The all-important ***signal-to-noise ratio***

- Estimate from the "CCD Equation":

$$\frac{S}{N} = \frac{N_*}{\sqrt{N_* + n_{pix}(N_S + N_D + N_R^2)}}$$

- N_* = photons (or equivalent e^-) from target object(s)
- n_{pix} = # of pixels
- N_S = photons/e^- from "background" ("empty" sky in astronomy)
- N_D = dark current
- N_R = read noise

Note that if $N_* >> $ the noise terms, then S/N ~ $\sqrt{(N_*)}$

Increases as *square root of* **integration time:**

$$\frac{S}{N} = \frac{Nt}{\sqrt{Nt + n_{pix}(N_S t + N_D t + N_R^2)}}.$$

Time Delay Integration / Drift Scanning

- Read out CCD ***while imaging***

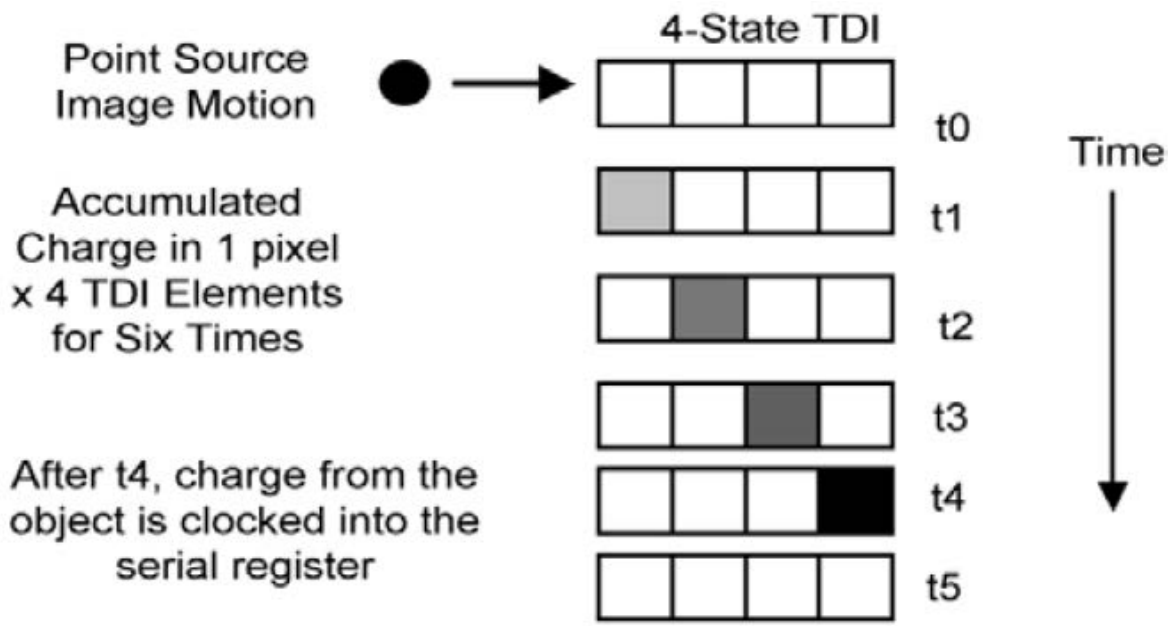
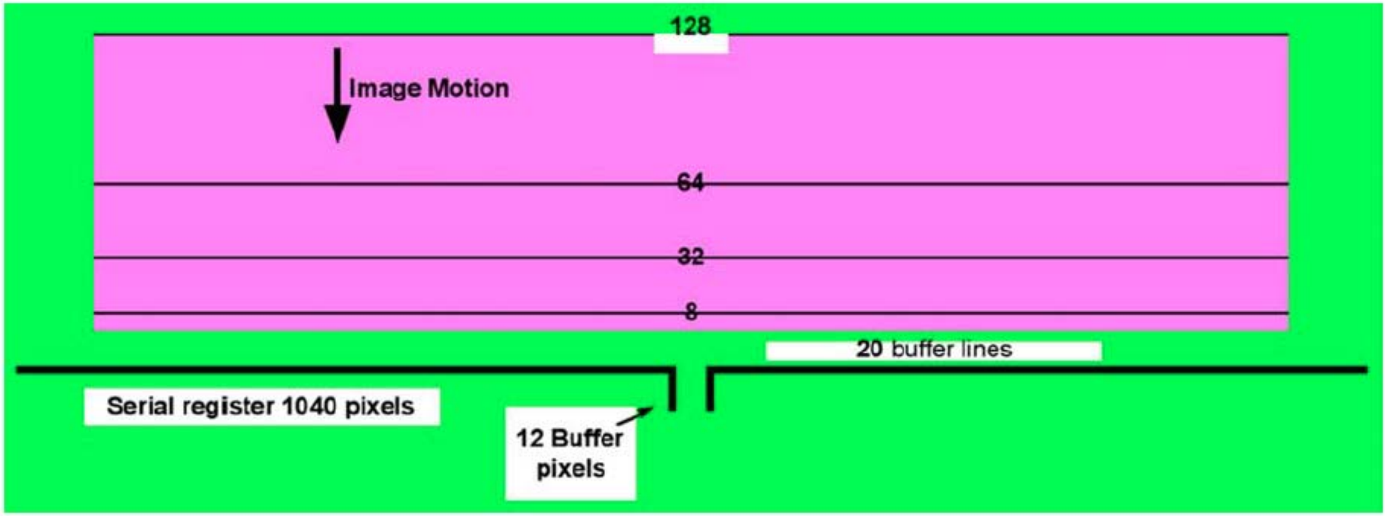


