

National Aeronautics and  
Space Administration



# EXPLORE SCIENCE

## **Cognitive Systems in Space: - a new paradigm for research**

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on detail to SCan.*

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Applications June 22, 2021*



A graphic on the left side of the slide depicts a space scene. It features a large blue planet (Earth) at the bottom, a bright yellow sun, a grey moon, a ringed planet (Saturn), and a reddish planet (Mars) against a starry background with a blue nebula. A white curved line separates this graphic from the text on the right.

# Outline

- Why cognitive systems? Why now?
- (Very) Brief biased history.
- Science drivers; Policy drivers.
- The Future.

A vibrant space-themed background featuring a large blue and white curved shape on the left. Inside this shape, there are illustrations of various celestial bodies: a brown planet, a ringed planet, a blue planet, and a bright yellow sun. The background is filled with stars and a blue nebula.

# Why cognitive systems?

Science has always been a collaborative endeavor. It requires free and open access to all types of 'vetted' data (including models) to better understand the Universe. This implies knowing who has done what and when.

- The most recent example of this is the development of the SARS-CoVID-19 vaccine, from concept to mass production in under 18 months, using a technique that dismissed as impractical 30 years ago!

Every time a science discipline delves deeper into itself, the realization is always the same: it is a *complex, interconnected system of systems.*



# Why now?

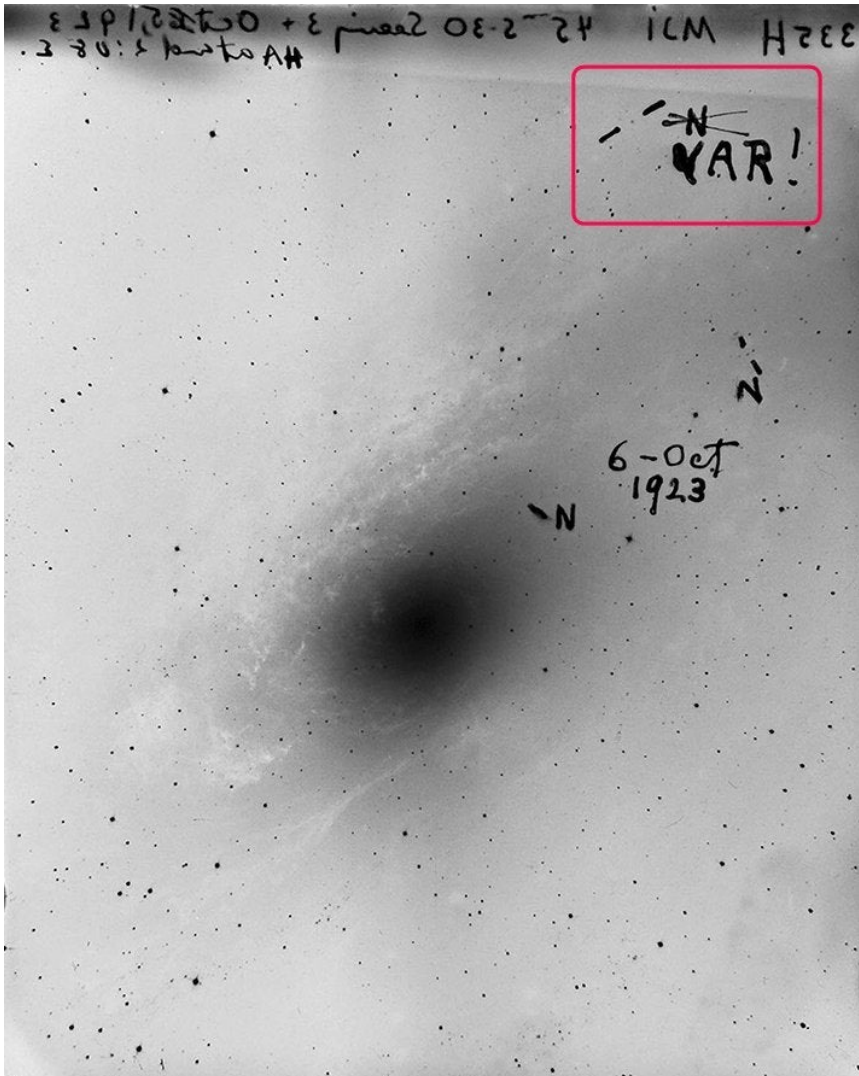
Simply put - *technology*.

