rifid Nebula • M20 **HST** • WFPC

ASA and J. Hester (Arizona State University) • STScI-PRC99-42

Звёзды и их эволюция.

Образуются в результате гравитационной неустойчивости. (Джинс)

сжатие $W_{tot} < 0$.

$$W_t = \frac{A}{\mu}\bar{\rho}\,T\,\frac{4}{3}\pi R^3, \quad A = 8.3\cdot 10^7 \,\frac{\text{эрг}}{(\text{моль}\times\text{град}}$$

μ – молярный вес

$$W_g \simeq -\frac{GM^2}{R} \simeq G\rho^2\cdot 16 R^5 \Rightarrow R > \lambda_Д$$

$$\lambda_Д \simeq \frac{0.2}{T}\cdot\frac{M}{M_\odot},\ \text{пс}$$

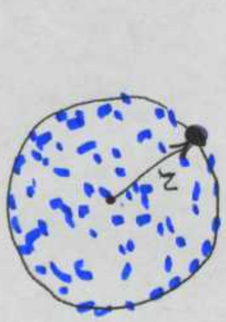
Характерные величины для Солнца

$R_\odot = 7\cdot 10^{10}$ см, $M_\odot = 2\cdot 10^{33}$ г, $L_\odot = 4\cdot 10^{33}$ эрг/с

- Звезда – газовый шар, находящийся в гидродинамическом и тепловом равновесии.

$$F_{грав} > P_{газа} \Rightarrow g = \frac{GM}{R^2}, \quad R = \frac{gt^2}{2} \Rightarrow$$

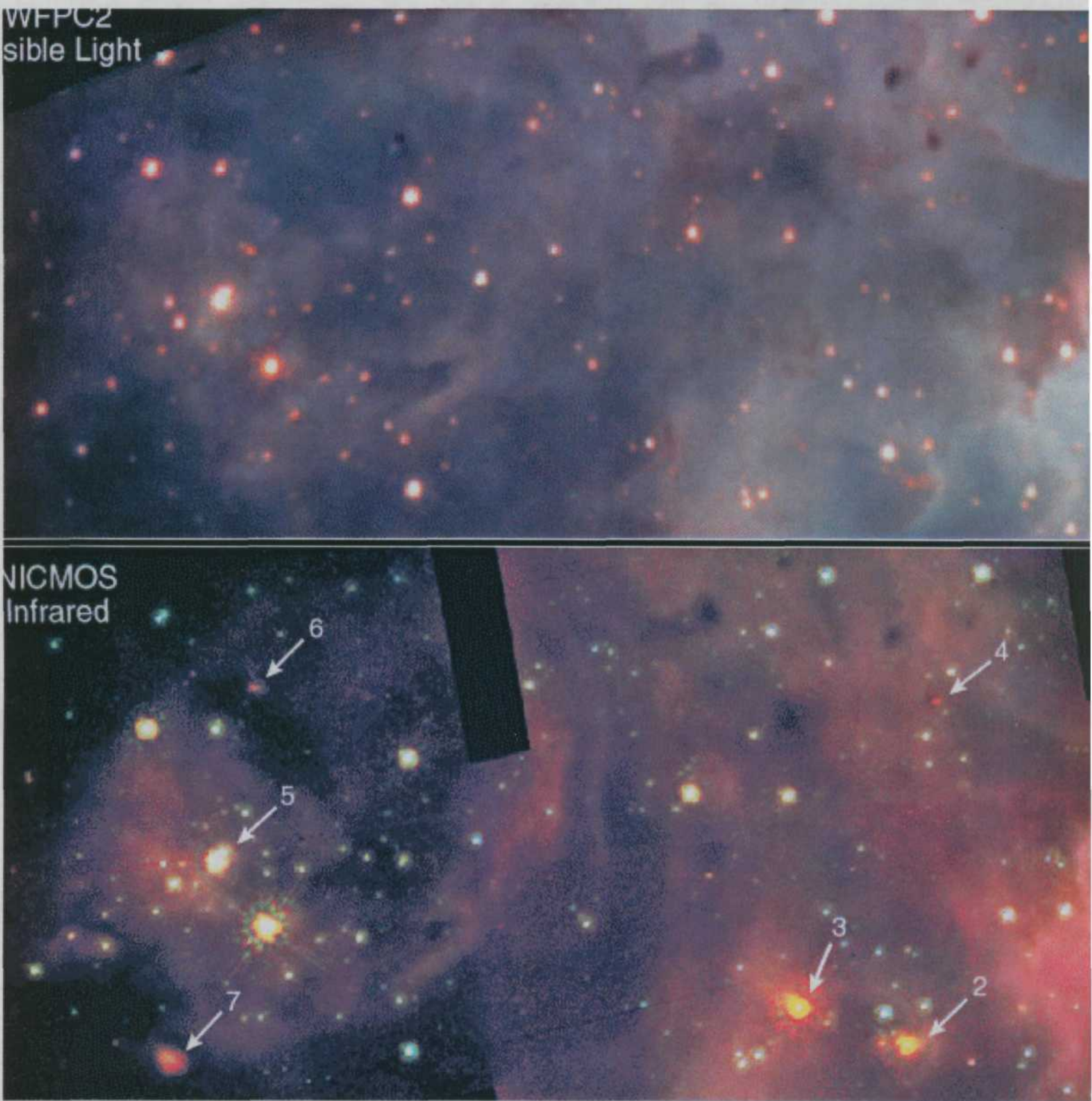
$$t_{гидр} \sim \left(\frac{R}{g}\right)^{1/2} = \left(\frac{R^3}{GM}\right)^{1/2} = \sqrt{\frac{7^2\cdot 10^{30}}{7\cdot 10^{-8}\cdot 2\cdot 10^{33}}} \simeq 10^3\,\text{с} \ !$$



в стационарном состоянии:

$$-\frac{dP}{dr} = \frac{G\cdot M(r)\cdot\rho}{r^2}$$

для простоты: $\rho = \bar{\rho}$, $P = \bar{P}$.

