

Binary Black Holes: An Introduction

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Inertial Confinement of Extended Radio Sources

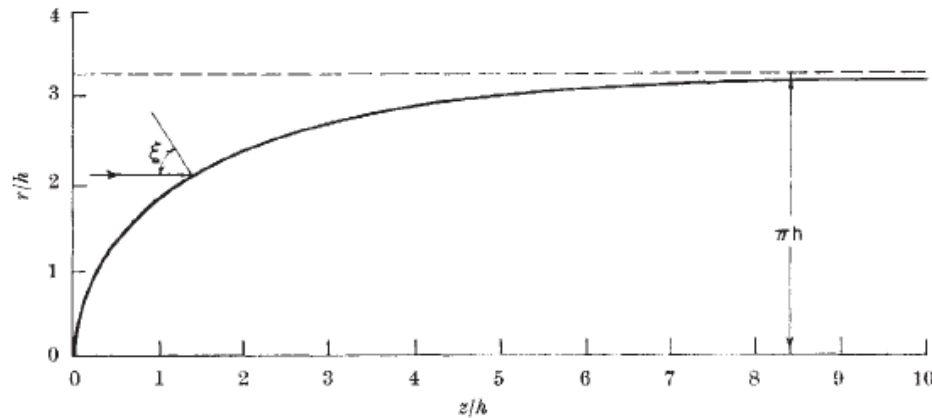


Fig. 1. Calculated shape of plasmon.

**Three-Dimensional
Magnetohydrodynamic
Simulations of Buoyant Bubbles
in Galaxy Clusters**

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

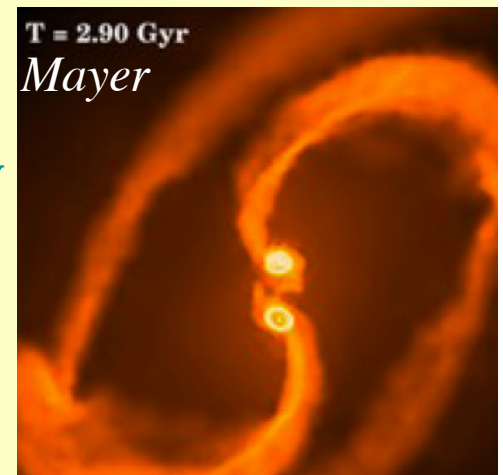
Mergers and Acquisitions

- Mpc Problem
- kpc Problem
- pc Problem
- mpc Problem

The Megaparsec Problem

- Galaxies with Spheroids have massive black holes (MBH)
 - $m_g \sim \sigma_{200}^4$; $m \sim 10^{-3} M_{\text{sph}}$
 - Evolution? (Treu et al)
- Galaxies assembled through hierarchical mergers of DM halos.
 - Major and minor
 - Halo Occupation Density
 - DM simulations quantitative; gas messy

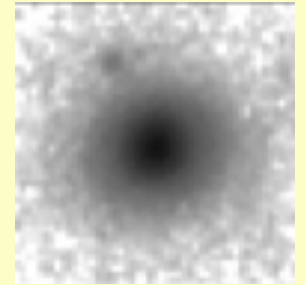
Can we calculate $R(m_1, m_2, z, \rho \dots)$?



Energy self-sufficiency?

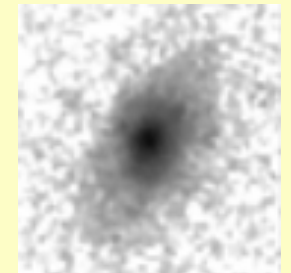
- Kocevski et al (2012) [CANDELS]

