Boosting the public engagement with astronomy through arts

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Abstract

Arts are a seamless way to introduce the general public to both basic and more sophisticated astronomical concepts. The visual richness of astronomy makes it attractive and easily incorporated in painting and literature. Astronomy is the only science with a muse – Urania – implying that, at least in the eyes of the ancients, it was an art itself. I review some less well known representation of astronomical concepts in literature with potential application in education.

1 Motivation

The most ancient art is discovered on the walls of caves and usually depicts everyday scenes – somewhat direct studies of the human condition in the immediate environments of its creators. The existence of such artistic examples is evidence that even in those much more difficult times than today, the humans have found resources to investigate the surrounding world, themselves and their place in that world via artistic tools. It is also a testament of the motivational power of art, needed to ensure those resources were allocated in epochs that we would call times of extreme scarcity.

I set here a modest goal – to use this power of art for educational purposes, taking advantage that it appeals to human emotions. The emotions are a key to long term memory. Furthermore, they provoke and feed human curiosity, posing with the same intensity the questions on different scales: what lies behind the neighboring hill and what lies behind the neighboring galaxy. Art equally provokes human imagination and charges the investigative spirit – two necessary tools for addressing these questions.

Many educators have invoked art before in teaching to bring in convenient examples and colorful illustrations of material that otherwise may seem to students unappealing and challenging at the same time. Michael Brotherton from the University of Wyoming in Laramie went even further and organized a series of Launch Pad workshops to teach some basic astronomical concepts to interested writers.

Here I consider a few less well known literary works with potential application in astronomical education. They are dominated by the genre of hard science fiction, which by construction is “science heavy”. Hopefully, they will be added to the astronomical teaching practices and will help both teachers and students. This summary is aimed at educators.

2 Primers

2.1 Architecture of planetary systems in the novel The Photon Starship

The discovery of the first hot jupiter 51 Peg b was a surprise for the astronomical community because our expectations for exoplanetary systems were based on the Solar system and it lacks an analogue of gi-
ant gas planets that move around their host stars on orbits tighter than that of Mercury. Later we discovered that the Solar system does not have representatives of another class of planets either – the so-called super-Earths or mini-Neptunes, reported by \cite{2} and \cite{12}, among others.

The system of 51 Peg posed a difficult question how giant gas planets can exist so close to their star. Such planets could not have formed in situ because of the tidal forces. This leaves the orbital migration as a likely explanation \cite{30}. It should be noted that the widely accepted Nice model of the Solar system evolution does include planetary migration (for a general description of the Nice model see \cite{41}).

Exotic exoplanets are well covered in fiction. Probably, the most scientifically accurate and useful is the anthology *A Kepler’s Dozen* (2009), edited by S. Howell and D. Summers. It contains 13 stories, taking place on planets, discovered by the *Kepler* space telescope. However, the concept of an evolving planetary system is less well covered.

A surprising example with a potential educational application was penned by Dr. Dimitar Peev (1919-1966), a science fiction writer and avid promoter of science from Bulgaria. His degree was in Law, but for the entire duration of his multi-decade career he worked as a science journalist, founding and contributing to the development of the two best known popular science publications in his native country – the magazine *Kosmos* and the newspaper *Orbita*.

Peev described in his novel *The Photon Starship* (1964; Fig. 1, left column) a crewed sub-light speed flight to our nearest neighbor in the constellation of Centaurus. The book follows the life of Aster, a kid born on the ship, who has never seen Earth. The story line includes the usual well-known surprises – “meteor attack, radiation attack, malfunctioning robotic kitchen”.

In the contest of this analysis, the most important element of the novel is the discovery that the expedition makes upon arrival: Proxima is surrounded by a ultra-rich system of more than hundred planets with sizes between those of Mercury and Neptune.

Here we should remind ourselves that Proxima, in addition to being the closest star to the Sun (at just over 4 light years), is the third component in a stellar system where the primary itself is a close stellar binary, known as Alpha Cen A and B. This is relevant for the analysis carried out by the fictional astronomers in the book. They find that the bodies orbiting Proxima fall into two distinct classes:

(i) “Native” planets, with orbits nearly aligned into a single plane, similar to the planets in the Solar system. The scientists in the book speculate that these have been formed in the protoplanetary disk that once have surrounded Proxima itself, much like the planet of our system have formed in the protoplanetary Solar disk.

Figure 1: Covers of the novel *The Photon Starship* and a collection *Prisoners of an Asteroid* that includes *Infra Draconis* (top, left and right) and portraits of their authors Dr. Dimitar Peev and Georgi Gurevich (bottom, left and right).
Accreted planets on highly elliptical orbits, with random orbital inclinations. These planets are likely descendants of captured planetesimals that have been ejected from the neighboring Alpha Cen A and B early in the history of that system. The stability of this system is not discussed.

