Modeling black hole mergers in galaxies and some of their observational features

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SMBHs, IMBHs, galaxy evolution

- Where do IMBHs and SMBHs come from?
- Are there series of mergers?
- What are the seed BHs?
- Where do the seeds come from? What masses?
- How can the formation process be traced?
- Connection with galaxy evolution

Modeling galaxy evolution

Monthly Notices
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ROYAL ASTRONOMICAL SOCIETY

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Shark: introducing an open source, free, and flexible semi-analytic model of galaxy formation

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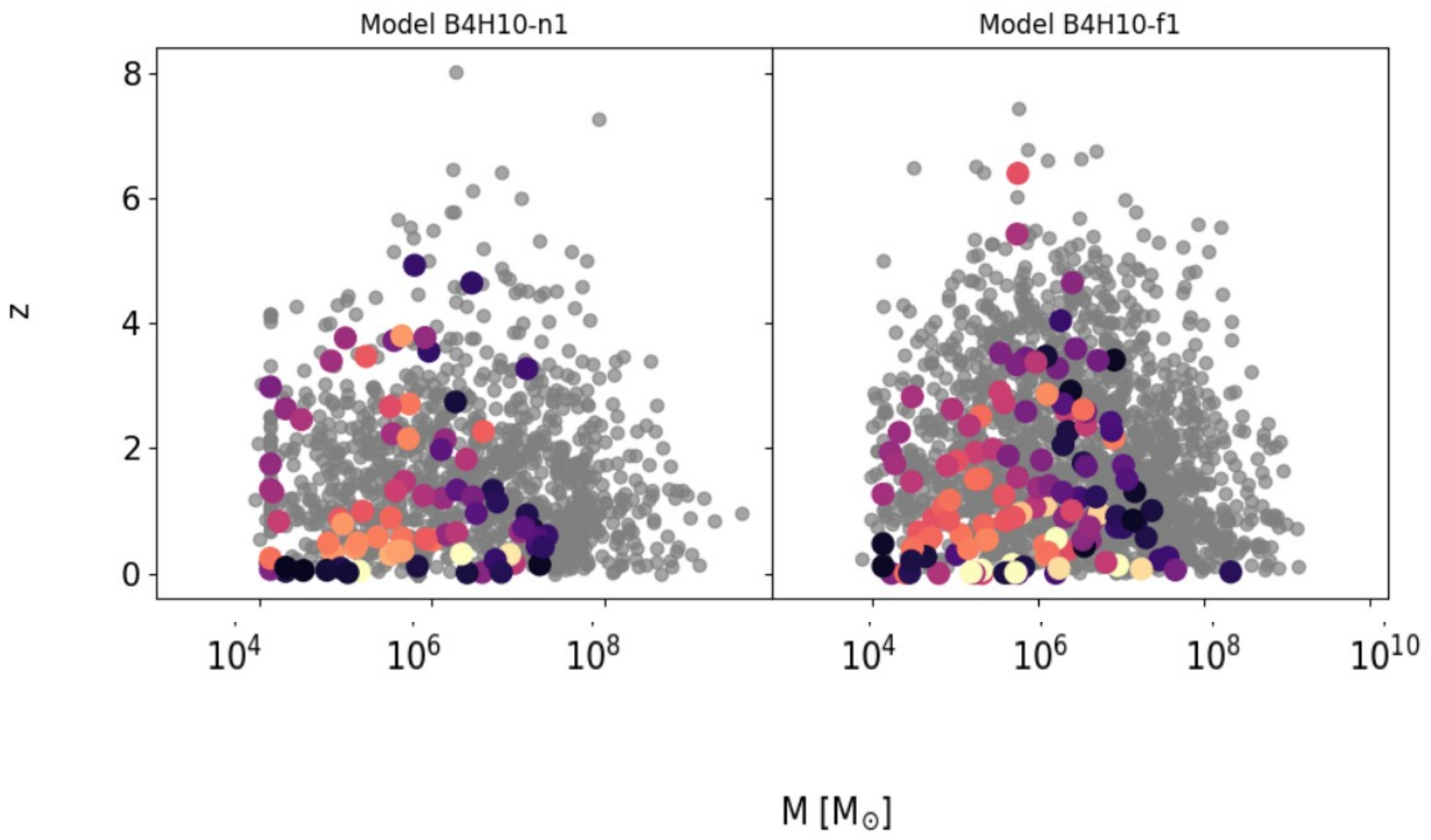
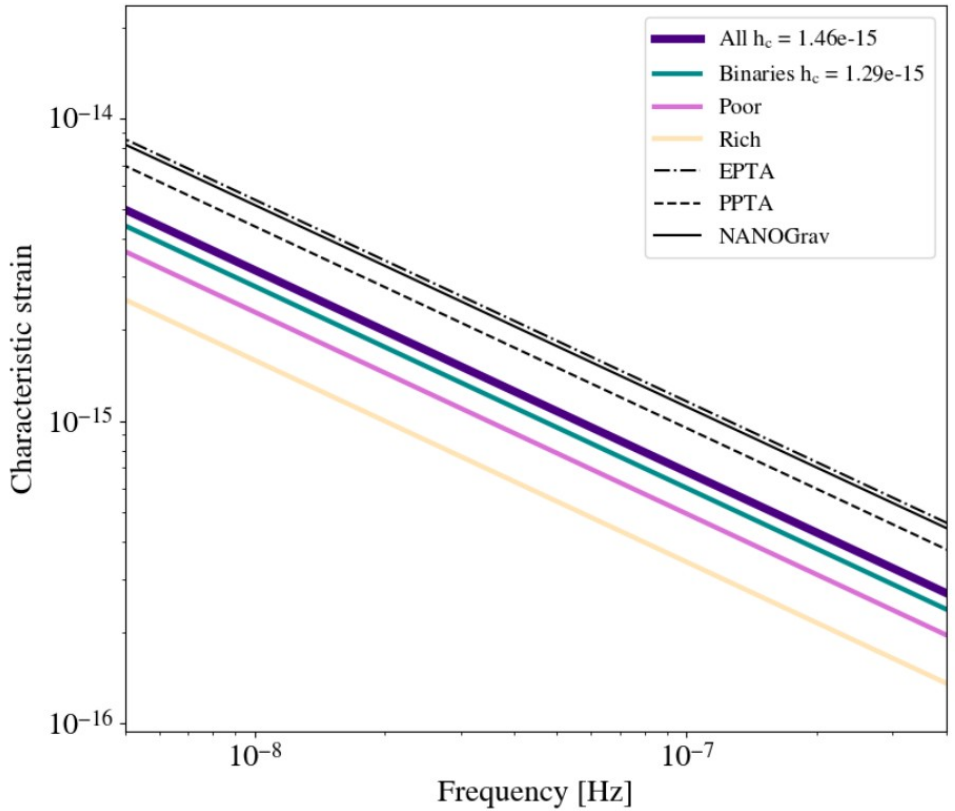
Observational features

