Curation and Planning Team for Extraterrestrial Materials

CAPTEM is a community-based, interdisciplinary **forum for discussion and analysis** of matters concerning the collection and curation of extraterrestrial samples, including planning future sample return missions

and

A standing review panel, charged with evaluating proposals requesting allocation of all extraterrestrial samples contained in NASA collections.

Signatories to CAPTEM R&A White Paper

Hap McSween (Tennessee)
Kevin McKeegan (UCLA)
Aaron Burton (NASA/JSC)
Conel Alexander (Carnegie)
James Day (UC San Diego)
George Flynn (SUNY)
Juliane Gross (Rutgers)
Kieren Howard (CUNY)
Rhiannon Mayne (TCU)
Larry Nyquist (NASA/JSC)
Dimitri Papanastassiou (Caltech)
Jeff Taylor (Hawai'i)
Allan Treiman (LPI)
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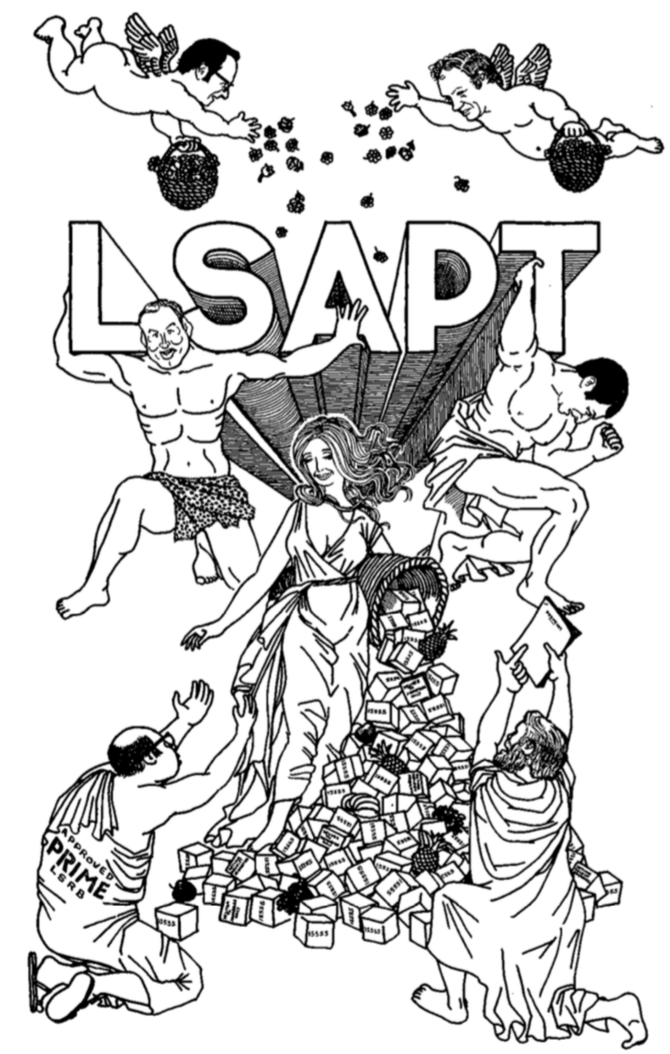

Figure 3 The Great Seal of LSAPT issued during Apollo 16 and used as a pass to the LRL. Persons shown are approved, overfed PI; poor, hungry, pleading unapproved scientist; and the LSAPT goddess doing late distribution of Apollo 15 samples of only one type (which investigators did not request). Jim Lovell and Tony Calio are holding up LSAPT, the cherubs are Paul W. Gast and G.J. Wasserburg. Created by John A. Wood during his term as deputy director (under commission to the LSAPT) using the government-supplied presentation pad, magic marker, and rubber cement in the leaky trailer.

LSAPT in ~1973

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Beginning with Apollo, NASA has built a powerful and diverse capability for analysis of extraterrestrial materials. That capability plays a vital role in ***motivating*** and ***enabling*** future missions

But that is a capability that must be nurtured to maintain both infrastructure and expertise. Once lost, it will be very expensive in time and money to recover


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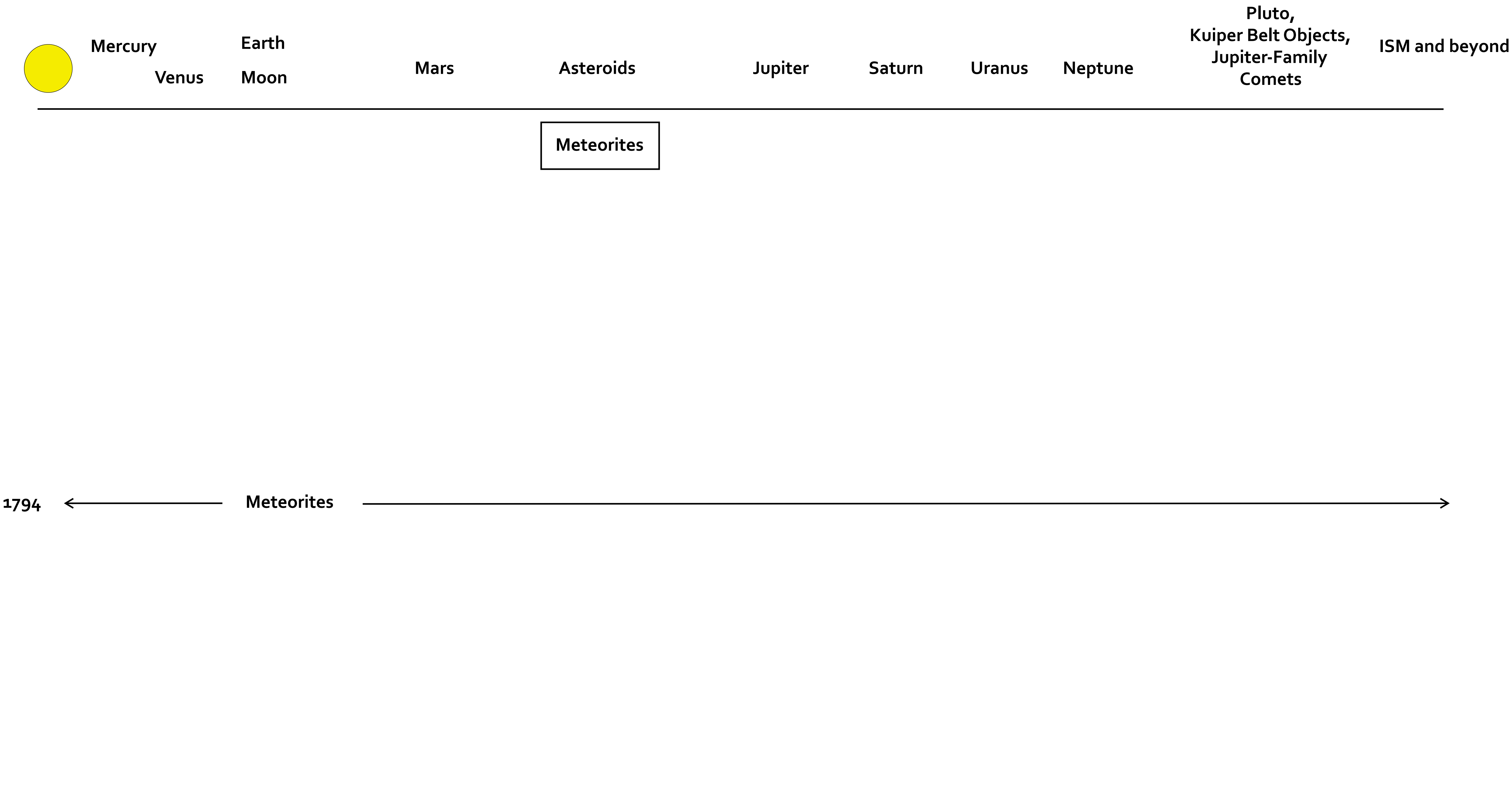
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ISM and beyond
Meteorites
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Meteorites


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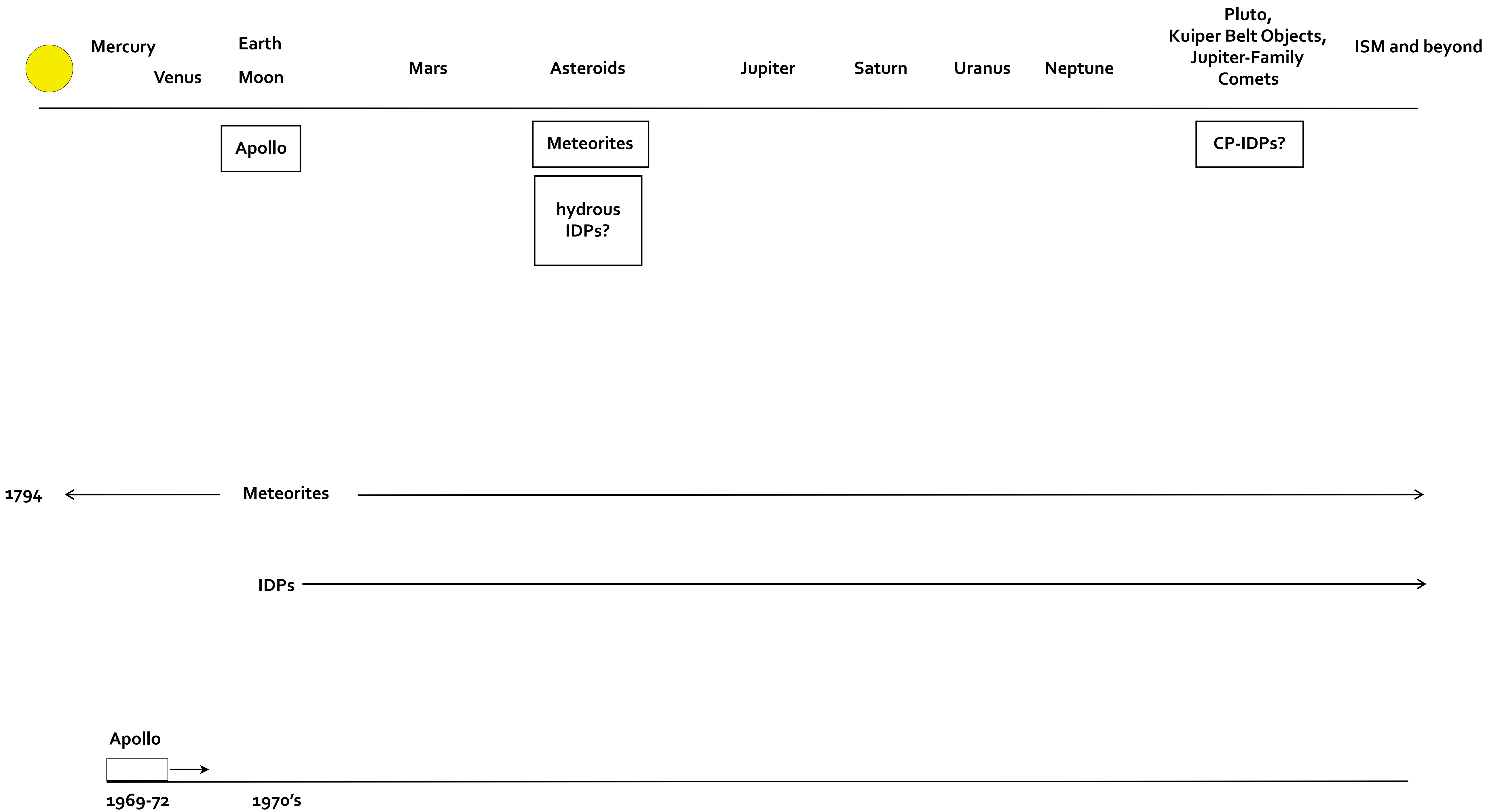
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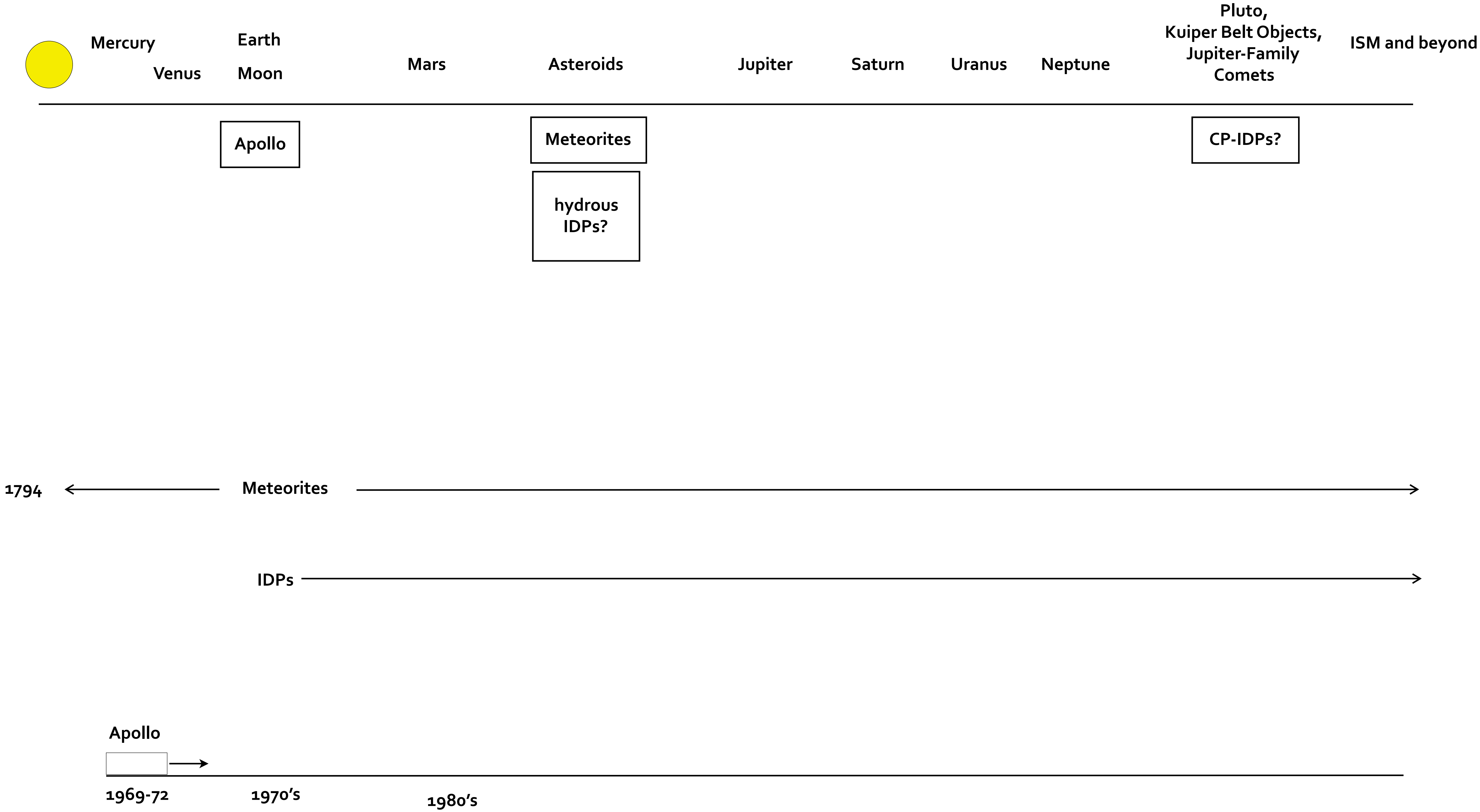

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ISM and beyond
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IDPs
Apollo
1969-72
1970's
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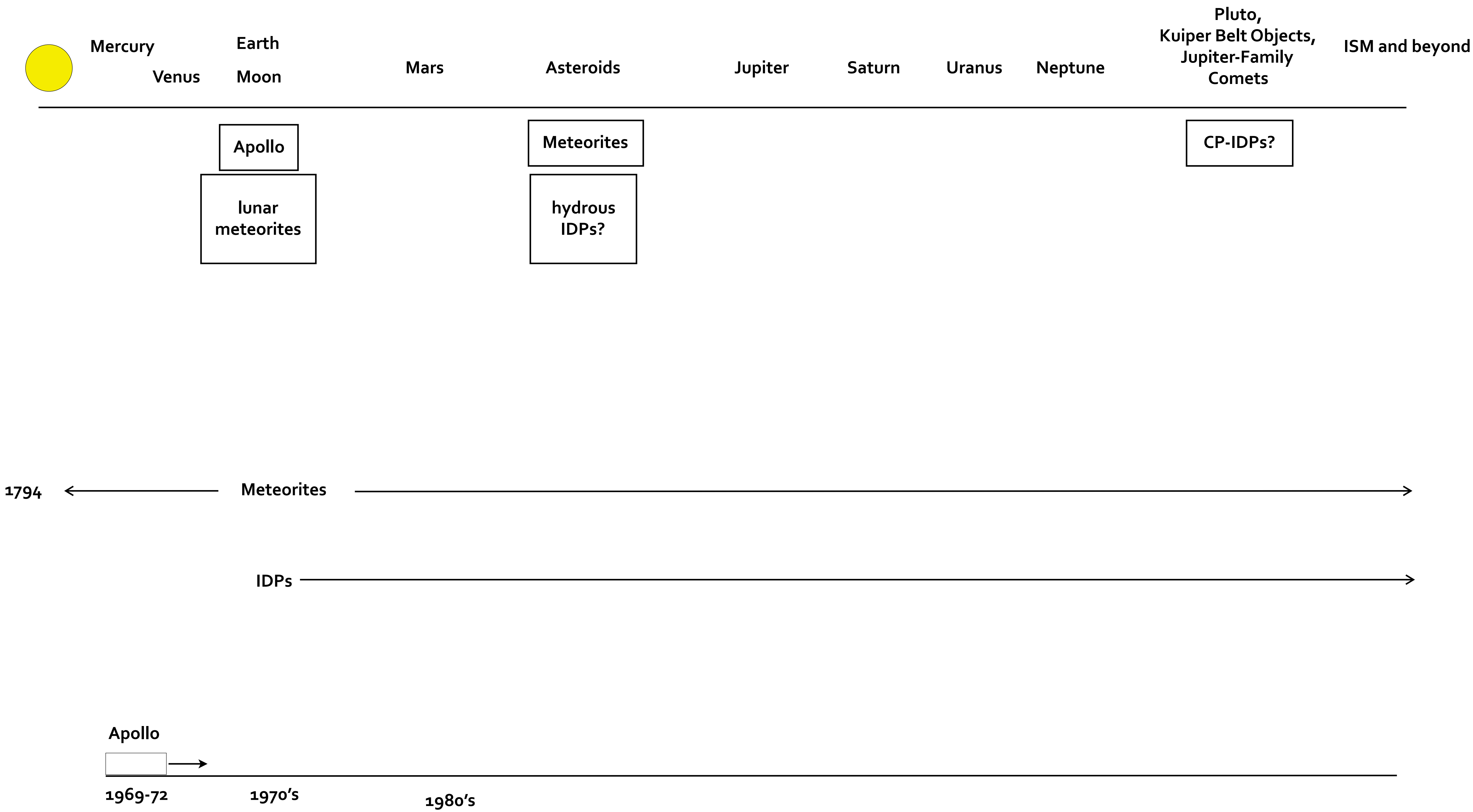

