"Hubble Who?"

Moshe Gai
Yale University
And
University of Connecticut at Avery Point

What did Edwin Hubble do to deserve a two billion dollar monumental project two hundred miles up? How did all the stuff around us (and the stuff we can't see) come to be? This will be one hour of unadulterated (i.e. no math) sheer fun.

Tilde Café, Branford, CT, May 14, 2011

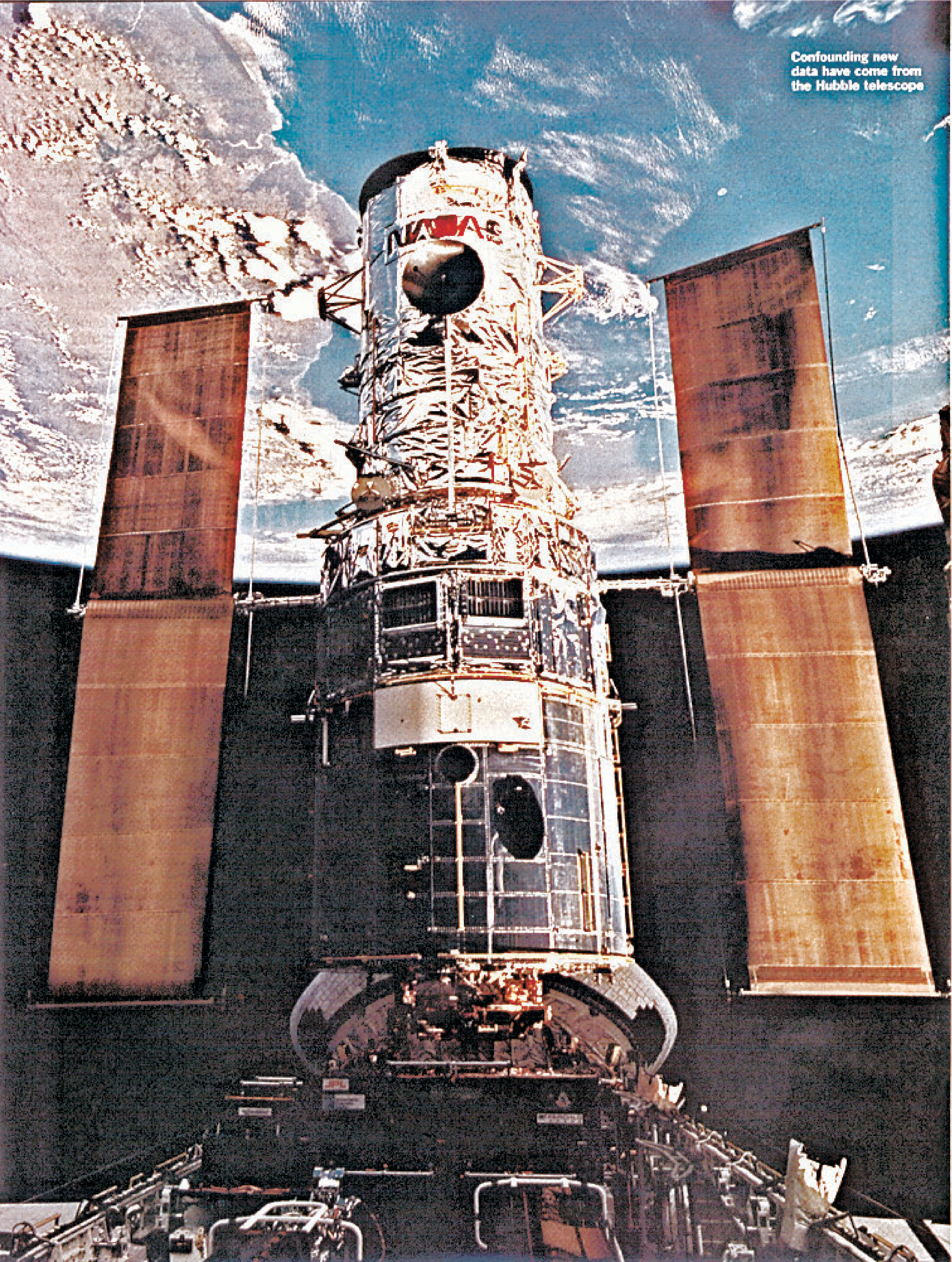
The Laboratory for Nuclear Science At Avery Point

MARCH 6, 1995 $2.95

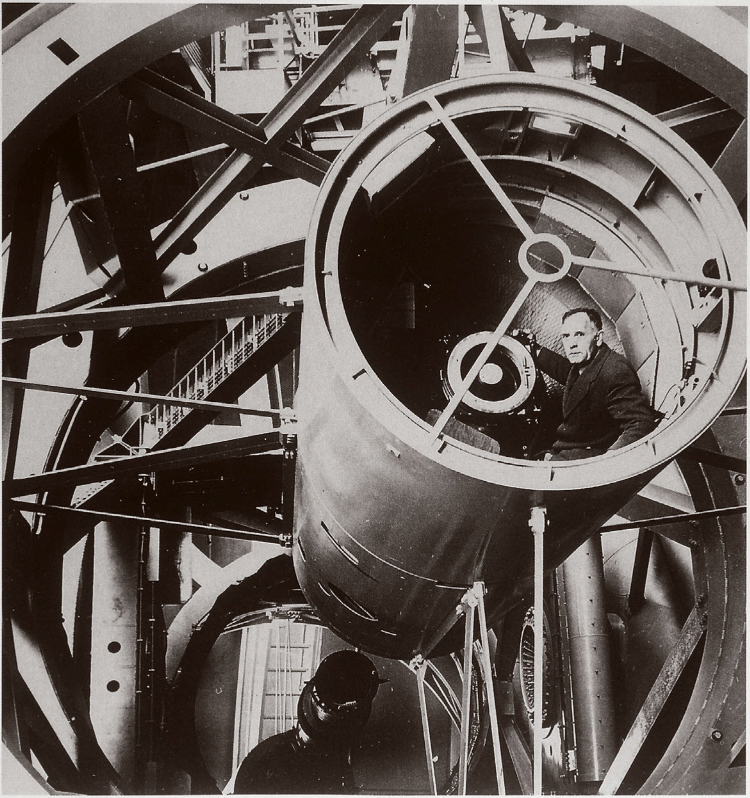
MARCH 6, 1995 $2.95

TIME

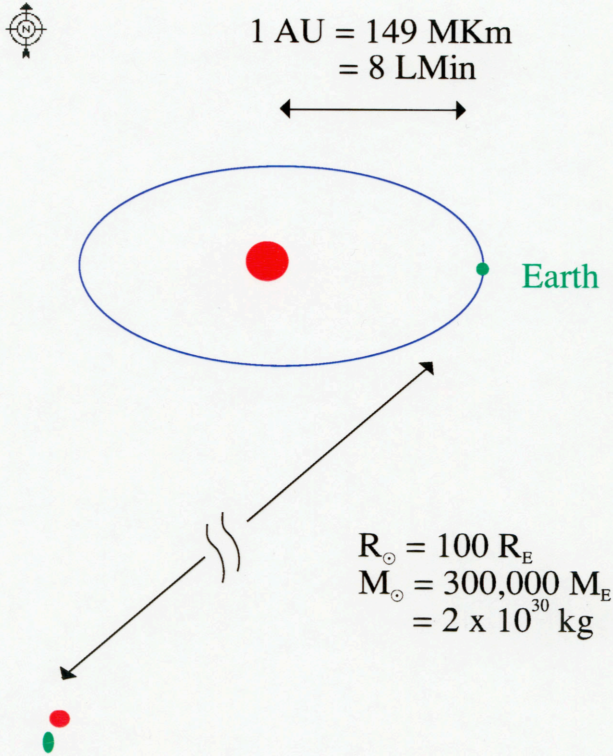
The galaxy M100, as seen by the Hubble Space Telescope. Images like this and other new discoveries are turning theories of the cosmos upside down