Figure 6. Illustration of 4-line Time Delay and Integration (TDI). HiRISE can use 8, 32, 64, or 128 TDI lines.

- Must transfer charge at exact rate of target motion relative to CCD
- Can greatly improve integration time (and thus S/N)

Time Delay Integration with HiRISE



dark

Figure 7. Layout of each HiRISE CCD. There are 4 sections of lines corresponding to the 4 TDI choices, plus 20 buffer lines (read out once at the beginning of each image). The data is read out into 2 channels from a tap in the middle of the array, beginning each line with 12 buffer pixels and ending with 16 masked pixels. Channel 0 is on the right and channel 1 on the left side, as viewed here, so the data from channel 1 must be "mirrored or flipped left to right to restore the proper image orientation. (Note that spacecraft motion is up here, whereas it is down in Figure 5.)

bias

HiRISE flat fielding

- Pre-launch data, onboard LEDs, and …

  imaging Mars sideways!

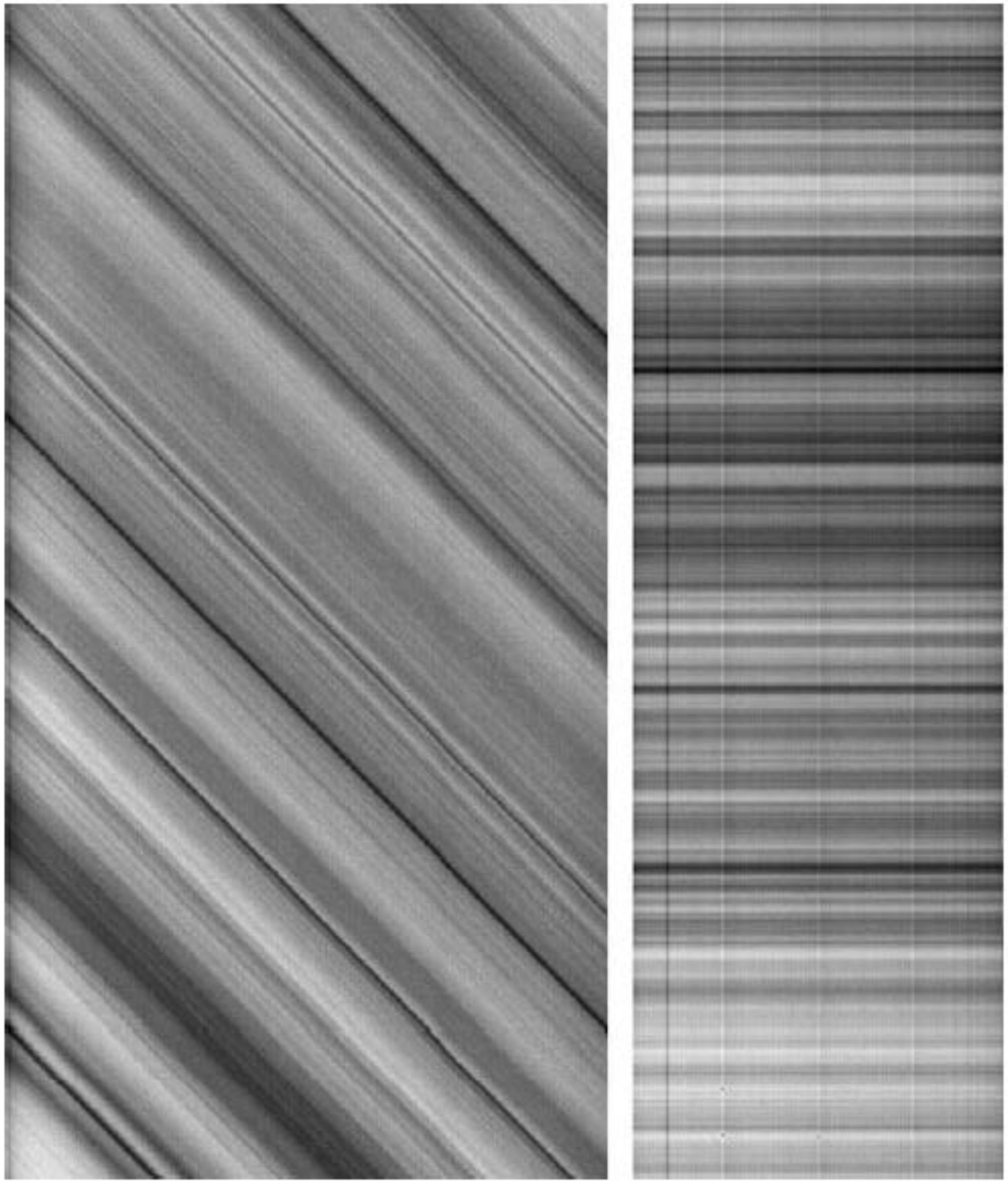


Fig. 5. HiRISE "flat-field" images produced by imaging when MRO was yawed 90° to the ground track. At left is a TDI 64 bin 2 single channel image. The slanted appearance of bright and dark bands is the result of the spacecraft motion during TDI integration, recording brightness variations on Mars that are smeared along each band. At right is a realigned TDI 128 bin 1 single-channel image useful for calibration.

