Survey of Weak Intensity Southern HI

Uncovering the hidden iceberg structure of the Galactic halo

Vanessa Moss
ASTRON/University of Sydney

IMAGE CREDIT: NASA/CXC/M.WEISS

The Galactic ecosystem

- Neutral atomic hydrogen is a **fundamental part** of a galactic ecosystem, playing the role of the galaxy's fuel resource and determining its eventual fate
- Accretion from the **circumgalactic medium** is believed to be central to the ongoing fuelling of a galaxy (**Tom's** talk, also **Tumlinson+2017**) — various ideas about how (**Marasco+2012, Fraternali+2013, Joung+2012, Zheng+2015**)
- In the Milky Way, the star formation rate is not entirely well-matched to the estimated HI fuel: where is the **missing gas?** Relation to **ionised**?
- Contribution of $< 0.4\ M_{\odot}\ yr^{-1}$ from the largest HVCs **(Putman+2012)**
- Detection of high velocity ionised Galactic gas in absorption **(Lehner+2012, Richter+2017, Fox+2018)**

Image credit: S. Janowiecki

A hidden population?

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HIGH-VELOCITY CLOUDS IN THE GALACTIC ALL SKY SURVEY. I. CATALOG

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ABSTRACT

We present a catalog of high-velocity clouds (HVCs) from the Galactic All Sky Survey (GASS) of southern sky neutral hydrogen, which has 57 mK sensitivity and 1 km s^{-1} velocity resolution and was obtained with the Parkes Telescope. Our catalog has been derived from the stray-radiation-corrected second release of GASS. We describe the data and our method of identifying HVCs and analyze the overall properties of the GASS population. We catalog a total of 1693 HVCs at declinations $<0°$, including 1111 positive velocity HVCs and 582 negative velocity HVCs. Our catalog also includes 295 anomalous velocity clouds (AVCs). The cloud line-widths of our HVC population have a median FWHM of $\sim$19 km s^{-1}, which is lower than that found in previous surveys. The completeness of our catalog is above 95% based on comparison with the HIPASS catalog of HVCs upon which we improve by an order of magnitude in spectral resolution. We find 758 new HVCs and AVCs with no HIPASS counterpart. The GASS catalog will shed unprecedented light on the distribution and kinematic structure of southern sky HVCs, as well as delve further into the cloud populations that make up the anomalous velocity gas of the Milky Way.

Key words: catalogs – Galaxy: halo – ISM: clouds – radio lines: general – surveys

Online-only material: color figures, machine-readable tables

1. INTRODUCTION

Fifty years after the discovery of high-velocity neutral hydrogen (H I) in the halo surrounding the Milky Way (Muller et al. 1963), current research still seeks to understand the nature, origins and interactions of this anomalous gas which does not follow normal Galactic rotation. It is well known that the densest forms of high-velocity H I occur as clouds organized into associations and complexes (Wakker & van Woerden 1991). It is clear that their physical origins can be diverse, with evidence for complexes both extragalactic (Wakker et al. 2002; Sembach et al. 2002; Lehner et al. 2009; Tripp & Song 2012) and Galactic (Lehner & Howk 2010; Smoker et al. 2011) in origin. These studies trace origins for extragalactic clouds based on their low metallicities, lack of molecular gas or association with the Magellanic system, and origins for Galactic clouds based on their ionization content and low upper distance limits from stellar absorption lines. In northern and southern sky surveys of high-velocity clouds (HVCs) the Magellanic system (consisting of the Magellanic Clouds, the Magellanic Stream and the Leading Arm) contributes a large fraction of clouds, forming a prime example of the interaction between the Milky Way and extragalactic gas. But it is also clear that a considerable amount of anomalous velocity gas appears to be associated with interactions between the disk and the halo of the Milky Way and may in fact be of Galactic origin. High velocity gas has been discovered in other nearby galaxies such as M101, M31, M33 and NGC 205 (Tenorio-Tagle & Bodenheimer 1988; Westmeier et al. 2005, 2007) and may be related to extraplanar gas observed in more distant galaxies (Sancisi et al. 2008; Kamphuis et al. 2011), with the origins of the gas indeterminate in many cases but most likely a combination of galactic activity and accretion of infalling gas to varying proportions depending on the galaxy (Boomsma et al. 2008; Heald et al. 2011).

The first surveys of Galactic HVCs focused on the northern hemisphere, with clouds identified to be inhomogeneous and hence grouped in complexes on the basis of their spatial and spectral proximity to other clouds (Wannier et al. 1972; Giovanelli et al. 1973; Hulsbosch 1978; Wakker & van Woerden 1991). Since then, many new surveys of H I with increasing sensitivity and resolution have been released in both northern and southern hemispheres, including the Leiden–Dwingeloo survey (Hartmann & Burton 1997), the high-sensitivity Green Bank survey of H I (Lockman et al. 2002), the Leiden–Argentina–Bonn (LAB) survey (Kalberla et al. 2005), and the GALFA-H I survey (Peek et al. 2012). Each new study of anomalous velocity gas at higher angular resolution or higher spectral resolution reveals different aspects of the nature of this gas, resulting in new classes of anomalous velocity clouds (AVCs) such as compact HVCs (Braun & Burton 1999), ultra-compact HVCs (Brüns & Westmeier 2004; Giovanelli et al. 2010), projection-affected low-velocity halo clouds (Peek et al. 2009) and cold/warm low-velocity clouds (LVCs; Saul et al. 2012).

The high spectral resolution of new H I surveys allows us to examine the velocity structure of HVCs, which probes their physical conditions and interactions with their surroundings. Based on northern hemisphere surveys it has been found that the cloud line-widths of HVCs have a median FWHM of $\sim$20–30 km s^{-1} (Cram & Giovanelli 1976; de Heij et al. 2002; Kalberla & Haud 2006), corresponding to a kinetic temperature of $\sim 10^4$ K. The nature of these clouds of H I as relatively cold concentrations of gas means that their existence in a hot $\sim 10^6$ K halo results in clear evidence of interaction. The form of the pressure and density gradients as a function of scale height position in the Milky Way is also thought to play a key role in the confinement and lifetime of these clouds. Based on the

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Moss+2013: *HIGH-VELOCITY CLOUDS IN THE GALACTIC ALL SKY SURVEY. I. CATALOG*

A hidden population?

The Astrophysical Journal Supplement Series, 140:331–365, 2002 June

A VERY SENSITIVE 21 CENTIMETER SURVEY FOR GALACTIC HIGH-VELOCITY H I

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Received 2001 September 13; accepted 2001 December 26

ABSTRACT

Very sensitive H I 21 cm observations have been made in 860 directions at $\delta \geq -43°$ in search of weak, Galactic, high-velocity H I emission lines at moderate and high Galactic latitudes. One-third of the observations were made toward extragalactic objects that are visible at optical and UV wavelengths. The median rms noise in the survey spectra is 3.4 mK, resulting in a median 4 σ detection level of $N_{\rm H\,I} = 8 \times 10^{17}$ cm^{-2} averaged over the 21′ beam of the telescope. High-velocity H I emission is detected in 37% of the directions; about half of the lines could not have been detected in previous surveys. The median FWHM of detected lines is 30.3 km s^{-1}. High-velocity H I lines are seen down to the sensitivity limit of the survey, implying that there are likely lines at still lower values of $N_{\rm H\,I}$. The weakest lines have a kinematics and distribution on the sky similar to that of the strong lines and thus do not appear to be a new population. Most of the emission originates from objects which are extended over several degrees; only a few appear to be compact sources. At least 75%, and possibly as many as 90%, of the lines are associated with one of the major high-velocity complexes. With the increased sensitivity of this survey, the Magellanic Stream is seen to extend at least 10° to higher Galactic latitude than previously thought and to be more extended in longitude as well. Wright's Cloud near M33 has an extended low-$N_{\rm H\,I}$ component in the direction of the Magellanic Stream. The bright H I features which have dominated most surveys may be mere clumps within larger structures, and not independent objects. Although there are many lines with low column density, their numbers do not increase as rapidly as $N_{\rm H\,I}^{-1}$, so most of the H I mass in the high-velocity cloud phenomenon likely resides in the more prominent clouds.

Subject headings: Galaxy: halo — Galaxy: structure — ISM: clouds — surveys
On-line material: machine-readable tables

1. INTRODUCTION

Emission in the 21 cm H I line is seen over a large fraction of the sky at velocities $-500 \lesssim V_{\rm LSR} \leq -100$ km s^{-1} and $+100 \leq V_{\rm LSR} \lesssim +400$ km s^{-1}: too large to arise solely from Galactic rotation, yet seemingly not part of the Hubble flow (see Wakker & van Woerden 1997 for a recent review; throughout this work we use the definition that high-velocity H I has $|V_{\rm LSR}| \geq 100$ km s^{-1} in directions where such velocities are not expected from Galactic rotation). These high-velocity clouds were discovered in the 21 cm line of H I (Muller, Oort, & Raimond 1963), and for many decades the 21 cm line was their primary spectral signature. Surveys of the sky in search of high-velocity H I are thought to be complete at the level of $N_{\rm H\,I} \geq 2 \times 10^{18}$ cm^{-2} for objects with an angular size of a degree or greater (Wakker 1991). The most prominent southern high-velocity clouds can be associated with the Magellanic Clouds (Mathewson, Cleary, & Murray 1974), and some high-velocity clouds lie in the Galactic halo (van Woerden et al. 1999), but the origin of most of the emission is unknown. It has been suggested that high-velocity clouds result from phenomena as diverse as extensions of the Galactic disk, material accelerated by supernovae or other energetic events, the remnants of a Galactic fountain, condensations in a Galactic halo, infall of debris from satellite galaxies, and objects in the Local Group of galaxies (Oort 1966; Habing 1966; Davies 1972; Shapiro & Field 1976; Bregman 1980; Norman & Ikeuchi 1989; Blitz et al. 1999; Kalberla & Kerp 1999; Mallouris et al. 1999). It is probable that high-velocity clouds are a heterogeneous population and all of these possibilities are correct for different subsets of the data.

A number of high-velocity absorption lines have been detected in the ultraviolet toward extragalactic sources (e.g., Savage et al. 1993; Bowen & Blades 1993; Bowen, Blades, & Pettini 1995; Lu, Savage, & Sembach 1994; Murphy et al. 2000; Gibson et al. 2000). The UV transitions are much more sensitive to small amounts of neutral gas than the 21 cm line: a cloud with $N_{\rm H\,I} = 10^{18}$ cm^{-2} will produce strong

[1] The National Radio Astronomy Observatory is a facility of the National Science Foundation operated under cooperative agreement with Associated Universities, Inc.

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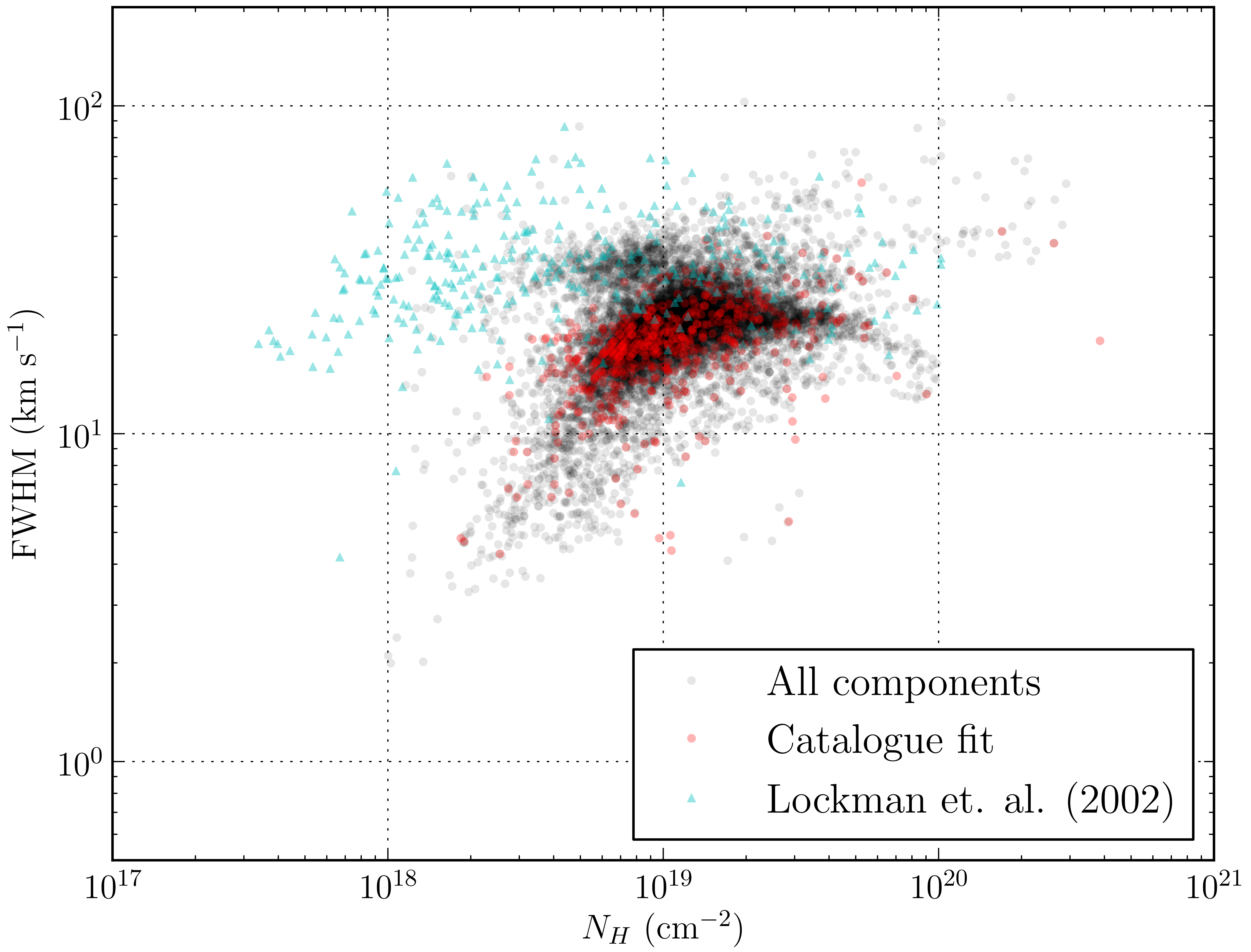

