Extreme Astrophysics

UNIVERSITY of GLASGOW

Dr Martin Hendry
Dept of Physics and Astronomy

Extreme astrophysics: Jan 2007

Extreme Astrophysics

Provisional schedule

22/01	Introduction / Life and death of	M. Hendry
29/01	stars / supernovae	
05/02	The search for gravitational waves	M. Pitkin
12/02	The story of cosmic rays	A. Mackinnon
19/02	The threat of asteroid impact	B. Steves
26/02	Gamma ray bursts	F. Speirits
05/03	A recipe for galaxy formation	L. Teodoro
12/03	Echoes of the Big Bang	L. Teodoro
19/03	Welcome to quantum gravity!	N. Gray / M. Hendry

Also: 03/02 Transits and Eclipses Day School

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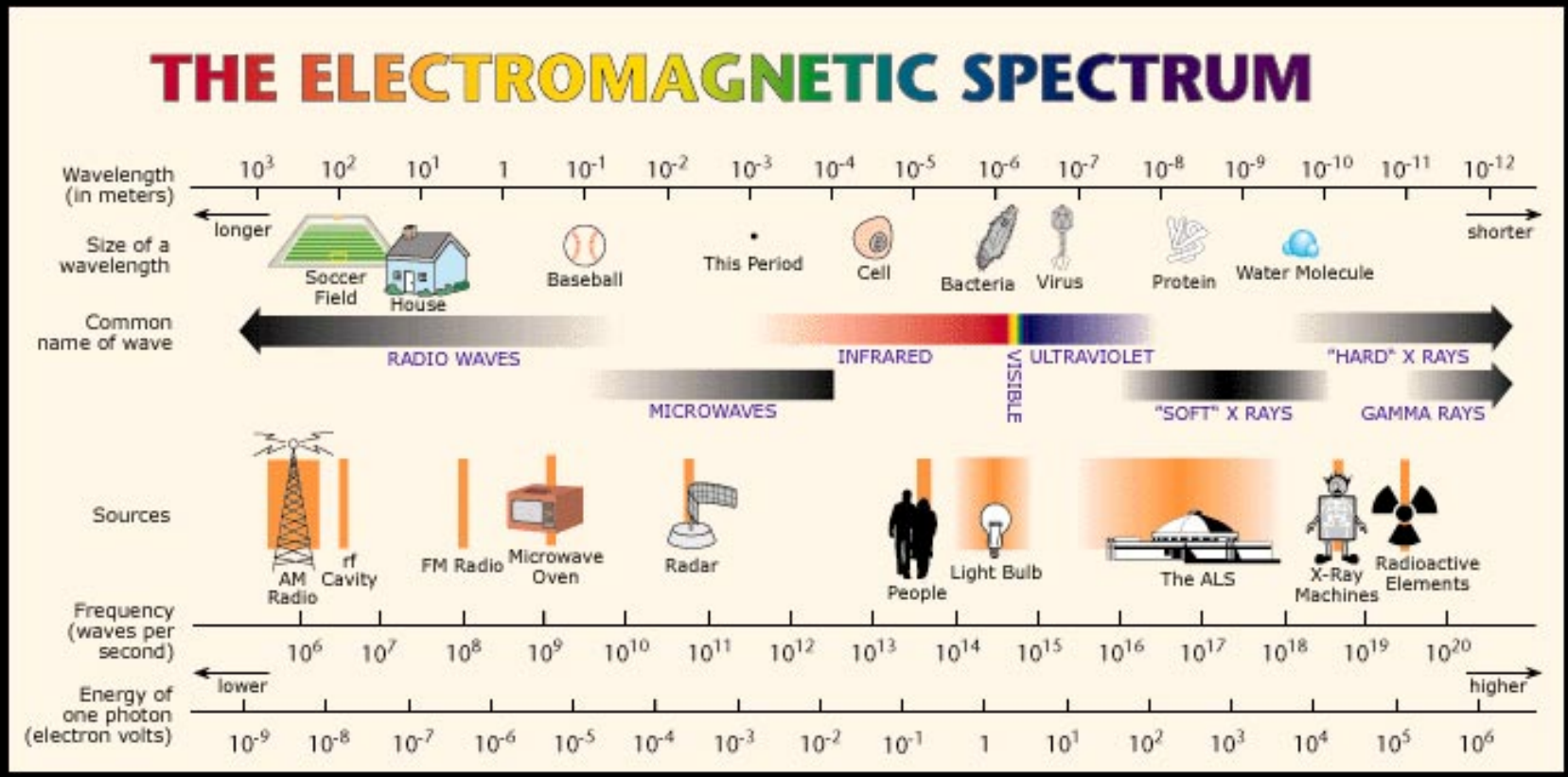
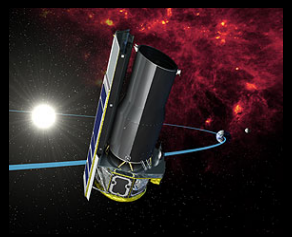
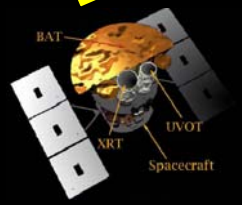
ASTRONOMY ★ ASTROPHYSICS

PPARC

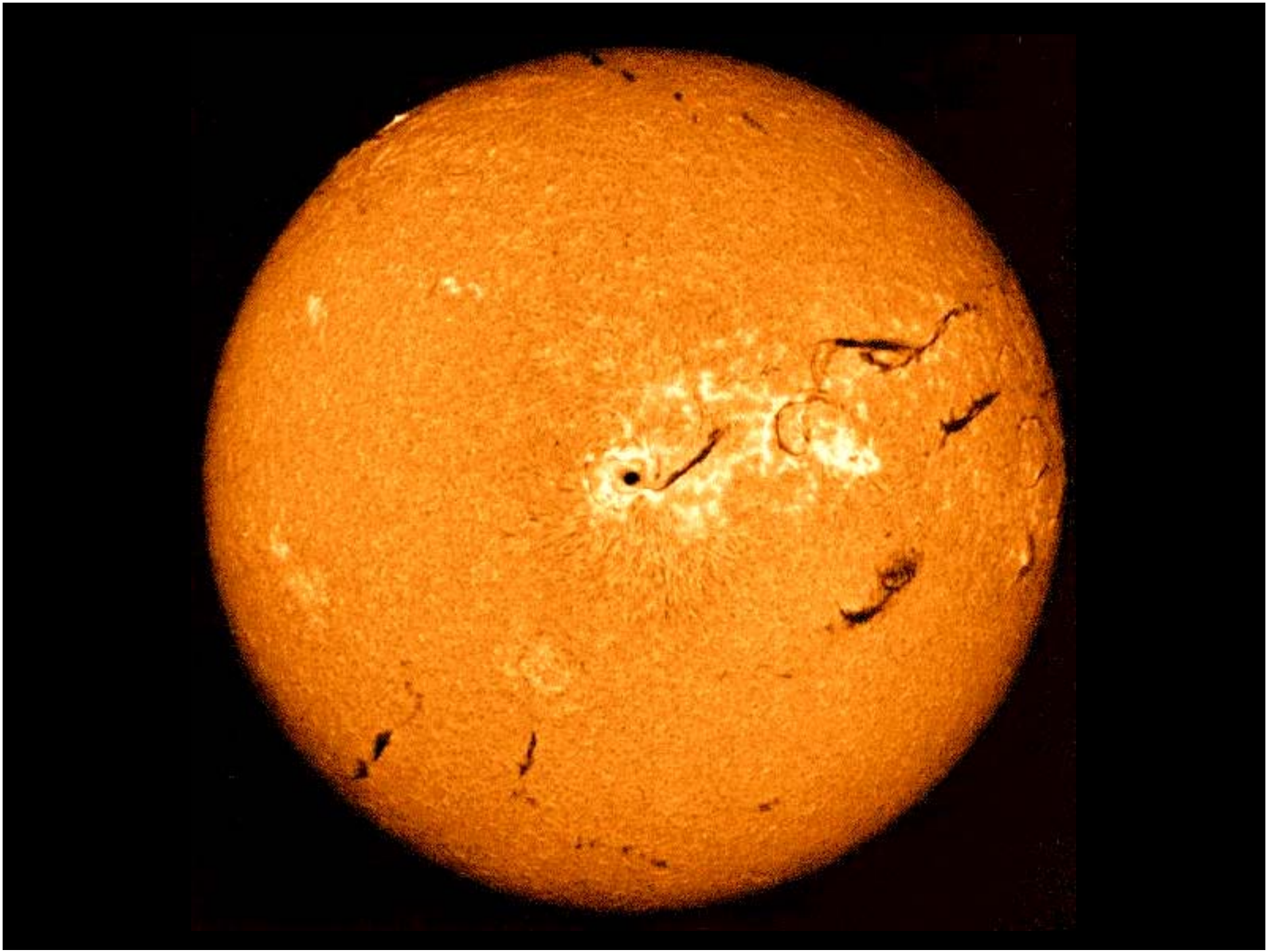
Extreme astrophysics: Jan 2007





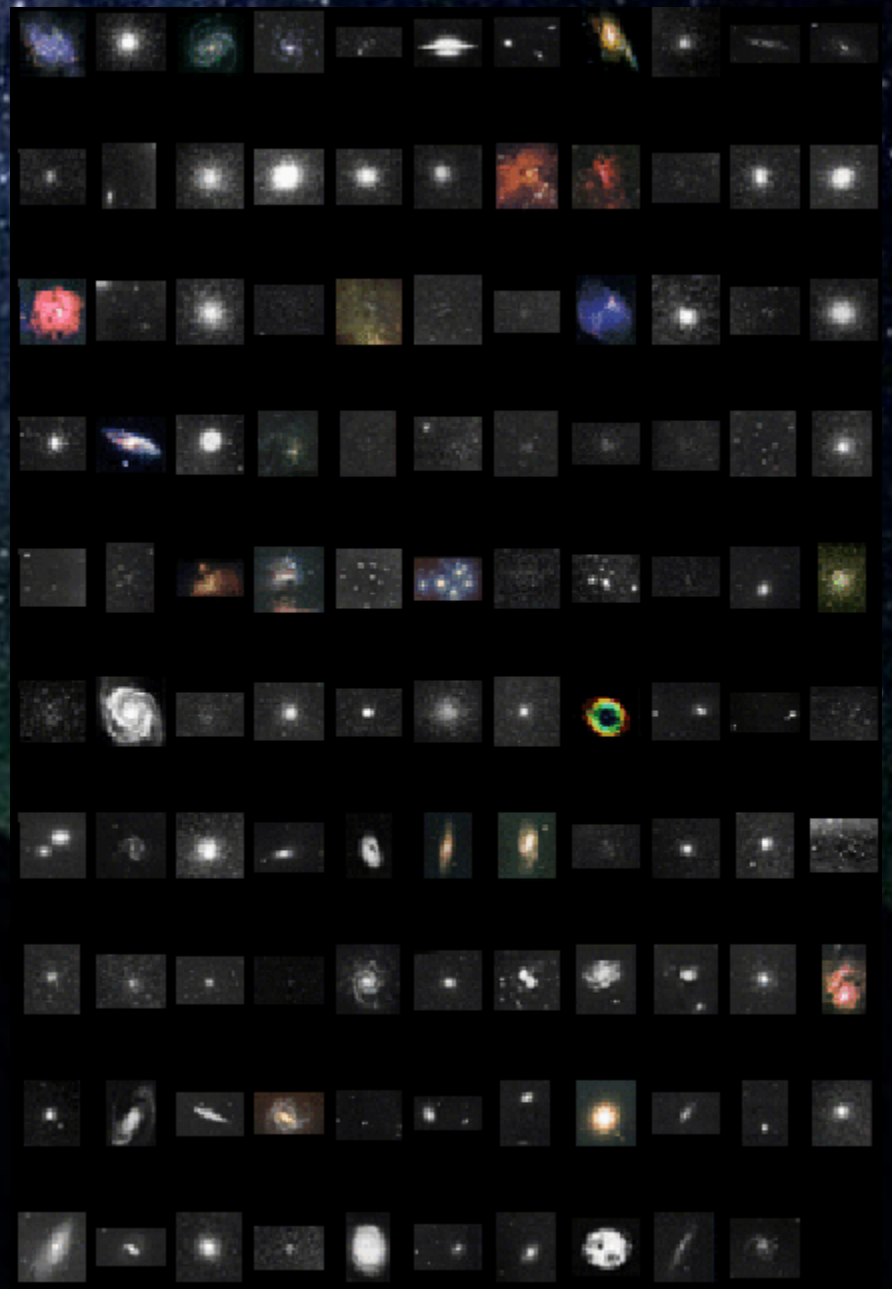


Temperature: 3K 100K 5000K 10^{5}K 10^{7}K 10^{9}K



How do stars and planets form?

from Nebulae



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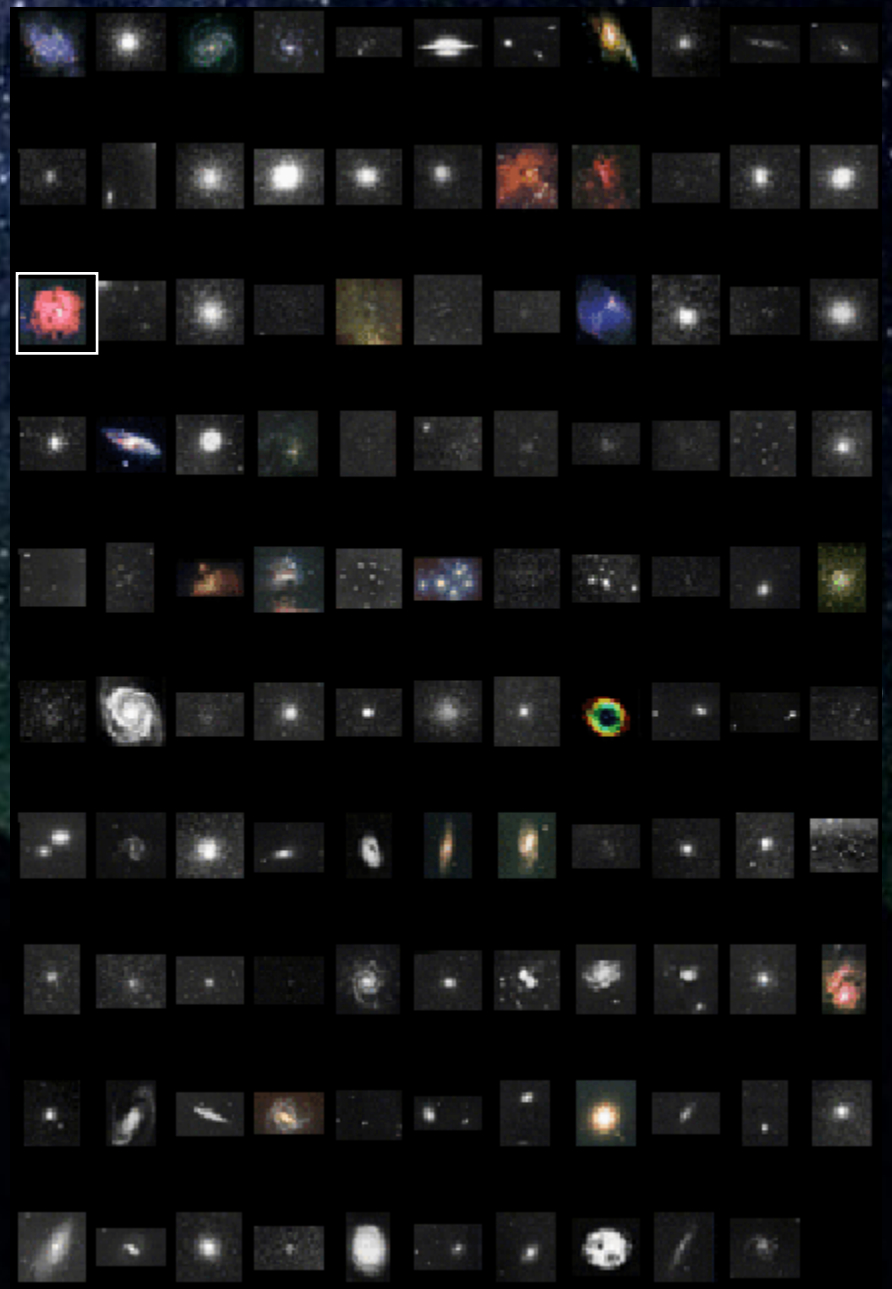


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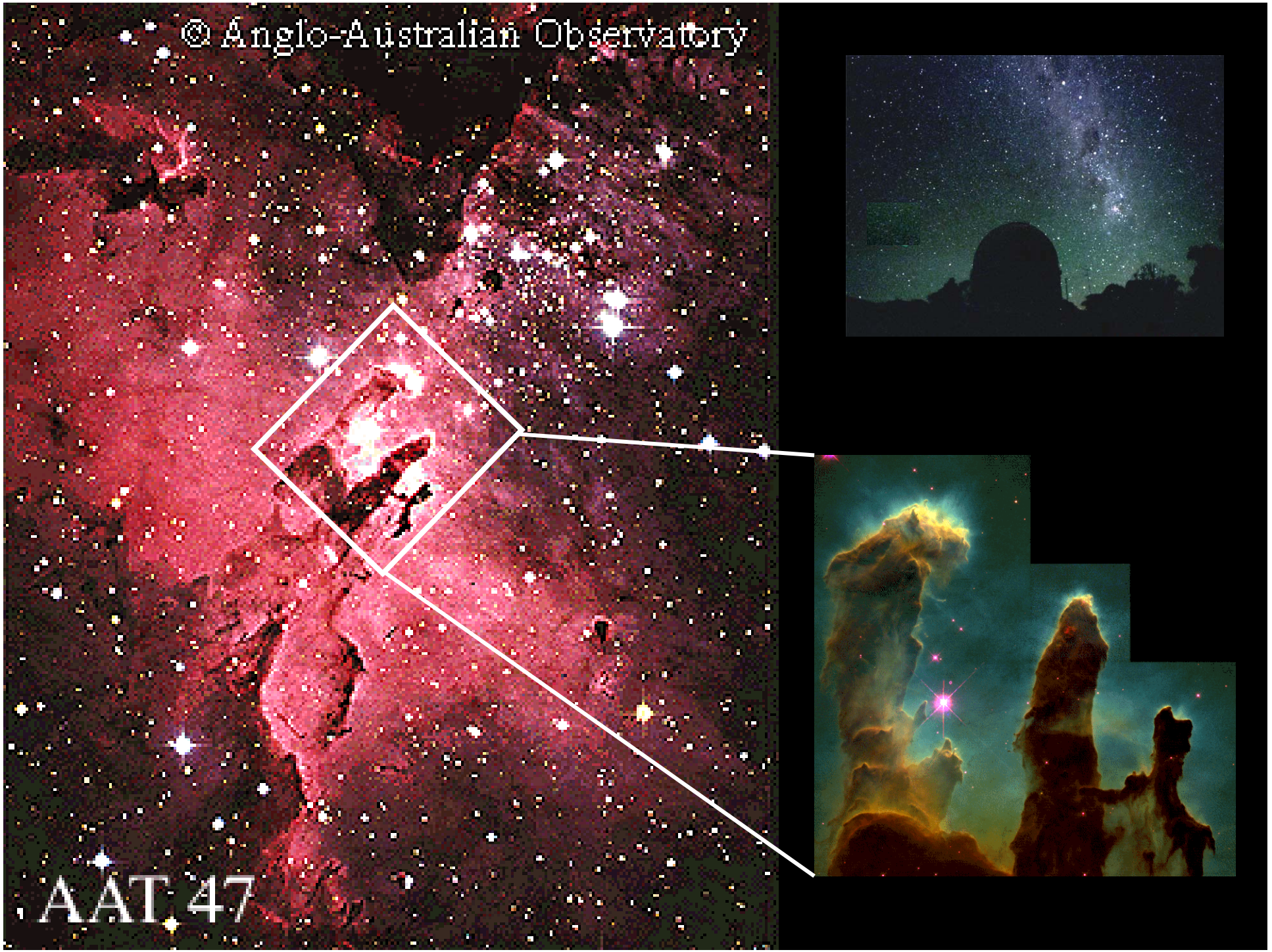
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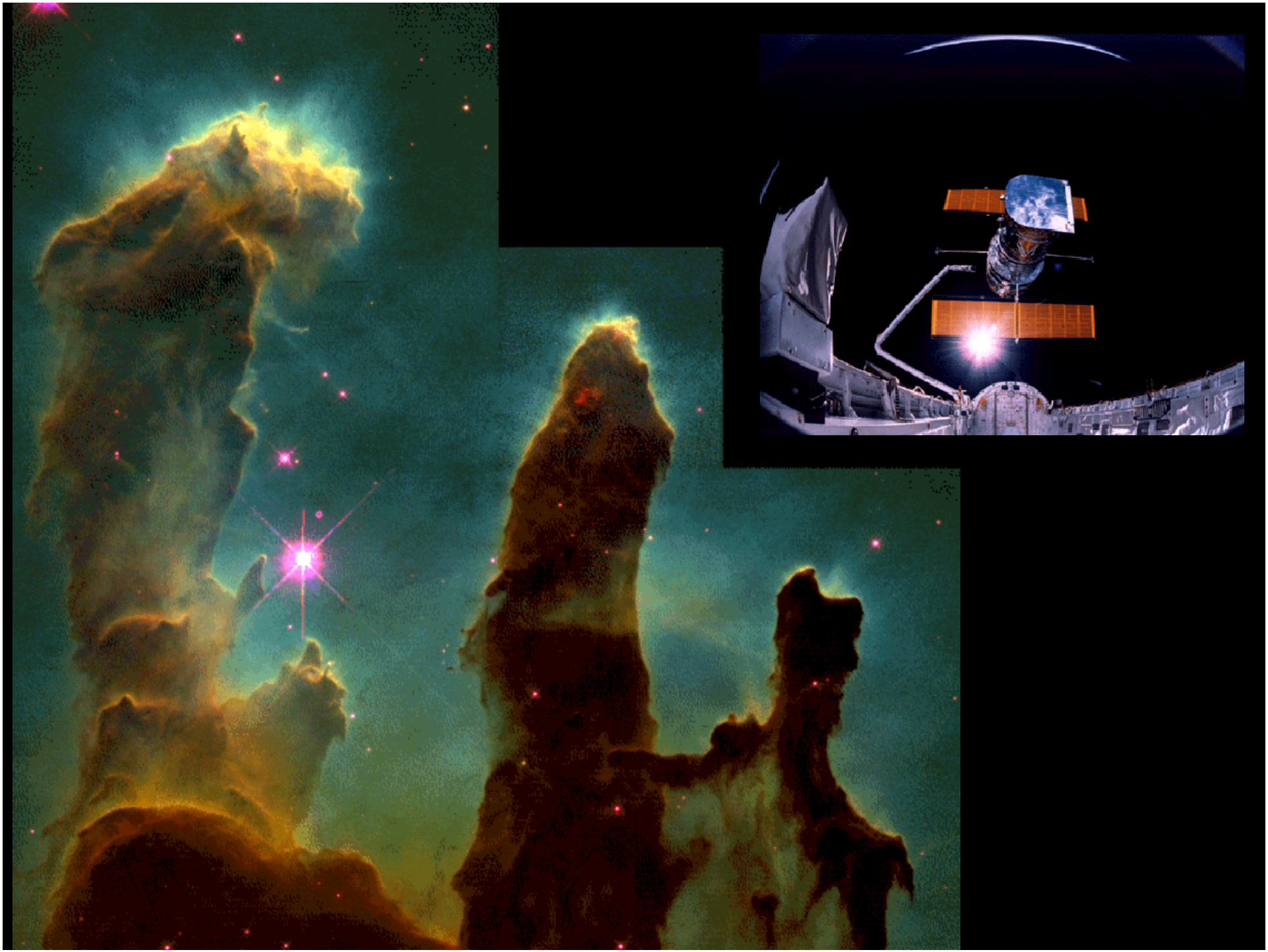
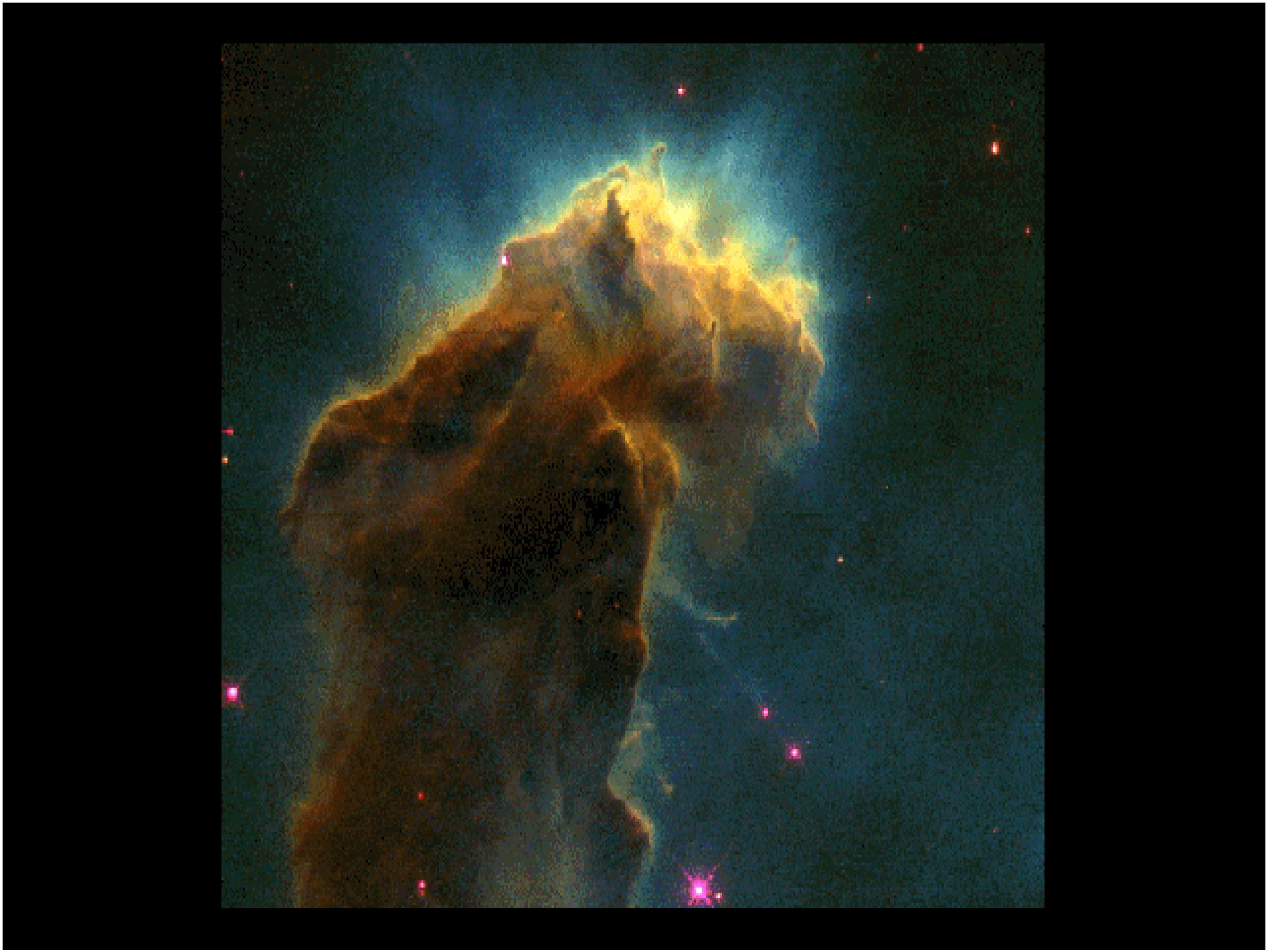
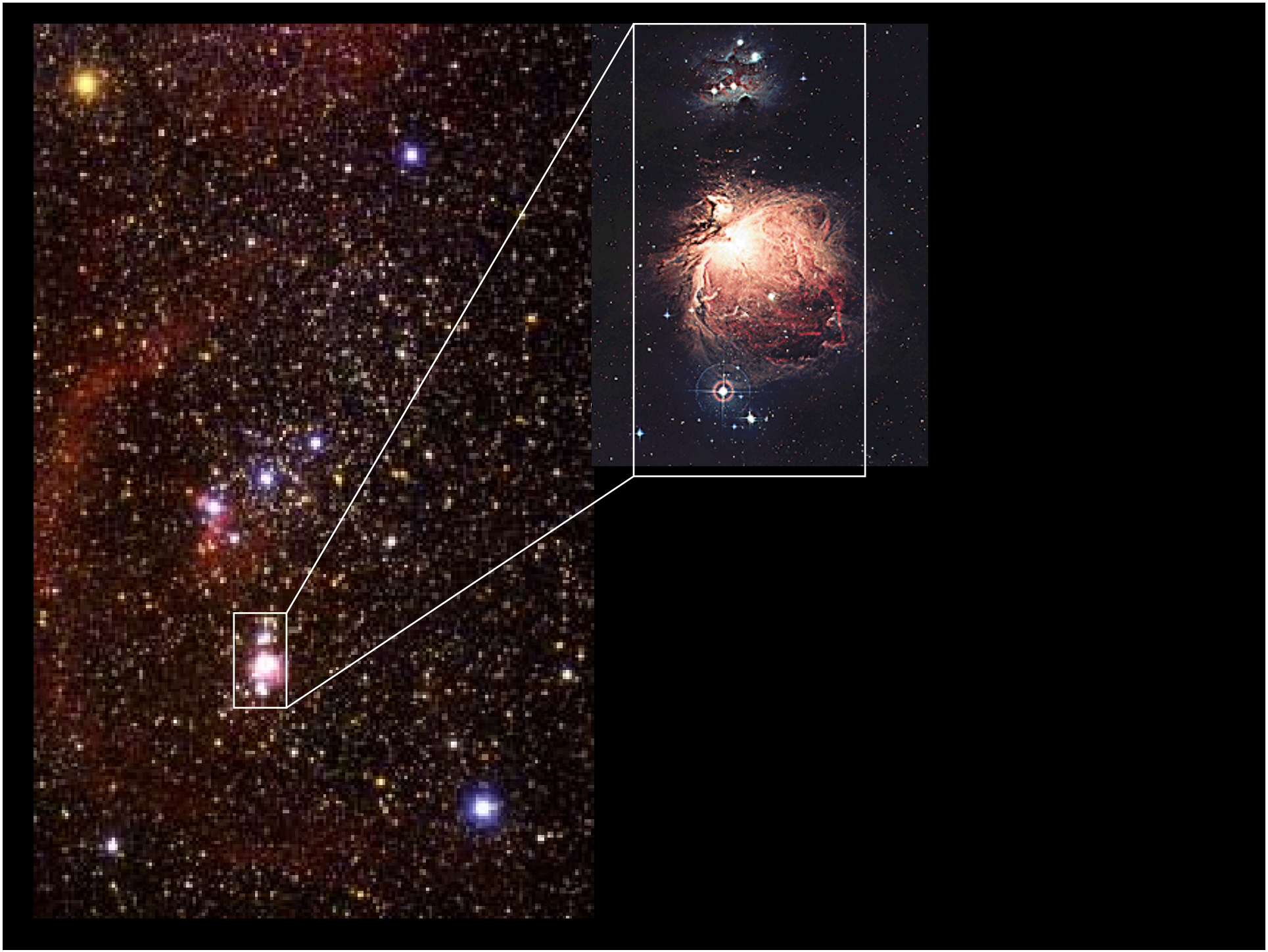
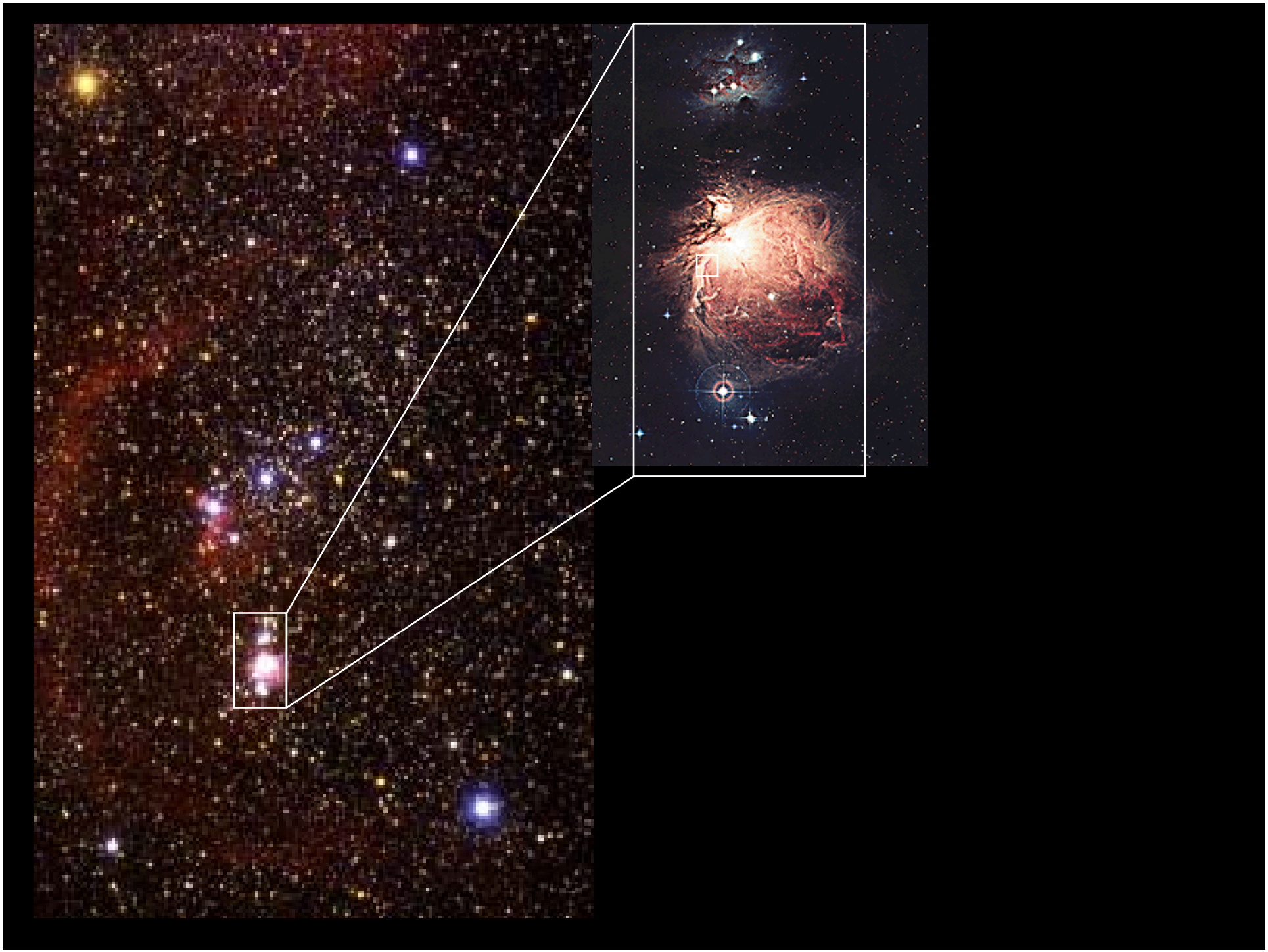
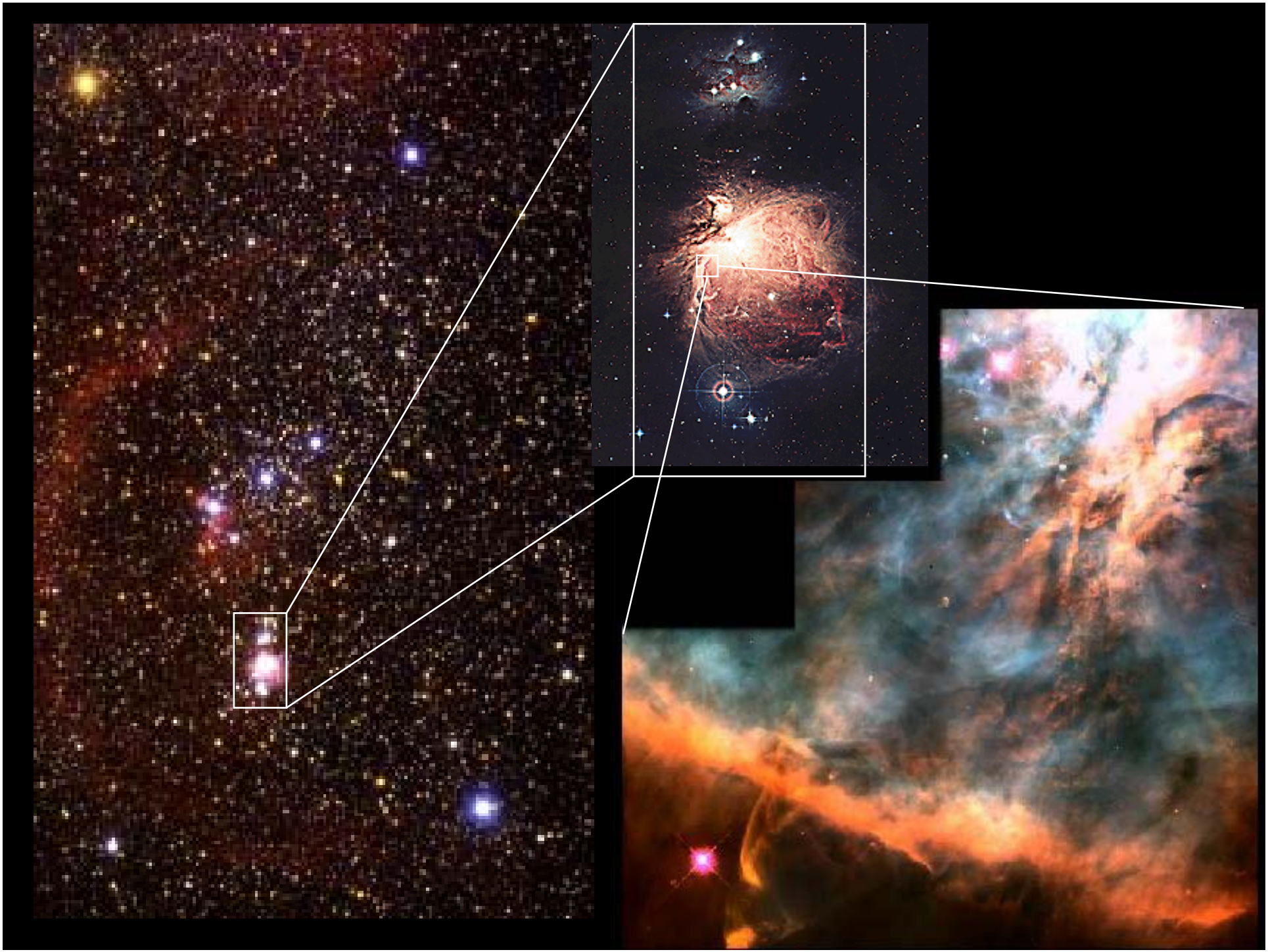










