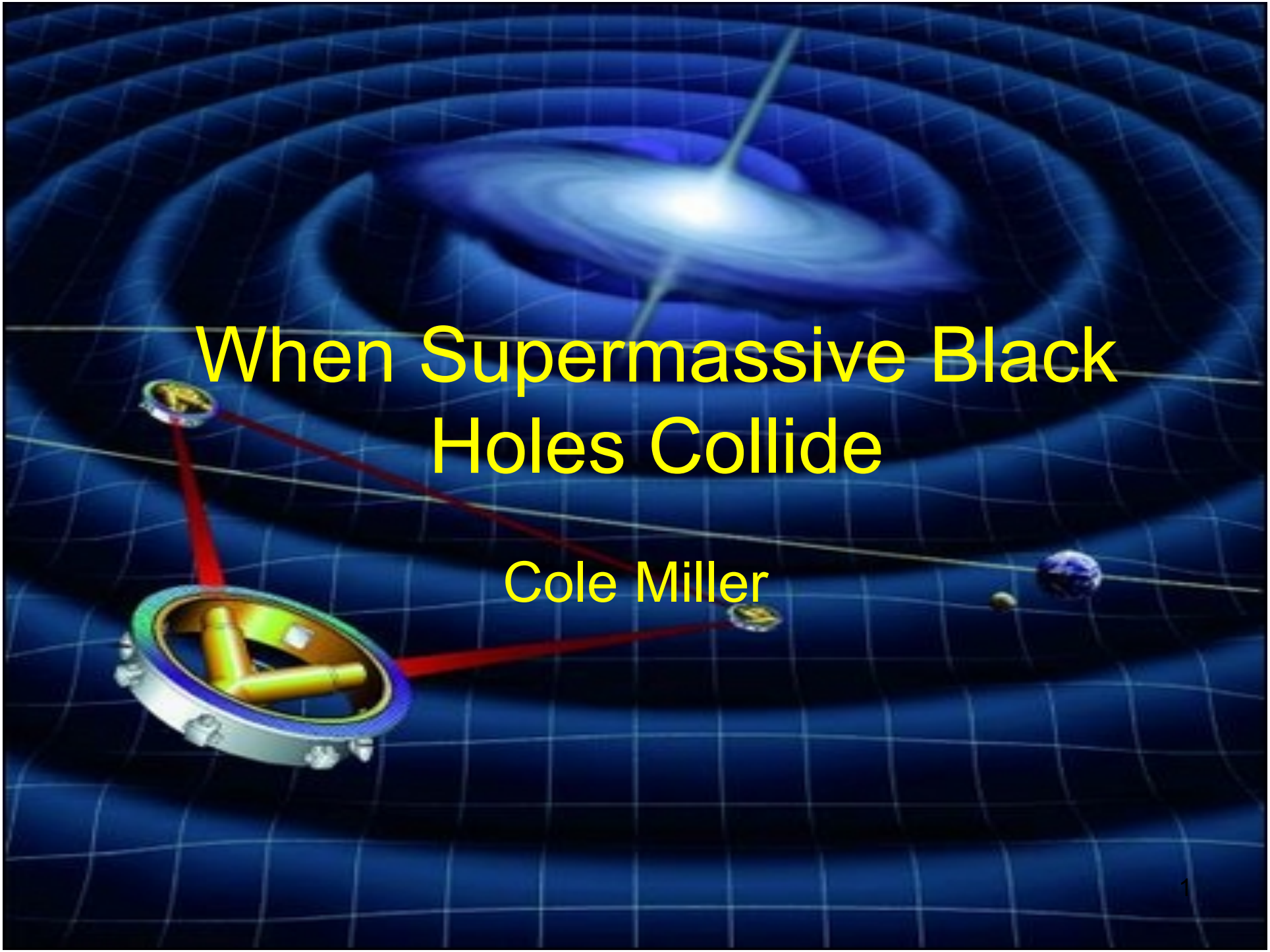
When Supermassive Black Holes Collide
Cole Miller

Outline

- Supermassive black holes and galaxies
- From gas to gravitational waves
- The search for EM signatures

So what happens when black holes collide?

