LIGO SCIENCE

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LIGO PAC Meeting

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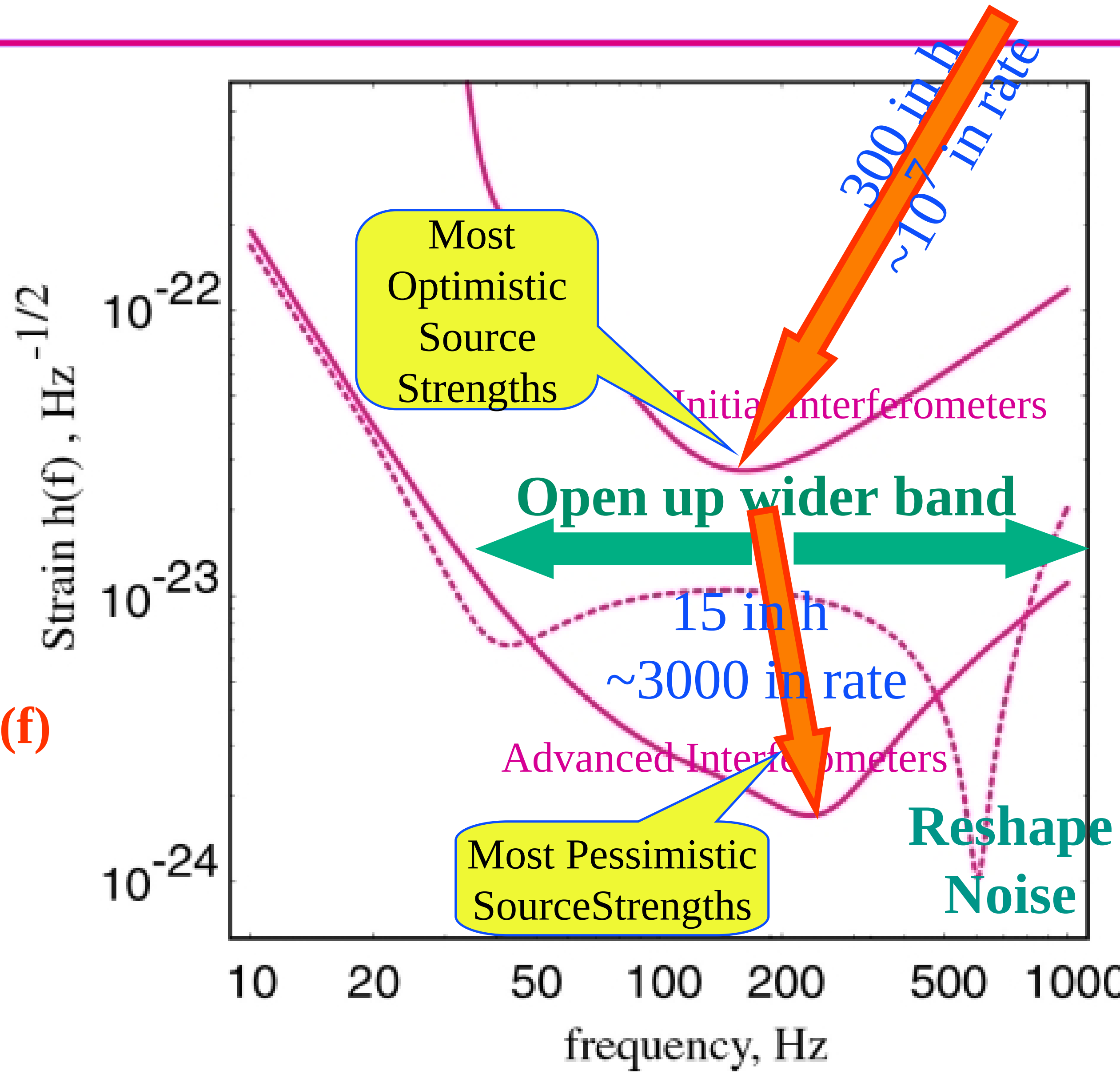
LIGO-G030293-00-R

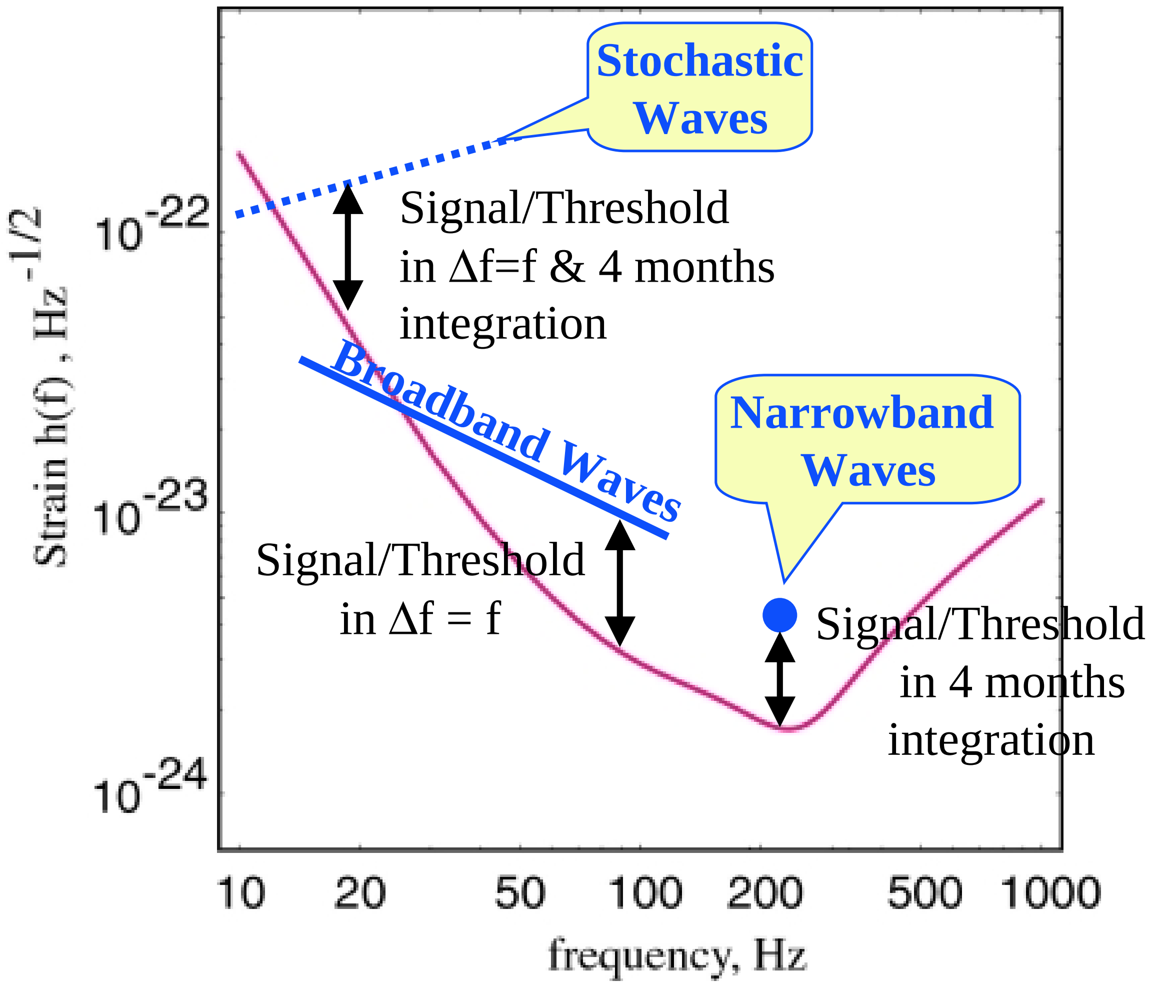
From Initial Interferometers to Advanced



$h_{rms} = h(f) \sqrt{f} \sim 10\ h(f)$

Conventions on Source/Sensitivity Plots

- **Assume the best search algorithm now known**
- **Set Threshold so false alarm probability = 1%**



