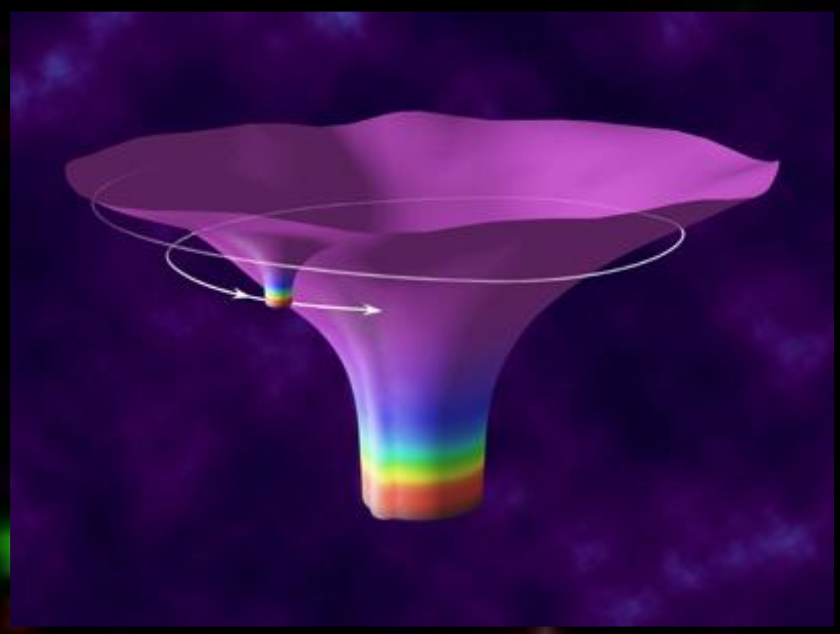
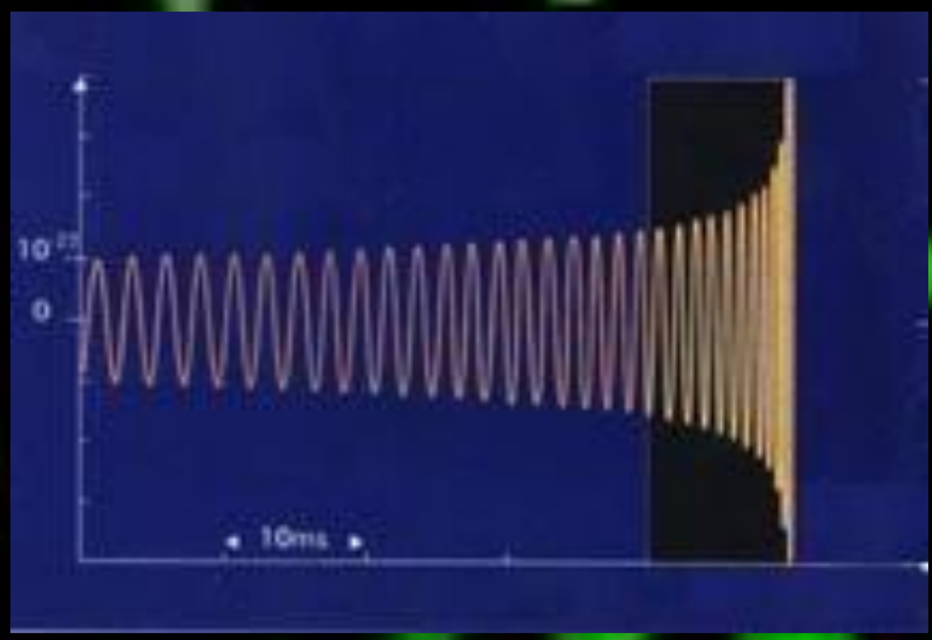
Gravitational Waves research @ IUCAA

