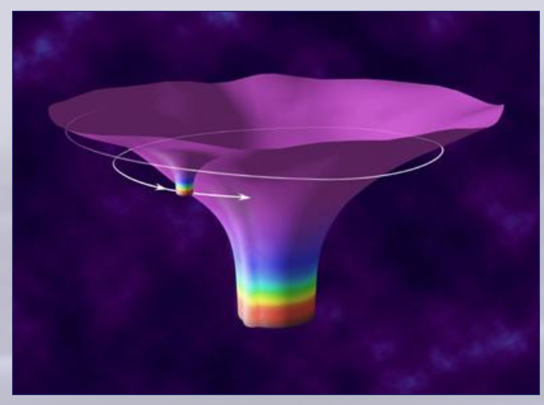
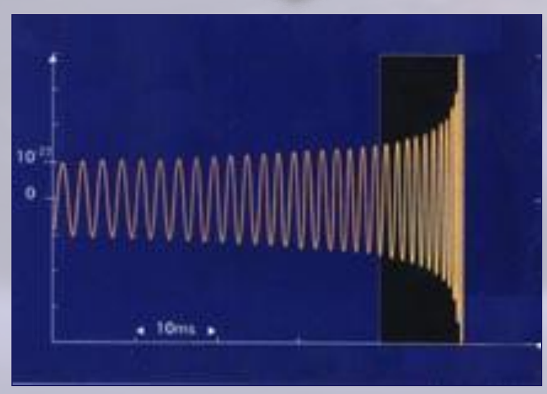
# Gravitational Waves Research @ IUCAA

## Inspiralling Binaries

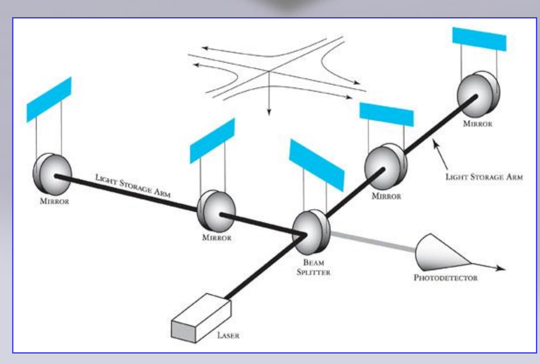
Near the end stages of their life, massive inspiralling compact binary stars emit "strong" gravitational waves (GW) in the sensitive frequency range of gravitational wave detectors like LIGO and LISA. Coalescing compact binaries are the most promising sources of GW and detecting them is probably the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