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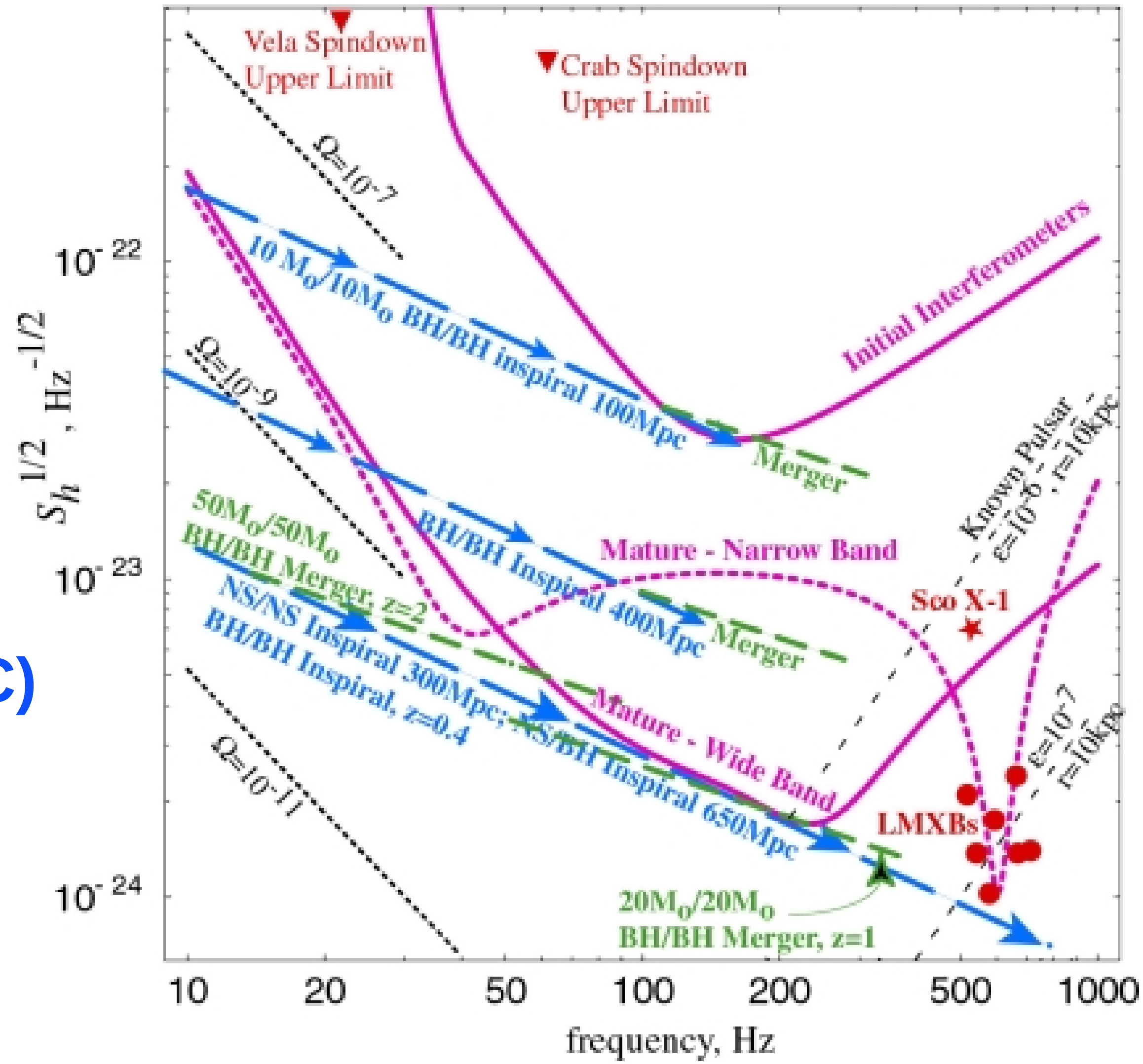
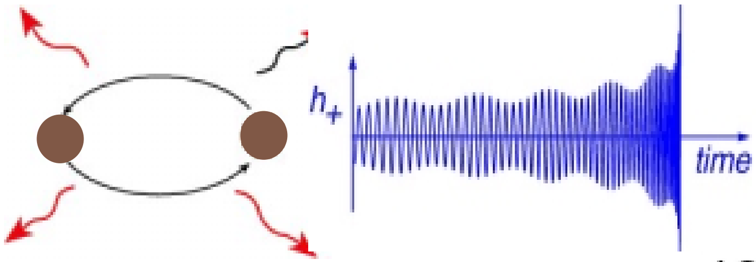
Overview of Sources

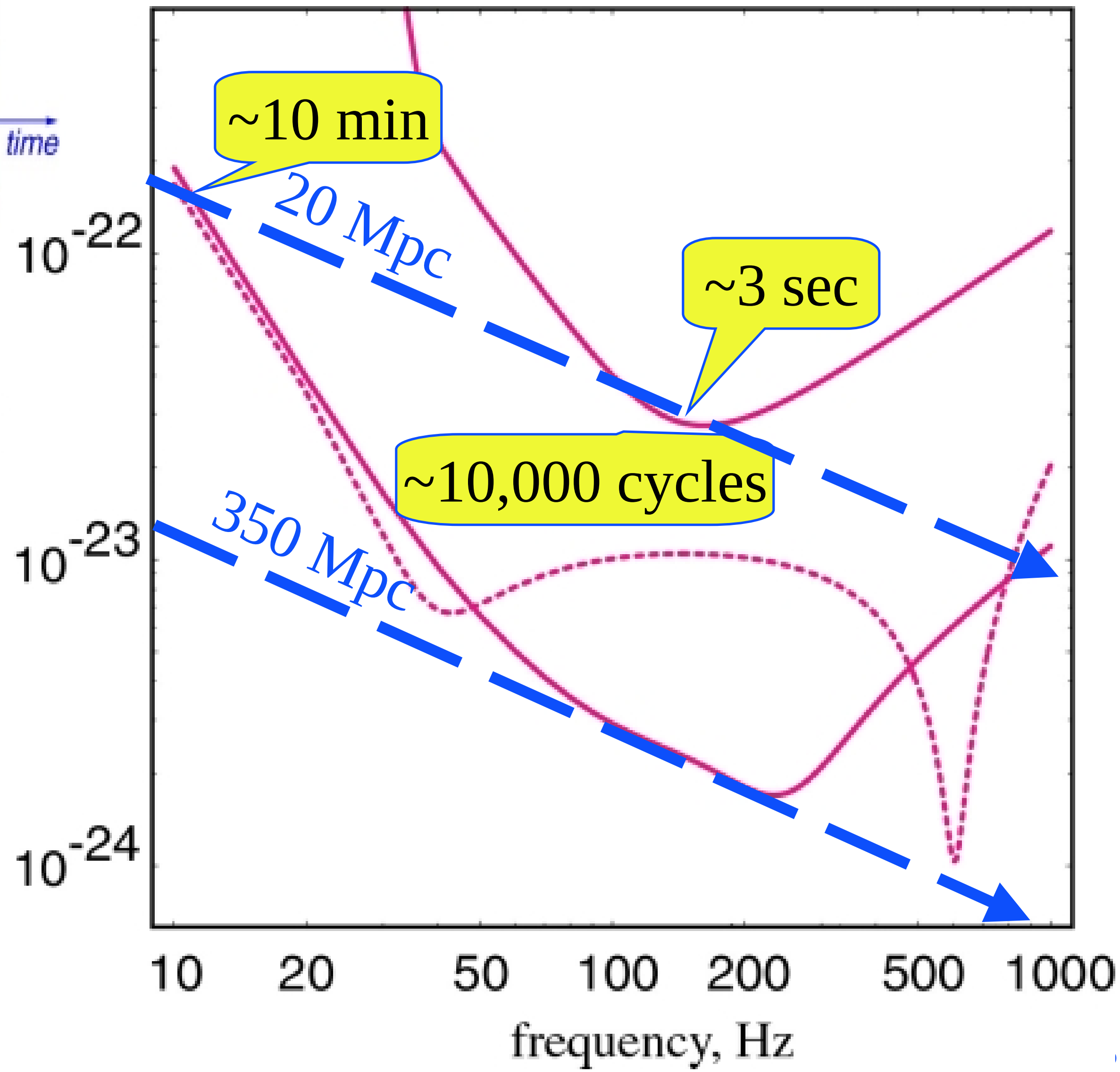
- **Neutron Star & Black Hole Binaries**
  - » inspiral
  - » merger
- **Spinning NS's**
  - » LMXBs
  - » known pulsars
  - » previously unknown
- **NS Birth (SN, AIC)**
  - » tumbling
  - » convection
- **Stochastic background**
  - » big bang
  - » early universe



