Radio astronomy, Lecture 14

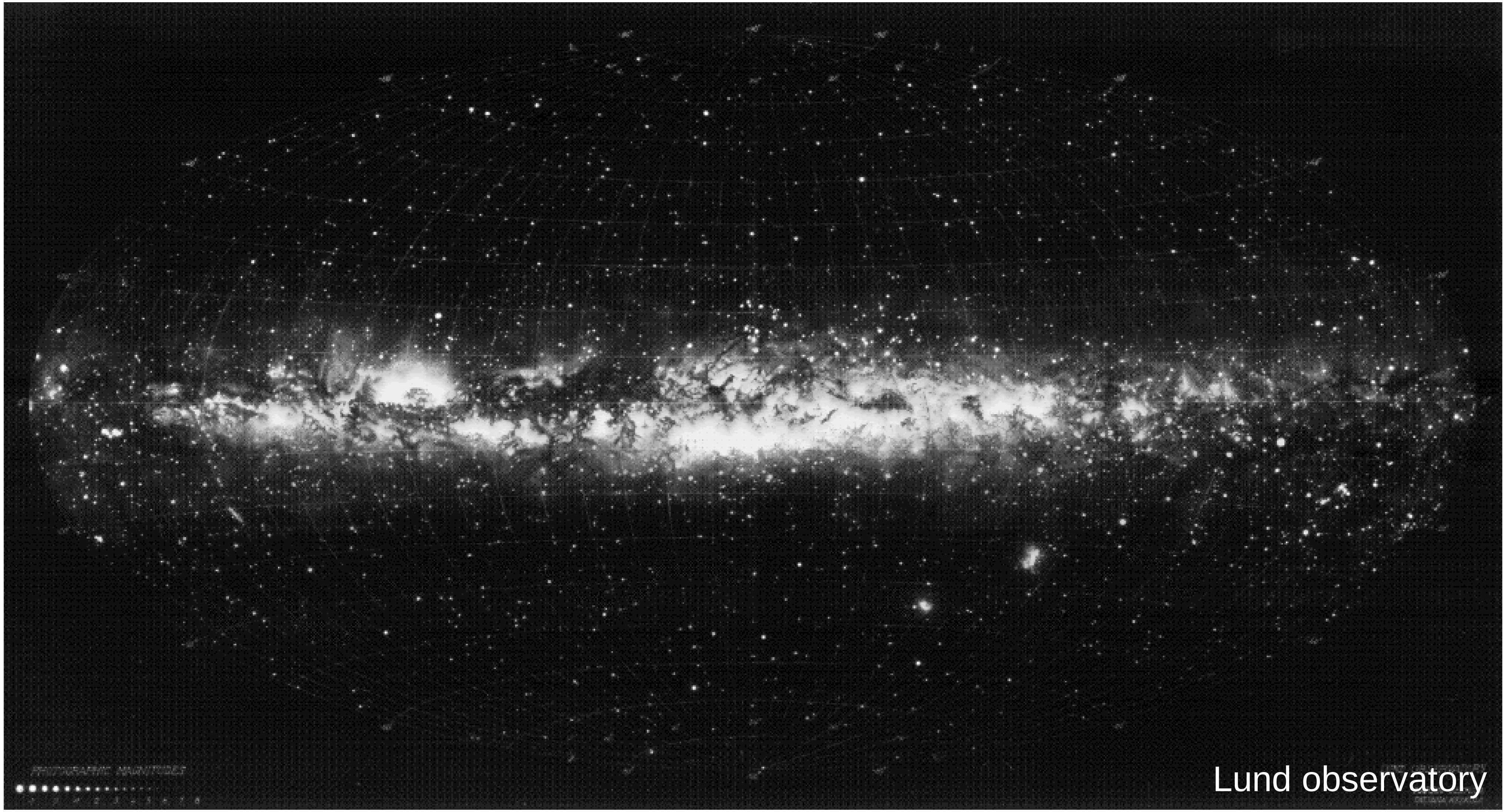
1) Molecular clouds

2) Dust

3) ALMA

Laboratory tour

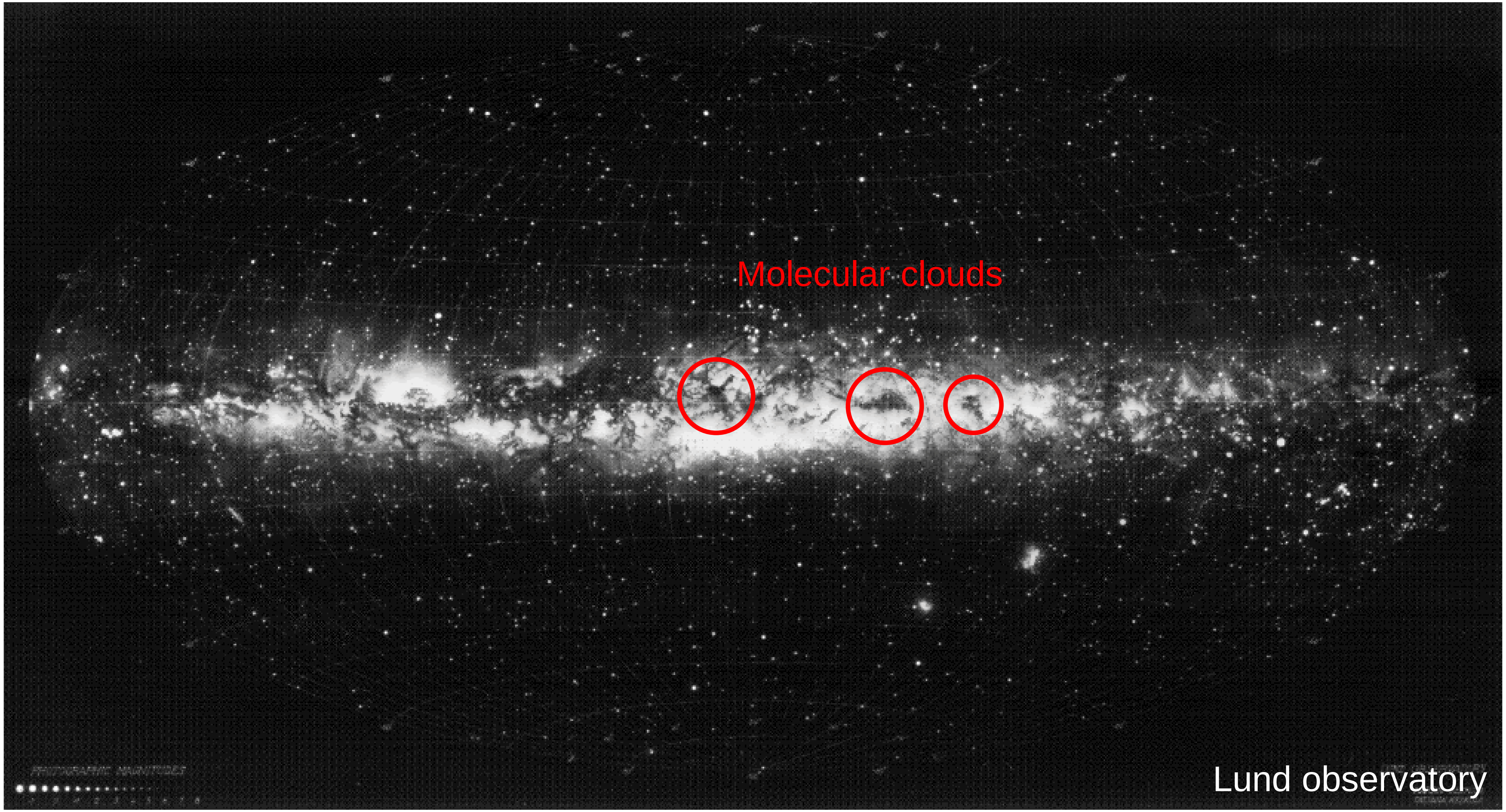
The whole sky (by eyes)



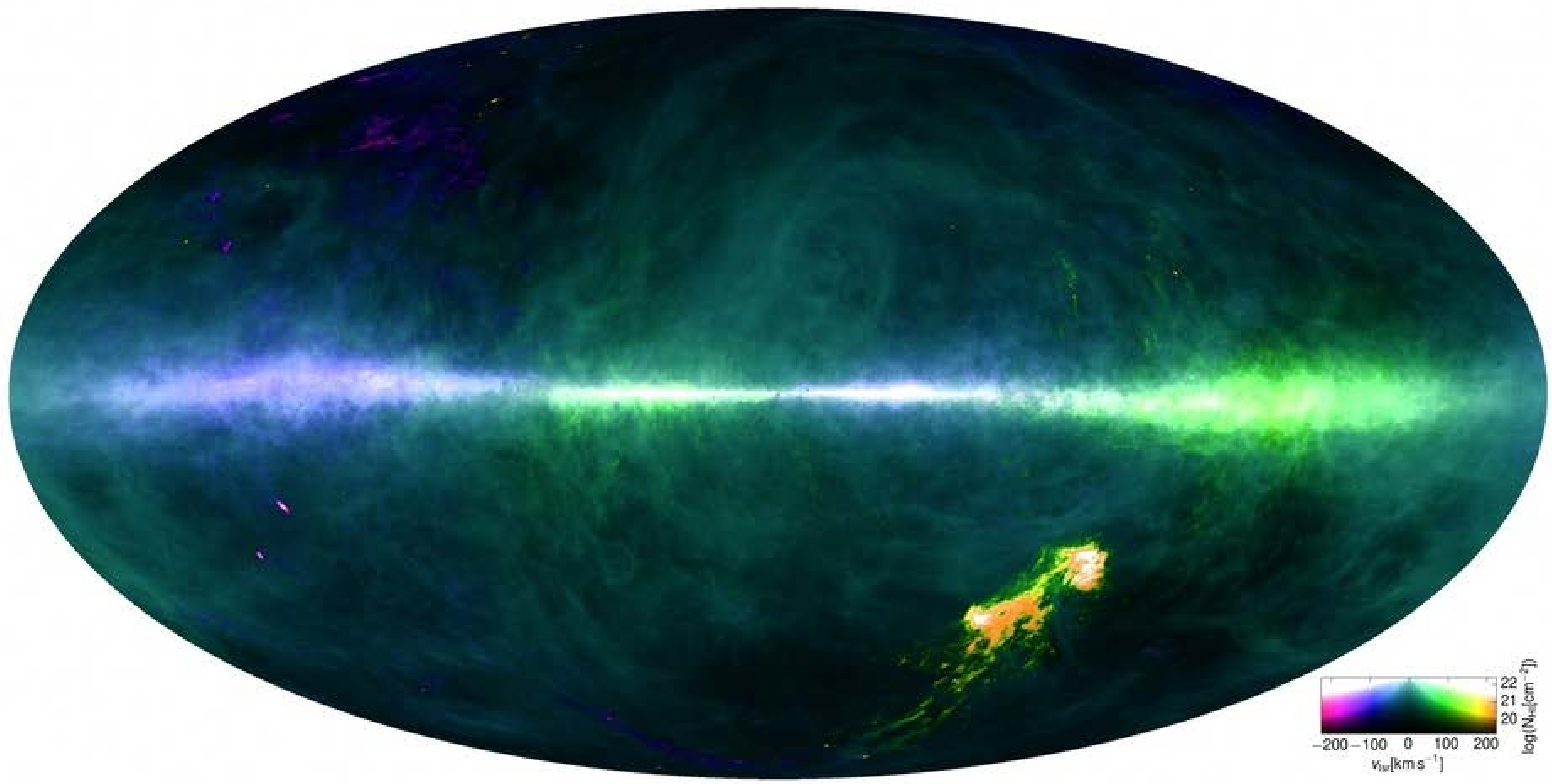
The whole sky (by eyes)

William Herschel: “holes in the Heavens”

The whole sky (by eyes)

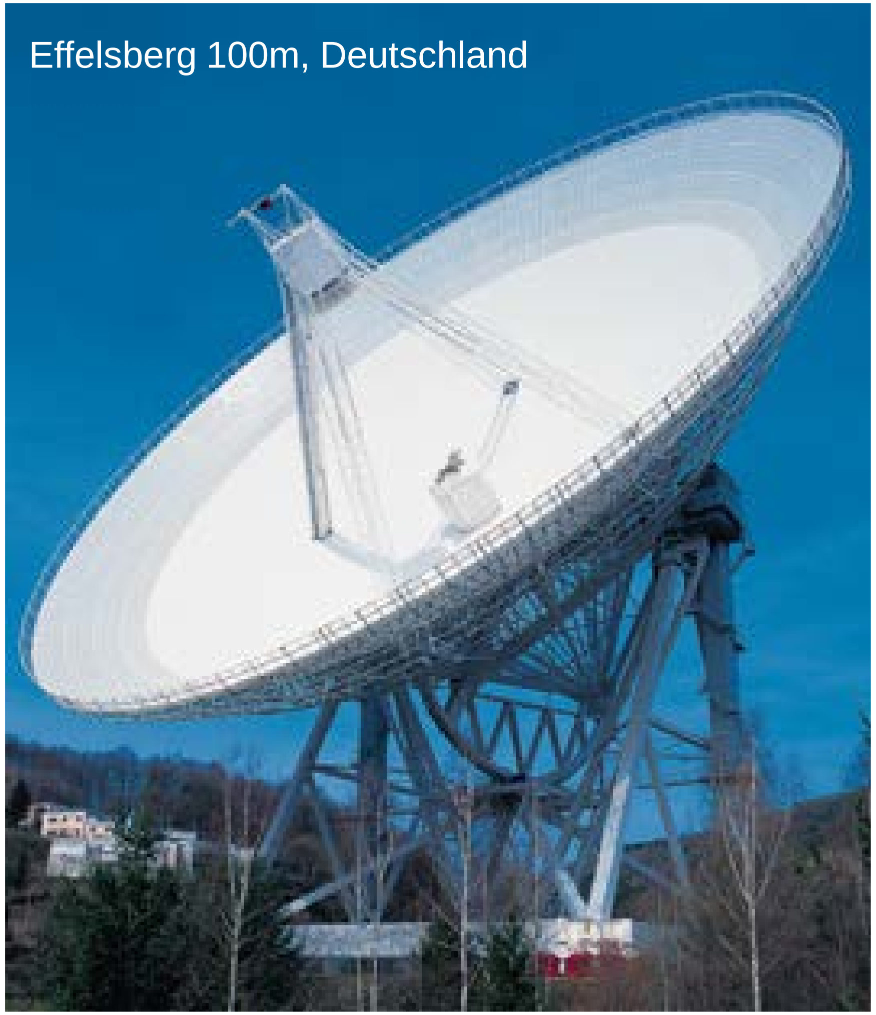


The whole sky (in the light of HI)

