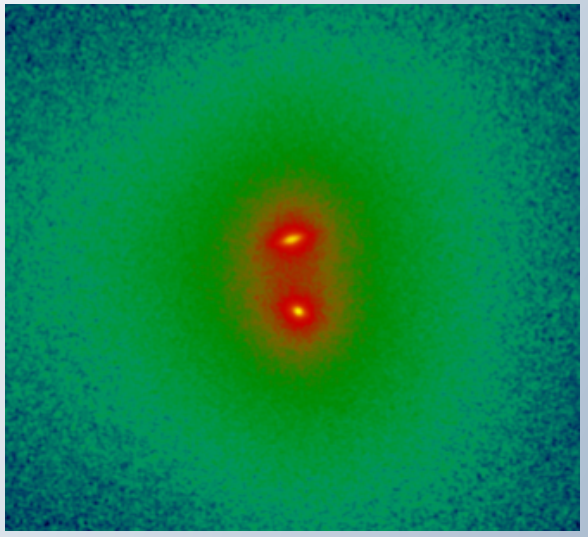
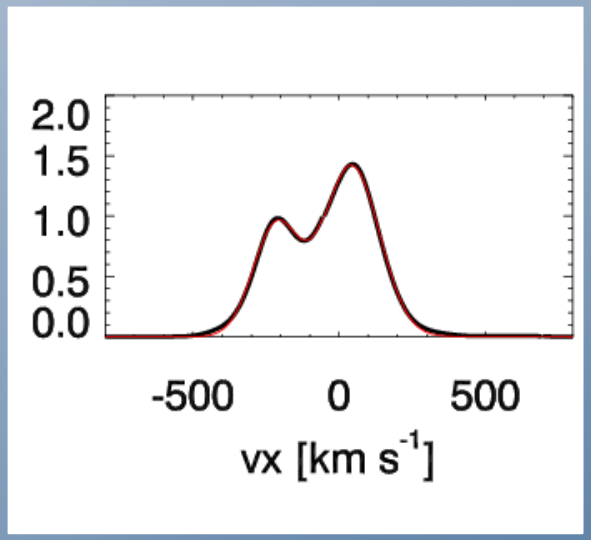
Connecting Dual SMBH and Double-peaked NL AGN





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In collaboration with Avi Loeb and Ramesh Narayan

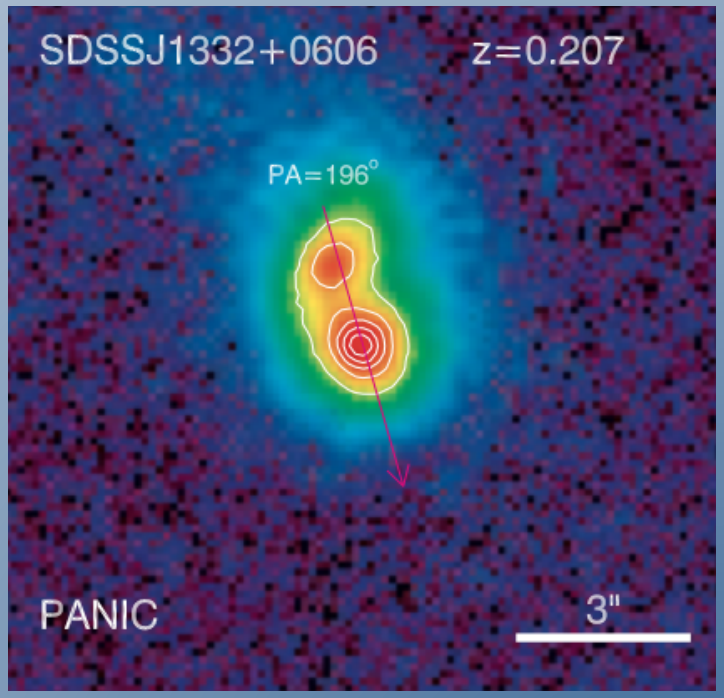
Harvard-Smithsonian CfA

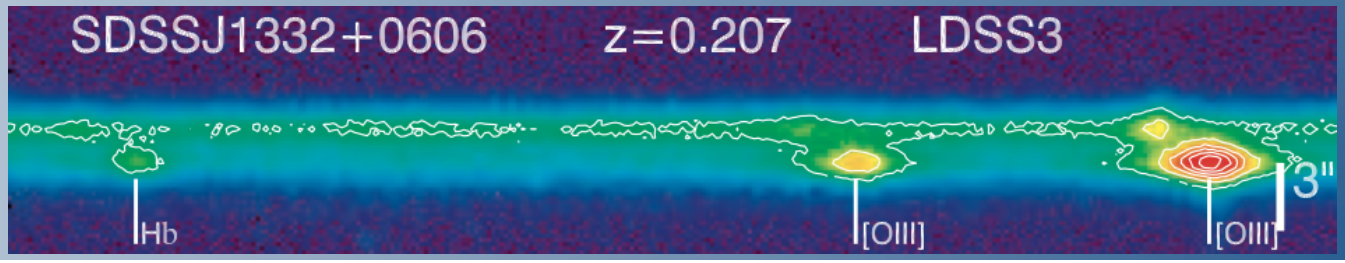
Single and Double Black Holes in Galaxies Workshop

University of Michigan, Aug 24, 2011

Double-peaked NL AGN

- Three AGN surveys reveal that ~ 1% of AGN have double-peaked NLs ([OIII]) *(Comerford et al. 2009a, Liu et al 2009, Smith et al 2009)*
- Follow-up imaging and 2D spectroscopy - at least 10% of these are good dual BH candidates *(Shen et al. 2011, Rosario et al. 2011)*





Galaxy Merger Simulations

- Use smoothed particle hydrodynamics code GADGET-3
- Contains prescriptions for star formation, BH accretion, and SF & AGN feedback
- Simulate merger of two galaxies containing gas, stars, DM, and central SMBHs
- High spatial and mass resolution (h_{soft} = 37 pc, $m_{gas} = 2.8 \times 10^4\ M_{sun}$)
- Implement a sub-resolution model for the NLR

Modeling the NLR in Simulations

- Estimate ionizing photon production rate, *Q*, from BH (Bondi) accretion rate
- Choose SPH (gas) particles that satisfy:

  (1) Nonzero mass in "cold" gas

  (2) Total covering fraction of cold clouds less than unity

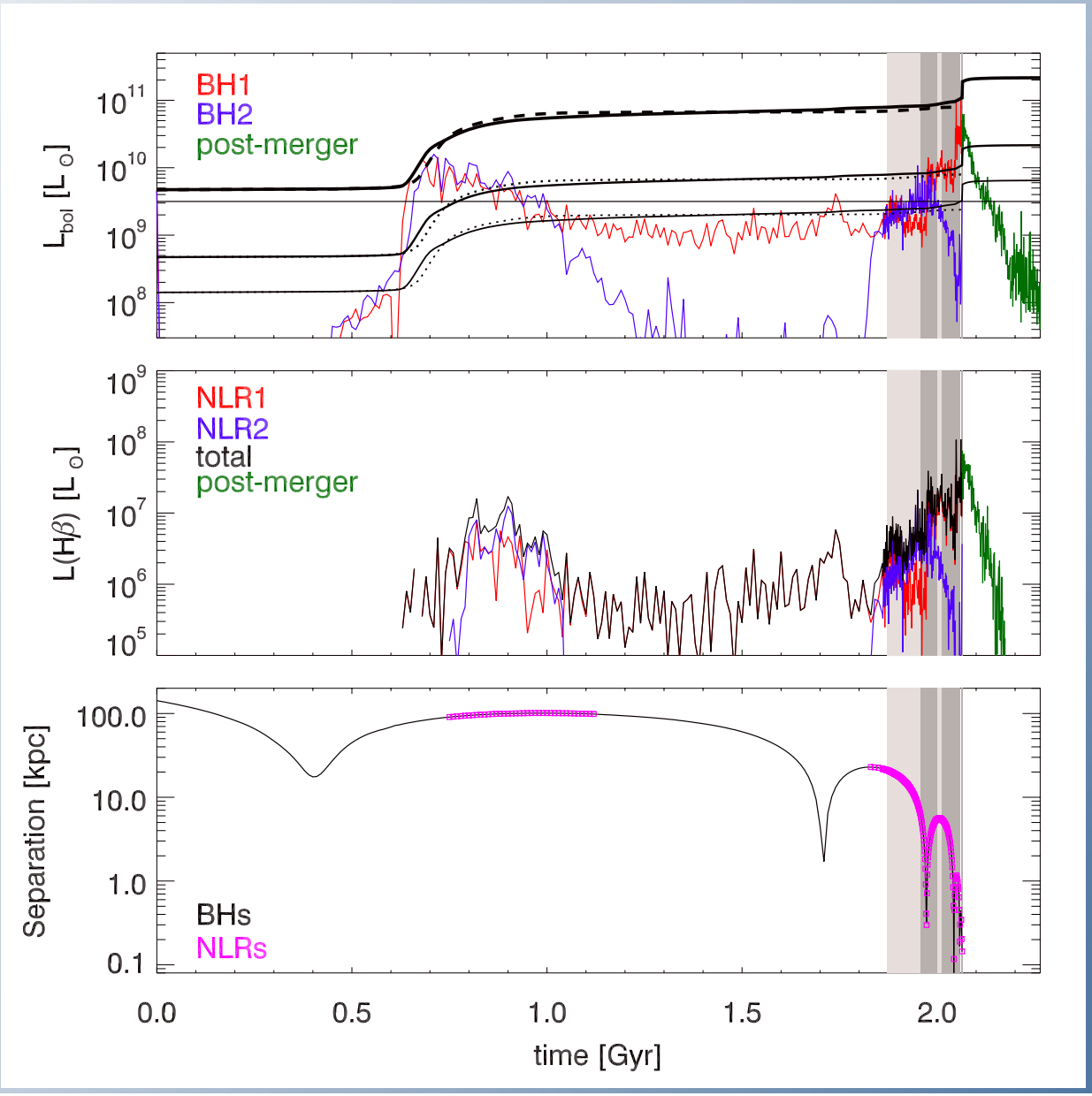
  (3) Reasonable ranges of ionization parameter and gas density

