CIBER Observation of the Near-Infrared Spectrum of the Zodiacal Light

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and
CIBER collaborators

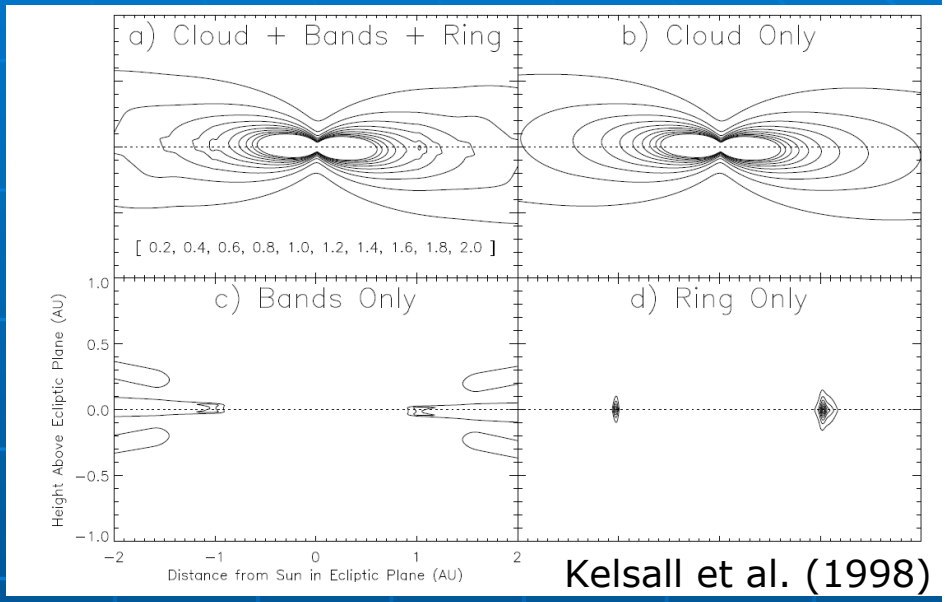
Zodiacal Light (ZL)

- Scattered light (Optical-NIR) or thermal emission (MIR-FIR) from the Interplanetary dust (IPD)
- Dominant diffuse IR emission from outside the terrestrial atmosphere
- Strong atmospheric OH emission

  → Space observation

Interplanetary Dust (IPD)

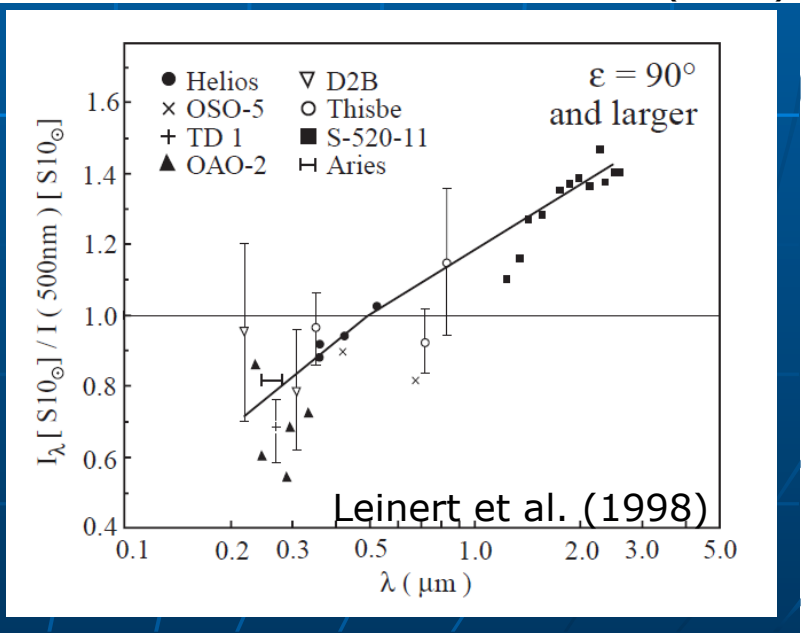
- Spatial structure has been well studied
  (e.g. ecliptic latitude and solar elongation dependant)
  - COBE/DIRBE model
    (Kelsall et al 1998)



Kelsall et al. (1998)

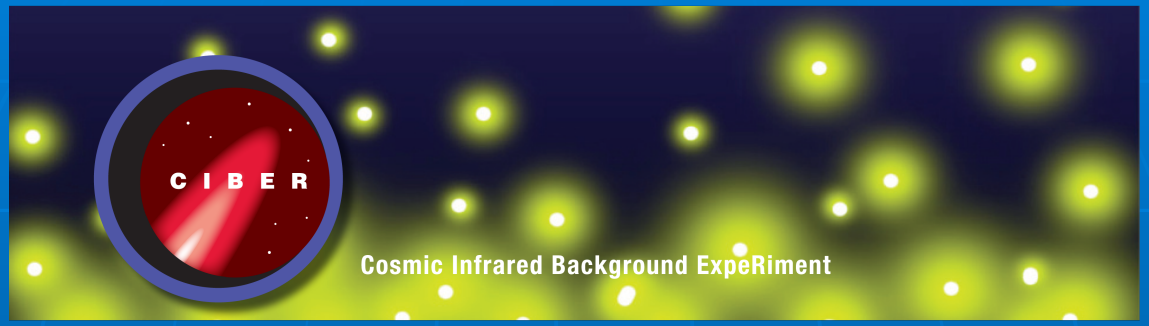
- What is origin of IPD?
  Asteroid : Comet
  37% : 45% stratosphere particles
  (Schramm et al 1989)
  26% : 74% dynamical analysis
  (Liou et al 1995)
  <10% : >90% dynamical analysis
  (Nesvorny et al 2009)

- It's very difficult to conduct the spectroscopy of diffuse emissions.



Leinert et al. (1998)

Spectroscopy of ZL is important!



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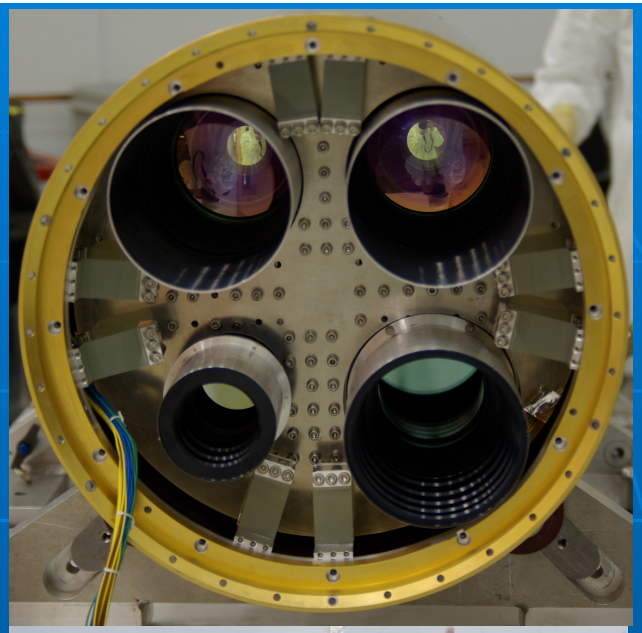
Sounding rockets:
Wallops Flight Facility