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Comets
ISM and beyond
Apollo
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Meteorites
IDPs
Apollo
1969-72
1970's
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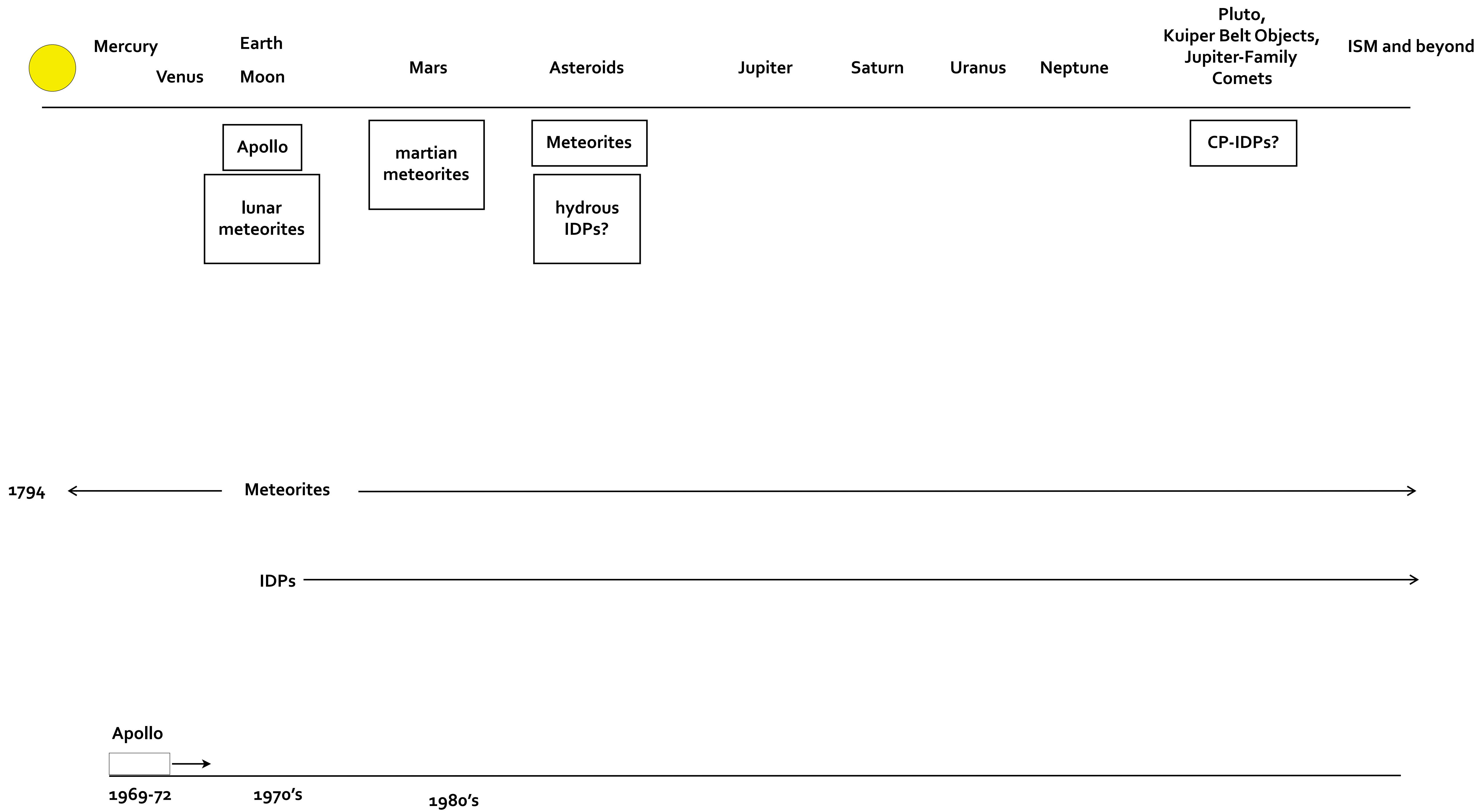
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ISM and beyond
Apollo
lunar meteorites
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CP-IDPs?
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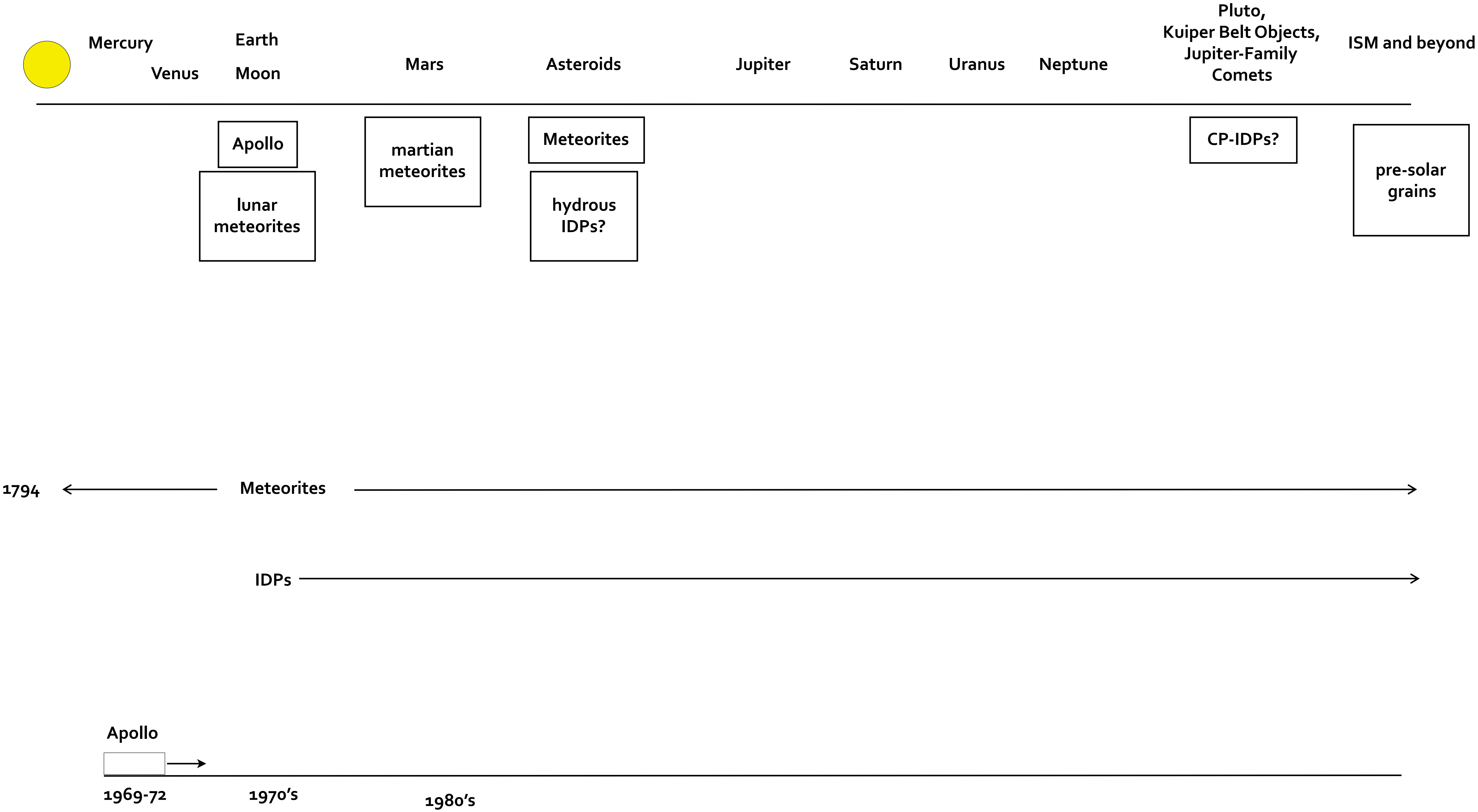
Meteorites
IDPs
Apollo
1969-72
1970's
1980's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Comets
ISM and beyond
Apollo
lunar meteorites
martian meteorites
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Meteorites
IDPs
Apollo
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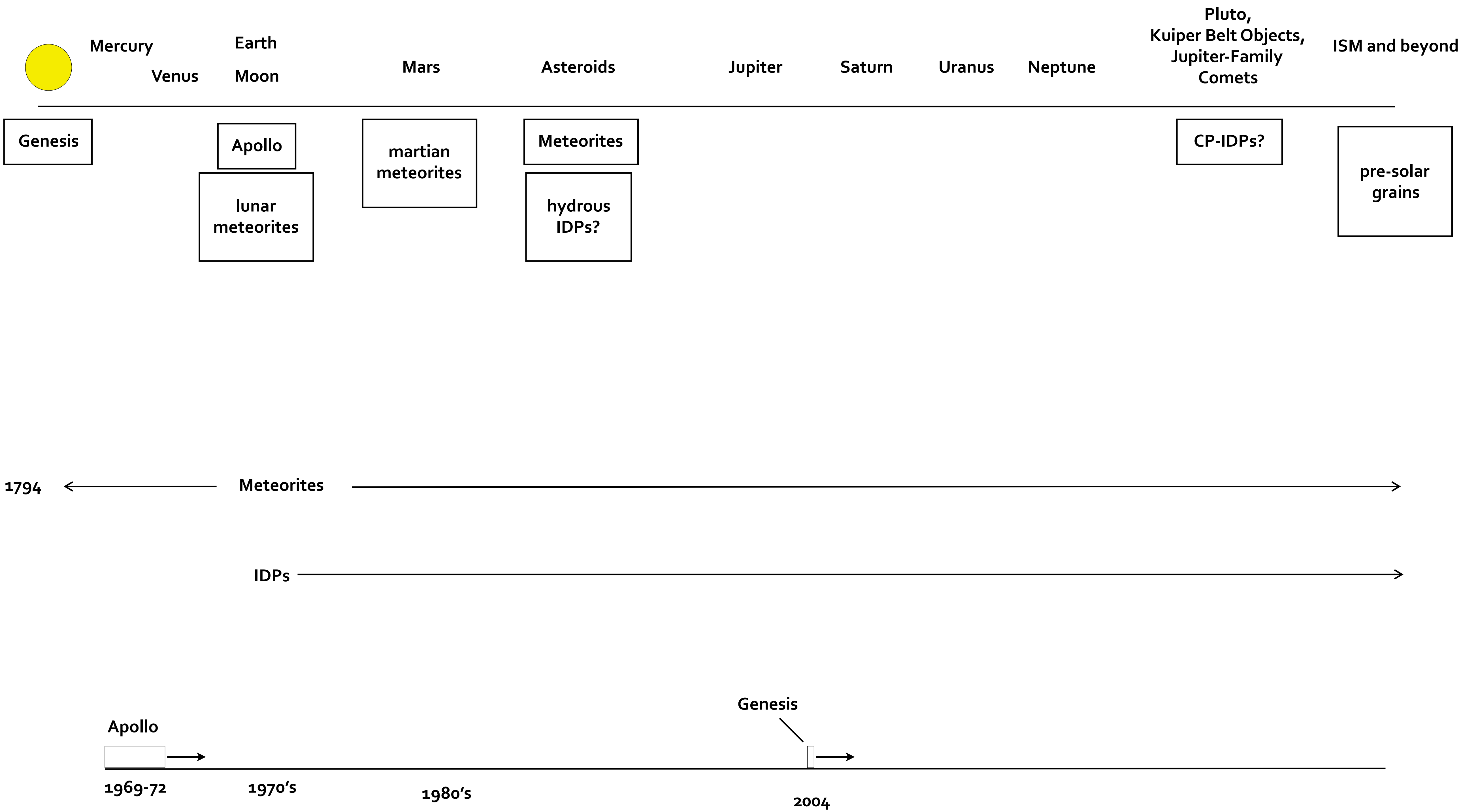
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Genesis
Apollo
lunar meteorites
martian meteorites
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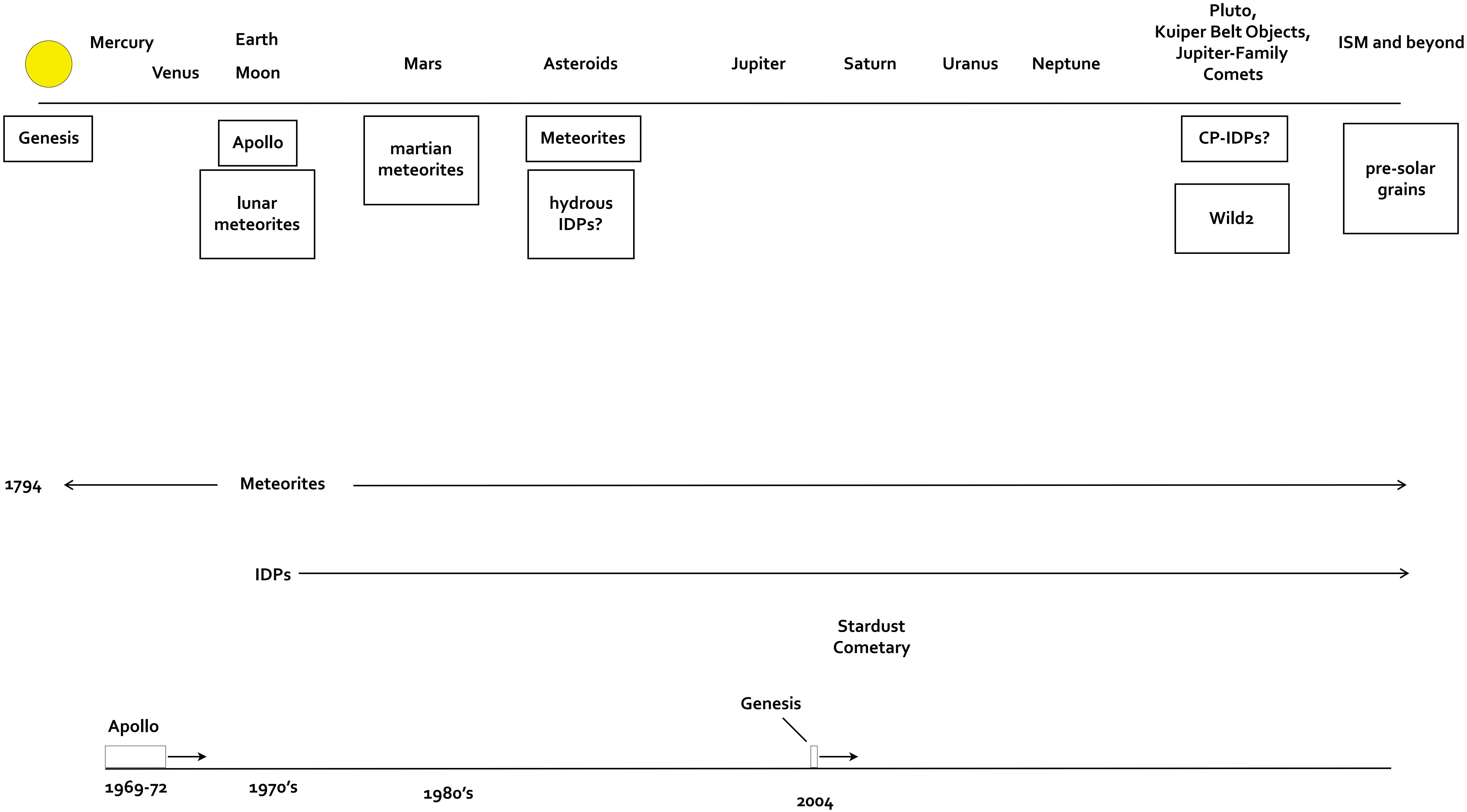

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ISM and beyond
Genesis
Apollo
lunar meteorites
martian meteorites
Meteorites
hydrous IDPs?
CP-IDPs?
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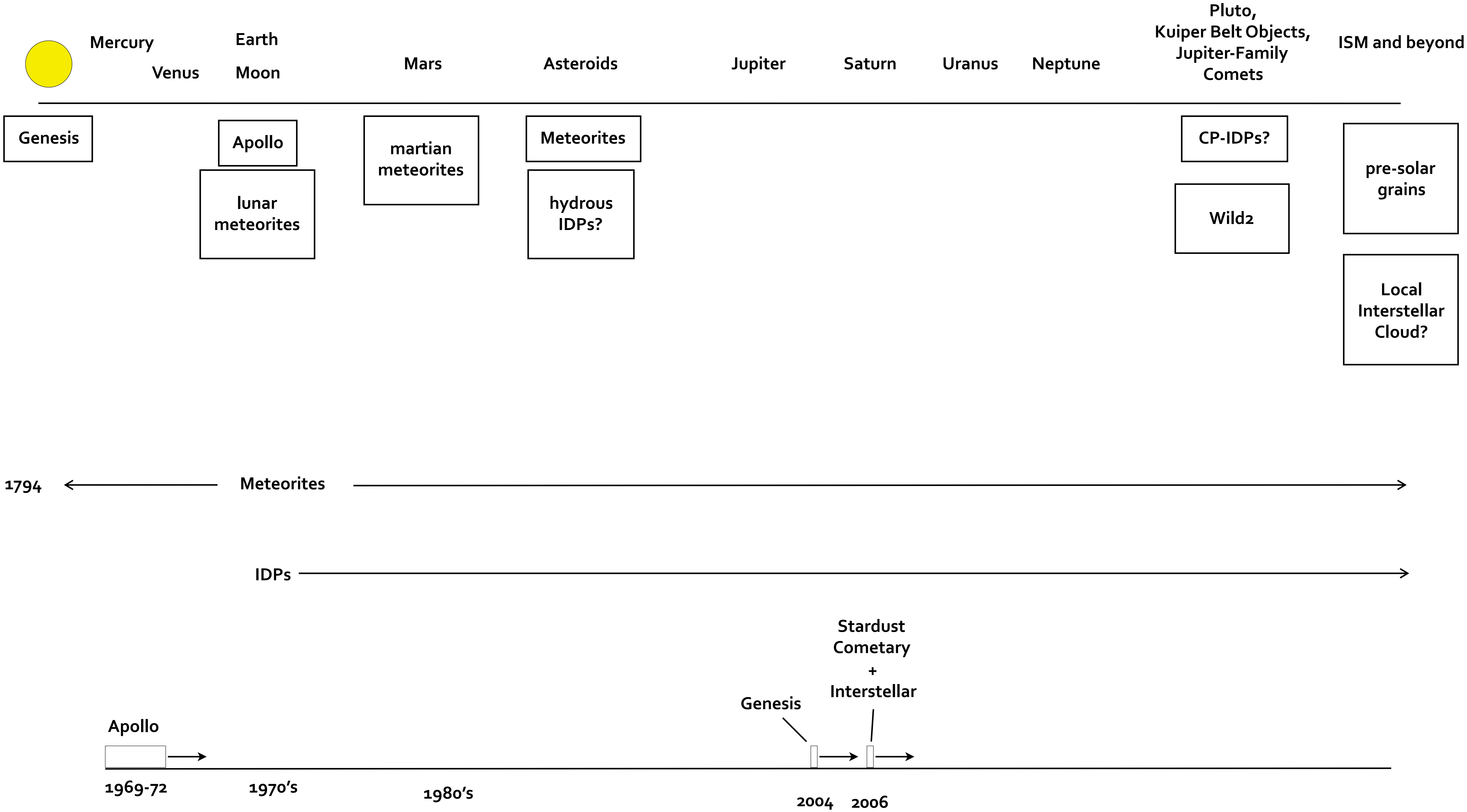
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ISM and beyond
Genesis
Apollo
lunar meteorites
martian meteorites
Meteorites
hydrous IDPs?
CP-IDPs?
Wild2
pre-solar grains
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IDPs
Apollo
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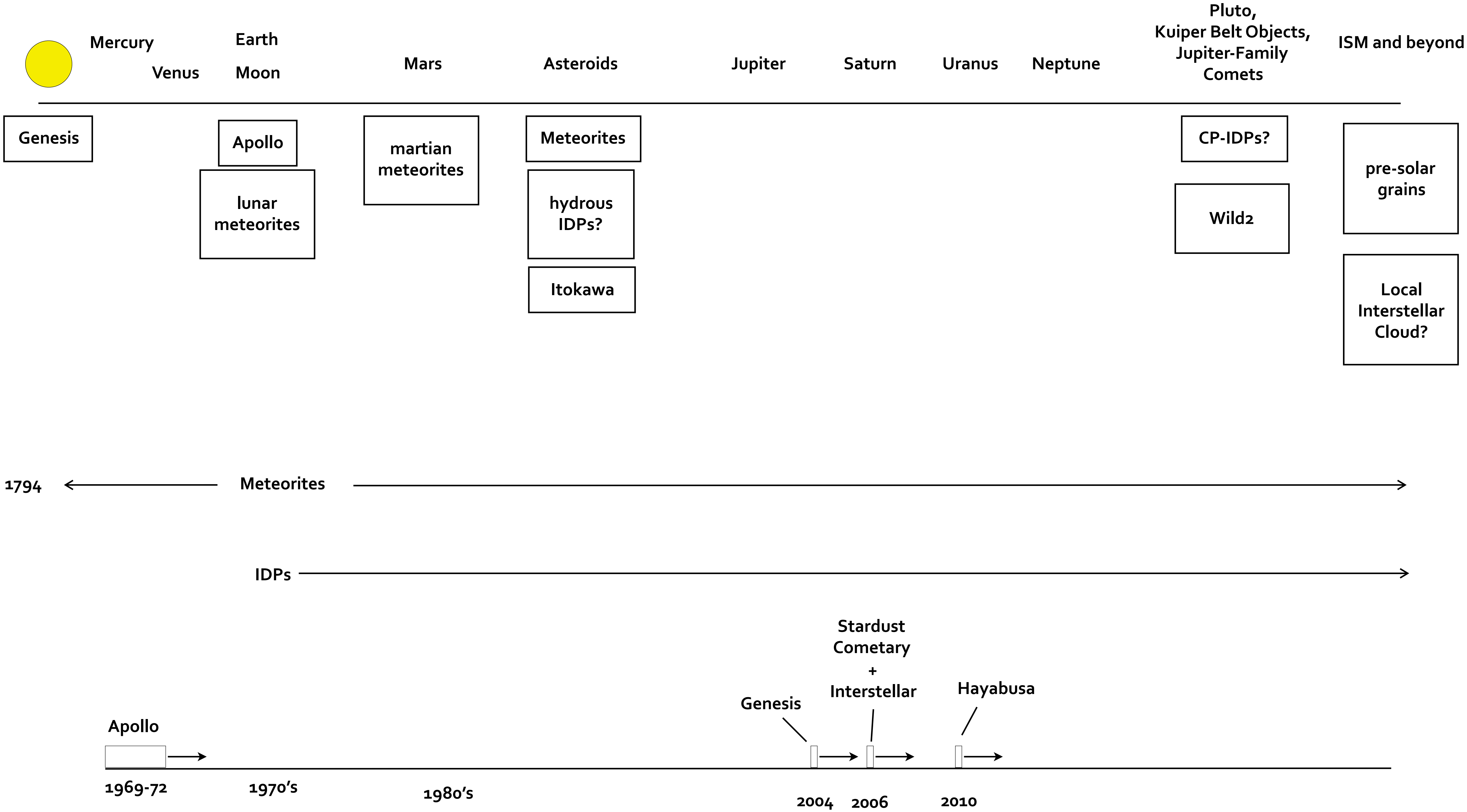

