

# Akhir Riwayat Bintang Bermassa Besar

Supernova, Bintang Neutron, dan Lubang Hitam



Hanindyo Kuncarayakti

*Warna*



*Kecerlangan*

# Bintang masif

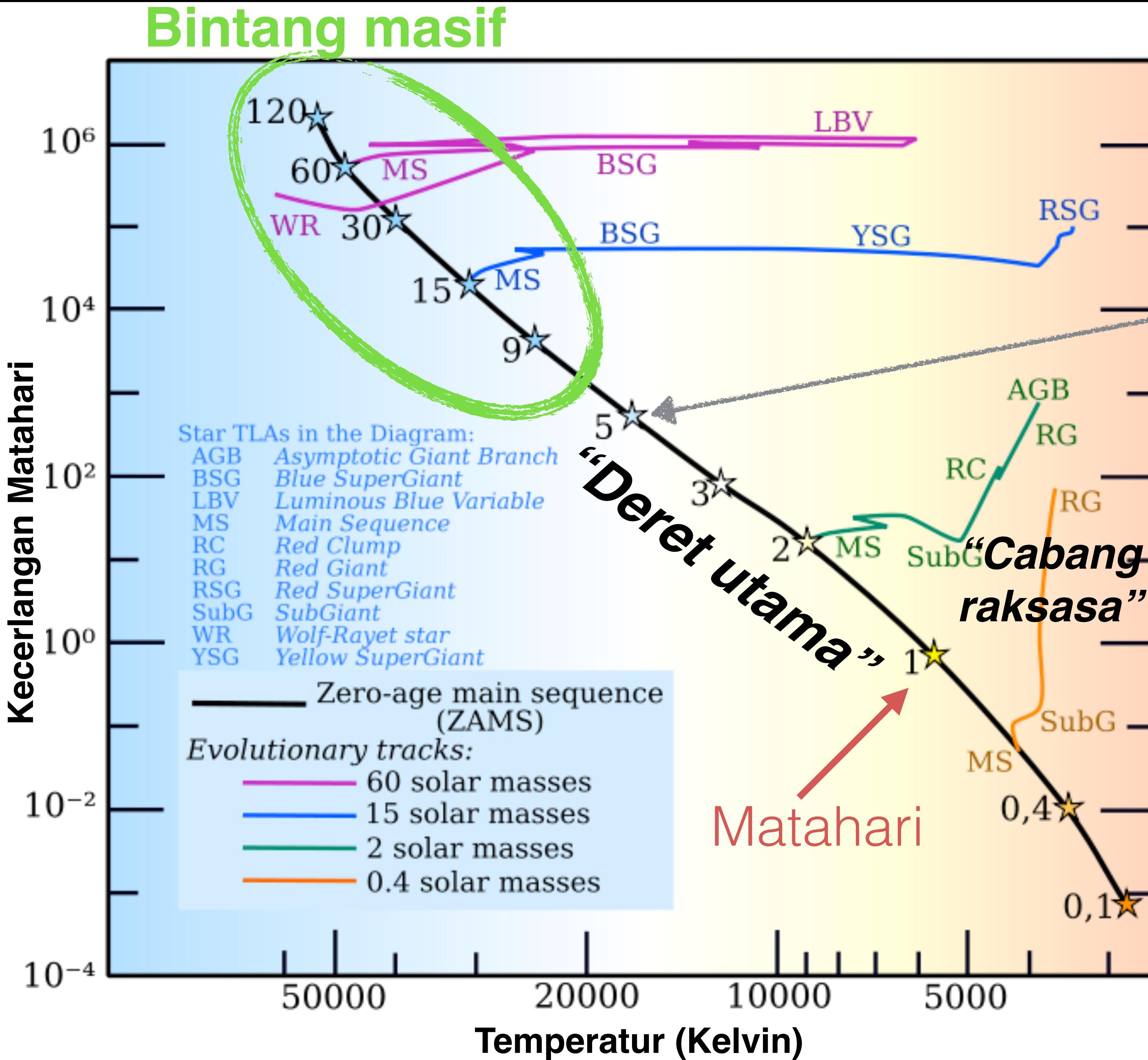


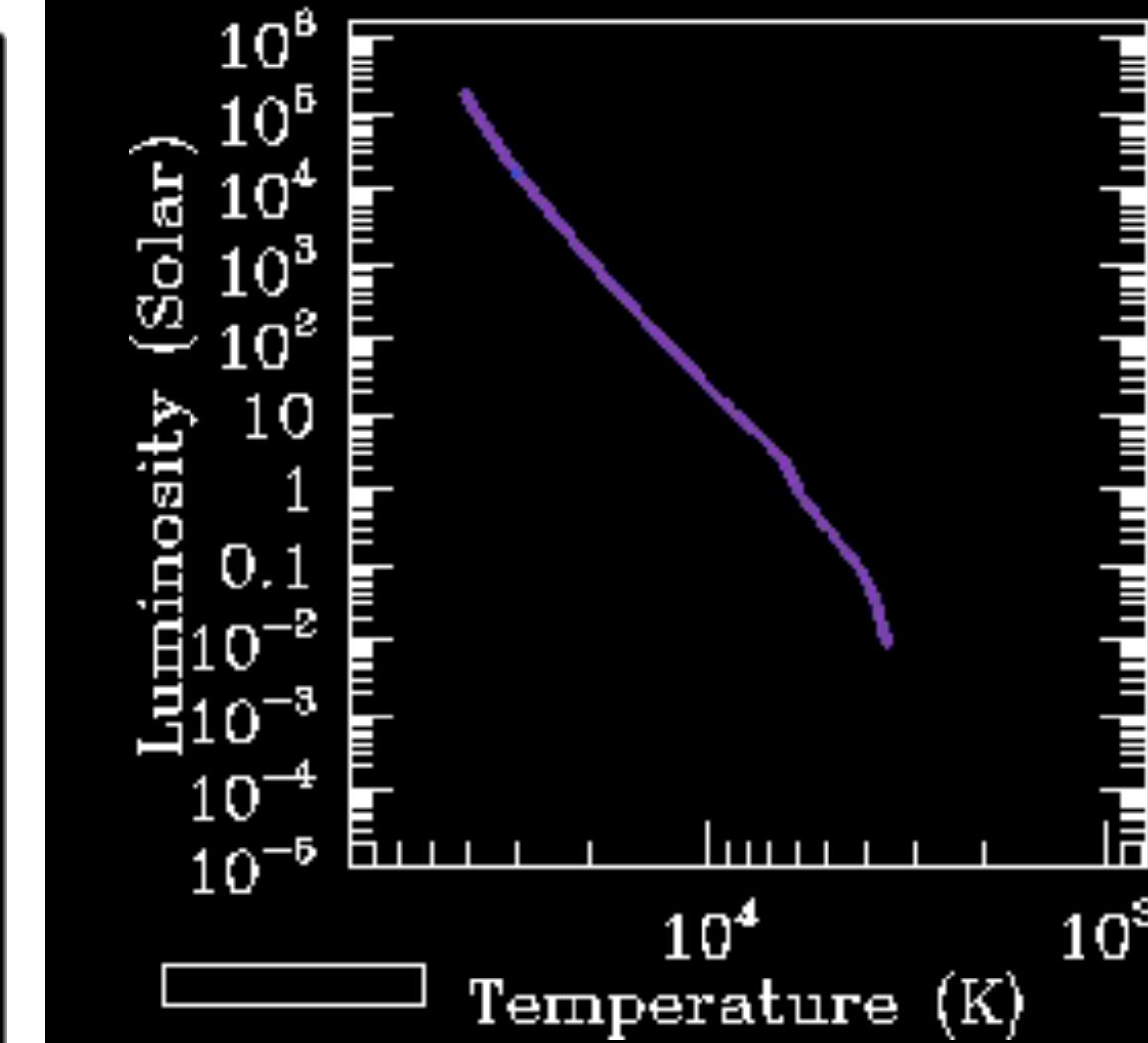
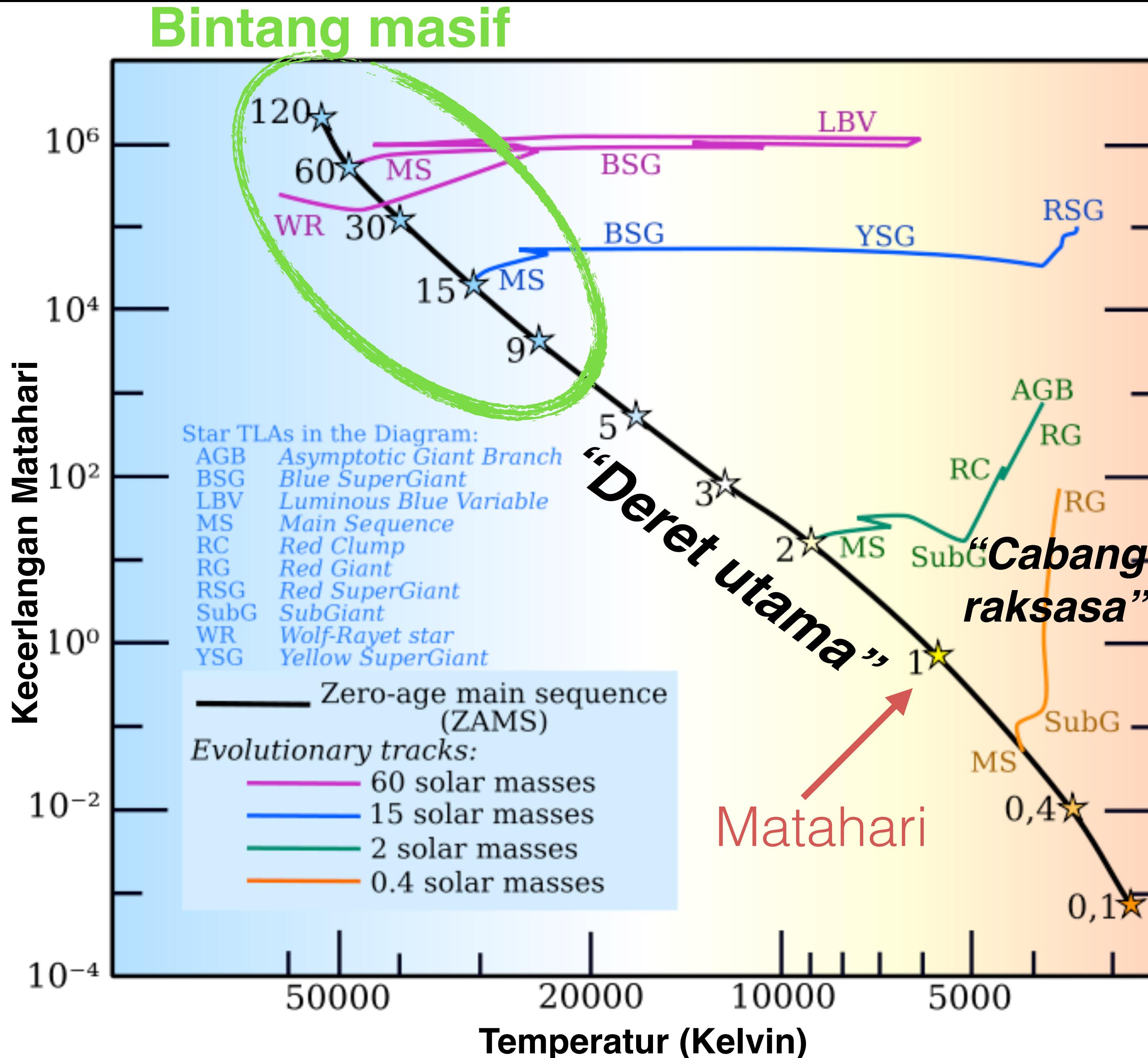
Diagram Hertzsprung-Russell  
(warna-kecerlangan)

Angka: massa awal bintang dalam satuan massa Matahari

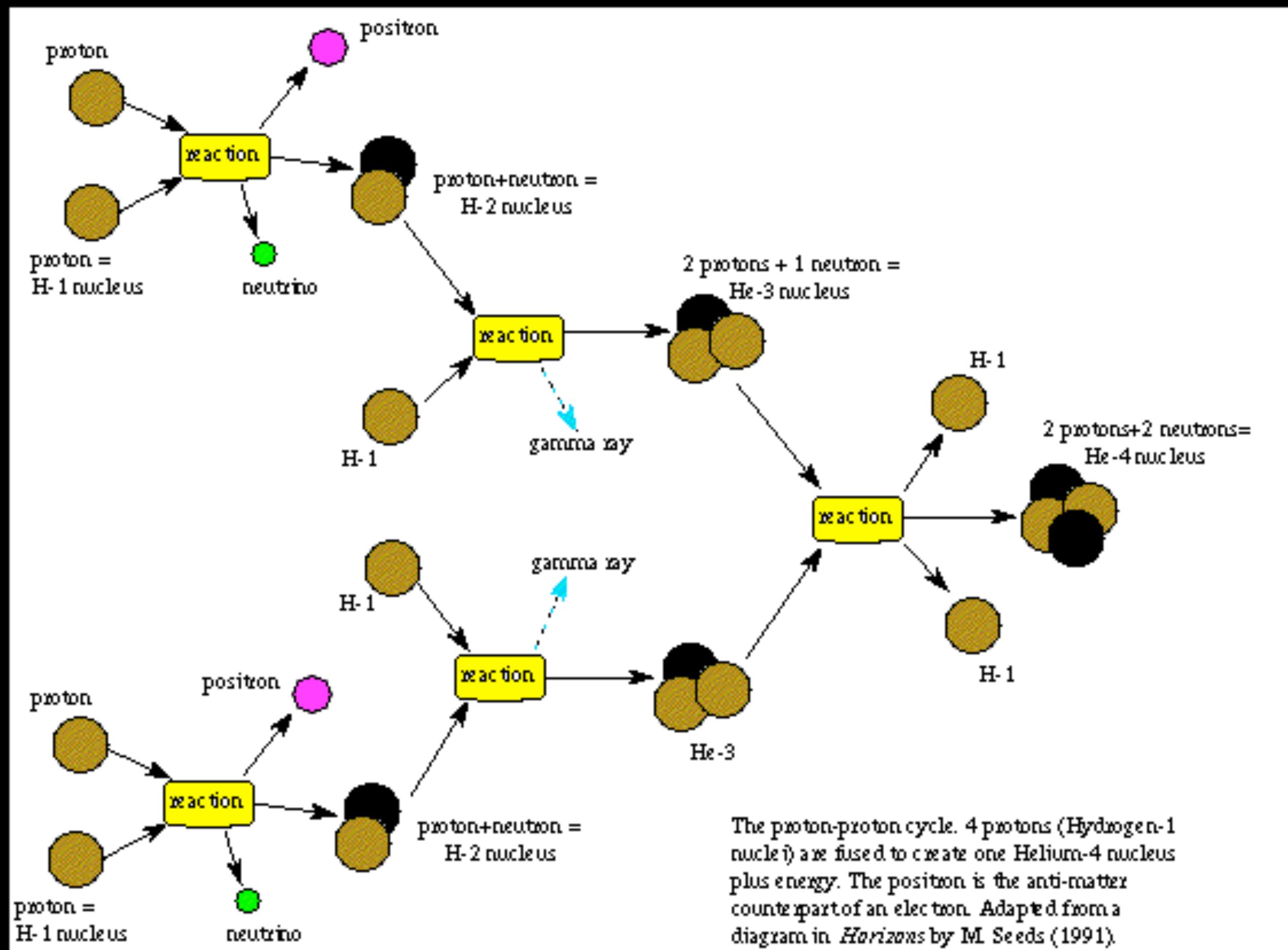
1 massa Matahari:  $2 \times 10^{30}$  kg

( 2 000 000 000 000 000  
000 000 000 000 000 kg )

