

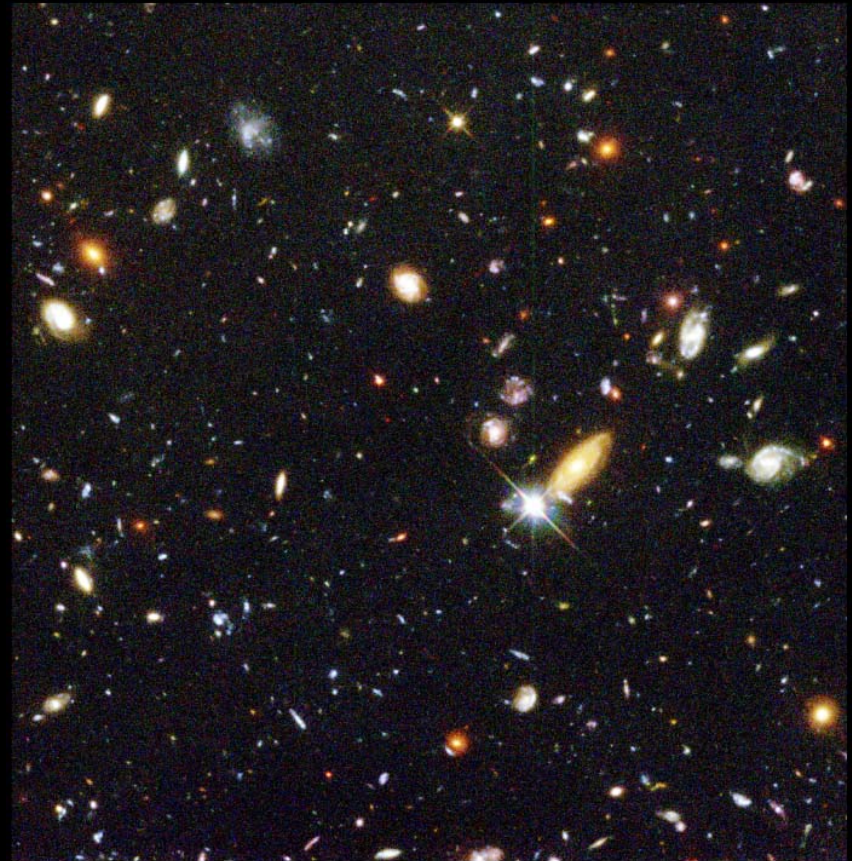
Hubble Vision

Dr Martin Hendry
Dept of Physics and Astronomy
University of Glasgow



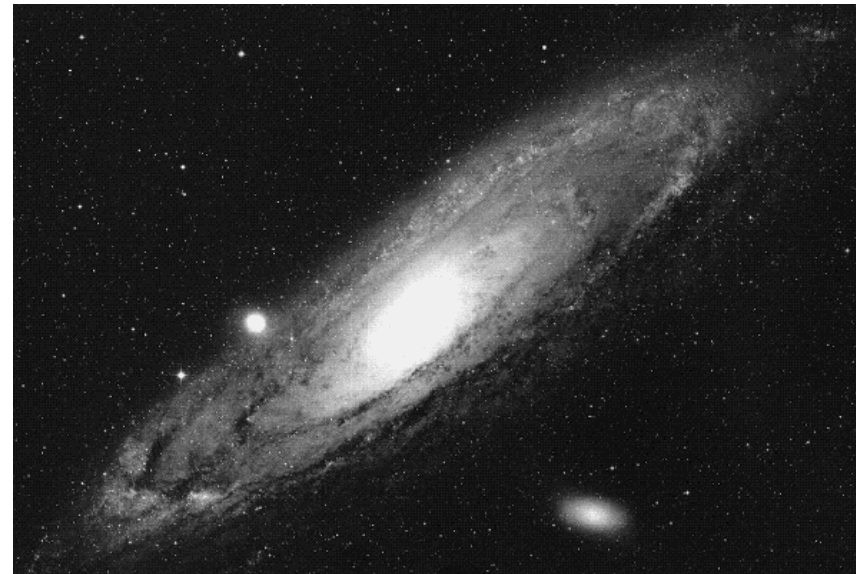
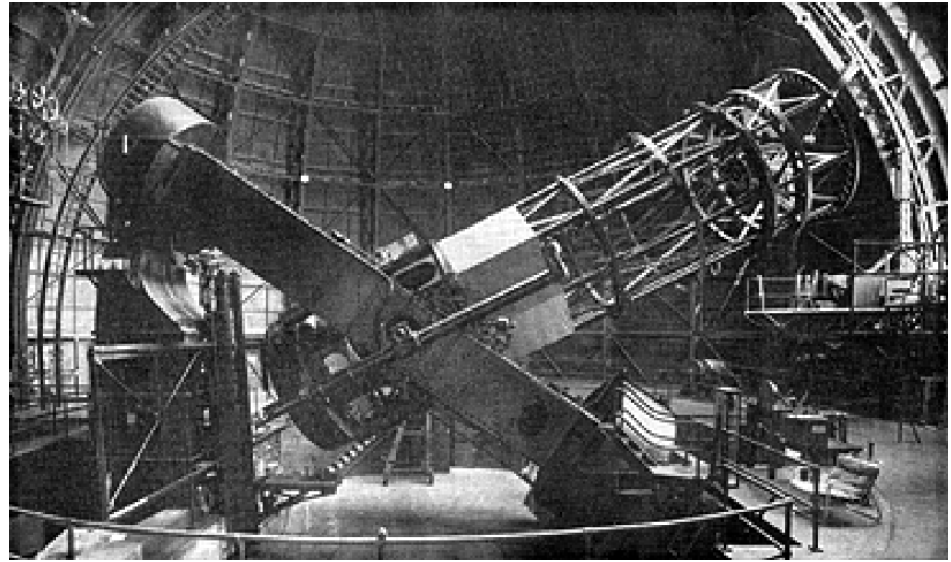
Cosmology - the study of the Universe as a whole:

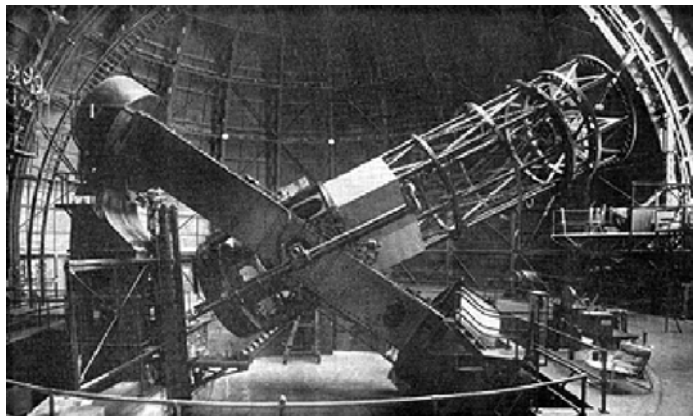
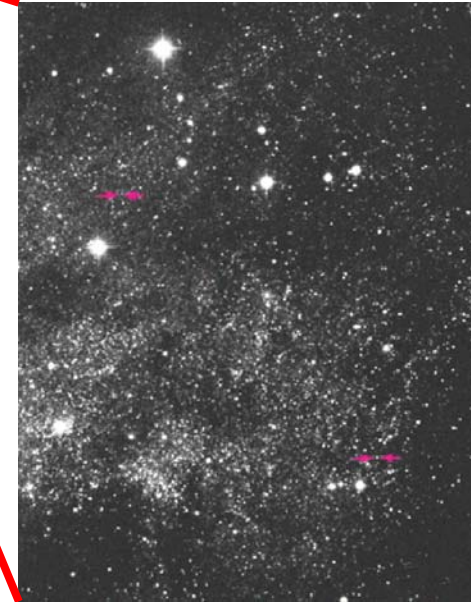
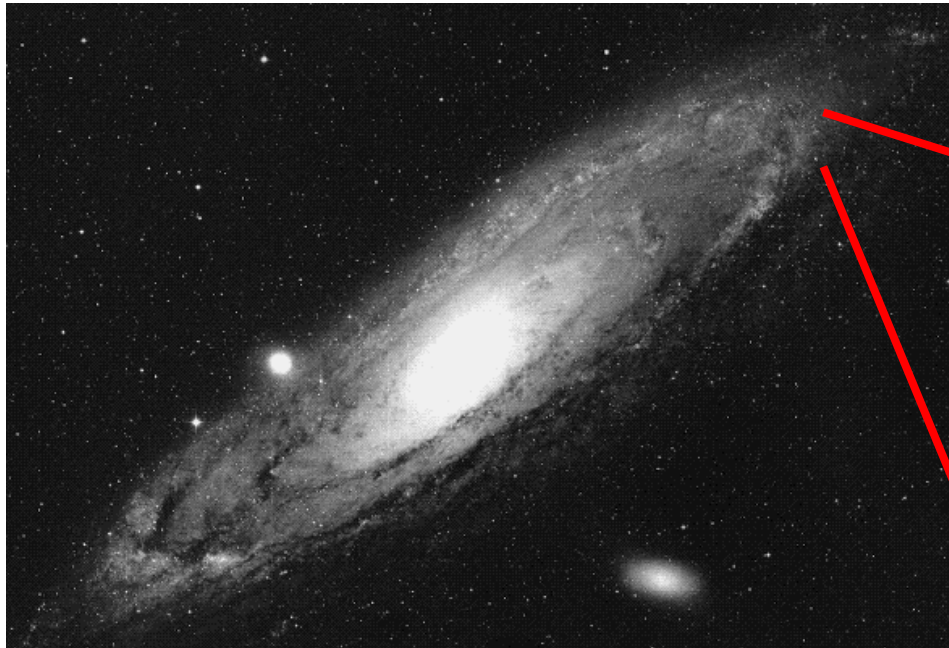
- Origin
- Evolution
- Eventual Fate



