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AFTA-C Introduction and Update

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The AFTA Mission

- The 2010 Decadal Survey recommended WFIRST, a wide-field infrared survey telescope, for dark energy and exoplanets (gravitational microlensing)
- The WFIRST SDT delivered its report in summer 2012
- The NRO offered a 2.4-m telescope to NASA in early 2012
- NASA requested the SDT to study the 2.4-m for WFIRST, with an optional coronagraph
- The SDT delivered its report on WFIRST-AFTA in May 2013.
- C. Bolden approved continuing to study AFTA in May 2013, with a coronagraph included (but descopeable)
- The SDT continues to study the mission, with a goal of a new start in FY17 and a launch in 2024
- AFTA is still a study, not an approved mission; there are options for smaller missions should AFTA not be selected
- Meanwhile, GSFC leads the study, JPL leads the telescope and coronagraph elements, and ExEP has started a selection process for the coronagraph

Coronagraph Science Goals

- Exoplanet abundances, clouds, temperatures as functions of orbit, stellar mass, metallicity, and planet mass
- Example 1: NH_3 clouds will evaporate and H_2O clouds will dominate around 4 AU, and inside that distance H_2O band will start to show up, giving the abundance of C and O
- Example 2: Inside 1 AU we lose H_2O clouds and start to see Na and K absorption, giving abundances of C, O, Na, K, and maybe N, all a "home run" in terms of exoplanet science

Exoplanet Detection vs. Contrast and Working Angle

Source: WFIRST-AFTA STDT Report, May, 2013

550 nm:
1 λ/D = 47 mas

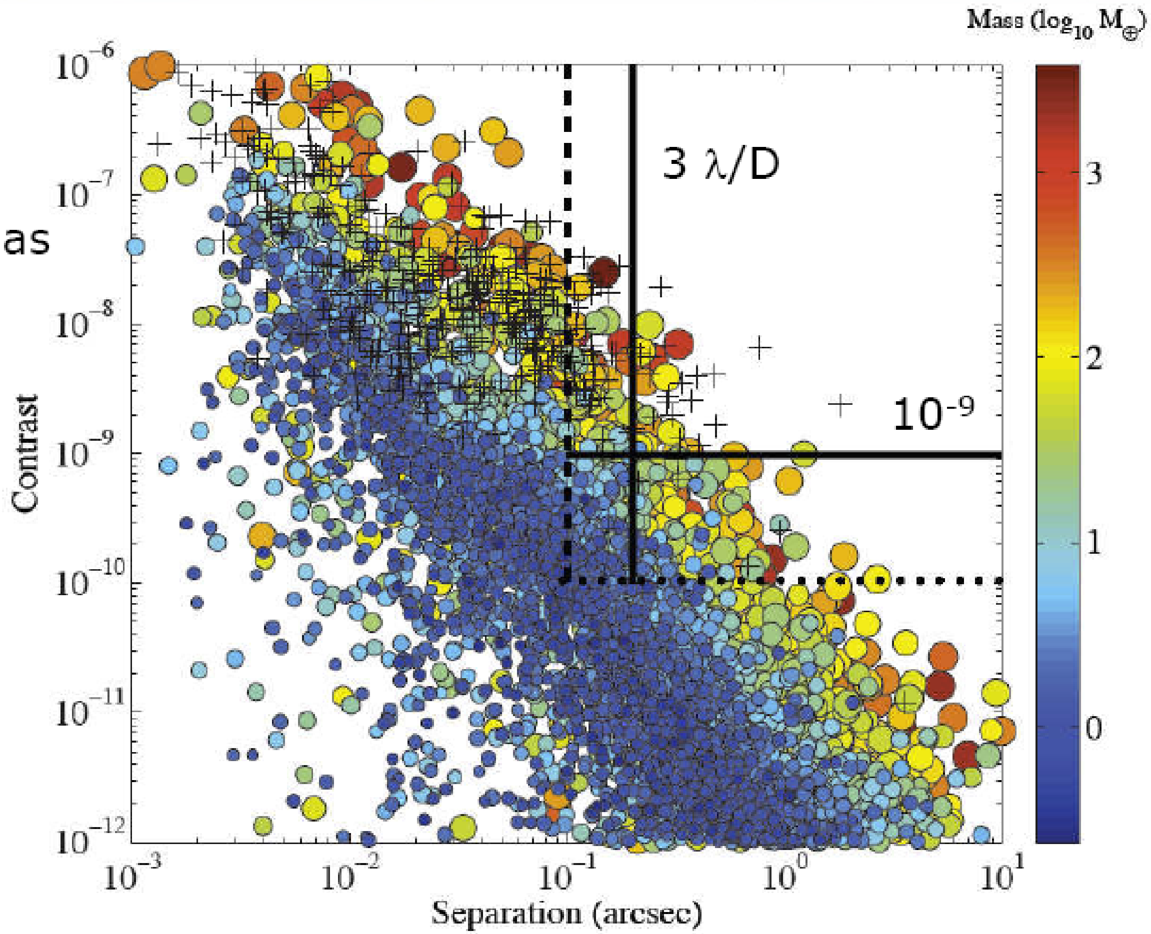
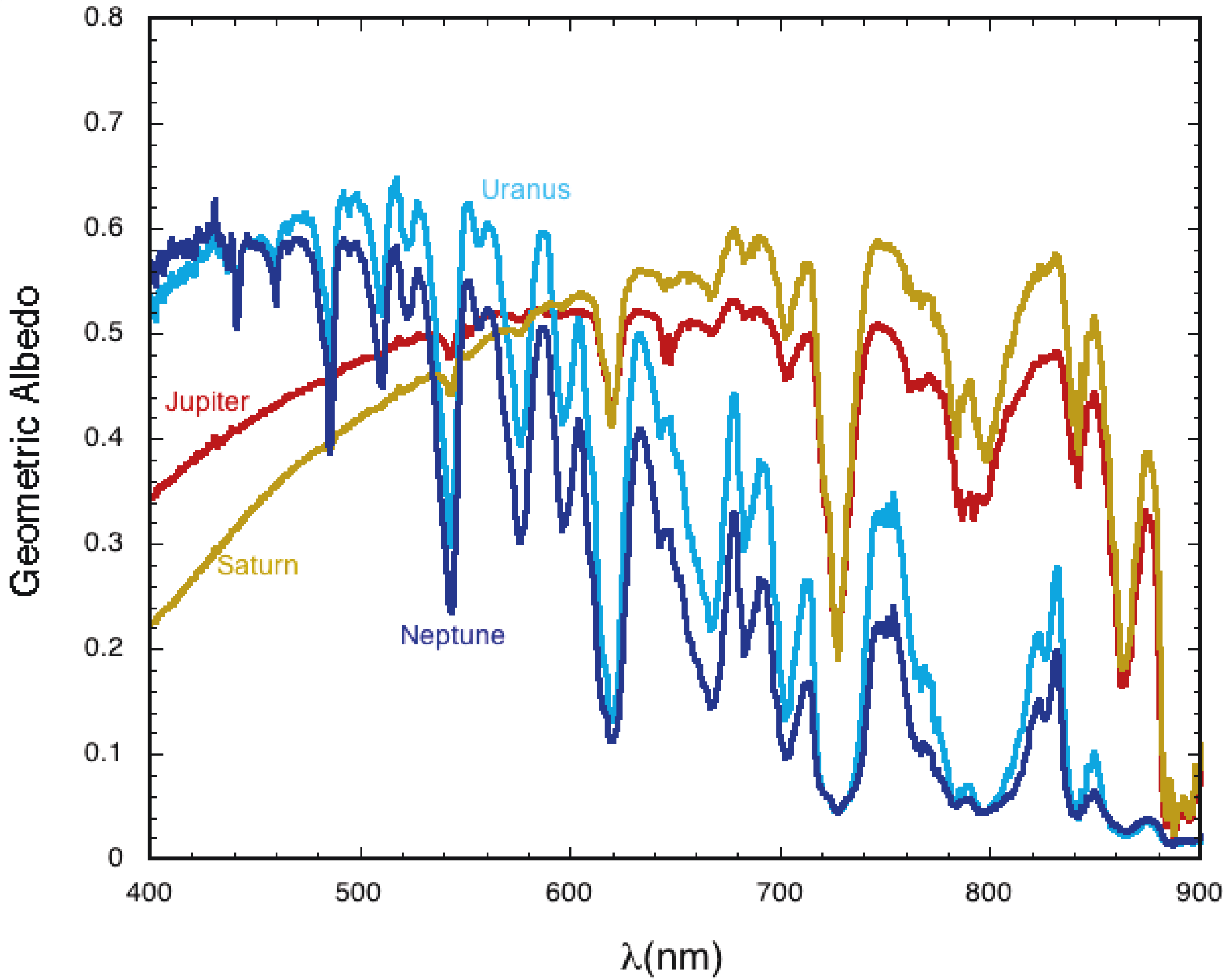


