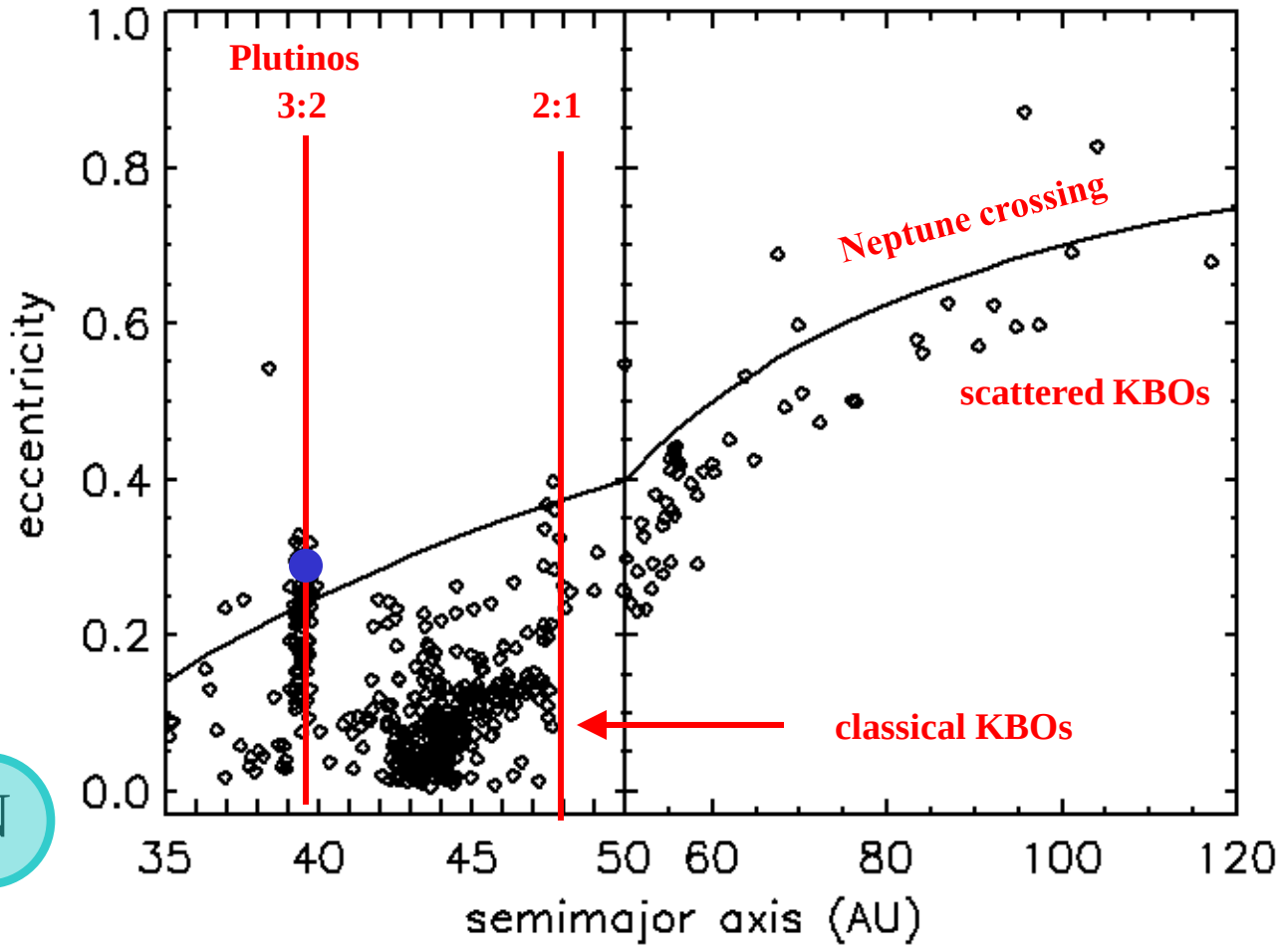
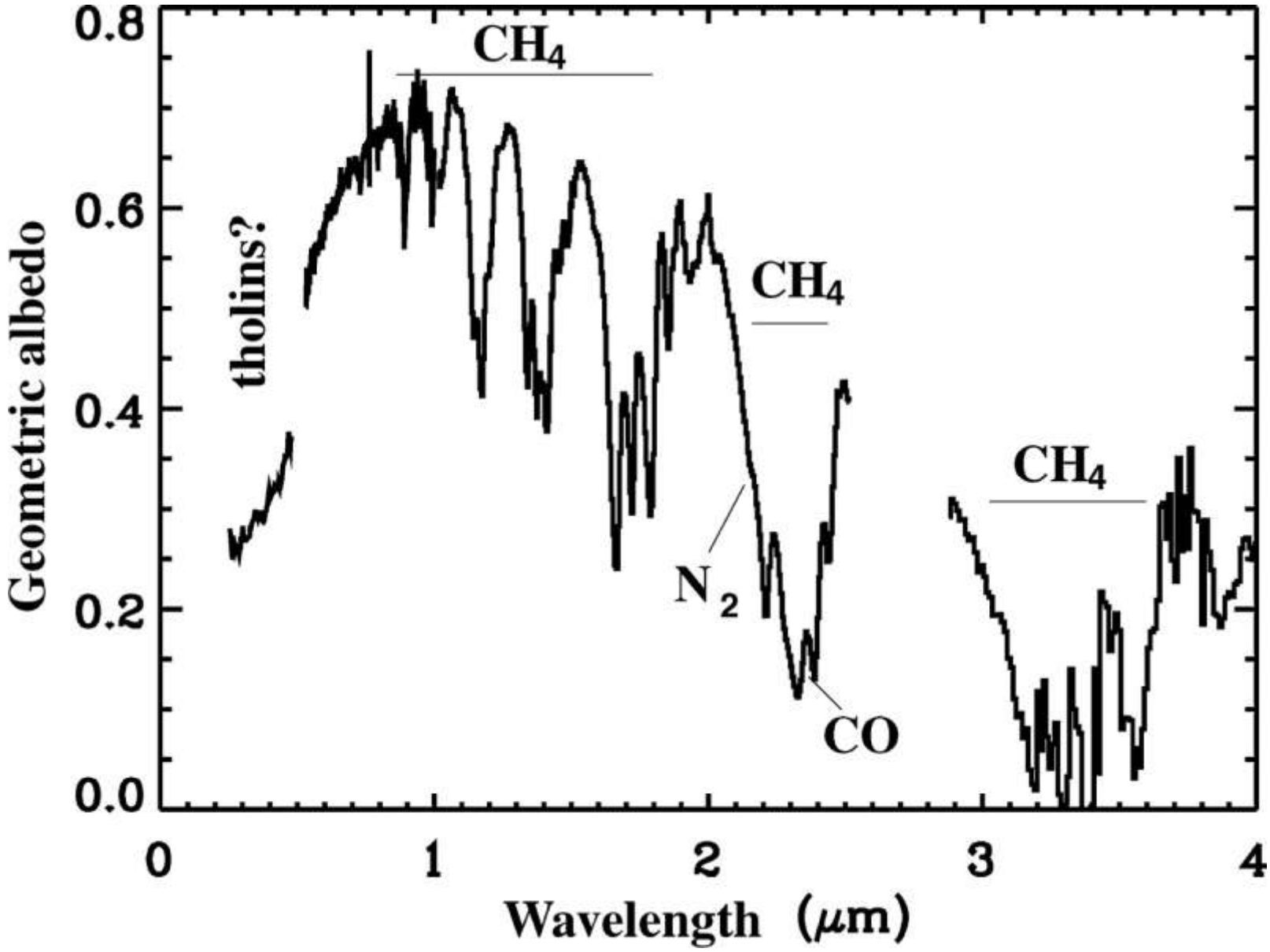
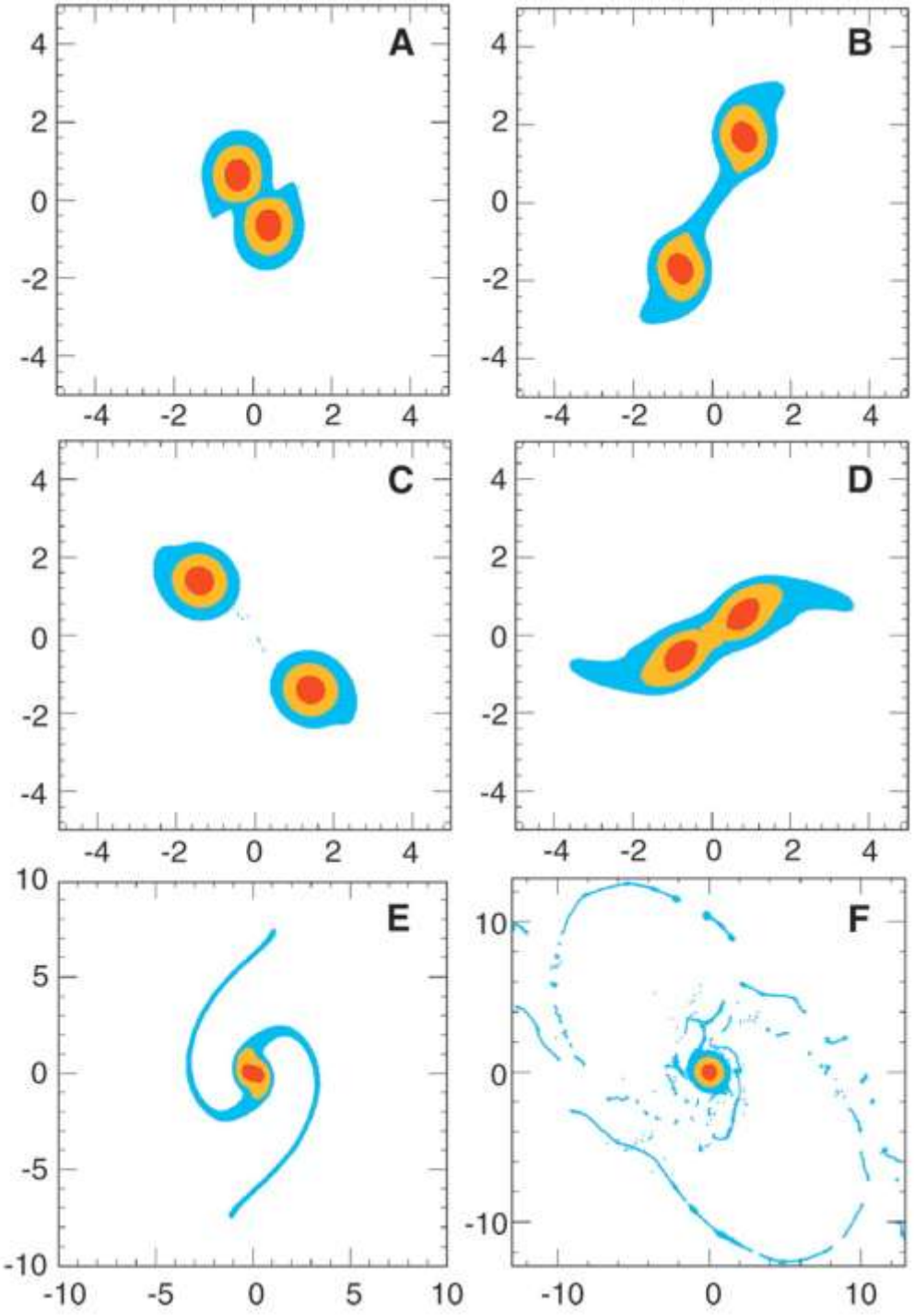
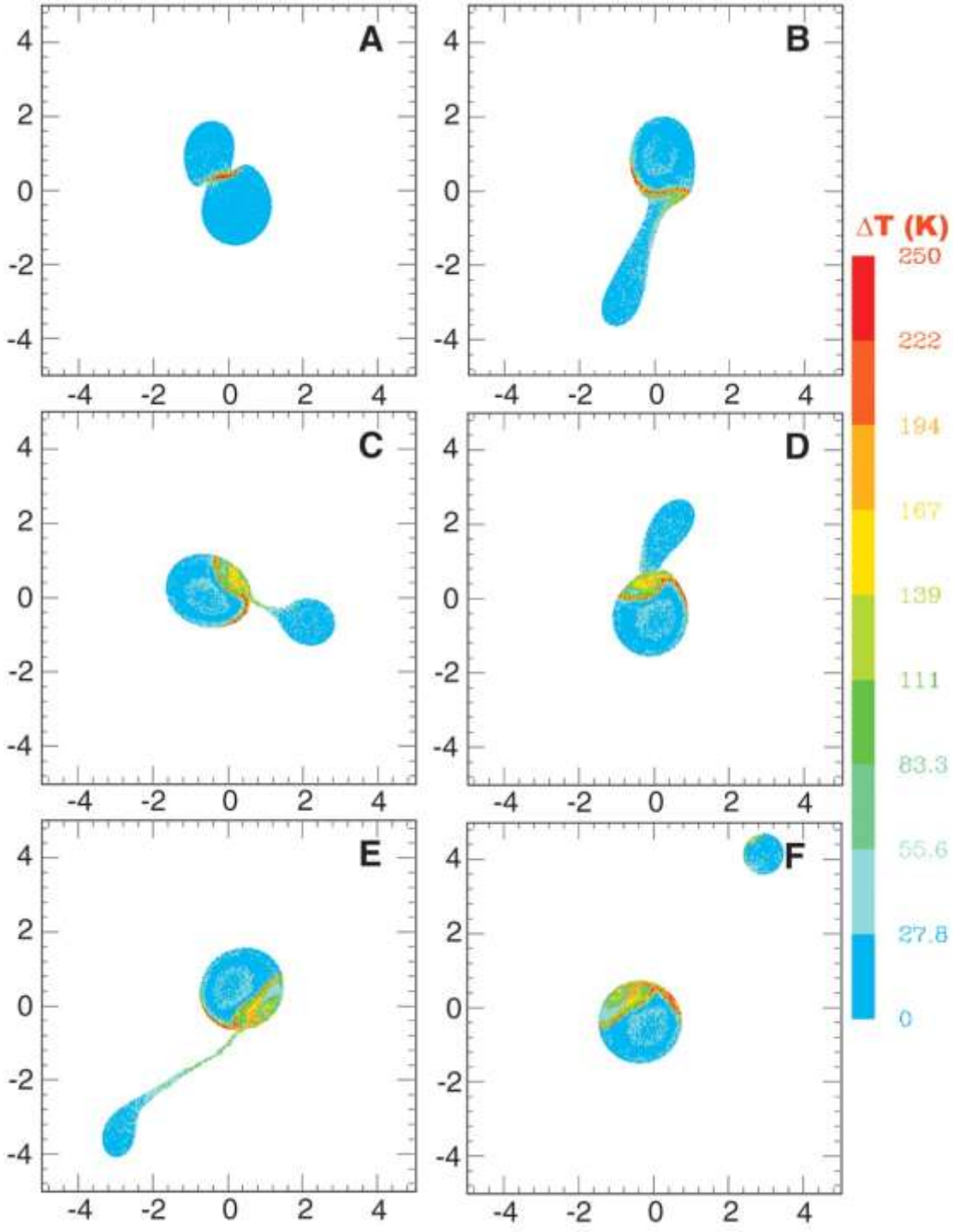
then….


