Ice, Dust, and Organics of Small Solar System Bodies with SPICA-MIR(+NIR)

Takafumi Ootsubo (Tohoku-U)

+

H. Kawakita (KSU), M. Ishiguro(SNU),

S. Hasegawa, F. Usui, Y. Sarugaku (ISAS/JAXA),

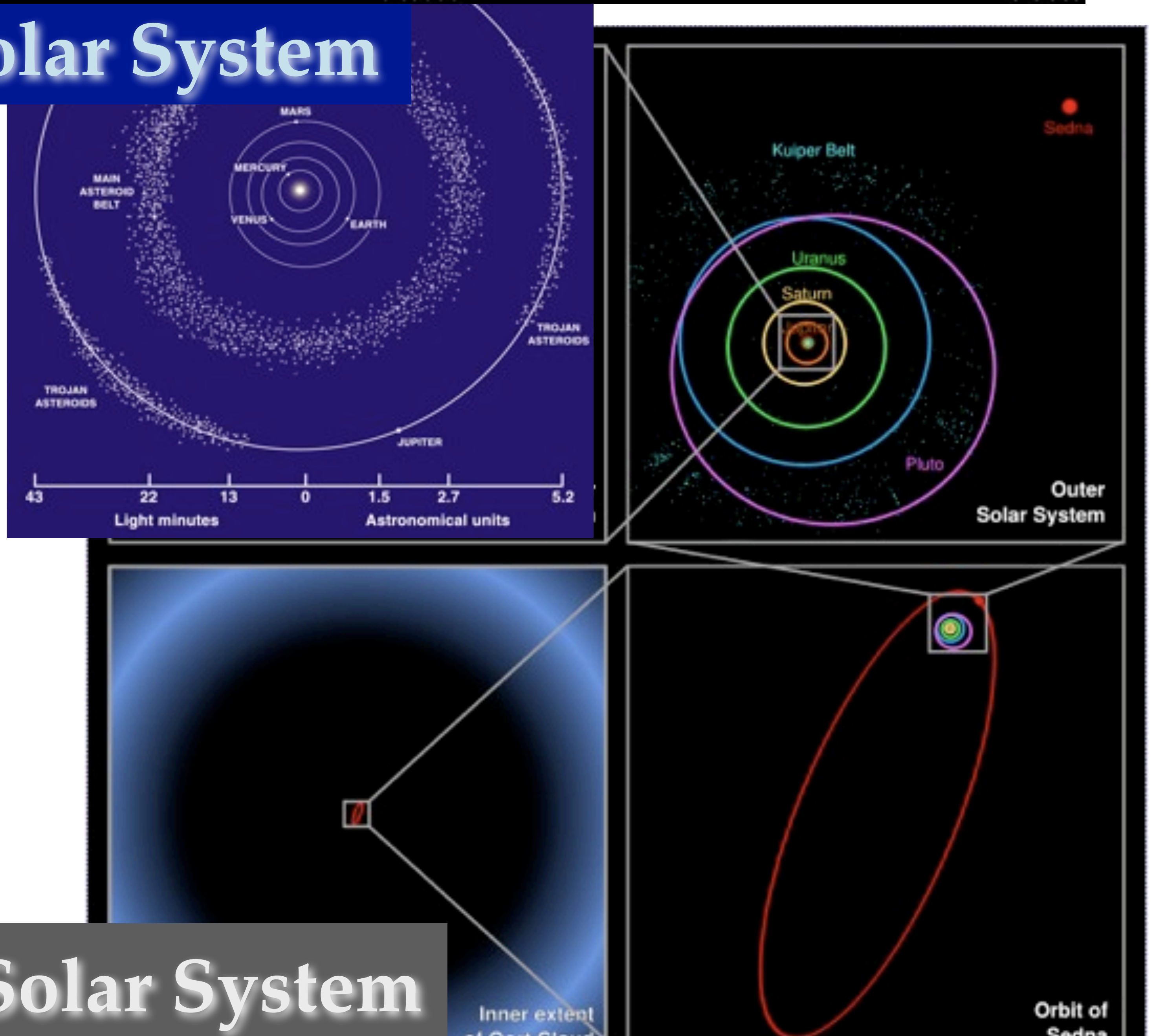
T. Sekiguchi (HUE)

+

Jun-ichi Watanabe (NAOJ)

SPICA SSSO group

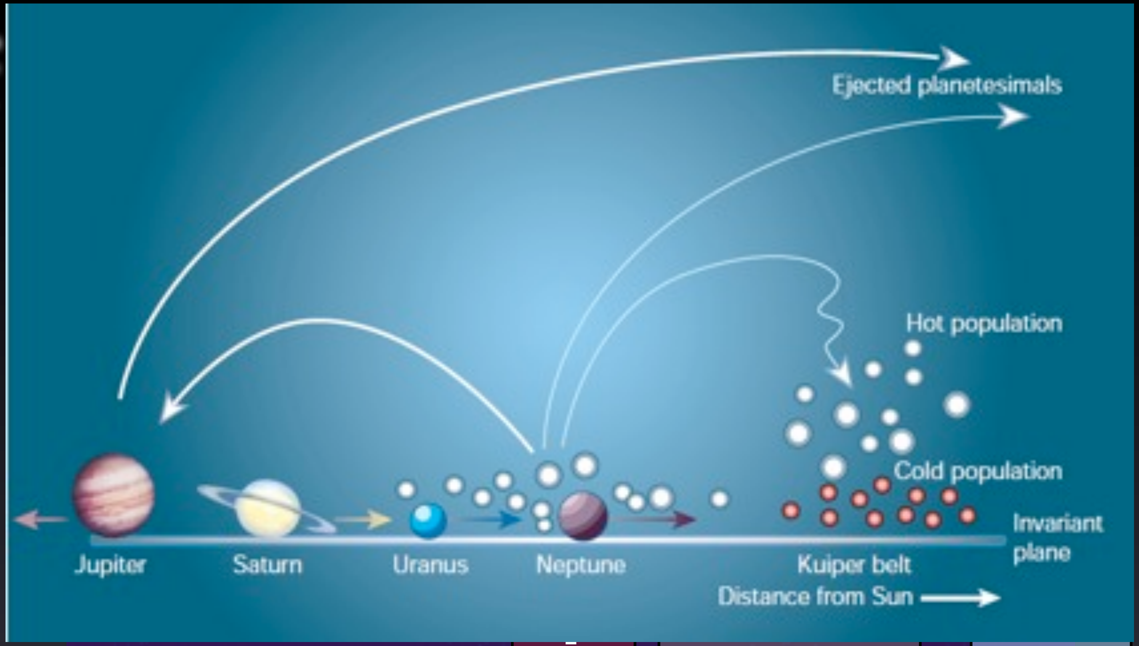
Inner Solar System



Outer Solar System

our view of the solar system is undergoing radical changes

Re-definitin of

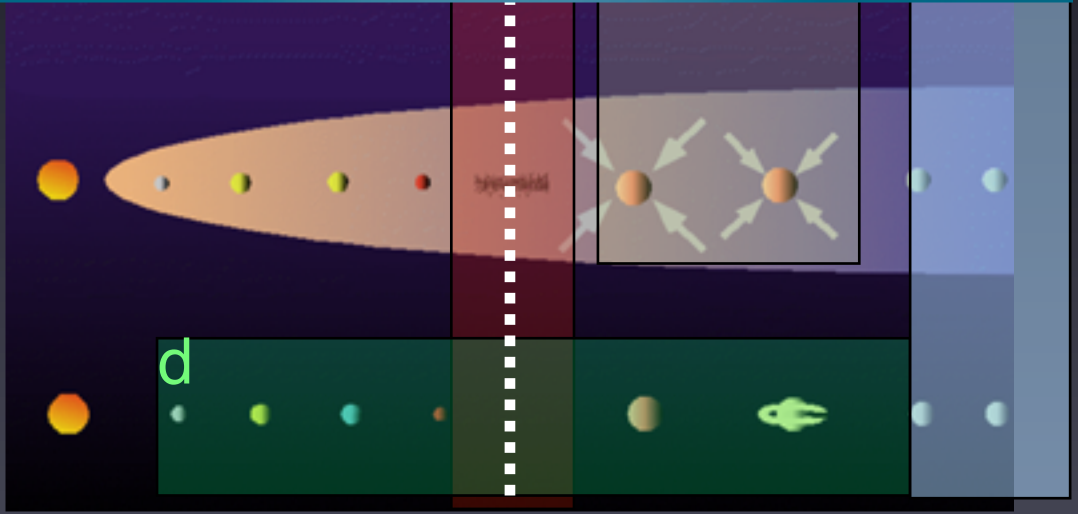


a. Asteroids

b. birth place of Oort cloud comets?

c. origin of Ecliptic comets? Trans-Neptunian objects

d. Interplanetary dust



Asteroids → Oort comets → Ecliptic comets, TNOs

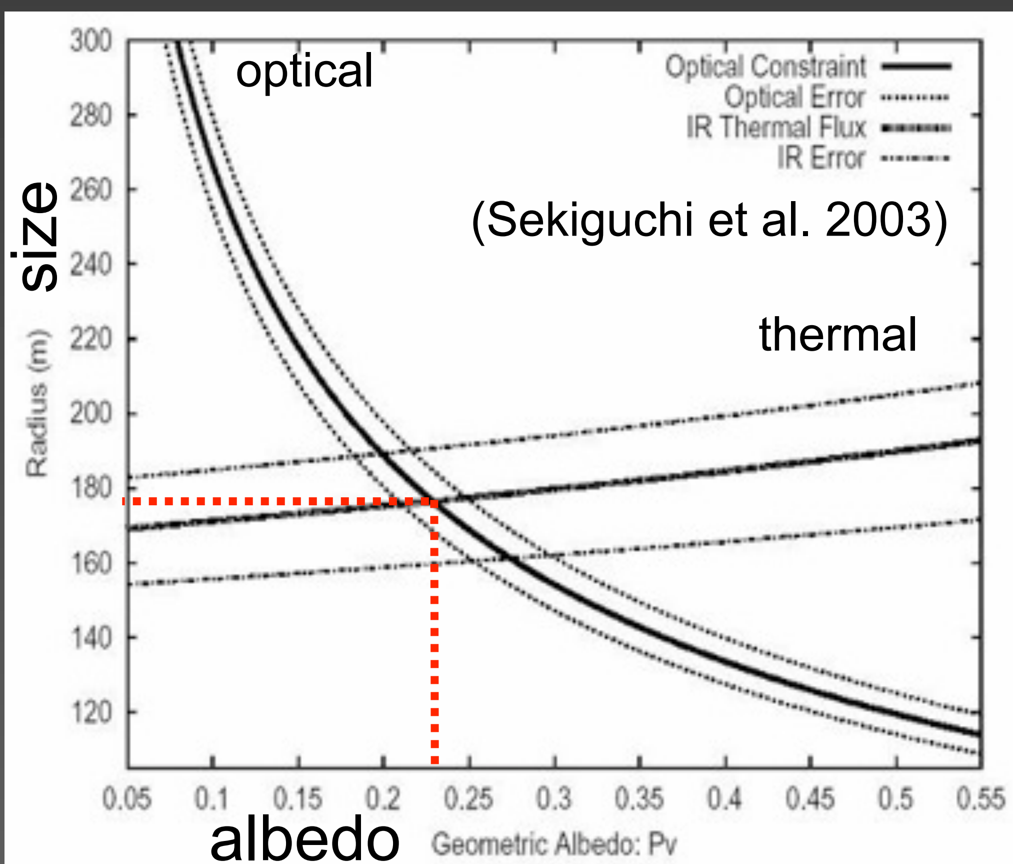
dynamical and thermal history of the early solar nebula

