# DiSCo

Discovering the Surface Composition of TNOs

A Large Program for the JWST

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EPSC 2022

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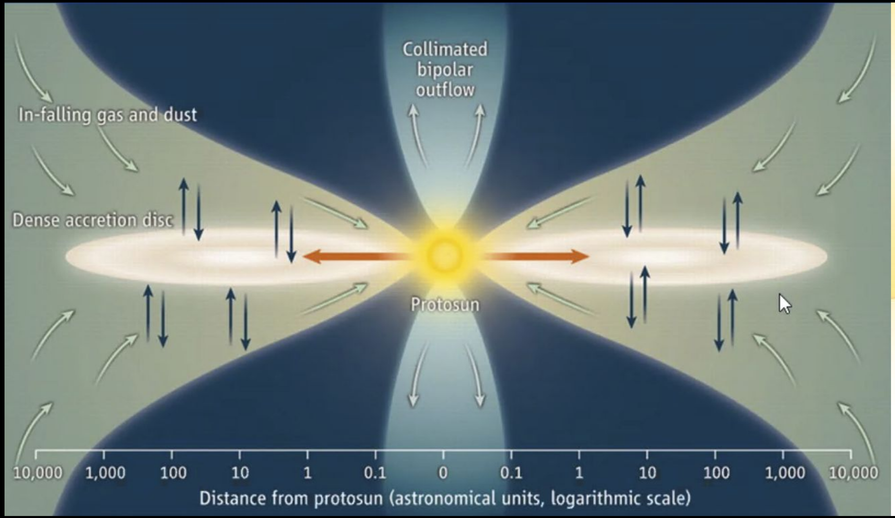
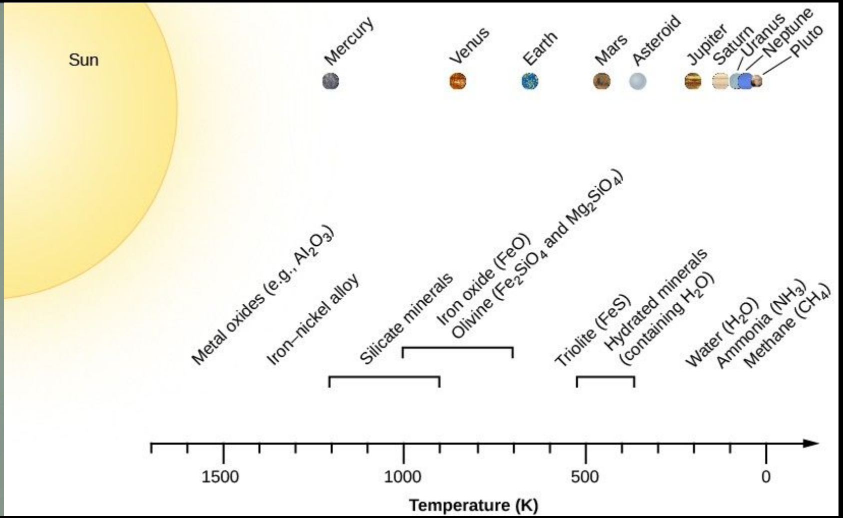
UNIVERSITY OF CENTRAL FLORIDA

# Fossils of the Solar System formation

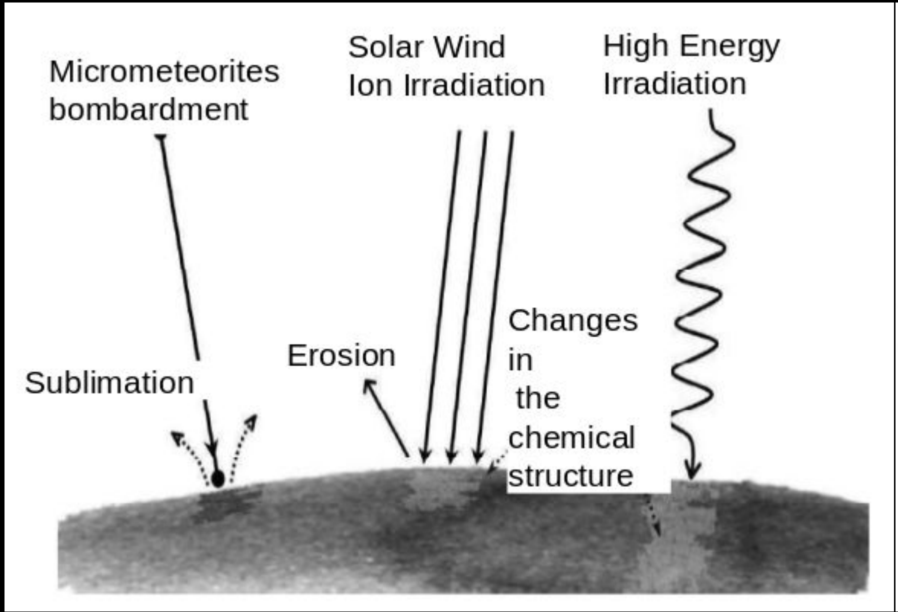


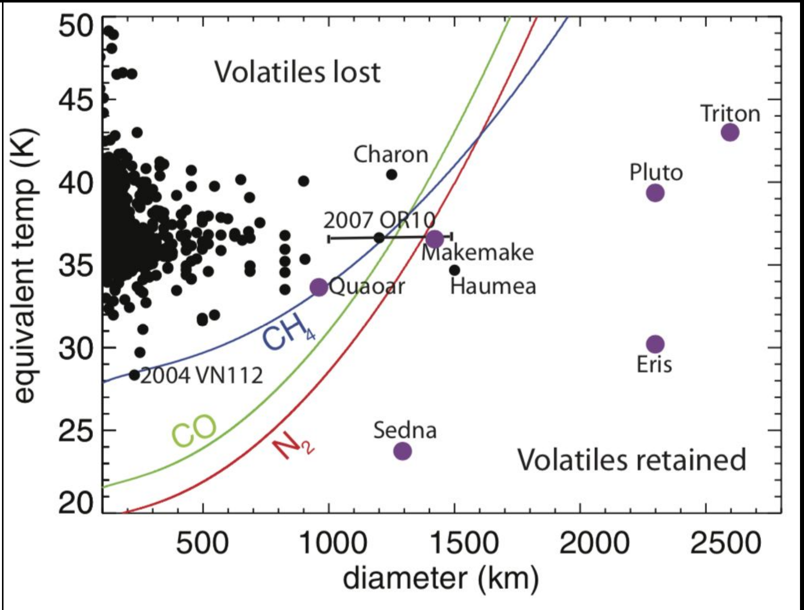




Ices and Organics in the protoplanetary disk are processed to greater or lesser extent depending on their location in the disk, and whether or not they circulate vertically above the plane as the star is beginning to emit light and charged particles

