We investigate the potential of using massive clusters as gravitational telescopes for supernovae searches. Massive galaxy clusters, used as gravitational telescopes (GTs), are extremely useful tools for the studies of faint high redshift galaxies in wavelengths ranging from optical to submillimetre as demonstrated e.g. in Ellis2001, Hu2002, Lemoine2002, Biviano, Smail. In this work we explore the potential of GTs for magnifying high redshift supernovae (SNe) in optical and near-infrared (NIR) wavelengths, thereby increasing the chances of detection. A competing effect related to the use of GTs is due to the spreading of the field by the lens, analogous to what happens when looking through a magnifying glass: a smaller, although magnified, portion of the field is actually observed. The effect is sometimes referred to as amplification bias. For any specific field-of-view (FOV) it is not obvious a priori which of the two effects dominates when looking for distant supernovae. The net gain depends upon 1) the lens and source parameters: the mass distribution of the lensing cluster, the intrinsic rate and brightness for core collapse and Type Ia supernovae as a function of redshift. 2) The observational set-up: the limiting search magnitude and the choice of wavelength band. In this paper we consider several scenarios relevant for supernova searches.

Studying supernova (SN) rates at the highest possible redshifts provides critical information for the understanding of cosmic star formation rate. Lensed SNe at high redshifts can in principle also be useful as distance indicators, provided the magnification is known to high precision. In addition, strongly lensed, multiply imaged supernovae may also be used to constrain cosmological parameters through the time delay measurements of the SN images multisne.

Similar work on the feasibility of galaxy clusters as GTs was carried out by Sulli. They focused on data sets through the HST $I_{814W}$-band with limiting magnitudes between 26.0 and 27.0. We extend this further by also investigating the $Z$- and $J$-bands where we find larger effects than in $I$-band. This is not surprising as the redder filters are sensitive to higher-redshift sources which in turn are fainter. In addition, we quantify the limiting search magnitudes and source brightness where GTs enhance or deplete the discovery rates. Also, Gaiya conducted an $I$-band search for SNe in HST fields with galaxy clusters. Earlier feasibility studies were also carried out by Saini. They concentrate their study to the lens cluster Abell 2218 where the assumed background sources were supernovae Type Ia and IIL and constrained their analysis to SN searches at shorter wavelengths.

Our study thus generalises previous work and is more applicable to instruments currently being used for high-$z$ SN searches, e.g. the $Z$-band search with the ACS camera on HST by the GOODS Treasury Team Goods, Goods2, or future missions such as JWST (formerly NGST). HST/ACS has a considerable depth but a relatively small field-of-view compared to optical cameras used for ground based SN searches. However, the small FOV makes a good match to the high amplification region of massive clusters at the moderate redshifts considered here.

Throughout the paper we use natural units in which $c = G = 1$. We have also adopted the “concordance” cosmology with $\Omega_{M} = 0.3$, $\Omega_{\Lambda} = 0.7$ and $h = 0.7$, where $h = H_{0}/100$ km $s^{-1}$ Mpc$^{-1}$. All magnitudes are in the Vega system.
The lens equation In almost all lensing situations of practical astrophysical interest, the deflection of the light takes place in a very small fraction of the total light path. This justifies the common approximation that all deflection occurs in a plane called the lens plane. So to compute the lensing properties of a halo we need to project its mass density onto this plane. This projected mass density we denote by $\Sigma$. Define the 2-D vector $\xi$ as the image position (or impact parameter) in the lens plane and $\xi_0$ as an arbitrary length scale in this plane which can be chosen suitably to simplify the appearance of the equations. Furthermore we introduce the corresponding quantities in the source plane: $\eta$ and $\eta_0 = \xi_0 D_s / D_d$. $D_s$, $D_d$ and $D_{ds}$ below are angular diameter distances between observer and source, observer and lens and lens and source respectively. $\eta$ is the source position. With these definitions, the lens equation in dimensionless form can be written as equation lenseq $y = x - \alpha(x)$