

Entropy Evolution of the Universe

Planck Epoch

$$t_{pl} := 10^{-43} \text{ sec} \quad T_{planck} := 10^{32} \text{ K}$$

Planck Total Entropy Horizon Volume

$$S_{Planck_HV} := 10^{17} k_b$$

Present-day CMB temperature

$$T_0 := 2.725 \text{ K}$$

Approximate particle horizon today

$$d_H := 1.4 \cdot 10^{26} \text{ m}$$

Effective relativistic degrees of freedom after e+e- annihilation

$$g_{star_ee} := 3.91$$

Function: radiation entropy density [J/(m³·K)]

$$s_{rad}(a) := \frac{2\pi^2}{45} \cdot g_{star_ee} \cdot \frac{k_b^4}{\hbar^3 \cdot c^3} \cdot \left(\frac{T_0}{a}\right)^3$$

Radiation Entropy in Universe Today

$$S_{rad}(a) := s_{rad}(a) \cdot \frac{4}{3} \pi d_H^3 \quad S_{rad}(1) = 1.35 \times 10^{86} \cdot k_b$$

Bekenstein-Hawking entropy formula for a black hole; AEH is the Area of the Event Horizon

$$M_{BH} := 10^8 \cdot M_{\odot} \quad A_{EH} := 4\pi \left(\frac{2G \cdot M_{BH}}{c^2}\right)^2 \quad S_{BH} := \frac{c^3 A_{EH} \cdot k_b}{4G \cdot \hbar}$$

Galactic Growth

$$Growth(a) := 10^{12} [(a-0.1)^{0.5}]$$

CMB Photons

$$S_{CMB} := 10^{88} k_b$$

Neutrinos

$$S_{Neut} := 2 \cdot 10^{87} \cdot k_b$$

Stars/Barvons

$$S_{Baryons} := 1.4 \cdot 10^{80} k_b$$

Dark Matter

$$S_{DM} := 10^{88} k_b$$

One Black Hole

$$S_{BH} = 1.675 \times 10^{92} \cdot k_b$$

Entropy of Single Black Hole At Galaxy Formation:

$$S_{BHgf}(a) := \text{if} \left(a < 0.1, 1 \cdot 10^{55}, \frac{S_{BH}}{k_b} \cdot 10^{-23} \cdot Growth(a) \right)$$

Assume 10¹¹ Galaxies with BHs - Total Universe:

$$S_{BH_Total} := 10^{11} \cdot S_{BH} \quad S_{BH_Total} = 1.675 \times 10^{103} \cdot k_b$$