- Gravitational waves
  - LISA
  - Pulsar Timing Arrays
- Electromagnetic imaging


Model B4H10-n1
Model B4H10-f1
z
0
2
4
6
8
10^4
10^6
10^8
10^4
10^6
10^8
10^{10}
M [$M_\odot$]

Pulsar Timing

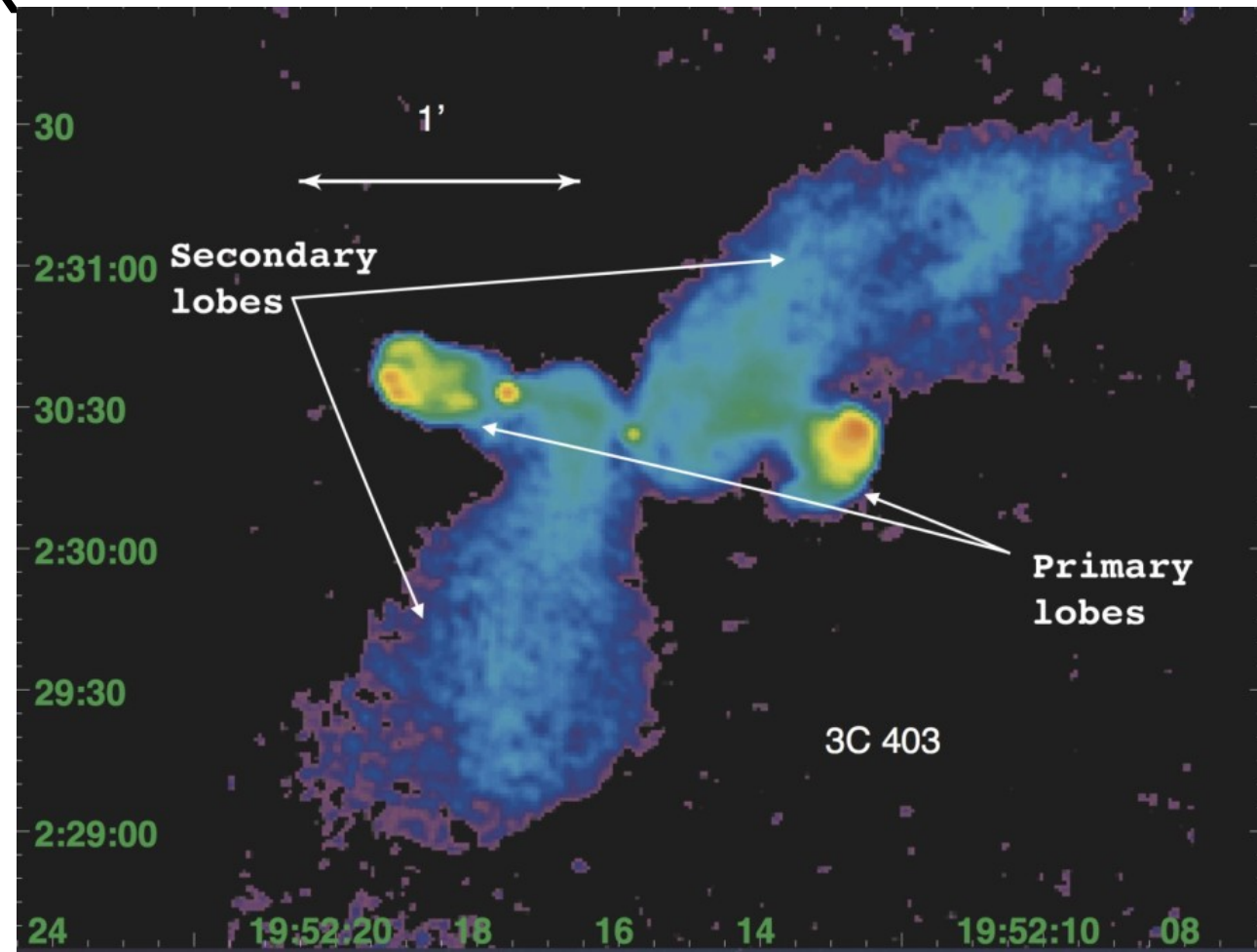


Predicted level weakly depends on the assumed delay between galaxy merger and BH merger.

