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Effects of Angle-Dependent Partial Frequency Redistribution on Polarized Line Profiles

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Abstract. Scattering of the solar limb-darkened radiation field on atoms and molecules produces linearly polarized spectrum of the Sun (Second Solar Spectrum). Partial frequency redistribution (PFR) plays a fundamental role in shaping the wings of linearly polarized profiles of strong resonance lines. Here we present the effects of the angle-dependent (AD) PFR on resonance polarization both in the presence and absence of magnetic fields. We consider scattering on a two-level atom with unpolarized lower level, and a one-dimensional isothermal atmosphere.

1. Introduction

Partial frequency redistribution (PFR) describes angle-frequency correlation in a scattering event. The thermal motion of the scattering atom gives rise to the angle-frequency coupling in the PFR functions. This intricate coupling makes the application of angle-dependent (AD-PFR) functions in polarized line transfer calculations computationally expensive. To simplify the numerical work Rees & Saliba (1982) replaced AD-PFR functions by their angle-averaged (AA) analogs. Since then the AA approximation has been used by several workers in the field (see e.g., the review by Nagendra 2014).

Solution of the polarized transfer equation including AD-PFR were presented by Dumont et al. (1977), McKenna (1985), Faurobert (1987, 1988) for resonance polarization, Nagendra et al. (2002) for Hanle effect, and Sampoorna et al. (2008, 2017) for scattering in arbitrary magnetic fields. The above cited papers solved the transfer equation in the Stokes vector basis. Although numerically expensive the solution in the Stokes vector basis is unavoidable, particularly in the presence of arbitrary strength magnetic fields. In the case of weak field Hanle effect and in the absence of magnetic fields, Frisch (2009, 2010) has shown that the non-axisymmetric Stokes vector and the corresponding source vector can be decomposed in to axisymmetric irreducible components. Such a decomposition considerably reduces the computational cost of the line transfer with AD-PFR. Numerical method based on this decomposition technique have been developed in Sampoorna et al. (2011), Sampoorna (2011b), and Nagendra & Sam-

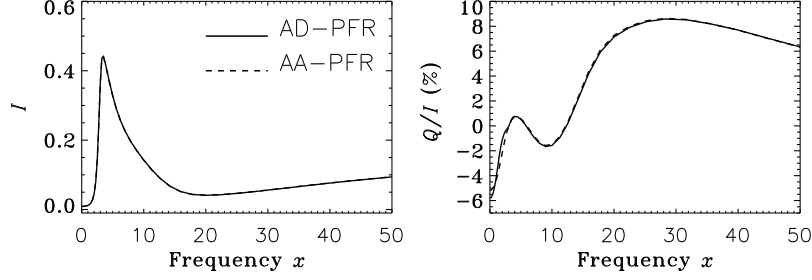


Figure 1. The emergent I and Q/I profiles at $\mu = 0.11$ and $\chi = 0^\circ$ computed for the angle-averaged (dashed lines) and the angle-dependent (solid lines) PFR. Model parameters are $(T, a, \epsilon, r) = (2 \times 10^6, 10^{-3}, 10^{-4}, 10^{-8})$.

poorna (2011). Here we present a comparison of polarized line profiles computed with AD-PFR and AA-PFR, both in the absence and presence of magnetic fields.

2. Polarized Line Transfer Equation with AD-PFR

In a planar atmosphere permeated by arbitrary magnetic field \mathbf{B} the polarized line transfer equation is given by

$$\mu \frac{\partial}{\partial \tau} \mathbf{I}(\tau, x, \mathbf{\Omega}) = \mathbf{K} \mathbf{I}(\tau, x, \mathbf{\Omega}) - \mathbf{S}(\tau, x, \mathbf{\Omega}), \quad (1)$$

where $\mathbf{I} = [I, Q, U, V]^T$. The quantity τ denotes the line integrated vertical optical depth scale, x the non-dimensional frequency, and $\mathbf{\Omega}(\theta, \chi)$ the ray direction with $\mu = \cos \theta$. The total absorption matrix $\mathbf{K} = \mathbf{\Phi} + r\mathbf{E}$, with \mathbf{E} being the 4×4 unity matrix, $\mathbf{\Phi}$ being the 4×4 line absorption matrix, and r the ratio of continuum to line averaged opacity. The total source vector $\mathbf{S}(\tau, x, \mathbf{\Omega})$ is given by