# Volatiles loss and Surface processing

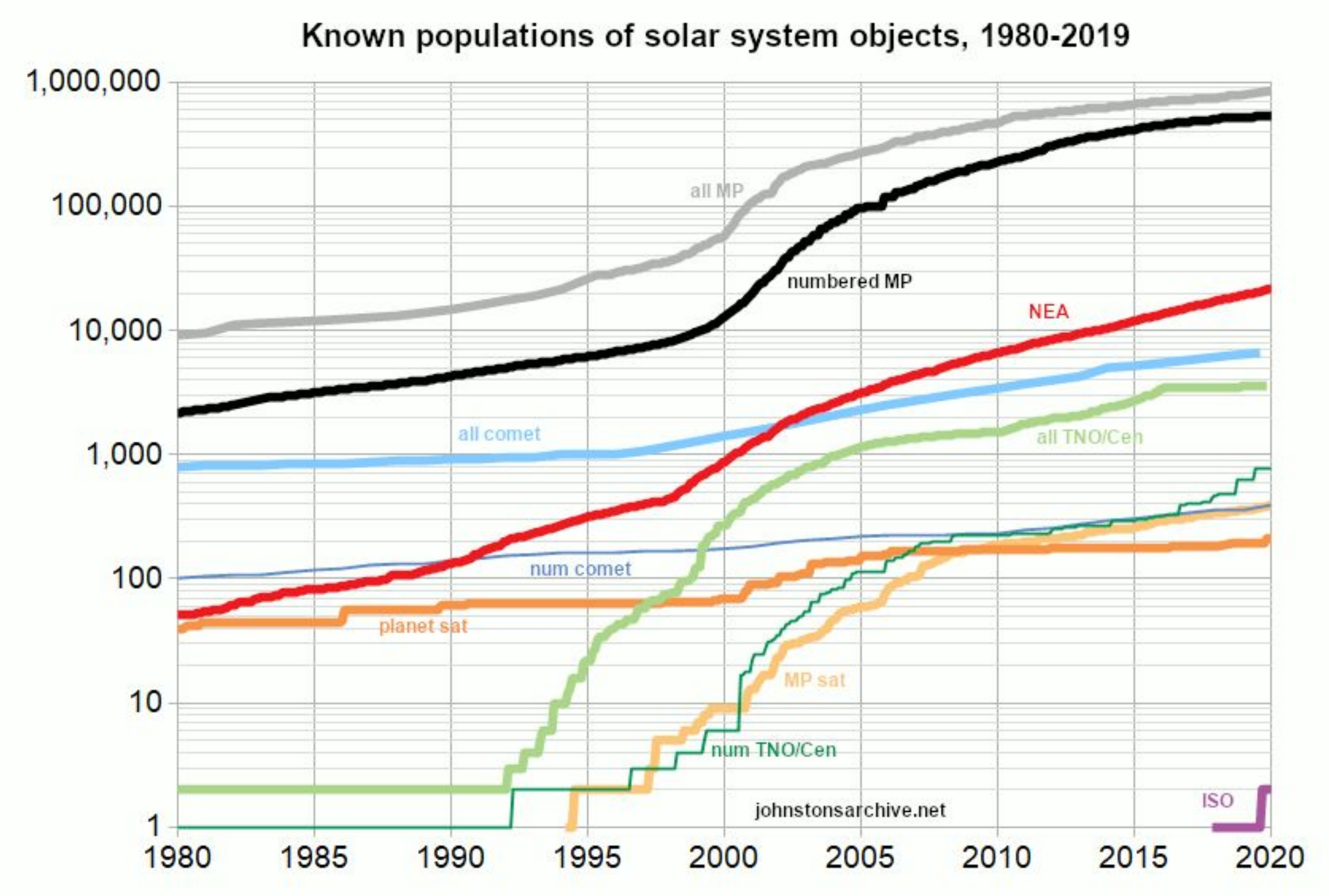
Schaller & Brown 2009




Space weathering and other physical processes related to the size and temperature of the TNOs play a significant role in shaping their surfaces

# What we know about TNOs



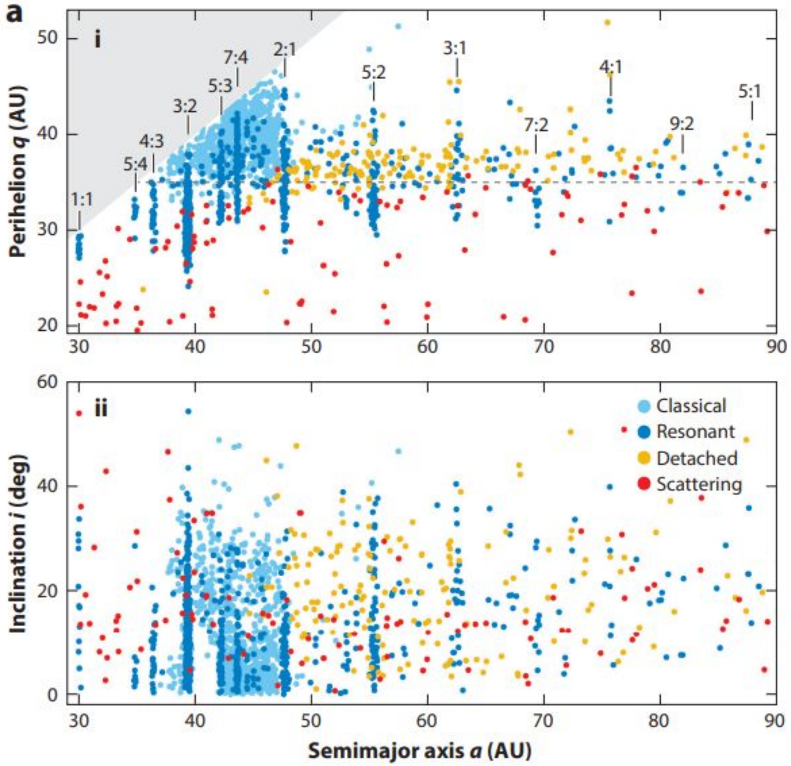

In 1992 Luu & Jewitt:
- 15760 Albion

Currently:
- ~2500 TNOs
- ~1085 Centaurs

Size range: tens of km to 2000 km. (smaller objects is an observational bias)