The calculations fall <u>below</u> the GW signal (Common Red Noise) detected by the Pulsar Timing Arrays.

Jet morphology – X shaped radio galaxies:

Tracers of mergers?



Conclusions

- Mergers of BH connected with galaxy evolution
- GW background in PTAs almost at the the level of common red noise (our is a lower limit)
- LISA detection rates from 7-68 yr^{-1} (also lower limit)
- LISA sources – extreme mass ratios!
- Binaries can be explored with X shaped radio galaxies – connected with spin flips in gas poor galaxies
- Population of IMBH and SMBH mergers can be investigated in many ways

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Massive black hole binaries as sources of low-frequency gravitational waves and X-shaped radio galaxies

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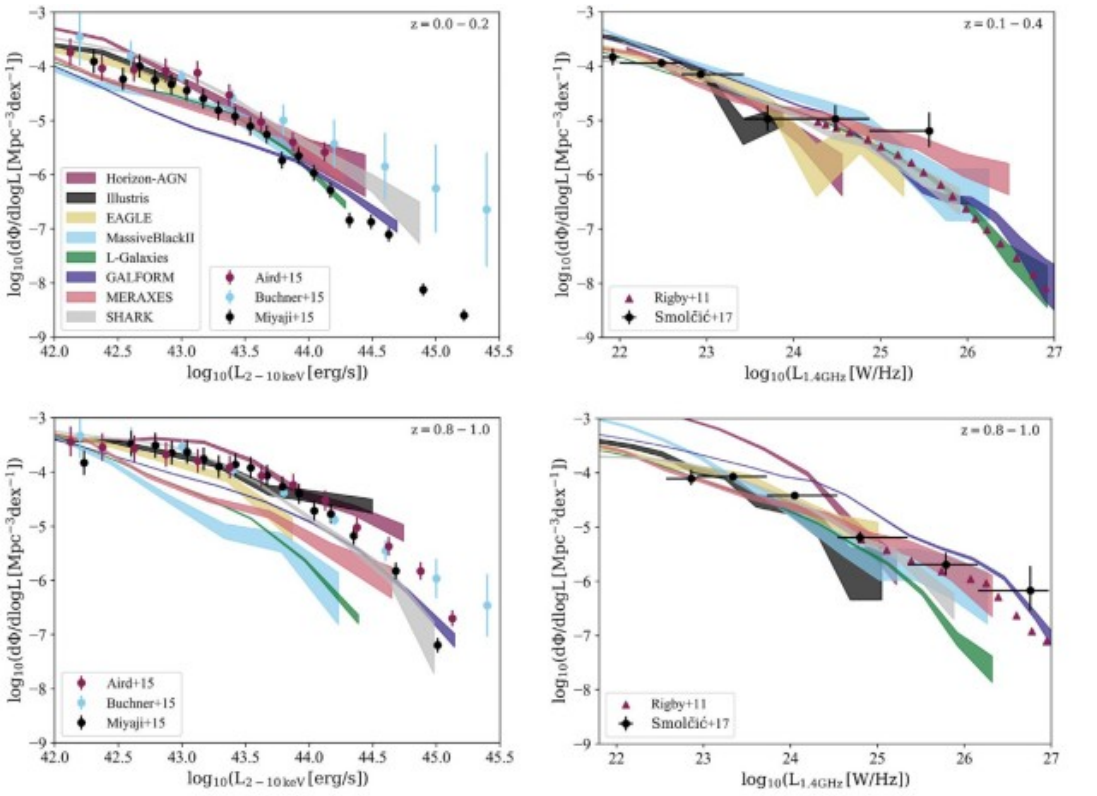
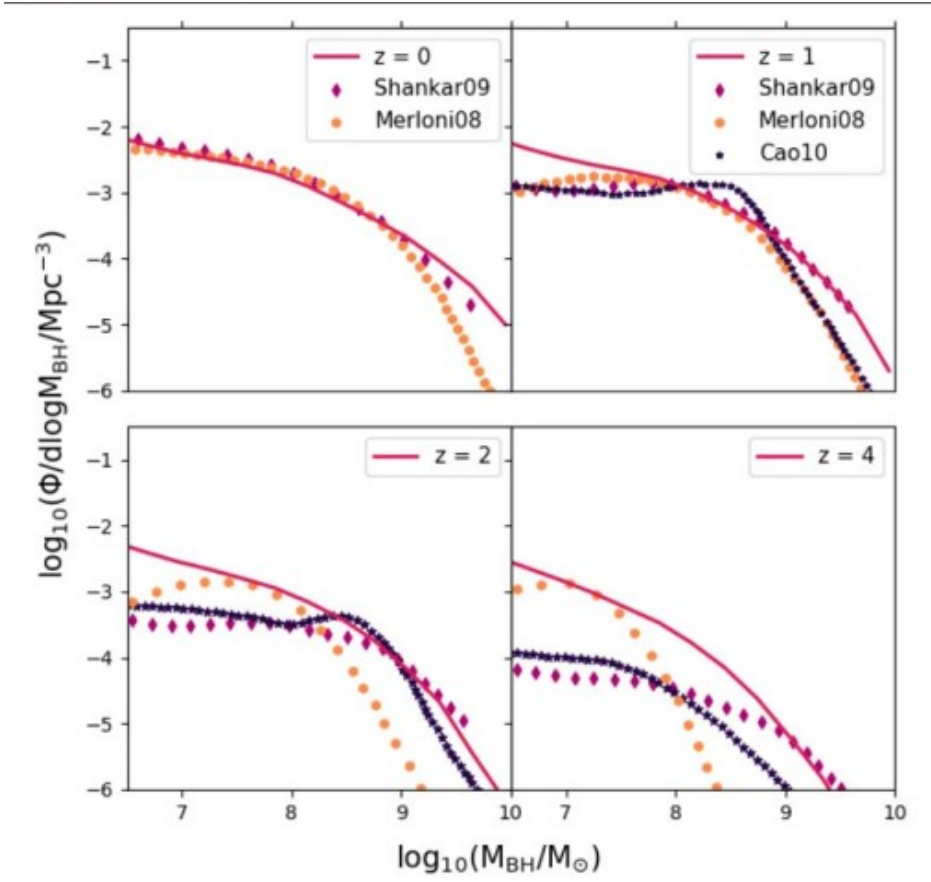
SHARK galaxy evolution code