- Modest power
- X-ray selected
- Imaged in NIR
- $z \sim 2$



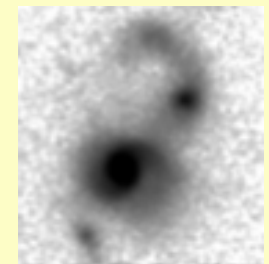
- AGN

- ~ 0.5 in disks; ~ 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

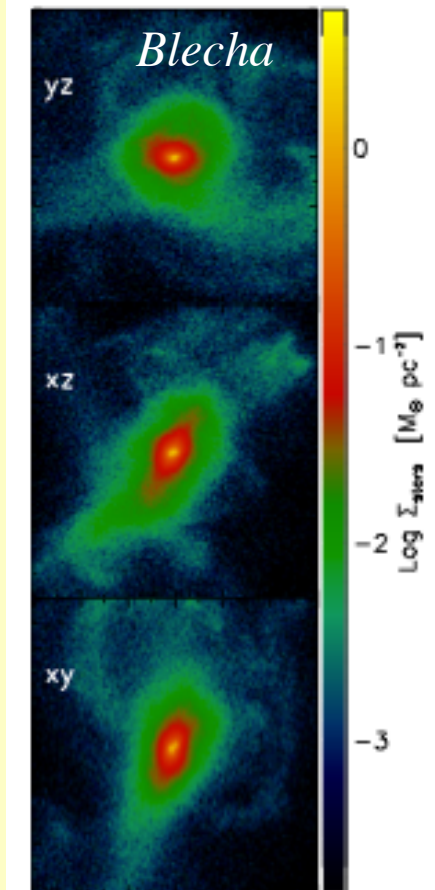
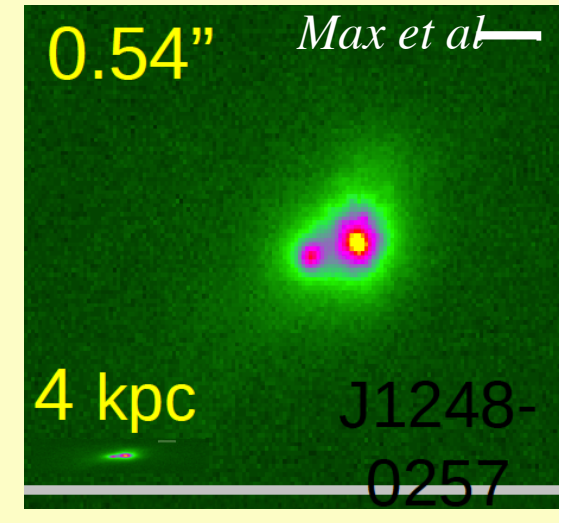
- **Circum-Nuclear Disks**
 - **ULIRGs** $\sim 100\text{pc}$
 - **Sgr A*** $\sim 1\text{ pc}$
- **Invoked to supply friction**
 - **Is it necessary for merger?**



Double AGN

- Sample
 - SDSSIII etc
 - Double-peaked spectra
 - O[III] 5007 $\Delta V \sim 300\text{-}1000 \text{ km s}^{-1}$
 - Adaptive optics
 - X-rays, radio
 - Spectra
- Are they outflows/jets/NLR?

Double gas, disks, holes, NLR?



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?

