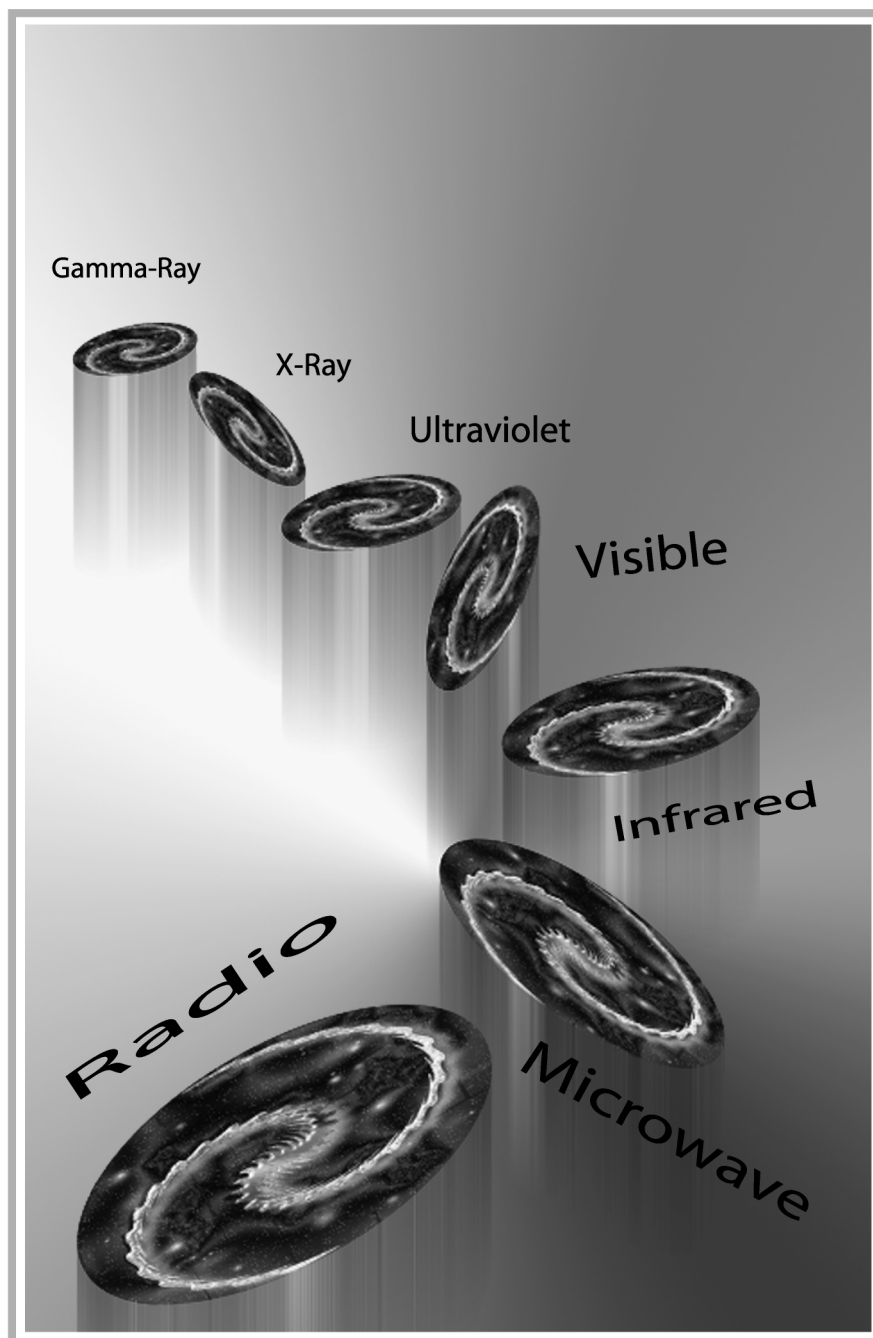


# Spin A Spectrum

Spin a Spectrum of Mysteries and Riddles

Grades 9-12





# Spin A Spectrum of Mysteries and Riddles

Many scientists say that the electromagnetic (EM) spectrum holds the keys to the Universe! While this may be an overstatement, it is clear that this standards-based topic can be used to assess many Grades 7-12 mathematics and science concepts. In the following booklet you will find mysteries and riddles (ranging from the curious to the silly) that will grab students' attention, yet not grab all of your class time! These short riddles can be used as warm-ups, homework, or good old fashioned assessments. Please don't use them to drive your curriculum; we've only meant them to be a high-interest supplement.