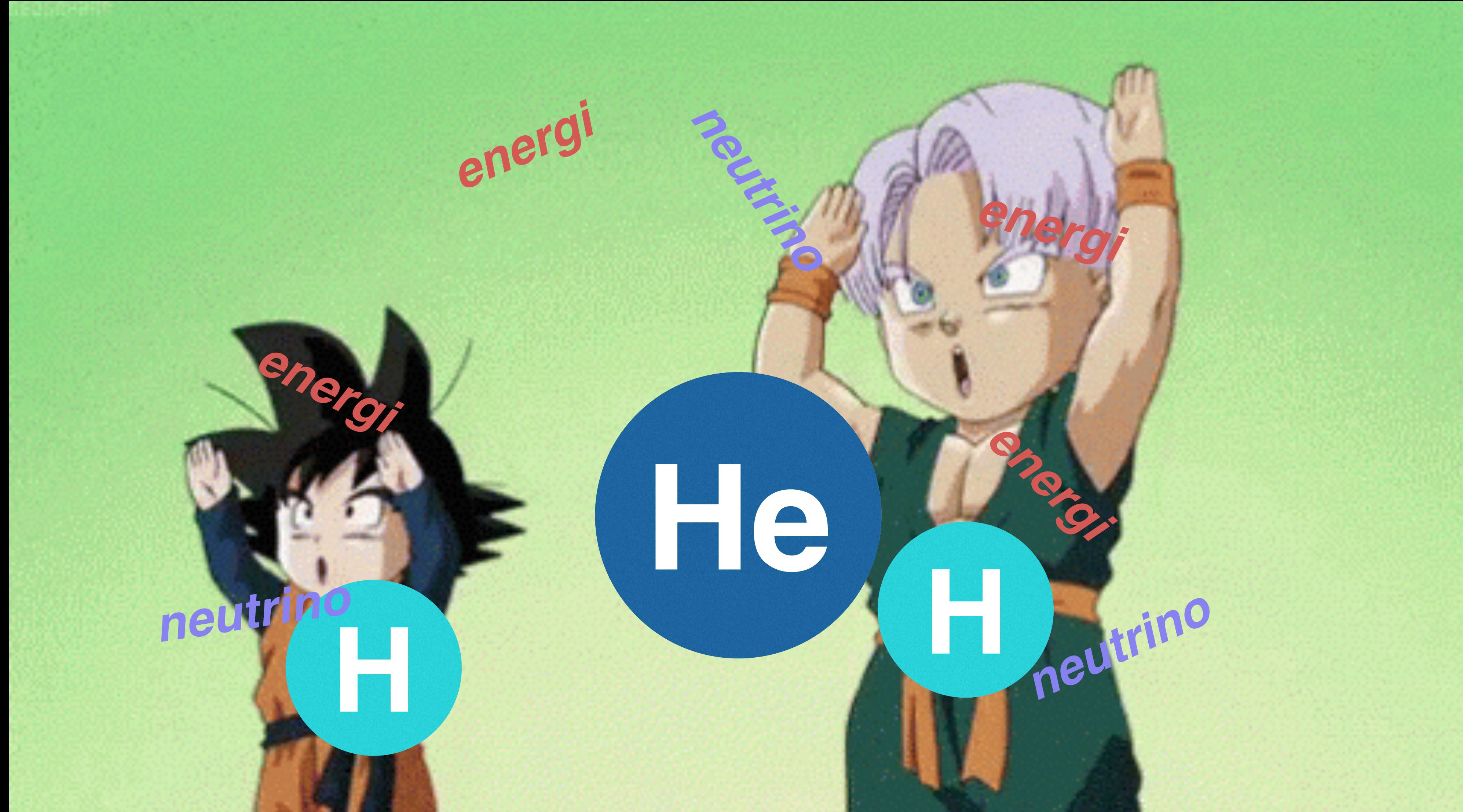
# Bintang masif



- **Jejak evolusi bintang** pada diagram warna-kecerlangan: dari deret utama menuju supernova



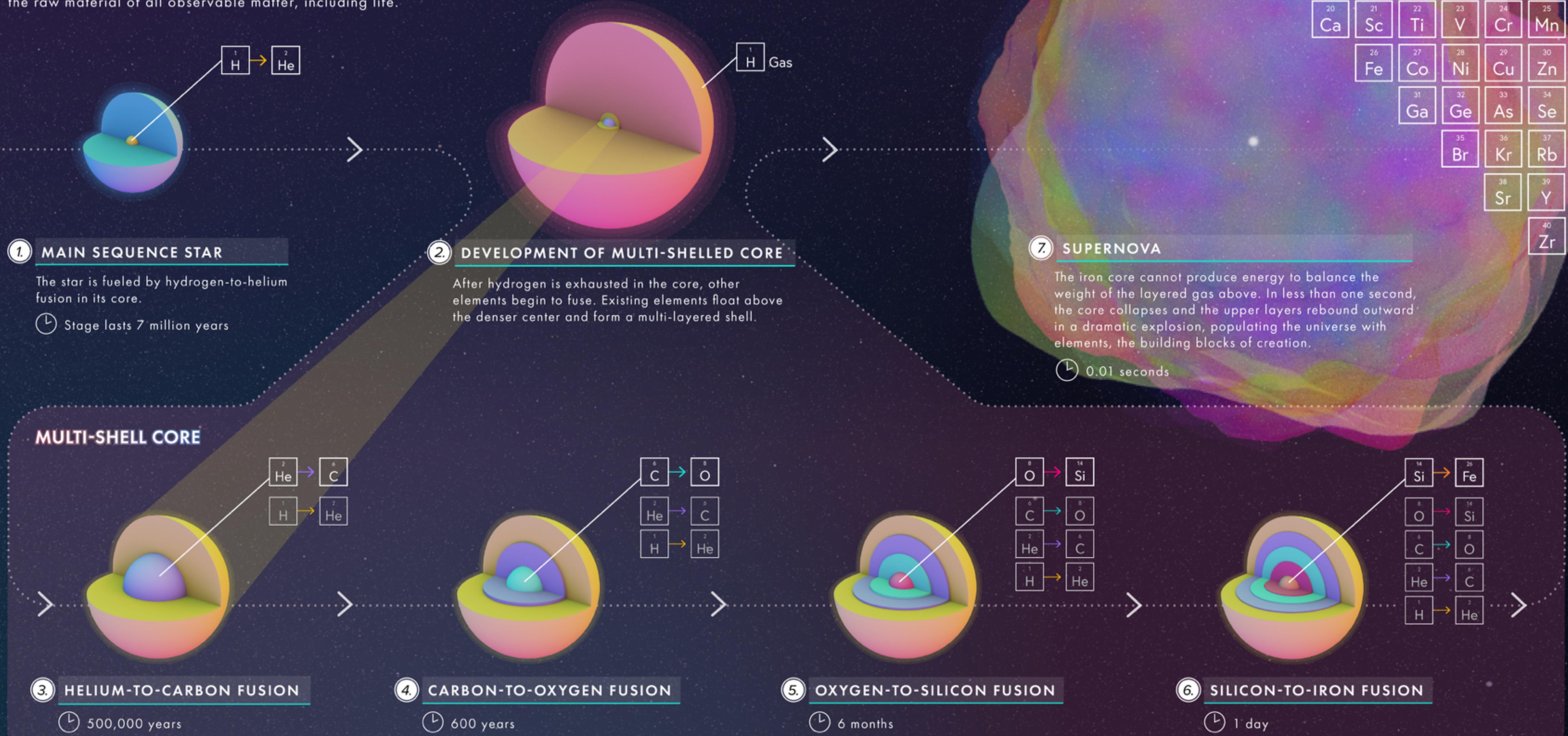
Reaksi **fusi** di pusat bintang: penggabungan inti atom menjadi elemen yang lebih berat + **energi** dan neutrino.



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# MASSIVE STARS: ENGINES OF CREATION

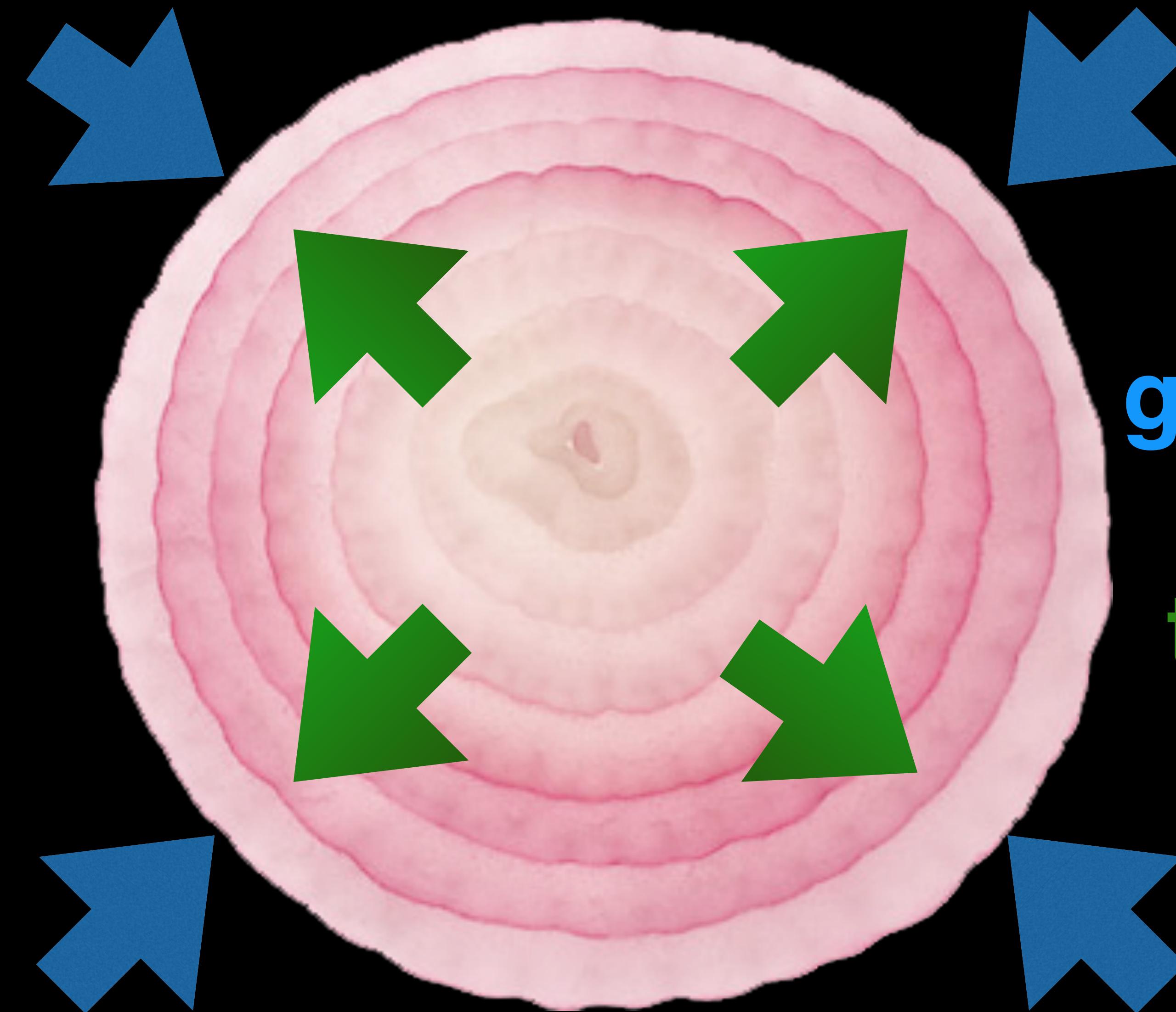
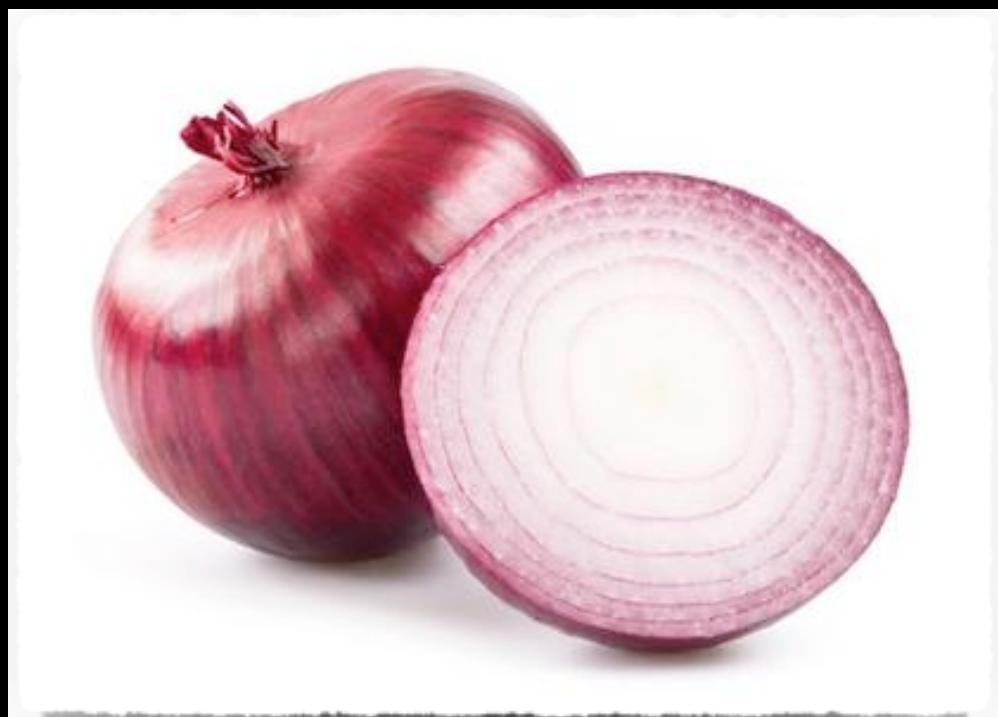
Through their cycle of formation, explosive "death" and reformation, massive stars (at least 8 times bigger than our sun) populate the universe with **new elements**, the raw material of all observable matter, including life.





