The Path to Measuring an Accelerating Universe

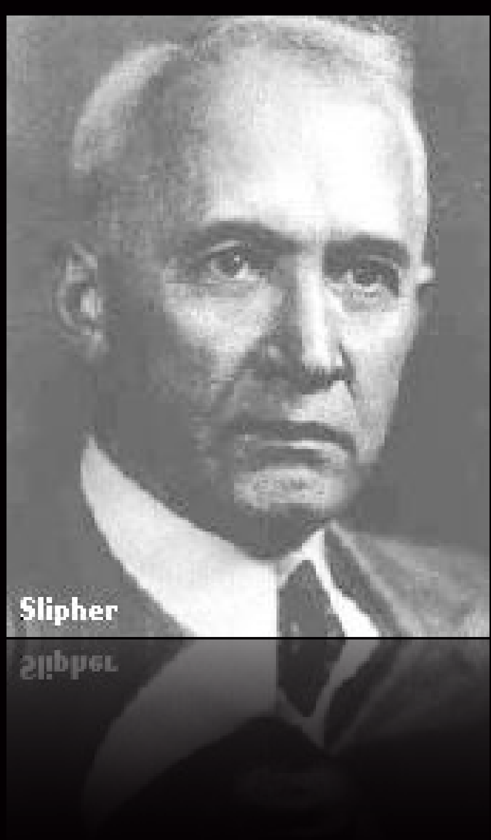
2011 Nobel Prize Lecture in Physics

BRIAN P. SCHMIDT

CAASTRO
ALL-SKY ASTROPHYSICS

ANU
THE AUSTRALIAN NATIONAL UNIVERSITY

THE RESEARCH SCHOOL OF ASTRONOMY & ASTROPHYSICS
MOUNT STROMLO AND SIDING SPRING OBSERVATORIES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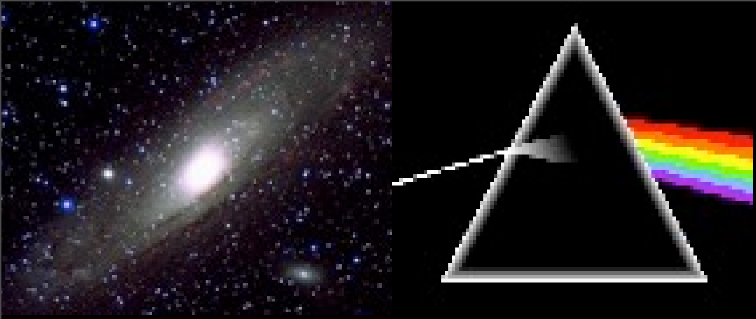

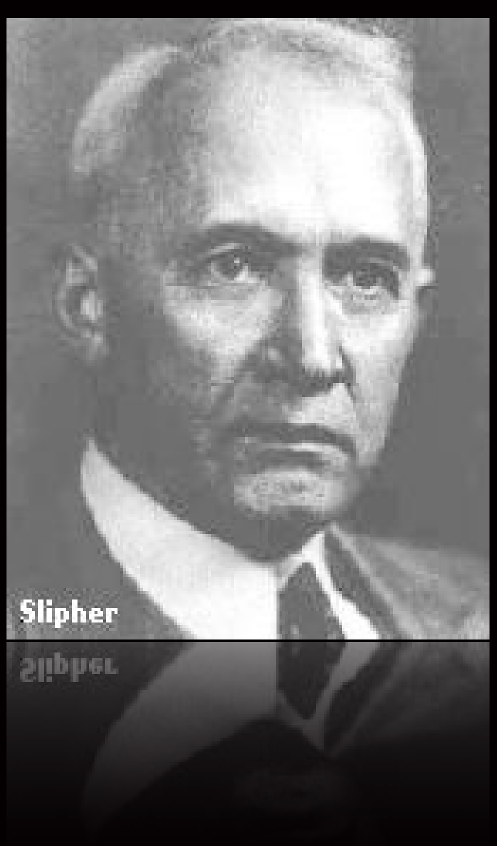
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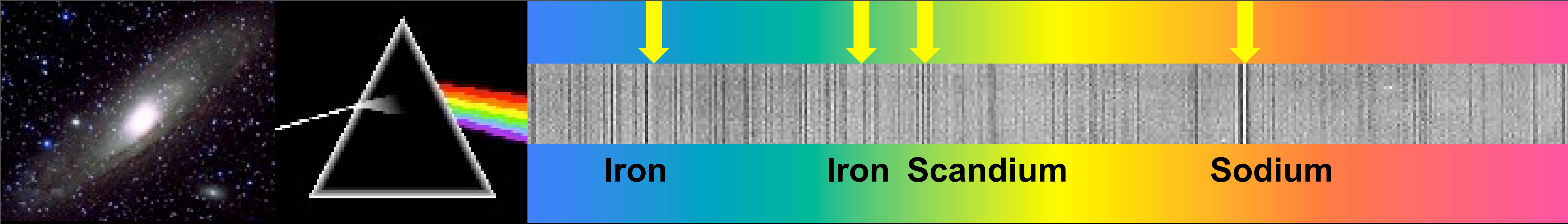
Iron
Iron
Scandium
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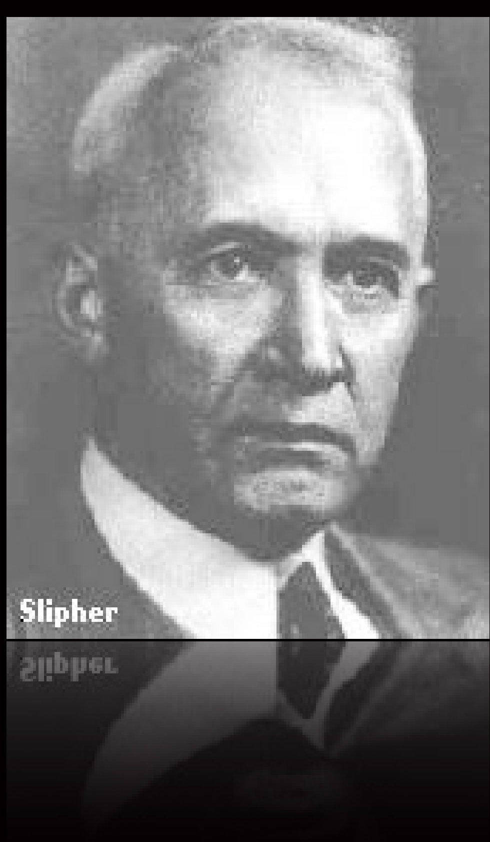
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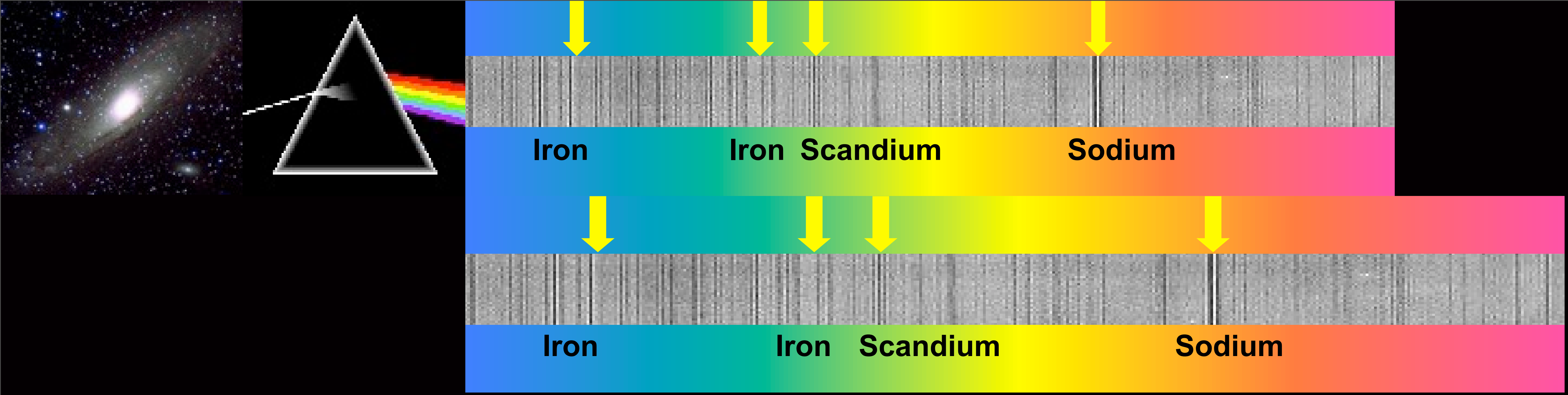
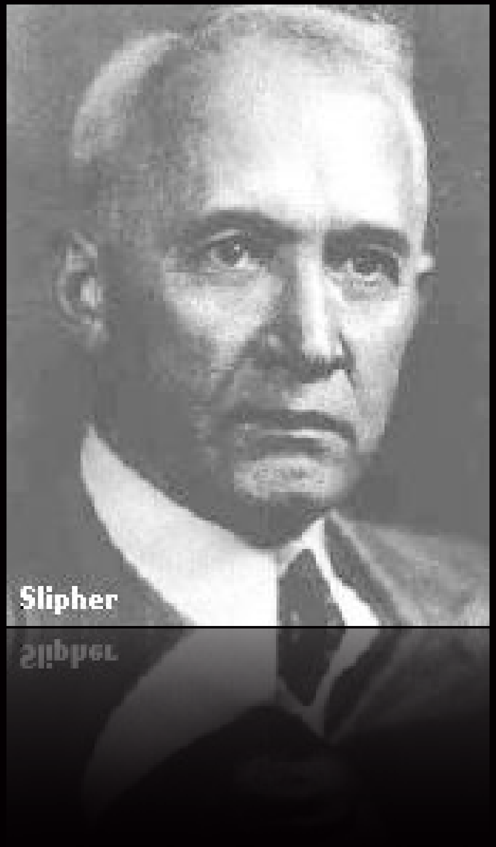
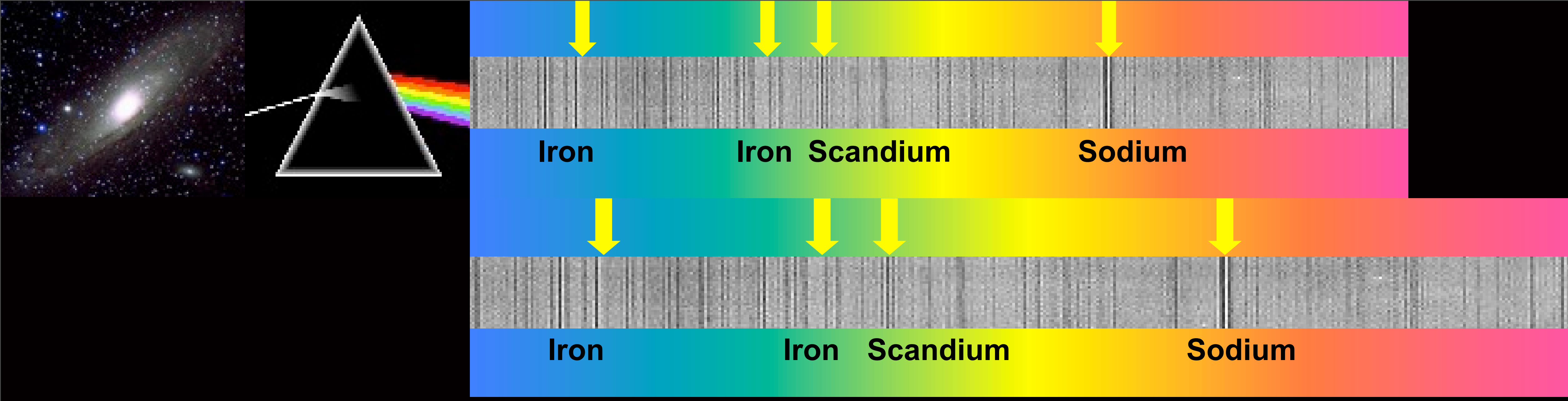
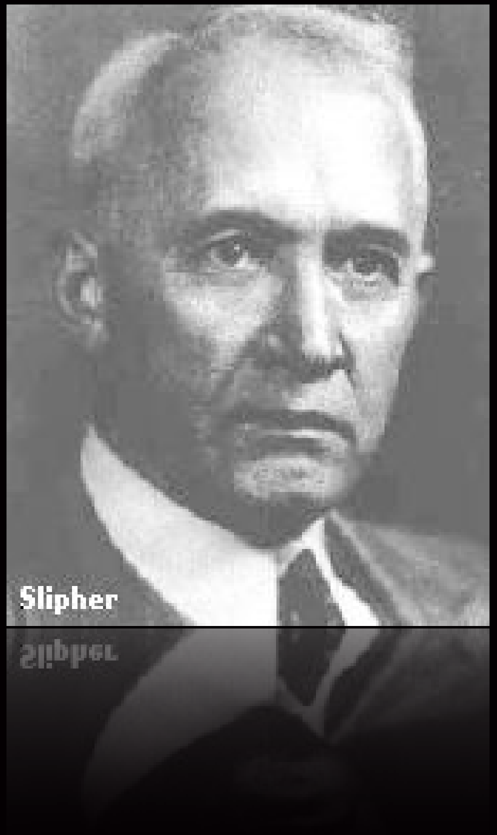


Doppler Shift Gives Velocity of Galaxy

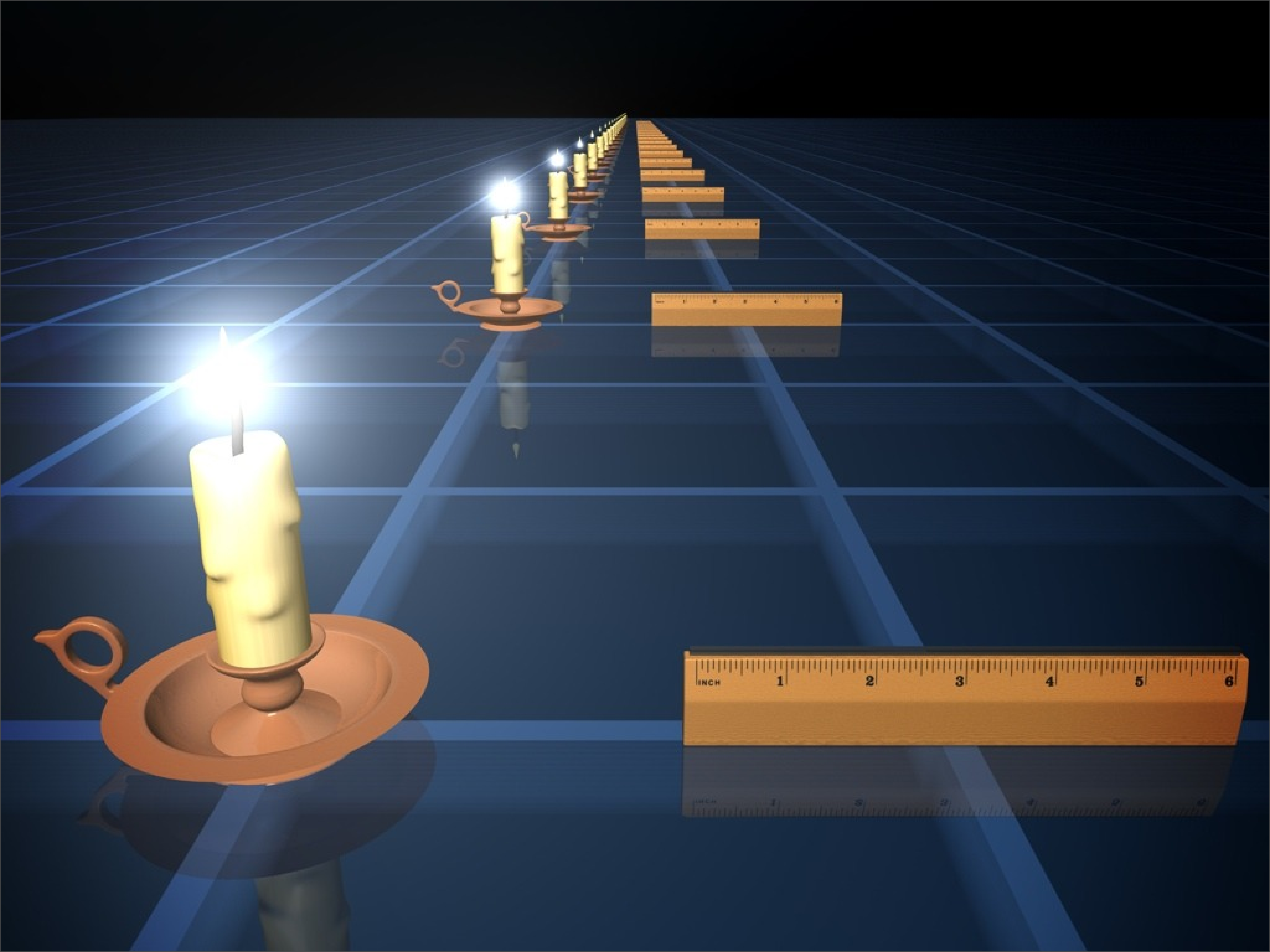




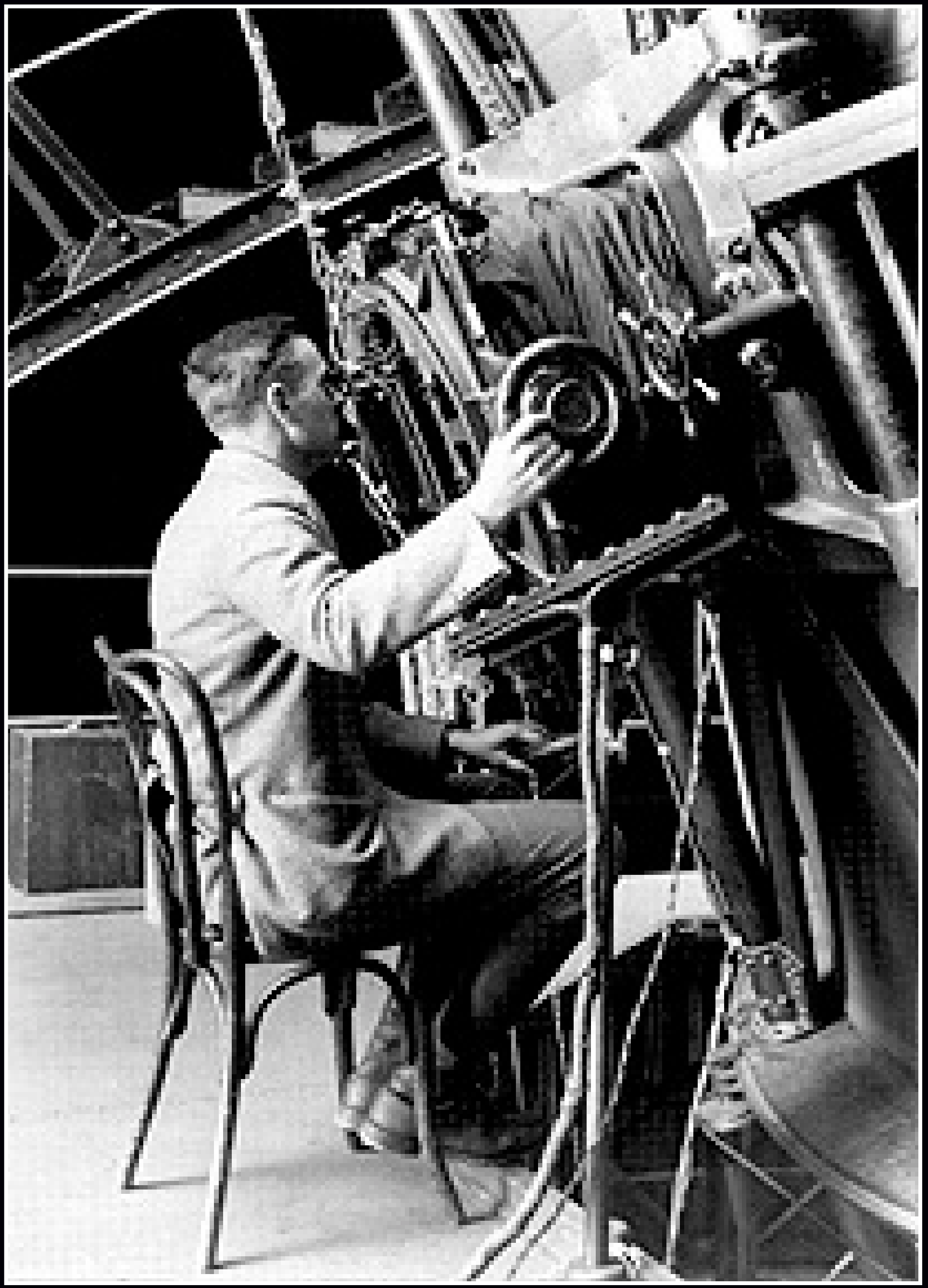
Doppler Shift Gives Velocity of Galaxy



In 1916 Vesto Slipher measured velocities to nearby galaxies, and discovered they were all moving away from us.


INCH 1 2 3 4 5 6

1929, Hubble uses brightest stars to measure the distances to the nearest galaxies.



He assumes the brightest stars are all the same brightness.

The faster the galaxy was moving, the fainter the stars!

