PHYS2082: Mystery Planet Part 2

Reminder of the Scenario from Part 1

It is the year 2076. You are all science officers on the starship USS Endeavour. Your mission to investigate the source of some mysterious radio signals coming from a distant part of the galaxy. The ship set off four years ago, but even with its advanced faster-than-light warp drive it has only just arrived in the vicinity of HD666123 (which the crew affectionately refer to as "Twinky"). The on-board robots have just defrosted you all from suspended animation, and you are keen to get to work.

Captain Kavanagh is a cautious woman. Contact with aliens could be disastrous both for you and for the whole human race, if it goes wrong. She is therefore keeping the USS Endeavour a long way from Twinky, hiding out in its comet belt. When the ship arrived it was, by incredibly bad luck, rather close to the path of a comet, so the captain ordered an emergency displacement, whilst keeping the same distance from Twinky. This delayed your activities by the time required to move to a new position.

From this (now hopefully safe) hiding place, she has ordered the science team to deploy your telescopes, and learn as much about this system and its inhabitants as you can. Once you have discovered everything to be learned from this distance, she will decide whether to approach closer.

The Story So Far

Due to persistent nagging from the science team, Captain Kavanagh eventually relented and sent a stealthy robot probe in close to take pictures. The probe got to 323 AU out, and took one close up picture of the dot. Communications were then abruptly broken off all contact with the probe has been lost. No further data were taken. This could have been a technical failure, but it got Captain Kavanagh very worried, so she quickly retreated to ten light-years away.

Danger in the neighbourhood

Captain Kavanagh has asked the science teams to evaluate the risk posed to the crew from the surrounding neighbourhood of Twinky. Unlike the Sun (and Earth!), Twinky is in a very dense region of the Galaxy, notably with some very large star clusters quite nearby. In particular she needs to know if the ship would be at risk from exploding stars in one of these clusters.

Fig. 1: Hubble image of a supernova.

Your Orders for Part Two: Individual Written Assignments

Refer to the Course Profile for the deadline and submission instructions.

Following the group discussions in class you must write up an individual report that is your own work.

You should deduce as much new information as possible about the source of the strange radio signals using the information in this handout as well as your course notes. The standard questions to address are:

1. What general conclusions can you make from the power and central frequency of the radio signal?
2. What can you infer about the planet motions from the graphs of the radio signals?
3. What can you infer based on the planet densities?
4. Is the radio source natural or from an alien civilisation? Give your reasons.
5. What risks to the crew are there from exploding stars in the region of the Galaxy near Twinky?
6. How much time (if any) would the Captain have to respond to any such events?
7. What action do you recommend to minimise the risks to the crew?

The challenge questions are:

8. Can you fit black body models to the planet photometry?
9. Make a model that explains all the photometry data.
10. What do the parameters of your model suggest about the possibility of life on either planet?

This part of the project is different from the first section in that you will need to download data from the course website for numerical analysis. A standard spreadsheet program should be sufficient for this purpose (Excel, or the free equivalents such as Open Office or the online Google Documents) although you may prefer a programmable option such as Matlab.

Report Instructions

1. The report is addressed to the captain who has some physics background. You can assume that she already has access to the material in your briefing sheets.
2. The aim of the report is to give the captain immediate advice about the origin of the radio signals and the safety of the ship.
3. You must include a summary of your conclusions.
4. The page limit for the report is 8 pages (12-point font) with no additional appendix, so concentrate on results that are relevant to this decision.
5. Support your conclusions with arguments and evidence: this should include concise calculations.
6. You must cite the sources of all material by other people, apart from data in the briefing sheets. Do this with numbers matched to a reference list (may be in 10-point font and/or on an additional 9th page).
7. You do not need a cover page, contents, general bibliography (e.g. list of books read) or an abstract.

