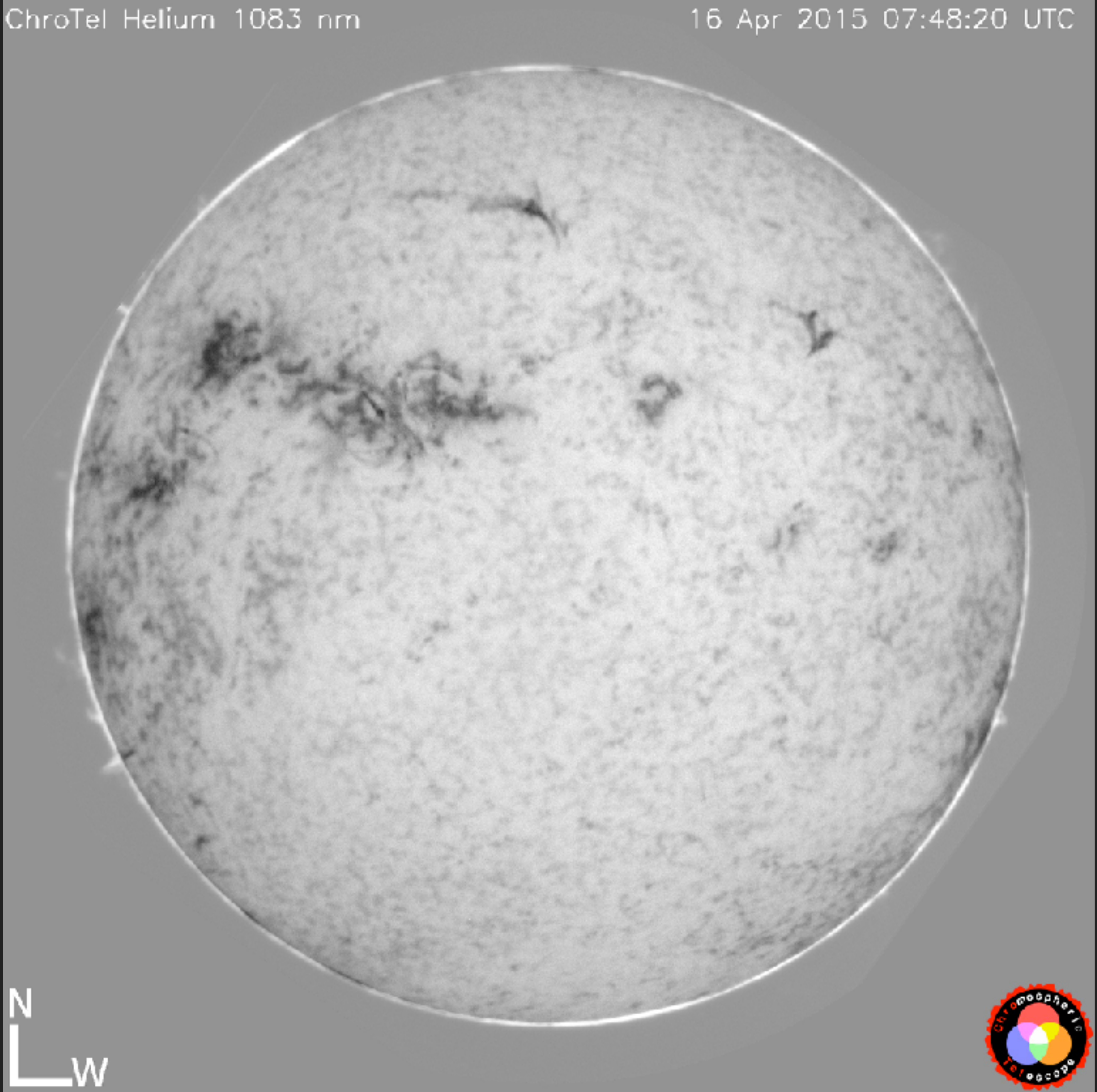
A. ASENSIO RAMOS

HE I MULTIPLETS: HAZEL PHYSICS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ADVANCED FORWARD MODELING AND INVERSION OF STOKES PROFILES RESULTING FROM THE JOINT ACTION OF THE HANLE AND ZEEMAN EFFECTS

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ABSTRACT

A big challenge in solar and stellar physics in the coming years will be to decipher the magnetism of the solar outer atmosphere (chromosphere and corona) along with its dynamic coupling with the magnetic fields of the underlying photosphere. To this end, it is important to develop rigorous diagnostic tools for the physical interpretation of spectropolarimetric observations in suitably chosen spectral lines. Here we present a computer program for the synthesis and inversion of Stokes profiles caused by the joint action of atomic level polarization and the Hanle and Zeeman effects in some spectral lines of diagnostic interest, such as those of the He I 10830 Å and 5876 Å (or D_3) multiplets. It is based on the quantum theory of spectral line polarization, which takes into account in a rigorous way all the relevant physical mechanisms and ingredients (optical pumping, atomic level polarization, level crossings and repulsions, Zeeman, Paschen-Back, and Hanle effects). The influence of radiative transfer on the emergent spectral line radiation is taken into account through a suitable slab model. The user can either calculate the emergent intensity and polarization for any given magnetic field vector or infer the dynamical and magnetic properties from the observed Stokes profiles via an efficient inversion algorithm based on global optimization methods. The reliability of the forward modeling and inversion code presented here is demonstrated through several applications, which range from the inference of the magnetic field vector in solar active regions to determining whether or not it is canopy-like in quiet chromospheric regions. This user-friendly diagnostic tool called "HAZEL" (from HAnle and ZEeman Light) is offered to the astrophysical community, with the hope that it will facilitate new advances in solar and stellar physics.