Modeling the NLR in Simulations

- Assume each SPH particle with cold gas contains discrete clouds that cover a fraction ε_A of the particle's incident area
- Calculate Hβ luminosity of the "NL-emitting" clouds in each SPH particle satisfying (1)-(3):

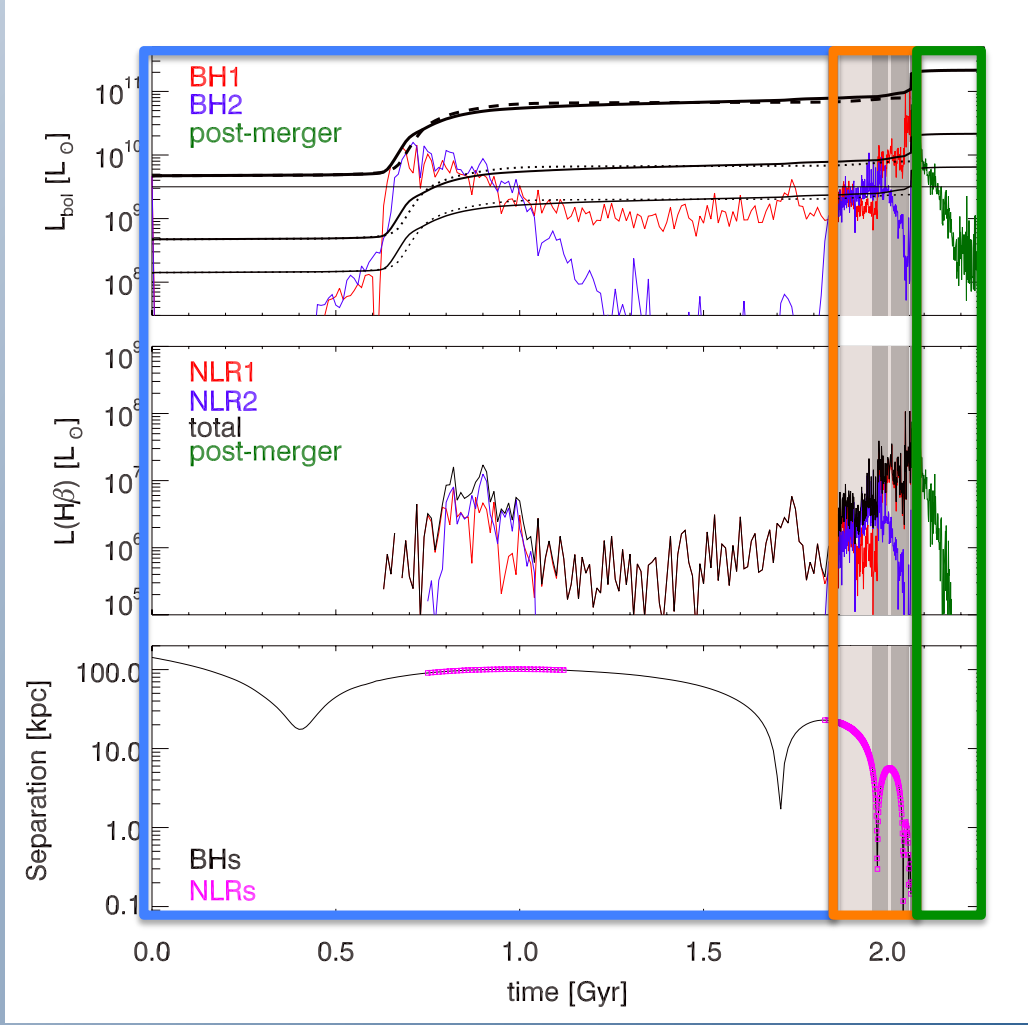
$$L_{\mathrm{H}\beta} = \frac{h\,\nu_{\mathrm{H}\beta}}{8.5}\,\frac{\epsilon_{\mathrm{A}}}{4\pi}\,(\Omega_{1,\mathrm{sph}}\,Q_1 + \Omega_{2,\mathrm{sph}}\,Q_2)$$

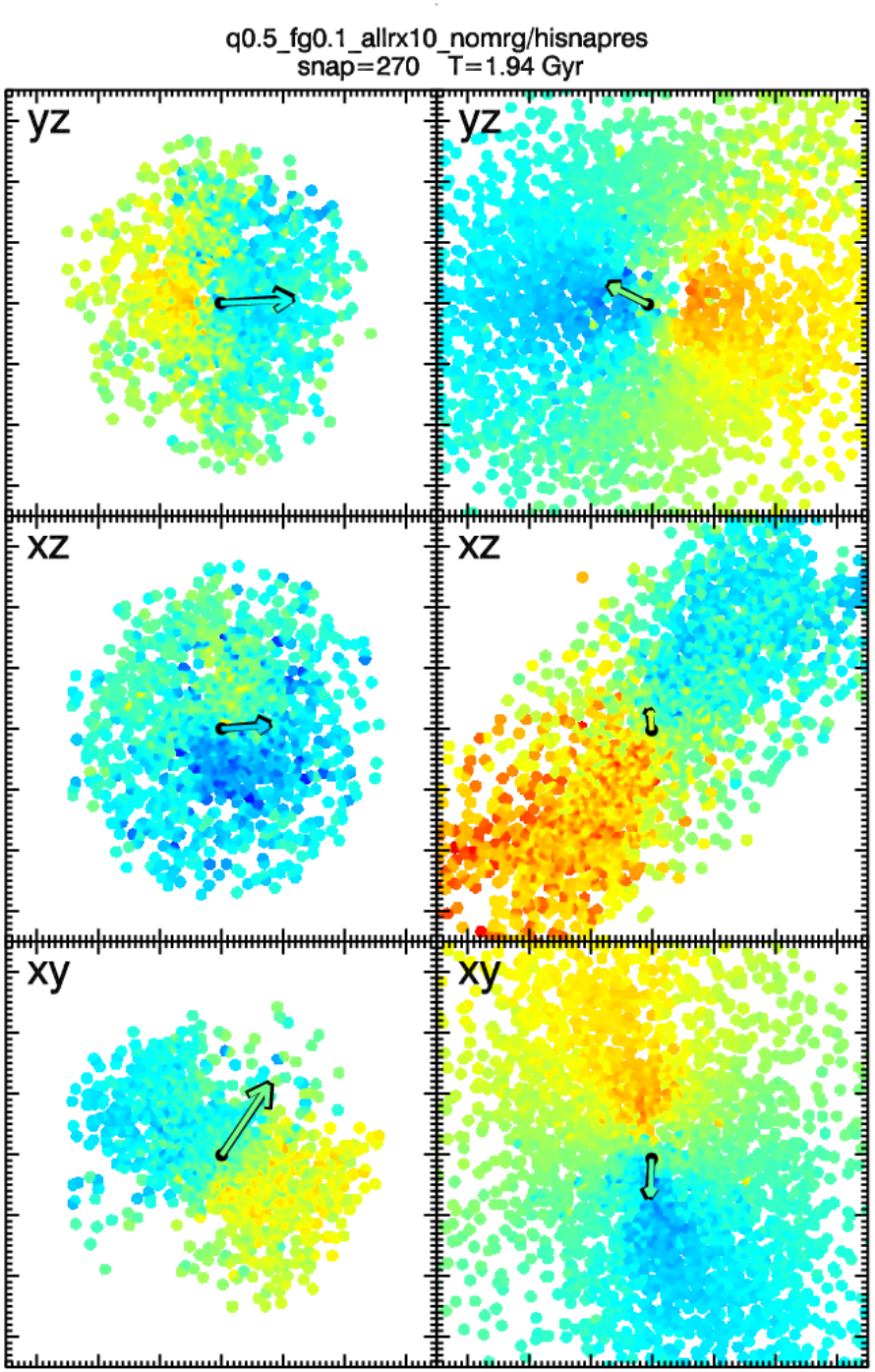
Evolution of Merger-driven NL Activity



Evolution of Merger-driven NL Activity

- **Phase I**: Early merger phase
- **Phase II (IIb)**: kpc-scale phase
- **Phase III**: Post-BH merger phase

