Choose Your Representations: How to Engage Non-Science-Majors in Meaningful, Rigorous Reasoning about General Relativity

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Representations and Affordances

Good educators know the importance of using multiple representations to teach the content of their disciplines. As both students and instructors of physics, we have all seen the moments of epiphany that can be inspired when engaging with a novel representation of a difficult concept. The formal study of the cognitive impact of different representations on learners is now an active area of education research.

In education research, the *affordances* of a representation are defined as the elements of disciplinary knowledge that students are able to access and reason about using that representation. Instructors with expert pedagogical content knowledge teach each topic using representations with complementary affordances, maximizing their students' opportunity to develop fluency with all aspects of the topic.

The work presented here examines how we have applied the theory of affordances to the challenge of teaching non-science-majors in an general-education introductory astronomy class (Astro 101) to engage in expert-like reasoning about general relativity as applied to detection of exoplanets.

Astro 101: Exoplanets and Microlensing

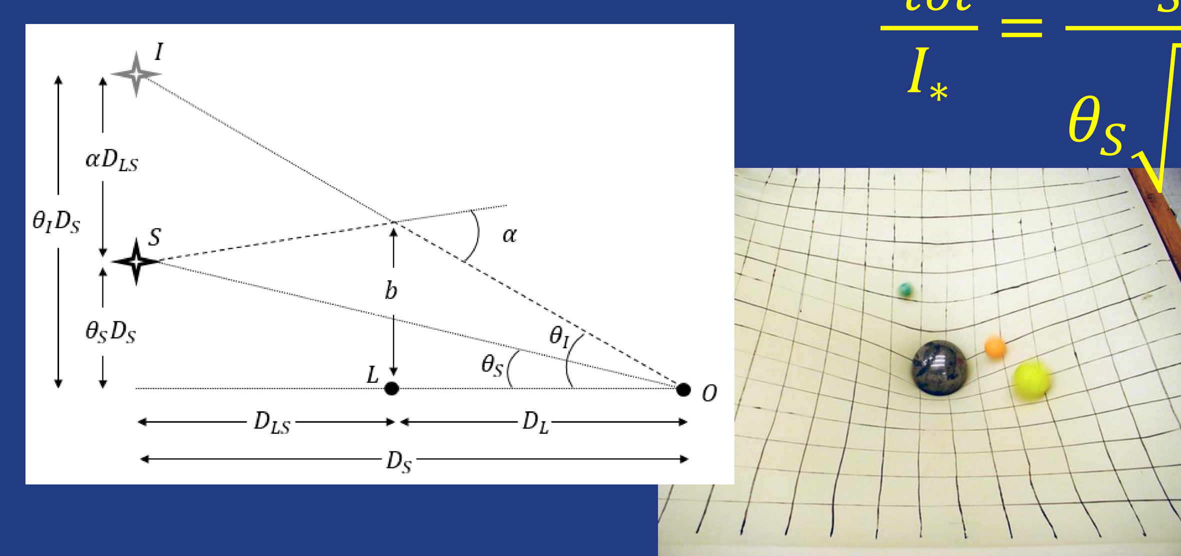
We are developing various curricula to bring modern, engaging astronomy content into the Astro 101 classroom; one topic of interest is the detection and characterization of exoplanets using gravitational microlensing events. Astro 101 students should be challenged to go far beyond recall-level tasks even for advanced topics in general relativity. To enable non-science-majors to engage in expert-like reasoning about phenomena in GR, we needed to use, adapt, or often create uniquely tailored representations of the discipline-specific phenomena coupled with developmentally appropriate cognitive tasks.

We define a *pedagogical discipline representation* (PDR) as a representation that has been especially tailored for the purpose of teaching a specific topic within a discipline. PDRs can be highly simplified versions of expert representations or can be highly contextualized with features that purposefully help unpack specific reasoning or concepts, and engage learners' pre-existing mental models while promoting and enabling critical discourse.

Relevant Relativistic Representations

Many representations of general relativistic phenomena exist, even within the context of introductory STEM teaching. These representations can be textual (written descriptions), pictorial (drawings of spacetime curvature), graphical (data plots), physical (a stretched rubber sheet), symbolic (curvature equations), etc. In designing curriculum, we must consider both the affordances of the representations per se, and also whether our students possess the prerequisite skills and knowledge to unpack the information contained therein. Converting a typical expert representation to an appropriate PDR requires balancing these factors without compromising the underlying physical principles and/or inhibiting the opportunity to engage in expert-like reasoning using the representation.

