The Black Cloud—a classic science fiction novel from the pen of an astronomer

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Abstract
Throughout the long history of astronomy, scientists have repeatedly written fictional stories, which often lend themselves to use in the classroom thanks to the authors’ in-depth knowledge and an appealing storyline. This article uses the novel 'The Black Cloud', written by the well-known astronomer Fred Hoyle, to show which physical-astronomical tasks can be derived from it. For this purpose, the use of text excerpts as well as the whole novel is conceivable. Beyond the examples of distance determination and the thermodynamics of the atmosphere presented here, the book also offers interesting insights into the work of astronomers in the 1950s, which Hoyle was able to report on first-hand.

Keywords: science fiction, literature in physics lessons, astronomy, scientists as novelists

1. Introduction
The year 2021 marks the 20th anniversary of the death of British astronomer and mathematician Fred Hoyle (1915–2001). In addition to his significant contributions to the nucleosynthesis of heavy elements in stars, Hoyle is known for his rejection of the interpretation of cosmic expansion in terms of a big bang. The term itself goes back to Hoyle, who used it as a derogatory remark. Until his death, he championed the idea of a static universe in the form of the steady state theory.

Less widely known is that he was also an author of science fiction literature and wrote a total of 19 novels in this field. His first novel, 'The Black Cloud', was published in 1957 and is written in the style of a report aimed at a reader in 2021 [1]. However, regardless of the coincidence of the two dates, the novel is of interest from the point of view of physics and astronomy. On the basis of a text of manageable length, it offers both possibilities for a physical examination of the text and insights into the working methods of astronomy and technology at the time of its creation, while at the same time providing an opportunity...
to critically discuss the interactions between science and politics that are presented.

The novel can be placed in the category of 'hard science fiction'. Although there is no real definition, the term can be outlined as follows: after the occurrence of a certain event, based on scientific facts and laws, certain conclusions are drawn. ‘The Black Cloud’, as a peculiarity of the sci-fi genre, is not set in a distant future, but starts in 1964. Hoyle thus refrains from incorporating highly advanced technologies, so that his novel is comparable in this respect in H G Wells’ ‘The War of the Worlds’ [2].

The fundamental benefits of using context-oriented [3] and fictional media have already been discussed elsewhere [4–6]. It has already been shown for movies that they have an influence on the scientific ideas of the audience as well as having a positive effect on their motivation [7]. At this point, the special features of the use of literature only shall be summarised again.

2. Literature in science lessons
An advantage of literature, compared to the use of film clips (e.g. [8]), is the direct availability of the facts. While those have to be laboriously recovered from a film sequence, the novelist necessarily provides the reader with information on the size, appearance and special features of, for example, spaceships. When dealing with the material in the classroom, one can thus turn to the physical aspects more quickly without having to take the detour of analysing the video material— which at this point is not to deny its positive effects!

In addition to the aforementioned direct availability of data in the text, there is another special feature of Hoyle’s novel. The calculations are—as long as they are not omitted due to their complexity (as is the case with the calculations on the perturbations caused by gravity)—fully presented and sometimes explained by simple sketches.

3. On the content of ‘The Black Cloud’
At this point, the contents of the novel are explained only to the extent necessary for understanding the tasks, so that the detailed plot and some essential turns of the story are not given in advance.

As mentioned at the beginning, the novel is in the style of a report that reaches a descendant of the protagonists 50 years after the fictional events. The plot is built around the appearance of a dark cloud on astronomical photographic plates that initially looks like a Bok globule (figure 1), an object that in fact has only been known since the 1940s [9]. American scientists—with quite detailed descriptions of their places of work, instruments and techniques that were well known to Hoyle—quickly come to the conclusion that the cloud is moving towards the solar system. British scientists also become aware of the phenomenon, and an international collaboration is developed to investigate it. In the course of this, the trains of thought and methods used to answer the pressing questions are always explained in detail. The claim to provide physical-astronomical education in addition to entertainment becomes clear without being intrusive. The cloud, which has an exceptionally high density, enters the solar system after only a few months and causes devastating damage on Earth by shielding the sunlight. The novel further describes the events from the point of view of a group of scientists who, in the meantime, have retreated to a country estate in England under pressure from the government. In addition to aspects of thermodynamics (such as the reaction of the Earth system to the absence of solar radiation and the interaction of the cloud with the irradiation as it approaches the sun), questions of communication with the public and the reactions of governments are also explored. The high point of the book is the launch of—at the time, still very new—intercontinental missiles equipped with hydrogen bombs.