- Advances in exceptionally sensitive detectors, and the compute power to drive them has transformed all of science.
- Data is now collected digitally, recorded and stored digitally, is now publicly accessible, with open-source software developed to analyze these data.
- Science is now suffering from a tsunami of data – genomes and other datasets now typically exceed exo-byte scales.

Big Data is *here* and we need to change the way we think about doing science.



# How Science was done just 40 years ago...

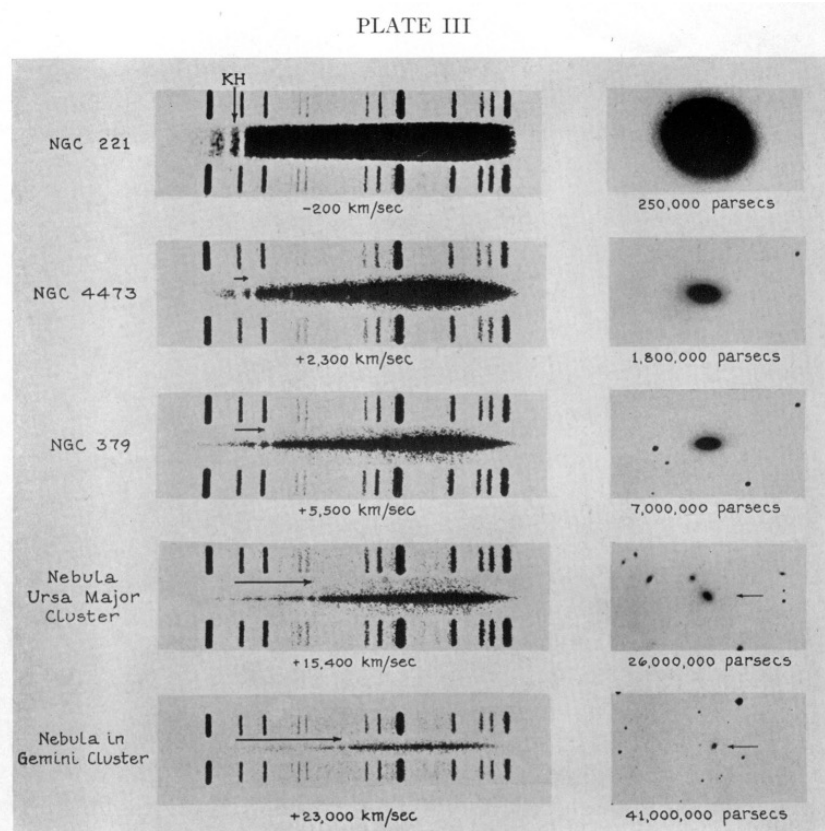


By way of an example, all optical astronomy and astrophysics *until the early 1980s* was done on glass photographic Plates(!) The one at left was taken by Hubble in 1923 showing the Andromeda galaxy and the first discovered Cepheid star outside our galaxy. Without that discovery, the size and scale of the universe would be unknown.

However, the image took over ~3 hours to produce and the emulsion on the plate had a detection efficiency of under 5%.

And it was analog – the only way to share it was to make a contact print and publish it in a journal.

# How Science was done just 40 years ago... - 2



RED-SHIFTS IN THE SPECTRA OF EXTRA-GALACTIC NEBULAE

Arrows above the spectra (enlarged twenty times from the original negatives) point to the H and K lines of calcium and show the amounts these lines are displaced toward the red. The comparison spectra are of helium.