The following are tips which educators might find useful in helping to integrate this material into their classrooms.

- In order to solve these riddles or mysteries, students must have access to the "Spin-A-Spectrum" wheel or the information it contains. If you would like to create your own "Spin-A-Spectrum" wheel, the template is available at <http://swift.sonoma.edu/epo/materials/wheel.html>. You can also just create a chart or table that displays ranges of the EM spectrum; the ranges of energy, frequency, and wavelength for each region of the spectrum; and the objects in the Universe best observed in various regions.

- Students will be expected to know and/or use the following equations:

$$E = h * f \dots E = \text{energy, } h = \text{Plank's constant, and } f = \text{frequency}$$

$$f * \lambda = c \dots f = \text{frequency, } \lambda = \text{wavelength, and } c = \text{speed of light}$$

$$\lambda_m * T = 2.898 \times 10^{-3} \dots \lambda_m = \text{wavelength and } T = \text{temperature}$$

This latter equation is known as Wien's (pronounced "veen's") Displacement Law. It gives the wavelength,  $\lambda_m$ , at which the maximum amount of energy is emitted by a blackbody at a given temperature, T. In these equations,

$$c = 3 \times 10^8 \text{ m/sec}$$

$$h = 6.626 \times 10^{-34} \text{ J-sec}$$

The text will allow students to make conversions between different units. Beside the standard conversions between cm and km, g and kg, they will need to know:

$$1\text{eV} = 1.6 \times 10^{-19} \text{ J}$$

$$1\text{MeV} = 10^6 \text{ eV}$$

- Keep in mind that some of the mysteries are meant to be open-ended discussions of the science concepts, while other mysteries only involve simple mathematical calculations. Please read through each mystery and its solution in order to determine its appropriateness for your classroom.

- The Kelvin temperature scale is used in many of the riddles. Devised by Scottish scientist Lord William Thomson Kelvin in the late 1800s, the Kelvin temperature scale precisely defines absolute zero and does not depend on the properties of any substance (most other scales are in some way related to the behavior of water). The relationship between the Kelvin scale and the Celsius scale is

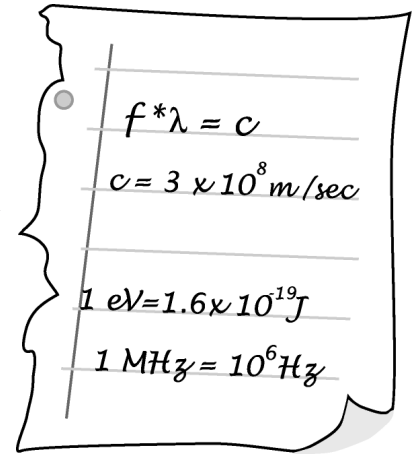
$$K = C + 273.15^\circ,$$

where the K and C correspond to the respective temperature readings.

# The Mysteries & Riddles

## Tuning In

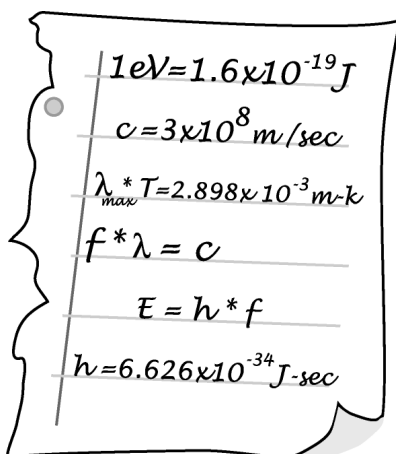
The North Point broadcasting bureau was about to bring the local radio station, FM100.3 on the radio dial, back on-air after a short period of maintenance and updating during the Fall of 2000. The faithful listeners of the county eagerly waited for the radio station to be “on-air” once more. The local paper informed the town that at noon that day the radio station would broadcast its regular programming once more, starting with a brief twenty-minute salute to the town’s local musicians. As it approached twelve, radios were switched on all over town. The police chief dialed into the radio station’s frequency, as he was waiting at a stop light, but the reception was distorted. “How disappointing,” he thought, “the updating was supposed to improve things - but I think this is clearly worse!” The Chief radioed into the station to see if anyone else had reported any problems. The dispatcher laughed, then said, “Try pulling the car forward a couple of meters.” Has the dispatcher lost his mind (and probably his job)? Or is there a method to his madness?



