TRAPPIST : TRAnsiting Planets and PlanetesImals Small Telescope

Emmanuël Jehin
STAR (Université de Liège, FNRS)

A robotic telescope to study planetary systems

The site : La Silla Observatory (ESO, Chile)

IAU I40
8 June 2010
2450m
300 clear nights/year

fnrs
LA LIBERTÉ DE CHERCHER

Université de Liège

The Telescope

- Optical design: Ritchey-Chrétien

- 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 :

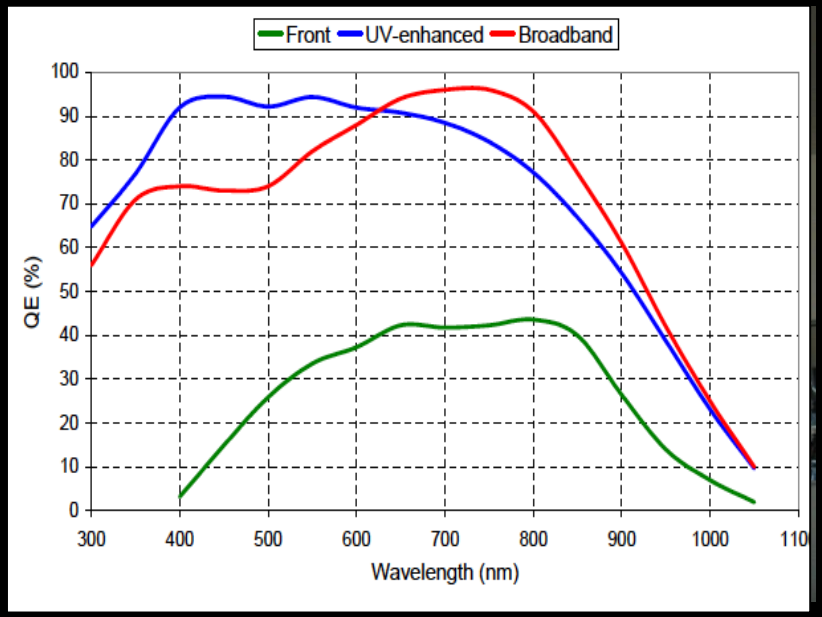
- "Direct drive" (50 deg/s)
- No periodic error
- Pointing altitude (5 deg)
- tracking : 1" / 4 minutes
("software guiding")

Jehin et al. 2011 (ESO Messenger)
http://www.orca.ulg.ac.be/TRAPPIST/

The INSTRUMENT

Camera CCD FLI Proline PL-3041-BB
- 2048x 2048 pixels (15 µm or 3x3cm)
- FOV/sampling : 22'x22' and 0.65" /pix

- QE = 96% à 790 nm / RON ~ 10 électrons
- 3 readout modes : 8s, 6s et 4s
- Temperature = -55° C below T° ambiant



Double filter wheel Apogee AI-FW50-10S

F1: Filters AstroDon BVRI,I+z,z, Exo (5x5cm)

F2: HB Cometary NASA narrow band filters
2"x2": OH, NH, CN, CO^+, C_3, C_2
+ UC, BC, GC, and RC continuum + NaI

TRAPPIST is robotic

TRAPPIST IS a ROBOT

- Coupola Ash-Dome 5m
+ rain sensor

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

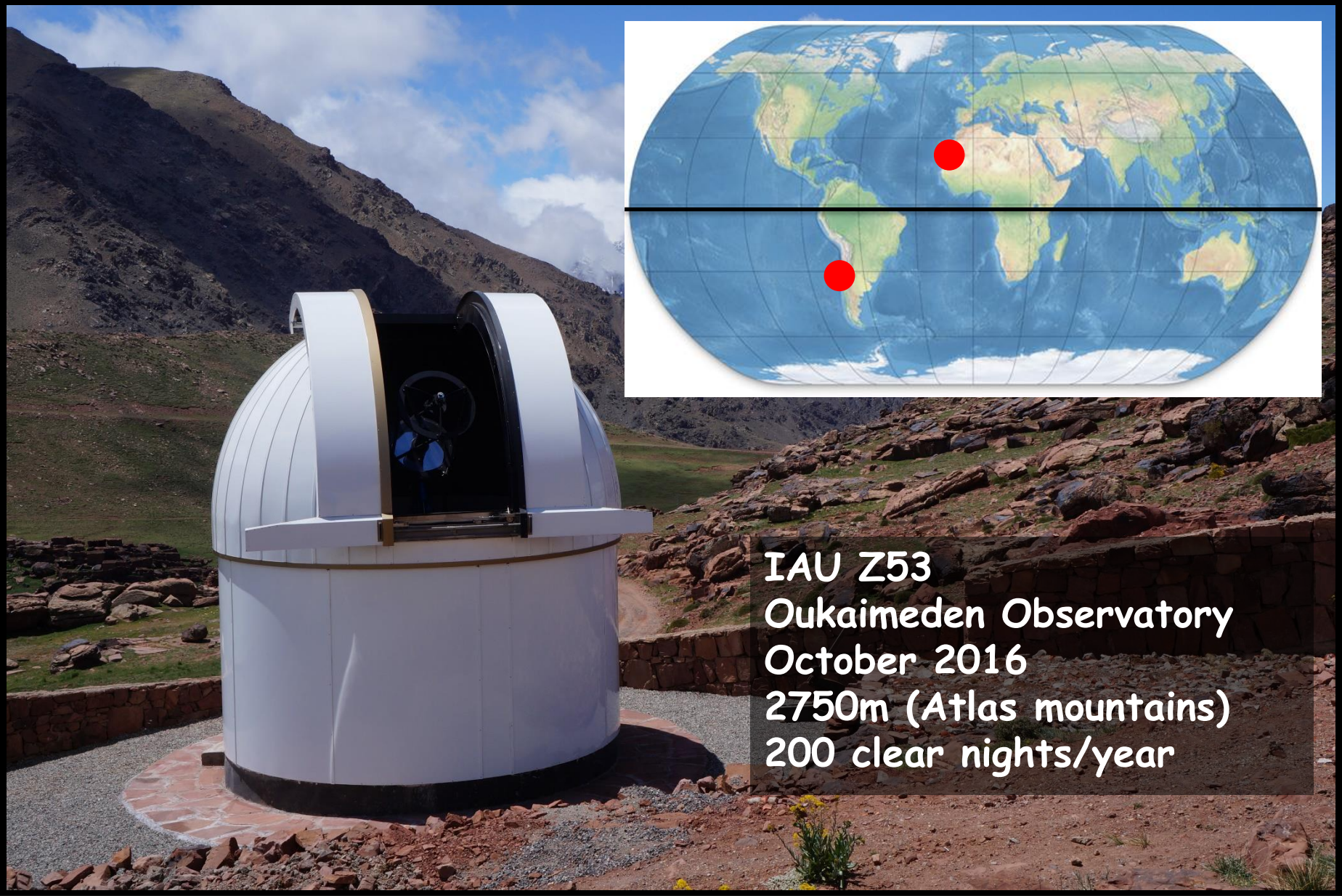
- Weather Station Boltwood II
+ direct link to dome – weather safety

- IP Power : every device can be power cycled through internet

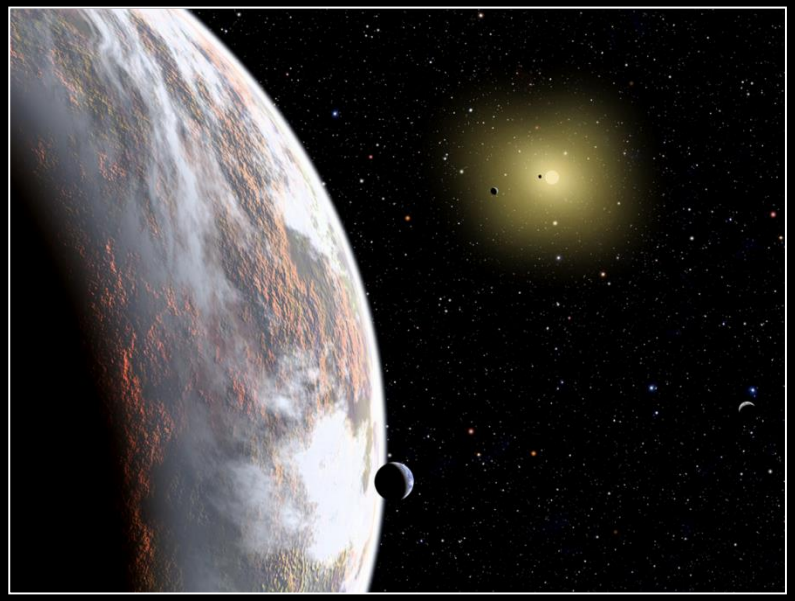
ACP Observatory Control Software
DC-3 Dreams

- Data : ~ 5-15 GB/night: "reduction Pipeline" on site
External disks (rack) → Liège (archive)

TRAPPIST-North (Oukaimeden, Morocco)



The existence of other worlds : <u>an old question</u>



"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)