comparison with protoplanetary disks and Vega-disks

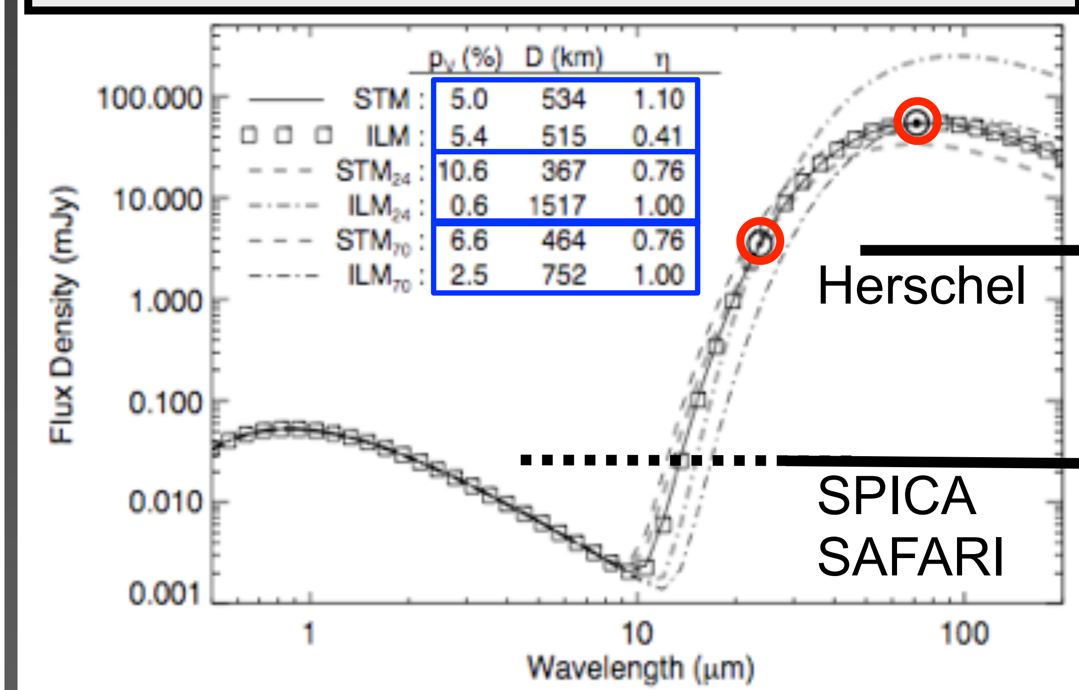
Observations of TNOs, Comets & asteroids are important

Size and albedo of TNO

- Photometry at several bands with a wide coverage (30-300 μm) would allow us to measure the accurate SEDs, and derive the size, albedo, and thermal inertia for a significant number of primitive objects in the solar system.
- Spectroscopy would give us clues to study on the (ice) composition of the surface materials.

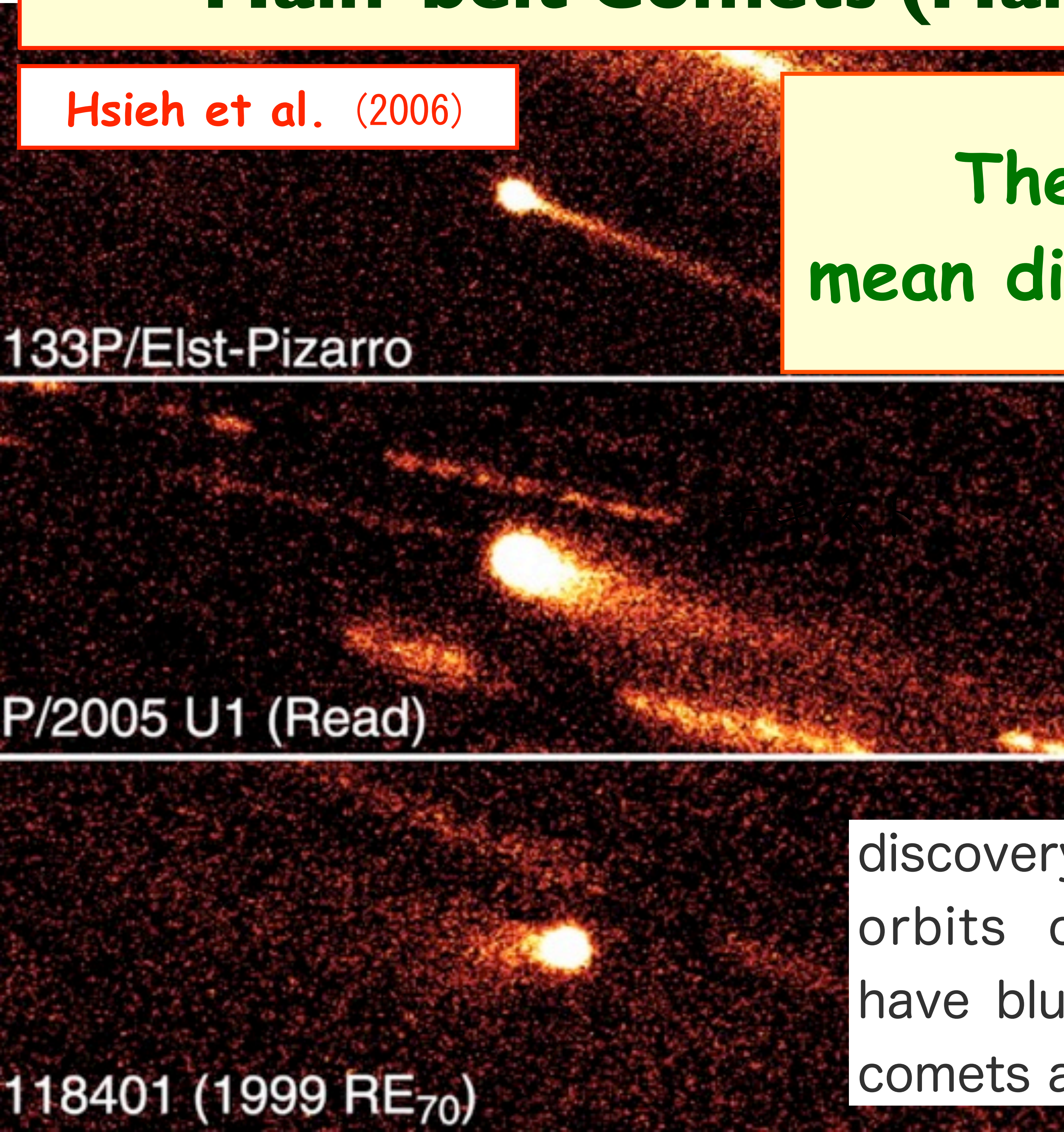


Spitzer observation of TNO Huya
at 40 AU (Stansberry et al. 2008)



Main-belt Comets (Mars-Jupiter)

Hsieh et al. (2006)



Themis family
mean distance 3.13AU

discovery in typical asteroidal orbits of main-belt comets have blurred the line between comets and asteroids

