DE LA POUSSIÈRE À LA POUSSIÈRE

La Vie et la Mort des Étoiles et le Cycle d'Enrichissement de la Matière

L. Pagani

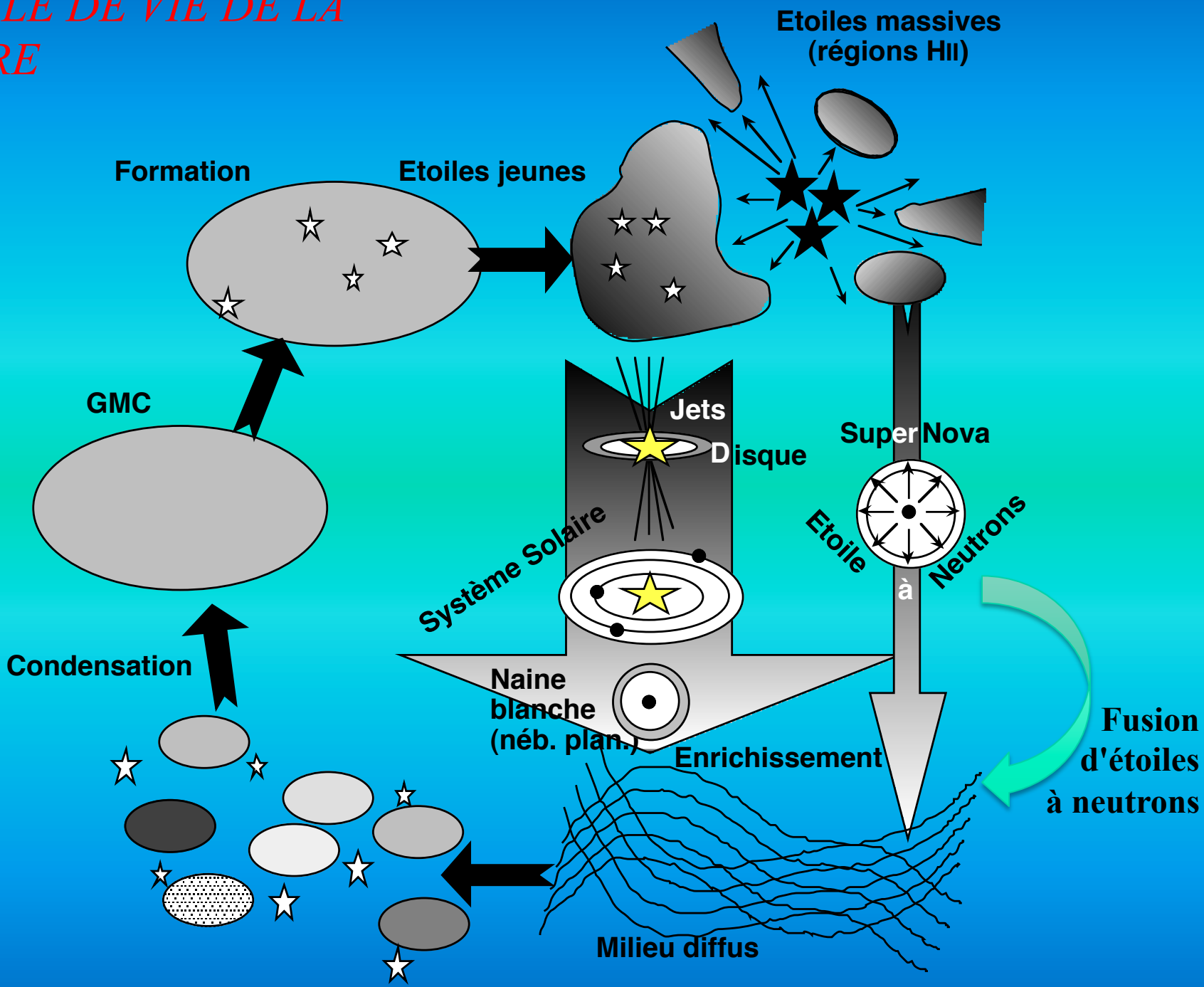
Observatoire de Paris & CNRS

LE CYCLE DE VIE DE LA MATIÈRE

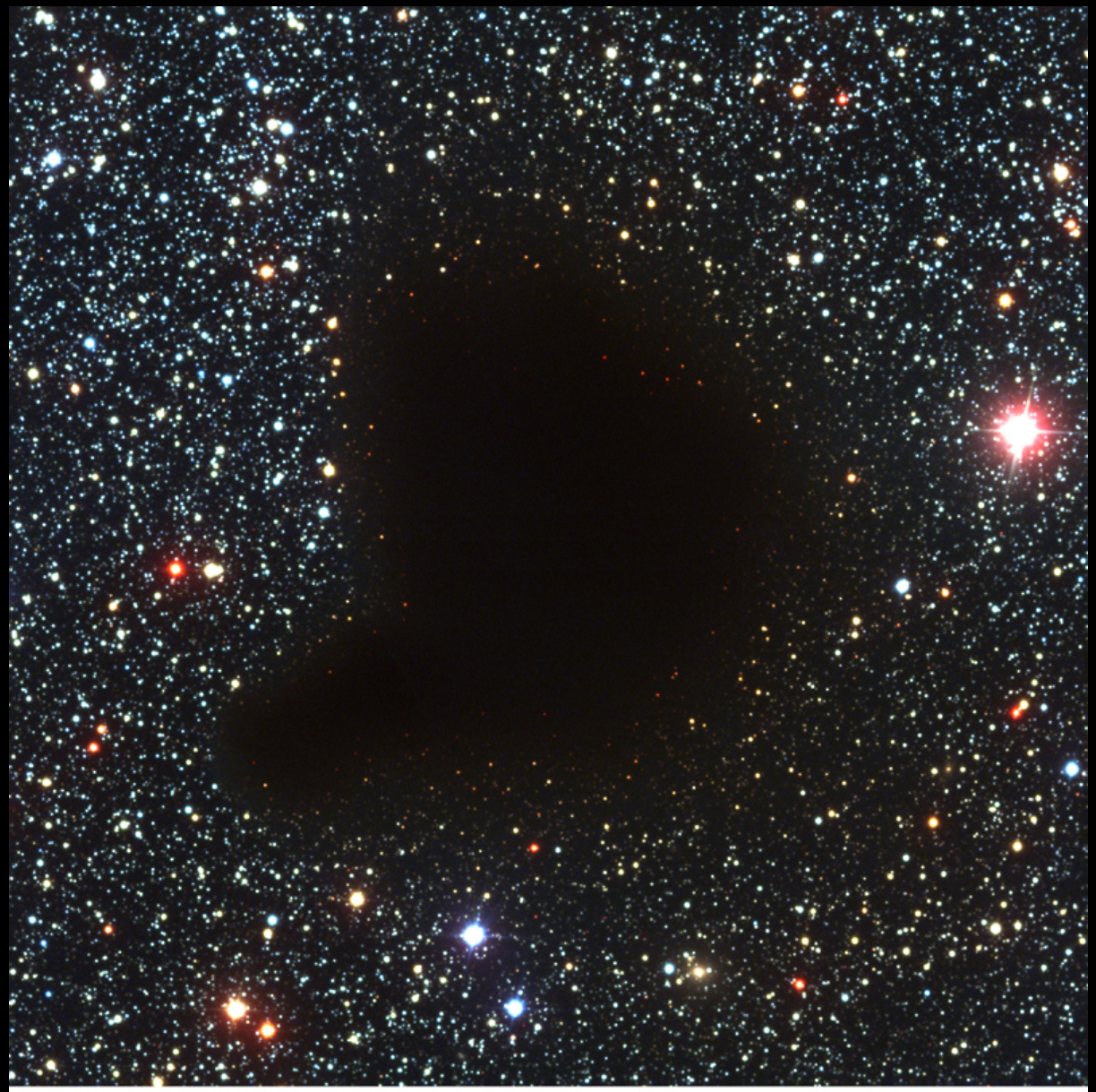
Grand Boum : ^{1}H, ^{4}He, *(^{7}Li)*.

...puis plus rien

LE CYCLE DE VIE DE LA MATIÈRE

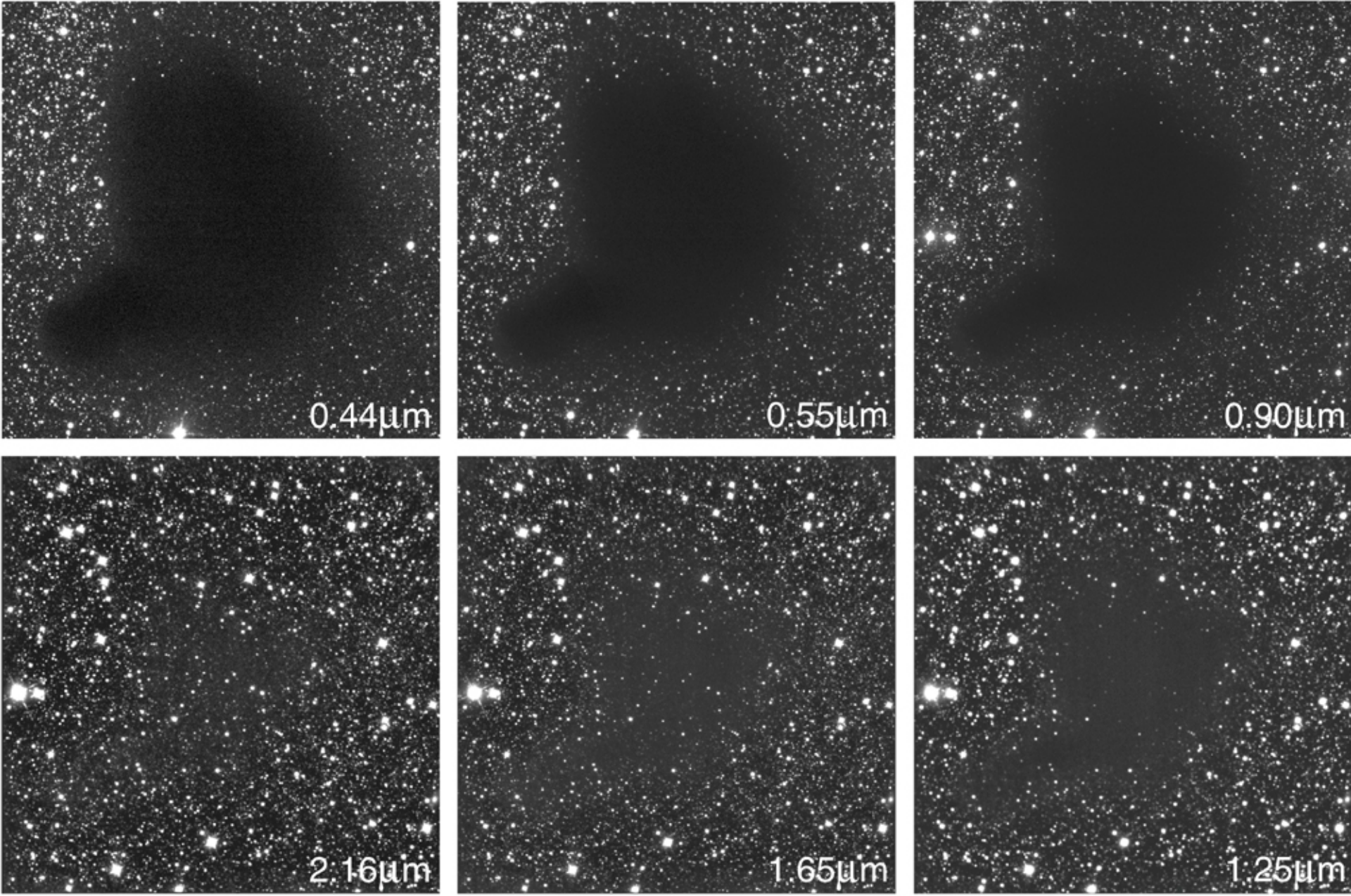


Le Milieu Interstellaire



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

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



The Dark Cloud B68 at Different Wavelengths (NTT + SOFI)

STAR-FORMING REGION RCW 108

round the Ara OB1 association in the southern Milky Way (in
t name - "The Altar") contains many young and bright stars.
nce of about 4000 light-years from the Sun.

lar cloud in this area that is in the process of being destroyed
radiation from heavy and hot stars in the nearby stellar
t). Most of this radiation comes from the bright object near
e, which is actually a binary system composed of two O-type
hat pervades most of the field is emission from hydrogen (H-
t reveals a massive stream of gas that flows away from the
it is being heated and ionized.

This cloud is the site of intense star formation. The small bright patch with several stars near the darkest part of the nebulosity (right) is the infrared source IRAS 16362-4845. It marks a site where a small cluster of stars is being formed at present.

The photo was obtained with the Wide Field Imager (WFI), a 67 million pixel camera at the MPG/ESO 2.2-m Telescope at the ESO La Silla Observatory.

The WFI is a joint project between the European Southern Observatory (ESO), the Max-Planck-Institut fur Astronomie (MPI-A) in Heidelberg (Germany) and the Osservatorio Astronomico di Capodimonte (OAC) in Naples (Italy).

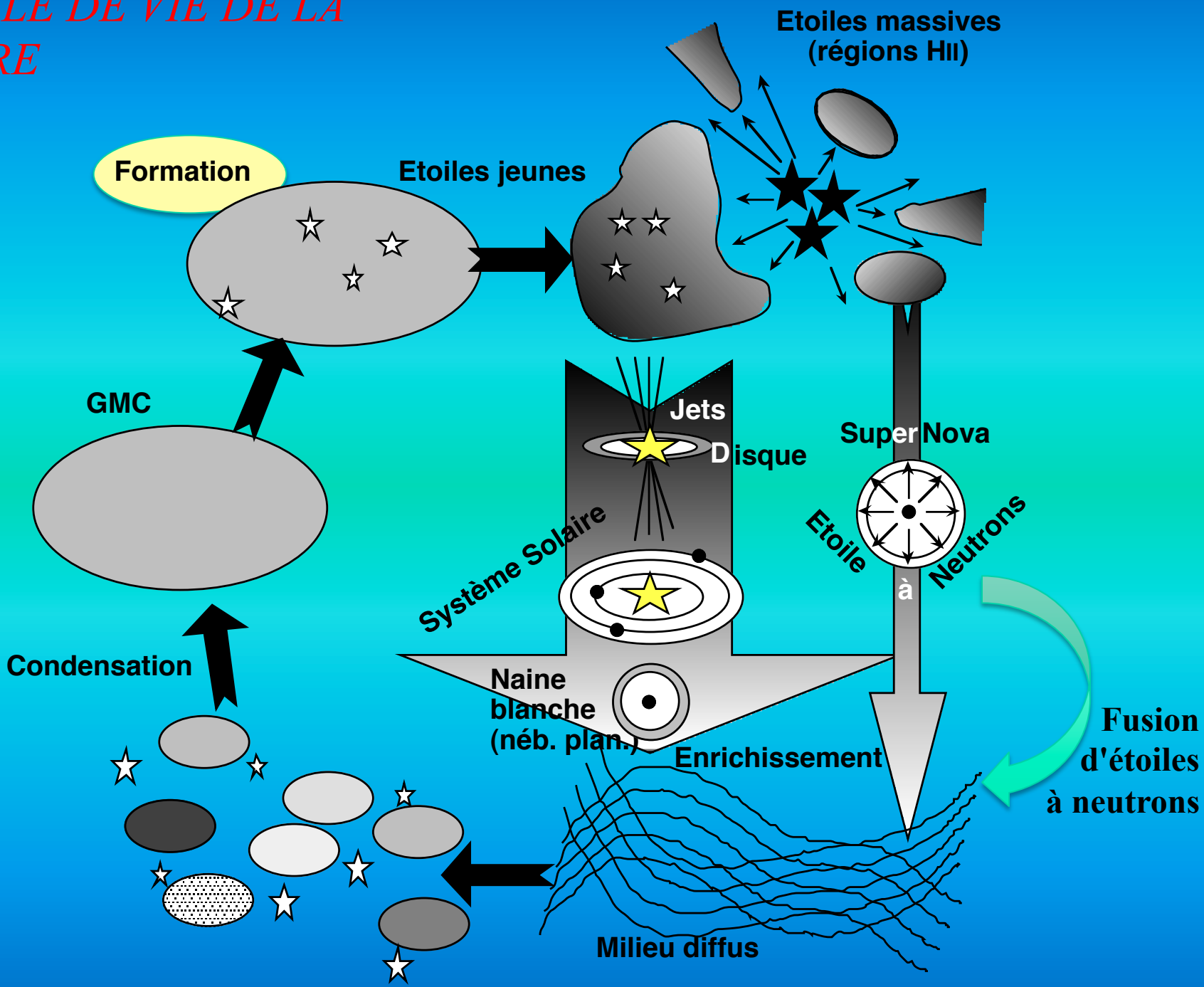
Technical information: This colour picture is a composite made from 12 separate WFI images, obtained on March 27, 1999. The blue component corresponds to the B-filter, the green to the V-filter and the red to the H-alpha filter. The images in each filter are the composite of 4 individual frames obtained with the telescope pointing at slightly different positions on the sky. The field measures about 32 x 32 sq.arcmin, or about 40 x 40 light-years square at the distance of RCW 38.

