Intermediate-mass-ratio inspirals into intermediate-mass black holes

Ilya Mandel, Duncan Brown,
Jonathan Gair, Cole Miller

APS 2007
4/16/2007

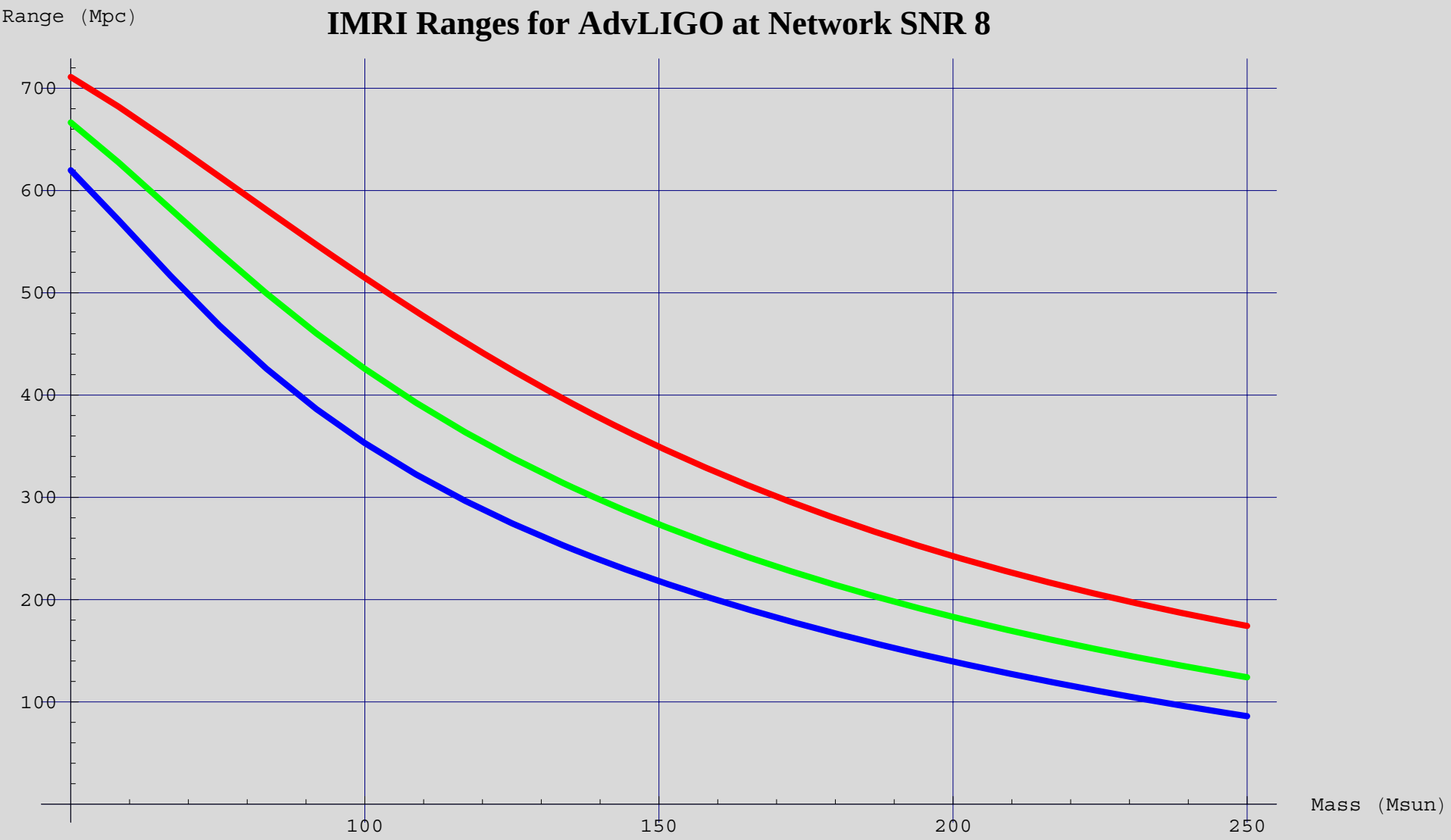
Intermediate-mass-ratio inspirals (IMRIs)