The Orion Nebula

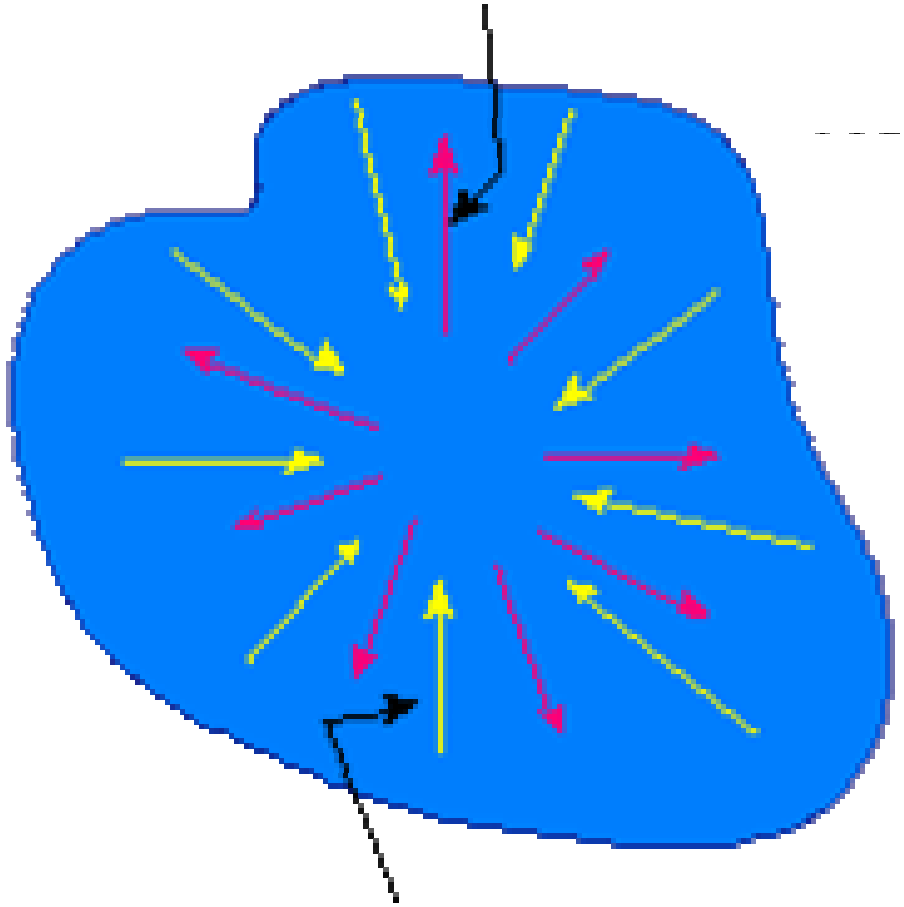
Forming stars

Forming stars

versus

Forming stars

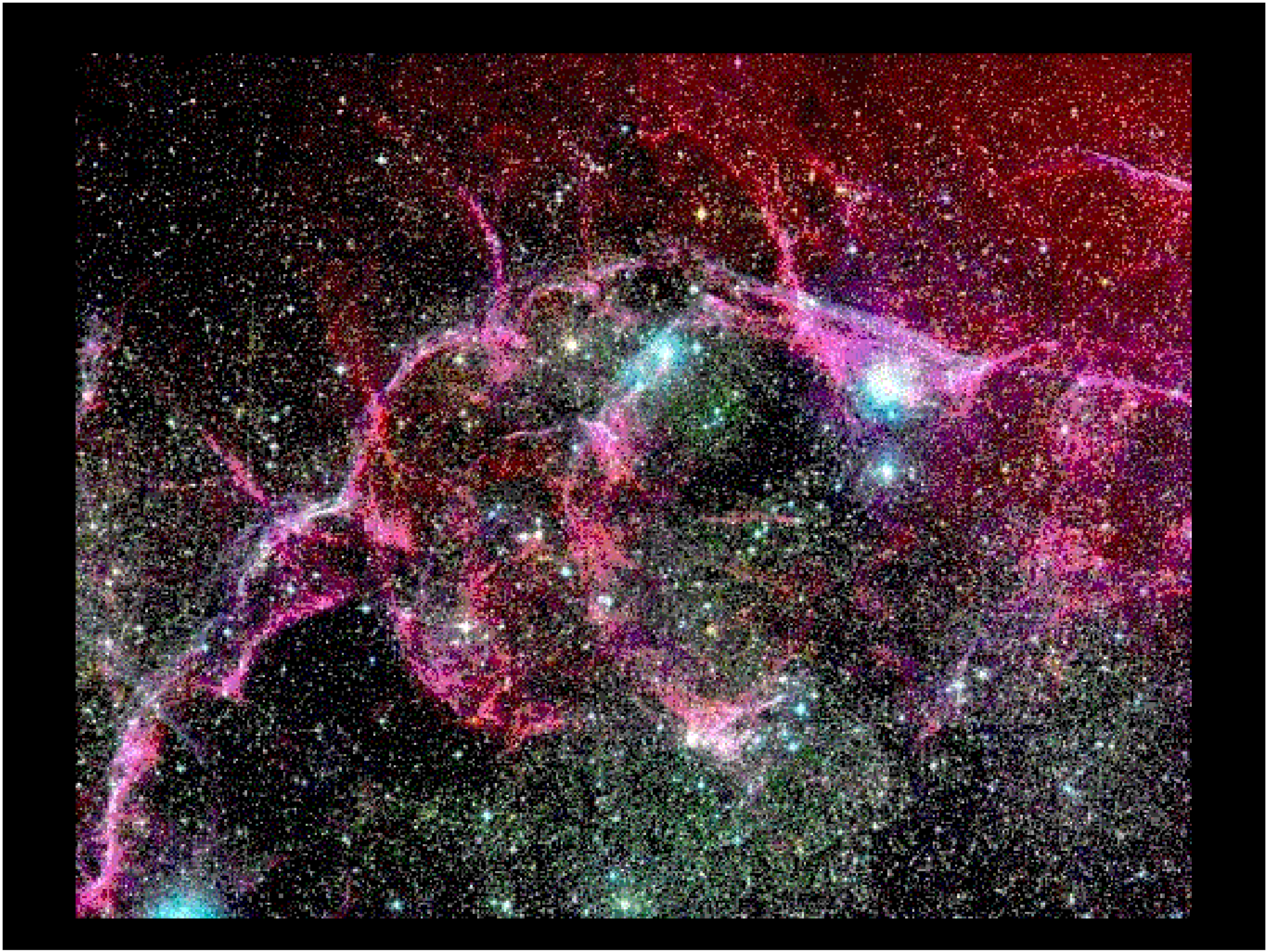
Gas pressure trying to expand the cloud



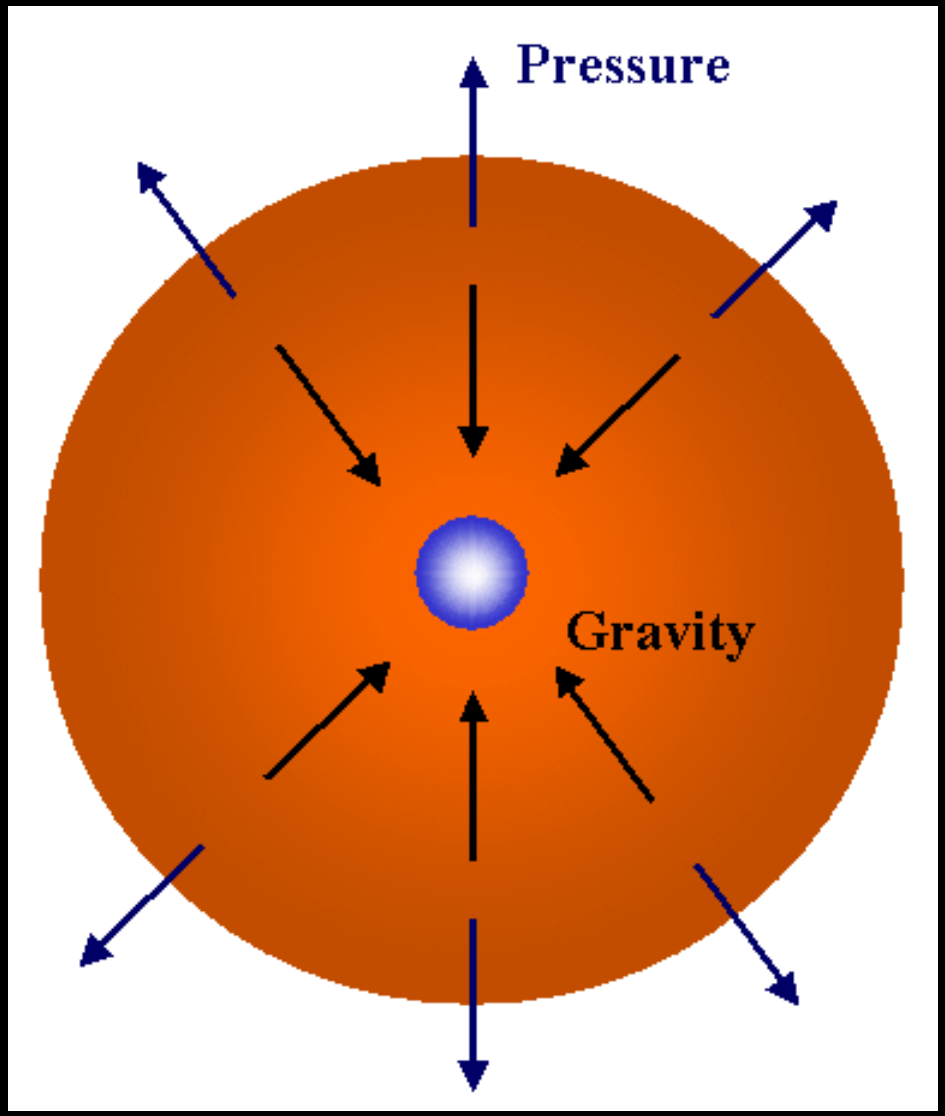
Gravity trying to collapse the cloud

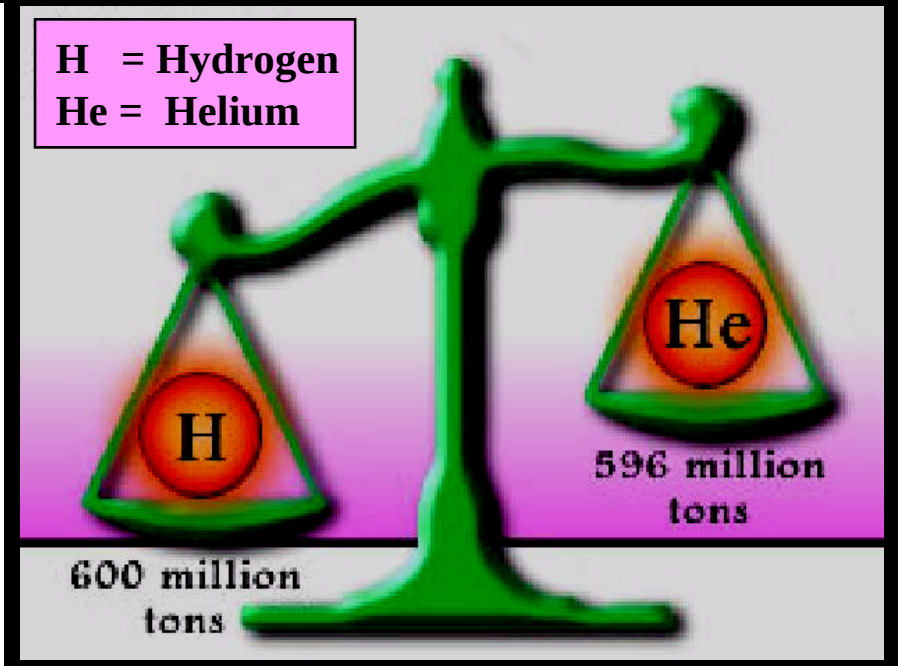
Pressure versus Gravity

Collapse often caused by the shock wave from a *Supernova*



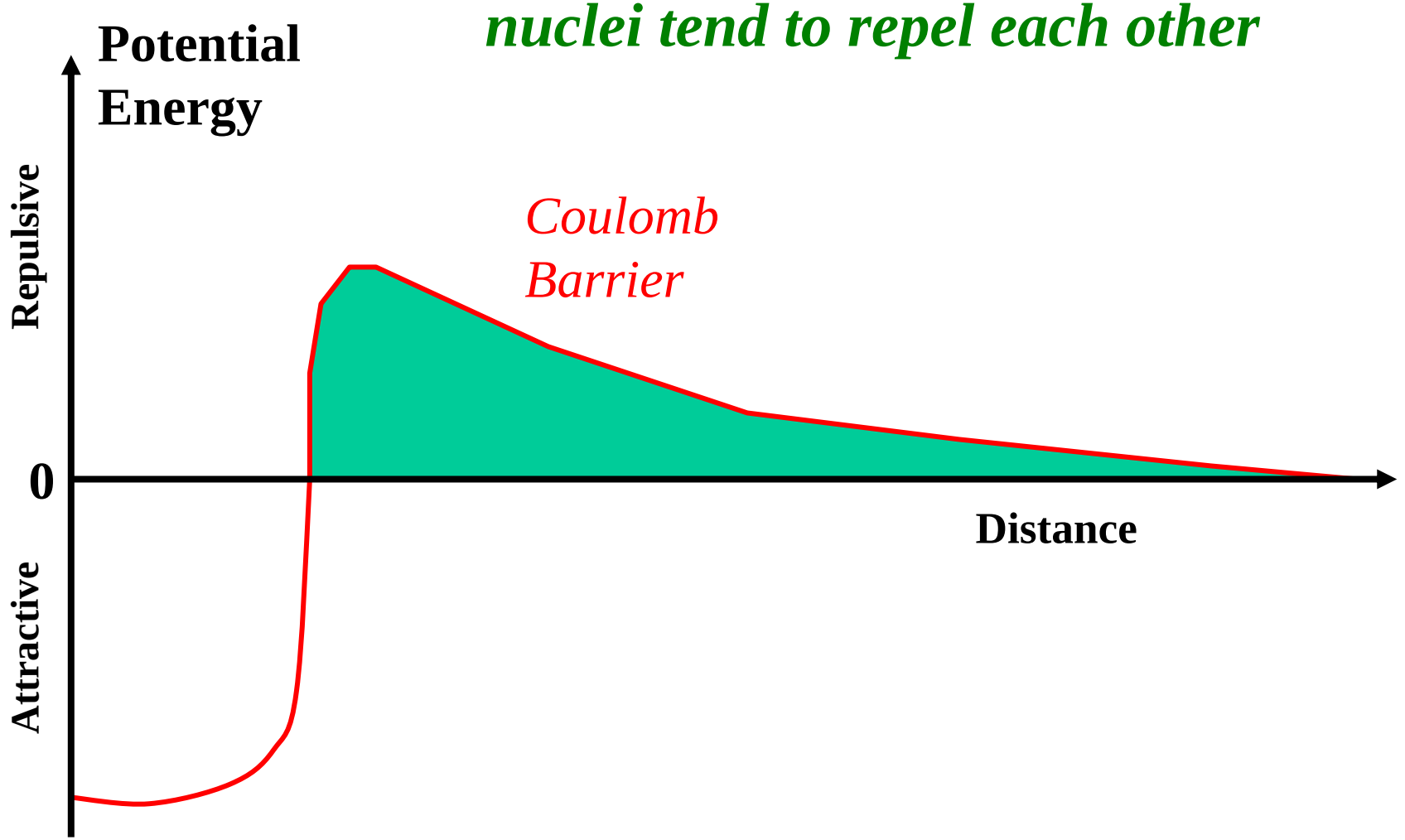
Hydrogen fusion – fuelling a star's nuclear furnace

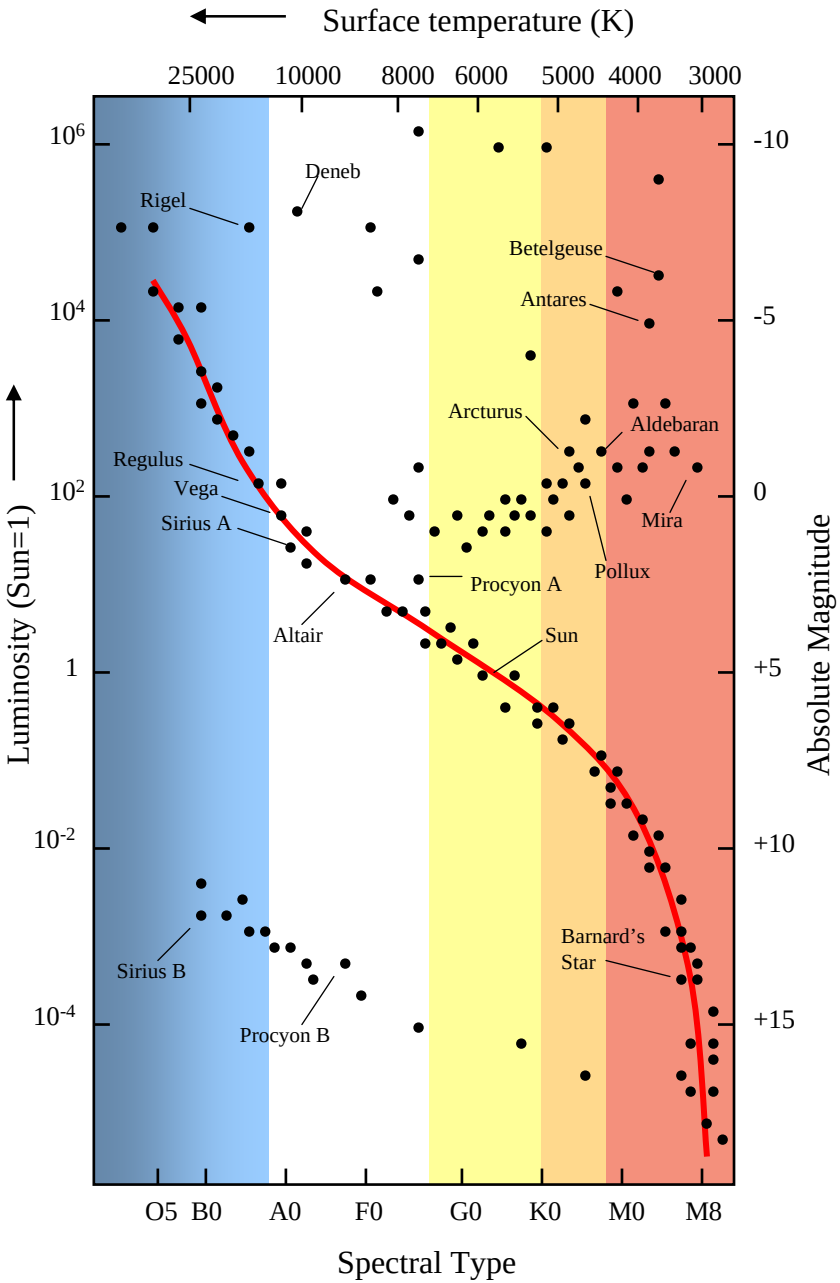




$$E = mc^2$$

Nuclear fusion only occurs at very high temperatures, because atomic nuclei tend to repel each other

