Show Me the Planets!

*NASA’s Search for Exoplanets and for Life in our Galaxy*

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There Are More Planets than Stars

“And on those other worlds, are there beings who wonder as we do?”

- Carl Sagan
ex·o·plan·et
[ˈeksɔˌplanət]
a planet which orbits a star outside our solar system
NASA Highlights

Show You the Exo Planets!

Search for Life in our Galaxy

Explore!

On the Brink of a New World: Outer Space!
NASA Highlights
Where’s NASA?
How is NASA Organized?

Mission Directorates:

• Human Exploration and Operations
• Science
• Space Technology
• Aeronautics Research
NASA Exploration Campaign

- LRO (2009)
- ARTEMIS (2010)
- ISS—Sustainable Low-Earth Capability (2000–)
- ORION SPACECRAFT 2020
- POWER & PROPULSION ELEMENT 2022
- ORION CREWED EXPLORATION
- GATEWAY IN LUNAR ORBIT 2026
- ADVANCED EXPLORATION LANDER 2026

Key Dates:
- 2018
- 2022
- 2026
NASA Key Science Themes

Discovering the Secrets of the Universe

Searching for Life Elsewhere

Safeguarding and Improving Life on Earth
Science Mission Directorate

Science by the NUMBERS

TECHNOLOGY INNOVATION
~$400M Invested Annually

RESEARCH
~10,000 U.S. Scientists Funded
~3,000 Competitively Selected Awards
~$600M Awarded Annually

SPACERCRAFT
105 Missions
85 Spacecraft

SMALLSATS/CUBESATS
31 Science Missions
24 Technology Demos

SOUNDING ROCKETS
16 Science Missions
3 Tech/Student Missions

EARTH-BASED INVESTIGATIONS
25 Major Airborne Missions
8 Global Networks

BALLOONS
13 Science Payloads
1 HASP with up to
12 student experiments
Parker Solar Probe
A NASA Mission to Touch the Sun
New Horizons at Ultima Thule

“Beyond the Borders of the Known World”
GRACE Follow-On
Tracking Earth’s Water Movement across the Whole Planet

GRACE Data 2002–2017
give the Red Planet its first thorough checkup since it formed 4 billion years ago

InSight Landing on Mars
November 2018
Voyager 2 Enters Interstellar Space
Outliers

The Story of Success

Malcolm Gladwell

Author of David and Goliath
Two Recent Cube Sats

ASTERIA
Arcsecond Space Telescope

MarCO
Mars Cube One
Space Launch System
James Webb Space Telescope

2021 Launch
Mars 2020
July 2020 Launch
Jet Propulsion Laboratory
Pasadena, California
Show Me the Planets!
The Early Exoplanet Explorers
How Many Exoplanets Are Confirmed?
Mamajek’s Law
Doubling Time for Confirmed Exoplanets

Credit: NASA/JPL
Eric Mamajek
How Are Exoplanets Named?
Seeing an Exoplanet Is as Hard as...
How Are Exoplanets Discovered?
Two Popular Methods

Doppler Spectroscopy
(Radial Velocity)

Transit
Microlensing Method
Another Way to Find Exoplanets
Where Are the Exoplanets?
When Were Exoplanets Discovered?

The History of Exoplanet Detection

Mass (Earth masses)

Period (years)

Hugh Osborn

Credit: Hugh Osborn
Kepler Mission: Three Key Results

1. There are more planets than stars in the galaxy

2. Small planets are common

3. Small planets in the Habitable Zone are common
A Familiar Habitable Zone
Average Number of Planets per Star

Planet Size (Earth=1)

Missing from our solar system
The Fulton Gap

Credit: Fulton et al. 2017
A rendering of newly discovered Earth-size planets orbiting a dwarf star named Trappist-1 about 40 light-years from Earth. Some of them could have surface water.
Trappist-1 System
The Richest Set of Earth-sized Planets Ever Found
Exoplanet Travel Bureau
Transmission Spectroscopy

Sunny with a Chance of Clouds

Primary Eclipse
- Measure size of planet
- See star’s radiation transmitted through the planet atmosphere

Secondary Eclipse
- See planet thermal radiation disappear and reappear
- Learn about atmospheric circulation from thermal phase curves

Starlight filters through the planet’s sodium-rich atmosphere.