Inspiralling Binaries

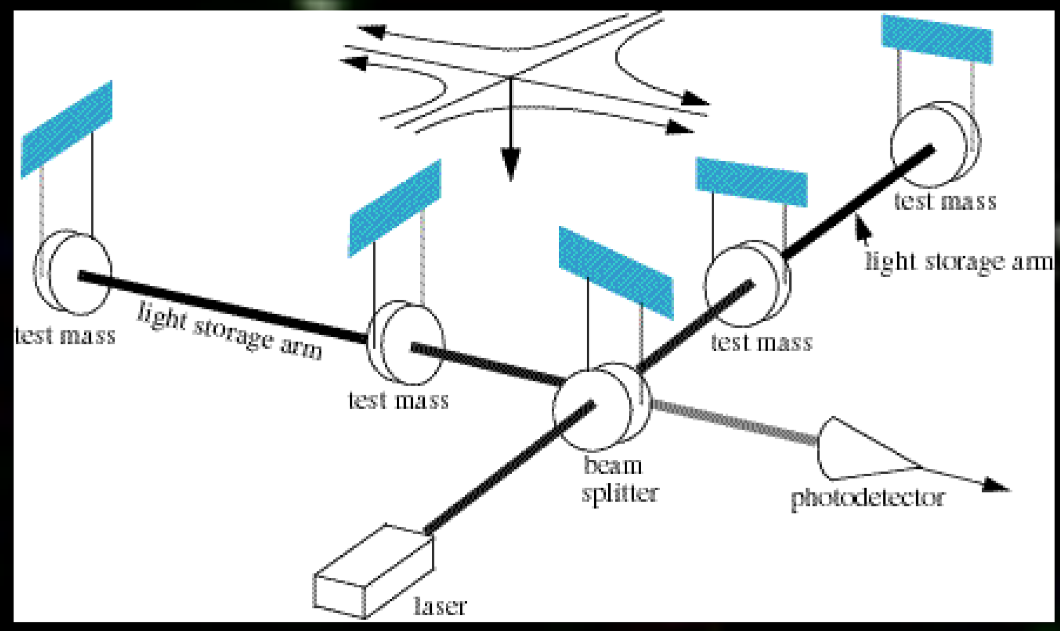
Near the end stages of their life massive compact binaries emit "strong" gravitational waves in the sensitive frequency range of the GW detectors like LIGO and LISA. Coalescing compact binaries are most promising sources of GW and detecting them is probably the most important challenge in current physics research.



Gravitational wave source



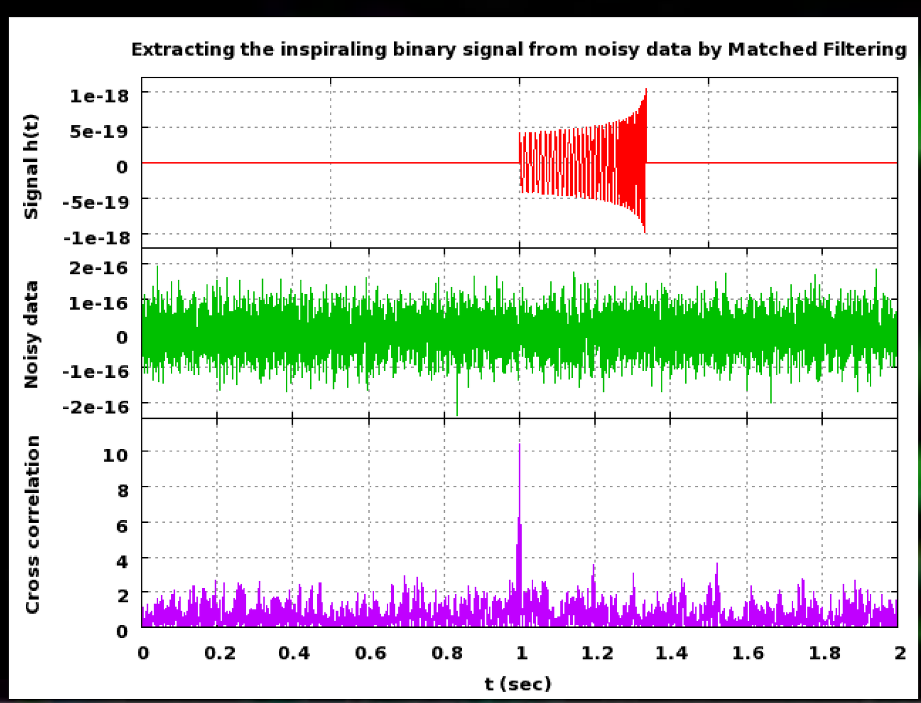
Chirp signal



Gravitational wave detector

Matched Filtering

- ❑ Chirp waveforms can be well modeled
- ❑ A model signal "h(t)", called a **Template** in figure, is cross-correlated with the data "s(t)" obtained from the instrument.
- ❑ If signal parameters are very close to the template parameters , correlation "X-Corr" is enhanced
- ❑ If it crosses certain threshold, one can claim detection of a GW source characterized by the above parameters.