The direct photographs (on the same scale and with approximately the same exposure times) illustrate the decrease in size and brightness with increasing velocity or red-shift.

NGC 4473 is a member of the Virgo Cluster; NGC 379 of a group in Pisces.

Now... how to do *correlated* science?

One has the morphology of the galaxy: how does one know its chemical composition, or distance, or how has it's moving?

Spectroscopy is the way to do it, but again suffers from being detected on a photographic plate and the record was again, analog.

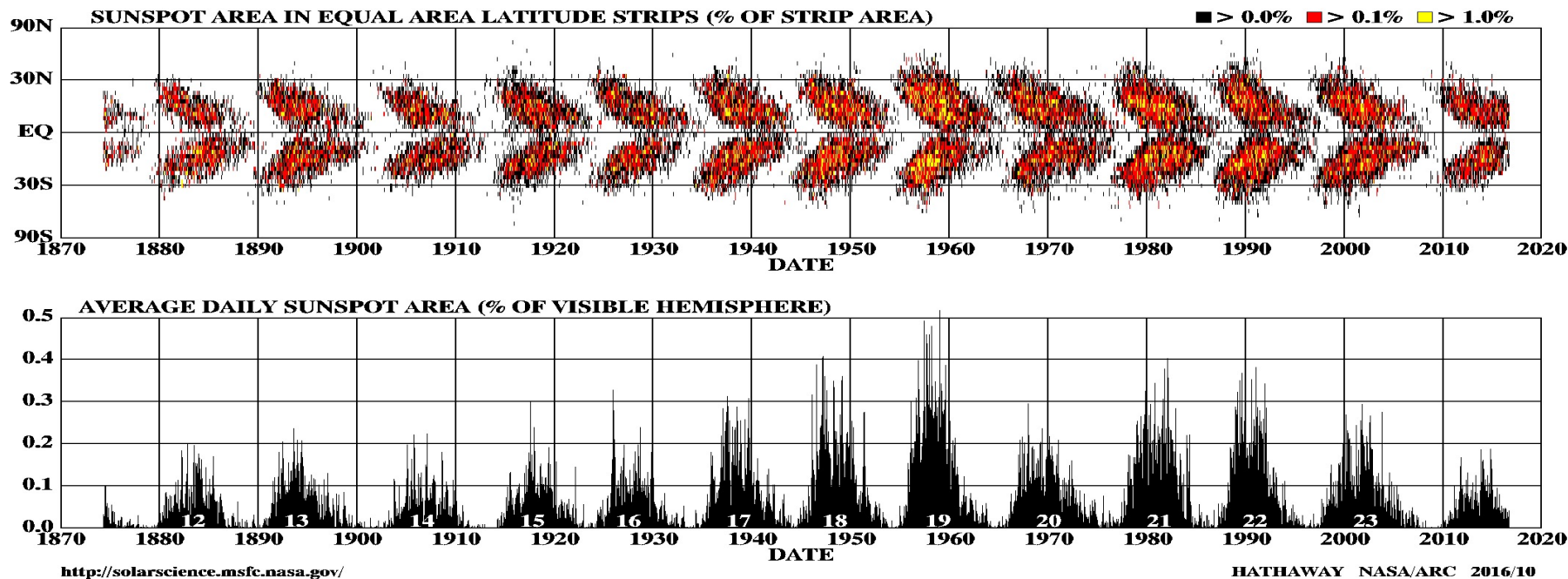
The image to the left was done by Humason in the 1930s and each spectrum required at least 5 hours on a 100-inch telescope of acquire.



# Science is complex – the more you know...

As the numbers and frequencies of observations and discoveries picked up, so too did the number of 'odd' coincidences.

**DAILY SUNSPOT AREA AVERAGED OVER INDIVIDUAL SOLAR ROTATIONS**



As people counted sunspots from year to year, they noticed that they changed position on the Sun's surface with time.