Figure 2-21: This figure is a snapshot in time of contrast and separation for model planets, ranging in size from Mars-like to several times the radius of Jupiter, for about 200 of the nearest stars within 30 pc. Color indicates planet mass while size indicates planet radius. Crosses represent known radial velocity planets. Solid black lines mark the baseline technical goal of 1 ppb contrast and 0.2 arcsec IWA, while the dotted lines show the more aggressive goals of 0.1 ppb and 0.1 arcsec IWA.

AFTA Giant Planet Survey

- About 150 stars can be searched for mature giant planets in reflected visible light over 1 year
  - Includes time for spectroscopic characterization
  - Limited sensitivity overlap with ground nIR AO imaging surveys
    - Worthwhile to see if AFTA can detect some young planets (perhaps HR 8799 ones at red wavelengths)
- Similar planet population sampled by RV (and somewhat by microlensing)
    - *Observing RV planets is important and unique: masses constrain atmospheric possibilities*
    - Significant object samples allow statistical comparisons of properties
- Some overlap with JWST for 10^8-9 yr gas giant planets
  - AFTA has much smaller inner working angle

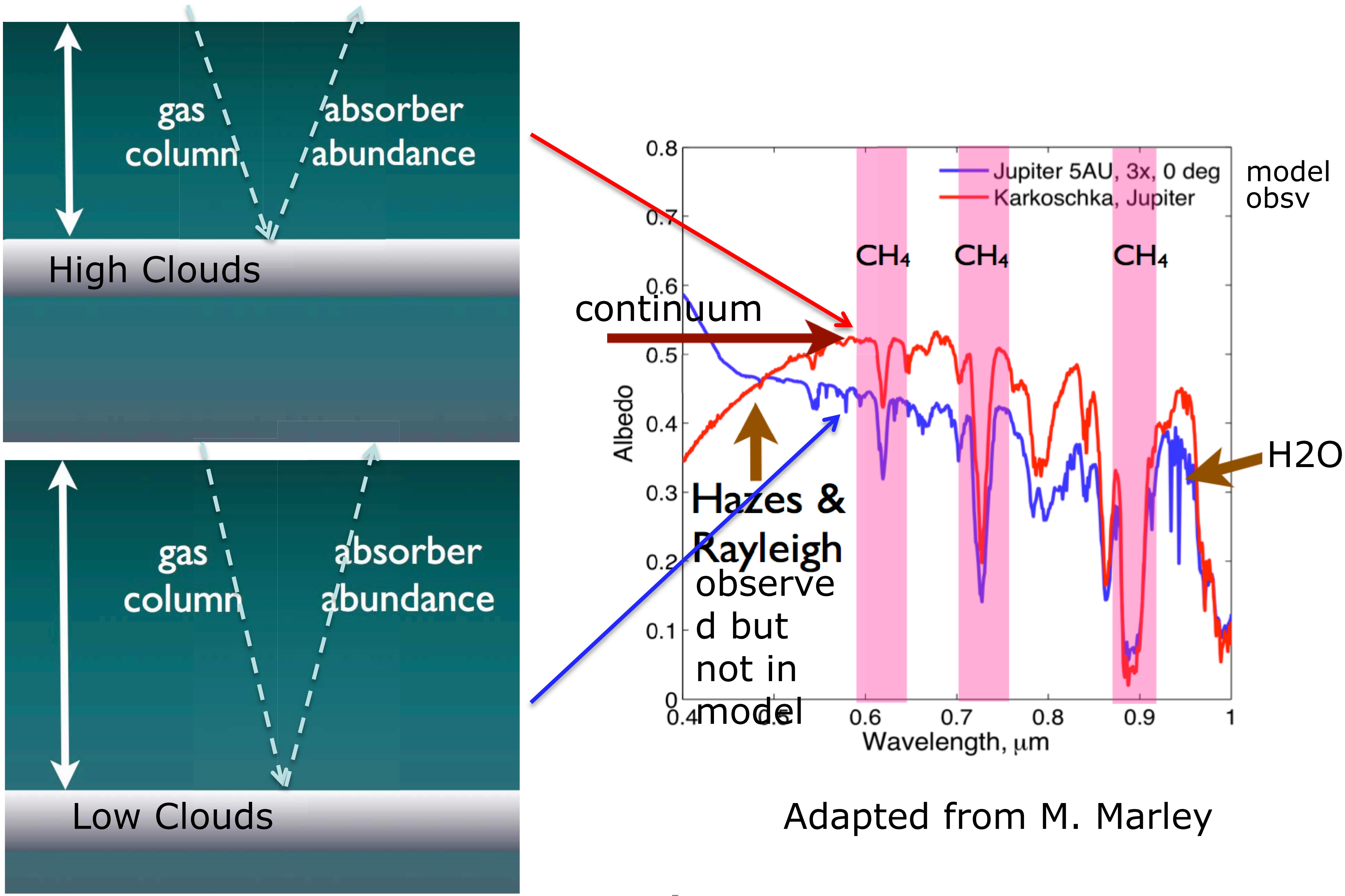
Giant Planet Spectra



Courtesy of M. Marley & PECO study

- Geometric albedo spectra (Karkoschka 1994) for the solar system giant planets.
- All four planets are darker at all wavelengths than perfect Rayleigh or Lambert scattering spheres.
- Jupiter contrast relative to Sun is 1E-9. This gets better in the mid-IR where thermal emission is up and the star is falling off (JWST imaging sweet spot)

Giant spectra: molecules, clouds, hazes



Adapted from M. Marley

Giant planet spectra: more than CH_4

- Atmospheric composition, abundances, and temperatures can be retrieved from spectra
    - R ~ 50 visible spectroscopy over 0.4 – 1 μm
    - RV masses add further constraints
    - Constrain formation scenarios:
        - Abundances give cluse to accretion
        - Sample planets within and beyond snow line
- Study Brightness changes with orbital phase
    - Phase gives scattering properties
- Statistical studies possible:
    - Variation of clouds and composition with planetary mass (known RV planets)
    - Variation of albedo / clouds and molecular features with effective temperature