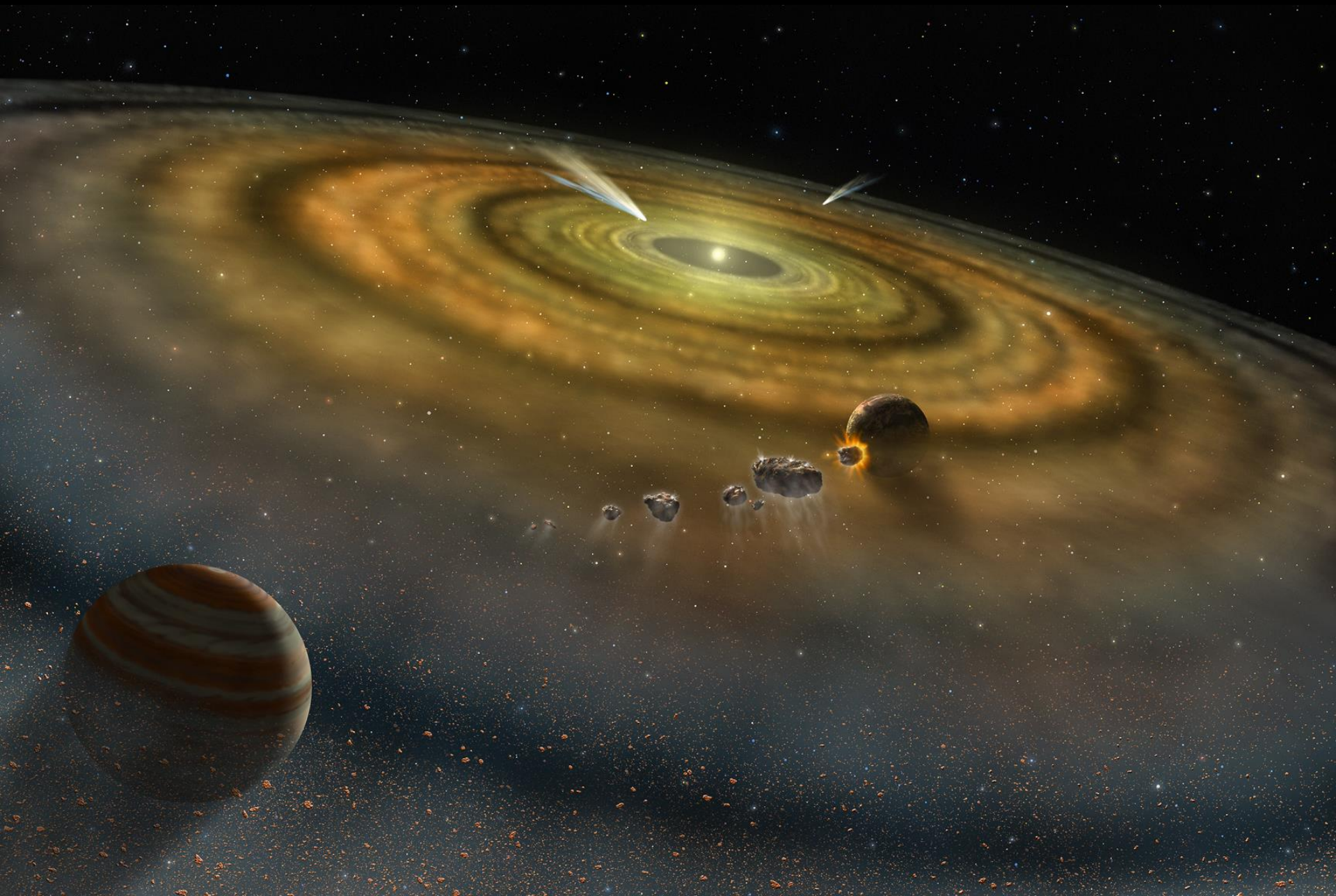
The comet and asteroid program of TRAPPIST

PI Emmanuël Jehin

1. Monitoring of bright comets (V < 12) with NB comet filters
   → support to Large Telescopes (High resolution spectroscopy)
2. Monitoring of faint comets (V < 19) with BVRI filters
   → support to space missions (EPOXI, ROSETTA)
3. TNO stellar occultations
4. Asteroids light curves (NEA, MBA)

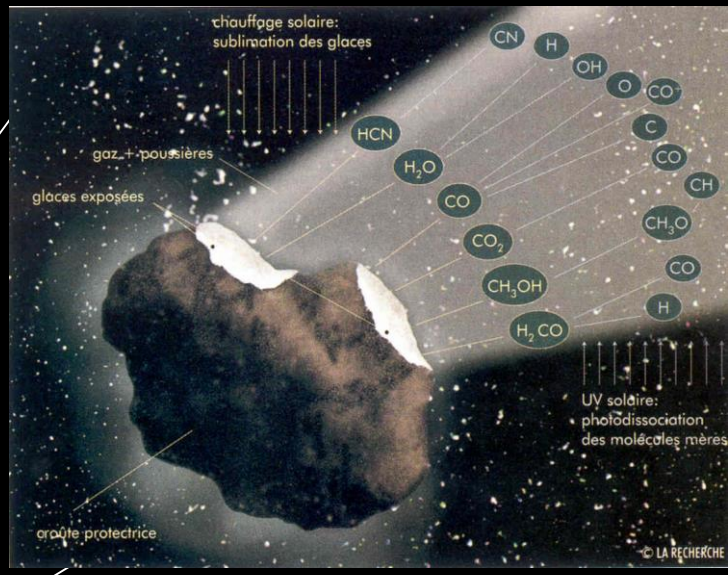
Comet C/McNaught ©2007 E. Jehin

Comets and asteroids: fossils of the Solar System

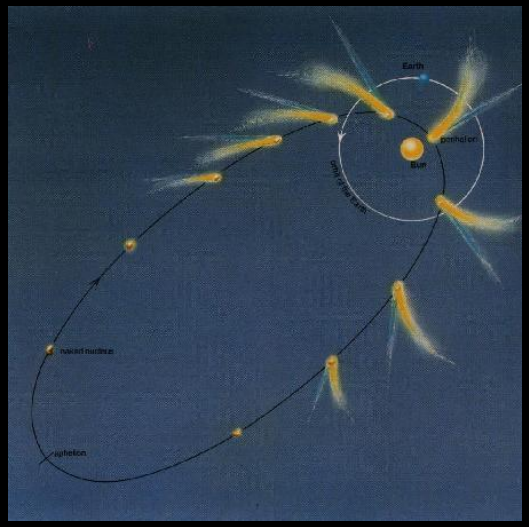


The nature of Comets

Dust and gaseous coma



The nucleus (few km)

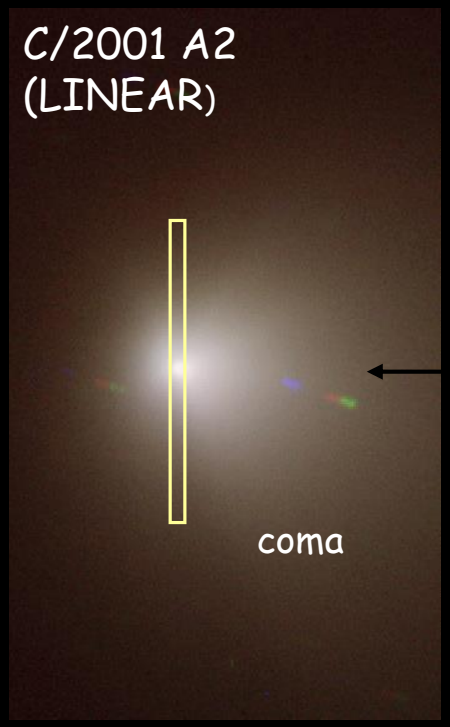


Orbits of comets
Origins : Oort Cloud and Kuiper Belt

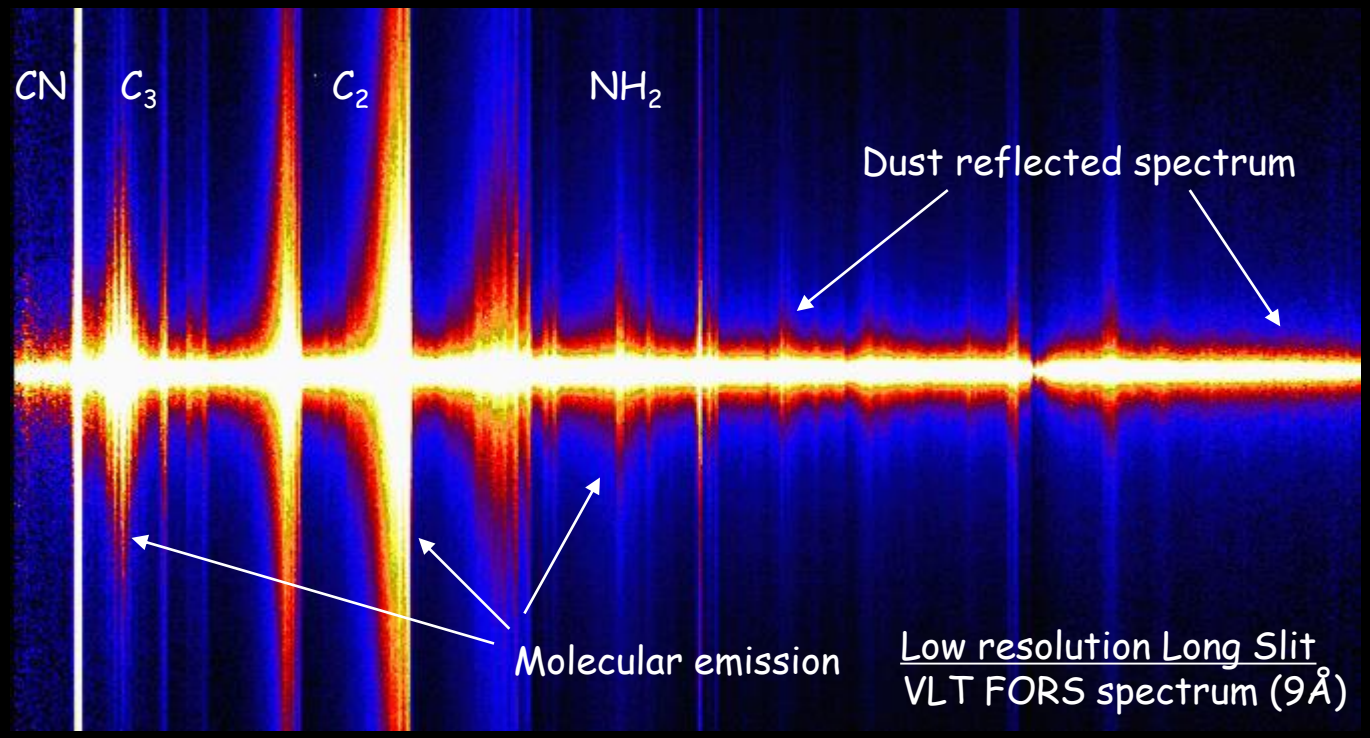
ROSETTA (ESA)

