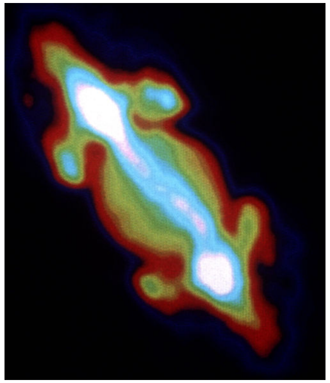
The Universe in my pocket



Radioastronomy

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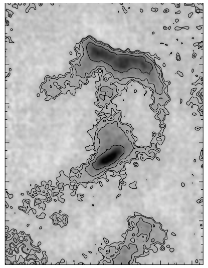
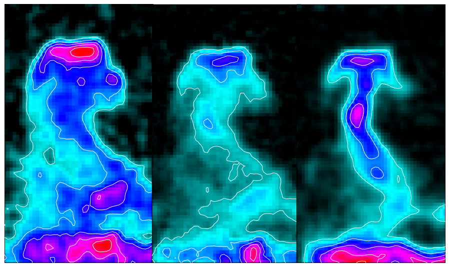
TUIMP No 46 — THE UNIVERSE IN MY POCKET

Question



Here are five images of the Horsehead Nebula in Orion. Which one does not come from the radio domain?

Answer on the back.



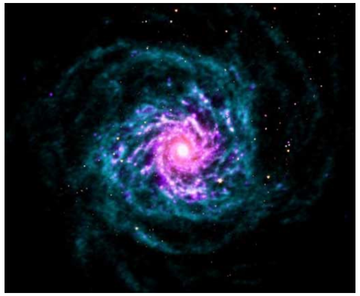
Radiogalaxies

Today it is believed that most galaxies have a supermassive black hole at their center. If some matter is nearby, this black hole accretes it via an 'accretion disk' (see tuimp 47). The black hole is said to become 'active'.

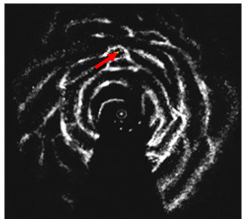
In some cases a pair of jets of ionized matter forms.

The cause of this phenomenon is not yet fully understood. It is believed that by rotating, the accretion disk generates a magnetic field which concentrates the matter of the disk in very fast jets, detectable by their radio wave emission.

Usually, the size of the jets does not exceed that of the galaxy. But in some spectacular cases the jets extend into intergalactic space over distances that can exceed several million light-years.



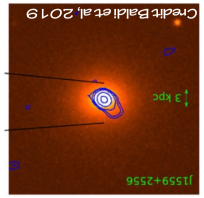
Neutral hydrogen emission from the spiral galaxy M74 (in false colors). Credit Walter et al. NRAO.



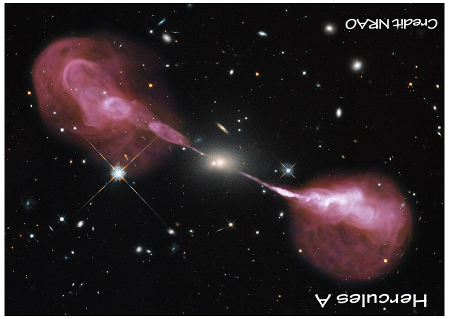
Neutral hydrogen emission from the Milky Way revealing its spiral arms for the first time. The arrow shows the position of the Sun. (credit J. Oort and WSRT)

The hydrogen atom

The wavelength of photons is inversely proportional to their energy and is unrelated to the size of their emitter. For example, the hydrogen atom, although very small (it would take 10 billion of them side by side to form a line 1 meter long), emits a signal at 21 cm wavelength. Hydrogen is the most abundant element in the Universe (10 times more abundant than helium and 2000 times more than oxygen) and is found everywhere. It traces galaxies from the earliest times to the present day. When we observe spectral lines (see tuimp 30) in radio, we can use the Doppler effect to measure the radial velocity of the emitting objects. By modeling the relation between velocity and distance, we can use this radio emission to map the spiral structure of the Milky Way, and to measure the rotation of other galaxies.



