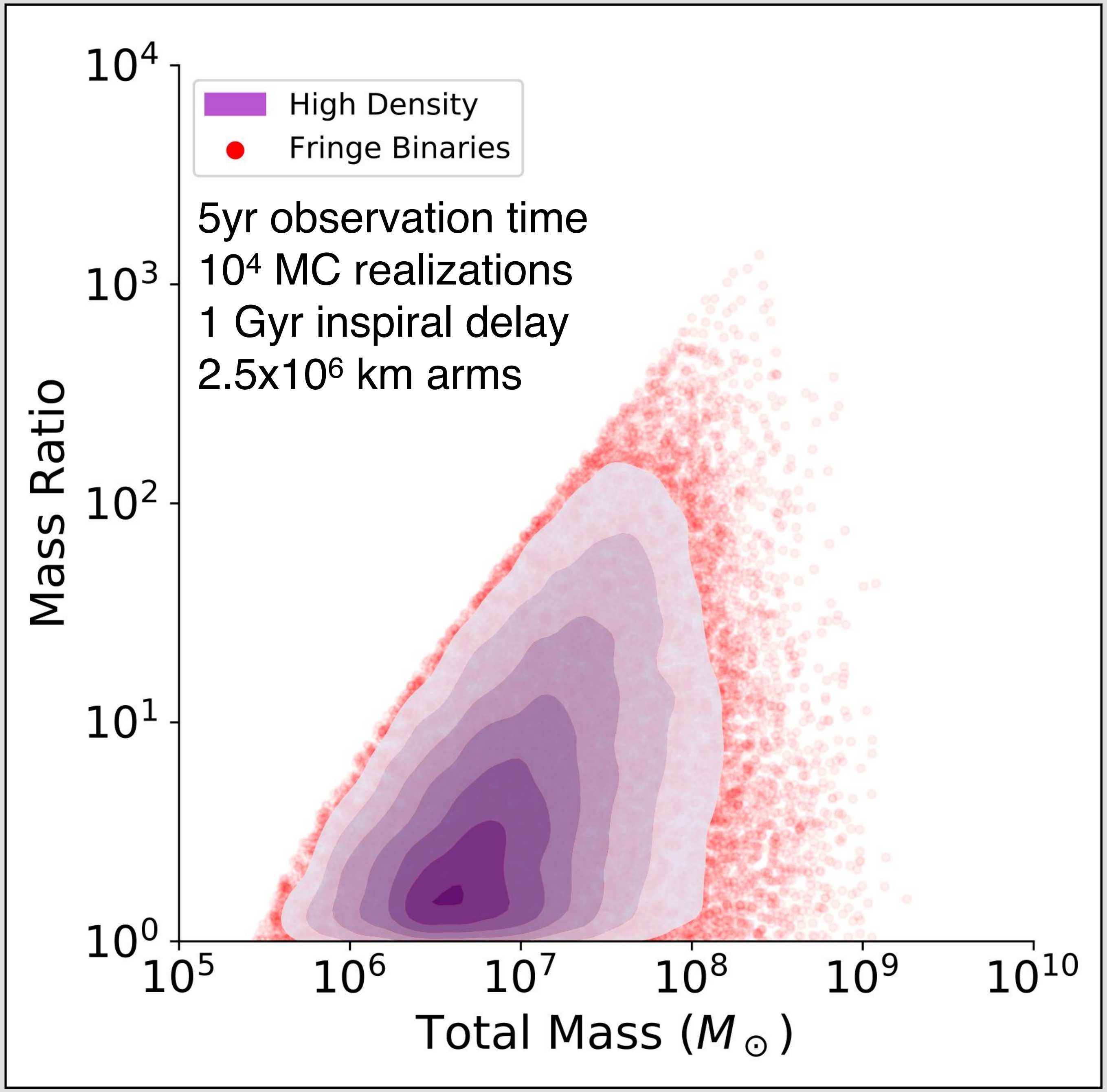
Kelley et al. 2018b

Modeling LISA event rates



Modeling LISA event rates

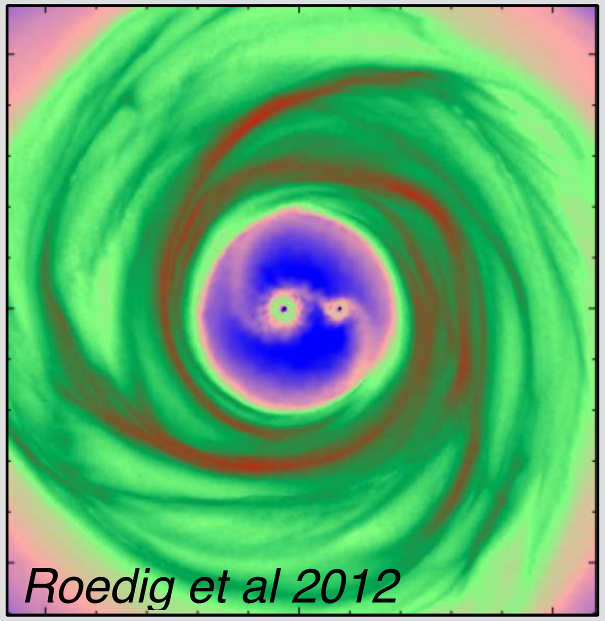
Michael Katz et al. in prep



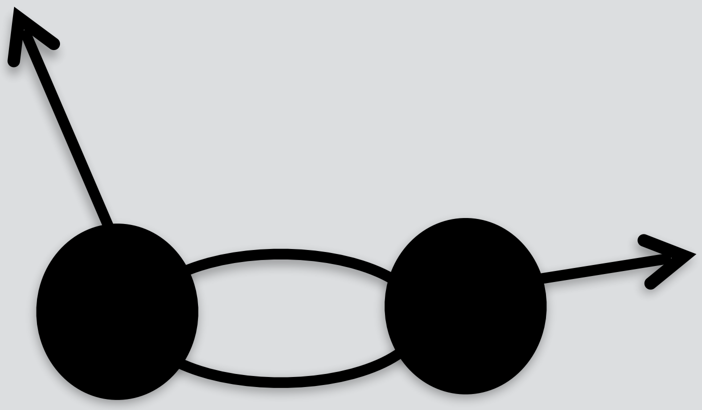
- **40%** have at least 1 BH < 10^6 $M_\odot$
- **7%** have *both* BHs < 10^6 $M_\odot$