The Universe is Expanding

Hubble's Data

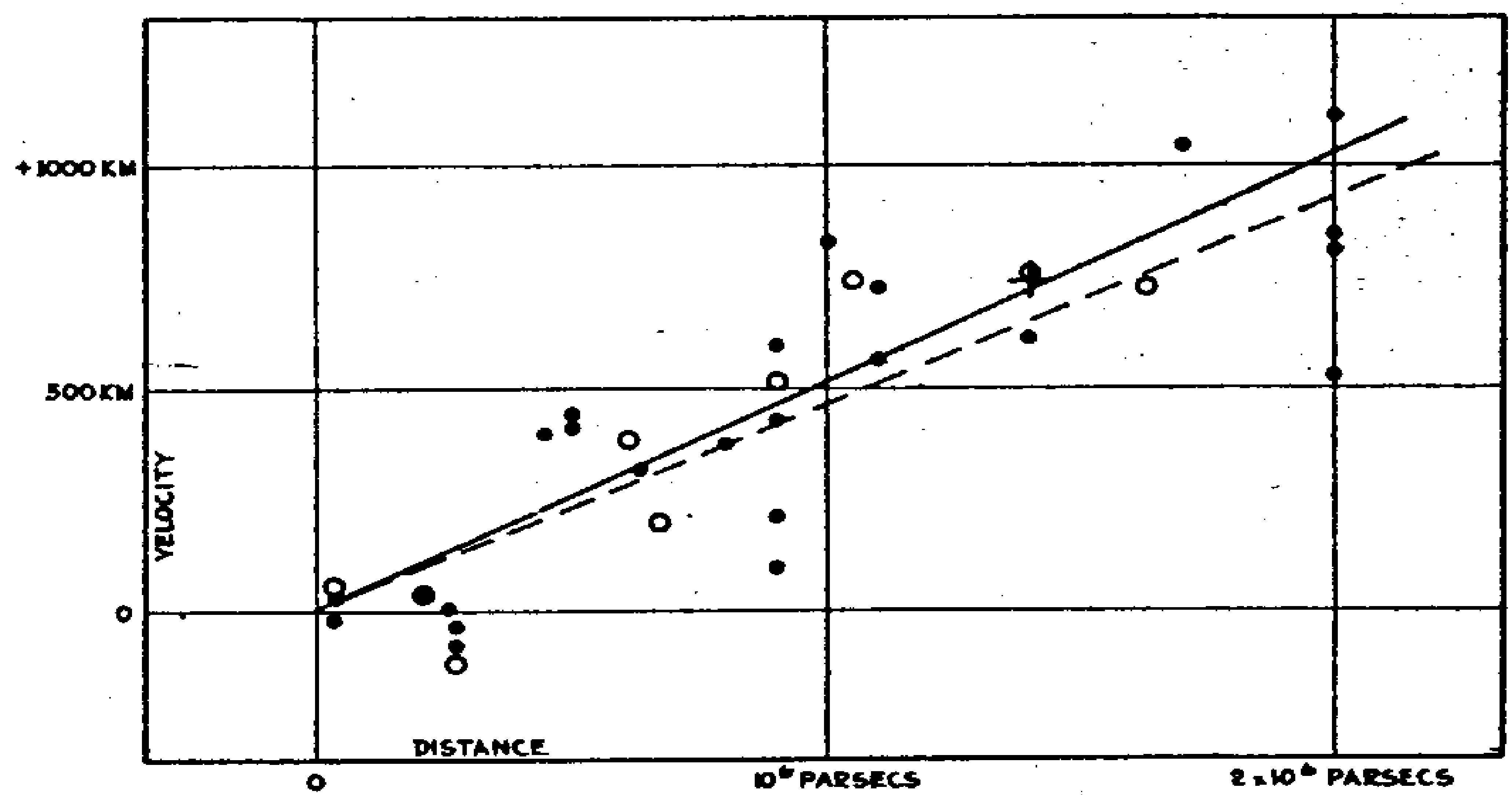
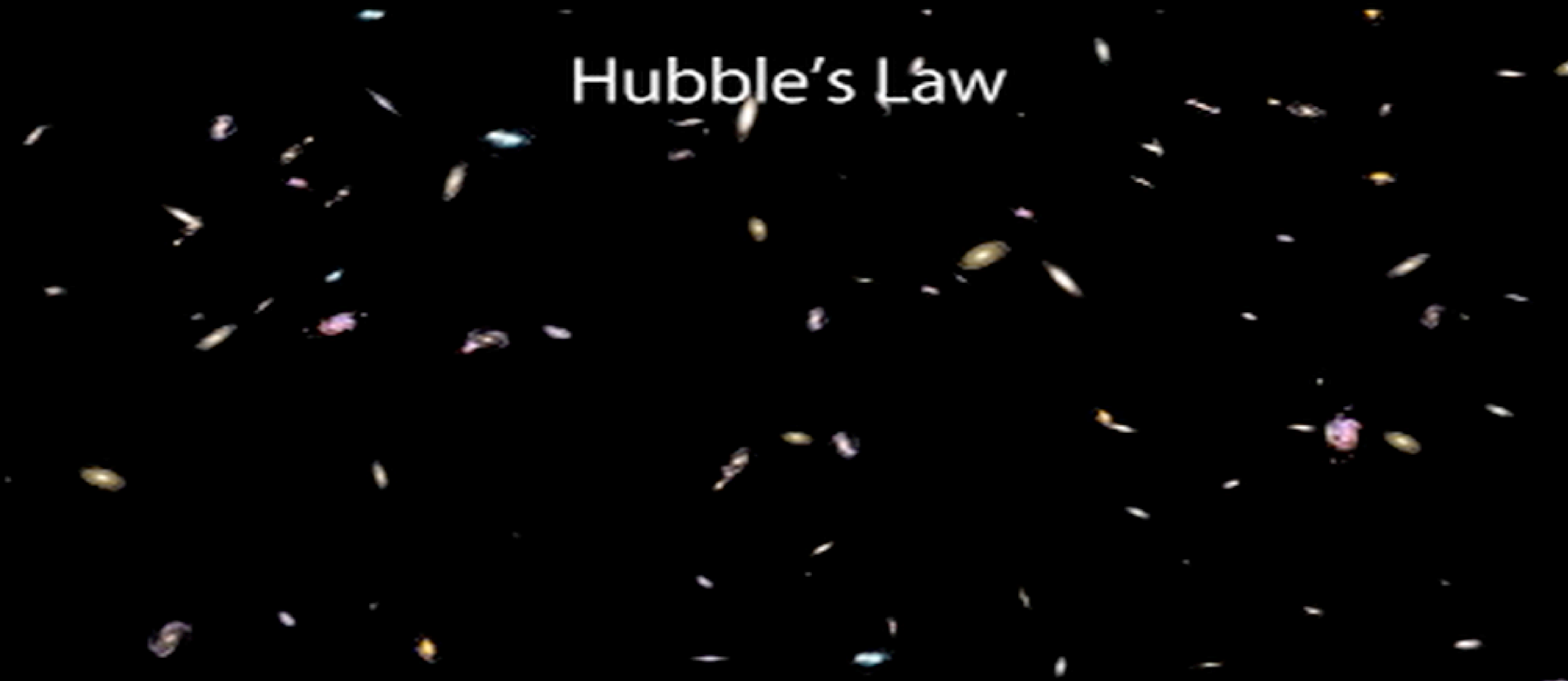
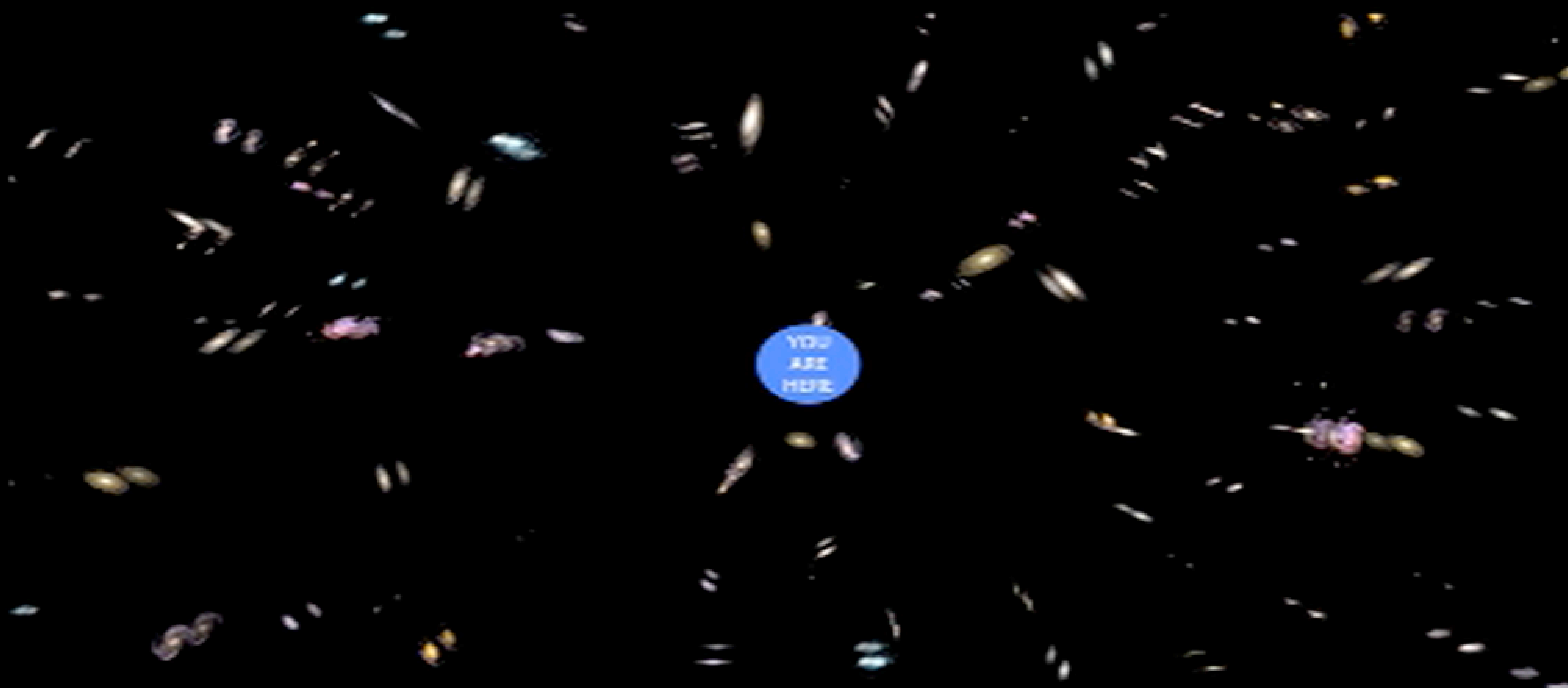


FIGURE 1

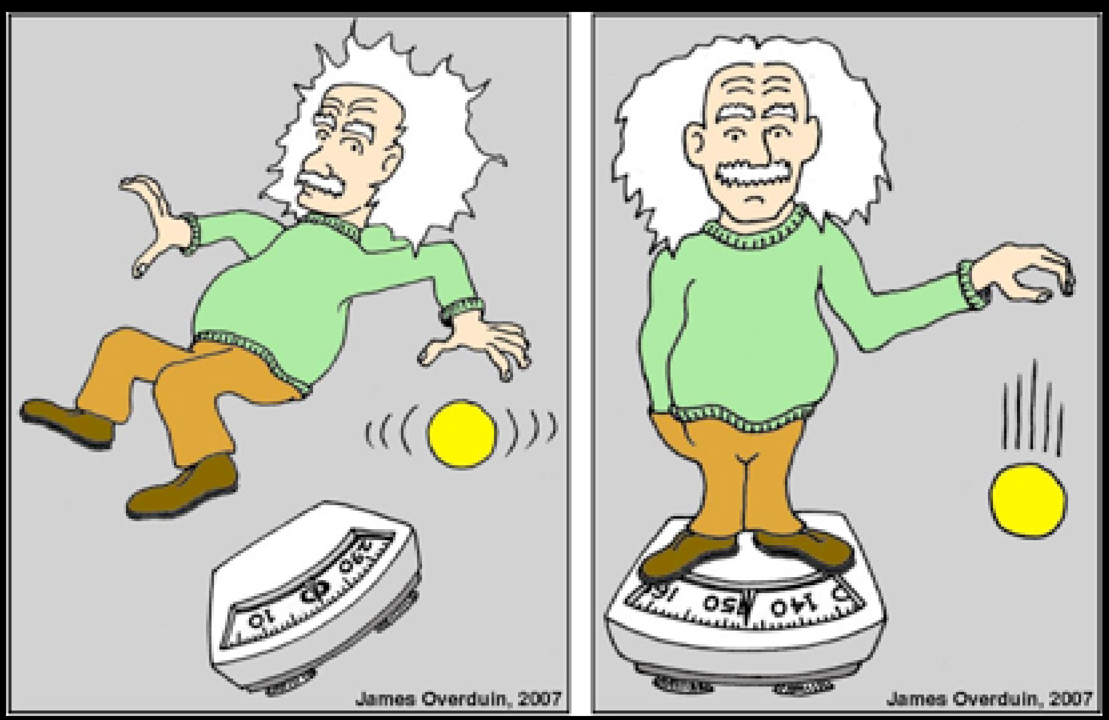
Hubble's Law

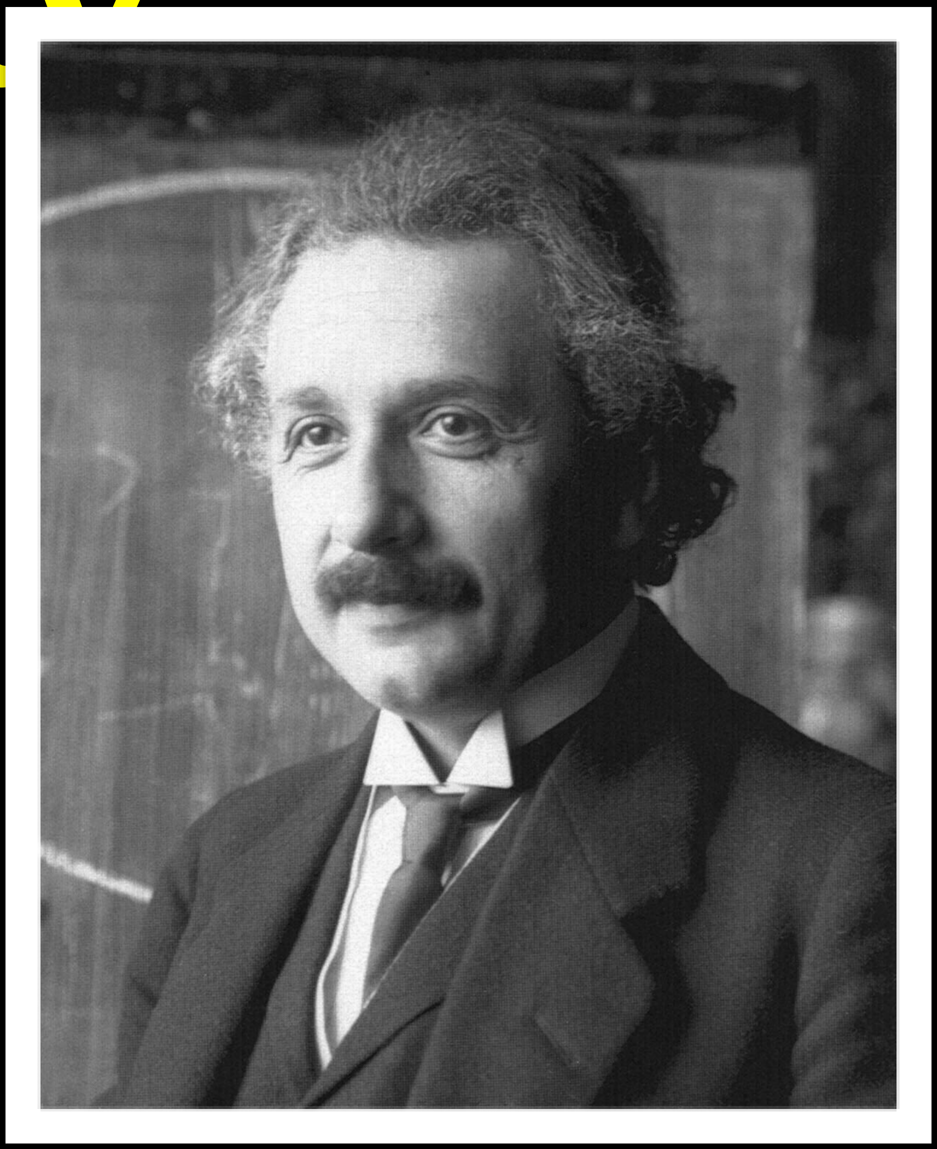


Hubble's Law


YOU
ARE
HERE

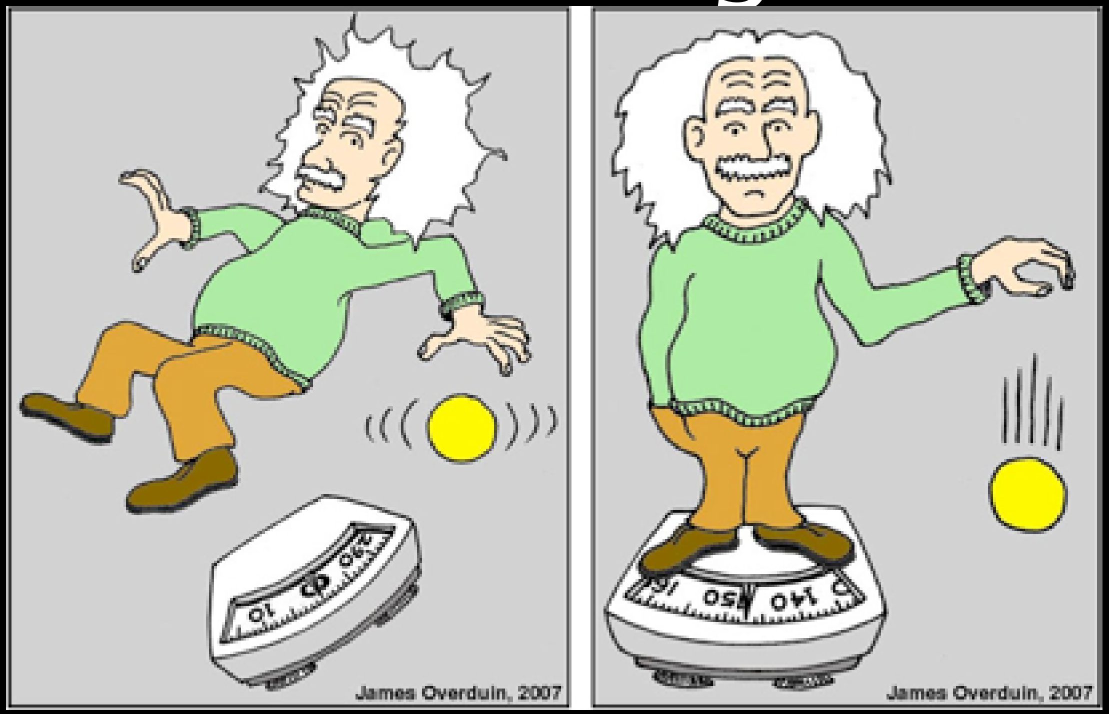
Einstein’s Theory of Gravity



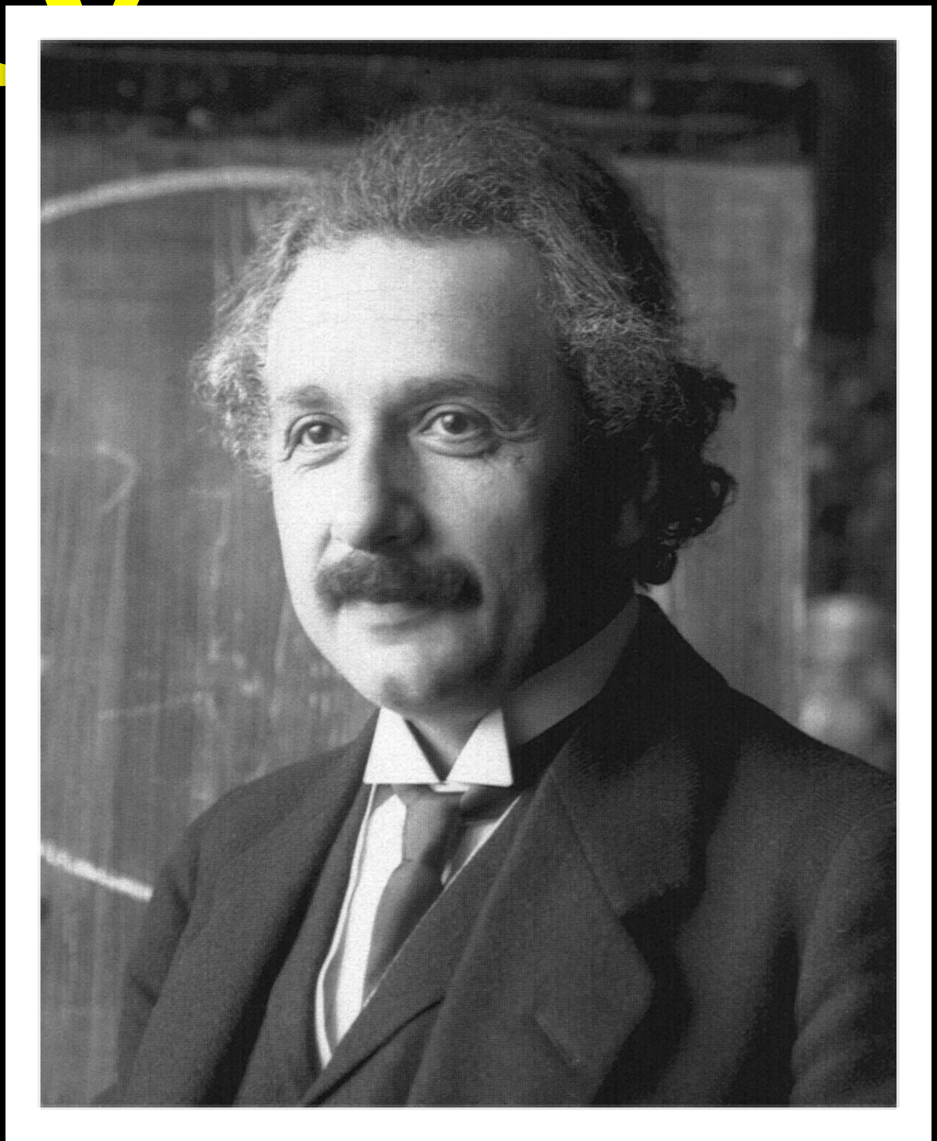


Einstein's Theory of Gravity

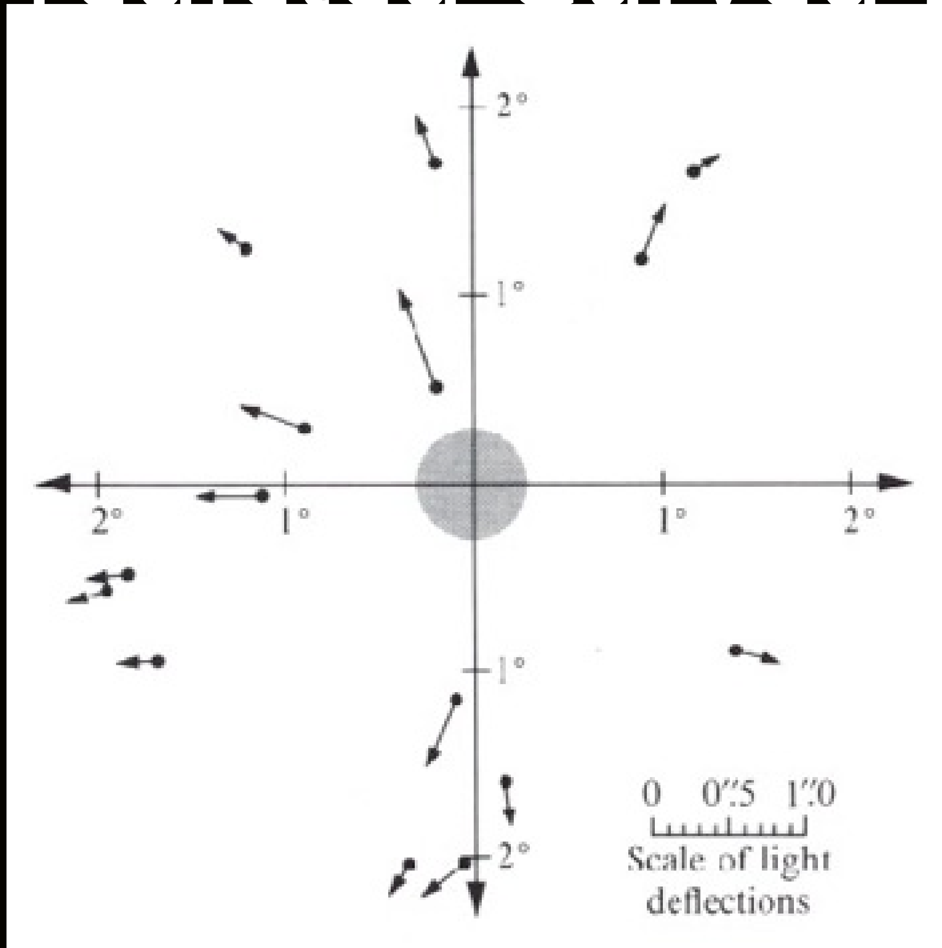
- In 1907 Einstein had a revelation that acceleration and gravity were indistinguishable.



1915...Equations of General Relativity



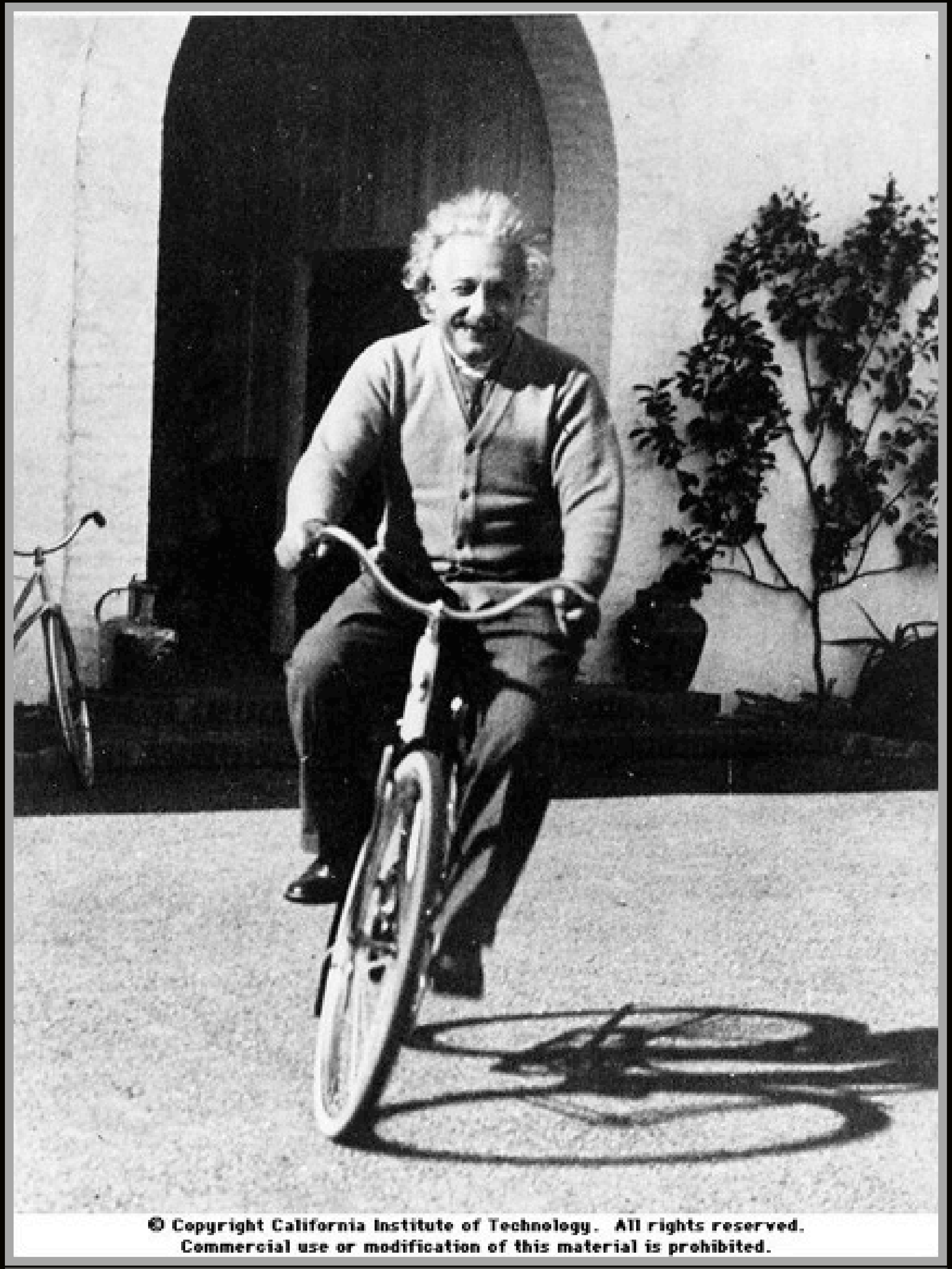
Predicted Curved Space



Allowed one to Solve Cosmology... But

solutions were dynamic – Universe should

The Cosmological Consta



Originally proposed by Einstein to counteract the Universe's gravitational attraction – it makes Gravity Push rather than Pull.

