TRAPPIST : a robotic telescope to study planetary systems

TRAPPIST =
*TRA*nsiting *P*lanets and
*P*lanetes *I*mals *S*mall *T*elescope

Emmanuël Jehin and TRAPPIST team
(Liège University Belgium – FNRS)

Université de Liège

fnrs
LA LIBERTÉ DE CHERCHER

OBSERVATOIRE DE GENÈVE
FONDÉ EN 1772

TRAPPIST : a robotic telescope to study planetary systems

AUTHENTIC TRAPPIST PRODUCT

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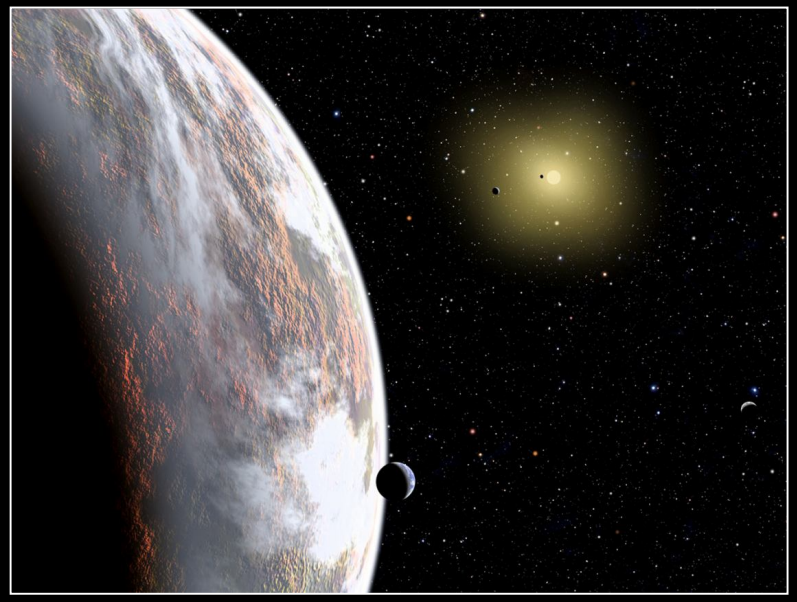
OBSERVATOIRE DE GENÈVE FONDÉ EN 1772

The existence of other worlds : An old question



"There are countless suns; countless land revolve around these suns, in the same way the seven planets revolve around the Sun"

Giordano Bruno (1548-1600)

TRAPPIST consortium

- Université de Liège (ULg Belgium)

Team : Michaël Gillon, Emmanuël Jehin, Pierre Magain, Jean Manfroid, Damien Hutsemékers, Aurélie Fumel, Alice Decock, Sandrine Sohy

- Observatoire de Genève (Switzerland)

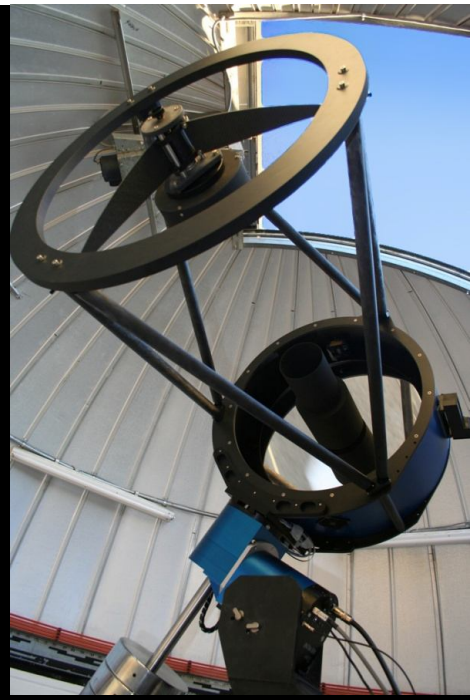
Team : Didier Queloz, Monica Lendl, Amaury Triaud, Stéphane Udry and Gregory Lambert on site

- Funds : Belgian FNRS + Swiss FNS

- European Southern Observatory (ESO)

The site : La Silla Observatory (ESO, Chile)

Timeline : a fast track

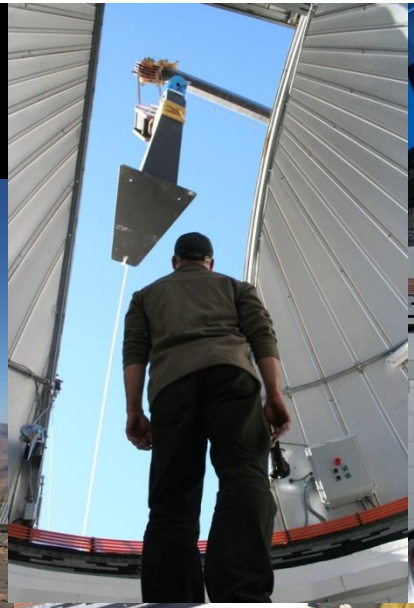


- Sep 07 : definition of the project
- Jan 08 : funds request FNRS
- Jan 09 : money is granted !
- Avr 09 : end of public market
- Avr - Dec 09 : building of telescope + CCD camera + devices

- Feb 10 : refurbishment of Swiss Dome in la Silla
- Avr 10 : installation of telescope (→ tests phase I)
- Jun 10 : first light (→ tests phase II)
- Nov 10 : start of robotic operations !

TRAPPIST installation

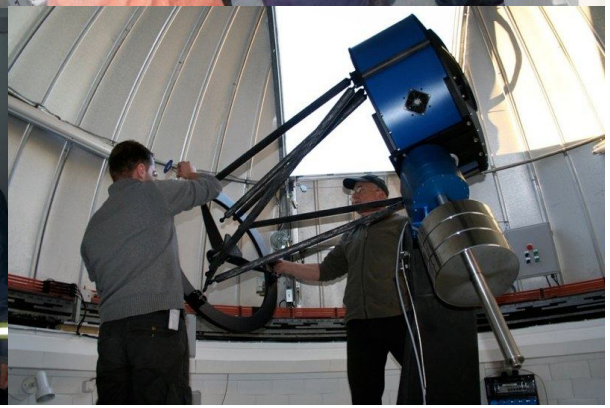












The Telescope

- Optical design: Ritchey-Chrétien

- Brand : ASTELCO GmbH
- mirror size Ø : 60 cm

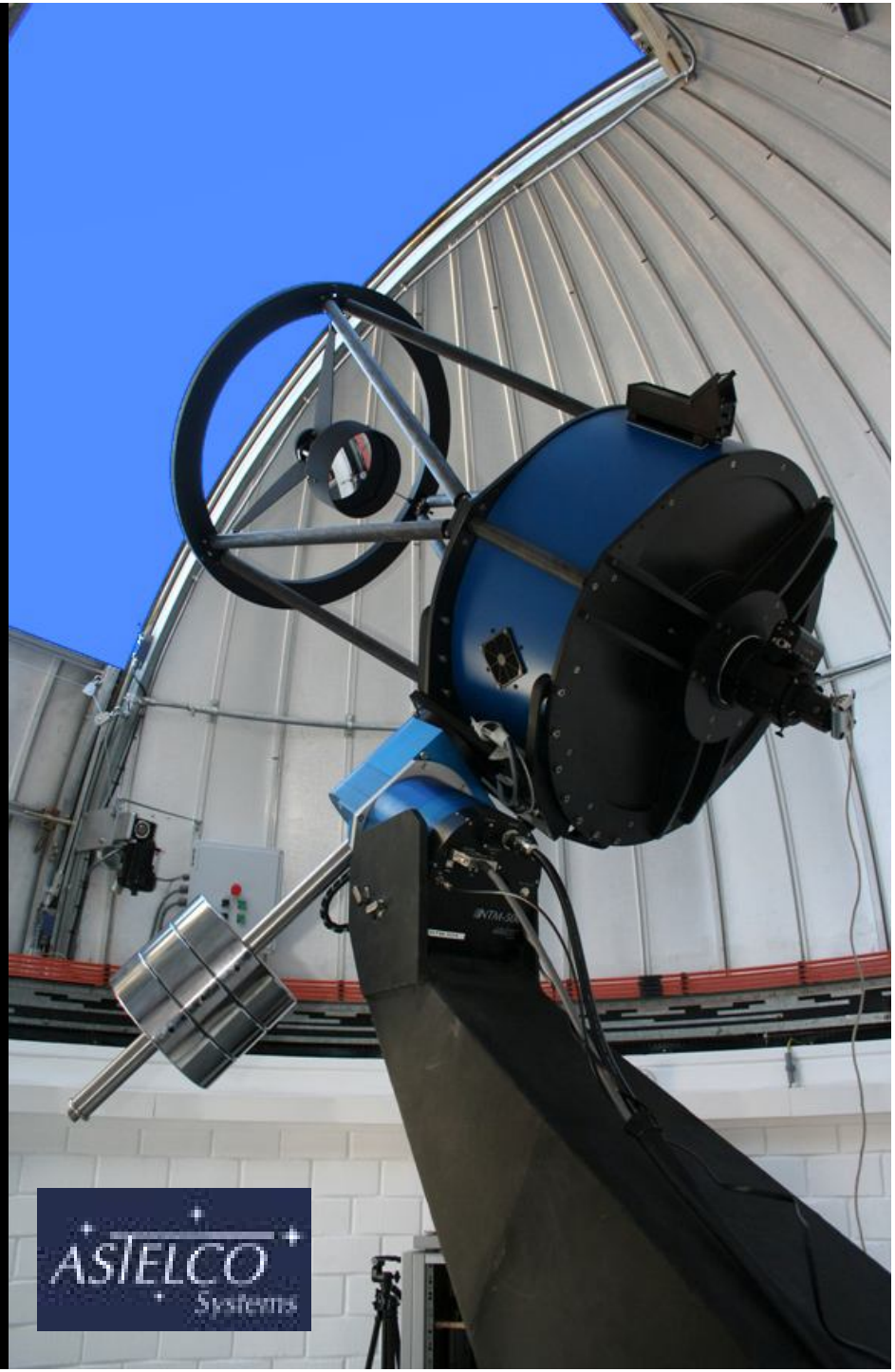
F = 4750 mm F/D = 8

- Clear aperture 50 mm
- Ultra light weight telescope (carbon fiber + aluminium) : 65 kg

- German Equatorial mount NTM-500 :

- “Direct drive” (50 deg/s)
- No periodic error
- pointing 30” (pointing model)
- tracking : 1” / 4 minutes (“software guiding”)

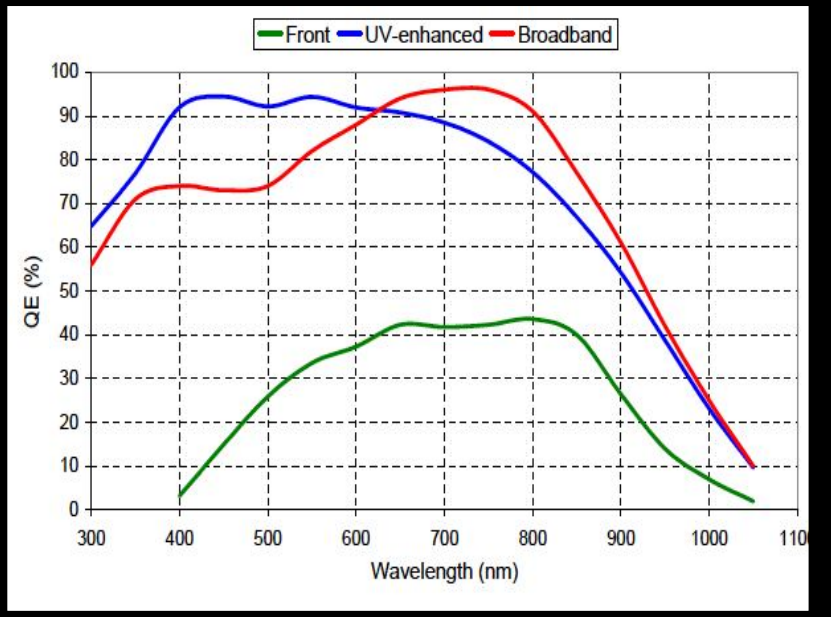
Jehin et al. 2011 (ESO Messenger)



INSTRUMENT

- Focuser TCFS-3” Optec
  - 10.000 steps of 2.5 µm (T° corrections)

- Camera CCD FLI Proline PL-3041-BB
  - 2048x 2048 pixels (15 µm or 3x3cm)
  - FOV/sampling : 22’x22’ and 0.65" /pix
  - CCD chip : Fairchild Imaging 3041 back illuminated
  - QE = 96% à 790 nm / RON ~ 10 électrons
  - 3 modes de lectures : 8s, 6s et 4s
  - Temperature = -55°C below T° ambiant



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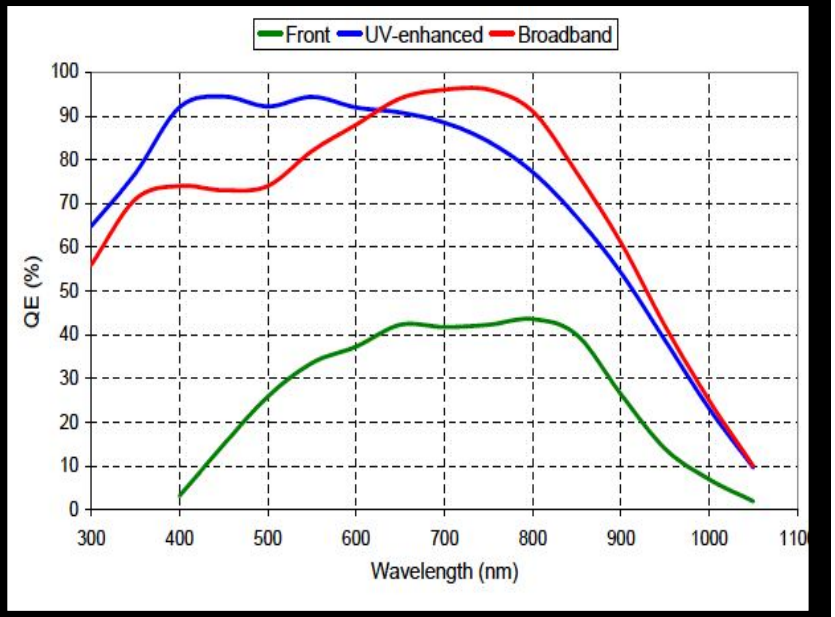
- Double filter wheel Apogee AI-FW50-7S

