Towards a Multi-Dimensional Classification Scheme for Minor Planets

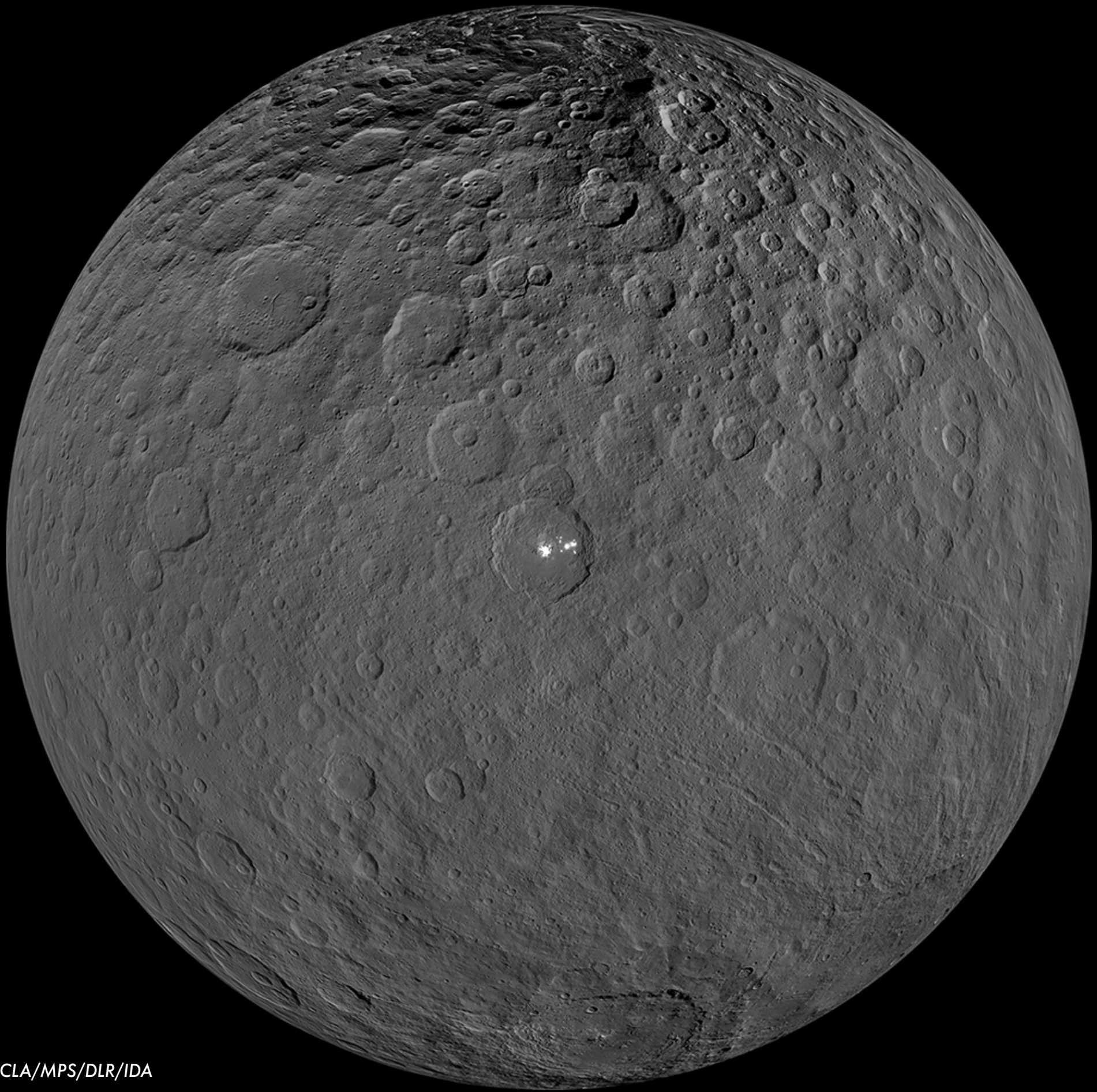
Max Mahlke
Centro de Astrobiología (CSIC-INTA)

in collaboration with Enrique Solano, Benoit Carry, Bruno Merín,
Remi Flamary, the Spanish Virtual Observatory
and the ESASky team

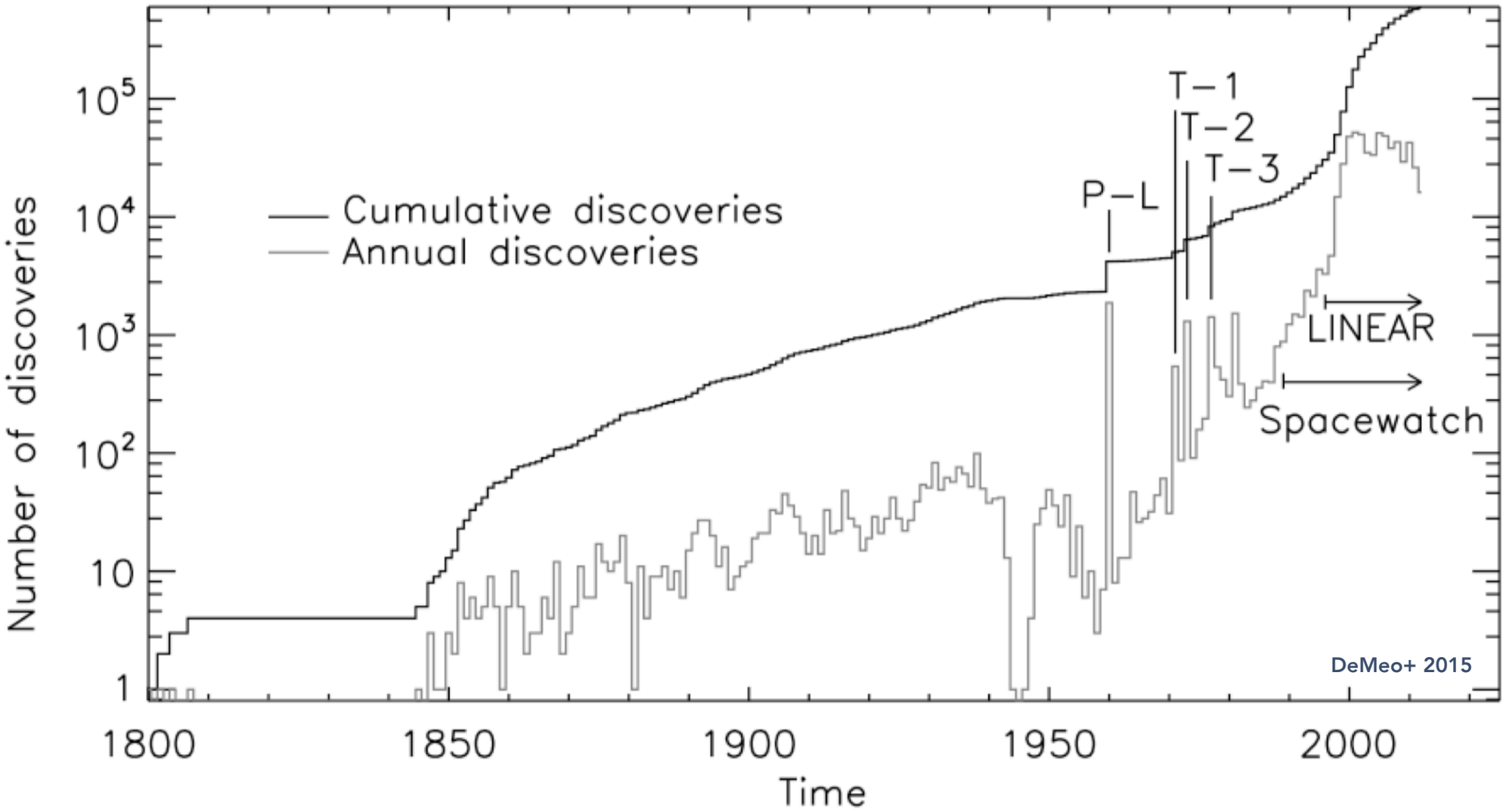
esa

CENTRO DE ASTROBIOLOGÍA
ASOCIADO AL NASA ASTROBIOLOGY INSTITUTE
CSIC INTA EXCELENCIA MARÍA DE MAEZTU

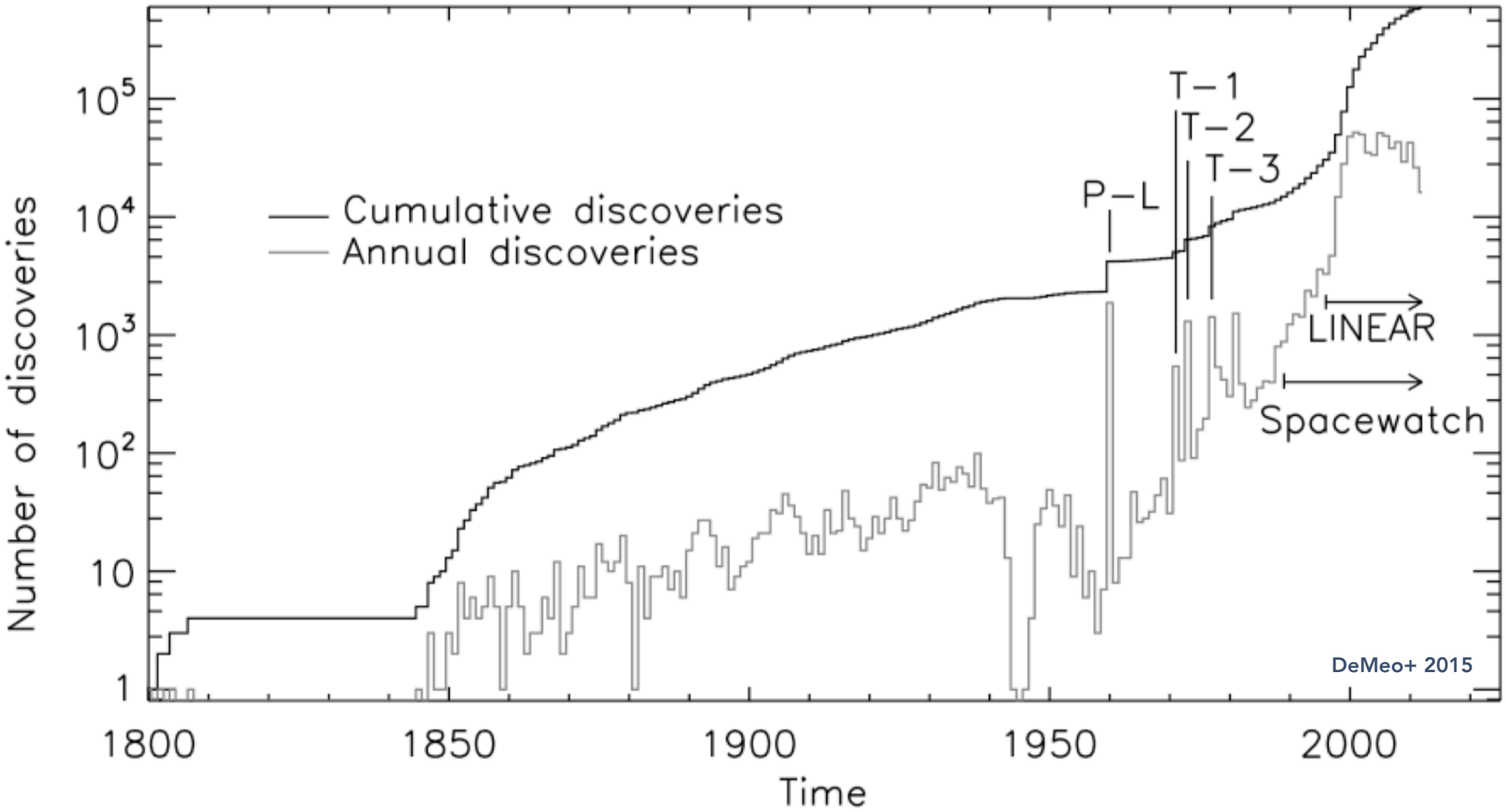
SVO Spanish Virtual Observatory



NASA/JPL-Caltech/UCLA/MPS/DLR/IDA


Cumulative discoveries
Annual discoveries
T−1
T−2
T−3
P−L
LINEAR
Spacewatch
DeMeo+ 2015
Number of discoveries
10⁵
10⁴
10³
10²
10
1
1800
1850
1900
1950
2000
Time

Mercury Venus Earth Mars Ceres Pallas Juno Vesta **Jupiter** Saturn Uranus



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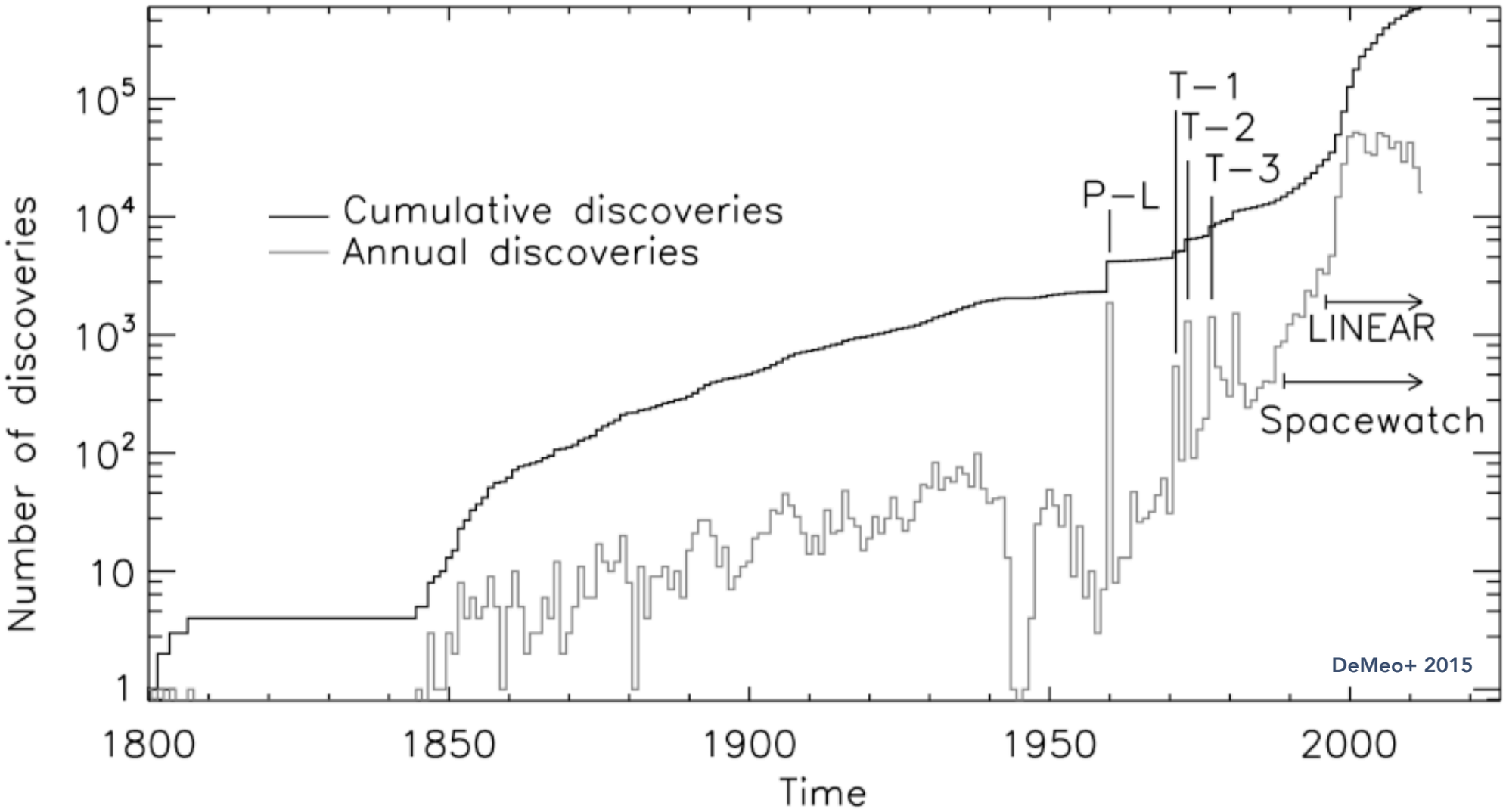

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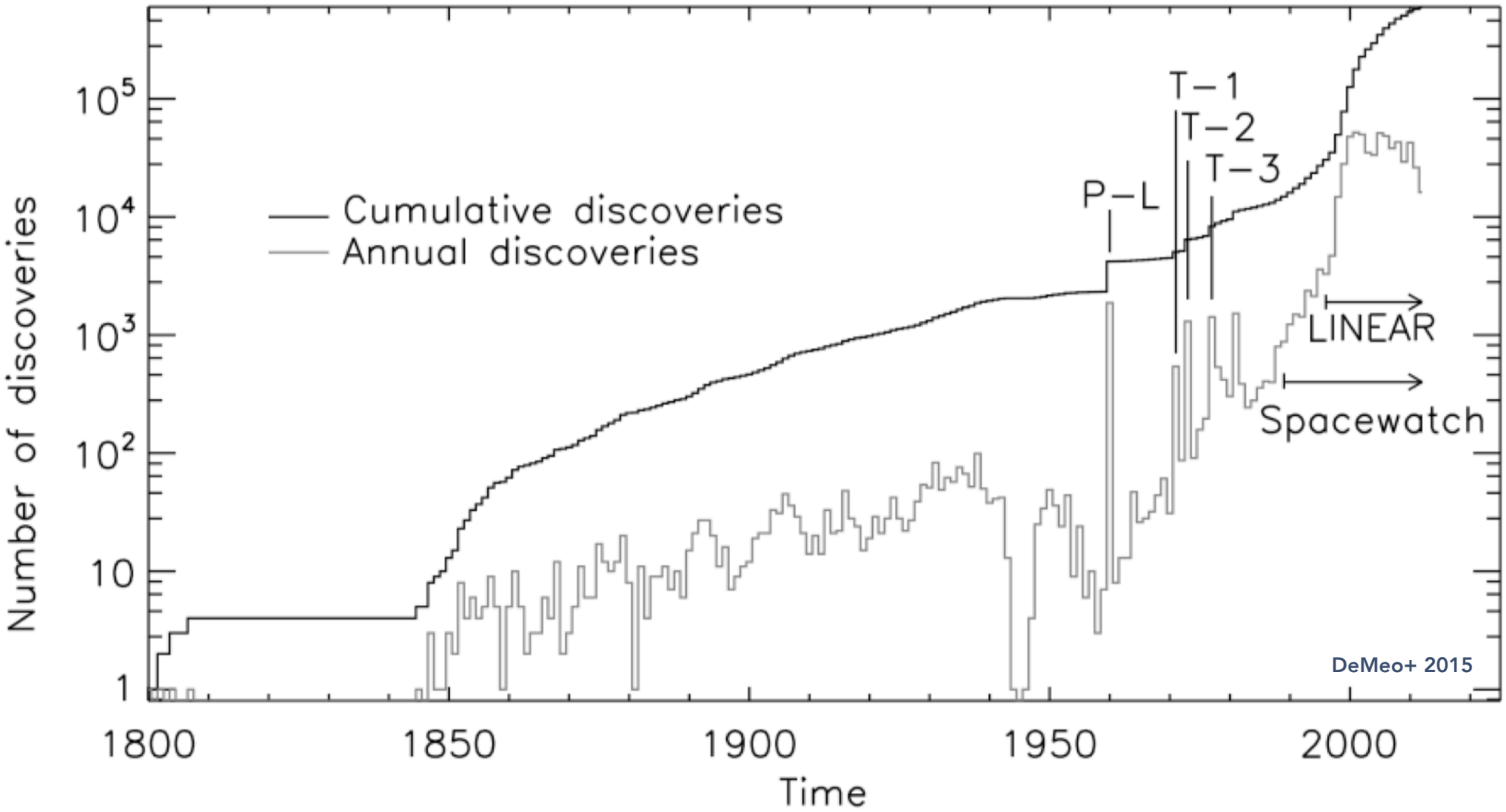

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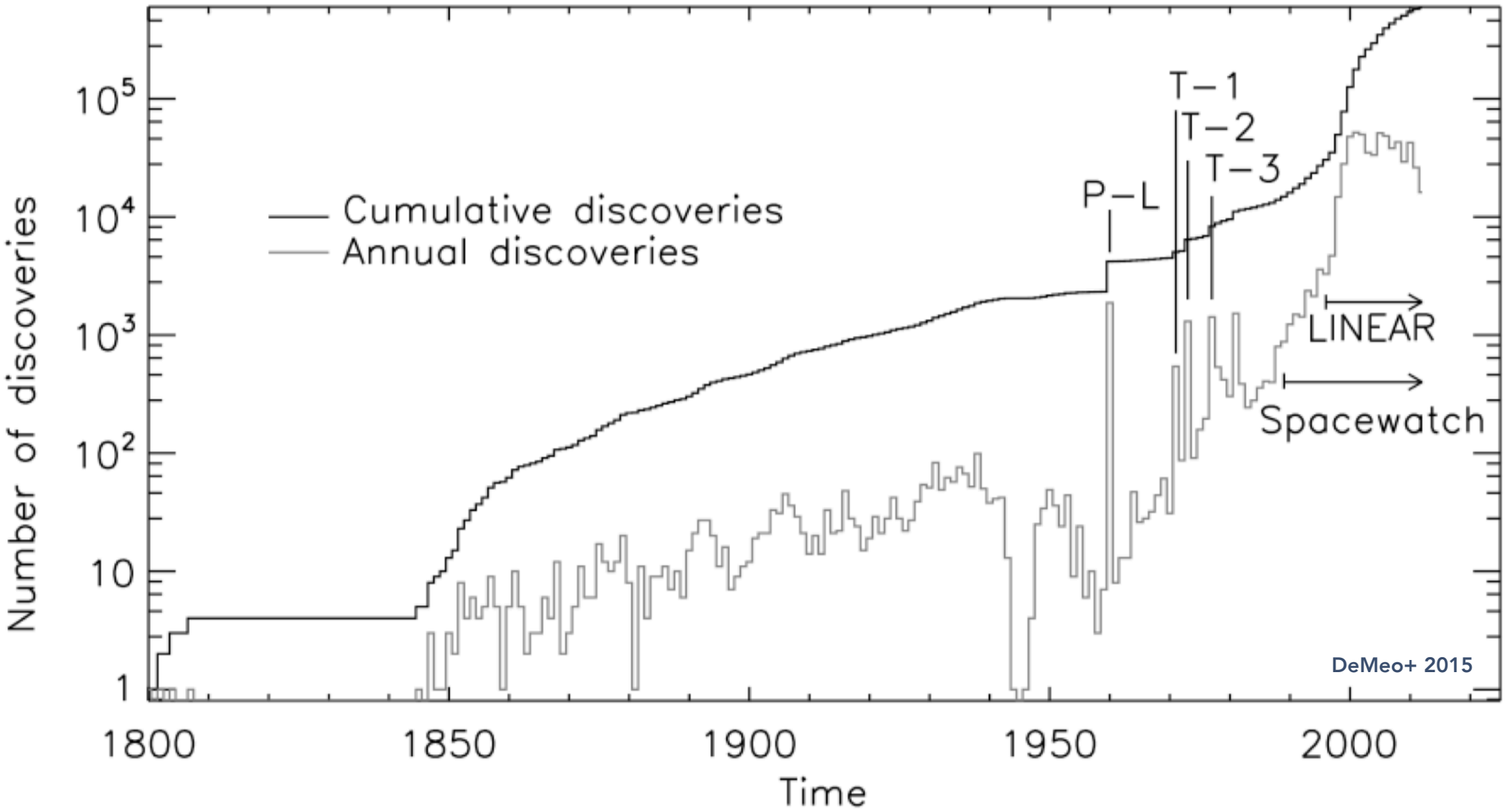