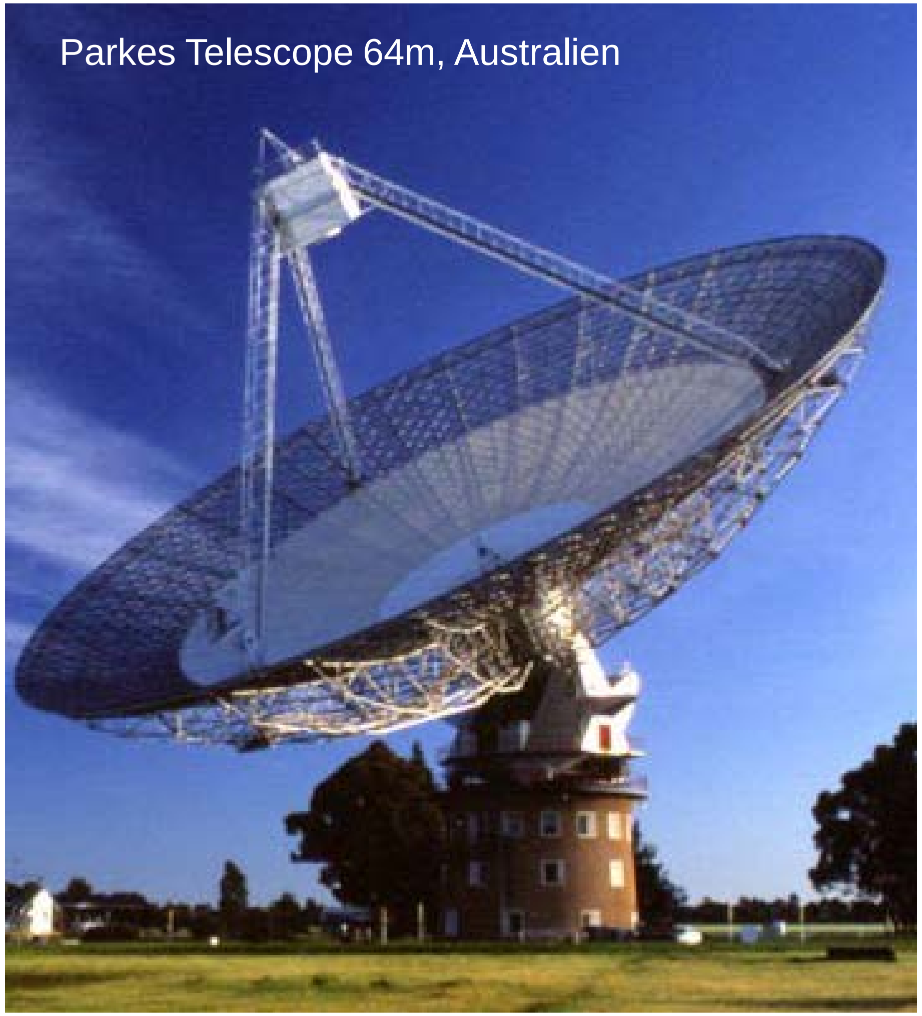


Credit: Max Planck Institute for Radio Astronomy

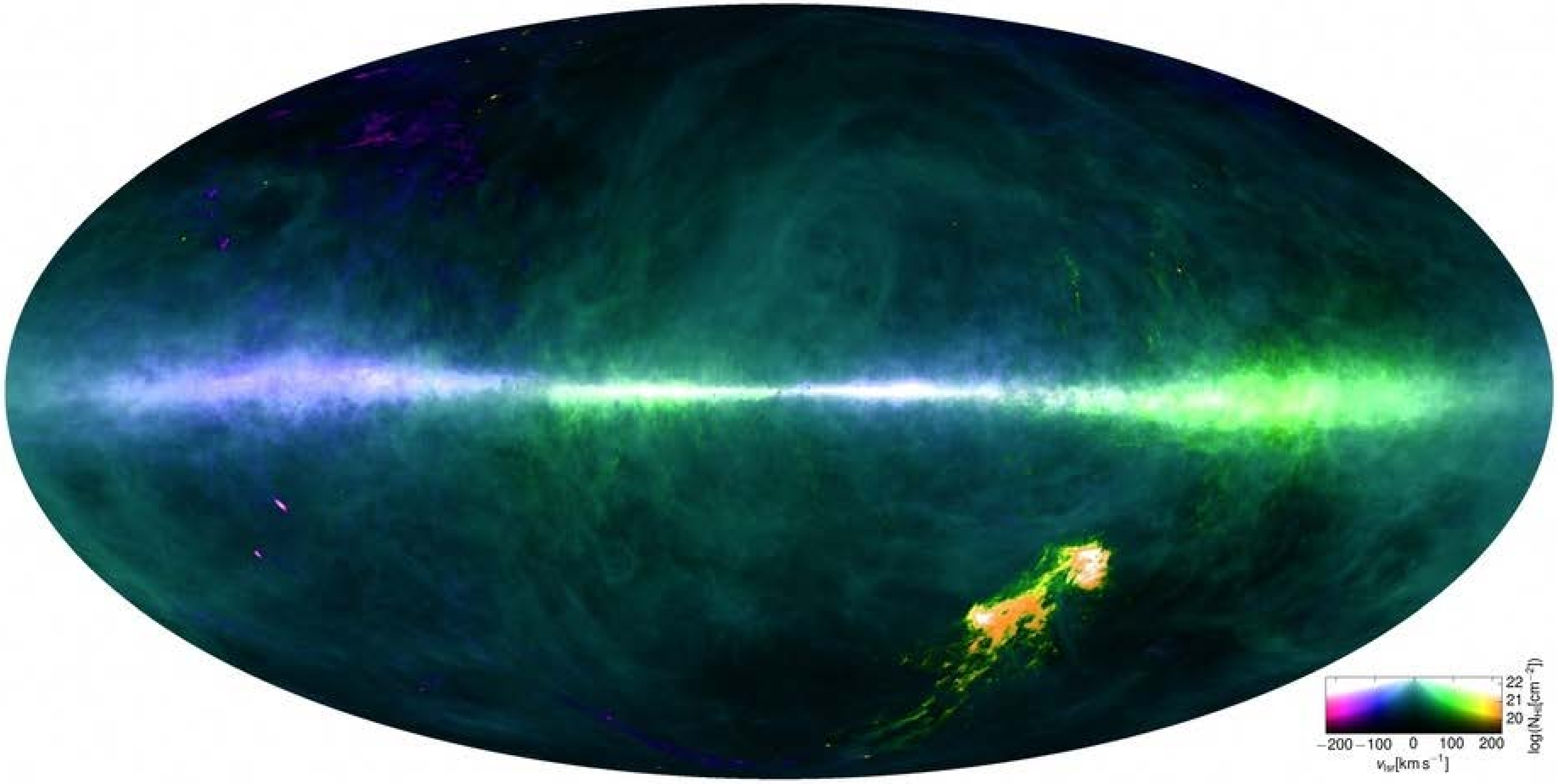
The whole sky (in the light of HI)



+



The whole sky (in the light of HI)

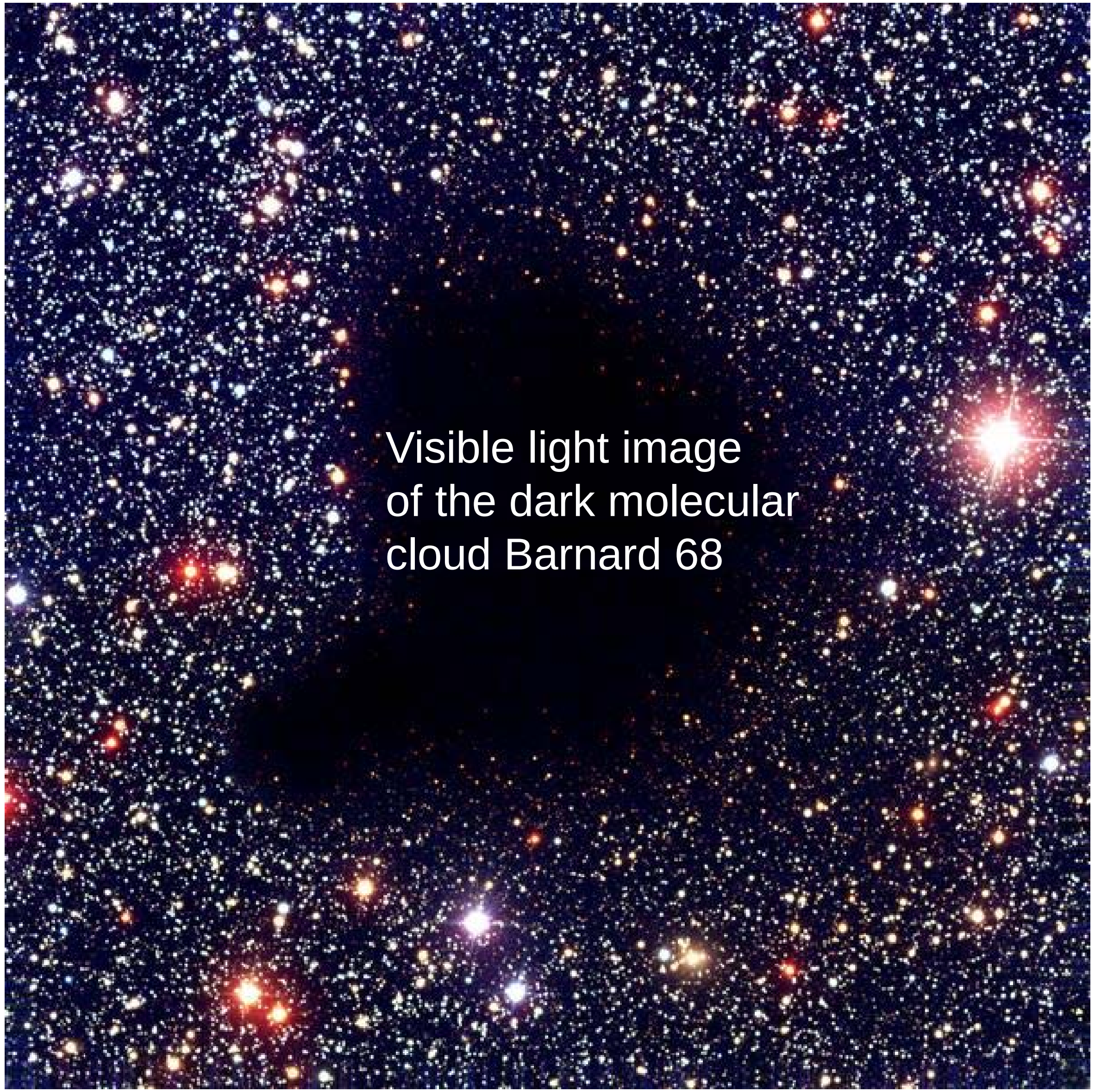


Credit: Max Planck Institute for Radio Astronomy

Our Galaxy

Credit: NASA

Molecular clouds



The place where stars and planets are born

The formation of the most important astronomical molecules

T = 100 – 10 K,
N = 10^3 – 10^6 molecules/cm^3
Size = 10 – 100 pc

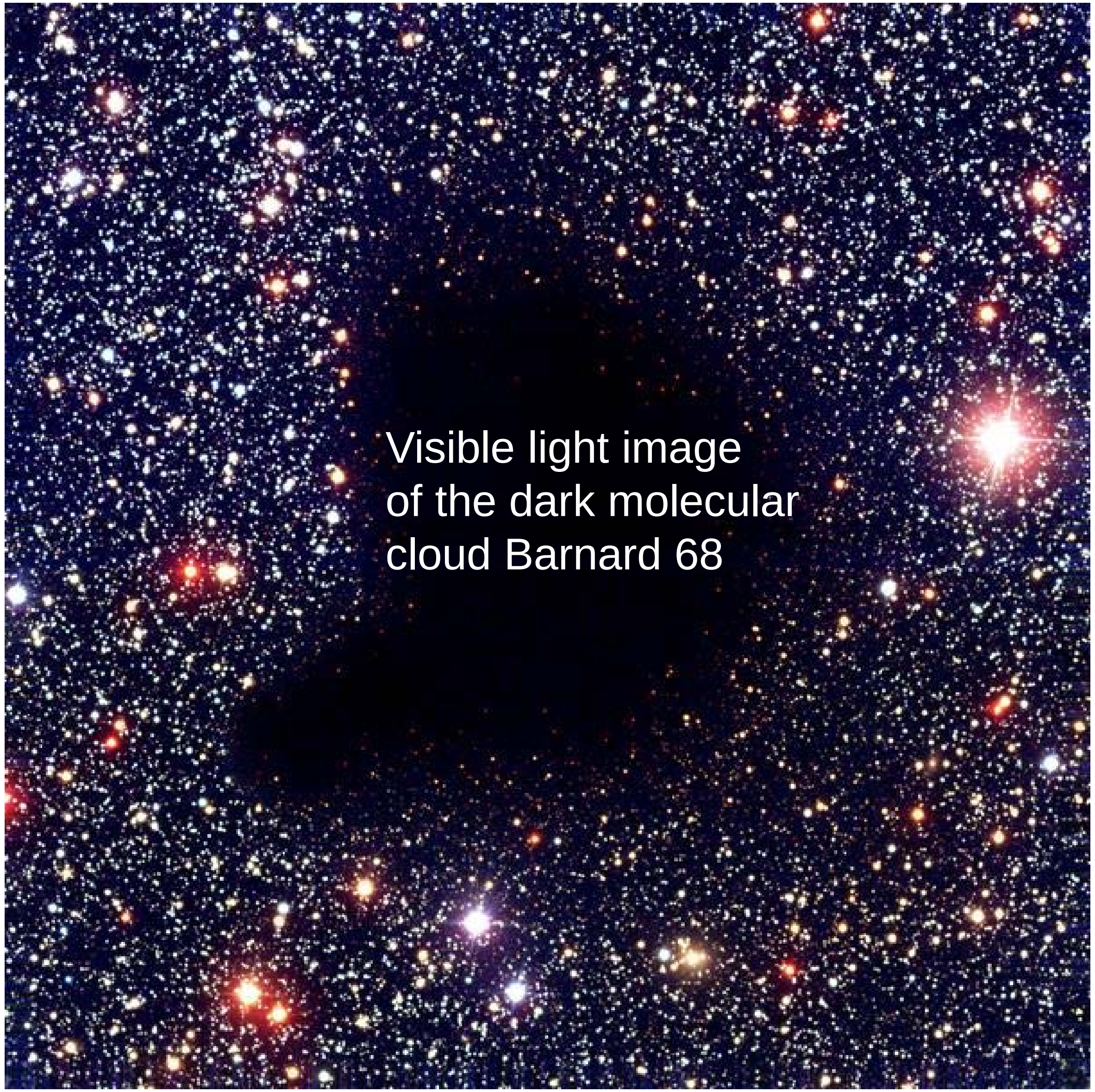
Molecular clouds

Table 1.1 *Characteristics of the phases of the interstellar medium*

Phase	n_0^a (cm^{-3})	T^b (K)	ϕ_v^c (%)	M^d ($10^9\ M_\odot$)	$< n_0 >^e$ (cm^{-3})	H^f (pc)	Σ^g ($M_\odot$pc^{-2})
Hot intercloud	0.003	10^6	~50.0	—	0.0015	3000	0.3
Warm neutral medium	0.5	8000	30.0	2.8	0.1^h	220^h	1.5
					0.06^h	400^h	1.4
Warm ionized medium	0.1	8000	25.0	1.0	0.025^i	900^i	1.1
Cold neutral medium^j	50.0	80	1.0	2.2	0.4	94	2.3
Molecular clouds	>200.0	10	0.05	1.3	0.12	75	1.0
HII regions	$1–10^5$	10^4	—	0.05	0.015^k	70^k	0.05

Credit: Alexander Tielens, 2005

Molecular clouds



The place where stars and planets are born

The formation of the most important astronomical molecules

T = 100 – 10 K,
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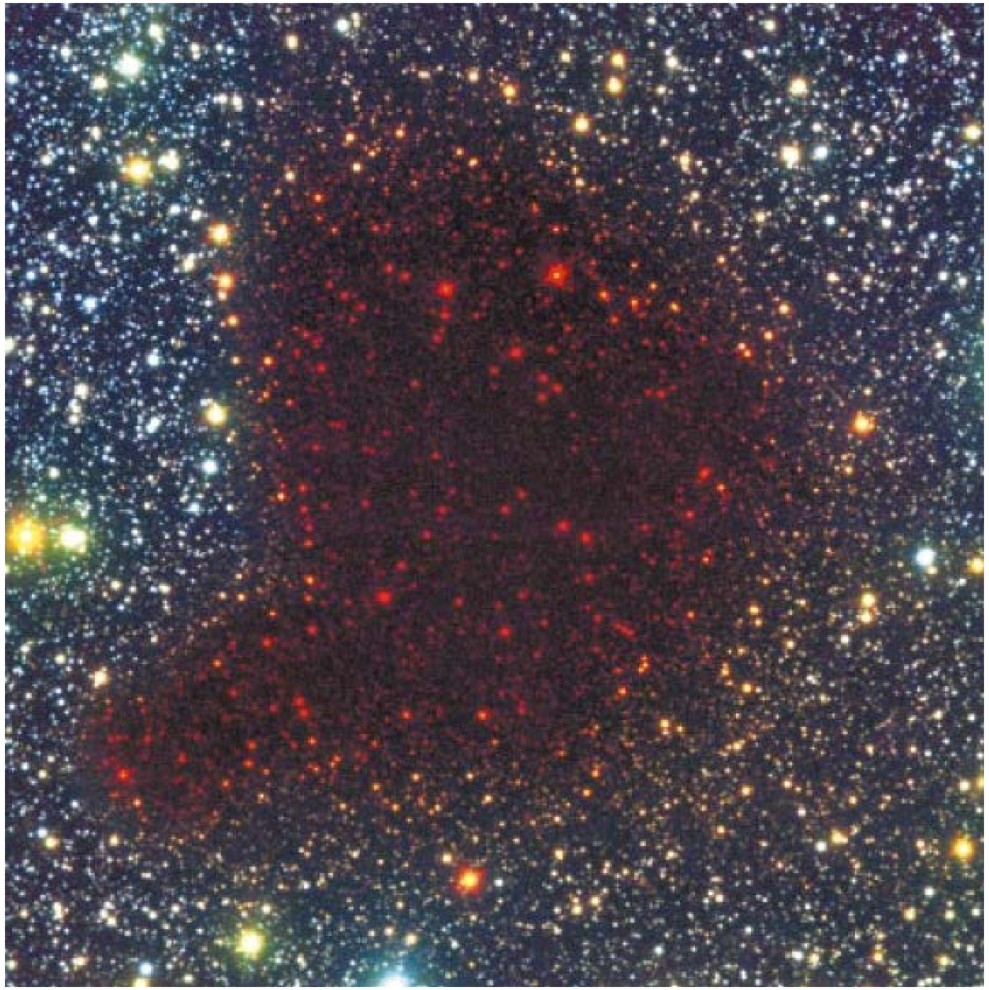
Barnard 68
The Horsehead Nebula
Taurus Molecular Cloud
The Coalsack Nebula
The R Corona Austrialis Molecular Cloud
The California Nebula