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ISM and beyond
Genesis
Apollo
lunar meteorites
martian meteorites
Meteorites
hydrous IDPs?
Itokawa
CP-IDPs?
Wild2
pre-solar grains
Local Interstellar Cloud?
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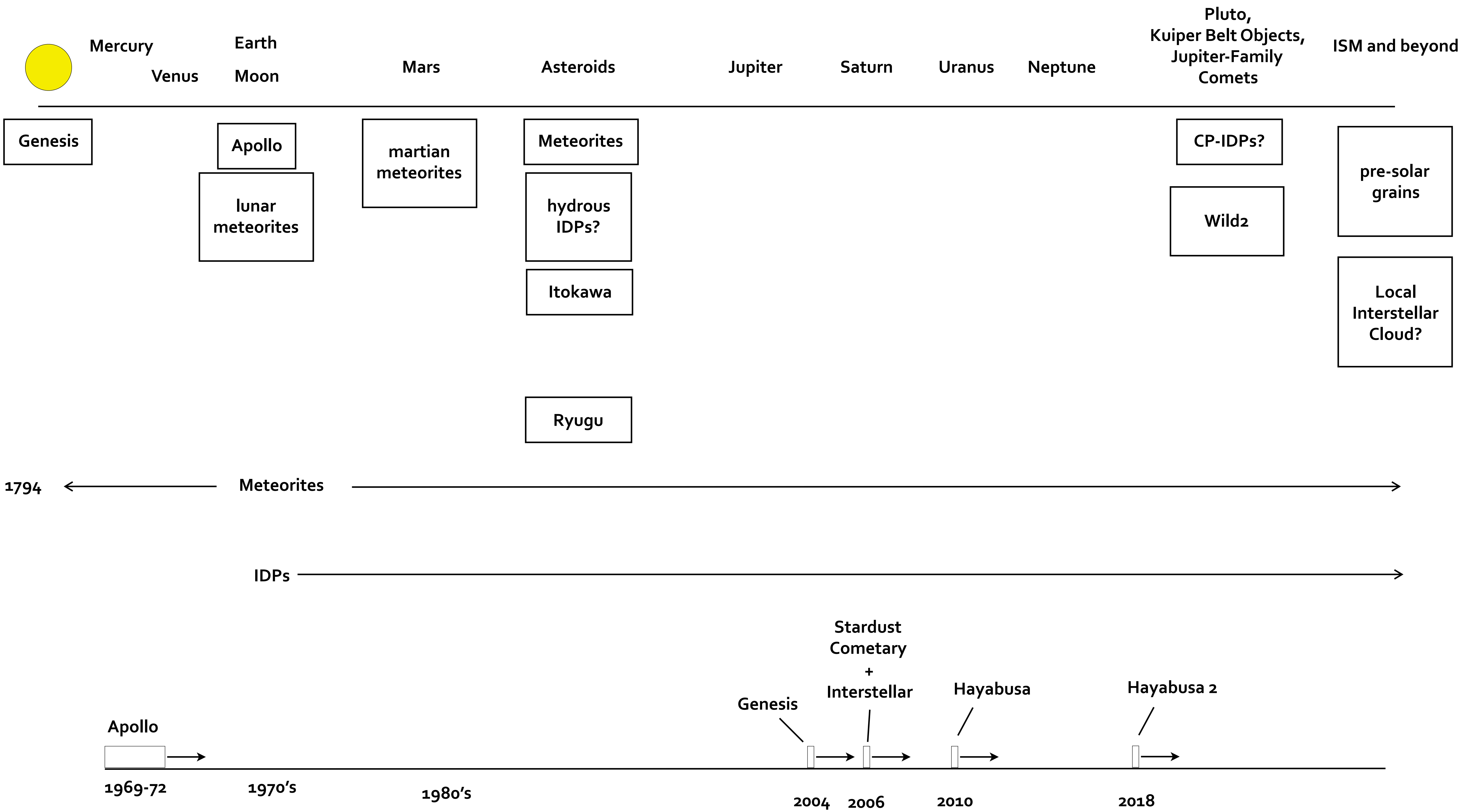
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ISM and beyond
Genesis
Apollo
lunar meteorites
martian meteorites
Meteorites
hydrous IDPs?
Itokawa
Ryugu
CP-IDPs?
Wild2
pre-solar grains
Local Interstellar Cloud?
1794
Meteorites
IDPs
Apollo
Genesis
Stardust Cometary + Interstellar
Hayabusa
Hayabusa 2
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1970's
1980's
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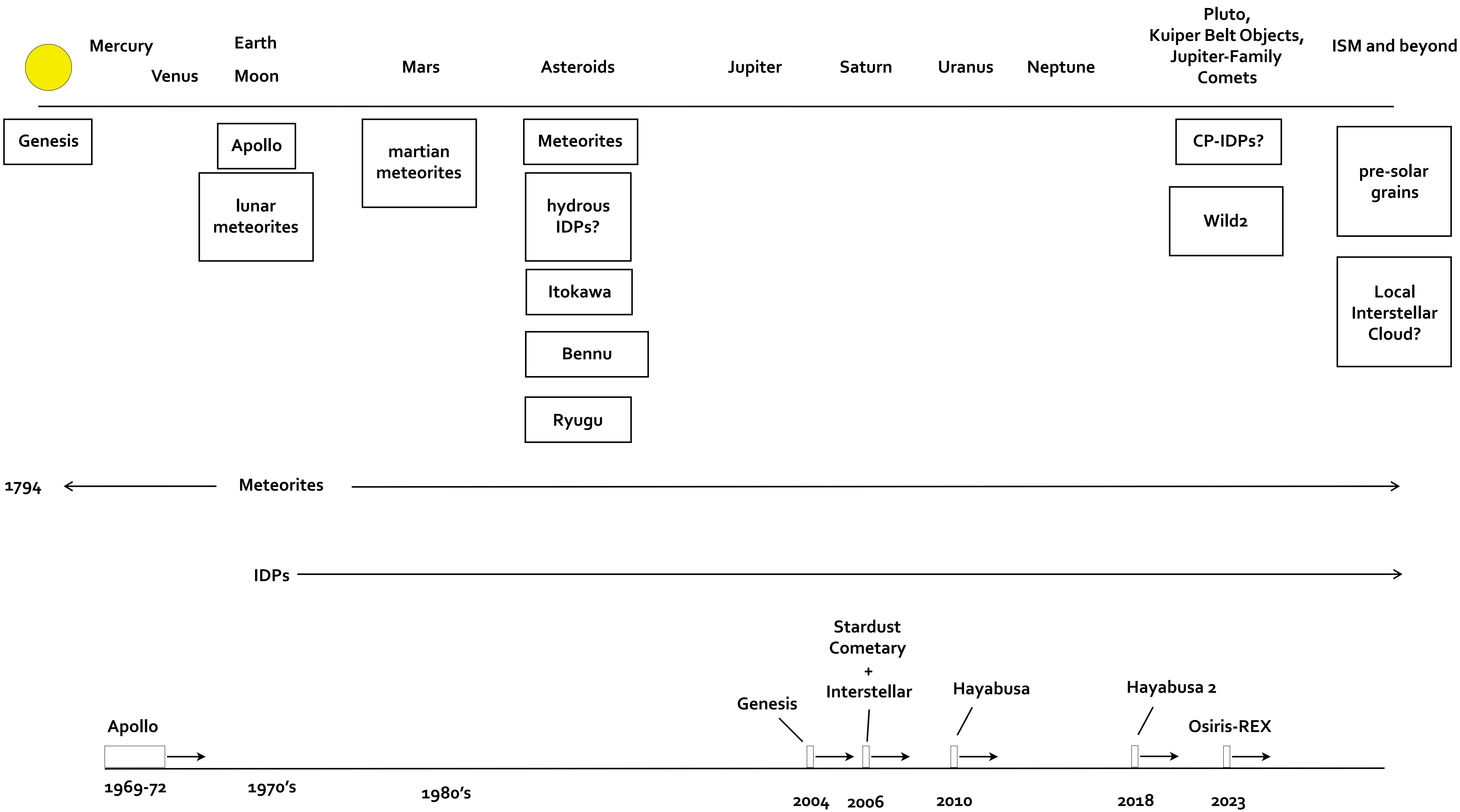
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ISM and beyond
Genesis
Apollo
lunar meteorites
martian meteorites
Meteorites
hydrous IDPs?
Itokawa
Bennu
Ryugu
CP-IDPs?
Wild2
pre-solar grains
Local Interstellar Cloud?
1794
Meteorites
IDPs
Apollo
Genesis
Stardust Cometary + Interstellar
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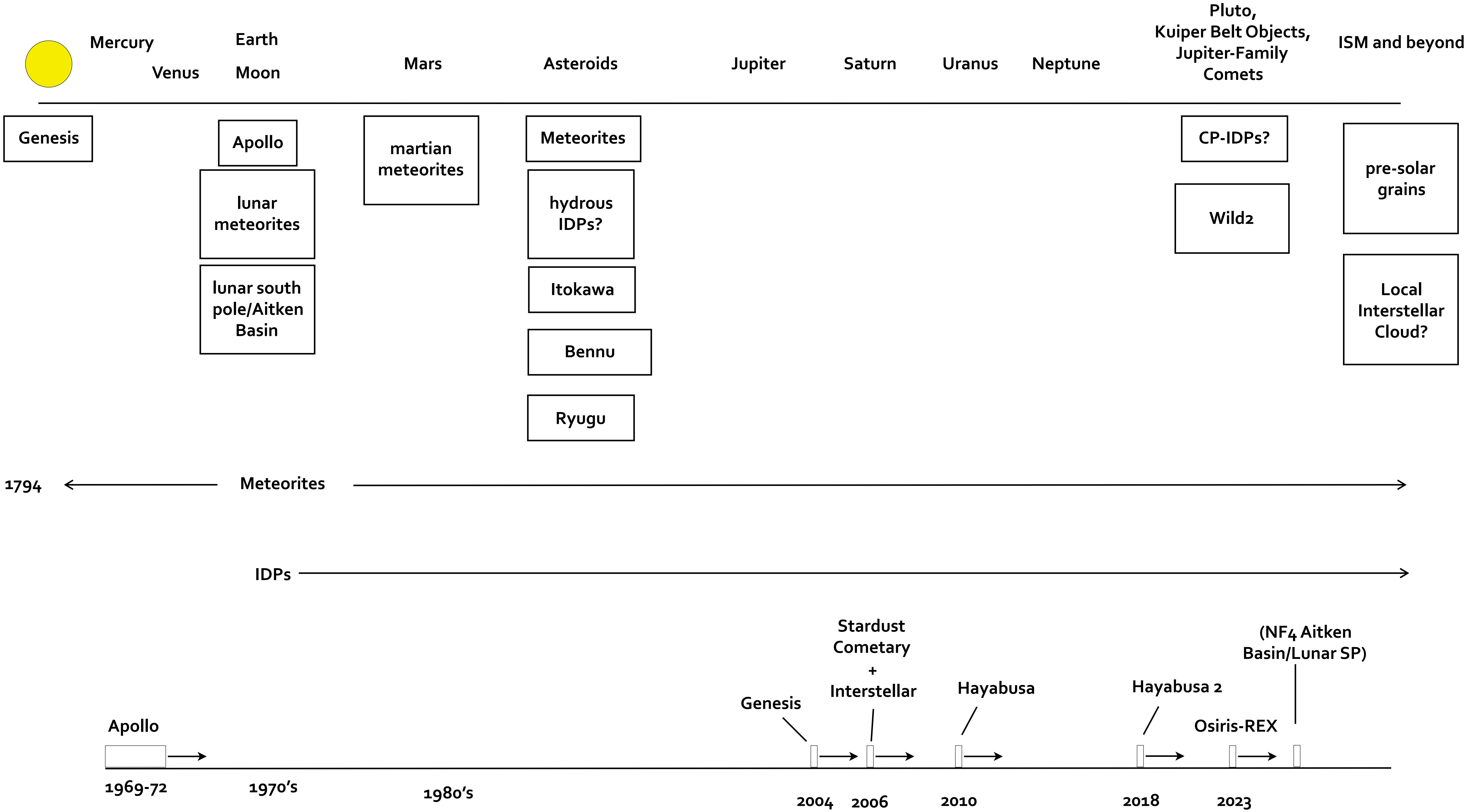
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Comets
ISM and beyond
Genesis
Apollo
lunar meteorites
lunar south pole/Aitken Basin
martian meteorites
Meteorites
hydrous IDPs?
Itokawa
Bennu
Ryugu
CP-IDPs?
Wild2
pre-solar grains
Local Interstellar Cloud?
1794
Meteorites
IDPs
Apollo
Genesis
Stardust Cometary + Interstellar
Hayabusa
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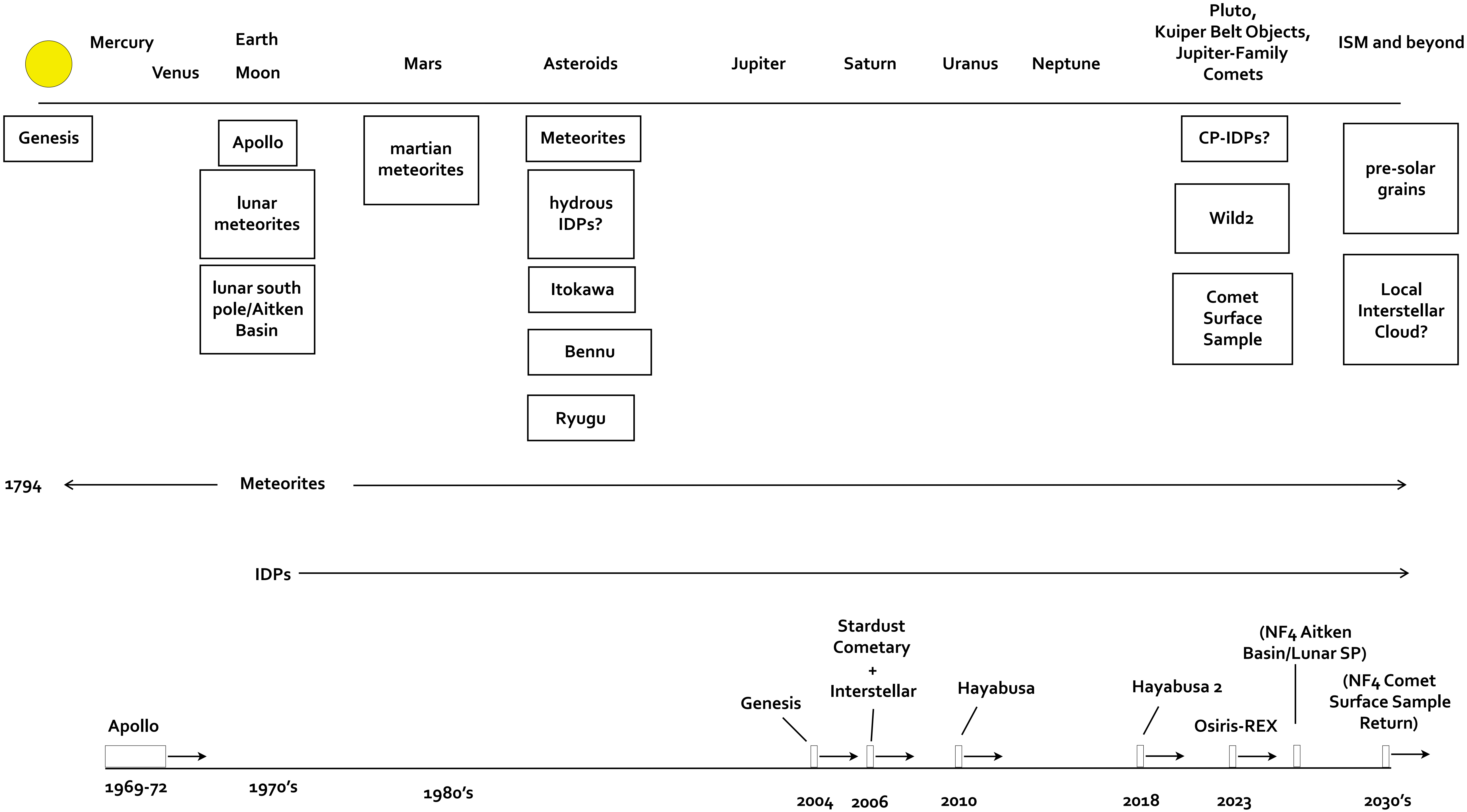
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ISM and beyond
Genesis
Apollo
lunar meteorites
lunar south pole/Aitken Basin
martian meteorites
Meteorites
hydrous IDPs?
Itokawa
Bennu
Ryugu
CP-IDPs?
Wild2
Comet Surface Sample
pre-solar grains
Local Interstellar Cloud?
1794
Meteorites
IDPs
Apollo
Genesis
Stardust Cometary + Interstellar
Hayabusa
Hayabusa 2
Osiris-REX
(NF4 Aitken Basin/Lunar SP)
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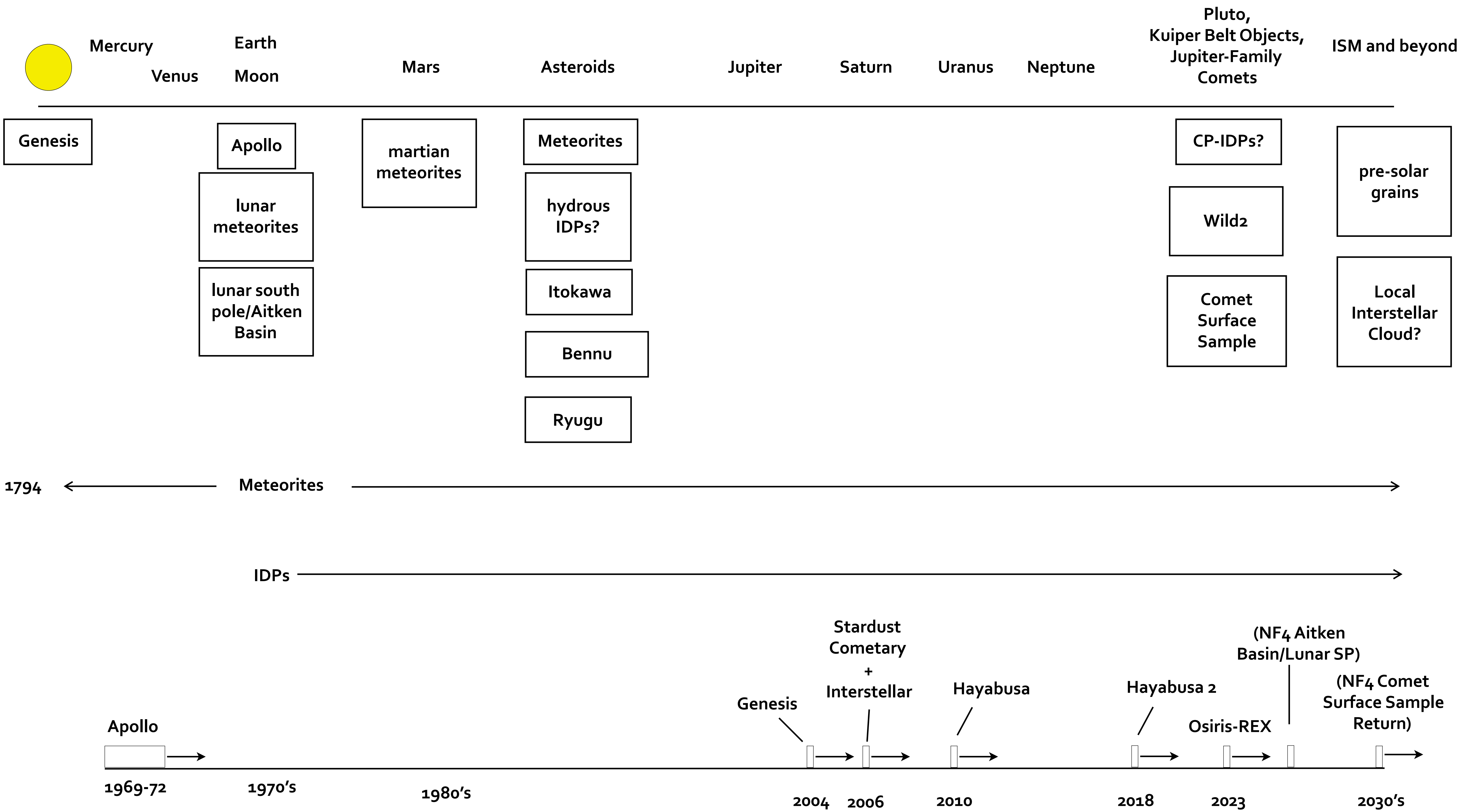