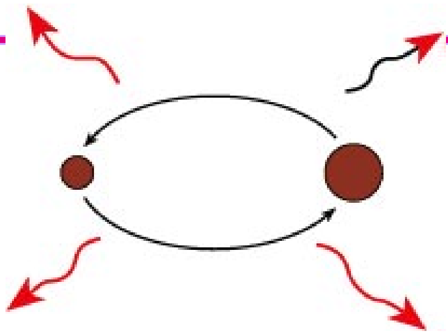
Neutron Star / Neutron Star Inspiral
(our most reliably understood source)

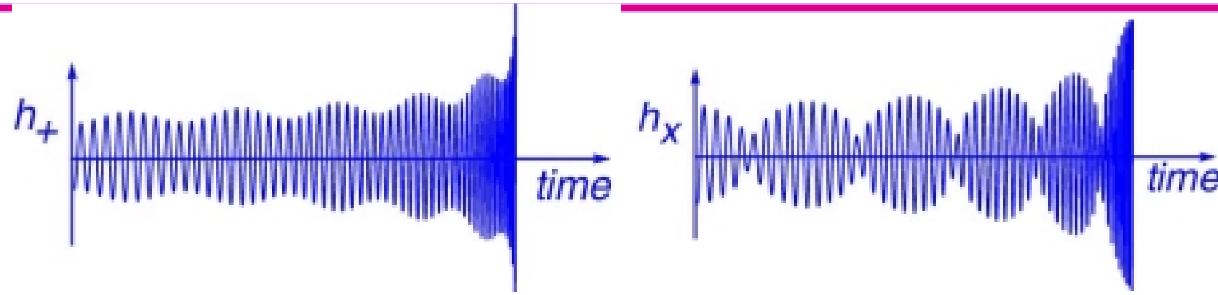


- **1.4 Msun / 1.4 Msun NS/NS Binaries**
- **Event rates**
  - » V. Kalogera, R. Narayan, D. Spergel, J.H. Taylor astro-ph/0012038; …
- **Initial IFOs**
  - » Range: 20 Mpc
  - » 1 / 3000 yrs to **1 / 3yrs**
- **Advanced IFOs -**
  - » Range: 350Mpc
  - » **3 / yr to 4 / day**

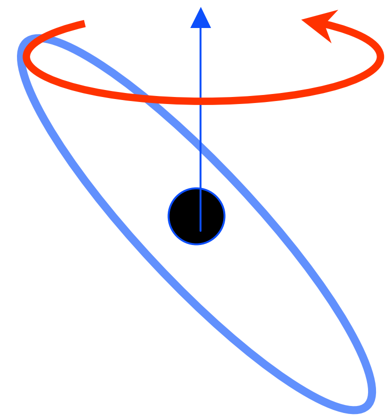


Science From Observed Inspirals: NS/NS, NS/BH, BH/BH



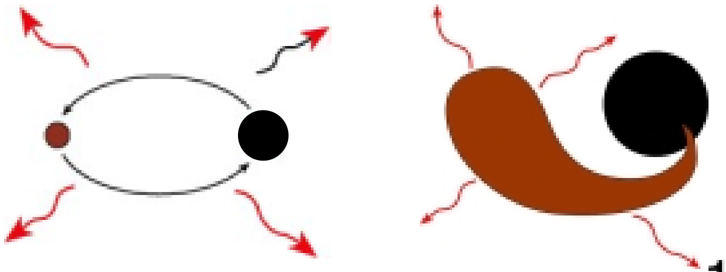


- Relativistic effects are very strong -- e.g.
  - » ***Frame dragging by spins ➔ precession ➔ modulation***
  - » ***Tails of waves modify the inspiral rate***

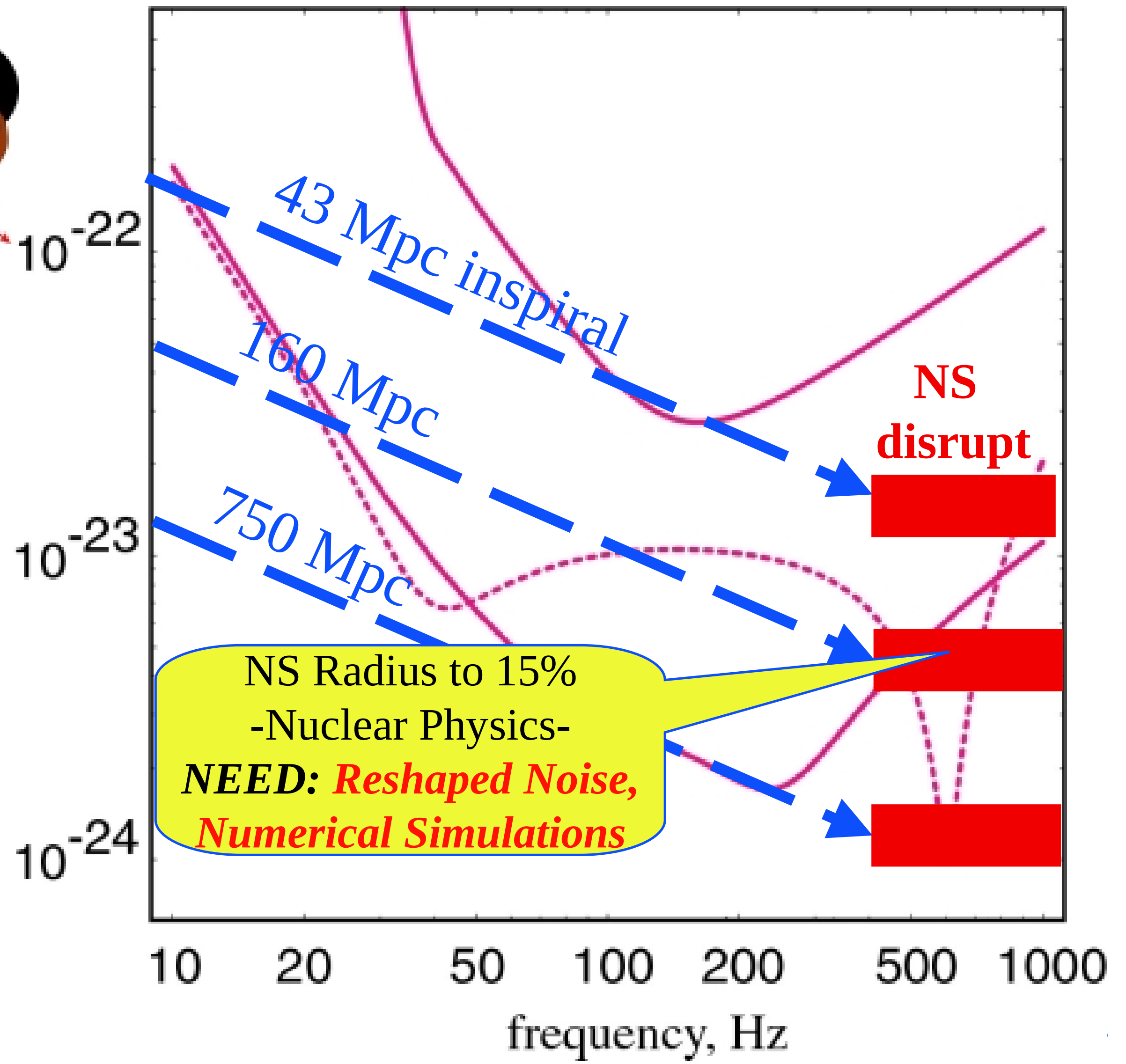


- Information carried:
  - » ***Masses (a few %), Spins (?few%?), Distance [not redshift!] (~10%), Location on sky (~1 degree)***
    - – $M_{\mathbf{chirp}} = \mu^{\mathbf{3/5}} M^{\mathbf{2/5}}$ to $\sim 10^{\mathbf{-3}}$
- Search for EM counterpart, e.g. γ-burst. If found:
  - » ***Learn the nature of the trigger for that γ-burst***
  - » ***deduce relative speed of light and gw's to ~ 1 sec / 3x10^9 yrs ~ 10^{-17}***