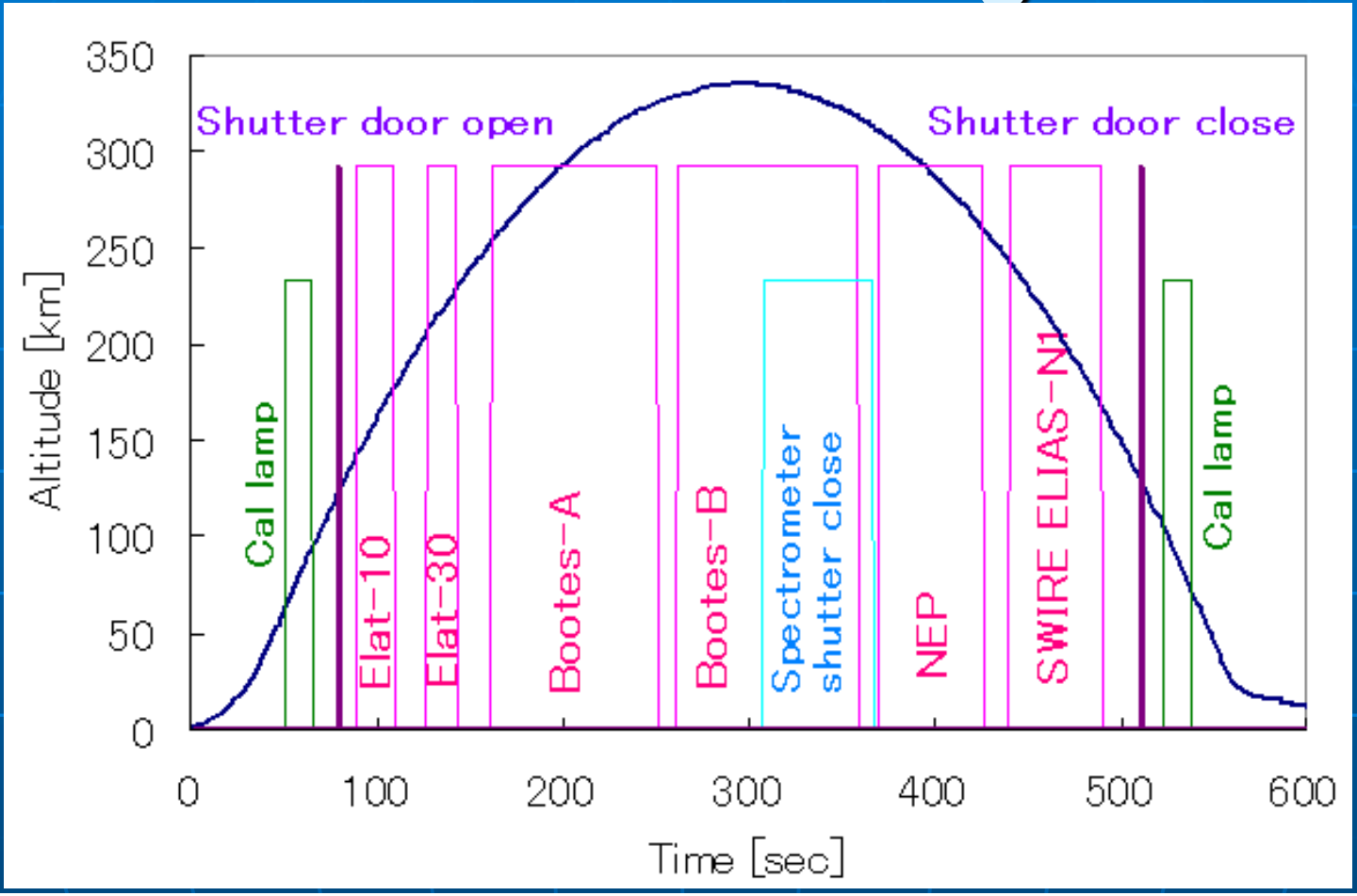
CIBER

(Cosmic Infrared Background Experiment)

- A rocket-borne mission designed for measuring the spectrum and fluctuation of the Cosmic Infrared Background (CIB).
- International collaboration
  - Japan: ISAS/JAXA, Nagoya University
  - USA: JPL, Caltech, UC Irvine, UC San Diego
  - Korea: KASI
- Successfully launched !
  - February 25th, 3:45am(UTC-8), 2009
  - White Sands Missile Range
  - Terrier-Black Brant rocket
  - Max altitude 330km
  - Observation for 425sec.
- We are preparing the 2nd flight on June 2010
- For details, please refer to the poster outside by Zemcov et al.

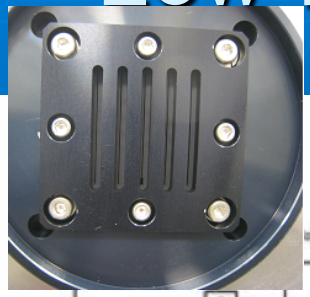


Observation targets



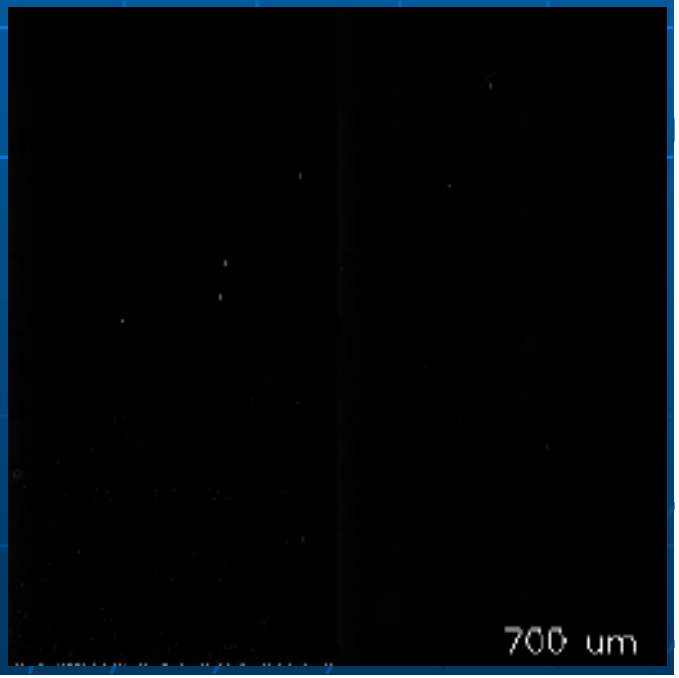
Field	Time [sec]	Altitude [km]	RA	Dec	λ	β	l	b	Solar Elogation
Elat 10	80.0–109.0	121.5–172.4	234.05	−8.32	233.76	10.711	357.23	36.634	102.0
Elat 30	109.0–141.7	172.4–220.4	222.75	20.56	212.82	35.101	25.895	61.956	117.1
Bootes A	141.7–249.6	220.4–310.1	218.63	34.84	201.23	46.278	58.59	66.68	119.3
Bootes B	249.6–307.5	310.1–315.3	217.33	33.39	202.23	47.278	55.433	68.016	119.3
NEP	367.5–426.3	289.3–232.4	270.29	65.88	90	90	95.601	29.69	89.9
Swire N1	426.3–490.4	232.4–134.5	242.56	55.21	208.4	72.629	85.212	44.661	100.6