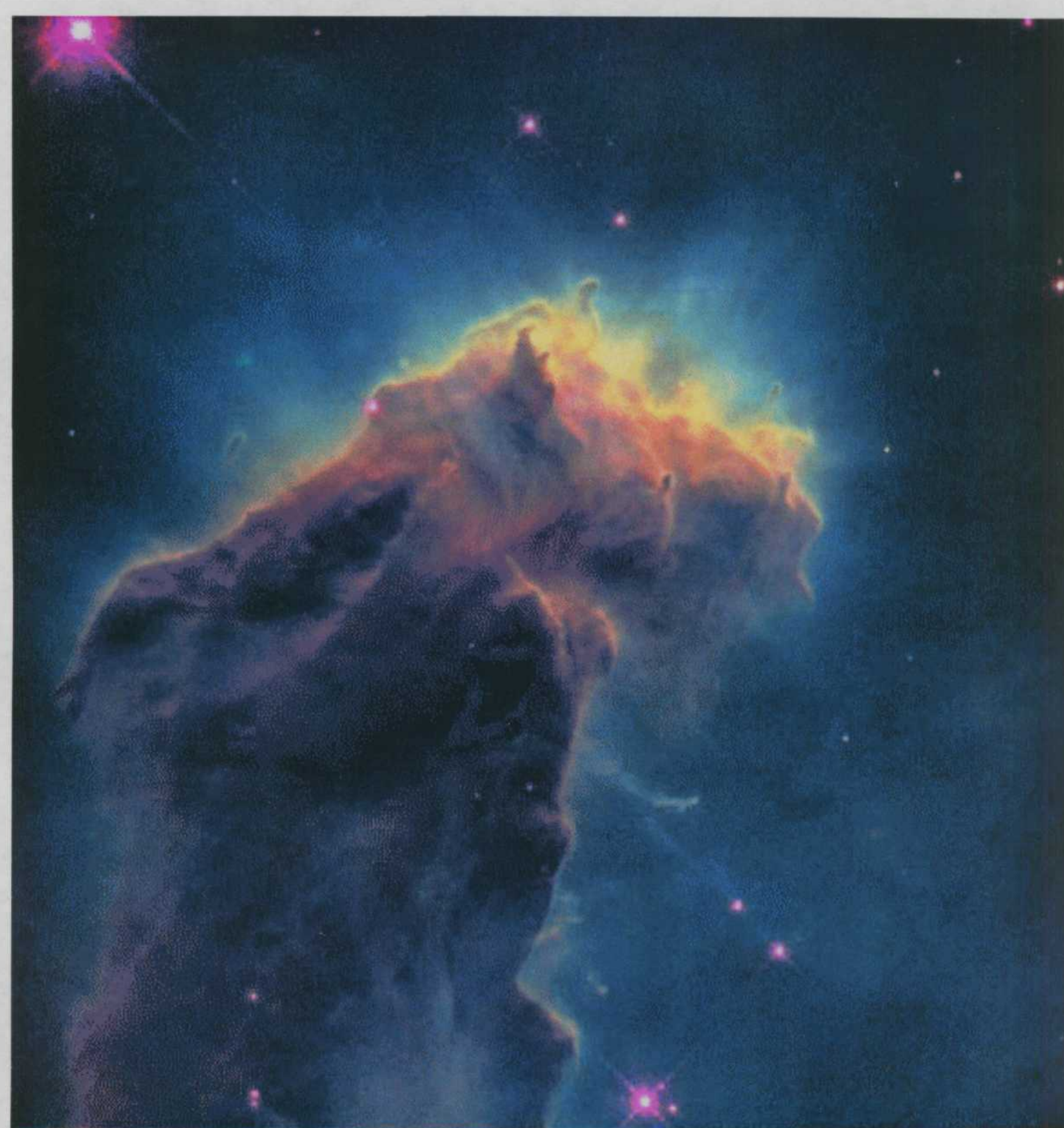


Doradus Nebula Details **HST • W**

RC99-33b • STScI OPO • N. Walborn (STScI), R. Barbá (La Plata Observatory) a

aseous Pillars · M16 HST · WFP

C95-44a · ST ScI OPO · November 2, 1995
Hester and P. Scowen (AZ State Univ.), NASA



tar-Birth Clouds · M16 HST · WFP

C95-44b · ST ScI OPO · November 2, 1995

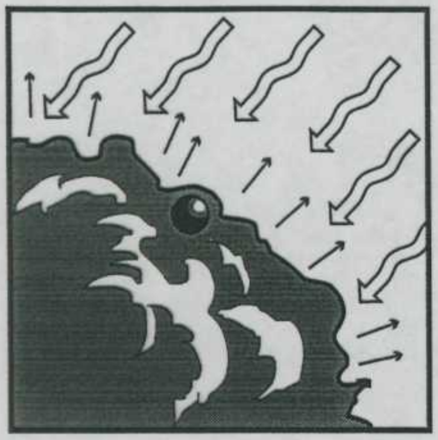
Hester and P. Scowen (AZ State Univ.), NASA

vaporating Globules · M16 HST · WFP

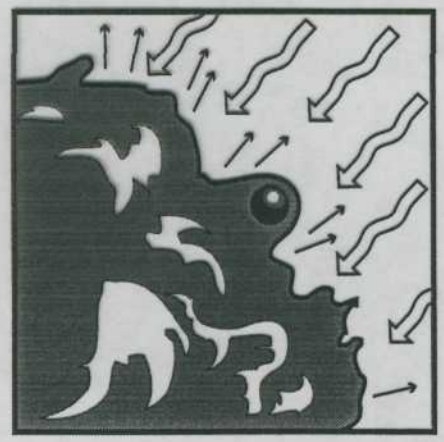
C95-44c · ST ScI OPO · November 2, 1995

Hester and P. Scowen (AZ State Univ.), NASA

Stellar EGGs in M16

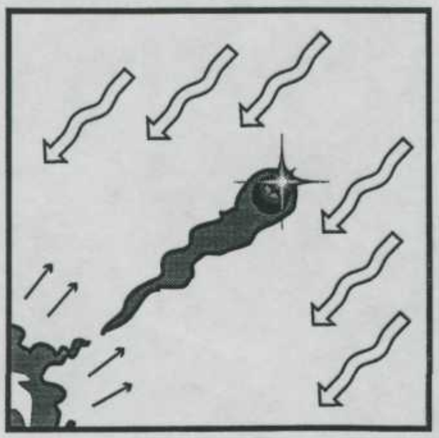


The surface of a molecular cloud is illuminated by intense ultraviolet radiation from nearby hot stars. The radiation evaporates material off of the surface of the cloud.



As the cloud is slowly eaten away by the ultraviolet radiation, a denser than average globule of gas begins to be uncovered

The EGG has now been largely uncovered. The shadow of the EGG protects a column of gas behind it, giving it a finger-like appearance.



Eventually the EGG may become totally separated from teh molecular cloud in which it formed. As the EGG itself slowly evaporates, the star within is uncovered and may appear sitting on the front surface of the EGG.

FOR RELEASE: August 28, 1995

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PRESS RELEASE NO.: STScI-PR95-32

HUBBLE SPACE TELESCOPE FINDS STELLAR GRAVEYARD

Peering deep into the globular star cluster M4 with NASA's Hubble Space Telescope, Canadian and American astronomers have discovered a large number of "stellar corpses," called white dwarf stars, which may be used eventually to refine age estimates of the universe.

The observation, made by a team led by Harvey Richer of the University of British Columbia, Vancouver, Canada, was so sensitive that even the brightest of the detected white dwarfs was no more luminous than a 100-watt light bulb seen at the Moon's distance (239,000 miles).

The Hubble results will allow astronomers to refine theoretical predictions of the rate at which white dwarfs cool -- an important prerequisite for making reliable estimates for the age of the universe and our Milky Way galaxy, based on white dwarf temperatures. Present estimates for the universe's age range from eight to twenty billion years, and refining this value is a key goal for modern astronomy and the Hubble telescope.

A white dwarf is the burned-out core of a collapsed star that, like a dying ember, slowly cools and fades away. However, the universe is not yet old enough for any white dwarfs to have cooled off completely to become invisible black dwarfs. White dwarf temperatures can therefore be used as "cosmic clocks" for estimating the age of the universe independently from other techniques.

A globular cluster like M4 contains hundreds of thousands of stars visible with ground-based telescopes. "We expected that the typical globular cluster should also contain about 40,000 white dwarfs. However, white dwarfs are extremely faint, and to date no ground or space-based telescope has been able to reveal more than a handful of them in any star cluster," said Richer. By exposing with Hubble's Wide Field and Planetary Camera 2 for five hours, Richer's team was able to detect more than 75 white dwarfs in one small area of M4. Analysis of the Hubble images, done with computer software developed by Peter Stetson at the National Research Council of Canada, Victoria, British Columbia. The faintest white dwarfs are 40 times fainter than the brightest ones in the cluster.