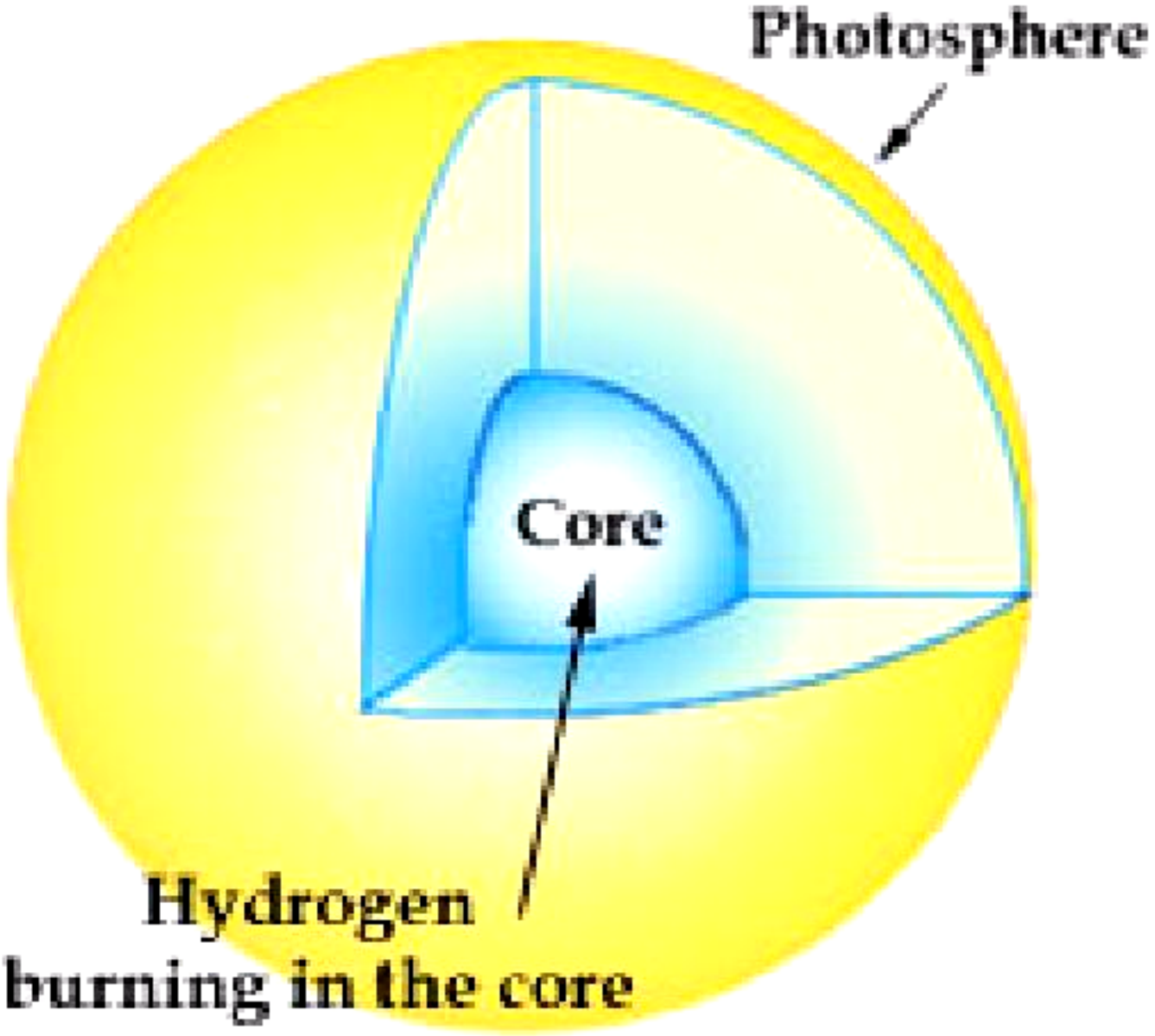




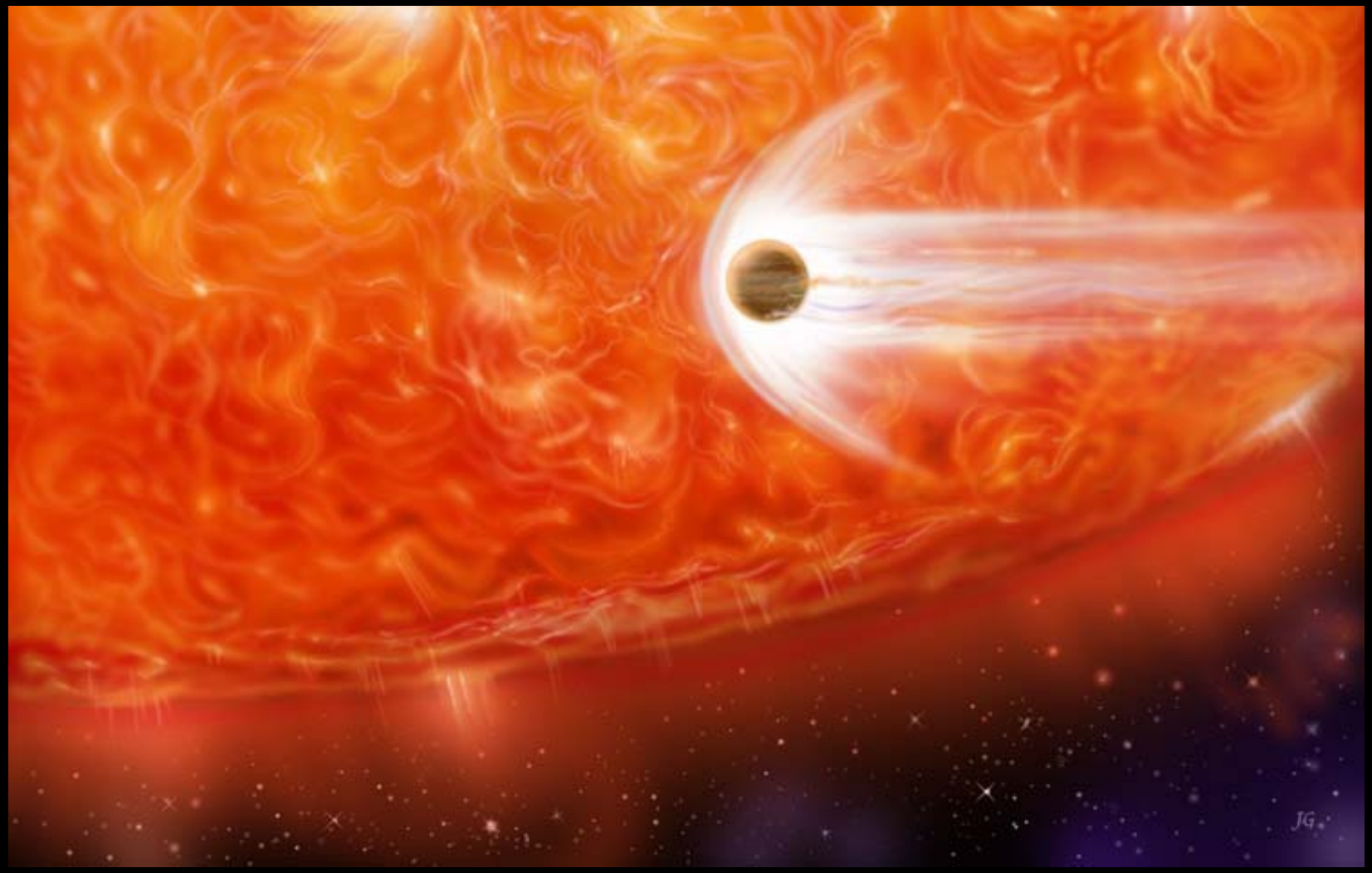
Stars on the **Main Sequence** turn hydrogen into helium.

Blue stars are much hotter than the Sun, and use up their hydrogen in a few million years

