

Little Red Dots



James Webb Space Telescope

Launched in 2021

Wavelength Coverage: 0.6 - 28.5 microns (this is the Infrared Band)

Diameter of primary mirror: 6.5 meters

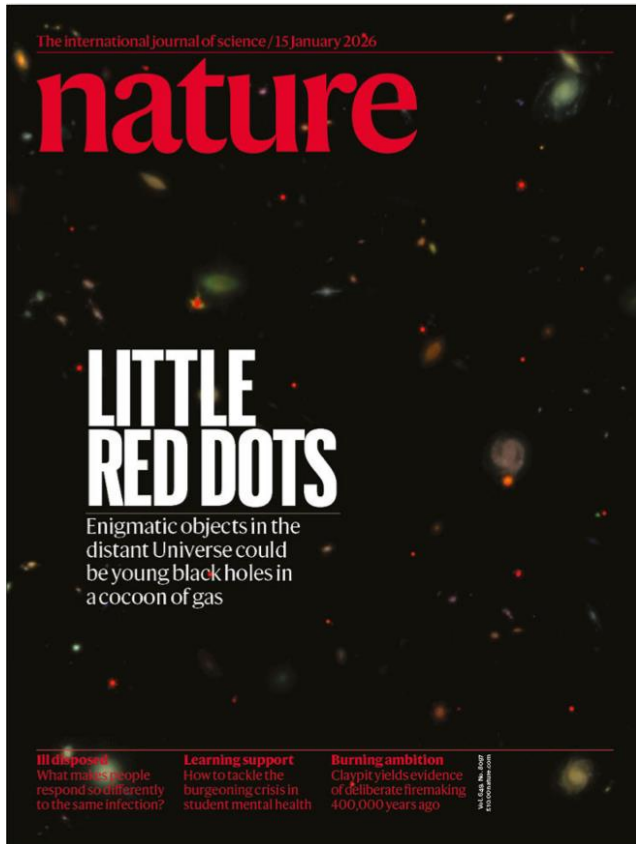
Designed to study the early universe

Has revealed unexpected populations of compact high-redshift sources





Discovery of Little Red Dots



Observations with the James Webb Space Telescope (JWST) show numerous, very bright, and extremely compact red points. These are now called Little Red Dots (LRDs).

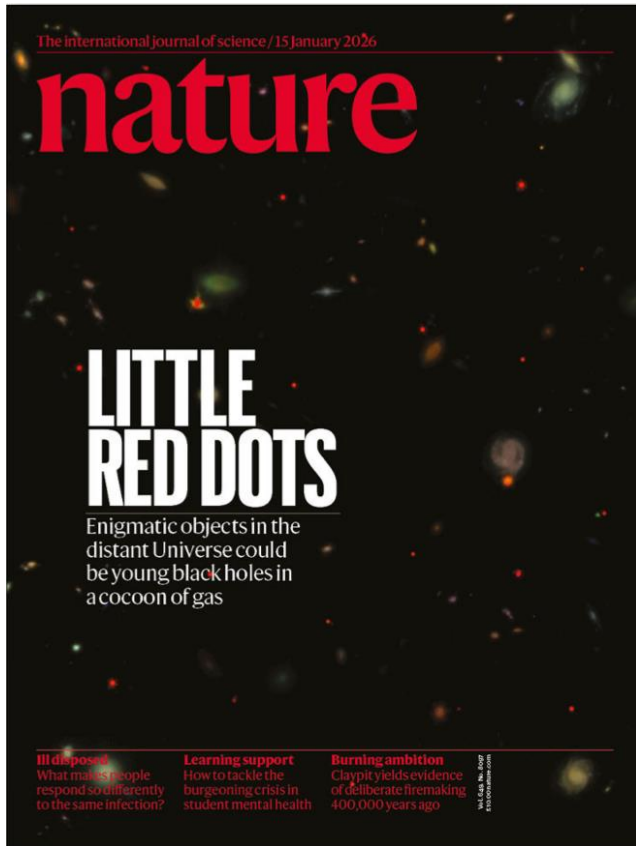
Many of them were formed just 600 million years after the Big Bang. By 1.5 billion years after the Big Bang, they mostly disappear.

Little Red Dots may be a new class of objects at redshifts $z = 4-8$.

Recent studies have proposed that LRDs might be quasi-stars (aka black hole stars), a concept first proposed ~20 years ago.

LRDs are red for two main reasons. Part of their red color is due to cosmological redshift, and the rest is due to reddening.

Little Red Dots: Why are they interesting?

