Abstract. In 1998 several papers claim the detection of an ubiquitous gaseous phase within the Galactic halo. Here we like to focus on the detections of X-ray emitting gas within the Galactic halo as well as the discovery of a pervasive neutral Galactic halo gas. We discuss critically the major differences between the recent publications as well as the limitations of the analyses.

1. The main constituents of the ISM

The detection of neutral interstellar clouds at large \( z \) -distances (Münch 1957) led to the hypothesis of a hot gaseous Galactic halo (Spitzer 1956). This high temperature (\( T \approx 10^6 \) K) low volume density gas was proposed to confine the neutral clouds high above the Galactic disk. Alternatively, a low temperature, almost neutral halo (\( T \approx 10^4 \) K) was postulated by Pikelner & Shklovsky (1958). Their model predicted emission lines of neutral species with velocity dispersions of 70 km s\(^{-1}\) due to turbulent motions.

In the early fifties optical polarization studies revealed that the Galaxy hosts an interstellar magnetic field, with a field strength of a few \( \mu \)G. This is, on the average, oriented parallel to the Galactic disk. Several years later, radio continuum surveys (Beuermann et al. 1985) gave clear evidence for radio synchrotron emission originating at distances of a few kpc above the Galactic plane. This indicates that magnetic fields are also present within the Galactic halo. Already in 1966 Parker pointed out that magnetic fields must be associated with gaseous counterparts.

UV absorption line measurement with the Copernicus satellite showed the presence of highly-ionized species within the Galactic halo. However, the detection of an ubiquitous gaseous component was not easy to establish. It took nearly 40 years, since Spitzer’s prediction. The ROSAT all-sky survey revealed the presence of an ubiquitous hot X-ray emitting plasma within the Galactic halo. Pietz et al. (1998) and Kerp et al. (1999) showed that the X-ray emitting halo gas is smoothly distributed across the whole sky. They performed a quantitative correlation the new Leiden/Dwingeloo HI 21-cm line survey and the ROSAT all-sky survey. These analyses gave evidence that the Galactic halo is the brightest diffuse soft X-ray source.

Also recently, evidence for an extended neutral Galactic halo was presented by Albert et al. (1994). Lockman & Gehman (1991) found \( \text{H}^1 \) gas with a velocity dispersion of up to 35 km s\(^{-1}\) towards the Galactic poles, which was
interpreted as emission originating from a Galactic halo. Kalberla et al. (1998a) disclosed the existence of a pervasive $\text{H}_\text{i}$ component with a velocity dispersion of 60 km s$^{-1}$ from the Leiden/Dwingeloo Survey (LDS, Hartmann & Burton 1997).

The X-ray as well as the neutral gas within the Galactic halo are consistent with a hydrostatic equilibrium model of the Milky Way on large scales (Kalberla & Kerp 1998). The X-ray data constrain the extent of the gaseous halo, while the high-velocity dispersion component determines the pressure balance of the equilibrium model. According to this equilibrium model of Kalberla & Kerp (1998), the Galactic halo has a vertical scale height of 4.4 kpc and a radial scale length of 15 kpc. These values are in agreement with those derived from the distribution of the highly-ionized atoms within the Galactic halo published by Savage et al. (1997): $h_z(\text{Si}^\text{iv}) = 5.1(\pm 0.7)$ kpc, $h_z(\text{C}^\text{iv}) = 4.4(\pm 0.6)$ kpc and $h_z(\text{N}^\text{v}) = 3.9(\pm 1.4)$ kpc. Kalberla et al. (1998a) as well as Savage et al. (1997) find that the observational data are fitted best by assuming a co-rotation of the Galactic disk and halo in addition to a turbulent motion of the gas with an averaged velocity dispersion of 60 km s$^{-1}$. Taking all in one, it is possible to construct a consistent model of the Galactic halo, consisting of gas, magnetic fields and cosmic rays.

In this paper we discuss the evidence for a gaseous halo in some detail. In Sect. 2 we describe observational evidence for the existence of soft X-ray plasma within the Galactic halo. In Sect. 3 we focus on H$\text{i}$ observations and model calculations of the Galactic disk/halo. In Sect. 4 we discuss the stability of a multi-phase disk-halo system.