Plutinos
3:2
2:1
Neptune crossing
scattered KBOs
classical KBOs
eccentricity
semimajor axis (AU)
1.0
0.8
0.6
0.4
0.2
0.0
35
40
45
50
60
80
100
120

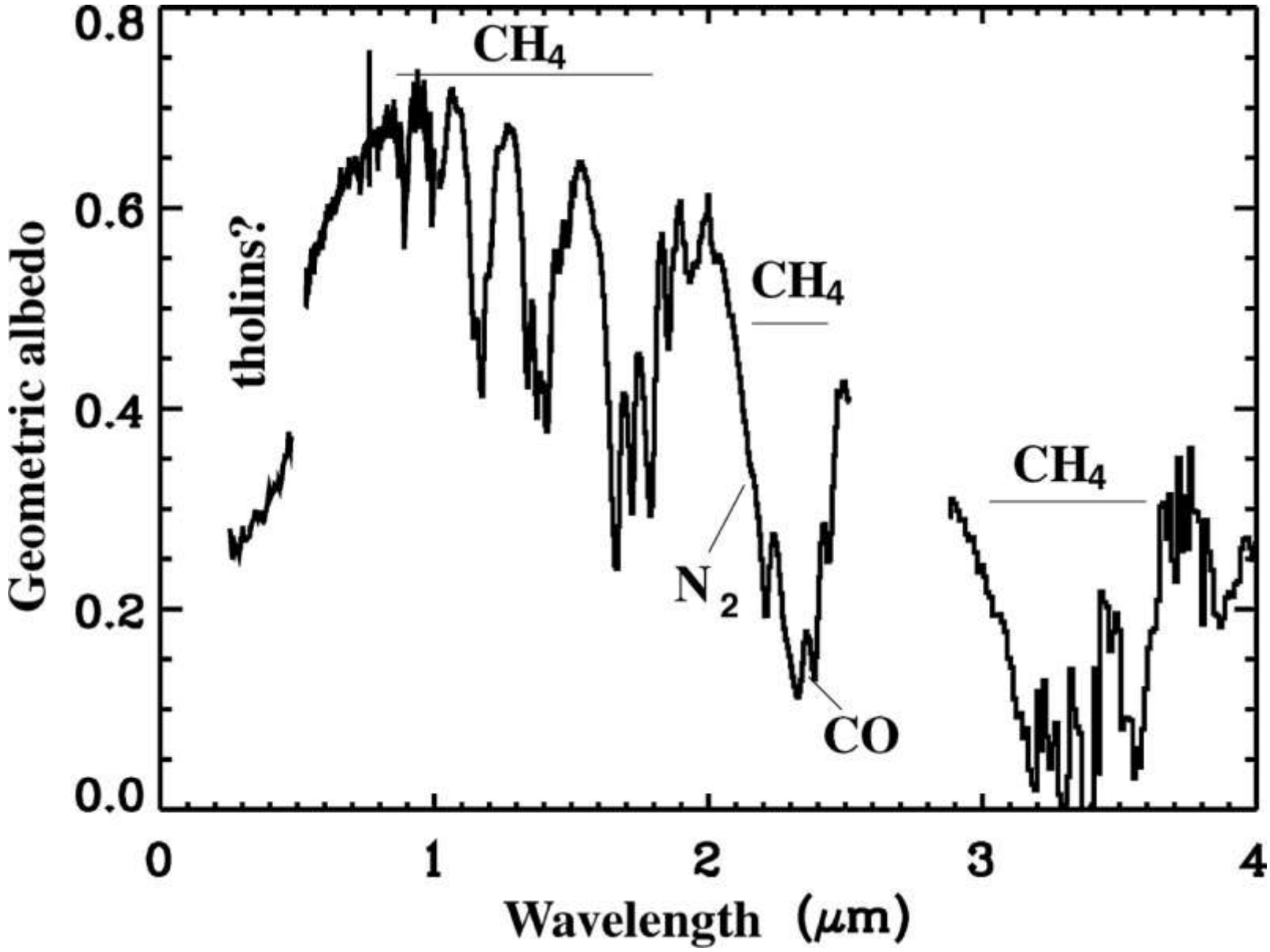

0.8
0.6
0.4
0.2
0.0
Geometric albedo
tholins?
CH4
CH4
CH4
N2
CO
0
1
2
3
4
Wavelength (μm)

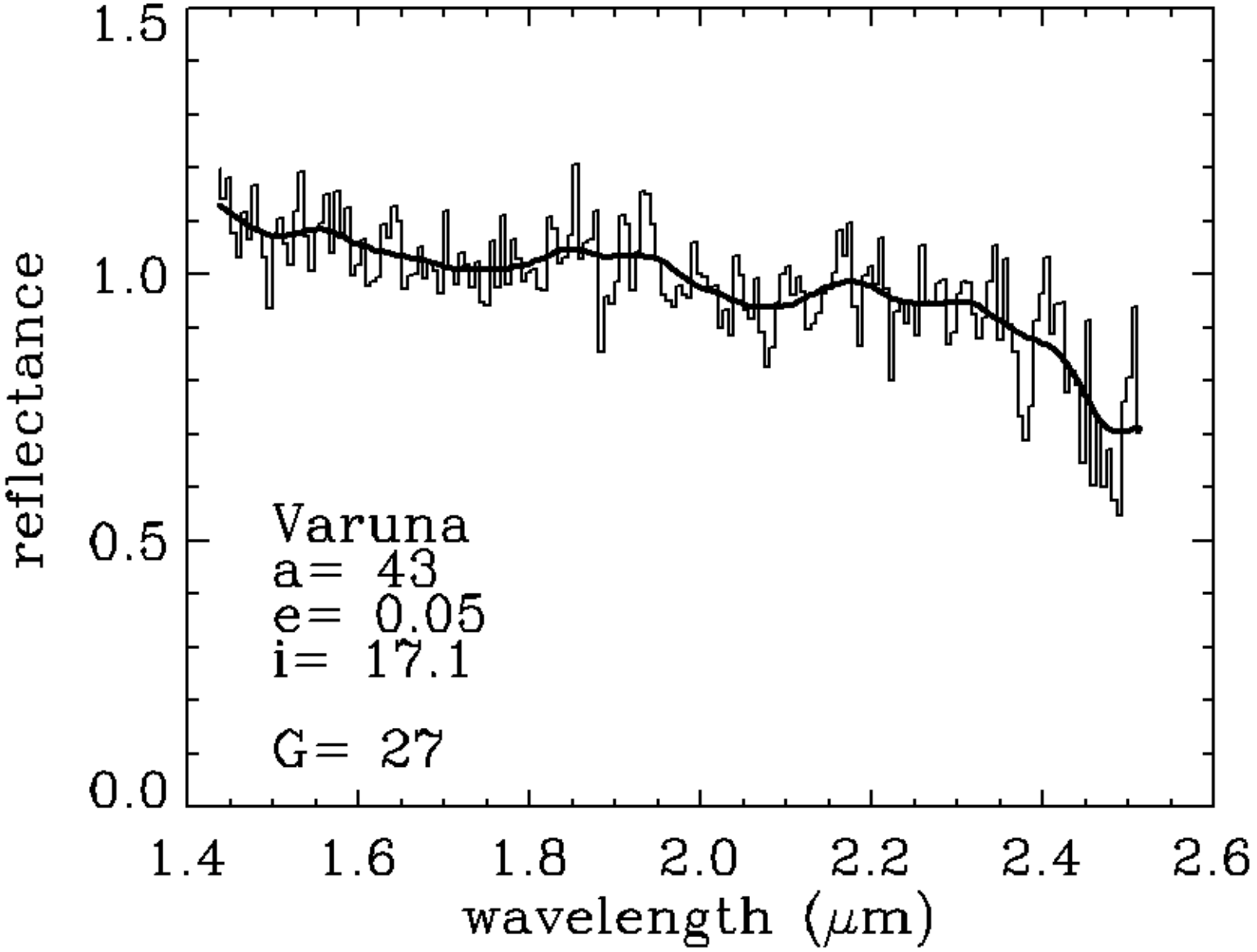


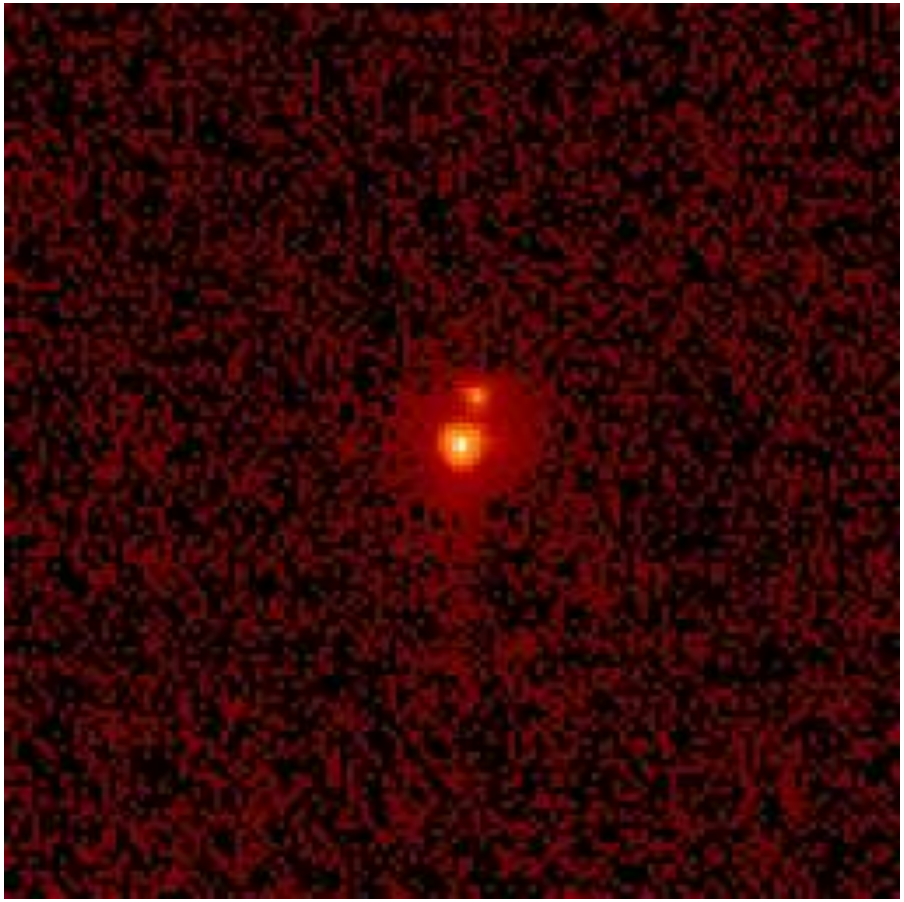
Canup 2005

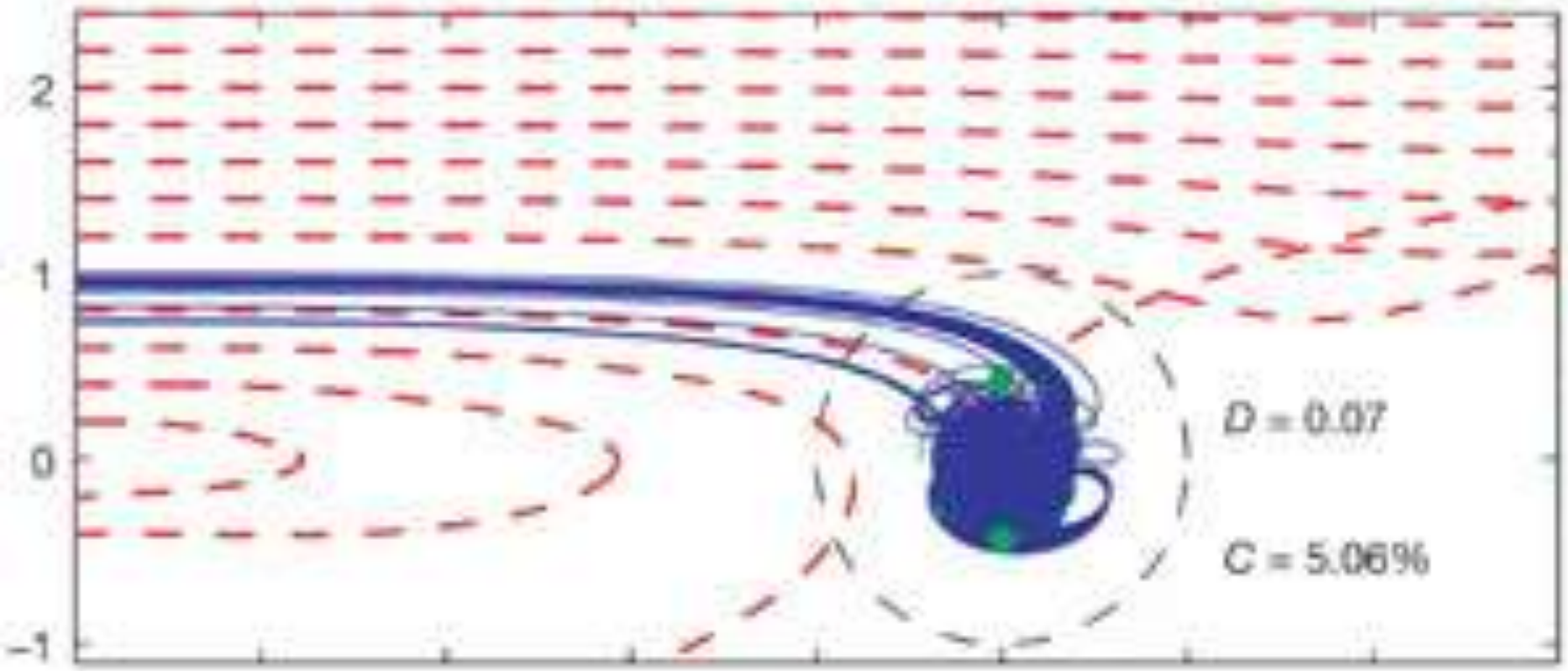


Canup 2005


0.8
0.6
0.4
0.2
0.0
Geometric albedo
tholins?
CH4
CH4
CH4
N2
CO
0
1
2
3
4
Wavelength (μm)

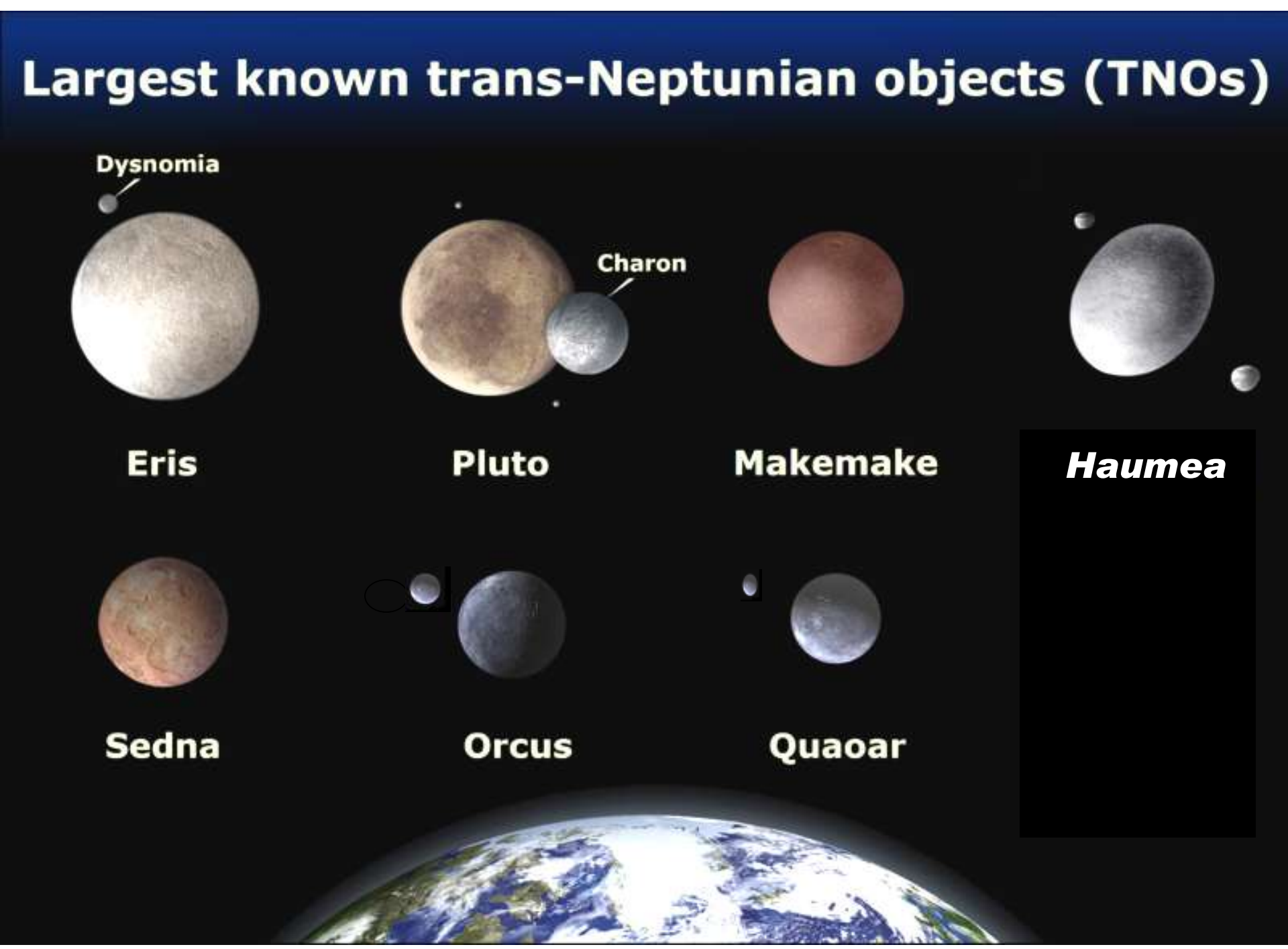

1.5
1.0
0.5
0.0
reflectance
Varuna
a= 43
e= 0.05
i= 17.1
G= 27
1.4
1.6
1.8
2.0
2.2
2.4
2.6
wavelength (μm)