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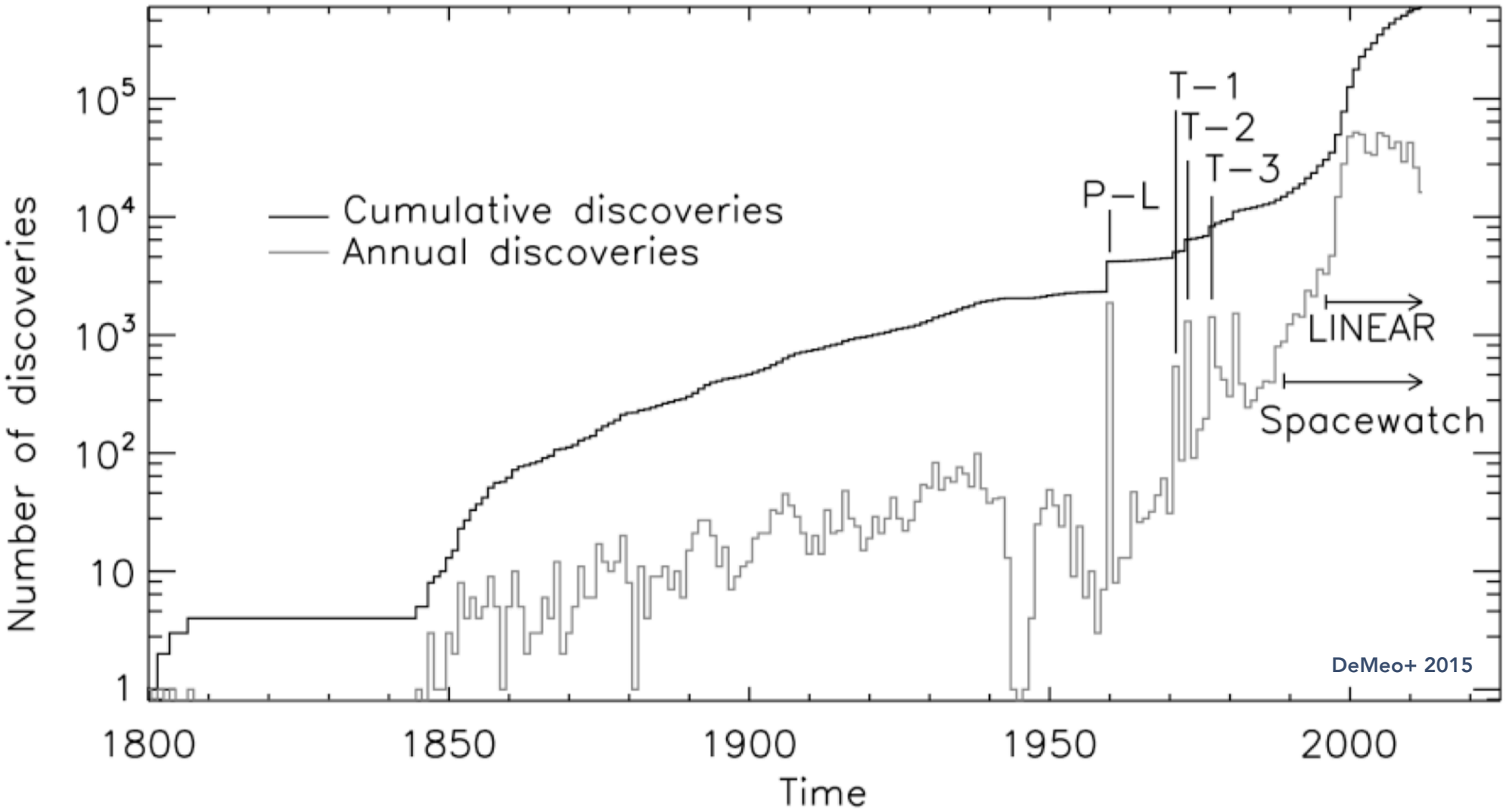

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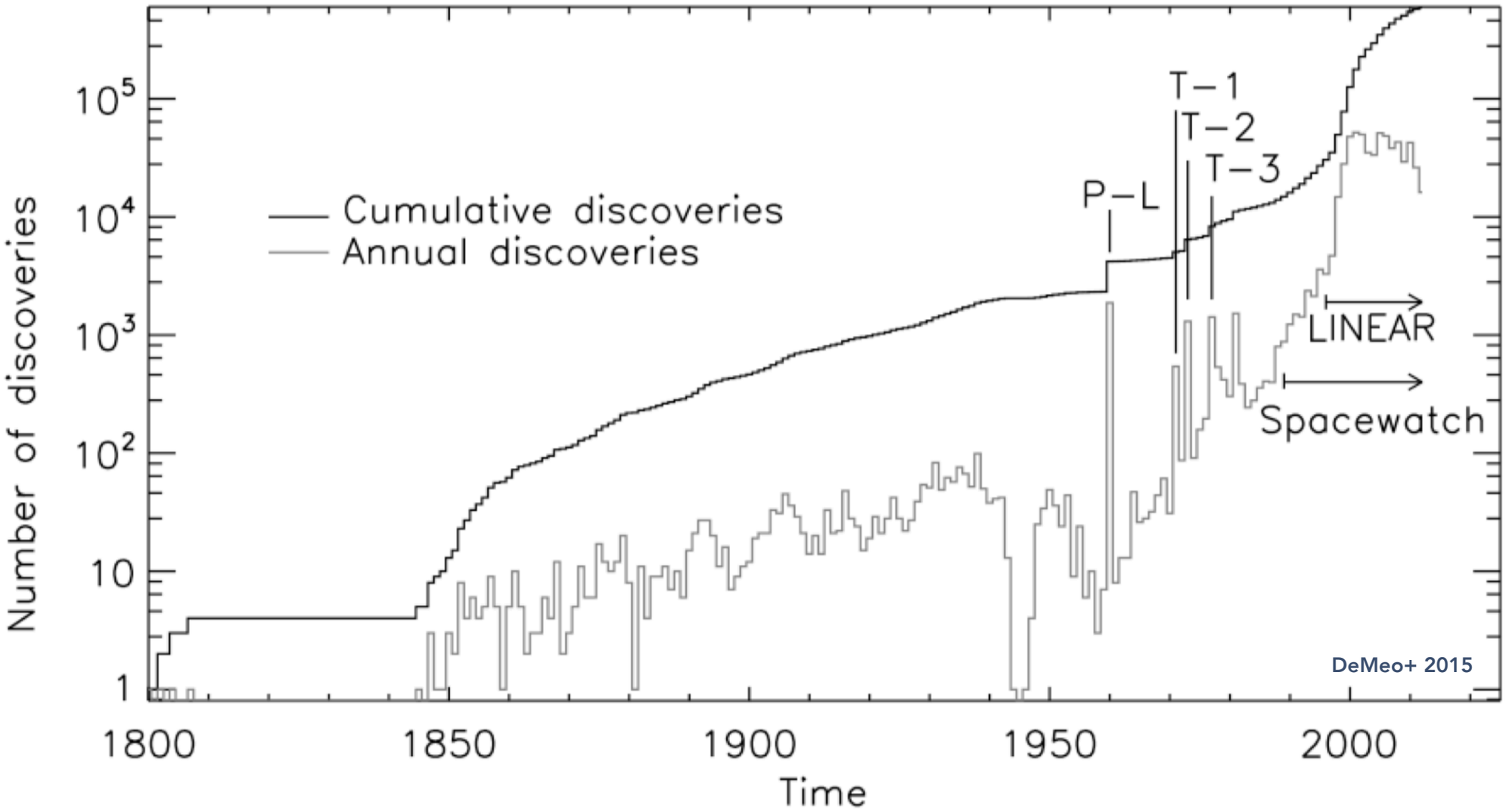

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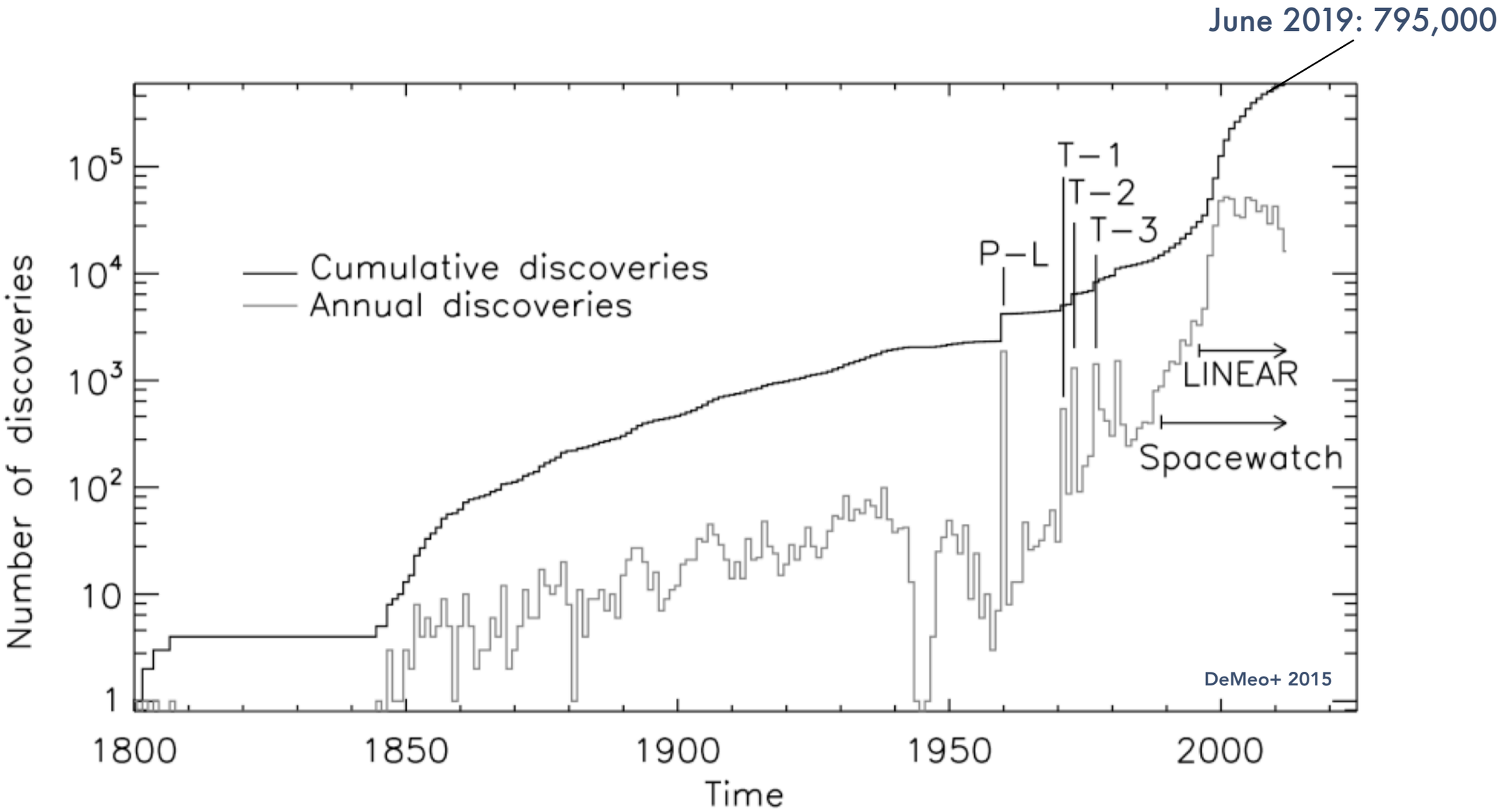
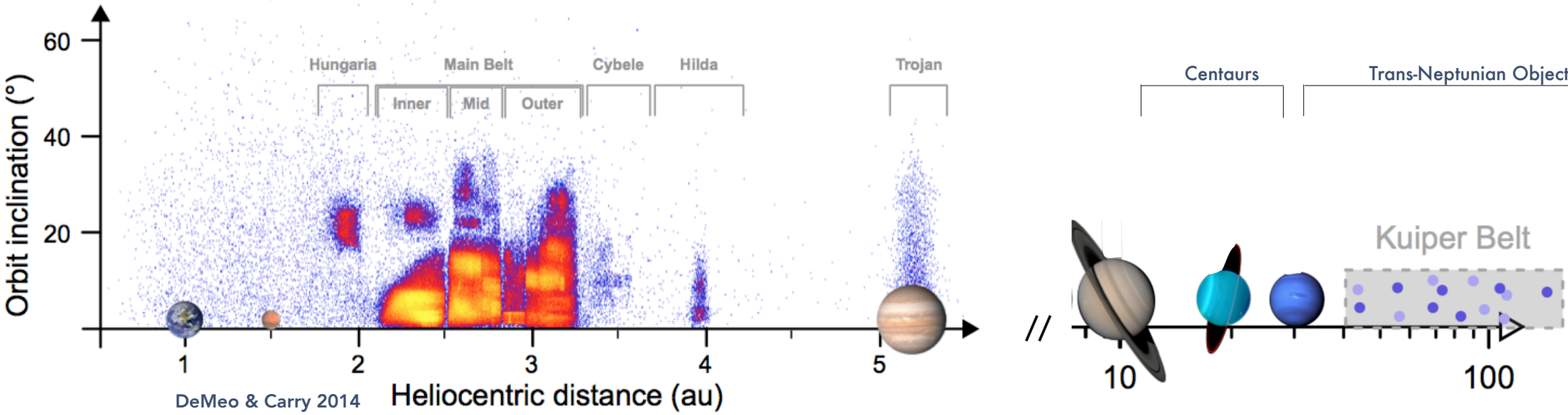


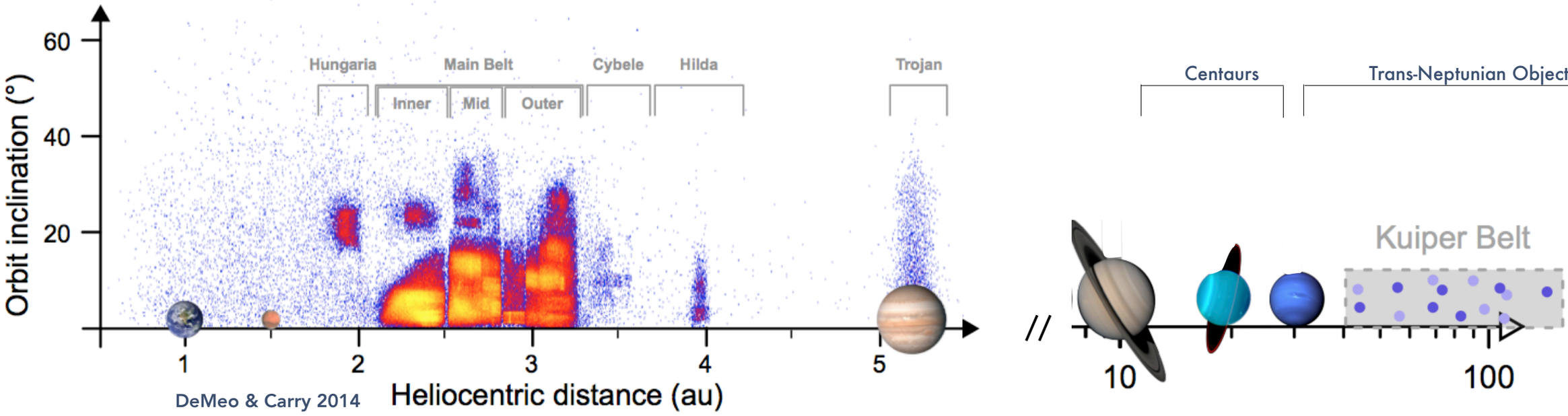


Heterogeneous

in heliocentric distance: <1AU to >100AU
in orbital inclination: 0° to 33° for Main Belt asteroids
in orbital eccentricity: 0. to 0.3 for Main Belt asteroids

in size: m to 10^3km
in composition: carbon- / silicate-compound rocks, ices

in shapes
in rotation: hours to days



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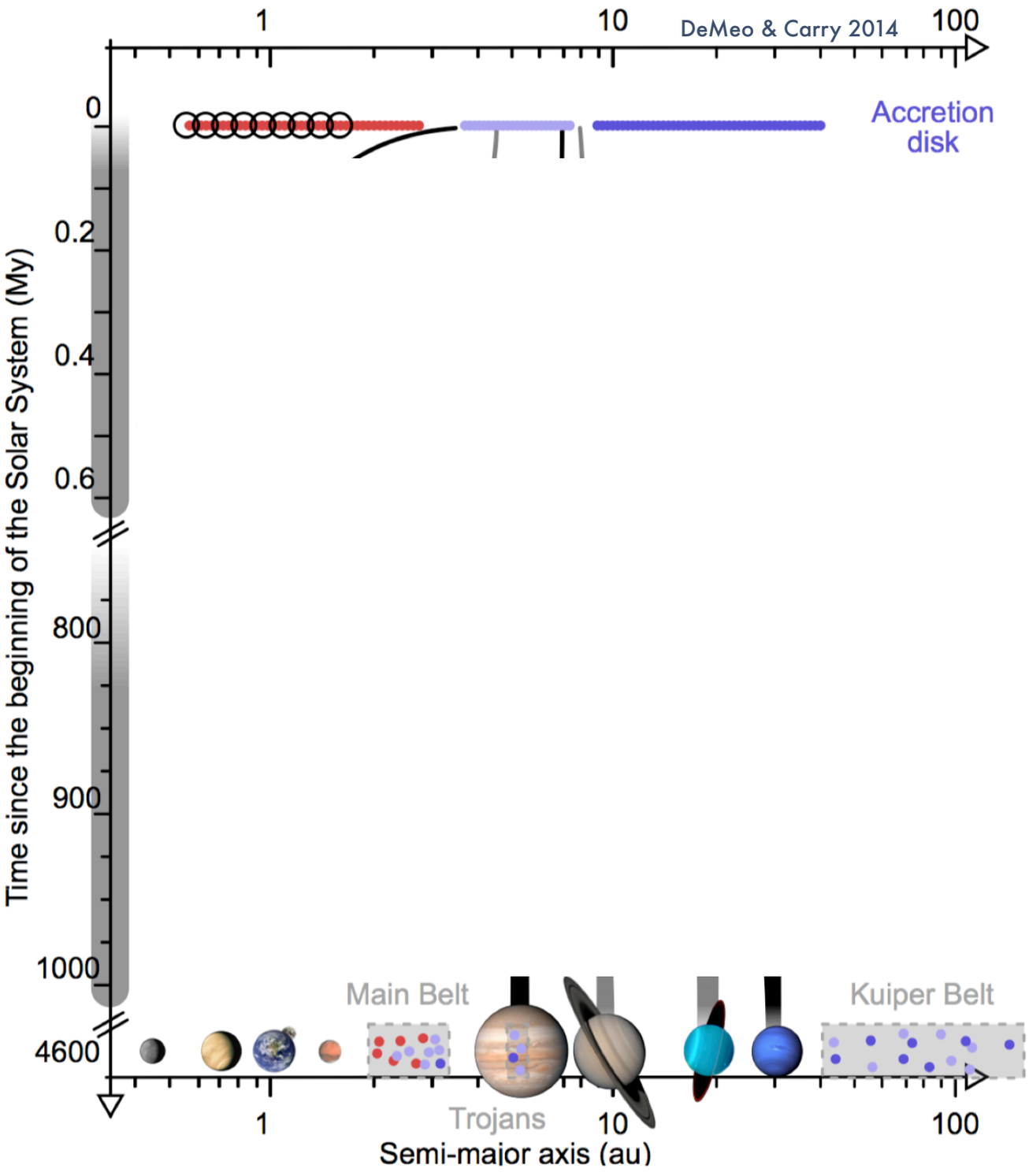
in common: they are all witnesses of the formation of the Solar System