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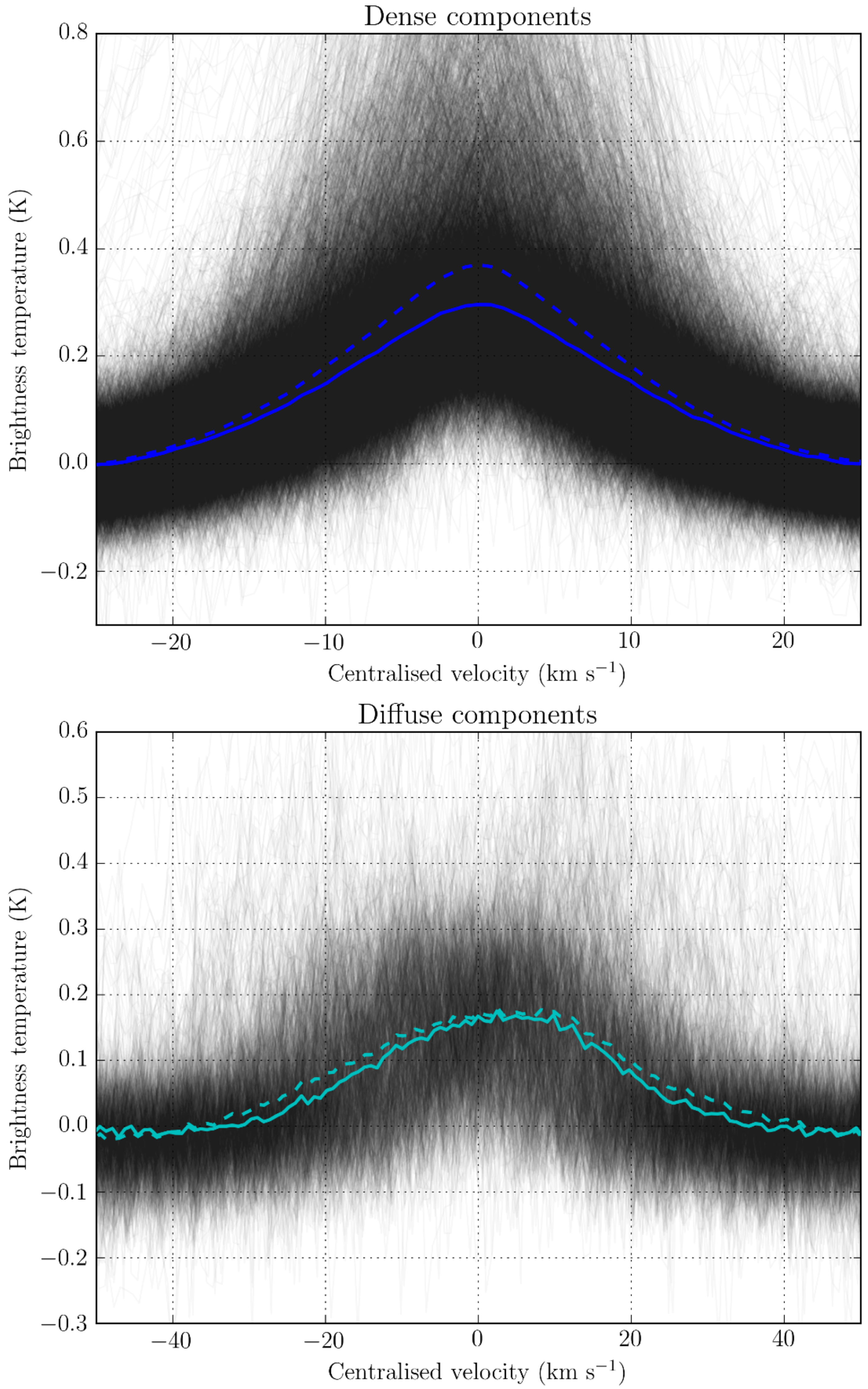
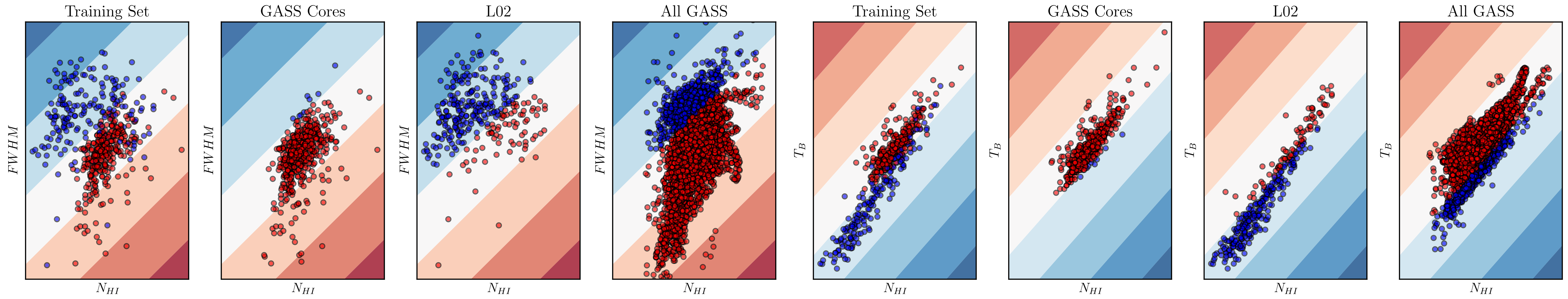
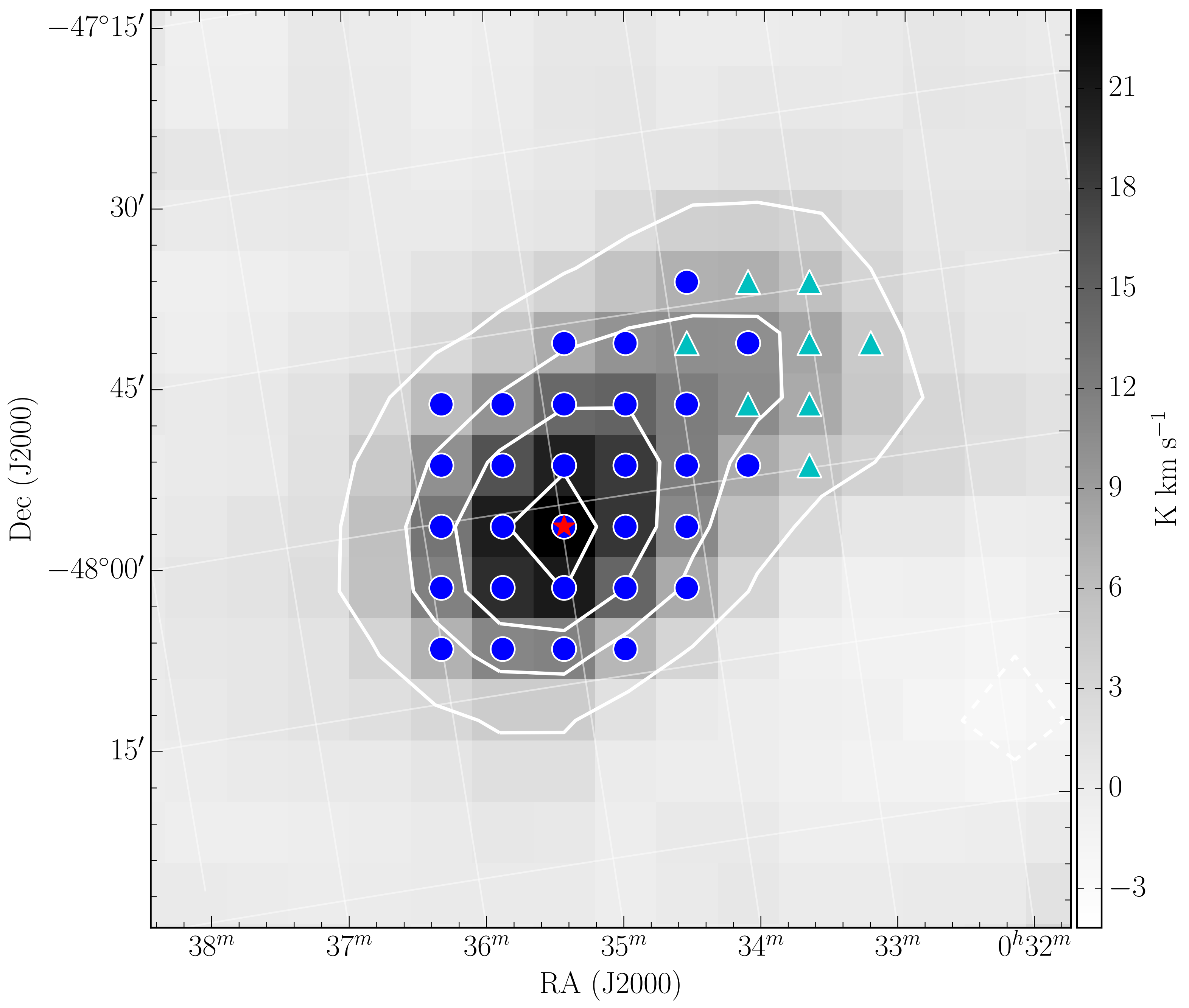
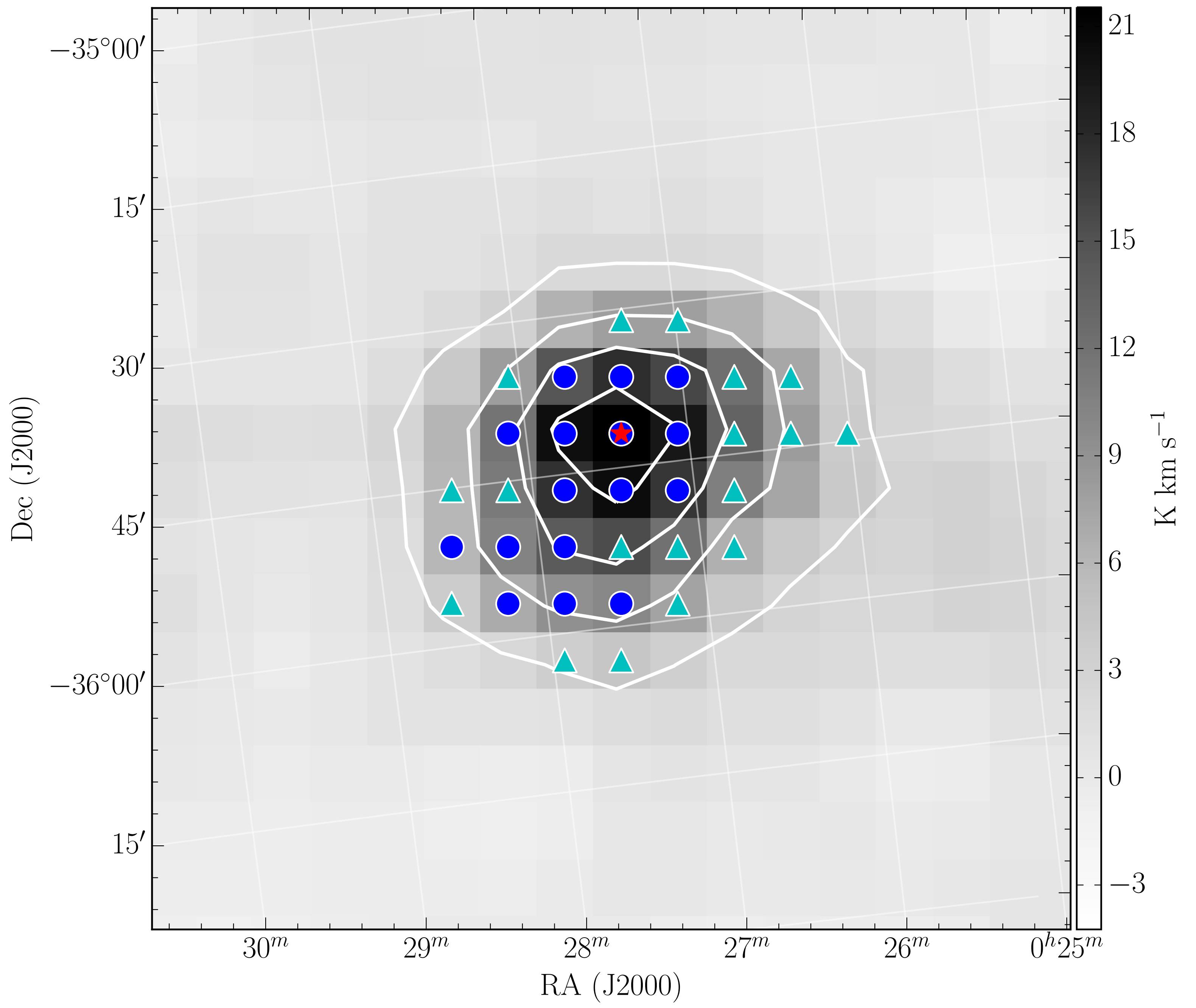
Results from Moss+2017