- Di bagian dalam bintang akan terbentuk lapisan-lapisan (elemen berat di pusat, ringan di luar), seperti bawang

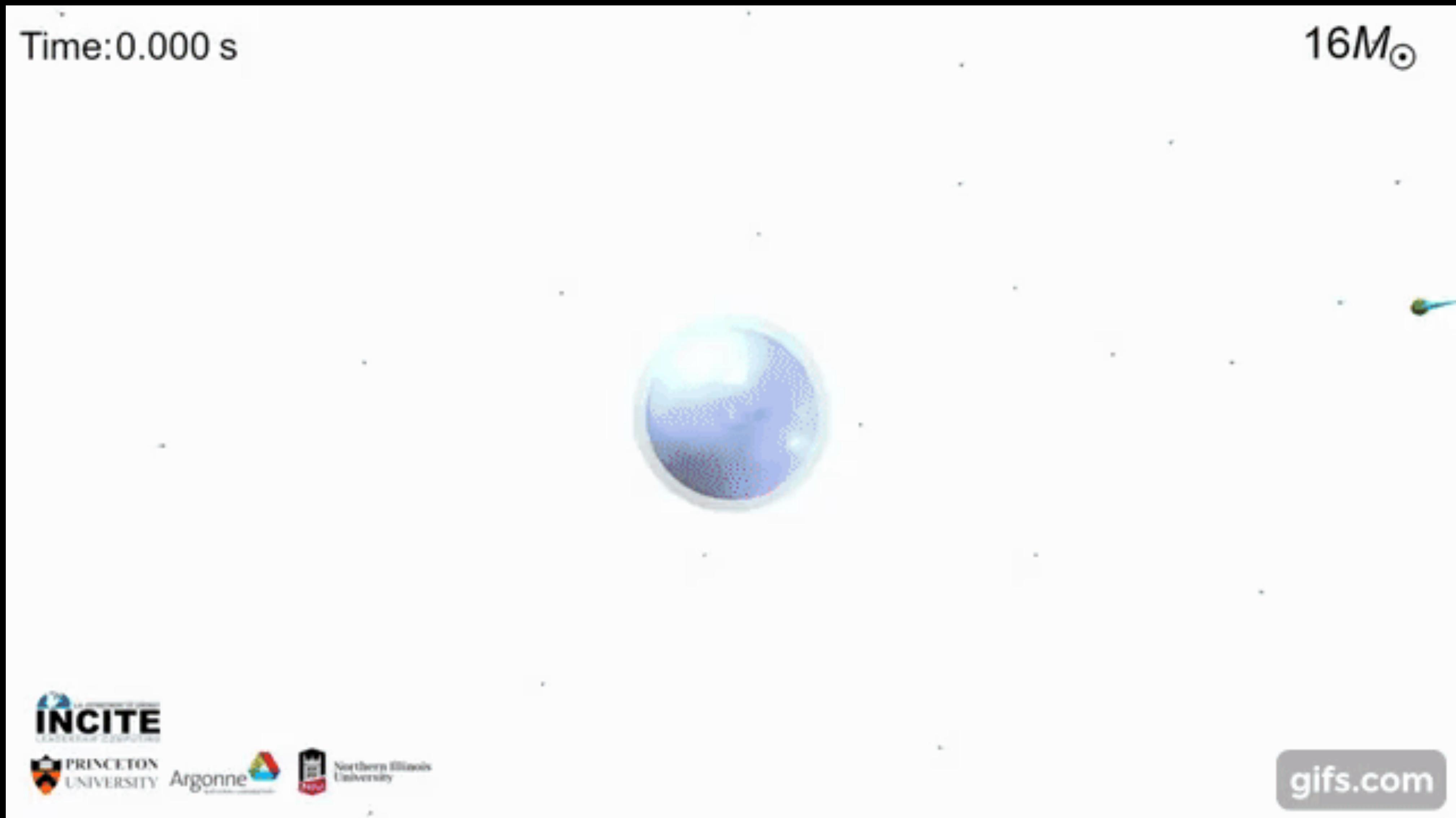
Bintang  
setimbang  
hidrostatik!



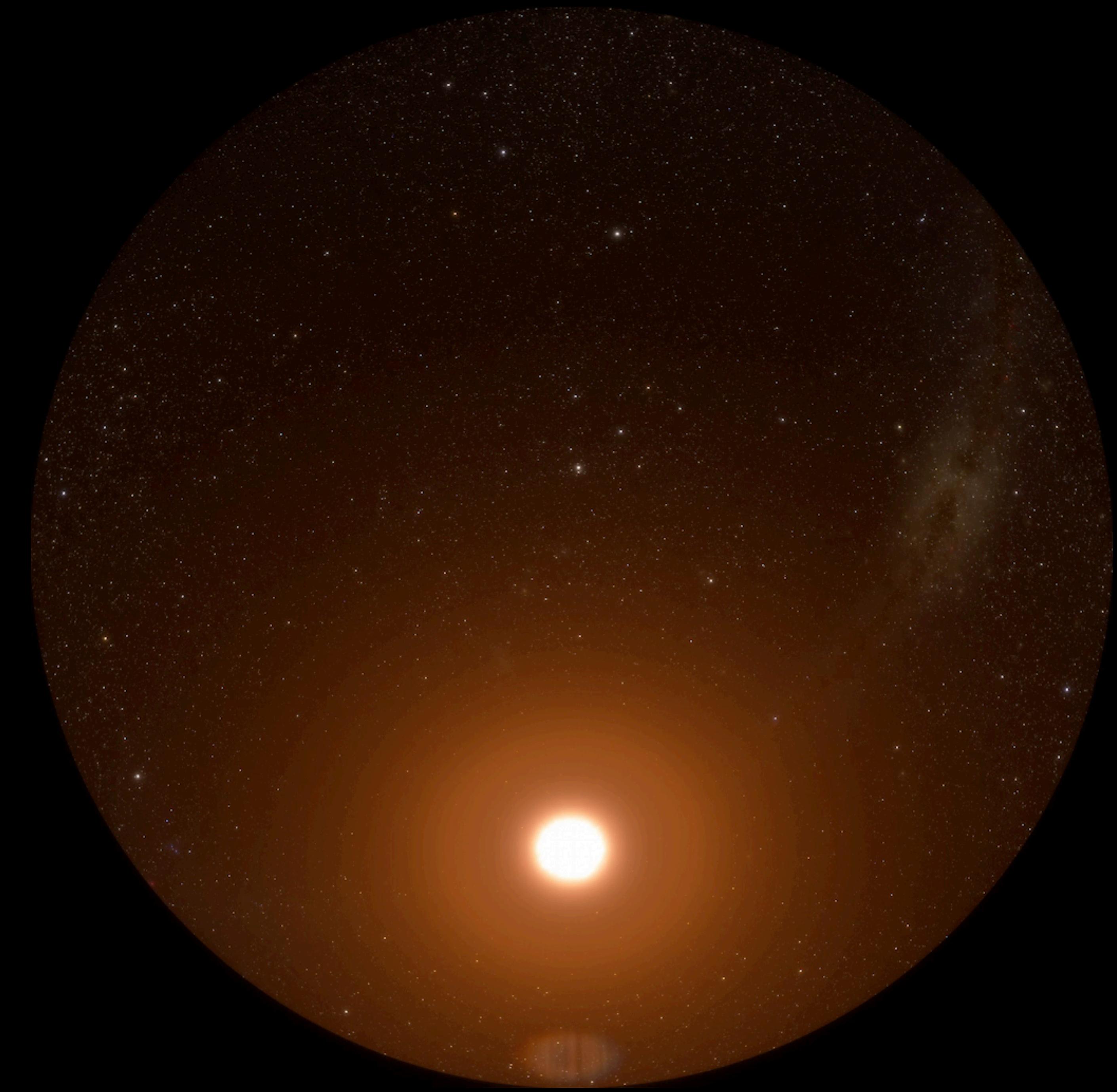
**gaya gravitasi**  
=  
**tekanan gas**

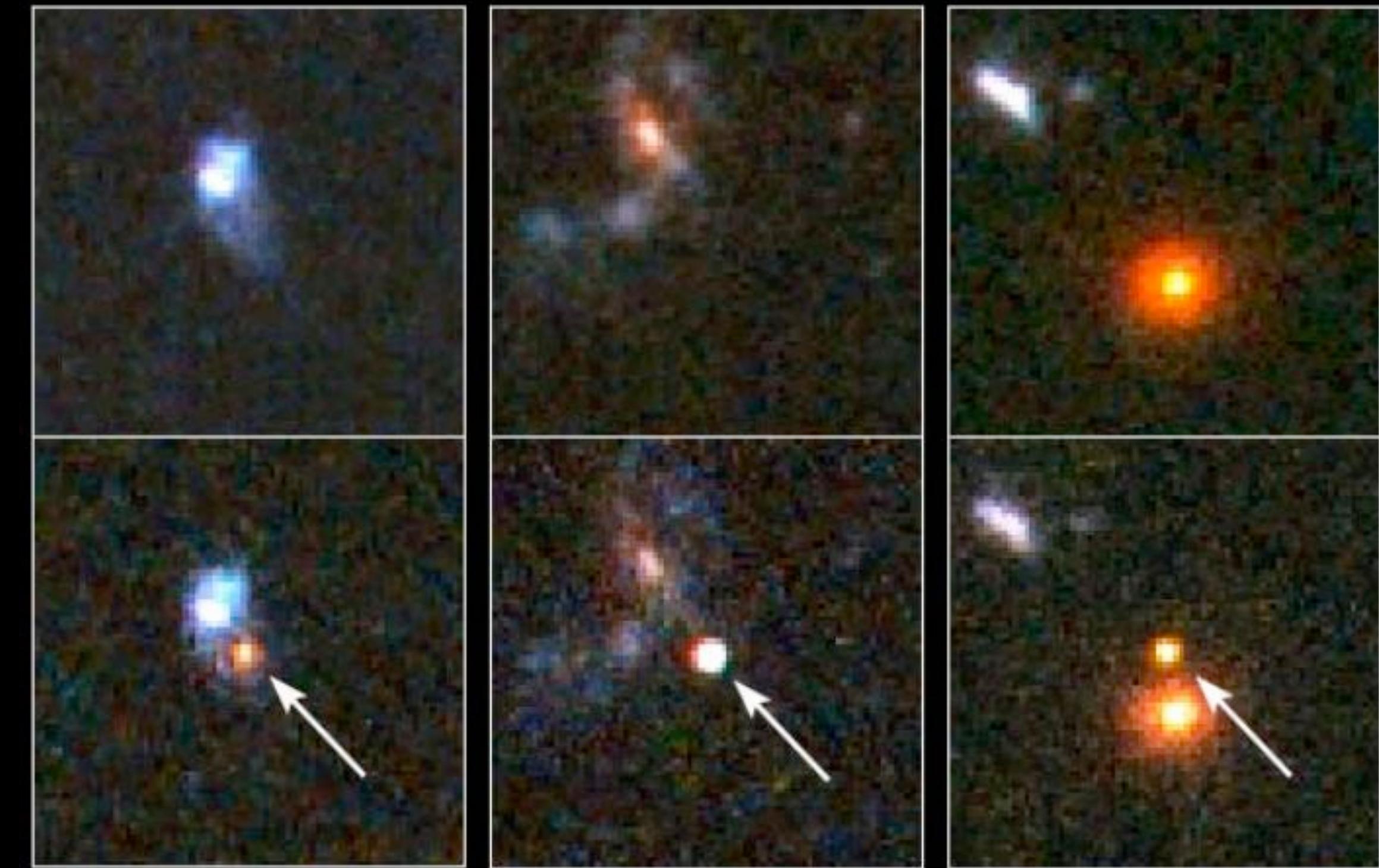
Pembentukan besi *menyerap* energi  
— bintang kehilangan tekanan gas

# Keruntuhan inti (*core collapse*)



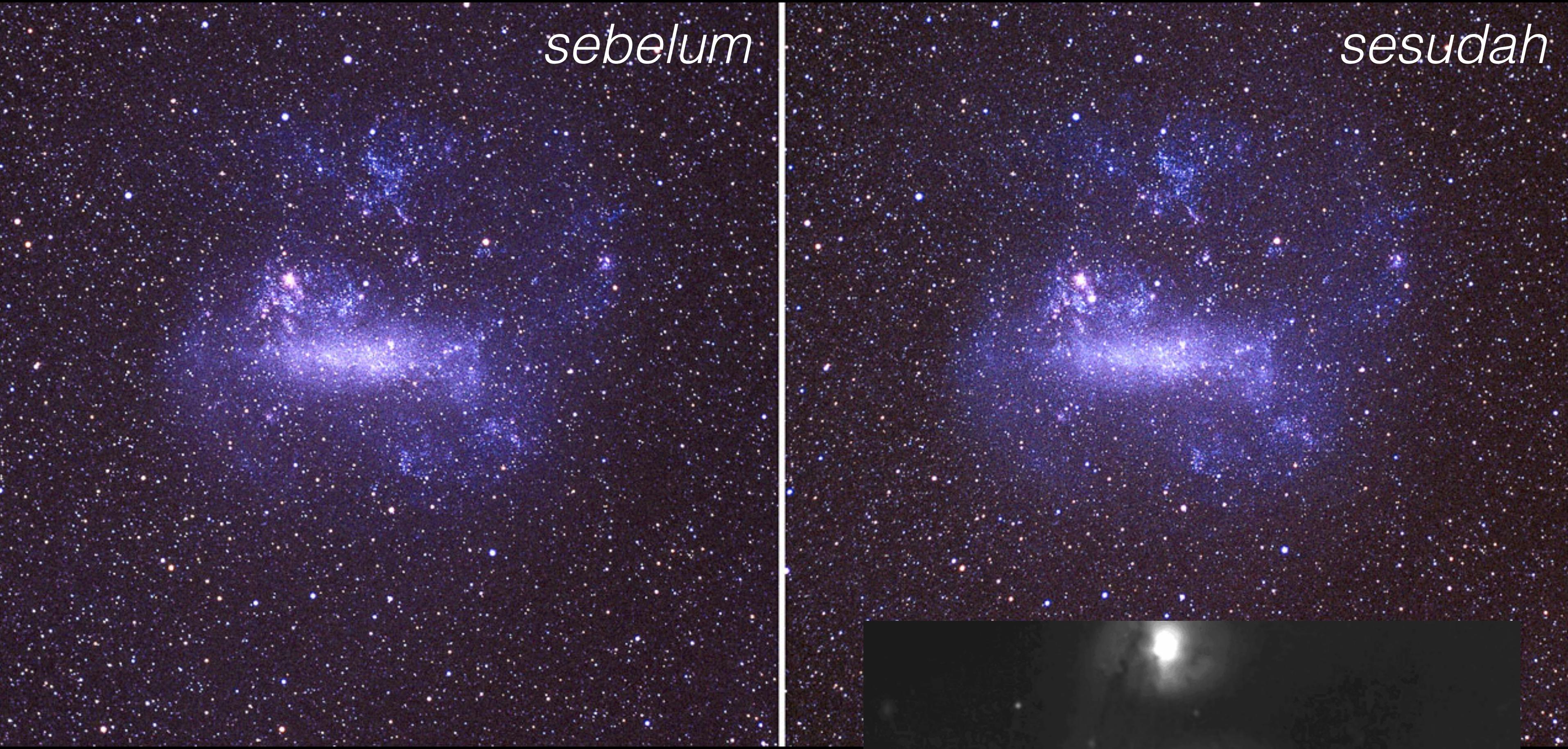






- Bisa seterang galaksi —  
100 000 000 000 Matahari
- 40 ledakan per detik di semesta
- 40 deteksi supernova baru per malam

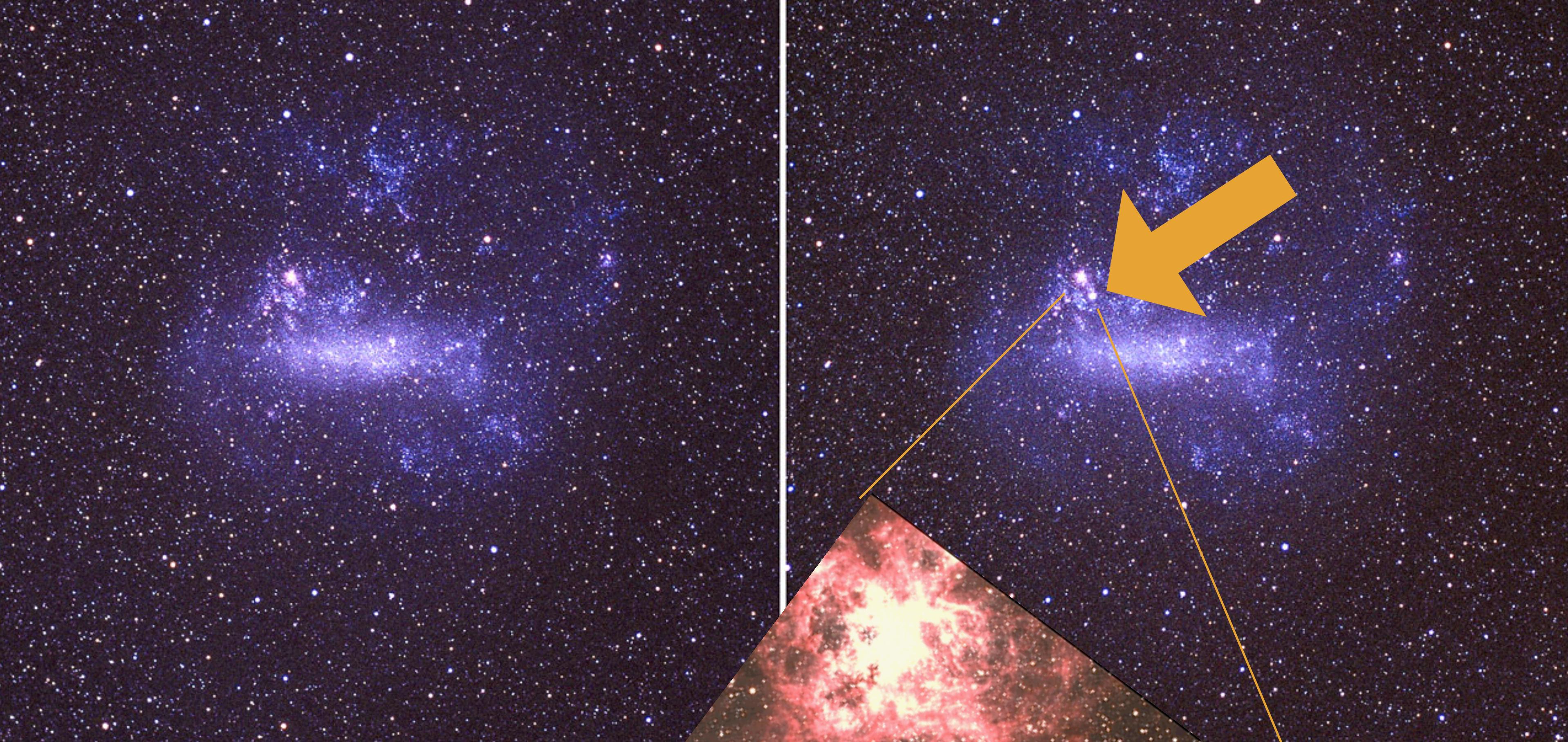
*sebelum*



*sesudah*

*nova* = baru (Latin)

Sebuah bintang ‘baru’!



