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LISA & Multi-Messenger Astronomy

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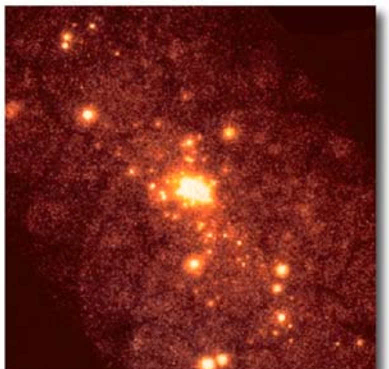
Penn State

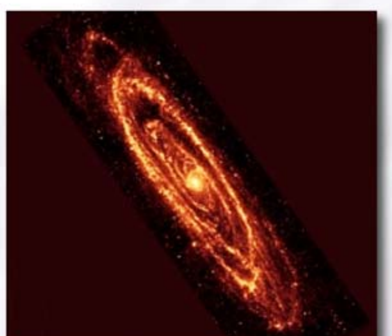
CENTER FOR GRAVITATIONAL WAVE PHYSICS

Multi-Spectral Astronomy

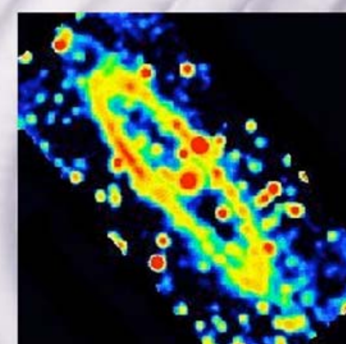

X-ray


UV


Optical

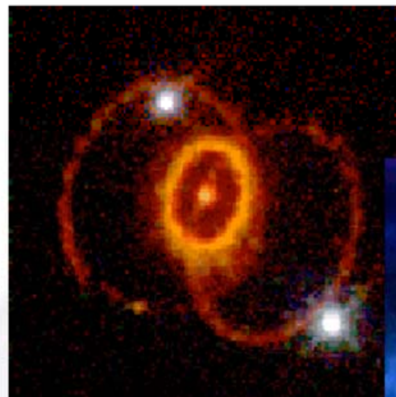

mid-IR


far-IR


Radio

Gravitational Wave Astronomy

- Energetic astronomical phenomena are associated with strong gravitational potentials
  - $(v/c)^2 \sim M/r$
- Strong gravitational wave sources are compact with internal bulk motion $v \sim c$
- *Gas, dust accumulate in strong potentials, obscure EM emission from central engine*



Super- & hyper-novae

Neutron star coalescence

Black hole binary coalescence

The universe is transparent to gravitational waves

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Galactic Structure

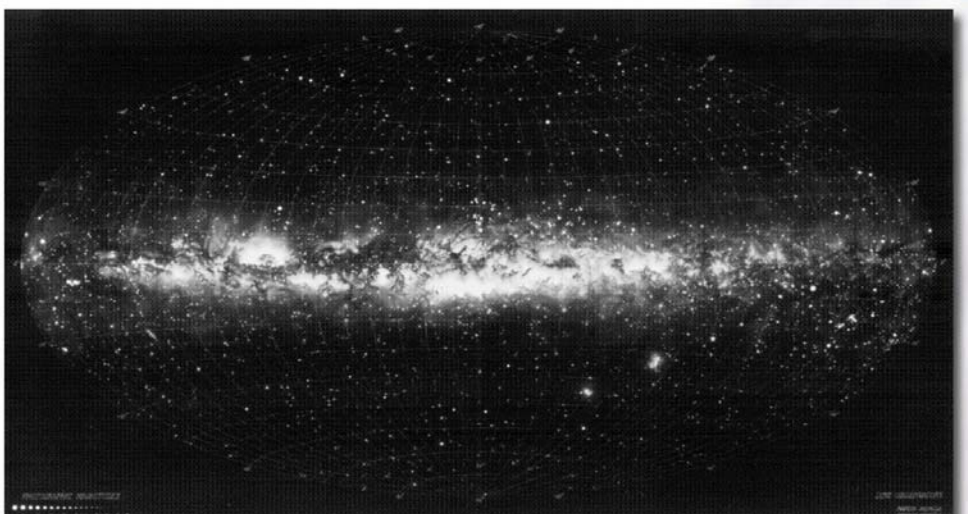
Dust, gas, faintness limit EM observations of galactic stellar density distribution