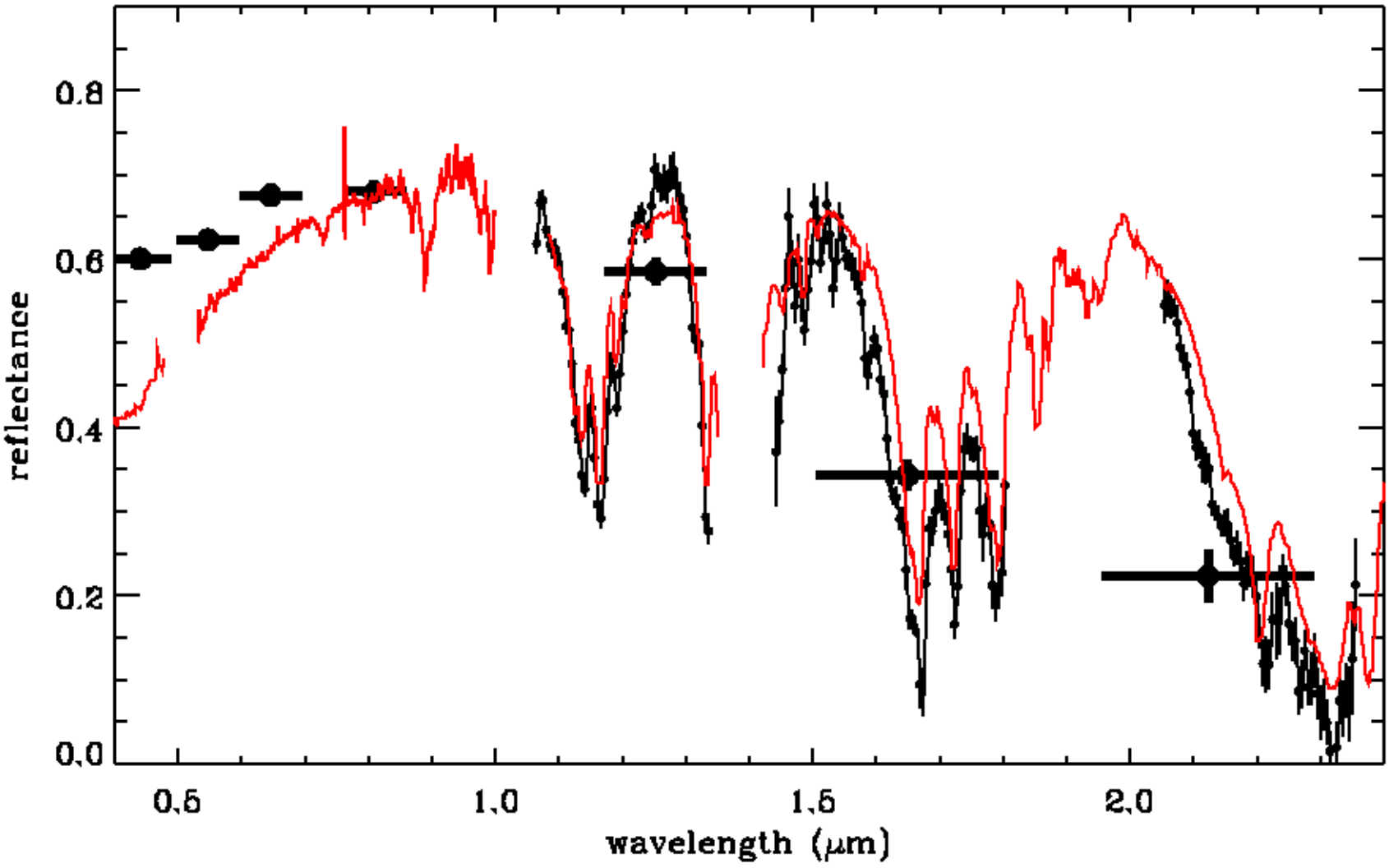


Goldreich et al.

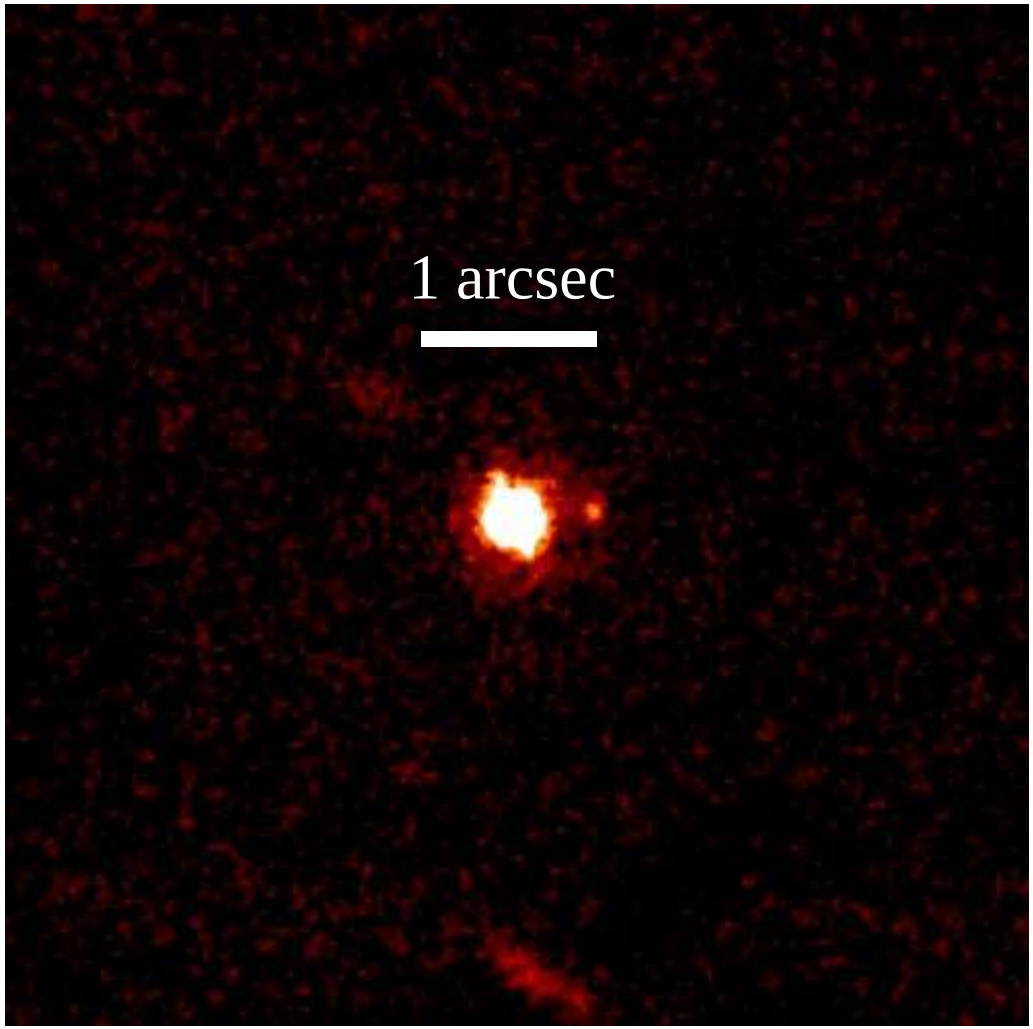
now…..

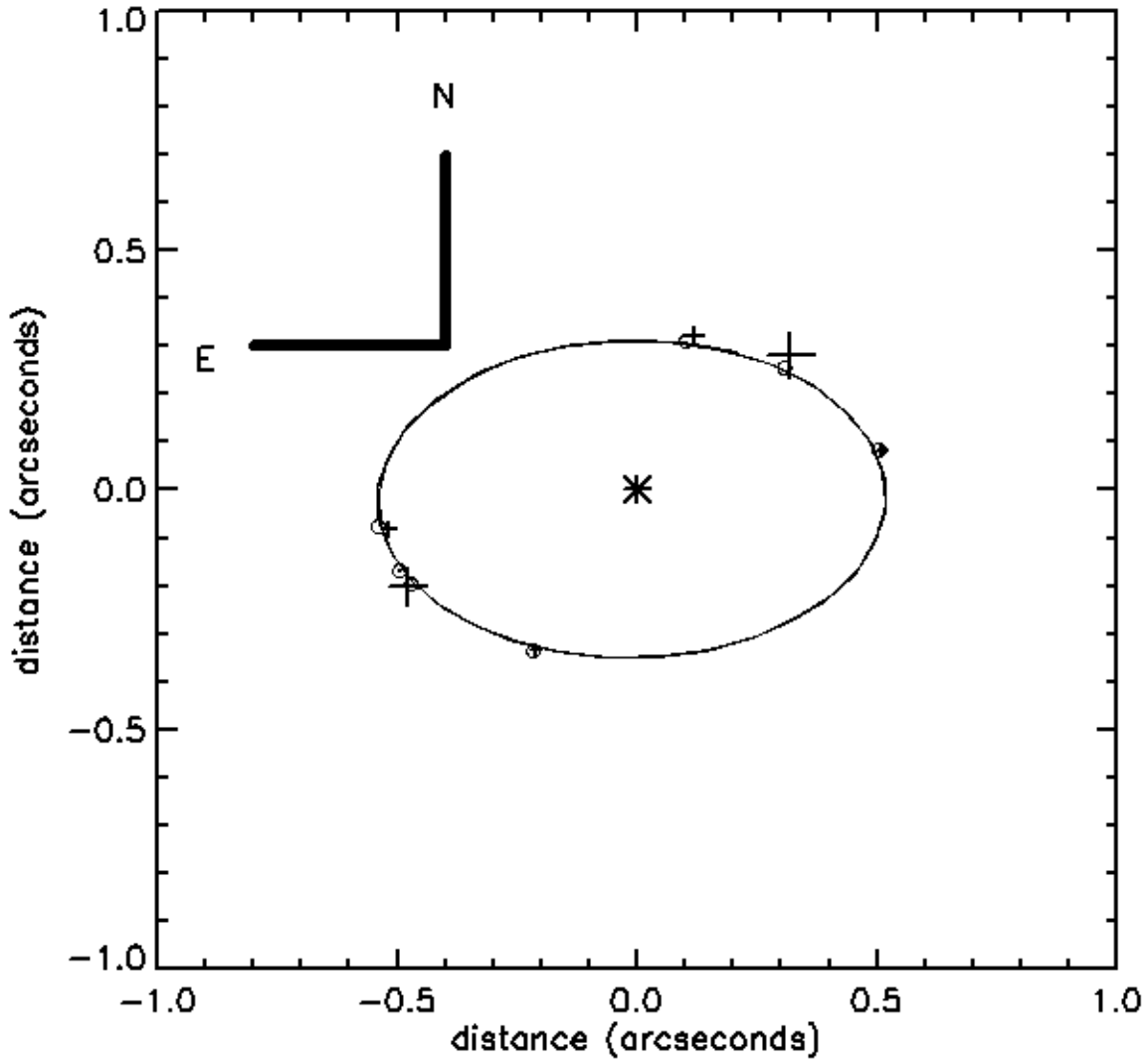

Largest known trans-Neptunian objects (TNOs)
Dysnomia
Charon
Eris
Pluto
Makemake
Haumea
Sedna
Orcus
Quaoar