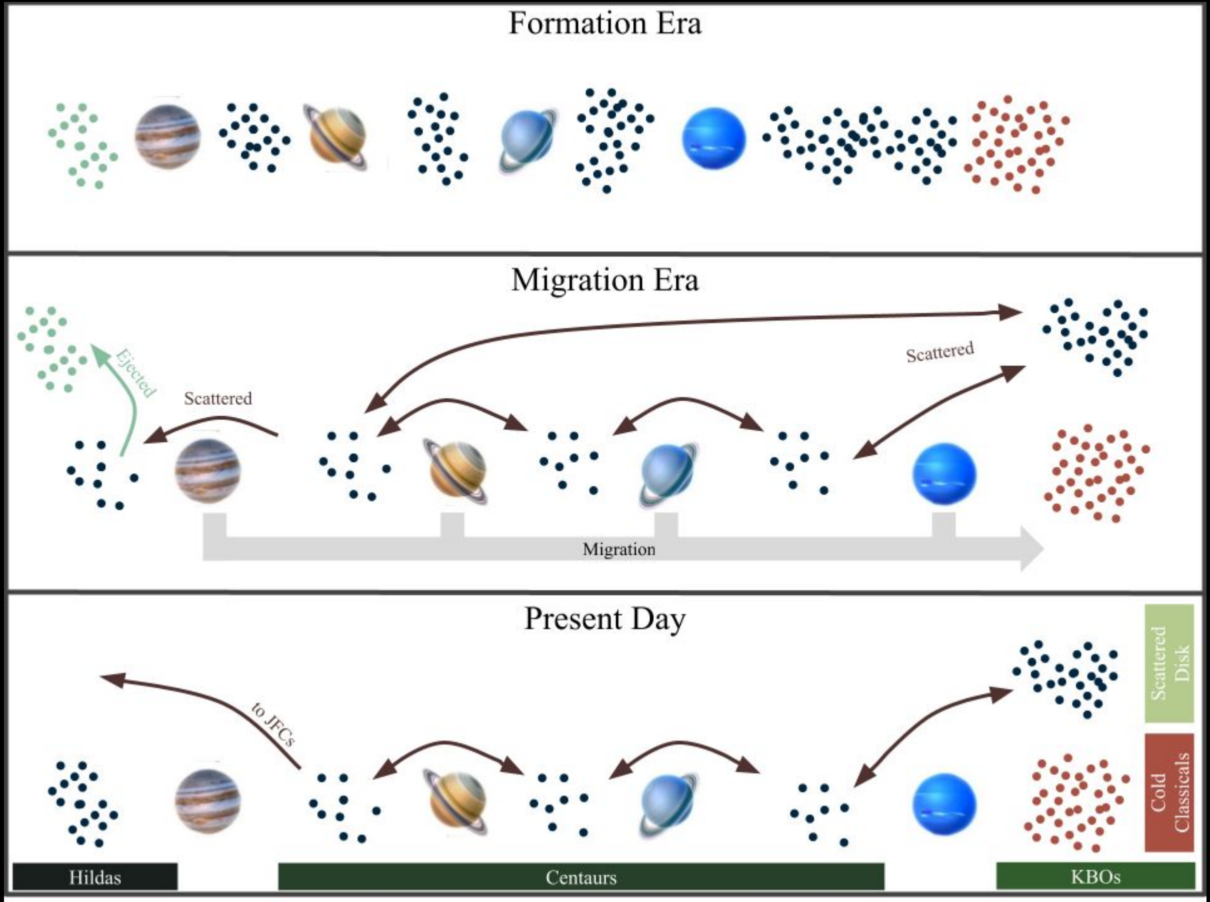
# TNOs : Orbital distribution

| Dynamical classifications | |
|---|---|
| Scattering | Definition: TNO whose $a$ Neptune can currently alter significantly on timescales $\ll$1 Gyr; typically $q \lesssim$ 38 AU (e.g., **Figure 3**) |
| | Interpretation: Likely a decaying remnant of a much larger primordial scattering population (see Section 4.2.1) |
| Resonant | Definition: TNO in a mean-motion resonance with Neptune (e.g., **Figure 2**) |
| | Interpretation: The abundant resonant TNOs were likely captured during the epoch of giant planet migration (see Sections 4.2.2 and 5.1) |
| Detached | Definition: Nonresonant TNO with $a > 47.4$ AU and $e > 0.24$ that is not scattering today (e.g., **Figure 3**) |
| | Interpretation: The formation mechanism(s) of this population remains an area of active research (see Sections 4.2.4 and 5.2) |
| Classical | Definition: A TNO that falls into none of the above categories. Divided into subcategories: |
| | *Main Belt*: $a$ between the 3:2 and 2:1 resonances ($39.4 < a < 47.7$ AU; e.g., **Figure 5**) |
| | Interpretation: Observed to have a bimodal $i$ distribution; likely a combination of TNOs that formed in place and others implanted from elsewhere (see Sections 4.1 and 4.2.3) |
| | *Inner Belt*: $a$ between Neptune and the 3:2 resonance ($30.1 < a < 39.4$ AU) |
| | Interpretation: Observed to only have a hot population (see below); either a dynamically excited remnant of the original planetesimal disk or an implanted population |
| | *Outer Belt*: $a$ beyond the 2:1 resonance ($a > 47.4$ AU) and $e < 0.24$ |
| | Interpretation: Only a few known. Origin unclear. |
| **Cold versus hot populations** | |
| Cold population | Observed concentration of low-$i$ ($i_{free} < 4$ deg), low-$e$ main-belt TNOs from $a$ = 42.5–47.5 AU; likely formed beyond 30 AU and survived in place with only minor $e/i$ perturbations and collisional evolution (see Section 4.1) |
| Hot populations | TNOs with large $e$ and/or $i$ orbits (existing in all dynamical classes); likely formed at $a < 30$ AU and scattered out to current locations, with the current population a small remnant of the initially scattered population (see Section 4.2) |

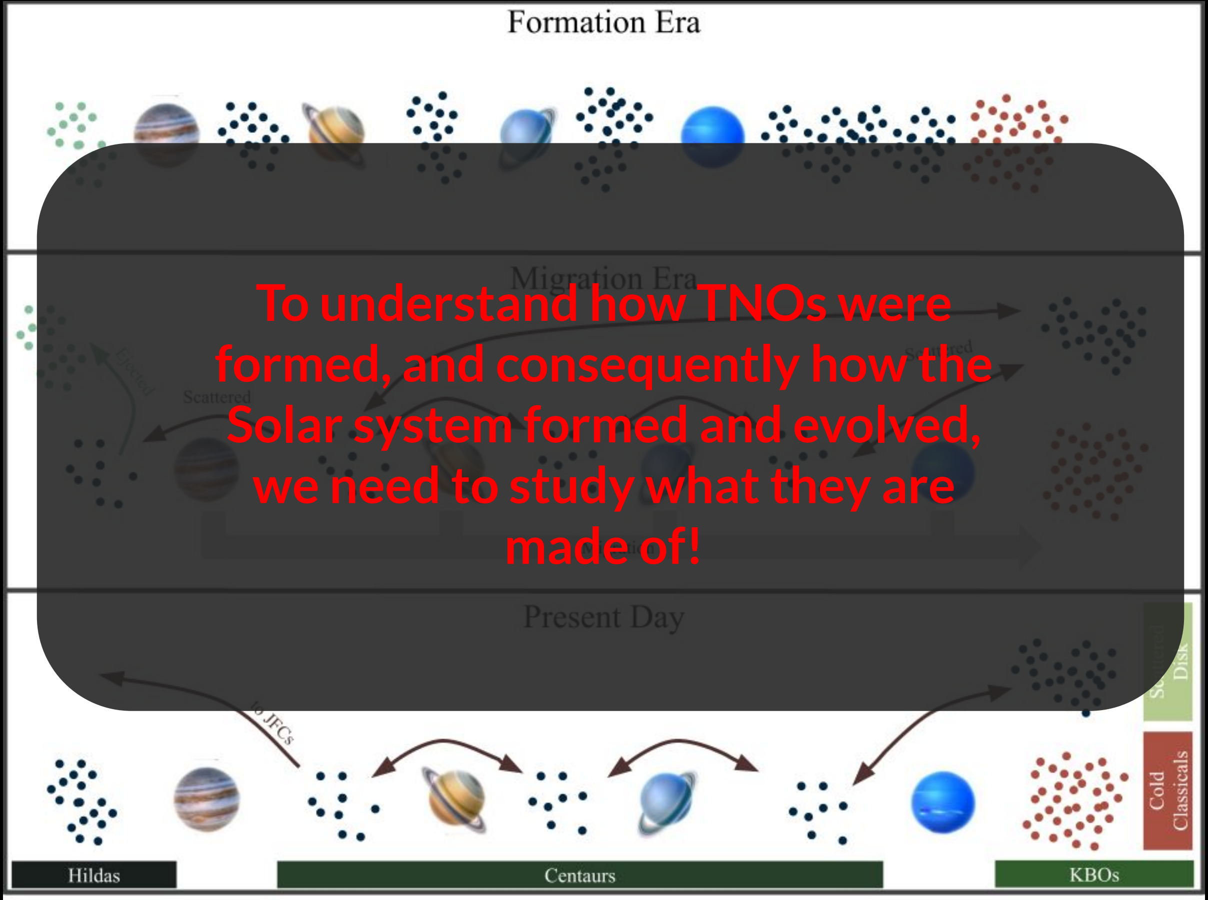



Gladman & Volk 2021

# How TNOs were formed?

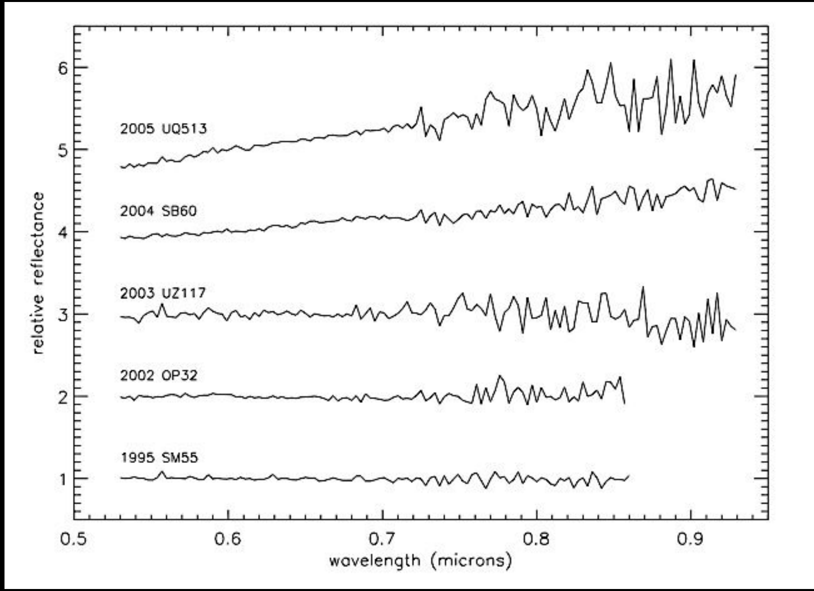


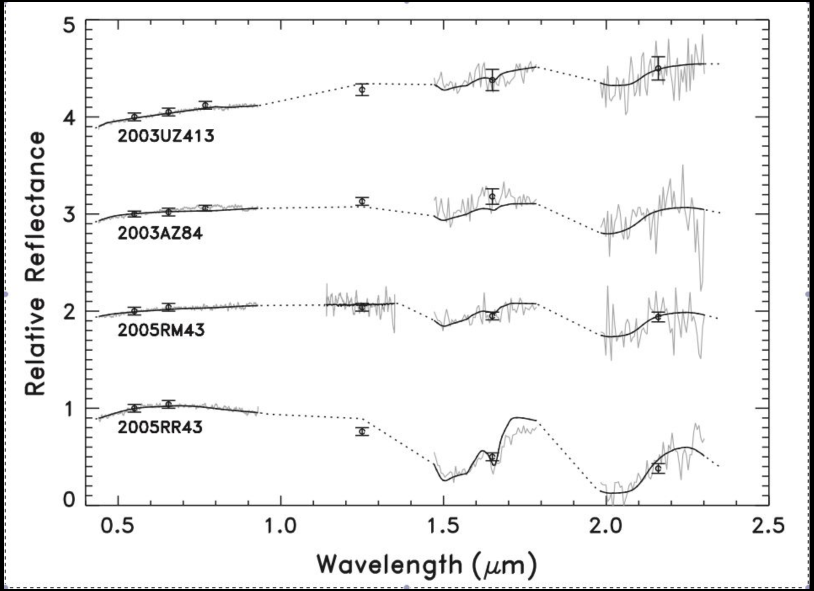
# How TNOs were formed?




