Introduction to AS7005 Laboratory Exercise

The purpose of this laboratory exercise is to solidify your understanding of of the fundamental radiation theory concept of polarization, introduce you to some basic tools for radiation transport, and get practice performing research, analysing results, and writing scientifically. These cover some of the learning outcomes of the course, but also some of the learning outcomes of the Master's program in general and is good preperation for the research project later on in the degree program.

There is a prelab exercise (one of the standard weekly exercises) to prep you for the content we will be looking at in the lab. The lab itself will be two parts. The first will guide you through the concepts of Thomson scattering, angular distributions, polarization, and net polarization. Then proceed to have you perform Monto Carlo simulations of radiation from aspherical supernovae in order to determine the net polarization of the signal. This will be the major work in the lab session. The second part will be writing a paper-like lab report to summarize the findings. Even though this research has been done before (we'll see this below), when writing the report, please work under the assumption you are doing this for the first time, typical for a scientific paper. Please read `https://www.nature.com/articles/d41586-019-02918-5` for tips on writing scientifically.

For the paper please follow the outline below and pay attention to the questions posed in the lab. We suggest using overleaf (`www.overleaf.com`), choose a new project with a template, choose either "Astronomy and Astrophysics" or "American Astronomical Society". Include an **Abstract** summarizing the paper and the findings. An **Introduction** where you give an general overview of the astrophysical system we are modelling, and any other background information needed for the paper. Include a summary of the layout of the paper. Have a **Methods** section where you discuss briefly the theoretical model and methods (including a brief description of the Monto Carlo transport). Include key equations (e.g., among others, the differential Thomson Scattering cross section, $d\sigma/d\Omega$) and key derivations. Have a **Results** section where you go through and present the verification of the Monte Carlo simulations and the results of the net polarization study. Please pay attention to the specific questions asked in the lab and ensure you provide an answer to them. End with a **Conclusions** section where you discuss and summarize the results. Wrap things up with assessing what you think are the main limitations of the methods (including sources of error) and possible improvements.

The lab write up is intended to be done independently. But you are encouraged to have dicussions with each other and the lab instructors during the lab itself, but please come to your own conclusions, present your own data in your own plots, answer the questions on your own, and submit your own paper. An A will be given for a well written paper that follows the above outline and shows a excellent understanding of the methods and results, perhaps with some extension, analysis, or insight beyond what what is presented in the lab notebook. An acceptable lab report is required to complete the course. The lab componant (the paper and the prelab exercise) is 15% of the total grade in the course. Please also save the notebook and include in your submission a pdf copy of the jupyter notebook you generated in the lab. This will be especially useful when you write up the lab, but also helps us with seeing your methods.

Practicals for the Lab

There is a git repository for this lab. `https://github.com/evanoconnor/MCPolarization`. Download (or run on `https://mybinder.org`). Please read Höflich "Asphericity effects in scattering dominated photosphere" A&A 246 481 (1991). This paper is in the git repository in the `docs/` directory (as it this document). The important parts of this paper are the methods (Section 2) and results (Section 3), but not so much the application to SN1987A (Section 4). The purpose of the lab and topic of your final paper is reproduce a selection of the results in this paper. Some methods and physical setups we use are different from Höflich (1991), this is mainly for ease of implementation. You are more than welcome to enhance this work to include some of these missing aspects, and please discuss with us your thoughts and we can aide in your endeavour and make sure you doesn't forget any key aspects.

As we saw in the the prelab exercise, Thomson scattering dominated atmospheres polarize the light coming from different regions. If the atmosphere is asymmetric than this can lead to an asymmetry polarization signal, and ultimately a net polarization from the source as a whole. In this lab, we will construct such asymmetric atmospheres and follow the trajectory of individual photons being emitted from the origin. Since the scattering will be due to Thomson scattering, the polarization state of the photons depends on the history of the photon. If we simulate enough photons we can determine the polarization pattern and the net polarization.

The notebooks associated with this lab guide you through this whole process. Several key steps are missing, which will focus your attention on the concepts relevant for this lab. Please go through the notebook slowly, read all the headers and comments and understand what is happening. This part should take an hour or an hour and a half. By the end you should be able to reproduce Figure 7 of Höflich (1991), reproduced below. There are several lines on this figure, our case most closely aligns with the dashed line (labeled #1).

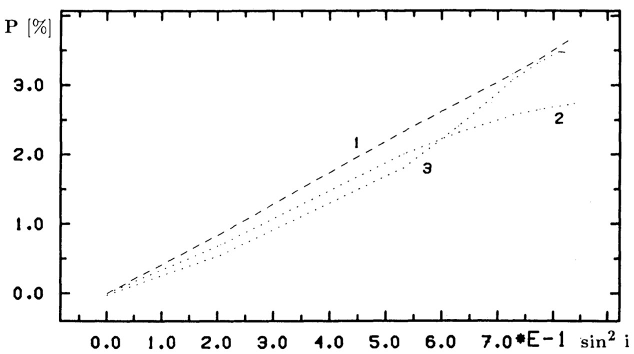

Fig. 7. Linear polarization as a function of the inclination i of the observer for an oblate ellipsoids with a spherical (*1*) and an ellipsoidal (*2*) core. In addition, the relation for a prolate ellipsoid is given (*3*) [$\tau_{max} = 1$; $N(r) \propto r^{-2}$; $\varepsilon = 0.01$; $E = 0.5$]

For the remainder of the lab please design numerical experiments exploring some of the other figures in Höflich (1991). Some require simply changing parameters, other require changing how routines are designed. We don't expect you to completely reproduce every figure, but a few would be nice. In addition to reproducing the figure, please generate and include any figures that may help you explain the methods and concepts in the paper.