Galaxy is transparent in gravitational waves

\# LISA resolvable compact binaries

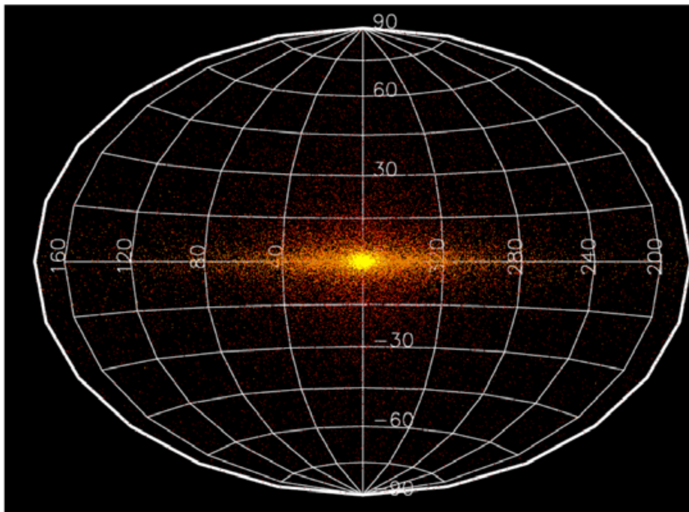
Type	Resolved	With df/dt
(wd, wd)	$>10^4$	~600
AM CVn	$>10^4$	~50
(ns,wd)	21	3
Other	2	0

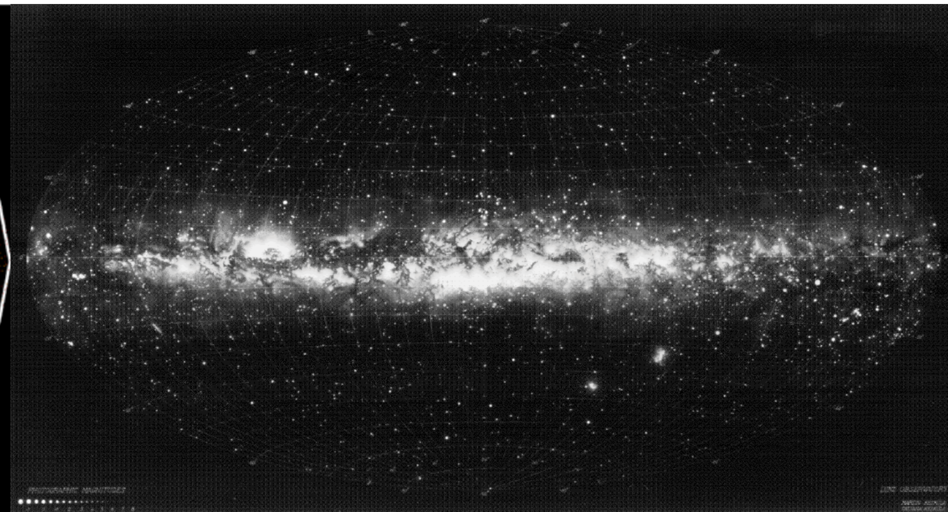
Nelemans 2003



Transparency provides detailed projected imagery of bulge, disk, halo
(Holley-Bockelmann, Rubbo, LSF)

