

# Astro 13 Galaxies & Cosmology

## LECTURE 10    Thurs 30 April 2009    D. Koo

- 10m    I    Ask An Astronomer Period
- 10m    II    Go over HW#2
- 30m    III    finish Evolution of Geometry of Universe
- 10m    IV    Break
- 25m    V    INFLATION
- 20m    VI    Early Universe: Overview, Evolution
- PICKUP: HW#2; HW#2 answers on web
- NOTE:    MID-TERM EXAM one week away
- NOTE!! HW#3 Due NEXT CLASS - *no late accepted*

# INFLATION

Alan Guth 1980 --- VERY RECENT DISCOVERY

## **What is Inflation?**

Explosive expansion of space about  $10^{-35}$  s after the Big Bang.

## **How Rapid was the Expansion?**

Universe doubled in size about every  $10^{-34}$  sec, so that after 100 doublings, the U was still only  $10^{-32}$  s young.

## **How Much Bigger was the U after Inflation?**

U grew by a factor of  $10^{50}$  with Inflation, versus a much more modest or normal factor of only  $10^{27}$  w/o Inflation.

## What Started Inflation?

U had energy stored in its vacuum during its “supercooled” state. This “FALSE VACUUM” acted like pressure and expanded the Universe.

## What is “Supercooled” State?

Temporary situation where energy is stored until it is suddenly released. For water, this is the liquid state **below** freezing temperature. Such a liquid can turn in moments of time, to ice and release a lot of energy.

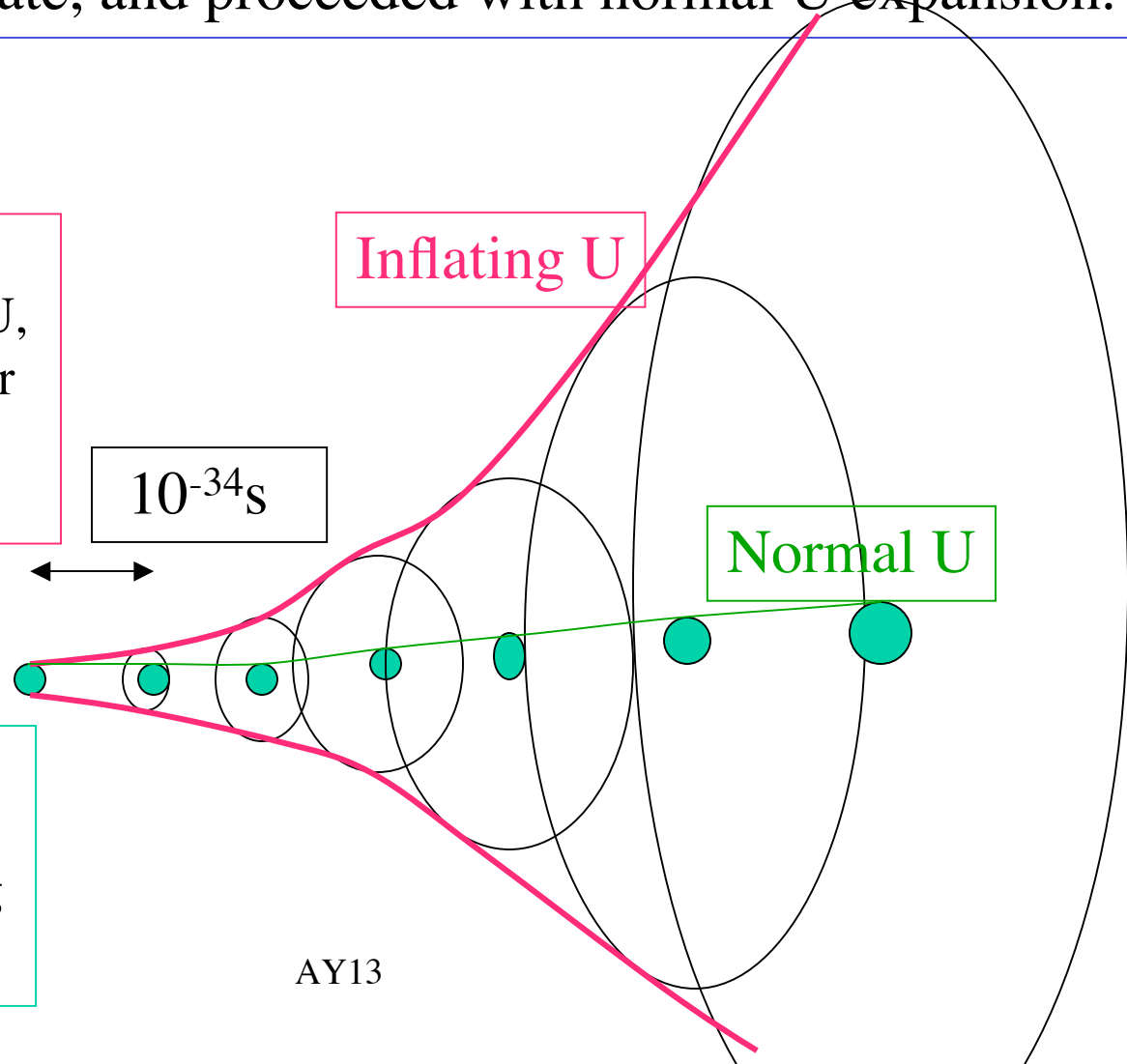
## Why did the U become “Supercooled”?

