You are the Cosmologist  
Inferring Cosmological Parameters using Clustering

Part 1

1. Attached is a picture labelled **Data**. It shows the locations on the sky of eleven galaxies, all of which are at the same redshift. We need to analyse this picture to measure how much the galaxies have clustered together under the influence of gravity.
2. Use the ruler to measure the distance between each pair of galaxies. Distances in this exercise are quoted in millions of light years. You don’t need to be very precise – simply determine which of the four categories (0-50, 50-100, 100-150 or over 150) the distance of each pair belongs to. Keep track of the results in the table on the next sheet: on each row put a tick in the correct column for that pair of galaxies. One person can measure while the other makes the tick marks.
3. When you are done, count up the number of ticks and enter this in the ‘Totals’ row.
4. Find another team with the **Data** picture and compare your results. Correct any mistakes!

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  |  | **Data** | | | |
|  |  | **Bin 1**  **0 – 50** | **Bin 2**  **50–100** | **Bin 3**  **100–150** | **Bin 4**  **Over 150** |
| **1** | **2** |  |  |  |  |
| **1** | **3** |  |  |  |  |
| **1** | **4** |  |  |  |  |
| **1** | **5** |  |  |  |  |
| **1** | **6** |  |  |  |  |
| **1** | **7** |  |  |  |  |
| **1** | **8** |  |  |  |  |
| **1** | **9** |  |  |  |  |
| **1** | **10** |  |  |  |  |
| **1** | **11** |  |  |  |  |
| **2** | **3** |  |  |  |  |
| **2** | **4** |  |  |  |  |
| **2** | **5** |  |  |  |  |
| **2** | **6** |  |  |  |  |
| **2** | **7** |  |  |  |  |
| **2** | **8** |  |  |  |  |
| **2** | **9** |  |  |  |  |
| **2** | **10** |  |  |  |  |
| **2** | **11** |  |  |  |  |
| **3** | **4** |  |  |  |  |
| **3** | **5** |  |  |  |  |
| **3** | **6** |  |  |  |  |
| **3** | **7** |  |  |  |  |
| **3** | **8** |  |  |  |  |
| **3** | **9** |  |  |  |  |
| **3** | **10** |  |  |  |  |
| **3** | **11** |  |  |  |  |
| **4** | **5** |  |  |  |  |
| **4** | **6** |  |  |  |  |
| **4** | **7** |  |  |  |  |
| **4** | **8** |  |  |  |  |
| **4** | **9** |  |  |  |  |
| **4** | **10** |  |  |  |  |
| **4** | **11** |  |  |  |  |
| **5** | **6** |  |  |  |  |
| **5** | **7** |  |  |  |  |
| **5** | **8** |  |  |  |  |
| **5** | **9** |  |  |  |  |
| **5** | **10** |  |  |  |  |
| **5** | **11** |  |  |  |  |
| **6** | **7** |  |  |  |  |
| **6** | **8** |  |  |  |  |
| **6** | **9** |  |  |  |  |
| **6** | **10** |  |  |  |  |
| **6** | **11** |  |  |  |  |
| **7** | **8** |  |  |  |  |
| **7** | **9** |  |  |  |  |
| **7** | **10** |  |  |  |  |
| **7** | **11** |  |  |  |  |
| **8** | **9** |  |  |  |  |
| **8** | **10** |  |  |  |  |
| **8** | **11** |  |  |  |  |
| **9** | **10** |  |  |  |  |
| **9** | **11** |  |  |  |  |
| **10** | **11** |  |  |  |  |
| **Totals** | |  |  |  |  |

Part 2

1. In the table at the top of the last sheet, fill in your counts for each bin both for the Data picture (which you have calculated) and for the Random picture (which other teams have calculated). We won’t use the ‘over 150’ count (why not?).
2. For each of the three distance bins calculate the percentage difference:  
    (Data Count – Random Count) / Random Count.  
   Example: If the Data count is 14 and the Random count is 10, then the percentage difference is 40%.  
     
   This is your Clustering Table.
3. Finally compare your Clustering Table to the Clustering Tables calculated by the theoreticians for a range of densities and ages. Where is the best fit? (You may need to interpolate between the density columns and/or the age rows).
4. So what is the age of the Universe? And what is its density?

**Our clustering table** (you can ignore the ‘Over 150’ counts)

|  |  |  |  |
| --- | --- | --- | --- |
|  | Data Totals | Random Totals | Percentage Difference:  (Data Total – Random Total) / Random Total |
| 0-50 |  |  |  |
| 50-100 |  |  |  |
| 100-150 |  |  |  |