1. Filters AstroDon BVR, I+z, z, Exo (5x5cm)

2. HB Cometary NASA narrow band filters 2"x2": OH, CN, C_2, C_3, H_2O^+, + BC and GC continuum (Lowell Observatory)

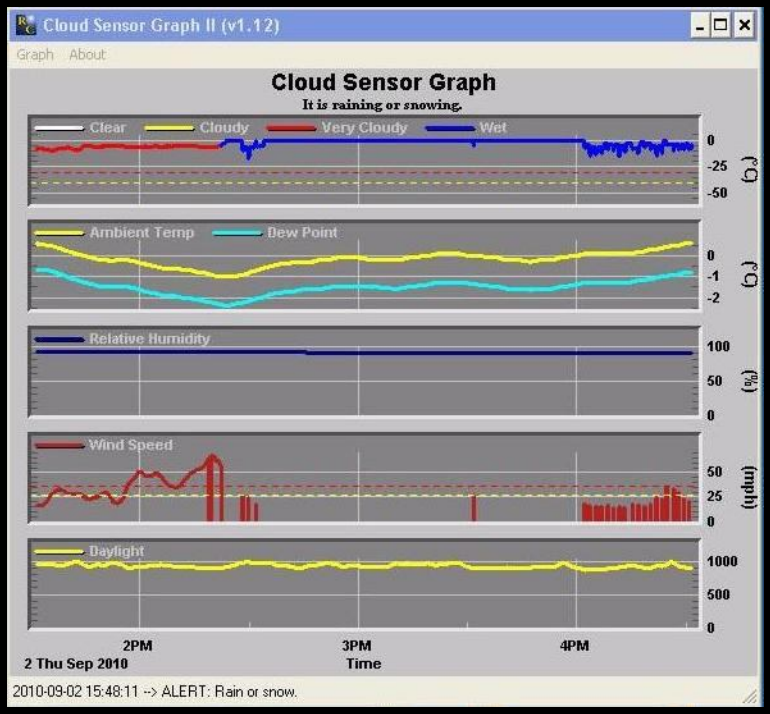


Dome and weather station

- Coupola Ash-Dome 5m
+ rain sensor

- Automation by ACE Smart Dome
(the dome is slaved to the telescope)

- Weather Station Boltwood II
+ direct link to dome



TRAPPIST is robotic

- Computers : PC Chimay : brain of TRAPPIST
  Mac Rochefort : pipeline exoplanets
  PC Orval : archive (ULg)

- ACP Observatory (DC-3 Dreams)

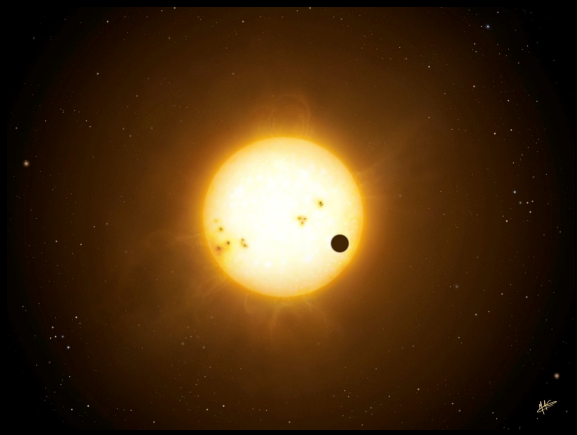
→ 1 sequence of observing blocks for the full night

- Bad weather : weather station → ACP closes the observatory
- Connection to TRAPPIST via VPN Ulg-La Silla (30Kb/s)
- IP Power : every device can be power cycled through internet
- Super driver : ASCOM

- To see and hear : 3 webcams IR
- Data : ~ 5-15 GB/night: "reduction Pipeline" on site

External disks (rack) → Liège (archive)

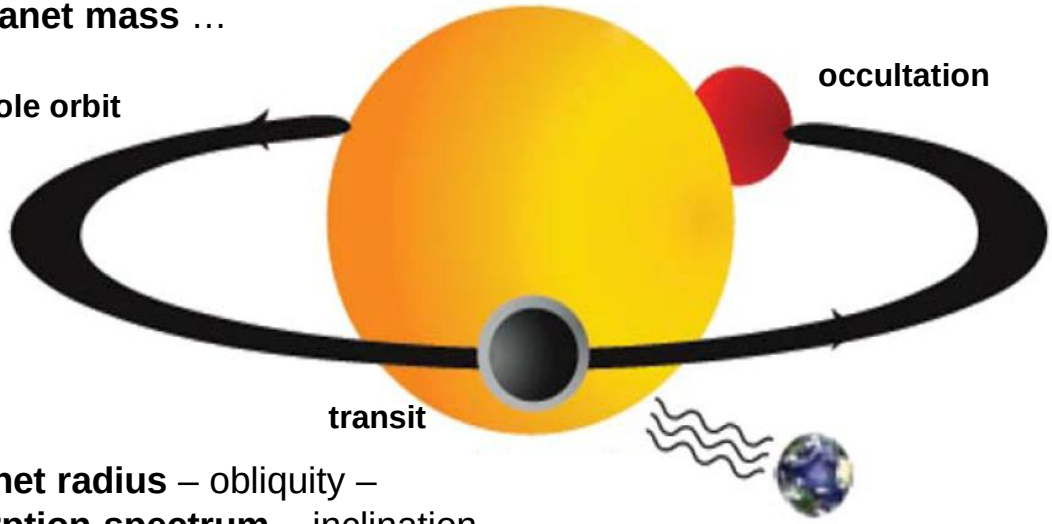
The exoplanet program of TRAPPIST



Transting planets characterization

Phase curve (heat transfer, albedo, rotation…), Trojan search, **planet mass** …

Emission spectrum – planet disk resolution - eccentricity…

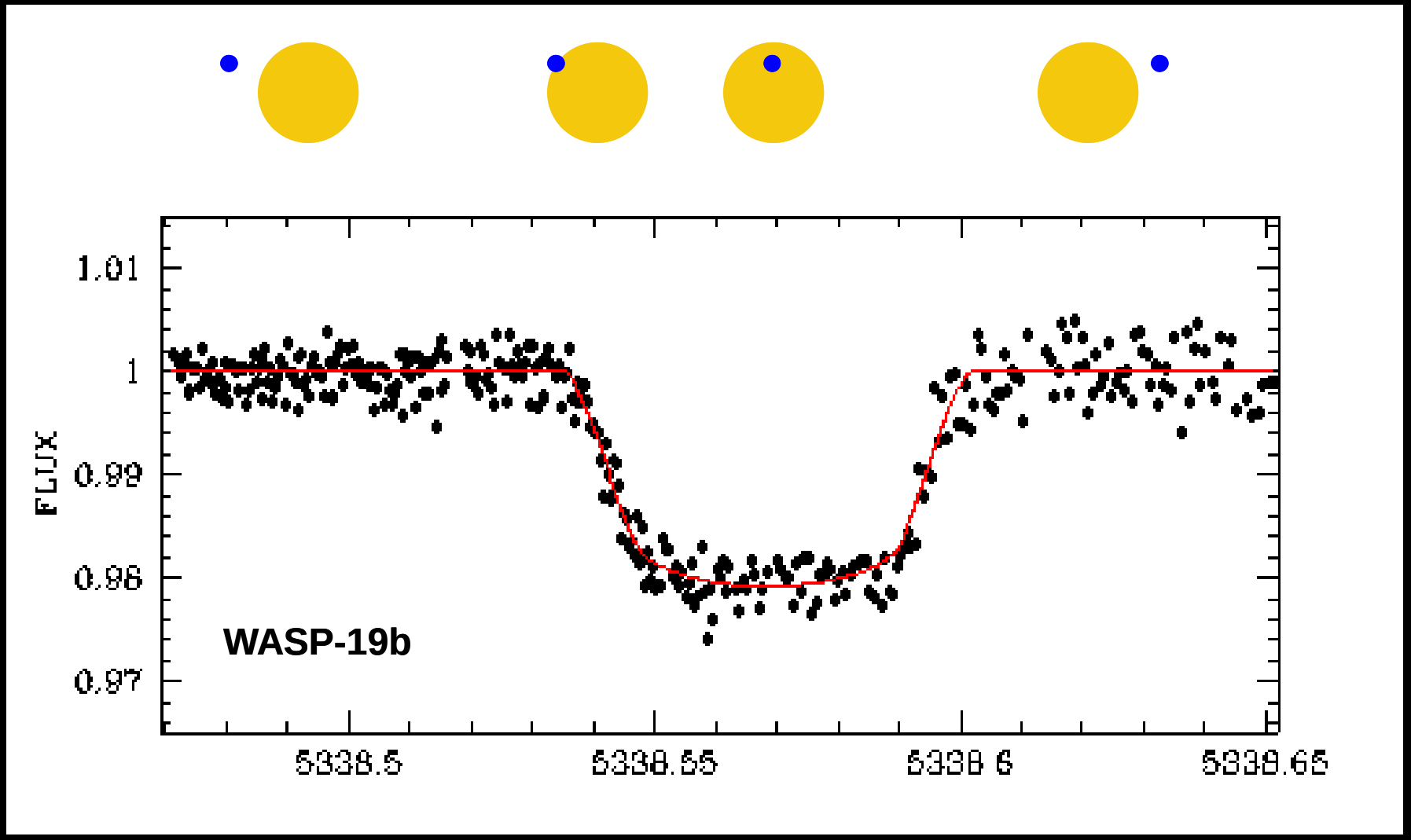


Planet radius – obliquity – Limb **absorption spectrum** – inclination - stellar density – spots – limb-darkening – satellite – rings…

Planet – planet interactions

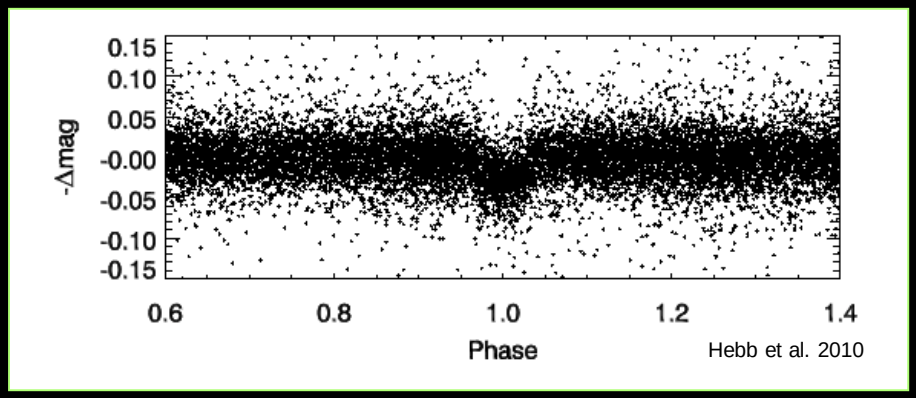
Dynamic – structure – atmosphere
No need for ultra high resolution/contrast imaging

The first TRAPPIST transit light curve !

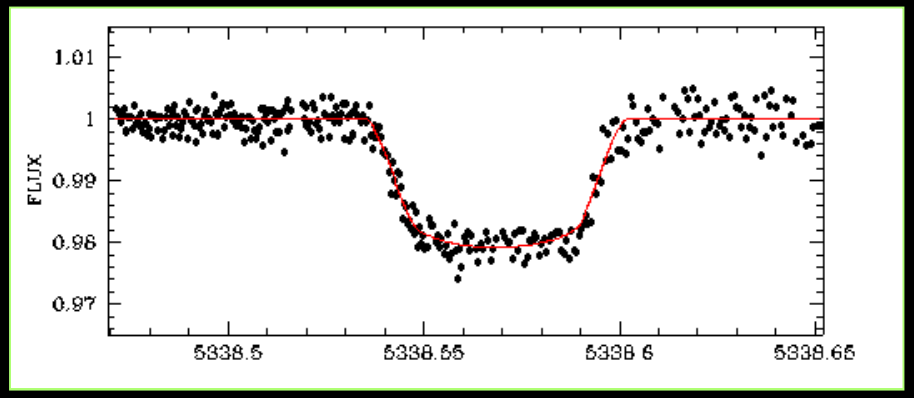


1. Support to WASP (Wide Angle Search for Planets)

- UK project
- 2 rotobic observatories
- 11 cm aperture
- FOV=488 deg^2
- World leading transit survey (> 70)
- 8 < V < 13 (atmospheric characterization)

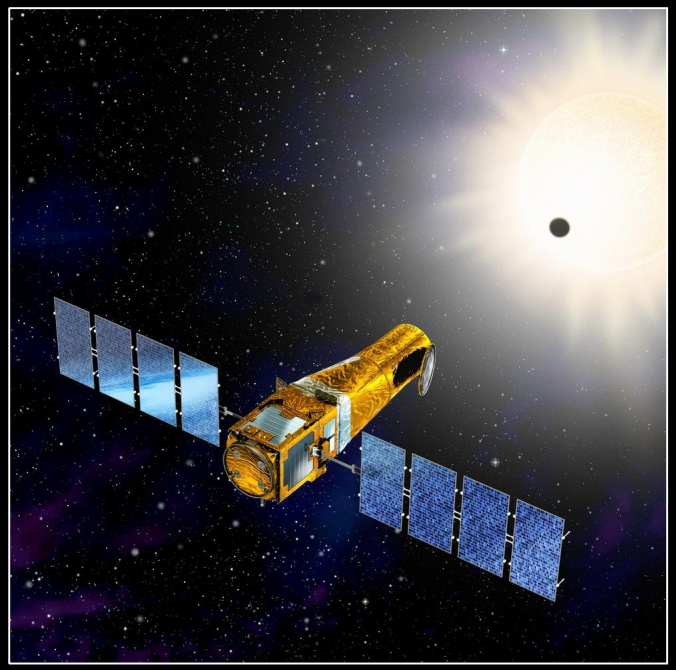


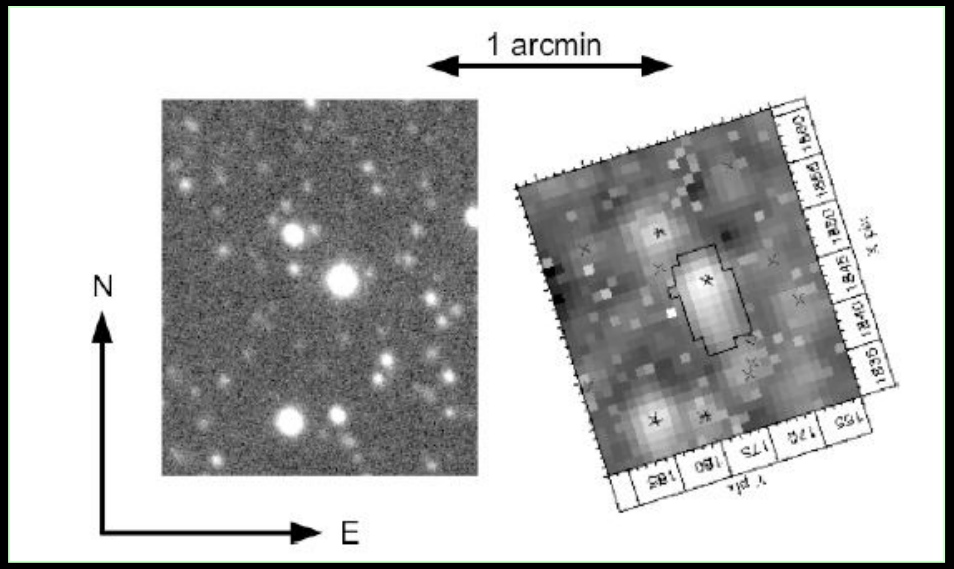
WASP-19



TRAPPIST !