Galactic Structure & the WD population





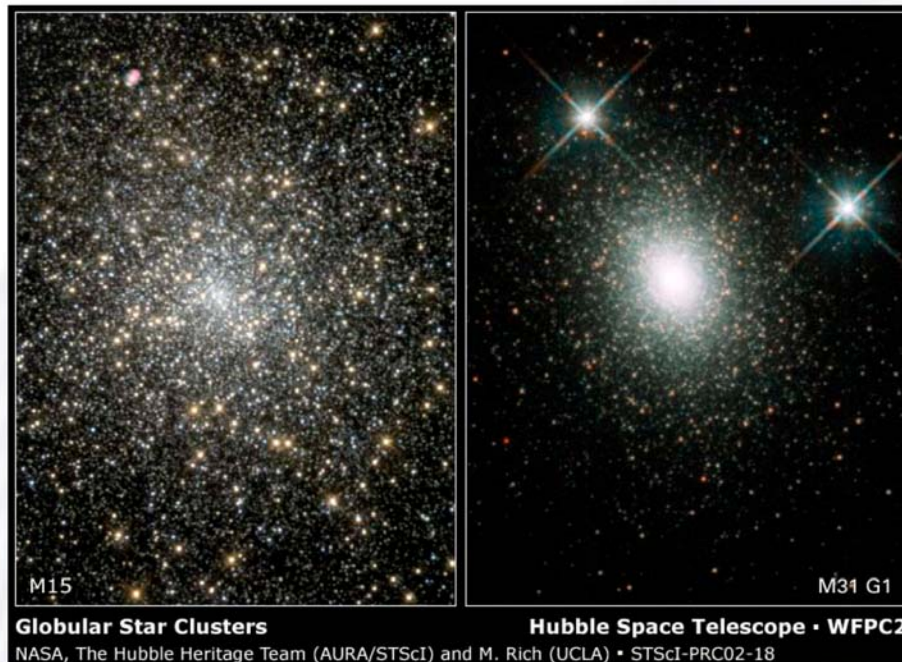
- Gravitational wave intensity, polarization, period, fixes orbital sin *i*, sky location, ratio of "chirp mass" $\mathcal{M}(m_1,m_2)^{5/3}$ to distance d
- Optical id as a single-line spectroscopic binary determines projected semi-major axis $a \sin i$ and mass function $f_m = (m_2 \sin i)^3 / (m_1 + m_2)^2$
- *Simultaneous gravitational wave, spectroscopic optical id fixes full orbital solution, component masses and absolute distance*

Joint gw, optical observations provide a 3-D map of galaxy

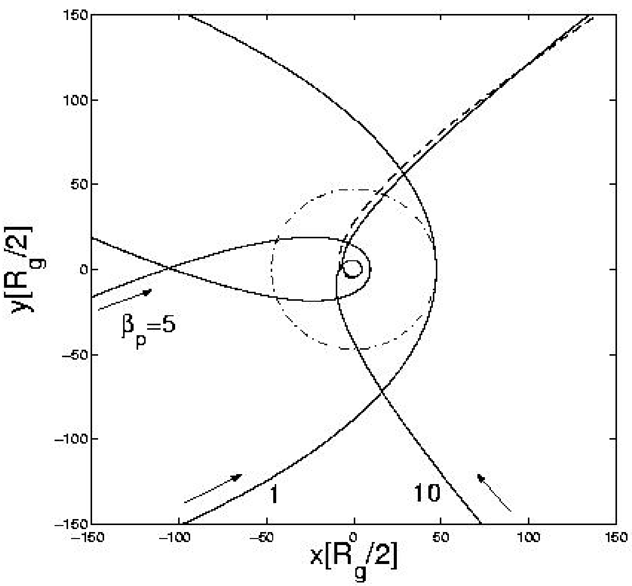
Gravitational Waves and the IMBH Population

Ultra-luminous X-ray sources (ULXs) & the dynamics of some globular cluster cores suggest the existence of IMBHs: black holes with mass ~ $10^2 - 10^5\ M_\odot$