The optical spectrum of a comet

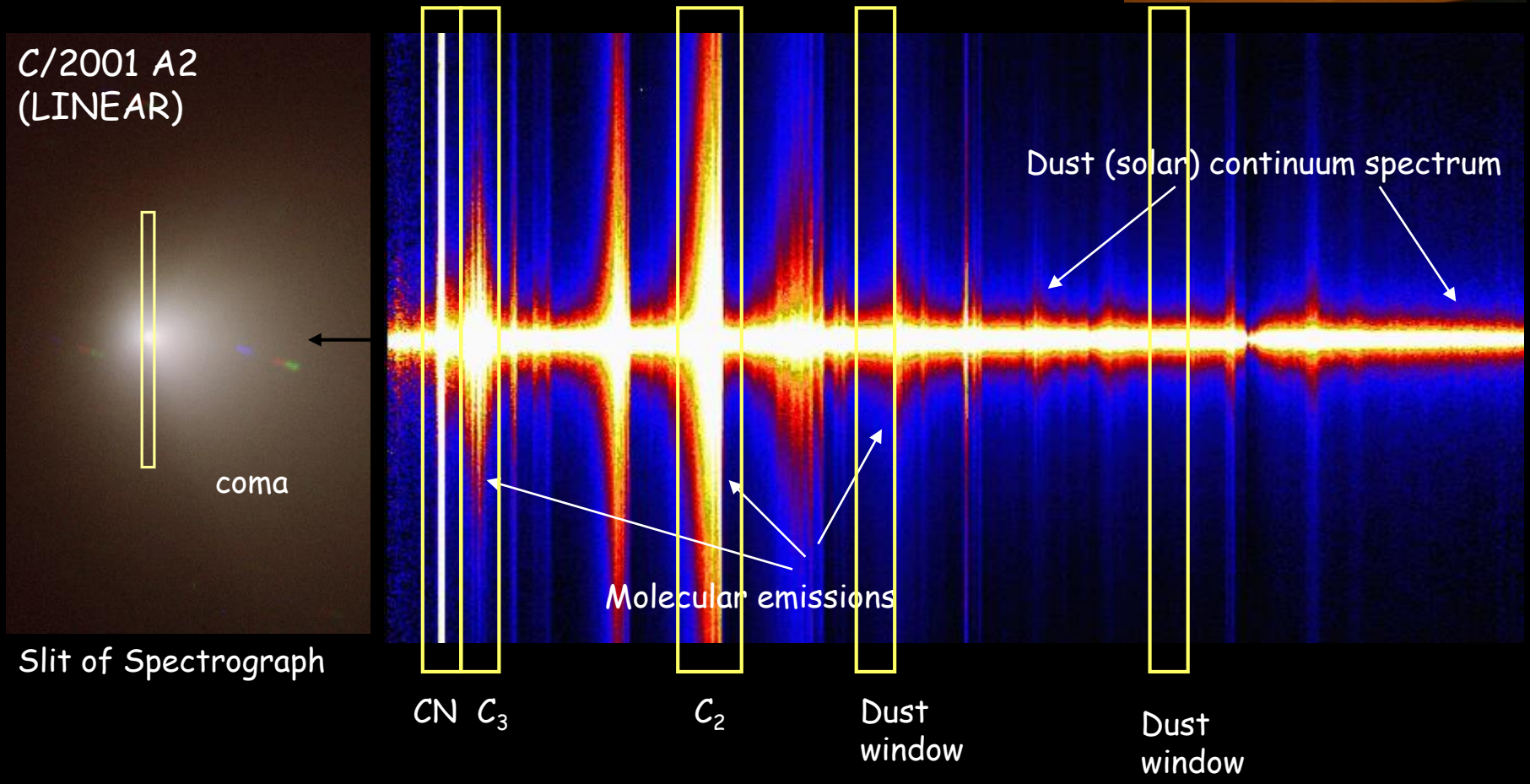
Cometary spectra consist of molecular emission from resonance fluorescence and a continuum resulting from sunlight scattered off dust.



