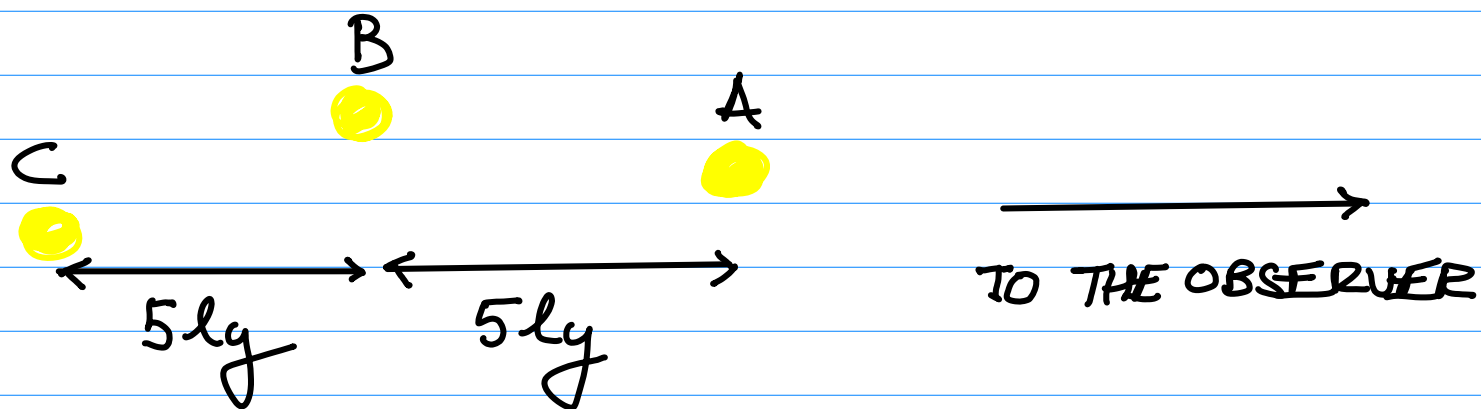


Why is the time over which the intensity of a source varies related to its maximum size?

EXAMPLE: THREE SOURCES SEPARATED BY  $5 \text{ ly}$



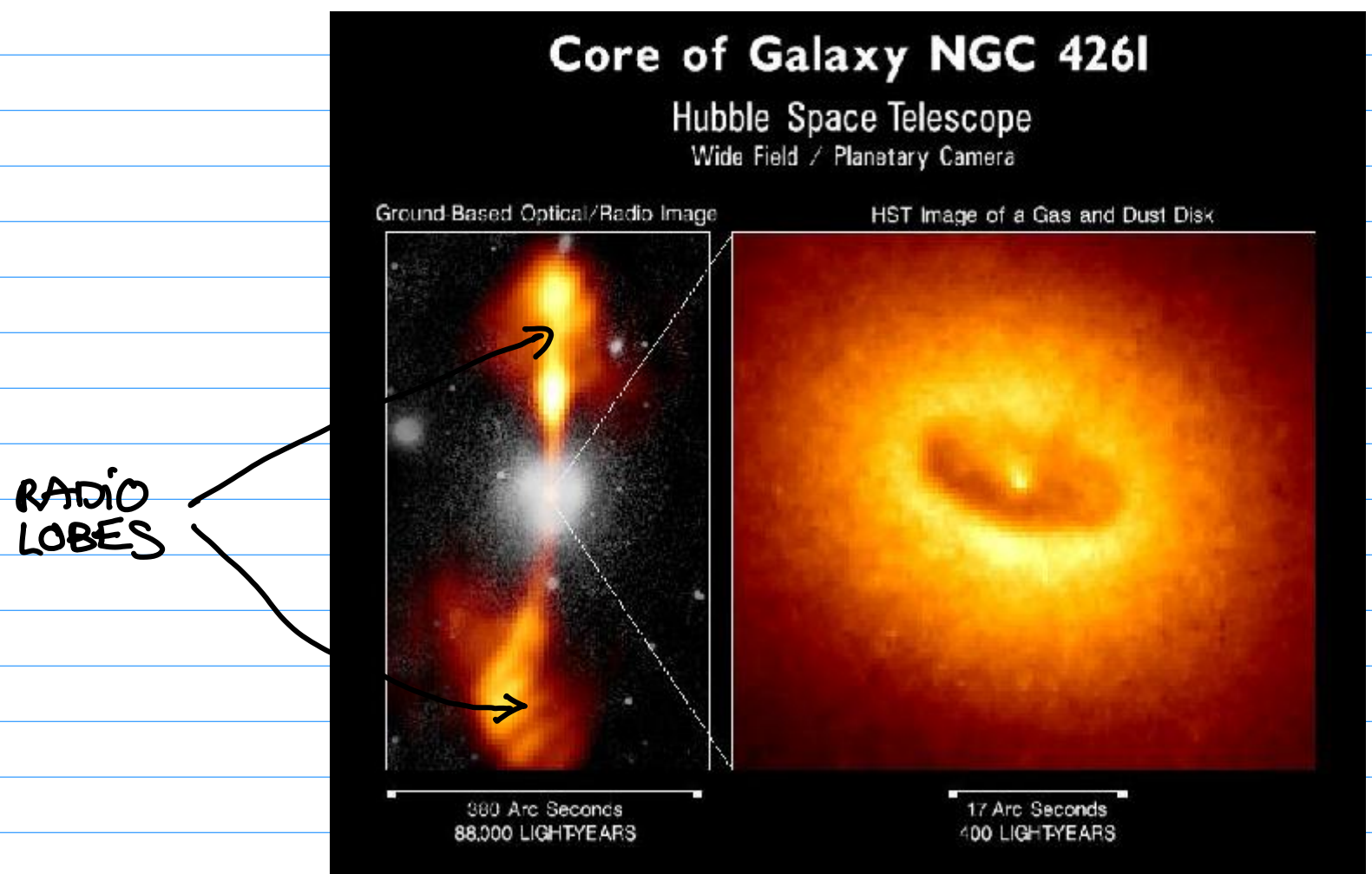
THE THREE SOURCES ARE TURNED ON AT THE SAME TIME:

- WE FIRST SEE A.
- 5 YEARS LATER WE SEE A & B (BUT NOT C).
- 10 YEARS LATER WE SEE ALL THREE SOURCES.

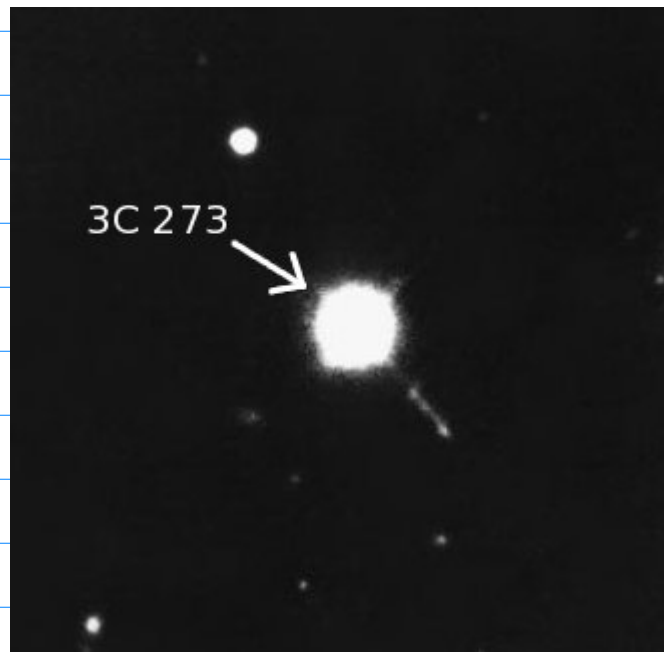
THE LIGHT INTENSITY HAS GONE

FROM 0 TO THE MAXIMUM VALUE IN 10 YEARS BECAUSE THE SIZE OF THE SOURCE (A+B+C) IS 10 ly.

