La recherche d'intelligence extra-terrestre (SETI) par la méthode des transits

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Plan

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1. SETI

- Recherche d'intelligence extra-terrestre (SETI)

- 1959: SETI radio
  - Recherche d’un signal
    - Soit émis intentionnellement à notre attention
    - Soit une 'fuite' d’émission radio, inhérente à l'activité interne d'une société ETI, dont le contenu ne nous serait pas destiné mais dont la forme serait clairement d'origine artificielle.

- Giuseppe Cocconi & Philip Morrison, physiciens à Cornell University en 1959
- Article fondateur dans *Nature*, September 19, 1959
- Mais leur demande d'observations est refusée par l'observatoire Jodrell Bank

SEARCHING FOR INTERSTELLAR COMMUNICATIONS

By GIUSEPPE COCCONI* and PHILIP MORRISON†

Cornell University, Ithaca, New York

NO theories yet exist which enable a reliable estimate of the probabilities of (1) planet formation; (2) origin of life; (3) evolution of societies possessing advanced scientific capabilities. In the absence of such theories, our environment suggests that stars of the main sequence with a lifetime of many billions of years can possess planets, that of a small set of such planets two (Earth and very probably Mars) support life, that life on one such planet includes a society recently capable of considerable scientific investigation. The lifetime of such societies is not known; but it seems unwarranted to deny that among such societies some might maintain themselves for times very long compared to the time of human history, perhaps for times comparable with geological time. It follows, then, that near some star rather like the Sun there are civilizations with scientific interests and with technical possibilities much greater than those now available to us.

To the beings of such a society, our Sun must appear as a likely site for the evolution of a new society. It is highly probable that for a long time they will have been expecting the development of science near the Sun. We shall assume that long ago they established a channel of communication that would one day become known to us, and that they look forward patiently to the answering signals from the Sun which would make known to them that a new society has entered the community of intelligence. What sort of a channel would it be?

The Optimum Channel

Interstellar communication across the galactic plasma without dispersion in direction and flight-time is practical, so far as we know, only with electromagnetic waves.

Since the object of those who operate the source is to find a newly evolved society, we may presume that the channel used will be one that places a minimum burden of frequency and angular discrimi-

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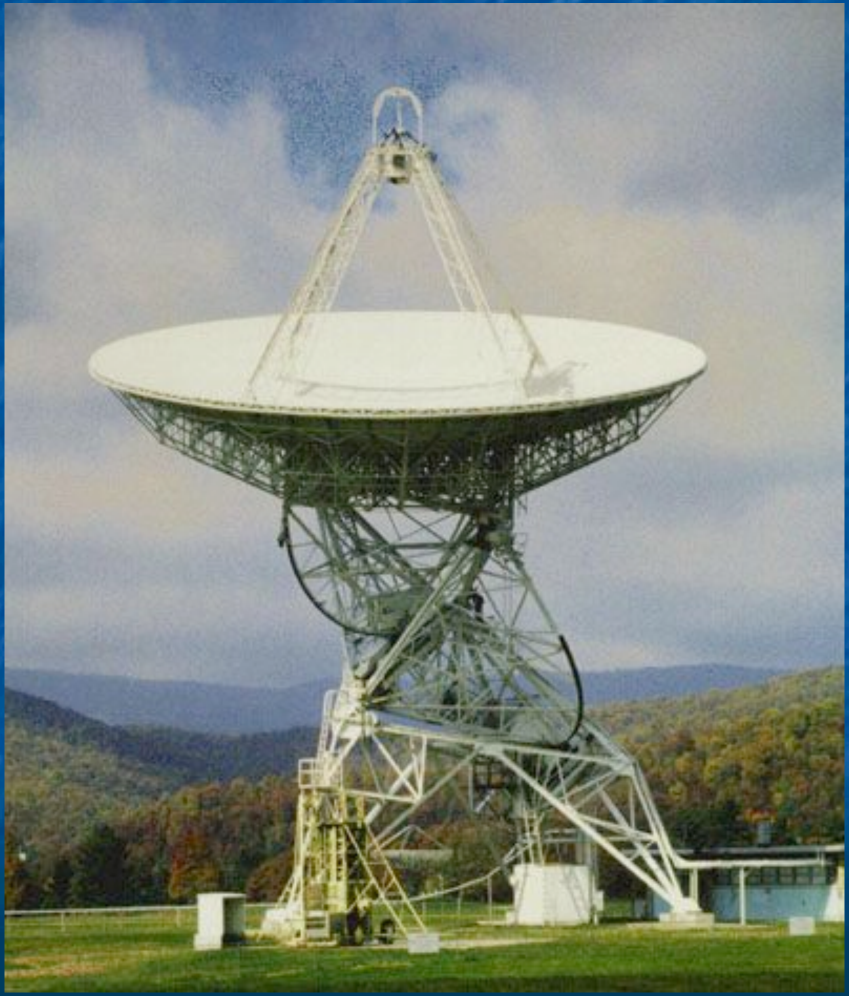
- Mars 1959: Frank Drake, indépendamment de Cocconi et Morrison, calcule que si un signal radio est émis depuis la Terre avec la techno humaine existante, il est détectable à 10 AL par cette même techno, une antenne de 26m.



- Avec le soutien de Otto Struve,

  Drake obtient des observations à Green Bank avec la nouvelle antenne de 26m

  -> Projet OZMA

  2 étoiles G

  tau Ceti, epsilon Eridani

- Les écoutes radio continuent, entre 1 et 3 GHz (transparence du ciel, *water hole*, 1.4 GHz hydrogène neutre, lambda 21cm)

  - 1971: NASA Cyclops report
  - OZMA II: 674 étoiles écoutées 500 h entre 1972 et 76, antenne 43m
  - Années 70's: META (NASA, Harvard), SERENDIP (NASA, Univ. California), Ohio State Univ. ('Wow!' signal en 1977)
  - 1984 création SETI Institute
  - 1985-95 META I (Million channels), META II en Argentine: 8,4 millions de canaux, 0.05Hz de résolution, 93% de sky coverage. 50 'alertes'.
  - 1992 NASA/JPL High Resolution Microwave Survey (HRMS), entre 1 et 3 GHz, 20 millions de canaux de 1 Hz.
  - NASA abandonne SETI en 1993, mais HRMS renaît de ses cendres... Project Phoenix (SETI Institute)
  - 1996 SERENDIP III, U.C. Berkeley, sur Arecibo, et SETI@home
  - Aujourd'hui BETA, SERENDIP IV (168 millions de canaux) et seti@home, Southern SERENDIP en Australie, etc.