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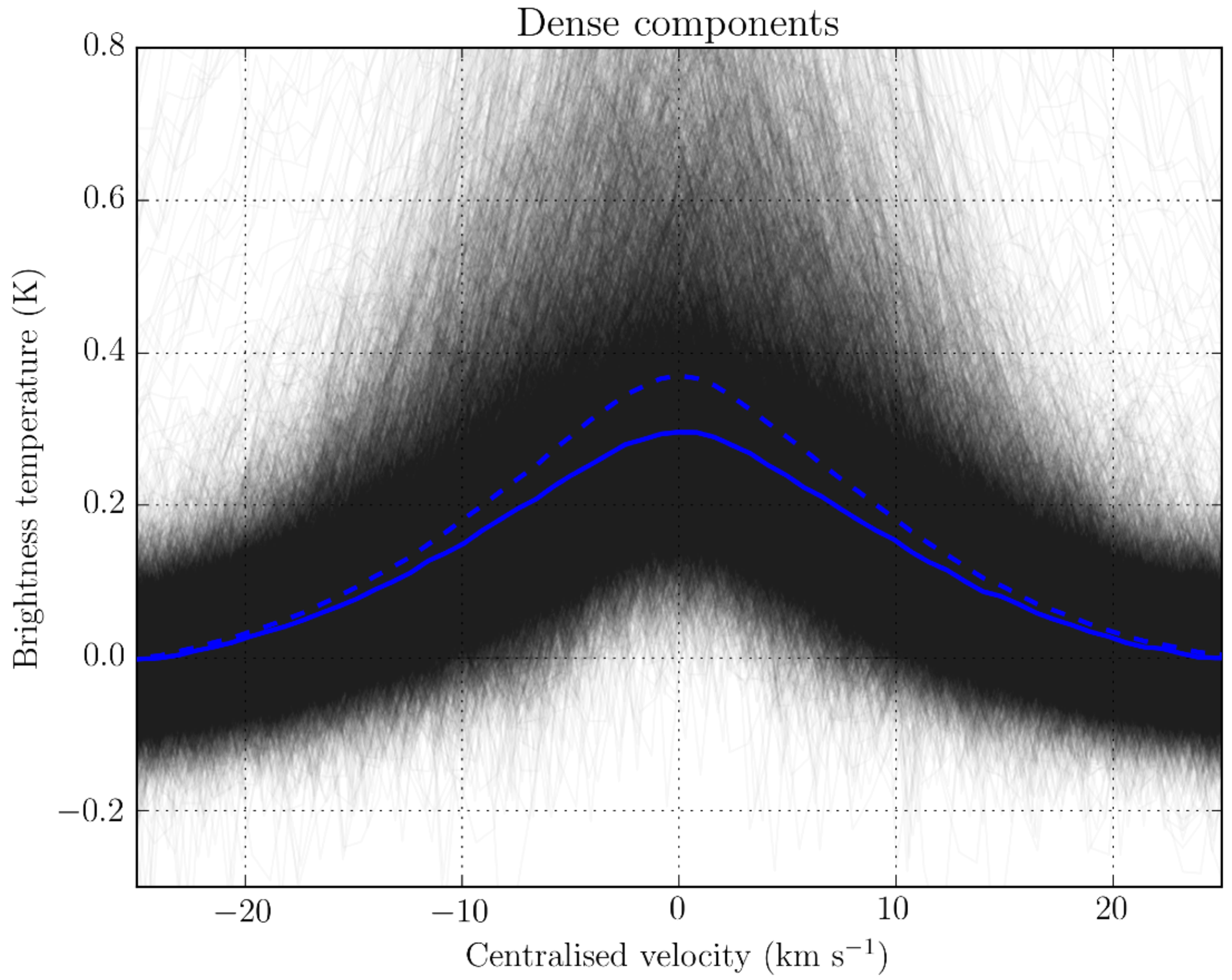
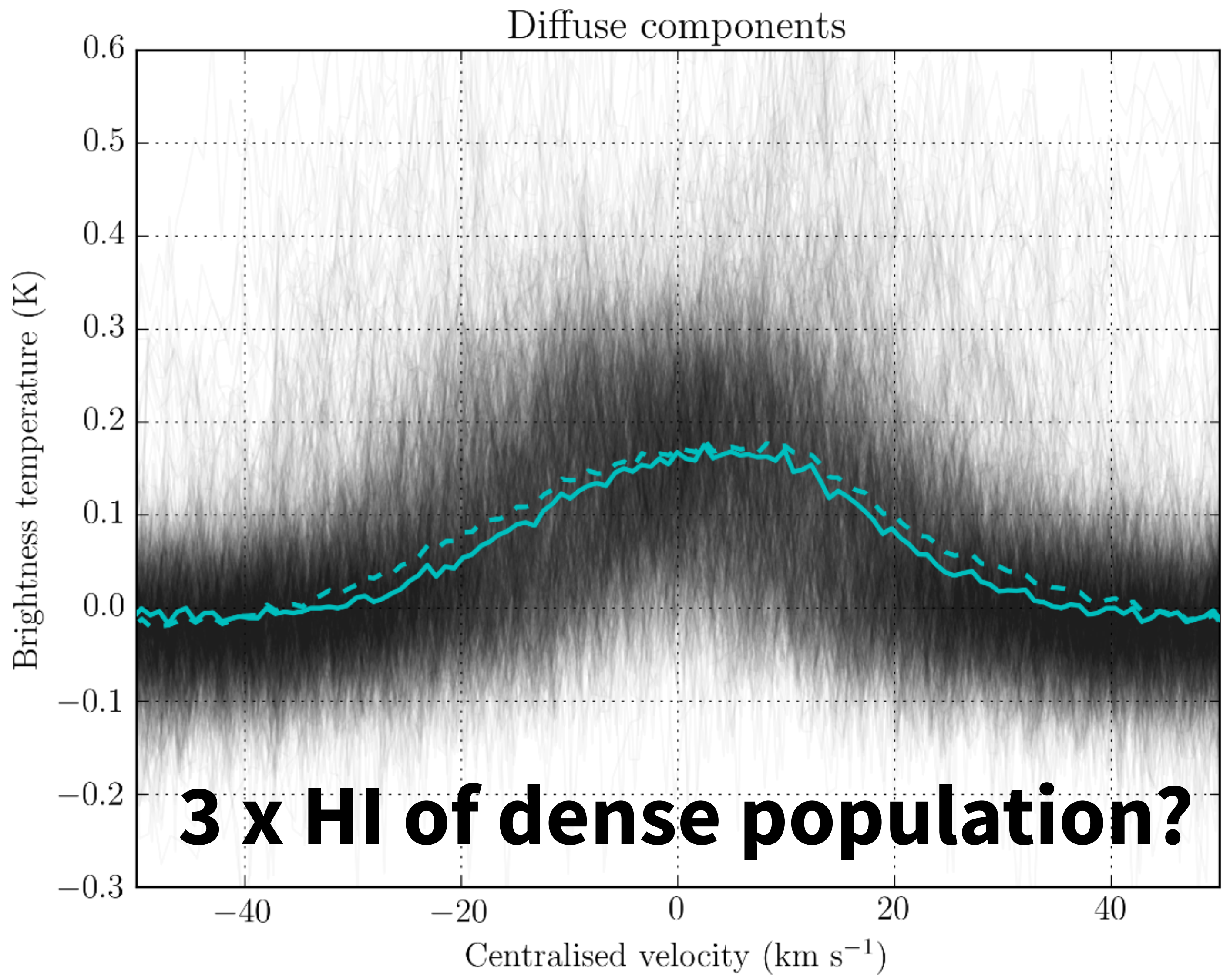
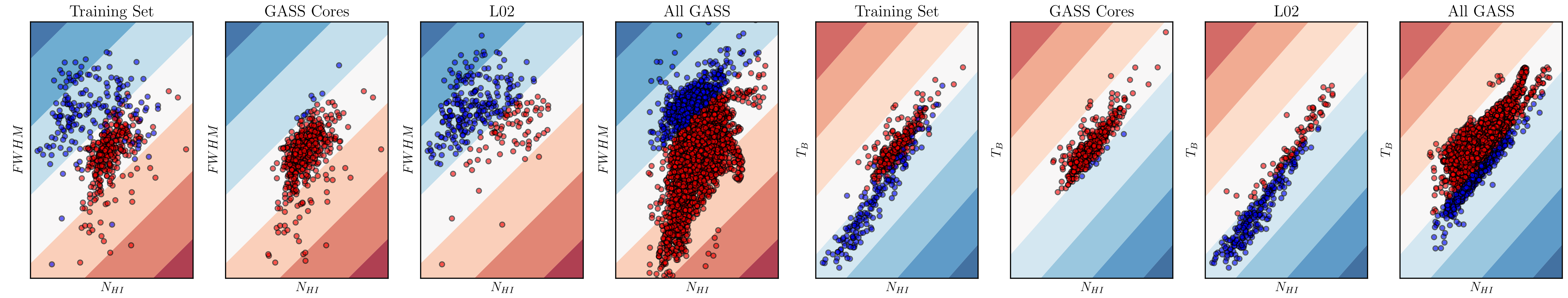
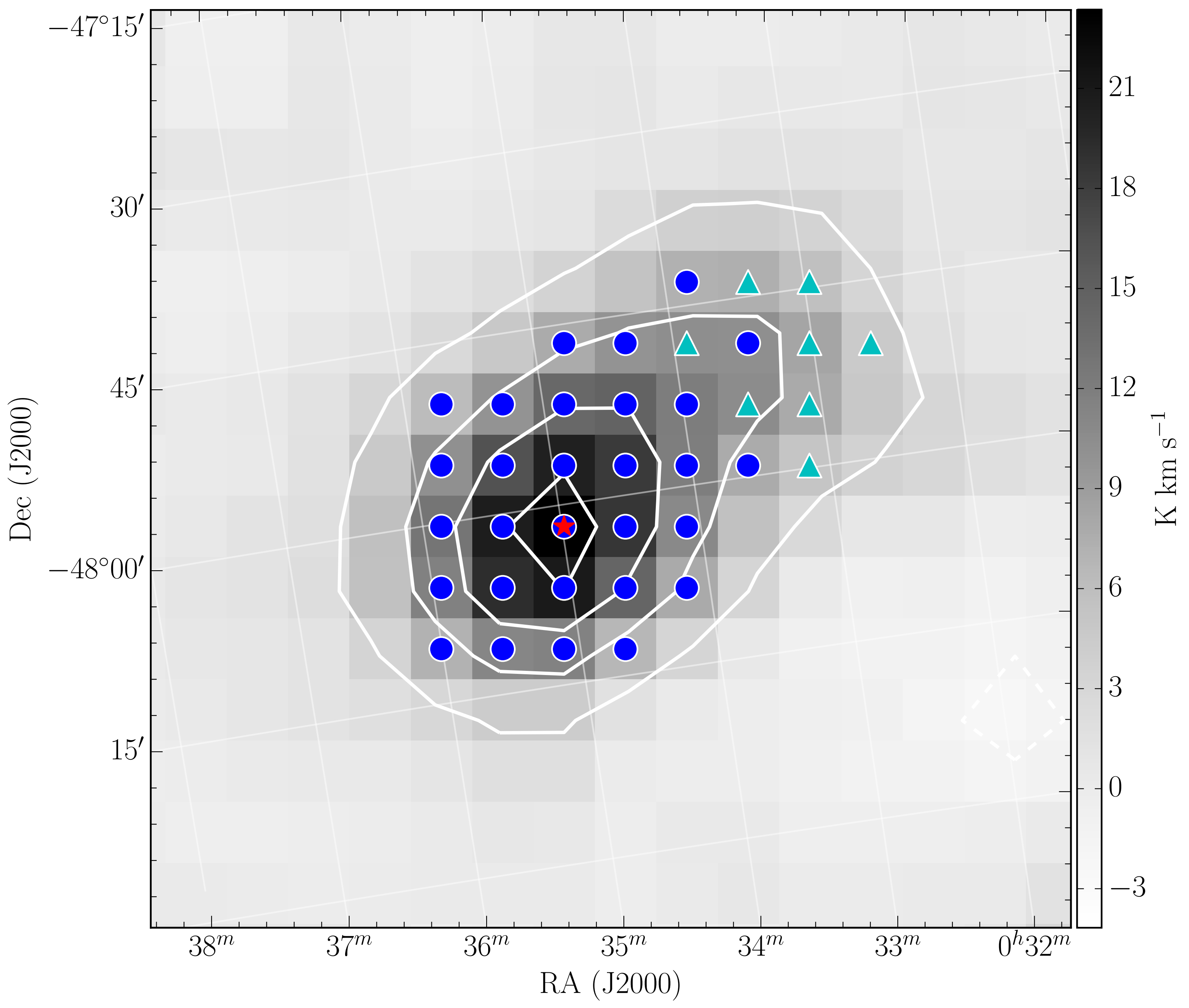
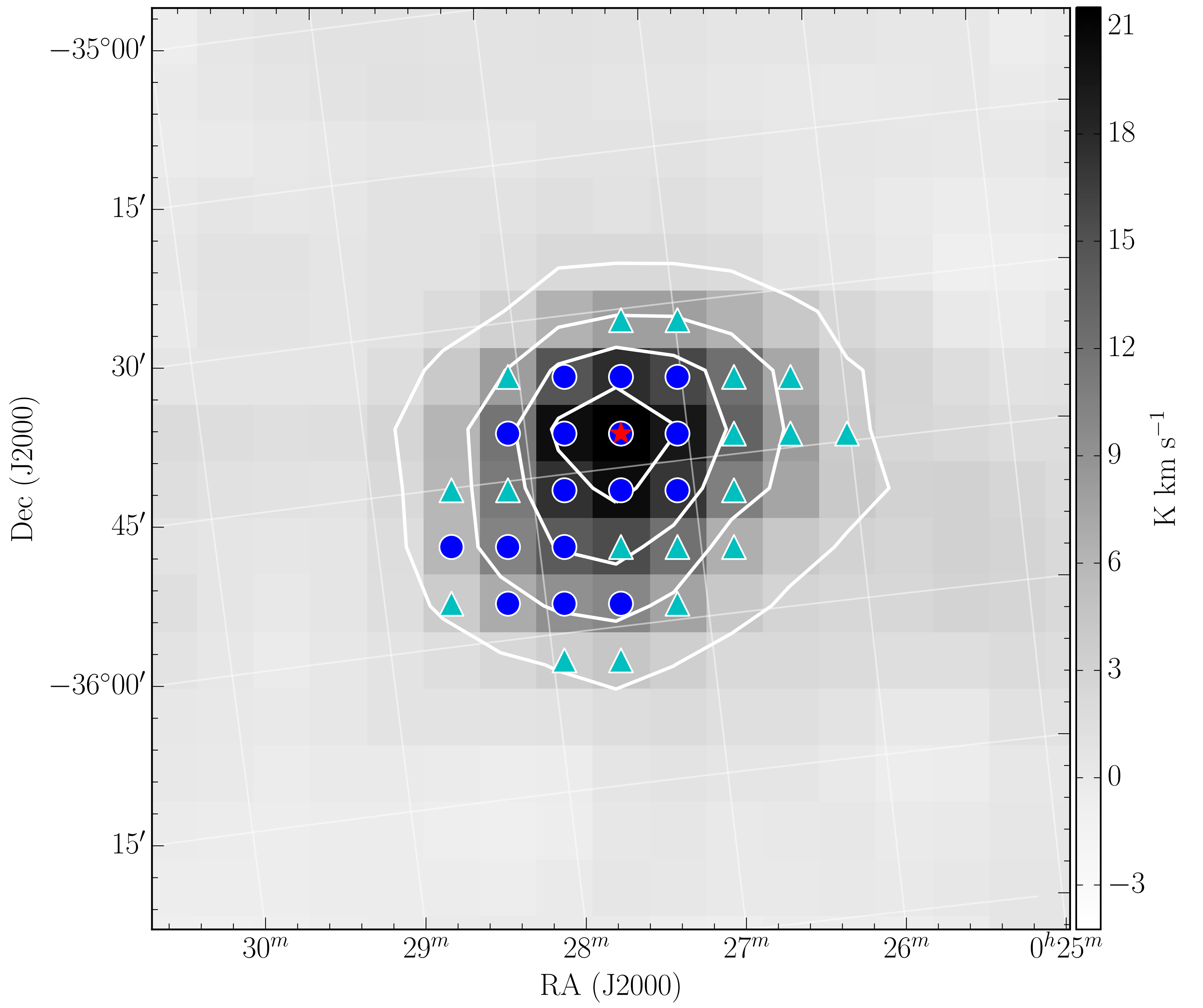