Low Resolution Spectrometer (LRS)



Composition	14 lenses, 2 filters, 1 prism, 5 slits
Aperture	50 mm
F number	2
FOV	5.5 degrees along a slit
Pixel size	1.4 arcminutes×1.4arcminutes
Slit	2 pixels×236 pixels
Wavelength range	0.75-2.1μm
Wavelength resolution	$\lambda/\Delta\lambda$=15-30
Optics efficiency	0.8
Detector	256×256 substrate removed 2.5μm cutoff PICNIC
Detector QE	0.9
Dark current	$< 0.6[e^-/\mathrm{s}]$
Readout noise	$< 26[e^-]$ CDS

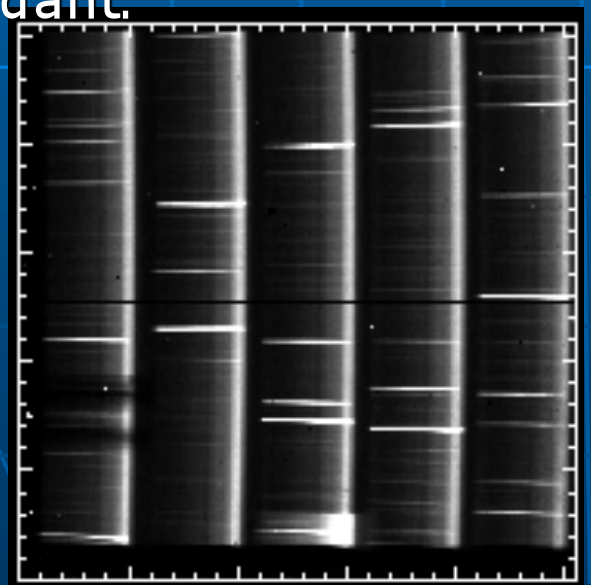
Low-Resolution Spectrometer Specifications

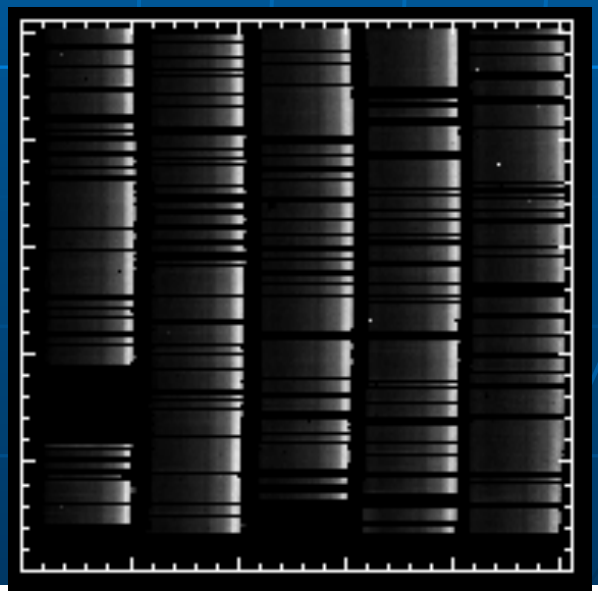


LRS data reduction

- We masked all point source (>~13mag), and averaged remaining diffuse spectra.

- Strong thermal stray light. We simply omit data at >1.8um.
- Airglow emission
  - Time-exponential time dependence
  - Peak at 1.6um and 1.1um <- OH molecule
  - Negligible except at Elat-10 and Elat-30
  - We subtracted the airglow emission based on the time-dependant.





Sky Spectrum

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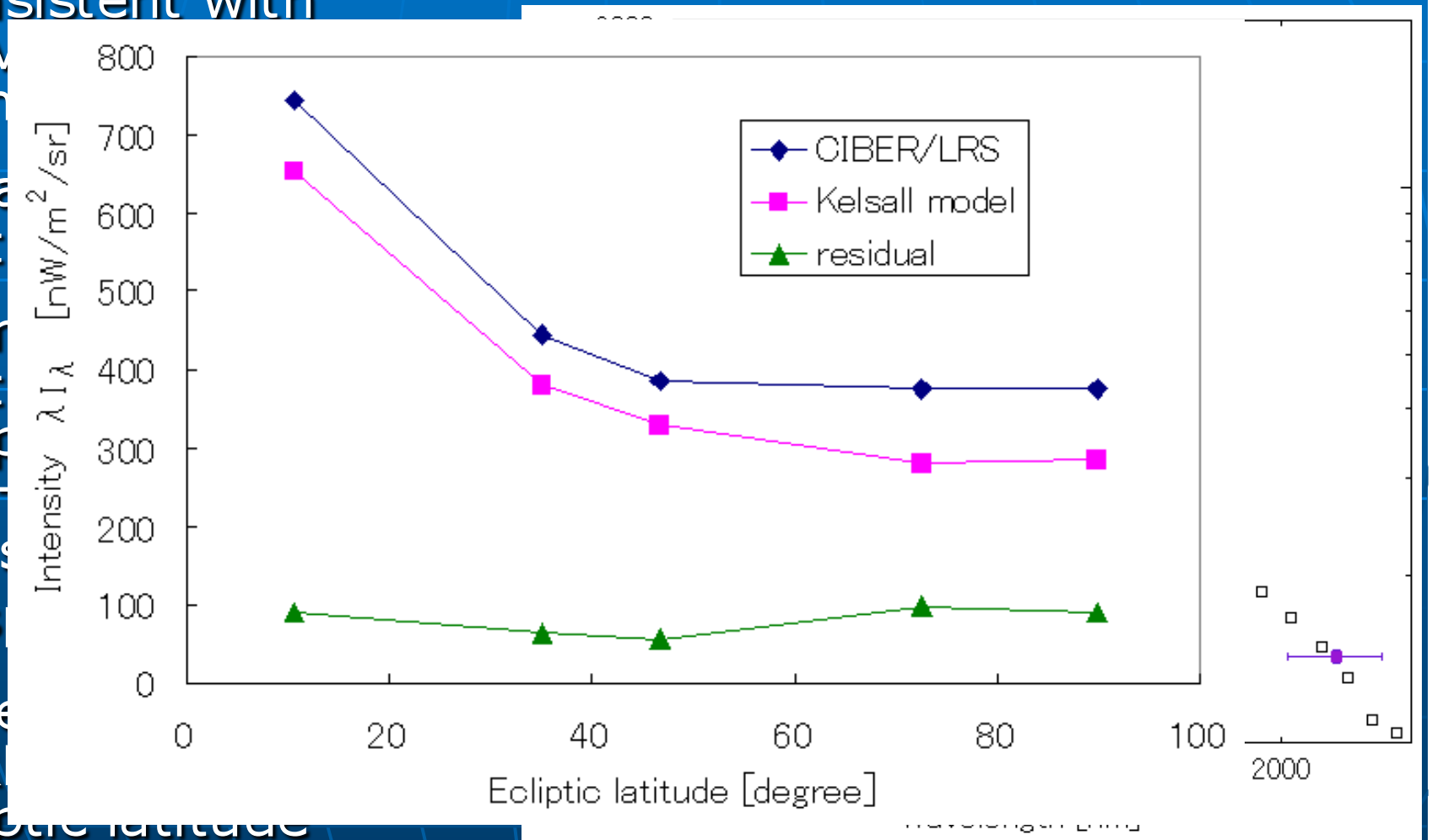
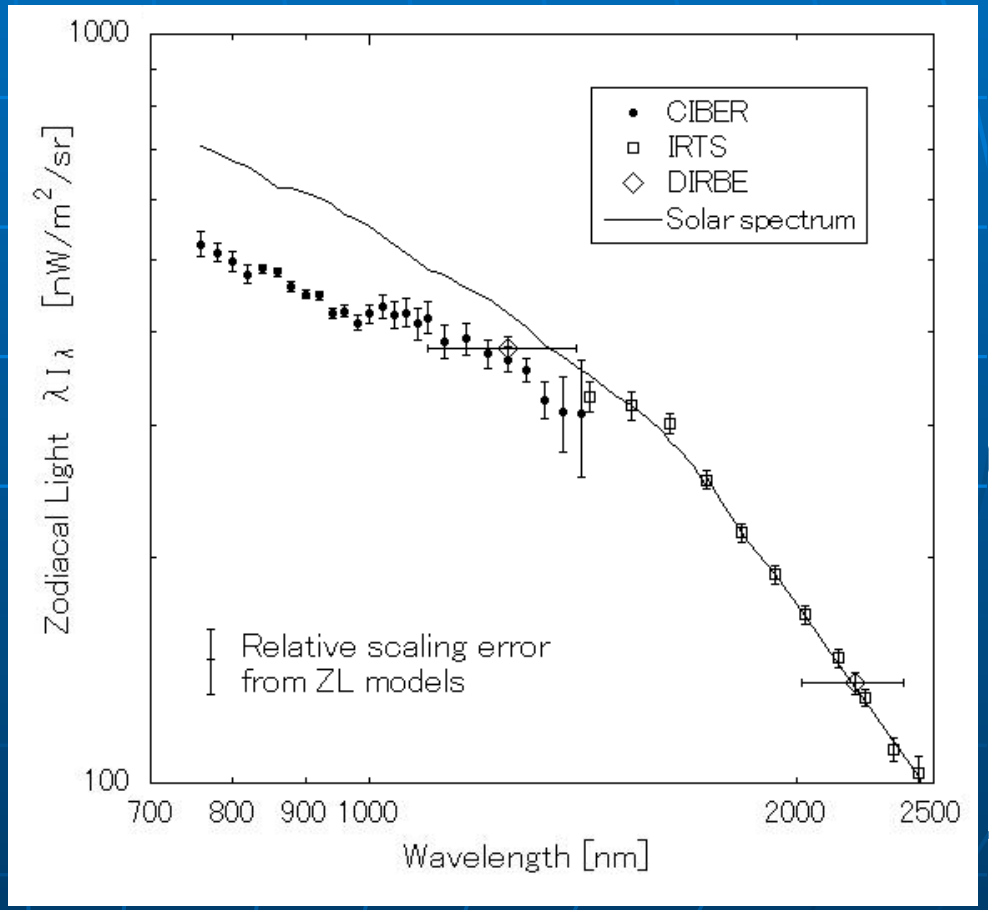