- These would be excluded with standard mass cuts
- Currently implementing with Kelley et al. inspiral models

BH Spin Evolution
(see talk by Mohammad Sayeb)

Gas-driven



GR precession



BH Spin Evolution
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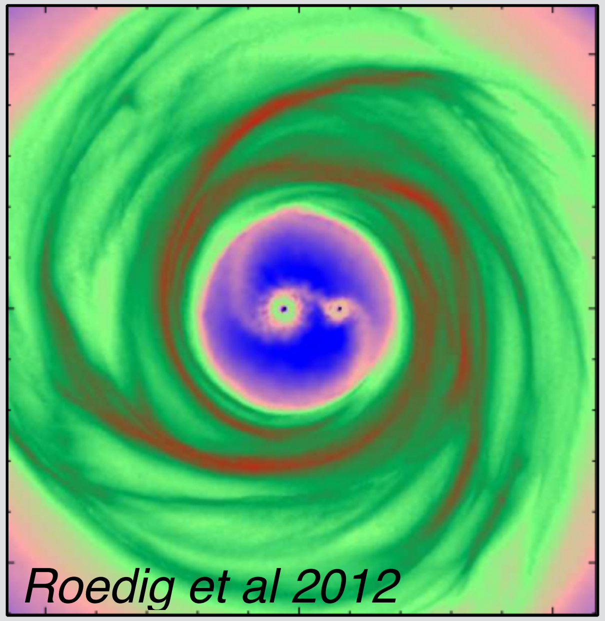
Gas-driven



