22139005

International Baccalaureate®
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SCHOOL BASED SYLLABUS

ASTRONOMY
STANDARD LEVEL
PAPER 2

Tuesday 30 April 2013 (morning)

1 hour 30 minutes

Candidate session number

0	0							

Examination code

2	2	1	3	–	9	0	0	5

INSTRUCTIONS TO CANDIDATES

- Write your session number in the boxes above.
- Do not open this examination paper until instructed to do so.
- Section A: answer all questions.
- Section B: answer one question.
- Write your answers in the boxes provided.
- A calculator is required for this paper.
- The maximum mark for this examination paper is *[60 marks]*.

0128

28 pages

The following information may be useful

$1\,\text{AU} = 1.496 \times 10^{11}$ m

$H_0 \approx 72\,\text{km s}^{-1}\ \text{Mpc}^{-1}$

1 light year $= 0.307$ parsecs $= 9.47 \times 10^{15}$ m

$c = 3.00 \times 10^{8}\,\text{m s}^{-1}$

$G = 6.67 \times 10^{-11}\ \text{N m}^2\,\text{kg}^{-2}$

$\sigma = 5.67 \times 10^{-8}\ \text{W m}^{-2}\,\text{K}^{-4}$

$L_{\odot} \approx 3.84 \times 10^{26}$ W

$T_{\odot} \approx 5770$ K

$M_{\odot} \approx 1.99 \times 10^{30}$ kg

$R_{\odot} \approx 6.96 \times 10^{8}$ m

$k = 1.38 \times 10^{-23}\ \text{JK}^{-1}$

$M_{\oplus} = 5.98 \times 10^{24}$ kg

1 parsec $= 206\,265$ AU $= 3.09 \times 10^{16}$ m $= 3.26$ light years

$1^{\circ} = 3600$ arcsec $= 1.75 \times 10^{-2}$ rads

$$M_J = \frac{9}{4}\left(\frac{1}{2\pi n}\right)^{\frac{1}{2}} \frac{1}{m^2}\left(\frac{kT}{G}\right)^{\frac{3}{2}}$$

$$F = \frac{GM_1M_2}{r^2}$$

$$e = \sqrt{1 - \left(\frac{b}{a}\right)^2}$$

$$z = \frac{H_0}{c}d = \frac{\lambda_{obs} - \lambda_{em}}{\lambda_{em}}$$

$$v = \frac{d}{t}$$

$$F = ma$$

$$c = f\lambda$$

$$\text{KE} = \frac{1}{2}mv^2$$

$$\lambda_{max} = \frac{2.90 \times 10^{-3}}{\text{T}}$$

$$\text{GPE} = mgh$$

$$v_{escape} = \sqrt{\frac{2GM}{R}}$$

$$m_B - m_A = -2.5\log\left[\frac{b_B}{b_A}\right]$$

$$\text{PE} = -\frac{GMm}{r}$$

$$\text{f} = \frac{[\text{a} - \text{b}]}{\text{a}}$$

$$E = mc^2$$

$$L \approx 4\pi R^2 \sigma T^4$$

$$L = F.4\pi d^2$$

$$N = R\,.\,f_p\,.\,n_e\,.\,f_l\,.\,f_i\,.\,f_c\,.\,L$$

$$L.\theta = d$$

$$F = \frac{L}{4\pi d^2}$$

$$d = \frac{1}{\phi}$$

$$\frac{\text{b}_1}{\text{b}_2} = 2.5^{(\text{m}_2 - \text{m}_1)}$$

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Answers written on this page
will not be marked.

SECTION A

*Answer **all** questions. Write your answers in the boxes provided.*

1. This question is about Kepler's third law of planetary motion.

Johannes Kepler (1571–1630) proposed three laws for planetary motion. The third law gives the relationship between a planet's orbital period (T) and its orbital distance (R) as

Equation 1: $$T^2 = \text{constant} \times R^3$$

Isaac Newton (1642–1727) explained this variation by considering his Law of Gravitation applied to circular motion, giving

Equation 2: $$T^2 = \frac{4\pi R^3}{GM}$$

(a) Using data for the orbit of the Earth, show that the value of the constant in Equation 1 is approximately 3×10^{-19}. Your answer should be given to 2 or 3 significant figures. *[3]*

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(b) Identify the SI units for the constant in Equation 1. *[1]*

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(Question 1 continued)

(c) The orbital distance of Jupiter is 7.78×10^{11} m. Calculate Jupiter's orbital period in seconds. *[2]*

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(d) Use the value of the constant in Equation 1 to calculate the mass of the Sun. *[3]*

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(e) Over time, the Sun loses mass in the form of a solar wind. On the assumption that given a long enough time, this would not be insignificant, briefly describe the effect you would expect this to have on Jupiter's orbital distance. *[1]*

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2. This question is about the search for extra-terrestrial intelligent life.