Eris



Keck LGS AO

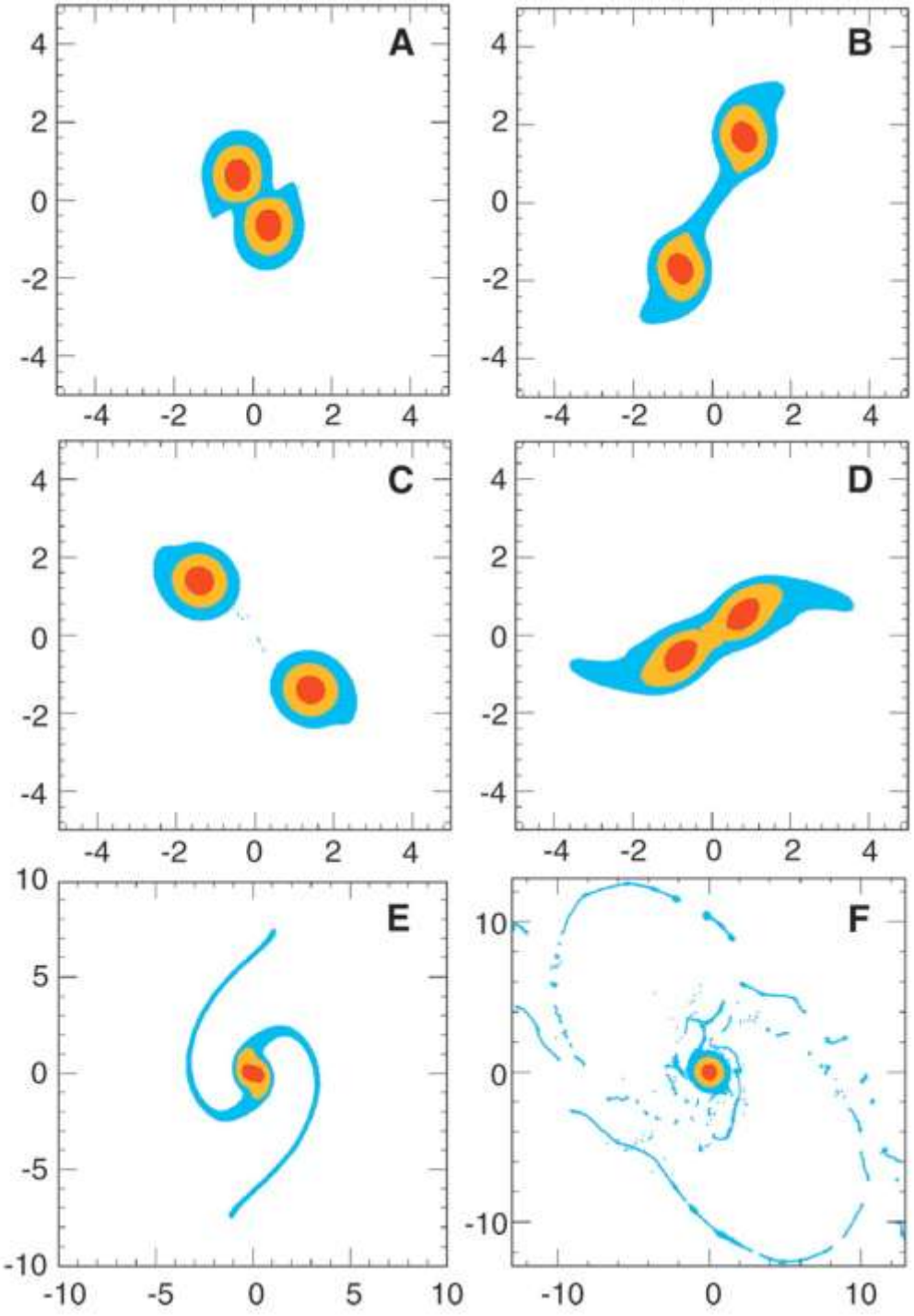




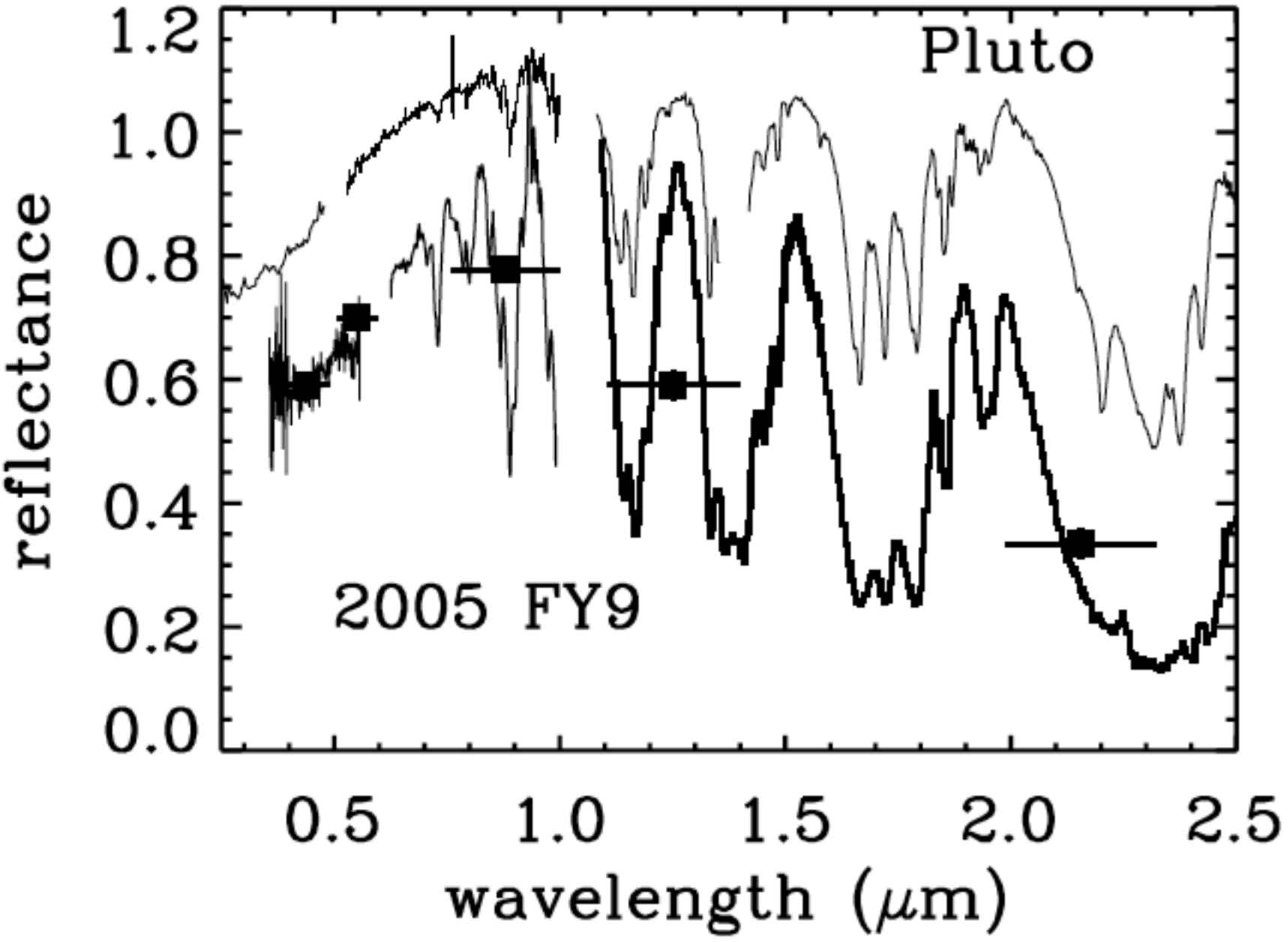
T = 15.7 d
a = 37 Mm
e < 0.06

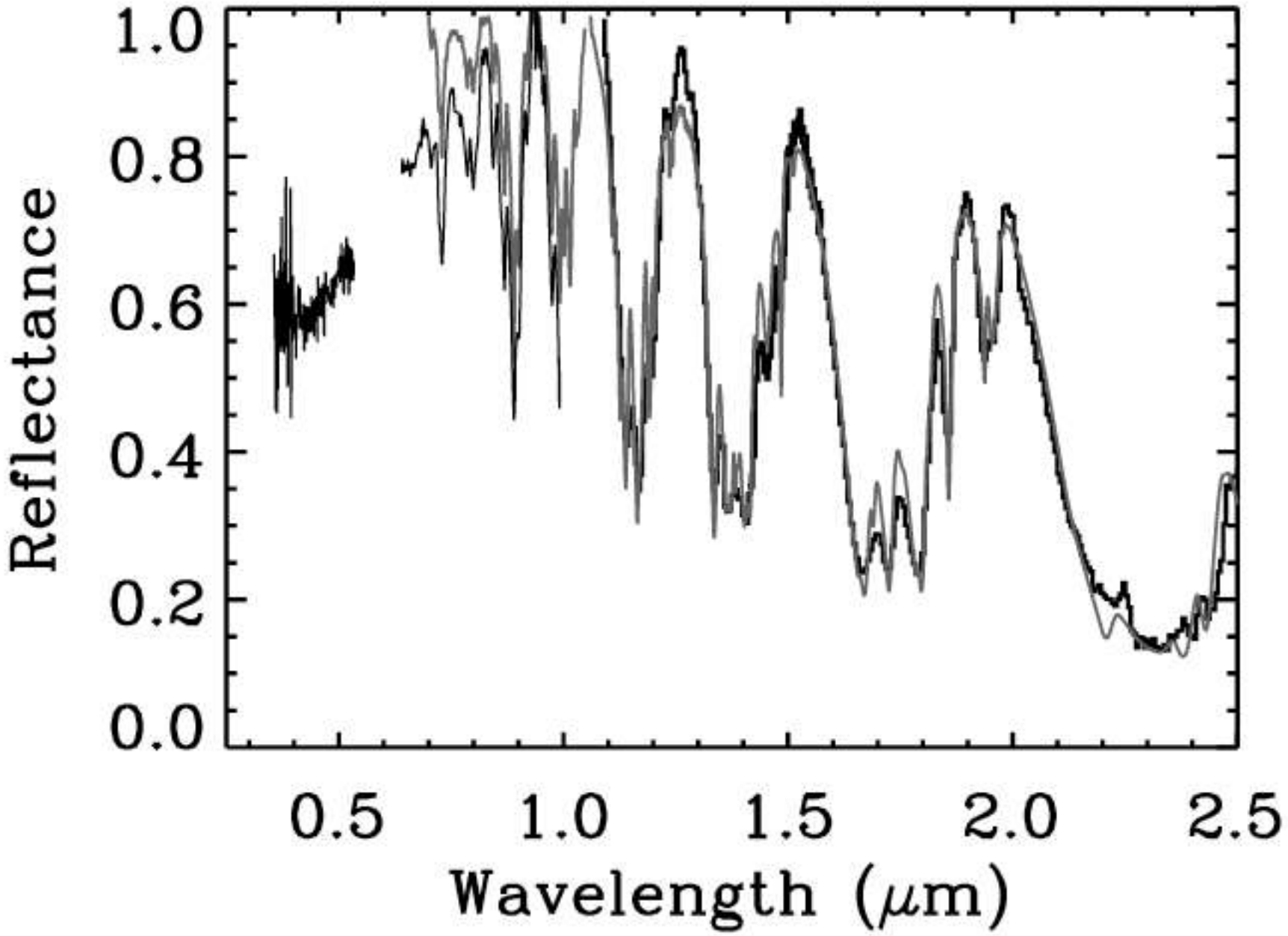
M = 1.27 Mp
ρ = 2.3 0.3 g/cc

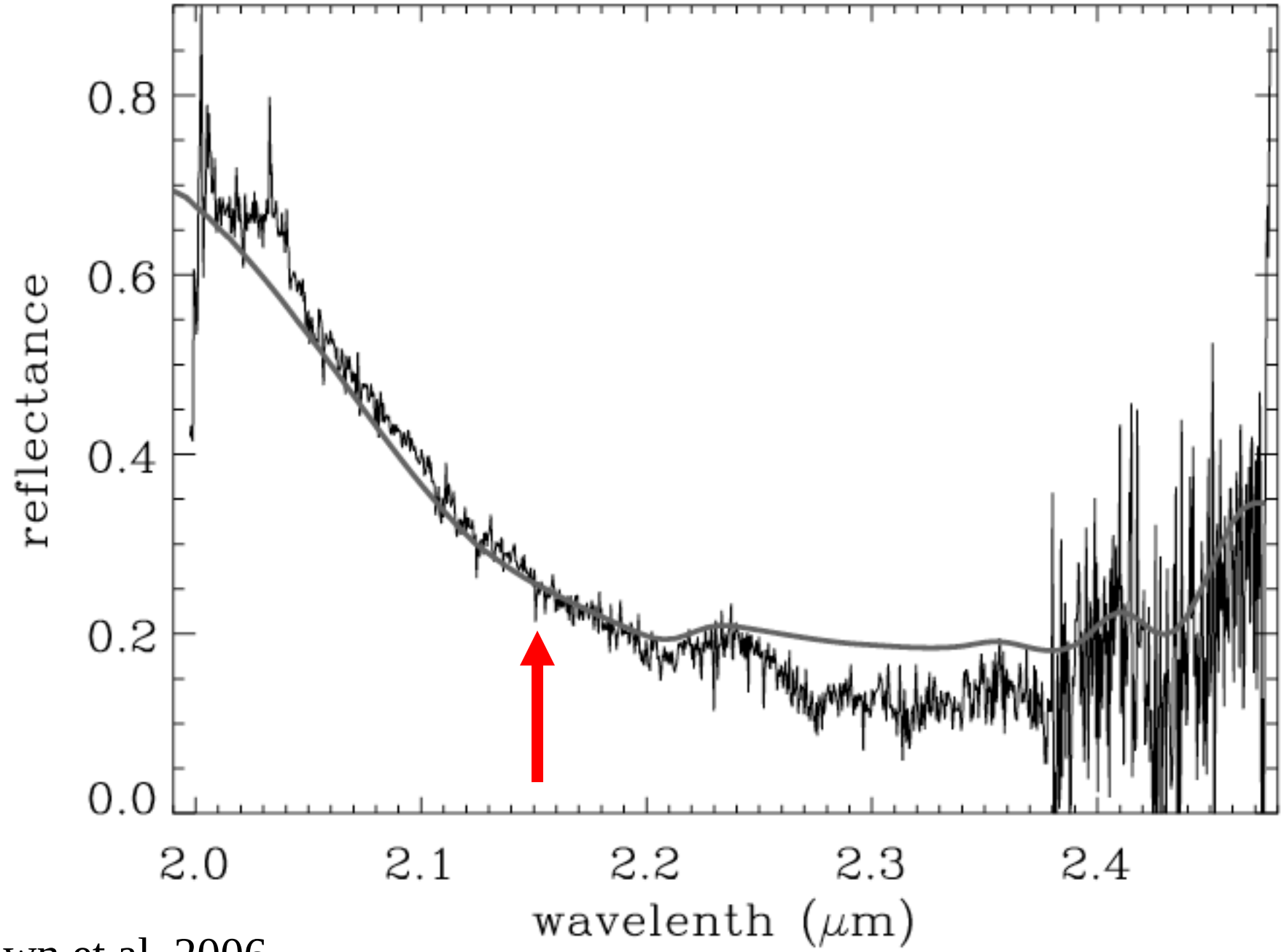
Brown and Schaller 2007



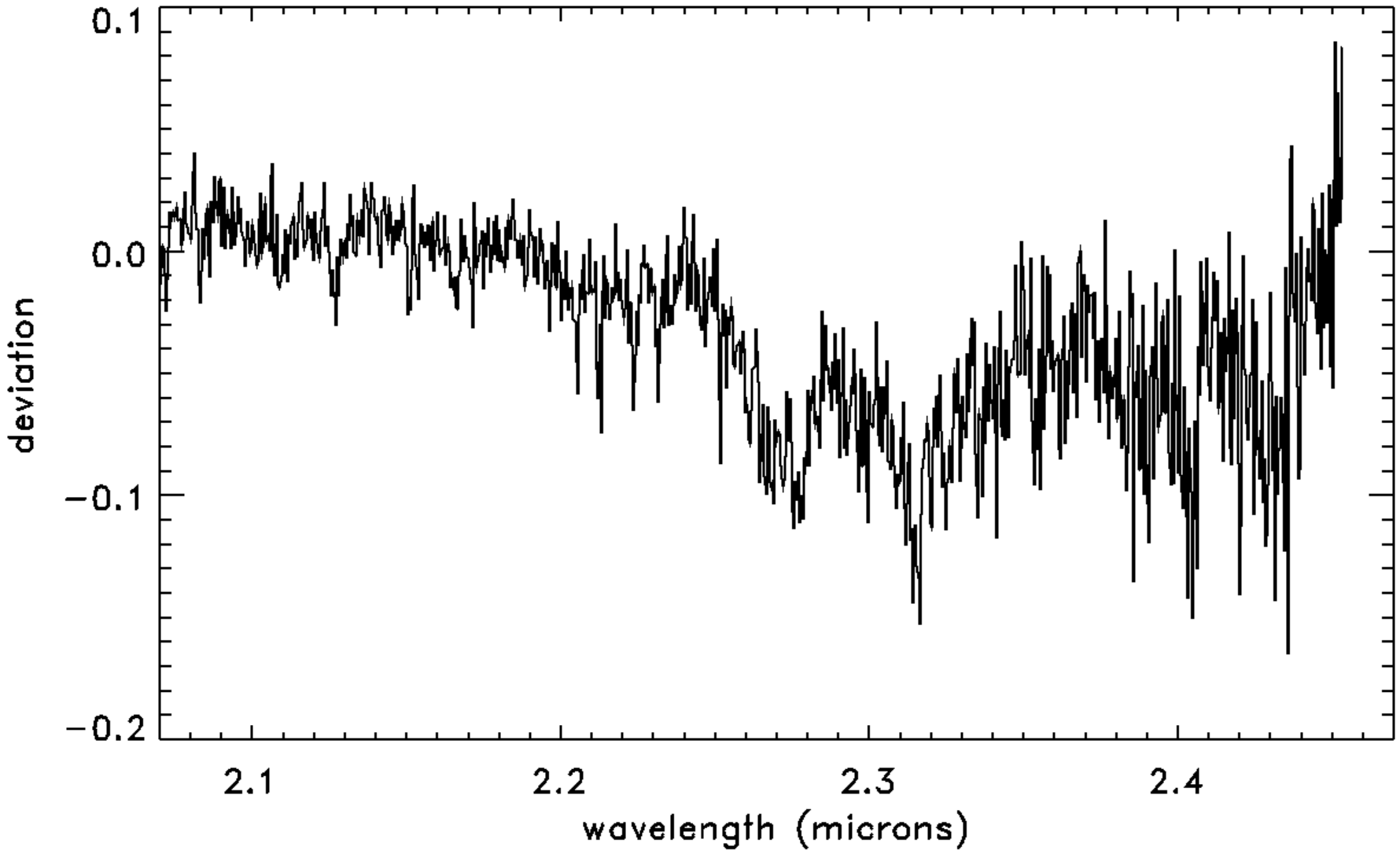
Canup 2005

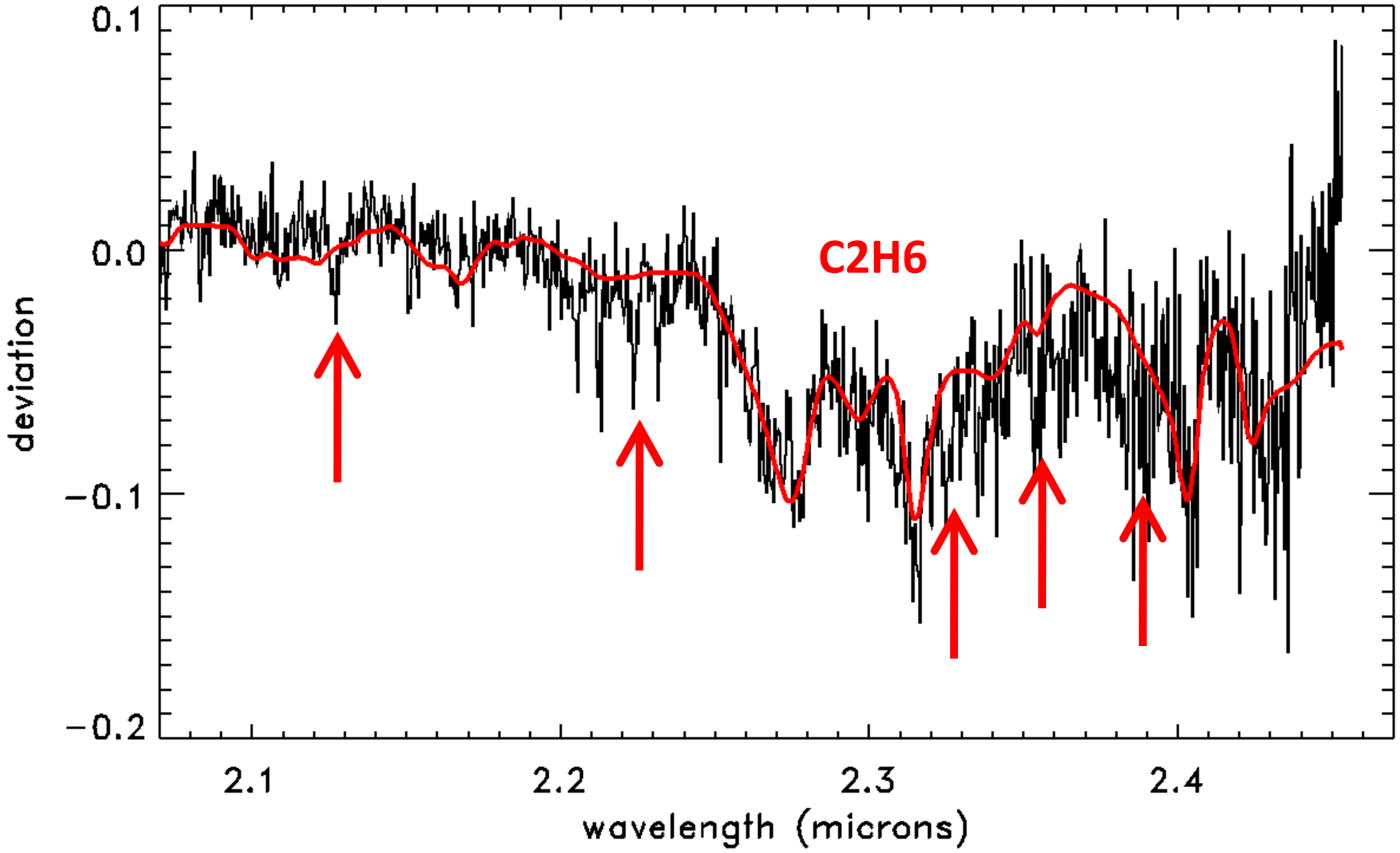

Pluto
2005 FY9
reflectance
wavelength (μm)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
0.5
1.0
1.5
2.0
2.5


Reflectance
1.0
0.8
0.6
0.4
0.2
0.0
0.5
1.0
1.5
2.0
2.5
Wavelength (μm)