"Even longer exposures with Hubble could conceivably reveal the ages of the faintest and oldest white dwarfs in M4. This would be a crucial way to distinguish between recent divergent values for the age of the universe, since its age cannot be less than the age of the oldest white dwarfs in M4," said team member Howard Bond of the Space Telescope Science Institute in Baltimore, MD.

A white dwarf contains most of the original mass of a star, but has contracted to an extremely dense and faint object about the size of the Earth. A golf ball-sized piece of a white dwarf would weigh more than a ton. Because of its small size, high density, and initially hot temperature, it takes billions of years for a white dwarf to radiate all of its residual heat into space.

Located 7,000 light-years away in the direction of the constellation Scorpius and visible in a pair of binoculars, M4 (the fourth object in the Messier catalog of star clusters and nebulae) is the nearest globular cluster to the Earth. Globular clusters like M4 were born early in the history of the Milky Way, and today are veritable stellar retirement communities. M4 is so ancient (estimated to be 14 billion years old) that all of its stars that began with 80% or more of the Sun's mass have already evolved to become red giants, followed by a collapse to a white dwarf. (Our Sun will not become a white dwarf for another five billion years.)

Details of the M4 study will be published in the Astrophysical Journal Letters in September. Other participants in the research are Gregory Fahlman, Rodrigo Ibata, and Georgi Mandushev (University of British Columbia), Roger Bell (University of Maryland), Michael Bolte (University of California, Santa Cruz), William Harris (McMaster University), James Hesser (National Research Council of Canada), Carlton Pryor (Rutgers University), and Don VandenBerg (University of Victoria).

* * * *

The Space Telescope Science Institute is operated by the Association of Universities for Research in Astronomy, Inc. (AURA) for NASA, under contract with the Goddard Space Flight Center, Greenbelt, MD. The Hubble Space Telescope is a project of international cooperation between NASA and the European Space Agency (ESA).

Image files in GIF and JPEG format may be accessed on Internet via anonymous ftp from oposite.stsci.edu in /pubinfo:

	GIF	JPEG
PRC95-32 White Dwarfs in M4	gif/M4WD.gif	jpeg/M4WD.jpg

The same images are available via World Wide Web from URL http://www.stsci.edu/pubinfo/Latest.html, or via links in http://www.stsci.edu/pubinfo/public.html.

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$$M \simeq \frac{4\pi}{3} R^3 \cdot \bar{\rho} \quad , \quad \frac{\bar{P}}{R} = \bar{\rho}\,\frac{GM}{R^2}$$

$$\bar{\rho} = \frac{3M}{4\pi R^3} = \frac{\cancel{3}\cdot \cancel{2}\cdot 10^{\cancel{33}\,3}}{2\,\cancel{4\pi}\,7^3\cdot \cancel{10^{30}}} \simeq 1.5 \text{ г/см}^3$$

$$\boxed{\bar{P}_\odot \simeq 10^3 \text{ атм} \quad , \quad \bar{T}_\odot \simeq 10^7 \text{ K}}$$

оценим характерное время тепловых процессов:

$$t_{\text{теп}} \simeq \frac{E_T}{L_\odot} \simeq \frac{3kT}{m_p}\cdot\frac{M_\odot}{L_\odot} \simeq \frac{3\cdot 1.4\cdot 10^{-16}\,\frac{\text{эрг}}{\text{К}}\cdot 10^7\text{ К}\cdot \cancel{2}\cdot \cancel{10^{33}}}{1.7\cdot 10^{-24}\text{ г}\cdot \underset{2}{\cancel{4}}\cdot \cancel{10^{33}}\,\frac{\text{эрг}}{\text{с}}} \simeq$$

$$\simeq 10^{15}\text{ с} / \pi\cdot 10^7\text{ с} \simeq 3\cdot 10^7 \text{ лет}. \quad \text{(30 млн лет!)}$$

E_T – тепловая энергия

- Если яд-не реакции остановятся $\odot$ будет светить еще в течение 30 млн лет!

Оценим время жизни Солнца.

$$t_{\text{жиз}} \simeq \frac{E}{L_\odot} = \frac{M_\odot c^2 \cdot k_1 \cdot k_2}{L_\odot} \simeq \frac{2\cdot \cancel{10^{33}}\cdot 3^2\cdot 10^{20}\cdot 10^{-2}\cdot 10^{-1}}{4\cdot \cancel{10^{33}}}$$

$k_1 \simeq 10^{-2}$ – кпд – яд. реакций слияния

$k_2 \simeq 10^{-1}$ – масса ядра, где идут реакции ($T > T_{\text{пор}}$

$$! \rightarrow \boxed{t_{\text{жиз}} \simeq \frac{4.5\cdot 10^{17}\text{ сек}}{\pi\cdot 10^7\text{ сек}} \simeq 10^{10} \text{ лет}}$$

! → $t_{\text{гидро}} \ll t_{\text{теп}}$.

! → $t_{\text{теп}} \ll t_{\text{жиз}}$.

Процесс теплоотвода:

$$L = 4\pi \cdot r^2 D \frac{dE}{dr} \sim T^4 \,!$$

L – поток энергии наружу.

D – коэф-т диффузии.

$E = \sigma T^4$ – закон Стефана – Больцмана. $\sigma = 5.67 \times 10^{-8}$, Вт/(м²·К⁴)

$$A_{\text{яд}} = A_0 \rho T^{\nu}$$

(p-p)-цикл, $T = (0.9 \div 1.3) \cdot 10^7 K$; $\nu = 4.5$

C-цикл, $T = (1.2 \div 1.6) \cdot 10^7 K$; $\nu = 20$

$$L \sim T^4, \quad A_{\text{яд}} \sim T^{4.5 \div 20}$$

⇒ любая функ-ия $A_{\text{яд}}$ приводит к взрыву ?

т.к. $t_{\text{гидро}} \ll t_{\text{теп}} \Rightarrow A_{\text{яд}} \nearrow \Rightarrow R \nearrow \Rightarrow \rho \searrow \Rightarrow T \searrow$

⇒ отрицательная обратная связь

Звезда устойчивое образование !

(Что, в принципе, и так очевидно.)

Эффективность различных источников энергии

Уголь: C_{12}

$$E = mc^2 = 12 \times m_p = 12 \text{ ГэВ}$$

$$\Delta E \simeq 10 \div 50 \text{ эВ}$$

$$\text{КПД} = \frac{10 \text{ эВ}}{12 \cdot 10^9 \text{ эВ}} \simeq 10^{-9} : mc^2$$