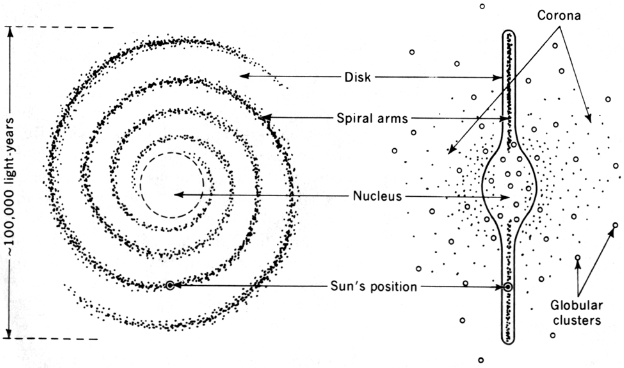
Confounding new data have come from the Hubble telescope



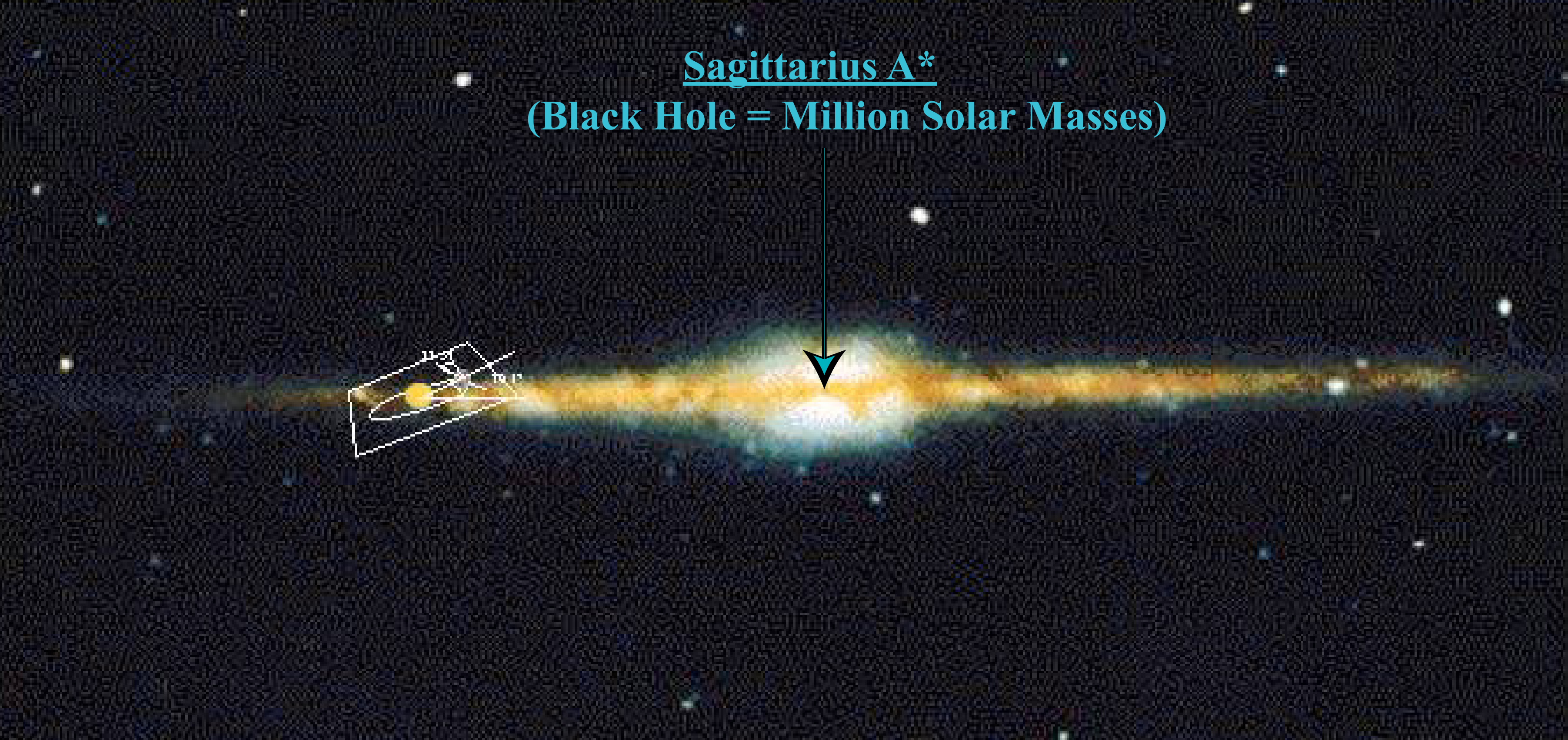
EDWIN HUBBLE drew on his observing experience, personal drive and access to top facilities to make a series of groundbreaking cosmological discoveries. He is seen here in the observing cage of the 200-inch Hale telescope, circa 1950.



α – Centauri,	Proxima	4.2 LY (1.3Pc)
	, A	4.3 LY
	, B	4.3 LY

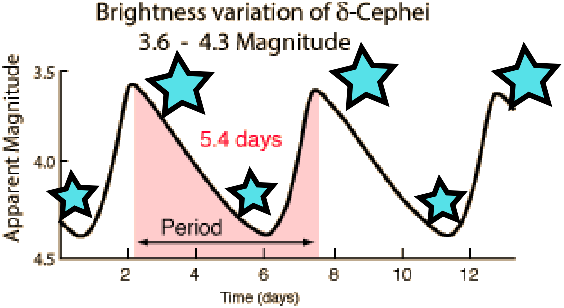


~100,000 light-years
Corona
Disk
Spiral arms
Nucleus
Sun's position
Globular
clusters

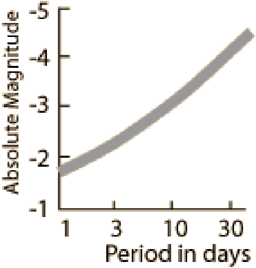

Sagittarius A*
(Black Hole = Million Solar Masses)

Cepheid Variable Stars (5 - 20 Solar Masses)

$^{+}He + Energy \longrightarrow ^{++}He + e^{-}$



The period-luminosity relation for Cepheid variables.



Henrietta S. Leavitt, 1868 - 1921

Henrietta Leavitt was born in Cambridge, Massachusetts, the daughter of a Congregational minister. She attended Oberlin College and the Society for Collegiate Instruction of Women (later Radcliffe College). As a senior in 1892, Leavitt discovered astronomy. After graduation she took another course in it, but then spent several years at home when she suffered a serious illness that left her severely deaf. She hadn't forgotten about astronomy, though. She volunteered at the Harvard College Observatory in 1895. Seven years later she was appointed to the permanent staff (at a salary of 30 cents an hour) by director Charles Pickering. She got little chance to do theoretical work, but did become head of the photographic photometry department. This group studied photo images of stars to determine their magnitude.