  - Projets futurs...actualité:
    - SETI Institute http://www.seti-inst.edu/
    - The Planetary Society http://www.planetary.org/


Arecibo, Puerto-Rico
Diamètre 305m

16 novembre 1974, vers M13 à 25000 AL

450 kW à lambda=12.6cm (2380 MHz)
dans une bande passante de 10 Hz

- SETI optique
  - Contexte historique: 1^{er} laser en 1960 par Maiman
  - 1961: R.N. Schwartz et C. Townes (Nobel en 1964, inventeur du maser en 1954) proposent de rechercher une émission d'un maser continu

(*Reprinted from Nature, Vol.* 190, *No.* 4772, *pp.* 205–208, *April* 15, 1961)

INTERSTELLAR AND INTER-PLANETARY COMMUNICATION BY OPTICAL MASERS

By Dr. R. N. SCHWARTZ and
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Institute for Defense Analyses, Washington, D.C.

LONG-RANGE communication by radio-waves is already well known, and the possibility of interstellar communication by radio-waves in the microwave region has been suggested in several interesting proposals[1-3] to search for signals from intelligent beings on planets associated with nearby stars. The supposition is that curiosity such as our own would motivate advanced civilizations associated with stars other than our Sun to make determined efforts to communicate with whatever other intelligent life might exist on neighbouring planetary systems. Radio-waves have, because of our present state of technological development, dominated the field of very long-distance communication, and perhaps for this reason these proposals gave particular attention only to the radio region. It appears, however, that we are now not very far from the development of maser oscillators and other appropriate apparatus in or near the optical region which will also allow detectable light signals to be beamed between planets of two stars separated by a number of light years.

Our own maser techniques in the optical and nearby spectral regions are still in a rudimentary stage; no such operating device was known a year ago[4,5]. Another ten years should bring very marked development. Further, only historical accident seems to have prevented discovery of optical masers thirty or more years ago, in which case they would probably already have been in an advanced stage of development. This implies that a separate civilization might have inverted our own history and become very sophisticated in the use of optical or infra-red masers rather than in the techniques of short radio-waves.

We propose to examine the possibility of broadcasting an optical beam from a planet associated with a star some few or some tens of light-years away at sufficient power-levels to establish communications with the Earth. There is some chance that such broadcasts from another society approximately as advanced as we are could be adequately detected by present telescopes and spectrographs,

* On leave from Columbia University, New York.

- 1965: Rechercher des impulsions laser émises vers la Terre
- M. Ross, "Search via Laser Receivers for Interstellar Communications," Proc. IEEE, 53, p. 1780 (1965).

Search via Laser Receivers for Interstellar Communications

It has been pointed out[1] that lasers, because they have a much higher spectral density than the sun and have such highly directional characteristics, may be suitable for interstellar communications.

Aside from the problem of receiving sufficient signal[2] from a source in our galaxy, given reasonable assumptions of transmitting power and beamwidth, there is the search problem of locating the proper carrier frequency. Because the optical and infrared spectrum is about 10^{14} c/s wide, the search time to locate a carrier frequency can become extremely long. At radio frequencies, the most likely carrier frequency is thought to be 1415 mc/s, or some multiple or submultiple, because this is the natural hydrogen line.[3] No such obvious selection exists in the optical and infrared spectrum.

The minimum sweep period, without excessive loss of sensitivity in a narrow-band receiver of CW signals, is given by $T=B_0/B_I^2$, where B_I is the IF bandwidth and B_0 is the optical spectrum to be swept. From a noise reduction viewpoint, we wish B_I to be as small as possible if one makes the likely assumption that any information modulation of the carrier would be at a very low rate, but this increases the search time such that for desired values of $B_0=10^{14}$ c/s and $B_I=1$ c/s, the sweep period is 10^{14} seconds. This would be the time spent looking at but one star (and its possible planets). By widening the IF bandwidth to 1 mc/s (thus increasing the noise), we could theoretically carrier—namely, 1415 mc/s or some multiple or submultiple. The information modulation may be some slow amplitude or frequency modulation about the subcarrier. By use of say, 10Å filters, over a range of 10 000Å, 1000 separate measurements for each star would be made. As an example, given an integration time of 10 seconds each, it would take approximately three hours to examine each star.

Some reasonable restrictions on carrier frequencies can be made. It is most likely that any transmitter choice would not be made near the highest spectral densities of the star (temperatures vary considerably from star to star), since this increases the background problem and, thus, decreases the signal-to-noise ratio. In the narrow-band receiver this problem will be substantially less than in the broader optical bandwidth subcarrier receiver discussed here; however, because of search considerations, scanning narrow-band receivers are not too likely to be used.

An optimum carrier frequency band for each star may be found if we assume that a fixed average laser power can be generated at specific frequencies over the IR and optical range. If we consider 1) the star spectral density vs. frequency and 2) that the number of signal photons/W decreases linearly as a function of frequency, we note that

a) the receiver background will be extremely dependent on the carrier frequency and star temperature;

b) because the more signal photons we receive, the better the signal-to-noise-in-signal ratio (the noise-in signal is a