Реакции деления: ${}^{92}U_{235}$

$$E = 235 \times m_p \simeq 235 \text{ ГэВ}.$$

$$\Delta E \simeq 200 \text{ МэВ/деление}$$

$$\text{КПД} = \frac{0.2}{235} \simeq 10^{-3} \times mc^2$$

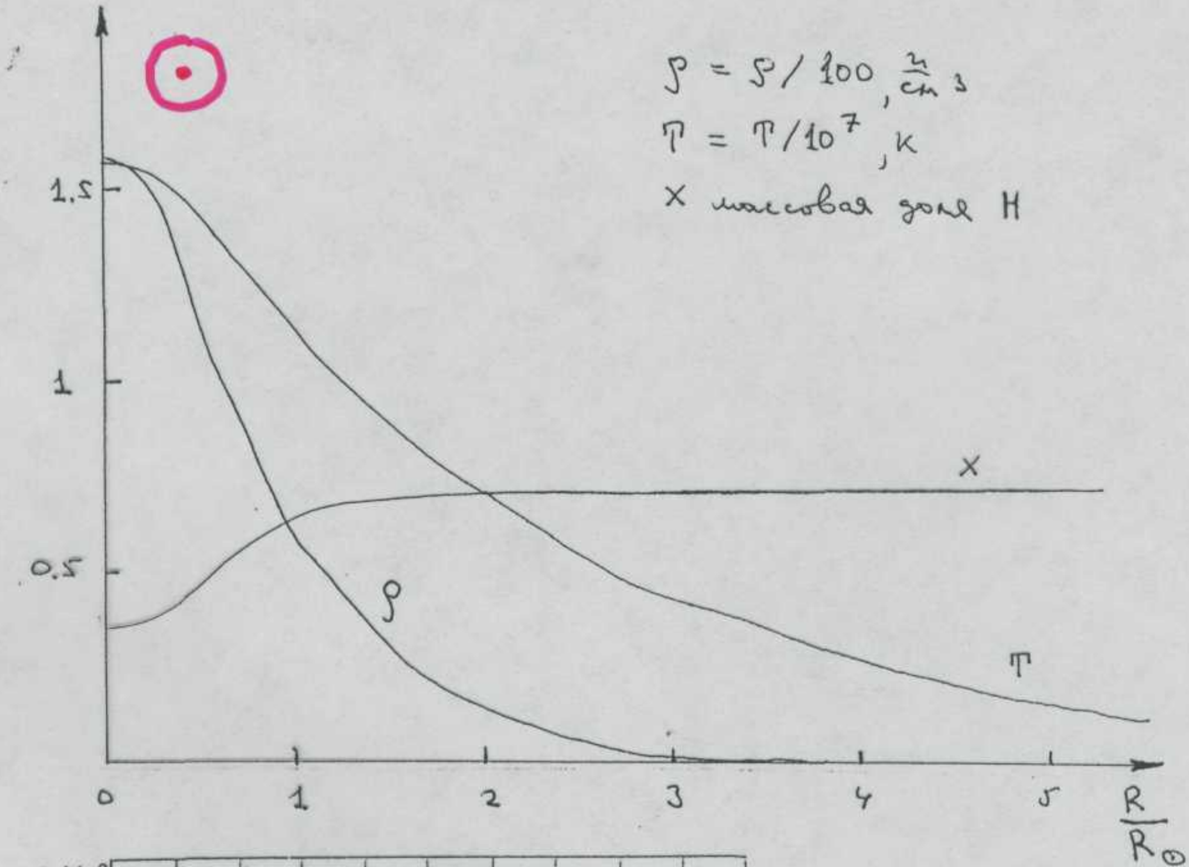
Реакции слияния: (термояд)

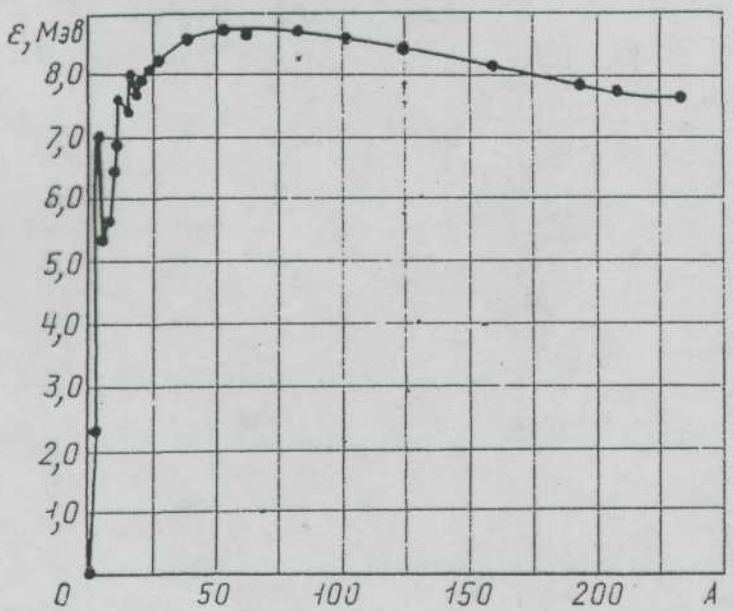
$$\text{КПД} \simeq 10^{-2} \times mc^2$$

Аккреция на чёрную дыру: $\text{КПД} = 7 \cdot 10^{-2} \times mc^2$

Аннигиляция:

$$\text{КПД} = 100\% \; !$$





$n \to p + e^- + \bar{\nu}_e$

$p \to n + e^+ + \nu_e$

и т.д. . . .

p-p - цикл

$\Delta E = 26.2$ МэВ.

$H^1 + H^1 \to D^2 + e^+ + \nu$	+ 1,44 *Мэв* (~ 10^{10} лет),
$D^2 + H^1 \to He^3 + \gamma$	+ 5,49 *Мэв* (~ 5 секунд),
$He^3 + He^3 \to He^4 + H^1 + H^1$	+ 12,85 *Мэс* (~ 10^6 лет).

C-N - цикл

$\Delta E \simeq 25$ МэВ

$C^{12} + H^1 \to N^{13} + \gamma$	+1,95 *Мэв* ($1{,}3 \cdot 10^7$ лет)
$N^{13} \to C^{13} + e^+ + \nu$	+2,22 *Мэв* (7 минут)
$C^{13} + H^1 \to N^{14} + \gamma$	+7,54 *Мэв* ($2{,}7 \cdot 10^6$ лет)
$N^{14} + H^1 \to O^{15} + \gamma$	+7,35 *Мэв* ($3{,}2 \cdot 10^8$ лет)
$O^{15} \to N^{15} + e^+ + \nu$	+2,71 *Мэв* (82 секунды)
$N^{15} + H \to C^{12} + He^4$	+4,96 *Мэв* ($1{,}1 \cdot 10^5$ лет)

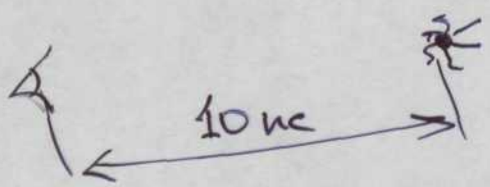
$$\frac{F_1}{F_2} = 2.5^{m_2 - m_1}, \qquad m_\odot = -26.73,$$

$$m_{min} \simeq 25$$

$$F_\odot = 1.37 \cdot 10^6 \frac{\text{эрг}}{\text{см}^2 \cdot \text{сек}}.$$

$$M = m - 5 - 5\lg r, \; ([r] - \text{пс}) \; M$$

М - абсолютная звёздная величина.