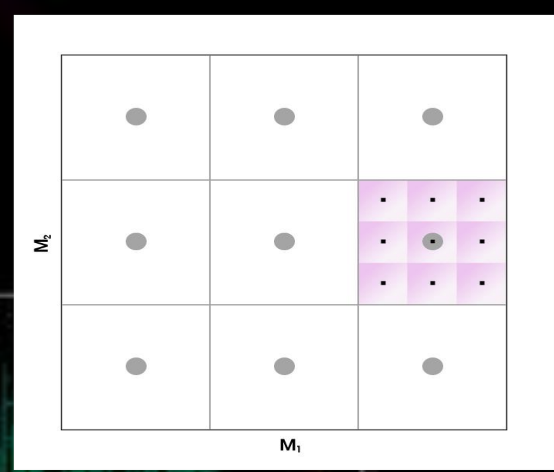


Both amplitude and frequency of GW signals emitted by inspiralling compact binaries increase with time and hence these waveforms are called **Chirps**.

Detection of gravitational waves largely depends on how well we can model the chirps. This is because signal is embedded in comparatively stronger noise and **matched filtering** techniques are needed to extract it.

Hierarchical Search @ IUCAA

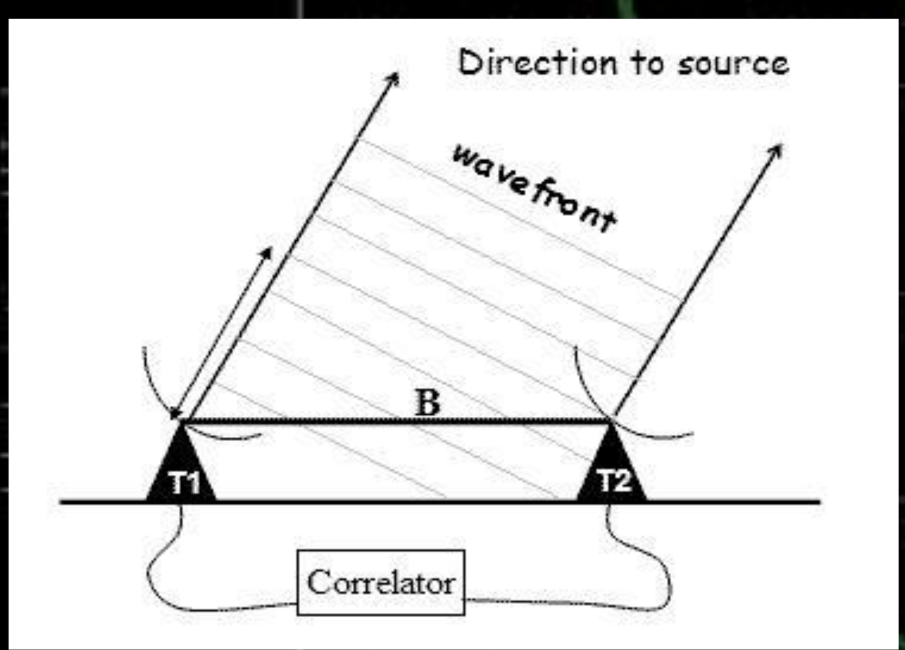
- ❑ Parameter space is divided into templates.
- ❑ First stage – signal is searched in a coarse template bank with a lower threshold.
- ❑ Subsequent stages - the region around the clicked template (if exists) is searched with higher threshold and finer template bank.

