Exoplanets and ELTs:
50 m or 100 m ?

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- What we want to know about exoplanets
- The benefits of imaging in the Vis/NIR
- 50 m /vs 100 m

Main objectives of extrasolar planets studies

Two main objectives

- Census of planetary systems in the Galaxy (*e.g.* RV, CoRoT, GAIA)

  Best characterization of them (*e.g.* ELT)
- Search for life

  ==> Earth-like planets in the habitable zone (HZ) of the parent star

Question:

Qualitative threshold or continuity from 50 m ---> 100 m ELT ?

The task of planet imaging studies

Observables in (reflected light) planet imaging	Characteristics we try to derive from the observables (with the help of modelisation)
• Planet position at different epochs: $x(t), y(t)$ • Planet flux $F_{pl}(\lambda, t, \vec{p})$ ($\vec{p}$ = polarizer angle)	Temperature Size (mass, radius) Atmosphere & clouds Surroundings Planet rotation (period and axis orientation) Surface properties (inhomegeneities) Seasons Volcanism Biosignatures Star-planet interaction

↔

Operating modes

- With high contrast dynamics: planet/star
- Without high contrast dynamics
  - Free-floatting planets (---> *Rebolo*)
  - Planetary transits : timing, spectroscopy (*e.g.* CoRoT transits)
  - Planet-induced stellar spots

Two flux regimes: thermal IR and visible reflected light (1/2)

- Thermal infrared

  Either/or:

  – Planet heated by star:

  $$T_{pl} = T_{*} \left(\frac{R_{*}}{2a} \right)^{1/2} (1 - A_{pl})^{1/4} G$$

  – Intrinsic internal heat (young planets)

  For a planet heated by its star:

  $$\frac{F_{pl}}{F_{*}} = \left(\frac{R_{pl}}{a} \right)^{2}$$

Two flux regimes: thermal IR and visible reflected light (2/2)

Reflected flux:

$$F_{pl}(t,\lambda)=F_*(\lambda)\left(\frac{R_{pl}}{d(t)}\right)^2\frac{A_{pl}(t,\lambda)}{4}\phi(t)$$

$\phi(t)$ = orbital phase factor

$A_{pl}(t,\lambda)$ = planet albedo

$d(t)$ = star-planet distance

Planet on circular orbit: $d(t) = a$

The flux is correlated with the planet position.

==> Makes easier the identification of the object as a planet

"Normalized" flux

After removal of

- orbital phase factor $\phi(t)$
- distance to star factor $d(t)^{-2}$
- stellar flux factor

« normalized flux » :

$$f_{pl}(t,\lambda) = A_{pl}(t,\lambda)\, R_{pl}^2$$

Units: for $A_{pl} = 1$ $1\, f_J = R_J^{\,2}$ $1\, f_\oplus = R_\oplus^{\,2} = 0.01\, f_J$

Benefits from large apertures

- Low flux: small planets
- Accurate photometry: small flux variations
- High spectral resolution (*e.g.* Atmospheric species)
- Time variations, short phenomena, Timing

Albedo (1/6)

Contributions: clouds + atmosphere (transparent) + surface

- clouds:
  - white
  - variable in time (randomly)
- atmosphere (transparent): dominated by Rayleigh scattering
- surface: variable in time:
  - short periods
  - annual var.

Characteristics: absolute value

colour/spectrum

time variation

Albedo (2/6)
Absolute value

The most difficult aspect of visible reflected light.

Only the product $A_{pl}(t,\lambda)\times R_{pl}^2$ is known

But two constraints:

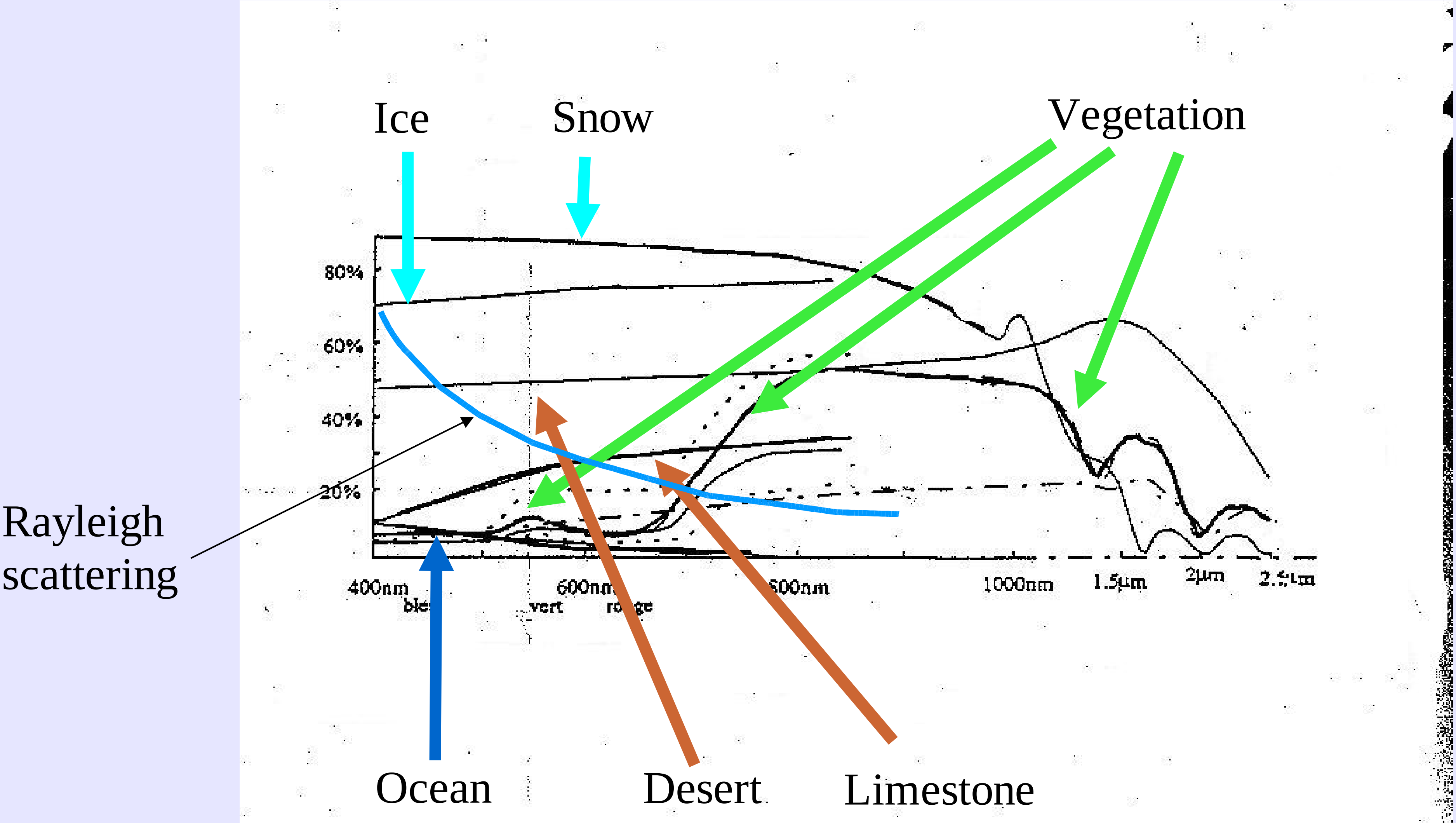
$$1 > A_{pl} > 0.05 \quad \text{and} \quad R_{pl} < R_J$$

==> Necessarily $A_{pl}(t,\lambda)\times R_{pl}^2 < R_J^2$ *i.e.* $f_{pl} < 1\, f_J$

In case of small/giant planet dichotomy, no confusion possible: either small or giant: $f_{pl} = f_J$ or $f_{pl} = f_{\oplus}$