2. X-ray emission from the halo

Since the first detection of the diffuse soft X-ray background in 1968 (Bowyer, Field and Mack) it was a matter of debate whether the radiation originates within the Galactic halo or in the local vicinity of the Sun. Because of the strong energy dependence of the photo-electric cross section on energy ($\sigma \propto E^{-3.3}$) the soft X-ray emission is strongly attenuated by the ISM on the line of sight. In the so called 1/4 keV band the cross section is about $\sigma = 0.5 \times 10^{-20}$ cm$^2$; thus, towards most of the high latitude sky we have at least an opacity of unity.

With the ROSAT X-ray telescope it was possible to study the diffuse soft X-ray background emission on a high signal-to-noise ratio. The angular resolution of 30" was sufficient to reveal individual shadows of clouds in front of an X-ray emitting source.

Here, we like to compile the major findings of two recent papers on the Galactic X-ray halo. Both are based on the ROSAT all-sky survey data, both assume that the soft X-ray background radiation is a superposition of the local hot bubble, the Galactic halo and extragalactic background emission. Despite these similarities, they derive a totally different Galactic halo X-ray intensity distribution. What may cause these differences and what are the implications?

The data-set: Snowden et al. (1998) analyzed ROSAT 1/4 keV band data, while Pietz et al. (1998) studied the X-ray intensity distribution of the ROSAT 3/4 keV and 1/4 keV energy band. Because of the strong energy dependence of the absorption cross section, the 3/4 keV emission is only attenuated weakly, while the 1/4 keV photons are strongly absorbed by the same amount of in-
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stellar matter. For example a neutral hydrogen column density of $N_{\text{H}_1} = 1.5 \times 10^{20} \text{ cm}^{-2}$ attenuates the 3/4 keV radiation by only 15%, while the same column density absorbs 75% of the 1/4 keV photons. This major difference indicates, that the 3/4 keV is more appropriate to study the intensity distribution of a hot Galactic halo gas.

**The plasma temperature:** Because of the moderate energy resolution of the ROSAT PSPC detector, the practical way to determine the plasma temperature across the Galactic sky is to evaluate energy-band ratios. Especially the 1/4 keV to 3/4 keV band ratio is very sensitive to variations of the plasma temperature. A log($T[K]$) = 6.0 plasma will emit most of the photons in the 1/4 keV range, but a minor increase in temperature, for instance to log($T[K]$) = 6.3 produces about an order of magnitude more 3/4 keV photons than the log($T[K]$) = 6.0 plasma.

Snowden et al. (1998) derived a LHB temperature of log($T[K]$) = 6.07 while the Galactic halo temperature is lower and about log($T[K]$) = 6.02. Both plasma do not contribute significantly to the 3/4 keV energy range. In contrast to this finding, Pietz et al. (1998) claimed that the temperature of the LHB is about log($T[K]$) = 5.85 and that of the halo log($T[K]$) = 6.2. The LHB plasma does not emit significant amounts of 3/4 keV photons, while the halo plasma accounts for about half of the observed 3/4 keV emission. Accordingly, the gap between the observed 3/4 keV intensity and the known sources of diffuse 3/4 keV radiation, already identified within the Wisconsin survey (McCammon & Sanders 1990), is overcome by the approach of Pietz et al.

**The method:** Snowden et al. fitted scatter-diagrams (H1 column density $N_{\text{H}_1}$ versus X-ray intensity $I_{\text{X-ray}}$). For this approach it is necessary to assume an *a priori* plasma temperature to determine the photo-electric cross section of the ISM. Snowden et al. analyzed the ROSAT 1/4 keV radiation splitted into the so-called R1 and R2 energy bands. In the second step, they derived the temperature of the plasma components, by evaluating the R1/R2 energy-band ratio. The R1/R2 band ratio is only a weak function of temperature. Using the same plasma temperatures as in the example above we find for log($T[K]$) = 6.0 a ratio R1/R2 = 0.9, while for log($T[K]$) = 6.3, R1/R2 = 0.6. The uncertainties within of the ROSAT R1 and R2 band are about 10%, accordingly the R1/R2-band ratio has a statistical uncertainty of about 20%. Thus, it is a difficult task to constrain the plasma temperature by analyzing the R1/R2-band ratio. In the final step, they derived the Galactic halo intensity by inverting the radiation transfer equation. Within the 1/4 keV band the product of $N_{\text{H}_1}$ and $\sigma$ is close to or larger as unity, the quotient $I_{\text{halo}} = \frac{I_{\text{LHB}} - I_{\text{ex}} e^{-\sigma N_{\text{H}_1}}}{e^{-\sigma N_{\text{H}_1}}}$ becomes uncertain, because the divisor is a small value.

