UNIVERSITÉ DE GENÈVE
FACULTÉ DES SCIENCES
Département d'astronomie

Les grandes missions spatiales pour l'Astrophysique
Saison 2 – Le système solaire

par Corinne Charbonnel, Professeure au Département d'Astronomie de l'Université de Genève

le mardi, du 21 septembre au 21 décembre 2021
de 17h45 à 18h30
Auditoire A300 - Sciences II, 30 quai Ernest-Ansermet, Genève

Inscription au cours sur place le 21 septembre
Renseignements : http://unige.ch/sciences/astro

Chaotic clouds on Jupiter (mission Juno). Image Credits: NASA/JPL-Caltech/SwRI/MSSS/Gerald Eichstädt /Seán Doran

Agenda

Le mardi de 17h45 à 18h30-18h45
Du 21 septembre au 121 décembre 2021
Amphi A300 – Sciences 2

Mardi 5 octobre 2021
!!!! Amphi A150 – Sciences 2 !!!!

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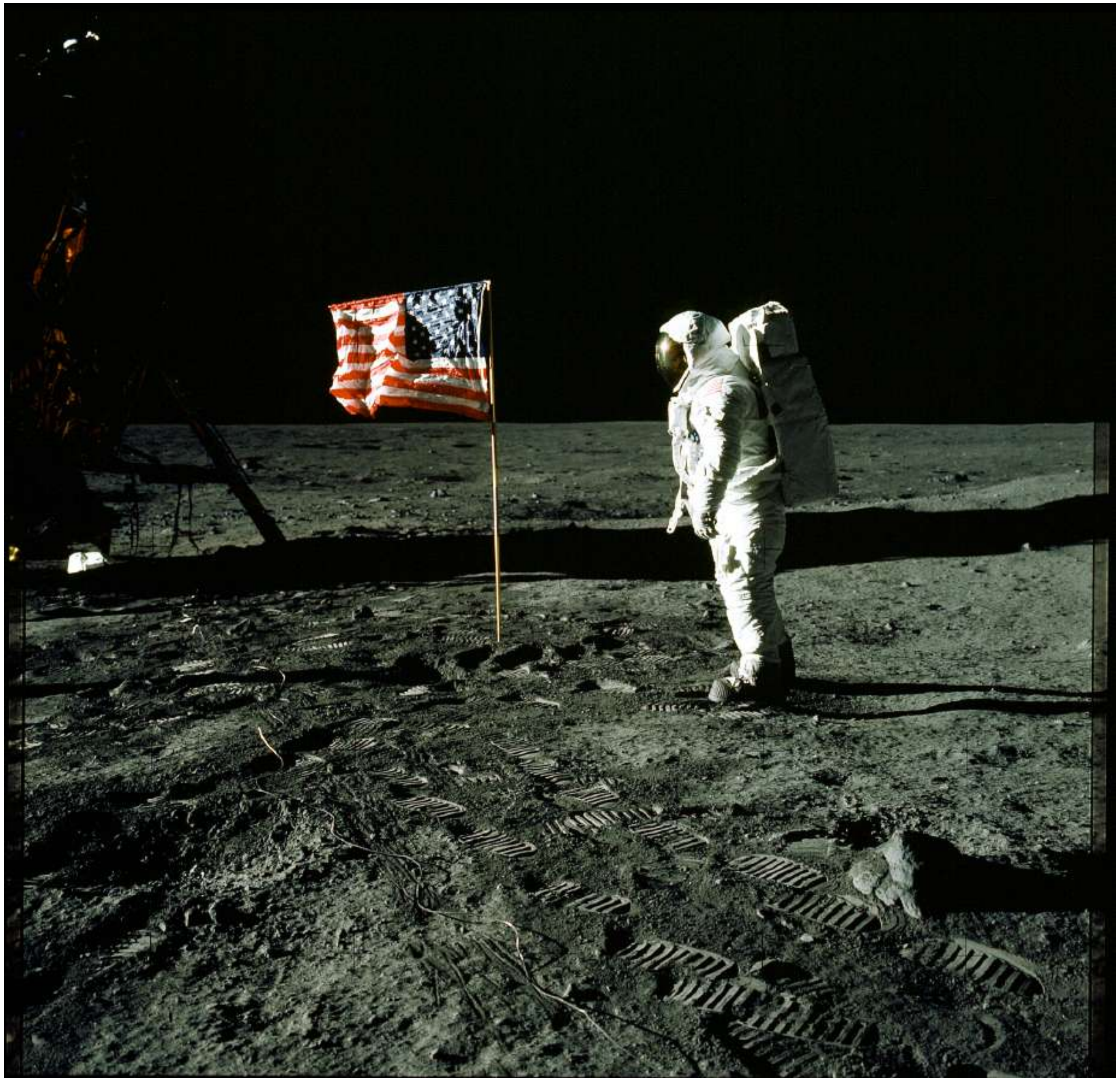
Cours 1 – 21 septembre 2021
Cours 2 – 28 septembre 2021

Pourquoi explorer Le système solaire ?
-
L'exemple de la Lune

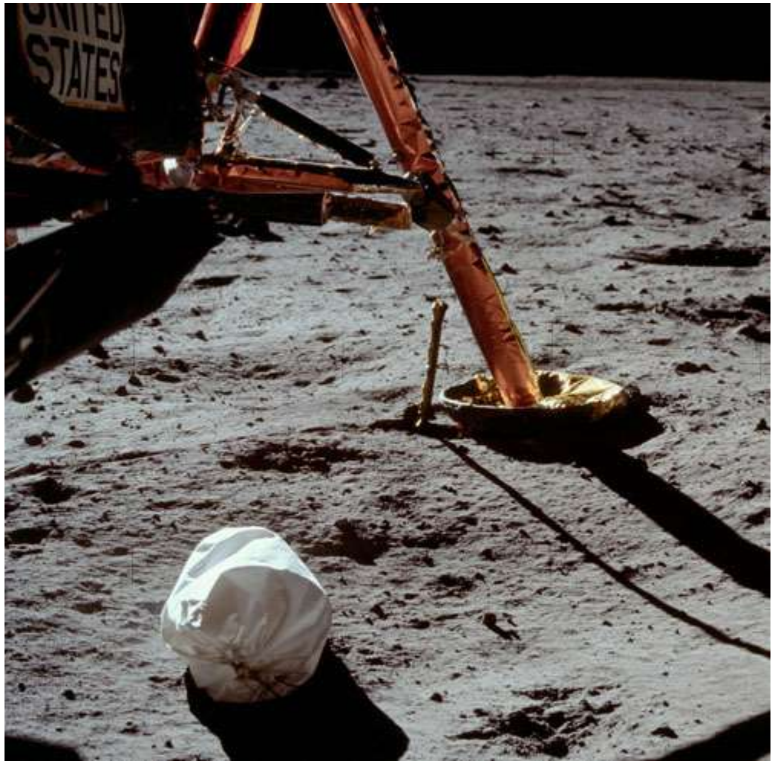
https://mediaserver.unige.ch/play/155171

Apollo 11

Neil A. Armstrong, commander
Michael Collins, command module Columbia pilot
Edwin E. Aldrin, Jr., lunar module Eagle pilot

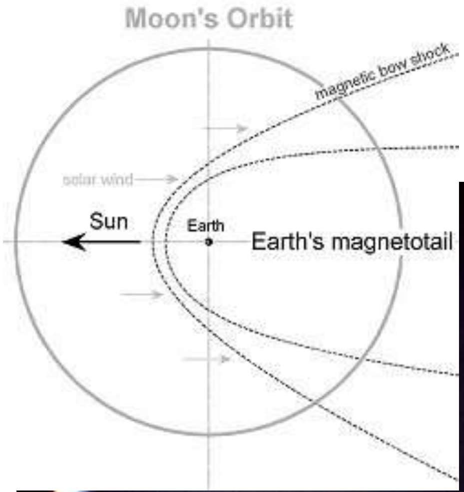


Apollo 11 Lunar Module pilot Edwin Aldrin at 03:15 UT on 21 July 1969 (20 July 1969, 11:15 EDT) and became the second person to walk on the Moon. (Apollo 11, AS11-40-5868)



Jettison Bag (Armstrong – NASA)

Solar wind experiment on the Moon



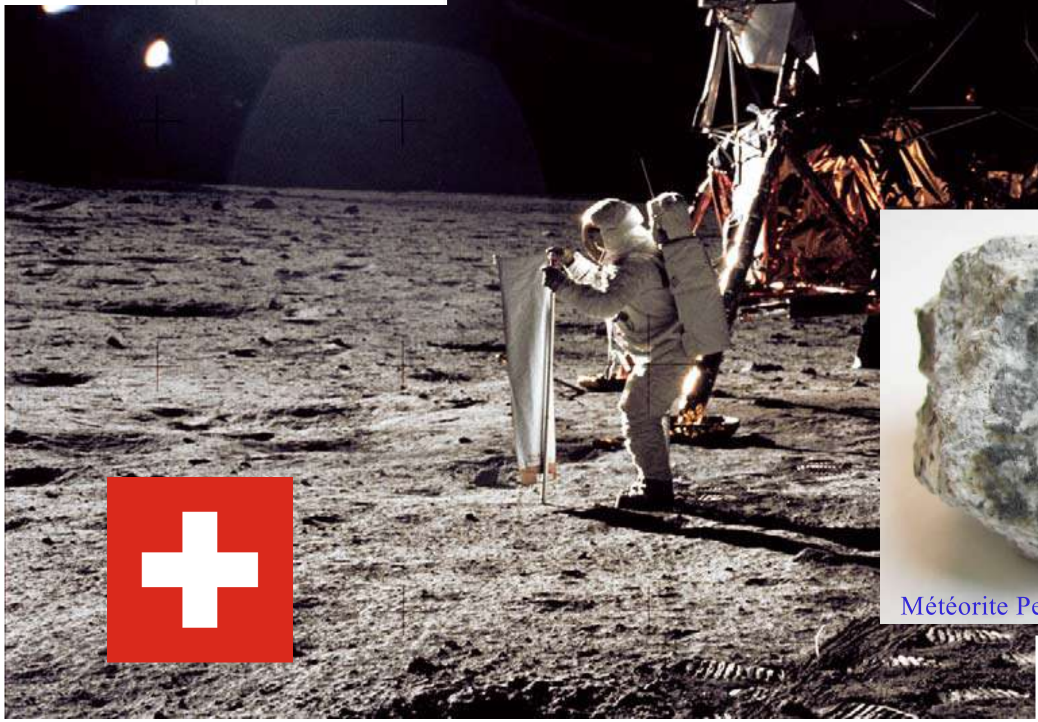
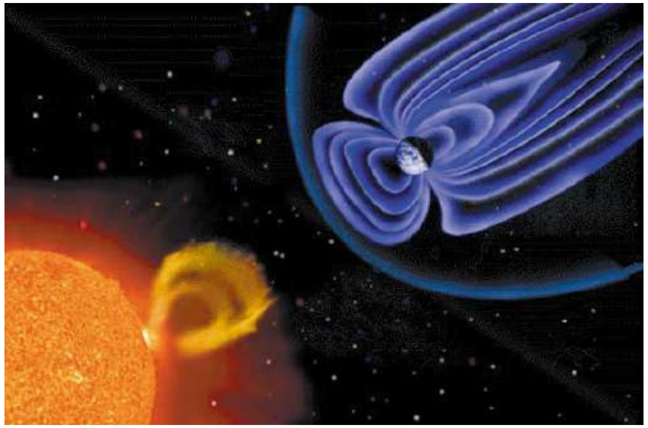


Figure 1. Apollo 11 Astronaut Edwin E. Aldrin deploying the SWC experiment in Mare Tranquillitatis on July 21, 1969. Photograph by Commander Neil A. Armstrong (NASA Photo S11-40-5872).

