A search for HI emission in a magnification >100 strong gravitational lens

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January 15, 2018

Overview

Observational constraints on the cosmic evolution of neutral hydrogen within galaxies are critical to our understanding of galaxy evolution. However, these remain limited due to the intrinsic faintness of the line itself. At present, the highest redshift detection of HI emission is at $z \approx 0.37$, detected as part of the CHILES survey with the VLA (Fernández et al., 2016). We propose to dramatically break the HI distance record with the GMRT through an observation of the highest magnification source (optical magnification of $\mu \sim 100$) identified in the Sloan Lens ACS (SLACS) Survey - the largest lensing programme to date, particularly at intermediate redshifts ($z < 1.5$). While the source is at a very large redshift by HI emission standards ($z \sim 1.3$), this proposal will make several arguments as to why this source may be detectable in a reasonable amount of uGMRT observing time. Pushing back the HI emission frontier is a key goal of the Square Kilometre Array (SKA) and one that the uGMRT is exceptionally well-placed to preempt.

SLACS lens sample

The SLACS lens sample, based on the SDSS spectroscopic survey with HST followup, is the largest set of strong lenses available (Newton et al., 2011; Shu et al., 2017). This is especially true for low redshifts ($z < 1$) and hence lends itself very well to selecting the most promising targets for lensed HI emission detection experiments. This is enhanced by the fact that these lenses are nebular emission selected and likely to be starforming, hence good candidates for large gas reservoirs. Moreover, this sample has used deep HST imaging to derive accurate lens models. Figure 1 shows the magnification versus redshift overview of the SLACS lens sample with "Grade A" lens models. This sample has just recently increased by a factor of $\sim$2 (see Shu et al. 2017), a significant increase to the number of possible lensed HI candidates. What is striking from this figure is the extreme magnification outlier in the upper right, a Grade A modeled magnification of $\mu = 105$ and the subject of this proposal.

SDSSJ0826+5630 - the highest magnification lens in SLACS

SDSSJ0826+5630 is a $z \approx 1.3$ galaxy-galaxy lens first reported in Shu et al. (2017). Assuming equal intrinsic luminosity for all SLACS sources and considering only the magnification gains vs the losses based on luminosity distance, we calculate that SDSSJ0826+5630 would have the highest apparent brightness of the sample (by a factor of 1.5) in Band 4 of the uGMRT. The lower redshift lensed objects that fall within

Band 5 ($z < 0.34$) are more likely to be resolved out by longer baselines of the GMRT and also are lower scientific priority due to their lower redshift (i.e. lower than the highest-z detection to date).

Proposed observations and technical justification

We need 2 hours of on-source observation time in order to enable detection within the predicted HI mass envelope in Figure 2. However, as HI is typically more extended than the stellar component, the mean magnification could be lower. Accounting for a factor 4 drop in total magnification, leads to a factor 8 increase in observing time. Hence, we propose 16 hours of on source observation. This should reach 0.62 mJybeam^{-1} in a 500 kHz channel, which corresponds to a velocity width of $\sim$ 250 kms^{-1}. In addition we estimate a time overhead of $\sim$ 60% for calibration and to account for RFI contamination and antennae downtime. We therefore request a total of $\sim$ 26 hours.

The declination of the source is ideal from a uv-coverage point of view, allowing for accurate deconvolution and subtraction of the continuum emission. The central frequency is situated in a central part of band 4 which is also a lower RFI environment relative to band 5. The large bandwidth available with uGMRT will allow the implementation of direction dependent calibration (e.g. differential gains) and hence a more accurate continuum subtraction. We propose to limit the bandwidth to 100 MHz with 4096 channels to improve RFI excision.

Team expertise

Blecher (PhD student), Deane and Heywood are specialists at radio interferometric calibration and imaging. In particular, the team includes significant experience on wide-band, wide-field interferometers - most notably on MeerKAT and ASKAP science commissioning observations. Blecher has written GMRT-specific pipeline which equals GMRT sensitivity best results per unit bandwidth (Blecher et al, in prep). Deane is an expert in lens modeling, having written his own Bayesian lens modelling software. Obreschkow is a leader in cosmological simulations tracing the cosmic evolution of cold gas in the Universe. With software maturity and the significant computing power at the disposable of the South Africa Radio Astronomical Observatory (SARAO) & Inter-University Institute for Data Intensive Astronomy (IDIA), our team is very well placed to handle technical and practical data processing challenges. All team members have strong collaborations with the SKA precursor teams in South Africa, Australia, India, as well as the broader international community.