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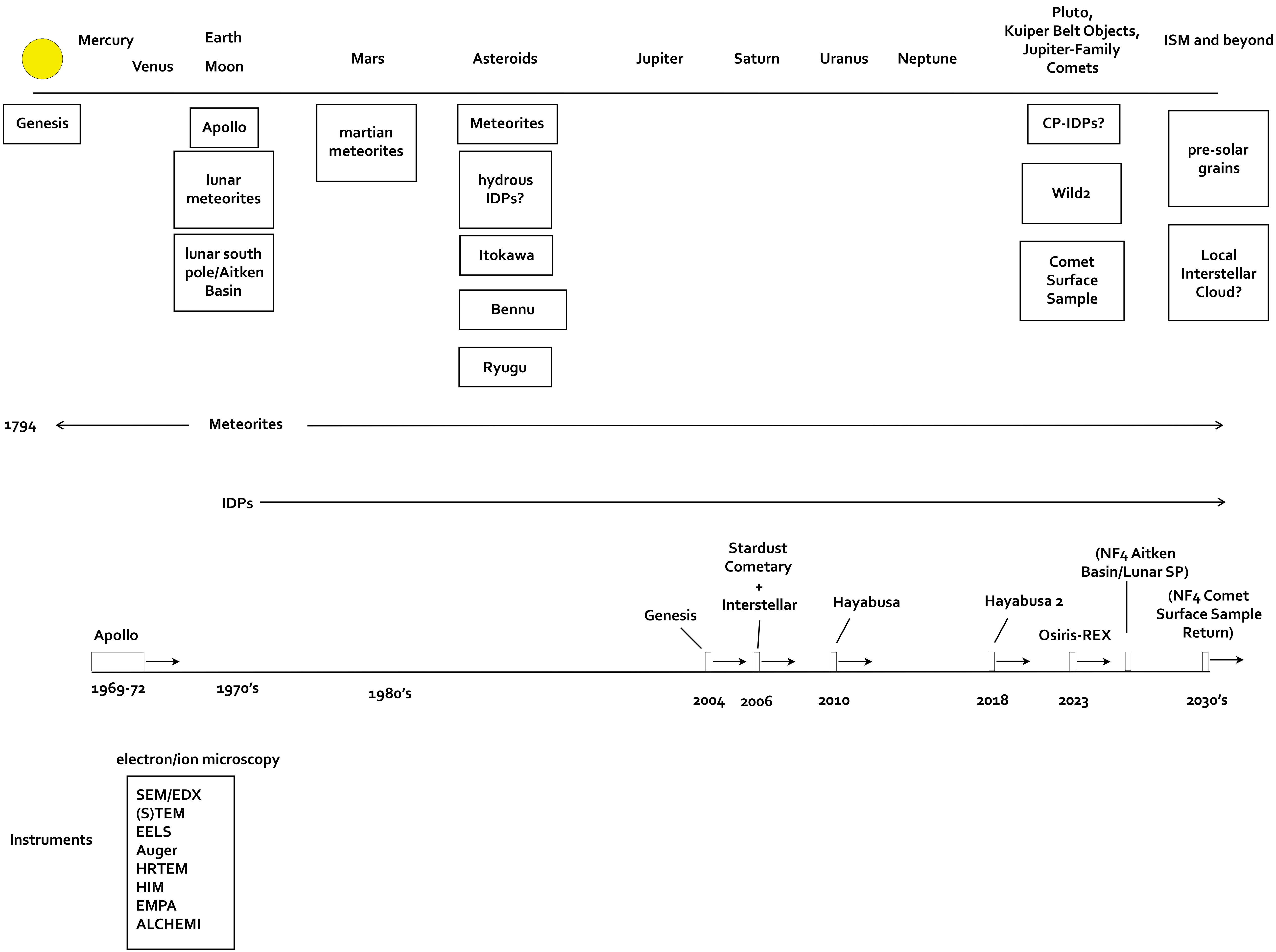
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ISM and beyond
Genesis
Apollo
lunar meteorites
lunar south pole/Aitken Basin
martian meteorites
Meteorites
hydrous IDPs?
Itokawa
Bennu
Ryugu
CP-IDPs?
Wild2
Comet Surface Sample
pre-solar grains
Local Interstellar Cloud?
1794
Meteorites
IDPs
Apollo
Genesis
Stardust Cometary + Interstellar
Hayabusa
Hayabusa 2
Osiris-REX
(NF4 Aitken Basin/Lunar SP)
(NF4 Comet Surface Sample Return)
1969-72
1970's
1980's
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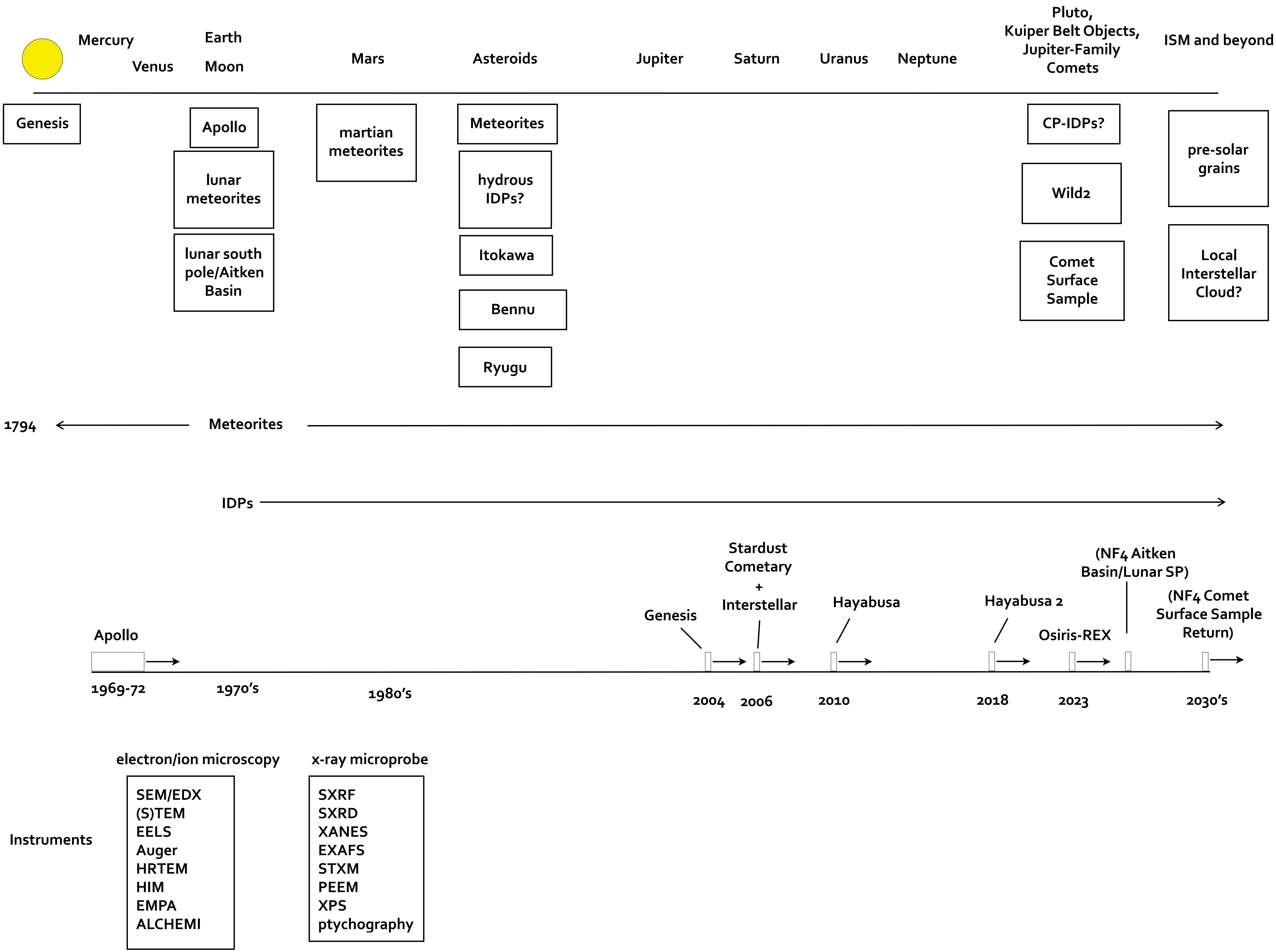
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ISM and beyond
Genesis
Apollo
lunar meteorites
lunar south pole/Aitken Basin
martian meteorites
Meteorites
hydrous IDPs?
Itokawa
Bennu
Ryugu
CP-IDPs?
Wild2
Comet Surface Sample
pre-solar grains
Local Interstellar Cloud?
1794
Meteorites
IDPs
Apollo
Genesis
Stardust Cometary + Interstellar
Hayabusa
Hayabusa 2
Osiris-REX
(NF4 Aitken Basin/Lunar SP)
(NF4 Comet Surface Sample Return)
1969-72
1970's
1980's
2004
2006
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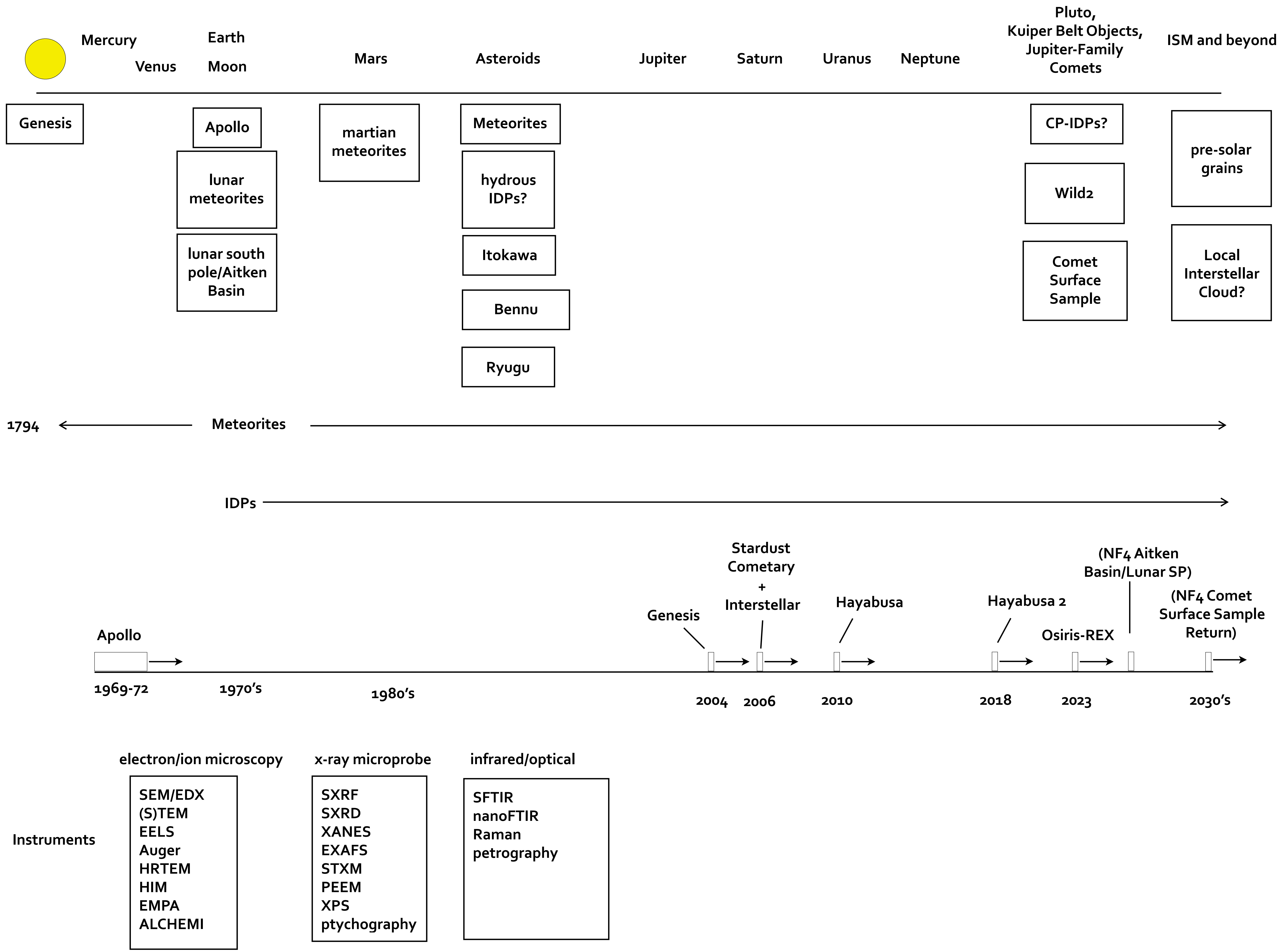
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ISM and beyond
Genesis
Apollo
lunar meteorites
lunar south pole/Aitken Basin
martian meteorites
Meteorites
hydrous IDPs?
Itokawa
Bennu
Ryugu
CP-IDPs?
Wild2
Comet Surface Sample
pre-solar grains
Local Interstellar Cloud?
1794
Meteorites
IDPs
Apollo
Genesis
Stardust Cometary + Interstellar
Hayabusa
Hayabusa 2
Osiris-REX
(NF4 Aitken Basin/Lunar SP)
(NF4 Comet Surface Sample Return)
1969-72
1970's
1980's
2004
2006
2010
2018
2023
2030's
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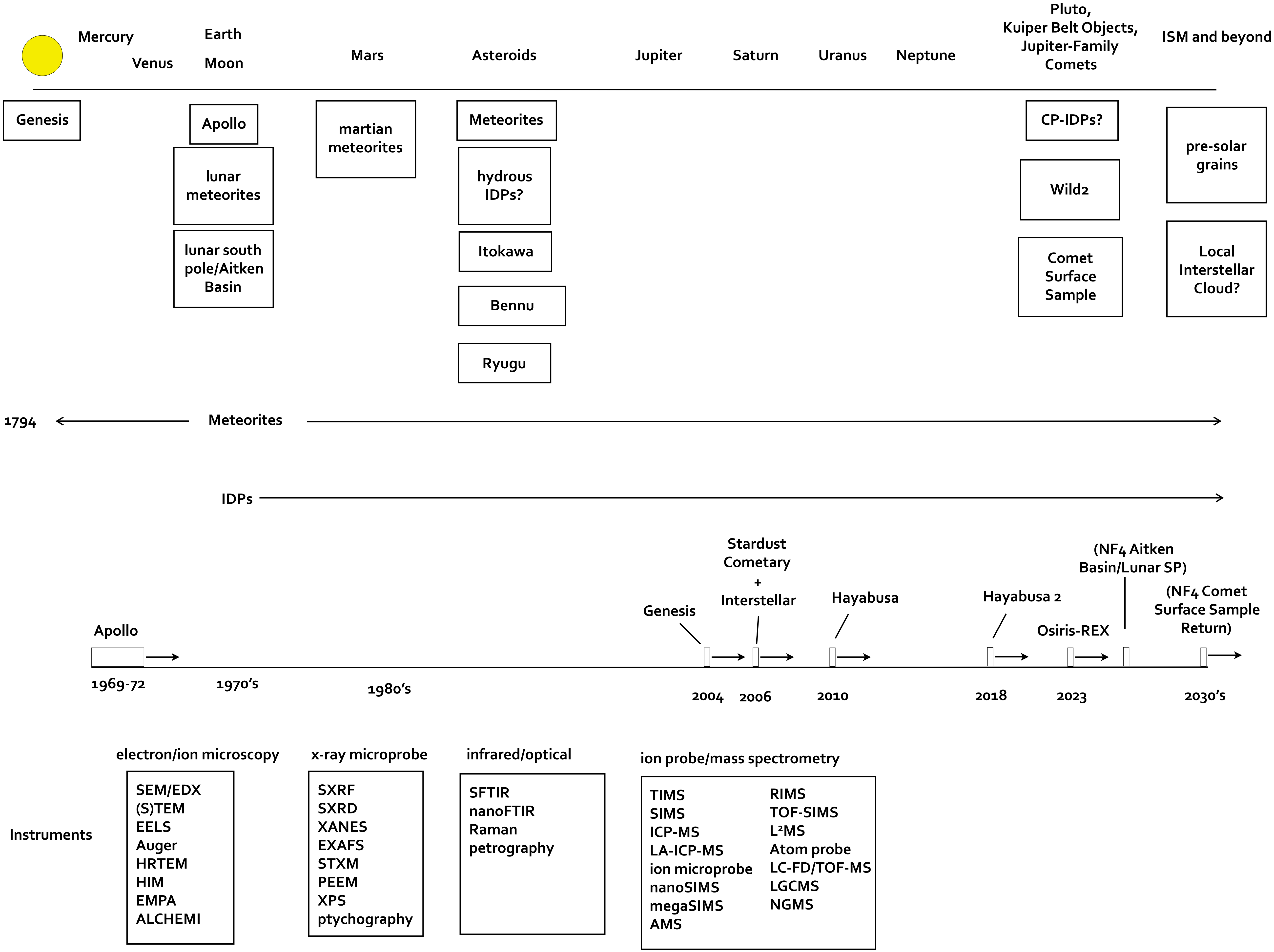
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ISM and beyond
Genesis
Apollo
lunar meteorites
lunar south pole/Aitken Basin
martian meteorites
Meteorites
hydrous IDPs?
Itokawa
Bennu
Ryugu
CP-IDPs?
Wild2
Comet Surface Sample
pre-solar grains
Local Interstellar Cloud?
1794
Meteorites
IDPs
Stardust Cometary + Interstellar
(NF4 Aitken Basin/Lunar SP)
Genesis
Hayabusa
Hayabusa 2
(NF4 Comet Surface Sample Return)
Apollo
Osiris-REX
1969-72
1970's
1980's
2004
2006
2010
2018
2023
2030's
electron/ion microscopy
x-ray microprobe
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Instruments
SEM/EDX
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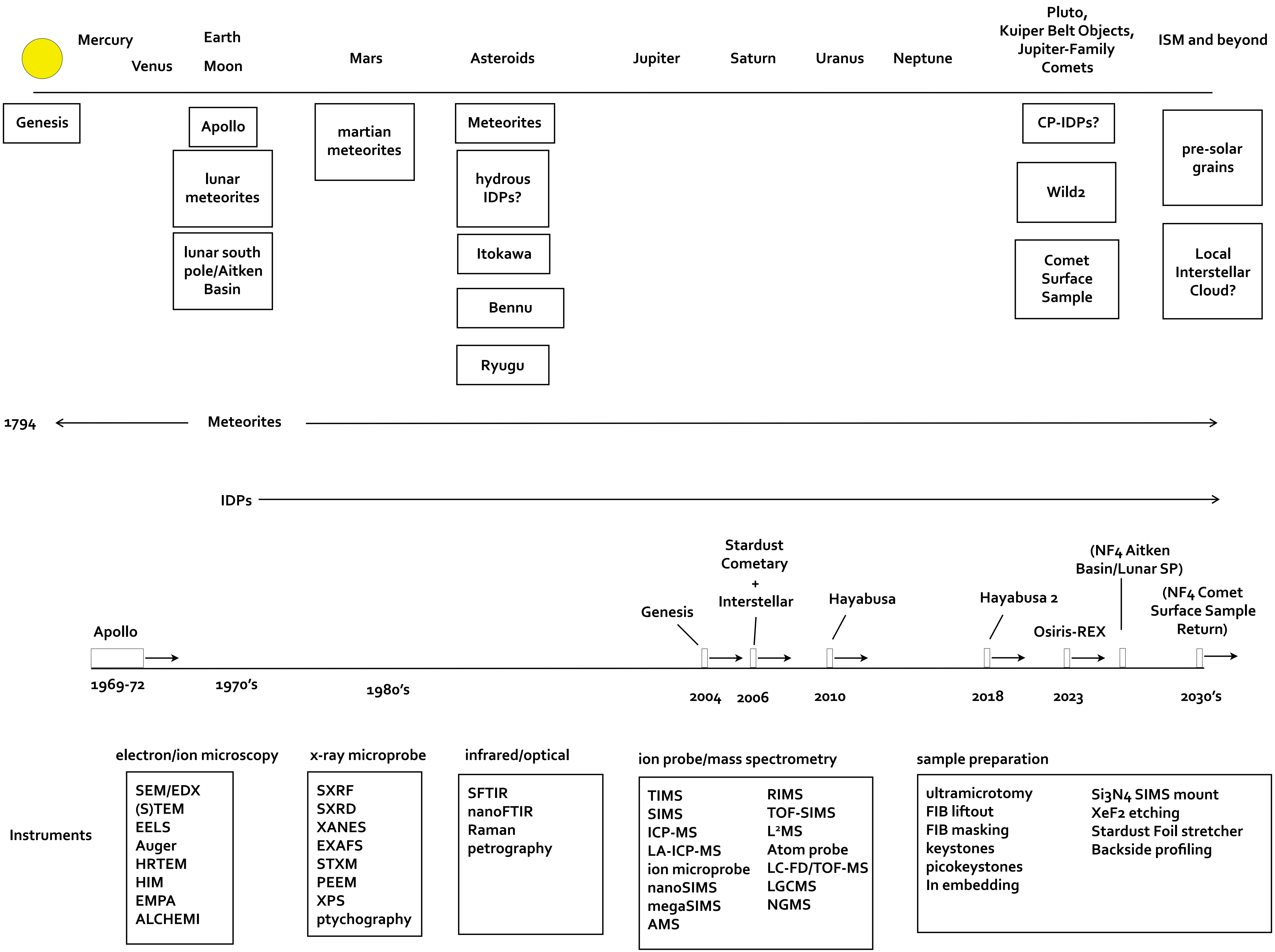

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Jupiter
Saturn
Uranus
Neptune
Pluto, Kuiper Belt Objects, Jupiter-Family Comets
ISM and beyond
Genesis
Apollo
lunar meteorites
lunar south pole/Aitken Basin
martian meteorites
Meteorites
hydrous IDPs?
Itokawa
Bennu
Ryugu
CP-IDPs?
Wild2
Comet Surface Sample
pre-solar grains
Local Interstellar Cloud?
1794
Meteorites
IDPs
Apollo
Genesis
Stardust Cometary + Interstellar
Hayabusa
Hayabusa 2
Osiris-REX
(NF4 Aitken Basin/Lunar SP)
(NF4 Comet Surface Sample Return)
1969-72
1970's
1980's
2004
2006
2010
2018
2023
2030's
Instruments
electron/ion microscopy
SEM/EDX
(S)TEM
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XeF2 etching
Stardust Foil stretcher
Backside profiling

Advantages of sample return

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Study samples for decades with high-cadence, adaptive, repeatable measurements on samples in the laboratory

Advantages of sample return

Advanced Photon Source at ANL

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Analyze planetary, interstellar and circumstellar materials with instruments that cannot be flown in space

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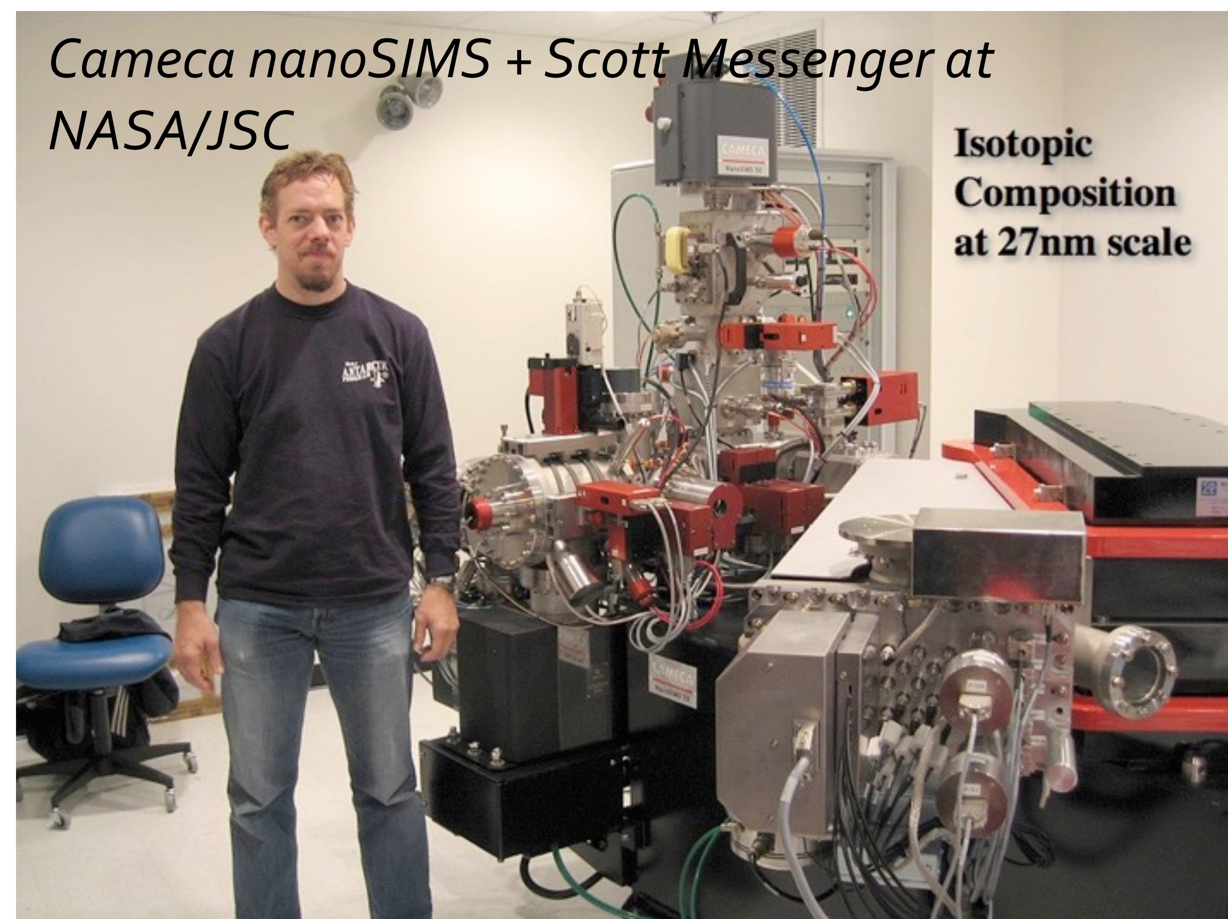
Advanced Photon Source at ANL



Cameca nanoSIMS + Scott Messenger at NASA/JSC

Advantages of sample return

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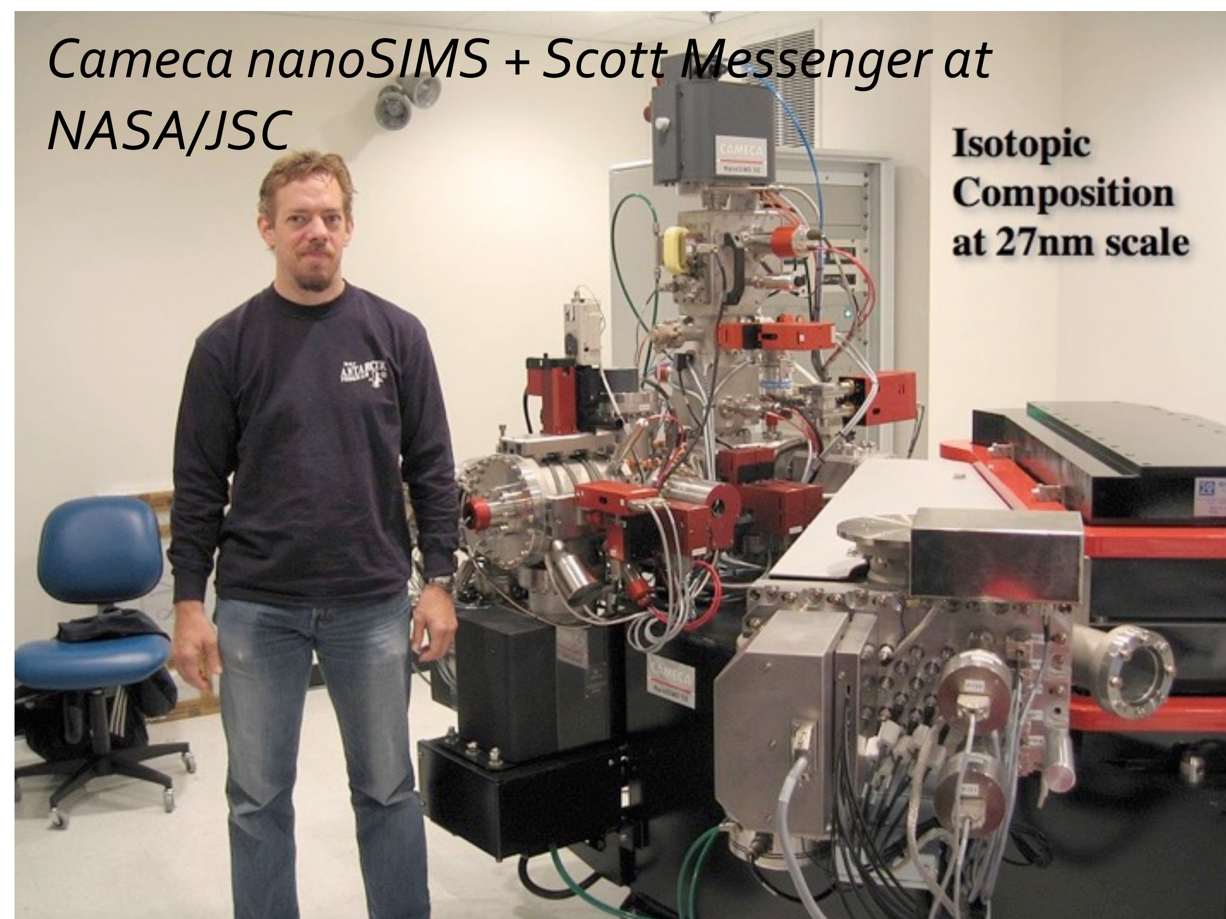
Sets stage for new questions to be addressed by new missions