Geiss *et al.* (1965, 1969)
1969 – 1972 (Apollo 11, 12, 14, 15, 16)

Johannes Geiss, Peter Eberhardt – Université de Bern
Peter Signer – EPFZ



1969 – 1972 (Apollo 11, 12, 14, 15, 16)

Solar wind experiment on the Moon

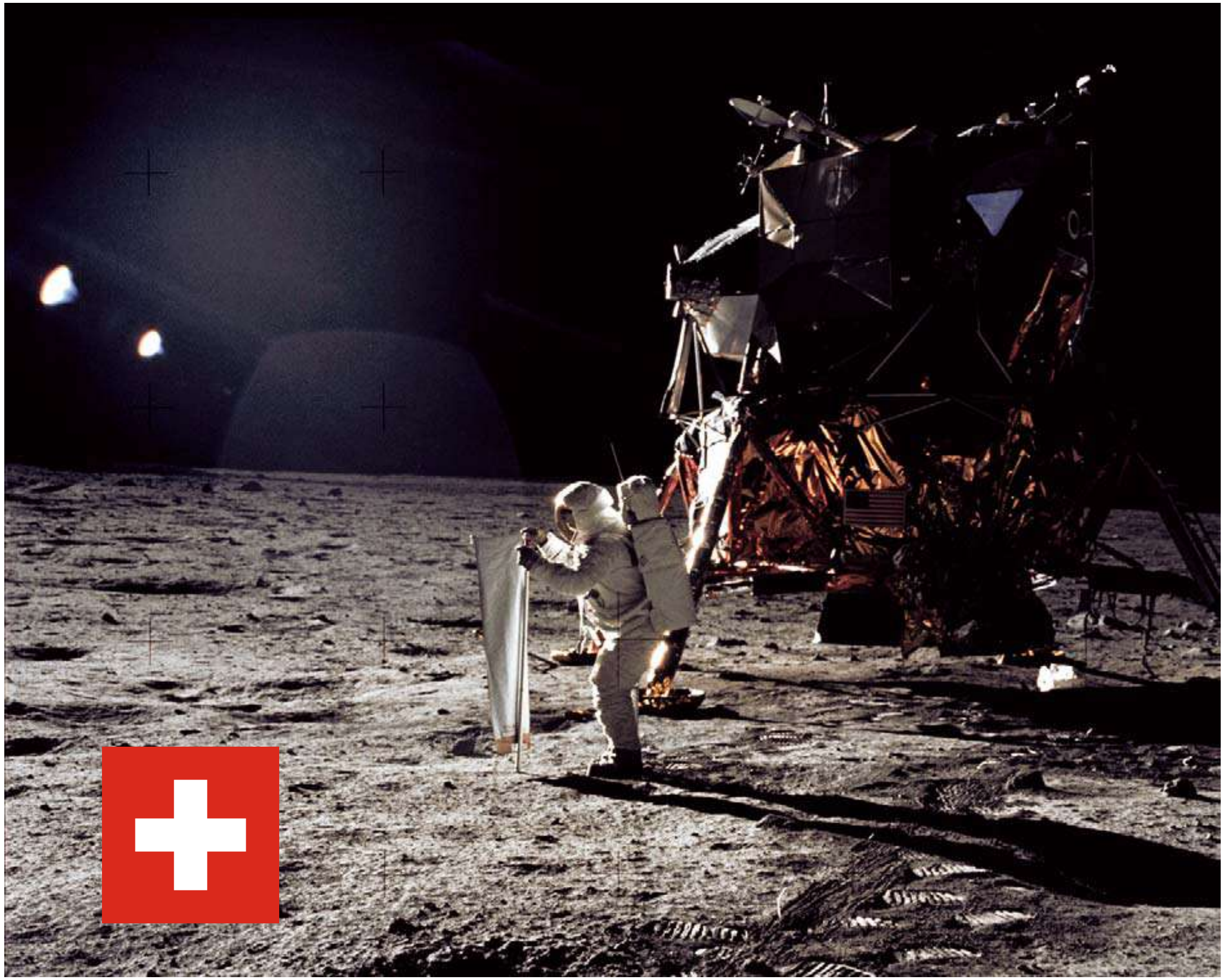


Figure 1. Apollo 11 Astronaut Edwin E. Aldrin deploying the SWC experiment in Mare Tranquillitatis on July 21, 1969. Photograph by Commander Neil A. Armstrong (NASA Photo S11-40-5872).

Abundances des isotopes
d' He, Ne, Ar

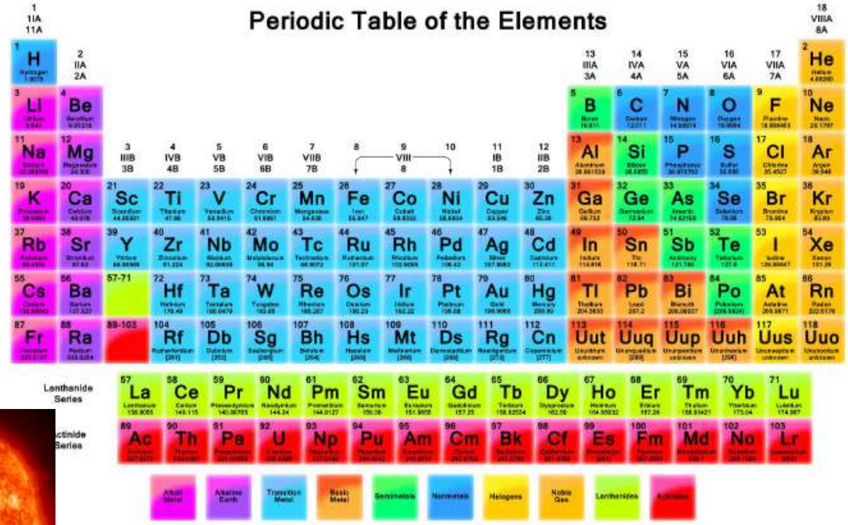
Informations sur le big bang
et sur l'évolution
du soleil, des étoiles,
et de la galaxie

L'énigme de l'évolution
de ^{3}**He** dans la galaxie

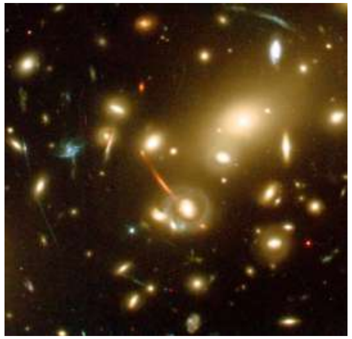
Geiss *et al.* (1965, 1969)
1969 – 1972 (Apollo 11, 12, 14, 15, 16)