Neutron Star / Black Hole Inspiral and NS Tidal Disruption

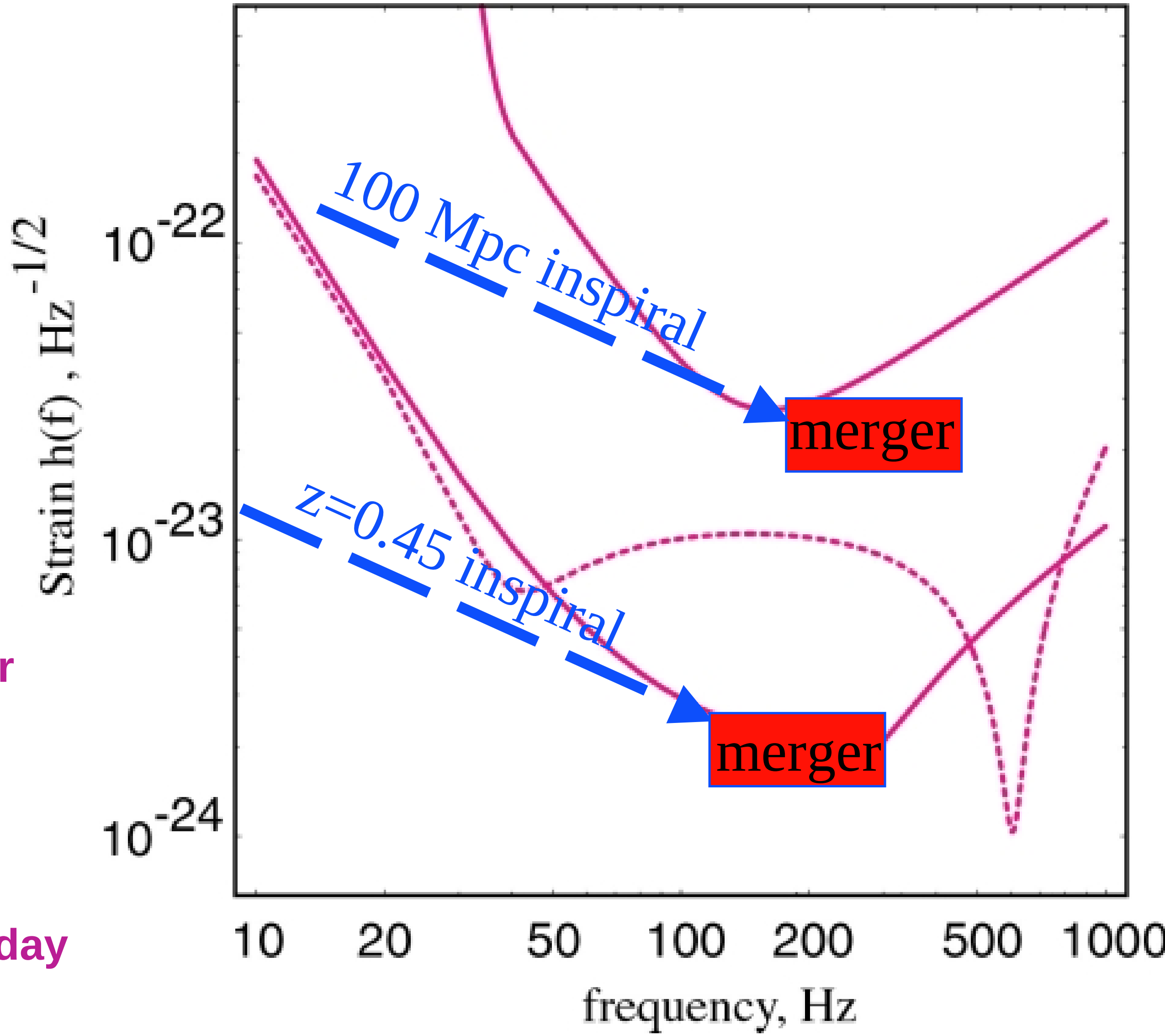


- **1.4Msun / 10 Msun NS/BH Binaries**
- **Event rates**
  - » Population Synthesis [Kalogera's summary]
- **Initial IFOs**
  - » Range: 43 Mpc
  - » 1 / 2500 yrs to **1 / 2yrs**
- **Advanced IFOs**
  - » Range: 750 Mpc
  - » **1 / yr to 6 / day**