- Semi analytic model of galaxy evolution
  - Physical modeling of galaxy formation and evolution
  - Halo evolution – including mergers and accretion of DM
  - Starbursts, star formation rates
  - Mergers of galaxies
  - Gas contents and properties
  - Black hole growth
- Assumed seeds

SHARK

BH mass function

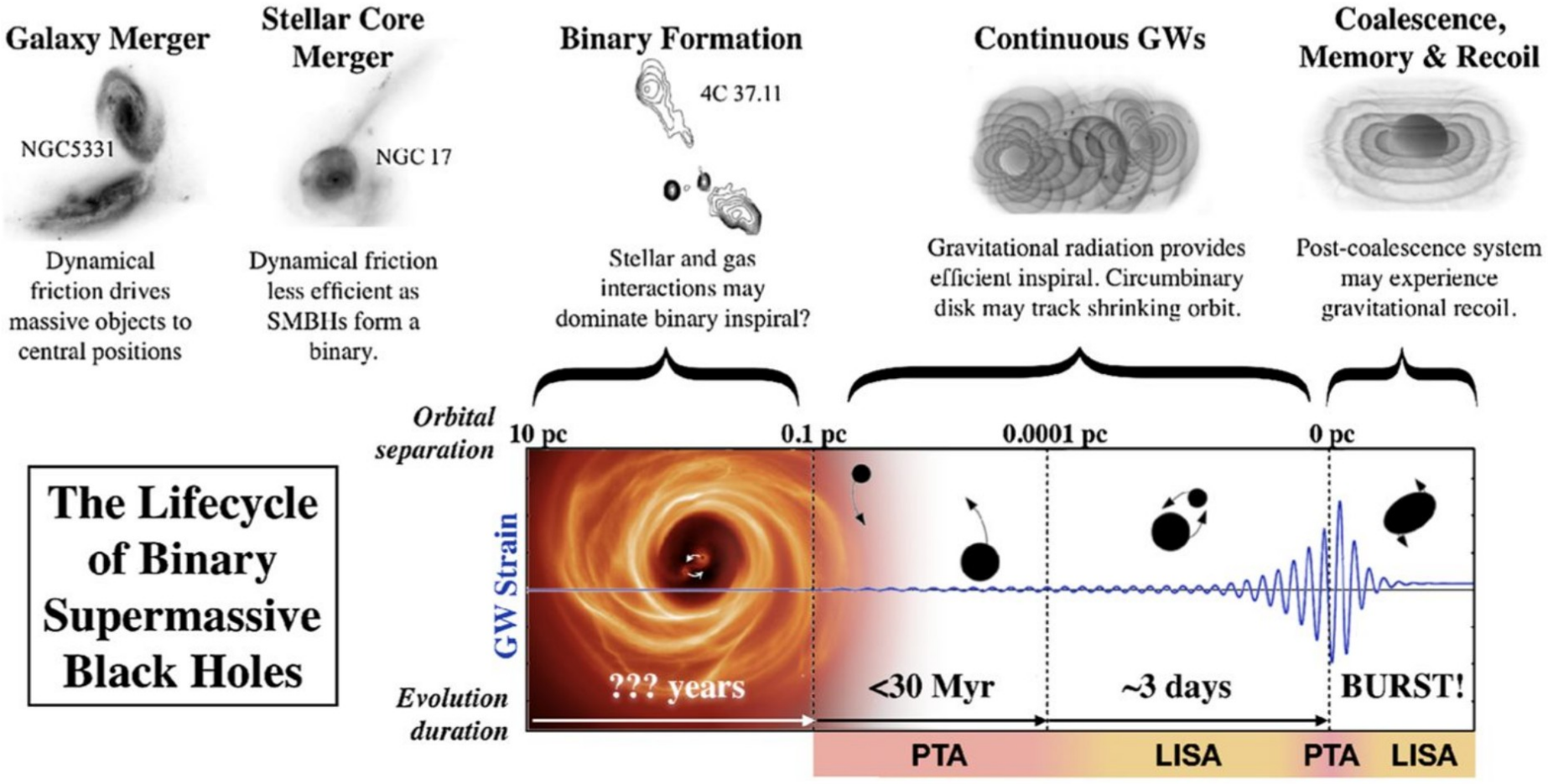




X-ray LF and radio LF

Amarantidis et al 2019

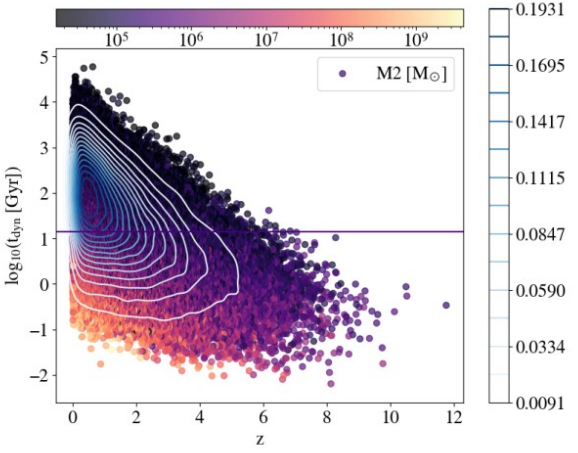
The Lifecycle of Binary Supermassive Black Holes