The book offers background material for explaining a number of astronomical concepts. The stellar multiplicity and the various mechanisms of binary formation are perhaps the most obvious ones. A suitable topic for discussion in class is the validity of the fictional hypothesis, explaining the existence of the accreted part of the Proxima’s planetary system: is it realistic in the light of the more recent – with respect to the publication year of the novel – discovery that the chemical composition of Alpha Cen A and B is different than that of Proxima? This was found during detailed abundance analysis of the three stars: [Fe/H] = 0.22 ± 0.10 to 0.26 ± 0.08 for Alpha Cen A and B, and [Fe/H] = −0.07 ± 0.14 to 0.05 ± 0.20 for Proxima (the statistical significance of that difference is yet another topic for discussion that I will only point at here). This implies that while the central pair has formed together, while Proxima is a later acquisition, most likely being accreted during a stellar flyby. The time of this flyby is unknown, but the probability that it might have happened early enough while the central binary still had multiple planetesimals is low, just because this is a short period – of up to a few tens of millions of years – with respect to the billion year age of the two main stars in the system. Dynamic studies of the Alpha Cen system also favor different origin of its components.

Stellar flybys like the one during which Proxima joined the Alpha Cen system are extremely rare on human lifetimes, but common by astronomical standards. Our Solar system underwent one only about 70 thousands of years ago, but the passing star had only ~15% of the Solar mass (Proxima is comparable – 12% of the Solar mass). Such events rise the question of the fragility of the planetary systems. They are difficult to detect, because the encounters are statistically likely to involve the most common type of stars in the Milky way – low-mass, cool and intrinsically faint objects – the reason why Proxima itself was discovered only in 1915 by Robert Innes when astronomical photography became a common tool, making it possible to carry out studies of proper motions of thousands of stars. The work of Innes was an early but important precursor of moderns space missions like HIPPARCOS and Gaia that draw detailed maps of the Milky Way and its nearest neighboring galaxies.

One can use the novel as a topic starter for a discussion on exoplanetary systems’ architecture as well. If we set aside the Solar system (keeping in mind the argument about the status of Pluto and about the hypothetical Planet IX – see), then the richest planetary system we know of is Kepler-90, with eight planets. Incidentally, Kepler-90 is a G type solar analog, but the majority of richest planetary systems are found around M stars, just like Proxima. An example of that is the seven-planet TRAPPIST-1. This apparent preference for late type host stars reflects the observational fact that low mass stars tend to be orbited by more, but lower mass planets, in comparison with Solar type stars, although some planets may have evaded detection. Indeed, noticed some time ago that hot Jupiters are rarely found around cool low-mass stars. Later on this was explained with the limitations of the planet formation in the protoplanetary disks – it is easy to understand this intuitively: the lower the stellar mass, the lower the mass of the protoplanetary disk, the lower the mass of the planets that can form inside them. The effect is boosted by an additional bias that the lower mass planets are easier to discover around lower mass stars, than around higher mass stars.

It is unlikely that Dimitar Peev predicted by a stroke of genius the fine details of the planetary formation in the vicinity of M stars. Still, the agreement between the properties of his fictional planetary system and the real planetary systems of M stars is not entirely a chance coincidence, because in an attempt to make his fictional world as realistic as possible, he based the reality of the novel on first physical principles. A number of important phenomena were taken into account: the scattering of protoplanets by

\[2\] A non-fictional account of the Pluto debate can be found in How I Killed Pluto and Why It Had It Coming, by Michael E. Brown, 2010.
the two close-in companions, the conservation of momentum that would preserve the orientation of planetary orbits in the plane of the protoplanetary disk. There are some inconsistencies or rather improbable elements, but they could only be recognized based on information that was not available at the time when the book was written.

2.2 Pre-discovery brown dwarfs in the novella Infra Draconis

The novella Infra Draconis was first serialized in a popular science magazine Knowledge – power in late-1958. It was written by Georgi Gurevich (1917–1998; Fig. 1, right column) – a Soviet and Russian science fiction writer. Interestingly, this novella has appeared in English twice, in collections of science fiction stories by Soviet writers: A Visitor from Outer Space (1961, Foreign Language Press, Moskow) and Soviet Science Fiction (1962, Collier, New York). The latter has an introduction by Isaac Asimov. Before becoming a full-time writer Gurevich had a successful career as a construction engineer. He also published many popular science articles in newspapers and magazines – which seems to be a common pattern among the writers who produced works suitable for educational purposes.

The story follows a space flight to an ultra-cool object, called infra, located in the Draco constellation. We learn that in the fictional world these are recently discovered objects, too small to sustain fusion in their cores. The infras are analogues of the real-world brown dwarfs (BDs).