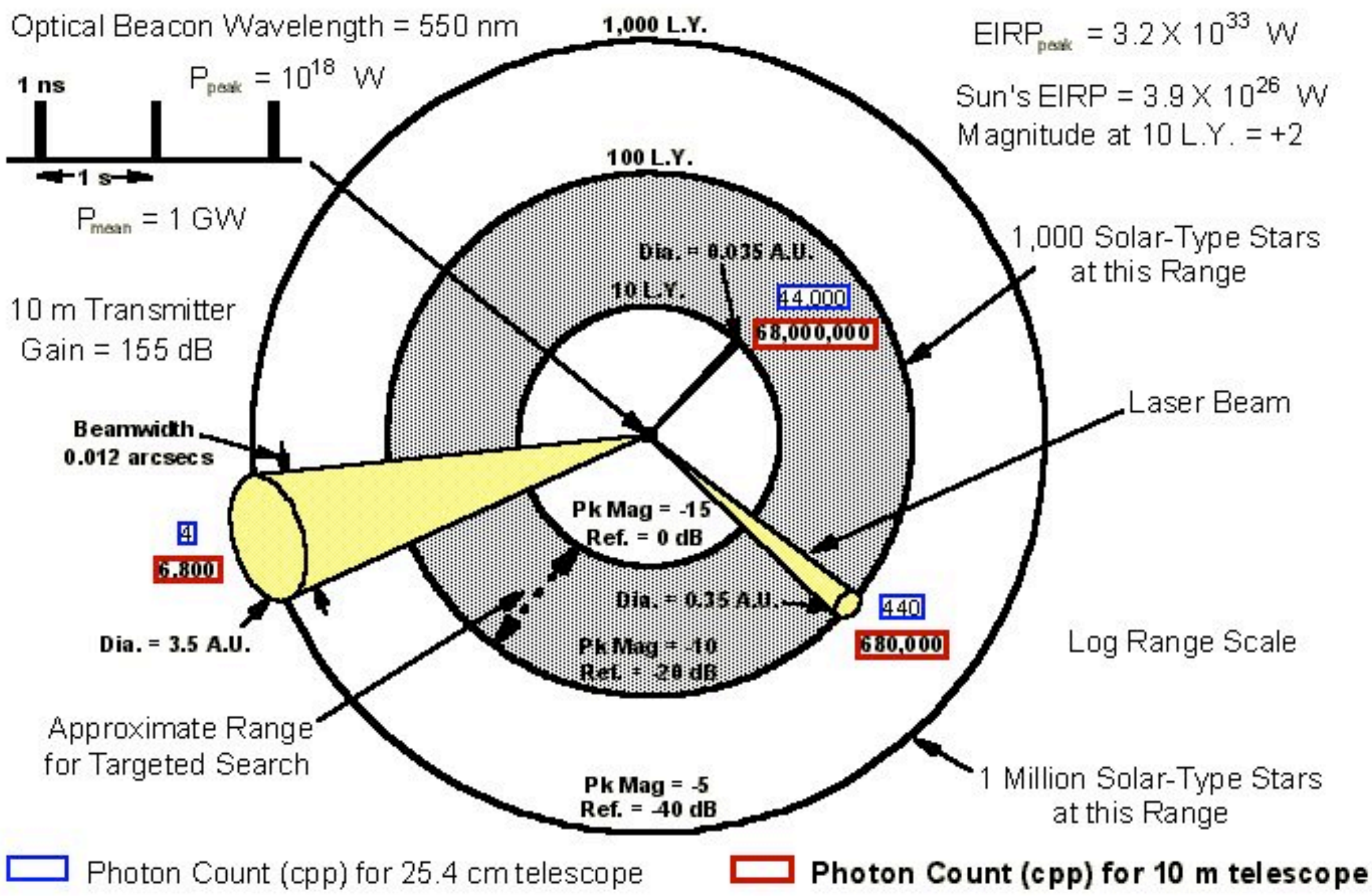
it is at present) where enormous peak powers at low-duty cycles can be obtained, this form of coding may be what one can expect.

For this case, as pertinent as the question what carrier frequency to expect, is the question: how often a pulse? Involved with this question is another: how wide the pulse?

If one is searching a band for a signal, obviously one has to wait in each part of the spectrum at least as long as the expected maximum interval between pulses before one can look at another part of the spectrum. Further, the receiver bandwidth must be wide enough to reproduce the narrowest expected pulse. With these restrictions, a scanning type receiver would have a wide bandwidth and slow sweep. The sweep speed is restricted to much less than it would be from IF bandwidth (pulse width) considerations, thus again indicating that nonscanning receivers may be more suitable (and certainly more practical at present).

Because the questions how often and how wide a pulse will determine the search times for each star, some careful thought is required to see if some logical choice exists. Perhaps some time standard related to light traversing some particular astronomical distance would be likely. It would seem that any time period related to our solar system or our length and time units would be meaningless for interstellar communicators. Perhaps some connection with the period of the 1415 mc/s line can be expected.

MONTE ROSS
Research and Development Dept.
Hallicrafters Co.
Chicago, Ill.



Optical Beacon Wavelength = 550 nm
1 ns
$P_{peak} = 10^{18}$ W
1 s
P_{mean} = 1 GW
10 m Transmitter
Gain = 155 dB
Beamwidth
0.012 arcsecs
4
6,800
Dia. = 3.5 A.U.
Approximate Range
for Targeted Search
1,000 L.Y.
100 L.Y.
10 L.Y.
Dia. = 0.035 A.U.
44,000
68,000,000
Pk Mag = -15
Ref. = 0 dB
Dia. = 0.35 A.U.
440
680,000
Pk Mag = -10
Ref. = -20 dB
Pk Mag = -5
Ref. = -40 dB
$EIRP_{peak} = 3.2 \times 10^{33}$ W
Sun's EIRP = 3.9×10^{26} W
Magnitude at 10 L.Y. = +2
1,000 Solar-Type Stars
at this Range
Laser Beam
Log Range Scale
1 Million Solar-Type Stars
at this Range
Photon Count (cpp) for 25.4 cm telescope
Photon Count (cpp) for 10 m telescope