The approach of Pietz et al. was totally different. They found evidence for a large scale 3/4 keV intensity gradient between the Galactic center and the Galactic anti-center direction. Because the 3/4 keV radiation is only to a minor fraction attenuated by the Galactic interstellar matter towards the high latitude sky, they attributed this gradient to a variation of the emissivity of the Galactic halo plasma. They modeled this 3/4 keV gradient and optimized the shape of the Galactic halo to fit the 3/4 keV diffuse X-ray background intensity distribution. The attenuation of the 3/4 keV radiation is much weaker than in the 1/4 keV energy range, but present. Pietz et al. estimated the Galactic halo plasma
temperature by the spectral fit of the diffuse X-ray background data of a deep pointed PSPC observation. This is the main source of uncertainty, because it is unknown whether this pointed observation is towards a representative direction or not. To overcome this source of uncertainty, they investigated the 1/4 keV to 3/4 keV energy ratio, which is, as shown above, a sensitive measure of the plasma temperature. They cross-correlated the 1/4 keV Galactic halo intensities of Kerp et al. (1999) with that of the modeled 3/4 keV sky and deduced a plasma temperature of log($T$[K]) = 6.2 ± 0.02 (compare their Fig. 10). In following step, they scaled the emissivity of 3/4 keV model to the 1/4 keV energy range.

The rôle of the extragalactic background radiation: The radiation transfer equation of Snowden et al. and Pietz et al. is the same. An important, but up to now not discussed diffuse soft X-ray component is the extragalactic background. The 1/4 keV to 3/4 keV energy-band ratio is not only a sensitive measure of the plasma temperature, but also a measure for the brightness of the extragalactic background. As pointed out by Kerp & Pietz (1998), if the extragalactic background spectrum is steep $I_{\text{extra}}(E) \propto E^{-2}$ (Hasinger et al. 1993) and the intensity within the 1/4 keV band high $I_{\text{extra}} \simeq 4.4 \times 10^{-4}$ cts s$^{-1}$ arcmin$^{-2}$ (Cui et al. 1996), the quantitative analysis of the ROSAT energy-band ratios allows only a low Galactic halo plasma temperature (log($T$[K]) < 6.1). If one assumes a flatter extragalactic background spectrum ($I_{\text{extra}}(E) \propto E^{-1.5}$, Gendreau et al. 1995) and a fainter 1/4 keV intensity ($I_{\text{extra}} \simeq 2.3 \times 10^{-4}$ cts s$^{-1}$ arcmin$^{-2}$, Barber et al. 1996), a higher Galactic halo plasma temperature is consistent with the energy band ratios.

Snowden et al. adopt the steep spectrum high 1/4 keV intensity set of parameters, and found accordingly a low temperature halo. Moreover, this choice of parameters for the extragalactic background determines that 66% of the 3/4 keV diffuse X-ray emission is of extragalactic origin, while low plasma temperatures derived for the Galactic halo and the LHB cannot account for the rest of the 3/4 keV emission. Thus, a significant fraction of the 3/4 keV diffuse X-ray radiation is not investigated.

Pietz et al. used the flatter background spectrum and low intensities for the extragalactic background, the second set of parameters, which allows a higher temperature for the Galactic halo plasma. The difference between the 3/4 keV extragalactic background level (also 66% of the total observed 3/4 keV intensity) and the observed 3/4 keV intensity is attributed to the Galactic halo plasma. Apparently, the 3/4 keV gap is filled with the Galactic halo plasma emission.