During her career, Leavitt discovered more than 2,400 variable stars, about half of the known total in her day. These stars change from bright to dim and back fairly regularly. Leavitt's work with variable stars led to her most important contribution to the field: the cepheid variable period-luminosity relationship. By intense observation of a certain class of variable star, the cepheids, Leavitt discovered a direct correlation between the time it took a star to go from bright to dim to how bright it actually was. Knowing this relationship helped other astronomers, such as Edwin Hubble, to make their own groundbreaking discoveries.

Leavitt also developed a standard of photographic measurements that was accepted by the International Committee on Photographic Magnitudes in 1913, and called the Harvard Standard. To do this she used 299 plates from 13 telescopes and used logarithmic equations to order stars over 17 magnitudes of brightness. She continued refining and enlarging upon this work throughout her life.

Leavitt was not allowed to pursue her own topics of study, but researched what the head of the observatory assigned. Because of the prejudices of the day, she didn't have the opportunity to use her intellect to the fullest, but a colleague remembered her as "possessing the best mind at the Observatory," and a modern astronomer calls her "the most brilliant woman at Harvard." She worked at the Harvard College Observatory until her death from cancer in 1921.

TABLE 1

The Chinese historical Records of the apparition of Halley's Comet

Return	Date	Reign/year	Return	Date	Reign/year
-40	-1057- -1056	The Conquest of Zhou by Wu-Wang	-20	AD 451	Song Yuanjia 28
-39			-19	530	Liang Zhongdatong 2
-38			-18	607	Sui Daye 3
-37			-17	684	Tang Guangzhai 1
-36			-16	760	Qianyuan 3
-35			-15	837	Kaicheng 2
-34	BC 614	Zhou Qing Wang 5	-14	912	Liang Qianhua 2
-33			-13	989	Song Duangong 2
-32	465	Zhou Zhending Wang 3	-12	1066	Zhiping 3
-31			-11	1145	Shaoxing 15
-30			-10	1222	Jiading 15
-29	240	Qin Wang Zheng 7	-9	1301	Yuan Dade 5
-28	162	Han Wen Di Houyuan 2	-8	1378	Ming Hongwu 11
-27	86	Wu Di Houyan 2	-7	1456	Jingtai 7
-26	11	Yuanyan 2	-6	1531	Jiajing 10
-25	AD 65	Yongping 8	-5	1607	Wanli 35
-24	141	Yonghe 6	-4	1682	Qing Kangxi 21
-23	218	Jianan 23	-3	1759	Qianlong 24
-22	295	Jin Yuankang 5	-2	1835	Daoguang 15
-21	374	Ningkang 2	-1	1910	Xuantong 2

All Messier Objects: sorted by Messier number

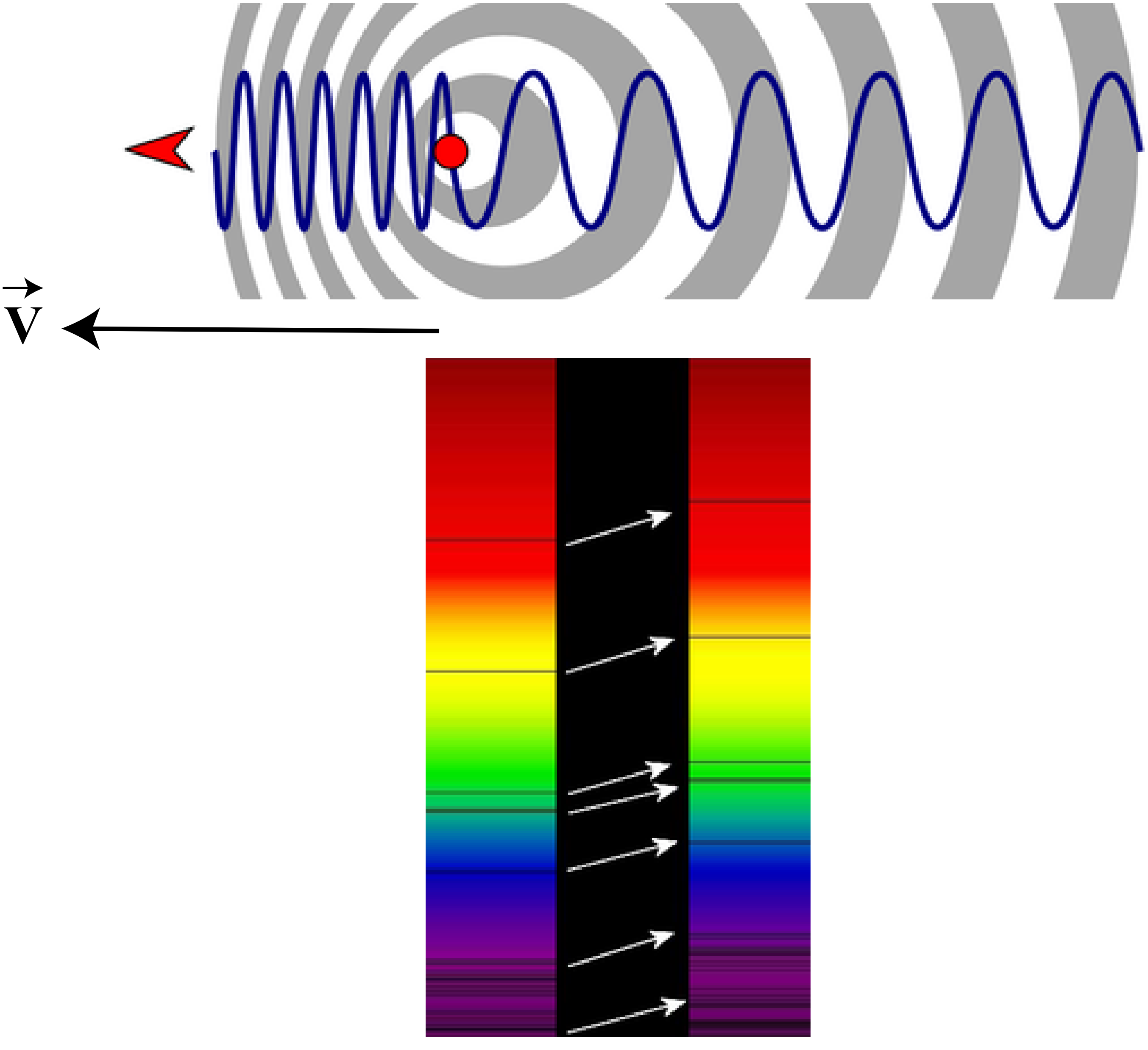
M	NGC	Con	RA	Dec	Mag	Size	Typ	Common Name	Date Sighted
1	1952	Tau	05 34.5	22 01	9.0	6 x 4	SNR	Crab Nebula	
2	7089	Aqr	21 33.5	-00 49	7.5	12.9	GCl		
3	5272	CVn	13 42.2	28 23	7.0	16.2	GCl		
4	6121	Sco	16 23.6	-26 32	7.5	26.3	GCl		
5	5904	Ser	15 18.6	02 05	7.0	17.4	GCl		
6	6405	Sco	17 40.1	-32 13	4.5	15.0	OCl	Butterfly Cluster	
7	6475	Sco	17 53.9	-34 49	3.5	80.0	OCl	Ptolemy's Cluster	
8	6523	Sgr	18 03.8	-24 23	5.0	60 x 35	C/N	Lagoon Nebula	
9	6333	Oph	17 19.2	-18 31	9.0	9.3	GCl		
10	6254	Oph	16 57.1	-04 06	7.5	15.1	GCl		
11	6705	Sct	18 51.1	-06 16	7.0	14.0	OCl	Wild Duck Cluster	
12	6218	Oph	16 47.2	-01 57	8.0	14.5	GCl		
13	6205	Her	16 41.7	36 28	7.0	16.6	GCl	Hercules Cluster	
14	6402	Oph	17 37.6	-03 15	9.5	11.7	GCl		
15	7078	Peg	21 30.0	12 10	7.5	12.3	GCl		
16	6611	Ser	18 18.8	-13 47	6.5	7.0	C/N	part of the Eagle Nebula	
17	6618	Sgr	18 20.8	-16 11	7.0	11.0	C/N	Omega Nebula, Swan Nebula, Lobster Nebula	
18	6613	Sgr	18 19.9	-17 08	8.0	9.0	OCl		
19	6273	Oph	17 02.6	-26 16	8.5	13.5	GCl		
20	6514	Sgr	18 02.6	-23 02	5.0	28.0	C/N	Trifid Nebula	
21	6531	Sgr	18 04.6	-22 30	7.0	13.0	OCl		