To understand how TNOs were formed, and consequently how the Solar system formed and evolved, we need to study what they are made of!

# TNOs: Spectroscopy




- Visible
  - ~100 TNOs
  - 97% of the visible spectra are featureless

- NIR

  ~30 TNOs

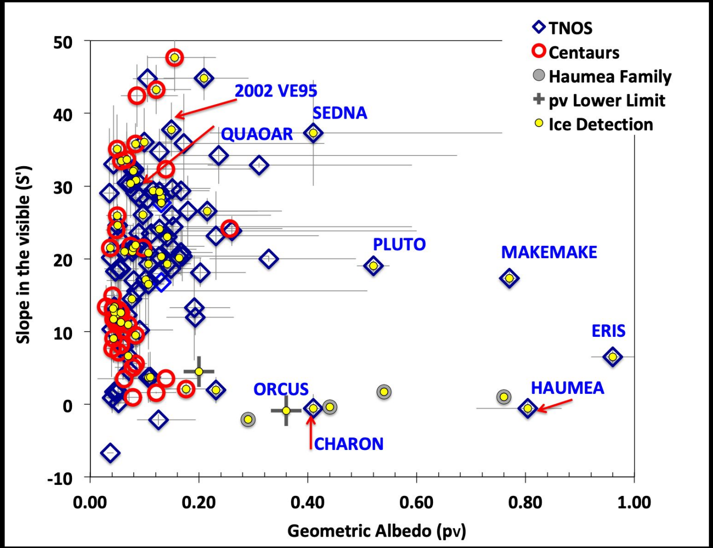
  ~50% has evidence of water ices

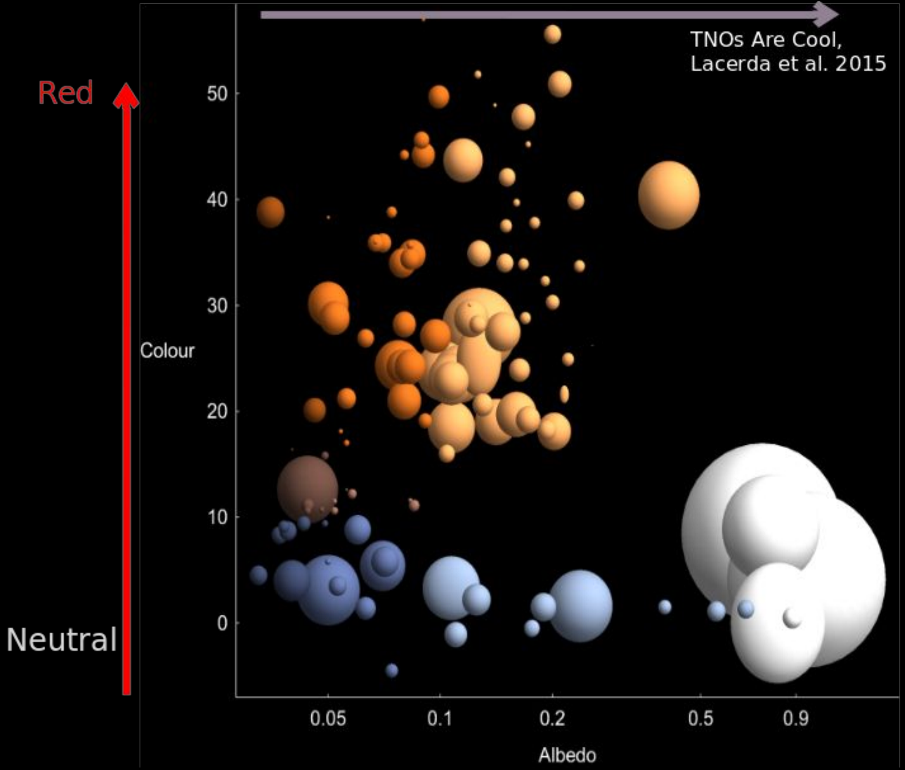
  ~90% has no detected feature of other ices

Pinilla-alonso et al 2008

Barucci et al. 2011

# TNOs : Surface Characterization

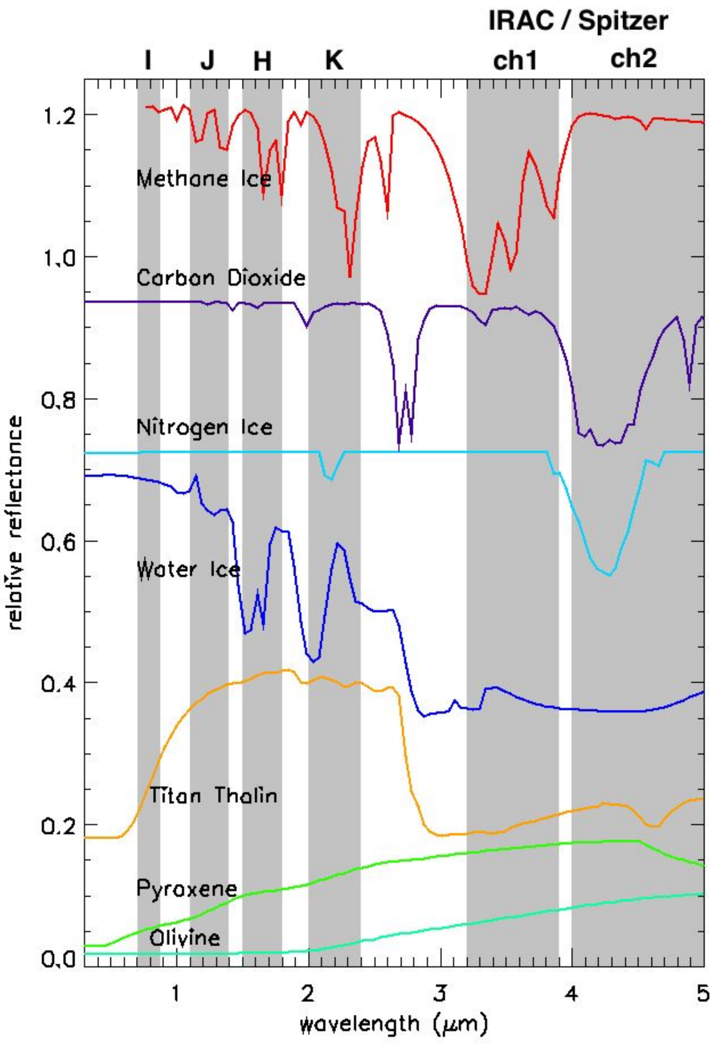



- ~170 TNOs have size and albedo determined
- No correlation D, pv & visible color
  - Dark ≠ red
  - Dark ≠ neutral
  - Small ≠ red or blue

# What we know about TNOs?

- TNOs can show a wide diversity of surface properties, which is probably related to their formation and evolution
- Due to their faintness, current data is not diagnostic of their compositions
- Atmospheric absorptions prevent spectroscopic observations of TNOs at the most diagnostic wavelengths of their compositions



More Power!

+

Better Wavelength Coverage!

+

Better methods to analyse the data!

More Power!