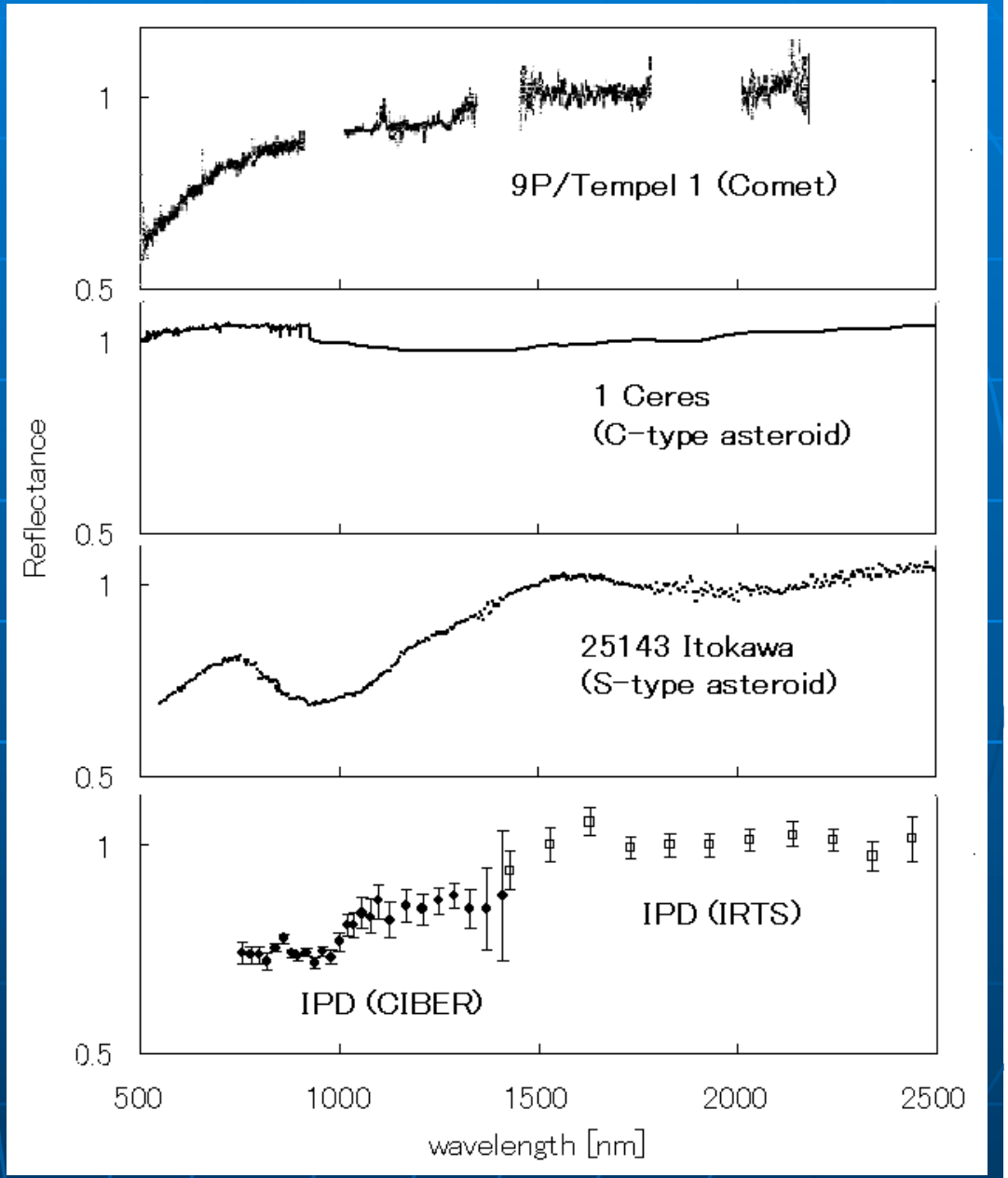
Zodiacal light spectrum

- ZL spectrum was derived by differencing in two fields
- Similar spectral shape from various differencing combination
- Redder than solar spectrum
- We normalized LRS and IRTS data to the brightness expected by DIRBE model



IPD reflectance

- IPD reflectance was derived by dividing ZL spectrum by the solar spectrum
- Similar to the S-type asteroid spectrum