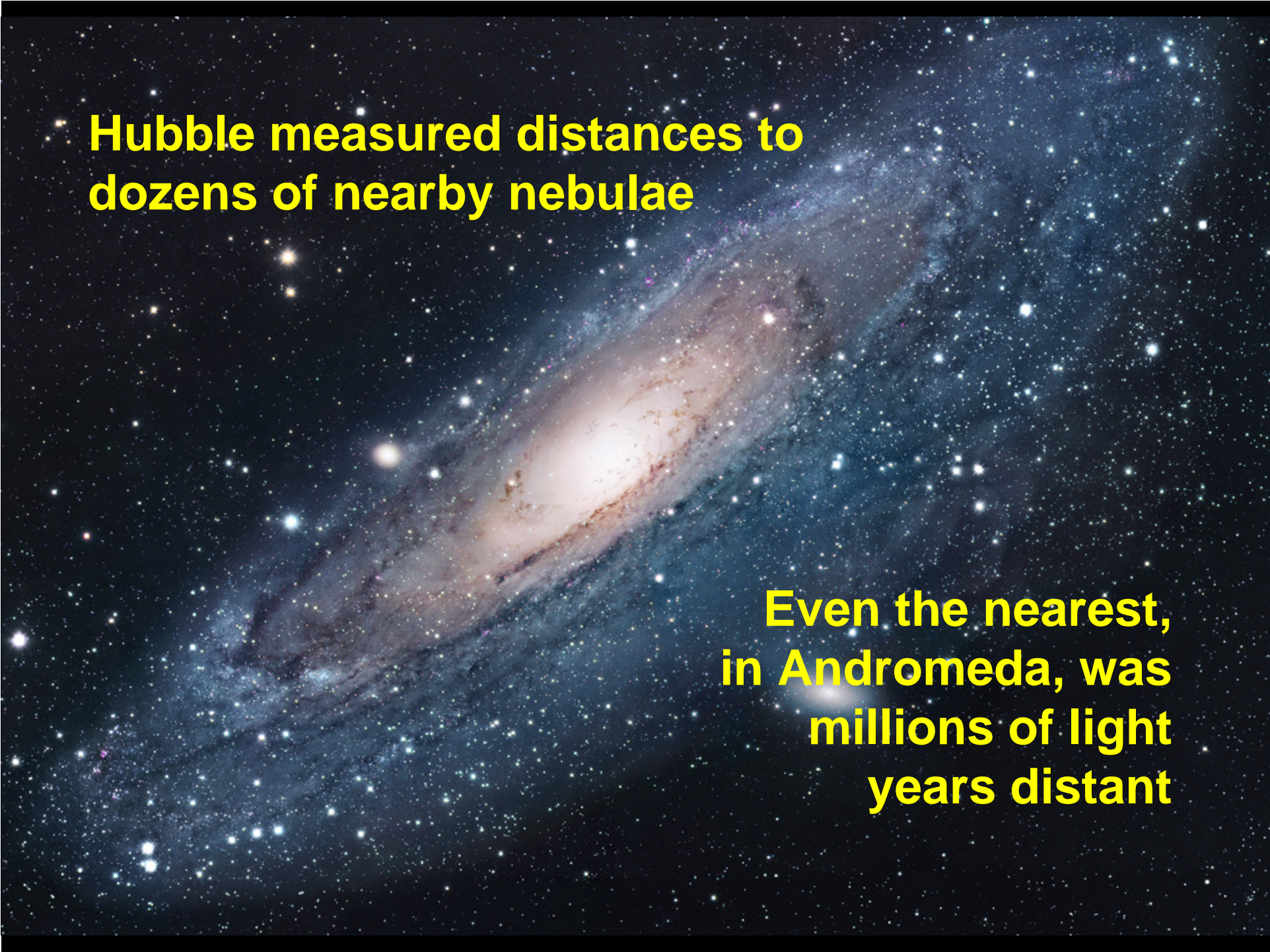


Edwin Hubble





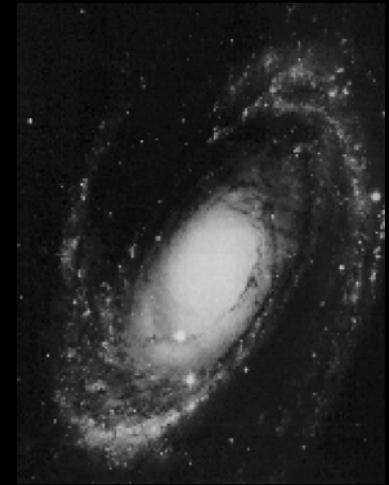
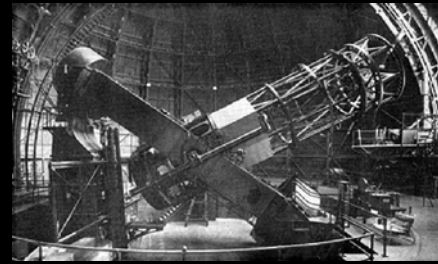
**1922: Hubble finds
Cepheids in the Great
Nebula in Andromeda**



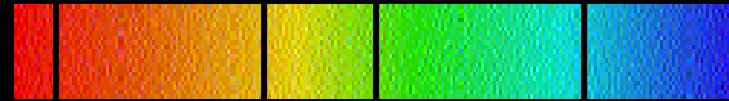
**Hubble measured distances to
dozens of nearby nebulae**

**Even the nearest,
in Andromeda, was
millions of light
years distant**

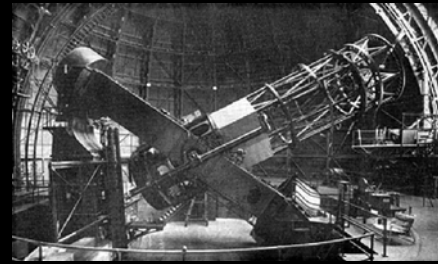
Hubble also measured
the shift in colour, or
wavelength, of the light
from distant galaxies.



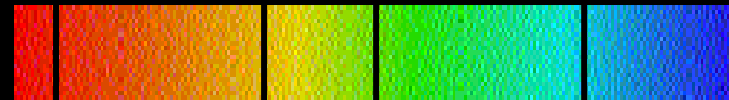
Galaxy



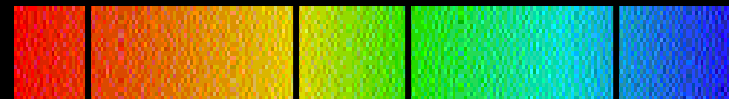
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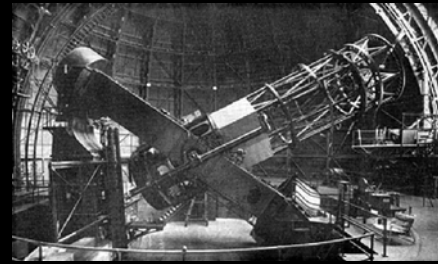
Galaxy



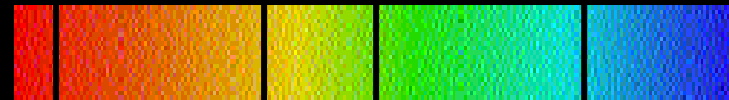
Laboratory



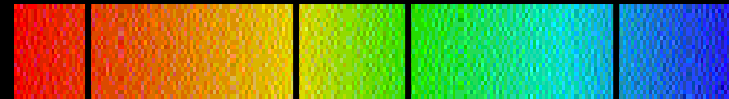
Hubble also measured the shift in colour, or *wavelength*, of the light from distant galaxies.



