National Aeronautics and Space Administration

NASA and Open Source Software

Dr. Steve Crawford

Science Data Officer

Contributions by:
Demitri Muna, Estelle Stokes, Jazmine Wise, Zoe Jenkins, Alexandra Lockwood, Chelle Gentemann, Kevin Murphy, Katie Baynes, Yaitza Luna-Cruz, Elena Steponaitis, Amy (Uyen) Truong, Yvonne Ivey, Cyndi Hall, Isabella Martinez, Paige Martin, Rachel Paseka, Kevin Ward, Andi Thomas, and many more.

Agenda

- Software and NASA
- Recent Open Software Success
- Challenges with Open Software
- Open Source Science
- Opportunities

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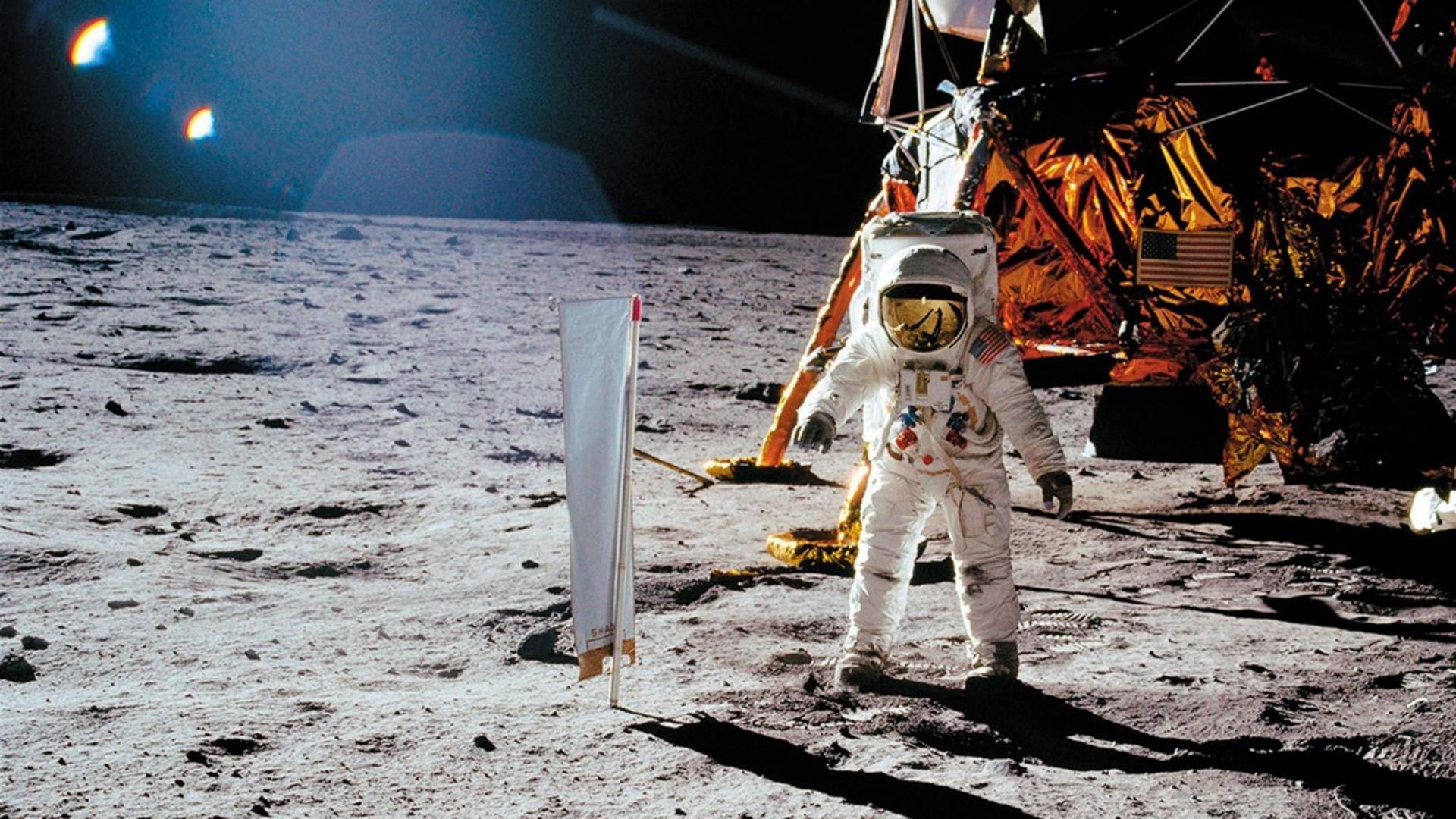
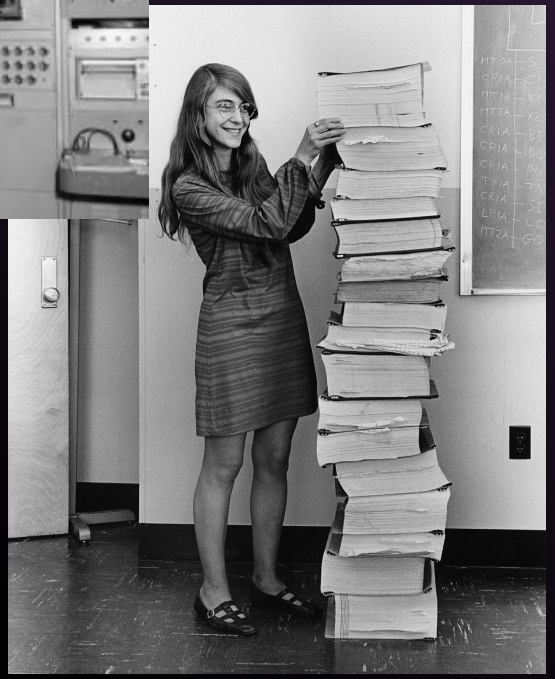


Apollo Software

```
SAPI  ASSEMBLE REVISION 001 OF AGC PROGRAM LMY99 BY NASA 2021112-061          16:27 JULY 14,1969  LNYAI

L       ATTITUDE MANEUVER ROUTINE                                    USER'S PAGE NO.

R0193                  ( 6    7    8)

R0194                                                                          *
R0196        INDEX REGISTER X1 MUST BE LOADED WITH THE COMPLEMENT OF THE STARTING ADDRESS FOR M1, AND
R0198                                                  *
R0199   LOADED WITH THE COMPLEMENT OF THE STARTING ADDRESS FOR M2.   THE ROUTINE USES THE FIRST 20 LOC
R0201   DOWN LIST.  THE FIRST ELEMENT OF THE MATRIX APPEARS IN PDO.  PUSH UP FOR M .
R0203                                                                    8
R0205
R0206        TRANSPOS
R0207        --------

R0208        THIS ROUTINE TRANSPOSES A 3X3 MATRIX AND LEAVES THE RESULT IN THE PUSH DOWN LIST. I.E..
R0210
R0211         *       * T
R0212         M   =   M1

R0213   INDEX REGISTER X1 MUST CONTAIN THE COMPLEMENT OF THE STARTING ADDRESS FOR M1.  PUSH UP FOR THE
R0215                                                  *
R0216   SEQUENT COMPONENTS OF M.   THIS SUBROUTINE ALSO USES THE FIRST 20 LOCATIONS OF THE PUSH DOWN L
R0218
R0219        CDU TO DCM
R0220        ----------

R0221        THIS SUBROUTINE CONVERTS THREE CDU ANGLES IN T(MPAC) TO A DIRECTION COSINE MATRIX (SCALED BY 2) RELATING
R0223   THE CORRESPONDING S/C ORIENTATIONS TO THE STABLE MEMBER FRAME.  THE FORMULAS FOR THIS CONVERSION ARE
R0225
R0226         M   =   COSY  COSZ
R0227          0

R0228         M   =   -COSY  SINZ  COSX  +  SINY  SINX
R0229          1

R0230         M   =   COSY  SINZ  SINX  +  SINY  COSX
R0231          2

R0232         M   =   SINZ
R0233          3

R0234         M   =   COSZ  COSX
R0235          4

R0236         M   =   -COSZ  SINX
R0237          5

R0238         M   =   -SINY  COSZ
R0239          6

R0240         M   =   SINY  SINZ  COSX  +  COSY  SINX
R0241          7
```

Mary W. Jackson worked at the Langley Research Center.



Margaret Hamilton with the Apollo software she and her team at MIT produced.