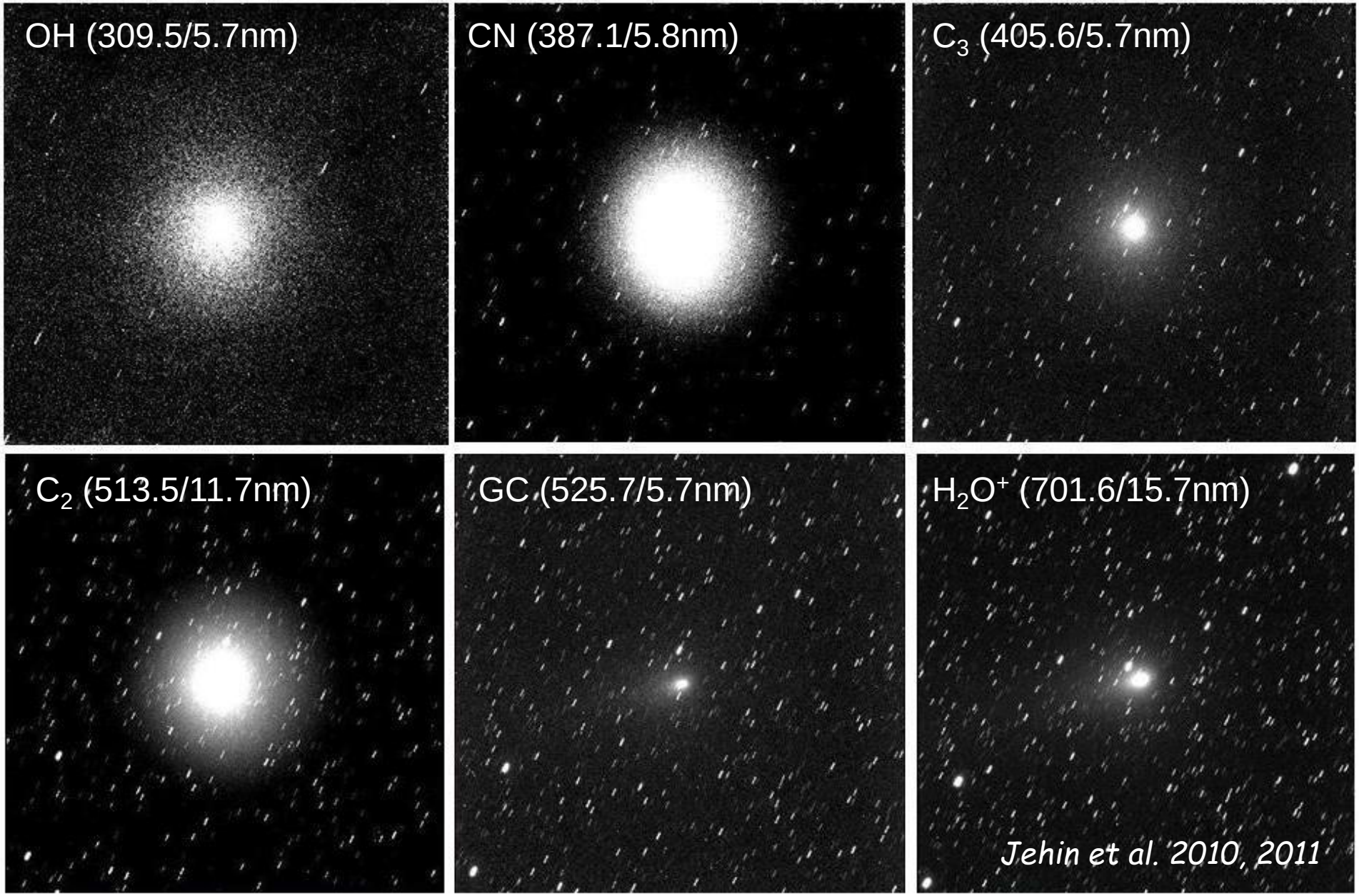
Slit view image



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

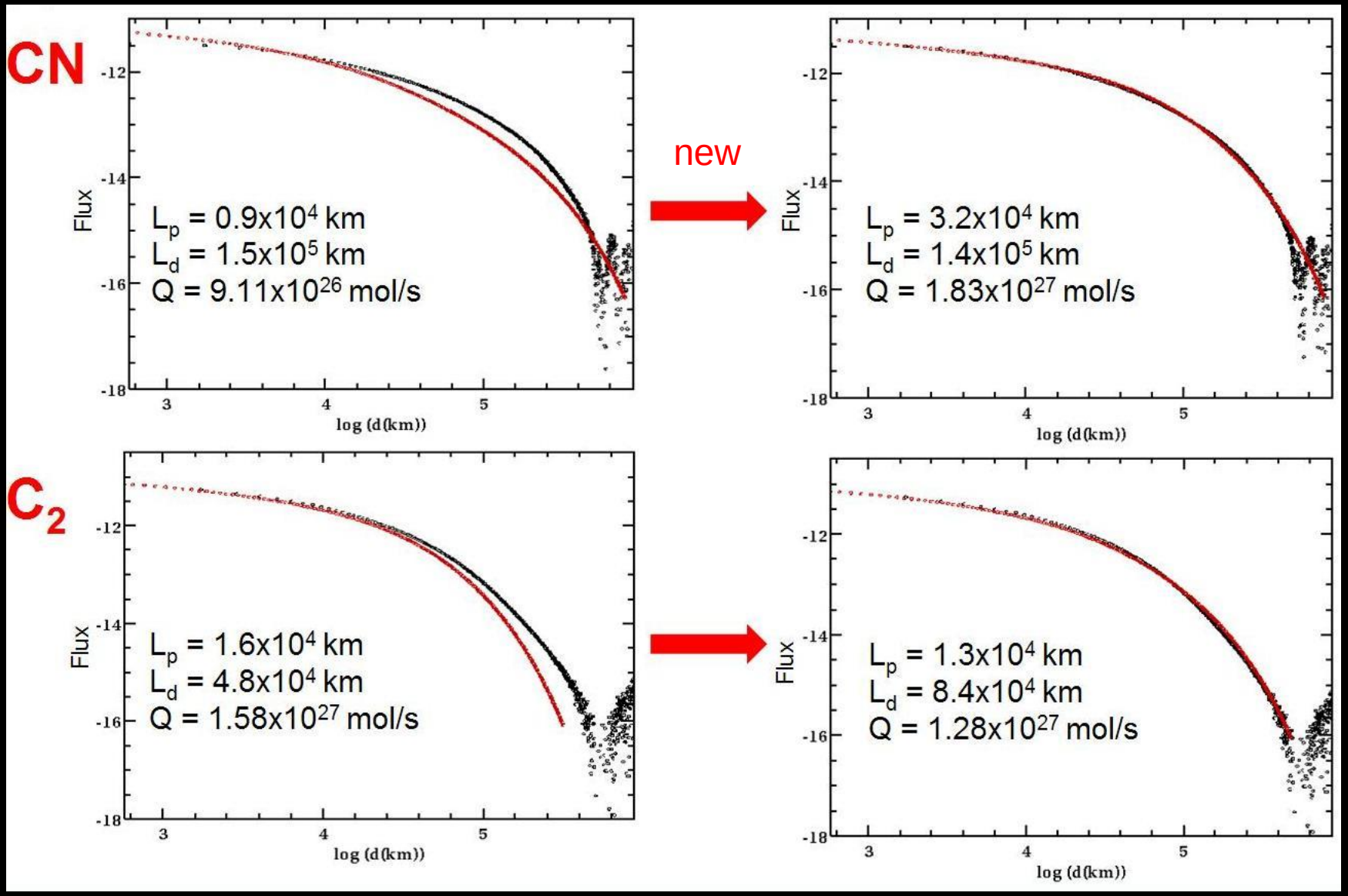


Narrow band images : 103P/Hartley 2



Radial profiles and Haser model
→ Production rates (at 10.000 km)

Vp=Vd=1km/s



1. The TRAPPIST survey of bright Comets

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

Coma composition (gas OH, CN, NH, C_2, C_3, CO^+, dust UC,BC,GC,RC)
→ gas production rates (Q (mol/s)) → abundance ratios
→ dust production rates (kg/s)

→ chemical peculiarities → types of comets ("taxonomy")

→ link composition / dynamical classes (JFC, OOC)

→ nucleus composition heteregeonity

→ variability/activity and composition along the orbit

→ are the chemical peculiarities pristine or evolutionnary ?

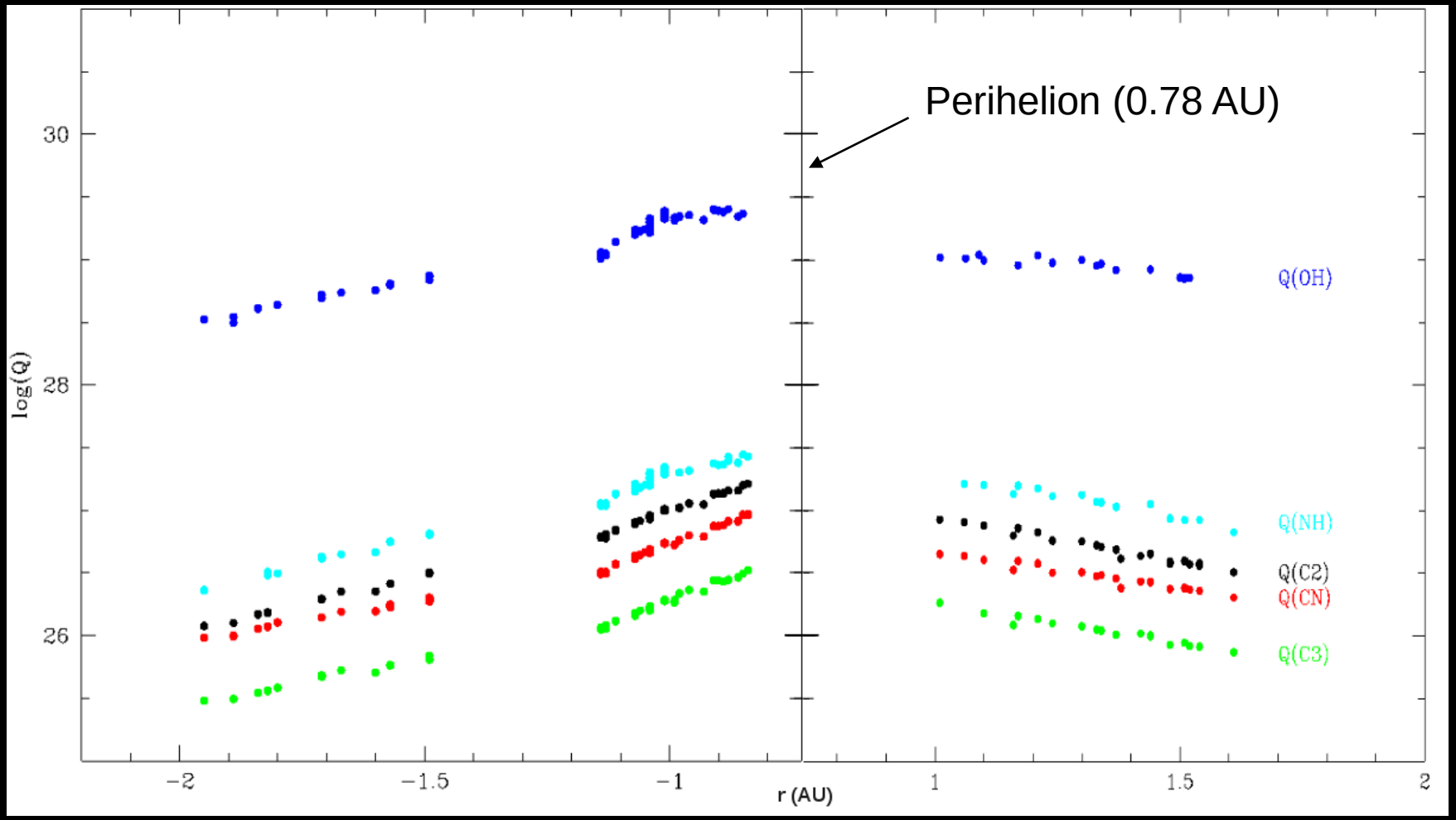
TRAPPIST Narrow band comet survey database

Comet	N	n
0002P	2	1
0010P	159	12
0026P	21	7
0029P	138	18
0045P	3	1
0063P	148	19
0078P	96	9
0081P	18	0
0096P	12	2
0103P	3761	70
0117P	3	1
0168P	295	18
0213P	18	1
0246P	54	11
0260P	12	1
0262P	53	7
0273P	7	2
PK13CC9U	9	3
PK13J020	9	3

Comet	N	n
CK06S030	26	5
CK09F040	23	3
CK09P010	915	64
CK10B010	15	1
CK10F87B	18	1
CK10G020	220	21
CK10S010	10	2
CK10X010	50	4
CK11C010	265	34
CK11F010	33	14
CK11L040	151	20
CK11Q040	47	5
CK11R010	94	19
CK11UU5F	2	1
CK12F060	1017	51
CK12K010	34	8
CK12K050	53	8
CK12K060	21	5
CK12S010	1	1
CK12V020	6	1
CK13E020	90	33
CK13G060	3	1