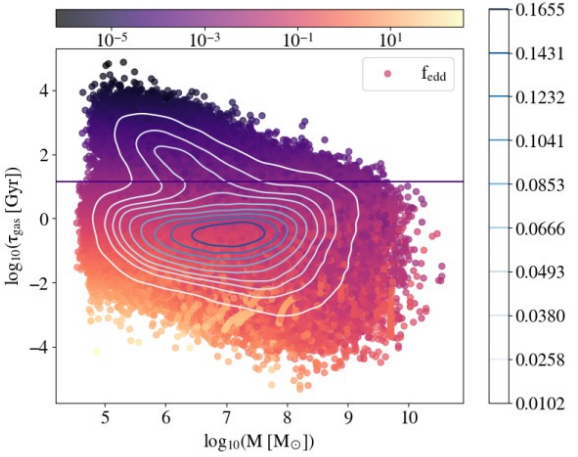


Burke-Spolaor 2019

Mergers and binary formation

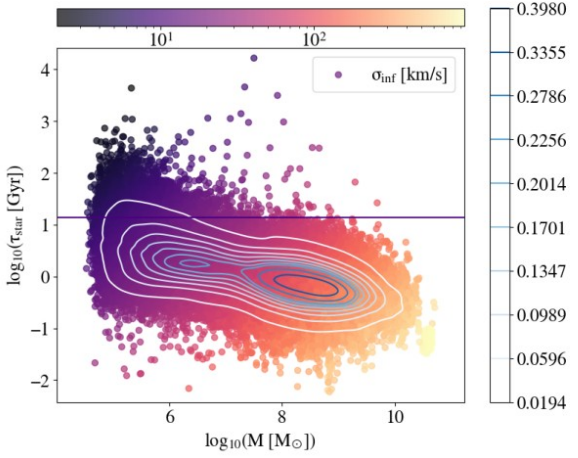
Dynamical friction





Viscous drag

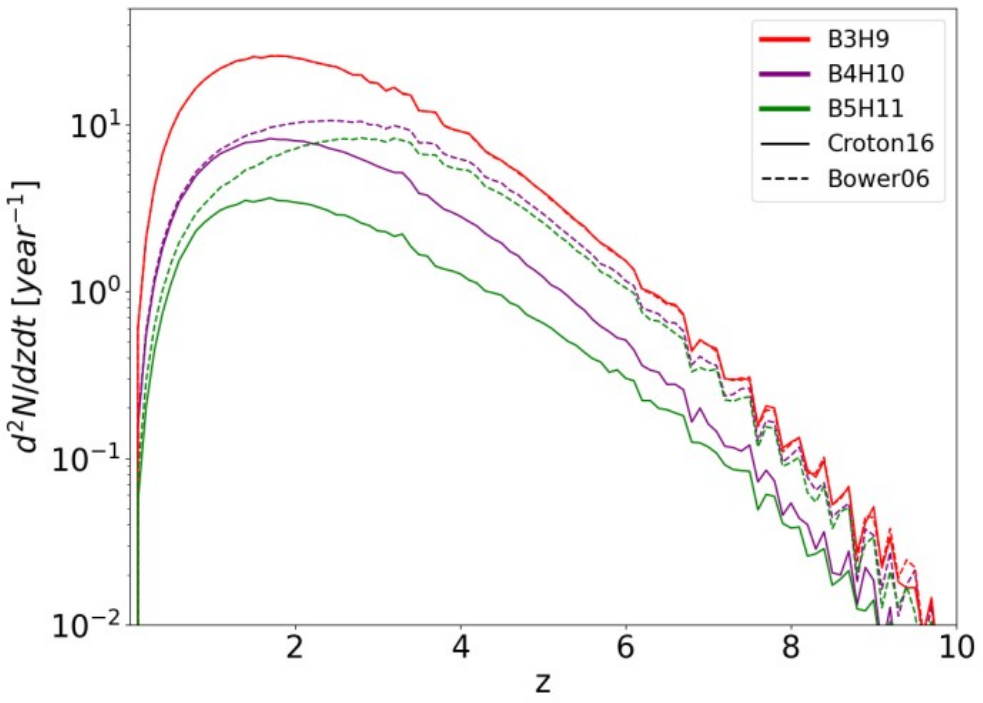
Stellar scattering



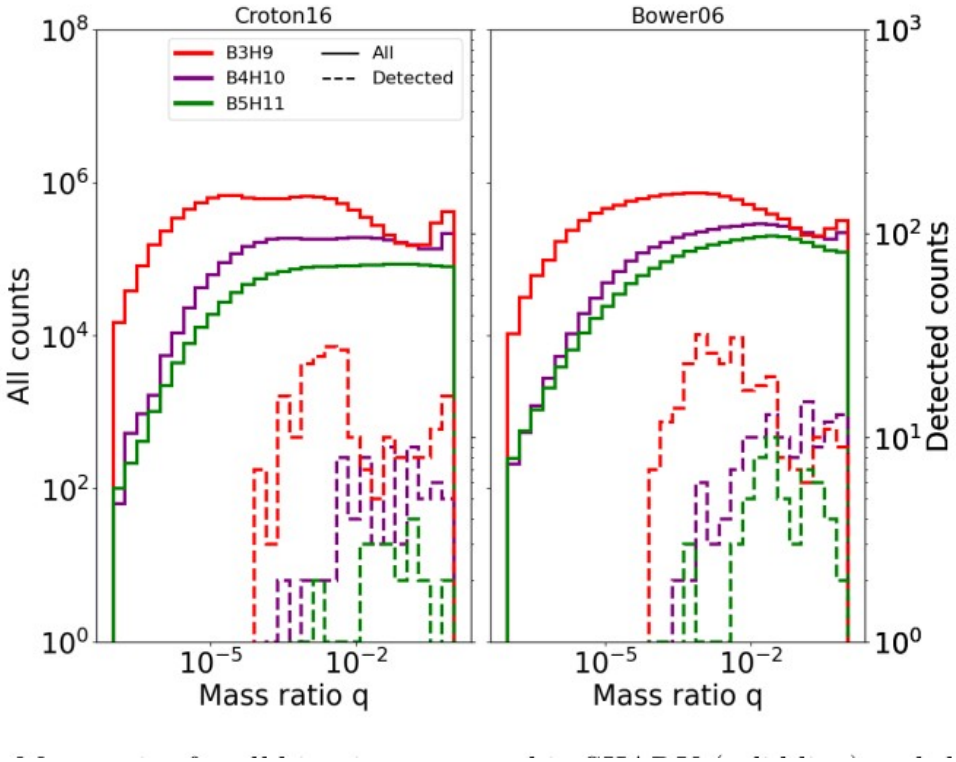
A significant portion of BH in galaxy merger has enough time to form binaries