The two questions now became:

- Why are there sunspots?
  - Why do they move that way?
- And then a *new* question:
- Why is there a cycle of ~11 years?

# It gets worse...

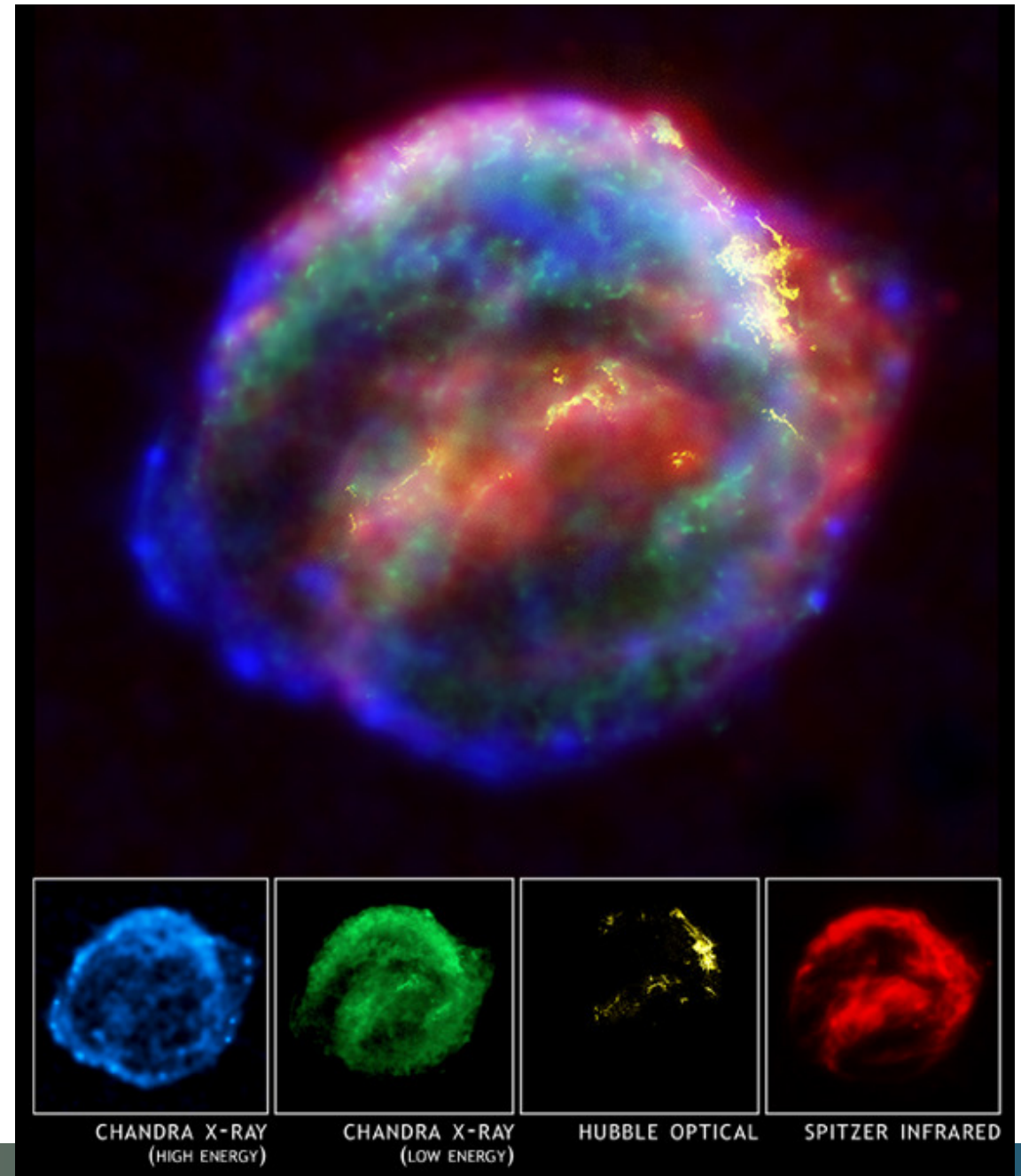
Depending on how one looks at an object, it may change it's observed characteristics...

