ARTICLE TYPE

The gaseous natal environments of GPS and CSS sources with ASKAP – FLASH

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GPS and CSS sources are thought to represent a young and/or confined sub-population of radio-loud active galactic nuclei (AGN) that are yet to evacuate their surrounding ambient interstellar gas. By studying the gaseous environments of these objects we can gain an insight into the inter-dependent relationship between galaxies and their supermassive black holes (SMBHs). The First Large Absorption Survey in \textit{H}\textsubscript{I} (FLASH) will build a census of the neutral atomic hydrogen (\textit{H}\textsubscript{I}) gas in galaxies at intermediate cosmological redshifts. FLASH is expected to detect at least several hundred \textit{H}\textsubscript{I} absorbers associated with GPS and CSS sources. These absorbers provide an important probe of the abundance and kinematics of line-of-sight neutral gas towards radio AGN, in some cases revealing gas associated with infalling clouds and outflows. Observations are now complete for the first phase of the FLASH Pilot Survey and early analysis has already yielded several detections, including the GPS source PKS 2311−477. Optical imaging of this galaxy reveals an interacting system that could have supplied the neutral gas seen in absorption and triggered the radio-loud AGN. FLASH will provide a statistically significant sample with which the prevalence of such gas-rich interactions amongst compact radio galaxies can be investigated.

KEYWORDS:
galaxies:active, radio continuum:galaxies, radio lines:galaxies, galaxies:ISM, galaxies:individual (PKS 2311−477)

1 | INTRODUCTION

The GHz-Peaked Spectrum (GPS) and Compact Steep Spectrum (CSS) radio sources are thought to be a young and/or confined sub-population, with linear sizes less than an about 20 kpc (O’Dea & Saikia 2021). As such, they provide excellent objects with which to study the interaction between radio-loud active galactic nuclei (AGN) and their host galaxies. In some cases multi-phase gaseous outflows are detected, possibly pointing to a form of radio-jet feedback in the early stages of radio AGN evolution (e.g. Holt, Tadhunter, & Morganti 2008). The \textit{H}\textsubscript{I} 21-cm line, when detected as absorption in the radio spectrum, is a particularly useful method of studying the natal gaseous environments of young radio galaxies. Detection rates of \textit{H}\textsubscript{I} absorption amongst GPS and CSS sources tend to be relatively high (∼ 30 per cent) and provide line-of-sight kinematic information on the cool neutral gas towards the source (see Morganti & Oosterloo 2018 for a review). However, the historical number of compact sources searched for \textit{H}\textsubscript{I} absorption remains insufficient to draw strong conclusions about the population, particularly at cosmological distances. Larger spectroscopic radio surveys with the new Square Kilometre Array (SKA) pathfinder telescopes are therefore required to build a statistically significant sample.
2 | THE FIRST LARGE ABSORPTION SURVEY IN H\textsc{i} (FLASH)

The First Large Absorption Survey in H\textsc{i} (FLASH; Allison et al. 2021) is a radio survey with the Australian Square Kilometre Array Pathfinder (ASKAP; Hotan et al. 2021) to detect the 21-cm absorption-line towards radio sources south of $\delta \approx +40$ deg, covering H\textsc{i} redshifts between $z = 0.4$ and 1.0. ASKAP is a 36-dish interferometer that has an instantaneous bandwidth of 288 MHz and a 31 deg$^2$ field of view at 800 MHz. The FLASH sensitivity ($3 - 5$ mJy beam$^{-1}$ per 18.5 kHz channel) and total sky area ($\approx 34 000$ deg$^2$) are such that we expect to detect more than a thousand H\textsc{i} absorbers, including the host galaxies of radio-loud AGN. Of these associated H\textsc{i} absorbers we expect that at least several hundred will be CSS and GPS radio sources, representing an order of magnitude increase over the current literature sample.