Current theory that “unifies” the 3 non-gravitational forces (weak, strong, and E&M), called the **Grand Unified theory (GUT)** predicts that the U would naturally be in a supercooled state at about  $10^{-35}$ sec after the Big Bang.

## What Stopped the Inflation?

U released the energy from its “supercooled” state (false vacuum state), created lots of new particles of matter, settled to its True Vacuum state, and proceeded with normal U expansion.

This drawing shows 6 doublings in an inflating U, while theory claims 100 or more doublings in the actual U.



Note that space expands at much much faster than speed of light  $c$  !!! during Inflation.

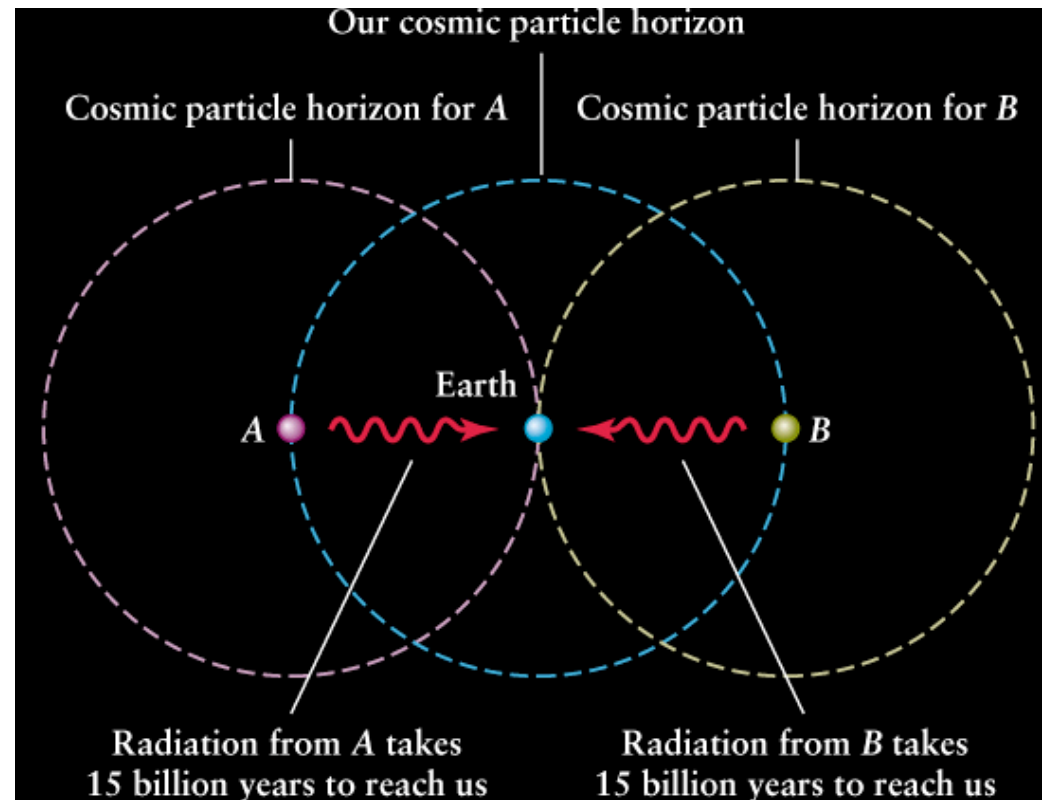
# Why is Inflation so Important in Cosmology?