Giant planet albedo with stellar distance

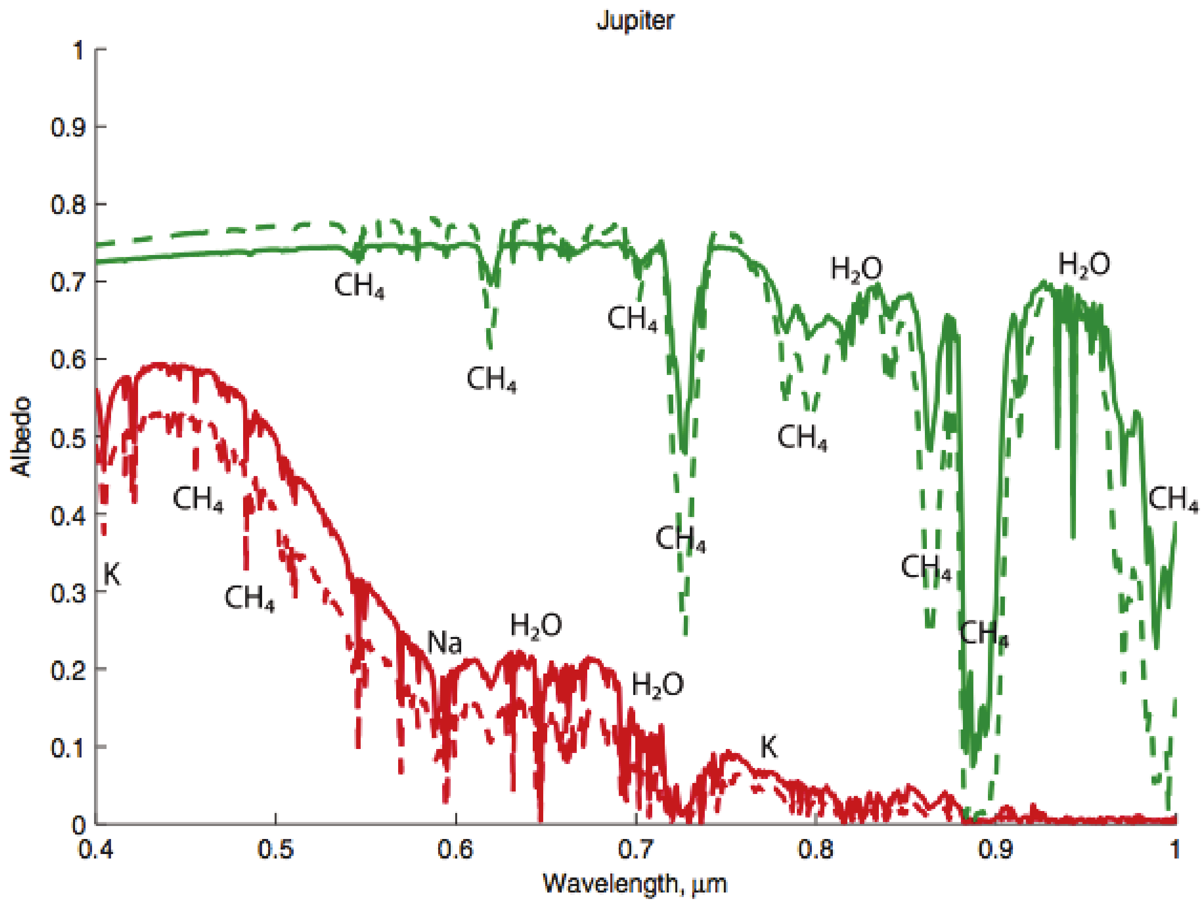


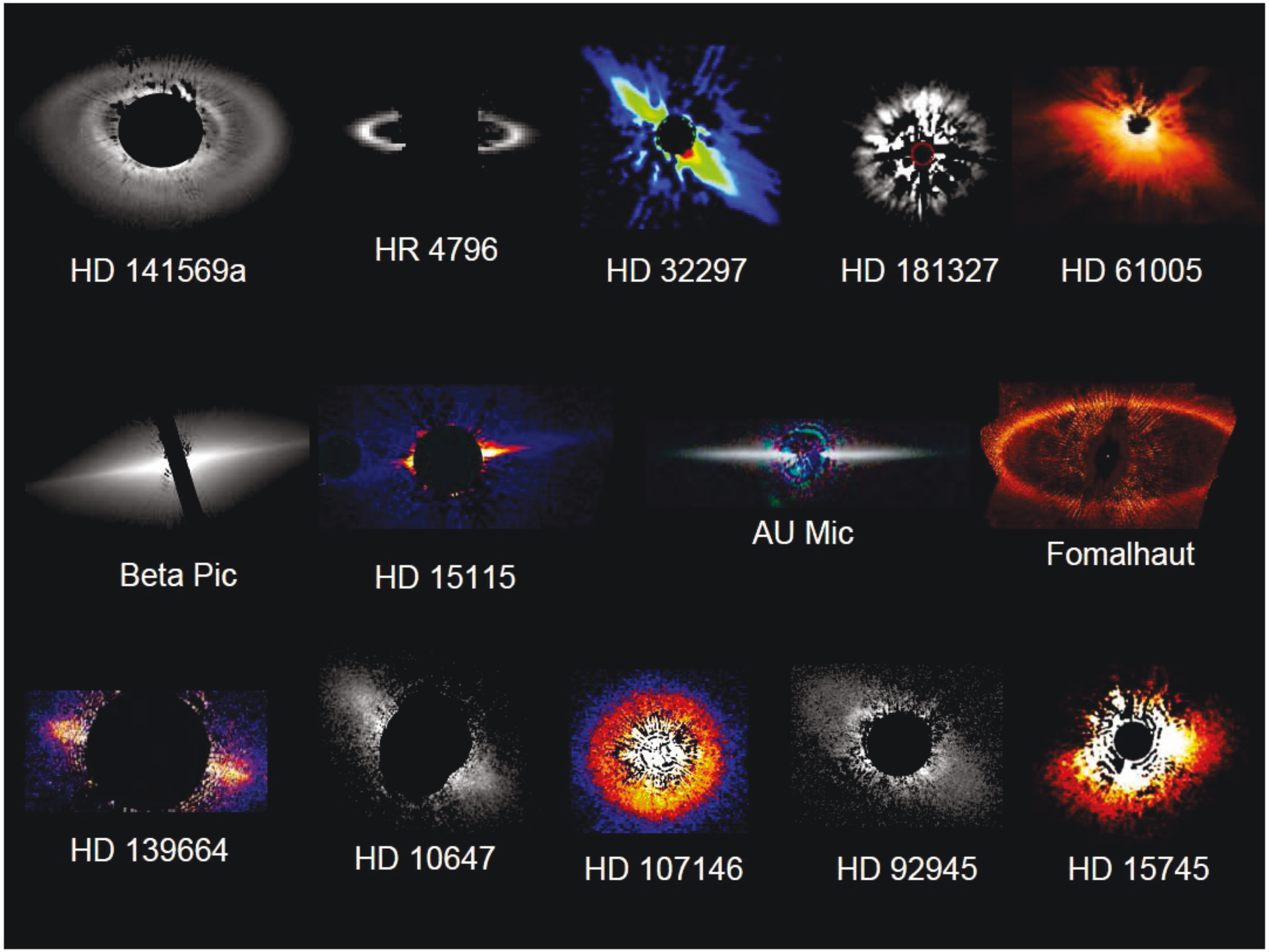
Figure 10. Geometric albedo spectra of Jupiter analogs at 0.8 AU (red) and 2 AU (green) and 1× (solid) and 3× (dashed) solar heavy element abundances; prominent spectral features are noted: CH_4, K, Na, and H_2O. See Table 3.