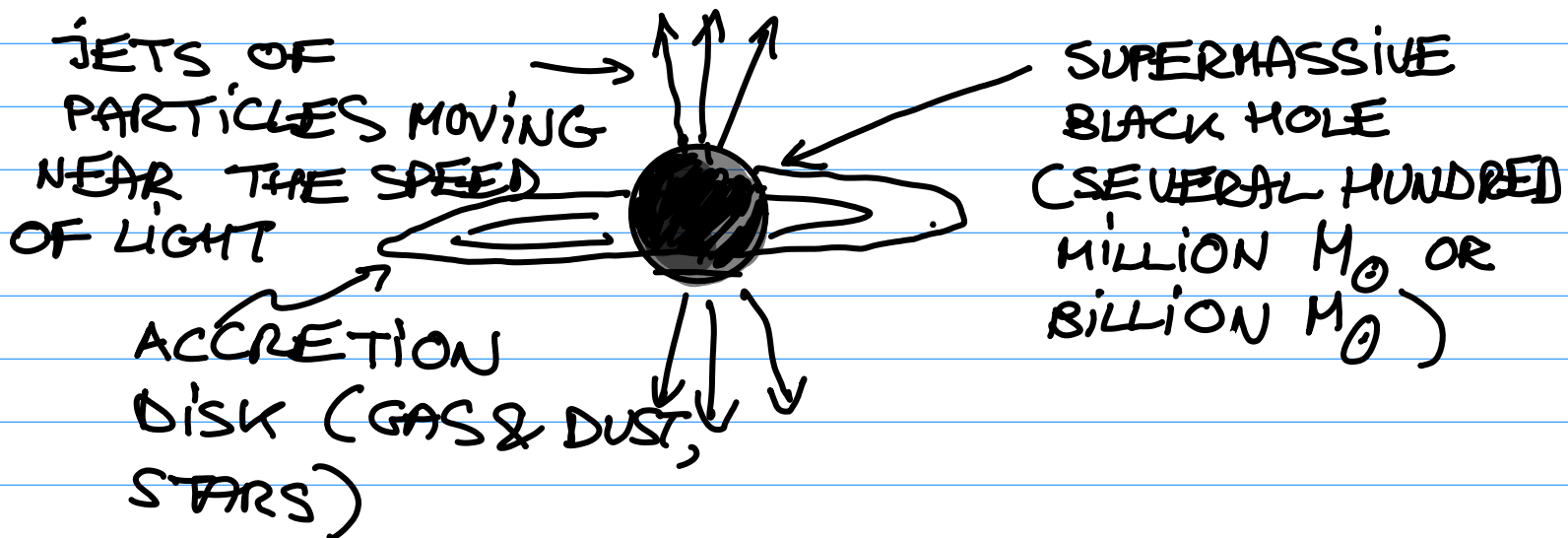
2) RADIO GALAXIES : ELLIPTICAL GALAXIES WHICH EMIT INTENSE RADIO WAVES FROM THEIR CORES AND FROM REGIONS OUTSIDE THE GALAXY (RADIO LOBES).



3) QUASARS (QUASISTELLAR RADIO SOURCES) - "STARS" WHICH ARE ALSO SOURCES OF INTENSE RADIO WAVES (NORMALLY, STARS DO NOT EMIT MUCH ENERGY AT RADIO WAVELENGTHS).



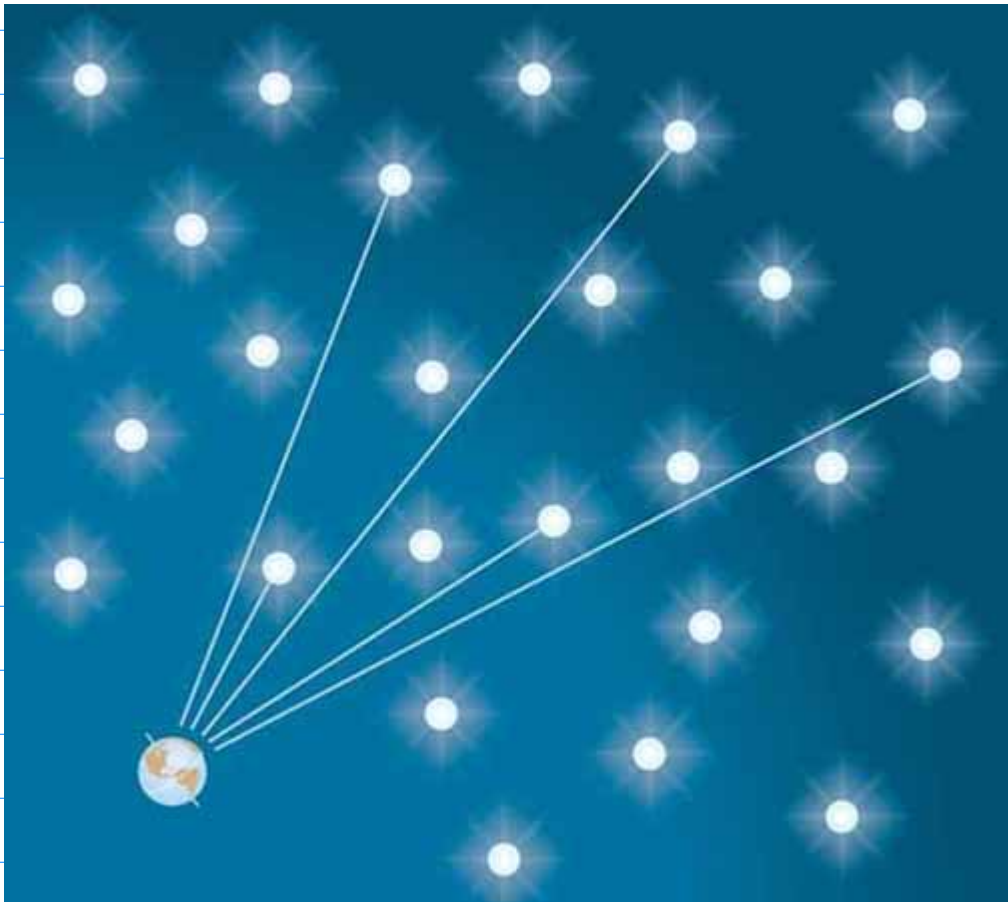
A MODEL FOR GALAXIES WITH ACTIVE GALACTIC NUCLEI:



# COSMOLOGY

THE UNIVERSE HAS A FINITE AGE.

OLBERS' PARADOX (1826): IF THE UNIVERSE EXISTED FOR EVER, IS INFINITE, AND IS UNIFORMLY FILLED WITH STARS THEN THE NIGHT SKY SHOULD NOT BE DARK:



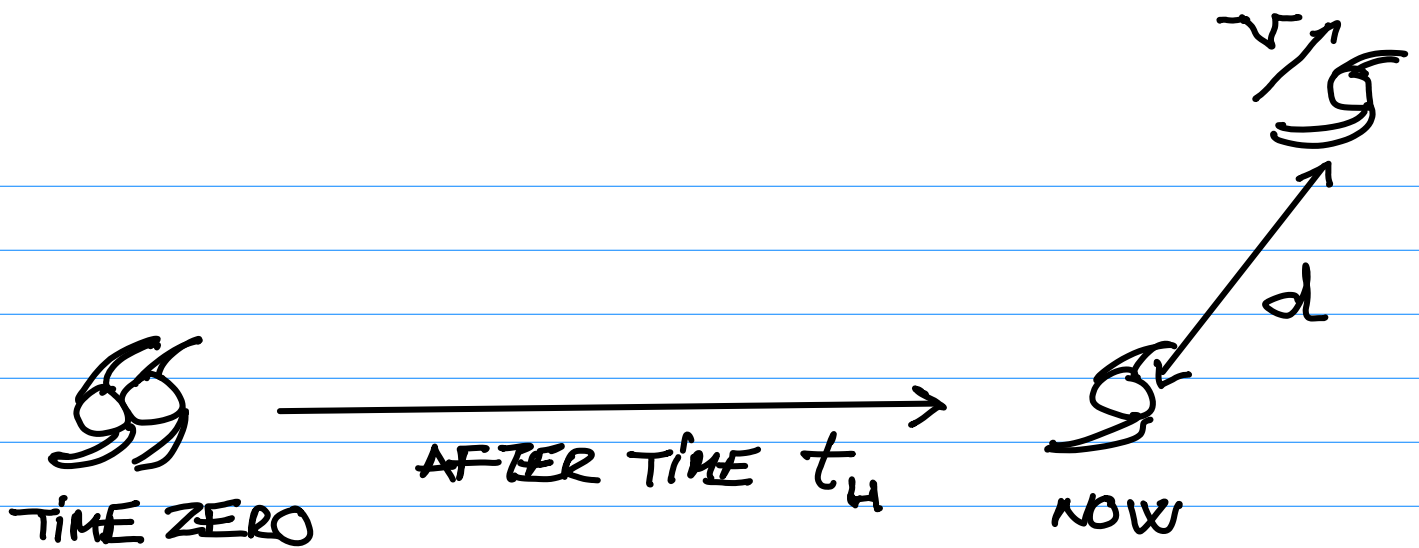
ANALOGY: A VIEW FROM DEEP WITHIN  
A FOREST





PLAUSIBLE RESOLUTION (EDGAR ALLAN POE, 1849):  
THE UNIVERSE IS NOT INFINITELY OLD AND THE  
LIGHT FROM DISTANT STARS DIDN'T HAVE  
TIME TO REACH US YET.