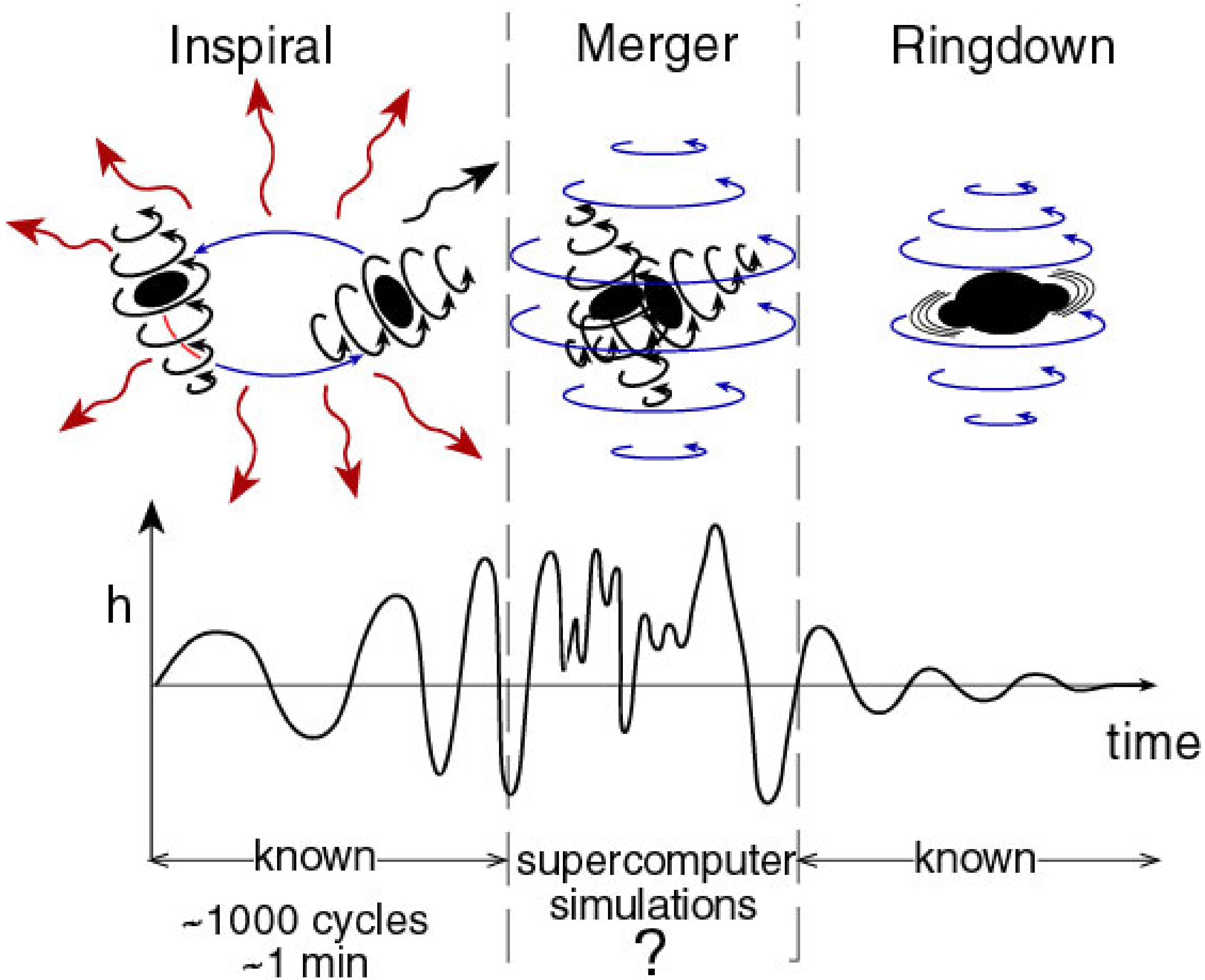


Black Hole / Black Hole Inspiral and Merger

- **10Msun / 10 Msun BH/BH Binaries**
- **Event rates**
  - » Based on population synthesis [Kalogera's summary of literature]
- **Initial IFOs**
  - » Range: 100 Mpc
  - » ≲1 / 600yrs to **~3 / yr**
- **Advanced IFOs -**
  - » Range: z=0.45
  - » **≲1/ month to ~30 / day**



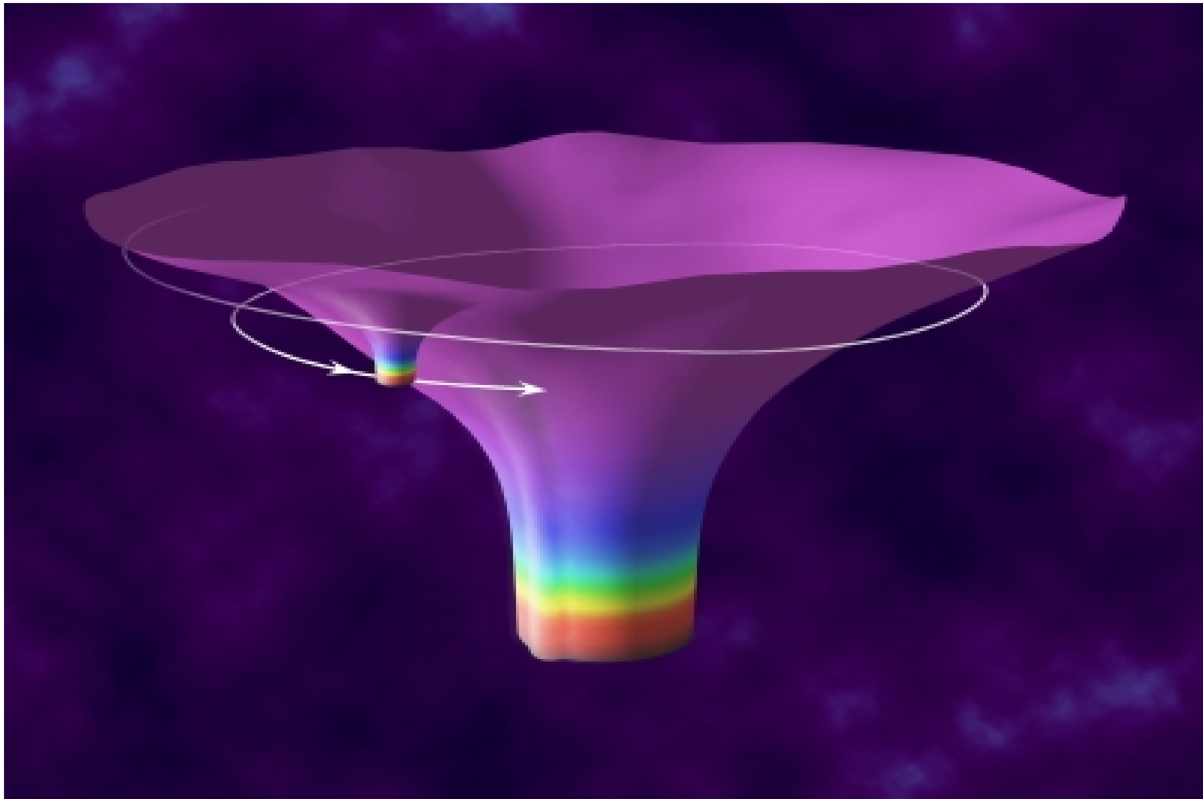
BH/BH Mergers: Exploring the Dynamics of Spacetime Warpage



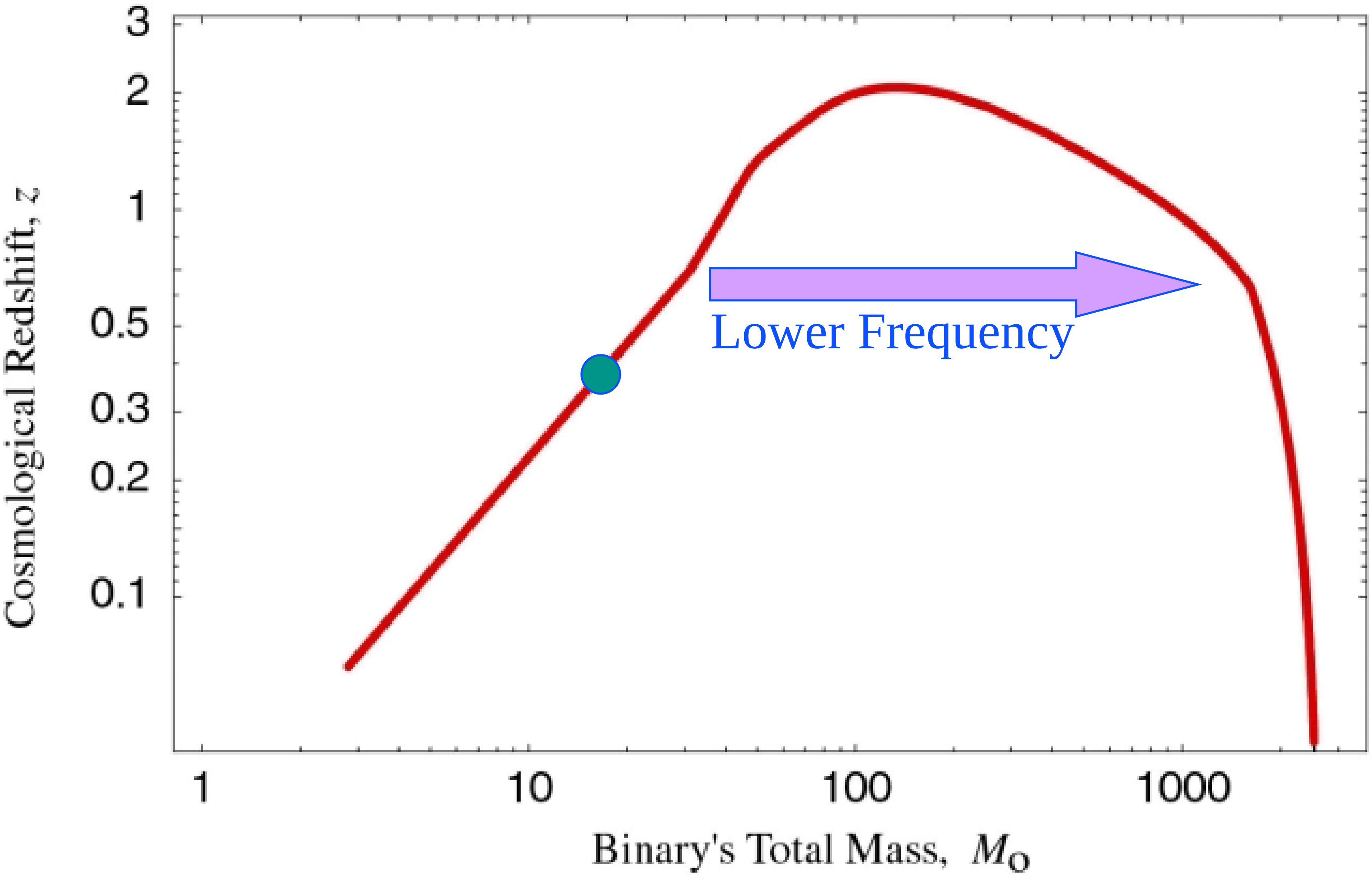
Numerical Relativity Simulations Are Badly Needed!