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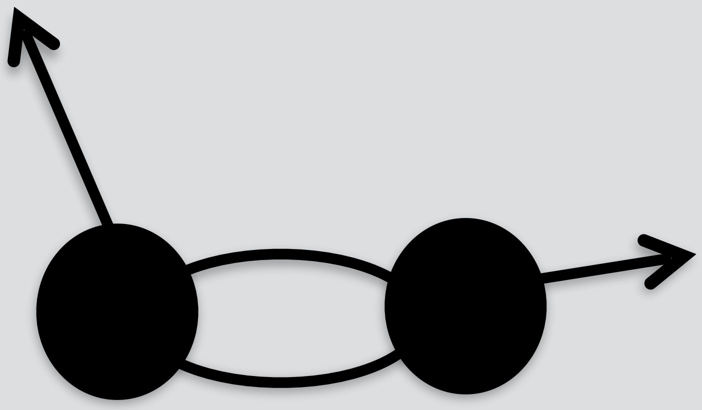
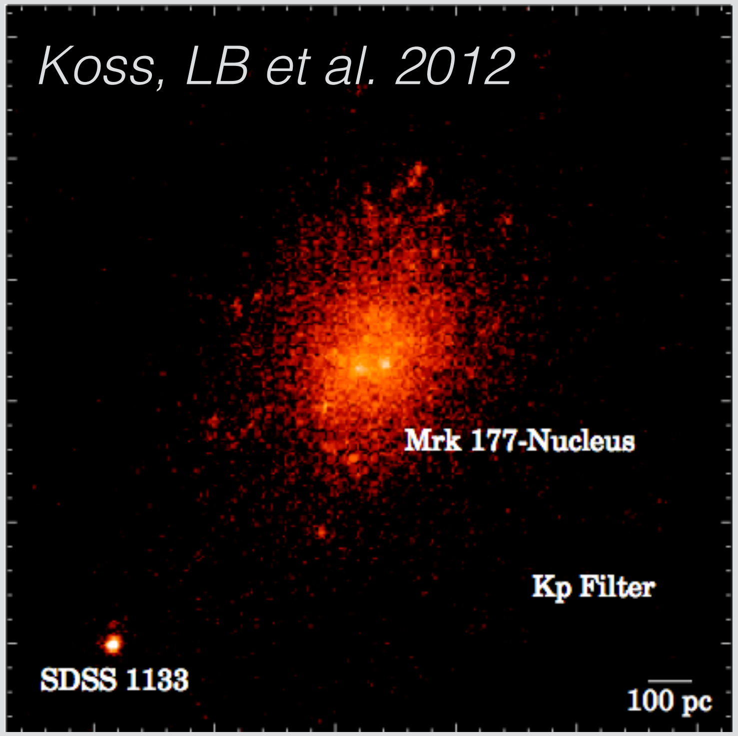
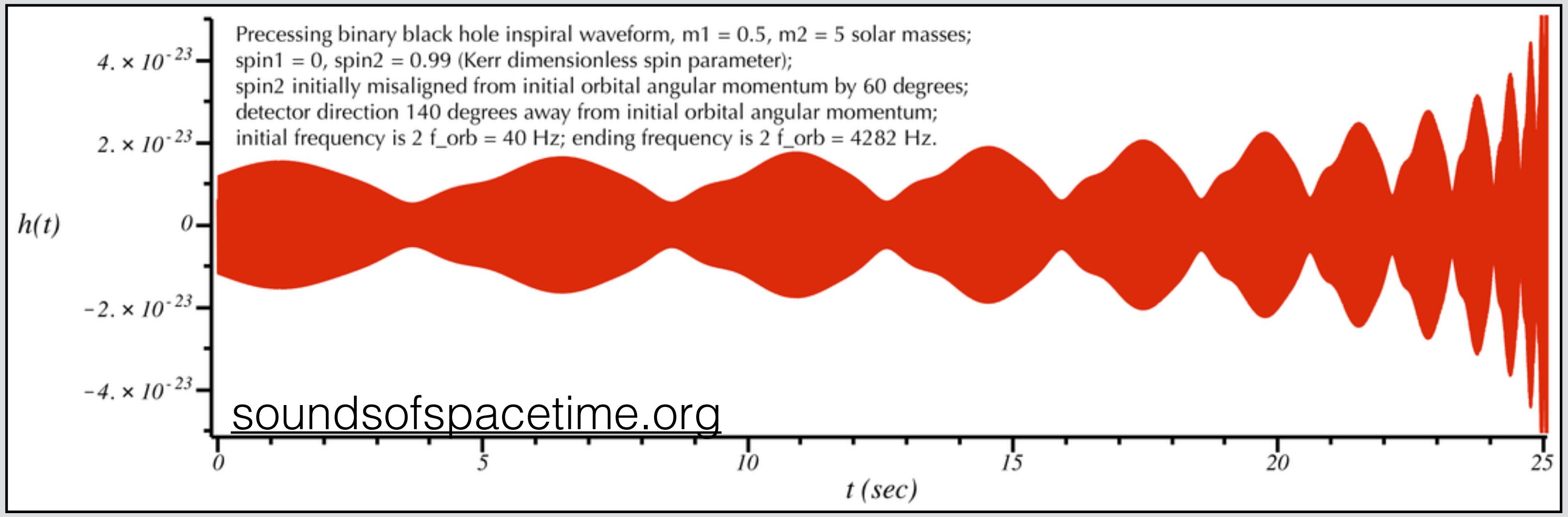