## The Milky Way

Looking toward the center of the Milky Way Galaxy, members of the North Point Astronomy Club were excited about what they were observing. The new optical telescope and CCD detectors that they had donated to the observatory were all in place and on-line. They were thrilled that the detectors were picking up so much detail. One member looked at the images that they were seeing on the computer and showed the group clouds that she claimed indicated an abundance of hydrogen in the cooler regions of the galactic disk. She also added that the denser areas in the clouds were stellar nurseries where stars were beginning their lives. The members looked at their colleague skeptically. The group was not as eager to assume such things about the observations they were making. Why not?

## To Nobel or Not to Nobel



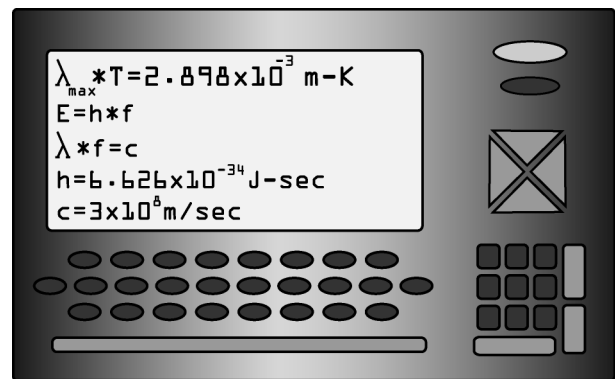
While working at the North Point Photonics Company, Valerie had made an amazing discovery. “I can win the Nobel Prize in Physics!” she thought. Her diligent efforts had created a material that would locate 0.13 eV photons with a spatial resolution of unimaginable accuracy. The only problem was that the material had to be used at room temperature. “This could change astronomy as we know it,” she thought. “Even if just the ground-based telescopes buy my detector... fame and fortune! They’re all mine!” Val’s plan had a flaw, however. What was it?

## News Flash

A news editor for the North Point Daily News was reviewing that week's news flashes taken from the Associated Press wire service. The editor was looking for a story to run the following day for the early morning edition. All the big stories had been done, with every aspect and angle dissected. Then the realization --a story no one else had covered. Aha! The editor began summarizing events on his laptop, and paused. A man and woman who had disappeared in the Alps had been found overnight by a helicopter patrol. The patrol had been searching for their downed commuter plane since its last transmission almost twenty hours earlier. The couple had no means to signal the passing vehicle, or to produce a fire; both were suffering from frostbite and hypothermia. How, he wondered, were they ever found, and at night?

## Best Laid Plans

"I have no idea what I am looking at!" cried Ensign Pat. She stared at a console of data from observations of the binary star system dead ahead. "Captain Robbie says that we need to measure the red star's temperature," barked Lieutenant Sally. "Should I send out a thermometer to stick in it?" Pat asked. "Optical observations of the star can tell us everything we need to know," Robbie said. "We find the peak emission frequency is at  $4.6 \times 10^{14}$  Hz. Using the what we know about electromagnetic waves and the Wien Displacement Law, we know that means the temperature is approximately \_\_\_\_\_ Kelvin." "Way cool," Lieutenant Sally replied.



## Stellar Dentistry?

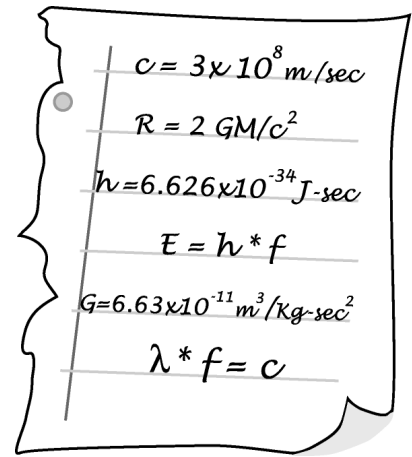
Phillip had had almost every bone and tooth in his body X-rayed at least twice. It was easy. All he had to do was hold still between the X-ray producing machine and the film. Imagine his confusion when he read in the North Point Times that NASA's orbiting *Chandra X-ray Observatory* had obtained an image of a star only 1,000 years old. Does the *Observatory* use film like the doctor, he wondered? And how did they get the star to hold still long enough to have its image taken? Would the X-ray emission harm him on the ground? He knew that he'd already had quite a few X-rays this year and that the human body could only tolerate a certain amount before it was lethal. Phillip decided to learn more about the *Chandra Observatory*. How could it see such a young star? It did not seem possible.