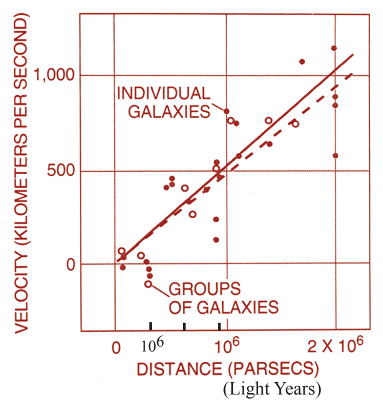

M32

The Doppler Effect:

Red Shift: $\lambda/\lambda_0 = 1 + Z$

$$Z \approx v/c \ (v << c)$$





VELOCITY (KILOMETERS PER SECOND)
1,000
500
0
INDIVIDUAL GALAXIES
GROUPS OF GALAXIES
0
10^6
10^6
2 X 10^6
DISTANCE (PARSECS)
(Light Years)

Hubble Constant

$$\text{V} = H \times R$$

$$\begin{aligned} \text{H} &= 500 \text{ Km/sec/MPc} \\ &= 500 \text{ Km/sec /3.2MLY} \\ &= 500\ /(3.2 \times c \times MY) \\ &= 500\ /3.2 \times 3 \times 10^5\ [\text{MYear}^{-1}] \\ &= 500/10^6 \\ &= 5 \times 10^{-4}\ [\text{Myears}^{-1}] \end{aligned}$$

$$\text{H}^{-1} = 2 \text{ BY !!!}$$

$$\text{T}_{\odot} = 4.6 \text{ BY}$$

$$\text{T} \approx 14 \text{ BY}$$

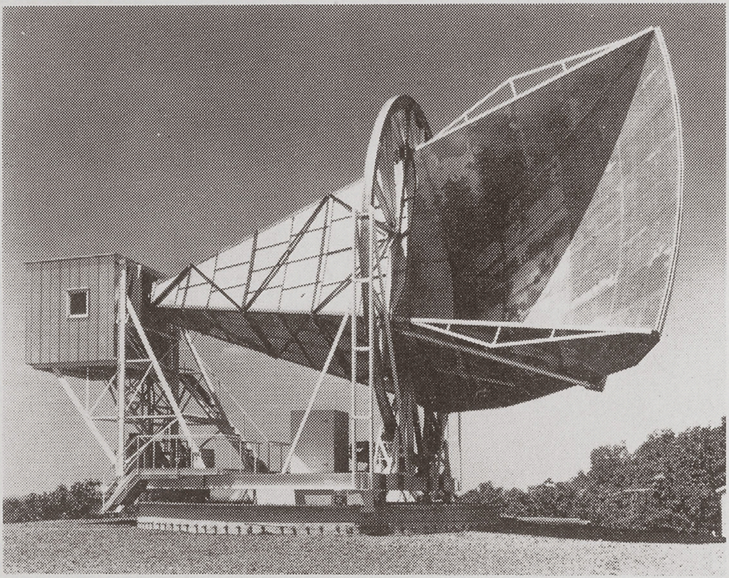


Fig. D.12 Horn antenna at Bell Lab, Holmdel, N.J. This antenna was designed for microwave communication experiments with the Echo and Telstar satellites.

A MEASUREMENT OF EXCESS ANTENNA TEMPERATURE AT 4080 Mc/s

Measurements of the effective zenith noise temperature of the 20-foot horn-reflector antenna (Crawford, Hogg, and Hunt 1961) at the Crawford Hill Laboratory, Holmdel, New Jersey, at 4080 Mc/s have yielded a value about 3.5° K higher than expected. This excess temperature is, within the limits of our observations, isotropic, unpolarized, and

Note added in proof.—The highest frequency at which the background temperature of the sky had been measured previously was 404 Mc/s (Pauliny-Toth and Shakeshaft 1962), where a minimum temperature of 16° K was observed. Combining this value with our result, we find that the average spectrum of the background radiation over this frequency range can be no steeper than $\lambda^{0.7}$. This clearly eliminates the possibility that the radiation we observe is due to radio sources of types known to exist, since in this event, the spectrum would have to be very much steeper.

A. A. Penzias
R. W. Wilson

May 13, 1965
Bell Telephone Laboratories, Inc.
Crawford Hill, Holmdel, New Jersey

REFERENCES

Crawford, A. B., Hogg, D. C., and Hunt, L. E. 1961, *Bell System Tech. J.*, 40, 1095.
DeGrasse, R. W., Hogg, D. C., Ohm, E. A., and Scovil, H. E. D. 1959, "Ultra-low Noise Receiving System for Satellite or Space Communication," *Proceedings of the National Electronics Conference*, 15, 370.
Dicke, R. H., Peebles, P. J. E., Roll, P. G., and Wilkinson, D. T. 1965, *Ap. J.*, 142, 414.
Hogg, D. C. 1959, *J. Appl. Phys.*, 30, 1417.
Ohm, E. A. 1961, *Bell System Tech. J.*, 40, 1065.
Pauliny-Toth, I. I. K., and Shakeshaft, J. R. 1962, *M.N.*, 124, 61.
Penzias, A. A. 1965, *Rev. Sci. Instr.*, 36, 68.
Penzias, A. A., and Wilson, R. W. 1965, *Ap. J.* (in press).

COSMIC BLACK-BODY RADIATION*

One of the basic problems of cosmology is the singularity characteristic of the familiar cosmological solutions of Einstein's field equations. Also puzzling is the presence of matter in excess over antimatter in the universe, for baryons and leptons are thought to be conserved. Thus, in the framework of conventional theory we cannot understand the origin of matter or of the universe. We can distinguish three main attempts to deal with these problems.

1. The assumption of continuous creation (Bondi and Gold 1948; Hoyle 1948), which avoids the singularity by postulating a universe expanding for all time and a continuous but slow creation of new matter in the universe.

2. The assumption (Wheeler 1964) that the creation of new matter is intimately related to the existence of the singularity, and that the resolution of both paradoxes may be found in a proper quantum mechanical treatment of Einstein's field equations.

3. The assumption that the singularity results from a mathematical over-idealization,

* This research was supported in part by the National Science Foundation and the Office of Naval Research of the U.S. Navy.