- IMRIs have mass ratios between 10 and 10^4
- LIGO IMRIs: Inspirals of compact objects into intermediate mass black holes (IMBHs)
- Indirect evidence for IMBH existence in globular clusters
- IMRIs could be the first proof of IMBH existence!
- IMBHs: 50 – 350 solar masses; Compact Objects (COs): 1.4 solar mass Neutron Stars to ~10 solar mass Black Holes

Event rates – upper limit

- Model-independent upper limit
- One suitable IMBH per globular cluster
- ~One globular cluster per Mpc^3
- IMBH grows from 50 to 350 solar masses by capture of COs in age of universe
- How far can Advanced LIGO see IMRIs?

Advanced LIGO range



Event rates – upper limit

- Model-independent upper limit
- ~One globular cluster per Mpc^3
- One suitable IMBH per core-collapsed globular
- IMBH grows from 50 to 350 solar masses by capture of COs in Hubble time
- Advanced LIGO could see IMRIs up to ~700 Mpc (depending on masses, spin)
- Advanced LIGO may see ~ ten IMRIs per year (< 1 per 1000 years with Initial LIGO)
- Issues: kicks above 50 km/s eject IMBH; lower rates late in cluster history [e.g. simulations by O'Leary et al., 2006]

Event rates – realistic model

- Late in cluster history, BH subcluster depleted; IMBH swaps into binaries, forms NS-IMBH binaries these are tightened by 3-body interactions, then merge via GW radiation reaction
- Rate per globular is ~ $3*10^{-9}$ yr^{-1}
- Advanced LIGO rate is ~ one per two years
- If AdvLIGO is optimized for sensitivity in low-frequency range, rate could increase to a few per year