## Here Comes the Sun

"I got burnt," John said. Thinking he was not talking about just his reddened face, Kara listened on. "I used this new sunscreen, guaranteed to block out UV radiation. I went out to make repairs on the North Point radio communications tower and here I am -- charred as a crispy critter." Kara looked at the sunscreen bottle, which read: for 100% protection up to 4 hours over the range  $10^{14} - 10^{16}$  Hz. Kara decided to enlighten John about the error of his ways.

## Jo's Big Dream

Jo wanted to build a radio telescope on the deck of her modest townhouse in North Point's Eagle Village to "listen to the skies for alien signals of life." She began researching information on dishes and the EM spectrum and other things that mattered in the construction (like local building codes). After much research, she decided to do her listening at 2 MHz. Besides alien communication signals, what else might she detect with her telescope? Given that you need a telescope dish that is at least twice the size of the wavelength that you would like to detect, will Jo's dream ever come true?



## Vitamin D

"What are you doing?" cried Lieutenant Michael. "I am attempting to absorb some more \_\_\_\_\_ waves so that my skin can create more Vitamin D," said Captain Olivia. She continued, "Dr. Charles informed me that due to the lack of milk and milk products in my diet, I needed to get more of this vitamin into my system." Lieutenant Michael questioned, "But these \_\_\_\_\_ waves are dangerous to your skin and can cause cancer, did you know that they carry an energy between \_\_\_\_\_ and \_\_\_\_\_ eV, which is at least \_\_\_\_\_ times the energy of a radio wave?" Captain Olivia replied, "Yes Lieutenant, but if I only face the star we are orbiting 15 minutes a day, I will only expose myself for a total of 10 hours for the \_\_\_\_\_ days that we are in orbit, Dr. Charles says I will achieve the results I need."

## Paradise Lost?

"Where are we?" asked Ensign Austin. "Dude, you're awake! We are deep in the Alpha Omega Rainforest. We are on a search mission to find Dr. Charles' uncle. While trying to get there, his helicopter crashed \_\_\_\_\_ hours ago. We know this because two Earth days have passed since a mayday from the pilot. We spent a day travelling here." "How have I missed all of this?", a groggy Austin asked, scratching his head. "You were asleep when AstroFleet beamed us here." Austin began to wake up. "Beaming, cool! Beaming still astounds me, being transported through the Universe at a velocity of \_\_\_\_\_ km/sec, the velocity of light. So I slept for a whole day...over a distance of \_\_\_\_\_ km? Remember when we could only travel by car?" "Dude, can you ever sleep! But our mission is at hand, we need to comb the mountainside for signs of life," explained Lieutenant Alex. "What weapons do we have to protect ourselves and locate Charles' uncle?" questioned Ensign Austin. "We have infrared goggles that can detect energy in the range of \_\_\_\_\_ to \_\_\_\_\_, which more than covers what the

body of a human being will emit. We also have \_\_\_\_\_ phasers to protect us from harmful lifeforms," said Alex. Austin summarized, "I've always been amazed by the phasers...something so little producing a wave covering the range \_\_\_\_\_ to \_\_\_\_\_ meters. But hey, good enough to zap dinner, good enough to protect us!"



## Jenny's Big Adventure

Jenny wanted to learn more about the creation of new elements in the Universe. She had been fascinated ever since she learned that only hydrogen, helium, and lithium had been created in the Big Bang and that all of other elements had been created by stars. She was starstuff - cool! Now, she wanted more details. Jenny learned that radioactive aluminum-26 was produced by nucleosynthesis in supernova explosions, and she wondered how much was made by a single catastrophic explosion. After searching the library, she learned that the decay of  $^{26}\text{Al}$  leads to the emission of a photon with an energy of 1.8 MeV. This led Jenny to consider several options: make observations from the Hubble Space Telescope, travel to Puerto Rico to obtain data at the Arecibo Radio Observatory, or dig into the data archives of the HEAO-3 gamma-ray detectors. Where should Jenny go to gather her data and what should she look for?