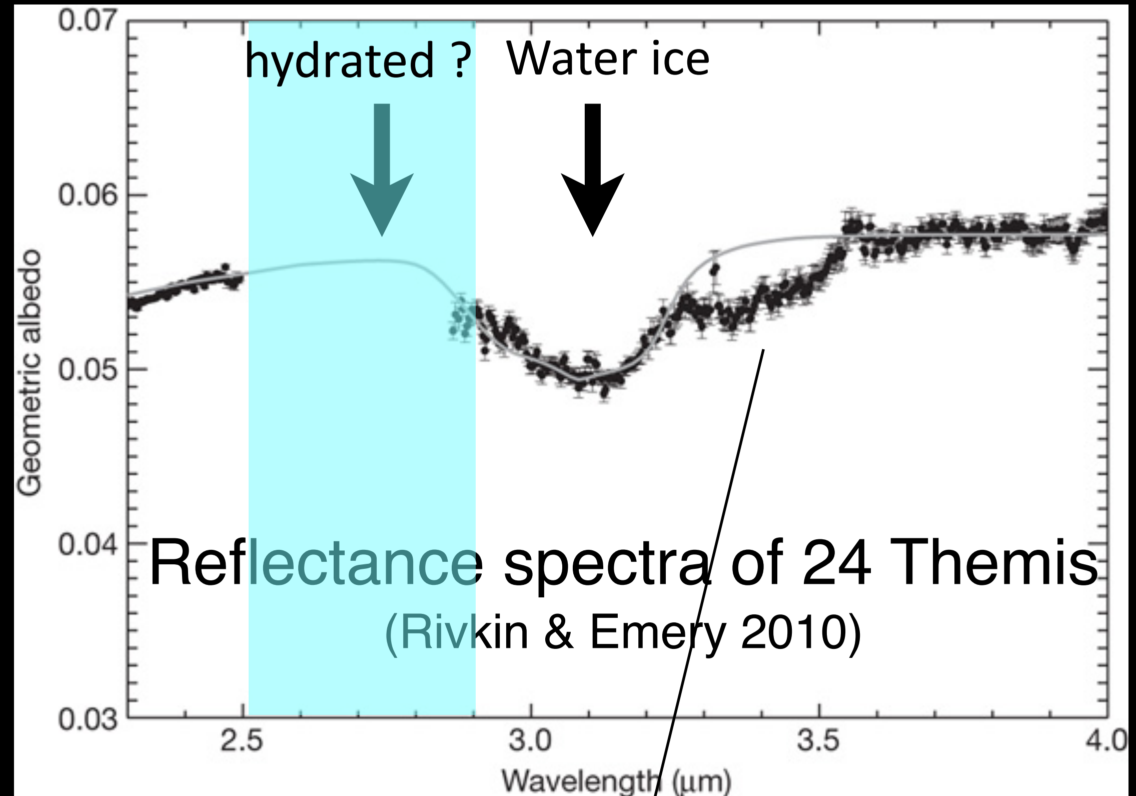
Asteroids

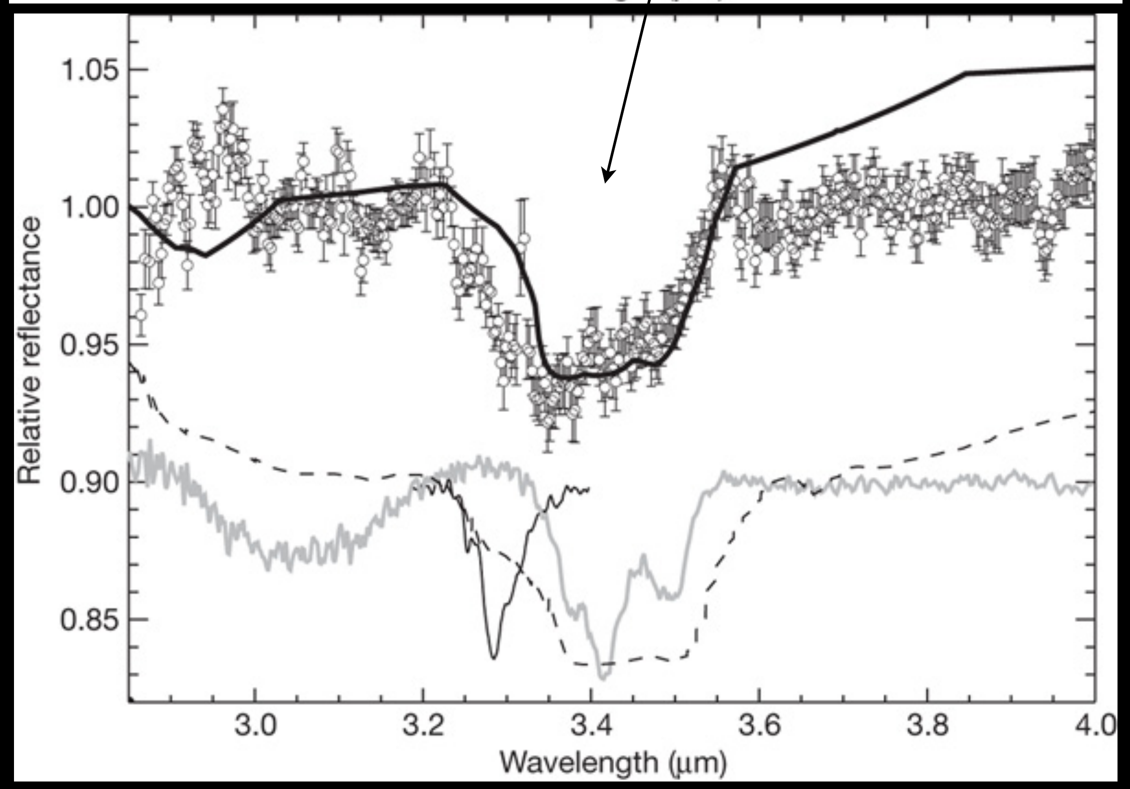
- water ice and organics on 24 Themis

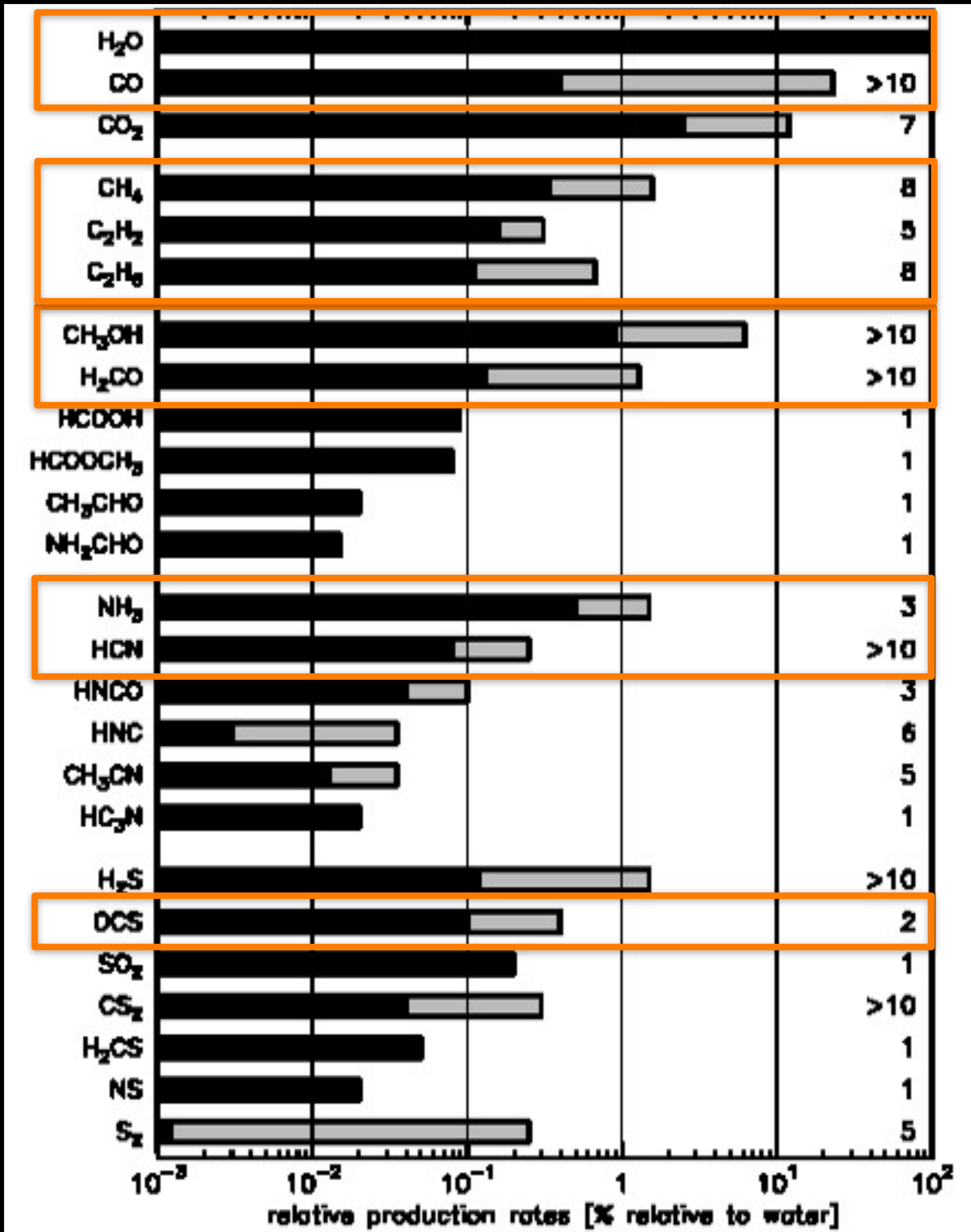
spectroscopic survey for ice and organics of small solar system bodies in various categories is very important

comets <--> asteroids?
comets <--> TNOs?

re-definition of solar system objects in SPICA era







Bockelée-Morvan et al. (2005)

Ice & Organic Volatiles in Comets

(Parent species)

＊Radio domain

＊Infrared region

(Daughter species, radicals)

＊Optical region

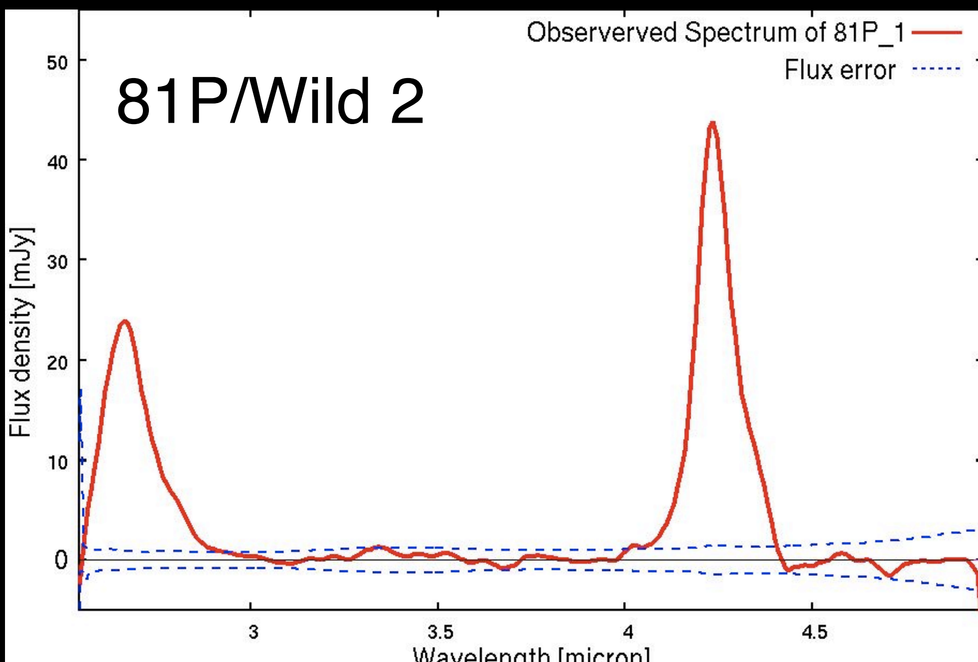
＊UV region

by Spectroscopy.