2. Support to space mission CoRoT





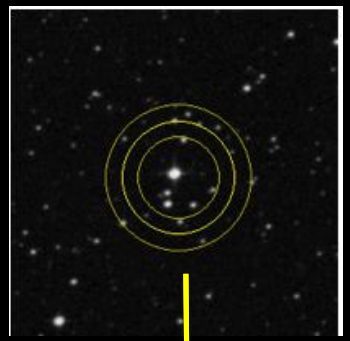
Higher resolution with TRAPPIST: help of CoRoT in case of blends

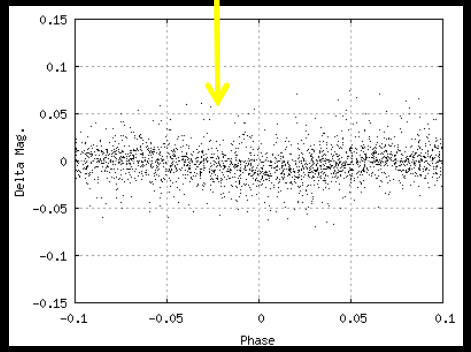
The follow-up of transit surveys candidates

WASP

Pixel scale = 13.7''

Typical precision ~ 1%

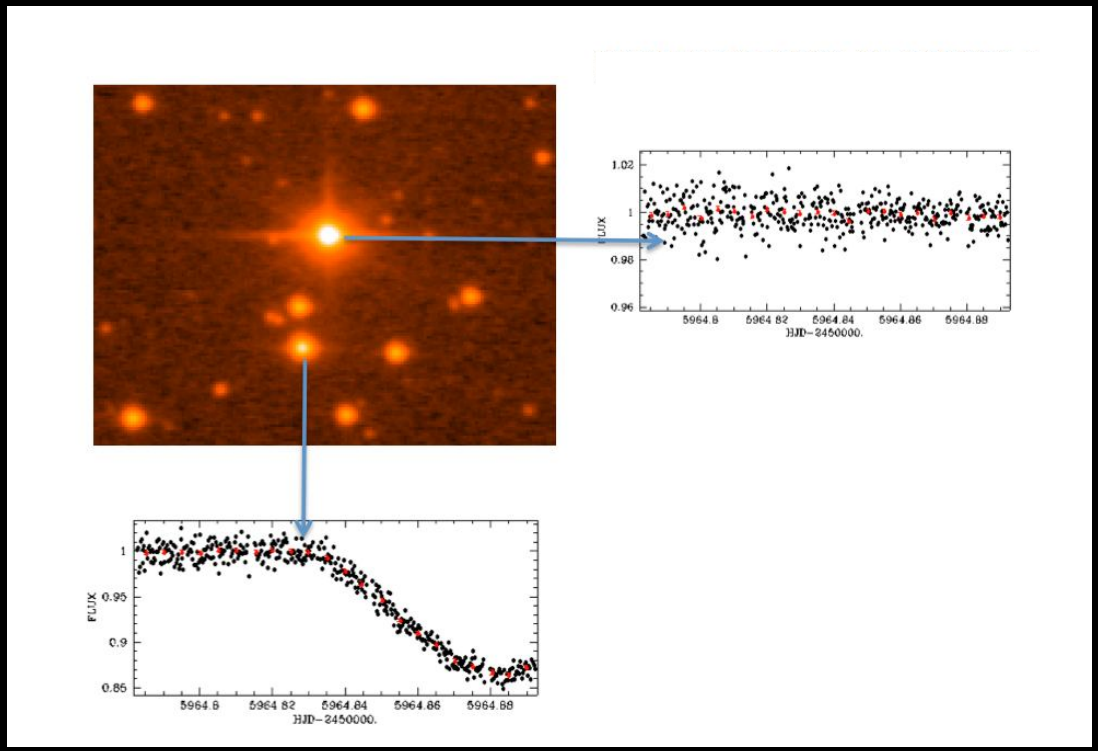




TRAPPIST

Pixel scale = 0.65''

Typical precision ~0.1%

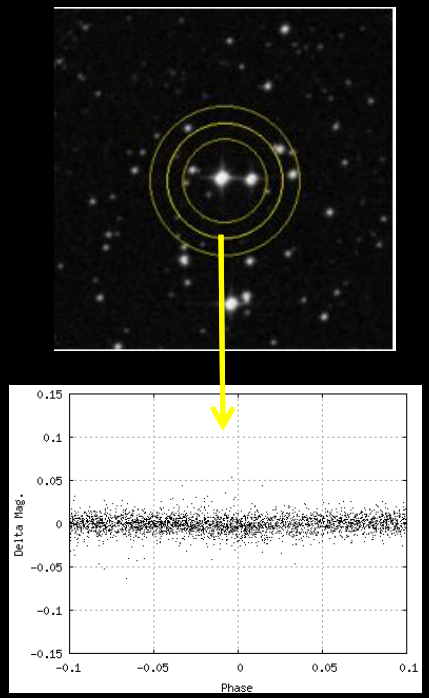


Example: a « blend » easily spotted by TRAPPIST

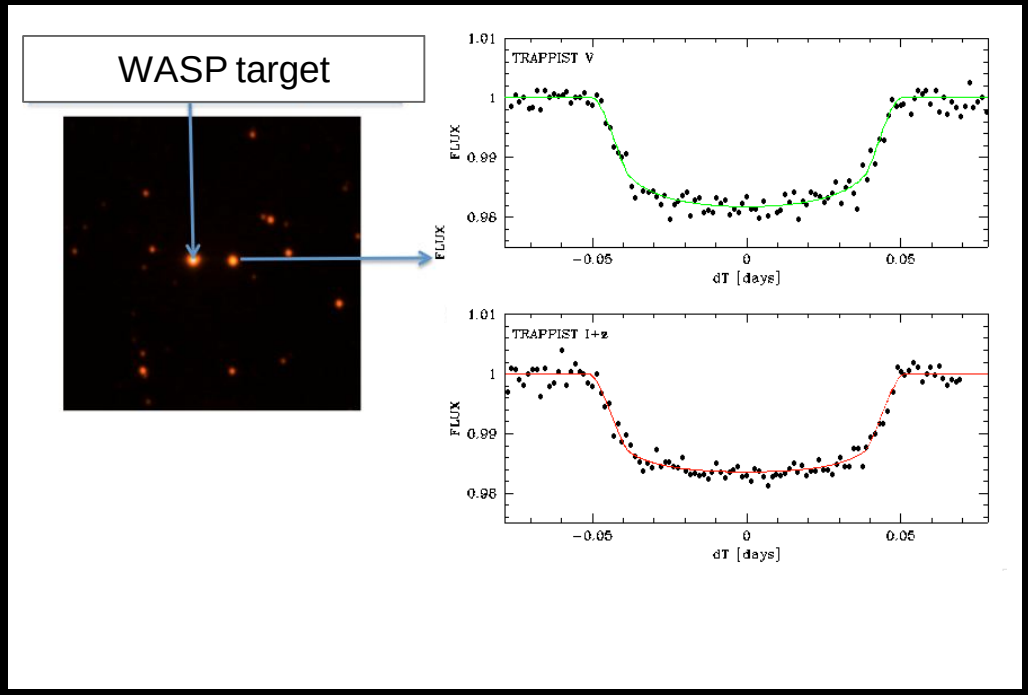
95 WASP candidates out of 170 observed + 2 COROT rejected by TRAPPIST

The follow-up of transit surveys candidates

WASP
Pixel scale = 13.7''
Typical precision ~ 1%



TRAPPIST
Pixel scale = 0.65''
Typical precision ~0.1%

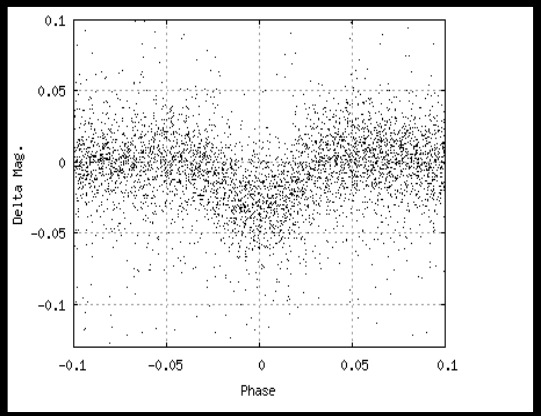


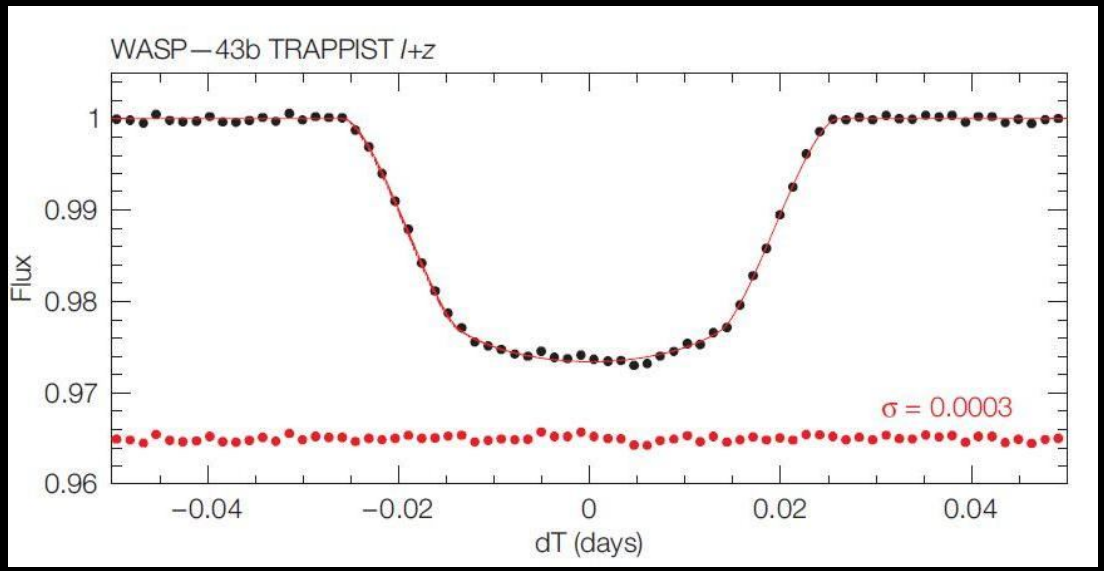
Example: a blend, but an interesting one;
this is a new highly irradiated planet, WASP-64 (Gillon et al, in prep)

Participation to the detection of 32 transiting planets (6 papers published)

The study of known transiting planets

WASP-43





20 TRAPPIST transits in one season (300 ppm)

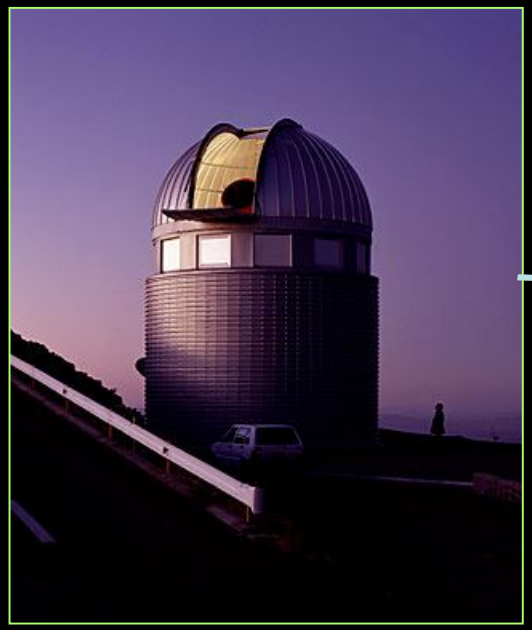
Gillon et al. (2012)

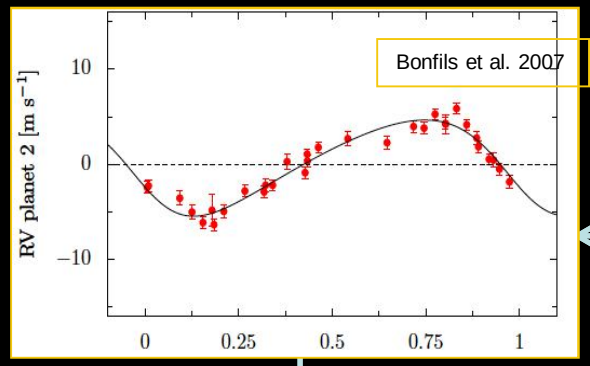
- to get many transits to better constrain the planet and star parameters
- to look for other planets in the same system or moons (TTV)
- + occultations in z band

212 eclipse light curves collected for 56 transiting planets

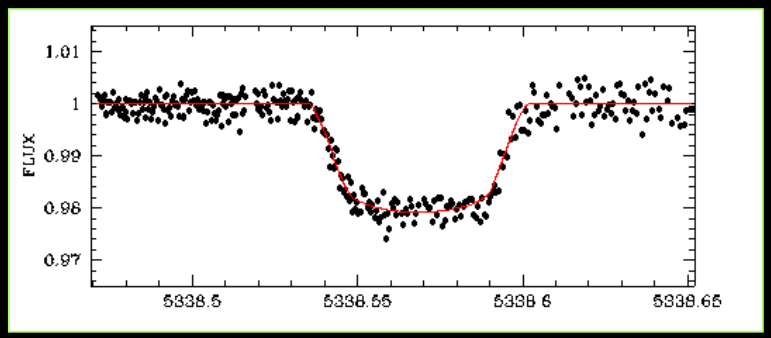
2. Search for transits of RV planets found by Coralie & HARPS