3 x HI of dense population?

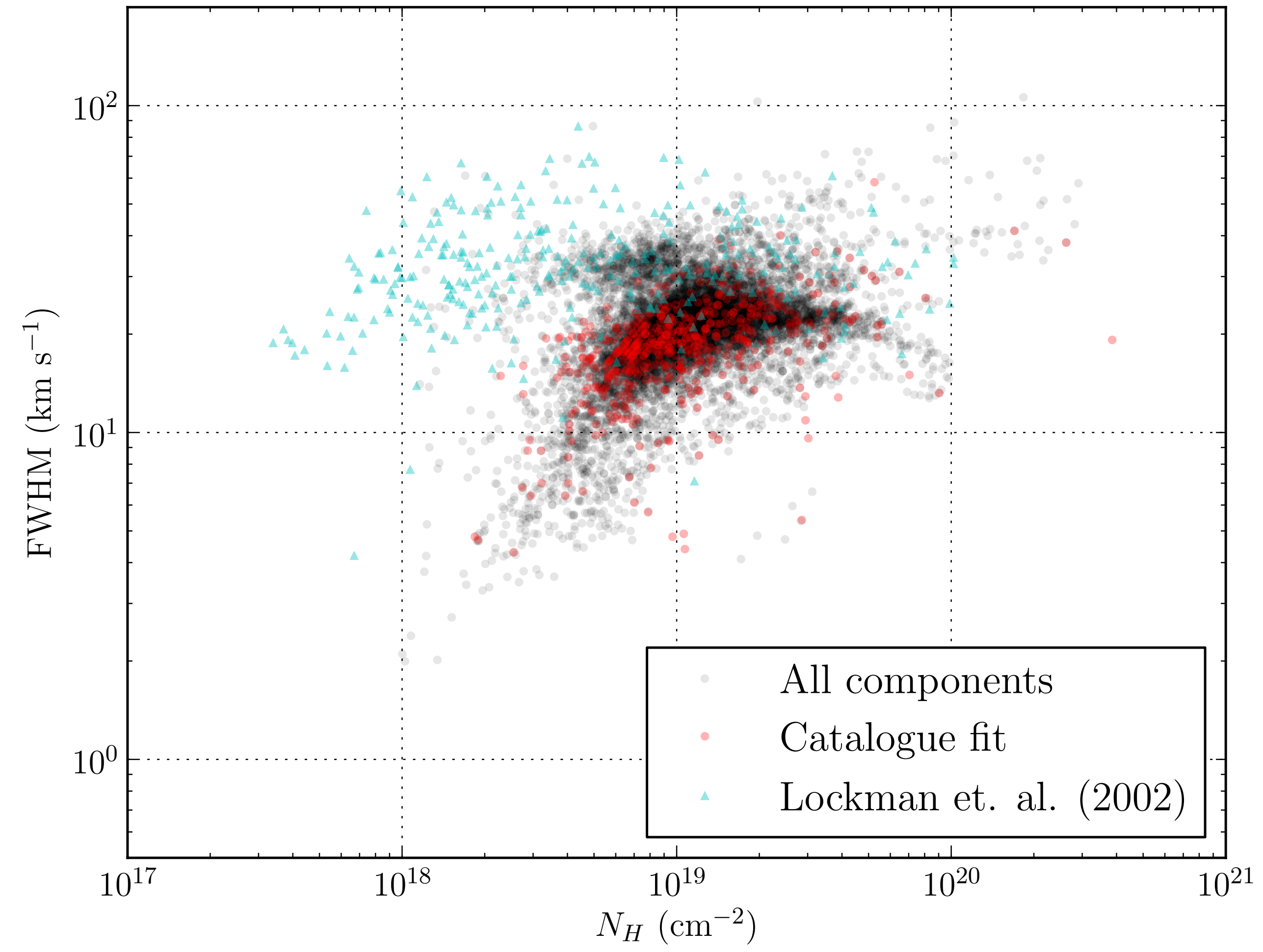


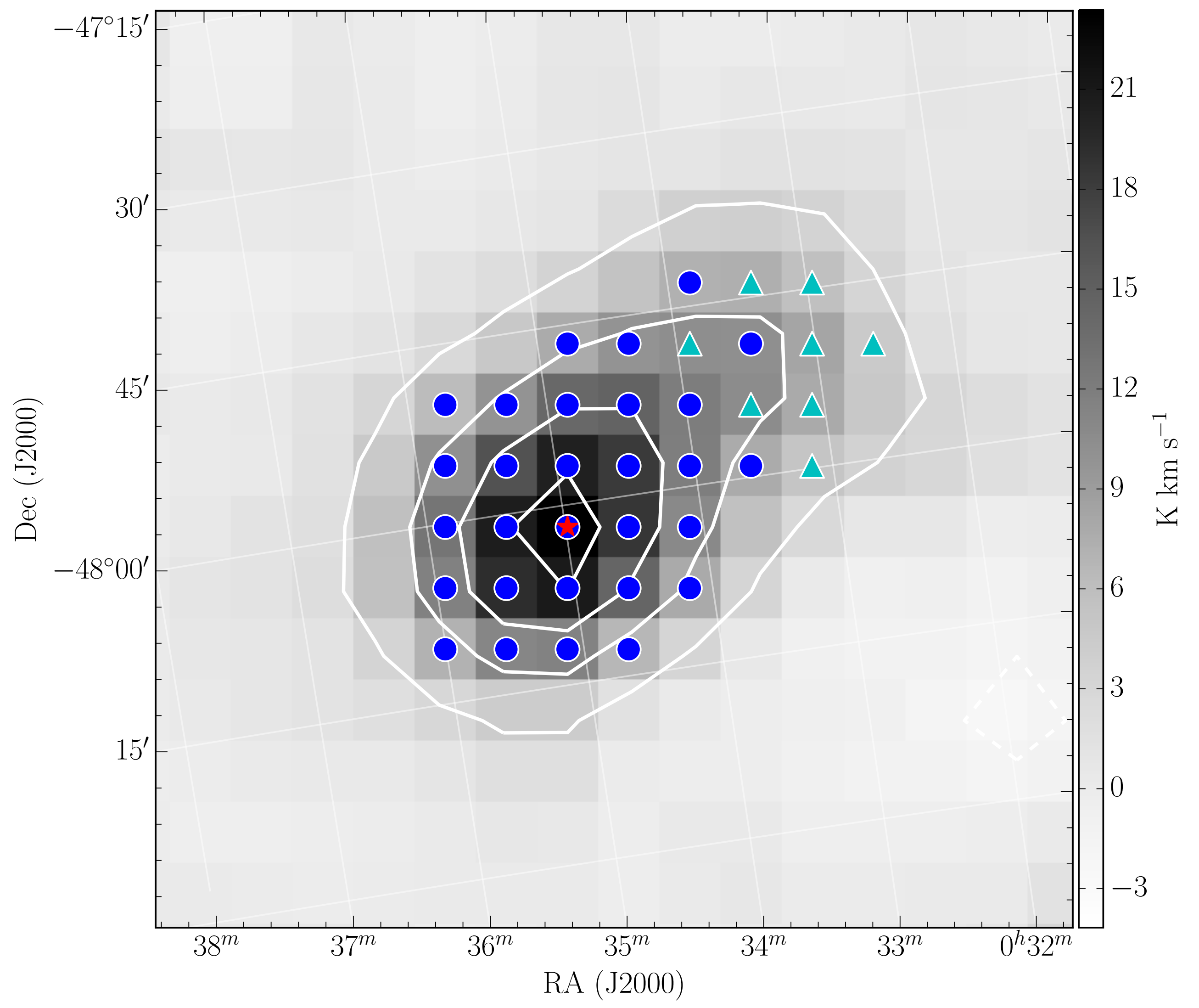




A SWISH with Parkes

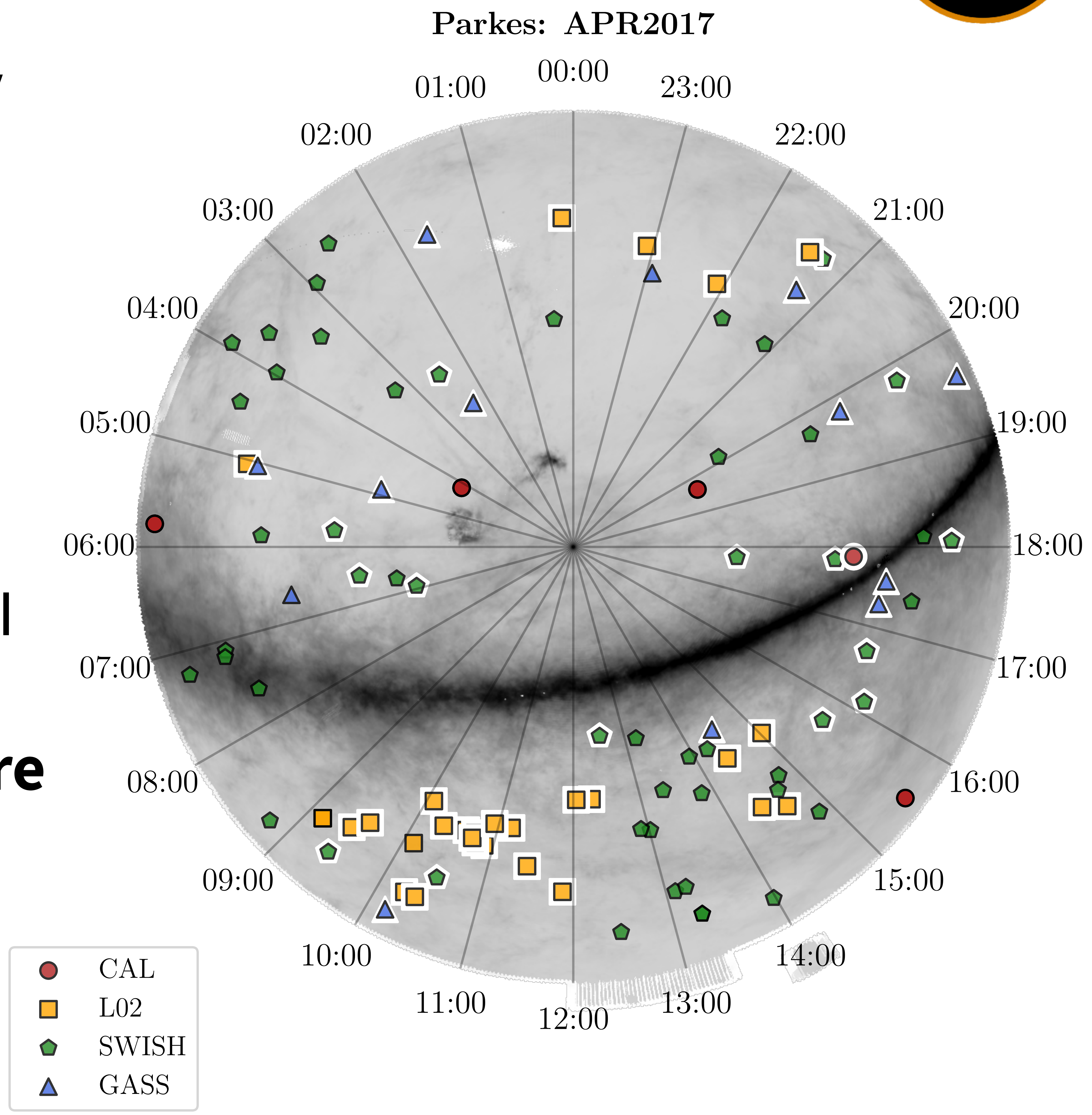
- **Moss+2017**: we found evidence for two types of HI in the spectra of high velocity clouds
- This led to the conclusion that there was **more HI in the Milky Way halo** than previously believed — SWISH (**Survey of Weak Intensity Southern HI)** will help illuminate this gas!
- **Team**: V. Moss, N. McClure-Griffiths, D.J. Pisano, E. di Teodoro, J. Lockman, D. Price, G. Rees, J. Peek, A. Fox, J. Blanchard, J. Dawson, T. Marshall
- **~100 hr** with Parkes last year (Apr/Sep 2017), and **~170 hr** in the current semester (Jun/Aug 2018)



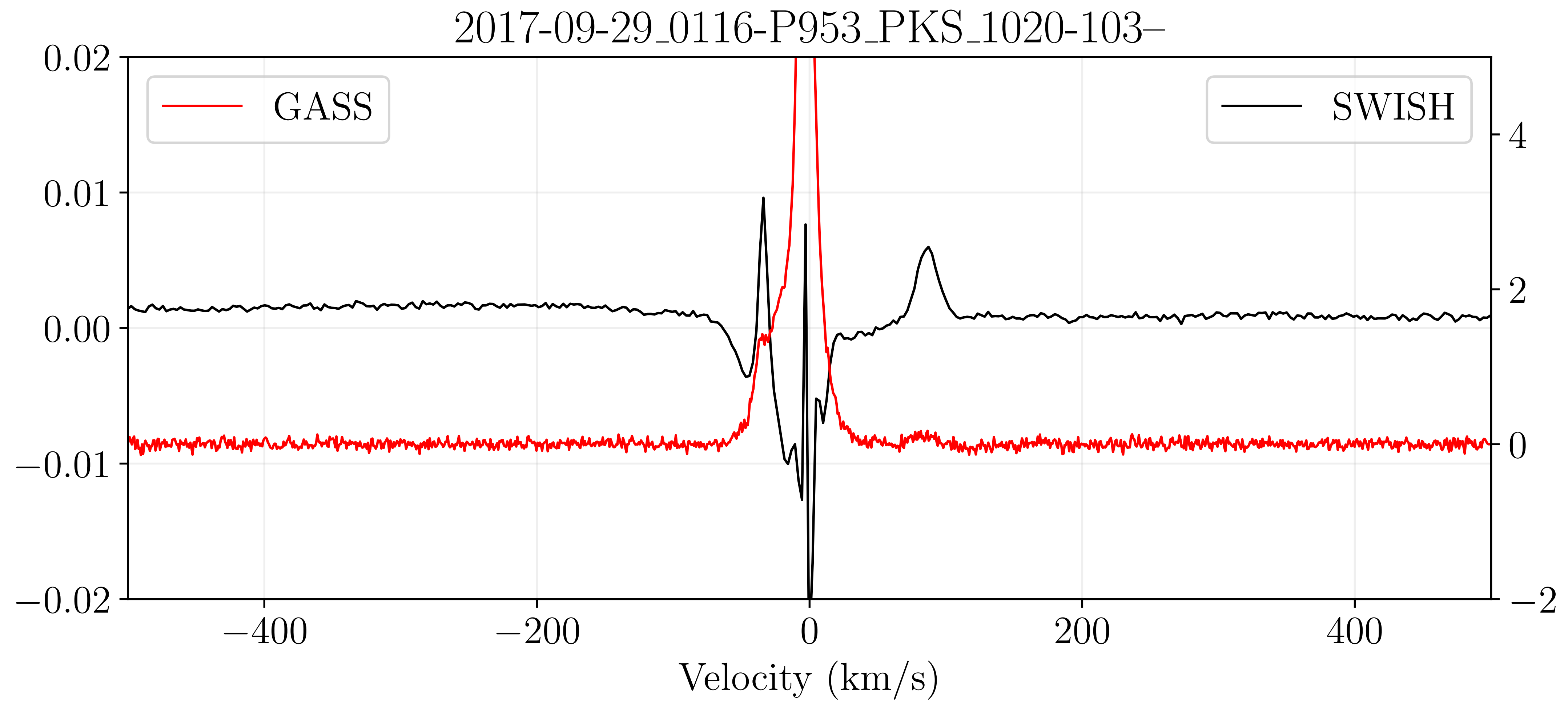


Goals of SWISH

- Measure **northern sightlines** to see how they compare (83 sightlines in total)
- Measure sightlines towards **known HI clouds** based on Galactic All Sky Survey data
- Measure sightlines that appear **“blank”** in GASS to see whether we detect faint diffuse HI
- **Outcome:** New understanding of the **structure** and **nature** of our Galactic halo, and how the Milky Way gets its gas!
- Complementary follow-up: **GBT**, ***HST***, more!