Origine des éléments chimiques

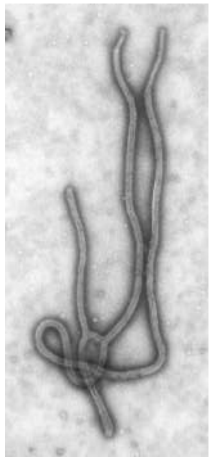


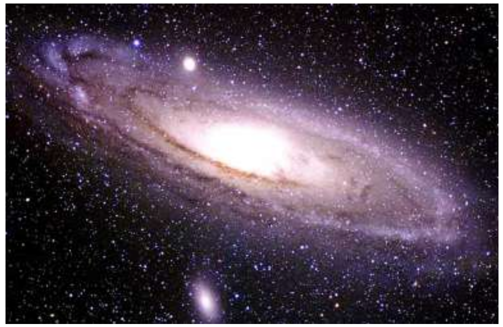





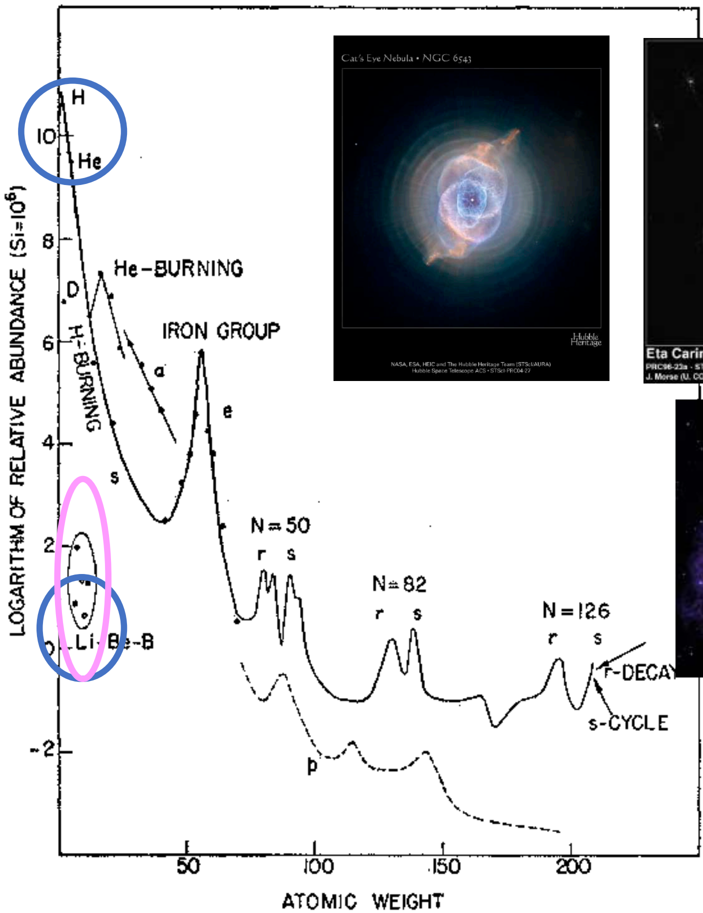


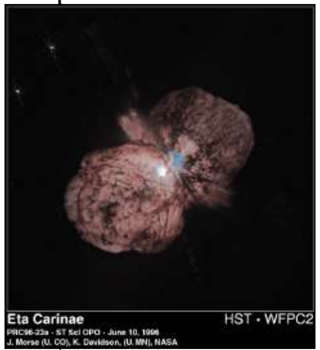


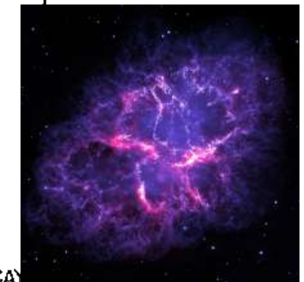


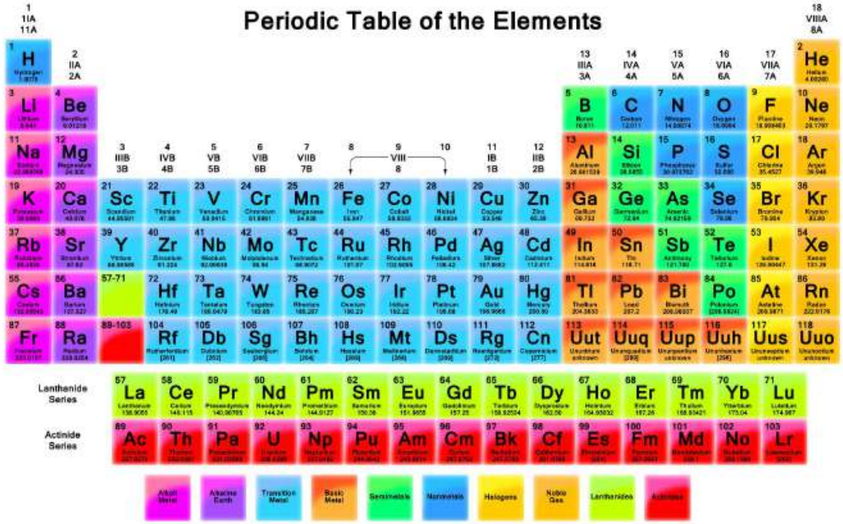


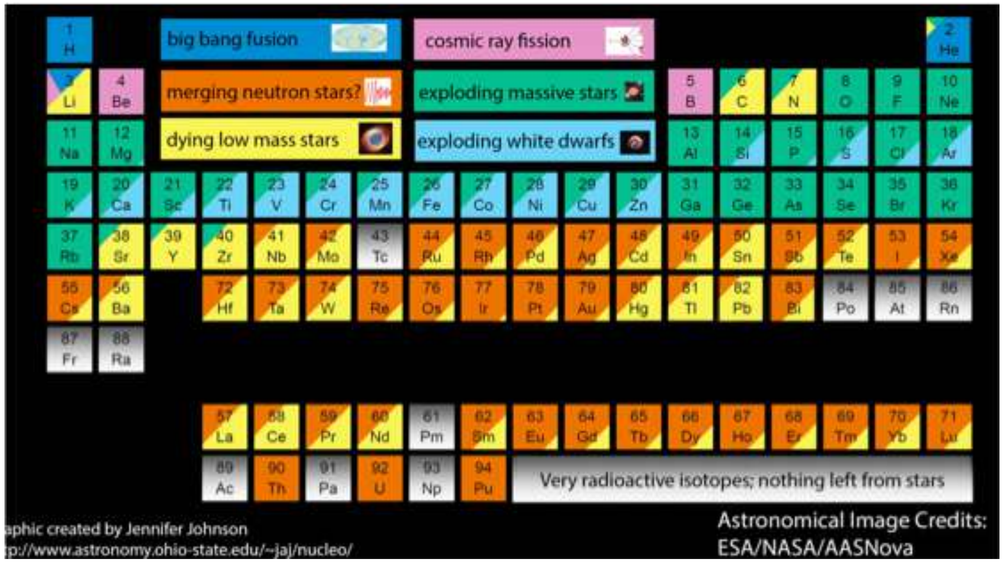
Origine des éléments chimiques









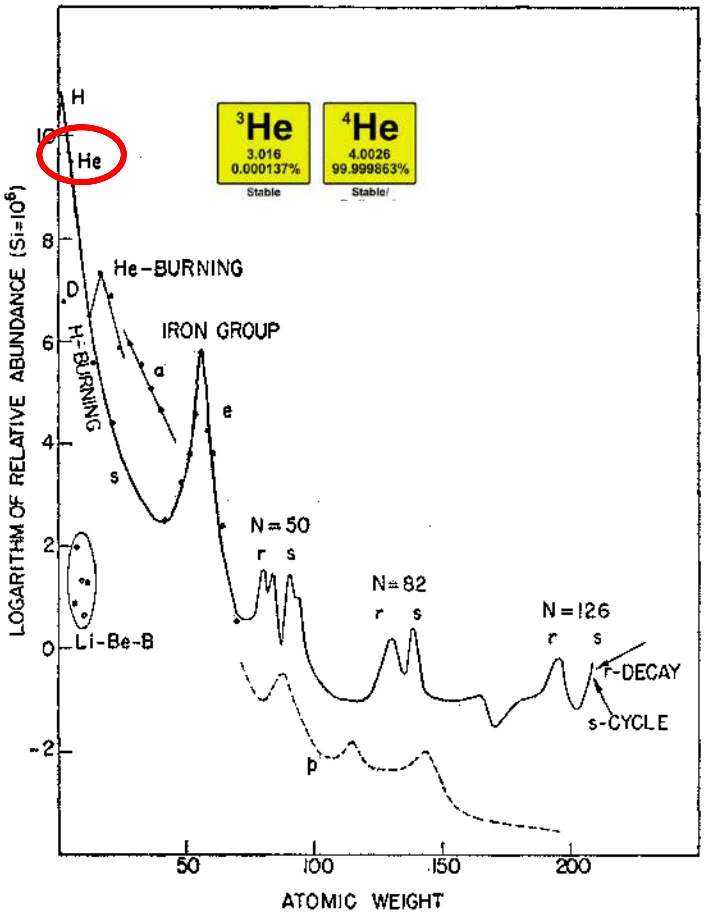


Atomic abundance curve

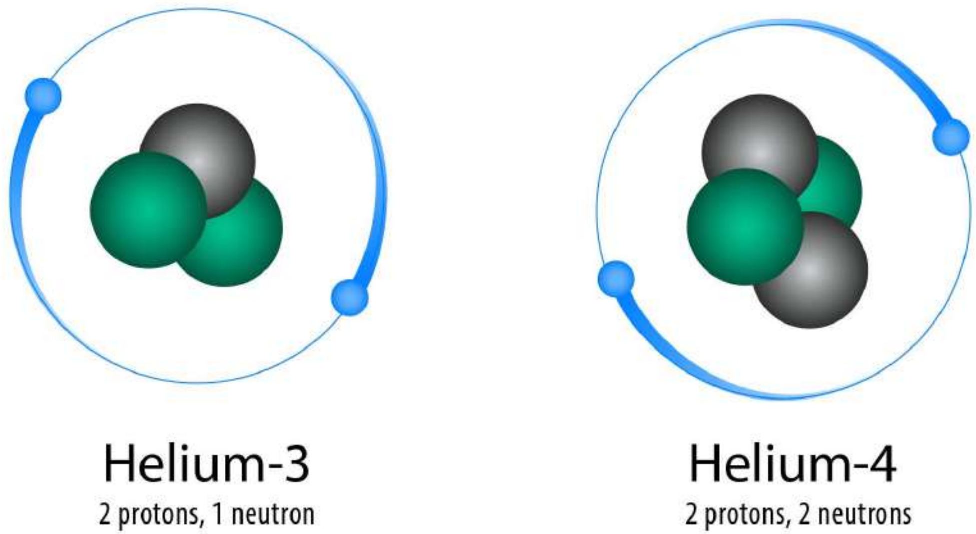
Burbidge *et al.* (1957 – Synthesis of the elements in stars)

Meteoritic, solar, and terrestrial data (Suess & Urey 1956)

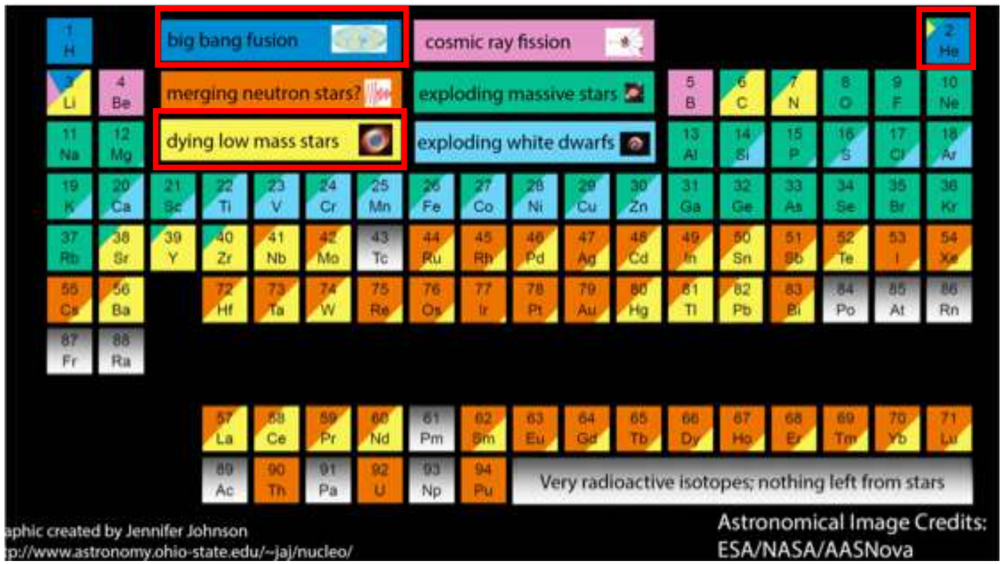
Origine de l’hélium 3



Atomic abundance curve
Burbidge *et al.* (1957 – Synthesis of the elements in stars)
Meteoritic, solar, and terrestrial data (Suess & Urey 1956)

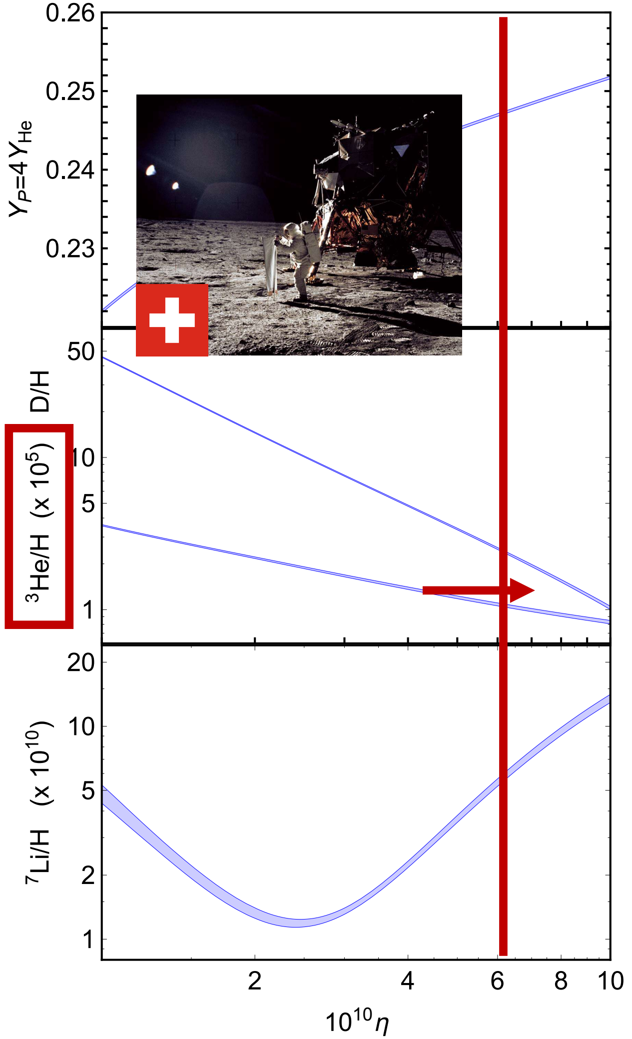


Atmosphère terrestre : 1 ^{3}He pour 1 million ^{4}He
Roches croute terrestre : 1 à 10 ^{3}He pour 1 million ^{4}He
Milieu interstellaire : 1000 ^{3}He pour 1 million ^{4}He



^{3}He produit au cours du Big Bang

✓ Première contrainte observationnelle sur la densité baryonique de l'univers



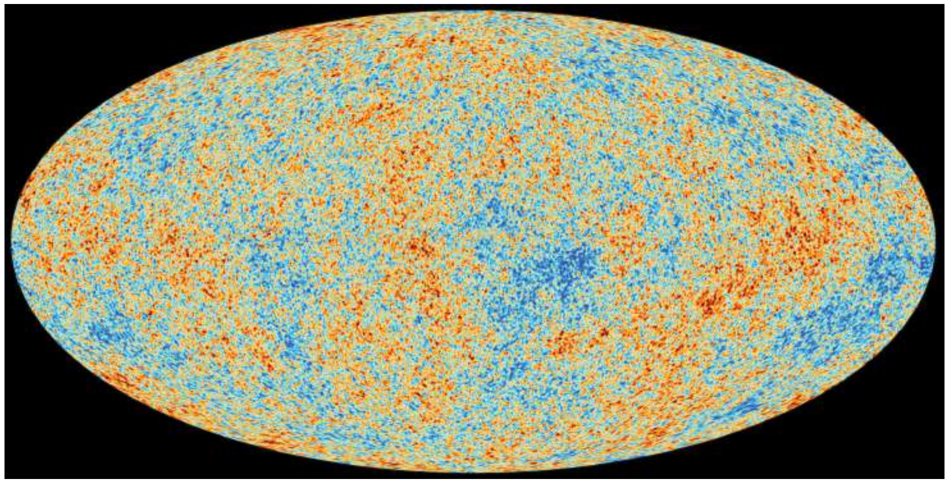
Abondances prédites par BBN
en fonction de la densité baryonique de l'univers (baryons (protons, neutrons) /photons)
Pitrou *et al.* (2018)

Les « piliers » observationnels du Big Bang

Production des éléments légers (H, D, ^{3,4}He, ^{7}Li)
dans les premières minutes après le Big Bang
Gamov *et al.* (1940), Peebles (1966), Wagoner *et al.* (1967)

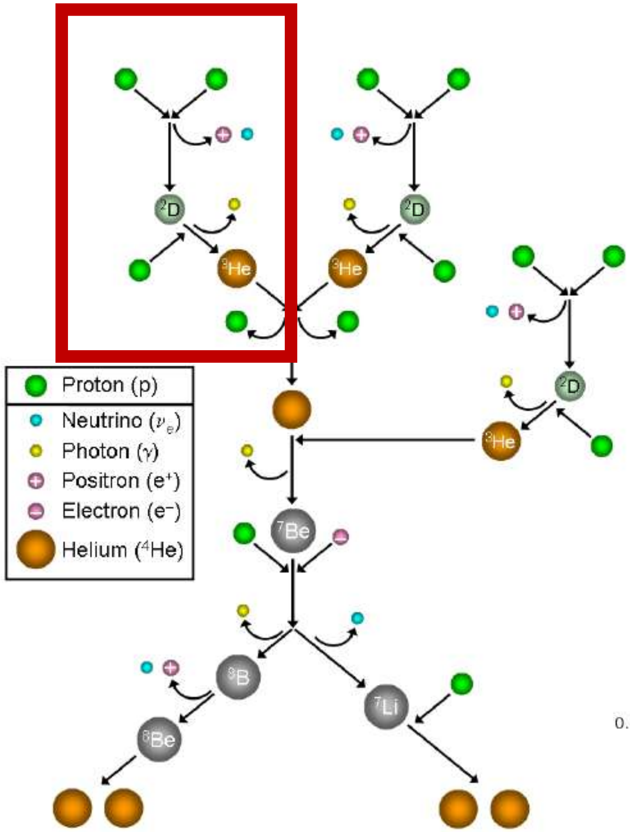
Expansion de l'Univers
Les galaxies s'éloignent de nous
Les galaxies les plus lointaines s'éloignent plus vite
Slipher (1914), Friedman, Lemaître, Hubble, Einstein