Frame Transfer or Interline CCDs

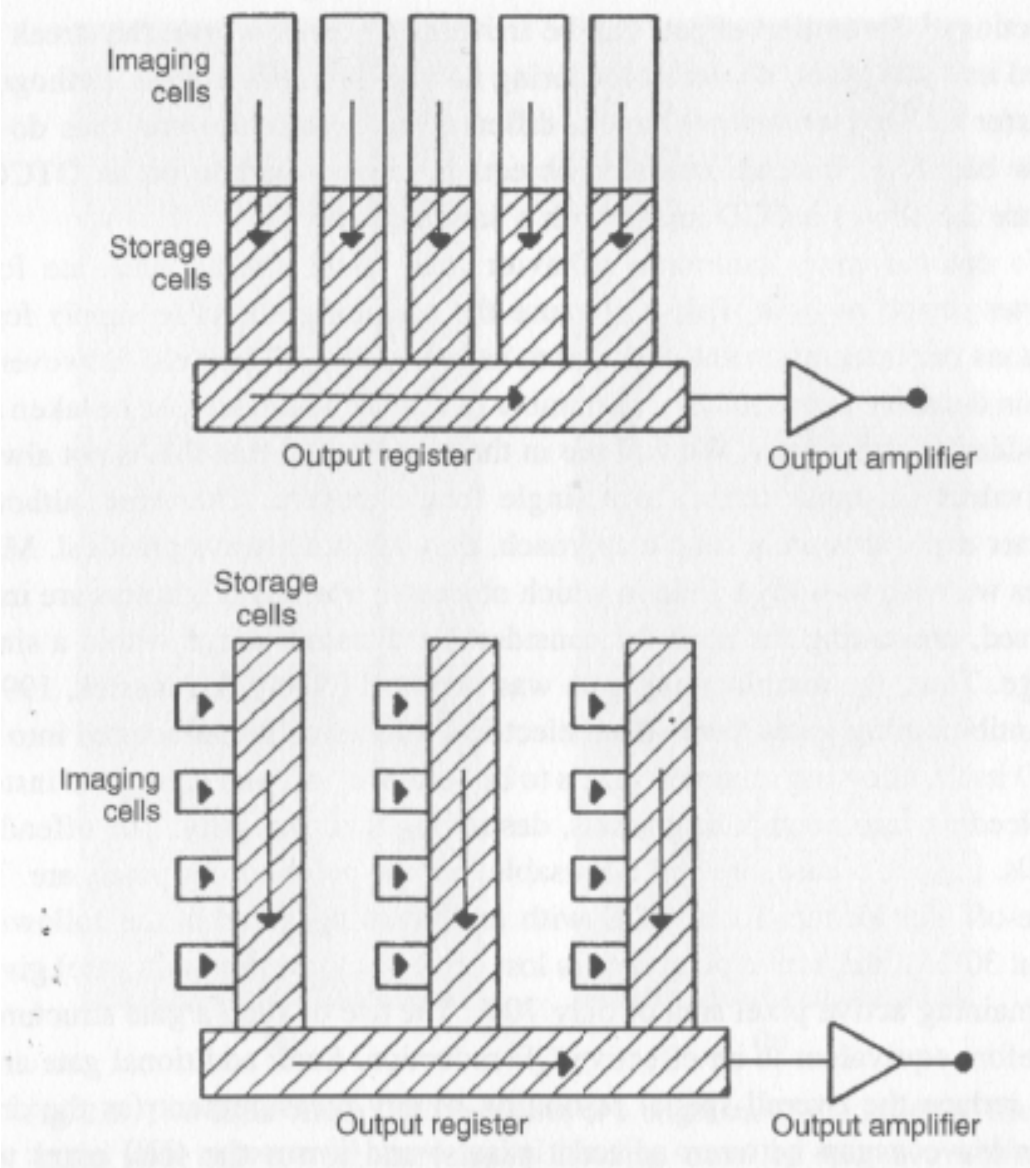


Fig. 2.5. Cartoon view of (top) a frame transfer CCD and (bottom) an interline CCD. From Eccles, Sim, & Tritton (1983).

Can take new image during readout, but "waste" half the array on shielded (inactive) pixels

Antiblooming CCDs

Devote ~30% of each pixel area to
"drain gate" for excess electrons
rather than imaging