Gravitational-wave recoil

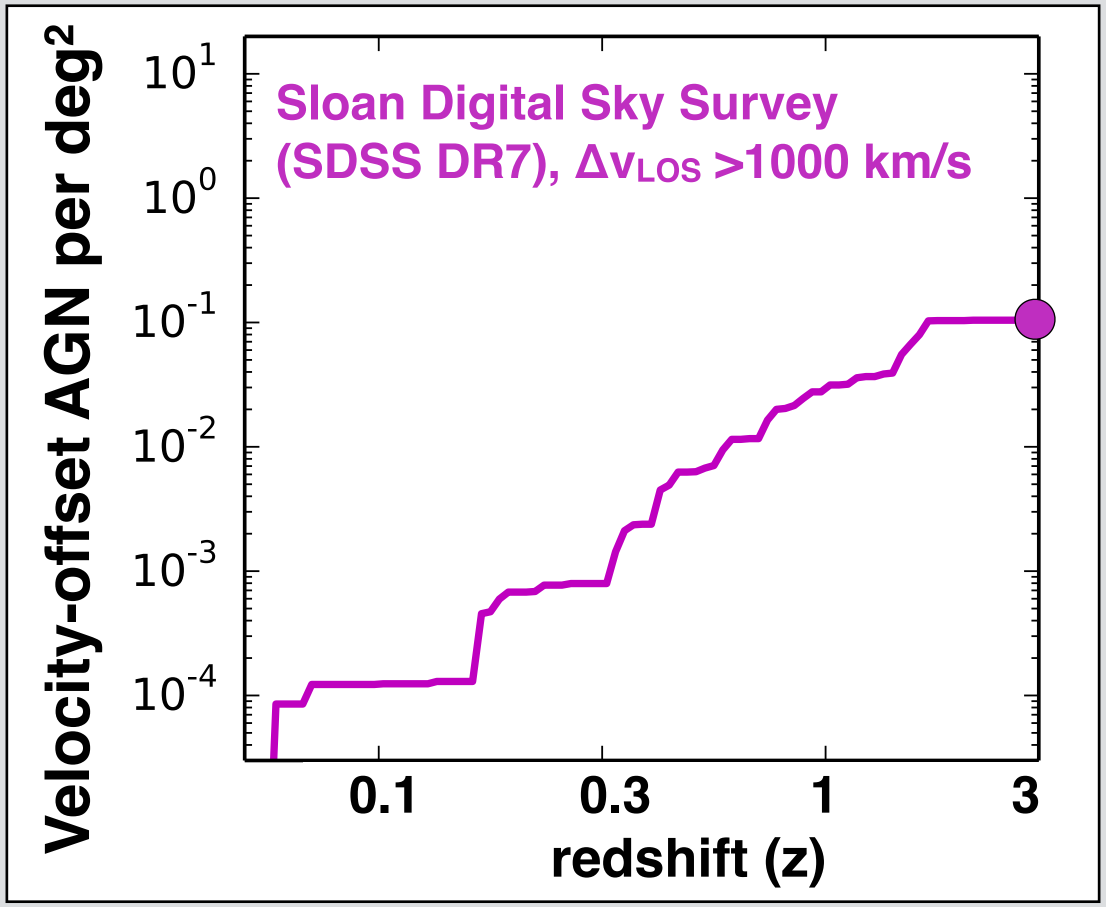


Precessing LISA waveforms

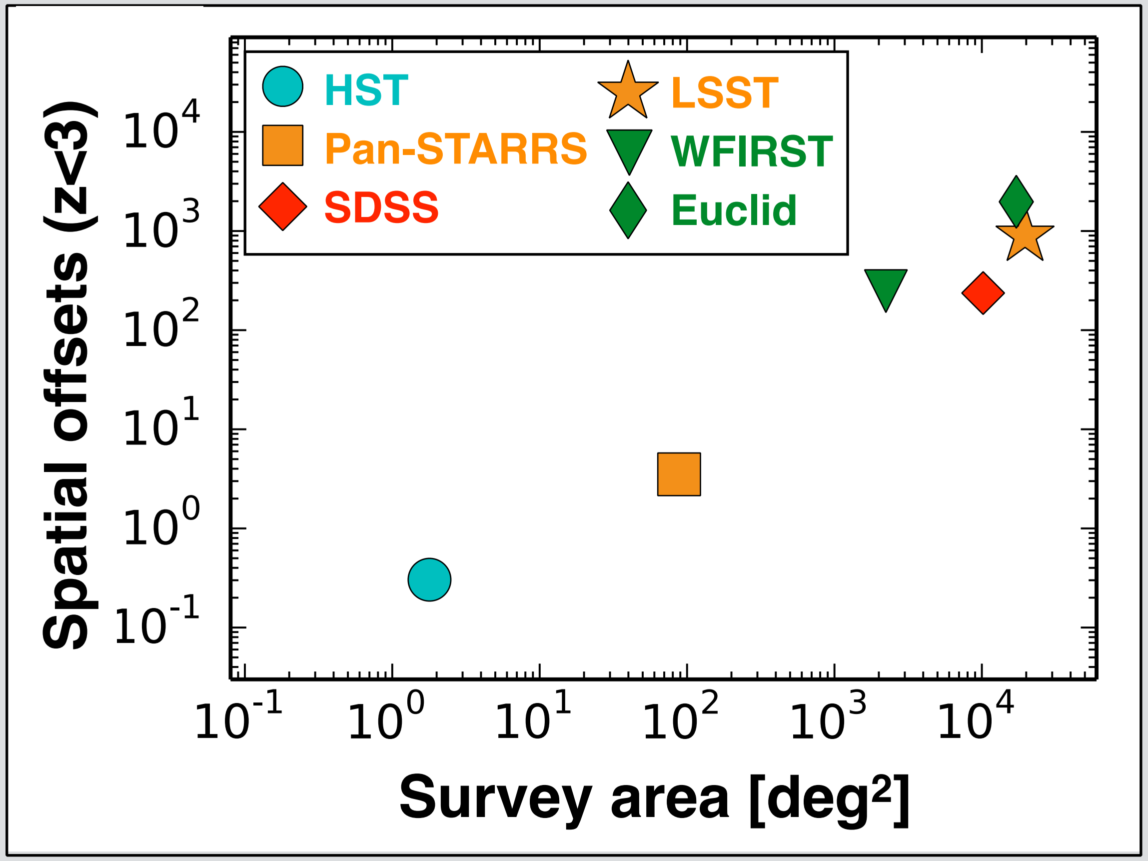


Observability of recoiling AGN:
predictions from the Illustris simulations

Velocity offset AGN
(random spins = high v_{kick})



Spatially offset AGN
(partially-aligned, gas-driven spins = lower v_{kick})



LB et al. 2016

- ***Gas dynamics*** aligns spins (lower v_{kick}), suppresses recoil trajectories
- Models + SDSS spectra suggest ***some spin alignment occurs***
- Still predict ***hundreds*** of spatial offsets in large surveys
- ***Time domain surveys*** (Pan-STARRS, LSST) uniquely capable of finding recoils *(see Kumar et al. 2015)*

BASS observations vs. simulations: possible synergies

- BH masses, Edd ratios, multi-wavelength SED bolometric corrections — connection with simulations
- Comparison b/t X-ray and IR: constrain torus models / covering fractions
- Use EM observations of dual AGN / AGN in mergers to constrain BH inspiral models — critical for GW predictions!
- Searches for offset AGN
- TNG50 - dwarf galaxies, higher res modeling of merger dynamics, galaxy structure, feedback
- Future cosmological simulations: lower mass BH seeds — compare with local low-mass analogs
- Use high-res observations to constrain feedback models in sims
- Other ideas?