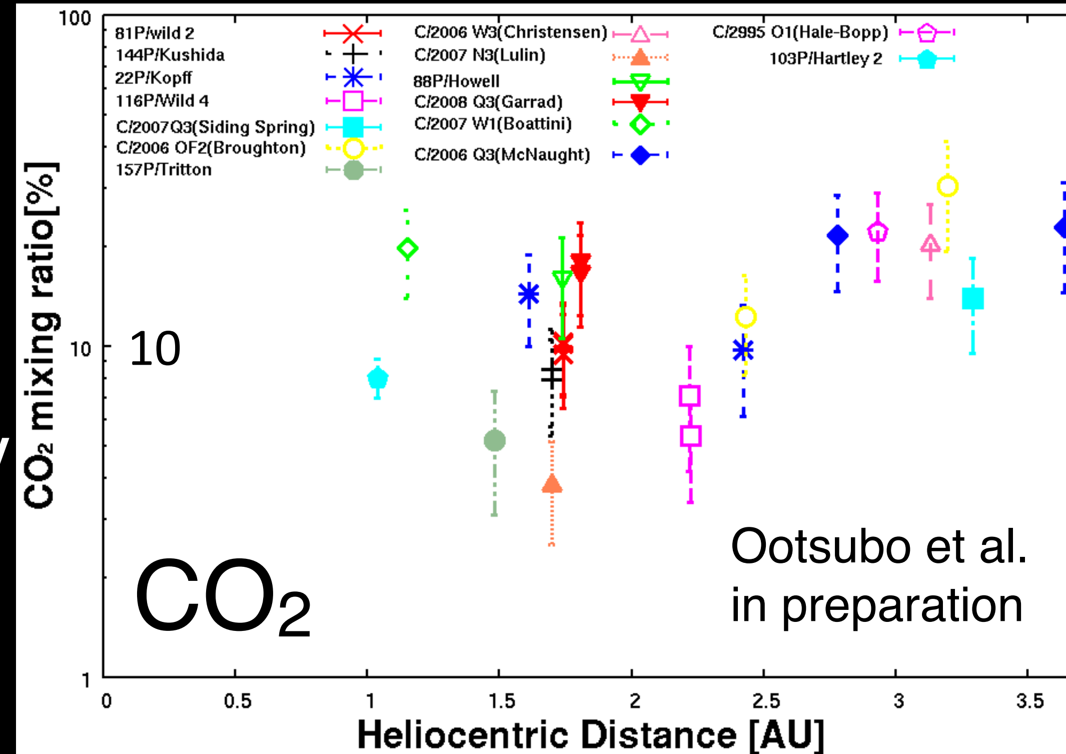
relative to **water**

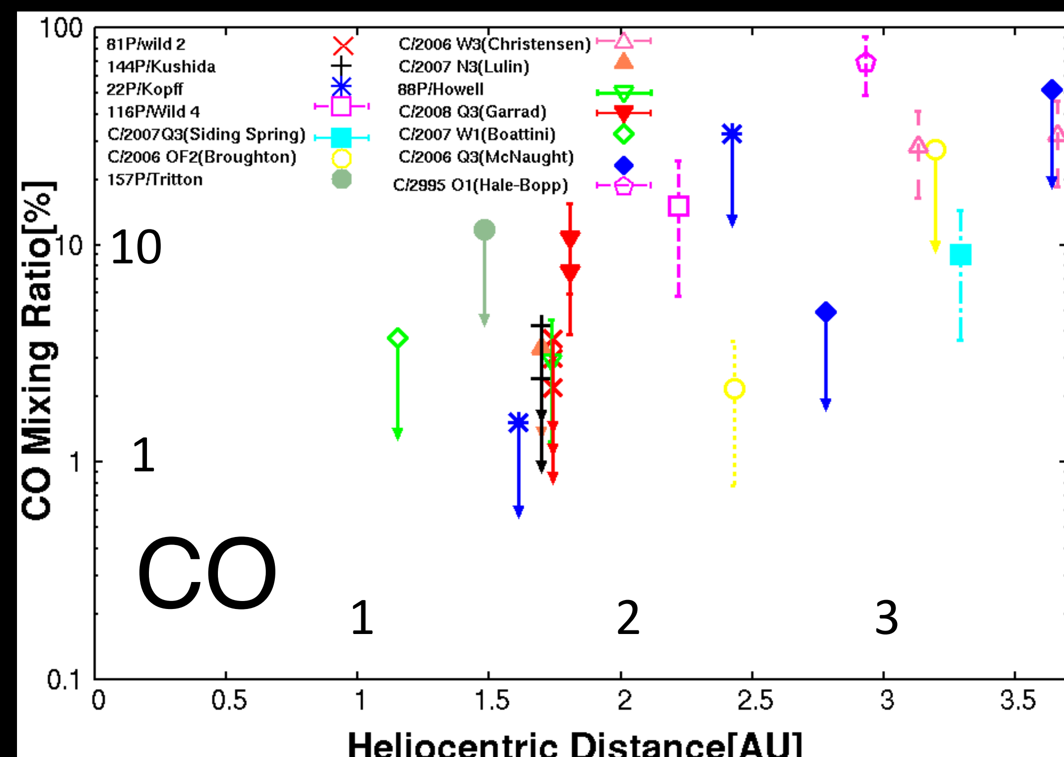
Ices (volatiles) in Comets

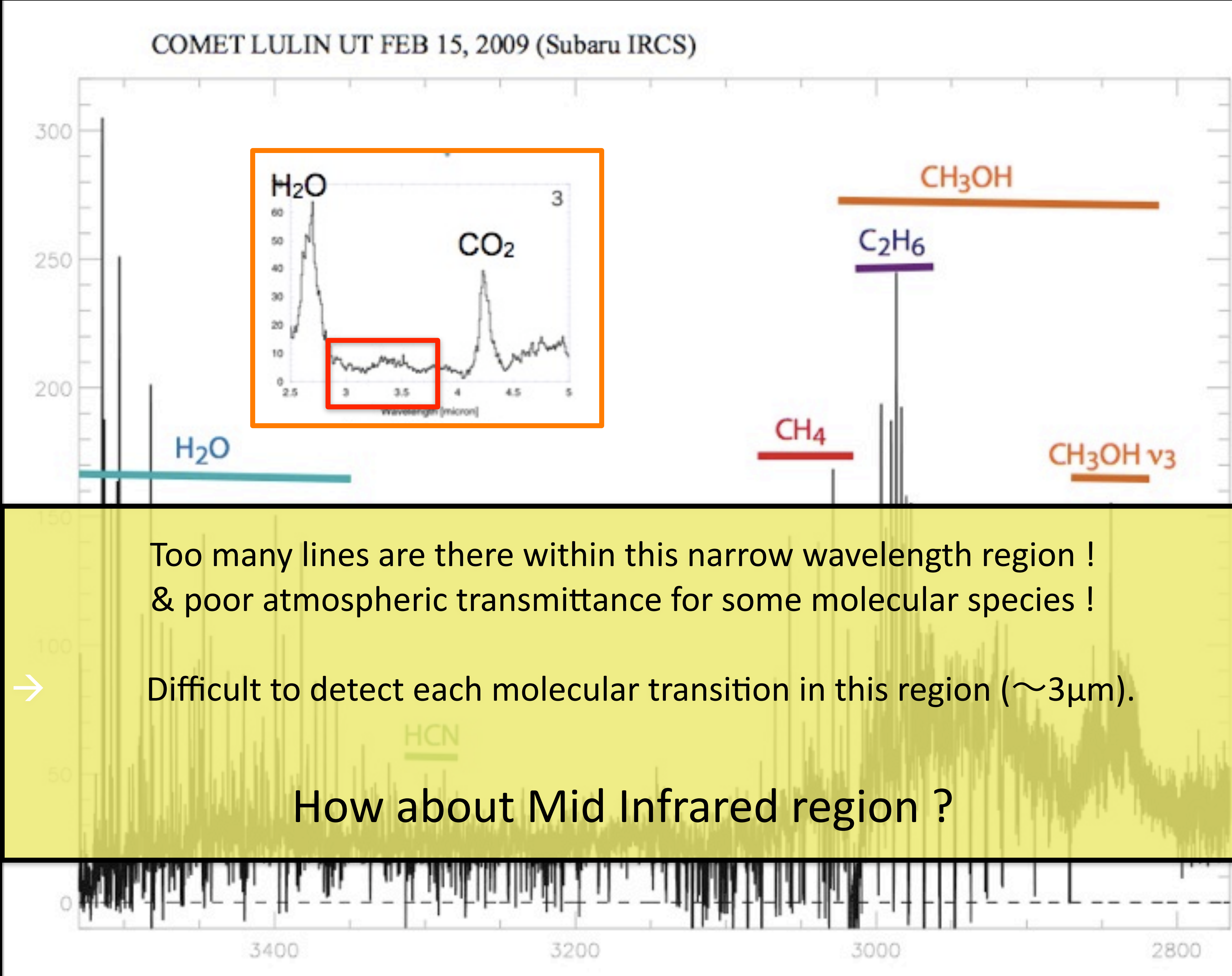
result of AKARI observations
13 comets by NG spectroscopy
4--5 micron --> CO, CO_2



simultaneous observation
at r < 2 AU is needed





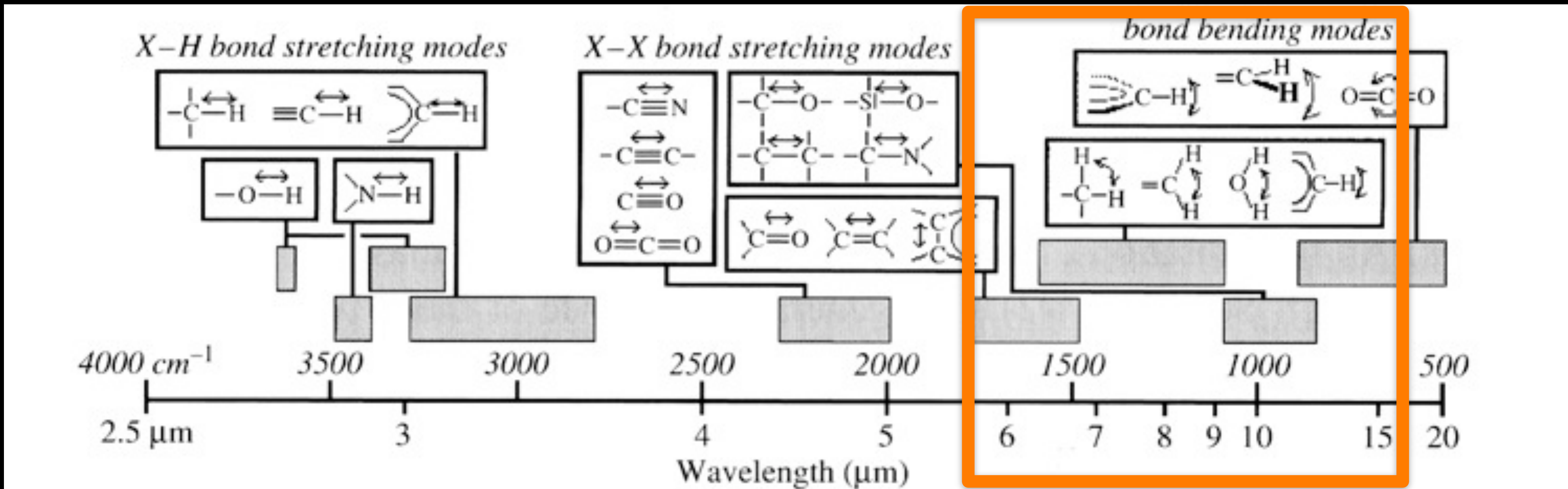


Too many lines are there within this narrow wavelength region !
& poor atmospheric transmittance for some molecular species !

→ Difficult to detect each molecular transition in this region (～3μm).

How about Mid Infrared region ?

Mid Infrared region



Tielens (2005)

Mid-infrared region --- Very fruitful region for organic molecules !!

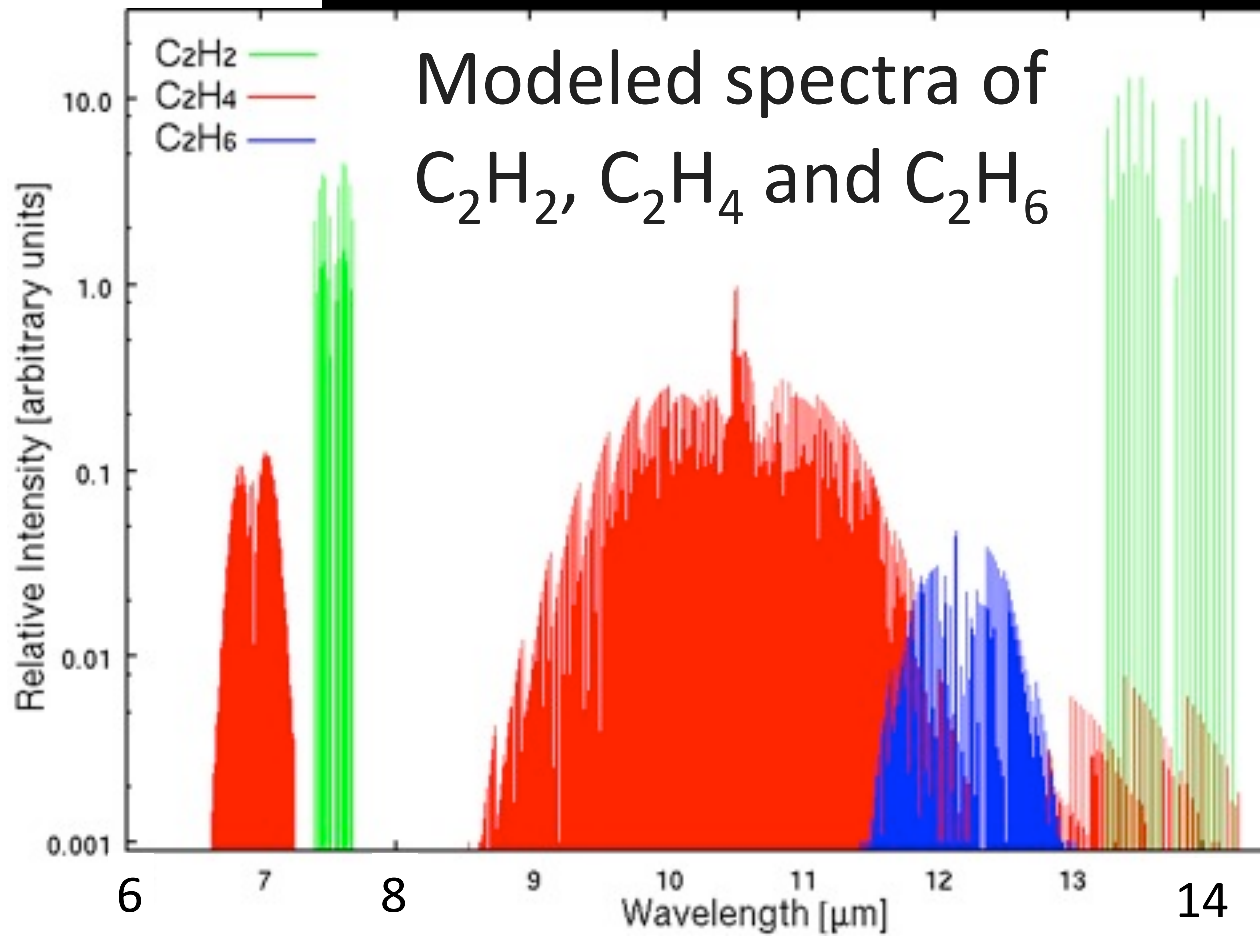
Examples of C – C molecules : C_2H_2, C_2H_6, **C_2H_4 (?), C_3H_8(?)** …

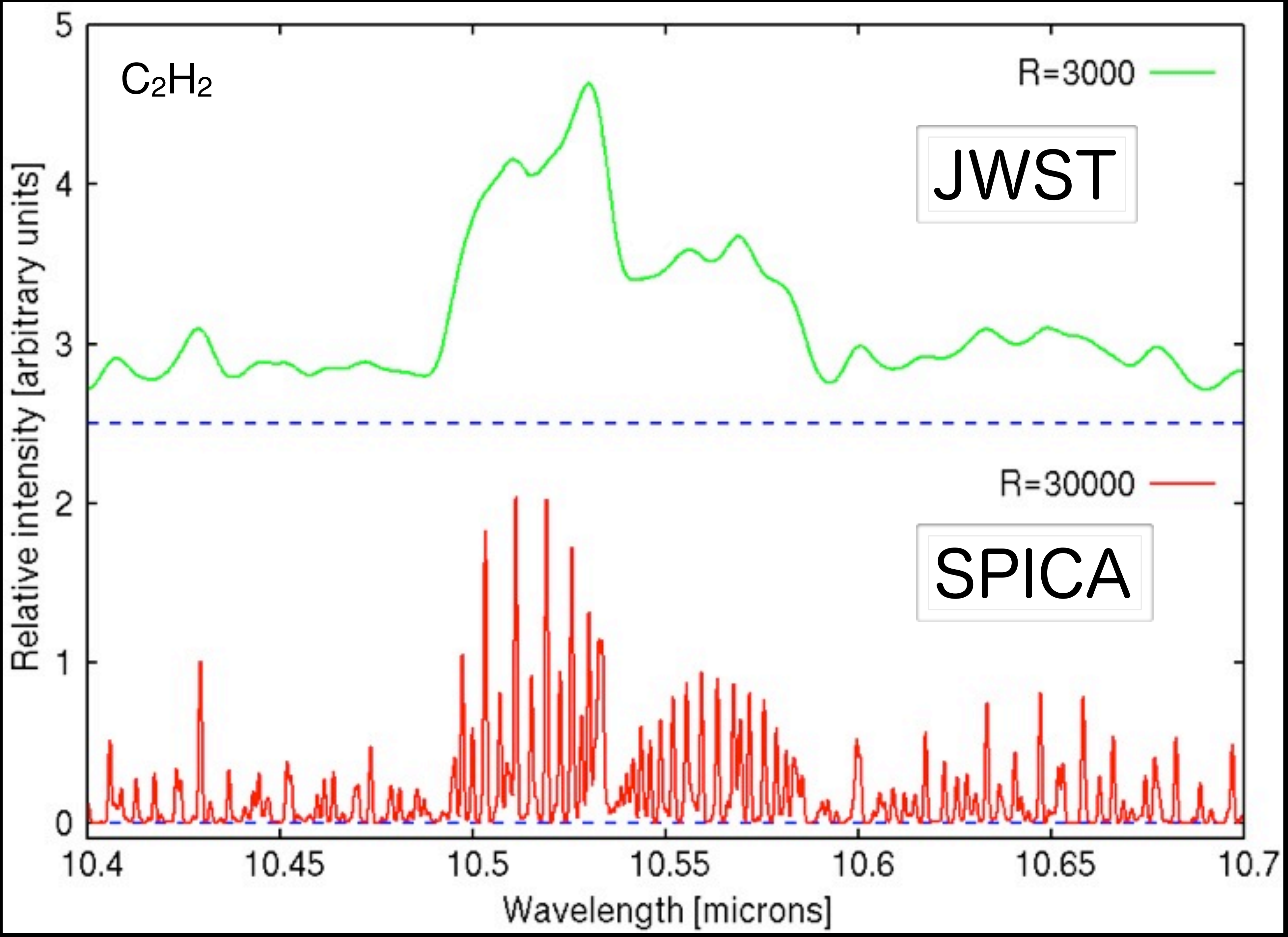
For example, C_2H_4 and C_3H_8 have not been detected in comet (3µm region).