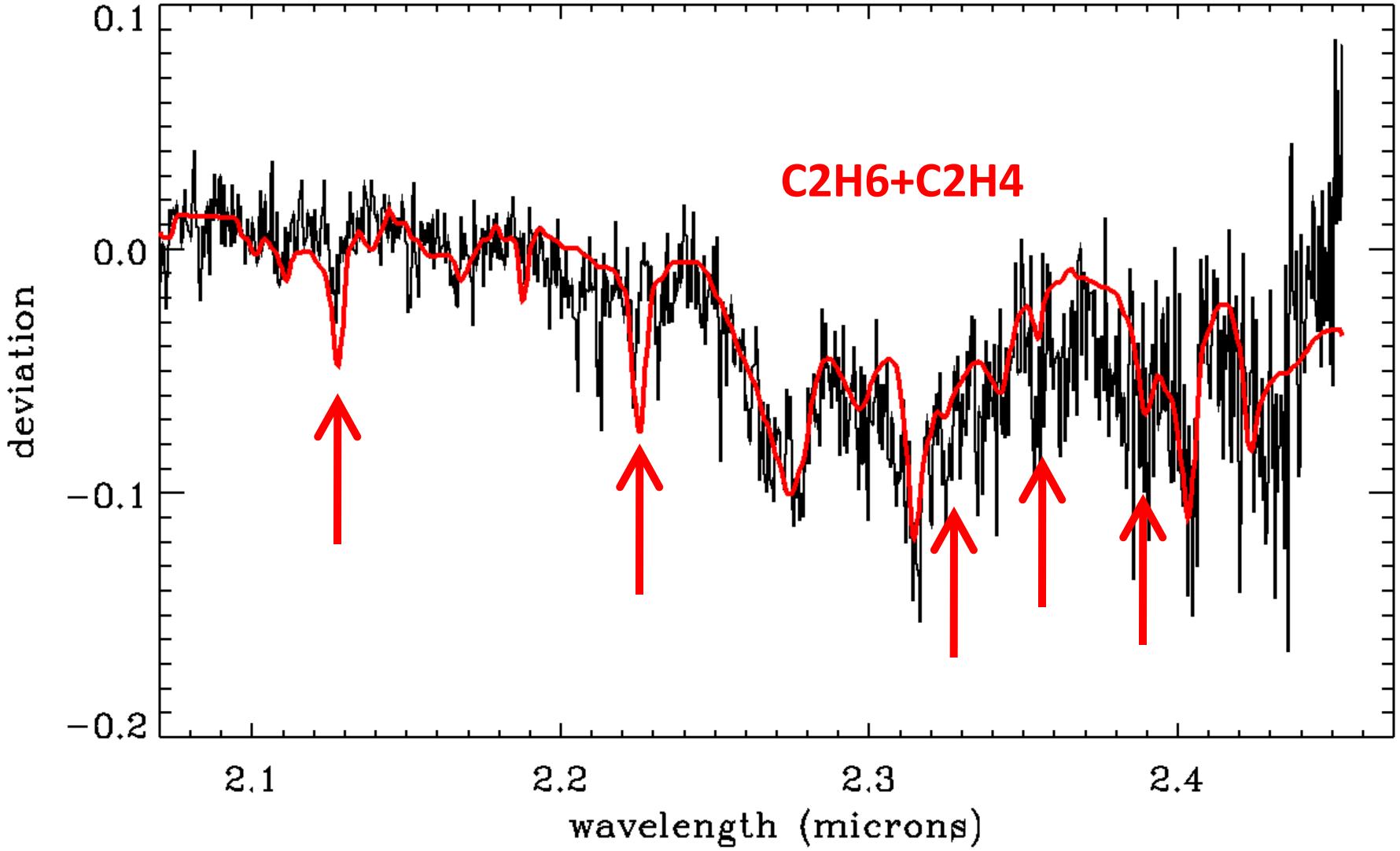


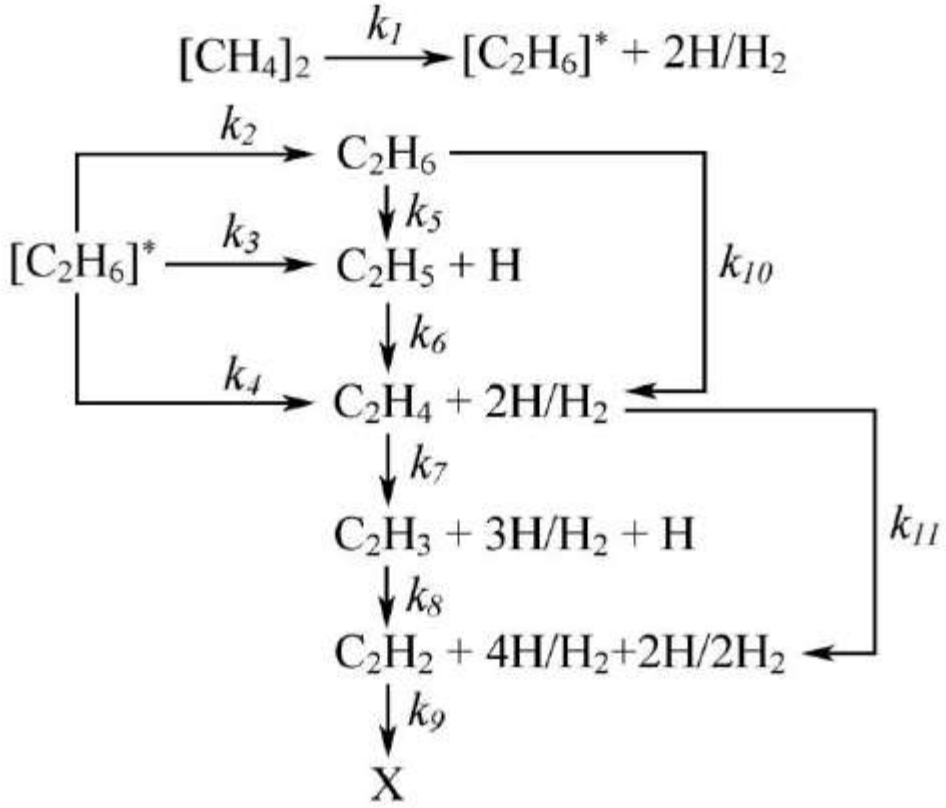
Brown et al. 2006


0.1
0.0
−0.1
−0.2
deviation
2.1
2.2
2.3
2.4
wavelength (microns)

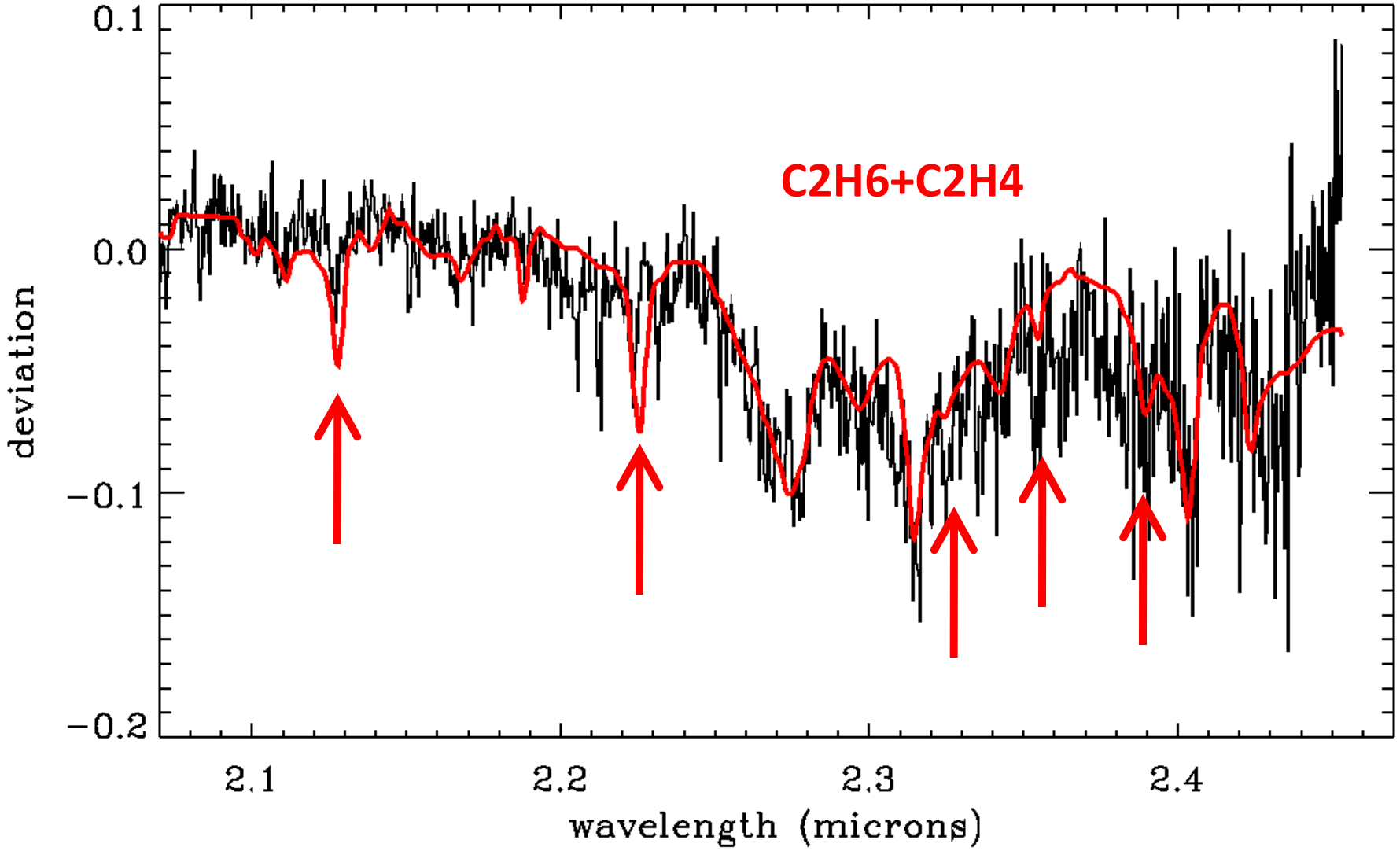

2005 FY9
C2H6
0.1
0.0
−0.1
−0.2
deviation
2.1
2.2
2.3
2.4
wavelength (microns)

2005 FY9

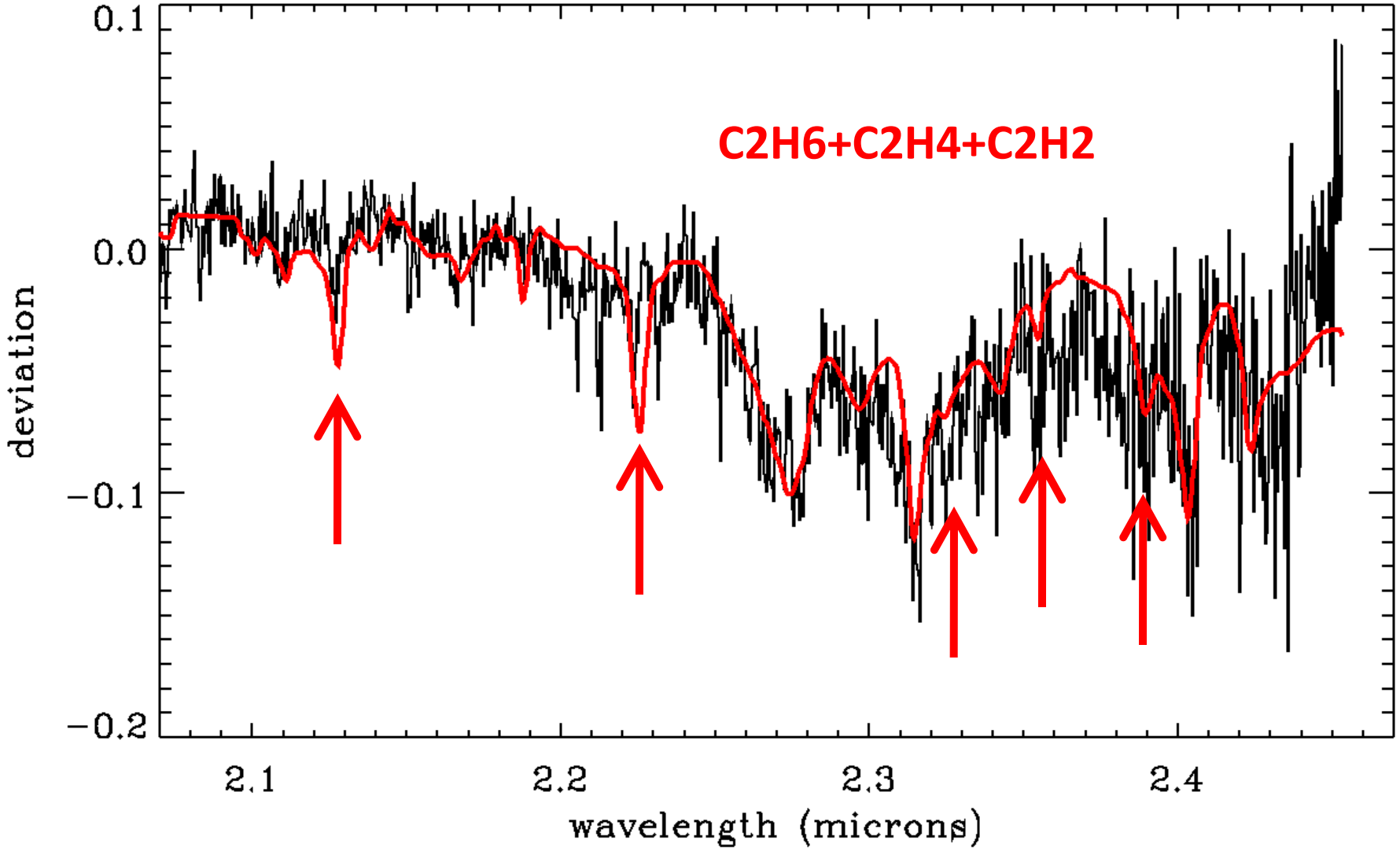

C2H6+C2H4
0.1
0.0
−0.1
−0.2
deviation
2.1
2.2
2.3
2.4
wavelength (microns)

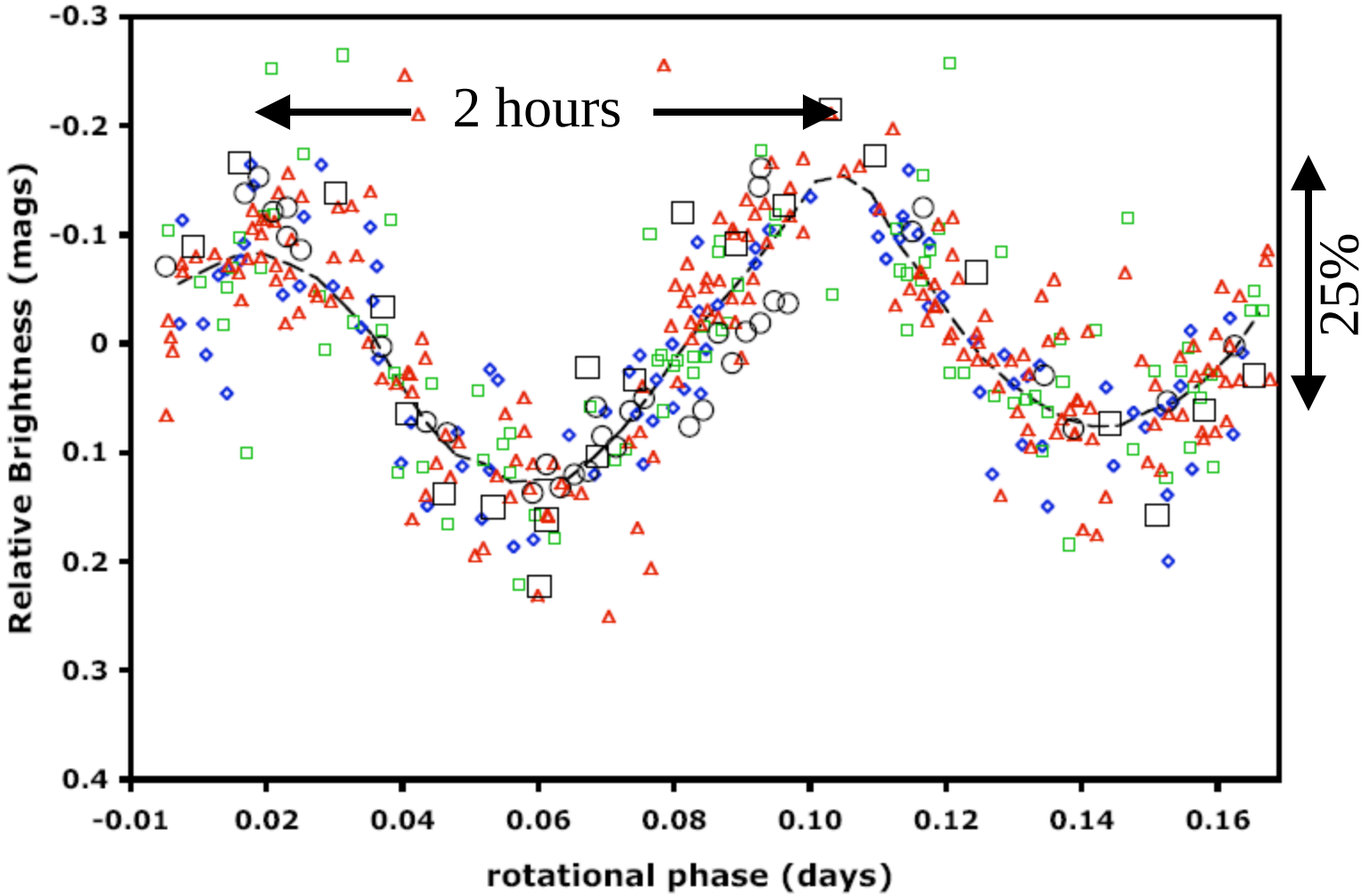

[CH4]2
k1
[C2H6]* + 2H/H2
k2
C2H6
k5
[C2H6]*
k3
C2H5 + H
k10
k6
k4
C2H4 + 2H/H2
k7
C2H3 + 3H/H2 + H
k11
k8
C2H2 + 4H/H2+2H/2H2
k9
X