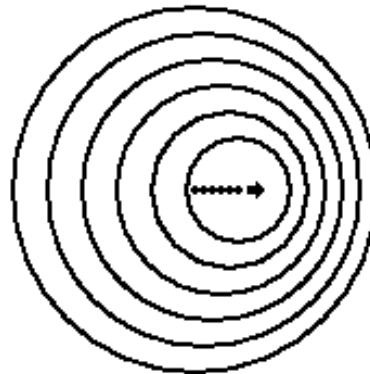
Galaxy



Laboratory



OBJECT RECEDING:
LONG RED WAVES



OBJECT APPROACHING:
SHORT BLUE WAVES



Hubble's Law

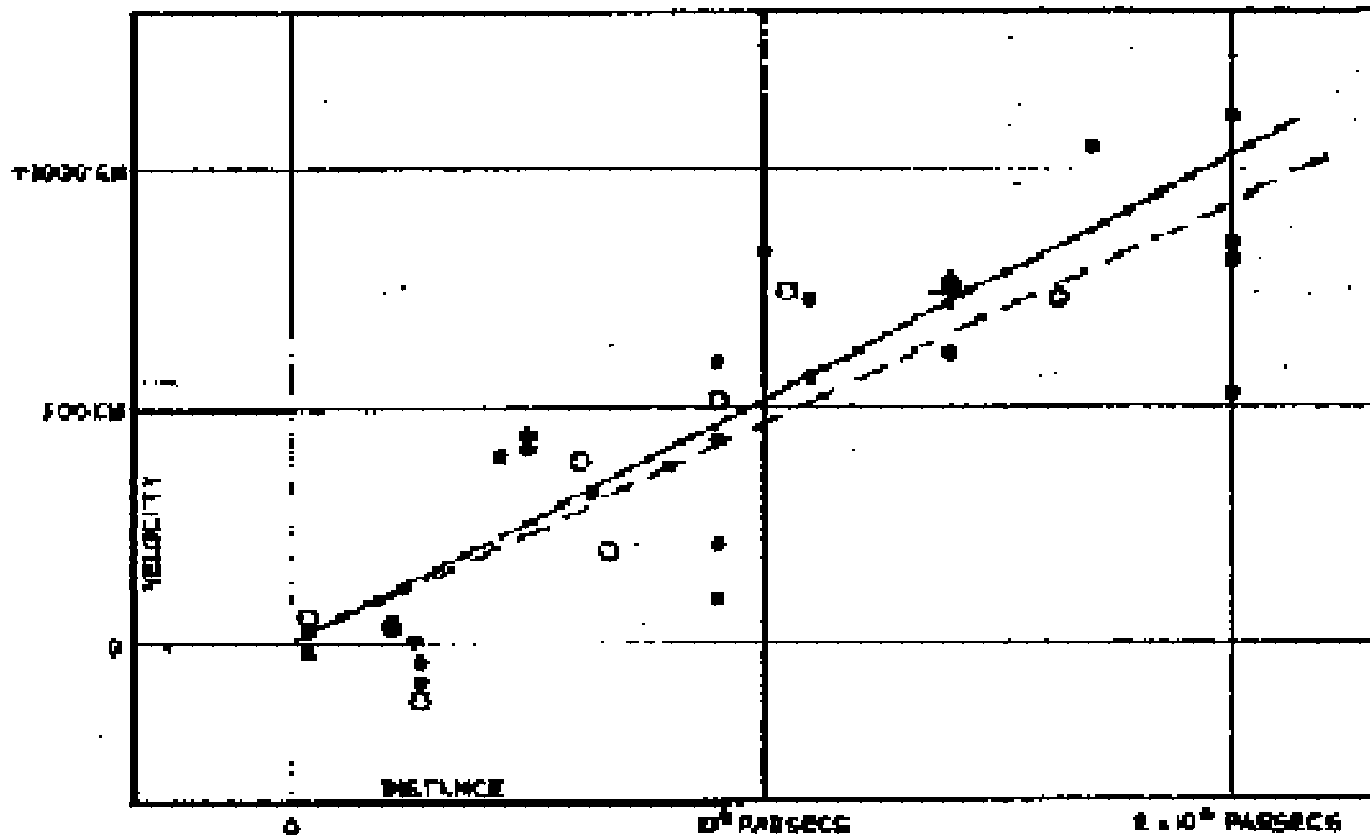
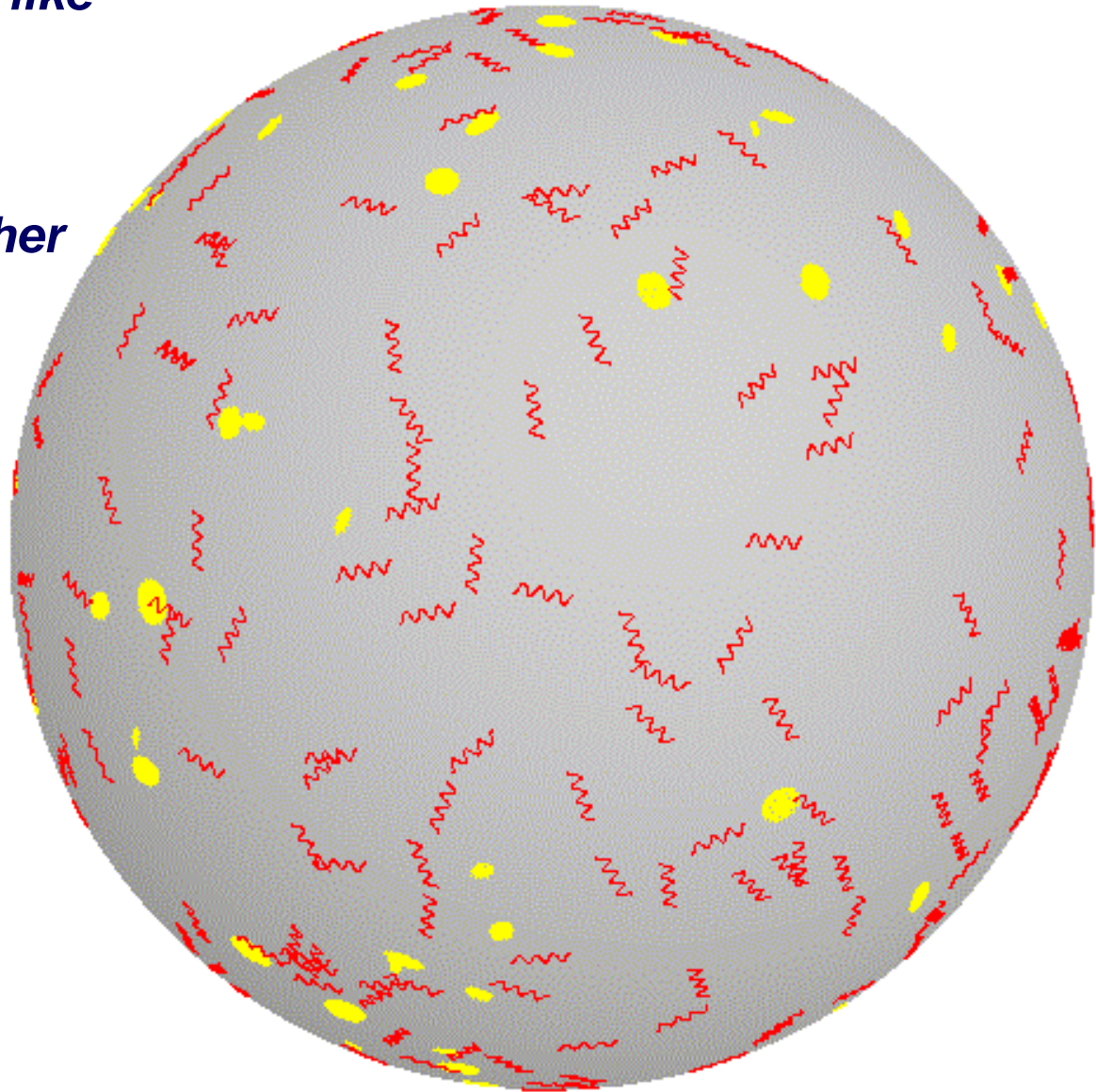
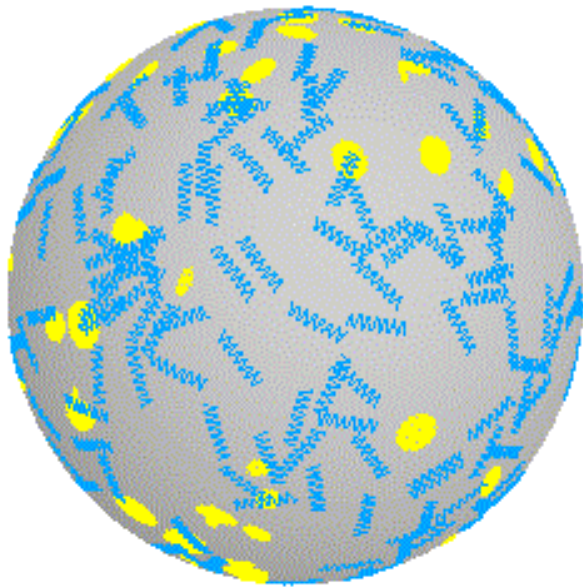


FIGURE 1

Distant galaxies are moving away from us with a speed proportional to their distance

***Spacetime is expanding like
the surface of a balloon.***

***As the balloon expands,
galaxies are carried farther
apart***





1916.

Nr. 7.

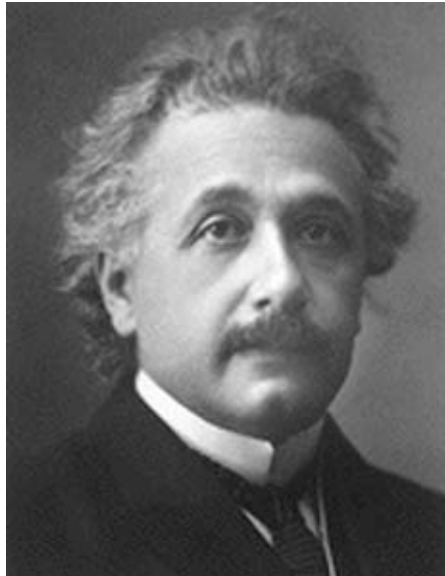
ANNALEN DER PHYSIK.

VIERTE FOLGE. BAND 49.

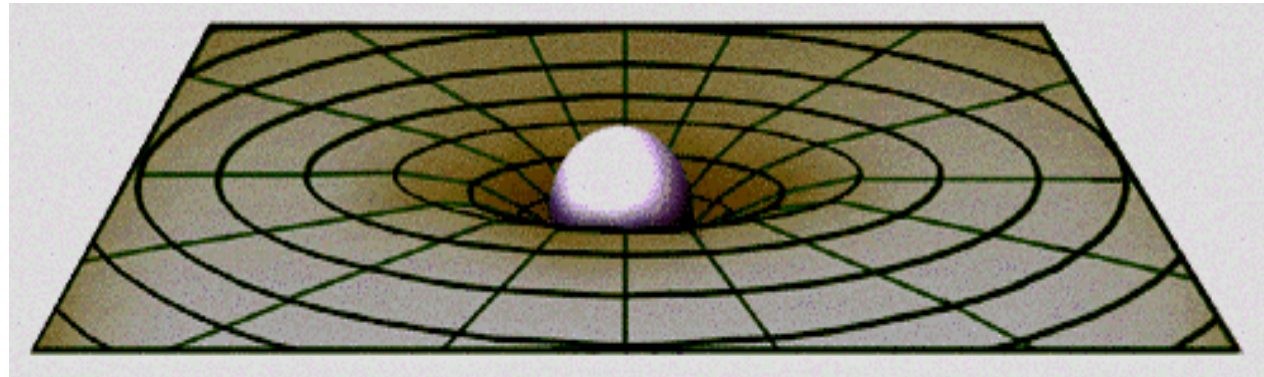
1. Die Grundlage der allgemeinen Relativitätstheorie; von A. Einstein.

Die im nachfolgenden dargelegte Theorie bildet die denkbar weitgehendste Verallgemeinerung der heute allgemein als „Relativitätstheorie“ bezeichneten Theorie; die letztere nenne ich im folgenden zur Unterscheidung von der ersteren „spezielle Relativitätstheorie“ und setze sie als bekannt voraus. Die Verallgemeinerung der Relativitätstheorie wurde sehr erleichtert durch die Gestalt, welche der speziellen Relativitätstheorie durch Minkowski gegeben wurde, welcher Mathematiker zuerst die formale Gleichwertigkeit der räumlichen Koordinaten und der Zeitkoordinate klar erkannte und für den Aufbau der Theorie nutzbar machte. Die für die allgemeine Relativitätstheorie nötigen mathematischen Hilfsmittel lagen fertig bereit in dem „absoluten Differentialkalkül“, welcher auf den Forschungen von Gauss, Riemann und Christoffel über nichteuklidische Mannigfaltigkeiten ruht und von Ricci und Levi-Civita in ein System gebracht und bereits auf Probleme der theoretischen Physik angewendet wurde. Ich habe im Abschnitt B der vorliegenden Abhandlung alle für uns nötigen, bei dem Physiker nicht als bekannt vorauszusetzenden mathematischen Hilfsmittel in möglichst einfacher und durchsichtiger Weise entwickelt, so daß ein Studium mathematischer Literatur für das Verständnis der vorliegenden Abhandlung nicht erforderlich ist. Endlich sei an dieser Stelle dankbar meines Freundes, des Mathematikers Grossmann, gedacht, der mir durch seine Hilfe nicht nur das Studium der einschlägigen mathematischen Literatur ersparte, sondern mich auch beim Suchen nach den Feldgleichungen der Gravitation unterstützte.