Draper Laboratory; restored by Adam Cuerden

Virtual AGC Project, MIT Museum, https://github.com/chrislgarry/Apollo-11

Sharing our NASA Discoveries since 1958

National Aeronautics and
Space Act of 1958,
As Amended

The National Aeronautics
and Space Administration

Section 203(a) of the law that created NASA notes…

FUNCTIONS OF THE ADMINISTRATION

Sec. 203. (a) The Administration, in order to carry out the purpose of this Act, shall–

(1) plan, direct, and conduct aeronautical and space activities;

(2) arrange for participation by the scientific community in planning scientific measurements and observations to be made through use of aeronautical and space vehicles, and conduct or arrange for the conduct of such measurements and observations;

(3) provide for the widest practicable and appropriate dissemination of information concerning its activities and the results thereof;

(4) seek and encourage, to the maximum extent possible, the fullest commercial use of space; and

(5) encourage and provide for Federal Government use of commercially provided space services and hardware, consistent with the requirements of the Federal Government.[10]

NASA Mission Directorates

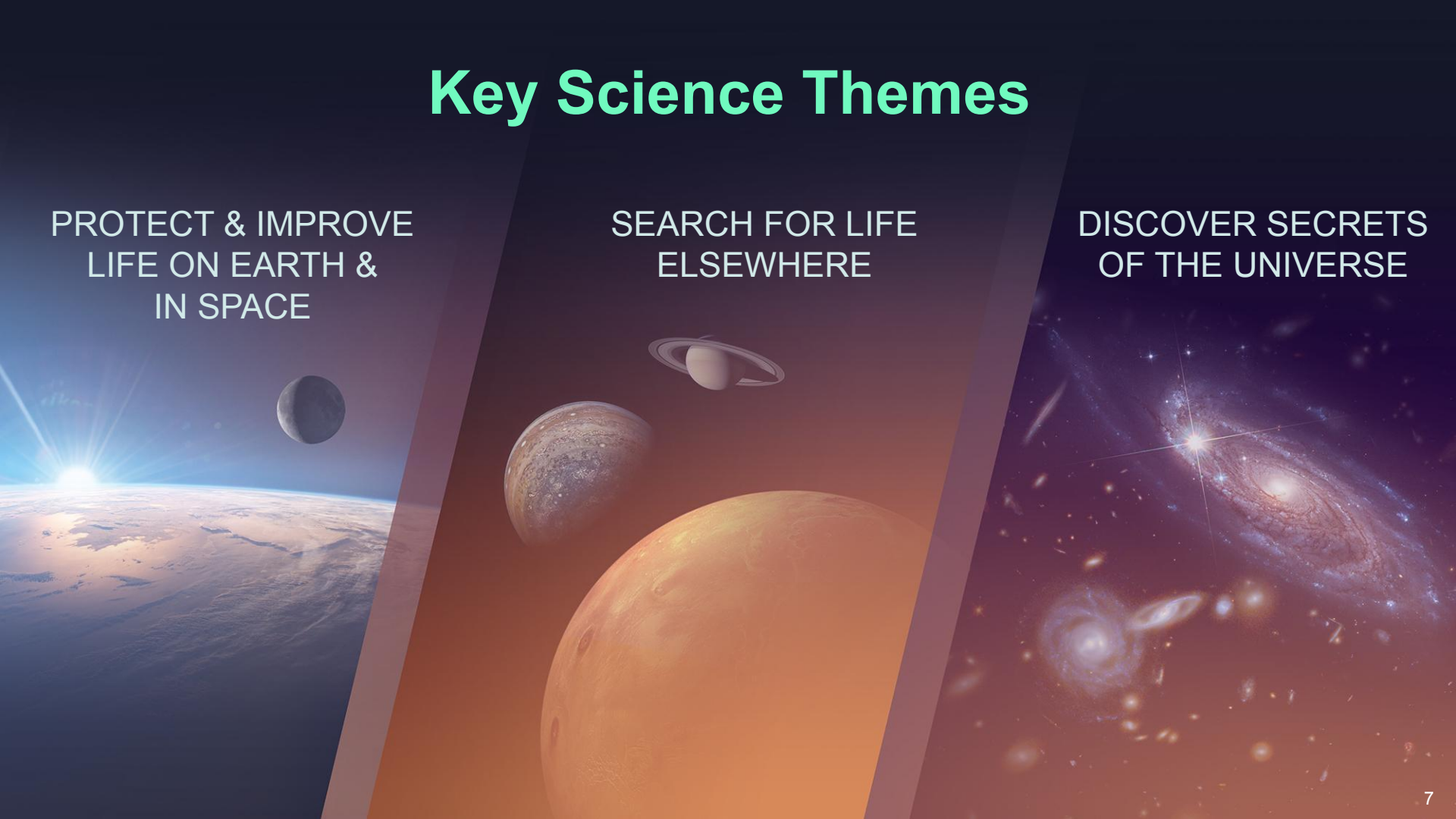
Exploration Systems Development Mission Directorate (ESDMD)	**Space Operations Mission Directorate** (SOMD)	**Science Mission Directorate** (SMD)	**Space Technology Mission Directorate** (STMD)	**Aeronautics Research Mission Directorate** (ARMD)

