6 High contrast imaging

6.2 Coronagraphy

Why coronagraphy ?
What do coronagraph do, when are they useful ?

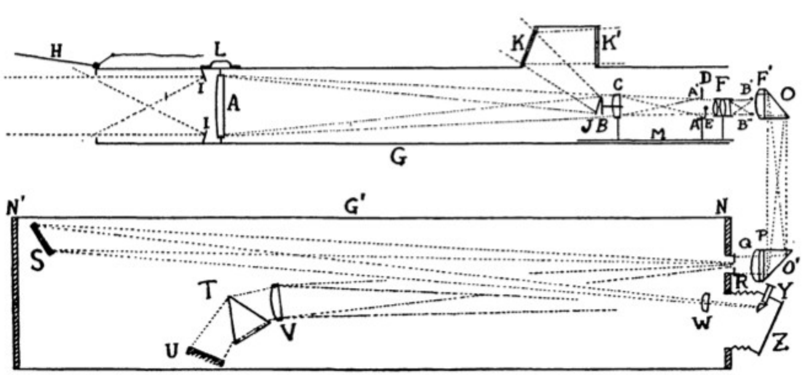
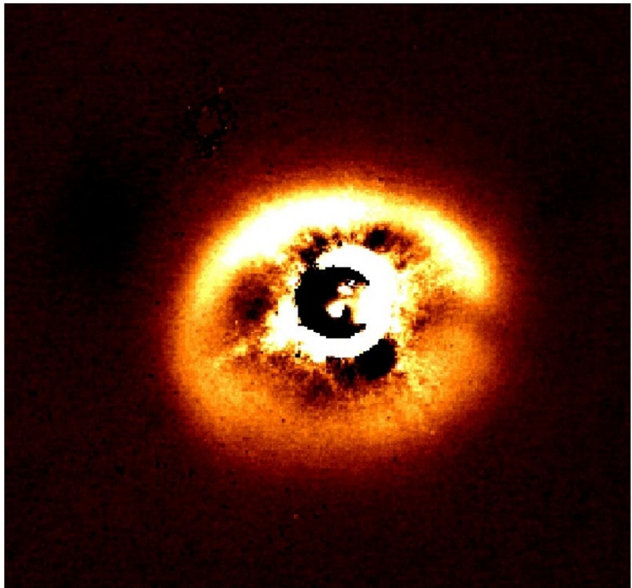
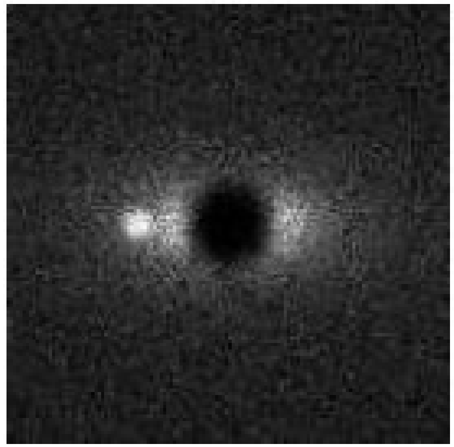


Fig. 4. Plan of the mounting of the coronograph (above) and the spectrograph.

