Spectroscopy of faint emission line nebulae

Ralf-Jürgen Dettmar
Astronomical Institute, Ruhr-University Bochum, 44780 Bochum, Germany

Abstract. Based on results obtained with FORS1 in long-slit mode we demonstrate the power of the VLT for the spectroscopy of faint emission line nebulae such as the gaseous halos of diffuse ionized gas (DIG) in spiral galaxies. It is shown that VLT spectra of DIG allow us to address the ionization and excitation processes for the interstellar medium on galactic scales and that in the future more detailed kinematical studies of DIG could help to constrain the origin of the observed thick H$^+$ layer in galaxies.

The currently available instrumentation with regard to this application is compared to other possible designs and efficiencies for integral field spectrographs, in particular Fabry-Perot systems.

1 Introduction

Emission lines originating in ionized gas provide very valuable diagnostics for physical conditions in several components of the interstellar medium (ISM) such as H$^\text{II}$ regions, supernova remnants (SNRs), planetary nebulae, or the warm ionized medium. To demonstrate the complex relation of these various components we show in Fig. 1 the H$\alpha$ emission of the central star-forming region of the nearby late-type galaxy NGC 55. Besides the presence of localized sources (i.e., H$^\text{II}$ regions and SNRs) this image demonstrates that a significant fraction of H$\alpha$ emission originates outside of “classical” H$^\text{II}$-regions (which are saturated black in the grey scale representation) in shells, loops, bubbles, filaments, and knots, as well as a smoothly distributed, diffuse component. This H$^+$ gas outside of H$^\text{II}$ regions is now frequently called (despite its morphological diversity) Diffuse Ionized Gas (DIG) or Warm Ionized Medium (WIM) and can be identified with the Reynolds-layer of the Milky Way. The H$\alpha$ emission of the Galaxy is currently being mapped in a northern sky survey by the Wisconsin H-Alpha Mapper (WHAM; Reynolds et al. 1998) and first results from WHAM (Haffner et al. 1998) show striking similarities between the DIG in NGC 55 (Fig. 1) and the Galaxy. A more complete documentation demonstrating the power of the WHAM Fabry-Perot survey for Galactic studies can be found at [9].

The filamentary structure of H$\alpha$ emitting DIG in Fig. 1 can be traced out into the halo on scales of several hundreds of pc and becomes an observational challenge with increasing distance from the mid-plane and decreasing flux. This faint extra-planar DIG corroborates scenarios of a large scale exchange of matter between the ISM in galactic disks and their halos driven by the energy input.
of star forming regions in the disk. More detailed reviews of this aspect can be found in, e. g., Dahlem (1997) or Dettmar (1999).

2 Detection of very extended DIG halos of spiral galaxies

The first imaging detection of a $\sim$1 kpc thick layer of DIG in NGC 891 (Rand et al. 1990, Dettmar 1990) was meanwhile confirmed spectroscopically (Rand 1997) extending the detection limit out to at least 5 kpc above the plane. The most active galactic disks with regard to their star formation rate possess spectacular gaseous halos, e.g., in the case of NGC 4631 an extend of 16 kpc in radius has been claimed from a narrow band imaging experiment by Donahue et al. (1995). Using FORS1 in long-slit mode we could recently establish by spectroscopy (Tüllmann et al. 2000) that also the DIG halo in NGC 5775 extents out to at least 10 kpc (Fig. 2), confirming and extending the work by Rand (2000).

This finding is in itself of interest in the context of the chemical evolution history of disk galaxies, since the gaseous halo and in particular its hot component could transport and maintain significant amounts of metals. The detailed physics of such mass exchanges or outflows are of course most important for the understanding of the metal enrichment processes in early phases of galaxy evolution. It is therefore of some importance that not even the energy balance of the ISM is well understood: the ionization and excitation conditions of the DIG component require more than photoionization by OB stars can directly supply. However, it is unclear what additional process(es) (turbulence, dust heating, shocks, magnetic reconnection) contribute(s) to the heating, in particular since
there is more and more observational evidence that the temperature is increasing with height above the plane $z$ (Reynolds et al. 1999, for the Milky Way; Rand 1997, for NGC 891; Tüllmann and Dettmar 2000, for a sample based on ESO/La Silla observations). Further progress with regard to the physical conditions of the ionized halo gas would require deep spectra that allow for the detection of faint diagnostic emission lines over a large wavelength range. This problem can be best treated with a specialized high-efficiency spectrograph and is addressed by Prieto (2001) elsewhere in this volume.

Fig. 2. Heliocentric velocities perpendicular to the disk (at $\sim 30''$ SE of the nucleus) of NGC 5775 for prominent emission lines extracted from a VLT FORS1 spectrum. The noise level of $1.26 \times 10^{-19}$ ergs cm$^{-2}$ s$^{-1}$ Å$^{-1}$ reached in 3 hrs allows for a detection out to 10 kpc above the disk. The dashed line indicates the systemic velocity (from Tüllmann et al. 2000).