Later "retracted" once the expansion was discovered

It represents the energy of the vacuum (What is there when there is nothing there!)

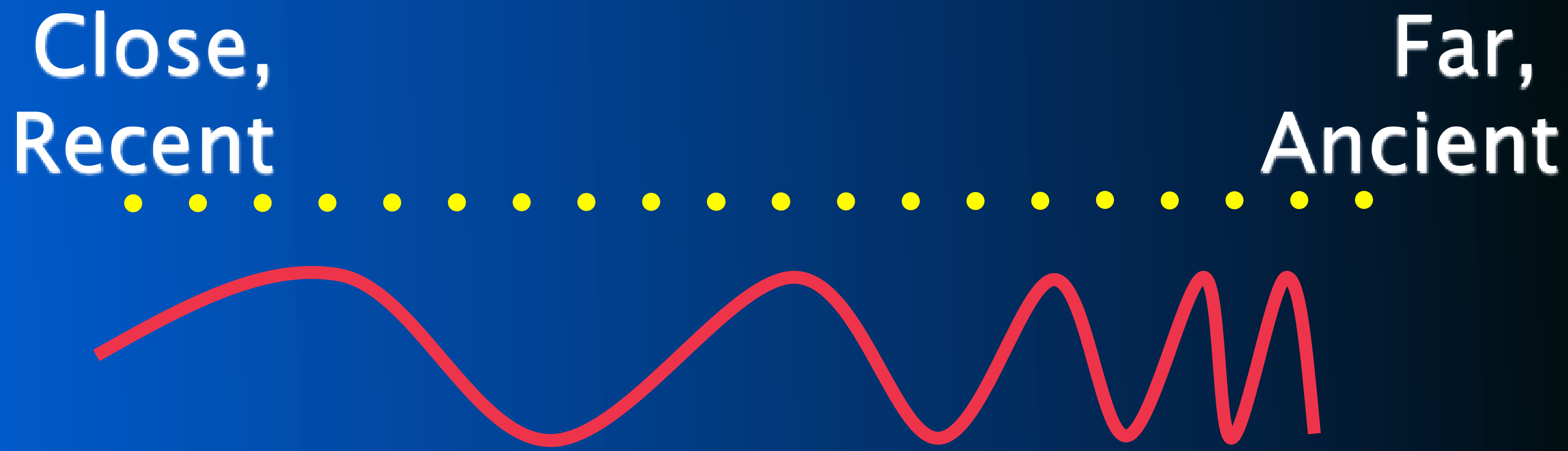
Our View of the Expanding Universe

Our View of the Expanding Universe

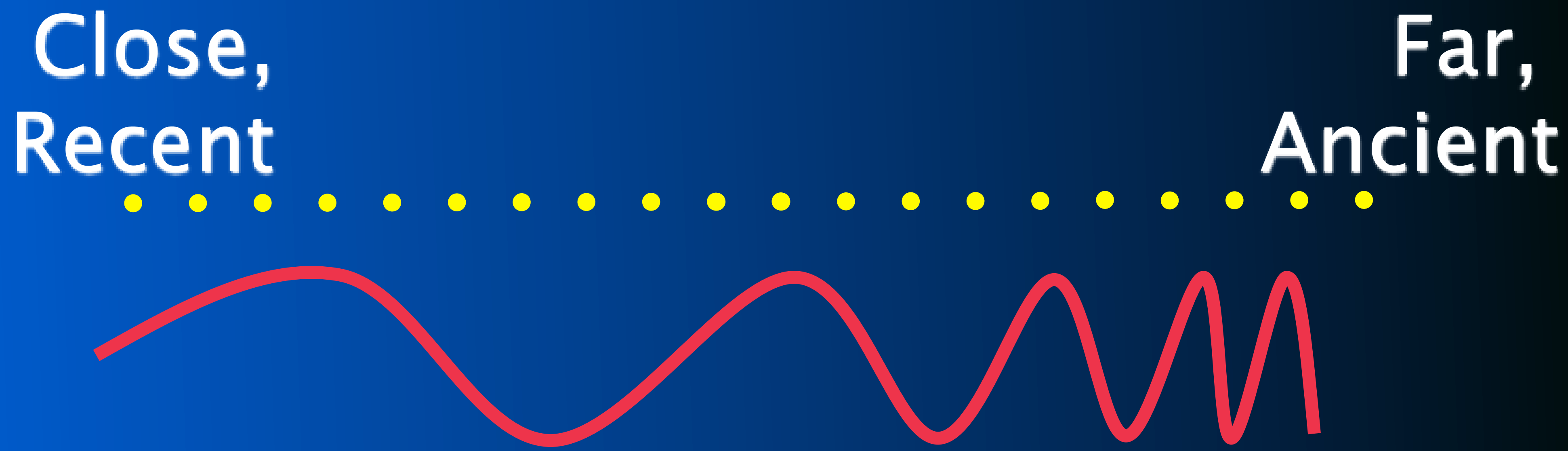
Close,
Recent

Far,
Ancient

Our View of the Expanding Universe



Our View of the Expanding Universe



Light is stretched as the Universe expands,

The Further an object is away, the more the Universe has expanded, so the more the light is stretched to the Red - Redshift

To the Future

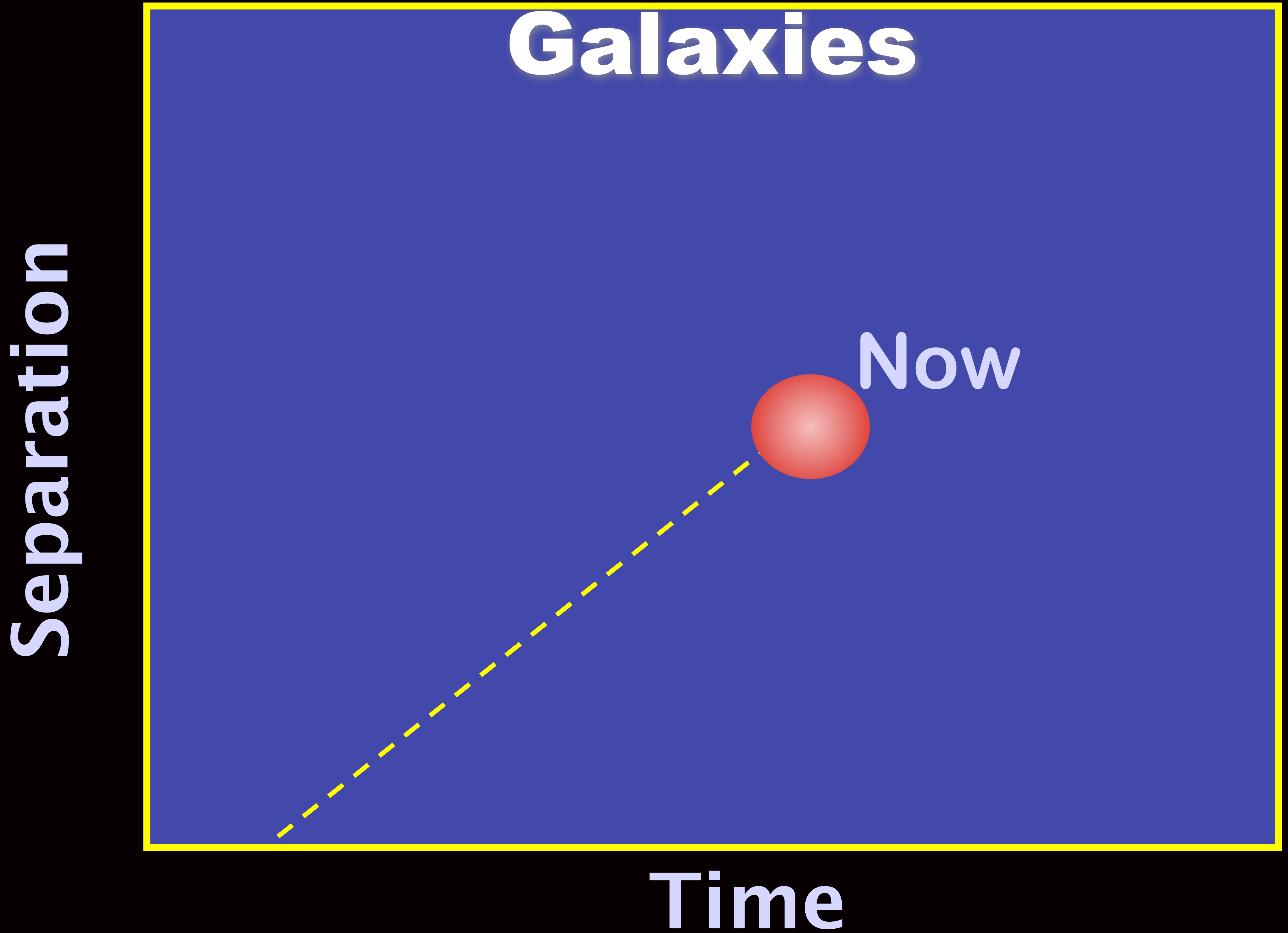
The Distance Between Two Galaxies

Separation

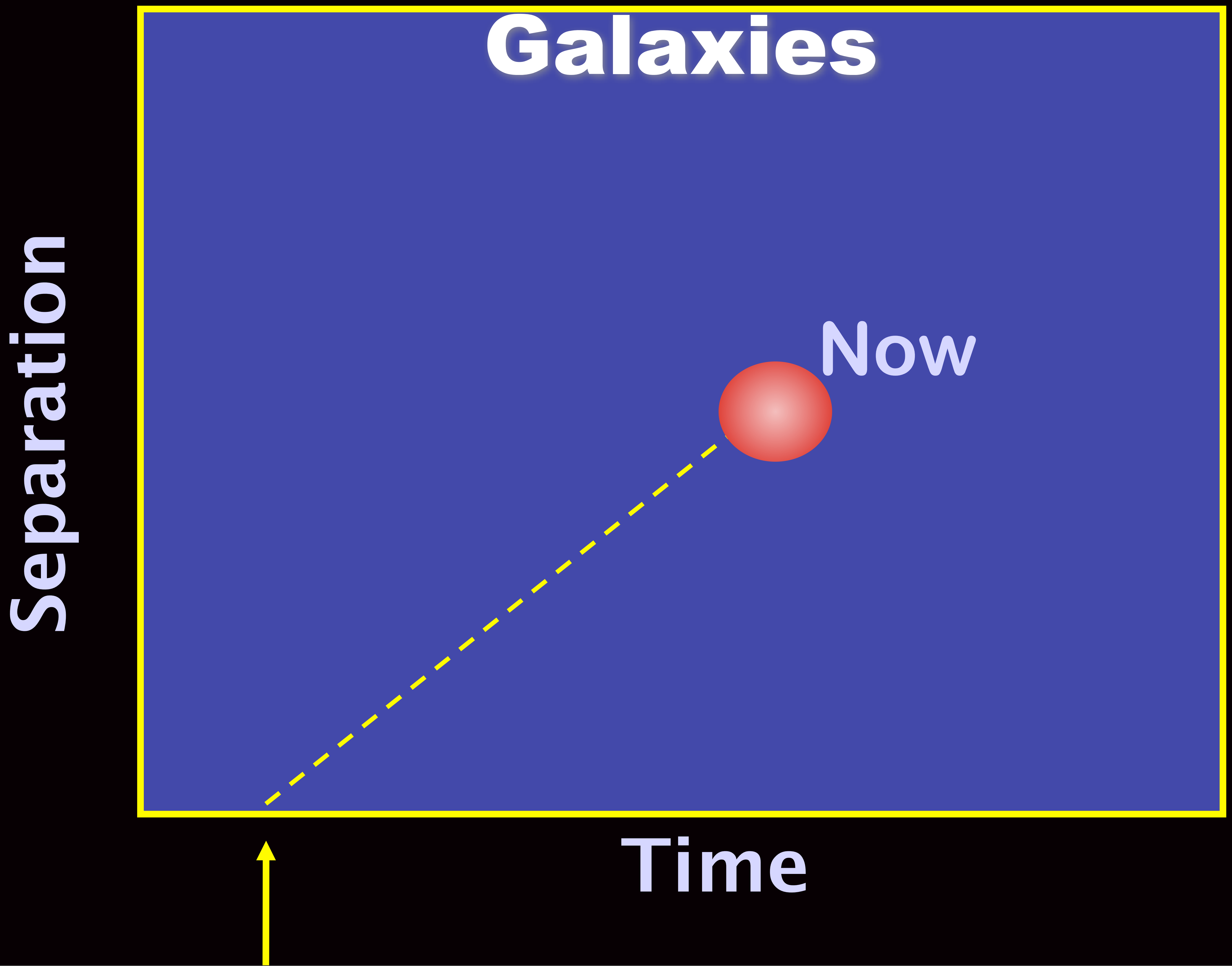
Time

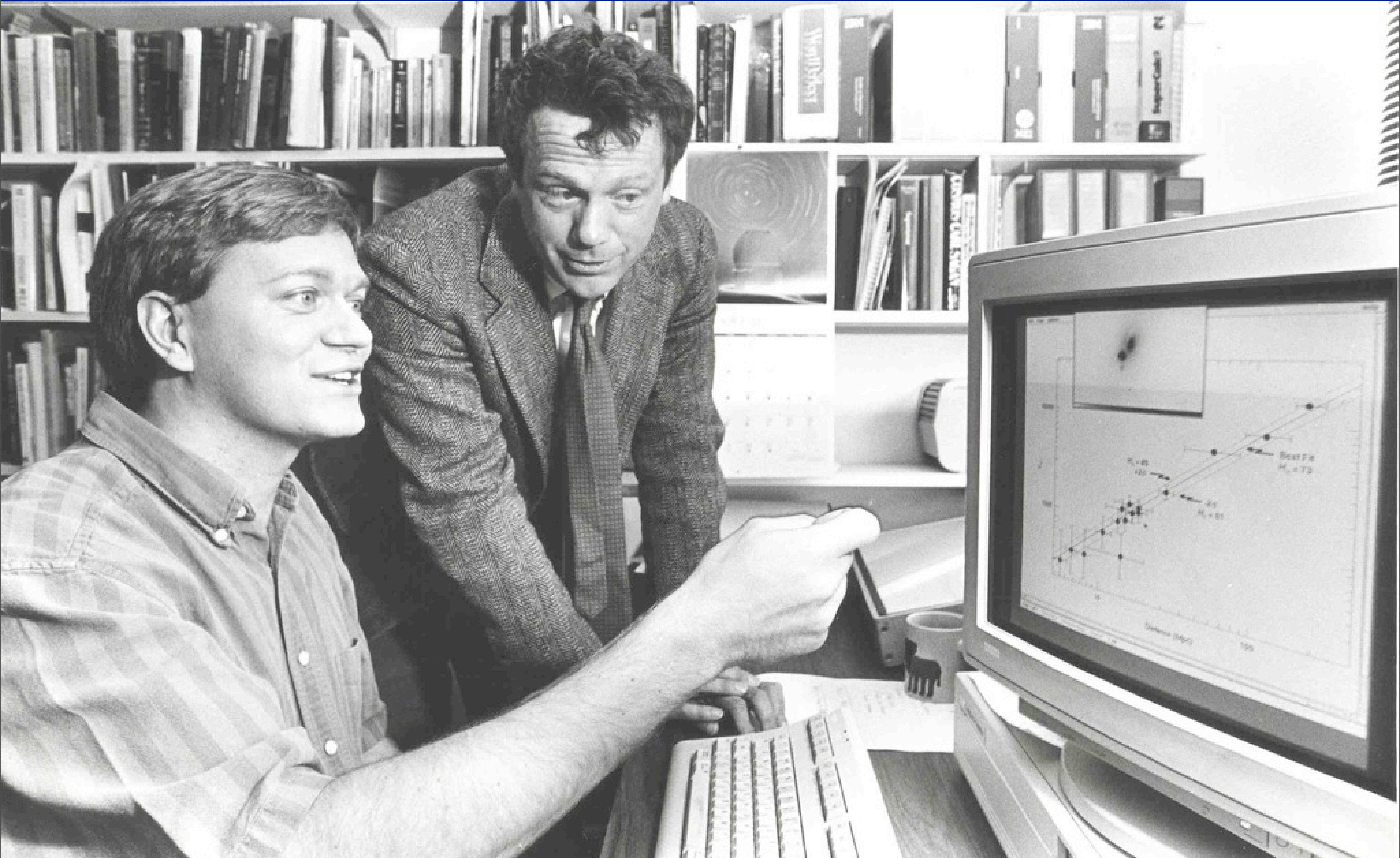
The Distance Between Two Galaxies

The Distance Between Two Galaxies



The Distance Between Two Galaxies




Best Fit

The Hubble Constant Tells us the age of the Universe...

The Hubble Constant Tells us the age of the Universe...

H_0=50 t=19.6 Billion Years
H_0=60 t=16.3 Billion Years
H_0=70 t=14.0 Billion Years
H_0=80 t=12.3 Billion Years
H_0=90 t=10.9 Billion Years
H_0=100 t= 9.8 Billion Years

The Hubble Constant Tells us the age of the Universe...

H_0=70 t=14.0 Billion Years

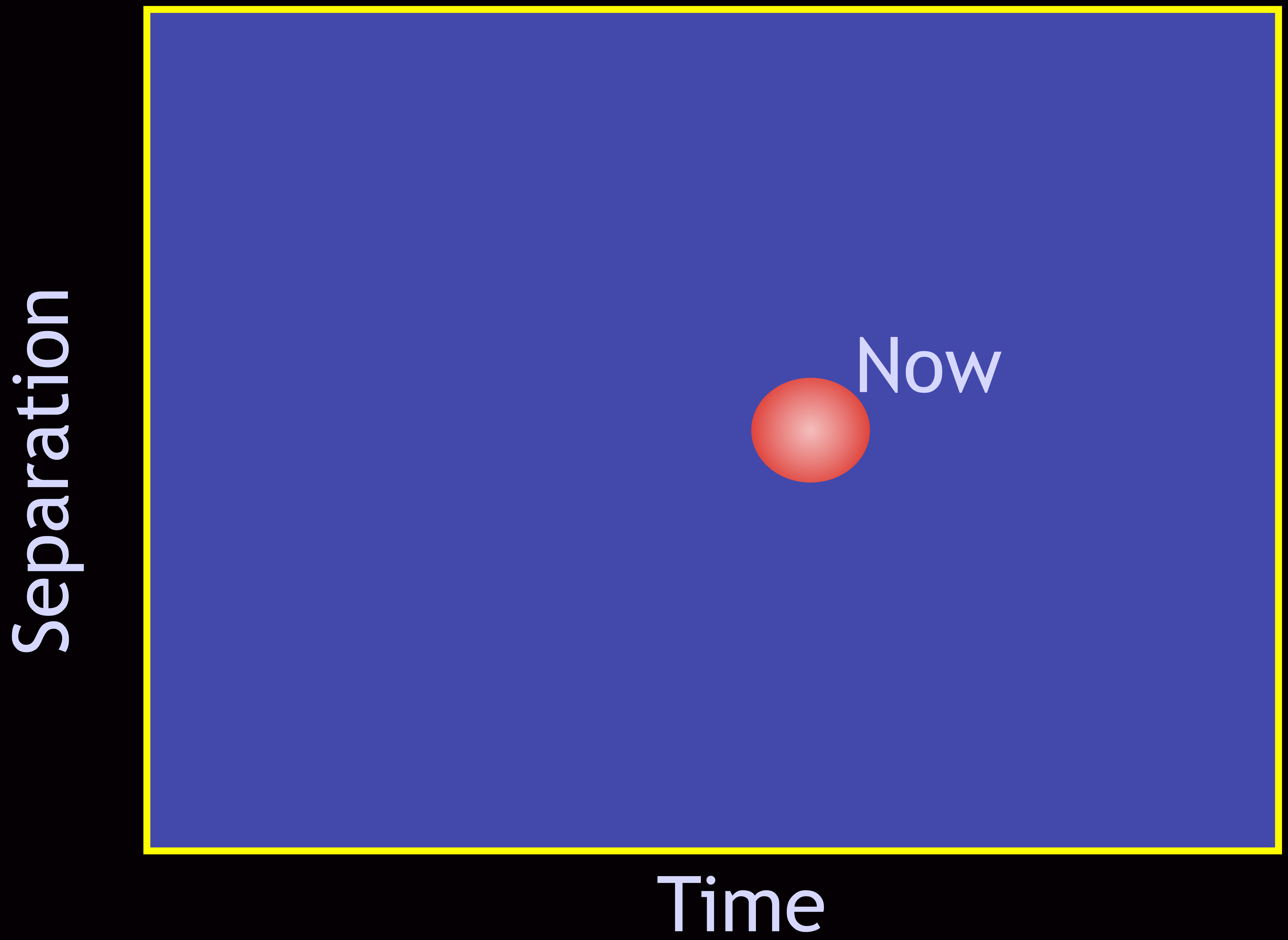
So how fast the Universe is expanding tells us about how old the Universe is...But...

So how fast the Universe is expanding tells us about how old the Universe is...But...

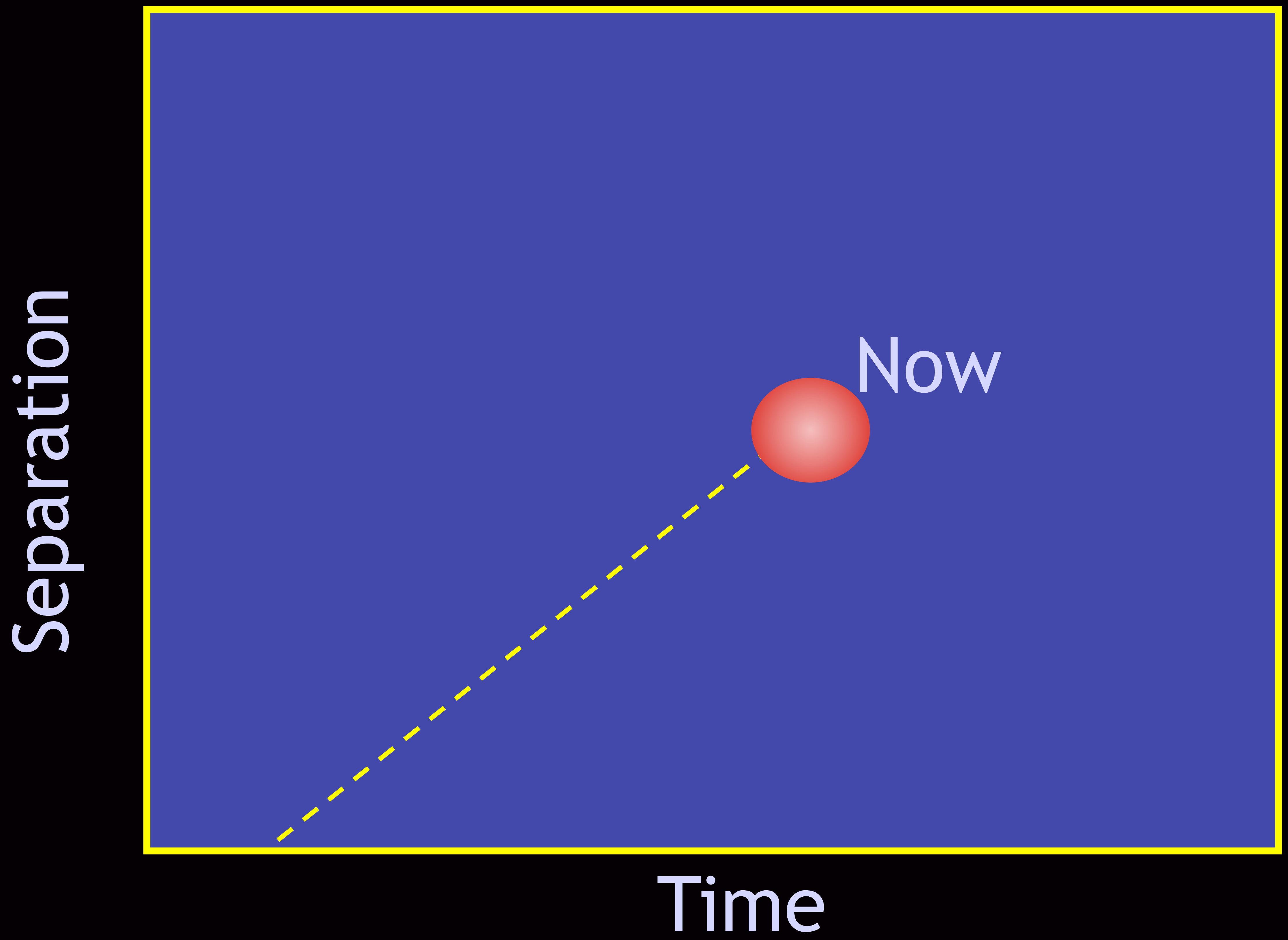
Gravity pulls on the Universe as it expands, slowing it down over time