Hypothetical dark substellar objects floating freely in space and not massive enough to sustain hydrogen fusion were first considered in the scientific literature only five years after the publication of Infra Draconis by 28 who named them black dwarfs. They still burn Lithium, though, unlike planets – their even lower mass “cousins”. The name was later replaced with “brown dwarf”, as a truer description of their colors, as suggested by Jill Tarter, better known for her SETI work. The first BD was observed in 1988 – it is a companion to the white dwarf GD165, but it was not recognized that it belongs to the class for a decade 35. Modern theoretical models suggest these objects span a range between \( \sim 12 \) and \( \sim 60 \, M_{\text{Jup}} \). 12

It is too late to ask the late Georgi Gurevich how he came up with the idea for sub-stellar objects. In a similar situation, Frederick Pohl was asked how he came up with the idea that a super-massive object resides at the center of every galaxy – a statement made by one of the characters in his novella “The Gold at the Starbow’s End” (1972). Apparently, he read it in a popular science journal and with some speculation this hypothesis – at the time – can be traced to works by Salpeter and Zeldovich published at around the same time. 50, 59

The closest infra in the fictional world of Gurevich is only seven light days away – a much smaller distance than to the nearest star Alpha Cen (discussed in the previous section). This is also the most interesting infra, because its surface temperature is 10°C – about the average winter day-time temperature on the Bulgarian Black Sea coast (at about 42 deg north of the equator). This puts Infra Draconis at the temperature range allowing existence of liquid water. Unlike Earth, with its significant diurnal-nocturnal (day-to-night) temperature variations, the infras have constant surface temperatures, because they are heated internally. Their energy source is contraction – for the same reason Jupiter emits more energy than the amount it receives from the Sun.

The kosmonavts from the novella spend fourteen years to reach their target, but in the middle of the journey they discover that the Earth-side observations were wrong – Infra Draconis is binary object. The two components have surface temperatures of \(-6\,\text{C}\) and \(24\,\text{C}\). The original planning sends the expedition to the cooler object – a giant methane and ammonia gas ball, similar to Jupiter in our Solar system. However, the warmer one turns out to be a liquid water world. The expedition’s leader makes the ultimate sacrifice, descending below the surface (captains going on away missions is not a tradition limited to Starfleet), only to discover in his last moments a thriving technological extraterrestrial civilization (ETC) at the bottom of the alien ocean.

In the real world the nearest binary BD we know of is Luh-16 (a.k.a. WISE J104915.57−531906.1), located at about 2 pc from the Sun 33, but the ef-
fective temperatures of both its components place them well above the liquid water regimen. Much closer analog of the fictional Infra Draconis is the BD WISE J085510.83−071442.5 (often abbreviated to W0855) – as far as we know, a single object – with an effective temperature \(\sim 250\) K (close to \(-20\) C) at a distance of 2.2 pc from the Sun \[34, 4\]. It is probably 3–10 times more massive than Jupiter and its age range is poorly constrained – it may lay anywhere between 1 and 10 Gyr.

Why were these nearby objects discovered only recently? In fact, Luh-16 was detected in a number of surveys going as far back as the 1970-90s \[36\], but its high proper motion \((8.1\pm0.1\) arcsec yr\(^{-1}\)) and the crowded region of the sky it resided in prevented astronomers from recognizing that these detections belong to the same object. The non-detection of W0855 is due to its intrinsic faintness \[4, 26, 35, 58\].

Life on planets around BDs was considered by \[31\] (in fact, the first directly imaged planet orbits a brown dwarf \[10, 11\]. They concluded that only more massive BDs \((M \geq 30 M_{\text{Jup}})\) are likely to sustain planets with habitable conditions on sufficiently long time scales. Surprisingly, the idea of Gurevich that life may thrive inside the atmospheres of a BD has also been studied by \[57\] and \[32\]. They argue that there are a few tens of W0855-like objects within ten parsecs from the Sun, and that the habitable volume in them may be hundred times larger than on Earth-like planets.

In the context of this summary the novella *Infra Draconis* is suitable to introduce the ultra-cool substellar mass objects, to underline their high spatial density, and the possibility that they may harbor life – either on planets or within their own atmospheres. The latter topic may be particularly appealing to the public: recent data suggests that our Solar system may harbor up to ten subsurface oceans, compared with only one planet with a habitable surface – Earth. If the subsurface oceans are viable habitable zones, this may increase the habitable space of a planetary system by an order of magnitude.

### 2.3 Astronomical methods and social environment in the astronomical community in the novel *Stars and Waves*

The novel *Stars and Waves* was written by the well-known astronomer Roberto Maiolino from University of Cambridge. He is specializing in extragalactic studies and observational cosmology. This book is different from previous examples. First, because it is a work of a professional astronomer who knows the research process and astronomical environment inside out. Second, because it is marketed as a thriller.