Subject headings: magnetic fields — methods: data analysis — methods: numerical — polarization — radiative transfer — scattering — Sun: chromosphere

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Hazel v2.0: synthesis and inversion of Stokes profiles caused by the joint action of atomic level polarization and the Hanle and Zeeman effects https://aasensio.github.io/hazel2/ind...

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52 commits | 2 branches | 0 releases | 1 contributor | MIT

Branch: master | New pull request | Create new file | Upload files | Find file | Clone or download

aasensio Fixed some issues — Latest commit 330de66 21 hours ago

docs	Fixed some issues	21 hours ago
examples	Fixed some issues	21 hours ago
gui	Fixed a bug appearing with newest gfortran compilers	3 months ago
hazel	Fixed some issues	21 hours ago
src	Fixed some issues	21 hours ago
test	Added badges for coveralls and travis	4 months ago
.gitignore	Notebooks added for docs. Improvements on inversion	3 months ago
.travis.yml	Added zarr in travis	3 months ago
LICENSE	Deployment to pypi	5 months ago
MANIFEST.in	Added tests to travis	5 months ago
README.md	Typo on README	3 months ago
TODO	Fixed issue #12	a day ago
deploy_testpypi	Deployment to pypi	5 months ago
setup.cfg	Removed gregor data	5 months ago
setup.py	Removed matplotlib as requirement	2 months ago

README.md

Hazel v2.0

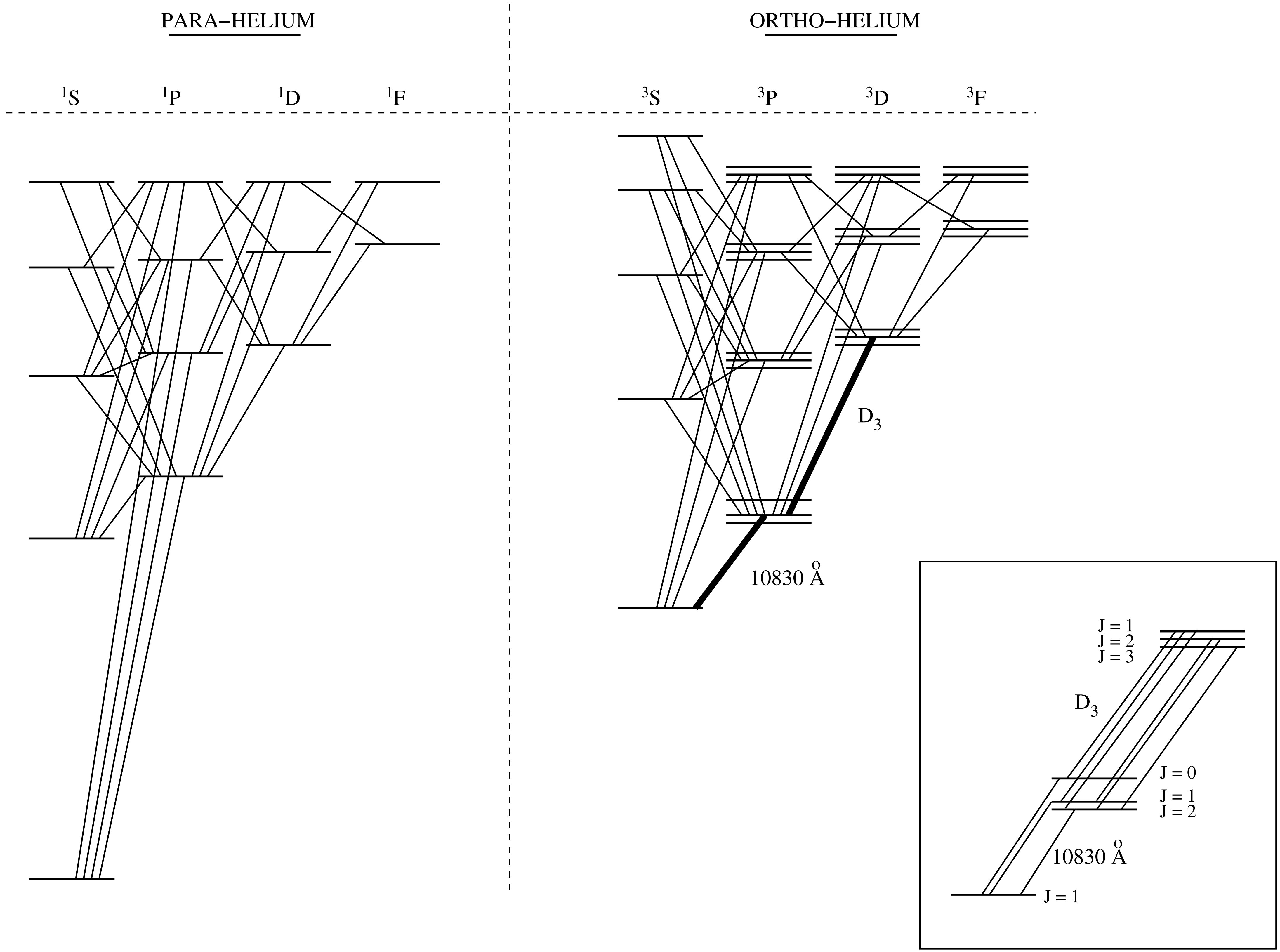
GitHub aasensio/hazel2 | build passing | coverage 33% | license MIT | ADS 2008ApJ...683..542A | arXiv 0804.2695