Detections of these molecules will give precious clues to understanding chemical evolution of hydrocarbon molecules in the solar nebula.

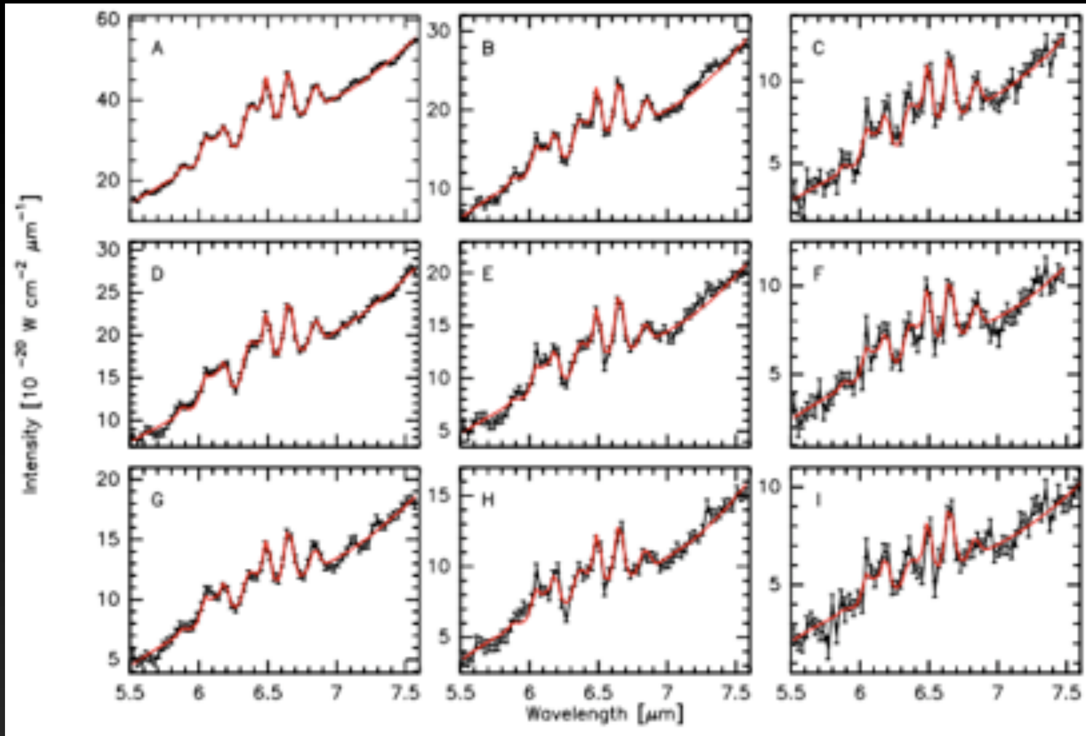
Table 3: Fingerprint region.

Group	Bond	range/μm	
amine	N-H bend	6.1–6.4	
amine	C-N stretch	7.4–9.8	
amide	N-H bend	6.3–6.7	
amide	C-N stretch	7.1–7.1	
nitro	N=O	6.4–6.7	2 peaks
nitro	N=O	7.3–7.7	2 peaks
alcohol	C-O stretch	8.7–9.5	
phenol	C-O stretch	7.5–7.2	2 peaks
		7.9–8.5	
ether	C-O stretch	8.7–9.3	symmetrical (R-O-R)
	C-O stretch	7.8–8.3	unsymmetrical (R-O-R'),
		9.3–9.8	2 peaks
acid	C-O stretch	7.6–8.3	
ester	C-O stretch	7.8–9.8	
alkene	C-H bending:		
	R-CH=CH2	10.1–10.2	2 peaks
	R-CH=CH2	10.9–11.0	
	R2C=CH2	11.1–11.4	
	R-CH=CH-R (Z)	13.1–13.7	
	R-CH=CH-R (E)	10.1–10.4	
	R2C=CH-R	11.9–12.7	
aromatic	C-H bending:		
	monosubstituted	13.0–13.7	2 peaks
	monosubstituted	14.1–14.5	
	disubstituted:		
	1,2 (ortho)	13.0–13.6	
	1,3 (meta)	12.3–13.3	2 peaks
	1,3 (meta)	13.8–14.7	
	1,4 (para)	11.9–12.7	
alkyne	C-H	14.3–16.4	
halides	C-Cl	11.8–18.2	
	C-Br	14.5–19.4	
	C-I	16.7–20.0	





C2H2
R=3000
JWST
R=30000
SPICA
Relative intensity [arbitrary units]
Wavelength [microns]
5
4
3
2
1
0
10.4
10.45
10.5
10.55
10.6
10.65
10.7



C/2003 K4(LINEAR) by Spitzer/IRS
(Woodward et al. 2007)

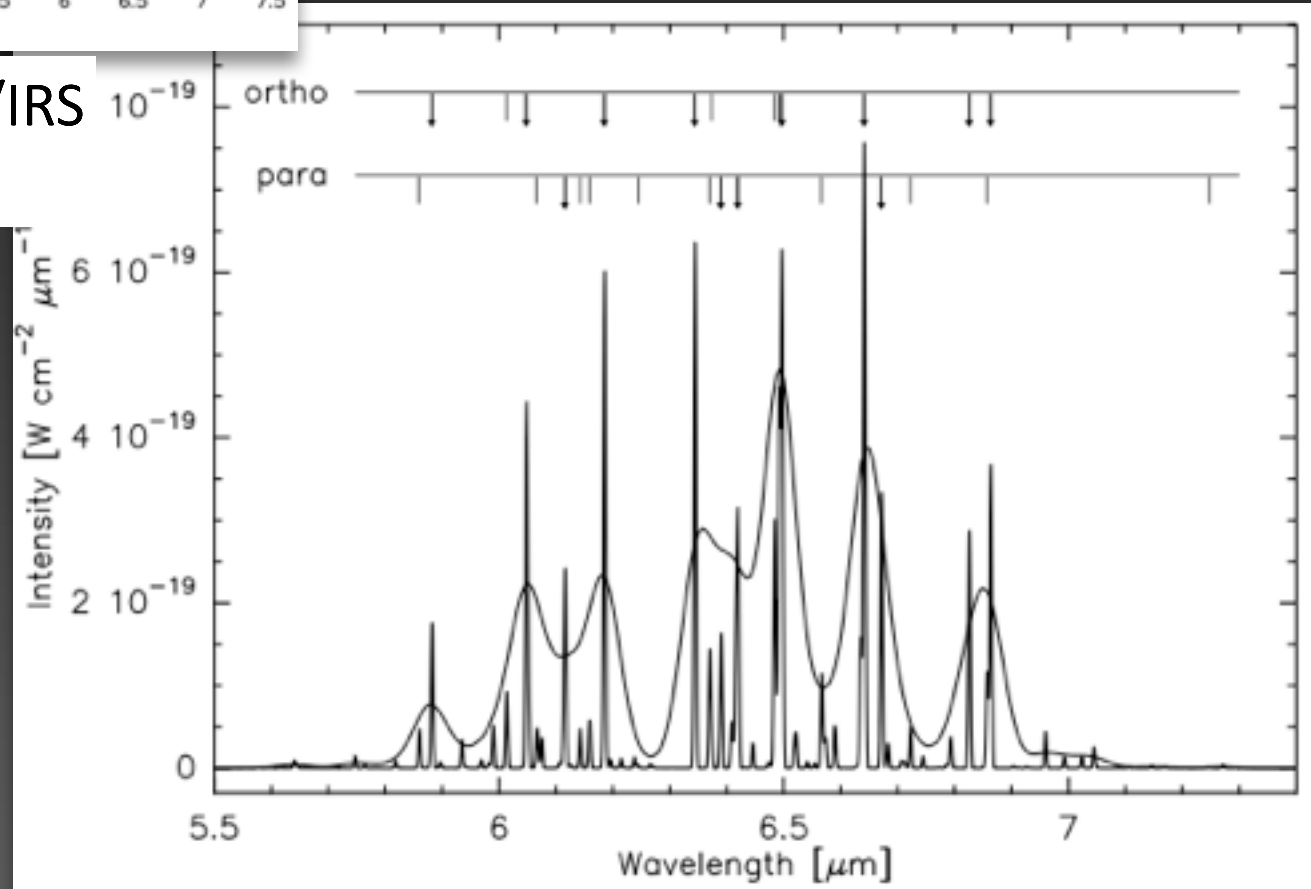
Water (essential)