Molecular clouds

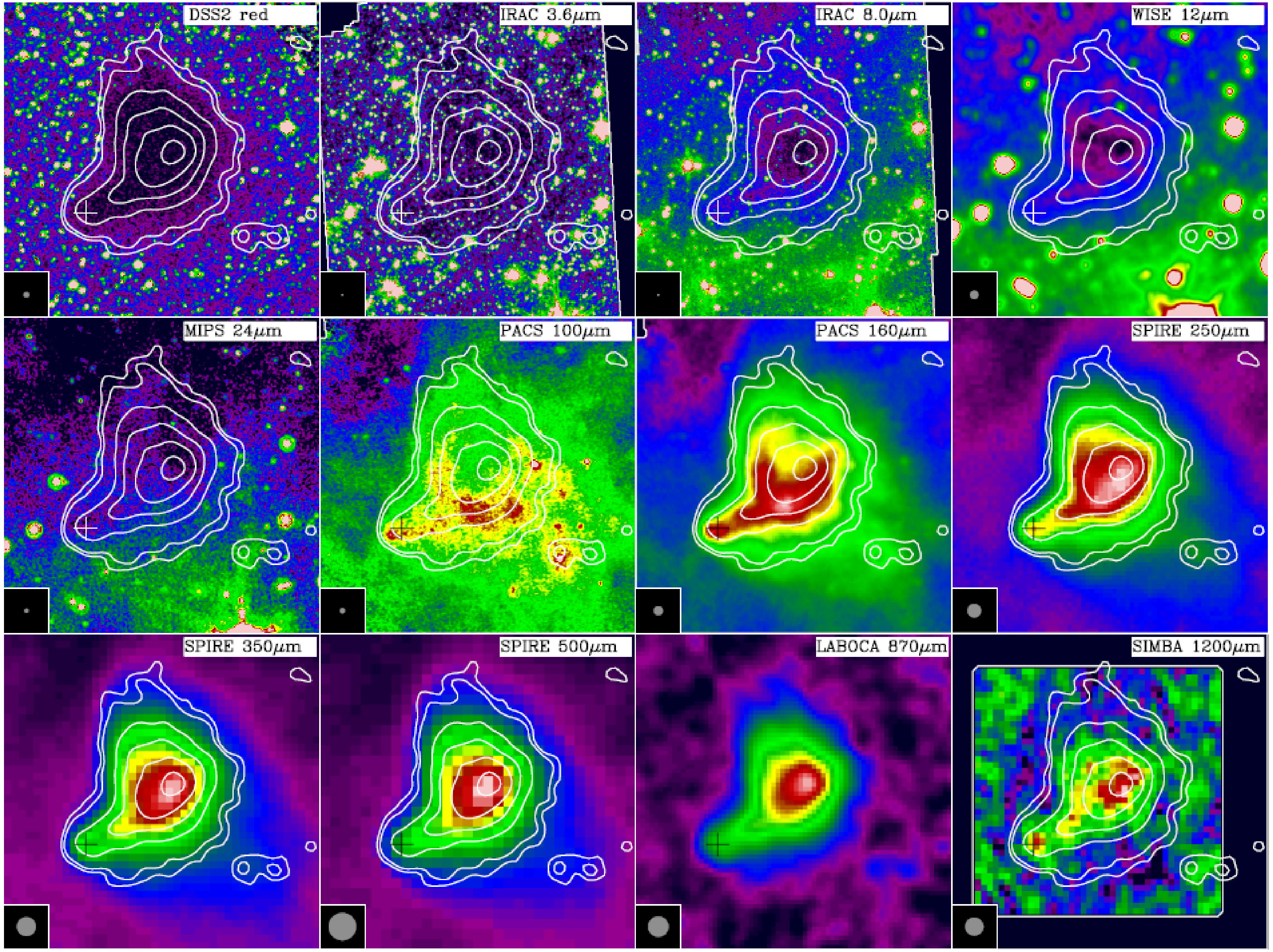
Visible



Near infrared

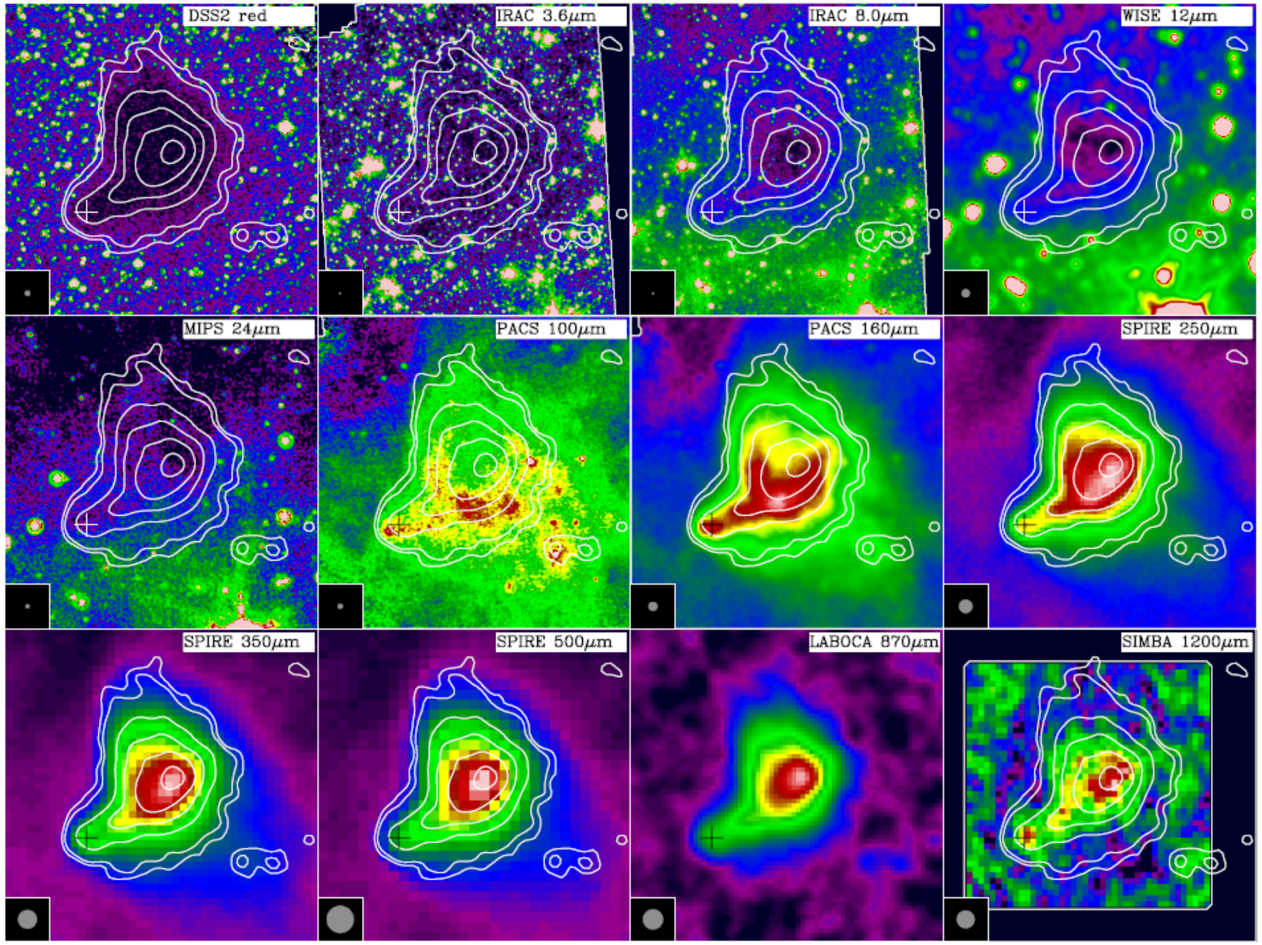
Alves et al. 2001

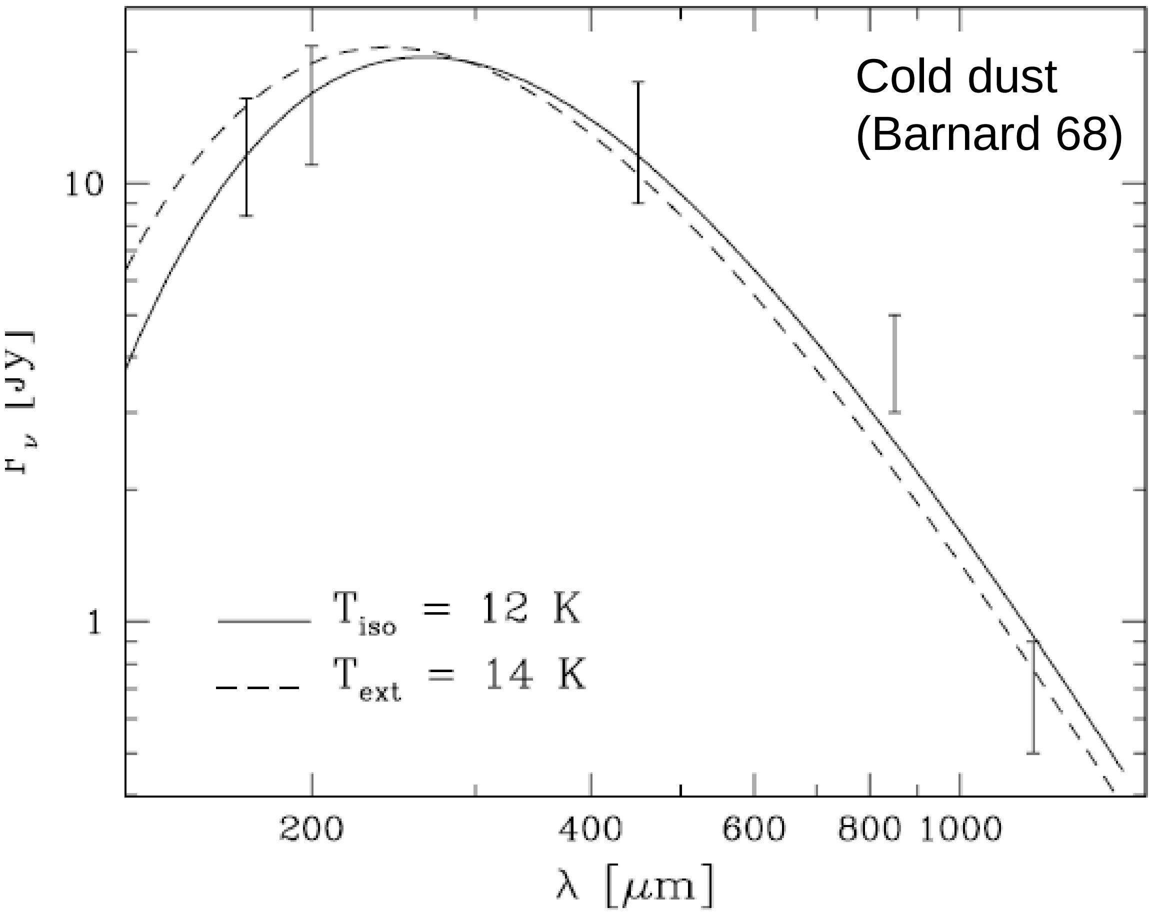
Molecular clouds



Nielbock et al. 2012

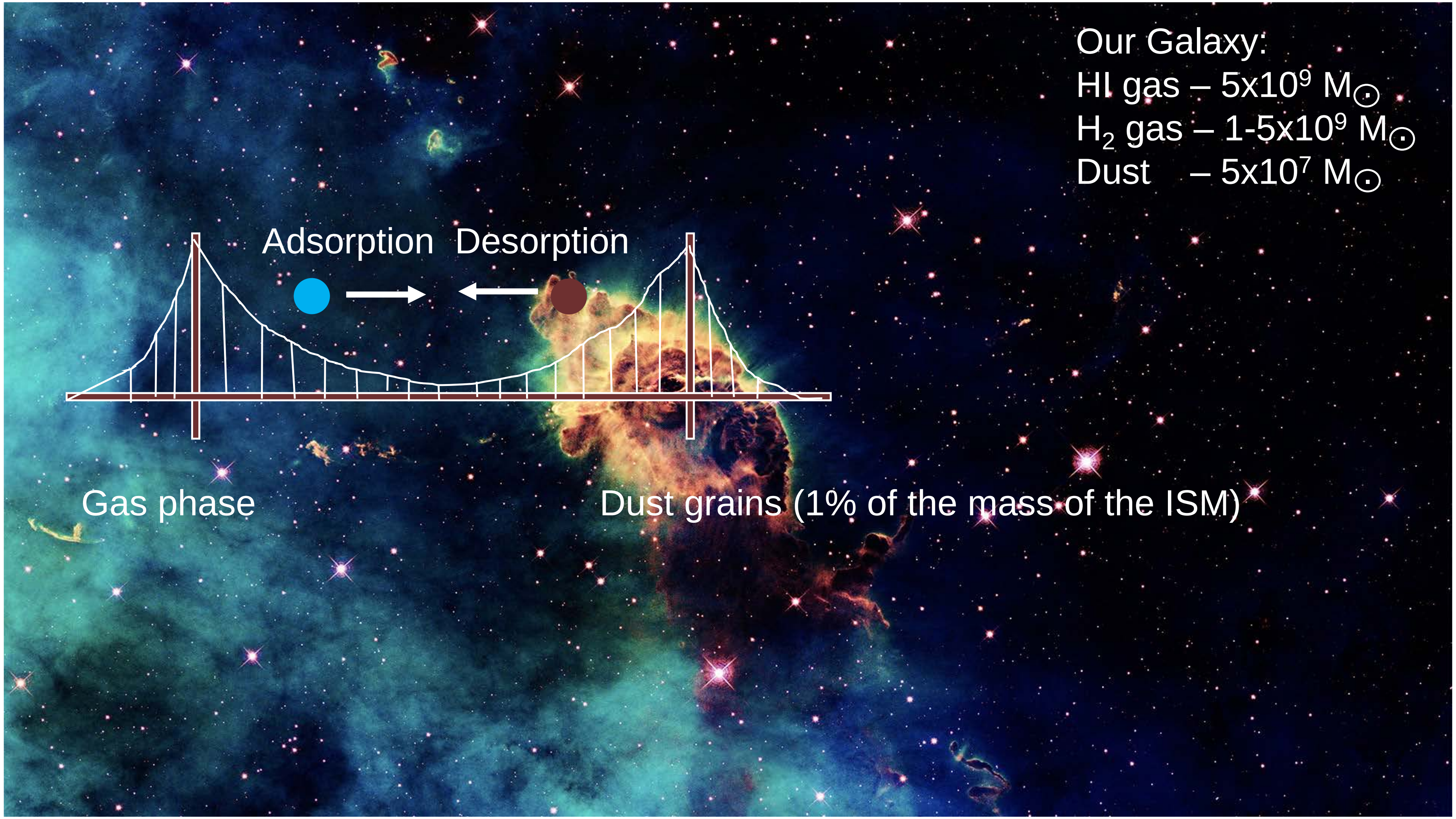
Dust emission in Molecular clouds





Bianchi et al. 2003

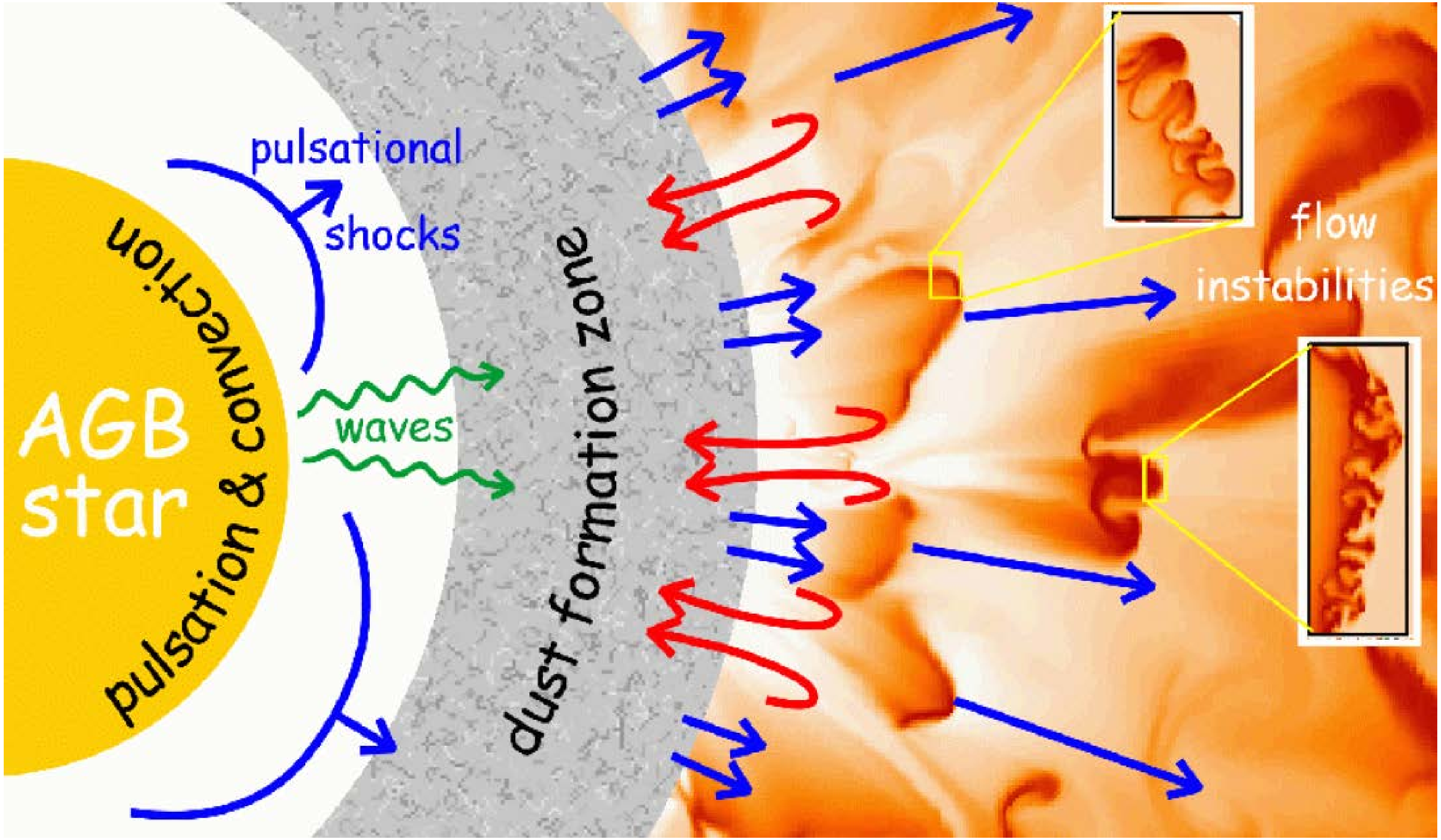
Gas and dust



Our Galaxy:
HI gas – 5x10^9 M☉
H2 gas – 1-5x10^9 M☉
Dust – 5x10^7 M☉
Adsorption
Desorption
Gas phase
Dust grains (1% of the mass of the ISM)

