A Theme

- Pathways to Life.
  - (Formation of stars)
  - Formation of planets & planetary systems
  - Where are the Earth-like planets? (Discovery)
  - Frequency of Earth-like planets? (Science)
  - Frequency of *habitable* Earth-like planets
  - Properties of Earth-like planets
    - surface features (solid? liquid? minerology?)
    - atmosphere properties (composition. density)
    - biomarkers

Terrestrials : A Wishlist

- Detect terrestrial planets in habitable zones
  - M < $10M_{\oplus}$. T~300K
- Collect photons from them
- Find lots of them (or not find them around lots of stars)

  Frequency. Freq wrt spectral type, age, Fe/H
- Orbits of them
- Photometric variability : phases (albedo), surface features, weather

- Understand statistics of planetary systems, and details of individual systems in their full context (ie all planets, not just habitable ones)

OPTICON

Constraints

- COROT/Kepler/Eddington will measure statistics, but not properties of exo-Earths.
  - Will *not* find targets for ELT follow-up
- Conservatively assume 1% have ⊕
  - Want statistics or meaningful null detection
  - => observe *at least* 1000 stars
  - => observe stars out to 30pc (⊕ at 33mas)
  - ExAO cannot suppress light within 10λ/D (10mas for 100m telescope at V)
  - => 50m telescope is marginal for detecting exo-Earths at 30pc

OPTICON

What we'd need to do.

- Star-Planet Δm=25 for 'habitable' exo-Earth
  - Scattered light dominates (I sky = 33 mag/sq.mas)
  - Science Requirement: Flux contrast =10^{-10}, *r =10-500mas*
- "Confirmed candidate"
  - Multiple (5?) detections over orbit consistent with Keplerian motion.
  - 1000 targets
  - Science Requirement: Detect exo-Earth in ~1h at 33mas with S/N=10 *wrt speckle noise* (from V to K)
    3h is worst case
  - Likely Requirement: simultaneous multiple passbands in camera
- Gas giants in such system out to 15au all found as well (as would Venus, and possibly Mars)

OPTICON

Follow-up of “CC”s

- Detailed orbit => period, eccentricity
- Phase variations => albedo => surface temperature, radius, mass estimate.
- Detailed photometric time series => rotation period, surface features

- Spectroscopy : 1h imaging at R=5 => R=250 possible in 50h.
  - Broad molecular features only need low res from V-K
  - Correct Earth’s atm with scattered light from star.
  - O_2, O_3, H_2O, CH_4 as biomarkers
  - NIR spectroscopy for minerology of surface (R<1000) for very interesting targets.

OPTICON

Wishlist

- ☑ Detect terrestrial planets in habitable zones
  - M < $10M_{\oplus}$. T~300K
- ☑ Collect photons from them
- ☑ Find lots of them (or not find them around lots of stars)
  Frequency. Freq wrt spectral type, age, Fe/H
- ☑ Orbits of them
- ☑ Photometric variability : phases (albedo), surface features, weather

- Understand statistics of planetary systems, and details of individual systems in their full context (ie all planets, not just habitable ones)

- Can also find most other planets. Do dust disks. Massive black holes. Imaging spectroscopy surfaces of nearby giants.
- Massive stars - need high dynamic range

OPTICON

When relevant?

- Darwin / TPF - 2014?
  - ELT 10 times more stars and potentially longer lifetime. Can be re-instrumented later with spectrographs much more cheaply
  - Darwin/TPF in thermal IR.
- 30m North American ELT
  - Possibly surveyed
- JWST
  - Won't find terrestrials
- COROT/Kepler/Eddington
  - Detect, but no detail follow-up. Not huge numbers (cf. 200,000 stars for 1 Earth [1% of stars with Earths])

ExAO on Gemini

- EL
  - than

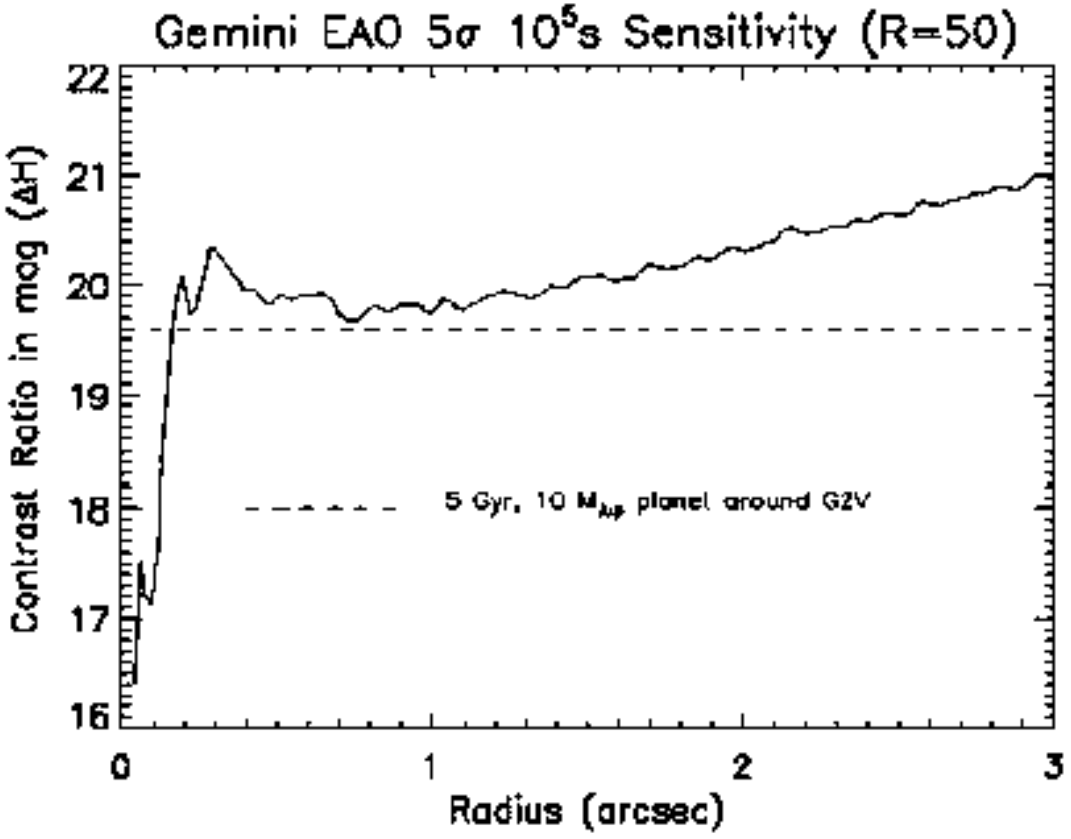

Figure 21 - A plot showing the sensitivity of a simulated coronagraphic imager as a function of radius from the host star (courtesy Rene Doyon).

OPTICON