Fonds diffus cosmologique
(Cosmic Microwave Background – CMB)
Rayonnement fossile émis ~ 380'000 ans après le Big Bang
Anisotropies → age, structure, densité de l'univers
Penzias & Wilson (1965)



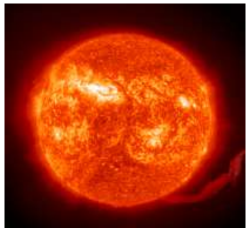
Anisotropies du CMB
Planck collaboration (2020)

^{3}He produit dans les étoiles

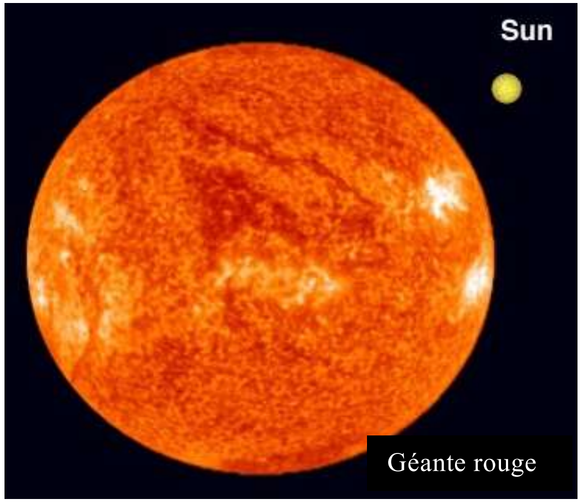


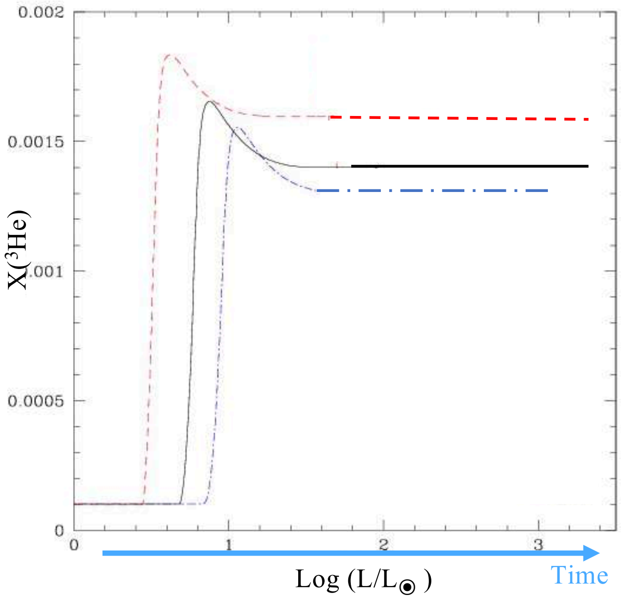
Réactions nucléaires au cœur du soleil
(chaines proton-proton)
T ~ 15 MK

Nébuleuse protosolaire

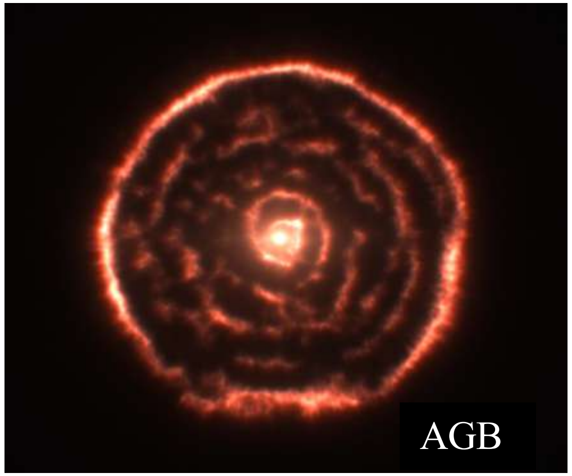


Synthèse des éléments dans les étoiles
Burbidge *et al.* (1958)
Premiers modèles d'évolution stellaire
Iben (1967)

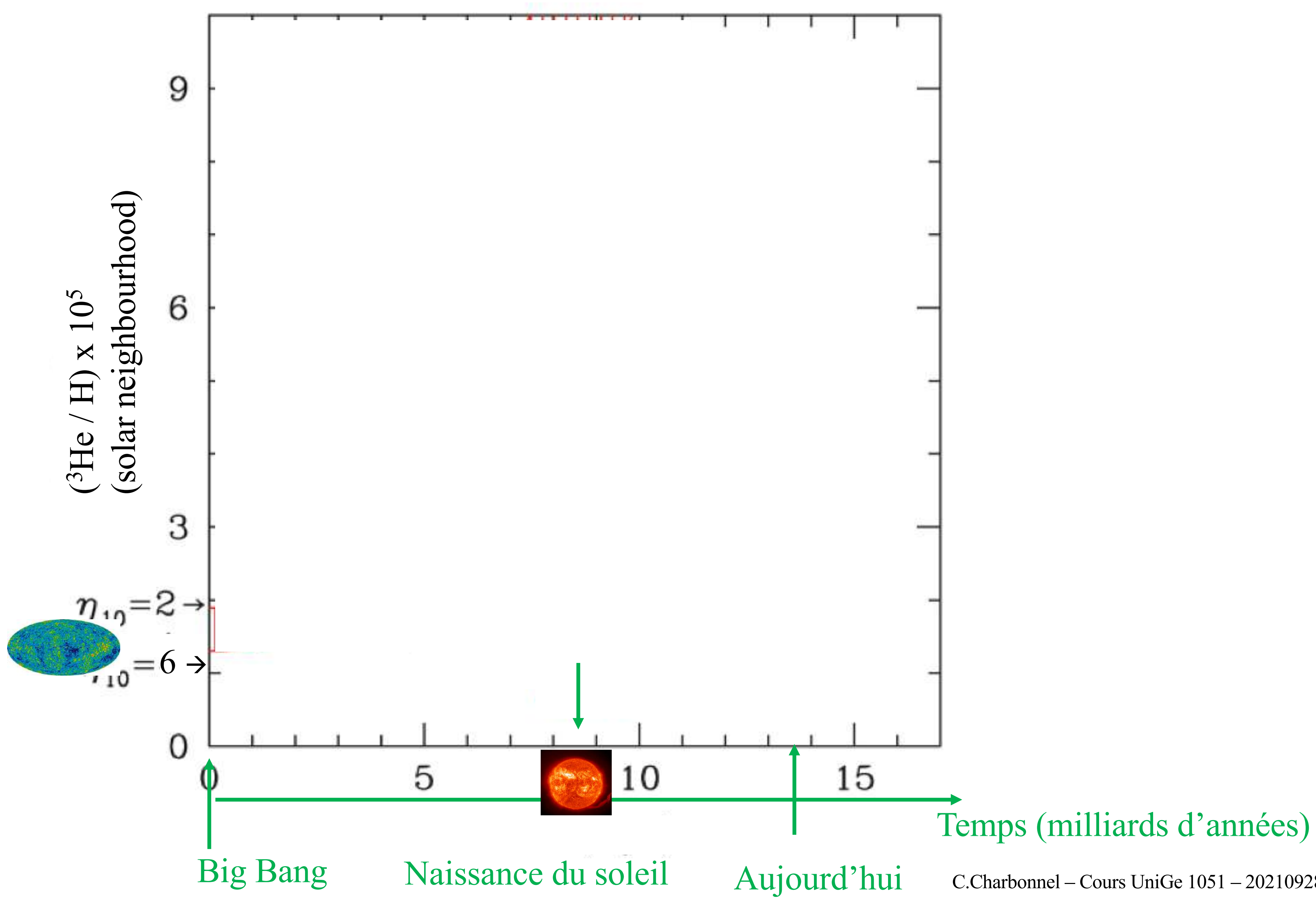




Evolution de l'abondance de ^{3}He dans des étoiles de faible masse

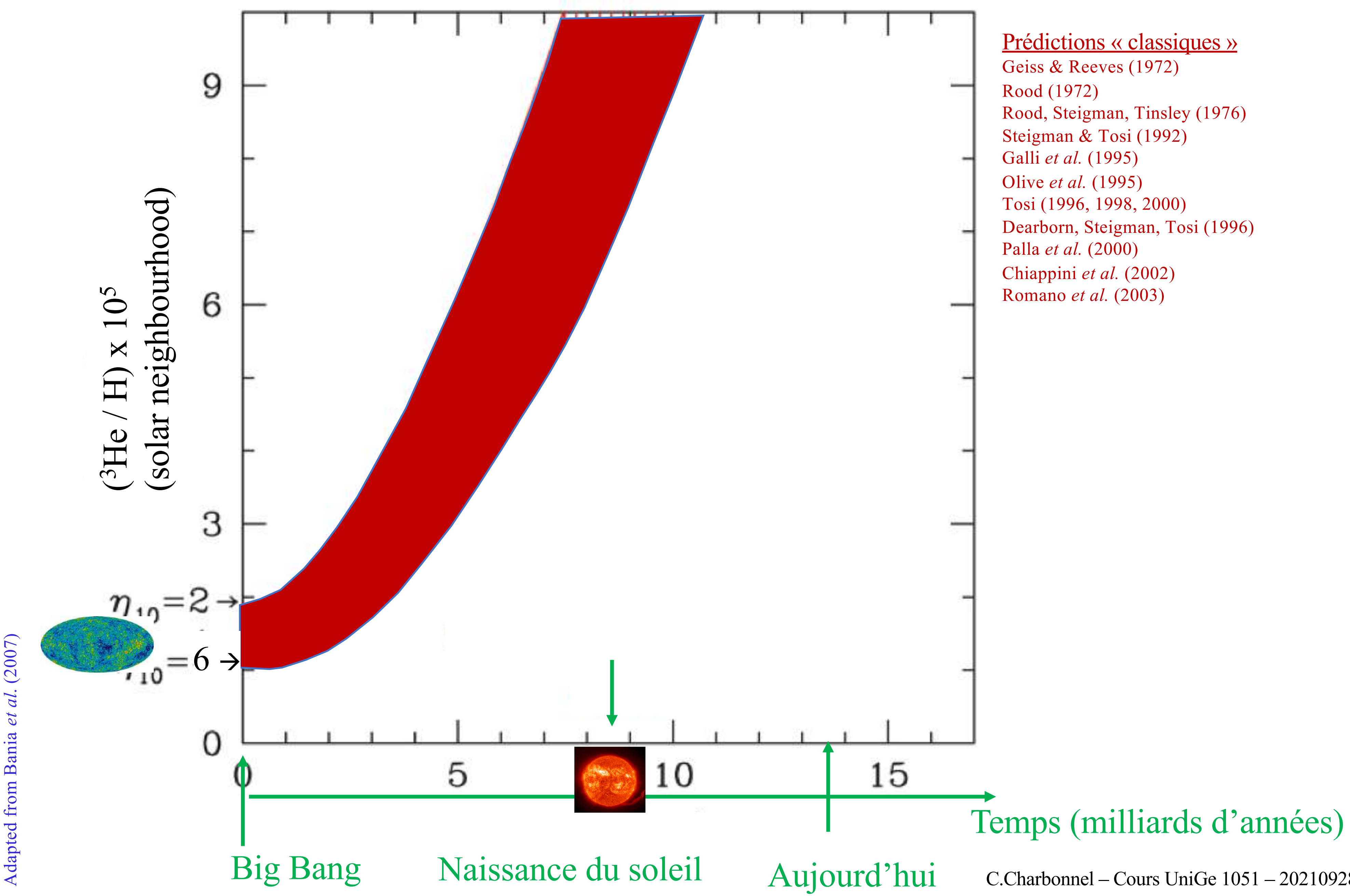


^{3}He – Evolution dans la Galaxie au cours du temps



Adapted from Bania *et al.* (2007)

^{3}He – Evolution dans la Galaxie au cours du temps



Prédictions « classiques »