22 periodic comets
35 OC comets

C/2012 F6 (Lemmon) production rates

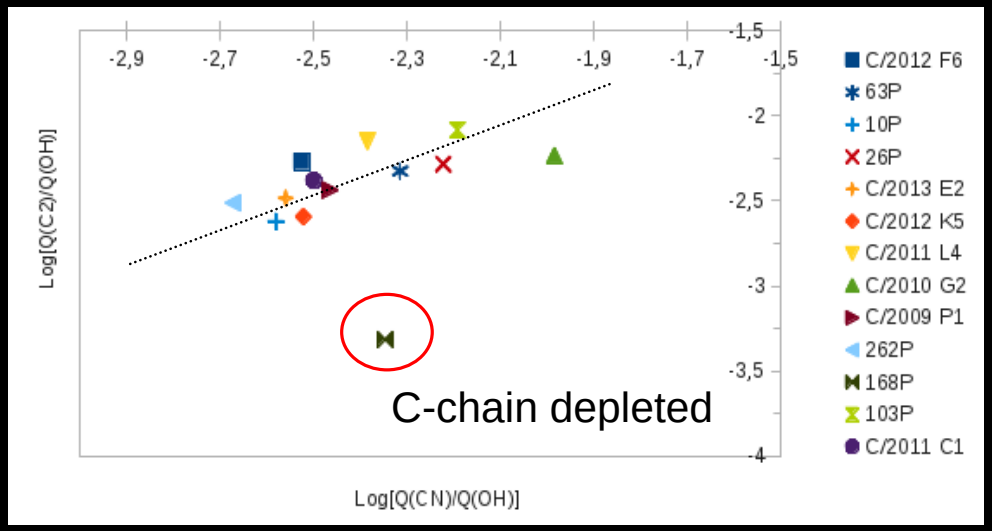


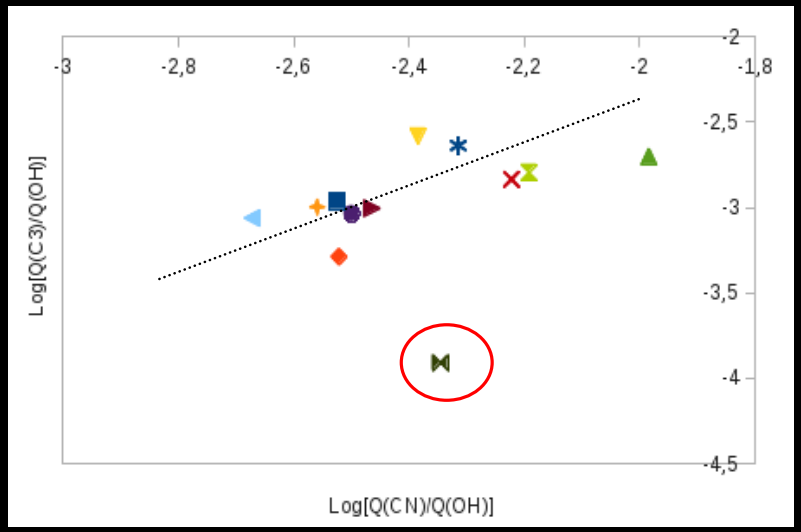
51 nights, 1017 NB images !

(Opitom et al. 2013)

35 Comets complete set narrow band images
→ abundance ratios

Comet Name	Epoch	n	N	r(AU)	Δ(AU)	q(AU)
10P/Tempel 2	14/09/10:11/10/10	92	7	1.60:1.74	0.67:0.79	1.42
103P Hartley 2	30/10/10:21/02/11	1539	69	1.06:1.81	0.14:1.00	1.06
C/2011 C1 (McNaught)	10/03/11:18/05/11	265	22	-1.12:1.04	0.94:1.41	
C/2009 P1 (Garradd)	02/05/11:21/10/11	897	55	-3.33:-1.77	3.73:1.93	1.55
C/2010 G2 (Hill)	12/12/11:15/01/12	220	21	2.32:2.54	1.38:2.08	1.98
168P/Hergenrother	24/09/12:17/10/12	295	12	1.42:1.43	0.42:0.48	1.41
C/2012 F6 (Lemmon)	11/12/12:11/06/13	1017	49	-1.95:1.61	1.97:1.77	0.73
262P/McNaught-Russel	17/12/12:12/01/13	53	6	1.29:1.38	0.92:1.11	1.28
C/2012 K5 (Linear)	03/01/13:08/02/13	53	7	1.27:1.59	0.31:1.16	1.14
C/2011 L4 (Panstarrs)	07/02/13:27/02/13	23	2	-0.88:-0.86	1.47:1.49	0.30
C/2013 E2 (Iwamoto)	15/04/13:–	59	2	1.51:-	2.00:-	1.41
63P/Wild 1	15/05/13:10/08/13	148	13	1.98:2.28	1.58:2.68	1.95
26P/Grigg-Skjellerup	10/07/13:–	21	7	1.09:-	1.21:-	1.09





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  → gas production rates (Q (mol/s)) → abundance ratios
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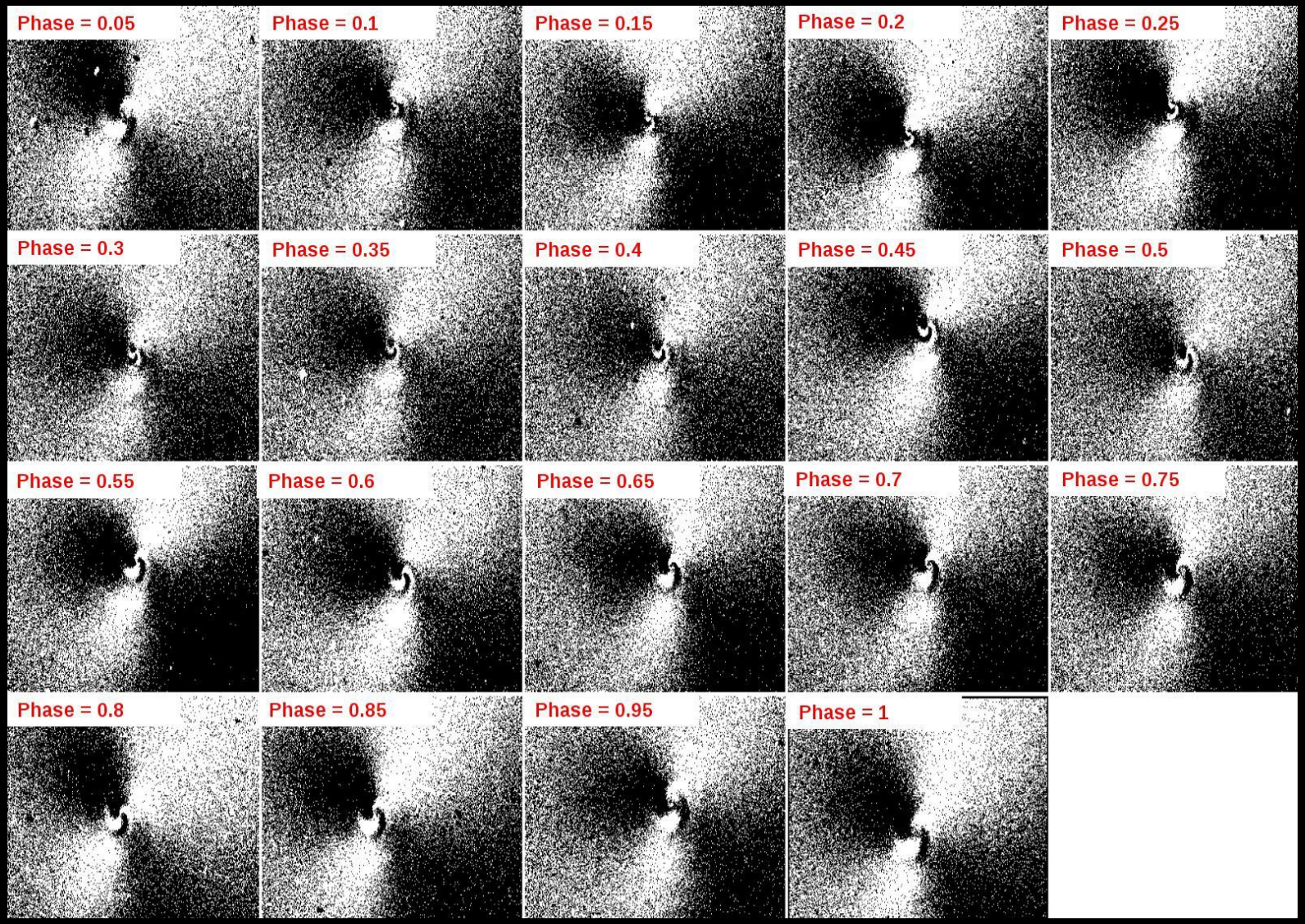
- Image analysis (structures in the coma)
  → number and behaviour of active regions → rotation period

Rotation period of F6 (Lemmon) nucleus



A period of 9.52 ± 0.12 h

Larson Sekanina filtering

(Opitom et al. 2013)

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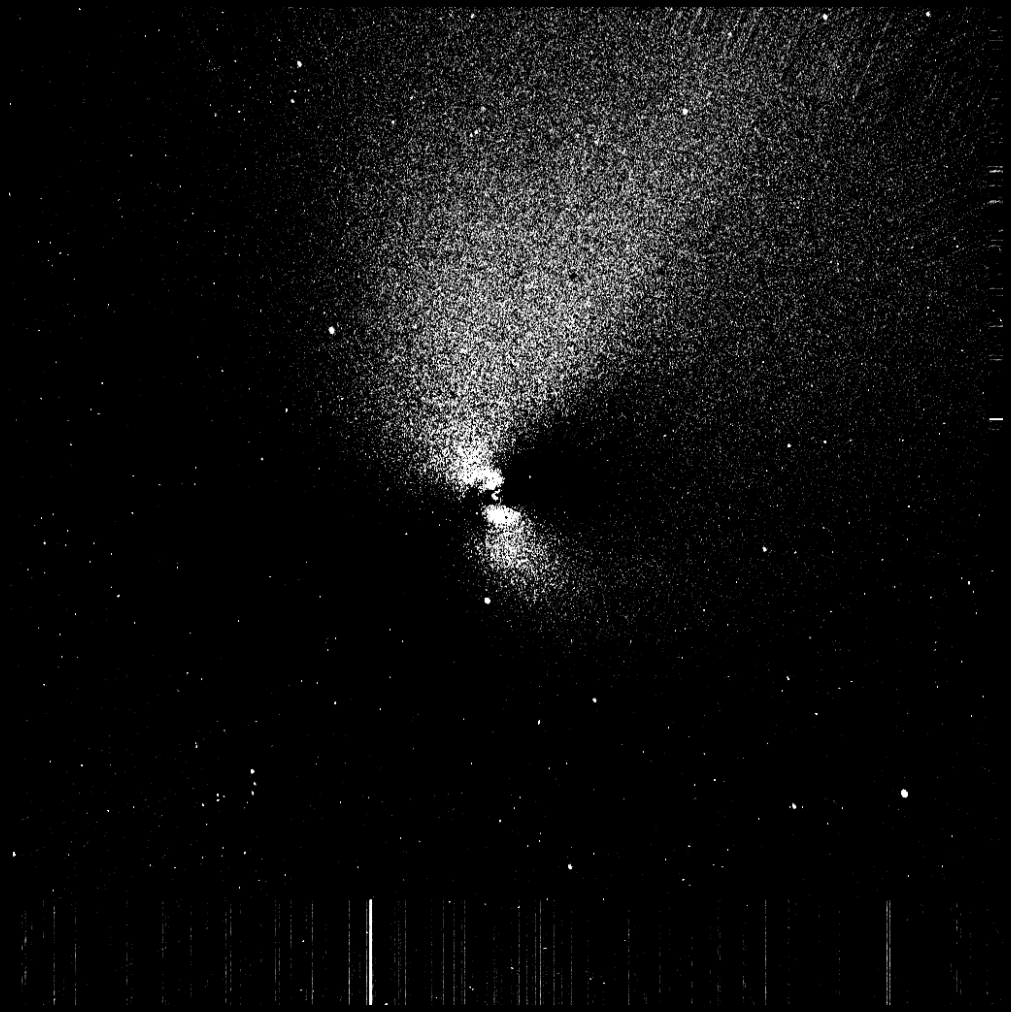