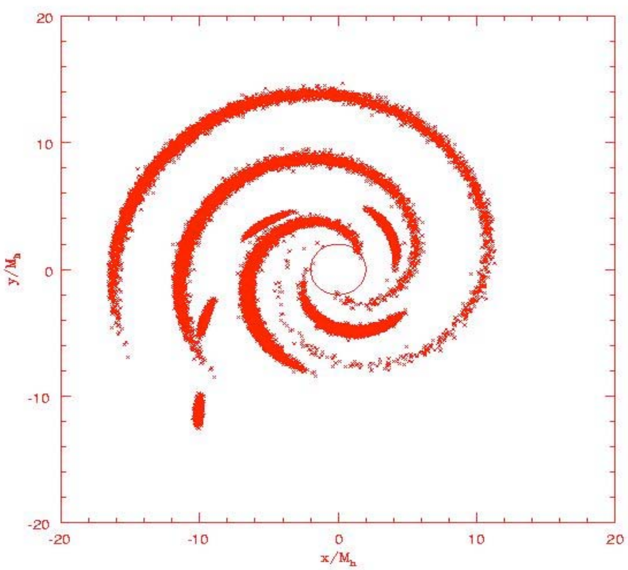
Capture of a star by an IMBH will give rise to coincident gravitational wave bursts and X-ray flares as the star is disrupted



WD capture & disruption by 10^3 $M_\odot$ IMBH



Orbits of penetration parameter β_p



SPH simulation

Kobayashi, Laguna, Phinney, Mészáros

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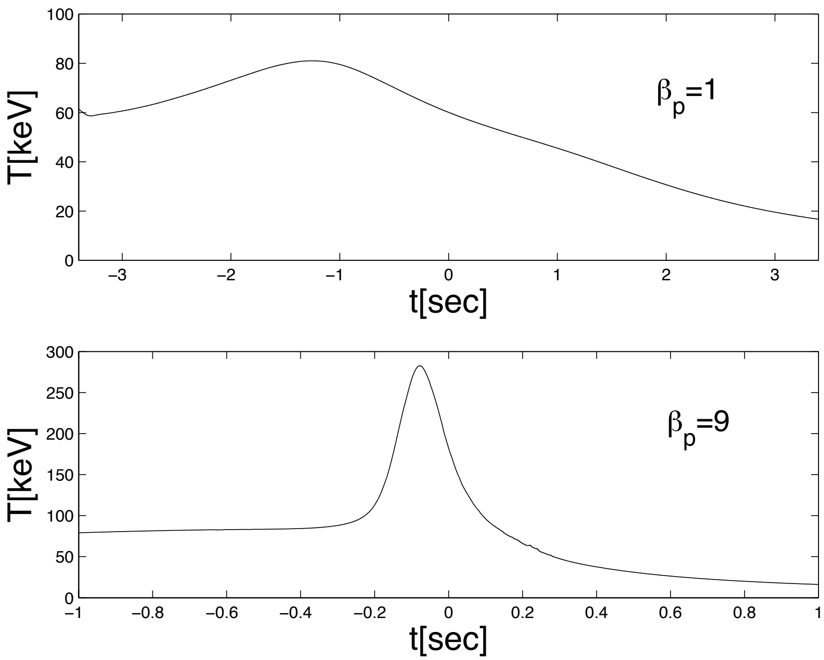
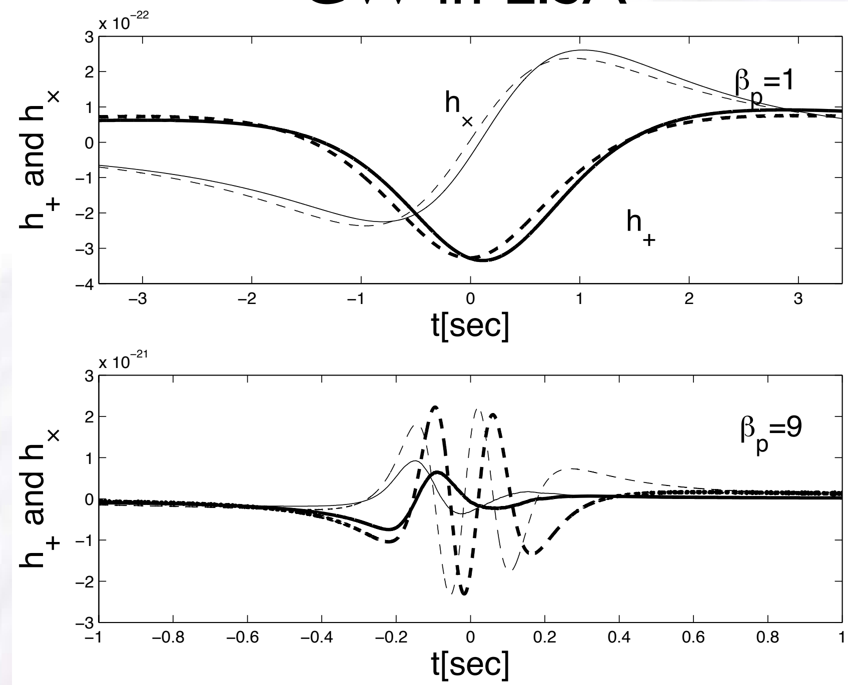
Prompt multi-channel signals from WD-IMBH disruption