The search for intelligent life in the universe is presently limited to our own galaxy. One of the favoured ways of doing this is to use radio signals.

(a) Explain why we do not send out probes or spaceships to search for life outside the solar system. *[2]*

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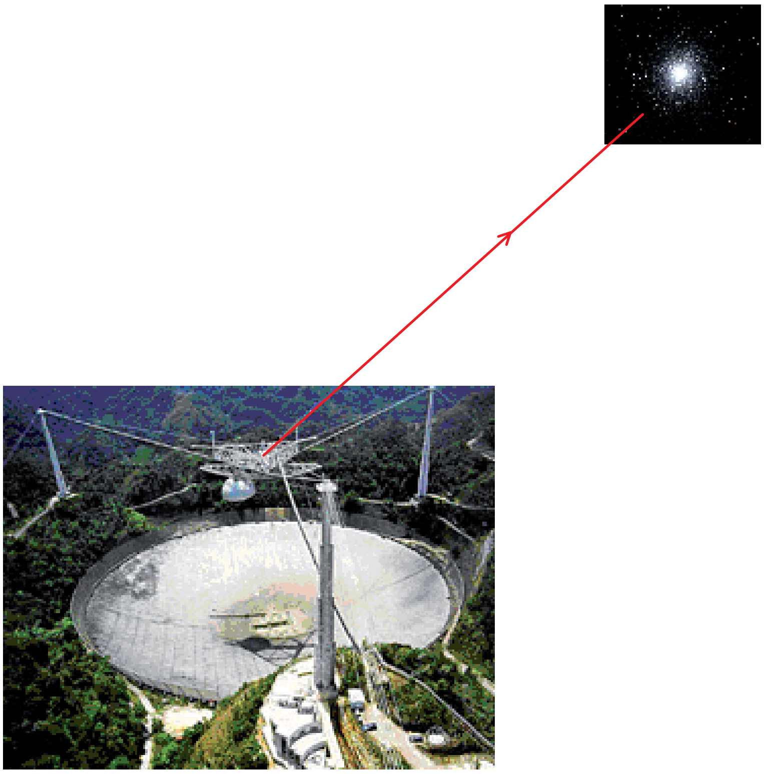
(Question 2 continued)

(b) Radio signals travel at the speed of light and in 1974 a signal was sent from the Arecibo telescope in Puerto Rico. The signal was sent in the direction of the globular cluster known as M13, about 25 100 light-years away (Figure 1).

Figure 1: Arecibo radio signal sent to M13



Considering the same point in the year 2007, calculate how far the signal had travelled towards M13. Express your answer in both light years **and** metres. *[3]*

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(Question 2 continued)

(c) The message sent towards M13 was coded information in the form of 1679 "bits" of data. Each bit can be considered as an individual dot making up an image. This produces an image made of 1679 dots.

The data was in a form such that each bit was either a "1" or "0" *ie*, the signal was a collection of "1"s and "0"s – a "1" indicating that the dot was black and a "0" indicating that the dot was white (or blank).

1679 is the product of the two prime numbers 23 and 73 *ie*, $23 \times 73 = 1679$.

Define what is meant by prime numbers. *[1]*

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(d) Explain how this fact would allow intelligent life to take the 1679 sequence of dots and reform an image that would make sense. *[2]*

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(Question 2 continued)

(e) If the message successfully reached M13, was seen by intelligent life, and then a message was sent back to us, calculate how much time the total trip there and back would have taken. *[2]*