Albedo (3/6)
Colour

Earth-like planet surface



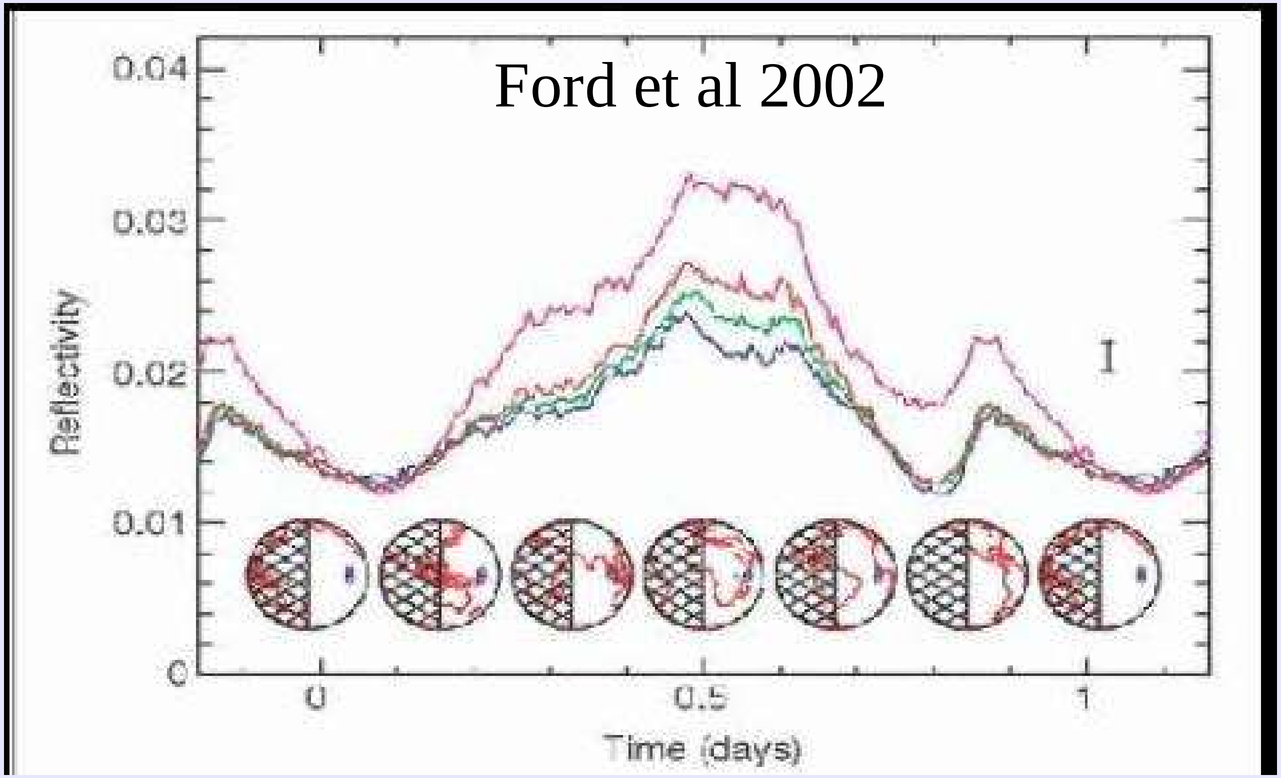
Albedo (4/6)
Time variation

- Diurnal
- Seasonal (<---> orbit)
- Erratic (clouds, meteorology, volcanism)

Albedo (5/6)
Time variation

- Diurnal

  (Earth-like planet)

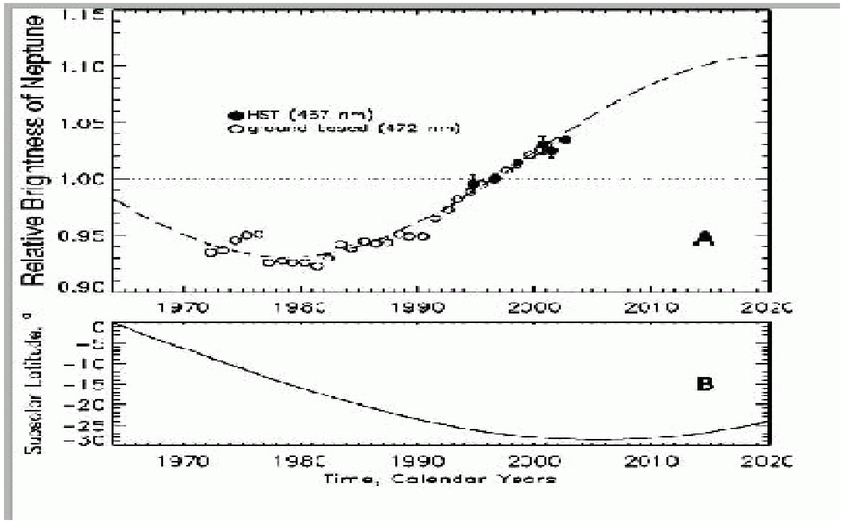


  - Shape of *A(t)* ==> size of oceans/continents
  - Period of *A(t)* ==> duration of the day

Albedo (6/6)
Time variation

- Seasonal

Neptune
(Sromovsky et al 2003)

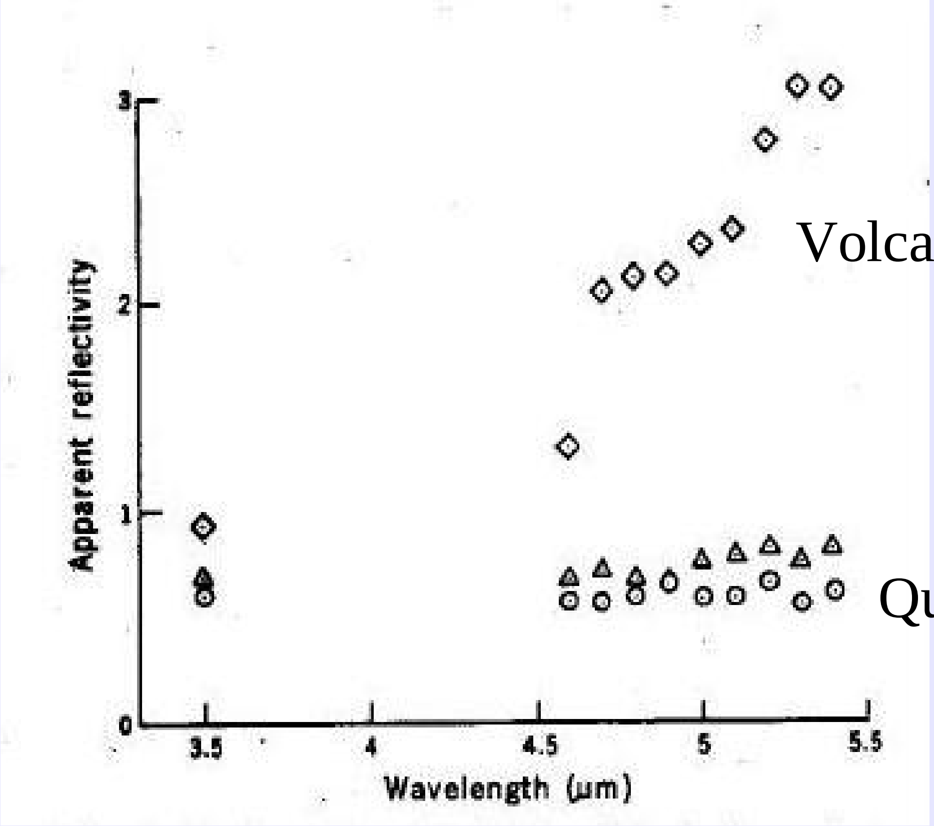


Volcanism

Volcanic activity:

Io activity

(Witteborn et al 1979)