Formation of dust grains in the ISM

Asymptotic
Giant
Branch
star



Credit: Ambra Nanni, SISSA

Formation of dust grains in the ISM

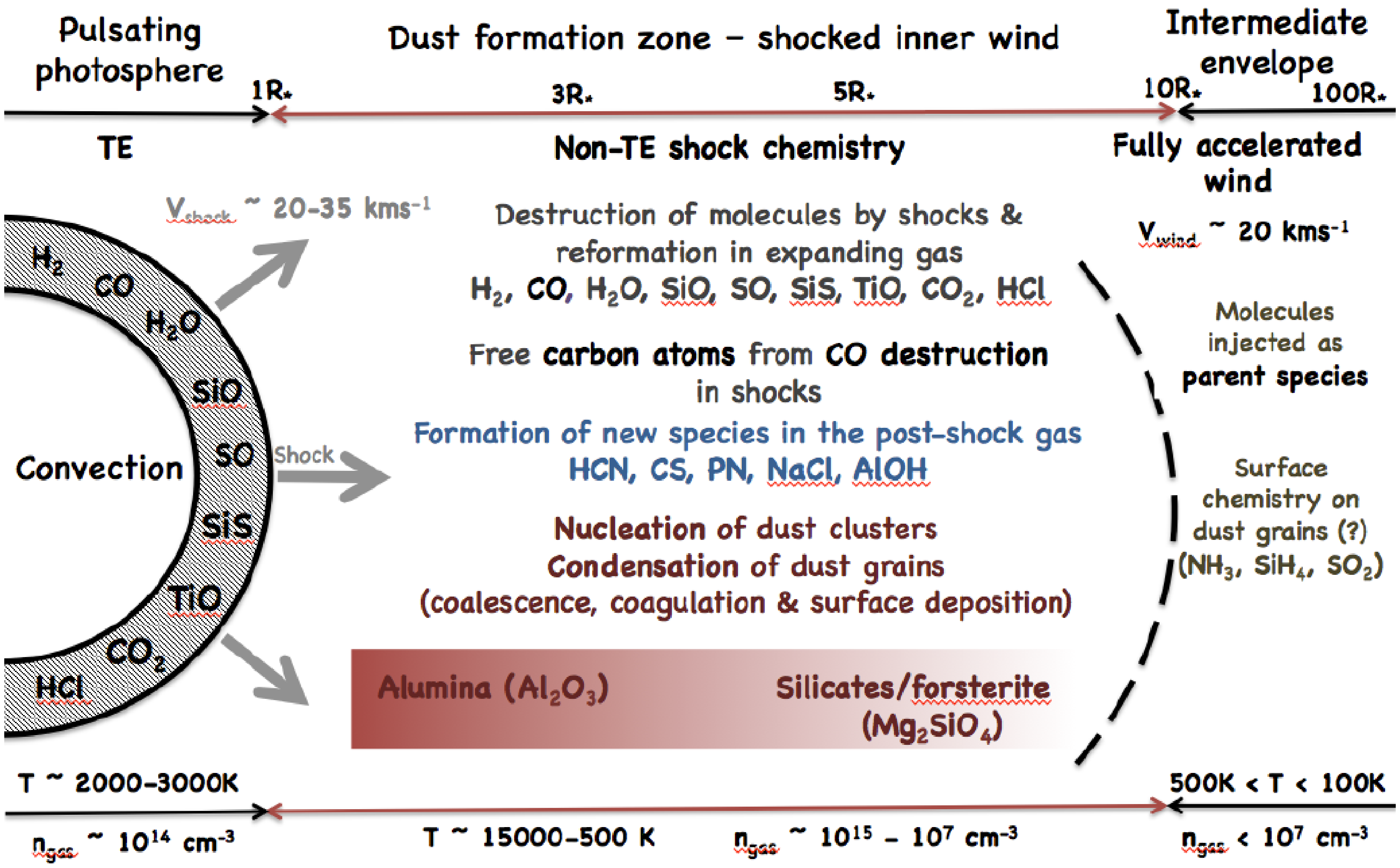
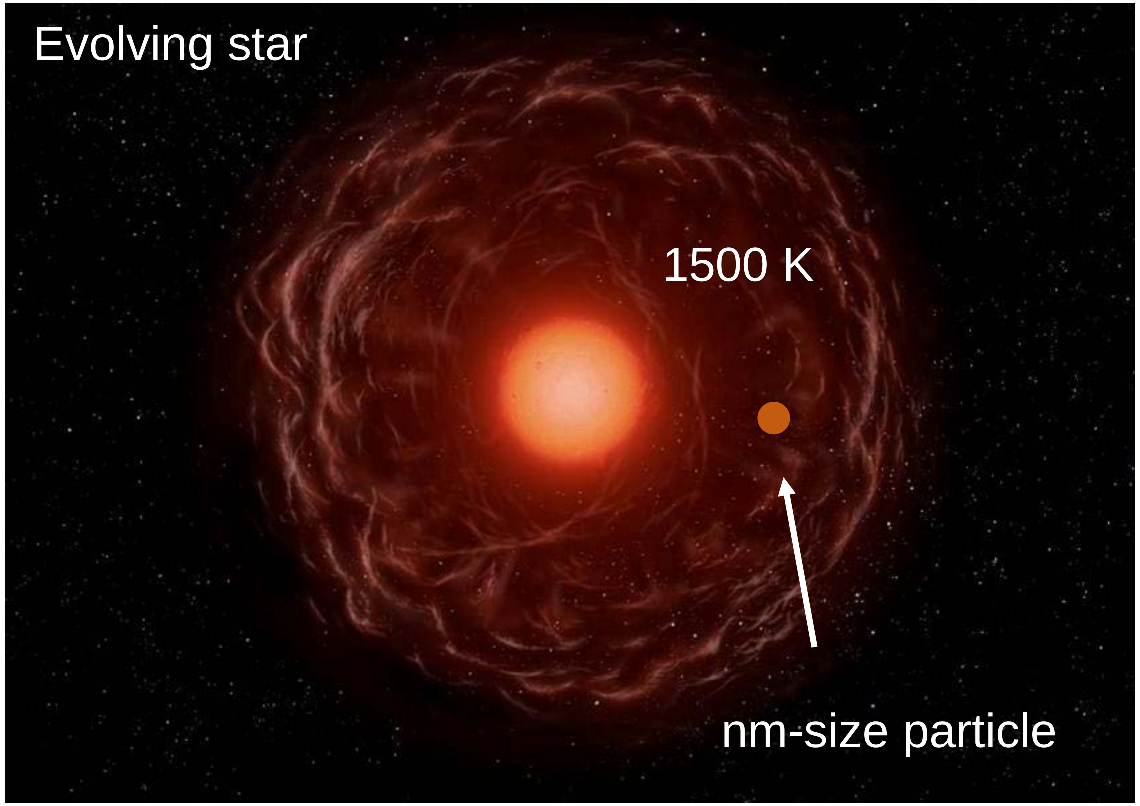
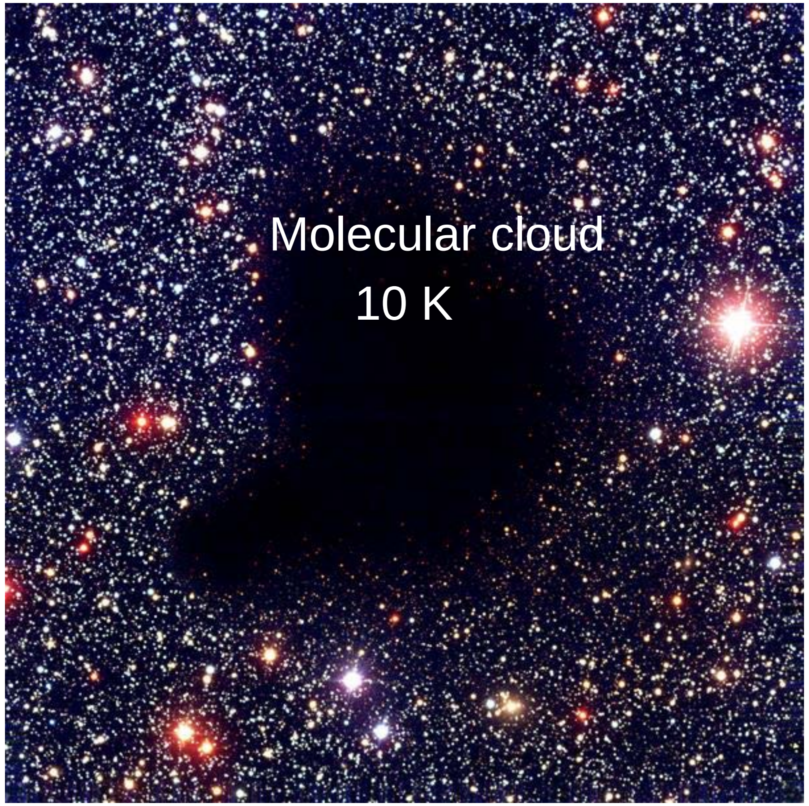


Fig. 1. Schematic view of the dust formation zone in O-rich AGB stars, which includes typical physical parameters and the prevalent chemical processes related to dust production. Molecules present under TE in the photosphere are shown.