Gravity in Einstein's Universe



“Spacetime tells matter
how to move, and
matter tells spacetime
how to curve”

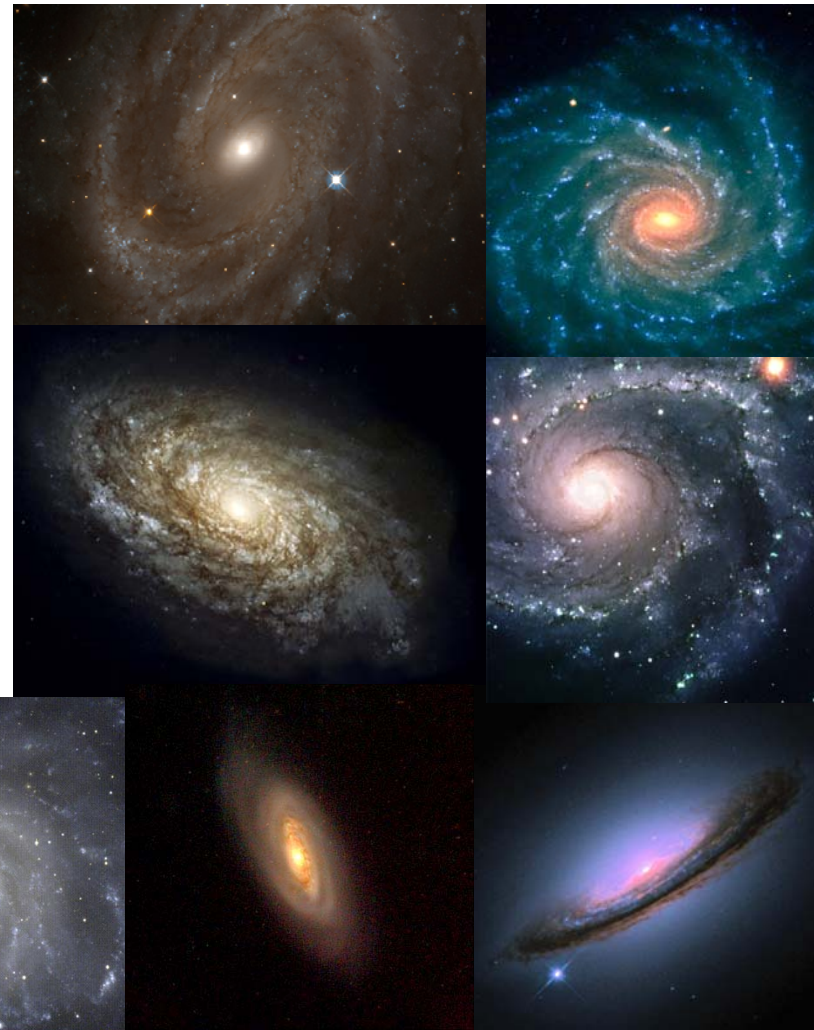


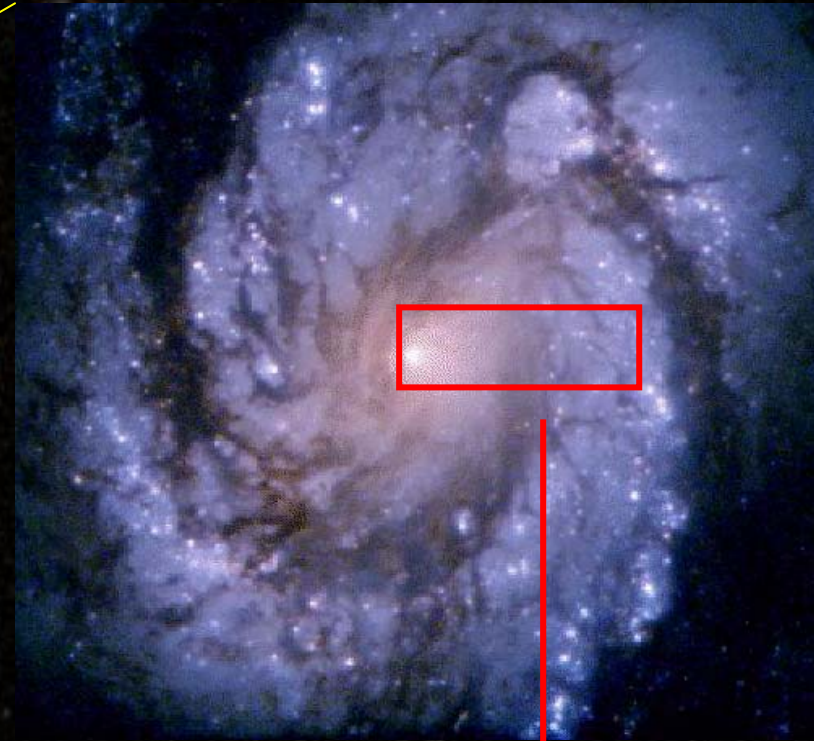
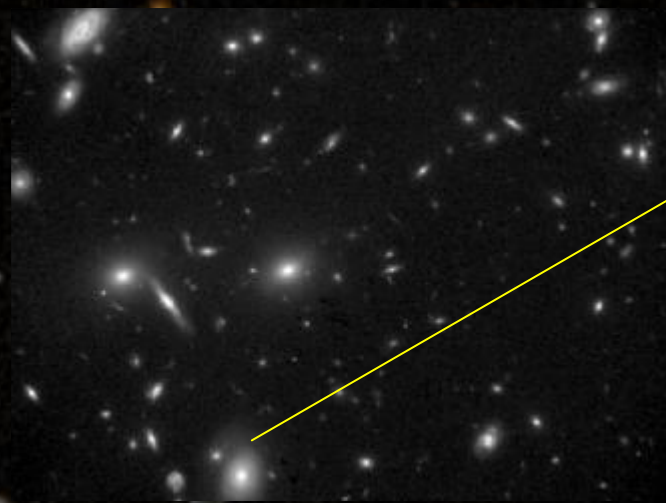
How fast is the Universe expanding?



*Hubble space Telescope
Key Project: 1990-2000*

Cepheid distances to ~30
galaxies, linking to other
standard candles



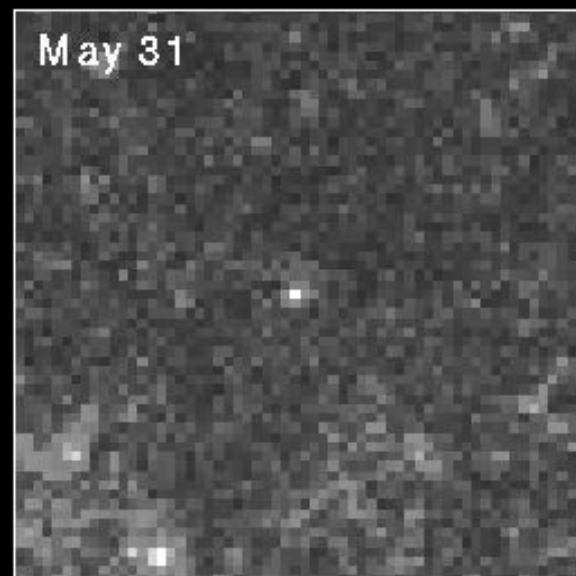
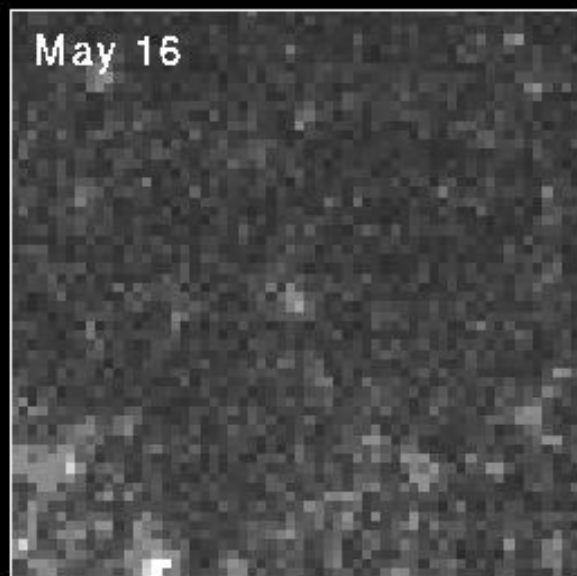
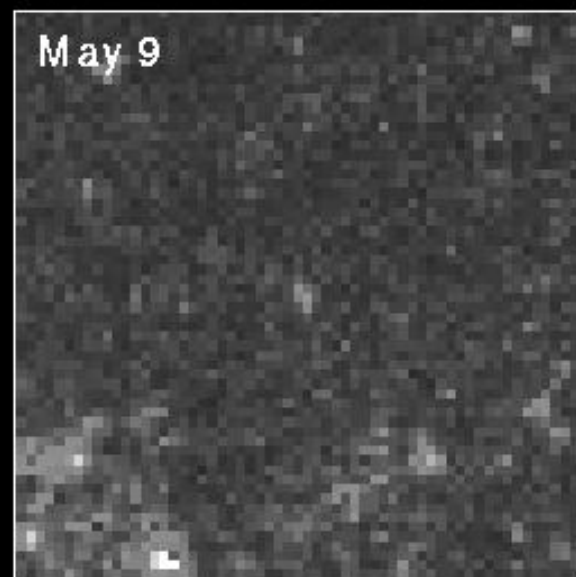
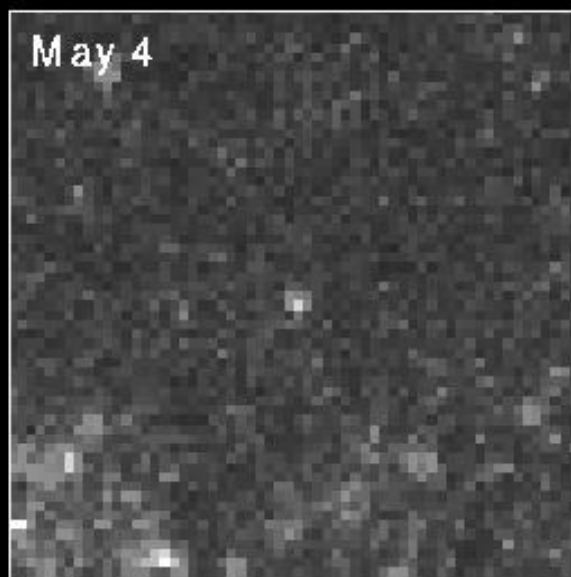