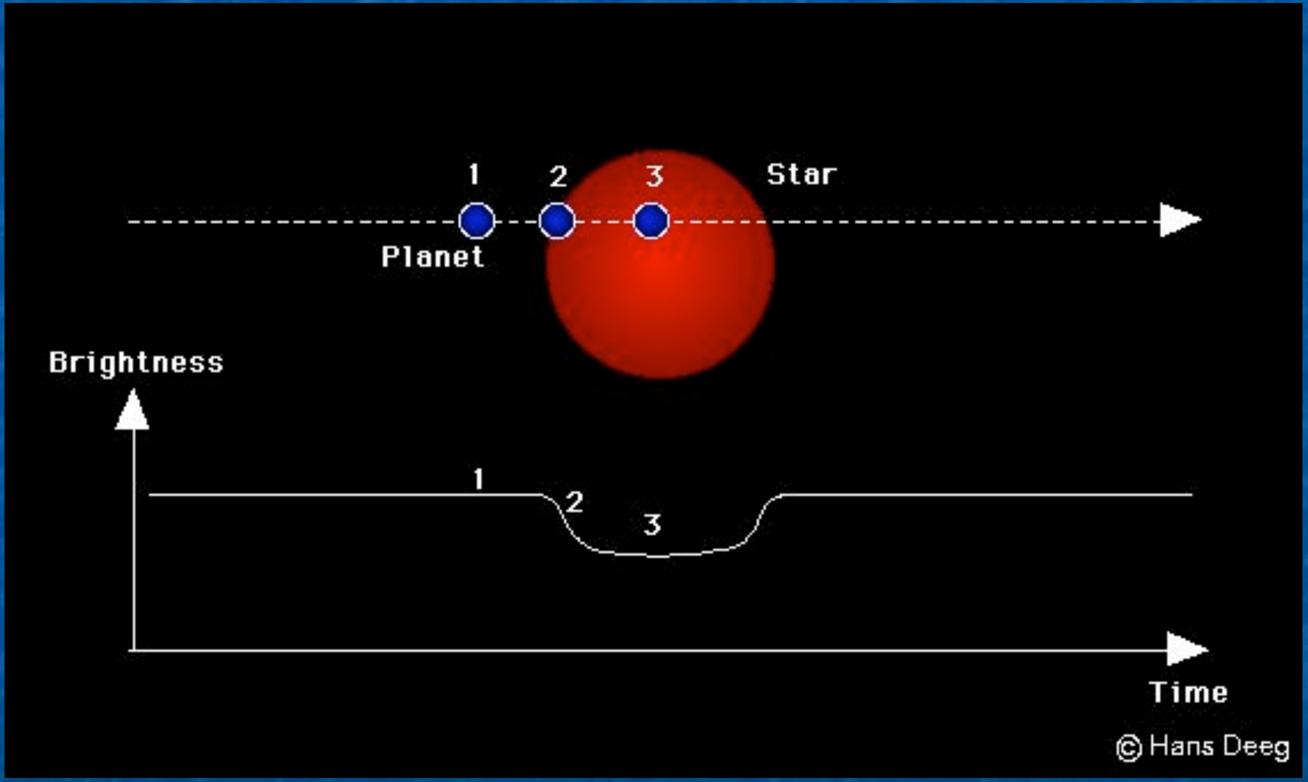
- Optical SETI: Harvard, Princeton, Berkeley
- COSETI Columbus Optical SETI http://www.coseti.org/

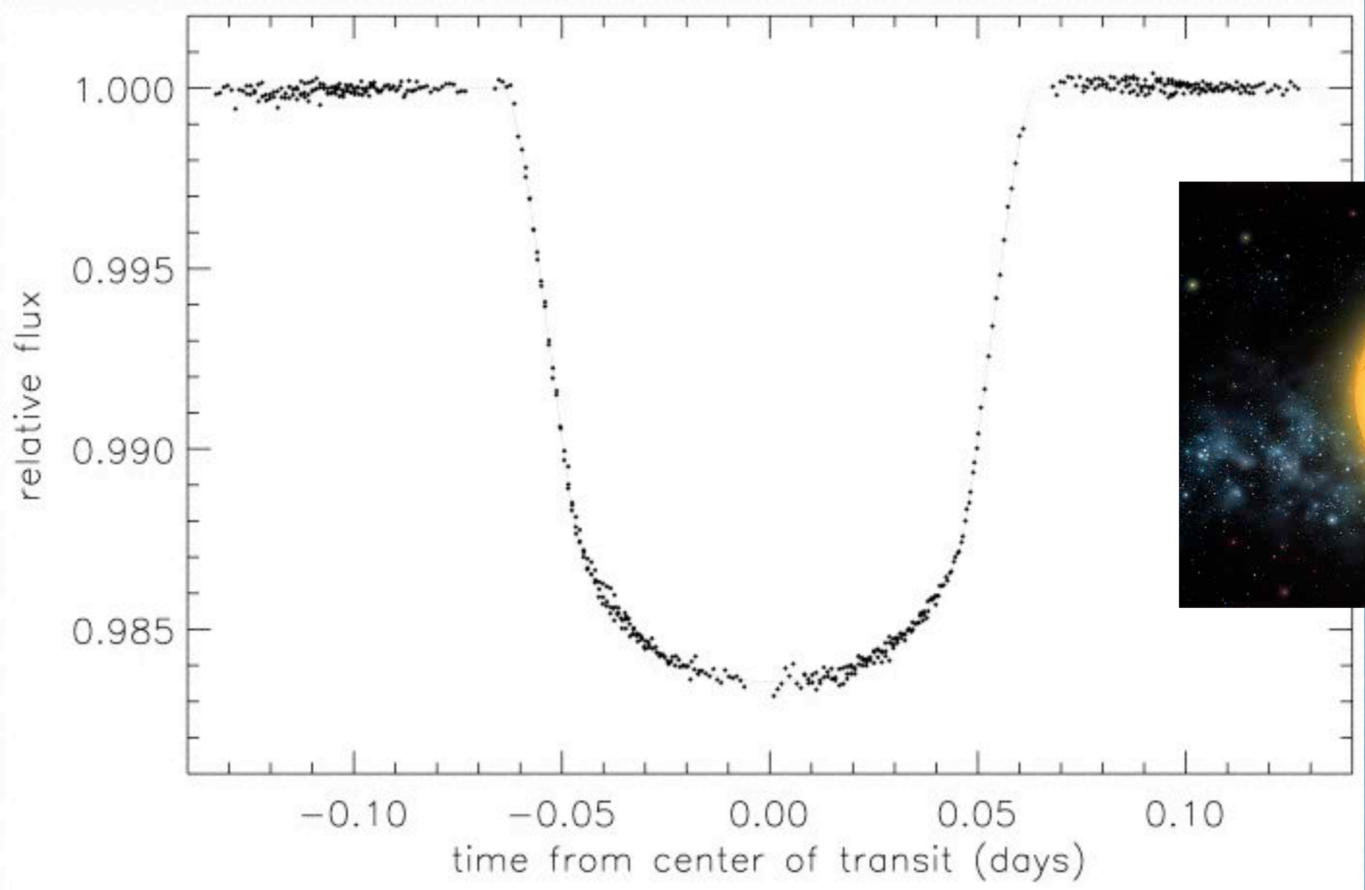
- Sources détectables jusqu'à 1000 Ly
- Utilisation de photomultiplicateurs rapides