- Geiss & Reeves (1972)
- Rood (1972)
- Rood, Steigman, Tinsley (1976)
- Steigman & Tosi (1992)
- Galli *et al.* (1995)
- Olive *et al.* (1995)
- Tosi (1996, 1998, 2000)
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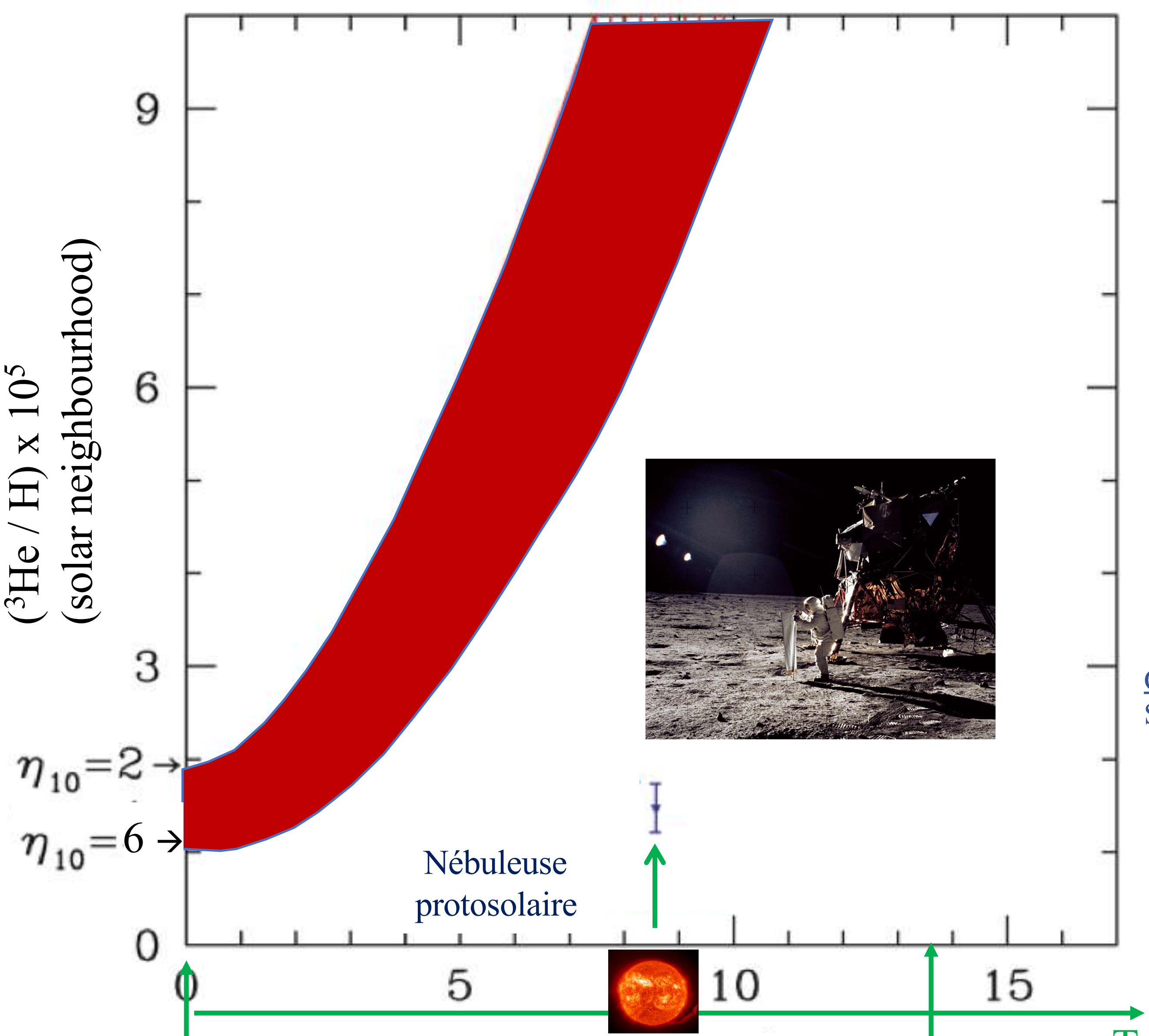
- Palla *et al.* (2000)
- Chiappini *et al.* (2002)
- Romano *et al.* (2003)

Le problème de ^{3}He



Temps (milliards d'années)

Big Bang

Naissance du soleil

Aujourd'hui

Prédictions « classiques »

Geiss & Reeves (1972)
Rood (1972)
Rood, Steigman, Tinsley (1976)
Steigman & Tosi (1992)
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Palla *et al.* (2000)
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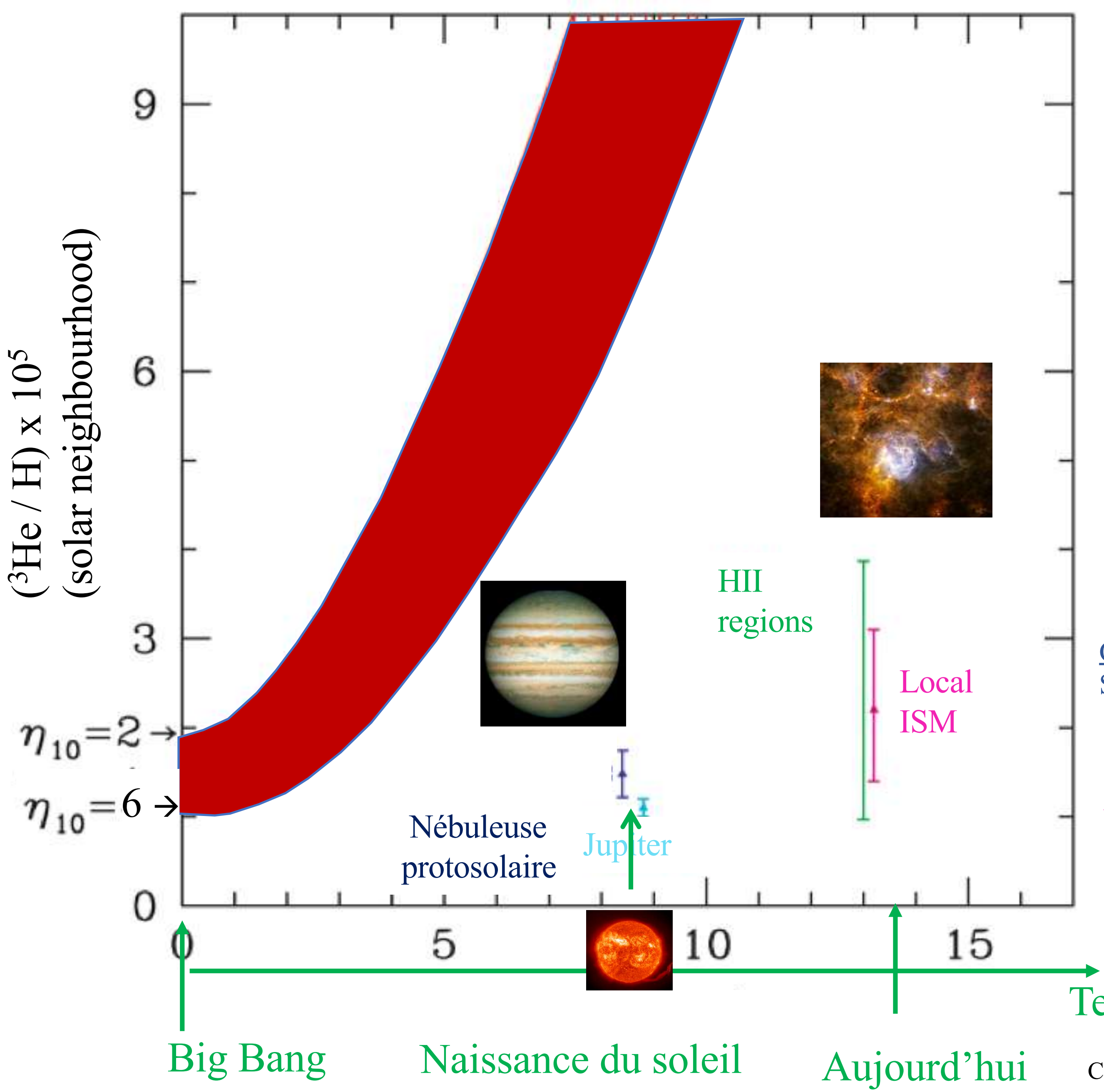
Romano *et al.* (2003)

Observations:

SWE@Moon
Geiss & Reeves (1972)

Le problème de ^{3}He



Temps (milliards d'années)

Prédictions « classiques »
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Romano *et al.* (2003)

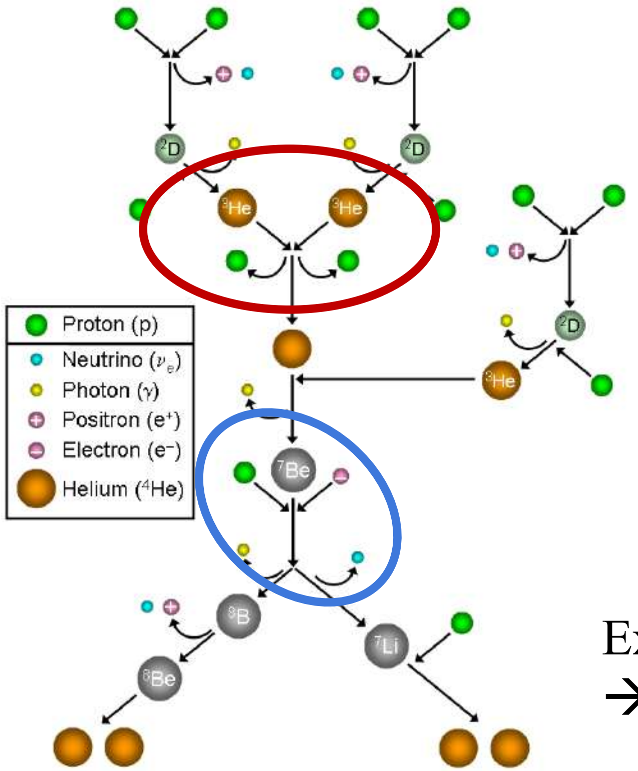
Observations:
SWE@Moon
Geiss & Reeves (1972)

Galileo probe
Mahaffy *et al.* (1998)
Ulysses
Gloeckler & Geiss (1996)
Green Bank radio-telescope
Balser & Bania (2018)

Un problème de physique nucléaire?

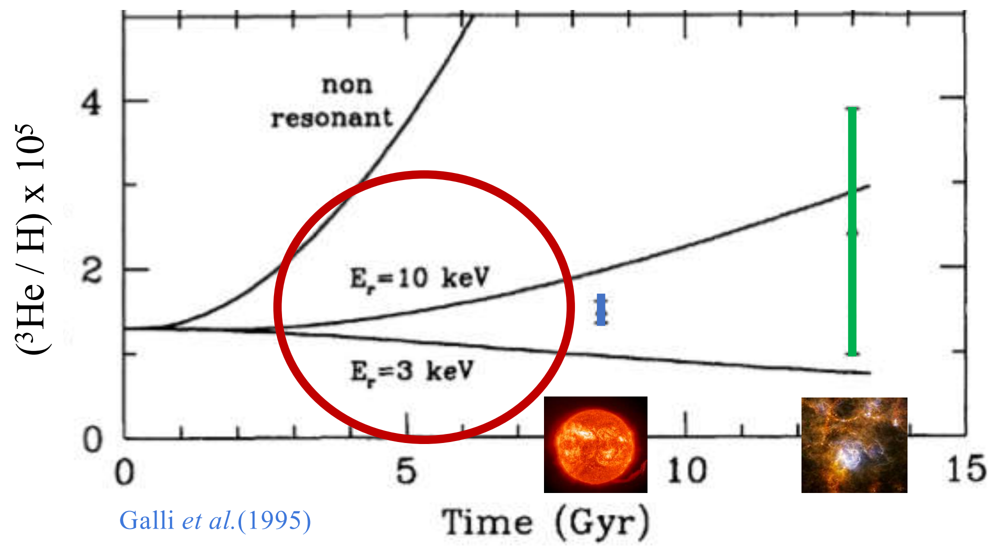
Taux de réaction sous-estimé pour la réaction ^3He (^3He, 2p)^4He ?
Solution similaire au problème des neutrinos solaires?

