M4111: Radiative Transfer in Stellar Atmospheres.

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This 12 hour course will be based on R.J. Rutten's excellent lecture notes of the same title **(http://www.astro.uu.nl/~rutten)**, also available locally at **http://www.maths.monash.edu.au/~judge/m4111**. The notes contain more than twice the material that can be covered, but should nevertheless be printed in full. The following sections will be emphasized (the schedule is rough):

Lectures 1-4: Chapter 2, *Basic Radiative Transfer*

Lectures 5-7: Chapter 4, *Analytical Radiative Transfer*

Lectures 8-11: Chapter 5, *Numerical Radiative Transfer*. To emphasize the fact that this subject has undergone a revolution since a breakthrough paper by Scharmer (1981), this material will be augmented by two papers:

"A Rapidly Convergent Iterative Solution of the non-LTE Line Radiative Transfer Problem", by Olson et al. (1986).

"Accelerated Lambda Iteration", by Hubeny (1992).

Lecture 12: Chapter 7, through section 7.3 only, *Atmospheres of Plane-Parallel Stars* (energy equation, radiative equilibrium).

This leaves

- Chapter 1, *Brief History of Stellar Spectrometry.* This will be ignored though it is short and worth a read.

- Chapter 3, *Bound-Bound and Bound-Free Transitions*, will be used just for reference.

- Chapters 6, *Polarized Radiative Transfer*, 8, *Continua from Plane Parallel Stars*, 9, *Lines from Plane-Parallel Stars* and 10, *Lines from Non-Plane-Parallel Stars* will not be discussed, except for illustrative purposes.

Problems will be set each week. An **assignment** will be set to build a computer program to solve the non-LTE transfer problem described by Olson et al. (1986), and examine the iteration schemes and results.

The aim is to provide a basis to the theory of both analytical and numerical radiative transfer, highlighting the new techniques that have developed in the last two decades for the efficient numerical solution of transfer problems using "approximate lambda operators". I hope that we can illuminate both the physical and mathematical bases for the development of these powerful techniques. The material will of course be **limited in scope and biased**. For context, here is a list of the **biases**:

- towards 1 dimensional transfer (simple stellar atmosphere applications)
- towards low energy, thermal, processes (electrons obey Maxwell-Boltzmann statistics)
- towards a semi-classical, phenomenological treatment (use of distribution functions, non-QED treatment of scattering)
- towards a non-relativistic treatment of the fluid and an $\mathcal{O}(v/c)$ treatment of the radiation.
- towards a static (or steady) fluid and a steady radiation field (no radiation hydrodynamics)
- away from polarized transfer (avoiding magnetic substate considerations, some high energy phenomena)

References

Hubeny, I.: 1992, "Accelerated Lambda Iteration", in U. Heber and C. S. Jeffery (Eds.), *The Atmospheres of Early-Type Stars*, Lecture Notes in Physics 401, Springer, Berlin, 377–392

Olson, G. L., Auer, L. H., and Buchler, J. R.: 1986, "A Rapidly Convergent Iterative Solution of the non-LTE Line Radiation Transfer Problem", *J. Quant. Spectrosc. Radiat. Transfer* **35**, 431–442

Scharmer, G. B.: 1981, "Solutions to Radiative Transfer Problems Using Approximate Lambda Operators", *Astrophys. J.* **249**, 720–730

Problem 1. (for section 2.1) Consider an object (it could be the Sun, moon) that is visible as a disk from the earth. Assume that the intensity emerging from the object is isotropic (not true in general but this is an exercise). What happens to the irradiance (flux received at earth) and the mean intensity if you double the distance between the earth and the object? If a camera is an instrument that records intensity (see problem 2), but can only do it effectively over narrow intensity ranges, how would you change the exposure time to get a good picture of the full moon if it were moved twice as far away? What change in exposure time would the Apollo astronauts need to take a picture of the moon's surface under their feet? If you stood on rocks on the earth with the same scattering properties of the moon, what exposure time would be needed to photograph them (assuming a clear day, and that the earth-sun and moon-sun distances are roughly identical)?

What happens to the irradiance and mean intensity if you put the object at the distance of α Centauri (roughly 3 light years[1])? Now consider observing α Centauri "A" (the "A" component of this binary star is actually very similar to the Sun: assume it is the same), with the Hubble Space Telescope (HST) in visible light at 500nm wavelength. Assume it is a perfect instrument with a primary mirror diameter of 2m. What is the solid angle of α Cen A subtended at the HST? Would the HST be able to measure **directly** the mean intensity? If not, how would you infer it from measuring the flux? How would exposure times change if α Cen A were 10 times closer or 10 times more distant?[2]

Refer to eq. (2.8) of the lecture notes, relating the irradiance to the mean intensity.

Problem 2. (for section 2.1) Consider a perfect camera. If it takes a photograph of an object with intensity I_1, what is the intensity I_2 of radiation at the focal plane? As a kid (or maybe a grown up!), did you ever burn holes in paper using the Sun and a magnifying glass? What properties of a magnifying glass allow it to be able to make the paper burn (explain in terms of the concept of intensity I)? If the surface temperature of the Sun is T, and $I \propto T^4$, what would be the highest temperature T that could be achieved at the focus of the magnifying glass? What would the temperature be if the magnifying glass were removed?

Problem 3. (for section 2.2) Derive (2.33), and convince yourself that you understand fig. 2.2.

Problem 4. (for section 2.2) Try Rob Rutten's exercises 1 and 2 on page 217 of your notes.

Problem 5. (for section 2.3) Prove (2.60). You might need to snoop around in the notes.

[1] The speed of light, solar radius and other constants are found on page 217 of the notes

[2] Hint: does HST spatially resolve the surface of the star?