SWISH-100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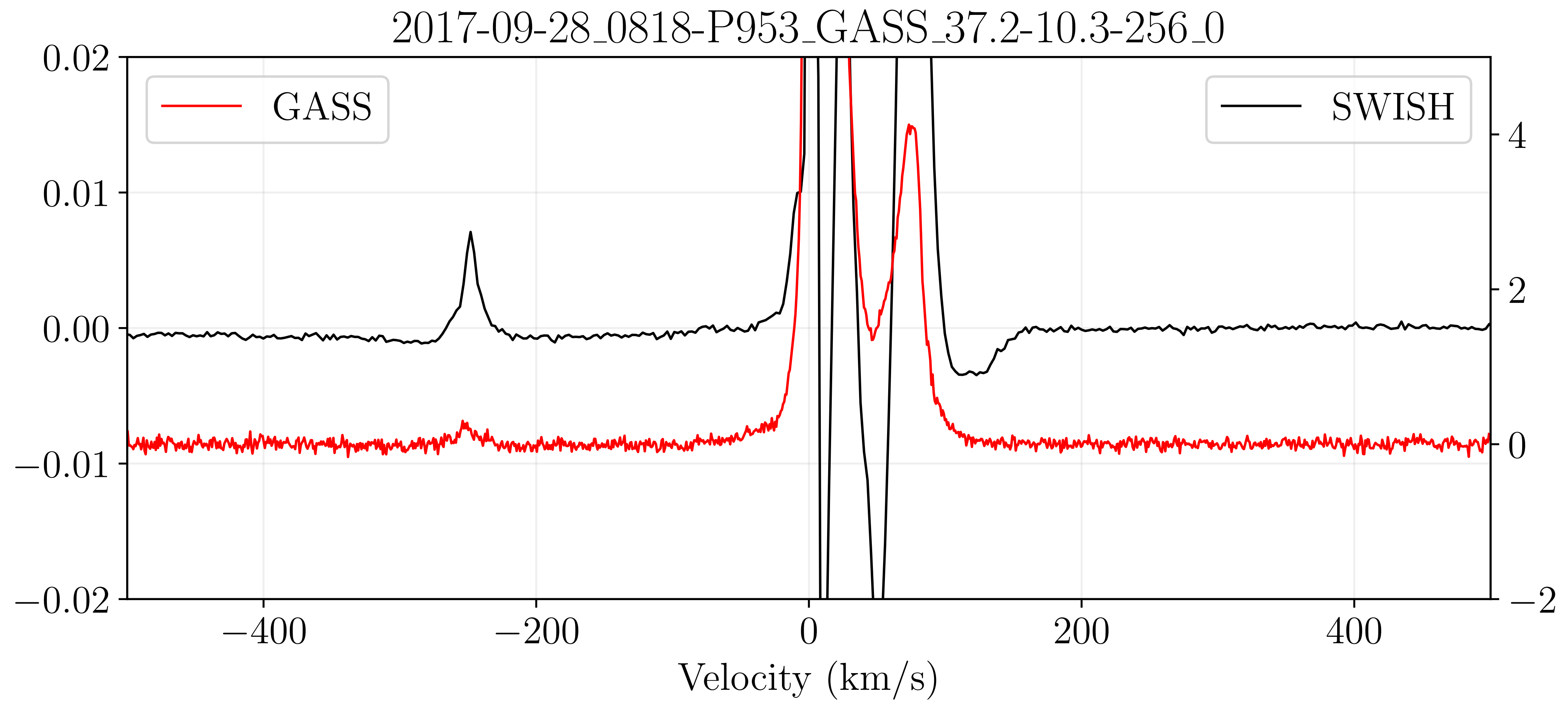
GASS
SWISH
Velocity (km/s)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GASS
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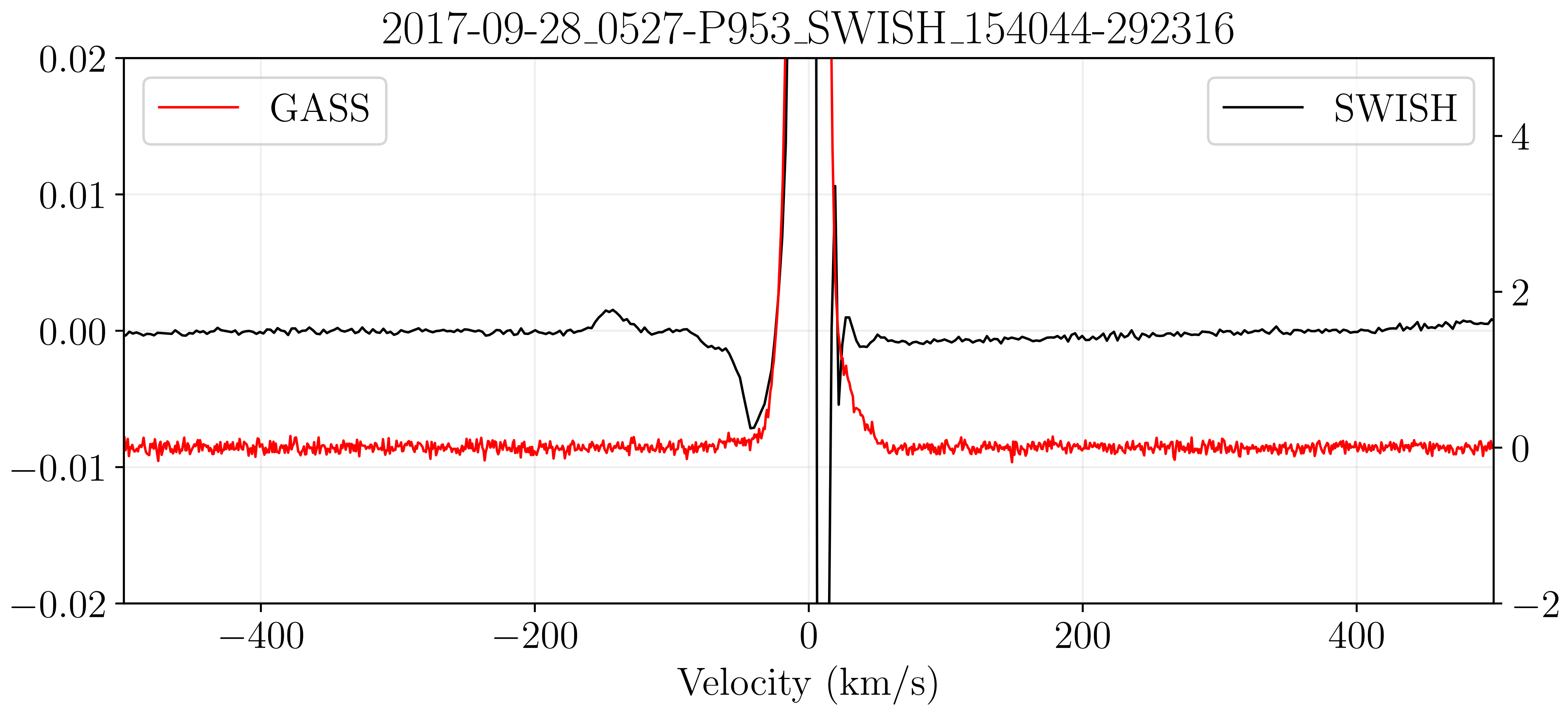
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GASS
SWISH
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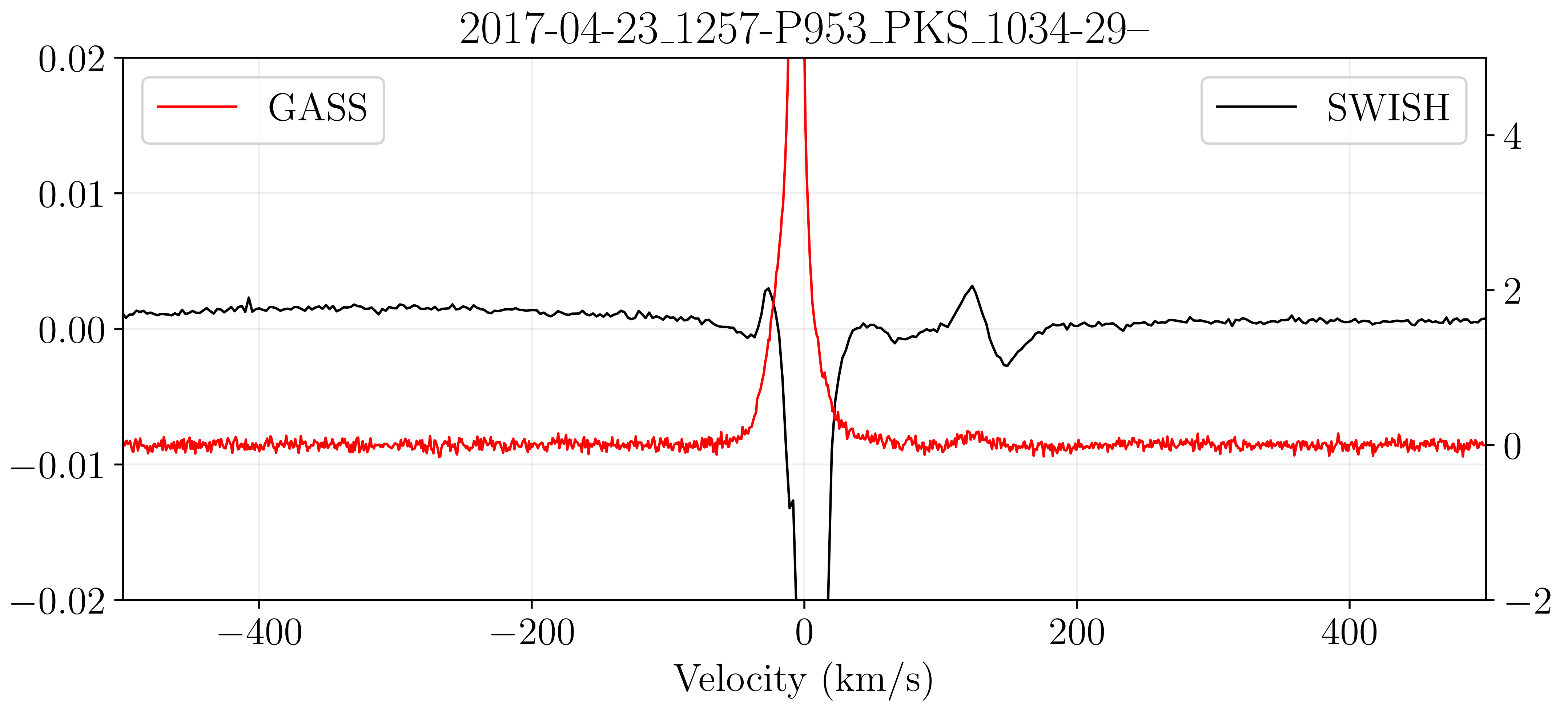
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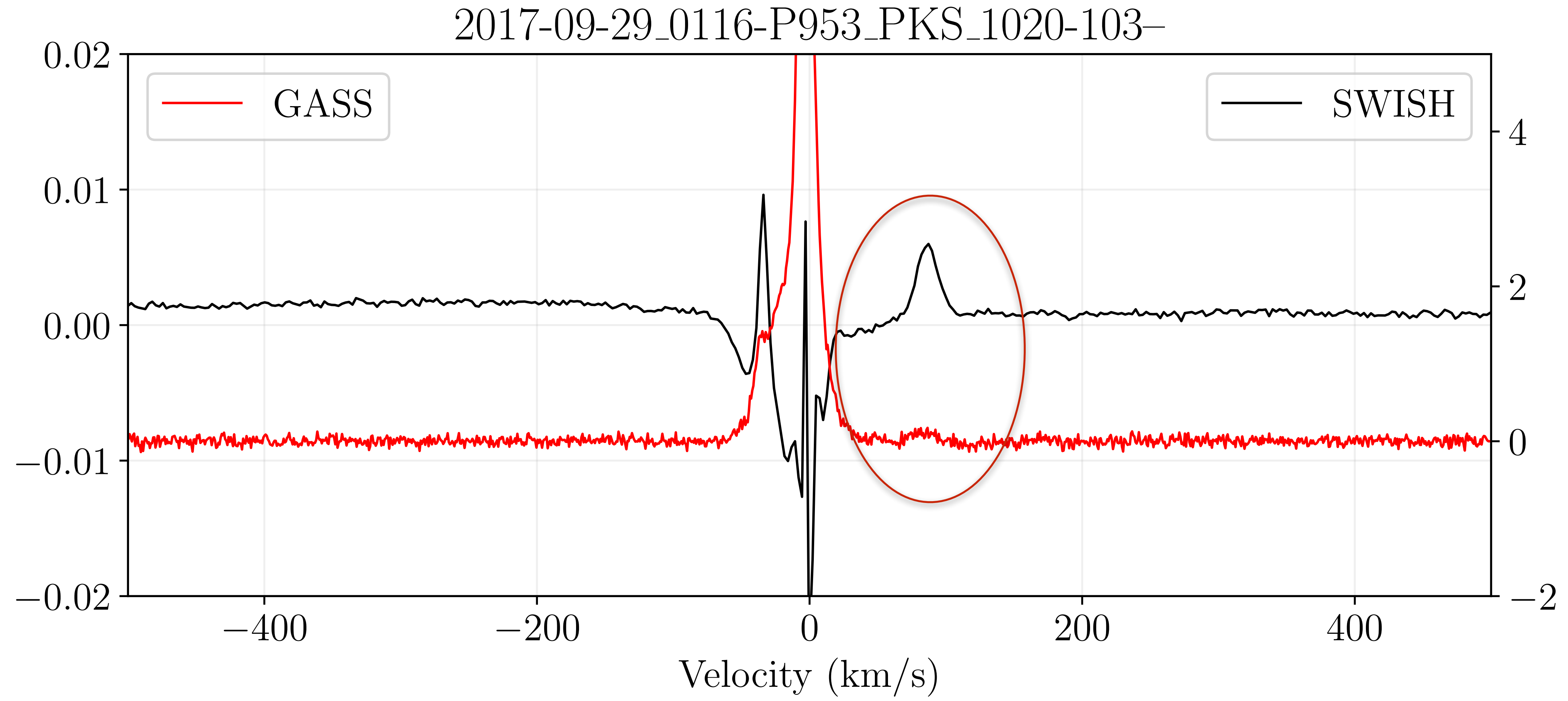
GASS
SWISH
Velocity (km/s)

