



GEORG-AUGUST-UNIVERSITÄT
GÖTTINGEN



Recycling im Universum

Der kosmische Materiekreislauf

Stefan Dreizler

Institut für Astrophysik

Georg-August-Universität Göttingen



Inhalt

Woher wissen wir, dass sich Sterne verändern?

Was wissen wir über den Sternaufbau und die Sternentwicklung?

Wie verläuft die Entwicklung von Sternen?

Wie hat alles begonnen?



H→He:

Sonnenmasse:

davon 1/10:

reicht für:

5000000000000000 s

bei etwa:

30000000 s/Jahr

also etwa

10000000000 Jahre $\approx$ Alter des Universums

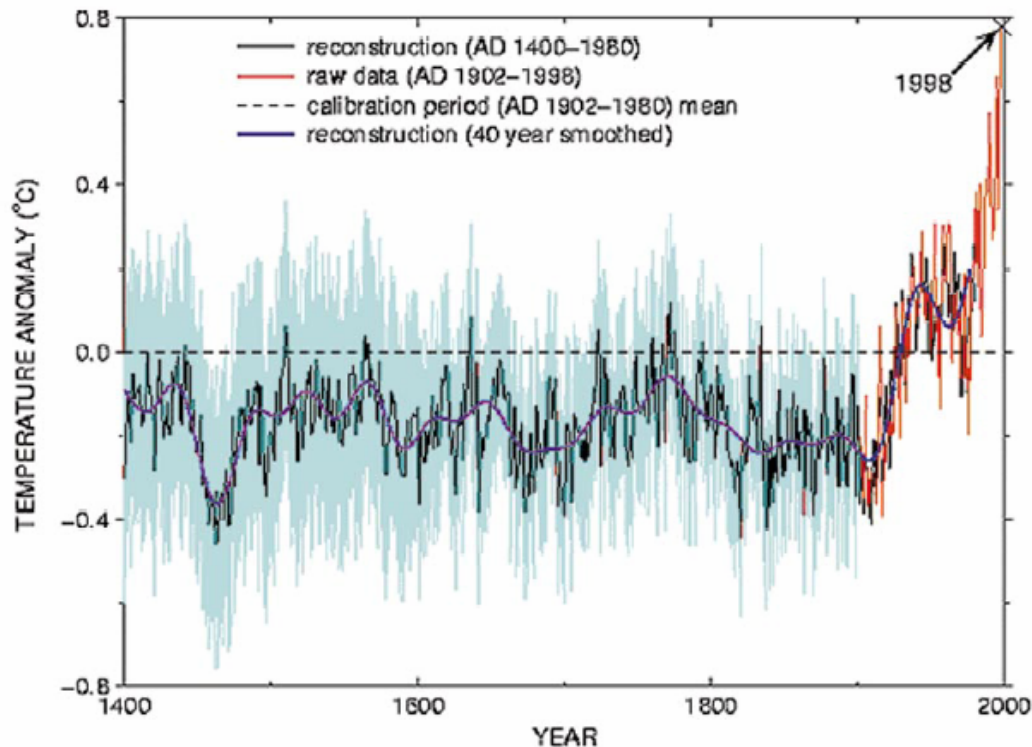




Sternentwicklung ist langsam

Sonne ist praktisch unveränderlich auf Zeitskalen von

Jahrhunderten - Klimaaufzeichnungen

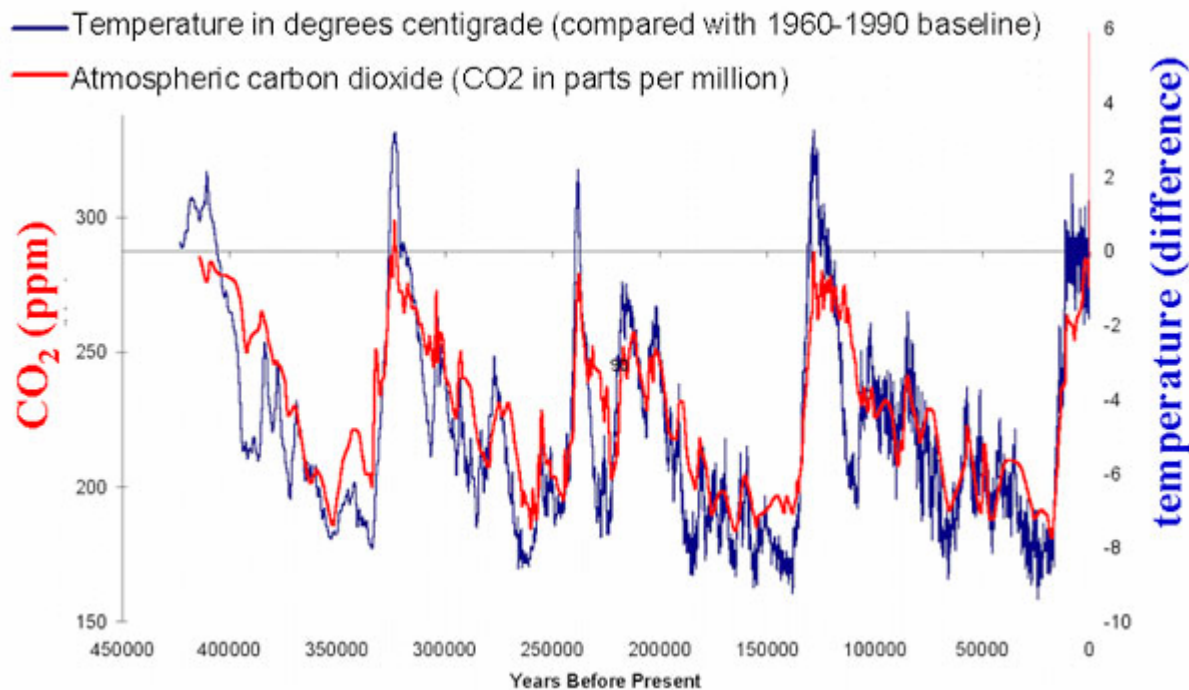




Sternentwicklung ist langsam

Sonne ist praktisch unveränderlich auf Zeitskalen von

Jahrtausenden - Klimarekonstruktion



Petit et al., Nature 399, 429

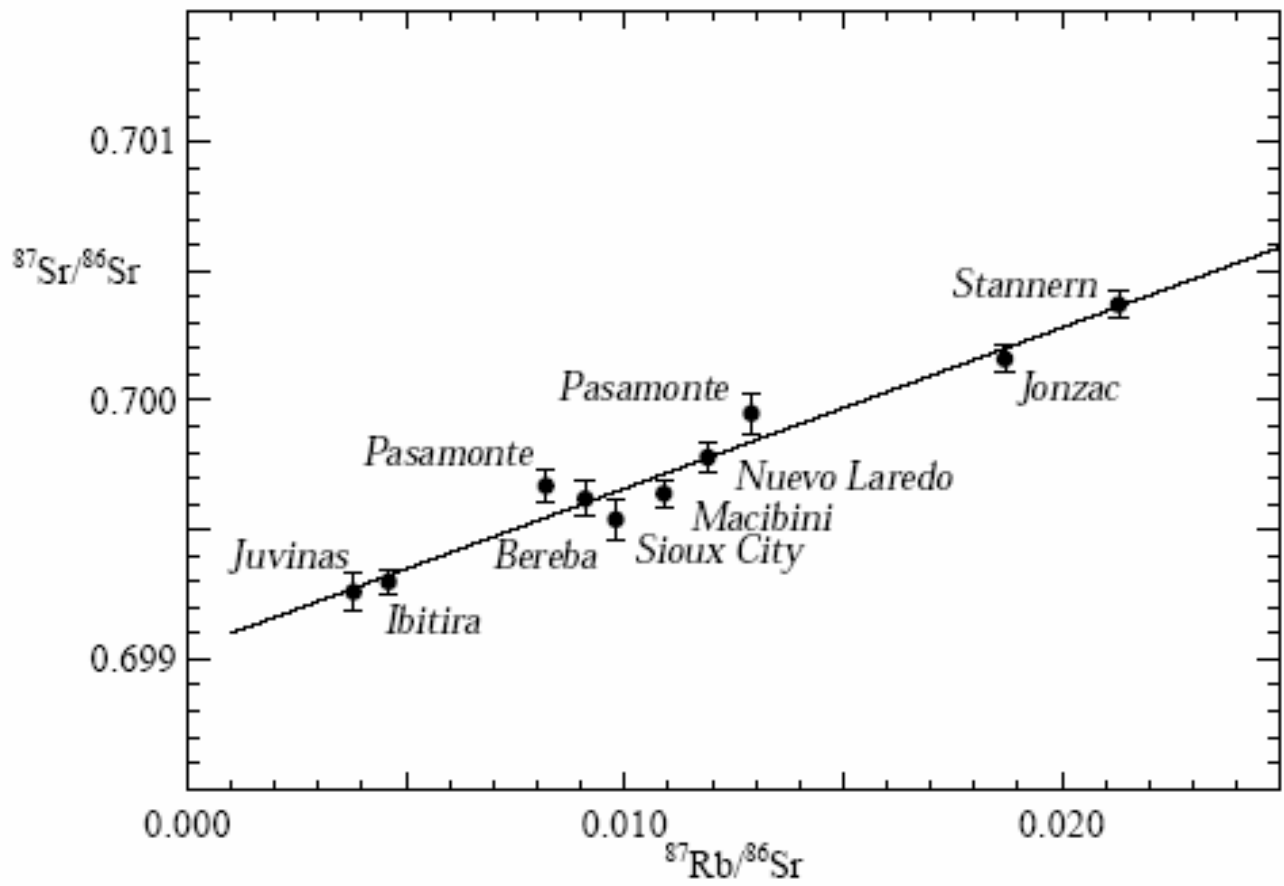


Jahrmillionen - Fossilien



Alter der Sonne

Kosmochronologie – 4.5 Milliarden Jahre





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Problem

Entwicklungszeit von Sternen » Lebenszeit eines Menschen

100000000000

: 100 Jahre

100

: 0.000001 Jahre = 30 s

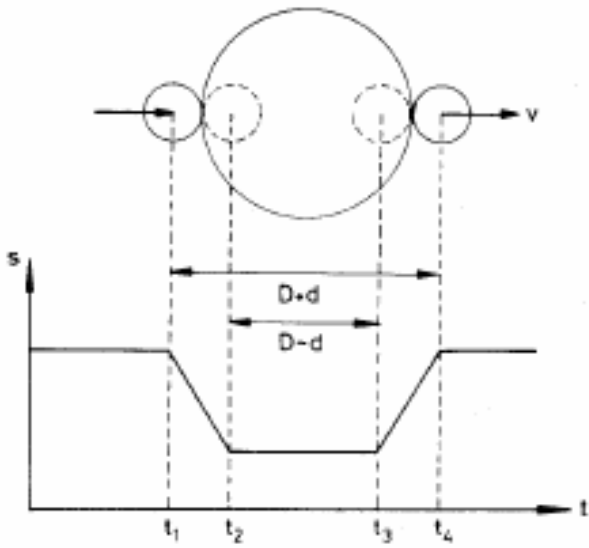
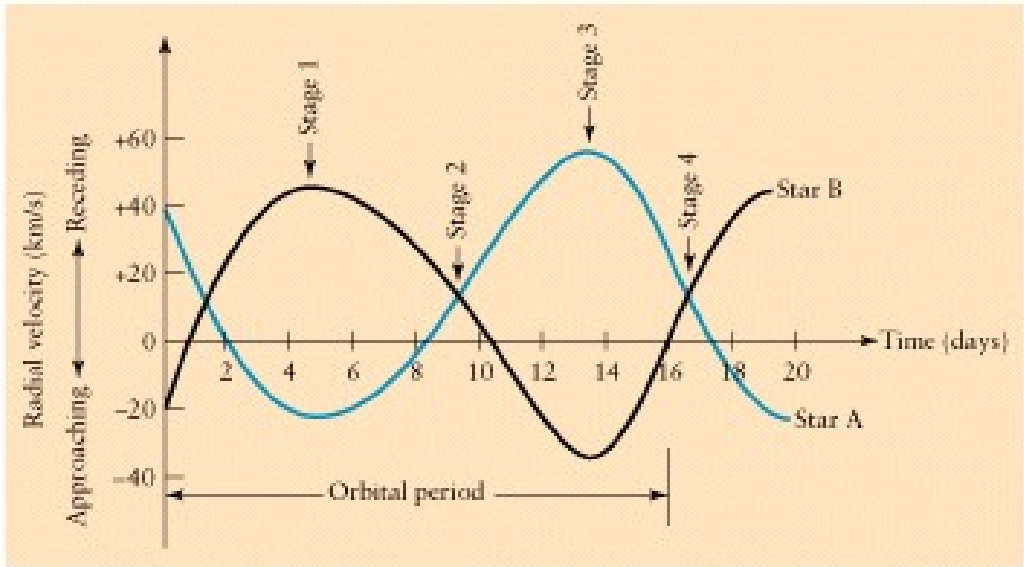
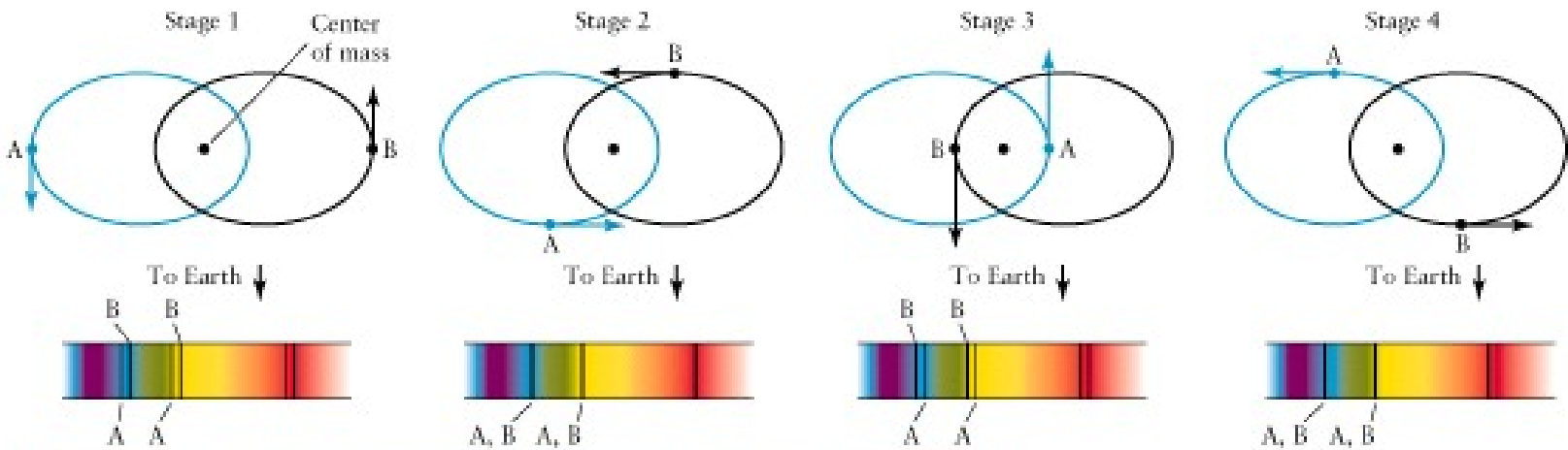
Messung von Größe, Masse, Temperatur, Farbe, chemische Zusammensetzung