Prompt X-ray Signal



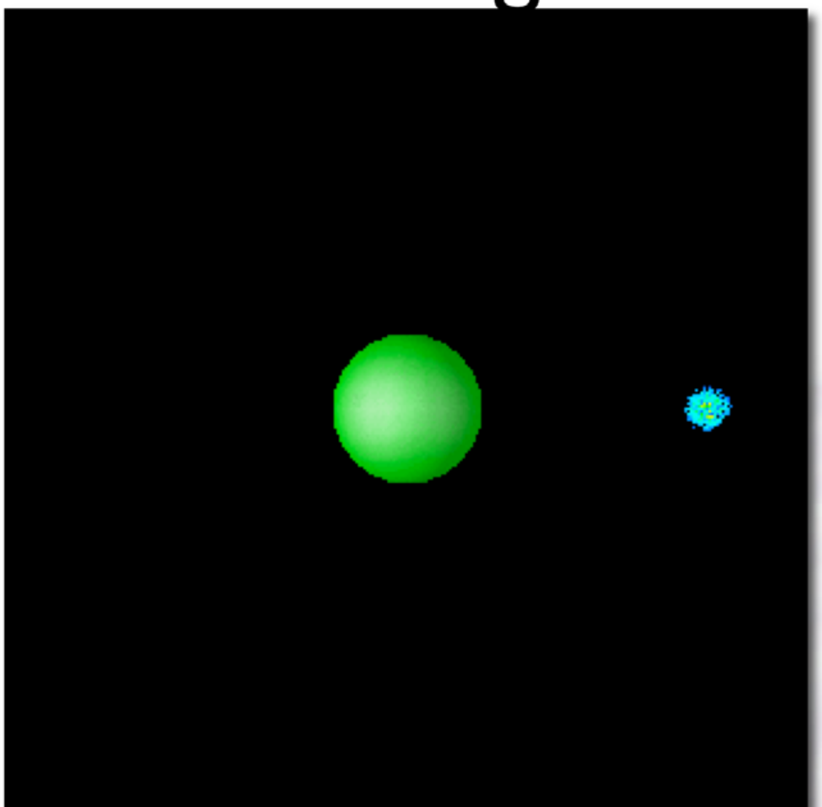
GW in LISA



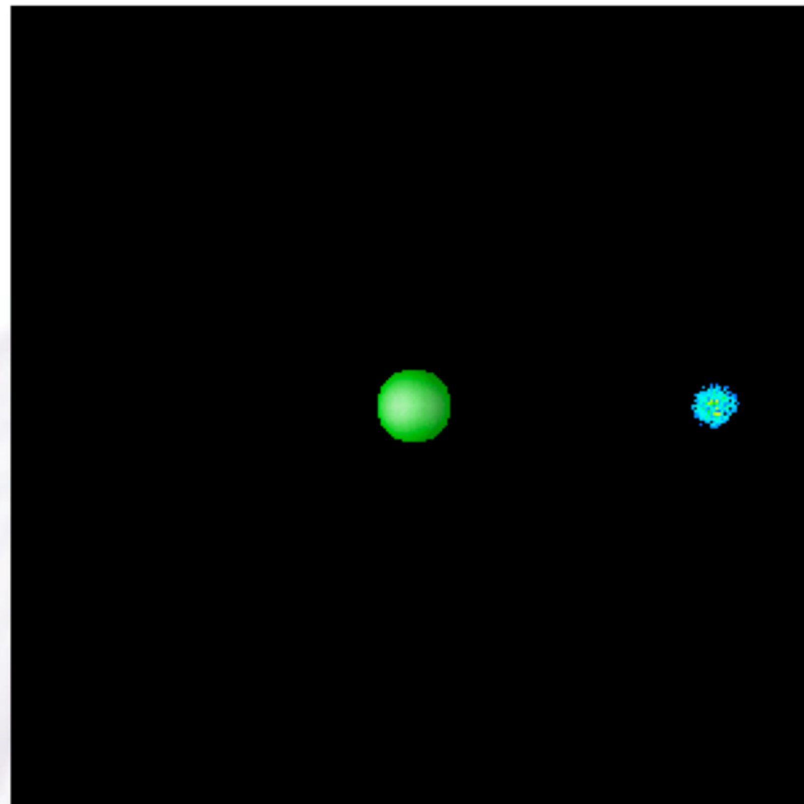
- X-ray timescale related to penetration, IMBH mass
- GW signal structure related to penetration
- *Together,* X-ray, GW break IMBH mass, penetration degeneracy

Kobayashi, Laguna, Phinney, Mészáros

X-ray, gravitational waves, and IMBH angular momentum



Schwarzschild

