The Physics of the Very Early Universe

— Alan Guth

Massachusetts Institute of Technology

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INFLATION (the standard model)

- Inflation is an add-on to the conventional big bang — modifies the first (perhaps) 10^{-35} sec of the conventional history.
- Provides the $\boxed{\textbf{BANG}}$ of the big bang — driving force behind expansion.
- Bang = repulsive gravity.
- Repulsive gravity is caused by negative pressure, which in turn can be caused by the potential energy of a scalar field.

Successes of Inflation

INFLATION: The proposal that the early universe went through a phase of nearly exponential expansion, driven by the repulsive gravity caused by a negative pressure. (Negative pressure can arise from the potential energy of a scalar field.)

1) The universe is big— about 10^{90} particles!

2) Hubble expansion— what was the repulsive driving force?

3) Homogeneity and isotropy— in the conventional big bang (without inflation), cosmic microwave background uniformity requires communication ~ 100 times speed of light.

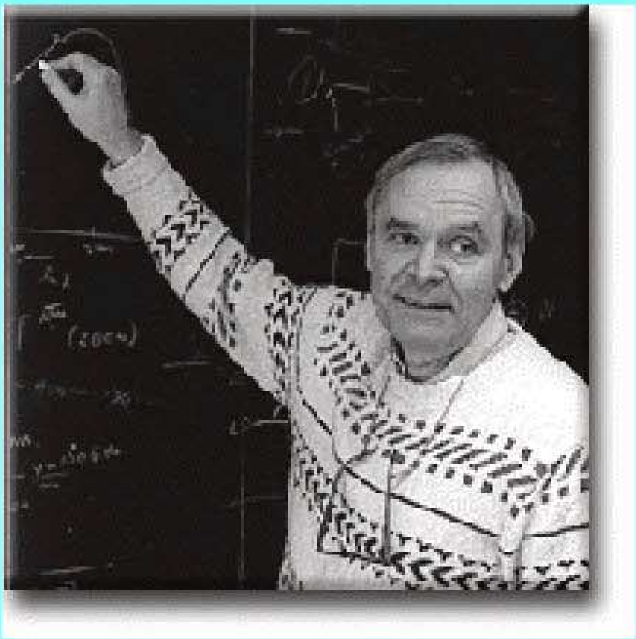
4) Flatness Problem — why was the mass density at $t = 1$ sec equal to the critical density to 15 decimal places?

5) Why no magnetic monopoles?

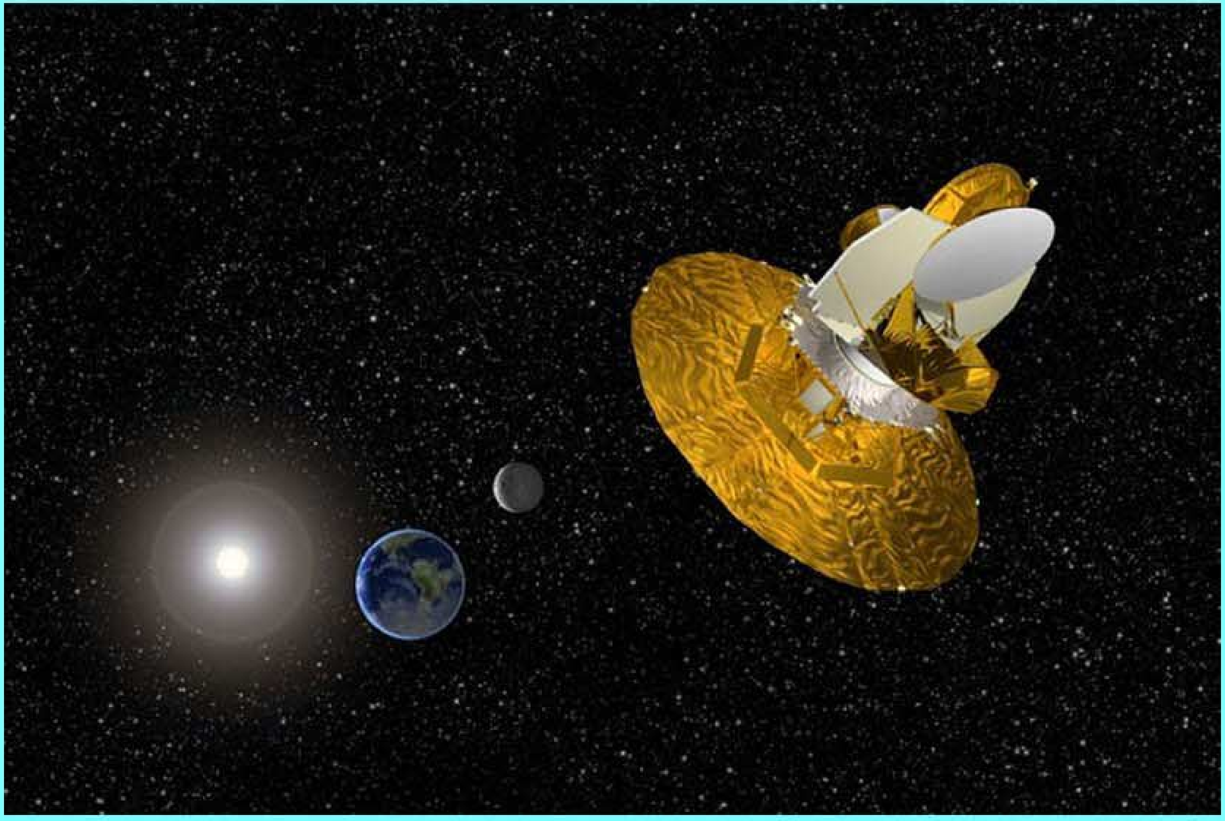
6) Nearly scale invariant, adiabatic, Gaussian density perturbations.