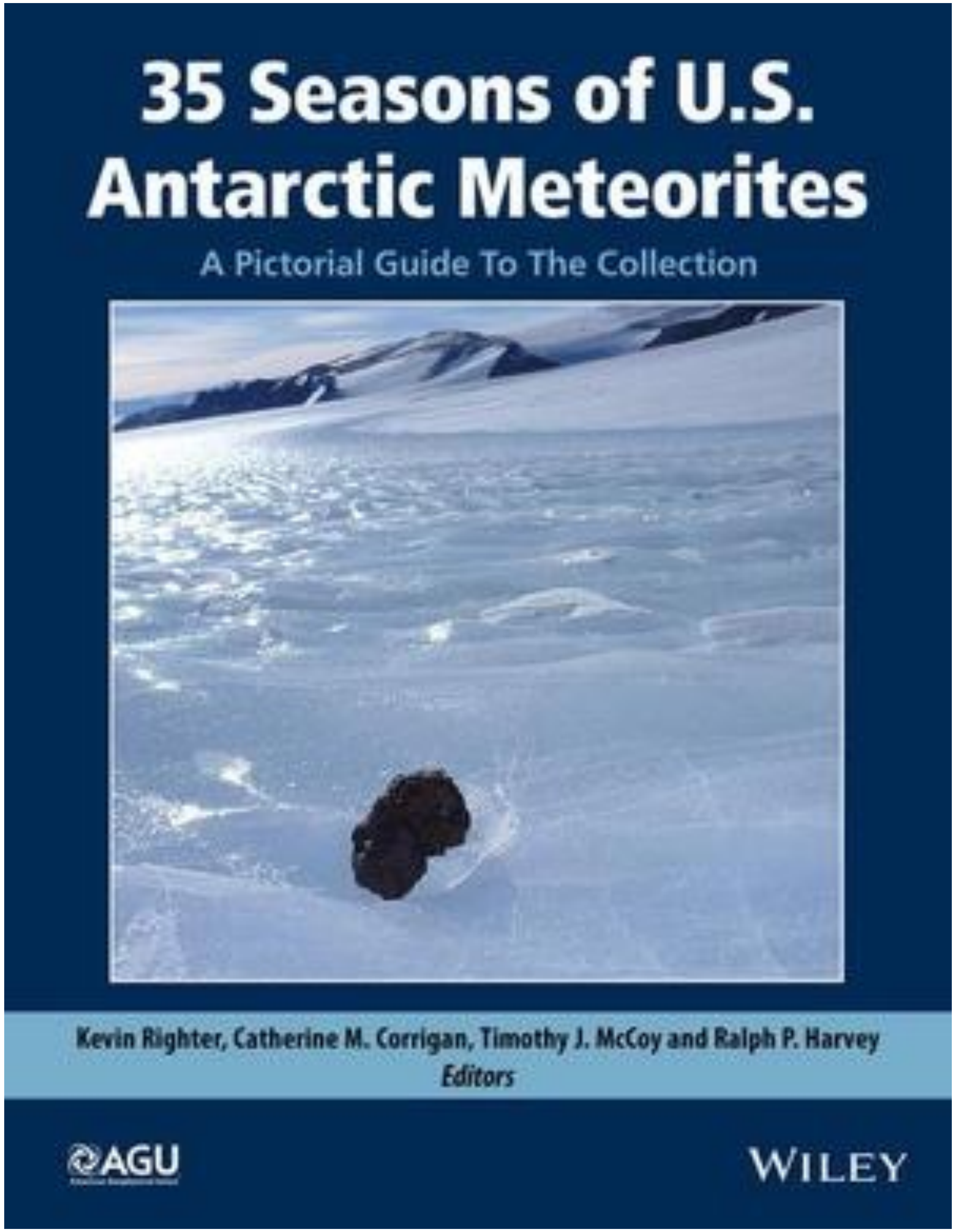
Advanced Photon Source at ANL



Cameca nanoSIMS + Scott Messenger at NASA/JSC

Antarctic Meteorite Collection

- In the 37 US expeditions since 1977, ***20,700*** meteorites have been collected.
- **>10,000** publications have resulted from research on ANSMET specimens, including papers, abstracts, books, dissertations, etc.
- Currently, around **100 proposals** for sample loans are received annually.
- Currently, around **700-800 specimens** (subsamples of meteorites) are prepared and loaned to investigators annually.

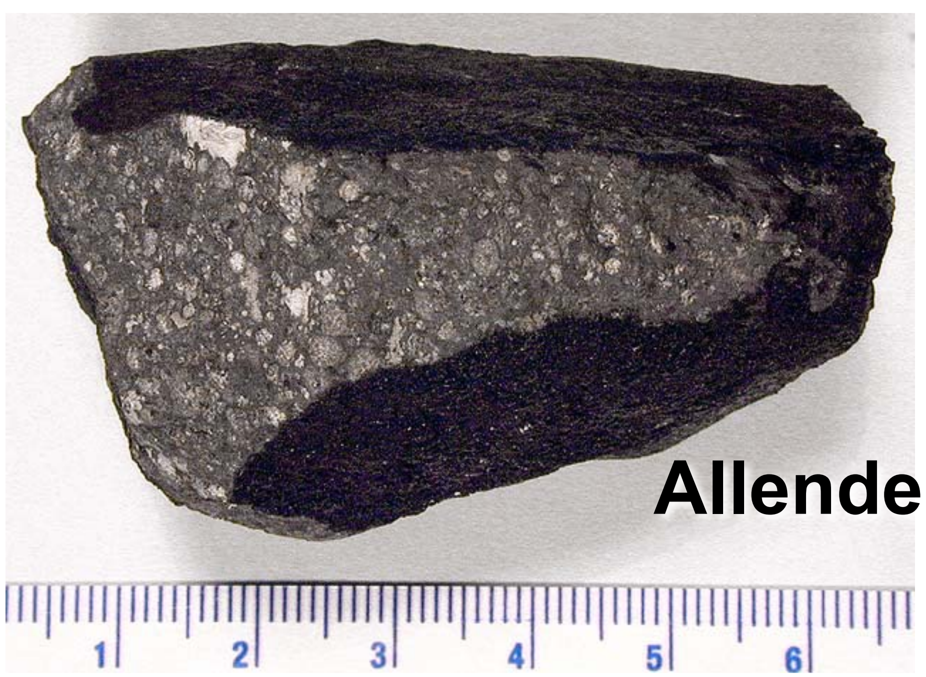


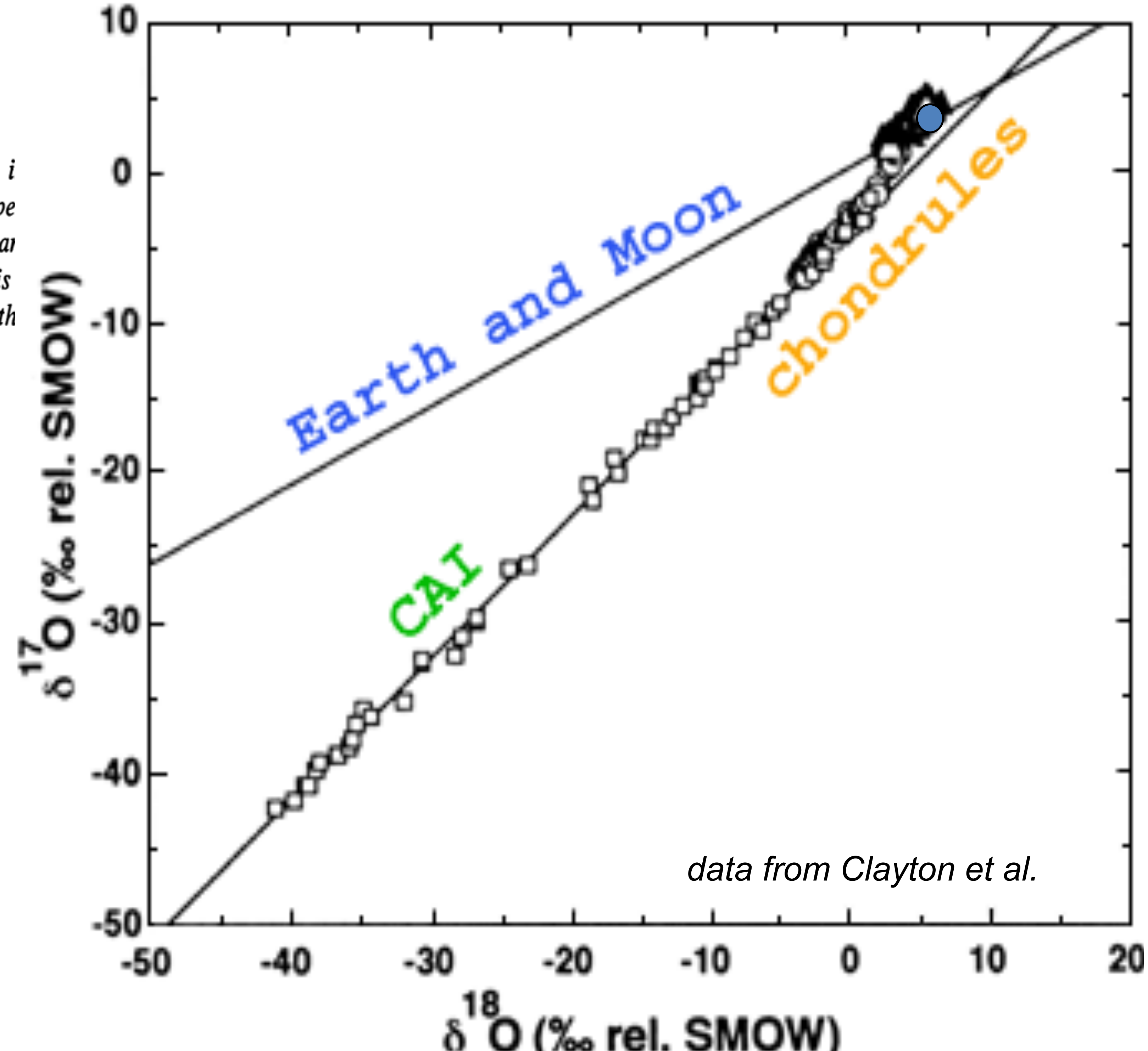
Discovery of oxygen isotope anomalies

A Component of Primitive Nuclear Composition in Carbonaceous Meteorites

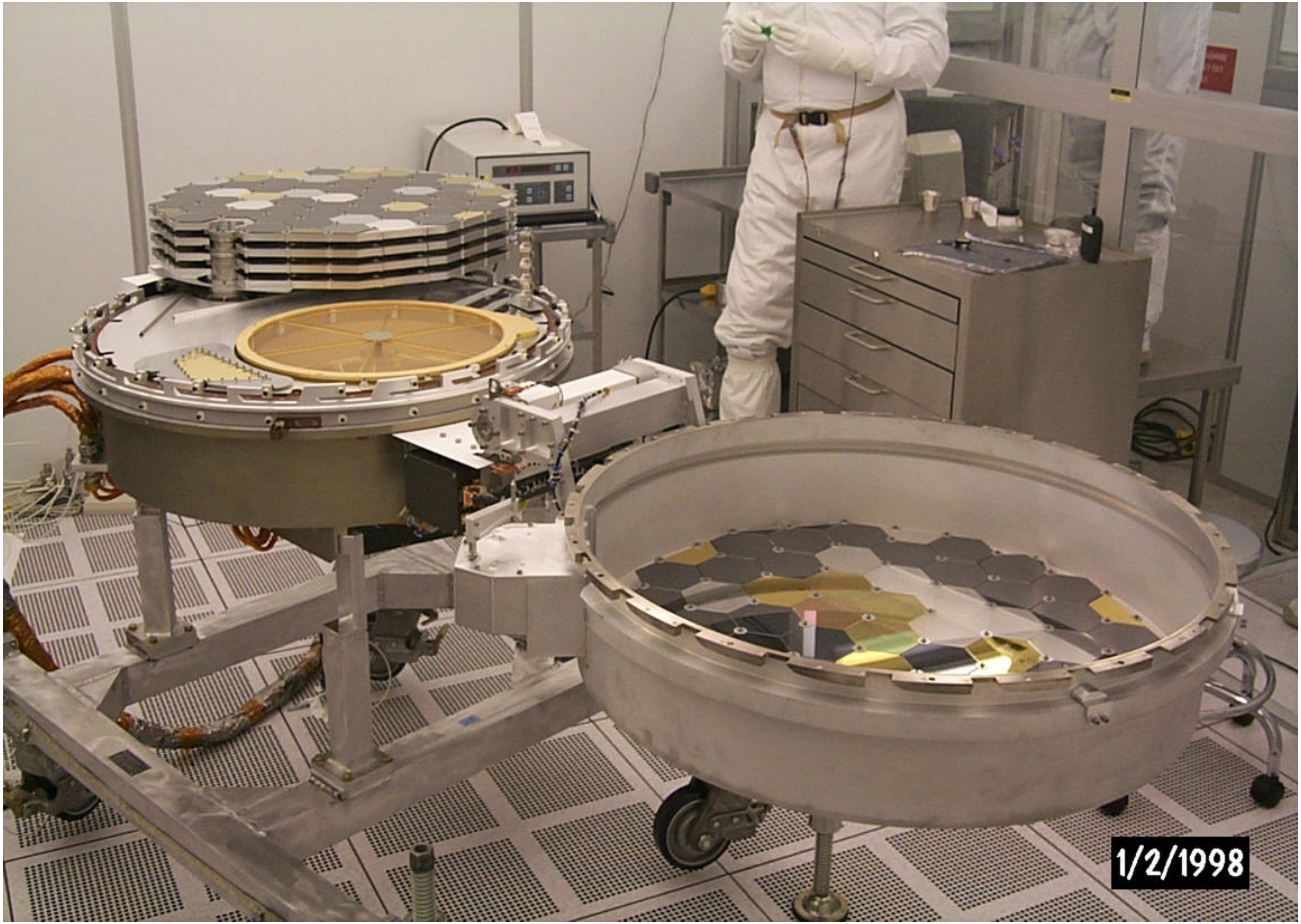
Abstract. *The oxygen of anhydrous, high-temperature minerals i ceous meteorites is strongly depleted in the heavy stable isotope ^{18}O. The effect is the result of nuclear rather than chemical processes ai results from the admixture of a component of almost pure ^{16}O. This may predate the solar system and may represent interstellar dust with history of nucleosynthesis.*

Clayton, Grossman, Mayeda, 1973

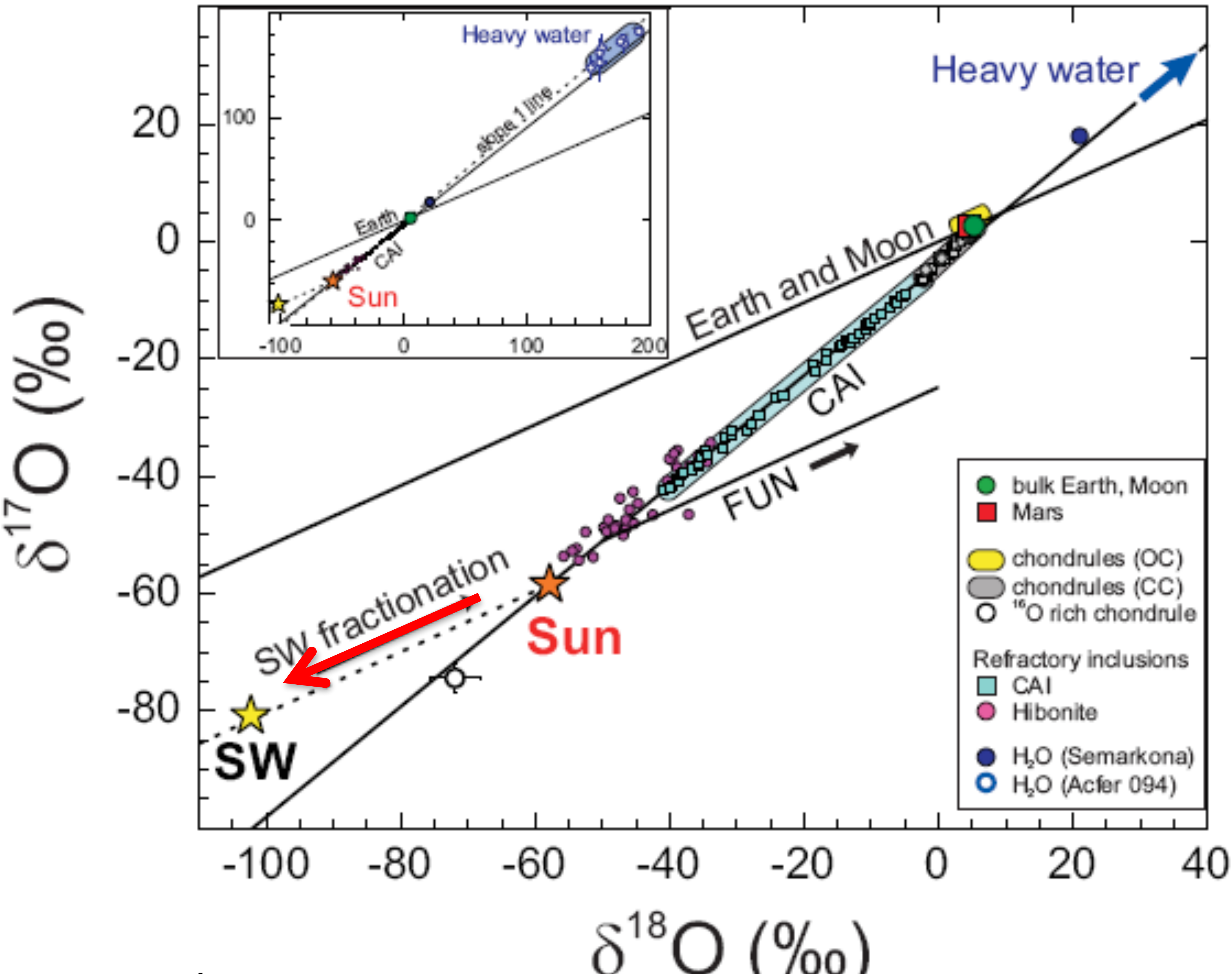




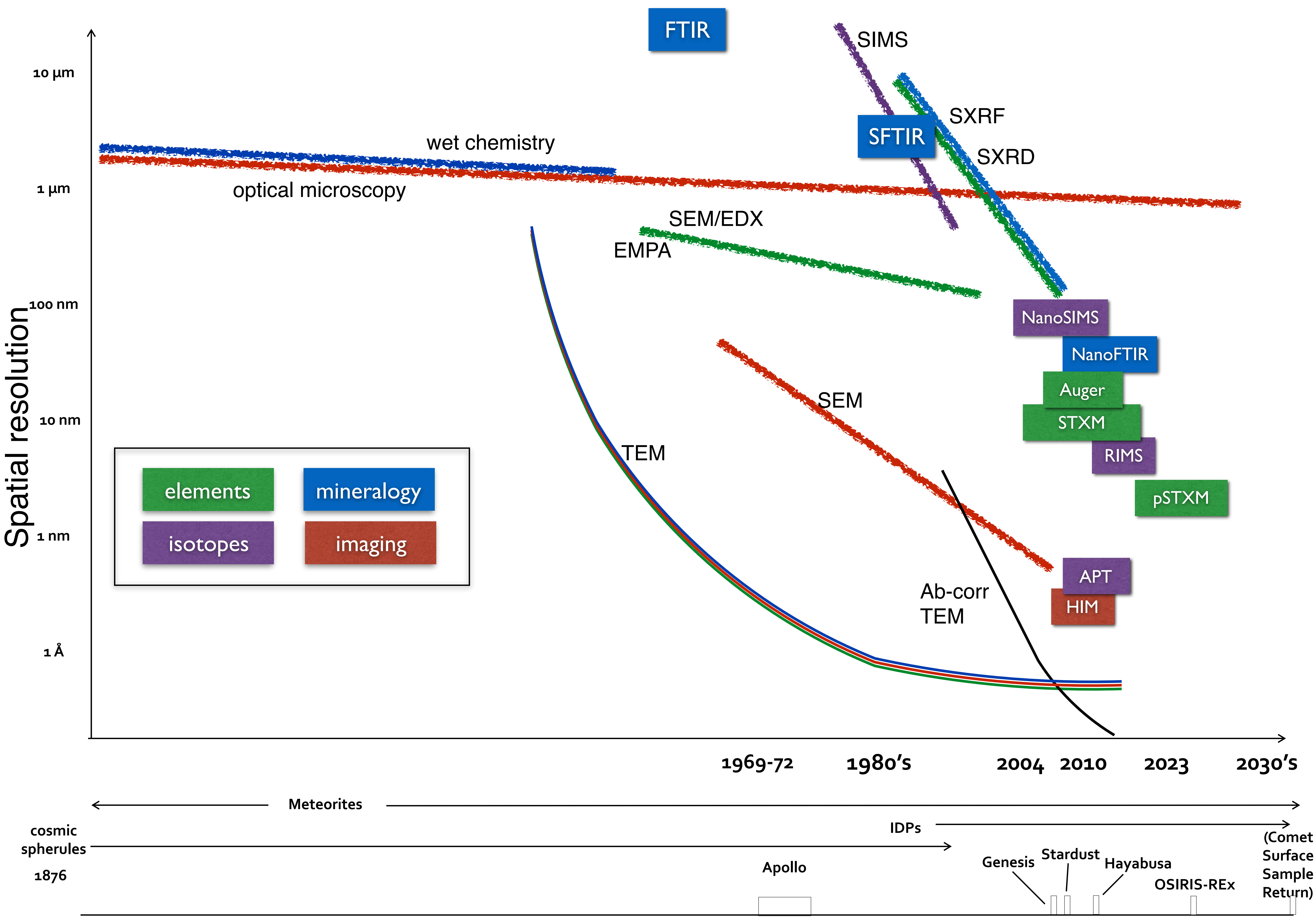
Genesis: Solar wind collection at L1



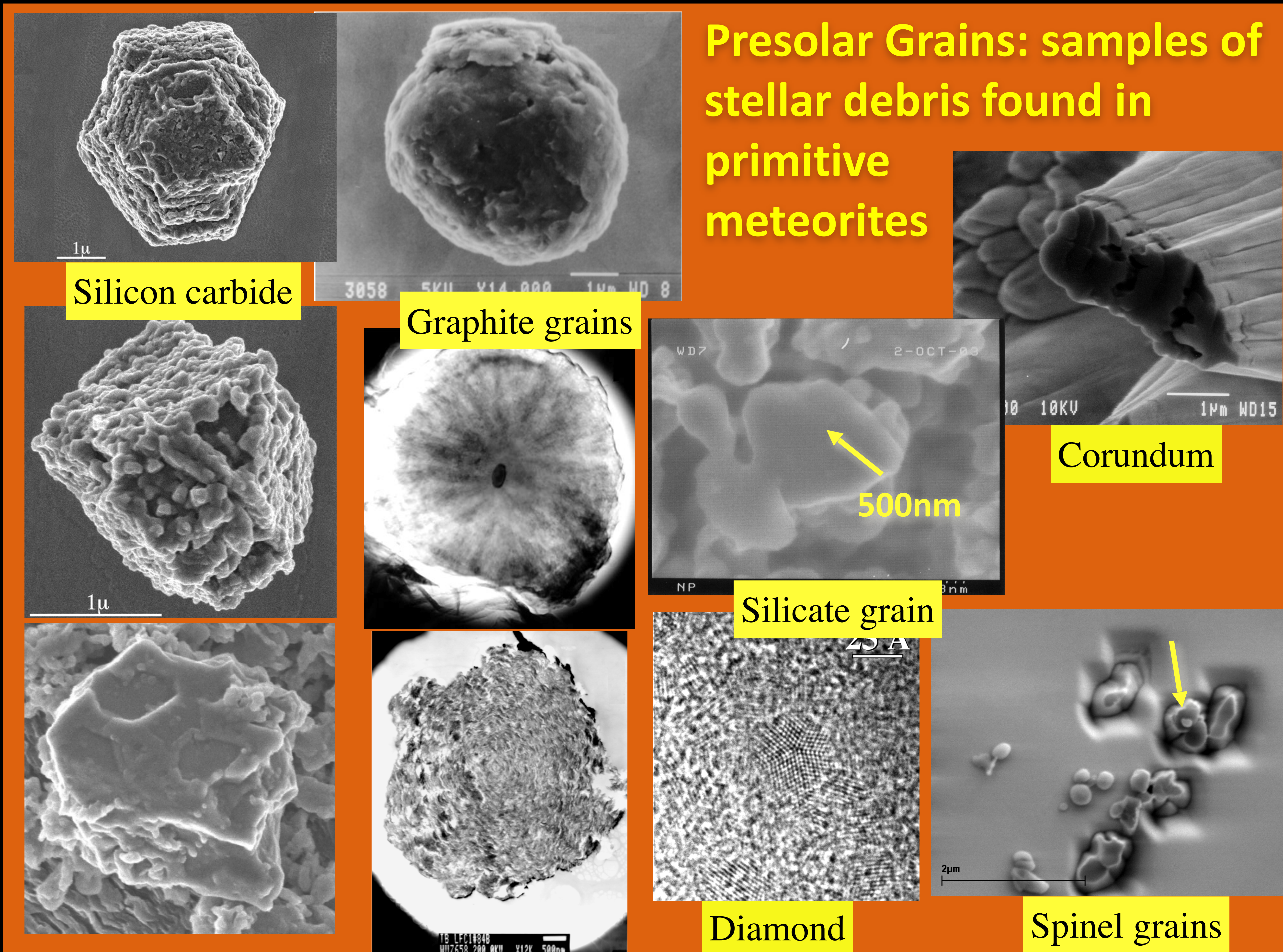
New map of solar system oxygen isotope compositions



