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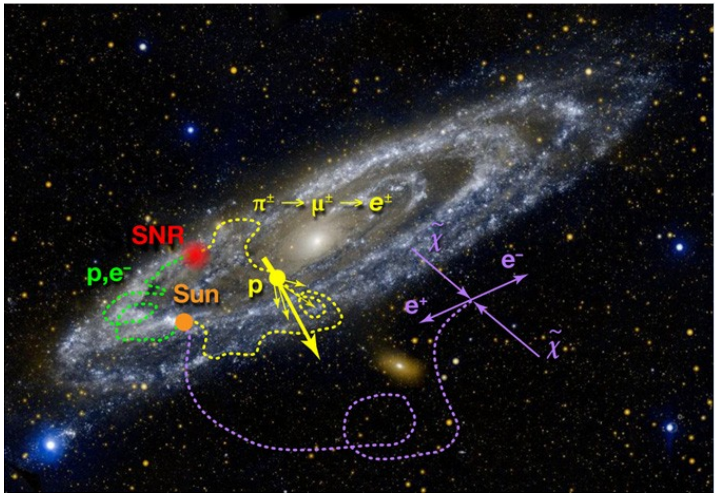

Introduction to Cosmo-micro physics Exam 2022

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M21-192

Pulsar timing arrays.

Pulsars are rapidly rotating, highly magnetized neutron stars formed during the supernova explosions of massive stars. They act as highly accurate clocks.

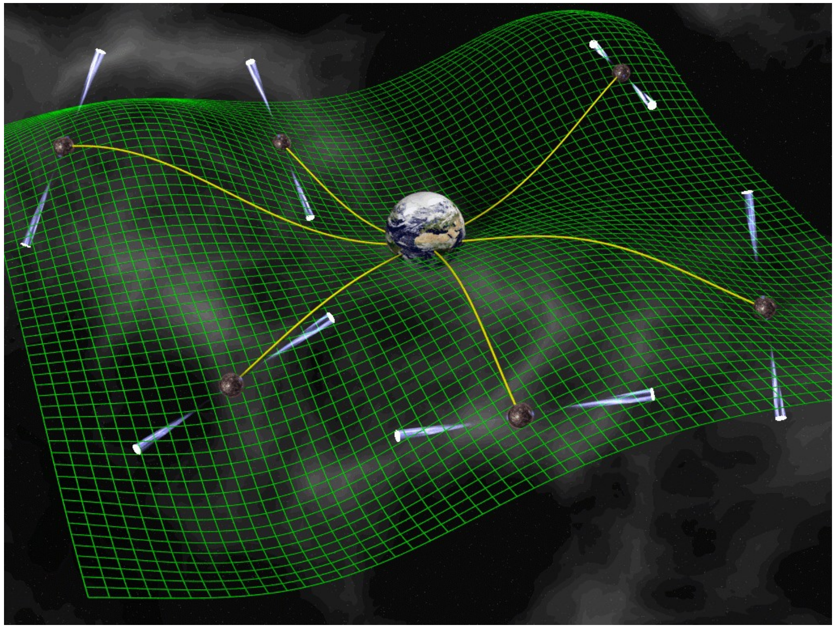
A pulsar timing array (PTA) is a set of pulsars which is analysed to search for correlated signatures in the pulse arrival times.

PTA is mainly used to detect and analyse gravitational waves.

Detailed investigation of the correlation between arrival times of pulses emitted by the millisecond pulsars as a function of the pulsars' angular separations.

The main goal of PTAs is measuring the amplitude (hint on the formation galaxies) of background gravitational waves caused by a history of supermassive black hole mergers.

PPTA, EPTA, NANOGrav and International Pulsar Timing Array are four active pulsar timing array projects.



NANOGrav result and it’s cosmological interpretation.