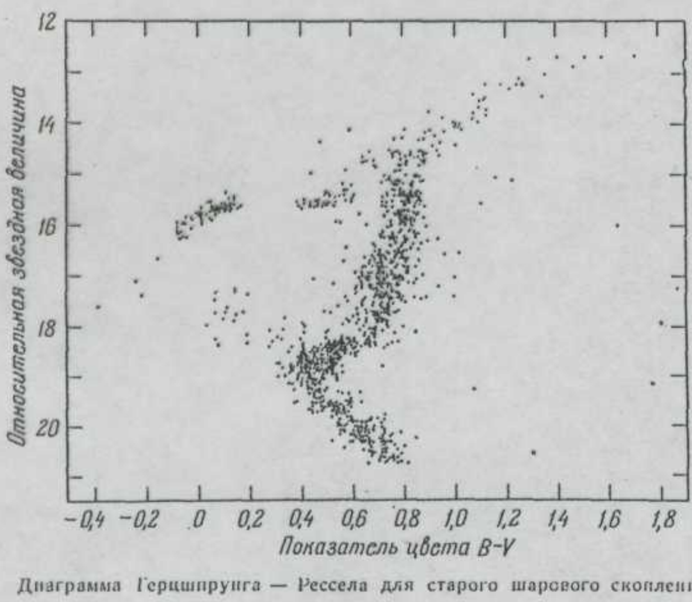
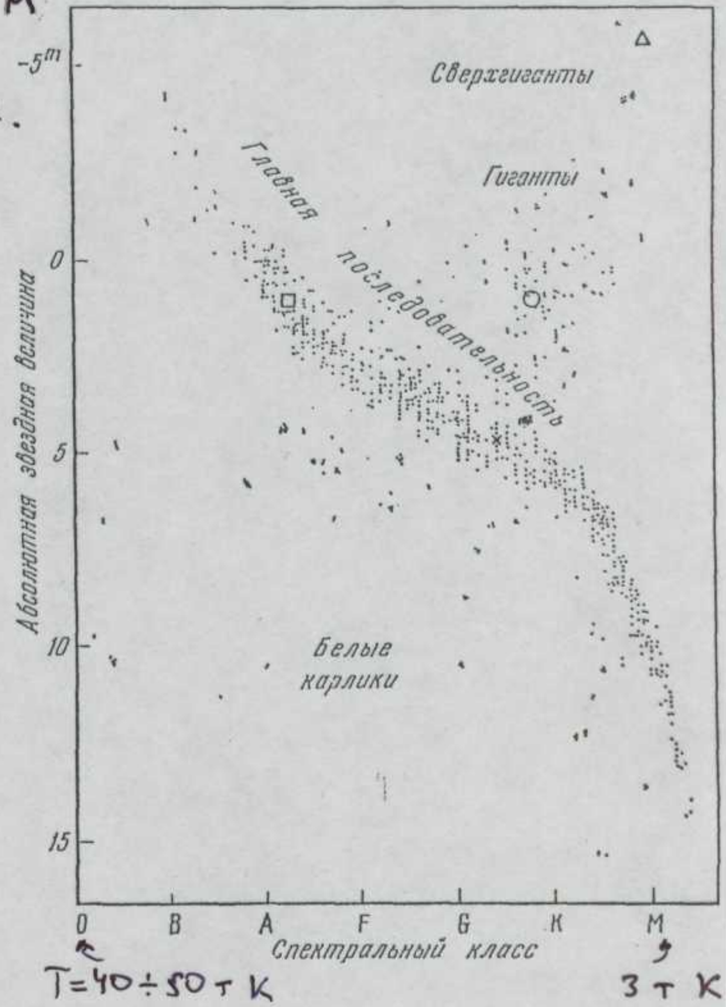
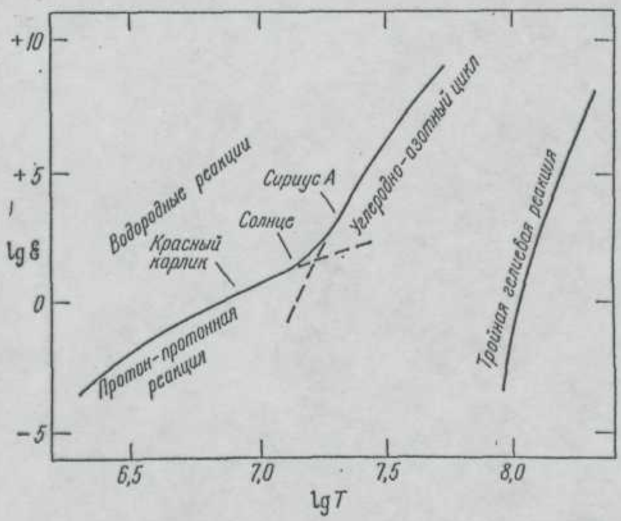


Диаграмма Герцшпрунга — Рессела для старого шарового скопления М 3.

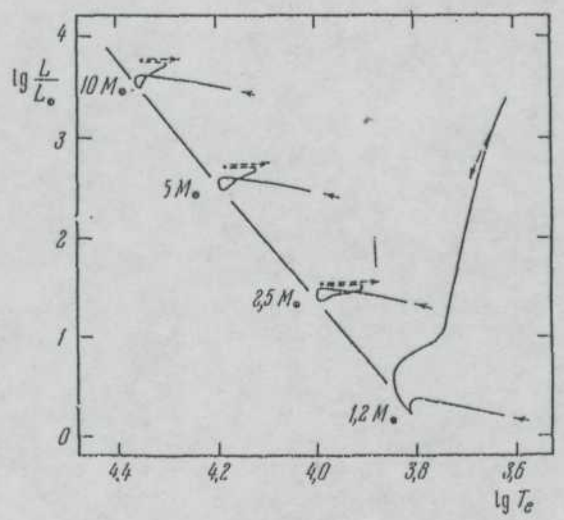


T=40÷50 т K

3 т K



Зависимость ядерного энерговыделения от температуры для трех реакций.



Теоретические эволюционные треки массивных звезд.