Makemake

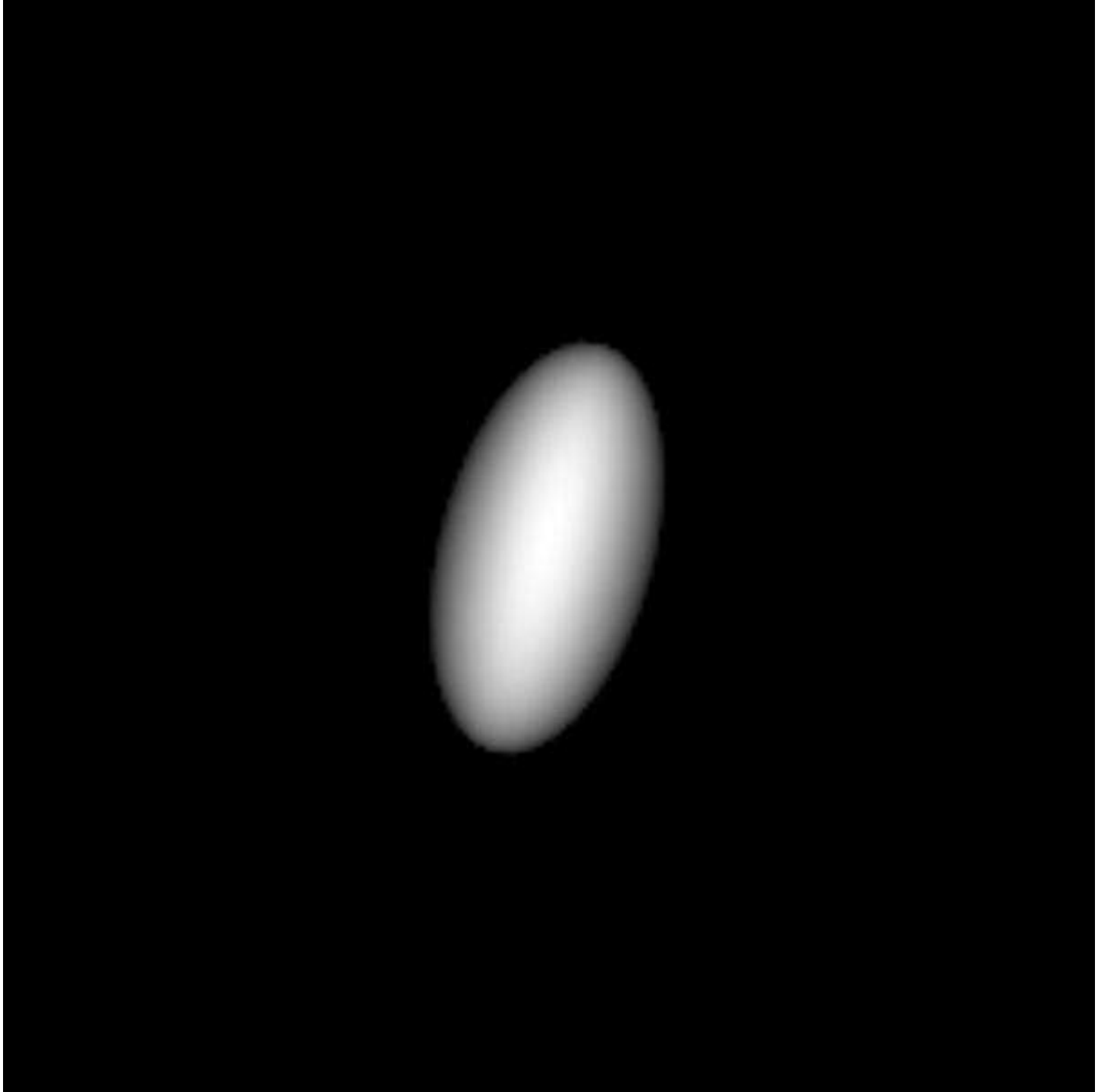

C2H6+C2H4
0.1
0.0
−0.1
−0.2
deviation
2.1
2.2
2.3
2.4
wavelength (microns)

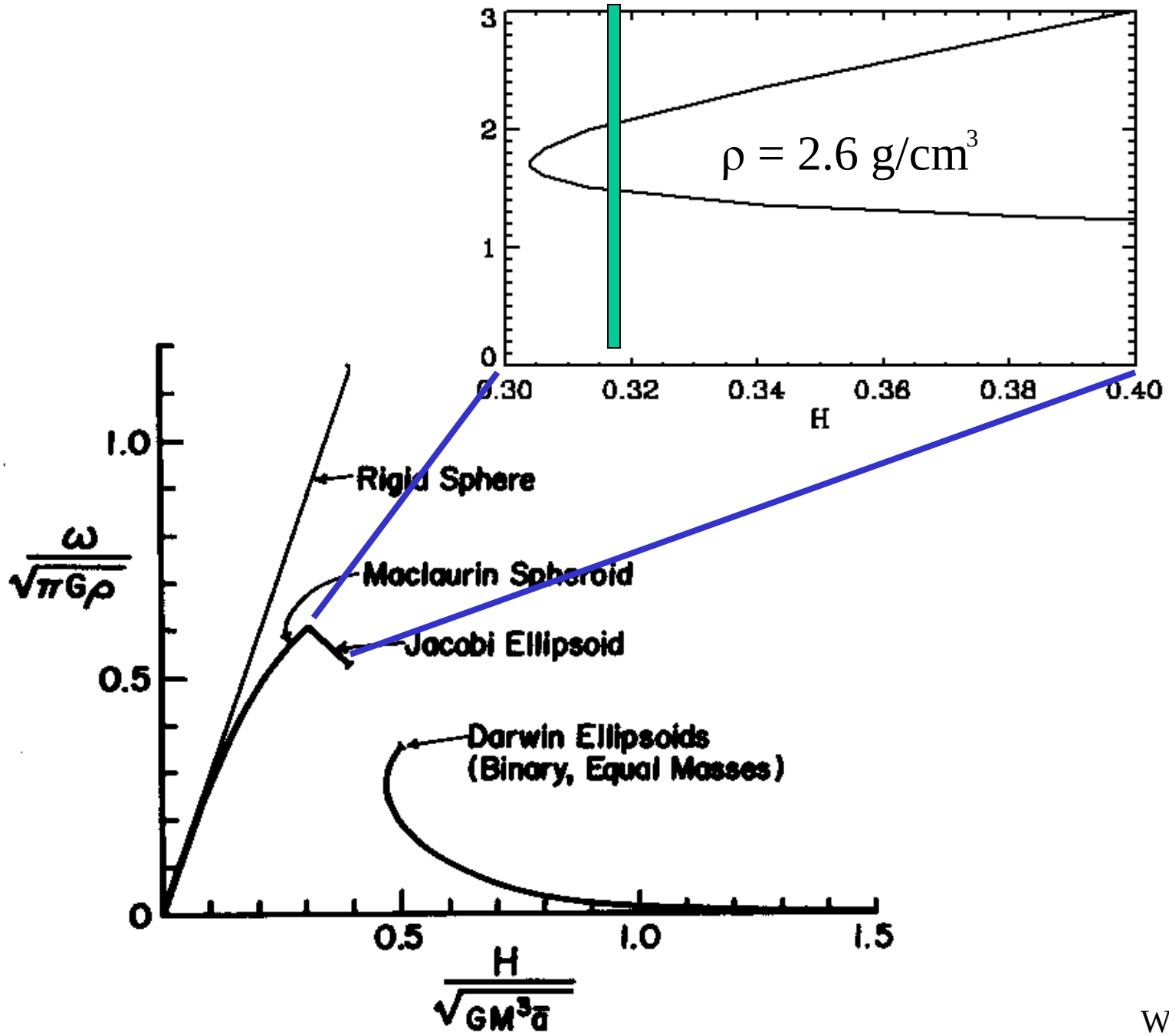
Makemake


C2H6+C2H4+C2H2
0.1
0.0
−0.1
−0.2
deviation
2.1
2.2
2.3
2.4
wavelength (microns)