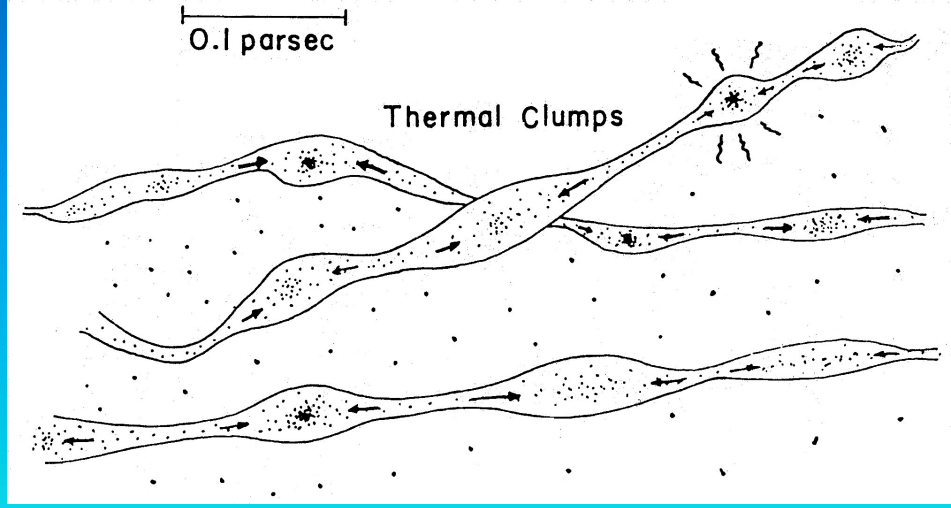
More information about ESO can be found at URL: http://www.eso.org

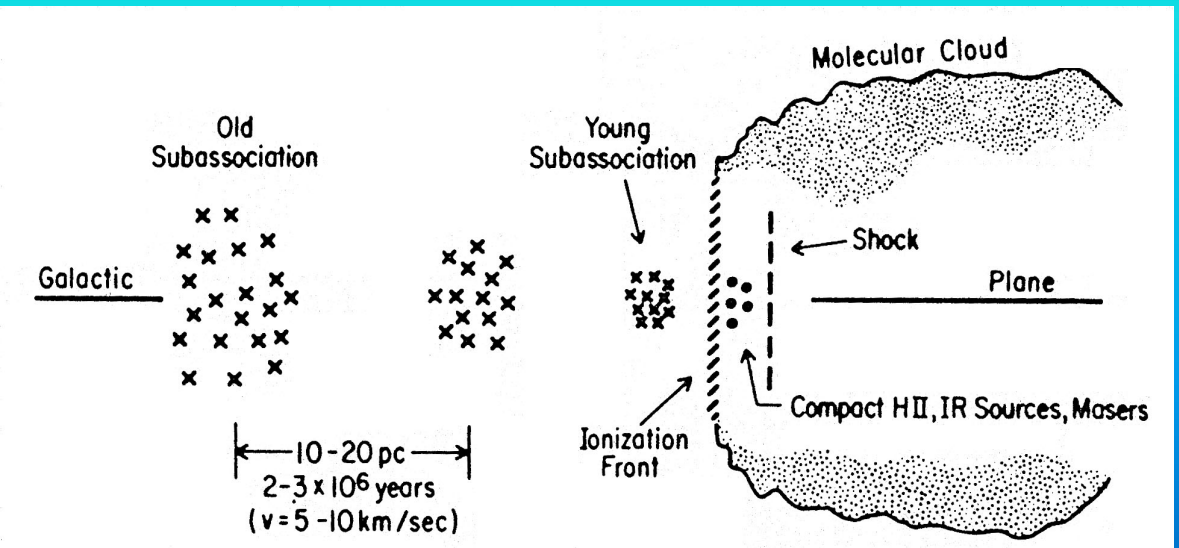
IMAGER (WFI) AT MPG/ESO 2.2-m TELESCOPE

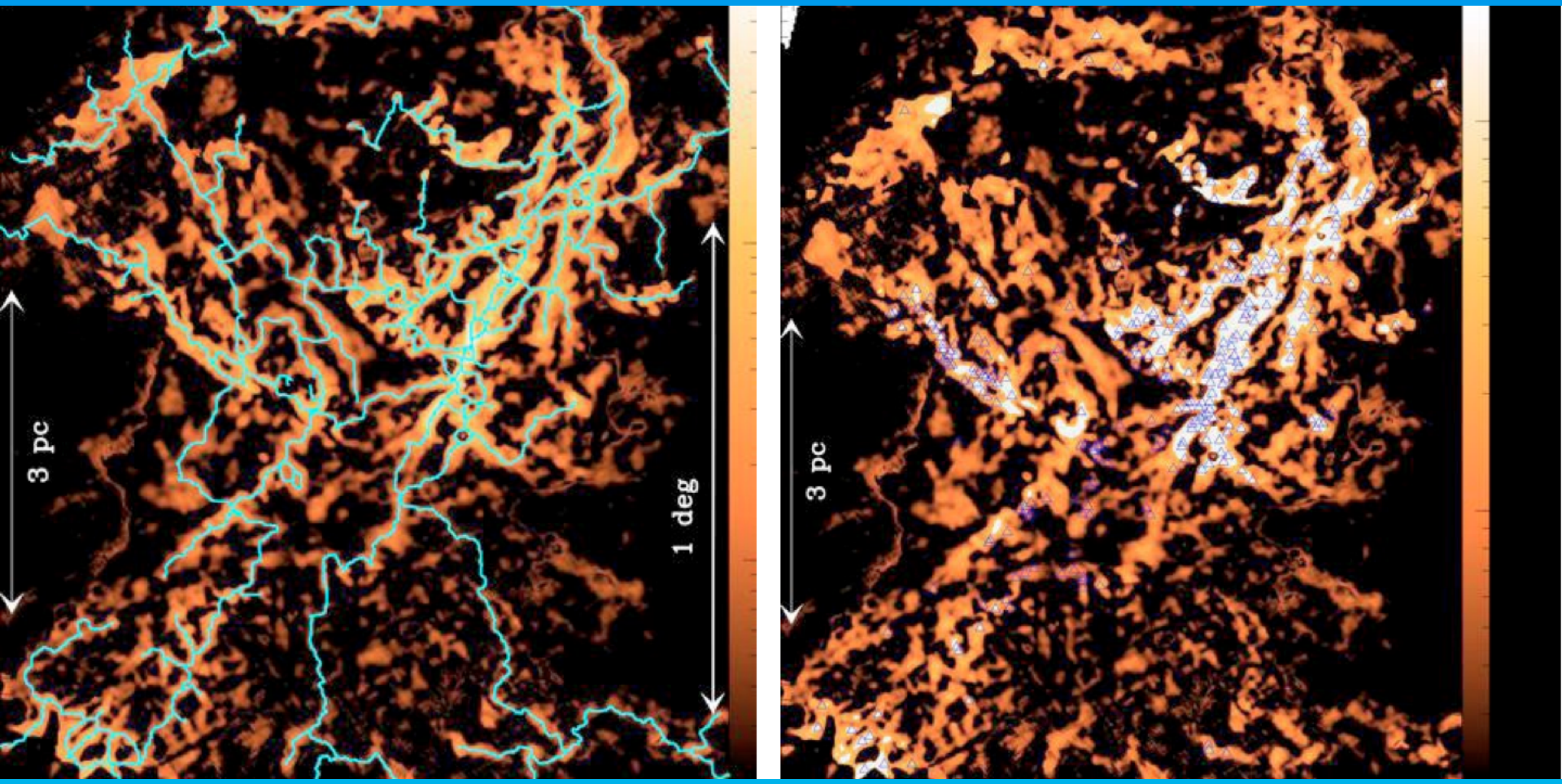
Formation des Étoiles

LE CYCLE DE VIE DE LA MATIÈRE



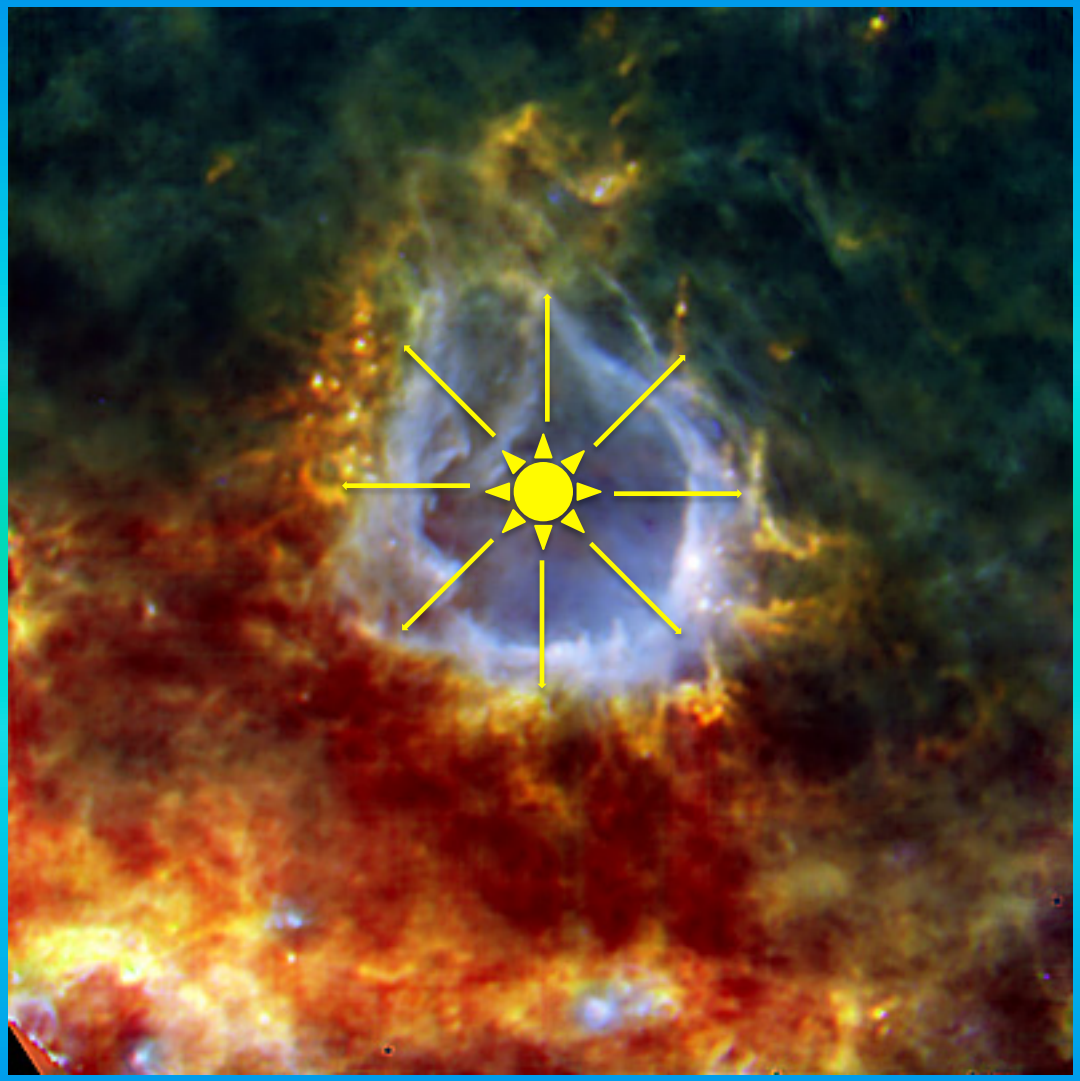

0.1 parsec
Thermal Clumps


Old
Subassociation
Galactic
10-20 pc
2-3 x 10^6 years
(v = 5 -10 km/sec)
Young
Subassociation
Molecular Cloud
Shock
Plane
Compact HII, IR Sources, Masers
Ionization
Front



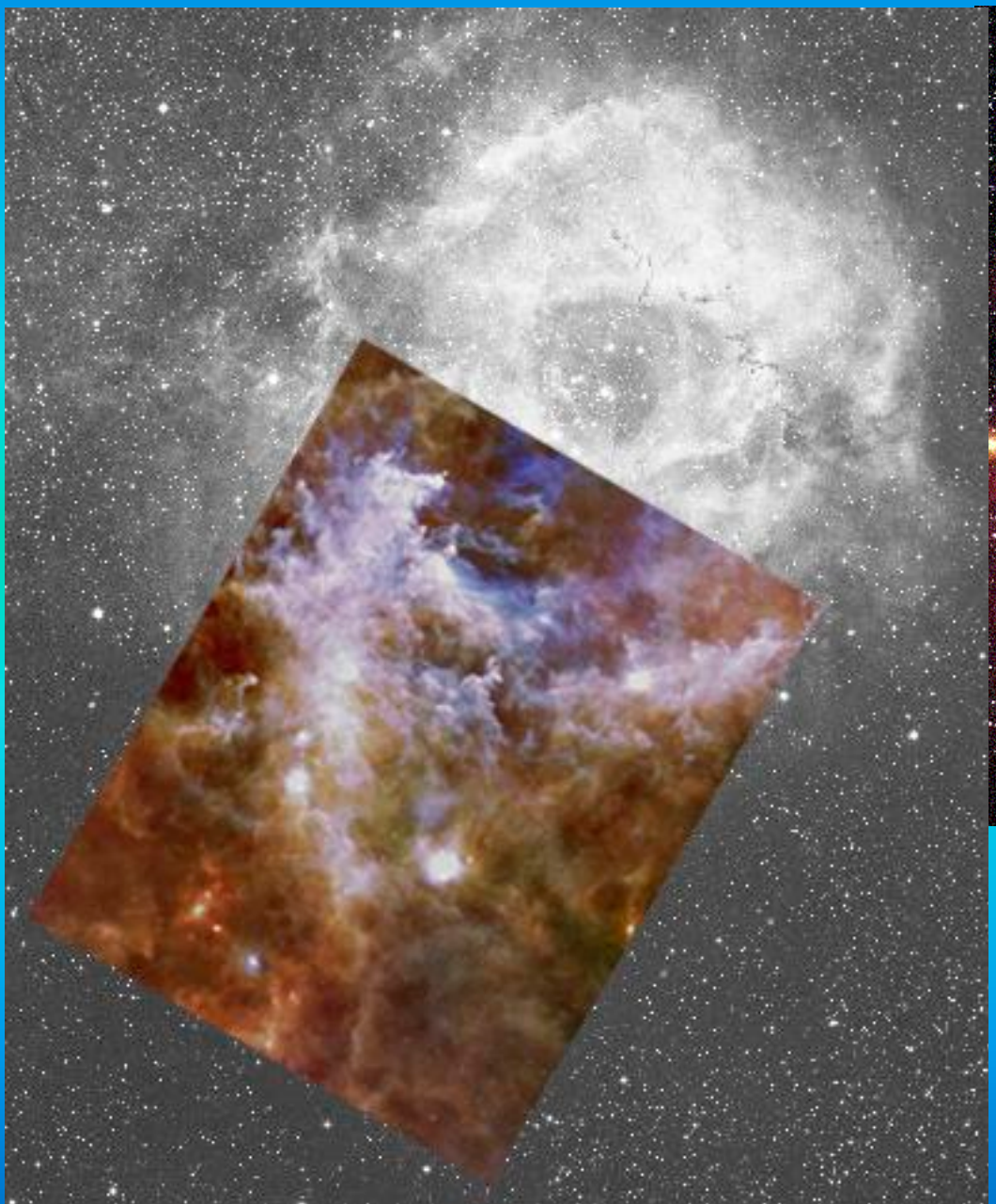
Filaments vus par Herschel & protoétoiles dans les filaments