Entwicklung aus
dem Zusammenhang

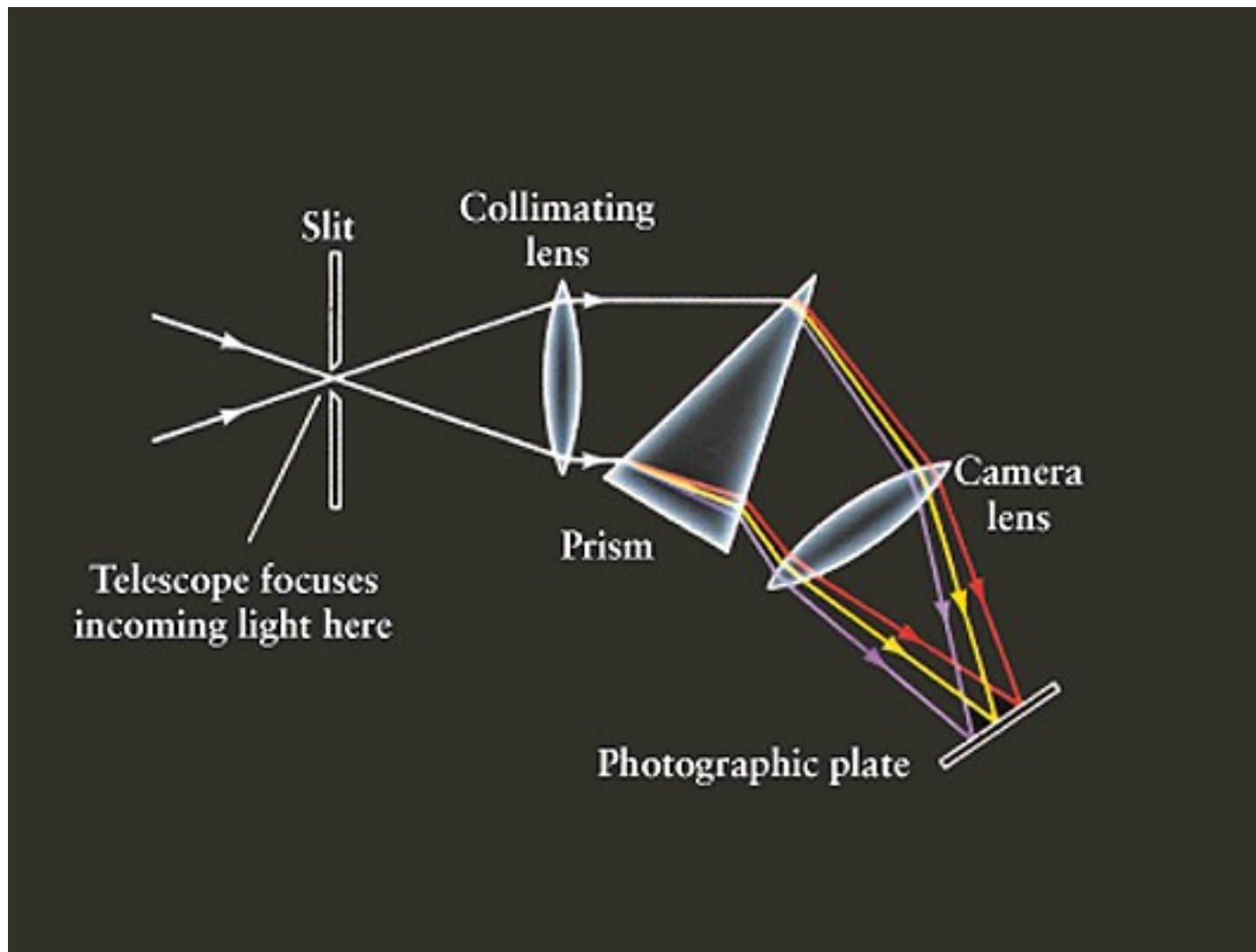




Masse und Radius



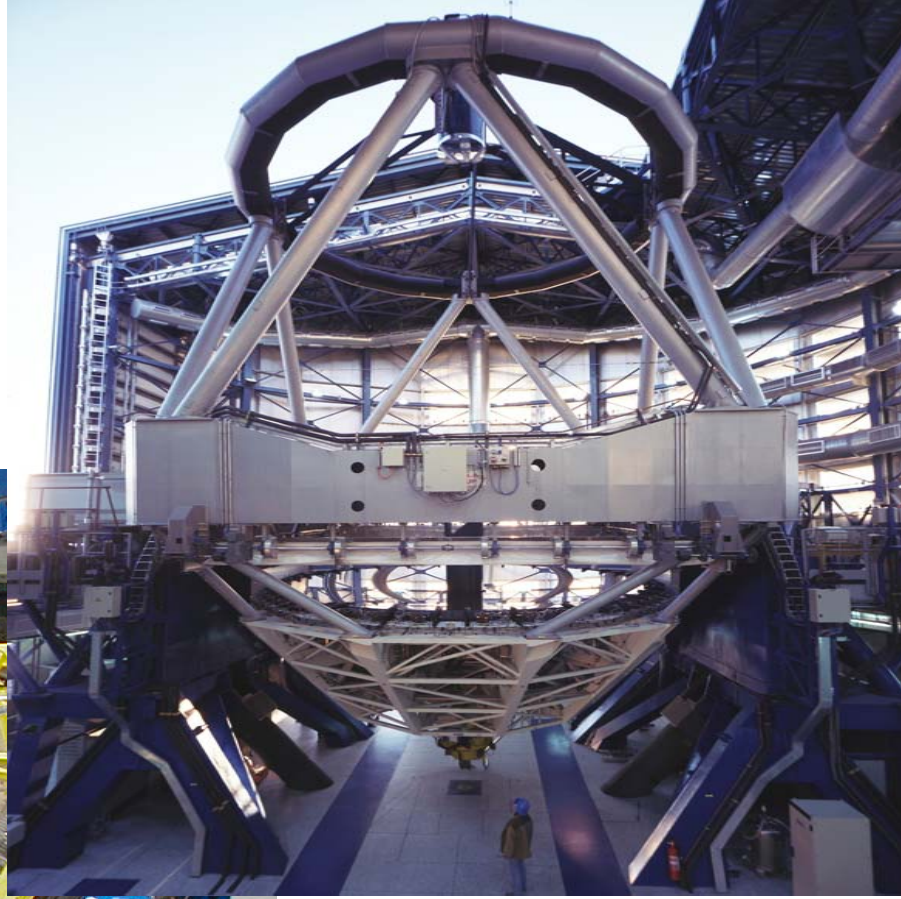
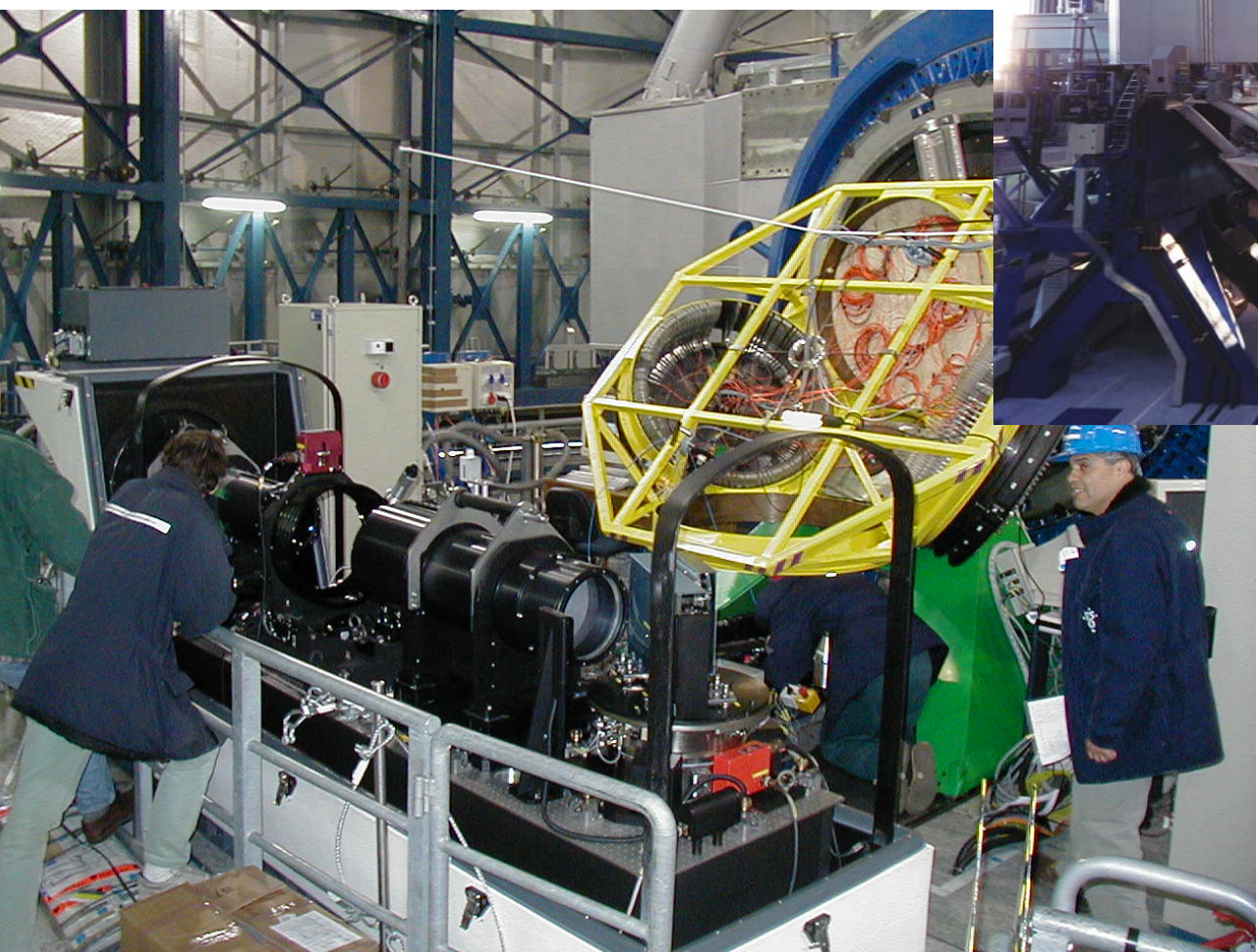
Temperatur und Farbe



Spektrograph zur Zerlegung des Lichts

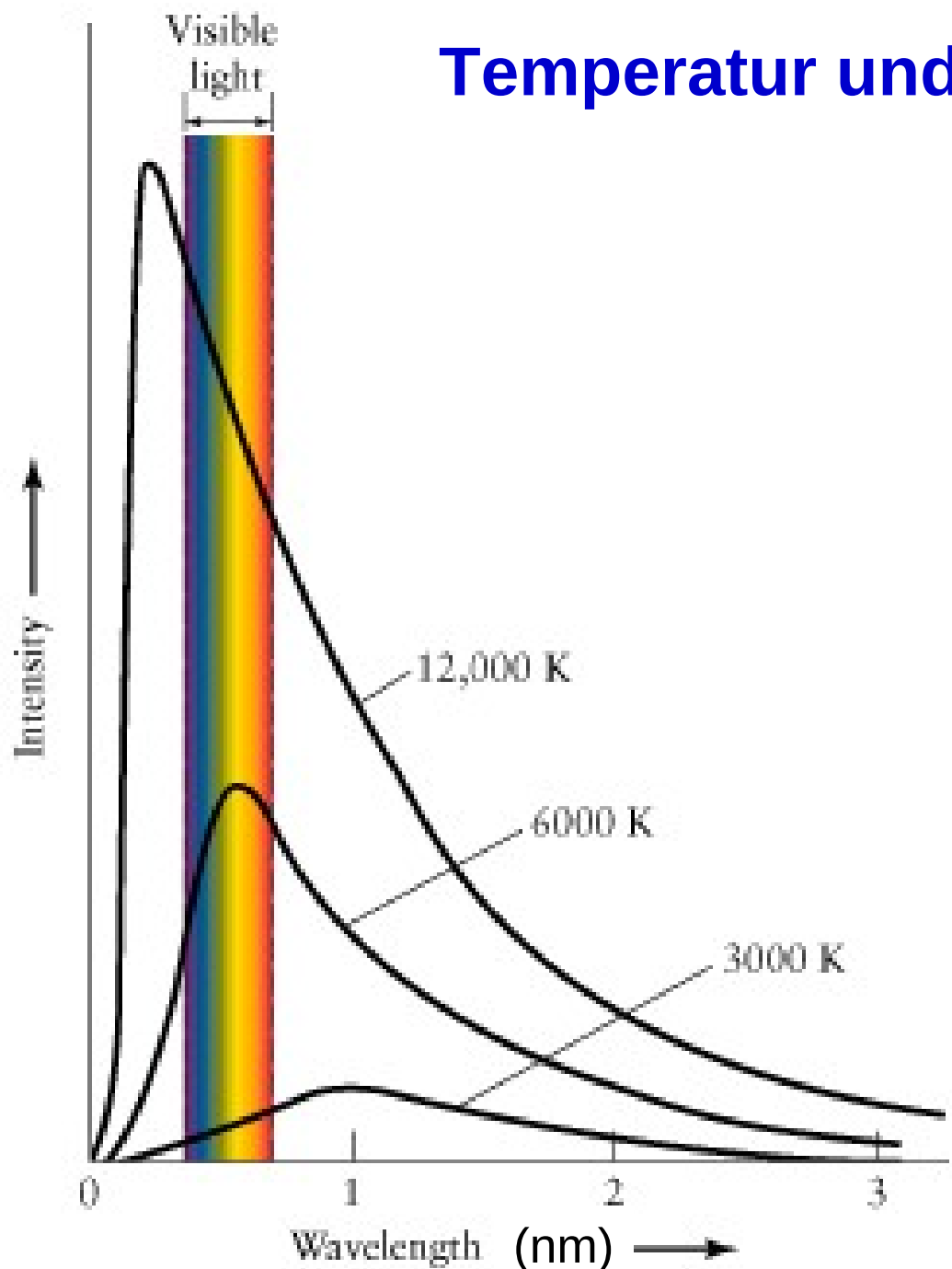


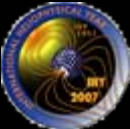
Temperatur und Farbe





Temperatur und Farbe





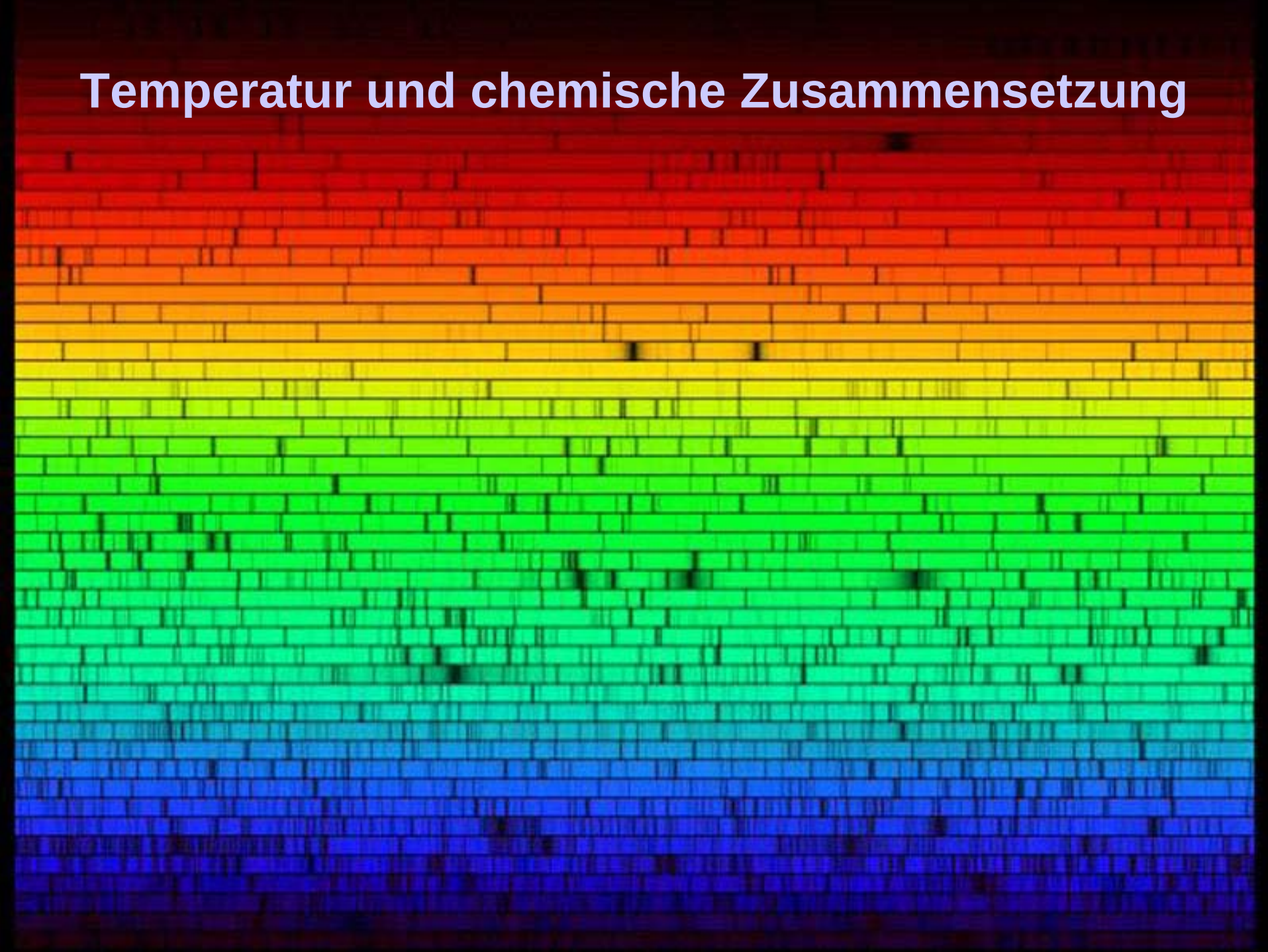
Globular Cluster NGC 6093

Sternfarben



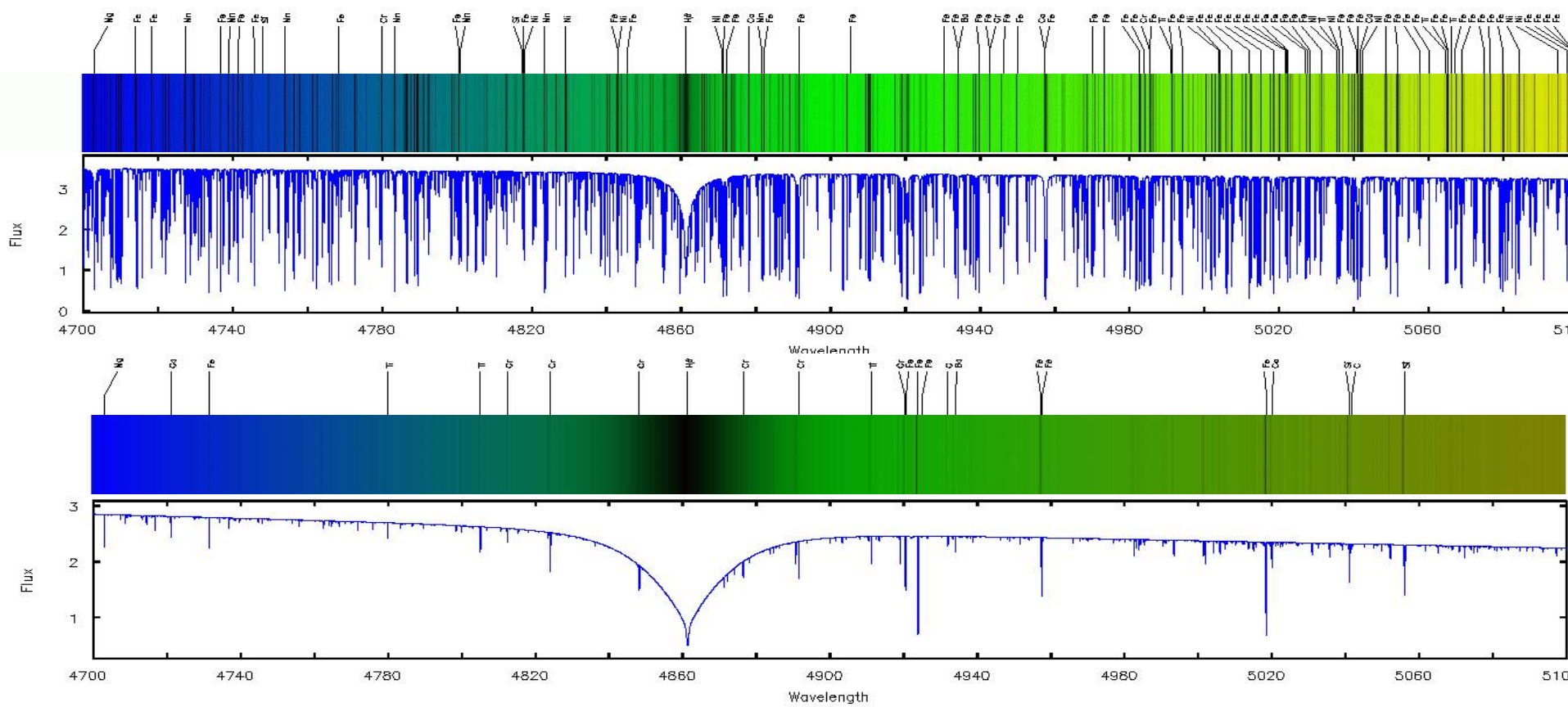
Hubble
Heritage

Temperatur und chemische Zusammensetzung

The background of the slide is a brick wall. The bricks are arranged in a standard pattern. A color gradient is applied to the entire image, starting with red at the top, transitioning through orange, yellow, green, and cyan, and finally reaching blue at the bottom. The text 'Temperatur und chemische Zusammensetzung' is written in white at the top left.