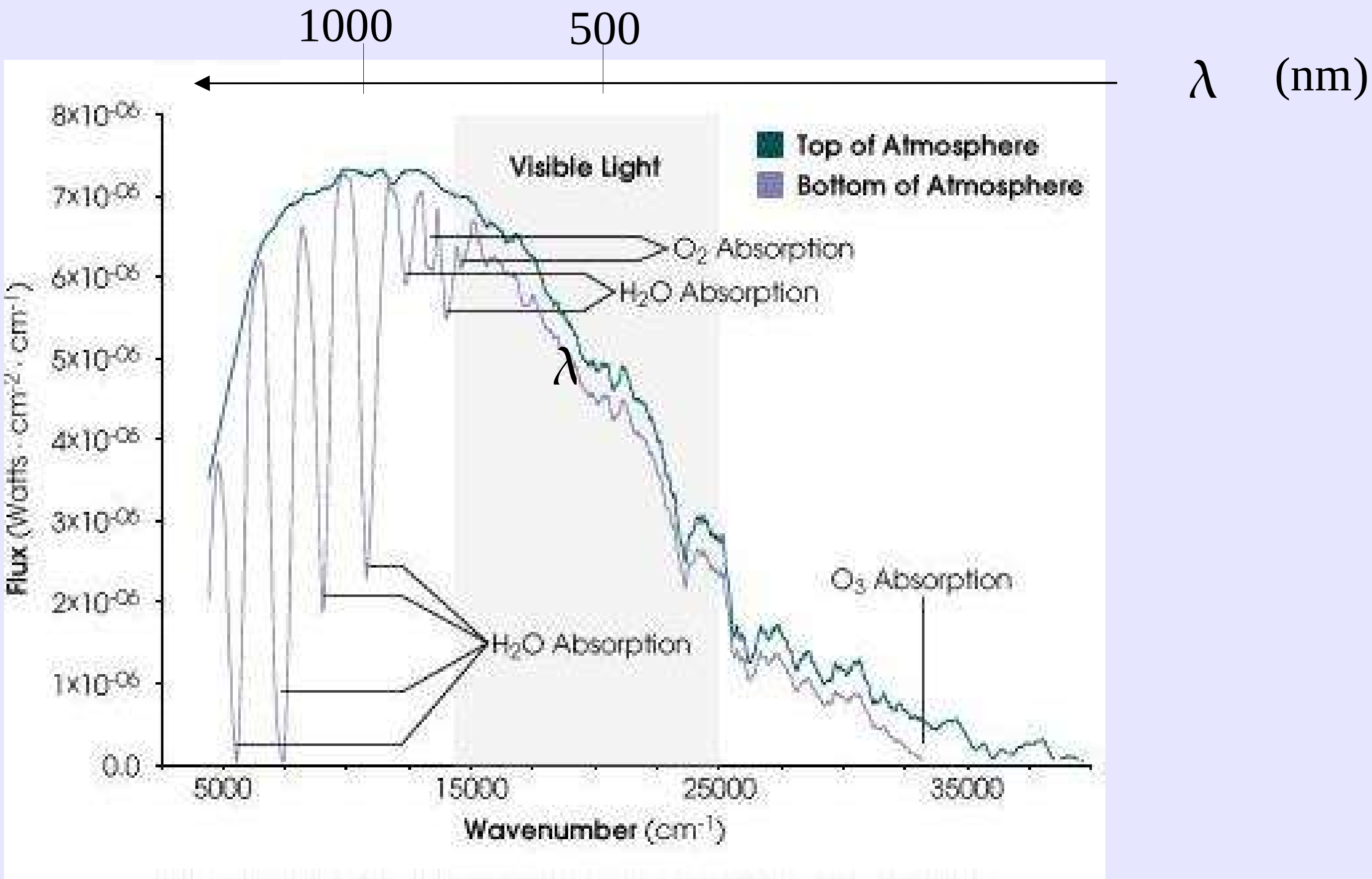


Volcanic phase

Quiet phase

Atmosphere (1/2)
Chemical composition

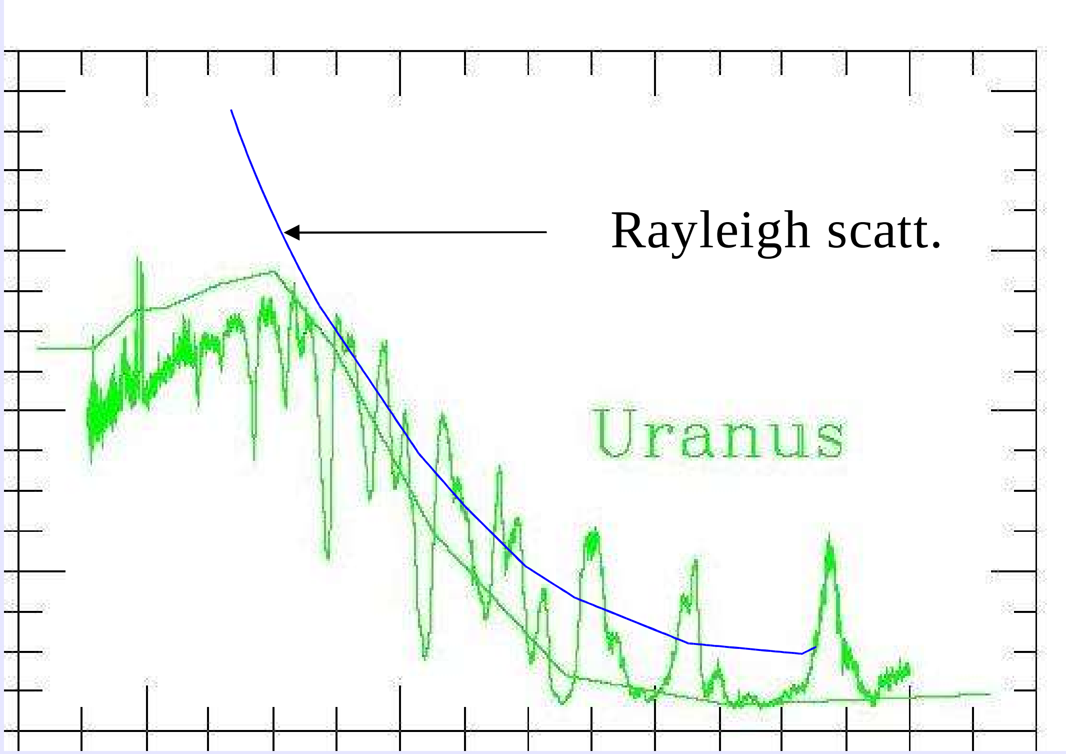
Earth:



Problem: confusion with Earth's atmospheric lines ==> forget it

Atmosphere (2/2)
Rayleigh scattering

Rayleigh scatt. + absorption ==> dense (transparent) atmosphere



Brown et al

300 nm

1100 nm

Size

- Mass (low masses)
  - By 2015 (10 orbital revolutions at 1 AU from now),

    M_{pl} known from RV and astrometry (PRIMA, SIM, GAIA ...)

    down to 1 - 10 $M_{\oplus}$ in a limited (*a*, *D*) region
  - Estimate from albedo colour:

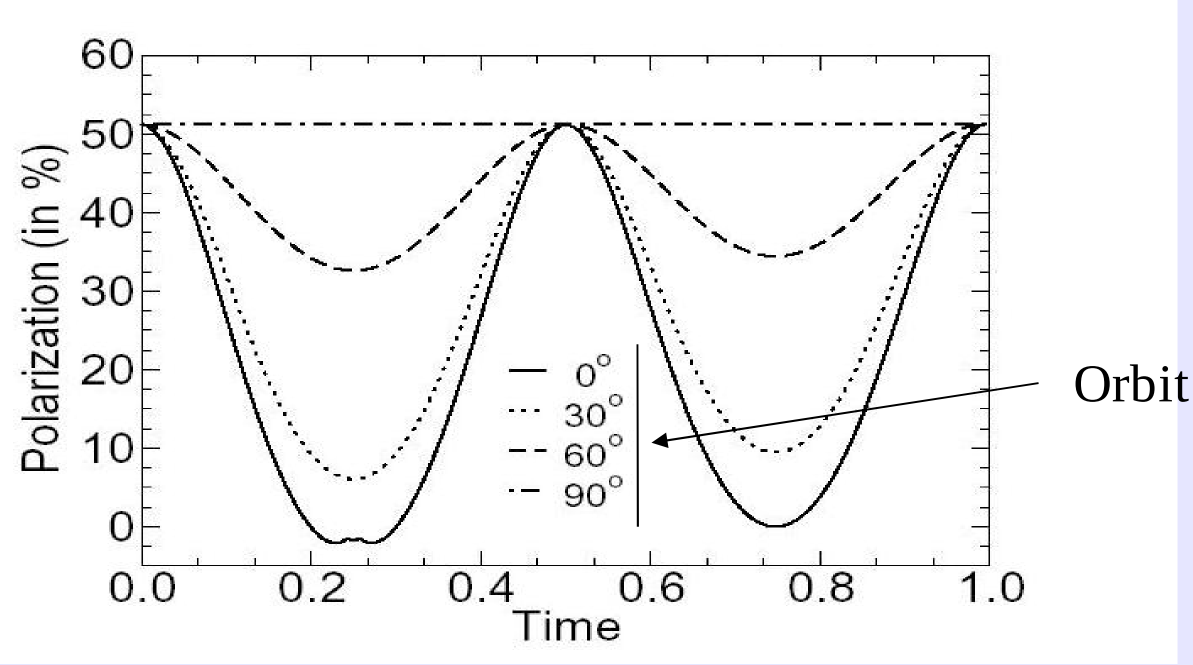
    if no Rayleigh scattering (atmosphere escaped): $M_{pl} < 0.1\, M_{\oplus}$
- Radius