Dust

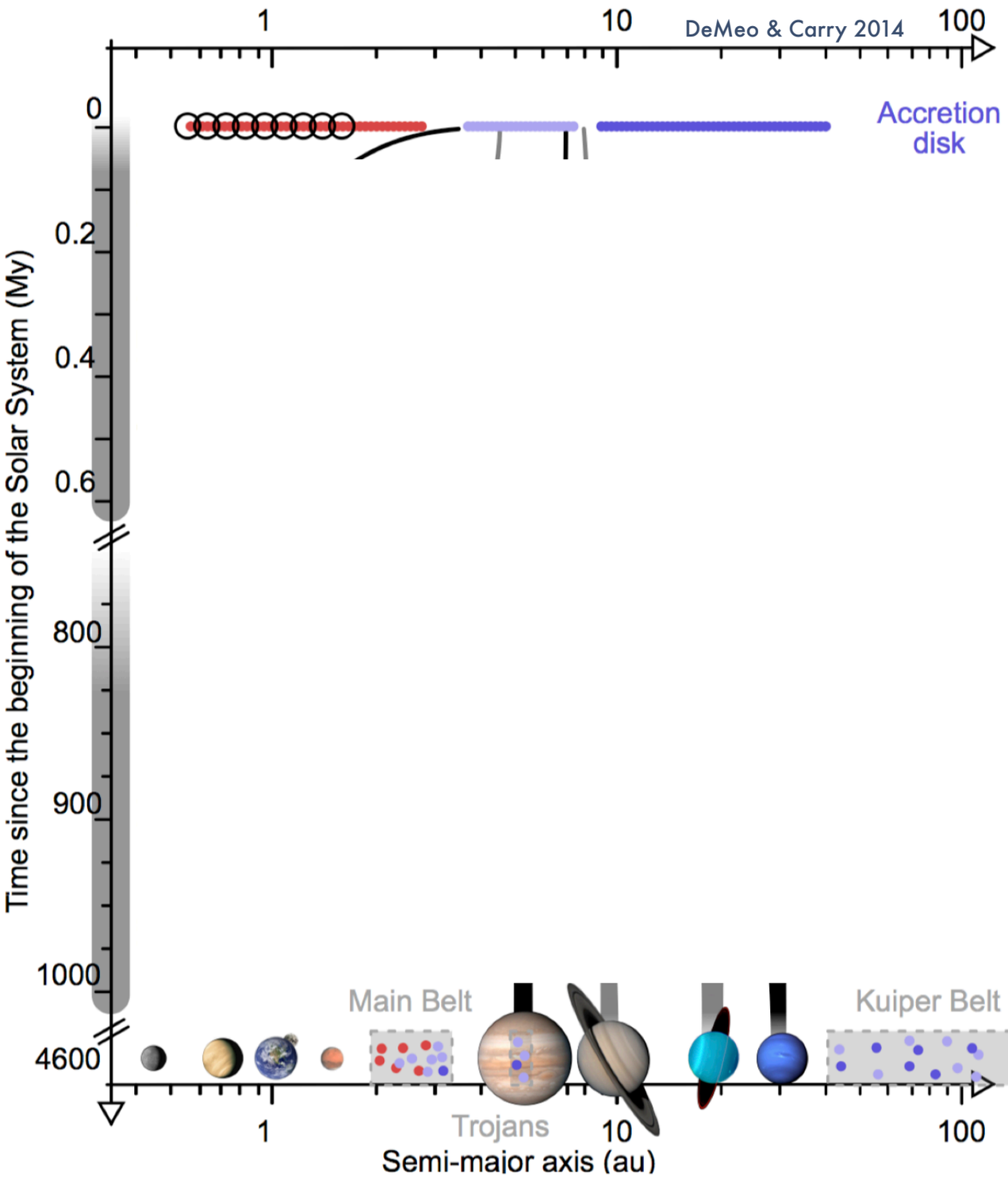
Gas

Pebbles

Planetesimals

Planetary Embryos → Gas Giants

Terrestrial Planets



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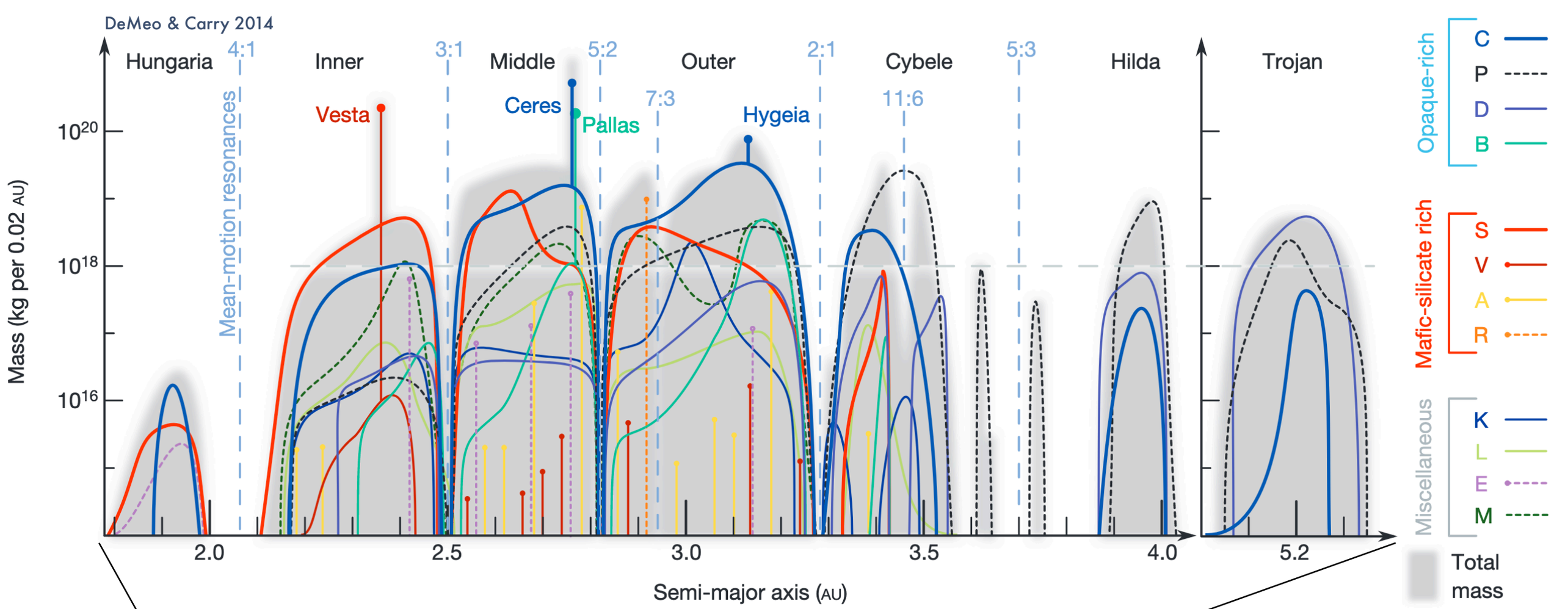
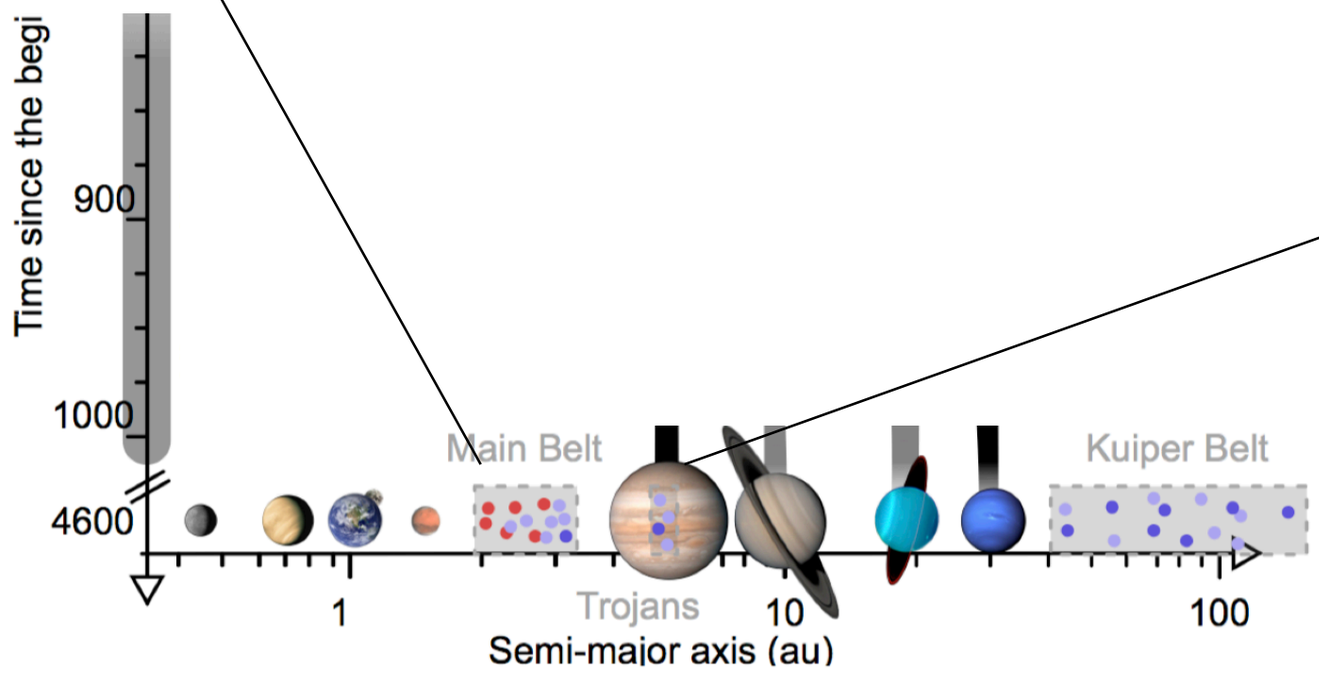
Asteroid puzzle

- Little mass in Main Belt (5×10^{-4} M_{Earth})
- Dynamically excited Main Belt
- Compositionally diverse Main Belt
- Compositionally homogeneous Trojans





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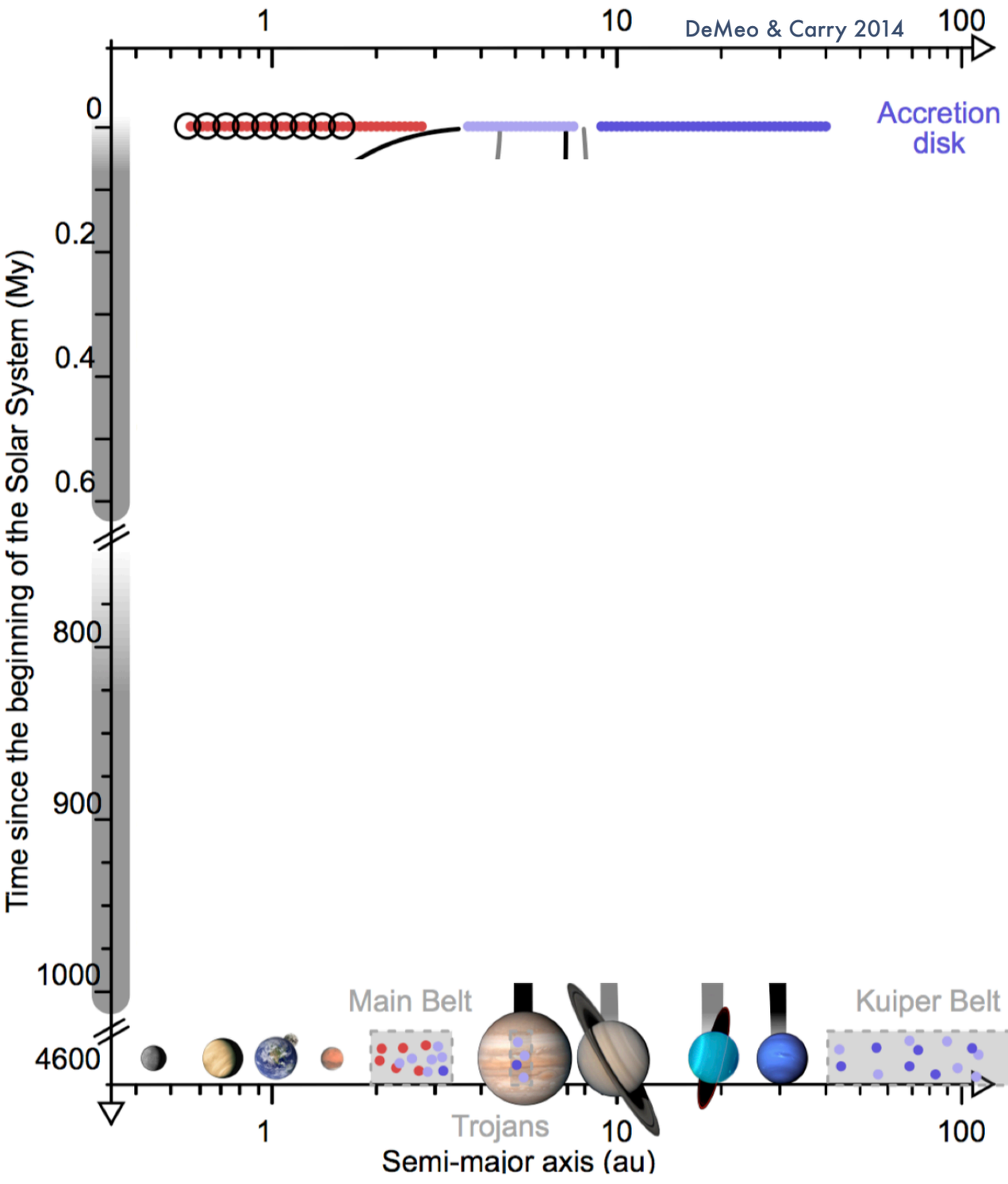

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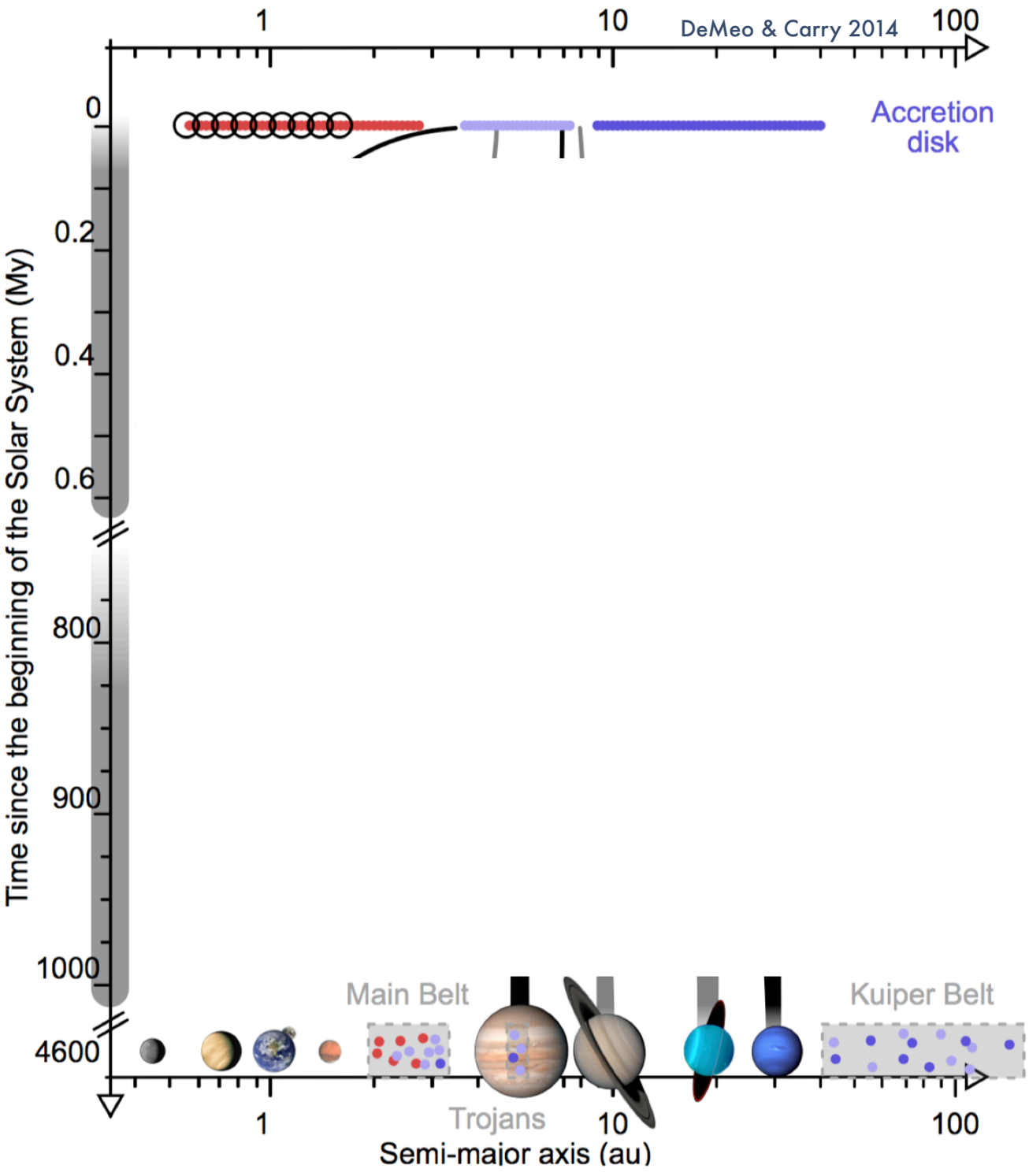

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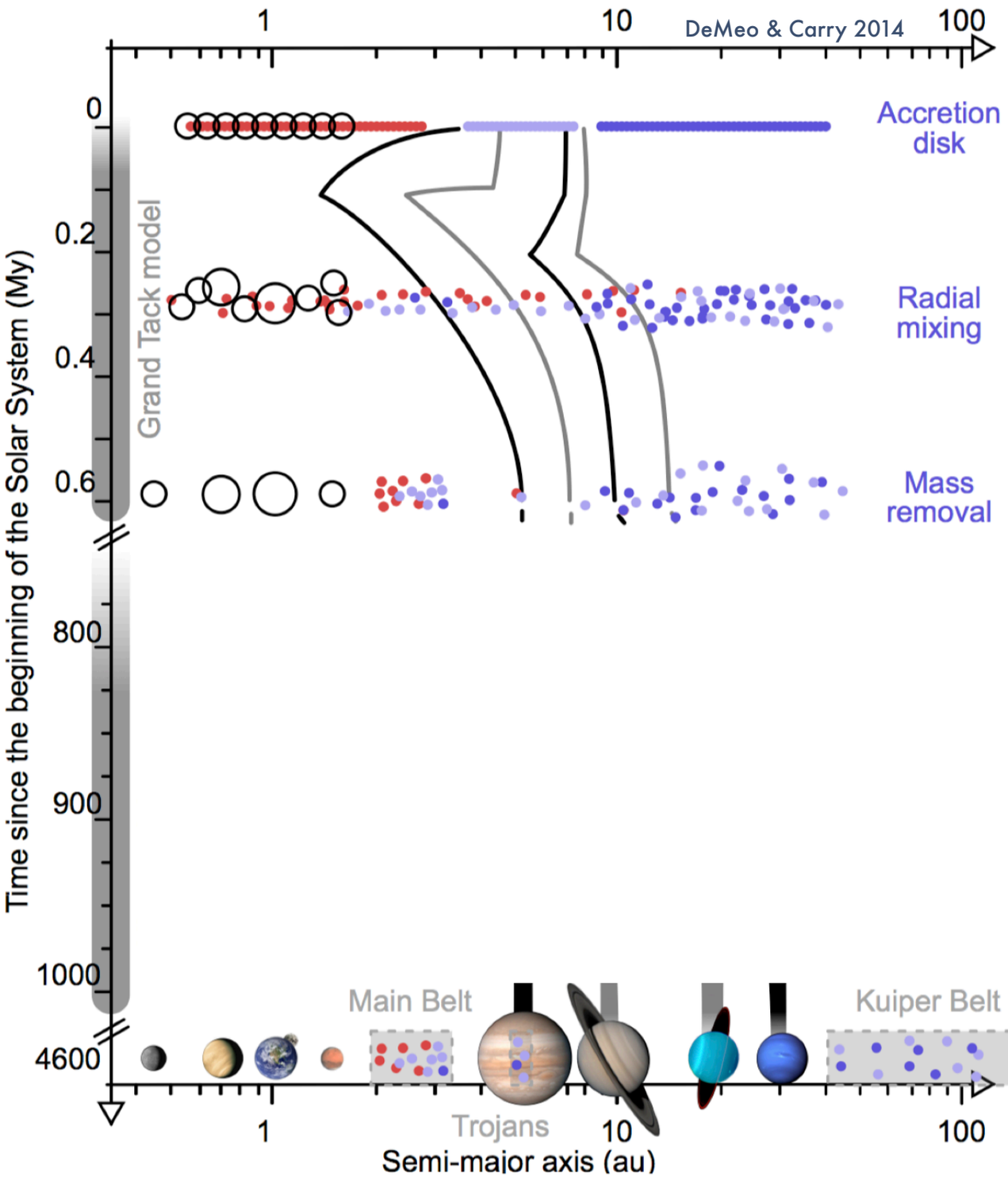

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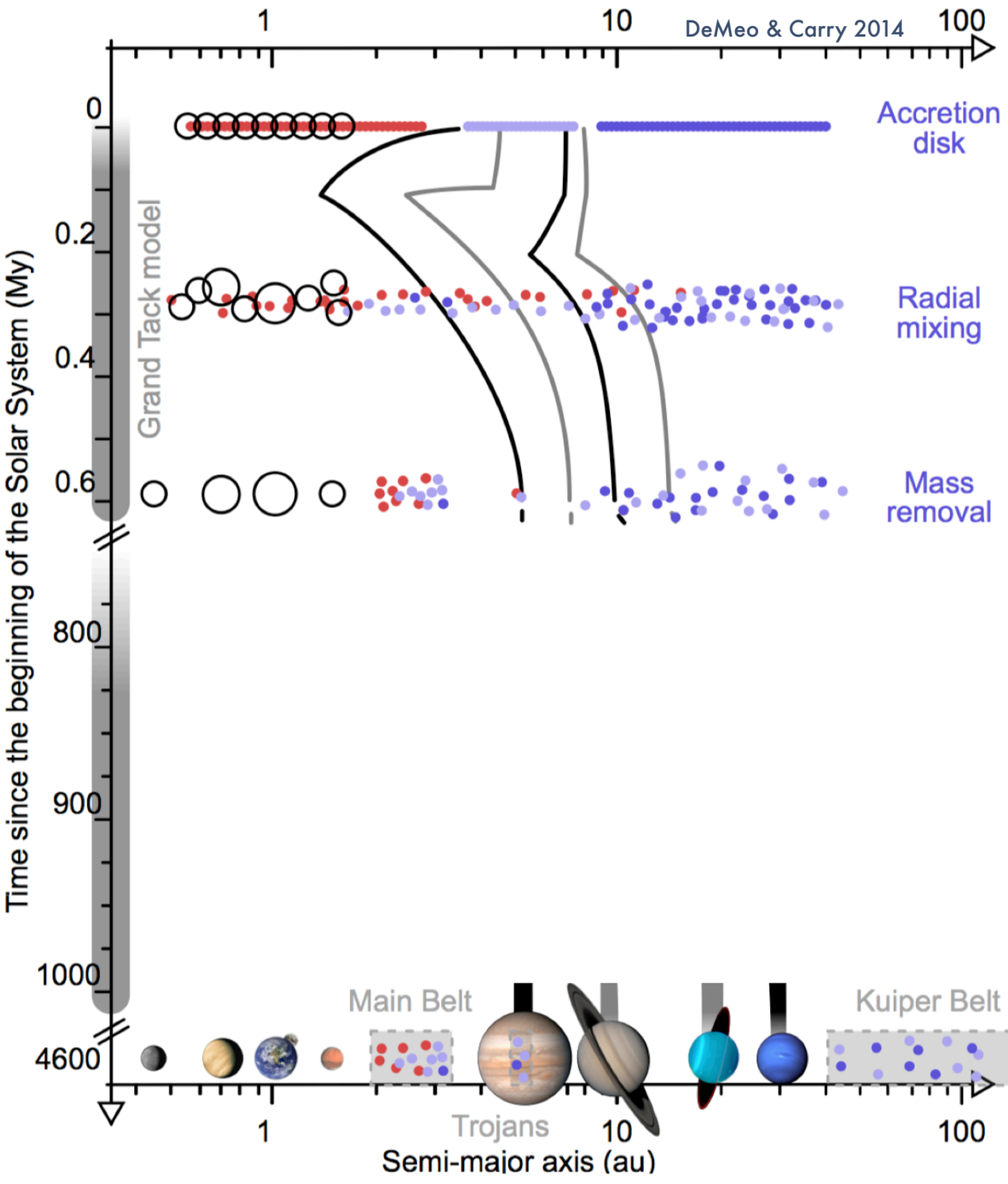