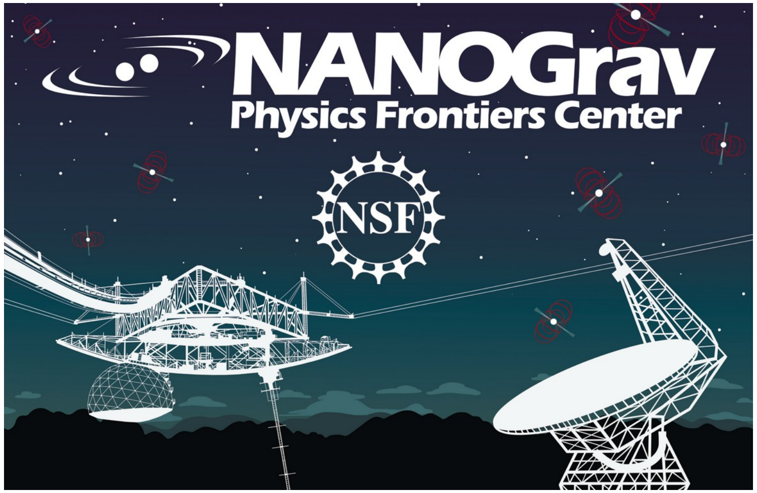
The North American Nanohertz Observatory for Gravitational Waves (NANOGrav) is a consortium of astronomers who share a common goal of detecting gravitational waves via regular observations of an ensemble of millisecond pulsars using the Green Bank and Arecibo radio telescopes.

NANOGrav exploits radio pulsars as both the light (radio) source and the clock against which the light travel time is measured. In an array of radio pulsars gravitational waves manifest themselves as correlated disturbances in the pulse arrival times.

Major goals :

1. Understanding the co-evolution of galaxies and supermassive black holes;
2. Searching for signatures of early-universe or exotic physics processes (e.g., inflation or cosmic strings);
3. Probing the nature of space-time, including the search for quantum gravity corrections to classical gravity;
4. Discovering sources of gravitational waves previously unrecognized.

In data gathered and analyzed over 13 years, the North American Nanohertz Observatory for Gravitational Waves (NANOGrav) has found an intriguing low-frequency signal that may be attributable to gravitational waves.



NANOGrav result and it’s cosmological interpretation

Pairs of supermassive black holes orbiting one another across the universe produce gravitational waves with much longer wave lengths than those detected by LIGO and Virgo - so long that it might take years for a single wave to pass by a stationary detector.

So while LIGO and Virgo can detect thousands of waves per second, NANOGrav's quest requires years of data. But they've found evidence of a gravitational wave background recently.

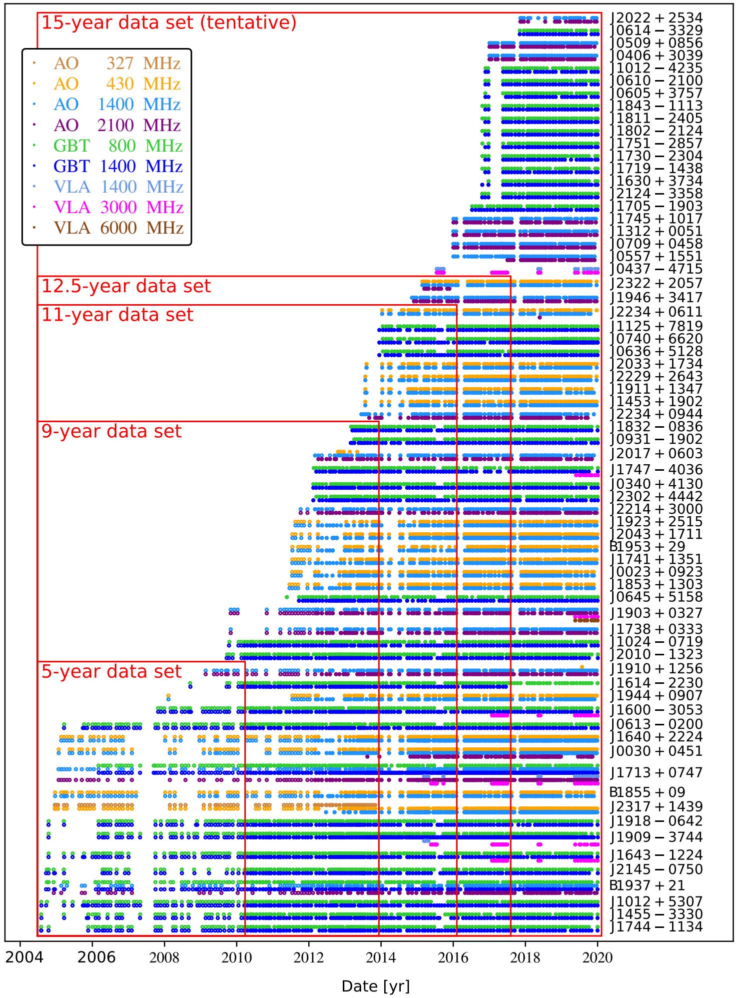
This new search from the International Pulsar Timing Array includes an extensive comparison between individual data sets from the large regional scientific collaborations and the combined data set.