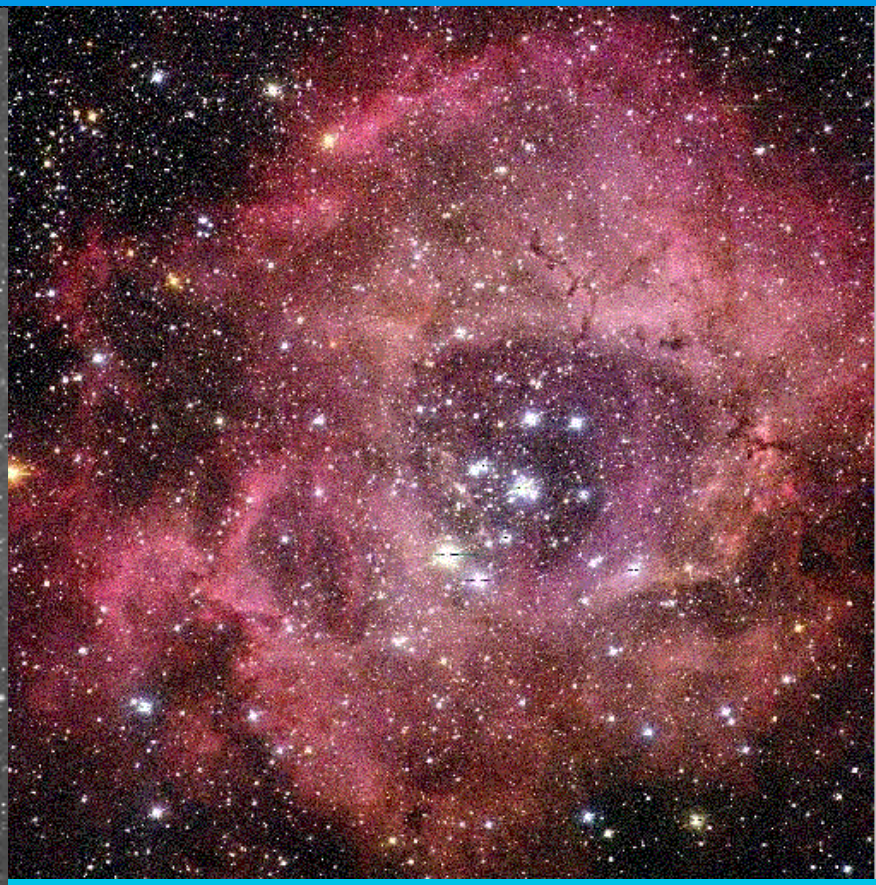
Formation par propagation

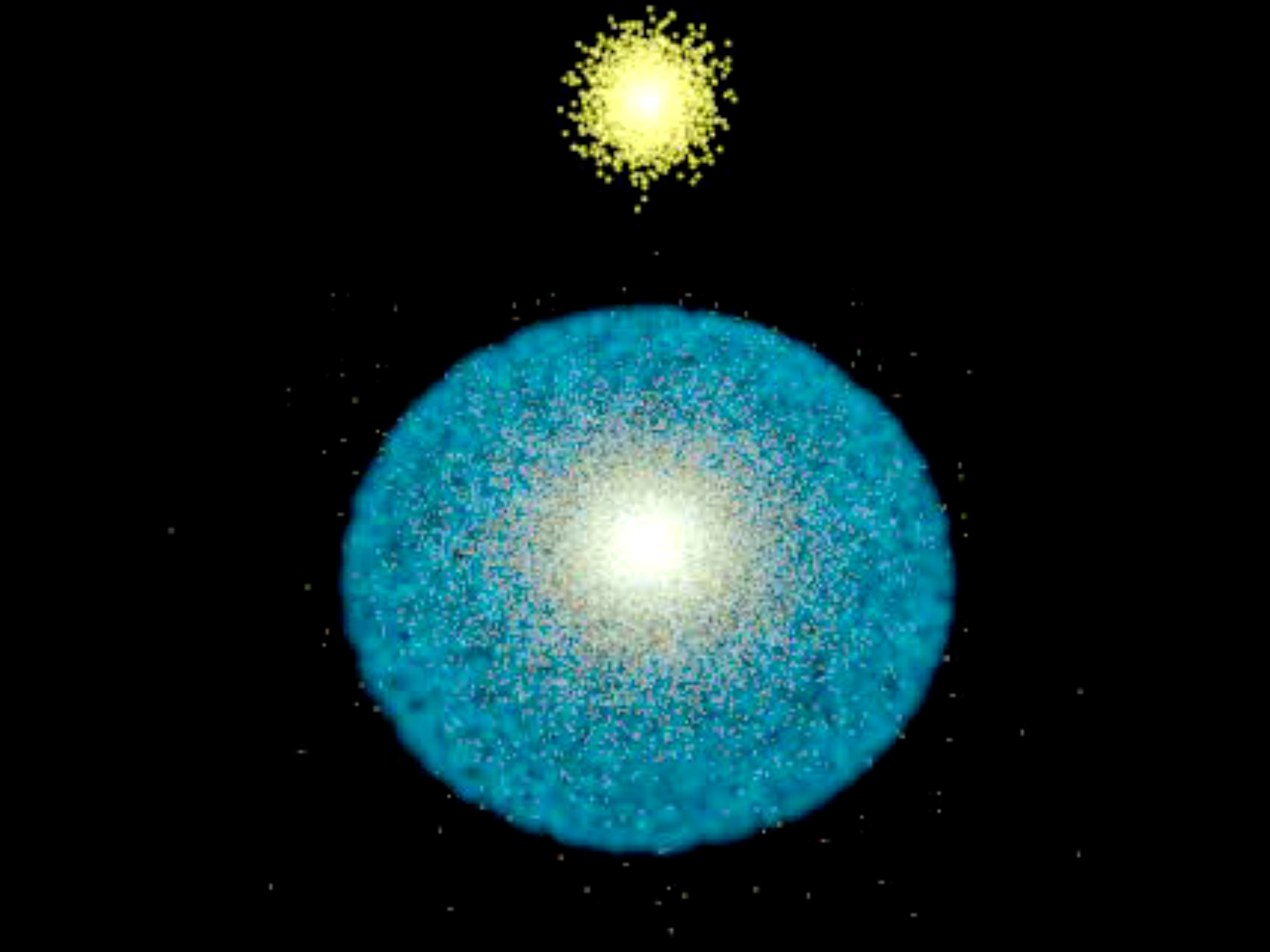


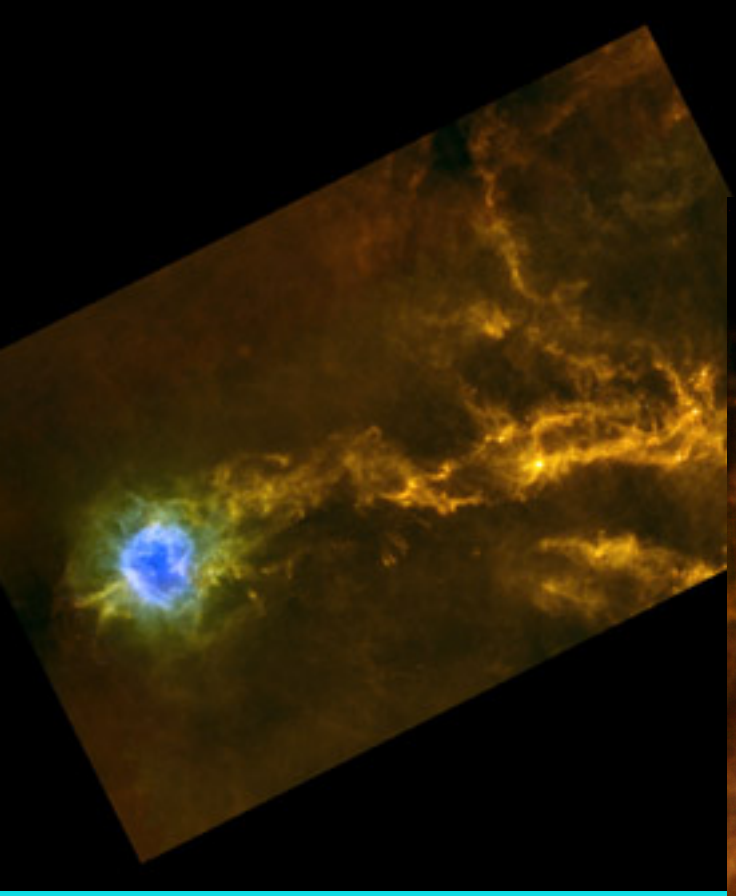
RCW120

Nébuleuse de la Rosette (NGC 2244)

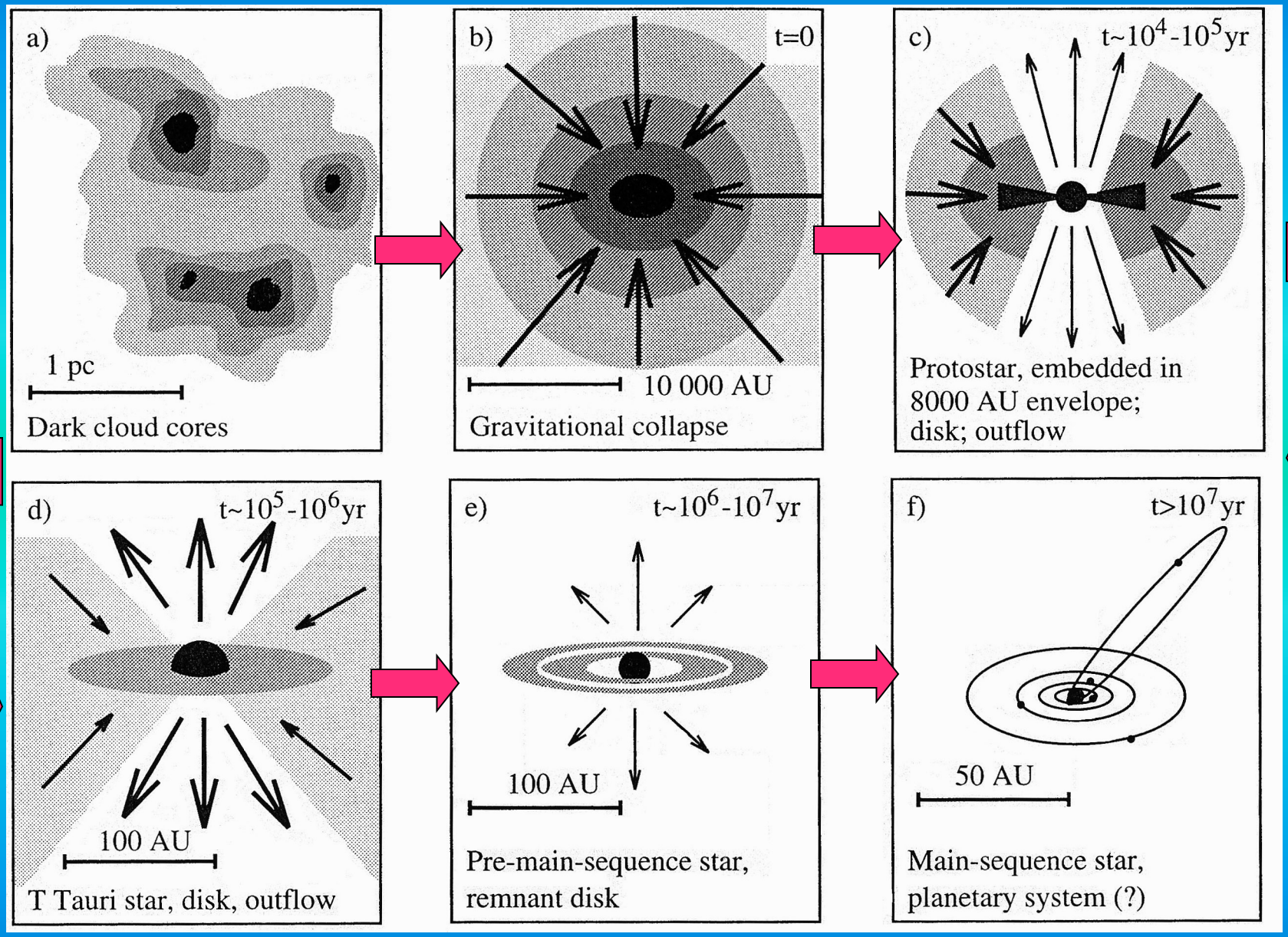




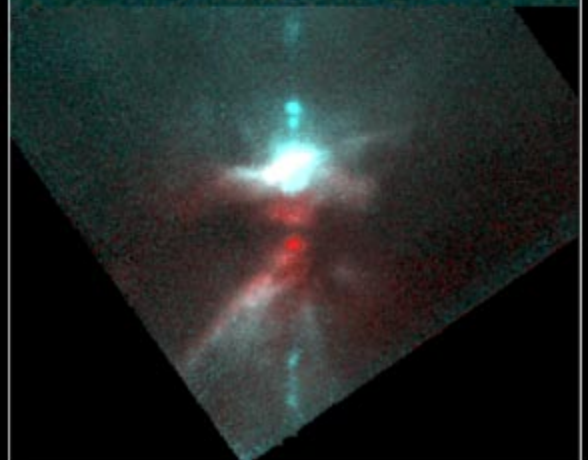




Formation dans
des filaments

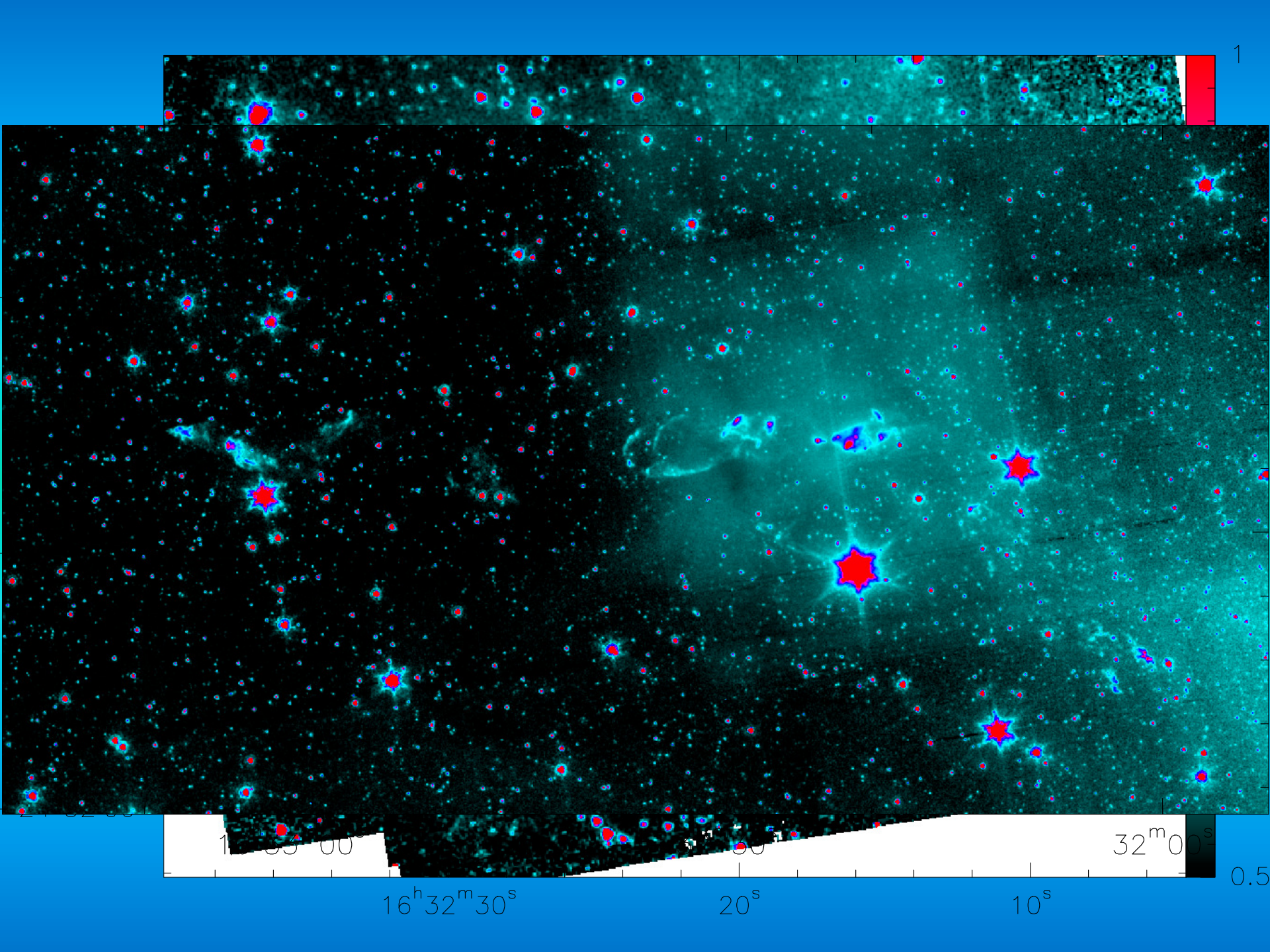

a)
1 pc
Dark cloud cores
b)
t=0
10 000 AU
Gravitational collapse
c)
t~10^4-10^5yr
Protostar, embedded in
8000 AU envelope;
disk; outflow
d)
t~10^5-10^6yr
100 AU
T Tauri star, disk, outflow
e)
t~10^6-10^7yr
100 AU
Pre-main-sequence star,
remnant disk
f)
t>10^7yr
50 AU
Main-sequence star,
planetary system (?)