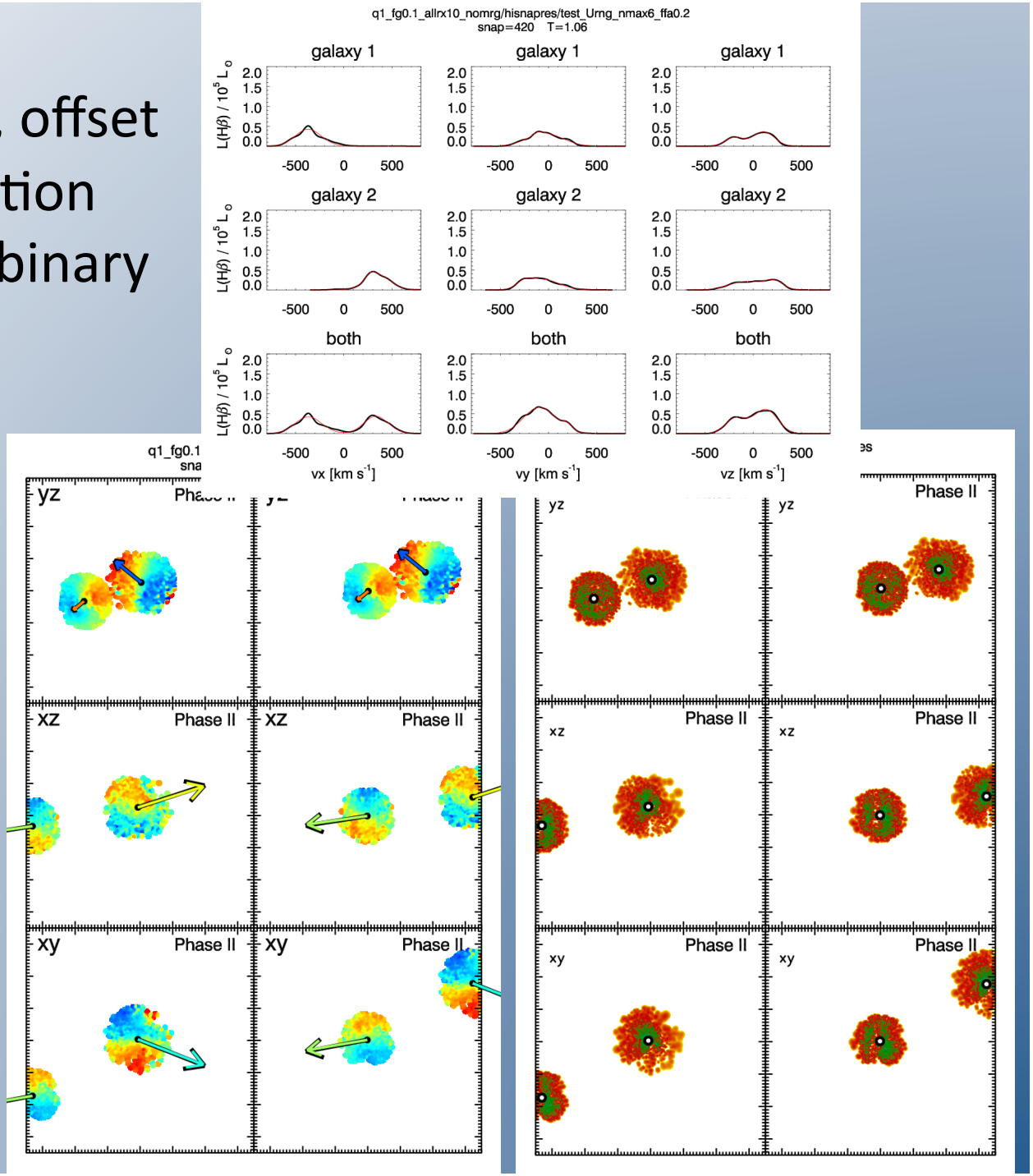



q0.5_fg0.1_allrx10_nomrg/hisnapres
snap=270 T=1.94 Gyr
yz
yz
xz
xz
xy
xy

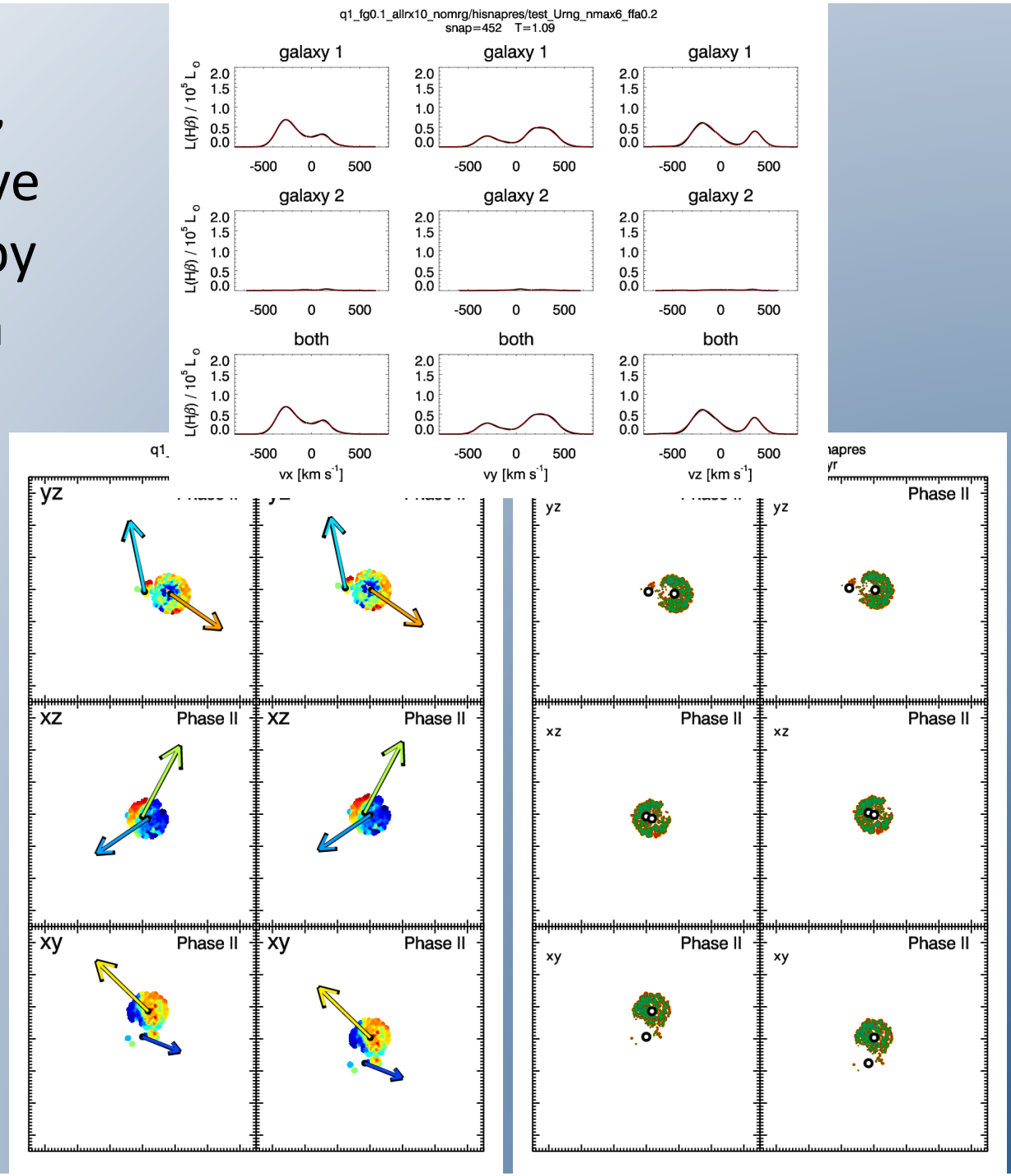
Kinematics of kpc-scale dNL AGN

- At times are induced ***directly*** by BH motion
- May also be ***indirectly*** caused or influenced by BH motion (e.g., offset rotation feature)
- Are also often simply ***concurrent*** with the kpc-scale phase (coincides with peak of NL/AGN activity; cf. Fu et al. 2011)

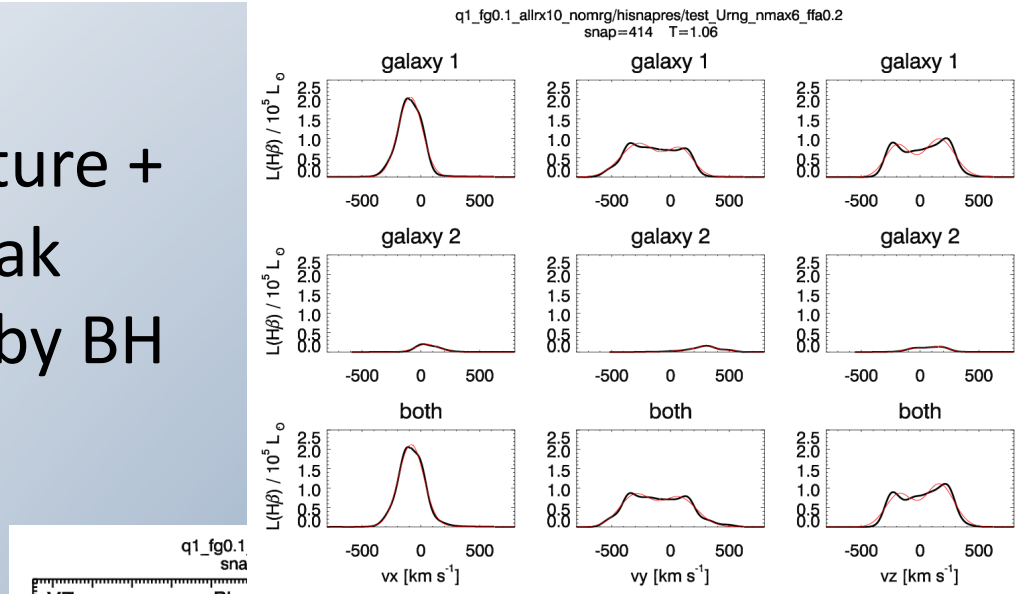
Two distinct NLRs, offset by rapid BH motion
→ dNL driven by binary motion