So what happens when black holes collide?

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Gravitational radiation in black-hole collisions at the speed of light. III. Results and conclusions

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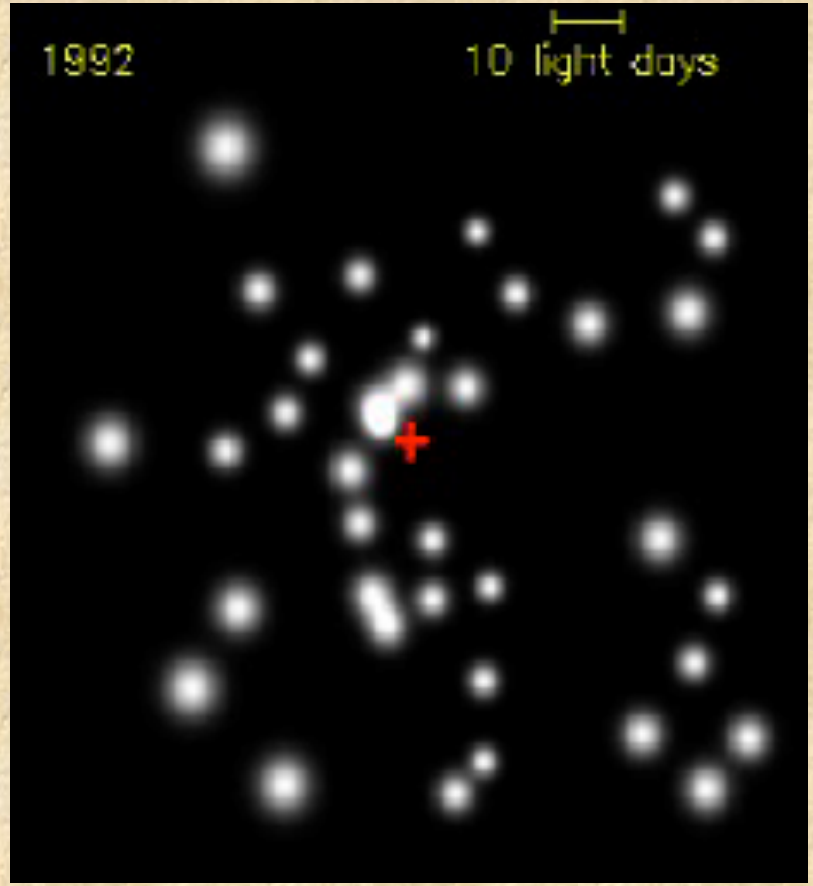
(Received 4 February 1992)

D'Eath and Payne!