Not only is Inflation a predicted consequence by one of the most successful theories of physics (GUT). But Inflation also solves several major problems in cosmology, which were previously assumed to part of **U's INITIAL CONDITIONS**, I.e. not understood why:

- HORIZON or ISOTROPY PROBLEM
- FLATNESS PROBLEM
- MONOPOLE PROBLEM

# Horizon Problem

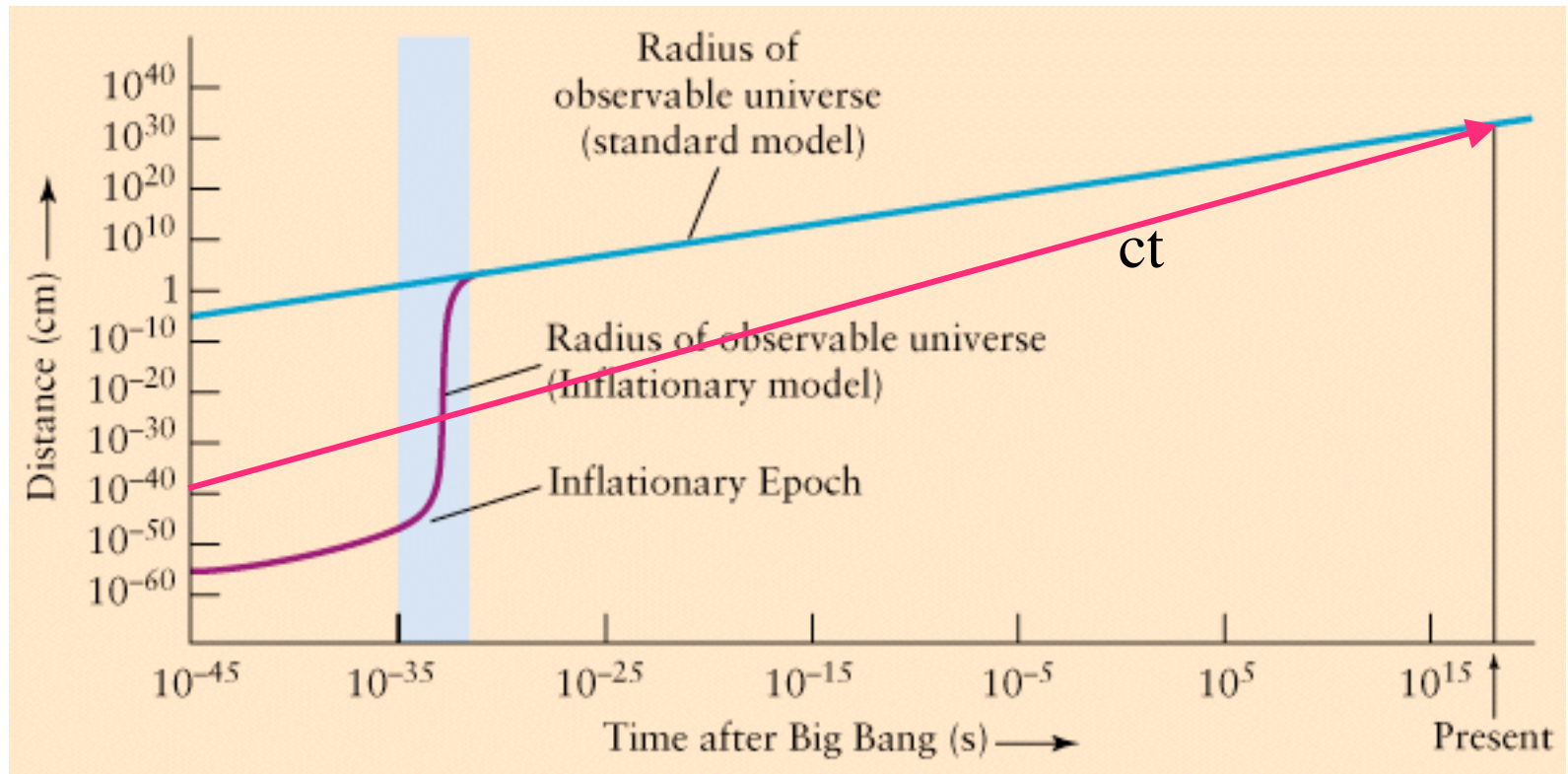
Why is the temperature of the Cosmic Background Radiation so UNIFORM in opposite parts of the sky, which have never been in communication?