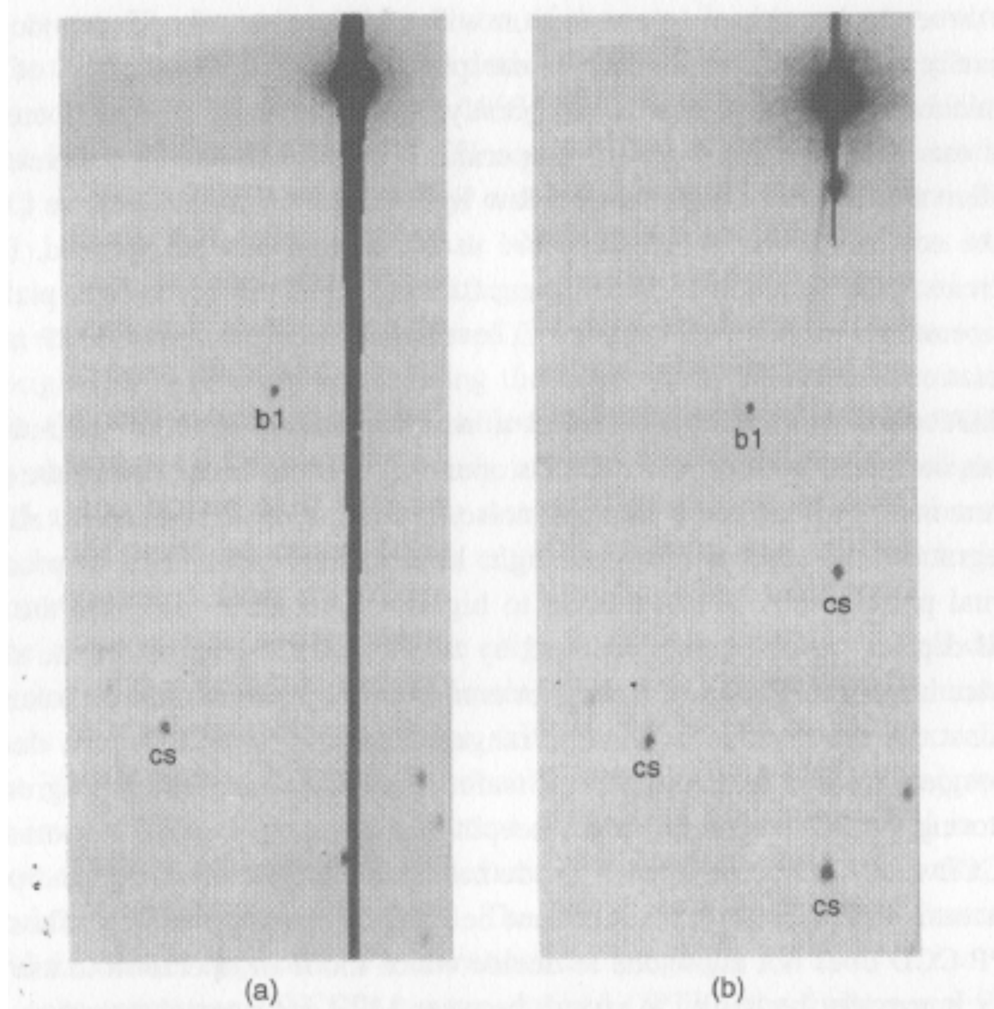


Fig. 2.6. Two equal-length CCD exposures of a bright star (SAO 110456). The normal CCD exposure (a) shows typical bleeding caused by saturation within the CCD. The CCD exposure on the right (b) was made with an antiblooming CCD and clearly shows the much reduced bleeding from the bright star. From Neely & Janesick (1993).

Related (non-CCD) devices

- Complementary Metal Oxide Semiconductor (CMOS) detector arrays incorporate extra circuitry into each pixel
  - *Each pixel produces its own DN!*
  - *Can do additional signal processing on the chip*
  - *Reduced QE (~20%)*
  - *Increasingly popular commercially (e.g., iPhone camera)*