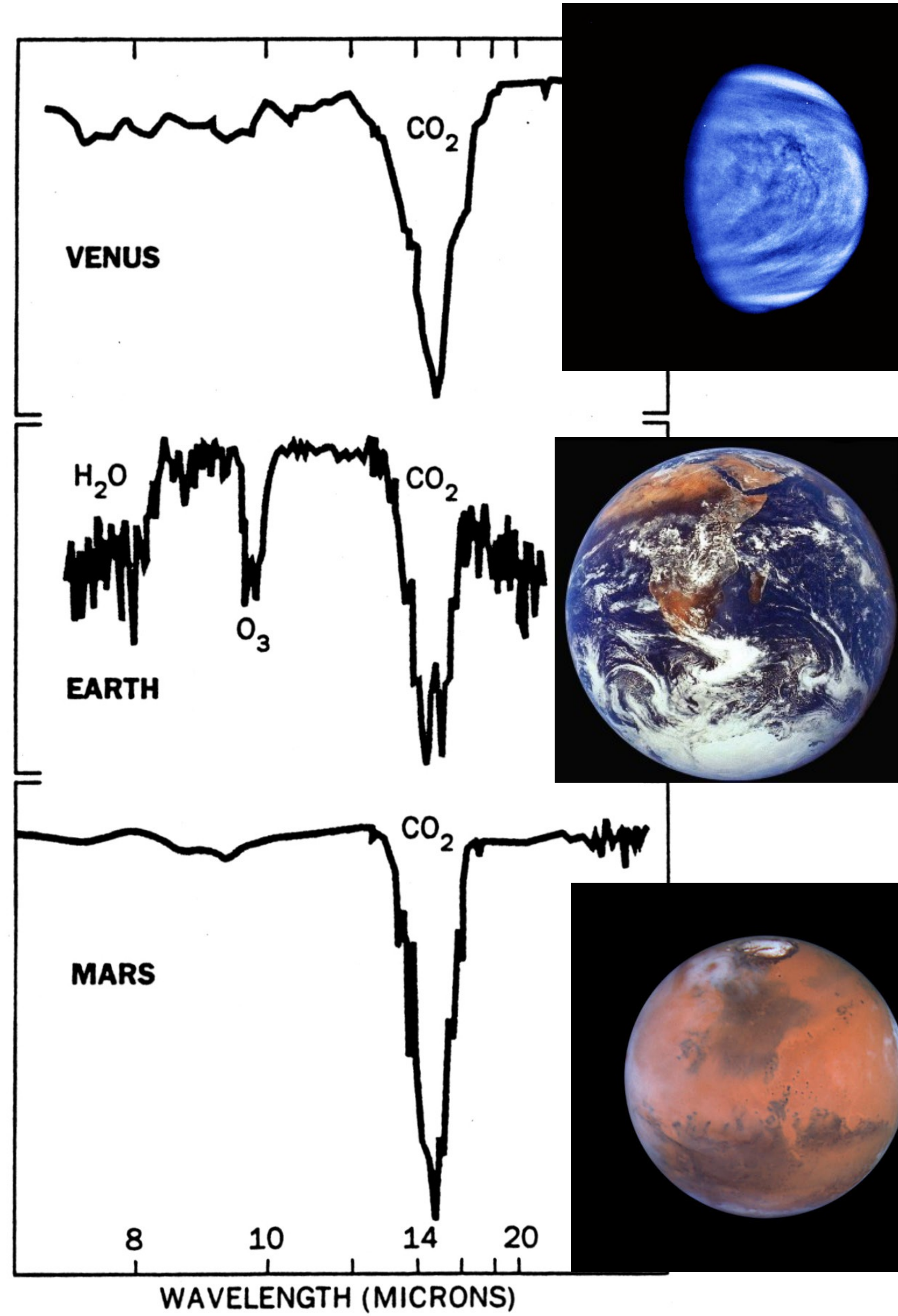


Coronagraphs allow direct imaging



- Orbit
- Atmosphere composition
- Continents vs. Oceans ?
- Rotation period
- Weather patterns
- Planetary environment :

  Planets + dust



Challenges

- **Contrast**
  - Visible:
    - 1e10 for Earth/Sun -> space
    - 1e9 for Jupiter/Sun -> space / ELTs ?
    - ~1e8 for close-in planets -> ground ExAO ?
  - Near-IR (~1.6 micron)
    - 1e10 for Earth/Sun
    - ~1e12 for Jupiter/Sun
    - ~1e7 for young giant planet / Sun -> Ground ExAO
  - Thermal IR (~10 micron)
    - 1e6 for Earth/Sun
    - 1e7 for Jupiter/Sun
- **Angular separation** (HZs at ~0.1”)
- **Exozodiacal light**

Why do we need coronagraphs ?

Coronagraph can only remove known & static diffraction pattern
BUT:
- static & known diffraction can be removed in the computer
- coronagraphs don’t remove speckles due to WF errors

Fundamental reasons:
(1) Photon Noise
(2) Coherent amplification between speckles and diffraction pattern

Practical reasons:
(3) Avoid detector saturation / bleeding
(4) Limit scattering in optics -> “stop light as soon as you can”

Coherent amplification between speckles and diffraction pattern

Final image = PSF diffraction (Airy) + speckle halo

This equation is true in complex amplitude, not in intensity.
Intensity image will have product term -> speckles are amplified by the PSF diffraction.