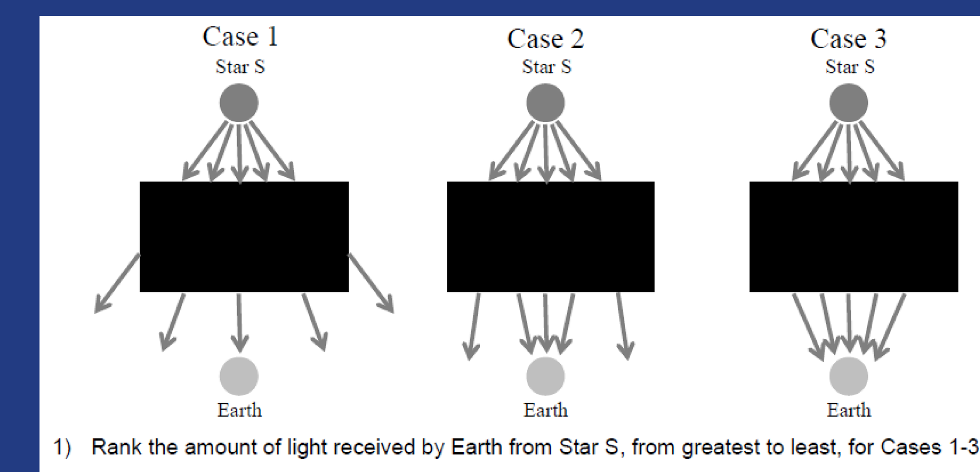
$$\frac{I_{tot}}{I_*} = \frac{\theta_S^2 + 2\theta_E^2}{\theta_S\sqrt{\theta_S^2 + 4\theta_E^2}}$$



One representation commonly used by researchers in gravitational lensing and exoplanet detection is the light curve: a graph of a light source's observed brightness vs. time. Fortunately, light curves also exemplify the properties of an ideal PDR! They contain information about physical variables (masses, angles, times…) and the processes (motion, spacetime curvature, light propagation…) that cause the observable results. Furthermore, the only prerequisite skill for unpacking this information is the ability to read a graph. This combination of factors means the affordances of the light curve are an excellent match for the rigorous, expert-like reasoning we want our Astro 101 students to engage in.

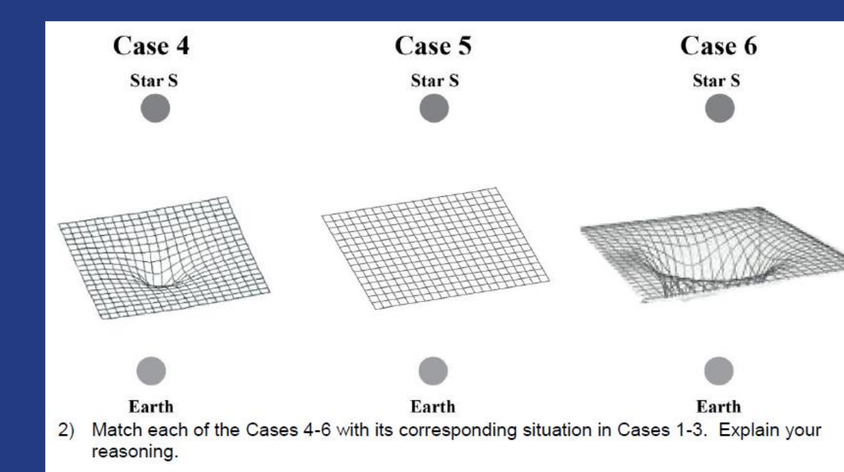
Having chosen the light curve as the PDR most central to our instructional goals, we assembled other PDRs that would help students understand relevant physical processes, and wrote sequences of questions that would guide students to construct sophisticated mental models of the phenomena through engaging with the PDRs. We then synthesized these components to produce a suite of instructional materials for teaching detection of extrasolar planets by gravitational microlensing.