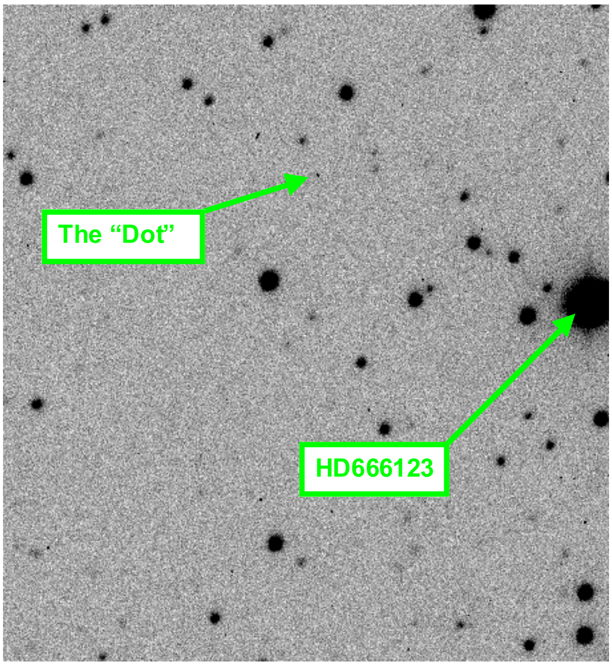

Figure 2: The radio signals are coming from the dot of light marked in this (negative) telescope image, which was taken at a wavelength of 500nm. The dot appears to be in orbit around the star HD666123, also indicated. It is too far away to make out any details with the best telescopes on Earth.

Your Orders for Group Work in Class

Session Two

Today we will give you a lot of new data to analyse. If you get stuck, please talk to one of the other groups and maybe form a collaboration.

Your aims for today are:

1. Assign members of your group to different data sets/projects. One must be scribe to record your answers on the back page.
2. Decide what properties you want to obtain from the available data.
3. Make a plan to produce the answer to at least two of the standard questions.
4. Prepare your answers for the 40-minute deadline

Photometry Team (2):

The Story So Far

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The New Photometry

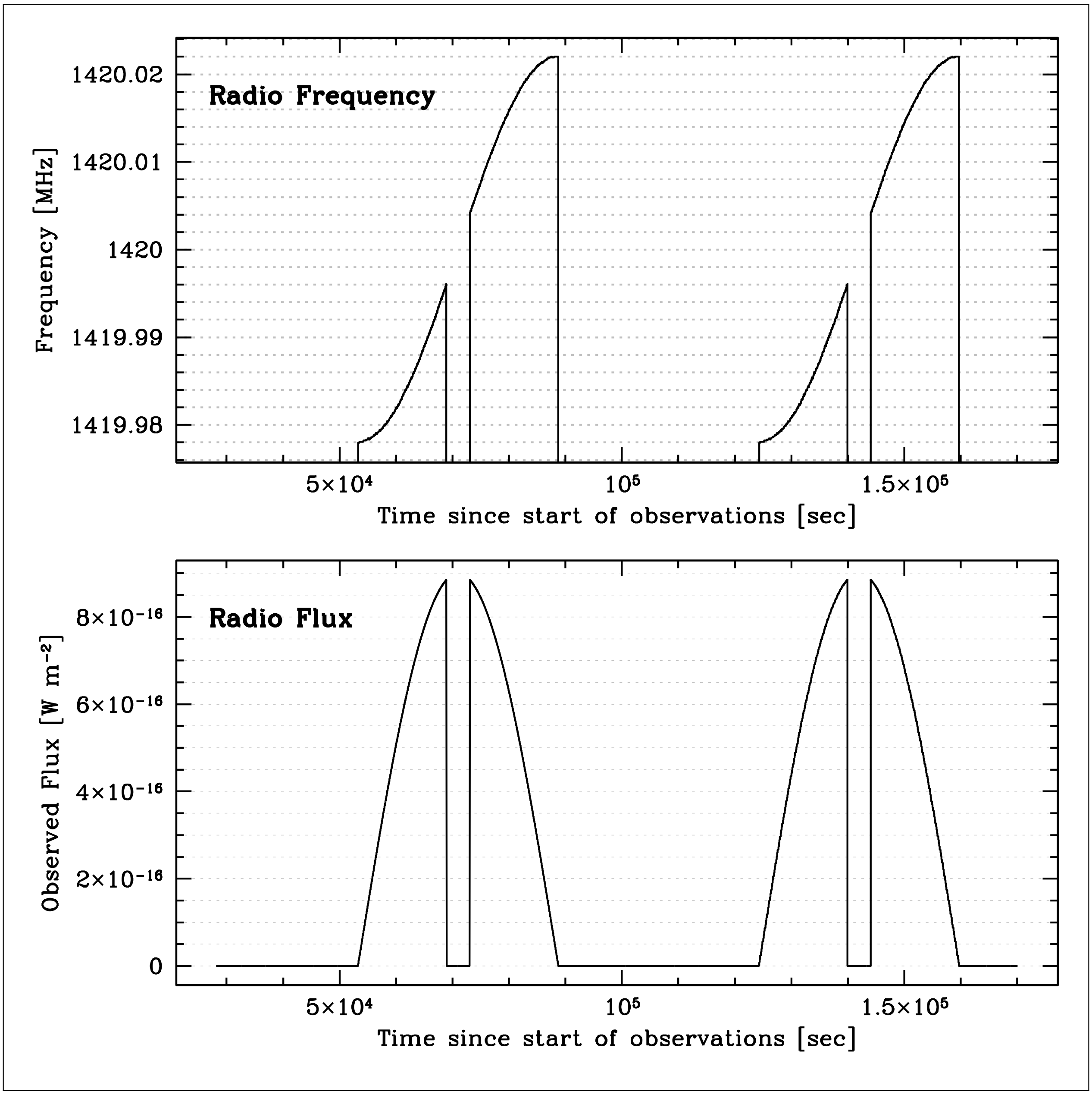
The single picture taken before communication was lost shows that the dot actually consists of two objects, a large one (component A) and a small one (component B).
The luminosity of the two components could be measured from the image at three wavelengths. These numbers are the total power put out by each component, summed over all directions, not just the flux that you detect. The values are actually specific luminosity, the value you would plot in a spectrum against wavelength (nm). You would integrate a range of the spectrum to get actual luminosity, but this is not necessary for most calculations.