Transmission spectroscopy only probes terminator of planet.
TESS
Planet
Predictions
ExoComm
Exploring a Galaxy of Worlds while Inspiring Our Own
“Exoplanet Earth” Edition
We Are a Leo Sun from Trappist-1
The Search for Life in Our Galaxy
Are We Alone?
Do We Understand Life?

NASA/Joyce Definition:
“A self-sustaining chemical system capable of Darwinian evolution”
Traits Common to Life on Earth

- Ordered structure
- Reproduction
- Growth and development
- Response to environment
- Homeostasis
- Evolutionary adaptation
- Energy utilization
What Is Essential for Life?

Source of Energy

Essential Elements

Solvent to Host Chemical Reactions
Extreme Environments Support Life
Exploring the Red Planet
Ocean Worlds

- Europa
- Callisto
- Titan
- Triton
- Ganymede

Shown to scale
Search for Technosignatures
Probing the Atmospheres of Exoplanets
Habitable Zone
Exoplanets in the Habitable Zone
HR 8799
Spectra of Our Solar System Planets
“Blue of the sky” measures total amount of atmosphere.

“Vegetation jump” indicates presence of land plants.

Carbon dioxide suggests possible volcanic activity.

Methane indicates presence of anaerobic bacteria.

Oxygen and ozone were produced by living organisms.

Water vapor suggests habitability.

Credit: M. Turnbull
Starlight Suppression

External Occulters (Starshades)

Internal Occulters (Coronagraphs)
Starshade (External Occulter)
Starshade Inner Disk Deployment
Starshade Optical Shield
A Simulated Image
Spectra Reveals the Type of Planet
Exoplanet Missions

- **NASA Missions**
  - Hubble
  - Spitzer
- **Non-NASA Missions**
  - Kepler
  - CoRoT
  - Gaia
  - CHEOPS
  - TESS
  - JWST
  - PLATO
  - WFIRST
  - LUVOIR
  - Starshade Rendezvous
  - HabEx
  - OST

**Ground Telescopes with NASA participation**
- W. M. Keck Observatory
- Large Binocular Telescope
- WIYN
- SMARTS 1.5m

**Partnerships**
- NASA/ESA Partnership
- NASA/ESA/CSA Partnership
- CNES/ESA
- ESA/Swiss Space Office
- NSF Partnership (NN-EXPLORE)
- 2020 Decadal Survey Studies
Exoplanet Mission Concepts

Large Scale

- Habitable Exoplanet Observatory
- Origins Space Telescope
- LUVOIR

Medium Scale Concepts

- EarthFinder
- Starshade Rendezvous
- Life-Finder Interferometer

Visionary

https://science.nasa.gov/astrophysics
**Tau Ceti e**

Likely Rocky Super-Earth Orbiting a Nearby Sun-like Star

Credit: F. Feng, University of Hertfordshire
“Astronomers think that many stars besides the sun have their own planetary systems, and that some of these planets may support some form of life”
Why Explore Exoplanets?
Explore!
Sagan Exoplanet Summer Workshop
Caltech, Pasadena CA

• Last Year: Did I really just find an Exoplanet?

• This Year: Astrobiology for Astronomers
On the Brink: Your Path to a New World!

- Canadian Space Agency
- Space Industry
- Universities: small satellites, interdisciplinary programs
- US universities => institutions like the Jet Propulsion Laboratory
“All these worlds are yours”
- Arthur C. Clarke

On the Brink of a New World: Outer Space!
Acknowledgements

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