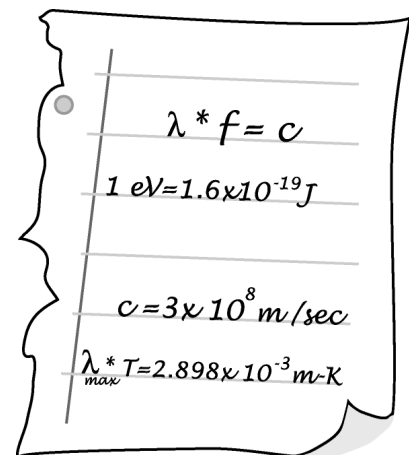


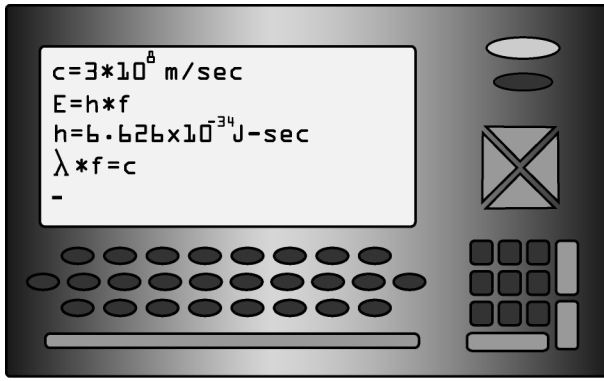
## A Class Project

After much debate Mrs. Swift's tenth grade astronomy class at North Point High School decided that their class time at the local observatory would be used to observe planets around distant stars. The class met at its usual time the following Monday at the observatory. They had written a guide so that all the necessary data would be recorded properly for analysis later in the week. The observatory's attendant listened as the class detailed what kind of observations they wanted to make. "Planets are best seen in the infrared," they proudly announced to the attendant. So we'd like to make IR observations on your telescope. The astronomer took Mrs. Swift aside and asked her why she allowed the class to go ahead with their project. Mrs. Swift was confused about the question. "But this telescope can see IR radiation that is near the visible waveband, right?" she inquired. "Yes," the attendant responded, "but that is not the point." What was wrong with the classes' observation plan?

## Mark's Big Discovery

Mark had tried the experiment in his condo kitchen in Eagle Village. He laid mini-marshmallows in rows on the bottom of his microwave and turned it on. After 15 seconds or so (depending on the power of the microwave), he could see a distinctive wave shape in the marshmallows. After turning on his ceiling fan to help with the terrible smell, and turning off his smoke alarm so as not to disturb the neighbors, he opened the oven door and used his ruler to examine the distance between "node points", places where the marshmallows had puffed up more than anywhere else. 6 cm. "This is way cool!" he thought. He wondered if this was really the wavelength of the microwave radiation, or if it was the interference pattern of the waves inside his oven. He made note of the following: his oven operated at a frequency of 2450 MHz, and the cavity measured 30 cm x 25 cm x 20 cm. What do you think?





## Bursts of High Energy

The Swift satellite has reported a major gamma-ray burst, with a total radiant energy of over  $10^{47}$  Joules, occurred at a location only 5 light-years (or \_\_\_\_\_ km) away from the AstroFleet outpost on planet Beta Omega. Knowing such an event would be catastrophic to life there, the Emergency Recovery Crew was dispatched to look for possible survivors. Arriving at the planet, the scene was overwhelming. Plants, animals, people...dying or dead. Everywhere.

Everything. Even inside the protective confines of the outpost lab, the short wavelength waves (gamma rays are less than \_\_\_\_\_ m) had penetrated and killed. The energy of each photon (a  $5 \times 10^{-14}$  m gamma ray has \_\_\_\_\_ eV of energy) was just too much. "Why didn't they evacuate before this happened?," cried Engineer First Class Rowell. "Such destruction! I guess there was just not enough time to react." "Get a grip, Rowell," interrupted Team Leader White, "we have work to do."