- Strong CH4 absorption in cool giants > 2 AU from Sun: DETECTABLE!
- Clouds disappear and albedo drops as Jupiter moves toward the Sun and heats up.
- Absorption from Alkalis Na and K dominate in visible (Cahoy, Marley & Fortney 2010)

Giant Planet Detection Feasibility

- 3 λ/D IWA is ~ 130 mas V band vs. 700 mas JWST 5 λ/D @ 4.5 μm
- ~33% EE in FWHM PSF (30% obstr+spiders), 50% eff, 1E-9 @IWA
  - Planet PSF is diluted against star and Exozodiacal light
  - Solar system twin at 10 pc (1 zodi) has Earth ~ 0.07 (exozodi + star) and Earth is within coronagraph IWA (2.2 vs 3 λ/D)
    - Look for HZ planets within 10 pc for GV and earlier (some stars)
  - Solar system twin at 10 pc (1 zodi) has 5 AU Jupiter ~ 1 (exozodi + star) in PSF, depends on contrast profile
- SNR ~ 10 on Jupiter continuum in solar system twin at 10 pc
  - ~25 hr integration time with R~70 IFU (0.18 throughput)
  - *Can detect 30% deep CH4 at SNR > 3*
- Expect to be able to detect up to ~10 known RV planets
  - Masses are a big plus for interpreting spectra
  - Trick is to catch them at max elongation

HST has imaged ~2 dozen disks, > 1000 zodi



Unique AFTA-C Disk Science in 2020s:

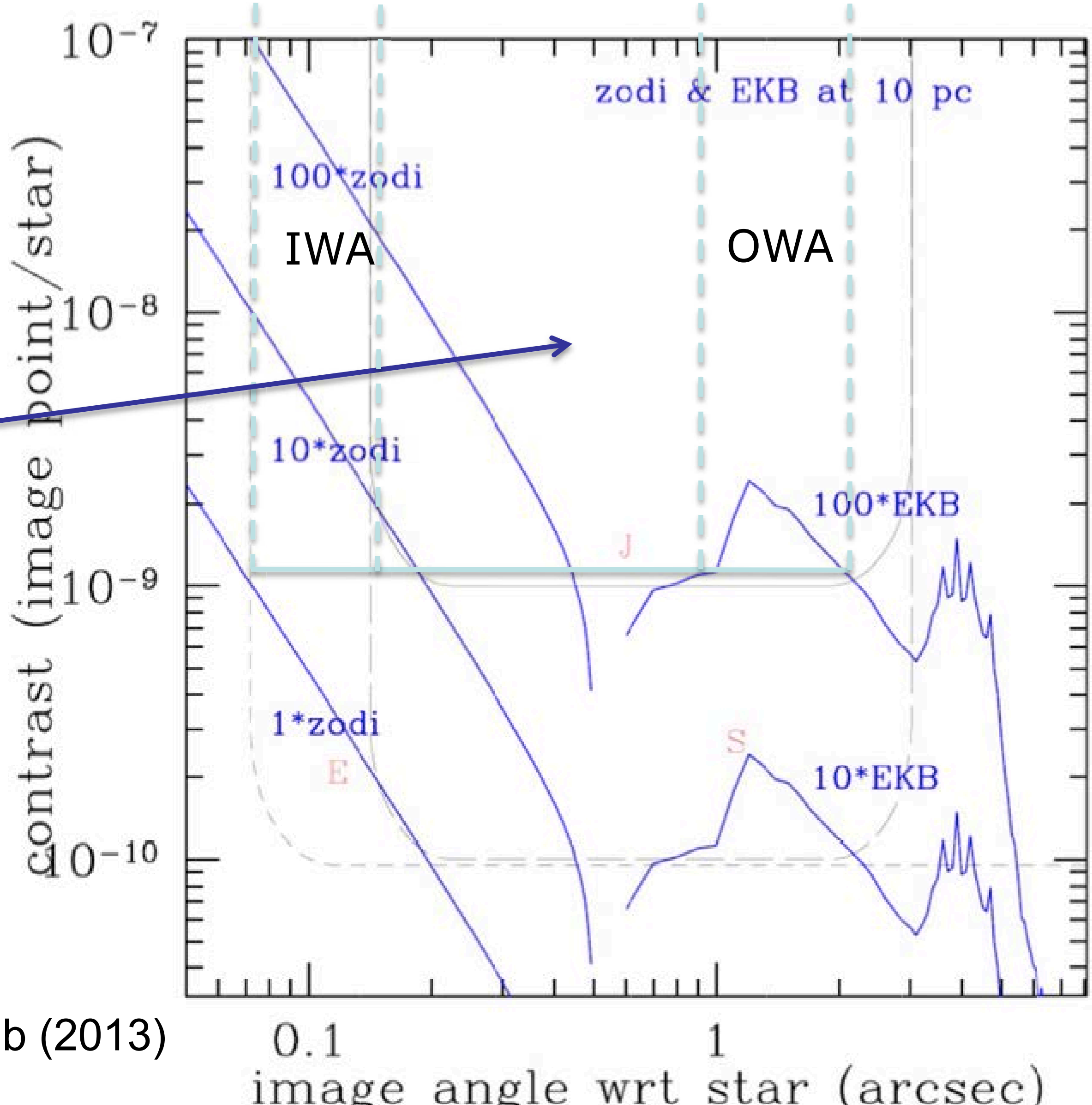
Reflected light imaging of nearby planetary systems