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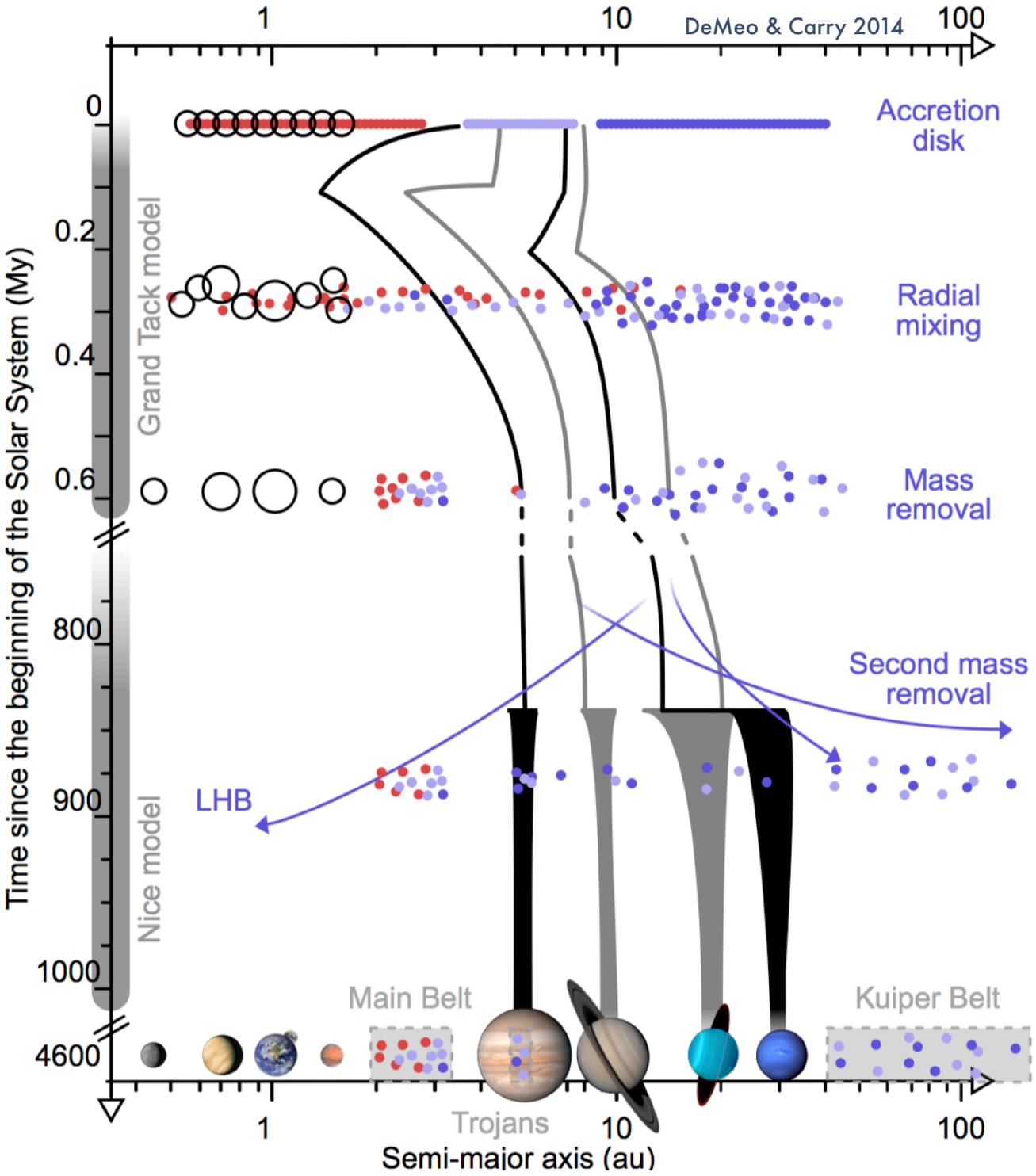

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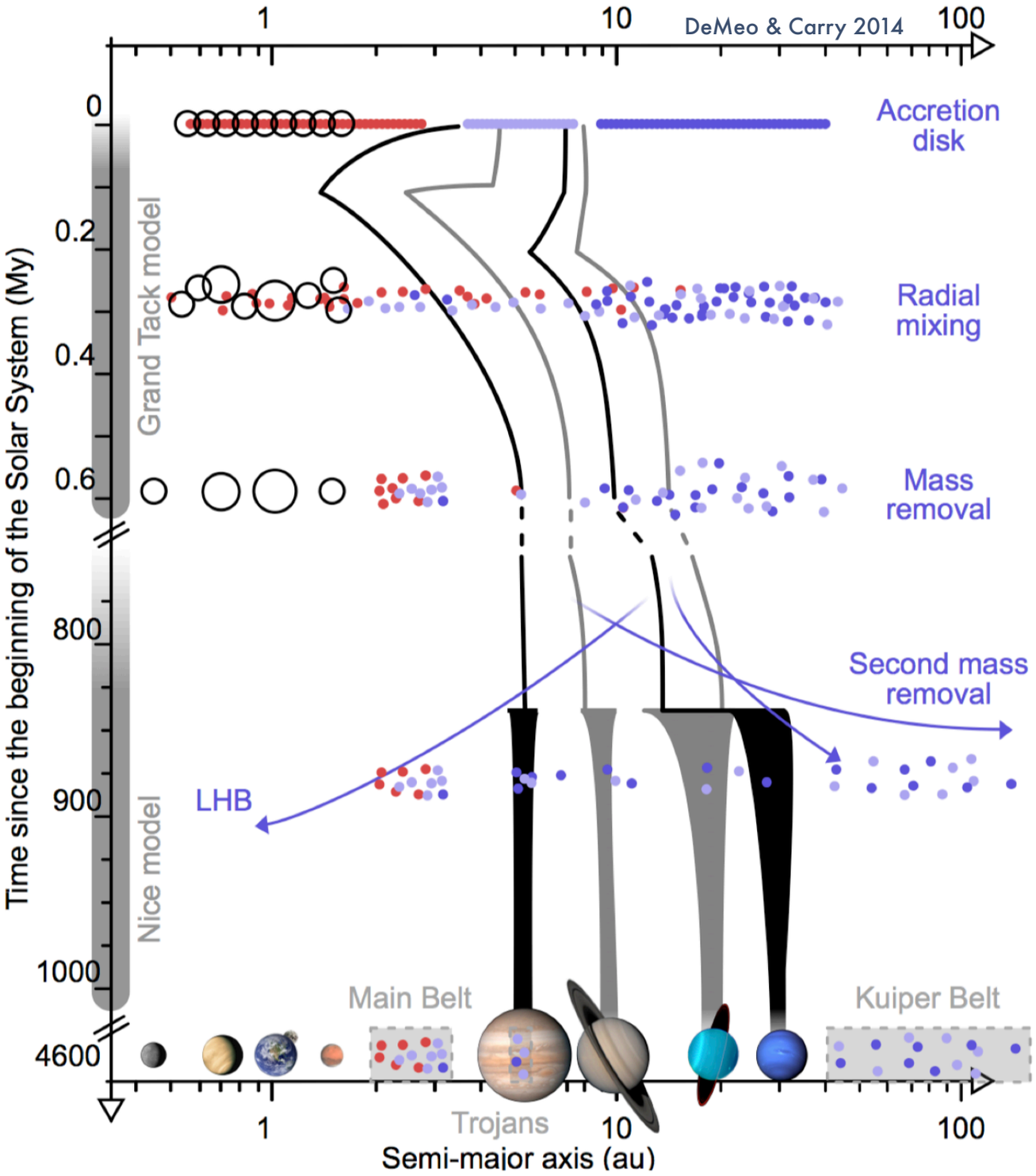

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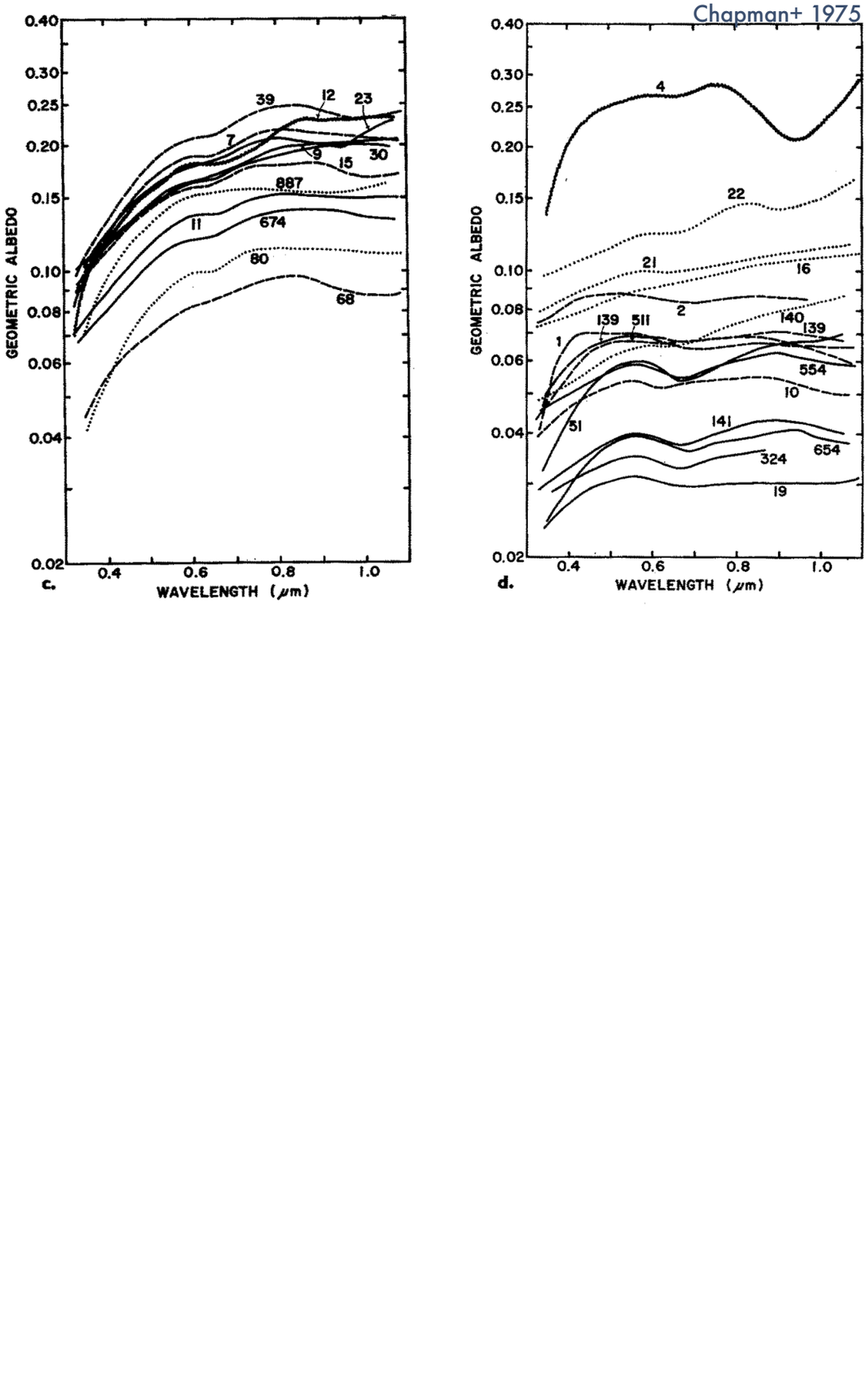
Chapman+ 1975



S

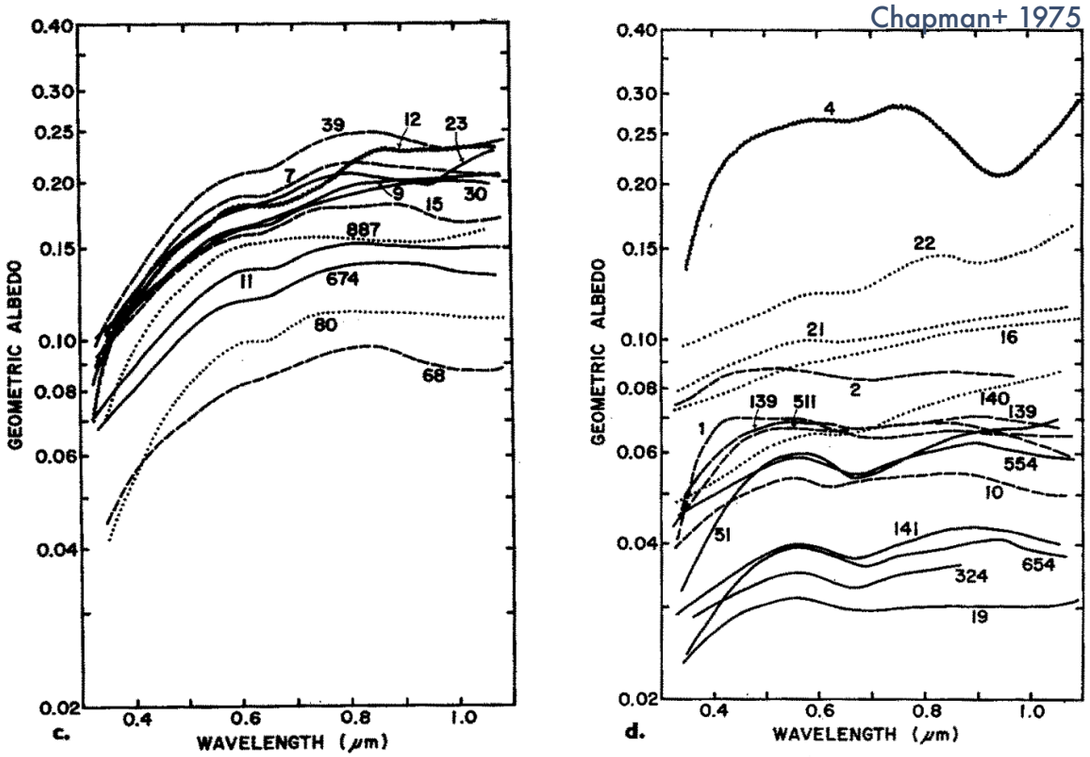
"stony", "silicaceous"

C

"carbonaceous"

U

"unclassified"



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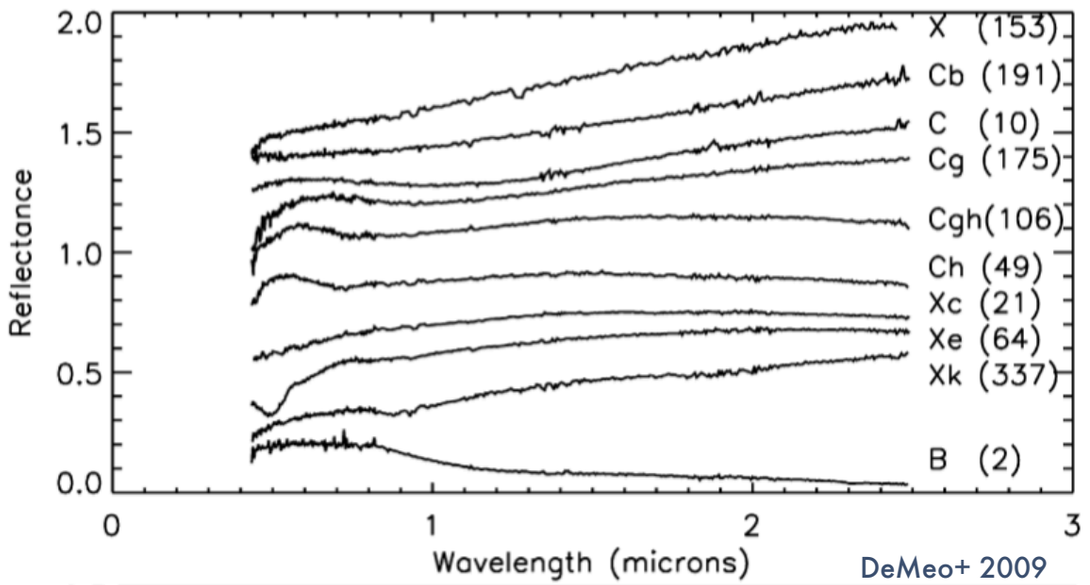

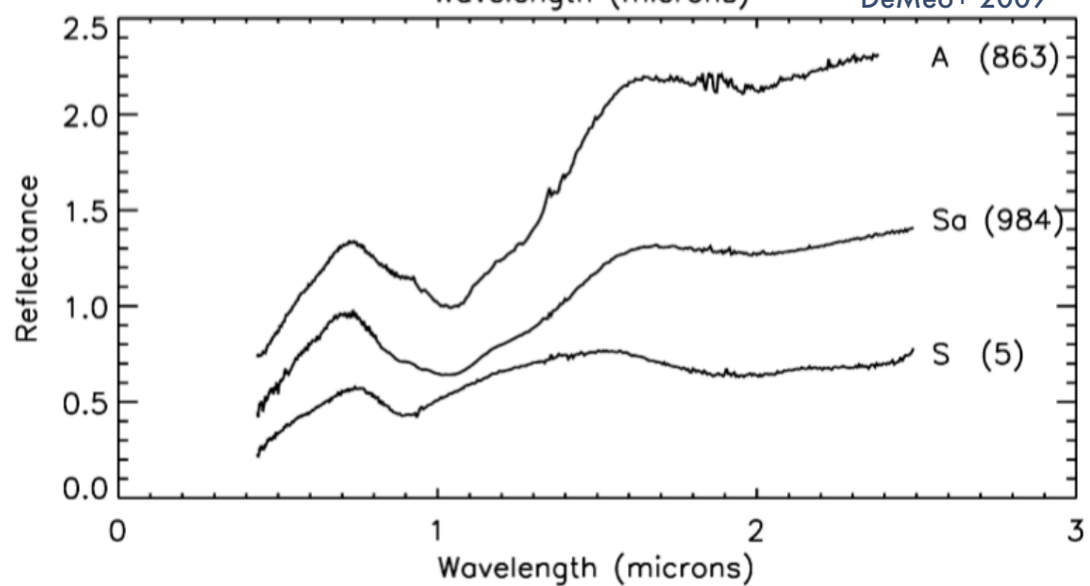

DeMeo+ 2009

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V	**P**	**X**
A	**B**	**M**
R	**D**	**E**
K	**L**	+ composite classes + hydrated cases

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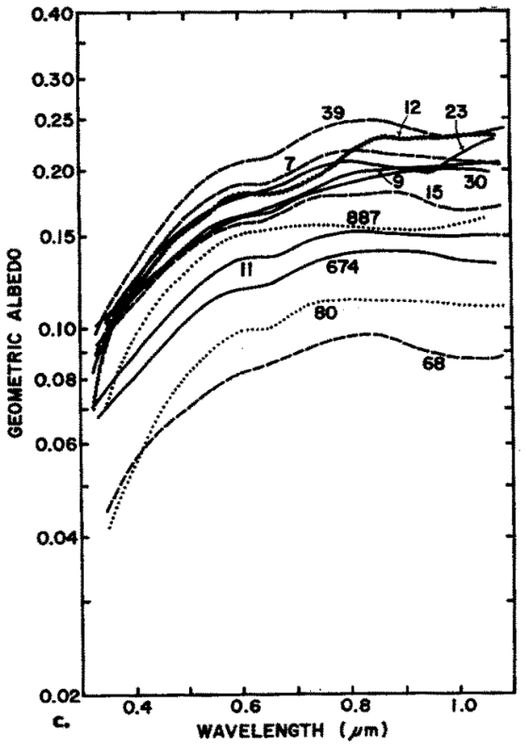

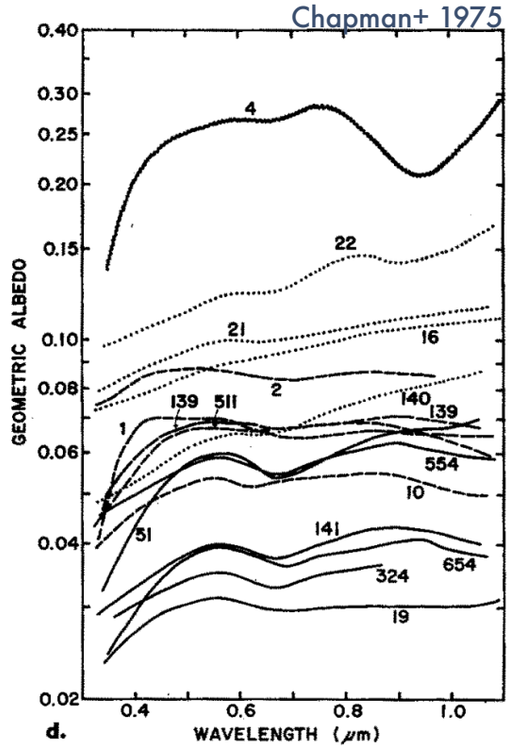

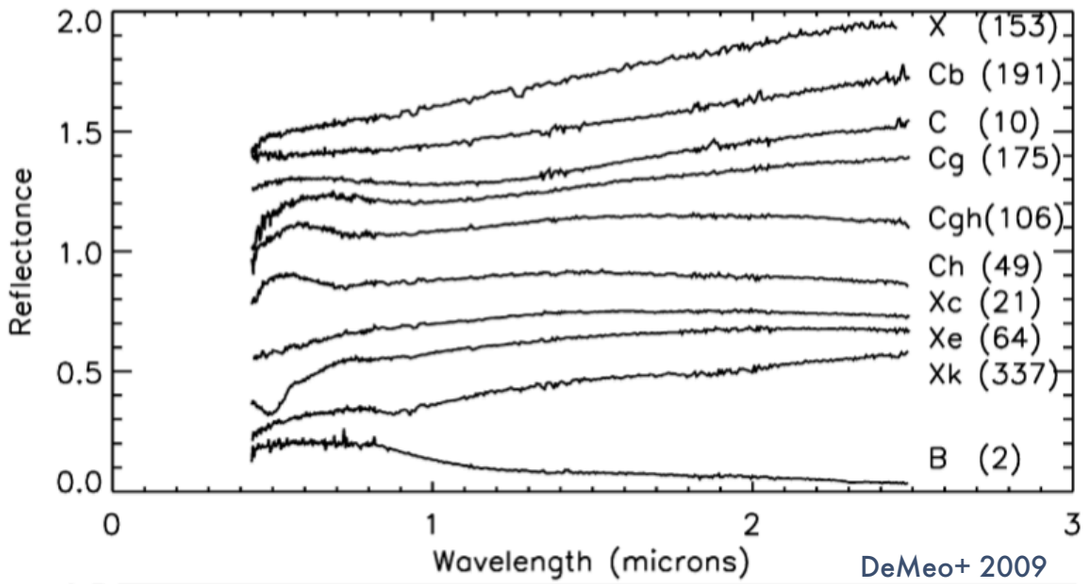

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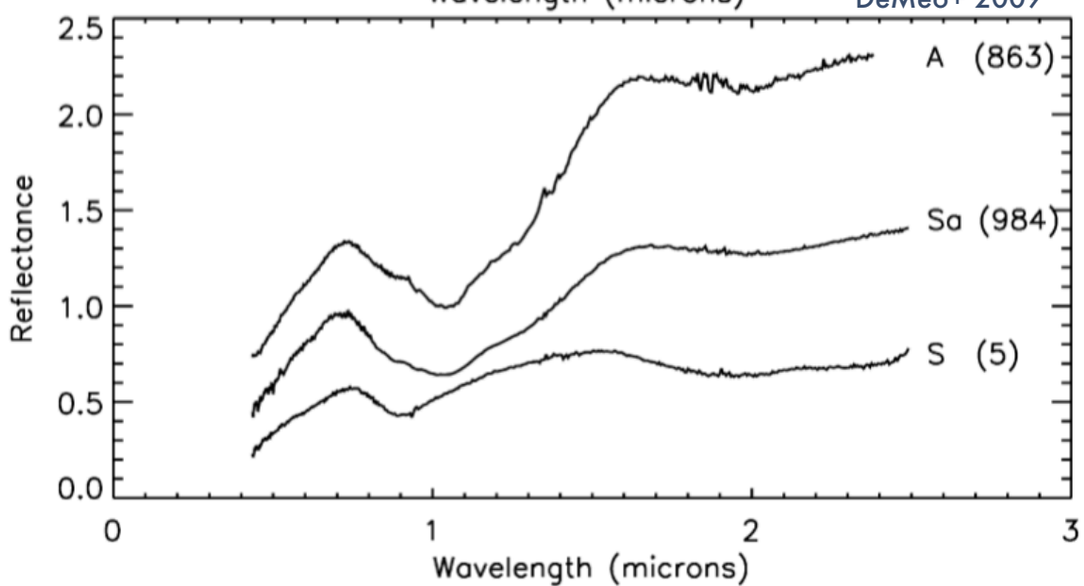