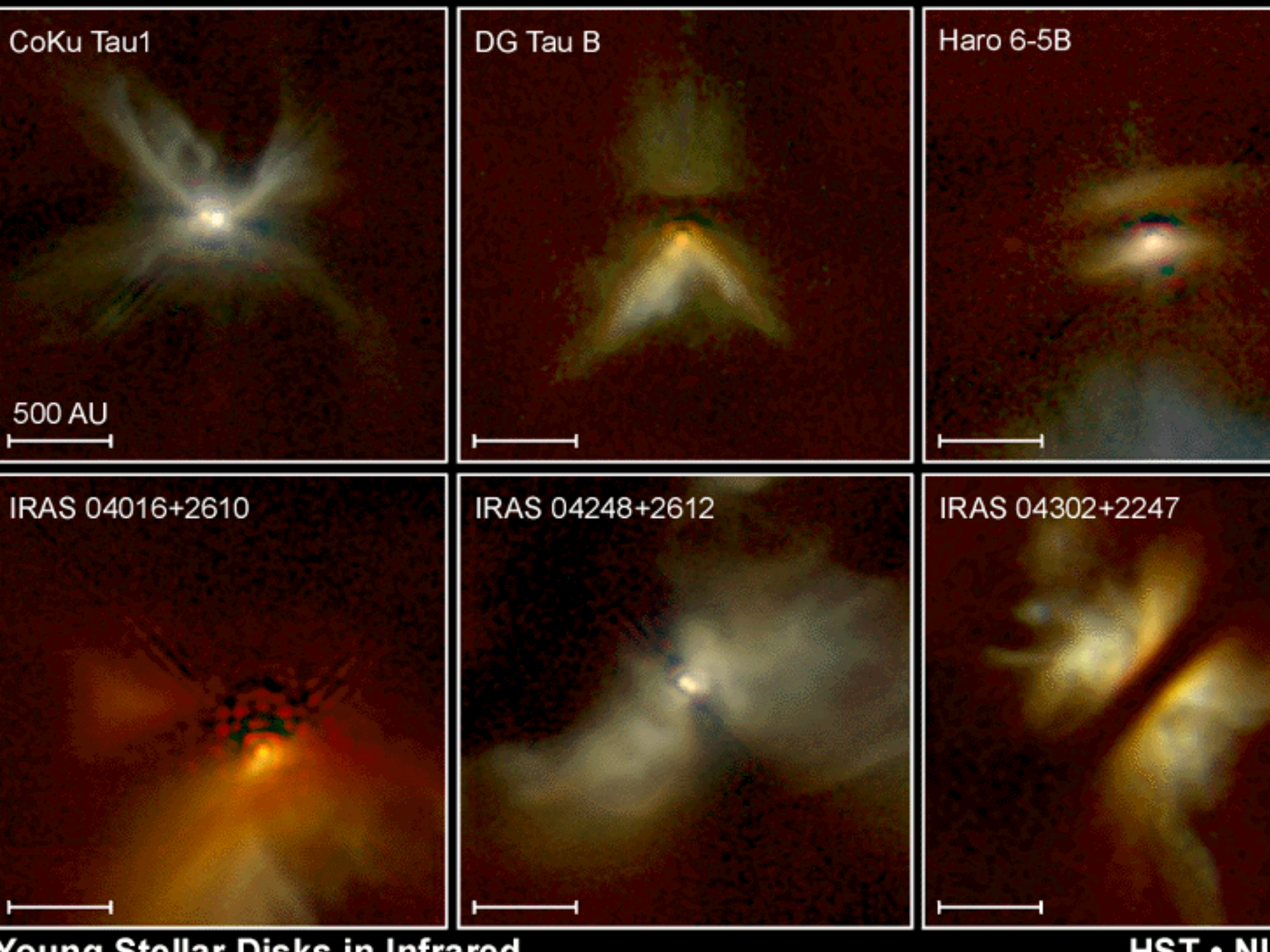
Visible • WFPC2



Infrared • NICMOS

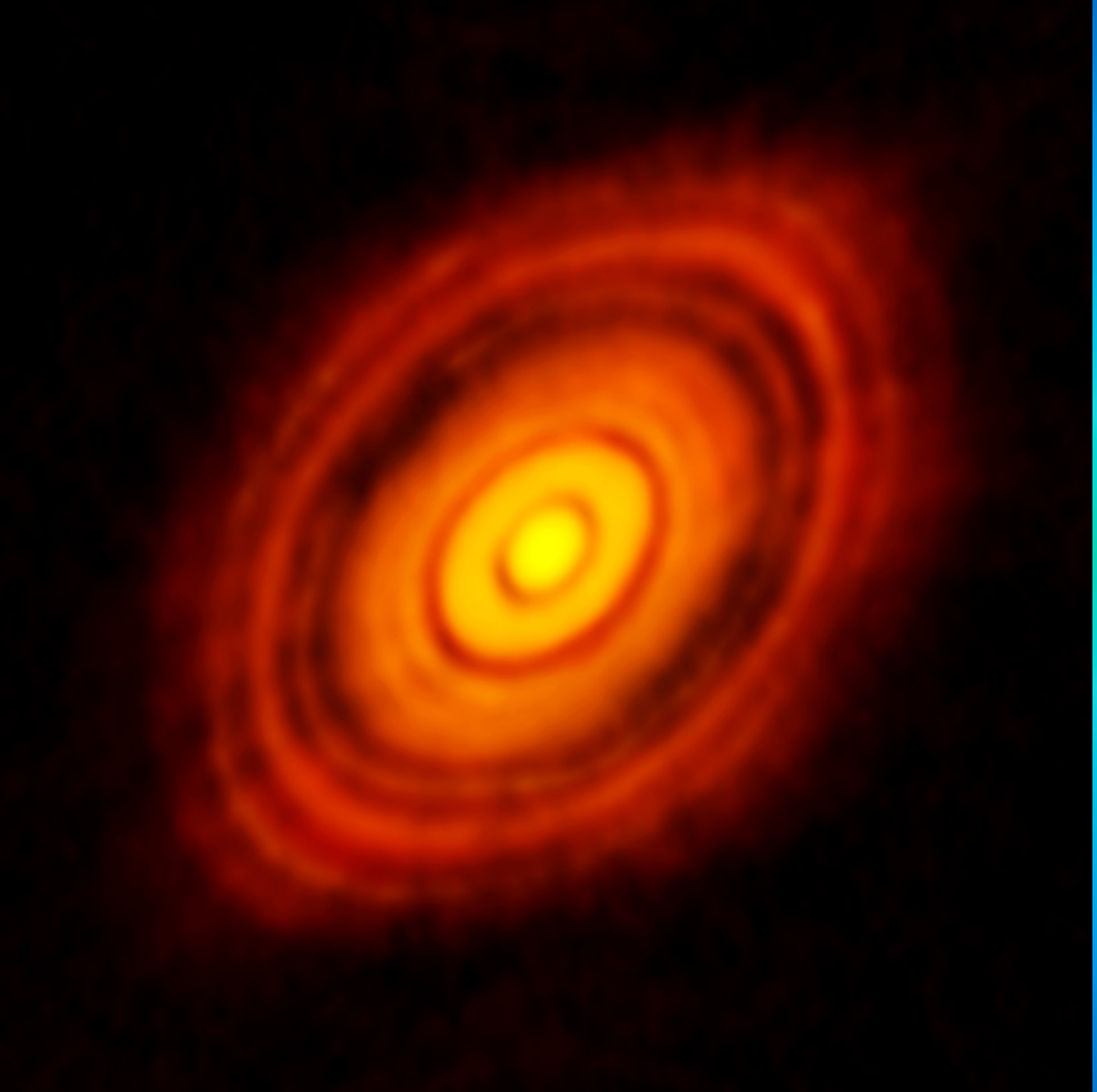
HH111
Hubble Space Telescope
WFPC2 • NICMOS