Red dwarfs

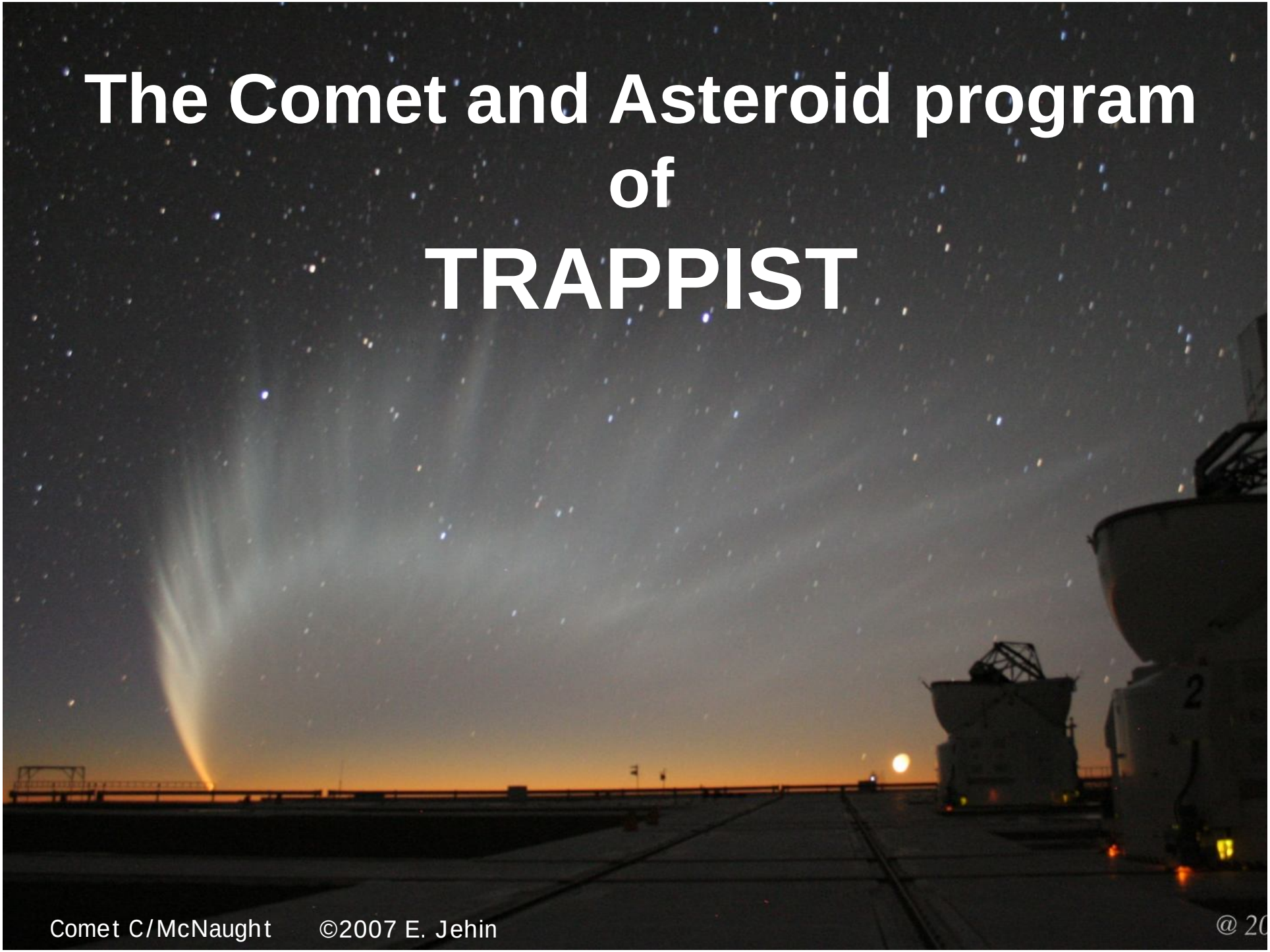


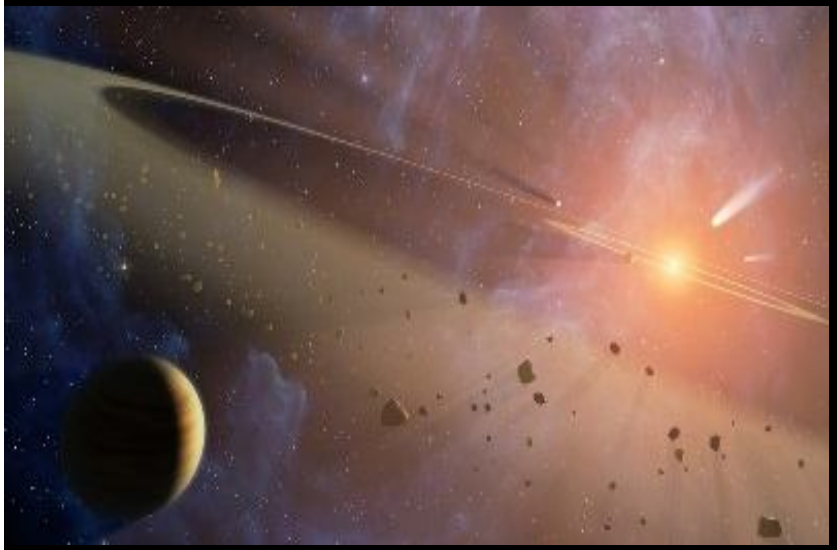


?

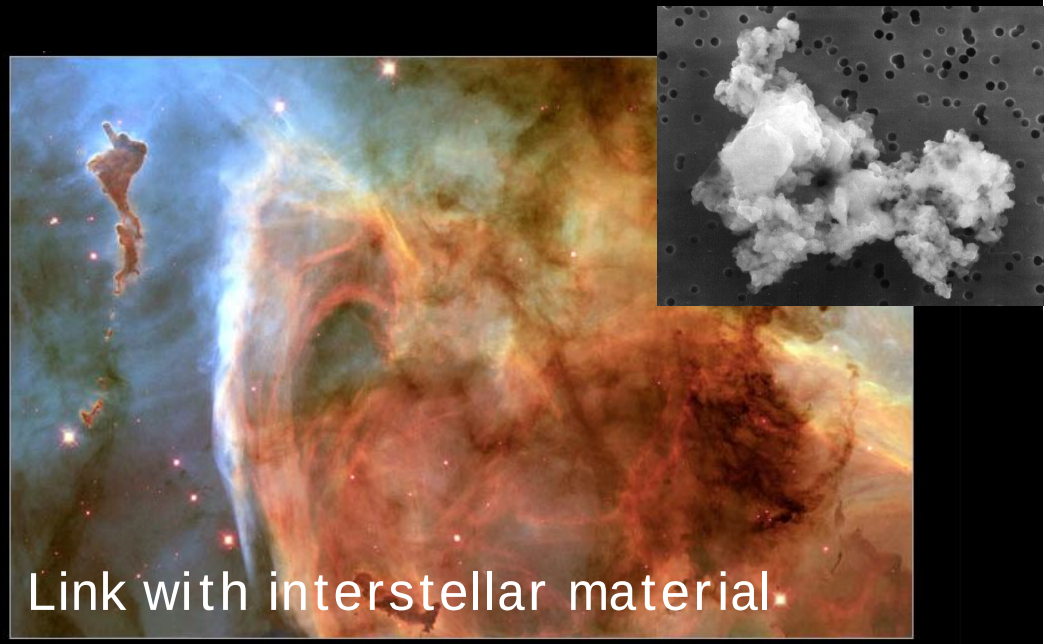


The Comet and Asteroid program of TRAPPIST



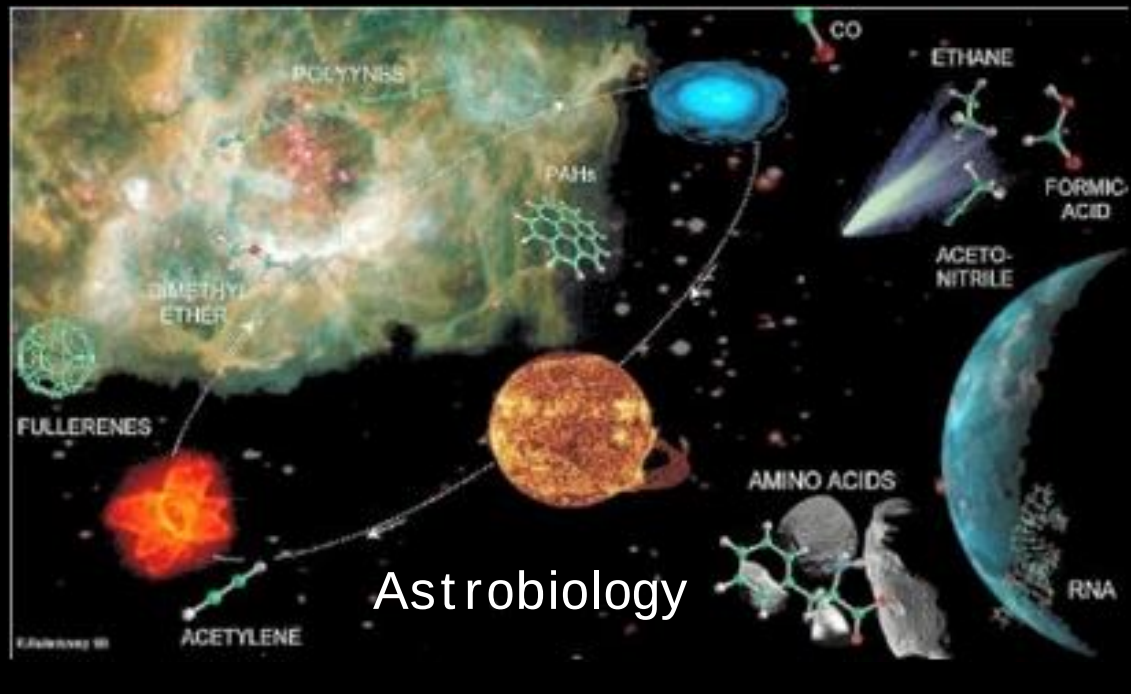


Planet formation



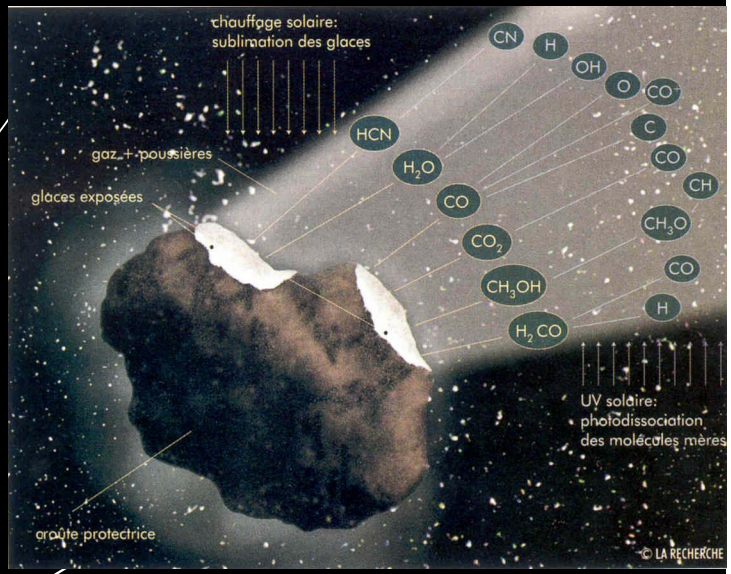
Link with interstellar material

Water on Earth (H_2O) ?
Organic material ?

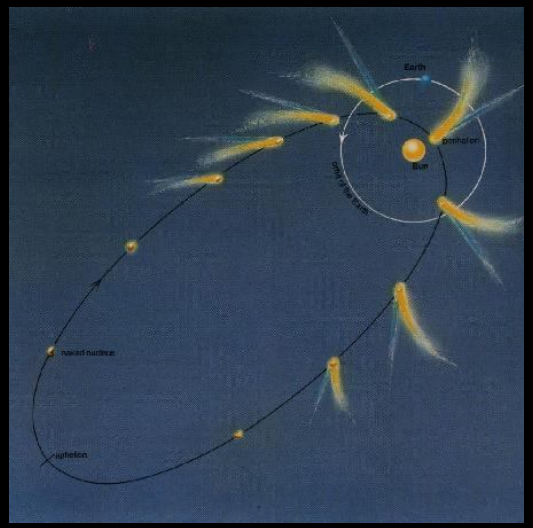


Astrobiology

The nature of Comets



nucleus

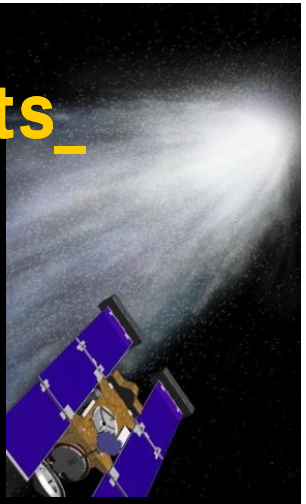


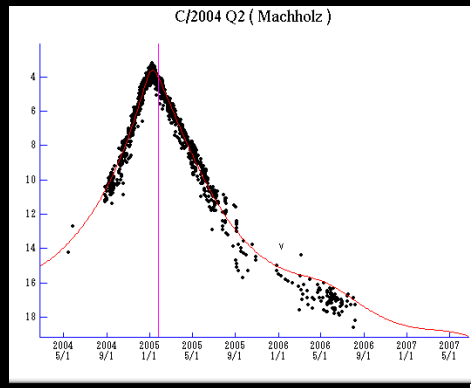
orbits of comets

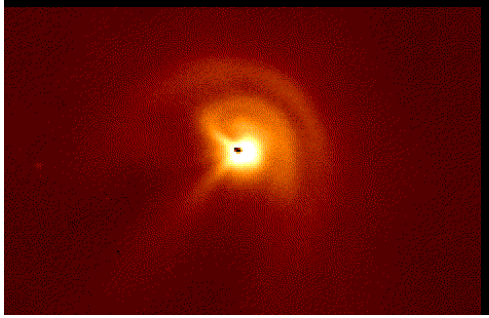
Dust and gaseous coma

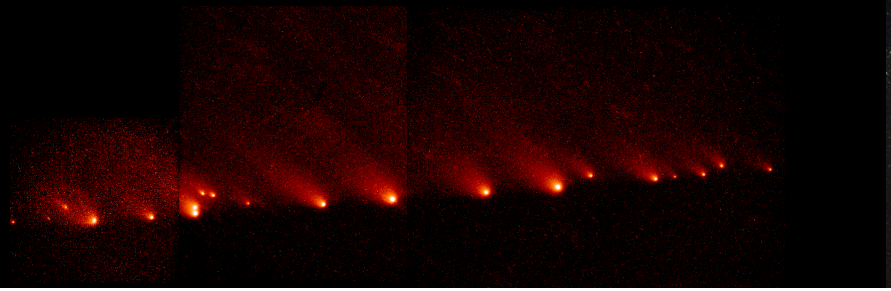
1. The TRAPPIST survey of bright Comets

- Monitoring of bright comets (V<11) with narrow band filters 2-3x/week : ~5 comets / year