Using the Kepler supernova remnant, if one looks at it in the optical (yellow) it quite underwhelming...

But if one looks at it in X-ray (blue or green), one sees very different object: it is far more dynamic and there is a lot of structure. The same holds for the IR detection.

*Seeing everything gives insight to the on-going physics.*

So how did we get to this point?





# NASA'S GREAT OBSERVATORIES

Spitzer Space Telescope



Hubble Space Telescope



Chandra X-Ray Observatory



Compton Gamma-Ray Observatory



Infrared

Visible

Ultraviolet

X-Rays

Gamma Rays



NASA/JPL-Caltech/L. Allen (Harvard-Smithsonian CfA)

**Spitzer:**  
Star-forming Region W5



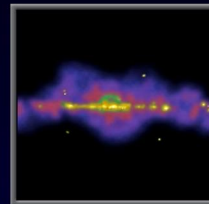
NASA, ESA, Hubble Heritage Team (STScI/AURA); P. Knezek (WIYN)

**Hubble:**  
Spiral Galaxy NGC 1300



NASA/U. Mass./D. Wang et al.

**Chandra:**  
Galactic Center



U. Calif., Riverside

**Compton:**  
Milky Way

## Multiwavelength / Hyperspectral science!

Astrophysics and the Earth Sciences quickly came to realize that by not studying phenomena using all available data, one has an incomplete picture of on-going physics.

We start moving from simple collection observations of objects and into the realm of wanting to coordinate those observations.

The next step is knowing when to coordinate them.

# Drivers - Science

The science endeavor supported in the US is amazingly successful but is going through 'growing pains.' The sheer amount and complexity of the data being collected every day, the sophistication and details of the models used, and the numbers of peer reviewed journal articles is now beyond everyday understanding.

In 2017 alone, 2.5 million papers in all disciplines were published worldwide in roughly 28,000 journals (U Ottawa stats). *And it is accelerating.* No one person or even group of people can possibly keep up.

The need for intelligent systems to sort through all the data and models and papers is clear, and Google does an okay job of it at a general level, but it's a *post-facto* aggregator. It can guess at completing search queries, but it can't anticipate the next search.

That requires a *cognitive* system that *learns*.



# Drivers – Science - 2

This avalanche of data is starting to cause scientists to rethink the need to collect all data all the time. There simply aren't enough people to process the data. What is the *important* data versus the 'routine' data, and how would one know and prioritize its collection? After all, if all data is a priority, then none of it is.

The question then arises as to whether a cognitive system can be developed / trained that could help do that prioritization autonomously? (And how does one verify that it is following that training?)

Logically, one would want the intelligent cognition to be at the source of the data, which in NASA's case means that one would want it within the on-board systems of spacecraft.

We have autonomy for some on-board subsystems already (mainly for fault protection), but not at the data collection end – that's a simple open pipe that collects data whenever the instrument is on. Also, the autonomy only applies to the one spacecraft.

# Drivers – Science - 3

As the various science disciplines have come to realize that the systems being studied are exceptionally complex and interconnected – the very definition of a system of systems – it is becoming evident that there is a growing need to have cognitive, autonomous systems that can collect the data, help prioritize which data to examine first, and to call upon other resources to augment and supplement the primary data source, when that *really* interesting science occurs.

A simple example that is all over the sciences there are transient phenomena – something happens in a seemingly random manner that could potentially help explain the underlying physics. Currently such observations happen through serendipity – the instrument was pointed in the right place at the right time.

*Why not develop a system that monitors a source that would then call up additional instruments automatically when specified conditions are met to study the ‘interesting’ condition with the full battery of detectors?* Numerous examples of such needs exist in all the sciences that NASA supports.



