Astronomy 74: Astrophysics
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Dartmouth College

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Paper discussion: Emission from an RS Oph outburst

In this assignment, you will read a scientific paper and prepare a short review. The goal of this assignment is for you to see some of the radiative transfer concepts from class in action. In class, we will review the paper together in your discussion groups following the worksheet format. Following the discussion, each of you will write a short (3 paragraph, 1/2-3/4 of a page single spaced) summary of the article, including a description of the relevant radiative transfer and the key findings. Upload a pdf to Canvas. The target audience for this summary is you and your classmates prior to taking this course, which means, for example, that you should define any words that could be considered "jargon." Please be attentive to presenting the material clearly.

- Expanding Bipolar X-Ray Structure After the 2006 Eruption of RS Oph, Montez et al. 2022, ApJ 926, 100: `https://iopscience.iop.org/article/10.3847/1538-4357/ac4583#apjac4583s4`

This paper focuses on RS Ophiuchi, a type of system called a recurrent nova. It is composed of a white dwarf and a red giant star. The red giant is so expanded that material flows out and is pulled into an accretion disk around the white dwarf. Every 10-100 years or so, enough material has accumulated on the white dwarf that the accumulated material ignites. This brief blast of hydrogen fusion causes the brightness of the system to rapidly increase, before fading. Here's a story about the 2021 outburst from RS Ophiuchu for those interested: `https://skyandtelescope.org/astronomy-news/recurrent-nova-rs-ophiuchi-just-blew-its-top/`.

The key radiative transfer section is §5.3 in the paper (recall free–free emission is another term for bremsstrahlung radiation). The paper introduces a concept called the "emission measure" (EM), for which I'll here provide some additional explanation (there actually seem to be multiple definitions for EM, the other I've seen being used for radio observations of HII regions in the absorption/Rayleigh-Jeans regime, which is NOT what's relevant here).

In the textbook and in lecture, we saw the definition for the emission coefficient, where $\epsilon \propto n_e n_i$. Generally, we can assume we have pure hydrogen so $n_e = n_i$, so $\epsilon \propto n_e^2$. Recall ϵ has units of erg s^{-1} cm^{-3}, so the emitted flux F_{emit} is proportional to ϵ integrated over the emitting volume. EM is defined as $\int n_e^2 dV$, so the $F_{emit} \propto$ EM. In the paper, F_{emit} isn't what's observed: we have to apply the inverse square law. This is captured in the η parameter, $\eta = \frac{10^{-14}}{4\pi D^2}$ where D is the distance to RS Ophiuchi. The 10^{-14} is just a normalization constant related to their model. The parameter they fit for in the model is η, not EM or D. After adopting a distance D they calculate EM and proceed with the further calculations described in §5.3.

Your summary is due on **Monday October 31 at 5pm** via Canvas. Your summary will be graded on three areas (10 points total):

- Scientific scope: did the summary cover the key areas of the article, without unnecessary detail? (3 points)
- Radiative transfer scope: did the summary cover the key radiative transfer concepts underpinning the research? The discussion questions can help guide. (3 points)
- Accuracy: was the summary factually accurate? (2 points)
- Clarity: was the summary coherent and understandable to the target audience? (2 points)

For Wednesday, October 26: Read the above articles (you won't understand everything!) before class. When you are reading the articles, consider the following questions:

- What motivated this study? What were the key discoveries?
- On what physics is this study based? Where and how do radiative transfer concepts get used?
- What questions did this paper bring up for you? What things didn't you understand? How would you go about answering them?

Questions for in class. These questions have a mix of goals: to zero-in on what I thought were key parts of the paper, to connect back to broader astrophysics context (e.g. A15/A25 material), and to highlight the specific radiative transfer connections.

One thing before we get started: the paper discussed the "point spread function" or PSF a lot. The PSF describes the telescope's response to a point source (which in practice will appear as some specific shape on the CCD, usually a more extended source with diffraction spikes). At the beginning of the analysis section, they are trying to remove the contribution of central point-like source the data so that they can accurately assess the properties of the extended emission. This is important because, for example, they note at the end of Sec 3.3 that a previous result is likely due to not having accurately characterized the PSF.

- What's the set-up that produces RS Oph? What's happening during the nova outburst to produce the extended emission that's the subject of this paper?
- What makes novae important for broader astrophysics questions?
- Observations
  - What facility was used to make the observations? At what wavelengths were the observations? Why was it necessary for the observatory to be located where it was?

- How much of the observations and data analysis sections was just completely confusing? Probably a fair bit – but note that despite this, you can move on to the remaining sections without missing too much of the big picture.
- To the best that your abilities, what are some of the general challenges faced when doing this data reduction?
- Looking at Fig. 1 and reviewing the description of the PSF above, why was it important to do the PSF subtraction?
- Based on Fig. 1, what does the extended emission look like?
- How did they fit the spectra? Where would you go to learn more about this code?

- Extended emission analysis
  - How do they quantify the size of the extended emission?
  - The article says that the overall model for the spectra is a combination of the `tbabs` and `apec` models. I googled the relevant line from the paper ("Sherpa using an absorbed thermal plasma model (tbabs x apec)") and the first hit was the list of models from the help manual for this software: `https://cxc.harvard.edu/sherpa4.2.2/ahelp/xs.html`. Based on this webpage, what are each of the two model components?
  - What's the parameter N_H? Why does it matter for interpreting the observations?
- What's happening to the angular size of the extended emission as a function of time? Which figure is related to this? What information do they need to turn this into an expansion velocity?
- §5.2 discusses the expansion in the context of previous work. What picture do they paint of the expanding material?
- What do they assume to calculate the cooling time? What corrections to this do they suggest are relevant to make?
- What electron density n_e would be required to produce cooling observable over the timescale of the observations?
- To calculate n_e from observables (specifically, η), what calculations do they do?
- What n_e and cooling time do they get?
- Where do they suggest the swept-up material responsible for the extended emission comes from? What makes them think this is reasonable?