LISA

Merger rate per unit redshift



Mass ratios



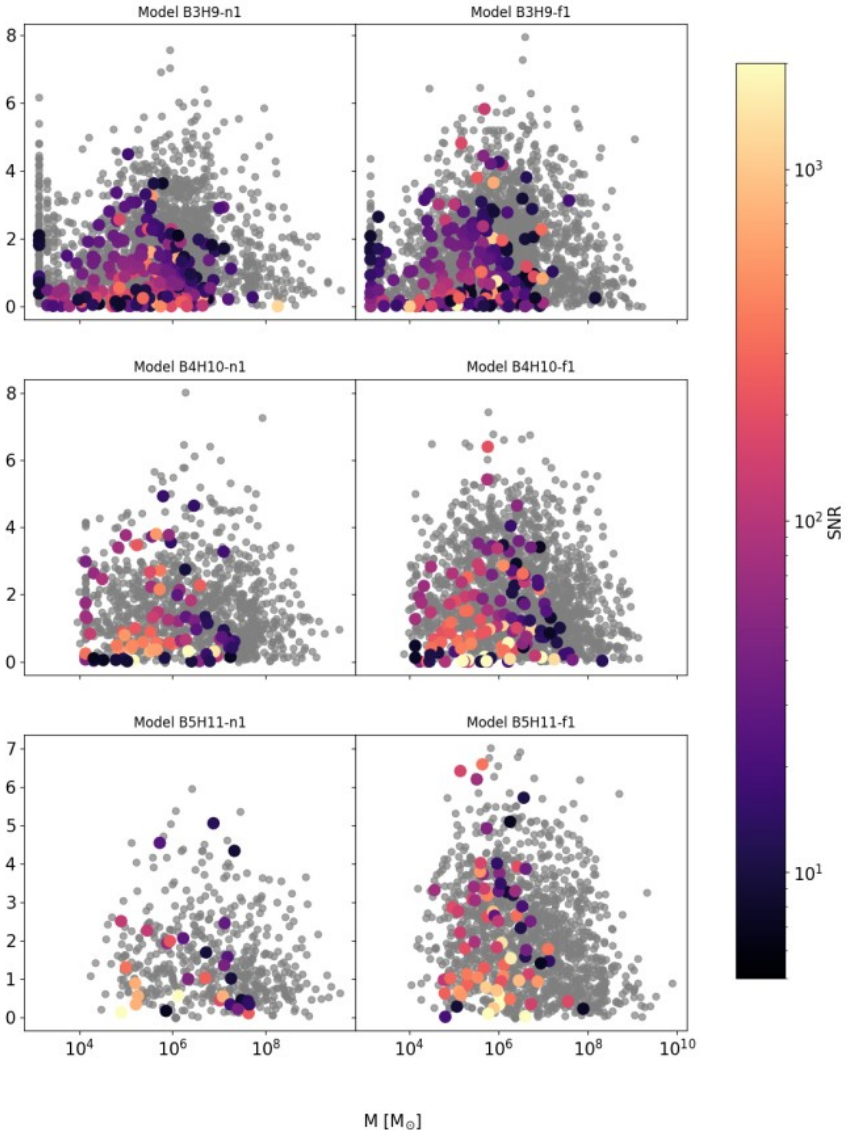
LISA range masses

Seed mass:

10^3 Msun

10^4 Msun

10^5 Msun



LISA detection rates

Rates are quoted per year

Depending on the models the detection rates vary from ~7 to ~70 per year.