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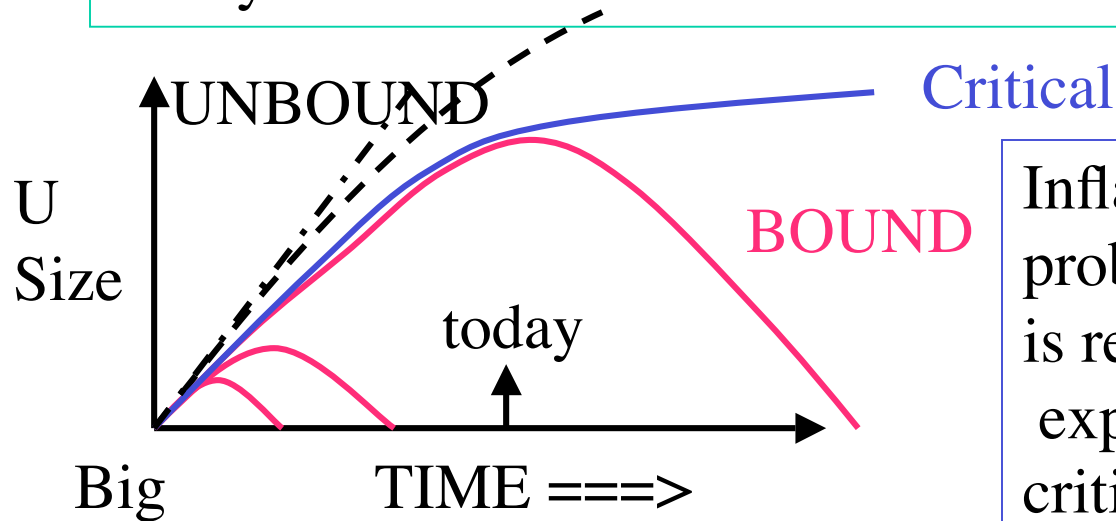
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# INFLATION and Size of Universe

