Binary Black Holes: An Introduction

Roger Blandford
KIPAC
Stanford

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Inertial Confinement of Extended Radio Sources

Three-Dimensional Magnetohydrodynamic Simulations of Buoyant Bubbles in Galaxy Clusters

De Young and Axford 1967, Nature
O’Neill, De Young and Jones 2011

Fig. 1. Calculated shape of plasma.
Mergers and Acquisitions

- Mpc Problem
- kpc Problem
- pc Problem
- mpc Problem
The Megaparsec Problem

- **Galaxies with Spheroids** have massive black holes (MBH)
  - \( m_8 \sim \sigma_{200}^4 \); \( m \sim 10^{-3} M_{\text{sph}} \)
  - **Evolution?** (Treu et al)

- **Galaxies assembled through hierarchical mergers of DM halos.**
  - Major and minor
  - Halo Occupation Density
  - DM simulations quantitative; gas messy

**Can we calculate** \( R(m_1, m_2, z, \rho \ldots) \)?
Energy self-sufficiency?

- Kocevski eg (2012) [CANDELS]
  - Modest power
  - X-ray selected
  - Imaged in NIR
  - $z \sim 2$

- AGN
  - $\sim 0.5$ in disks; $\sim 0.3$ in spheroids
  - $>0.8$ undisturbed like control sample

- Selection effects rampant!
  - Opposite conclusions drawn from other studies

How do we ask the right questions observationally?
The kiloparsec Problem

- **Circum-Nuclear Disks**
  - ULIRGs $\sim 100$ pc
  - Sgr A* $\sim 1$ pc
- **Invoked to supply friction**
  - Is it necessary for merger?
Double AGN

• **Sample**
  – SDSSIII etc
  – Double-peaked spectra
    • O[III] $5007 \Delta V \sim 300$-1000 km s$^{-1}$
  – Adaptive optics
  – X-rays, radio
  – Spectra

• **Are they outflows/jets/NLR?**

**Double gas, disks, holes, NLR?**

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Deadbeat Dads?

- Are quasars mergers of two gas-rich galaxies?
- Is there a deficit of dual AGNs?
- If so, why?
  - Selection effects?
  - Dust?
  - Need both galaxies to be gas rich before merger?
- ALMA very important; spectra!

Will EVLA, ALMA, VLBI solve this problem?
The parsec Problem

- Bound within $\sim 10^6 m$
  - $r \sim M_7 pc$
- Can binaries harden?
  - Can stars do the job?
    - Dynamical friction
    - Evaculate core vs loss cone filling
    - Bars minor mergers
  - Can gas provide the friction?

Are there sufficient stars to provide dynamical friction?
Eccentricity and Multiplicity

- Three bodies can change orbits
  - Resonances
  - Ejection
- Dynamical friction can make eccentric
  - At apapse, large lever, small speed
  - Friction changes L (p) not E
- Gravitational radiation and gas likely to circularize

Graphs showing the reduction of binary separation and growth of the eccentricity over time.
The milliparsec Problem

• **Is GR correct?**
  – We know it is good to $\sim 10^{-5}$ in weak field limit
  – **Stationary strong field in Kerr metric**
    • Gas flow
  – **Dynamic strong field in mergers**
    • Gravitational radiation

• **How do AGN release most power?**
  – Disks?
  – Winds?
  – Jets?

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Velocity

- **Velocity Difference**
  - $z \sim 0.4, \Delta V \sim 3500 \text{km s}^{-1}, m \sim 10^7, 10^9 M_{\text{sun}}$ (Lauer, Boroson)

- **Velocity Change**
  - Acceleration (Eracleous)

- **May not be Binary**
  - Emission line region dynamics

What are standards of proof?

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Wages of Spin?

- Dual twin jets rare
  - eg 3C75

- Disk or spin; field or gas?
  - Magnetically-choked, accretion
  - Jets are efficient, robust and pliable

- Alignment with disk?
  - Bardeen-Petterson?
  - Magnetic torques more important?

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Black Hole Imaging

- Sgr A* and M87
  - 4 million and 7 billion $M_{\odot}$
  - Same angular size m/d $\sim 5\mu$as!
  - Event Horizon Telescope
  - Submm VLBI (ALMA), space
  - SgrA* may vary too fast
  - Fringes from $\sim 5m!$ (Doeleman et al)

Can we convert hydro to mm images?

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McKinney
Pulsar Timing Arrays

- NanoGRAV, EPTA, PPTA, MeerKat, SKA... = IPTA!
- Background vs nearby strong sources
  - Sazhin, Rajagopal & Romani, Sesana....
- Best timers have 40 ns arrival times $\tau$

$$\tau = \frac{1}{2} \int dzh \sim 3 - 10\text{ns}$$

Depends on angular momentum, $L$!

$$\tau(\tau) = \frac{L}{s}[C_+(d,s)D_+(e,\phi,\theta) + C_x(d,s)D_x(e,\phi,\theta)]$$

Will pulsar timing be the first to detect a binary black hole?

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Harbingers and Repercussions

- **LISA/eLISA/NGO…**
  - Test GR in strong field limit; Standard sirens
  - $2m_3^{-1}$ Hz at ISCO, sensitive to $10^5-10^7M_{\text{sun}}$
  - Probe galaxy/hole co-assembly at early time

- **GW signal and 1° field predicting merger**
  - Seek tiny fraction of $c^5/G$ in ROX with GW phase
  - Identify galaxy and observe merger with all telescopes
  - Also for EMRI
  - At this point this seems a fantasy!

- **Peculiar X-ray signal as gas falls in after BH merger**
  - Could be years for small $m$ (Phinney, Milos…)
  - Nice simulations (MacFadyen)

What are the capabilities of a realizable space mission?
Questions

• Can we calculate $R(m_1, m_2, z, \rho ...)$?
• How do we ask the right questions observationally?
• Double gas, disks, holes, NLR?
• Are there sufficient stars to provide dynamical friction?
• Will EVLA, ALMA, VLBI solve this problem?
• What are standards of proof?
• Can we convert hydro to mm images?
• Will pulsar timing be first to detect a binary black hole?
• What are the capabilities of a realizable space mission?