BIG BANG THEORY: THE UNIVERSE  
(INCLUDING SPACE & TIME) WAS CREATED  
IN A GIANT EXPLOSION AND HAS BEEN  
EXPANDING EVER SINCE. THE HUBBLE'S  
LAW IS CONSISTENT WITH THIS SCENARIO.  
HOW OLD IS THE UNIVERSE BASED  
ON HUBBLE'S LAW (SO-CALLED HUBBLE'S  
TIME)?



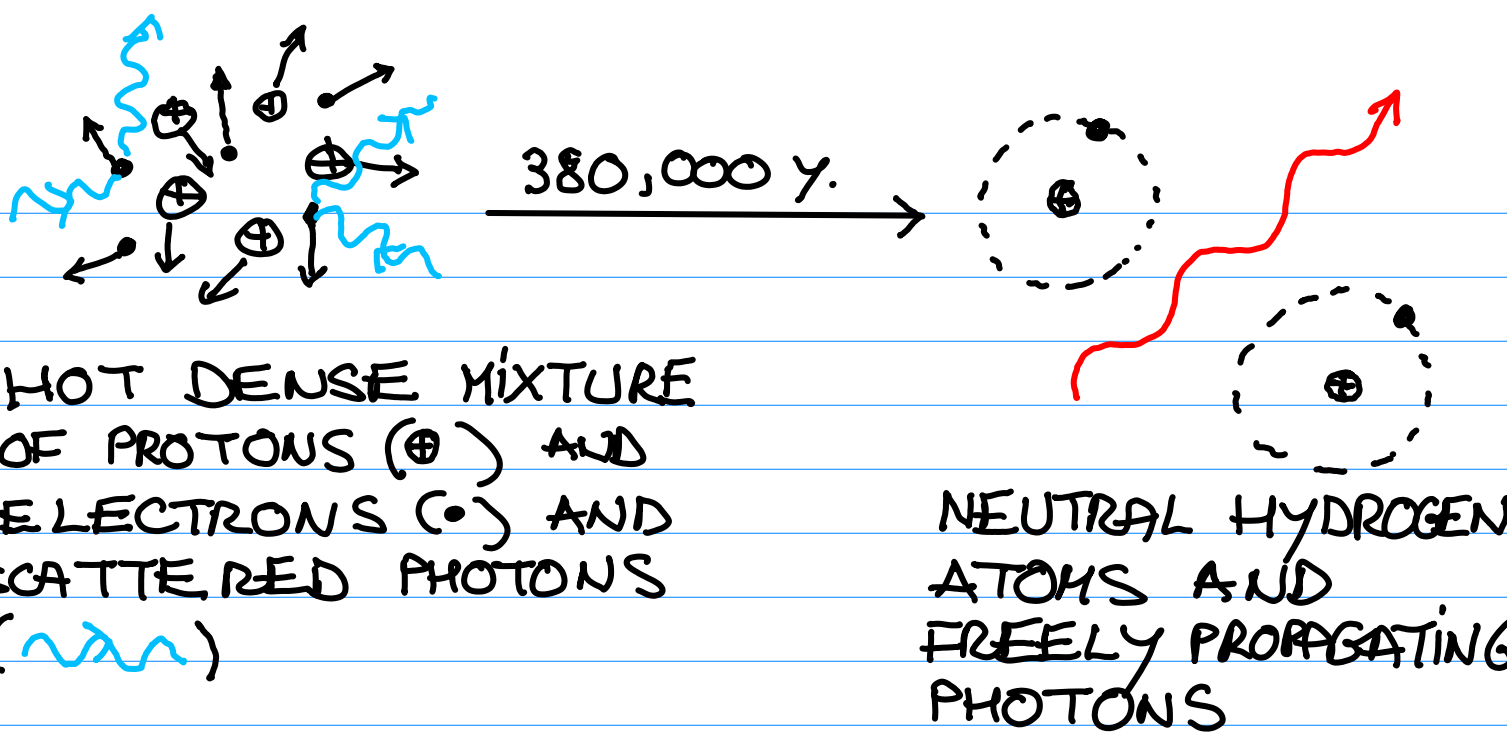
$$\begin{aligned}
 d &= V t_H \\
 V &= H d
 \end{aligned}
 \left. \vphantom{\begin{aligned} d &= V t_H \\ V &= H d \end{aligned}} \right\} \Rightarrow d = H d t_H$$