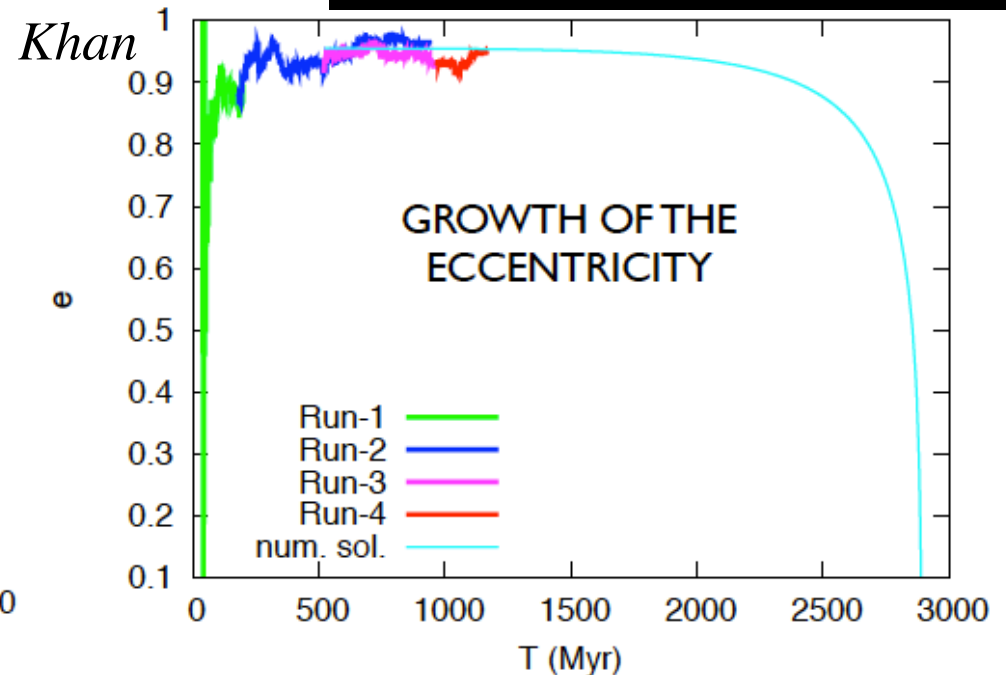
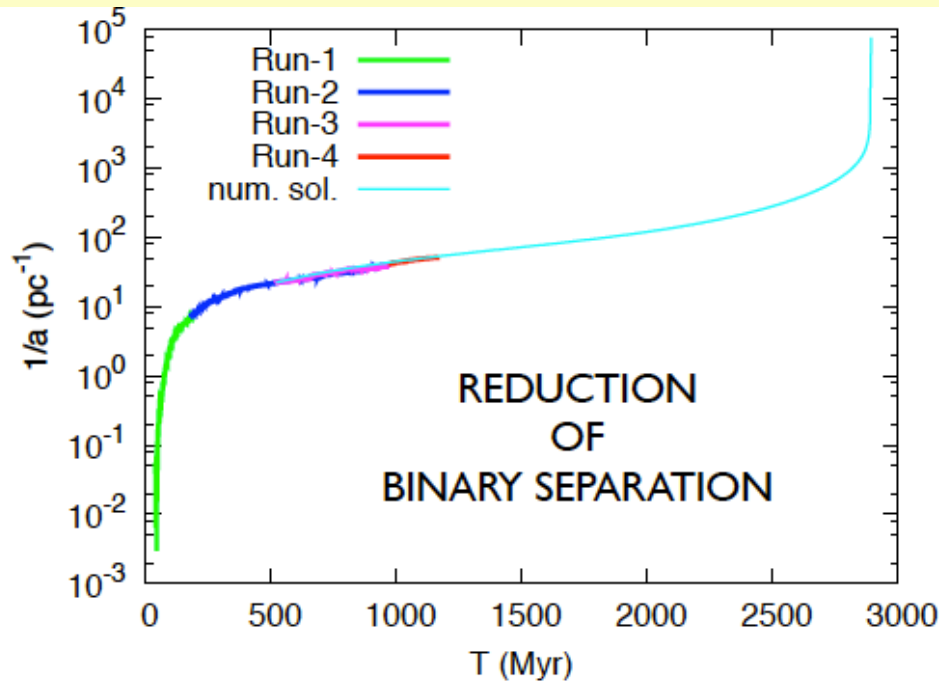
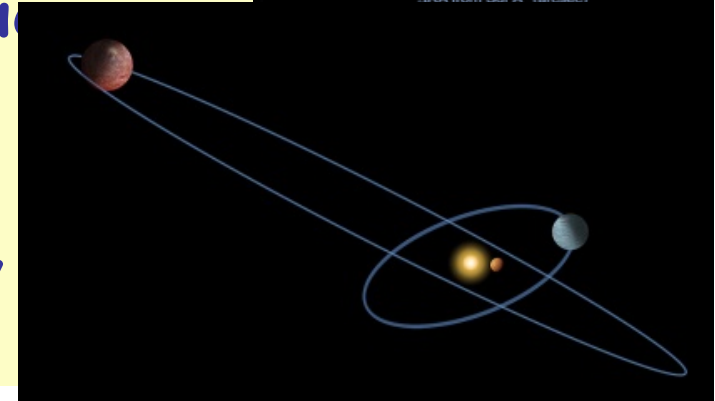
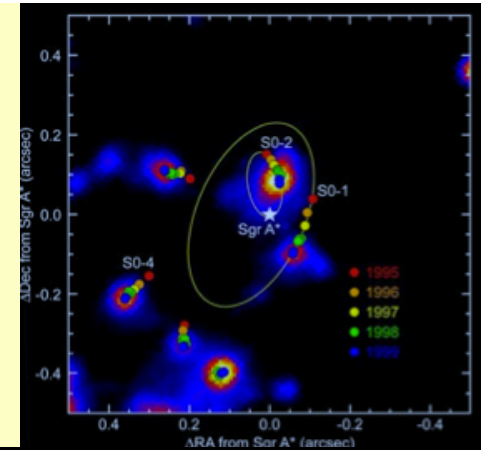
The parsec Problem

