NASA's Kepler mission announced Wednesday the discovery of 715 new planets. These worlds orbit 305 stars, revealing multiple-planet systems much like our own solar system.

Nearly 95 percent of these planets are smaller than Neptune, which is almost four times the size of Earth. This discovery marks a significant increase in the number of known planets similar in size to Earth.

The Kepler mission surveyed 190,751 stars similar to our own sun in the constellation Cygnus the Swan. It searched for the tell-tail dimming of light that means a planet has 'eclipsed' the face of the star as viewed from Earth. As of February 2014, the Kepler spacecraft and its follow-up observations has detected 3670 stars with transit events, of these 1140 were later identified as binary stars, and 779 were eliminated because their transits were misidentified. The remaining transits included 340 stars that had more than one transit event suggesting that they were multi-planet systems (called Multis) with a total of 851 individual planet transits. Thirty four of these Multis were already catalogued stars which had 83 planet transits.

Problem 1 - Draw a branching diagram that shows how each of different groups and numbers are related to each other. How many single star/single transits were discovered among the 3670 stars with transits? What was the total number of new stars and planets announced by Kepler in the Multi systems?

Problem 2 - A subsample of 739 of the 851 discovered Kepler planets could be measured for their sizes. The result was 102 planets that were Earth-sized, 215 planets that were super-Earth sized up to twice the diameter of Earth, 373 that were Neptune-sized, and 13 that were Jupiter-sized or larger. Draw a histogram of this ensemble. What percentage of multi-planet system detected by Kepler have Earth-sized planets?

Problem 3 - If the amount of solar energy falling on Earth to keep it warm is defined as 1.0, for Venus it is 2.0 and for Mars it is 0.4. From the 851 planets detected in orbit around the 340 stars, there were 18 planets orbiting 16 stars found to be in the solar energy 'habitable zone' from 0.4 to 2.0 so that liquid water could exist on their surfaces. What is the probability that, given a multi-planet system you will find an Earth-sized planet in its Habitable Zone?

Problem 4 - The Milky Way is estimated to have about 1 trillion stars from red dwarfs to brilliant super giants. From various surveys, about 20% are similar to our sun. From the Kepler survey data, A) how many multi-planet systems would you expect to find if the Kepler survey could be conducted for all the stars in the Milky Way? B) How many Earth-sized planets in multi-planet systems would you expect to find? C) How many Earth-like planets in their Habitable Zones would you expect to find?

NASA's Kepler Mission Announces a Planet Bonanza, 715 New Worlds
February 26, 2014
http://www.nasa.gov/press/2014/february/nasas-kepler-mission-announces-a-planet-bonanza-715-new-worlds/

Teacher Note: The number '715' is a revised version of the 768 new planets reported by the Kepler Team in the paper by Rowe et al. 'Validation of Kepler's Multiple Planet Candidates: III (Table III), based on combining other surveys after the paper was published, but before the press conference public announcement on February 26.

Problem 1 -   190,751 stars

                              3670 stars with transits

         779 false positive   1751 valid transits   1140 binary stars   (total=3670)

                              1411   340 Multis   (total=1751)
                              Single   (851 planets)
                              Stars

                                              306 stars   34 stars   (total=340)
                                              768 planets   83 planets

Answer: There were 1751-340=1411 single star transits. The total number of new stars and planets was 340-34 = 306 stars and 851-83 = 768 planets.

Problem 2 - A subsample of 739 of the 851 discovered Kepler planets could be measured for their sizes. The result was 102 planets that were Earth-sized, 215 planets that were super-Earth sized up to twice the diameter of Earth, 373 that were Neptune-sized, and 13 that were Jupiter-sized or larger. Draw a histogram of this ensemble. What percentage of multi-planet system detected by Kepler have Earth-sized planets?   Answer: 102/739 = 13.8 %

Problem 3 - If the amount of solar energy falling on Earth to keep it warm is defined as 1.0, for Venus it is 2.0 and for Mars it is 0.4. From the 851 planets detected in orbit around the 340 stars, there were 18 planets orbiting 16 stars found to be in the solar energy 'habitable zone' from 0.4 to 2.0 so that liquid water could exist on their surfaces. What is the probability that, given a multi-planet system you will find an Earth-sized planet in its Habitable Zone?   Answer: **There are 340 multiplanet systems, so for 16 stars having such a planet, the probability is 16/340 = 0.047 or 4.7%. Alternatively, for 851 planets in multiplanet systems we have 18/851 = 0.021 or 2.1%.**

Problem 4 - The Milky Way is estimated to have about 1 trillion stars from red dwarfs to brilliant super giants. From various surveys, about 20% are similar to our sun. From the Kepler survey data, A) how many multi-planet systems would you expect to find if the Kepler survey could be conducted for all the stars in the Milky Way? B) How many Earth-sized planets in multi-planet systems would you expect to find? C) How many Earth-like planets in their Habitable Zones would you expect to find?

Answer: A) 1 trillion x 0.2 x (340 multiplanets /190,751 stars searched) = **357 million**.
B) 357 million x (102/739) = **49 million**.
C) 49 million x (16 / 340) = **2.3 million Earth-sized planets in their HZ in the Milky Way.**

Note: The Kepler survey only sees planetary systems if their orbit planes are along the line of sight to the star and Earth. Statistically this only happens about 5% of the time, so we can multiply the Kepler results by 20 to account for planetary systems we miss using this technique. That means for Answer C, there could be nearly **50 million planets like Earth**. Also, in our solar system Neptune and Jupiter-sized planets can have moons the size of Earth, so that means ANY planet found in the HZ could be potentially habitable if we include its moons, so we eliminate the step in Answer B and so have 357 million x (16/340) x 20 = **336 million possible Earth-sized planets (or moons) in the Habitable Zone!**