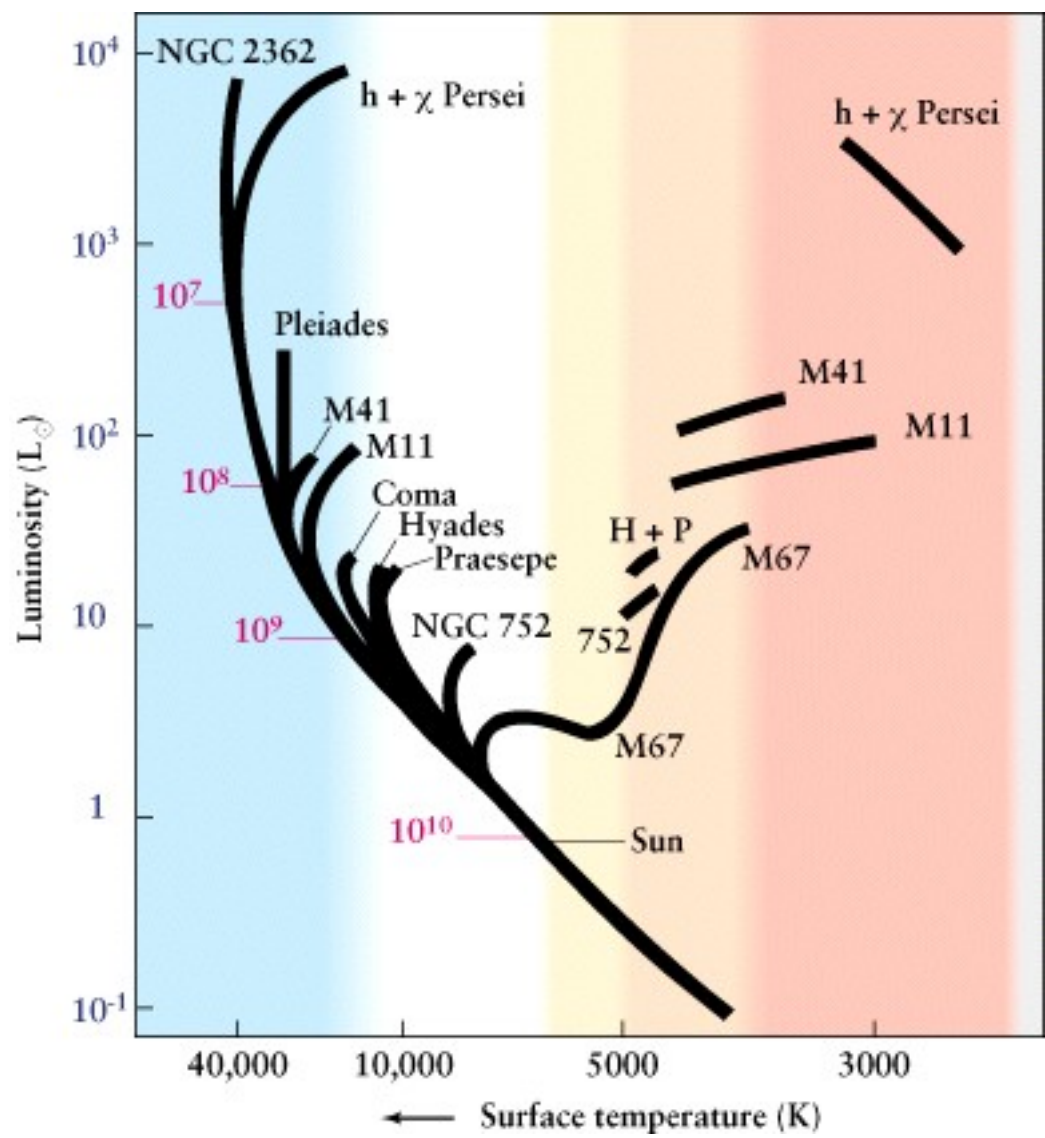


Temperatur und chemische Zusammensetzung





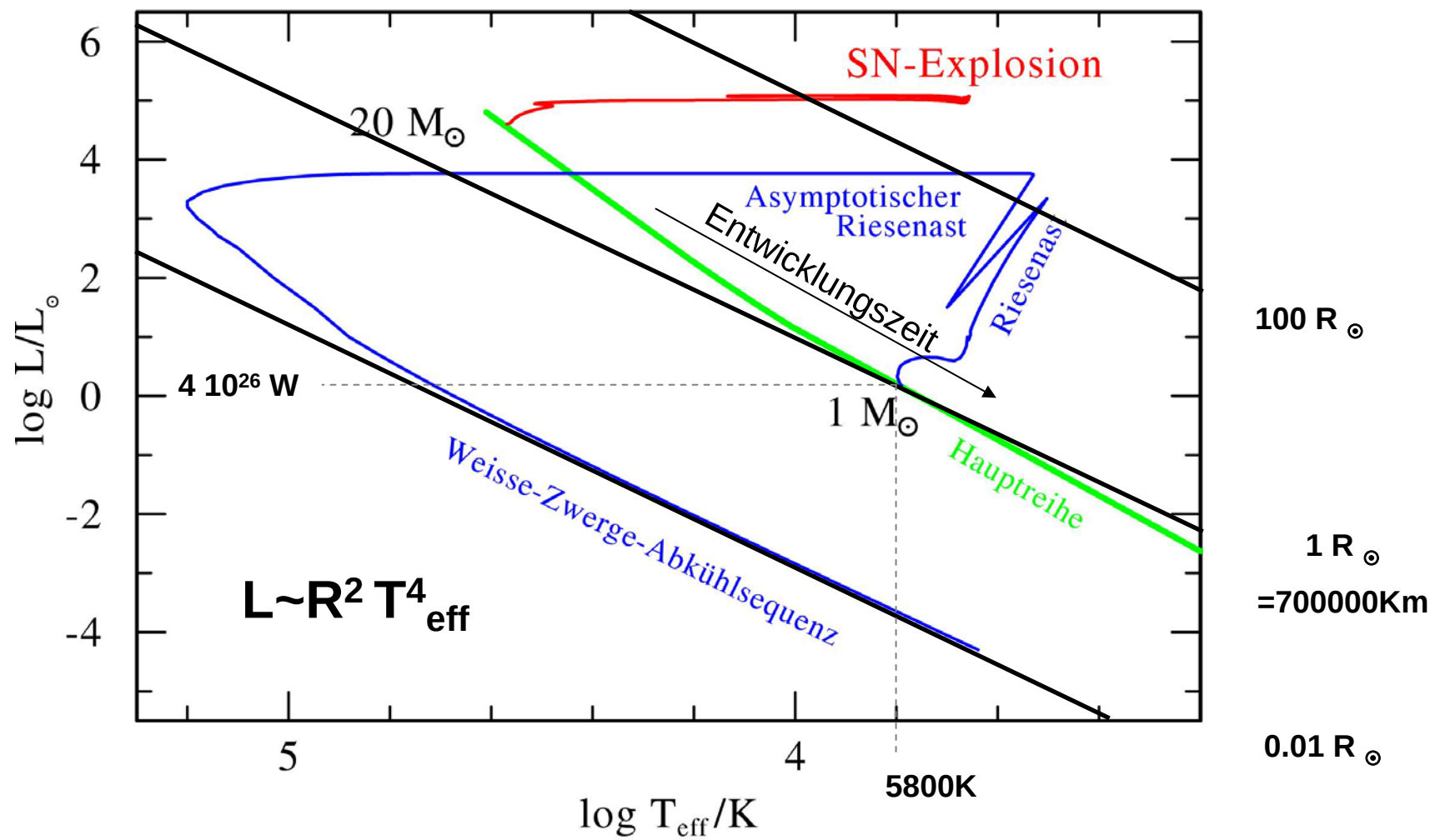
Hertzsprung-Russell-Diagramm





Sternaufbau und Entwicklung

Massenerhaltung, Impulserhaltung, Energieerhaltung
Energietransport





Sternaufbau und Entwicklung

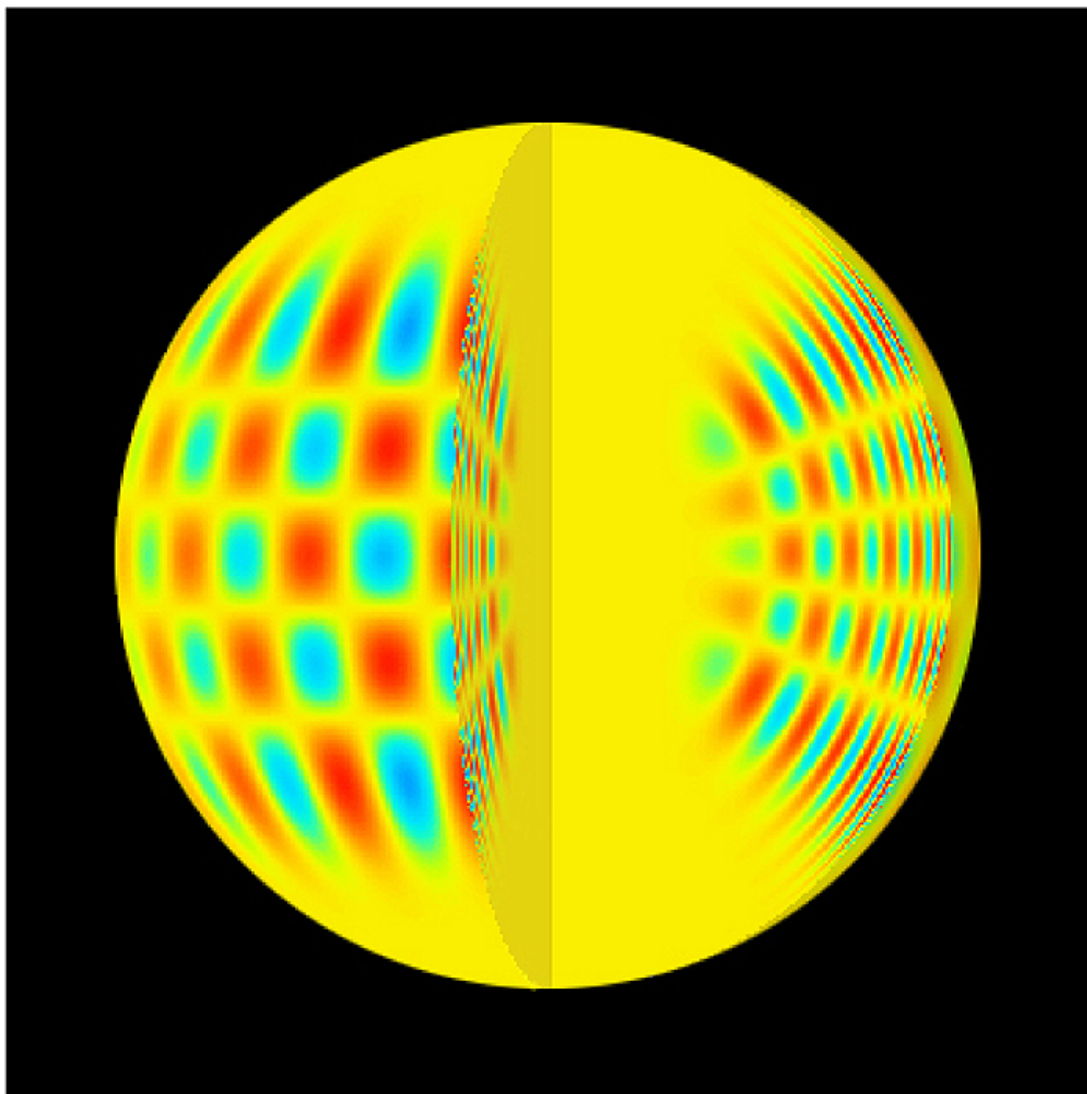
Sind die Modelle realistisch?





Sternaufbau und Entwicklung

Sind die Modelle realistisch?





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Woher wissen wir, dass sich Sterne verändern?

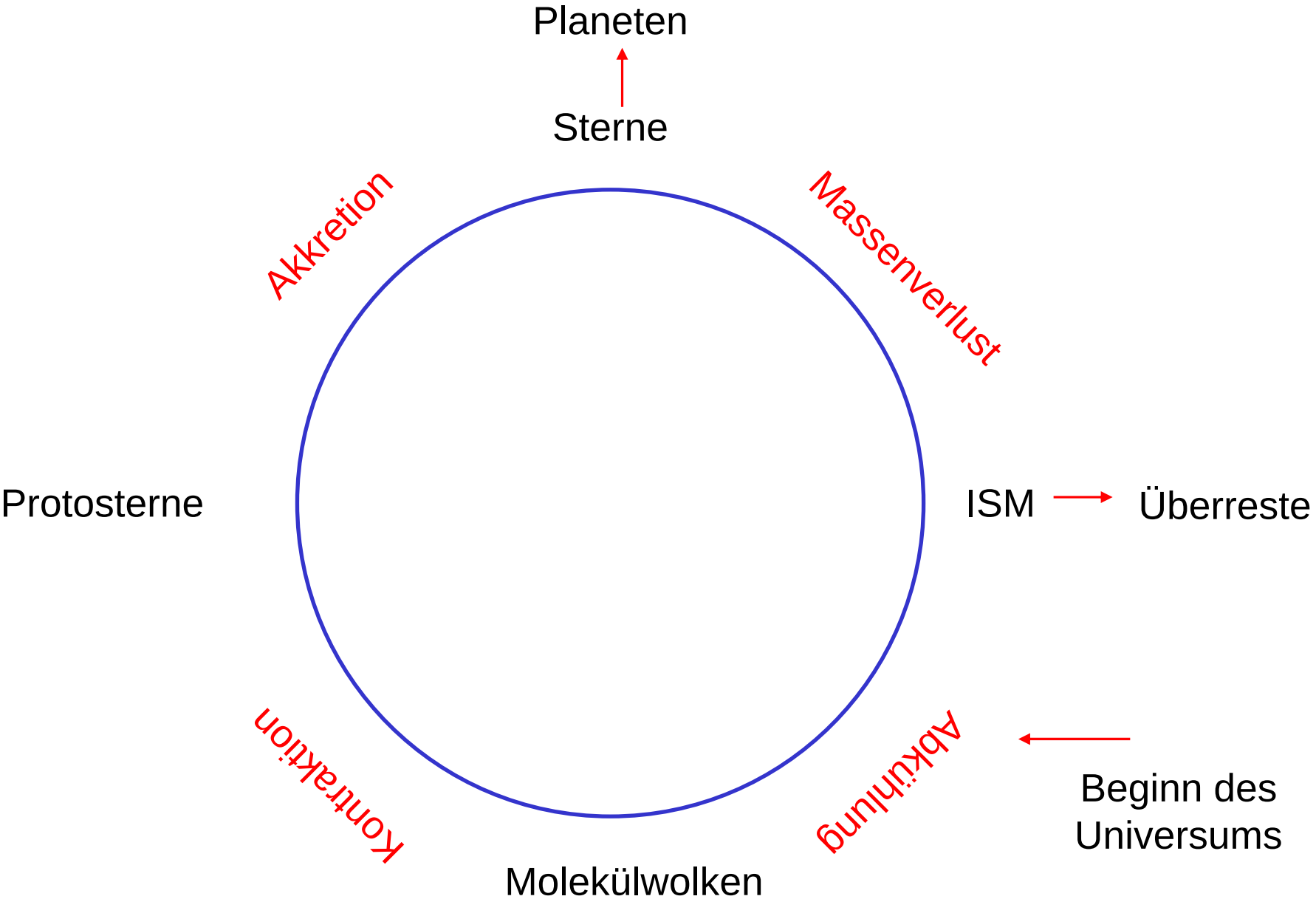
Was wissen wir über den Sternaufbau und die Sternentwicklung?

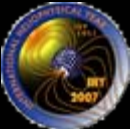
Wie verläuft die Entwicklung von Sternen?

Wie hat alles begonnen?



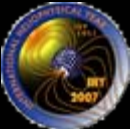
Materiekreislauf





Molekülwolken





The "Black Cloud" B68
(VLT ANTU + FORS1)

ESO PR Photo 20a/99 (30 April 1999)

© European Southern Observatory

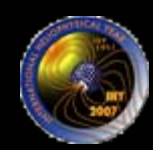


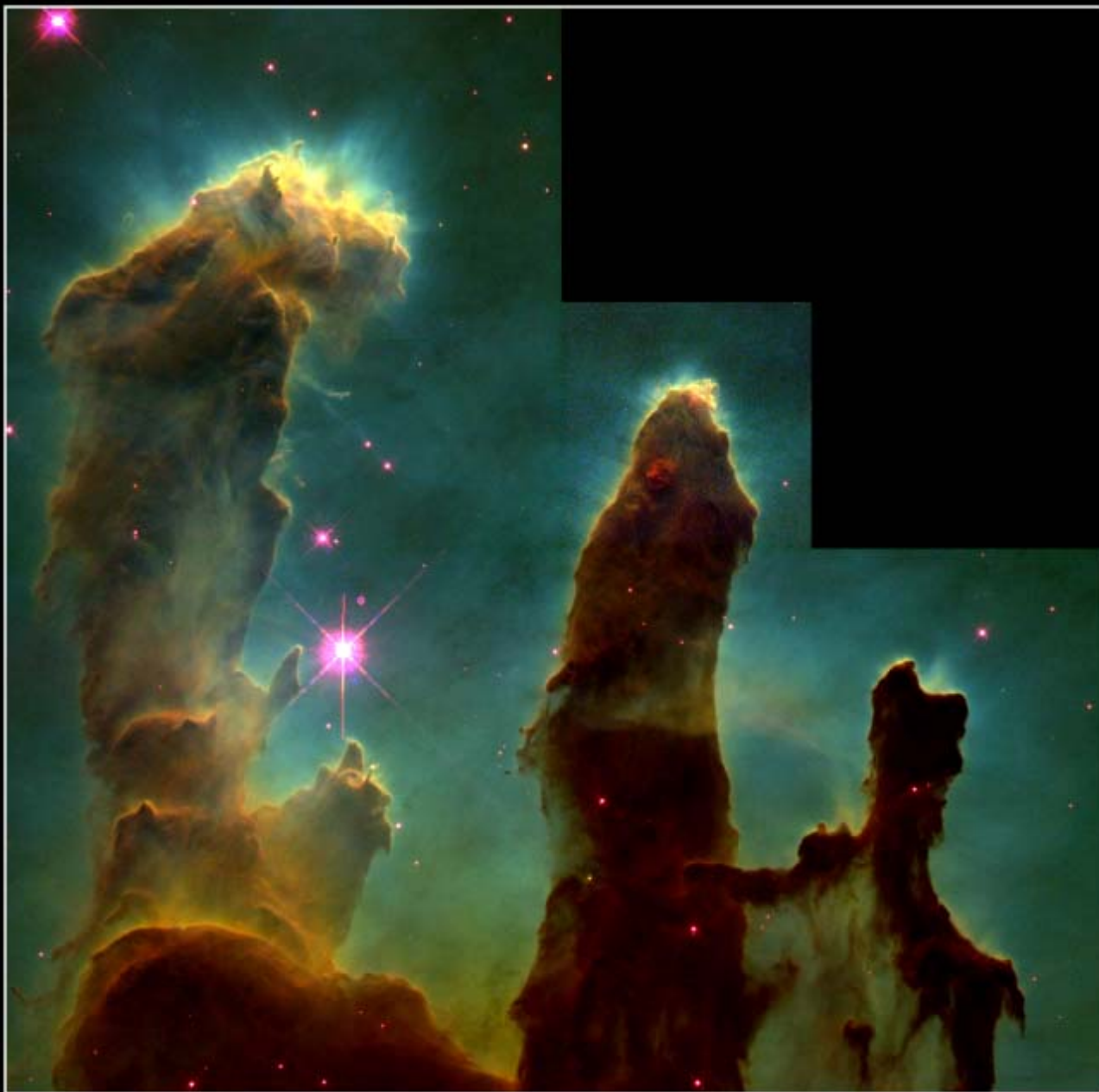
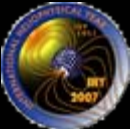


Thackeray's Globules in Nebula IC 2944



HUBBLESITE.org

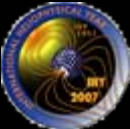




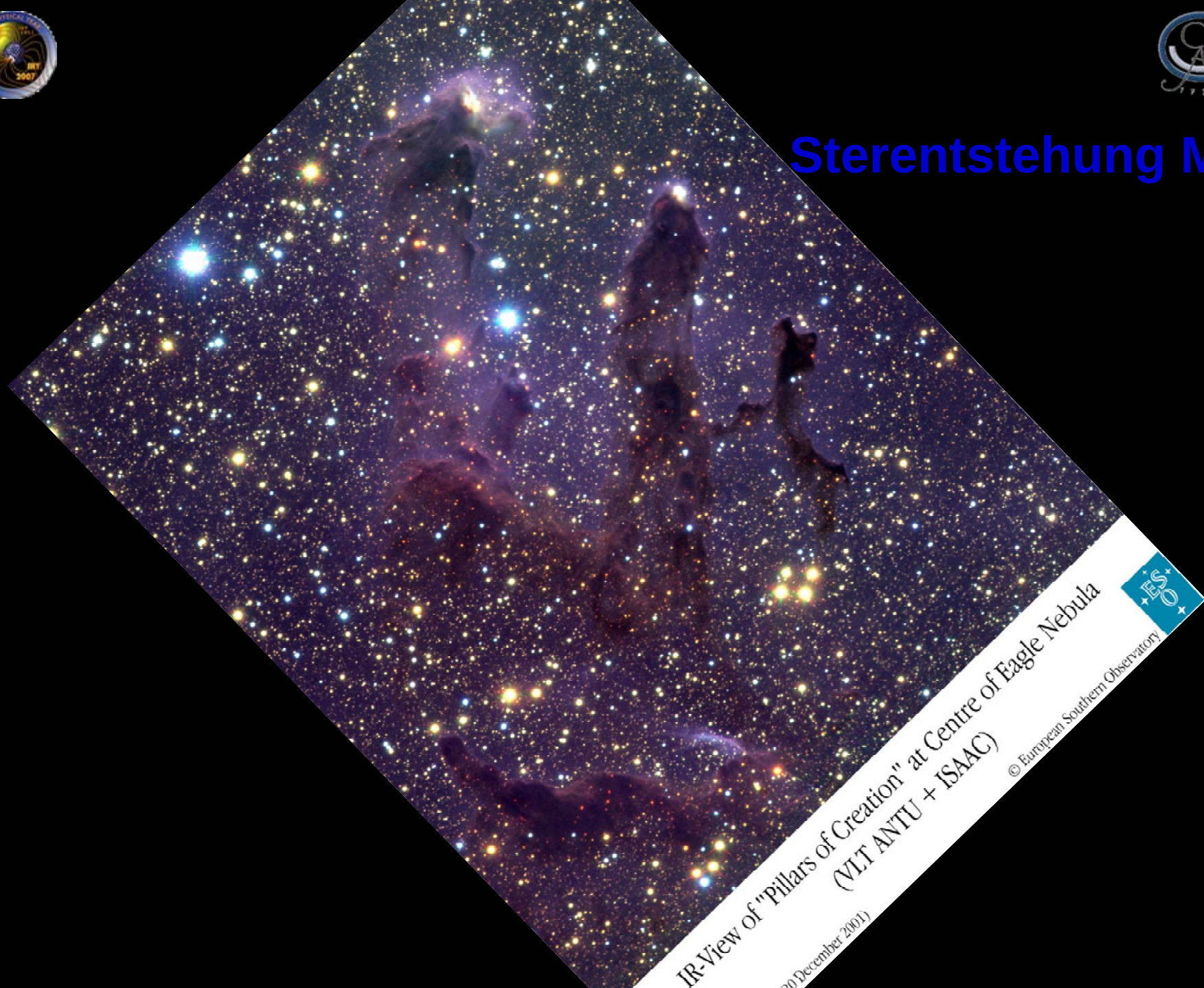
Gaseous Pillars • M16

HST • WFPC2

PRC95-44a • ST Sci OPO • November 2, 1995
J. Hester and P. Scowen (AZ State Univ.), NASA



Sterentstehung M16



IR-View of "Pillars of Creation" at Centre of Eagle Nebula
(VLT ANTU + ISAAC)