6--7μm; R ~ 1000--1500

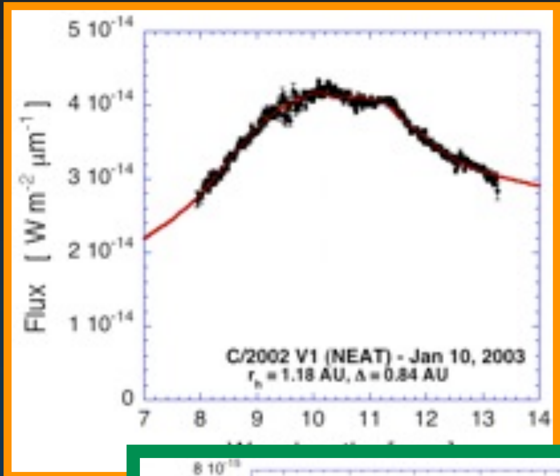
rotation temperature
ortho/para ratio

for parent molecules
near-IR (2--5 micron)
is better

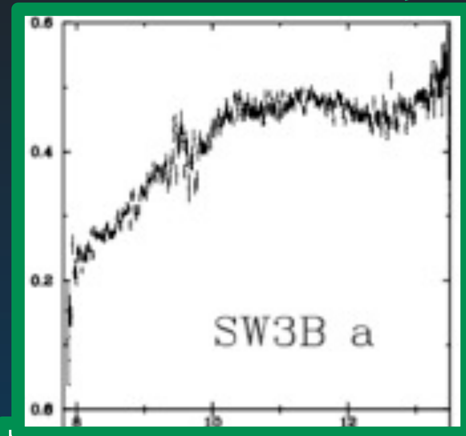
4--8 micron
R>10,000
are highly desired

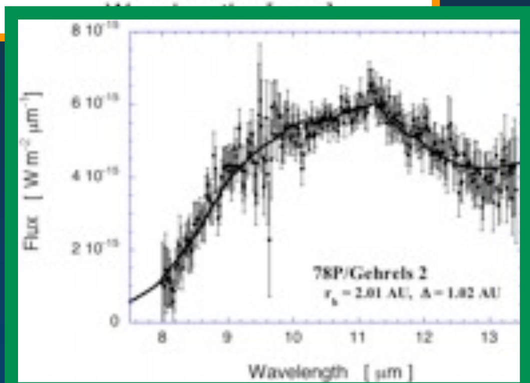


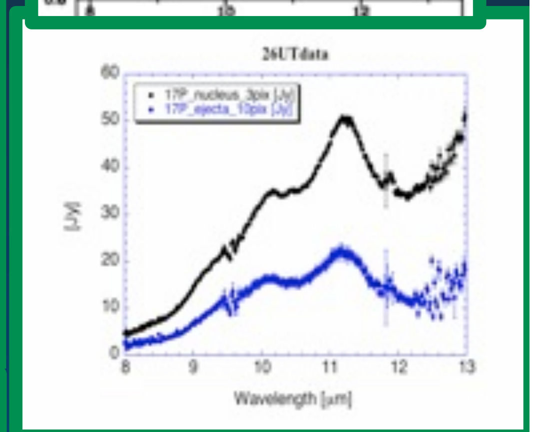
Oort cloud comets

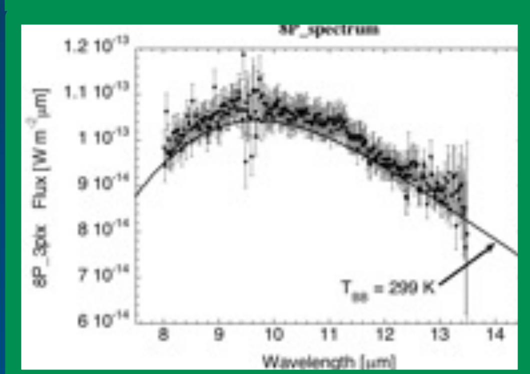


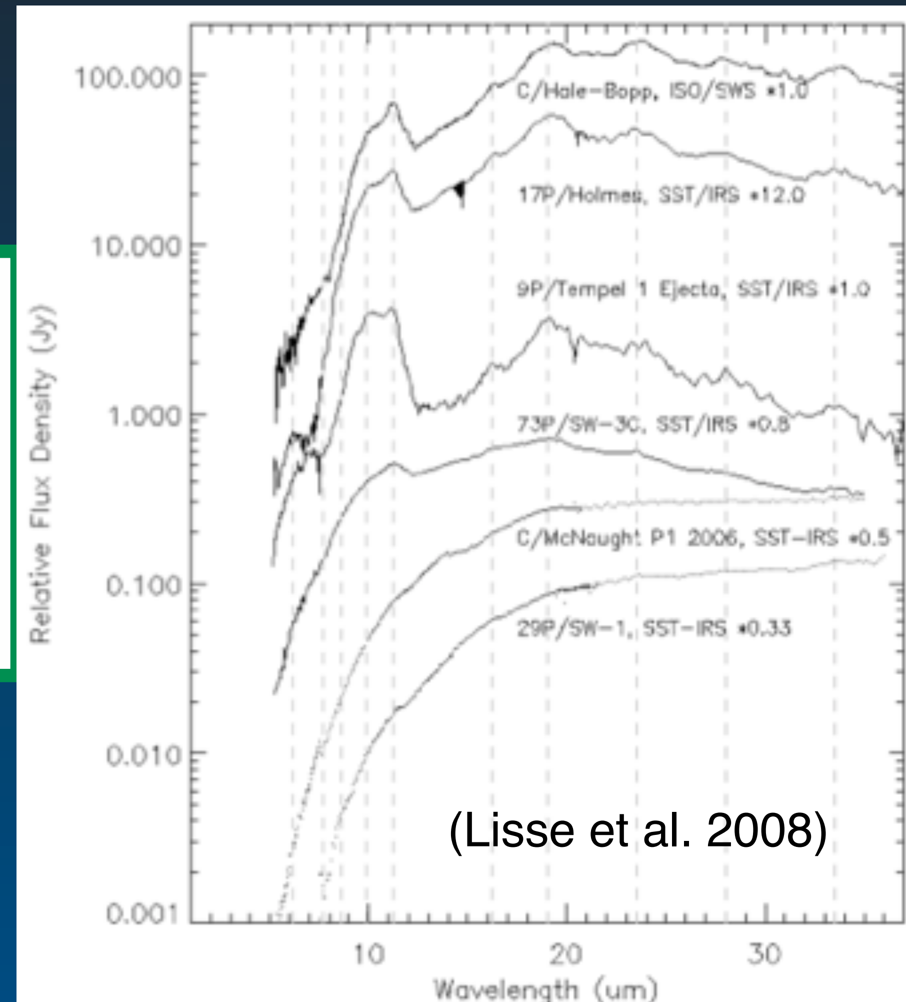
active Jupiter family comets











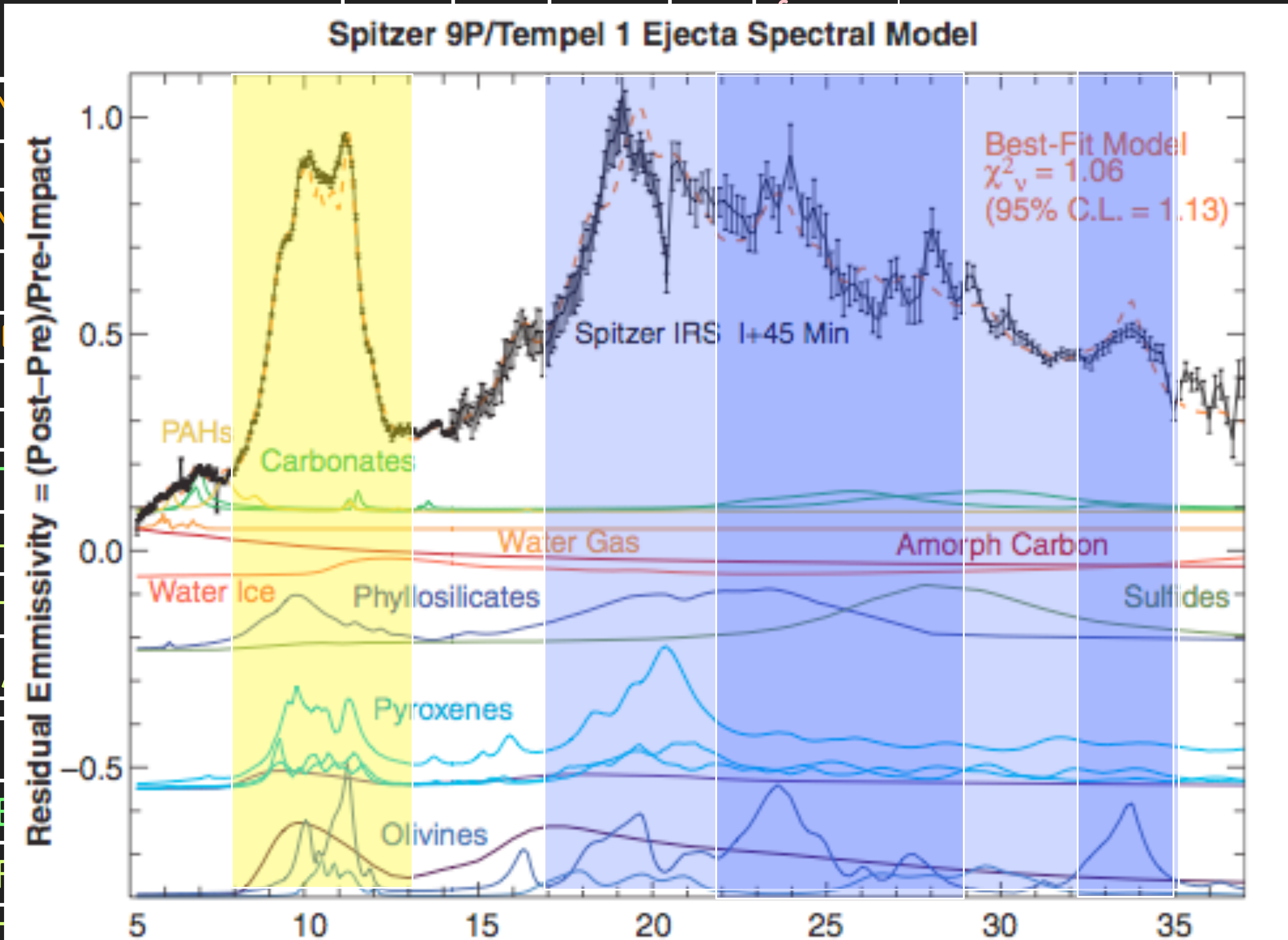
Jupiter family comets

crystalline-to-amorphous silicate ratio

silicate feature strength

→ orbital parameters?

Q4 N
V1 N
Hale-
9P/T
73P-
73P-
17P/
78P
2P/E
4P/F
8P/T



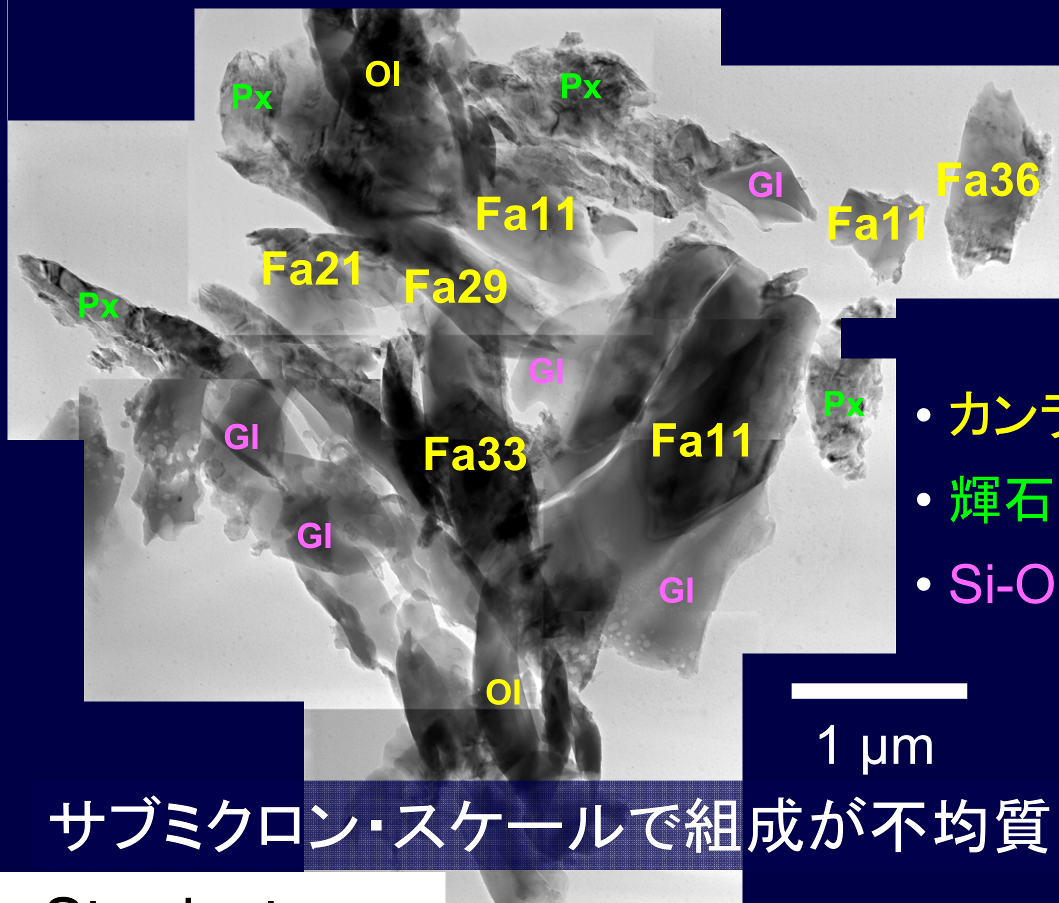
(Lisse et al. 2006)