  From $f_{pl} = A_{pl} \times R_{pl}^2$ and A_{pl} (model dependent) absolute value:

  ==> R_{pl}

Polarization

- Induced by reflected star-light scattering (typically 10% - 50%):
  - Atmospheric Rayleigh scattering ==> wavelength dependent
  - Surface scattering (including « vegetation ») ==> modulated by planet rotation
- Correlated with orbital phase:



Orbit inclination

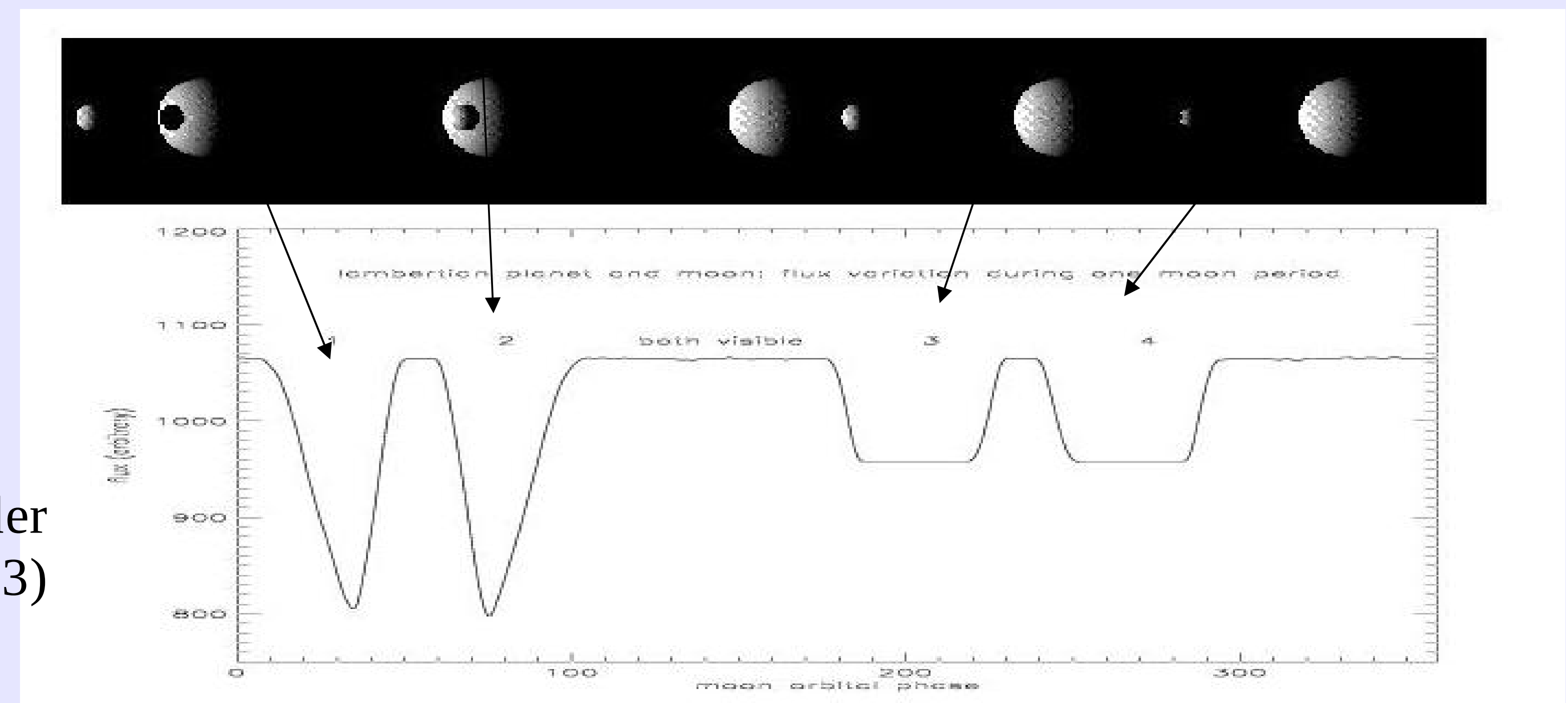
Surroundings (1/3)

What if $f_{pl} = A_{pl} \times ? R_{pl}^2 > R_J^2$

- Large moon, binary planet ? ($f_{tot} = f_{pl} + f_{moon} > f_J$).

Note:
Binary TNOs, Asteroids

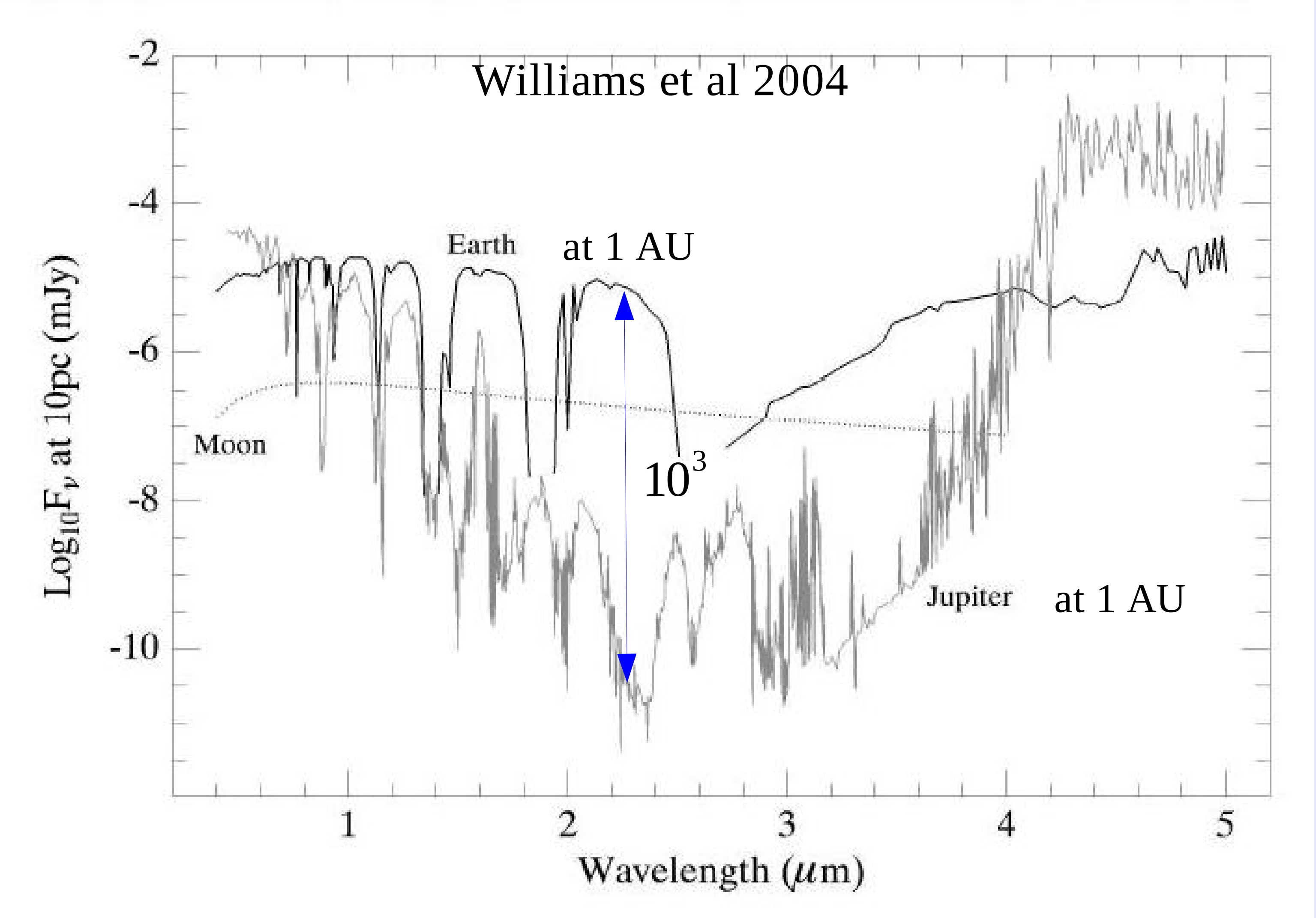
Detectable by mutual shadows (prob ~ 1) and mutual transits (prob. ~ 10%)