20 December 2001



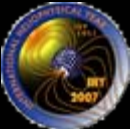
© European Southern Observatory



The Cone Nebula — NGC 2264



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Orion Nebula Mosaic

HST • WFPC2

PRC95-45a • ST ScI OPO • November 20, 1995

C. R. O'Dell and S. K. Wong (Rice University), NASA

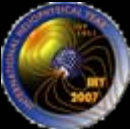


Protoplanetary Disks Orion Nebula

HST · WFPC2

PRC95-45b · ST ScI OPO · November 20, 1995

M. J. McCaughrean (MPIA), C. R. O'Dell (Rice University), NASA



Protostar HH-34 in Orion (VLT KUEYEN + FORS2)

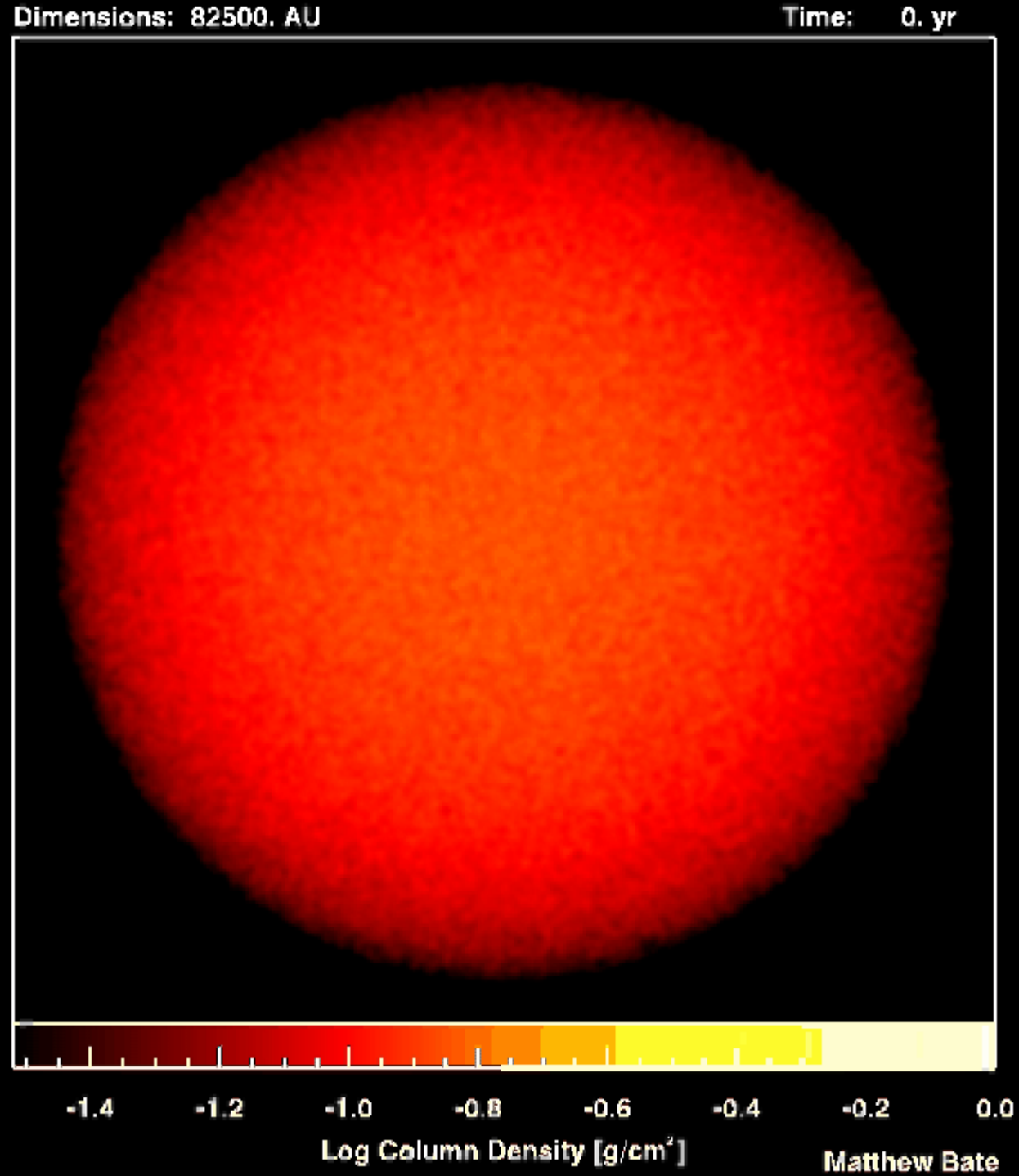
ESO PR Photo 40b/99 (17 November 1999)

© European Southern Observatory



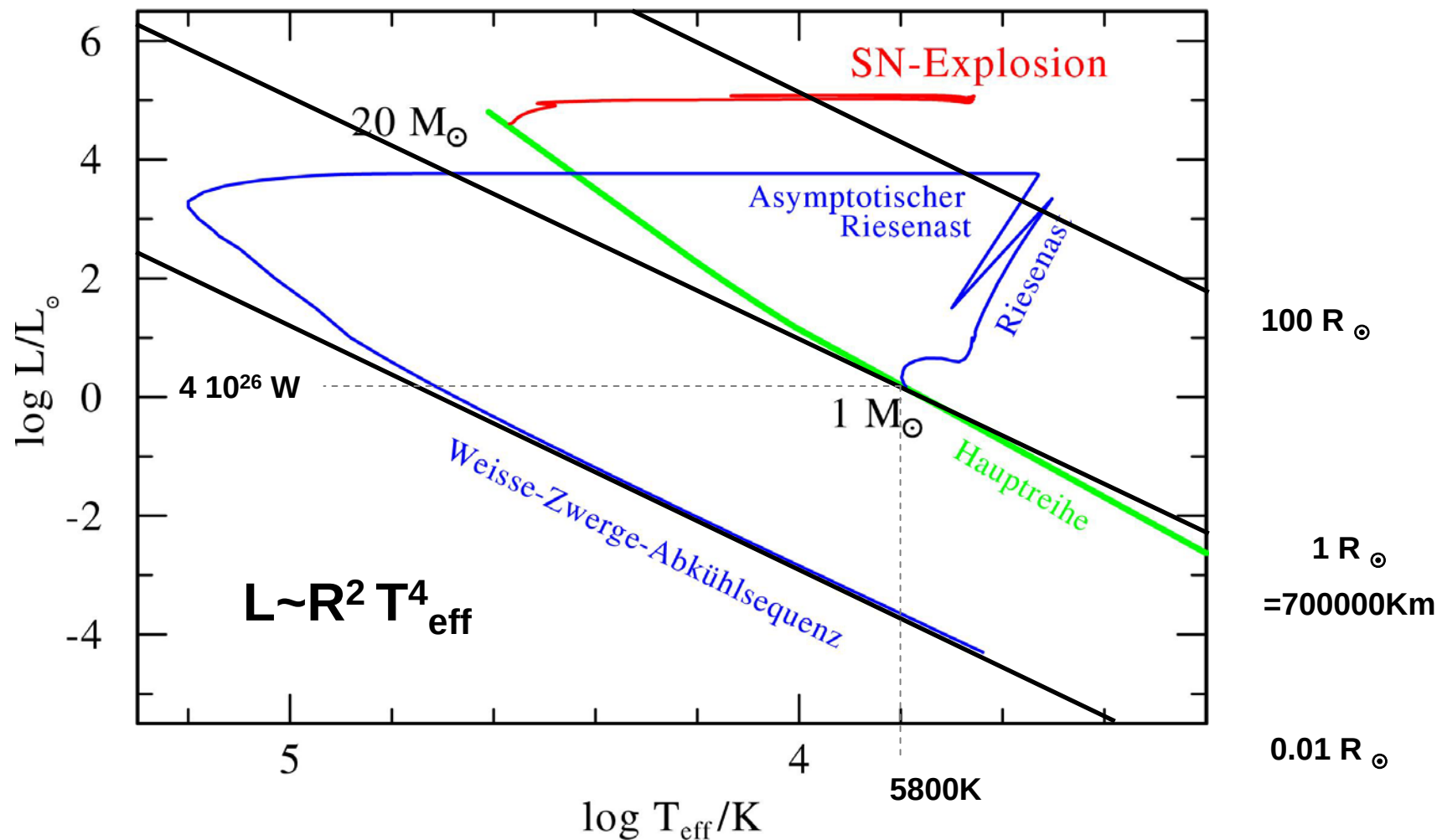


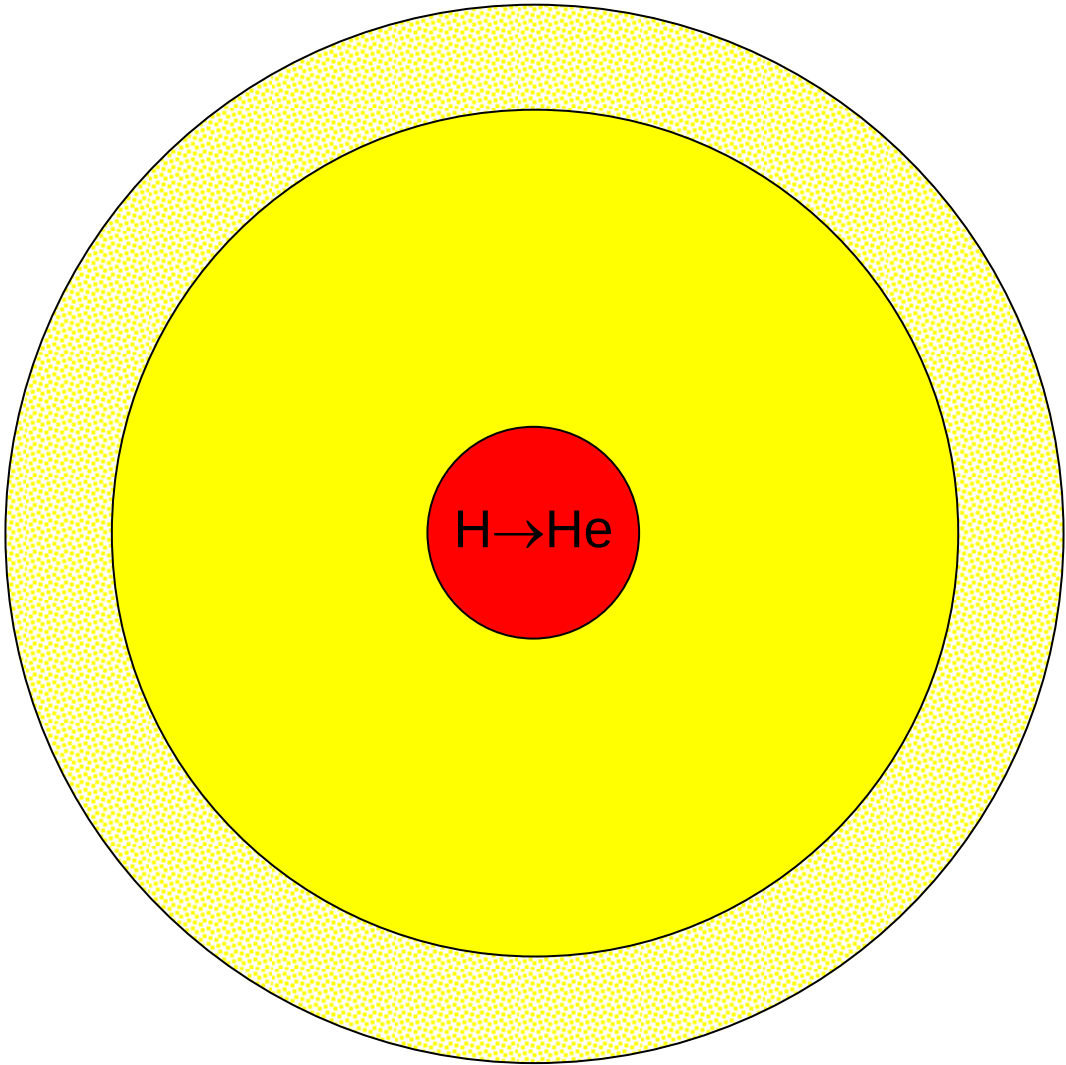
Sternentstehung im Computer



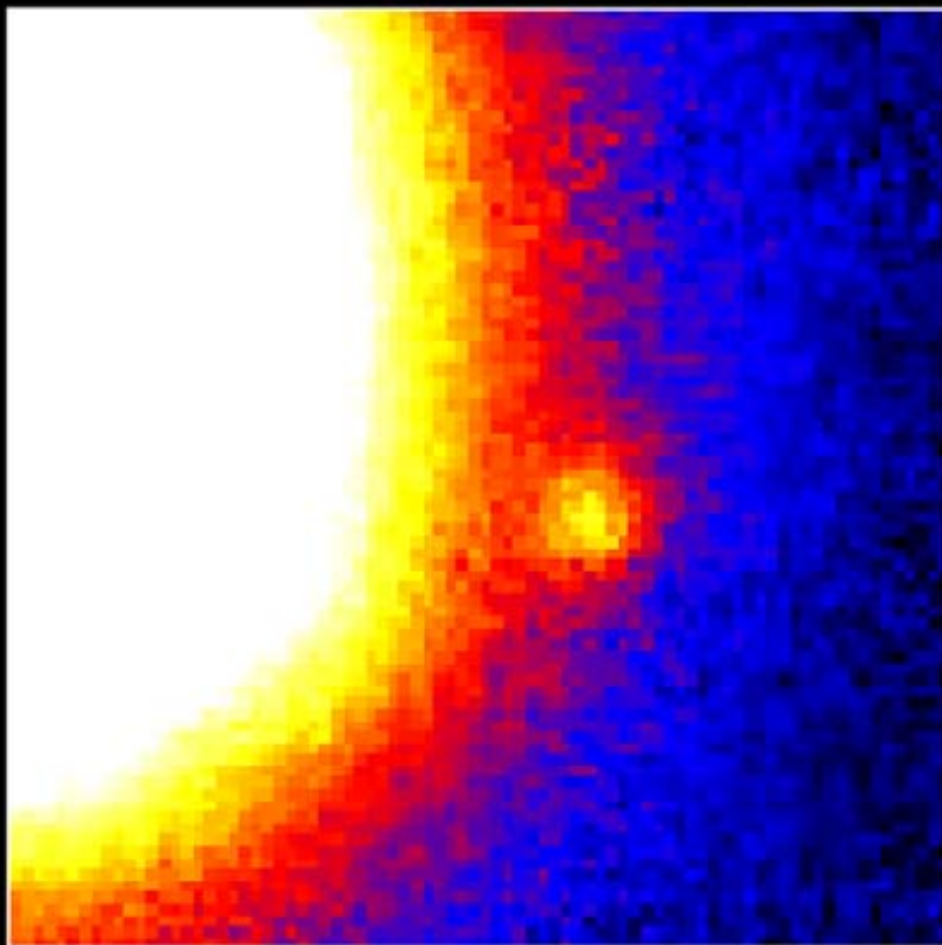


Hertzsprung-Russell-Diagramm

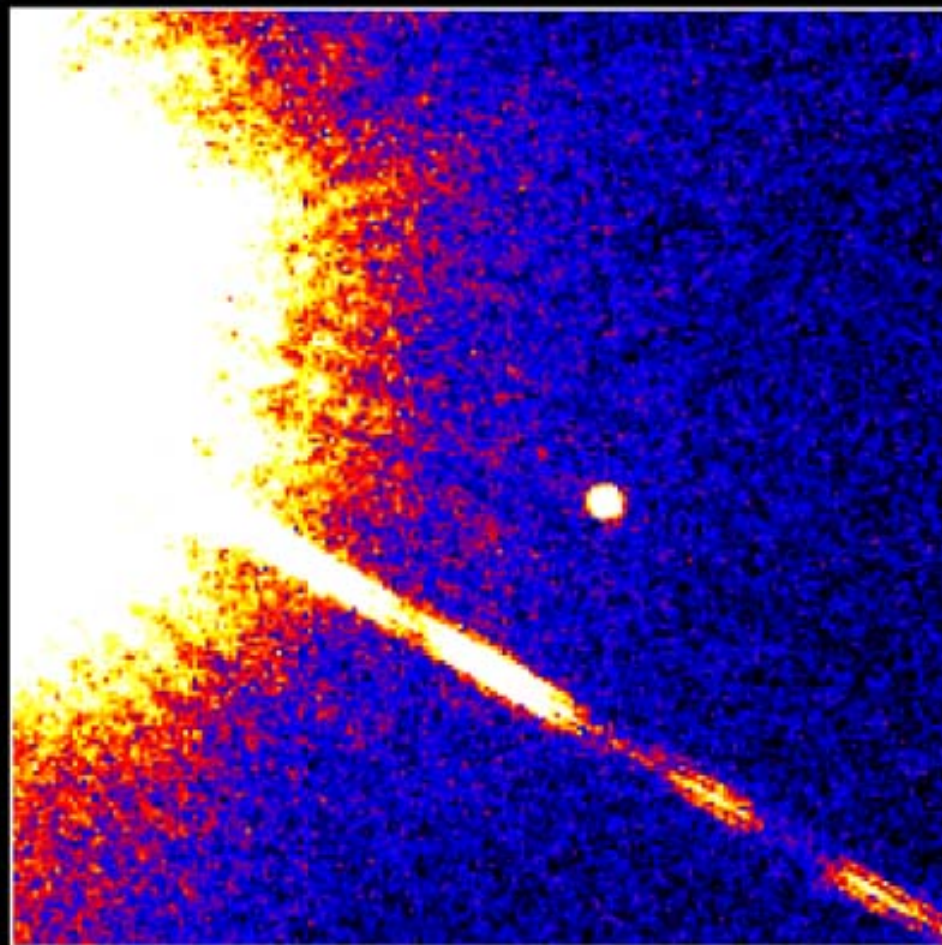




Brown Dwarf Gliese 229B



Palomar Observatory
Discovery Image
October 27, 1994



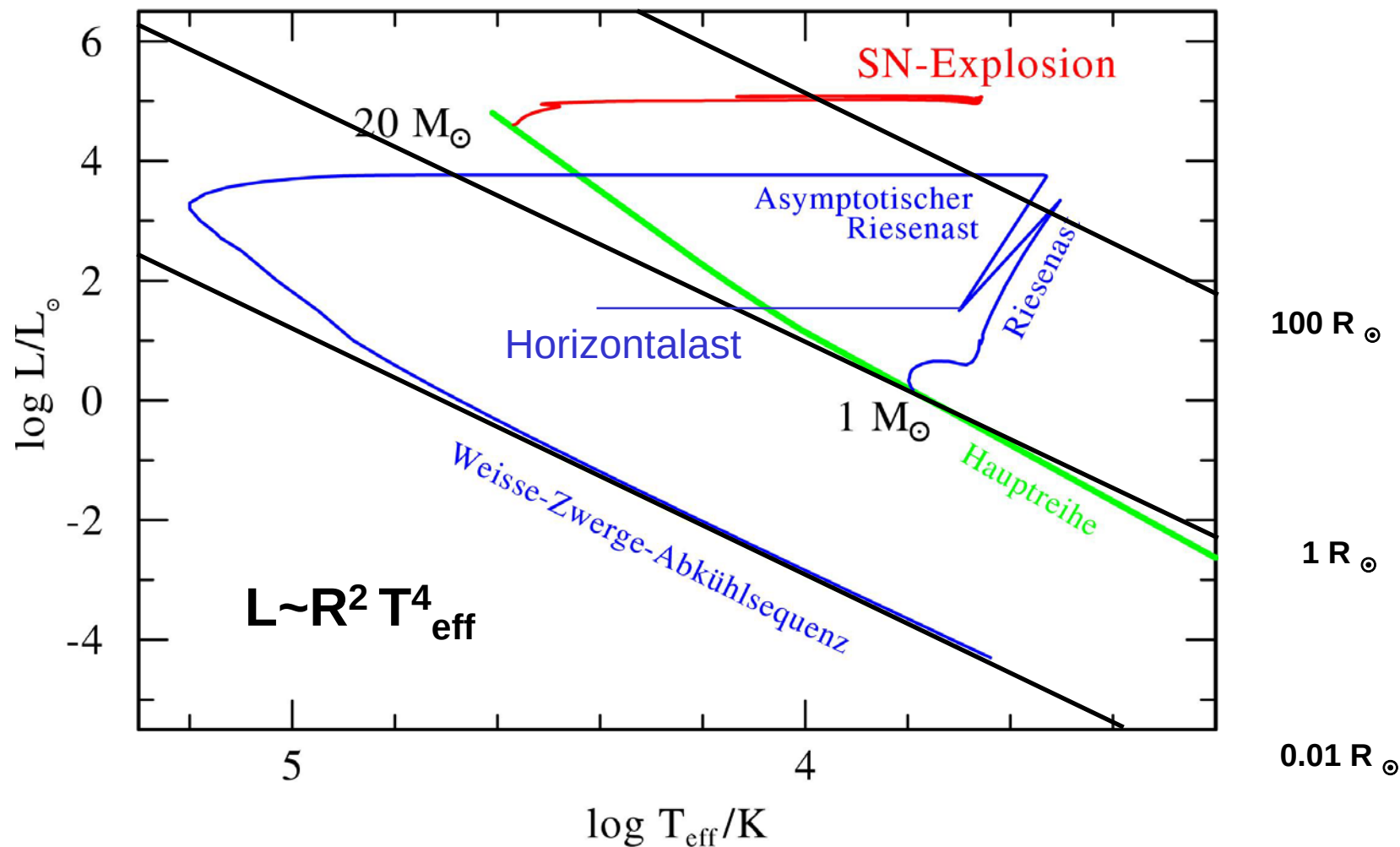
Hubble Space Telescope
Wide Field Planetary Camera 2
November 17, 1995