The description of the catastrophic consequences of the appearance of the cloud is largely omitted. They would of course be all too well known to the recipient of the report. Even today’s readers are probably familiar with visually bombastic apocalyptic scenarios of current Hollywood productions and can therefore imagine the events just with the same ease.

4. Approaches for the use in teaching
The relative brevity of the novel makes it possible to read it in its entirety as preparation for class. Especially when focusing on the connections...
The Black Cloud

Figure 1. Astronomical image of a Bok globule. In ‘The Black Cloud’ the appearance of the approaching cloud shares a description with such a molecular cloud. Reproduced from [10]. CC BY 4.0.

Figure 2. The method presented in the book for determining the time at which the cloud reaches the earth.

between politics and science and the reactions of scientists, this approach is the most sensible.

However, text excerpts, with a brief indication of the general content of the whole novel, can also be used as a context-oriented task in class. In the following, two examples with different focuses and degrees of difficulty are presented, which follow the latter approach.

4.1. The approach of the cloud

After the still unknown object has been sighted, it quickly turns out that it appears larger and larger on the photo plates as time passes. An understandably urgent task for the protagonists is therefore to estimate the arrival time of the cloud in the inner solar system.

As with any astronomical object, the distance, speed and direction of the cloud’s movement are initially unknown and cannot be determined from a single observation. The cloud itself does not emit any radiation in the visible spectrum, so that it stands out from the star background with complete blackness. The conspicuous appearance covering parts of the constellation Orion arouses the interest of astronomers, who identify the cloud in the photo plate archives in earlier photographs and note its rapidly increasing apparent diameter.

At an early stage, Hoyle lets his protagonists make an estimate of the cloud’s arrival time on Earth, which does not require a measurement of its speed. At this point, there are now various approaches for use in teaching. First, the novel could be read up to this point, i.e. the first 18 pages, and then left as an open question. Alternatively, the presented calculation can be reviewed and examined critically under the guiding question of whether and how it should be possible to calculate the arrival time without the distance or speed being given.

At this point, the second way is taken, for which basic knowledge in differential calculus is necessary. The protagonists define the following quantities: the angle of the diameter of the cloud in radians $\alpha$, the linear diameter $x$, the distance...
Earth-cloud $X$, the approach speed $V$ and the time until arrival $T$ (figure 2, in the book, the distance and size of the cloud are denoted by $d$ and $D$ respectively, which has been changed due to the risk of confusion with the differential notation). It is then

$$\alpha = \frac{x}{X}.$$ 

Differentiating this equation according to $t$, to take into account the time dependence of these quantities, yields

$$\frac{d\alpha}{dt} = -\frac{x}{X^2} \frac{dX}{dt}.$$ 

For the velocity, $V$ can be written:

$$V = -\frac{dX}{dt}$$

respectively

$$\frac{d\alpha}{dt} = \frac{x}{X^2} V.$$ 

The quotient $\frac{x}{p}$ is the time $T$ that elapses until arrival. This allows the velocity $V$ to be eliminated from the equations:

$$\frac{d\alpha}{dt} = \frac{x}{X^2} \frac{1}{T}.$$ 

It follows:

$$T = \alpha \frac{dt}{d\alpha}.$$ 

You can now approximate $\frac{d\alpha}{dt}$ by finite intervals and use the time interval of one month from the book for $\Delta t$. Likewise, the quotient $\frac{d\alpha}{dt}$ is obtained with the increase of the apparent magnitude from 5% to 20%. The time until arrival is finally obtained from

$$T = 20 \cdot \Delta t.$$ 

In this way Hoyle demonstrates how a combination of mathematics and physics can be used to describe the approach of an object without knowing its distance and speed.