We deeply appreciate the helpfulness of Drs. Penzias and Wilson of the Bell Telephone Laboratories, Crawford Hill, Holmdel, New Jersey, in discussing with us the result of their measurements and in showing us their receiving system. We are also grateful for several helpful suggestions of Professor J. A. Wheeler.

R. H. Dicke
P. J. E. Peebles
P. G. Roll
D. T. Wilkinson

May 7, 1965

Palmer Physical Laboratory
Princeton, New Jersey

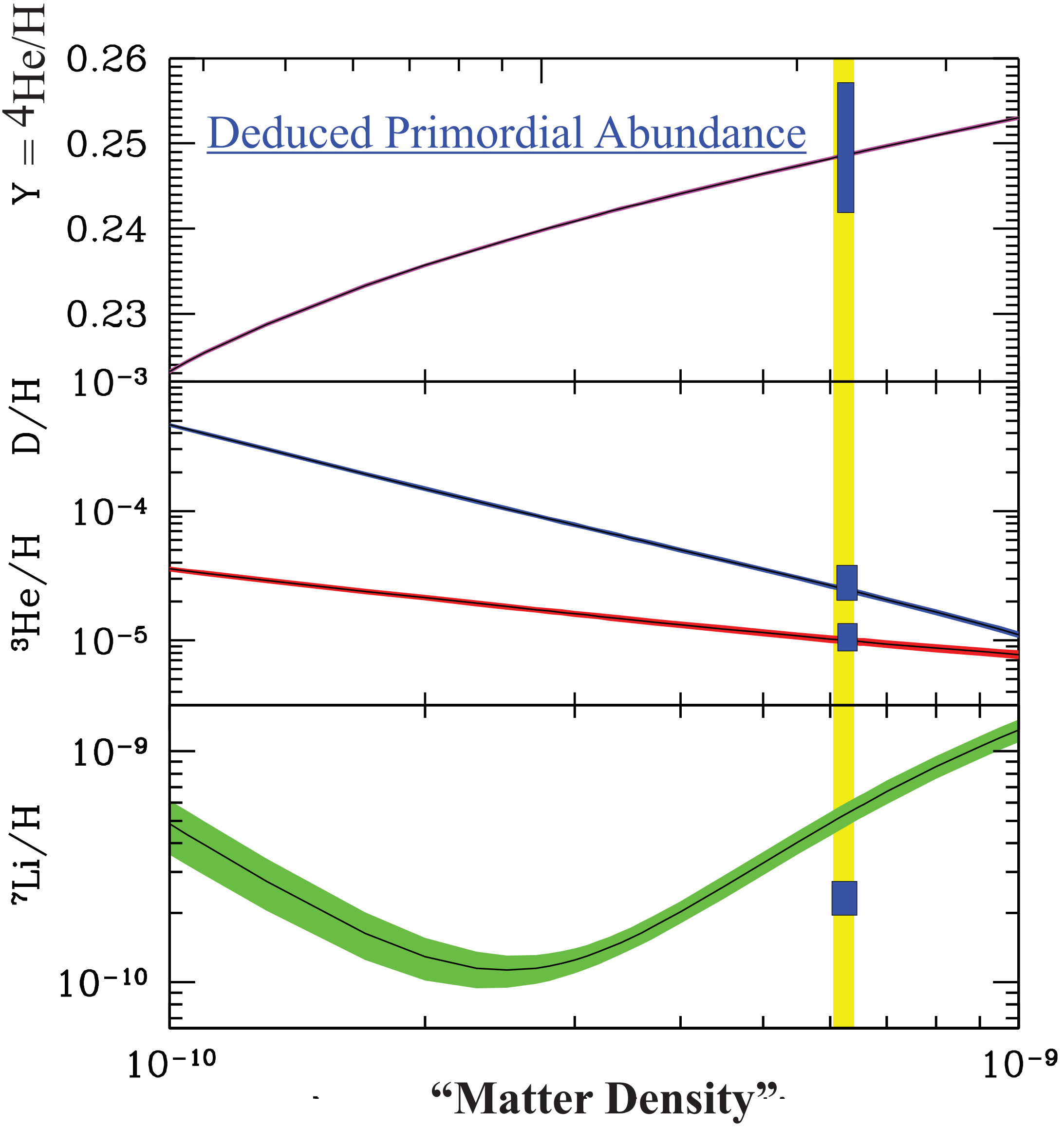
Einstein and Lemaître, Le Coq (Belgium), 1933.

Eddington and Lemaître, IAU Stockholm, August 1938.

