R.T.J McAteer **CUME #407** **April 2016**

This CUME is based on the accompanying paper by Elliott et al, 2016, ApjS, 223, 19 As this is a long and detailed paper, I do not expect you to read the entire paper in detail. Instead, I strongly suggest you initially read the abstract and the Introduction to get a flavor for the content. I refer you to specific sections and specific figures for each question in the CUME.

There are 60 total points available.
A total of 45 points is *expected* to be a passing grade.
There are 3 questions, each with 20 points available.
Do not allow yourself to get stuck on any one question. Allow yourself to spend a maximum 30 minutes per question and you'll then have 30 minutes remaining at the end to go back and complete any parts you have skipped.

Calculators are only to be used for calculations. You may not store equations. You may not use your cell phone at any time.
Show all work for full points.
Attempt all parts of all questions.
Take a new page for each question. This makes it much easier to award partial credit for incorrect answers.

Some Constants and Equations.

SOLUTIONS AND GRADING

1AU = 215 Solar radii
1 Solar radius = 6.95×10^5 km
1 arcsec = 4.85×10^{-6} radians
By definition, 1 Mx cm^{-2} =1 G
Bohr magneton, $U_B = 9.27 \times 10^{-21}$ ergs G-1
Planck constant, $h = 6.63 \times 10^{-27}$ erg s
Speed of light, $c = 3 \times 10^8$ m s^{-1}
Ampere's law, $\nabla \times B = \mu_o J$
By conversion, 1 Joule = 10^7 ergs
Boltzmann constant, $k_B = 1.38 \times 10^{-16}$ erg K^{-1}
Energy gained by an electron across 1 volt, 1eV =1.6×10^{-19} J
Mass of a proton, $m_p = 1.67 \times 10^{-24}$ g
$G = 6.674\times10^{-11}$ N m^2 kg^{-2} = 6.674×10^{-8} cm^3 g^{-1} s^{-2}

1: This question asks you about the text in Section 3 and the content of Figure 1 and Figure 2. There is a total of 20 points available for this question.

Consult Figure 1 and Figure 2:

(i) Sketch a version of Figure 1 that includes Sun, Earth, Jupiter, and Pluto for the entire NH trajectory, *with an emphasis on the spacecraft v_{radial} / v_{total} at Earth, Jupiter and Pluto.* Provide 2-3 sentence summary of the evolution of the spacecraft v_{radial} / v_{total} in your figure.

(Do not attempt to draw to scale!)

5 points

Solutions and Grading:
The orbit has to start at Earth, get a gravity assist from Jupiter, and encounter Pluto
The orbit should start off non radial, be almost radial at Jupiter, then take a large swing to become more non-radial. At Pluto it should be radial again.
3 points for figure
2 points for discussion

(ii) Consider the basic physics involved in the formation of a bow shock. As New Horizons moves towards an encounter with Kuiper belt object 2014 MU69, should New Horizons eventually encounter the potential Solar Wind Bow Shock? Why or why not?

2 points

Solutions and Grading:
No bow shock encounter expected. Even is a Solar Wind bow does exist, from Fig1, NH is not moving towards the incoming IS wind. Hence, even if a Bow Shock does exist, NH will not move through it.

Consult Figure 2:

(iii) Show that the initial total speed of New Horizons is consistent with the escape velocity of the solar system from launch at 1AU

5 points

Solutions and Grading:
Calculation of escape velocity of the solar system from R=1AU.
Answer is 42 km/s - agrees with Fig 2.
2 points for escape velocity equation
3 points for correct calculation and comparison to plot

(iv) The blip in speed in early 2007 is clearly a result of the gravity assist from the Jupiter fly-by, which then clearly affected the speed of the spacecraft for the rest of its journey. By considering the radial profile for velocity that would have occurred without this fly-by, calculate the resulting extra Δv that the New Horizons was still experiencing from this fly-by, when it finally reached Pluto at 33AU.

6 points

Solutions and Grading:
Assume coasting speed starting at escape velocity at 1AU.
Speed will drop as 1/sqrt(r), resulting in 42 / 33^0.5 at 33Au, so about 7 km/s. Δv = 15-7=8km/s
2 points for recognizing this is a 1/r^0.5 drop off. 4 points for correct calculation and comparison to plot. partial credit for estimating drop off from plot

(v) Consider the Grand Voyage of Voyager 1, and the wealth of planetary data we obtained because of the trajectory it took. Although New Horizons was the fastest orbital speed at launch, it is now actually traveling slower than Voyager 1 (Voyager was traveling at 17km/s in 2015). Why?

2 points

Solutions and Grading:
V1 got an series of fly-bys from Jovian planets. (Being a TA in 105 or 110 would have assisted here, but I expected they would remember this from their own UG -also clue in 'grand voyage')
3 points for recognizing this is an effect of flybys with Saturn
(partial credit 2 points for discussion that does not mention Jovian flybys)

2: This question asks you about Figures 3 and 4 (the corresponding text is in Section 3), and the comprehensive forward model employed to then produce the Figures we'll see in the next question. The forward model is described in detail in Section 4, but you only need to read the first paragraph of this section, prior to Equation 1.

There is a total of 20 points available for this question.

Consult the first paragraph of Section 4

(i) The authors discuss the details of their 'Forward model'. Discuss one advantage and one major drawback about employing a 'forward model' such as this to extract plasma parameters from raw data.