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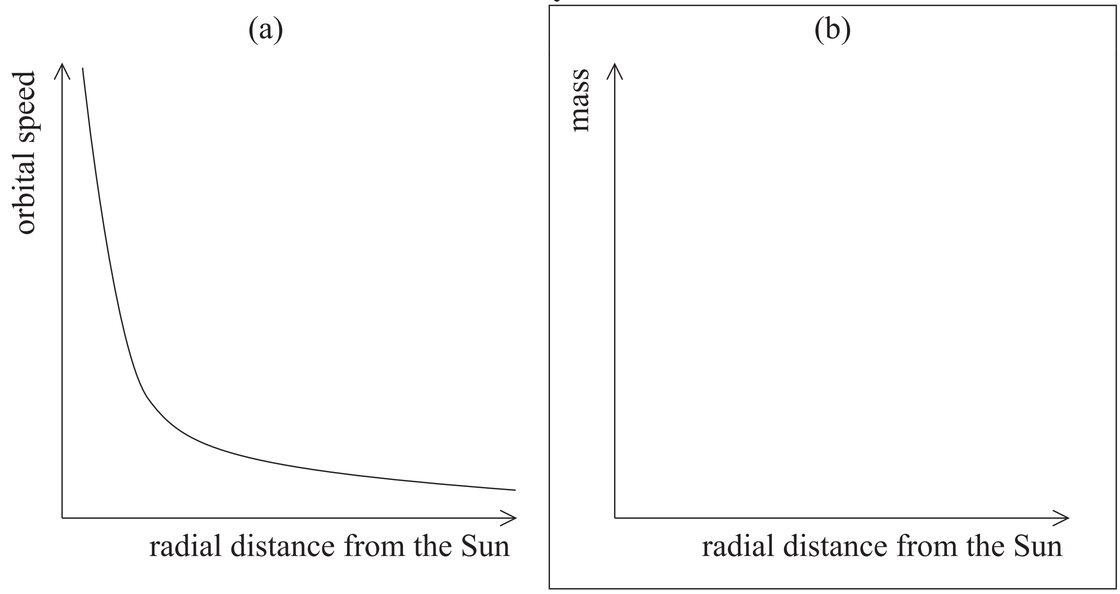
3. This question is about rotation curves.

For a galaxy, the rotation curve is a plot of the speed (v) of an object (*eg*, a star) against its distance from the centre of the galaxy. Two situations are often considered as being extreme cases:

1. The rotation curve of the solar system.
2. The rotation curve for an object with uniform density.

(a) Figure 2(a) shows the rotation curve for the solar system. Sketch on the axis shown in Figure 2(b), the variation for the mass distribution curve for the solar system. Your answer should include some estimate of size for the y-axis (*ie*, the mass). *[2]*

Figure 2: The rotation curve (a) and mass distribution curve (b) for the solar system



(b) The second extreme is that of an object with uniform density. For such an object, as the radius increases, the mass contained within this radius also increases. For such a spherical system for example, if the radius were to double (*ie*, increase by a factor of 2), calculate how this would change the mass contained within this radius. *[2]*

(Note: $\text{Density} = \frac{\text{mass}}{\text{volume}}$ and the volume of a sphere is given by $V = \frac{4}{3}\pi r^3$).

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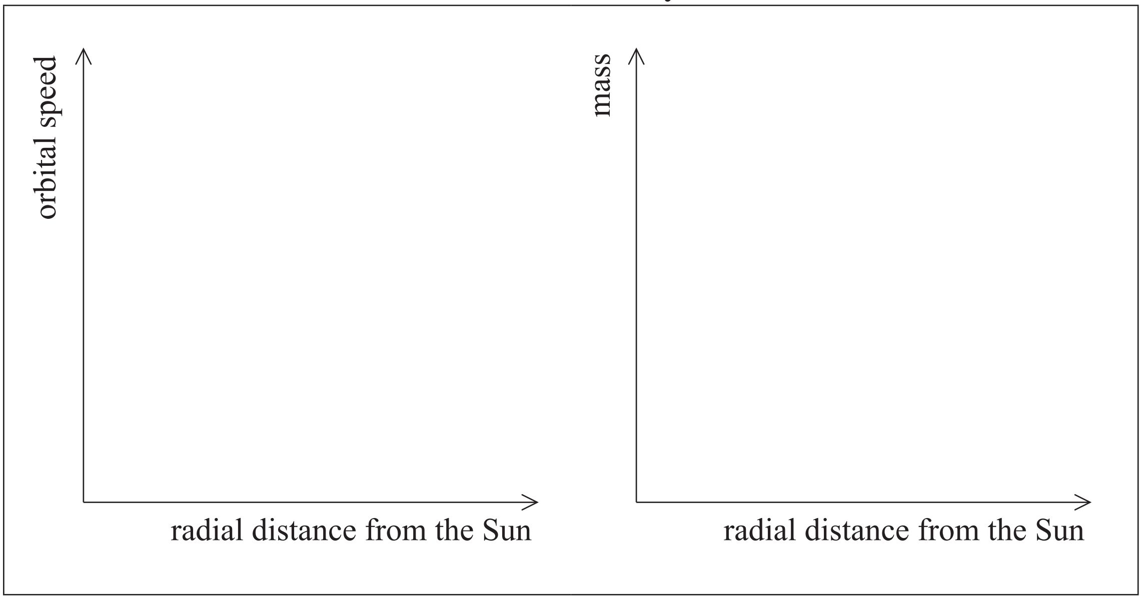
(Question 3 continued)