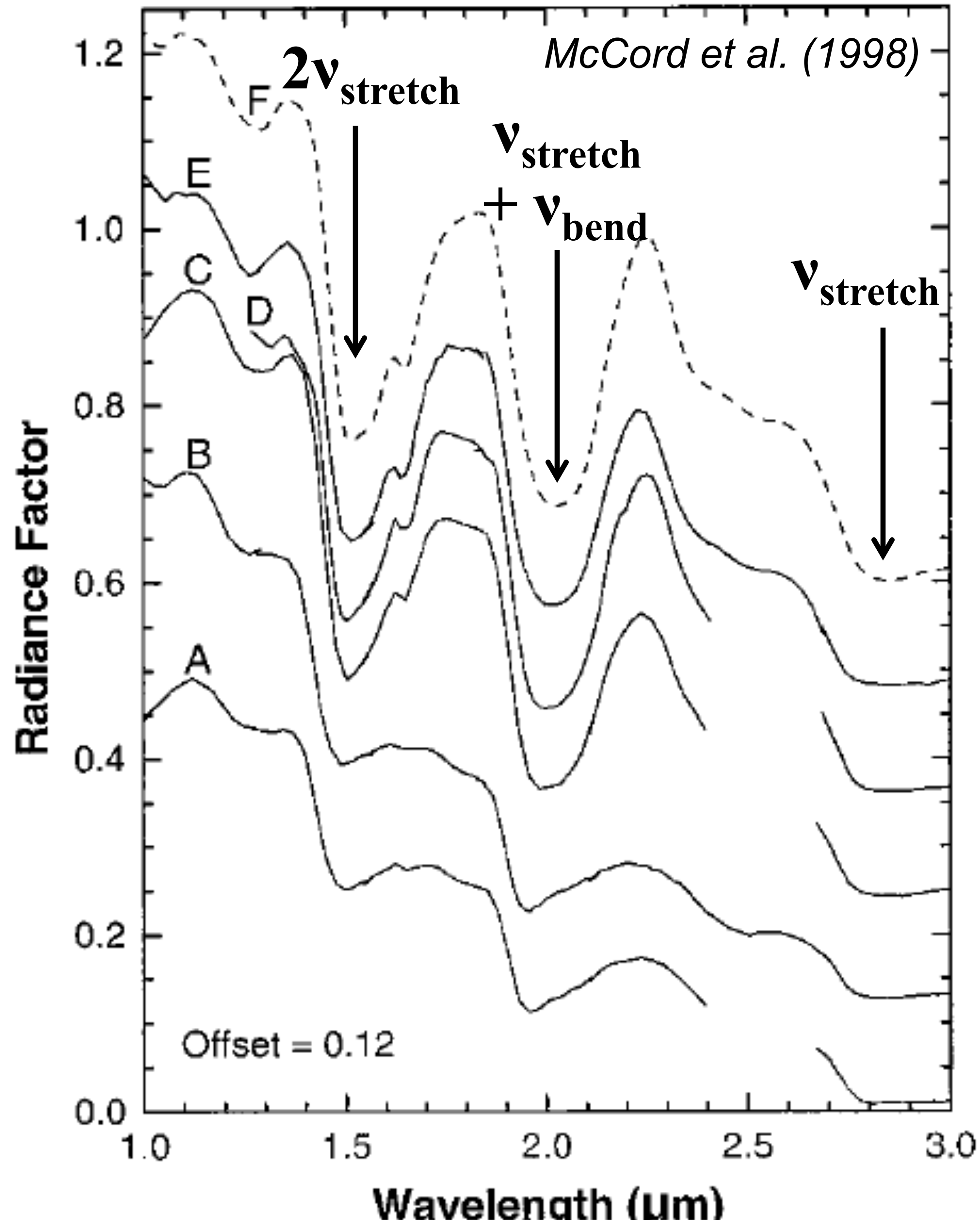
- Superconducting Tunnel Junction (STJ) devices generate multiple electrons from each incident photon
  - *# is proportional to photon energy → instant spectra!*
  - *CCDs do this with X-ray photons; STJs can do it with UV/visible/IR*