SMBH and Galactic Centers

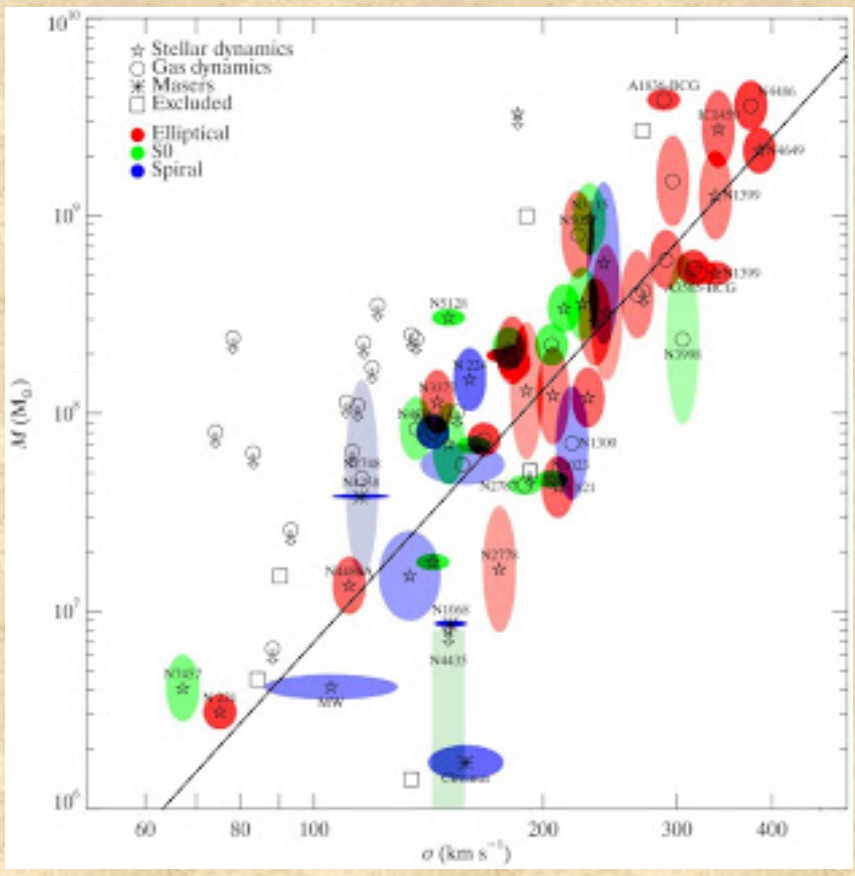
- All large galaxies with bulges appear to have SMBH in center
- Direct dynamical evidence for our MW
- M-σ relation:
  σ=velocity dispersion
  $M_{BH} \sim \sigma^4$
- Co-evolution?