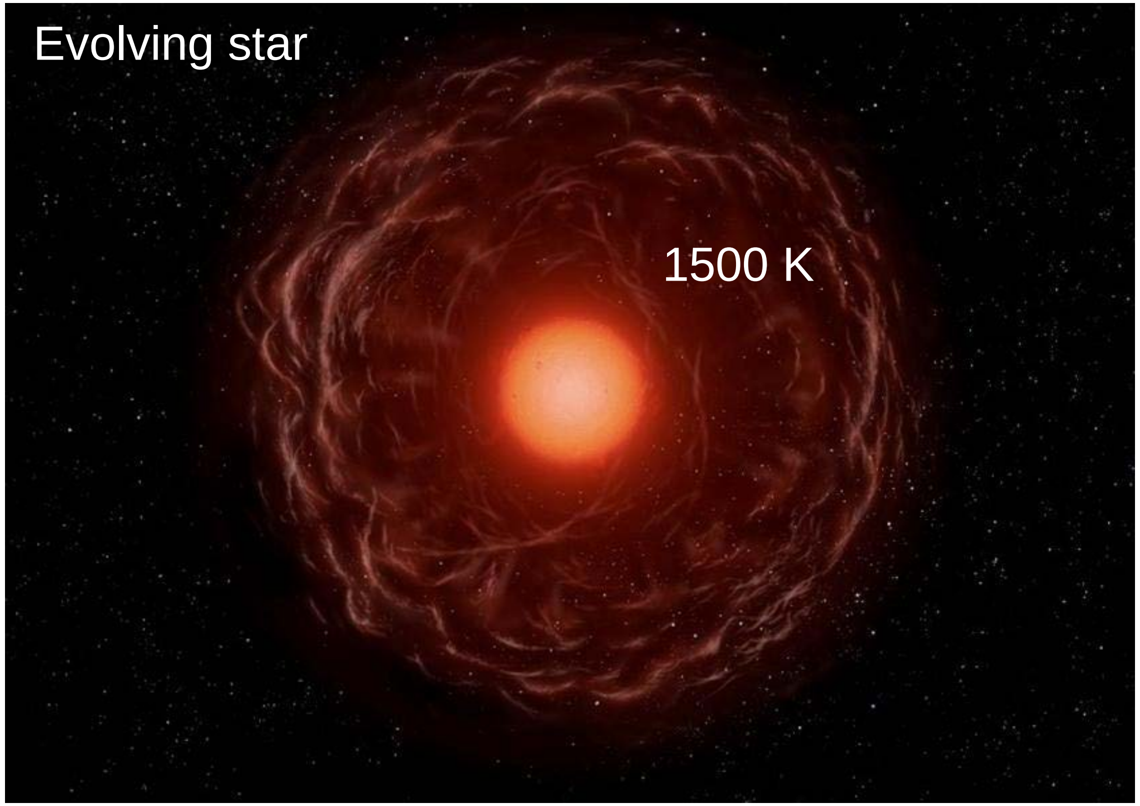
Gobrecht et al. 2016

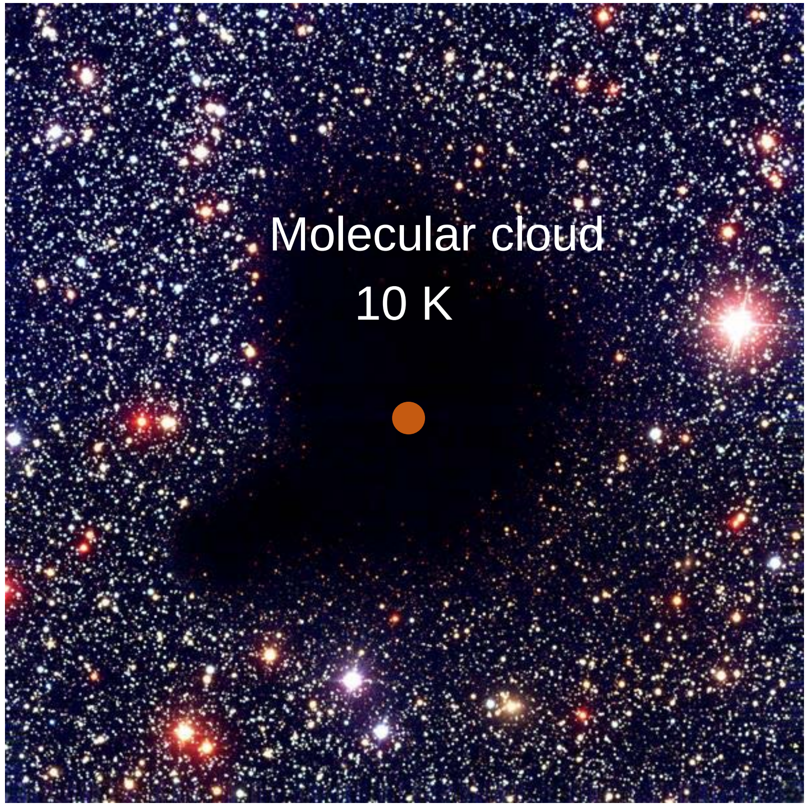
Formation of dust grains in the ISM



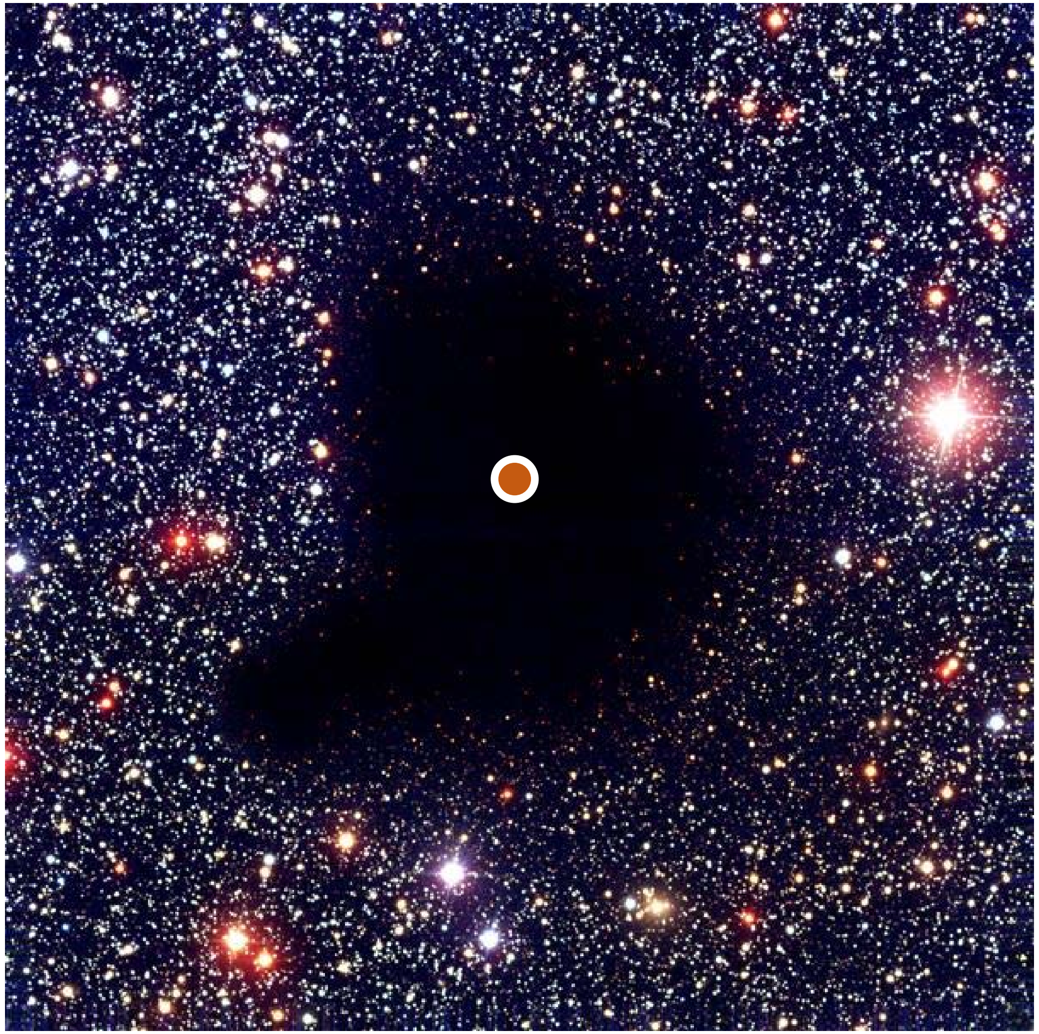


Formation of dust grains in the ISM



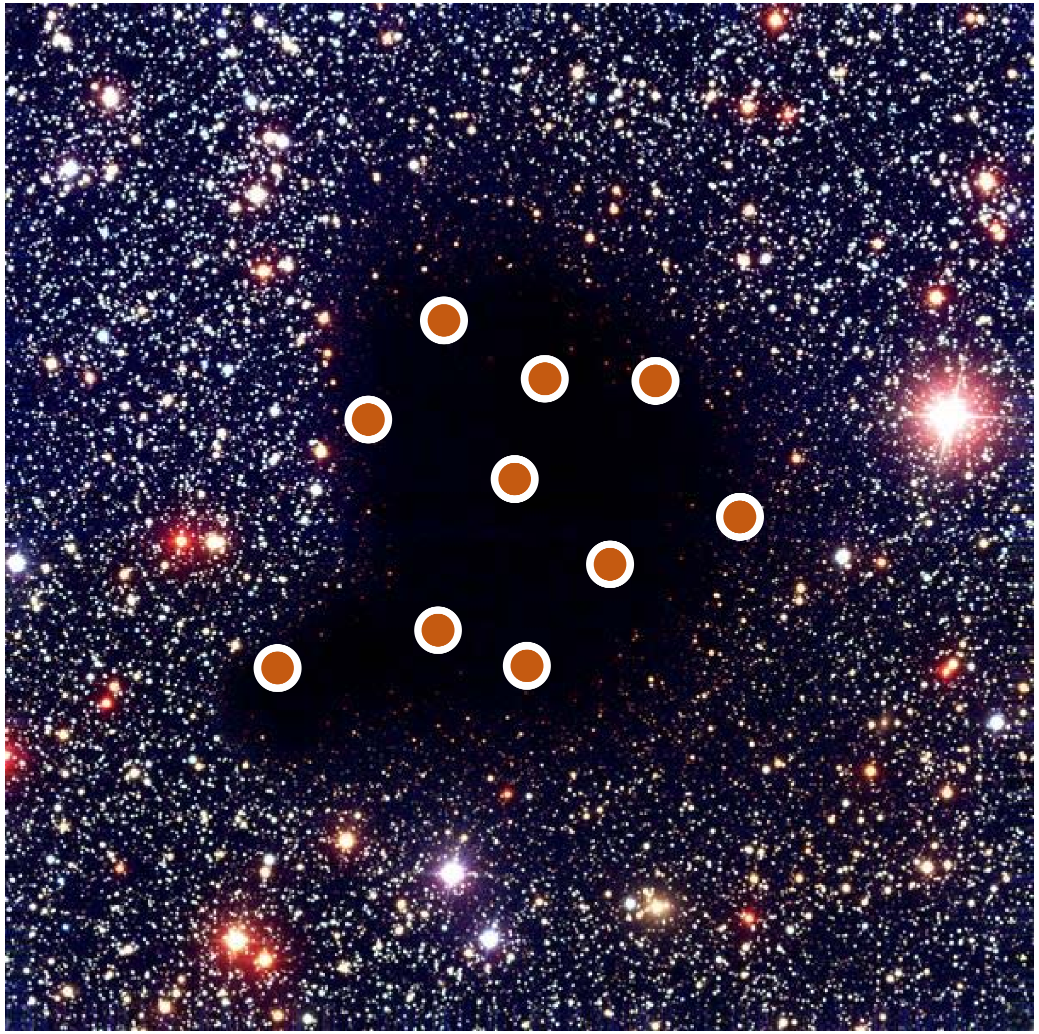


Formation of dust grains in the ISM



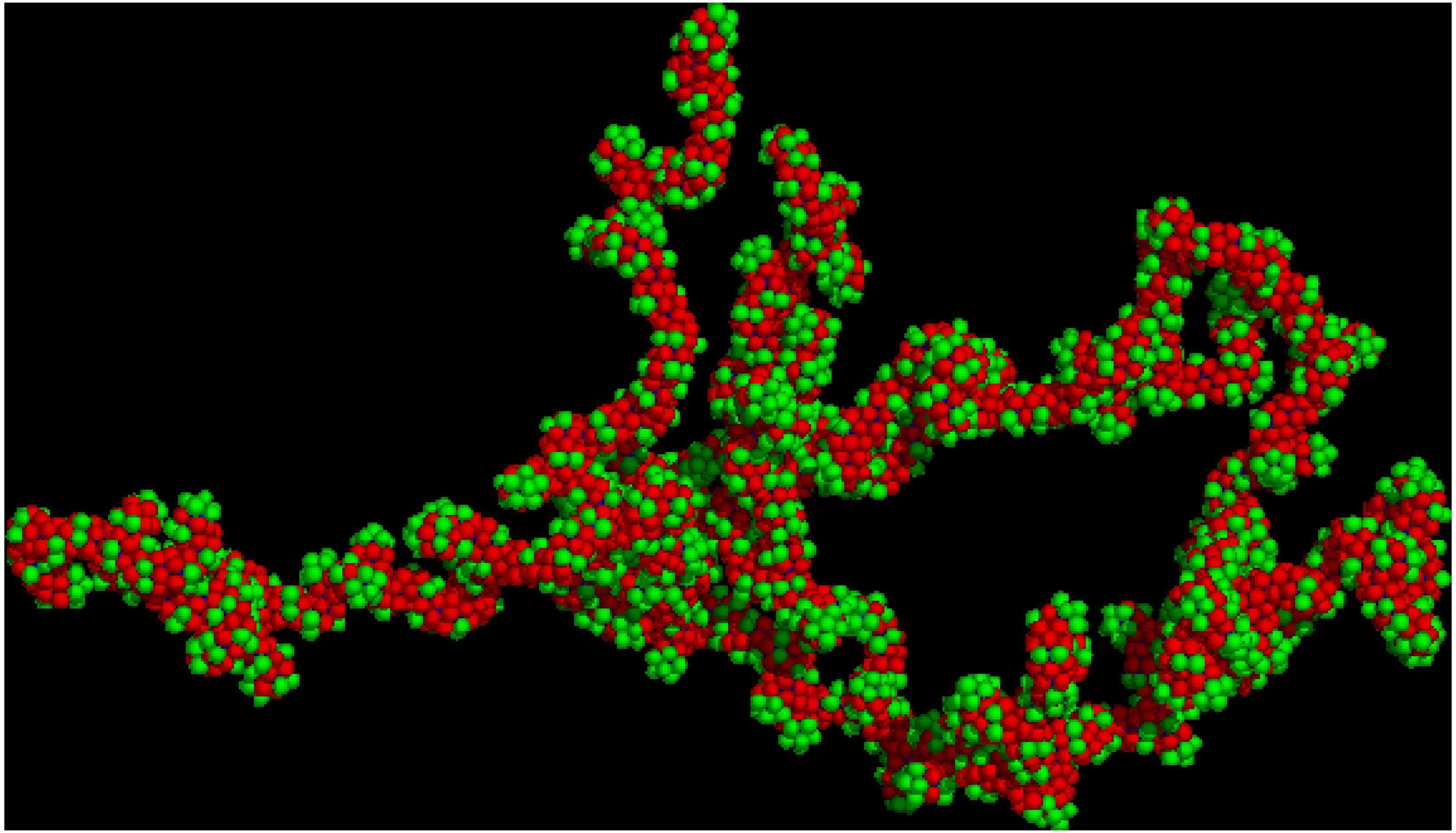
„Cometary“ ice: H_2O, CO, CO_2, NH_3, CH_4, CH_3OH

Formation of dust grains in the ISM



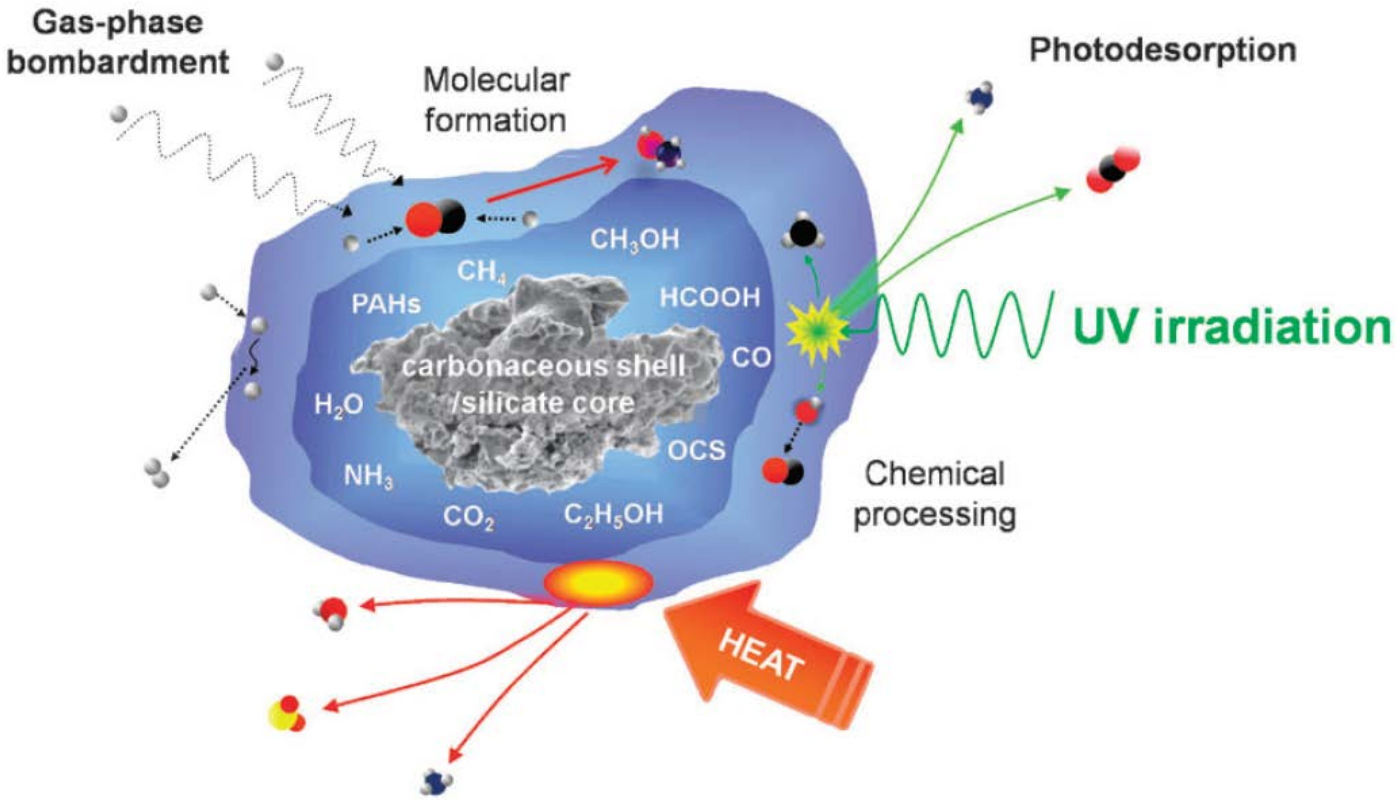
Formation of dust grains in the ISM

Dust grains in the ISM



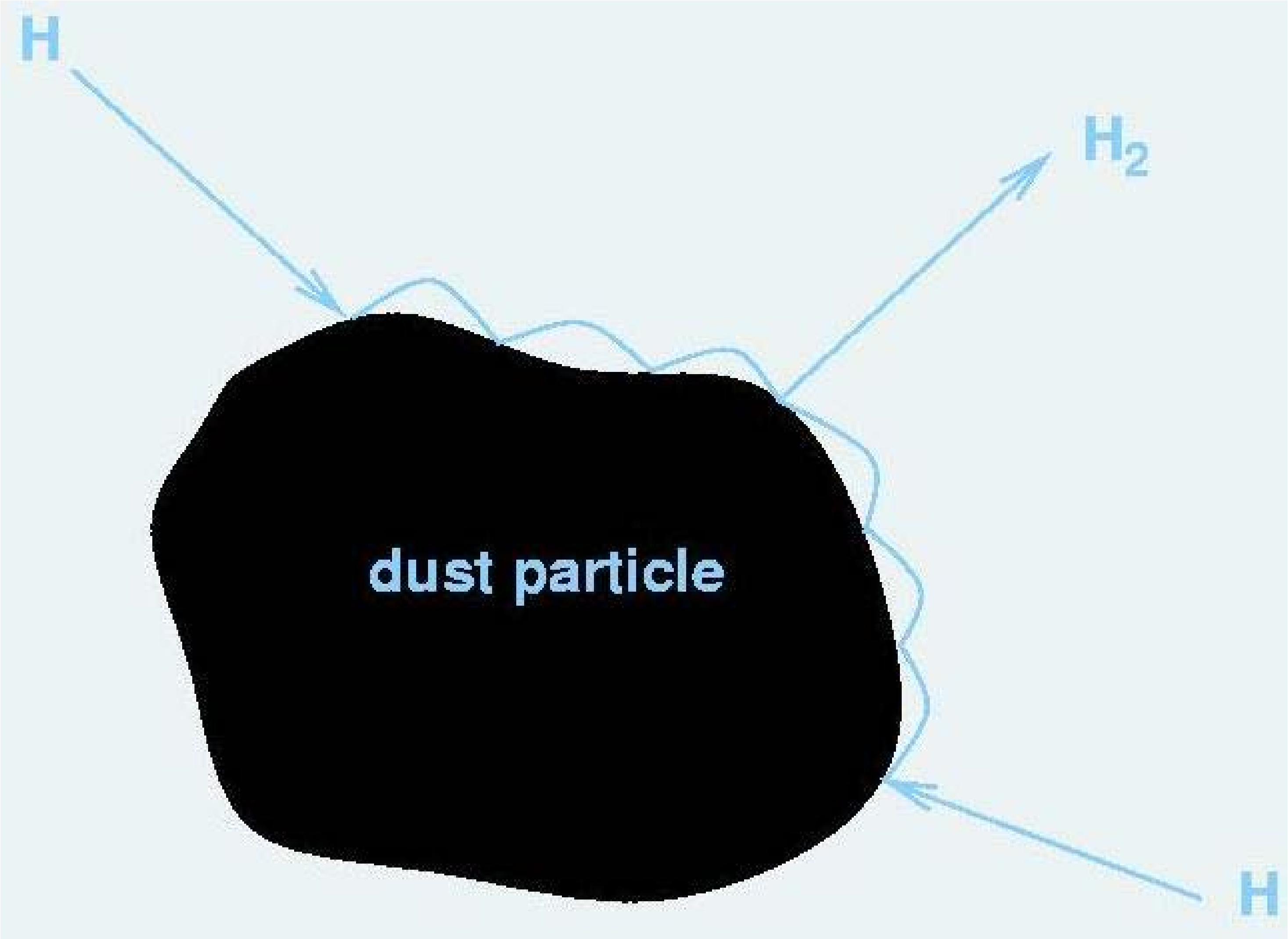
Ned Wright's Fractal Dust Model (University of California)

Physics and chemistry of the ice/dust grains in the ISM



D. Burke, W. Brown, 2012, PCCP

Physics and chemistry of the ice/dust grains in the ISM



Credit: Herma Cuppen

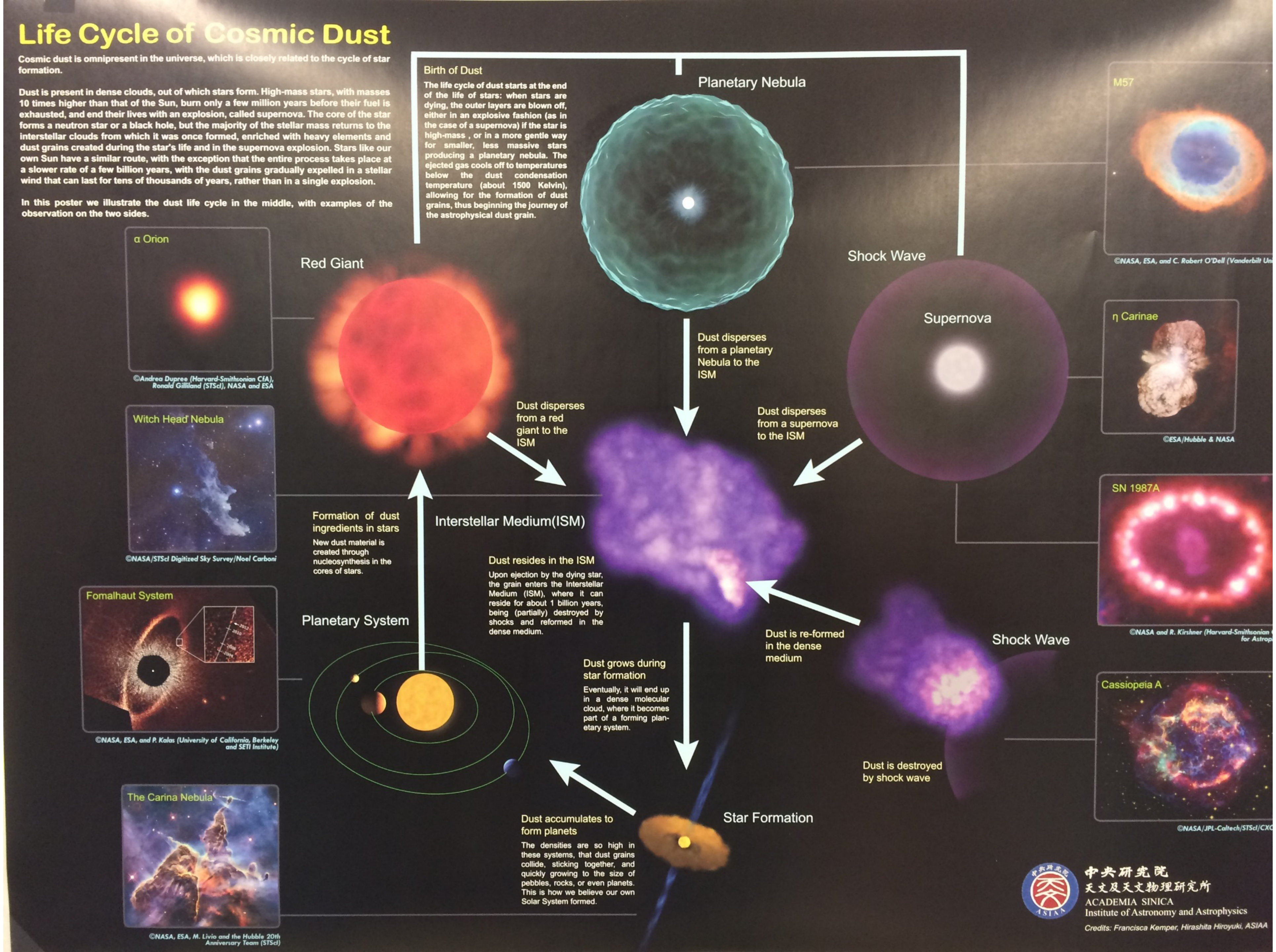
Dust in the ISM

Carbon-rich dust:
hydrogenated amorphous carbon, graphite, silicon carbide (SiC)

Oxigen-rich dust:
silicates (pyroxene $Mg_xFe_{1-x}SiO_3$, olivine $Mg_{2y},Fe_{2-2y}SiO_4$), metal oxides (Al_2O_3, SiO, FeO)

Detection:
Absorption, Emission, Polarisation, Scattering of starlight

Importance:
Decoding of astronomical spectra, Surface chemistry, Physical conditions, Growth processes


Life Cycle of Cosmic Dust
Cosmic dust is omnipresent in the universe, which is closely related to the cycle of star formation.
Dust is present in dense clouds, out of which stars form. High-mass stars, with masses 10 times higher than that of the Sun, burn only a few million years before their fuel is exhausted, and end their lives with an explosion, called supernova. The core of the star forms a neutron star or a black hole, but the majority of the stellar mass returns to the interstellar clouds from which it was once formed, enriched with heavy elements and dust grains created during the star's life and in the supernova explosion. Stars like our own Sun have a similar route, with the exception that the entire process takes place at a slower rate of a few billion years, with the dust grains gradually expelled in a stellar wind that can last for tens of thousands of years, rather than in a single explosion.
In this poster we illustrate the dust life cycle in the middle, with examples of the observation on the two sides.
Birth of Dust
The life cycle of dust starts at the end of the life of stars: when stars are dying, the outer layers are blown off, either in an explosive fashion (as in the case of a supernova) if the star is high-mass , or in a more gentle way for smaller, less massive stars producing a planetary nebula. The ejected gas cools off to temperatures below the dust condensation temperature (about 1500 Kelvin), allowing for the formation of dust grains, thus beginning the journey of the astrophysical dust grain.
Planetary Nebula
M57
©NASA, ESA, and C. Robert O'Dell (Vanderbilt Un
α Orion
©Andrea Dupree (Harvard-Smithsonian CfA), Ronald Gilliland (STScI), NASA and ESA
Red Giant
Shock Wave
Supernova
η Carinae
©ESA/Hubble & NASA
Dust disperses from a planetary Nebula to the ISM
Dust disperses from a red giant to the ISM
Dust disperses from a supernova to the ISM
Witch Head Nebula
©NASA/STScI Digitized Sky Survey/Noel Carboni
Formation of dust ingredients in stars
New dust material is created through nucleosynthesis in the cores of stars.
Interstellar Medium(ISM)
SN 1987A
©NASA and R. Kirshner (Harvard-Smithsonian
Dust resides in the ISM
Upon ejection by the dying star, the grain enters the Interstellar Medium (ISM), where it can reside for about 1 billion years, being (partially) destroyed by shocks and reformed in the dense medium.
Fomalhaut System
©NASA, ESA, and P. Kalas (University of California, Berkeley and SETI Institute)
Planetary System
Dust is re-formed in the dense medium
Shock Wave
Dust grows during star formation
Eventually, it will end up in a dense molecular cloud, where it becomes part of a forming planetary system.
Cassiopeia A
Dust is destroyed by shock wave
©NASA/JPL-Caltech/STScI/CXC
The Carina Nebula
Dust accumulates to form planets
The densities are so high in these systems, that dust grains collide, sticking together, and quickly growing to the size of pebbles, rocks, or even planets. This is how we believe our own Solar System formed.
Star Formation
©NASA, ESA, M. Livio and the Hubble 20th Anniversary Team (STScI)
中央研究院
天文及天文物理研究所
ACADEMIA SINICA
Institute of Astronomy and Astrophysics
Credits: Francisca Kemper, Hirashita Hiroyuki, ASIAA