Undetected – outside of the frequency range or weak.

Let wait for the data...

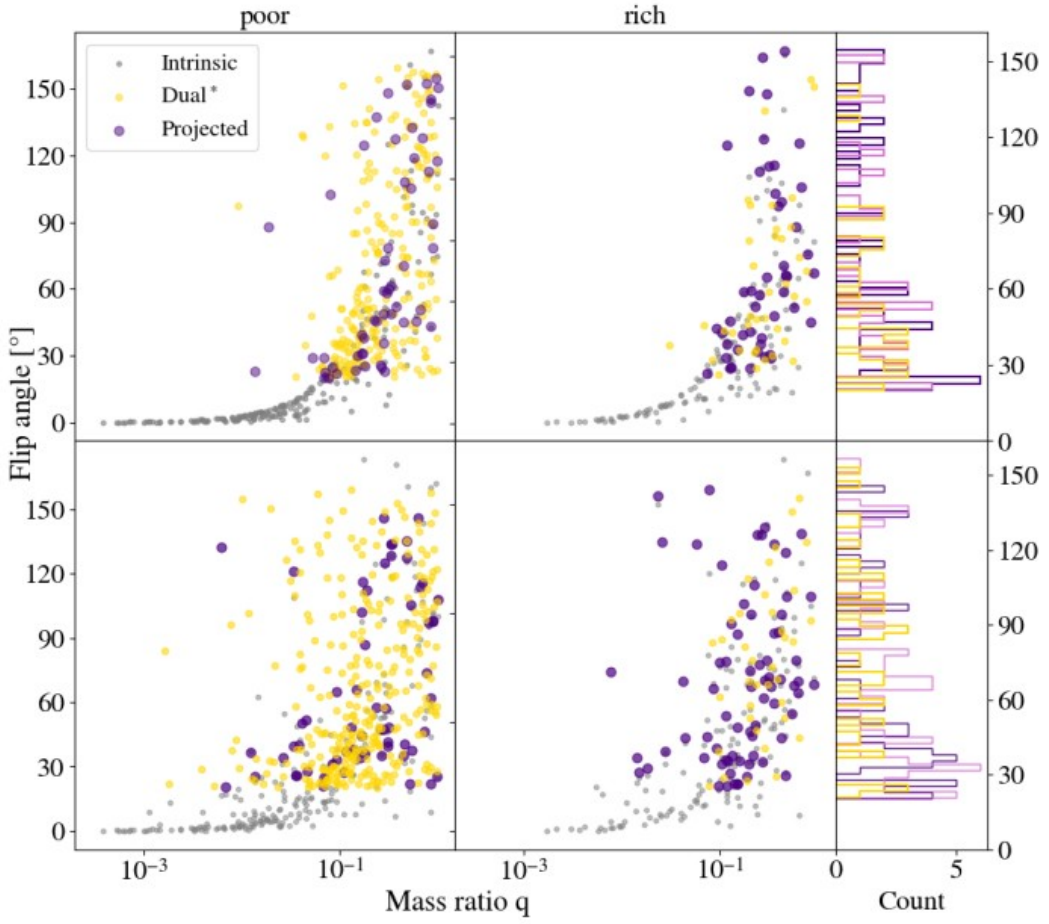
Model	Detected	Total
Croton16		
B3H9-n1	55.5	84.32
B4H10-n1	17.3	26.42
B5H11-n1	7.0	11.73
B3H9-n2	62.0	84.37
B4H10-n2	22.5	26.44
B5H11-n2	11.3	11.73
Bower06		
B3H9-f1	68.5	84.17
B4H10-f1	31.0	40.01
B5H11-f1	15.3	30.37
B3H9-f2	65.0	84.16
B4H10-f2	31.0	40.01
B5H11-f2	22.0	30.36

Angle between jets

Model spin direction change in a merger:
- one active BH
- initially random spin wrt orbital
- masses from simulation
- spin direction change in a merger
- include projection effects
- small preference for small angles