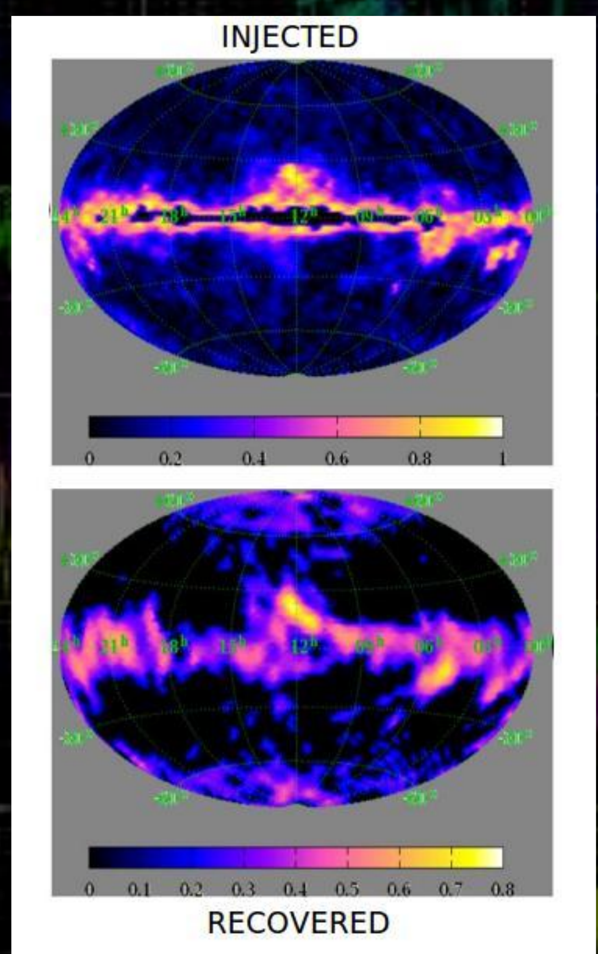


Brute force search can be computationally **expensive**, as millions of templates must be searched over.

Gravitational wave Radiometry

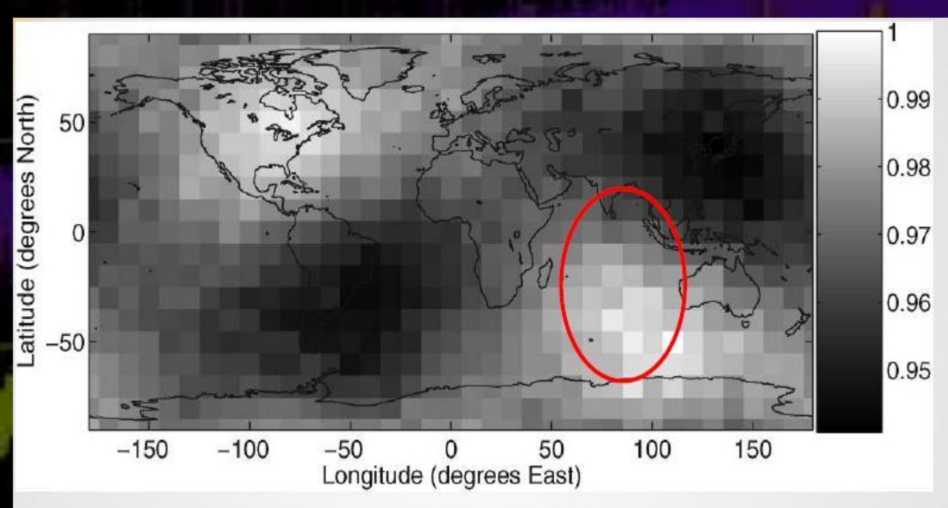
- ❑ Similar to radio interferometry
- ❑ Interference between signals received at spatially separated detectors
- ❑ Higher resolution
- ❑ Lower cost





Search with a network of detectors

Optimum location of new detector in Australia (LIGO Australia) given the current network of detectors.
Indian participation through INDIGO consortium.