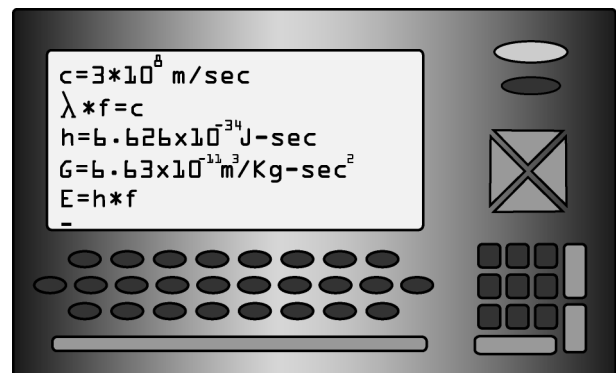
## To Go Where No One has Gone Before

"Careful!," cried Captain Kelly, "we must not approach too close to the black hole. It's a big one -- 50 times the mass of the Sun or \_\_\_\_\_ kg." "We must stay at least \_\_\_\_\_ km away!," Lieutenant Colton added. "How do you know that?!", Lieutenant Tyler screamed, slightly panicking. Tyler retrieved the equation for the event horizon radius of a black hole,  $R = 2GM/c^2$ , and plugged in the values for G and c, the gravitational constant and the speed of light. "Aha," Tyler exclaimed, "I see that indeed for a 50 solar mass black hole, the event horizon is equal to \_\_\_\_\_ times the radius of the Sun, which is \_\_\_\_\_ km."

Captain Kelly acted methodically and turned on the shields. She said, "The shields will help to protect us from the radiation environment we are in." "But I thought no light could escape from a black hole?" Tyler asked. In his calm, scientific manner, Colton explained. "The radiation comes from just outside the event horizon. The material being pulled into the event horizon heats up as it falls in. The temperatures reach over 5,000,000 Kelvin. Heat from this hot material radiates out into space before the material crosses the event horizon. This produces the peak of its radiation in the \_\_\_\_\_ band of the EM spectrum. It would not be healthy to be here without the shields." Tyler quickly brought up the equation for the relationship between photon temperature and peak emission wavelength,  $\lambda_m * T = 2.898 \times 10^{-3}$  (where the wavelength is in meters and Temperature is in Kelvin), and verified Colton's conclusions.

Suddenly Engineer Tanaka appeared on deck and said, "My sensors have picked up enormous \_\_\_\_\_ radiation increases. I think we may have entered a jet. The shields can't hold. We must leave at once!" "Make it so," ordered Captain Kelly.

Sun Fact Sheet  
 Mass -  $1.99 \times 10^{30}$  Kg  
 Gravity - 28 times that of Earth  
 Age - about 4.5 billion years  
 Equatorial Diameter - 1.39 million Km



## Let's Play Cosmic Journeys!

“It’s time to play *Cosmic Journeys*,” cried Alex Triphysics, host of North Point’s favorite game show. “Remember the further down in a column you go, the harder the questions get - but the more points you earn for the correct response!”

Here are your categories on today’s game of *Cosmic Journeys*:

- “Catch a Wave...length”, where every response names the region of the EM spectrum corresponding to that wavelength ,
  - “Everyday Objects in the Universe”,
  - “Hot-Hot-Hot Spots”,
  - “Cold as Deep Space”,
- and, finally,
- “Scientists of the Universe”, where every response is the name of a famous scientist or scientists who contributed to our understanding of the EM spectrum and the Universe.

Cold As Deep Space	Everyday Objects in the Universe	Catch the Wave...length	Hot, Hot, Hot Spots	Scientists of the Universe
Absolute Temperature scale	They shine by nuclear fusion	$5.8 \times 10^{-7}$ m	Hottest spot in our solar system	He gave the first mathematical reason for Roy G Biv
It's 3K	$10^{12}$ Gauss magnetic field, 20 km diameter, 1.4 solar masses	$10^{-15}$ m	Stellar coronae can be 5 million K, and emit primarily these	He found energy "beyond the visible"
Current Wavelength of the Big Bang Background	Radioactive decay here shows new elements were created in the blast	$10^{-4}$ m	It's the hottest radiation, but rarely does the cosmos create it thermally	The first human X-ray he took was of his wife's hand, wedding ring included
Current Frequency of the Big Bang Background	They'd emit IR, but we know about them thanks to gravity	100 m	It's the reason material spiraling into a neutron star heats up	They discovered the cosmic microwave background radiation
Wavelength from the spins of cosmic hydrogen atoms	You only see it because of its effect on nearby things	$10^{-8}$ m	These blast away from just outside the event horizon, and travel far into space	He showed you could change H to He, and get some gamma-rays in the process

# The Answers

**Tuning In** - A radio wave at a frequency of 100.3MHz corresponds to a wavelength of 2.99 meters. Usually, you get interference when your antenna is sitting at the trough of the radio wave you are trying to detect. So, to increase your signal, you just need to pull forward about 1/2 a wavelength, or about 1.5 meters in this case.

**The Milky Way** - You can't see neutral H with an optical telescope (it only emits 21 cm radiation, which is microwave). Nor star-forming regions, which primarily emit IR.