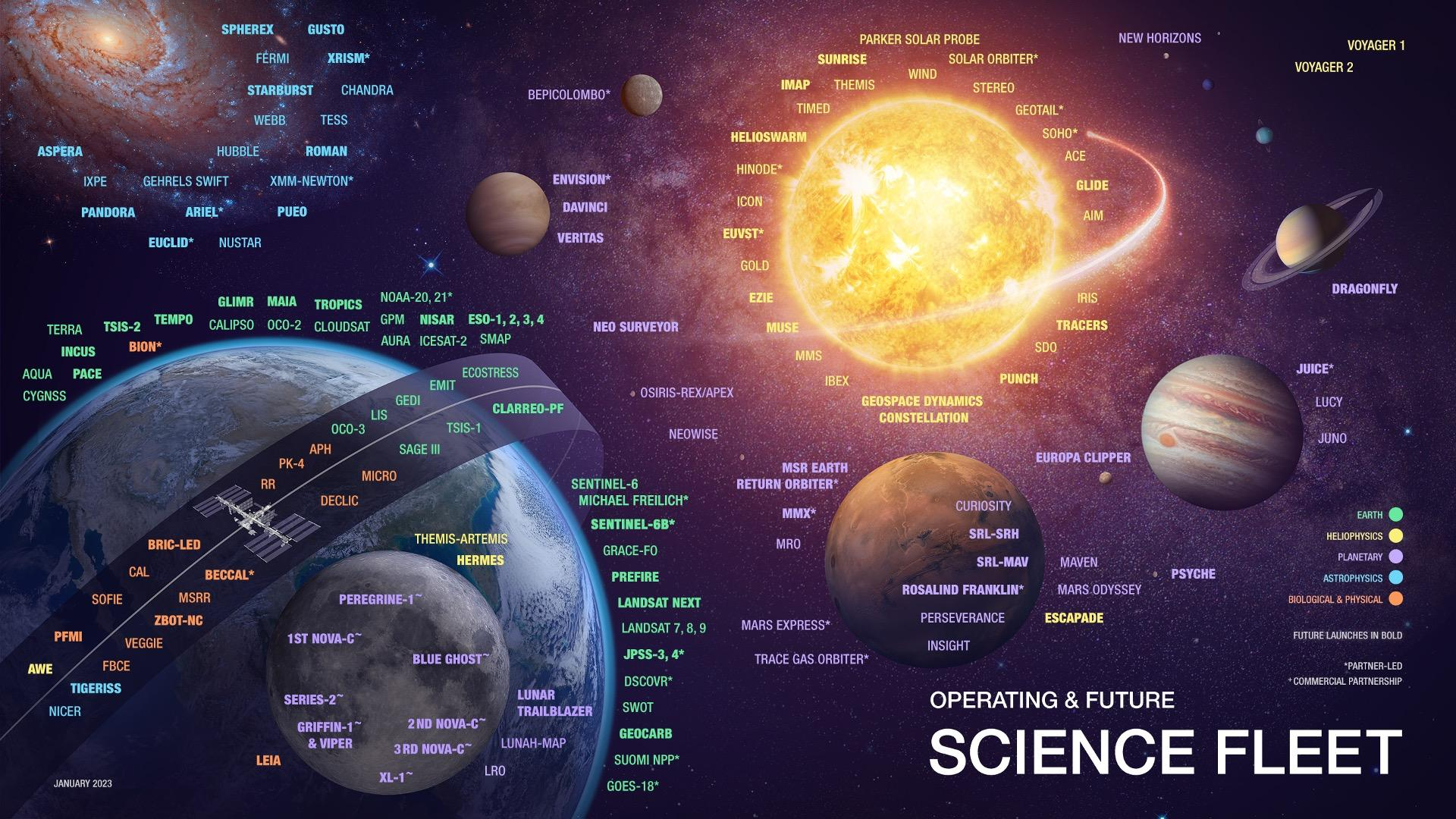
Key Science Themes

PROTECT & IMPROVE LIFE ON EARTH & IN SPACE

SEARCH FOR LIFE ELSEWHERE

DISCOVER SECRETS OF THE UNIVERSE




SPHEREX
GUSTO
FERMI
XRISM*
STARBURST
CHANDRA
WEBB
TESS
ASPERA
HUBBLE
ROMAN
IXPE
GEHRELS SWIFT
XMM-NEWTON*
PANDORA
ARIEL*
PUEO
EUCLID*
NUSTAR
BEPICOLOMBO*
ENVISION*
DAVINCI
VERITAS
PARKER SOLAR PROBE
NEW HORIZONS
VOYAGER 1
VOYAGER 2
SUNRISE
SOLAR ORBITER*
WIND
IMAP
THEMIS
STEREO
TIMED
GEOTAIL*
HELIOSWARM
SOHO*
ACE
HINODE*
GLIDE
ICON
AIM
EUVST*
GOLD
DRAGONFLY
GLIMR
MAIA
TROPICS
NOAA-20, 21*
TERRA
TSIS-2
TEMPO
CALIPSO
OCO-2
CLOUDSAT
GPM
NISAR
ESO-1, 2, 3, 4
AURA
ICESAT-2
SMAP
NEO SURVEYOR
INCUS
BION*
EZIE
IRIS
AQUA
PACE
MUSE
TRACERS
CYGNSS
ECOSTRESS
EMIT
MMS
SDO
GEDI
OSIRIS-REX/APEX
IBEX
PUNCH
LIS
CLARREO-PF
GEOSPACE DYNAMICS CONSTELLATION
OCO-3
TSIS-1
NEOWISE
JUICE*
APH
SAGE III
LUCY
PK-4
JUNO
RR
MICRO
MSR EARTH RETURN ORBITER*
EUROPA CLIPPER
DECLIC
SENTINEL-6 MICHAEL FREILICH*
CURIOSITY
MMX*
SENTINEL-6B*
SRL-SRH
BRIC-LED
THEMIS-ARTEMIS
MRO
GRACE-FO
SRL-MAV
MAVEN
HERMES
CAL
PREFIRE
ROSALIND FRANKLIN*
PSYCHE
BECCAL*
LANDSAT NEXT
MARS ODYSSEY
SOFIE
MSRR
PEREGRINE-1~
LANDSAT 7, 8, 9
PERSEVERANCE
ESCAPADE
ZBOT-NC
PFMI
1ST NOVA-C~
JPSS-3, 4*
MARS EXPRESS*
INSIGHT
VEGGIE
BLUE GHOST~
DSCOVR*
TRACE GAS ORBITER*
AWE
FBCE
SWOT
LUNAR TRAILBLAZER
TIGERISS
SERIES-2~
GEOCARB
NICER
2ND NOVA-C~
GRIFFIN-1~ & VIPER
SUOMI NPP*
LUNAH-MAP
3RD NOVA-C~
LEIA
LRO
XL-1~
GOES-18*
EARTH
HELIOPHYSICS
PLANETARY
ASTROPHYSICS
BIOLOGICAL & PHYSICAL
FUTURE LAUNCHES IN BOLD
*PARTNER-LED
+COMMERCIAL PARTNERSHIP
JANUARY 2023
OPERATING & FUTURE
SCIENCE FLEET

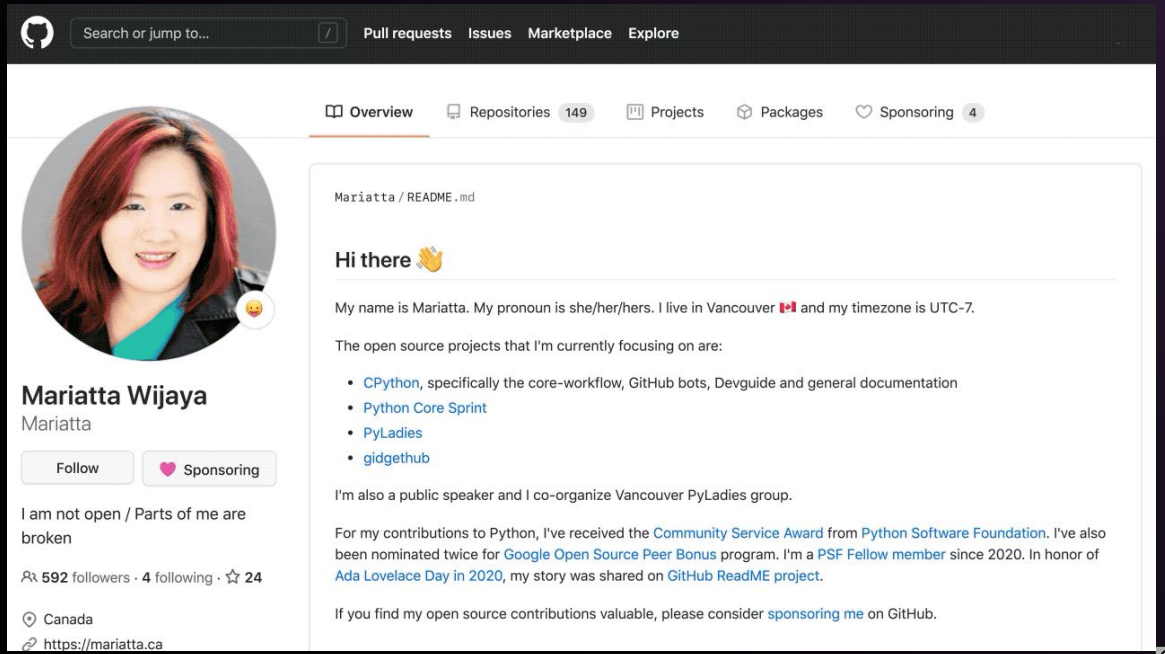
Ingenuity made its first flight in 2021 as part of the Mars Perseverance.

F Prime, its Open Source Flight Control software, was released by JPL in 2017.

Open Source Drives NASA Missions

To celebrate Ingenuities first flight, GitHub and JPL recognized the more than 12,000 people that contributed to Open Source dependencies of the project

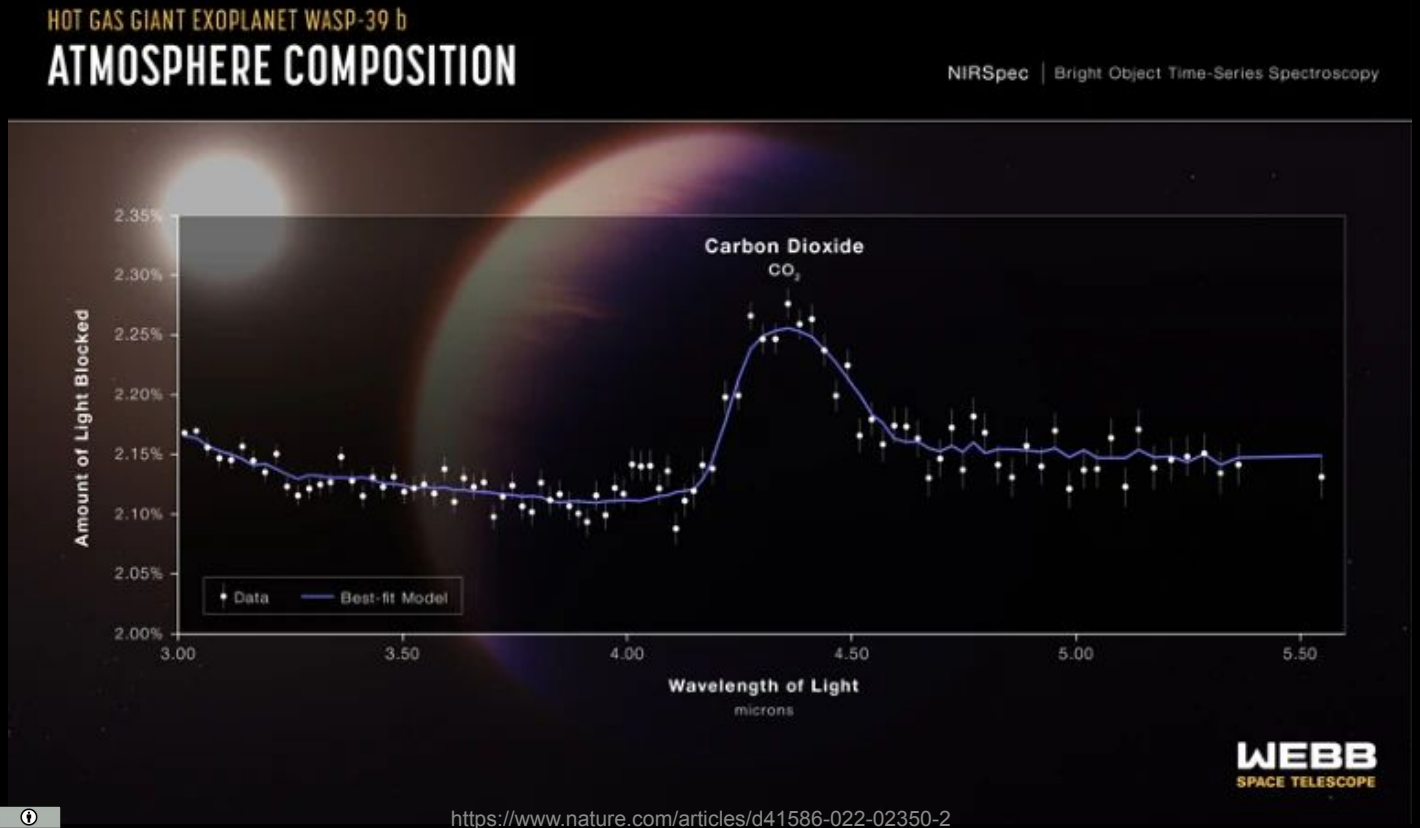
https://github.com/readme/featured/nasa-ingenuity-helicopter