(c) In Figure 3, sketch the rotation curve and the mass distribution curve for the case of an object with uniform density. *[2]*

Figure 3: The rotation curve and mass distribution curve for an object with uniform density



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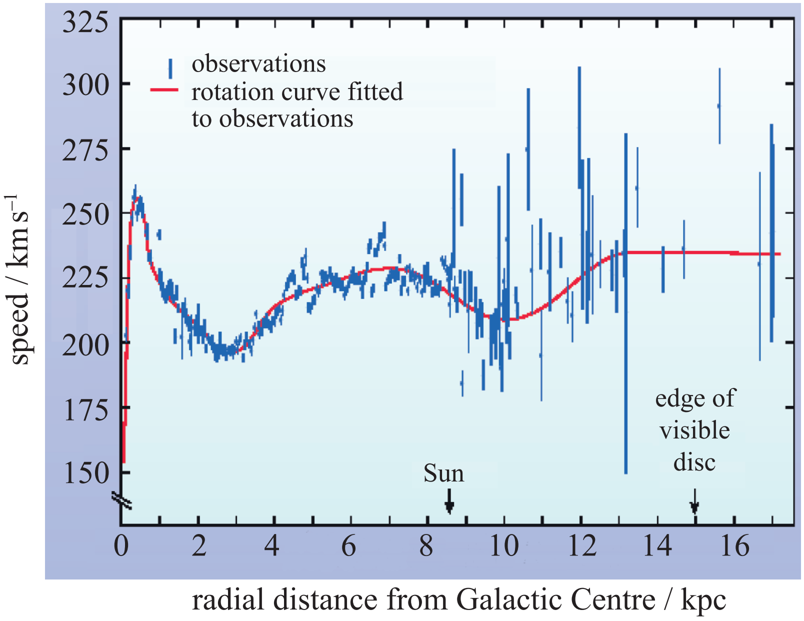
(Question 3 continued)

(d) The experimentally determined rotation curve for the Milky Way is shown in Figure 4.

Figure 4: Rotation curve for the Milky Way



Explain what is meant by the phrase "edge of visible disc" at a distance of 15 kpc in Figure 4. *[1]*

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(e) Explain why the data for radial distances is greater than the visible edge obtained. *[1]*

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(Question 3 continued)

(f) It is seen that, for radial distances from 13 kpc to 17 kpc, the rotation curve is approximately horizontal. Explain the significance of this result for the mass contained within the galaxy. *[2]*

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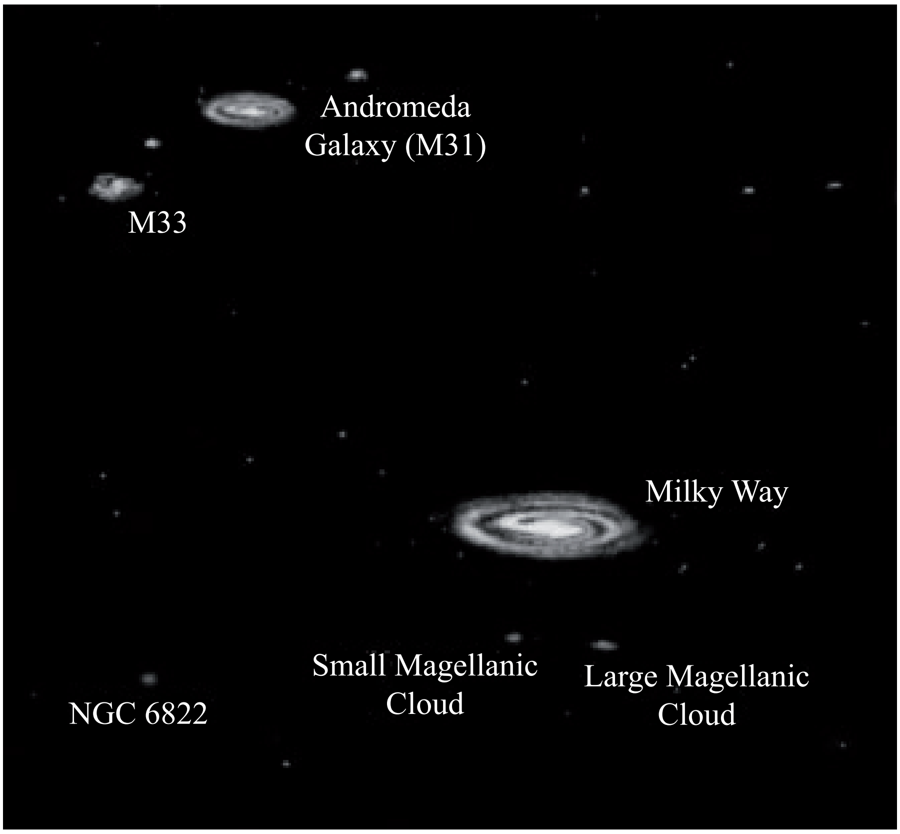
4. This question is about the large scale structure in the universe.