Spectral feature

- Sp
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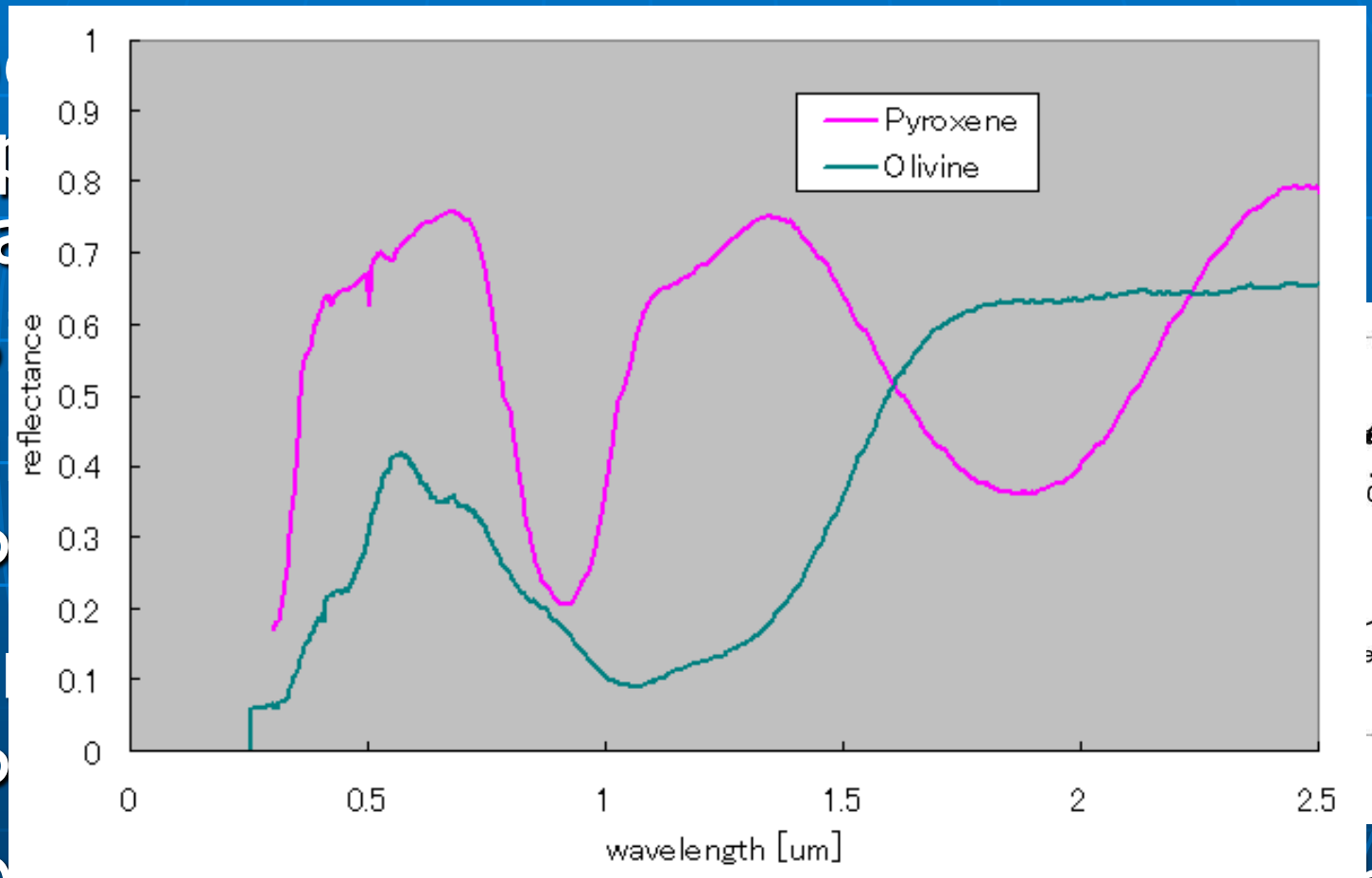
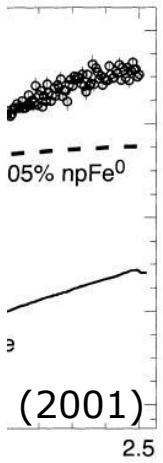
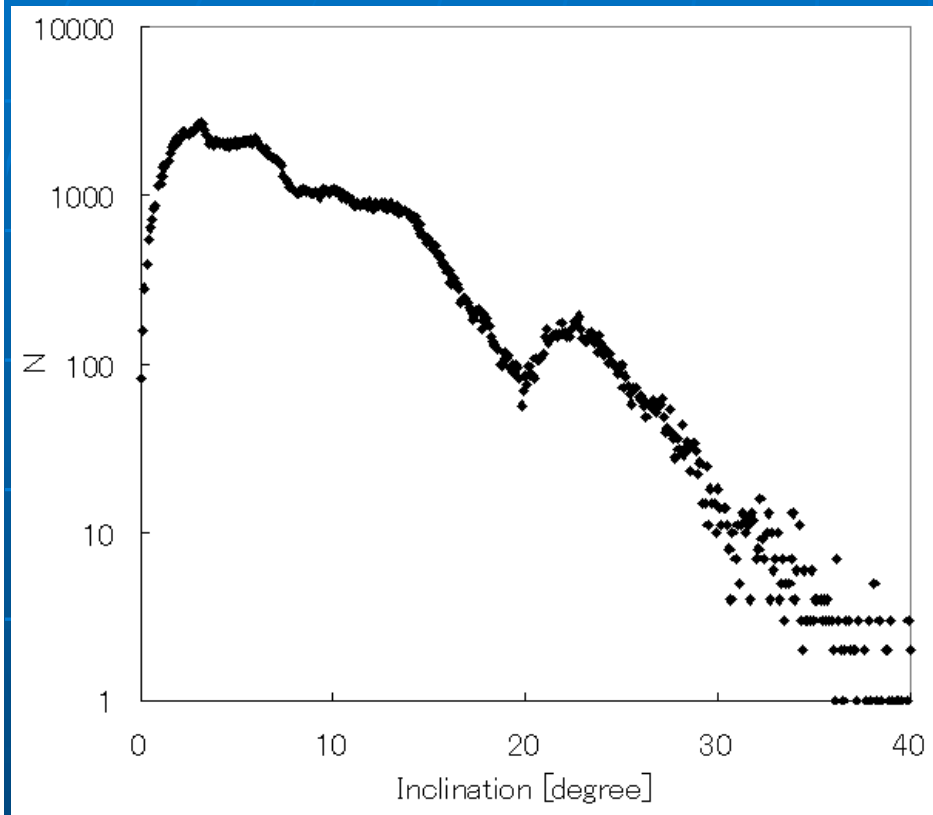
  (B
- 1μ
  P
- 2μ
  P