NASA
esa
CSA ASC

Webb – A Product Of The United States, Europe, and Canada

First evidence of CO2 in exoplanet atmosphere

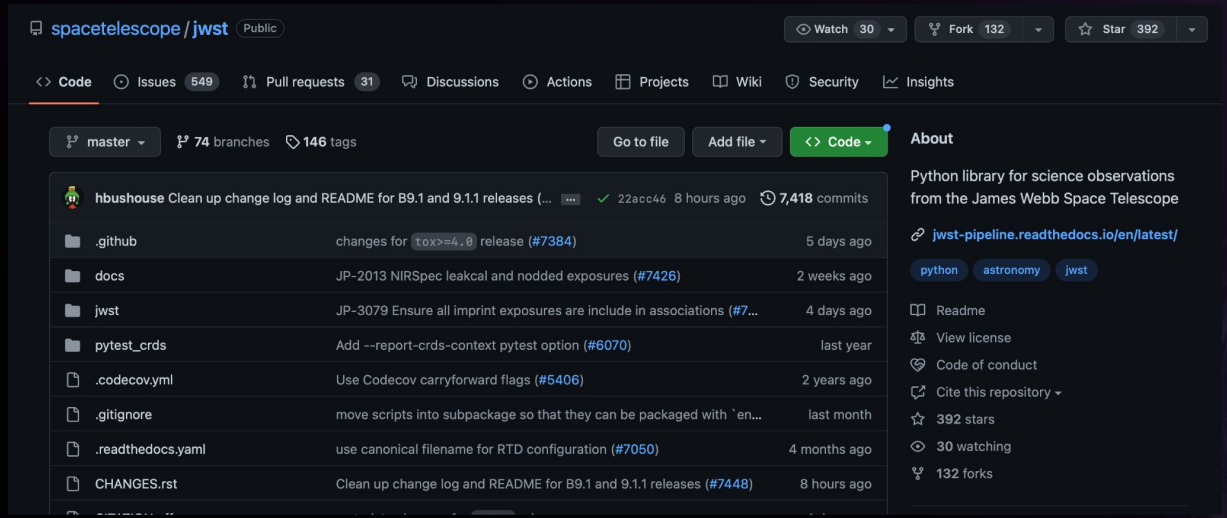


https://www.nature.com/articles/d41586-022-02350-2

"NASA's open science guiding principles are centered in our Early Release Science work, supporting an inclusive, transparent, and collaborative scientific process."

– co-author
Dr. Natasha Batalha

JWST Calibration Software



Developed openly on GitHub.

Enables scientists to test their projects.

Builds on the scientific Python environment and contributes back to the community.

https://github.com/spacetelescope/jwst

https://github.com/readme/featured/webb-telescope-astropy

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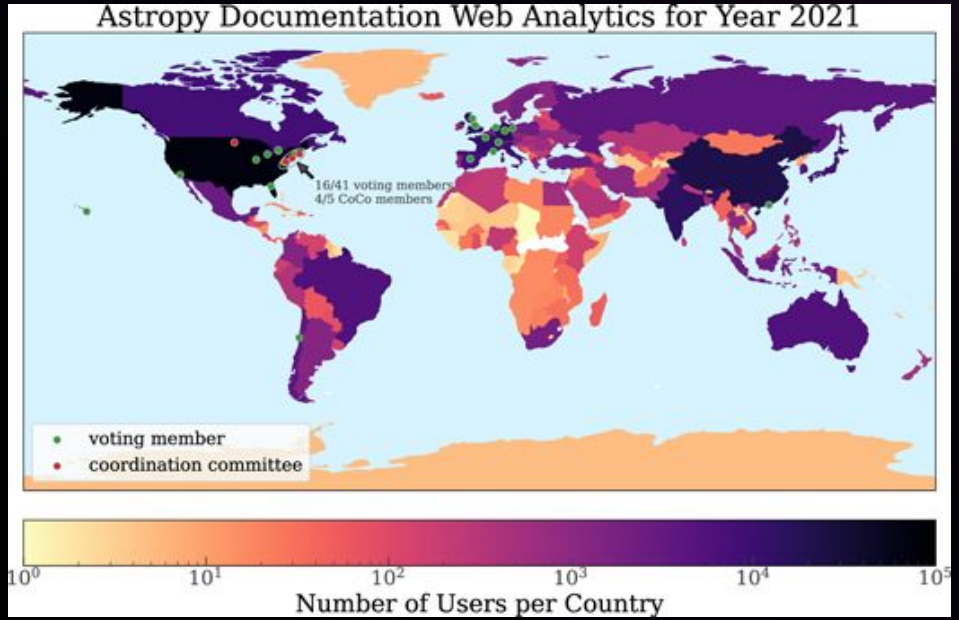
The Astropy Project



Astropy Collaboration et al. 2022

Common Python library for astronomy; builds on NumPy.

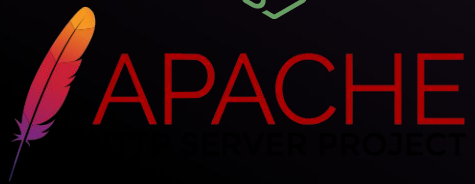
Started in 2011 from an astronomy and Python mailing list.

Original contributors include Hubble and Chandra Space Telescopes.

Has been cited over 10,000 publications.

https://www.astropy.org/

Open Source Used by NASA (A Small Sampling!)

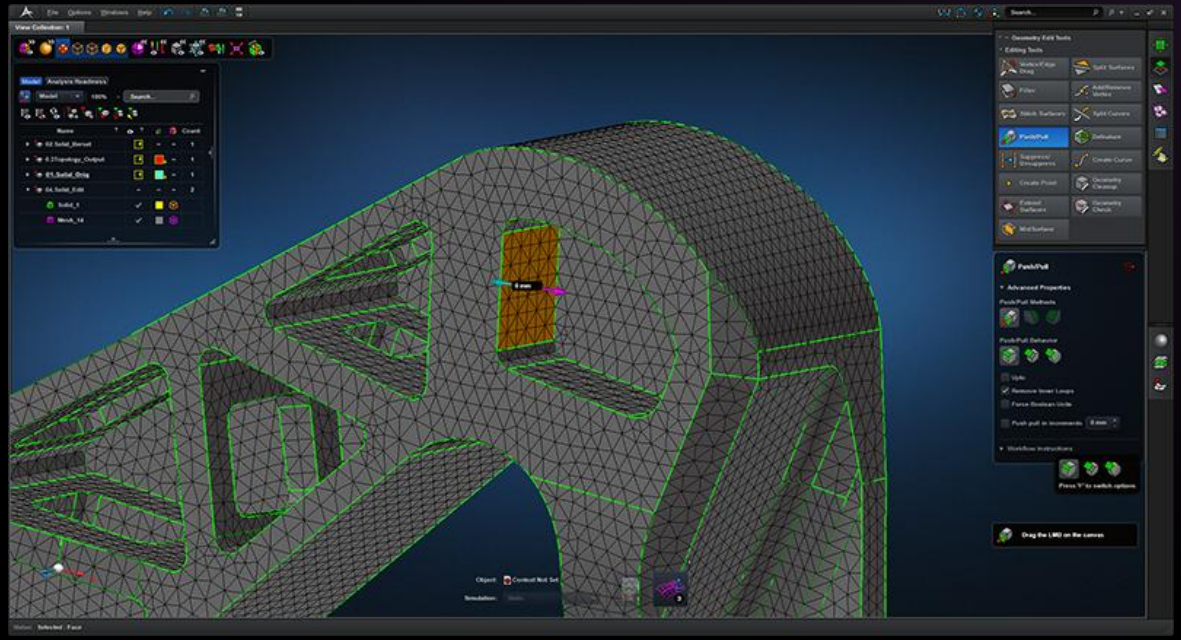


NASA Has a Wealth of Open Source Software

- das2 - space data visualization • http://das2.org
- Autoplot - used for analysis of fields & particle space data • http://autoplot.org
- Astrogeology - https://github.com/USGS-Astrogeology/ISIS3
- Astrogeology Planetary Input / Output (PLIO) • https://github.com/USGS-Astrogeology/plio
- PlanetaryPy - Python tools for Planetary Science • https://github.com/planetarypy
- NASA Ames Stereo Pipeline (ASP) • https://github.com/NeoGeographyToolkit/StereoPipeline
- MHEST - Mixing Height Estimation Toolbox • https://github.com/NASA-DEVELOP/MHEST
- NASA-DEVELOP - Earth observation • https://github.com/NASA-DEVELOP/dnppy
- VOCAL - visualize satellite data • http://nasa-develop.github.io/VOCAL/
- Space Telescope Science Institute code • https://github.com/spacetelescope

…this is just a small sampling!