It is known that in deep space, we see galaxies "linked" together through gravitational forces, into galactic clusters, superclusters and even larger structures.

Figure 5 shows the Milky Way's local group of galaxies.

Figure 5: The Local Group of galaxies



[Source: http://hendrix2.uoregon.edu/~imamura/123/lecture-3/lecture-3.html]

The following information is known about the Milky Way and one of its neighbouring galaxies, Andromeda.

Mass of the Milky Way	$= 1.3 \times 10^{12}$ solar masses
Mass of Andromeda	$= 7.1 \times 10^{11}$ solar masses
Distance between the Milky Way and Andromeda	$= 2.6 \times 10^{6}$ light years

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(Question 4 continued)

(a) Calculate the mass of the Milky Way and Andromeda in kg. Your answer should be given to 2 significant figures. *[2]*

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(b) Assuming that the masses calculated in (a) are entirely due to protons, if the proton mass is 1.67×10^{-27} kg , calculate the number of protons in the Milky Way and Andromeda. *[2]*

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(c) State the distance between the two galaxies in SI units. *[1]*

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(Question 4 continued)

(d) Show that the gravitational force (F_G) between the two galaxies is approximately 4×10^{29} N. Your answer should be given to 2 significant figures. *[1]*

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(e) It is assumed that both the Milky Way and Andromeda have an overall zero charge. This is because the electrons and protons can be thought of as being in pairs and, therefore, the galaxies have the same numbers of electrons as protons, each having the same magnitude of charge (1.60×10^{-19} C).

Consider how this situation would change if the charge of a proton was 1 % larger than it is thought to be. This would mean that the electron-proton pairs are not cancelling out but now have an overall positive charge.

If the magnitude of the charge of an electron is 1.60×10^{-19} C, estimate the net charge for each electron-proton pair. *[1]*

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(Question 4 continued)

(f) The small positive charge from the electron-proton pairs, now produces an overall charge for the two galaxies of

$$Q_{MW} = 2.47\times10^{48}\,\text{C}$$
$$Q_A = 1.35\times10^{48}\,\text{C}$$

The electric force (F_E) between two charges Q_1 and Q_2, a distance (d) apart, is given by

$$F_E = 9.0\times10^{9}\,\frac{Q_1\times Q_2}{d^2}$$

Use this formula to calculate the electric force that would now exist between the Milky Way and Andromeda. *[2]*

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(g) Consider your answers to (d) and (f) and state what this tells you about the forces acting between local galaxies. *[1]*

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SECTION B

*Answer **one** question. Write your answers in the boxes provided.*

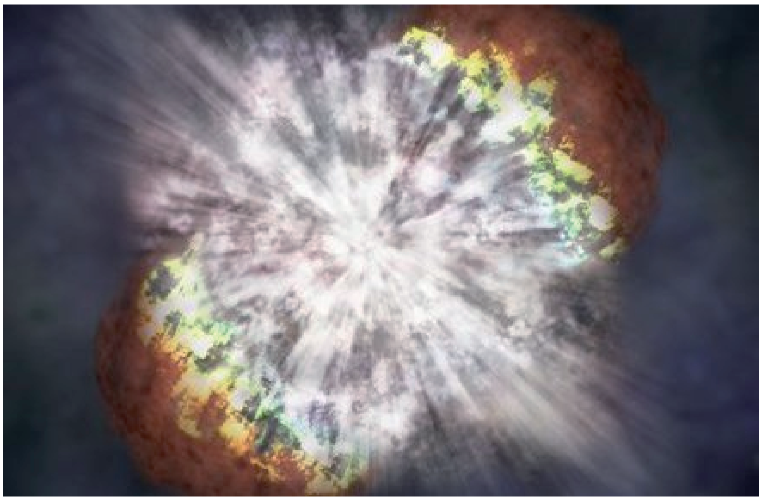
5.

