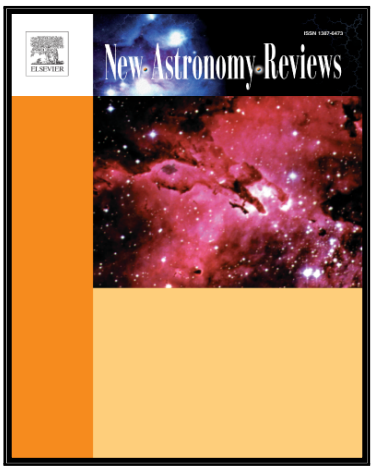

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THE FORMATION OF STELLAR BLACK HOLES

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Abstract: It is believed that stellar black holes (BHs) can be formed in two different ways: Either a massive star collapses directly into a BH without a supernova (SN) explosion, or an explosion occurs in a proto-neutron star, but the energy is too low to completely unbind the stellar envelope, and a large fraction of it falls back onto the short-lived neutron star (NS), leading to the delayed formation of a BH. Theoretical models set progenitor masses for BH formation by implosion, namely, by complete or almost complete collapse, but observational evidences have been elusive. Here are reviewed the observational insights on BHs formed by implosion without large natal kicks from: (1) the kinematics in three dimensions of space of five Galactic BH X-ray binaries (BH-XRBs), (2) the diversity of optical and infrared observations of massive stars that collapse in the dark, with no luminous SN explosions, possibly leading to the formation of BHs, and (3) the sources of gravitational waves produced by mergers of stellar BHs so far detected with LIGO. Multiple indications of BH formation without ejection of a significant amount of matter and with no natal kicks obtained from these different areas of observational astrophysics, and the recent observational confirmation of the expected dependence of BH formation on metallicity and redshift, are qualitatively consistent with the high merger rates of binary black holes (BBHs) inferred from the first detections with LIGO.

1. Introduction

The formation of stellar BHs is of topical interest for several areas of astrophysics. Stellar BHs are remnants of massive stars, possible seeds for the formation of supermassive BHs, and sources of the most energetic phenomena in the universe, such as the gravitational waves produced by fusion of BHs.

BHs and NSs are the fossils of stars with masses above ~8 $M_{\odot}$. It is known that some fraction of NSs have large runaway motions, probably due to strong natal kicks (NKs) imparted to the compact object. NKs have also been invoked in models of the core collapse of massive stars that lead to the formation of BHs. Such models predict in addition, that under specific conditions, BHs can also be formed by implosion with no energetic kicks[6,95], depending on mass, binarity, metallicity, angular momentum, and magnetic fields, among others properties of the progenitor star. NKs are of interest in Gravitational Wave Astrophysics since from population synthesis models of isolated binary evolution it is inferred that