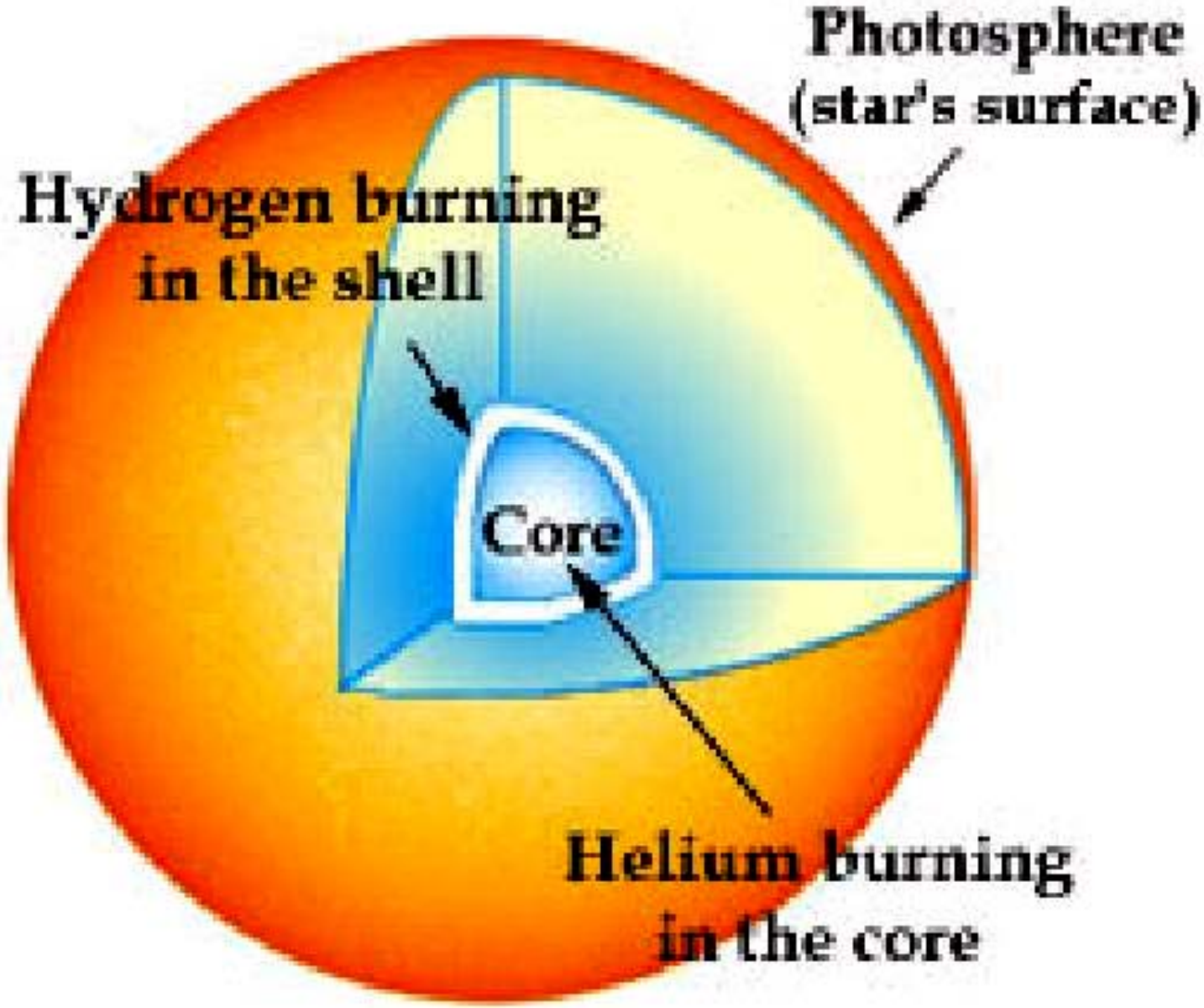
Interior of a solar-type star

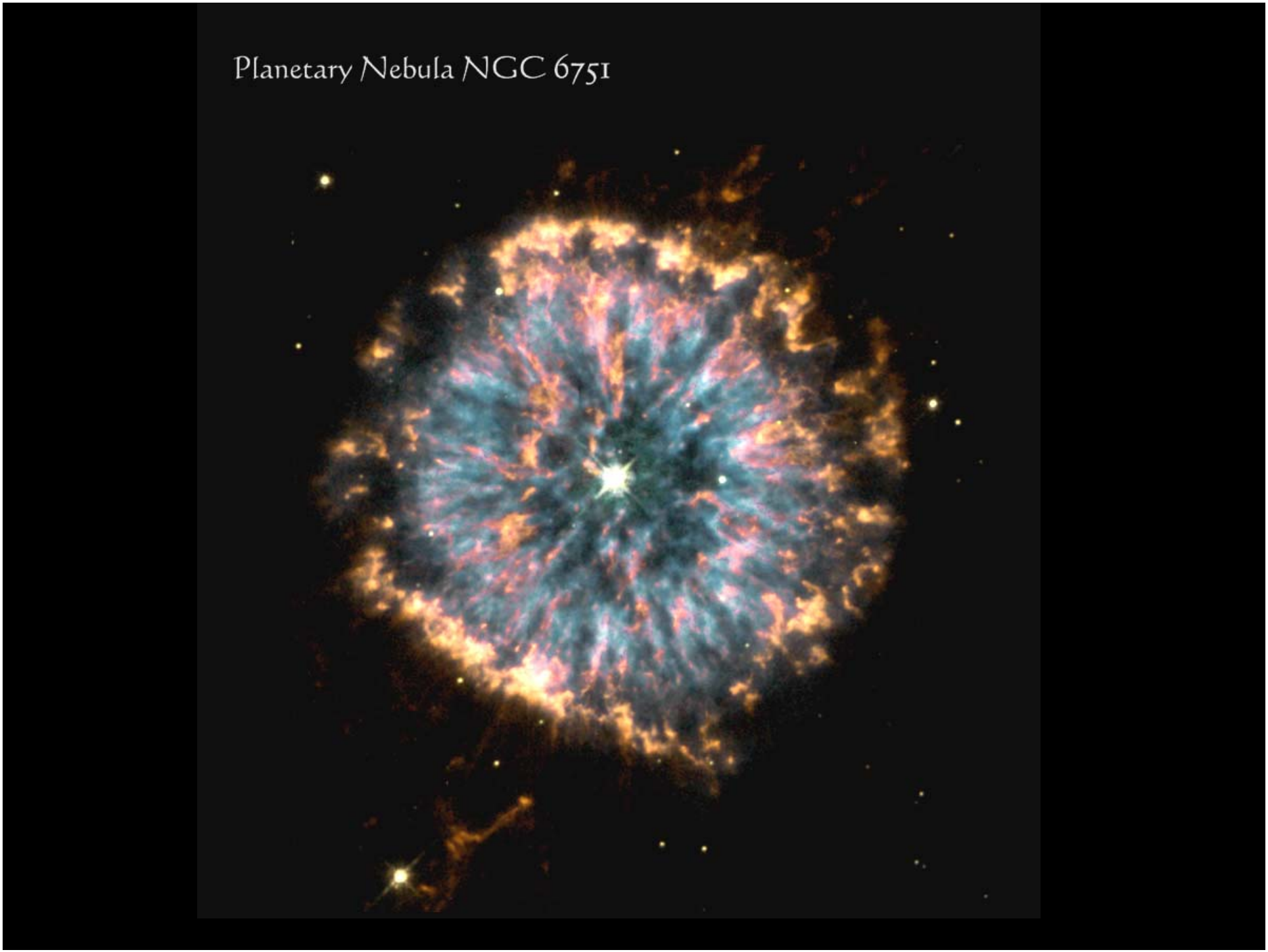


When the fuel runs out: formation of a red giant

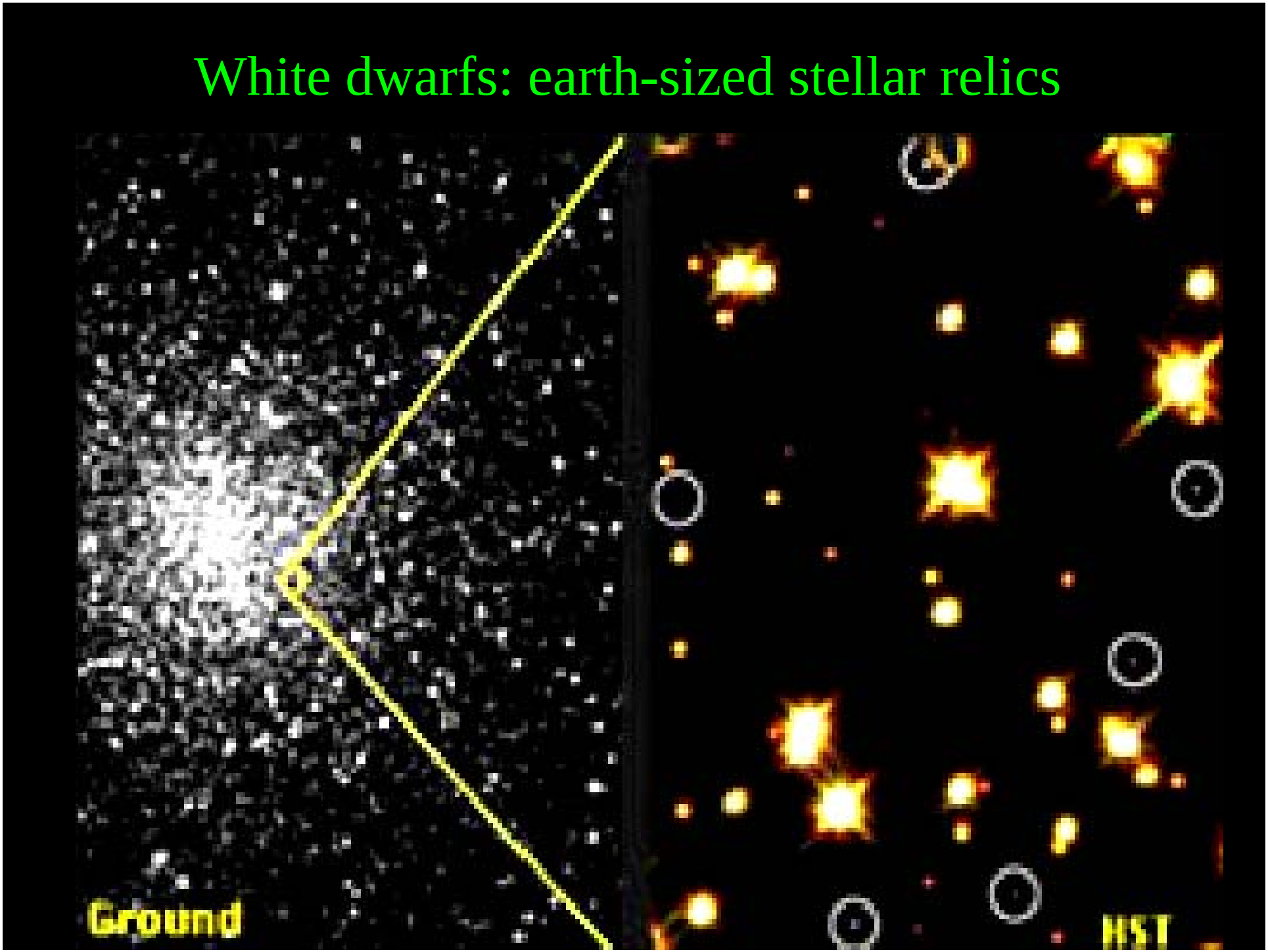


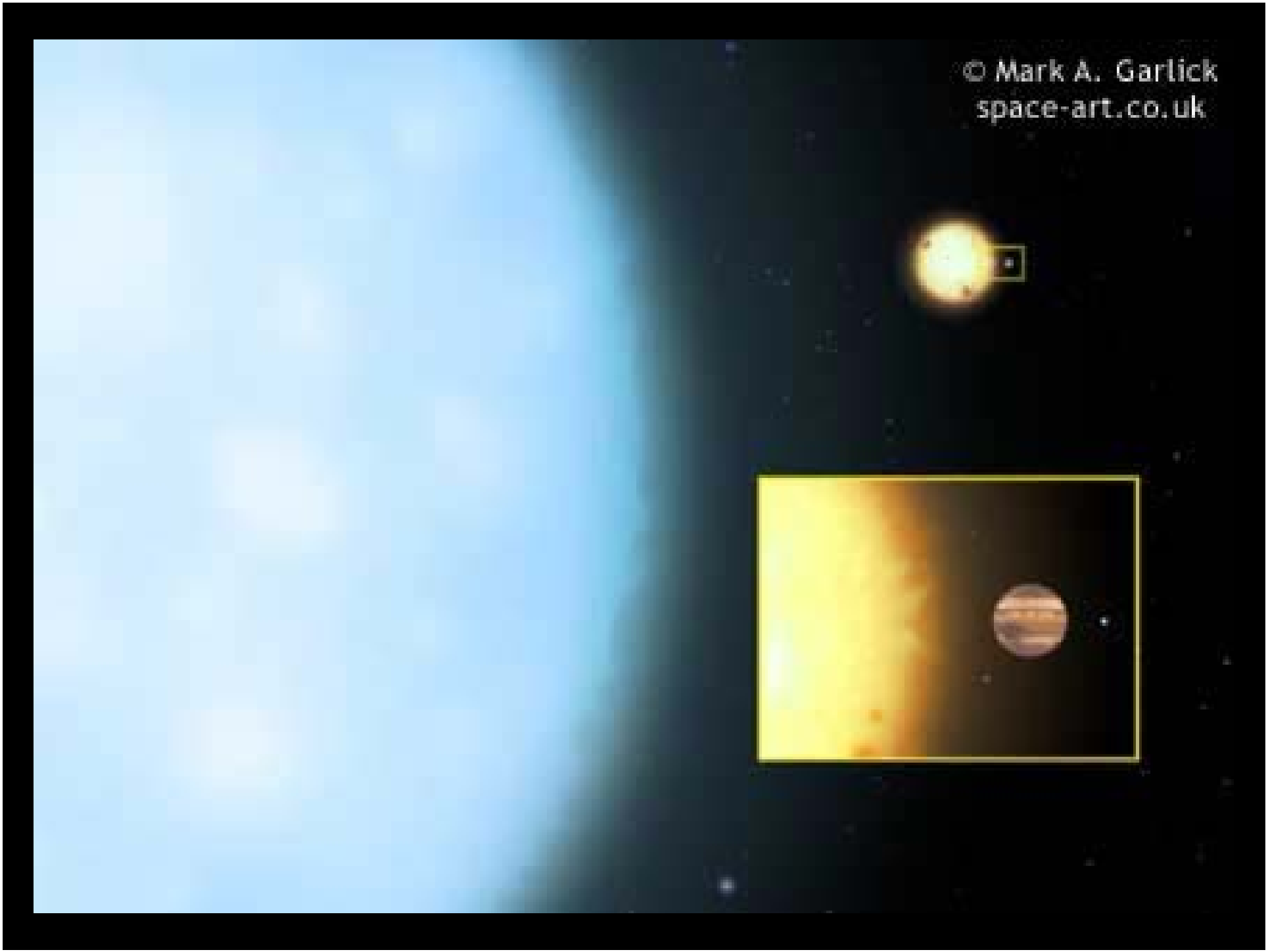
Interior of a red giant star




Planetary Nebula NGC 6751

White dwarfs: earth-sized stellar relics

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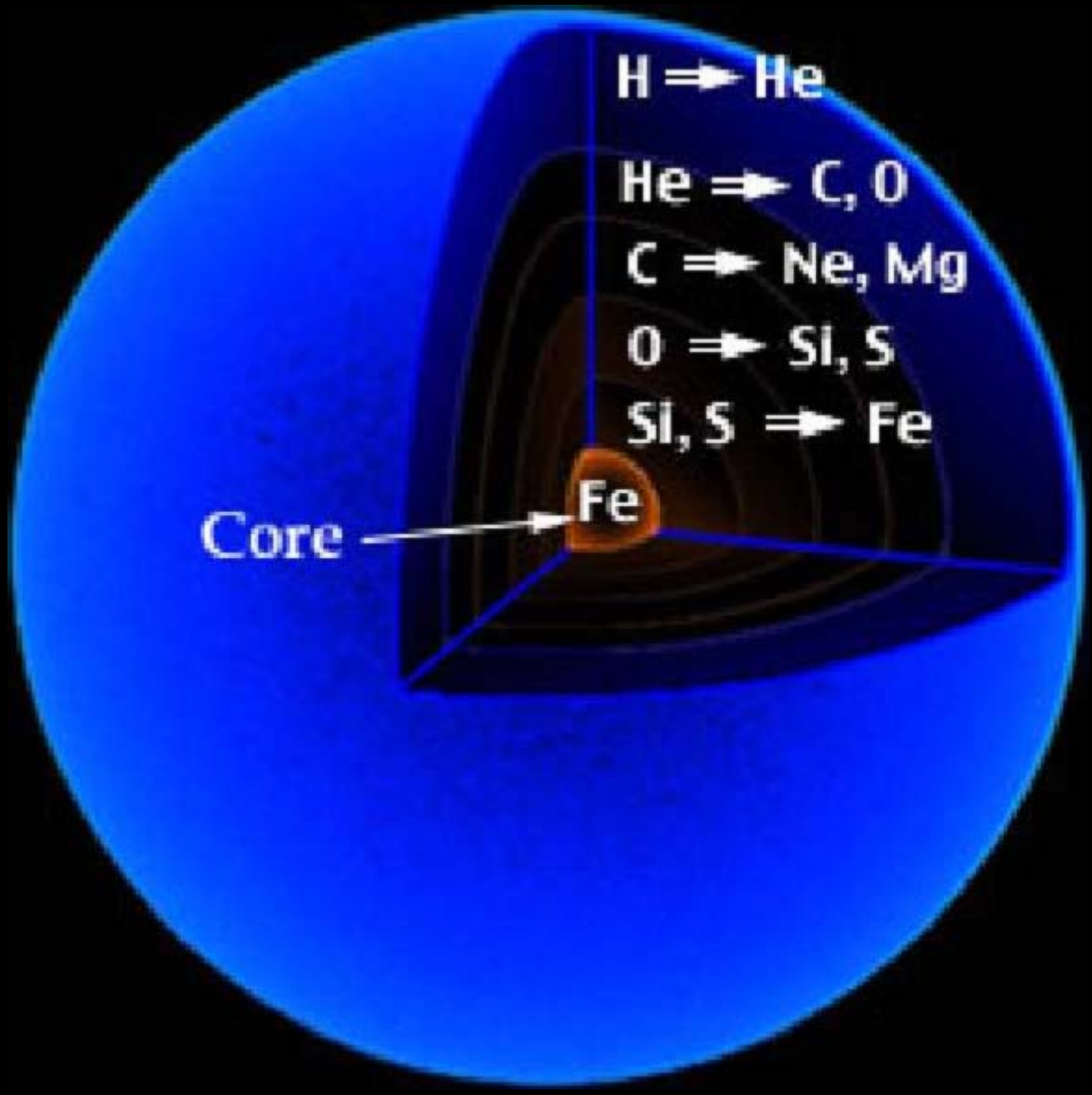
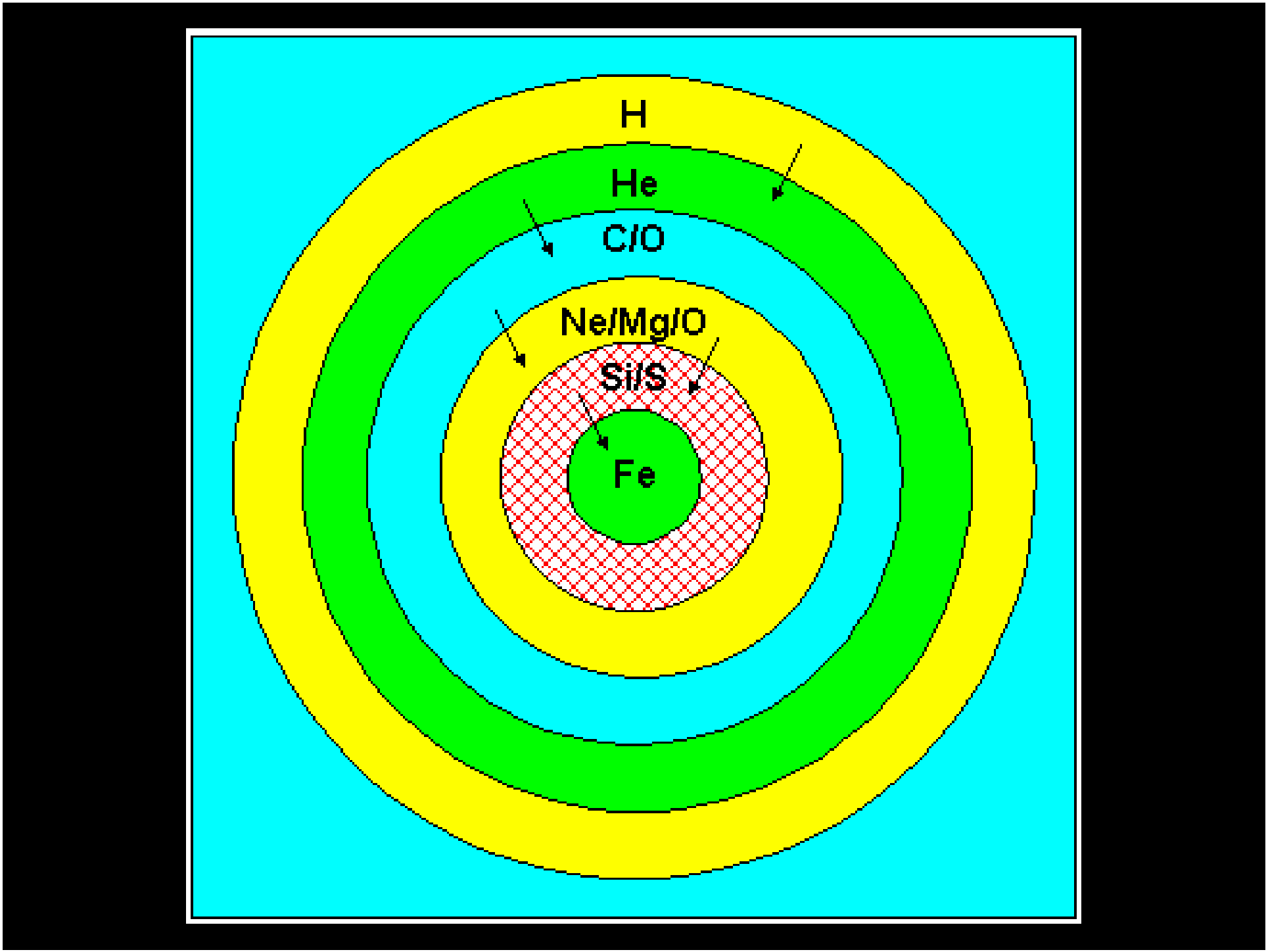
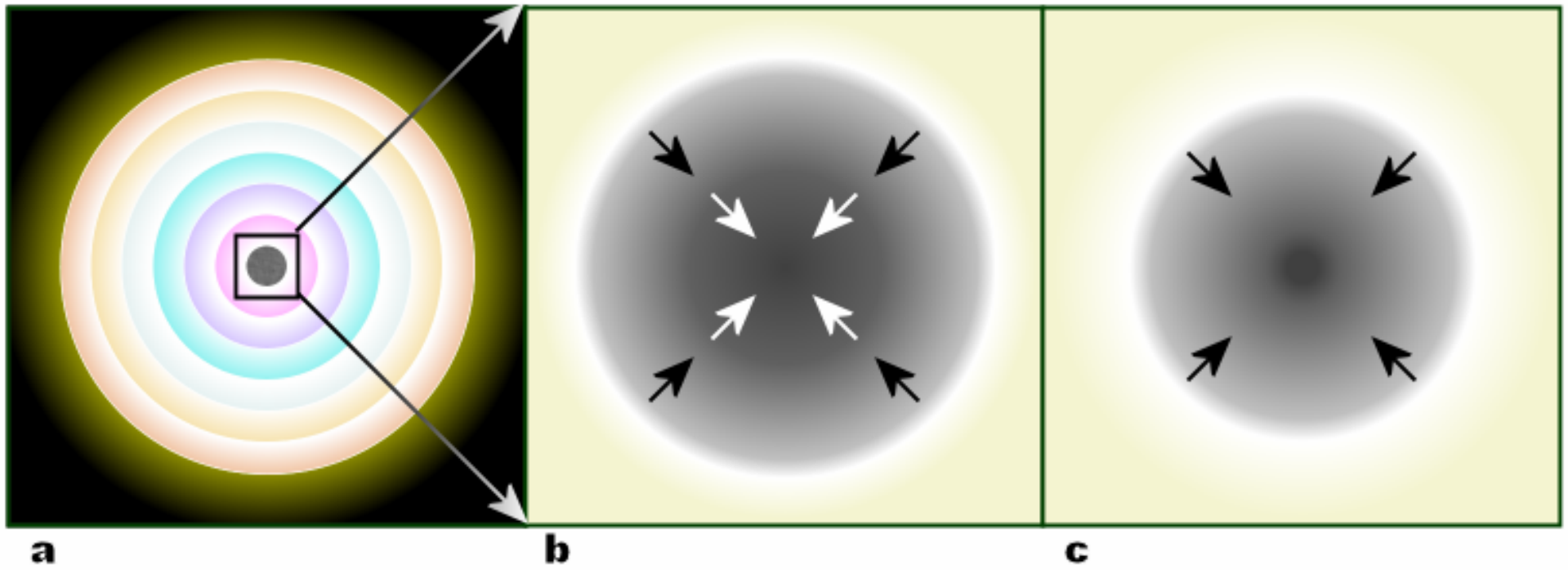
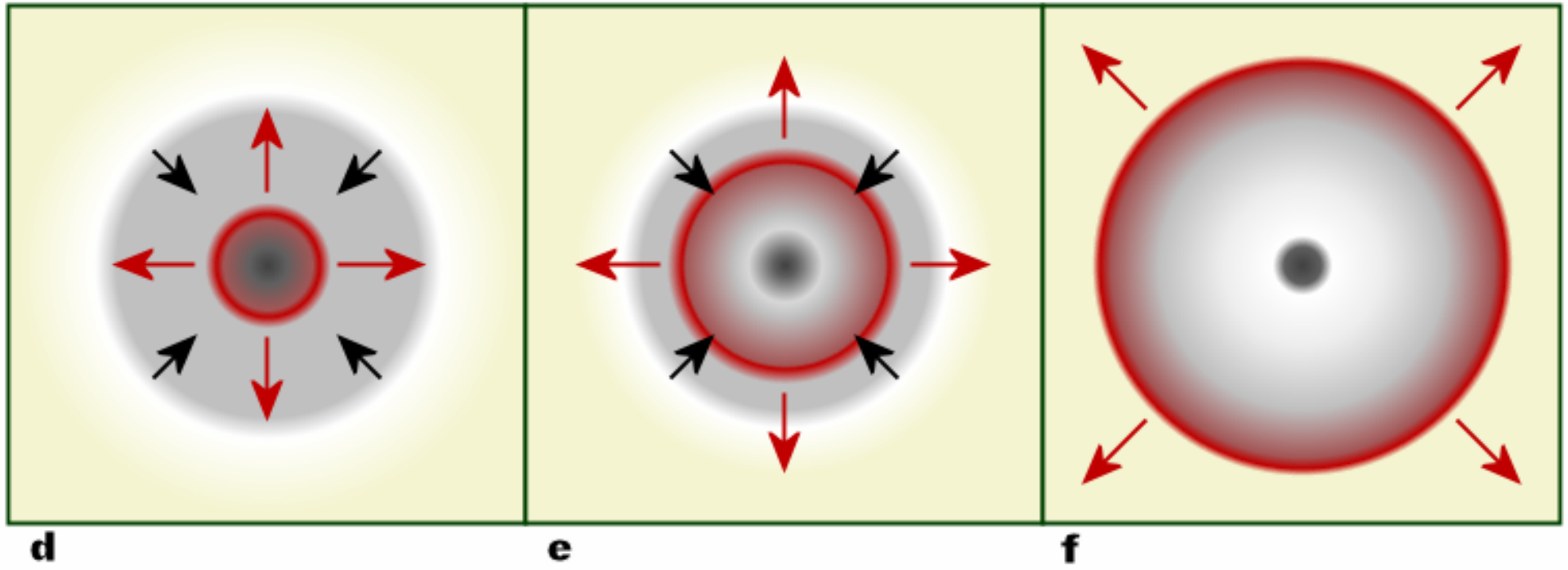
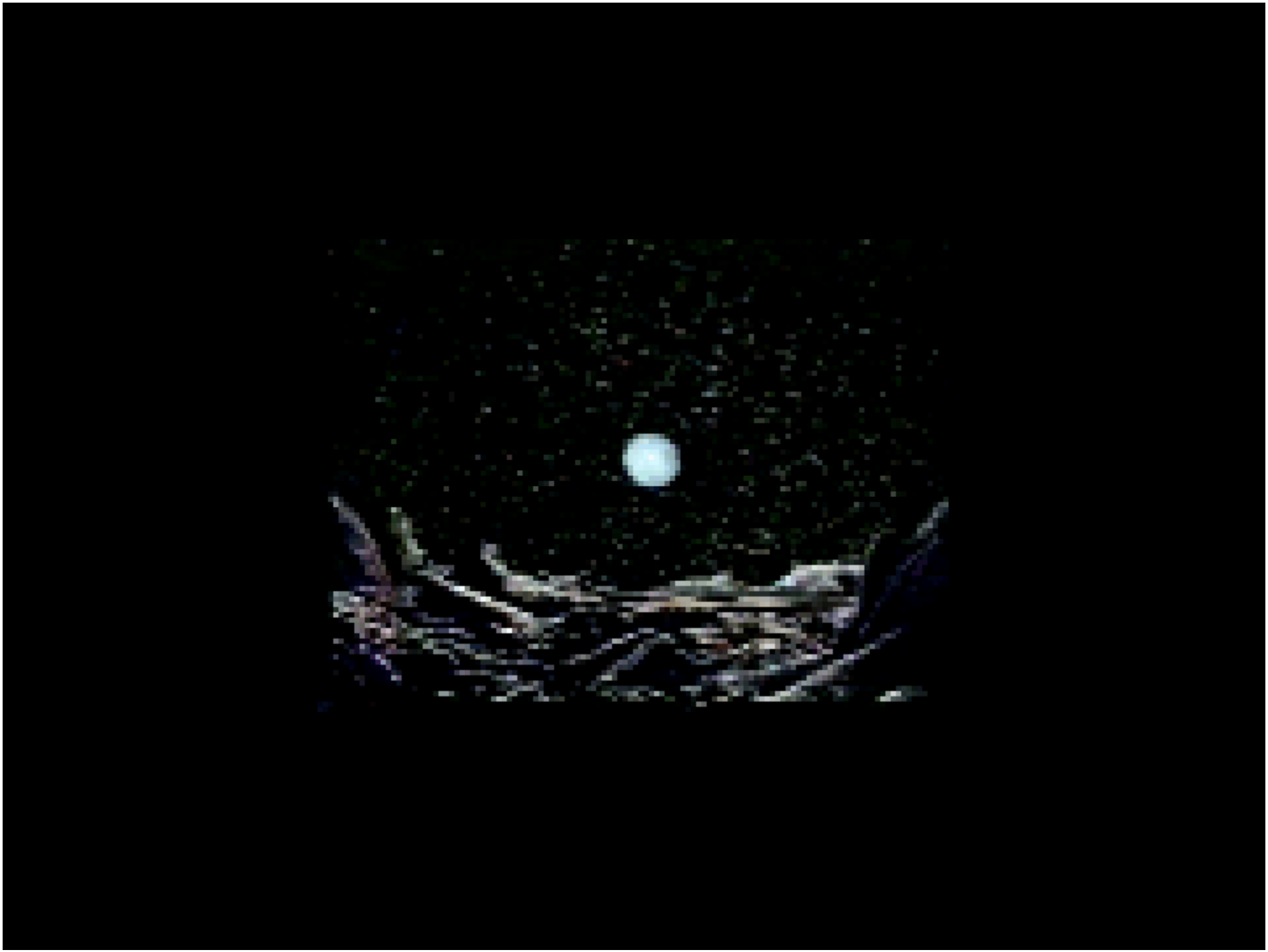
Interior of a very massive star

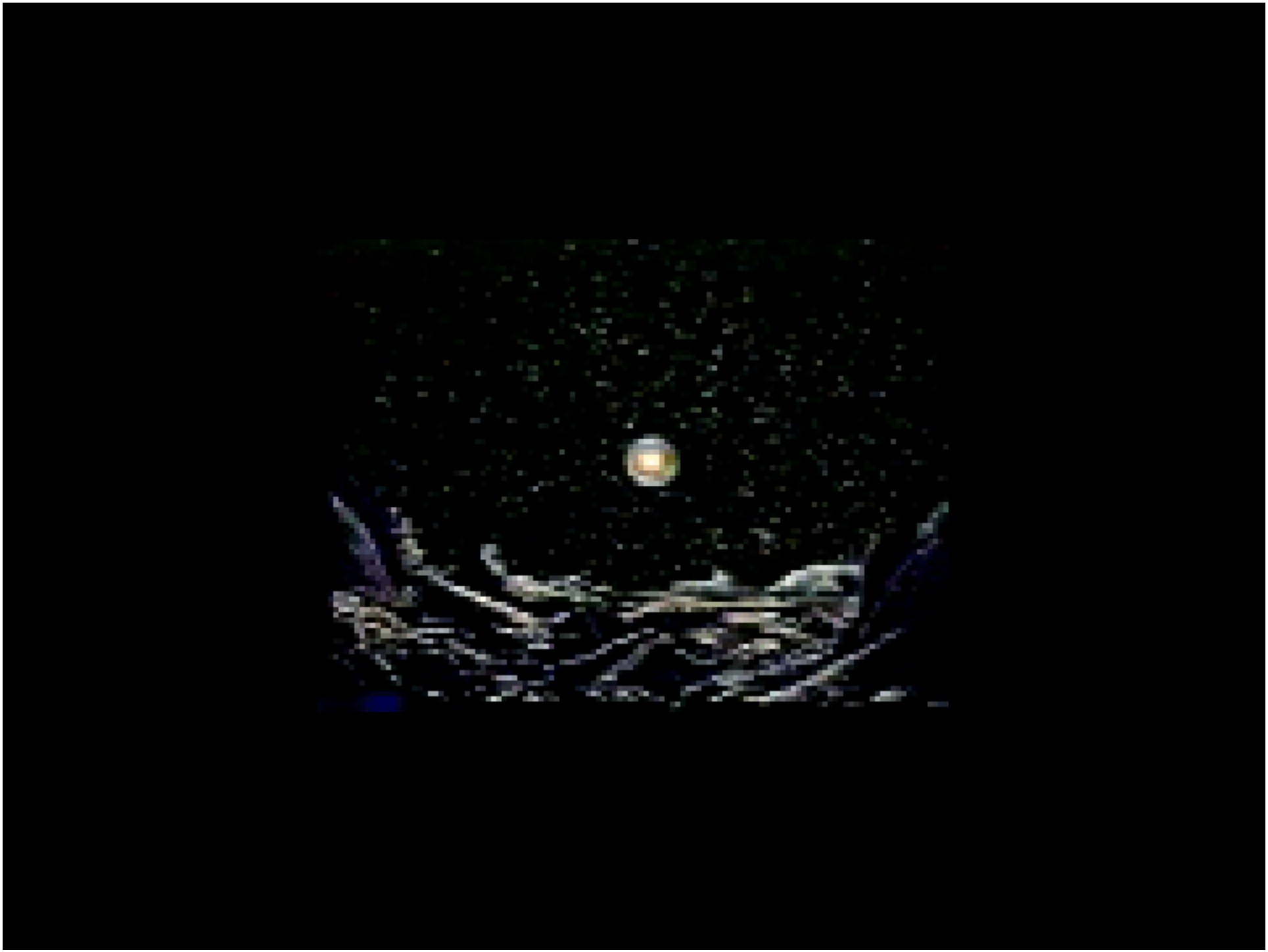


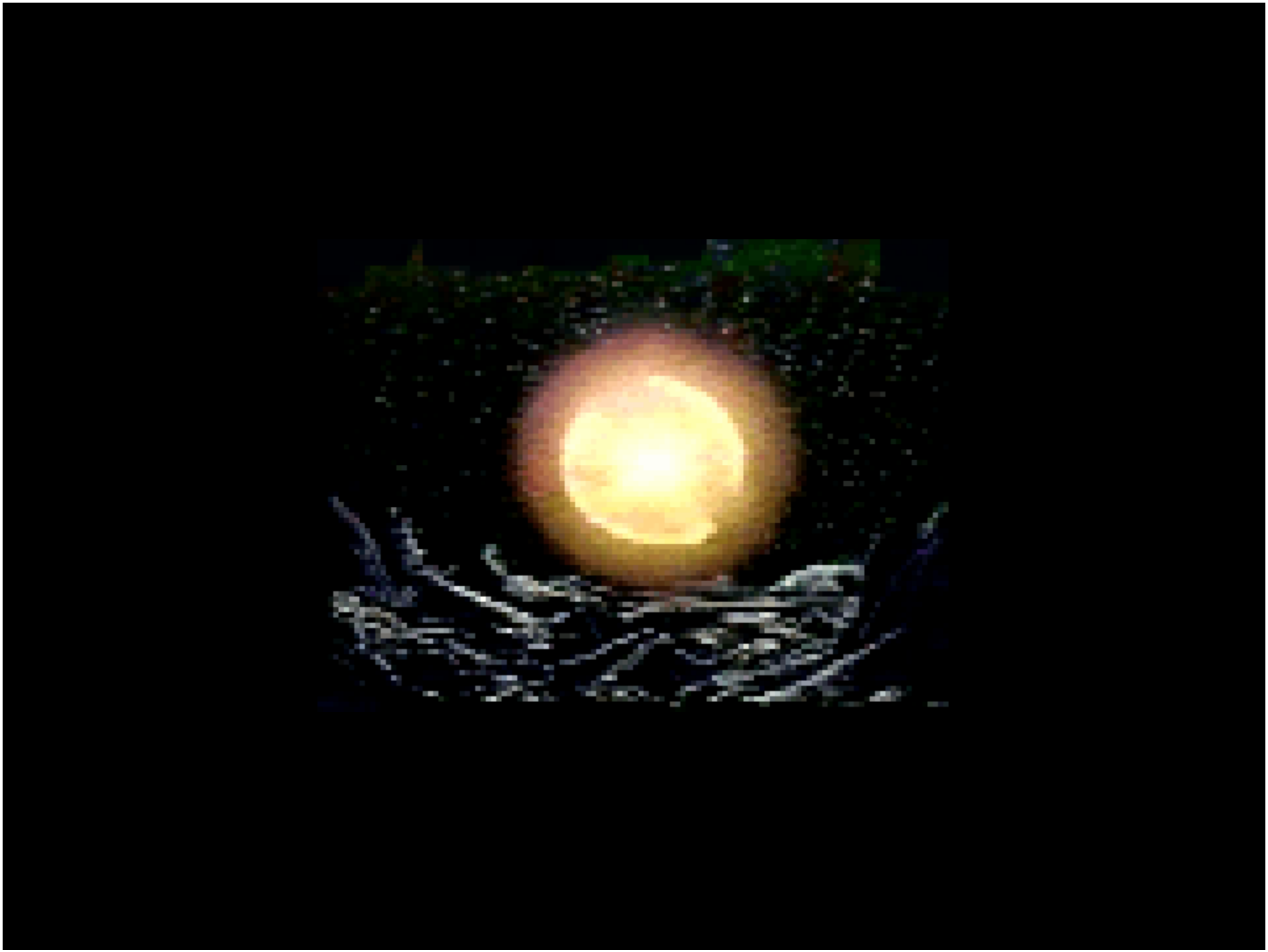

H
He
C/O
Ne/Mg/O
Si/S
Fe


a
b
c


d
e
f

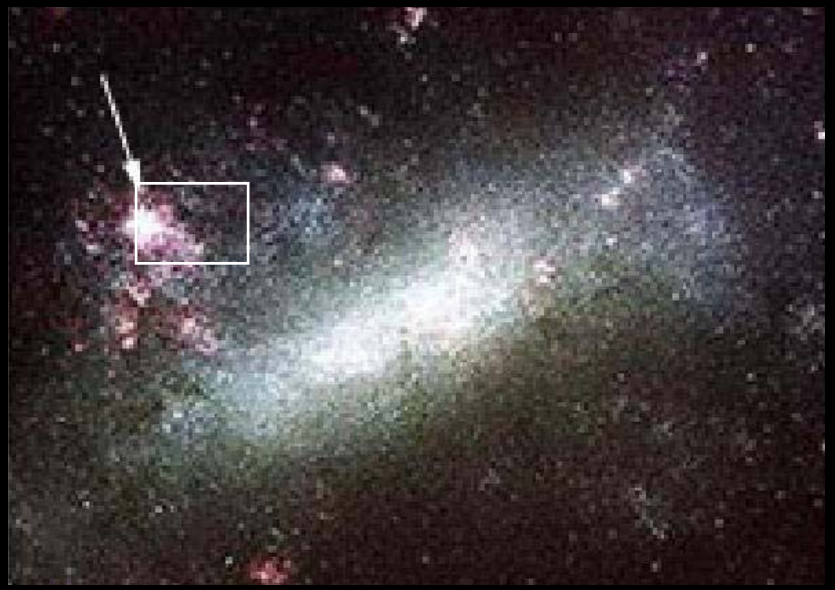


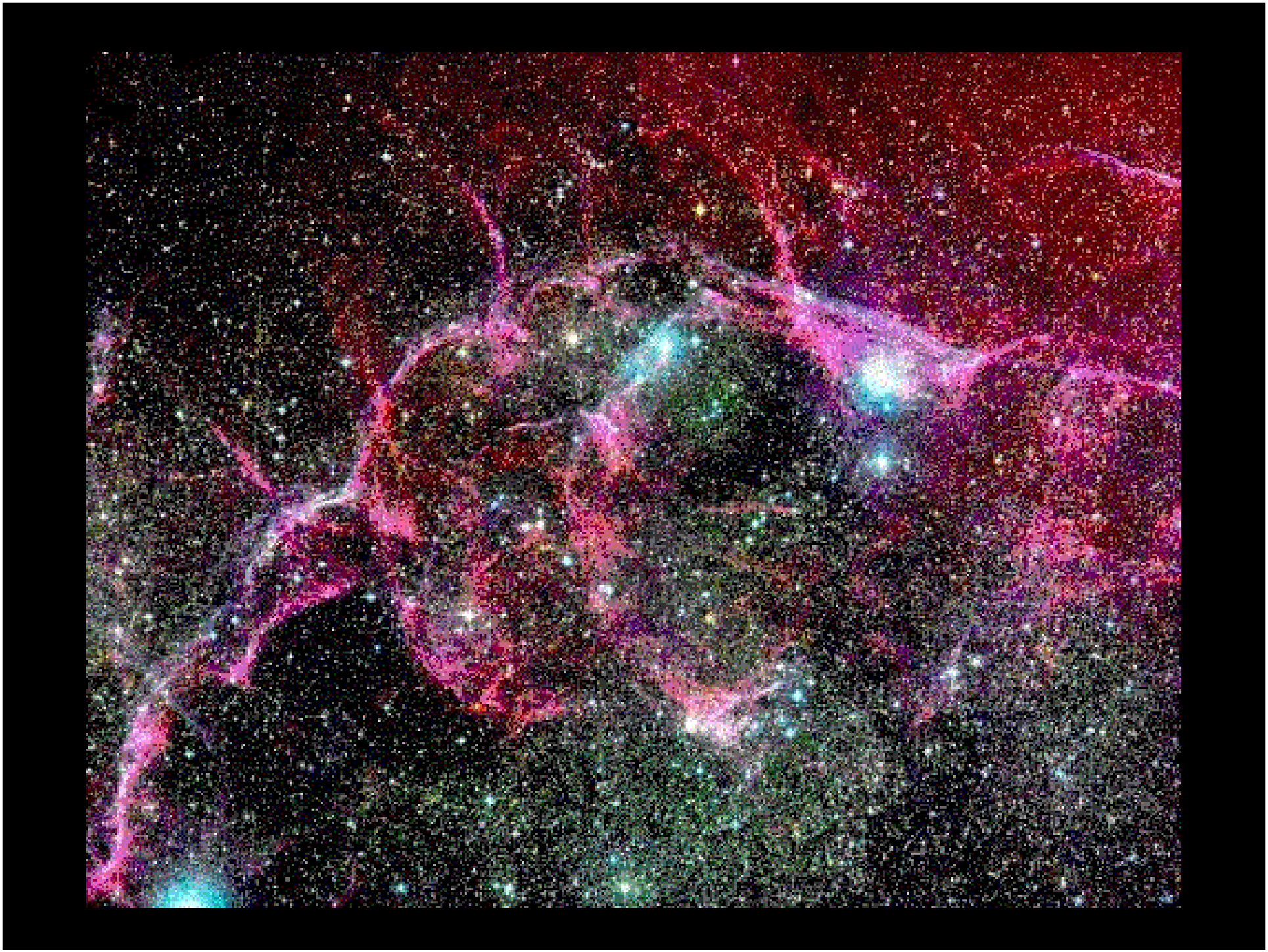




Crab Nebula: supernova of 1054

Supernova 1987A, in the Large Magellanic Cloud

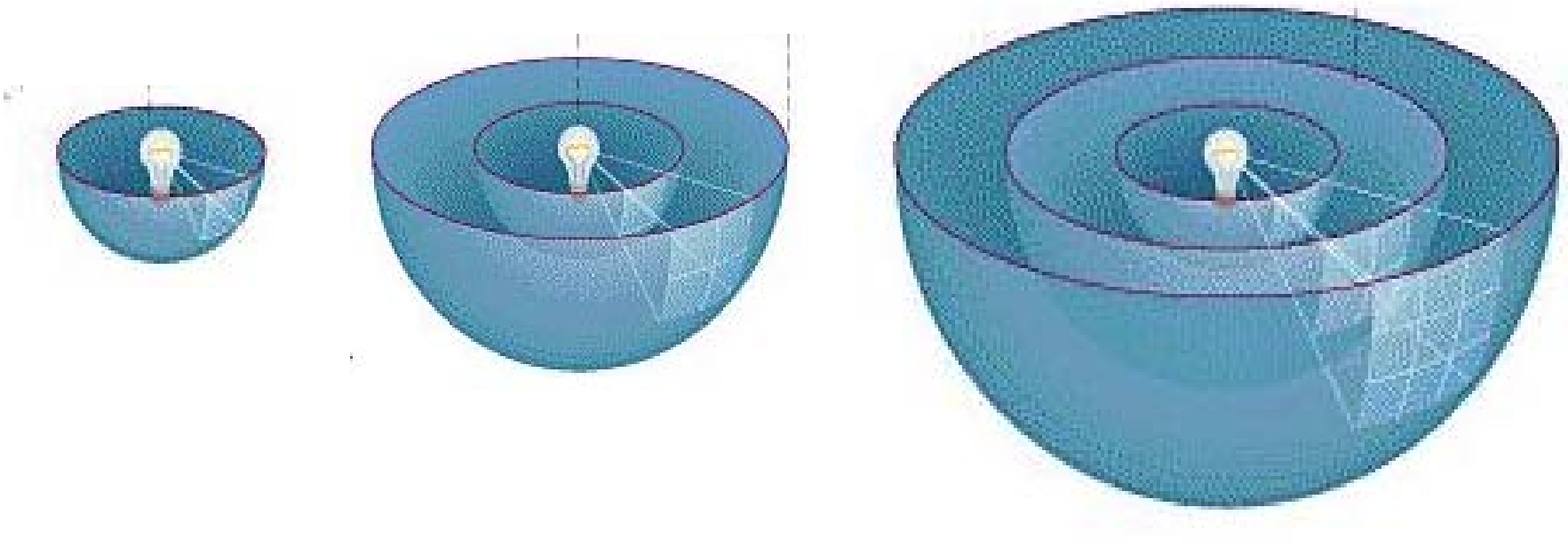




Supernovae

Putting the Iron in ***Irn Bru***

Stars radiate equally in all directions



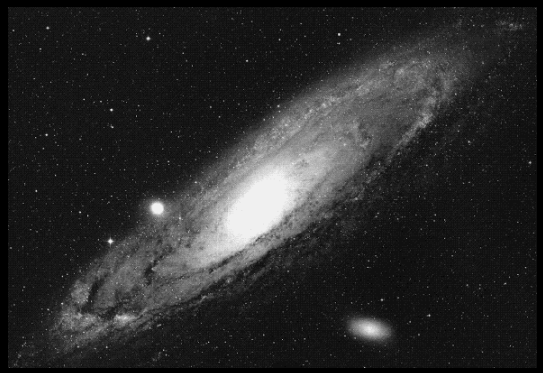
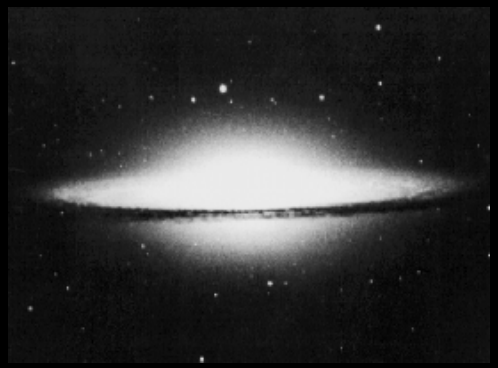
This gives rise to the ***Inverse-Square Law:***