HUBBLE'S TIME  $\rightarrow t_H = \frac{1}{H} \approx 13.7$  BILLION YEARS

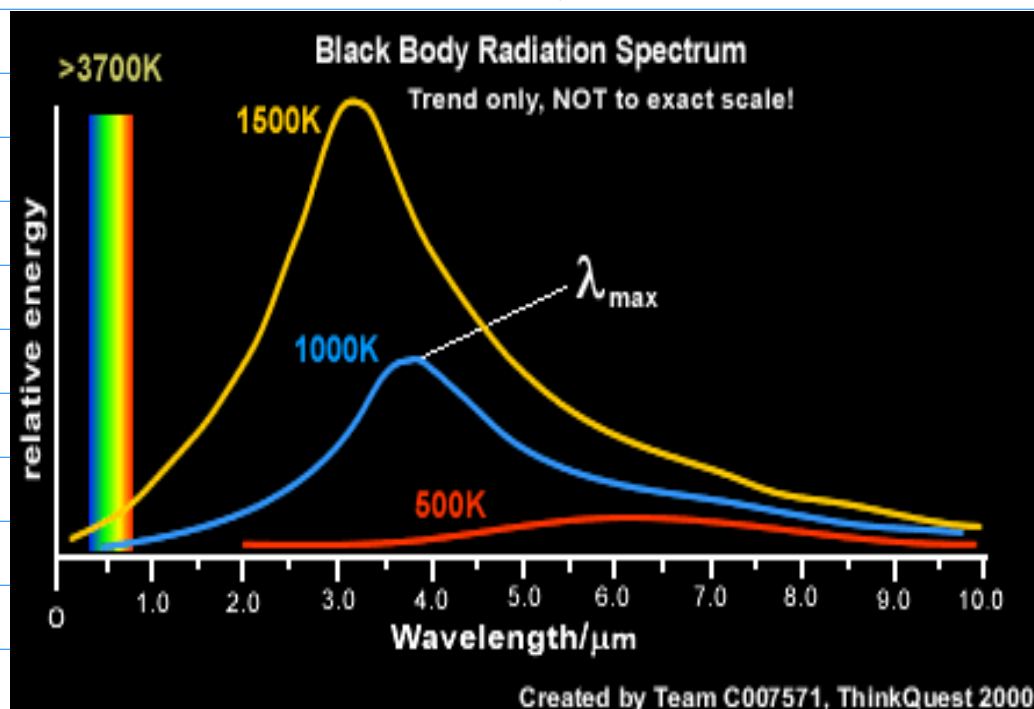
WHAT IS THE EVIDENCE FOR THE BIG BANG?

RIGHT AFTER THE EXPLOSION THE UNIVERSE HAD TO BE VERY HOT AND DENSE, BUT IT COOLED AS IT EXPANDED.

WHEN THE TEMPERATURE DROPPED TO ABOUT 3000 K, ABOUT 380,000 YEARS AFTER THE BIG BANG, IT WAS POSSIBLE FOR PROTONS TO CAPTURE ELECTRONS AND FORM NEUTRAL HYDROGEN ATOMS:



THE UNIVERSE BECAME TRANSPARENT TO LIGHT. THE RADIATION WAS IN EQUILIBRIUM WITH MATTER AT 3,000 K AND THUS SATISFIED THE WIEN'S LAW (BLACK BODY RADIATION LAW):



$$\lambda_{max} = \frac{3 \times 10^6}{T} \quad \text{OR} \quad T = \frac{3 \times 10^6}{\lambda_{max}}$$

For  $T = 3,000 \text{ K}$   $\lambda_{\text{max}} = 1,000 \text{ nm}$

SINCE THEN THE UNIVERSE EXPANDED IN SIZE 1000 TIMES AND THE COSMOLOGICAL REDSHIFT INCREASED  $\lambda_{\text{max}}$  TO  $10^6 \text{ nm} = 10^{-3} \text{ m} = 1 \text{ mm}$  WHICH  
 $10^{-9} \text{ m}$

IS IN MICROWAVE RANGE AND THE CORRESPONDING TEMPERATURE IS ABOUT  $3000 \text{ K} / 1000 = 3 \text{ K}$ . THIS RELIC RADIATION, SO-CALLED MICROWAVE BACKGROUND RADIATION, SHOULD BE OBSERVABLE IN ALL DIRECTIONS, DAY AND NIGHT.

IT WAS FIRST OBSERVED IN 1964 BY ARNO PENZIAS AND ROBERT WILSON OF BELL LABS. SINCE THEN, SEVERAL SATELLITE MISSIONS WERE PERFORMED TO EXAMINE THE DETAILS OF THE MICROWAVE BACKGROUND RADIATION