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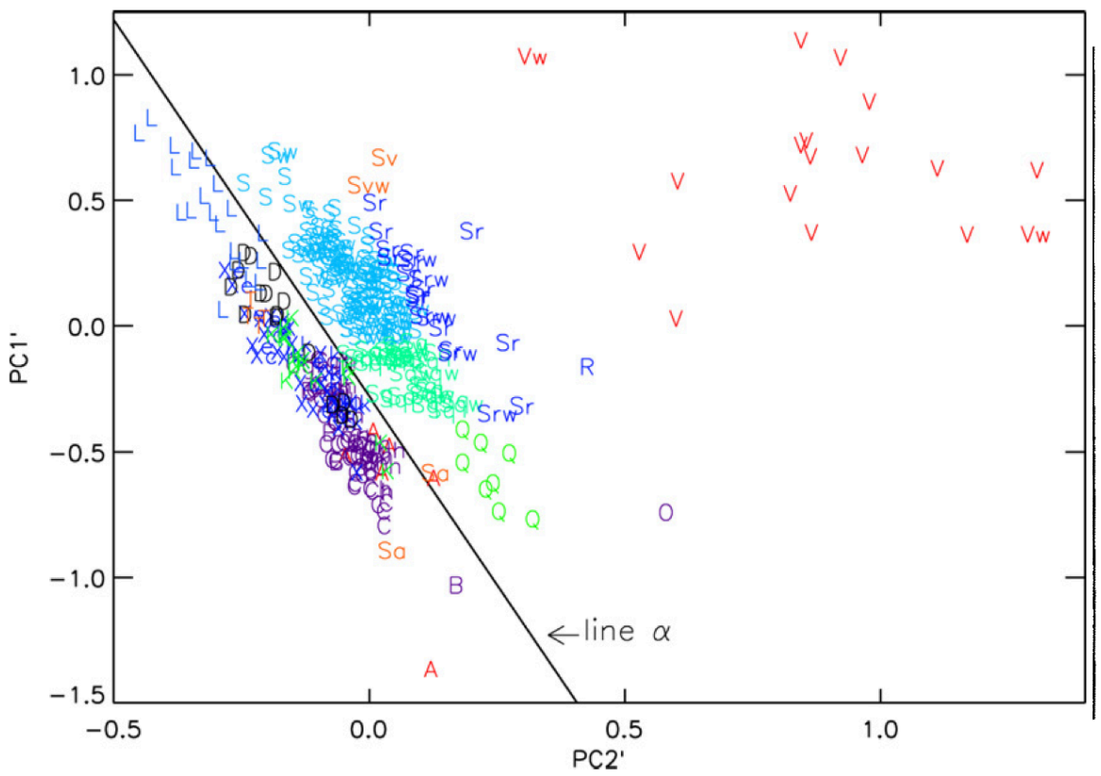
Classes are defined by features in the asteroid spectra

VIS / NIR slope
Absorption bands, most importantly at 1mu (olivine)
2mu (pyroxene)

Some caveats

Classes are degenerate when regarding only VIS or only NIR
In general, low number of asteroid spectra to define classes



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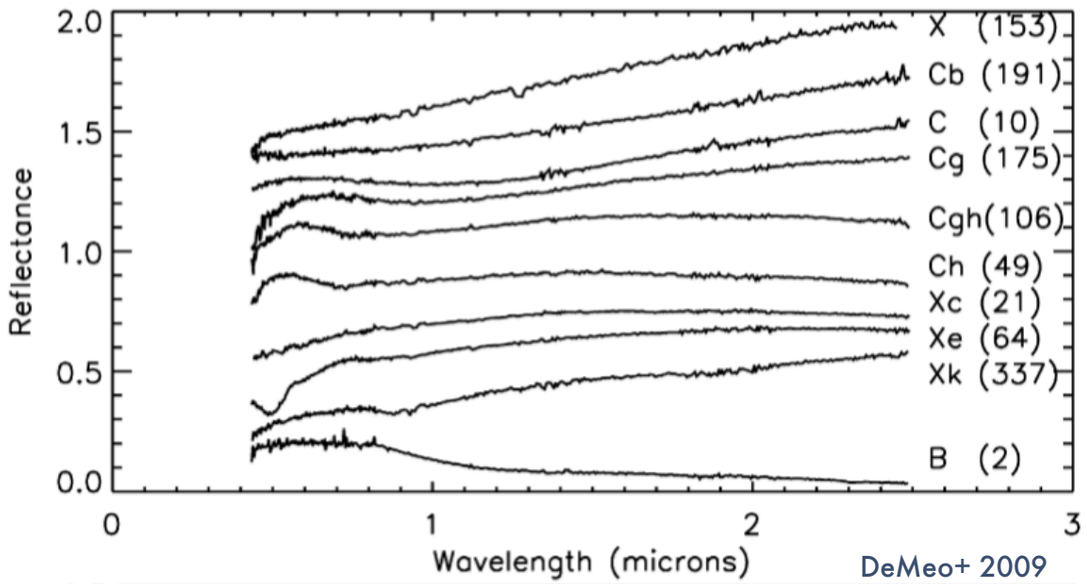

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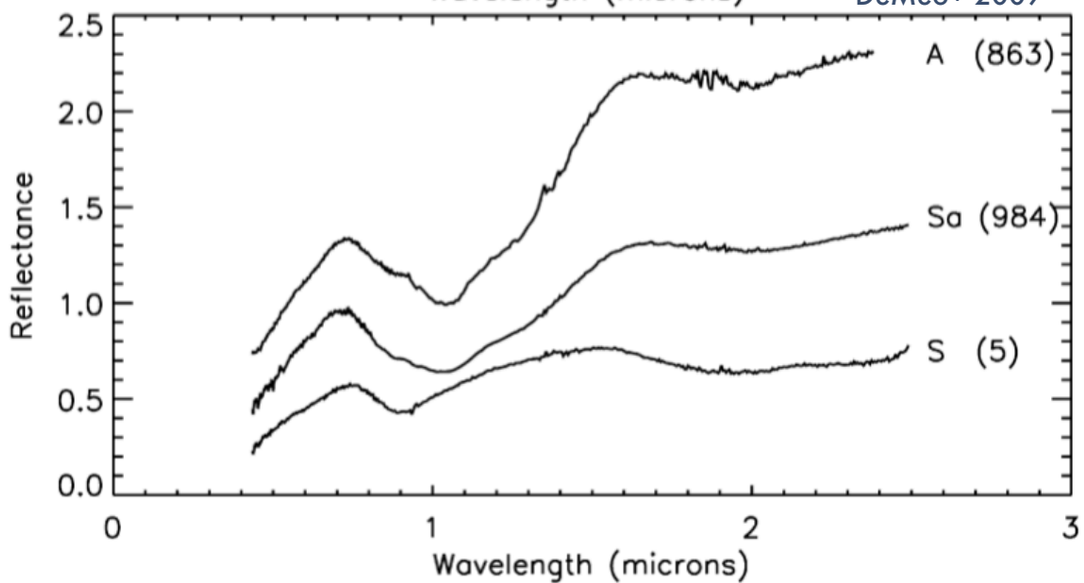

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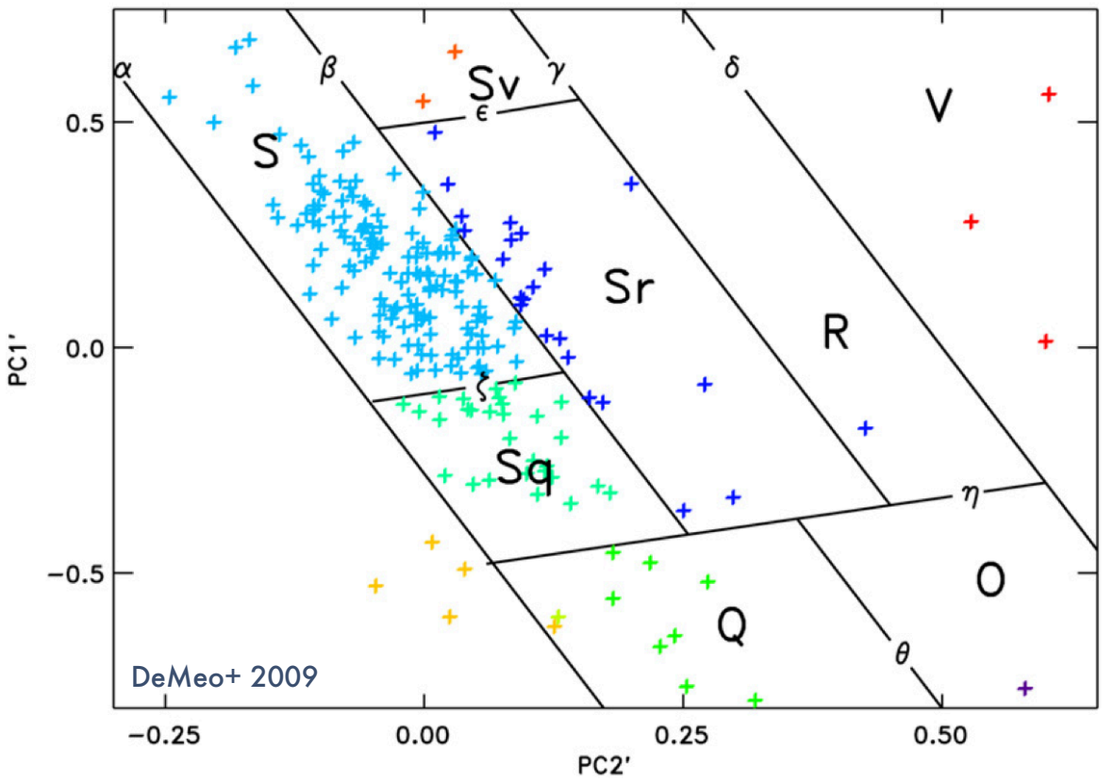

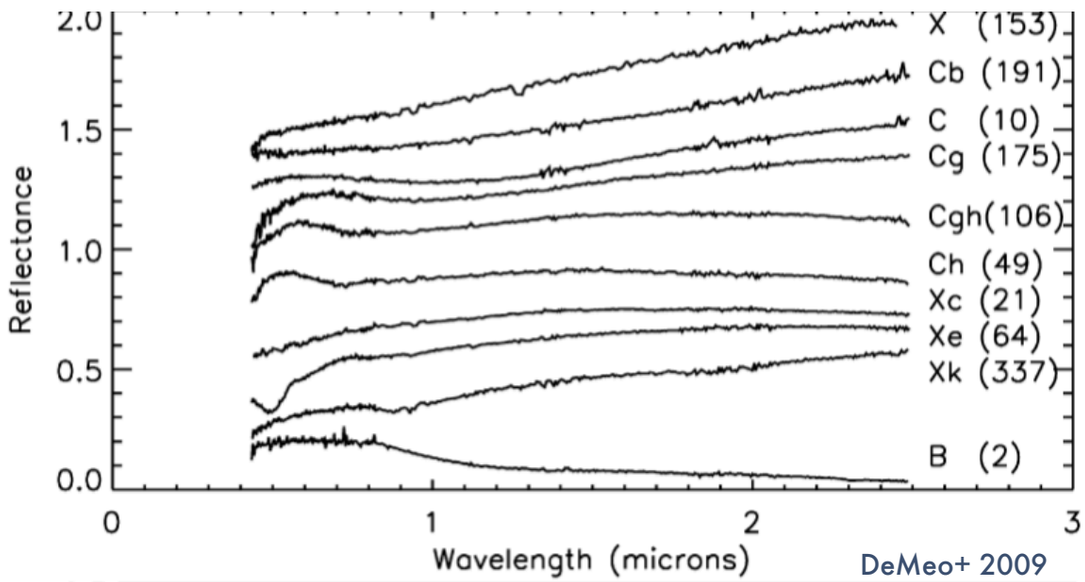

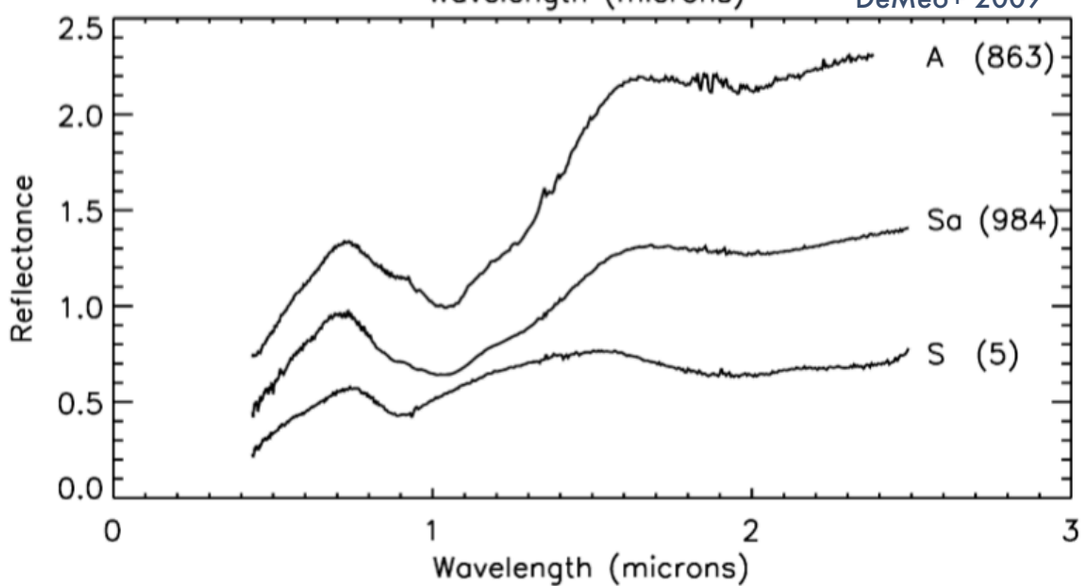

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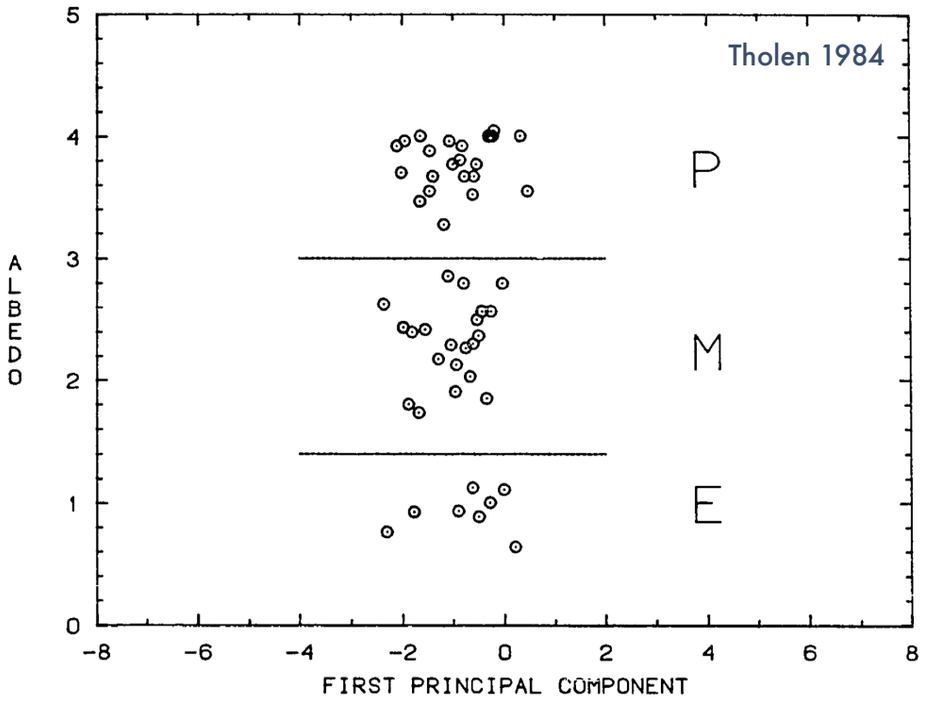
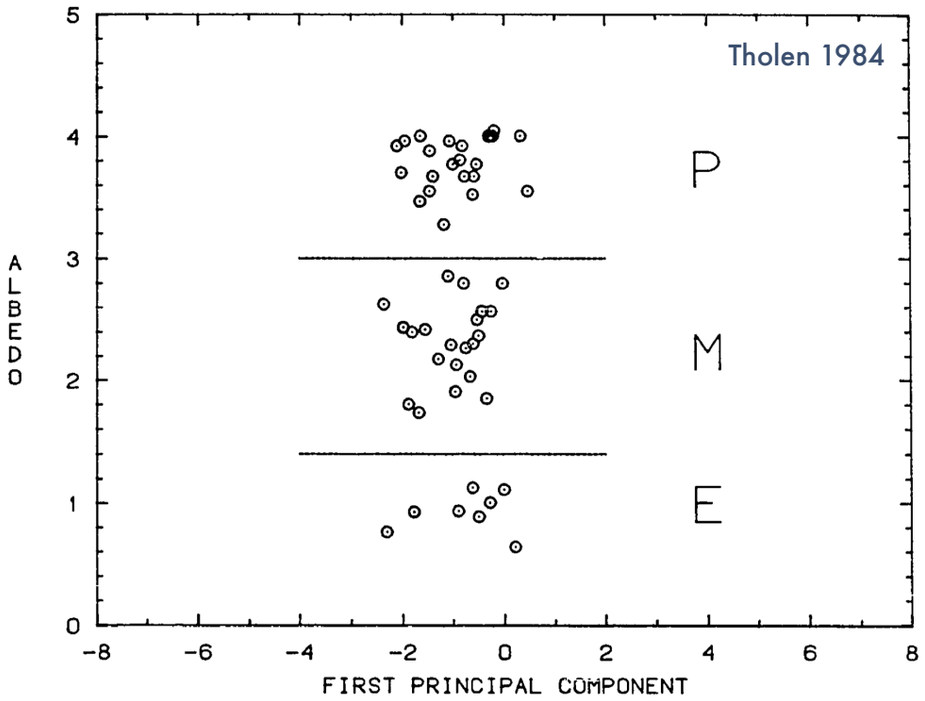


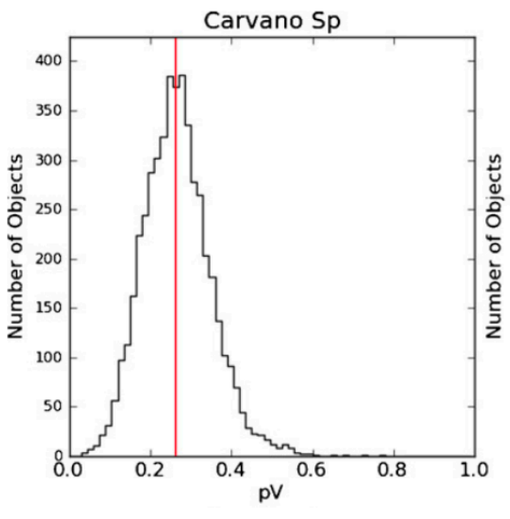
Asteroids can also be classified by their albedos

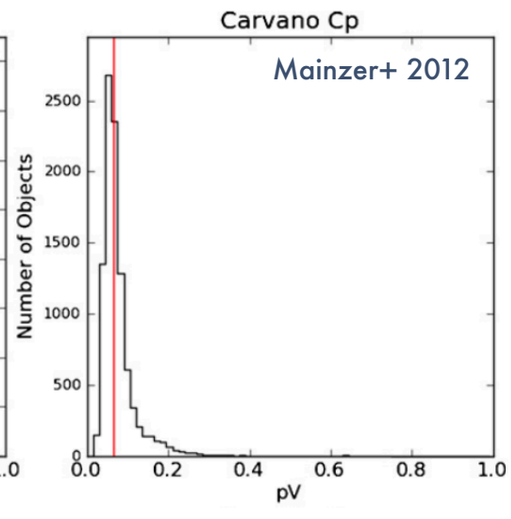
albedo is the "capability to reflect light"

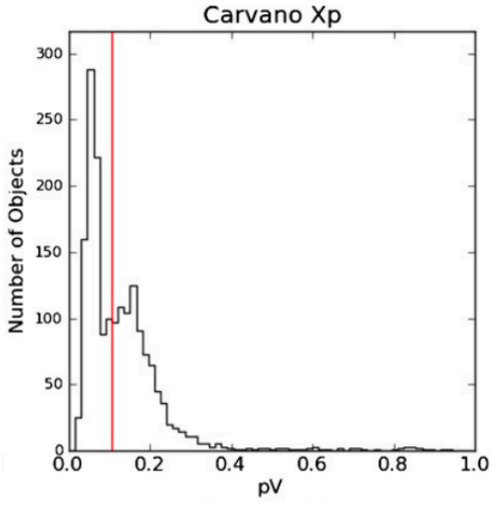
visual albedo, infrared albedo, and their ratios

the albedo carries less information, but is more readily available than the spectra