- Extremely sensitive, high spatial resolution imaging of zodi and Kuiper disks of nearby, mature stars
  - Can sample habitable zones of some (10-20) nearby stars
  - Find signs of un/seen planets and collisions (gaps, belts, shepherding)
  - Dust data useful for future terrestrial planet imaging
  - Sensitivity close to LBT-I with better spatial resolution:
    - AFTA visible + LBT-I MIR yield grain albedos
- Image inner regions of ~20 extreme debris disks found with HST
- Image transition disks of young stars found in mm or IR (secondary):
  - How much material is in the inner "clear" regions?
  - What are particle sizes, and how do disks clear?
- Scattered light imaging of well-studied T Tauri disks (secondary)
  - Study grain albedos and dust distributions during planet formation era

AFTA can detect zodiacal and Kuiper Belts

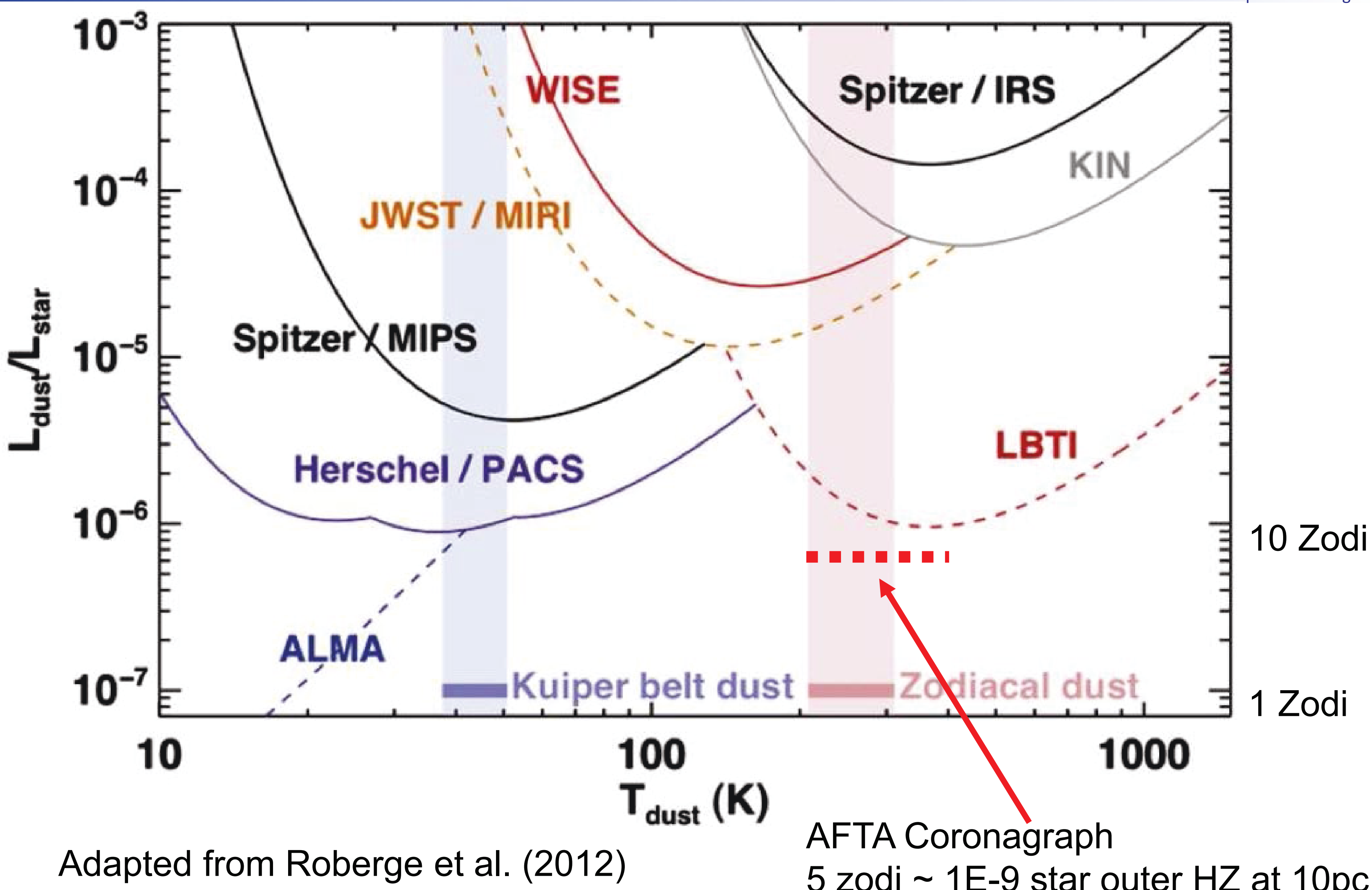
AFTA Niche:

- Small IWA good for zodi
- Current OWA is set by 48 x 48 DMs and is not great



Adapted from W. Traub (2013)