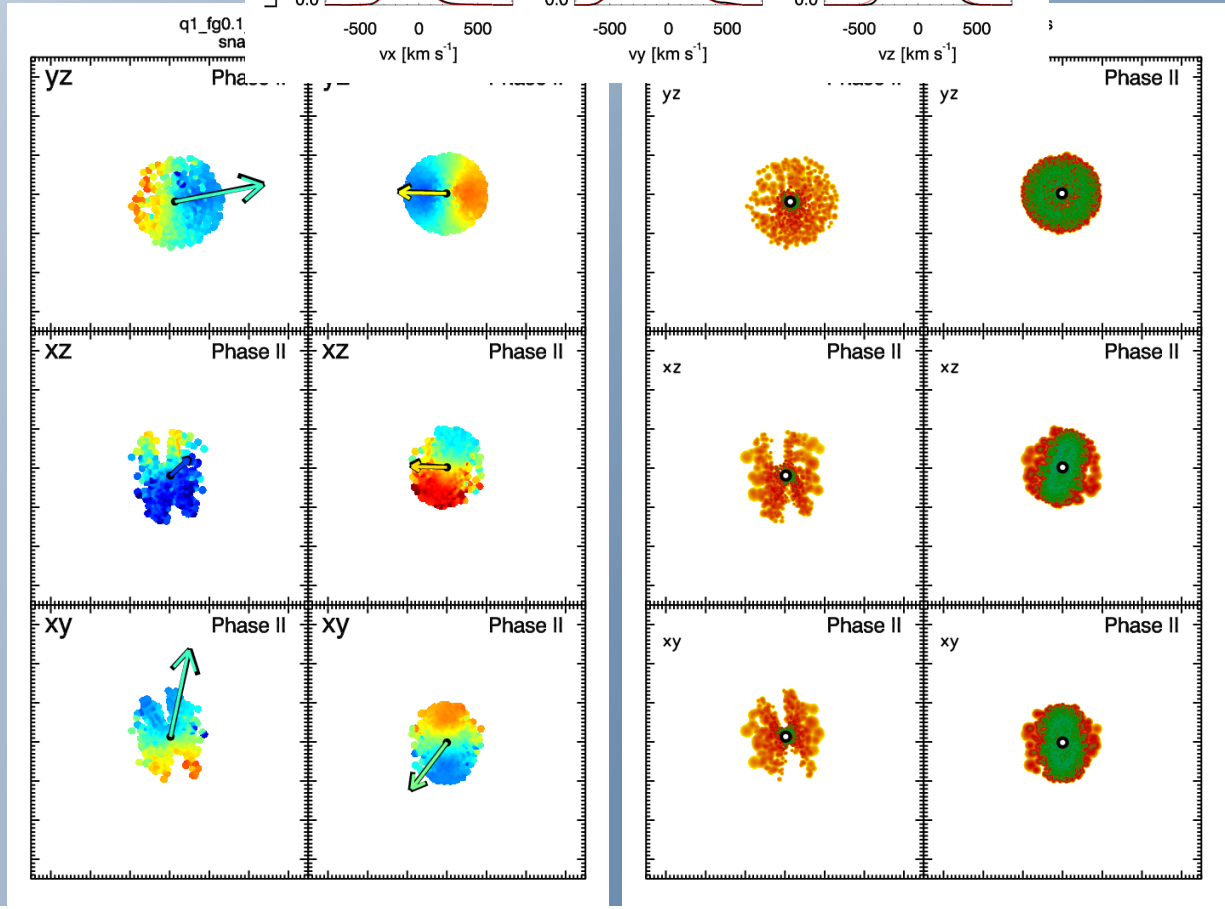


Common NLR,
1 BH more active
→ dNL driven by
binary motion

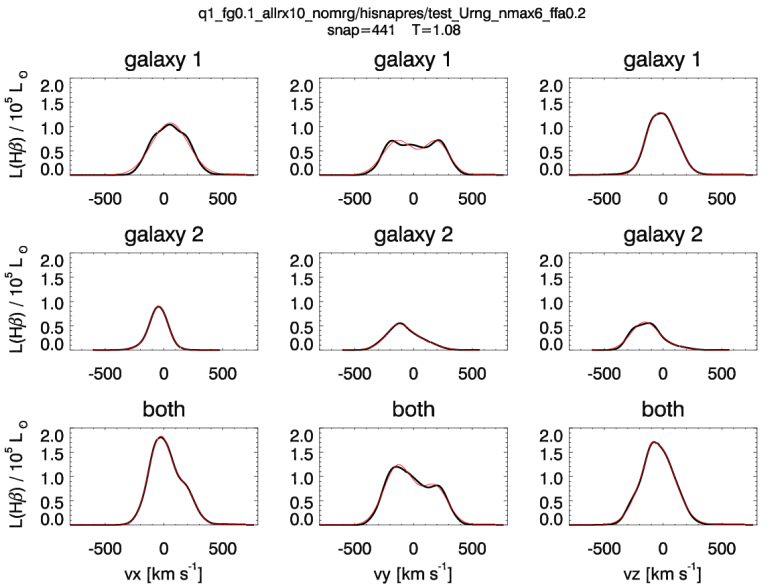


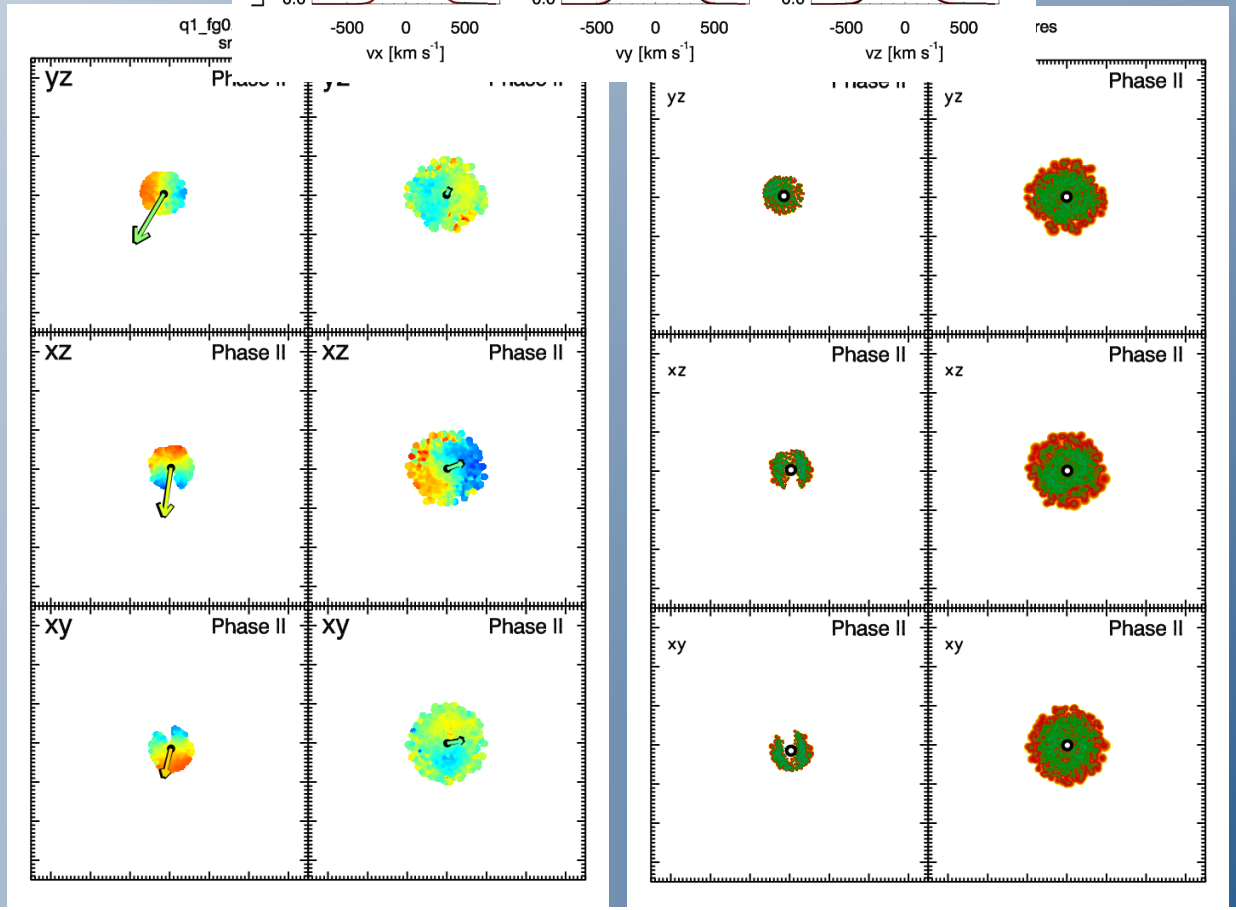
Offset rotation feature + offset single peak
→ dNL influenced by BH motion