NASTRAN



NASTRAN is a finite element analysis program that was originally developed for NASA in the late 1960s and publicly released in the 1970s.

NASTRAN source code is integrated in a number of different software packages, which are distributed by a range of companies.

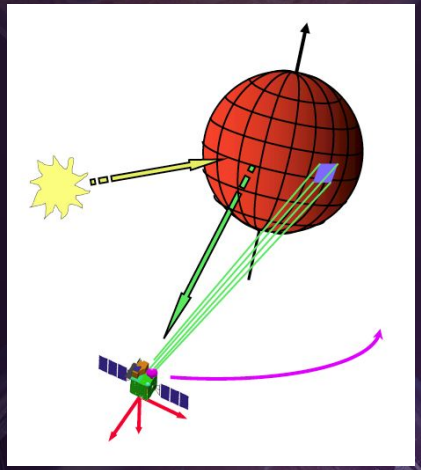
https://software.nasa.gov/software/LAR-16804-GS

NASA Spin Offs

openstack®

APACHE OODT

JPL SPICE Toolkit



S - Spacecraft ephemeris
P - Planet, satellite, comet, or asteroid ephemerides
I - Instrument information
C - Orientation information (“C matrix”)
E - Events information

SPICE can determine:

- positions & velocities of planets, satellites, comets, asteroids, spacecraft
- size, shape, orientation of planets, satellites, comets, asteroids
- orientation of a spacecraft and its moving structures
- instruments field-of-view location on a planet's surface or atmosphere

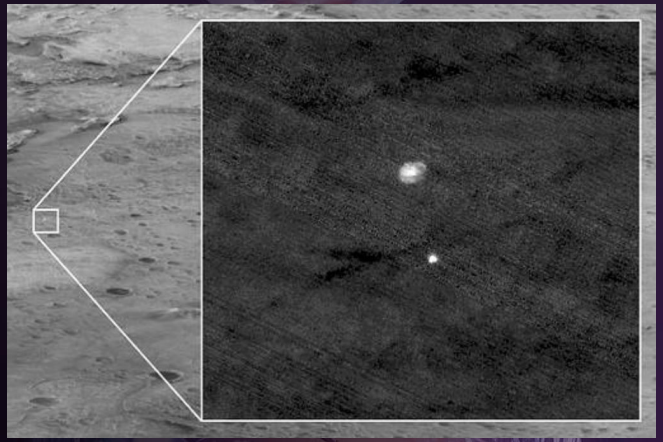
Interfaces for Java, C, FORTRAN, Matlab, IDL, Python. Open source since 1996.
Funded as part of the Planetary Data System.

https://naif.jpl.nasa.gov/naif/toolkit.html

SpiceyPy - Python Wrapper for SPICE Toolkit

Created by Andrew Annex, used by:

- Cassini
- Mars Reconnaissance Orbiter to capture an image of the Perseverance rover landing
- Parker Solar Probe
- Maven (Mars orbiter)
- Europa Clipper Mission
- Work to locate Kuiper Belt objects / New Horizons
- Used by ~80% of SPICE users
- Many missions using ISIS3 Astrogeology / USGS
- many more!



Perseverance rover descent stage

https://github.com/AndrewAnnex/SpiceyPy

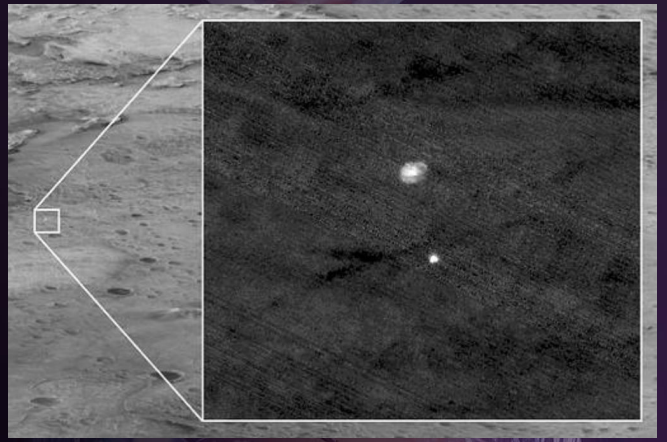
CC BY

SpiceyPy - Python Wrapper for SPICE Toolkit

SPICE's usage and audience was greatly extended beyond the authors' original vision because it was accessible.

SpiceyPy was started by Andrew as undergraduate (!) student working on the Cassini mission… "I wanted to use SPICE in Python."

Andrew continued development for two years *in his spare time* while no longer working as an astronomer.



Perseverance rover descent stage

(Don't worry; he's currently a postdoc at CalTech.)

Open source success! – heavily used by community, documented, full code coverage in testing, CI/CD, but…

… no direct funding, limited recognition (e.g. citations).

https://www.andrewannex.com

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Challenges

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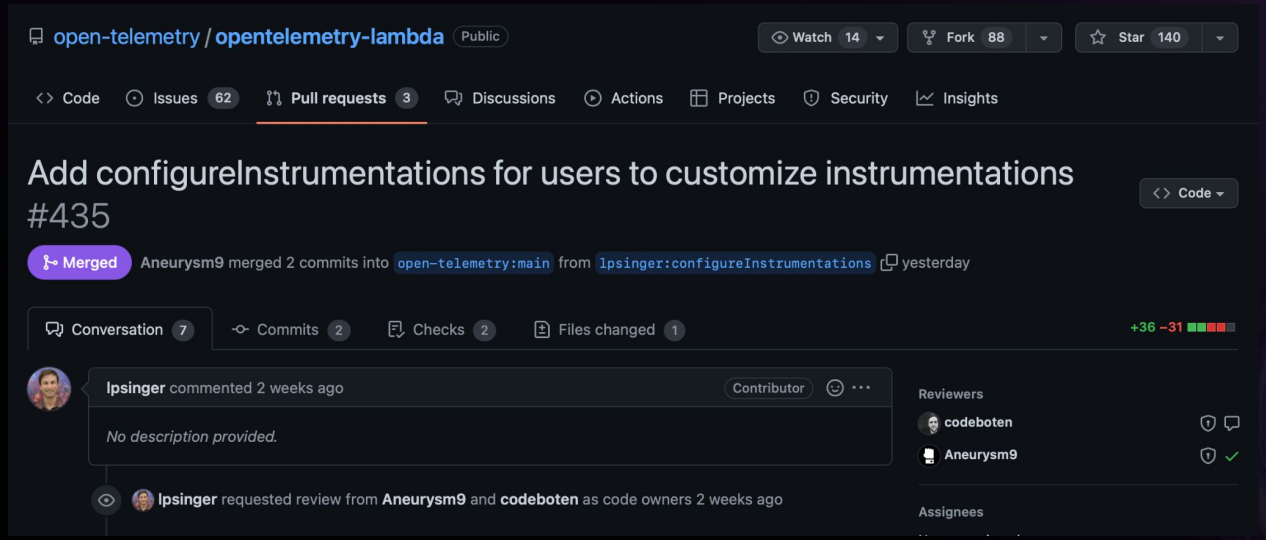
Contributing to Open Source



NASA has contributed to many open source projects…

…but that is often done on the side (not in an official capacity) or without clear instructions.

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Licensing Open Source

NASA created the NASA Open Source Agreement in 2003 to enable the release of software by civil servants…

…but it isn't widely used in the community, recognized by Free Software Foundation, and complicates the reuse of NASA software.

CC BY

Bureaucracy at NASA

daniel:// stenberg://
@bagder

I keep getting emails from NASA where they request I inform them about curl. They can land on Mars, sure, but I think they have some other issues left to sort out...

Good afternoon Daniel,

My name is [redacted] and I work for the NASA Commercial IT Acquisition Team. In compliance with Section 208 of the Further Consolidated Appropriations Act, 2020, Public Law 116-94, enacted December 20, 2019, I am required to obtain Country of Origin information from the Company that develops, produces, manufactures, or assembles any product defined as "Information Technology" by the Federal Acquisition Regulation (FAR).

Please provide an email response or a formal document (a PDF on company letterhead is preferred, but a simple statement is sufficient) specifically identifying the country, or countries, in which the **curl** is developed and maintained.

If the country of origin is outside the United States, please provide any information you may have stating that testing is performed in the United States prior to supplying products to customers.