2.1 | FLASH Pilot Survey

The first phase of the FLASH Pilot Survey is now complete and data analysis is underway. Observations comprised mostly 2-hr pointings that reached FLASH sensitivity over a total sky area of approximately 1000 deg$^2$ (i.e. about 3 per cent of the full survey). To enable rapid interpretation of detected H\textsc{i} absorbers, the pilot fields were selected from existing surveys at optical wavelengths. These surveys include the Sloan Digital Sky Survey (SDSS) Baryon Oscillation Spectroscopic Survey (BOSS; Dawson et al. 2013), the Galaxy And Mass Assembly survey (GAMA; Liske et al. 2015), the Molonglo Reference Catalogue (McCarthy et al. 1996) and the Dark Energy Survey (DES; The Dark Energy Survey Collaboration 2005). Full details of the observations, data processing and results from the FLASH Pilot Survey will be given in a forthcoming paper by Yoon et al. (in preparation).

2.2 | PKS 2311−477

As an example, we present here a FLASH detection of H\textsc{i} absorption towards the GPS radio source PKS 2311−477. This source was observed with ASKAP during the FLASH Pilot Survey. Details of the observations and data processing, which uses the ASKAPsoft pipeline (Wieringa, Raja, & Ord 2020), will be discussed in detail by Yoon et al. (in preparation). A section of the ASKAP spectrum, centred on the detected H\textsc{i} absorption line at $z = 0.5810$, is shown in Figure 1. The line has a peak optical depth of $\tau \approx 0.1$ and FWHM of $\Delta v \approx 150$ km s$^{-1}$, with an asymmetric tail that extends to about $+300$ km s$^{-1}$ from the peak.

![Figure 1](https://example.com/figure1.png)

**Figure 1** An example H\textsc{i} 21-cm absorption spectrum towards PKS 2311−477, from ASKAP observations during the FLASH Pilot Survey. The flux density (black line) has been subtracted and normalised by the source continuum. The shaded red region denotes the measured rms noise per 18.5 kHz channel. The velocity axis is given with reference to the peak absorption at a redshift of $z = 0.5810$.

The spectral energy distribution (SED) of the background radio source is shown in Figure 2. Using the least-squares method we fit the analytical GPS model of Snellen et al. (1998), obtaining a peak flux density of $S_{\text{peak}} = 1.3$ Jy at 1.6 GHz and optically thick and thin spectral indices of $\alpha_{\text{tk}} = 1.1$ and $\alpha_{\text{tn}} = -0.9$, respectively. Based on this best-fitting SED model, we use the redshift of the H\textsc{i} absorption-line to obtain a lower limit for the 1.4 GHz radio luminosity of $L_{\text{1.4}} \gtrsim 1.0 \times 10^{27}$ W Hz$^{-1}$, which is typical of powerful GPS sources.

As yet no optical spectroscopic information could be found for this source and so the absorber association remains unknown. However, the line width is more consistent with the width distribution for detected associated/intrinsic absorbers than intervening absorbers. We use recent machine learning analysis by Curran (2021) of the literature sample to estimate that there is about 80 per cent probability that this absorber is associated with the host galaxy of PKS 2311−477. The line profile is also consistent with that of H\textsc{i} absorbers detected in luminous compact radio galaxies, which tend to be more asymmetric and broader, possibly tracing the irregular kinematics of neutral gas influenced by proximity to the radio source and AGN (Gerèb, Maccagni, Morganti, & Oosterloo 2015, Maccagni, Morganti, Oosterloo, Gerèb, & Maddox 2017). To verify this interpretation we are currently pursuing optical spectroscopy of this object as part of a larger follow up program of the FLASH Pilot Survey.

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1 Publicly released ASKAP data can be found at [https://research.csiro.au/casda/](https://research.csiro.au/casda/) PKS 2311−477 was observed in scheduling block SBID 15873.
FIGURE 2 The spectral energy distribution (SED) of PKS 2311−477 at radio wavelengths, compiled using data from the literature and this work. The frequency axis is given in the observer rest frame. The dashed line denotes a best-fitting model that includes optically thick and thin power-law spectra (Snellen et al. 1998). References for the data: Int17 – Intema et al. (2017); Hur17 – Hurley-Walker et al. (2017); Mau03 – Mauch et al. (2003); Mur10 – Murphy et al. (2010).

In Figure 3 we show a grz-band optical image of PKS 2311−477, overlaid with contours showing the 856 MHz continuum from FLASH. The optical image reveals at least two interacting galaxies at the position of the radio source; such interactions are thought to be progenitors of luminous radio galaxies and, if gas-rich, could be the reason why we detect a significant reservoir of H I gas towards this source (e.g. Chiaberge, Gilli, Lotz, & Norman 2015; Ramos Almeida et al. 2012).