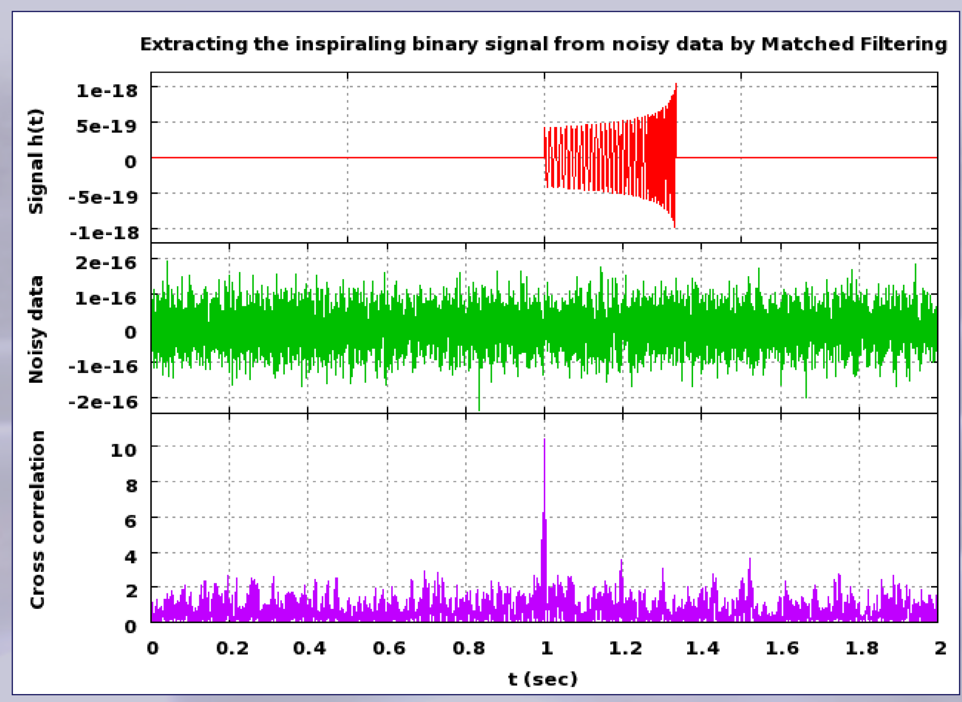


Both amplitude and frequency of GW signals emitted by inspiralling compact binaries increase with time and hence these waveforms are called **Chirp**s.



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.



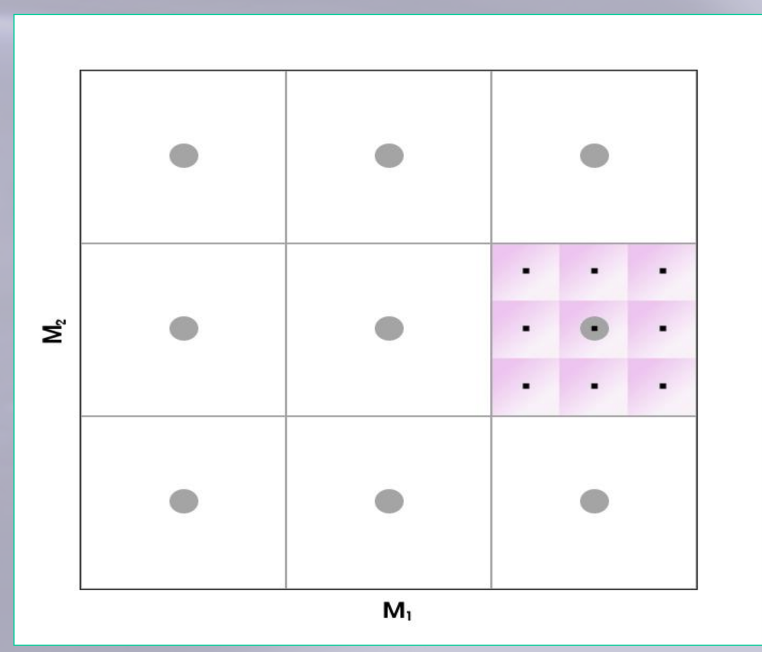



## Matched Filtering

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

## Hierarchical Search @ IUCAA

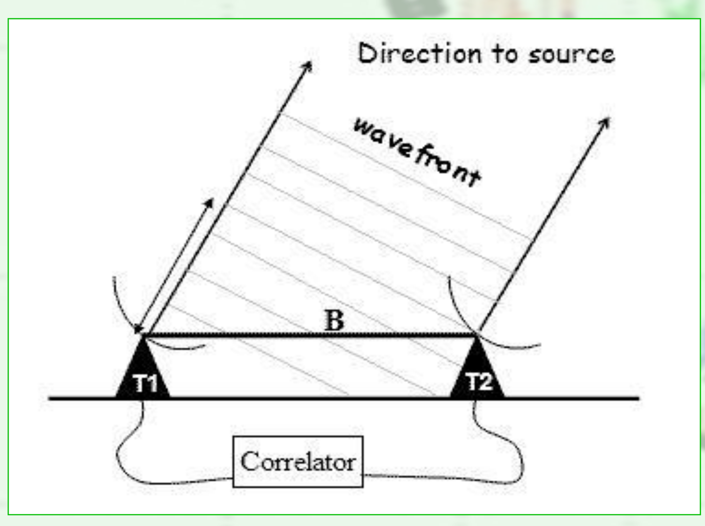
✓ Parameter space is divided into templates.
✓First stage – signal is searched in a coarse template bank with a lower threshold.
✓Subsequent **stages - the region around the clicked template (if exists) is searched with higher threshold and** finer template bank.