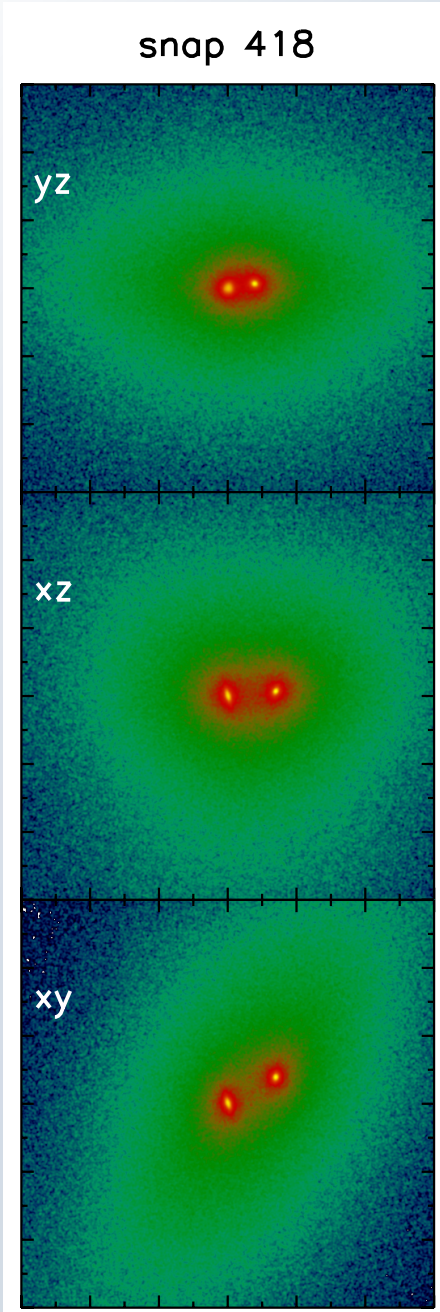




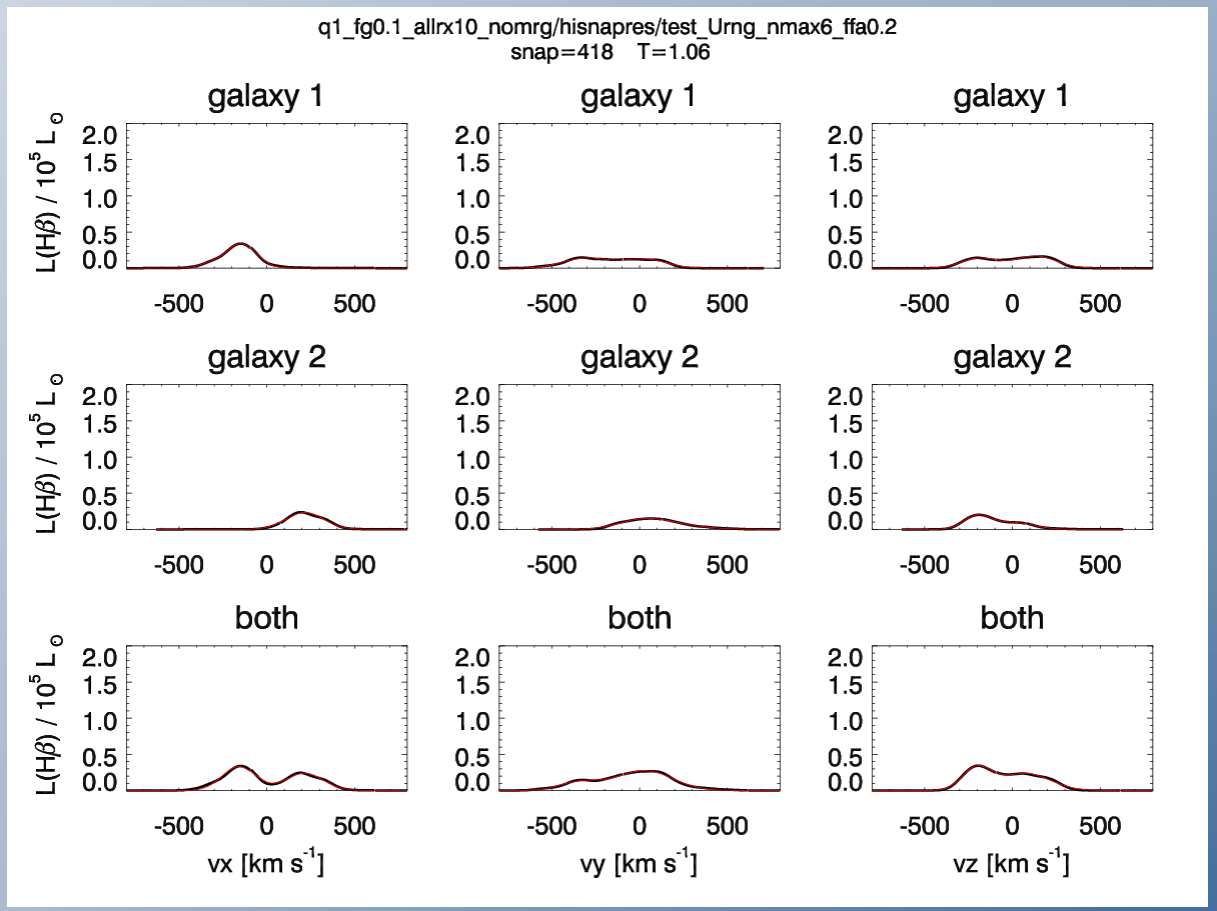
Rotation feature +
offset peak
→ uneven-peaked dNL



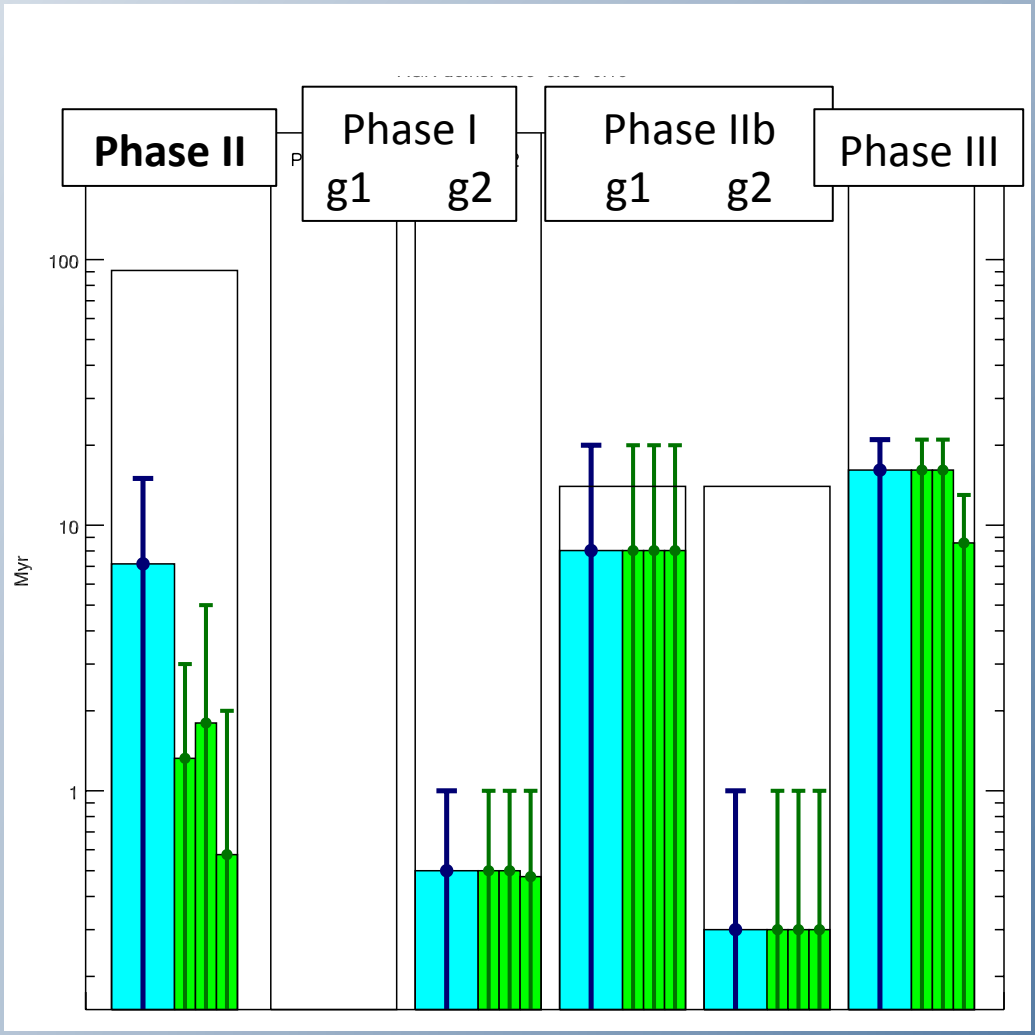




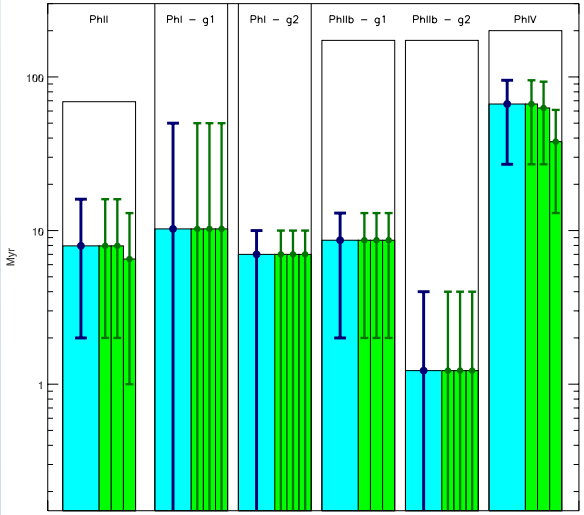
Double stellar cores



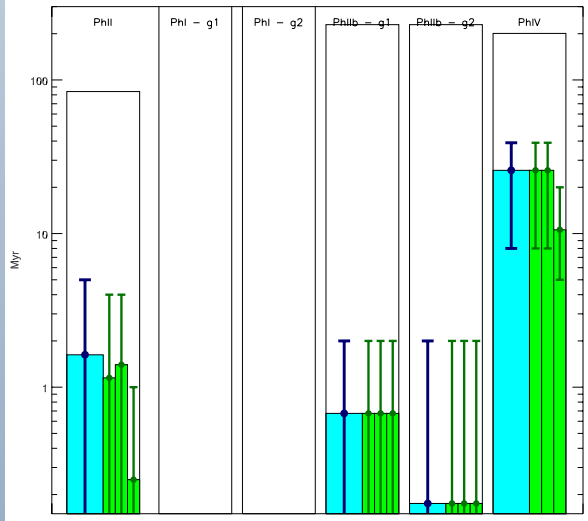
Lifetime of dNL AGN in each merger phase



