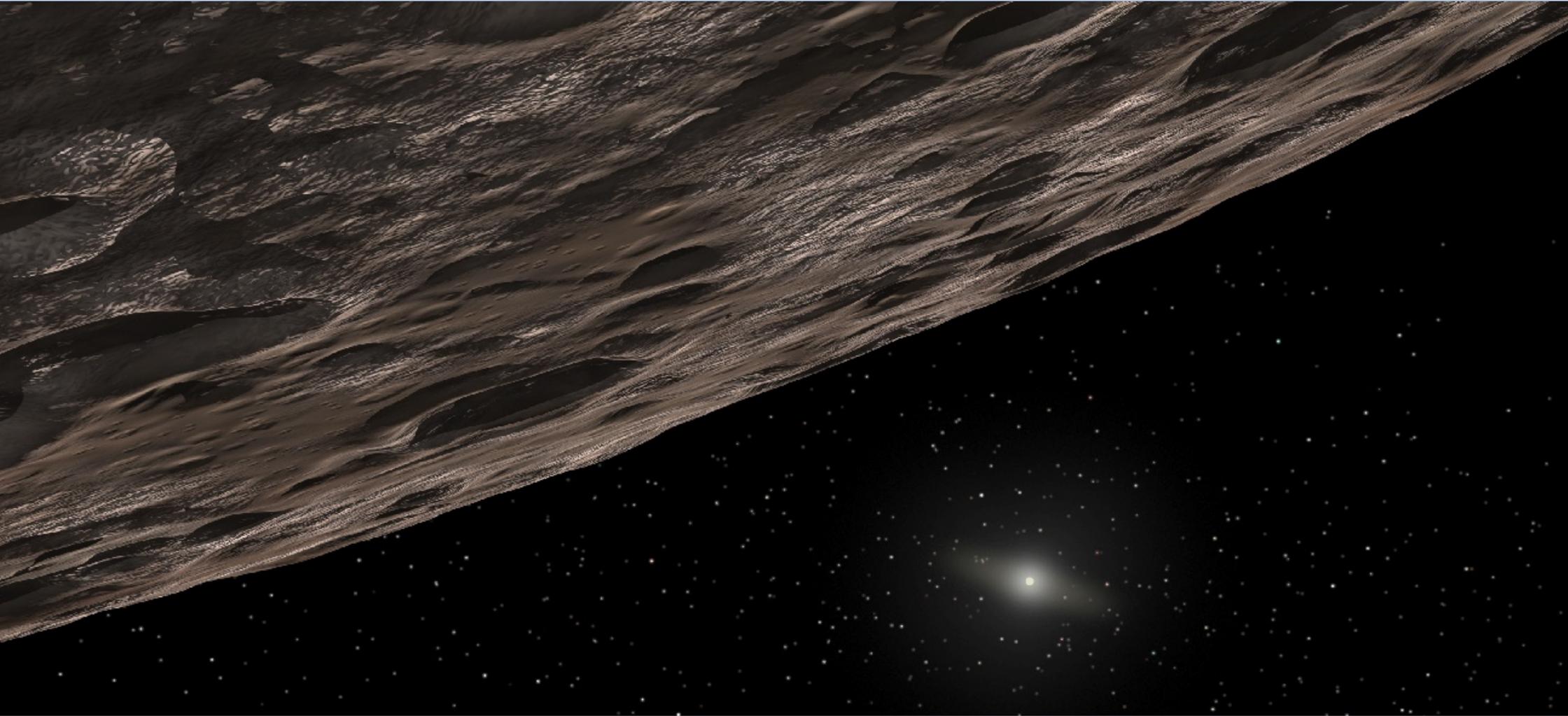


TNOs are Cool:

A Survey of the Transneptunian Region



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MPE Garching

The TNOs-are-Cool Team
(37 members, 19 institutes, 9 countries)

Overview



- OT KP with 370 hours
- PACS and SPIRE photometric point-source observations
- characterisation of about 140 Trans-Neptunian Objects (with known orbits)
- target with a few mJy up to 400 mJy
- Key element: highly reliable photometric accuracy in 3 (6) bands
- time-critical observations with follow-on constraint (confusion noise)

Science Goals in a Nut Shell

- **Radiometric size and albedo solutions**
 - accurate sizes (→ volumes) of TNOs
 - **primordial ($D > 200$ km) size distribution**
 - accurate spectroscopic and polarimetric modeling
 - albedo vs Size vs Colour vs Composition vs Orbit vs Binariness vs ...
 - **probe formation and evolution processes**
- **Thermophysical properties** (from 3 to 6 Pacs/Spire bands)
 - temperatures & thermal inertia
 - **ice vs rock surface, surface type**
 - emissivity → **grain size information**
 - beaming parameter → **surface roughness**
- **Binary densities:** mass from Kepler's 3rd law, volume from Herschel
 - **basic geophysical parameter**
 - **interior structure/composition**
 - **binary formation mechanism**
- **Thermal lightcurves**
 - **disentangle albedo/shape**
 - spin-axis orientation
 - thermal inertia
 - large surface structures



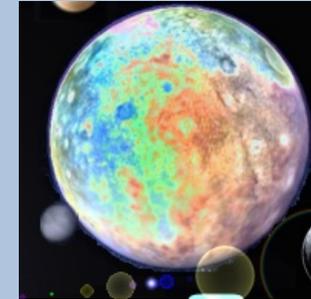
Herschel Study of the Kuiperbelt & TNOs:

→ a benchmark for understanding the solar system debris disk, and extra-solar ones as well!