Homestake
Fowler (1972)
Fetisov & Kopysov (1972)



Nuclear reactions of the pp-chains

Galactic chemical evolution



Galli *et al.*(1995)

Expérience LUNA (Gran Sasso)
→ Taux de réactions corrects

Junker *et al.* (1998)

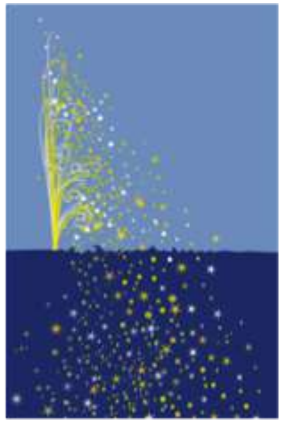
✓ Oscillation des neutrinos

Super-Kamiokande & Sudbury
2015 Nobel Prize in Physics
Kajita & McDonald

Un processus hydrodynamique?

Modèle hydrodynamique en 3D d'une étoile géante
Apparition d'une étrange instabilité hydrodynamique
Eggleton *et al.* (2006)

$\Rightarrow$ Inversion du poids moléculaire moyen

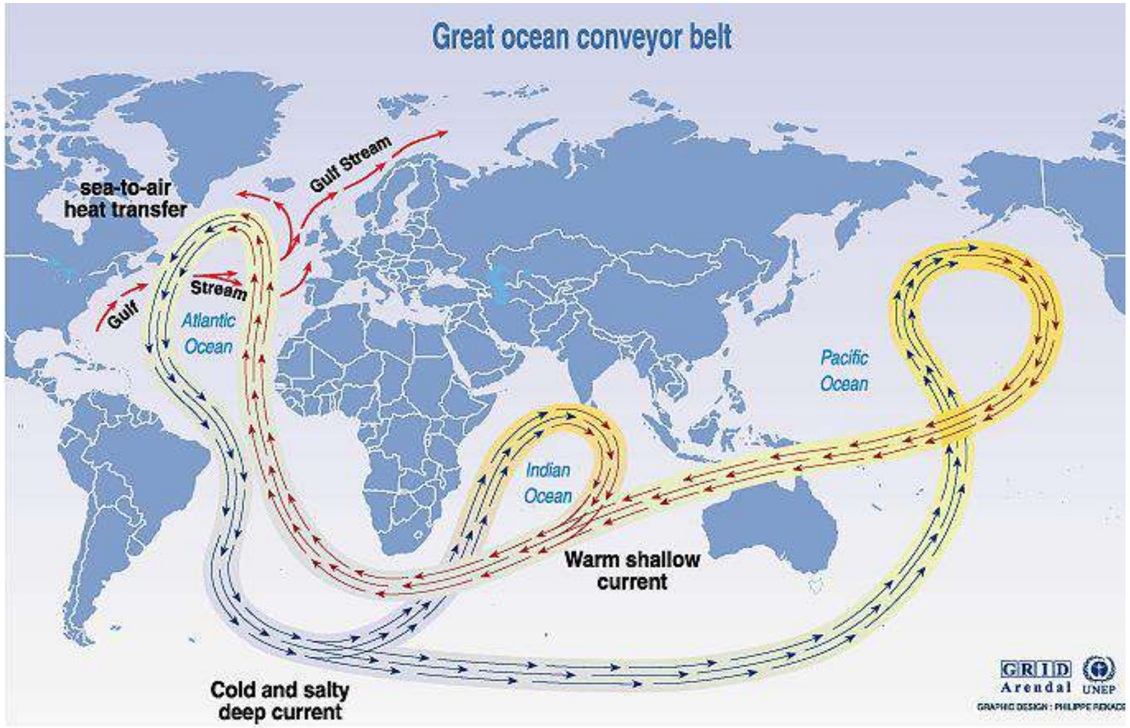


^{3}He(^{3}He,2p)^{4}He reaction

→ Instabilité thermohaline

Charbonnel & Zahn (2007a, b)
Stern (1960)
Analytical prescriptions: Ulrich (1972), Kippenhahn (1980)

Hot, salty water overlying cool, fresh water ultimately becomes unstable, forming salt fingers
Image: Cantiello

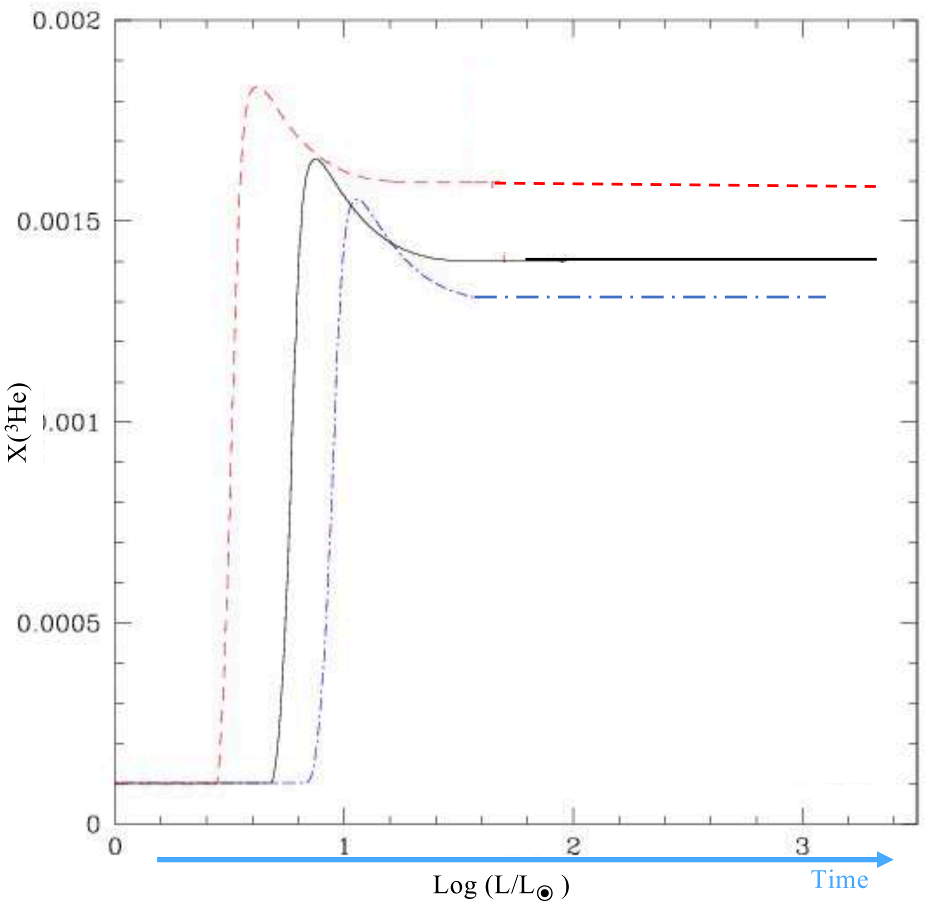


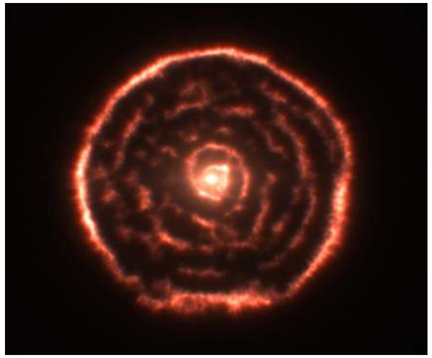
Source: Broecker, 1991, in Climate change 1995, Impacts, adaptations and mitigation of climate change: scientific-technical analyses, contribution of working group 2 to the second assessment report of the intergovernmental panel on climate change, UNEP and WMO, Cambridge press university, 1996.

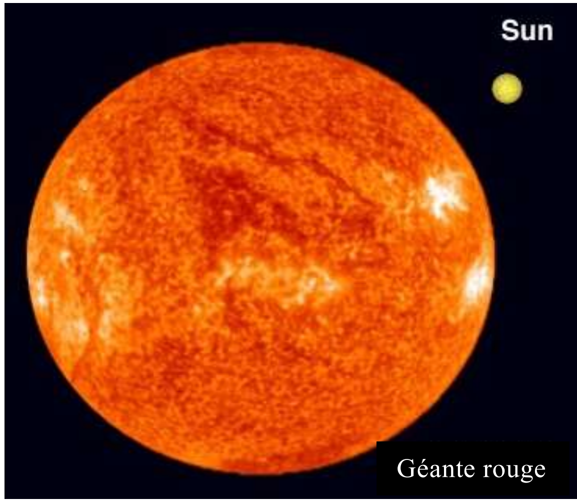
Circulation thermohaline à grande échelle - Océans terrestres

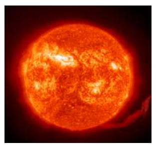
^{3}He produit dans les étoiles

✓ Production de ^{3}He



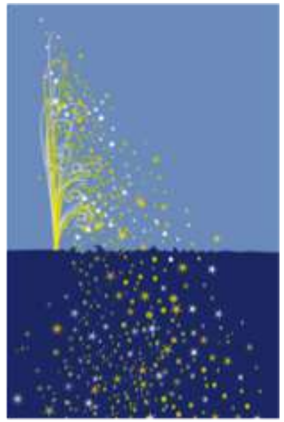




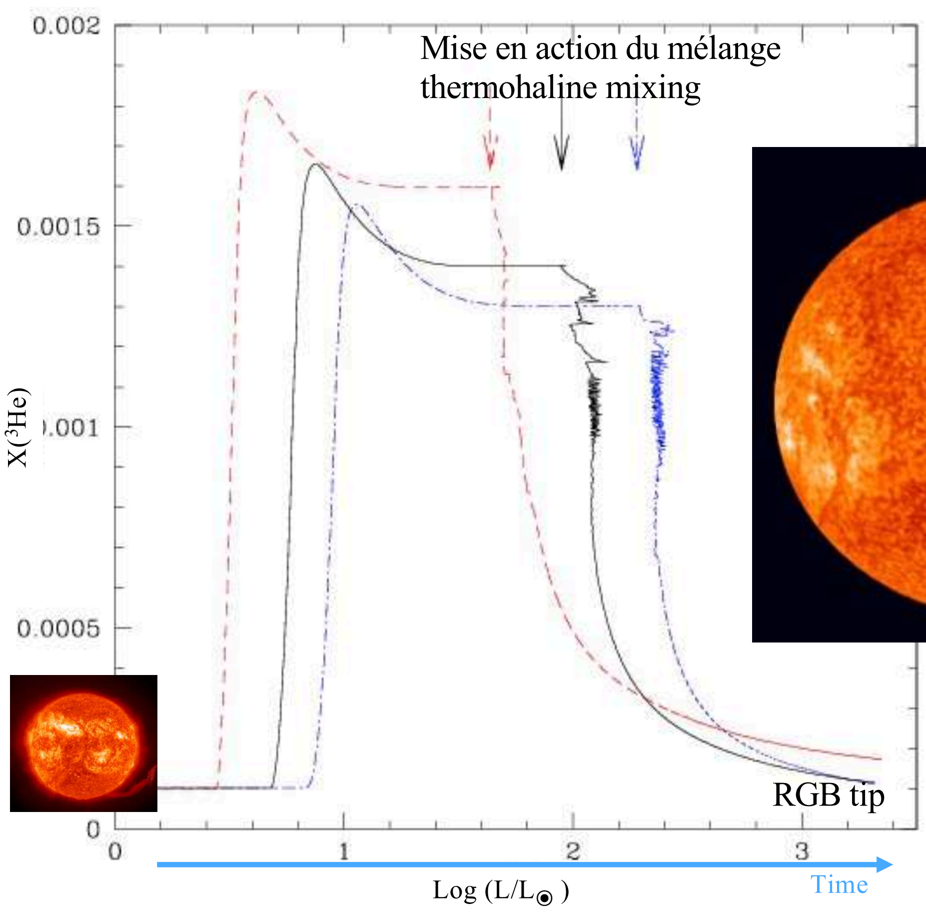


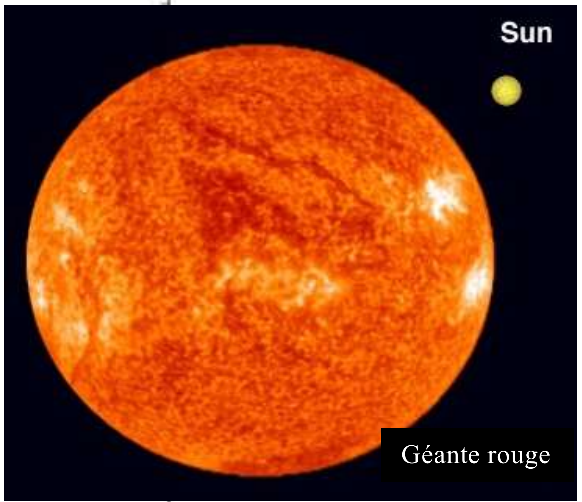
Evolution de l'abondance de ^{3}He dans des étoiles de faible masse
Charbonnel & Zahn (07a)