The apparent brightness of a star falls off with the square of its distance

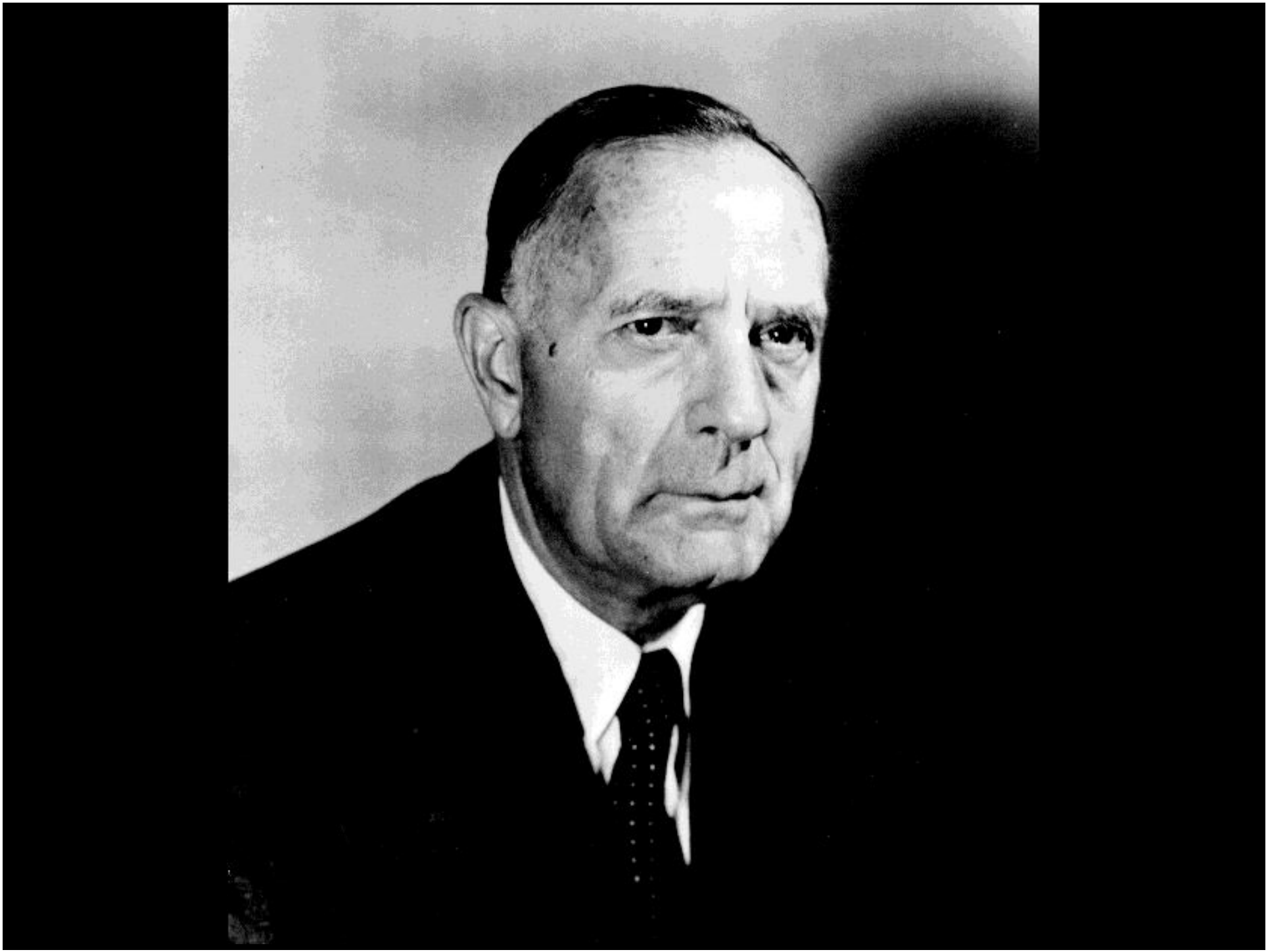
Early 20th Century

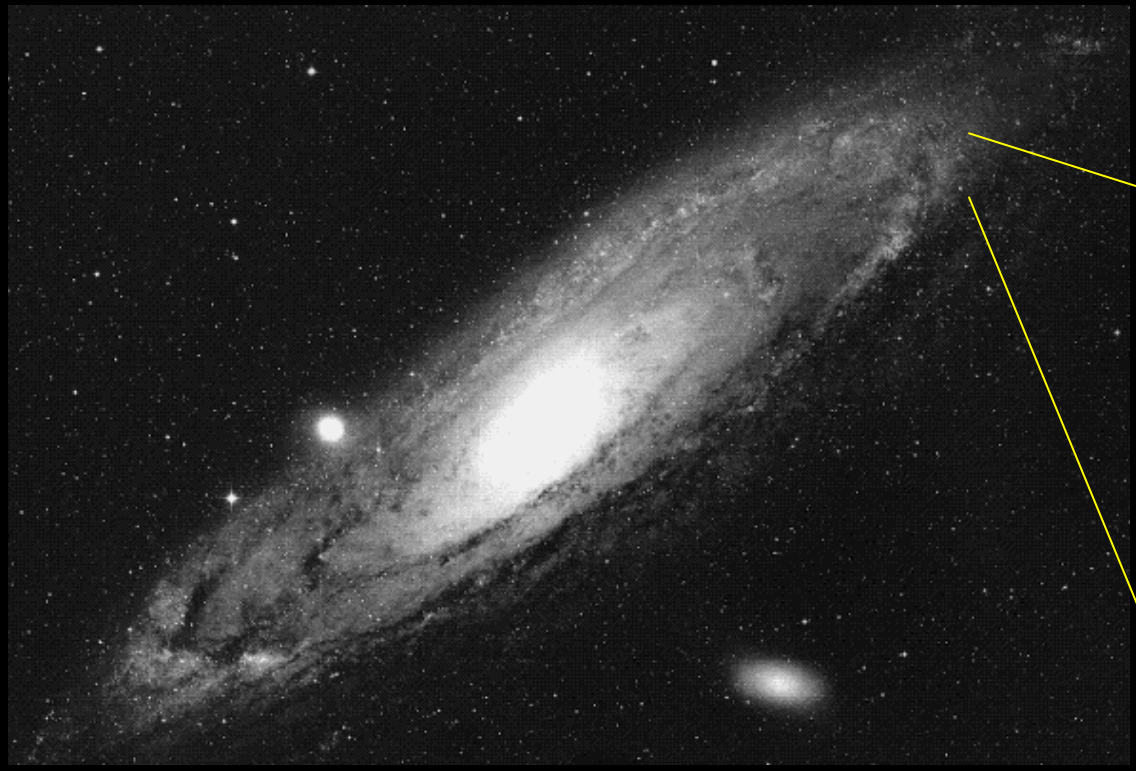
The nature of the nebulae?…

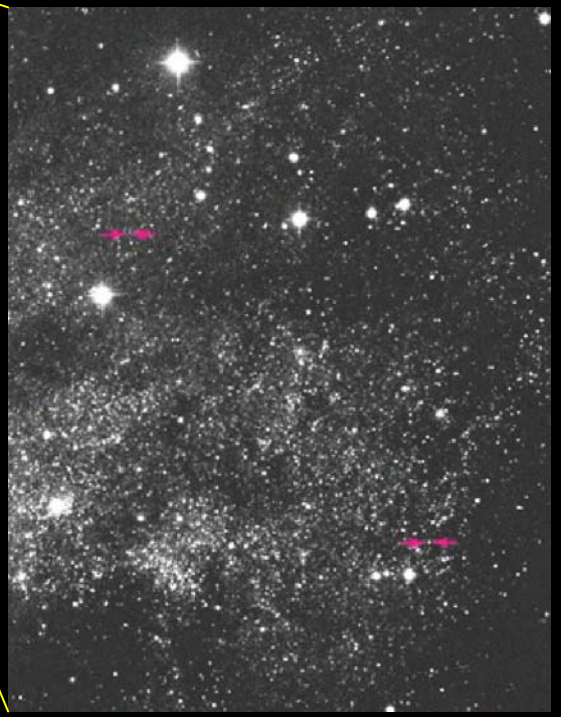


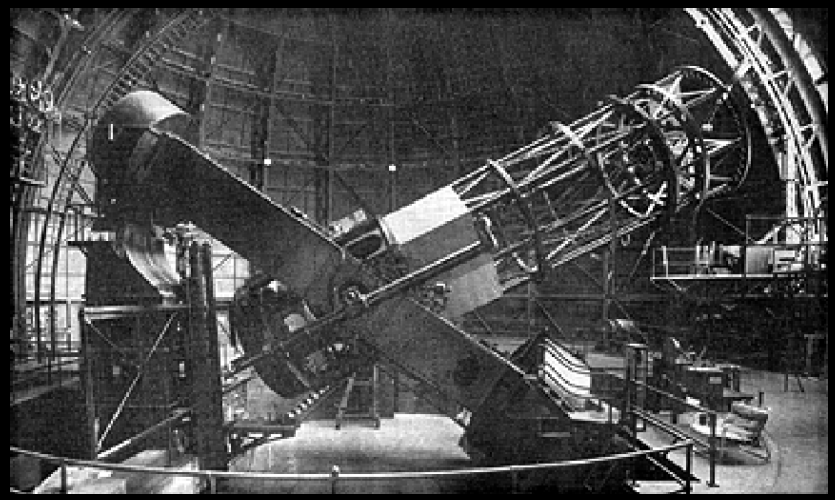



Gas clouds within the Milky Way,
or Island Universes?….

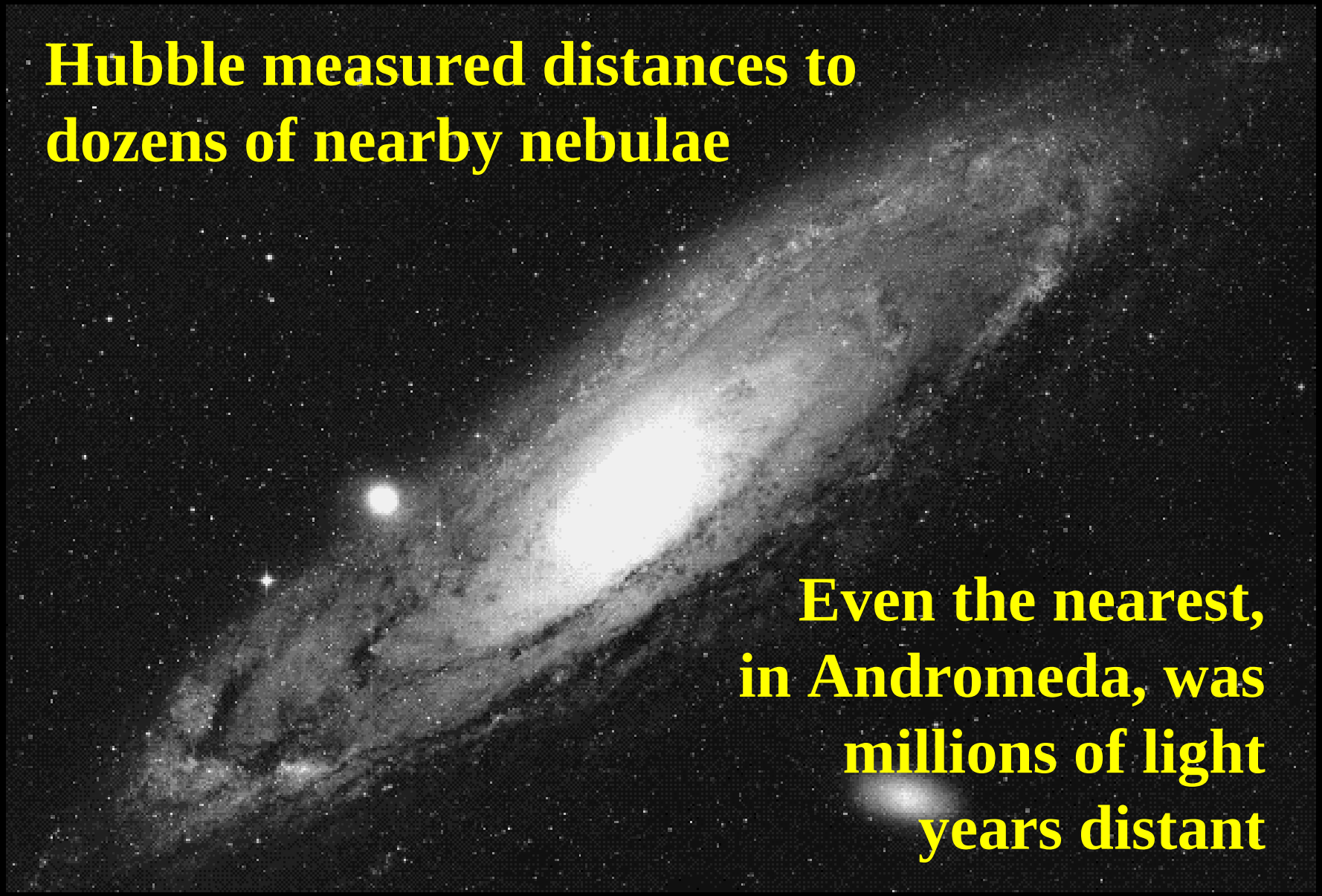




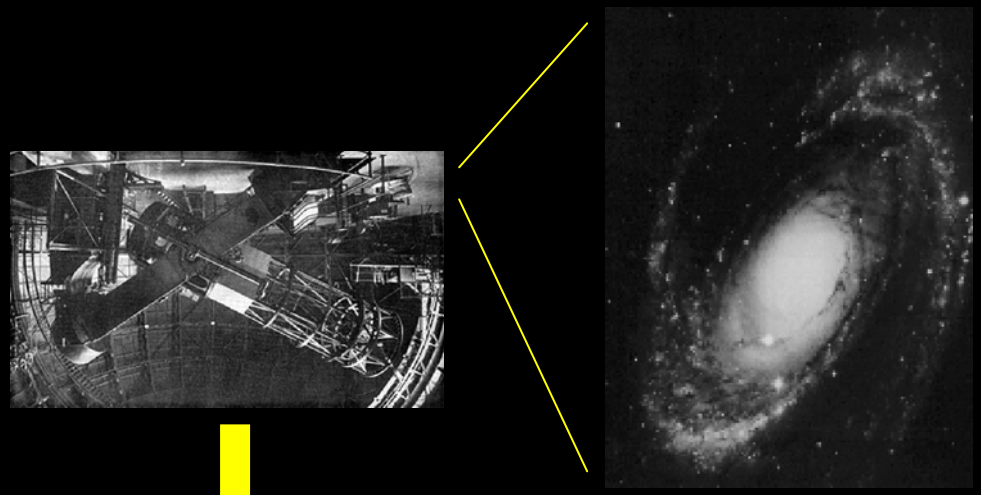




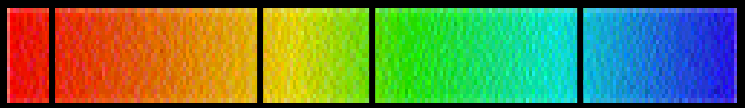
1922: Hubble finds Cepheids in the Great Nebula in Andromeda


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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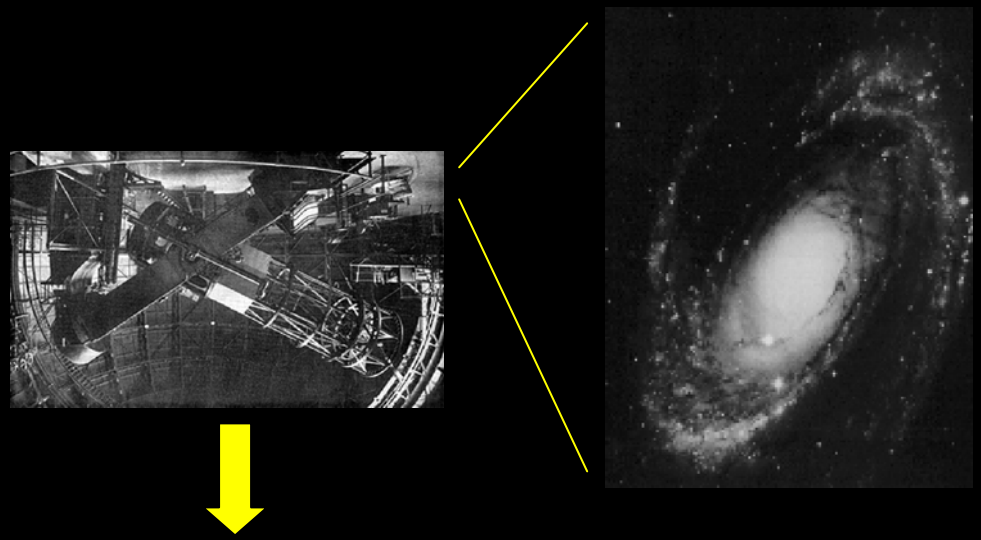
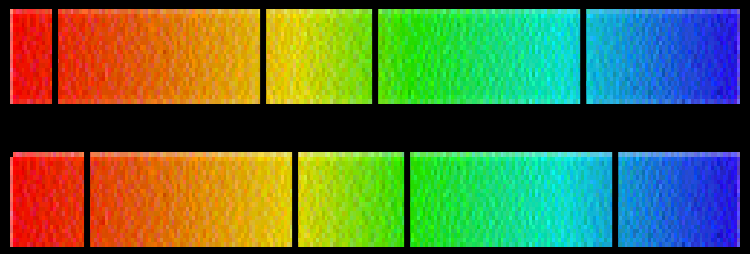




Hubble's Law: 1922

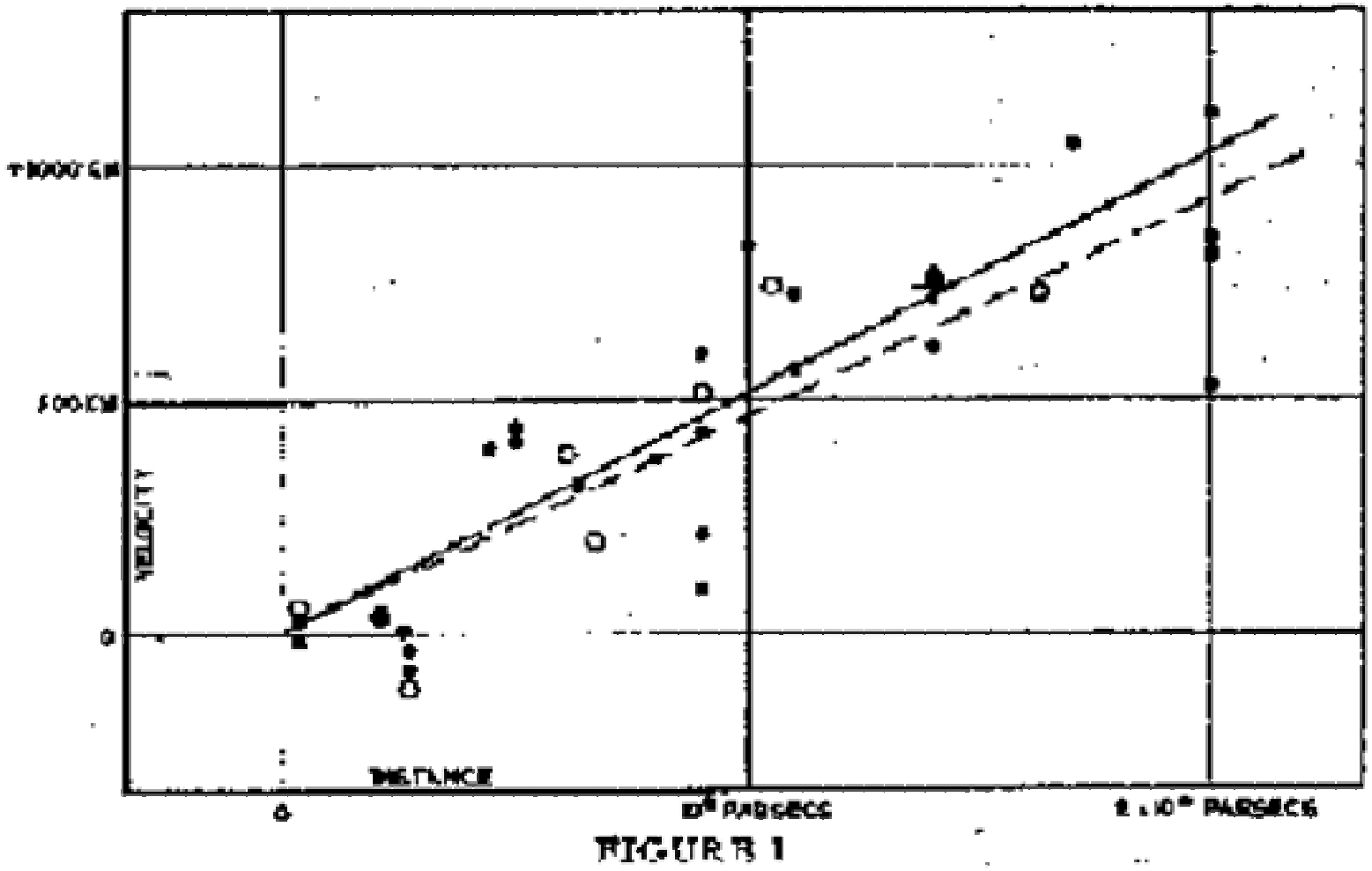
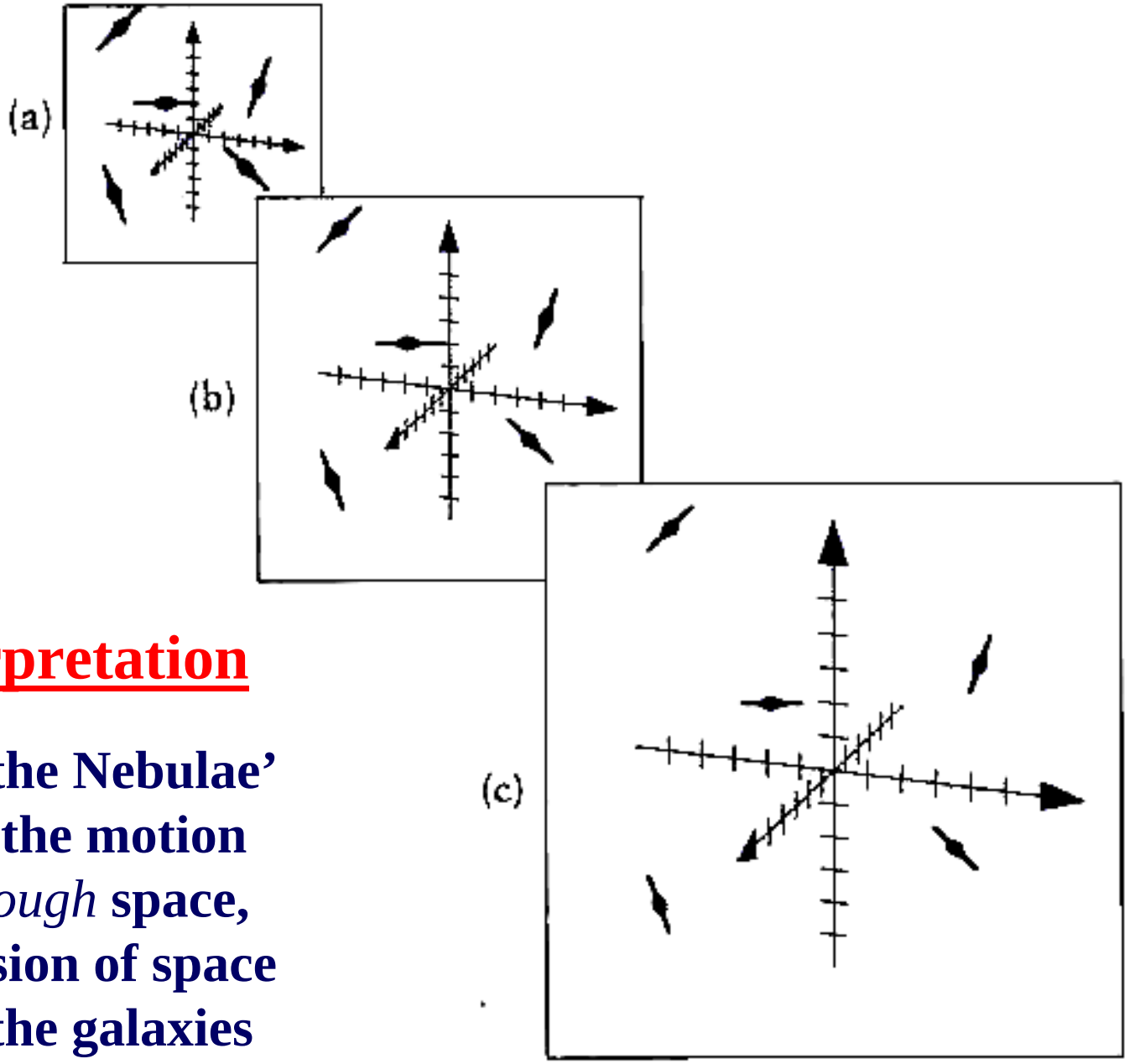


FIGURE 1

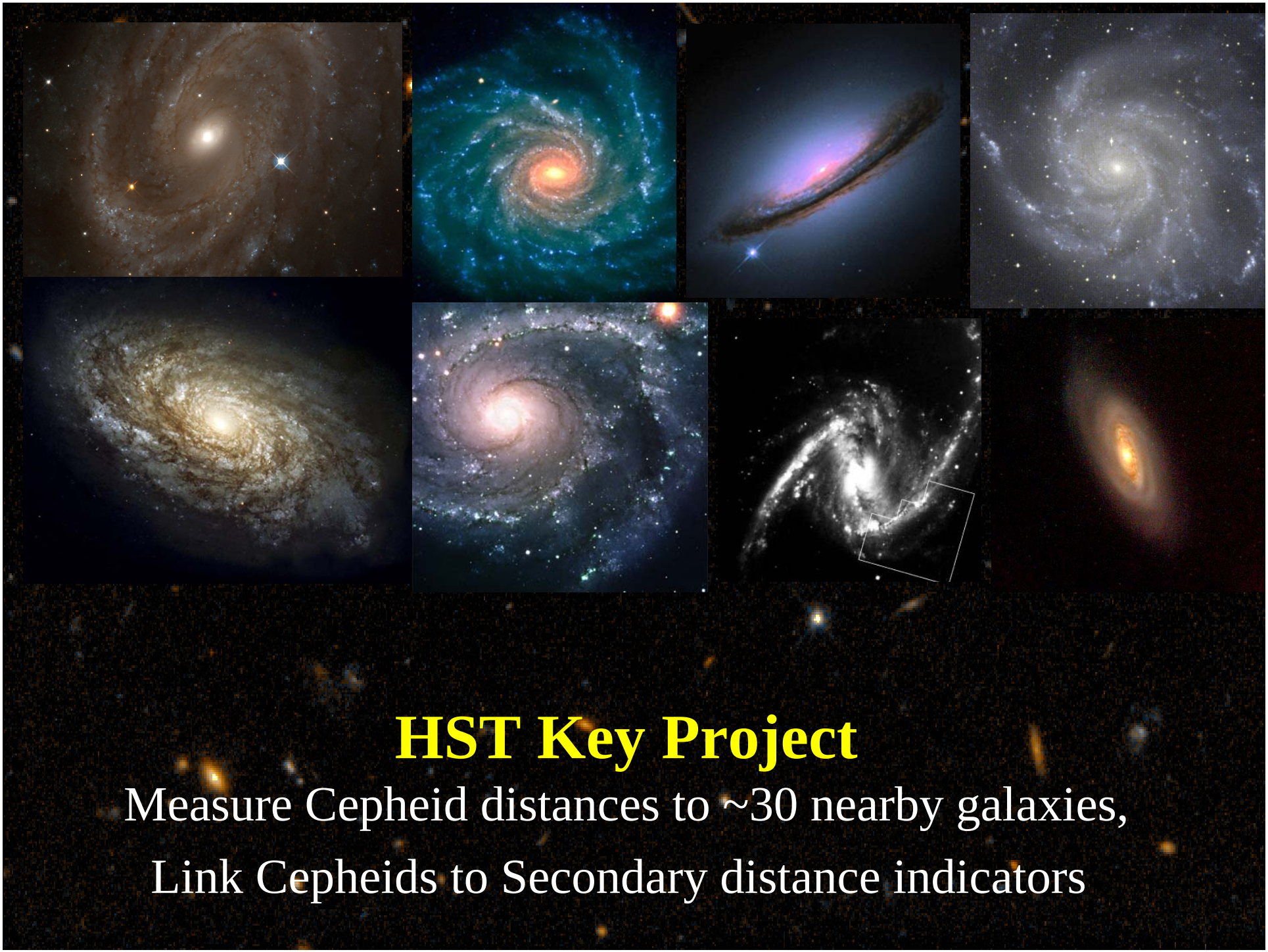
Distant galaxies are receding from us with a velocity proportional to their distance



Hubble's Interpretation

'Recession of the Nebulae' caused not by the motion of galaxies *through* space, but the expansion of space itself *between* the galaxies

How fast is the Universe expanding?