The Brightest Supernova Ever

The brightest stellar explosion ever recorded may be a long-sought new type of supernova, according to observations by NASA's Chandra X-ray Observatory and ground-based optical telescopes. This discovery indicates that violent explosions of extremely massive stars were relatively common in the early universe, and that a similar explosion may be ready to go off in our own galaxy.

"This was a truly monstrous explosion, a hundred times more energetic than a typical supernova," said Nathan Smith of the University of California at Berkeley, who led a team of astronomers from California and the University of Texas in Austin. "That means the star that exploded might have been as massive as a star can get, about 150 times that of our Sun. We've never seen that before."

Figure 6: An artist's illustration of supernova SN 2006gy

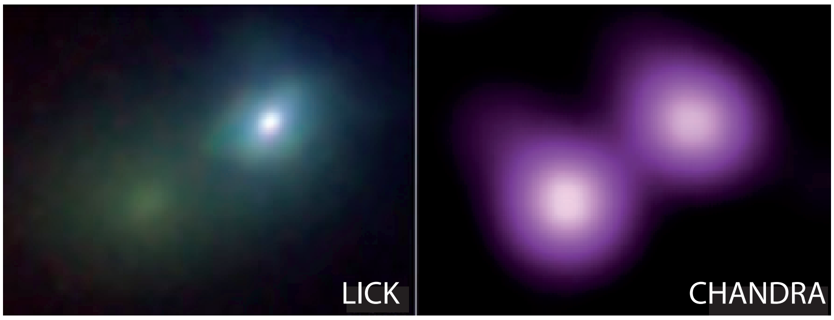


Astronomers think many of the first stars in the universe were this massive, and this new supernova may thus provide a rare glimpse of how those first generation stars died. It is unprecedented, however, to find such a massive star and witness its death. The discovery of the supernova, known as SN 2006gy, provides evidence that the death of such massive stars is fundamentally different from theoretical predictions.

"Of all exploding stars ever observed, this was the king," said Alex Filippenko, leader of the ground-based observations at the Lick Observatory at Mt. Hamilton, California, and the Keck Observatory in Mauna Kea, Hawaii. "We were astonished to see how bright it got, and how long it lasted."

The Chandra observation allowed the team to rule out the most likely alternative explanation for the supernova: that a white dwarf star with a mass only slightly higher than the Sun exploded into a dense, hydrogen-rich environment. In that event, SN 2006gy should have been 1000 times brighter in X-rays than what Chandra detected.

Figure 7: Optical (left) and X-ray (right) images of SN 2006gy. The dimmer source at lower-left is the nucleus of the host galaxy. The brighter source at upper-right is the stellar explosion. The supernova was as bright as the entire core of a galaxy!



"This provides strong evidence that SN 2006gy was, in fact, the death of an extremely massive star," said Dave Pooley of the University of California at Berkeley, who led the Chandra observations.

The star that produced SN 2006gy apparently expelled a large amount of mass prior to exploding. This large mass loss is similar to that seen from Eta Carinae, a massive star in our galaxy, raising suspicion that Eta Carinae may be poised to explode as a supernova. Although SN 2006gy is intrinsically the brightest supernova ever, it is in the galaxy NGC 1260, some 240 million light years away. However, Eta Carinae is only about 7500 light years away in our own Milky Way galaxy.

"We don't know for sure if Eta Carinae will explode soon, but we had better keep a close eye on it just in case," said Mario Livio of the Space Telescope Science Institute in Baltimore, who was not involved in the research. "Eta Carinae's explosion could be the best star-show in the history of modern civilization."

Figure 8: To the right is an image of Eta Carinae – a supernova waiting to happen in our own galaxy? The giant star is highlighted by diffraction spikes in this astrophoto taken by Brad Moore.

Supernovas usually occur when massive stars exhaust their fuel and collapse under their own gravity. In the case of SN 2006gy, however, astronomers think that a very different effect may have triggered the explosion. Under some conditions, the core of a massive star produces so much gamma-ray radiation that some of the energy from the radiation converts into particle and anti-particle pairs. The resulting drop in energy causes the star to collapse under its own huge gravity.

After this violent collapse, runaway thermonuclear reactions ensue and the star explodes, spewing the remains into space. The SN 2006gy data suggest that spectacular supernovas from the first stars that spew their remains – rather than completely collapsing to a black hole as theorized – may be more common than previously believed.

"In terms of the effect on the early universe, there's a huge difference between these two possibilities," said Smith. "One (sprinkles) the galaxy with large quantities of newly made elements and the other locks them up forever in a black hole."