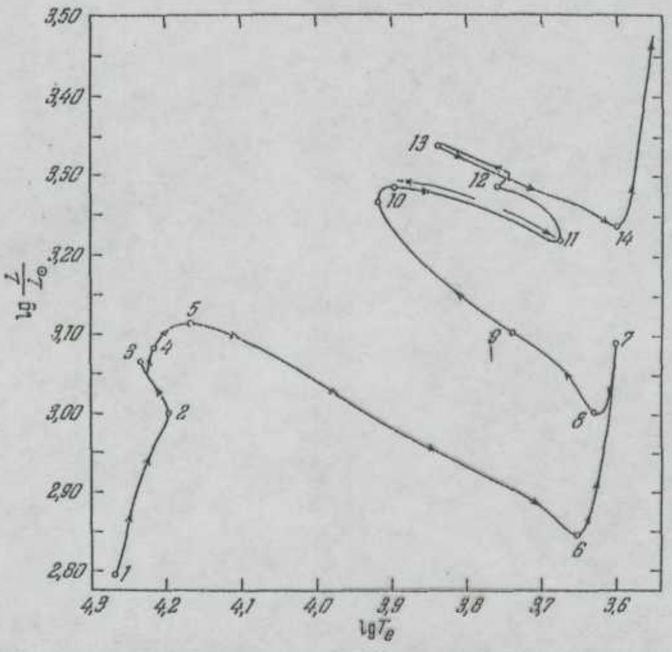
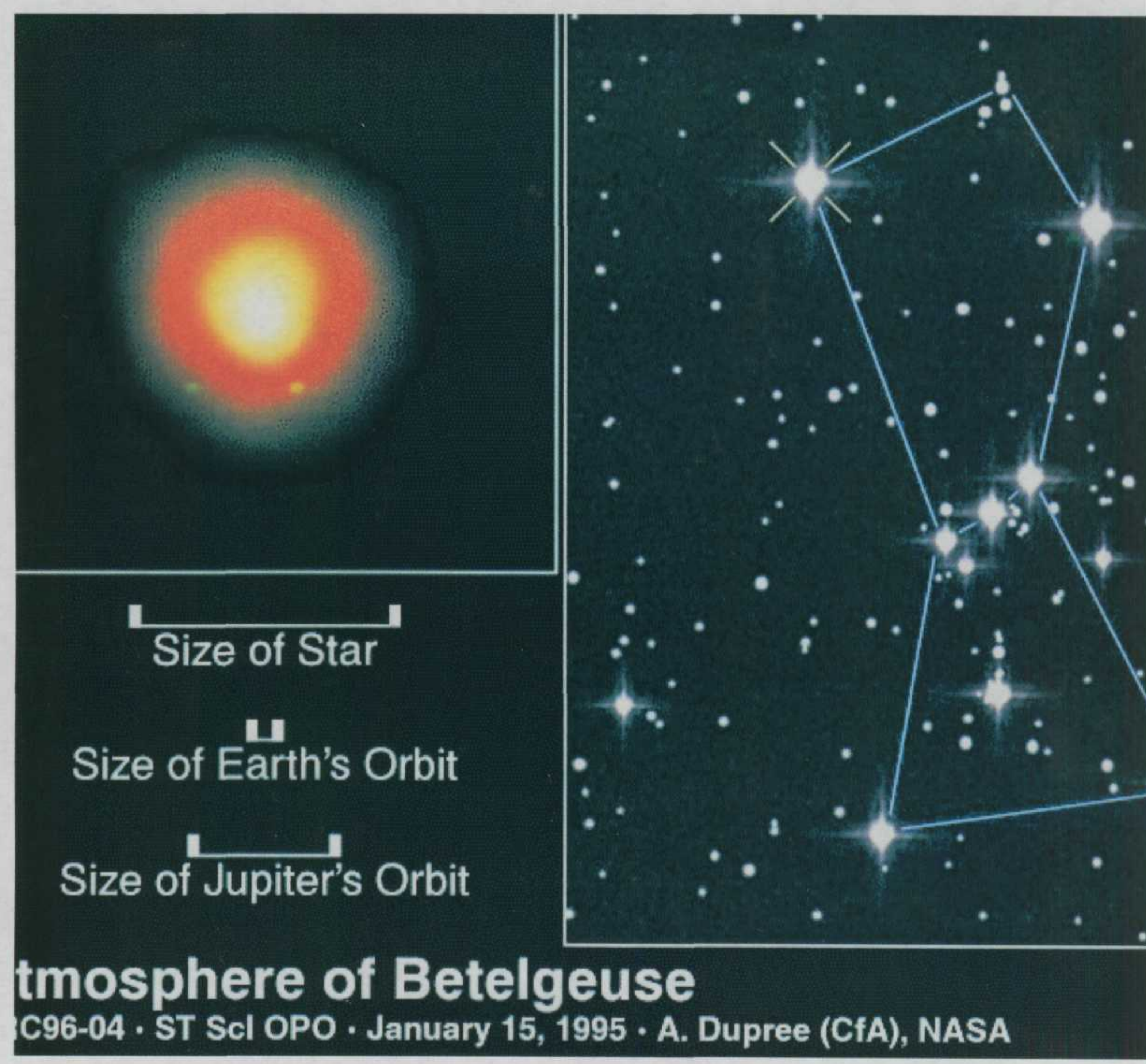
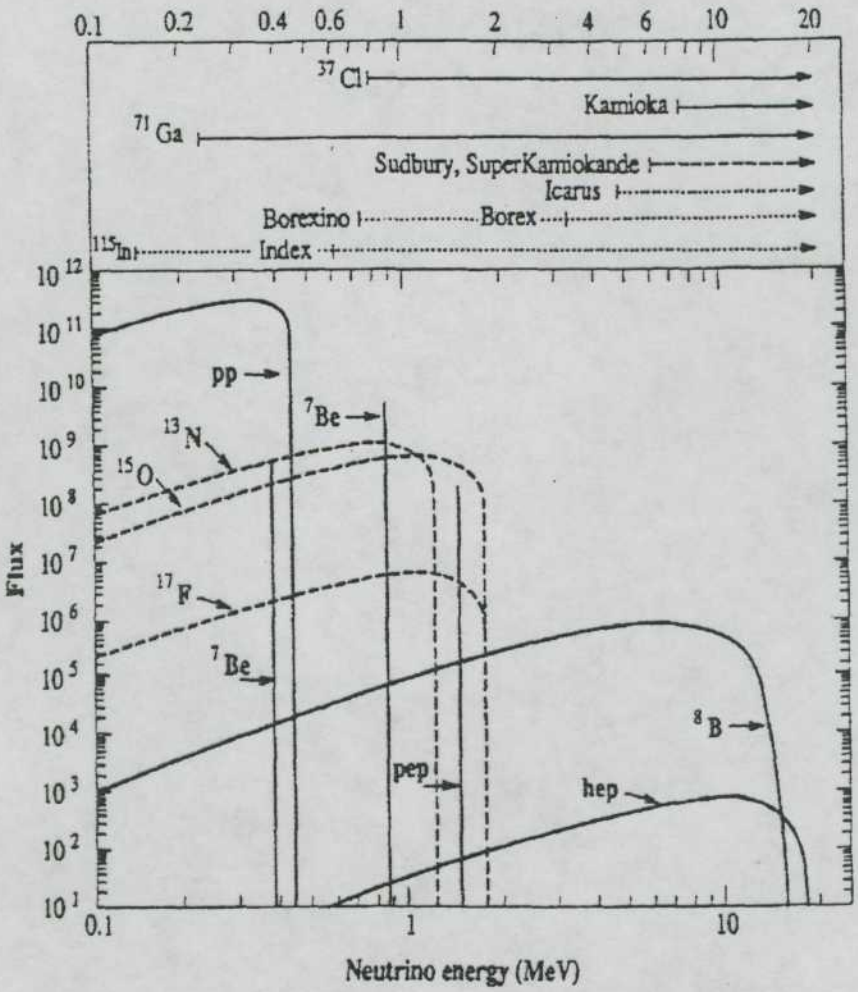
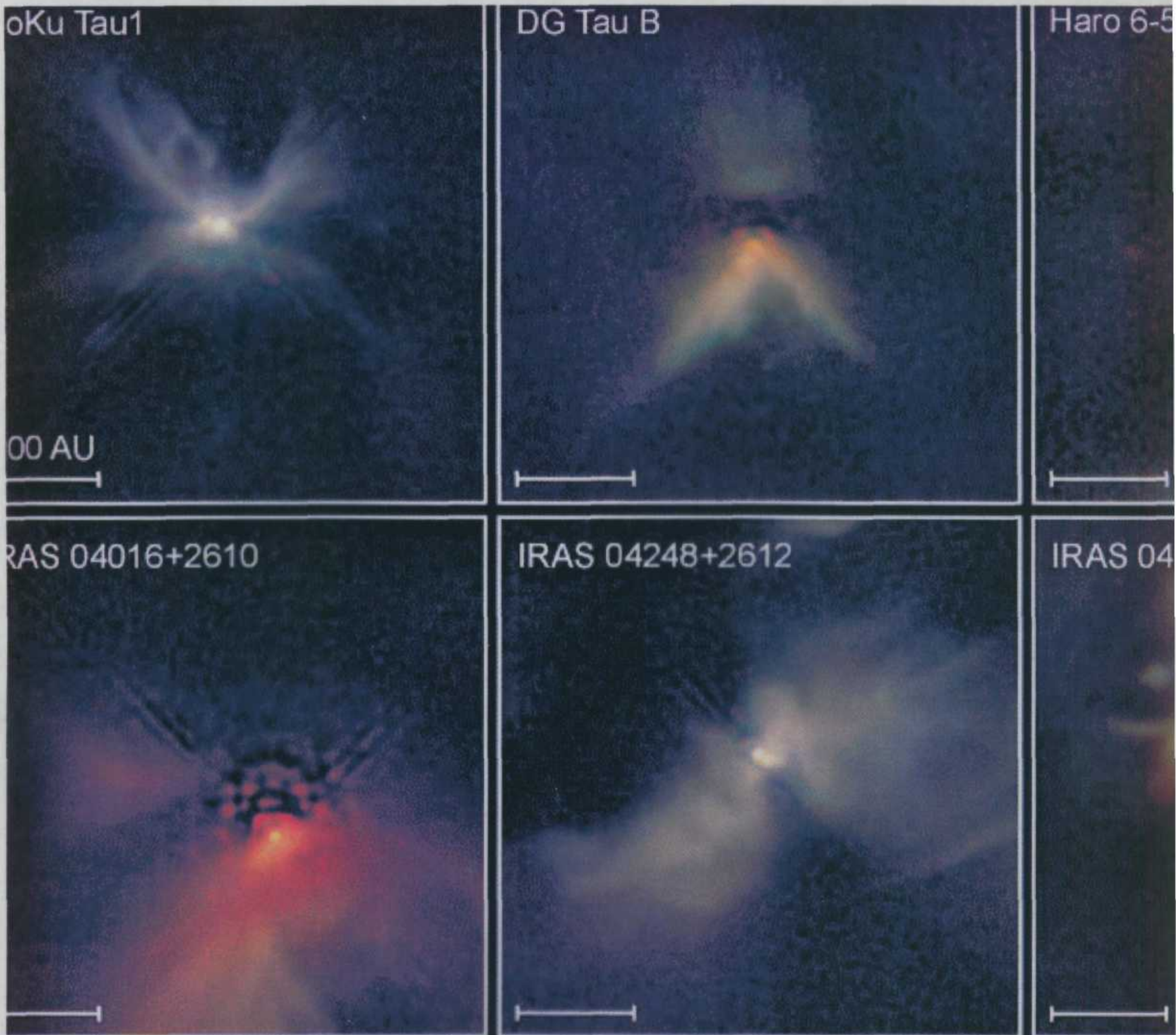