**To Nobel or Not to Nobel** - A detector at room temperature ( $\sim 30^\circ\text{C}$ ) would radiate with a peak flux at  $9.56 \times 10^{-6}$  m, which corresponds to a frequency of  $3.14 \times 10^{13}$  Hz, which is equivalent to an energy of 0.13 eV. Your own detector would interfere with any signal you'd hope to get. In addition, this energy infrared photon does not easily get through the Earth's atmosphere, causing an additional problem.

**News Flash** - An infrared camera could be used to see the heat from the living (although cold!) bodies

**Best Laid Plans** - If the frequency of the maximum emissions is  $4.6 \times 10^{14}$  Hz, then using  $\lambda = c/f$ , we get a value of the peak emission wavelength of  $6.52 \times 10^{-7}$  meters. Plugging this value into Wien's Displacement Law, gives you a temperature of 4444.8 Kelvin.

**Stellar Dentistry?** - X-rays from stars in space are like the X-rays from the machine in the doctor's office. The X-ray films that the doctors use are like the X-ray detectors on *Chandra*. The *Chandra* detectors take very quick snapshots and can see stars that are forming in our galaxy. These X-rays don't penetrate the Earth's atmosphere, which is why *Chandra* observations must be made from space. But let it be very clear - the objects in the Universe generate and emit the X-rays, not the *Chandra Observatory*!

**Here Comes the Sun** - UV goes up to  $10^{17}$  Hz, so there is still considerable radiation to produce a sunburn.

**Jo's Big Dream** - The wavelength corresponding to a 2 MHz radio wave is  $3 \times 10^8 \text{ m} / 2 \times 10^6 \text{ Hz} = 150 \text{ m}$ . It would be hard to get a dish twice this size on the deck of a modest townhouse.

**Vitamin D** - Ultraviolet, Ultraviolet, 10 and 1000 eV,  $10^7$ , 40 days

**Paradise Lost?** - 48 hrs,  $3 \times 10^5$  km/sec,  $2.592 \times 10^{10}$  km, 1 to  $10^{-3}$  eV, microwave, 1 to  $10^{-3}$  m

**Jenny's Big Adventure** - Jenny must look at the HEAO-3 gamma-ray archive data.  $^{26}\text{Al}$  decays by positron emission with a mean life of  $\sim 1$  Myr into  $^{26}\text{Mg}$ , which is stable. This decay is an important source of Galactic gamma ray line emission at 1.809 MeV. This decay and its observability were predicted by Ramaty and Lingenfelter in 1977, and it was discovered by Mahoney *et al.* in 1984.

**A Class Project** - Our current technology allows us to discern the existence of planets around distant stars by observing the star, not the planet itself. Stars are best seen in optical, and you need the best observation you can get to look for evidence of planets. Gravitational pulls and pushes introduce a wobble in the light curve. It is not possible to detect planets directly using ground-based telescopes through their infrared emission as they are too small and faint...especially compared to the nearby star which emits lots of IR compared to a planet!

**Mark's Big Discovery** - Mark's microwave oven operates at 2450 MHz, which has a wavelength of 12 cm. Since the nodes were every 6 cm, they were due to interference.

**Bursts of High Energy** -  $4.7 \times 10^{13}$  km,  $10^{-12}$  m,  $2.5 \times 10^7$  eV or 25 MeV

**To Go Where No One has Gone Before** -  $9.95 \times 10^{31}$  kg, 147 km,  $2.1 \times 10^{-4}$ ,  $7 \times 10^5$  km, X-ray, gamma-ray

**Let's Play Cosmic Journeys!** -

Cold As Deep Space	Everyday Objects in the Universe	Catch the Wave...length	Hot, Hot, Hot Spots	Scientists of the Universe
The Kelvin scale	Stars	Visible	The Sun	Isaac Newton
Cosmic Microwave Background temperature, or the current temperature of the "big bang background"	Neutron Stars	Gamma-ray	X-rays	William Herschel
$9.66 \times 10^{-4}$ m	Supernovae remnants	Infrared	Gamma-rays	Wilhelm Roentgen
$3.1 \times 10^{11}$ Hz	Planets	Radio	Conservation of energy	Arno Penzias and Robert Wilson
21 cm	Black hole	Ultraviolet	Jets	Hans Bethe

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<http://swift.sonoma.edu/epo/>