+

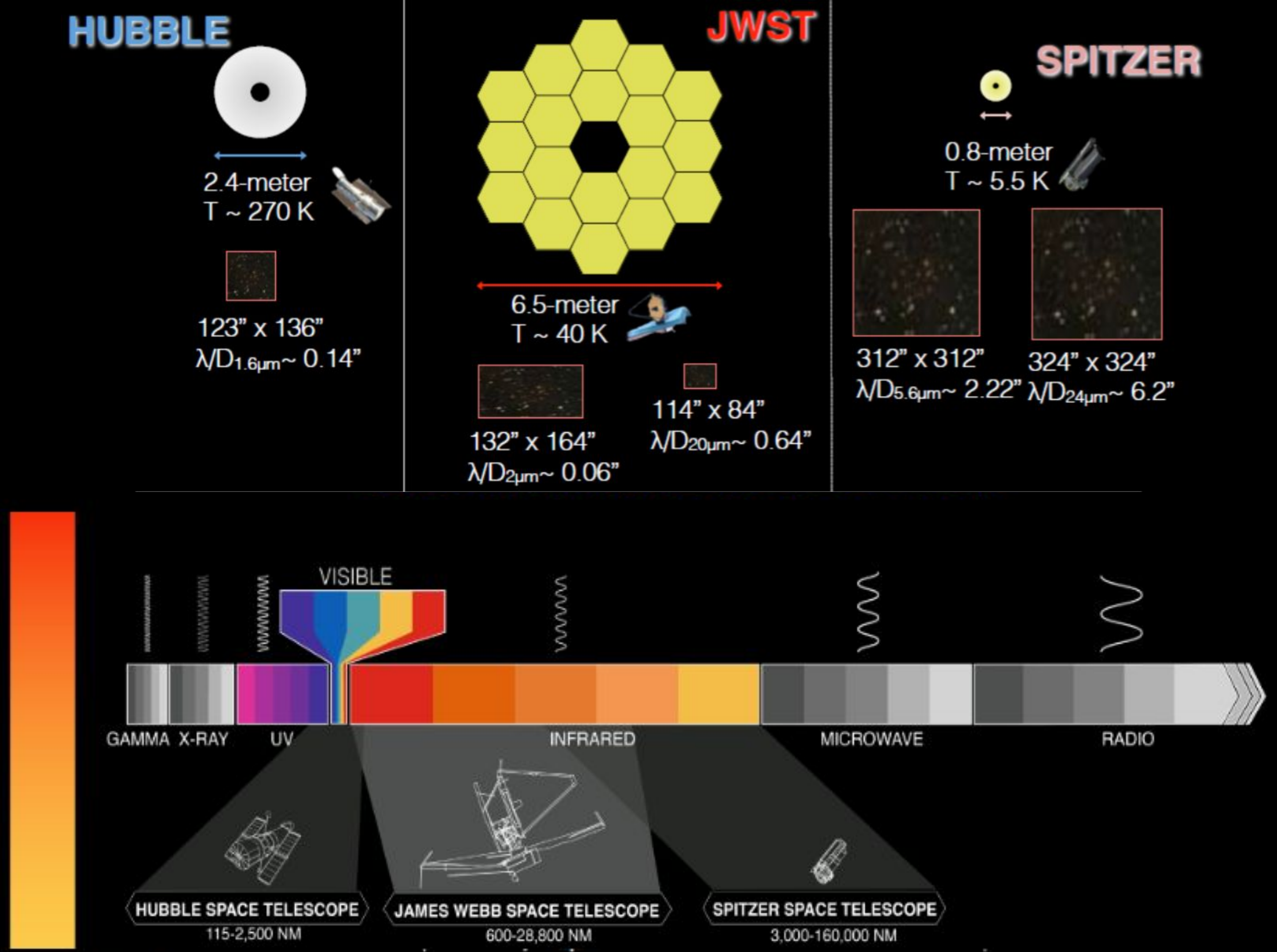
Better Wavelength Coverage!