McKeegan et al. 2011



FTIR
SIMS
SXRF
SFTIR
SXRD
wet chemistry
optical microscopy
SEM/EDX
EMPA
NanoSIMS
NanoFTIR
Auger
STXM
RIMS
pSTXM
SEM
TEM
Ab-corr
TEM
APT
HIM
elements
mineralogy
isotopes
imaging
Spatial resolution
10 µm
1 µm
100 nm
10 nm
1 nm
1 Å
1969-72
1980's
2004
2010
2023
2030's
Meteorites
cosmic
spherules
1876
IDPs
Apollo
Genesis
Stardust
Hayabusa
OSIRIS-REx
(Comet
Surface
Sample
Return)

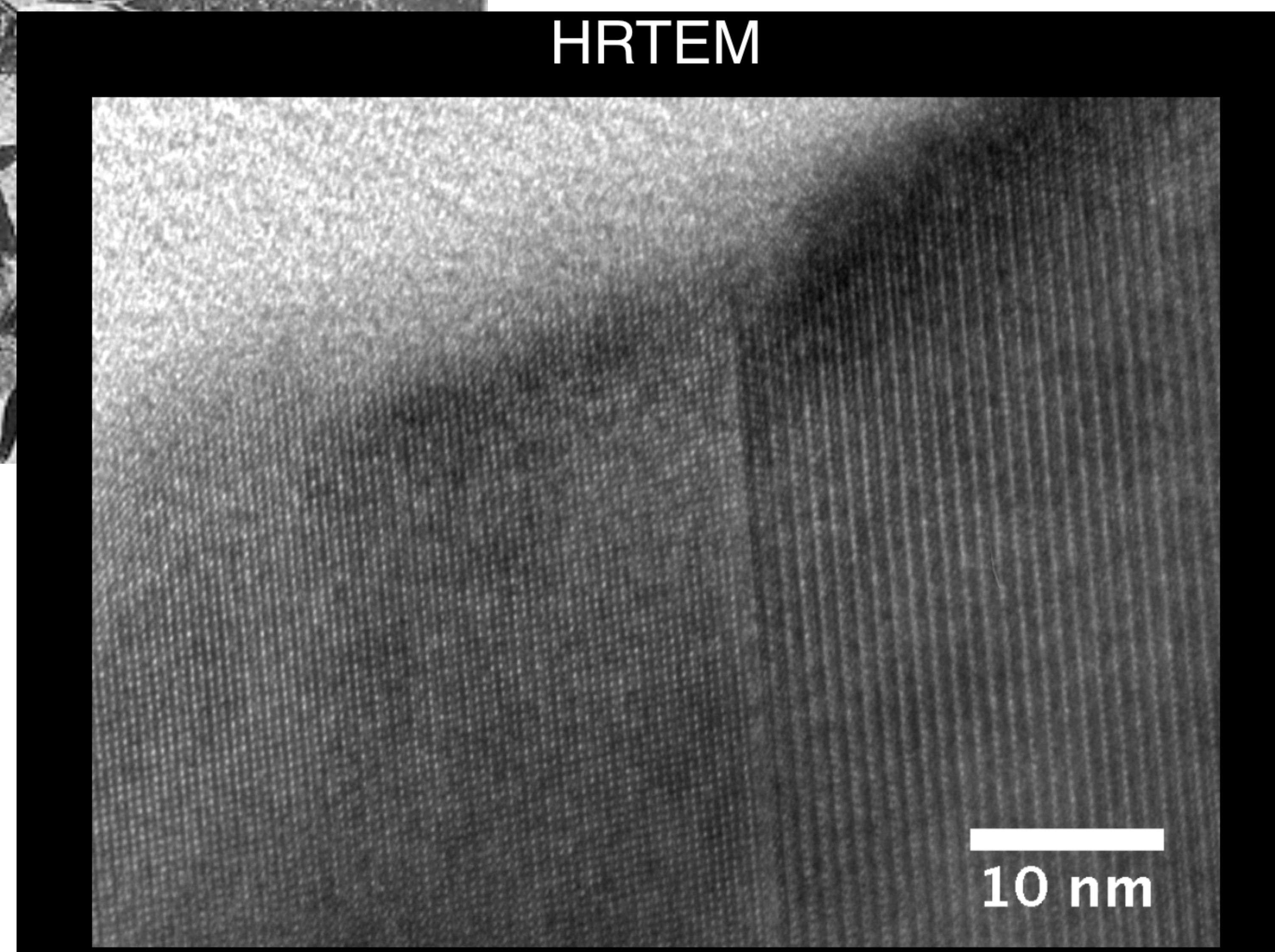


Presolar Grains: samples of stellar debris found in primitive meteorites
Silicon carbide
1μ
1μ
Graphite grains
3058
WD 8
Corundum
10KV
1μm WD15
WD7
2-OCT-03
500nm
NP
Silicate grain
Diamond
Spinel grains
2μm

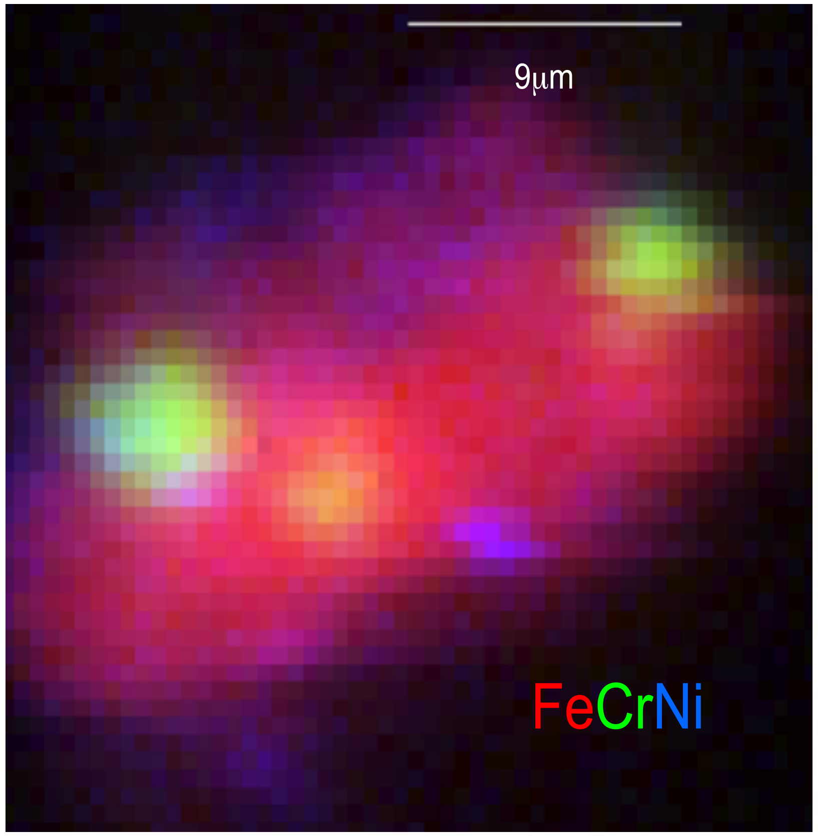
Progress in viewing comets

Great Comet of 1577

Progress in viewing comets



Iris and Jupiter

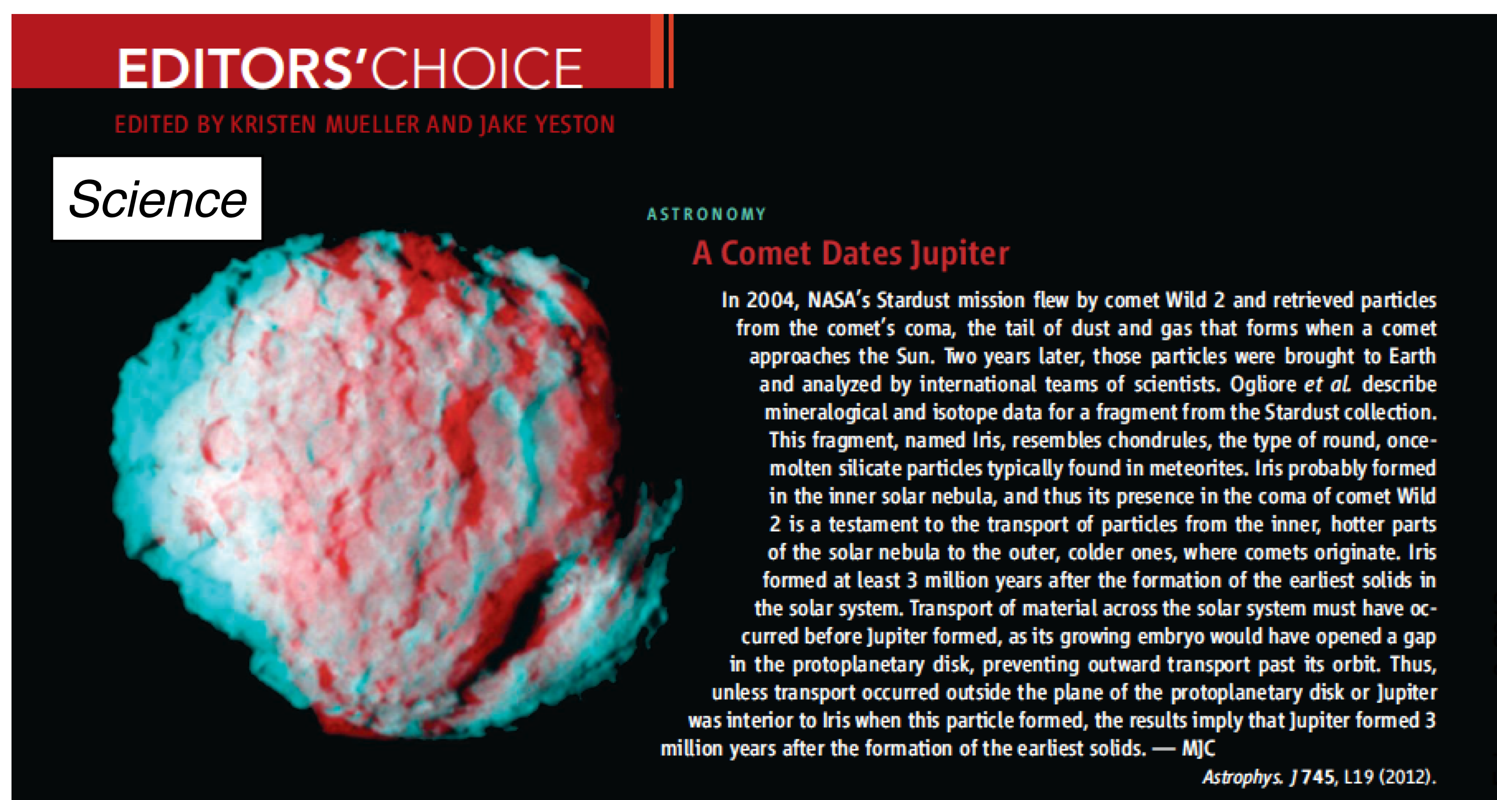


Analysis of the smallest particles tells us about the largest objects in the solar system

Required coordinated analysis by:

- keystoning sample prep
- petrographic microscopy
- synchrotron XRF
- synchrotron XANES
- synchrotron XRD
- ultramicrotomy
- analytical TEM
- FIB
- ion microprobe

… and >90% of the particle is still pristine for future generations


EDITORS' CHOICE

EDITED BY KRISTEN MUELLER AND JAKE YESTON

Science

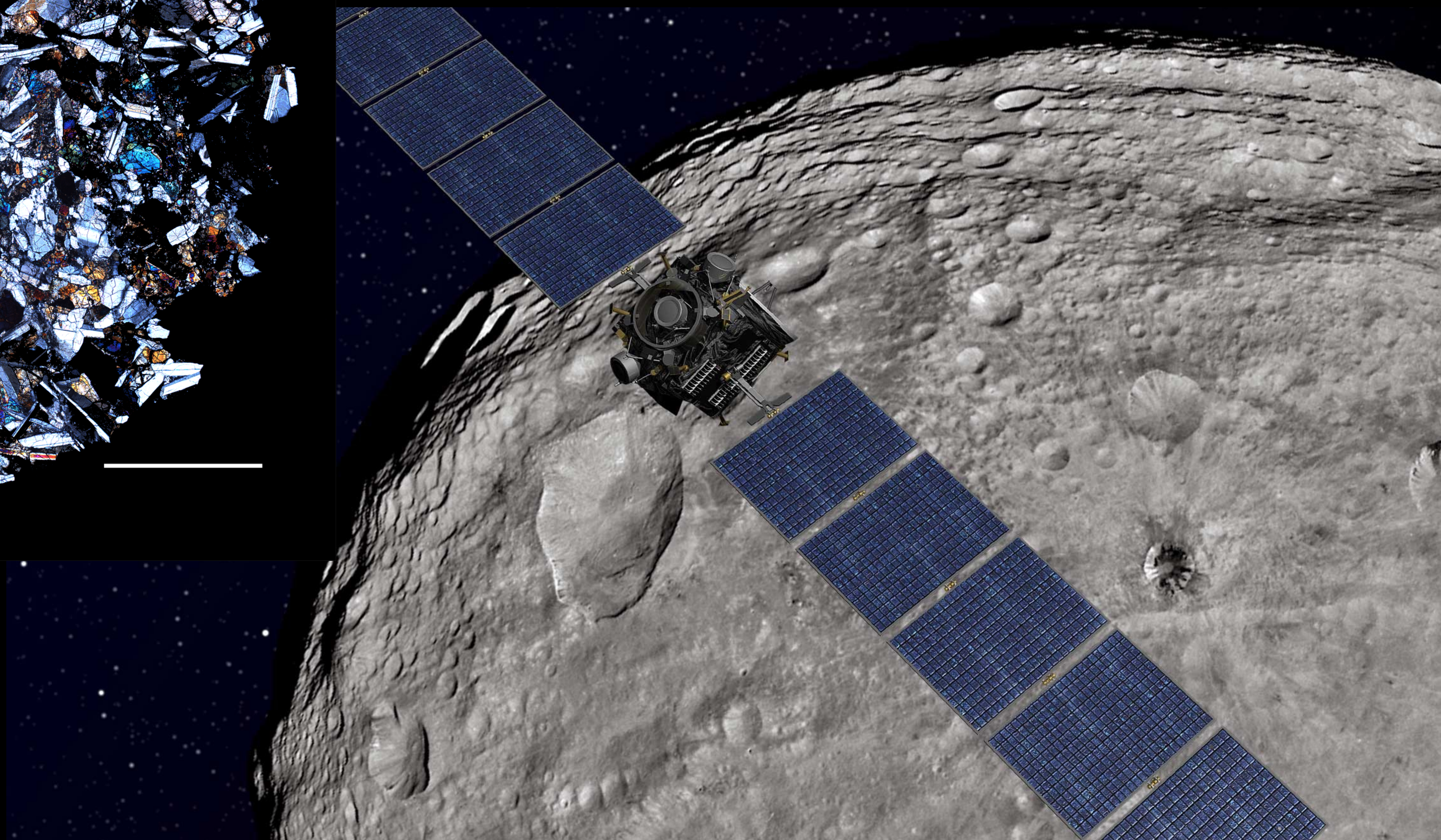
ASTRONOMY

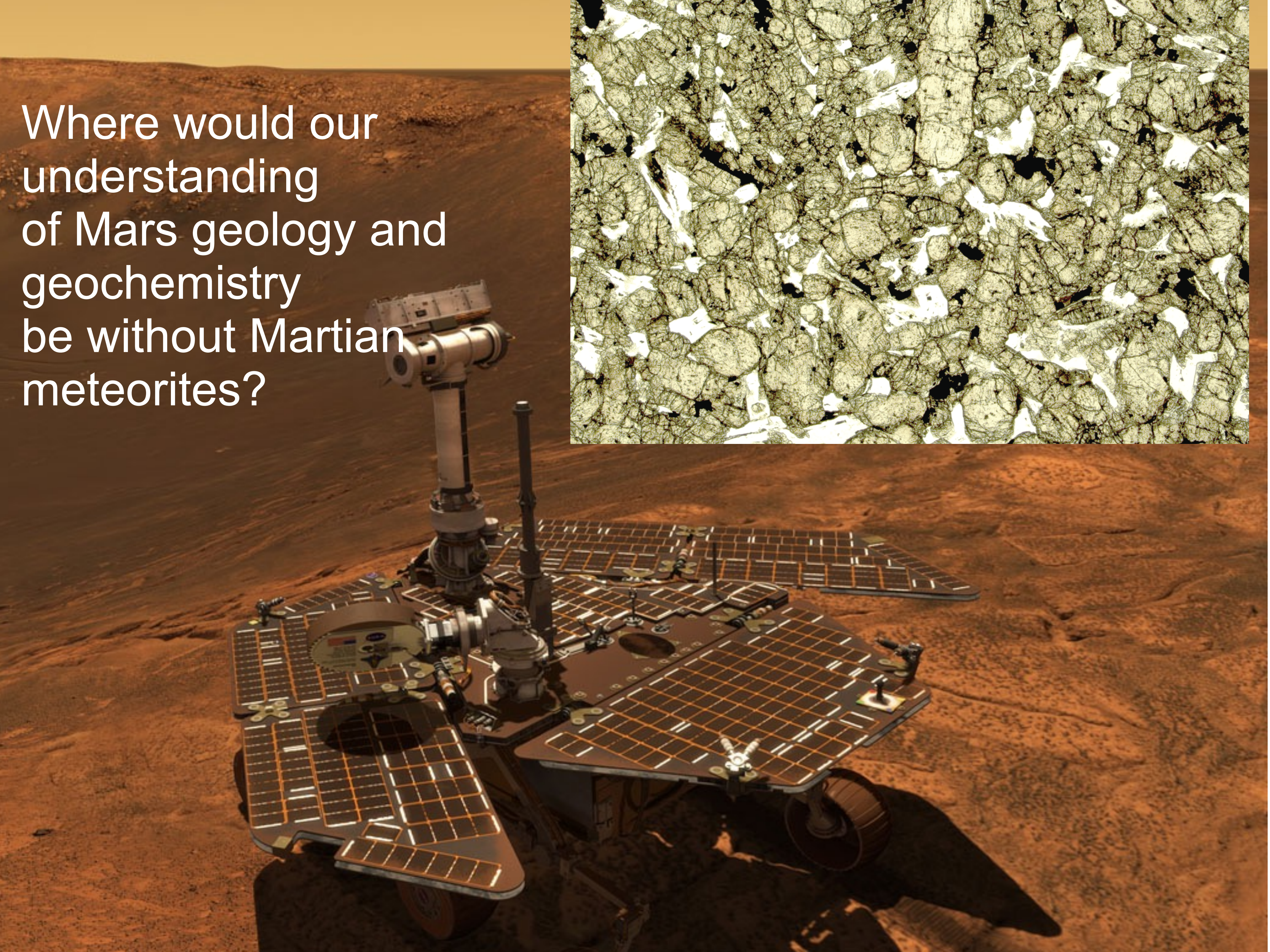
A Comet Dates Jupiter

In 2004, NASA's Stardust mission flew by comet Wild 2 and retrieved particles from the comet's coma, the tail of dust and gas that forms when a comet approaches the Sun. Two years later, those particles were brought to Earth and analyzed by international teams of scientists. Ogliore *et al.* describe mineralogical and isotope data for a fragment from the Stardust collection. This fragment, named Iris, resembles chondrules, the type of round, once-molten silicate particles typically found in meteorites. Iris probably formed in the inner solar nebula, and thus its presence in the coma of comet Wild 2 is a testament to the transport of particles from the inner, hotter parts of the solar nebula to the outer, colder ones, where comets originate. Iris formed at least 3 million years after the formation of the earliest solids in the solar system. Transport of material across the solar system must have occurred before Jupiter formed, as its growing embryo would have opened a gap in the protoplanetary disk, preventing outward transport past its orbit. Thus, unless transport occurred outside the plane of the protoplanetary disk or Jupiter was interior to Iris when this particle formed, the results imply that Jupiter formed 3 million years after the formation of the earliest solids. — MJC

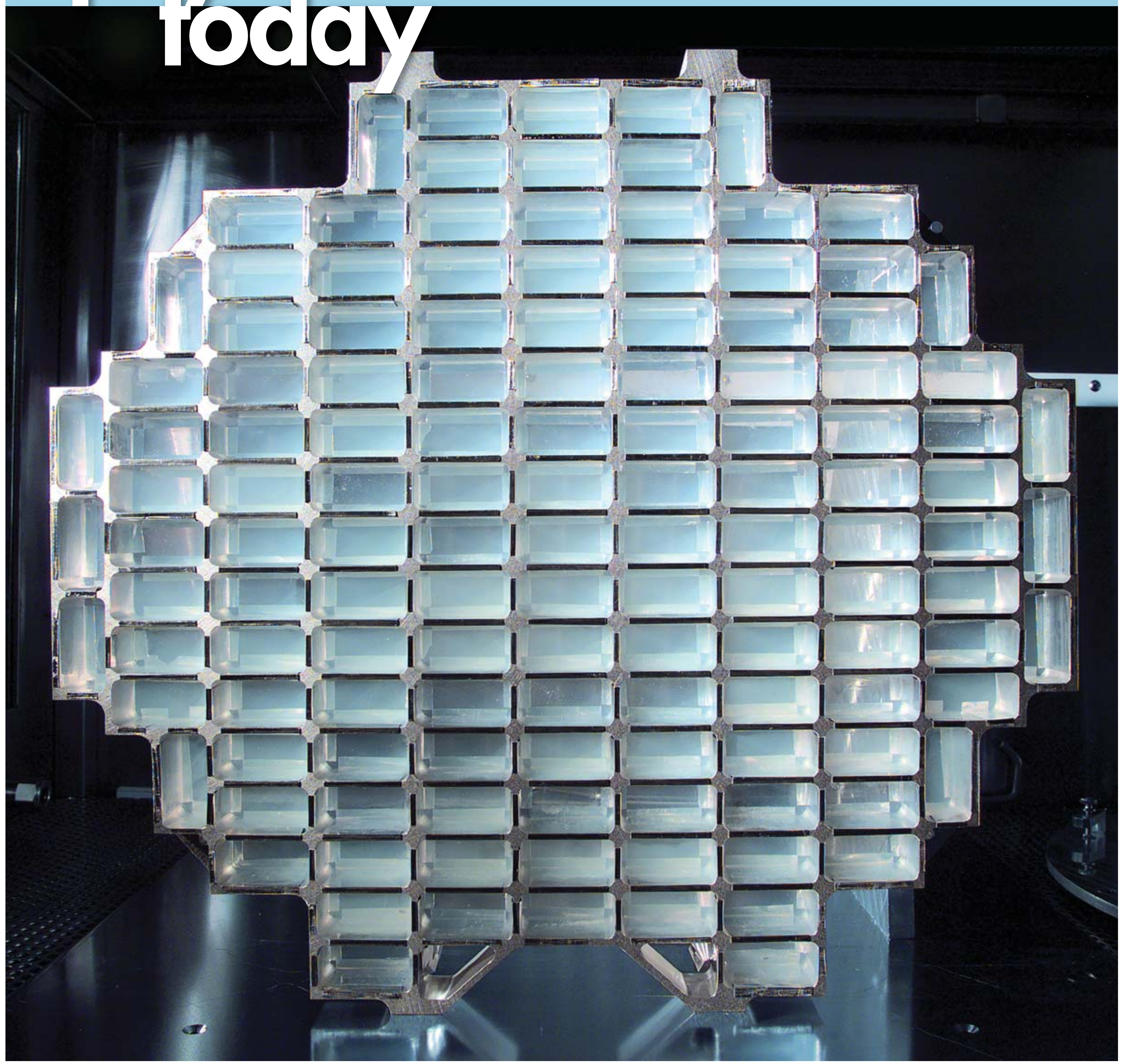
Astrophys. J **745**, L19 (2012).