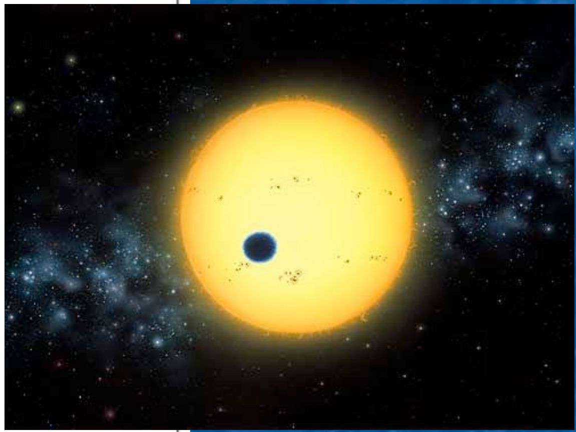
Télescope 61'' (1,5m)
OSETI Harvard

2. SETI par transit

- Recherche de planètes extrasolaires par transit proposée par Otto Struve (1952)

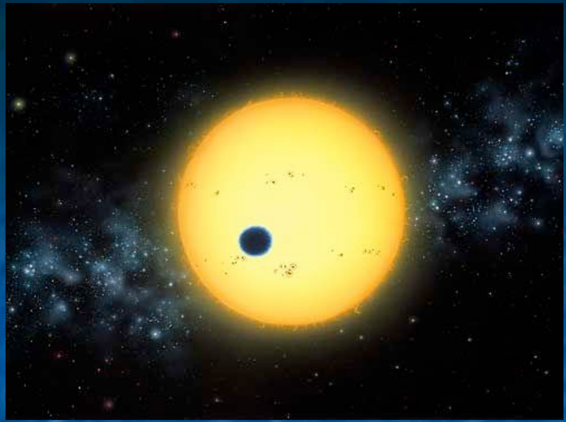






Vue d'artiste
de HD209458

Observation du transit de HD209458b par HST (Brown et al 2000)



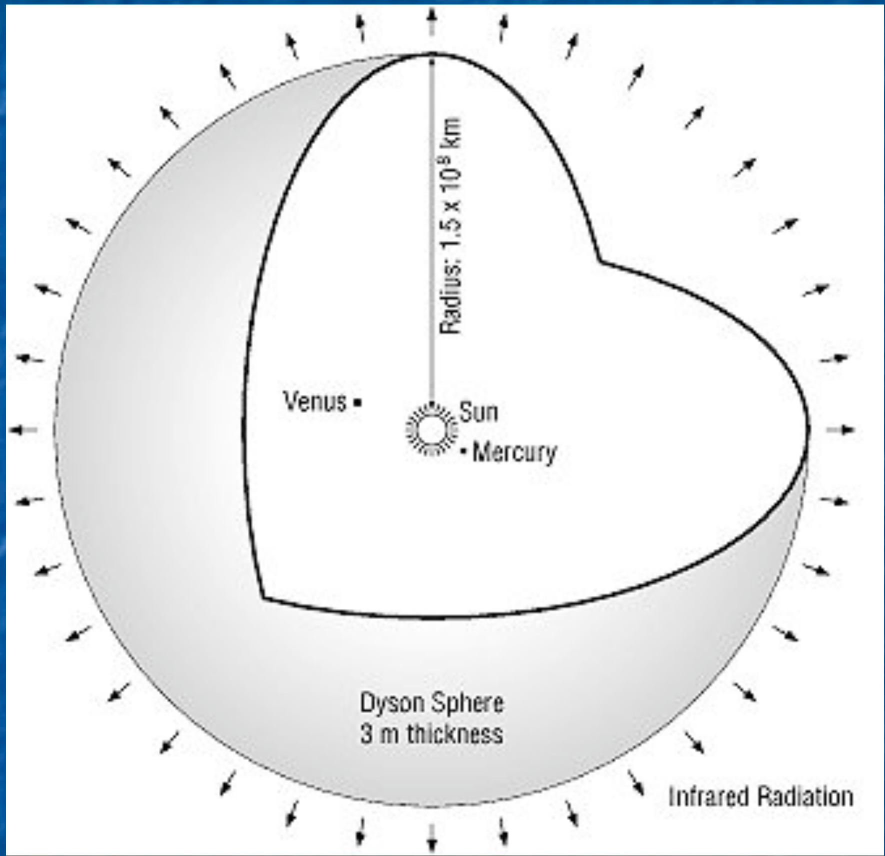
Proposition:

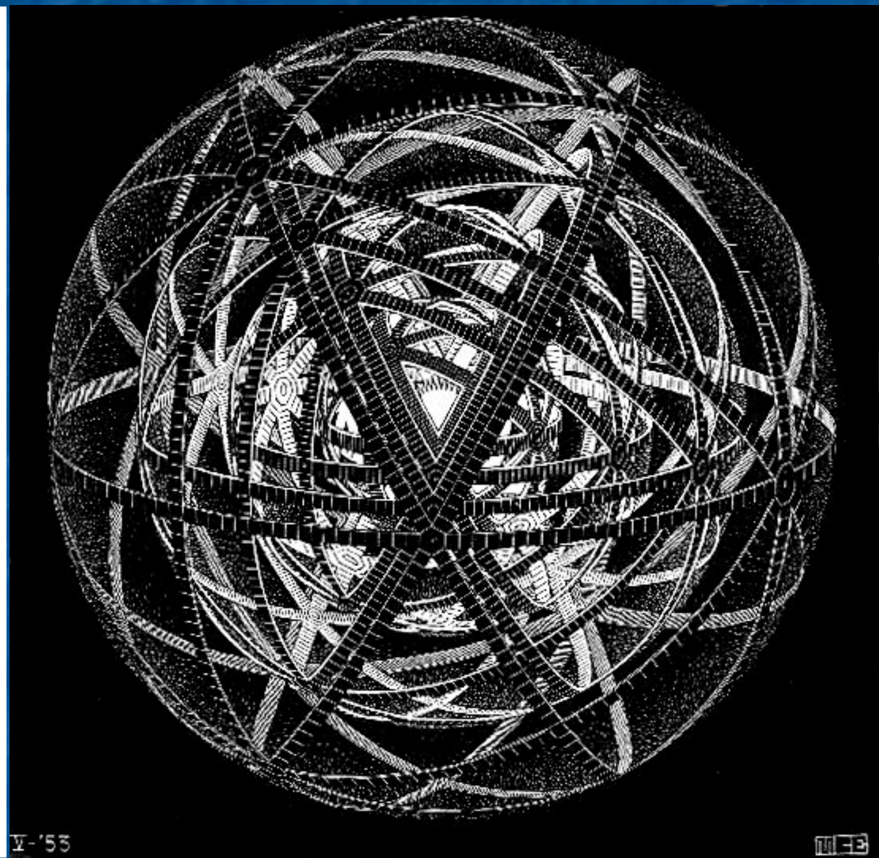
- 1. Hypothèse: on suppose que des objets artificiels de la taille d'une planète peuvent être construits par une civilisation *avancée* dans l'environnement d'une étoile (à 1 UA)