- Enhanced sensitivity
- Better resolution
- Polarization information

Space based telescopes

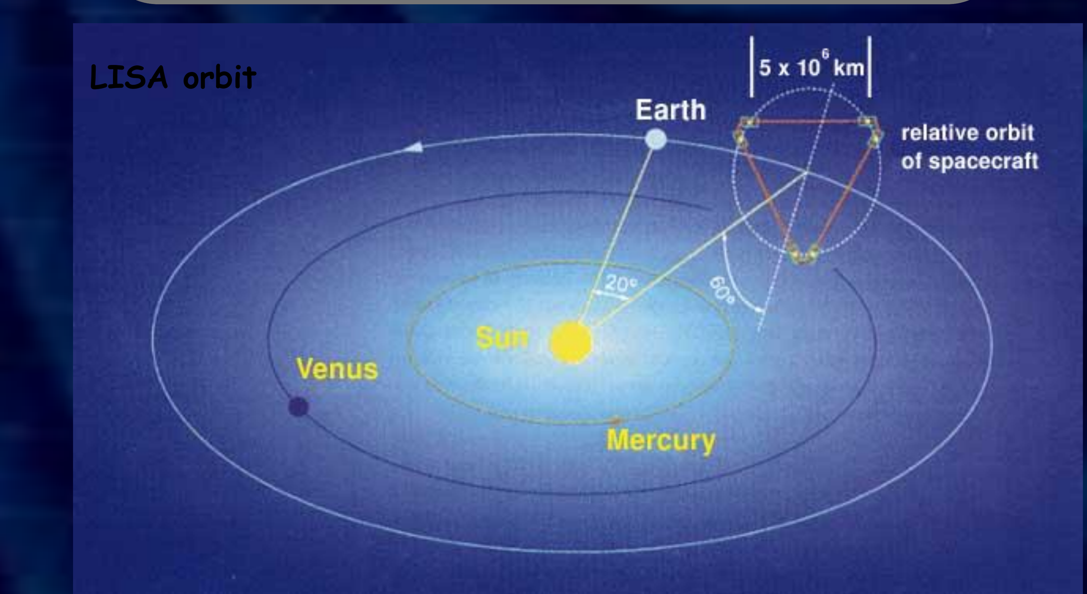
Stability of LISA spacecraft configuration

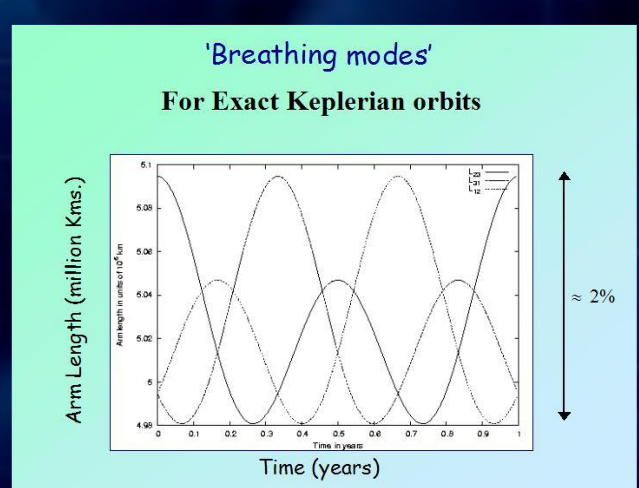
The Laser Interferometric Space Antenna (LISA)

- ❑ Three spacecraft forming a equilateral triangle.
- ❑ Triangle follows the earth's orbit with a 20^o phase lag with respect to the earth.
- ❑ Each of the space crafts exchanges LASER beams with the other two.
- ❑ Can be used as 3 independent interferometers

IUCAA scientists have **analytically** shown that, to the first order in eccentricity **any** configuration formed by **any** number of spacecraft can be stable, provided **all** of them lie on a plane at an angle 60^o with the ecliptic.

Furthermore, the analysis of the general exact Keplerian orbit equations (without external perturbations) shows that, the distance between any two points on the LISA plane steadily oscillates about their mean distance causing a less than 2% fractional distance fluctuation.





Reduction of LASER frequency noise in LISA

Canceling the LASER frequency noise is crucial for attaining the goal sensitivity for LISA. This noise is 7-8 orders of magnitude above other noise sources. A scheme based on abstract algebra is given which suppresses this noise.

GW detectors are essentially Michelson Interferometers. If $\Phi_1(t)$ and $\Phi_2(t)$ are two data streams received from two arms of lengths L_1 and L_2 respectively, then

$\Phi_1(t) = \Phi(t-2L_1/c) - \Phi(t)$

$\Phi_2(t) = \Phi(t-2L_2/c) - \Phi(t)$.