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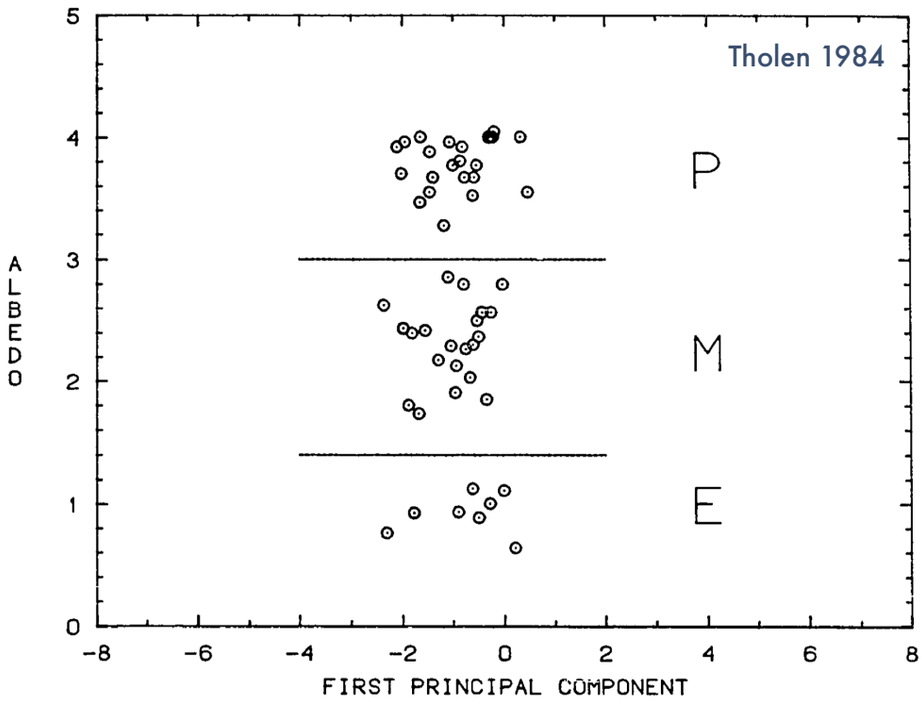

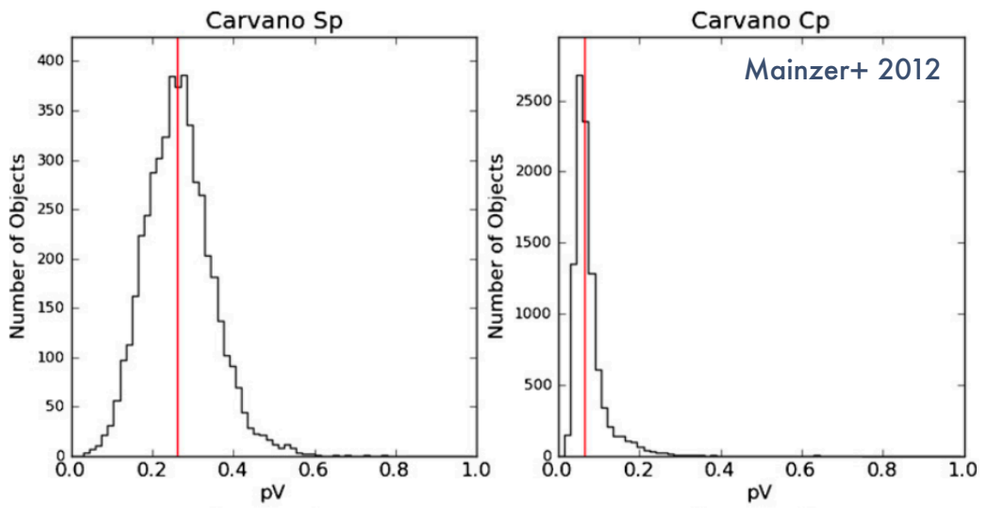

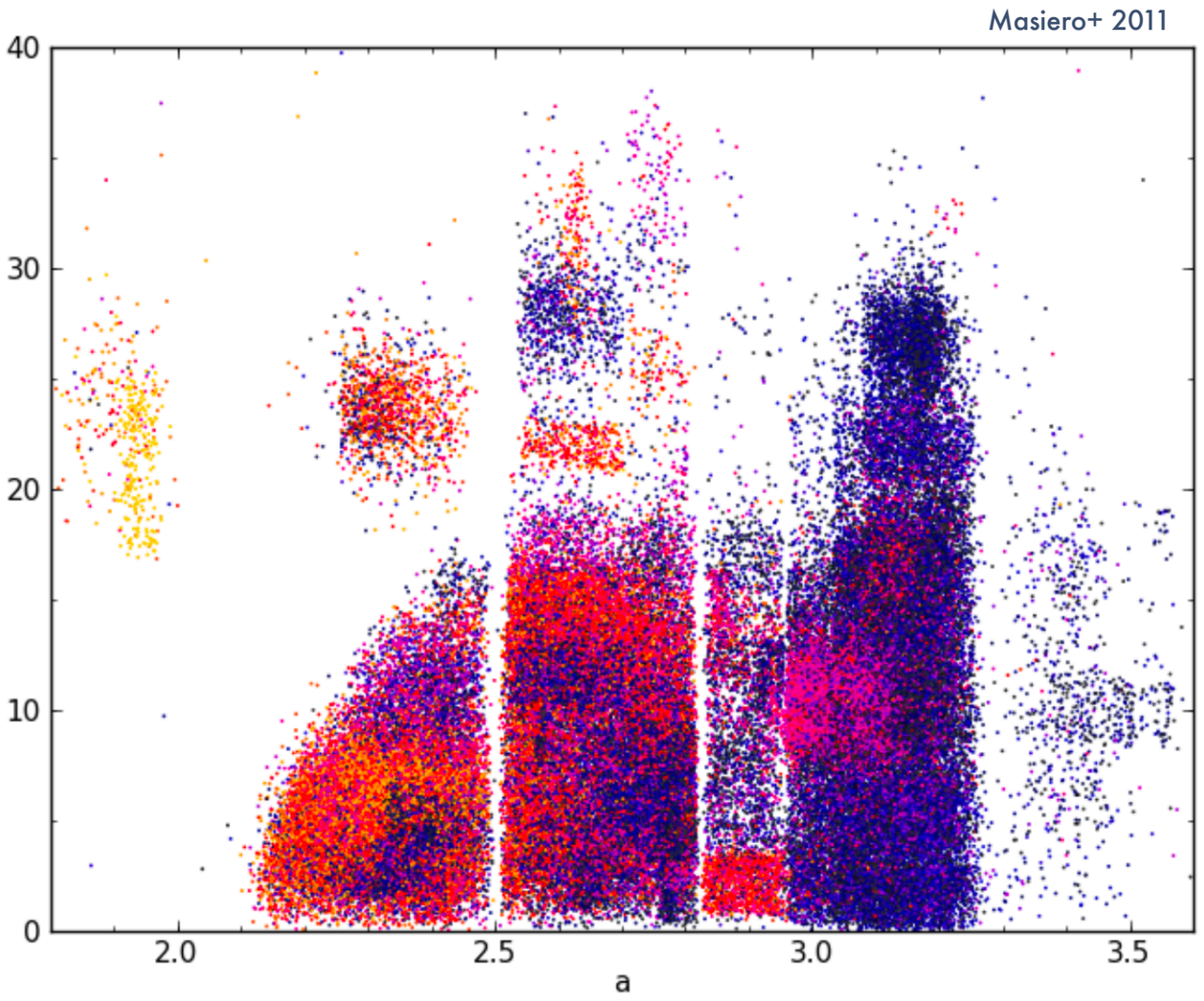

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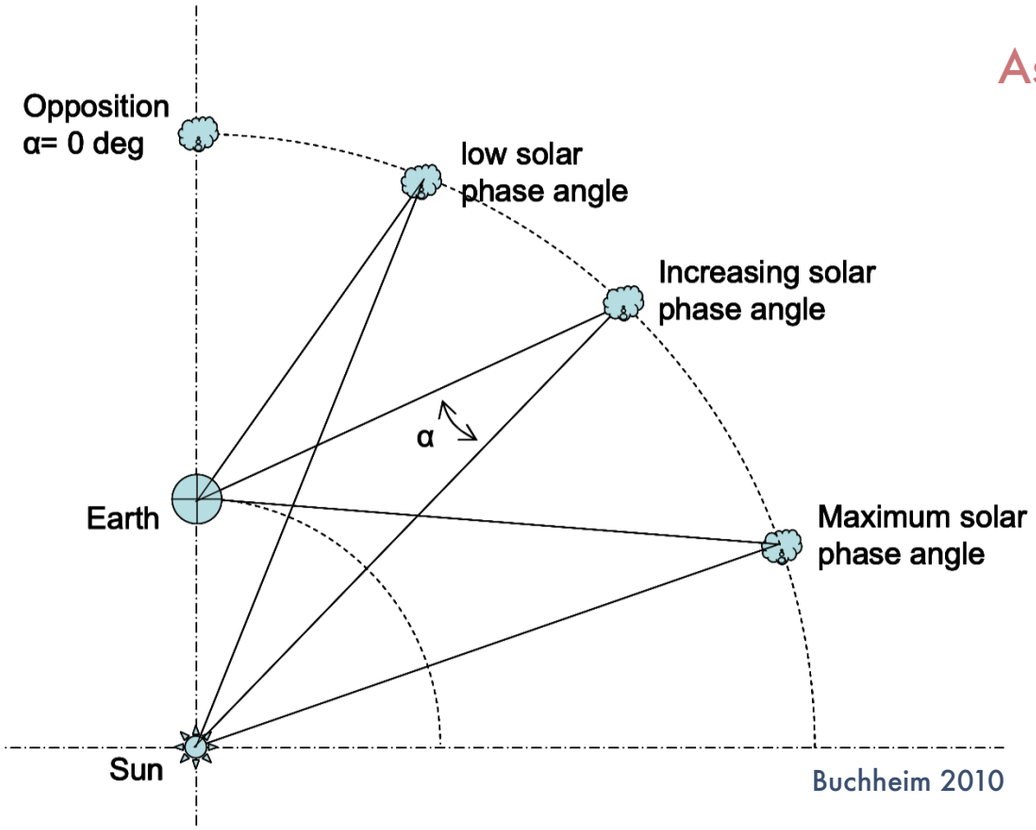
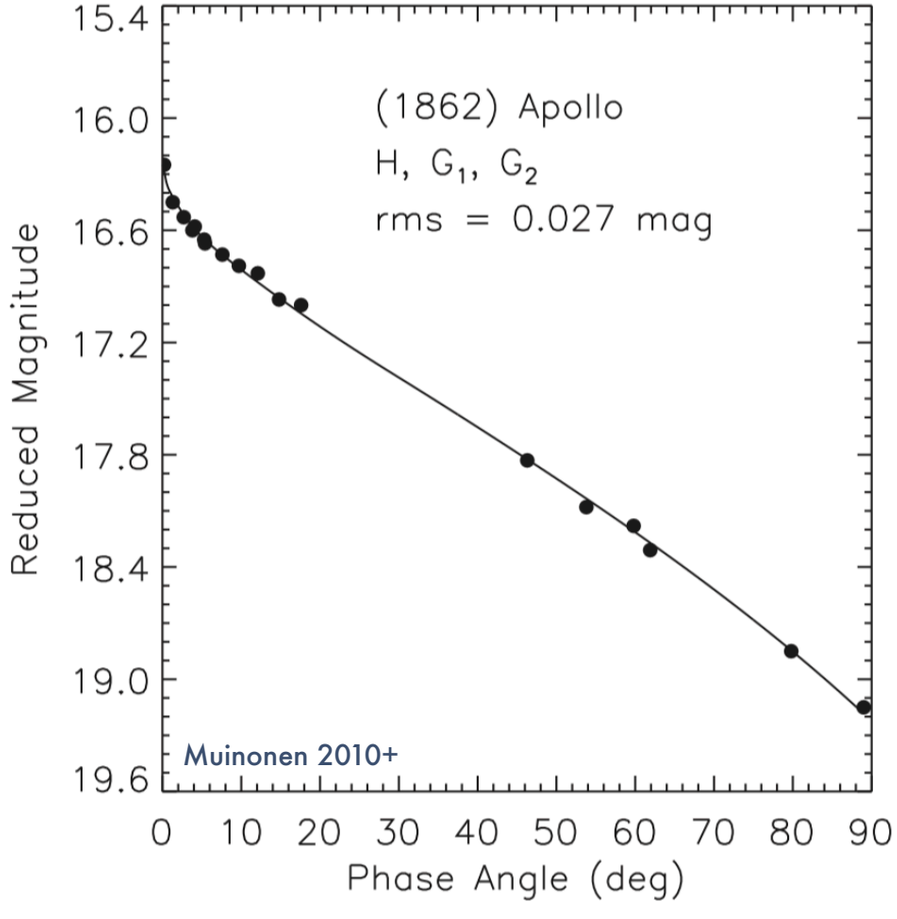


Buchheim 2010

slope parameters G_1 and G_2 defining the decrease in brightness as the solar phase angle increases

less information than than albedos and spectra, but available from serendipitous observations



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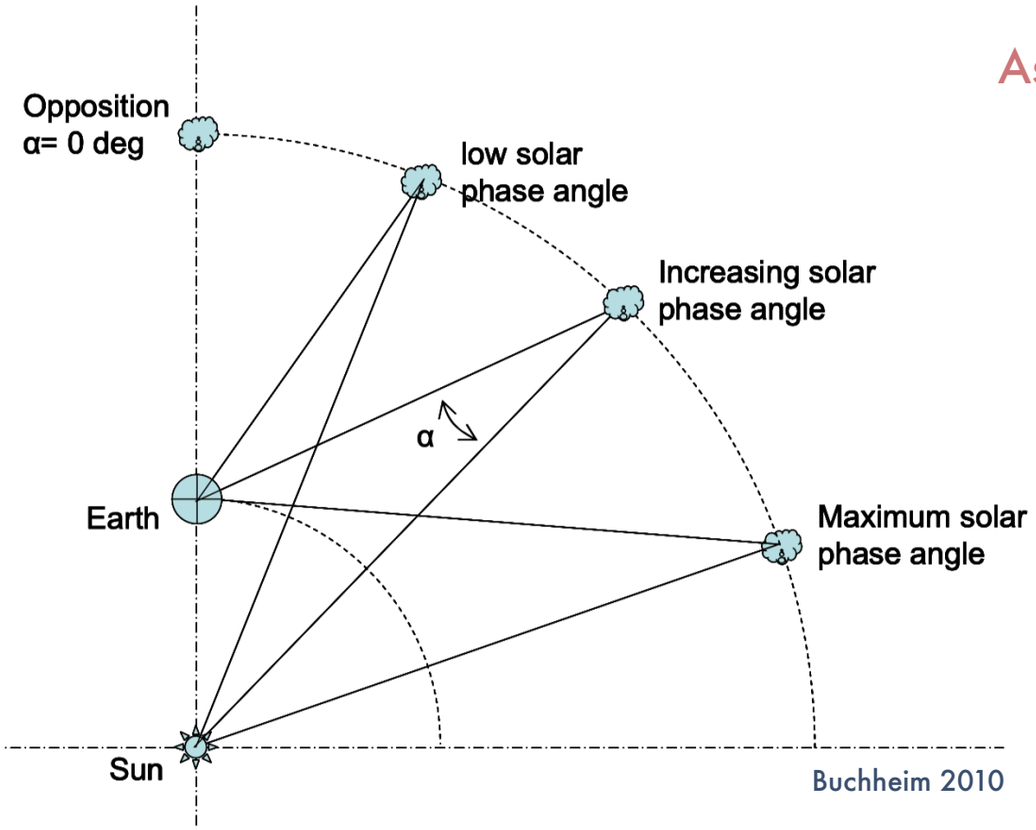

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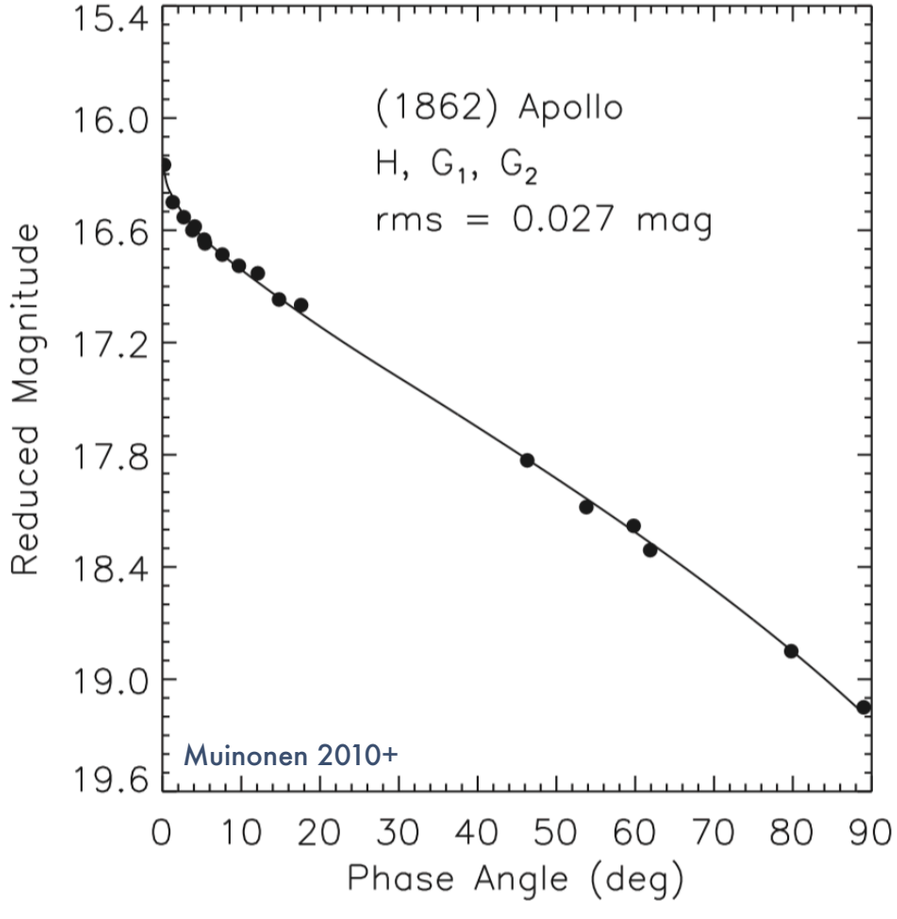
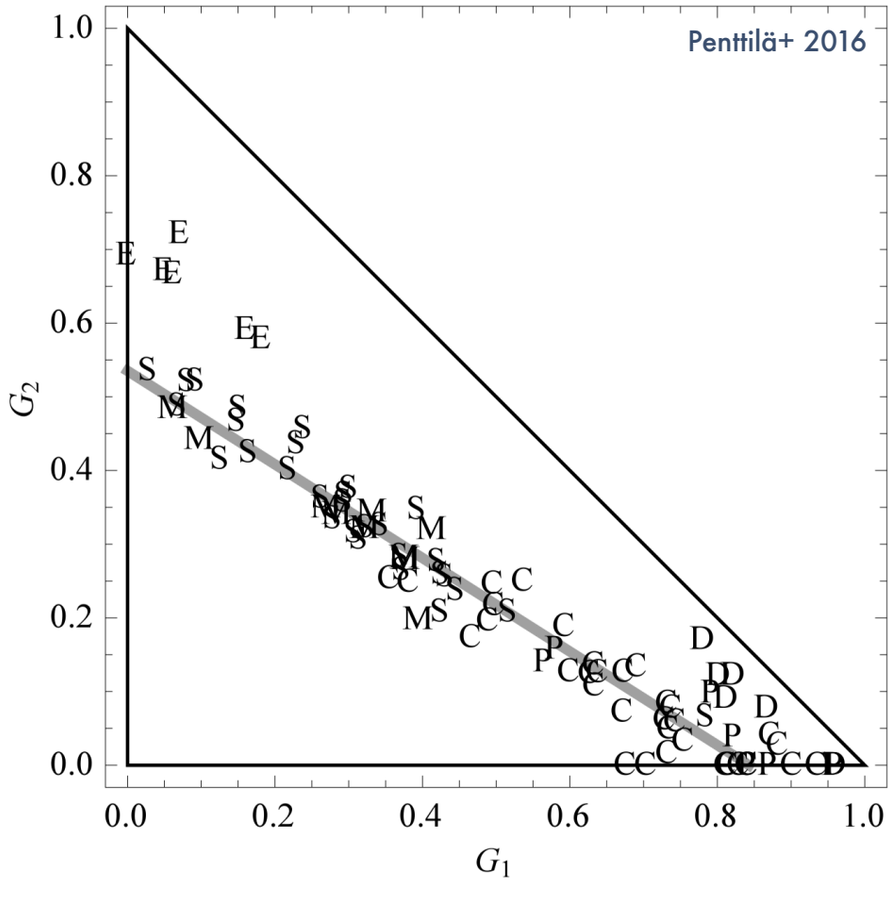
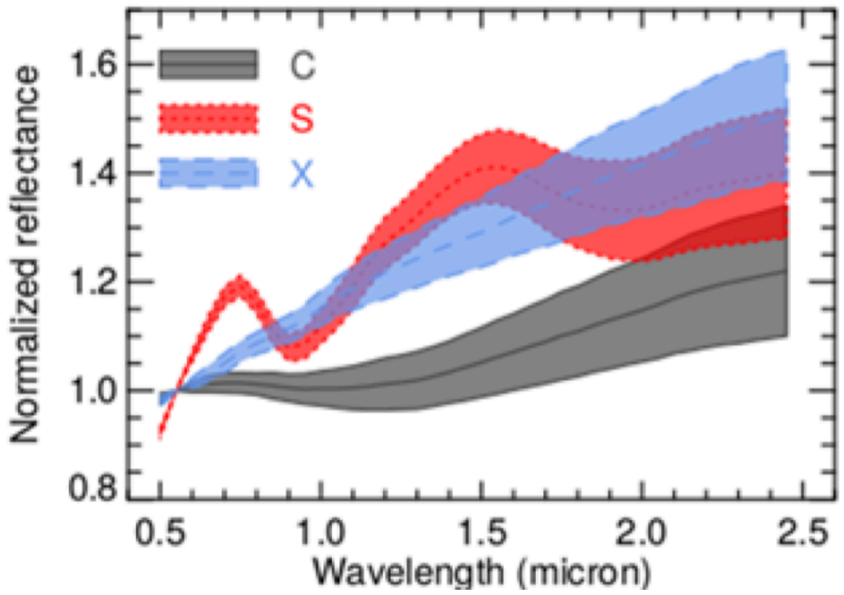
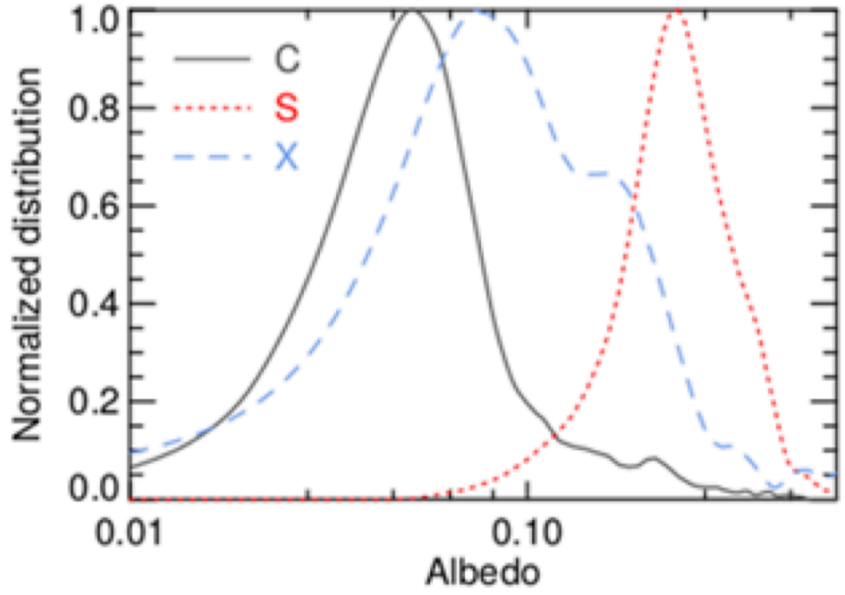
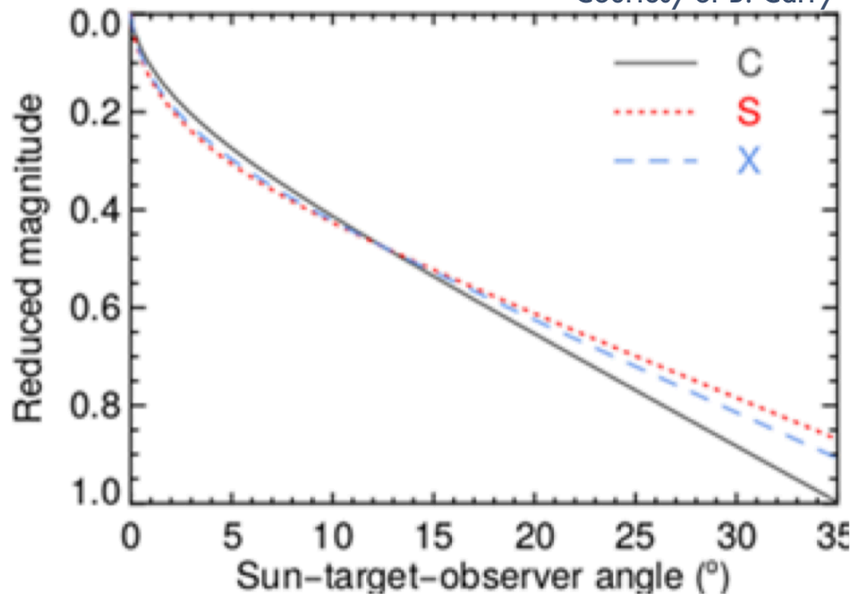