La solution thermohaline



✓ Production puis destruction de ^{3}He

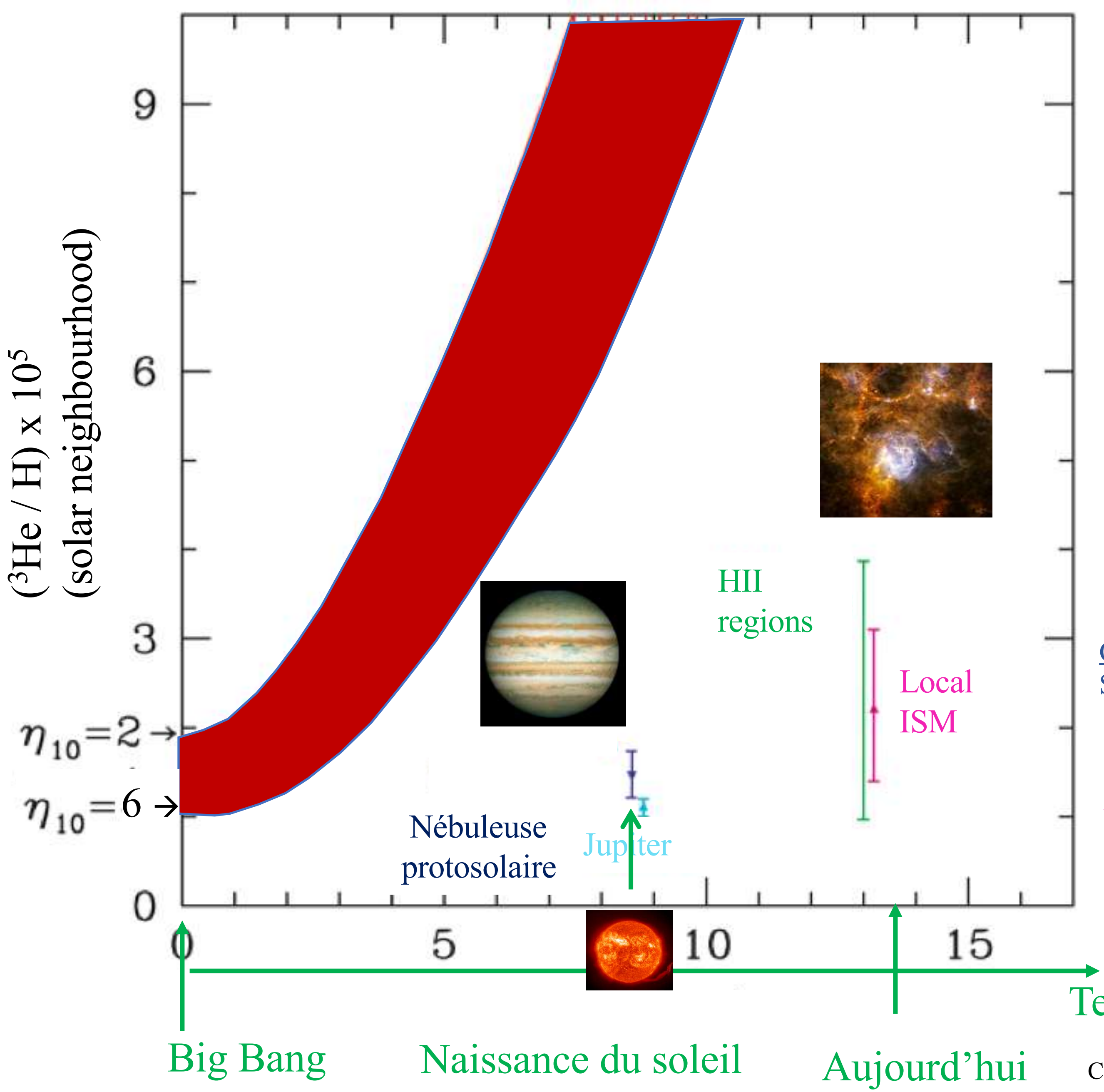




Evolution de l'abondance de ^{3}He dans des étoiles de faible masse
Charbonnel & Zahn (07a)

❖ Explique d'autres "anomalies"
$^{12}C/^{13}C$, Li, C/N

Le problème de ^{3}He



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<u>Observations:</u>

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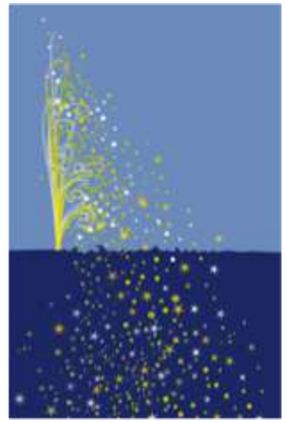
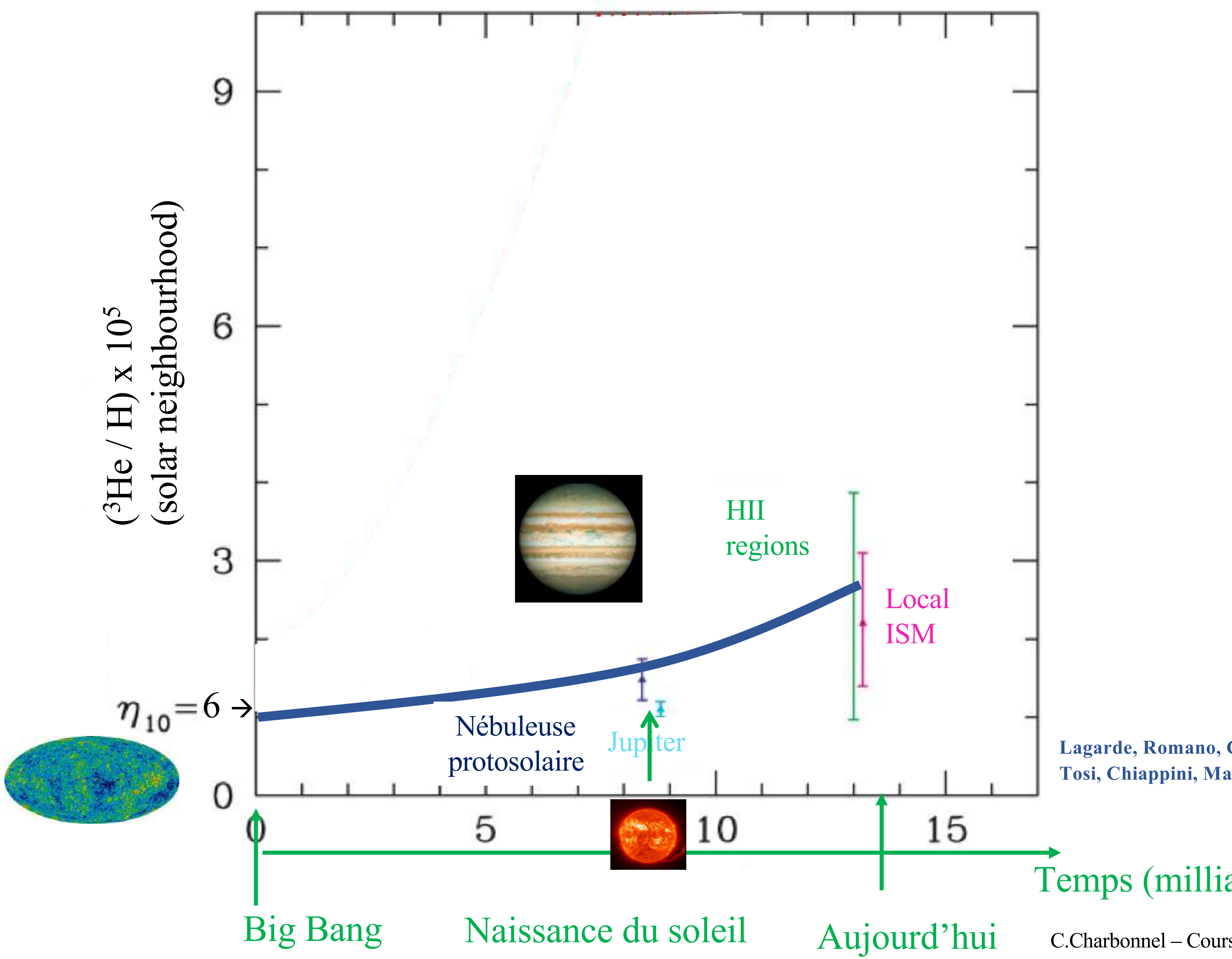
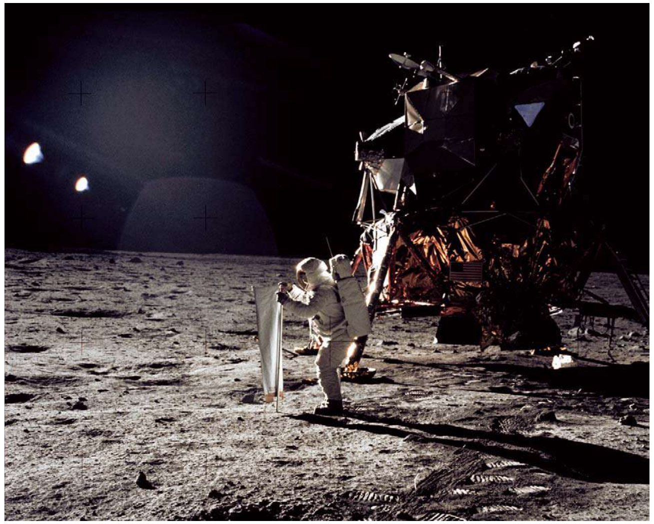
La solution thermohaline





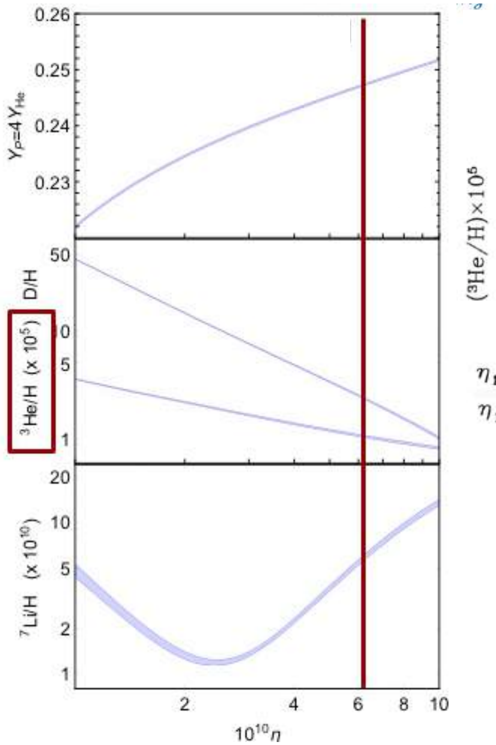
Lagarde, Romano, Charbonnel, Tosi, Chiappini, Matteucci (2012)

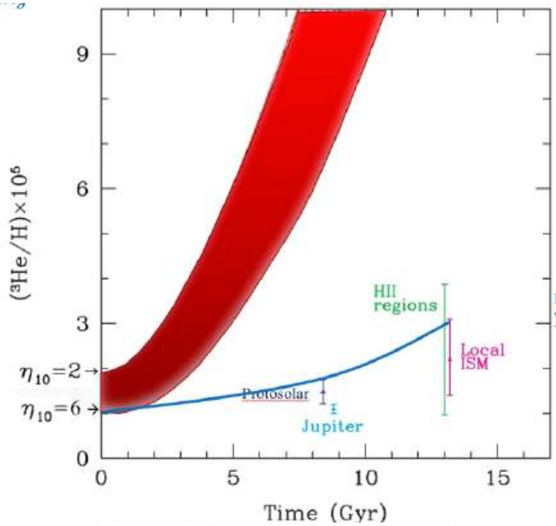
From Switzerland to the Moon, and back

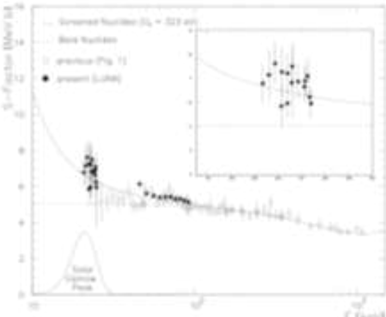


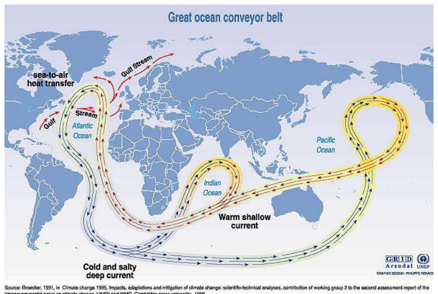
Un voyage scientifique pluridisciplinaire