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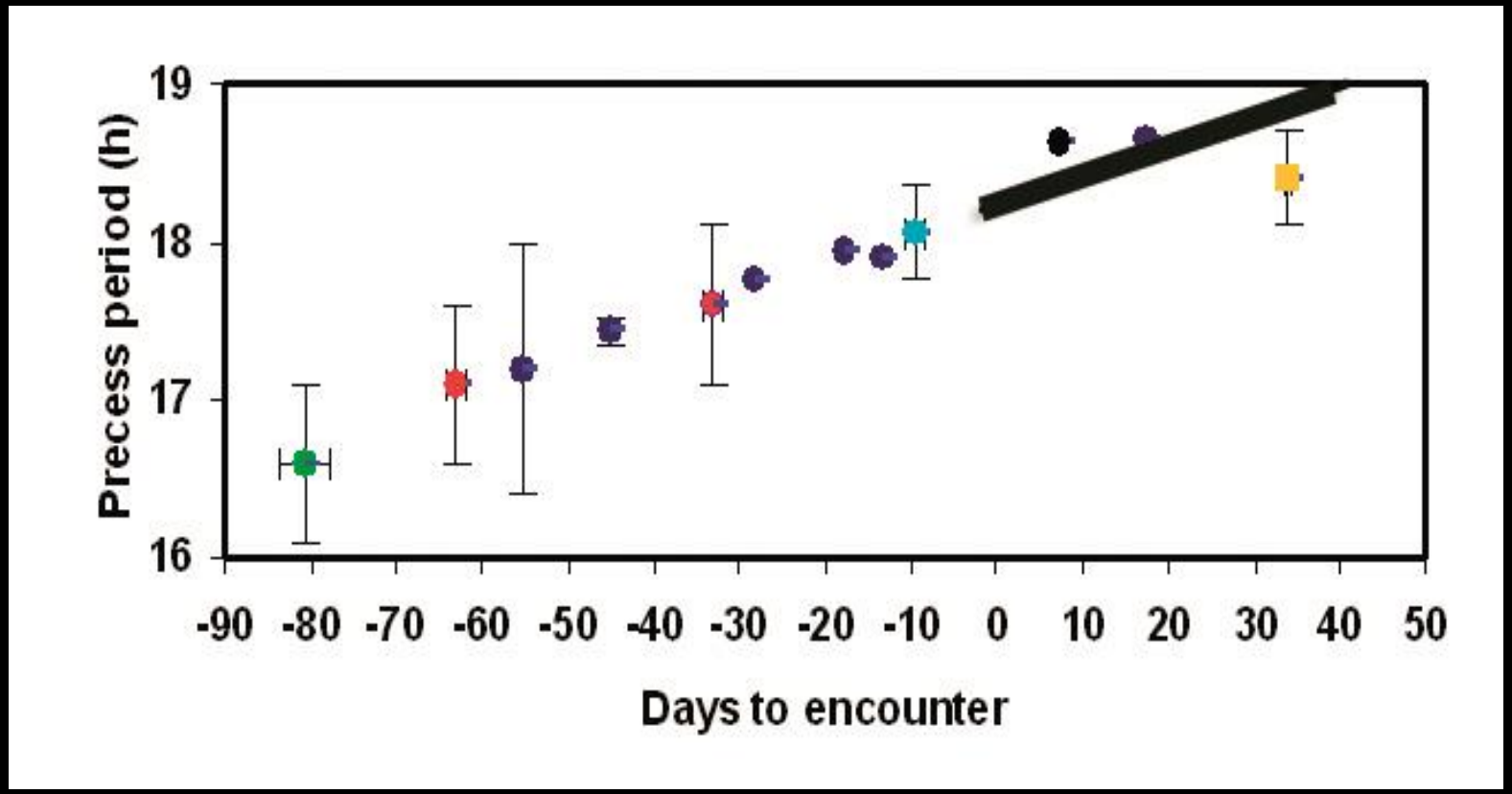
Rotation period of 103P/Hartley 2 nucleus

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)
~ 2h in 100 days , ok with other data (Arecibo, EPOXI, etc.) A'Hearn et al. 2011

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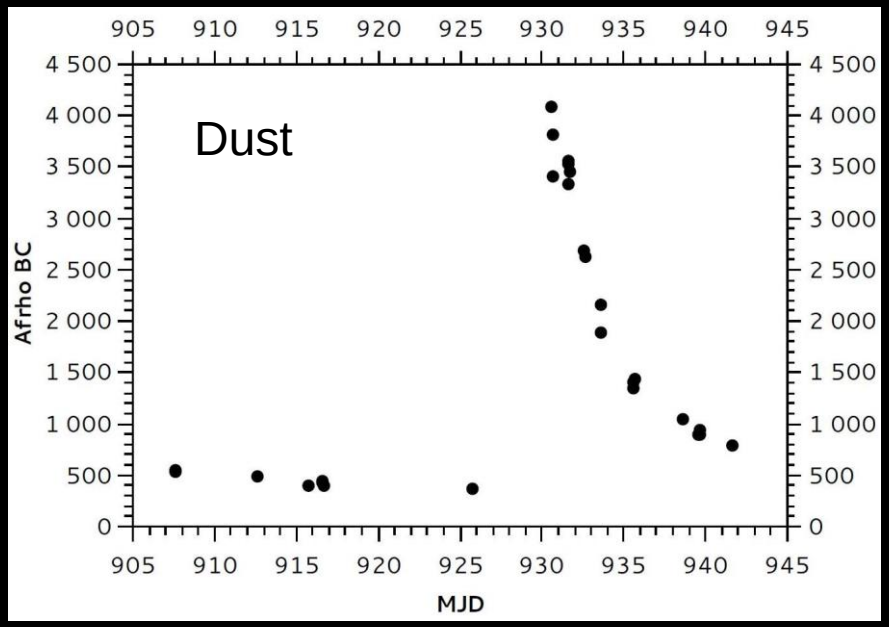
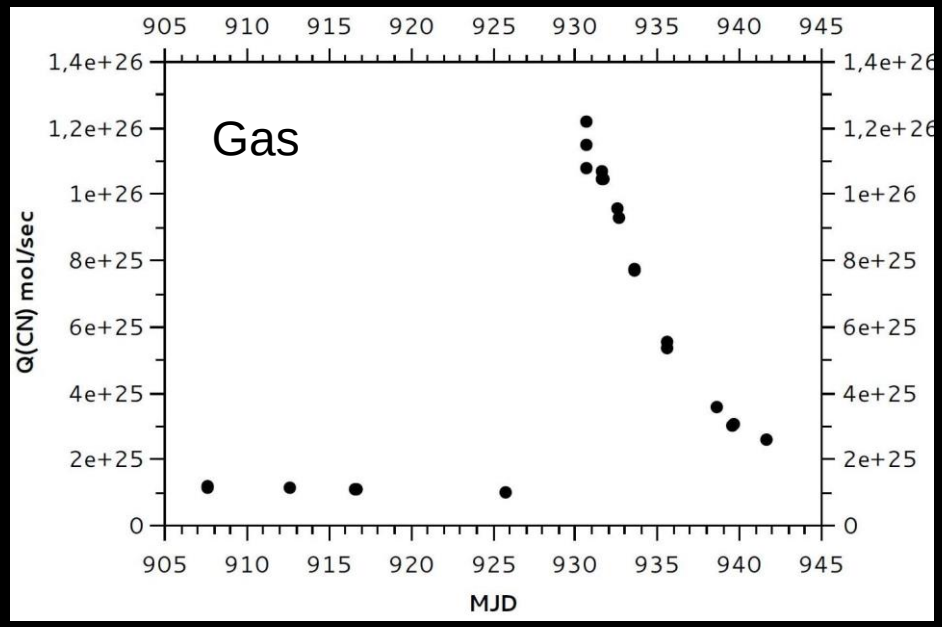
Comet C/2010 G2 (Hill) outburst

CN coma expansion in 10 days (~900m/s)





« Extremely Organic-rich Coma of Comet C/2010 G2 (Hill) during Its Outburst »
Kawakita et al. 2014 NIRSPEC data