- 2. Fait géométrique (cause): ces objets transitent toujours devant l'étoile pour un observateur dans une direction donnée

- 3. Conséquence (effet): si ces objets existent, on devrait pouvoir les détecter, voire les caractériser, par la méthode des transits

- Les sphères de Dyson (Freeman Dyson, Science, 1960) sont plus grandes que des ‘planètes’ artificielles !





- Lecture: Dyson Shell: A Retrospective, Bradbury 2001, http://www.aeiveos.com/~bradbury/

- Classification de Kardashev (1964), physicien russe
  - Civilisation de Type I domestique 10^{17} W (énergie reçue du Soleil)
  - Civilisation de Type II domestique 10^{26} W (énergie totale du Soleil)
  - Civilisation de Type III domestique 10^{37} W (énergie de toute la Galaxie)

-> Dyson

-> Comm

- *Transits artificiels ?* Pour attirer l'attention de civilisations *émergentes*, une civilisation *avancée* émet des signaux détectables au cours de l'exploration astronomique normale de la civilisation émergente (Tarter 2001)

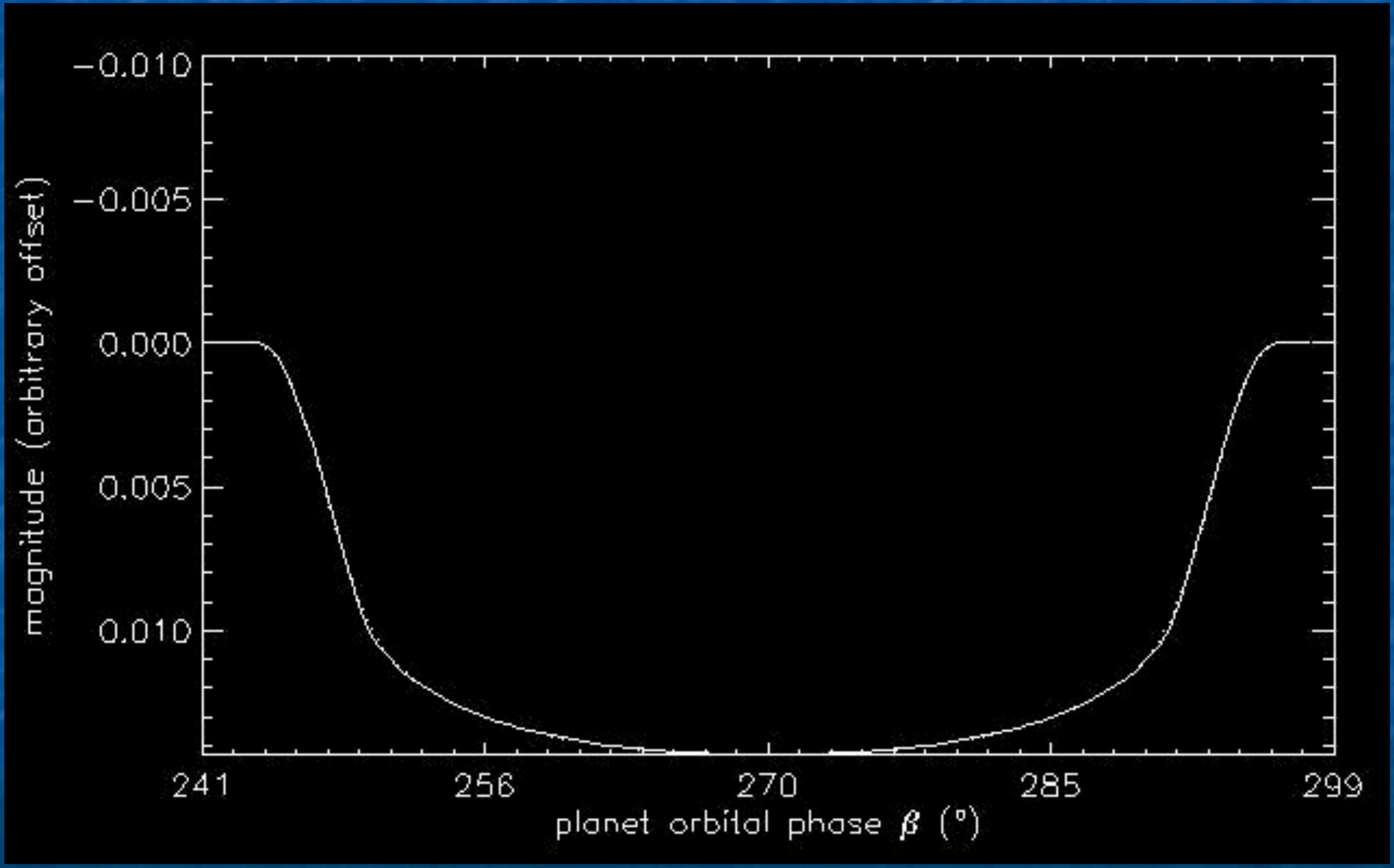
- Exemples:
  - Radio astronomie -> SETI radio
  - méthode des transits pour la recherche des exoplanètes -> SETI par transits ?

- COROT: 60 000 étoiles (en 2006)
- KEPLER: 100 000 étoiles (en 2007)
- Découvririons-nous des transits artificiels ? Tests bientôt possibles !