Рис. 49. Эволюционный трек звезды с массой $5M_{\odot}$. (1—2) — горение водорода в конвективном ядре, $6{,}44 \cdot 10^7$ лет; (2—3) — общее сжатие звезды, $2{,}2 \cdot 10^6$ лет; (3—4) — возгорание водорода в слоистом источнике, $1{,}4 \cdot 10^5$ лет; (4—5) — горение водорода в толстом слое, $1{,}2 \cdot 10^6$ лет; (5—6) — расширение конвективной оболочки, $8 \cdot 10^5$ лет; (6—7) — фаза красного гиганта, $5 \cdot 10^5$ лет; (7—8) — возгорание гелия в ядре, $6 \cdot 10^6$ лет; (8—9) — исчезновение конвективной оболочки, 10^6 лет; (9—10) — горение гелия в ядре, $9 \cdot 10^6$ лет; (10—11) — вторичное расширение конвективной оболочки, 10^6 лет; (11—12) — сжатие ядра по мере выгорания гелия; (12—13—14) — слоистый гелиевый источник; (14—?) — нейтринные потери, красный сверхгигант.


Size of Star
Size of Earth's Orbit
Size of Jupiter's Orbit
tmosphere of Betelgeuse
C96-04 · ST ScI OPO · January 15, 1995 · A. Dupree (CfA), NASA



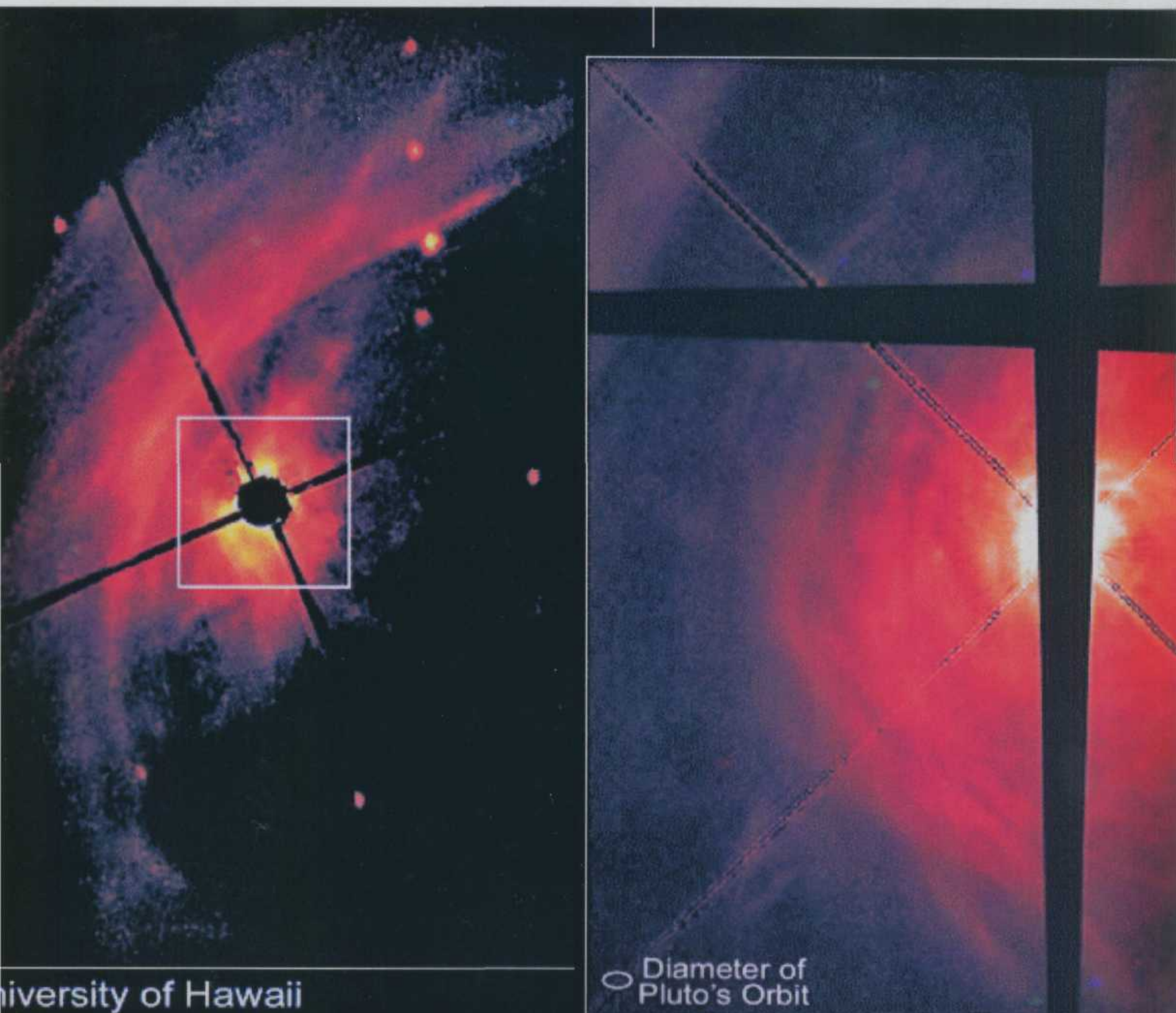
$p + p \to D + e^+ + \nu_e$ (pp neutrinos)
$p + p + e^- \to D + \nu_e$ (pep neutrinos)
ppII chain: $^7Be + e^- \to ^7 Li + \nu_e$ (^7Be neutrinos)
ppIII chain: $^7Be + p \to ^8 B$ $^8B \to ^8 Be^* + e^+ + \nu_e$
$^8Be^* \to 2^4He$ (^8B neutrinos)
$p + ^3 He \to \nu_e + e^+ + ^4 He$ (hep neutrinos)
CNO I cycle: $^{13}N \to ^{13} C + e^+ + \nu_e$ (^{13}N neutrinos)
$^{15}O \to ^{15} N + e^+ + \nu_e$ (^{15}O neutrinos)
CNO II cycle: $^{17}F \to ^{17} O + e^+ + \nu_e$ (^{17}F neutrinos)