Our previous efforts at detecting lensed HI in the SLACS sample with the GMRT have been focused towards $z \sim 0.4$ sources, where we have a tentative detection. However, these efforts are limited by the close proximity to the lower edge of the L-Band of the old backend and RFI in that region of the spectrum. Moreover, we are far more likely to be spatially-resolve $z < 0.4$ (scale < 5.4 kpc/arcsec) lensed sources when compared to targets that lie within Band 4 (scale $\sim$ 8.5 kpc/arcsec at $z = 1.3$). We are in the process of writing an paper reporting the the previous GMRT observations of $z \sim 0.4$ sources, including the tentative detection and upper HI mass limits.

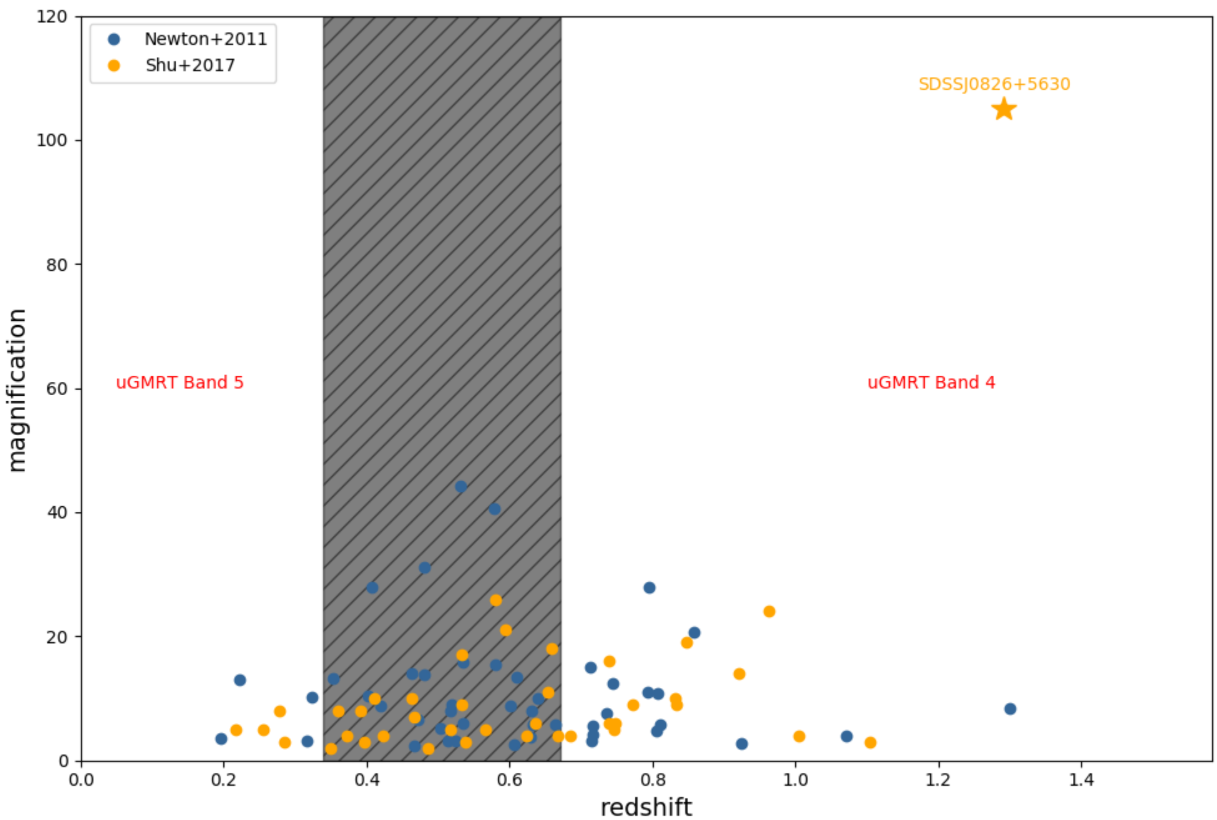

Figure 1: Magnification versus redshift for all 'Grade A' strong lens systems in the SLACS sample, showing the extreme outlier SDSSJ0826+5630 to the top right. The bandgap between uGMRT Band 4 and Band 5 is indicated by the shaded region. Note that this includes both the Newton et al. (2011) and Shu et al. (2017) samples.