HAZEL

- 5-term atom
- Simple slab with constant physical properties
- Line formation is “hidden” on the optical depth
- Atomic level polarization + Zeeman (Paschen-Back) + Hanle effect
- Flat spectrum
- Fixed pumping radiation field
- Very simple formal solution
- Serial/MPI version

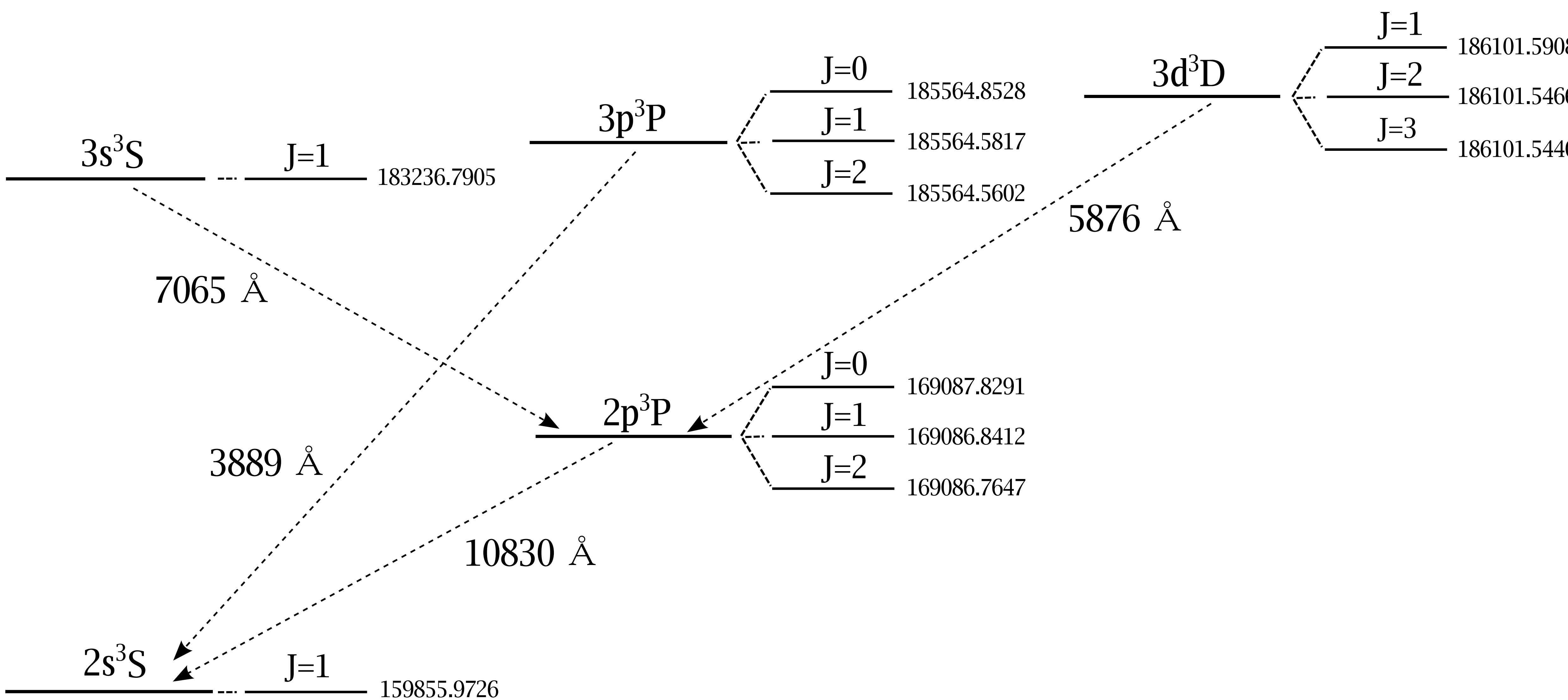
HAZEL2

- Invert He I (many lines simultaneously) + photospheric + telluric lines
- Flexibility on how to define topology: (ph1+ph2) -> (ch1+ch2) -> te1
- Sparsity (and other) regularization (WIP)
- 2D regularization (TBD)
- Python with wrappers to the time computing parts
- Fast versions using deep learning (TBD)
- Collaborations are welcome: https://github.com/aasensio/hazel2