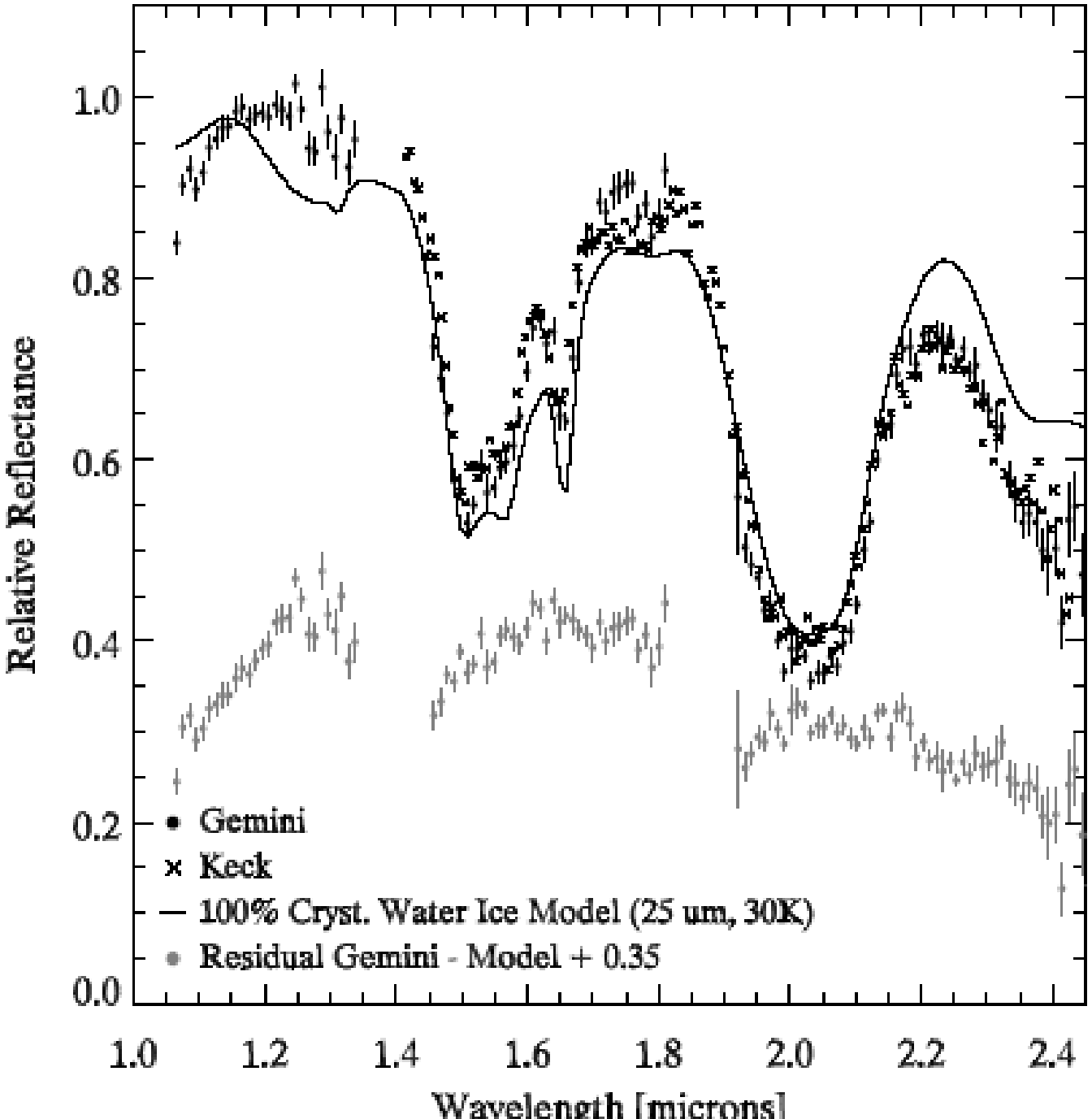


Rabinowitz et al. 2005

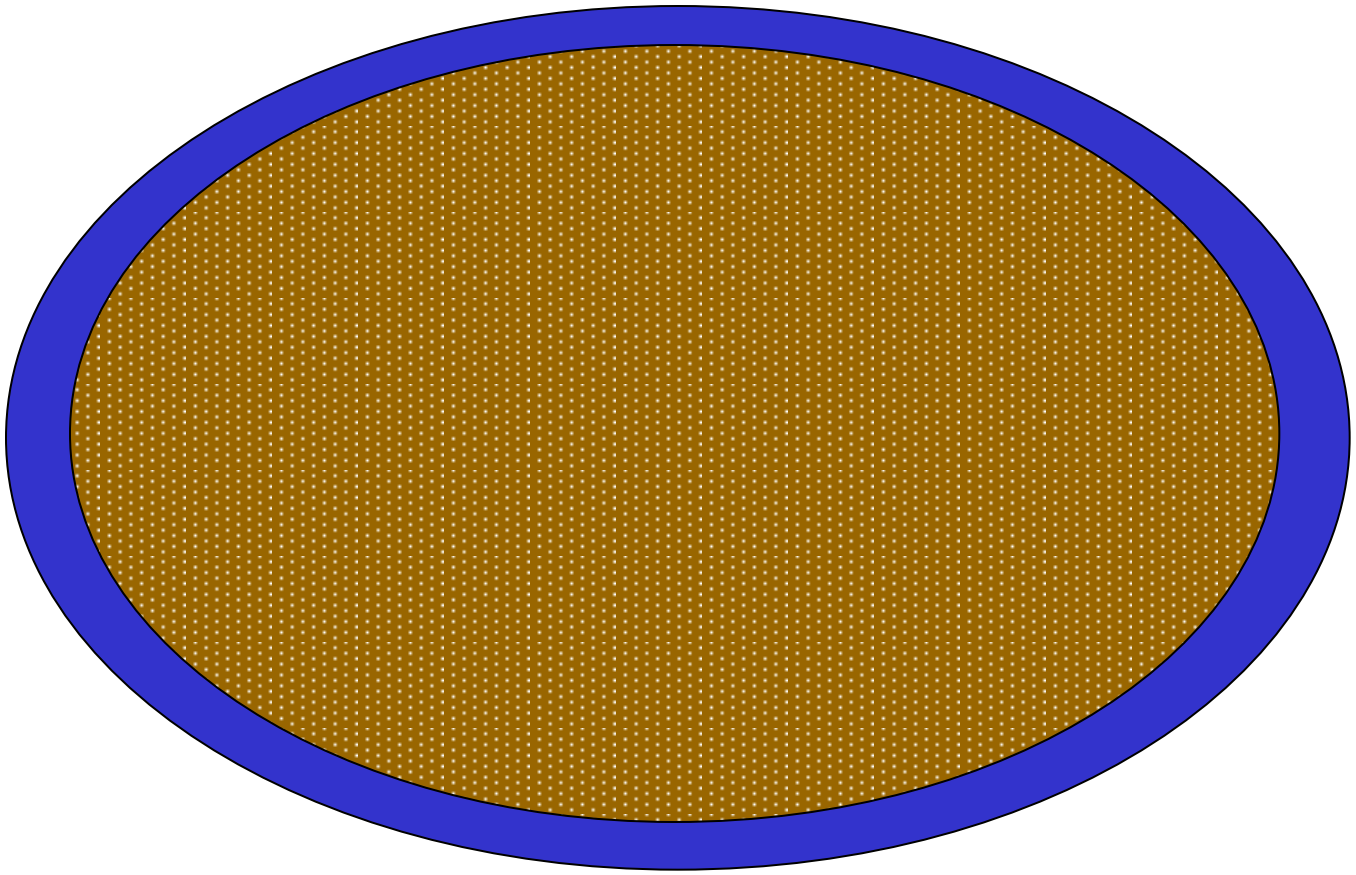


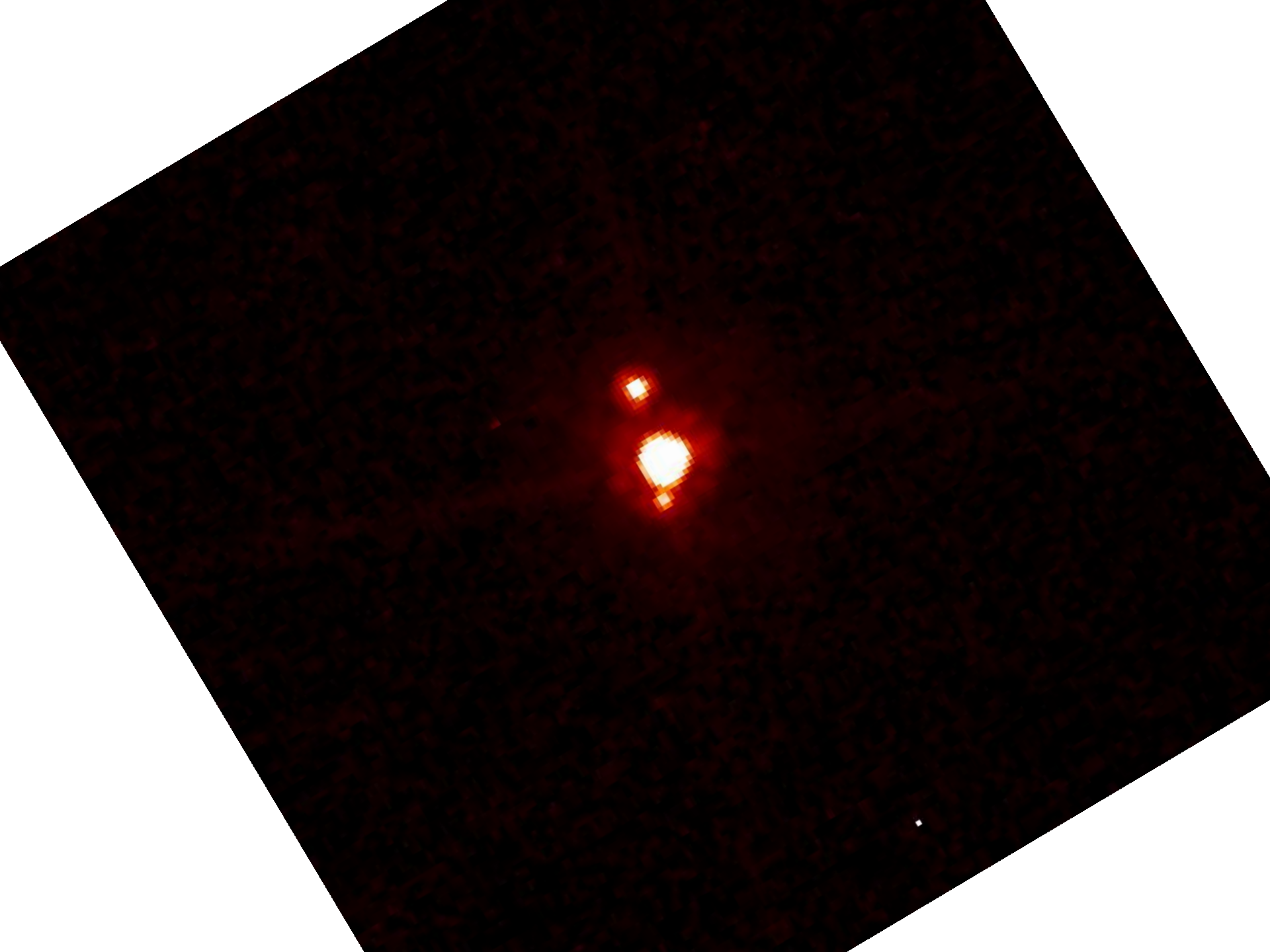


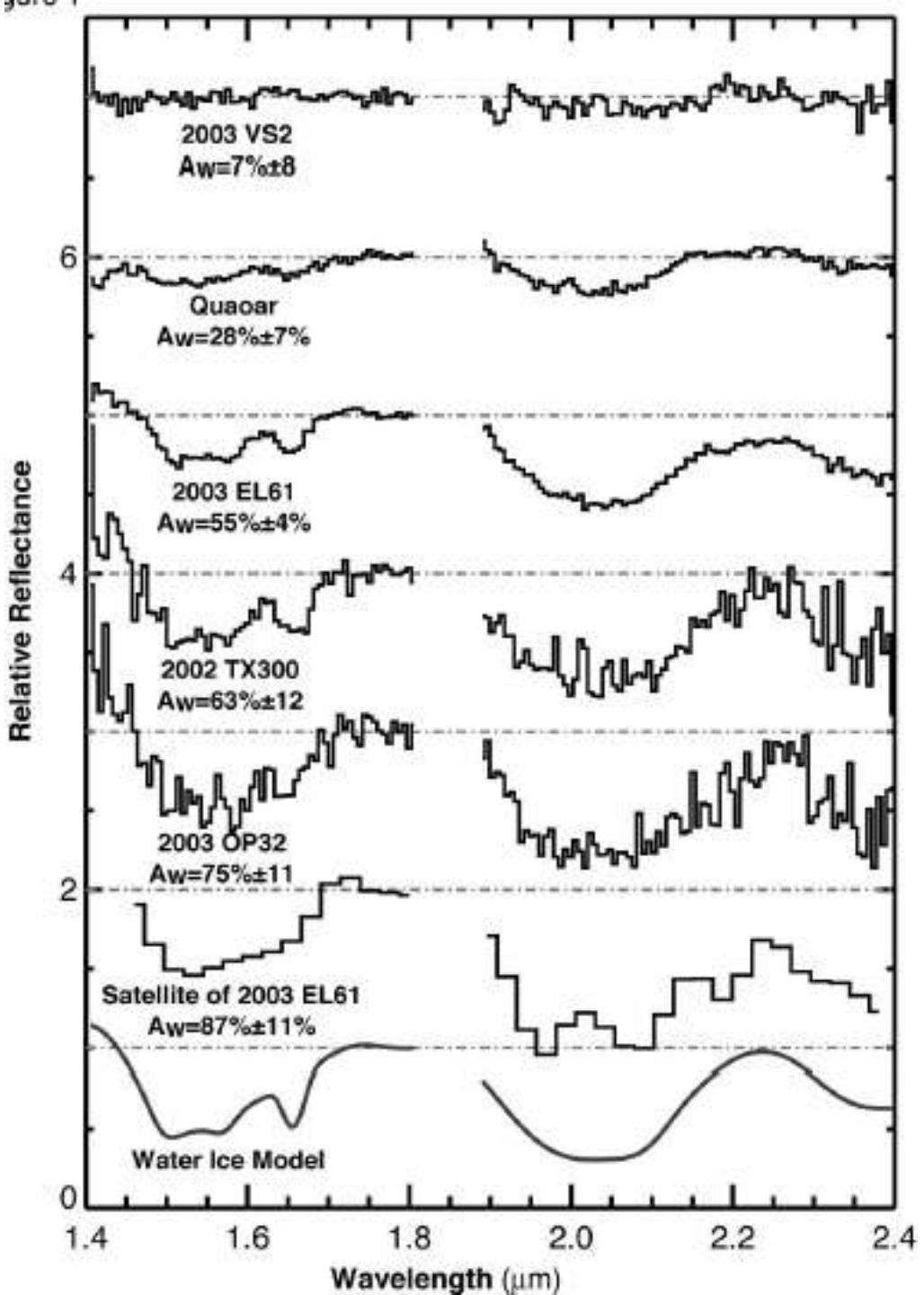
Weidenshilling 1983



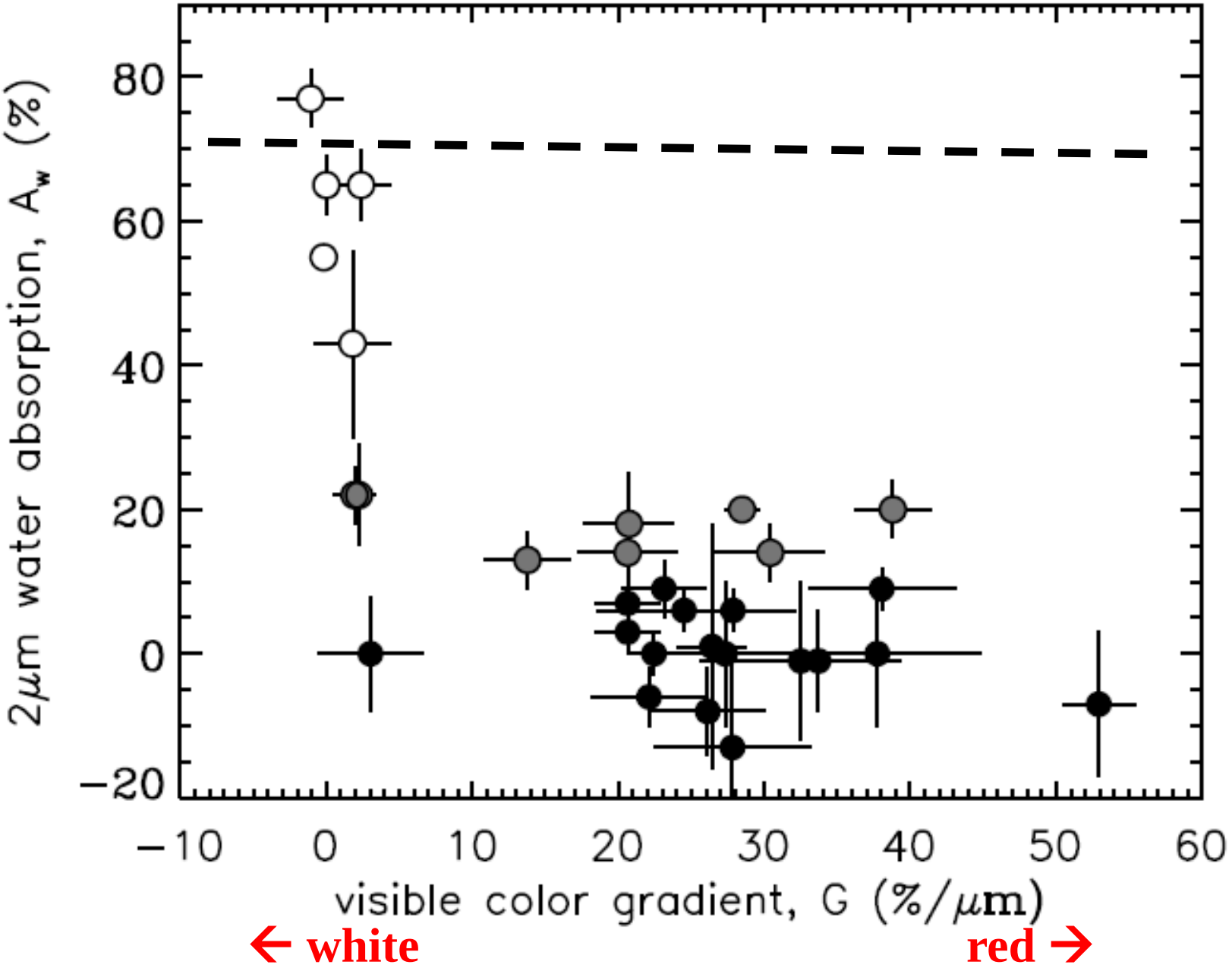
Trujillo et al. 2006



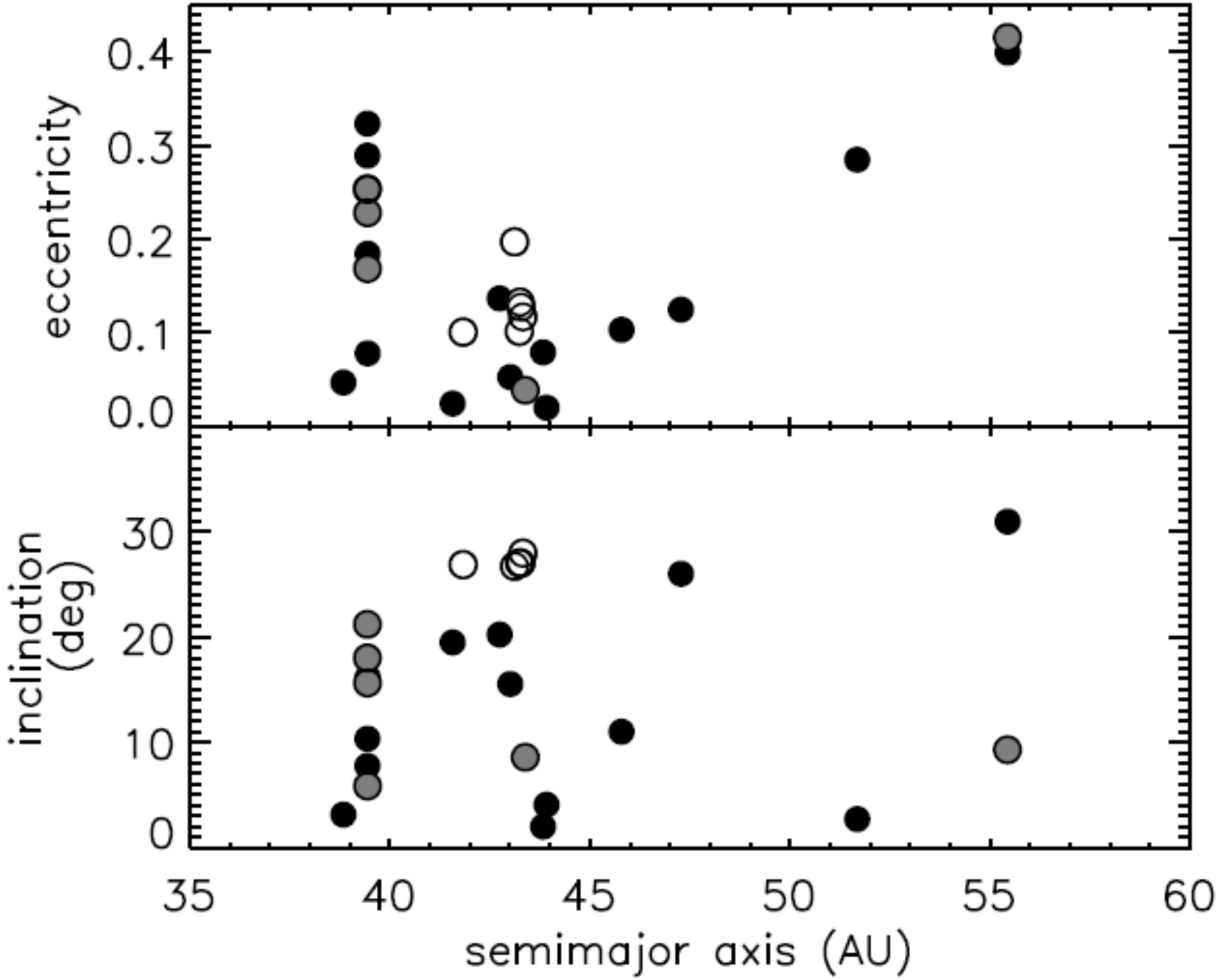


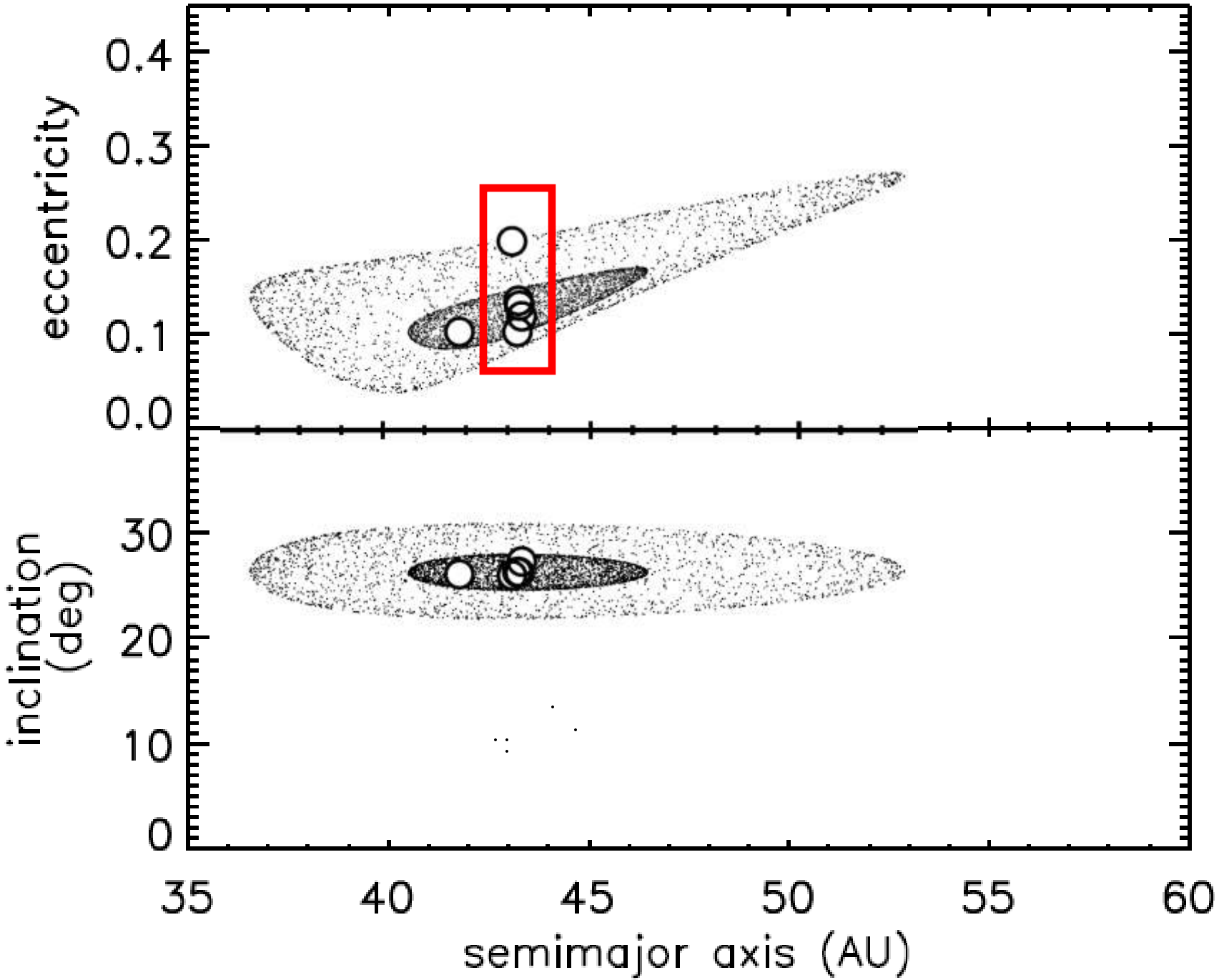


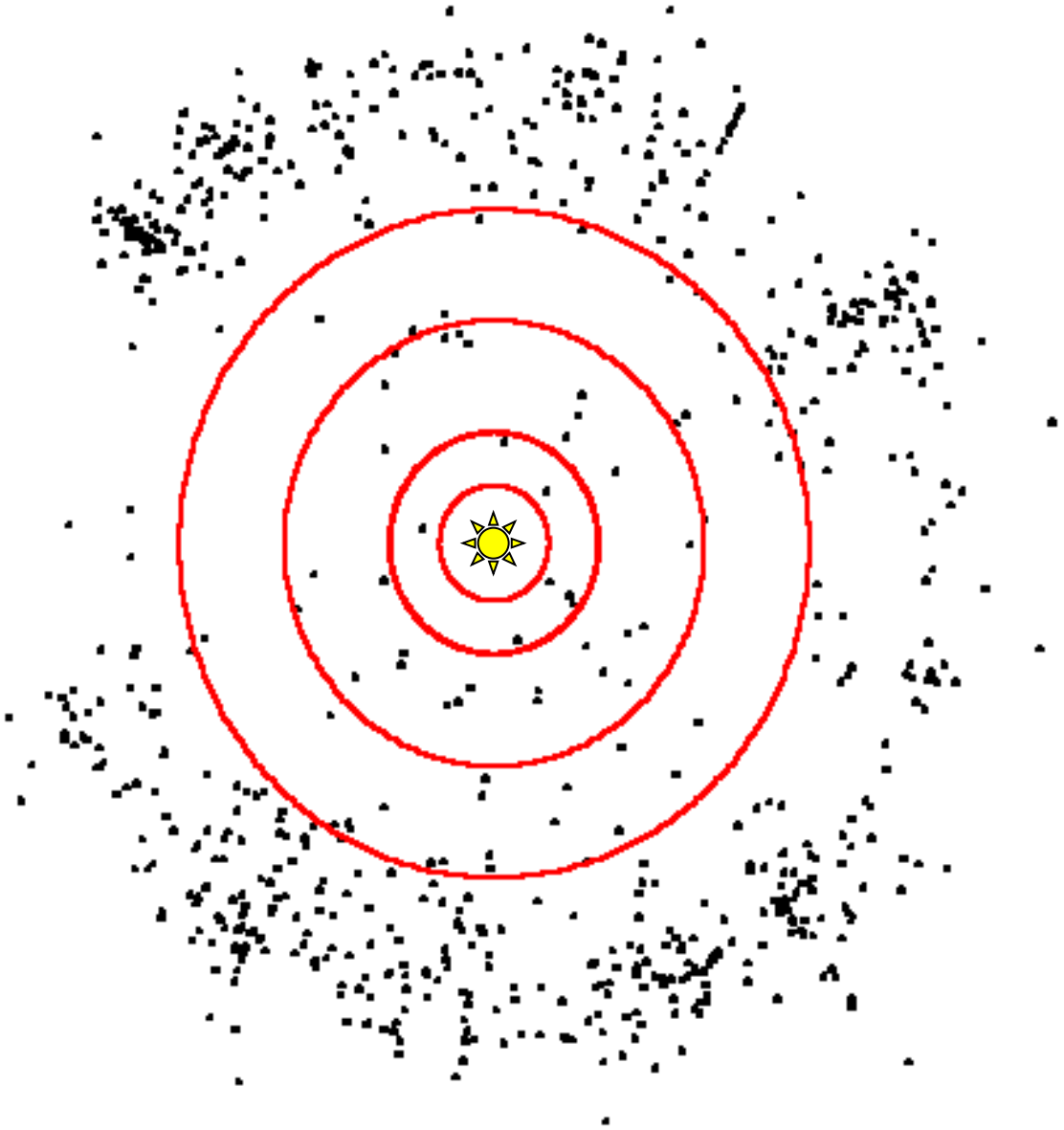
Brown et al. 2007

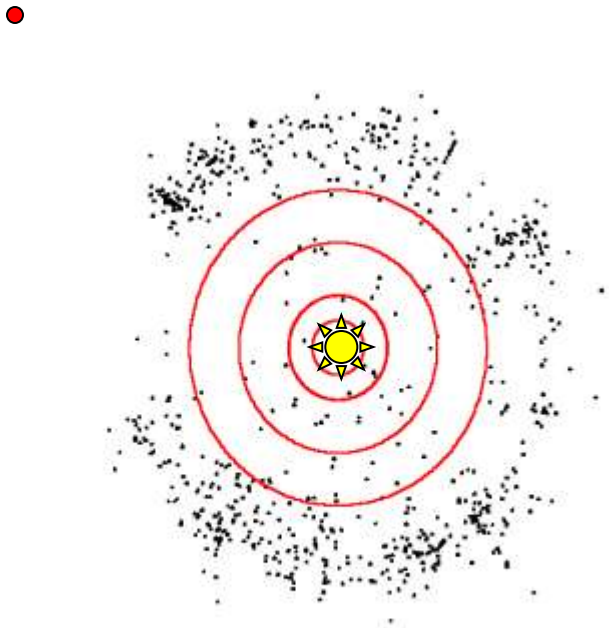


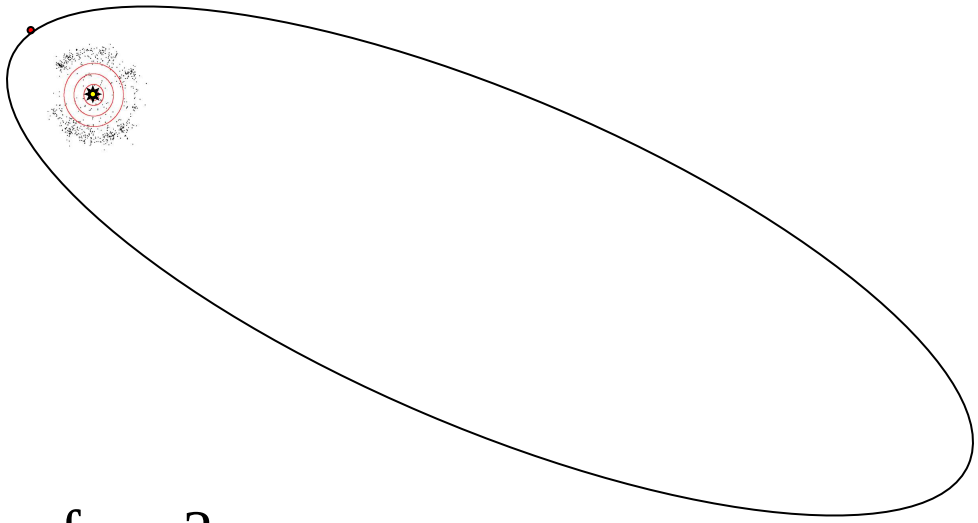
Brown et al. 2007


eccentricity
0.0
0.1
0.2
0.3
0.4
inclination (deg)
0
10
20
30
35
40
45
50
55
60
semimajor axis (AU)

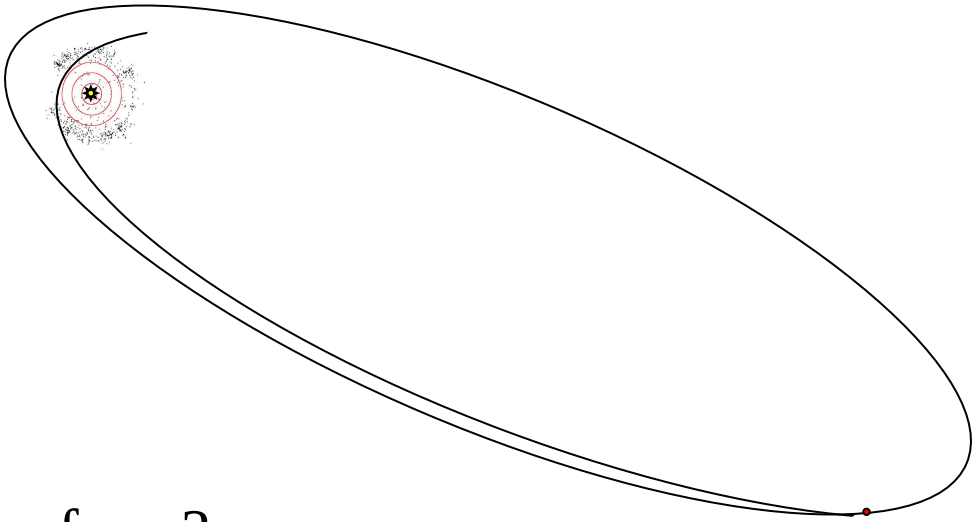

eccentricity
0.4
0.3
0.2
0.1
0.0
inclination (deg)
30
20
10
0
35
40
45
50
55
60
semimajor axis (AU)



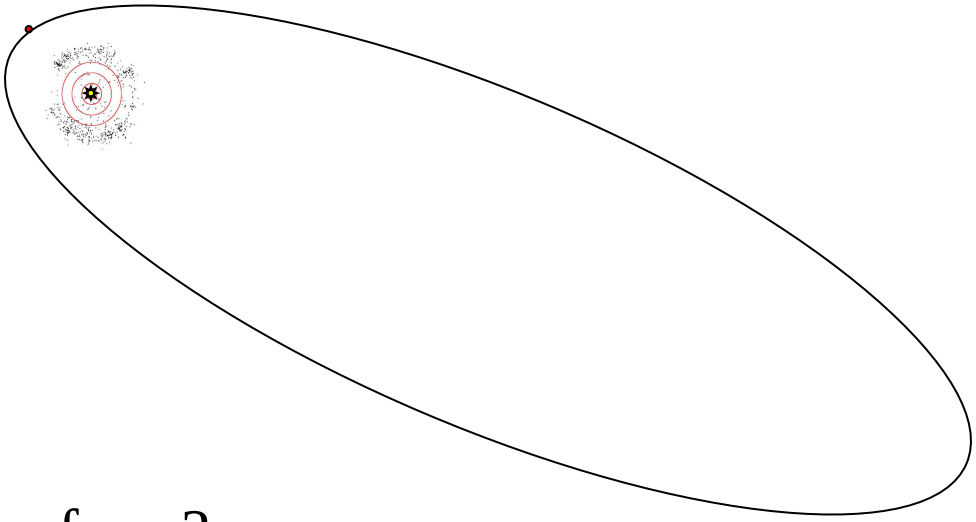