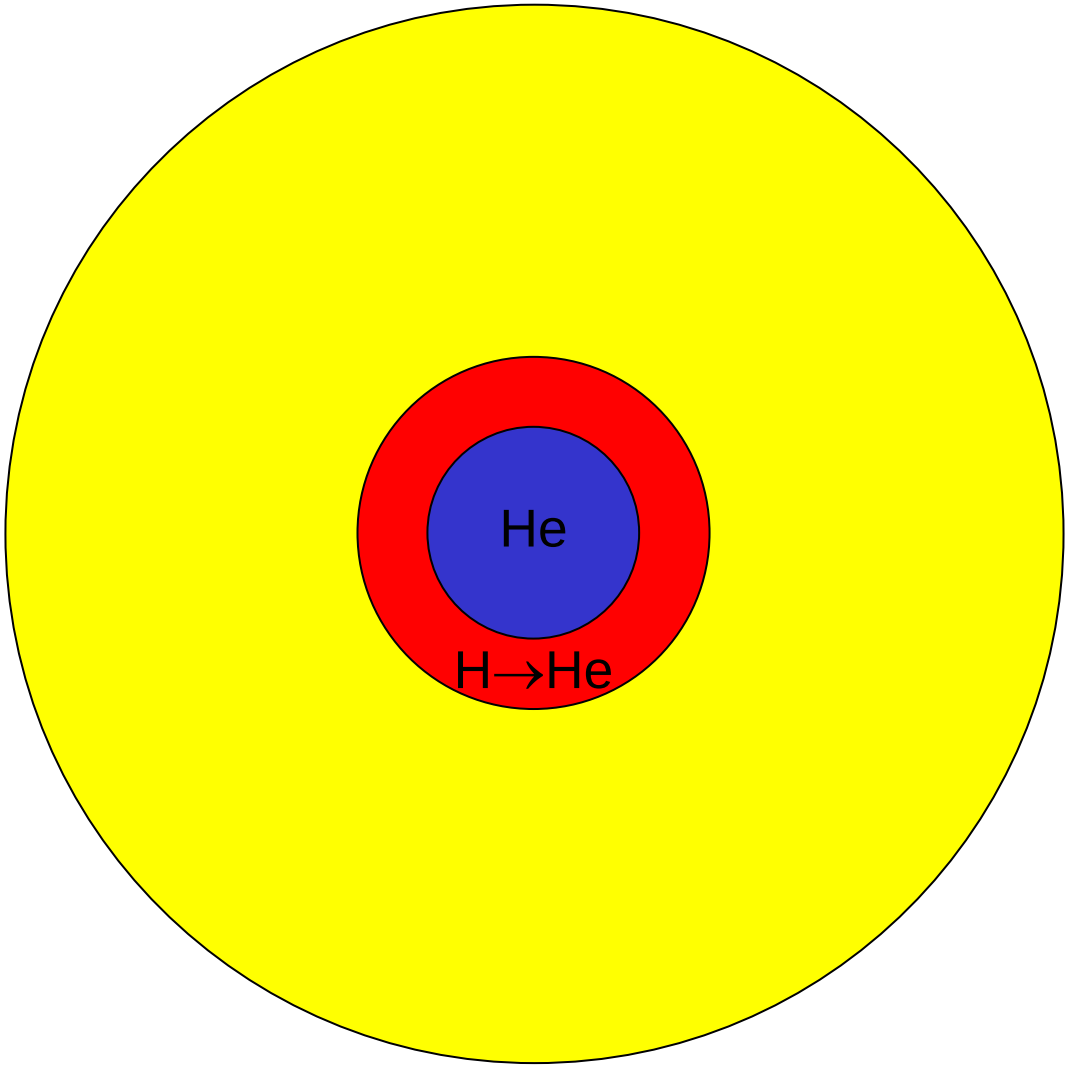
PRC95-48 • ST Sci OPO • November 29, 1995

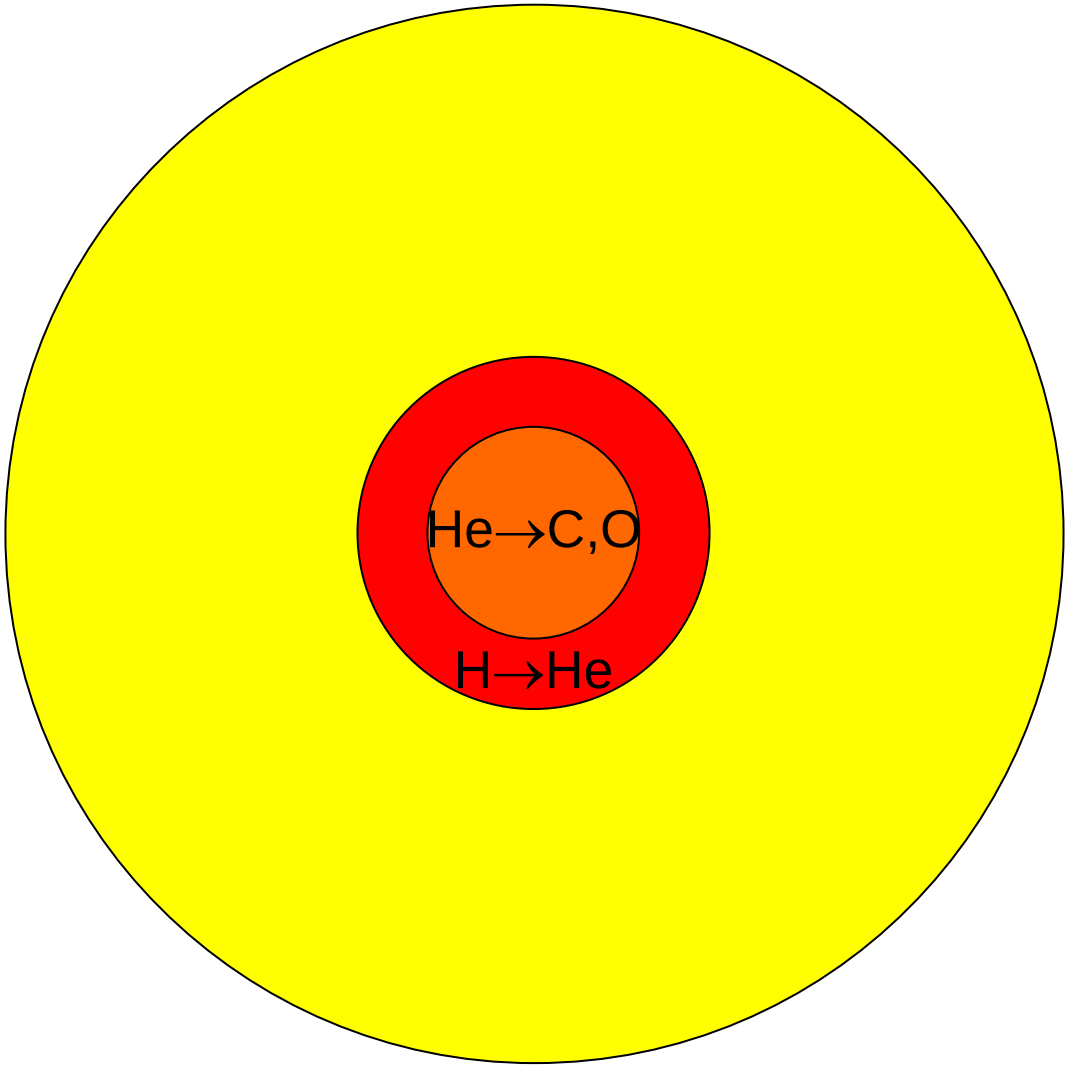
T. Nakajima and S. Kulkarni (CalTech), S. Durrance and D. Golimowski (JHU), NASA

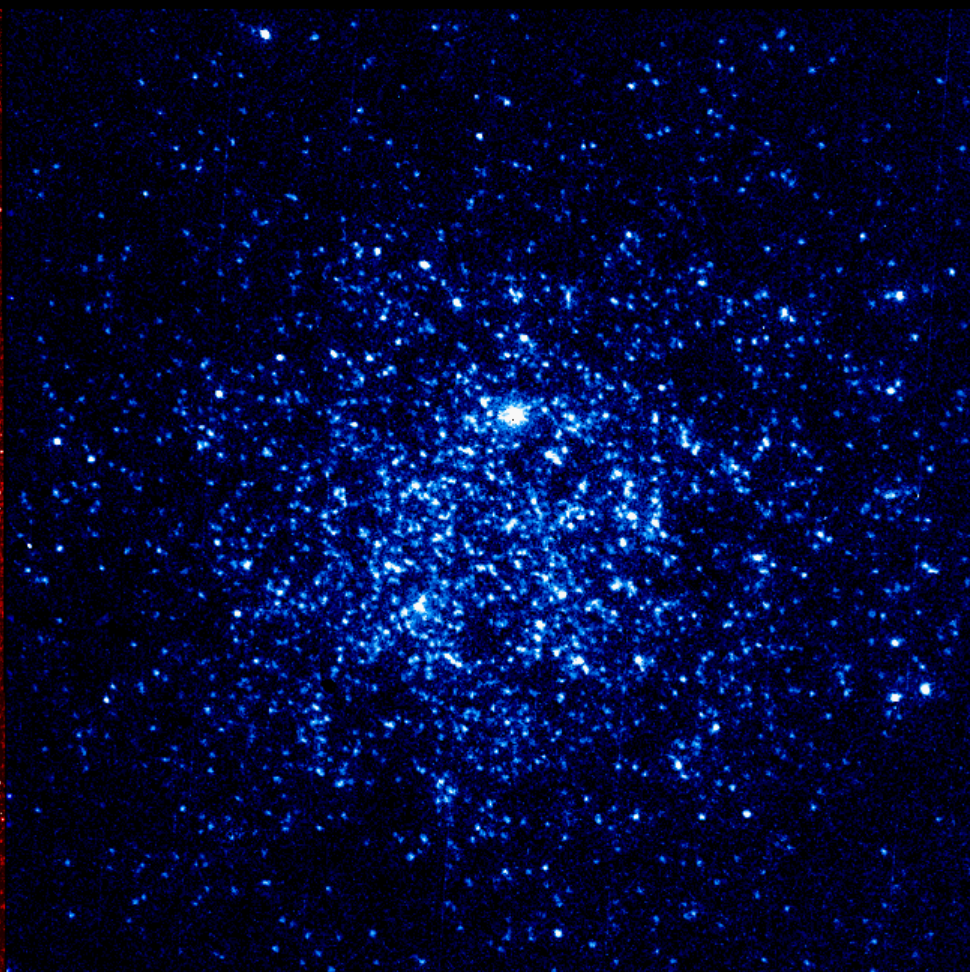
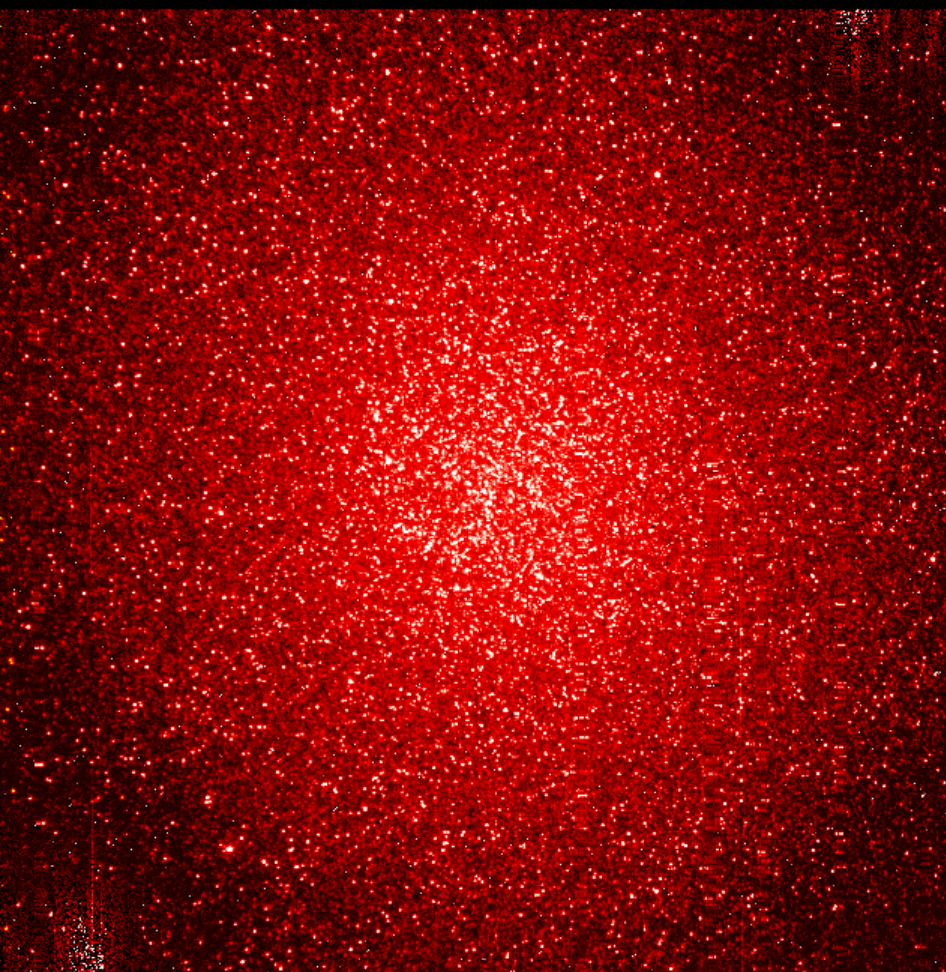