Centeno et al. (2008)

MODEL ATOM



3s^{3}S
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3p^{3}P
J=0
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J=1
185564.5817
J=2
185564.5602
3d^{3}D
J=1
186101.5908
J=2
186101.5466
J=3
186101.5440
5876 Å
7065 Å
2p^{3}P
J=0
169087.8291
J=1
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3889 Å
10830 Å
2s^{3}S
J=1
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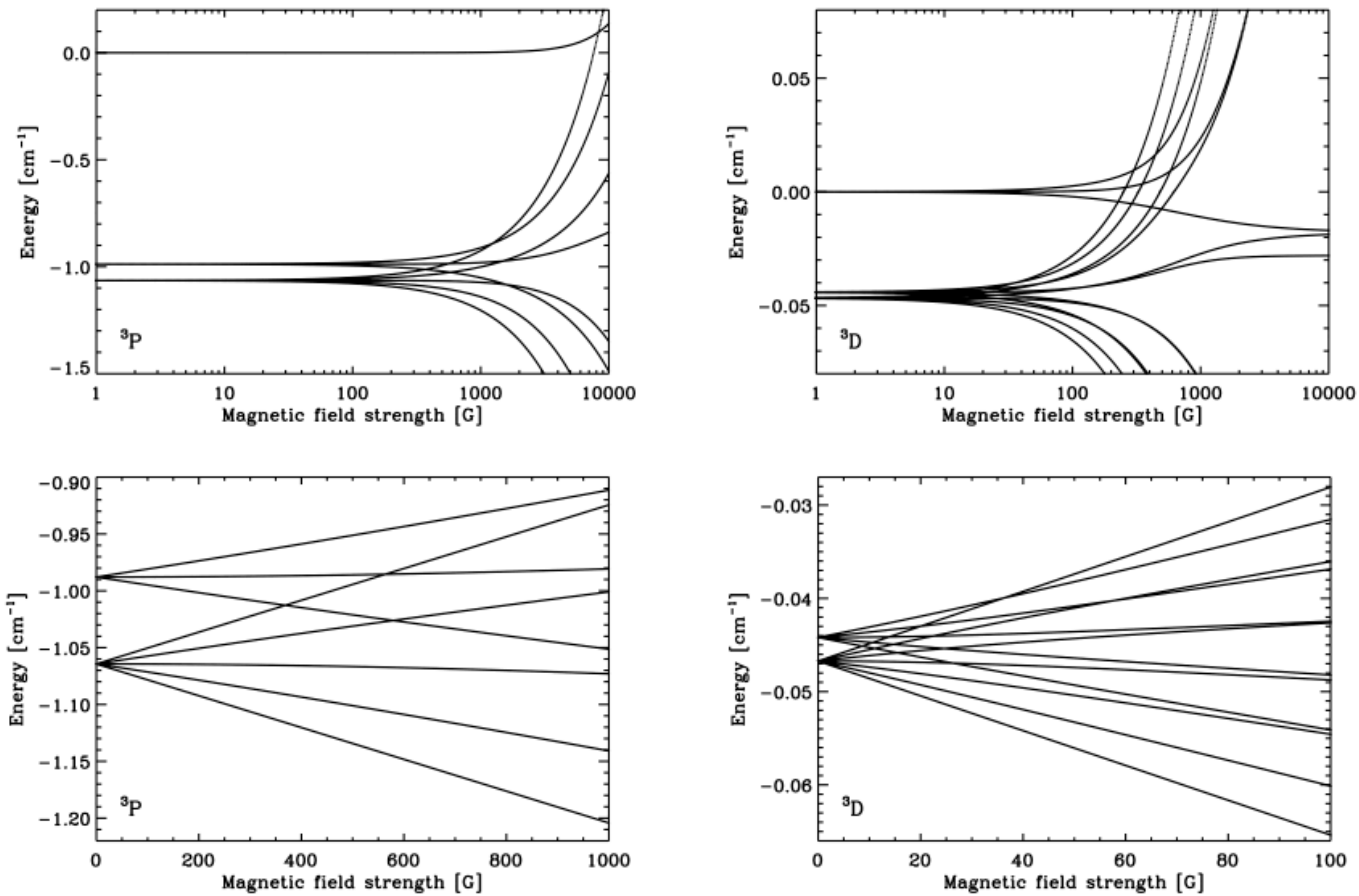
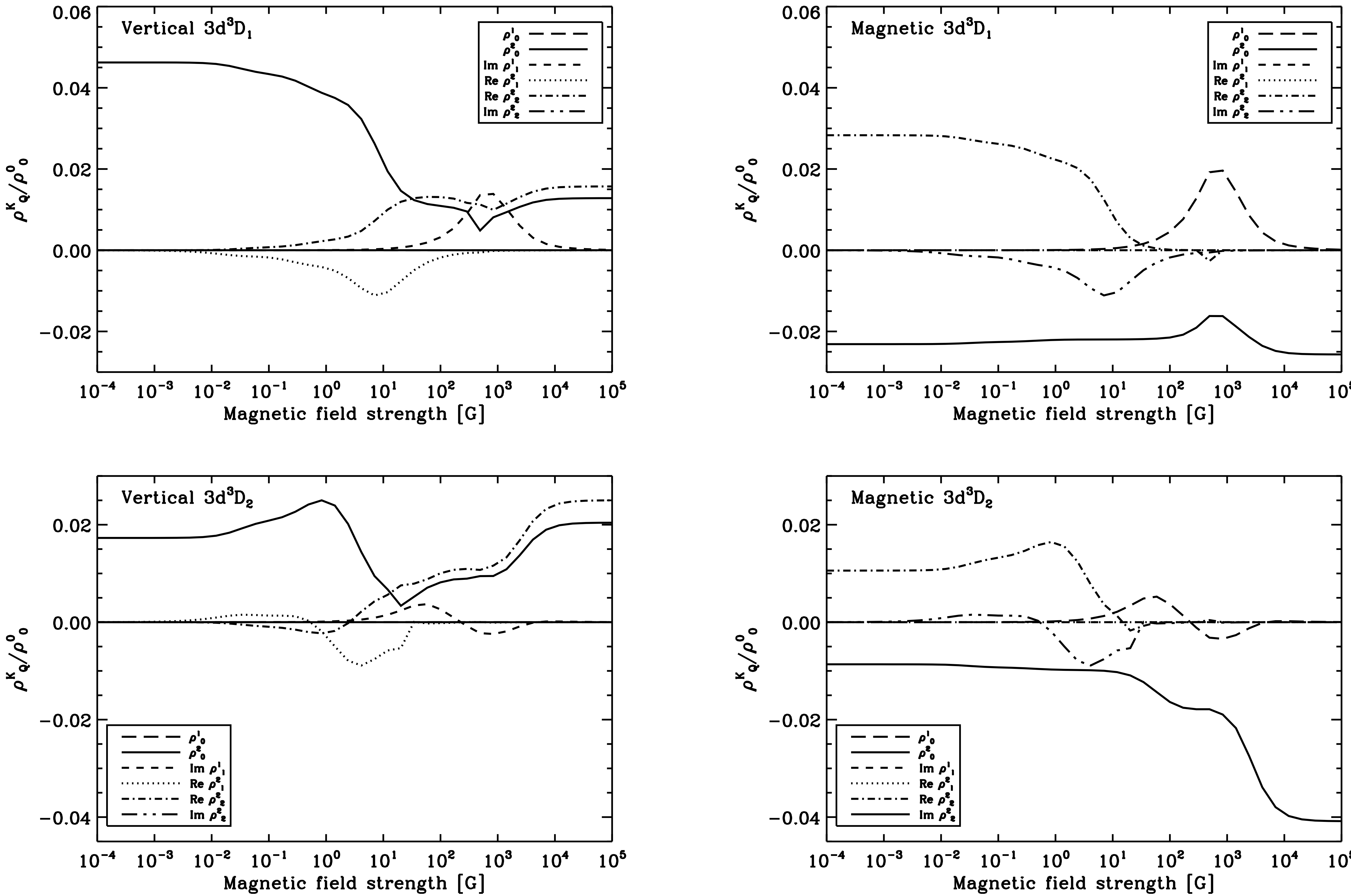
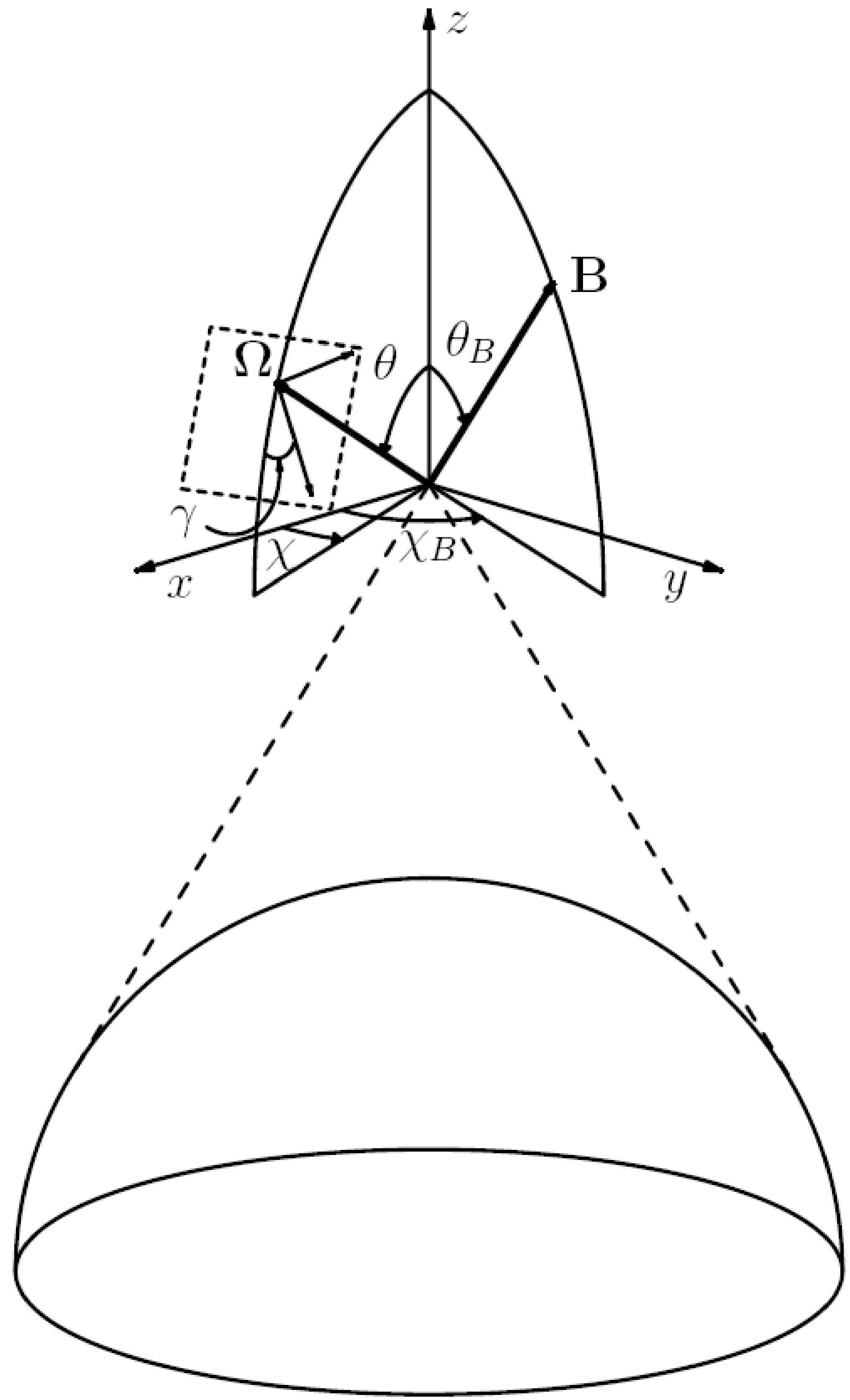
ENERGY SPLITTING