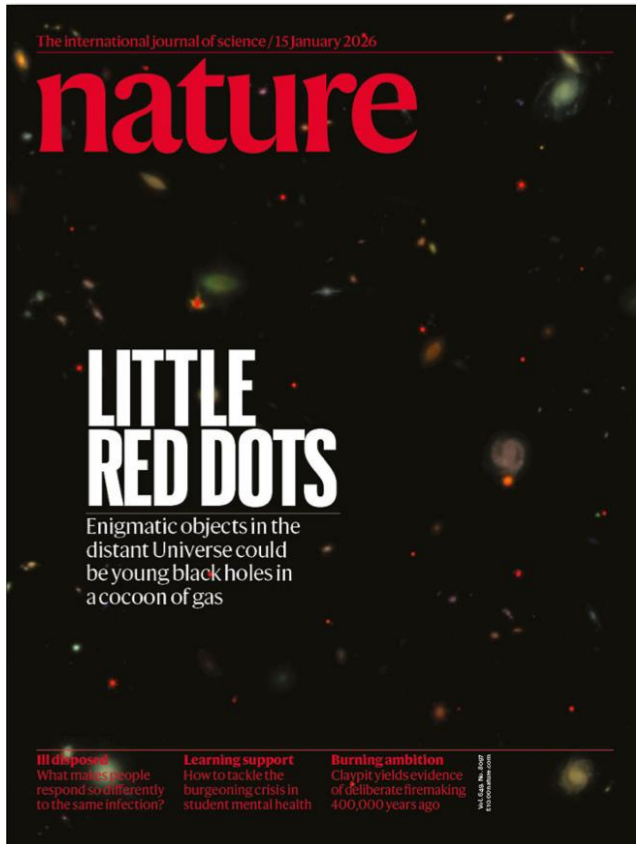


Appear too massive and luminous for normal early galaxies

May contain rapidly growing black holes

Challenge existing models of early galaxy formation

Discovery of Little Red Dots



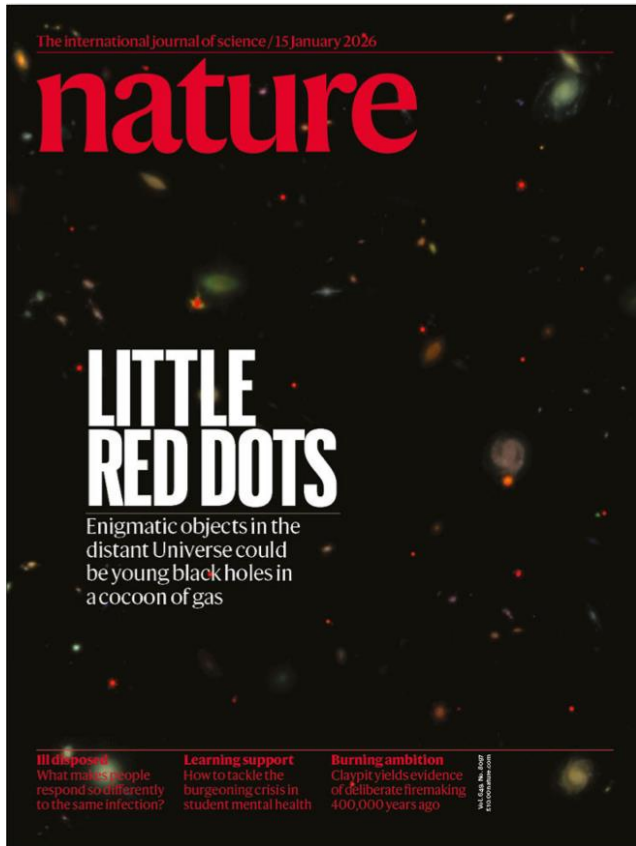
LRDs appear to be red point sources enshrouded and surrounded by blue star-forming clumps. (Jorjyt Matthee of the Institute of Science wrote one of the first scientific papers on the dots and he gave them the name Little Red Dots.)

The JWST is designed to be sensitive to the mid-infrared light and can easily detect them. HST can't see that light.

One key aspect of LRDs is that their spectra typically contain a strong **Balmer Break** (continuum discontinuity at $3646 \text{ \AA}$).

This suggests that there must be a large fraction of electrons in the surrounding hydrogen in level $n = 2$, and nearby bright UV sources (ie, young hot A stars) that can ionize the H atoms.

Nature of Little Red Dots



Are LRDs dusty starbursts? Are they shrouded active galactic nuclei? Are they something new instead? Or all of the above?

LRDs show no evidence of X-ray emission, which is common for black holes, or of the kind of light that we know surrounds other dust-reddened active galactic nuclei.