R. Genzel et al.

M-sigma; Limitations?

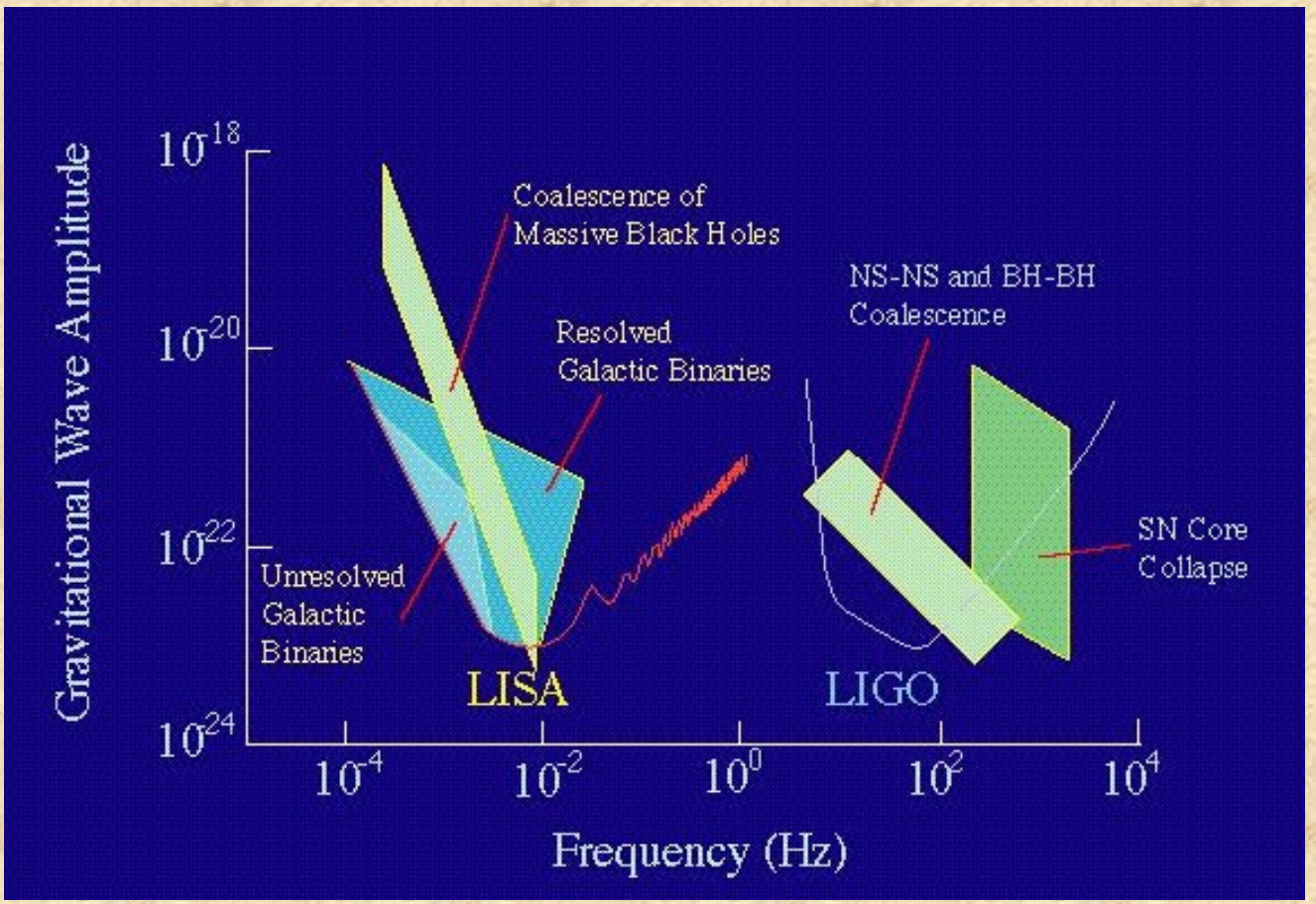
- Correlation works well for 10^7-10^9 M_{sun} black holes
- But sigma doesn't go above 400 km/s
- Not clear if lower masses fit, either
- Dynamics? Feeding?