- Bound within $\sim 10^6 m$
 - $r \sim M_7 pc$
- Can binaries harden?
 - Can stars do the job?
 - Dynamical friction
 - Evacuate 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 circularize



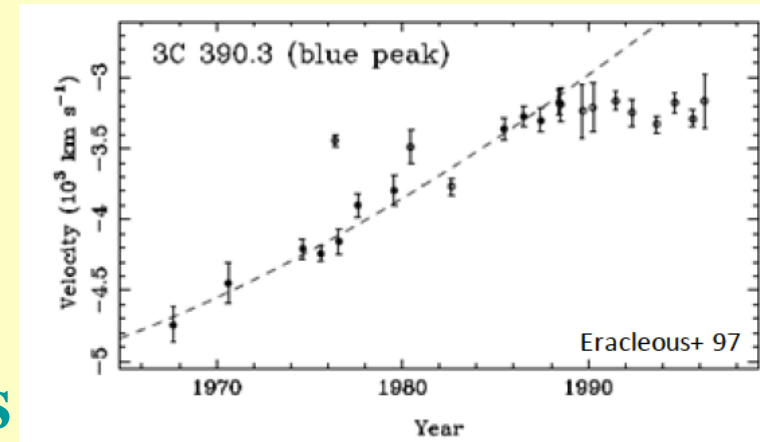
The milliparsec Problem

- **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?

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



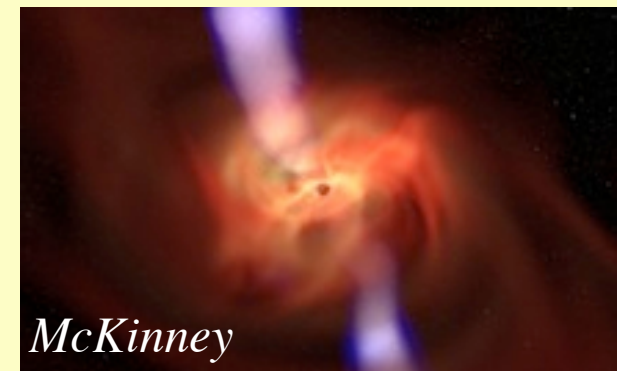
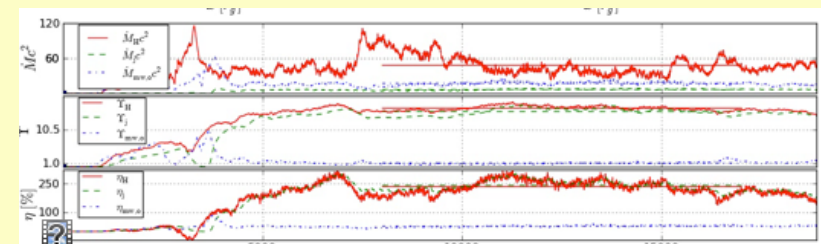
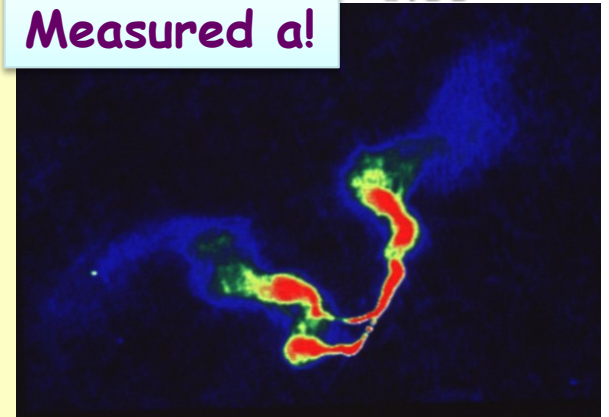
What are standards of proof?

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?

$$\begin{aligned}
 &0.60-0.78^{2,3} \\
 &0.56-0.73^{2,5,6} \\
 &> 0.98^{11,12} \\
 &> 0.94^{13} \\
 &0.37-0.59^6, > 0.98^{7,8} \\
 &< 0.32^2 > 0.88^{16}
 \end{aligned}$$