Filter	Wavelength	Luminosity of component A (W/nm)	Luminosity of component B (W/nm)
B	500nm	8.67×10^{12}	7.19×10^{11}
K	2,100nm	5.93×10^{10}	4.92×10^{9}
L	10,000nm	1.23×10^{10}	2.18×10^{10}
M	20,000nm	2.96×10^{11}	1.15×10^{11}

Spectroscopy Team (2):

Captain Kavanagh eventually relented and sent a stealthy robot probe in close to take pictures. Your new data are the radio signals from the dot. You have some startling results.

1. The radio signal is entirely emitted in a narrow frequency range, near 1420 MHz. This is the same frequency that was seen from Earth.
2. The signal is neither amplitude nor frequency modulated it is a pure sine wave.
3. The intensity of the signal does, however, change with time. This was not observed from the Earth. The graph of intensity against time shows a curious pattern.
4. The frequency of the emission, while always close to 1420 MHz, does slowly change, again with an interesting pattern

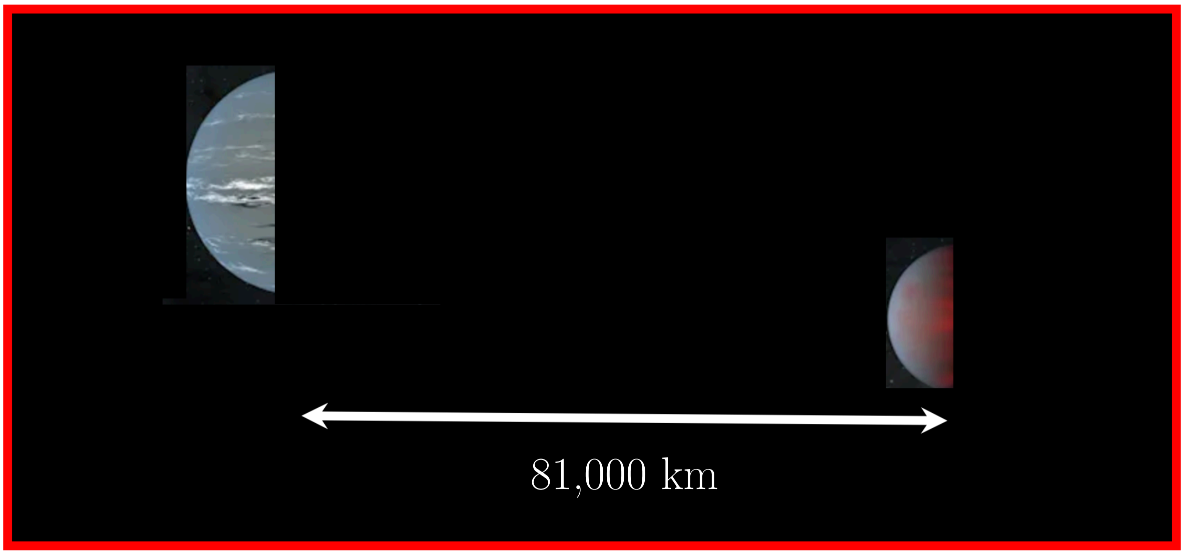


Imaging Team (2):

Due to persistent nagging from the science team, Captain Kavanagh eventually relented and sent a stealthy robot probe in close to take pictures. The probe got to 323 AU out, and took one close up picture of the dot. Communications were then abruptly broken off all contact with the probe has been lost. No further data were taken. This could have been a technical failure, but it got Captain Kavanagh very worried, so she quickly retreated to ten light-years away.

The Picture

The single picture taken before communication was lost was taken while the radio signal was at its maximum frequency, **1420.022** MHz, ie. just before one of the long cut-offs started. HD666123 was to the left of the field imaged.



The dot actually consists of two objects, a large one (component A) and a small one (component B). They are 81,000 km apart. The radius of component A is 15,000 km, while component B has a radius of 4,800 km.

Theory Team (2):

Theoretical Perspective

While the observers were having all this drama you got to thinking about the interpretation of their results. There is a lot more to be learned from their data than some of them realise. Here are some of the theoretical results they will shortly be knocking on your cabin door to ask for.

1. The Doppler shift can be approximated by $\frac{\Delta\nu}{\nu} = \frac{\Delta\lambda}{\lambda} = \frac{v}{c}$, where ν is frequency and v the velocity.
2. The black body spectrum is given by the Planck Law

