Constraints on Variable Chaplygin Gas Cosmological Model from GW Merger Events

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1. Background Motivation

Observations have the ability to help us better comprehend the universe, and one such observation of type Ia SN establishes that the expansion of the universe is accelerating. Several cosmological models with dark energy as a component with an equation of state which doesn't obey the strong energy condition have been used to describe the observed universe. The most favoured candidate for dark energy is the cosmological constant (Λ) in the ΛCDM cosmological model. A trustworthy model should explain why the present amount of dark energy is so small in comparison to the fundamental scale and why it is comparable with the critical density today. The cosmological constant suffers from both these problems. Hence, we investigate the variable Chaplygin gas (VCG) as a viable cosmological model.

3. Standard Candle & Siren

Standard candles are fictitious objects of constant luminosity giving us a way to measure distances.

Type-Ia SN: The consistent luminosity curve and homogeneous properties of a type-Ia SN make it the perfect choice as a standard candle.

Gravitational waves (GWs): GWs encode the distance to their source. The GWs from the merger events doesn't lose it's energy on interaction with any gravitating object, be it Baryonic matter or exotic matter; hence, more reliable than standard candles and an independent way to measure distance to the source.

2. Variable Chaplygin gas

The universe's accelerated expansion is modelled by introducing a cosmic fluid component with an exotic equation of state

$$\rho_{ch} = \frac{A(a)}{p} \tag{1}$$

Assuming universe is composed of Baryonic matter, radiation and VCG, Freidmann equation is written as

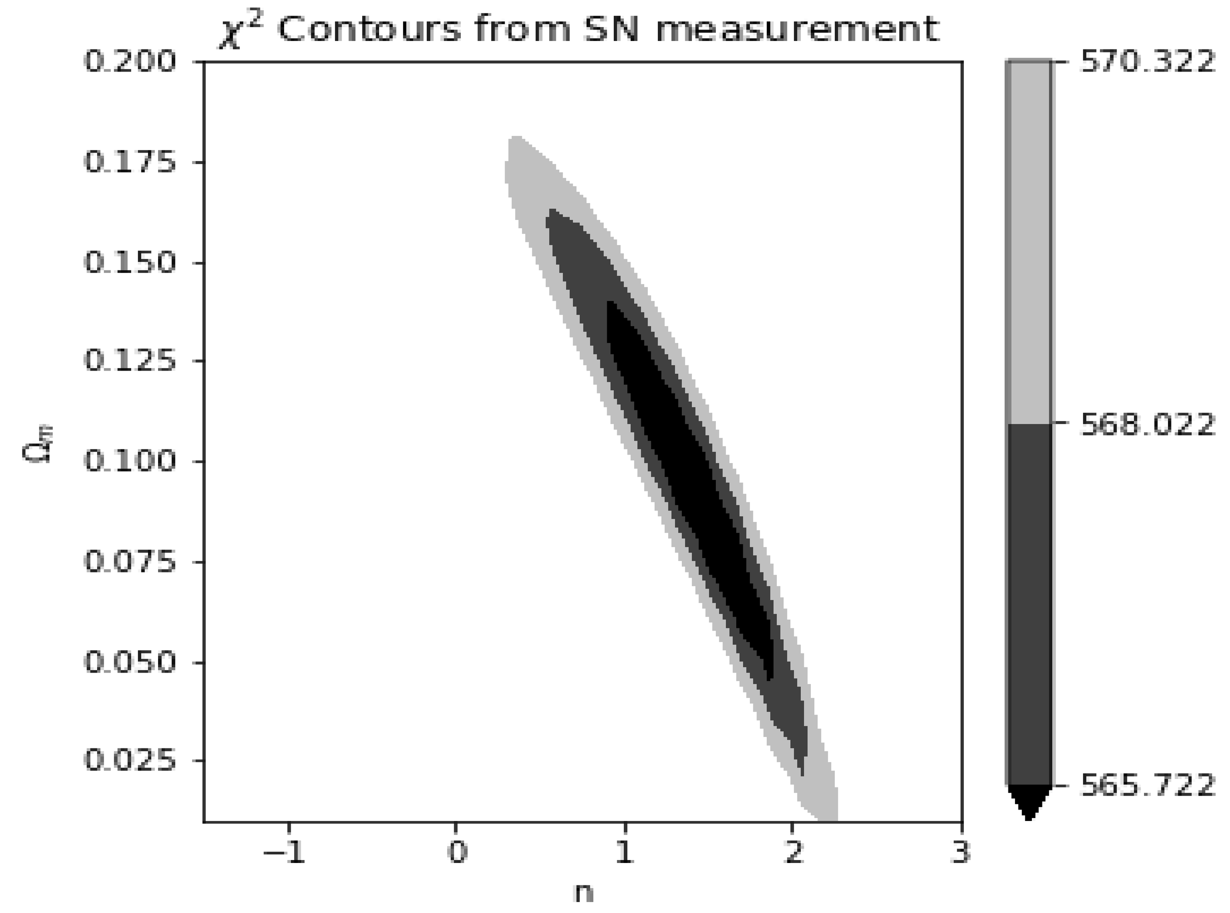
$$H^2 = H_0^2(1+z)^4\left\{\Omega_{r0} + \frac{\Omega_{b0}}{(1+z)} + (1-\Omega_{r0}-\Omega_{b0})\frac{(\Omega_m(1+z)^6+(1-\Omega_m)(1+z)^n)^{1/2}}{(1+z)^4}\right\} \tag{2}$$