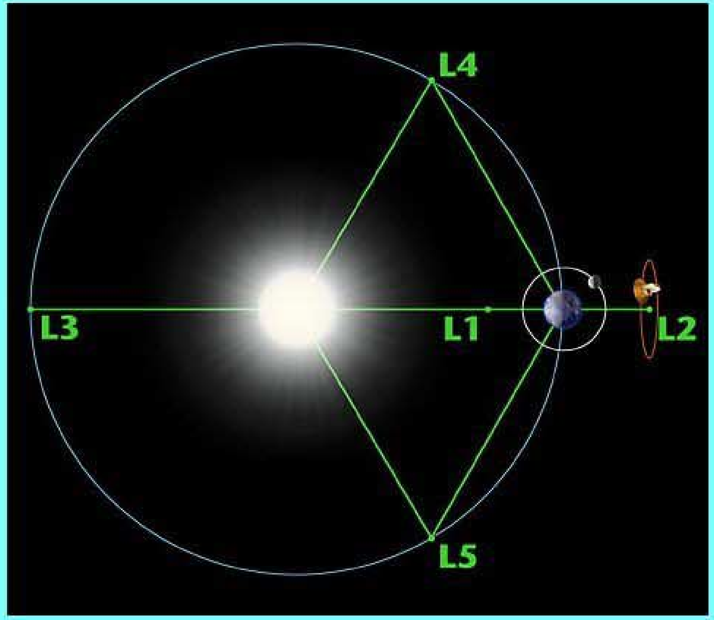
WMAP: Wilkinson Microwave Anisotropy Probe

Images courtesy of NASA/WMAP Science Team



David T. Wilkinson





WMAP Power Spectrum

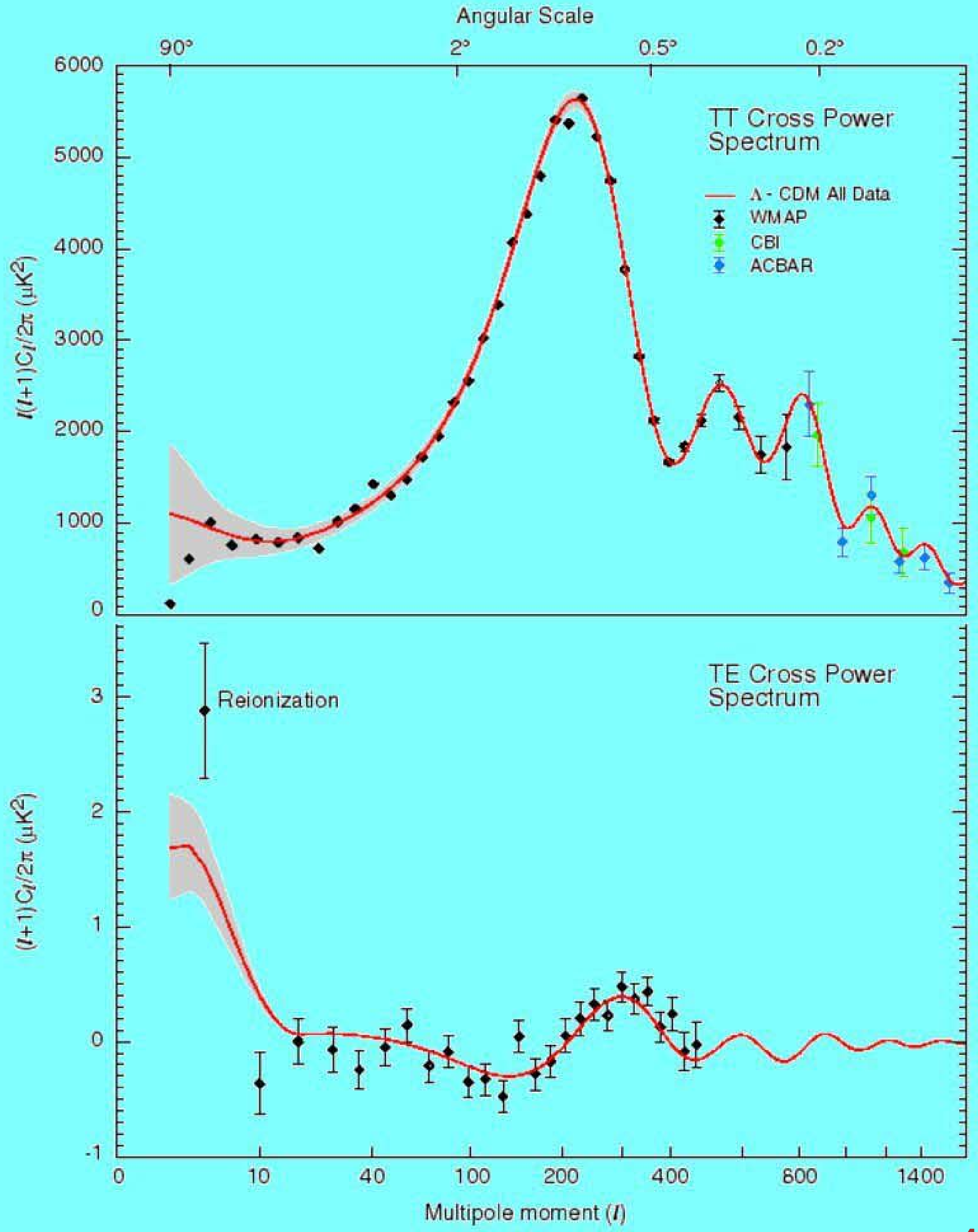
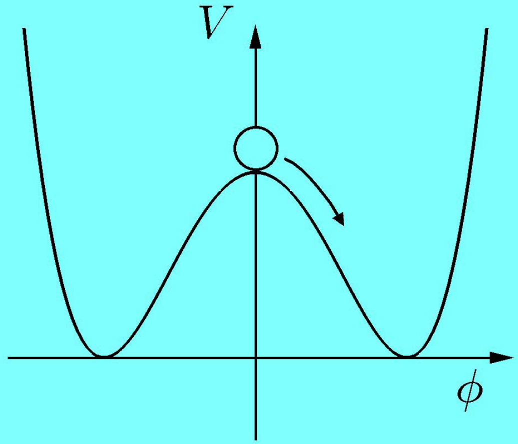