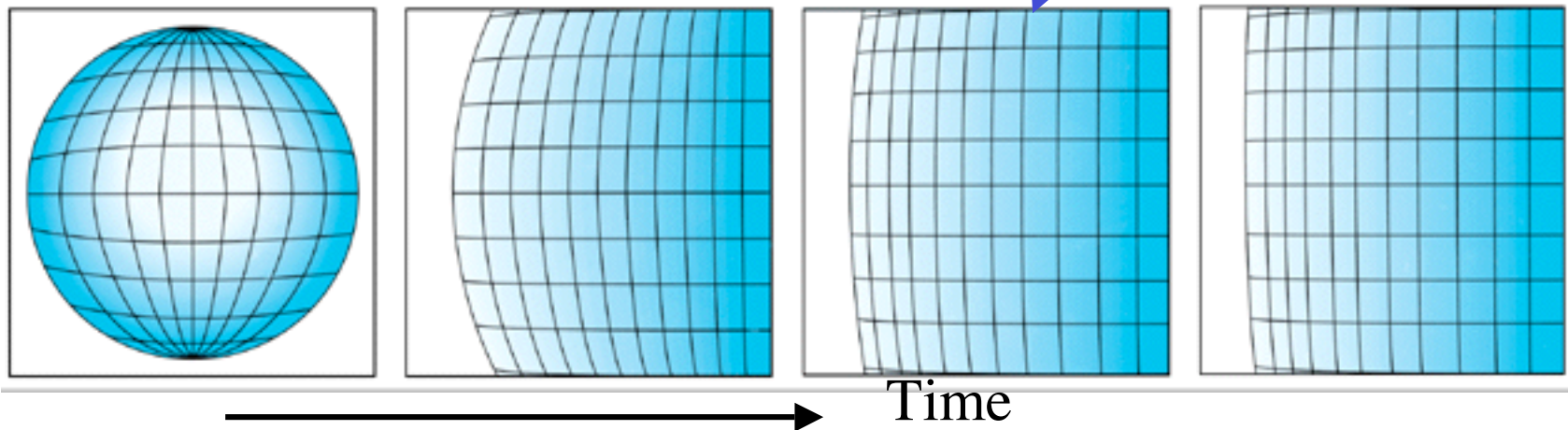


# FLATNESS PROBLEM

Why is our U so close to critical (flat U), rather than one of the many other Bound or Unbound U that are possible in principle.



Inflation naturally solves this problem because the curvature is reduced by the enormous expansion so U is exactly critical if no  $\Lambda$ .



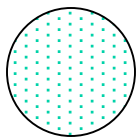
# MONOPOLE PROBLEM

Grand Unified Theories (GUTs) predict huge numbers of monopoles in the U created moments after the Big Bang. Yet they are not observed...why?

**Problem is resolved by Inflation:**

During Inflation, huge amount of space is created for any given number of Monopoles, so we expect only ONE monopole in the entire observable U.

Before Inflation

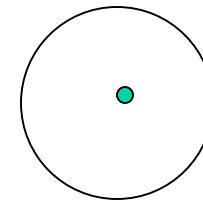


Large Density of Monopoles

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After Inflation

One monopole



Observable U today

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# Different Inflation Models

## 1) **OLD or ORIGINAL Inflation Model**

Who: Alan Guth 1980      When:  $10^{-35}$ s to  $10^{-32}$ s (GUT period)

How Much Expansion:  $\sim 10^{50}$

Problem: difficult to get U to inflate coherently

## 2) **NEW Inflation Model**

Who: A. Linde, A. Albrecht, P. Steinhardt ~1982

When:  $10^{-43}$ s to  $10^{-35}$  (Planck to GUT Period)