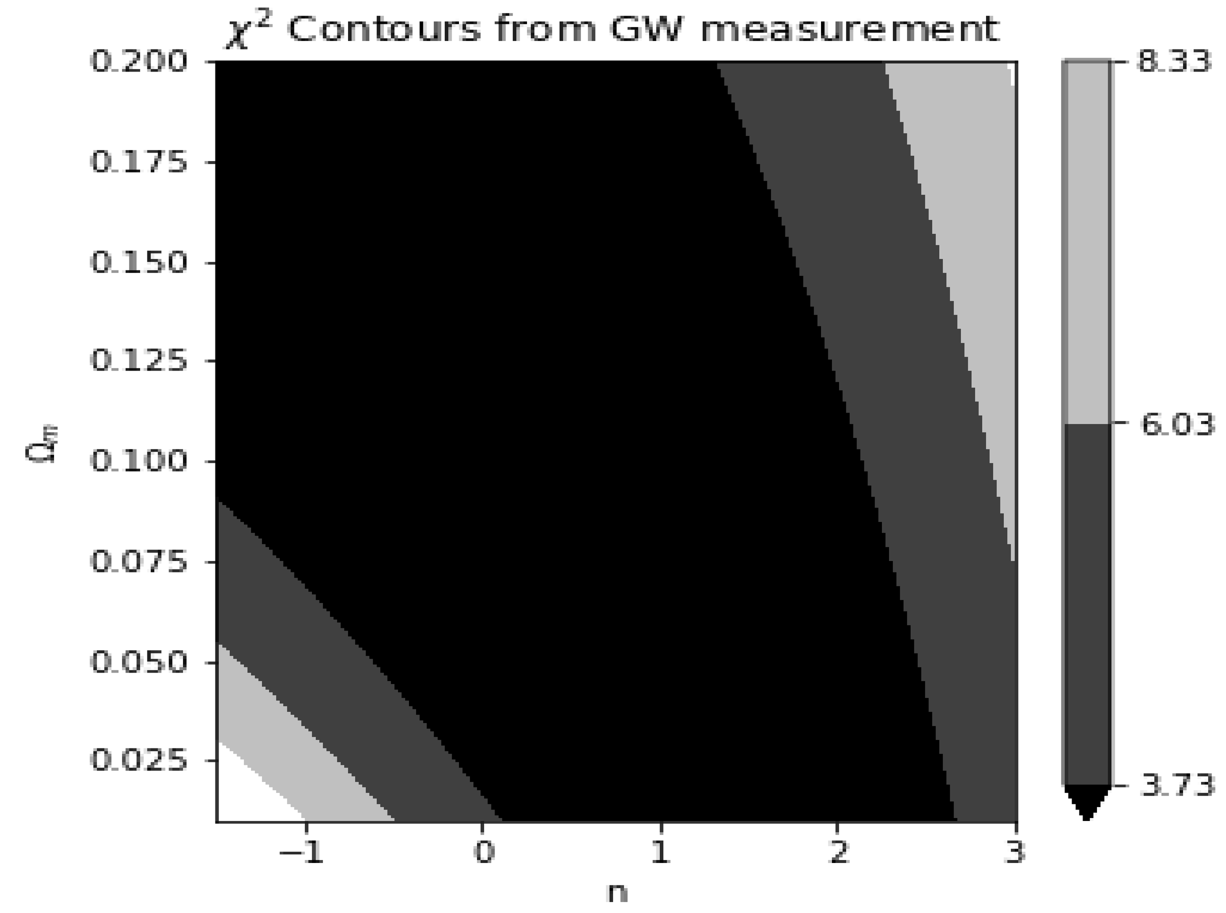
4. Statistical Methods

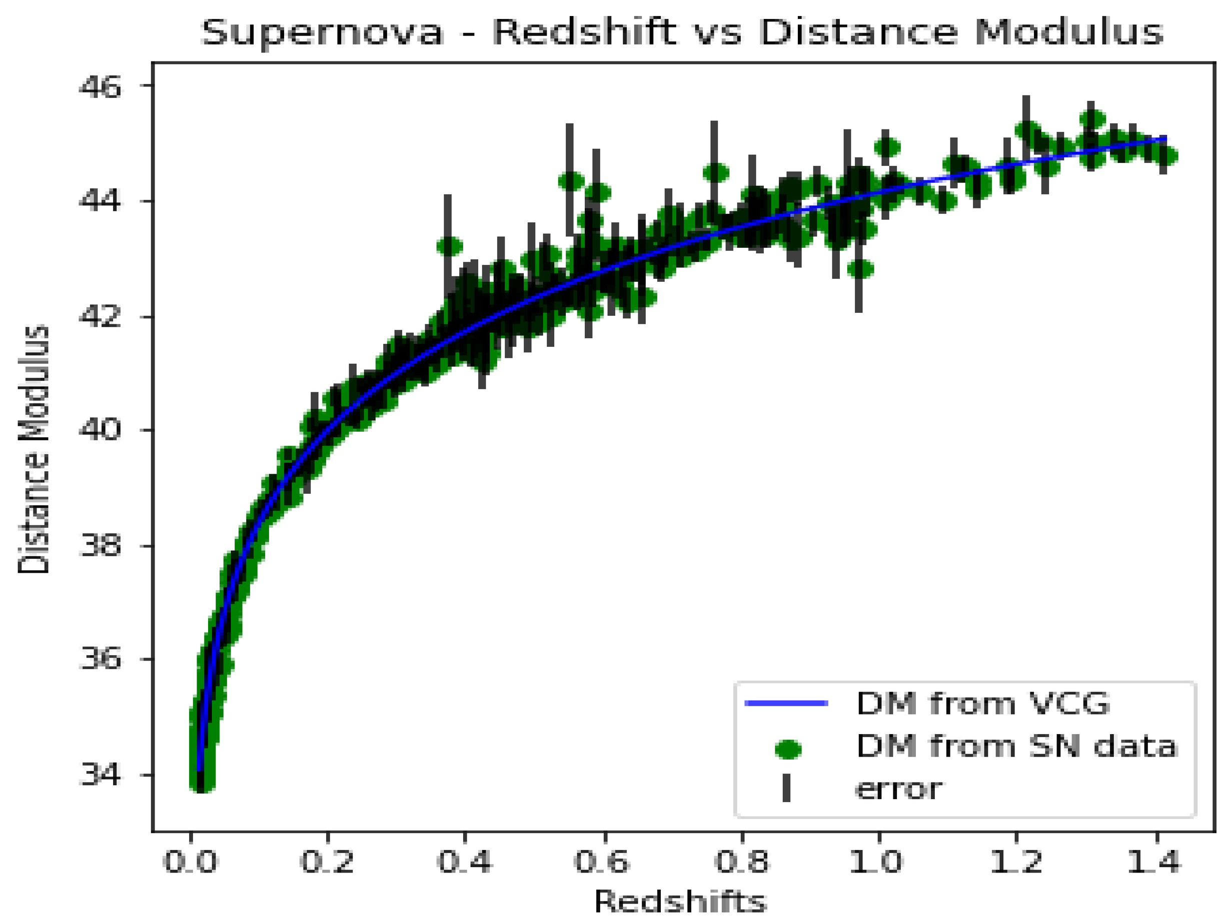
We examine the VCG model to establish stringent constraints using the latest observational data: the SCP "Union2.1" SN Ia dataset and the GWTC-3 catalog, describing all the GW transients found in observing runs O1, O2 and O3 of GW merger events. We selected 580 SN events, and used the chi-square test to obtain the constraints. Further, we selected 88 GW events, and using the chi-squared test, we obtained the constraints on the parameters by taking into account the average of the non-Gaussian errors.