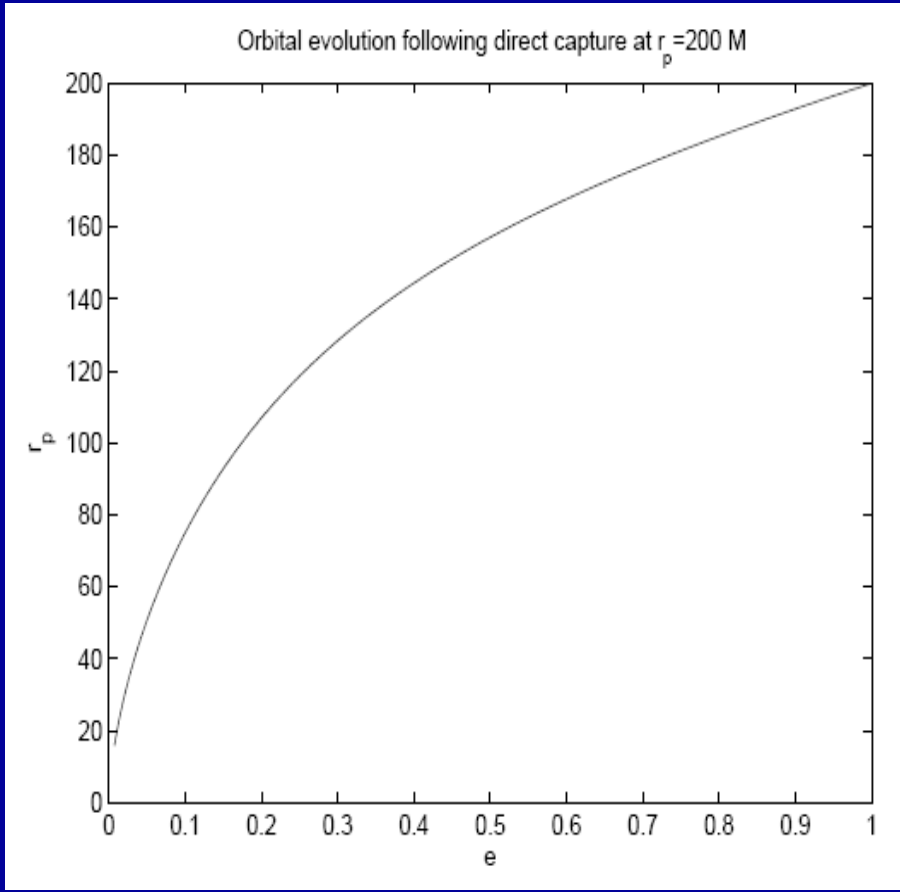
Eccentricities in AdvLIGO band

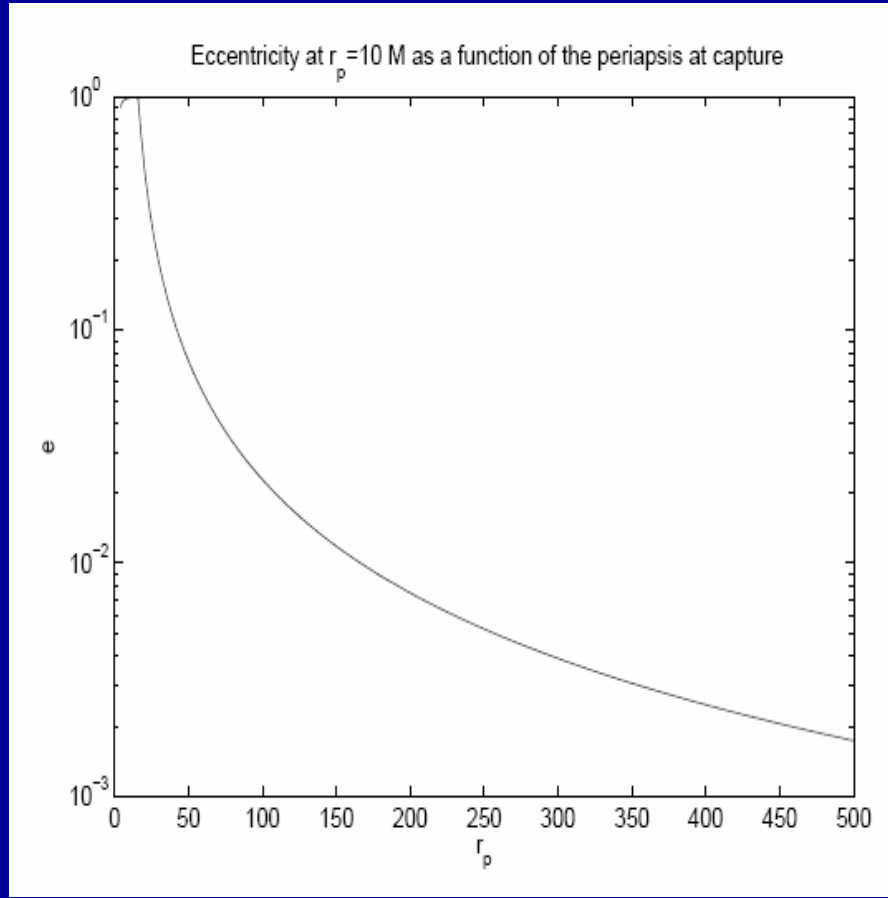
- Eccentricities depend on capture mechanism
- 3-body hardening
  - Circularized to $e<10^{-4}$ when $f_{GW}=10$ Hz
- Direct capture
  - 90% of IMRIs circularize to $e<0.1$,
  - 67% circularize to $e<0.01$ by $f_{GW}=10$ Hz
- Kozai resonance
  - Eccentricity under 0.1 in Advanced LIGO band
- Can use circular waveforms for detection

Summary & Outstanding Issues

- Expected Advanced LIGO event rates for IMRIs are one per two years -- few per year
- Eccentricities will be low, circular waveforms can be used for detection
- IMRIs can probe the IMBH spacetime in the strong gravity regime (M/m cycles)
- Can test whether IMBH is a Kerr black hole (measure quadrupole moment with interesting accuracy)
- Further study of practical methods for detecting and analyzing IMRI gravitational waves is required (e.g., building waveforms for detection)

Direct capture - eccentricities





$P(b) \sim b \Rightarrow P(r_p) \sim \text{const}$