# Drivers – Policy

In talking about the avalanche to data, it must be realized that those data are used (if albeit imperfectly) to inform decisions affecting people.

While pure *curiosity-based* science is still pursued, it lives within a context of science that has potential applications to the populace as a whole and can affect the health and wellbeing of nation states.

In the US, the last four administrations have all articulated a policy of open and accessible science data and science results paid through taxpayer funds.

# Drivers – Policy - 2

With the era of Big Data well and truly upon us, the US government has issued a number of policies and laws to take advantage of it and embrace it. As a federal agency NASA must respond to OMB directives and statutory requirements such as:

- M-13-13: Open Data Policy-Managing Information as an Asset (2013)
- M-16-16: Agency Open Government Plans (2016)
- Public Law 115-435: Foundations for Evidence-Based Policymaking Act of 2018 (2019)

In addition, SMD has sponsored a number of studies by the National Academies of Science, Engineering and Medicine (NASEM) to explore this brave new world:

- Open Science by Design: Realizing a Vision for 21st Century Research (2018)
- Open Source Software Policy Options for NASA Earth and Space Sciences (2018)
- Advancing Open Science Practices: Stakeholder Perspectives on Incentives and Disincentives: Proceedings of a Workshop in Brief (2020)



# Drivers – Policy - 3

NASA's science data, and the instruments and spacecraft that collect it, are fast becoming part of a critical national infrastructure.

Past and the current administrations look to NASA to provide, *timely, accurate, and reliable* data of the effects of space weather, and climate change for the planet and the nation. The space weather aspect is now codified into law under the PROSWIFT Act (PL 116-181) which sets forth provisions concerning improving the ability of the US to forecast space weather events and mitigate their effects. NASA needs to maintain and to augment the data and models required to understand and potentially predict space weather events.

As the need for space weather and Earth climate data comes to the fore, the way that data is collected, analyzed, stored, and made accessible must change. This is where autonomy and cognition on spacecraft, real-time telemetry, accurate position knowledge, and computation in the cloud become essential.



# The Future

Where do we go from here?

What are science's needs for the next 3 years?

Over the next 10 years?

Over the next 20 years?



The background of the slide is a vibrant, stylized depiction of outer space. It features a large, bright sun in the lower-left quadrant, casting a warm glow. Several planets are visible, including a ringed planet (Saturn) and a reddish planet (Mars). The Earth is partially visible at the bottom, showing its blue oceans and white clouds. The sky is filled with numerous stars and a colorful nebula in shades of blue and green. A white, curved graphic element separates the text area from the background.

# The Future - 2

Science at NASA is driven by activities called ‘Decadal Surveys’. SMD contracts with NASEM to undertake community-wide discipline-based studies of what the priorities should be for the next 10 years, based on the current state of the discipline. These decadal surveys then form the basis of the Strategic Plan for SMD and hence the Agency, as far as science is concerned. Budget priorities are then set to match the recommendations and findings of the decadal surveys, and Congress *expects* to see that the various recommendations and findings are followed, in some manner.

There are 5 Decadal Surveys – one for each science division.