If we combine the data streams as:

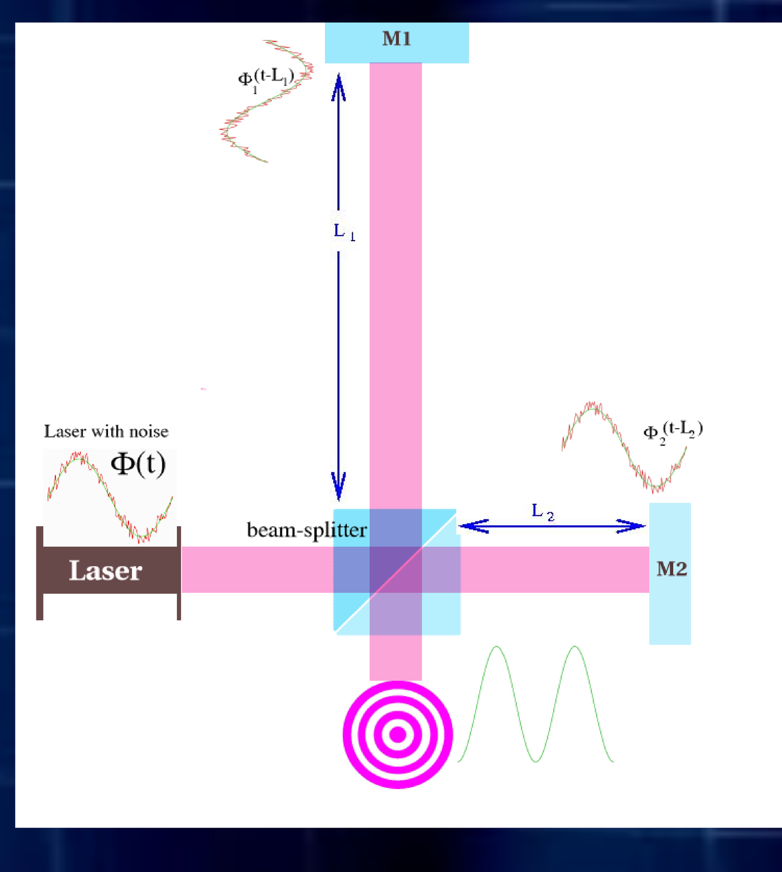
$X(t) = \Phi_2(t) - \Phi_1(t)$,

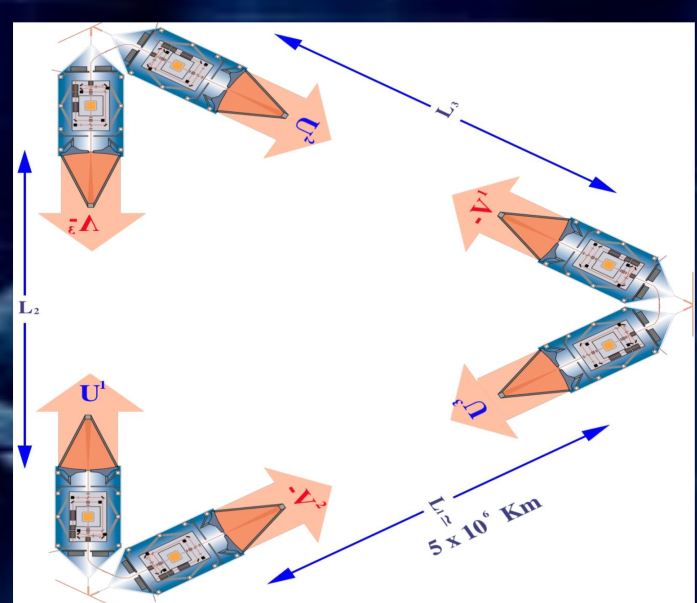
noise is cancelled only if arms are equal.

For unequal arms (as shown in the figure) a combination

$Y(t) = [\Phi_1(t-2L_2/c) - \Phi_1(t)] - [\Phi_2(t-2L_1/c) - \Phi_2(t)]$

cancels the LASER frequency noise.





However, LISA is much more complicated as it generates 6 data trains and one must use abstract algebra of rings and modules to construct data combination that will cancel LASER frequency noise.