Mapping Black Hole's Curvature & Probing Its Horizon

- **BH captures in globular clusters ➔ intermediate-mass BH: 100 - 1000 Msun** [Cole Miller]
- **Inspiral of ~ 1 Msun NS or few Msun BH into ~1000 Msun BH ➔ first cut at one of LISA's prime goals:**
  - » Map of big hole's spacetime curvature
  - » Probe of big hole's horizon

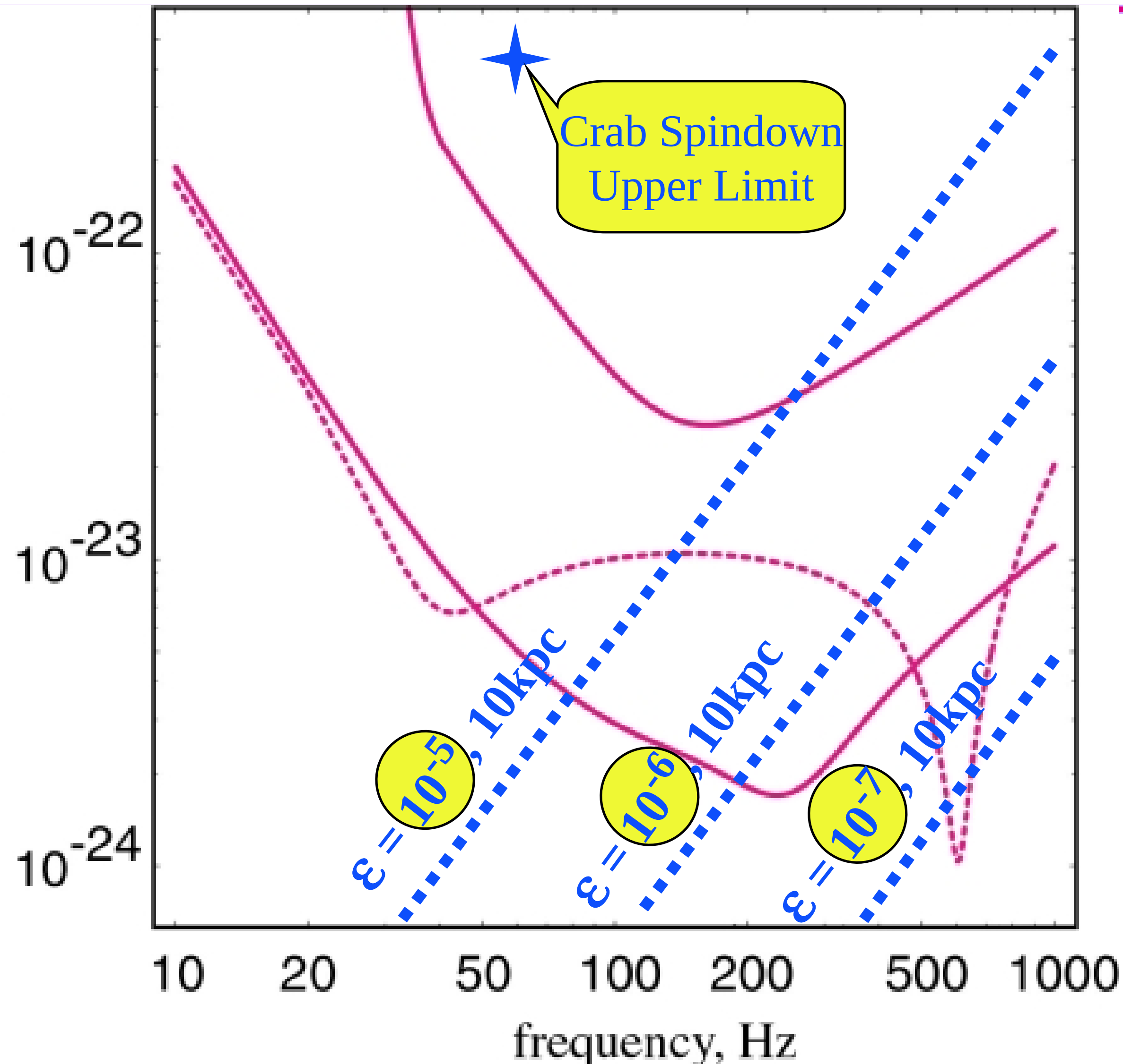


Massive BH/BH Mergers with Fast Spins - Advanced IFOs



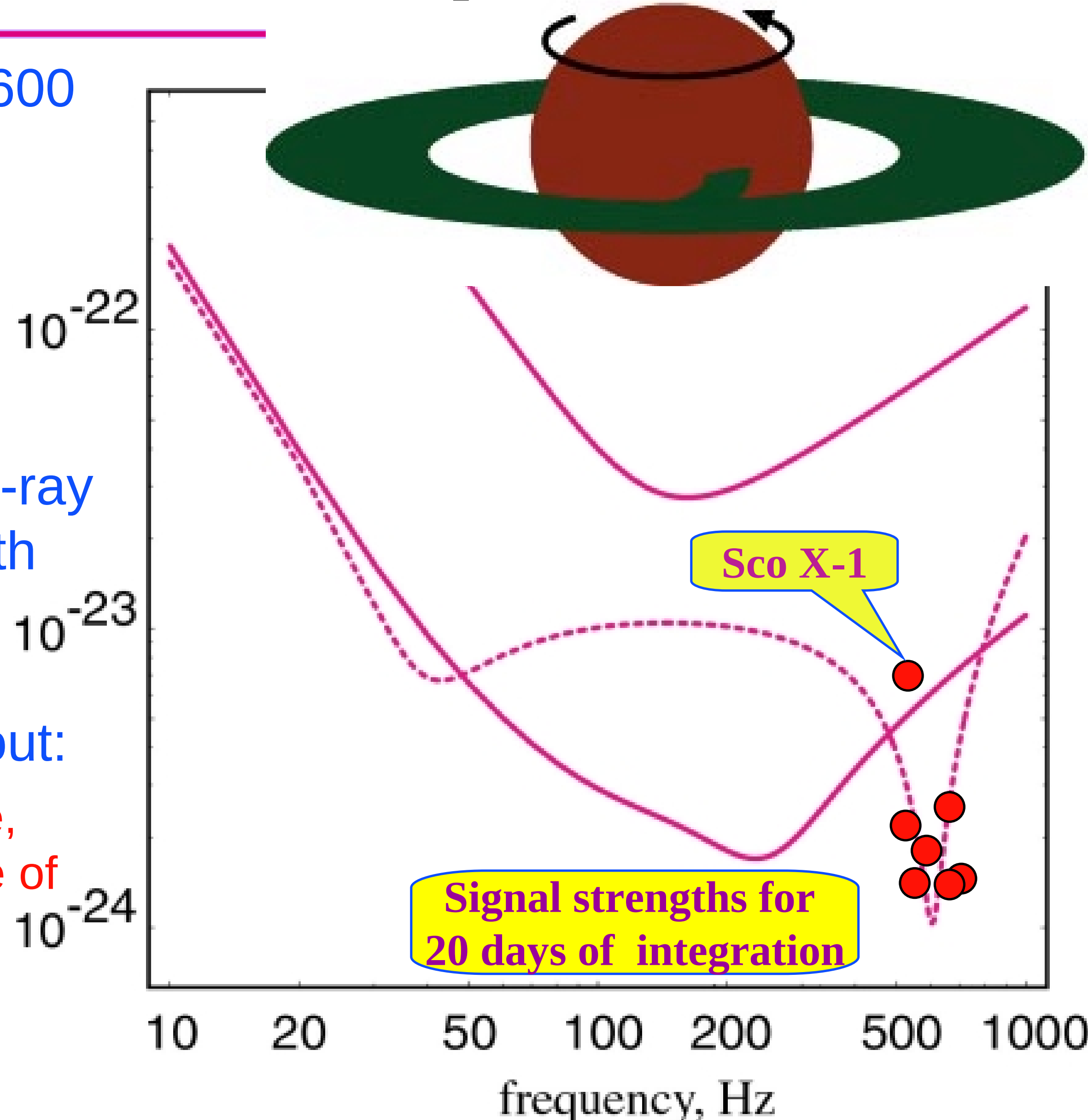
Spinning NS's: Pulsars

- NS Ellipticity:
  - » Crust strength
    $\varepsilon \lesssim 10^{-5}$
- Known Pulsars:
  - » First Interferometers:
    $\varepsilon \gtrsim 3\times10^{-6}$ (1000Hz/f) x (distance/10kpc)
  - » Narrowband Advanced
    $\varepsilon \gtrsim 2\times10^{-8}$ $(1000Hz/f)^2$ x (distance/10kpc)
- Unknown NS's - All sky search:
  - » Sensitivity ~5 to 15 worse



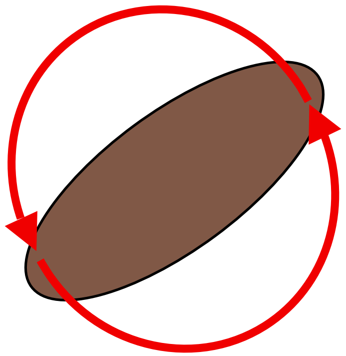
Spinning Neutron Stars: Low-Mass X-Ray Binaries

- Rotation rates ~250 to ~600 revolutions / sec
  - » Why not faster?
  - » **Bildsten**: Spin-up torque balanced by GW emission torque
- If so, and steady state: X-ray luminosity ➔ GW strength