1
0.5
$16^h32^m30^s$
20^s
10^s
32^m00^s

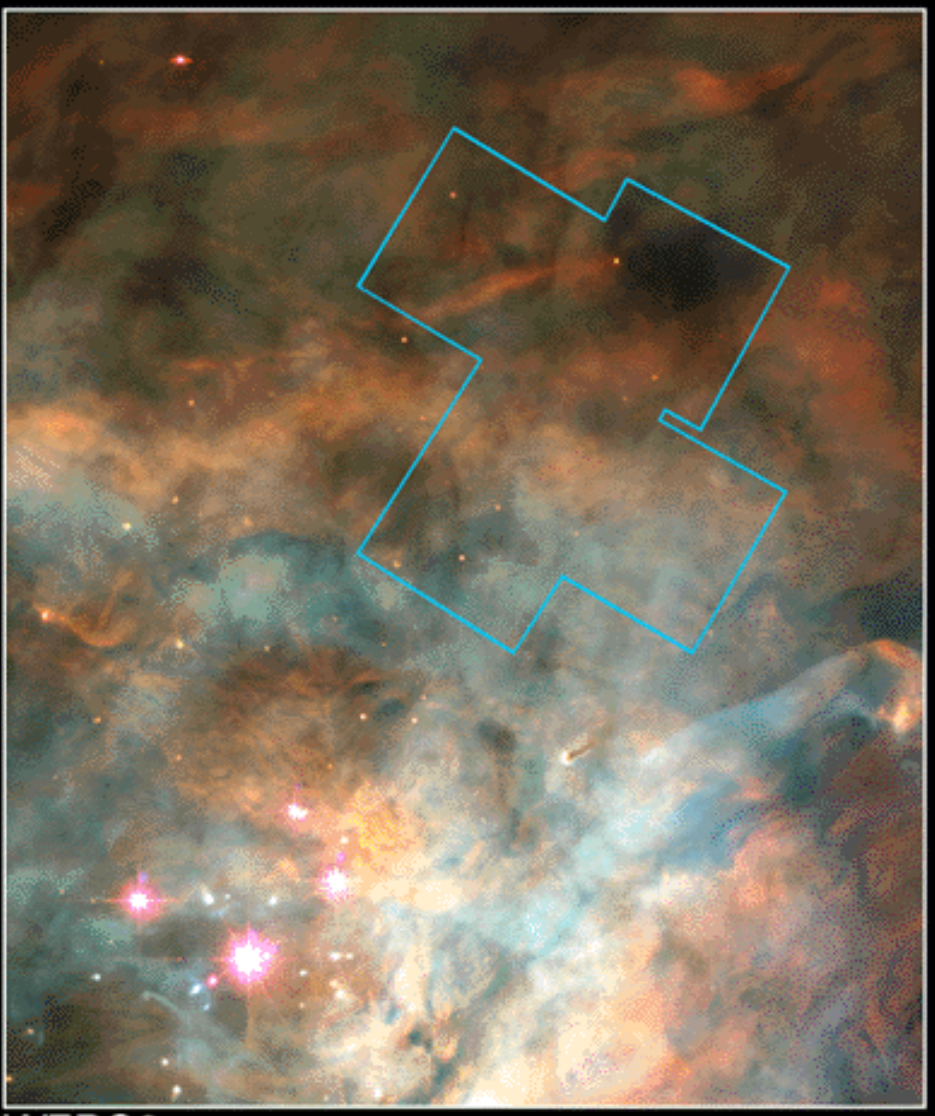


Young Stellar Disks in Infrared

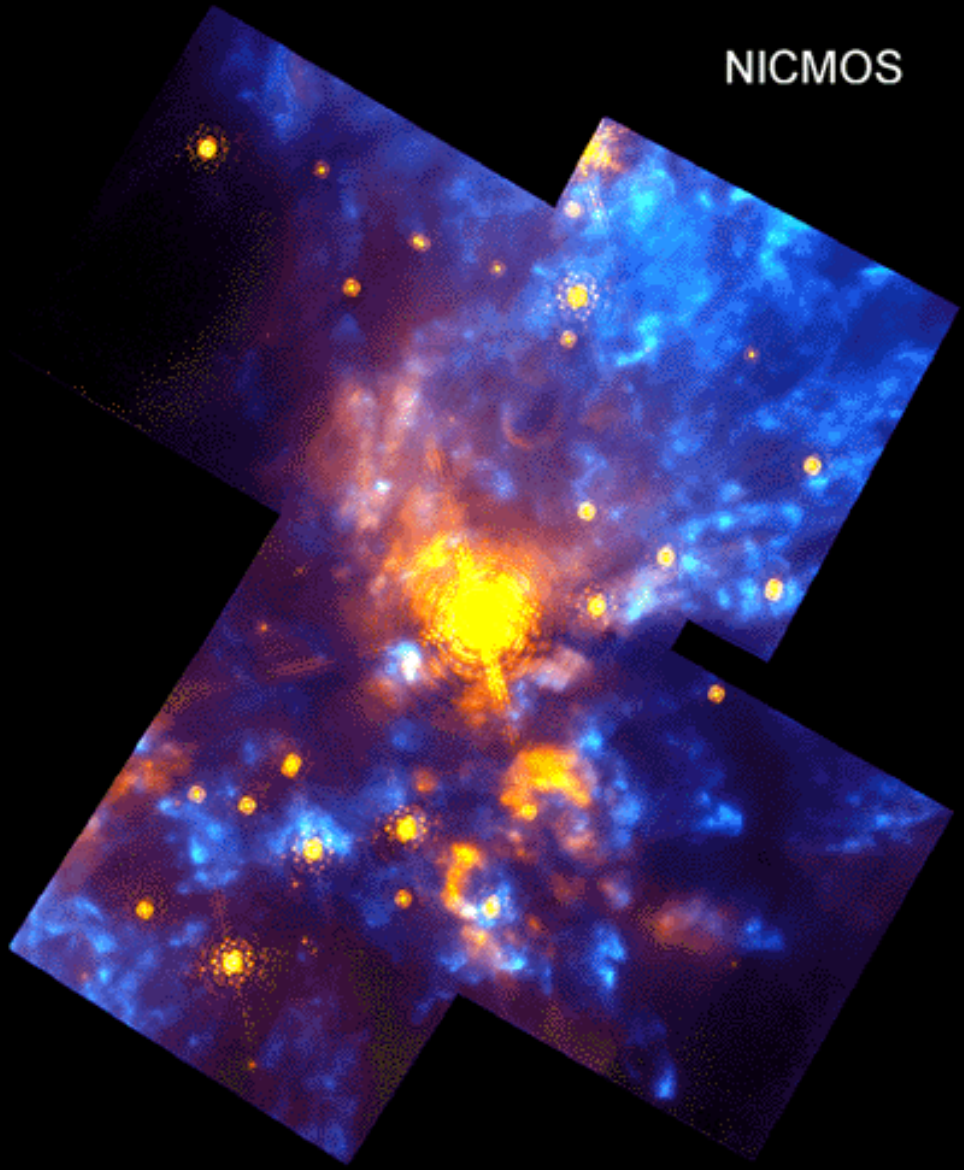
HST • NI



HL Tau vu
par ALMA



WFPC2



NICMOS

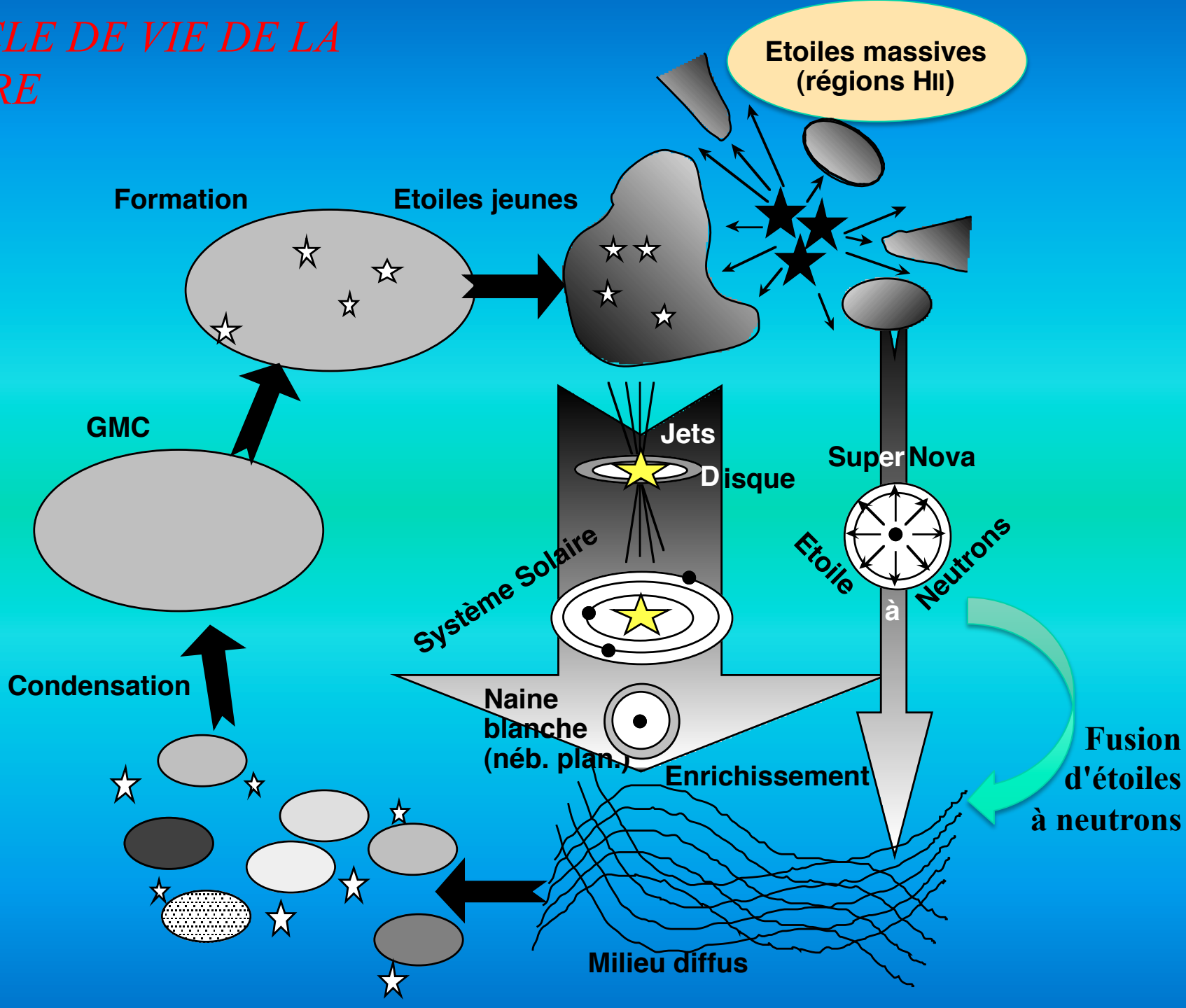
Orion Nebula • OMC-1 Region

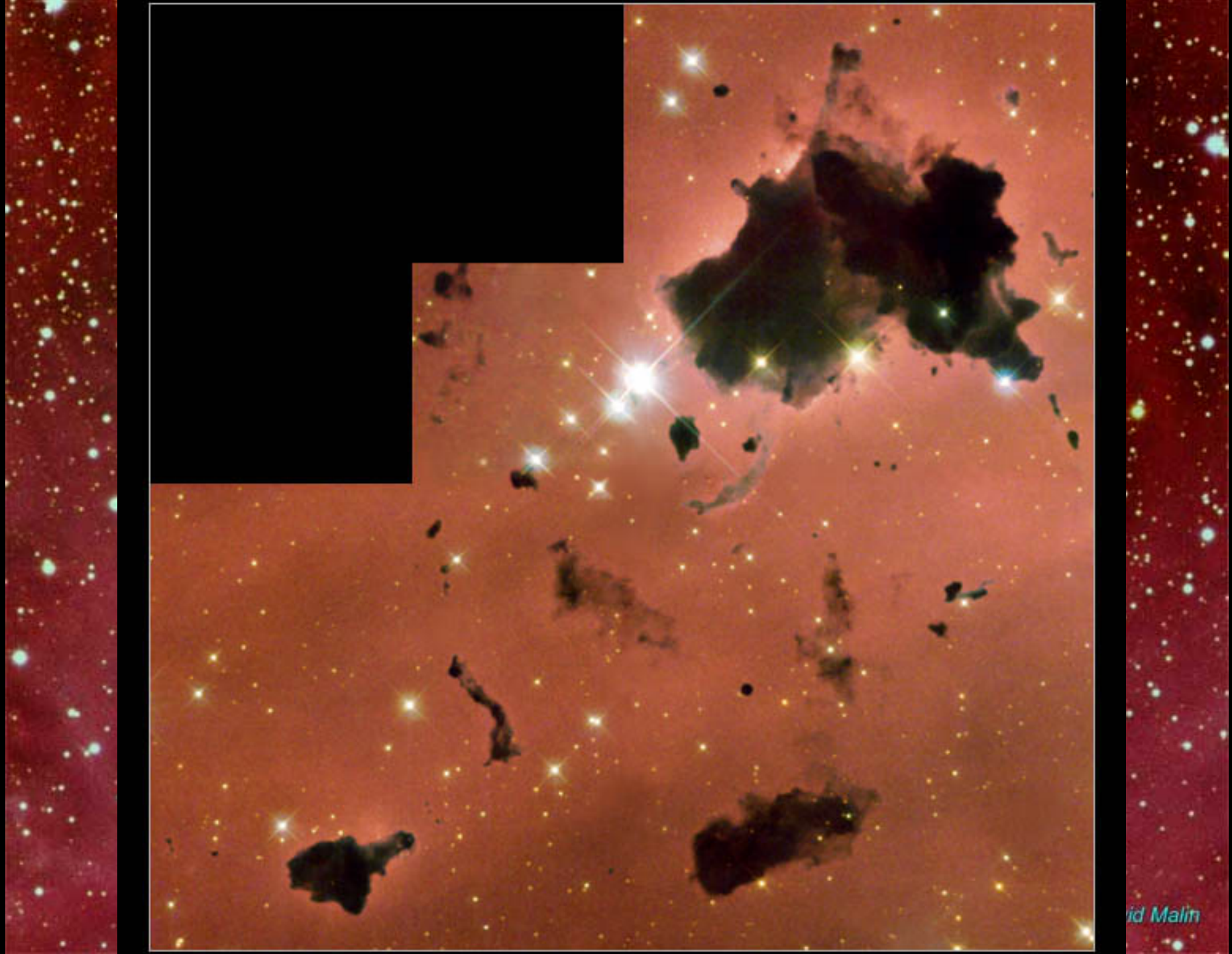
Hubble Space Telescope

PRC97-13 • ST ScI OPO • May 12, 1997

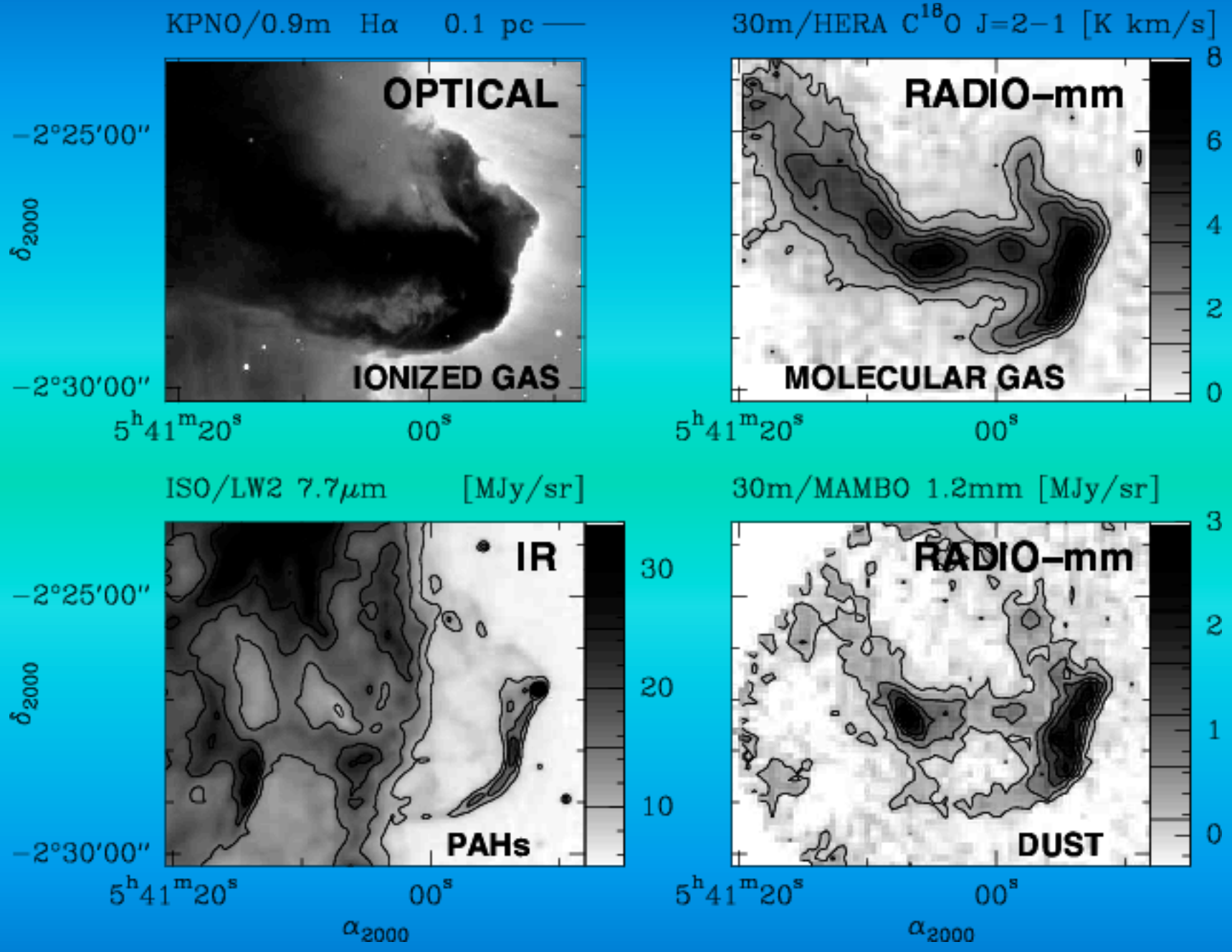
R. Thompson (Univ. Arizona), S. Stolovy (Univ. Arizona), C.R. O'Dell (Rice Univ.) and NASA

LE CYCLE DE VIE DE LA MATIÈRE

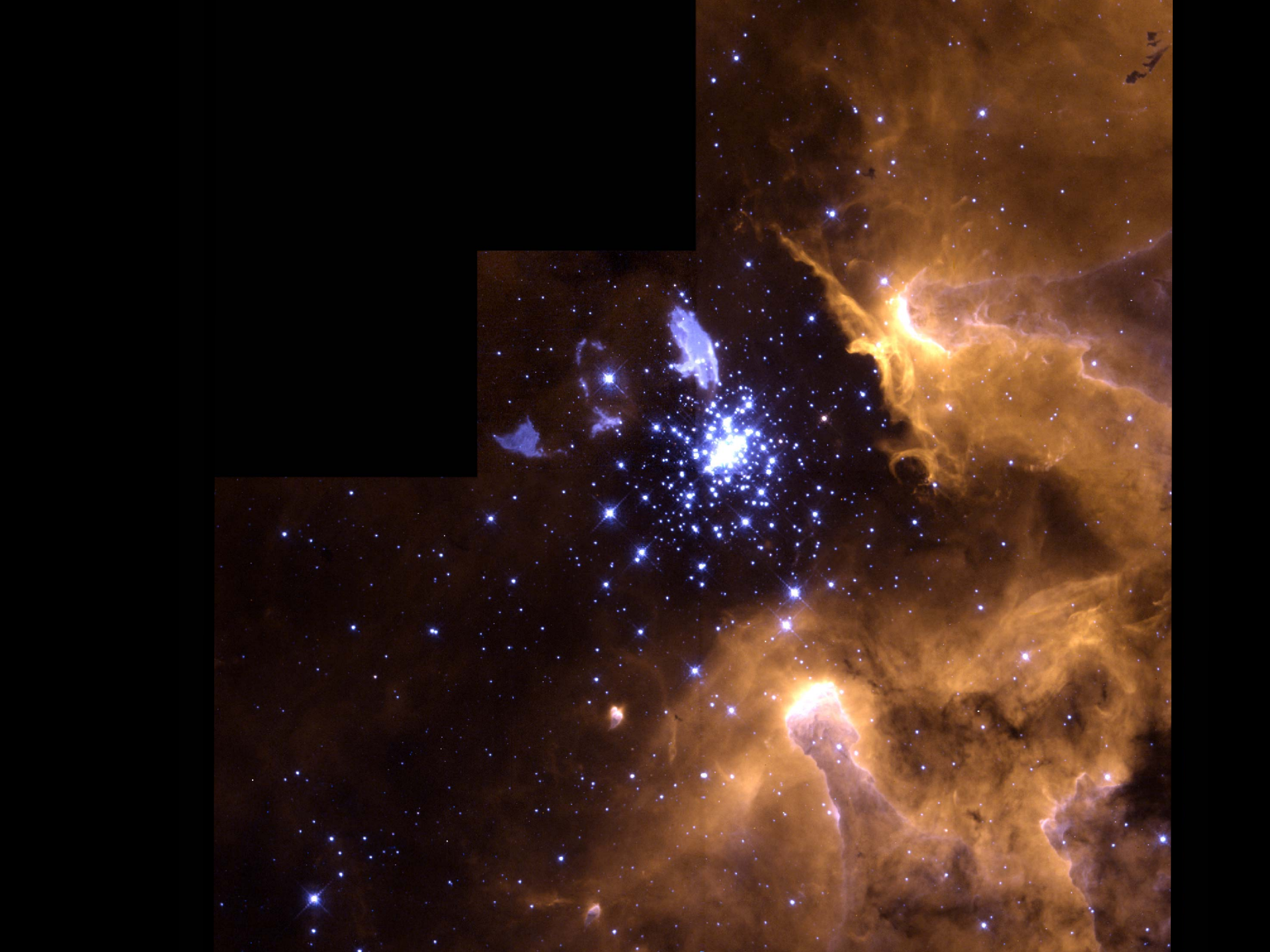



id Malin

Horsehead Nebula


KPNO/0.9m Hα 0.1 pc
OPTICAL
IONIZED GAS
30m/HERA C18O J=2−1 [K km/s]
RADIO–mm
MOLECULAR GAS
ISO/LW2 7.7μm [MJy/sr]
IR
PAHs
30m/MAMBO 1.2mm [MJy/sr]
RADIO–mm
DUST
−2°25′00″
−2°30′00″
δ2000
5h41m20s
00s
α2000
8
6
4
2
0
30
20
10
3
2
1
0

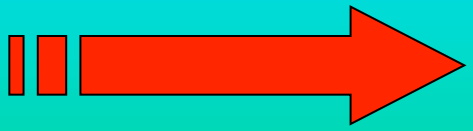
The Tarantula Nebula (VLT KUEYEN + FORS2)

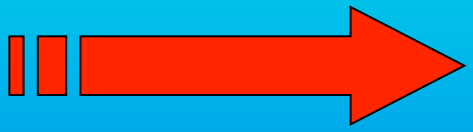


La Vie des Étoiles

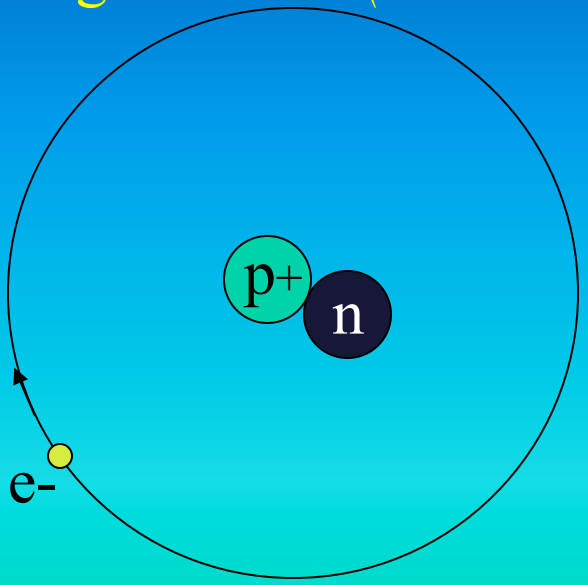
- D’où vient l’énergie des étoiles ?
- Pourquoi sont-elles bleues, jaunes ou rouges ?
- Quelle est leur masse ?
- Quelle est leur durée de vie ?

Contraction  Echauffement

Echauffement  Réactions Nucléaires

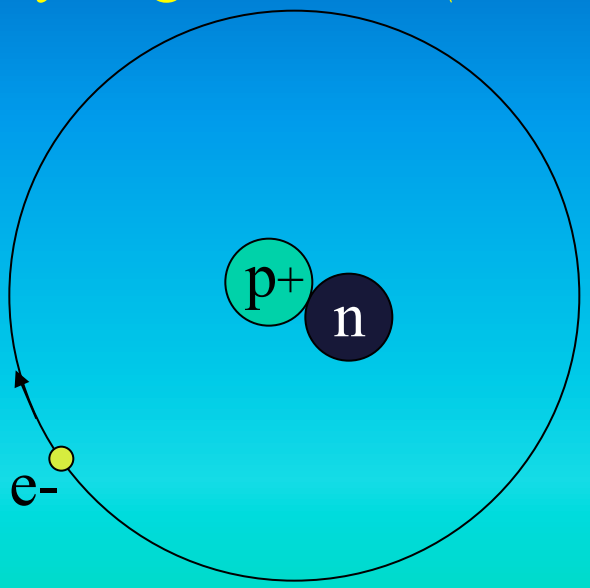
Réactions Nucléaires  Equilibre

Hydrogène lourd *(deuterium)*



+

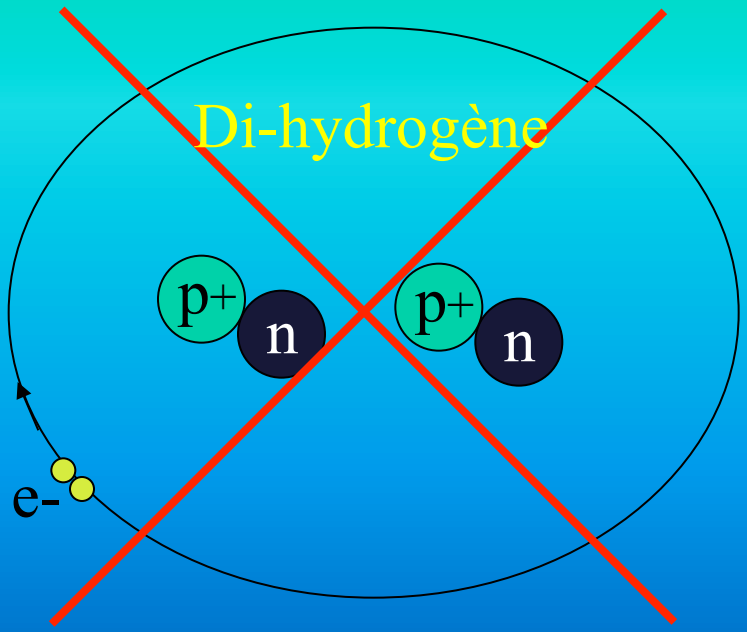
Hydrogène lourd *(deuterium)*

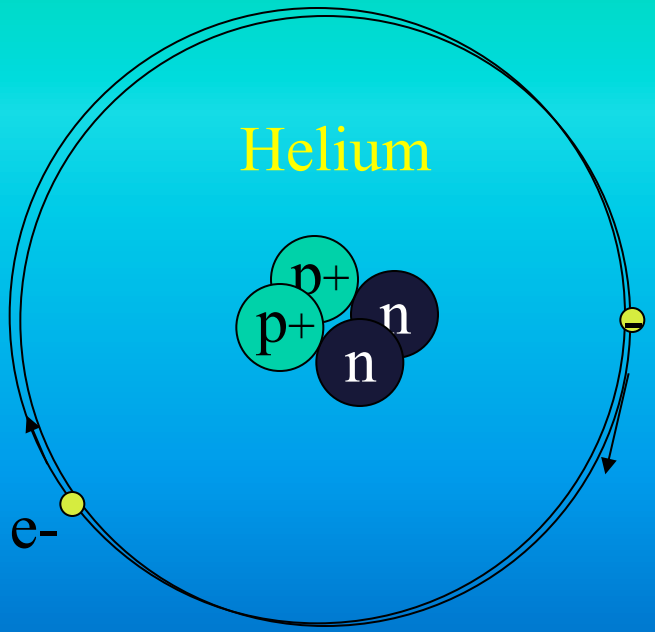


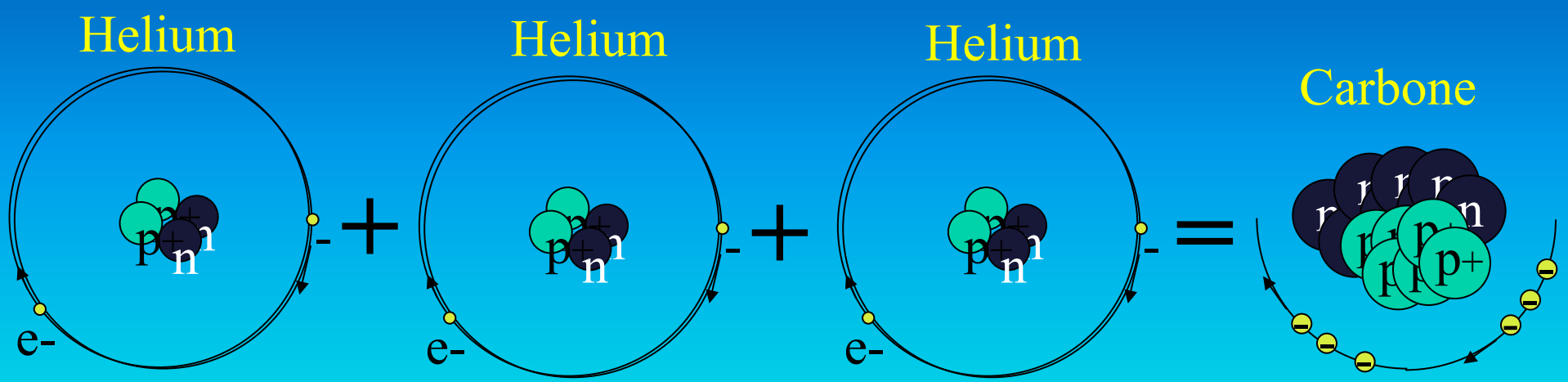
Réaction chimique

= ?