The Distance Between Two Galaxies

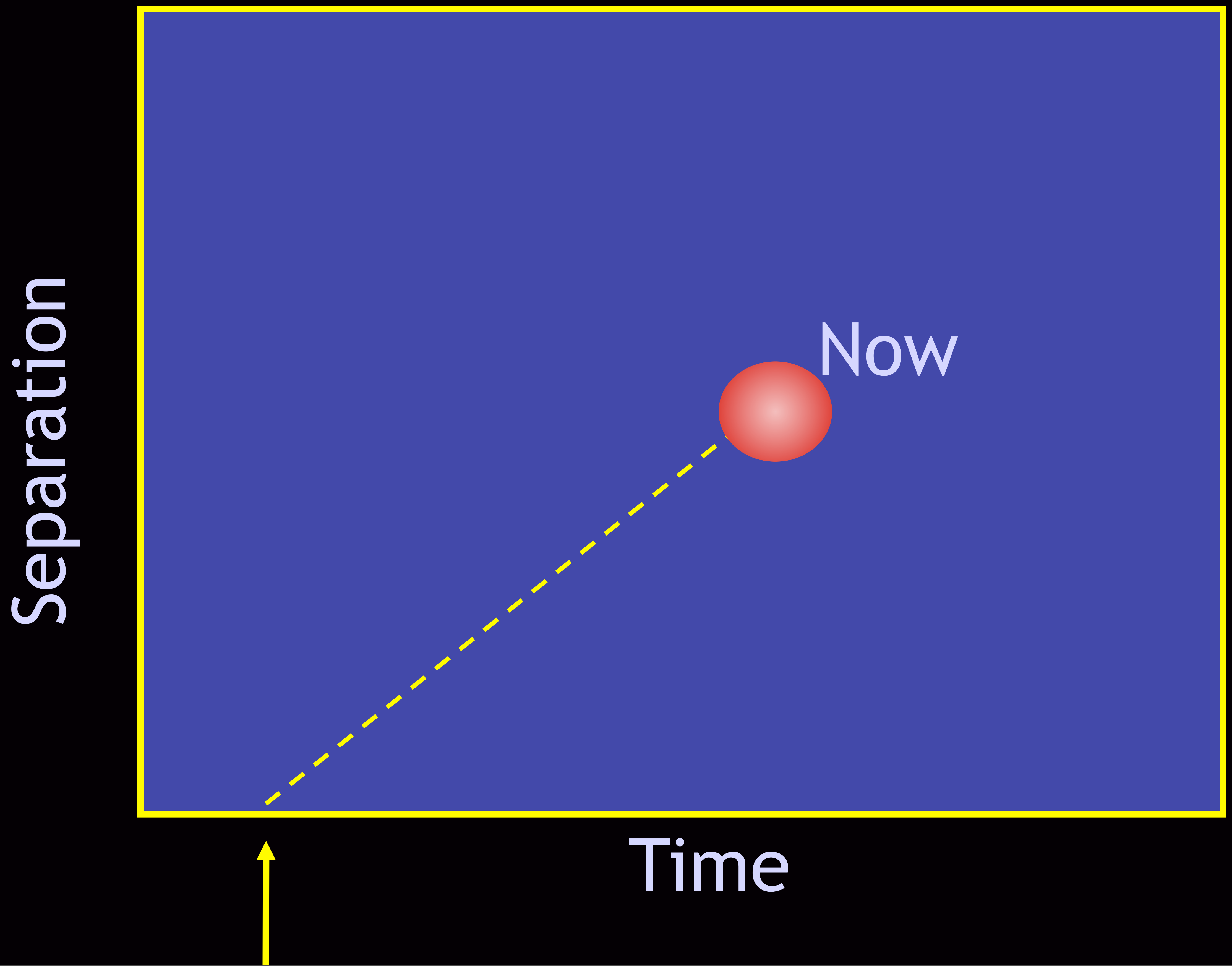
The Distance Between Two Galaxies



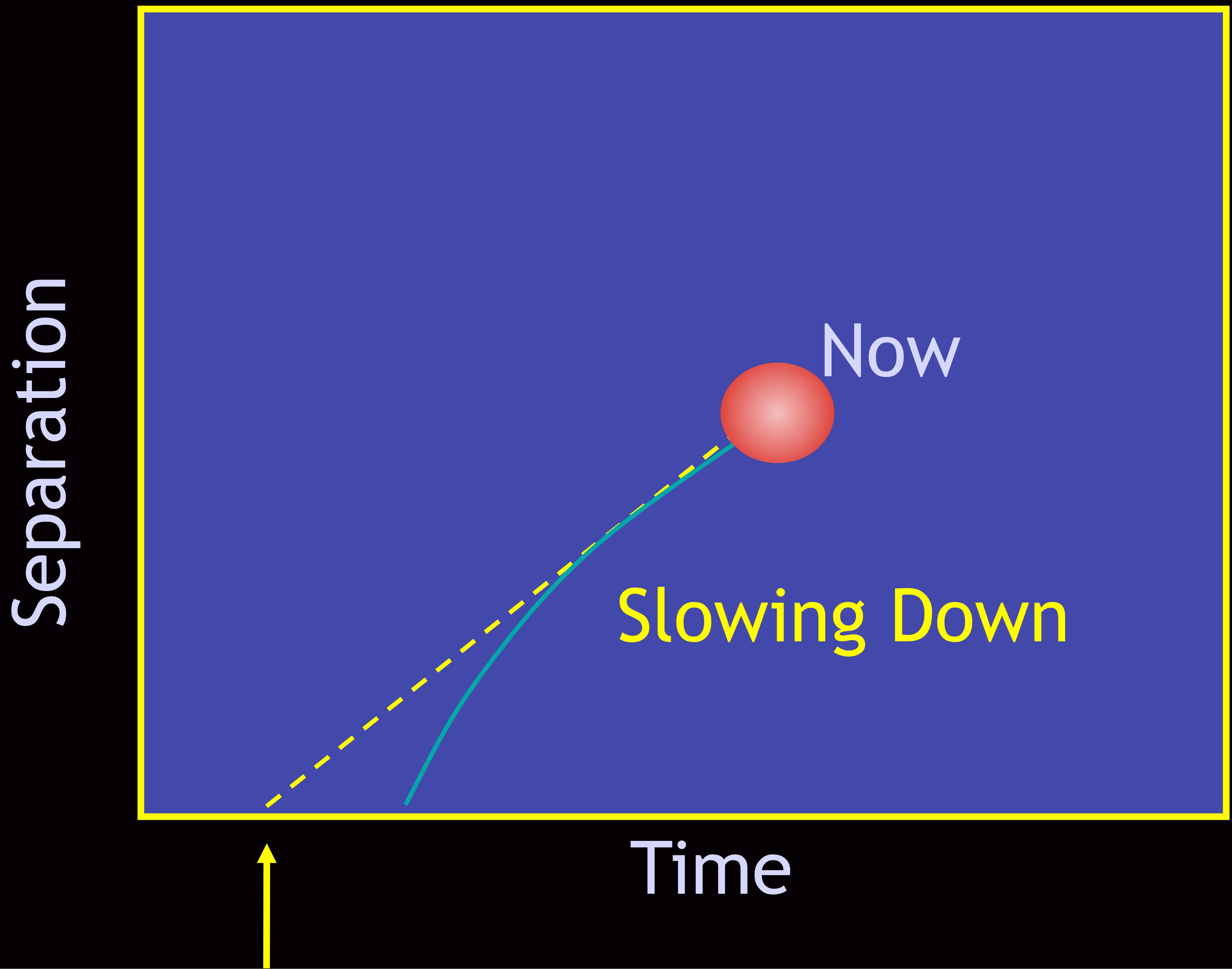
The Distance Between Two Galaxies



The Distance Between Two Galaxies



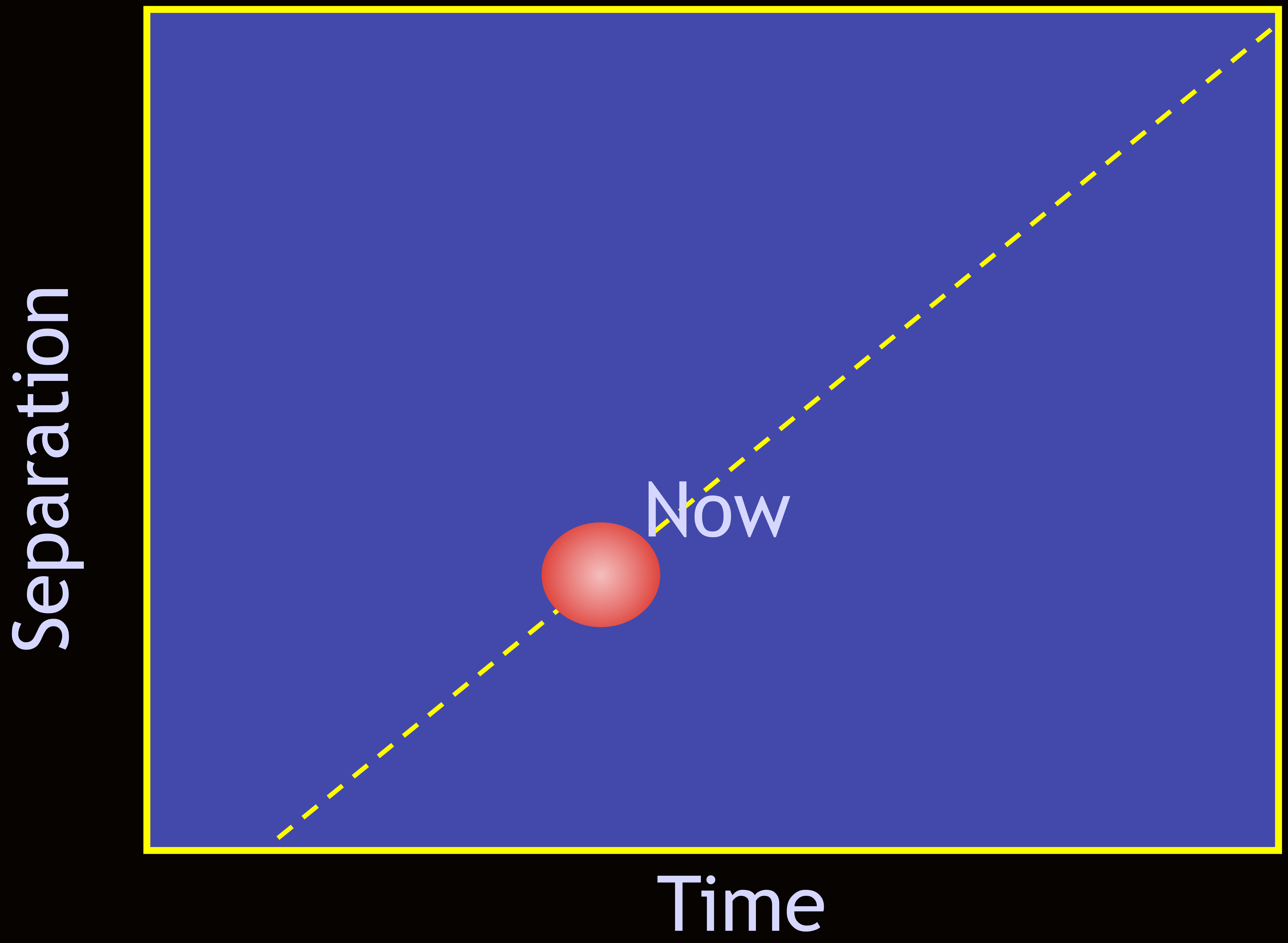
The Distance Between Two Galaxies



Looking towards the Future

Looking towards the Future

Looking towards the Future



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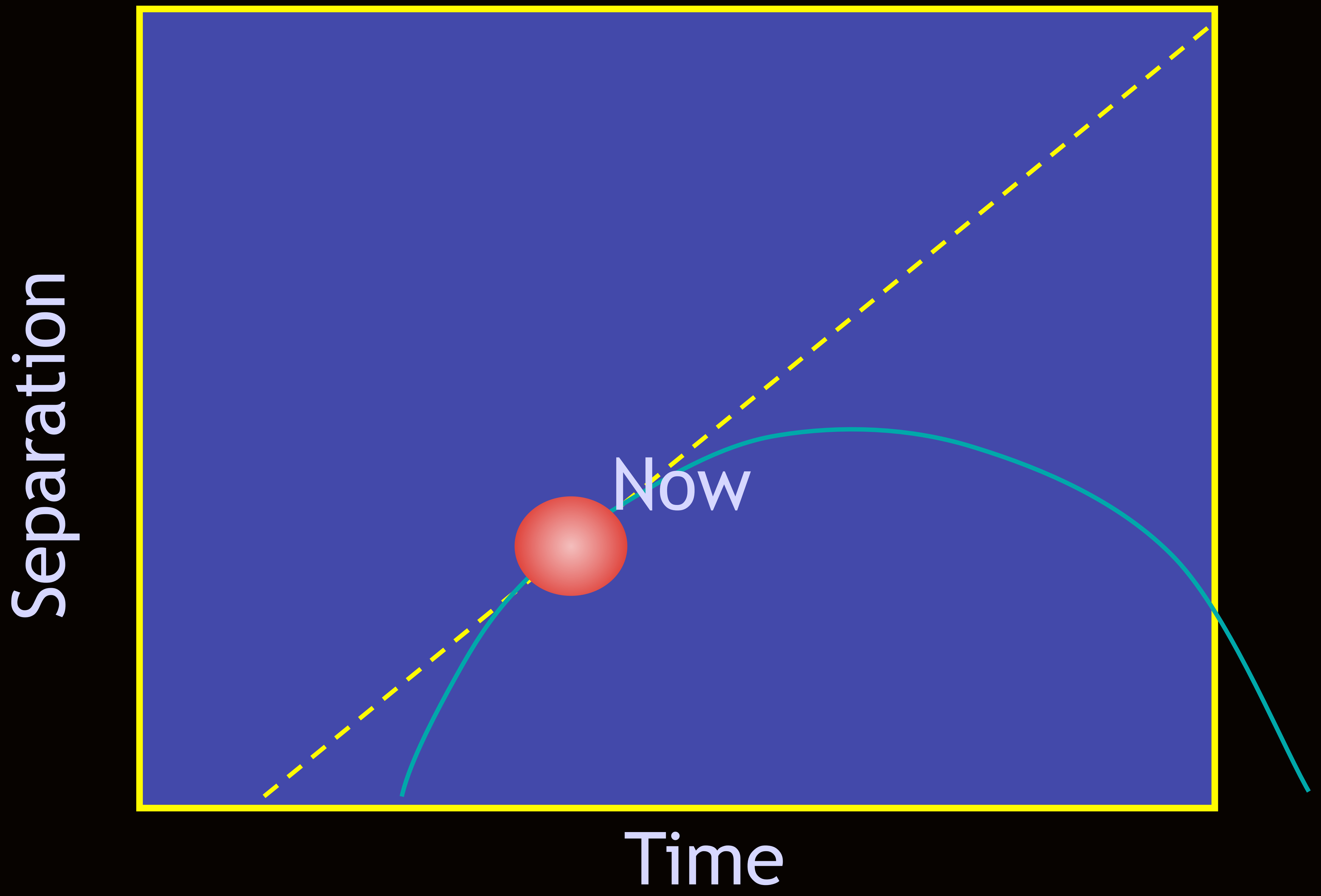

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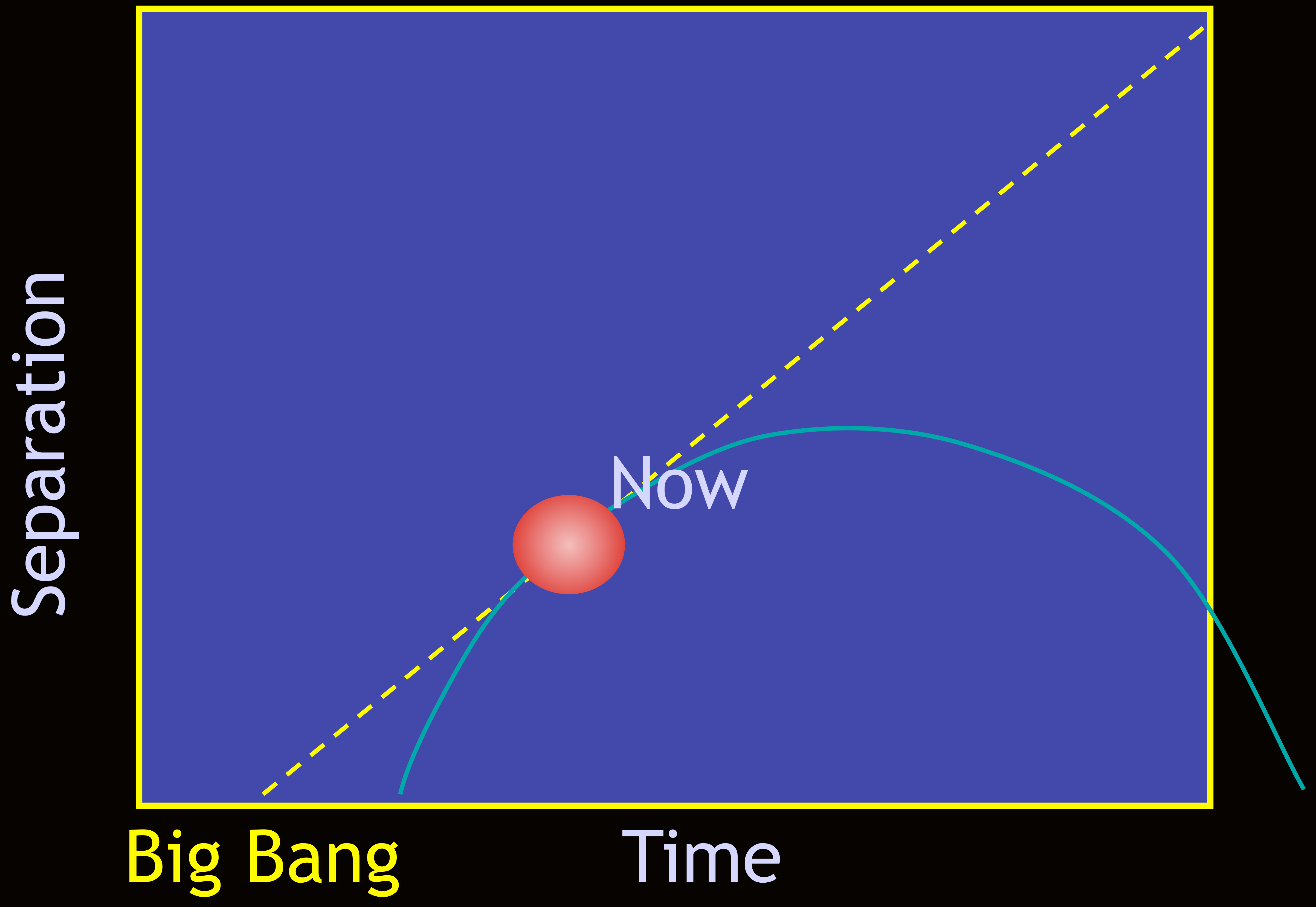

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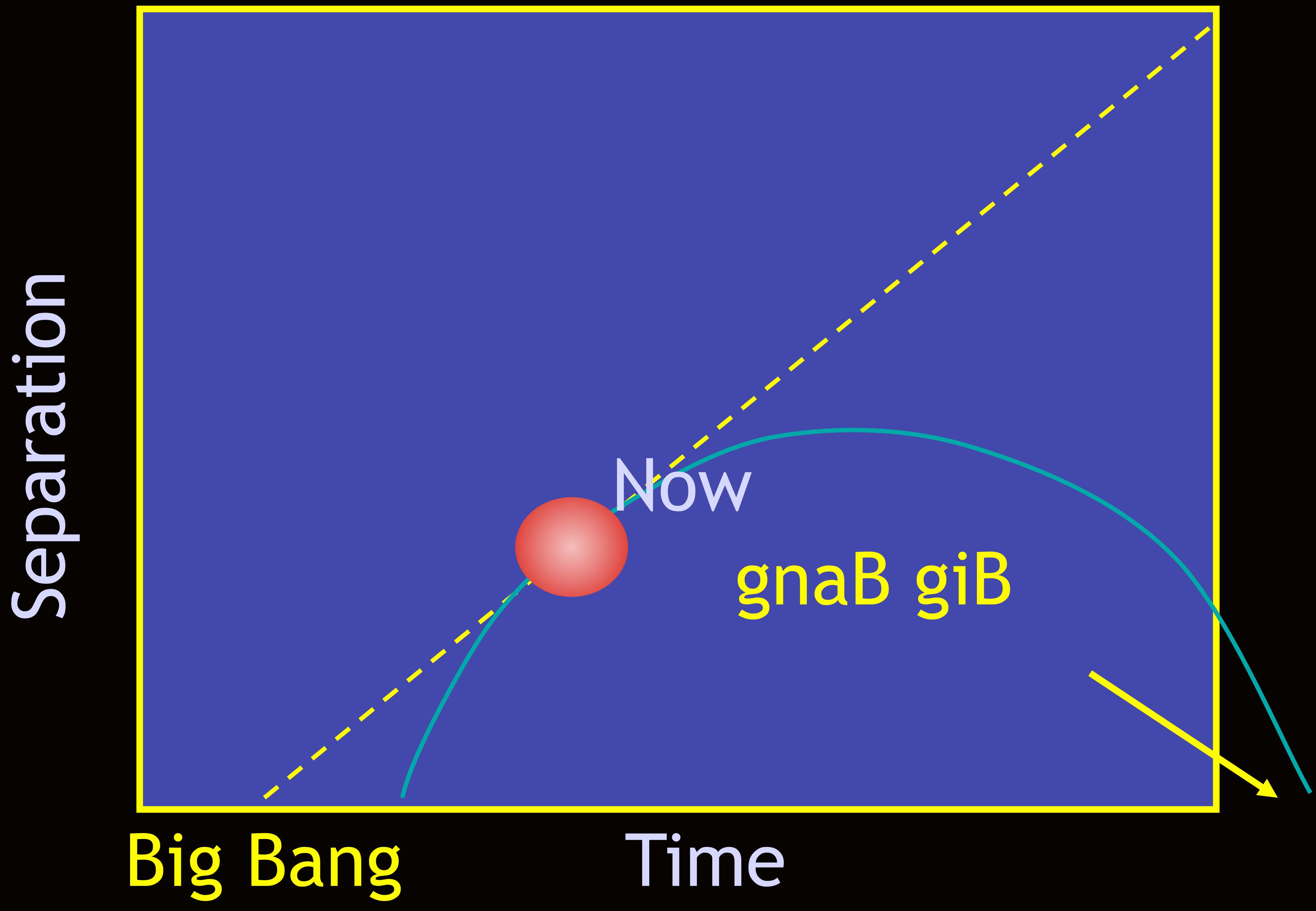
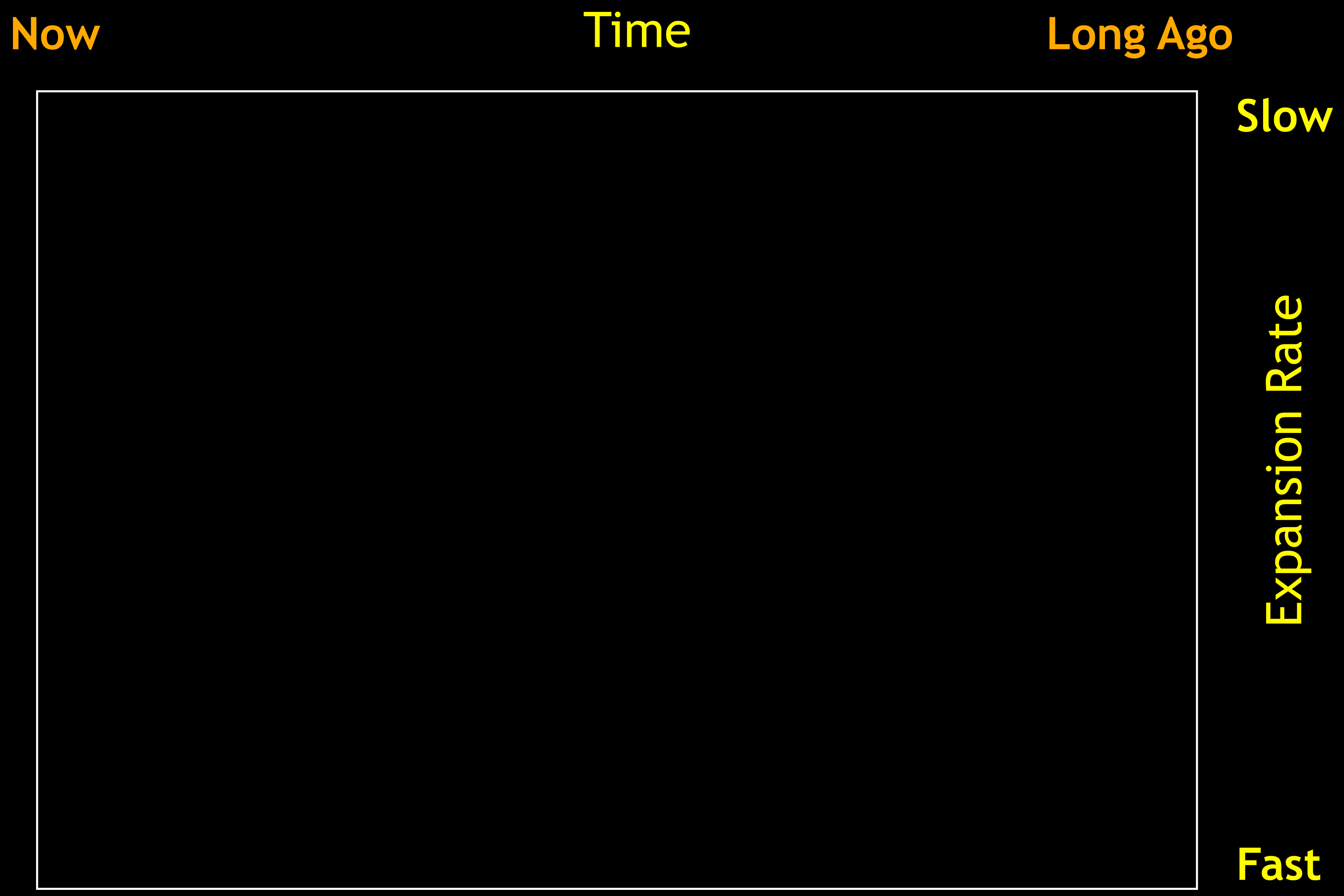