9P

サンプルリターン

C2115-24-22-1-8

Tomeoka et al. 2008

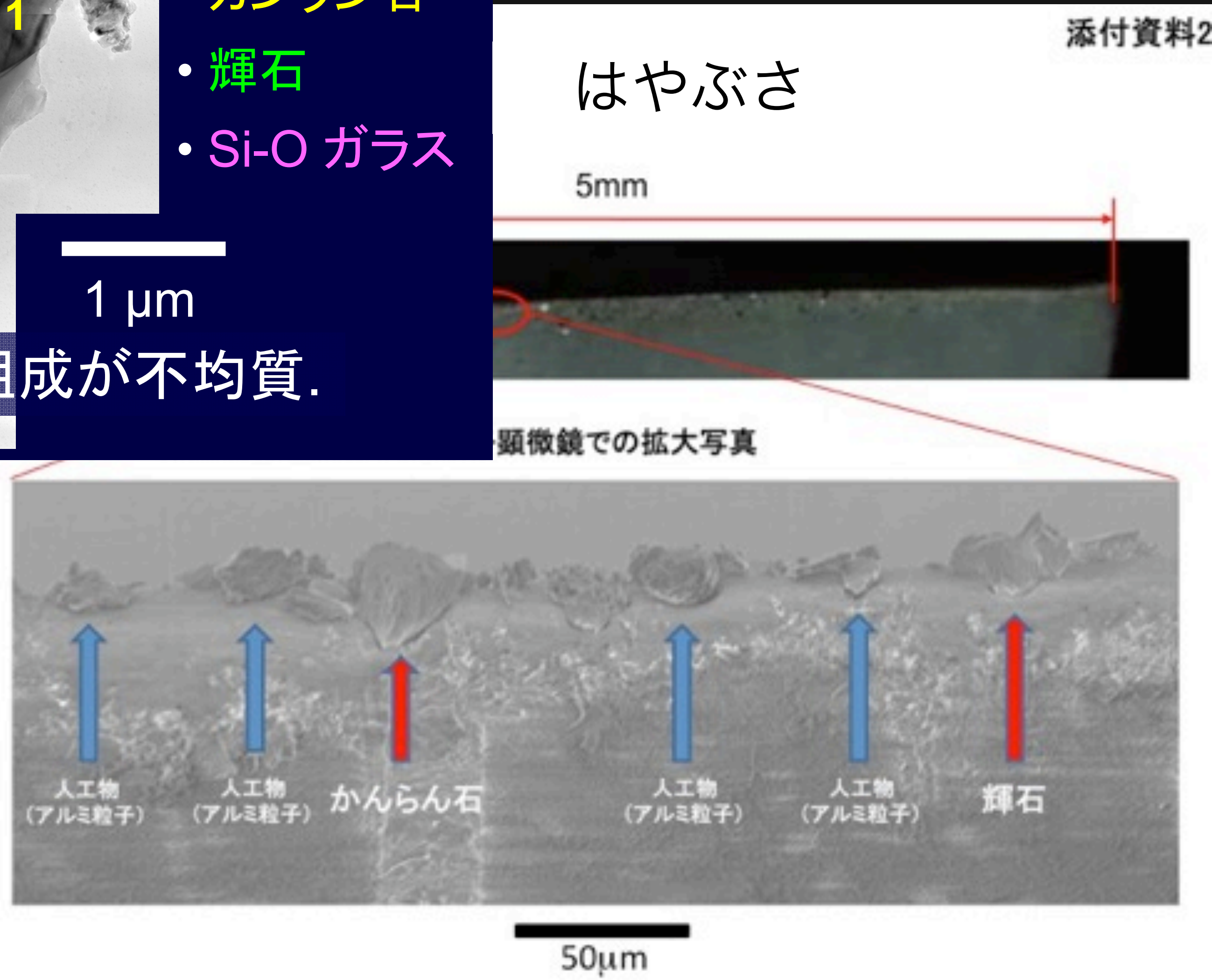


- カンラン石
- 輝石
- Si-O ガラス

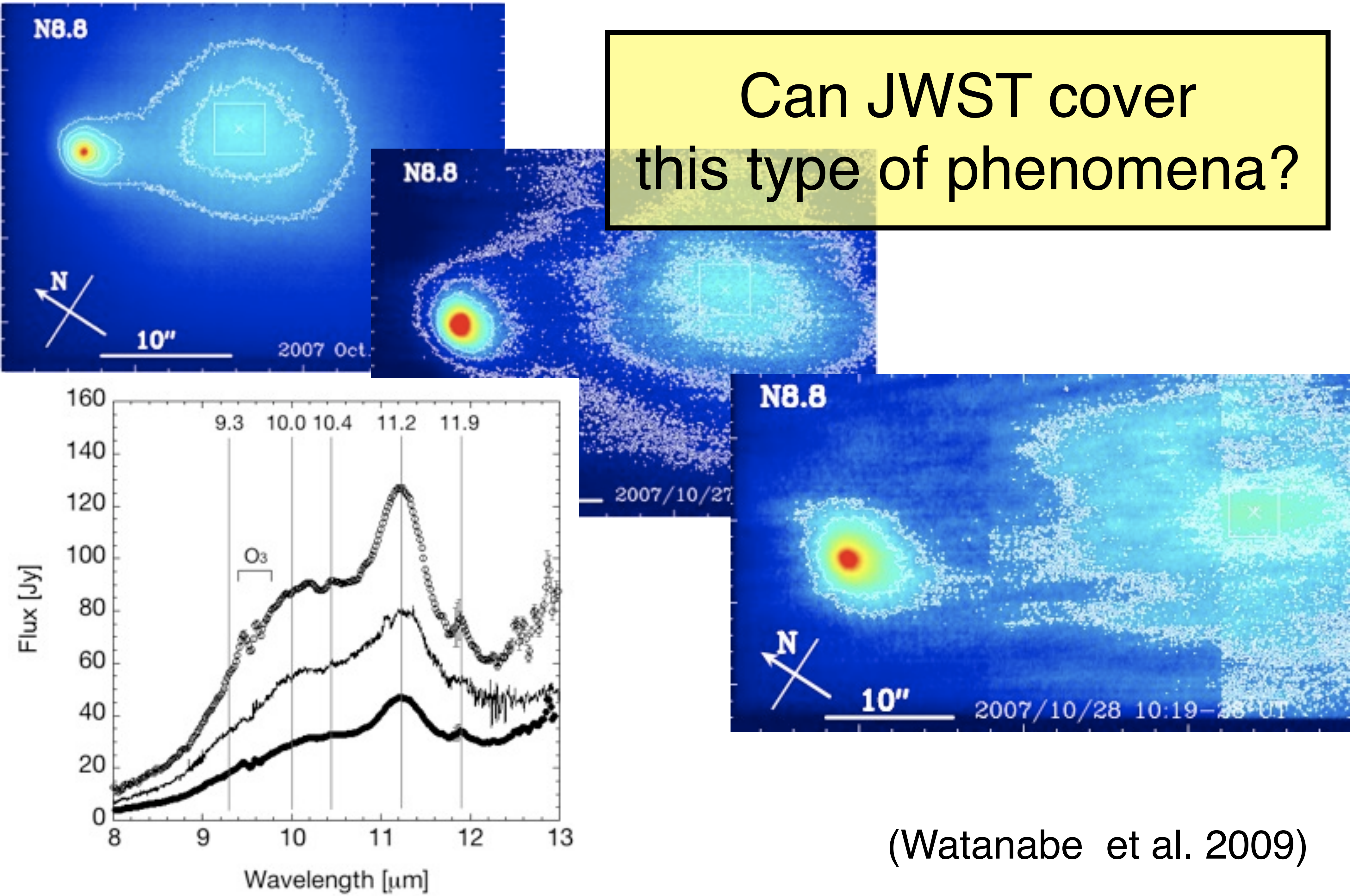
サブミクロン・スケールで組成が不均質.

Stardust

Comet 81P/Wild



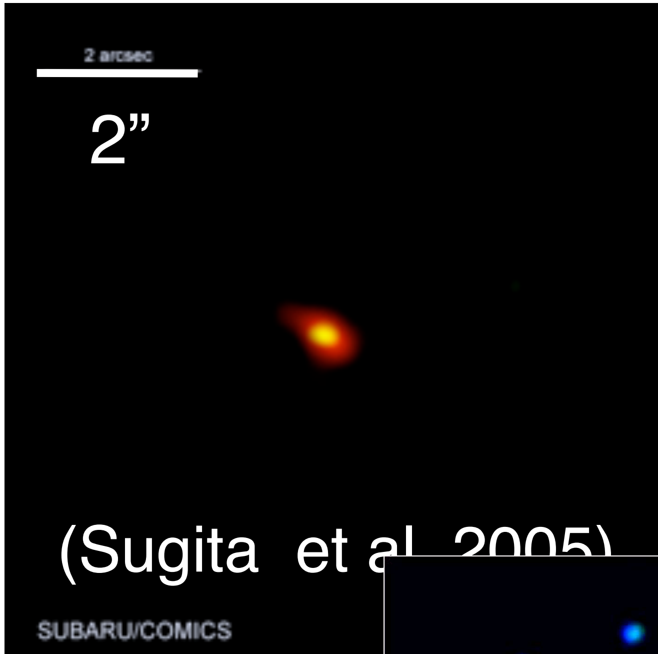
Detached Dust Cloud of 17P/Holmes

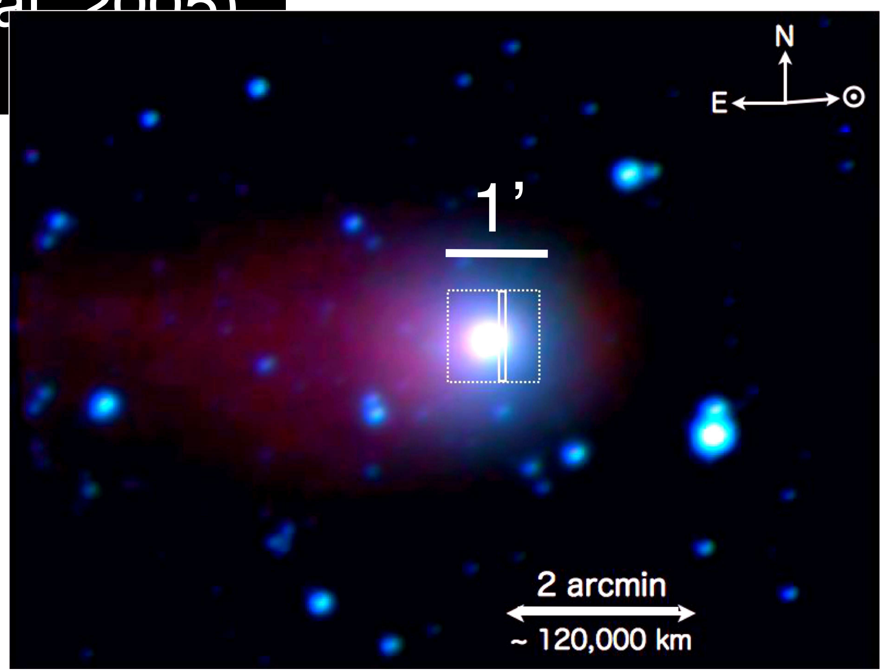


Can JWST cover this type of phenomena?