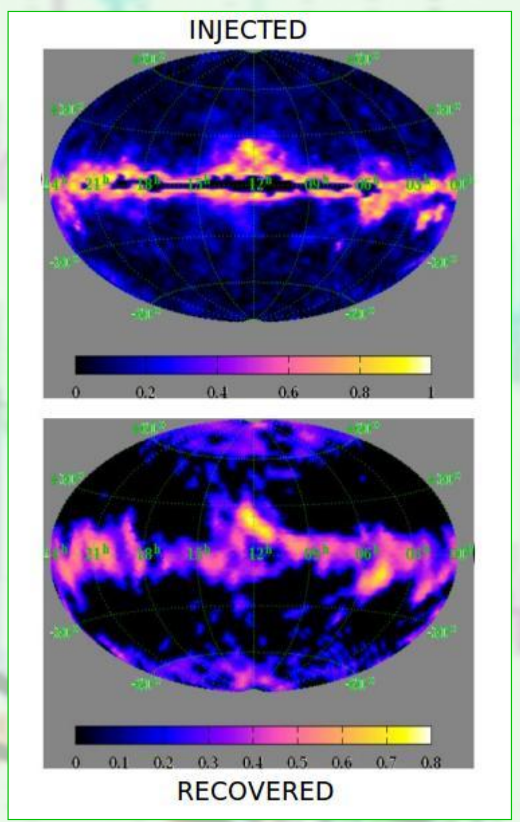



Brute force search can be computationally **expensive**, as millions of templates must be searched over.

## Gravitational wave Radiometry

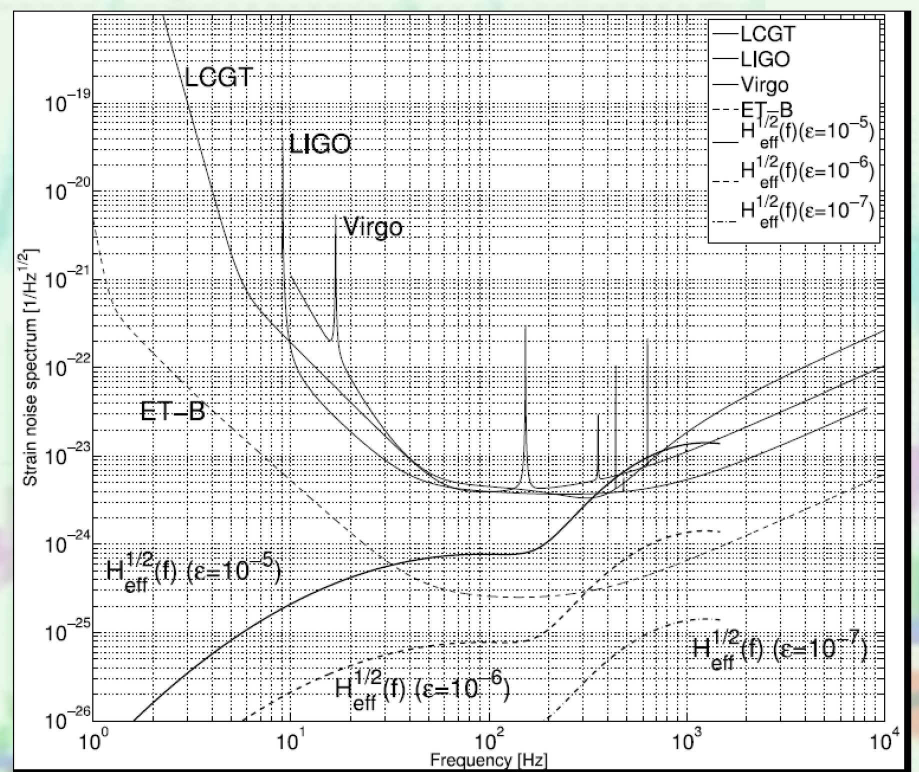
✓ Similar to radio interferometry
✓ Cross-correlate data from detectors with appropriate phase delay to account for the light travel time delay between sites
✓ Higher resolution



