Analysis and Possible Methods of Detection of Quark Stars

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Abstract

The observation of events like GW170817 have provided enormous opportunities and data to study many celestial objects. Among these infinite celestial objects, today we discuss and provide theoretical analysis and possible methods of detection of Quark Stars.

Keywords: Neutron stars, Quark stars, Quark-Gluon Plasma (QGP)

Then even nothingness was not, nor existence,

There was no air then, nor the heavens beyond it.

What covered it? Where was it? In whose keeping

Was there then cosmic water, in depths unfathomed?

Naasadiiya Suktha (Rigveda)

Introduction and Analysis

Multiple scientists like Bodmer (1971) have pointed out theoretical possibility of presence of quark matter and its composition of up, down and strange quarks.This startling theory provide possibilities about superdense matter and if verified by future technologies, would change our understanding of early universe, and cosmology itself. When the degeneracy pressure inside a neutron star is surpassed, and at extreme temperature and pressure, the neutrons undergo deconfinement transitions to a new phase of quarks inside the star as observed in heavy-ion collision. This creates an ultra dense phase of quark matter, and the star is called a Quark star. Though the equation of state (EoS) of a quark star might not be completely certain at this time, this analysis will provide theoretical evidence about their existence.

A localised assembly of quark-gluon in chemical equilibrium is termed at QGP and is believed to be filled throughout the space during early stages of the universe. The theory predicting deconfinement transition to QGP [1] is termed as quantum chromodynamics or QCD. Integrating astrophysical observations and theoretical ab initio calculations, we observe that neutron stars with mass similar to 1.4 times the solar mass exhibit this deconfined state, QGP providing the first base of evidence for the existence of quark stars. The three lightest quark flavor states, i.e up, down and strange are its main constituents. The energy per baryon of such a state is very low. Due to finite strange-quark mass, electrons concentration at low densities maintains electrical neutrality. The presence of these electrons provides a second base for existence of a nuclear crust surrounding the quark star. Quark stars may further be distinguished onto bare and dressed. Mass of such stars have been found to vary inversely with radius. They have smaller mass shedding periods than neutron stars, and can sustain extremely rapid rotations. From the study performed by Zdunik *et al.* (2001), crustal inertia is ratioed to total between 10^{-3} to 10^{-5}, a change in crustal inertia would cause a giant pulsar glitch. If quark stars have rotation around the axis, they should be threaded with rotational vortex lines. The vortices would be expelled from the star during stellar spin-down. At high baryon density QCD's exotic phases exist. Such high density QCD phases may arise inside the cores of neutron stars and possibly quark stars. Different QCD phase transitions correspond to different symmetrical patterns. CFL transition exhibits properties like strings and textures. Kibble mechanism allows the study of such density fluctuations arising due to formation of topological defects. Thus we can identify specific transitions occurring inside a pulsar too. Random density fluctuations lead to non-zero off diagonal components of MI leading to wobbling of stars. Correlation of multiple such observations can point out transition occurring inside the star providing the third base of evidence. As the separation between quarks decrease, their properties get difficult to determine due to asymptotic freedom.

Detection

The detection of GW from GW170817 neutron star merger, demonstrated the collision of two neutron stars and their transition. The transition had quark matter of about 20% of baryonic mass. One critical observation showed the dephasing of gravitational waves as the quark matter was increased. The maximum gravitational frequency [2] is dependent on tidal deformability which further is dependent on the celestial object providing details about the structure. Another study which used models to demonstrate the transition, and out of 22 models used, the models allowing quark transition deviate from the above phenomenon by 1 kilohertz. Further studies showed breaking of star yielding electron-proton pairs which form neutrons and some residual high density material. These high density residual matter [3] emit a distinct pattern of X-rays which is directly dependent on temperature of the core material. Thermal emissions from neutron stars older than 100,000 years haven't been observed. At K_bT of 200 MeV, nucleons are highly probable to transition to quarks. A study by Oliver Drapier uses a unique signature of QGP. The suppression of J/psi production, a particle composed of charmed quark and antiquark bound together. The production rates for J/psi can be evaluated based on rates in proton-proton reactions. However, J/psi gets unstable and thus collapses in QGP because of higher interaction probabilities in the plasma. Thus a deficit of J/psi may indicate QGP and hence provides the first base of detection.

The production of low mass lepton pairs in heavy ion collisions are also sensitive probes of reaction dynamics. They may provide the second base of detection. Strong interaction QCD vacuum has plenty of structure, as demonstrated by its multiple condensates. Evidence suggests that the chiral symmetry is spontaneously broken in the vacuum of QCD. To restore them, quark masses have to become small, and since hadrons are made up of quarks, eventually hadrons would undergo mass reduction. This technique, though highly dependent on relatively rare probes, verified its statistical accuracy. This provides the third base.

Gravitational radiation emitted by stellar pulsation modes could be detected by LIGO/Virgo. Any generic perturbation with *l* greater than or equal to 2, emits strong gravitational waves. The fundamental or *f* mode gravitational detection can also provide statistics for solving equations of mass, radius and EoS of the star. It has been verified that oscillating frequency *f* of fundamental modes are linearly dependent on density and many other properties of the star. Another type of modes we will be using will be *g* modes or gravitational modes. If density discontinuity exists inside a neutron star about to be transitioned, due to the presence of a quark core, the detection of *g* mode would verify the results. These mainly arise due to smoothening of material inhomogeneities along equipotential level surfaces. They differ from pressure or *p* modes interim of their tangential displacement being much bigger than radial displacement. The *g* mode is dependent on amplitude of discontinuity. Another metric: color-superconductivity lowering transition pressure, shows hybrid stars with di-quark cores.

The previous results hold for non rotating objects [4]. However, the observations show at least some degree of rotation in all neutron stars whether transitioning or not. Rotating compact objects are influenced by non axisymmetric dynamical and secular instabilities. But in practice, very young proto-neutron stars are impacted by differential rotations. Secular instabilities, which require dissipation due, are associated with large currents coupled to gravitational radiation. This viscous damping makes the star stable at low frequencies. These findings establish our last base of detection. Future studies solving multiple base equations mentioned in the studies could find a numerical equation or data corresponding to a quark star and confirm its presence in the universe.

Suggestions for future studies

With better theoretical understanding, to confirm quark stars, studies in the field of gravitational instabilities due to rotational with statistical emphasis and limit on rotation posed by mass loss at the equator should be promoted.

Conclusion

With advancing technologies and large projects like NICER and advanced LIGO/Virgo in cosmology and new statistical data continuously being recorded by them, we are very close to confirming quark stars. This paper presented an overview analysis of cosmology studies related to quark stars, and provided adapted versions of their possible detections.

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Thank You!