Overview SDP TNO Programme (~ 25 h)

- **PACS (1st part, completed)**
 - chop-nod point-source photometry with dither, tracking
 - 2 or 3 band photometry, repetition factors 10...36
 - 7 targets, including Pluto, Typhon and Makemake
- **PACS (2nd part, partly scheduled)**
 - mini scan map, array angles 63/117 deg (grouped)
 - 3.5' length, 10 scans, 4'' separation
 - 3...10 repetitions, follow-on in selected cases
 - 7 targets, including Haumea lightcurve
- **SPIRE (SDP completed)**
 - Mode: Large Map, Scan Angles A and B, 4' length, 12 rep.
 - repetition (follow-on) after 44/66 hours, tracking
 - 2 targets: 90482 Orcus and 136472 Makemake

SPIRE Results

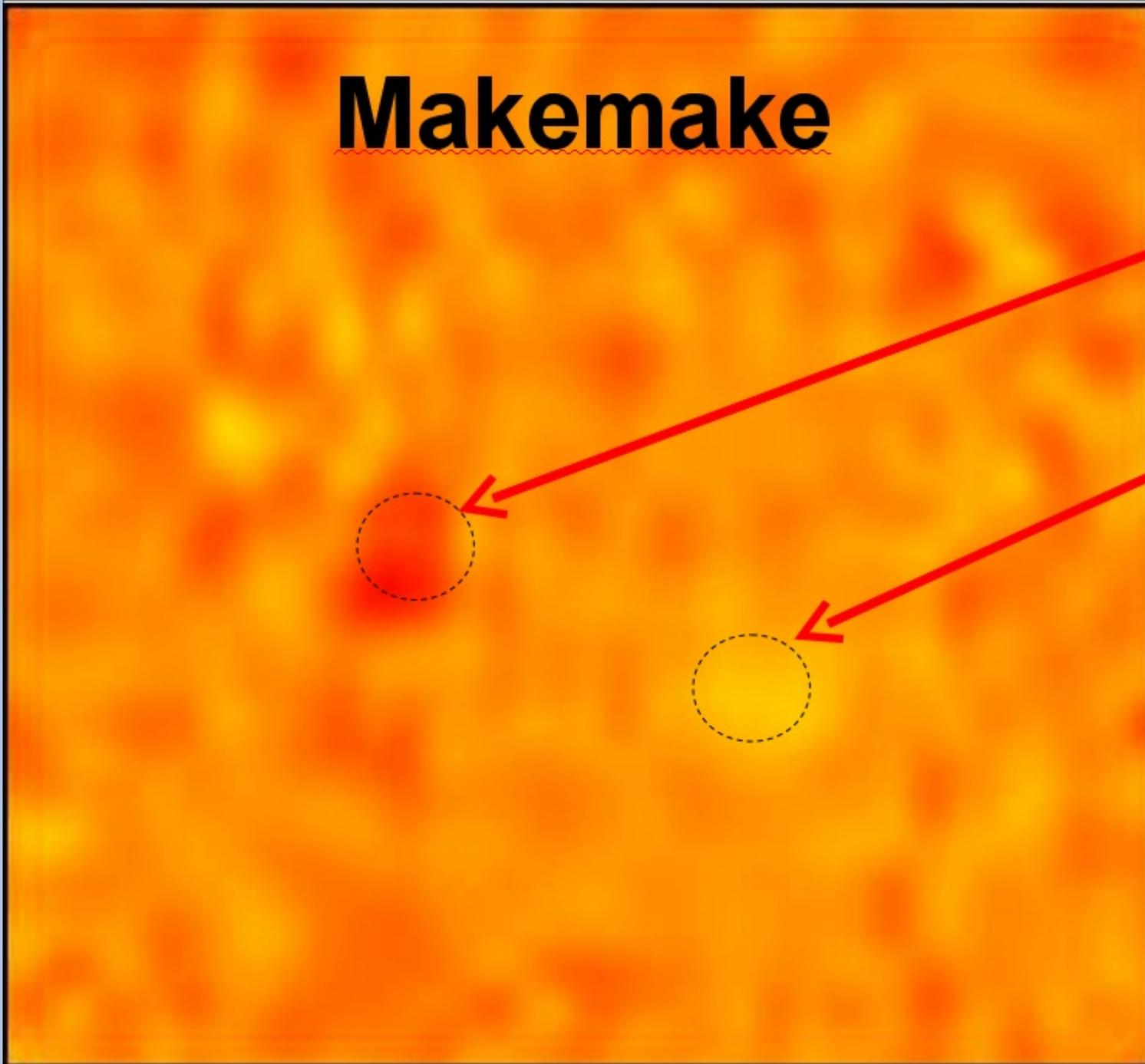


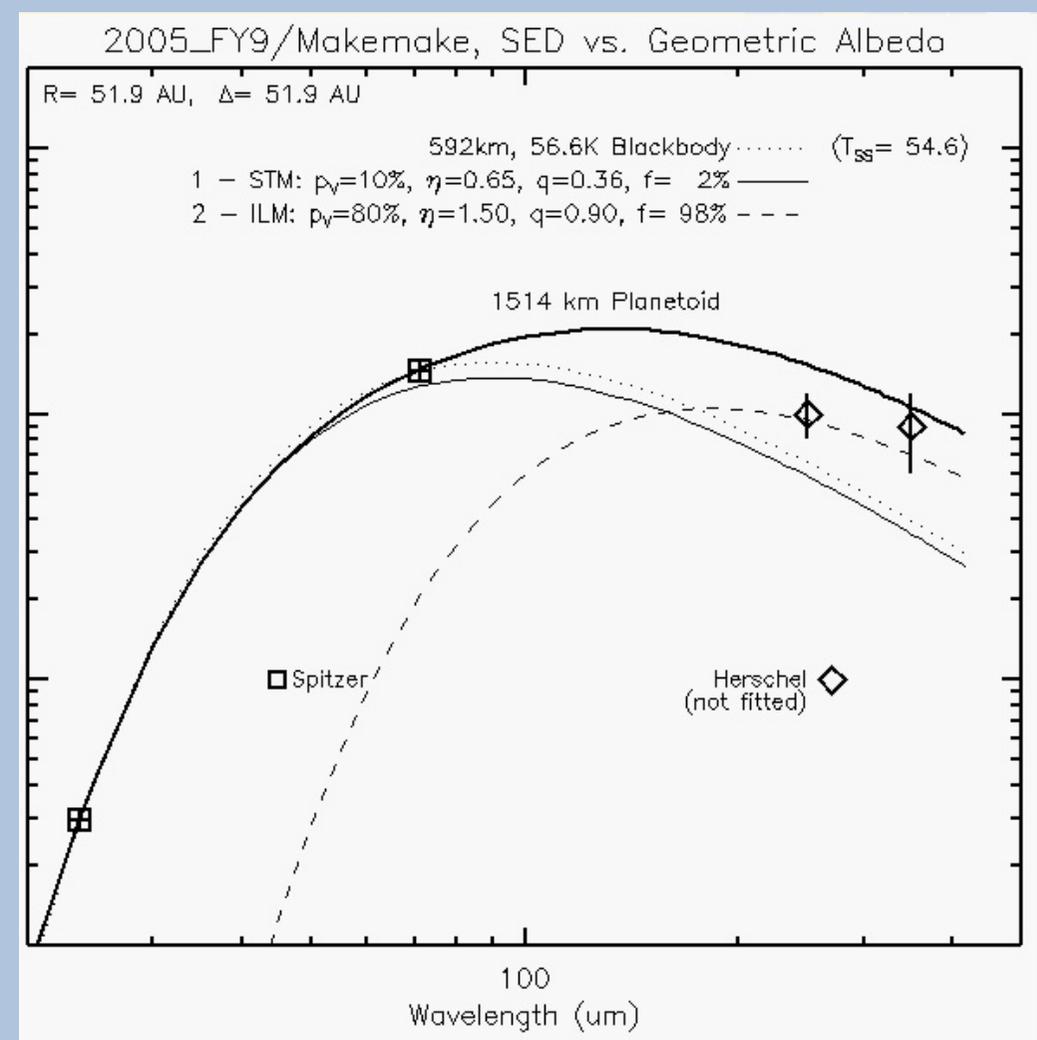
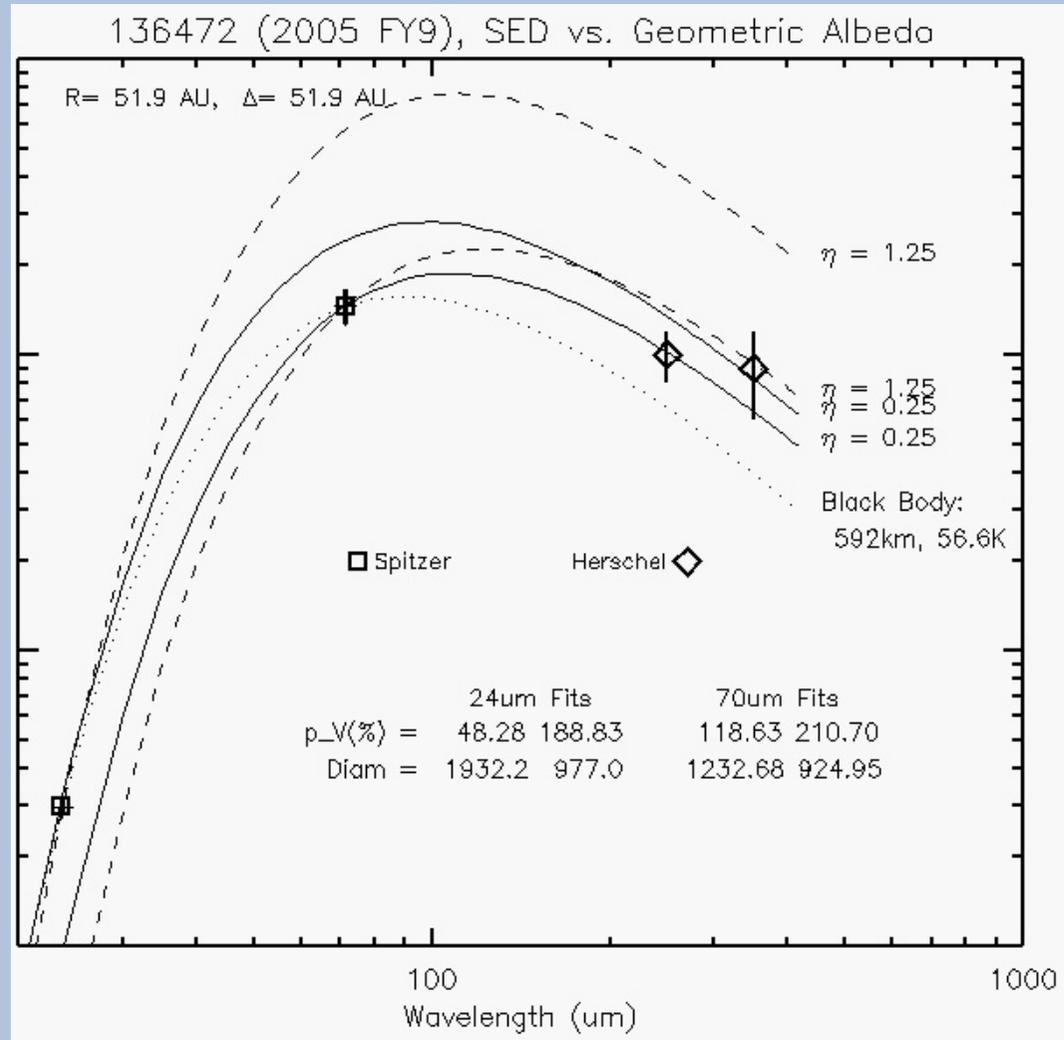
- Both SPIRE targets are nicely detected:
"Follow-on" is the key technique for these faint moving targets!
- Flux density of both TNOs at 250 and 350 μm is about 10 mJy (not final)
- Preliminary thermophysical analysis of Spire photometry already indicates the very high scientific potential: the measurements will constrain the size, albedo, thermal properties, surface properties, ... in an unprecedented way
- analysis of multi-band photometry has just started