Interplanetary dust

"A few million tonnes of interstellar dust enter the solar system within Jupiter's orbit per day". (Williams, 2000, Astronomy & Geophysics)

ESA/Rosetta/NavCam

Interplanetary dust on Earth

"A few million tonnes of interstellar dust enter the solar system within Jupiter's orbit per day. Some of this will mix with interplanetary dust, and about 100 tonnes of interplanetary dust arrives at Earth per day."
(Williams, 2000, Astronomy & Geophysics)

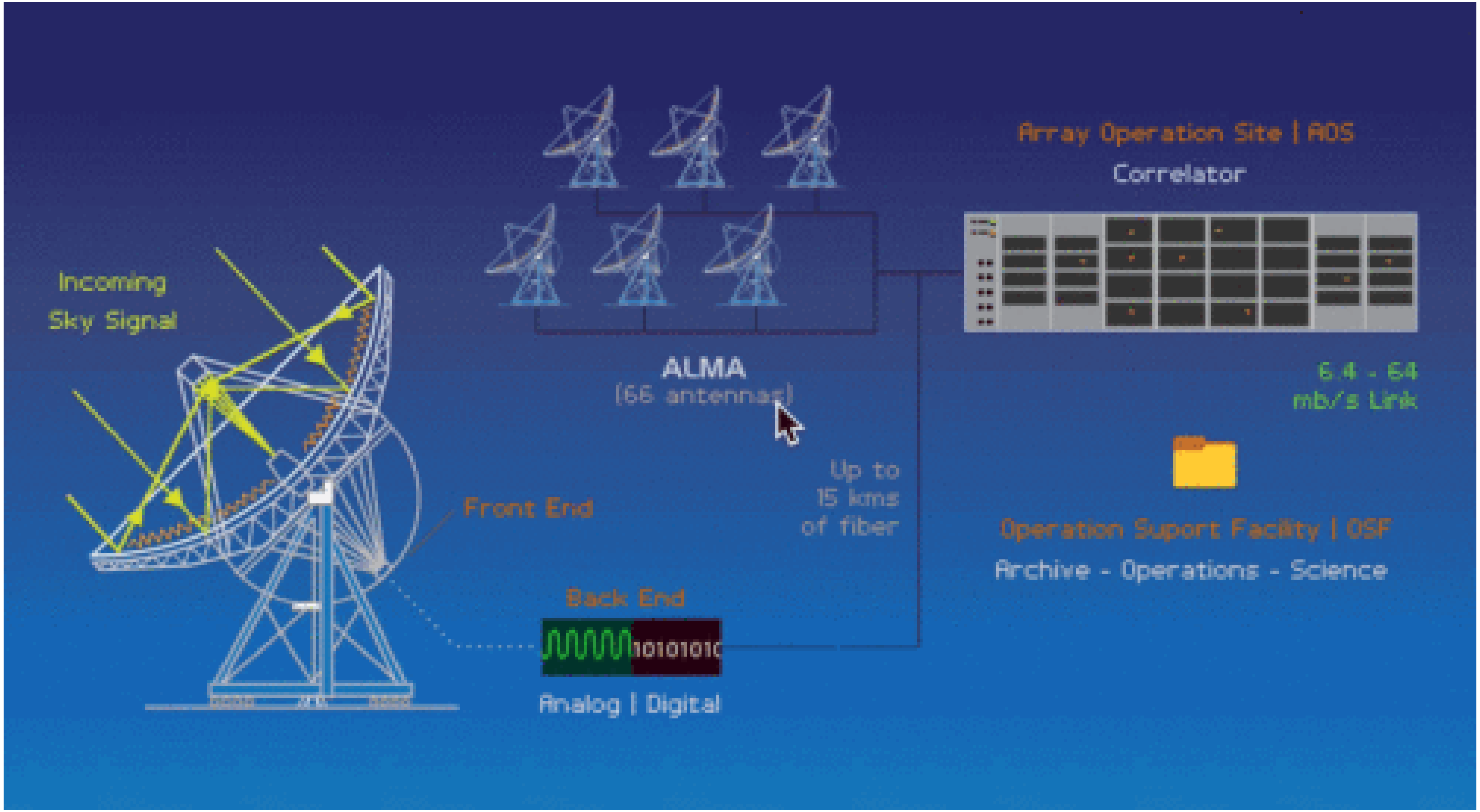
Credit: Melbourne Museum

ALMA


the Atacama Large Millimeter/submillimeter Array (ALMA)

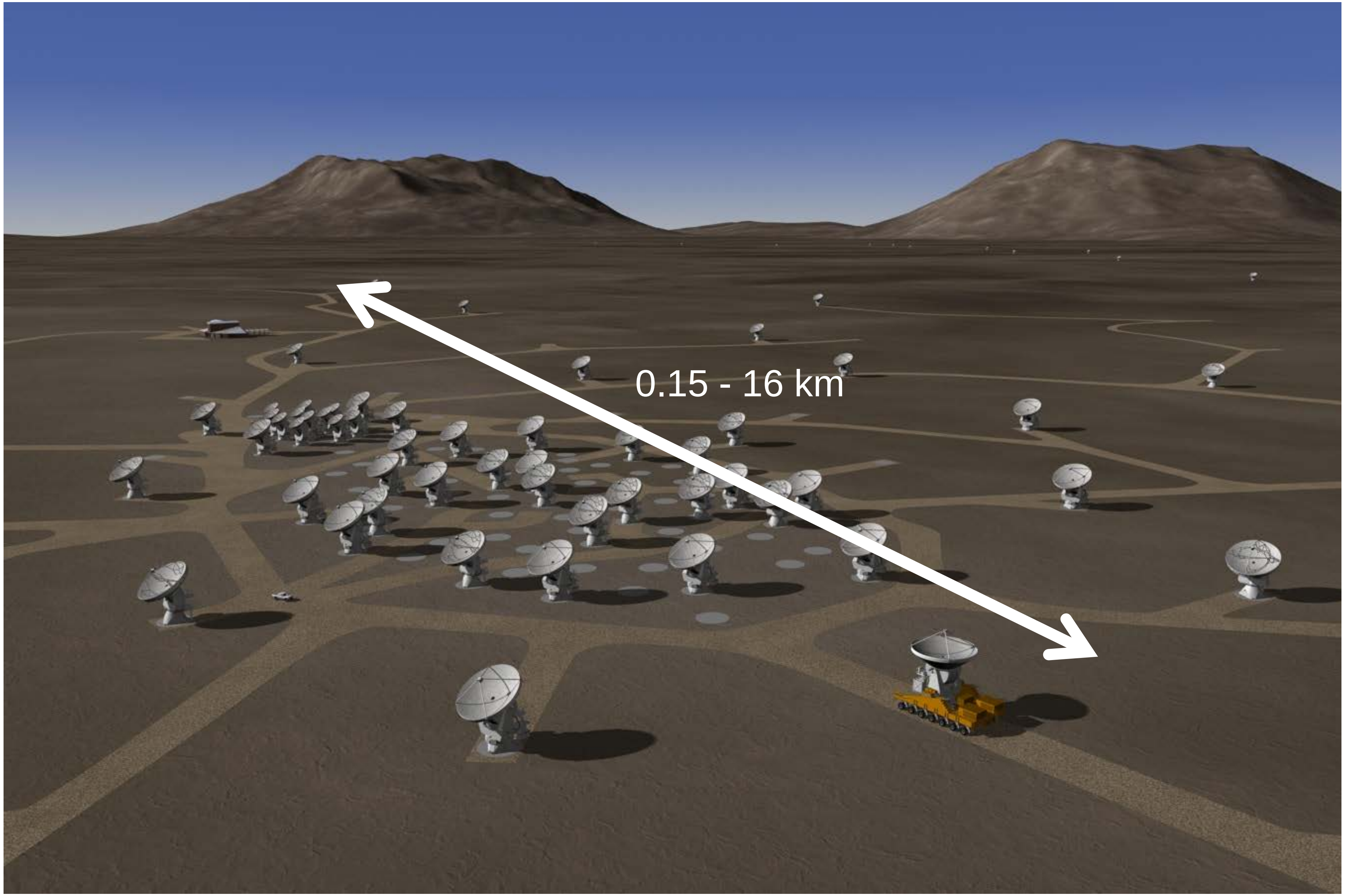
http://www.almaobservatory.org/en/videos/the-movie-alma-in-search-of-our-cosmic-origins/

ALMA

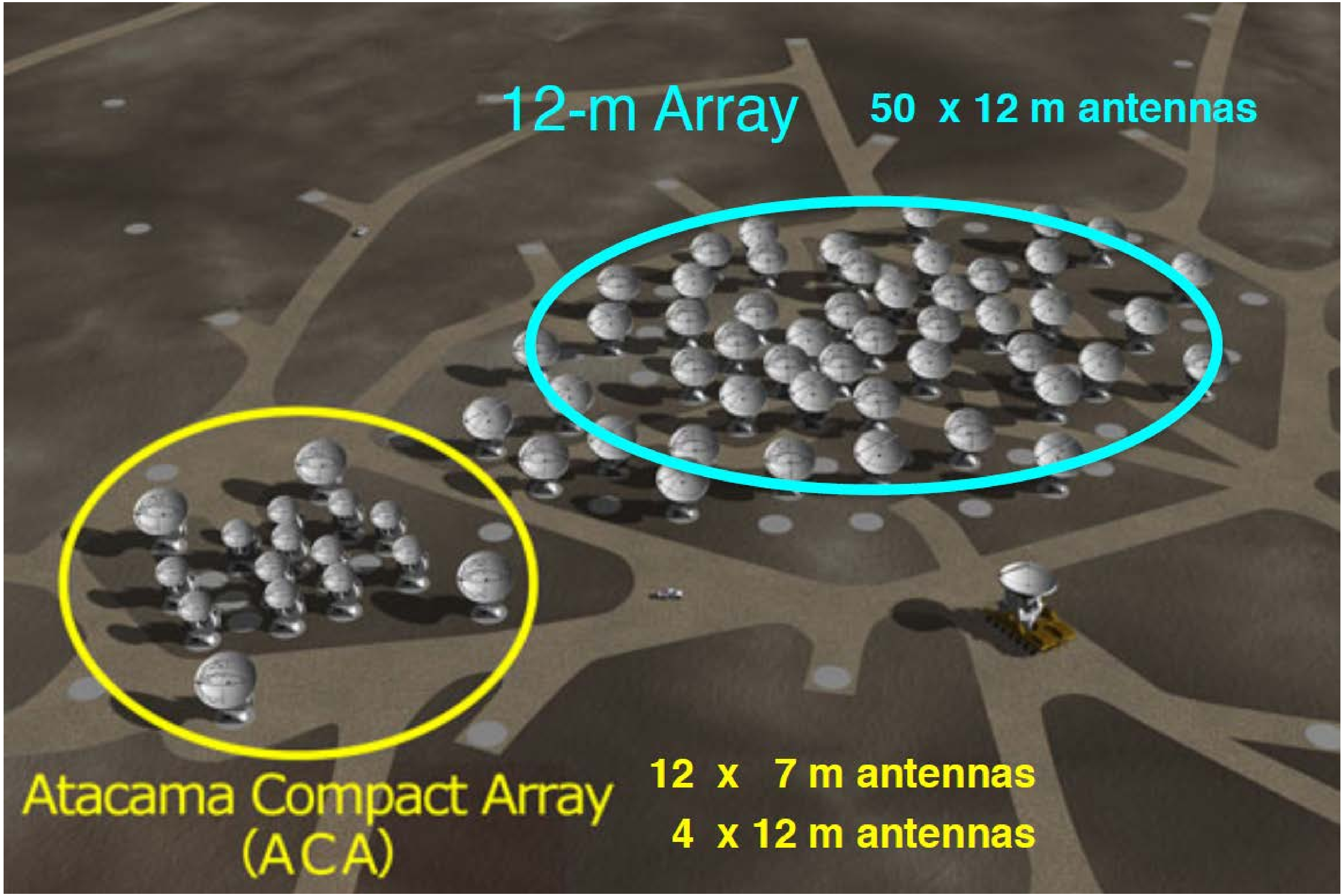


Incoming
Sky Signal
Array Operation Site | AOS
Correlator
ALMA
(66 antennas)
6.4 - 64
mb/s Link
Up to
15 kms
of fiber
Front End
Operation Suport Facility | OSF
Archive - Operations - Science
Back End
10101010
Analog | Digital

