Simulation of Magneto-Optical Filter Transmission Profiles

Giuseppe Severino¹, Maurizio Oliviero¹
and Egidio Landi Degl’Innocenti²

¹INAF-Osservatorio Astronomico di Capodimonte, Napoli, Italia
²Dip. di Astronomia e Scienza dello Spazio, Università di Firenze, Italia

Abstract. We present a numerical simulation of a potassium Magneto-Optical Filter (MOF) enabling to compute the filter transmission. The results of the simulation are compared with experimental transmission profiles at different heating temperatures, measured with a diode laser system. The comparison reveals a significant amount of agreement but also shows some important differences.

1. Introduction

Magneto-Optical Filters (MOF) are widely used in astronomy as well as in other fields of research because of their characteristics which include: narrow passband (≈50 mA at transmission peaks); high transmission (max. 50% for incoming unpolarized light); high out-of-band rejection ($10^5$); large field of view, which makes them suitable for imaging; absolute wavelength reference and, hence, spectral stability. Therefore, it would be worthwhile to implement a theoretical simulation of the filter which enables to make reliable predictions of the filter transmission as a function of the two main parameters controlling the filter performances, i.e. the temperature at which the cell is heated and the external magnetic field in which the cell is embedded.

2. Method

Experimental cell transmission profiles for several heating temperatures and different magnetic fields are measured with a diode laser system. The diode laser by Sacher Lasertechnik works in Littman configuration. Its central wavelength is 769.45 nm; the full wavelength range is >10 nm; the fine tuning range is >30 GHz, i.e. 600 mA at 770 nm; the present resolution is 0.33 mA at 770 nm. The sensors are two PMTs with a dynamical range of $10^7$. A portable PC controls the whole measurement procedure with a software running on a LabView platform.

On the track of the pioneering work of Cacciani et al. (1994), we carried out a numerical simulation of a potassium MOF which can compute the filter transmission, taking into account: spatial variations of temperature, potassium density and magnetic field inside the cell, line broadening induced by the buffer gas, and hyperfine structure of the K I D₁ resonance line, including isotopic shifts between the $^{39}$K and $^{41}$K isotopes.
Figure 1. Experimental transmission profiles for several temperatures in the interval from 70°C to 130°C. The magnetic field at the center of the cell holder is 1400 G.

The temperature \( T \) inside the vapour cell satisfies a Laplace equation for thermal conduction with constant conductivity:

\[
\nabla^2 T = 0.
\]

The gas is a binary mixture, the potassium vapour being a minor constituent respect to the buffer gas. The number density of potassium \( N \) solves a steady-
Figure 2. Results of the simulation for several temperatures in the range from 70°C to 160°C and for a central magnetic field of 1400 G.

The variation of the magnetic field along the cell axis was assumed as due to four “monopoles” located at the stem sides, the top charges being of opposite

state diffusion equation:

\[ \nabla \cdot (D \nabla N) = 0, \tag{2} \]

where \( D \) is the diffusion coefficient. Both \( T \) and \( N \) distributions are found analytically in terms of the temperature on the cell boundary and of the vapour pressure of potassium at the liquid-gas interface.

The variation of the magnetic field along the cell axis was assumed as due to four “monopoles” located at the stem sides, the top charges being of opposite
sign with respect to the bottom ones. Stokes parameters inside the cell are the solution of the LTE transfer equations for polarized light, which are integrated numerically with the fourth-order Runge-Kutta method (Landi Degl’Innocenti 1975, Beckers 1969). Note that the K I D1 line hyperfine structure includes isotopic shifts between the $^{39}$K and $^{41}$K isotopes (Landi Degl’Innocenti 1978, Bendali et al. 1981, Fricke-Begemann 2004). Moreover K I D1 line broadening induced by the buffer gas (argon) is based on experimental data and the 6-8-12 theory (Andretta et al. 1991).

3. Results and Conclusions

The results of the simulation are compared with experimental transmission profiles acquired at different heating temperatures and measured with the diode laser system (Figs. 1 and 2). The comparison reveals that:

(i) for lower heating temperatures (slightly above the potassium fusion point), a definite discrepancy appears: experimental transmission has a central peak; this peak is missing in the simulation which shows only the expected Righi bandpass at the wavelengths of the two Zeeman components.

(ii) for higher heating temperatures, there is a significant amount of agreement, provided that suitable simulation heating temperatures are selected to best fit the experimental transmission profiles.

Particular care was taken to make the experimental data reliable. The three-peak transmission profiles at low heating temperatures are confirmed by measurements at various magnetic fields ($B_{\text{max}} = 1100, 1400, \text{and } 2200 \text{ G}$) and with different cells. The unexpected central peak should not be due to the Macaluso-Corbino effect, since the whole bandpass changes by similitude when the heating temperature or the magnetic field are varied. We conclude that a significant difference between experimental and current theoretical MOF transmission profiles at low heating temperatures does exist and deserves further work to be fully explained, also from the theoretical side.

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References