Makemake

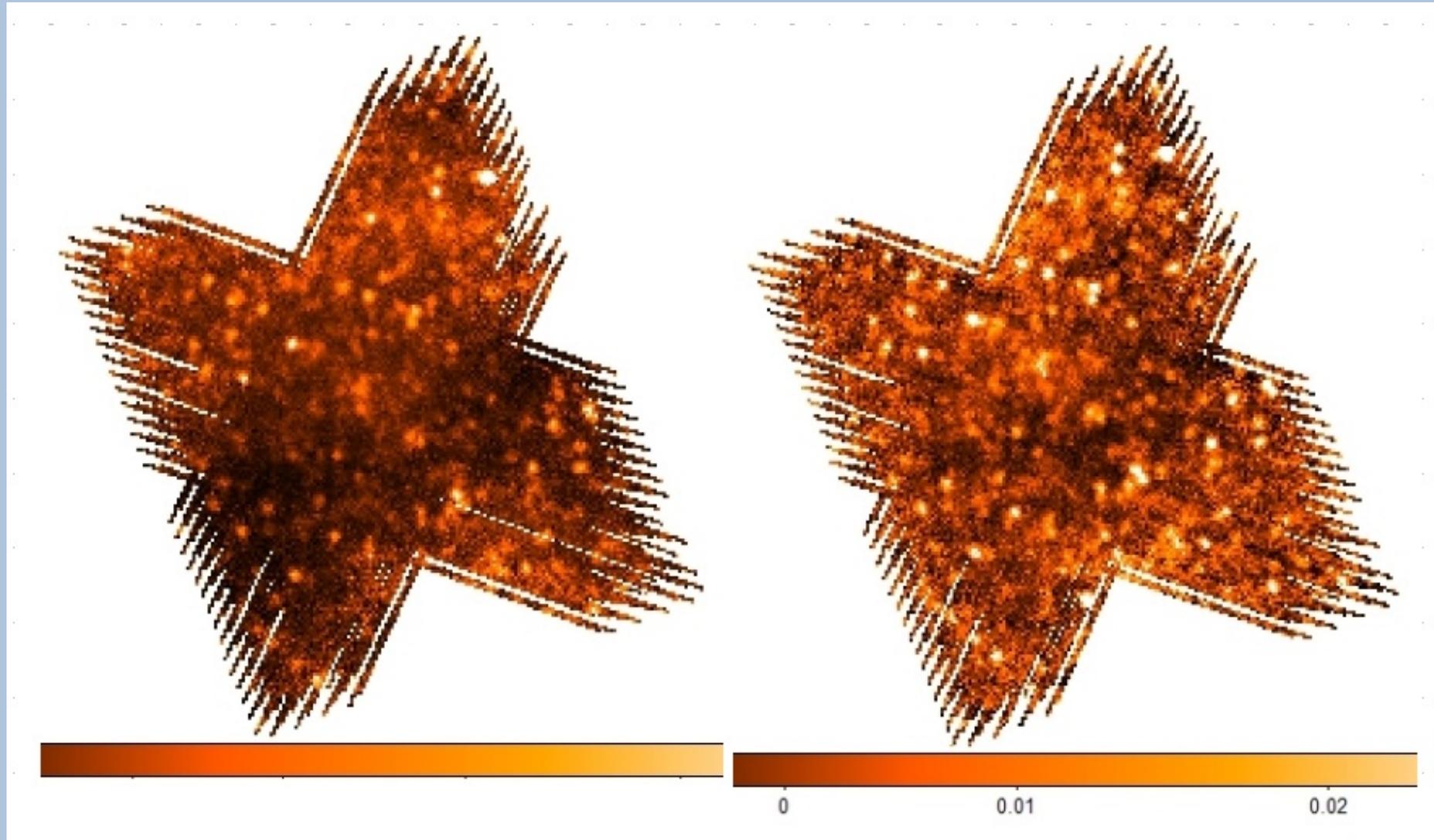
**Negative
image**

**Positive
image**

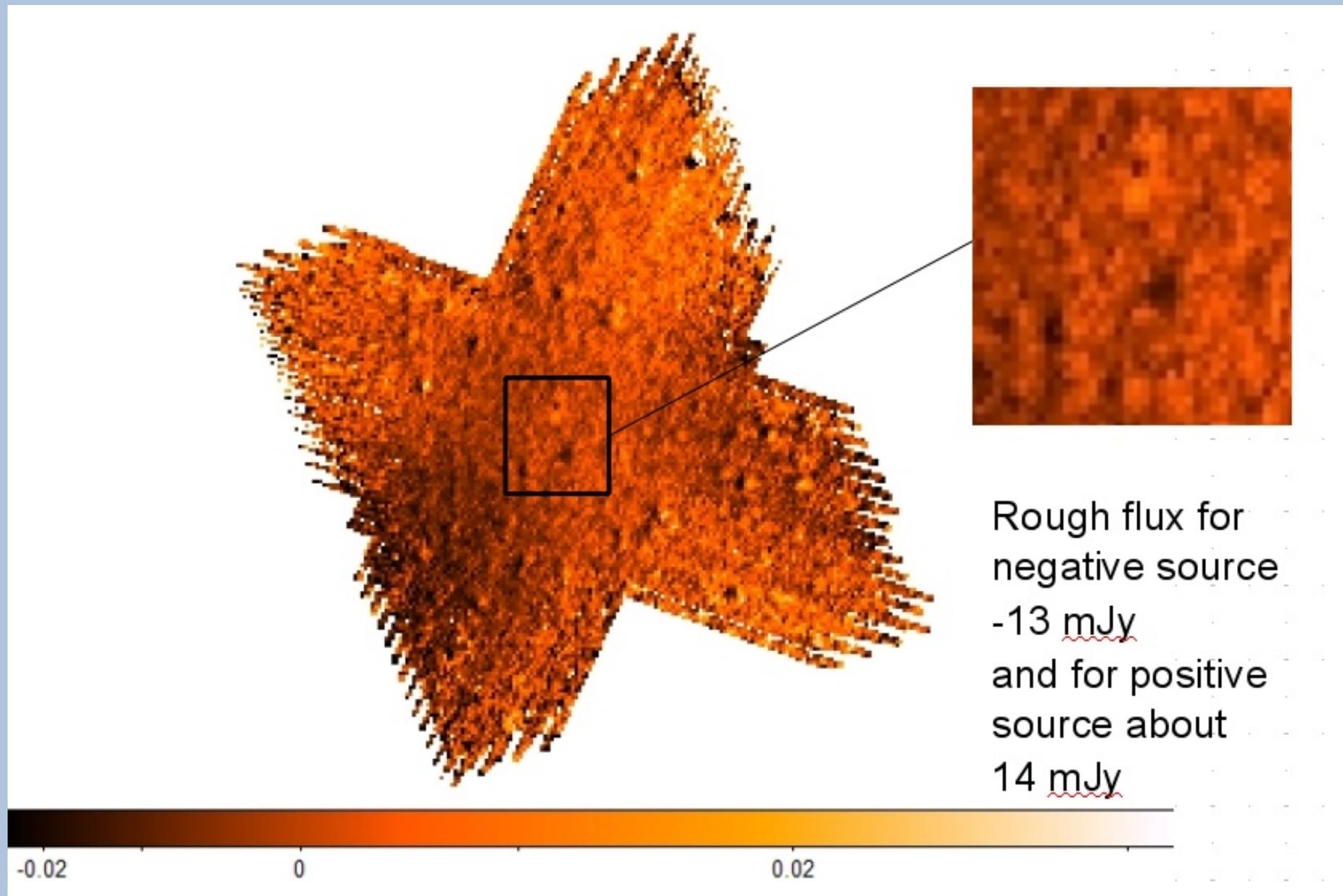




135472 Makemake: Model fits for combined Spitzer/Herschel fluxes



90482 Orcus (2004 DW), SPIRE scan maps 250 μm



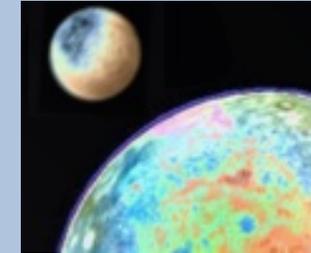
90482 Orcus (2004 DW), differential neg./pos. image¹

¹the negative [background minus (background + TNO)] and positive [(background + TNO) minus background]

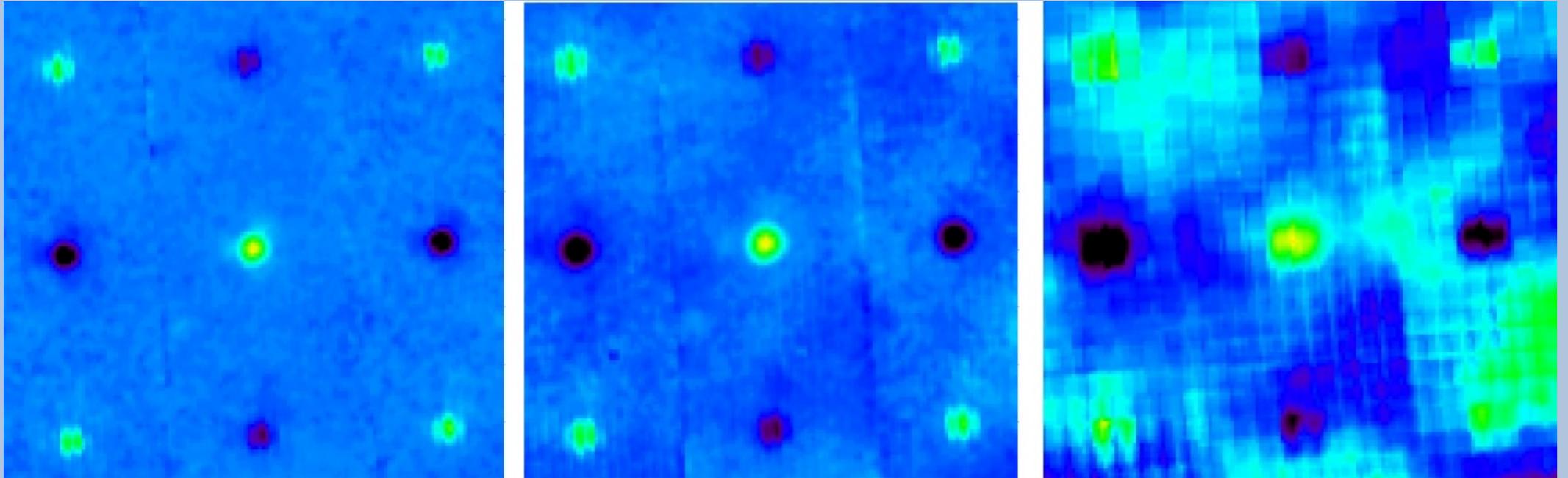
- **90482 Orcus**: has a significantly higher albedo than previously assumed (→ larger size)
- Dwarf planet **136472 Makemake**: belongs to the 3 biggest TNOs (Eris, Pluto), but among these "giant dwarf planets" it is the only one without satellite.

The Spire $250\ \mu\text{m}$ measurement can either be explained by a very extreme albedo (>0.8), leading to a diameter between 1500 and 2000 km, or by a high thermal inertia, indicative of a bare rock or densely packed ice surface (the Pacs/Spire multi-band analysis will give the answer).