- Combined GW & EM obs's ➔ information about:
  - » crust strength & structure, temperature dependence of viscosity, ...

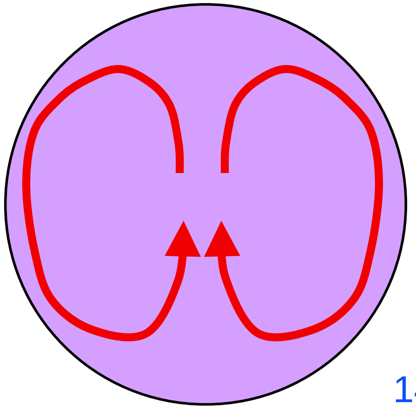


NS Birth: Tumbling Bar; Convection

- **Born in:**
  - » Supernovae
  - » Accretion-Induced Collapse of White Dwarf
- **If very fast spin:**
  - » Centrifugal hangup
  - » **Tumbling bar** - episodic? (for a few sec or min)
  - » ***If modeling gives enough waveform information,*** detectable to:
    - – Initial IFOs: ~5Mpc (M81 group, ~1 supernova/3yr)
    - – Advanced IFOs: ~100Mpc (~500 supernovae/yr)

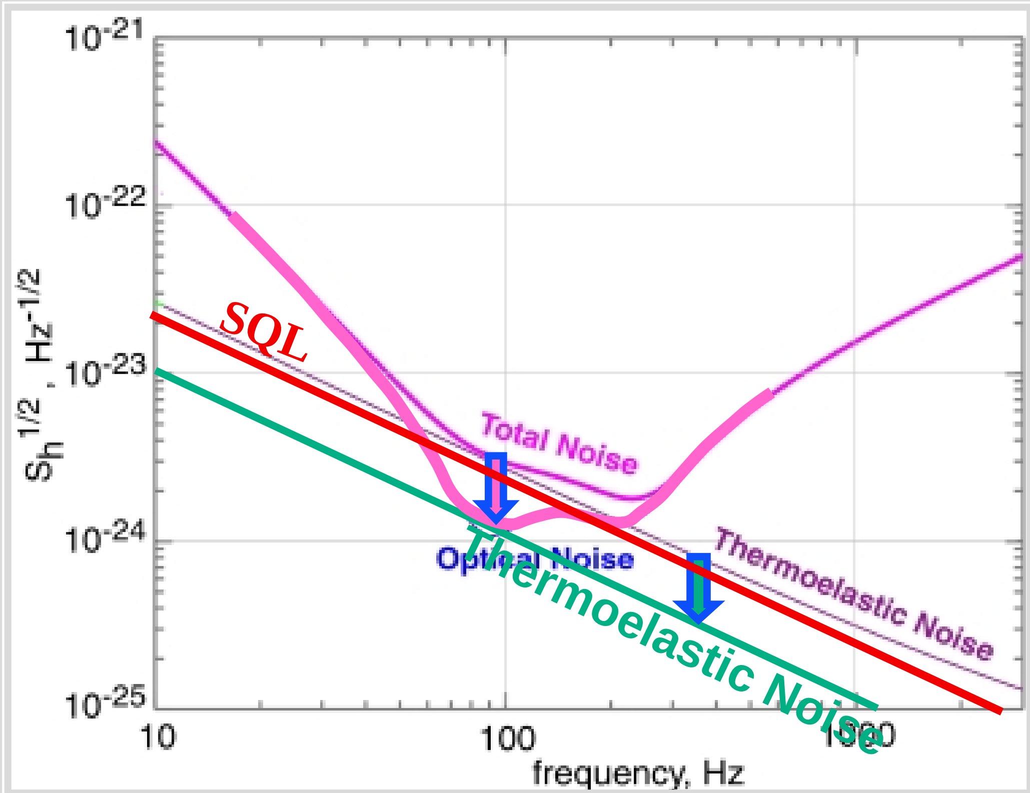


- **If slow spin:**
  - » **Convection** in first ~1 sec.
  - » Advanced IFOs: Detectable only in our Galaxy (~1/30yrs)
  - » GW / neutrino correlations!



Some Payoffs from Later Incremental Upgrades

- **Monitoring & removing Newtonian grav'l noise**
  » Increase by factor 1.75 the mass of most massive intermediate black holes that can be studied
- **Replace Gaussian beams by top-hat beams in IFO arms**
  » Increase event rate for NS/NS, NS/BH, BH/BH by factor 3
  » Beat Standard Quantum Limit (circumvent Heisenberg Uncertainty Principle for 40 kg "particles")