Hertzsprung-Russell-Diagramm



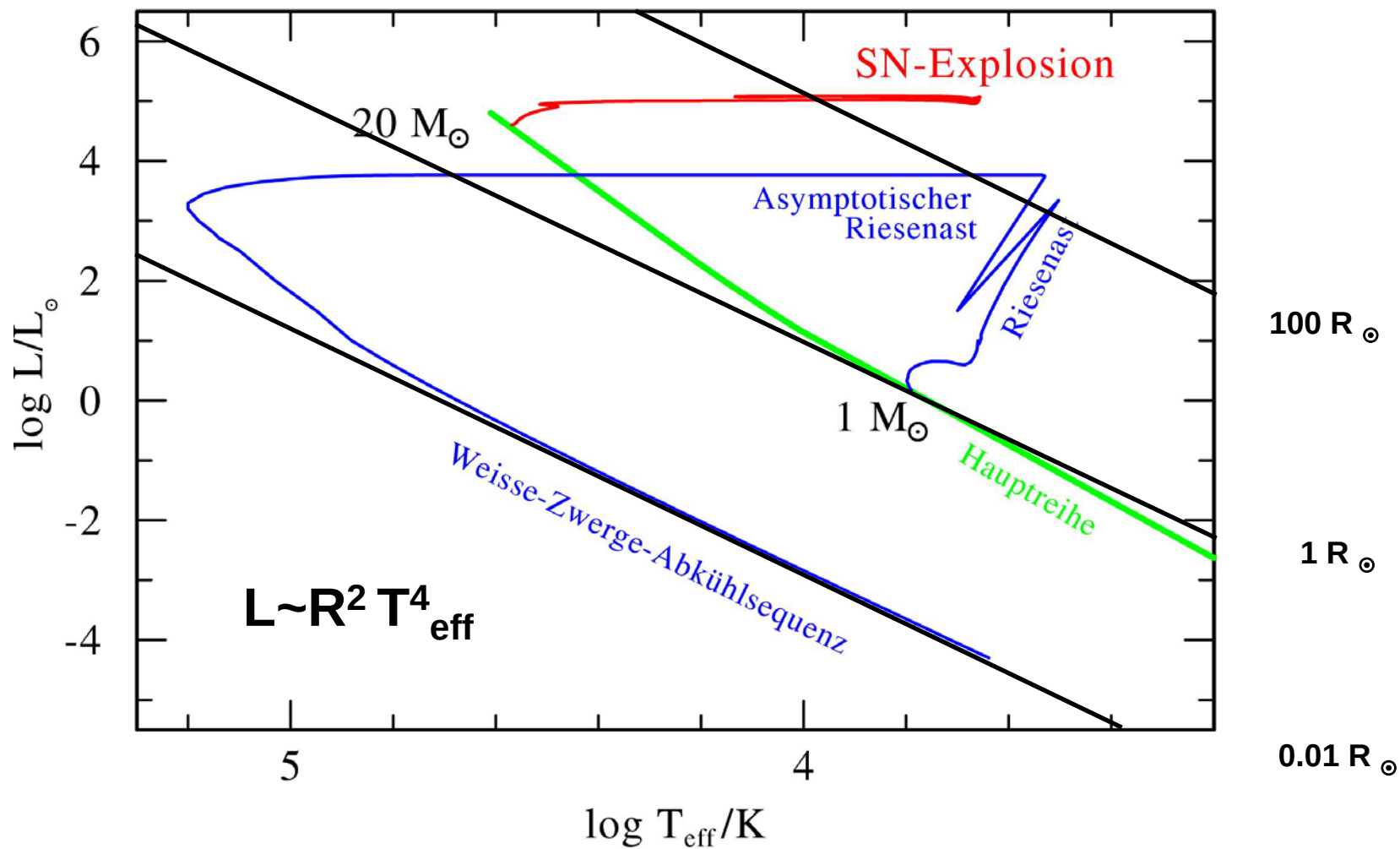


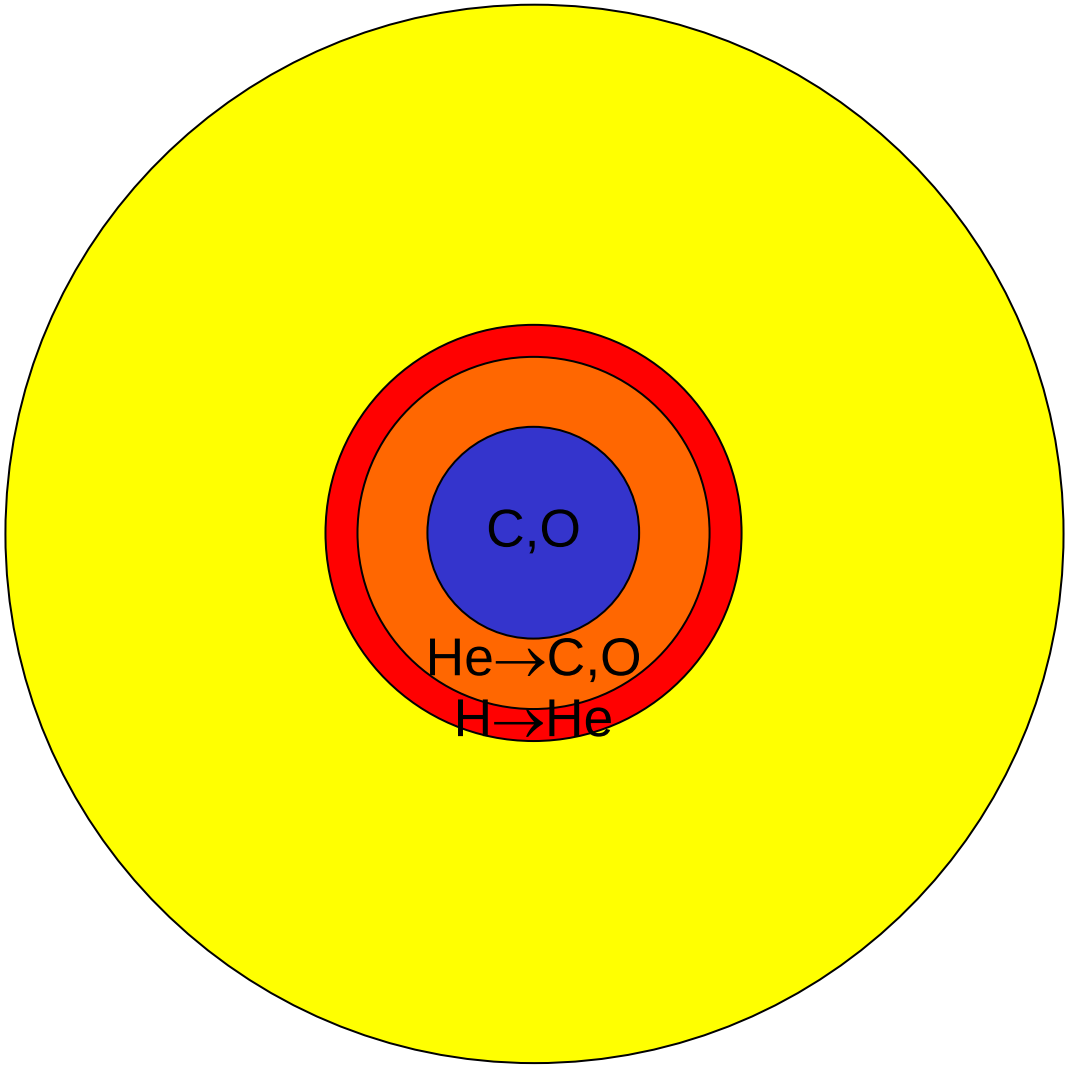


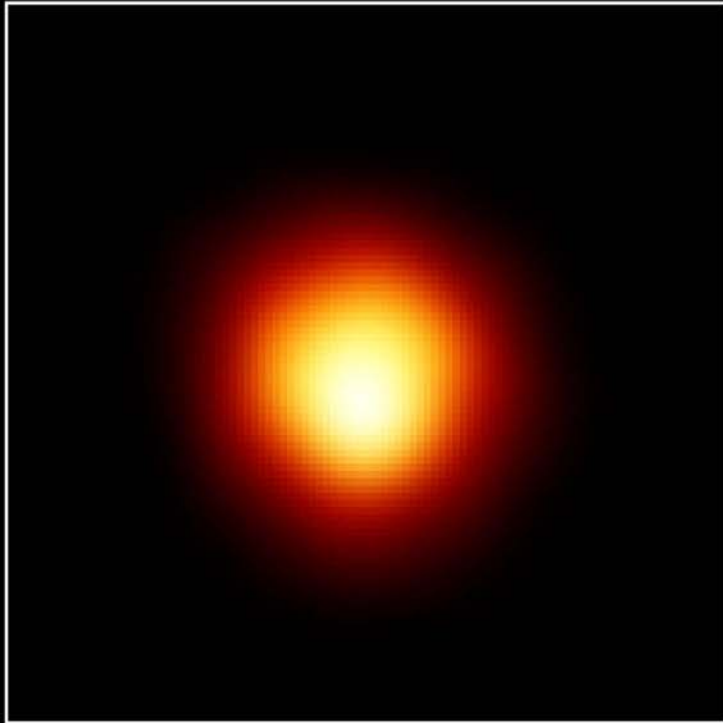




Hertzsprung-Russell-Diagramm







Size of Star



Size of Earth's Orbit



Size of Jupiter's Orbit

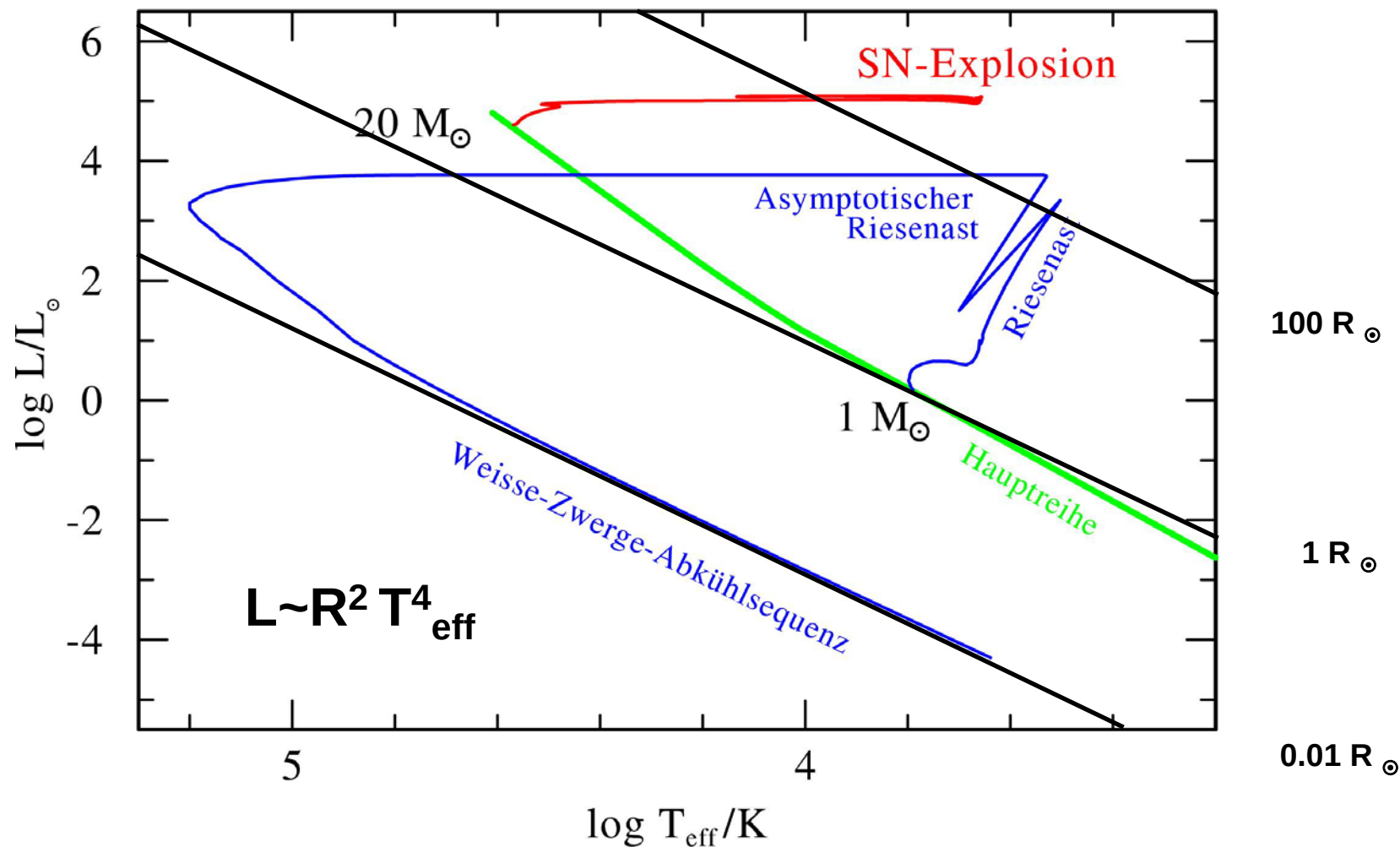


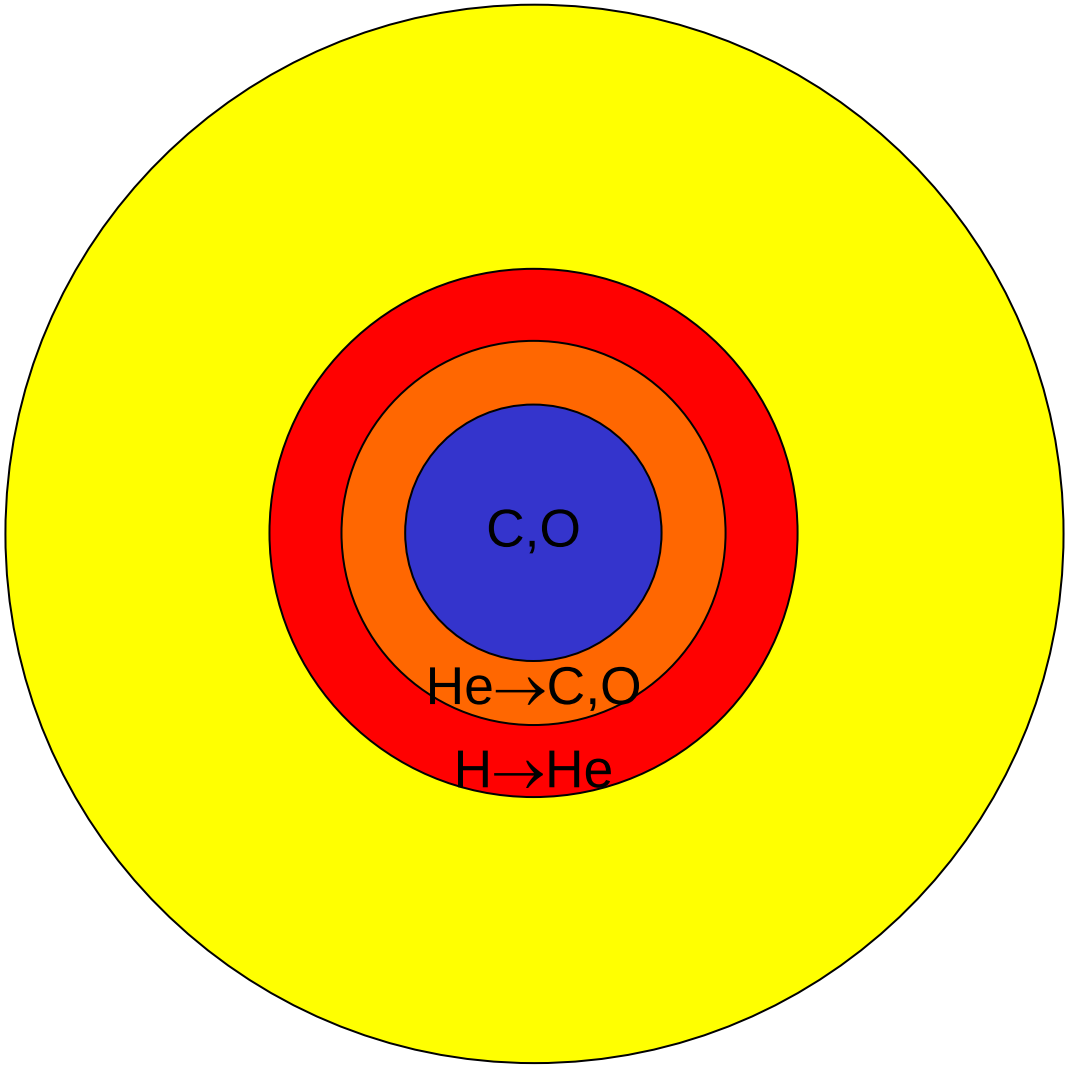
Atmosphere of Betelgeuse · Alpha Orionis

Hubble Space Telescope · Faint Object Camera

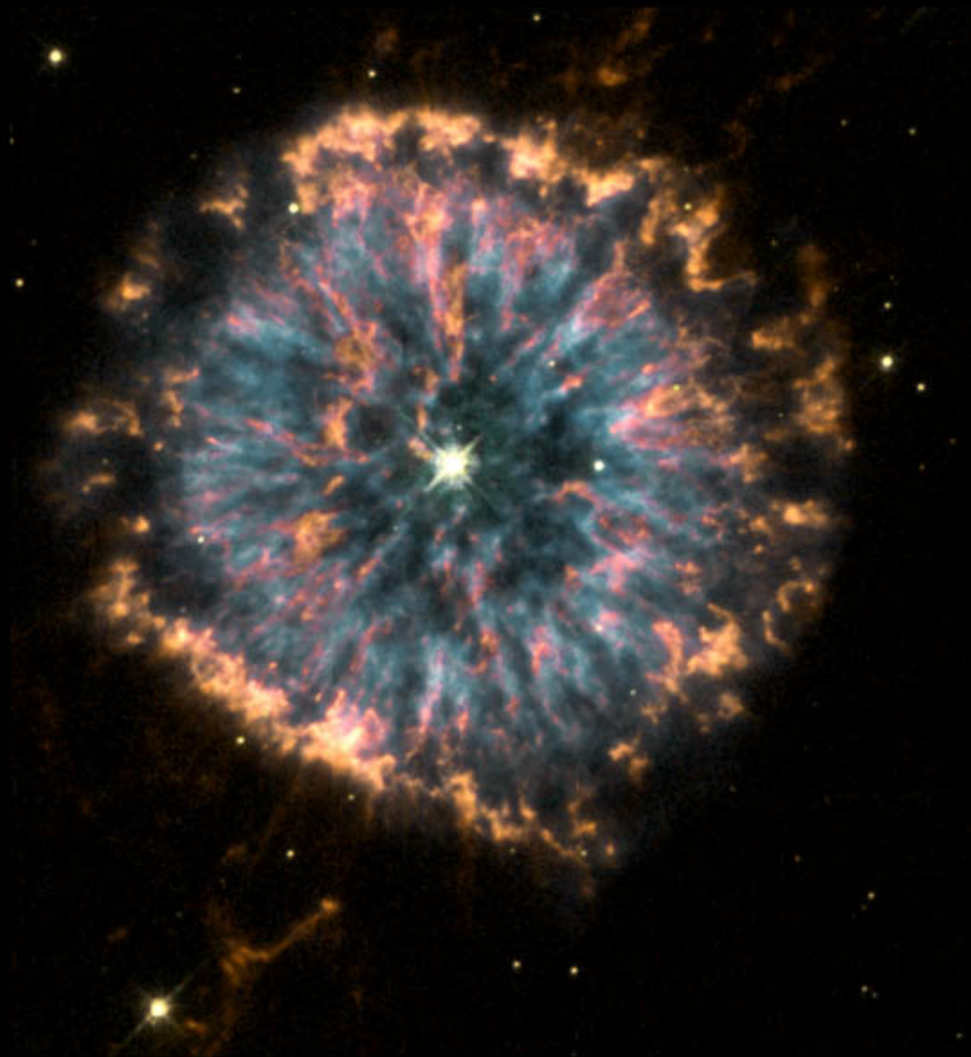


Hertzsprung-Russell-Diagramm





Planetary Nebula NGC 6751



Hubble
Heritage



The Helix Nebula — NGC 7293



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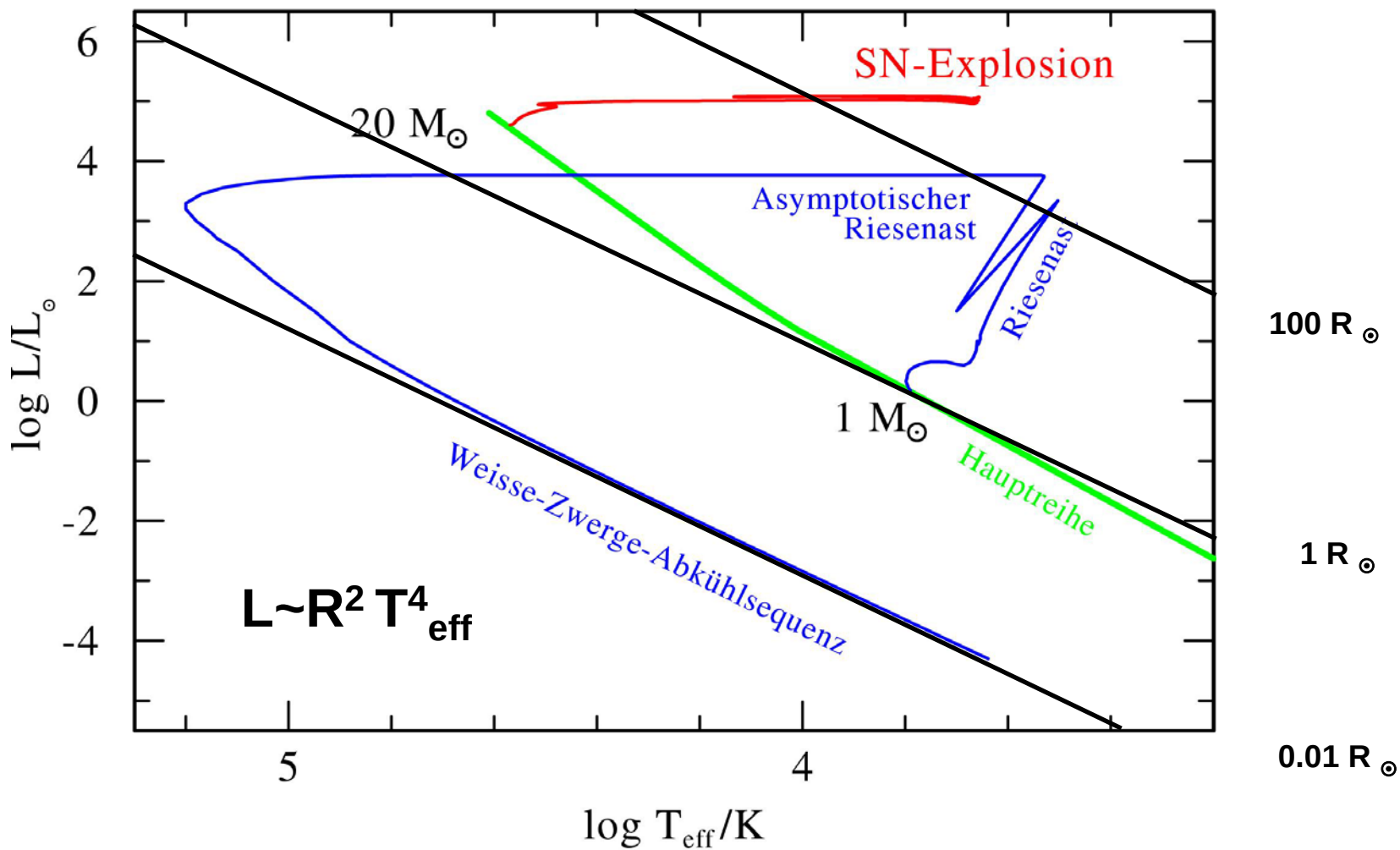
The Cat's Eye Nebula — NGC 6543