Adapted from an article released on 7 May 2007 from the NASA web site.

The Brightest Supernova Ever

(a) Identify what the article refers to as the largest mass for a main sequence star. *[1]*

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(b) The lowest possible mass for a main sequence star is given by the mass needed to produce a large enough core temperature to allow nuclear fusion to occur. Explain why there is a largest possible mass for a main sequence star. *[2]*

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(c) What typically supports a massive main sequence star against the collapse due to gravity? *[1]*

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(d) SN 2006gy was viewed using the Chandra X-ray observatory and ground-based optical telescopes. Give **one** advantage and **one** disadvantage of using ground-based telescopes. *[2]*

Advantage: . . . .

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Disadvantage: . . . .

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(Question 5 continued)

(e) State whether you would expect the star that produced SN 2006gy to have a large or small main sequence lifetime. Briefly explain your answer in terms of the core nuclear processes. *[3]*

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(f) Explain why it is unusual to witness the death of such a large star. *[1]*

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(g) State the distances to SN 2006gy and Eta Carinae. Your answers should be in light years. *[2]*

Distance to SN 2006gy: . . . . ly

Distance to Eta Carinae: . . . . ly

(h) The luminosity of a star depends on its physical size and temperature. As Eta Carinae leaves the main sequence, state what happens to its luminosity and why. *[2]*

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(Question 5 continued)

(i) If Eta Carinae produces a supernova with the same luminosity as SN 2006gy, calculate how much brighter it would be compared to SN 2006gy. *[3]*

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(j) Briefly explain why supernovas are important for the development of our kind of life within the universe. *[2]*

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(k) Briefly explain why black holes lower the probability of the development of our kind of life within the universe. *[1]*

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6.

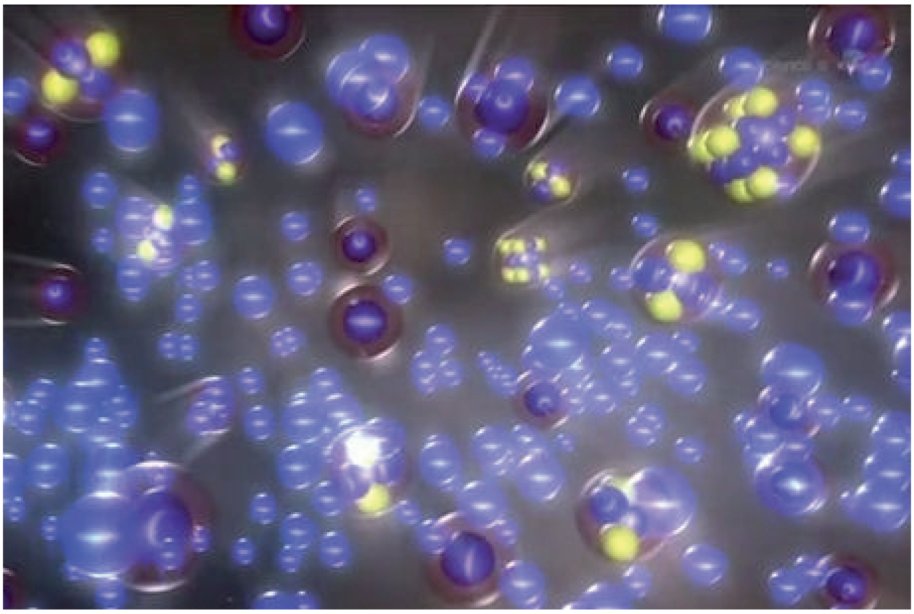
Alien Matter in the Solar System: A Galactic Mismatch

News just in: The solar system is different from the space just outside it.

Researchers announced the finding at a press conference on January 31, 2012. It's based on data from NASA's IBEX spacecraft, which is able to sample material flowing into the solar system from interstellar space.

"We've detected alien matter that came into our solar system from other parts of the galaxy, and, chemically speaking, it's not exactly like what we find here at home," says David McComas the principal investigator for IBEX at the Southwest Research Institute in San Antonio, Texas.

Figure 9: Artist's impression of the flow of interstellar atoms



Our solar system is surrounded by the heliosphere, a magnetic bubble that separates us from the rest of the Milky Way. Outside the heliosphere lies the realm of the stars or "interstellar space"; inside lies the Sun and all the planets. The Sun blows this vast magnetic bubble using the solar wind to inflate the Sun's own magnetic field. It's a good thing: The heliosphere helps protect us from cosmic rays that would otherwise penetrate the solar system.