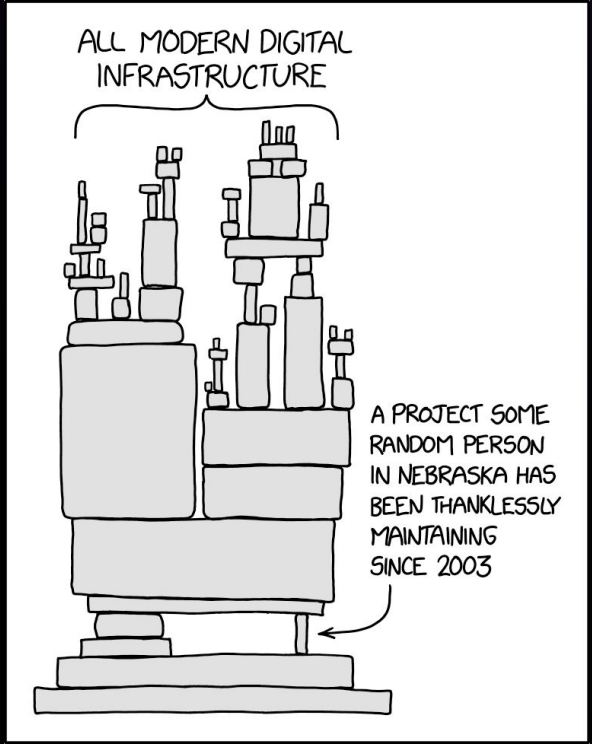
Additionally, if available, please identify all authorized resellers of the product in question.

4:44 PM · Apr 7, 2021

NASA has over 500 officially released open source packages but the process can be long.

NASA does not always engage well with the open source community.

Sustainability of Open Source



xkcd.com/2347 • Randall Munroe

Open source software has a range of support modes and sustainability is often an open question.

NASA needs reliable and secure software, especially for space operations.

SOME RIGHTS RESERVED

Open Source Science Initiative

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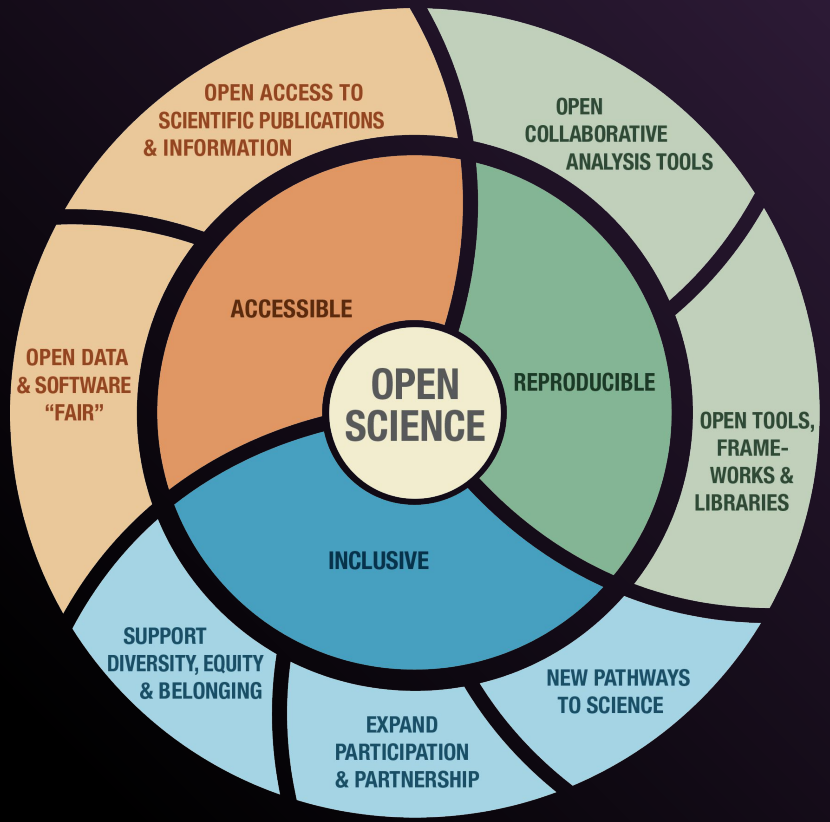
What is Open Science?

Open Science is the principle and practice of making research products and processes available to all, while respecting diverse cultures, maintaining security and privacy, and fostering collaborations, reproducibility, and equity.



https://open.science.gov/

Open-Source Science in Practice

- **Open** the entirety of the scientific process, ***from start to finish***
- **Broaden** community involvement in the scientific process
- **Increase** accessibility of data, software, & publications
- **Facilitate** inclusion, transparency, and reproducibility of science

NASA is supporting scientists to integrate open science principles into the entire research workflow.

NASA's Open-Source Science Initiative

SMD's new policy on Scientific Information

As open as possible, as restricted as necessary, always secure

- Publications are made openly available with no embargo period.
- Research data and software are shared at the time of publication.
- Mission data are released as soon as possible and is freely available.
- Unrestricted mission software is developed openly.
- Recognizes software as a scientific product.
- Data should be released with Creative Commons Zero and software with permissive, commonly used licenses
- Encourages using and contributing to Open Source Software.

Scientific Information Policy Website & FAQ

CC BY

Lowering Barriers for Open Source Software

NASA is working to make it easier to

- contribute,
- release,
- use

open source software.

Sustaining Open Source Software

NASA selected 16 proposals in 2021-22 supporting 22 different open source projects to provide sustainable support.

NASA's Transform to Open Science

NASA's Transform to Open Science (TOPS) is a $40 million 5-year mission to accelerate adoption of open science

TOPS' Strategic Goals:

- Support 20K researchers to earn NASA's open science badge
- Double the participation of historically excluded groups across NASA science
- Enable five major scientific discoveries through open science principles