=

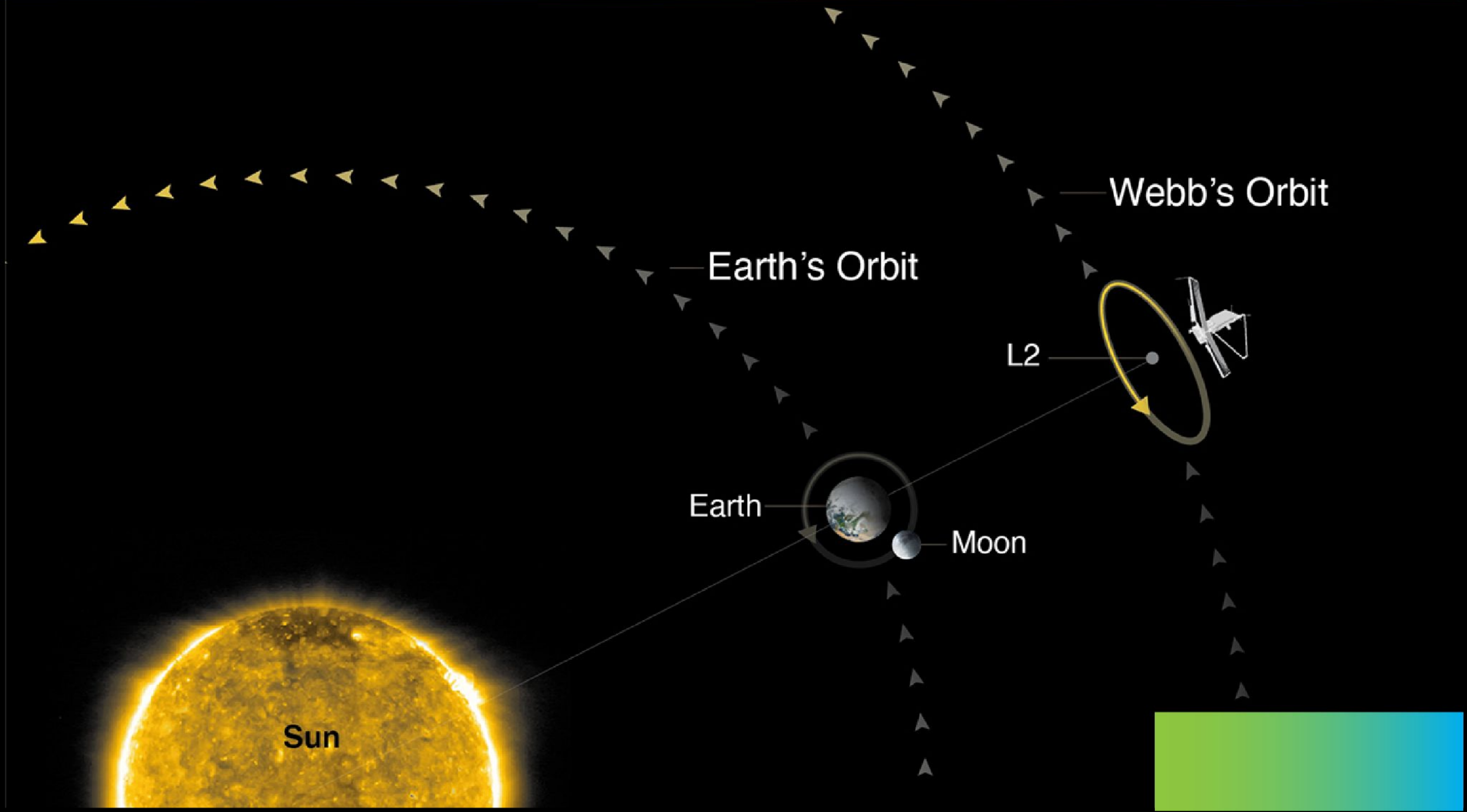
James Webb Space Telescope

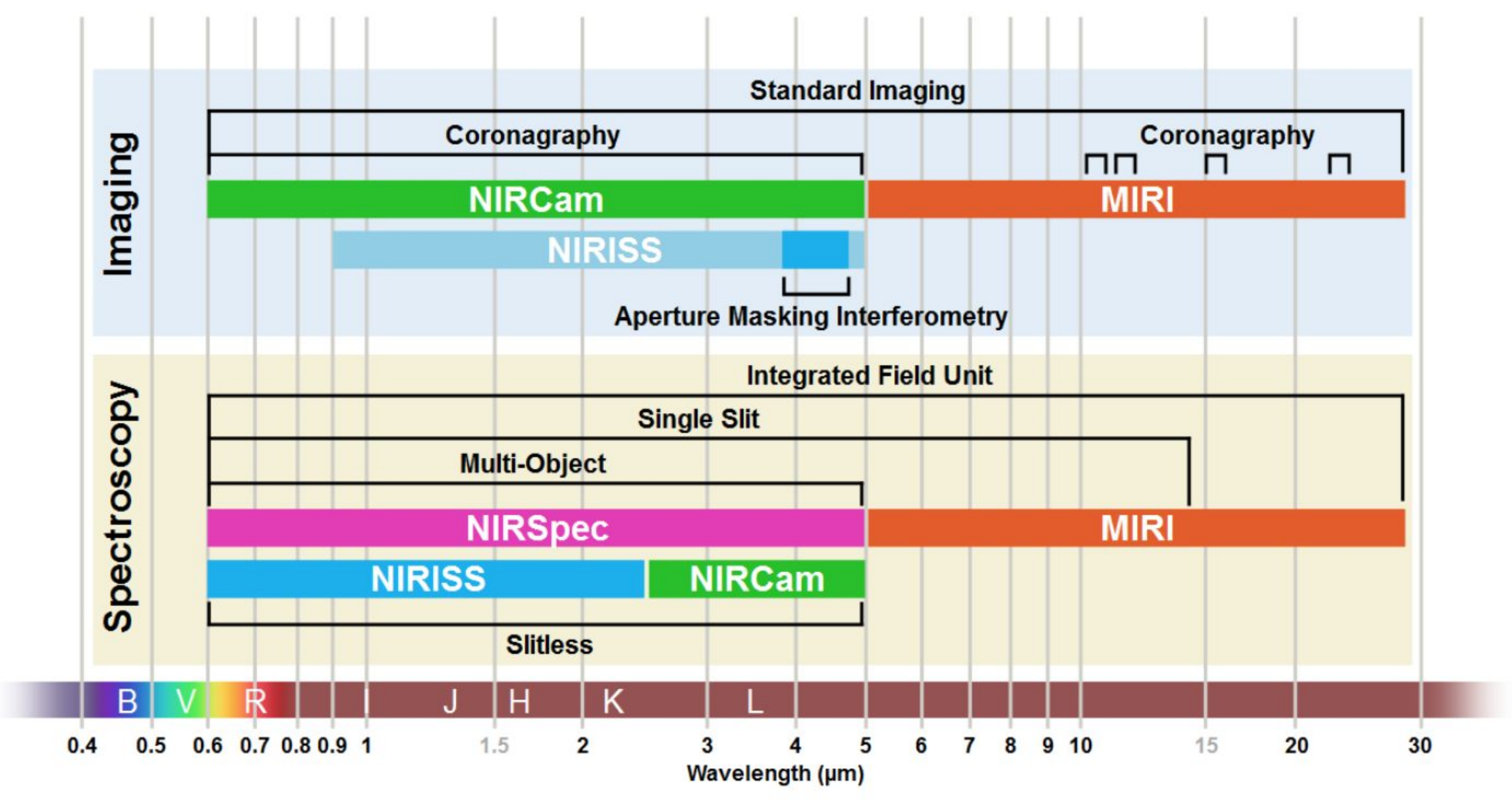
JWST

NASA • ESA • CSA

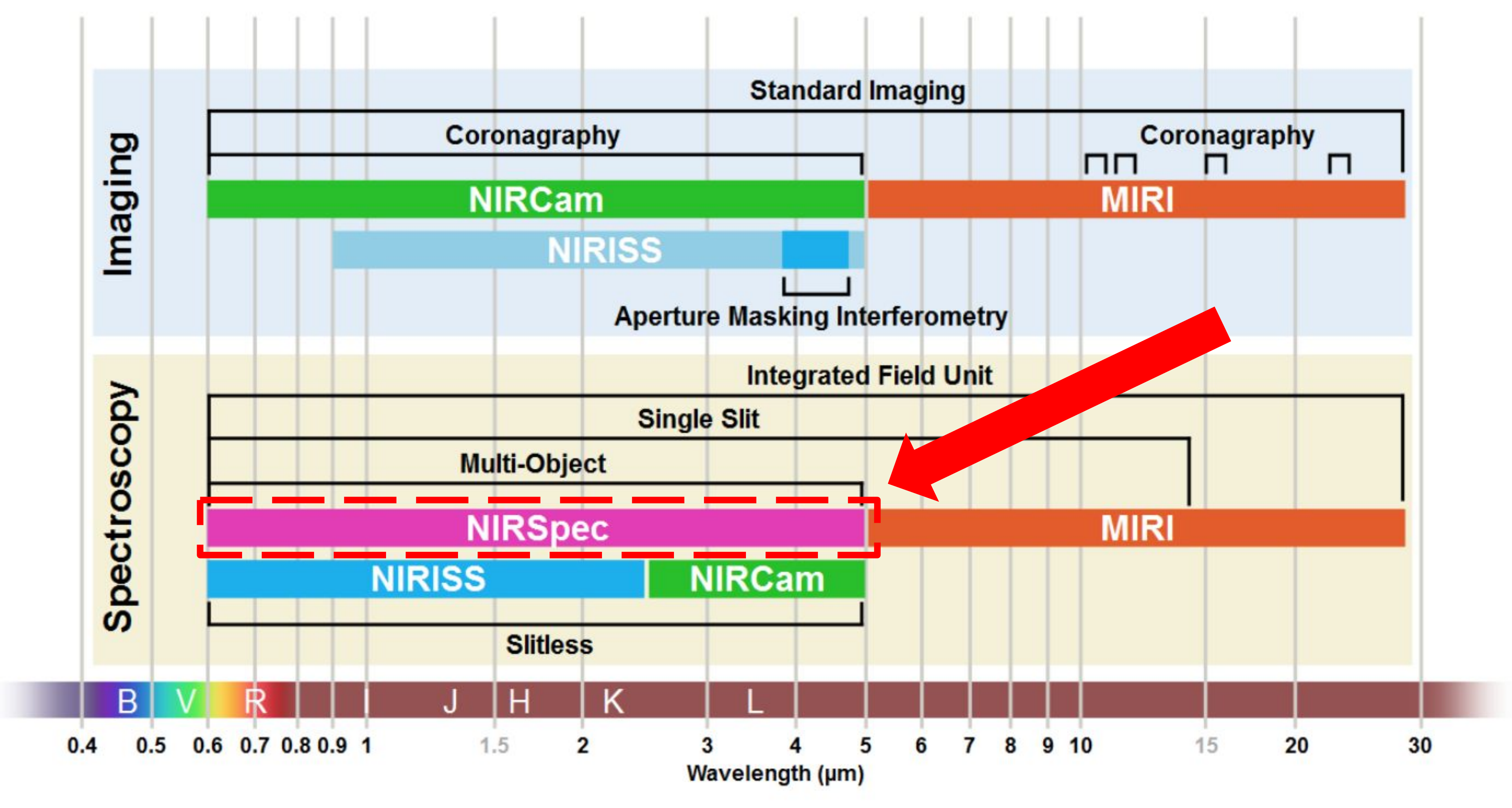

HUBBLE
2.4-meter
T ~ 270 K
123" x 136"
λ/D1.6μm~ 0.14"
JWST
6.5-meter
T ~ 40 K
132" x 164"
λ/D2μm~ 0.06"
114" x 84"
λ/D20μm~ 0.64"
SPITZER
0.8-meter
T ~ 5.5 K
312" x 312"
λ/D5.6μm~ 2.22"
324" x 324"
λ/D24μm~ 6.2"
VISIBLE
GAMMA
X-RAY
UV
INFRARED
MICROWAVE
RADIO
HUBBLE SPACE TELESCOPE
115-2,500 NM
JAMES WEBB SPACE TELESCOPE
600-28,800 NM
SPITZER SPACE TELESCOPE
3,000-160,000 NM

# Where is JWST?





Imaging
Standard Imaging
Coronagraphy
Coronagraphy
NIRCam
MIRI
NIRISS
Aperture Masking Interferometry
Spectroscopy
Integrated Field Unit
Single Slit
Multi-Object
NIRSpec
MIRI
NIRISS
NIRCam
Slitless
B V R I J H K L
0.4 0.5 0.6 0.7 0.8 0.9 1 1.5 2 3 4 5 6 7 8 9 10 15 20 30
Wavelength (µm)


Imaging
Standard Imaging
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Slitless
B V R I J H K L
0.4 0.5 0.6 0.7 0.8 0.9 1 1.5 2 3 4 5 6 7 8 9 10 15 20 30
Wavelength (μm)

# Webb’s 1st year in the Solar System

- Doubled the number of Solar System proposals requests for Cycle 1 vs. HST

- Cycle 1 GO call had 1173 proposals submitted and 286 selected i.e. 24%
  - SoSys 70 proposals (6%) and had 22 selected (31%) of which 6% total time asked

- ERS + GTO + GO: 7% of time allocated so SoSys including
  - 1 ERS
  - 5 archival programs
  - 1 LP

| | | | | | | |
|---|---|---|---|---|---|---|
| 2418 | DiSCo-TNOs: Discovering the Composition of the Trans-Neptunian Objects, Icy Embryos for Planet Formation | **PI:** Noemi Pinilla-Alonso | 12 | 98.2 | NIRSpec/IFU | GO |

DISCOVERING THE SURFACE COMPOSITION OF TNOs

DiSCo

A LARGE PROGRAM FOR THE JWST

- Large program (98.2 h) that will observe 59 TNOs with JWST NIRSpec at wavelengths 1-5 microns

- Targets contain representatives of all TNOs dynamical classes, including centaurs

- Observations will start on September 2022, and end on August 2023

- Team:
    - PI: Noemi Pinilla Alonso
    - 15 researchers
    - 8 different countries
    - 1 Post-doc
    - 2 Ph.D Students