Jehin 2014

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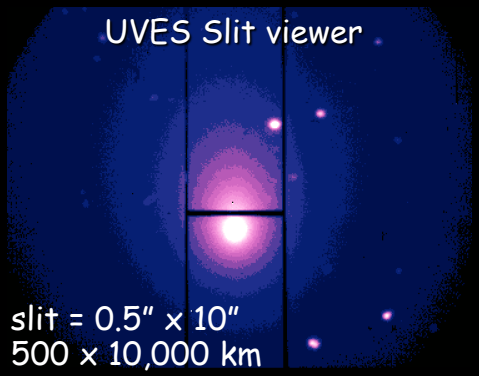
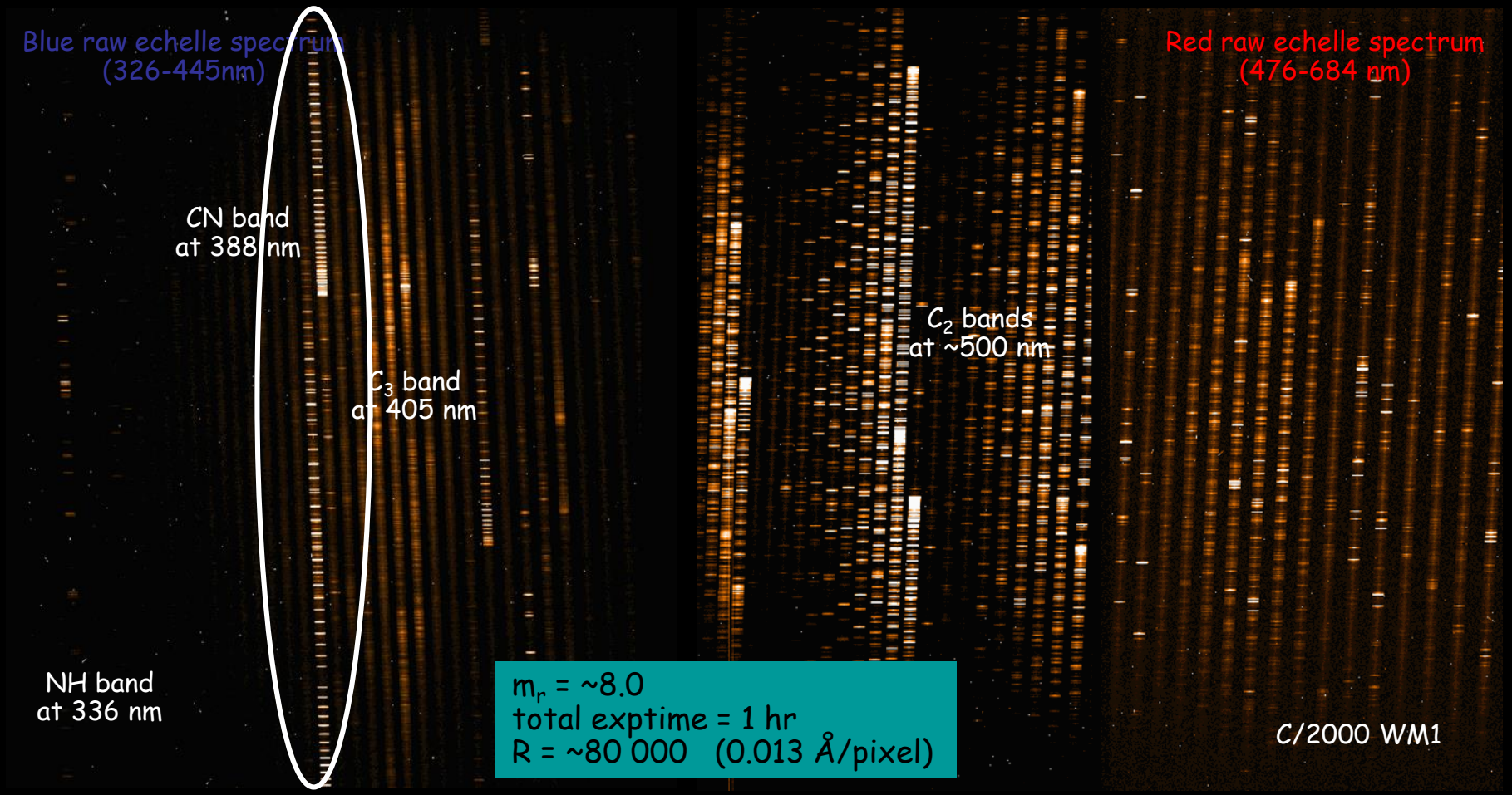
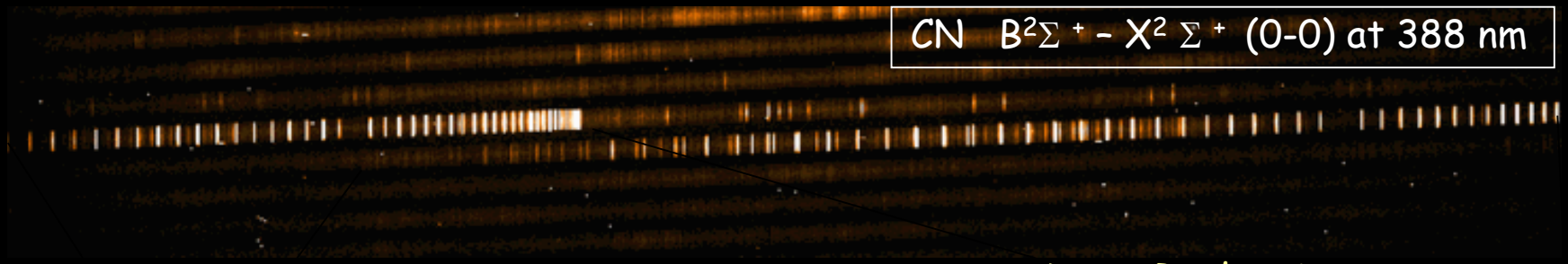


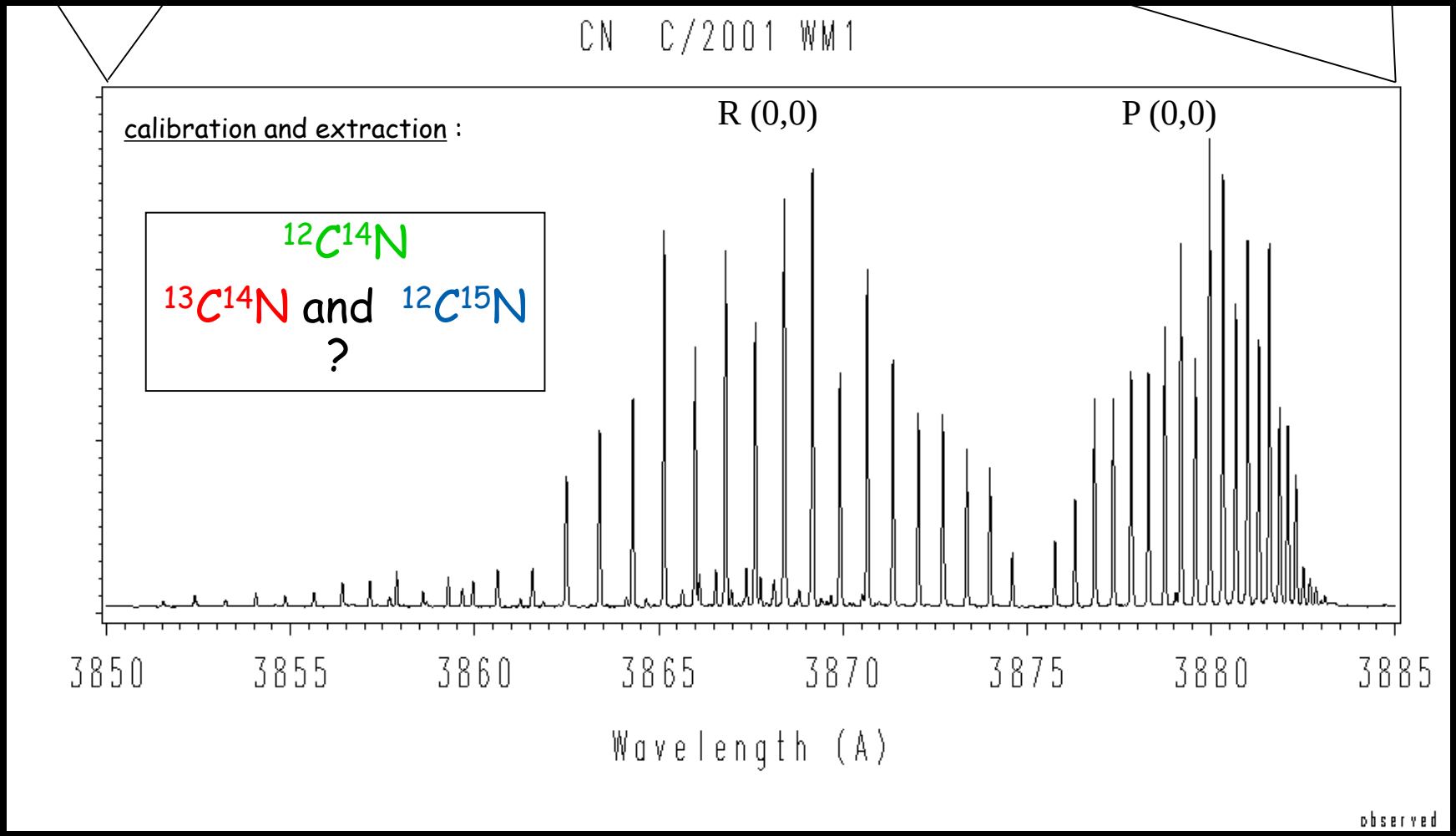
Isotopic ratios from optical spectroscopy : CN



m_r = ~8.0
total exptime = 1 hr
R = ~80 000 (0.013 Å/pixel)