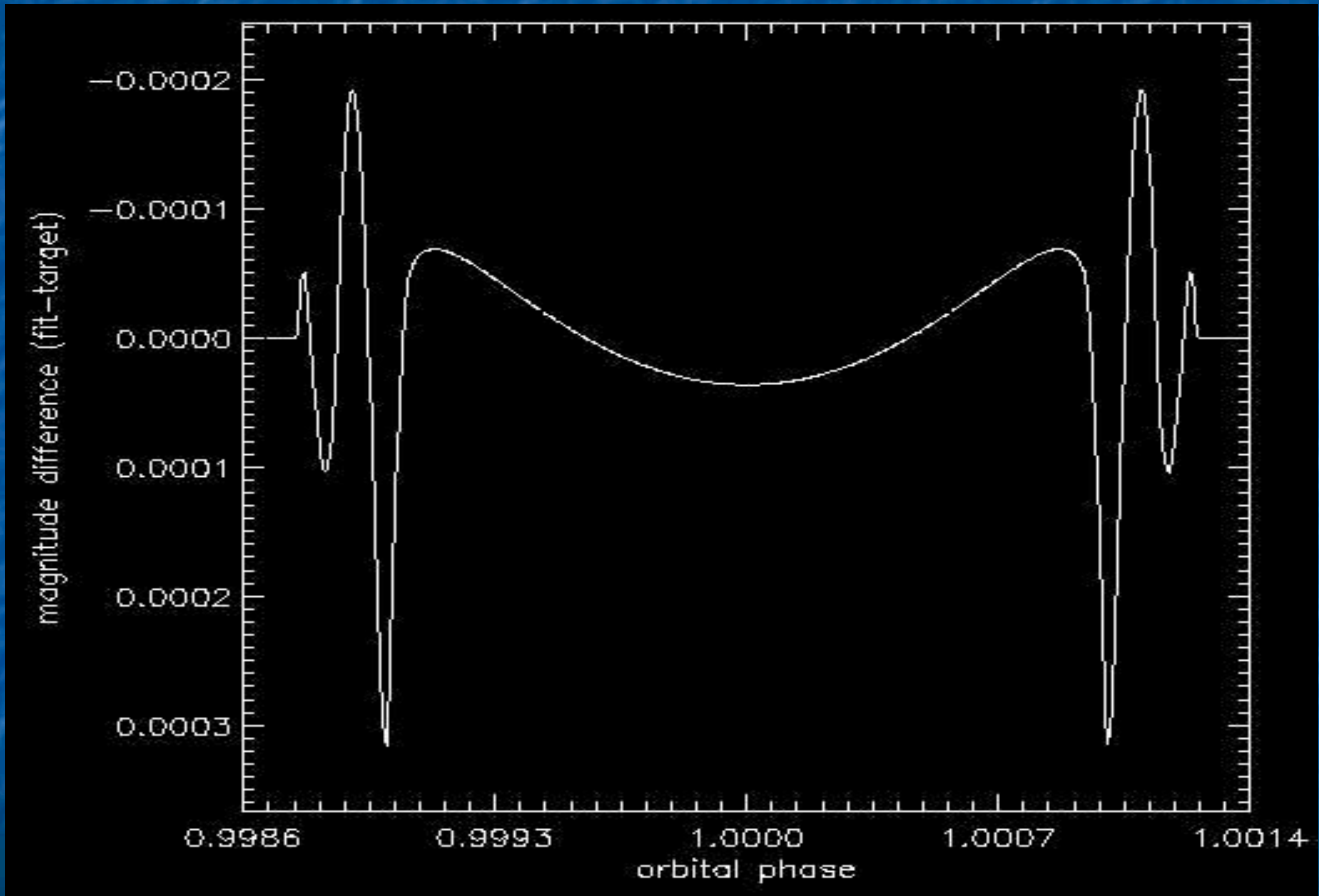
3. Illustration par quelques exemples

- Transit simple d’un objet non-sphérique

- Les courbes photométriques sont différentes... un peu...