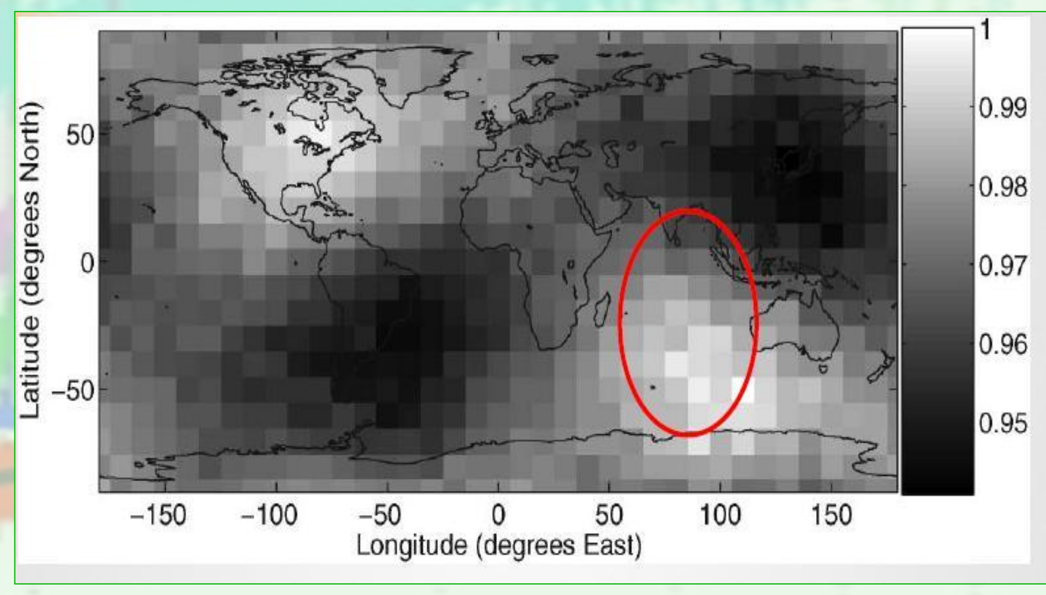

## Potential Astrophysical Stochastic Sources

A forest of pulsar GW emission lines can form a stochastic background if the pulsars have significant mass asymmetry (~10^-6). These sources may be detectable by the advanced detectors. These signals carry information on the statistical properties of these interesting astrophysical objects.




## Constructing and using a network of GW detectors

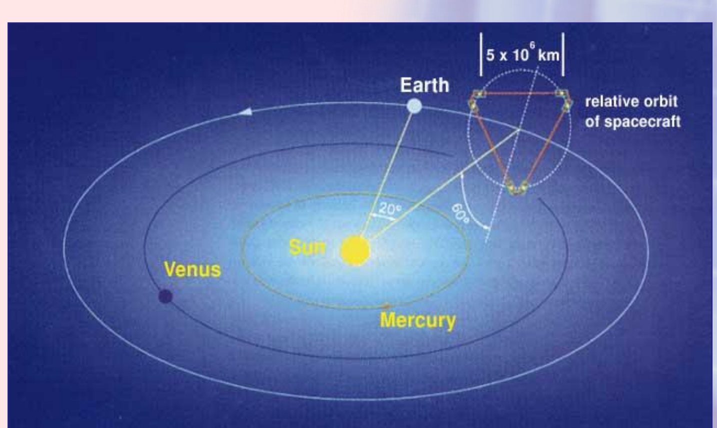
A GW detector somewhere around the Indian ocean would significantly improve the search performance. Indian scientists are taking part in this worldwide effort, both in theory, data analysis and instrumentation, through the IndIGO (Indian Initiative in Gravitational-wave Observations) consortium. Possibility of building a LIGO like 4km detector in India as part of the international GW network is being explored.