Measure Universe's Past



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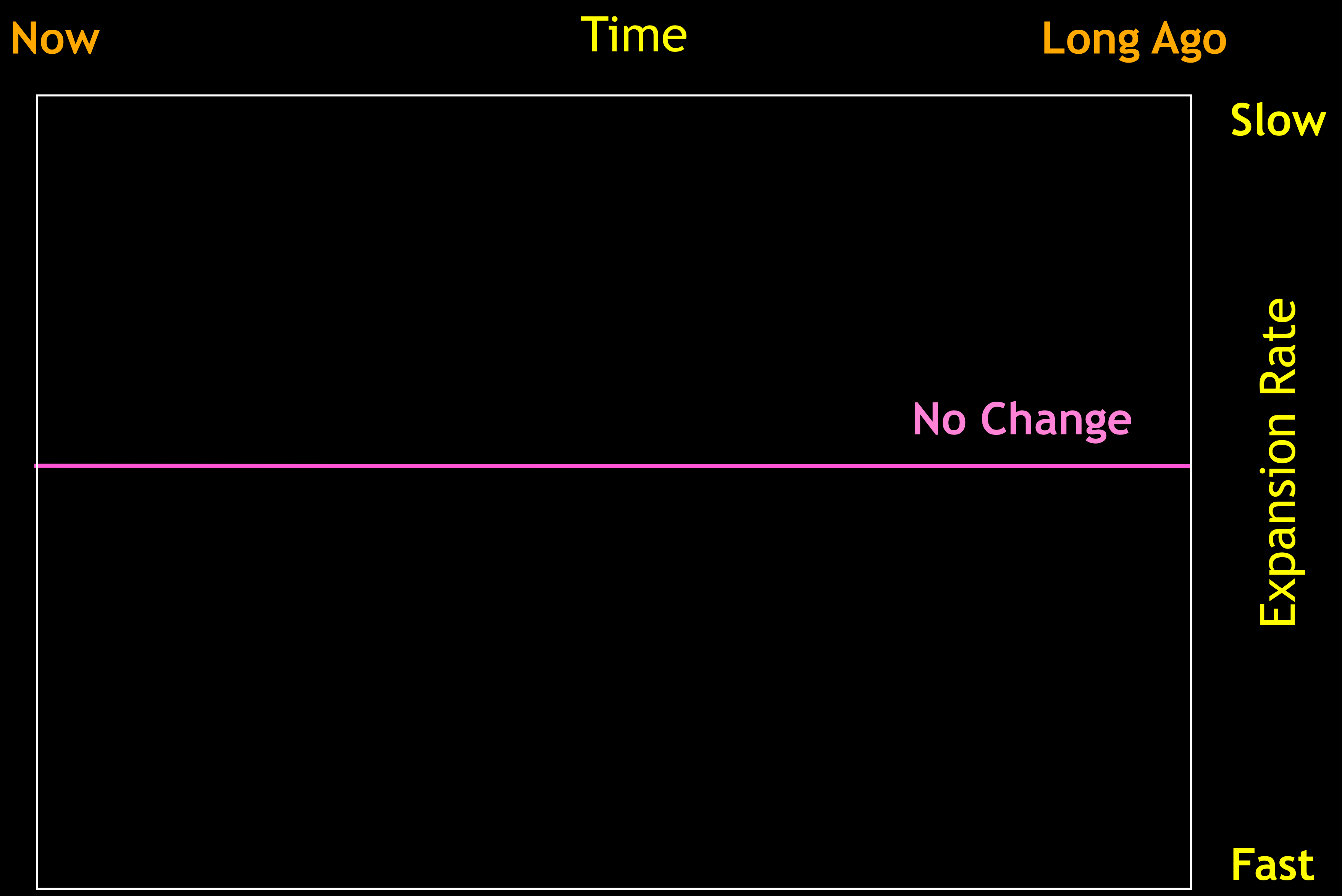

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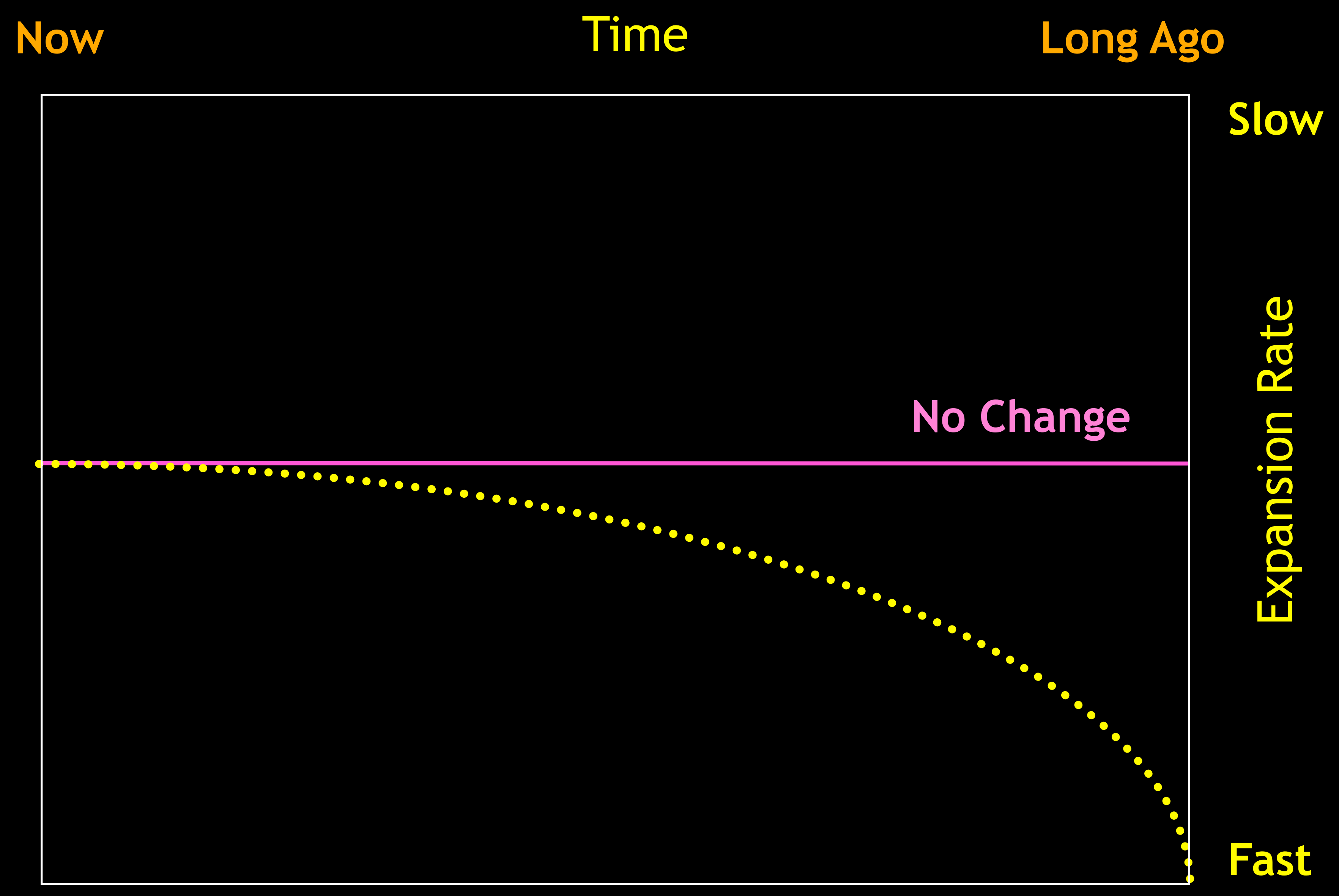
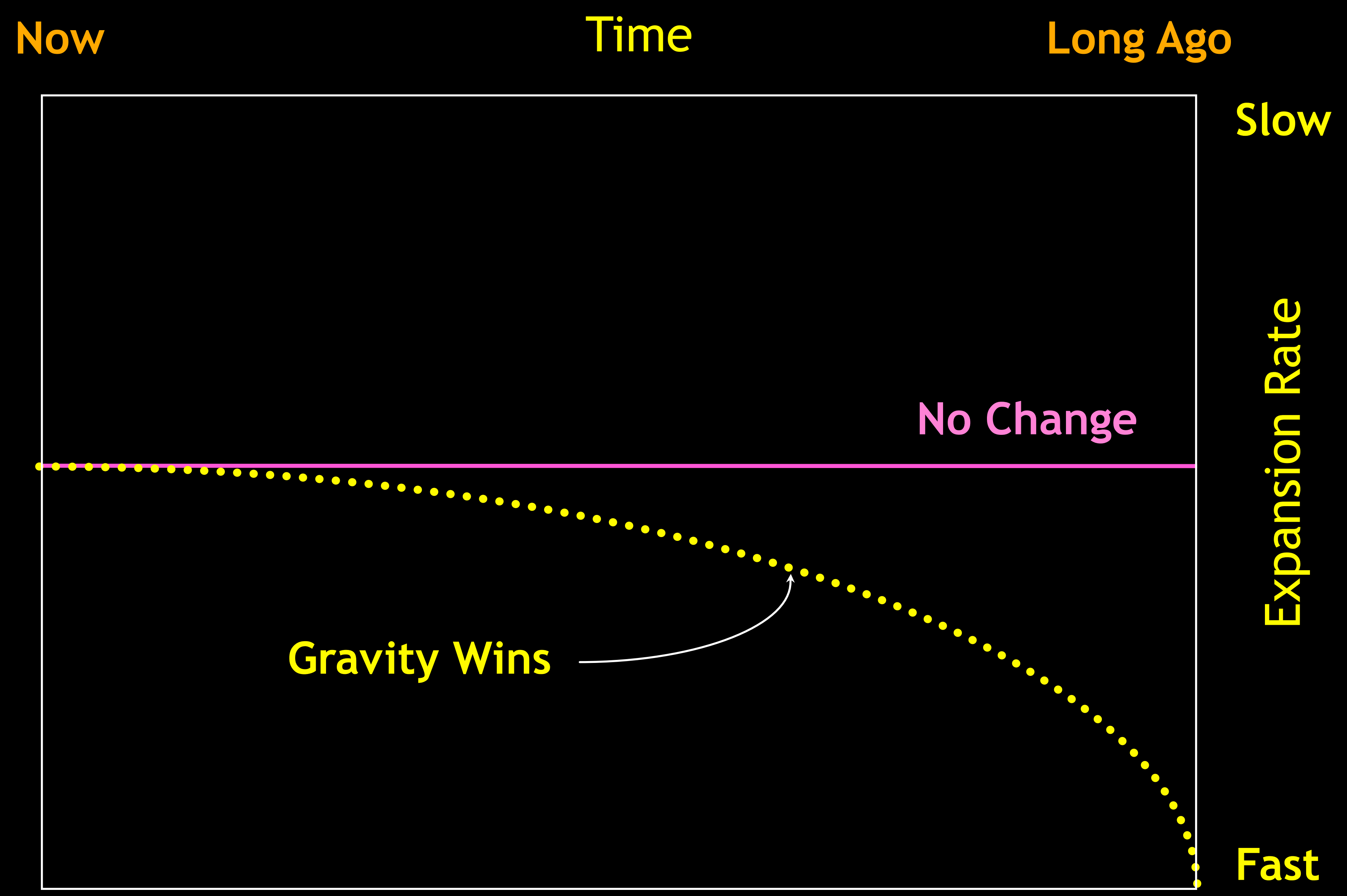
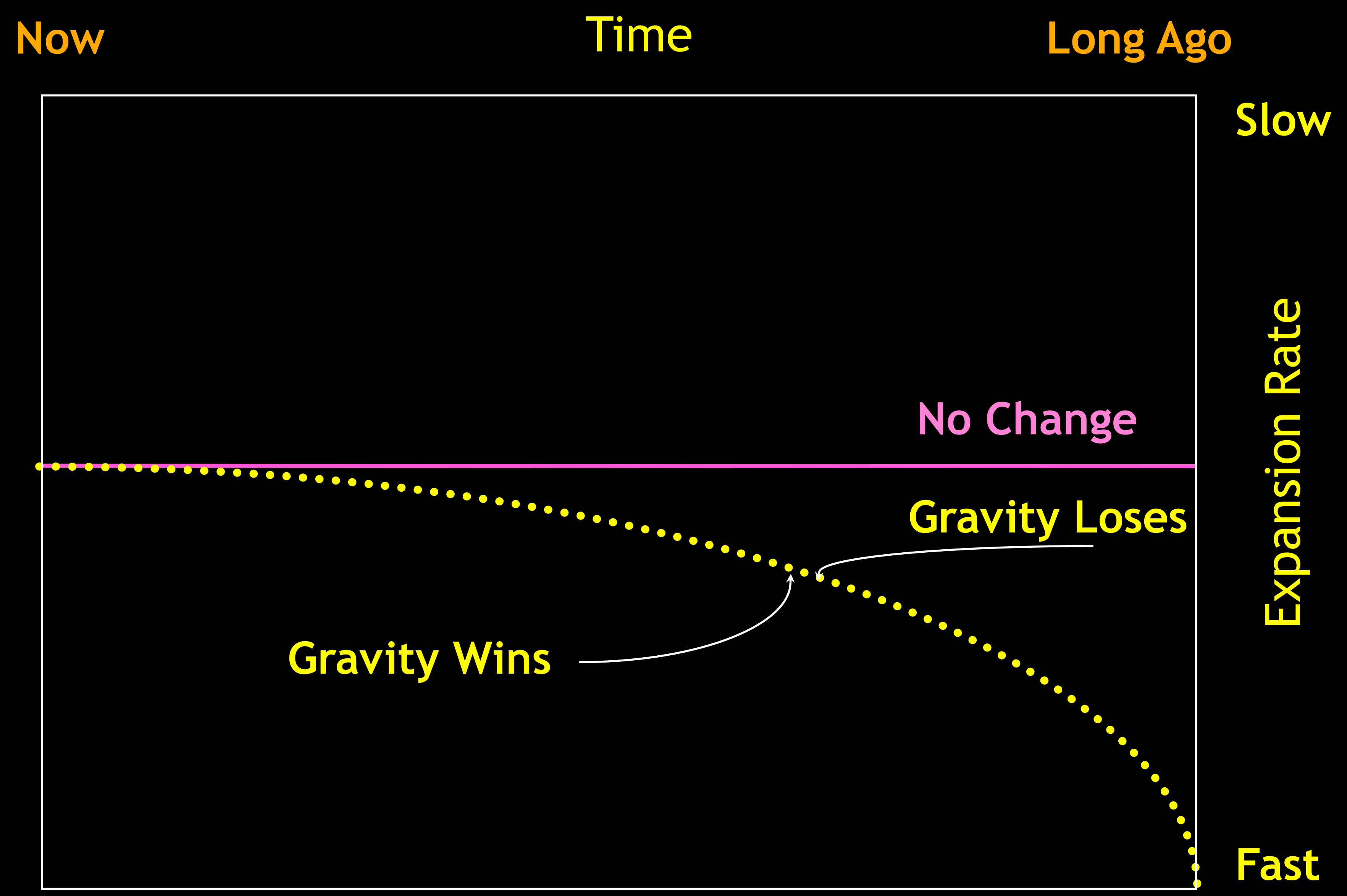


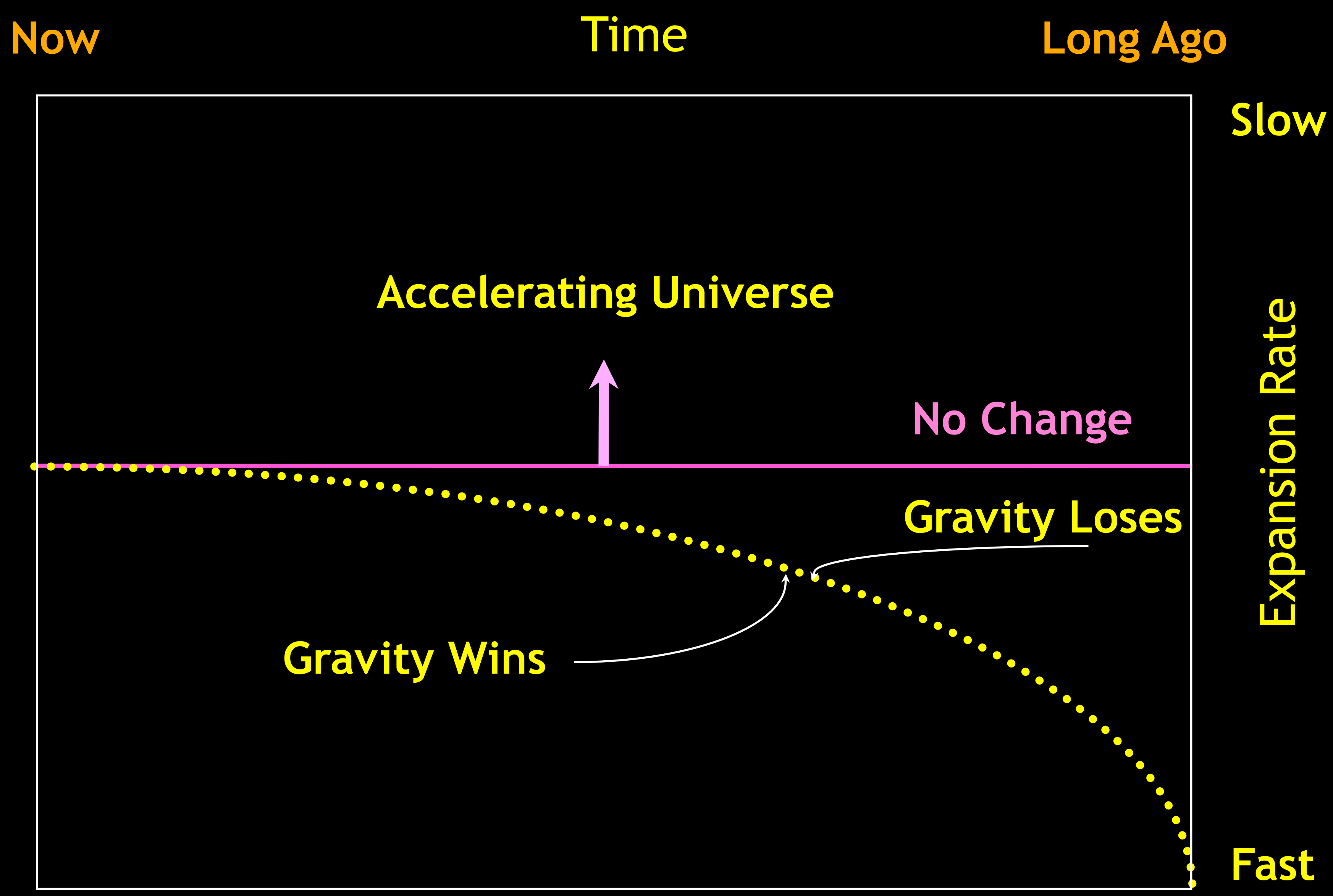
Measure Universe's Past



Measure Universe's Past



Measure Universe's Past



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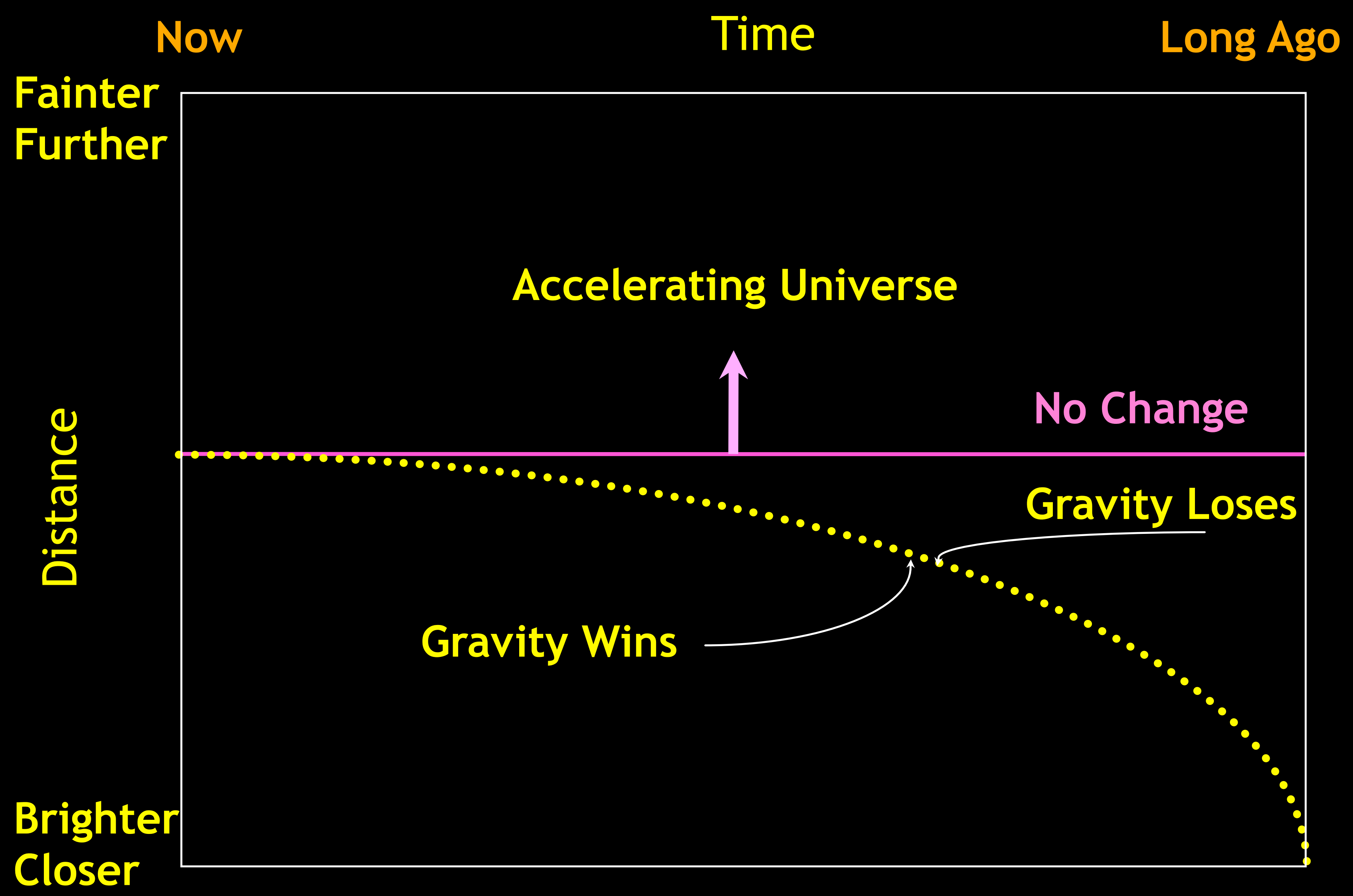
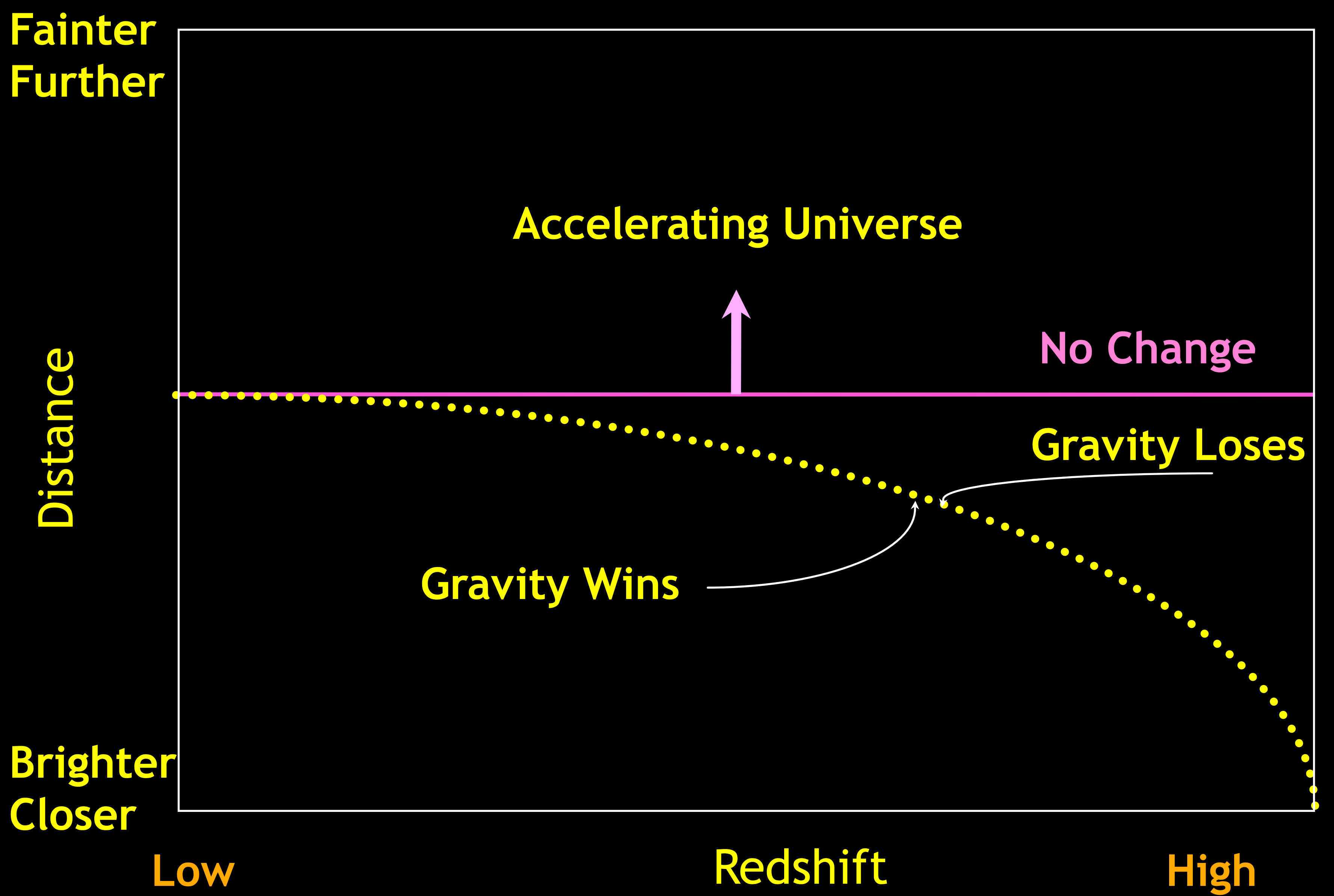