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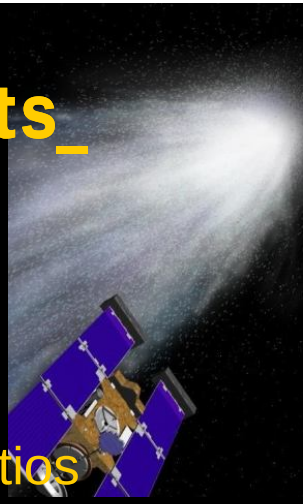
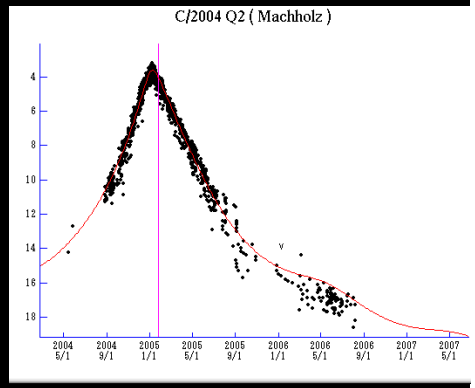
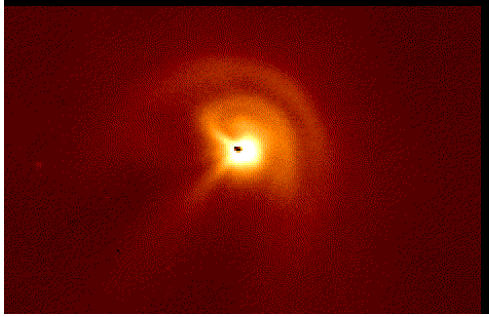
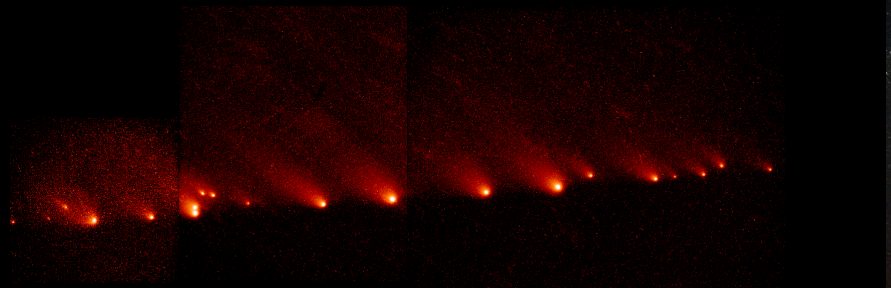


- Monitoring ~ 5 bright comets (V<11) / year with narrow band filters 2-3x/week: ~5 comets pe year

- Composition (OH, CN, NH, C_2, C_3, CO^+, dust BC and GC)
  - → gas and dust production rates (Q (mol/s)) → abundance ratios
  - → variability/activity and composition along the orbit
  - → chemical peculiarities → types of comets ("taxonomy")
  - → link composition / dynamical classes (JFC, OOC)
  - → nucleus composition heteregeonity







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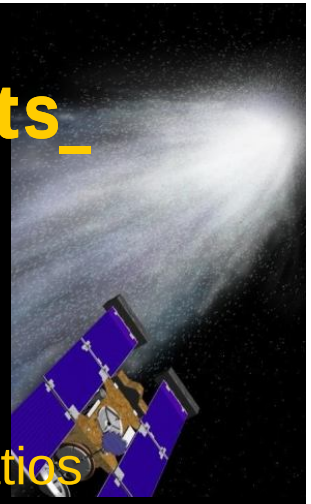

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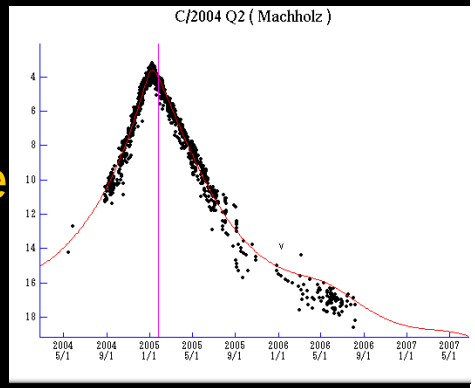
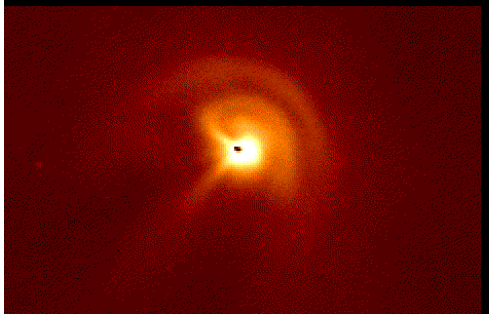
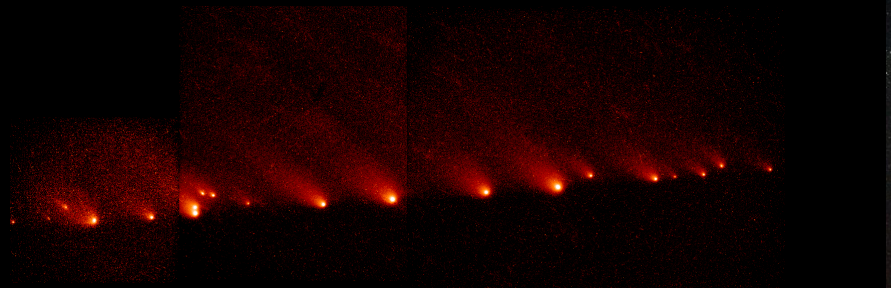
  - → nucleus composition heteregeonity
- Image analysis (structures in the coma)
  - → number and behavour of active regions, rotation pe
- Follow up of rare events (outburst, splitting,…)
- Support to VLT and space missions

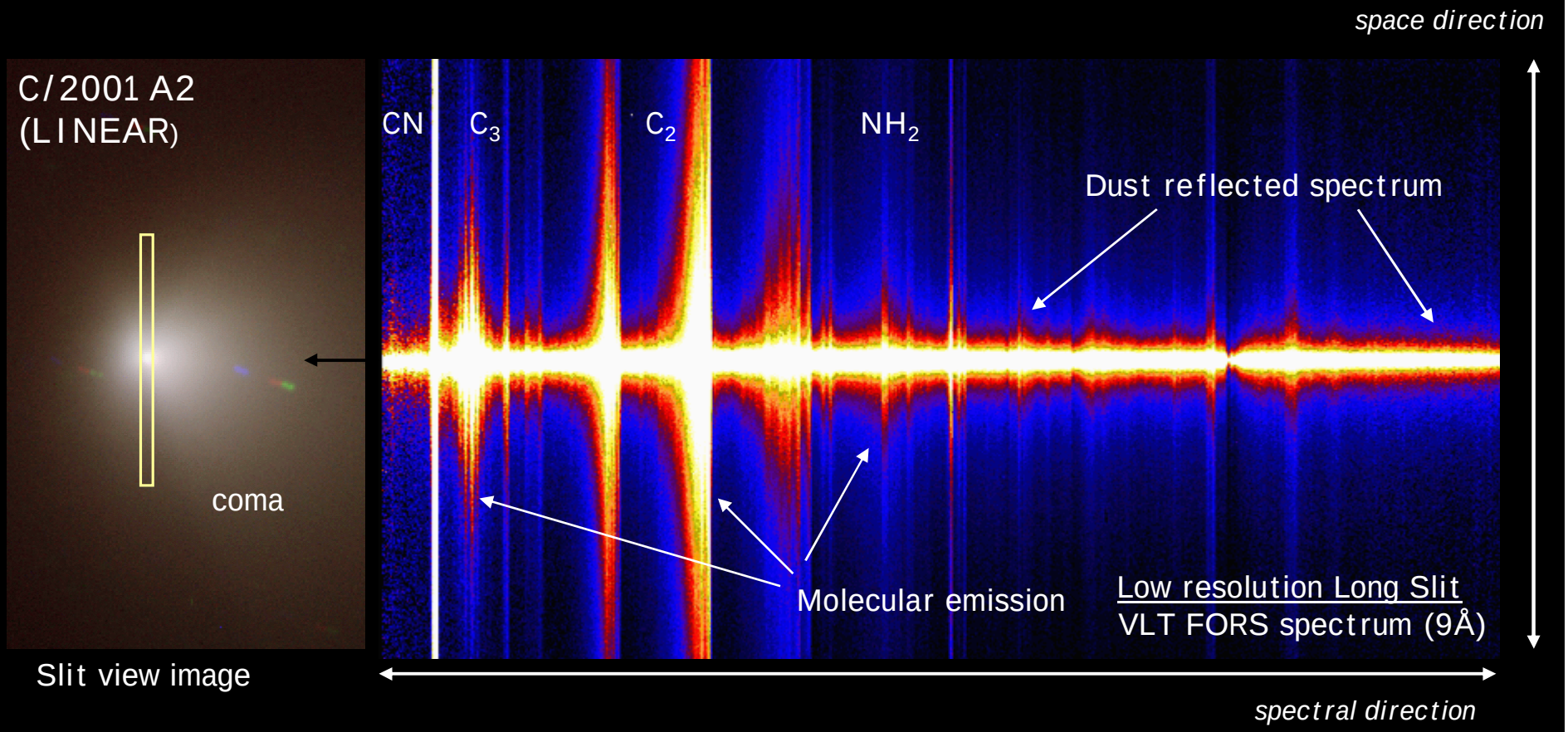






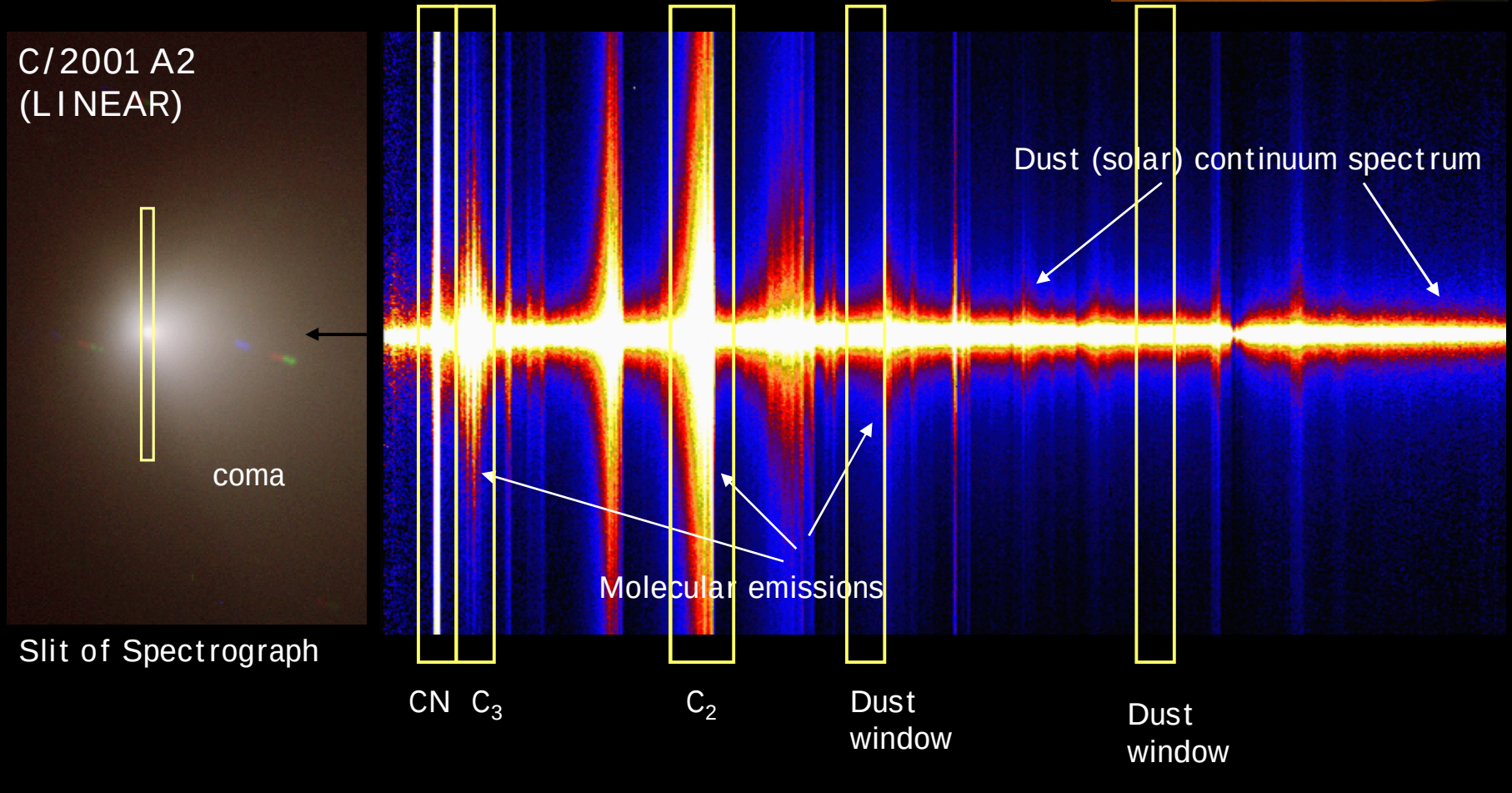
Optical spectrum of a comet

Cometary spectra consist of molecular emission from resonance fluorescence and a continuum resulting from sunlight scattered off dust.