$$\mathbf{S}(\tau, x, \mathbf{\Omega}) = (r\mathbf{E} + \epsilon\mathbf{\Phi})B_{\nu_0}\mathbf{U} + \oint \frac{d\mathbf{\Omega}'}{4\pi} \int_{-\infty}^{+\infty} dx' \mathbf{R}(x, \mathbf{\Omega}, x', \mathbf{\Omega}', \mathbf{B}) \mathbf{I}(\tau, x', \mathbf{\Omega}'), \quad (2)$$

where $\mathbf{U} = [1, 0, 0, 0]^T$, B_{ν_0} is the Planck function, and ϵ is the thermalization parameter. For the case of a two-level atom with unpolarized lower level $\mathbf{\Phi}$ is the Zeeman line absorption matrix (Stenflo 1994) and PFR matrix \mathbf{R} is given in Bommier (1997b, see also Sampoorna et al. 2007a,b; Sampoorna 2011a).

In weak fields, the Stokes V gets decoupled from I , Q , and U , and the line absorption matrix can be approximated by $\mathbf{\Phi} \approx \phi(x)\mathbf{E}$ with $\phi(x)$ being the line profile function. The weak field Hanle PFR matrices under different levels of approximation are given in Bommier (1997b) and the non-magnetic PFR matrix is given in Domke & Hubeny (1988); Bommier (1997a).

3. Polarized Profiles Computed with AD-PFR and AA-PFR

For our numerical studies, we consider isothermal ($B_{\nu_0} = 1$), self-emitting plane-parallel atmospheres with no incident radiation at the boundaries. Such models are

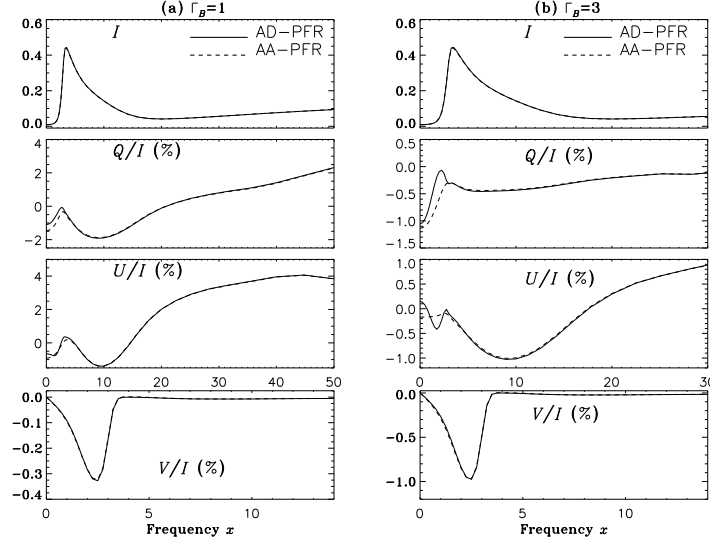


Figure 2. Same as Figure 1 but for the presence of a magnetic field. The magnetic field orientation are $(\theta_B, \chi_B) = (90^\circ, 45^\circ)$.

represented by (T, a, ϵ, r) , where T is the optical thickness of the slab and a is the damping parameter. The magnetic field is parameterized through the field strength parameter $\Gamma_B = g_{J_u} \omega_L / \Gamma_R$, and the field orientation θ_B and χ_B . All the results presented here are computed taking into account the full Zeeman line absorption matrix and the PFR matrix for arbitrary fields.

A comparison of emergent polarized profiles obtained with AD-PFR and AA-PFR is shown in Fig. 1 for the non-magnetic case and in Figs. 2 and 3 for the magnetic case. For the optically thick line considered here, the differences in Q/I and U/I profiles appear mainly near the line core. These differences are ignorable in the non-magnetic case. However, they are significant in the presence of a magnetic field, particularly in the saturated Hanle regime of $\Gamma_B = 3$. The differences between AD-PFR and AA-PFR solutions continue to persist for fields in the intermediate Hanle–Zeeman regime and for Γ_B as large as 100. AD-PFR effects are negligible in the intensity I and the V/I profiles irrespective of the field strength.