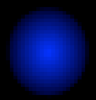
Measure Universe's Past



Type Ia Supernovae

Sun Earth (10 billion years)

0 days



First use of Supernovae to Measure Distances

Fritz Zwicky

18in Schmidt Telescope

Charlie Kowal 1968

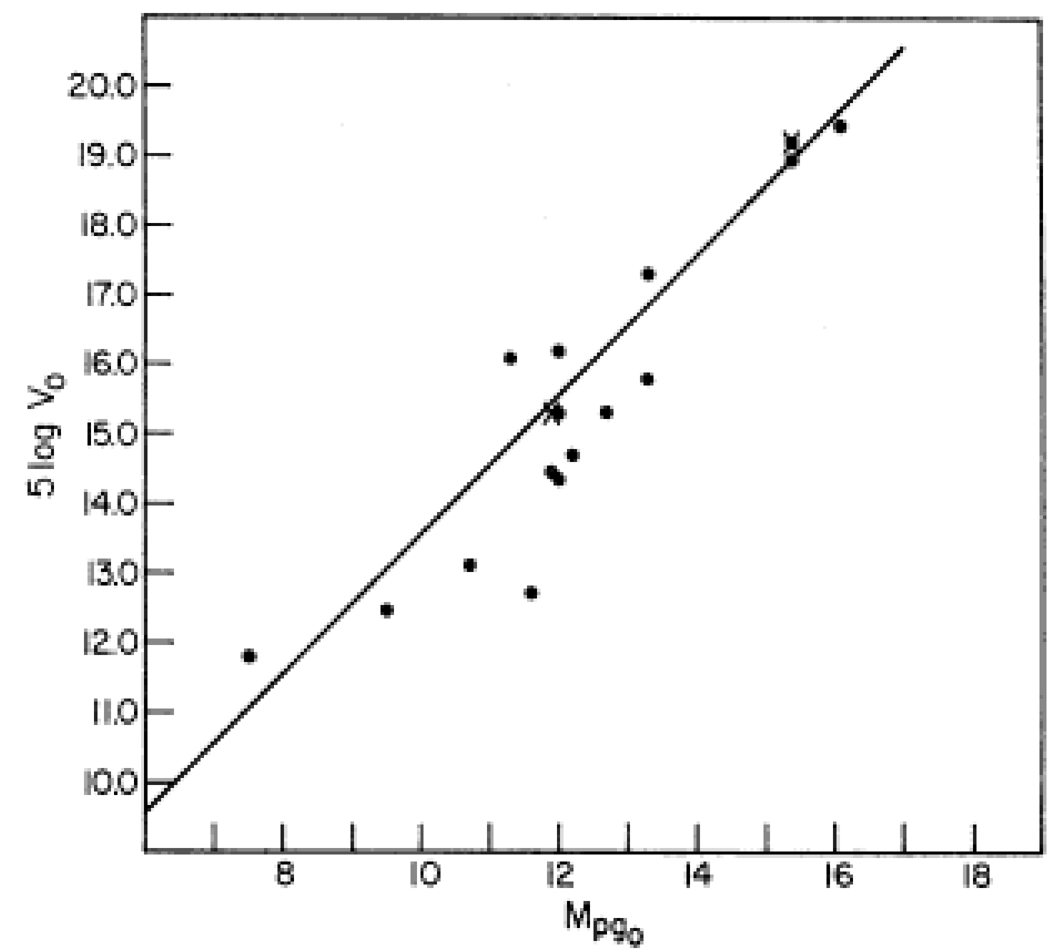


FIG. 1. The redshift–magnitude relation for supernovae of type I. The dots refer to individual supernovae, and the crosses represent averages for the Virgo and Coma clusters, as explained in the text.

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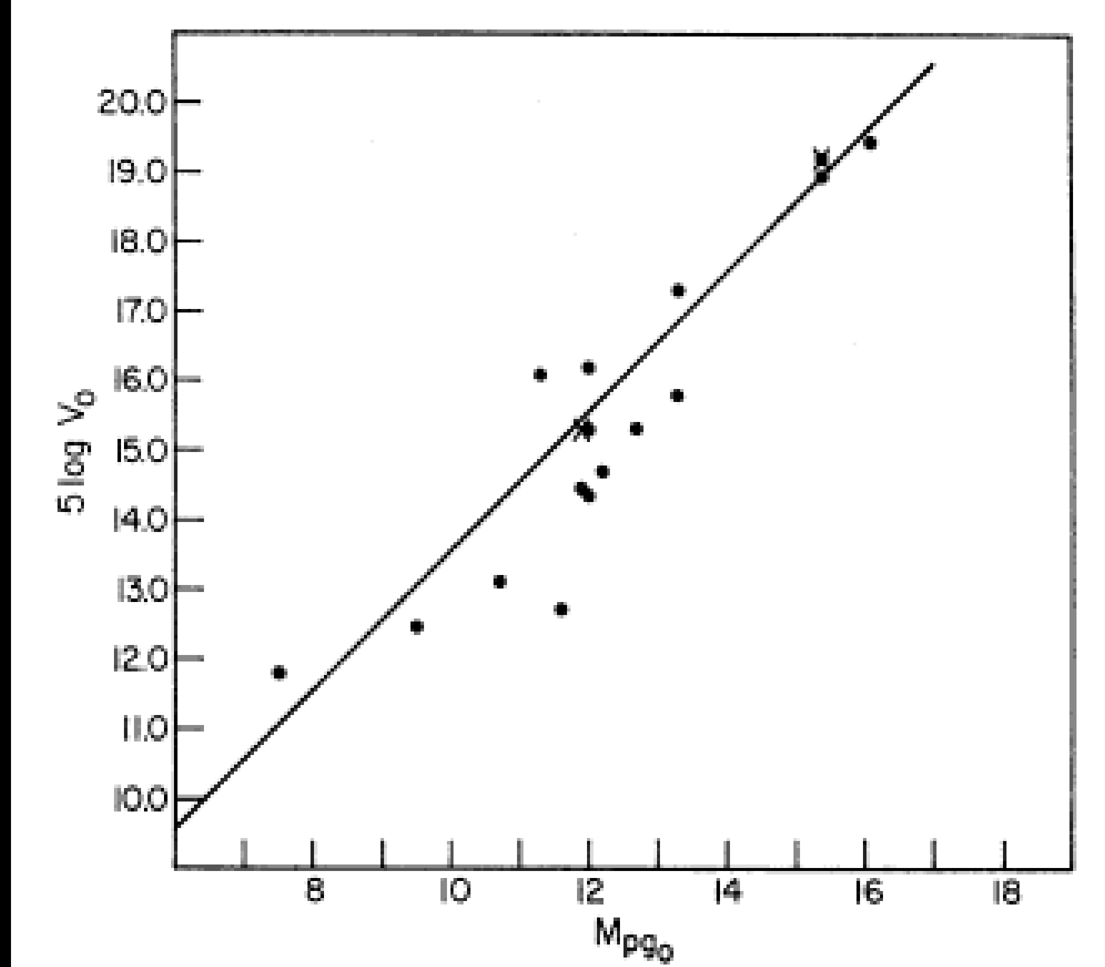


FIG. 1. The redshift–magnitude relation for supernovae of type I. The dots refer to individual supernovae, and the crosses represent averages for the Virgo and Coma clusters, as explained in the text.

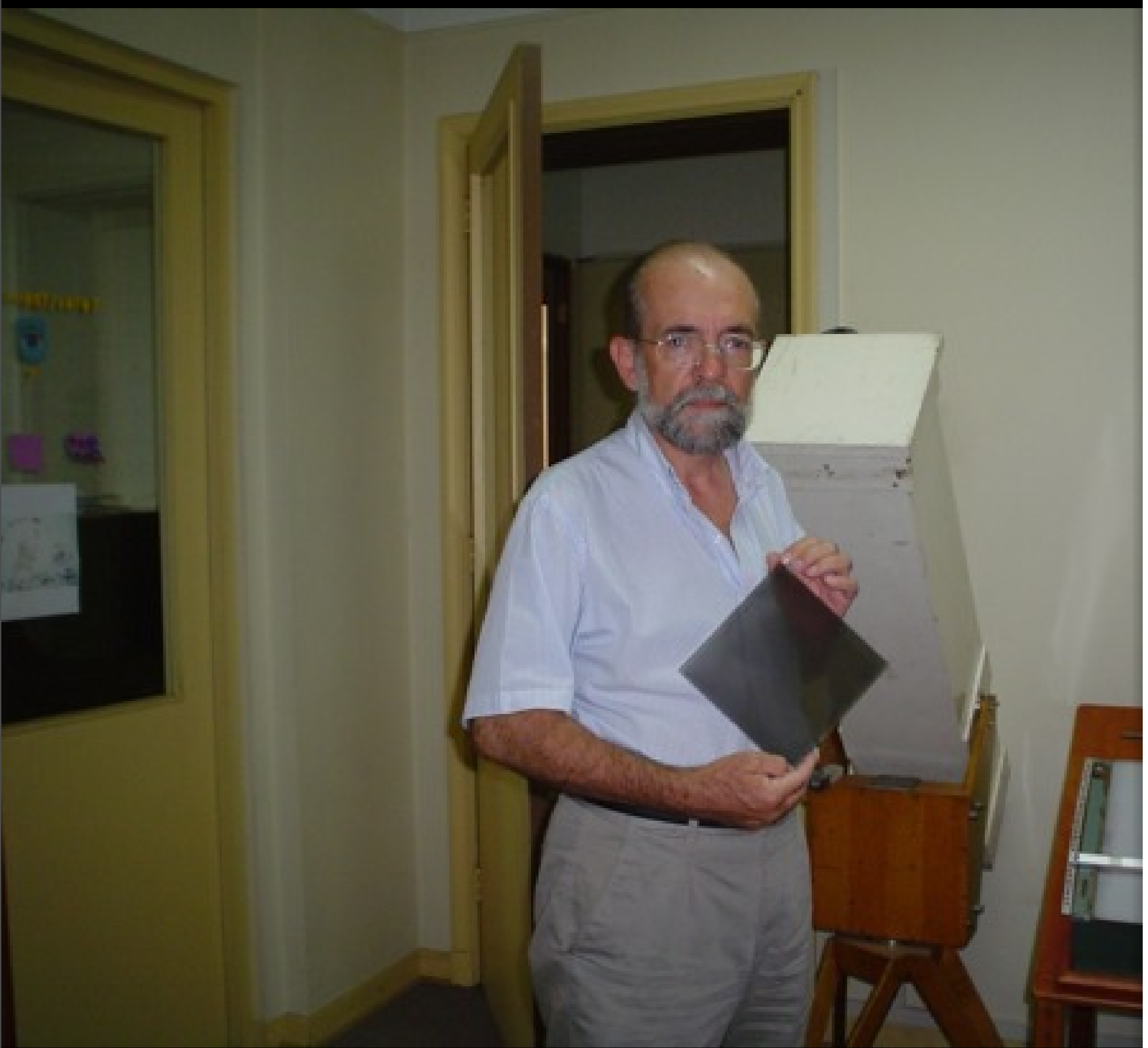
First Distant SN detected in 1988 by Danish Team

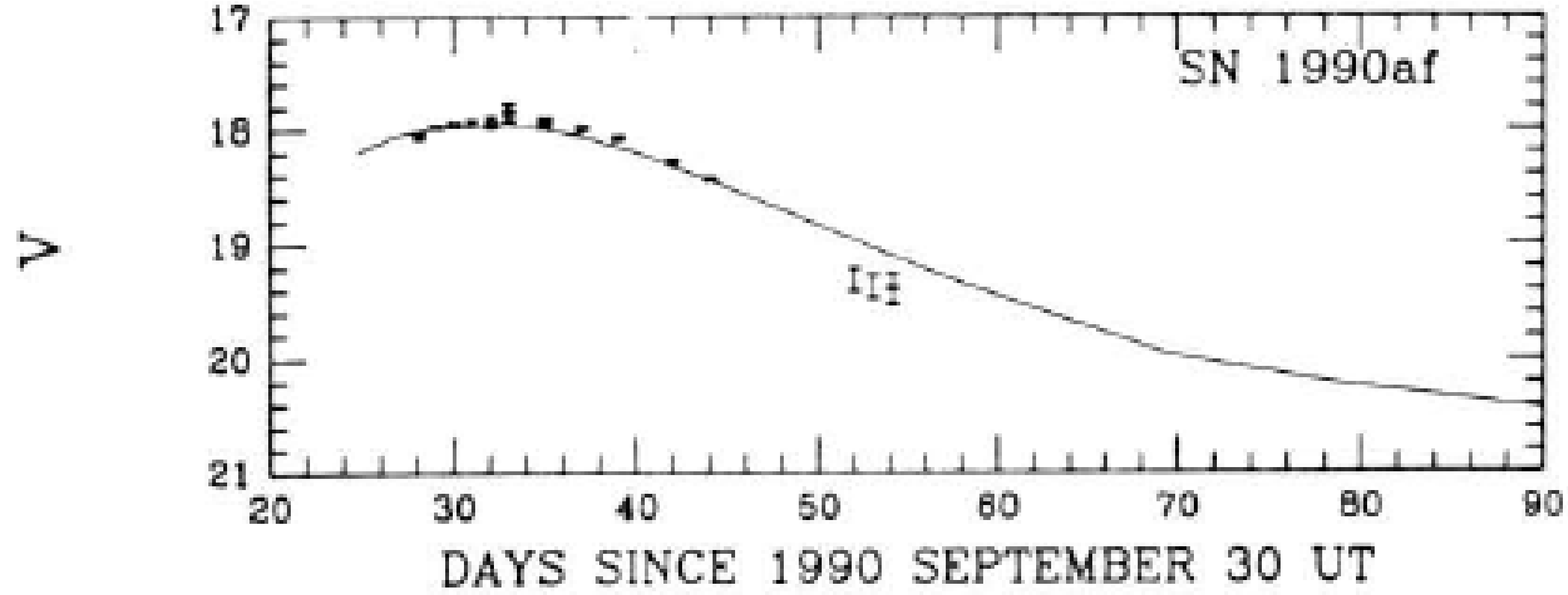
ANTEZANA

AVILES

WISCHNJEWSKY

Calan-Tololo SN Search





SN 1990af
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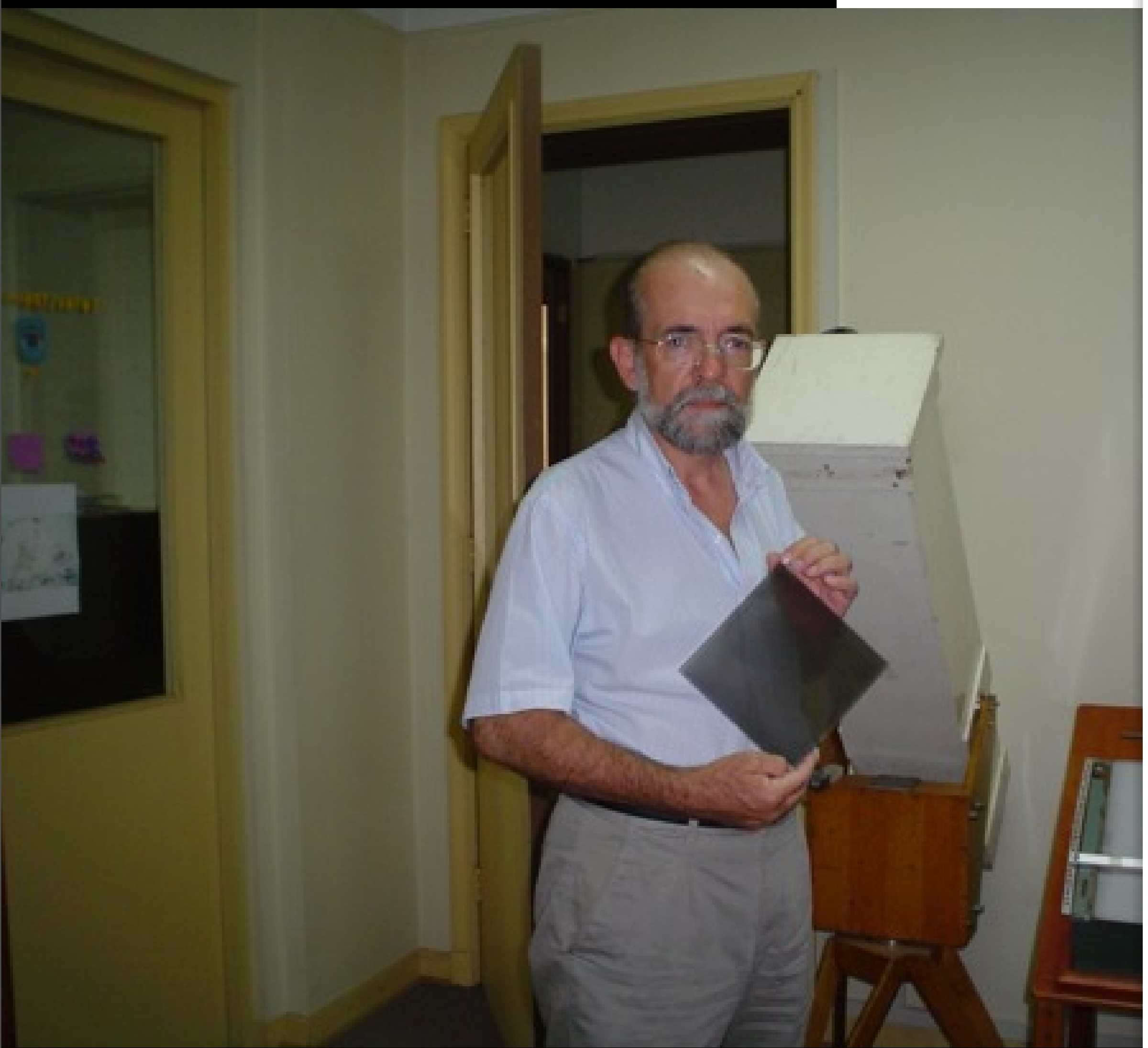
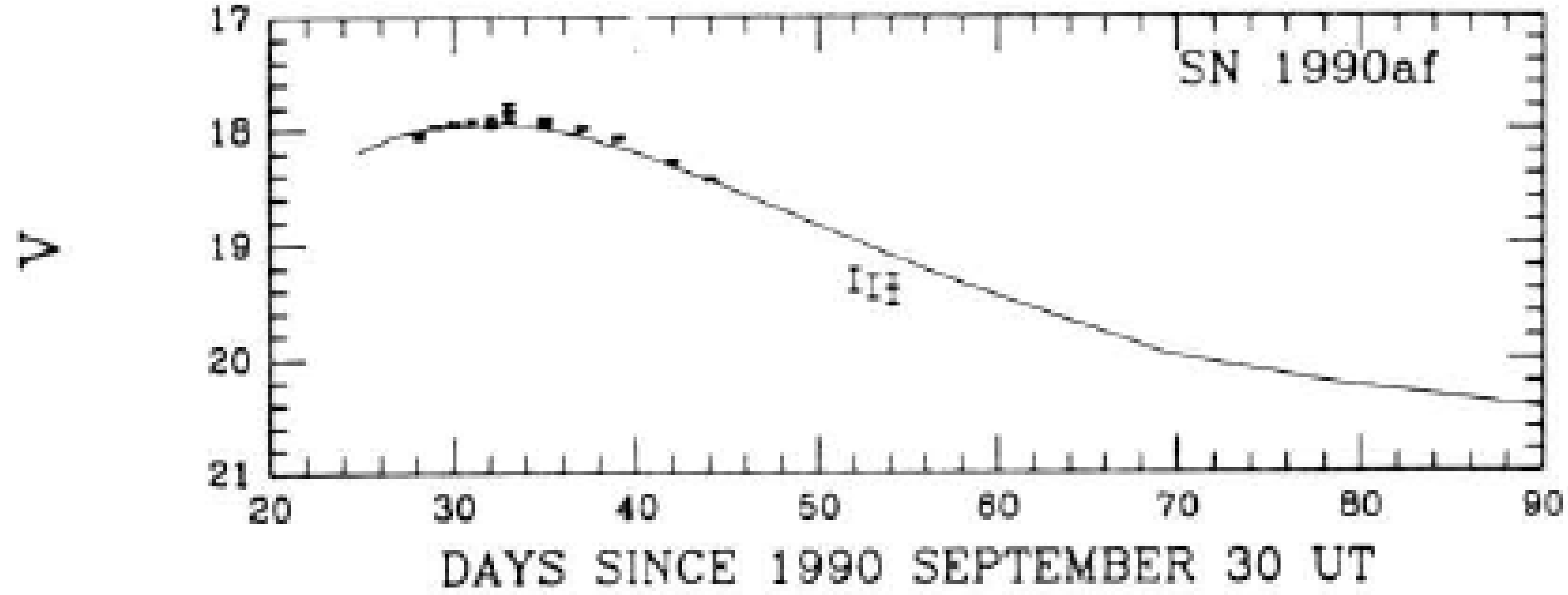
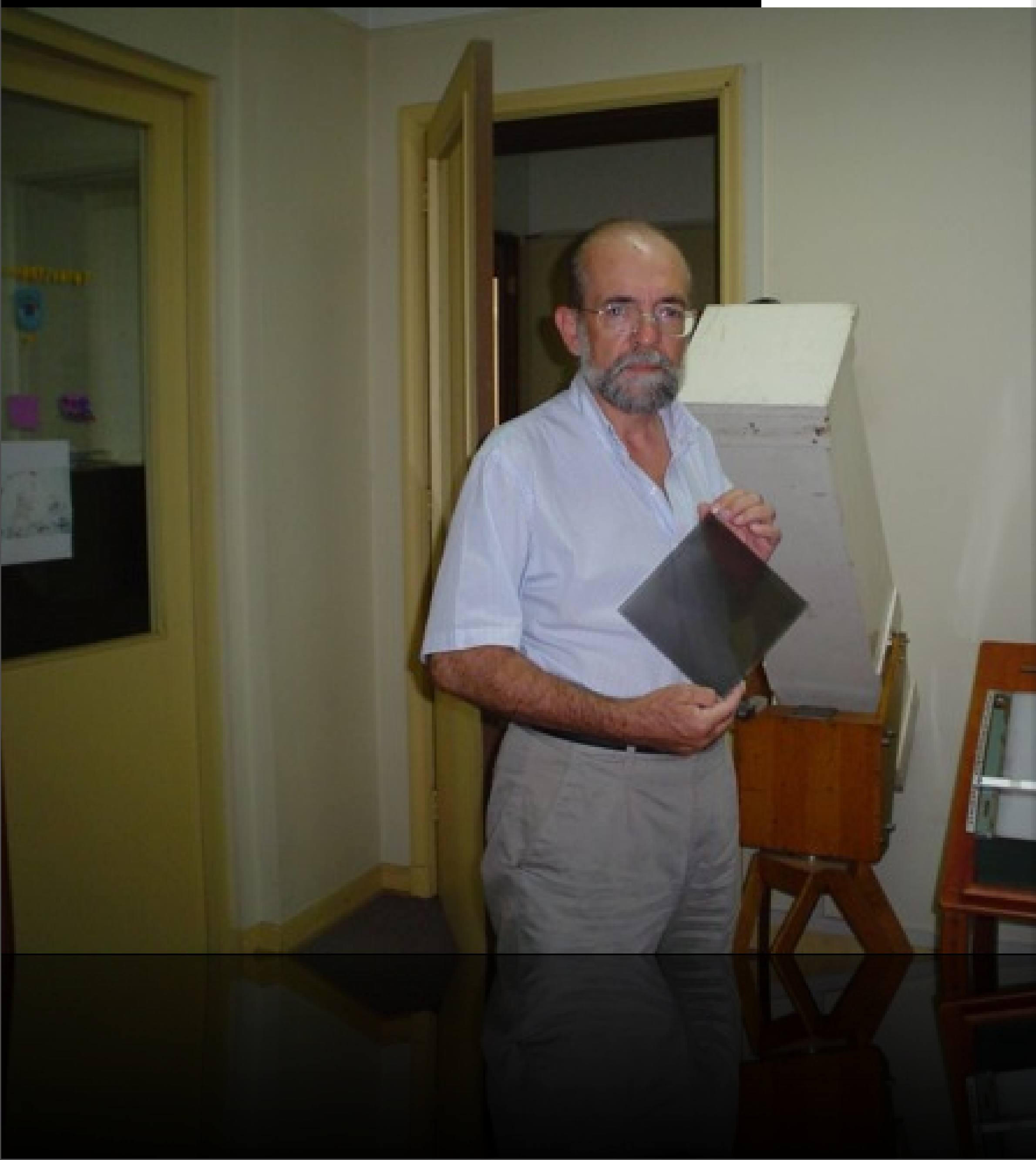
DAYS SINCE 1990 SEPTEMBER 30 UT