Engagement

Capacity Sharing

Incentives

Coordination

Join us as we embark on the 2023 Year of Open Science

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Opportunities

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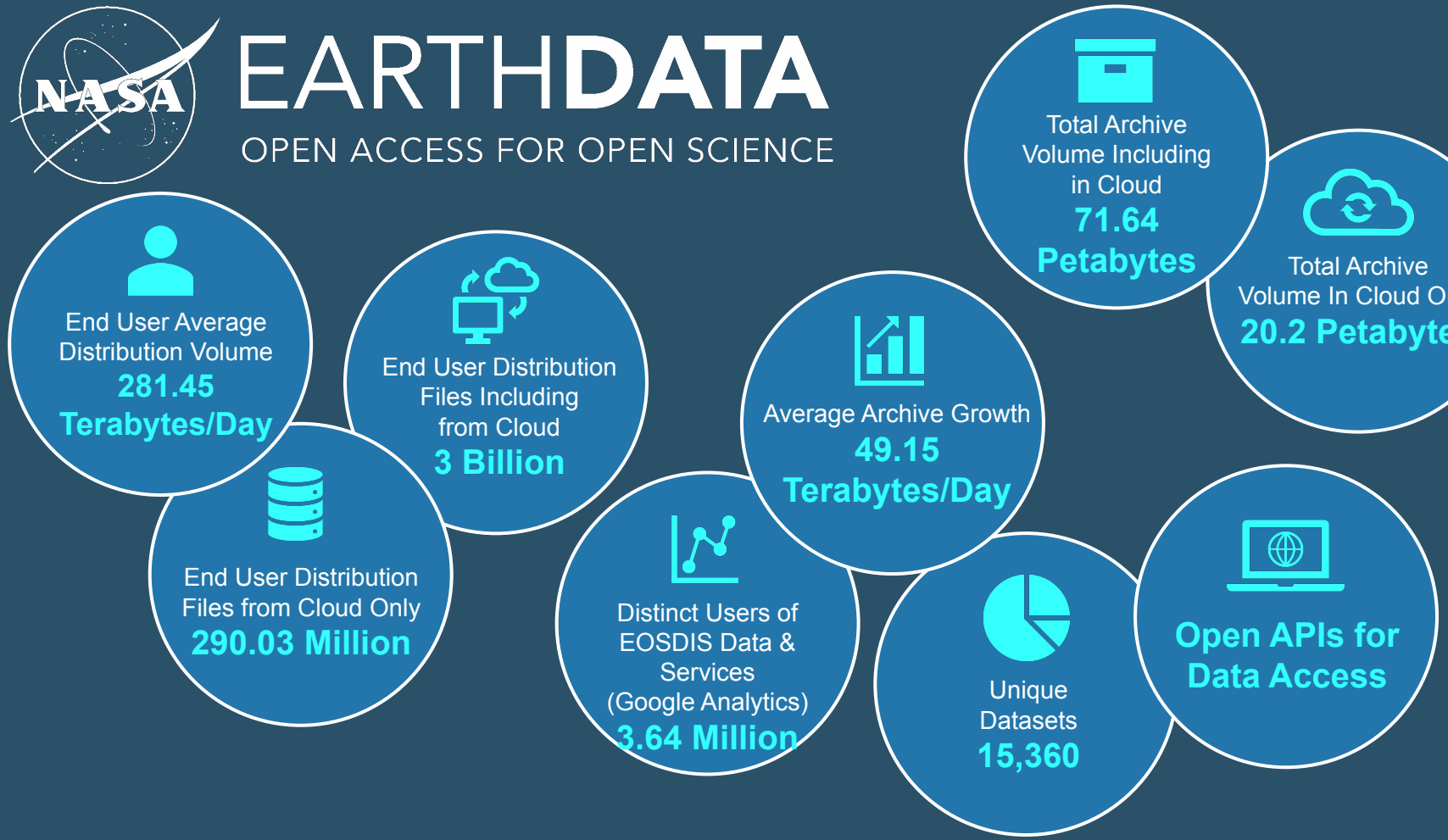
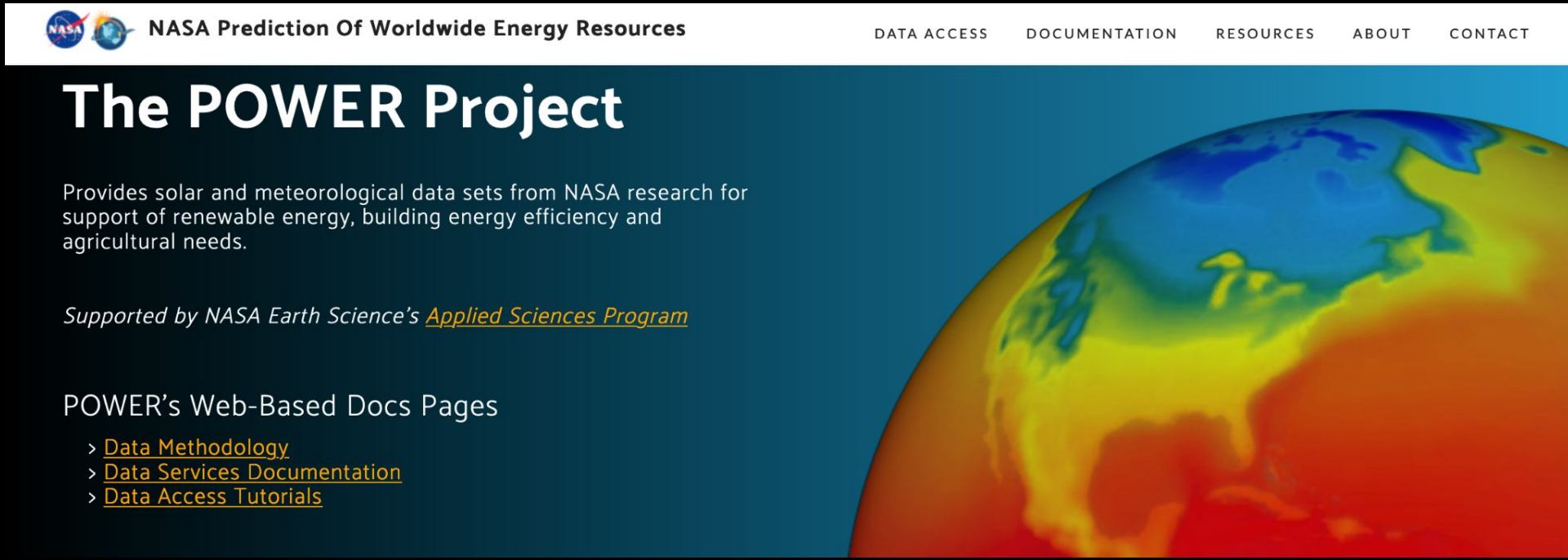
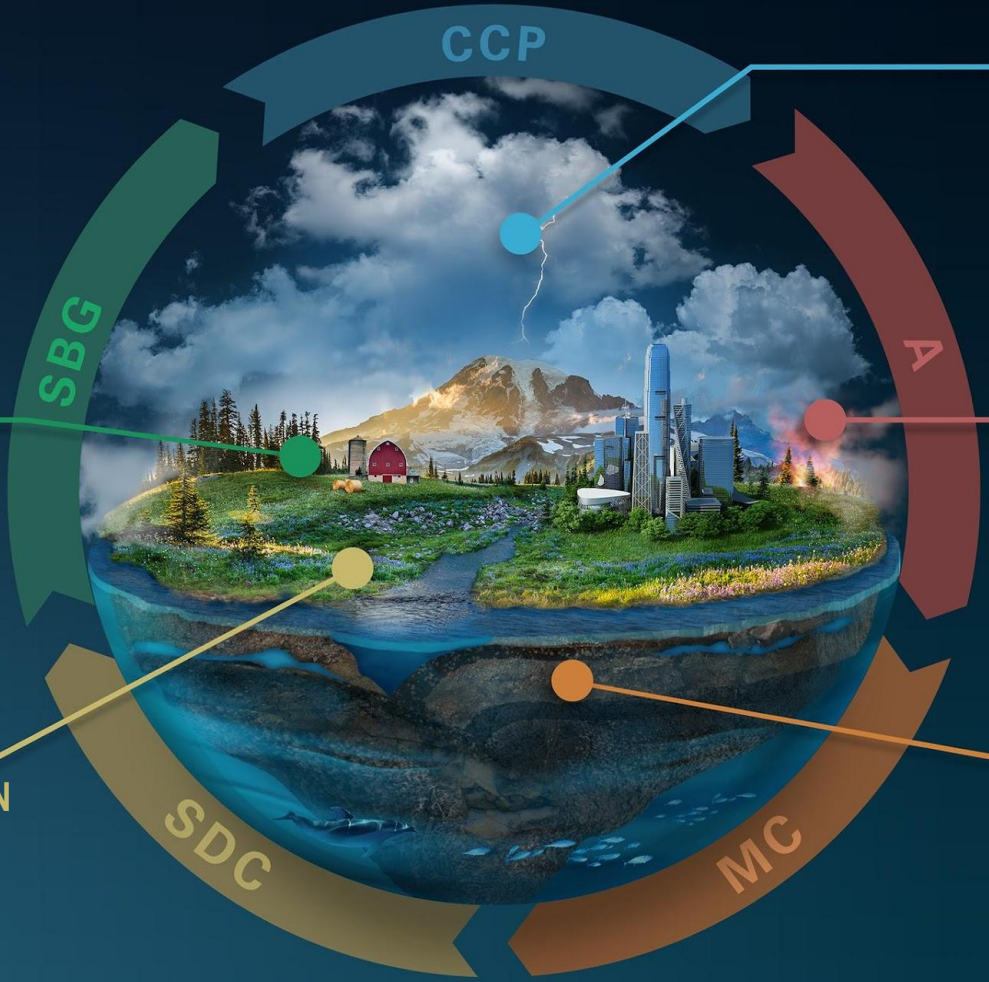

NASA
EARTHDATA
OPEN ACCESS FOR OPEN SCIENCE
Total Archive Volume Including in Cloud
71.64 Petabytes
Total Archive Volume In Cloud Only
20.2 Petabytes
End User Average Distribution Volume
281.45 Terabytes/Day
End User Distribution Files Including from Cloud
3 Billion
Average Archive Growth
49.15 Terabytes/Day
End User Distribution Files from Cloud Only
290.03 Million
Distinct Users of EOSDIS Data & Services (Google Analytics)
3.64 Million
Unique Datasets
15,360
Open APIs for Data Access



Data is also freely available in the AWS Public Data Registry.