**SN 1987A @ LMC**

AAT 48

# “SN 2020A”

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supernova

tahun ditemukan

urutan:  
A, B, C... Z  
aa, ab, ac... zz  
aaa, aab, aac... zzz

# “SN 2020A”

supernova

tahun ditemukan

urutan:

A, B, C... Z

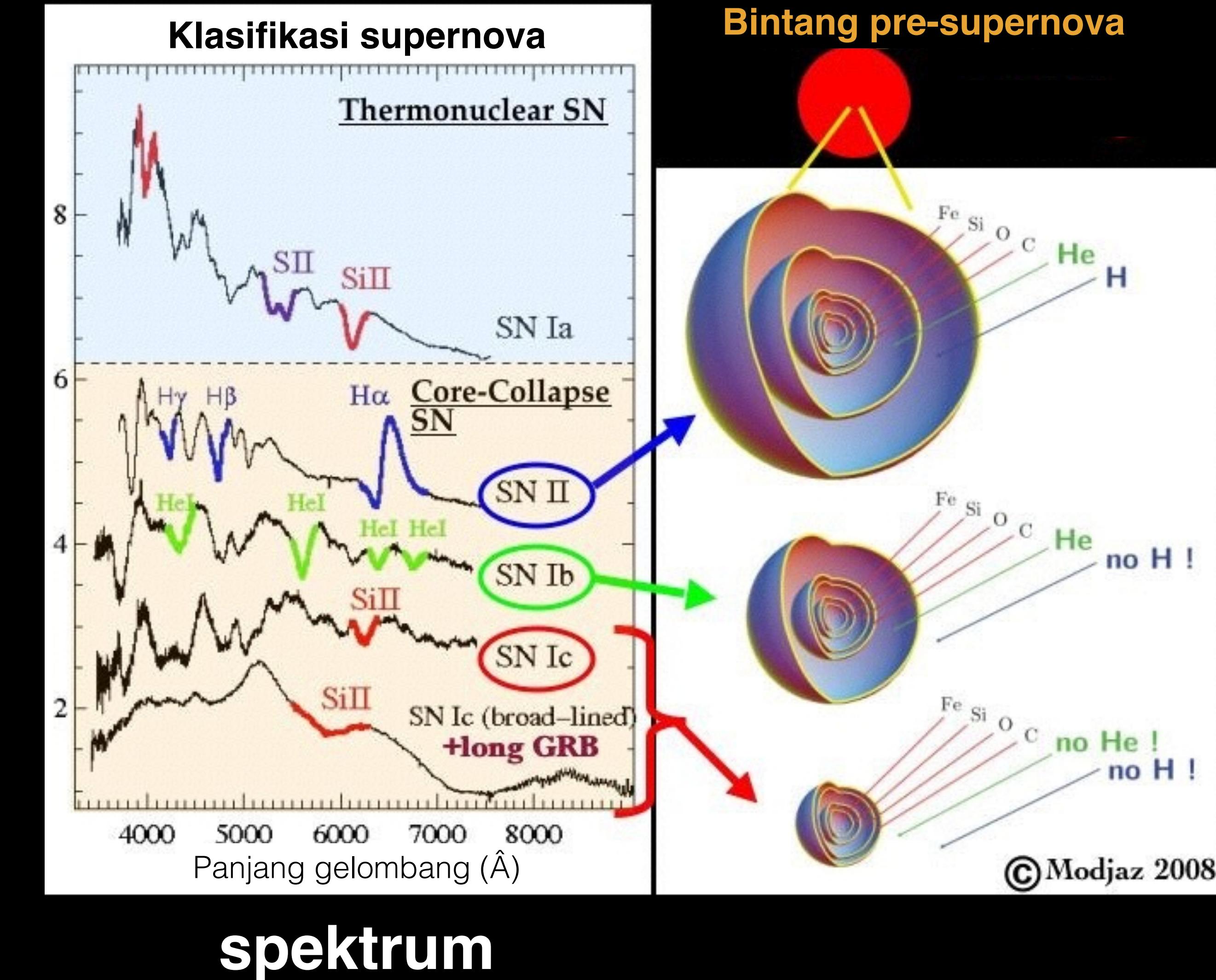
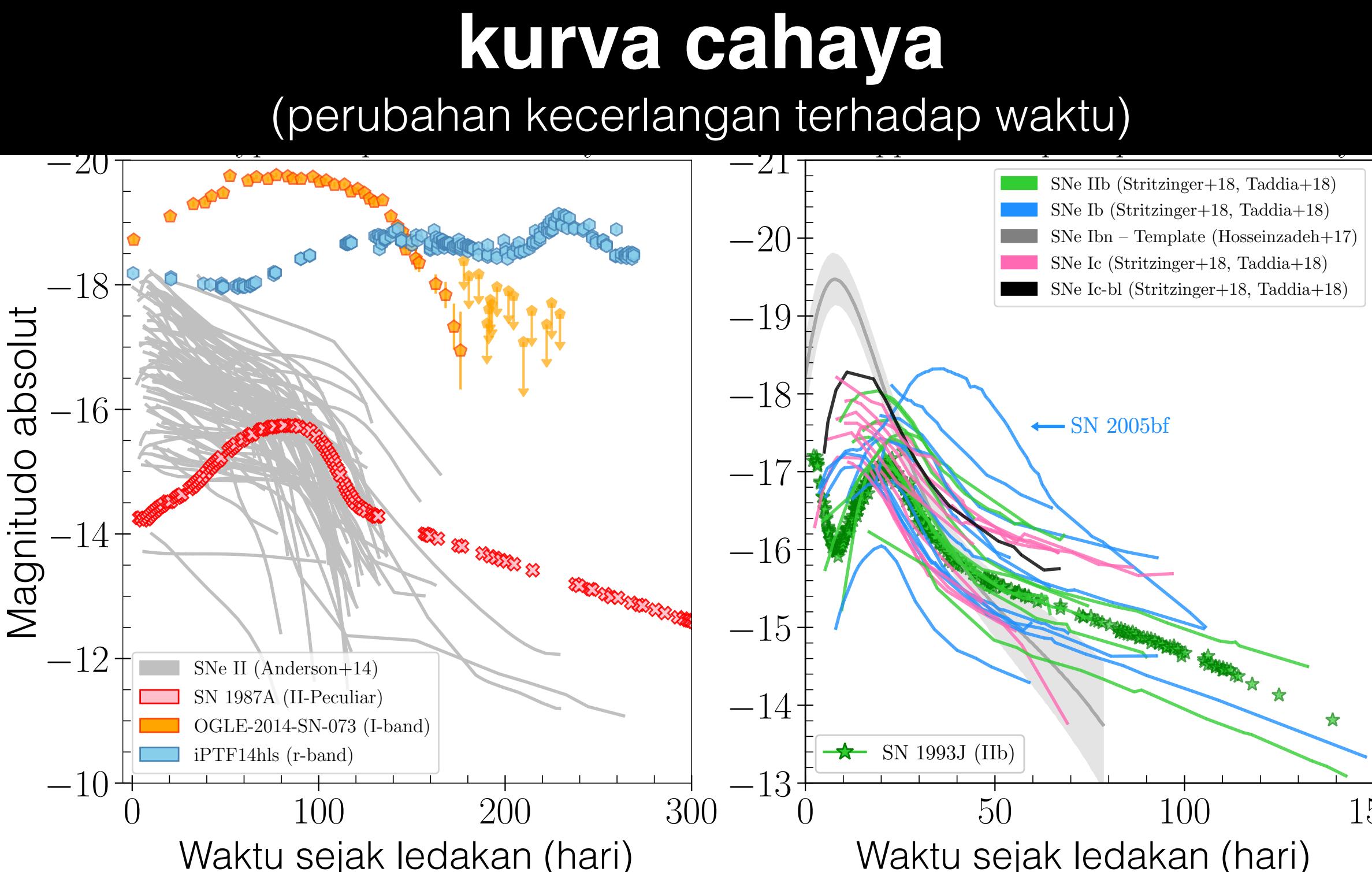
aa, ab, ac... zz

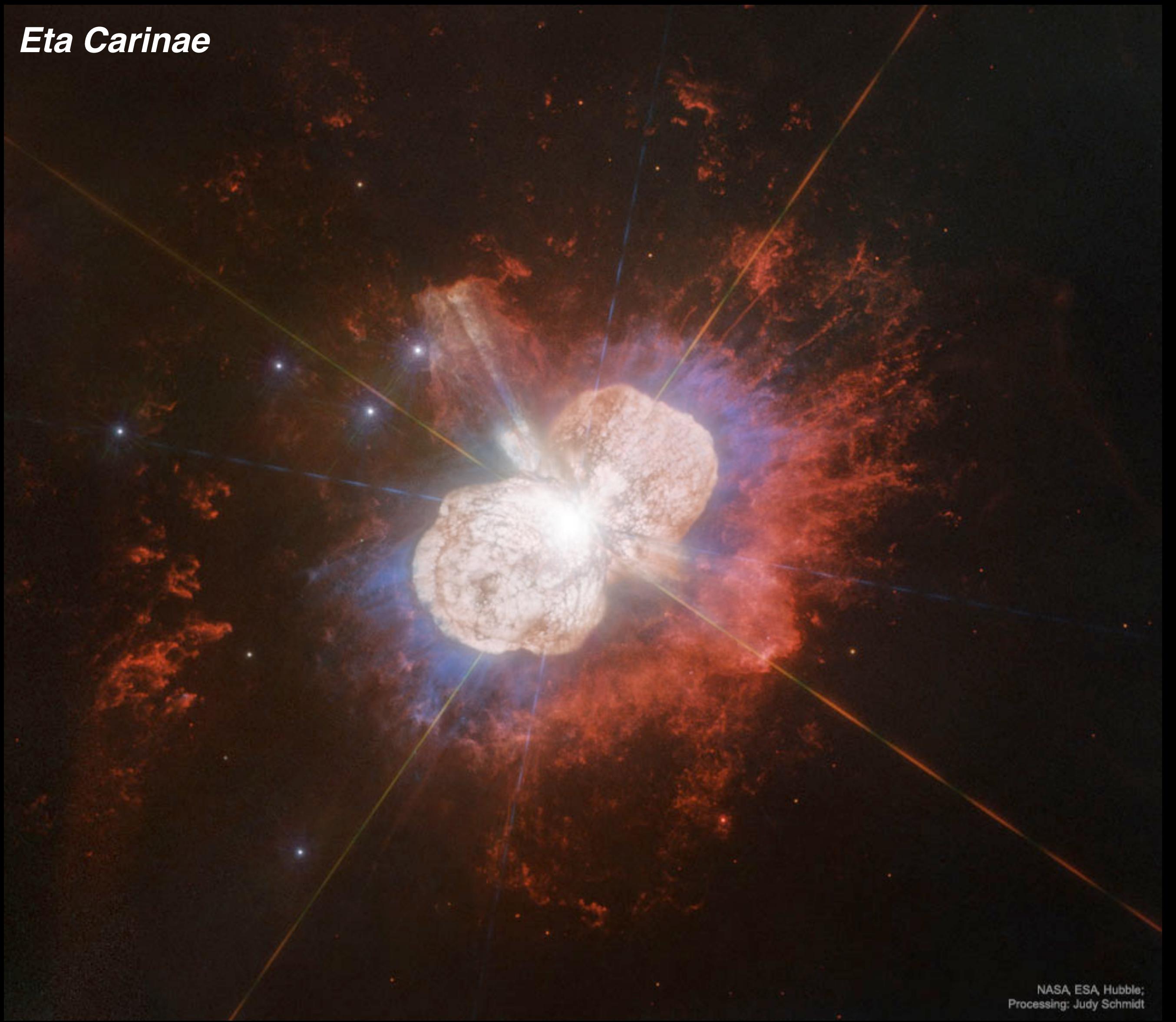
aaa, aab, aac... zzz

The screenshot shows the TNS interface for supernova AT 2019hk. At the top left is the TNS logo with a stylized tree and star. To its right is the text "TRANSIENT NAME SERVER". Below the logo is the identifier "AT 2019hk". The main background image is a colorful, multi-colored nebula or galaxy. In the top right corner of the image area is the IAU Supernova Working Group logo. The bottom half of the screen contains various data fields and navigation tools. On the left, there are coordinates: RA/DEC (2000) 09:47:05.370 -04:00:16.41 and Type Redshift --. Below these are reporting group details: Pan-STARRS1. In the center, there's a small map showing the object's position relative to the SDSS footprint, with cardinal directions N, S, E, W. To the right of the map is a small image of the astronomical object itself, with a purple arrow pointing to it. Above the image are coordinates J2000 09 47 5.37 and Dec 16.41. Below the image are buttons for search and other data sources like NED, SIMBAD, and DECaLS. At the very bottom, there's a footer with reporting group information: Reporting Group Pan-STARRS1, Discovering Data Source Pan-STARRS1, Discovery Date 2019-01-04 13:58:04.000, TNS AT Y, Public Y, Discovery Mag 20.07.