ALMA

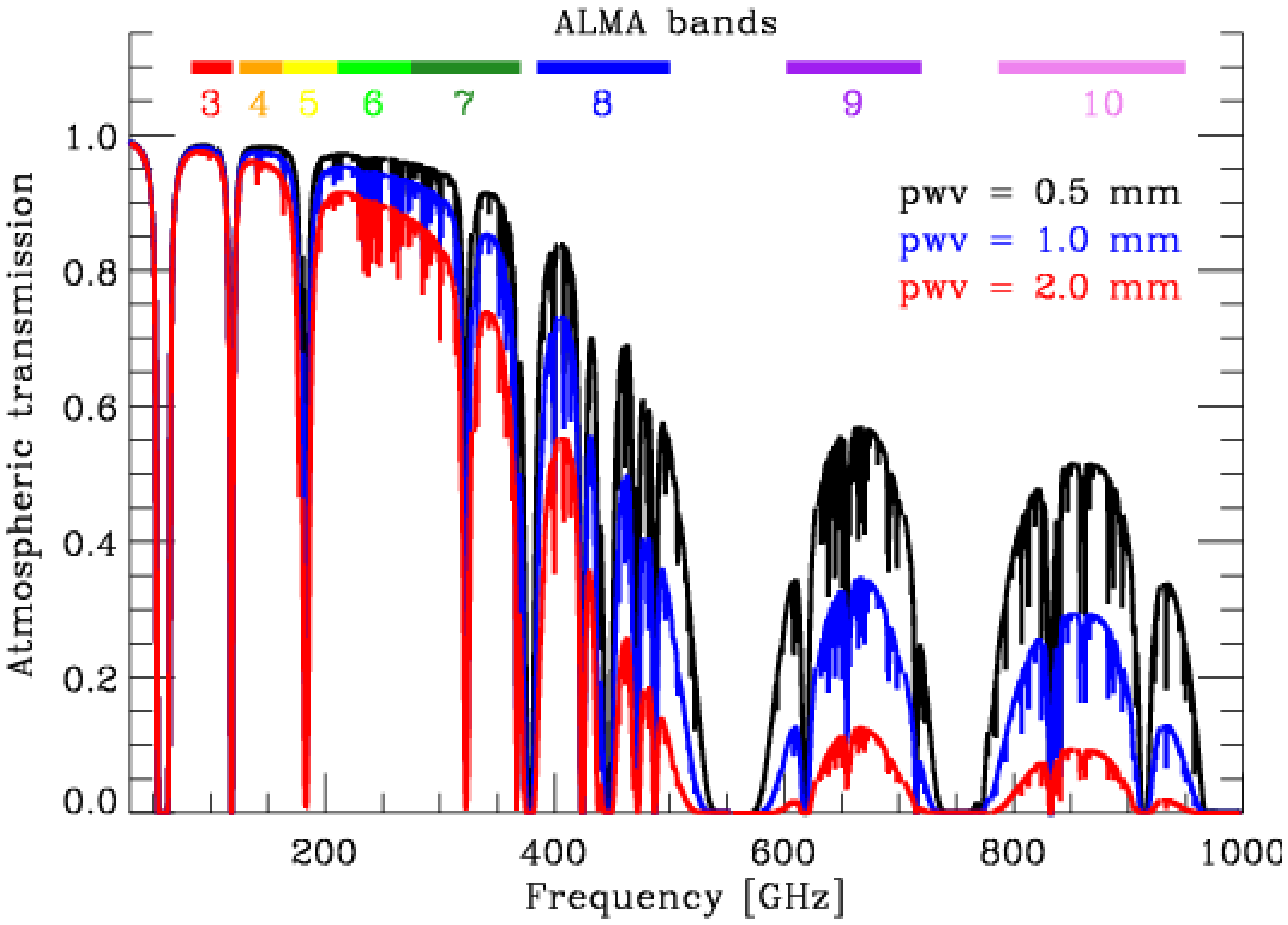


ALMA



Credit: John Carpenter, 2017

ALMA



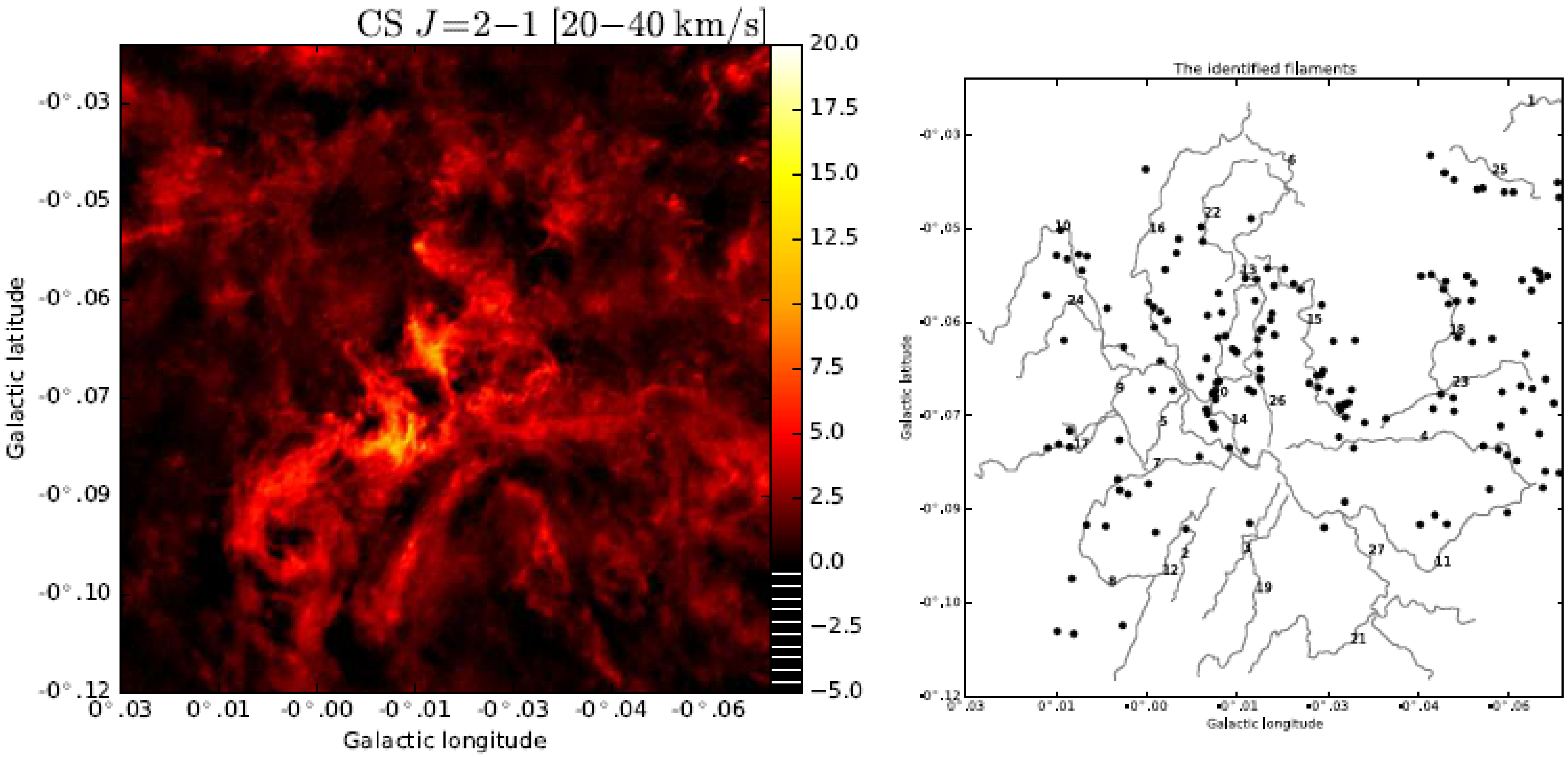
pwv - precipitable water vapor

ALMA

- Frequencies: 86– 950 GHz (250 µm–1 mm)
- Spatial resolution: 0.01" @ 950 GHz
- Spectral resolution: >20 m/s

ALMA: from molecular clouds to planets and distant galaxies

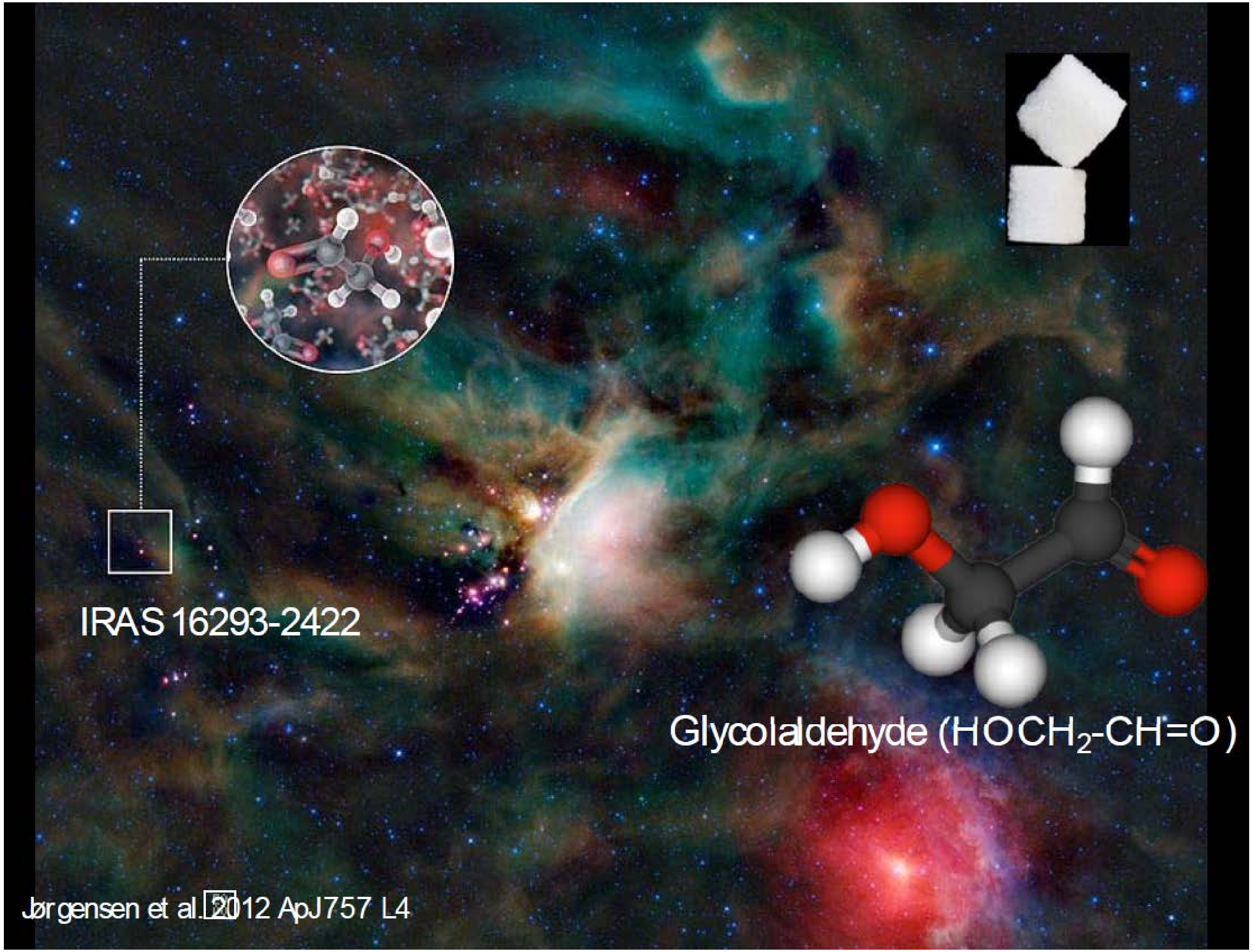
The first attempt of filament-finding in the Galactic Center Region



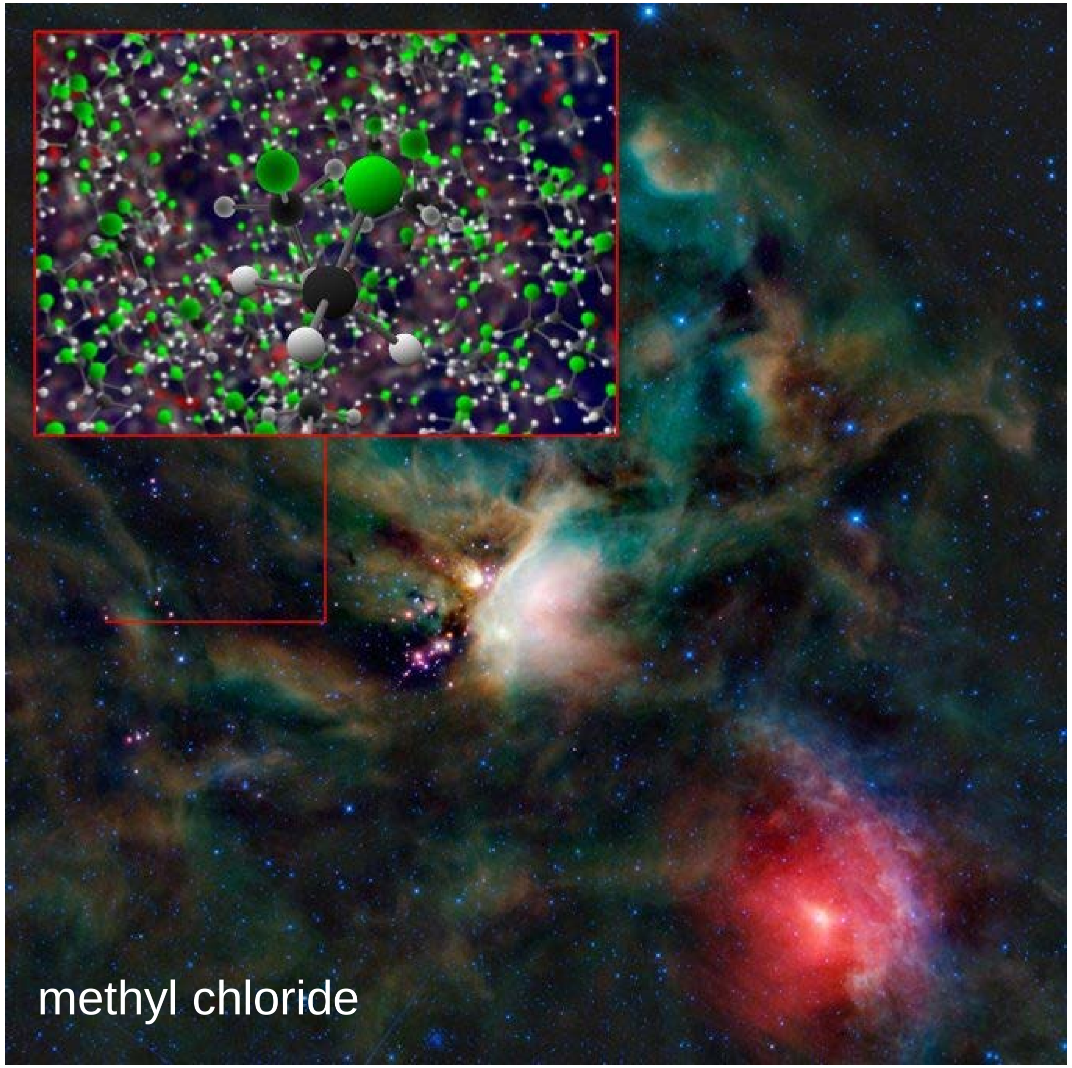
[left]The 50 km s^{-1} molecular cloud in an integrated intensity map of CS J = 2−1. The integrated velocity range is VLSR = 20 − 40 km s−1.
[right]The location of the filaments. Gray thick lines show the central axes of the MCFs and black filled circles show the molecular cloud cores.

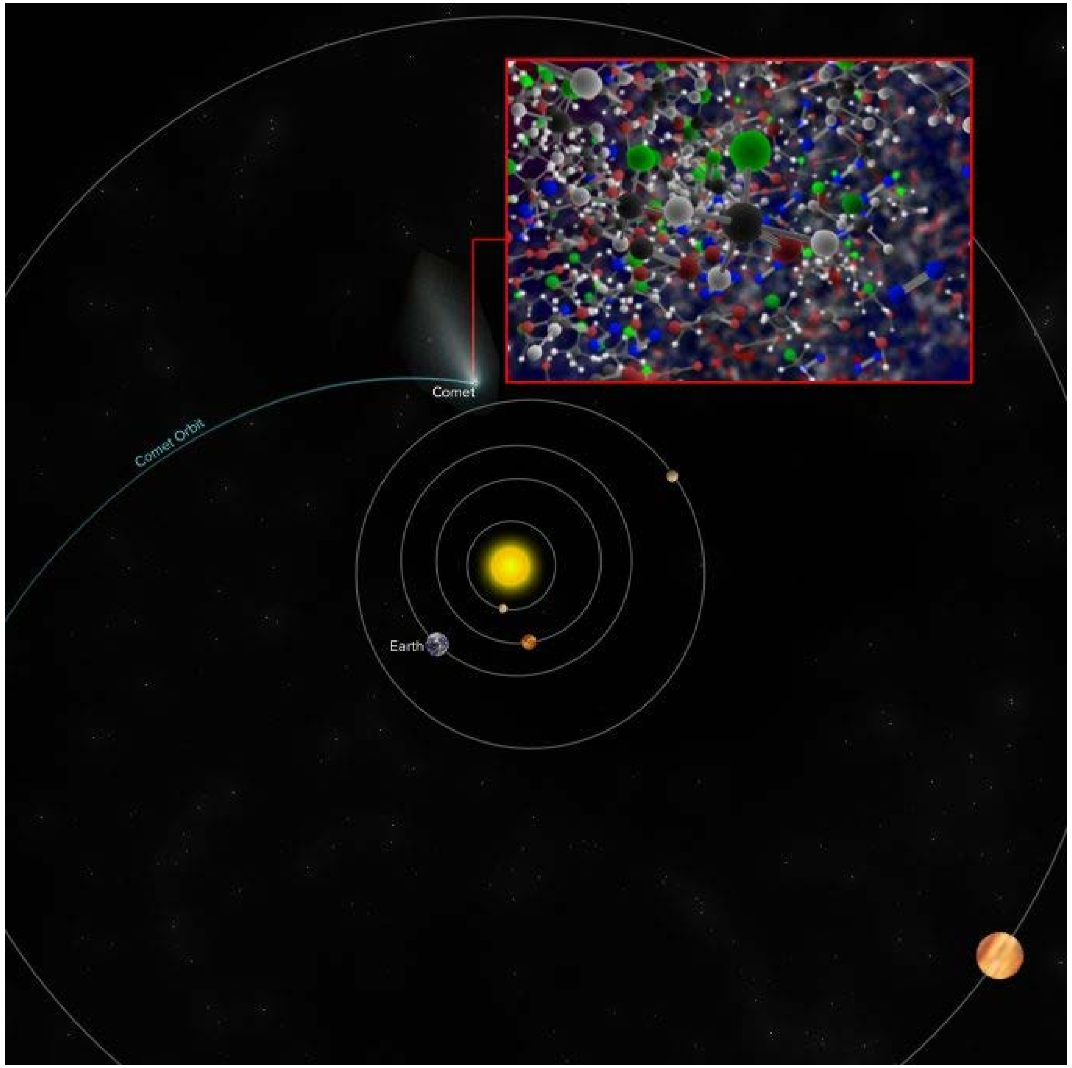
Uehara et al. 2016

ALMA: from molecular clouds to planets and distant galaxies



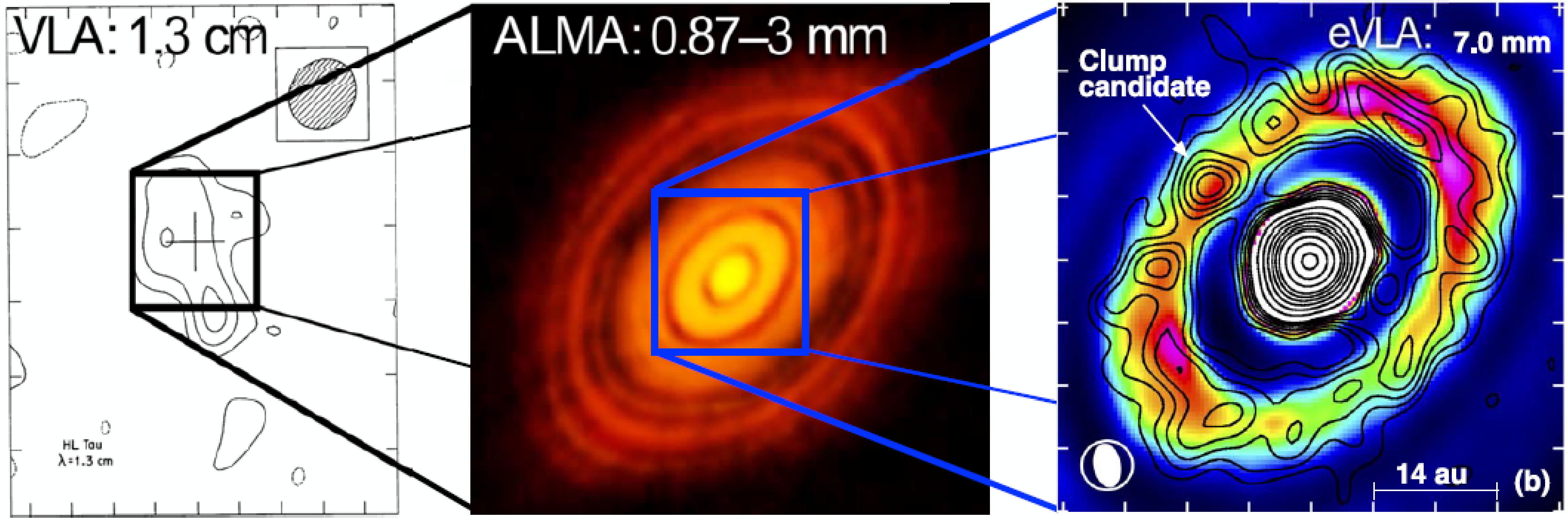
ALMA: from molecular clouds to planets and distant galaxies