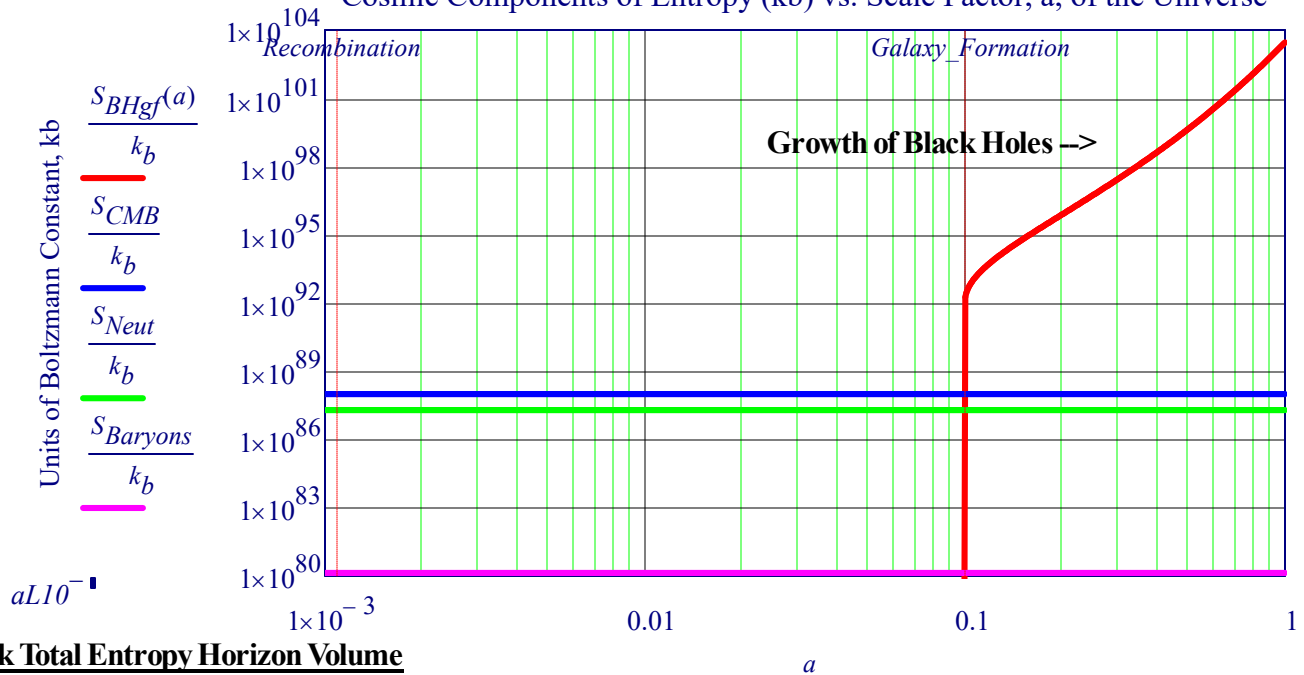
Why is Entropy of Black Holes So Large?

$S_{BH} \propto M^2$ Not just matter, M, but M^2 . Maximally compresses matter. Gravitational Entropy dominates the universe today.

The Major Portion of the Entropy of the Universe after Galaxy Formation is in Black Holes

Time's arrow is intimately connected to gravitational collapse. Black holes represent the final "destination" of entropy growth.

Cosmic Components of Entropy (kb) vs. Scale Factor, a, of the Universe



Planck Total Entropy Horizon Volume

$$S_{Planck_HV} := 10^{17} k_b$$

Scale Factor, a

History of Numbering of the Stars - Cosmology

We Live in a Time of Exponential Growth in Our Knowledge of the Universe (Cosmology)

Estimate of Order of Magnitude (# of Zeros) of Number of "Known Stars"

List Number of Stars that were Cataloged, Known, or Estimated Based on Observations.