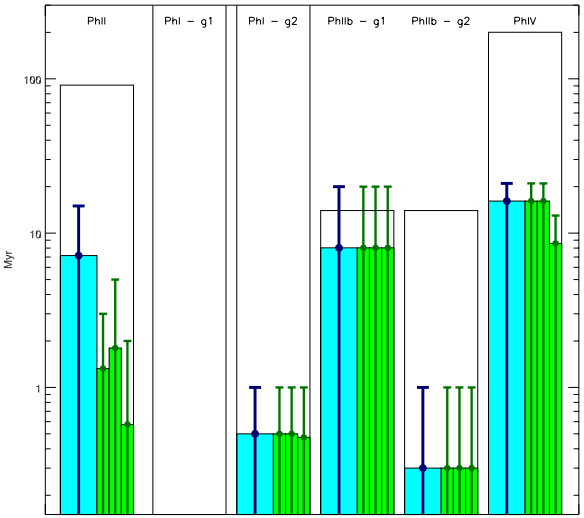
q = 1, fgas = 0.1



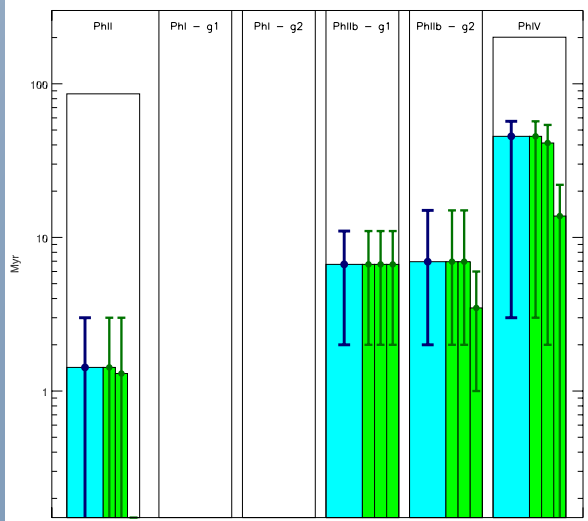
q = 1, fgas = 0.04



q = 0.5, fgas = 0.1



q = 0.333, fgas = 0.3



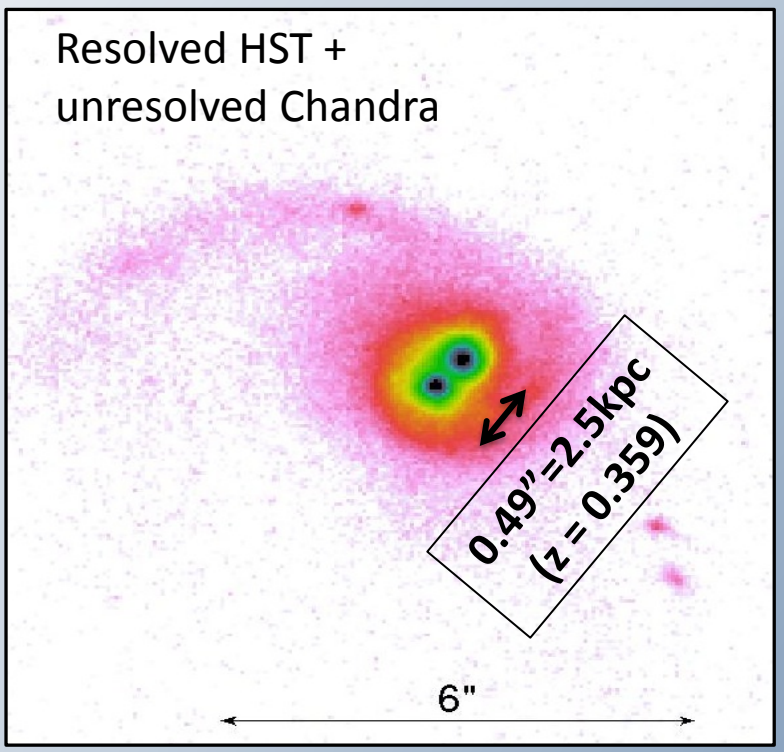
Summary: Main Results

- The kpc-scale phase is a small fraction of the total merger time
- dNLs in the kpc-scale phase are a short-lived but fairly generic feature of gaseous major mergers
- kpc-scale dNL AGN can be:
  - directly induced by binary motion
  - Indirectly caused or altered by binary motion
  - Rotational features concurrent with the kpc-scale phase
- Brightest dNL AGN associated with peaks in Lbol, most commonly soon before or after the BH merger
- Comparable-mass mergers and higher gas fractions produce more dNL AGN activity (but may have more obscuration…)

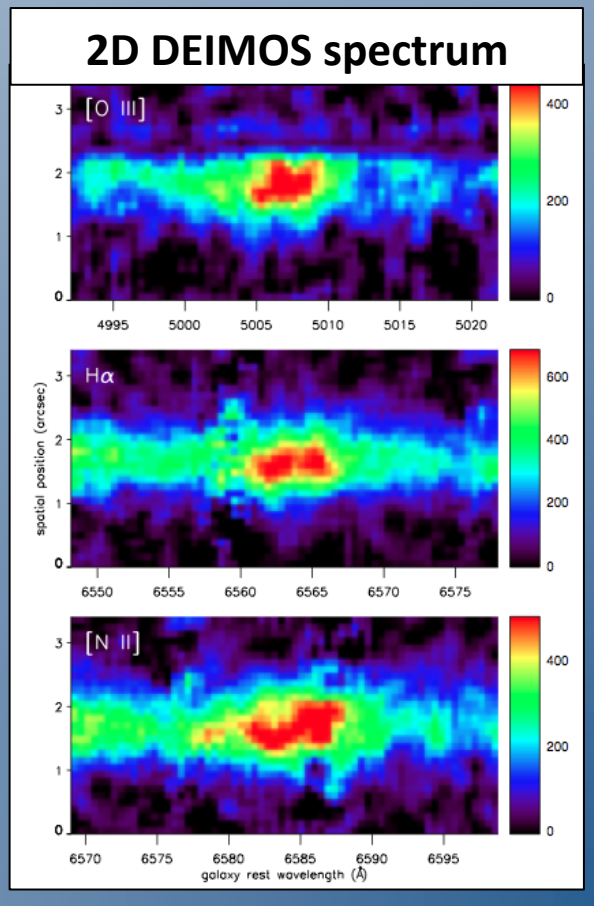
Summary: Open Questions

- How do observables change when dust obscuration/RT are considered?
- What is the role of secular AGN fueling (vs. merger-triggered) in producing dNL AGN?
- What are the implications of having substantial post-merger dNL AGN lifetimes? (relaxed galaxy morphology? Recoils??)

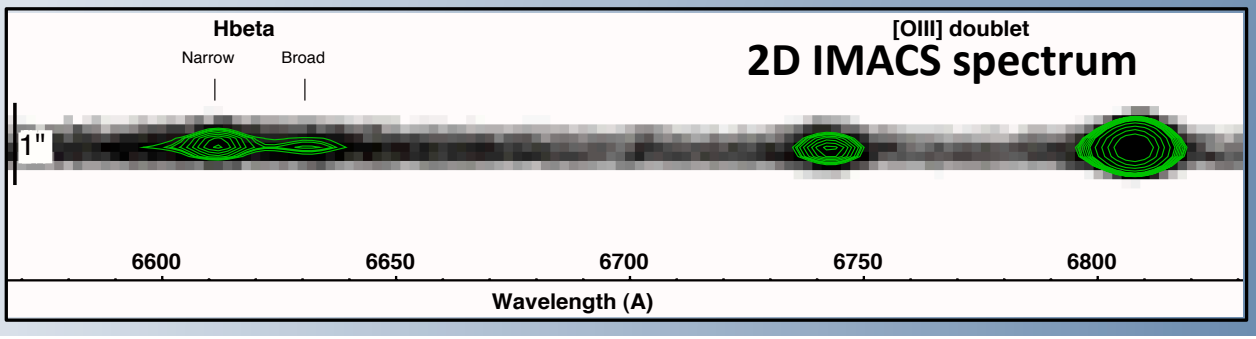
A (tangentially) related discussion topic: the nature of CID-42