(Schneider et al 2003)

Surroundings (2/3)

Satellite in « CH4 hole » of giant planet:



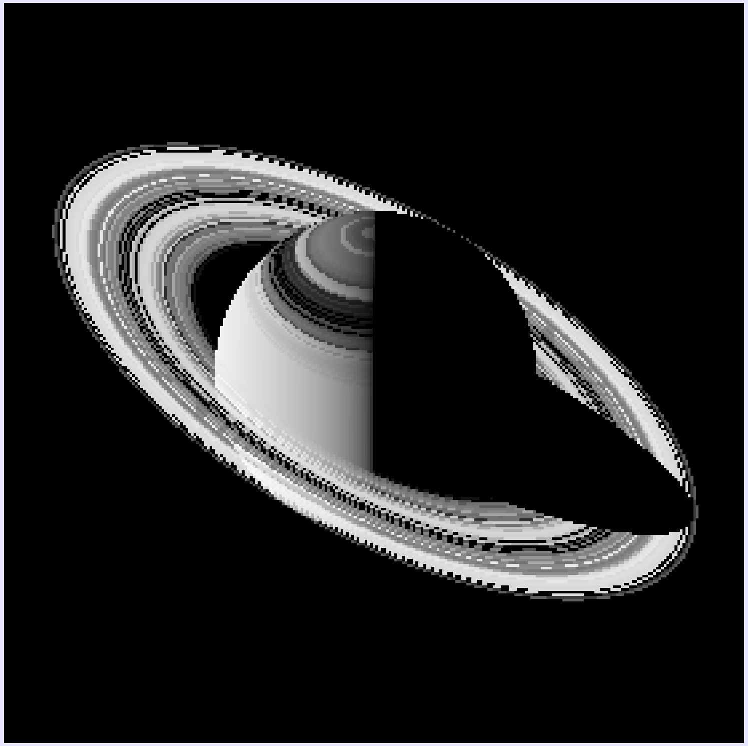
Surroundings (2/2)

- Rings:

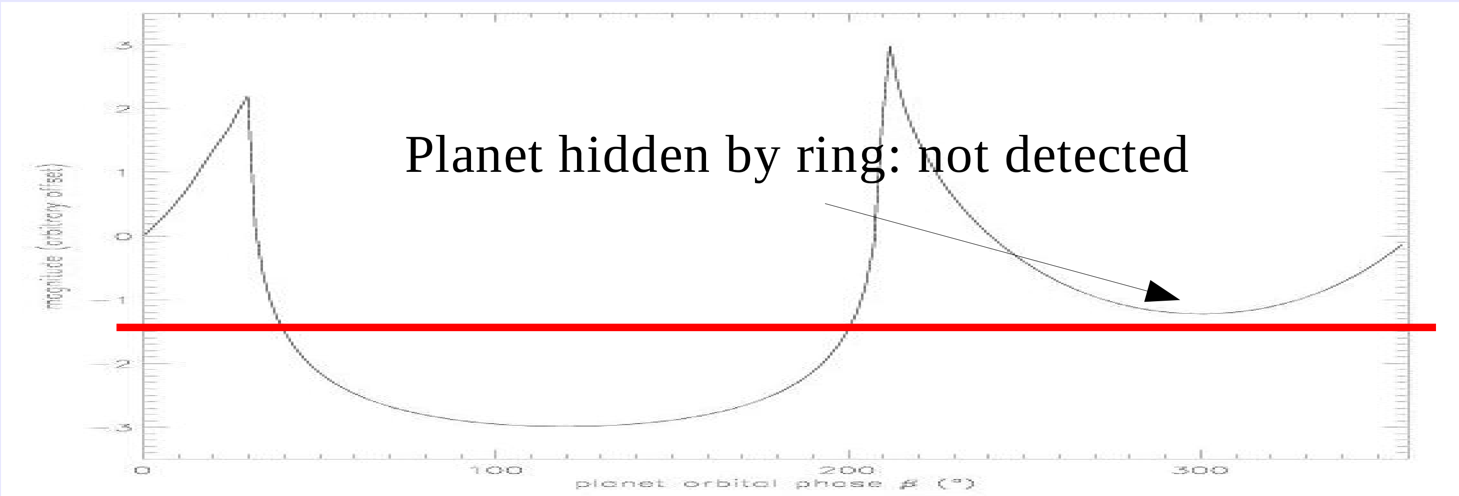
Detectable by the light curve shape

(Impossible in thermal IR)

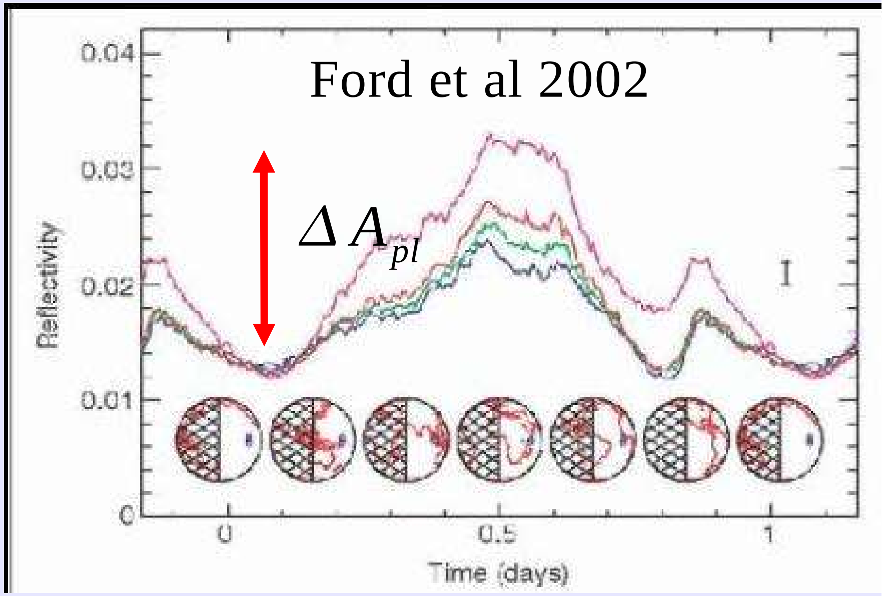
High photom. accuracy LC:
- Size: $\rightarrow \quad R_{ring} = (M_{pl} / \rho)^{1/3}$
- Orientation == > planet axis
- Optical depth



Schneider 2001
Arnold & Sch. 2004



Biosignatures (1/3)
Presence of liquid water



- From the ground:
  Not detectable from water vapor
- How to know if liquid water is present?
  - Estmation of T_{pl} from planet - star distance
  - Presence of ocean from albedo contrast variation ΔA_{pl}
    - If $\Delta A_{pl} > 0.3$
      - $\Delta A_{pl} = A_{Ice} - A_{Continent}$? ==> Ice + continents
      - Or $\Delta A_{pl} = A_{Continent} - A_{Ocean}$? ==> Continents + ocean

      Difficult to know
    - If $\Delta A_{pl} < 0.2$: Continents only
  - Second hint: random albedo variation. Water vapour clouds?