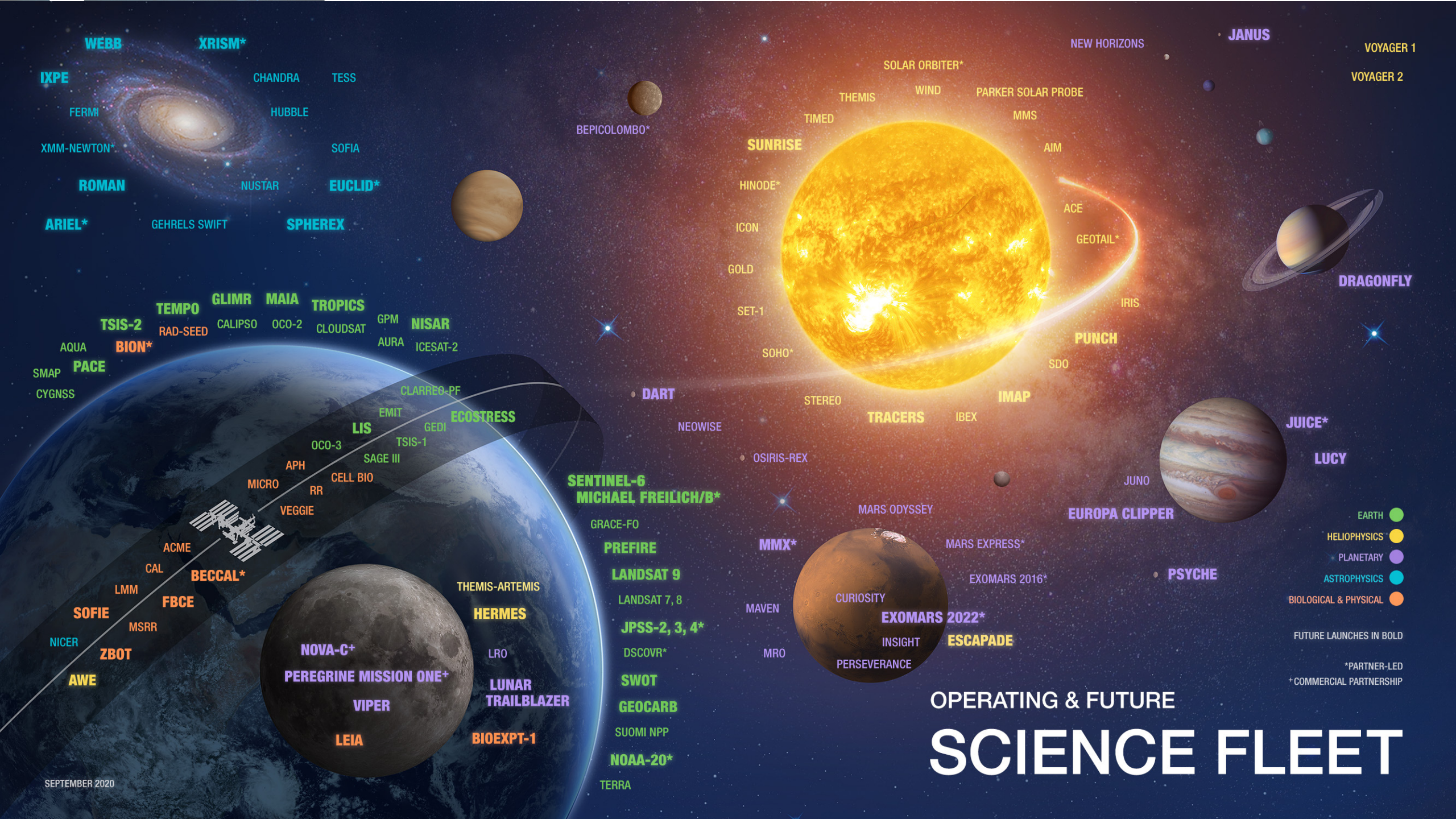
# The Future - 3

SMD has identified a number of overall trends of where science is driving future communications and navigation needs. Within these are drivers for autonomy, real-time data drops, and much more. The preliminary findings are (in no particular order):

- A growing need for smallsat support (including constellations / swarms of 30+ spacecraft),
- An increase in missions at Earth-Sun L1/L2 – and maybe L5,
- An increase in cislunar missions, including far-side operations,
- Multi-messenger science requiring real-time alerts (not only from LEO),
- Very deep-space, long-duration missions out to 1000 AU.
- Maintain the current suite of missions for as long as possible (see next slide).