**Virgo Cluster galaxy
M100, 60 million light years distant.....**



Cepheid Variable Star in Galaxy M100

HST-WFPC2

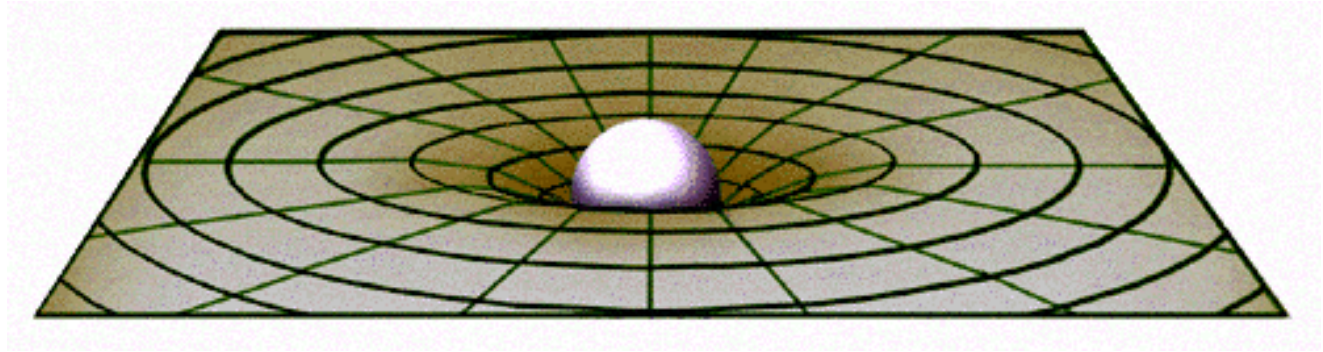


Will the Universe continue to expand forever?

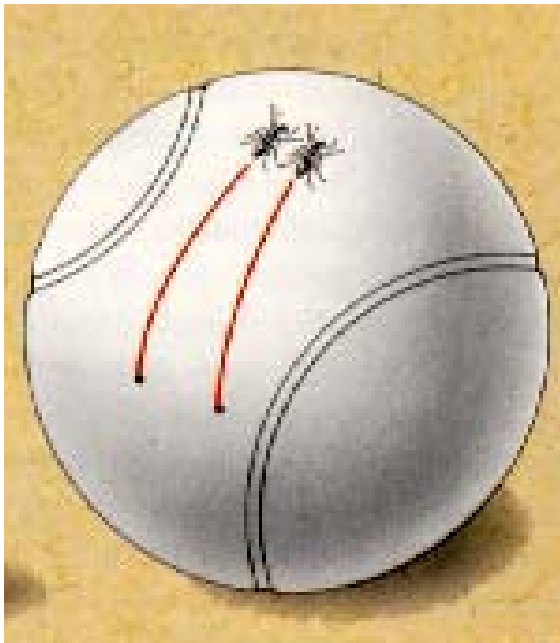
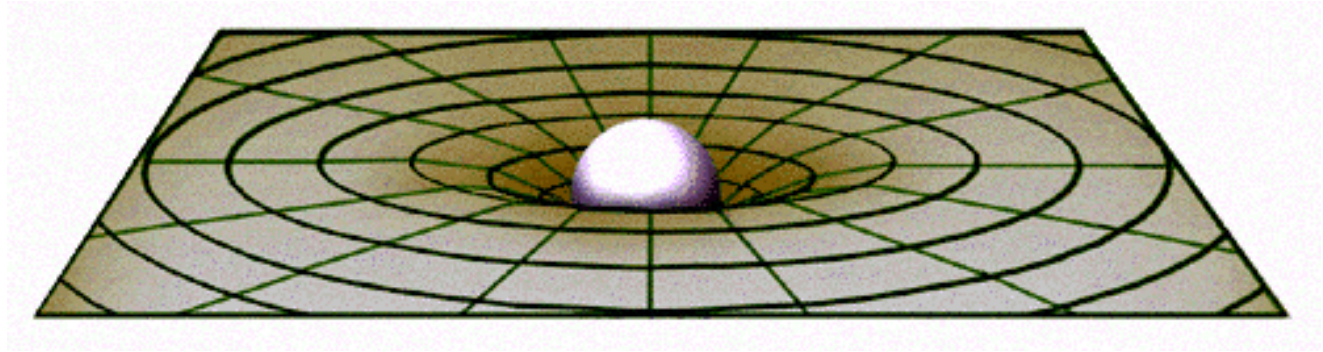
To find out we need to compare the expansion rate now with the expansion rate in the distant past...

Is the Universe speeding up or slowing down?

Answer depends on the shape of the
Universe

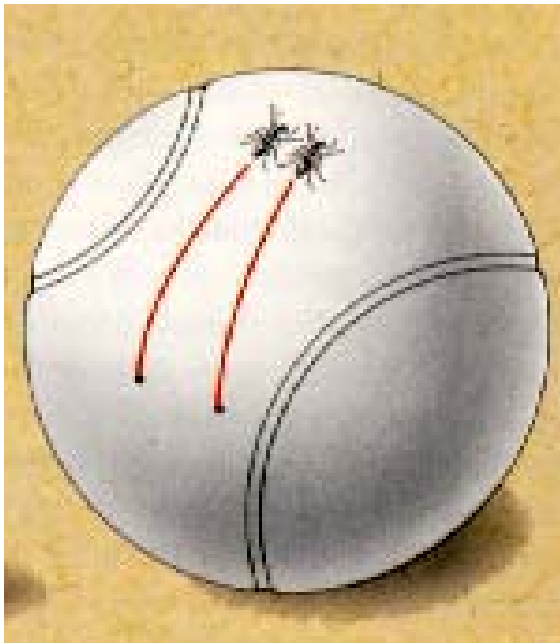
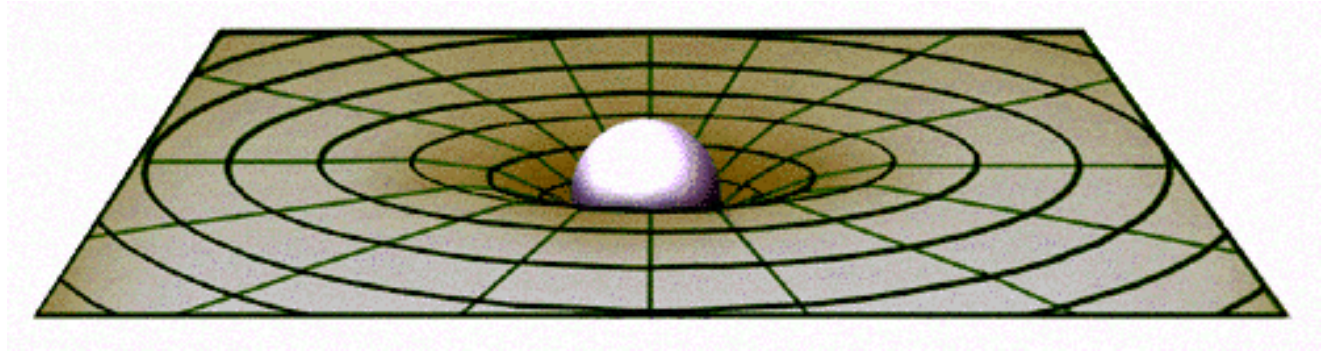


Answer depends on the shape of the Universe

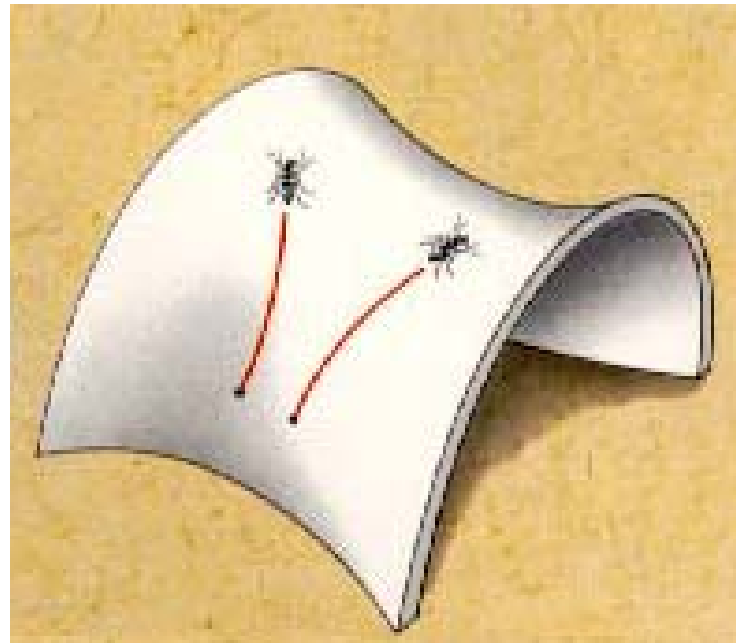


Closed

Answer depends on the shape of the Universe

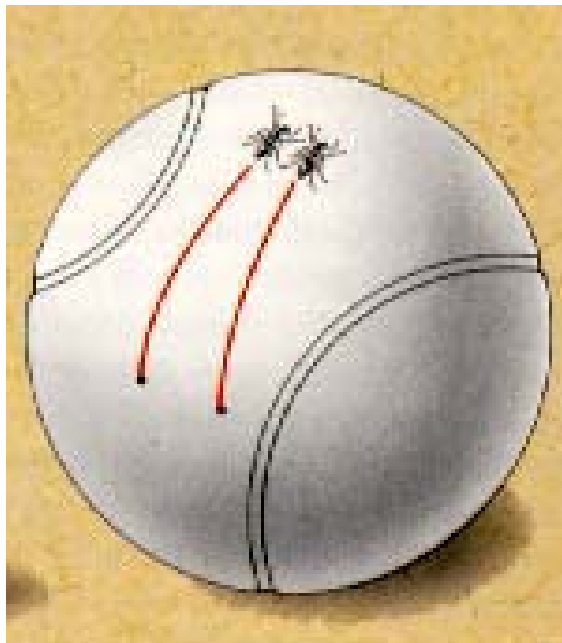
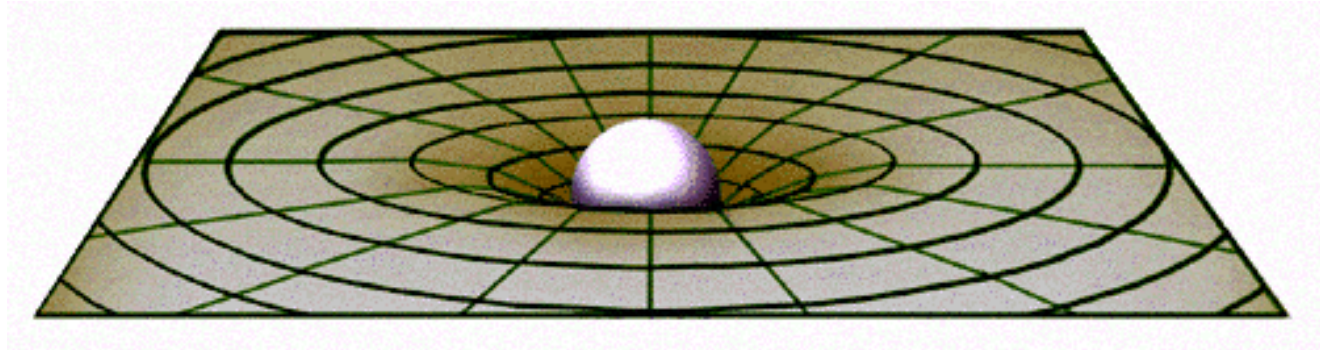