The First Three Minutes

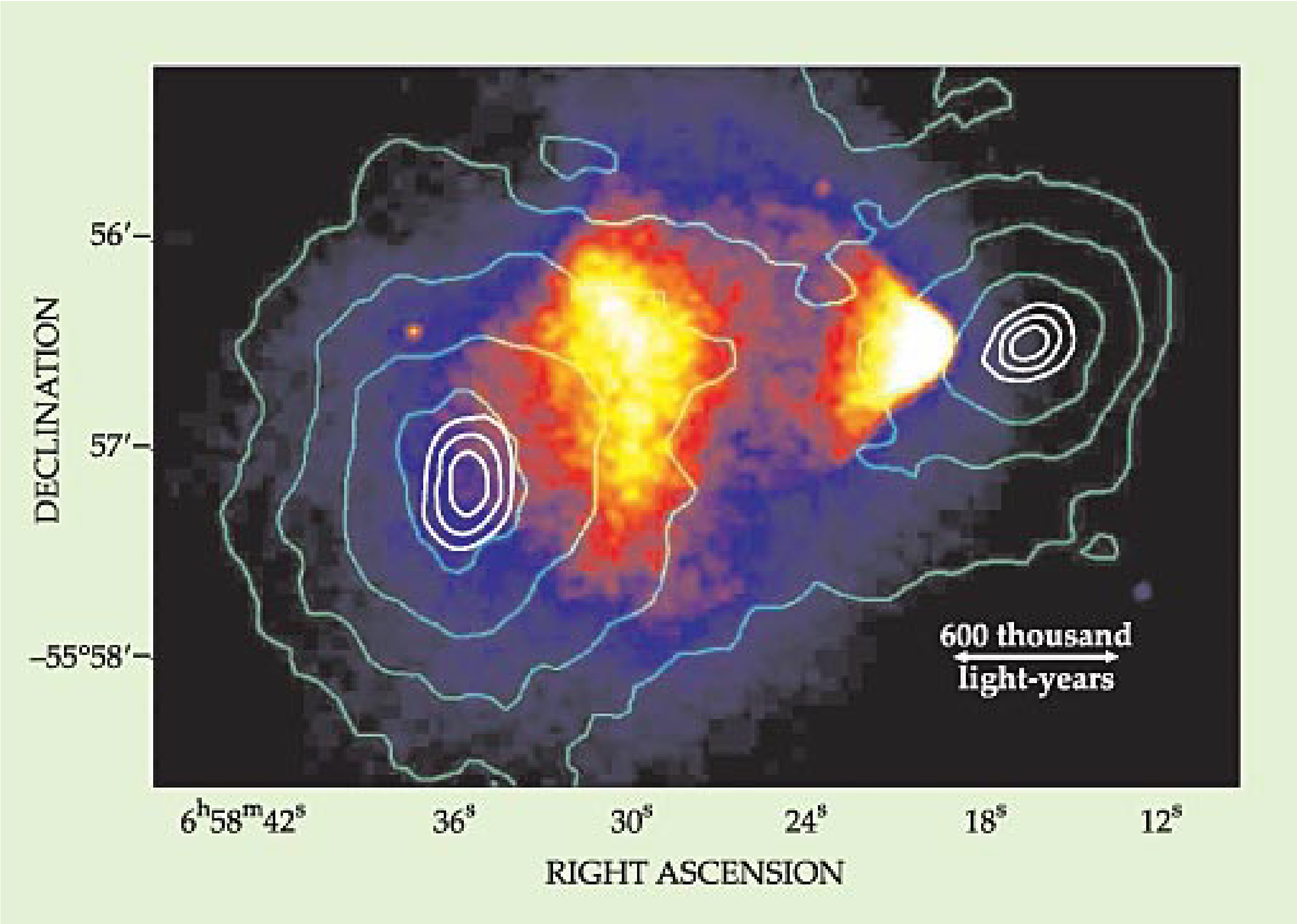
Big-Bang Nucleosynthesis

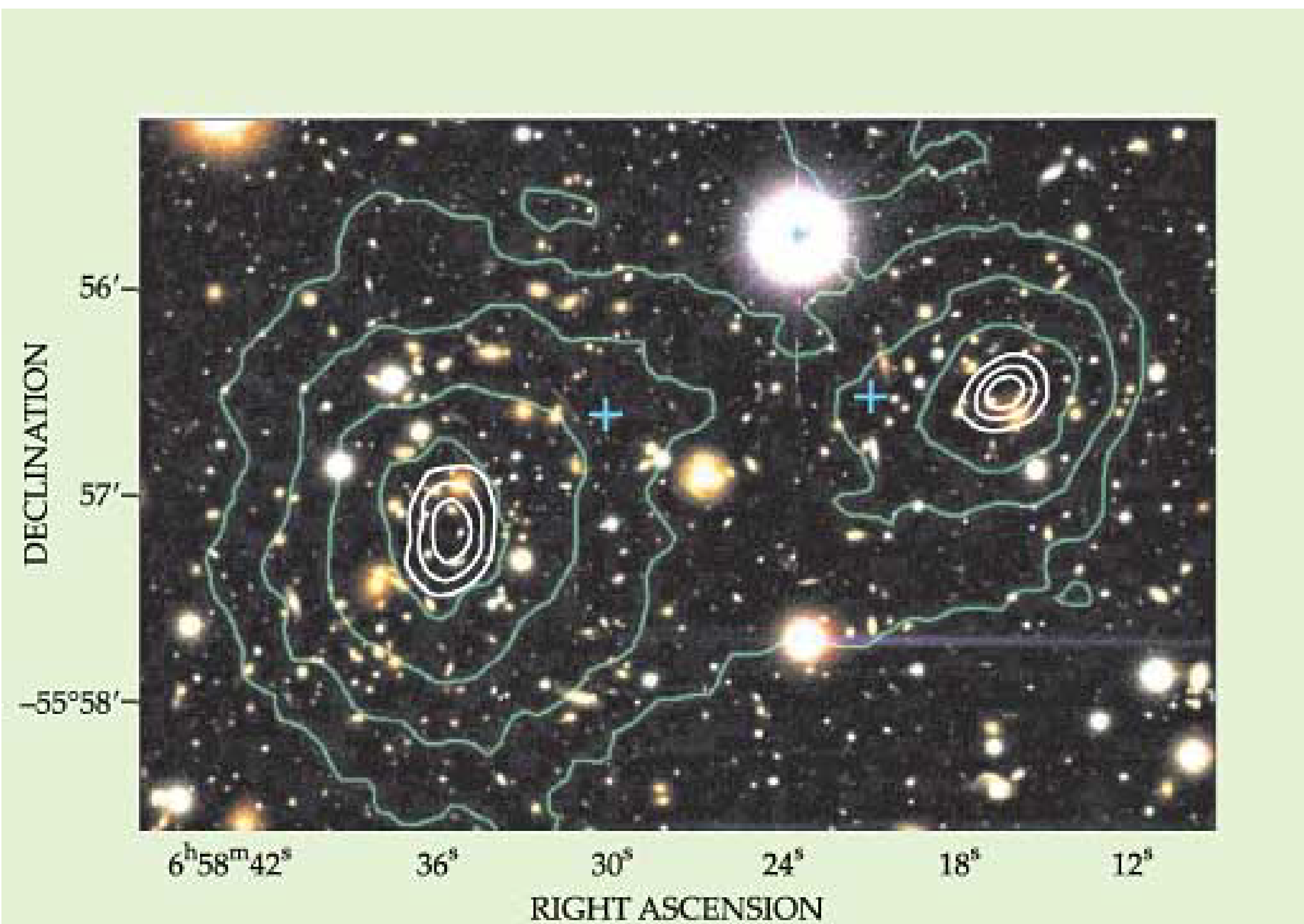
Hydrogen (76%) + Helium (24%)