J. Comerford et al. 2009b

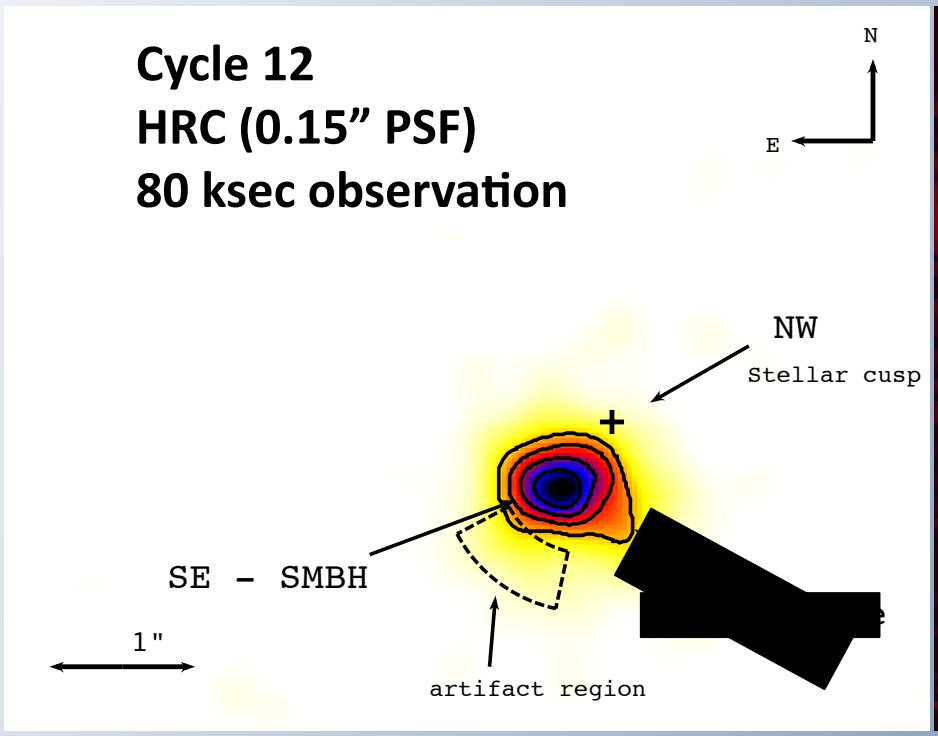


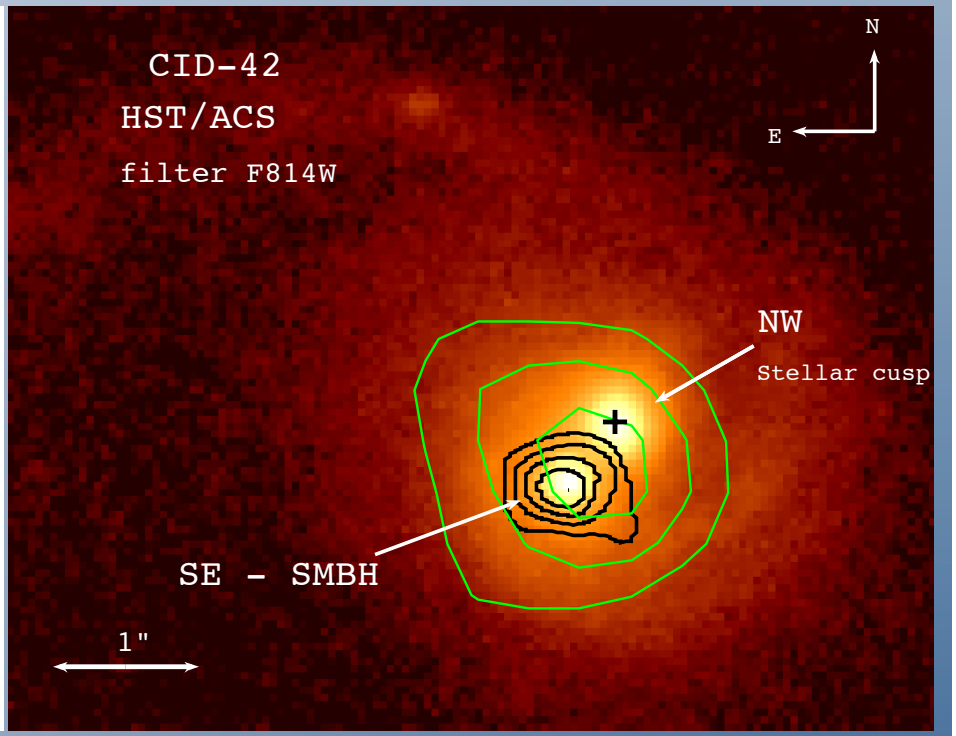
F. Civano et al. 2010



New Chandra HRC DATA

Only 1 AGN detected - supports GW recoil scenario





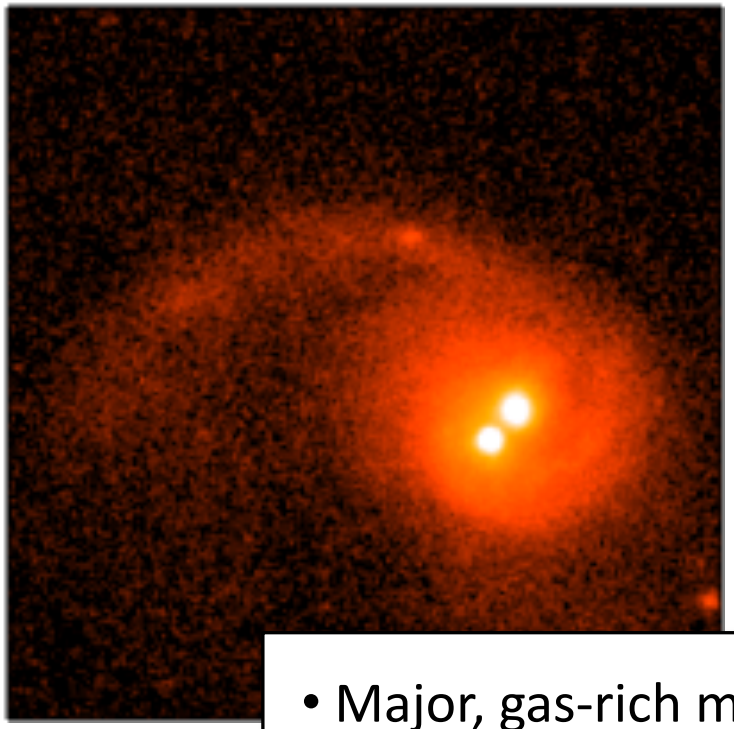
SE HST source 318 counts

NW HST source < 3% (9 counts at 3sigma)

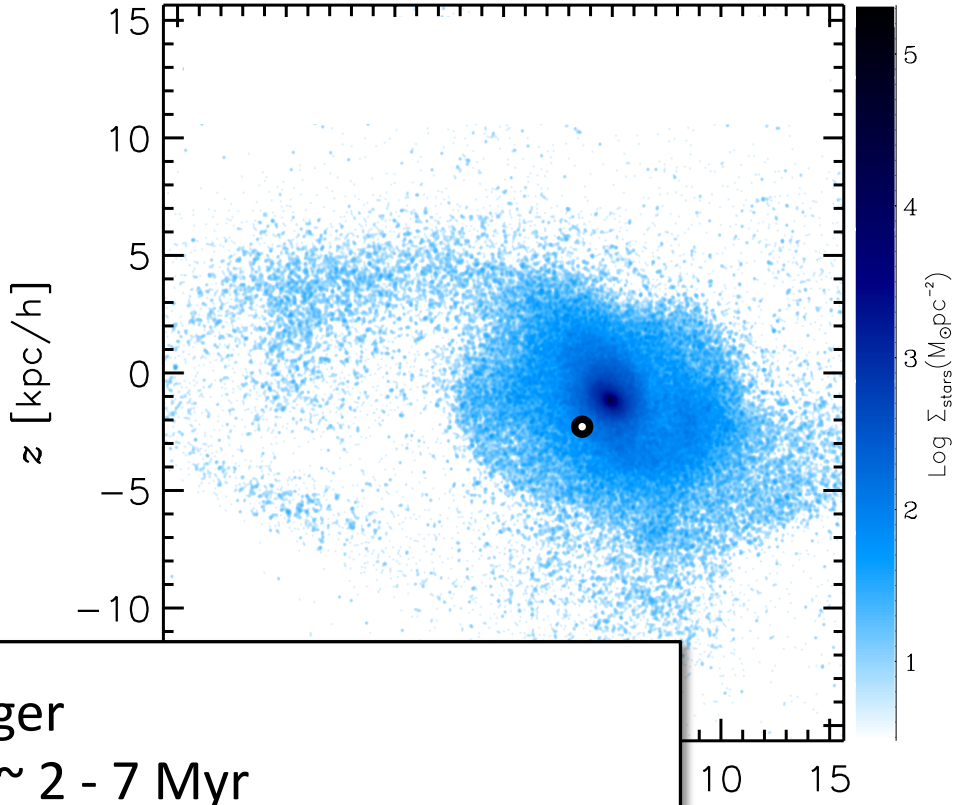
Civano et al. 2011, ApJL in prep.

Comparison with simulations

HST image

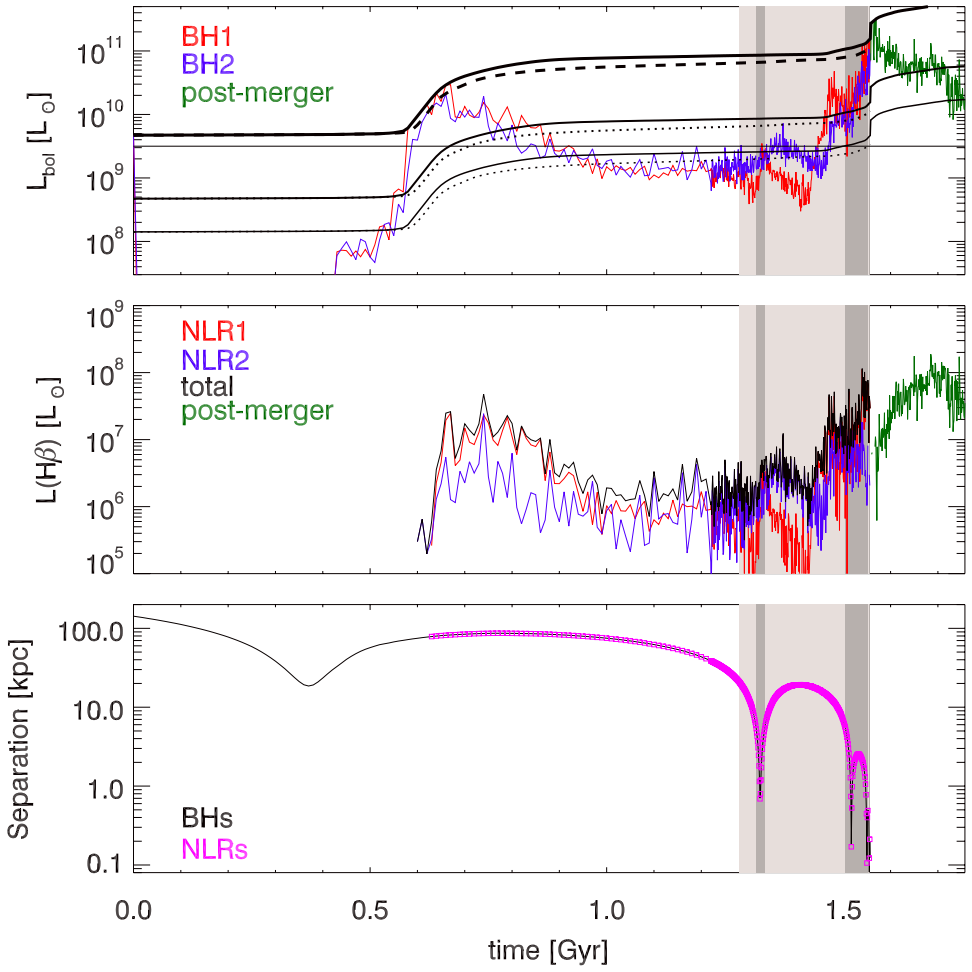


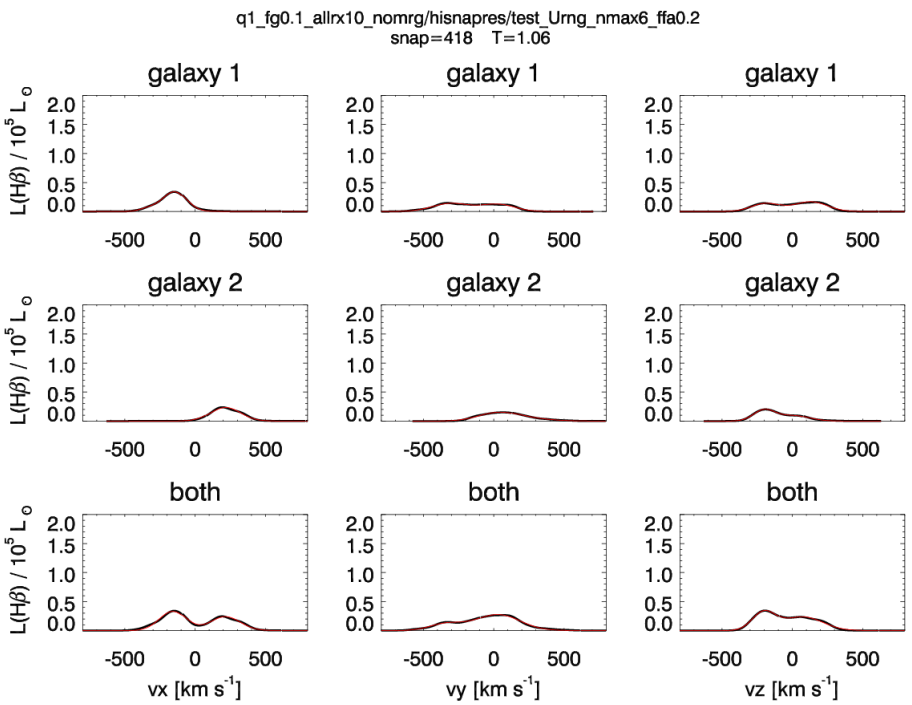
Simulation (stellar density)



- Major, gas-rich merger
- Time since merger: ~ 2 - 7 Myr
- Kick velocity: ~ 1400 – 2500 km s^{-1}
- BH mass (10^7 M_{sun}), global SFR (~ 25 M_{sun} yr^{-1}), & f_{Edd} (~ 1%) consistent with observations

(Blecha et al. 2011, in prep.)