Gultekin et al. 2009

Gravitational Radiation

- Produced by moving masses, e.g., SMBH-SMBH
- Contains info on strong gravity, SMBH evol
- Rates very uncertain!



Getting from Here to There

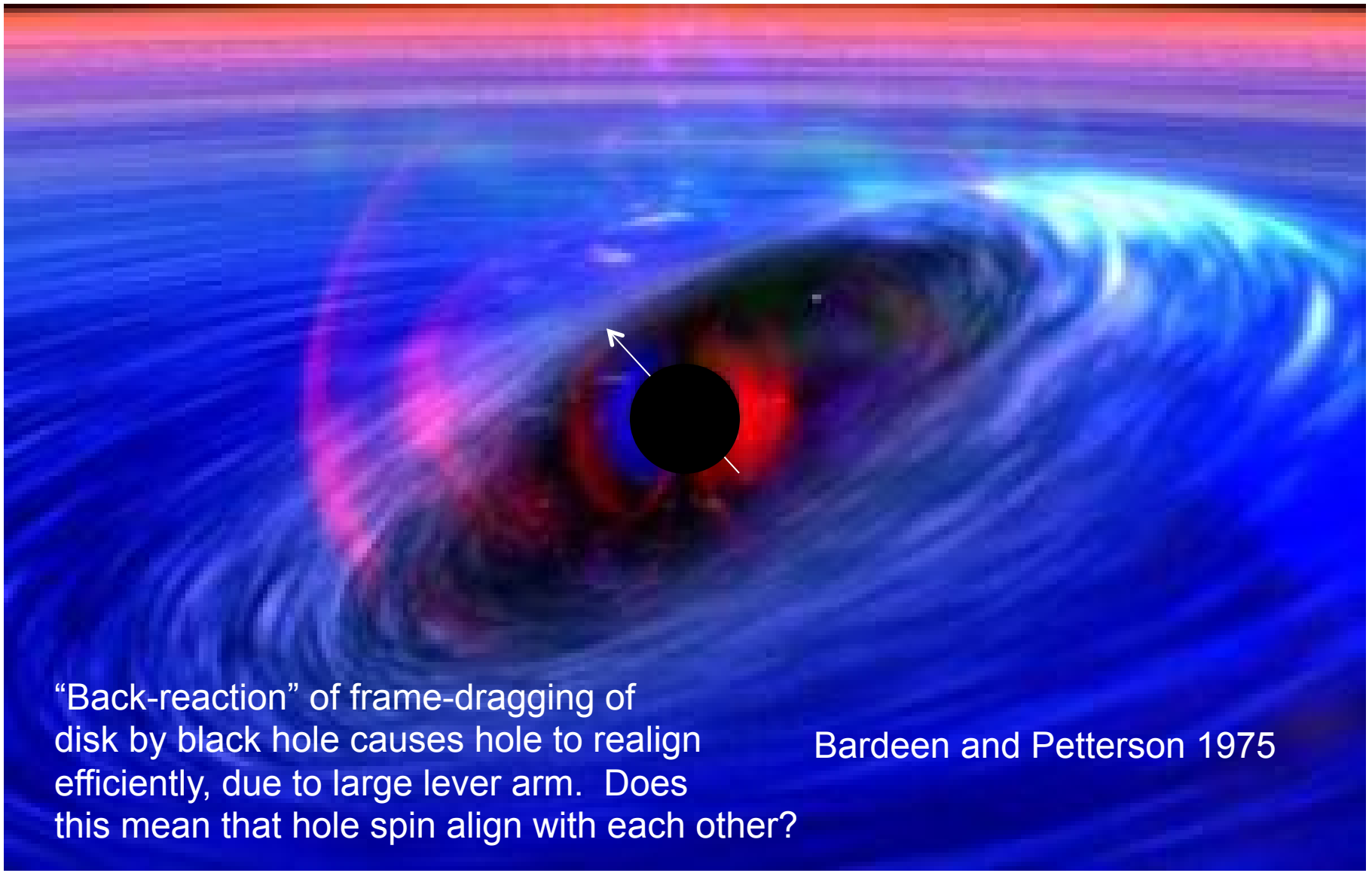
- Galaxy collisions start at ~10-100 kpc
- Bulges spiral together to 100-1000 pc
- SMBH dynamical friction to ~1-10 pc
- Gravitational radiation takes over at 10^{-3} to 10^{-2} pc
- What can bridge the gap? If the galactic centers are just stars in ~spherical orbits, not so easy. Triaxiality can help, or...

Gas Drag

- Stars might get kicked out never to return
- But gas around a binary can cool, follow the binary
- Role of magnetic fields?