The model predictions: Snowden et al. (1998) confirm the LHB model of (Snowden et al. 1990) only slightly modified because of the Galactic halo emission. In the Snowden et al. (1998) model the Galactic halo contains some patches of soft X-ray emitting halo gas, which are distributed across the high latitude sky. The 3/4 keV emission is not entirely explained by the model, because the gap between the extragalactic X-ray background intensity level and the observed intensity is still present.

The Pietz et al. model explains entirely the 3/4 keV and 1/4 keV X-ray background emission towards high latitudes. The derived Galactic halo plasma temperature of log($T$[K]) = 6.2 emits most of the soft X-ray photons in the 1/4 keV energy band. Accordingly, they scaled the emissivity of the 3/4 keV model to that of the 1/4 keV X-ray emission. They attribute the difference
between the large-scale averaged observed 1/4 keV and modeled 1/4 keV Galactic halo emission to the LHB. The derived LHB emission is smoothly distributed across the sky.

Conclusions: Snowden et al. confirmed the LHB model, in which a displacement of X-ray plasma and \( N_{\text{HI}} \) produces the apparent Galactic plane to Galactic pole X-ray intensity gradient. They found evidence for some low temperature soft X-ray emitting plasma patches within the Galactic halo gas. They conclude that temperature and intensity of the halo emission must be highly variable which excludes any pervasive Galactic halo plasma.

Pietz et al. constructed a model of the X-ray halo which is consistent solution for the detected diffuse soft X-ray emission across the entire ROSAT X-ray energy range. They proposed, that the 3/4 keV emission is a superposition of the Galactic halo and extragalactic background emission. The Galactic halo plasma appears to be isothermal on large angular scales, accordingly it is possible to scale the 3/4 keV model to the 1/4 keV energy regime. They derived a smooth intensity distribution of the LHB, which is significantly cooler than the Galactic halo plasma. The smooth LHB intensity distribution is a function of the Galactic latitude. Towards the northern Galactic pole, the LHB is about 1.5 times brighter than towards the southern Galactic pole. The residuals between the observed and modeled X-ray intensity distributions show some individual excess X-ray emitting structures which are identified as star forming regions, supernova remnants or attributed to the high-velocity cloud phenomenon (Kerp et al. 1999).

The Pietz et al. Galactic X-ray halo model predicts the existence of a hot gaseous phase within the Galactic halo. This hot gas phase is the environment of cosmic-rays, magnetic fields and neutral clouds, accordingly, we can prove the X-ray model parameters by the quantitative comparison with recent all-sky surveys of \( \text{H} \) gas, radio continuum and \( \gamma \)-ray emission (Kalberla & Kerp, 1998).

3. \( \text{H} \) gas in the halo

On large scales, the vertical distribution of H\(_1\) gas in the Galaxy can be characterized by a layered structure (Dickey & Lockman 1990). The layers which are associated with the disk have an exponential scale height of up to 400 pc. Until recently there was also agreement that H\(_1\) gas associated with the halo must have a scale height of \( 1 < h_z < 1.5 \) kpc (e.g. Kulkarni & Fich 1985 or Lockman & Gehman 1991). Such a scale height corresponds to a component with a velocity dispersion of 35 km s\(^{-1}\). This was questioned by Westphalen (1997) and Kalberla et al. (1998a) who found a velocity dispersion of 60 km s\(^{-1}\), corresponding to a scale height of 4.4 kpc. Here we discuss the major differences between both approaches.

The data-set: A component with a velocity dispersion of \( \sigma \approx 35 \) km s\(^{-1}\)was derived by different authors from H\(_1\) profiles extracted from the Bell Laboratories H\(_1\) survey (BLS, Stark et al. 1992). The main reason for using this horn-antenna for such a kind of analysis was the high main beam efficiency of 92%, which means that the observations are only little affected by stray radiation from the antenna side-lobes.
A high velocity dispersion component of $\sigma \approx 60 \text{ km s}^{-1}$ was found by Westphalen (1997) using the LDS. This survey was observed with a parabolic dish. Usually, such a telescope suffers from spurious emission which disables any analysis of H I components with high-velocity dispersion. In the case of the LDS, however, the stray radiation was removed in a numerical way by Hartmann et al. (1996). These authors claim that they reduce spurious emission on average by two orders of magnitude. They demonstrated, that even reflections from the ground can affect H I observations. Subsequently, such effects have been corrected by Kalberla et al. (1998a) who suggested that systematic uncertainties due to residual stray radiation in wings of the H I spectra are below 15 mK.