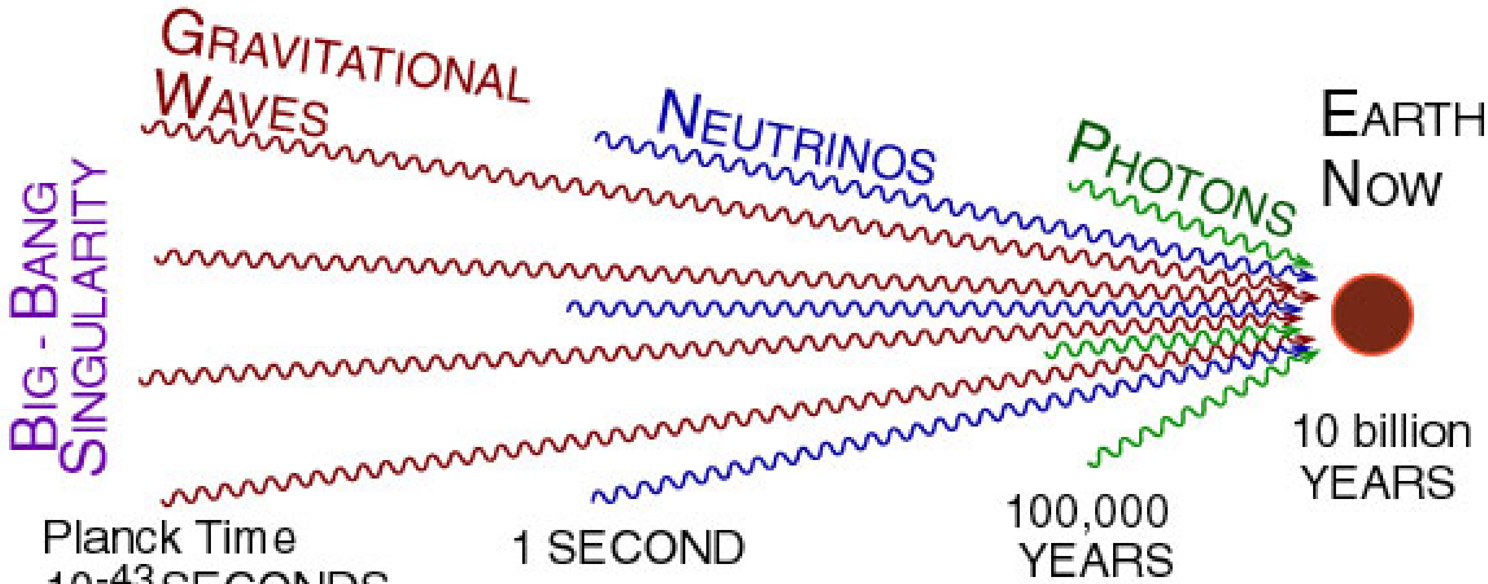


Some Payoffs from Later Incremental Upgrades

- **Insert squeezed vacuum into dark port**
  - » Reduce laser power, for given sensitivity, by up to factor 10
  - » Improve sensitivity in wide-band mode at frequencies ~300 to 1500 Hz by factor 2 or more
- **Variable transmission SR mirror**
  - » Improve sensitivity in searches for spinning neutron stars at frequencies ~ 300 to 1500 Hz by factor ~ 2
  - » Improve sensitivity for studies of NS tidal disruption by BH's

Stochastic Background from Very Early Universe

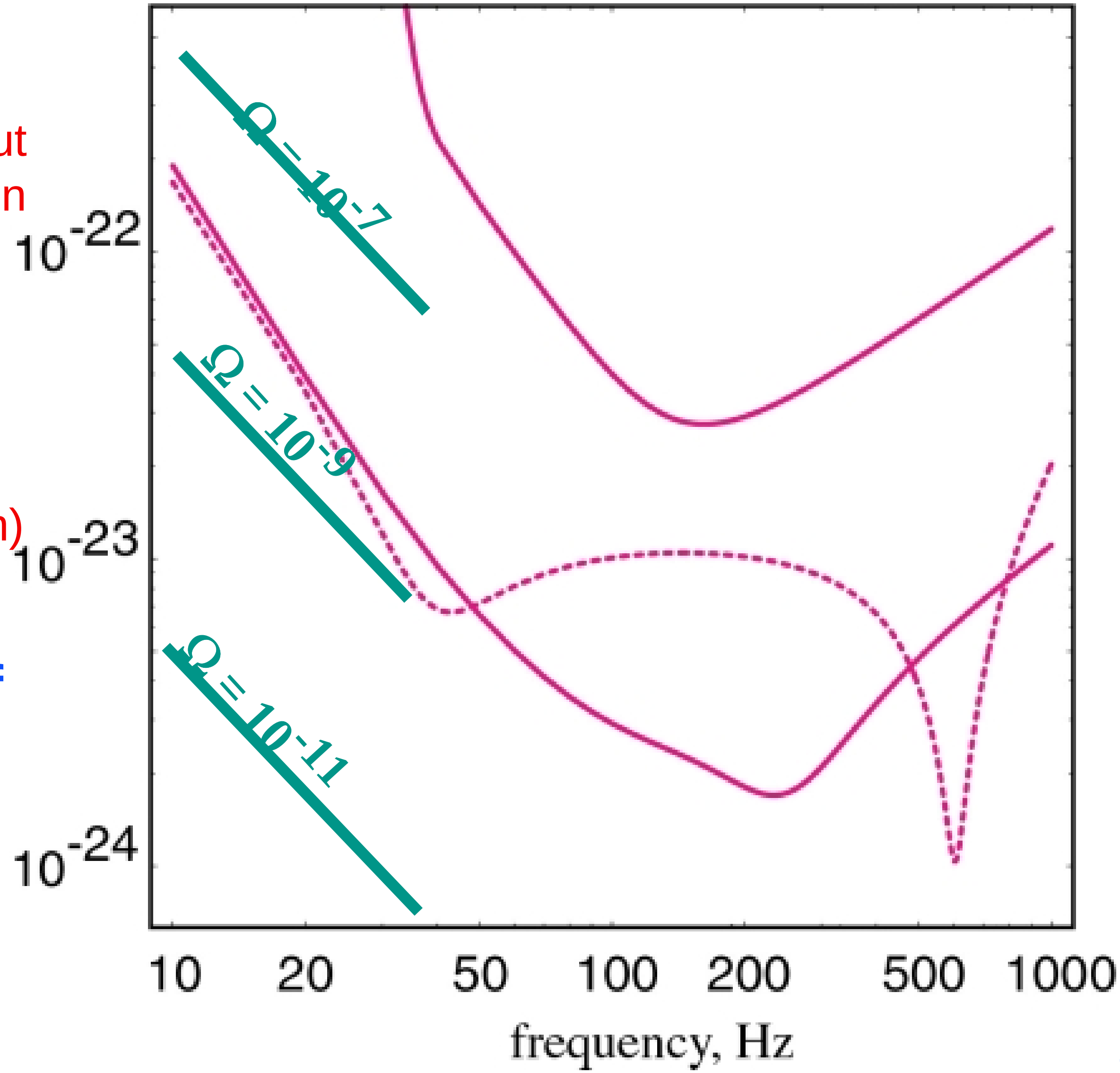
- **GW's are the ideal tool for probing the very early universe**



- **Present limit on GWs**
  - » From effect on primordial nucleosynthesis
  - » Ω = (GW energy density)/(closure density) $\lesssim \mathbf{10^{-5}}$

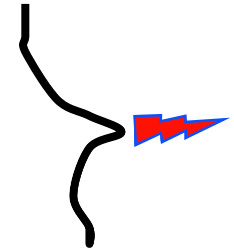
Stochastic Background from Very Early Universe

- **Detect by**
  - » cross correlating output of Hanford & Livingston 4km IFOs
- **Good sensitivity requires**
  - » (GW wavelength) $\gtrsim$ **2x**(detector separation)
  - » f $\lesssim$ 40 Hz
- **Initial IFOs detect if**
  - » $\Omega \gtrsim 10^{-5}$
- **Advanced IFOs:**
  - » $\Omega \gtrsim 5\times10^{-9}$



Grav'l Waves from Very Early Universe. ***Unknown Sources***

- Waves from standard inflation: $\Omega \sim 10^{-15}$: much too weak
- ***BUT:*** Crude superstring models of big bang suggest waves ***might be strong enough*** for detection by Advanced IFOs



- GW bursts from cosmic strings: possibly detectable by Initial IFOs
- Energetic processes at (universe age) ~ 10^{-25} sec and (universe temperature) ~ 10^{9} Gev ♏ GWs in LIGO band
  - » **phase transition at 10^{9} Gev**
  - » **excitations of our universe as a 3-dimensional "brane" (membrane) in higher dimensions:**
    - **Brane forms wrinkled**

    - **When wrinkles "come inside the cosmological horizon", they start to oscillate; oscillation energy goes into gravitational waves**
    - **LIGO probes waves from wrinkles of length ~ 10^{-10} to 10^{-13} mm**
    - **If wave energy equilibrates: possibly detectable by initial IFOs**
- Example of hitherto ***UNKNOWN SOURCE***

Conclusions

- **LIGO's Initial Interferometers bring us into the realm where it is plausible to begin detecting cosmic gravitational waves.**
- **With LIGO's Advanced Interferometers we can be confident of:**
  - » detecting waves from a variety of sources
  - » gaining major new insights into the universe, and into the nature and dynamics of spacetime curvature, that cannot be obtained in any other way