## Scattering (9)

2014 LV28
2014 YF50
1999 OX3
2005 QU182
2010 VW11
1996 TL66
Typhon
2001 FZ173
2001 FP185

## Resonant (10)

Mors-Somnus
2002 XV93
2004 EW95
1999 DE9
Huya
2007 JF43
2003 UZ413
Dziewanna
Lempo
2002 TC302

## Detached (9)

2003 FY128
2005 TB190
G!kun||homdima
2004 XA192
2004 PG115
2007 OC10
2008 NW4
2010 ET65
2010 ER65

## Extreme TNOs (4)

2010 VZ98
2005 PU21
2015 SO20
2012 DR30

## Centaur (9)

2002 KY14
Okyrhoe
2003 WL7
Thereus
2007 RW10
2003 UY413
2013 LU28
2010 KR59
2005 CC79

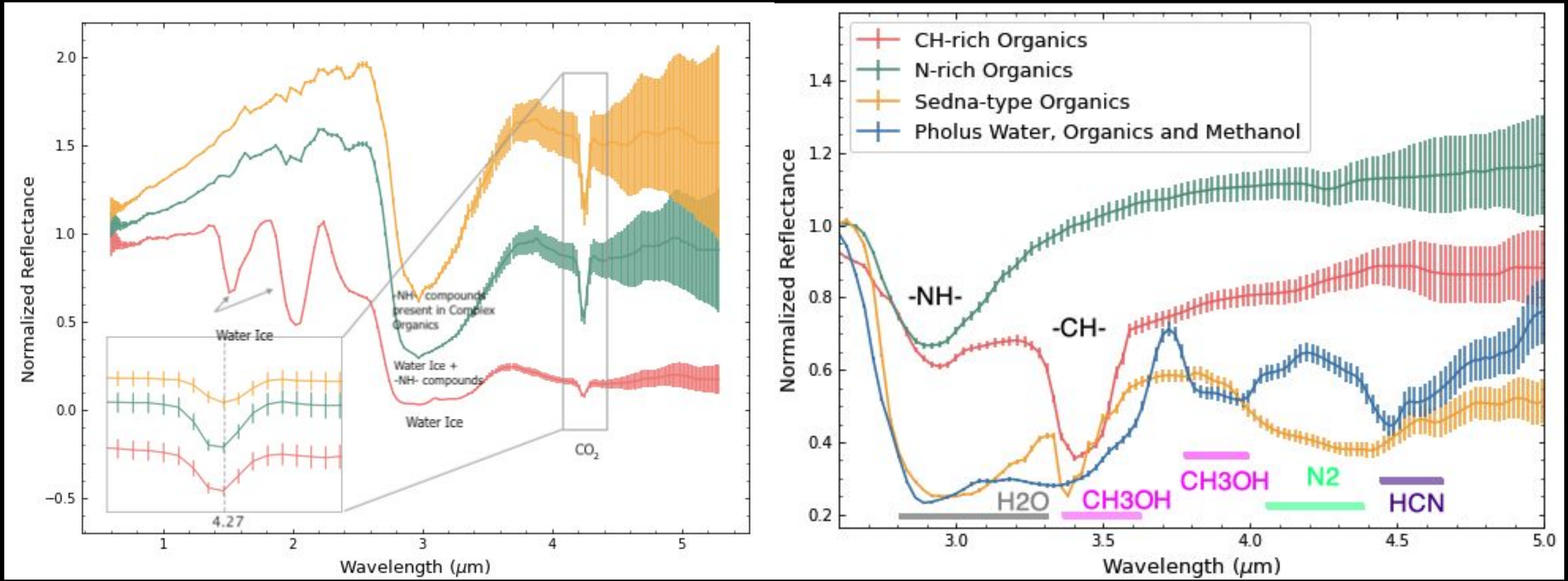
## Cold Classicals (9)

2000 OK67
2001 QY297
1998 SN165
2003 GH55
Kagara
1995 TL8
2001 QD298
Borasisi
Sila-Nunam

## Hot Classicals (9)

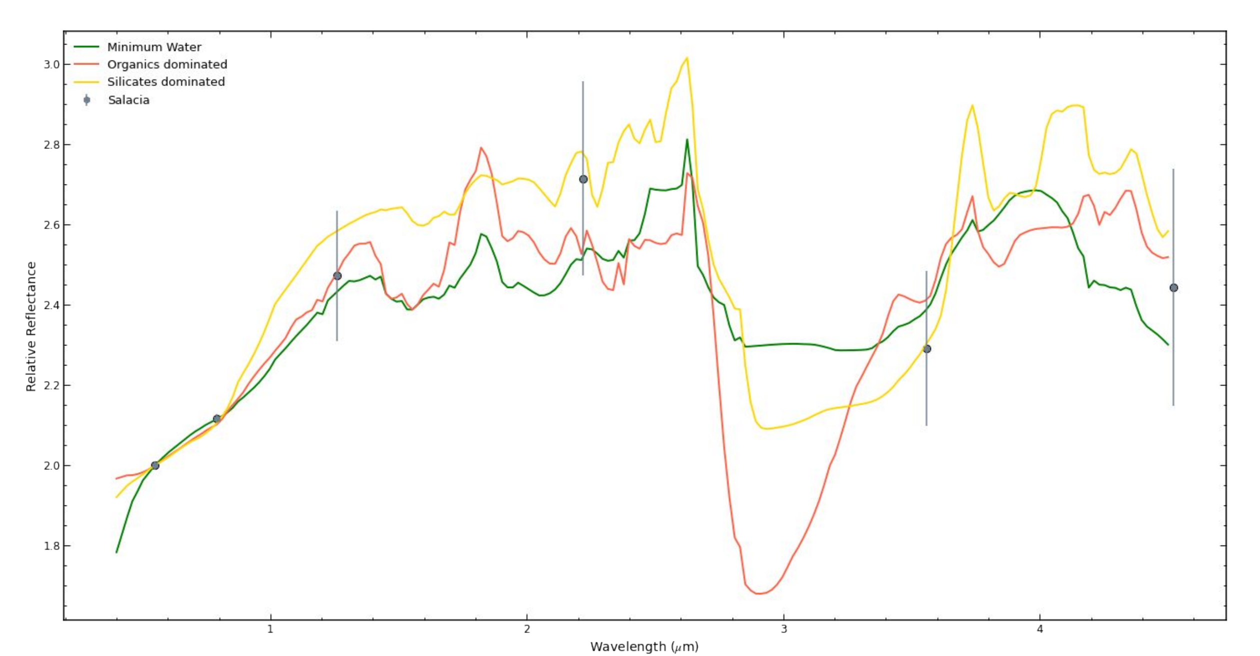
2003 UR292
2004 TY364
2004 UX10
2005 RN43
Varda
2004 PF115
2003 UZ117
2004 NT33
2002 UX25

# What can we see?




NIRSpec data will allow for the detection of several ices, such as Water, Methane, Methanol, Ethane, Ammoniated ices, CO2, CO, and else

# What can we see?




NIRSpec data will allow to investigate which are the reddening agents: Silicates or Organics?

More Power!

+

Better Wavelength Coverage!

+

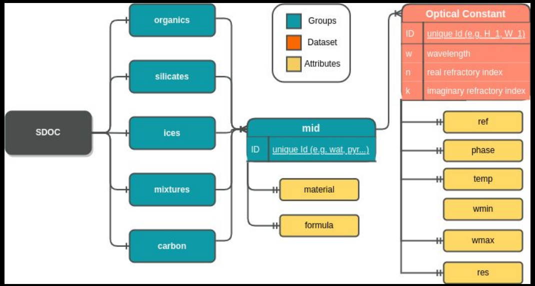
Better methods to analyse the data!

CANA

Handle spectra (trim, mask region, clean, rebin) , taxonomic classification, slopes, reflectance models (Shkuratov).

Available at:
*https://github.com/cana-asteroids/cana*

## SDOC

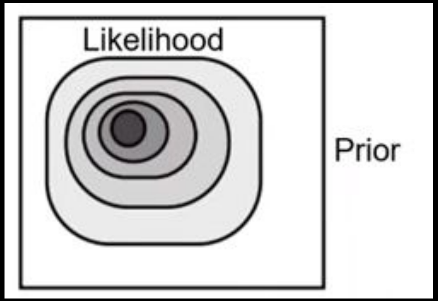



HDF5 Database of Optical Constants.

- Ices
- Silicates
- Organics
- Misc

Available at:
*https://github.com/cana-asteroids/sdoc*

## CATUABA




Inference method using reflectance models on CANA and DYNESTY for the Nested Sampling.