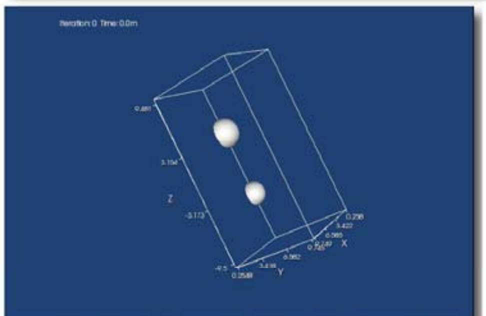


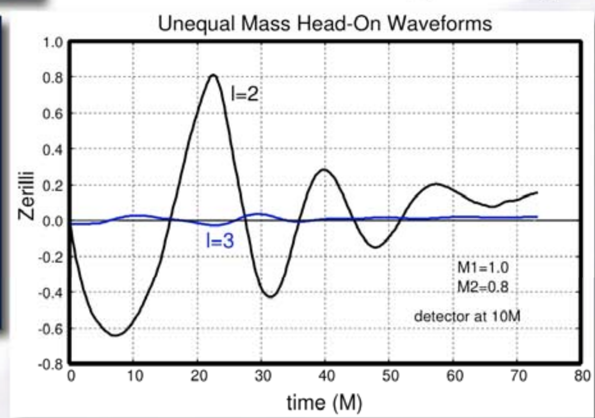
Maximal Kerr

Laguna, Rasio, Rantsiou, Kobayashi

Accretion disk formation about SMBH black holes

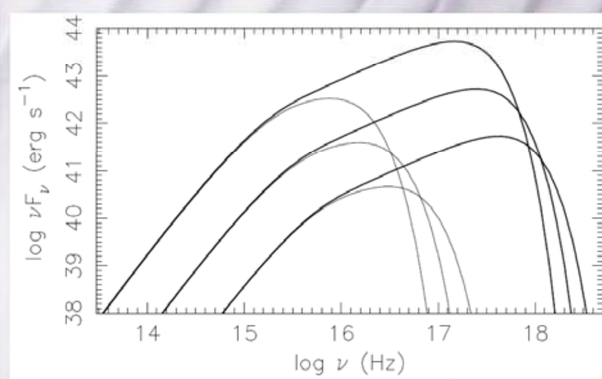
Colliding galaxies lead to supermassive black hole binaries. Before coalescence binary sweeps central region free of gas, dust & stars, truncating accretion disk and reducing X-ray emission