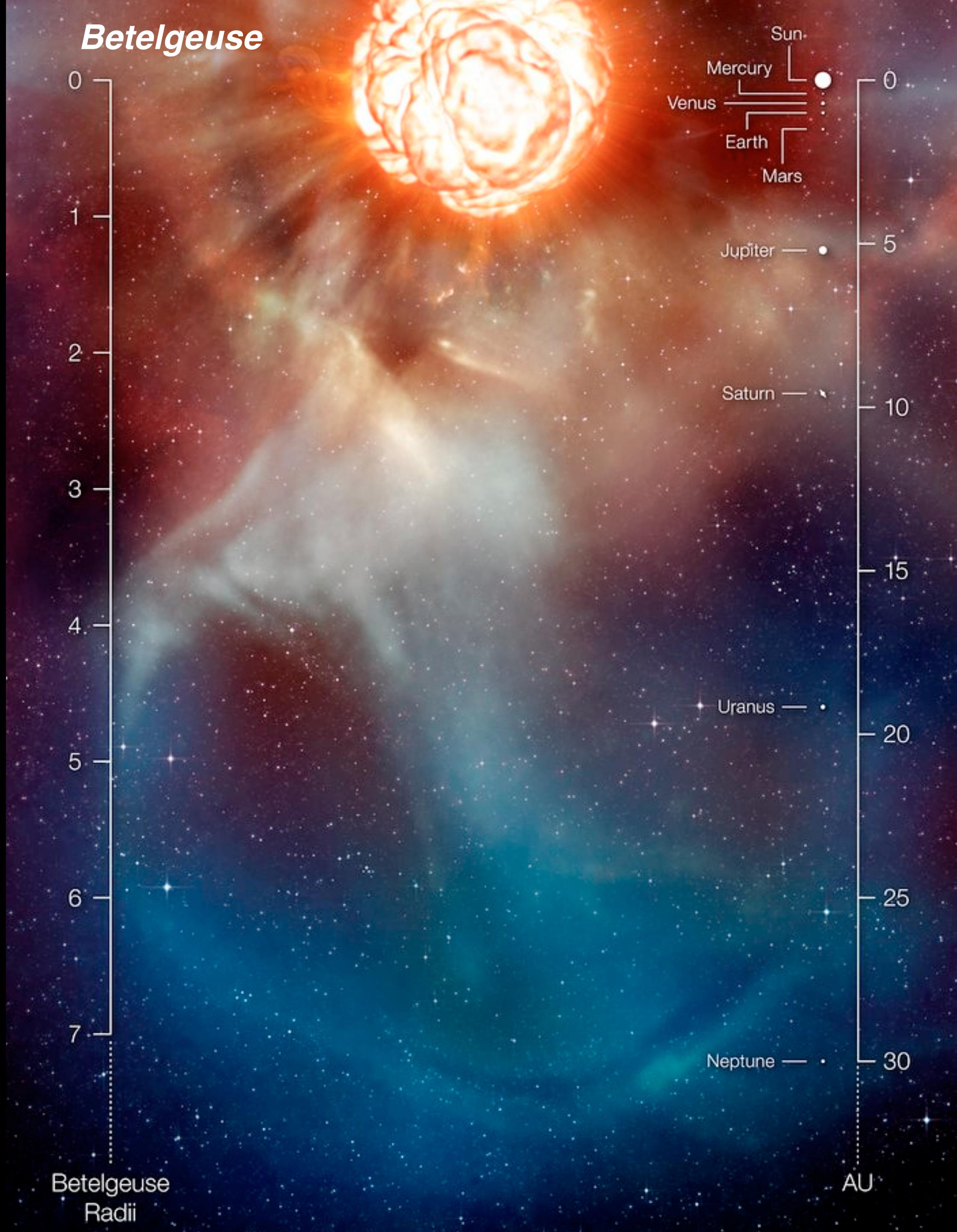
[https://wis-tns.weizmann.ac.il/  
object/2019hk](https://wis-tns.weizmann.ac.il/object/2019hk)