oung Stellar Disks in Infrared

C99-05a • STScI OPO

Padgett (IPAC/Caltech), W. Brandner (IPAC), K. Stapelfeldt (JPL) and NA



niversity of Hawaii

B Aurigae Disk

C99-21 • STScI OPO • C. Grady (NOAO at NASA Goddard Space Flight Cente

STScI-PR99-05
February 9, 1999

Vast Stellar Disks Set Stage for Planet Birth in New Hubble Images

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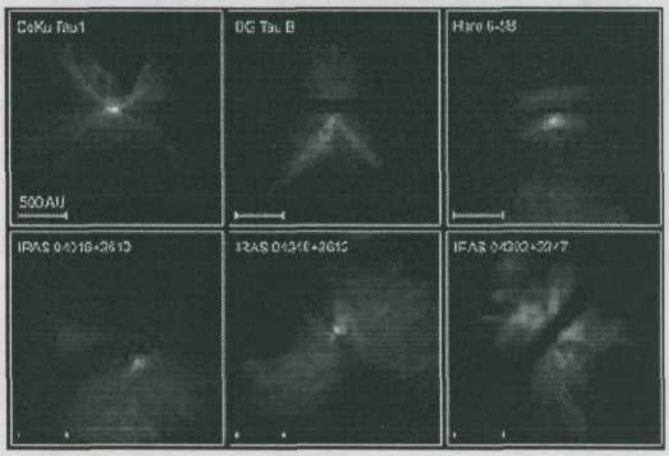

Dramatic pictures of eerie disks of dust encircling young stars are giving astronomers a new look at what may be the early formative stages of planetary systems.

tour the cosmos
webcast

Catch a glimpse of how it all began... visit Tour the Cosmos: Spinning Stardust into Planets for a multimedia foray into our universe's tempestuous childhood.

Photo Credit: D. Padgett (IPAC/Caltech), W. Brandner (IPAC), K. Stapelfeldt (JPL) and NASA

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Hubble Picture Adds to Planet-Making Recipe

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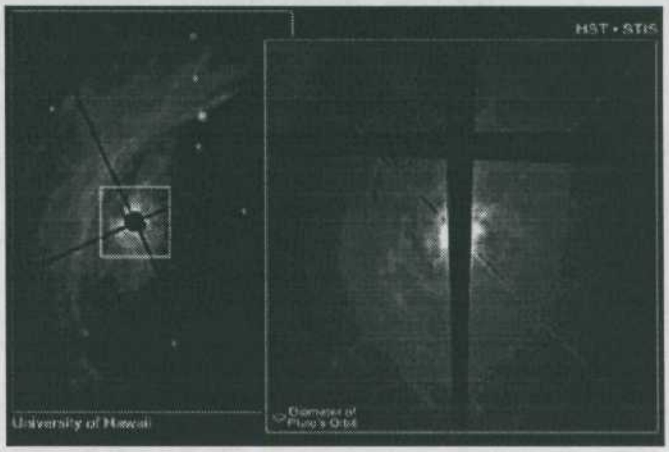

NASA's Hubble Space Telescope has snapped a nearly face-on view of a swirling disk of dust and gas surrounding a developing star called AB Aurigae. The Hubble telescope image, taken in visible light by the Space Telescope Imaging Spectrograph, shows unprecedented detail in the disk, including clumps of dust and gas that may be the seeds of planet formation.

Normally, a young star's bright light prevents astronomers from seeing material closer to it. That's why astronomers used a coronograph in these two images of AB Aurigae to block most of the light from the star. The rest of the disk material is illuminated by light reflected from the gas and dust surrounding the star.

The image on the left represents the best ground-based coronographic observation of AB Aurigae. Paul Kalas of the Space Telescope Science Institute took the image with the University of Hawaii's 2.2-meter telescope. The telescope's coronograph eclipsed a 33.5-billion-mile (53.6-billion-kilometer) area centered on the star.

This area is nine times larger than our solar system. The picture shows that the star resides in a region of dust clouds - the semicircular-shaped material to the left of the star. The Hubble telescope image on the right shows a windowpane-shaped occulting bar -- the dark bands running vertically through the middle of the image and horizontally across the upper part of it. The occulting bar covers the innermost part of the disk and star, about 7.1 billion miles (11.5 billion kilometers) or 1.4 times our solar system's diameter. The diagonal lines are the remnants of the diffraction spikes produced in Hubble telescope images of bright stars.

The disk is extremely wide: its diameter is roughly 1,300 times Earth's distance from the Sun. The disk material seen in this image is at a distance equivalent to well beyond Pluto's orbit. One faint background star is visible at 5 o'clock.

The star's disk shows a wealth of structure, with bright spiral-shaped bands from 9 o'clock to 6 o'clock and closer to the star from 12 o'clock to 3 o'clock. The outermost of these bands are seen in the ground-based image. The imaging spectrograph data show that these bands are themselves composed of numerous smaller bands. The smallest features include some bright knots of material to the left of the star. These knots are close in size to the resolution limit of the Hubble telescope and have diameters 1.3 to 3 billion miles (2 to 5 billion kilometers) wide or 14 to 32 times Earth's distance from the Sun. The brightest knot is at 9 o'clock.

The image was taken Jan. 23 and 24, 1999. False colors were used to bring out details in AB Aurigae's disk. The wavelength range is 2,000 to 10,100 Angstroms.

Credit: C.A. Grady (National Optical Astronomy Observatories, NASA Goddard Space Flight Center), B. Woodgate (NASA Goddard Space Flight Center), F. Bruhweiler and A. Boggess (Catholic University of America), P. Plait and D. Lindler (ACC, Inc., Goddard Space Flight Center), M. Clampin (Space Telescope Science Institute), and NASA.

The ground-based image is courtesy of P. Kalas (Space Telescope Science Institute).

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Фазы эволюции звёзд.

Фаза сжатия: $\tau \simeq 5\cdot 10^7 \left(\frac{M_\odot}{M}\right)^2$, лет

Фаза горения: $\tau = 10^{10}\cdot \frac{L_\odot}{L}\cdot \frac{M}{M_\odot}$, лет

$$\tau \sim \frac{m_{яд}}{L}\ ;\ m_{яд} \sim M\cdot 0{,}1$$

Фаза красного гиганта: $\tau \simeq 10^4$ лет,

выгорание яд-ого топлива: сжатие ядра, разбухание внешней оболочки.

Разнообразие состава звёзд: $\frac{He^3}{He^4} = 4 \div 10^{-7}$

Молодые звёзды: H/He/тяжёлые металлы (70/29/1)

Эволюция звезды определяется её начальной массой

$M = M_\odot$, $T_{жиз} \simeq 5\cdot 10^9$ лет.

$M = 30 M_\odot$, $T_{жиз} \simeq 6\cdot 10^6$ лет.

Белый карлик: конечный продукт эволюции звезды с $M \simeq M_\odot$

НЗ: — » — $1.5 M_\odot < M < (2.5 \div 3.0) M_\odot$

ЧД: — » — $M > 3\cdot M_\odot$.