Courtesy of B. Carry







VISNIR: Available for 800 objects
VIS/NIR: Available for 4,000 objects

Available for 200,000 objects

Available for 500,000 objects

Our data collection so far includes ***7,500*** spectra of ***3,500*** unique objects, including 1,000 VISNIR spectra, provided to us by >30 PIs

Compared to the DeMeo classification from 2009

Larger sample size (factor 2 for VISNIR, factor 10 for VIS/NIR)
Multi-dimensional: spectra, albedo, phase curve
Give probabilistic classifications

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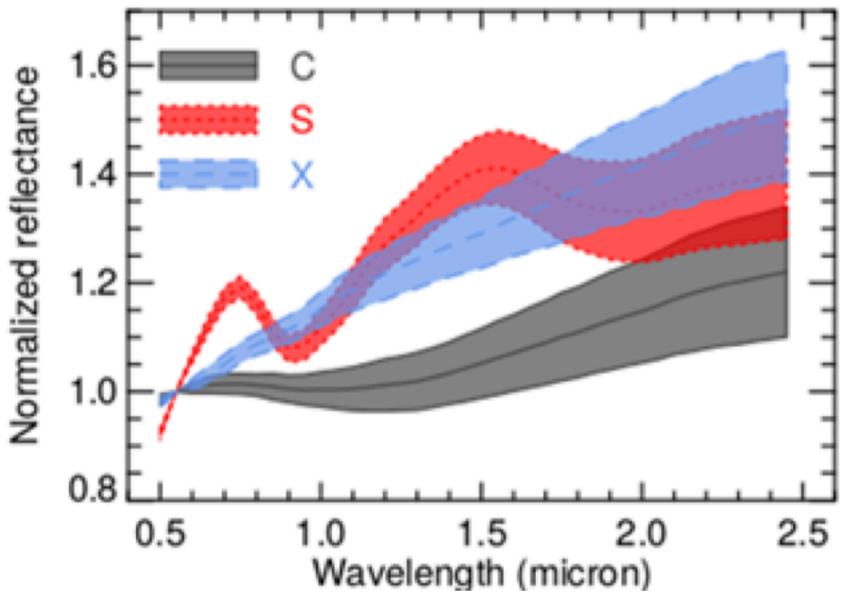

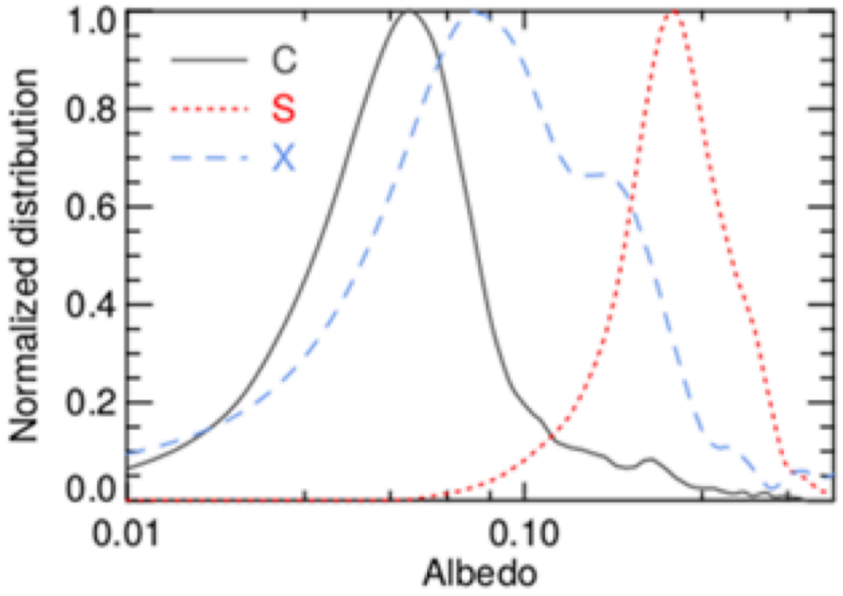

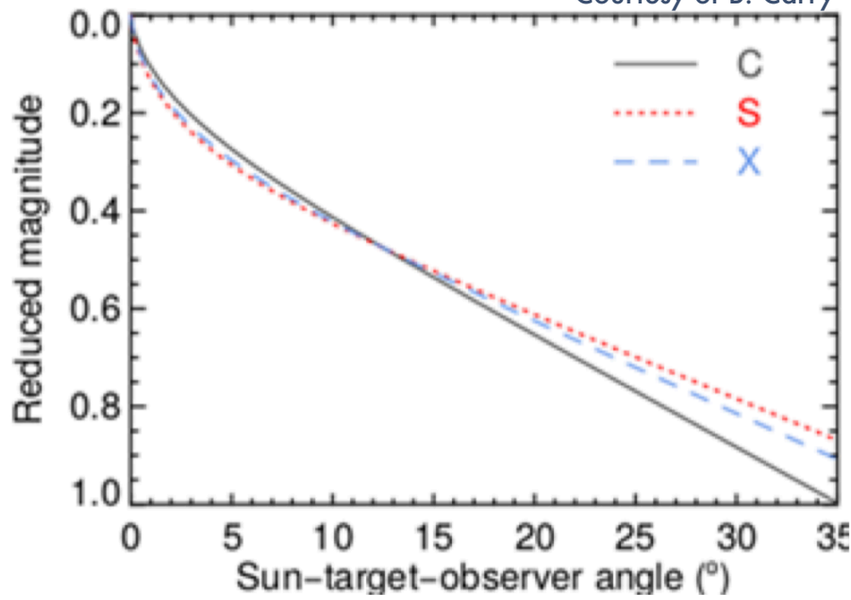

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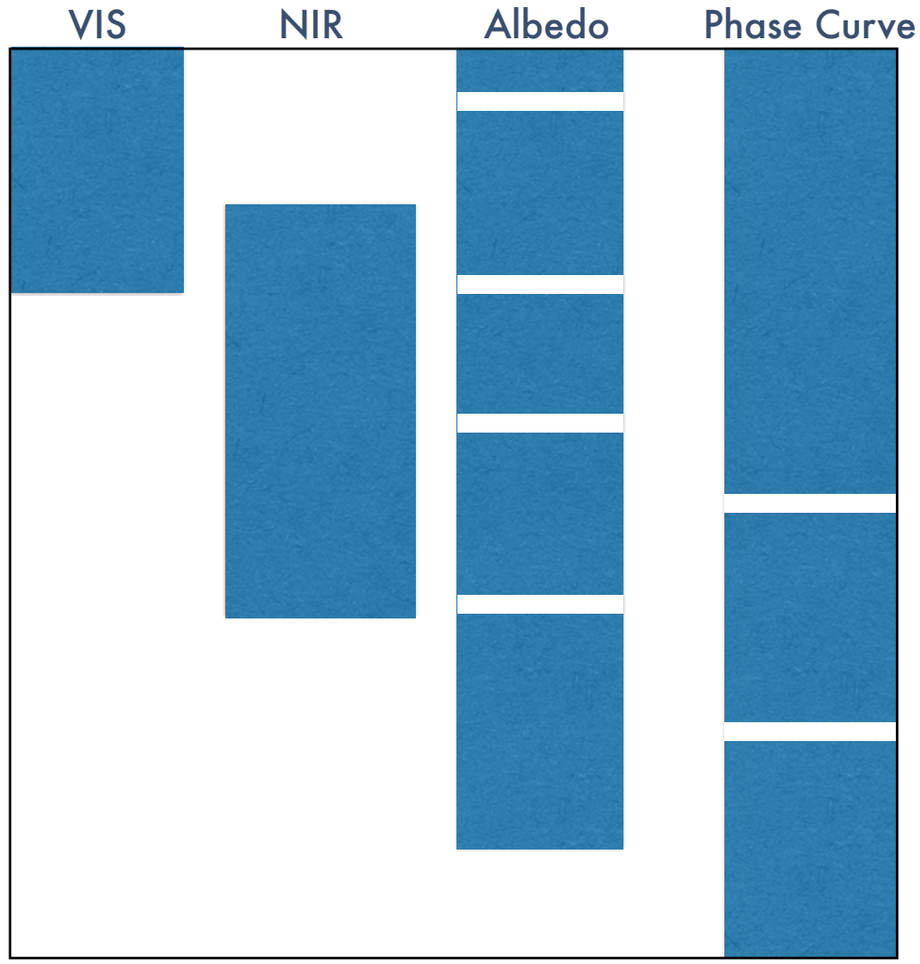

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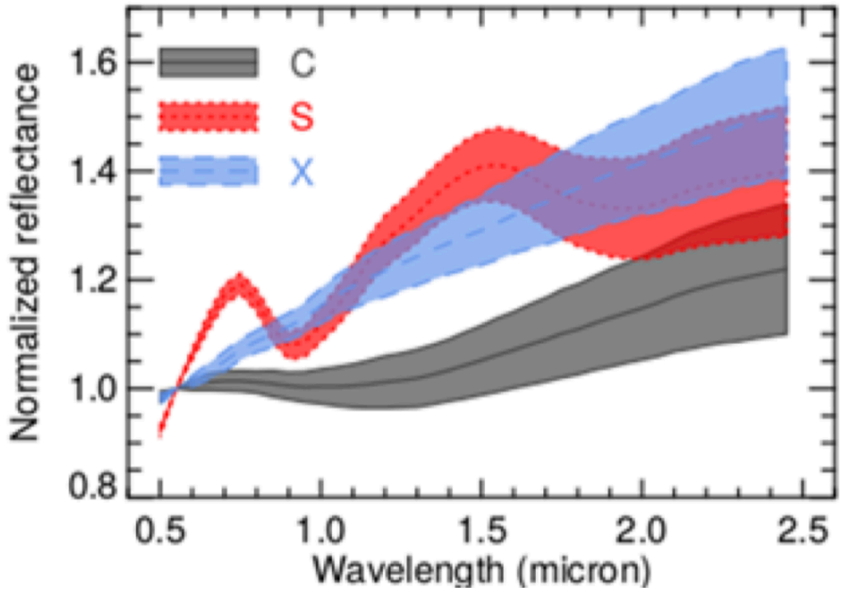

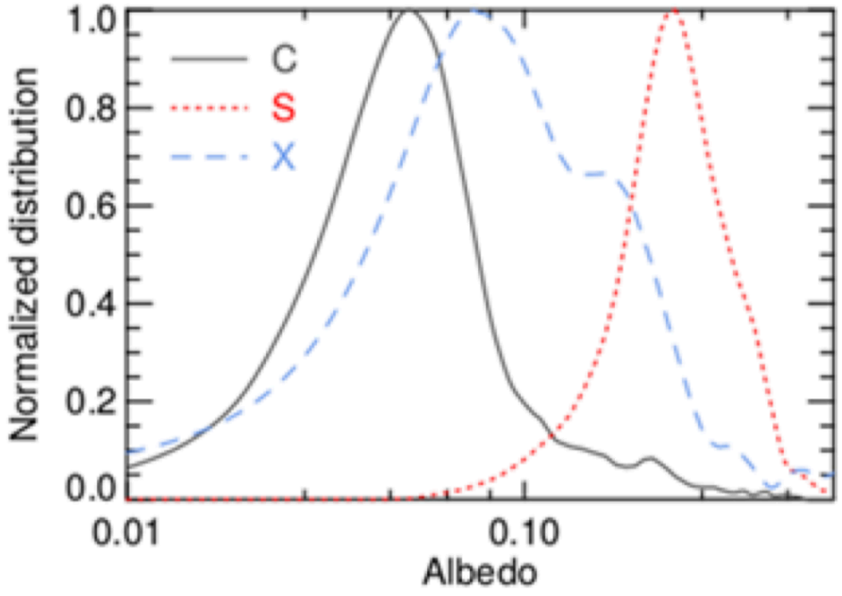

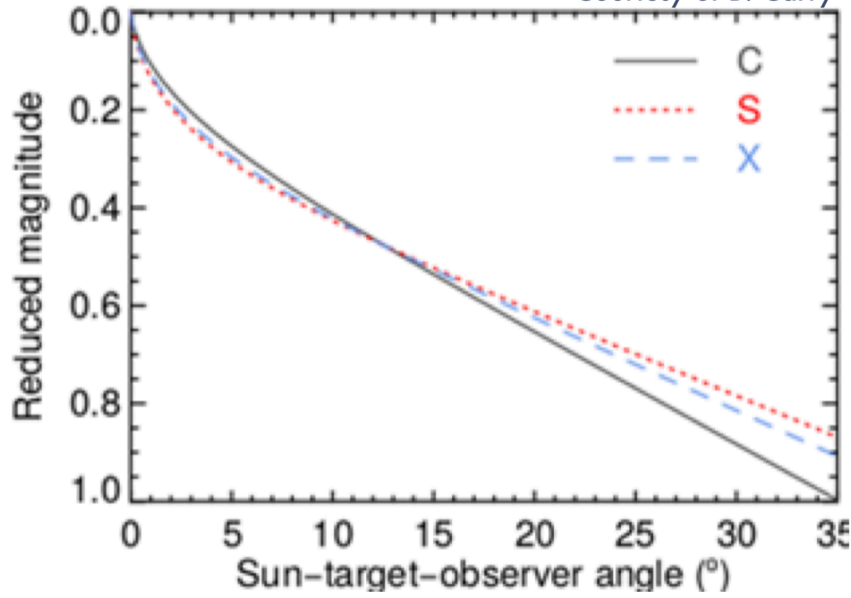

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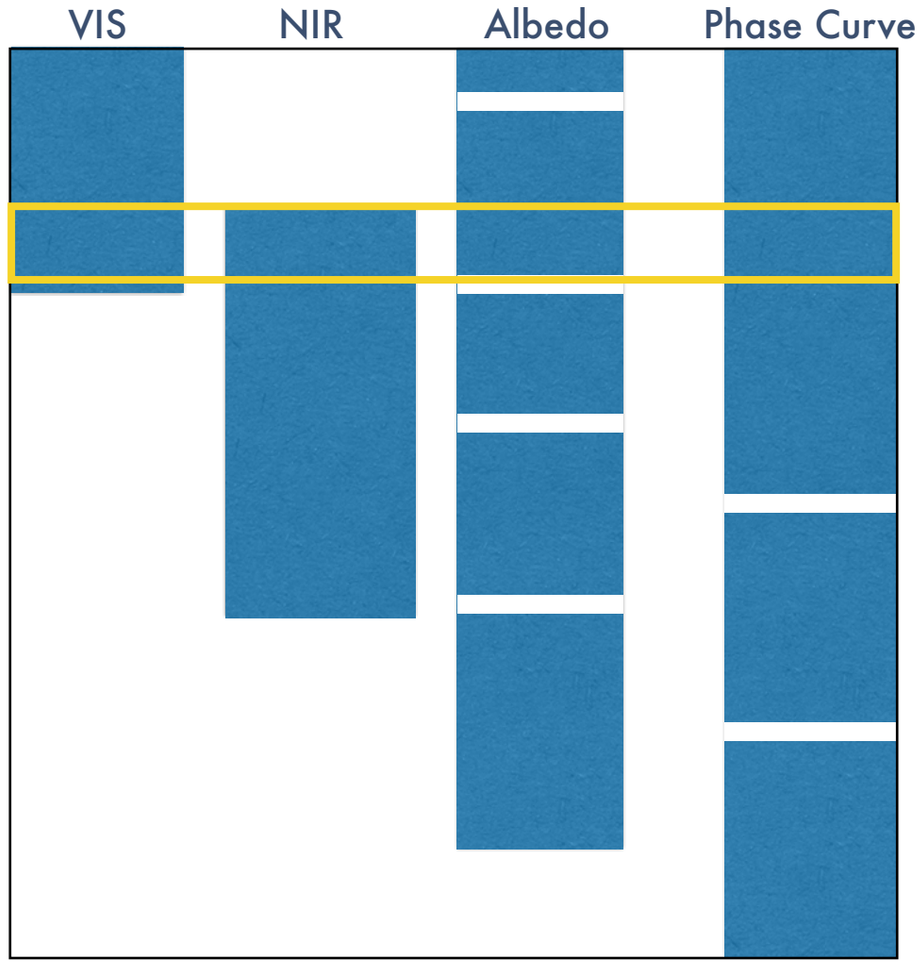

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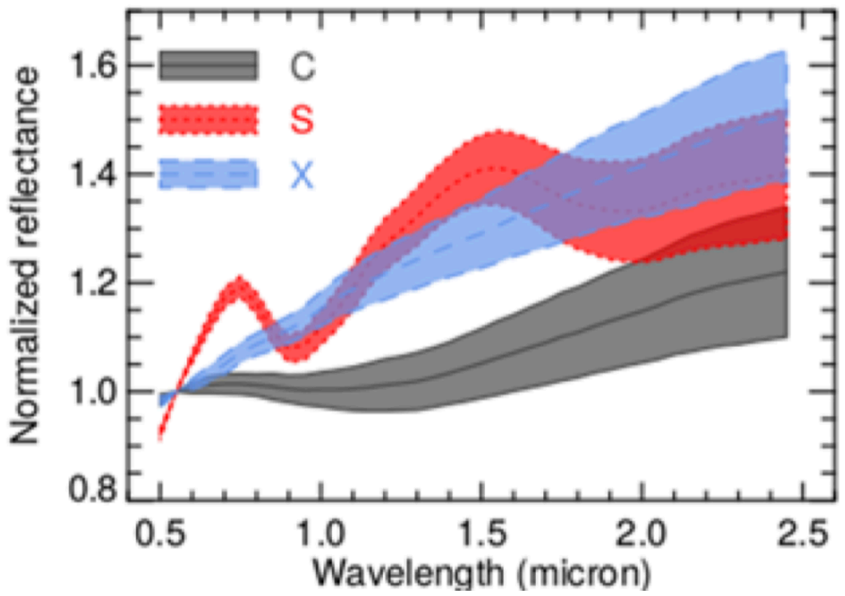