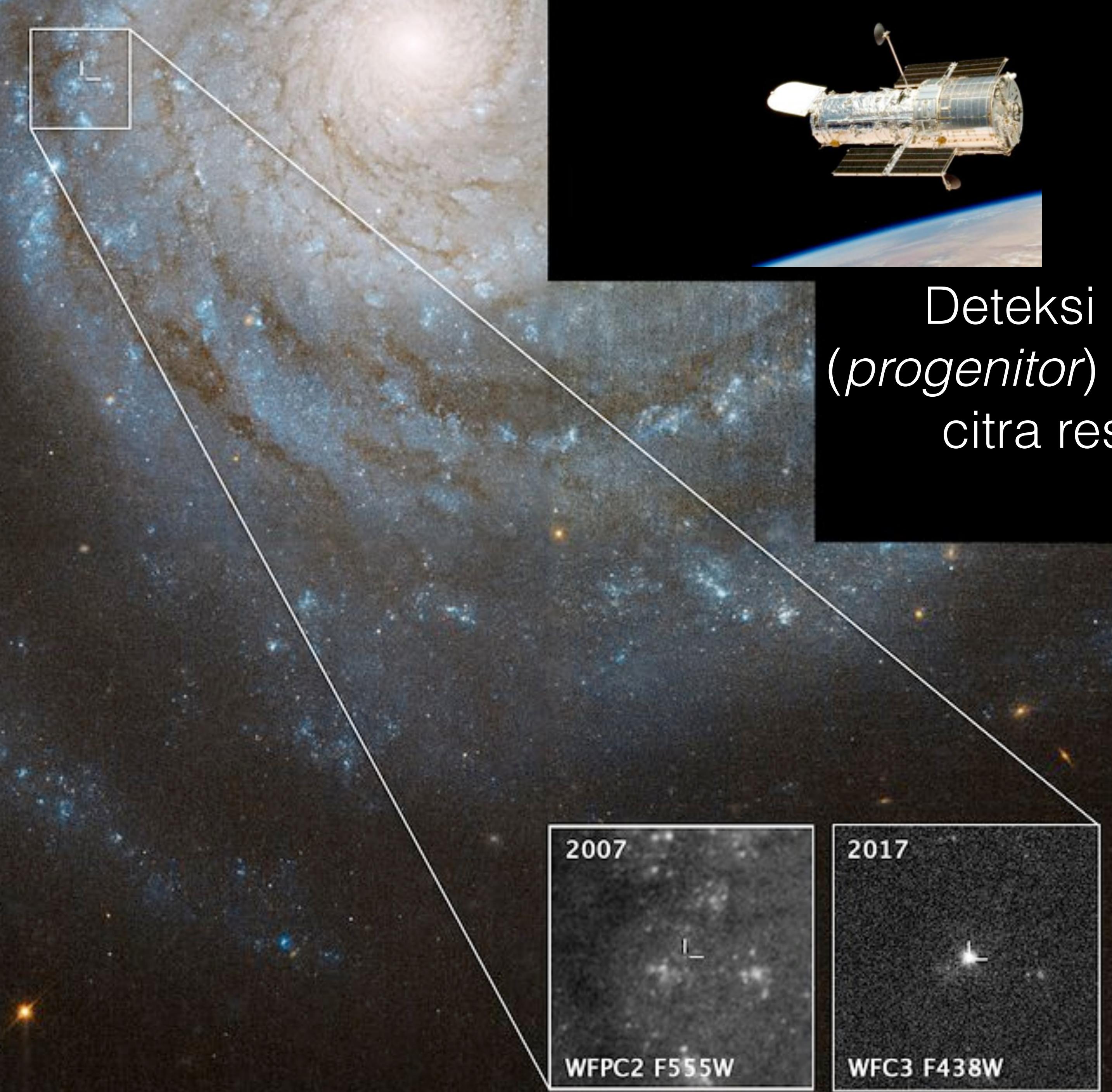
# Supernova, berbagai macam rasa



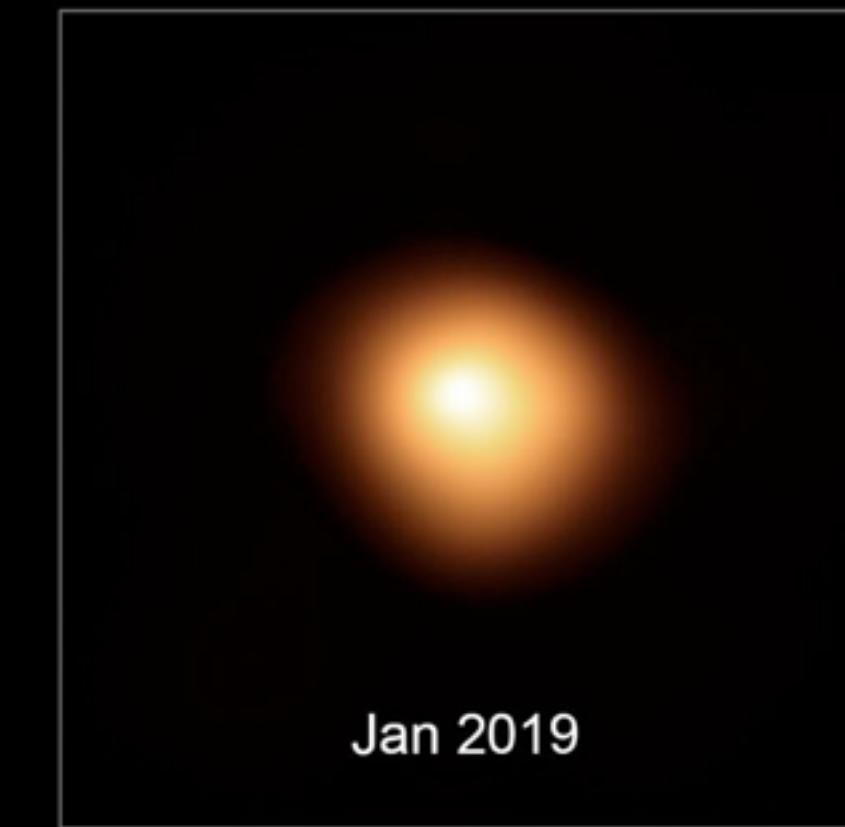


Bintang kehilangan massa

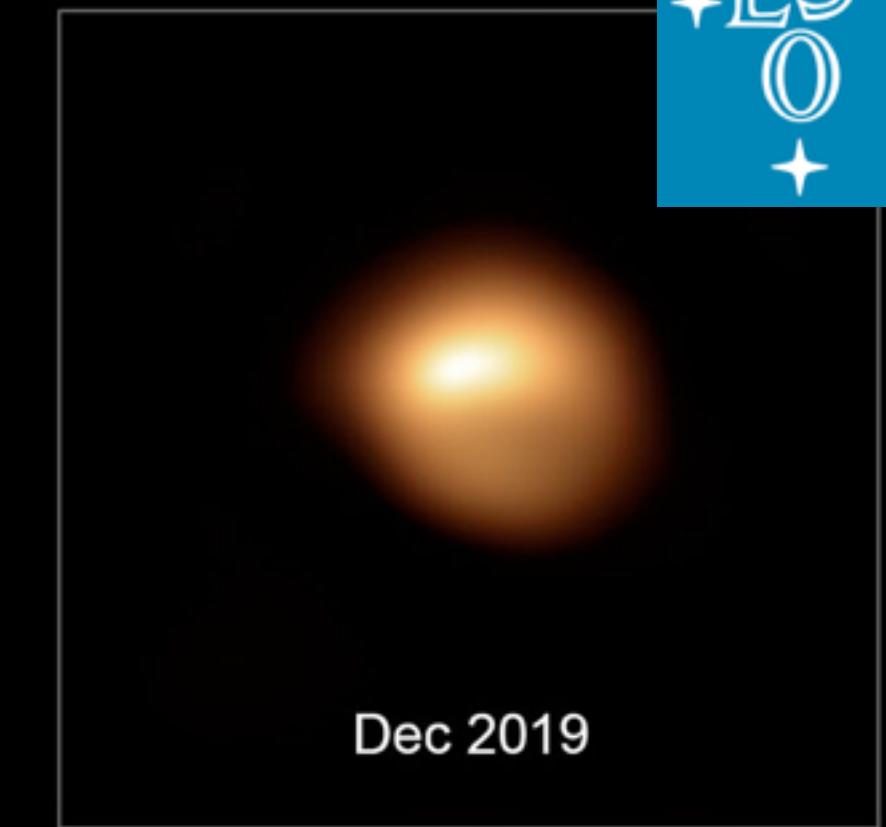




Deteksi bintang asal  
(*progenitor*) supernova pada  
citra resolusi tinggi



Jan 2019

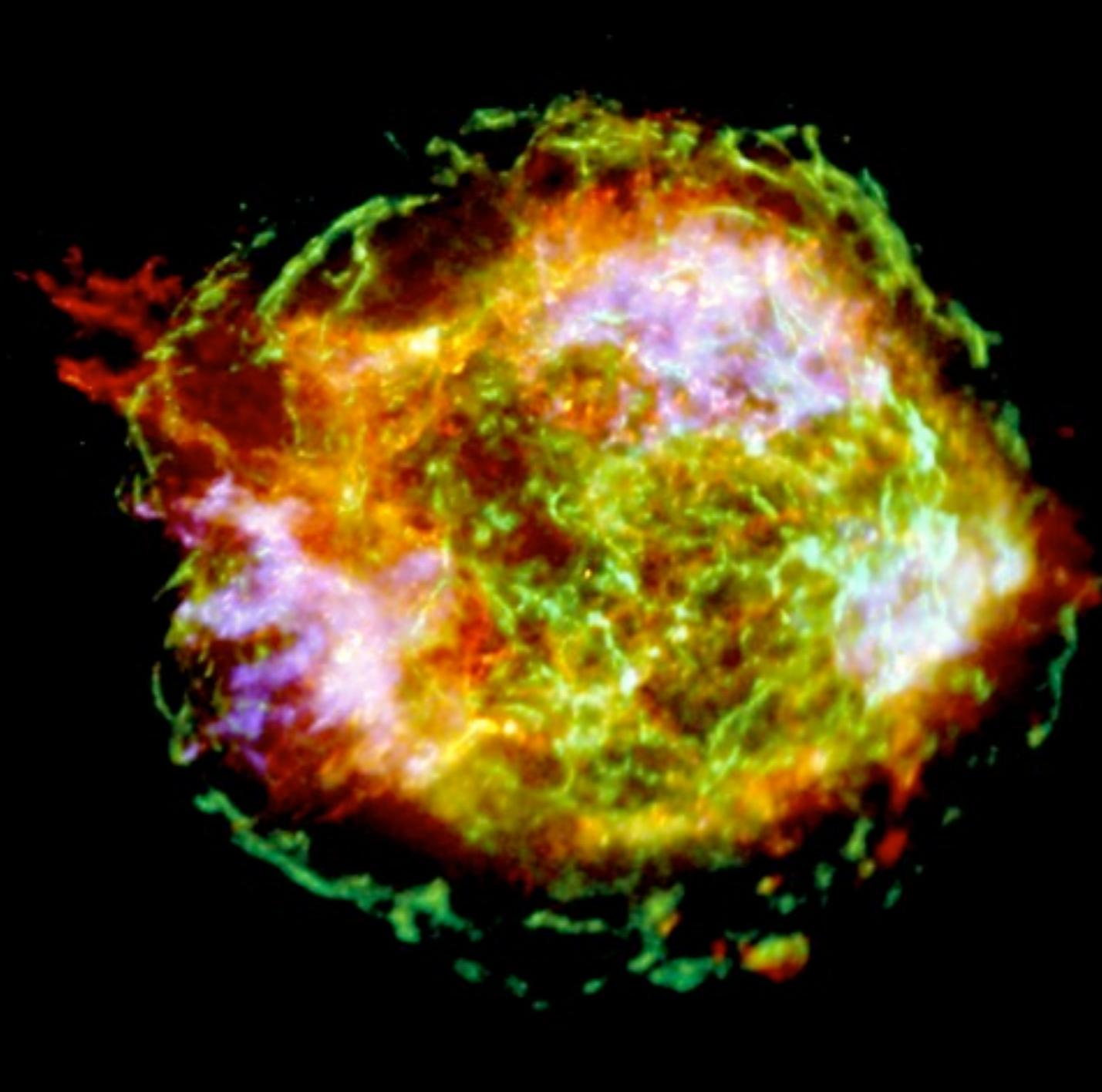
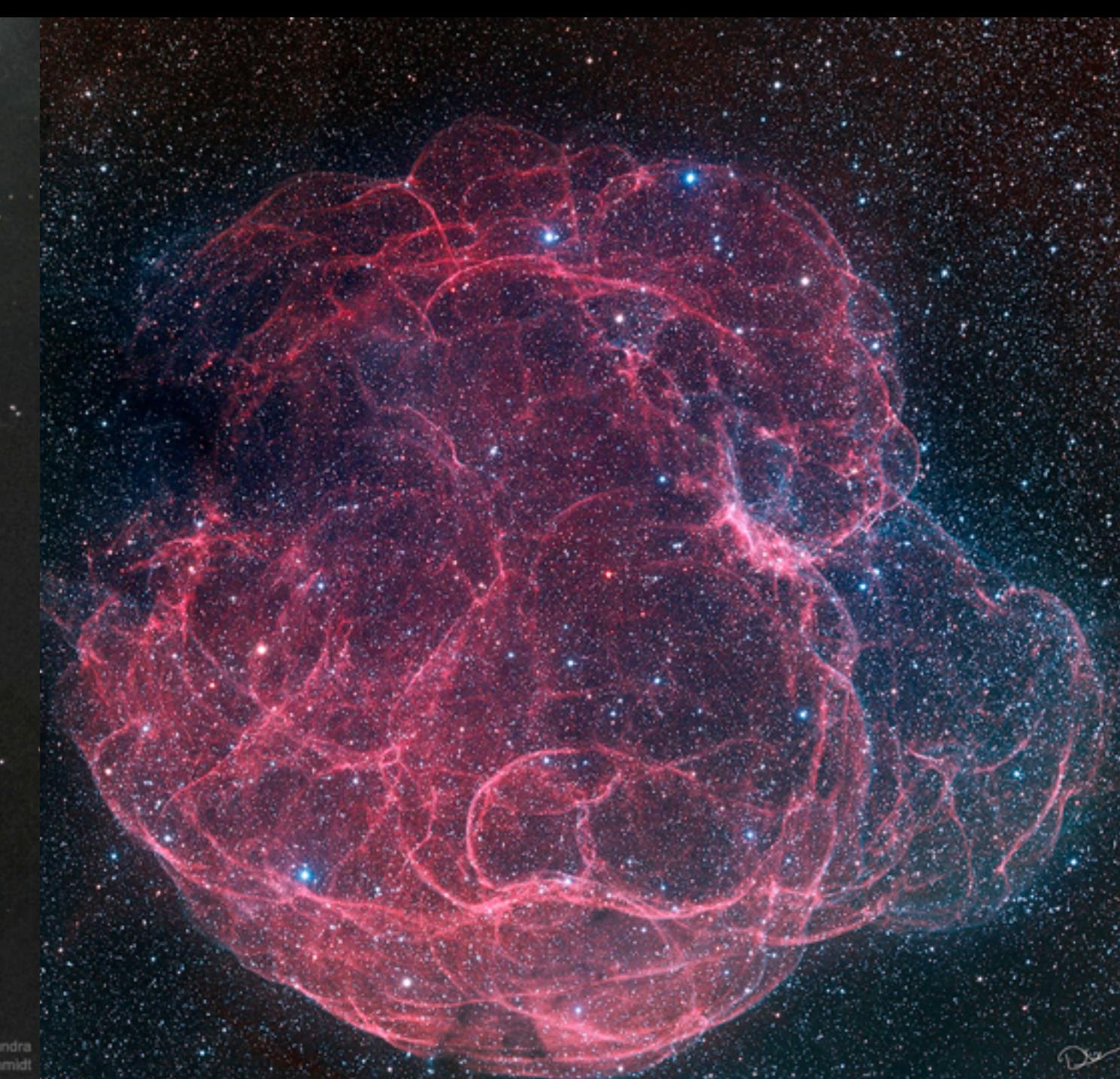
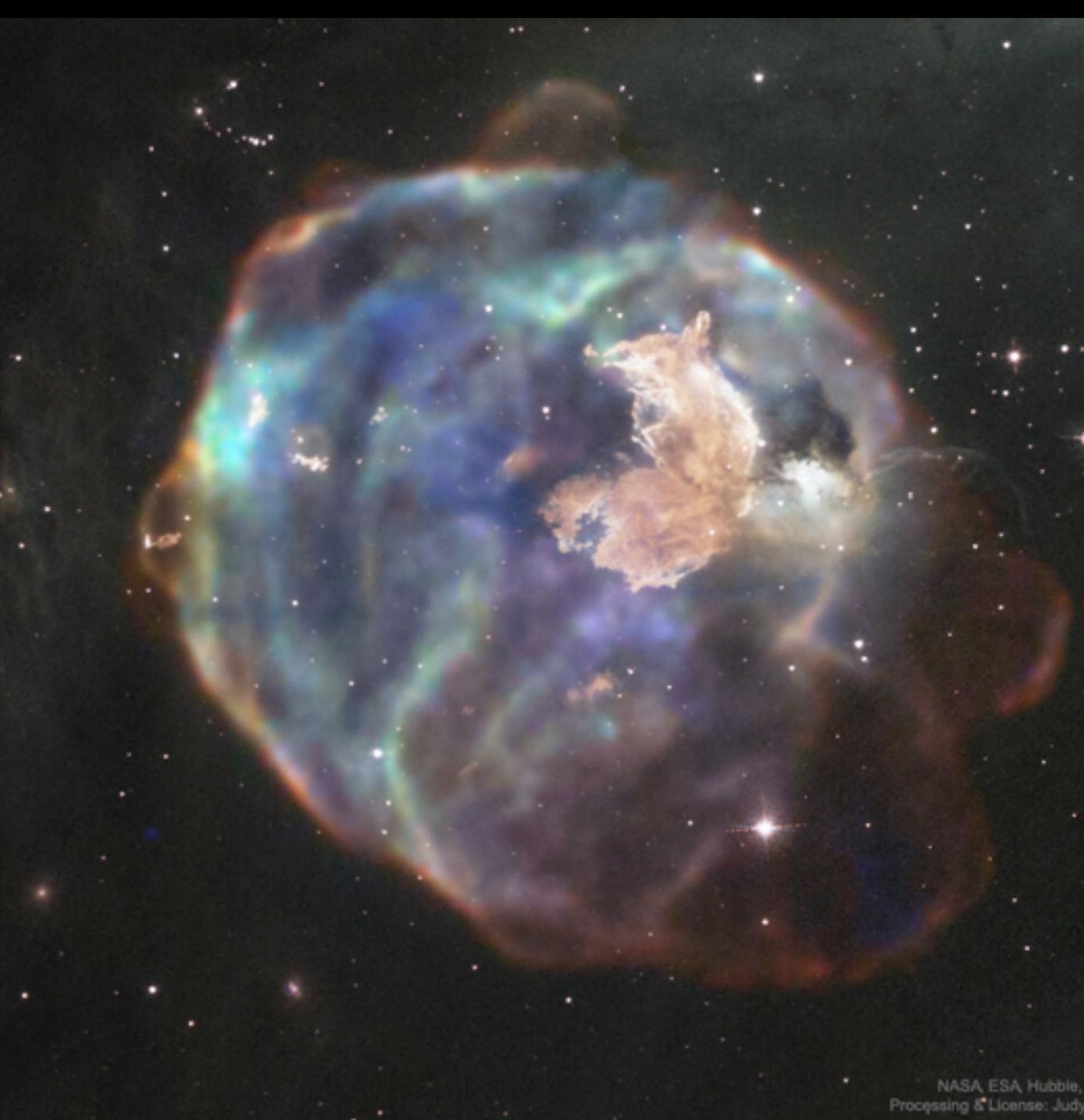


Dec 2019

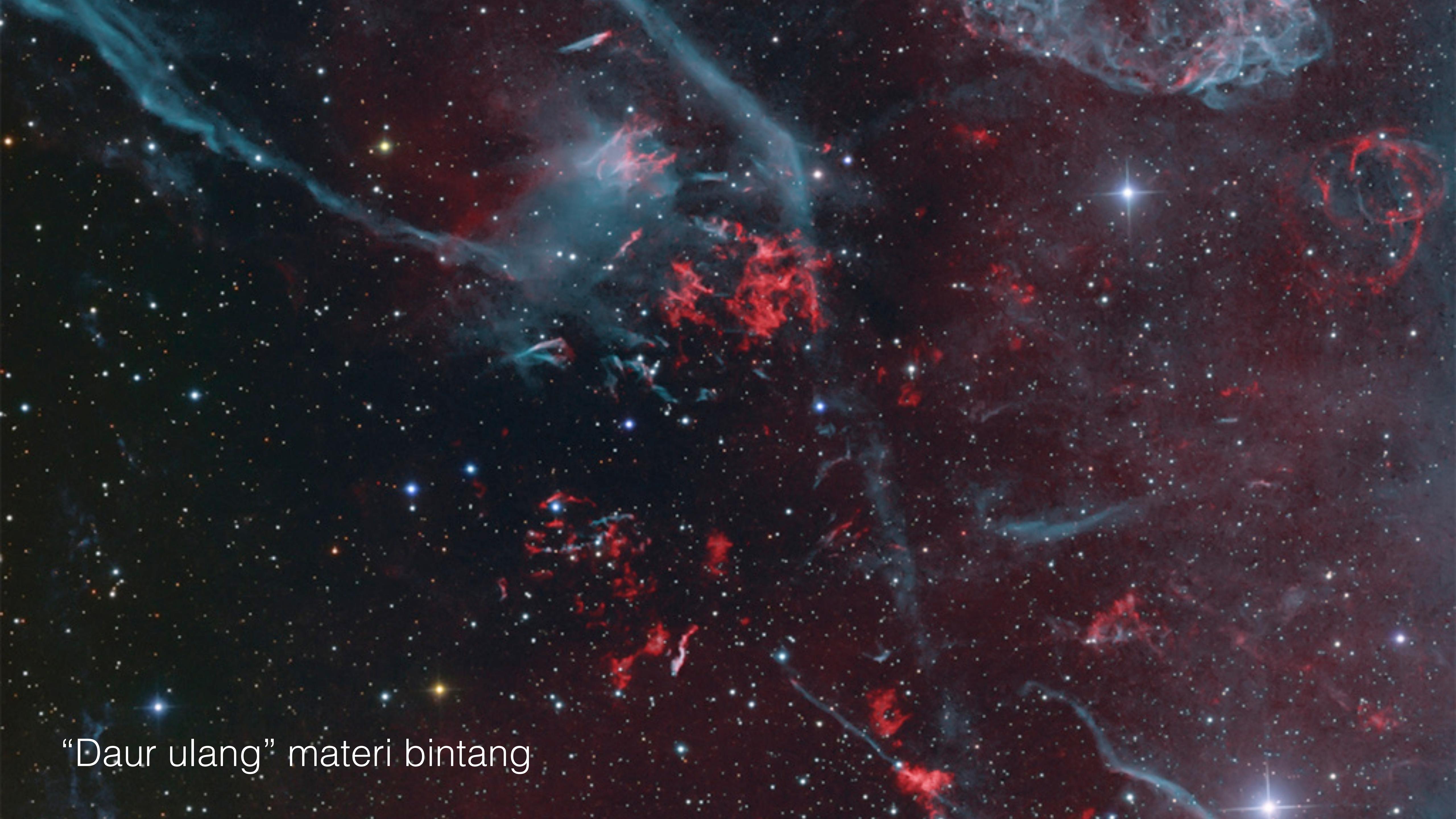
Beberapa mirip Betelgeuse



Setelah supernova?

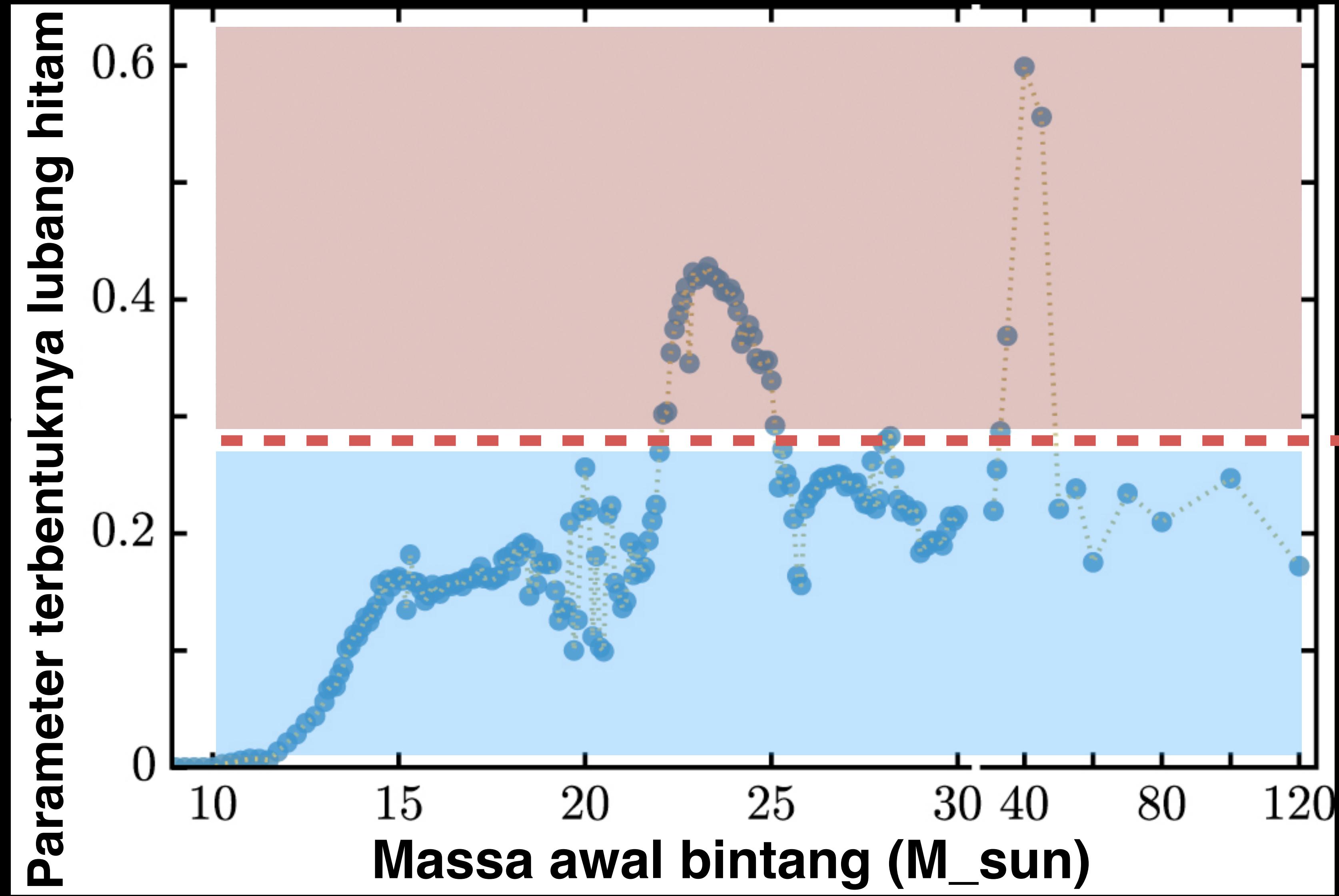


Puing-puing  
supernova



“Daur ulang” materi bintang

- Bagaimana dengan objek kompak yang tersisa?
- Apa yang membedakan proses evolusi bintang hingga menghasilkan bintang neutron atau lubang hitam?