Excellent Exozodi sensitivity



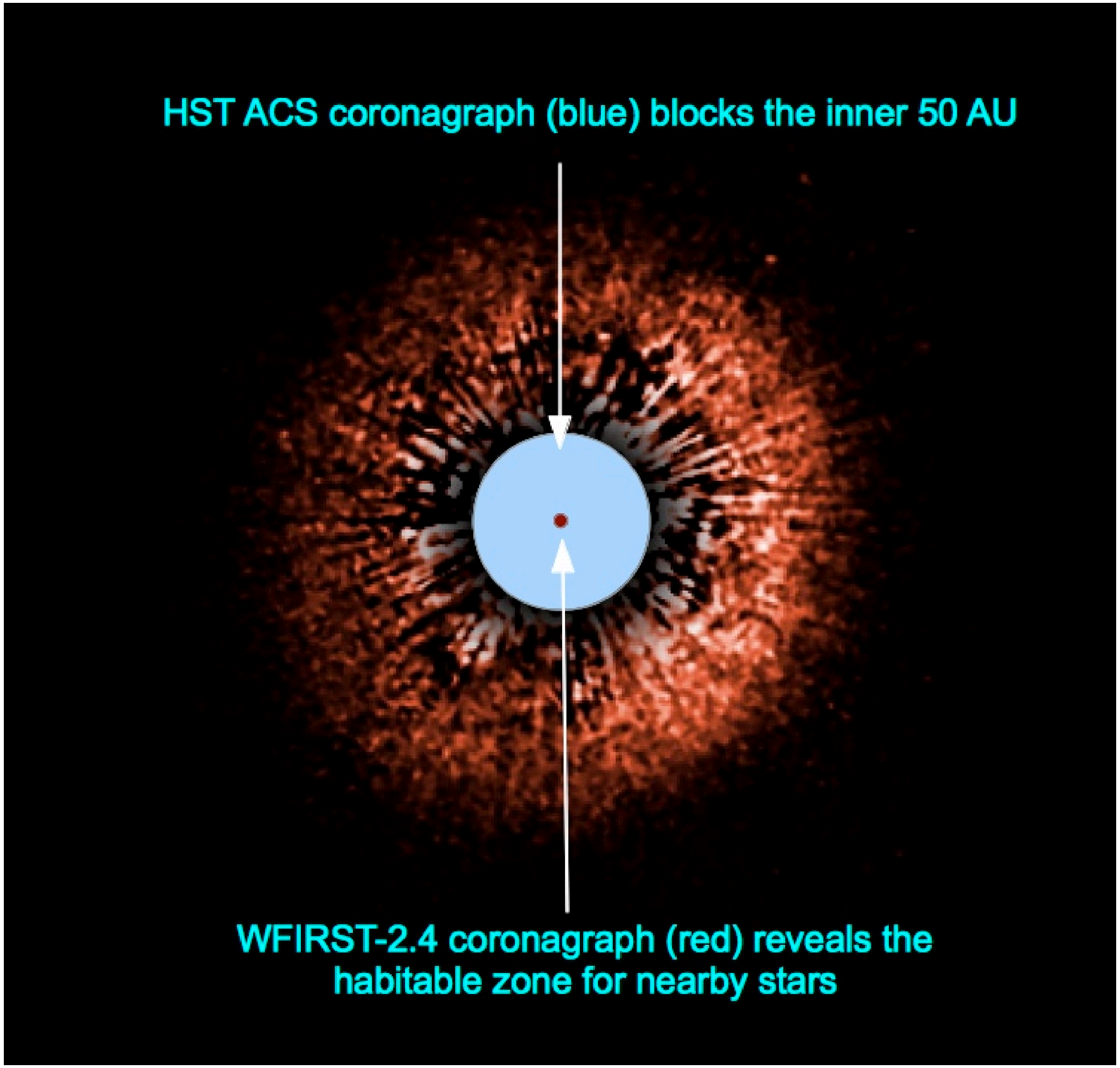
Adapted from Roberge et al. (2012)

Exozodiacal Dust Imaging Feasibility

- Most sensitive visible dust imaging yet and high resolution
- Searching for planets around nearby stars should reveal disks in the same images
- Exozodi sensitivity per res. element is not a strong function of distance due to IWA and $r^{-2.x}$ disk flux dropoff:

  5 zodi Exozodi ~ 1E-9 star at 10 pc at 1.6 AU (3.5 λ/D)
- ~10 hr exposure time for SNR ~10, R=10 res el. (5 zodi, 10pc)
  - Res. element is 50 mas V band or 0.5 AU at 10 pc
  - Trace disks to large radii if you bin azimuthally
- 2x higher spatial resolution than LBT-I: locate the dust!
  - LBT-I resolution is ~10 μm / 20-m = 100 mas