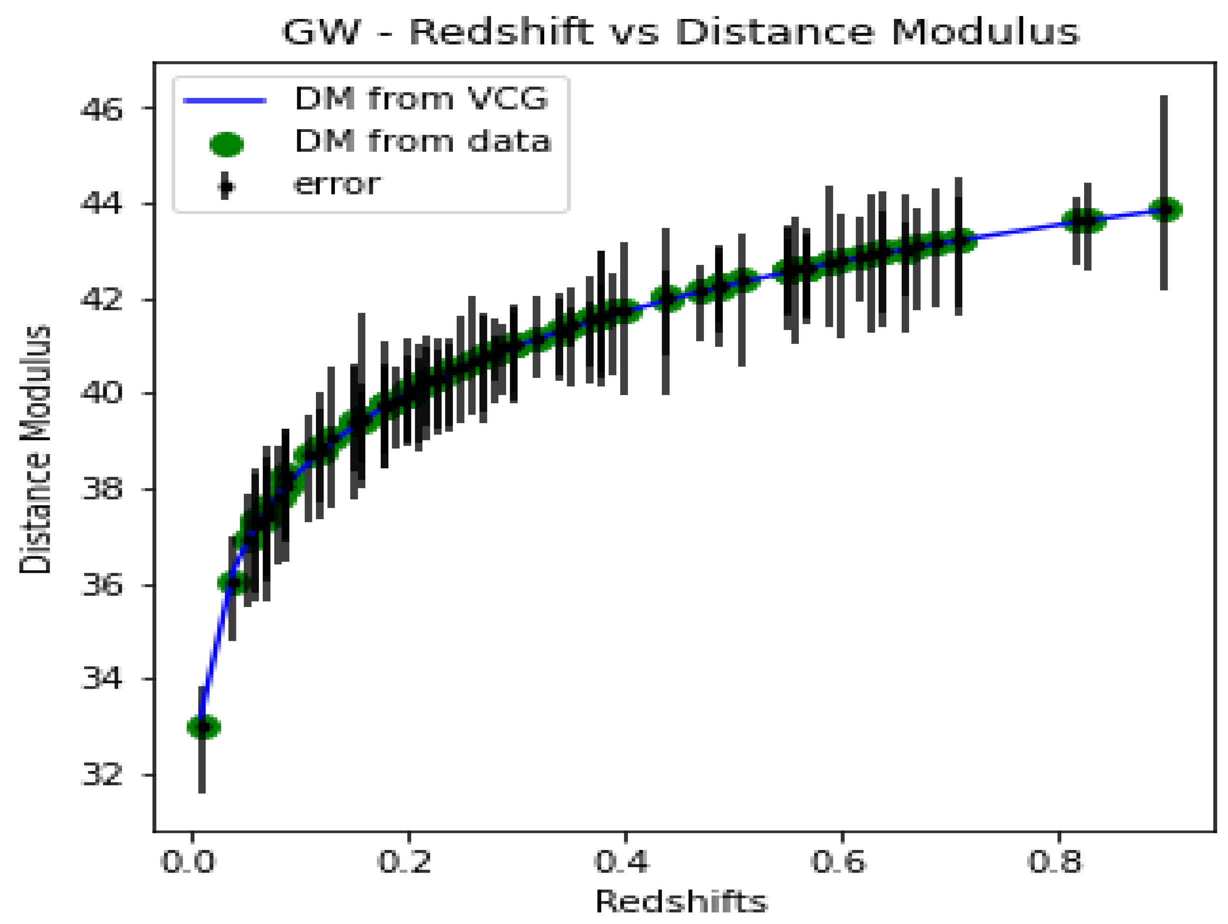
Using the obtained parameters, we inferred the Hubble constant value with SNe-Ia as a standard candle and GW as a standard siren using the least squares fitting method and orthogonal distance regression method respectively.

