Midterm

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Due at start of lecture (11 am) on Friday Nov 1, 2019.

This entire midterm is based on a 1957 novel by the astronomer Sir Fred Hoyle, who was responsible among other things for the term "Big Bang". The novel, called The Black Cloud[1], looks at the consequences of a dense interstellar cloud inhabited by a benevolent super-intelligence arriving at the solar system, and interacting with the Earth's population. Here, you will place yourselves in the shoes of the fictional astronomers in the novel to try and figure out what's going on.

Instructions: *Points will be awarded equally for sufficiently detailed explanations of your reasoning, and for reasonably accurate numerical answers. Although most questions depend on previous answers, partial points will be awarded even if previous answers were incorrect. Please only refer to class notes (lecture notes plus those taken by you in class), homework solutions, and the textbook.*

Question 1. (2 points) One afternoon, an astronomer colleague bursts into your office with some pressing news... the coffee has run out! While you accompany them to a nearby cafe, they mention that they saw something odd in last night's sky-survey data: a dark 1-arcminute diameter cloud near the star Sirius (RA 06h45m, DEC $-16°$) that blotted out several background stars. You remember that a friend has time on a sub-millimeter telescope at Palomar observatory that night (Oct 31), which could be useful to determine the temperature of the cloud. But can you observe the cloud, and at approximately what local time (to the nearest hour) will it transit the meridian (i.e., be as high above the horizon as possible)?

[1] After the midterm, I recommend reading it – it's surprisingly good, although certainly a product of the times.

Question 2. (5 points) To your amazement, you find that the cloud has a flux density of 2695 Jy (Janskys) at a frequency of 115 GHz, and a flux density of 10781 Jy at a frequency of 230 GHz.

(a) Is the spectrum of the cloud consistent with the Rayleigh-Jeans law?

(b) What is the effective temperature of the cloud?

(c) Did your telescope, which has a 3 m diameter aperture, resolve the cloud structure at either frequency?

(d) You begin thinking about contacting other astronomers to observe the cloud in the infrared. By applying either the Rayleigh-Jeans law or the Planck law, estimate the surface brightness of the cloud at the blackbody-peak wavelength of 29 μm, in units of Jy str^{-1}.

Question 3. (6 points) You are not the only astronomer to have noticed this object. The next day, posts on the astronomer's unnamed-social-media company page confirm the blackbody nature of the cloud spectrum, and report a total bolometric (frequency-integrated) flux of 1.20×10^{-4} erg s^{-1} cm^{-2}.

(a) Using the angular diameter of the cloud and its effective temperature, calculate the cloud diameter and distance from the Earth.

(b) 30 days later, the most surprising result of all is reported: the angular diameter of the cloud has grown by 226 milliarcseconds! If this is because the cloud is moving towards the Earth, what is the velocity of the cloud?

Question 4. (6 points) Detailed infrared spectra show that the cloud is indeed approaching the solar system. They also reveal the presence of silicate dust grains that are 1 μm in size and have masses of 10^{-11} g.

(a) Estimate the opacity (which is the cross section per unit mass) of the dust, assuming that all photons that impact a dust grain are absorbed or scattered.

(b) Assume that dust scattering is the dominant opacity mechanism in the photosphere of the cloud, and that the cloud is supported against gravitational collapse by radiation pressure. By applying the equation of hydrostatic equilibrium, estimate the mass of the cloud.

Question 5. (2 points) Eventually, once communication is established with the super-intelligent being inhabiting the cloud, you learn that nuclear fusion reactions of hydrogen are used as a power source. Based on the cloud luminosity, estimate how much hydrogen fuel is required to power the cloud each year.

Question 6. (Optional, for extra credit: 5 points) The cloud is on its way to the solar system! Given the cloud properties you've derived, at approximately what distance from the Sun is it in danger of being tidally disrupted (i.e., shredded by tidal forces due to the Sun)?