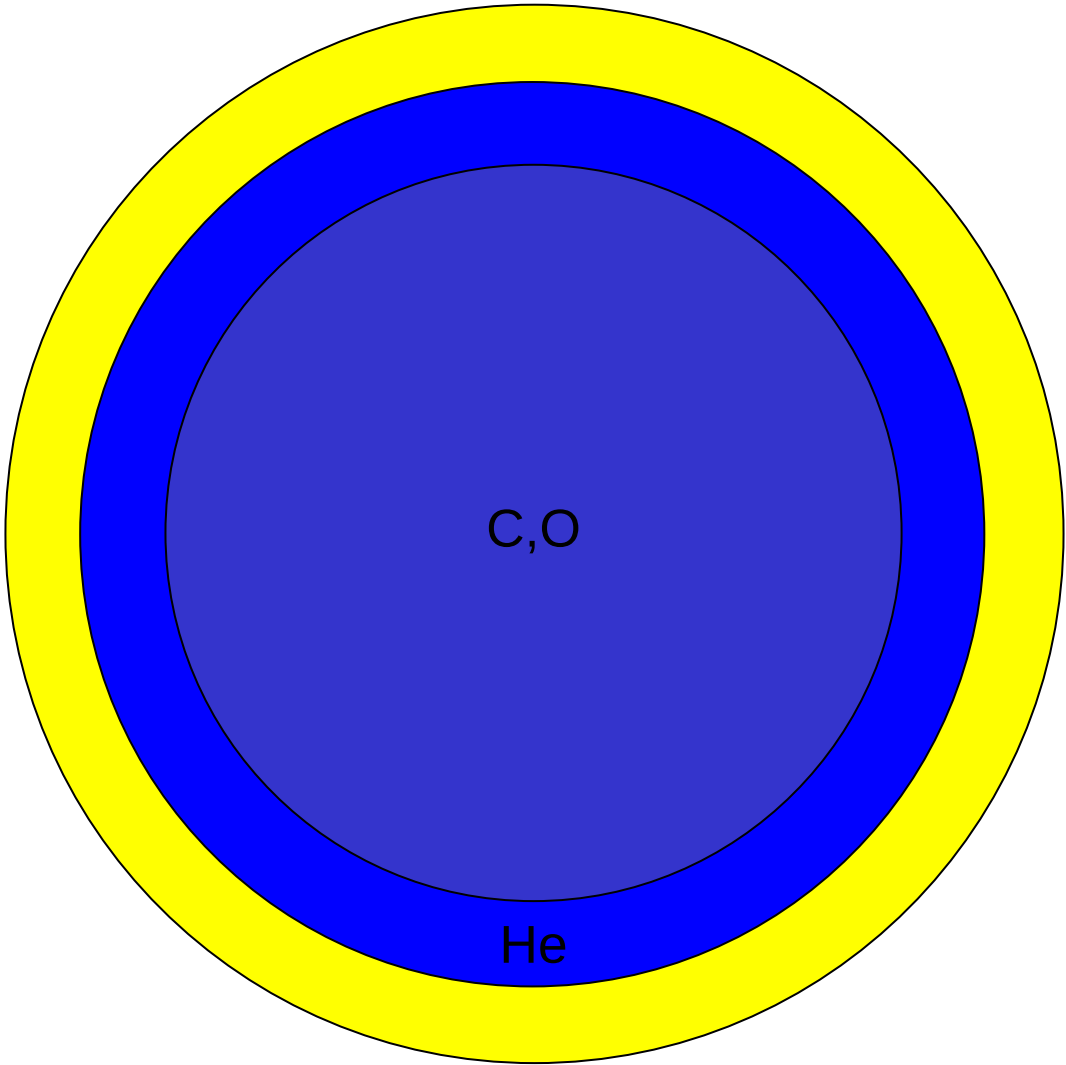


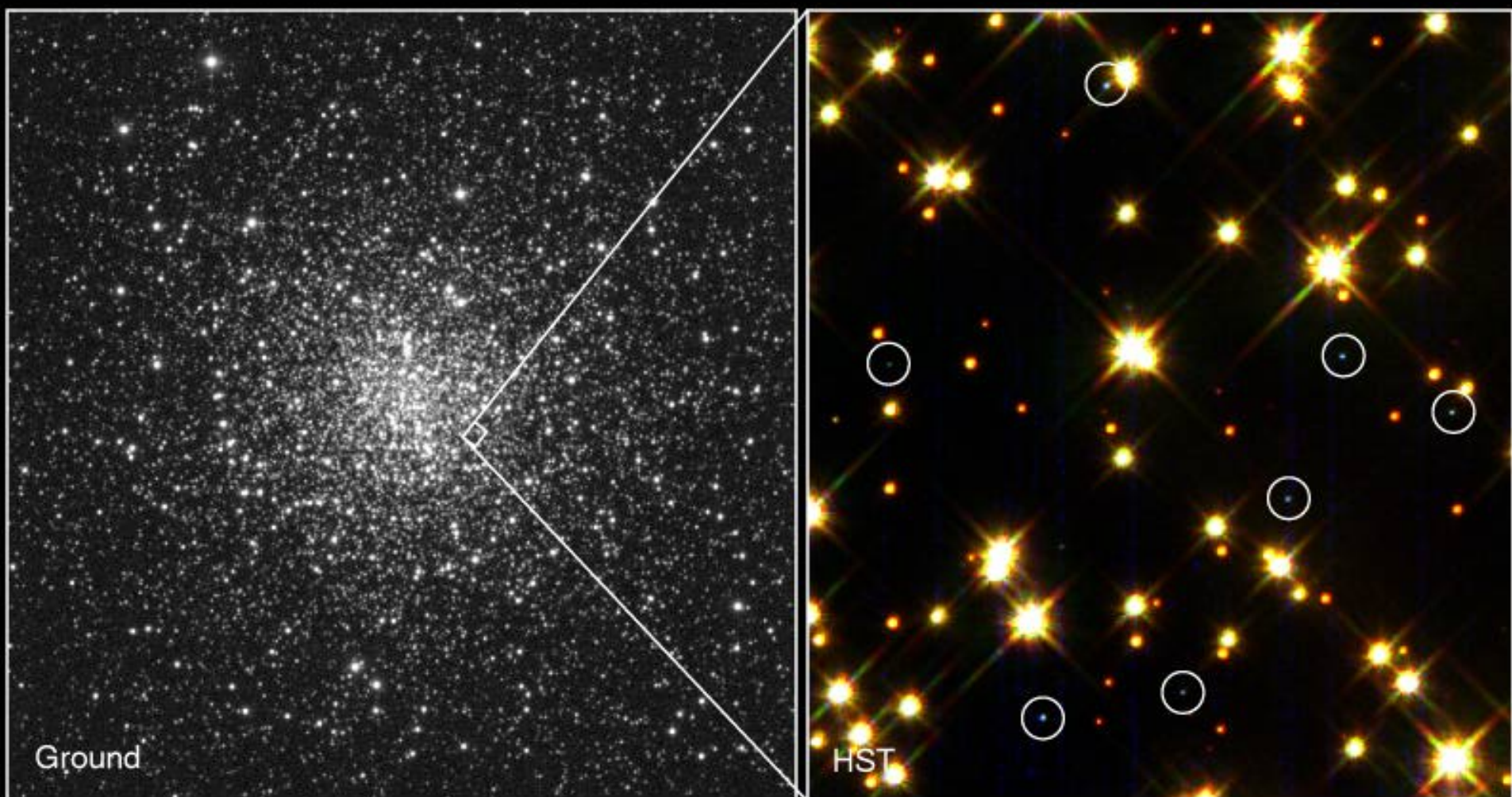
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Hertzsprung-Russell-Diagramm







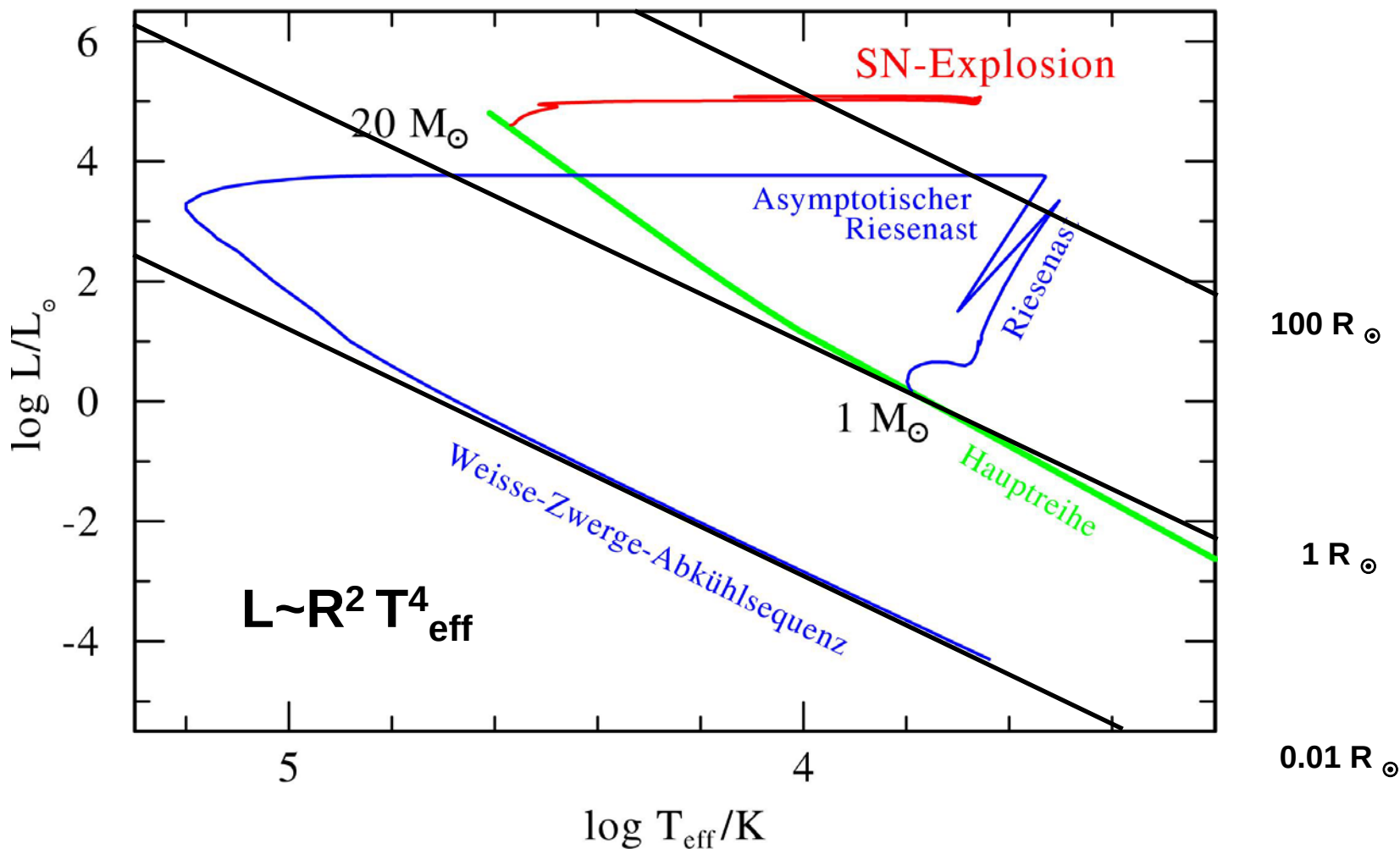
White Dwarf Stars in M4

PRC95-32 · ST ScI OPO · August 28, 1995 · H. Bond (ST ScI), NASA

HST · WFPC2



Hertzsprung-Russell-Diagramm





Eta Carinae

HST · WFPC2

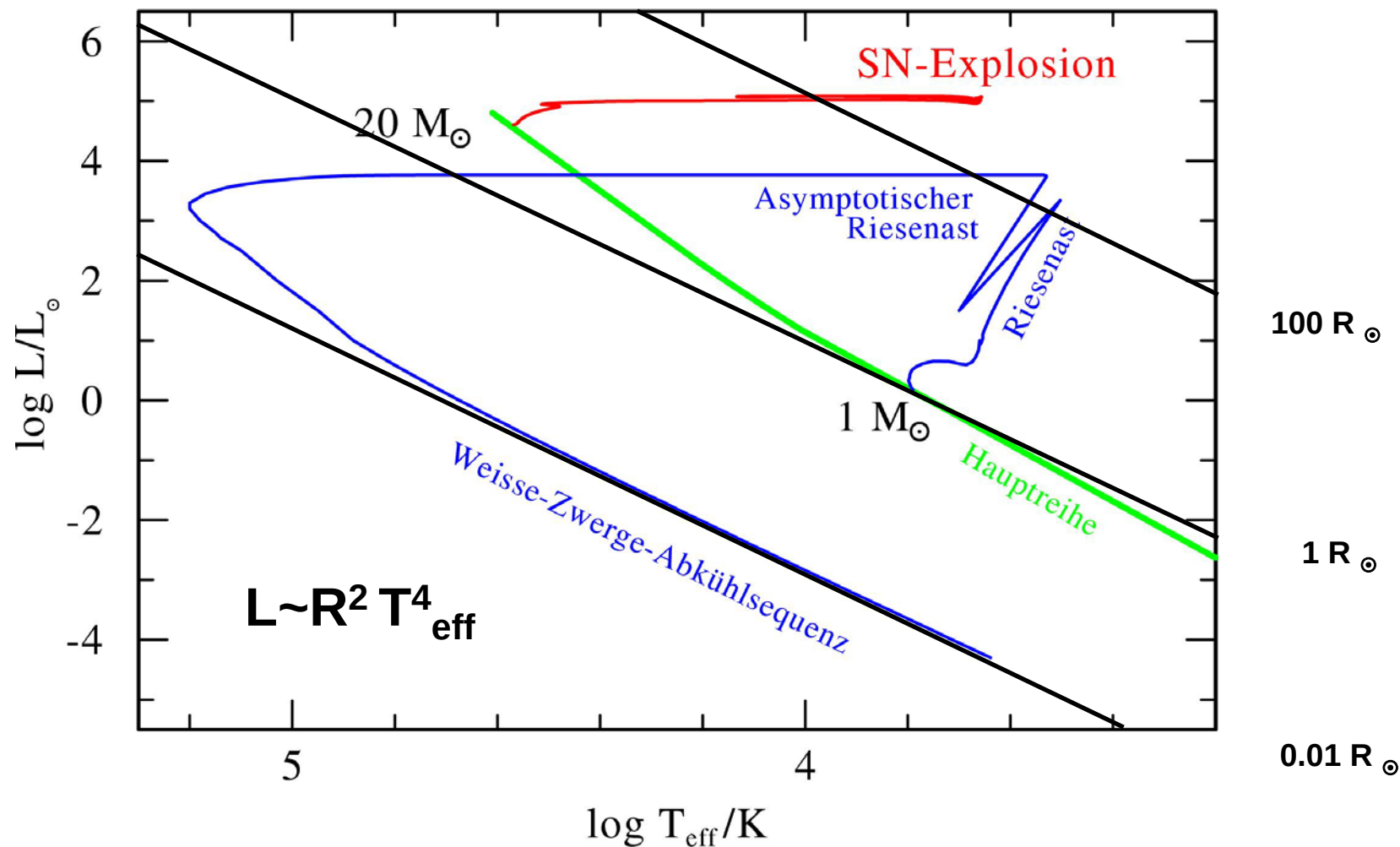
PRC96-23a · ST ScI OPO · June 10, 1996

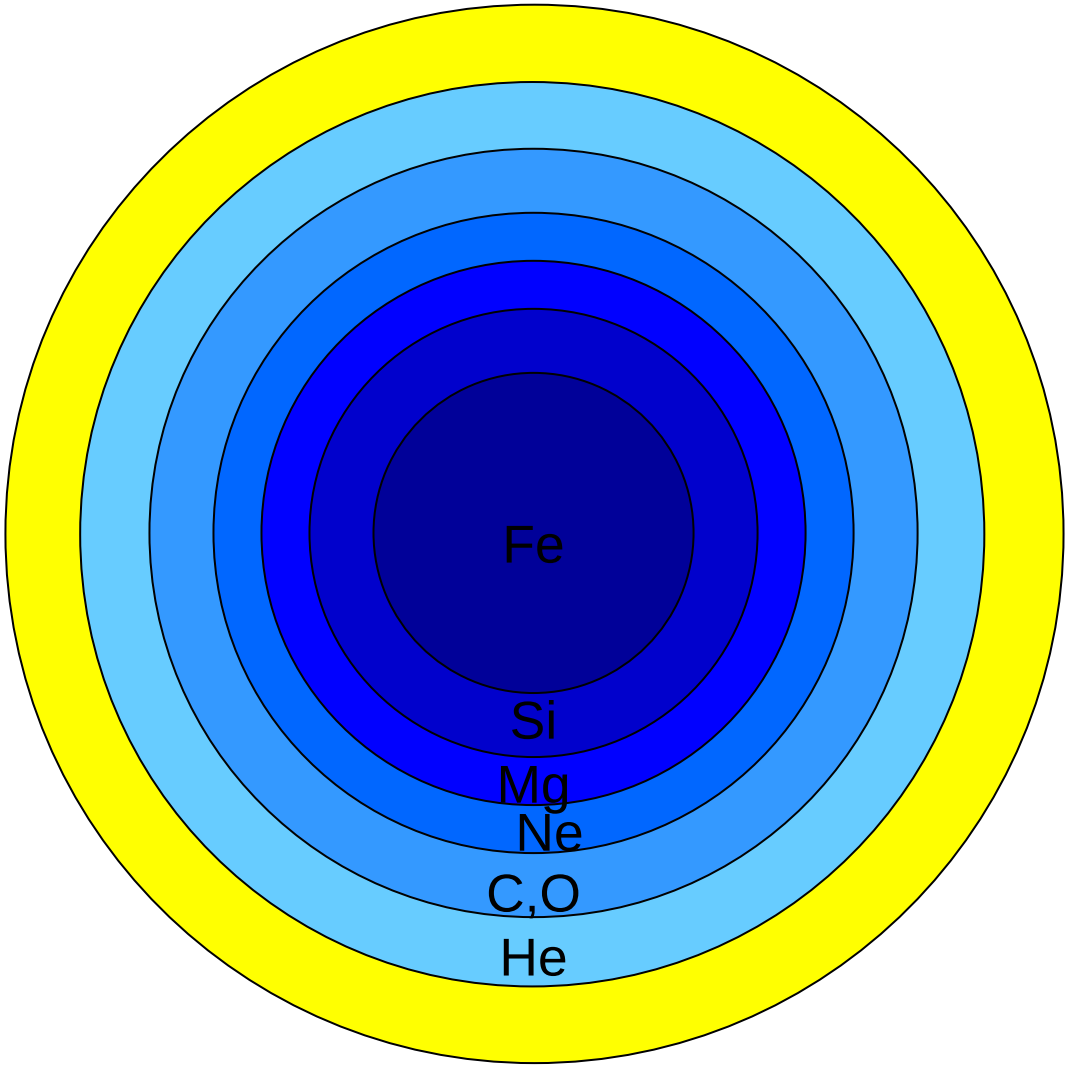
J. Morse (U. CO), K. Davidson, (U. MN), NASA

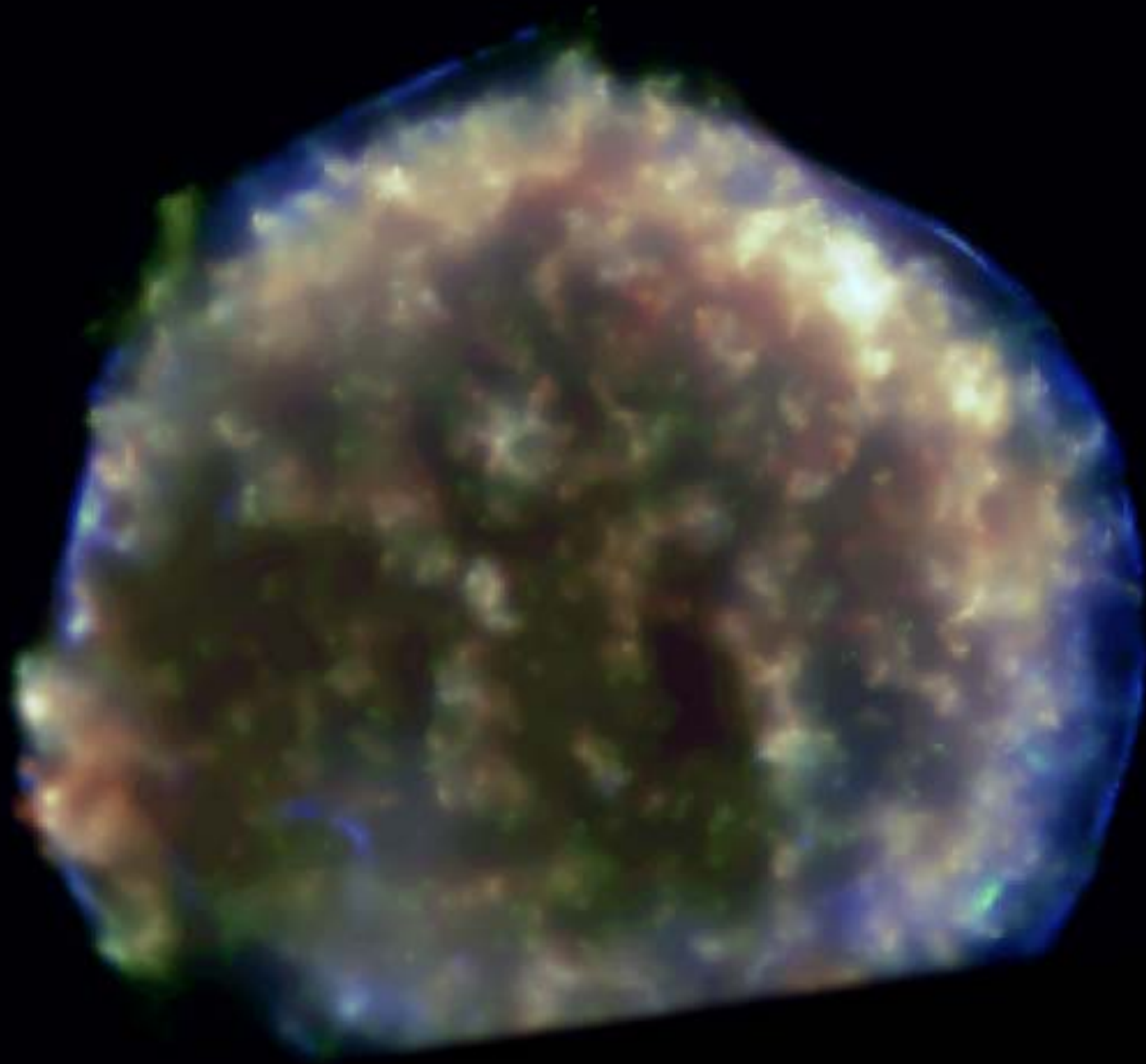
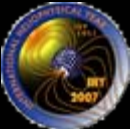