Where would Dawn's exploration of Vesta be without laboratory investigations of HED meteorites?




Where would our
understanding
of Mars geology and
geochemistry
be without Martian
meteorites?

www.physicstoday.org
physics today
A publication of the American Institute of Physics
October 2014
volume 67, number 10



Cosmic dust catcher

also:

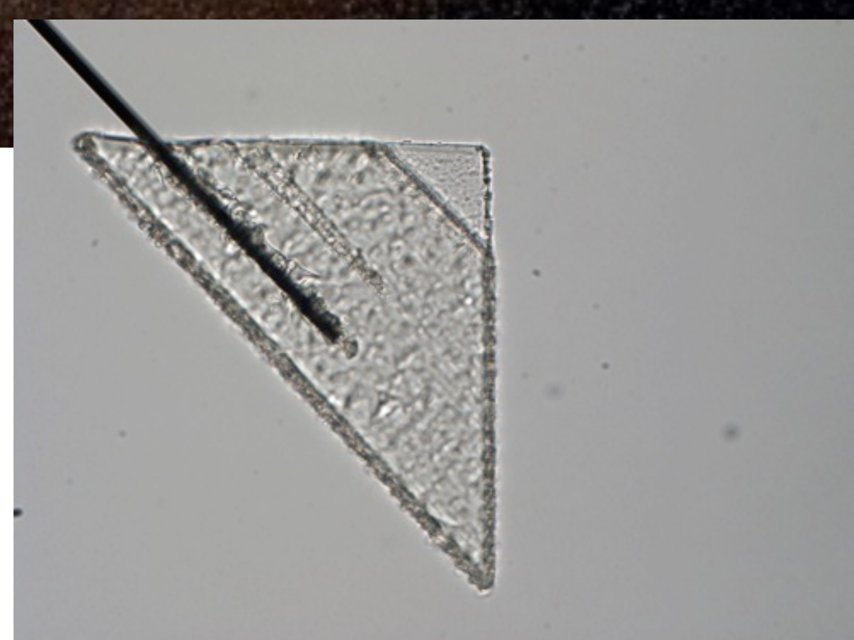
Nanotube templates ◀

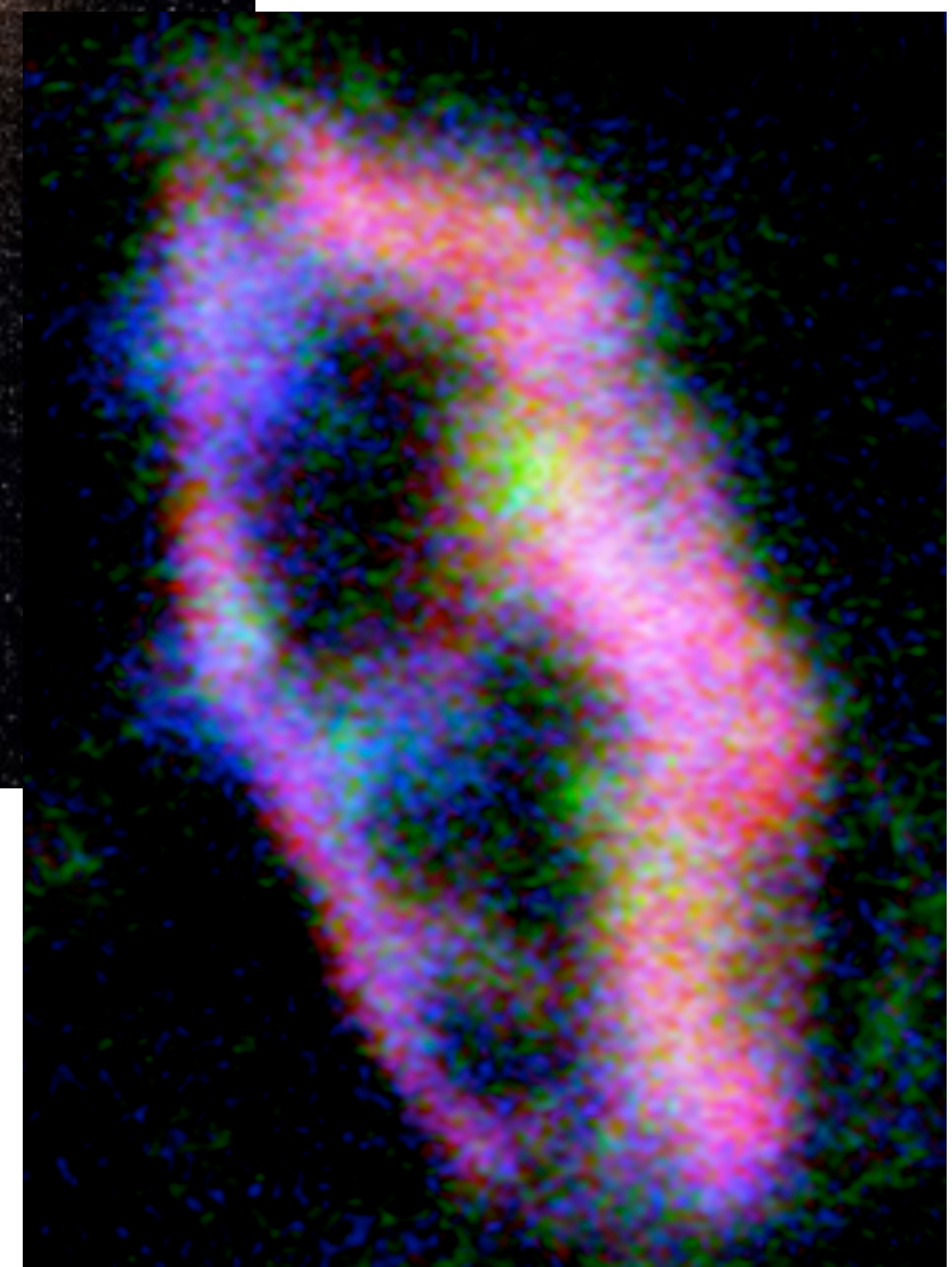
Atom-like crystal defects ◀

Theorists and the developing world ◀

Progress in viewing interstellar dust

Progress in viewing interstellar dust





PSD Science goals

1. Explore and observe the objects in the solar system to understand how they formed and evolve.

2. Advance the understanding of how the chemical and physical processes in our solar system operate, interact and evolve.

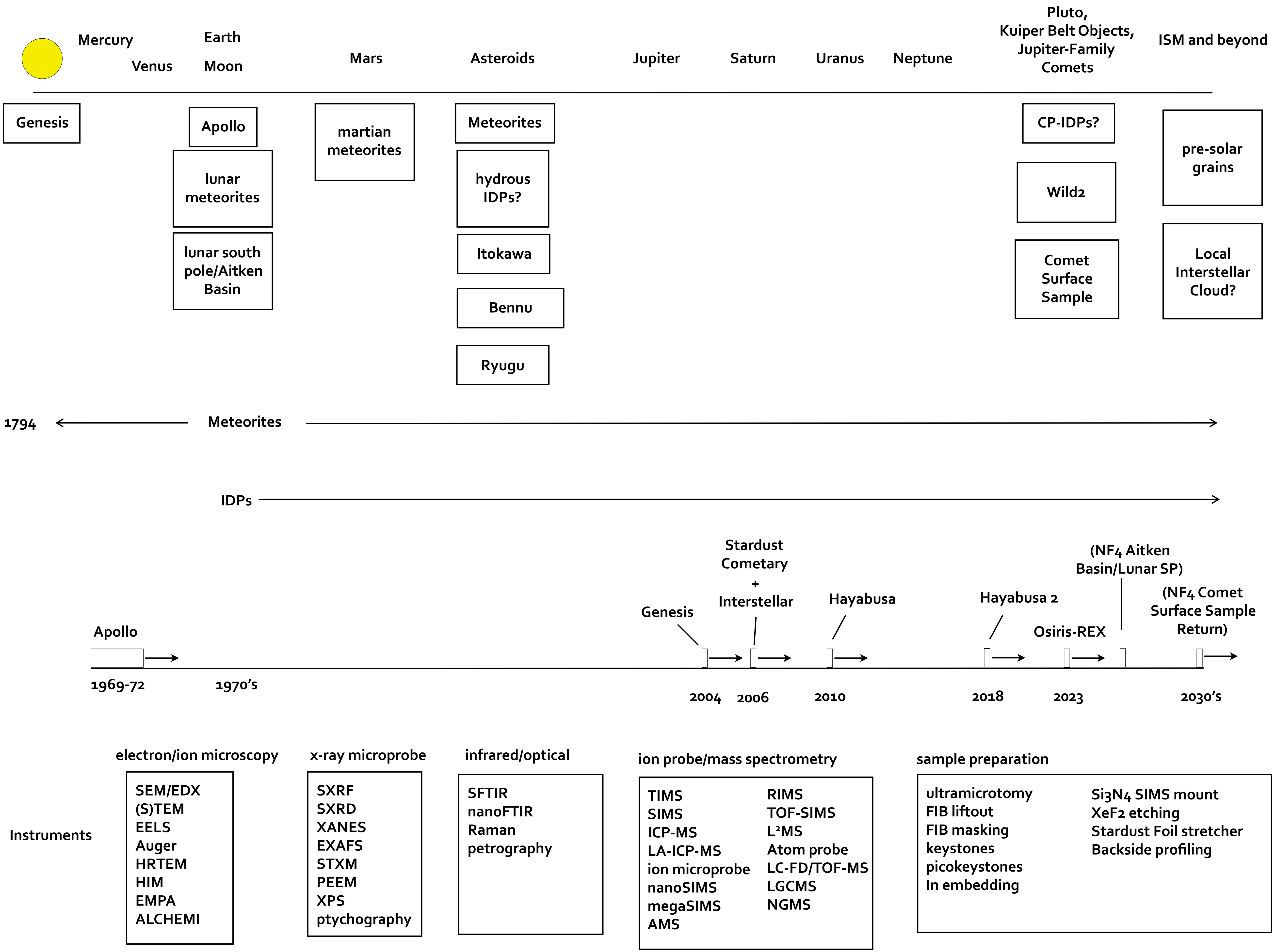
3. Explore and find locations where life could have existed or could exist today.

4. Improve our understanding of the origin and evolution of life on Earth to guide our search for life elsewhere.

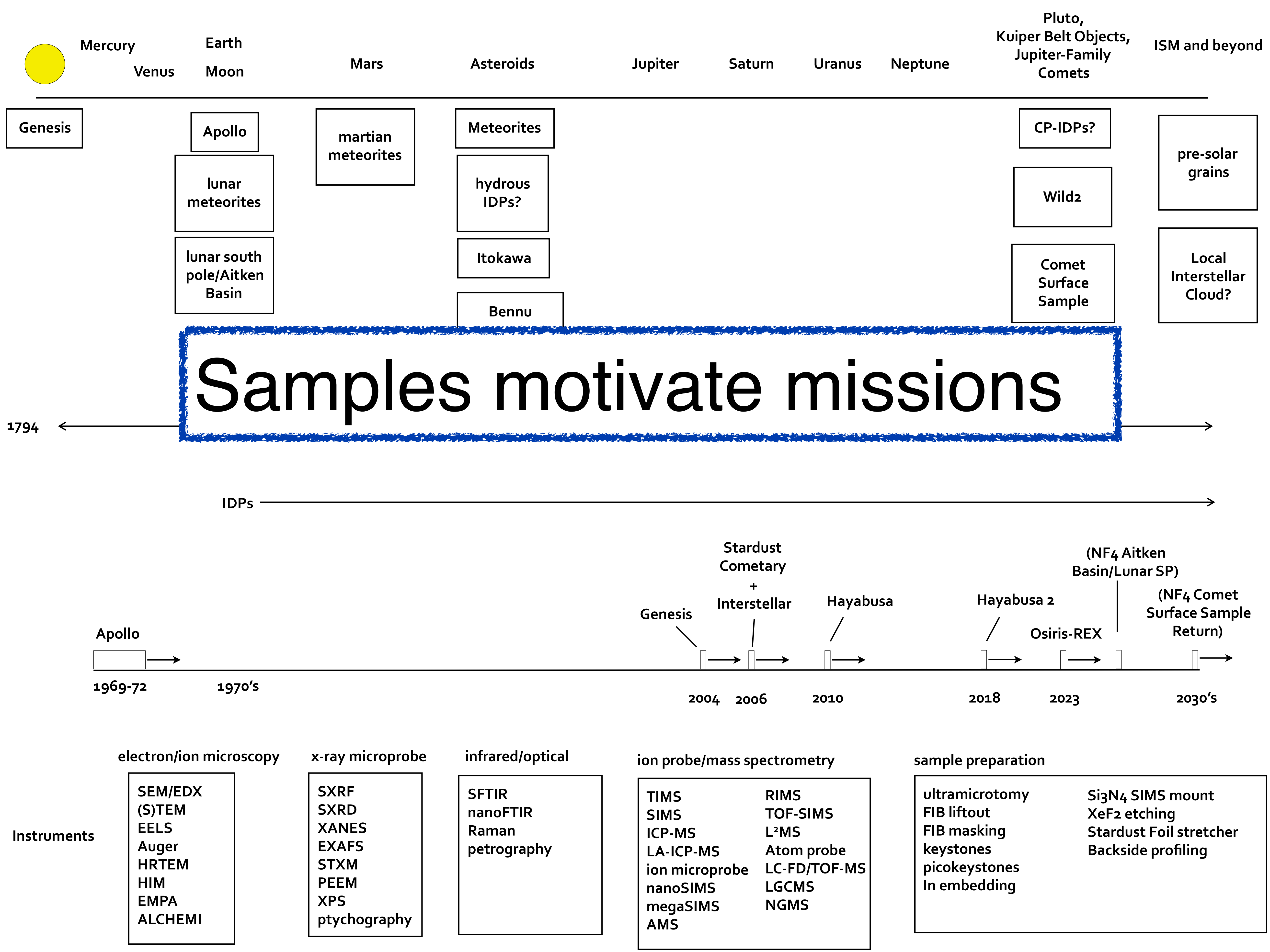
5. Identify and characterize objects in the solar system that pose threats to Earth, or offer resources for human exploration.

PSD top-level science goal	science goal	candidate mission	laboratory capabilities	supporting sample collections	laboratory capabilities for mission planning and ops	laboratory capabilities for mission completion
1,2,4,5	Laboratory analysis of ~50g of asteroidal regolith	NF Osiris-ReX	mineralogy and petrology, geochemical analysis, radiogenic and high-precision stable isotopic composition and mapping, organic compound analysis, magnetism	Antarctic meteorites, Interplanetary dust, Hayabusa	collector design and ops, target selection, planetary protection, contamination control	microanalysis, small particle handling and sample preparation, contamination control,magnetism long-term curation
1, 2, 4, 5	Laboratory analysis of ~500g of cometary material	NF comet surface sample return	mineralogy and petrology, geochemical analysis, radiogenic and stable isotopic composition and mapping, organic compound analysis	Interplanetary dust, Stardust cometary samples, primitive meteorites	collector design and ops, target selection, planetary protection, contamination control	microanalysis, small particle handling and sample preparation, contamination control, long-term curation
1, 2, 3	Mars sample return	Mars sample return*	mineralogy and petrology, geochemical analysis, radiogenic and stable isotopic composition and mapping, organic compound analysis	SNC meteorites	collector design and ops, target selection, planetary protection, contamination control	microanalysis, small particle handling and sample preparation, contamination control, long-term curation
1,2,4	Analysis of lunar polar samples	NF Lunar South Pole- Aitken Basin	precision of age measurements to better than ±20 million years and accuracy of trace elemental compositions to the parts-per-billion level	Lunar samples (Apollo, Luna, lunar meteorites)	collector design and ops, target selection, contamination control	High-precision radioisotope measurements, trace elements
3	Search for life at Enceladus	NF/Flagship Enceladus orbiter/lander	in situ organics analysis supported by laboratory analysis, e.g., high-sensitivity microfluidics capability	carbonaceous chondrites, terrestrial analogs (e.g., Atacama)	quantitative organics analysis (mass spectra, enantiomeric excess)	terrestrial analogs measurements (cf Viking organics analyses)

*Space-X DragonLab enabled?



Mercury
Venus
Earth
Moon
Mars
Asteroids
Jupiter
Saturn
Uranus
Neptune
Pluto, Kuiper Belt Objects, Jupiter-Family Comets
ISM and beyond
Genesis
Apollo
lunar meteorites
lunar south pole/Aitken Basin
martian meteorites
Meteorites
hydrous IDPs?
Itokawa
Bennu
Ryugu
CP-IDPs?
Wild2
Comet Surface Sample
pre-solar grains
Local Interstellar Cloud?
1794
Meteorites
IDPs
Apollo
Genesis
Stardust Cometary + Interstellar
Hayabusa
Hayabusa 2
Osiris-REX
(NF4 Aitken Basin/Lunar SP)
(NF4 Comet Surface Sample Return)
1969-72
1970's
2004
2006
2010
2018
2023
2030's
Instruments
electron/ion microscopy
SEM/EDX
(S)TEM
EELS
Auger
HRTEM
HIM
EMPA
ALCHEMI
x-ray microprobe
SXRF
SXRD
XANES
EXAFS
STXM
PEEM
XPS
ptychography
infrared/optical
SFTIR
nanoFTIR
Raman
petrography
ion probe/mass spectrometry
TIMS
SIMS
ICP-MS
LA-ICP-MS
ion microprobe
nanoSIMS
megaSIMS
AMS
RIMS
TOF-SIMS
L^{2}MS
Atom probe
LC-FD/TOF-MS
LGCMS
NGMS
sample preparation
ultramicrotomy
FIB liftout
FIB masking
keystones
picokeystones
In embedding
Si3N4 SIMS mount
XeF2 etching
Stardust Foil stretcher
Backside profiling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SFTIR
nanoFTIR
Raman
petrography
ion probe/mass spectrometry
TIMS
SIMS
ICP-MS
LA-ICP-MS
ion microprobe
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megaSIMS
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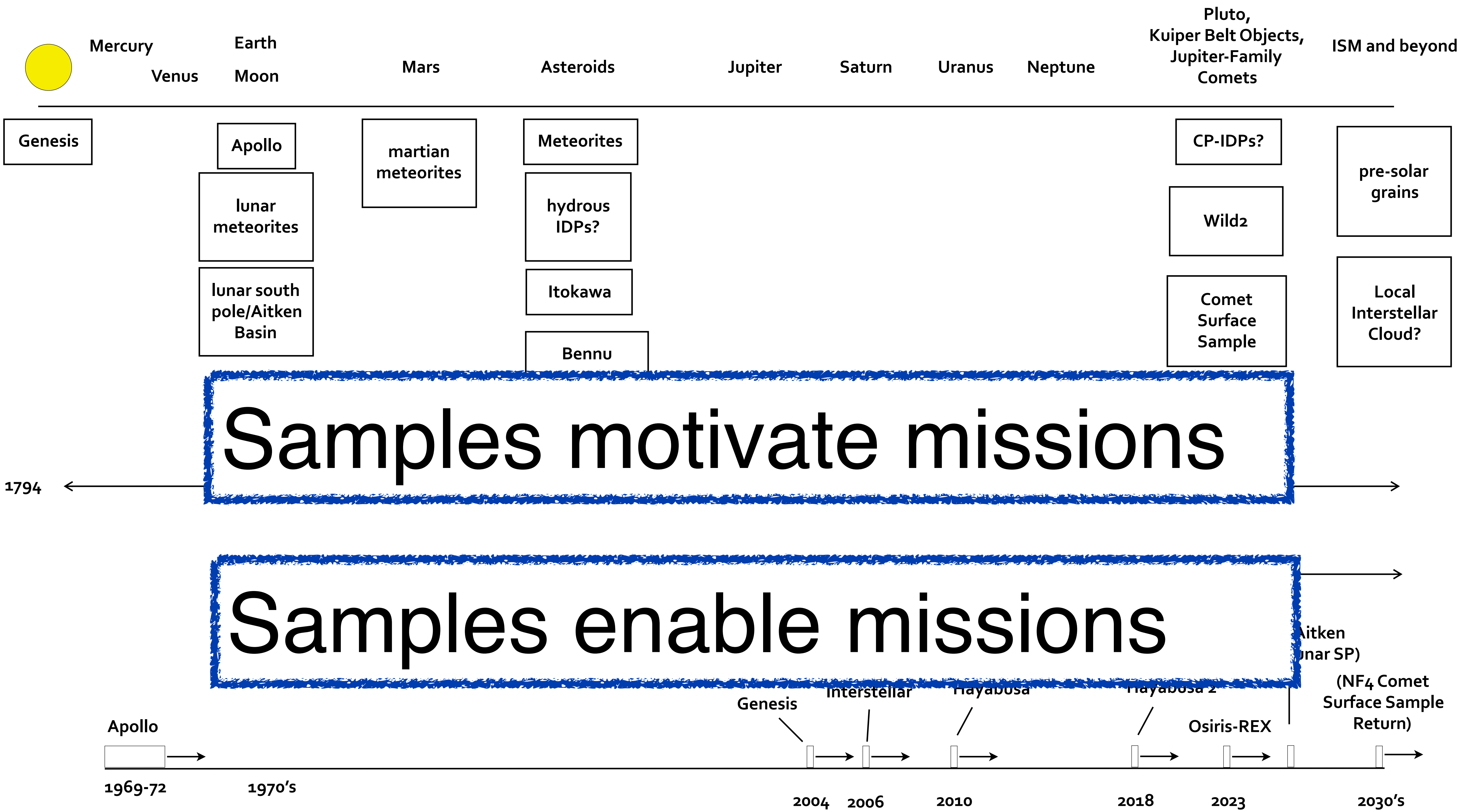

Samples motivate missions

Samples enable missions

Instruments

electron/ion microscopy	x-ray microprobe	infrared/optical	ion probe/mass spectrometry		sample preparation	
SEM/EDX	SXRF	SFTIR	TIMS	RIMS	ultramicrotomy	Si3N4 SIMS mount
(S)TEM	SXRD	nanoFTIR	SIMS	TOF-SIMS	FIB liftout	XeF2 etching
EELS	XANES	Raman	ICP-MS	L²MS	FIB masking	Stardust Foil stretcher
Auger	EXAFS	petrography	LA-ICP-MS	Atom probe	keystones	Backside profiling
HRTEM	STXM		ion microprobe	LC-FD/TOF-MS	picokeystones	
HIM	PEEM		nanoSIMS	LGCMS	In embedding	
EMPA	XPS		megaSIMS	NGMS		
ALCHEMI	ptychography		AMS			

The number of selected proposals for extraterrestrial material research has decreased sharply in the last two years.