SWISH-100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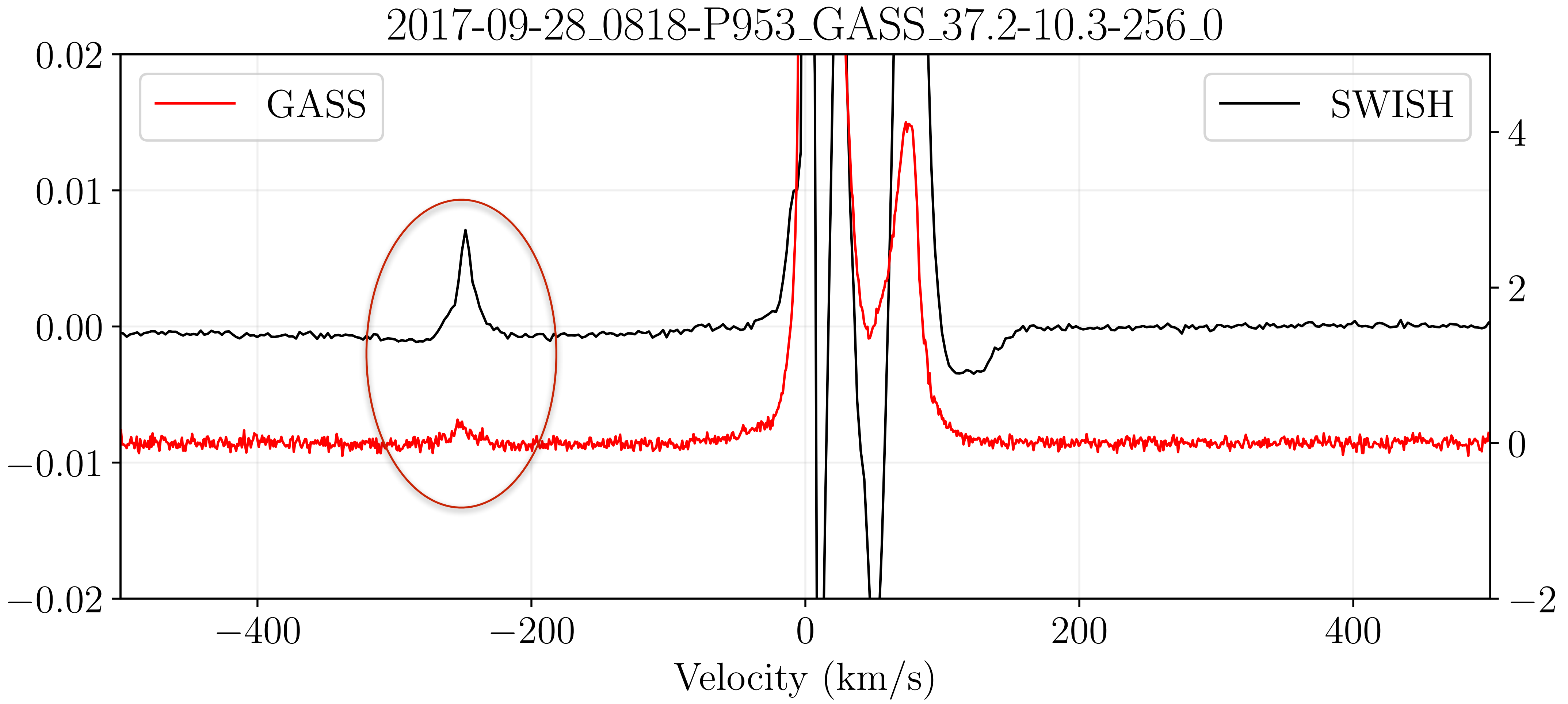
Velocity (km/s)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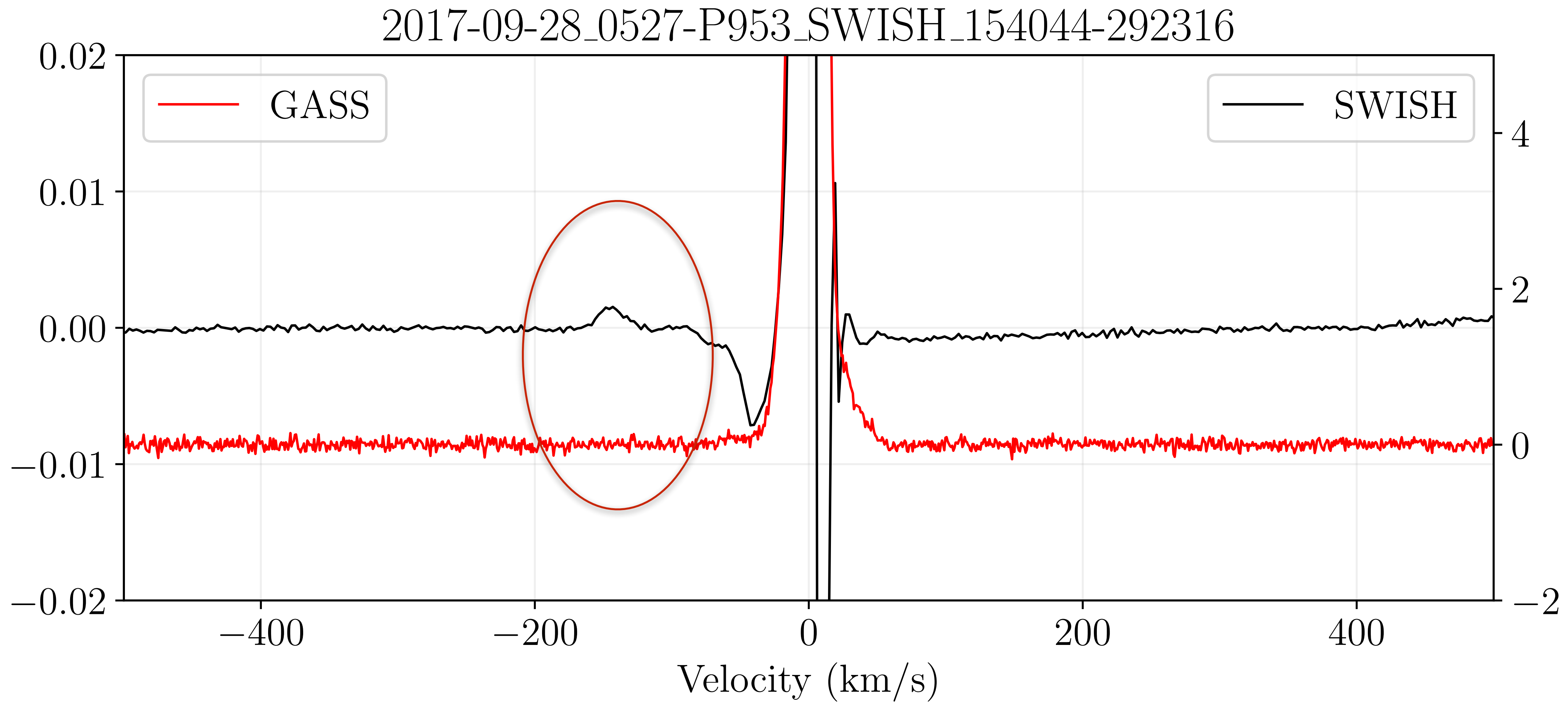
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