SN1990af: faded quickly and was fainter than normal

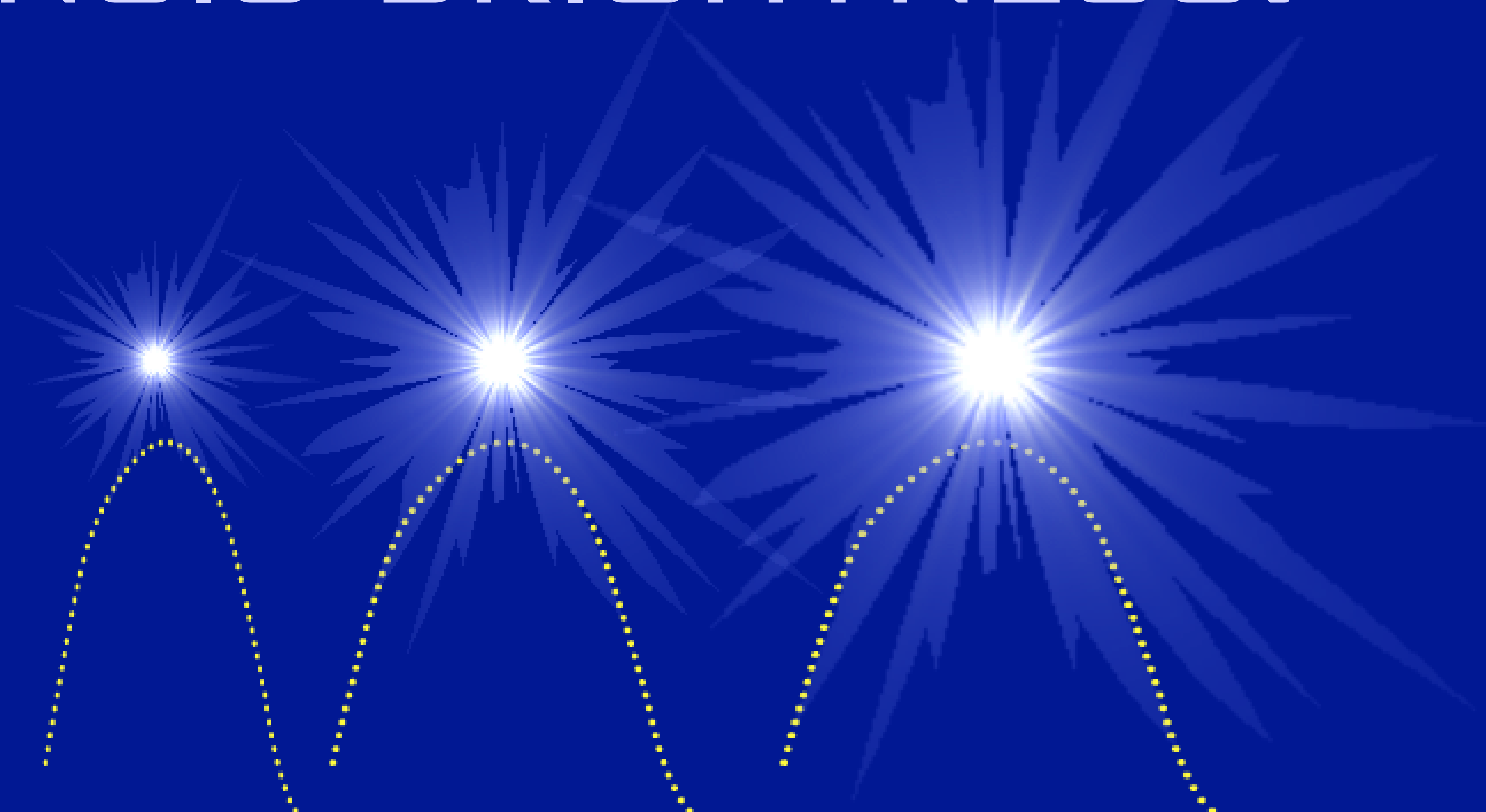




Refining Type Ia Distances

Mark Phillips (1993)

How fast a Supernova Fades is related to its intrinsic brightness.



Adam Riess will explain

1994 Visit to Harvard
Mario Hamuy showed
us this Diagram.

SN Ia are Precision
Distance Indicators!

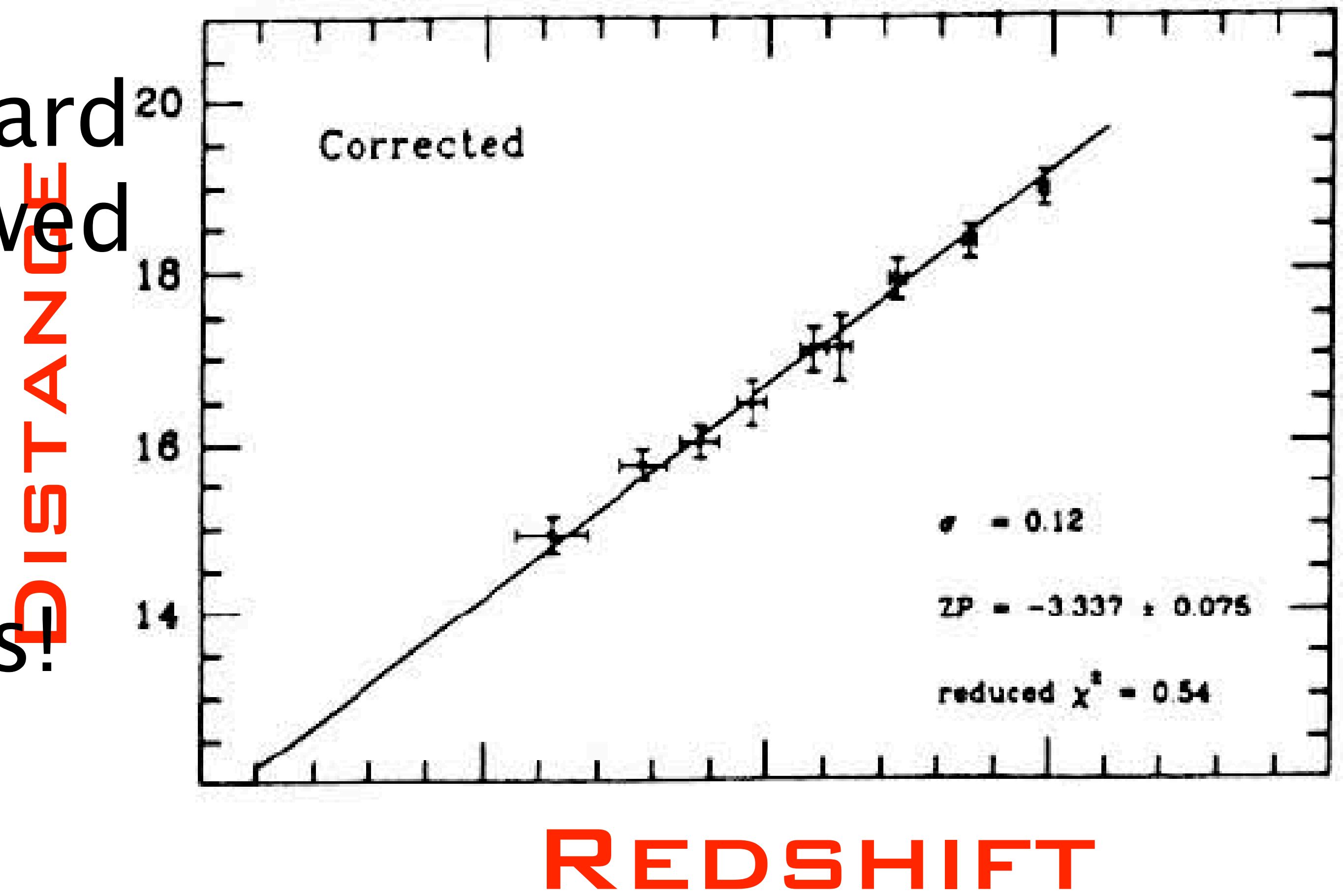


Figure 1: Hubble diagram of SNe Ia in the Calán/Tololo SN survey.

1994 Visit to Harvard
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SN Ia are Precision
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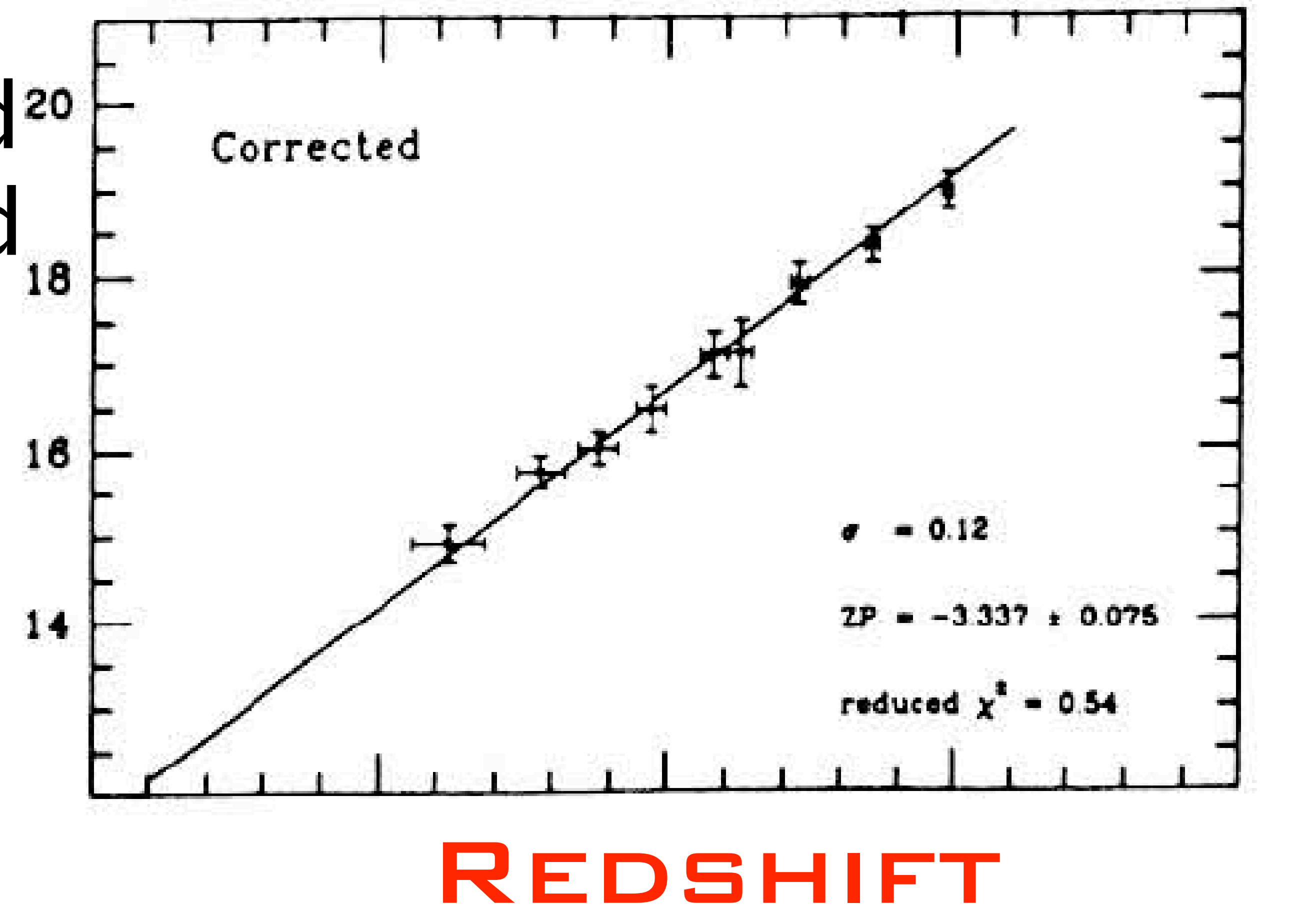

Figure 1: Hubble diagram of SNe Ia in the Calán/Tololo SN survey.

Eventually 29 Type Ia supernovae

Provided the fundamental basis of using SN Ia as accurate distance indicators

The Birth of the High-Z Team

- A month later, Saul Perlmutter asked us at Harvard to confirm a possible supernovae – we found it to be a distant SN

SUPERNOVAE 1994F, 1994G, 1994H

S. Perlmutter, C. Pennypacker, G. Goldhaber, A. Goobar, R. Pain, B. Grossan, A. Kim, M. Kim, and I. Small, Lawrence Berkeley Laboratory and the Center for Particle Astrophysics, Berkeley, report three discoveries from a search for pre-maximum-light, high-redshift supernovae by themselves and R. McMahon, Institute of Astronomy, Cambridge; P. Bunclark, D. Carter, and M. Irwin, Royal Greenwich Observatory; M. Postman and W. Oegerle, Space Telescope Science Institute; T. Lauer, National Optical Astronomy Observatory; and J. Hoessel, University of Wisconsin. Following are given the designation, date of first detection, discovery magnitude and telescope (INT = 2.5-m Isaac Newton Telescope; KPNO = 4-m Kitt Peak telescope), supernova position for equinox 1950.0, offsets from the host galaxy's center, and date of the previous image of the galaxy not showing the supernova (to limiting mag about 24): SN 1994F, Jan. 9, R = 22.0, INT, R.A. = 11h47m25s.15, Decl. = +10o59'38".8, 1".1 west, 0".2 north, 1993 Dec. 22; SN 1994G, Feb. 13, I = 21.8, KPNO, R.A. = 10h16m17s.38, Decl. = +51o07'23".5, 1".4 east, 0".1 north, 1994 Jan. 16; SN 1994H, Jan. 8, R = 21.9, INT, R.A. = 2h37m32s.22, Decl. = -1o46'57".5, 1".2 west, 0".1 south, 1993 Dec. 20. On Jan. 18, spectra of SN 1994F were obtained by J. B. Oke with the Keck Telescope Low Resolution Imaging Spectrograph; the host galaxy redshift is 0.354, and the spectrum of SN 1994F matched that of a type-Ia supernova a week past maximum light. On Mar. 9 and 10, spectra of SN 1994G were obtained by A. Riess, P. Challis, and R. Kirshner at the Multiple Mirror Telescope, in which emission lines of [O II] and [O III] from the host galaxy give a redshift of z = 0.425; the spectrum of the SN 1994G, though noisy, is consistent with a type-I supernova about a week past maximum light. SN 1994H was observed on numerous nights from Jan. 10 to Feb. 16 at the INT, at Kitt Peak by G. Jacoby and others, at the European Southern Observatory by M. Turrato, and at Siding Spring Observatory by M. Dopita; the resulting photometry is consistent with a type-Ia supernova at an implied redshift of about 0.32 (the host galaxy is on the periphery of a cluster with that redshift), with maximum light around Jan. 12.

The Birth of the High-Z Team

- I was down visiting Nick Suntzeff in July 1994, and we discussed the idea of doing our own High-Z SN Ia

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Observing Proposal
Cerro Tololo Inter-American Observatory

Date: September 29, 1994 *Proposal number:*

TITLE: A Pilot Project to Search for Distant Type Ia Supernovae

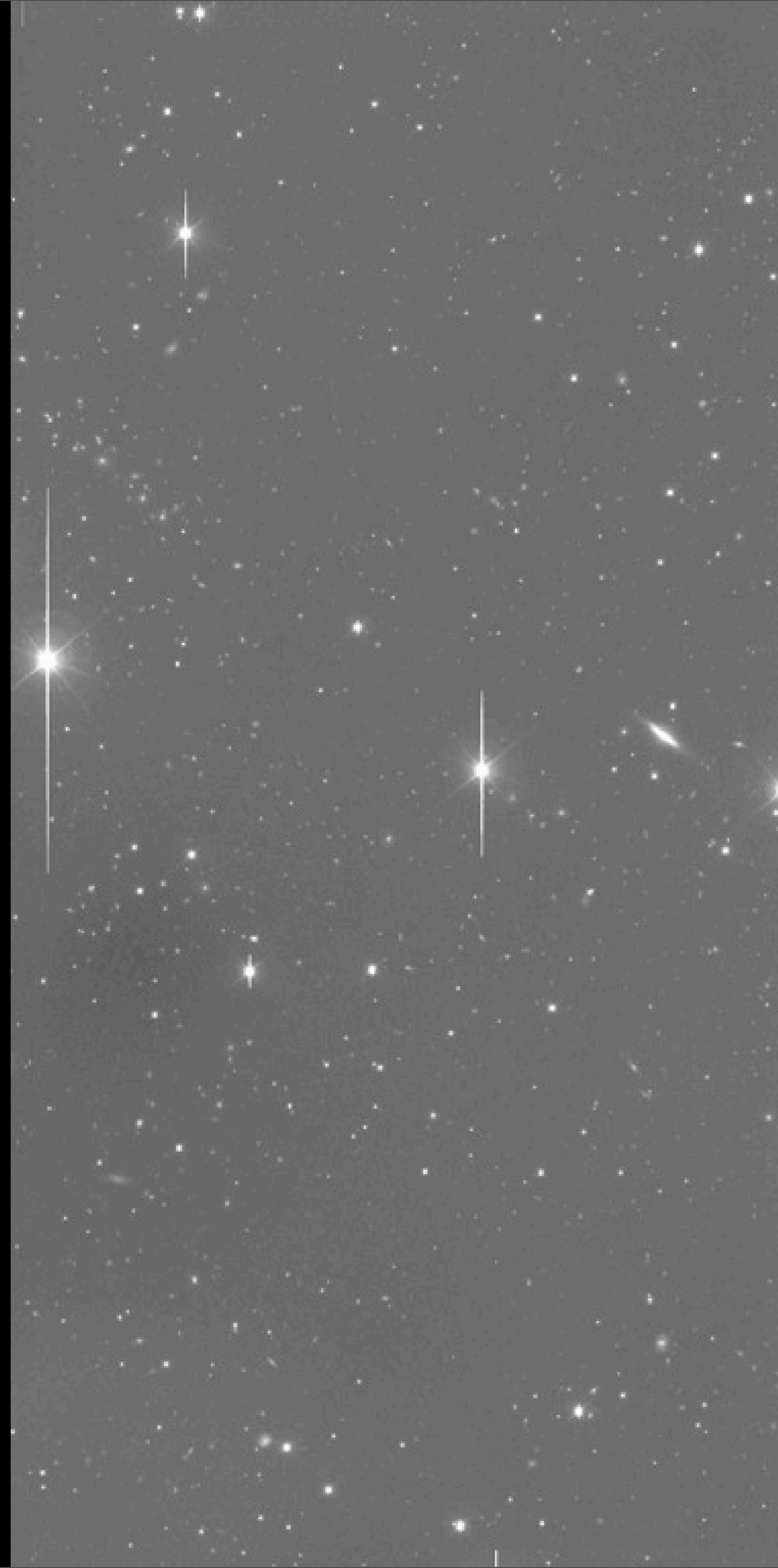
PI: N. Suntzeff Grad student? N nsuntzeff@ctio.noao.edu
CTIO, Casilla 603, La Serena Chile 56-51-225415

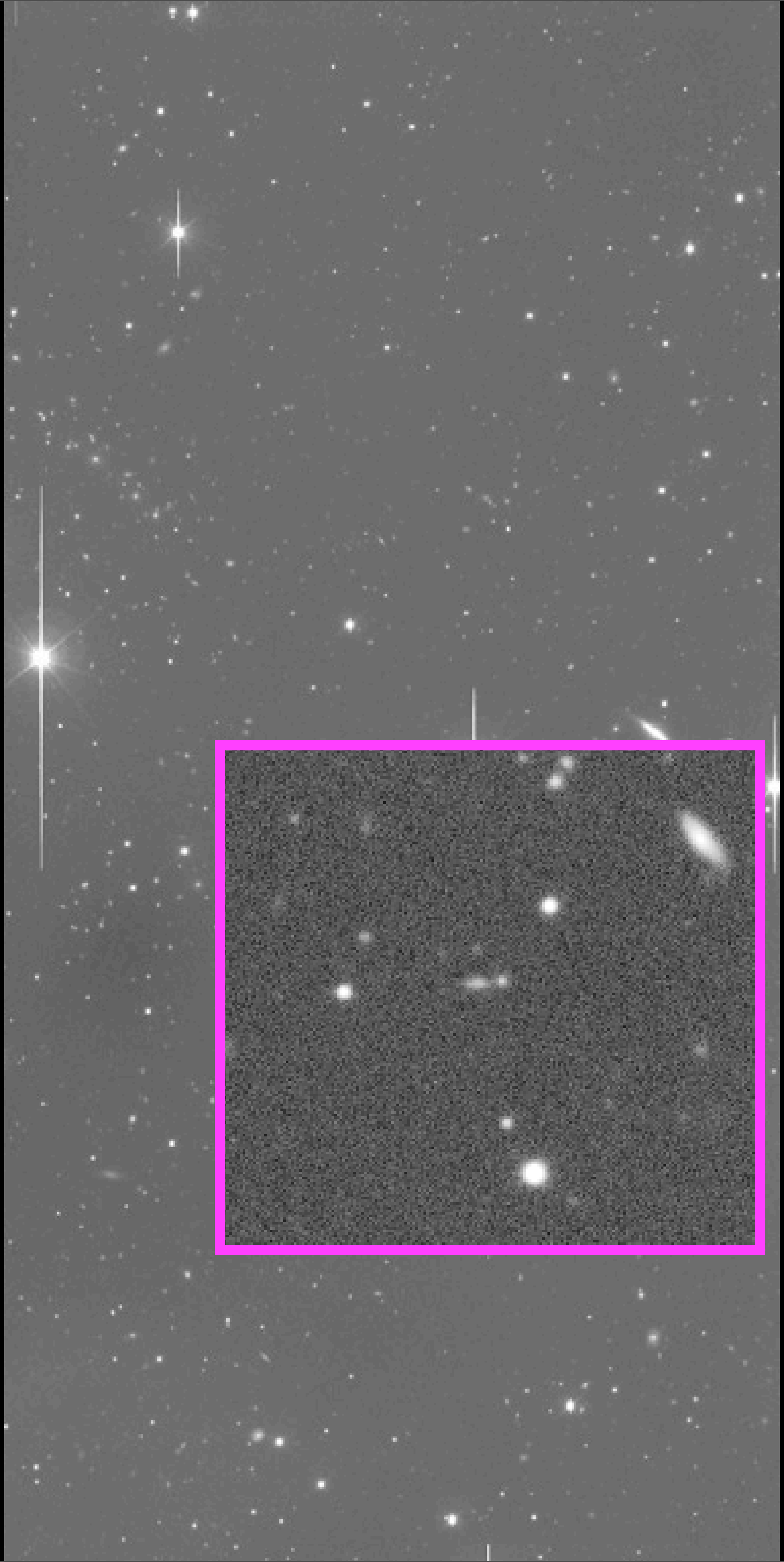
CoI: B. Schmidt Grad student? N brian@cfanewton.harvard.edu
CfA/MSSSO, 60 Garden St., Cambridge, MA 02138 617 495 7390