Available at:
*https://github.com/cana-asteroids/catuaba*
* private repository

# Modeling TNO's surface composition

- Generative model: Shkuratov 1999
    - Inputs: Optical Constants, Fractions, Grains sizes
    - Porosity fixed at 0.5

- Inference with Bayesian statistics

$$p(\theta|D) = \frac{1}{Z} p(D|\theta) p(\theta)$$

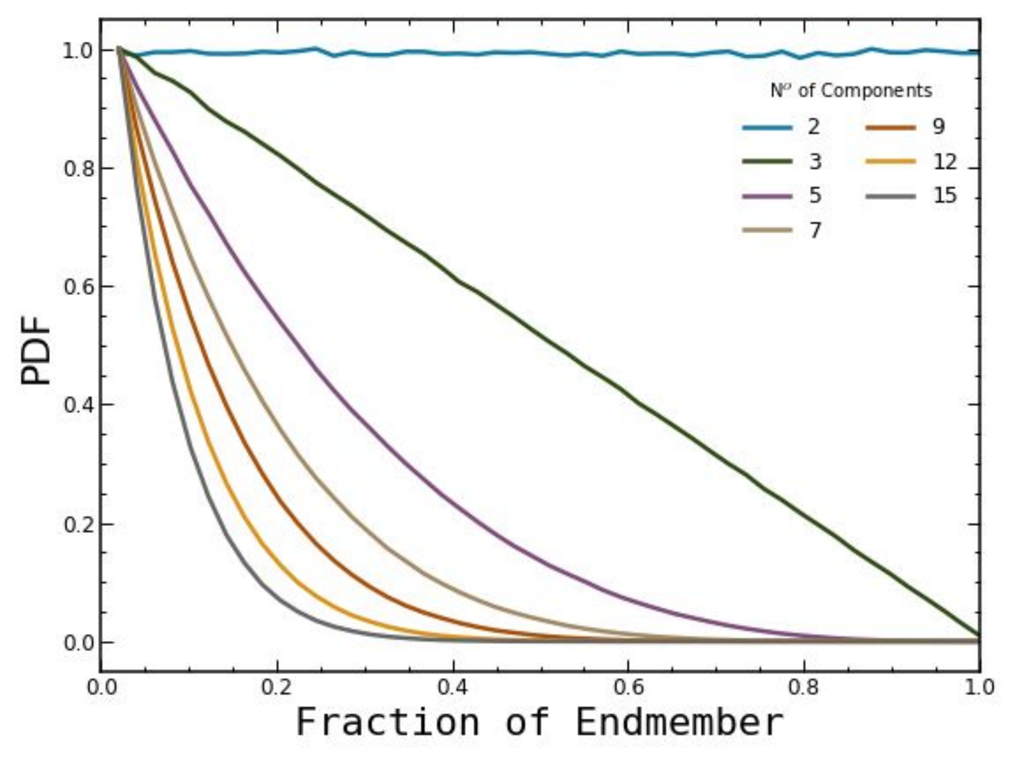
Posterior Evidence Likelihood Prior

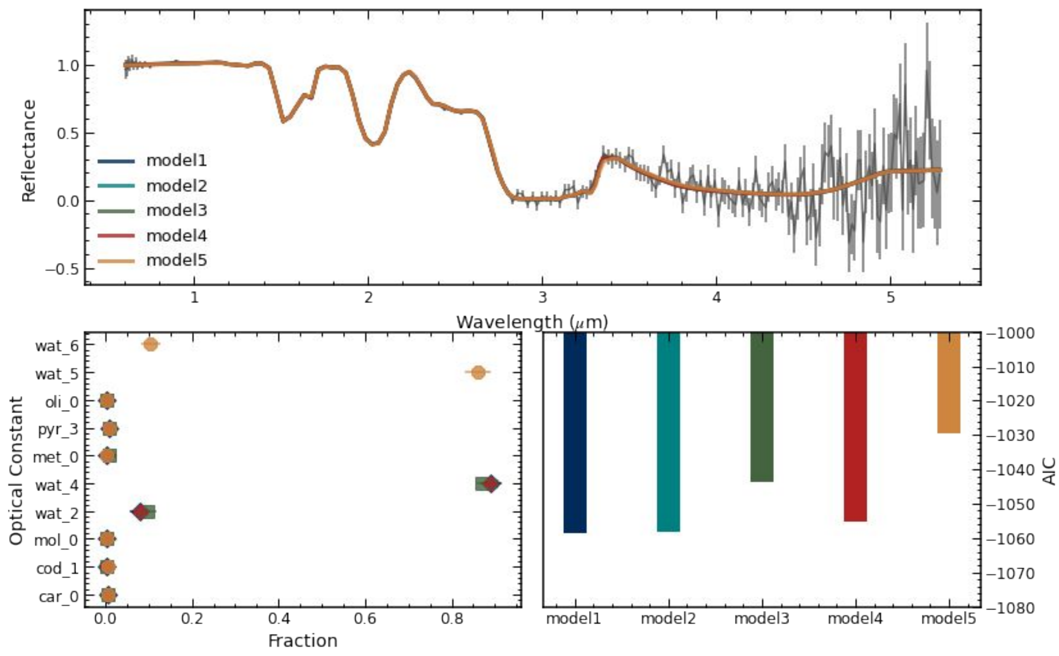
    - Fractions prior assumes a Dirichlet Distribution
    - Grain sizes prior assumes an Uniform Distribution

- Sampling algorithm uses a Nested Sampling technique with the dynesty python package

# Advantages of the modeling technique

- Slice sampling of the parameters space is efficient in navigating fractional prior
- Nested sampling allows to calculates the evidence
- Technique allows to used model comparison and selection metrics






- Model was able to retrieve the correct inputs of the synthetic spectra.
- AIC revealed which ice was used to create the synthetic spectra

| Model | Materials | Optical Constants | Running Parameters |
|---|---|---|---|
| | Carbon | car_0 | |
| | Carbon dioxide | cod_1 | |
| | Methanol | mol_0 | sampler = rslice |
| Model 1 | Amorphous Water | wat_2 | nlive = 1000 |
| | Crystalline Water | wat_4 | grain sizes range= 5-30 $\mu$ |
| | Methane | met_0 | |
| | Pyroxene | pyr_3 | |
| | Olivine | oli_0 | |
| | Carbon | car_0 | |
| | Carbon dioxide | cod_1 | |
| | Methanol | mol_0 | sampler = rslice |
| Model 2 | Amorphous Water | wat_2 | nlive = 1000 |
| | Crystalline Water | wat_4 | grain sizes range= 5-300 $\mu$ |
| | Methane | met_0 | |
| | Pyroxene | pyr_3 | |
| | Olivine | oli_0 | |
| | Carbon | car_0 | |
| | Carbon dioxide | cod_1 | |
| | Methanol | mol_0 | sampler = slice |
| Model 3 | Amorphous Water | wat_2 | nlive = 1000 |
| | Crystalline Water | wat_4 | grain sizes range= 5-30 $\mu$ |
| | Methane | met_0 | |
| | Pyroxene | pyr_3 | |
| | Olivine | oli_0 | |
| | Carbon | car_0 | |
| | Carbon dioxide | cod_1 | |
| | Methanol | mol_0 | sampler = rslice |
| Model 4 | Amorphous Water | wat_2 | nlive = 8000 |
| | Crystalline Water | wat_4 | grain sizes range= 5-30 $\mu$ |
| | Methane | met_0 | |
| | Pyroxene | pyr_3 | |
| | Olivine | oli_0 | |
| | Carbon | car_0 | |
| | Carbon dioxide | cod_1 | |
| | Methanol | mol_0 | sampler = rslice |
| Model 5 | Amorphous Water | wat_5 | nlive = 1000 |
| | Crystalline Water | wat_6 | grain sizes range= 5-30 $\mu$ |
| | Methane | met_0 | |
| | Pyroxene | pyr_3 | |
| | Olivine | oli_0 | |

# Perspectives

- First data will arrive in the last week of September or beginning of October

- Status of the tools
    - Pipeline for the data reduction ✅

    - Optical Constants database *✅

    - Band analysis *✅

    - Compositional Modeling *✅

- DiSCo-TNOs will for obtain high SNR data of 59 TNOs within the next year at the
    - This data will finally reveal the surface composition of TNOs, allowing for the detection and characterization of several ices, organics and silicates that have been proposed to exist on their surfaces, and unveil their formation and evolutionary processes

Gracias!

Thank you!

Obrigado!