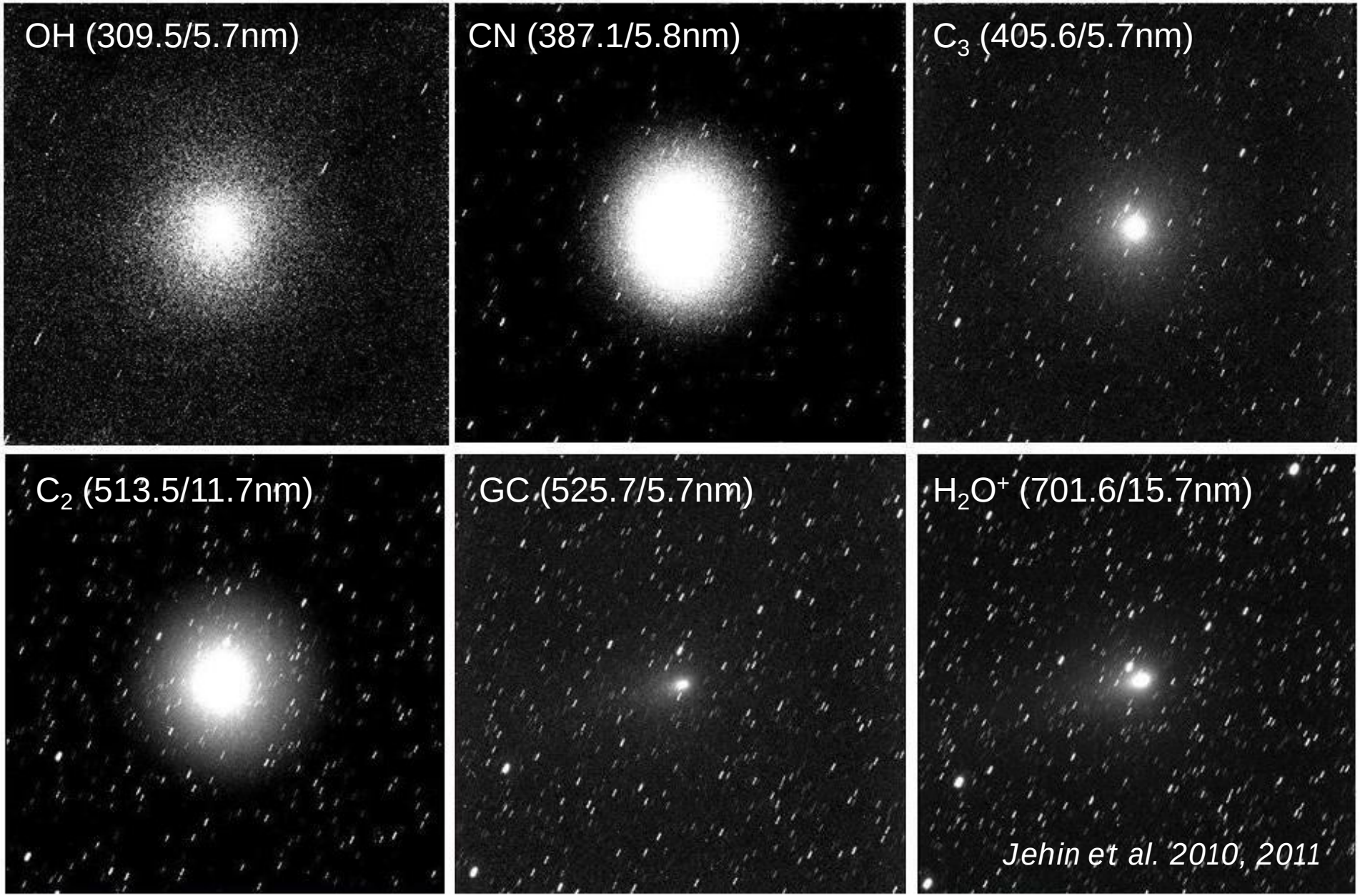


Jehin et al. 2002

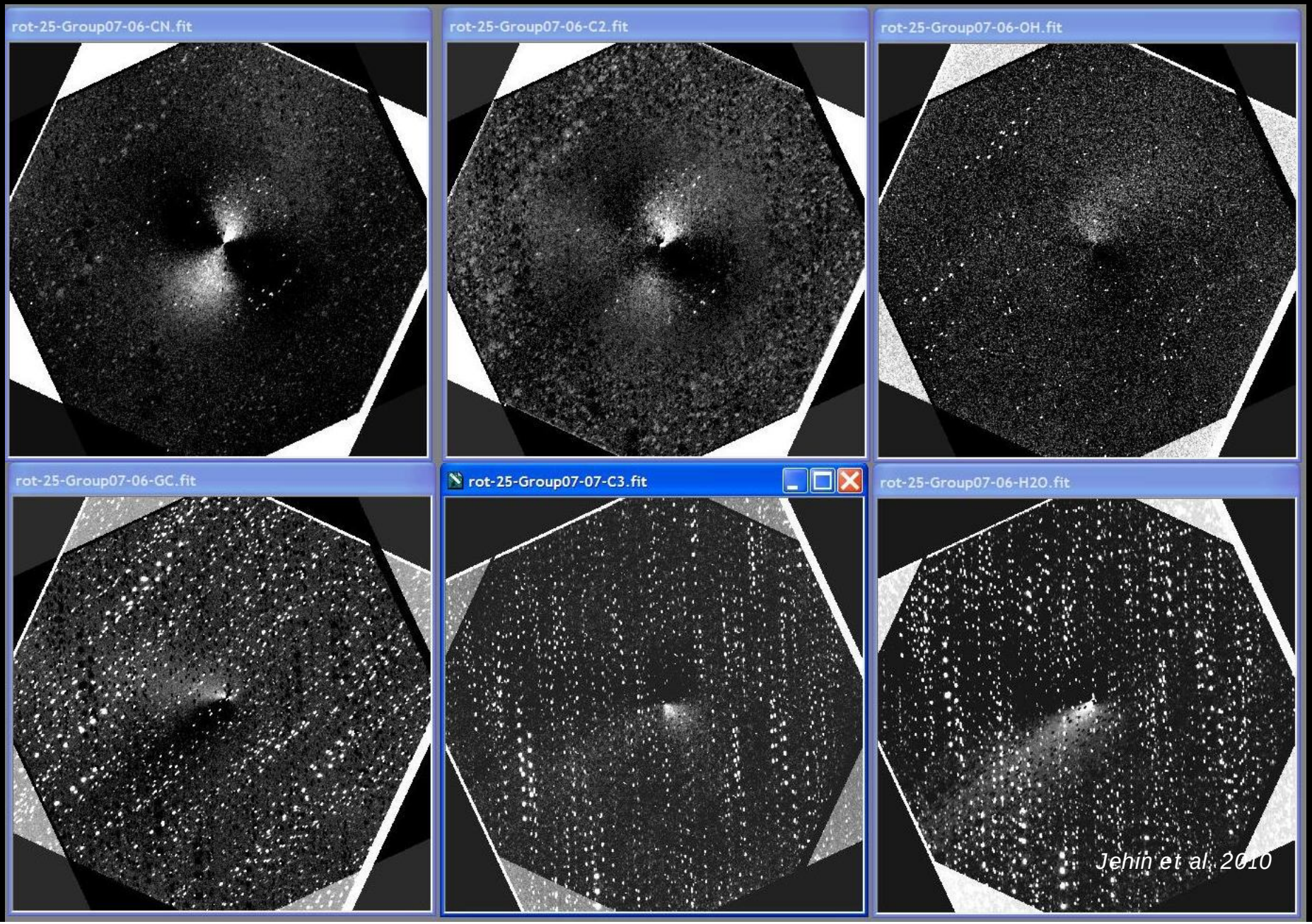
HB Cometary Filters (NASA) (narrow band) (Farnham et al. 2000)



Narrow band filters : 103P/Hartley 2 Nov. 4 2010



Coma features 103P/Hartley 2 :



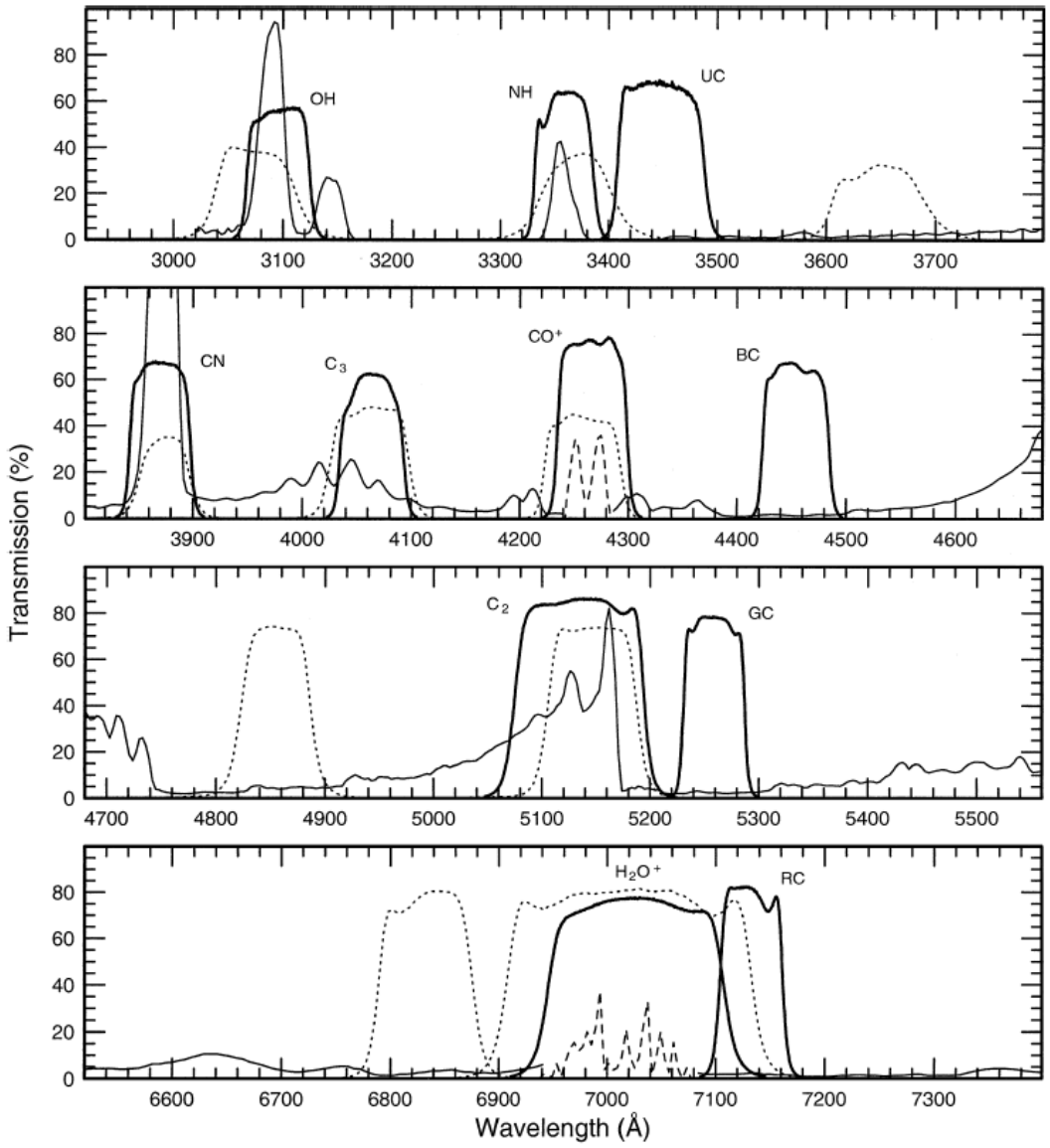


FIG. 1. Transmission profiles for the HB filters (thick lines) and for the IHW filters (dotted lines). For comparison, measured comet spectra illustrate the locations of the different emission bands. The neutral species and continuum regions are depicted by a spectrum of Comet 122P/deVico (spectral resolution = 12 Å) in the three top panels and a spectrum of Comet 8P/Tuttle (resolution ~40 Å) in the bottom panel (thin solid lines). Because these comets do not exhibit clear ion bands, the 2-0 band of CO^+ from Comet 29P/Schwassmann–Wachmann 1 (resolution = 12 Å) has been inserted from 4240–4265 Å in the second panel and the 0-6-0 band of H_2O^+ from Comet Kohoutek 1973 E1 (resolution = 5 Å) has been inserted from 6940–7080 Å in the bottom panel (dashed lines). The 122P/deVico spectrum is courtesy of A. Cochran, and the 8P/Tuttle spectrum, created by S. Larson and J. Johnson, is courtesy of S. Larson. The CO^+ band was extracted from Cochran and Cochran (1991) and Cochran *et al.* (1991) and the H_2O^+ band was extracted from Wehinger *et al.* (1974) and Wyckoff and Wehinger (1976).

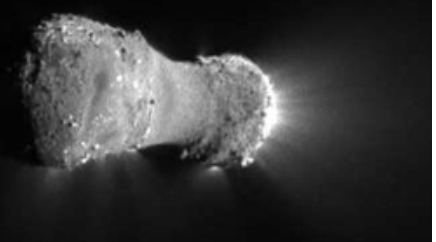
TABLE I
Representative Filter Characteristics

Species	ID	Designation	Transmission[a] (%)	CW[b] (Å)	Power point width[c] (Å) 80%	50%	10%	1%
OH (0-0)	OH	3090/62	56	3097	52	58	68	87
NH (0-0)	NH	3362/58	63	3361	47	54	64	81
UV continuum	UC	3448/84	67	3449	72	79	93	116
CN (Δv=0)	CN	3870/62	67	3869	50	56	65	82
C_3 (Swings system)	C3	4062/62	62	4063	43	58	69	84
CO^+ (2-0)	CO+	4266/64	77	4266	58	64	74	90
Blue continuum	BC	4450/67	65	4453	55	61	71	86
C_2 (Δv=0)	C2	5141/118	85	5135	109	119	140	171
Green continuum	GC	5260/56	78	5259	52	56	65	79
H_2O^+ (0,6,0)	H2O+	7020/170	75	7028	148	164	193	239
Red continuum	RC	7128/58	80	7133	53	58	71	92

[a] Measured mean peak transmission.
[b] Measured center wavelength.
[c] Measured full-width power points.

NASA HB narrow band filters (Farhnam et al. 2000)

103P/Hartley 2 observing campaign (Nov 2010 – Feb 2011)



NASA (EPOXI)

Data set

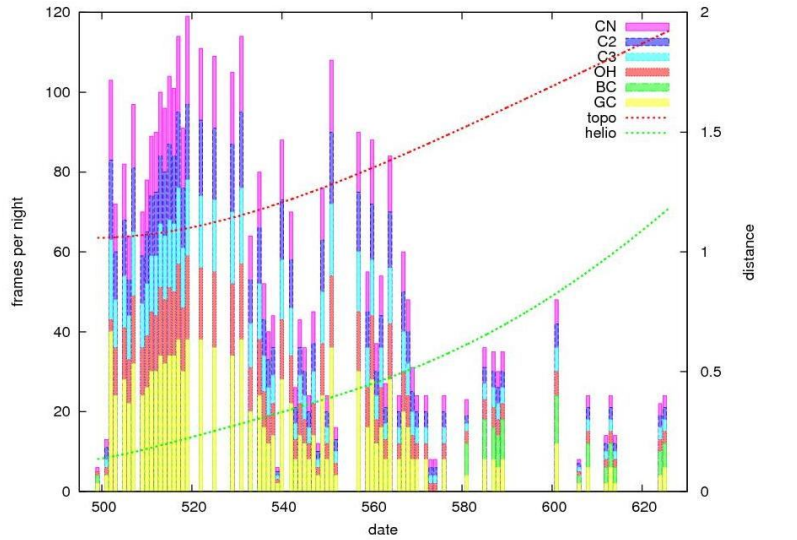
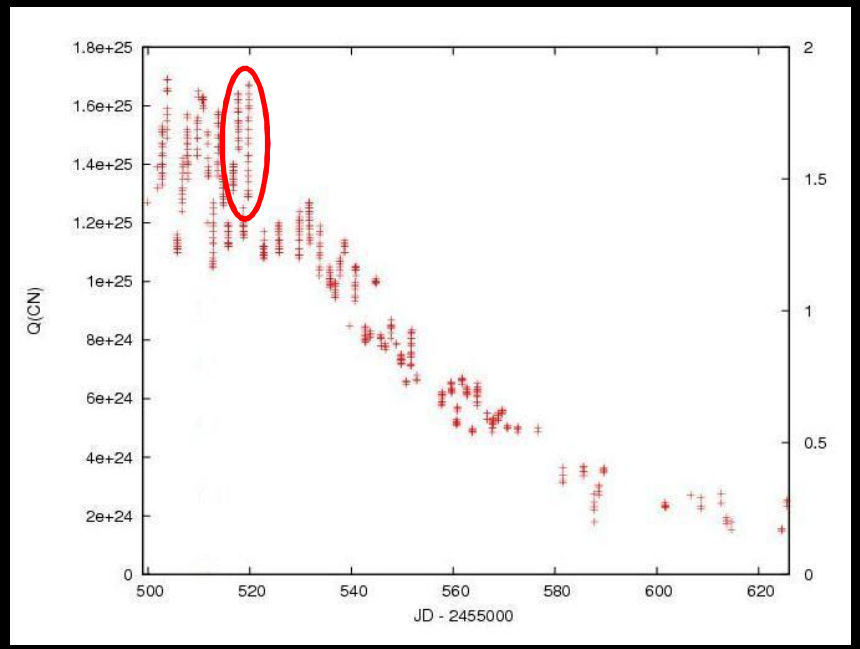


Figure 1: Distribution of the observations made with the narrow-band filters GC, BC, OH, C_2, C_3 and CN. The lines show the heliocentric and topocentric distances. The date is JD−2 455 000.