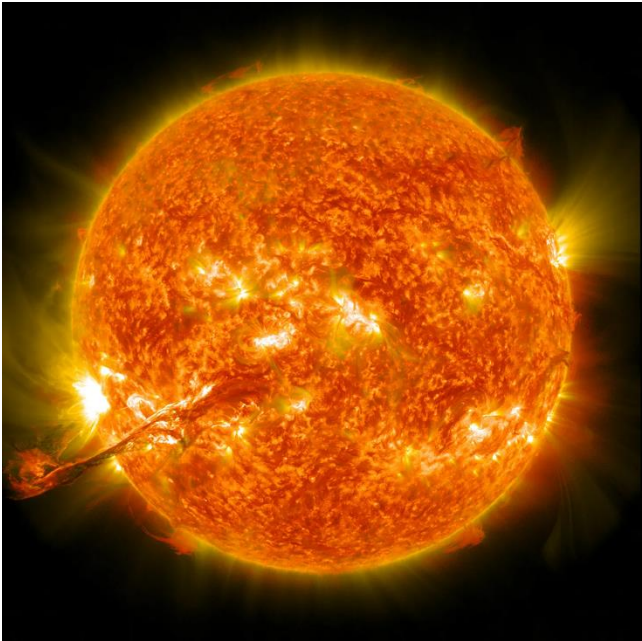
Kohei Inayoshi, an astrophysicist at the Kavli Institute for Astronomy and Astrophysics at Peking University, calculated that a cloud of gas in front of a black hole would produce a signature similar to that of the LRD light. “That kind of killed the idea that these are massive galaxies,” Kocevski says.

QUASI-STARS

Astrophysicist Mitch Begelman proposed that “Quasi-Stars” could form within hot clouds of gas, which would quickly collapse to ignite a gargantuan star that undergoes nuclear fusion for a short time. Within a few million years, after its supply of hydrogen burns out, the core contracts, implodes, and forms a black hole.

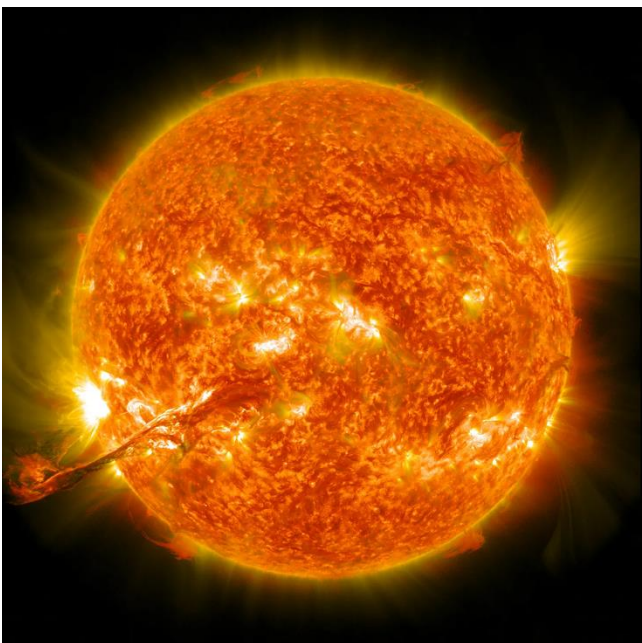
The black hole would be in the center of the quasi-star, so it is releasing energy, but not through nuclear fusion”—in other words, it’s shining because the black hole is gobbling gas, instead of a stellar furnace powering the glow.

Quasi-stars could have masses that are a million times the mass of the sun.



QUASI-STARS

Do black hole stars represent an early phase of black holes in the universe?



If LRDs are black hole stars they could help solve a mystery about how the large ones formed early in the universe.

Most models of black hole growth can't produce SMBHs in the early universe from stellar-mass black holes.

Direct Collapse Black Holes



Direct collapse black holes (DCBHs) are high-mass black hole seeds (black holes that will later accrete to form supermassive black holes) **that form from the direct collapse of a large amount of gas.**

They are putatively formed at redshifts $z=15\text{--}30$, when the Universe was about 100–250 million years old. Proposed masses of DCBHs range from 10^4 to 10^5 solar masses.

Direct Collapse Black Holes



The environmental physical conditions to form a DCBH (as opposed to a cluster of stars) are the following:

1. Metal-free gas (gas containing only hydrogen and helium).
2. Atomic-cooling gas.
3. Sufficiently large flux of Lyman–Werner photons, in order to destroy hydrogen molecules, which are very efficient gas coolants.

These conditions are necessary to avoid gas cooling and fragmentation of the primordial gas cloud, which would lead to star formation.