HST Key Project

Measure Cepheid distances to ~30 nearby galaxies,

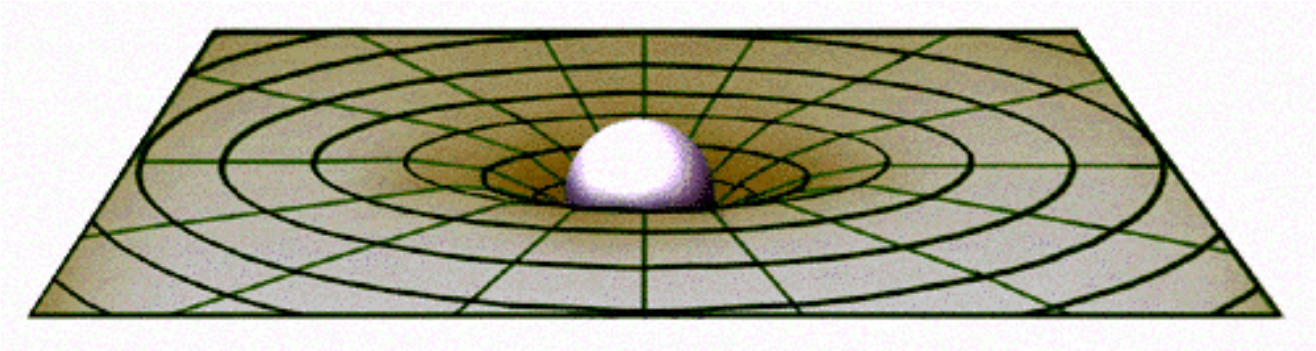
Link Cepheids to Secondary distance indicators

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 **geometry** of the Universe



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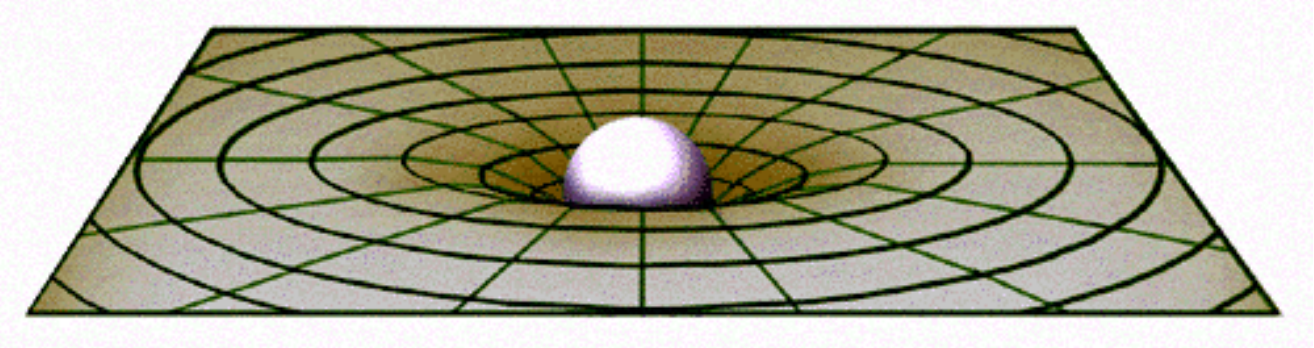
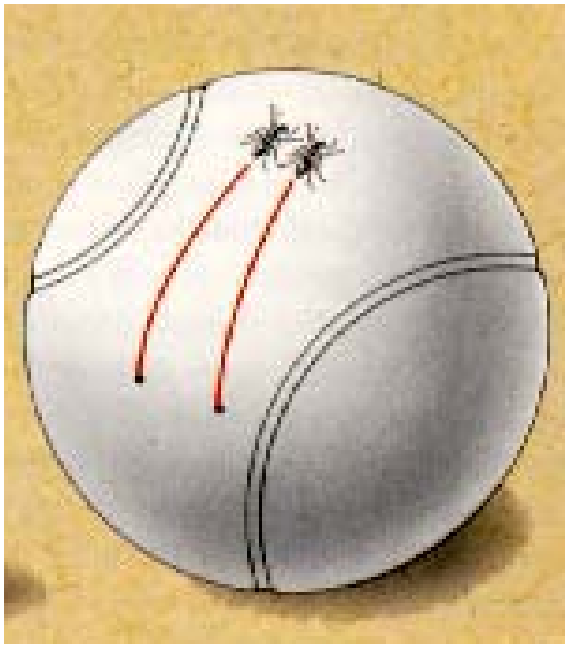
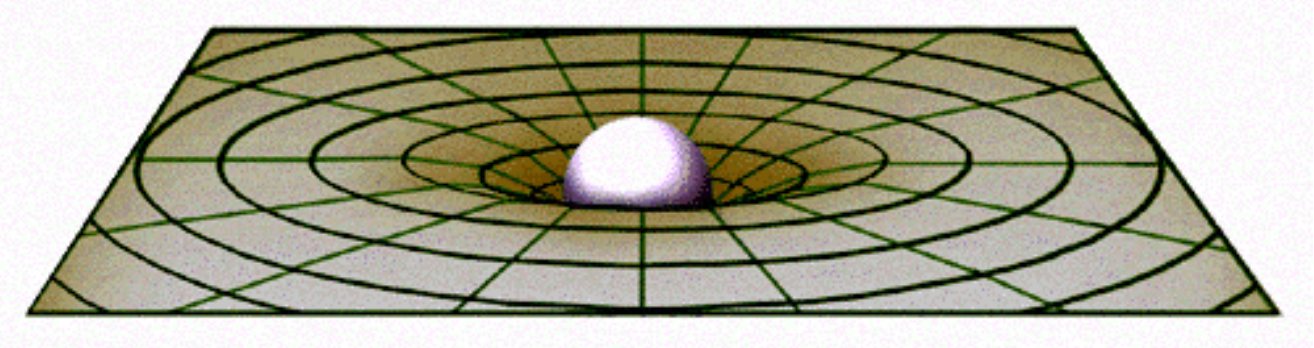
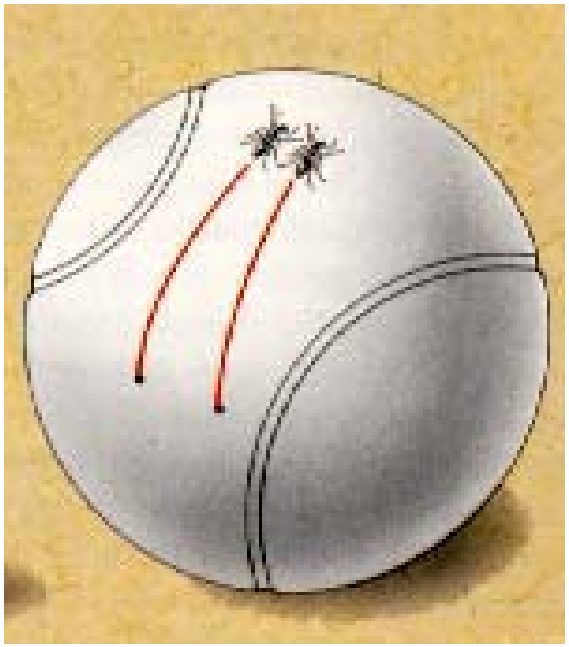




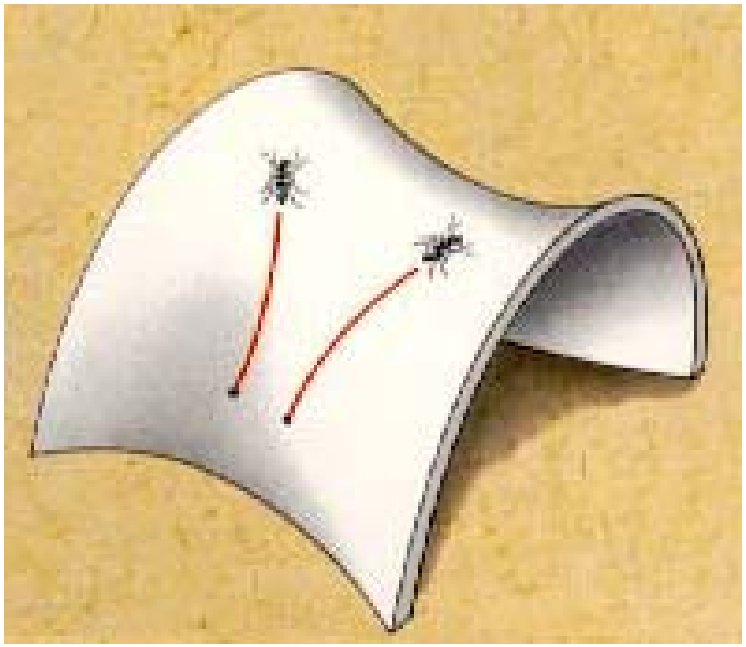
Closed

Answer depends on the **geometry** of the Universe



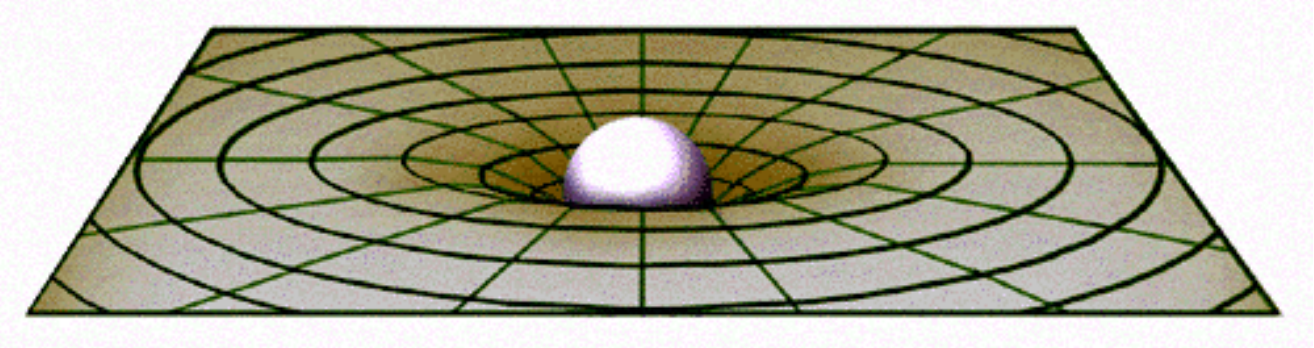


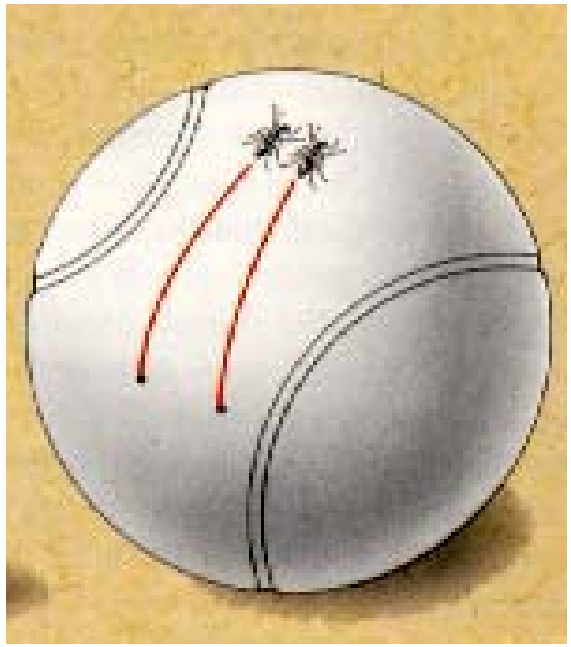
Closed



Open

Answer depends on the **geometry** of the Universe





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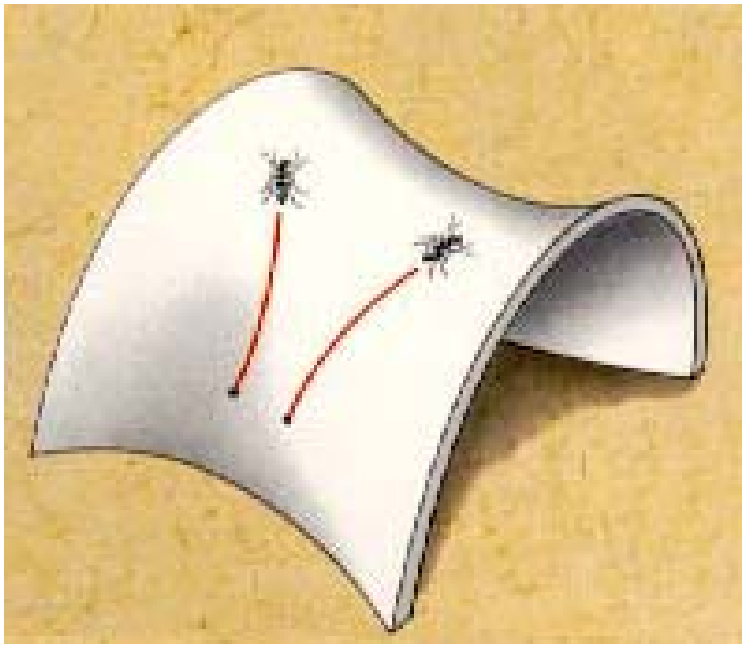

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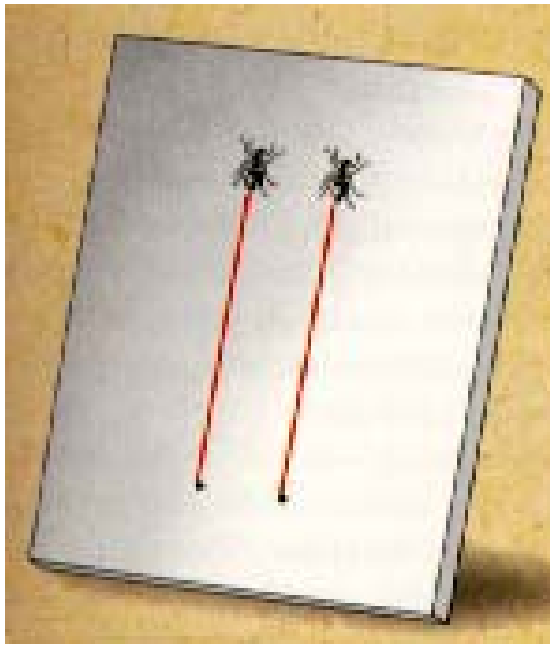
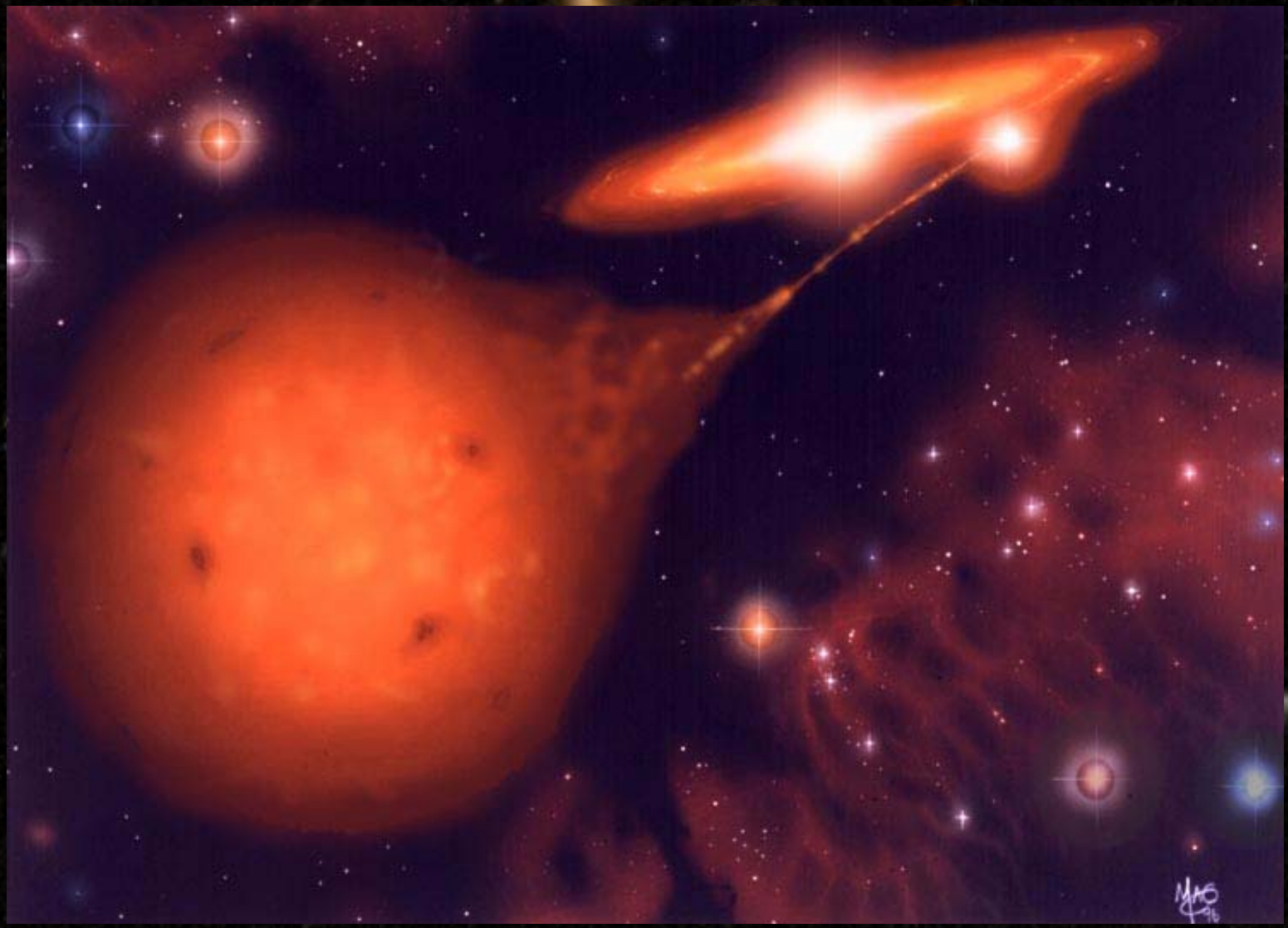


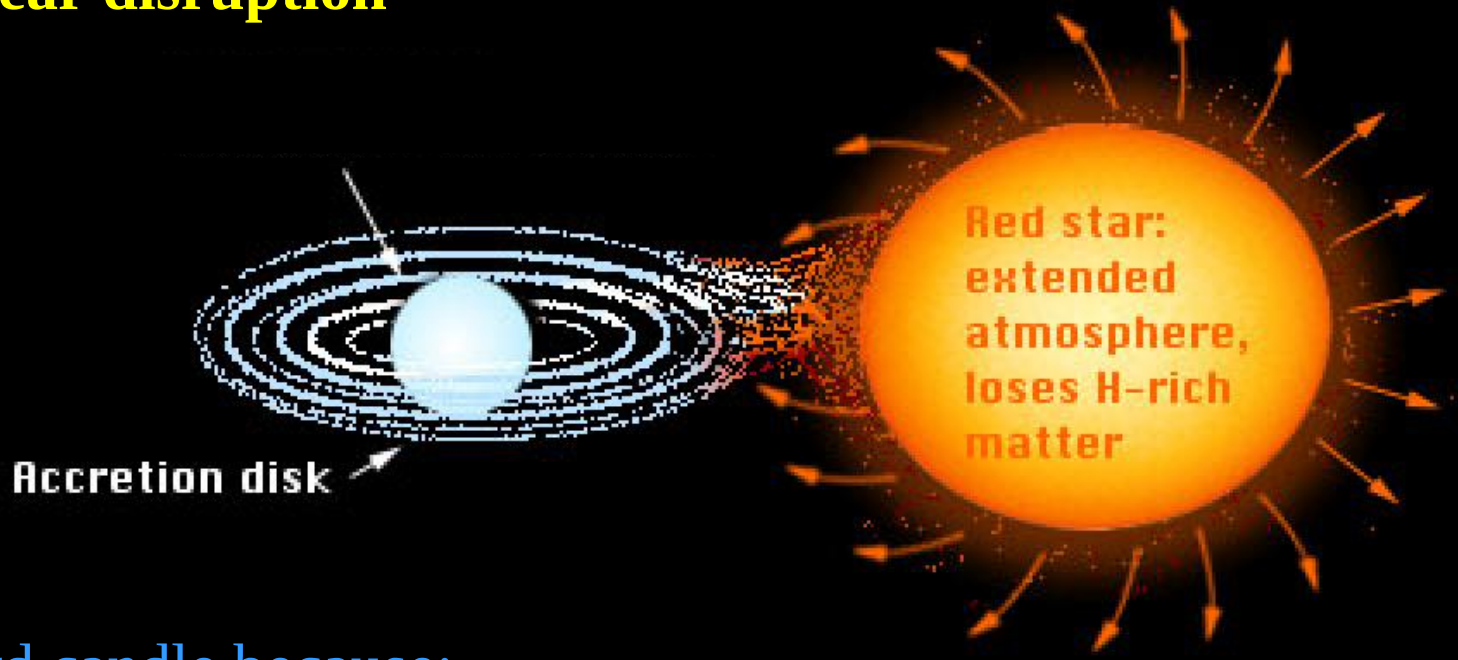
Flat

We can measure this using Supernovae



Type Ia Supernova

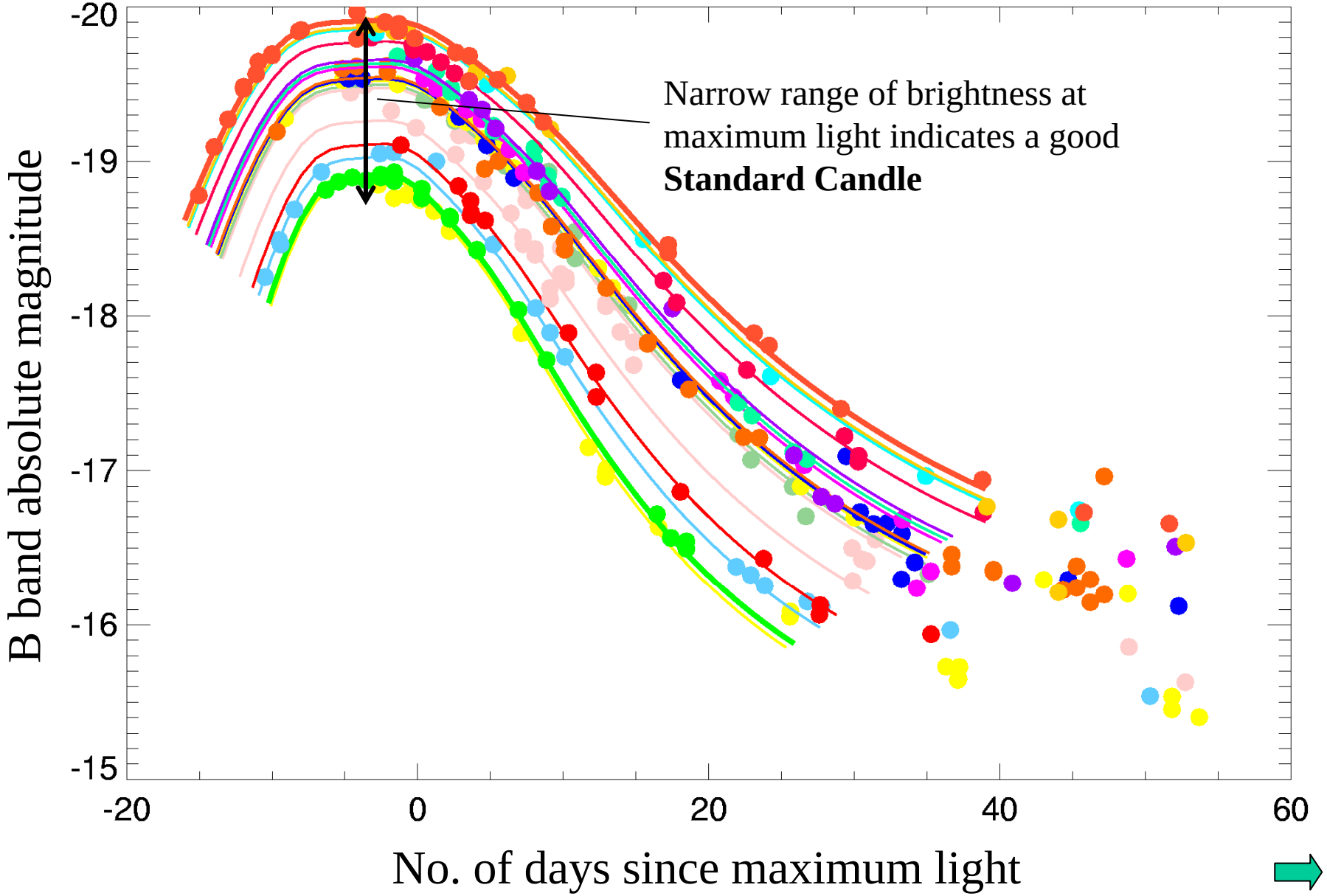
White dwarf star with a massive binary companion. Accretion pushes white dwarf over the Chandrasekhar limit, causing **thermonuclear disruption**