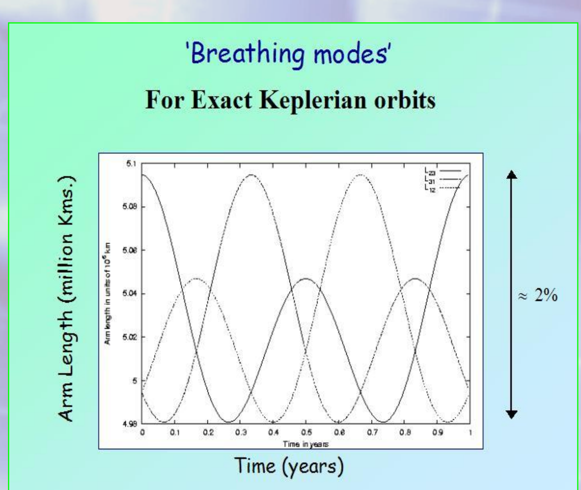

## Space based telescopes

The (european) Laser Interferometric Space Antenna (eLISA)
✓ Three spacecrafts forming an 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

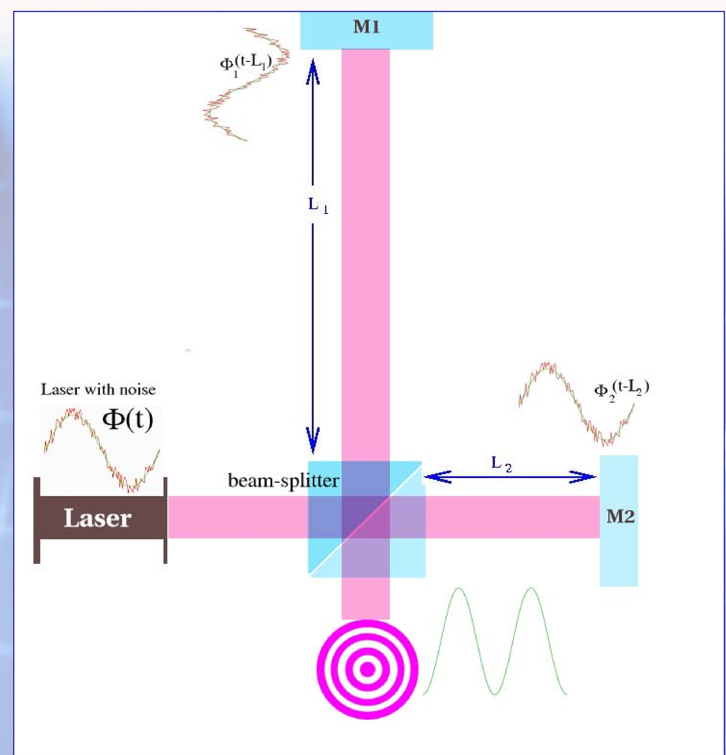
### Stability of LISA spacecraft configuration



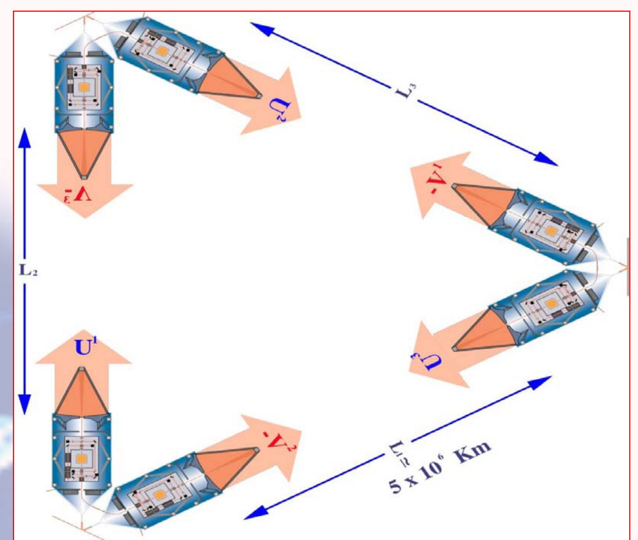

IUCAA scientists have **analytically** shown that, to the first order in eccentricity **any** configuration formed by **any** number of spacecrafts can be stable, provided **all** of them lie on a plane at an angle **60$^{o}$** with the ecliptic.




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.




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

### Reduction of LASER frequency noise in eLISA

Canceling the LASER frequency noise is crucial for attaining the goal sensitivity for eLISA. This noise is 7-8 orders of magnitude larger than other noise sources. A scheme based on abstract algebra was developed which suppresses this noise.