Binary inspiral and coalescence leads to observable gravitational wave signal & localizes the host galaxy

Hermann, Hinder, Laguna, Shoemaker



Gas & dust fall back, "restoring" accretion disk on timescale of ~$7(1+z)(M/10^6 M_\odot)^{1.32}$ yr. *Thermal emission evolution traces accretion disk formation*

Milosavljevic & Phinney

LISA Analysis Challenges

- LIGO: sources weak, rare
- LISA: sources strong, abundant
- $P_{orb} > 10^3$ s wd binaries are so plentiful they can't be individually resolved!
- > 1 yr^{-1} SMBH coalescence with SNR > 100
- Challenges:
  - How well can we separately resolve, characterize so many overlapping sources?
  - Binary waveforms are sinusoidal and any signal can be expressed as a sum over sinusoids: how well can we distinguish an arbitrary source from a collection of binaries?

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Nelemans 2003

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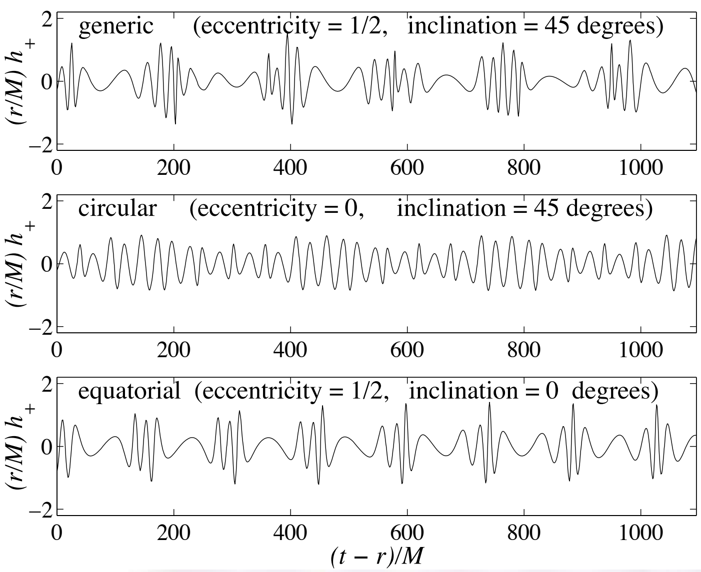
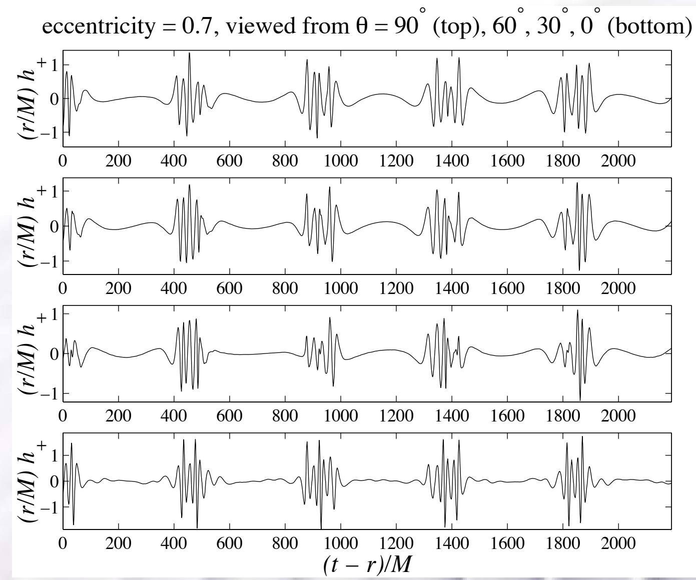
LISA Analysis Challenges

- Model, identify and characterize extreme mass ratio inspirals and bursts



Drasco & Hughes



- Modeling: Radiation reaction, interaction with black hole drives orbital evolution
- Identify, characterize: "matched filtering" impossible/impractical

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Synergy: the interaction or cooperation of two or more agents to produce an effect greater than the sum of their separate effects...

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