Closed

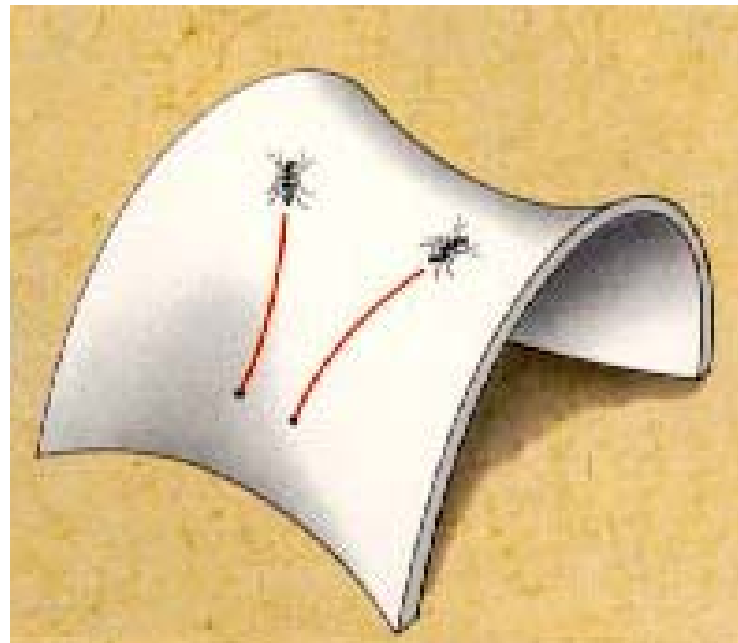


Open

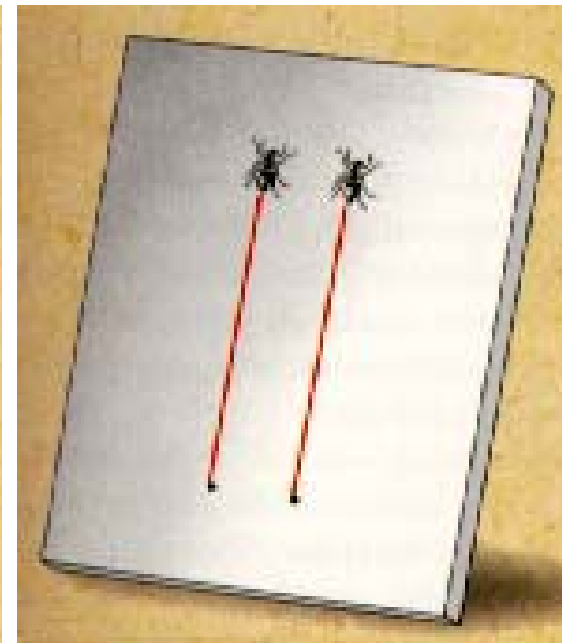
Answer depends on the shape of the Universe



Closed

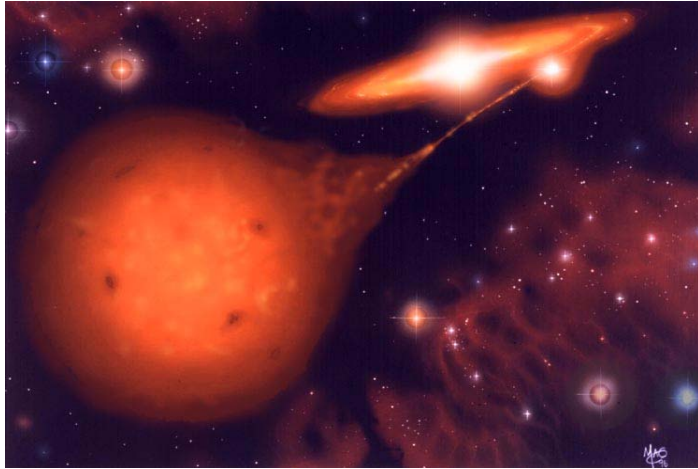


Open

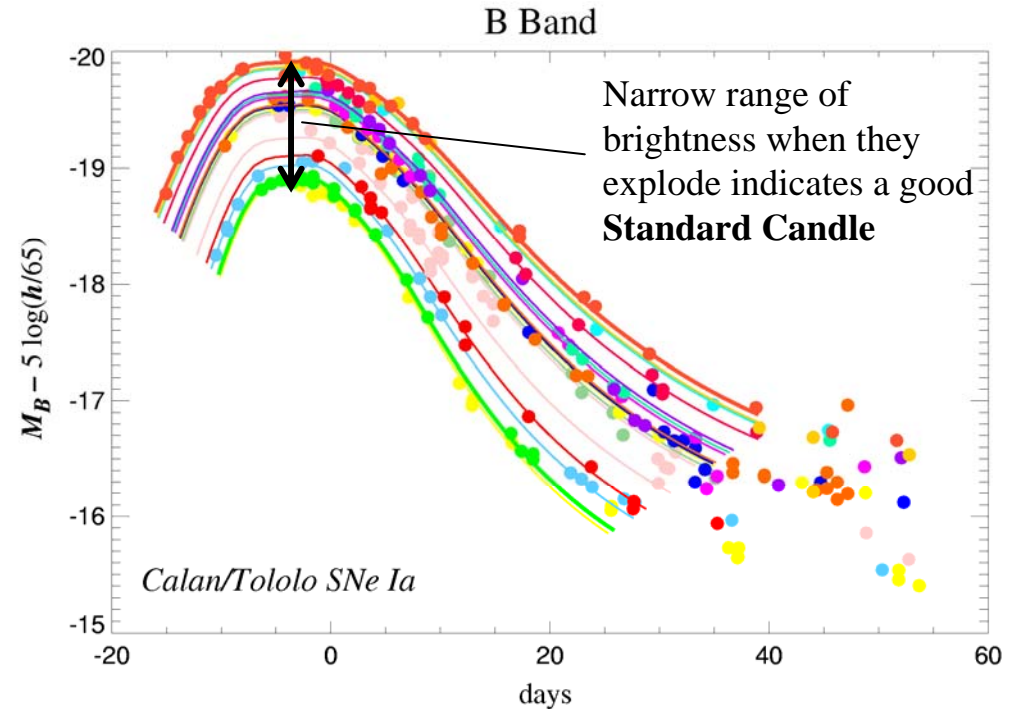


Flat

Is the Universe speeding up or slowing down?



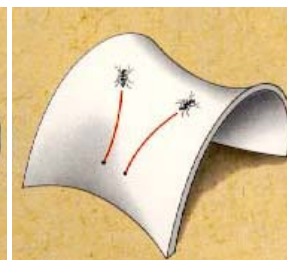
We can answer this question using **type Ia supernovae**



Shape of the universe affects the relationship between redshift and distance of remote supernovae