$$B_\lambda(T)d\lambda = \frac{2hc^2/\lambda^5}{e^{hc/\lambda kT} - 1}d\lambda \qquad (1)$$

   where B is the luminosity emitted per unit area per unit wavelength **per unit solid angle (steradian). This means that to convert B to the luminosity of a star of radius R you have to integrate over angle as well as the surface area of the star, so: $L(T) = 4\pi^2 R^2 B(T)$.**

You have also been pondering more generally about planetary atmospheres. These observers probably haven't even stopped to wonder about conditions for life on the planet! The simple derivation of an equilibrium surface temperature of a planet can be quite wrong if there is a lot of cloud or CO_2 that blocks the radiated heat. On the Earth for instance we would predict Tp=255 K (for an albedo a=0.3) which is much too cold. Our planet is suitable for life because of the greenhouse effect reducing the heat loss by radiation. Another simple way you can check out the atmosphere of a planet is to just calculate its mean density. In our Solar System, the rocky terrestrial planets have mean densities of about 5 gm cm^{-3}, whereas the gaseous Jovian planets have mean densities of only about 1 gm cm^{-3}.

Supernova Risks

Advanced as your space ship might be, the level of protection it offers against cosmic rays and radiation is quite low compared to the atmosphere of a planet, so you can base your calculations on the early work by Michael Richmond on the radiation risk to an astronaut from a supernova Type-1a if it produces a peak x-ray luminosity of 10^{42} erg s^{-1}. He calculated the time required for a lethal dose of x-rays for different distances as in the following table reproduced from Richmond (2005)[1]. Core-collapse supernovae are about 10 times less luminous (10^{41} erg s^{-1}) in x-ray radiation.

Distance to SN Type-1a	Time to lethal dose
1 pc	< 1 sec
10 pc	30 sec
100 pc	3,000 sec = 1 hour
1,000 pc = 1 kpc	300,000 sec = 3.5 days
10,000 pc = 10 kpc	30,000,000 sec = 1 year

[1]Internet link: `http://www.tass-survey.org/richmond/answers/snrisks.txt`

Star Cluster Analysis Team

A: Star Cluster "Melpomenia"

Like many astronomers you have lots of old data on your computers waiting to be processed. For example, you have measurements of this star cluster close to the Earth. You took the data a year before the ship left home and still haven't analysed them! The cluster has a measured parallax: 0.017 arc seconds from the Earth. You were very interested in the variable stars, and you measured their 550 nm fluxes as well as the period.