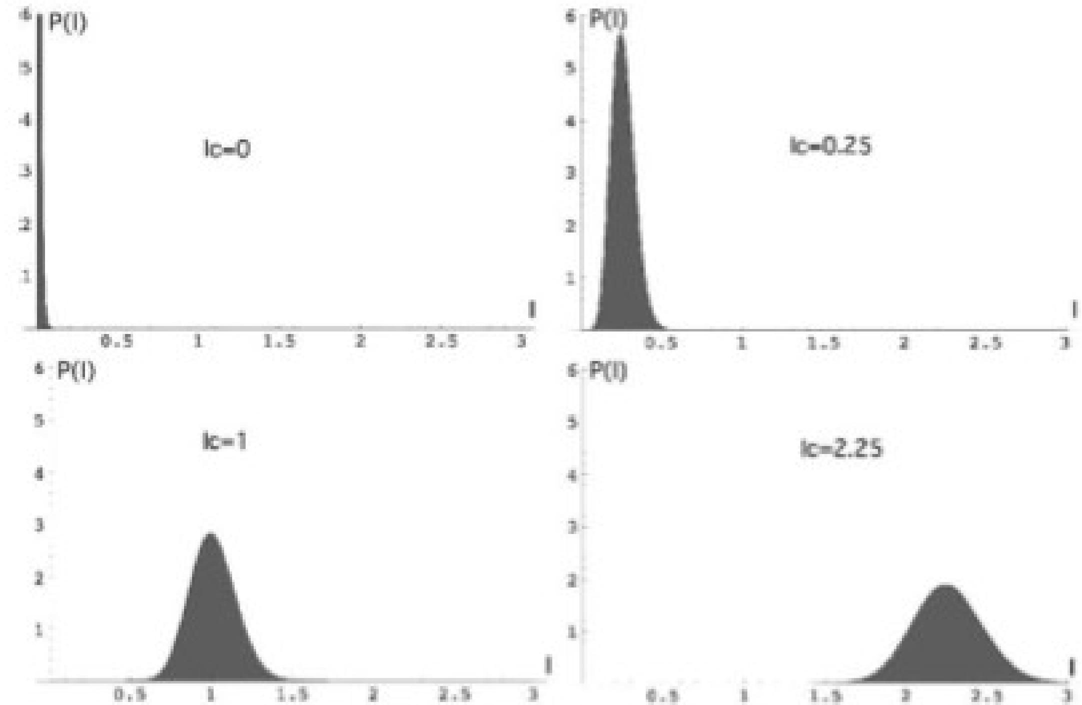


FIG. 3.—PDF of the light intensity at four different constant background intensity levels I_c and a single value of $I_s = 0.1$. High values of I_c correspond to locations near the perfect PSF maxima (rings), and low values of I_c correspond to locations near the zeros of the perfect PSF or far from the core. For $I_c = 0$ we have the pure speckle exponential statistics. The width of the distribution increases with an increase in the level of I_c. This explains speckle pinning; speckle fluctuations are amplified by the coherent addition of the perfect part of the wave.

Aime & Soummer 2004

When do we need coronagraphs ?

Coronagraphs serve no purpose if dynamic speckle halo is > diffraction
-> Very important to keep in mind to **avoid over-designing the coronagraph**, as this usually would mean giving up something (usually throughput)

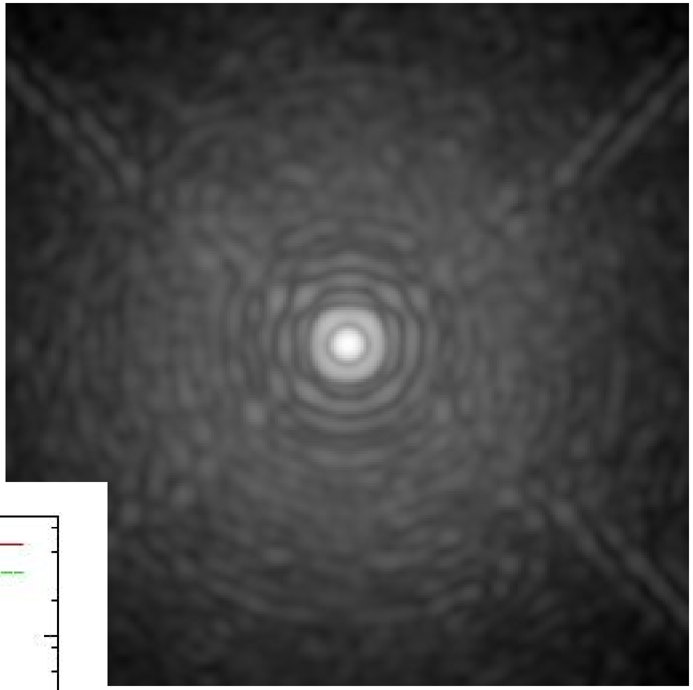
“Side effects” of coronagraphs :