Data reduction: H I emission lines with high-velocity dispersion may be seriously affected by the instrumental baseline and the correction algorithm which was used. Individual BLS profiles were corrected by fitting a second order polynomial to emission free profiles regions which have been determined in an iterative way. In case of the LDS, a third order polynomial fit was applied after determining the emission free regions with polynomials up to 5th order.
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Figure 2. H\textsc{i} 21-cm line spectra averaged across all longitudes as in Fig. 1, but extracted from the Bell Labs Survey (BLS). The solid lines represent the neutral atomic hydrogen layer model of Lockman & Gehman (1991, their model 2).

The resulting BLS baselines are believed to be accurate to 50 mK. Averaging observations in time should improve the baseline accuracy. However, the averaging of H\textsc{i} spectra of the BLS does not show this expected behavior (Stark et al. 1992). In opposite to this finding, the individual spectra of the LDS are noisier and have a typical rms noise level of 70 mK. Averaging the LDS spectra however leads to the expected improvement of the rms noise up to a limit of a few mK.

In comparing BLS and LDS spectra after averaging across regions of $5^\circ \times 5^\circ$ Kalberla et al. (1998b) found significant deviations, indicating incompatible baselines between both surveys.

The majority of the averaged BLS H\textsc{i} spectra reveal negative brightness temperatures in the baseline regions. Kalberla et al. (1998b) concluded, that probably an improper baseline correction algorithm was used by the reduction of the BLS data. In turn this led to a subtraction of the faint and broad H\textsc{i} line emission of the high-velocity dispersion component. Polynomial baseline corrections are designed to \textit{remove} features from the H\textsc{i} spectra which are assumed to be artificial. Accidentally, broad emission line components may be affected.
The question, whether the baseline correction procedure applied to the LDS may have added an artificial broad emission line component was studied by Kalberla et al. (1998a) in detail. The complete LDS data analysis was repeated. No evidence was found that the high-velocity dispersion component is due to instrumental or computational artifacts.

Data analysis: Both surveys have been analyzed regarding low surface brightness components with high-velocity dispersion. In case of the BLS Kulkarni & Fich (1985) as well as Lockman & Gehman (1991) averaged large regions in direction to the Galactic poles ($|b| > 80^\circ$ and $|b| > 45^\circ$). Such averages were decomposed into Gaussian components.

Westphalen (1997) considered individual $10^\circ \times 10^\circ$ fields in all directions with latitudes $|b| > 30^\circ$. After a Gaussian decomposition of the individual averaged profiles, the average property of a component with high-velocity dispersion was determined. In each case the rms deviations between the individual observations have been determined on a channel by channel basis; rms-peaks indicating interference, HVCs or instrumental problems have been used to flag velocity intervals, which need not to be fitted by a Gaussian component. To verify, that the determined components are not affected by residual stray radiation, the stray radiation itself was decomposed into Gaussian components. Since a Gaussian analysis may be biased by initial constraints, each fit was repeated several times using different criteria for the derivation of components with high-velocity dispersion.

To compare the BLS and LDS datasets and the models based on a high-velocity dispersion component, we plot data and corresponding models. Fig. 1 is based on LDS data. We include the model derived by Kalberla et al. (1998a). Fig. 2 represents the BLS data and the model 2 published by Lockman & Gehman (1991) for comparison.

4. Halo models

The basic hydrostatic halo model is due to Parker (1966). In this classical publication it was shown that a single phase halo must be unstable. Since then, attempts have been made by various authors to derive conditions for a stable halo. We consider only the most recent papers.