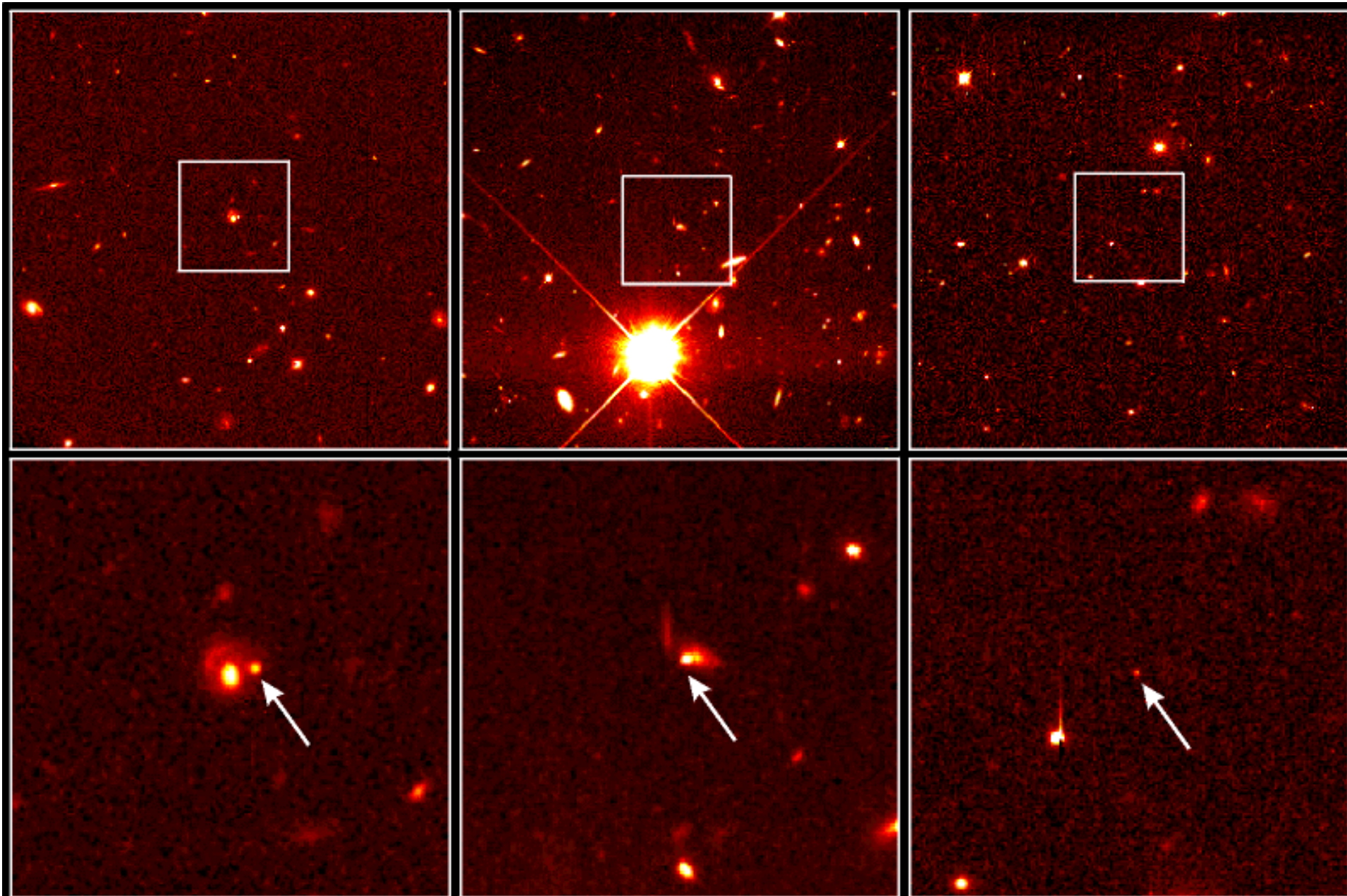
Closed



Open



Flat



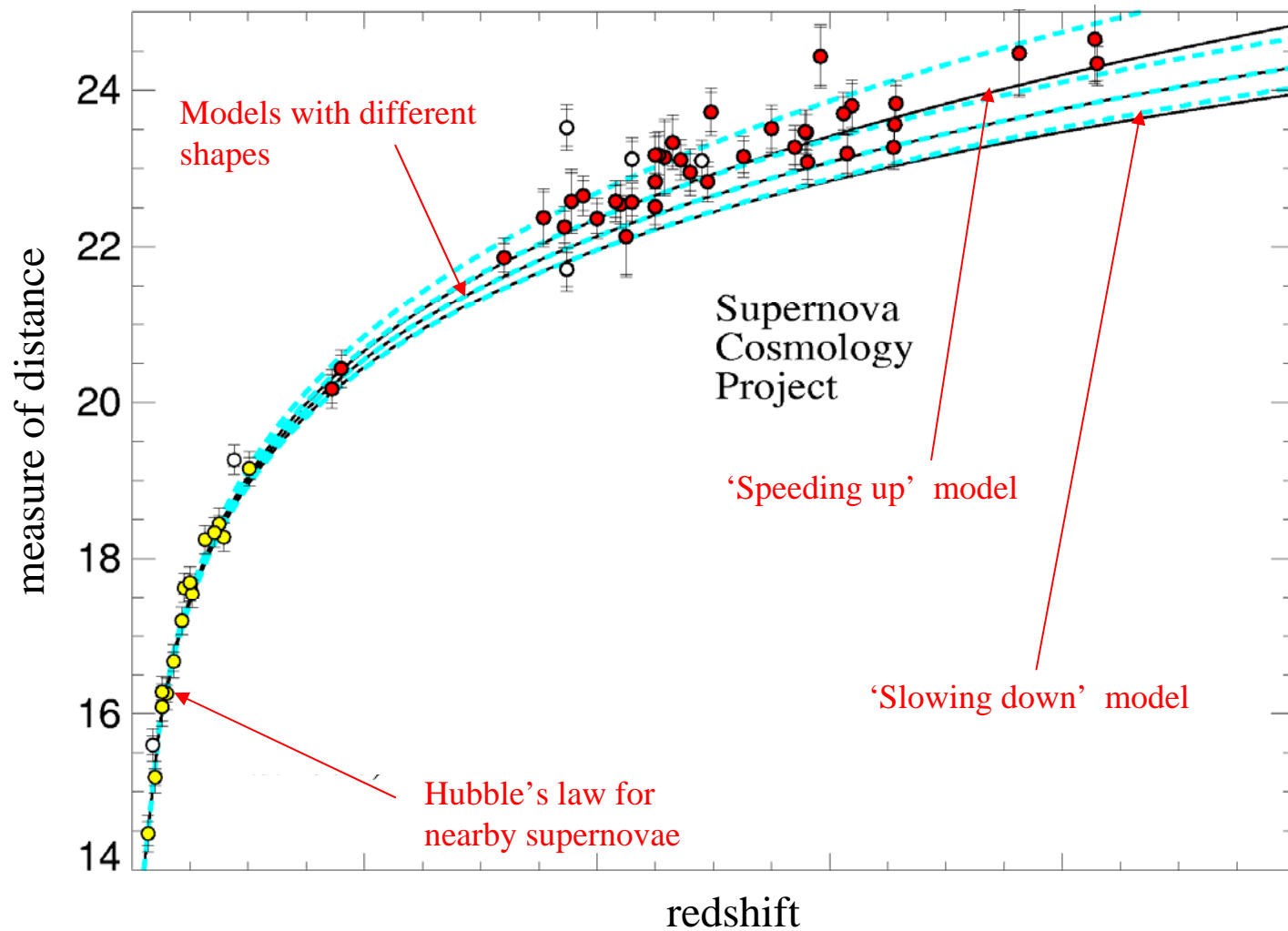
Distant Supernovae

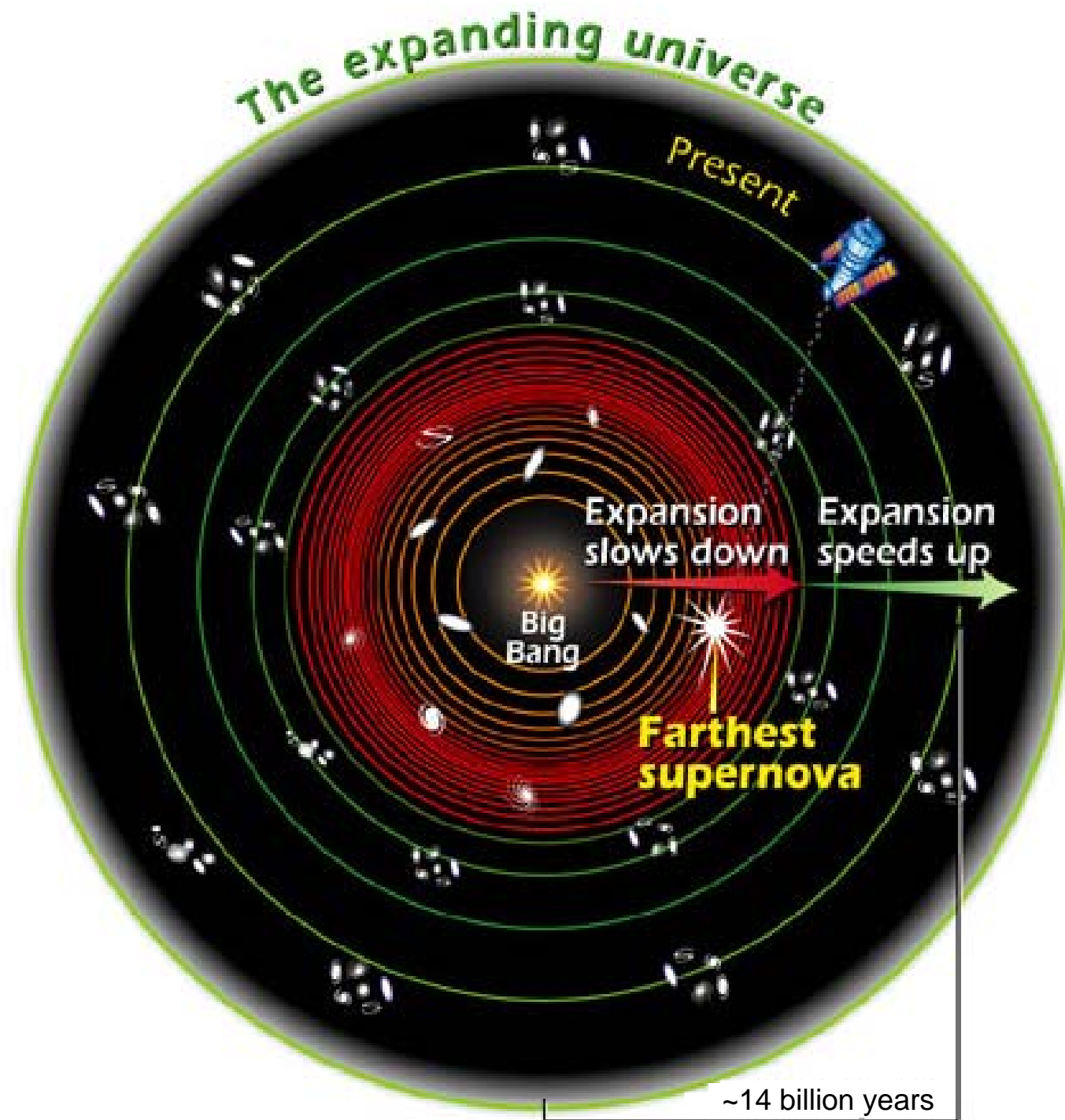
PRC98-02 • January 8, 1998 • ST ScI OPO

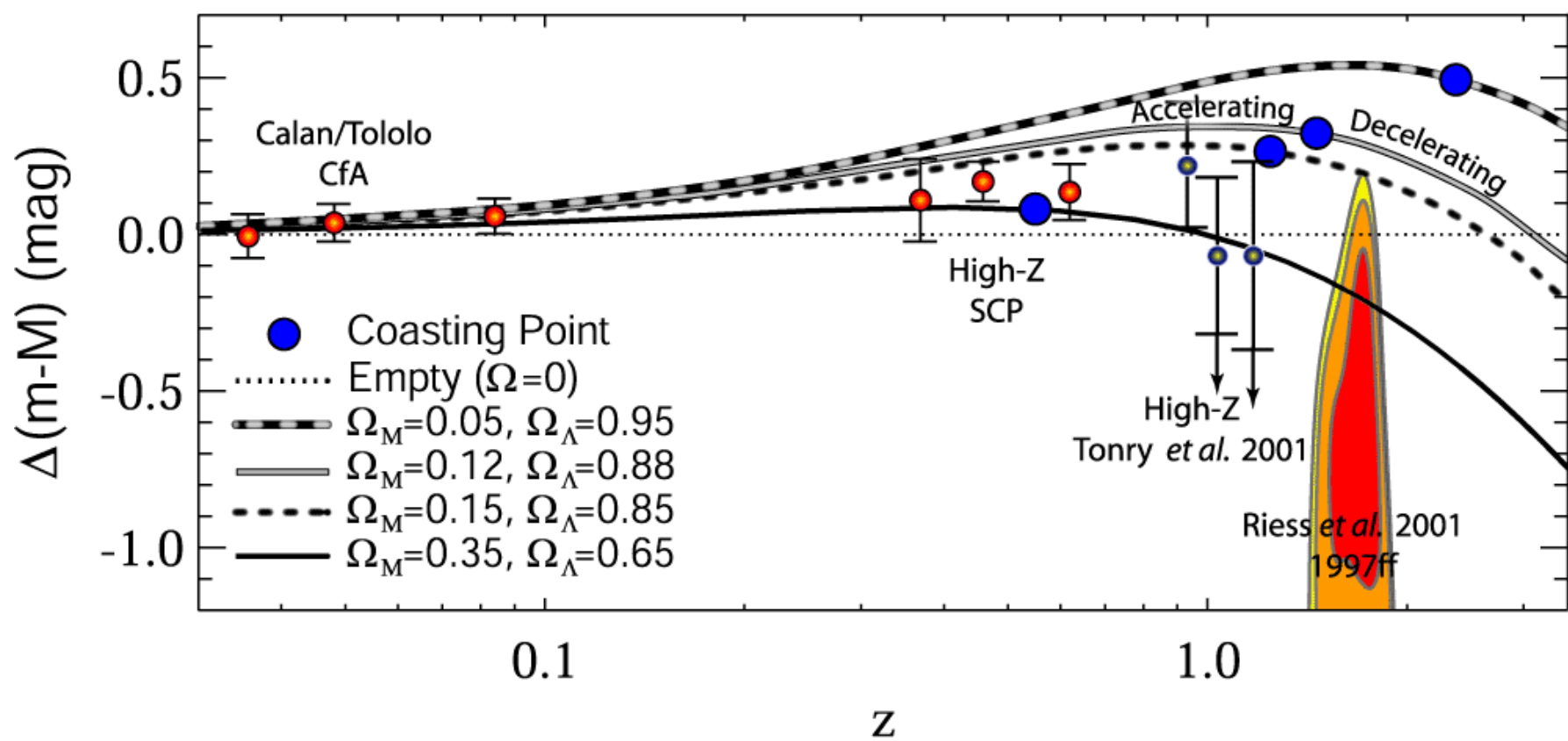
P. Garnavich (Harvard-Smithsonian Center for Astrophysics) and NASA

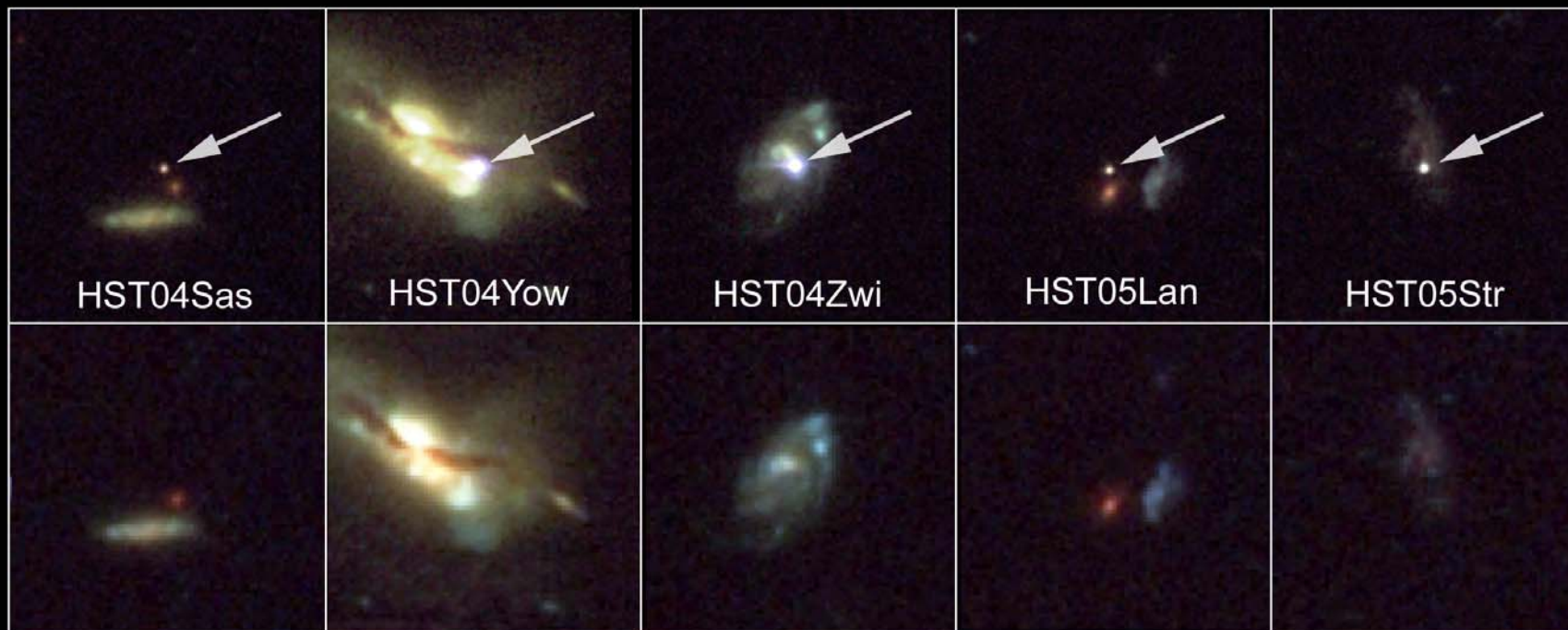