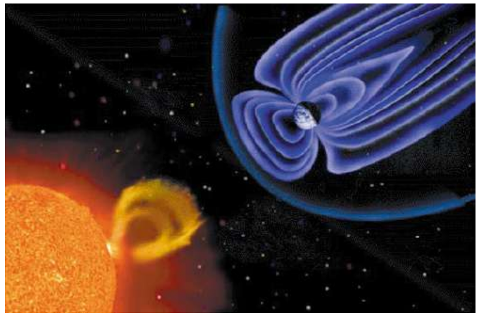
Ou comment une invention simple **et suisse** a révolutionné notre compréhension de l'évolution chimique de l'Univers avec la 1ère expérience scientifique sur la **Lune**











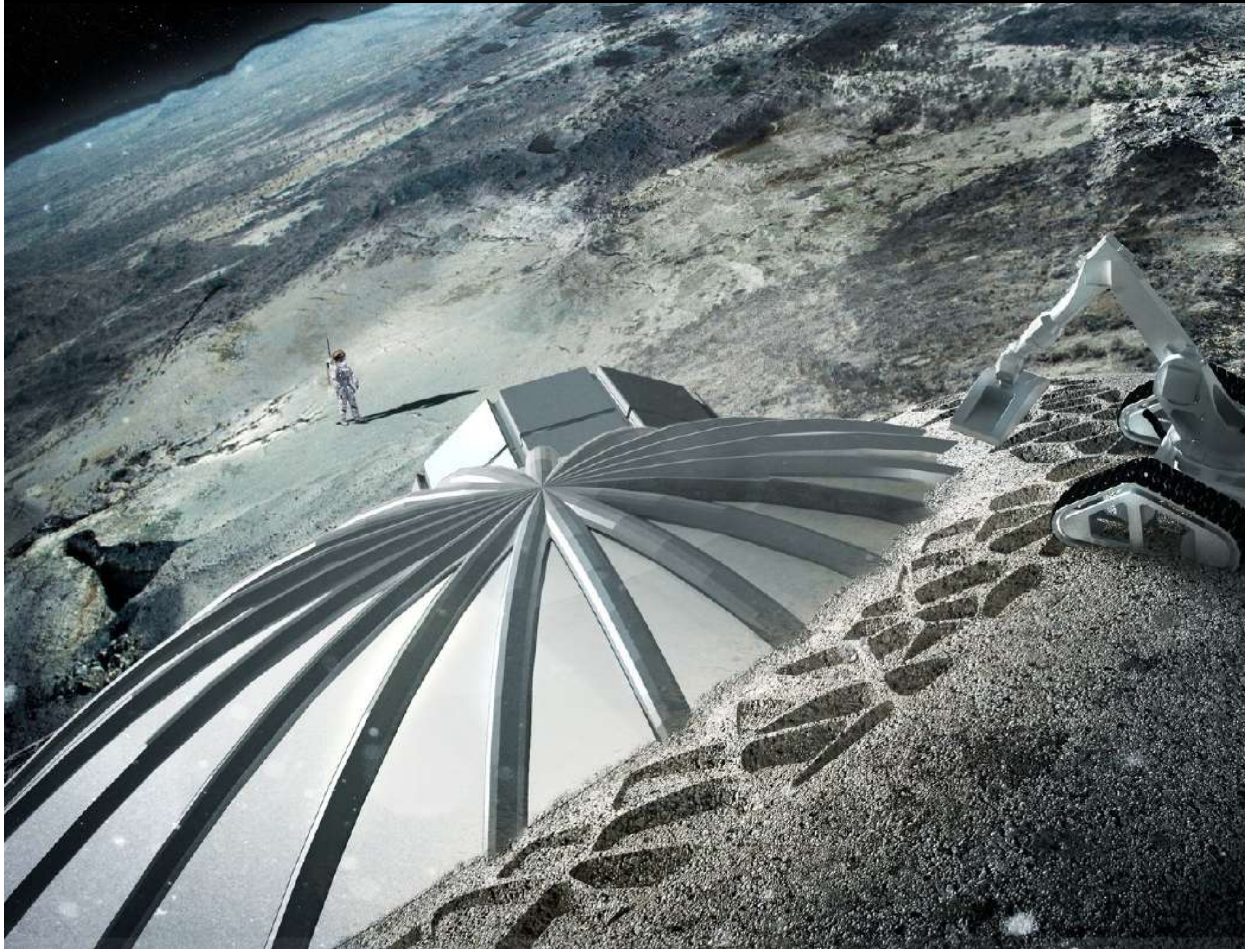
C.Charbonnel – Cours UniGe 1051 – 20210928

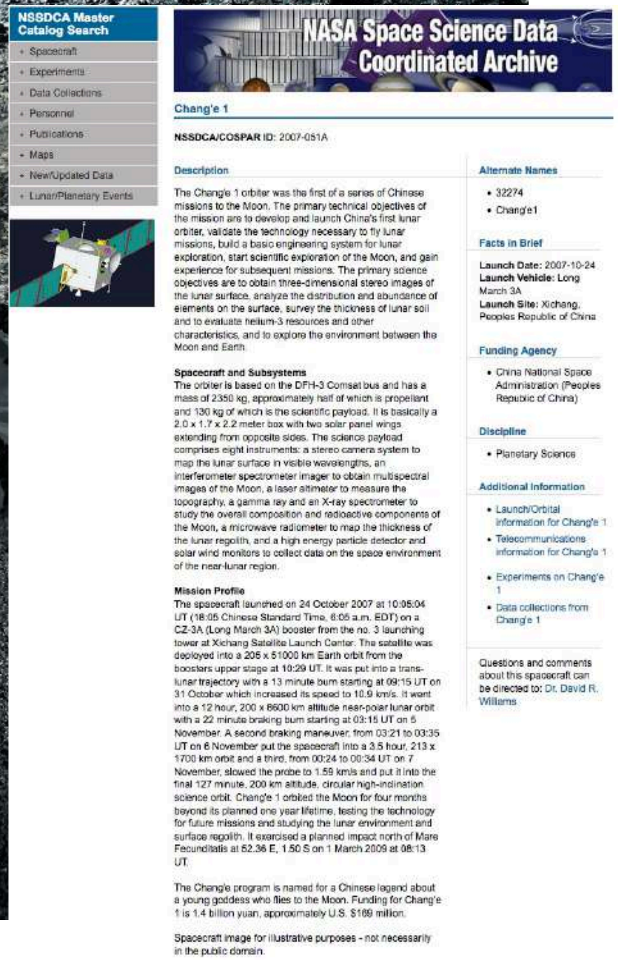
^3He – Une intéressante source d'énergie ?

Centrales nucléaires à fusion contrôlée de 2ème génération (pas de pollution ni de radioactivité)

25 tonnes de ^3He → énergie consommée par les USA en 1 an

100'000 tonnes de ^3He dans le régolite lunaire (Missions Apollo, Change'1 – 2007-2009)





NSSDCA Master Catalog Search

- Spacecraft
- Experiments
- Data Collections
- Personnel
- Publications
- Maps
- New/Updated Data
- Lunar/Planetary Events

NASA Space Science Data Coordinated Archive

Chang'e 1

NSSDCA/COSPAR ID: 2007-051A

Description

The Chang'e 1 orbiter was the first of a series of Chinese missions to the Moon. The primary technical objectives of the mission are to develop and launch China's first lunar orbiter, validate the technology necessary to fly lunar missions, build a basic engineering system for lunar exploration, start scientific exploration of the Moon, and gain experience for subsequent missions. The primary science objectives are to obtain three-dimensional stereo images of the lunar surface, analyze the distribution and abundance of elements on the surface, survey the thickness of lunar soil and to evaluate helium-3 resources and other characteristics, and to explore the environment between the Moon and Earth.

Spacecraft and Subsystems
The orbiter is based on the DFH-3 Comsat bus and has a mass of 2350 kg, approximately half of which is propellant and 130 kg of which is the scientific payload. It is basically a 2.0 x 1.7 x 2.2 meter box with two solar panel wings extending from opposite sides. The science payload comprises eight instruments: a stereo camera system to map the lunar surface in visible wavelengths, an interferometer spectrometer imager to obtain multispectral images of the Moon, a laser altimeter to measure the topography, a gamma ray and an X-ray spectrometer to study the overall composition and radioactive components of the Moon, a microwave radiometer to map the thickness of the lunar regolith, and a high energy particle detector and solar wind monitors to collect data on the space environment of the near-lunar region.

Mission Profile
The spacecraft launched on 24 October 2007 at 10:05:04 UT (18:05 Chinese Standard Time, 6:05 a.m. EDT) on a CZ-3A (Long March 3A) booster from the no. 3 launching tower at Xichang Satellite Launch Center. The satellite was deployed into a 205 x 51000 km Earth orbit from the boosters upper stage at 10:29 UT. It was put into a trans-lunar trajectory with a 13 minute burn starting at 09:15 UT on 31 October which increased its speed to 10.9 km/s. It went into a 12 hour, 200 x 8600 km altitude near-polar lunar orbit with a 22 minute braking burn starting at 03:15 UT on 5 November. A second braking maneuver, from 03:21 to 03:35 UT on 6 November put the spacecraft into a 3.5 hour, 213 x 1700 km orbit and a third, from 00:24 to 00:34 UT on 7 November, slowed the probe to 1.59 km/s and put it into the final 127 minute, 200 km altitude, circular high-inclination science orbit. Chang'e 1 orbited the Moon for four months beyond its planned one year lifetime, testing the technology for future missions and studying the lunar environment and surface regolith. It exercised a planned impact north of Mare Fecunditatis at 52.36 E, 1.50 S on 1 March 2009 at 08:13 UT.

The Chang'e program is named for a Chinese legend about a young goddess who flies to the Moon. Funding for Chang'e 1 is 1.4 billion yuan, approximately U.S. $169 million.

Spacecraft image for illustrative purposes - not necessarily in the public domain.

Alternate Names

- 32274
- Chang'e1

Facts in Brief

Launch Date: 2007-10-24
Launch Vehicle: Long March 3A
Launch Site: Xichang, Peoples Republic of China

Funding Agency

- China National Space Administration (Peoples Republic of China)

Discipline

- Planetary Science

Additional Information

- Launch/Orbital information for Chang'e 1
- Telecommunications information for Chang'e 1
- Experiments on Chang'e 1
- Data collections from Chang'e 1

Questions and comments about this spacecraft can be directed to: Dr. David R. Williams

http://www.esa.int/Enabling_Support/Preparing_for_the_Future/Space_for_Earth/Energy/Helium-3_mining_on_the_lunar_surface

UNIVERSITÉ DE GENÈVE
FACULTÉ DES SCIENCES
Département d'astronomie

Les grandes missions spatiales pour l'Astrophysique
Saison 2 – Le système solaire

par Corinne Charbonnel, Professeure au Département d'Astronomie de l'Université de Genève

le mardi, du 21 septembre au 21 décembre 2021
de 17h45 à 18h30
Auditoire A300 - Sciences II, 30 quai Ernest-Ansermet, Genève

Renseignements : http://unige.ch/sciences/astro

Chaotic clouds on Jupiter (mission Juno). Image Credits: NASA/JPL-Caltech/SwRI/MSSS/Gerald Eichstädt /Seán Doran

Cours 1 – 21 septembre 2021
Cours 2 – 28 septembre 2021

Pourquoi explorer
Le système solaire ?
-
L'exemple de la Lune

Un voyage scientifique pluridisciplinaire

Plus d'informations sur la Lune
dans un document annexe

Mardi 5 octobre 2021
!!!! Amphi A150 – Sciences 2 !!!!