Bloemen (1987) concluded that a gaseous halo is needed to provide the pressure necessary to stabilize the halo. He proposed an extended high-temperature halo. At a vertical distance of $1 < |z| < 3$ kpc the halo gas temperature should be $T \simeq (2 - 3) \times 10^5$ K while within the disk and above $|z| > 3$ kpc the temperature should be $T \simeq 10^6$ K. This halo plasma should emit significant amounts of X-ray photons within the 1/4 keV and 3/4 keV energy bands.

Boulares & Cox (1990) studied the Galactic hydrostatic equilibrium including magnetic tension and cosmic-ray diffusion. They found, that the gas pressure, based on recent observations at that time, was not sufficient to stabilize the halo against Parker instabilities. For a stable Galactic halo, they proposed a halo $\text{H}_1$ phase with a velocity dispersion of 20 km s$^{-1}$ in the disk ($z = 0$) and of 60 km s$^{-1}$ at $z = 4$ kpc. This is close to the high-velocity dispersion component established by Kalberla et al. (1998a). The LDS observations indicate however, that the $\text{H}_1$ emission in the halo seems to be isothermal with a velocity disper-
sion which is independent from \( z \)-height. We calculated the H\textsc{i} distribution as proposed by Boulares & Cox (1990) and found that this distribution is similar to the distribution derived from the Lockman & Gehman (1991) model which is plotted in Fig. 2.

4.1. A new approach

To describe the large scale properties of the Milky Way in the sense of a steady-state solution, Kalberla & Kerp (1998) assumed a hydrostatic halo model, as proposed by Parker (1966). Kalberla & Kerp (1998) re-analyzed the hydrostatic equilibrium model of the Milky Way, including the most recent all-sky surveys, ranging from the \( \gamma \)-ray to the radio synchrotron emission regime. They distinguished three main components of the Galaxy which can be characterized by their vertical scale heights \( h_z \): the cold and warm neutral interstellar medium (ISM) with \( h_z = 150 \) pc and \( h_z = 400 \) pc (Dickey & Lockman, 1990), the diffuse ionised gas (DIG) with \( h_z = 1 \) kpc (Reynolds, 1997), and halo gas with \( h_z = 4.4 \) kpc. The major difference to previous investigations (e.g. Bloemen 1987, Boulares & Cox 1990) is, that Kalberla & Kerp (1998) included the neutral (Kalberla et al. 1998a) and X-ray (Pietz et al. 1998) gas phase, located within the Galactic halo, into their calculations. Such a layered disk-halo model was found to fit the large scale distribution of the neutral and ionized hydrogen gas throughout the whole Galaxy. Gas, magnetic fields and cosmic rays were found to be in pressure equilibrium.

As discussed by Kalberla & Kerp (1998) in detail, such an equilibrium situation does not only explain the large scale distributions of gas, magnetic fields and cosmic rays, but results also in a stable configuration. It is essential, that the multi-phase halo is supported by the pressure of the gaseous layers with low \( z \) scale-heights, belonging to the Galactic disk and to the disk-halo interface. Without such layers, the halo would be instable as described by Parker (1966).

Kalberla & Kerp (1998) found that the halo is stable on average only. Pressure fluctuations may cause instabilities above \( z \) distances of \( \sim 4 \) kpc, but not below. Considering activities in the Galactic disk (e.g. Norman & Ikeuchi 1989) one expects that such pressure fluctuations will affect the halo gas. Necessarily, instabilities will trigger the condensation of HVCs in the halo. Kalberla et al. (these proceedings) studied the large scale distribution of HVCs and found that turbulent motions within the halo have considerable effects on the observed column density distribution. Except from turbulence, the scenario, derived from hydrostatic considerations, is in close agreement with predictions of hydro-dynamical models. Fountain parameters which have been favored by Bregman (1980) are in close agreement with the parameters derived by Pietz et al. (1998) from observations.

A gaseous multi-layer structure was found also by Avillez (these proceedings) from 3D hydro-dynamical simulations. In his calculations a halo, and at the same time a disk-halo interface is built up after a short period of time, reaching a steady state situation soon. Scale heights, densities and temperatures of these layers are found to be comparable to the values listed by Kalberla & Kerp (1998).
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