There is a common perception in the community that this is a direct (but perhaps unintended) consequence of the HQ decision to apply equal selection rates of 20% to all new programs.

No matter the cause, this raises a concern about ***decreasing*** support for analytical capabilities for extraterrestrial materials, in an era in which ***increasing*** support is needed to meet NASA's strategic goals

Once NASA defines its *strategic* priorities, are there *tactical* reasons for variable selection rates?

Portfolio management

Portfolio management

Support of mission-critical assets:

Portfolio management

Support of mission-critical assets:

- Expensive instruments

Portfolio management

Support of mission-critical assets:

- Expensive instruments
- Knowledgable and experienced laboratory scientists

Portfolio management

Support of mission-critical assets:

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- Support and training of the next generation of scientists (students and post-docs)

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Rainer Wieler
ETH, Zurich

Veronika Heber
ETH, Zurich

Ansgar Grimberg
ETH, Zurich
(Currently, Physikalisches Institut, Bern)

International collaboration is healthy, but reliance on non-US laboratories is risky

In a zero sum game, what is the cost of supporting extraterrestrial materials research? What other mission critical infrastructure is at risk given reorganization and budget cuts?

The idea of proposals is to allow the community to weigh those questions on the fly. Why shouldn't this be the mechanism used to make decisions?

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> Review panels think tactically, not strategically. They have a stack of proposals to evaluate, and do not have the big picture.

> Systematic cross-calibration may be difficult between sub-panels in broad programs like EW or SSW

1. Are the PSD R&A program elements appropriately linked to, and do they encompass the range and scope of activities needed to support the NASA Strategic Objective for Planetary Science and the Planetary Science Division Science Goals, as articulated in the 2014 NASA Science Plan?

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No, in practice? Low selection numbers are a red flag to CAPTEM

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Yes, in principle.

No, in practice? Low selection numbers are a red flag to CAPTEM

PSD should prioritize its critical needs and not necessarily be tied to equal selection rates for the various defined programs

2. Are the PSD R&A program elements appropriately structured to develop the broad base of knowledge and broad range of activities needed both to enable new spaceflight missions and to interpret and maximize the scientific return from existing missions?

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The NRC's 2010 report, *An Enabling Foundation for NASA's Earth and Space Science Missions*, concluded that "NASA must fly critical Solar System missions with focused scientific objectives, balanced with a portfolio of mission enabling activities." The defined enabling activities included:

(1) A knowledge base that allows NASA and the scientific community to explore new frontiers in research and to identify, define, and design cost-effective space and Earth science missions

(2) A wide range of technologies that enable NASA and the scientific community to equip and conduct spaceflight missions

(3) A robust, experienced technical workforce to plan, develop, conduct, and utilize the scientific missions

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No, in practice? Low selection numbers are a red flag to CAPTEM

The current R&A structure *as currently implemented* may put at risk:

(1) A knowledge base that allows NASA and the scientific community to explore new frontiers in research and to identify, define, and design cost-effective space and Earth science missions

Low selection rates weaken astromaterial research, which motivates and enables new missions

(2) A wide range of technologies that enable NASA and the scientific community to equip and conduct spaceflight missions

"The most important instruments for any sample return mission are the ones in the laboratories on Earth" — 2010 Decadal

(3) A robust, experienced technical workforce to plan, develop, conduct, and utilize the scientific missions

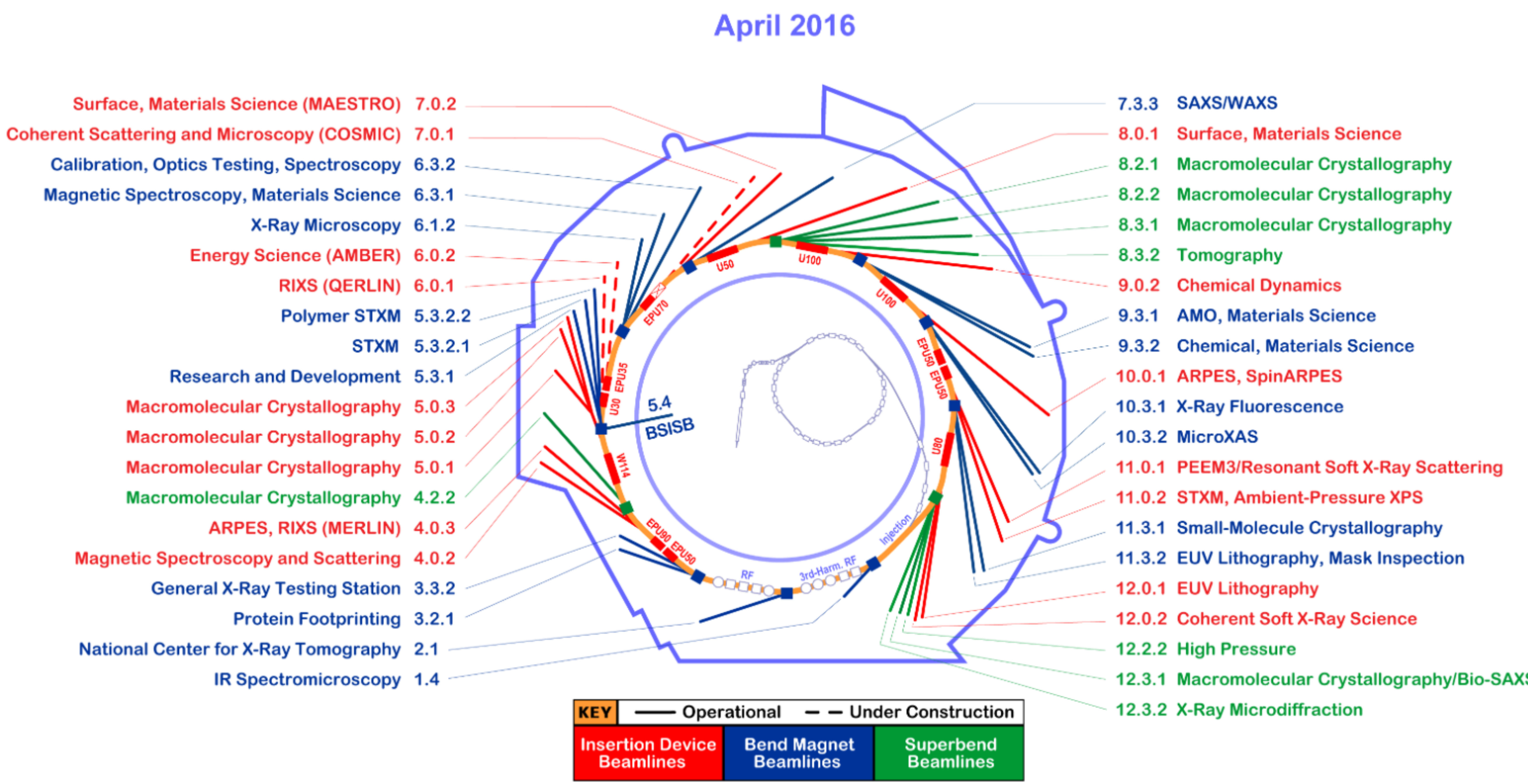
Low selection rates may drive knowledgable, experienced US scientists out of the field, fail to nurture the next generation, and leave NASA to rely on non-US scientists to complete missions

supplemental slides

Advanced Photon Source

Selection rate for synchrotron beamlines varies dramatically

<20% selection



Selection rate for synchrotron beamlines varies dramatically

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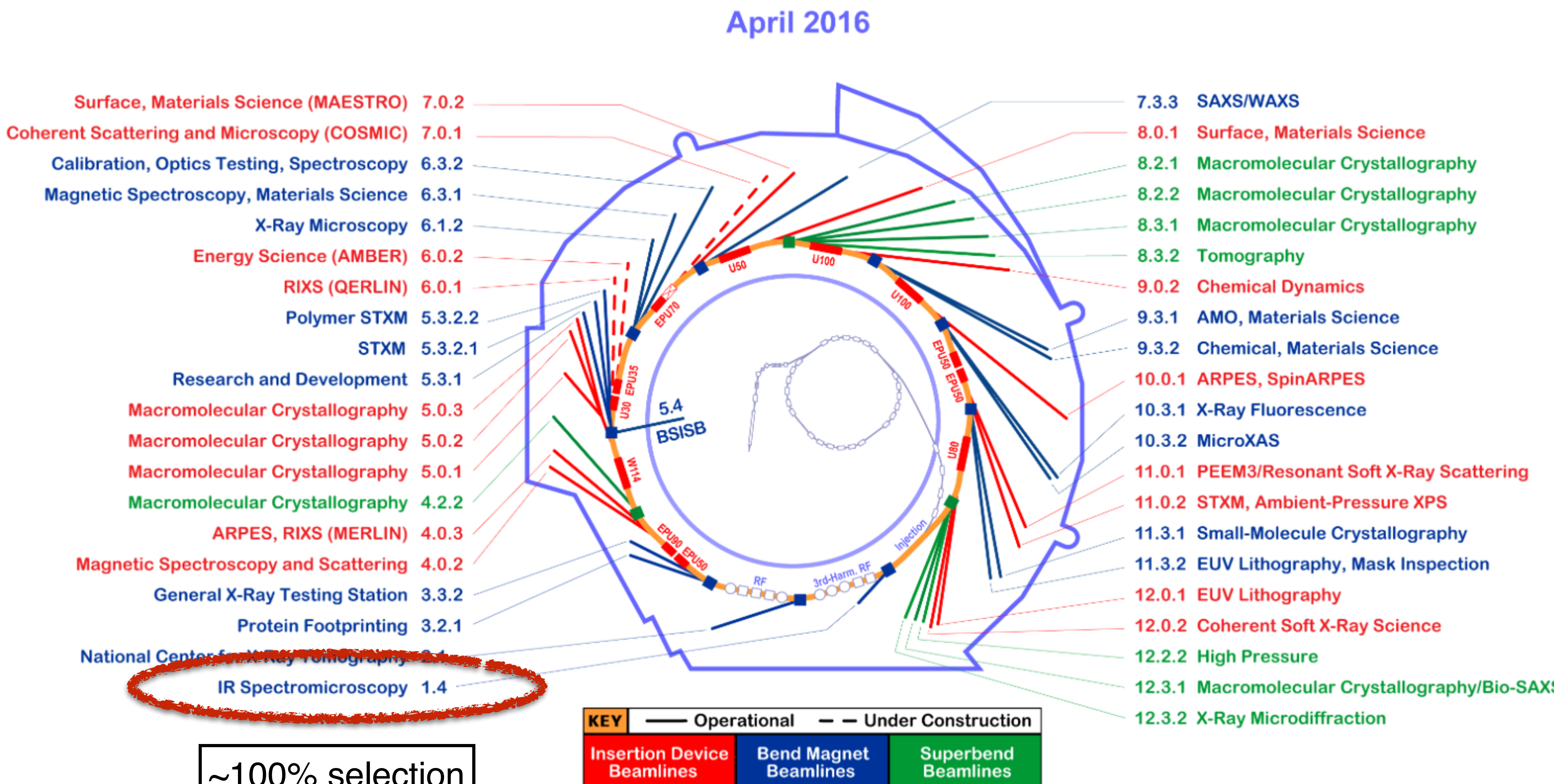
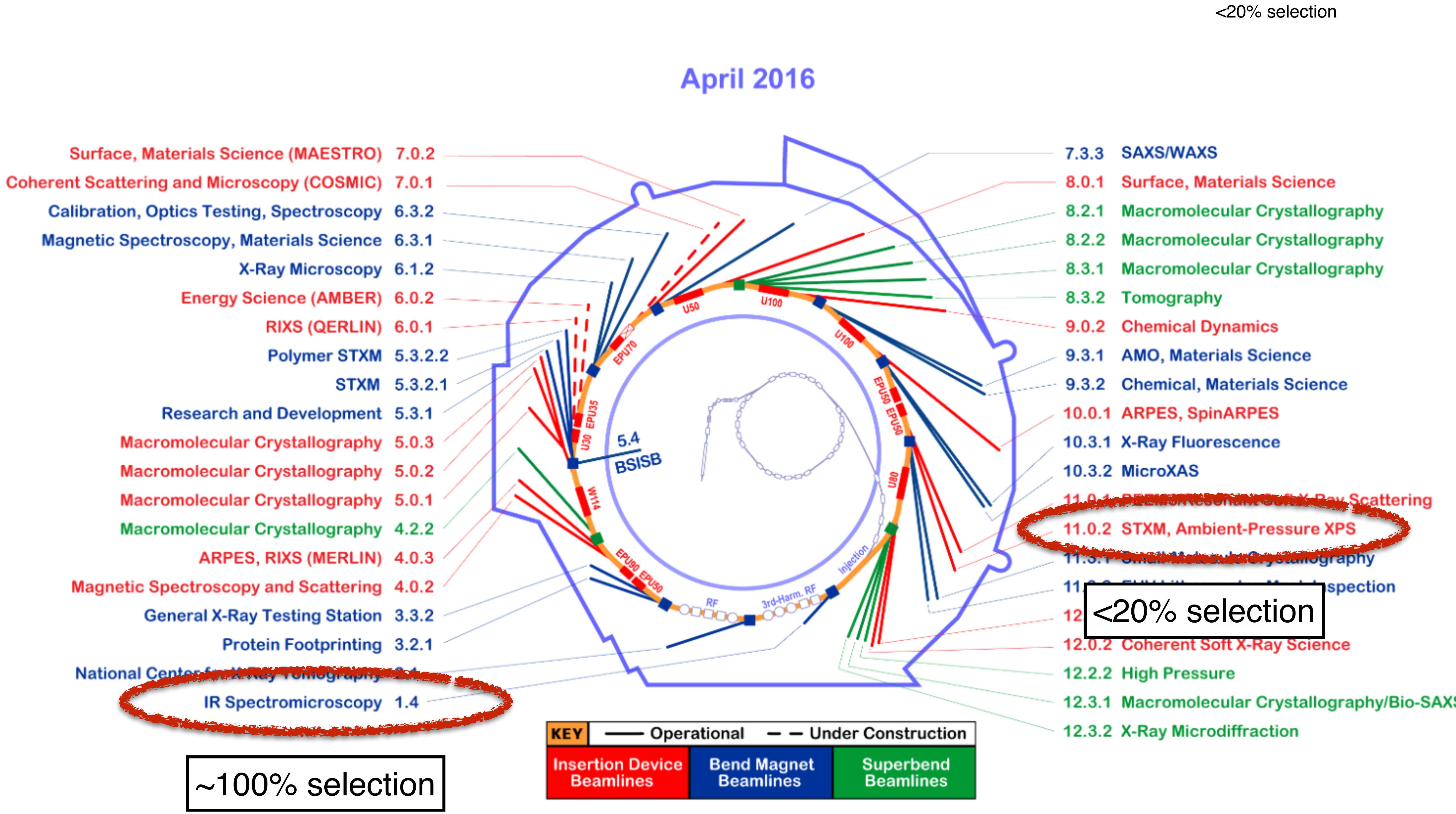


~100% selection

Selection rate for synchrotron beamlines varies dramatically



Selection rate for DOE mission-critical infrastructure over review cycles: ~100%

Advanced Light Source

Advanced Photon Source

National Synchrotron Light Source II

Stanford Synchrotron Light Source

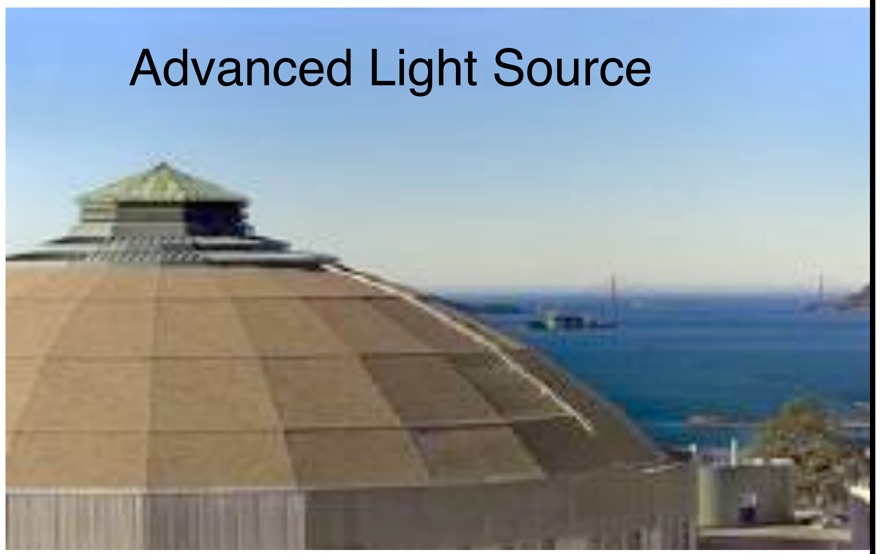
Selection rates for extraterrestrial material research:

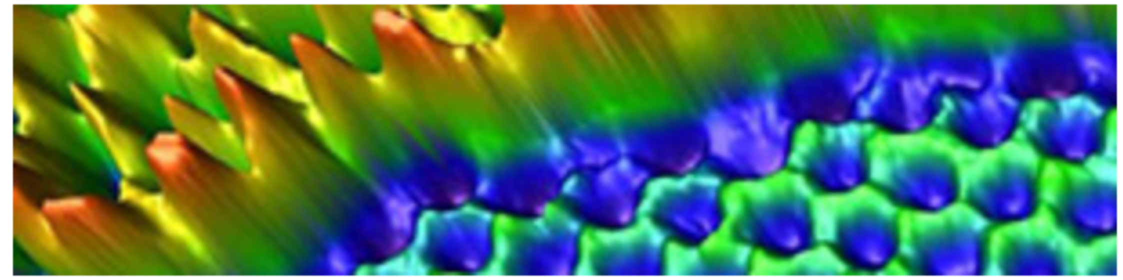
2014: ~17 in Emerging Worlds and ~11 in Solar System Workings

2015: ~20 in Emerging Worlds and ~TBD in Solar System Workings

… from an historical average of 38-40 in Cosmochemistry and Origins

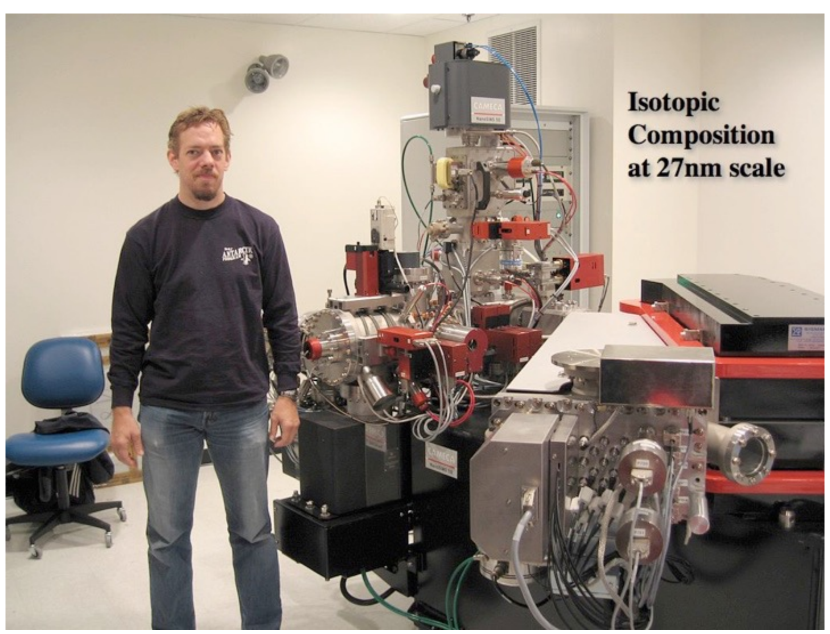
Leveraging





The National Center for Electron Microscopy (NCEM)

Non-NASA analytical facilities



NASA investments

Rainer Wieler
ETH, Zurich

Veronika Heber
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International collaborations and laboratories

Non-NASA Launch opportunities

Astromaterials research and the search for extraterrestrial life

Laboratory analyses are critical to confirming life detection if made by *in situ* instruments*

*Unless an alien poses for a picture, of course

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Laboratory analyses are important to understanding environments where life may exist

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Knowledge base and instrumental capability is essential for mission design and implementation

- Collection medium design
- Target selection
- Post-recovery sample handling planning
- Contamination control, definition of witness coupons
- Analysis and long-term curation of spacecraft materials

Knowledge base and instrumental capability is essential for Mission Ops

- Site Selection
- Sample selection
- Contamination control

Gene Shoemaker and Apollo astronauts at Meteor Crater

Knowledge base and instrumental capability is essential for post-recovery analysis

- Sample handling
- Sample preparation
- Coordinated microanalysis and interpretation
- Contamination control
- Long-term curation of samples, spacecraft components, and witness coupons

CAPTEM R&A White Paper observations and recommendations

Observation: Because many of the missions in the next decade are not yet defined, we can only offer a generalized list of astromaterials needs [to support] NASA missions. These needs include expertise and instrumentation (especially micro-analytical techniques) for mineralogical and petrological characterization, geochemical (elemental) analysis, radiogenic and stable isotope measurements, and organic compound analysis. Other techniques, such as magnetic measurements, will also likely be required.

Recommendation: Identify (and update, as missions are selected) specific needs for analytical measurements and ensure that a sufficient number of highly capable laboratories are supported to meet projected mission requirements.

Observation: R&A reorganization during the first funding year has resulted in a significant decrease in astromaterials research capabilities.

Recommendation: Examine how reorganization has resulted in redistribution of effort, whether this change in the diversity of core components of planetary exploration is desired or accidental, and whether the scores of astromaterials proposals are systematically different from those in other areas.

Observation: *Astromaterials research programs cannot be turned off and on annually, because of the investments needed for instrument acquisition and development and of the personnel training required for effective operation and technical innovation.*

Recommendation: *Provide a mechanism to take into account the requirement for sustained funding for high-performing laboratory facilities that are critical for missions and other NASA goals.*

Observation: *Real innovation in astromaterials instrumentation comes from individual Principal Investigators. Facilities instruments provide valuable opportunities for many investigators, but NASA history indicates that such facilities do not generally develop innovative instruments and applications.*

Recommendation: *In setting funding priorities, general-use facilities should not be viewed as replacements for the laboratories of individual investigators who develop innovative analytical technologies.*