(Watanabe et al. 2009)

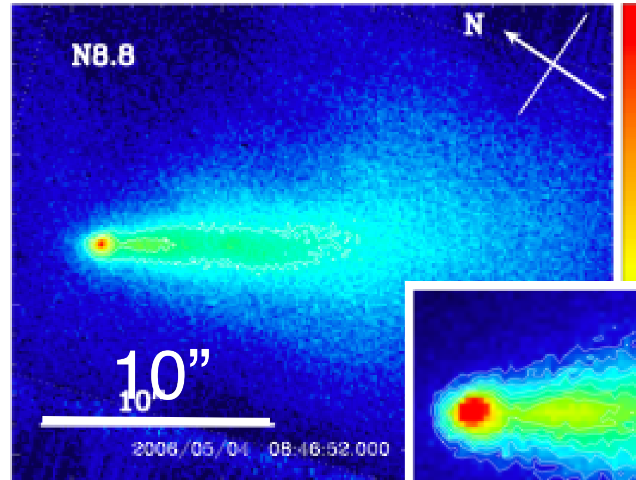
9P/Temple Deep Impact

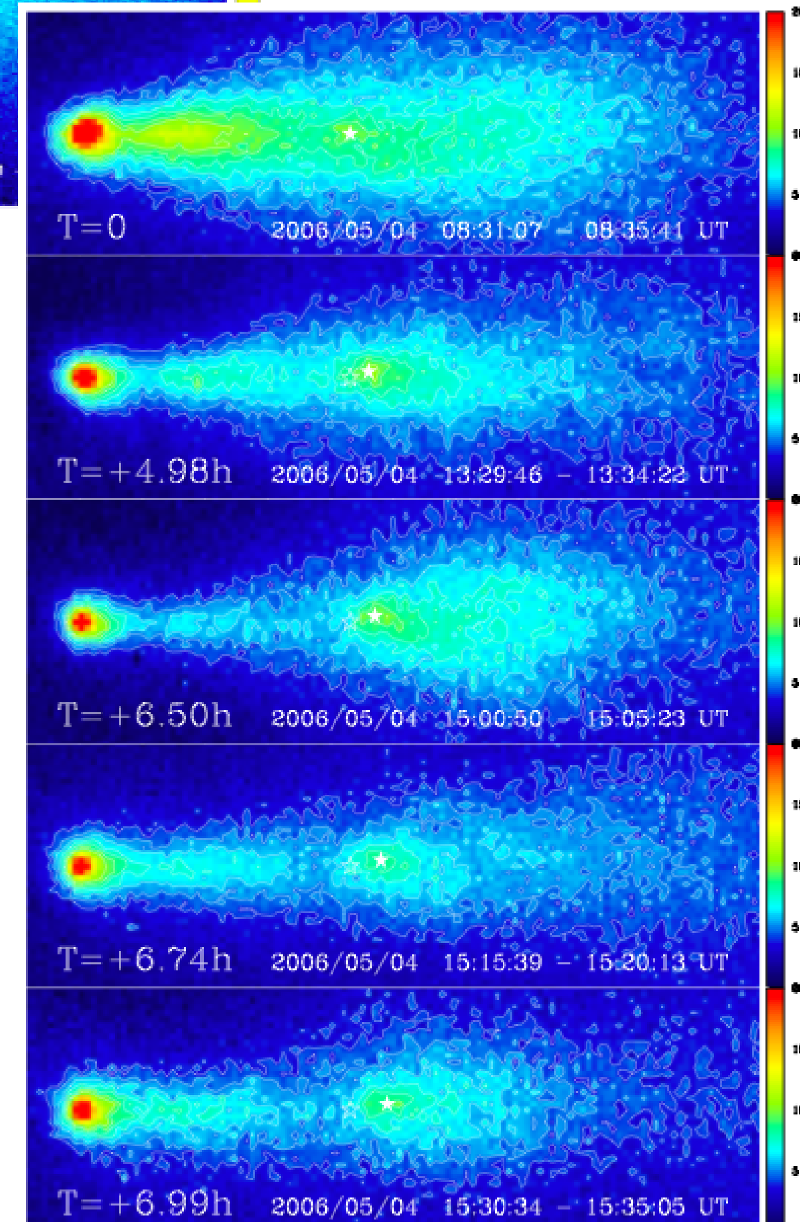


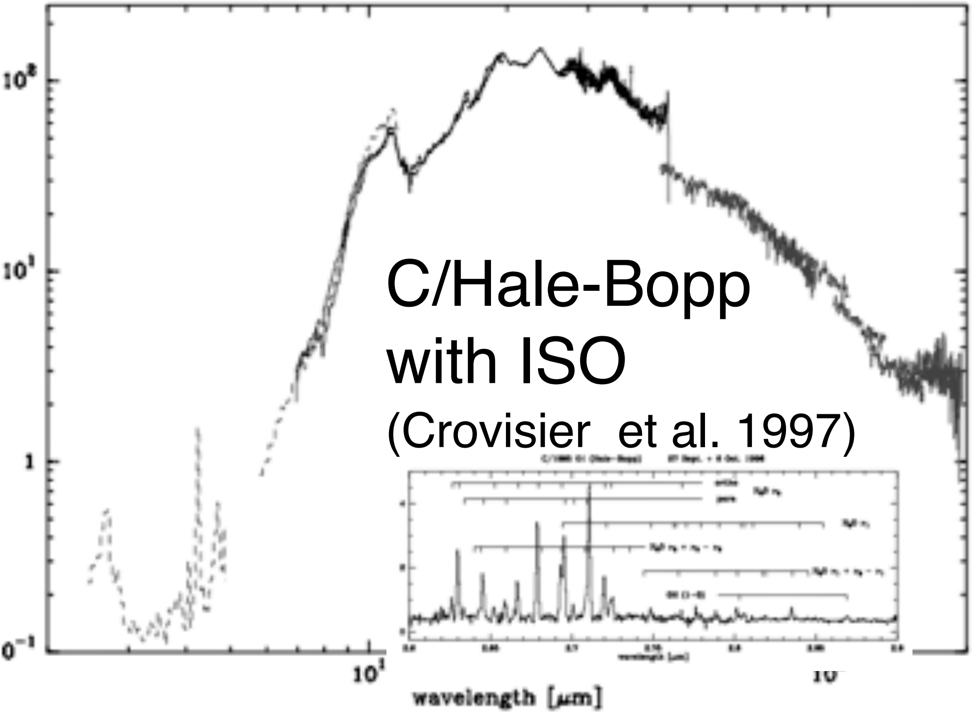


LRS with slit length > 30”
(& non-sidereal tracking) is desirable

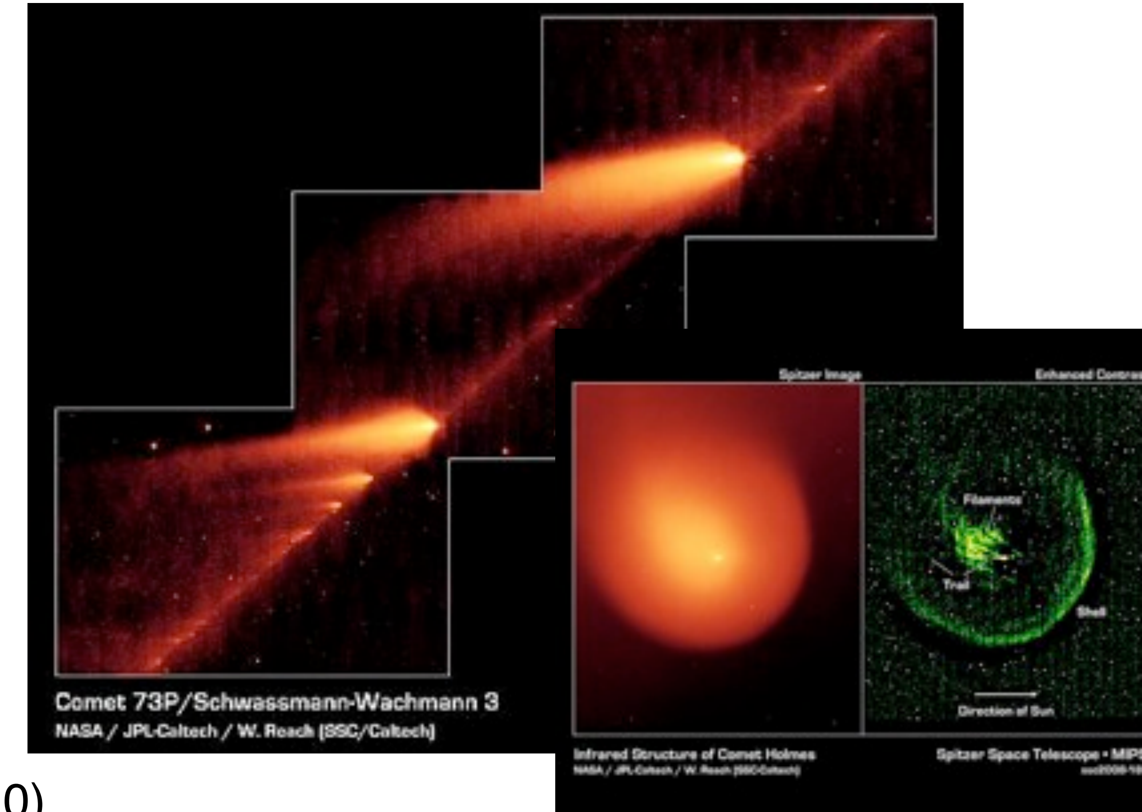
73P/SW3 B fragmentation





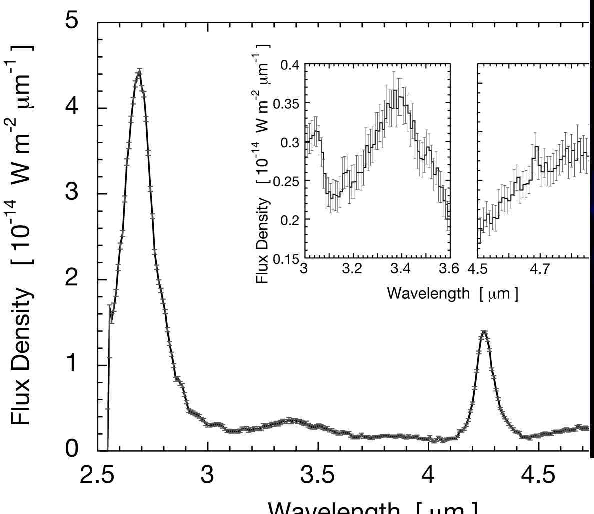


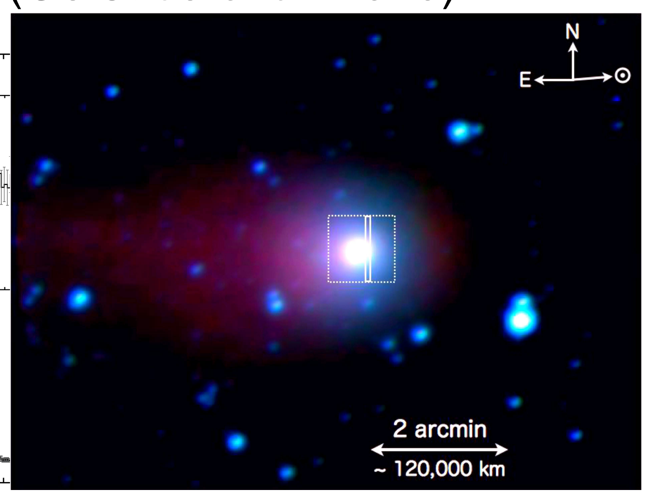
C/Hale-Bopp
with ISO
(Crovisier et al. 1997)

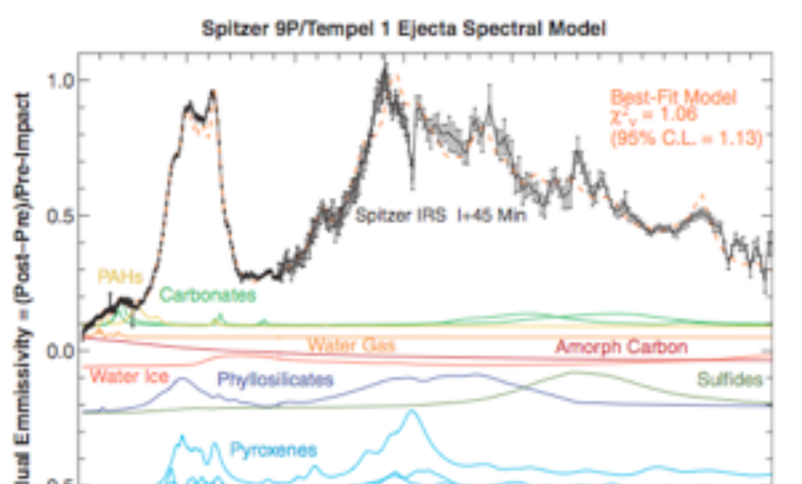


9P & 73P & 17P
with Spitzer
(Lisse et al. 2006;
Reach et al. 2009, 2010)

C/Lulin with AKARI (Ootsubo et al. 2010)







SSSBs are capricious ... not us

both JWST & SPICA are important

Summary of SSSBs science

- Ice, dust, and organics of the small solar system objects;

  - Ices (volatiles), dust, and organics study of correlation between the dynamical and physical properties for SSOs

(ices, organics)

  - CO_2, CO, CH_4 (alkanes), C_2H_4 (alkenes) + various organics
  - Water (Ice) is essential for the determination of mixing ratio
    - ➡ 4--8 micron is highly desired with R~30000 --> HRS-S
    - ➡ (pararell?) near-IR (2--5 micron) obs is still important because parent molecules can be detected easier --> FPC-S

(dust)

  - LRS is suitable.
  - Long slit or FOV (> 30 arcsec) with 5--35 micron is desirable

  - Systematic search of surface material for TNOs. Mid-IR spectroscopy (reflected light) together with far-IR with SAFARI