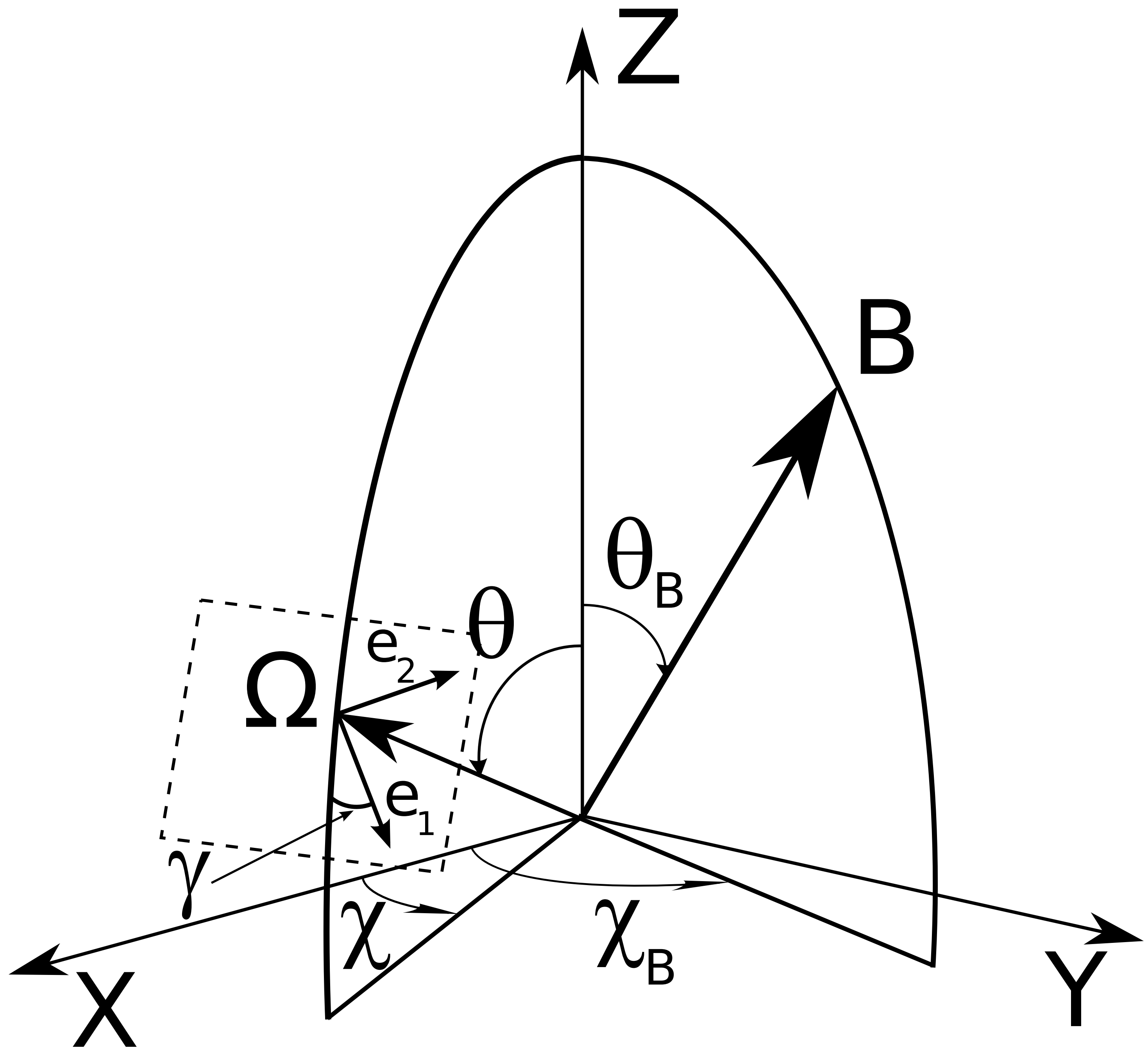
ENERGY SPLITTING



GEOMETRY



GEOMETRY



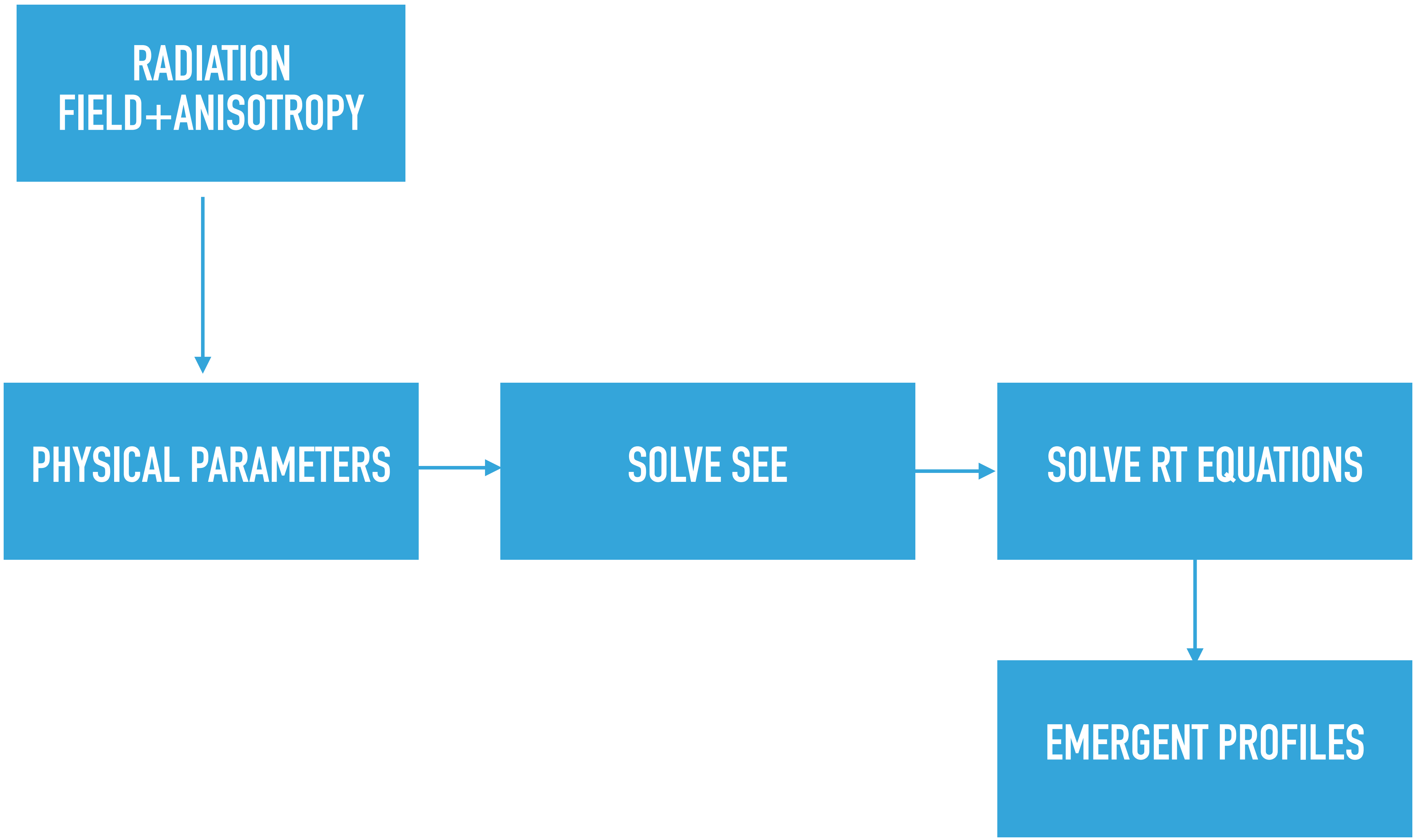
STATISTICAL EQUILIBRIUM EQUATIONS

$$
\begin{aligned}
\frac{d}{dt}{}^{\beta LS}\rho^K_Q(J,J') &= -2\pi\mathrm{i}\sum_{K'Q'}\sum_{J''J'''} N_{\beta LS}(KQJJ',K'Q'J''J''')^{LS}\rho^{K'}_{Q'}(J'',J''') \\
&+ \sum_{\beta_\ell L_\ell K_\ell Q_\ell J_\ell J'_\ell} {}^{\beta_\ell L_\ell S}\rho^{K_\ell}_{Q_\ell}(J_\ell,J'_\ell)\mathbb{T}_A(\beta LSKQJJ',\beta_\ell L_\ell SK_\ell Q_\ell J_\ell J'_\ell) \\
&+ \sum_{\beta_u L_u K_u Q_u J_u J'_u} {}^{\beta_u L_u S}\rho^{K_u}_{Q_u}(J_u,J'_u)\Big[\mathbb{T}_E(\beta LSKQJJ',\beta_u L_u SK_u Q_u J_u J'_u) \\
&\qquad\qquad + \mathbb{T}_S(\beta LSKQJJ',\beta_u L_u SK_u Q_u J_u J'_u)\Big] \\
&- \sum_{K'Q'J''J'''} {}^{\beta LS}\rho^{K'}_{Q'}(J'',J''')\Big[\mathbb{R}_A(\beta LSKQJJ'K'Q'J''J''') \\