3 Kinematics of the extraplanar DIG in NGC 5775

The deep VLT spectra of NGC 5775 are, however, of interest also with respect to the kinematical information as Fig. 2 shows that the rotational velocity of the DIG halo drops to systemic high above the plane. In addition, it was shown (Tüllmann et al. 2000), that the DIG halo is associated with highly ordered magnetic fields, surprising in view of the energy input (i.e., turbulence, flows etc.) from the star formation activity in the underlying disk.
These findings now allow us to discuss some new physical processes to explain the ionization/excitation as well as the kinematics of the halo gas. The surprising kinematical information can be used to study the (magneto?)hydrodynamics of a possible large scale outflow. Since the observed drop in velocity is dramatic, one has to expect that the shape of the dark matter distribution plays an important role, too. Since the magnetic field structure with a strong vertical component also is very suggestive for outflows – such a magnetic field structure actually would favour outflow rather than suppressing it – and the question of the gas metallicities in the halo becomes even more important for chemical enrichment processes.

Another interesting aspect is added by the recent finding from an UV absorption line study of galactic halos. Côté et al. (2000) report that absorption lines associated with galactic halos are observed at the systemic velocity of the host galaxy independent of the impact parameter for the line-of-sight.

![Fig. 3. Wavelength resampled channel of a TAURUS data cube of NGC 891 before (left) and after (right) removal of interfering night sky line (from Dettmar, Allen, & van der Hulst).](image)

4 The need for high-resolution integral field spectroscopy

For both applications mentioned in the two previous sections – the detection of faint emission and the extraction of kinematical information – a higher spectral
resolution than typically reachable with grism spectrographs would be an advantage. Considering the manifold of integral field spectrographs already available at the VLT and discussed at this meeting as possible future VLT instruments, a Fabry-Perot design may best meet this requirements, in particular if good spatial coverage is another constraint. The power of a Fabry-Perot spectrograph is well demonstrated in several applications by Bland-Hawthorn (see e.g. Bland-Hawthorn et al. 1997) and the more specialist use of a Fabry-Perot as a tunable filter attached to the VLT was recently discussed as a modification to FORS (Jones et al. 2001).

To demonstrate the gain in S/N for the detection of emission lines in the presence of bright night sky lines by using a Fabry-Perot we reproduce in Fig. 3 a channel of a TAURUS data cube of NGC891 before and after correction for the night sky contribution. With an integration time of 2 min per channel a detection of $\sim 2 \times 10^{-17}$ ergs cm$^{-2}$ s$^{-1}$ arcsec$^{-2}$ could be reached at the 4m WHT.

5 Conclusions

The examples of NGC 5775 and NGC 4631 given above demonstrate that the extent of ionized gaseous halos around spiral galaxies is limited by the detection limit reached. Also kinematical studies would much benefit from higher spectral resolution over a large field of view, with $R$ between 10000 and 30000, depending on the scientific case. A scanning Fabry-Perot spectrograph seems to be a very versatile instrument to meet these requirements and compared favourable to other integral field spectrometer designs with regard to spatial sampling and spectral resolution. It would therefore ideally complement the current VLT instrumentation.

Acknowledgements. Its a pleasure to thank Ron Allen and Thijs van der Hulst for the patient collaboration on our “long term” Fabry-Perot project. Thanks also to staff and students at Ruhr-University for contributing the “real” work presented here. The author acknowledges partial financial support in this field by DFG through SFB 191.

References

1. Bland-Hawthorn, J., Freemann, K. C., Quinn, P. J. 1997 ApJ 490, 143
2. Côté, S., Broadhurst, T., Carignan, C., Freeman, K., Wyse, R. F. G. 2000 in: Cosmic Evolution and Galaxy Formation, J. Franco et al. (eds.), ASP Conf. Proc. Vol. 215, p. 287
3. Dahlem, M. 1997 PASP 109, 1298
4. Dettmar, R.-J. 1990 A&A 232, L15
5. Dettmar, R.-J. 1999 in: The Physics and Chemistry of the Interstellar Medium, V. Ossenkopf et al. (eds.), CGA-Verlag (Herdecke) p. 18
6. Dettmar, R.-J., Allen, R. J., van der Hulst, J. M. in prep.
7. Donahue, M., Aldering, G., Stocke, J. T. 1995 ApJ 450, L45
8. Haffner, L. M., Reynolds, R.-J., Tufte, S. L. 1998 A&A 501, L83
9. http://www.astro.wisc.edu/wham
10. Jones, H., Renzini, A., Rosati, P., Seifert, W. 2001 ESO Messenger 103, 10
11. Otte, B., Dettmar, R.-J. 1999 A&A 343, 705
12. Prieto, A. 2001, this volume
13. Rand, R. J. 1997 ApJ 474, 129
14. Rand, R. J. 2000 ApJ 537, L13
15. Rand, R. J., Kulkarni, S. R., Hester, J. J. 1990 ApJ 352, L1
16. Reynolds, R. J., Tufte, S. L., Haffner, L. M., Jaehnig, K., Percival, J. W. 1998 PASA 15, 14
17. Tüllmann, R., Dettmar, R.-J. 2000 A&A 362, 119
18. Tüllmann, R., Dettmar, R.-J., Soida, M., Urbanik, M., Rossa, J. 2000 A&A 364, L36