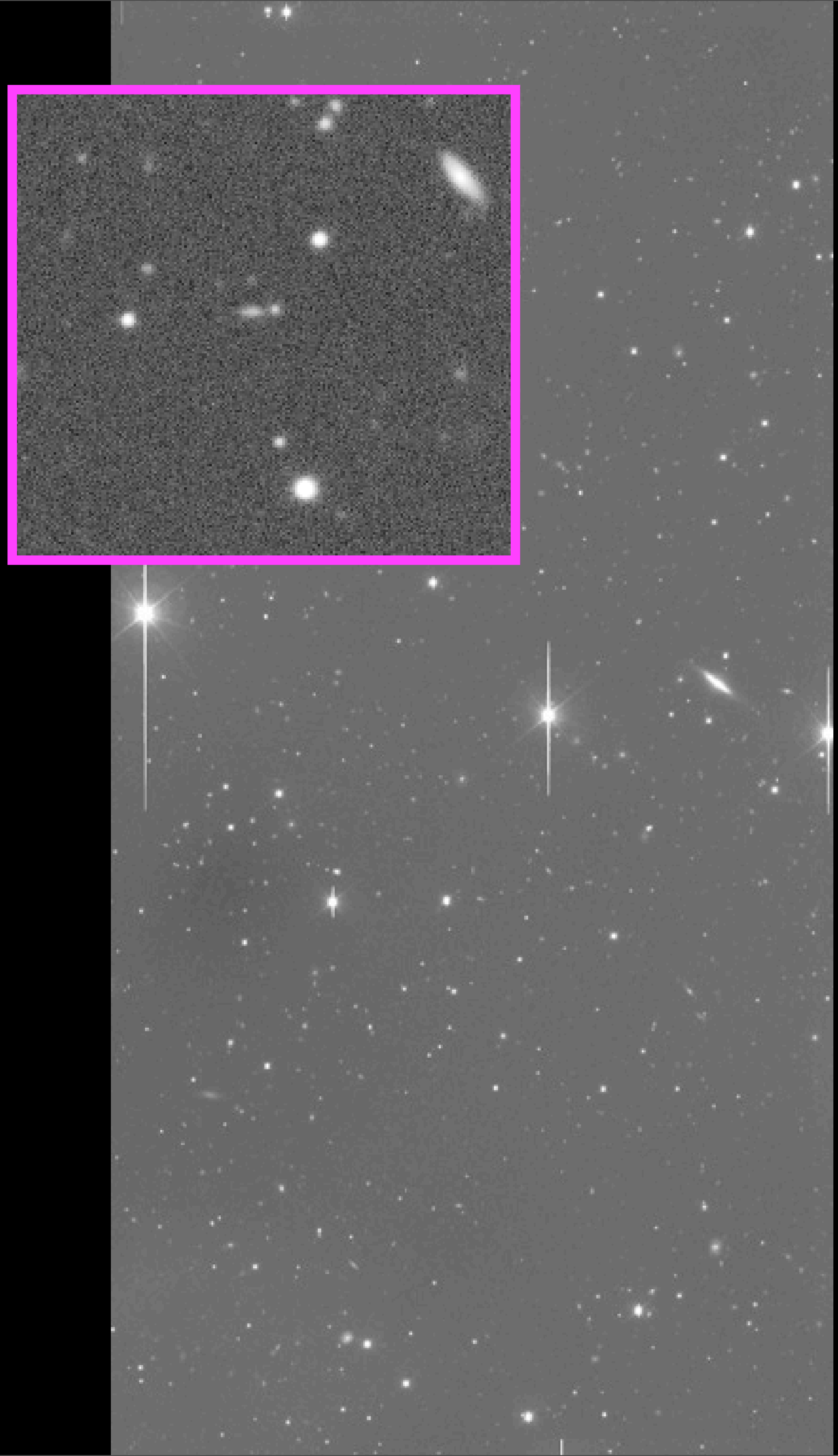
Other CoIs: C. Smith, R. Schommer, M. Phillips, M. Hamuy, R. Aviles (CTIO); J. Maza (UChile); A. Riess, R. Kirshner (Harvard); J. Spyromilio, B. Leibundgut (ESO)

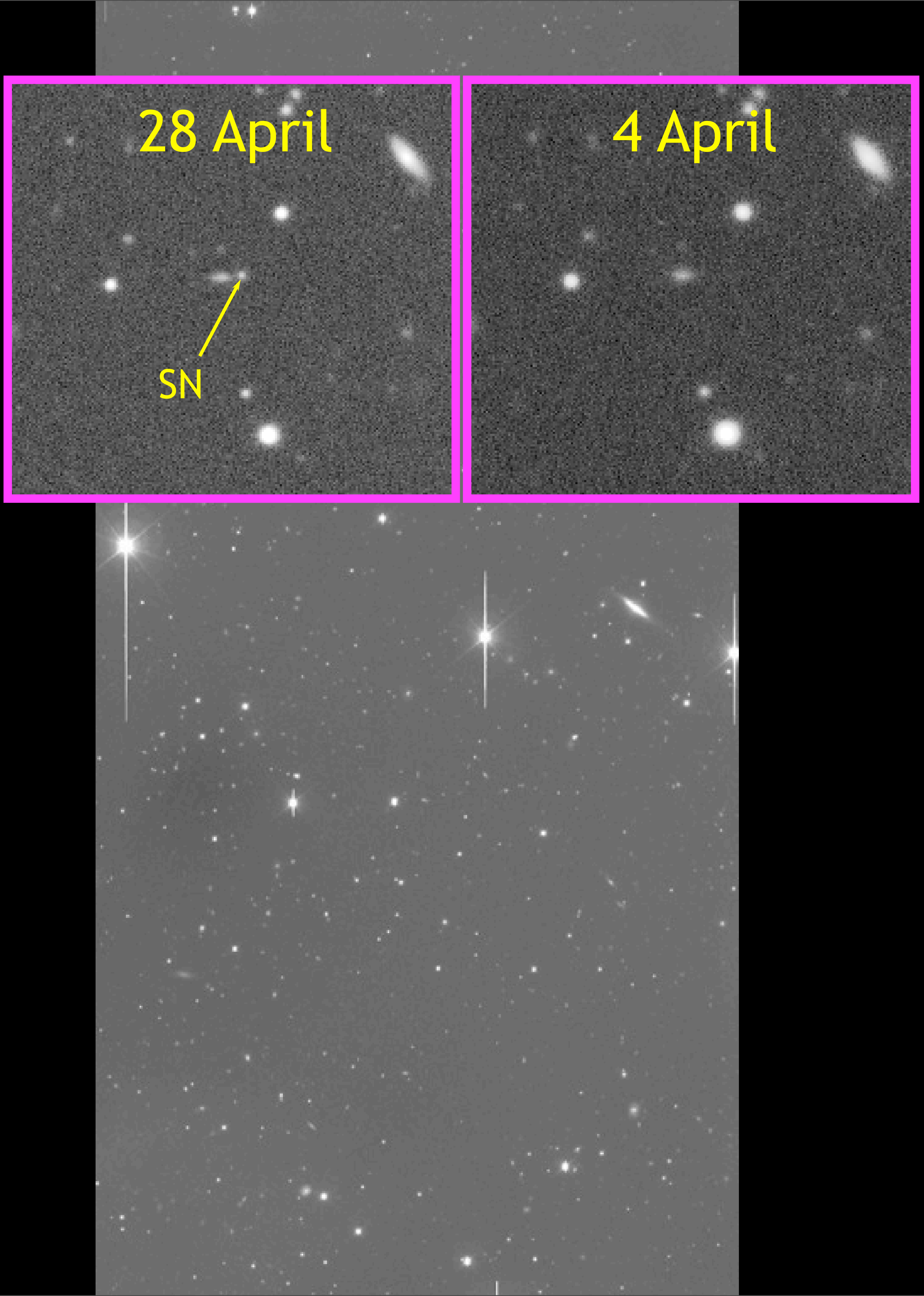
Abstract of Scientific Justification:

We propose to initiate a search for Type Ia supernovae at redshifts to $z \sim 0.3 - 0.5$ in equatorial fields using the CTIO 4m telescope. This program is the next step in the Calán/Tololo SN survey, where we have found ~ 30 Type Ia supernovae out to $z \sim 0.1$. The proposed program is a pilot project to discover fainter SN Ia's using multiple-epoch CCD images from the 4m telescope. We will follow up these discoveries with CCD photometry and spectroscopy both at CTIO and at several observatories in both hemispheres. With the spectral classification and light curve shapes, we can use our calibrations of the absolute magnitudes of SN Ia's from the Calán/Tololo survey to place stringent limits (Figure 2) on q_0 in a reasonable time-frame. Based on the statistics of discovery from the Calán/Tololo SN survey, we can expect to find about 3 SNe Ia per month.



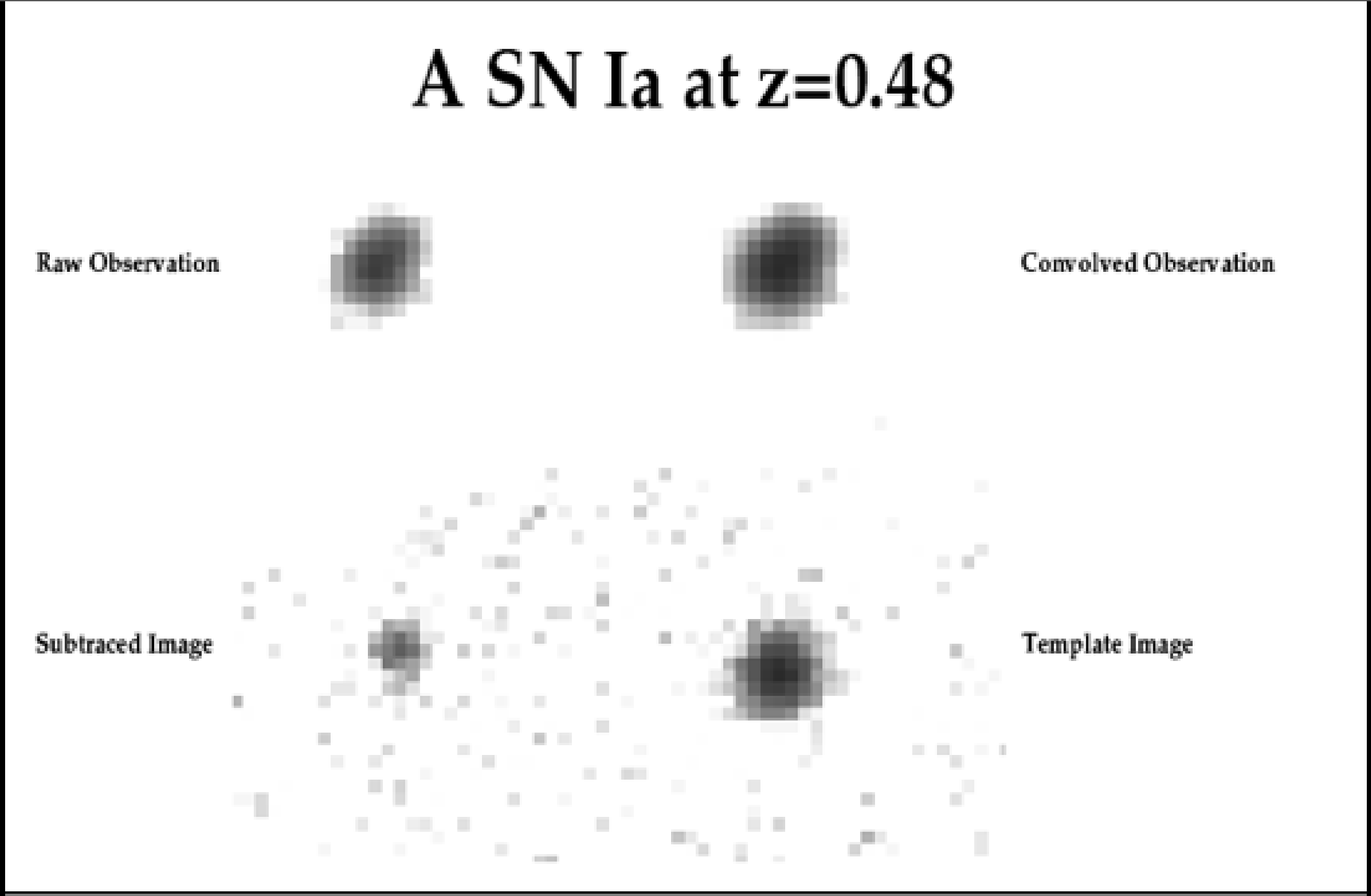





28 April
SN
4 April

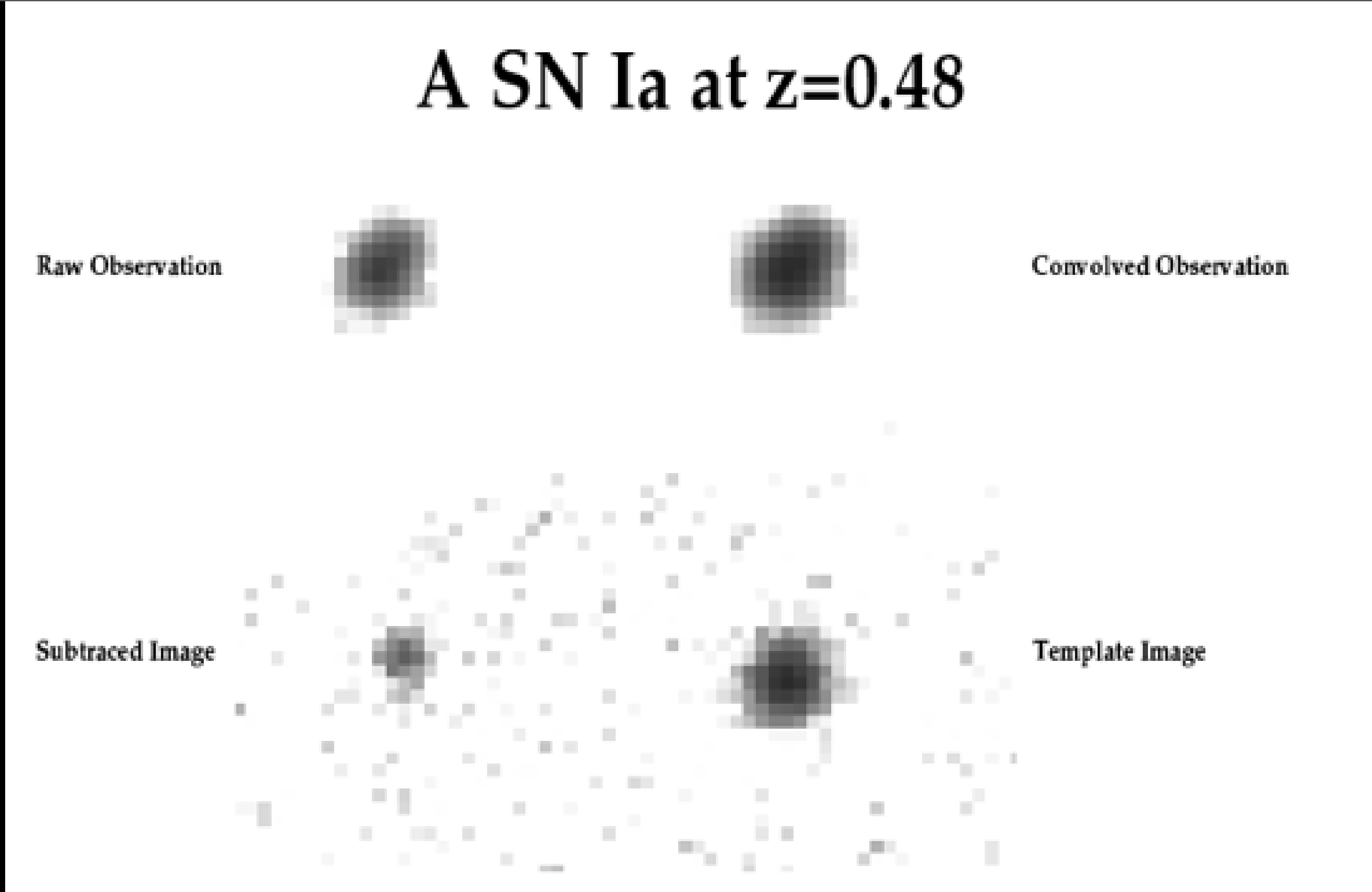

File Folders
Portfolios

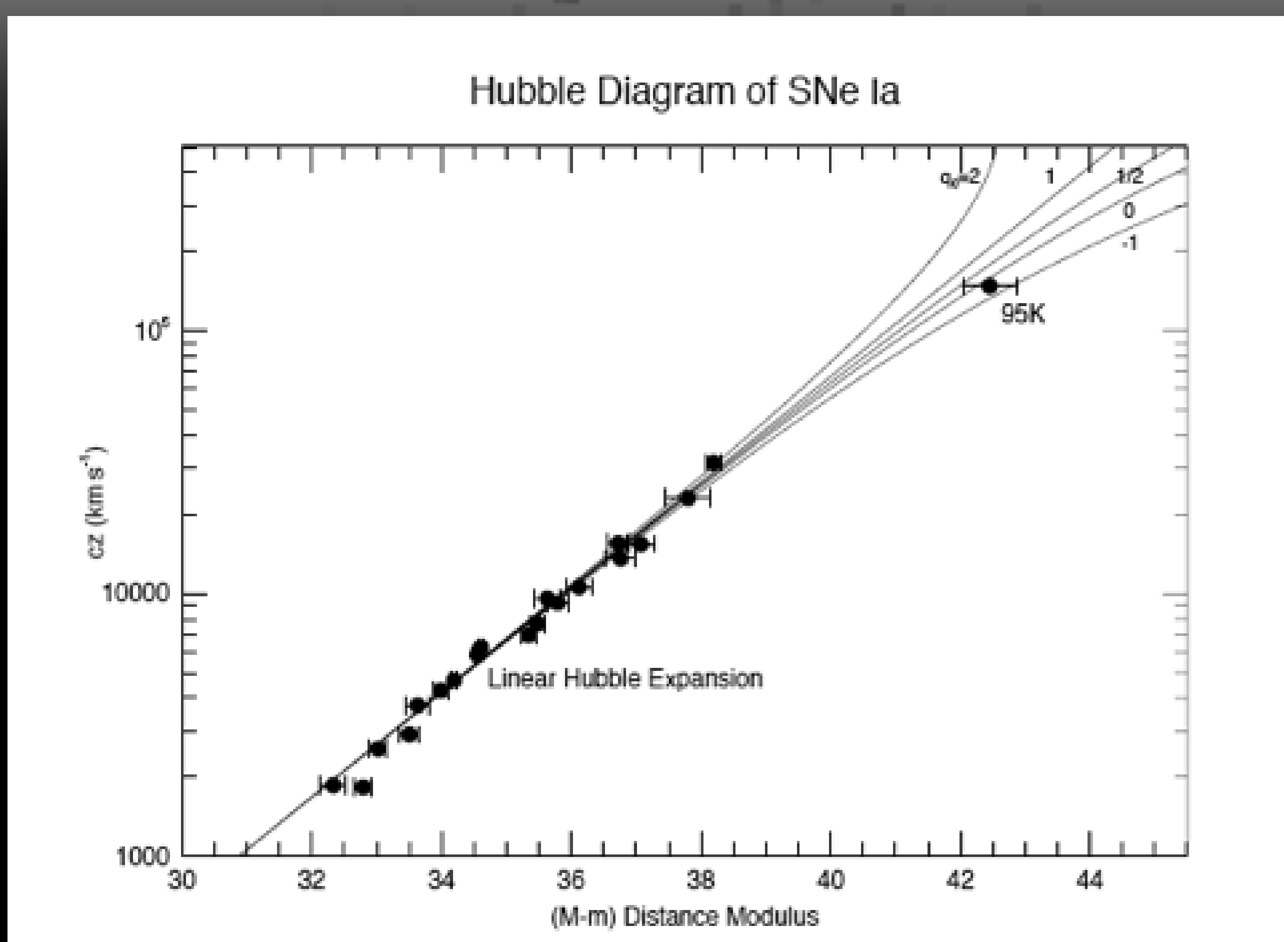

Sun

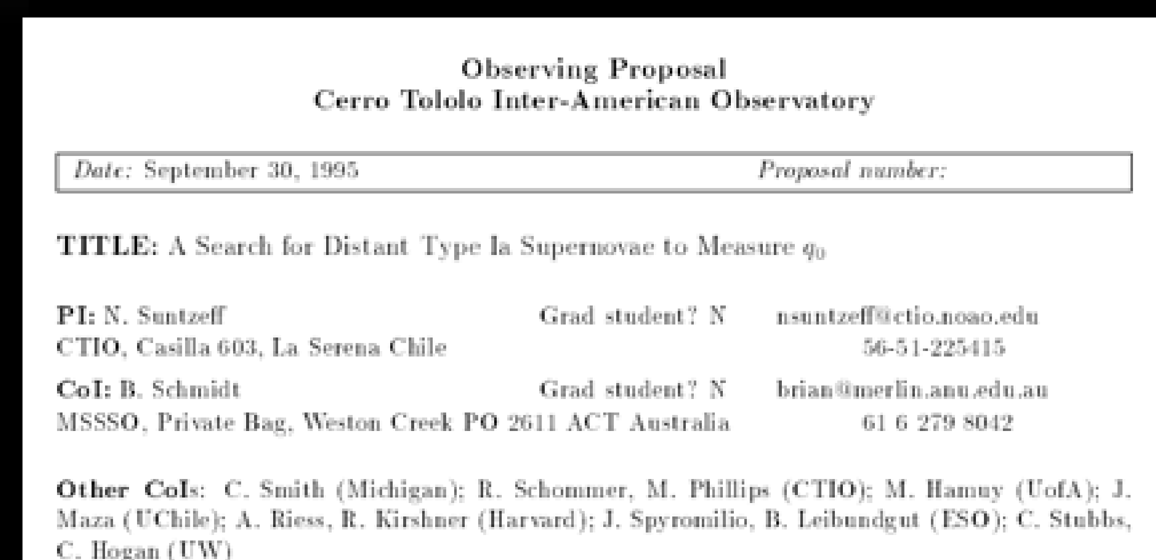


Our First Supernova
SN 1995K

Our First Supernova
SN 1995K







Observing Proposal
Cerro Tololo Inter-American Observatory

Date: September 30, 1995 *Proposal number:*

TITLE: A Search for Distant Type Ia Supernovae to Measure q_0

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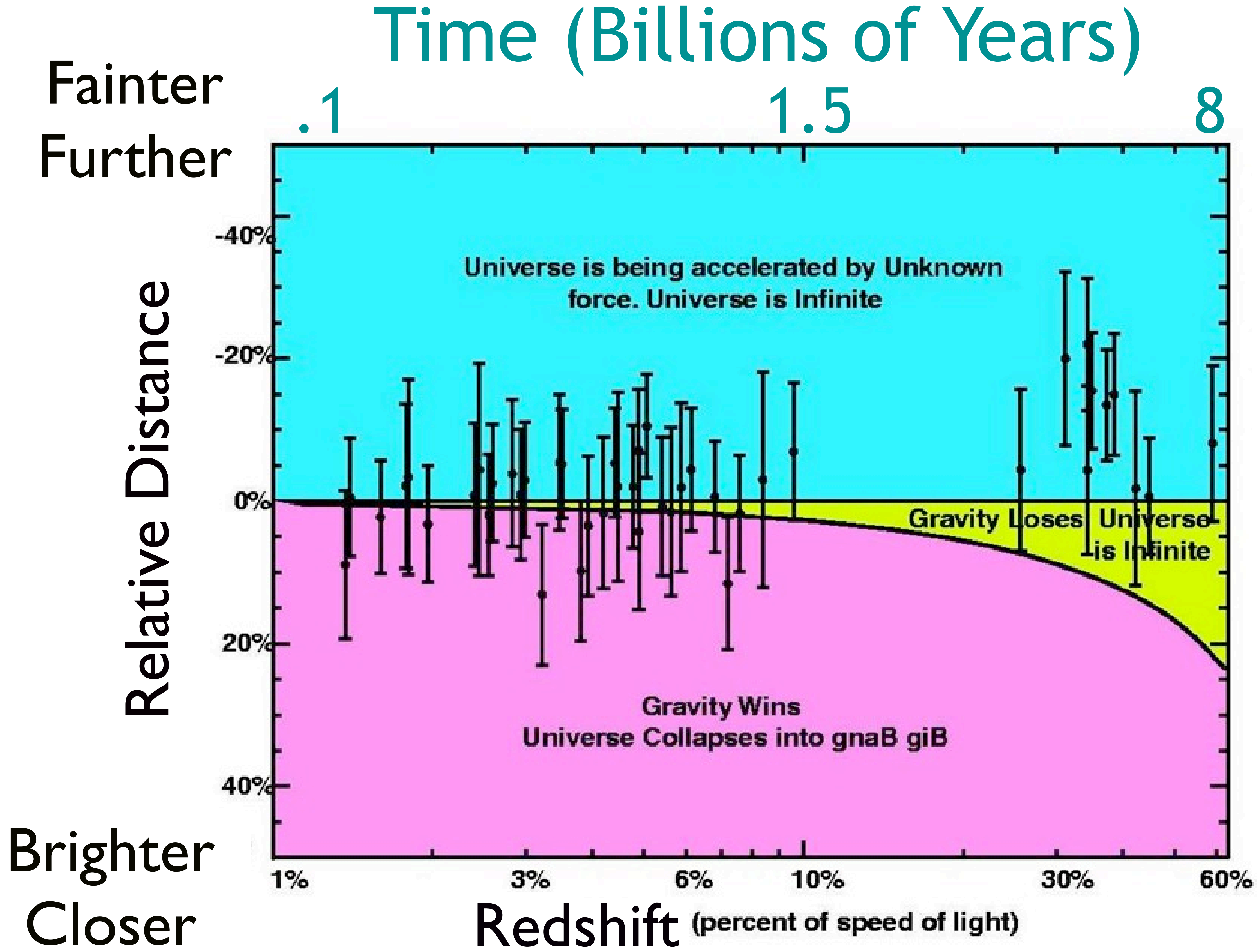
Time (Billions of Years)
.1
1.5
8
Fainter
Further
Brighter
Closer
Relative Distance
-40%
-20%
0%
20%
40%
Universe is being accelerated by Unknown force. Universe is Infinite
Gravity Loses Universe is Infinite
Gravity Wins
Universe Collapses into gnaB giB
1%
3%
6%
10%
30%
60%
Redshift (percent of speed of light)