



The eXtreme Deep Field (XDF) image was created by astronomers by combining thousands of images of the same spot in the sky. When the data from 2,000 images were carefully combined, astronomers could identify 5,500 galaxies in the combined image.

Some of these galaxies, which appear as the large round spots in the photograph, are nearby galaxies. But in between these are the faint spots of light from the more distant galaxies. Some of these were formed only 500 million years after the Big Bang!

A simple study of this image can tell us a lot about our universe!

Problem 1 - Astronomers use angular measure when referring to locations and areas in the sky. In ordinary angle measure 1 degree can be subdivided into 60 arcminutes. 1 arc minute can be subdivided into 60 arcseconds. How many arcseconds are there in one degree of angular measure?

Problem 2 – The dimensions of the XDF patch are approximately 2.3 arcminutes wide and 2.0 arcminutes tall. What are the dimensions of this patch of the sky in degrees?

Problem 3 - What is the area of this patch of sky in square degrees?

Problem 4 – The full surface area of the entire sky can be found using the formula for the surface area of a sphere, where the ‘radius’ is equal to 1.0 radians. A radian is an angular measure equal to $180/\pi = 57.296$ degrees. What is the surface area of the entire sky in square degrees?

Problem 5 – How many of the XDF sky patches would cover the entire sky?

Problem 6 - If astronomers counted 5,500 galaxies in the XDF, about how many galaxies would you estimate across the entire sky?

Problem 7 - Astronomers studying the galaxies in the XDF have found about 10% are seen as they were less than 5 billion years ago, 30% are seen as they were between 5 billion and 9 billion years ago, and 60% are being seen as they were more than 9 billion years ago. Across the entire sky, how many galaxies might there be that are more than 9 billion years?

Problem 1 - $1 \text{ degree} \times (60 \text{ arcmin}/1 \text{ deg}) \times (60 \text{ arcses}/1 \text{ arcmin}) = \mathbf{3600 \text{ arcseconds}}$.

Problem 2 – $2.3 \text{ arcmin} \times (1 \text{ deg}/60 \text{ arcmin}) = \mathbf{0.038 \text{ degrees wide}}$ and
 $2.0 \text{ arcmin} \times (1 \text{ deg} /60 \text{ arcmin}) = \mathbf{0.033 \text{ degrees tall}}$.

Problem 3 - $0.038 \text{ degrees} \times 0.033 \text{ degrees} = \mathbf{0.00125 \text{ square degrees}}$.

Problem 4 – $4 \pi (57.296)^2 = \mathbf{41,253 \text{ square degrees}}$.

Problem 5 – How many of the XDF sky patches would cover the entire sky?
 $41,253 / 0.00125 = \mathbf{33,000,000 \text{ patches}}$. (for 2 significant figure accuracy)

Problem 6 - If astronomers counted 5,500 galaxies in the XDF, about how many galaxies would you estimate across the entire sky? $N = 5,500 \text{ galaxies/patch} \times (33000000 \text{ patches}) = \mathbf{182 \text{ billion galaxies!}}$ With 2 significant figure accuracy this is 180 billion galaxies.

Problem 7 - Astronomers studying the galaxies in the XDF have found about 10% are seen as they were less than 5 billion years ago, 30% are seen as they were between 5 billion and 9 billion years ago, and 60% are being seen as they were more than 9 billion years ago. Across the entire sky, how many galaxies might there be that are more than 9 billion years?

60% of the total would be galaxies seen as they were more than 9 billion years ago, so $0.60 \times 182 \text{ billion} = \mathbf{109 \text{ billion galaxies}}$. With 2 significant figure accuracy this is 110 billion.

Note: Since the Big Bang occurred 13.7 billion years ago, these galaxies are 13.7-9 or less than 4.7 billion years old!