- 3965 frames (OH, CN, C_3 , C_2 , GC (dust), H_2O^+) + Std stars
- 69 nights from Oct. 29 to Feb. 28 (~4 months)
- 2-5 hrs/night (exp=120s), data about every 2 nights

Poduction Rates (Q in molecules/s)



Using the Haser model (1957)
Following A'Hearn et al. (1995) and Scleicher et al. (2008)

AFRho (dust production rate)

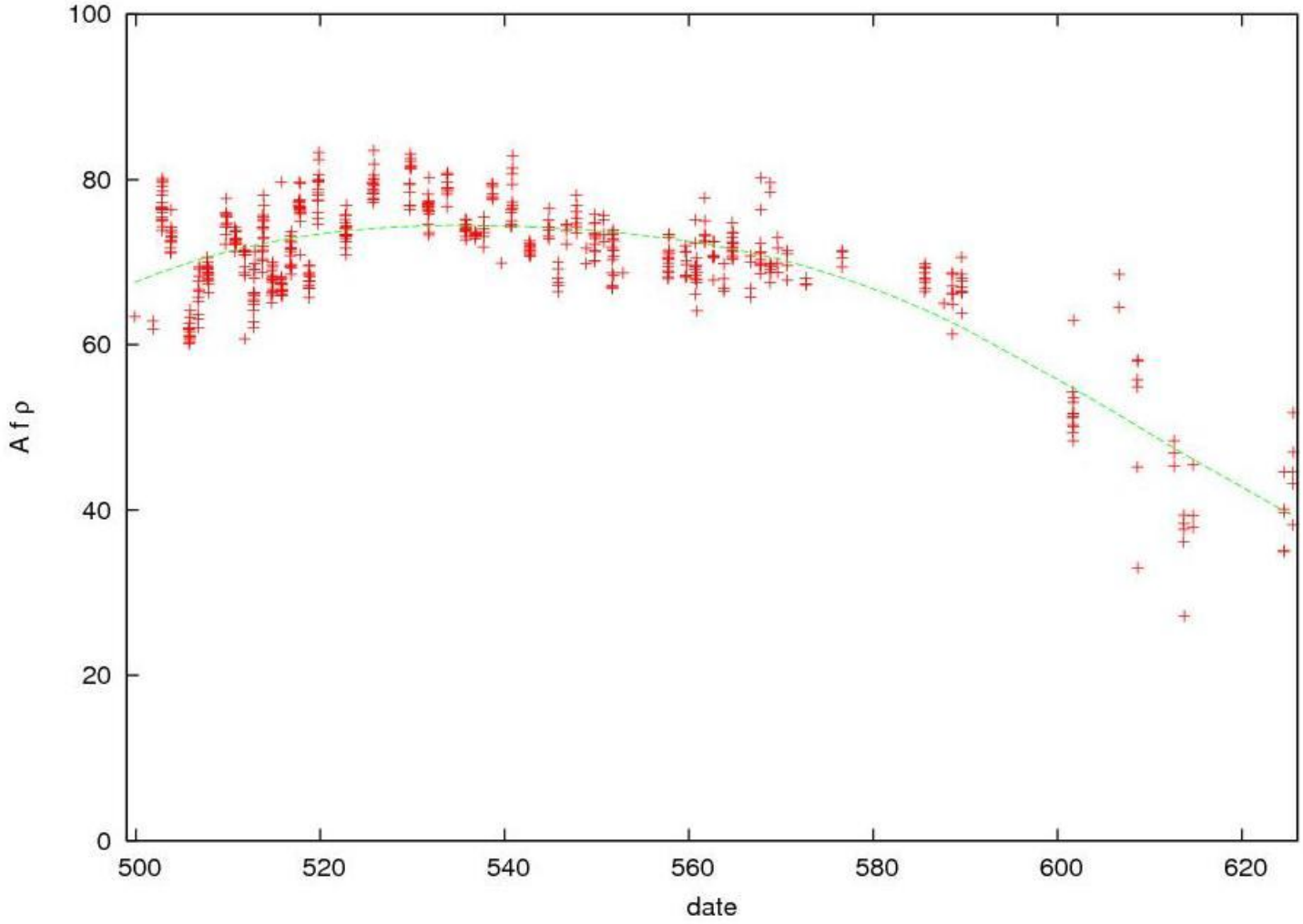
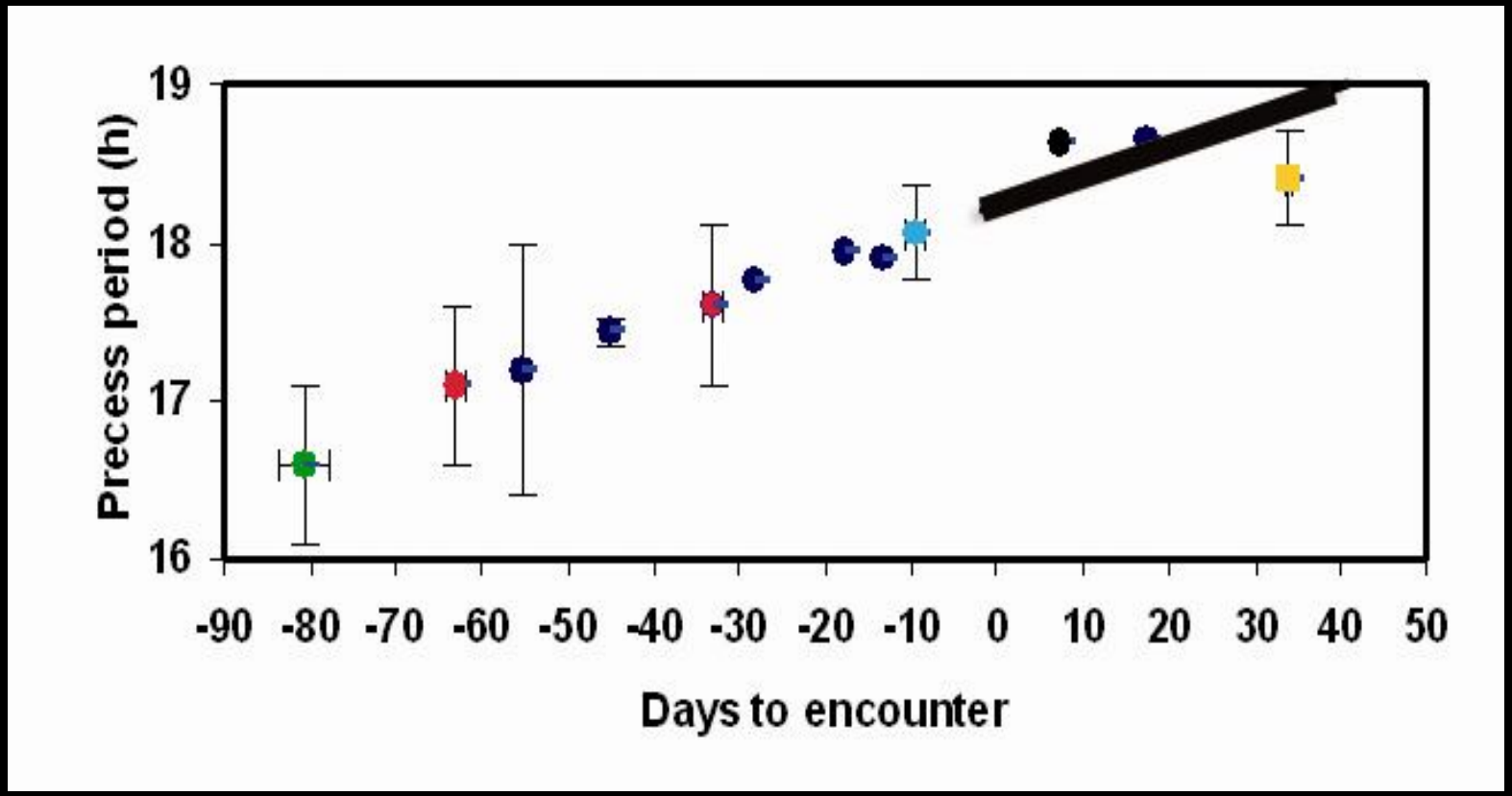


Figure 2: $AF\rho$ in cm, versus JD−2 455 000.

Rotation period of 103P/Hartley 2 nucleus

Phase diagram (CN) : Nov 4-15, Nov 15-25 and 25 Nov-05 Dec



➔ Rotation period 18.2h → ~19h (Nov → Dec)
rotation is slowing down (Jehin et al. 2010 CBET#2589)
~ 2h in 100 days , ok with other data (Arecibo, EPOXI, etc.) A'Hearn et al. 2011

Rotation period of 103P/Hartley 2 nucleus

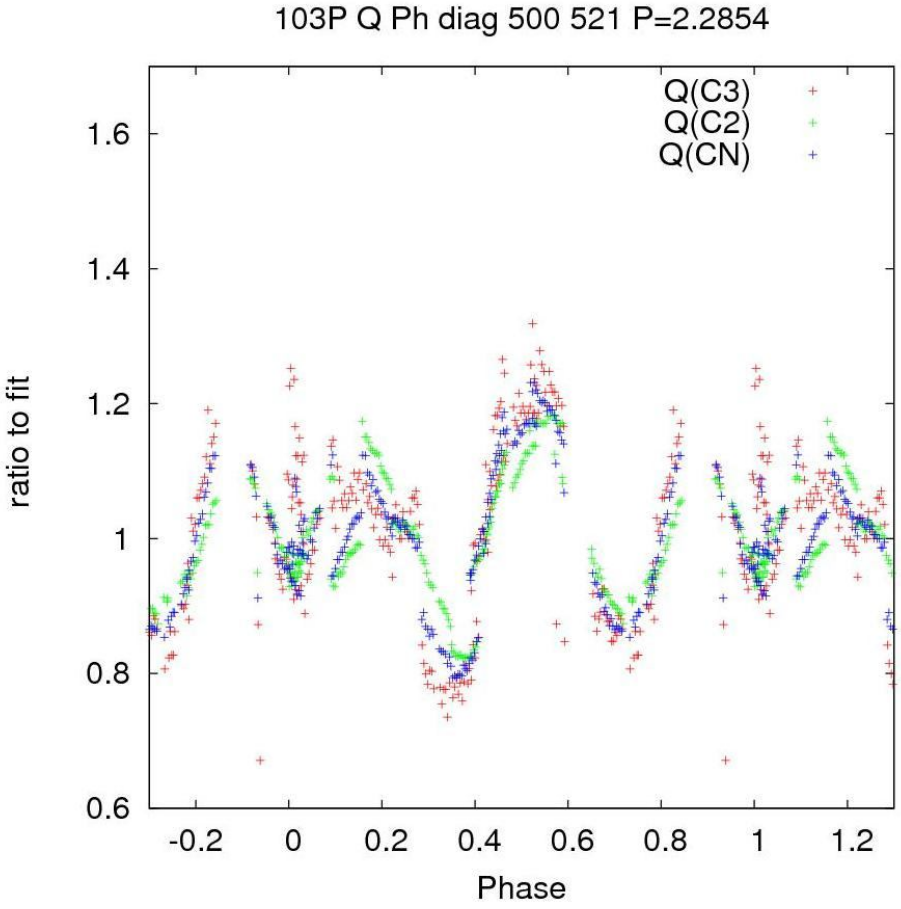
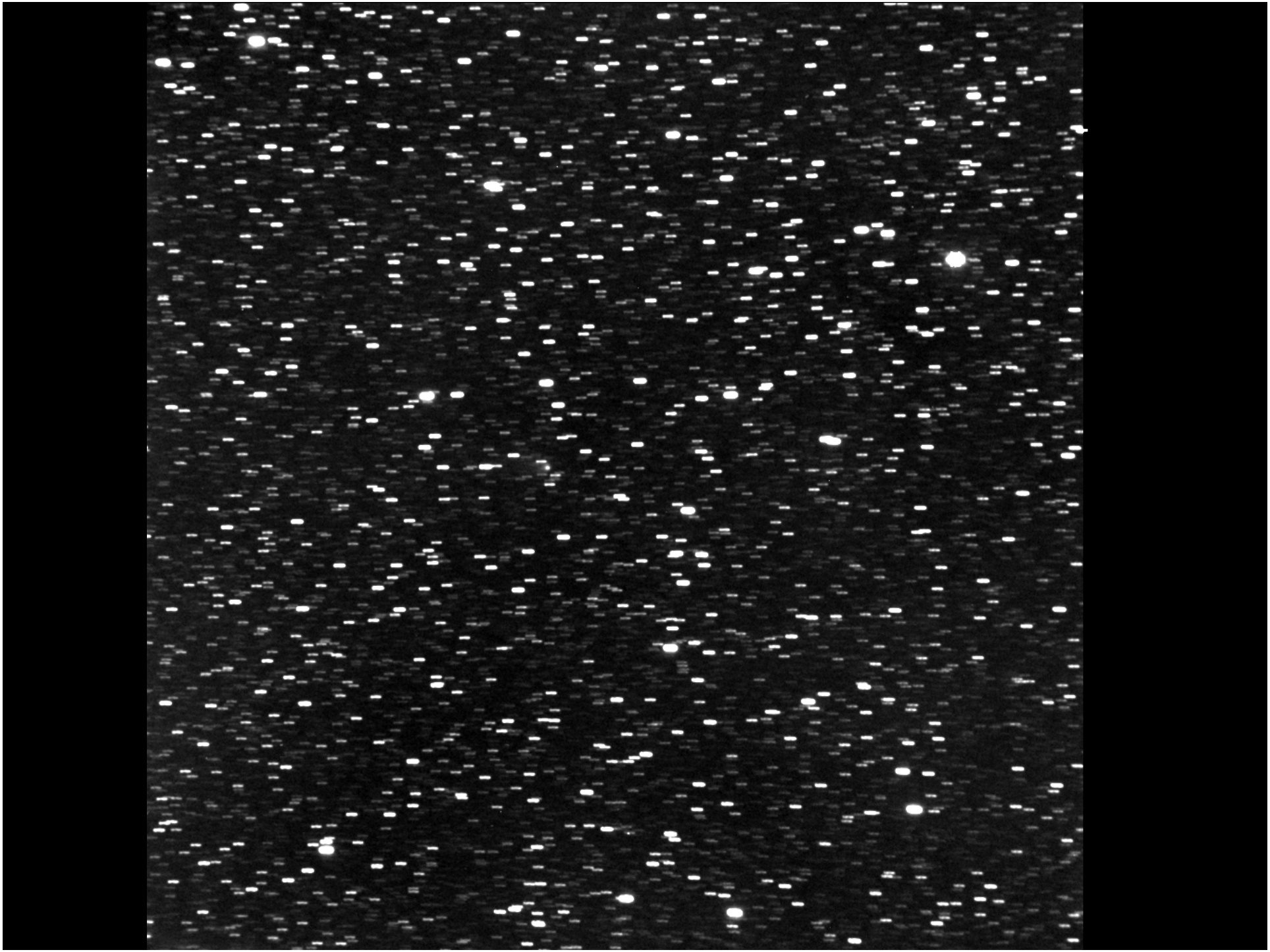
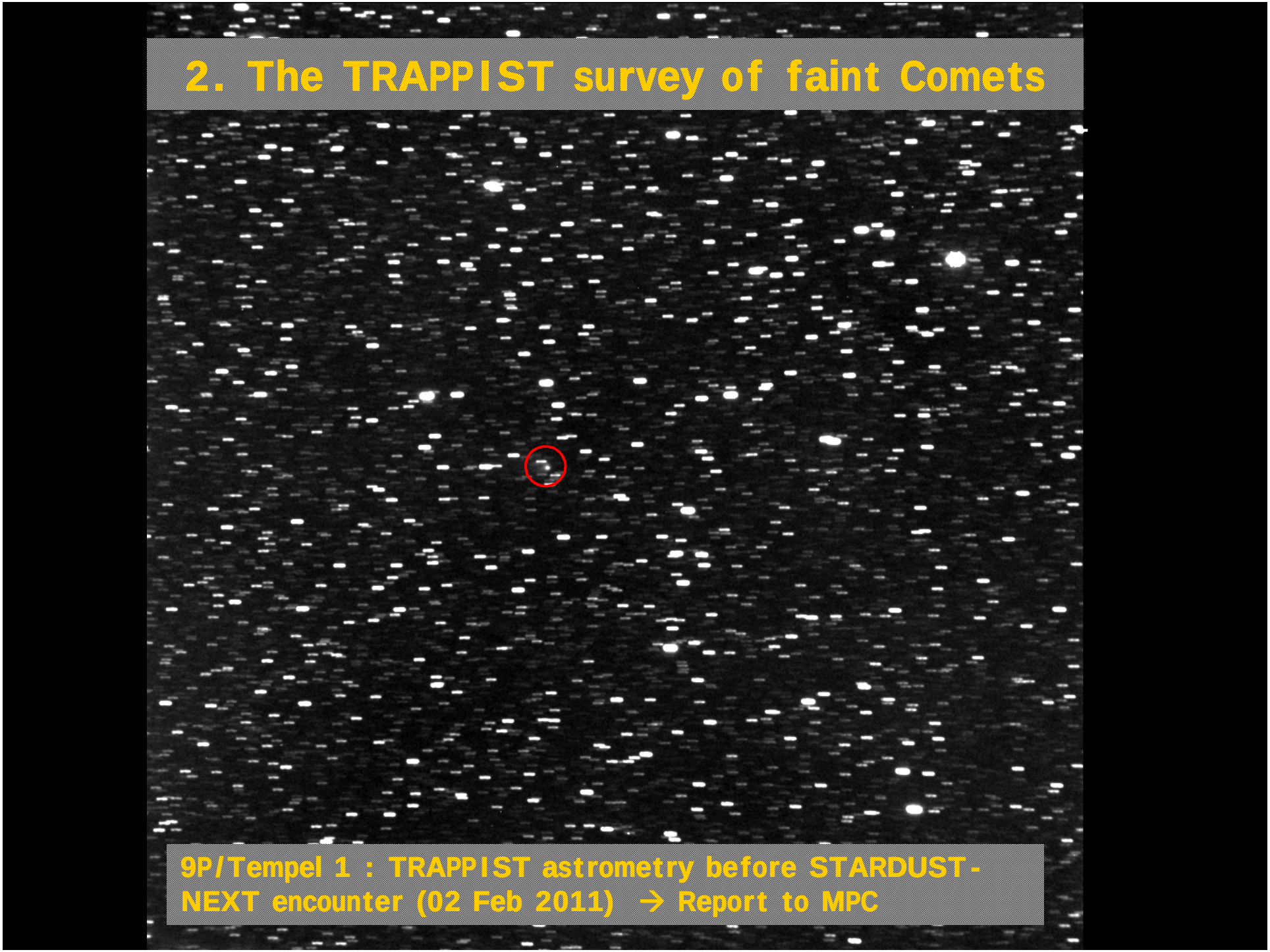