Fig. 3: Image of Melpomenia

$Flux_{550}$ ($W\ m^{-2}\ nm^{-1}$)	Period (h)
1.9512e-11	47.367
1.1562e-11	35.545
7.3716e-16	20.365
3.8559e-11	56.145
2.4206e-16	14.401
5.8355e-16	16.075
8.0054e-16	16.936
2.1382e-15	24.741
2.4079e-11	42.435
6.2455e-16	15.065
2.9341e-11	56.127
3.3514e-11	46.451
9.1825e-12	35.260
7.2678e-16	18.879
3.7917e-16	13.913
1.0885e-15	20.650
3.0403e-11	51.047
5.0499e-16	14.505
1.6730e-10	63.856
2.4263e-11	41.316

More data is available online.

B: Star Cluster "Machkaputt"

This is one of the star clusters visible from the ship. Unfortunately, it is too distant to measure a parallax angle when the ship moved. You have been monitoring it since the ship moved and found some of the stars are variable. You recorded specific fluxes (you would never use old- fashioned magnitude units) at three wavelengths (440, 550, and 660 nm) and the periods for the few variable stars detected.

Fig. 4: Image of Machkaputt

Flux_{440} [W m^{-2} nm^{-1}]	Flux_{550} [W m^{-2} nm^{-1}]	Flux_{660} [W m^{-2} nm^{-1}]	Period [h]
2.458e-15	7.563e-15	2.036e-14	0.00
2.188e-15	8.223e-15	2.062e-14	0.00
3.404e-15	1.262e-14	2.671e-14	0.00
2.083e-15	9.907e-15	1.781e-14	0.00
1.092e-18	6.315e-18	4.124e-17	0.00
1.096e-17	4.392e-17	1.880e-16	19.77
6.714e-15	1.690e-14	4.654e-14	0.00
9.682e-19	5.308e-18	3.594e-17	0.00
8.046e-18	3.669e-17	1.874e-16	18.25
2.129e-14	7.281e-14	1.210e-13	0.00
6.338e-16	2.550e-15	6.685e-15	0.00
2.367e-17	1.094e-16	3.359e-16	24.40
4.077e-19	1.952e-18	1.585e-17	0.00
1.496e-17	6.855e-17	2.873e-16	22.10
6.572e-18	3.211e-17	1.518e-16	17.40
6.609e-19	3.807e-18	2.989e-17	0.00
2.652e-16	1.127e-15	2.906e-15	0.00
3.142e-14	7.888e-14	1.395e-13	0.00
7.059e-19	2.815e-18	2.128e-17	0.00
1.478e-14	4.671e-14	9.255e-14	0.00

More data is available online.

C: Star Cluster "Coruscant"

This star cluster must be very distant, as you could not measure any parallax angle for it when the ship moved. Since then you have been monitoring it and found several variable stars. You know these are very important so you have measured them carefully for your data set: you were able to record fluxes (you would never ever use old-fashioned magnitude units) at three wavelengths (440, 550, and 660 nm) and the periods.