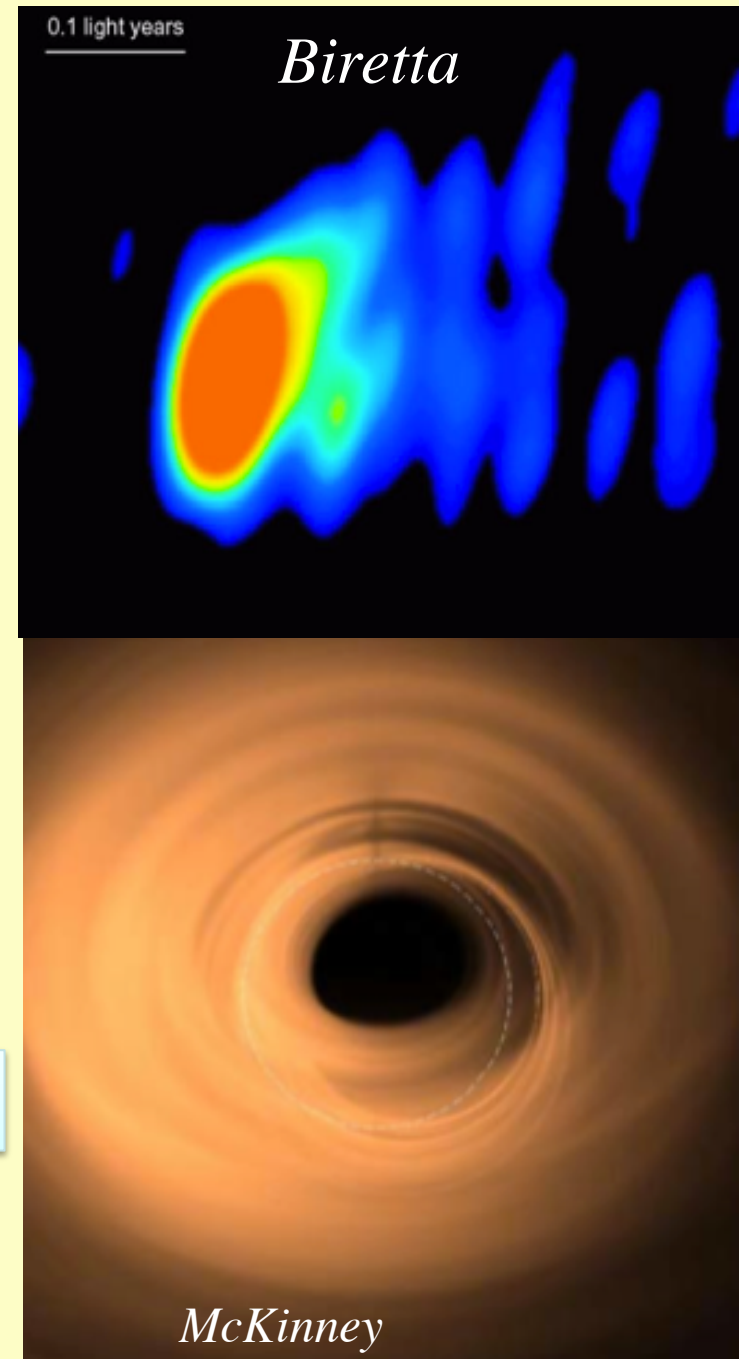
Measured!



Black Hole Imaging

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

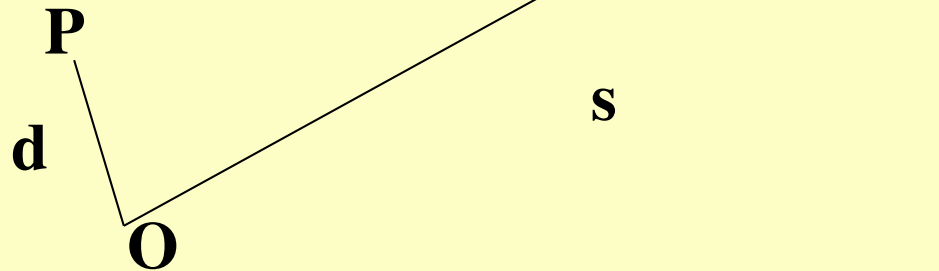
Can we convert hydro to mm images?



Pulsar Timing Arrays

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

$$\tau = \frac{1}{2} \int dz h \sim 3 - 10 ns$$



Depends on angular momentum, L!

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

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

Harbingers and Repercussions

- **LISA/eLISA/NGO...**
 - Test GR in strong field limit; Standard sirens
 - $2m_3^{-1}$ Hz at ISCO , sensitive to 10^5 - $10^7 M_{\text{sun}}$
 - 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 $R(m_1, m_2, z, \rho \dots)$?
- 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?