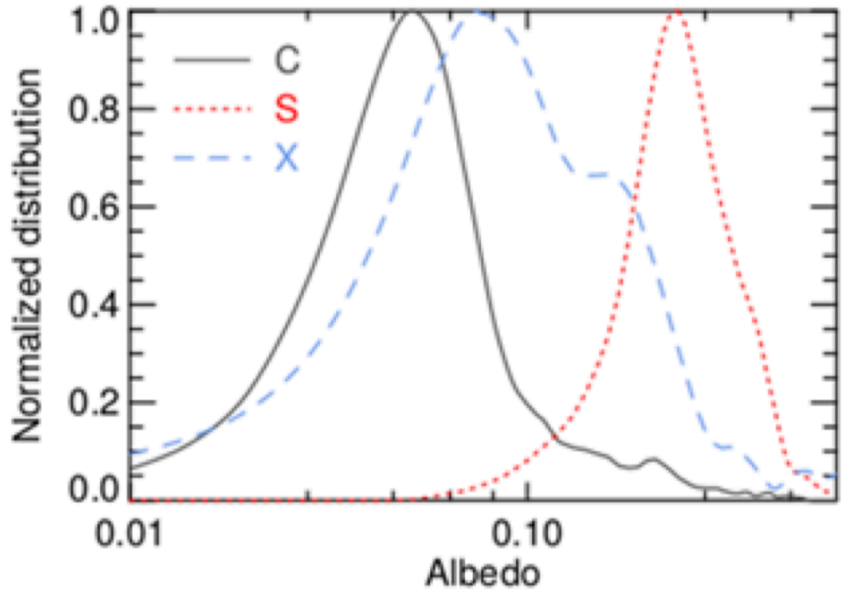

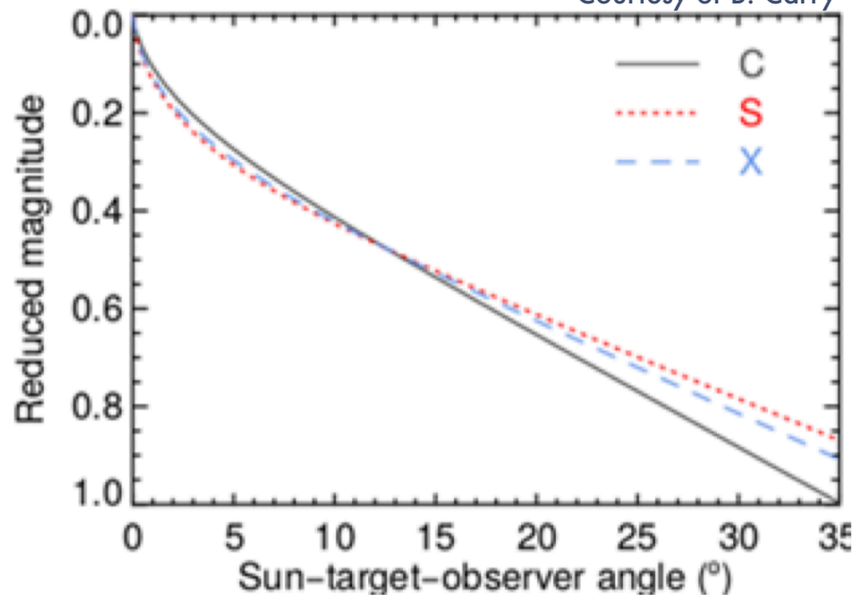

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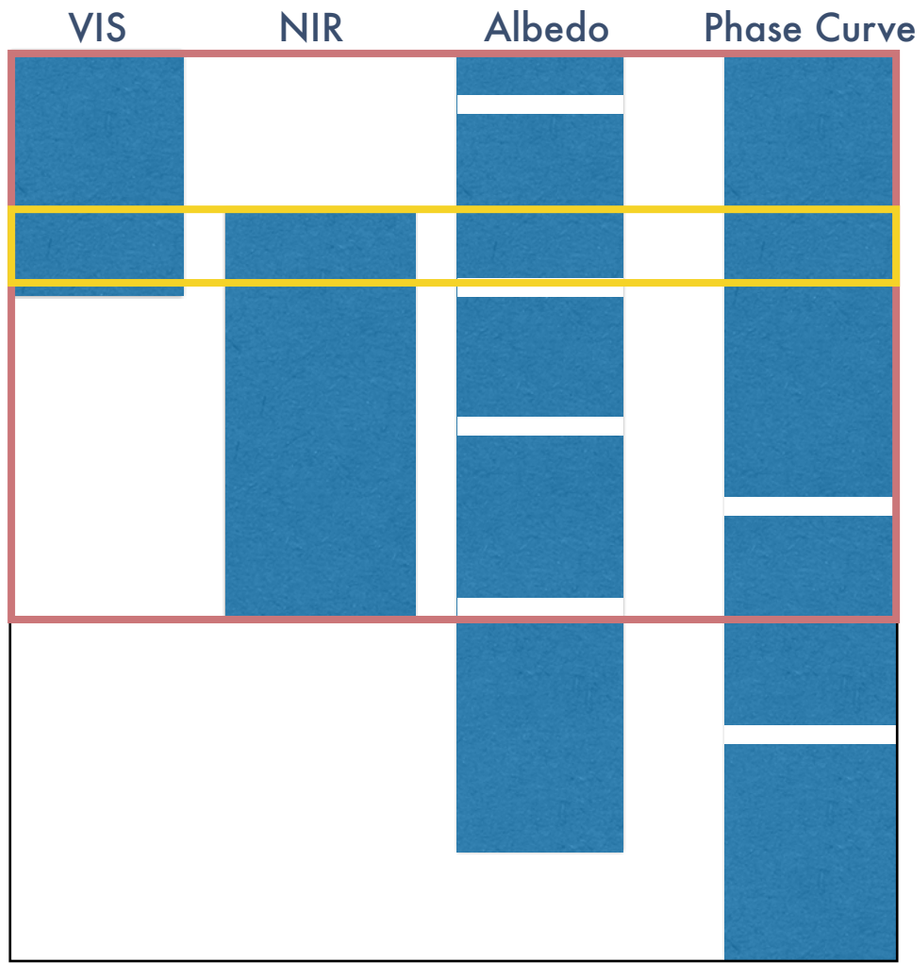

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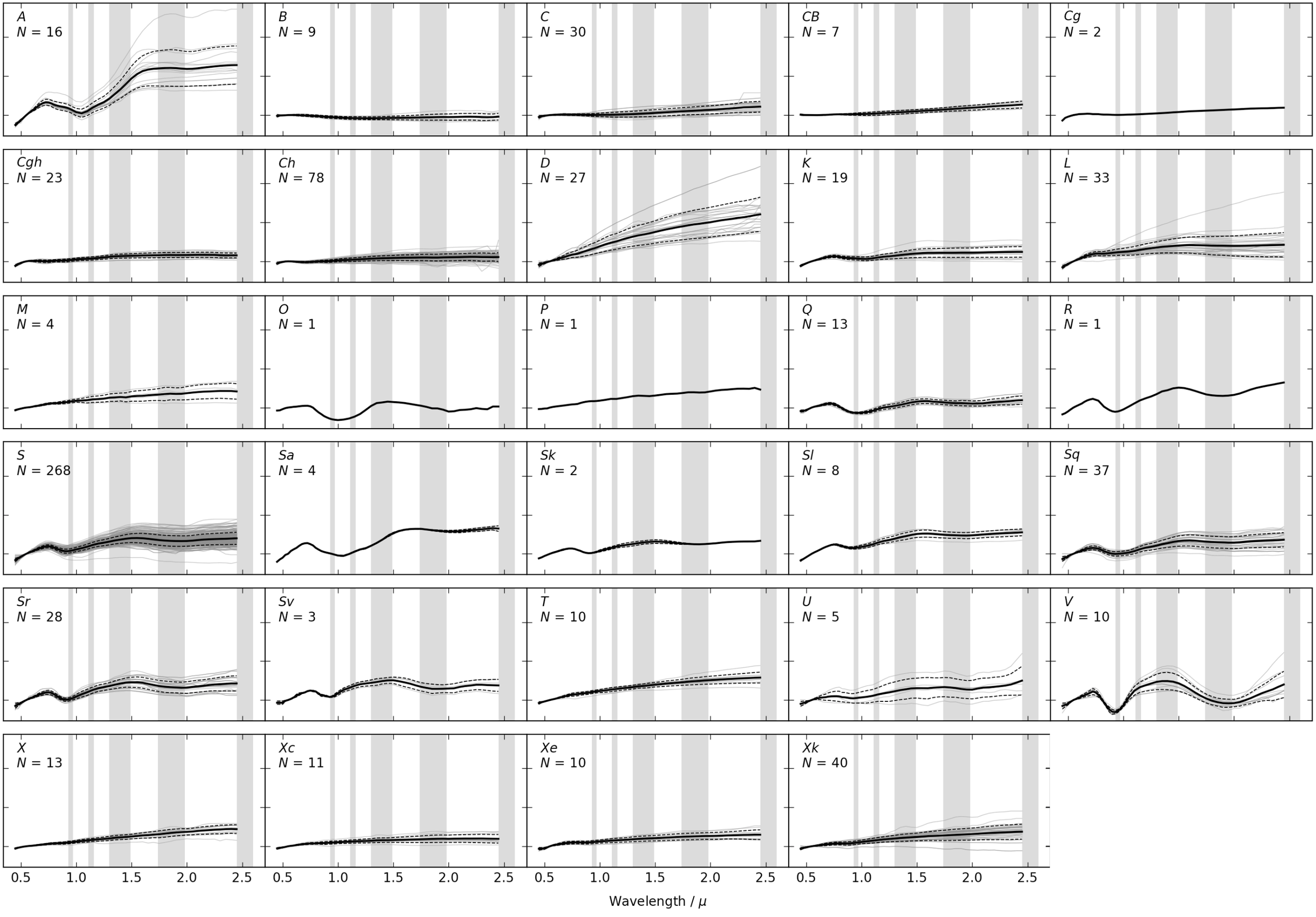
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C
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CB
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Cg
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Cgh
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Ch
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D
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P
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Q
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R
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S
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Sa
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Sk
N = 2
Sl
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Sq
N = 37
Sr
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Sv
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T
N = 10
U
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V
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X
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Xc
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Xe
N = 10
Xk
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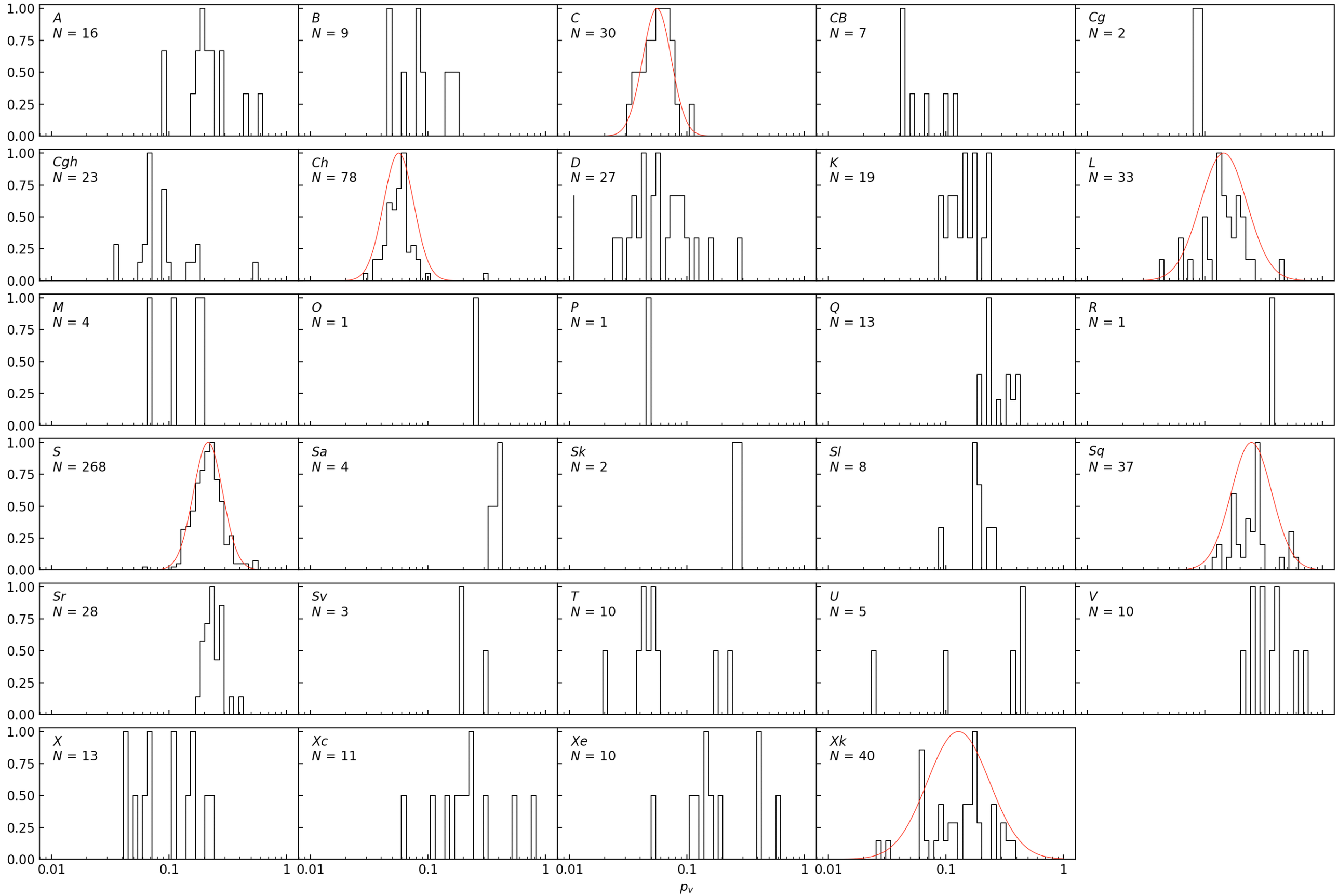
Reflectance
Wavelength / μ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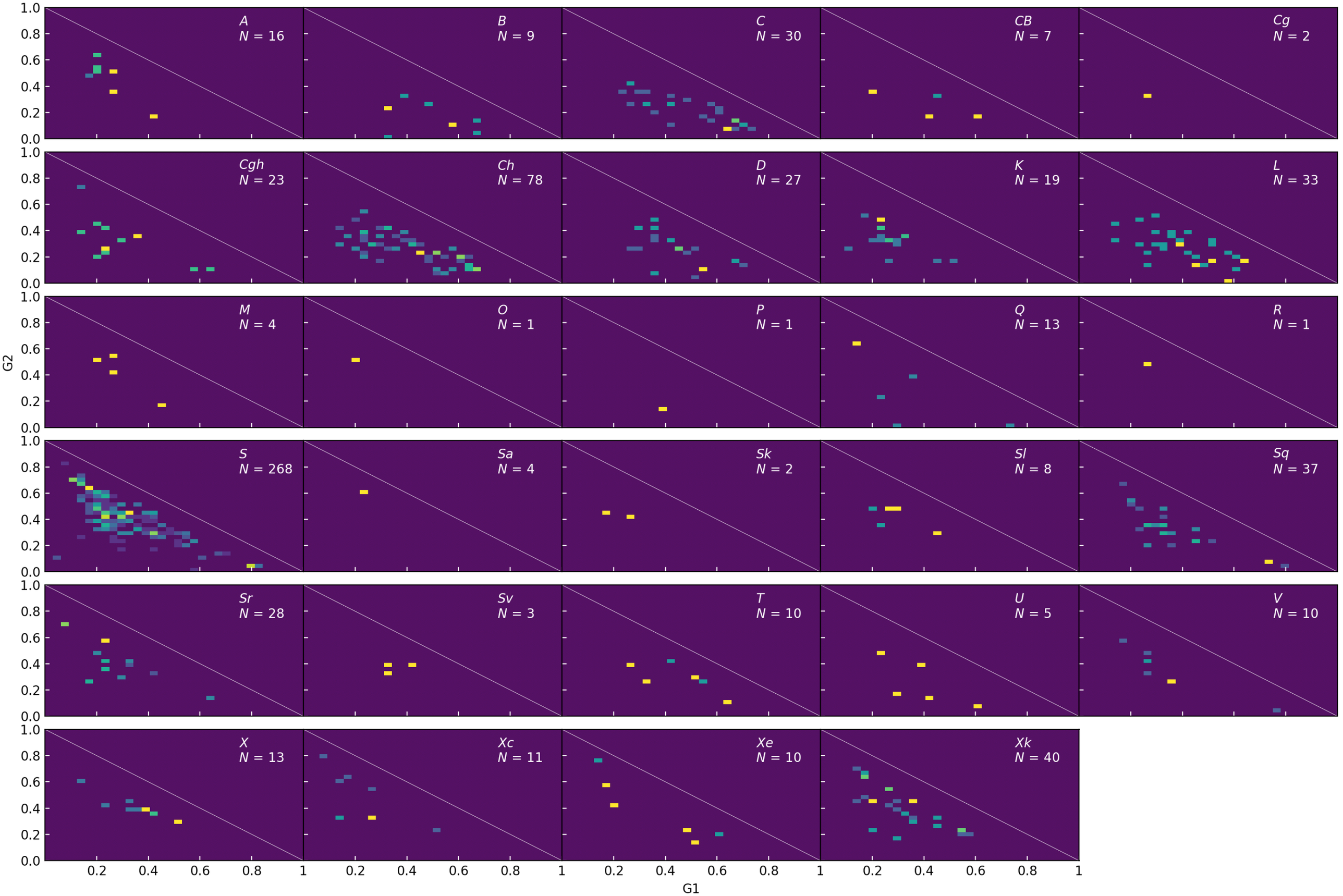
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Xc
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Xe
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Xk
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0.8
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1


Xk
Xe
Xc
X
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Sv
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Sr
A
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R
Q
O
L
K
D
Ch
CB
C
B

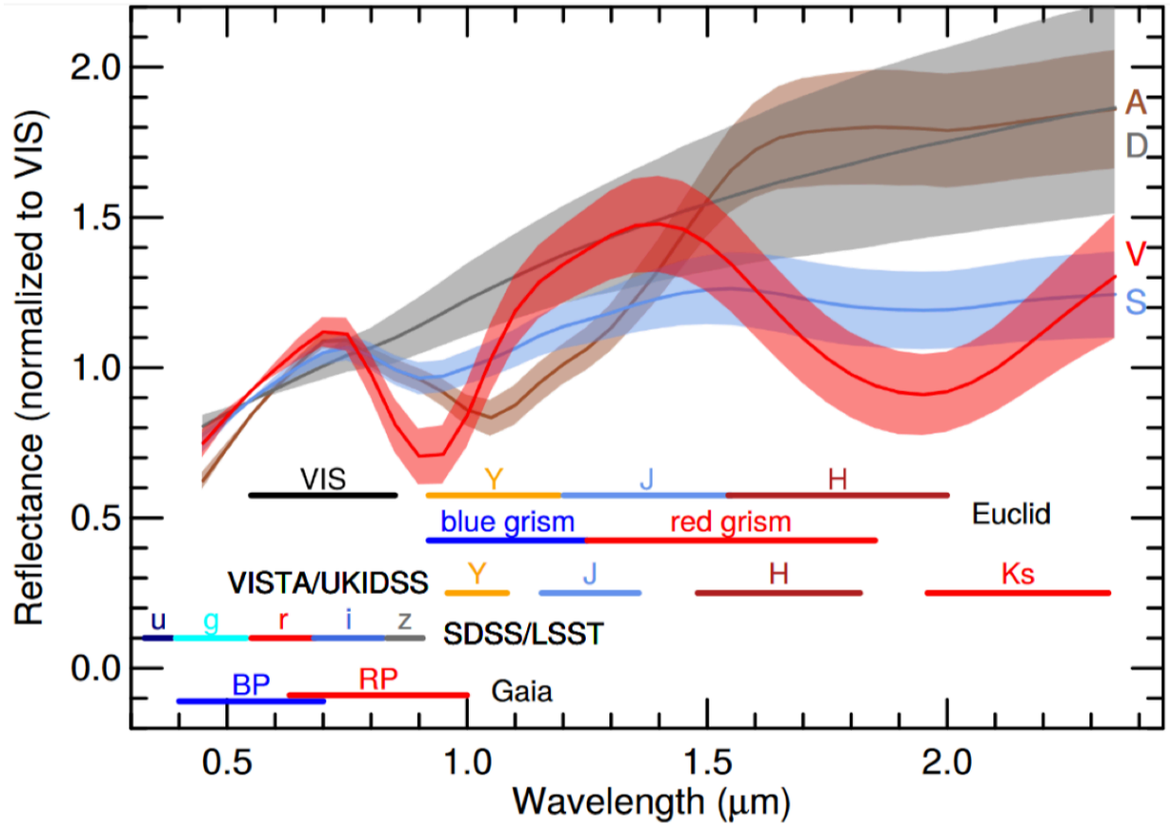
Conclusions

Asteroids are the remnants of the building blocks of the Solar System

Their current orbital and chemical distributions constrain models on the evolution of the Solar System

They are heterogeneous in many ways and we are still trying to work out the best way to group them

Their spectral features are most useful in characterizing them, while the albedo and phase curve parameters are more readily available



Outlook Upcoming gamechangers

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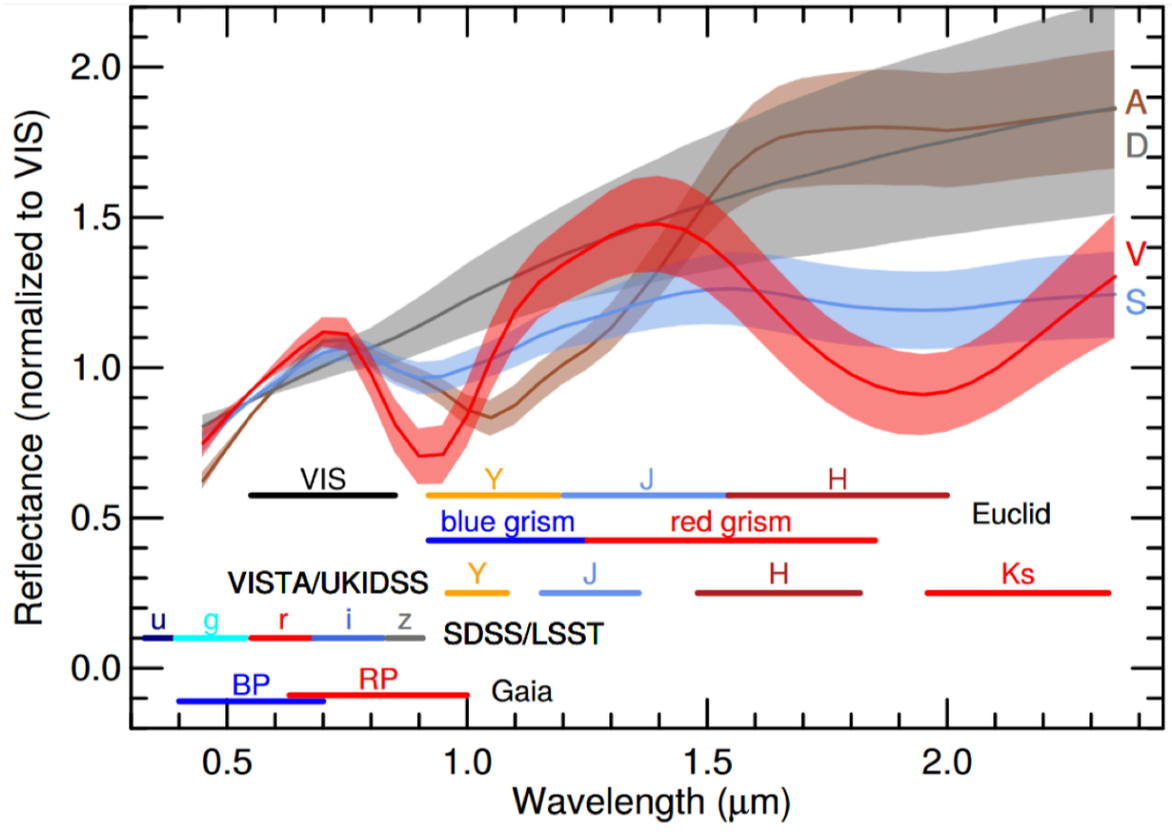

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Personal Outlook *PhD supported by ESA NPI*

Benoit Carry

Bruno Altieri
Nicolas Altobelli
Michael Küppers