EARTH SYSTEM OBSERVATORY

INTERCONNECTED CORE MISSIONS



CLOUDS, CONVECTION AND PRECIPITATION

Water and Energy in the Atmosphere

AEROSOLS

Particles in the Atmosphere

MASS CHANGE

Large-scale Mass Redistribution

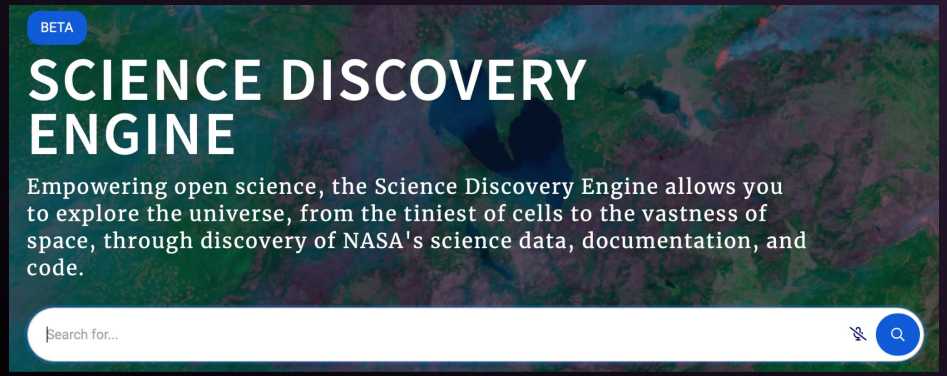
SURFACE BIOLOGY AND GEOLOGY

Earth Surface & Ecosystems

SURFACE DEFORMATION AND CHANGE

Earth Surface Dynamics

Discover NASA Software



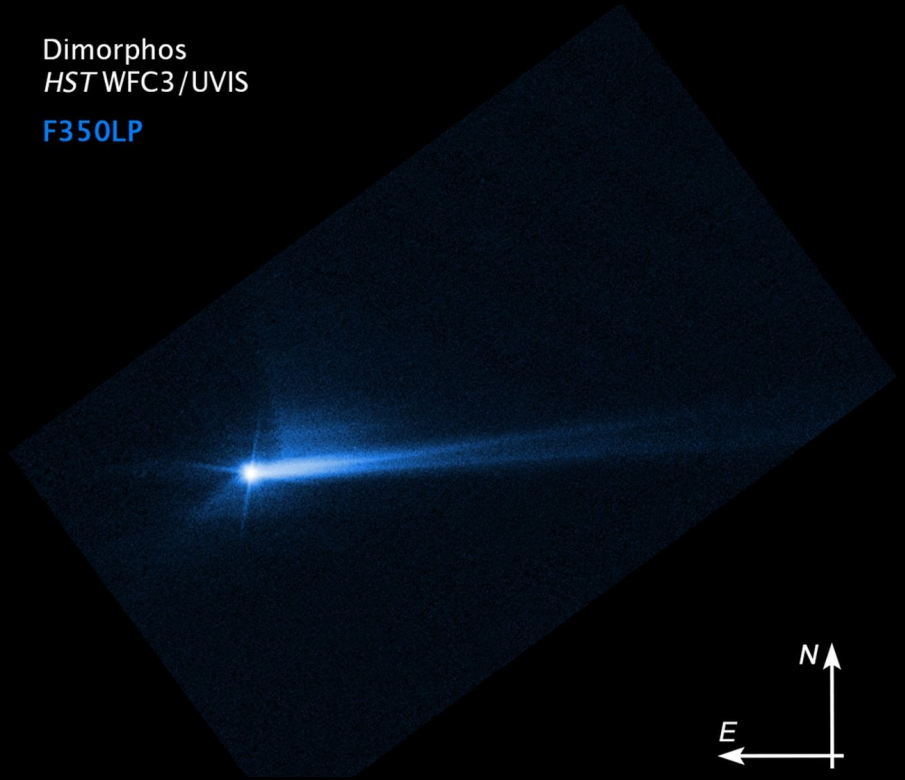
SOFTWARE CATALOG

NASA GitHub

Astrophysics Data Service

Software Heritage

NASA is looking ahead at really big challenges



We need ***more*** WE science rather than ME science[1]– openly sharing data, software, & results.

Credit: Science: Nasa, ESA, Jian-Yang Li (PSI); animation: Alyssa Pagan (STScI)

1: quote from Harlan Krumholz, Yale School of Medicine at 2022 CZI meeting

We need ***more*** people - more hands, more eyes, more brains - with diverse experiences to participate so that we ask the best questions and find the best solutions.

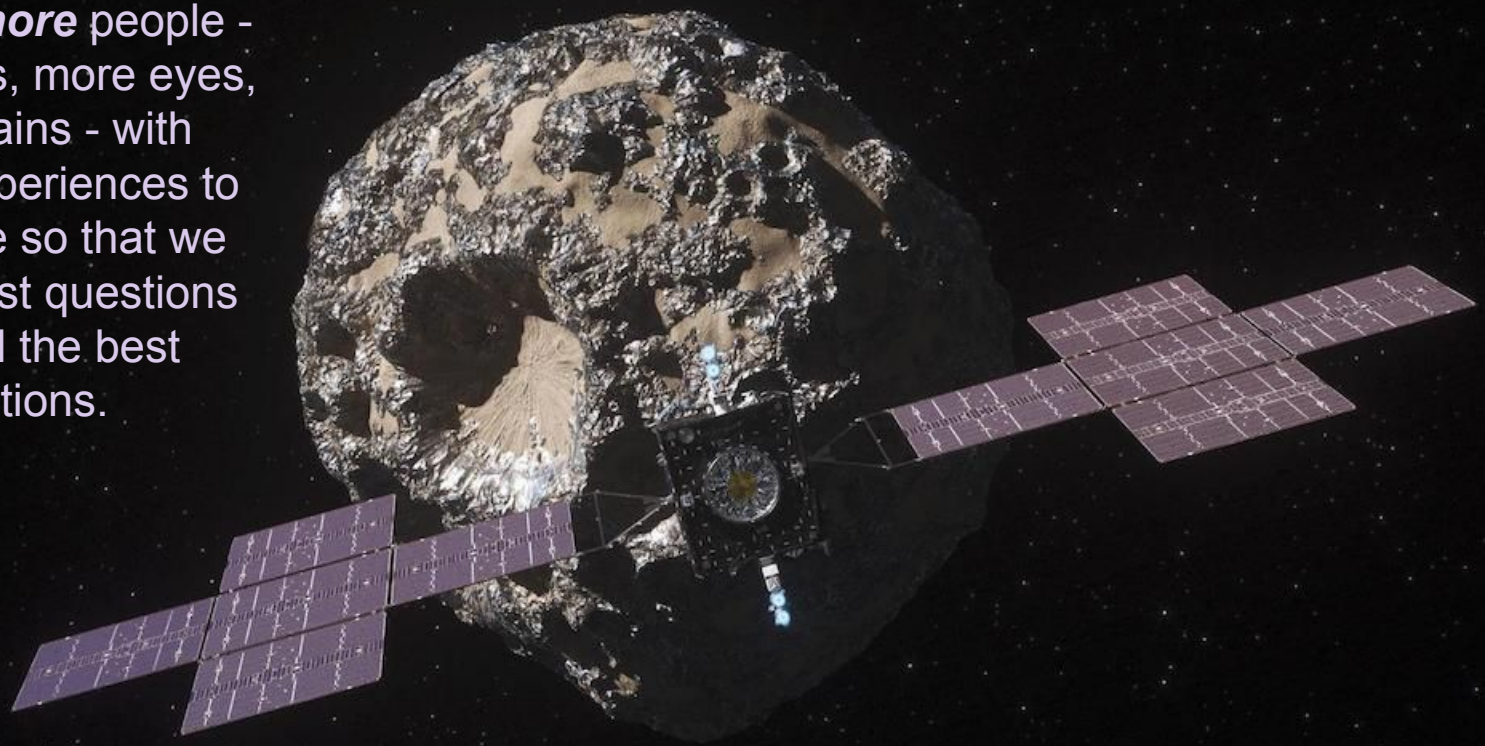


Image credit: JPL

CC BY

Contribute to NASA Open Source Code

Keep contributing, building,
and sustaining your code.

Come work with us!

PROTECT & IMPROVE LIFE ON EARTH & IN SPACE

SEARCH FOR LIFE ELSEWHERE

DISCOVER SECRETS OF THE UNIVERSE

Thank you for contributions.

Q&A

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Learn more and
collaborate with us!

TOPS Website

TOPS Email List

CC BY

The White House announces

A Year of Open Science 2023

NASA ✦ NSF ✦ NOAA ✦ DOE ✦ GSA ✦ NEH ✦ NIH ✦ NIST ✦ USDA ✦ USGS

Along with other organizations, including CENDI, voluntary collaboration among federal managers, and HELIOS, a coalition of 80+ universities.

A multi-agency initiative across the federal government to spark change and inspire open science engagement through events and activities that will advance adoption of open science.

Website: https://open.science.gov/

WH: https://www.whitehouse.gov/ostp/news-updates/

Nature: https://doi.org/10.1038/d41586-023-00019-y

National Aeronautics and Space Administration

HELIOPHYSICS BIG YEAR

Elizabeth MacDonald*, Ha-Hoa Hamano, Denise Hill,
Kelly Korreck, Marc Kuchner*, Alex Young*, Nicky Fox

http://go.nasa.gov/HelioBigYear/

Email: hq-heliobigyear@mail.nasa.gov

* At AAS

CC BY

2023 is NASA's Year of Open Science

TOPS will be energizing and uplifting open science across the scientific community through:

Visibility

Publishing articles, appearing on podcasts, developing targeted communication that expands footprint

Integrating Open Science into themes at large-scale events and conferences

Capacity Sharing

Producing online, free, Open Science curriculum on Open edX

Hosting workshops, events, cohorts, science team meetings, hackathons

Constructing multiple pathways to Open Science Badge

Incentives

Developing Open Science Badge/Certification

Sponsoring high profile prizes and challenges

Establishing high profile awards in support of open science research

Moving toward Openness

Recognizing open science practices

Holding open meetings

Sharing hidden knowledge

Inclusive collaboration

Breakthrough discoveries: First image of a black hole

“We’re deeply grateful to all the open source contributors who made our work possible.”
- Dr. Katie Bouman

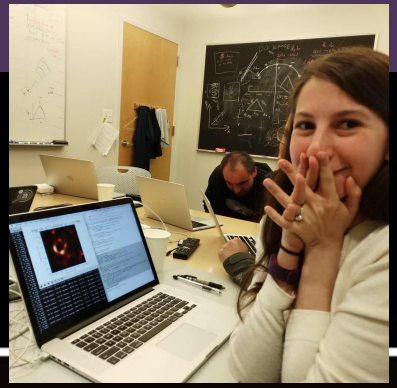

Photo: EHT collaboration; NASA/CXC/Villanova University