BH1
BH2
post-merger
L_{bol} [$L_\odot$]
10^{11}
10^{10}
10^{9}
10^{8}
NLR1
NLR2
total
post-merger
L(Hβ) [$L_\odot$]
10^{9}
10^{8}
10^{7}
10^{6}
10^{5}
Separation [kpc]
100.0
10.0
1.0
0.1
BHs
NLRs
0.0
0.5
1.0
1.5
time [Gyr]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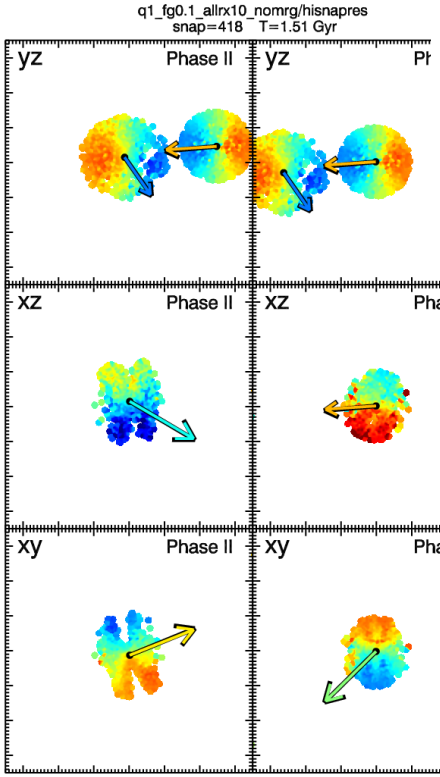
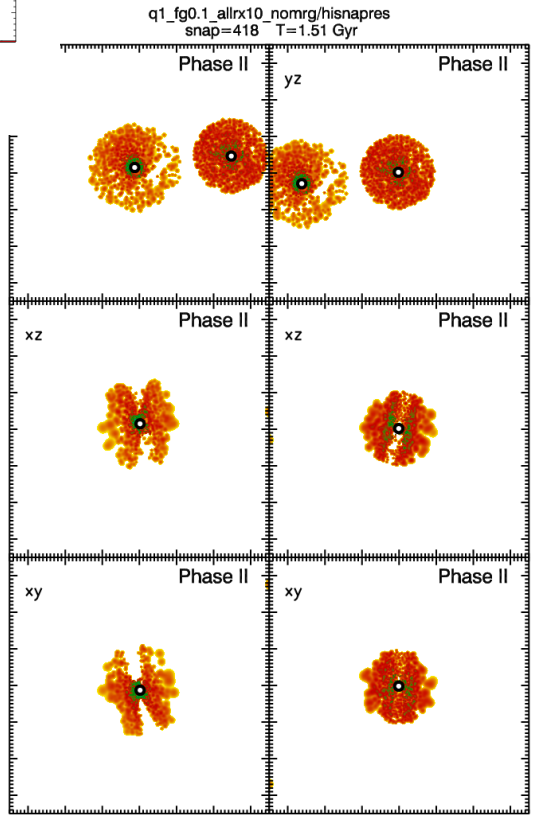
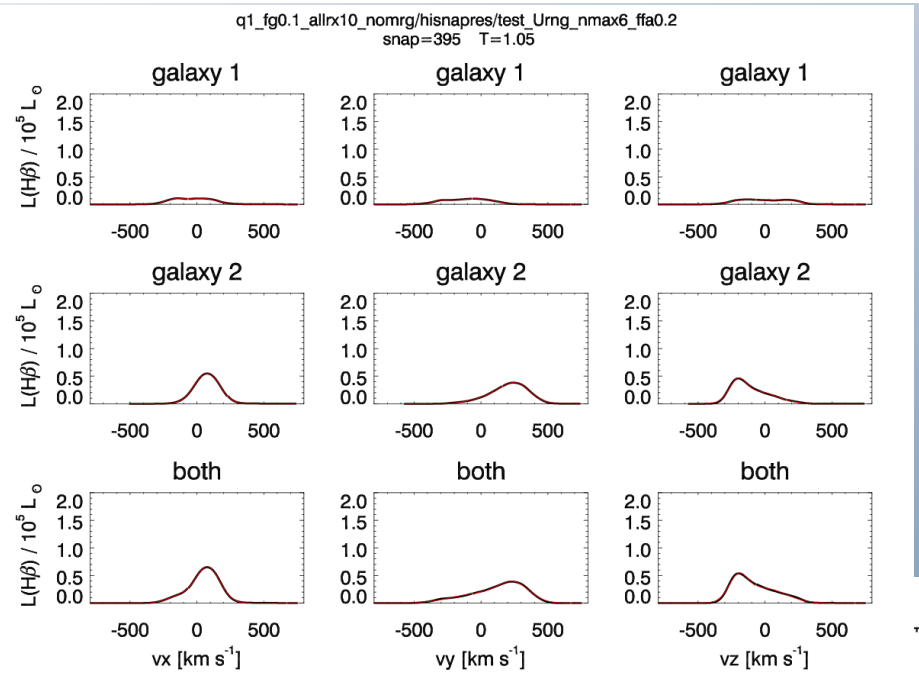
snap=418 T=1.06
galaxy 1
galaxy 2
both
L(Hβ) / 10^5 L_o
2.0
1.5
1.0
0.5
0.0
-500
0
500
vx [km s^-1]
vy [km s^-1]
vz [km s^-1]


q1_fg0.1_allrx10_nomrg/hisnapres
snap=418 T=1.51 Gyr
yz
xz
xy
Phase II


q1_fg0.1_allrx10_nomrg/hisnapres
snap=418 T=1.51 Gyr
yz
xz
xy
Phase II

(offset)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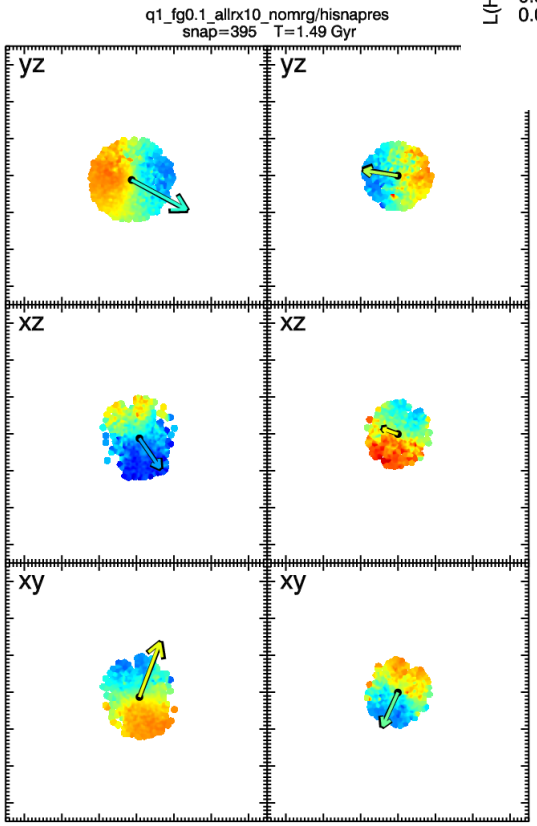
snap=395 T=1.05
galaxy 1
galaxy 2
both
L(Hβ) / 10^5 L_o
vx [km s^-1]
vy [km s^-1]
vz [km s^-1]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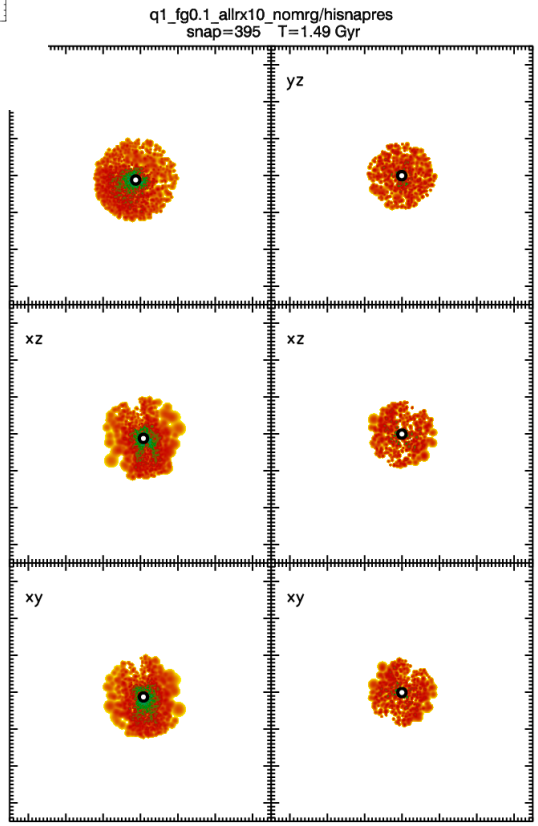
yz
xz
xy


q1_fg0.1_allrx10_nomrg/hisnapres
snap=395 T=1.49 Gyr
yz
xz
xy