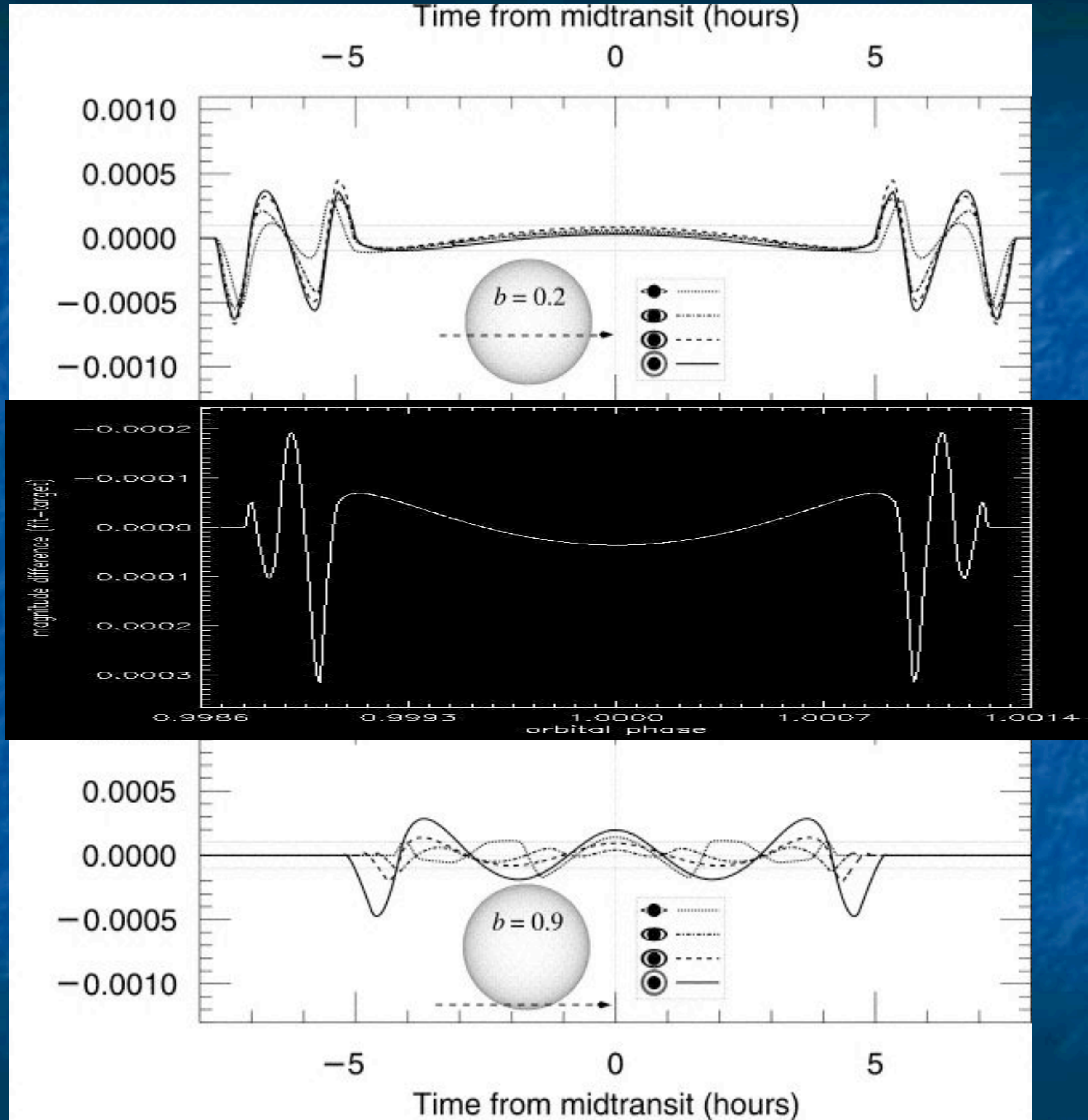


- Différence entre les courbes de transit de l'objet et celle de la 'meilleure sphère'



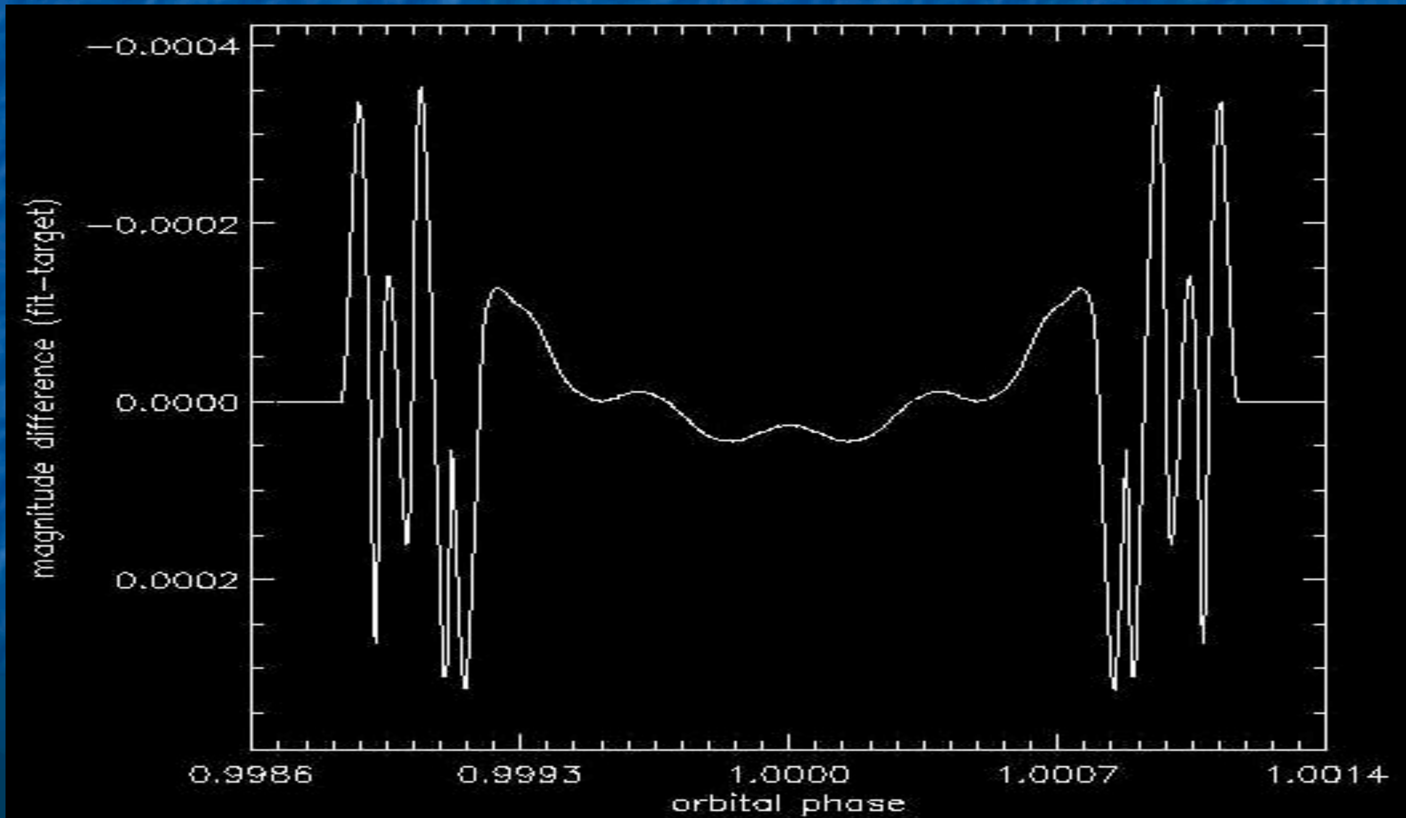
- Écarts (résidus) de quelques 10^{-4}
- Ecarts de quelques 3 % par rapport à la profondeur du transit

  => Signal sur Bruit nécessaire sur le transit > 100
- A la portée de COROT et KEPLER
- Problème: ambiguïté possible avec une planète à anneaux ? (voir Barnes & Fortney 2004, ApJ)



Time from midtransit (hours)
−5
0
5
0.0010
0.0005
0.0000
−0.0005
−0.0010
b = 0.2
magnitude difference (fit−target)
−0.0002
−0.0001
0.0000
0.0001
0.0002
0.0003
0.9986
0.9993
1.0000
1.0007
1.0014
orbital phase
0.0005
0.0000
−0.0005
−0.0010
b = 0.9
−5
0
5
Time from midtransit (hours)

- Et un triangle tournant ?



- Objet à 2 écrans