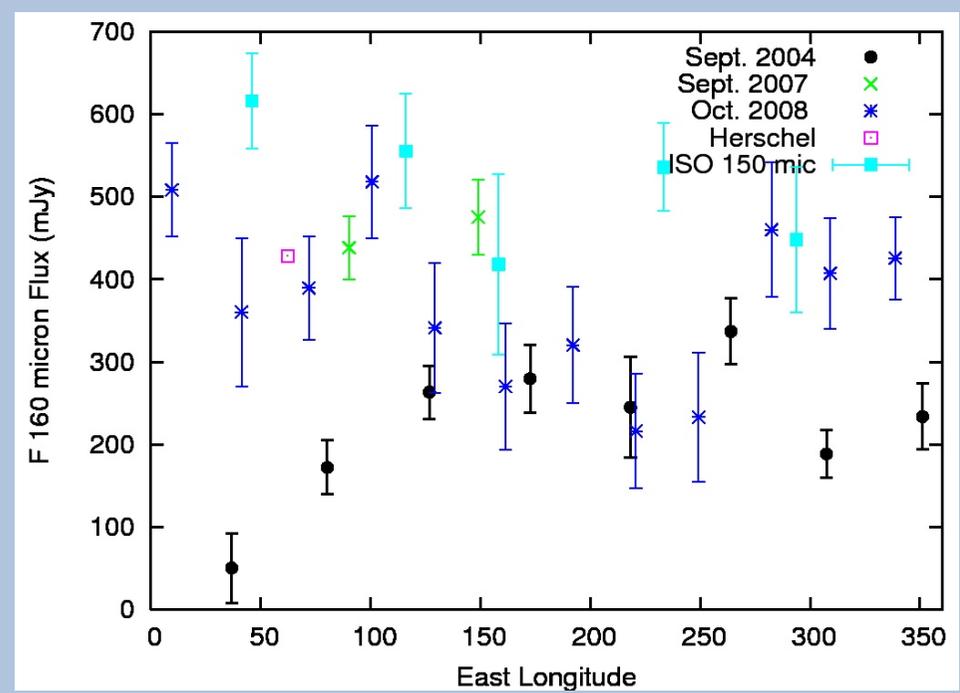
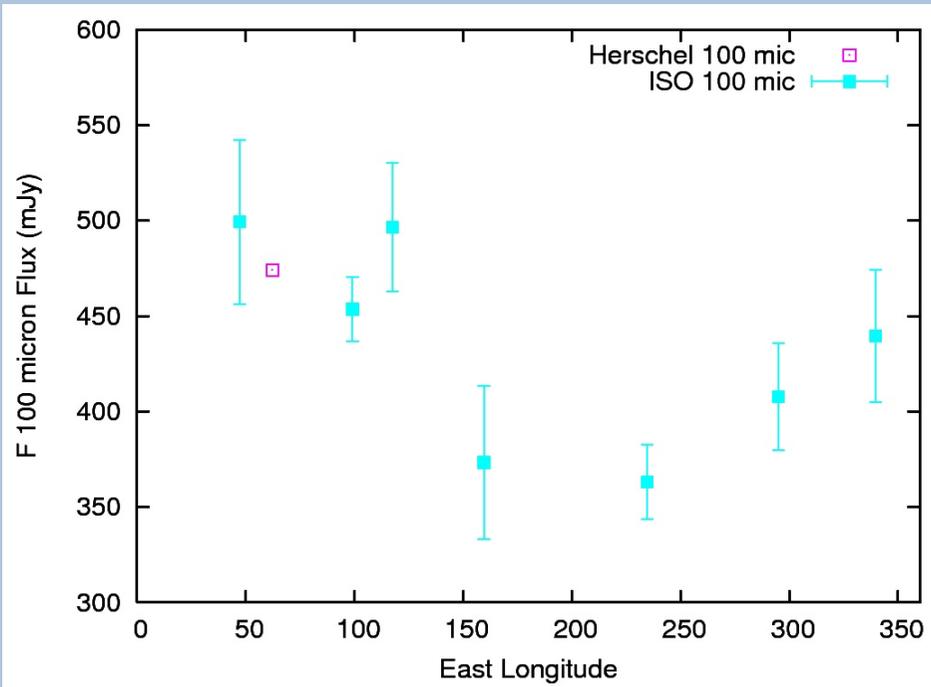
PACS Results