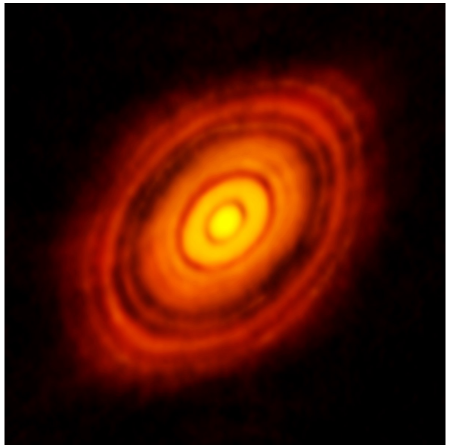
A so-called 'compact' radio galaxy. It is a red elliptical galaxy. The radio emission at 4.5 GHz, represented by blue contour lines, does not exceed the boundaries of the galaxy.



The radio galaxy Hercules A. The image in visible light (shown in white) comes from the Hubble Space Telescope. It is superimposed with the radio image (shown in pink) obtained by the Very Large Array radio telescope.

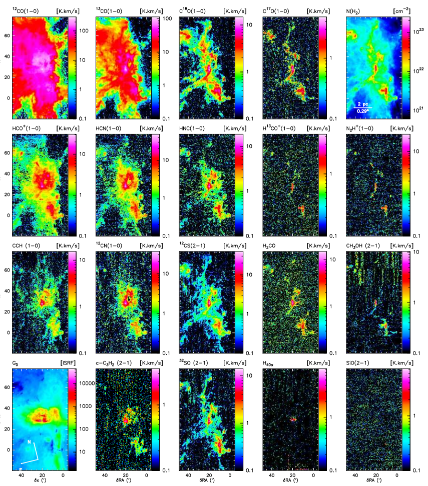
The dust

Any body that is not at absolute zero emits radiation whose intensity and 'color' will depend mainly on its temperature. The surface of the Sun at around 5500°C shines in yellow, the human body at 37°C shines in the infrared at a wavelength of 10 µm (you can see it with infrared glasses even at night). All interstellar dust shines. If the grains are very cold they will only shine in the far infrared or radio. This is how we are able to study extremely cold dark clouds (at 10 Kelvin). When stars form in the clouds, a disk of dust and gas appears around them, in which furrows are revealed: these are planets in the process of forming, by collecting the material along their orbits, and leaving dust-free lanes.



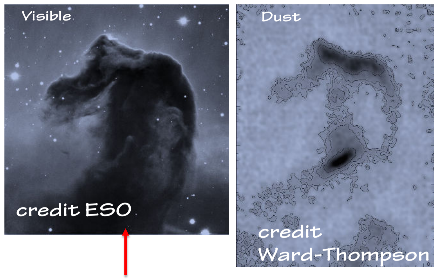
The disk of the T Tauri star, which is a star in the process of forming, is rich in dust and gas. Here is a radio image showing rings of dust, separated by furrows where planets are in the process of forming (false colors).

Credit ALMA.

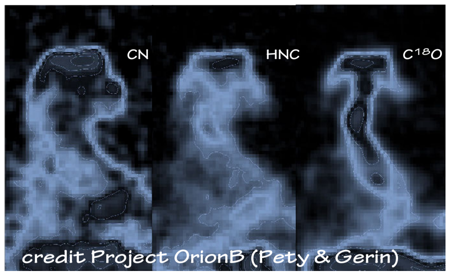


A star-forming region in Orion traced in radio waves emitted by different molecules (CO, HCO+, HCN, N2H+, C_2H, CN, CS,... in false colors).

Credit P. Gratier et al. 2021.



Answer: we see the stars, so it's an image in the visible!



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This booklet was written by Laurent Pagani of the Observatoire de Paris/CNRS and revised by Grażyna Stasińska of the Observatoire de Paris and Stan Kurtz (IRyA, Morelia, Mexico).