*Stars and Waves* offers information about various aspects of exoplanet research and paints a realistic and detailed view of the life in the astronomical community at a page-turning pace. An important disclaimer: in the real world the astronomers’ lives do not lead to untimely ends as a result of fierce competition to publish, and generally, the life in academia is not amply sprinkled with violence, as the readers may be led to believe – these are only plot drivers and concessions to the genre. The book can be used as educational tool, but for more mature audience.

The novel often detours into the history of astronomy – the work of Newton, Galileo and others are prominently featured in an inspirational manner. Some relevant past and present-day technologies are also explained, so the novel can provide background for a discussion how fast the technological progress enables the astronomical progress.

The central scientific question in *Stars and Waves* – not revealed at the beginning – is of finding life elsewhere in the Universe. The answer had been pursued in two ways. The typical programs to search for advanced technological extraterrestrial intelligence (SETI) usually rely on various leaked emission – for example, radio from communications or heat from massive computation or from Dyson spheres \[49, 48, 56\]. We argued in \[20\] that advanced technological ETCs are likely to reduce such losses, rendering these strategies inefficient. This leaves us with the options of communicating either with advanced ETCs that are willing to set up beacons intention-

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[31]: https://www.starsandwaves.net/
ally aimed at and optimized for “younger” cousins like us, or with nearby (in both space and development) peer-level ETCs that allow significant radio or thermal leaks.

The second path to search for life in the Universe is to look for traces of the natural products of this life – the so-called biosignatures. An excellent introductory reading material can be found at the NASA Astrobiology page. The Oxygen and Ozone are the most informative biosignatures. Strictly speaking, water is not a biosignature, but it is an important solvent and its presence is considered critical for life as we know it. The Carbon dioxide and Methane are other potential indicators of life, although some geological sources can contribute to their content in the atmospheres of exoplanets.

*Stars and Waves* presents to the reader an intriguing combination of bio- and technosignature based ETC searches.

On more technical level, Maiolino introduces the transmission spectroscopy as a main exoplanet characterization tool – in the real world this is a commonly used technique that brought up the first direct detections of exoatmospheres. This method can be traced further back to the Russian scientist Mikhail Lomonosov (1711-1765) who discovered the atmosphere of Venus during a transit of that planet across the Sun in 1761. summarizes the present-day status of the transmission spectroscopy.

The novel is written in what almost qualifies for a semi-documentary style, the action takes place on existing (and exotic) astronomical locations and it draws quite realistic picture of every-day’s life of researchers and astronomical institutions. Some concessions to action have been made, though: most large, modern observatories maintain stringent account for every second of observing time, or every obtained image or a spectrum, especially if they are funded by public money. Unsanctioned target changes at such observatories are hardly ever possible. Finally, the book spectacularly succeeds conveying the competitive academic atmosphere.

*Stars and Waves* can be used to stimulate discussion and interest towards a number of subjects, ranging from astronomical instrumentation, including spectroscopy; concepts why a certain site is suitable or not for observations, including dryness and light pollution. A rarely touched upon topic is how actually the work at observatories is organized and the novel invites a comparison with the Commencement address that the famous astronomer Edward Pickering (1846-1919) gave at Case School of Applied Science in Cleveland on May 27, 1909. He outlined his uniquely insightful view of astronomical institutions of the future, and they look surprisingly similar to the modern observatories that Maiolino describes.

### 3 Summary

I describe a few literary works that can be useful for astronomical education. They help to introduce many basic concepts, including binary stars, planet formation, brown dwarfs. The big question about the search for other life in the Universe is also covered.

This material can be used in different manners – as introductory points, as basis for class discussion, or as cases to be troubleshooted by the students – and for students at different level, from high school to amateur astronomers and even graduate level students who can exercise debugging some of the false concepts and conclusions that were present in these works.

A number of novels and stories that can be useful to educators were omitted. Among them are the anthologies *Diamond in the Sky* (2008) and *Science Fiction by Scientists* (2017; both edited by M. Brotherton), the novel *Les Robinsons du Cosmos* (1955) by the French SciFi writer Francis Carsac (1919-1981), the upcoming astrobiological anthology *Life Beyond Us* (2022, Eds. S. Forest, L. K. Law, J. Nováková), and in particular the excellent non-fiction teaching manual *Exploring Science Through Science Fiction* (2013) by B. B. Lukkala.

Finally, this paper offers an eclectic mix of references, ranging from fiction, to popular articles and research works to help educators in finding sources.
that match the level of their audience.

Acknowledgements

This is an extended write up of a poster presented at the European Astronomical Society (EAS) Annual Meeting held on line, Jun 28 – Jul 2, 2021, Special Session SS6 (Jul 2, 2021): Diversity and Inclusion Day. I thank the organizers for giving me the opportunity to demonstrate the power of art as an educational tool.

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