3 SUMMARY

FLASH is a wide-field survey for H I 21-cm absorption using the ASKAP radio telescope, covering intermediate cosmological redshifts between z = 0.4 and 1.0 (Allison et al. 2021). The survey is expected to detect at least several hundred absorbers in the host galaxies of GPS and CSS sources, providing a statistically significant radio-selected sample with which to study the interaction between young and/or confined radio galaxies and their ambient environments. Spanning a broad range of intermediate cosmological redshifts, and by comparing with previous and contemporaneous H I absorption surveys at other redshifts, this sample will be used to determine if there is evidence for late-time evolution in the population of these objects.

Observations for the first 1000 deg$^2$ of the FLASH Pilot Survey are now complete (Yoon et al. in preparation) and data analysis is underway. Several absorption lines have been confirmed so far, including H I absorption towards the GPS radio source PKS 2311−477. Although no optical spectroscopic redshift yet exists for this source, the width and asymmetry of the line profile is consistent with neutral gas associated with the host galaxy of a luminous compact radio galaxy. Optical images available from the DESI Legacy Imaging Surveys (Dey et al. 2019) show that PKS 2311−477 is undergoing a significant merger or interaction with at least one other galaxy. We expect that the full FLASH survey will discover many more such systems, allowing us to test whether galaxy-galaxy interactions are an important feature in supplying the gas required to trigger such luminous young and/or confined radio galaxies.

ACKNOWLEDGMENTS

JRA acknowledges support from a Christ Church Career Development Fellowship. Parts of this research were conducted by the Australian Research Council Centre of Excellence for All-sky Astrophysics in 3D (ASTRO 3D) through project number CE170100013. The Australian SKA Pathfinder is part of the Australia Telescope National Facility which is managed by CSIRO. Operation of ASKAP is funded by the Australian Government with
support from the National Collaborative Research Infrastructure Strategy. ASKAP uses the resources of the Pawsey Supercomputing Centre. Establishment of ASKAP, the Murchison Radio-astronomy Observatory and the Pawsey Supercomputing Centre are initiatives of the Australian Government, with support from the Government of Western Australia and the Science and Industry Endowment Fund. We acknowledge the Wajarri Yamatji people as the traditional owners of the Observatory site.

The Legacy Surveys consist of three individual and complementary projects: the Dark Energy Camera Legacy Survey (DECaLS; Proposal ID #2014B-0040; PIs: David Schlegel and Arjun Dey), the Beijing-Arizona Sky Survey (BASS; NOAO Prop. ID #2015A-0801; PIs: Zhou Xu and Xiaohui Fan), and the Mayall z-band Legacy Survey (MzLS; Prop. ID #2016A-0453; PI: Arjun Dey). DECaLS, BASS and MzLS together include data obtained, respectively, at the Blanco telescope, Cerro Tololo Inter-American Observatory, NSF’s NOIRLab; the Bok telescope, Steward Observatory, University of Arizona; and the Mayall telescope, Kitt Peak National Observatory, NOIRLab. The Legacy Surveys project is honored to be permitted to conduct astronomical research on Iolkam Du’ag (Kitt Peak), a mountain with particular significance to the Tohono O’odham Nation.

We have made use of Astropy, a community-developed core Python package for astronomy [Astropy Collaboration et al. 2018 [2013]; APLPy, an open-source plotting package for Python [Robitaille & Bressert 2012]; NASA’s Astrophysics Data System Bibliographic Services; and the VizieR catalogue access tool operated at CDS, Strasbourg, France.

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How cite this article: Allison J. R., Sadler E. M., Mahony E. K., and Moss V.A. (2021), The gaseous natal environments of GPS and CSS sources with ASKAP-FLASH, Astronomische Nachrichten, xx,xx:xx–x.}

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How cite this article: Allison J. R., Sadler E. M., Mahony E. K., and Moss V.A. (2021), The gaseous natal environments of GPS and CSS sources with ASKAP-FLASH, Astronomische Nachrichten, xx,xx:xx–x.