Cover image: Synchrotron emission (radiation emitted by relativistic electrons moving in a magnetic field) of Jupiter seen at 20 cm wavelength by the VLA radio telescope. The emission reveals belts of electrons trapped in the magnetic field outside the planet (False colors), Credit NRAO/AUI/VLA.

To learn more about this collection and the topics presented in this booklet, visit http://www.tuimp.org

Translation: Stan Kurtz

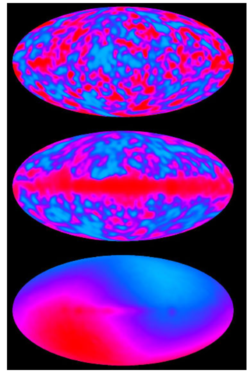
Light is the richest of the five celestial messengers (tuimp 43).

For a long time, all of Astronomy was based on what the eye could see, that is to say, on things that emit visible light – in particular, stars.

Are there other celestial bodies in the Universe than stars? Objects that do not emit in the visible but at other wavelengths? For example, in radio waves?

We now know how to build specialized telescopes to detect radio waves (tuimp 45).

This is how radio astronomy, which dates back less than a century, has revealed unexpected and fascinating worlds to us. This booklet presents a few examples. (See also tuimp 31 which presents a spectacular radio phenomenon: the emission of pulsars, which are a class of neutron stars).

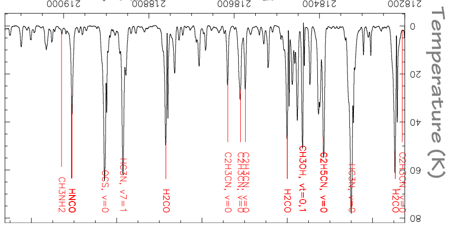


The sky seen in radio at 53 GHz by the COBE satellite. At the top, the cosmological radiation at 2.72 Kelvin (very close to absolute zero), blued in the direction of movement of the Milky Way. In the middle, the residual fluctuations when the effect of this motion is removed. Our Galaxy (in red) dominates. At the bottom, our Galaxy is subtracted. The images are in false colors. (Credit NASA)

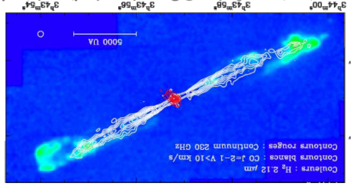
Molecules

Atoms can only emit light when their electrons change energy levels (except for hydrogen). These changes release a lot of energy and they generally emit in the visible, near infrared or ultraviolet. Molecules, assemblies of several atoms (at least two, such as CO, carbon monoxide, or three such as H_2O, water), also have the possibility of vibrating or rotating about themselves. This rotation requires very little energy and the changes of energy levels emit light as radio waves. We have thus been able to detect more than 300 different molecules in the Universe.

Stars being born often emit a pair of spectacular molecular jets, seen in certain molecules (CO, SO, SiO,...) that radio telescopes allow us to see.



Emission lines of molecules in the Orion nebula. Each peak indicates the presence of a molecule (some examples are labeled). Credit L. Pagani.



Radio emission of the CO molecule (in white) in the outgoing jets of a proto-star. The red contours show radio emission of warm dust, as in the T Tauri system (false colors). Credit C. Dougados.

The radio 'cosmological background'

The Universe appeared 13.8 billion years ago. It was very dense and hot and it immediately began to expand (see tuimp 12). Since then, the energy it contained has been diluted in an increasingly large volume of space and the very energetic light of the beginning has given way to radiation at 2.72 Kelvin. This very cold radiation is only visible by its isotropic radio emission. As the Earth, the Sun and our Galaxy move, they modify the apparent frequency of this emission, and we see it shift towards the blue in the direction we are moving and shift towards the red in the opposite direction. Measuring this shift allows us to know our overall direction and speed of movement, which is 600 km/s (the Earth moves at 30 km/s around the Sun). The residual fluctuations in the cosmic background radiation reveal the embryos of the large structures that have formed in the Universe.