Figure 9: Three-wave phase diagram over the first three weeks

A better match with 3 cyles ?
~54h (Drahus 2011, A'Hearn 2011). Excited rotation



2. The TRAPPIST survey of faint Comets



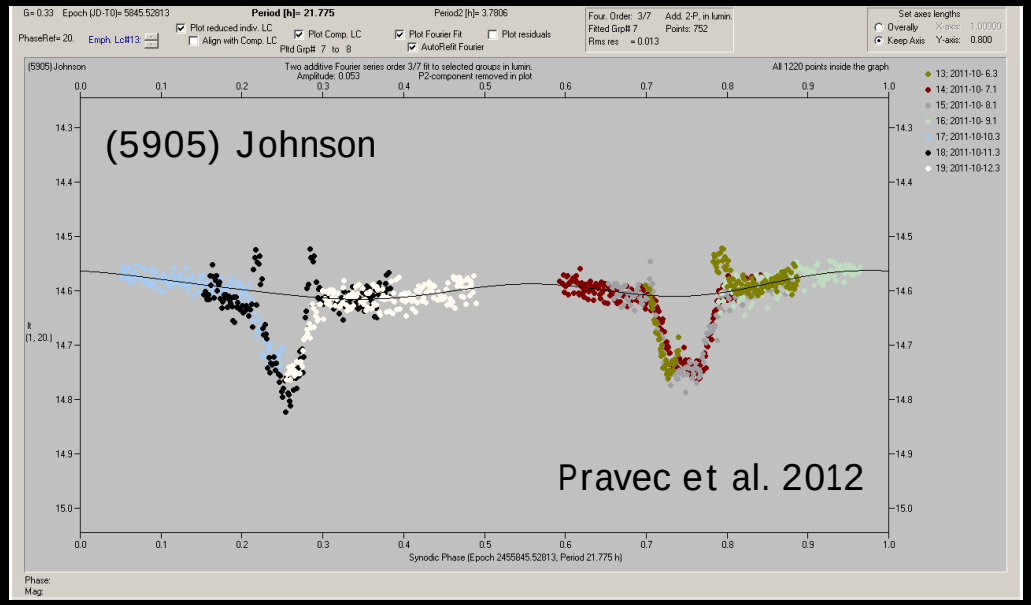
9P/Tempel 1 : TRAPPIST astrometry before STARDUST-NEXT encounter (02 Feb 2011) → Report to MPC

(536) Scheila from 11/12-18/12/10 : A collision in the Main Belt

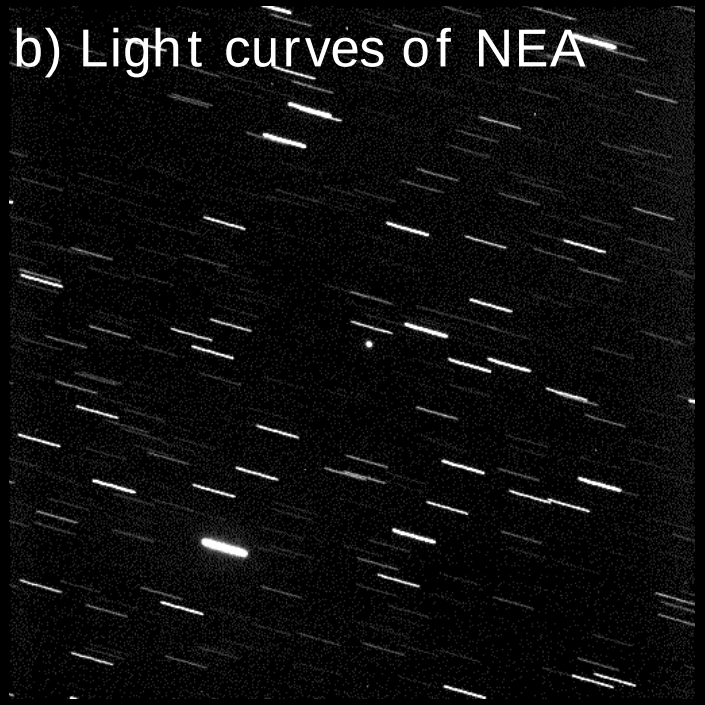
Jehin et al. 2010

3. Asteroids Light Curves (~0.01 mag)

a) Eclipses of binary asteroïds

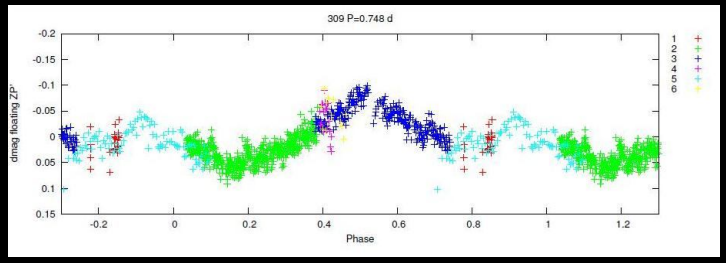


b) Light curves of NEA



c) Light curves of large asteroïds

Support to VLT NACO AO program
(Carry et al.) → accurate volumes (10%)
→ densities

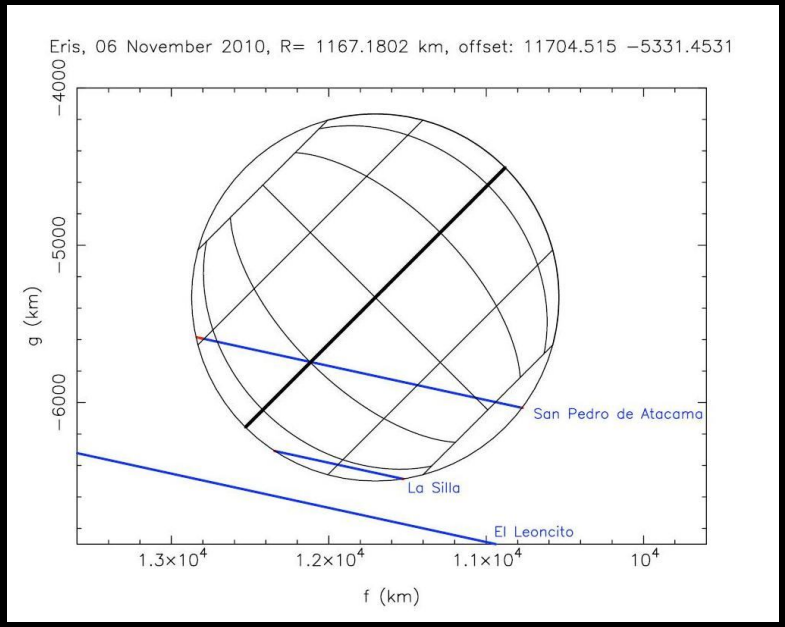


NEA 2005 YU55 (Nov 10-18 2011) : P~18h
+ AO Keck data (Carry et al.)

4. Stellar Occultations by TNOs_

Eris, UB313, 10th planet…?!, 2006, 14 10^9 km, a TNO of ~2400 km < Ø < 3000 km → Pluto (and Eris) is a dwarf planet…

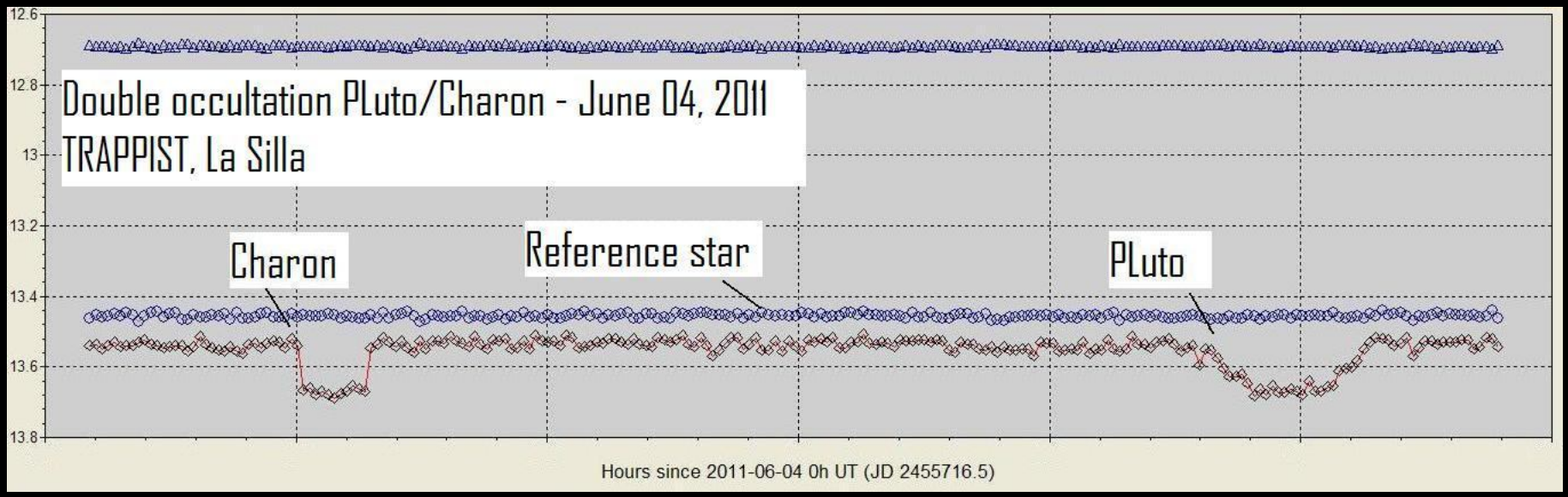
- Stellar occultation by Eris 6/11/10 : 30.4 +- 0.1s (TRAPPIST)
- 70.0 +- 0.1s (San Pedro)



- No atmosphere
- Radius : 1163 km ± 6 km
  Pluton : 1150 - 1200 km

→ Density 2.5 g/cm^3 and albedo ~96% !

Sicardy et al. Nature 2011



The same star is occulted by Charon then Pluto ! *Jehin et al. 2011*
→ strong constrain on the orbit of Charon

http://www.ati.ulg.ac.be/TRAPPIST/