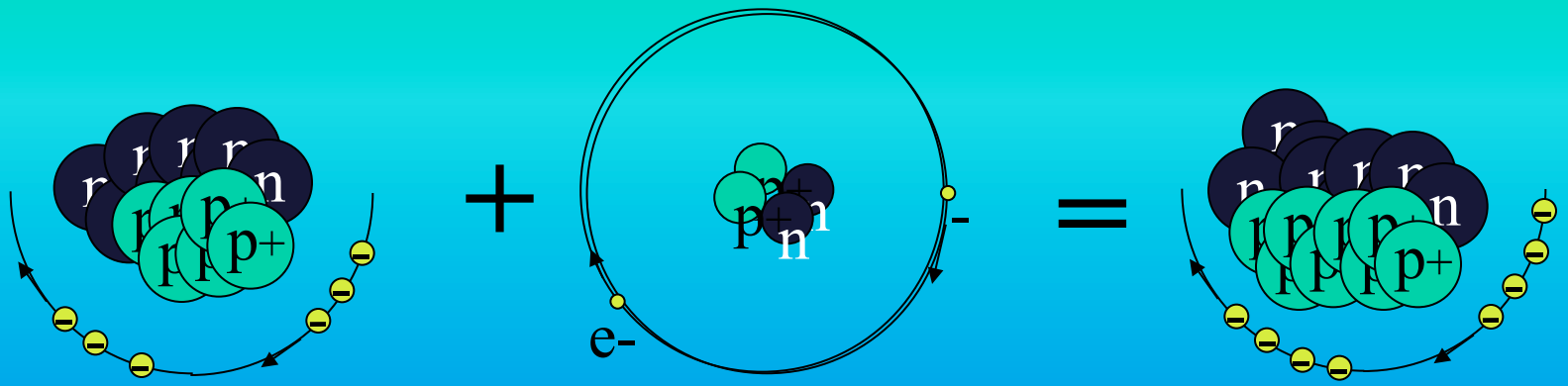
Réaction nucléaire







La fusion nucléaire dans les étoiles…



Carbone

Helium

Oxygène

Etc…

• Étoiles de masse faible ⟹ Compression faible ⟹ Température peu élevée ⟹ Rouge, combustion lente, ⟹ Vie longue (milliards d'années)

Transmutation de l'Hydrogène jusqu'à l'Oxygène

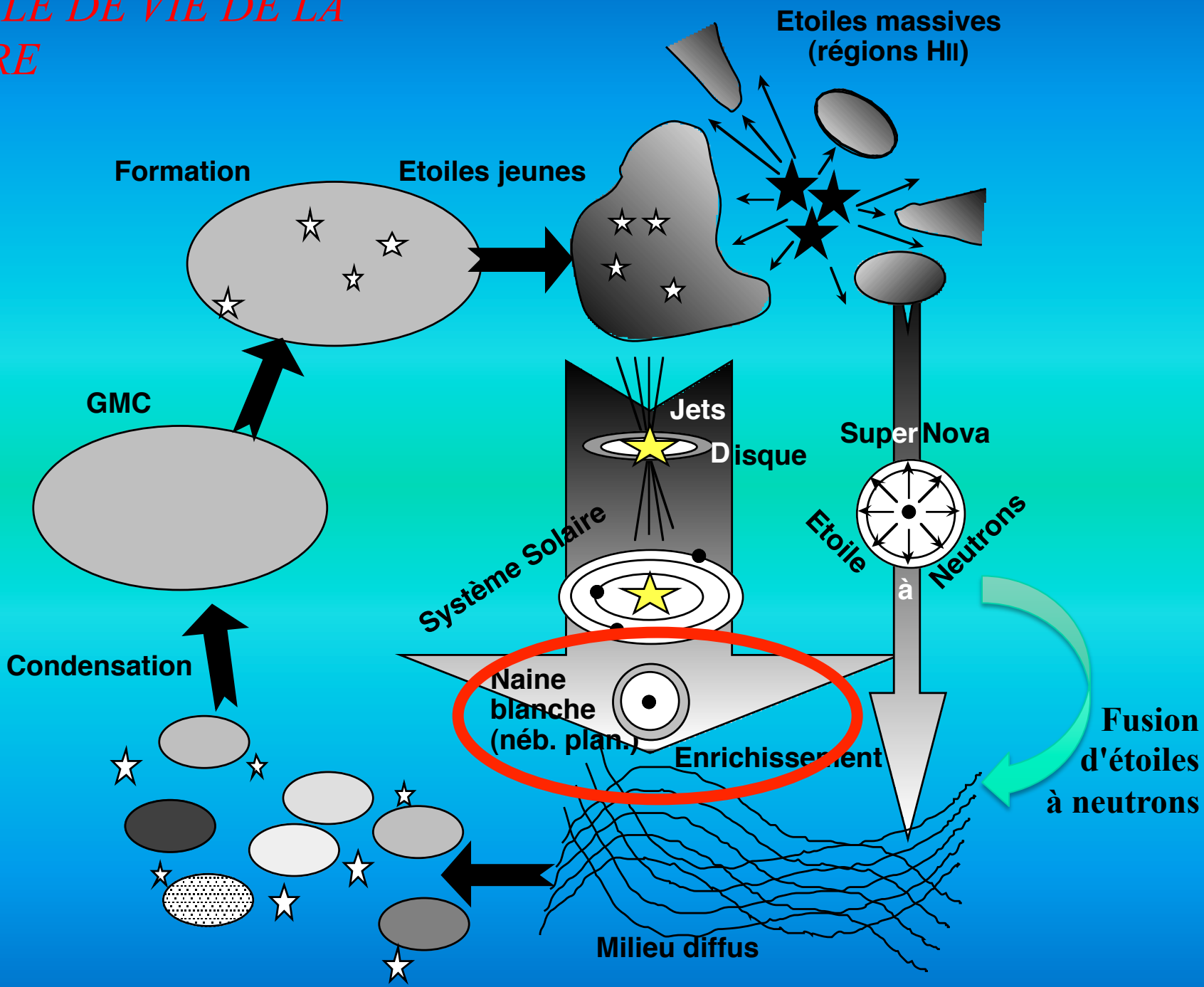
• Étoiles de masse élevée ⟹ Compression forte ⟹ Température élevée ⟹ Bleue, combustion rapide, ⟹ Vie courte (millions d'années)

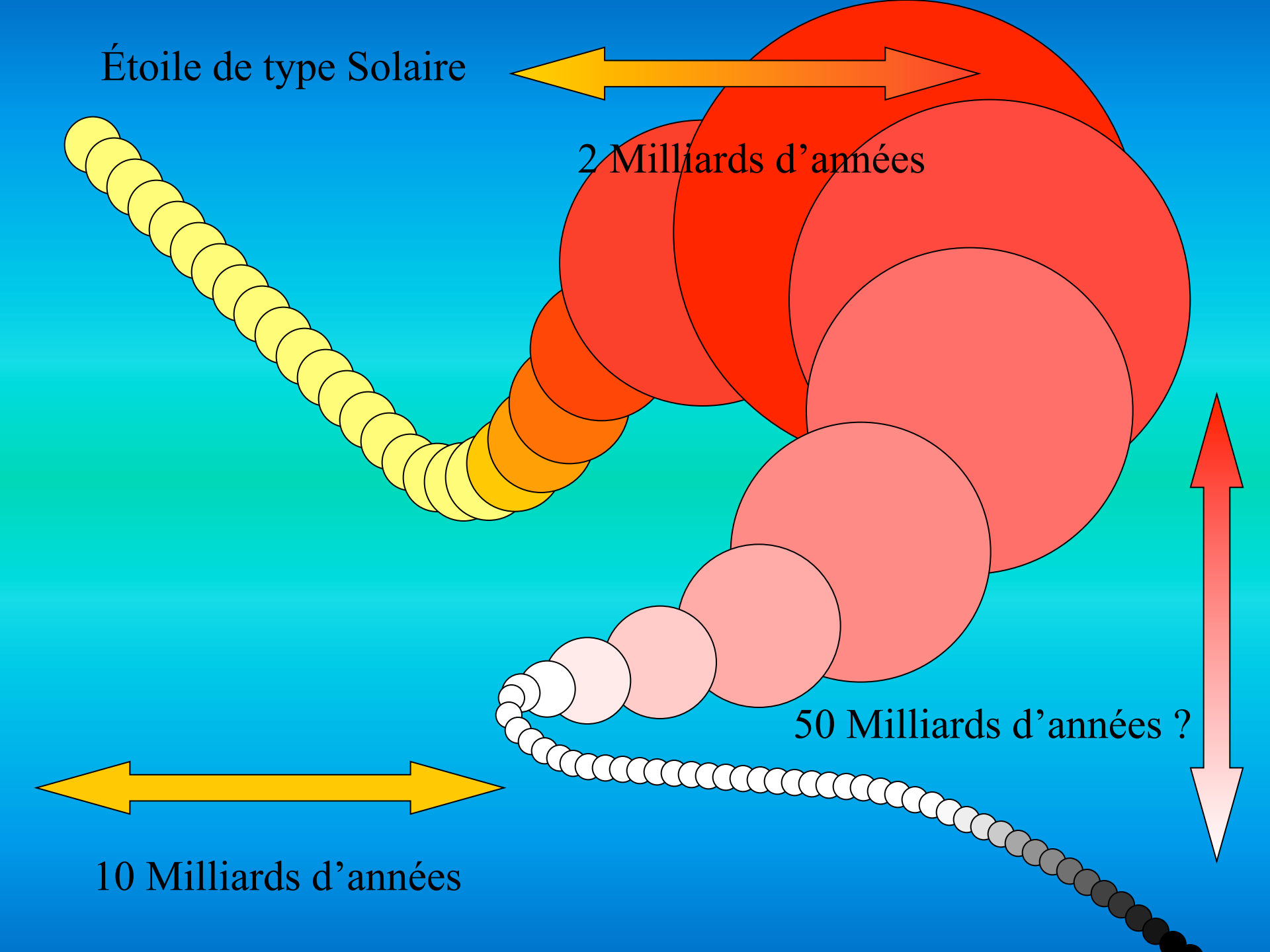
Transmutation de l'Hydrogène jusqu'au Fer

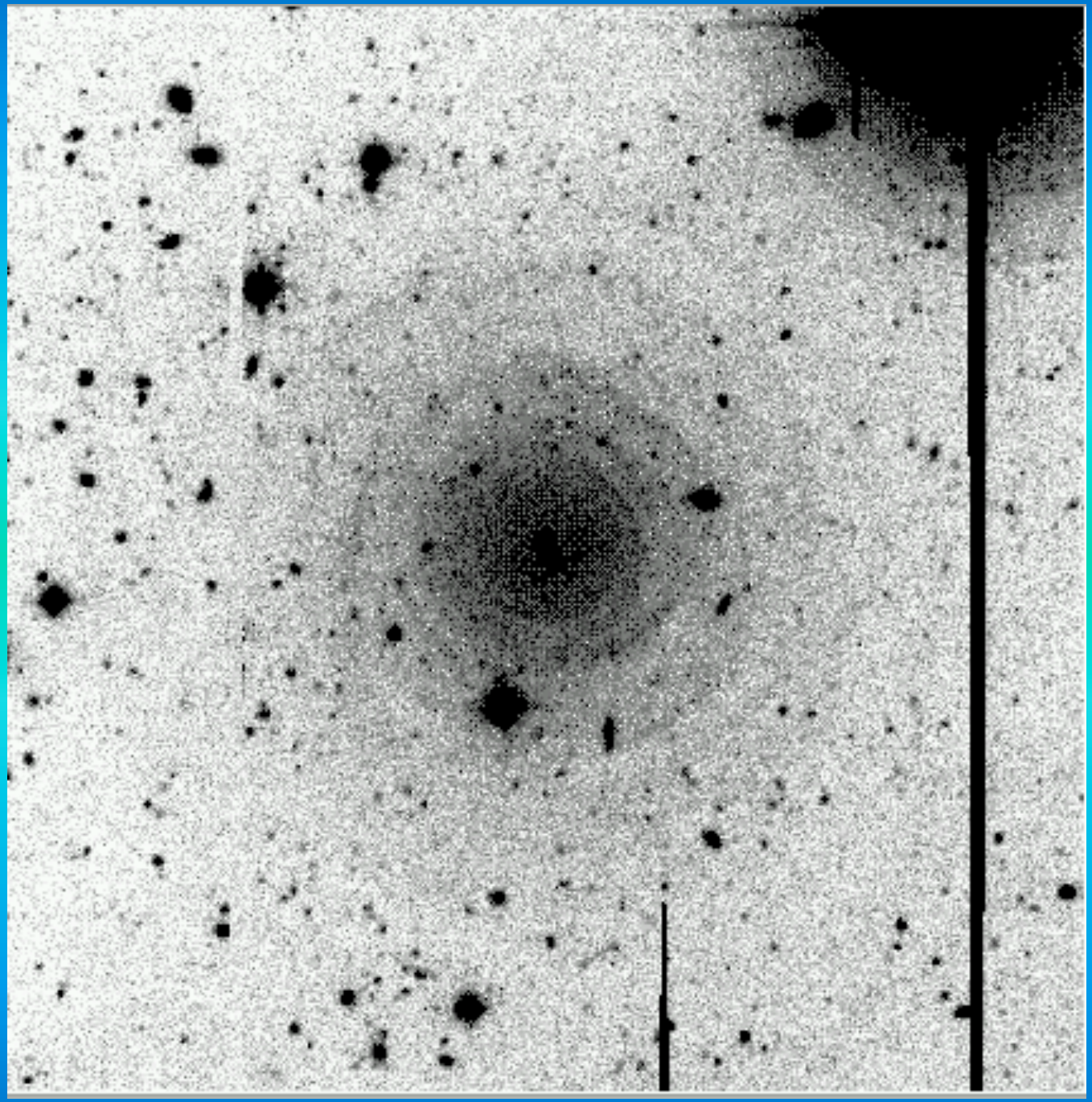
Fin de vie des étoiles…

…et retour au MIS

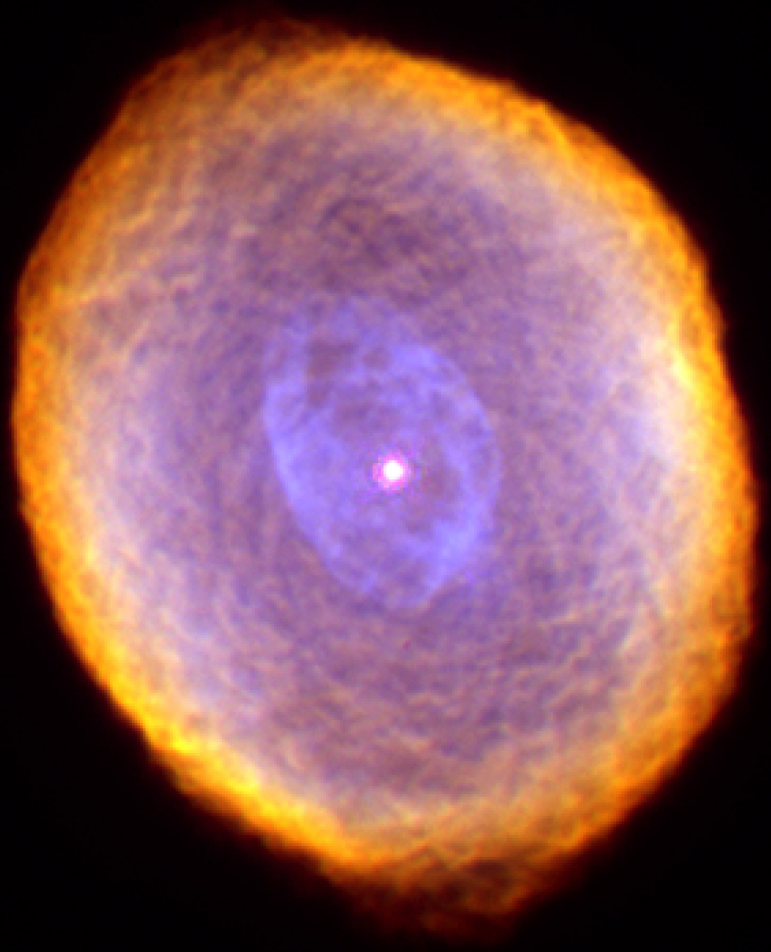
LE CYCLE DE VIE DE LA MATIÈRE



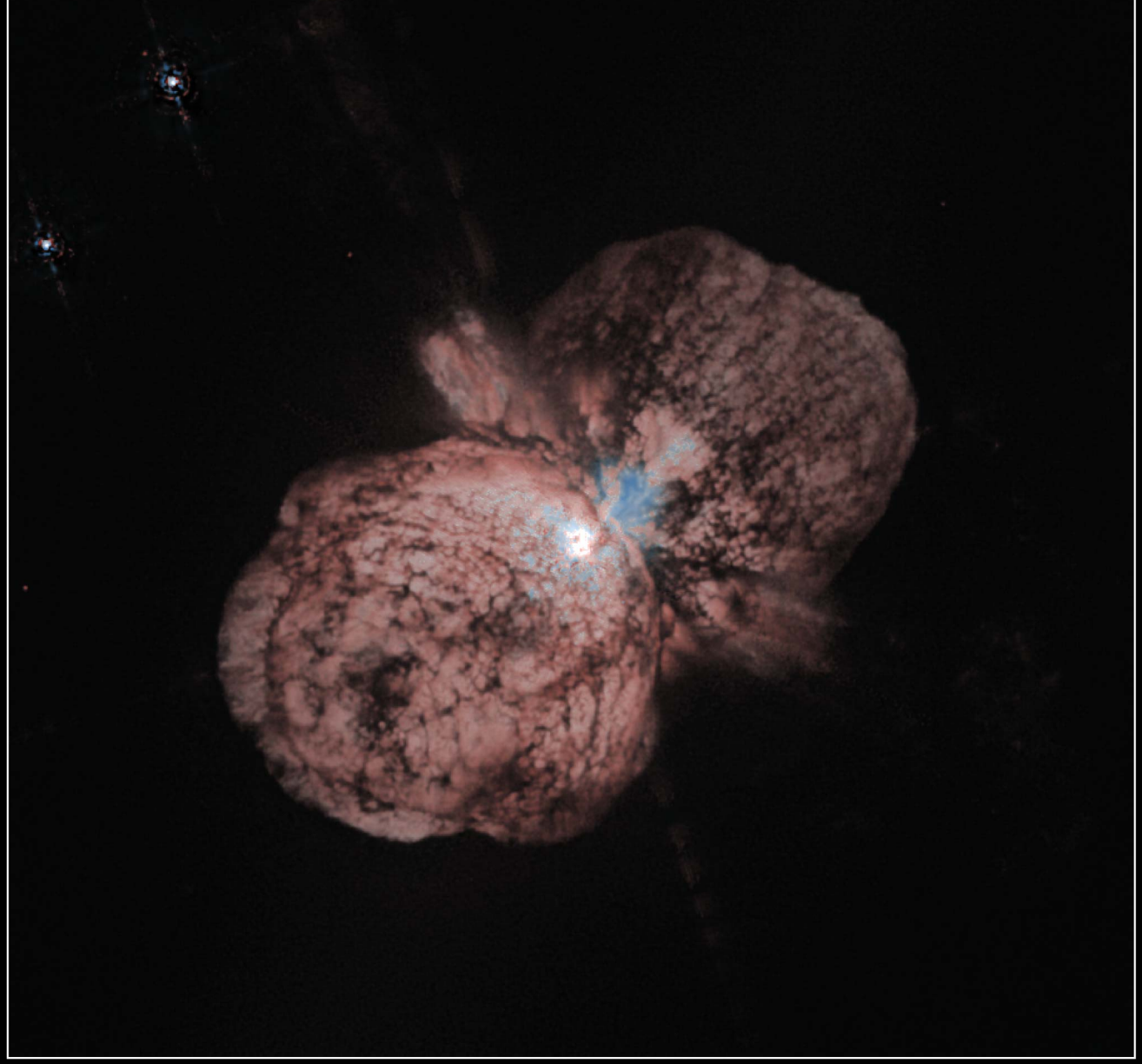

Étoile de type Solaire
2 Milliards d’années
50 Milliards d’années ?
10 Milliards d’années