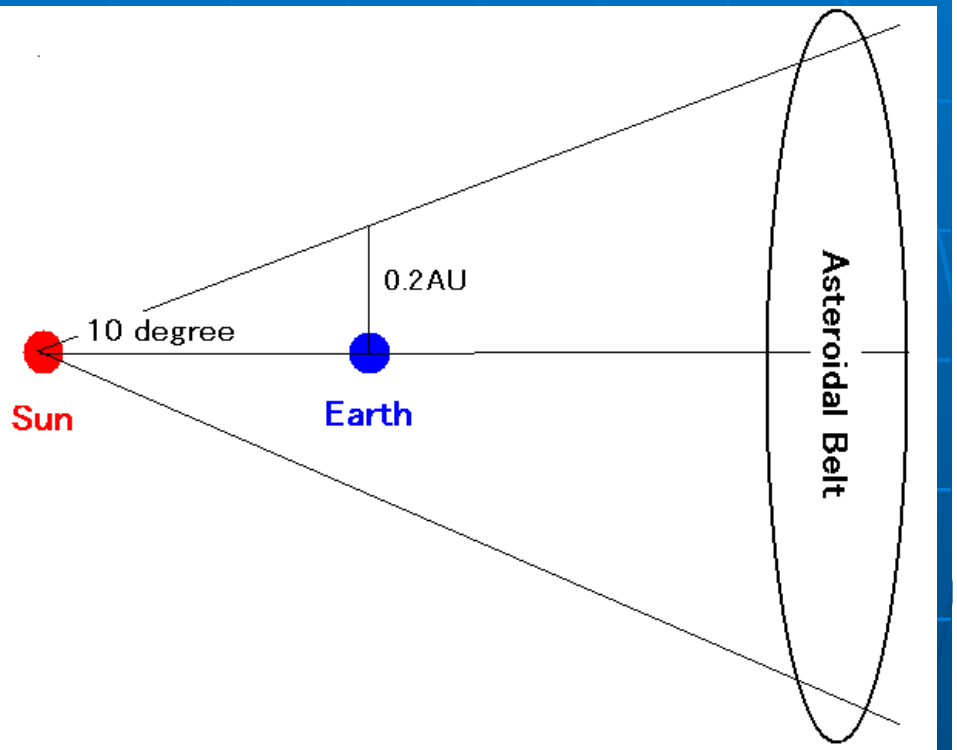




Our 2L spectrum is also explained by Silicate dust with space weathering

Asteroid vs Comet



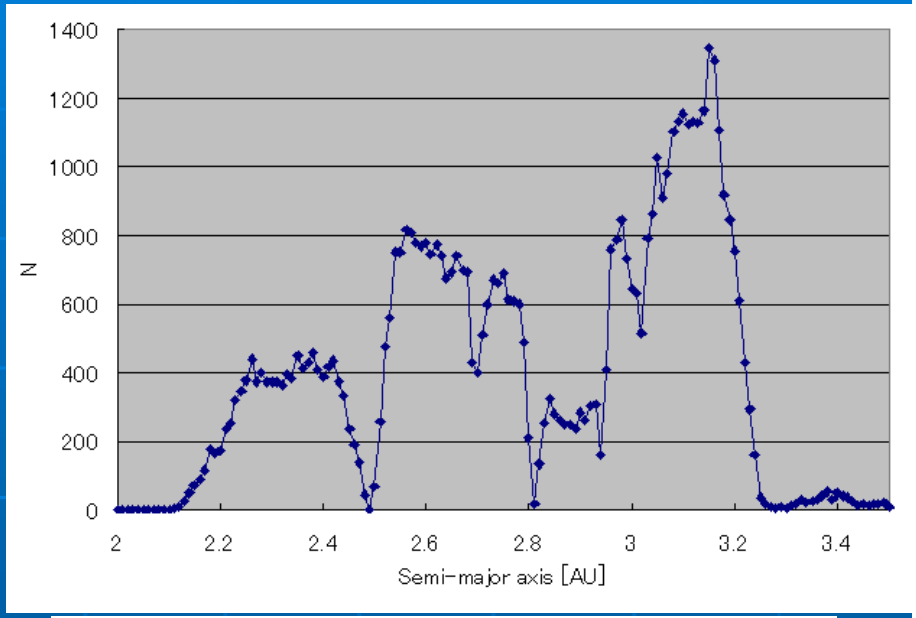


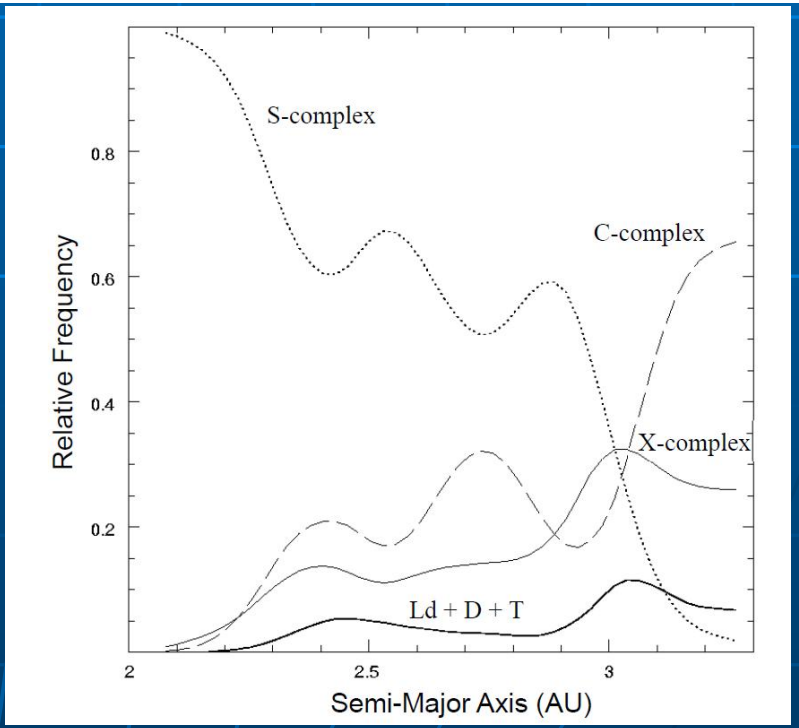
C-type / Comet ~0.05

- Existence of Asteroidal dust bands.

S-type vs C-type

- Dust production rate ∝ n^2
  → S:C = 5:3
- S-type has higher albedo (~0.2) than C-type (~0.05)