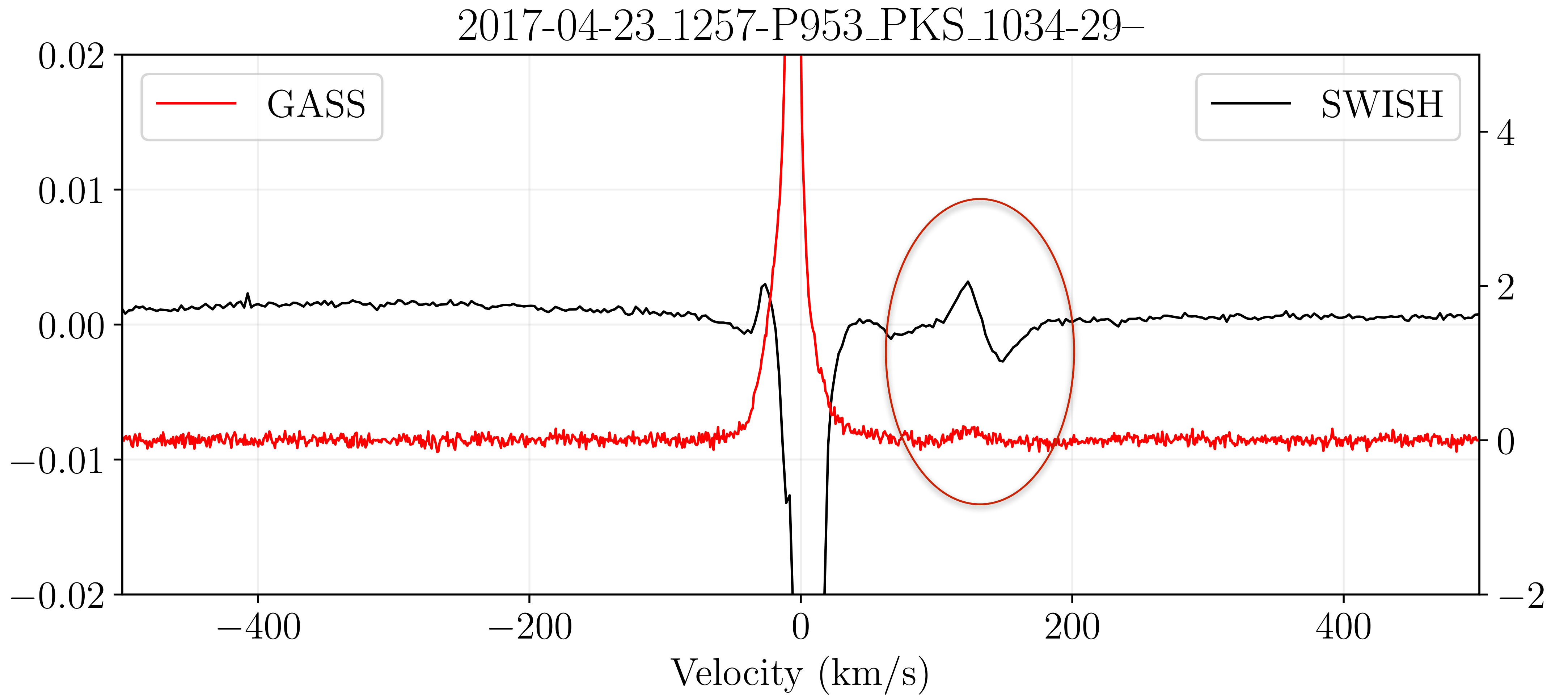
Velocity (km/s)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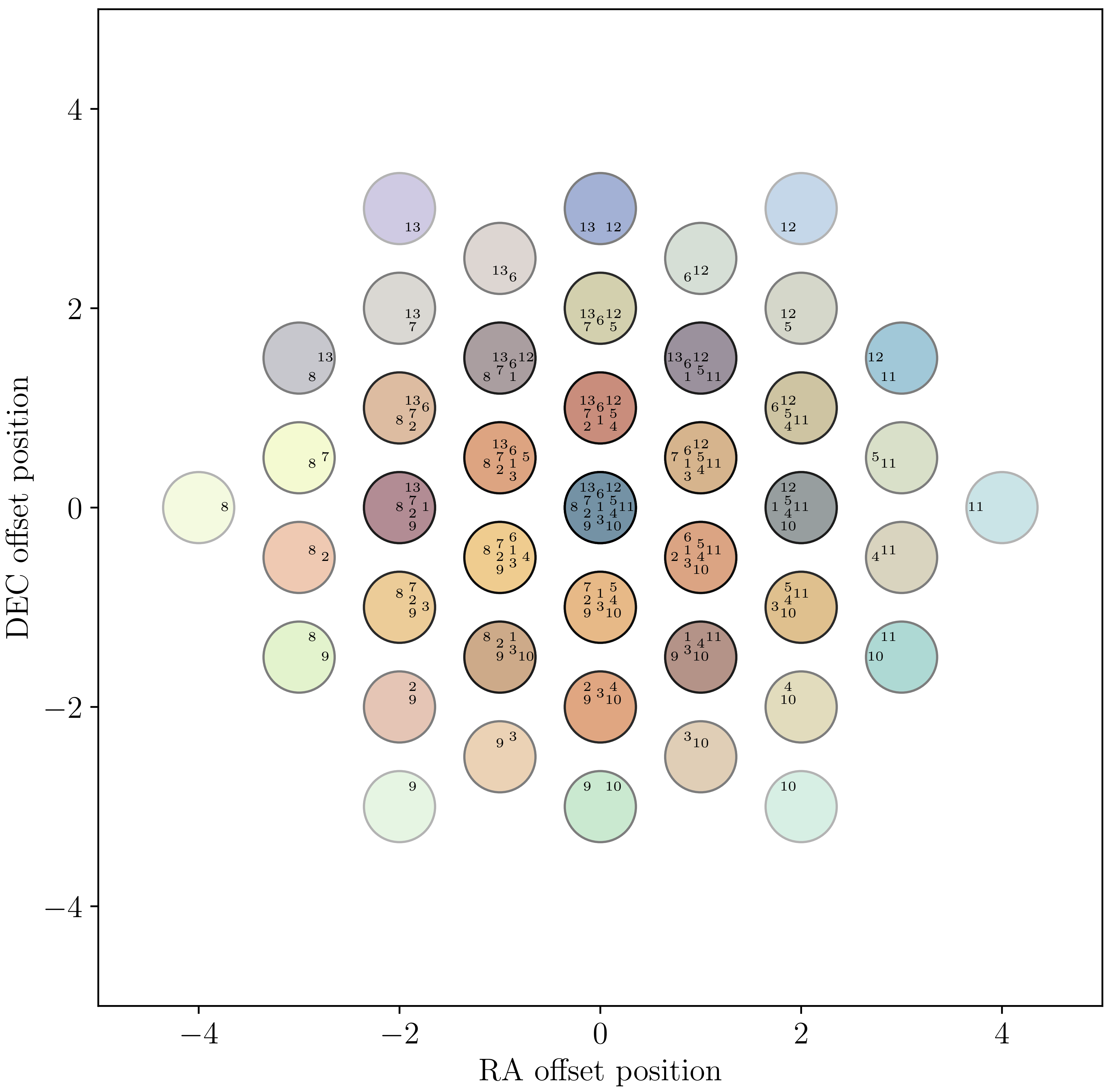
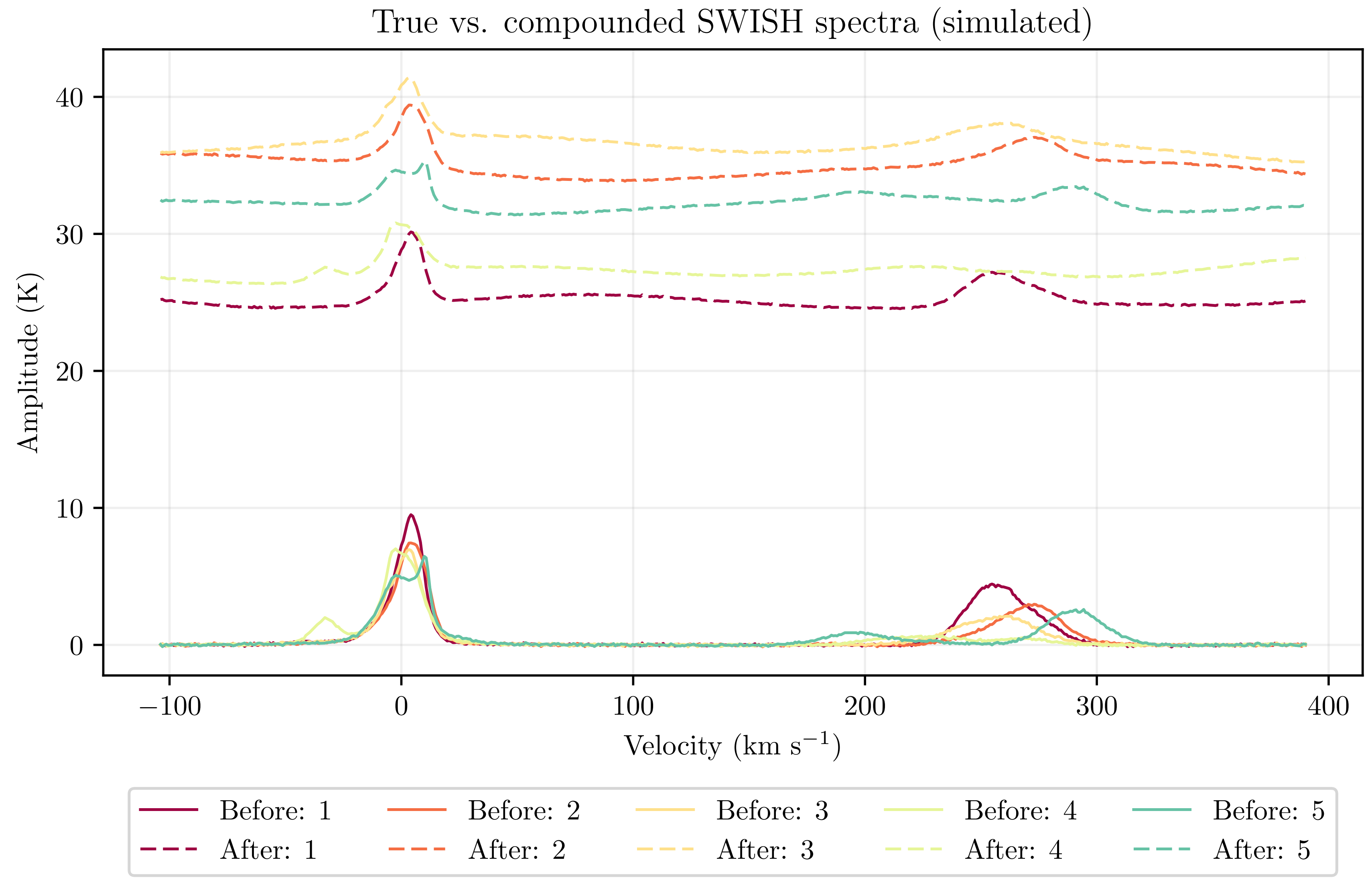
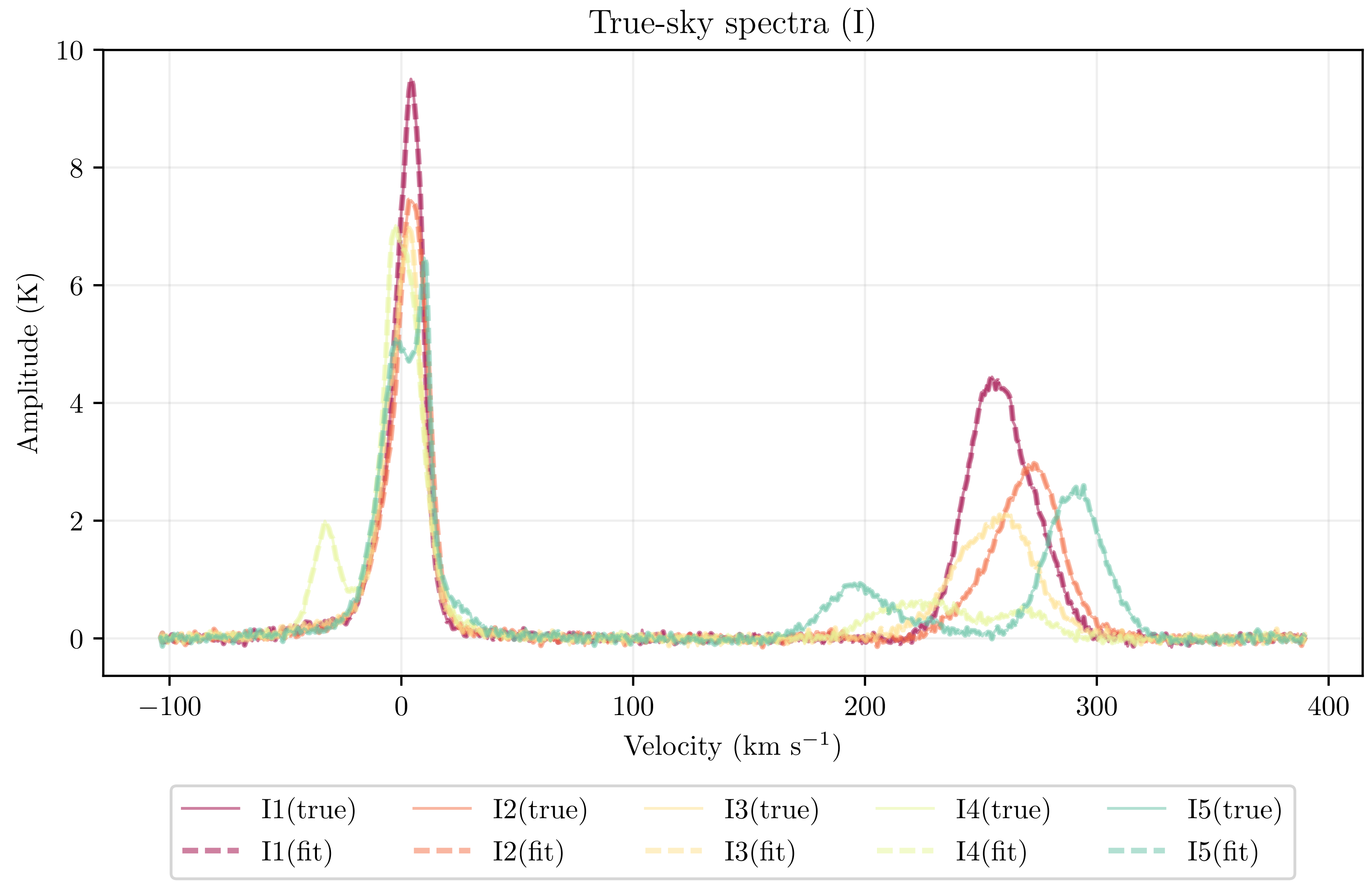
Velocity (km/s)