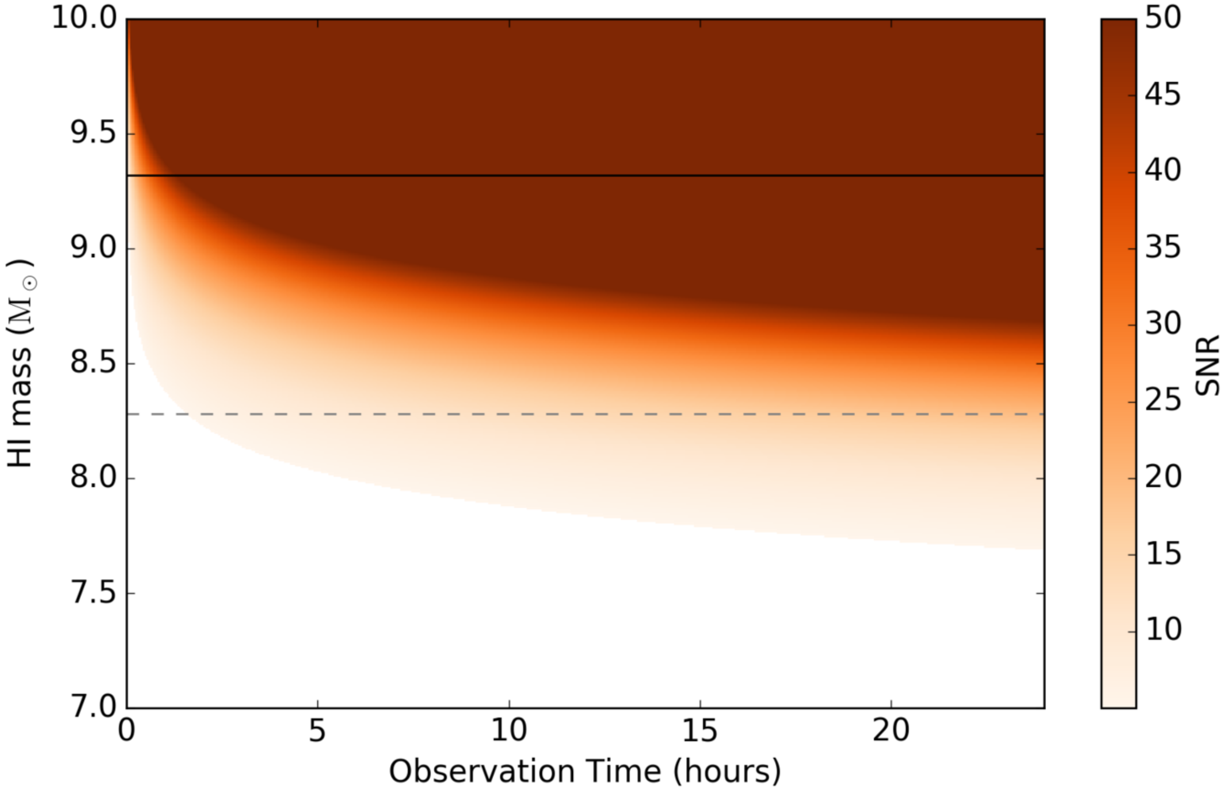

Figure 2: SNR as a function of observation time and intrinsic (unlensed) HI mass. We assume the HI line is a boxcar function of width 500 kHz (~ 250 kms^{-1} width) observed with the equivalent channel width and at a magnification of 105. All values of SNR < 5 have been blanked and the color scale saturates at SNR $= 100$. The solid and dashed line represent the mean and the lower 2σ HI mass estimates respectively. The estimate was made using the mean and RMS stellar masses from the original SLACS sample (Newton et al, 2011), converted to HI using the Maddox et al. (2015) $M_{HI} - M_\star$ galaxy relation.

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