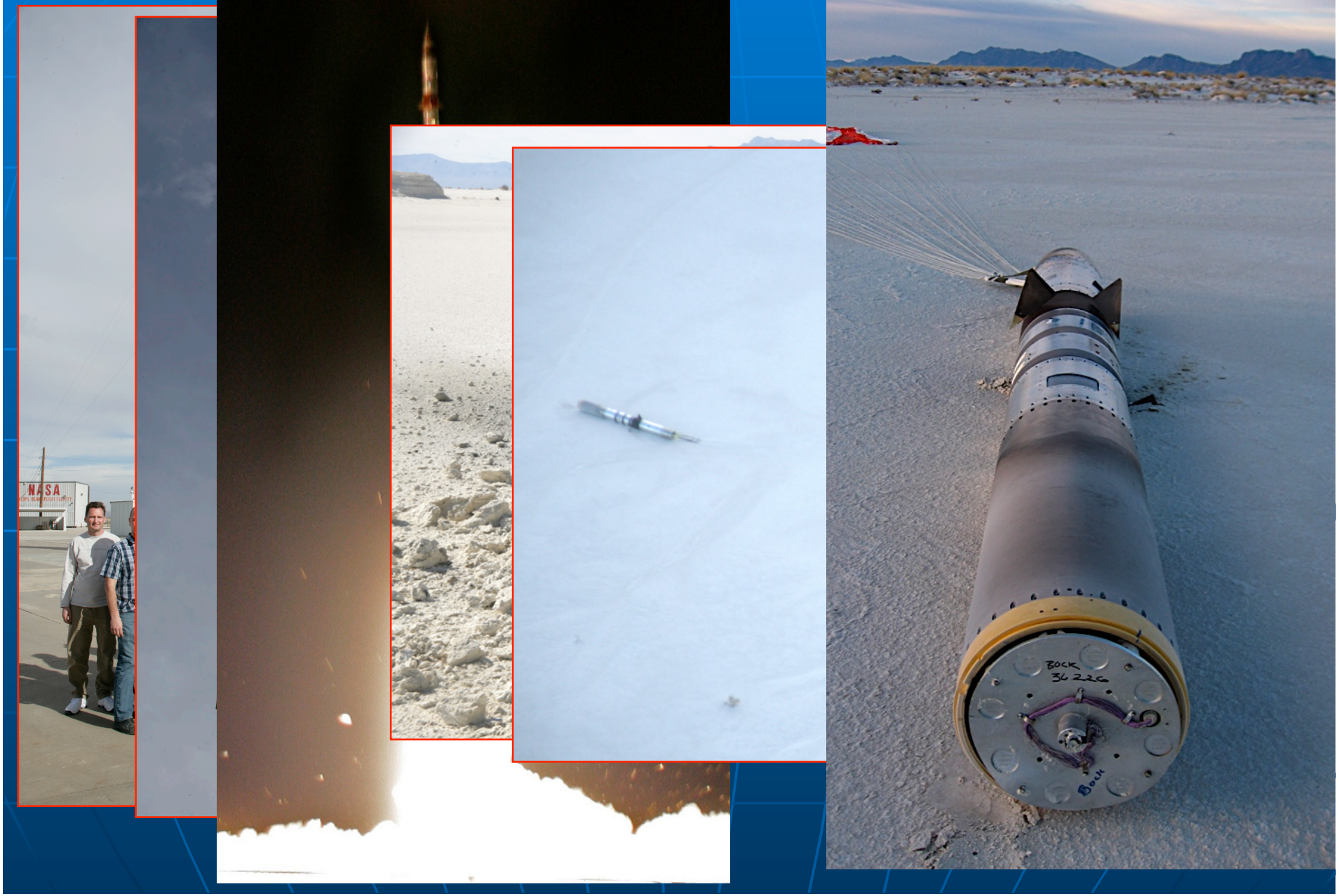
Mothe-Diniz et al. (2003)

Summary

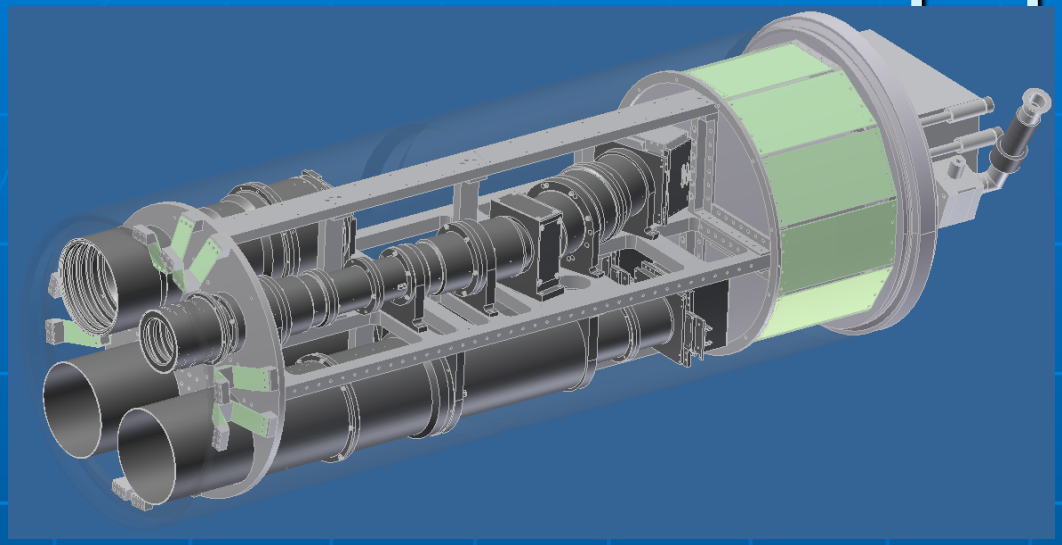
- We successfully launched CUBER and obtained 750-1400nm spectrum of the zodiacal light
  - Redder spectrum than the solar spectrum
  - Similar spectrum over the wide range of ecliptic latitude (10-90 degree)
- Broad absorption band at ~900nm
  - Pyroxene and/or Olivine
- Derived IPD reflectance was similar to S-type asteroid
- CIBER 2nd Flight is coming soon! (June 2010)

Appendix

The X day



CIBER equipments



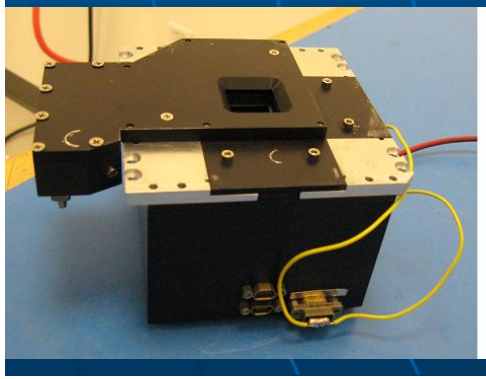
← CIBER cryostat

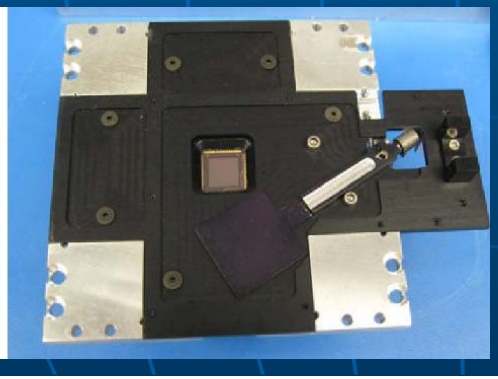
cooling by LN2 to reduce the thermal emission.