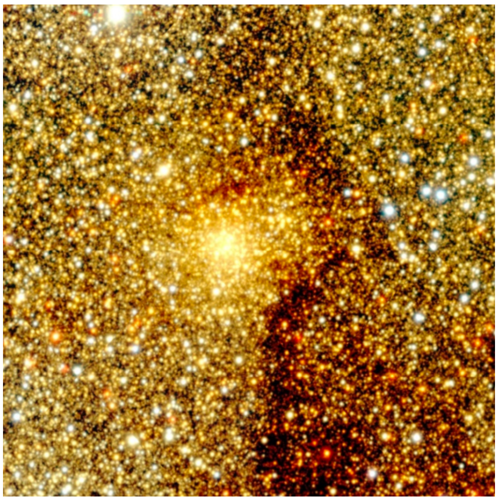


Fig. 5: Image of Coruscant

Flux_{440} [W m^{-2} nm^{-1}]	Flux_{550} [W m^{-2} nm^{-1}]	Flux_{660} [W m^{-2} nm^{-1}]	Period [h]
2.259e-13	1.674e-13	1.975e-13	66.75
3.366e-16	1.016e-15	2.245e-15	0.00
1.301e-19	7.950e-19	3.231e-18	0.00
1.638e-14	2.410e-14	3.805e-14	0.00
2.775e-12	3.456e-12	2.652e-12	0.00
1.171e-16	2.663e-16	7.752e-16	0.00
5.497e-14	5.880e-14	8.116e-14	48.72
1.136e-20	6.130e-20	3.992e-19	0.00
2.187e-15	4.429e-15	7.323e-15	0.00
4.374e-19	1.729e-18	8.016e-18	0.00
1.917e-12	1.268e-12	1.310e-12	0.00
3.055e-20	1.835e-19	9.863e-19	0.00
1.002e-12	8.445e-13	9.457e-13	0.00
4.033e-14	5.530e-14	6.108e-14	46.98
2.424e-20	1.372e-19	9.637e-19	0.00
3.693e-16	8.132e-16	2.138e-15	0.00
3.362e-12	3.455e-12	3.146e-12	0.00
5.045e-16	1.328e-15	2.622e-15	0.00
8.136e-16	1.837e-15	3.142e-15	0.00
1.908e-18	7.650e-18	2.734e-17	0.00

More data is available online.

PHYS2082 Project Report Marking Scheme

V1. 2017-08-04

The grade awarded will be the average of the different criteria. If your work is on the borderline between two grades, we will include your discussion board posting(s) in the "Depth" grade.

Grade	Clarity	Conciseness	Accuracy	Depth
7	All text is easy to understand. Language and style appropriate for target audience. Summary presents clear results.	All material is essential to argument. No repetition. Meets page limit.	All calculations correct with appropriate significant figures and units.	As for 6, with consistent evidence of originality in analysing assumptions, creating solutions, and generating alternative arguments
6	Most text is easy to understand. Most language and style appropriate for target audience. Summary presents mostly clear results.	Most material is essential to argument. Very little repetition. Meets page limit.	Most calculations correct. All have appropriate significant figures and units.	As for 5, with frequent evidence of originality in analysing problems and in creating solutions. Identifies assumptions.
5	Most text is easy to understand. Language and style appropriate for target audience. Summary presents some results.	Small amounts (but less than ¼) of non-essential or repeated material. Meets page limit.	Most calculations correct. Most have appropriate significant figures and units.	Demonstrates substantial understanding of fundamental physical concepts and ability to apply them in a variety of contexts. Presents convincing arguments with justification.
4	Some text is easy to understand. Language or style inappropriate for target audience. Summary presents unclear results.	Large amounts (but less than half) of non-essential or repeated material.	Many (but less than half) of calculations incorrect with wrong significant figures or units.	Demonstrates adequate understanding and application of the fundamental physical concepts. Presents routine arguments and acceptable justification.
3	Most text is not easy to understand. Language or style inappropriate for target audience. Summary presents no results.	Text dominated by non-essential or repeated material.	Most calculations incorrect with wrong significant figures or no units.	Demonstrates superficial or faulty understanding of the fundamental physical concepts and limited ability to apply them. Presents undeveloped arguments with no justification.
2	Language largely inaccurate, unclear and not cohesive. Summary absent or has no answers.	All text is non-essential or repeated.	All calculations incorrect with wrong significant figures and no units.	Demonstrates clear deficiencies in understanding and applying fundamental physical concepts.
1	Aspect absent or clearly incomplete	No submission.	No calculations.	No concepts presented.

Progress Report on Group Work for Mystery Planet part 2

Work with your group to get answers or a method for at least two basic questions; write your answers below. Deadline: 40 minutes after the start of class today

Group Number...

Basic questions:

1. What general conclusions can you make from the power and central frequency of the radio signal?

2. What can you infer about the planet motions from the graphs of the radio signals?

3. What can you infer based on the planet densities?

4. Is the radio source natural or from an alien civilization? Give your reasons.

5. What risks to the crew are there from exploding stars in the region of the Galaxy near Twinky?

6. How much time (if any) would the Captain have to respond to any such events?