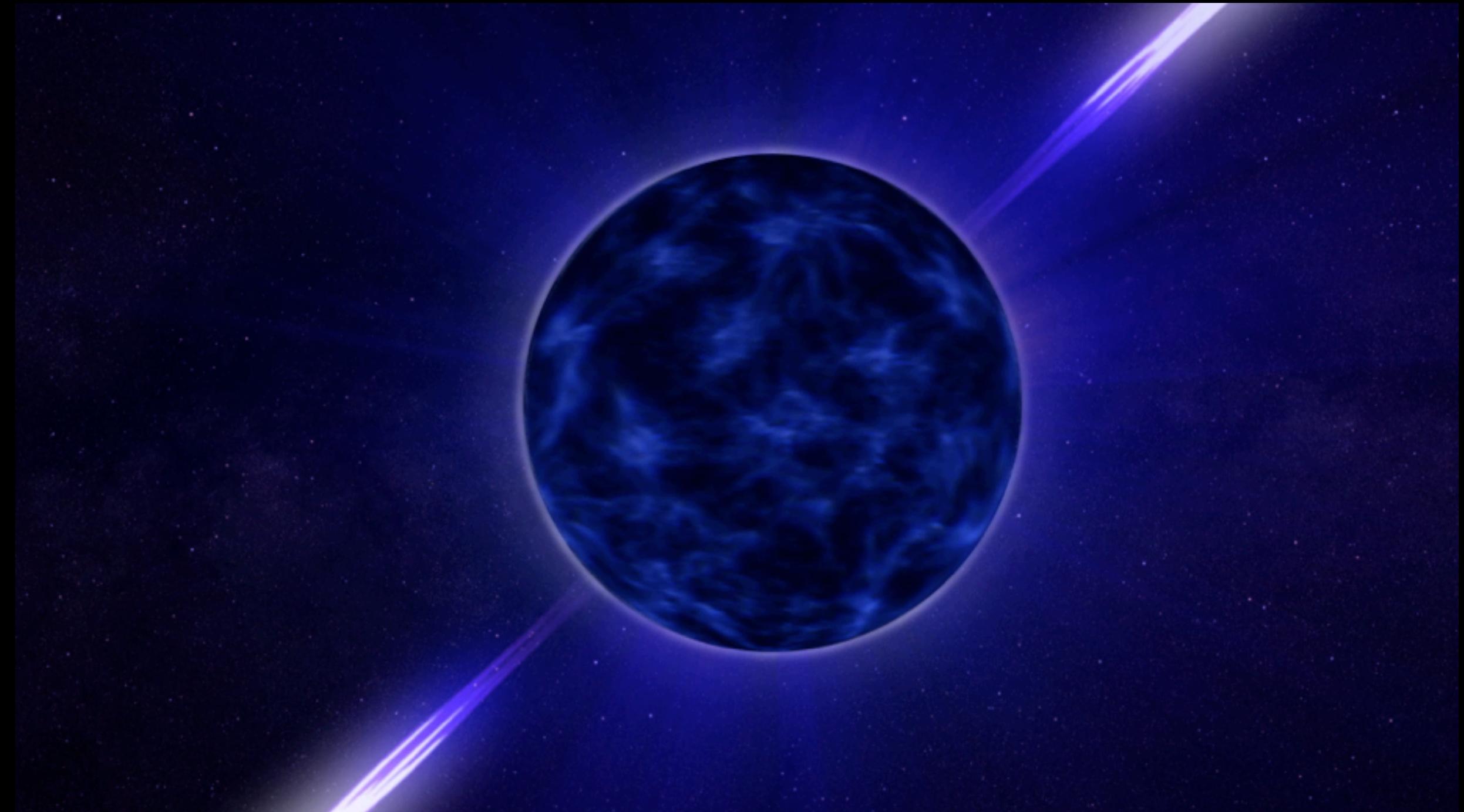


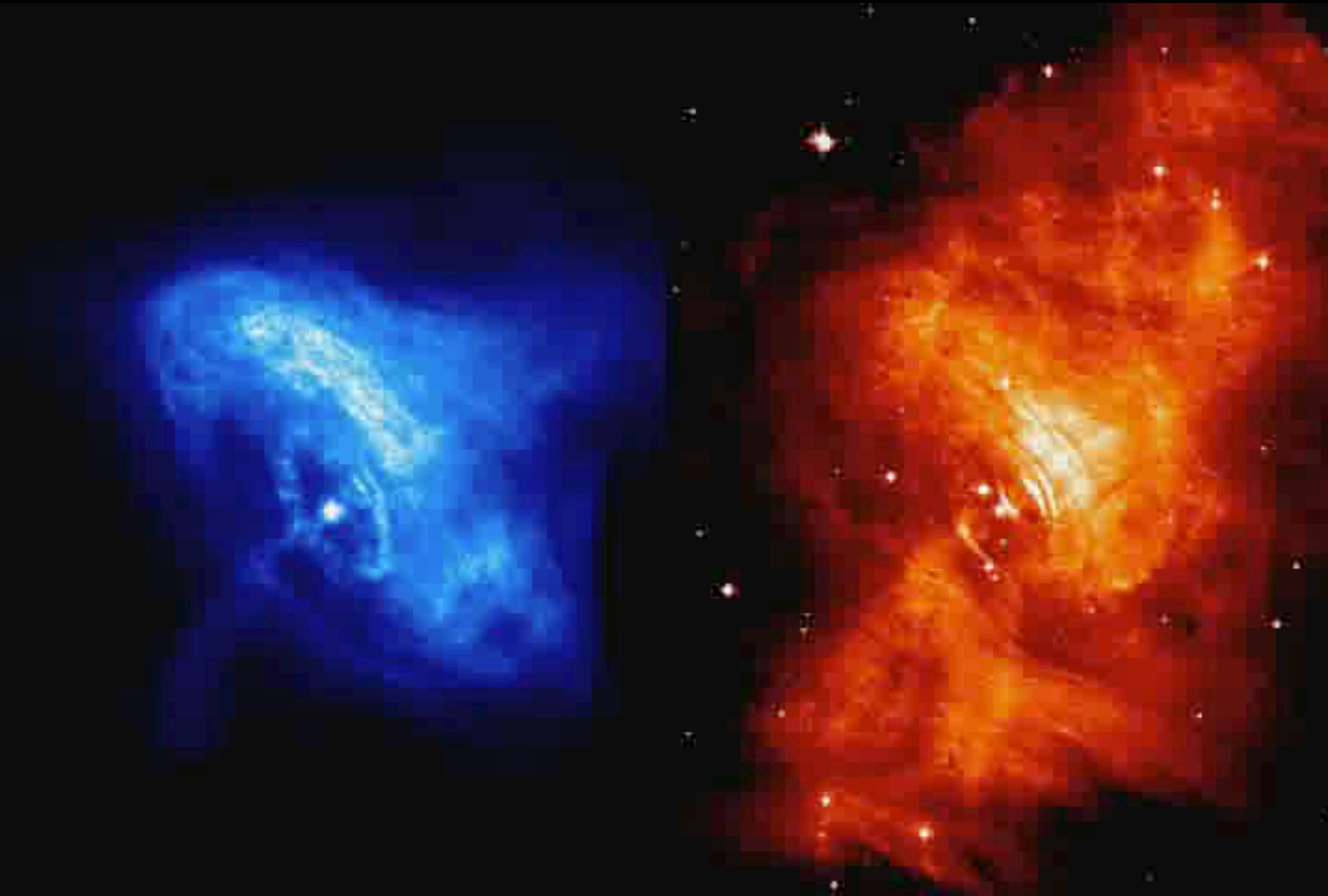
*Lubang  
hitam*

*Bintang  
neutron*

# Bintang neutron dan pulsar

- Inti bintang termampatkan hingga berukuran  $\sim 10$  km
- 1-2 massa Matahari, berputar hingga ratusan kali per detik
- Kerapatan tinggi, 100 juta ton per 1 sendok teh materi!

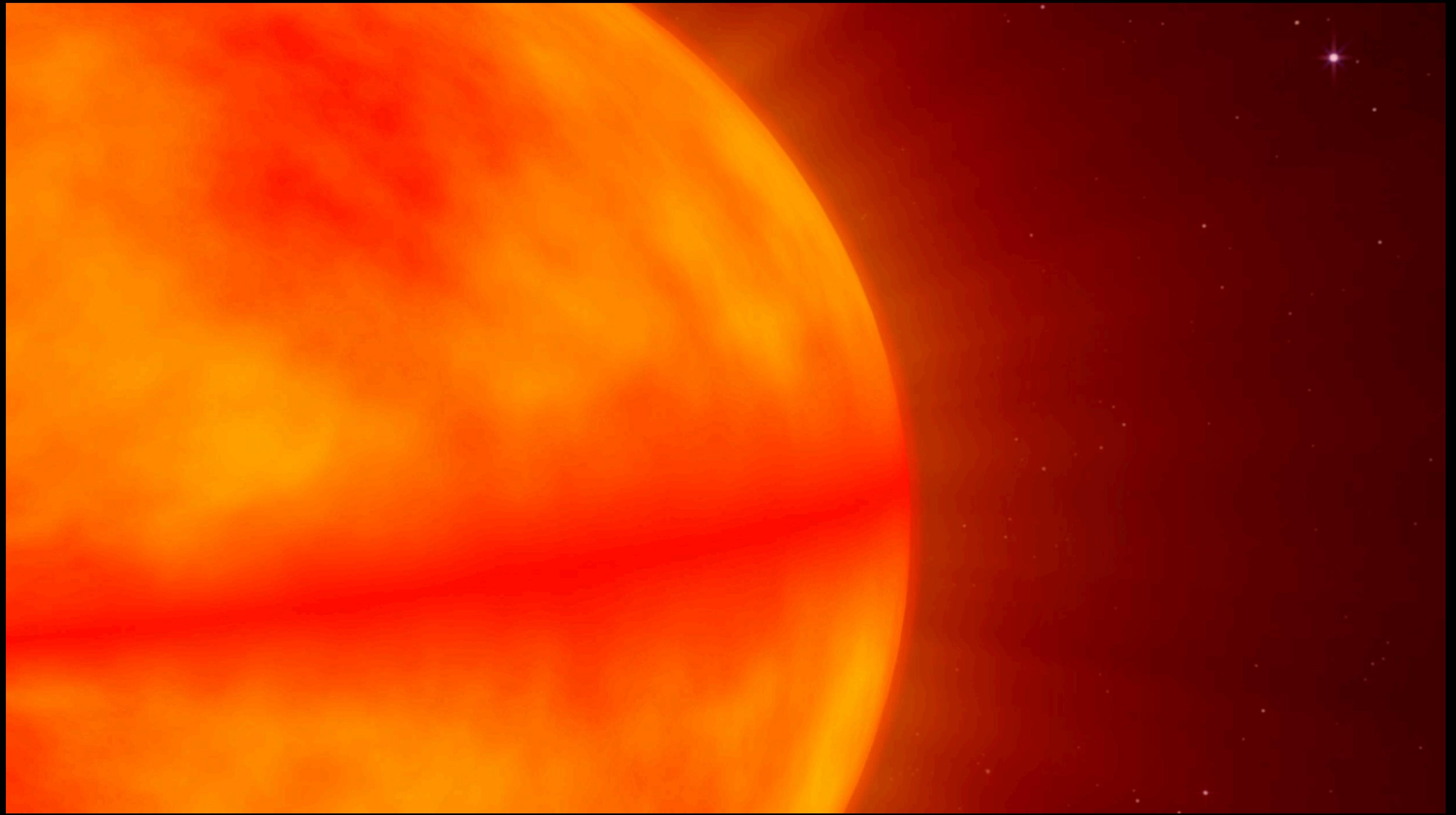


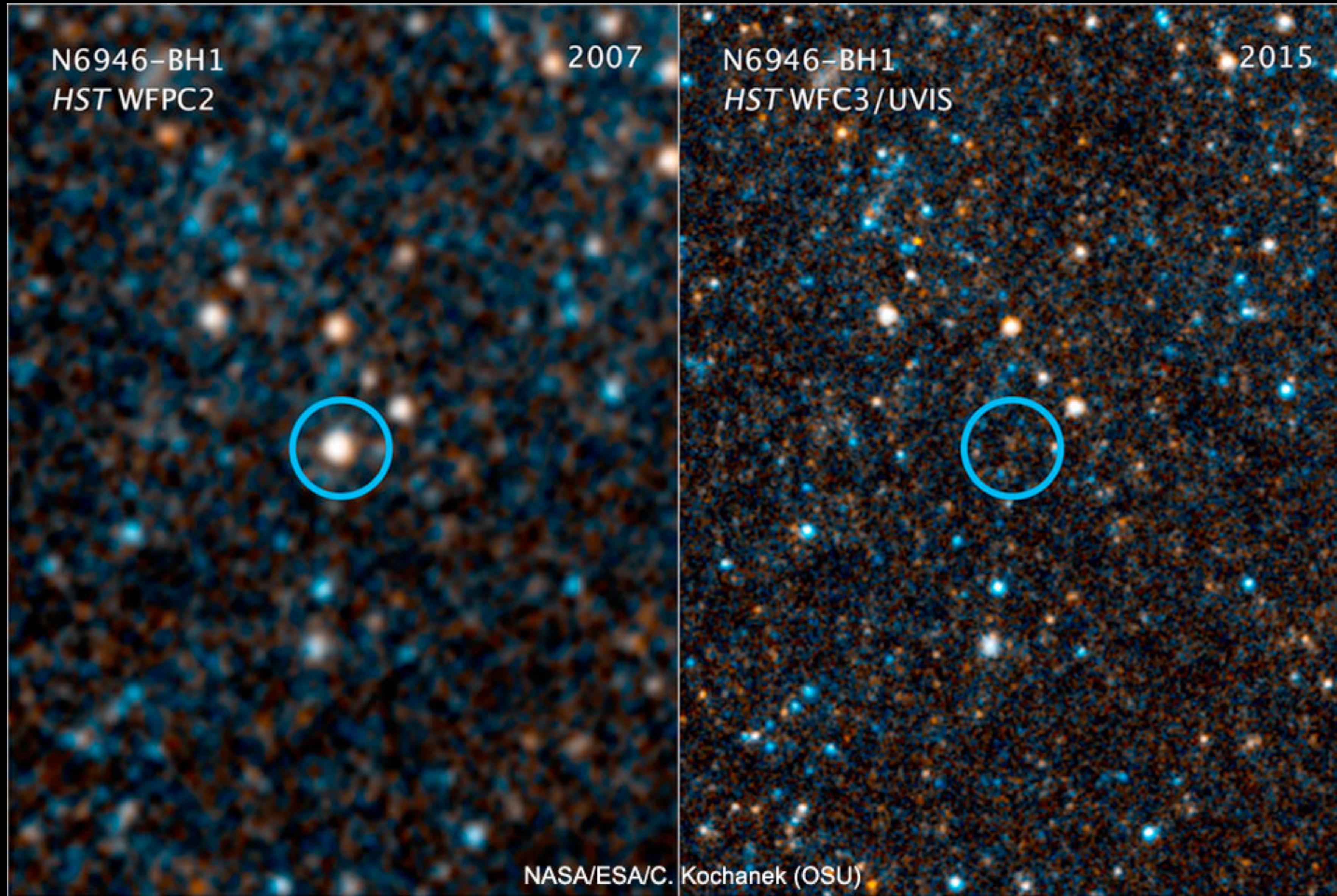


Pulsar Nebula Kepiting,  
pengamatan teropong angkasa *Chandra* (kiri) dan *Hubble* (kanan)