Biosignatures (1/2)

- Atmospheric gas content:

  Essentially O_2/O_3 by-product of photosynthesis:

  Major problem from the ground:

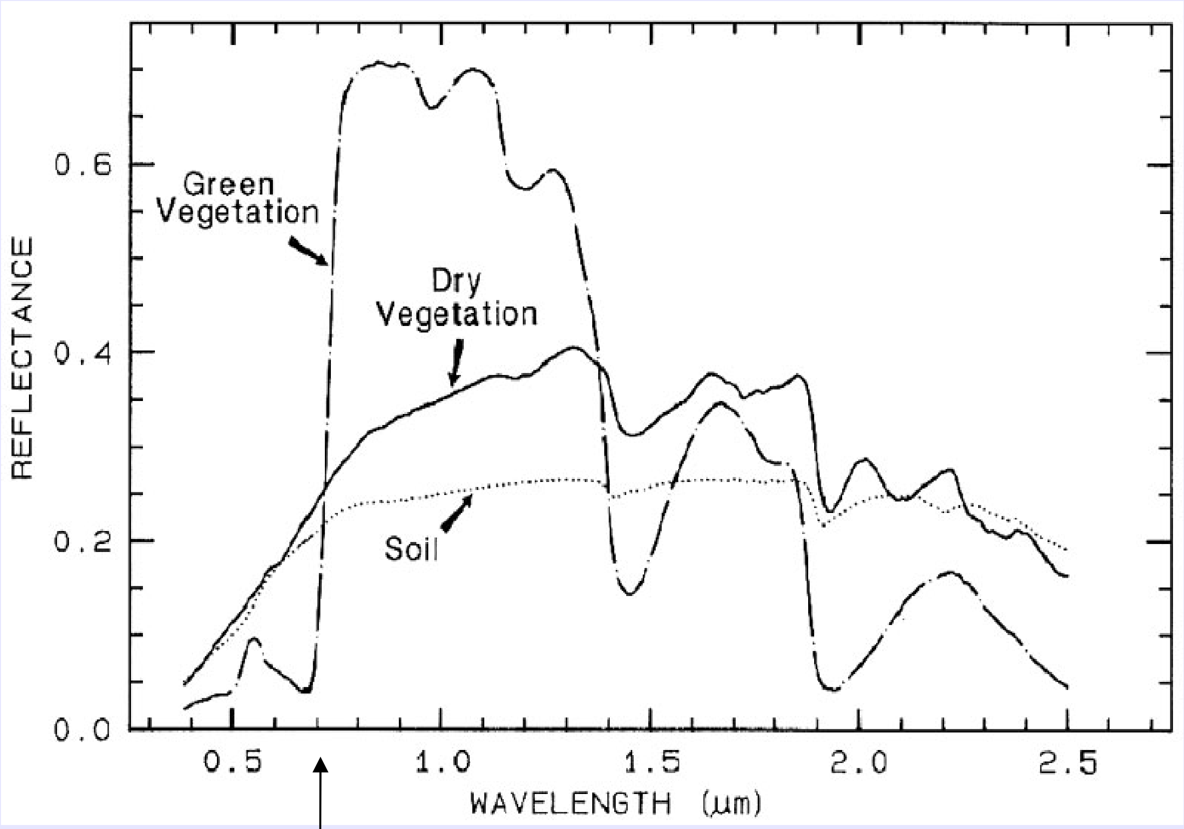
  confusion with atmospheric water and oxygen lines and bands.

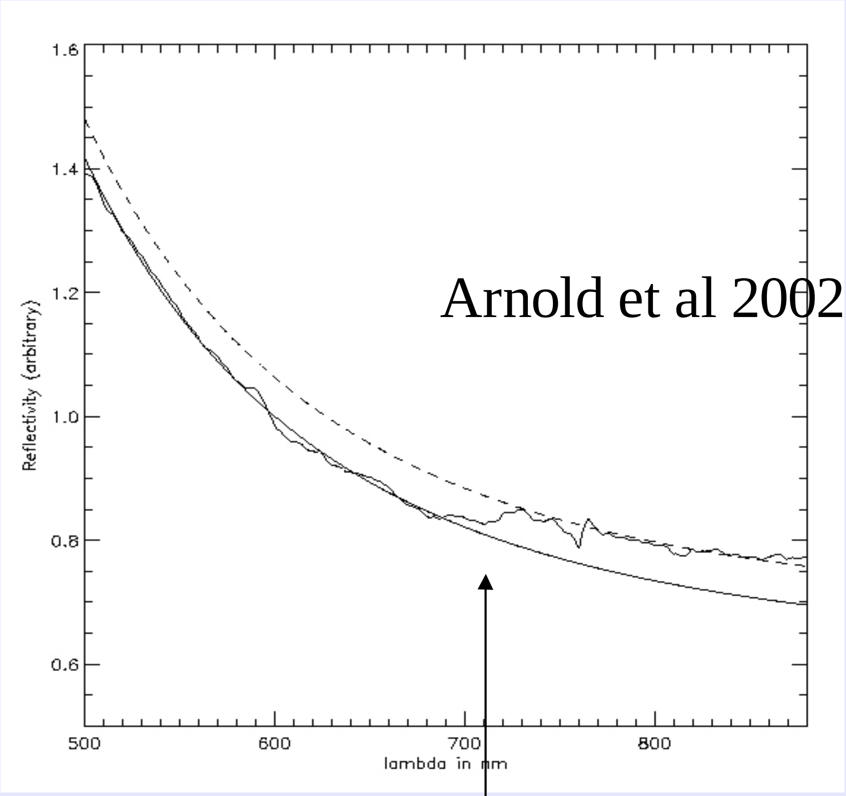
Possible solution: use O2 and H2O bands fine structure + Doppler shift

Biosignatures (2/2)

- Surface « vegetation »

Test of detectability: global Earth spectrum





Arnold et al 2002

Veget. Red edge

Artefacts and ambiguities

- On planet radius

If $f_{pl} = A \times R_{pl}^2 > R_J^2$, error on R_{pl}

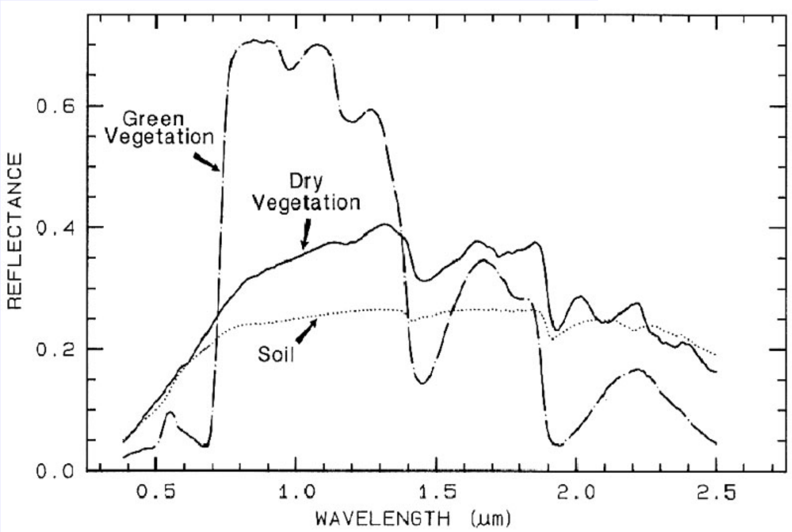
  - Large moon, Binary planet: $R_{eff} = \sqrt{R_{pl}^2 + R_{moon}^2}$
  - Rings: $R_{eff} = \sqrt{\cos i}\, R_{ring}$

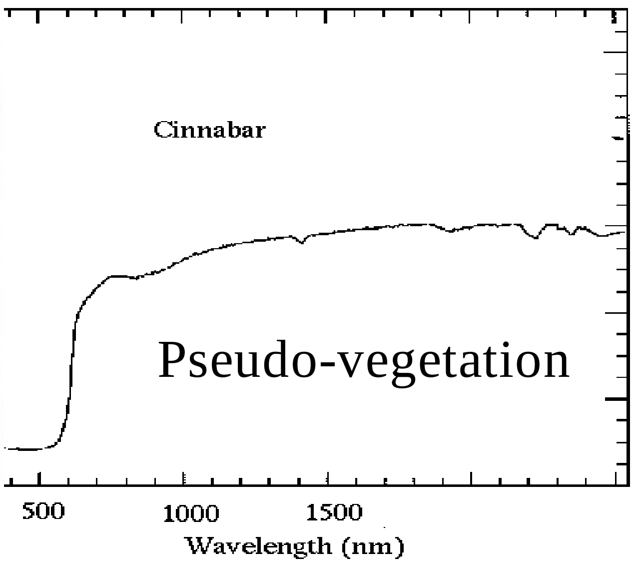
Solution:

(detectable by shadows and transits)

(detectable from orbital light curve)

- On biosignature:





Solution: under study

Chart flow for planet characterization: the importance of modelization

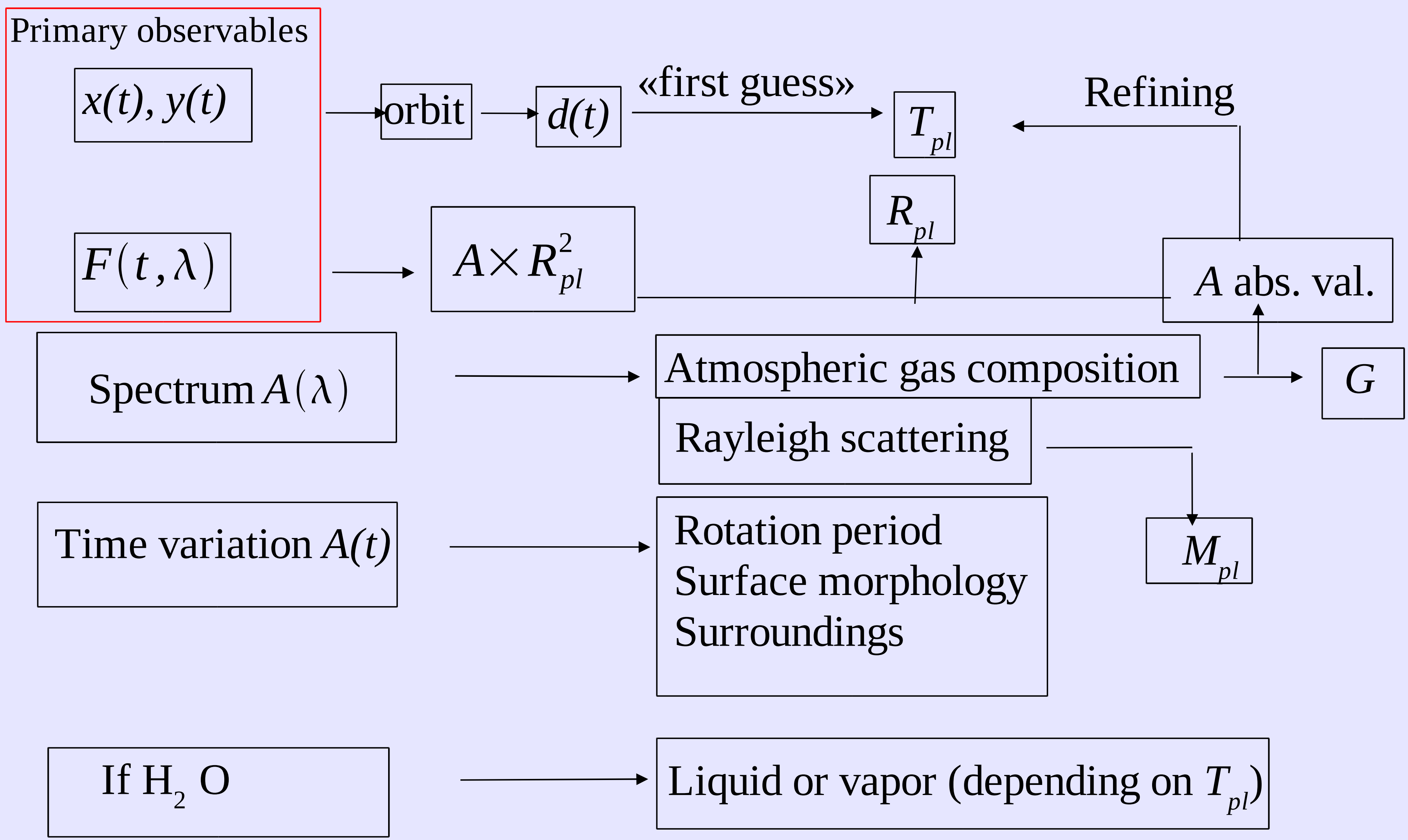
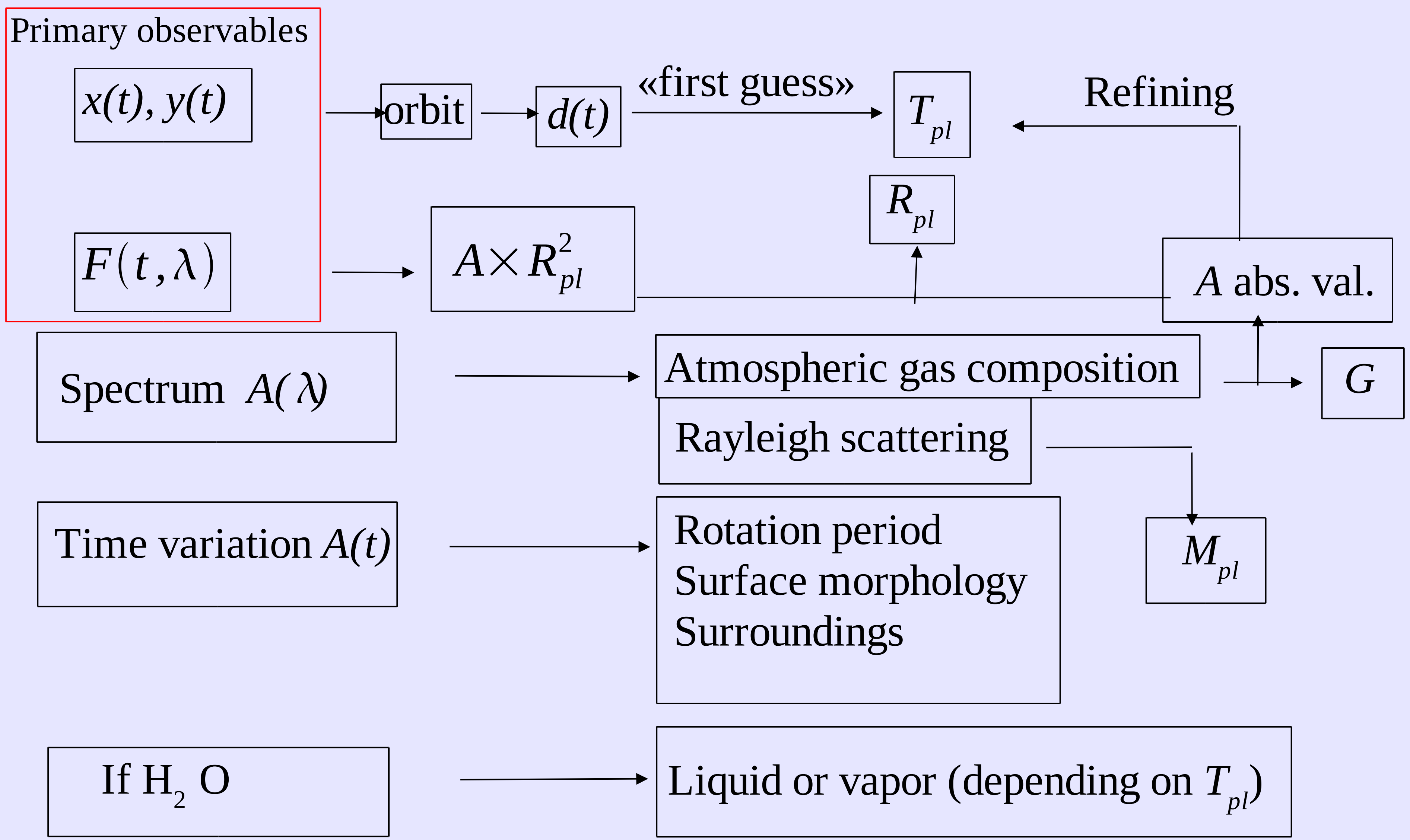
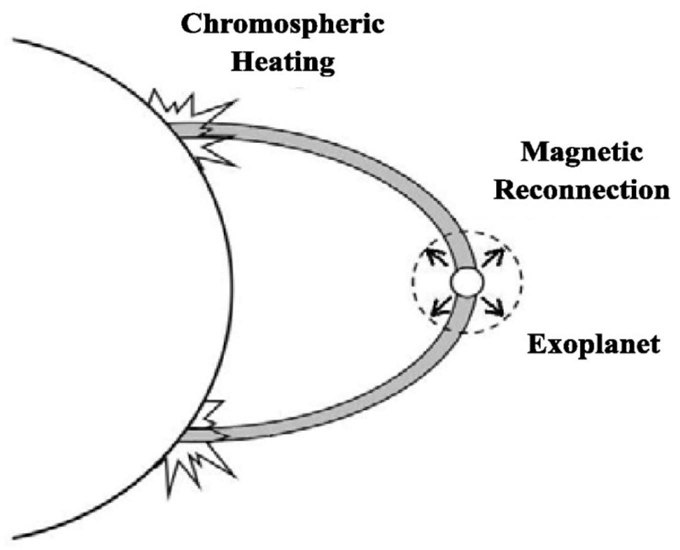
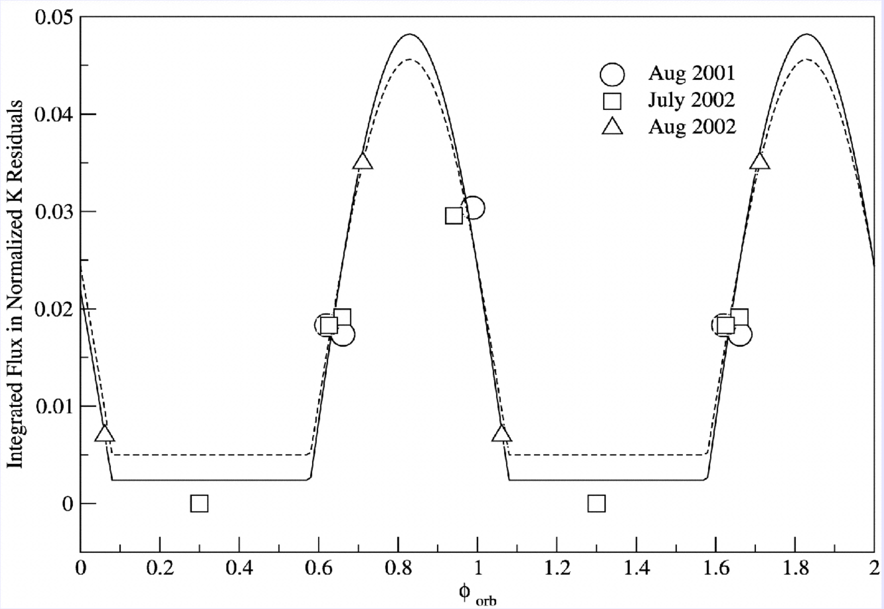