Absolute self-calibration?







Environment of sightlines

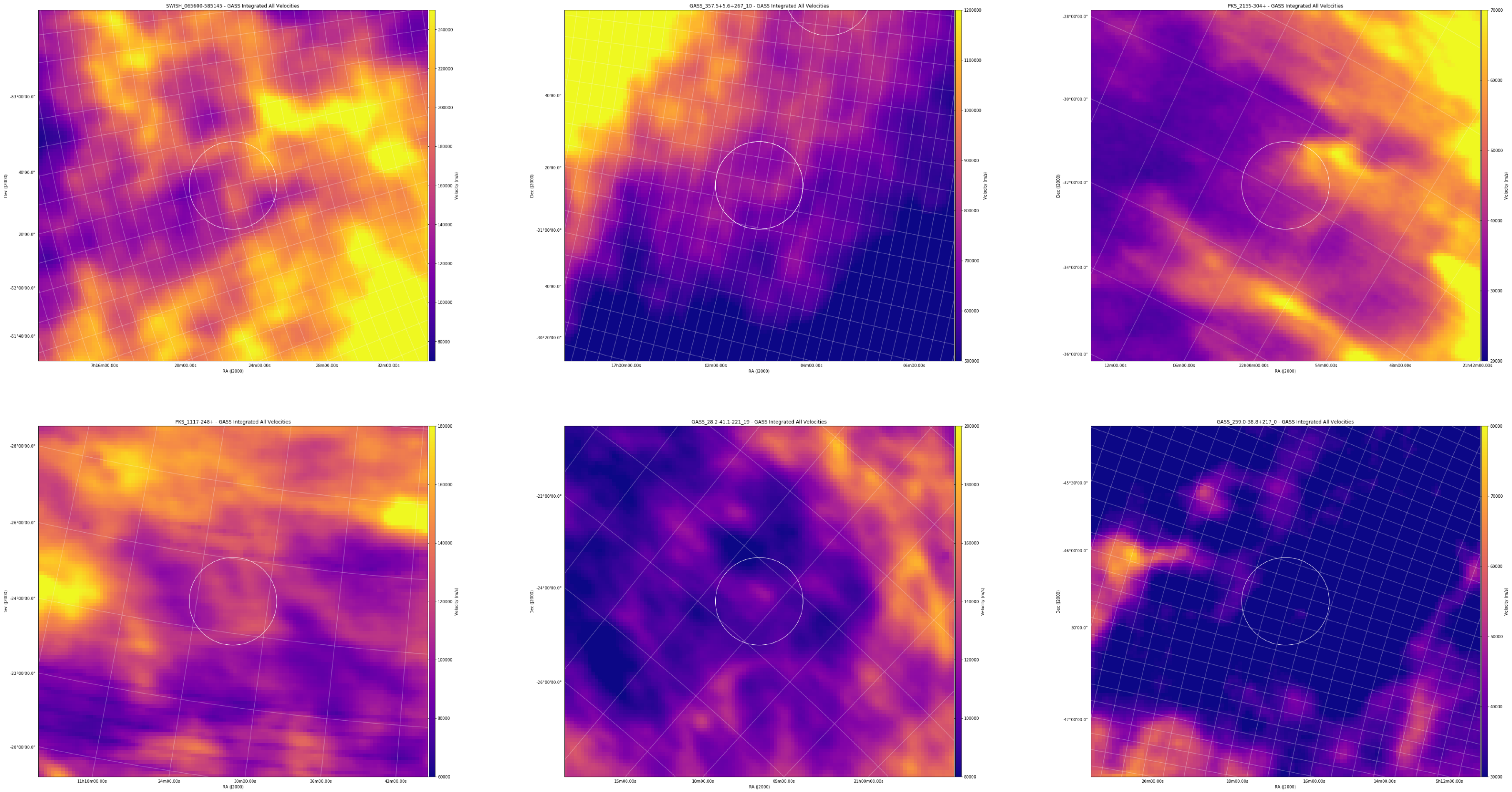
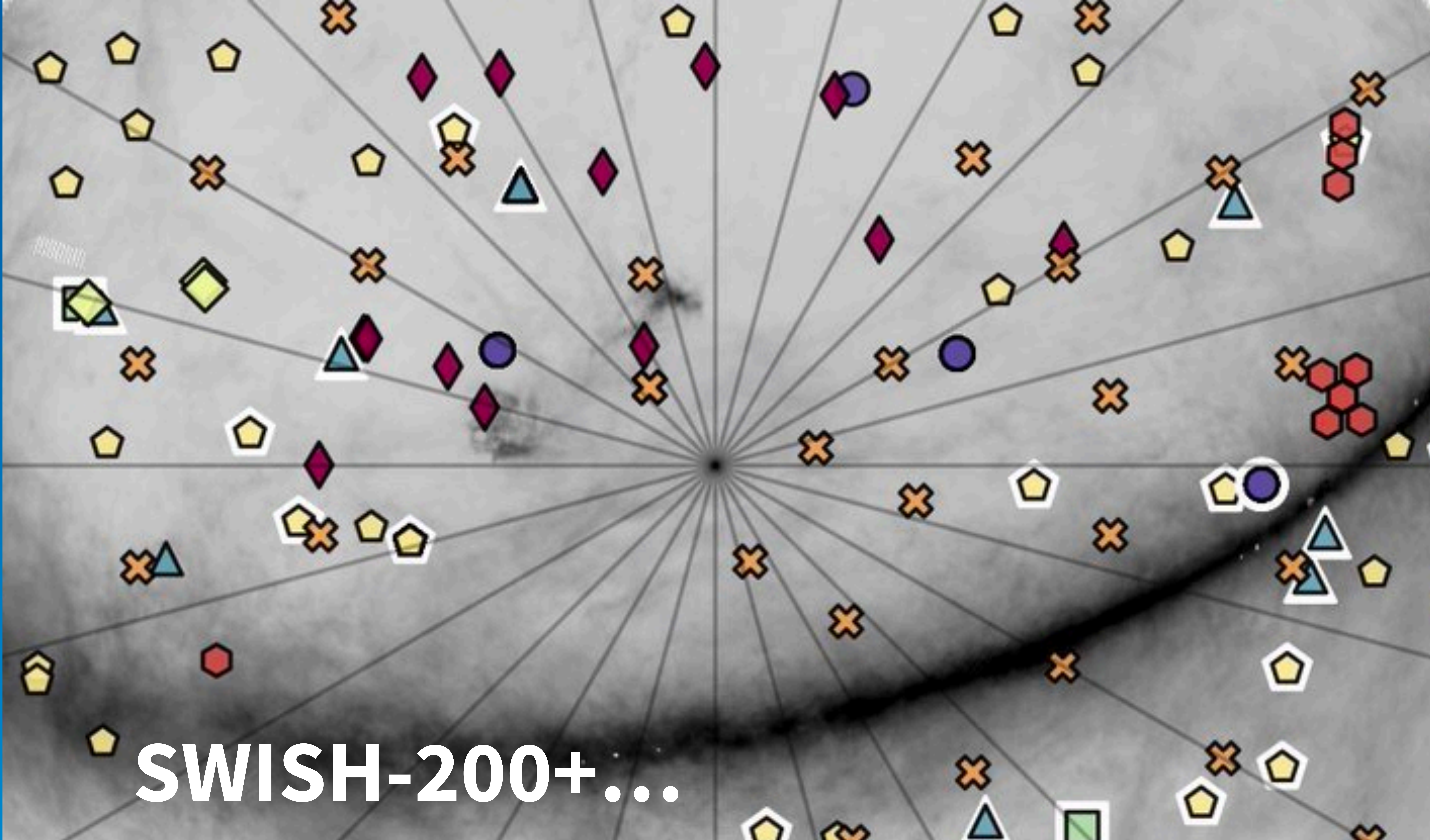


Image credit: T. Marshall



SWISH-200+...