Water vibrations: ice vs. hydrated minerals

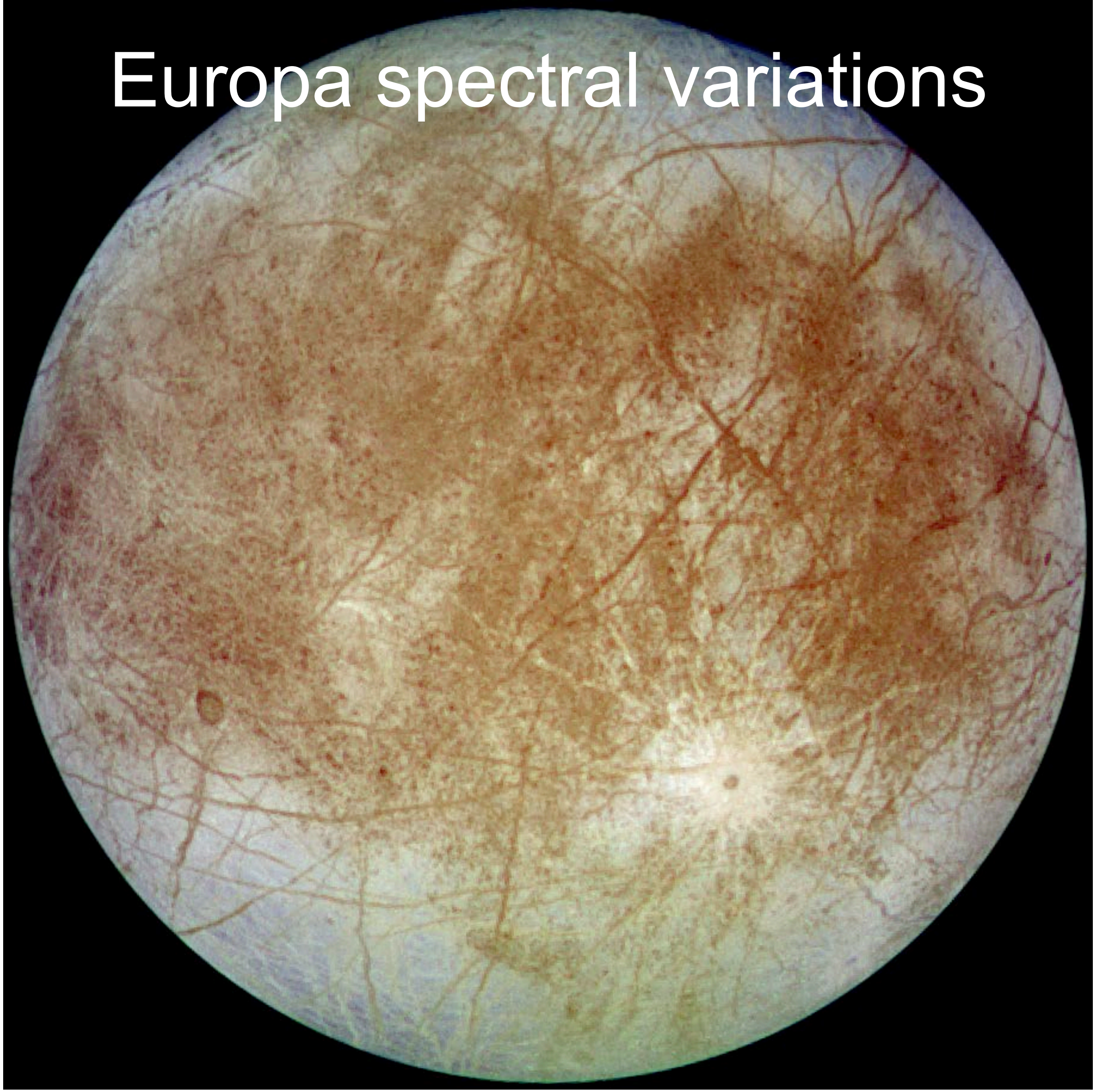
A – D are Europa,

E is Ganymede,

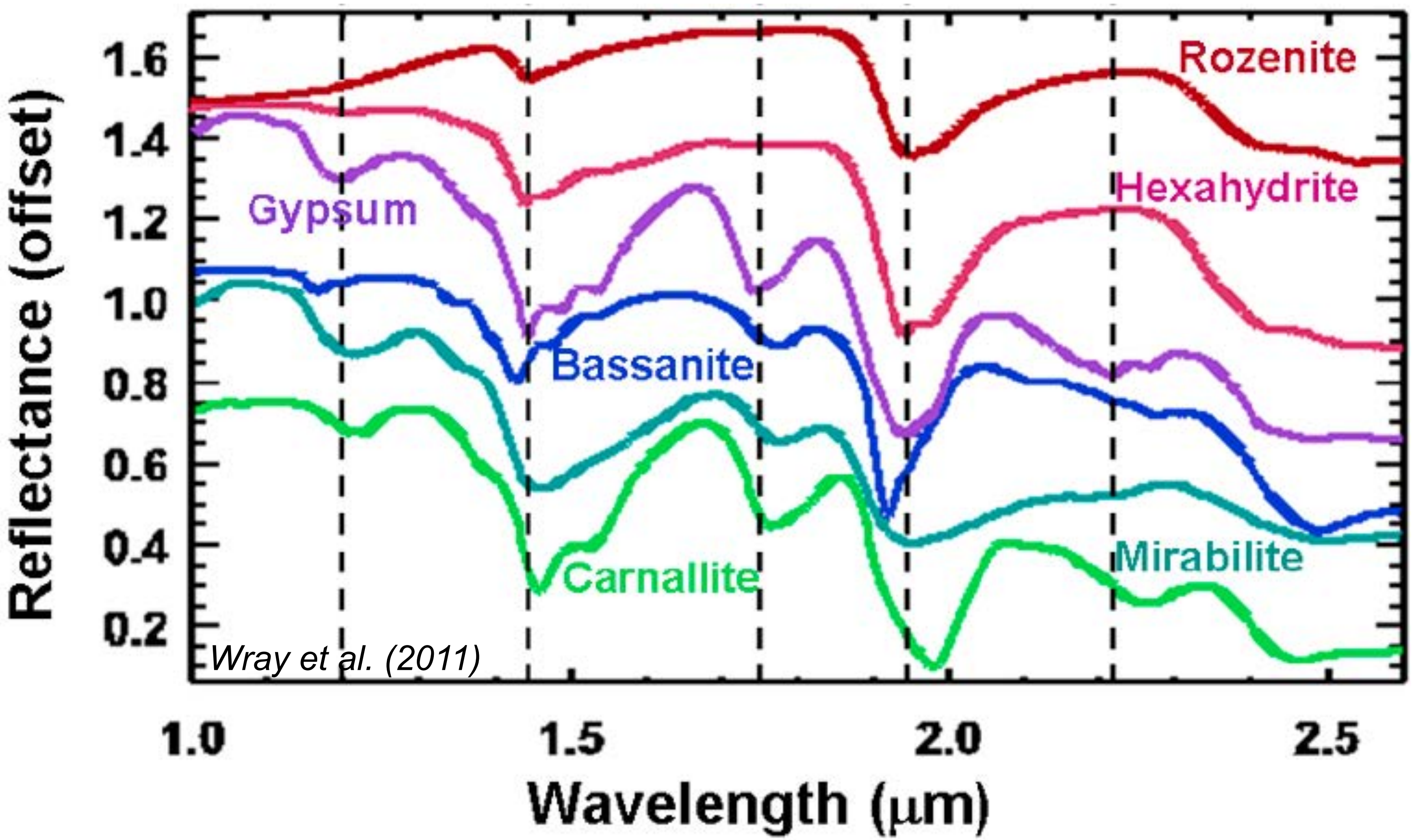
F is model ice spectrum



Europa spectral variations



Hydrated salt spectra



Essentially all features due to H_2O/OH vibrations