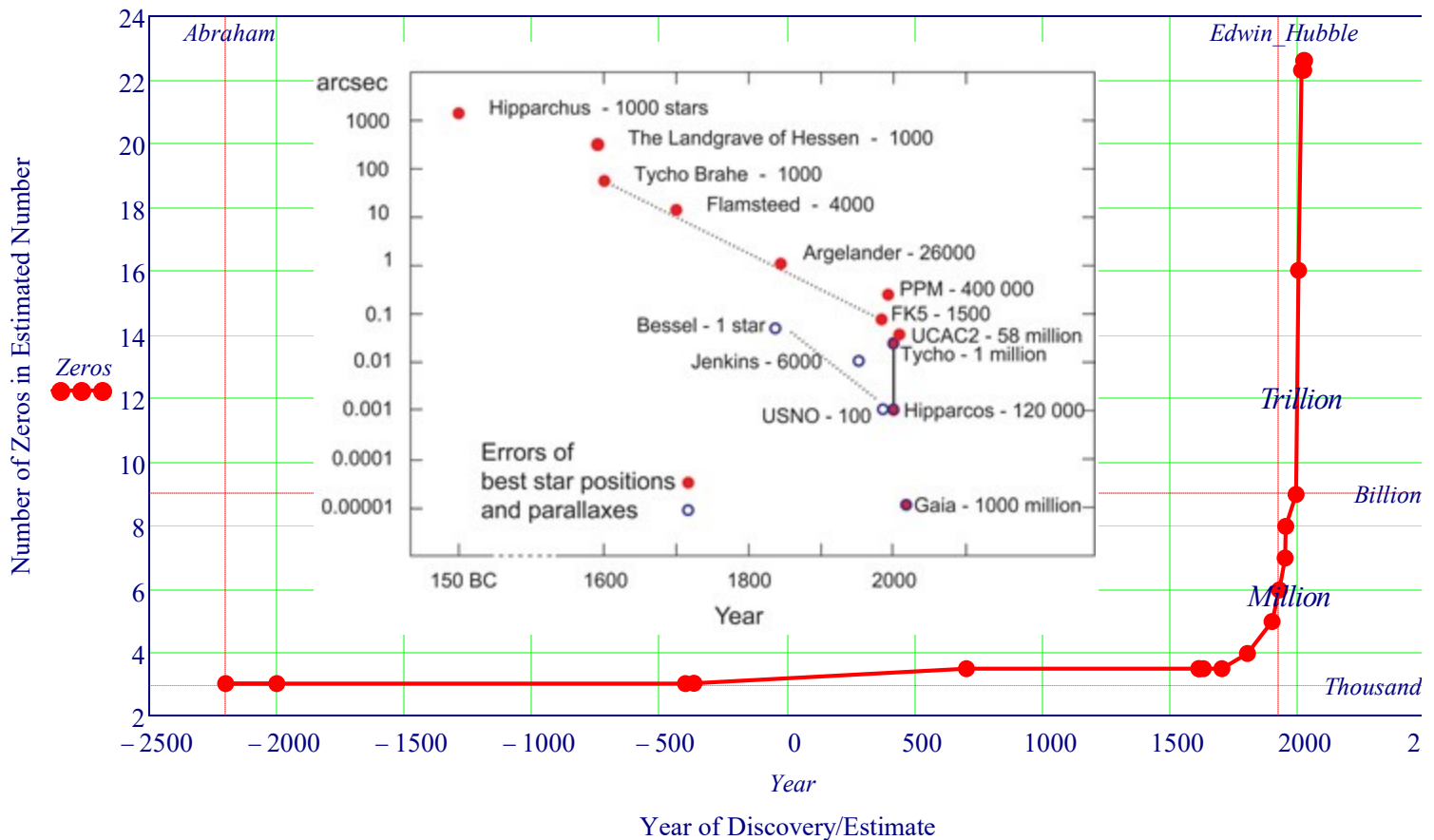
Example: 2500 BC could only see about 3,000, Yerkes Observatory cataloged 13,655 stars in 1800.

We are interested only in obtaining the Order of Magnitude of the Known, Cataloged, or Estimated Stars.

```

N_stars := READPRN("Num of Stars2.txt")    Abraham := -2200    Edwin_Hubble := 1925
Zeros := log(N_stars <1>)                 Year := N_stars <0>    rows(N_stars) = 20
    
```

History: Discovery of Number of Observable Stars (#Tens) & Errors in Position vs. Year of Discovery



Ratio of Baryonic to Dark Matter

To calculate this ratio in a specific galaxy, astronomers **measure the rotation speed of the galaxy at various distances** from its center. They then create a rotation curve based on the visible matter (using the mass of stars, gas, etc.) and compare it with the observed rotation curve. The difference between these curves indicates the amount of dark matter. By integrating the mass profiles of both baryonic and dark matter, astronomers can estimate their respective contributions to the galaxy's total mass. While the exact ratio of dark matter to baryonic matter varies, a commonly cited average is that dark matter makes up about 85% of the total matter content in galaxies, with baryonic matter constituting about 15%. This implies a ratio of approximately 5.7:1 (dark matter to baryonic matter).

Applying this ratio gives for the total Matter in Universe

$$Tot_{matter} := M_{Baryon} \cdot (1 + 5.7) = 5.331 \times 10^{54} \text{ kg}$$