# Lubang hitam

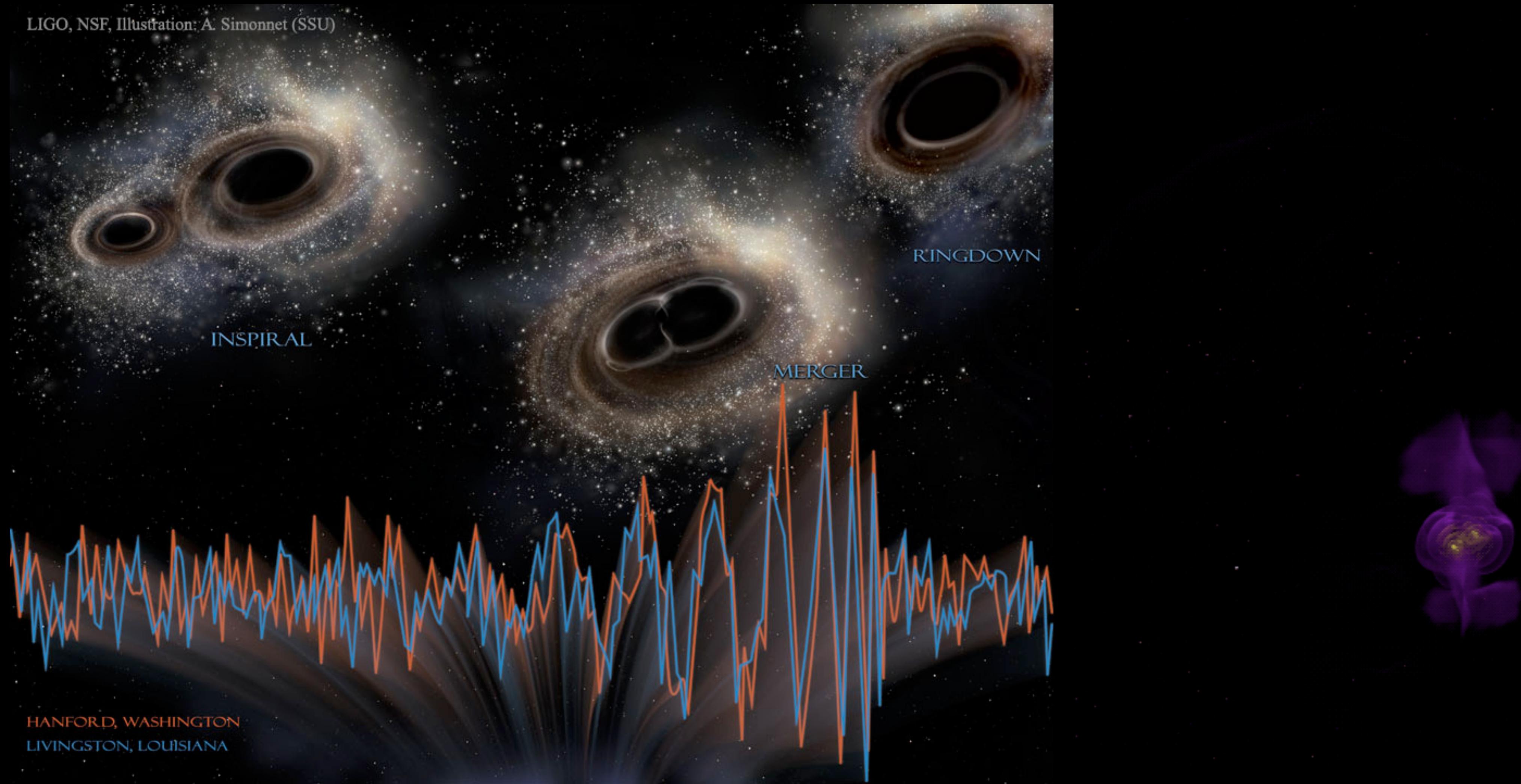






Bintang menghilang tanpa supernova → runtuh dan membentuk lubang hitam?

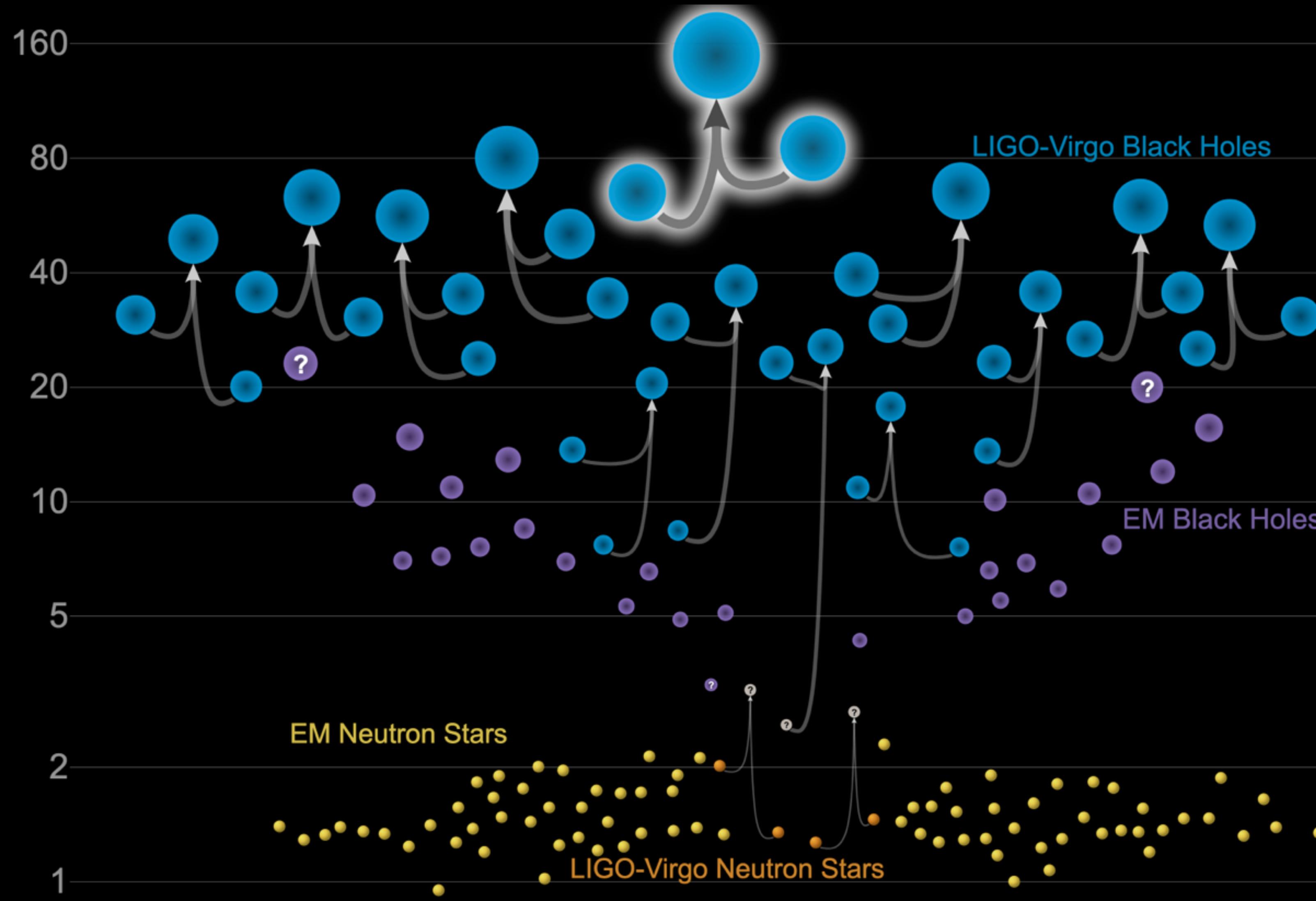
LIGO, NSF, Illustration: A. Simonnet (SSU)



Gelombang gravitasi: jendela baru ke alam semesta

# Objek-objek di ‘kuburan bintang’

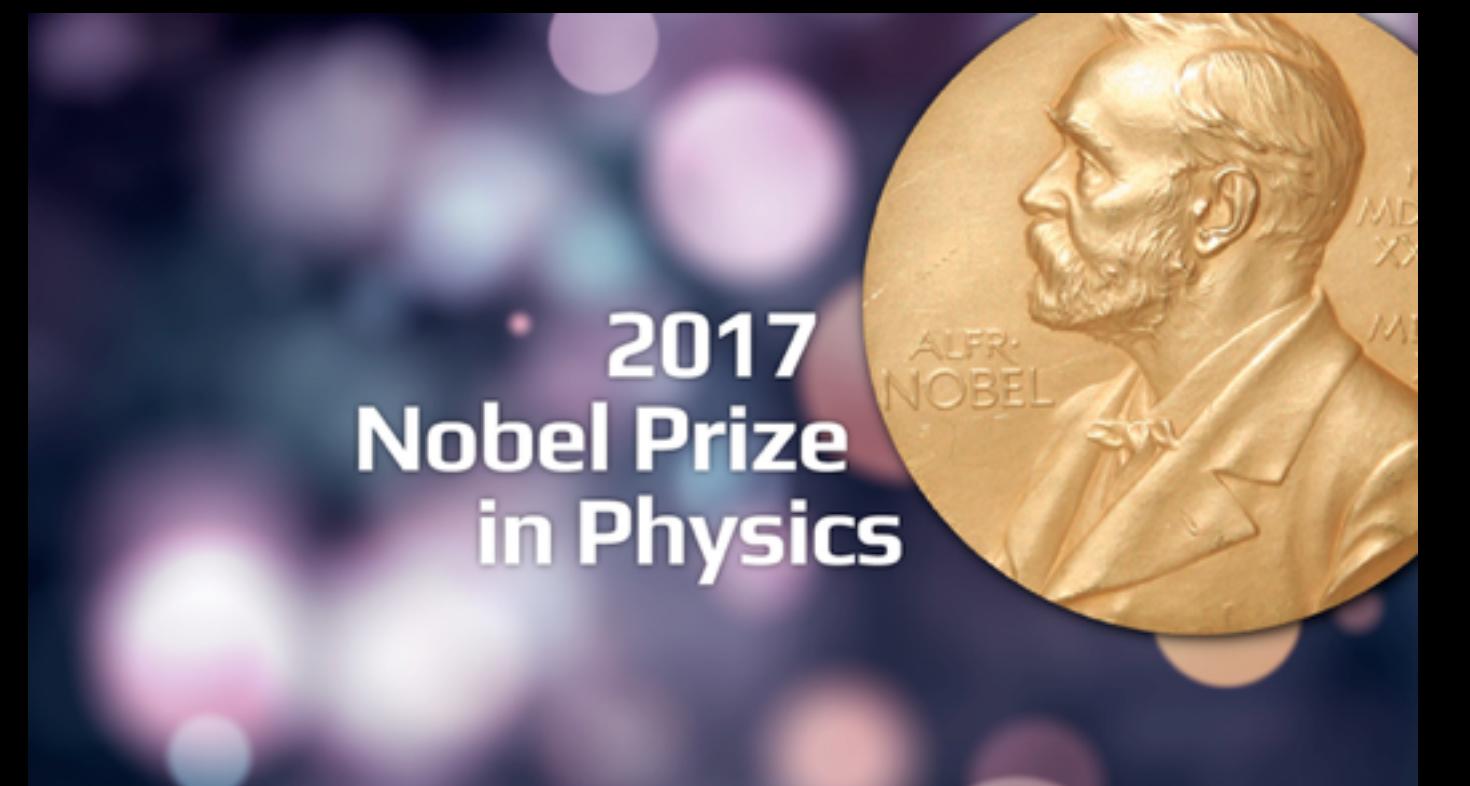
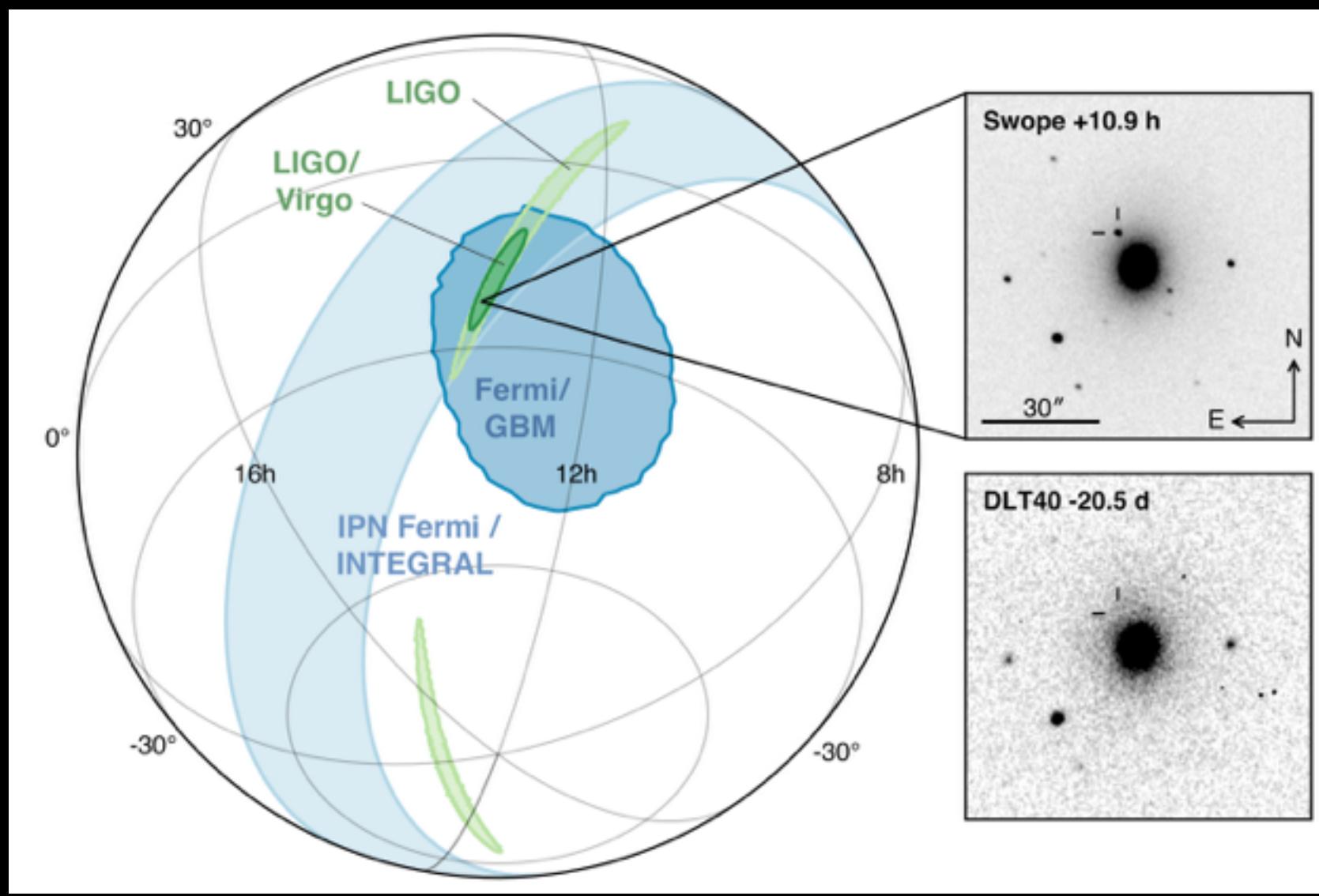
dalam satuan massa Matahari



Updated 2020-09-02

LIGO-Virgo | Frank Elavsky, Aaron Geller | Northwestern

**Kilonova** 17 Agustus 2017 



# hidrogen

# helium

# natrium

# kalsium

# besi nikel tembaga

karbon nitrogen oksigen

# sulfur

**Fusi  
big  
bang**

**Fisi  
sina  
kosm**

**Bintan  
massa  
rendah**

**Merge  
bintan  
neutro**

# **Supernova bintang masif**

# **Supernova katai putih**

B	C	N	O	F	Ne
5	6	7	8	9	10
Al	Si	P	S	Cl	Ar
13	14	15	16	17	18
Ga	Ge	As	Se	Br	Kr
31	32	33	34	35	36
In	Sn	Sb	Te	I	Xe
49	50	51	52	53	54
Tl	Pb	Bi	Po	At	Rn
81	82	83	84	85	86

# \_perak

— emas

Wikipedia: Cmglee  
Data: Jennifer Johnson (OSU)

# uranium



**Sumber gambar & video:**

[nasa.gov](http://nasa.gov)

[eso.org](http://eso.org)

[hubblesite.org](http://hubblesite.org)

[rainman.astro.illinois.edu/ddr/stellar/beginner.html](http://rainman.astro.illinois.edu/ddr/stellar/beginner.html)

[chandra.harvard.edu/index.html](http://chandra.harvard.edu/index.html)

[astrobetter.com](http://astrobetter.com)

[lanl.gov](http://lanl.gov)

[ligo.org](http://ligo.org)