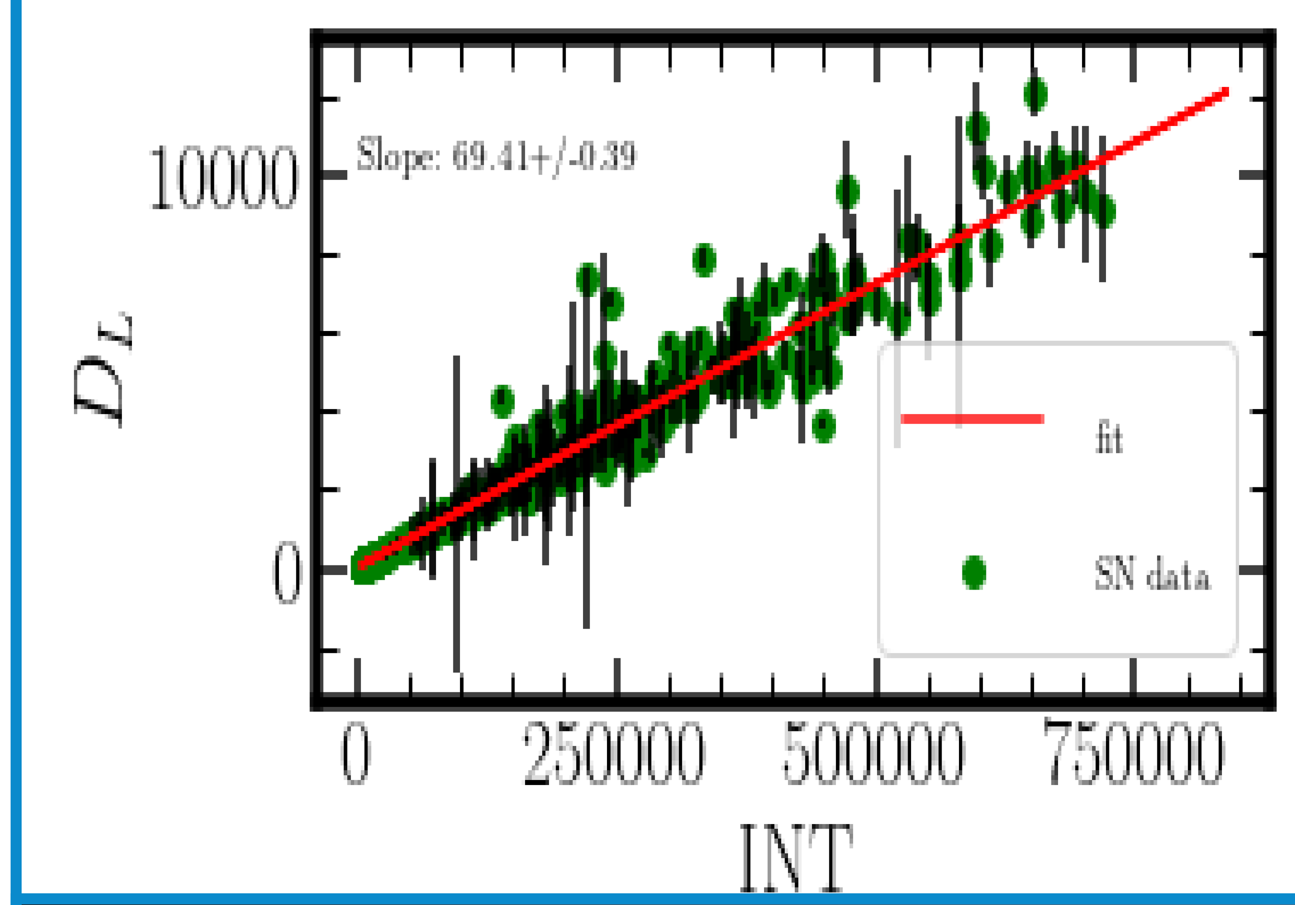
5. Results

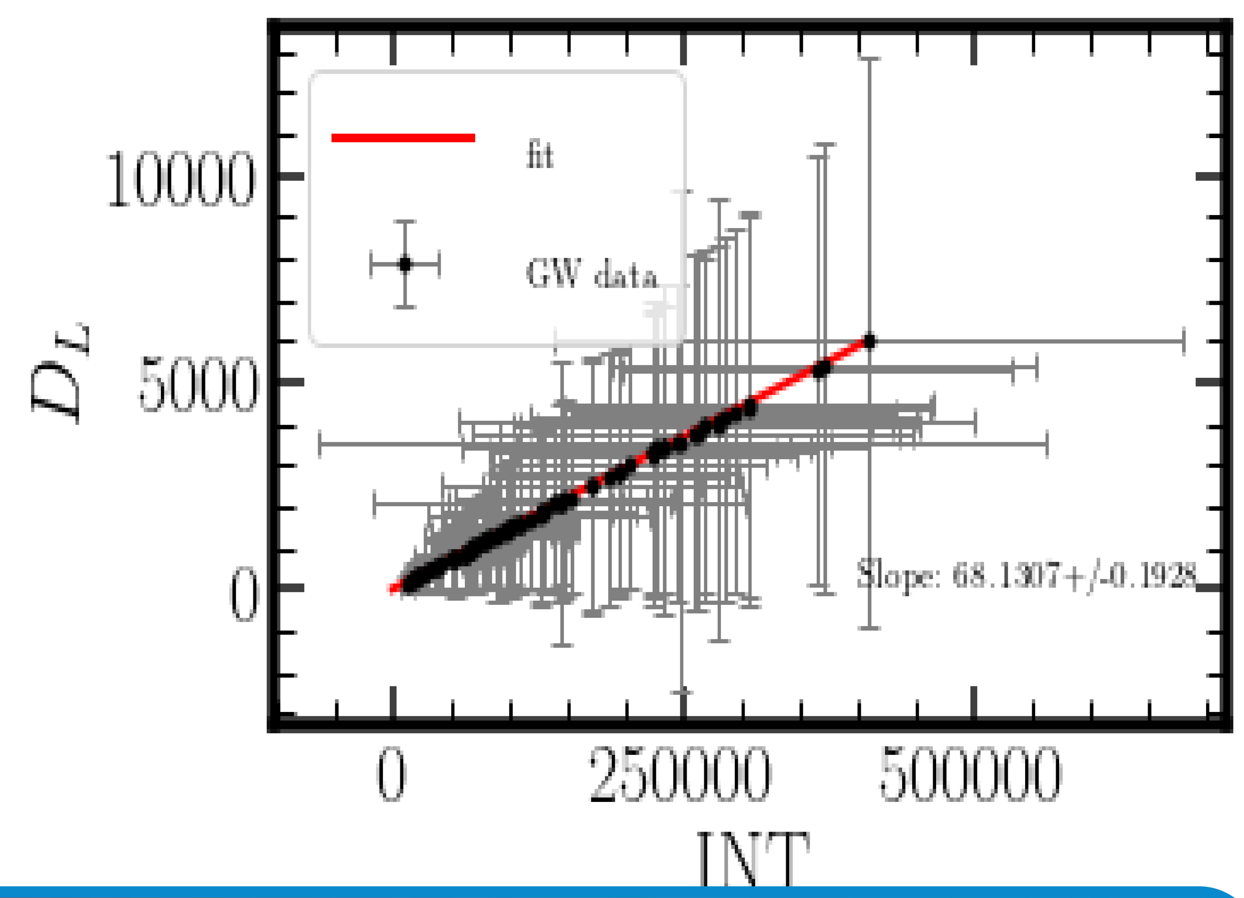












6. Conclusions & Future Work

With the contours of GW events overlapping with the SN results, they are shown to be a viable way of constraining the parameters of the cosmological model and calculating the Hubble constant. We have shown the viability of the model by plotting cosmological observables against the data, and shown that VCG model performs equally well as ΛCDM model.

In this work, as we have taken the average of the non-Gaussian errors in GW merger events, we are unable to gain insight into the Hubble constant using the constraints from GW merger events. Hence, in the future, we aim to employ the Markov Chain Monte Carlo method to constrain the parameters of the VCG model and deduce the Hubble constant value independently from the cosmic distance ladder.

8. References

[1] Geetanjali Sethi. Variable chaplygin gas: Constraints from supernovae, bao, look back time, and grbs. 2014.

[2] Geetanjali Sethi and Singh S. Variable chaplygin gas: constraints from cmbr and sne ia. *International Journal of Modern Physics.*