http://www.das.uchile.cl/~drodrigu/images/hd98800.jpg

Bardeen-Petterson Effect

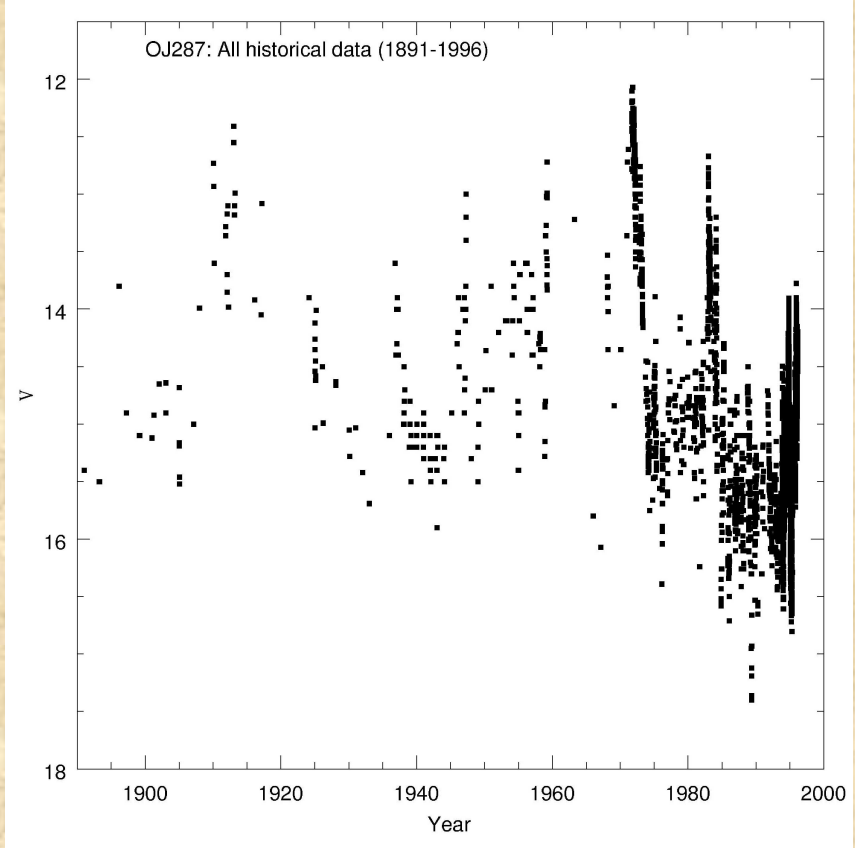


Identifying SMBH Binaries

- We'll have to wait a while for gravitational wave detectors that could see the low frequencies associated with SMBH merger
- What EM signatures might we find?
- Ongoing work, and a topic of my research
- Remember: AGN do all sorts of crazy things, so we need something unique!

Periodicity?

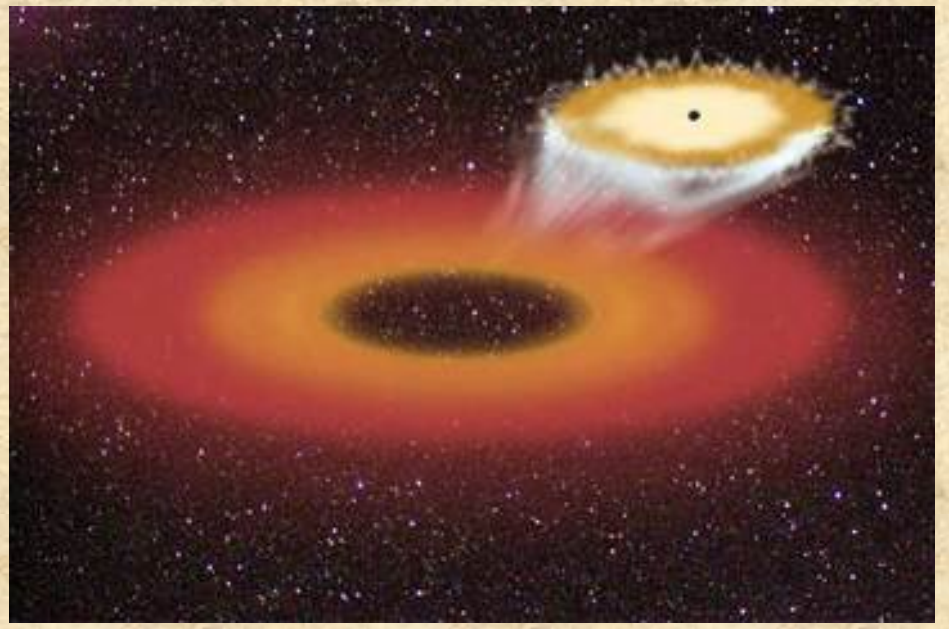
- Only one even quasi-periodic signal seen from AGN.
- Might see periodicity at late stages of SMBH coalescence
- ~12 yr periodicity claimed for OJ 287 (right); do you see it?



Work by Valtonen and colleagues

Kicks?

- When black holes with different masses or spins collide, grav. radiation is emitted anisotropically
- Kicks can be up to 5000 km/s!
- But most galaxies have SMBH...



Not a photograph

Many Open Questions

- Is there strong evidence that SMBHs do eventually merge?
- How can we identify SMBH binaries among all sorts of erratic AGN behavior?
- Are SMBHs typically spin-aligned when they merge, or could they be kicked completely out of galaxies?
- Need dynamics, MHD to resolve