All of those come from the various decadal. Implementation is left up to NASA, but the majority will be be competed via an Announcement of Opportunity (AO). Only very large missions (think Webb) would be a strategic directed missions formulated by NASA itself. Even then, the instruments and the science teams responsible for the science productivity, would be competed under some form of peer reviewed competition.





**WEBB** **XRISM\*** **CHANDRA** **TESS** **NEW HORIZONS** **JANUS** **VOYAGER 1**

**IXPE** **FERMI** **HUBBLE** **SOFIA** **BEPICOLOMBO\*** **SOLAR ORBITER\*** **THEMIS** **WIND** **PARKER SOLAR PROBE** **VOYAGER 2**

**XMM-NEWTON\*** **ROMAN** **NUSTAR** **EUCLID\*** **ACE** **AIM** **MMS**

**ARIEL\*** **GEHRELS SWIFT** **SPHEREX** **HINODE\*** **TIMED** **IRIS** **DRAGONFLY**

**TSIS-2** **TEMPO** **GLIMR** **MAIA** **TROPICS** **GOLD** **SDO** **PUNCH** **SDO**

**AQUA** **BION\*** **RAD-SEED** **CALIPSO** **OCO-2** **CLOUDSAT** **GPM** **NISAR** **STEREO** **TRACERS** **IBEX** **IMAP** **JUNO** **JUICE\*** **LUCY**

**SMAP** **PACE** **CLARREO-PF** **ECOSTRESS** **NEOWISE** **OSIRIS-REX** **EUROPA CLIPPER** **PSYCHE**

**CYGNSS** **LIS** **EMIT** **GEDI** **SENTINEL-6** **MICHAEL FREILICH/B\*** **GRACE-FO** **PREFIRE** **LANDSAT 9** **LANDSAT 7, 8** **JPSS-2, 3, 4\*** **DSCOVR\*** **SWOT** **GEOCARB** **SUOMI NPP** **NOAA-20\*** **TERRA**

**APH** **RR** **CELL BIO** **VEGGIE** **MARS ODYSSEY** **MARS EXPRESS\*** **EXOMARS 2016\*** **HERMES** **LRO** **LUNAR TRAILBLAZER** **BIOEXPT-1**

**MICRO** **ACME** **BECCAL\*** **THEMIS-ARTEMIS** **MAVEN** **CURIOSITY** **EXOMARS 2022\*** **INSIGHT** **ESCAPADE** **NOVA-C+** **PEREGRINE MISSION ONE+** **VIPER** **LEIA**

**SOFIE** **FBCE** **NICER** **ZBOT** **AWE** **MSRR**

**CLARREO-PF** **EMIT** **GEDI** **ECOSTRESS** **NEOWISE** **OSIRIS-REX** **EUROPA CLIPPER** **PSYCHE** **HERMES** **LRO** **LUNAR TRAILBLAZER** **BIOEXPT-1** **NOVA-C+** **PEREGRINE MISSION ONE+** **VIPER** **LEIA**

- EARTH
  - HELIOPHYSICS\*
  - PLANETARY
  - ASTROPHYSICS
  - BIOLOGICAL & PHYSICAL
- FUTURE LAUNCHES IN BOLD
- \*PARTNER-LED  
+ COMMERCIAL PARTNERSHIP

# OPERATING & FUTURE SCIENCE FLEET





# Implications for the Future

From the science-driven needs mentioned, future requirements are becoming evident.

- Increasing spacecraft autonomy – the need for intermittent / unscheduled links to Earth,
- Inter-bus communication within swarms and constellations (i.e. sensor webs),
- Relay locations to support both cislunar and L1 (and perhaps L2) missions,
- Multi-messenger science and space weather alerts requiring real-time alerts (and not only from LEO),
- The ability to store, analyze, access, and publish the giga-bytes of data per day being generated,
- Do all of this in a secure manner so that researchers can be confident that they are not victims of ‘fake data’.

The technology exists – the question is *not* how to implement it, but whether we have the will to.



**Questions?  
Comments?**