**Clustering tables created from theory**

|  |  |  |  |
| --- | --- | --- | --- |
|  | Density = 3g per Jupiter Volume | Density = 5g per Jupiter Volume | Density = 7g per Jupiter Volume |
| Age = 16 billion y | |  |  | | --- | --- | | 0-50 | 133.5% | | 50-100 | 100.4% | | 100-150 | 14.9% | | |  |  | | --- | --- | | 0-50 | 153.2% | | 50-100 | 120.6% | | 100-150 | 16.1% | | |  |  | | --- | --- | | 0-50 | 184.2% | | 50-100 | 140.7% | | 100-150 | 19.7% | |
| Age = 14 billion y | |  |  | | --- | --- | | 0-50 | 123.7% | | 50-100 | 91.1% | | 100-150 | 11.7% | | |  |  | | --- | --- | | 0-50 | 142.9% | | 50-100 | 109.0% | | 100-150 | 9.3% | | |  |  | | --- | --- | | 0-50 | 162.3% | | 50-100 | 129.6% | | 100-150 | 9.7% | |
| Age = 12 billion y | |  |  | | --- | --- | | 0-50 | 112.1% | | 50-100 | 79.9% | | 100-150 | 5.0% | | |  |  | | --- | --- | | 0-50 | 132.7% | | 50-100 | 100.2% | | 100-150 | 5.1% | | |  |  | | --- | --- | | 0-50 | 154.0% | | 50-100 | 120.4% | | 100-150 | 6.0% | |

**Age of Universe = \_\_\_\_\_\_\_\_\_\_\_\_ Density of Universe = \_\_\_\_\_\_\_\_\_\_\_\_**

You are the Cosmologist  
Inferring Cosmological Parameters using Clustering

Part 1

1. Attached is a picture labelled **Random**. It shows the locations on the sky of eleven randomly selected positions. We need to analyse this random data in order to determine how much clustering is likely to happen by chance.
2. Use the ruler to measure the distance between each pair of galaxies. Distances in this exercise are quoted in millions of light years. You don’t need to be very precise – simply determine which of the four categories (0-50, 50-100, 100-150 or over 150) the distance of each pair belongs to. Keep track of the results in the table on the next sheet: on each row put a tick in the correct column for that pair of galaxies. One person can measure while the other makes the tick marks.
3. When you are done, count up the number of ticks and enter this in the ‘Totals’ row.
4. Find another team with the **Random** picture and compare your results. Correct any mistakes!

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  |  | **Random** | | | |
|  |  | **Bin 1**  **0–50** | **Bin 2**  **50–100** | **Bin 3**  **100–150** | **Bin 4**  **Over 150** |
| **1** | **2** |  |  |  |  |
| **1** | **3** |  |  |  |  |
| **1** | **4** |  |  |  |  |
| **1** | **5** |  |  |  |  |
| **1** | **6** |  |  |  |  |
| **1** | **7** |  |  |  |  |
| **1** | **8** |  |  |  |  |
| **1** | **9** |  |  |  |  |
| **1** | **10** |  |  |  |  |
| **1** | **11** |  |  |  |  |
| **2** | **3** |  |  |  |  |
| **2** | **4** |  |  |  |  |
| **2** | **5** |  |  |  |  |
| **2** | **6** |  |  |  |  |
| **2** | **7** |  |  |  |  |
| **2** | **8** |  |  |  |  |
| **2** | **9** |  |  |  |  |
| **2** | **10** |  |  |  |  |
| **2** | **11** |  |  |  |  |
| **3** | **4** |  |  |  |  |
| **3** | **5** |  |  |  |  |
| **3** | **6** |  |  |  |  |
| **3** | **7** |  |  |  |  |
| **3** | **8** |  |  |  |  |
| **3** | **9** |  |  |  |  |
| **3** | **10** |  |  |  |  |
| **3** | **11** |  |  |  |  |
| **4** | **5** |  |  |  |  |
| **4** | **6** |  |  |  |  |
| **4** | **7** |  |  |  |  |
| **4** | **8** |  |  |  |  |
| **4** | **9** |  |  |  |  |
| **4** | **10** |  |  |  |  |
| **4** | **11** |  |  |  |  |
| **5** | **6** |  |  |  |  |
| **5** | **7** |  |  |  |  |
| **5** | **8** |  |  |  |  |
| **5** | **9** |  |  |  |  |
| **5** | **10** |  |  |  |  |
| **5** | **11** |  |  |  |  |
| **6** | **7** |  |  |  |  |
| **6** | **8** |  |  |  |  |
| **6** | **9** |  |  |  |  |
| **6** | **10** |  |  |  |  |
| **6** | **11** |  |  |  |  |
| **7** | **8** |  |  |  |  |
| **7** | **9** |  |  |  |  |
| **7** | **10** |  |  |  |  |
| **7** | **11** |  |  |  |  |
| **8** | **9** |  |  |  |  |
| **8** | **10** |  |  |  |  |
| **8** | **11** |  |  |  |  |
| **9** | **10** |  |  |  |  |
| **9** | **11** |  |  |  |  |
| **10** | **11** |  |  |  |  |
| **Totals** | |  |  |  |  |

Part 2

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|  |  |  |  |
| --- | --- | --- | --- |
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| 50-100 |  |  |  |
| 100-150 |  |  |  |

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|  |  |  |  |
| --- | --- | --- | --- |
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**Age of Universe = \_\_\_\_\_\_\_\_\_\_\_\_ Density of Universe = \_\_\_\_\_\_\_\_\_\_\_\_**