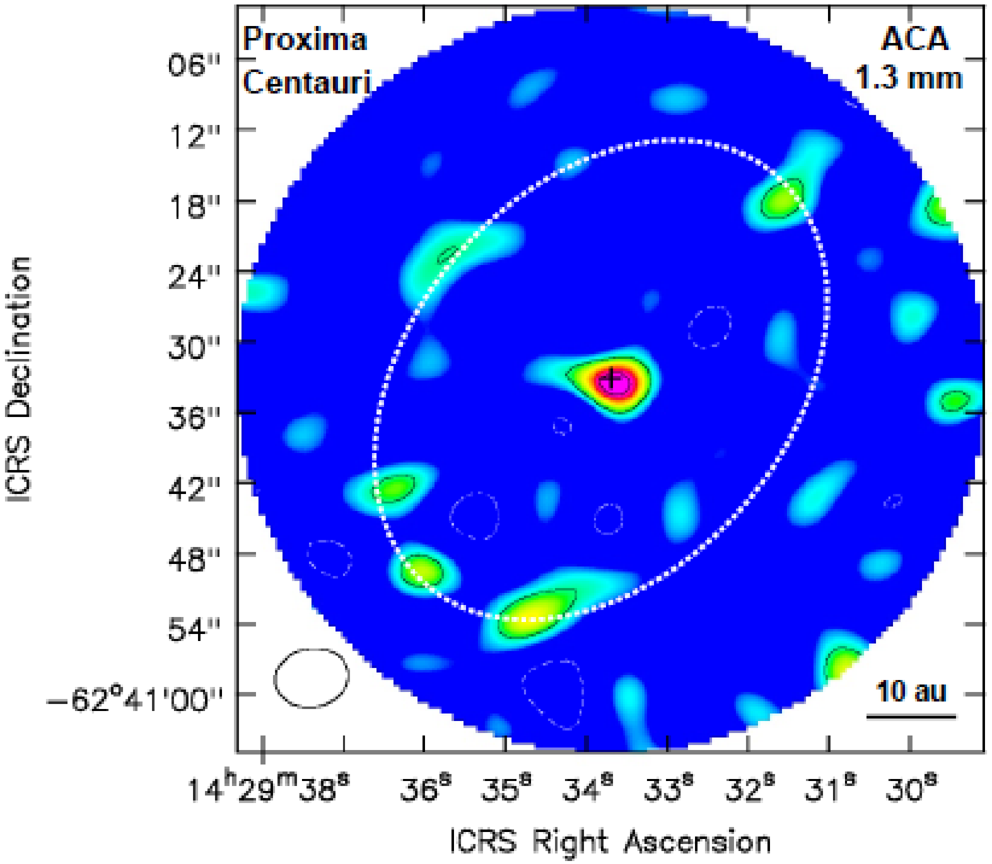
Organohalogen methyl chloride discovered by ALMA around the infant stars in IRAS 16293-2422. These same organic compounds were discovered in the thin atmosphere surrounding 67P/C-G by the Rosetta space probe (Credit: B. Saxton (NRAO/AUI/NSF))

Detailed structures: dust in HL Tau



Rodriguez et al. (1992) ALMA Partnership (2015) Carrasco-Gonzalez et al. (2016)

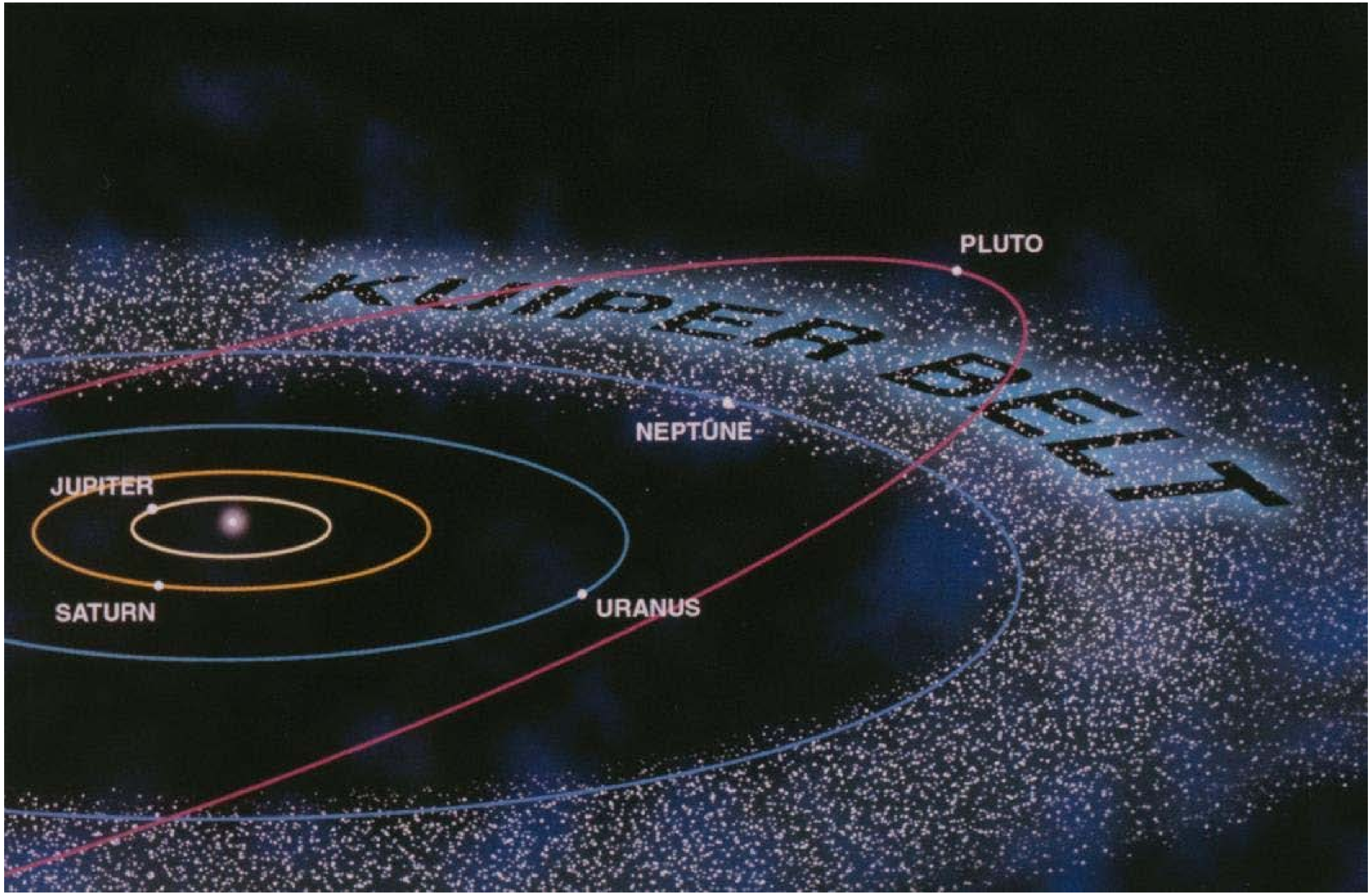
ALMA: from molecular clouds to planets and distant galaxies



Dust around the closest star to the Solar System, Proxima Centauri. The data may indicate the presence of an elaborate planetary system. These structures are similar to the much larger belts in the Solar System and are also expected to be made from particles of rock and ice that failed to form planets

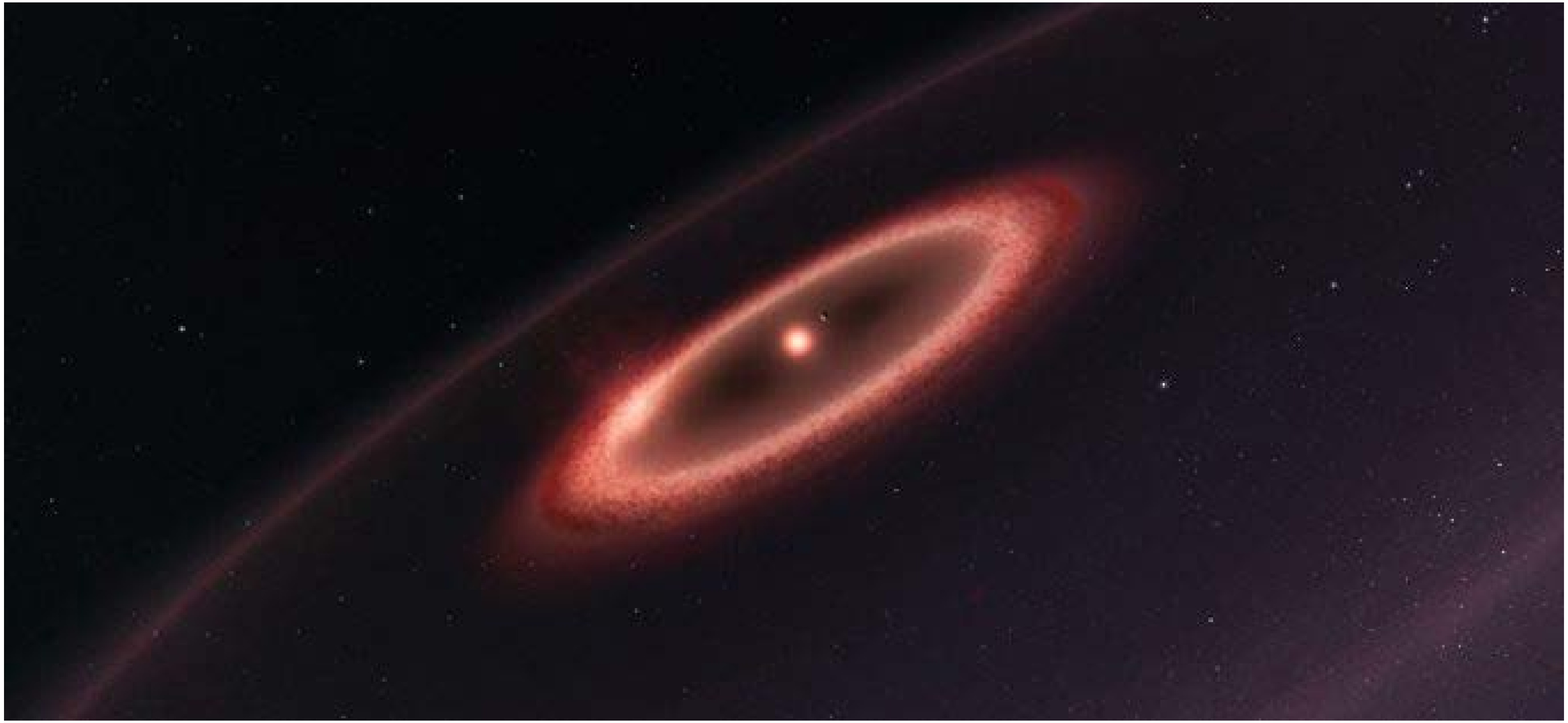
(Credit: ALMA Observatory and Anglada et al. 2017)

ALMA: from molecular clouds to planets and distant galaxies



Credit: NASA

ALMA: from molecular clouds to planets and distant galaxies

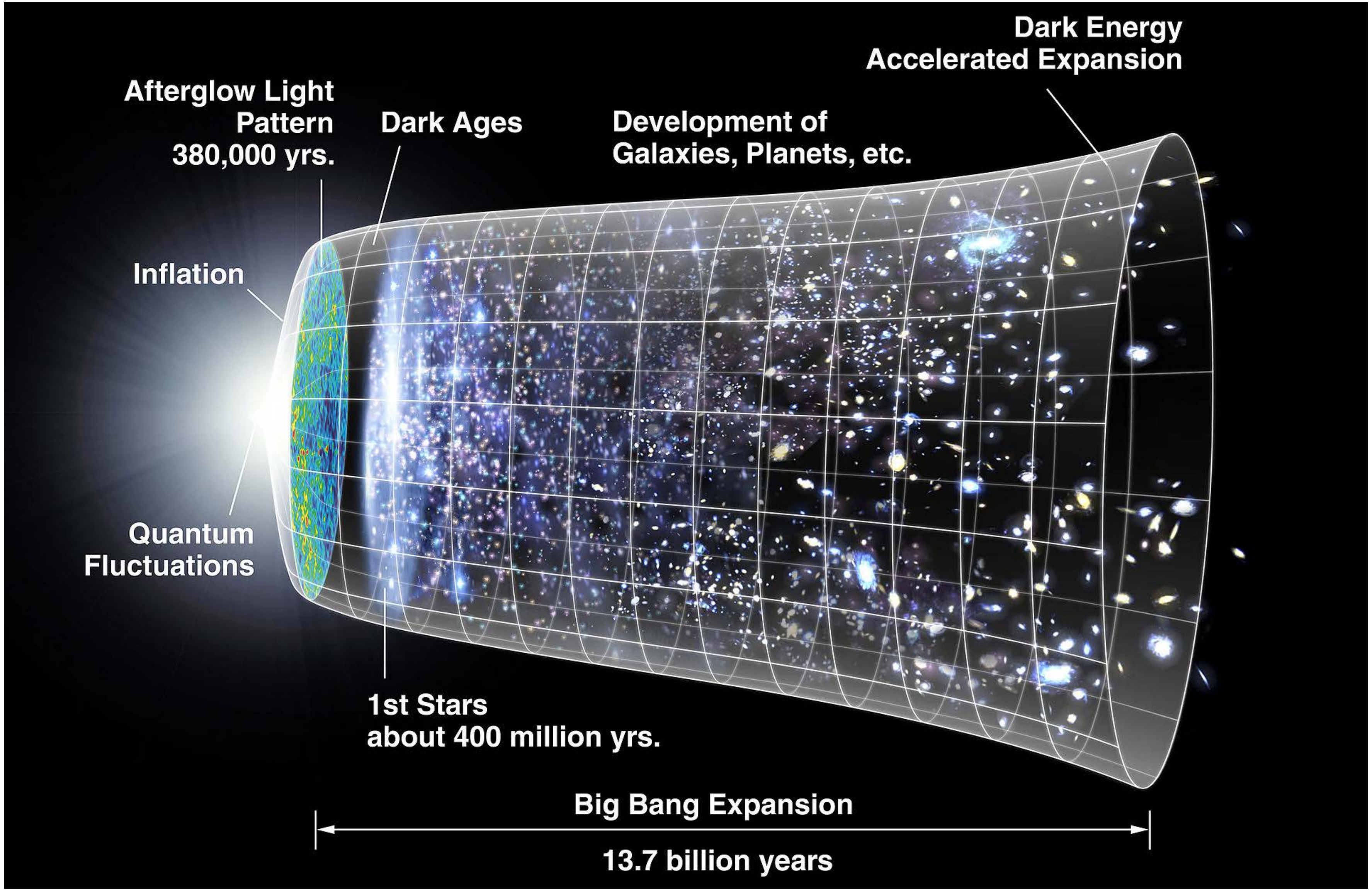


Dust around the closest star to the Solar System, Proxima Centauri. The data may indicate the presence of an elaborate planetary system. These structures are similar to the much larger belts in the Solar System and are also expected to be made from particles of rock and ice that failed to form planets (Credit: ALMA Observatory)

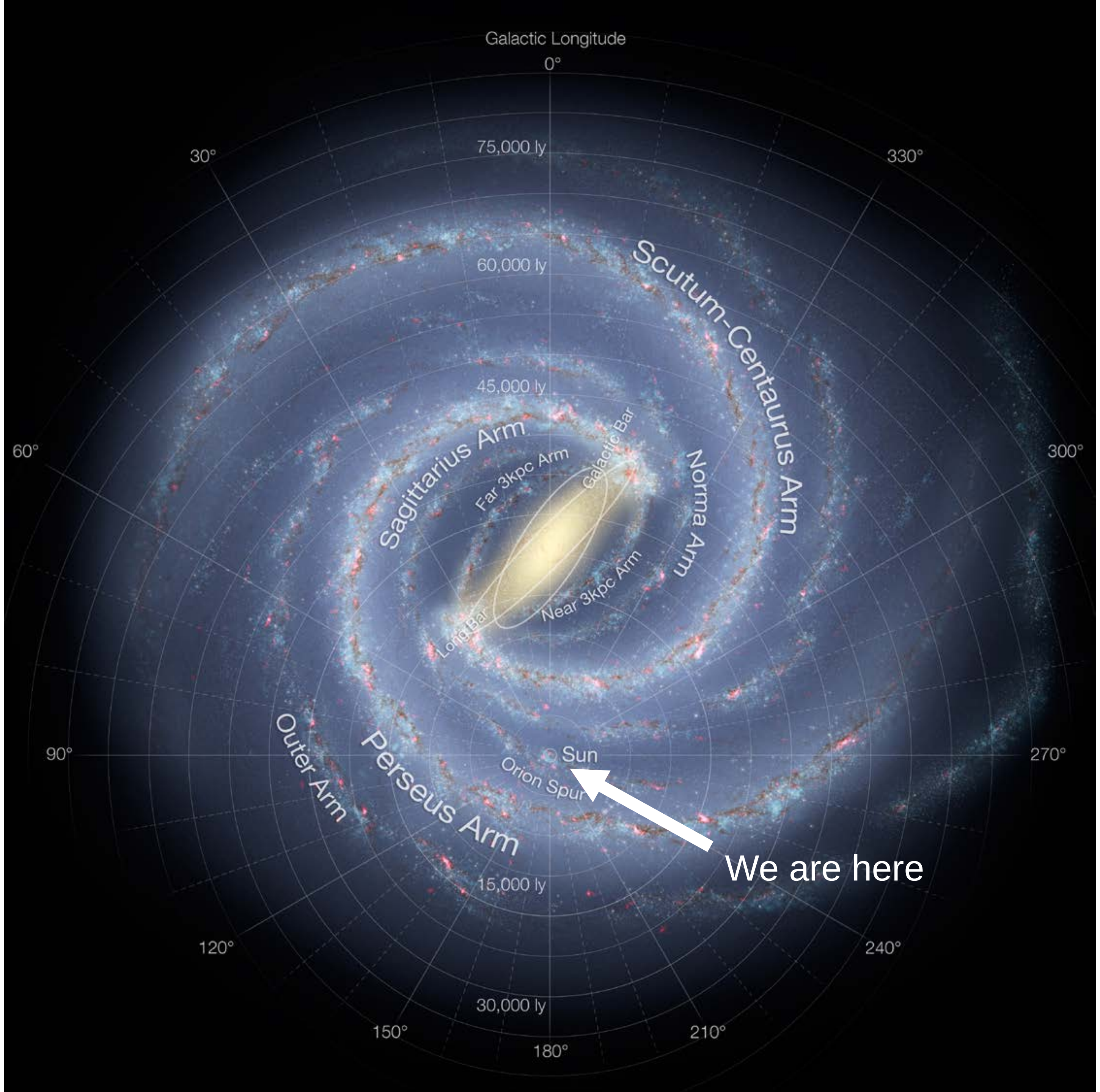
ALMA: from molecular clouds to planets and distant galaxies

Back to a time soon after the Big Bang, the earliest galaxies to have formed in the Universe, nearly 13 billion years ago (Credit: Amanda Smith, University of Cambridge)

ALMA: from molecular clouds to planets and distant galaxies



Credit: Wikipedia


Galactic Longitude
0°
30°
330°
75,000 ly
60,000 ly
45,000 ly
Scutum-Centaurus Arm
Sagittarius Arm
Far 3kpc Arm
Galactic Bar
Norma Arm
60°
300°
Long Bar
Near 3kpc Arm
Outer Arm
Perseus Arm
Sun
Orion Spur
90°
270°
We are here
15,000 ly
120°
240°
30,000 ly
150°
210°
180°

The evolution of the Universe?

The synthesis of complex organic molecules?

The formation of stars, planets, planetary systems?

The origin of Life on Earth?

Life on other planets?