The GW search of the IPTA DR2 has revealed strong evidence for a low-frequency signal detected by many of the pulsars in the combined data.

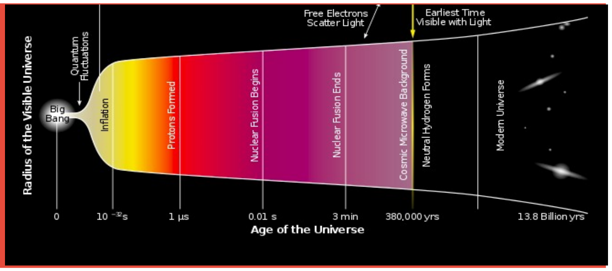
The characteristics of this common-among-pulsars signal are in broad agreement with those expected from a GW “background” (GWB).

This background is formed by many different overlapping GW signals emitted from the cosmic population of supermassive binary black holes (i.e., two supermassive black holes orbiting each other and eventually merging), analogous to background noise from the many overlapping voices in a crowded hall.

NANOGrav works to detect minute changes in the Earth’s position due to gravitational waves stretching and shrinking space-time.



Inflation



During 1970s , the researches faced with numerous constraints in the Big bang model :

Horizon problem - The horizon problem is the problem of determining why the Universe appears statistically homogeneous and isotropic in accordance with the cosmological principle. Also, CMB is nearly very isotropic.

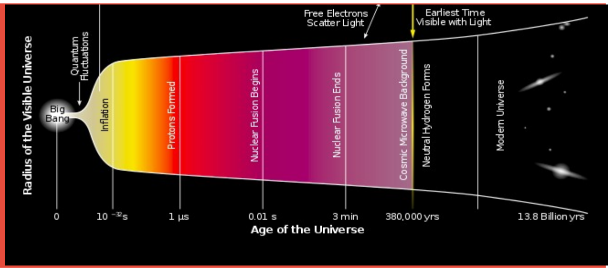
Flatness problem - Regardless of the shape of the universe the contribution of spatial curvature to the expansion of the Universe could not be much greater than the contribution of matter. The flat geometry is an unstable situation for the Universe.

Magnetic monopole problem - The magnetic monopole problem, sometimes called the exotic-relics problem, says that if the early universe were very hot, a large number of very heavy, stable magnetic monopoles would have been produced.

The model of Inflation came into effect to address these major problems in cosmology.

The exponential expansion of the Universe lasted from 10^−36 seconds after the conjectured Big Bang singularity to some time between 10^−33 and 10^−32 seconds after the singularity. The universe expanded around 10^78 times.

Inflation



The period in the evolution of the Universe during which the scale factor was accelerating is called Inflation.

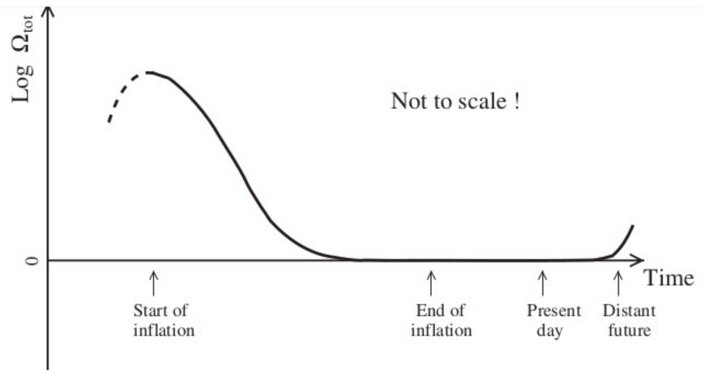
$$\text{INFLATION} \iff \ddot{a}(t) > 0\,.$$

From acceleration equation it means that $\rho c^2 + 3p < 0.$

Therefore: $p < -\frac{\rho c^2}{3}\,.$

From Friedman equation : $H^2 = \frac{8\pi G}{3}\rho - \frac{k}{a^2} + \frac{\Lambda}{3}\,.$

$$H^2 = \frac{\Lambda}{3}\,.$$



As first two terms are rapidly reduced by the expansion while the last one remains constant.

Hence , it can be deduced that : $a(t) = \exp\left(\sqrt{\frac{\Lambda}{3}}\,t\right)\,.$

Universe is dominated by a cosmological constant, the expansion rate of the Universe is much more dramatic than those we have seen so far.

After some amount of time, inflation must come to an end, with the energy in the cosmological constant being converted into conventional matter. One should think of this as a decay of the particles acting as the cosmological constant into normal particles.

Thank you for your attention