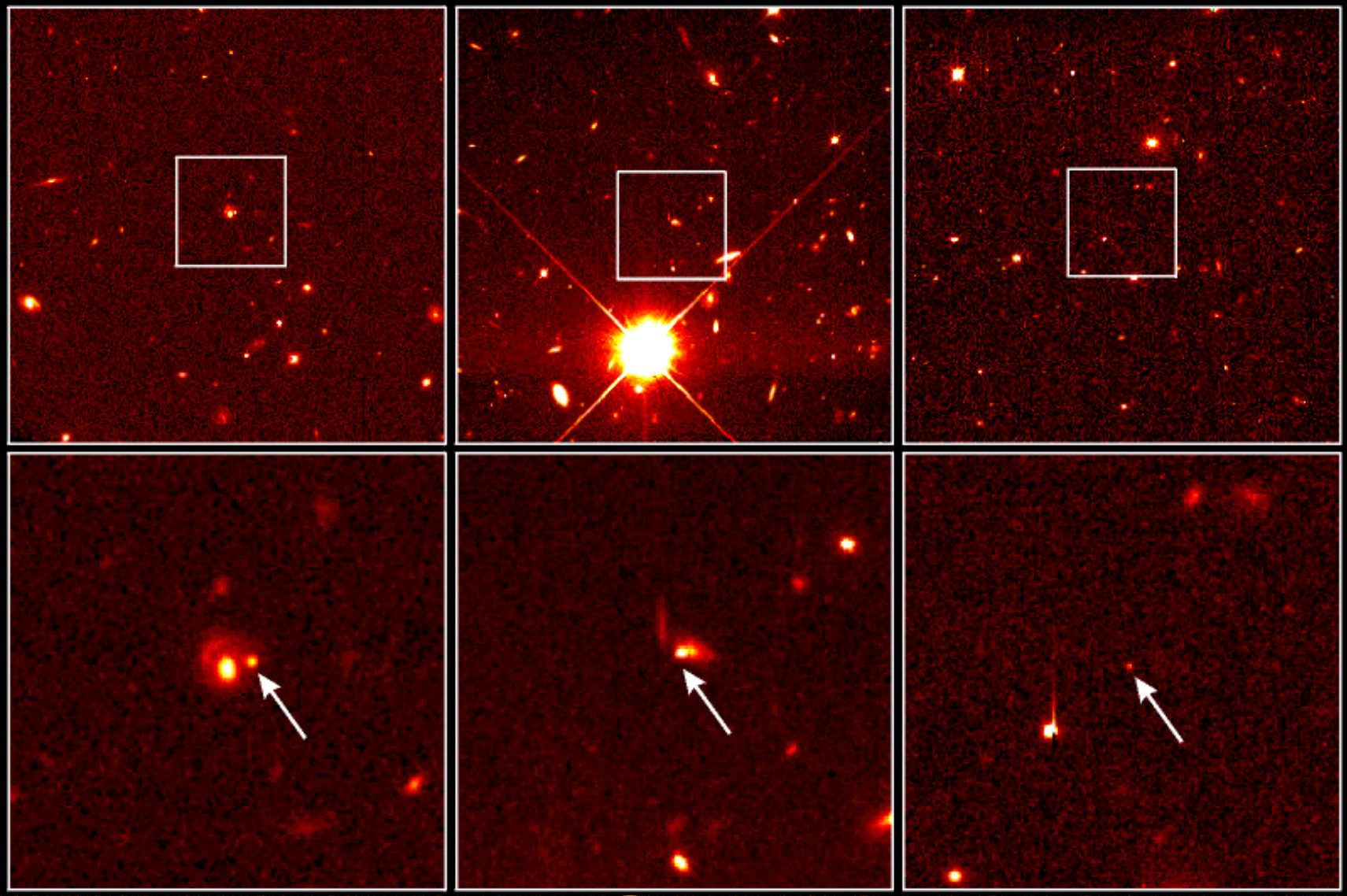
Good standard candle because:-

Narrow range of luminosities at maximum light
Observable to very large distances

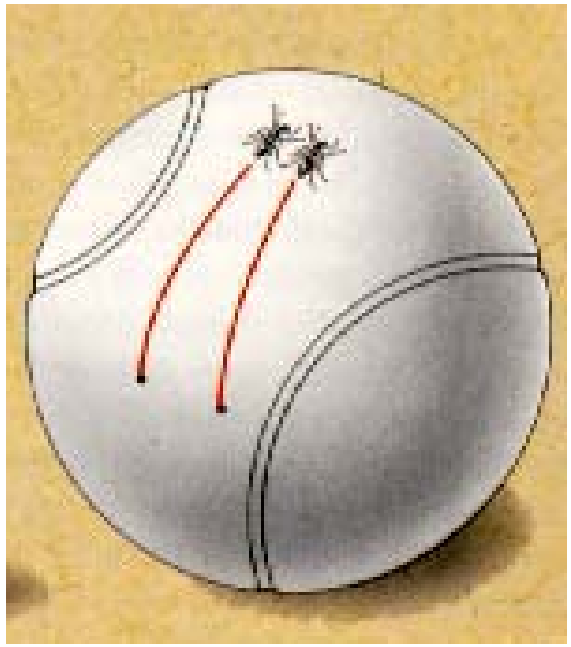
Some examples of B band SNIa light curves



We can measure this using Supernovae and the background radiation



Geometry of the Universe affects the relationship between distance and redshift of the supernovae



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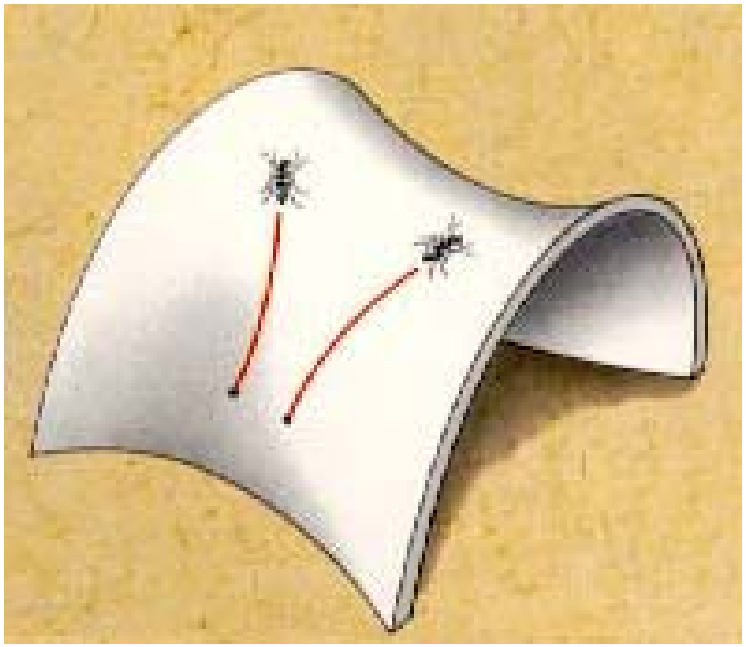

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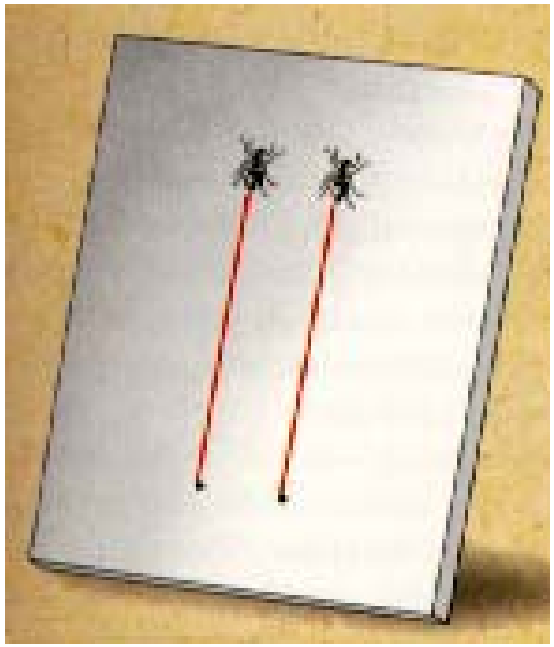
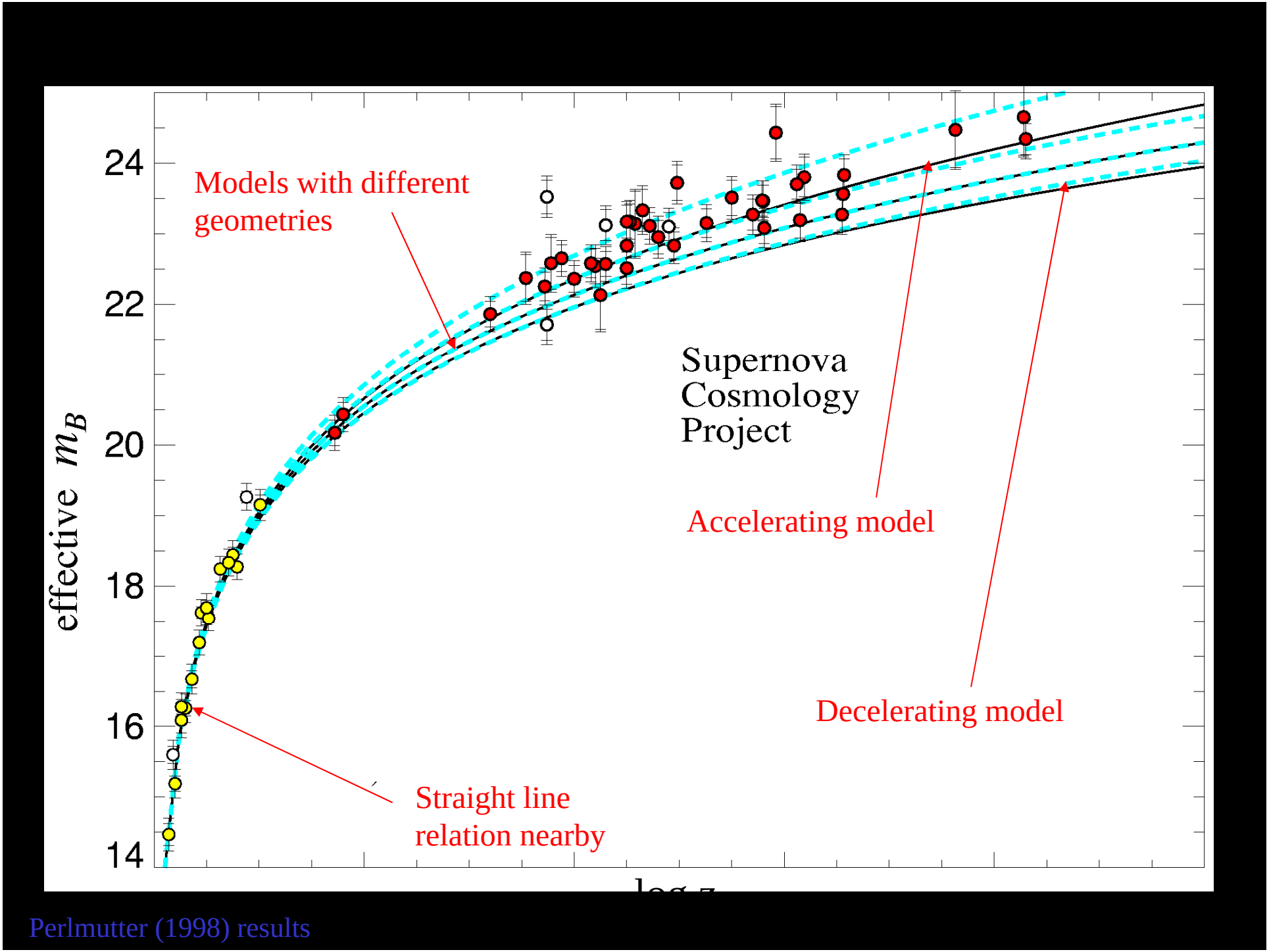
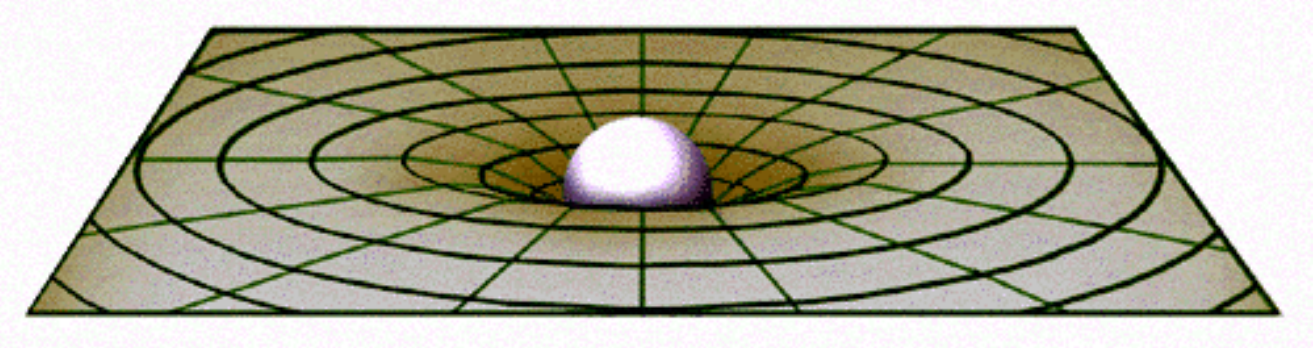


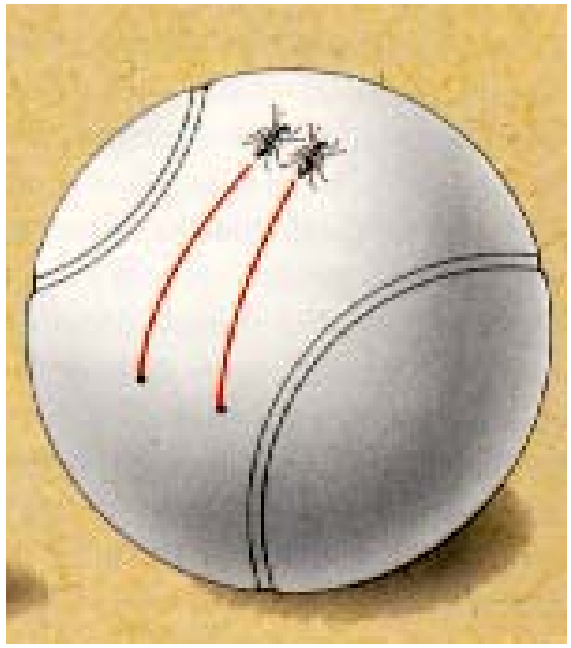
Flat



Perlmutter (1998) results

Answer depends on the **geometry** of the Universe





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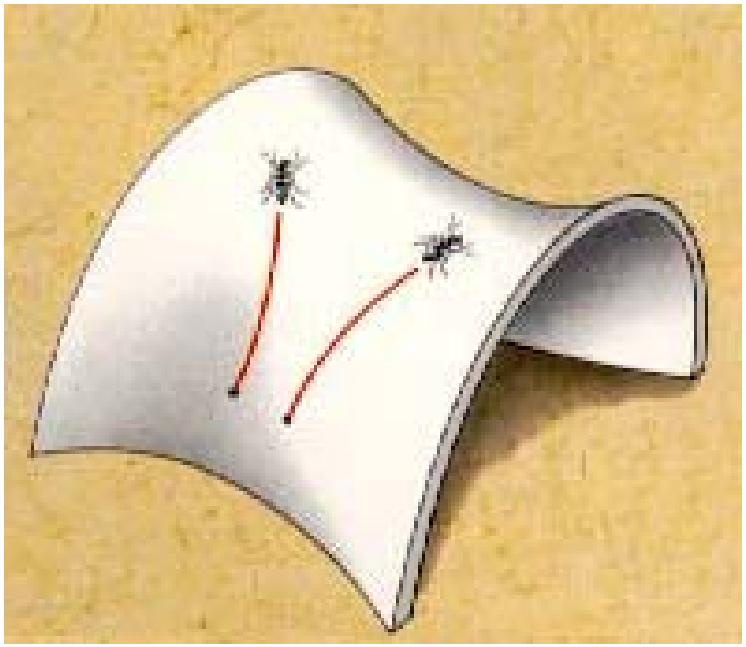
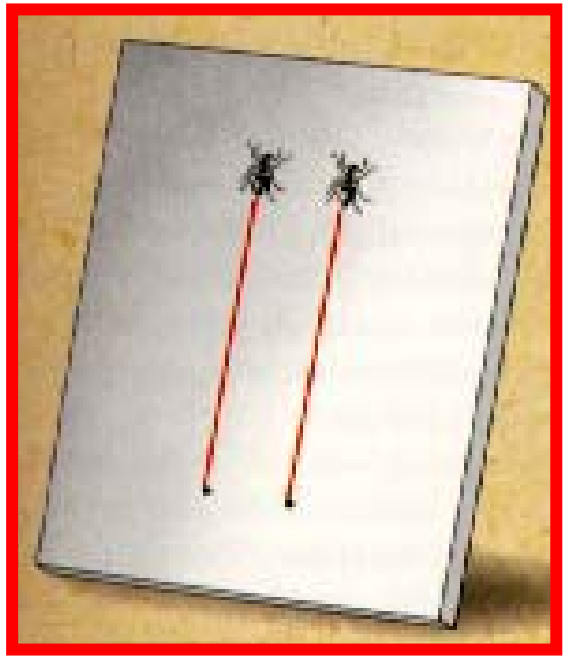


Open



Flat


Results:
The geometry of the Universe is FLAT
The Universe will continue to expand indefinitely
The expansion is accelerating

1916. № 7.

ANNALEN DER PHYSIK.

VIERTE FOLGE. BAND 49.

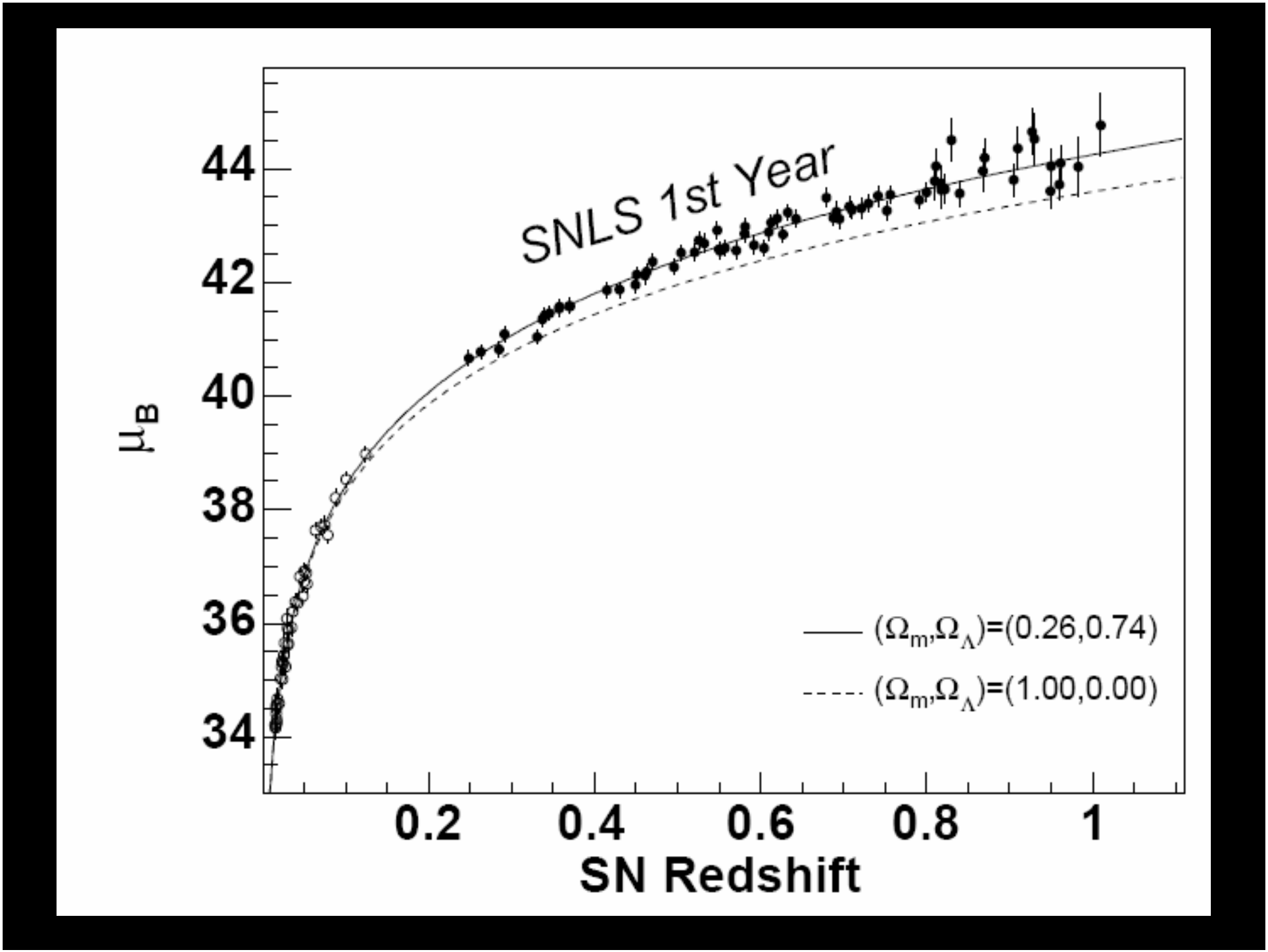
1. *Die Grundlage der allgemeinen Relativitätstheorie;* von *A. Einstein.*

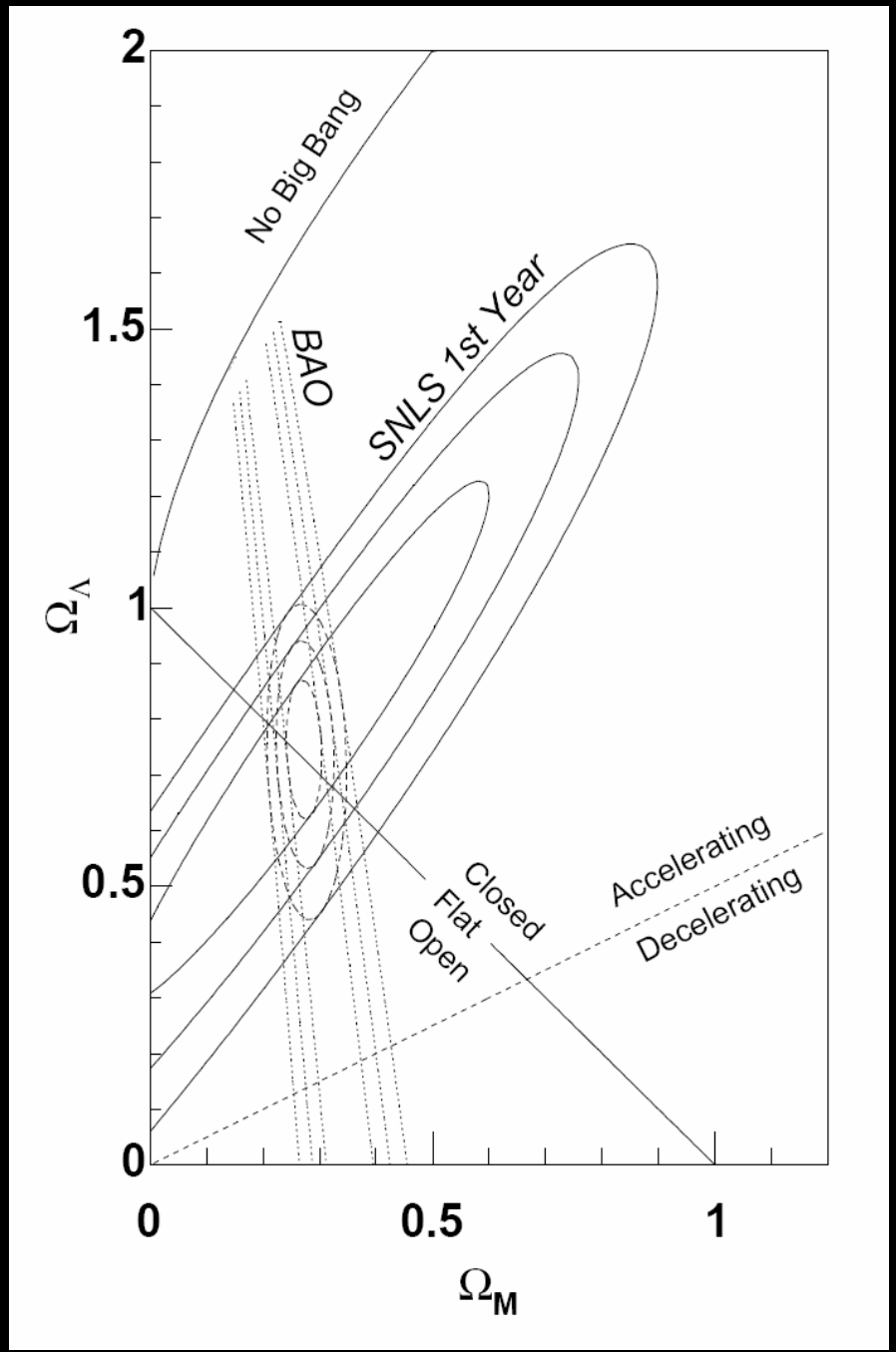
Die im nachfolgenden dargelegte Theorie bildet die denkbar weitgehendste Verallgemeinerung der heute allgemein als „Relativitätstheorie" bezeichneten Theorie; die letztere nenne ich im folgenden zur Unterscheidung von der ersteren „spezielle Relativitätstheorie" und setze sie als bekannt voraus. Die 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.