↓ Shutter door

↓ Focal Plane Assembly

HgCdTe detector array
Cold shutter
Read-out electronics

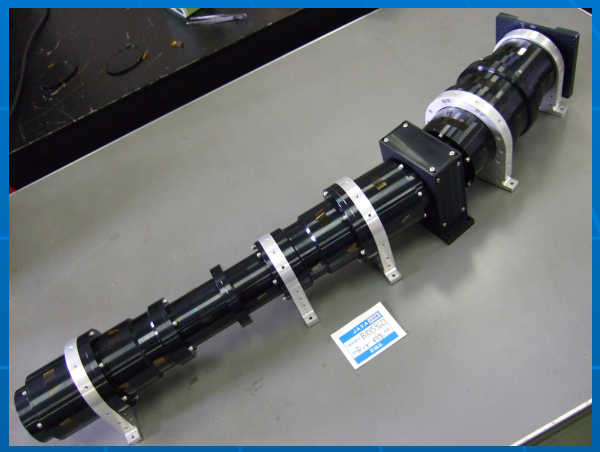


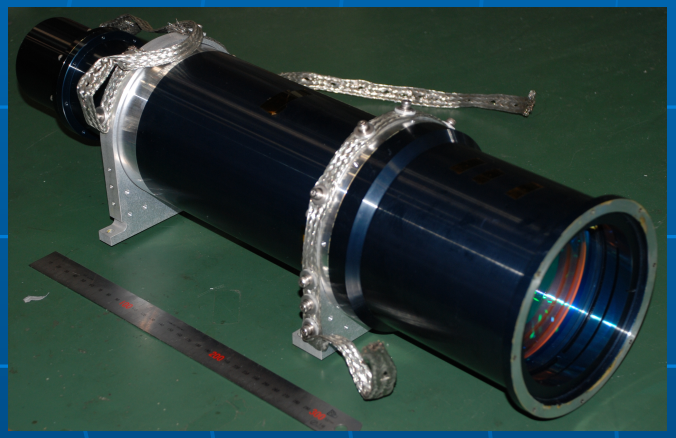


CIBER optics

Low Resolution Spectrometer (LRS)

- Spectroscopy at 0.7μm~2.1μm
- 5cm apertures, Multi-slits
- Prism dispersion (λ/Δλ~20)



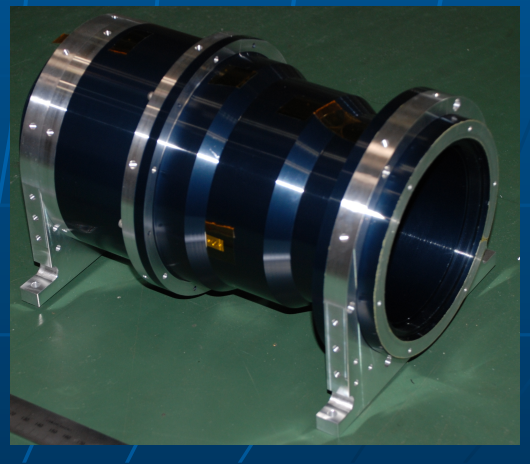


Two-Color Wide-Field Imagers

- 7arcsec~2deg fluctuation
- Two color imaging (H and I band)
- 11cm aperture

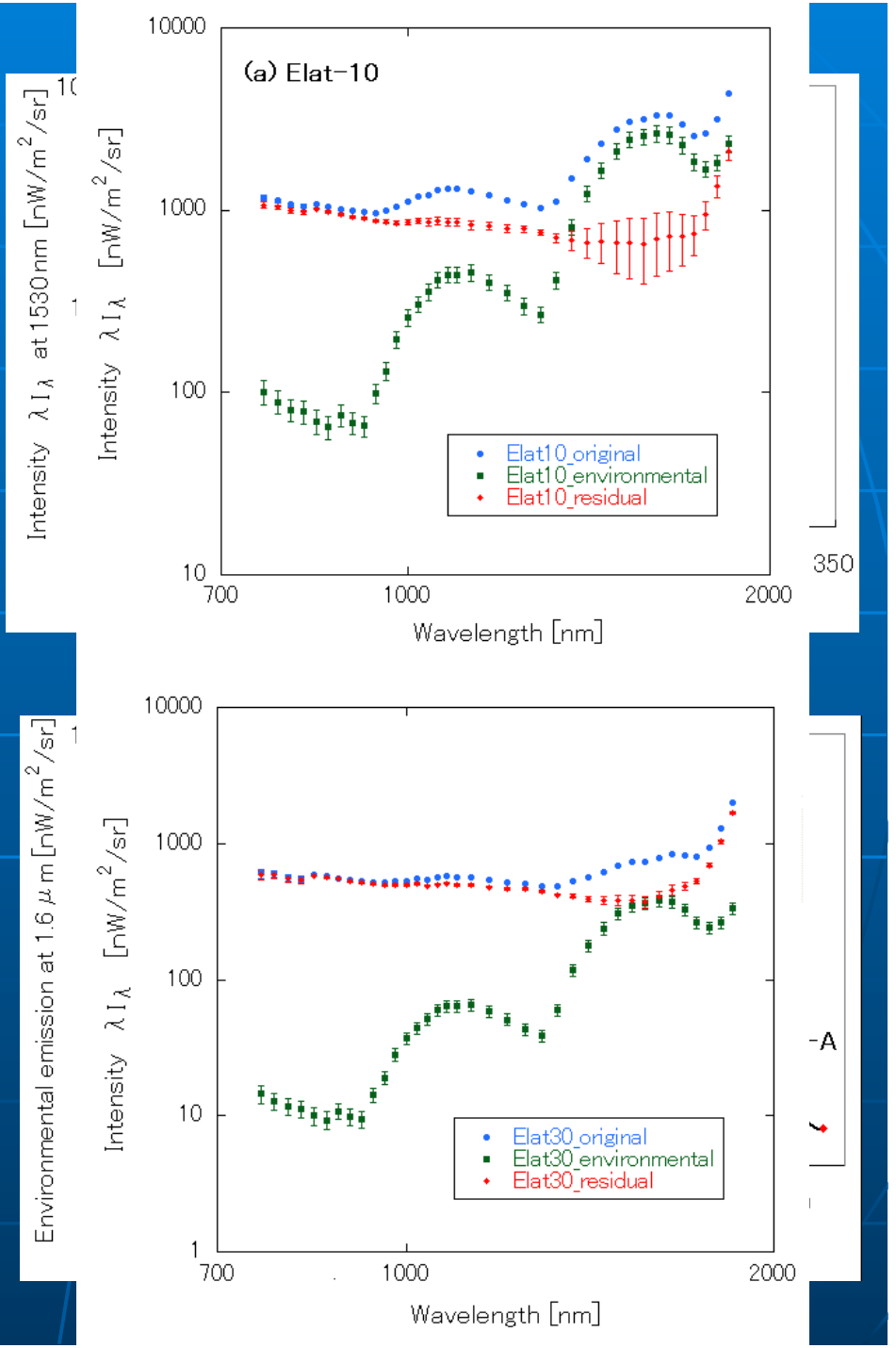
Narrow Band Spectrometer (NBS)

- Fraunhofer line (854.2nm CaII) observation for ZL photometry
- 7.5cm aperture
- Fabry-Perot dispersion (λ/Δλ~1000)



Stray emission

- Strong thermal stray light
  - We simply omit data at >1.8um.
- Airglow emission
  - Time-exponential time dependence
  - Peak at 1.6um and 1.1um <- OH molecule
  - Negligible except at Elat-10 and Elat-30
  - We subtracted the airglow emission based on the time-dependant.



Zodiacal light -> Near-Earth IPD

- ZL in near-IR is the scattered light of the sunlight
  - Biased by high-albedo dust

    Albedo: S-type ~0.2

    C-type / Comet ~0.05
- ZL is dominated by near-earth IPD

$$\frac{I(\mathrm{R})}{I(1\ \mathrm{AU})} = R^{-2.5\pm0.2}$$

Toller & Weinberg (1985)
with Pioneer 10

Contribution to ZL from R>2.5AU is <3%