Planetary Nebula IC 418

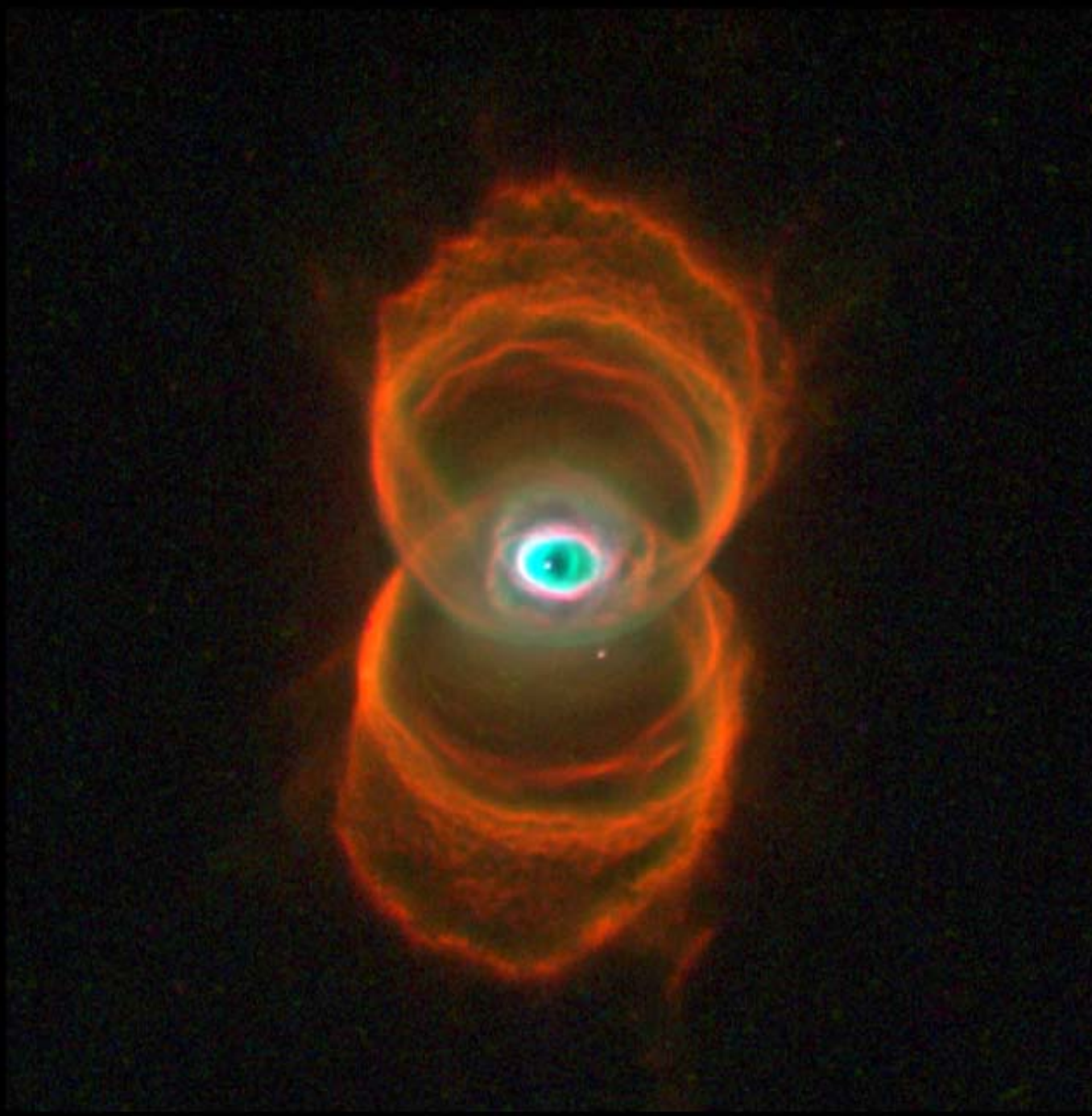


Hubble Heritage



Eta Carinae

Hubble Space Telescope • WFPC2

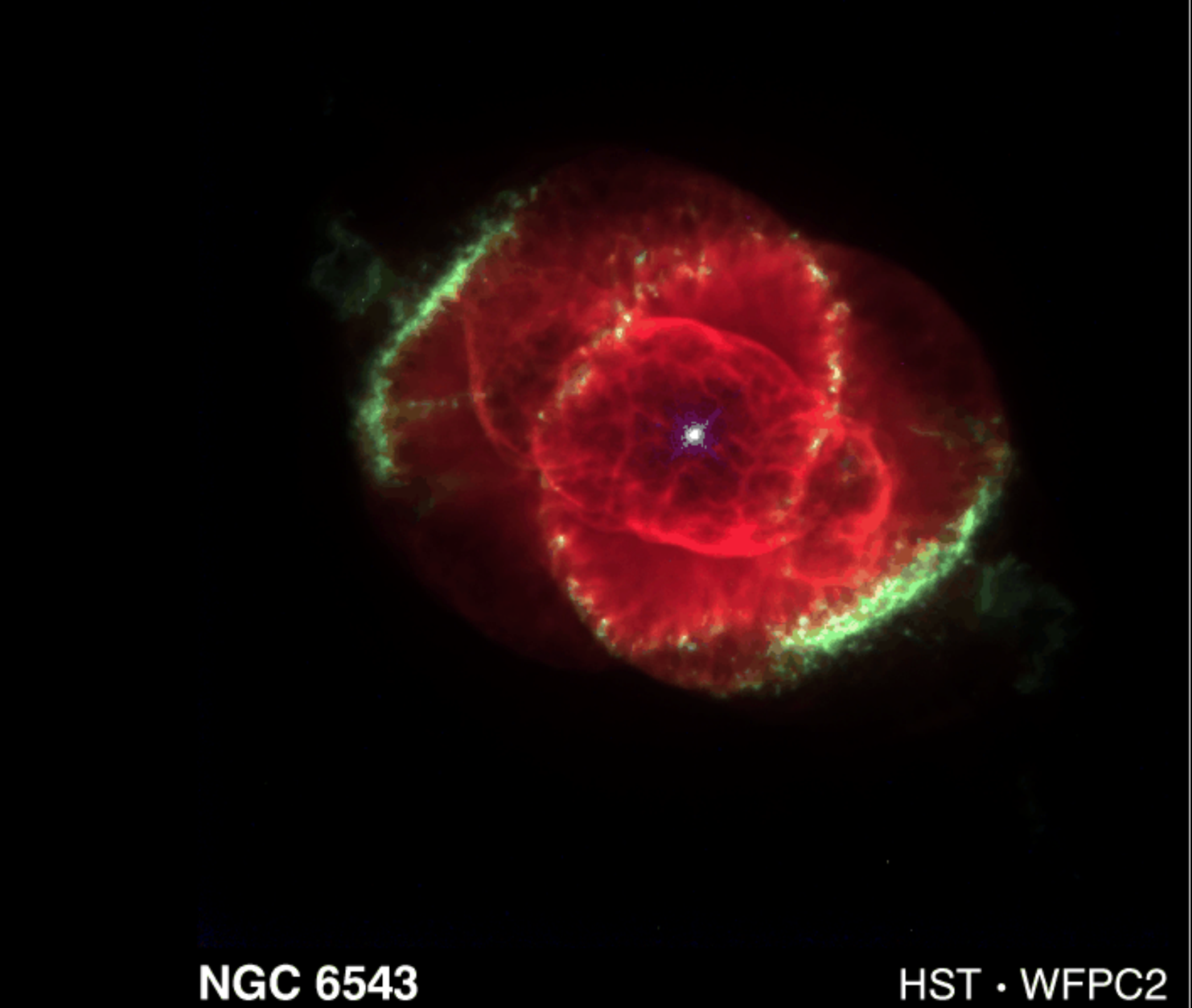


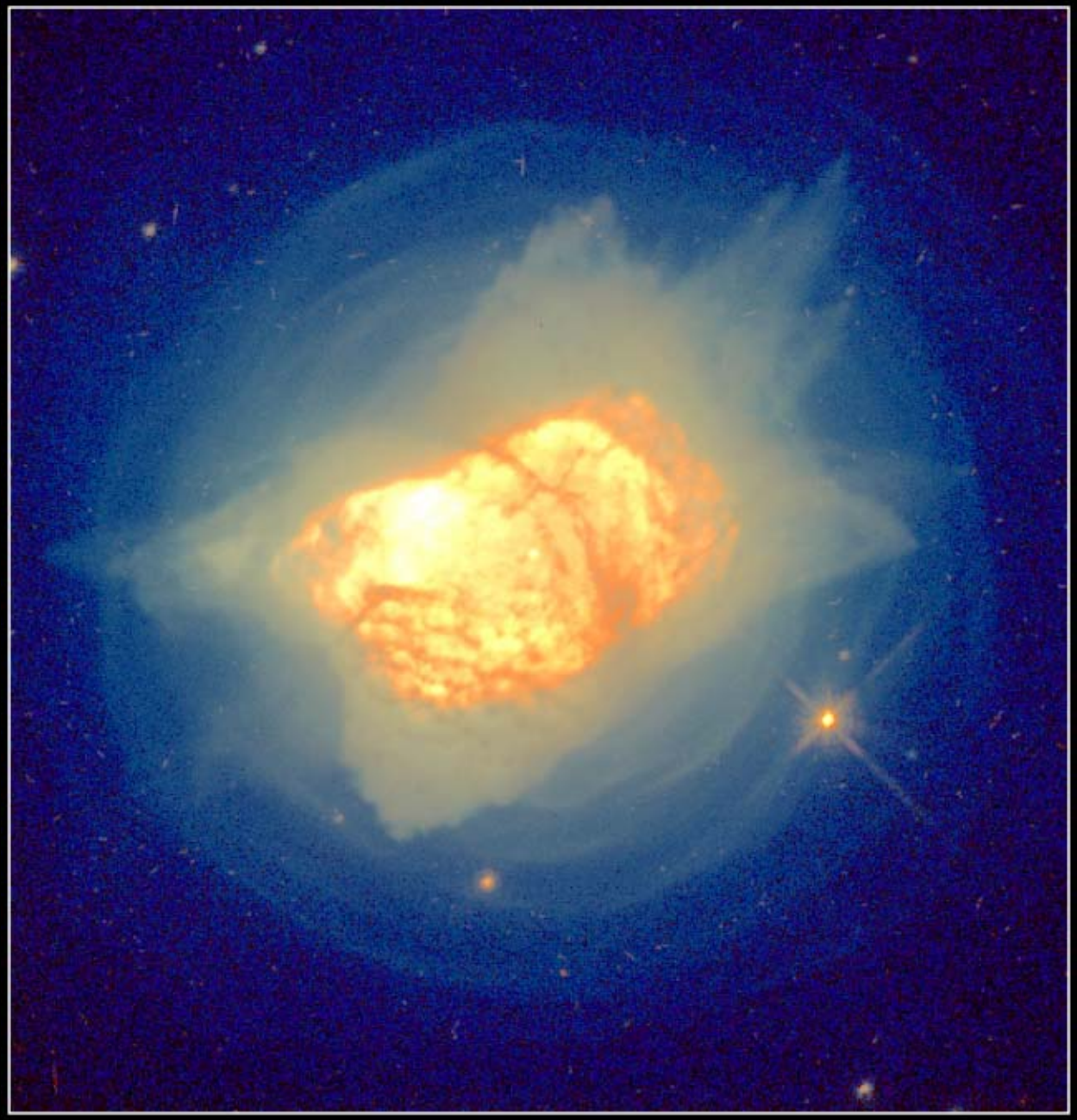
Hourglass Nebula • MyCn18 HST • WFPC2

Planetary Nebula NGC 3132

Hubble Heritage

PRC98-39 • Space Telescope Science Institute • Hubble Heritage Team

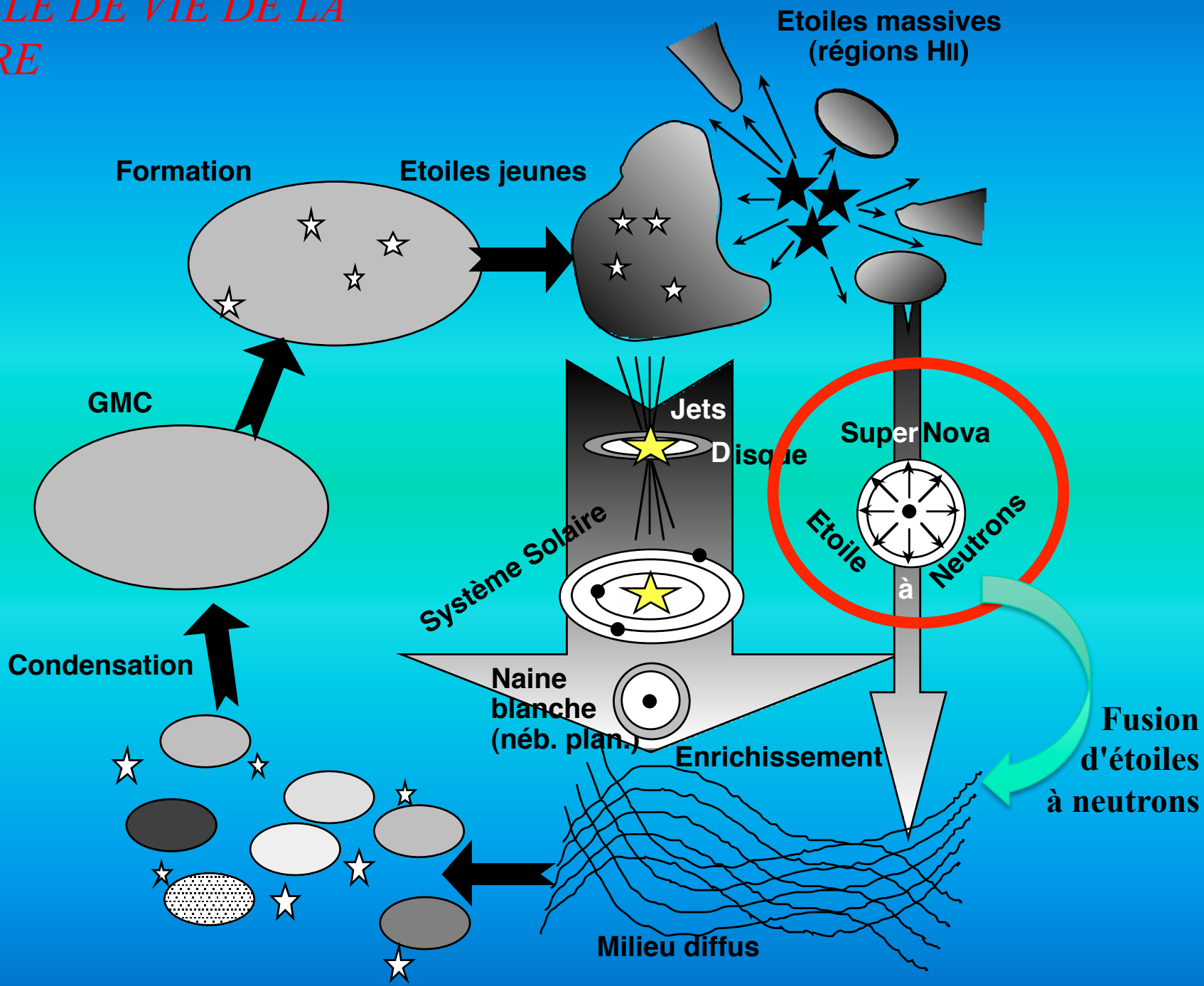

NGC 6543
HST · WFPC2



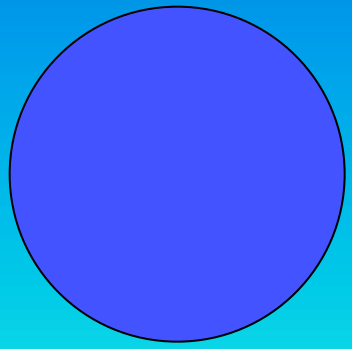
Planetary Nebula NGC 7027 HST • WFPC2

PRC96-05 · ST ScI OPO · January 16, 1996 · H. Bond (ST ScI) and NASA

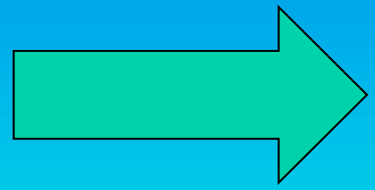
LE CYCLE DE VIE DE LA MATIÈRE



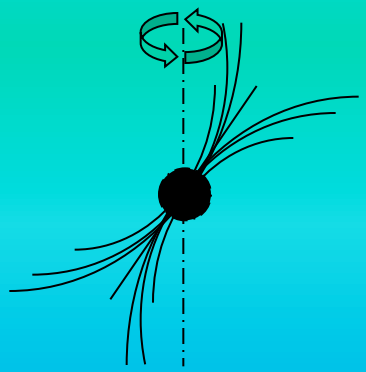
Étoile massive (> 8 Masses solaires)