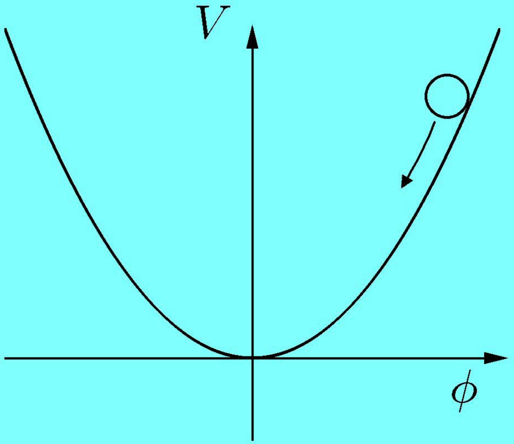
Image courtesy of NASA/WMAP Science Team

Inflation is (future) Eternal

Essentially all known inflationary models are eternal — once inflation starts it ***never*** stops.



New (Small Field) Inflation



Chaotic (Large Field) Inflation

1) Classically, inflating state is unstable.
2) Quantum mechanically, there is always a tail of the wave function describing possibility that inflation continues.
3) Rate of inflation $\gg$ rate of decay of the wave function tail.

$\therefore$ Volume of inflating region increases with time!

Inflation in String Theory

Pre - Big Bang Inflation — Veneziano and Gasperini, 1992.

Brane Inflation — Dvali and Tye, 1998.

Brane Inflation with warped compactifications — KKLMMT (Kachru, Kallosh, Linde, Maldacena, McAllister, & Trivedi), 2003: "Our arguments show that if the functional form of the superpotential is generic then inflation does not occur. Nevertheless, it seems quite likely, given the range of available fluxes and background geometries, that cases exist which are sufficiently non-generic to permit inflation."

Unanswered Questions

1) In the underlying quantum (string) theory, are degrees of freedom created as the universe expands without limit? Is the number infinite from the start? Is "degree of freedom" an ill-defined phrase?

2) Can inflation help to save the predictive power of string theory? I.e., is it possible that inflation favors a small subset of the $\sim 10^{1000}$ vacua of string theory?

3) How can one calculate probabilities in eternal inflation? The probability of anything is ∞/∞. Attempts at regularization lead to ambiguities.

4) How did it all begin?? Inflation is eternal into the future, but it appears that it still needs a beginning. One can prove that any backward-going timelike or null geodesic for the which the average expansion rate is positive must have finite length.

The Bottom Line

- Never have we had a model for the early universe that worked so well, in terms of fitting observations.

- But we are just as clueless as ever about how to describe the universe in terms of fundamental physics.