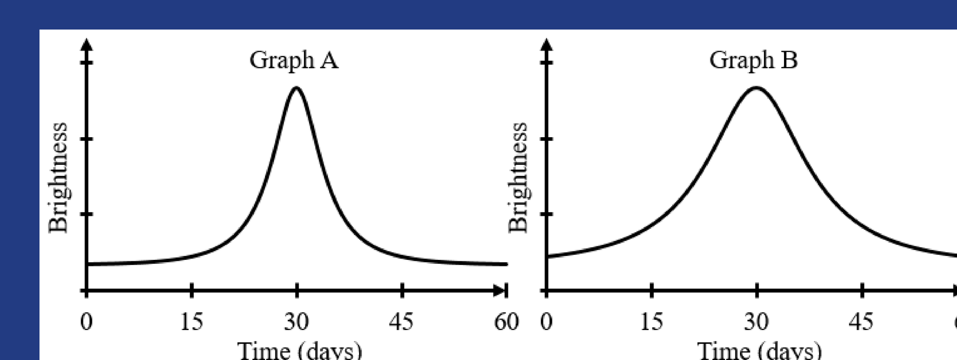
Sequential PDRs In Practice



The *Lecture-Tutorial* first requires students to reason about which hidden region of this PDR must contain the most mass based on the number of light rays that are bent toward Earth.

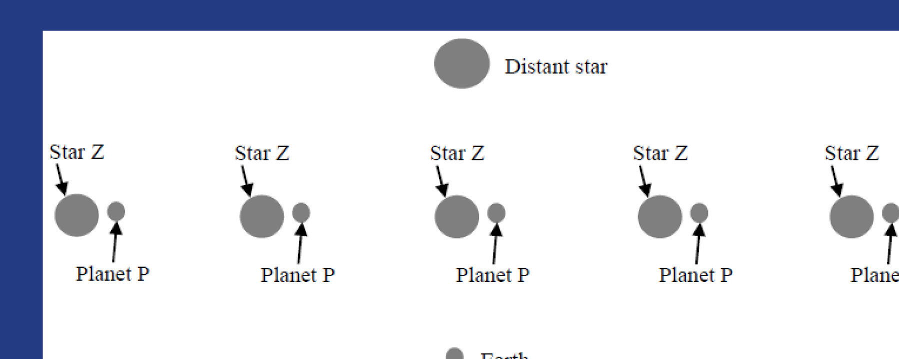
Students then extend their model to connect the warping of spacetime depicted in this PDR to the mass in a region, and the corresponding amount by which light passing through that region is bent.

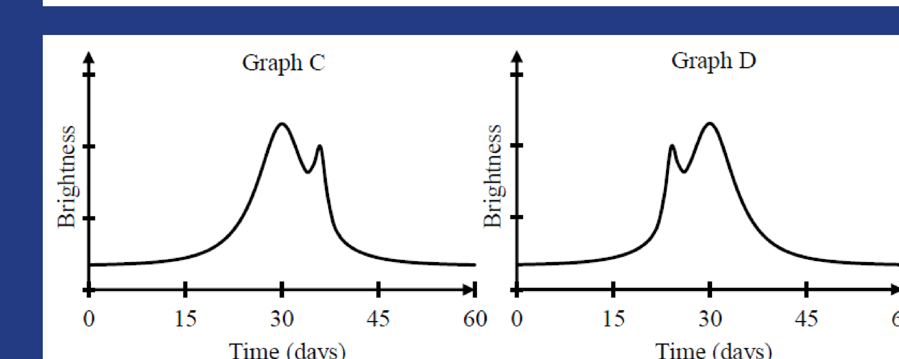




Students can now reason about how the light curve of Star S will vary with the mass of the gravitational lens.

Once students have developed a model to explain how a mass can gravitationally lens a light source, they can begin to reason about a planet's lensing effects and how a light curve might look with an extrasolar planet in the lensing system.





This sequence of PDRs, in concert with scaffolded questions and reasoning tasks, enables students to meaningfully engage in expert-like thinking about multiple physical variables, the relationships between them, and their observable consequences.

Acknowledgements

This material is based in part upon work supported by NASA's Exoplanet Exploration Program. We would like to thank Michael Greene and the NASA JPL Exoplanet Exploration Program (ExEP) for their continued support of the research, professional development, and curriculum development efforts of the Center for Astronomy Education (CAE) and the broader CAE community. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of NASA.