HST • WFPC2

Hubble diagram of distant supernovae



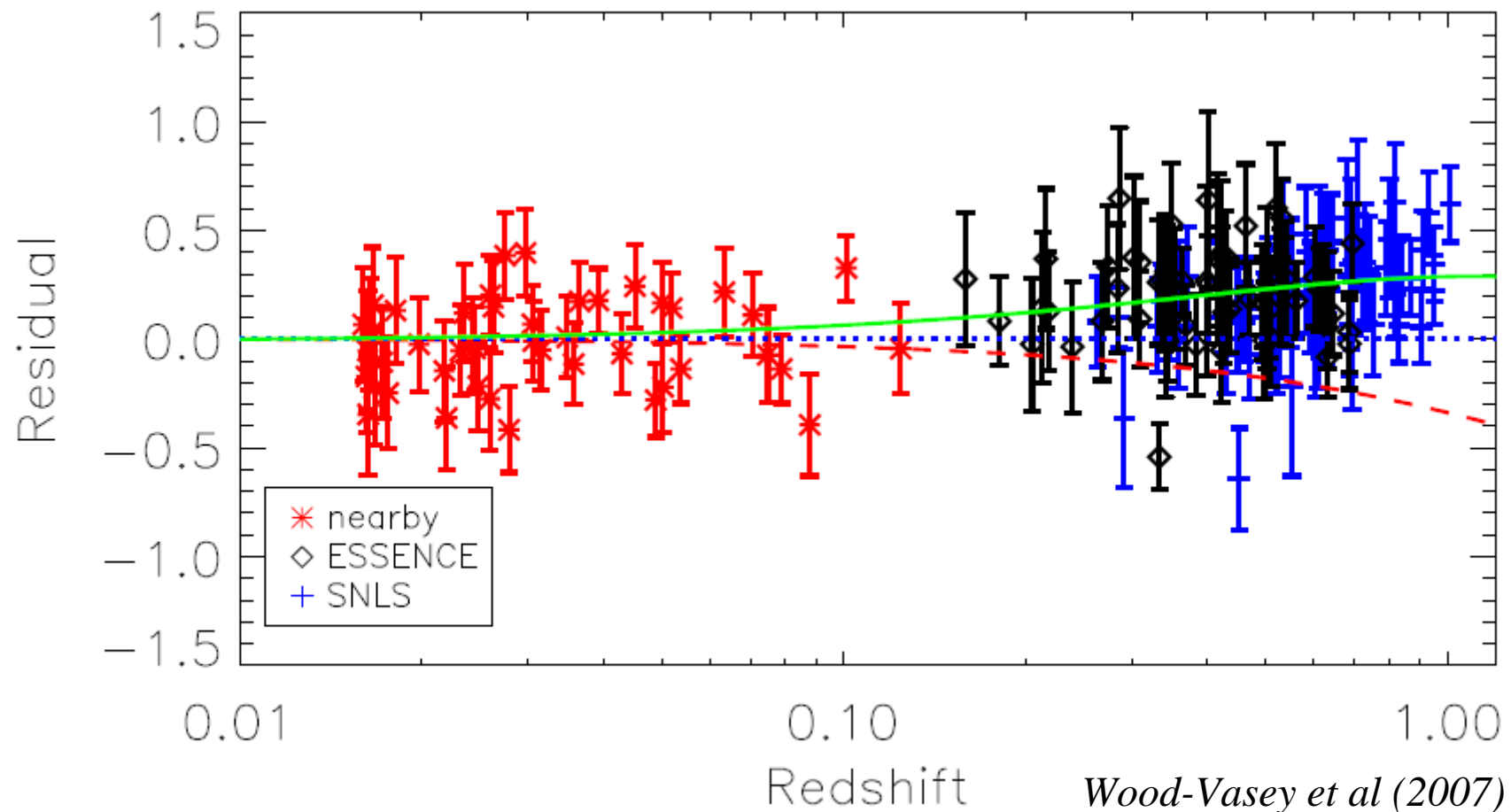






Host Galaxies of Distant Supernovae
Hubble Space Telescope ■ Advanced Camera for Surveys

Latest results: still speeding up!!!



**We can measure the shape of the Universe using the
cosmic microwave background radiation**