(I am looking for 2-3 sentences on 1 advantage, and 2-3 sentences on 1 major drawback)

4 points

Solutions and Grading:
2 points for any reasonable advantage (e.g., allows to invert data, allows for complex inversions, permits you to use Bayesian)
(partial credit 1 or 2 points for something relating to obtaining useful parameters from data)
2 points for any reasonable drawback (e.g., model dependent, underdetermined, non-linear)
(partial credit 1 or 2 points for something relating to difficulty)

Consult Figure 3:

(ii) Why was the SWAP instrument designed with the largest opening azimuth angle for any in-situ instrument of this type?

4 points

Solutions and Grading:
Specifically designed for Pluto, where number density of solar wind is very low. (2 points)
As flow is radial, this opening should be in azimuth (2 point)
(partial credit 1-3 point for some relating to difficulty of mission, without reference to density or direction)

Consult Figure 4:

(iii) Show that the energy to charge ratio of He^{++} compare to the energy to charge ratio of H^{+} is consistence with Figure 4.
(HINT: Use figure 4 to check your answer)

4 points

Solutions and Grading:
He++ has four times the mass (hence 4 times the energy), but twice the charge
partial credit for estimation of equipartition energy

(iv) Interstellar Pick-Up Ions are created by the kinetic interaction of the solar wind protons with neutral ISM material. The ISM neutrals seep thru the Heliopause (at 100AU), with a velocity of ~25 km s^{-1} and with a density of 10^{-2} cm^{-3}. This kinetic interaction is described by

$$p^{+}(\mathbf{v}_{sw}) + H(\mathbf{v}_{ISM}) \rightarrow H(\mathbf{v}_{sw}) + p^{+}(\mathbf{v}_{ISM})$$

By consideration of the relative *kinetic energy density* of the ISM neutral protons to those of the solar wind, show that the pick-up ions can obtain a maximum energy to charge ratio consistent with Figure 4.
(HINT: at the Heliopause the solar wind number density has dropped to 10^{-4}, but the solar wind velocity remains around 500 km s^{-1})

8 points

Solutions and Grading:
this is a comparison of 0.5 rho v^2. (2 points)
Solar wind number density of 10^-4 by 100AU however the solar wind speed remains around 500. (2 points)
hence solar wind KED compared to ISM protons is (500/25)^2 / (10^-4/10-2) = 400x10^-2 = 4 (2 points)
assuming a kinetic interaction, the ISM protons could pick up about 4 X energy / charge compared to solar wind protons, agrees with plot (2 point)

3. This question asks you about the text in Section 4 and 5, but you should focus on the content and discussion of Figures 18, 19 and 24. There are a total of 20 points available for this question.

Consult Figure 18 and 19, with the accompanying discussion on the bottom right of page 7 and the first few paragraphs of page 8

(i) Consider a parcel of solar wind in a spherically expanding geometry, explain in a few sentences why we expect the number density of the solar wind to follow an inverse square relationship with distance.

2 points

Solutions and Grading:
as surface area is 4PIr^2, density drops off with increasing surface area, so should vary as r^-2

(ii) As the solar wind has a mass density of 8 x 10^{24} g cm^{-3} at 1AU, use the information in Figure 18 (left) to calculate the distance of New Horizons from the Sun in the latter half of 2012
(HINT: you can confirm the result of your calculation by referring to Figure 19)

3 points

Solutions and Grading:
Use rho to get number density at 1AU (1 point).
then as rho drops off as r^-2, calculate distance at the number density value in the plot (1 point).
distance of 22UA agrees with fig 19 (1 point)

(iii) Assume a spherically symmetric solar wind mass loss, such that the mass flow through any shell, volume dV is given by dM = ρ dV, show that the mass loss rate is given by

$$dM/dt = (4\pi r^2) f$$

where f is the solar wind flux (i.e, g cm^{-2} s^{-1})

7 points

Solutions and Grading:
standard solar wind mass loss rate derivation (2 points per step)
realize f=nv (1 point)
allow for proof by form (proof by units)

(iv) Using 3(iii) above, and from Figure 18 (left), determine the mass loss of the Sun resulting from the solar wind to be ~10^{-14} solar masses per year.

4 points

Solutions and Grading:
get n and v from fig 18 (2 points)
standard calculation to get to 10^-14 solar mass / year (2 points)

(v) From your answer to 3(iii) above, discuss the timescale of the effect of the present day solar wind on the evolution of the Sun, as compared to other usual stellar evolution timescales.

2 points

Solutions and Grading:
10^-14 mass loss would result in lifetime of 10^14 years
so solar wind mass loss has less effect that changes in fusion process
comparison of lifetime to fusion (2 points)
(partial credit 1 point for not relating to fusion. also allow particle credit if student gets (iii) incorrect)

wrong question copied here. OK in exam itself.

(v) From your answer to 3(iii) above, discuss the timescale of the effect of the present day solar wind on the evolution of the Sun, as compared to other usual stellar evolution timescales.

2 points

Solutions and Grading:
the periodicity found is solar rotation rate (and fraction thereof) (1 points)
solar rotation rate is slower at higher latitudes so expect peaks in periodogram to move right (1 points).
partial credit for relating density drop and therefore expect some drop in signal.