How Much:  $10^{1000}$

## 3) **Chaotic Inflation Model**

Who: A. Linde ~1983      When: **All the TIME ==>  $\infty$  of U!!!**

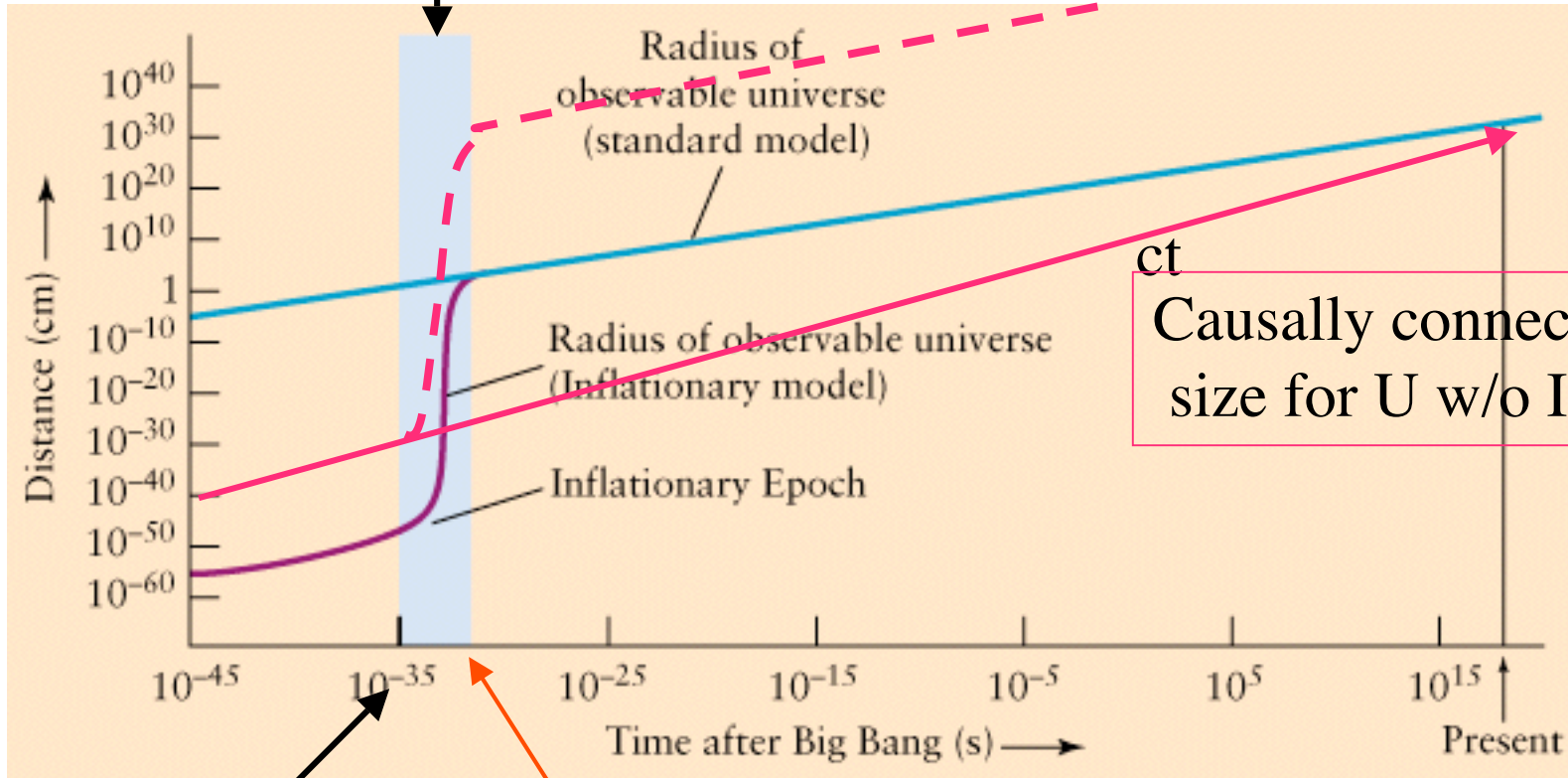
How Much:  $10^{10,000,000}$

Comment: No beginning or end of U creation. Different U have Different properties but only those that support life are observable--  
Anthropic Cosmological Principle

# OLD INFLATION

Inflation Period

Causally connected size for U w Inflation



Causally connected size for U w/o Infl.

Phase transition  
From GUT

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U has settled to True Vacuum from False Vacuum

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