&\qquad\qquad + \mathbb{R}_E(\beta LSKQJJ'K'Q'J''J''') + \mathbb{R}_S(\beta LSKQJJ'K'Q'J''J''')\Big]
\end{aligned}
$$

EMISSION/ABSORPTION

$$
\begin{aligned}
\eta_i^{\mathrm{A}}(\nu,\mathbf{\Omega}) &= \frac{h\nu}{4\pi}\mathcal{N}\sum_{\beta_\ell L_\ell S \beta_u L_u}(2L_\ell+1)B(\beta_\ell L_\ell S\rightarrow \beta_u L_u S) \\
&\times \sum_{KQK_\ell Q_\ell}\sqrt{3(2K+1)(2K_\ell+1)} \\
&\times \sum_{j_\ell J_\ell J'_\ell J''_\ell j_u J_u J'_u}\ \sum_{M_\ell M'_\ell M_u q q'}(-1)^{1+J''_\ell-M_\ell+q'}C^{j_\ell}_{J_\ell}(\beta_\ell L_\ell S, M_\ell)C^{j_\ell}_{J''_\ell}(\beta_\ell L_\ell S, M_\ell) \\
&\times C^{j_u}_{J_u}(\beta_u L_u S, M_u)C^{j_u}_{J'_u}(\beta_u L_u S, M_u)\sqrt{(2J_\ell+1)(2J'_\ell+1)(2J_u+1)(2J'_u+1)} \\
&\times \begin{pmatrix} J_u & J_l & 1 \\ -M_u & M_l & -q \end{pmatrix}\begin{pmatrix} J'_u & J'_l & 1 \\ -M_u & M'_l & -q' \end{pmatrix}\begin{pmatrix} 1 & 1 & K \\ q & -q' & -Q \end{pmatrix} \\
&\times \begin{pmatrix} J''_\ell & J'_\ell & K_\ell \\ M_\ell & -M'_\ell & -Q_\ell \end{pmatrix}\begin{Bmatrix} L_u & L_\ell & 1 \\ J_\ell & J_u & S \end{Bmatrix}\begin{Bmatrix} L_u & L_\ell & 1 \\ J'_\ell & J'_u & S \end{Bmatrix} \\
&\times \mathrm{Re}\left[\mathcal{T}^K_Q(i,\mathbf{\Omega})^{\beta_\ell L_\ell S}\rho^{K_\ell}_{Q_\ell}(J''_\ell, J'_\ell)\Phi(\nu_{\beta_u L_u S j_u, \beta_\ell L_\ell S j_\ell M_\ell}-\nu)\right].
\end{aligned}
$$

EMISSION/ABSORPTION



HAZEL: THINGS TO IMPROVE

- 5-term atom
- Simple slab with constant physical properties ✗
- Line formation is “hidden” on the optical depth
- Atomic level polarization + Zeeman (Paschen-Back) + Hanle effect
- Flat spectrum ✗
- Fixed pumping radiation field ✗
- Very simple formal solution ✗
- Serial/MPI version