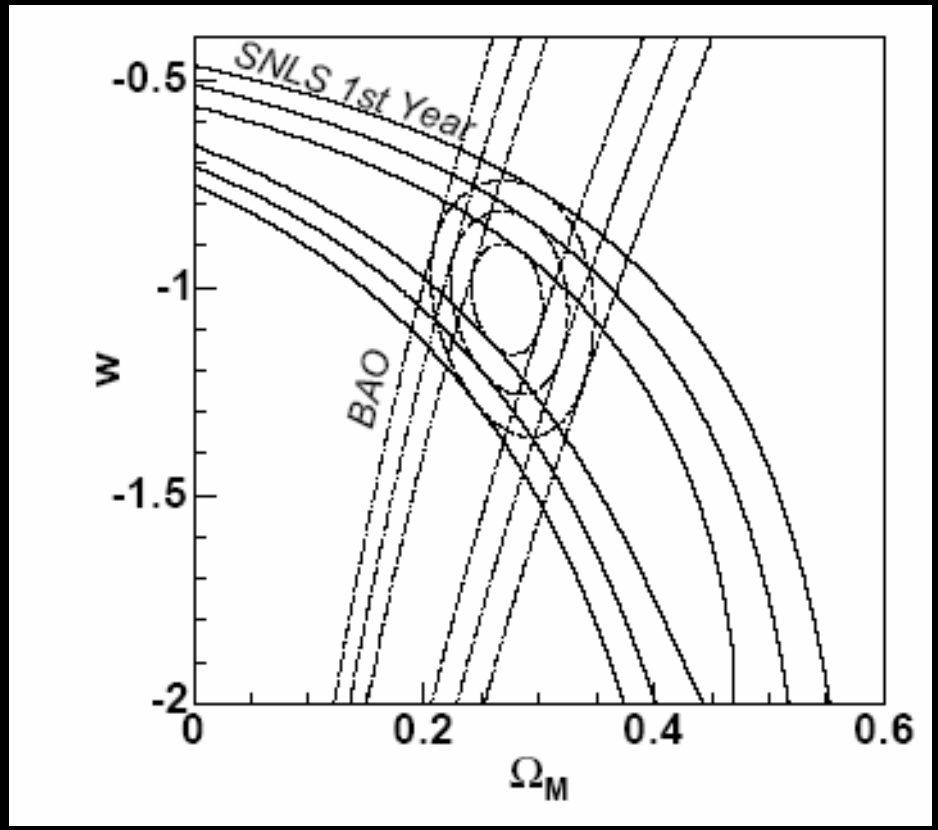
What is driving the cosmic acceleration?…

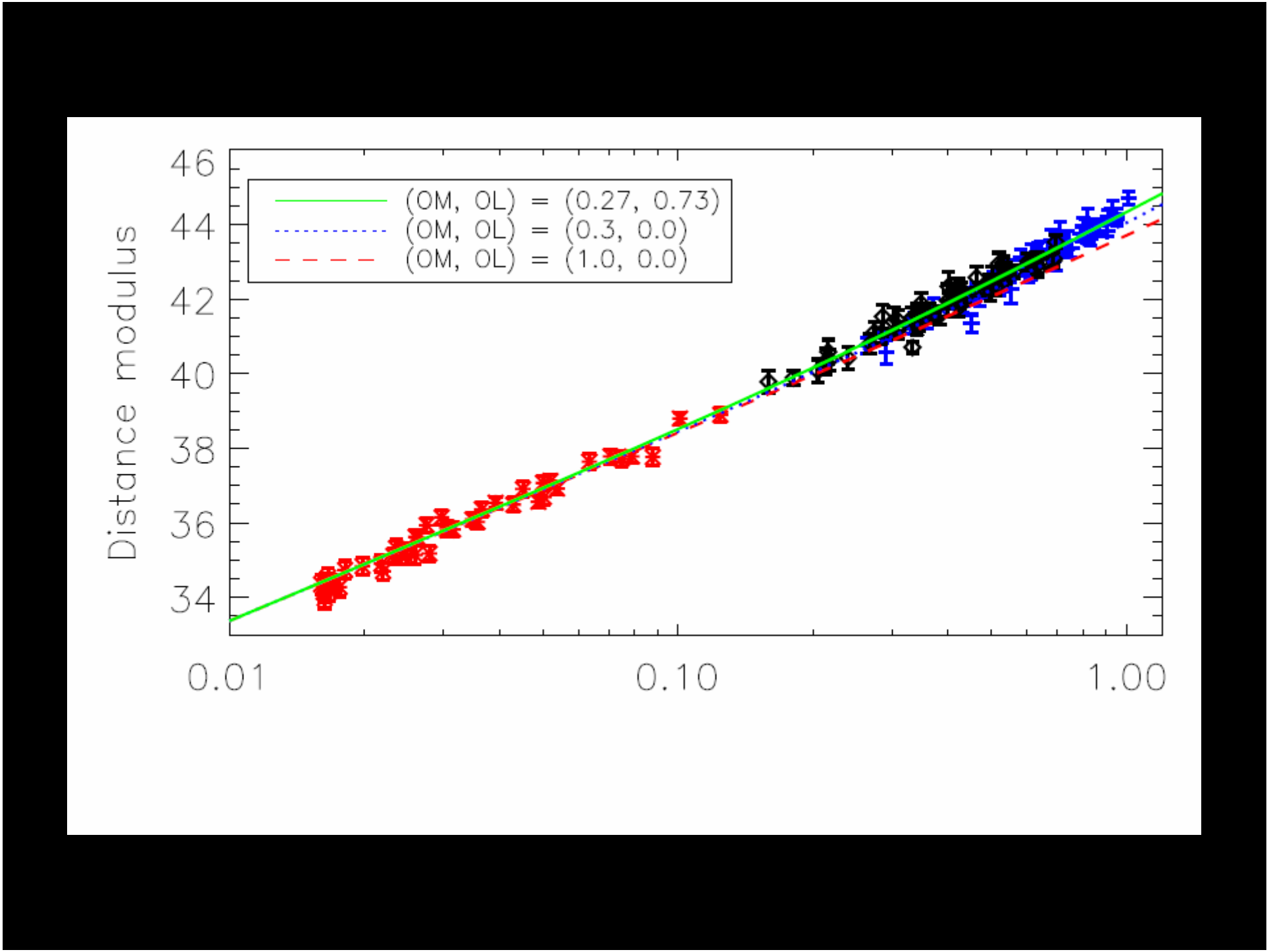
Dark Energy

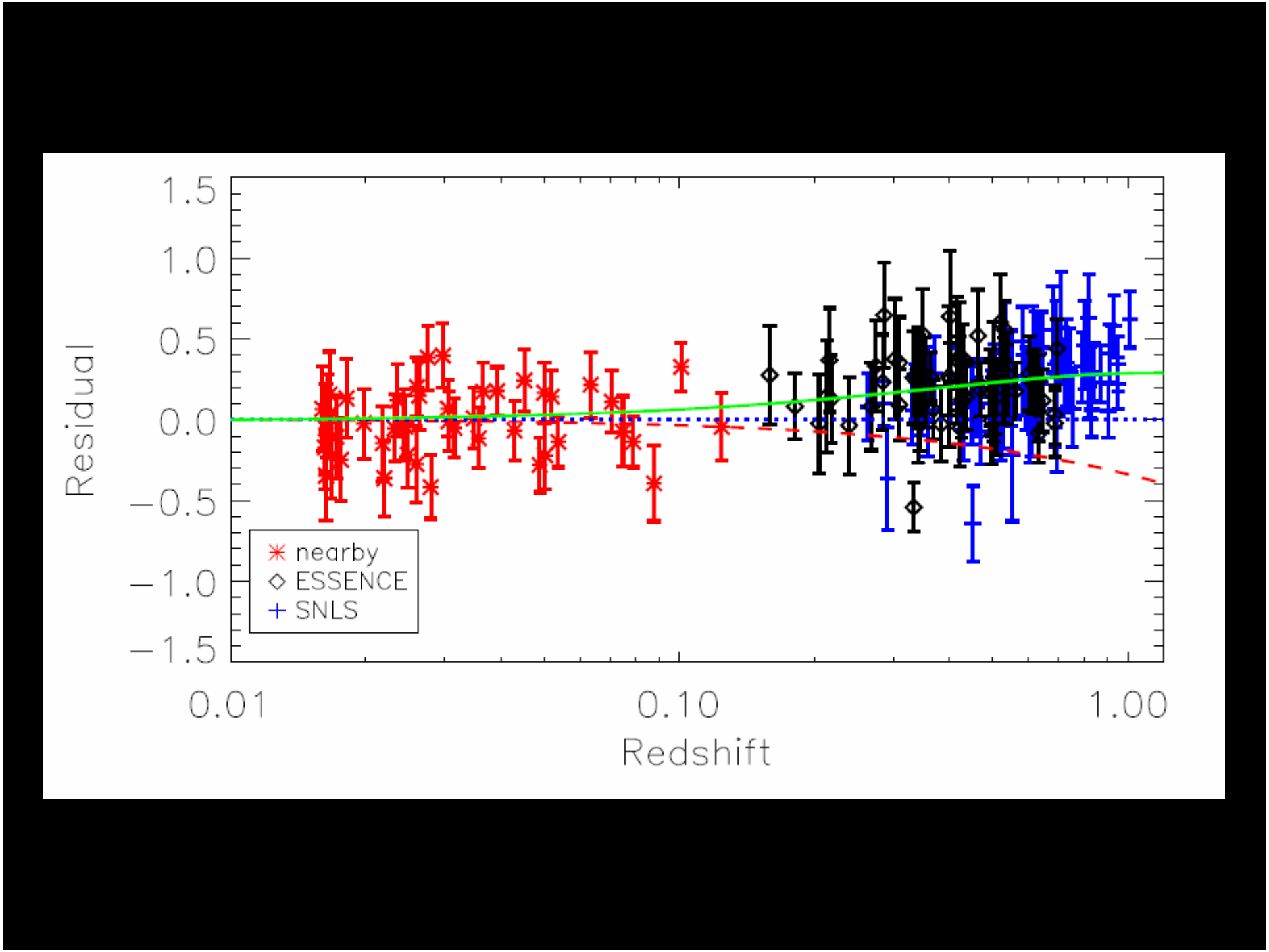
Dark Energy

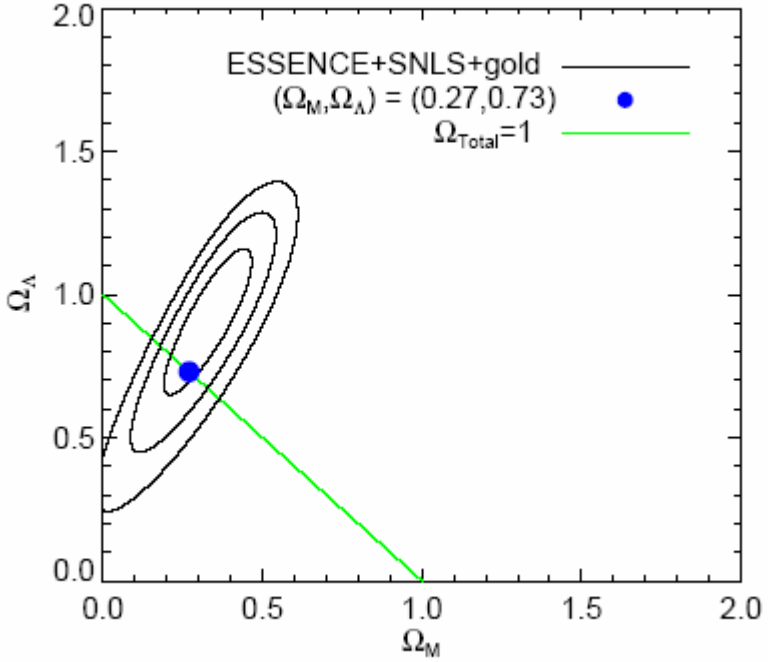

SNLS 1st Year
μ_B
44
42
40
38
36
34
0.2
0.4
0.6
0.8
1
SN Redshift
$(\Omega_m,\Omega_\Lambda)=(0.26,0.74)$
$(\Omega_m,\Omega_\Lambda)=(1.00,0.00)$

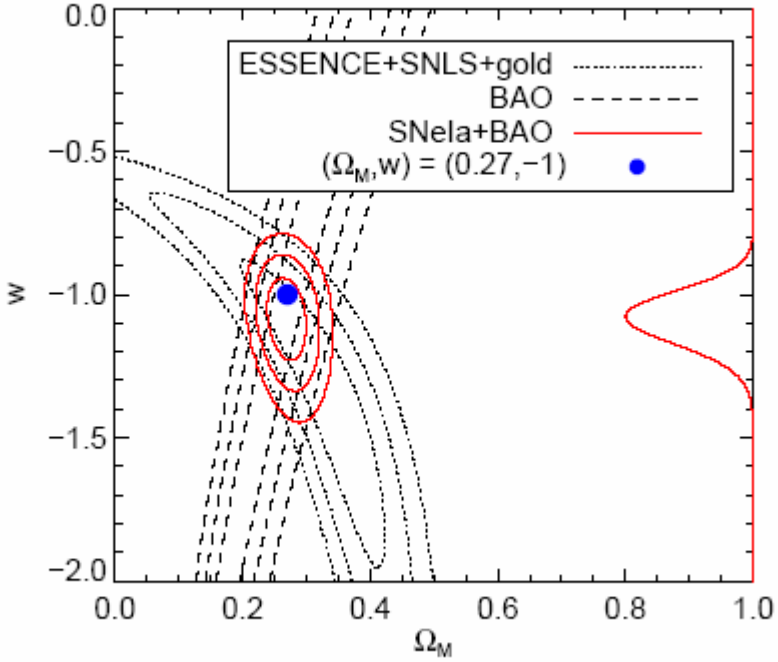

2
1.5
1
0.5
0
0
0.5
1
Ω_Λ
Ω_M
No Big Bang
BAO
SNLS 1st Year
Closed
Flat
Open
Accelerating
Decelerating

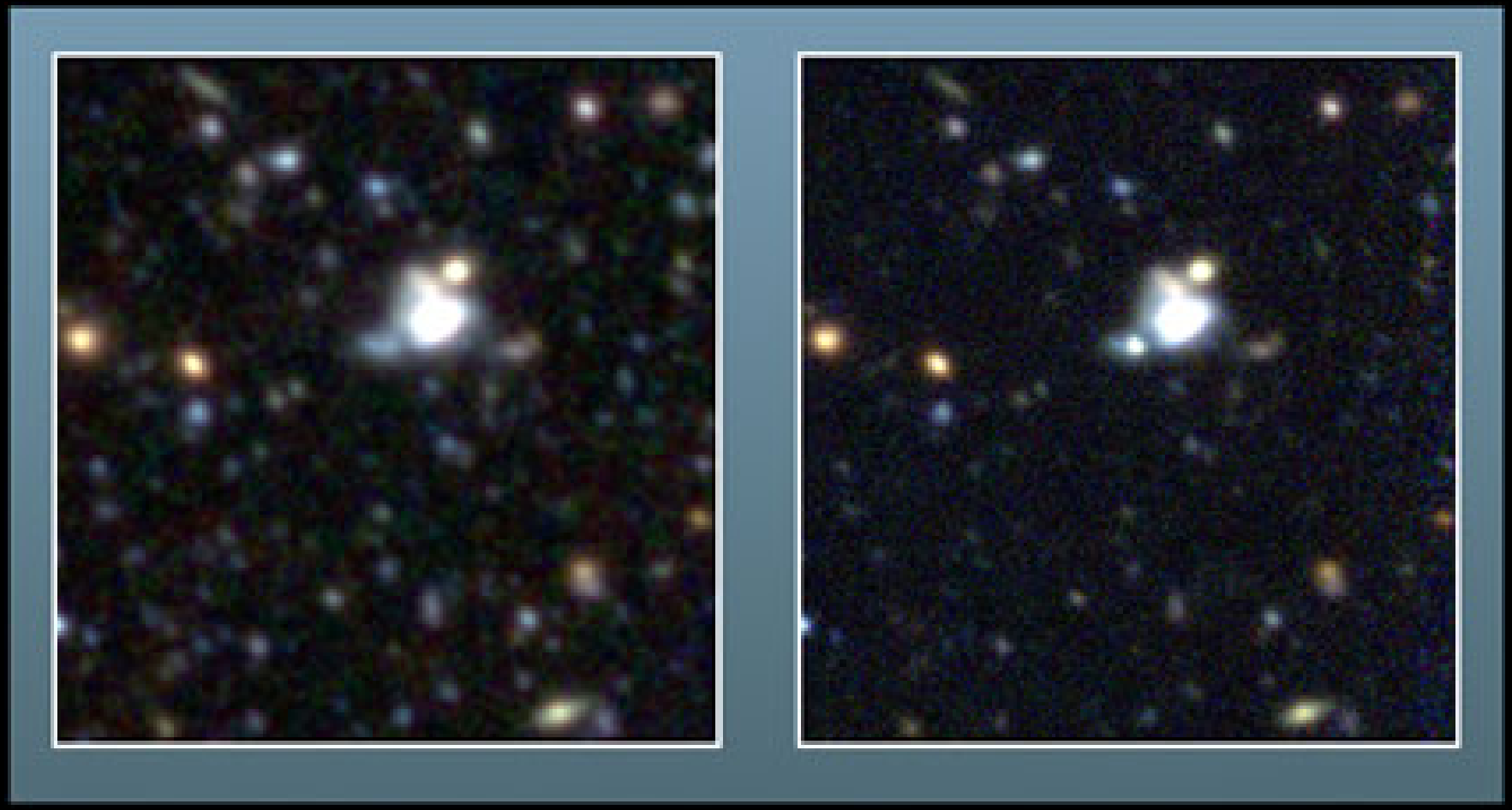

-0.5
-1
-1.5
-2
0
0.2
0.4
0.6
w
Ω_M
SNLS 1st Year
BAO


Distance modulus
46
44
42
40
38
36
34
0.01
0.10
1.00
(OM, OL) = (0.27, 0.73)
(OM, OL) = (0.3, 0.0)
(OM, OL) = (1.0, 0.0)


1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
Residual
nearby
ESSENCE
SNLS
0.01
0.10
1.00
Redshift


ESSENCE+SNLS+gold
$(\Omega_M,\Omega_\Lambda) = (0.27,0.73)$
$\Omega_{Total}=1$
Ω_Λ
Ω_M
0.0
0.5
1.0
1.5
2.0


ESSENCE+SNLS+gold
BAO
SNela+BAO
$(\Omega_M,w) = (0.27,-1)$
w
Ω_M
0.0
−0.5
−1.0
−1.5
−2.0
0.2
0.4
0.6
0.8
1.0



SNLS-03D3bb

The type Ia supernova SNLS-03D3bb from a super-Chandrasekhar-mass white dwarf star

D. Andrew Howell[1], Mark Sullivan[1], Peter E. Nugent[2], Richard S. Ellis[3], Alexander J. Conley[1], Damien Le Borgne[4], Raymond G. Carlberg[1], Julien Guy[5], David Balam[6], Stephane Basa[7], Dominique Fouchez[8], Isobel M. Hook[9], Eric Y. Hsiao[6], James D. Neill[6], Reynald Pain[5], Kathryn M. Perrett[1], Christopher J. Pritchet[6]

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[3]*California Institute of Technology, E. California Blvd., Pasadena, CA 91125, USA*
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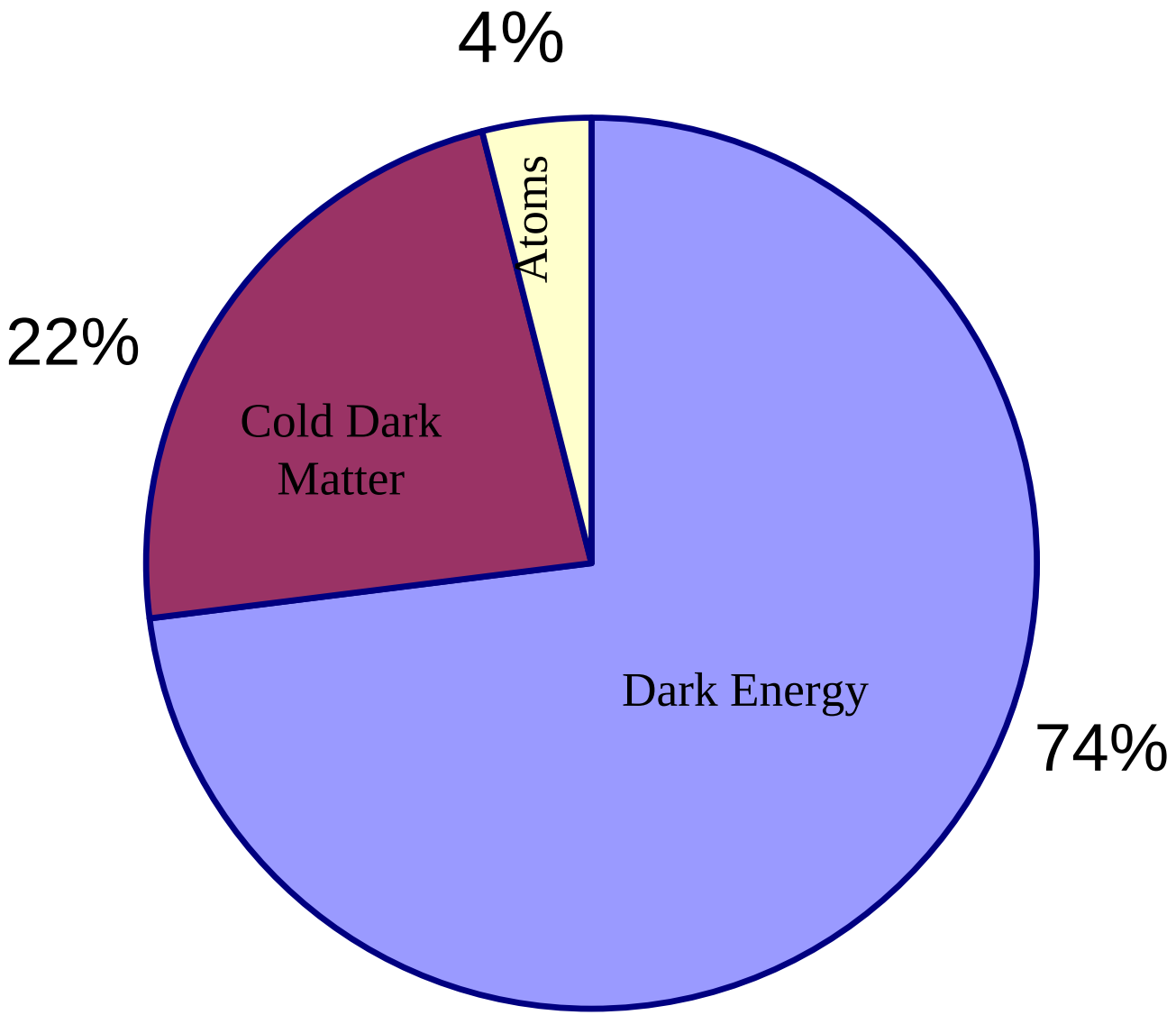
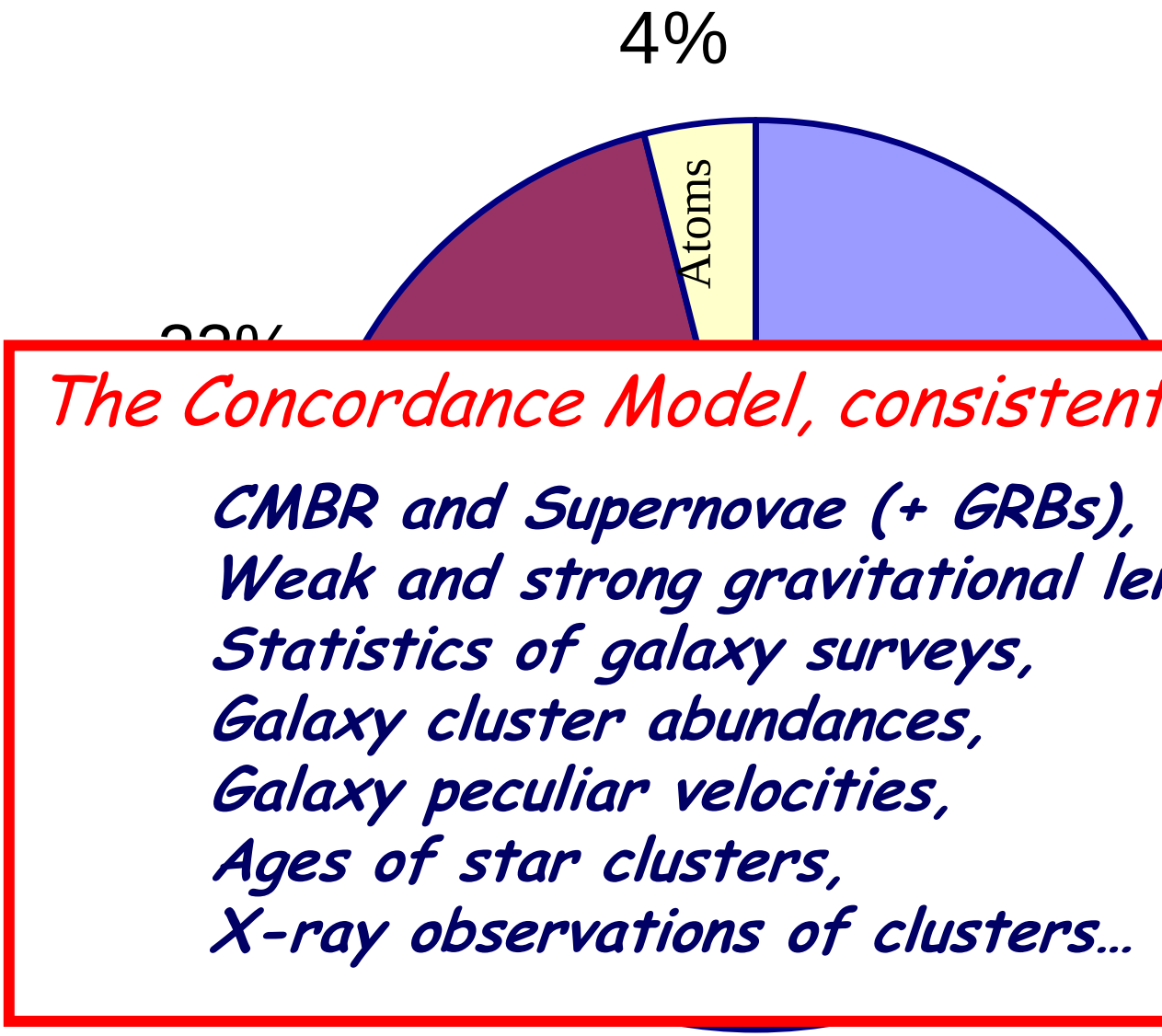
[5]*LPNHE, CNRS-IN2P3 and University of Paris VI & VII, 75005 Paris, France*
[6]*Department of Physics and Astronomy, University of Victoria, PO Box 3055, Victoria, BC V8W 3P6, Canada*
[7]*LAM CNRS, BP8, Traverse du Siphon, 13376 Marseille Cedex 12, France*
[8]*CPPM, CNRS-IN2P3 and University Aix Marseille II, Case 907, 13288 Marseille Cedex 9, France*
[9]*University of Oxford Astrophysics, Denys Wilkinson Building, Keble Road, Oxford OX1 3RH, UK*

The acceleration of the expansion of the universe, and the need for Dark Energy, were inferred from the observations of Type Ia supernovae (SNe Ia)[1;2]. There is consensus that SNe Ia are thermonuclear explosions that destroy carbon-oxygen white dwarf stars that accrete matter from a companion star[3], although the nature of this companion remains uncertain. SNe Ia are thought to be reliable distance indicators because they have a standard amount of fuel and a uniform trigger — they are predicted to explode when the mass of the white dwarf nears the Chandrasekhar mass[4] — 1.4 solar masses. Here we show that the high redshift supernova SNLS-03D3bb has an exceptionally high luminosity and low kinetic energy that both imply a *super*-Chandrasekhar mass progenitor. Super-Chandrasekhar mass SNe Ia should preferentially occur in a young stellar population, so this may provide an explanation for the observed trend that overluminous SNe Ia only occur in young environments[5;6]. Since this supernova does not obey the relations that allow them to be calibrated as standard candles, and since no counterparts have been found at low redshift, future cosmology studies will have to consider contamination from such events.

State of the Universe – Jan 2007



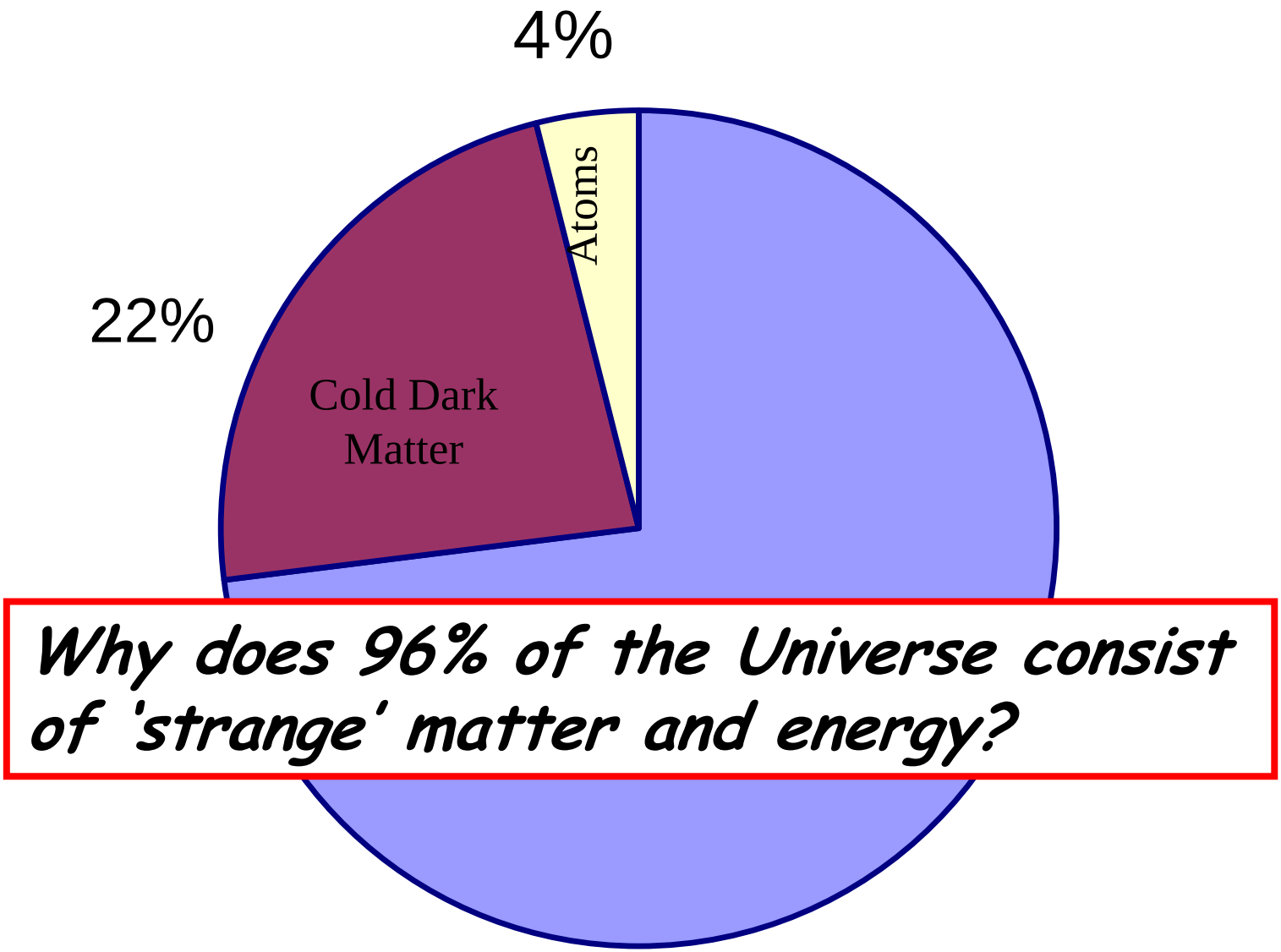
State of the Universe – Jan 2007



The Concordance Model, consistent with:

CMBR and Supernovae (+ GRBs),
Weak and strong gravitational lensing,
Statistics of galaxy surveys,
Galaxy cluster abundances,
Galaxy peculiar velocities,
Ages of star clusters,
X-ray observations of clusters…

State of the Universe – Jan 2007



Why does 96% of the Universe consist of 'strange' matter and energy?


The future of the Universe:-
No
Big Crunch!!!