4. Conclusions

In a series of papers we have developed efficient iterative methods to solve the polarized transfer equation with AD-PFR. Here we present a comparison of polarized profiles computed with AA-PFR and AD-PFR. AA-PFR can safely be used to compute the non-magnetic (I , Q/I) profiles. AD-PFR effects are significant in the line cores of (Q/I , U/I) profiles, for $\mathbf{B} \neq 0$. For some field strengths, U/I profiles show a higher sensitivity to AD-PFR than the Q/I profiles. This is because Stokes Q and U respectively are sensitive to the anisotropy and non-axisymmetry of radiation field in the presence of magnetic fields. V/I profiles are unaffected by AD-PFR effects. AD-PFR effects in (Q/I , U/I) profiles persist for fields as large as $\Gamma_B = 100$. Thus AD-PFR need to be taken into account for magnetic field determination.

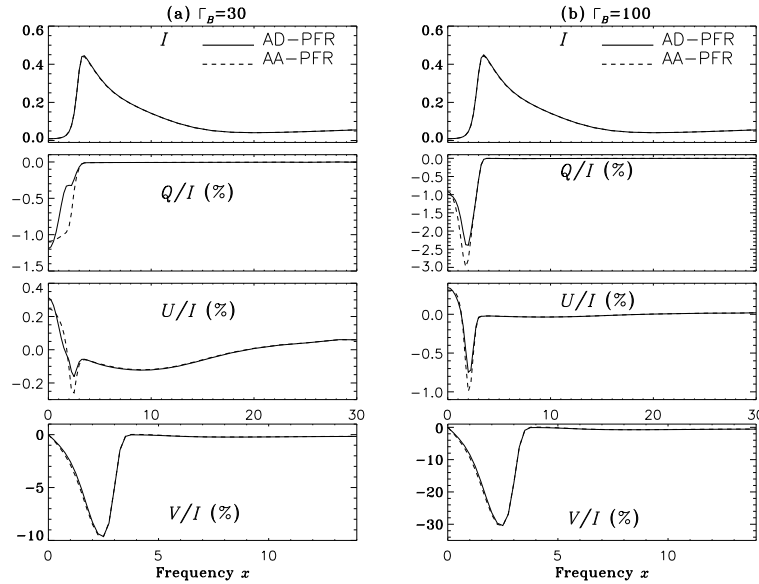


Figure 3. Same as Figure 1 but for the presence of a magnetic field. The magnetic field orientation are $(\theta_B, \chi_B) = (90^\circ, 45^\circ)$.

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References

- Bommier, V. 1997a, *A&A*, 328, 706
 — 1997b, *A&A*, 328, 726
 Domke, H., & Hubeny, I. 1988, *ApJ*, 334, 527
 Dumont, S., Omont, A., Pecker, J. C., & Rees, D. 1977, *A&A*, 54, 675
 Faurobert, M. 1987, *A&A*, 178, 269
 — 1988, *A&A*, 194, 268
 Frisch, H. 2009, in *Solar Polarization 5: In Honor of Jan Stenflo*, edited by S. V. Berdyugina, K. N. Nagendra, & R. Ramelli (San Francisco: ASPCS), vol. 405 of ASPCS, 87
 — 2010, *A&A*, 522, A41
 McKenna, S. J. 1985, *Ap&SS*, 108, 31
 Nagendra, K. N. 2014, in *Solar Polarization 7*, edited by K. N. Nagendra, J. O. Stenflo, Q. Qu, & M. Sampoorna (San Francisco: ASPCS), vol. 489 of ASPCS, 179
 Nagendra, K. N., Frisch, H., & Faurobert, M. 2002, *A&A*, 395, 305
 Nagendra, K. N., & Sampoorna, M. 2011, *A&A*, 535, A88
 Rees, D. E., & Saliba, G. J. 1982, *A&A*, 115, 1
 Sampoorna, M. 2011a, *ApJ*, 731, 114
 — 2011b, *A&A*, 532, A52
 Sampoorna, M., Nagendra, K. N., & Frisch, H. 2011, *A&A*, 527, A89
 Sampoorna, M., Nagendra, K. N., & Stenflo, J. O. 2007a, *ApJ*, 663, 625
 — 2007b, *ApJ*, 670, 1485
 — 2008, *ApJ*, 679, 889
 — 2017, *ApJ*, 844, 97
 Stenflo, J. O. 1994, *Solar magnetic fields - Polarized radiation diagnostics* (Dordrecht: Kluwer)