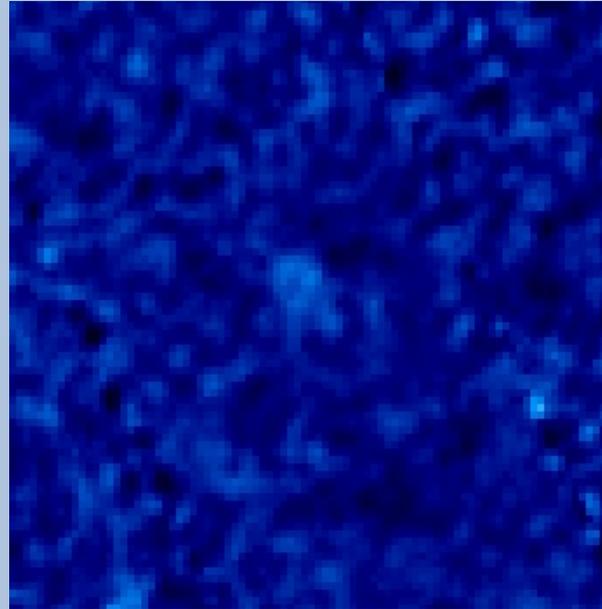
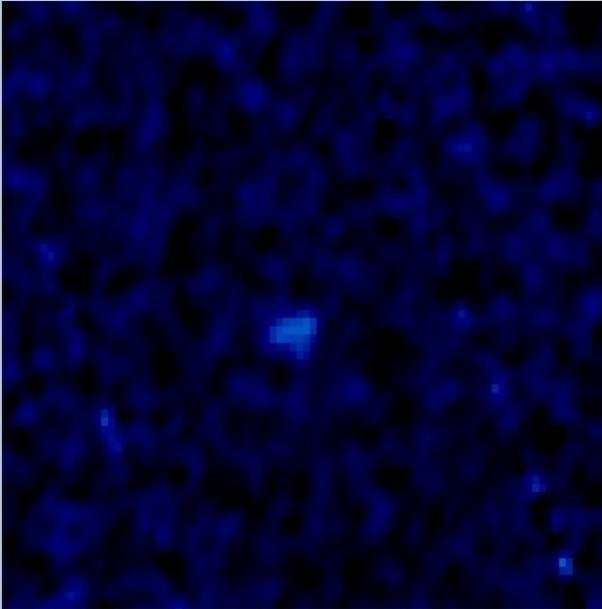


- very nice and highly accurate measurement of Pluto in 3 bands (just before Pluto entered the galactic plane/centre region)
- 6 targets analysed (based on own flux calibration/color correction):
 - + 2 are significantly fainter than predicted
 - + 3 are about at the right flux level
 - + 1 was significantly brighter than predicted
- just below 10 mJy was the faintest detected target
- improvement in analysis still needed
- poor or no detections in the red channel (single measurement, no follow-on)
- in general: S/N values are significantly lower in chop-nod mode than expected from HSpot

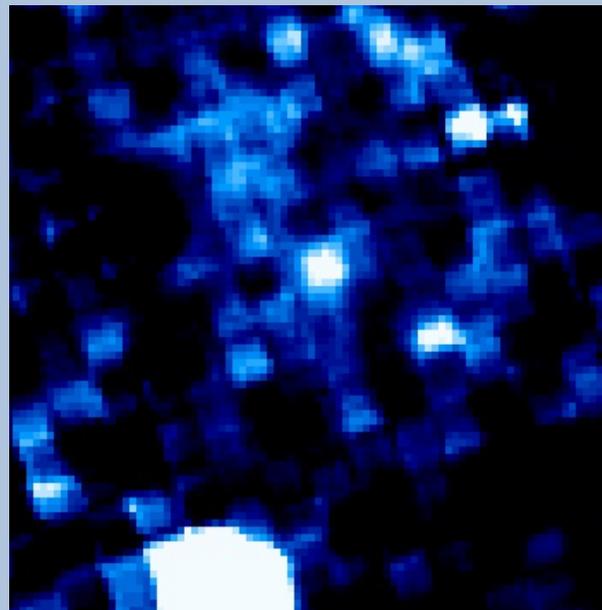
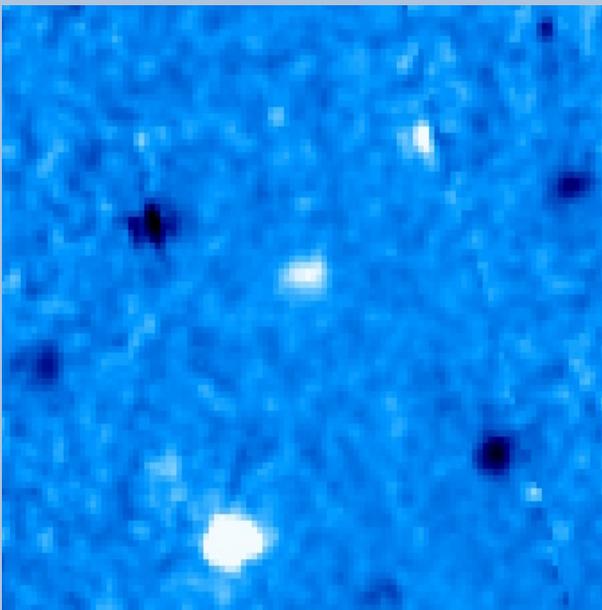


PLUTO





**42355 Typhon
70 & 100 micron**



**208996 2003 AZ84
70 & 160 micron**

Outlook & Conclusions



- SPIRE programme can go ahead, but AORs require timing constraints and have to be split for the implementation of "follow-on"
- PACS programme will be switched to "mini scan maps" for better sensitivity and better background characterisation

TNOs are Cool!

... and waiting to be observed by Herschel!