Double jet scenario

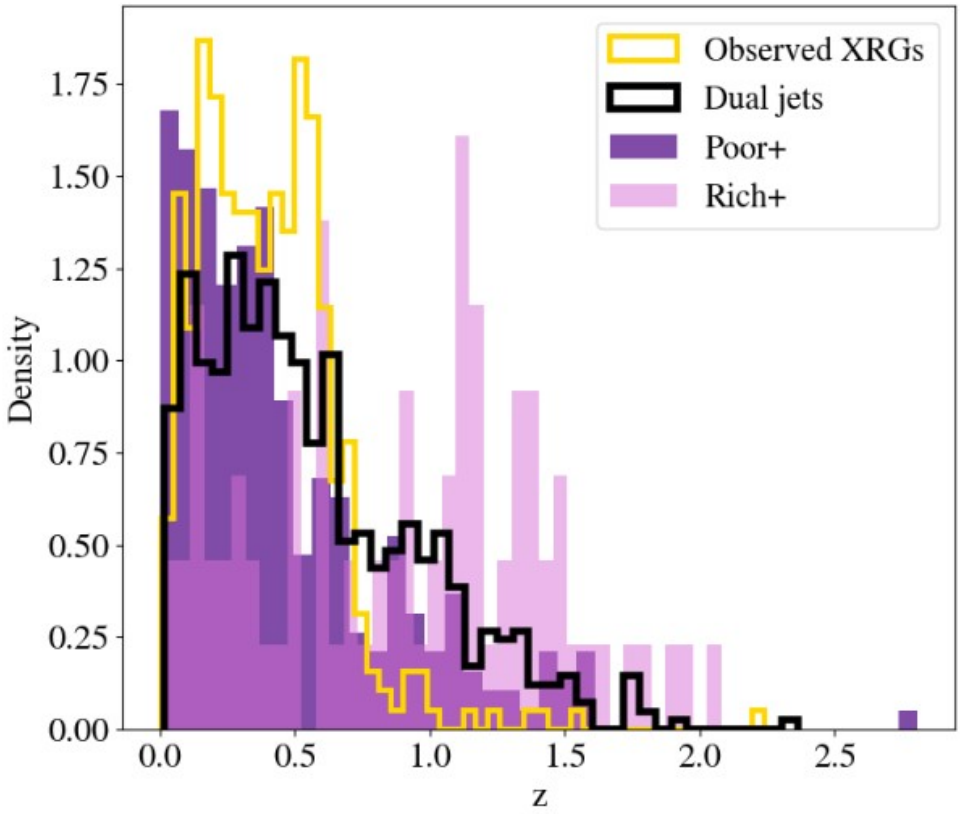
- no preferred angles



Redshift distribution

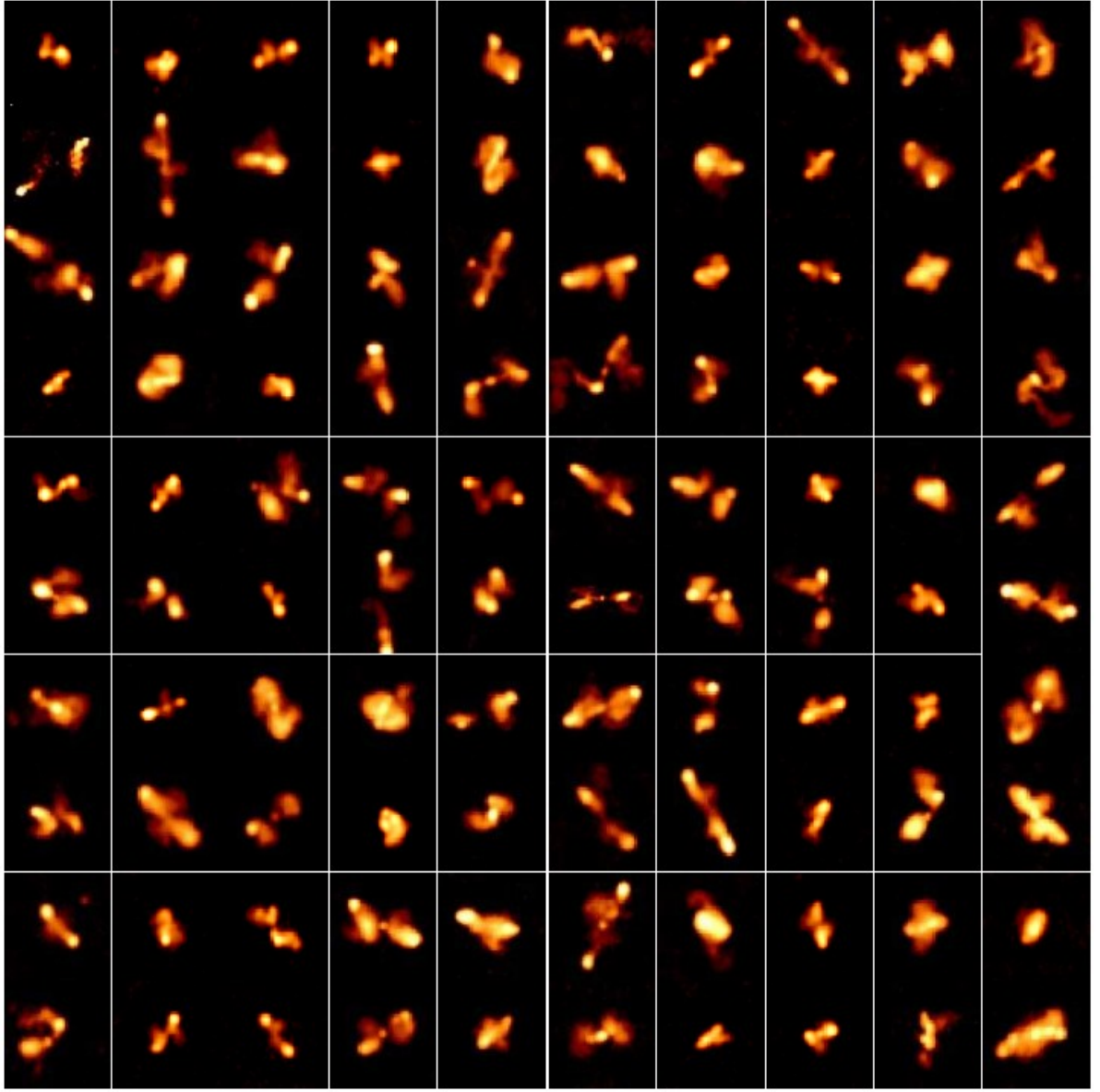
Preference for spin flip scenario in gas poor galaxies.

Comparison may not include all selection effects...



Scenarios

- Mergers that induce a spin flip
- Double BHs - two independent jets



Cheung 2007