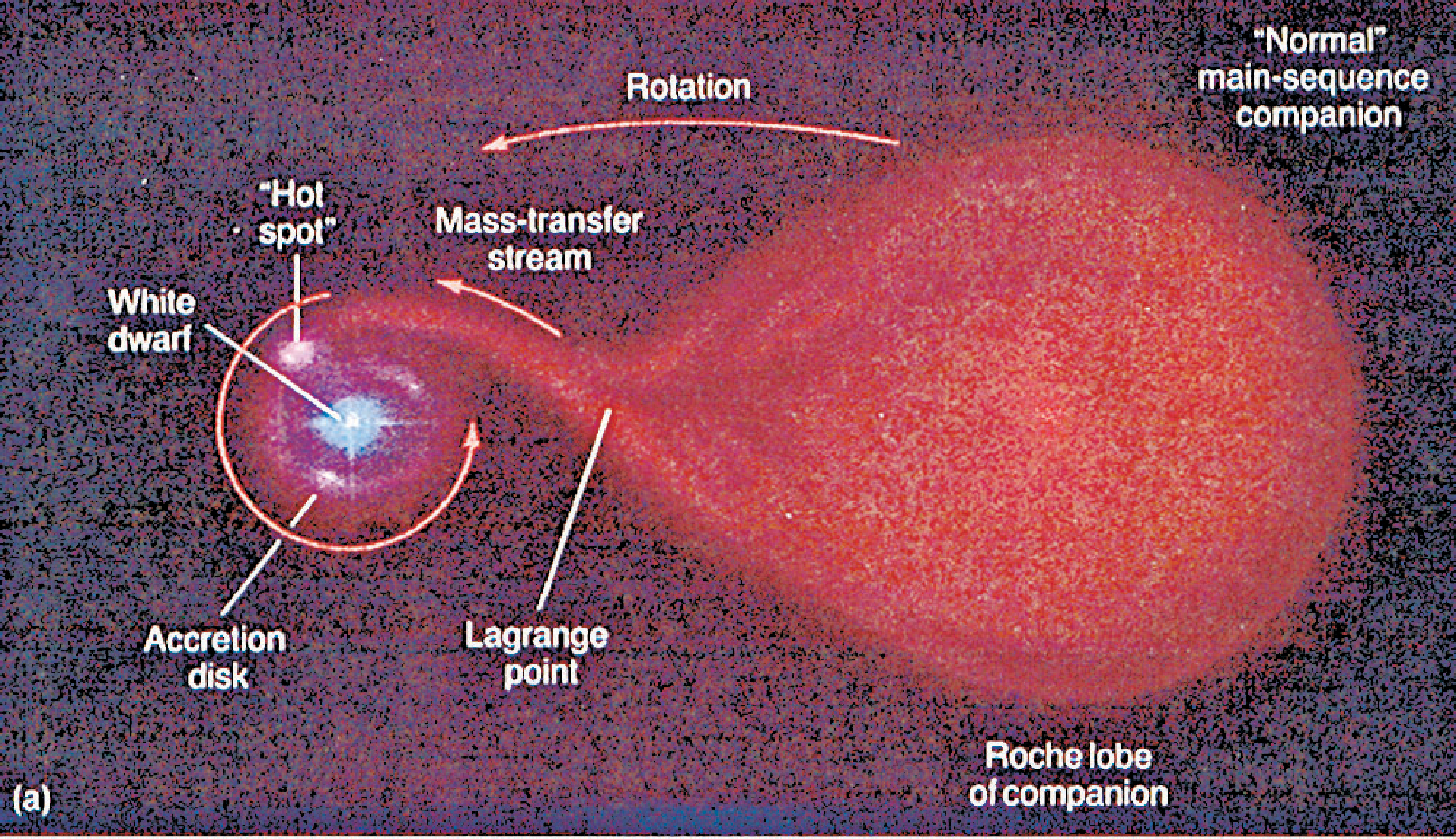


Matter Density is Larger (x6) than "Observed"

Dark Matter !!!


56′
57′
−55°58′
DECLINATION
600 thousand
light-years
6h58m42s
36s
30s
24s
18s
12s
RIGHT ASCENSION


56′
57′
−55°58′
DECLINATION
6h58m42s
36s
30s
24s
18s
12s
RIGHT ASCENSION

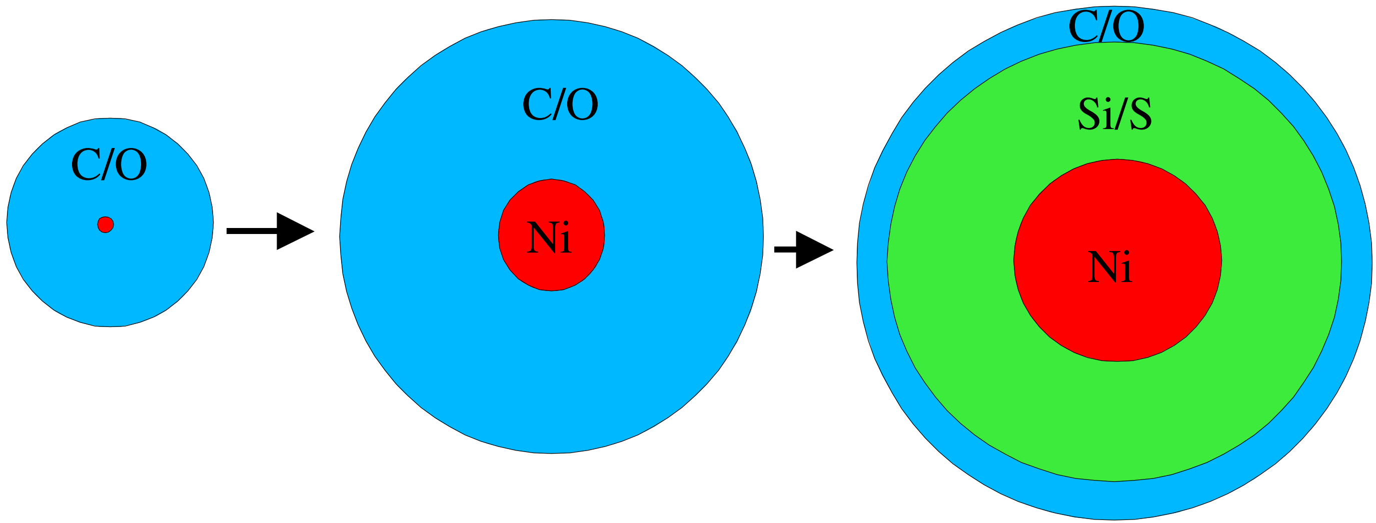

"Normal" main-sequence companion
Rotation
"Hot spot"
Mass-transfer stream
White dwarf
Accretion disk
Lagrange point
Roche lobe of companion
(a)

Explosion of a White Dwarfs (Defl., Delayed Det. & Merger)

Initial WD

Deflagration phase(2...3sec)
preexpansion of the WD

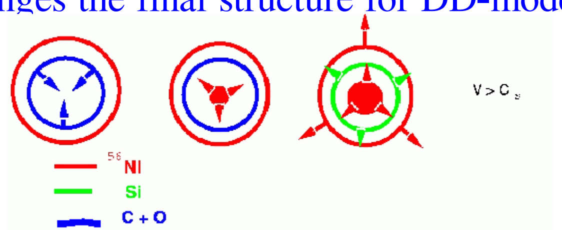
Detonation phase (0.2...0.3 sec)
hardly any time for further expansion



Deflagration: Energy transport by heat conduction over the front, v <<v(sound)=> ignition of unburned fuel (C/O)
Detonation: ignition of unburned fuel by compression, v = v(sound)

Rem1: Pre-expansion depends on the amount of burning. The rate of burning hardly changes the final structure for DD-models (Dominguez et al. ApJ 528, 590)

Rem.2: HeDs (sub-MCh)



- disagree with LCs and spectra

(Nugent et al. 96, Hoeflich et al. 96)

了。至使臺官無端見逐，尤為駭愕，請並 命推考。○以尹暾為工曹判書，[illegible] 尹泂為坡城君，申欽為兵曹參判，李時充為大同府使，柳希奮為司諫，文勵為司贍寺副正，黃是為刑曹正郎，蔡慶先為修撰，尹暾為正言，任兗為兵曹佐郎，李彥為檢詳，權盼為司書，黃致中為說書，鄭廣成為侍教。丁卯○定州牧使[illegible]許[illegible]。上以備忘記諭之曰：我國北連靺鞨，西接山戎，數百年來，外寇侵虐，皆不足慮者。今建州有老酋稱名者，崛起排我境，不出數日，觀其所為，殊非尋常之胡，西歸，大有憂乎。予觀本道，無關塞險阨可以守禦之處，坦坦長驅，直四戰之地。雖有一二長江，衆合則不足恃耳。乃於居中設定州一鎭，意亦有在，而城非據險，而且疎生齒不繁，軍民鮮少，終日長慮，但見其平蕪赤草數接於天，揆此氣勢，猝遇大賊，必不免有土崩之勢，而人不以為虞。曾見壬辰之亂，有以倭賊為虞者乎？老酋方與羅里爭衡，不幸而老酋勝，更無其敵之釁，其後者則我為次，界受兵必無疑矣。其及此時治兵整衆，以待敵至，不可緩也。未審本道監司，有意於此否也？定州是大將鎭守，與邊城可以犄角之處，爾須著意蘇民除弊，積穀鍊兵，就然為關西保障焉。有變名可無於竹苗父在近侍，今當遠離，賜豹皮一令。○[illegible]戊辰○夜有一更客星在尾宿十度，去極一百一十度，形體小於歲星，色黃赤，動搖。五更有霧○諫院啓曰：南以敎金大德為人