4.2. Considerations on thermodynamics

The scientists assume that due to its high density, the cloud will completely absorb the sunlight when it reaches the sun. Once its size and speed have also been determined, it is easy to calculate how long the total eclipse will last, which is calculated to be one month. Hoyle has the scientists discuss the possible effects on the terrestrial biosphere:

‘Well, let’s go into it from the scratch,’ began Kingsley. ‘After a normal sunset the temperature goes down. But the decline is limited by two effects. One is the heat stored in the atmosphere, which acts as a reservoir that keeps us warm. But I reckon that this reservoir would soon become exhausted, I calculate, in less than a week. You’ve only got to think how cold it gets at night out here in the desert.’ (Hoyle 1957, p 48)

Hoyle does not give detailed calculations to the discussions on thermodynamics, but only allows those acting to exchange qualitative arguments. The passage therefore offers the opportunity to make one’s own estimations in order to be able to check the presented impacts for their plausibility.

4.2.1. Estimation on temperature trends. For a simple model, we first assume that the Earth receives its energy from the Sun alone (influences of geothermal energy are neglected), that this radiation is completely absent and is not partially compensated by any radiation emitted by the cloud (figure 3).

The first step in determining the temperature drop is to consider the heat capacity of the terrestrial atmosphere. It is given by:

$$Q = mc_{\text{Air}} \Delta T.$$  

(1)

The first part of the task consists of estimating the mass of the Earth’s atmosphere. This can be done directly on the basis of the air pressure at sea level $p_{\text{Air}}$ and on the Earth’s surface area, $A_{\text{Earth}}$, as this is caused by the load of the air column above.
\[ p_{\text{Air}} = \frac{F}{A_{\text{Earth}}} = \frac{m \cdot g}{A_{\text{Earth}}} \Rightarrow m = \frac{p_{\text{Air}} \cdot 4\pi r_{\text{Earth}}^2}{g} \] 

The mass of the Earth’s atmosphere results from this to \(5.2 \cdot 10^{18}\) kg. To calculate the heat loss, knowledge of the Stefan–Boltzmann law is necessary:

\[ P = \sigma \cdot A_{\text{Earth}} \cdot T^4. \] 

Here, \(P\) is the resulting radiated energy, \(\sigma\) the Stefan–Boltzmann constant \((5.67 \cdot 10^{-8} \text{ W m}^{-2} \text{ K}^{-4})\) and \(T\) the absolute temperature in K.

This shows that radiation is strongly dependent on temperature. Such a strong non-linear dependence does not allow a linear approximation. This also makes it obvious why Hoyle refrains from stating the basis of calculation at this point and instead lets his protagonists discuss the results directly.

The necessary calculation steps are manageable for an approach that is limited to considering the energy content of dry air and can be handled with spreadsheet software. In fact for first estimations, the consideration of a smaller temperature interval is sufficient, so that even an estimation in the form of a constant radiation would not carry too much weight.

The example calculation is based on a spreadsheet in which the radiation, the amount of heat remaining in the air and the resulting temperature are calculated in steps of one hour. If equations (1)–(3) are combined, the new temperature is calculated after each time interval:

\[ T_{\text{new}} = \frac{\sigma \cdot A_{\text{Earth}} \cdot T_{\text{old}}^4 \cdot \Delta t}{m_{\text{Air}} c_{\text{Air}}} + T_{\text{old}}. \]

Using the mass of the atmosphere calculated above and the specific heat capacity of air of \(1.005 \text{ kJ kg}^{-1} \text{ K}^{-1}\), the temperature curve can now be tracked. The starting point is the global average temperature of 288 K, which is required as a starting parameter. This makes it possible to determine the period of time during which the Earth has cooled down to the temperature of the surrounding universe. More interesting are the intermediate steps, e.g. the point in time when the global average temperature falls below the freezing point of water, which is the case after 5 d. After 1000 h (just under 42 d), the temperature is only 214 K.

One point of criticism of this estimation could be the starting point of the temperature. Although the value of 288 K corresponds to the average surface temperature and it can be assumed that even the lowest layers of the atmosphere have approximately this temperature, it is not easy to estimate the temperature of the entire atmosphere. However, the temperature decreases with increasing altitude (by about 9.5 K per km), but at the same time the air pressure is reduced, i.e. the contribution of the individual layers to the average temperature is lower. If only the first 10 km are included in the calculation, the heat capacity is \(9.5 \cdot 10^{23} \text{ J}\), as opposed to \(1.45 \cdot 10^{24} \text{ J}\) used in the above calculation. However, the effect on the cooling period is negligible.