Séquence principale

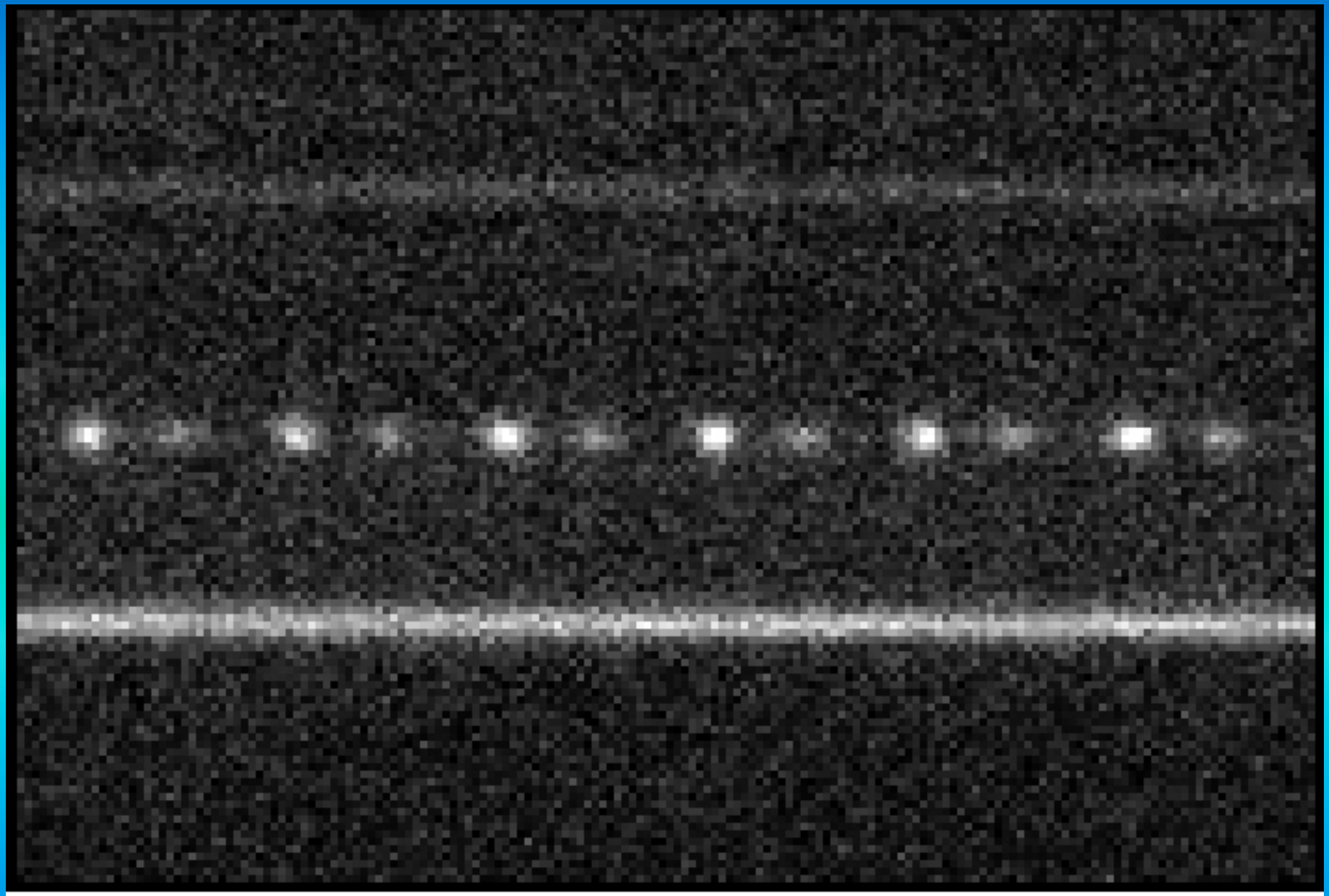


Supergéante



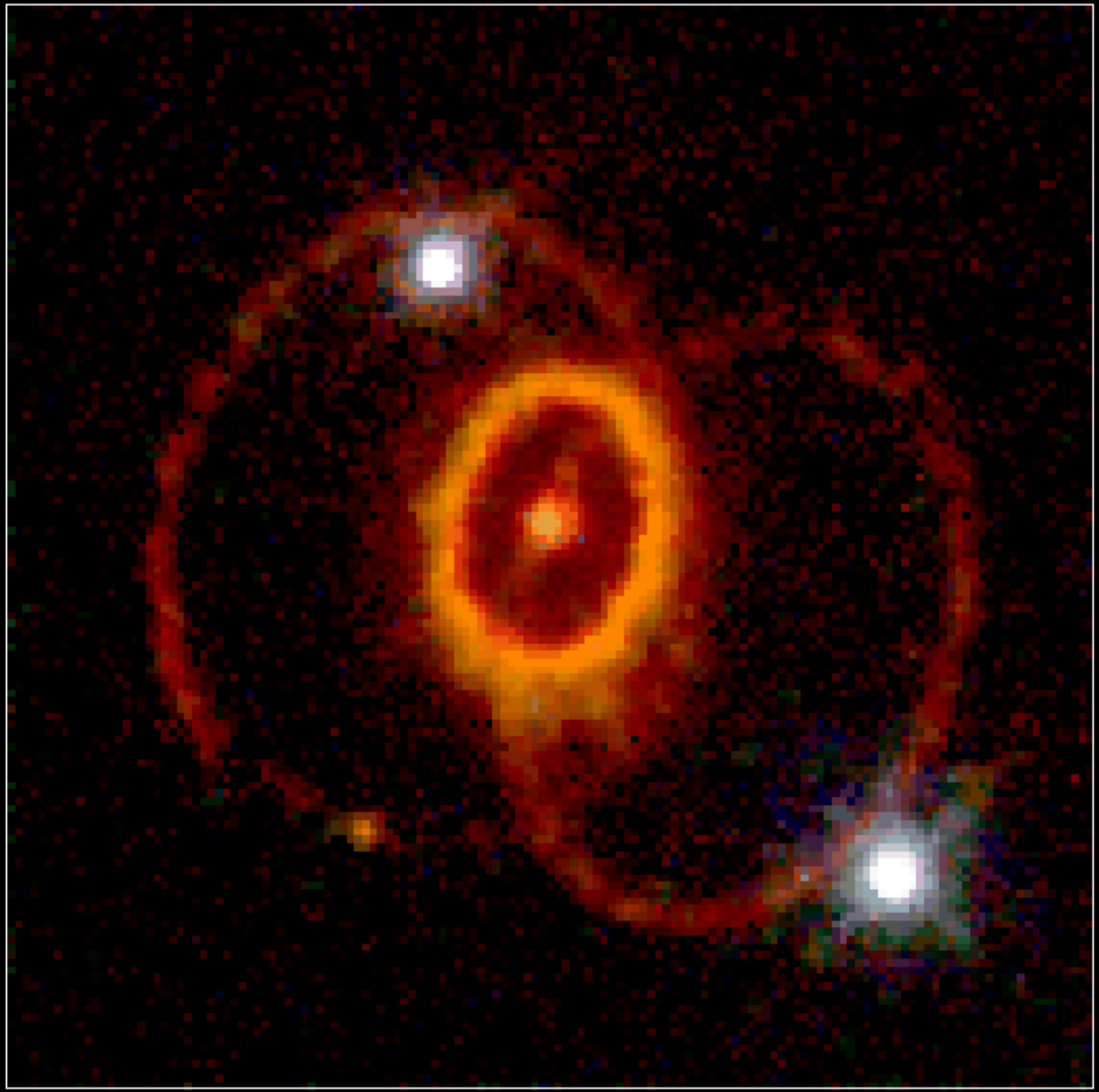
Étoile à Neutrons
(5 km, 10^{15} g.cm^{-3})

Trou noir



Time Sequence of Crab Pulsar (VLT KUEYEN + FORS2 + FIERA)

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




© Anglo-Australian Obs/Royal Obs. Edinburgh

Nouveau depuis quelques années :

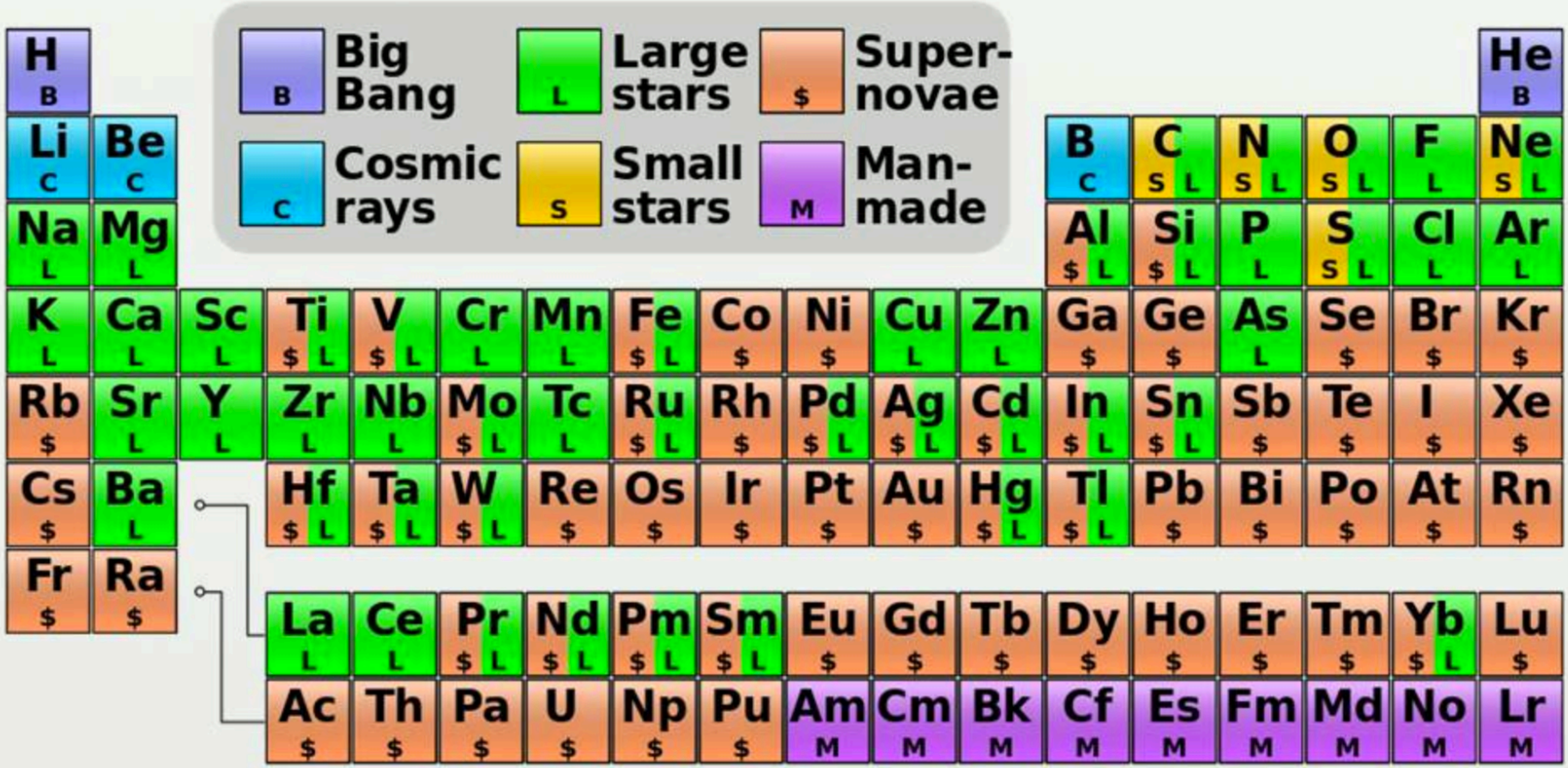
La fusion d'étoiles à neutrons ou kilonova

(le r-process et le s-process)

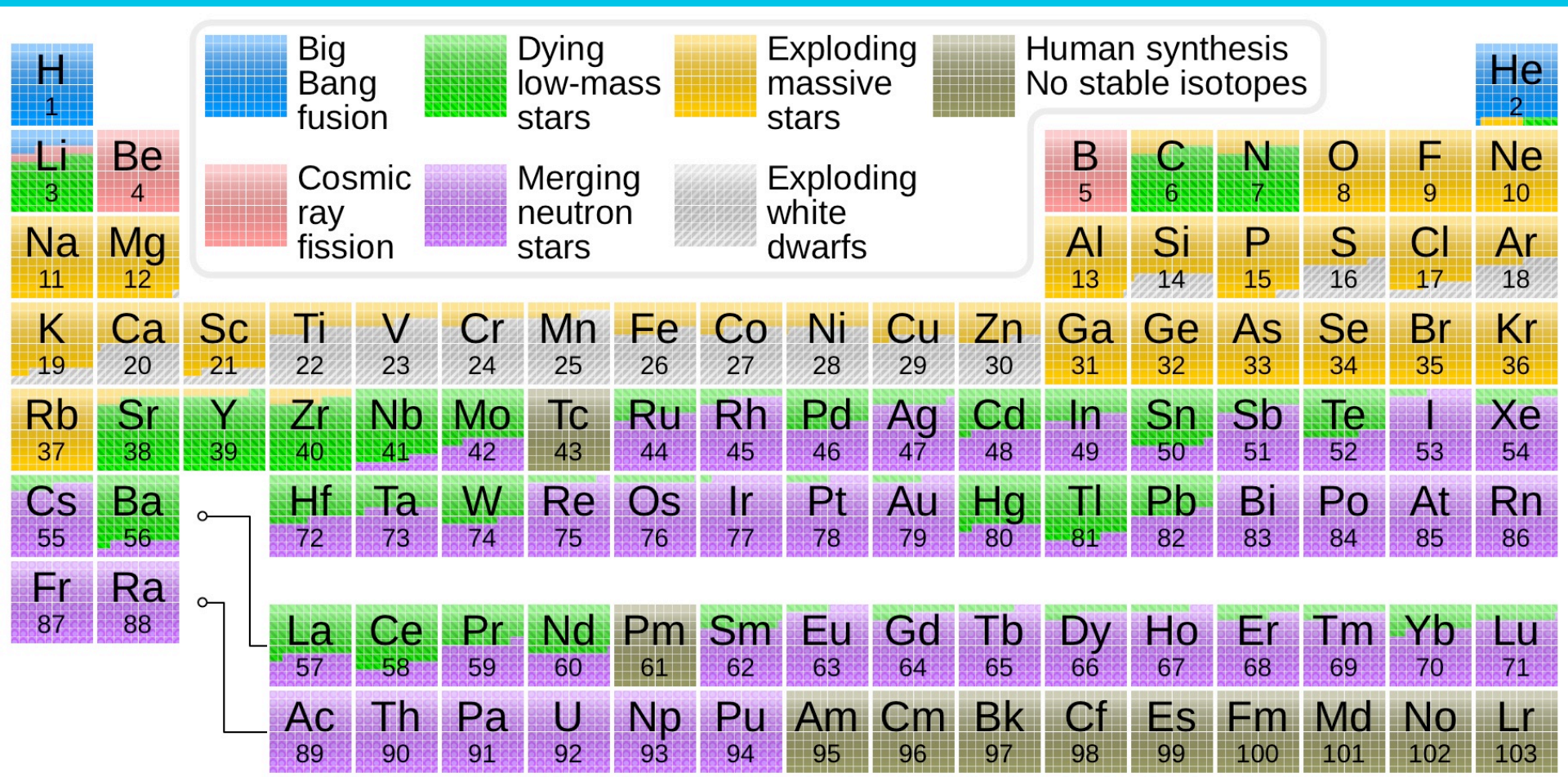
La matière dans l'Univers actuel :

- 92% d' Hydrogène (~74% en masse)
- 7,8% d' Hélium (~25 % en masse)
- 0,08-0,11% d'Oxygène, Carbone, Azote et Néon (~1% en masse)
- 0,013% de métaux, etc. (~0,37 % en masse) : Fe, Si, Mg, S

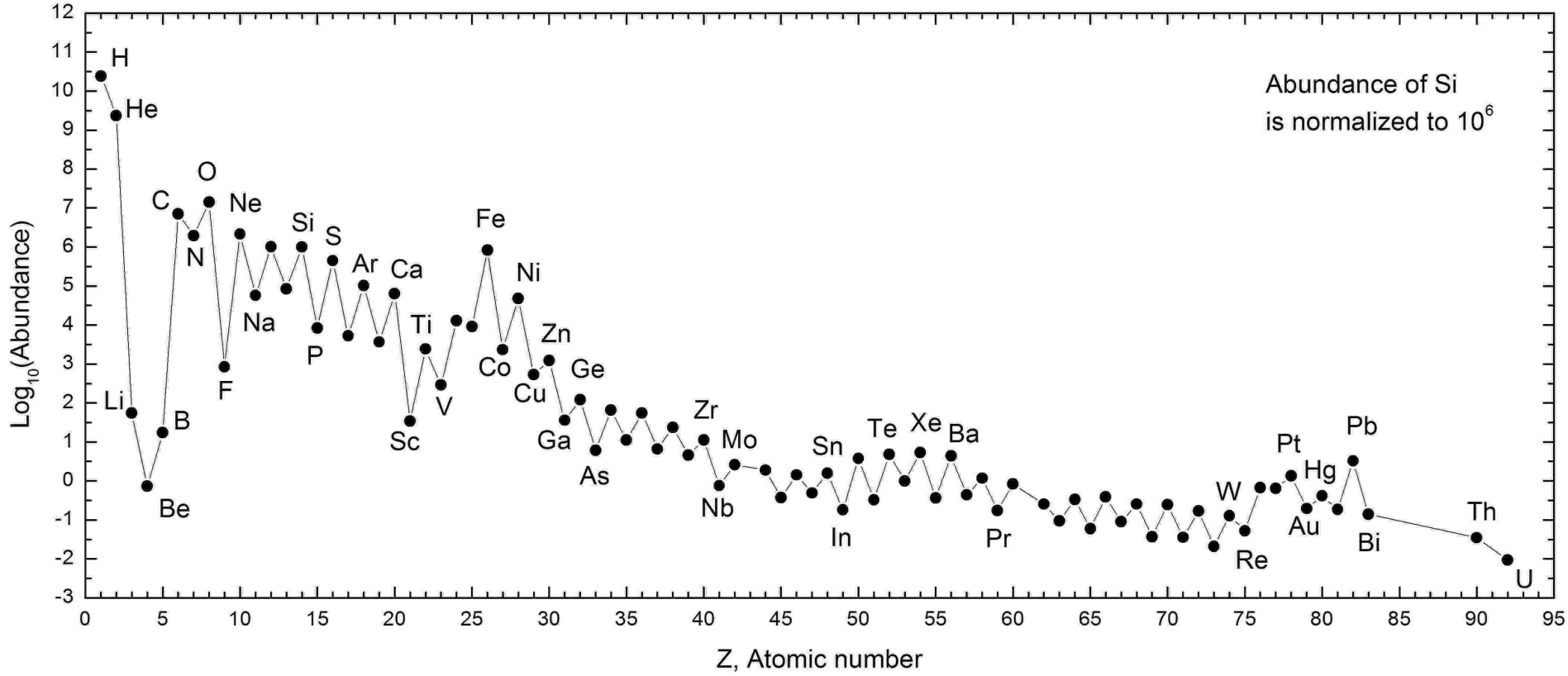
La nucléosynthèse en deux tableaux : 1) avant 2017



La nucléosynthèse en deux tableaux : 2) depuis 2017



Abondance cosmique des éléments



La vie : H,C,N,O,…

…vient des étoiles

Merci pour votre attention

et vos bijoux en or des fusions d'étoiles à neutron!