LRDs, precursors to supermassive black holes

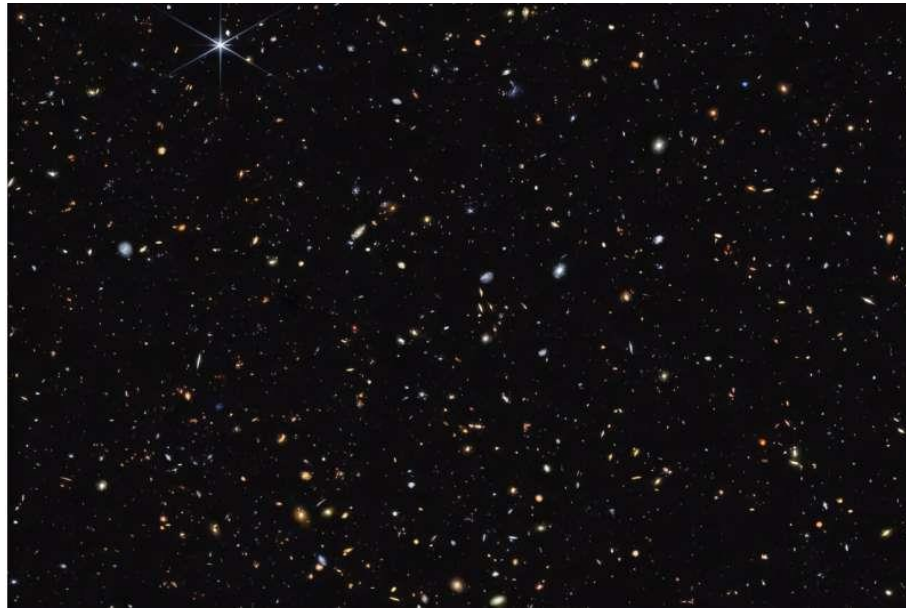


Several scientists think that LRDs are a short-lived, efficient growth phase in the early lives of supermassive black holes.

LRDs may also have contributed to the reionization of the universe during cosmic dawn, a turning point sometime between 50 million and 100 million years after the Big Bang, when the first stars ignited.

UV light from these first stars is thought to have reionized the universe's neutral hydrogen (epoch of reionization). LRDs may have played an important role in reionization.

LRDs from spinning dark matter halos?



Fabio Pacucci and Abraham (Avi) Loeb of the CfA, along with his colleagues, argue that **LRDs could have formed in dark matter halos that spin very slowly.**

These low-spin halos would naturally create extremely compact galaxies.

This hypothesis also explains why luminous dots are relatively rare: they account for only 1% of the abundance of typical galaxies.

As the universe evolves, dark matter halos grow larger and acquire more angular momentum, making it harder for them to form compact, low-spin galaxies.

LRDs: Spectroscopic Clues?

Broad H α emission seen in several sources

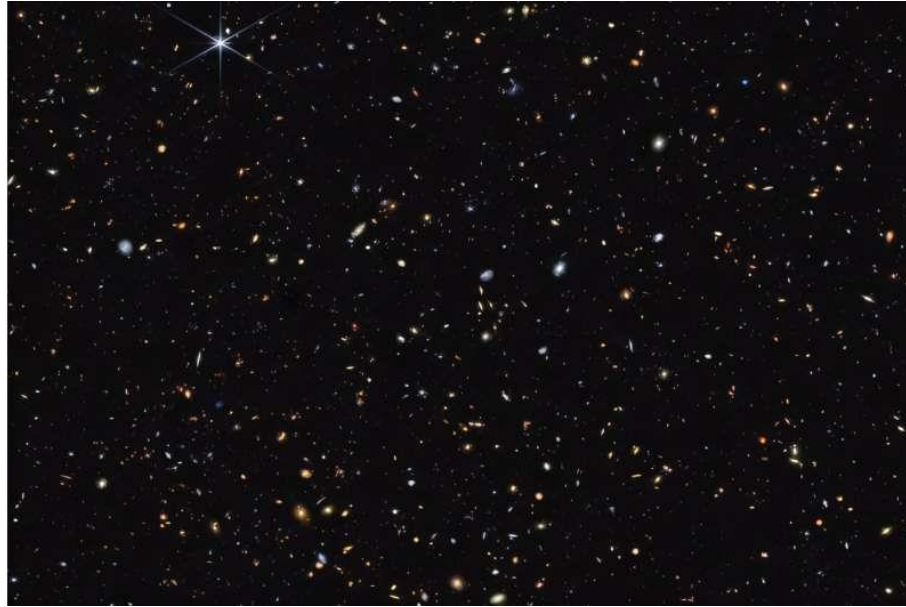
High line widths ($\sim 1000\text{--}3000$ km/s)

Suggests accretion onto massive black holes

However, interpretation is still debated



Mass of LRDs?



A top priority in future observations is determining how massive the Little Red Dots are, which will help scientists determine what types of objects they could be and whether they might be many different things at once. Current methods for measuring black holes fail for the dots

LRDs: Future Observations

Deeper JWST spectroscopy

X-ray observations to detect AGN activity

ALMA observations of gas and dust

Improved theoretical modeling