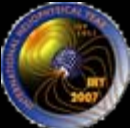


Hertzsprung-Russell-Diagramm

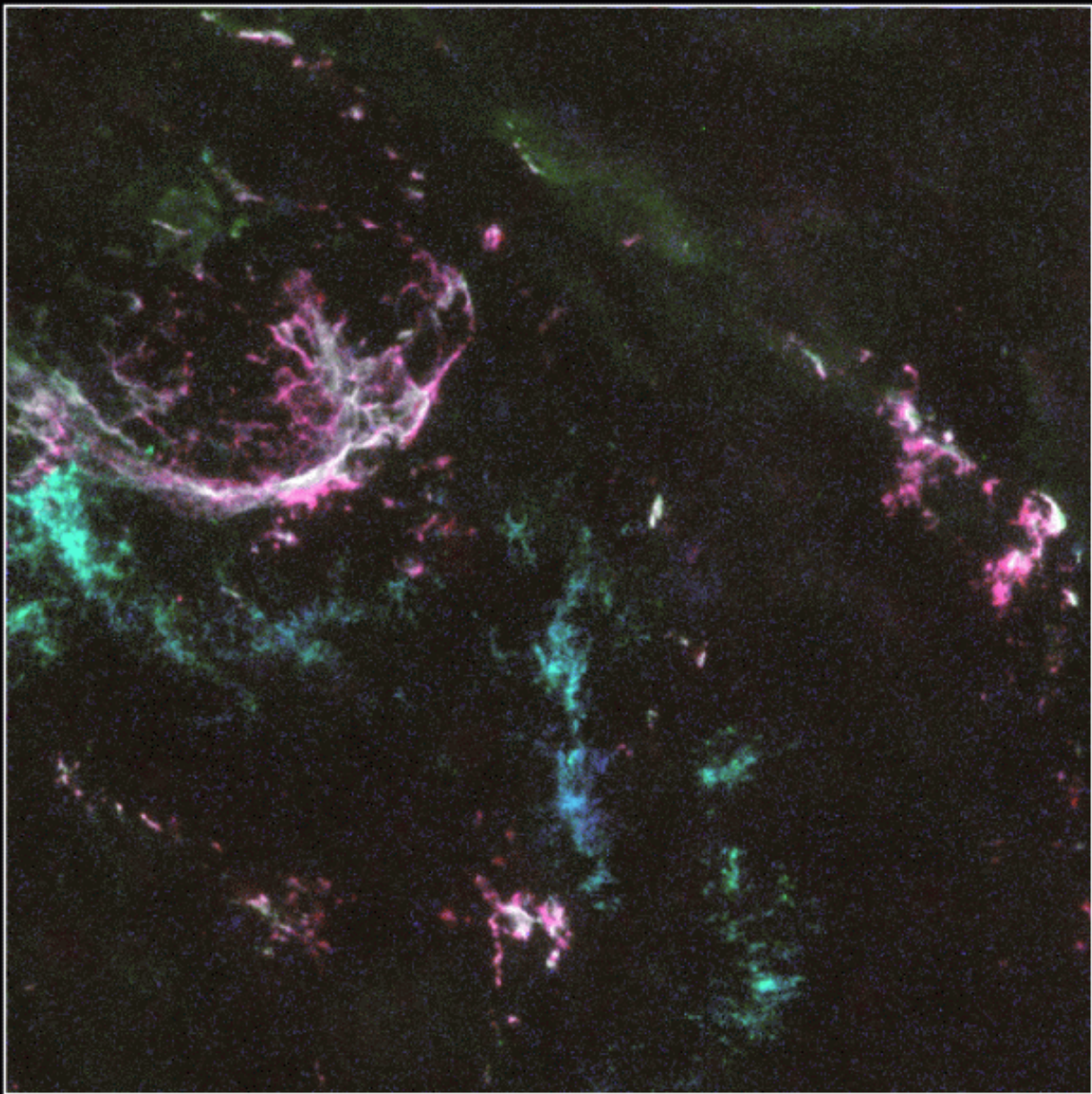
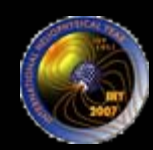












N132D

HST • WFPC2

SN Remnant in LMC

PF95-13 • ST ScI OPO • April 10, 1995 • J. Morse (ST ScI), NASA



Inhalt

Woher wissen wir, dass sich Sterne verändern?

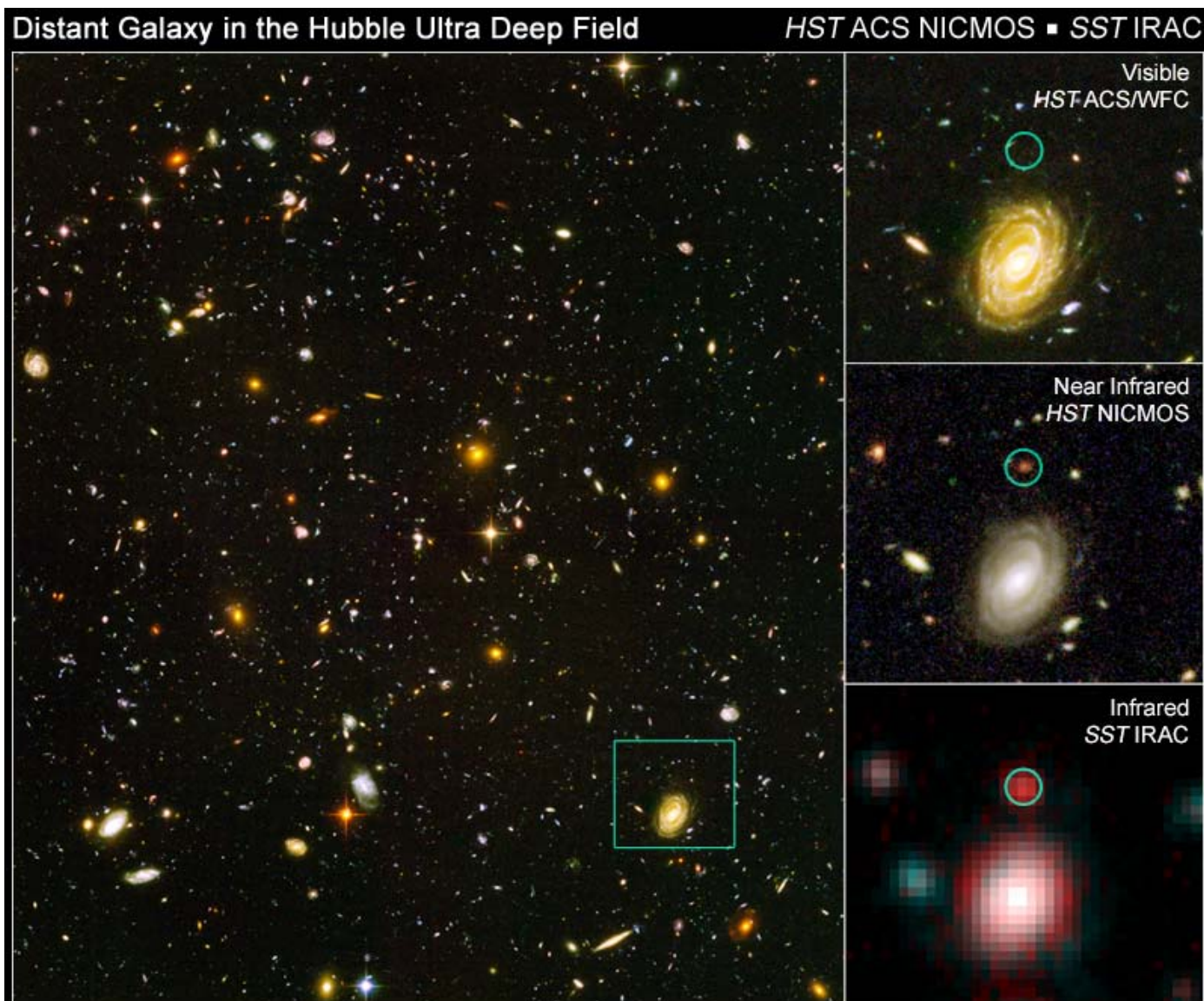
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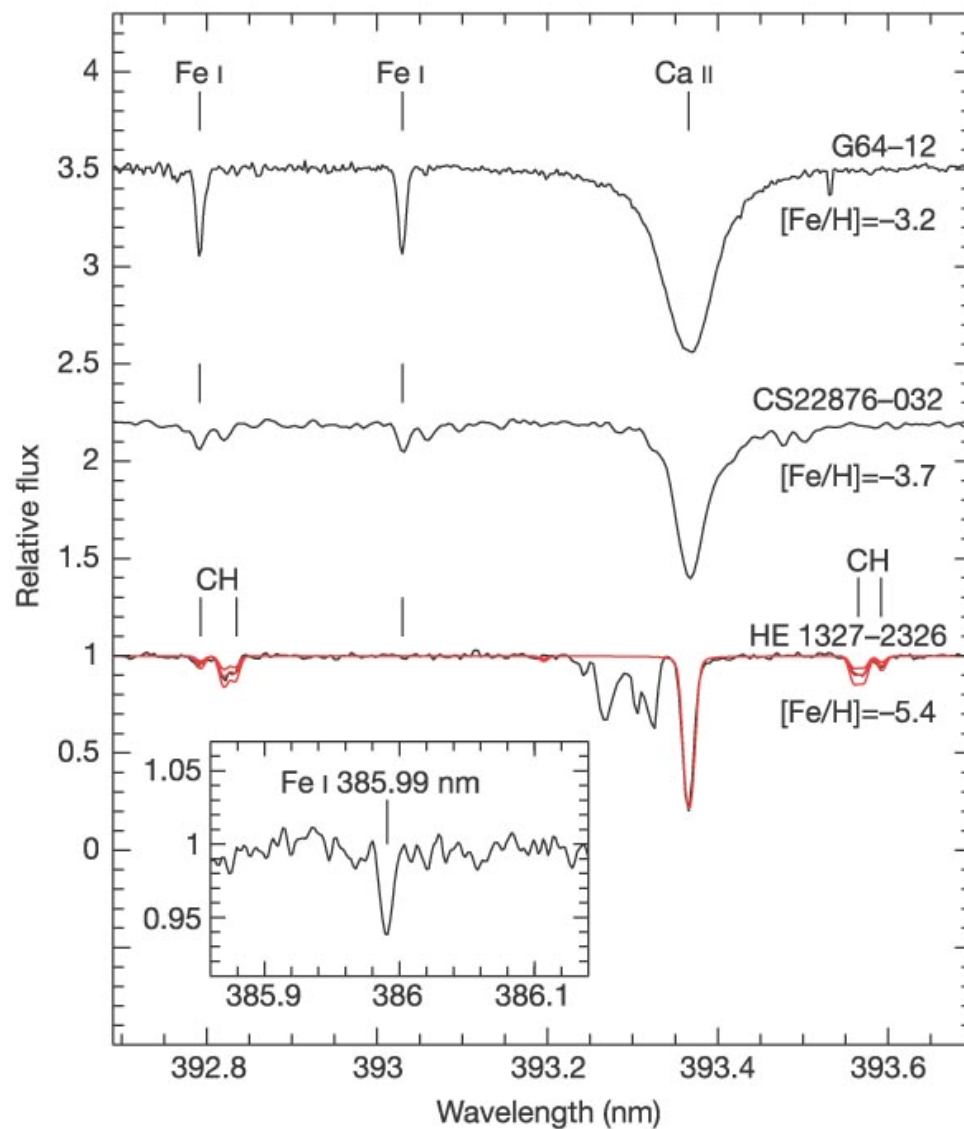
Die Rahmenbedingungen: Erste Galaxien



$t \leq 1\text{G yr}$



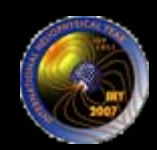
Älteste Sterne



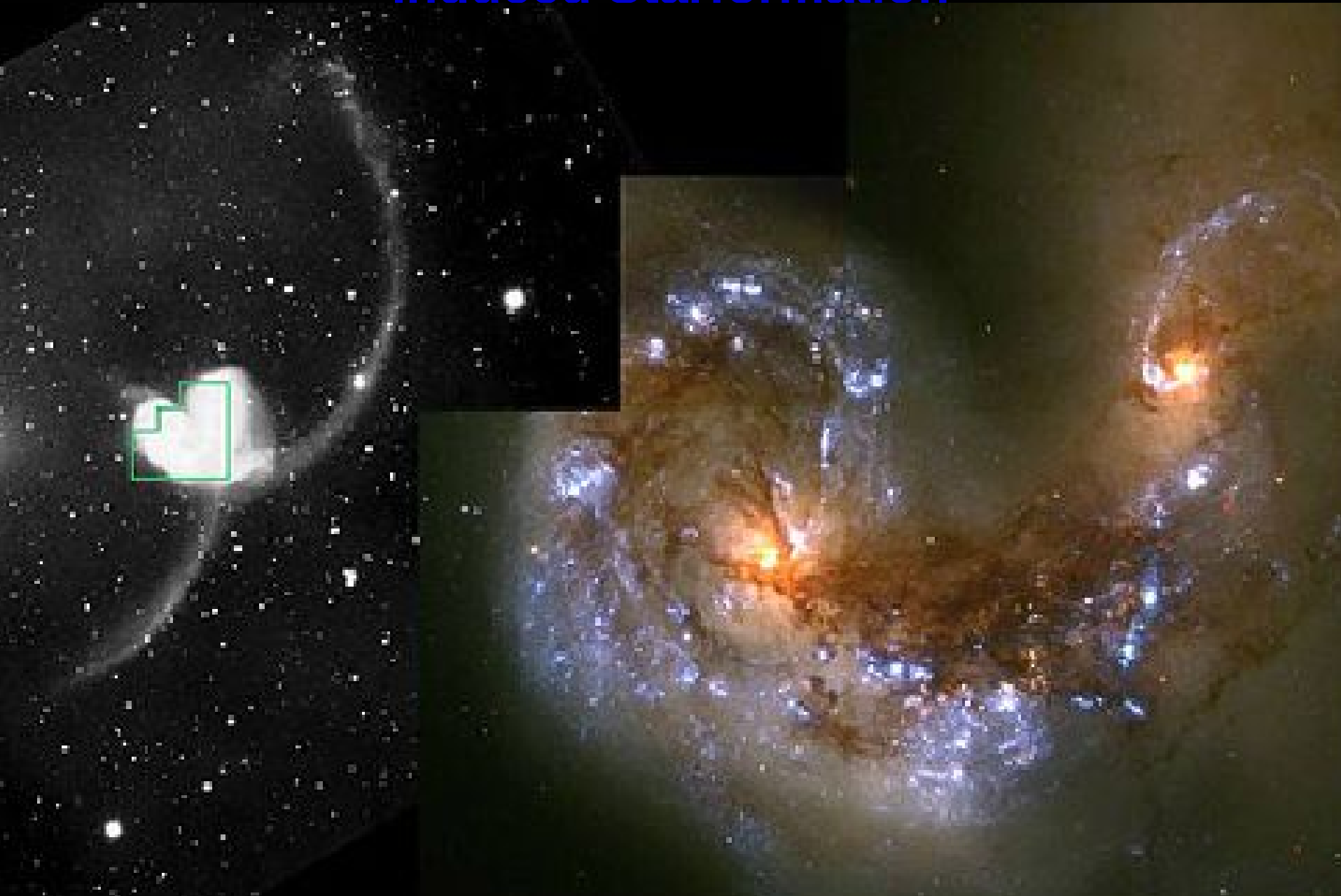
Frebel et al. Nature 2005



$t \leq 1 \text{ G yr}$



Induced Starformation

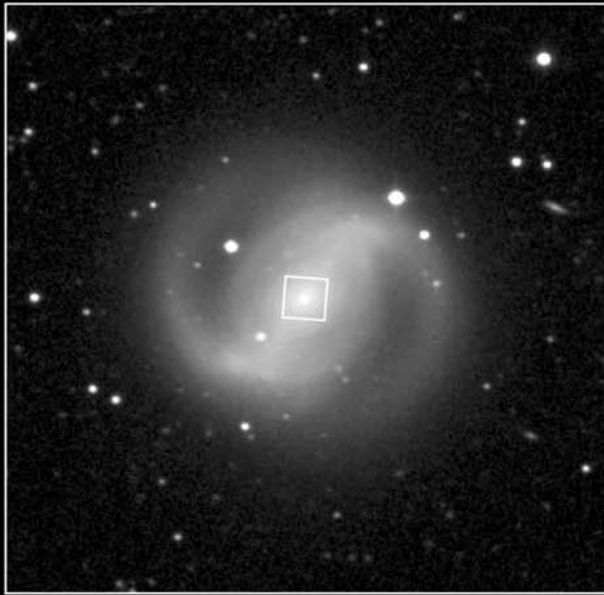




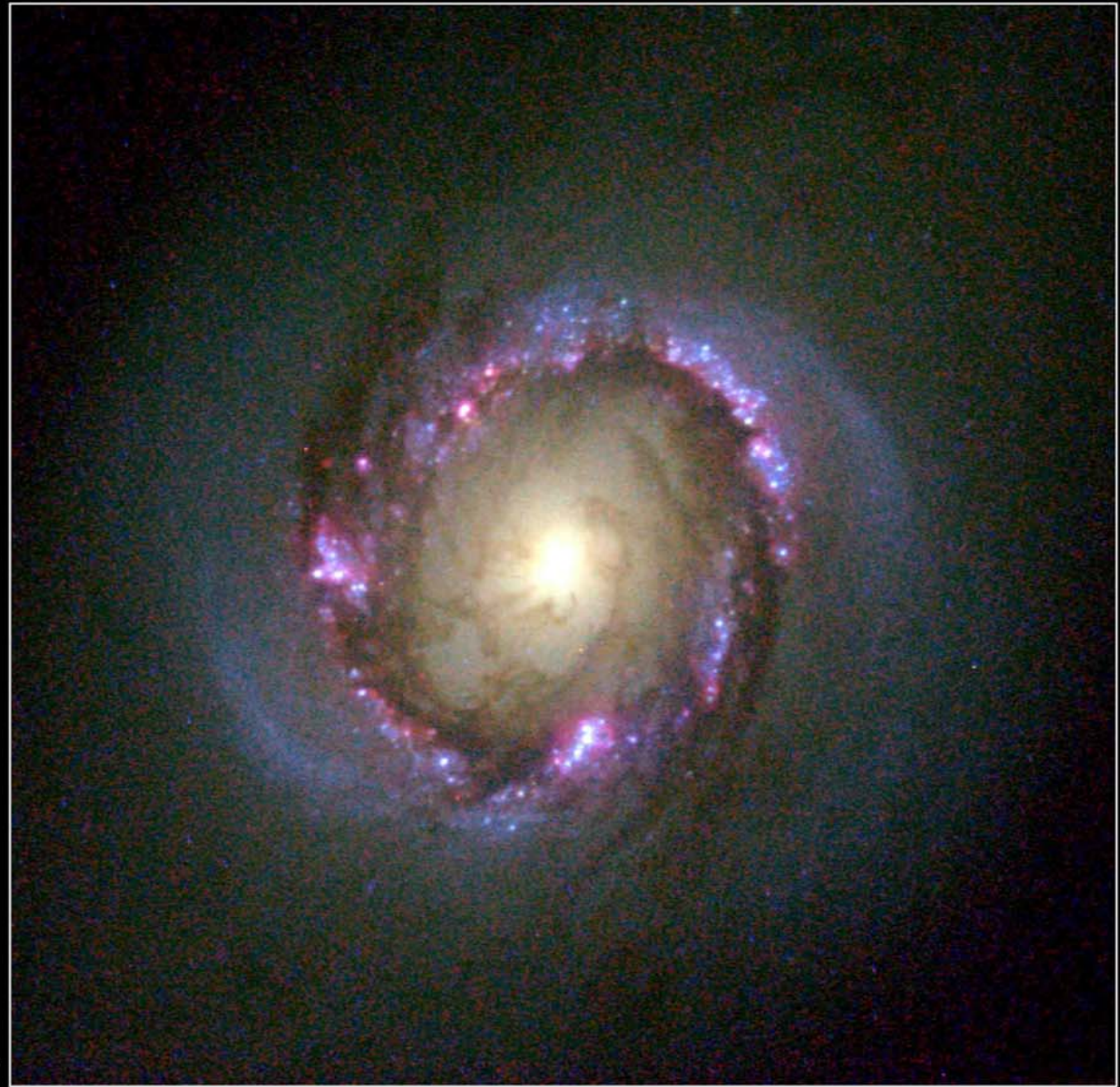
The Tadpole Galaxy — UGC 10214



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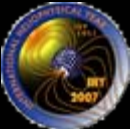


McDonald Observatory



HST

Galaxy NGC 4314 • Nuclear-Ring
Hubble Space Telescope • Wide Field Planetary Camera 2



Ende