Chart flow for planet characterization: the importance of modelization



Without high contrast dynamics: Planet-induced stellar spots





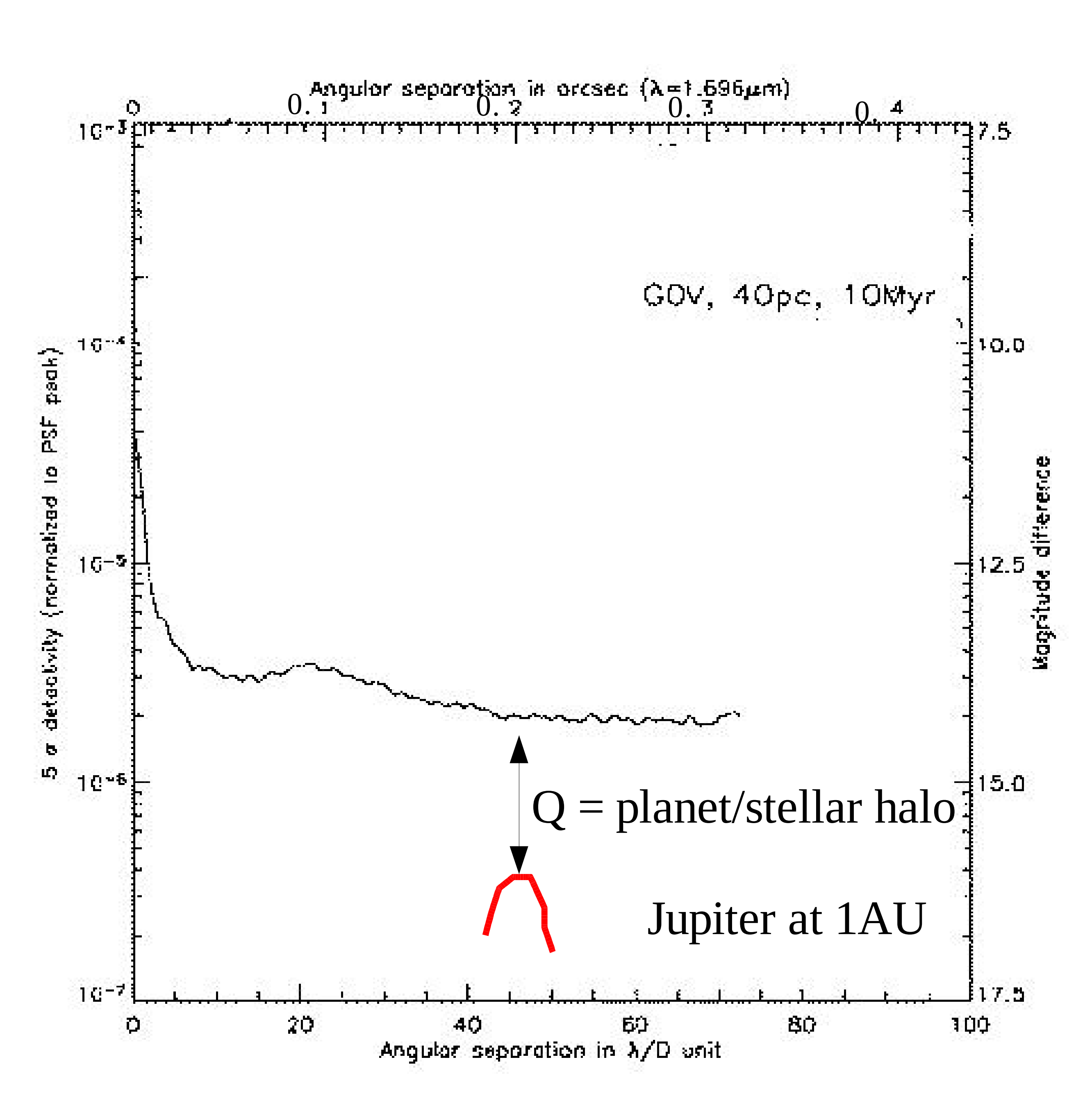
Spot modulated by planet revolution (Ip et al 2004)

HD 179949 CaII 393 nm (Shkolnik et al 2003)

Planet signal in stellar halo

Condition for detectability (SNR = 7):

$$S_{pl} > 7\sqrt{\text{star glare}}$$



50 m / 100 m
NUMBERS TO BE CHECKED

Planet photons in 1 hour $N_{ph} = 120\ \epsilon A(m^2) \times (f_{pl}/f_{\oplus})$ $(0.4-1\ \mu, m_* = 5)$

Exposure time for SNR = 7 ($\epsilon = 5\%$, $Q = 0.01$ - scales like $1/\sqrt{Q}$)

	50 m		100 m	
	Earth	**Jup.**	**Earth**	**Jup.**
Detect.	80 min	1 min	20 min	15 sec
Rayleigh (R=5)	6 hr	-	90 min	-
Continent (5%)	24 hr	-	6 hr	-
Season (5%)	24 hr	15 min	6 hr	4 min
Volcanos (50%)	3 hr	-	45 min	-
Satell. (10%)	15 hr	8 min	4 hr	2 min
Ring	80 min	1 min	20 min	15 sec
Veget. (1%)	120 hr	-	30 hr	-
Transits (0.1%, m_* =15)	0.1 sec		0.02 sec	
Star-pl. Inter. (R=100,000)	10 sec		2.5 sec	

Strategy of observations

- No major impact on the design
- But useful to think about it.

Two philosophies:

  - Survey mode for search for planets
  - Selection of planets provided by RV, astrometry searches and in-deep characterization of these planets

Conclusions

- No obvious threshold effect in general exoplanetology benefits from 50 m to 100 m ELT
- More work to do:
  - PSF critical
  - Site atmosphere critical for biosigntures (O2, H2O)
- Earth-like planet characterization may make the difference
- Not discussed here: ang. Resolution <--> baseline (==> outriggers?)