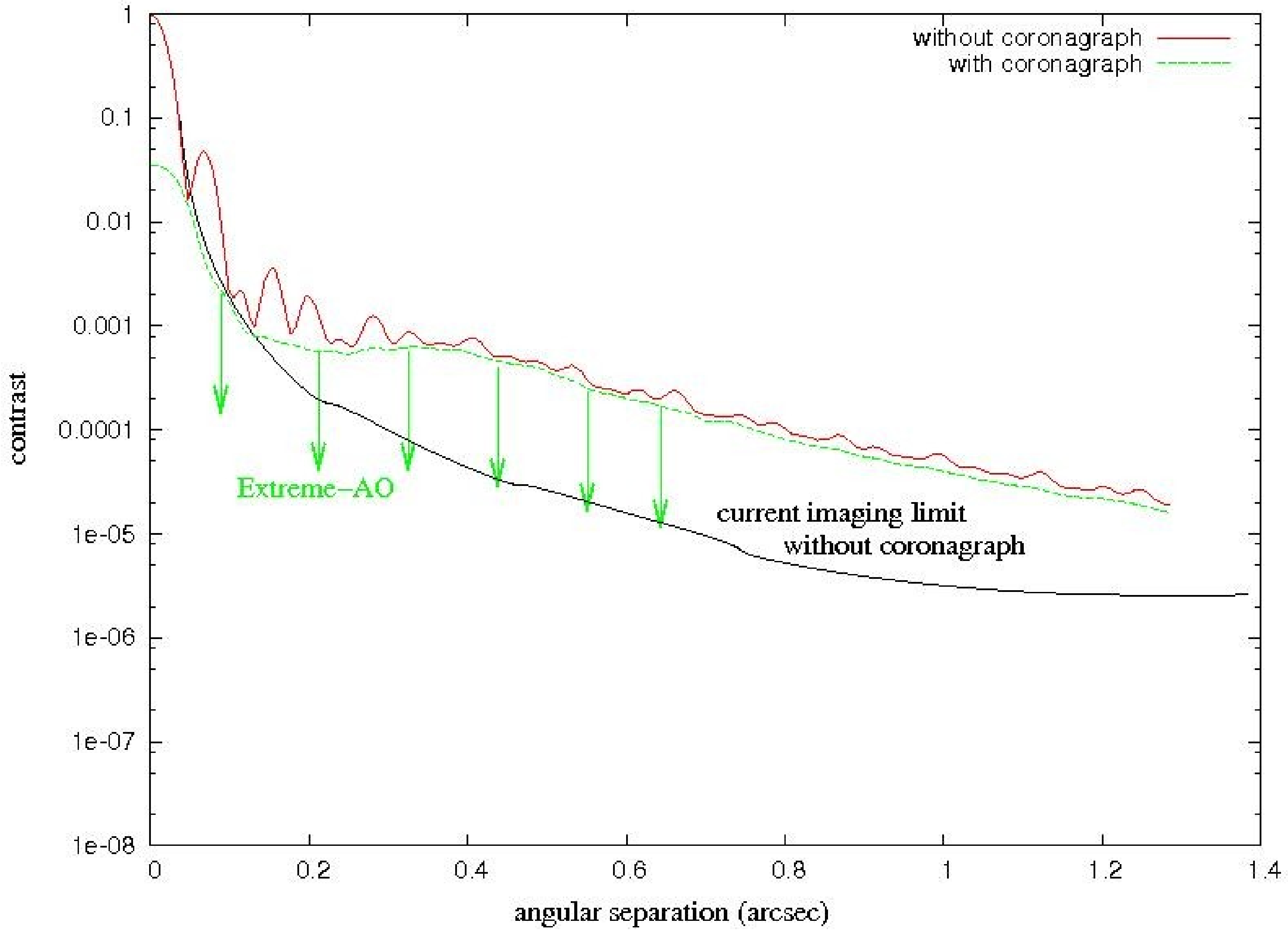
- (Usually) requires very good pointing. Risk of low order aberrations (for example pointing) creating additional scattered light in the region of interest

- data interpretation & analysis can be challenging (especially at inner working angle)

- Astrometry more difficult (solutions exist)

- None of the recent ground-based planet discoveries has been done with coronagraph
- With current Telescopes+AO systems, coronagraphs offer almost no help beyond ~0.3” in H band
- PSF calibration with coronagraphs is more complicated





ExAO systems currently under construction improve contrast with AO + coronagraphy

PSF calibration strategies

- **“classical” PSF subtraction**
- **Angular Differential Imaging**
  - works well at large angular separations, where aberrations have large static component
  - poor performance close in to the star
- **Spectral / Polarimetric differential imaging**
  - works great IF source has expected spectral signature or is polarized
- **Coherent differential imaging**
  - highly flexible, does not make any assumption about source
  - combined wavefront sensing / PSF calibration
  - works within control radius of DM