Launched in 2008, the IBEX satellite spins in Earth orbit scanning the entire sky. IBEX's special trick is detecting neutral atoms that slip through the heliosphere's magnetic defences. Without actually exiting the solar system, IBEX is able to sample the galaxy outside.

The first two years of counting these alien atoms have led to some interesting conclusions:

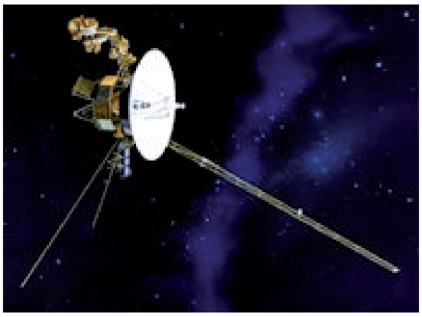
"We've directly measured four separate types of atoms from interstellar space and the composition just doesn't match up with what we see in the solar system," says Eric Christian, mission scientist for IBEX at NASA's Goddard Space Flight Centre in Greenbelt, Maryland.

Among the four types of atoms detected – H, He, O and Ne – the last one, neon, serves as a particularly useful reference. “Neon is a noble gas, so it doesn’t react with anything. And it’s relatively abundant, so we can measure it with good statistics,” explains McComas.

Using data from IBEX, the research team compared the neon-to-oxygen ratio inside vs. outside the heliosphere. In a series of six science papers appearing in the *Astrophysical Journal*, they reported that for every 20 neon atoms in the galactic wind, there are 74 oxygen atoms. In our own solar system, however, for every 20 neon atoms there are 111 oxygen atoms.

That translates to more oxygen in any given slice of the solar system than in local interstellar space.

Figure 10: An artist’s concept of Voyager approaching the edge of the solar system



Where did the extra oxygen come from?

“There are at least two possibilities,” says McComas. “Either the solar system evolved in a separate, more oxygen-rich part of the galaxy than where we currently reside or a great deal of critical, life-giving oxygen lies trapped in interstellar dust grains or ices, unable to move freely throughout space – and thus undetectable by IBEX.”

Either way, this affects scientific models of how our solar system – and life – formed.

“It’s a real puzzle,” he says.

While IBEX samples alien atoms from Earth orbit, NASA’s Voyager spacecraft have been travelling to the edge of the heliosphere for nearly 40 years – and they could soon find themselves on the outside looking in. Researchers expect Voyager 1 to exit the solar system within the next few years. The new data from IBEX suggest the Voyagers are heading for a new frontier, indeed.

Adapted from an article released on 10 February 2012 from the NASA web site.

Alien Matter in the Solar System: A Galactic Mismatch

(a) Two options for the generation of basic life on Earth are (1) seeding from outer space and (2) the creation of basic particles from simpler compounds as a result of the conditions on Earth. Briefly state **one** argument in favour of basic life being seeded from outer space. *[1]*

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(b) The next three question parts consider the solar wind.

(i) Identify the two most abundant constituents of the solar wind and the property they share which allows them to affect the heliosphere. *[3]*

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(ii) For such particles to escape into interstellar space, caluclate what their minimum speed must be as they leave the photosphere. *[2]*

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(iii) Give **two** reasons why it is highly unlikely that such particles could be prevented from escaping the solar system by interactions with planets. *[2]*

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(Question 6 continued)

(c) The IBEX satellite was launched in 2008 and orbits the Earth 0.11 times per day. Using this additional information

(i) show that the orbital period of the satellite is approximately 8×10^5 s. Your answer should be given to 2 significant figures. *[2]*

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(ii) caluclate how many orbits of the Earth the satellite was expected to undergo in its initially planned mission duration of 2 years. *[1]*

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(d) Explain why neon was chosen by the engineers of IBEX to be a particularly important atom to monitor. *[1]*

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(e) Explain why neon was not monitored on its own, but the amount was measured with respect to the amount of oxygen. *[2]*

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(Question 6 continued)

(f) (i) If we only consider the presence of neon and oxygen, using figures from the article, calculate the percentage of neon atoms in the galactic wind and the solar system. *[2]*

% Ne in galactic wind: . . . .

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% Ne in solar system: . . . .

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(ii) Indicate which location has the greater relative amount of oxygen by circling your answer below. *[1]*

The Galactic Wind / The Solar System

(g) Suggest **one** possible explanation for your answer to (ii). *[1]*

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(h) Aside from oxygen, state **two** other factors required for the development of life on Earth. *[2]*

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