### 4.2.2. Including condensation.

So far, the atmosphere has been considered in the form of an overly simplified model. However, hardly any consideration can be done without the moisture contained in the atmosphere, which, although small at 0.25% of the mass, has an immense impact. Also in the novel the effects of the water vapour content on the temperature development are addressed immediately:

‘You can see what will happen,’ continued Kingsley. ‘For the first day or two after the Sun is hidden – if it is shut out, that’s to say – there won’t be a great deal of cooling, partly because the air will be still warm and partly because of the water vapour. But as the air cools the water will gradually turn, first into rain, then into snow, which will fall to the ground. So the water vapour will be removed from the air. It may take four or five days for that to happen, perhaps even a week or ten days. But then the temperature will go racing down. Within a fortnight we shall have a hundred degrees of frost, and within a month there’ll be two hundred and fifty or more.’ (Hoyle 1957, p 44)
With a value of 2257 kJ kg\(^{-1}\), the latent heat of vaporisation is comparatively very high. The question now is, how big the contribution to the reduction of impending cooling can actually be, with the very small water vapour content of the atmosphere.

For the estimation, some assumptions have to be made. In the following, we assume that when an average temperature of 0 °C is reached, all water vapour has condensed.

Furthermore, it is to be assumed that condensation should occur evenly over the interval from 288 K down to 273 K. A certain fraction of the total enthalpy of vaporisation \( Q_V = H_v \cdot m \) is thus released per time interval:

\[
Q_C = \left( \frac{T_n - 1 - T_n}{T_{\text{Start}} - 273 \text{ K}} \right) H_v \cdot m.
\]

The implementation in a spreadsheet shows that the mean global temperature reaches the 273 K mark after 165 h due to the released energy. From here on, the further cooling proceeds as in the first example, so that again after 1000 h the temperature is approximately 216 K.

### 4.2.3. Comparison with the novel

The estimation made here is therefore consistent with the information in the novel for the period until the water vapour has completely condensed.

What cannot be confirmed, on the other hand, is the alleged lightning-like fall after the rain and snowfalls have stopped.

In a similar way, the influence of the oceans could be discussed, as it is scarcely done in the book. The influence of the high heat capacity of large quantities of water can easily be seen in the climate diagrams of towns on the coast and inland. Here, the influence of the ice that forms is added, which hinders the heat exchange between water and atmosphere. While this aspect is not to be pursued further here, another source of error should not remain unmentioned in the above considerations: the atmospheric downward radiation.

It is generally known that clouds have an effect on nightly cooling. With a clear sky, like something in dry desert areas, the cooling is much stronger than with a cloudy sky. Downward radiation is the radiation of heat from the atmosphere, which is the opposite of the radiation from the planet. Especially under the assumption that the global temperature drop leads to a strong cloud formation, the influence of the effect is significant, because the counter radiation can easily reach values of more than 300 W m\(^{-2}\). The cooling of the Earth would be correspondingly slow if the Sun were to darken for a longer time.

A direct reference to astronomy is also possible, if one considers the nature of the cloud itself. For instance, the question can be raised which temperature prevails within a Bok globule and what effect this has on the considerations made by Hoyle. In fact, it turns out that the temperature within such a molecular cloud must be extremely low for it to contract under its own gravity and eventually form a new star. Therefore, it would not be reasonable to assume that such a cloud would in turn counteract the cooling of the Earth.

### 5. Concluding remarks

In the examples presented here, even the short text passages can only give an impression of the considerations that might arise from them. Already the first considerations about the thermodynamics of planet Earth offer rich opportunities to apply, test and extend physical knowledge, which is also of great importance in real-world applications.

In addition to the astronomical-physical tasks presented here, science fiction novels very often offer a number of other possible perspectives that go beyond the natural sciences.

Significantly in ‘The Black Cloud’ it is noticeable that the protagonists show an aversion towards government representatives. The scientists themselves take control and exert great influence on government agencies. The question could be asked what attitude Hoyle himself had with regard to the cooperation between science and politics. It should be noted that he also had personal experience in this area through his work in the field of radar technology during the Second World War. The sceptical attitude of one of his central characters could thus be interpreted as an expression of Hoyle’s own views.
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