AFTA Debris Disk Imaging



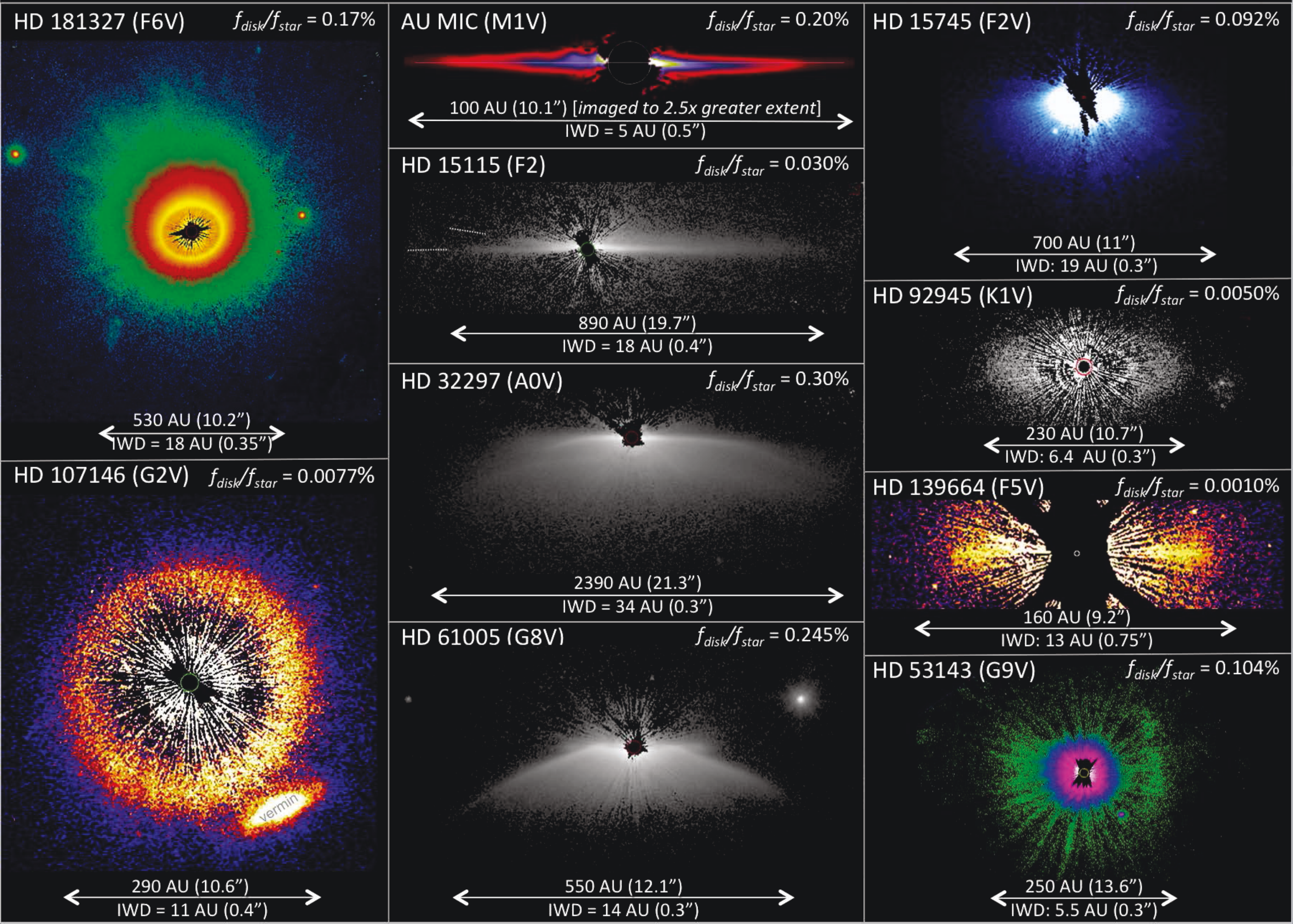
http://hubblesite.org/newscenter/archive/releases/2004/33/image/c/

AFTA will:

- Measure the amount and distribution of circumstellar dust.
- Measure the large scale structure of disks, revealing the presence of asteroid belts and gaps due to unseen planets.
- Measure the size and distribution of dust grains.
- Provide measurements of the zodiacal cloud in other systems.

Debris disk around the young (~100 Myr), nearby (28 pc) sun-like (G2 V0) star HD 107146 (Ardila et al. 2004)

The HST/GO 12228 Debris Disk Sample (G. Schneider & the HST GO/12228 Team)



Exolanet Science L1 Requirements

1. AFTA imaging channel will operate from 450 to 950 nm (goal 400 to 1000 nm) and support five filters of 10% bandwidth at roughly 450, 550,650, 800, 950 nm
2. The AFTA spectroscopic channel will operate from 600 – 950 nm microns at R~70 with the coronagraph operating over 10% bandpass at any single setup.

- It is a strong goal to cover at least 15% bandpass in a single coronagraphic setup to allow a broad absorption line and surrounding continuum to be measured in a single exposure

3. AFTA will be capable of spectroscopically characterizing at SNR=10 per resolution element from 600-850 nm at least 6 previously-known Doppler planets in a total of 3 months of mission time (assuming orbits are known and observations are targeted to the most favorable observing conditions) distributed over the full 5 year mission, assuming grey planetary albedo of 0.1

- Note that there's no explicit requirement on spectra of previously-unknown planets, though models indicate that a subset of the discoveries will be characterisable

Exolanet Science L1 Requirements

3. AFTA shall achieve a total imaging completeness for objects from r1=0.3 rj to r2=1.1 rj and 0.1<a<5 of *200* over a survey of 200 stars observing at 550 nm with total survey time of 3 months distributed over the 5 year mission

- We probably need to specify an albedo (critical) and eccentricity (not as critical), recommend 0.2

4. For a fiducial jupiter-radius planet at 3 au, 10 pc, G0 star, AFTA shall be capable of measuring the planet to star contrast ratio at all five bands with a precision of $5x10^{-10}$

5. AFTA will achieve a total imaging completeness for objects of r<4re over all semi-major axes of *10* observing at 550 nm with a total survey time of 3 months distributed over the 5 year mission. It is a strong goal to achieve a completeness of 4 for r<2 re at 800 nm

- This also needs an albedo, recommend 0.2

Exolanet Science L1 Requirements

6. AFTA will be capable of astrometrically measuring the position of discovered planet relative to the parent star with a accuracy in each axis of 5 mas for a SNR=20 detection

- There will be subsequent requirements on frequency and span of these measurements but since we're focused on the coronagraph right now they're not being defined.

7. Threshold: AFTA will be capable of obtaining <1000 nm photometry on self-luminous planets of 5 MJ at an age of 100 Myr around a G type star at 10 pc at 5 AU separation *(or tie to real objects or GPI models?)*

Science FOMs for each coronagraph

- Calculate "detection" of model planets, spectra, & disks, based on photon-limited noise and a TBD-sigma criterion (10 charts, not shown here).

- Calculate cumulative number vs time in mission, to give 10 FOM values:
  - known RV planets: (1) detections, (2) colors, (3) spectra
  - new planets : (4) detections, (5) colors, (6) spectra
  - zodi disks: (7) images, (8) colors
  - Kuiper belts: (9) images, (10) colors

- Balance these modes to maximize a TBD aspect of science for the mission, using a common rule for all coronagraphs if possible