丁至使臣官無端見逐尤為駭悖請並命推考 以尹暾為工曹判書[illegible]尹泂為茂城君申𣶏為兵曹參判李時允為大司成柳帝審為司諫文啓為司贍寺副正黃是為弘教孫慶先為修撰尹時為正言任寬為兵曹佐郎李諿為獻納權聃為司諫黃瓛中為說書鄭廣成為待教 ○丁卯 定州牧使許醇辭朝 上以備忘記諭之曰我國北連遼瀋西接山戎數百年來塞外殘虜皆不足慮者今遼州有老酋稱名者崛起於我境不出數日觀其所為殊非尋常之胡西鄙亦有受予予觀本道無關塞險阨可以守禦之處坦坦長驅直抵四戰之地雖有一二邑江水合則不足恃耳乃於居中設定州一鎮為亦有在而城堞險阻而且疎生齒不繁軍民鮮少終日長慮低見其平難跡草窠接於天攝此氣勢猝遇大賊必不免有土崩之勢而人不必為虜曾見壬辰之亂有以倭賊為虜者乎老酋方與羅里爭鬪不幸而老酋勝更無其敵之讎其後者則我為次界受兵必無疑矣其及此時治兵整衆以待敵至不可緩也未審本道監司有意於此否也定州是大將鎮守與邊城可以犄角之處爾須着意應民除弊積穀鍊兵既然為關西保障萬 有變名奇甚於竹邑父在近侍今當遠離眠豹夜令勿辭出戊辰 ○夜有一更客星在尾宿十度去極一百一十度形體小於歲星色黃赤動搖五更有霧 ○諫院啓曰前教授金大德為人

夜有一更	10 PM at night
客　星	Guest star
在尾宿十度	10 deg in the Ophiuchus
去極百十度	110 deg in the Latitude
形体小於歲星	dimmer than Jupiter
色黃赤動搖	Yellowish red and shaking
五更有霧	4 am there was mist

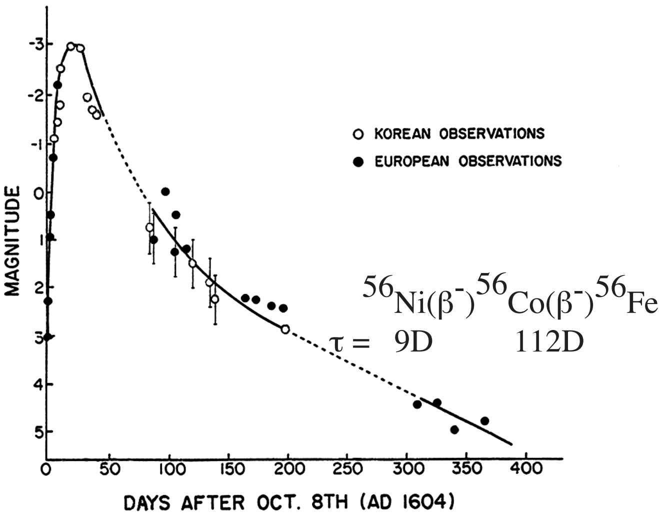
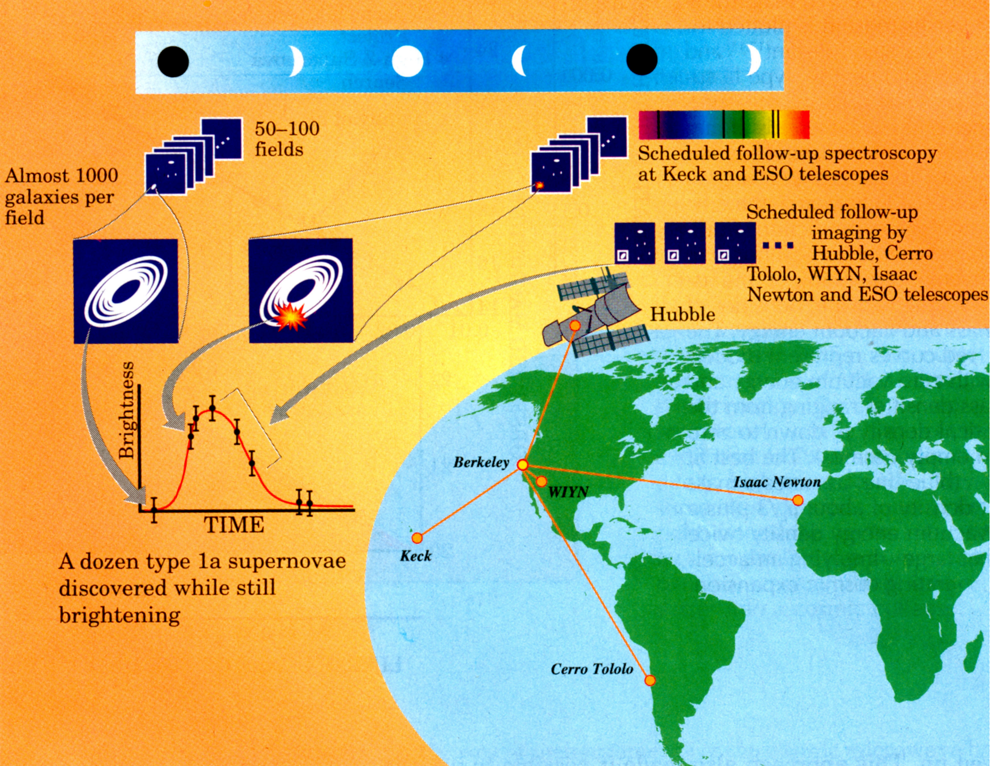
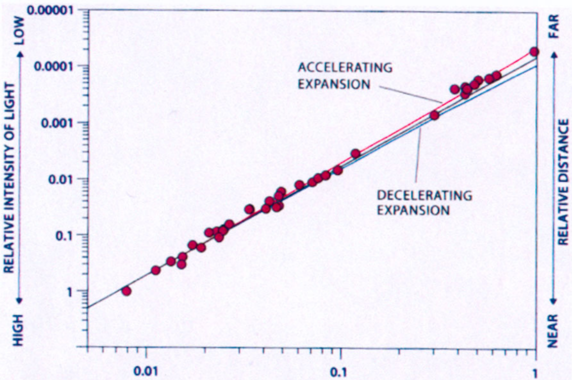

KOREAN OBSERVATIONS
EUROPEAN OBSERVATIONS
MAGNITUDE
-3
-2
-1
0
1
2
3
4
5
0
50
100
150
200
250
300
350
400
DAYS AFTER OCT. 8TH (AD 1604)
56Ni(β-)56Co(β-)56Fe
τ = 9D 112D

그림 3



50–100 fields
Almost 1000 galaxies per field
Scheduled follow-up spectroscopy at Keck and ESO telescopes
Scheduled follow-up imaging by Hubble, Cerro Tololo, WIYN, Isaac Newton and ESO telescopes
Hubble
Brightness
TIME
A dozen type 1a supernovae discovered while still brightening
Berkeley
WIYN
Isaac Newton
Keck
Cerro Tololo


0.00001
0.0001
0.001
0.01
0.1
1
0.01
0.1
1
LOW
RELATIVE INTENSITY OF LIGHT
HIGH
FAR
RELATIVE DISTANCE
NEAR
ACCELERATING
EXPANSION
DECELERATING
EXPANSION

Red Shift (Z)

Why me?
Why now?

Nancy Kerigan
/Mike Turner

73% of the Universe is made of
Dark Energy

Dark Matter	23%
Dark Energy	73%
Normal Matter*	4%
	100%

* Observed Stars 1%