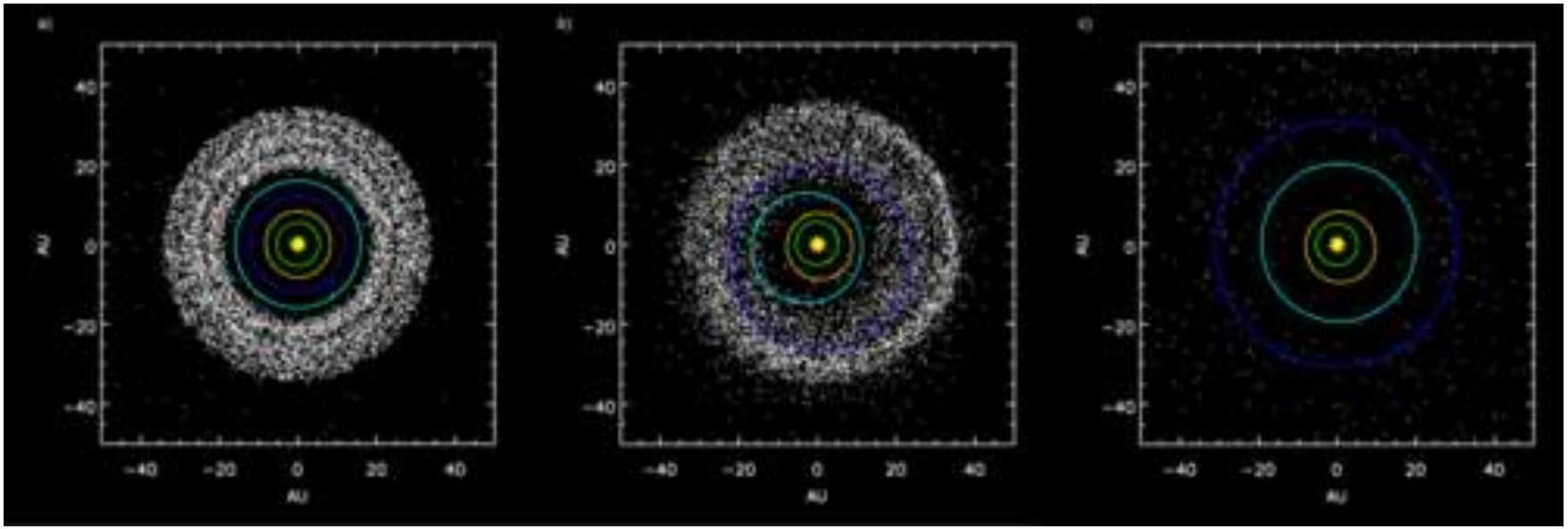
Where did it come from?
-*in situ* formation
-scattered by modest-sized planet @ ~70AU
-close stellar encounter

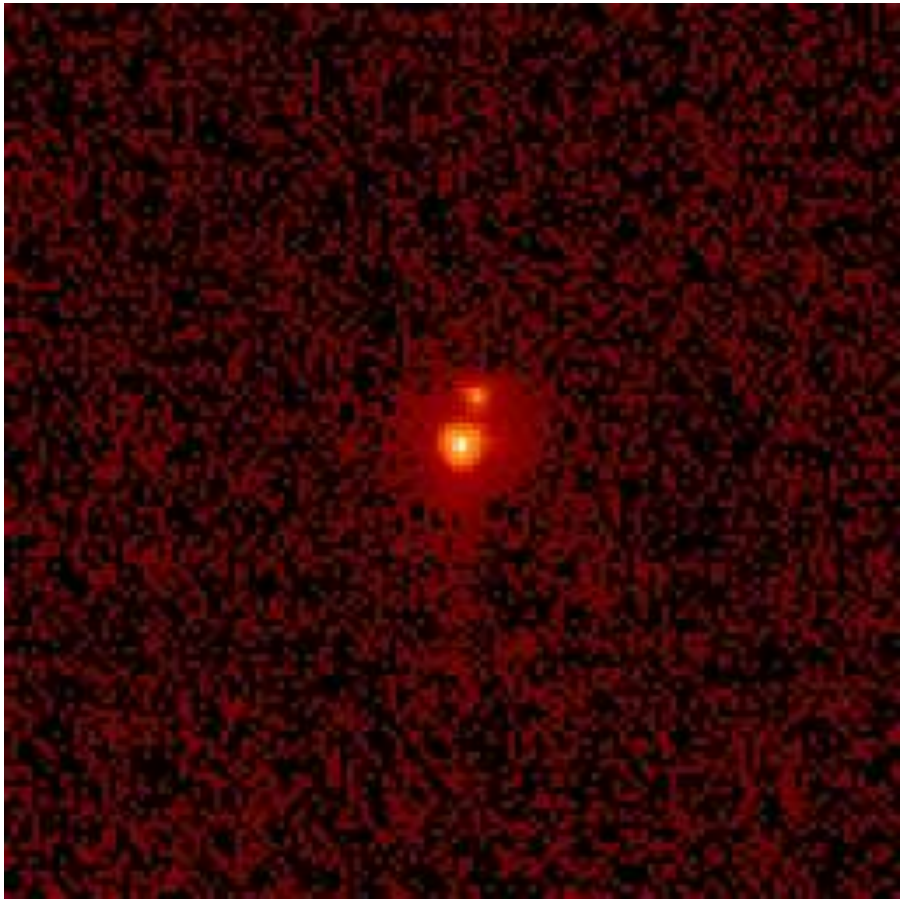


Where did it come from?
-*in situ*
-scattered by modest-sized planet @ ~70AU
-close stellar encounter



Where did it come from?
-*in situ*
-scattered by modest-sized planet @ ~70AU
-close stellar encounter
-dense stellar birth environment


a)
b)
c)
40
20
0
−20
−40
AU
−40
−20
0
20
40



Solar system formation
-dynamical history of the outer solar system
-birth environment of the sun
-accretional/collisional history

[LSST, LSST, LSST, LSST, LSST]

Physics and chemistry on distant icy worlds
-comparative icy planetology
-radiation chemistry
-collisional physics
-surface/atmosphere intereactions
-internal activity

[ELTs, JWST, ALMA]