Data Reduction

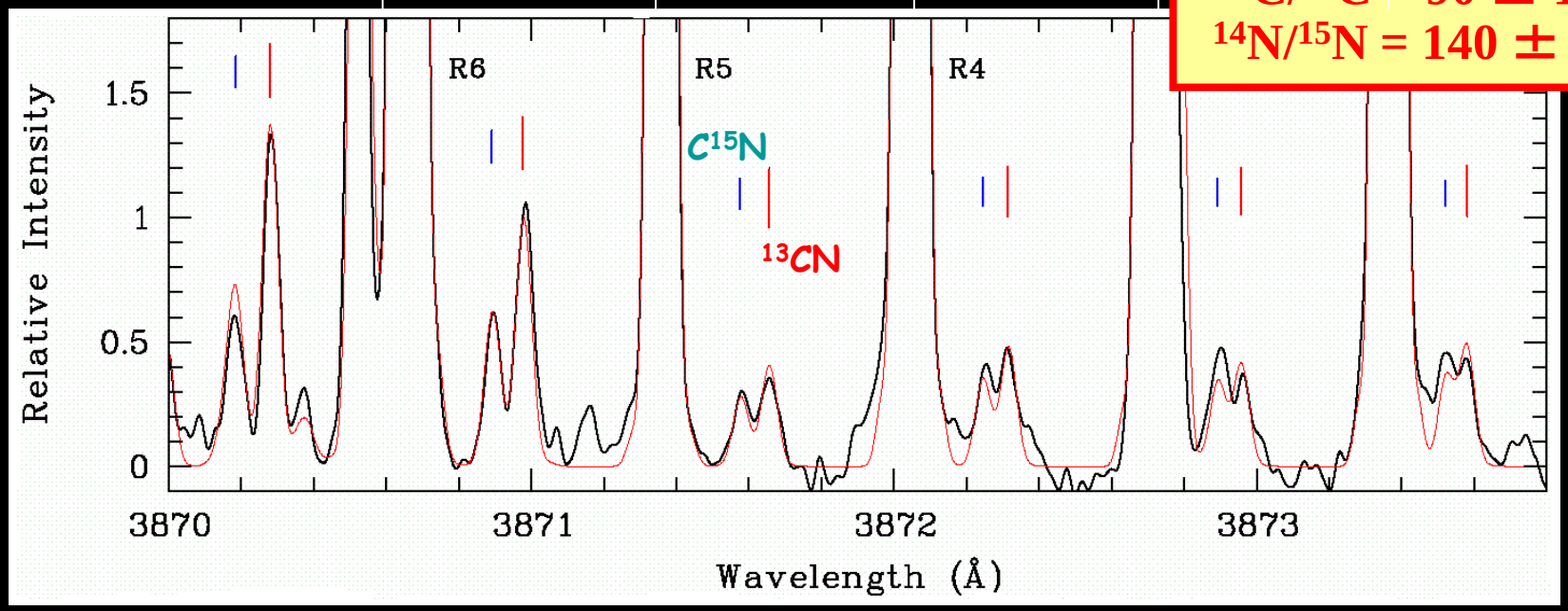


The first C and N ratios in a Jupiter Family Comet 88P/Howell :

Hutsemékers et al. A&A 2005

$^{12}C^{14}N$

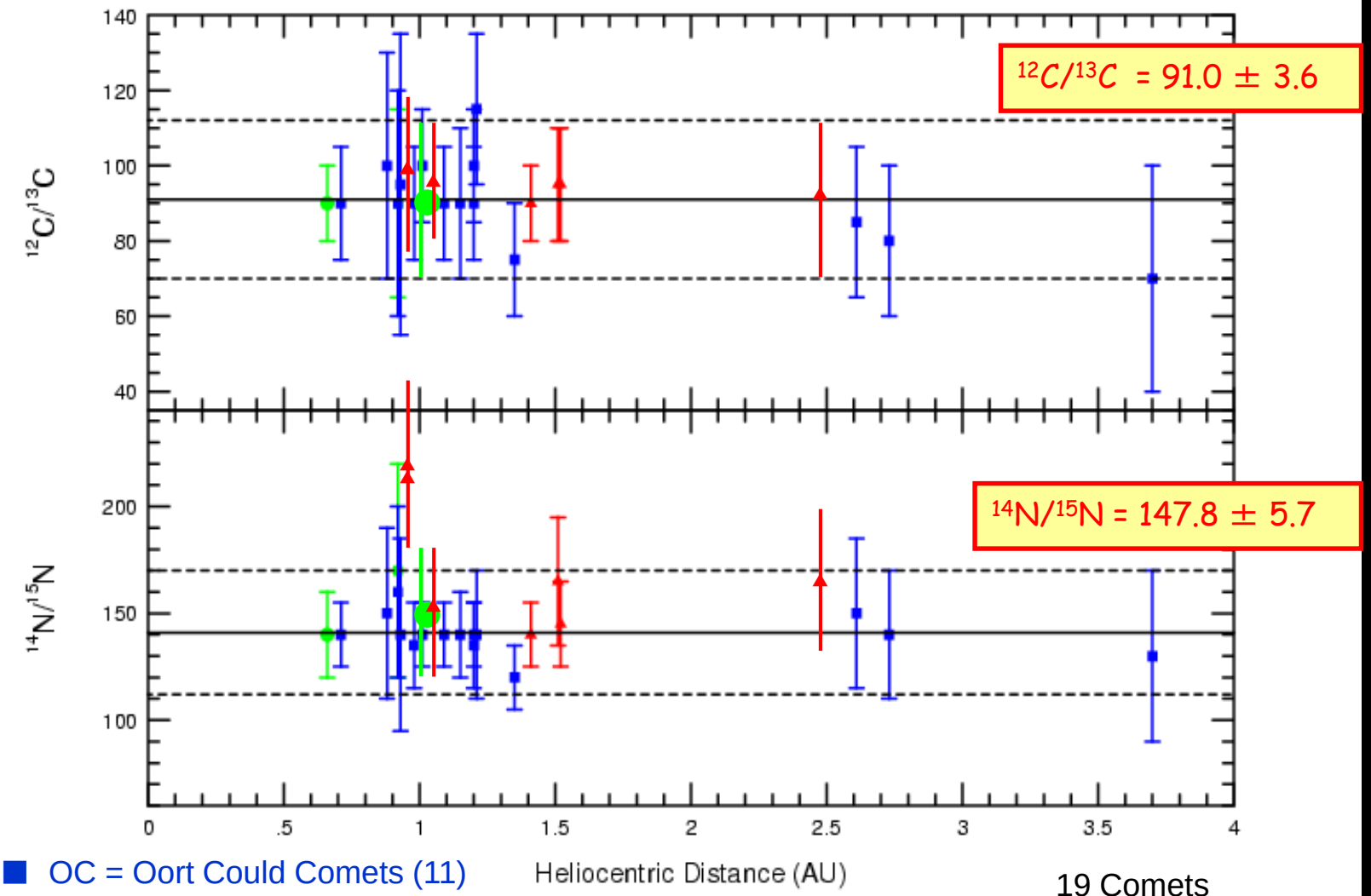
$^{12}C/^{13}C = 90 \pm 15$
$^{14}N/^{15}N = 140 \pm 20$



A section of the UVES spectrum of the CN (0,0) violet band in comet 88P/Howell (m_r ~ 8.0).

Thick (black) line: mean observed spectrum **(total of 12 hrs exptime);**
Thin (red) line: synthetic spectrum of $^{12}C^{14}N$, $^{12}C^{15}N$ and $^{13}C^{14}N$ with the adopted isotopic abundances. The lines of $^{12}C^{15}N$ are identified by the *short ticks* and those of $^{13}C^{14}N$ by the *tall ticks*. The quantum numbers of the R lines of $^{12}C^{14}N$ are also indicated.

$^{12}CN/^{13}CN$ and $C^{14}N/C^{15}N$ with heliocentric distance

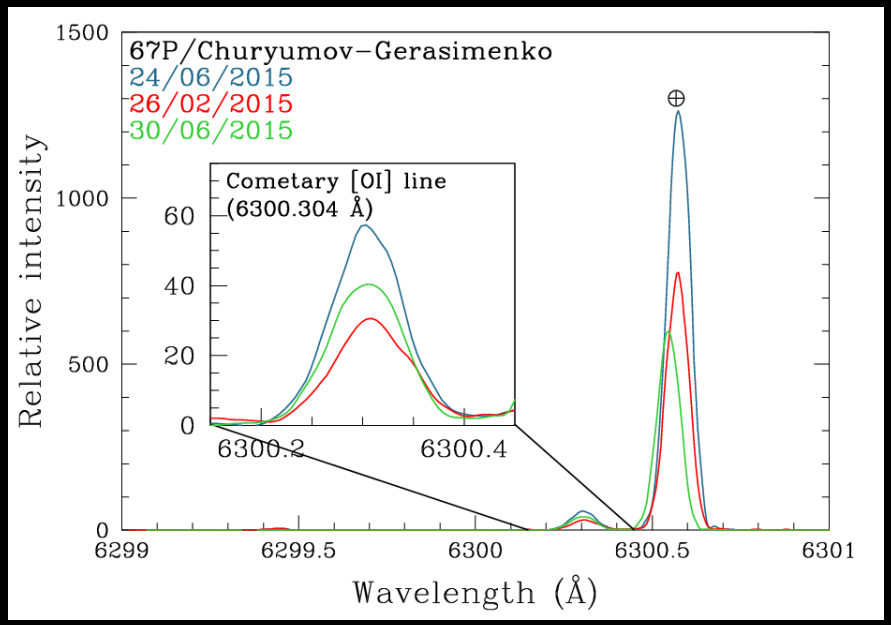


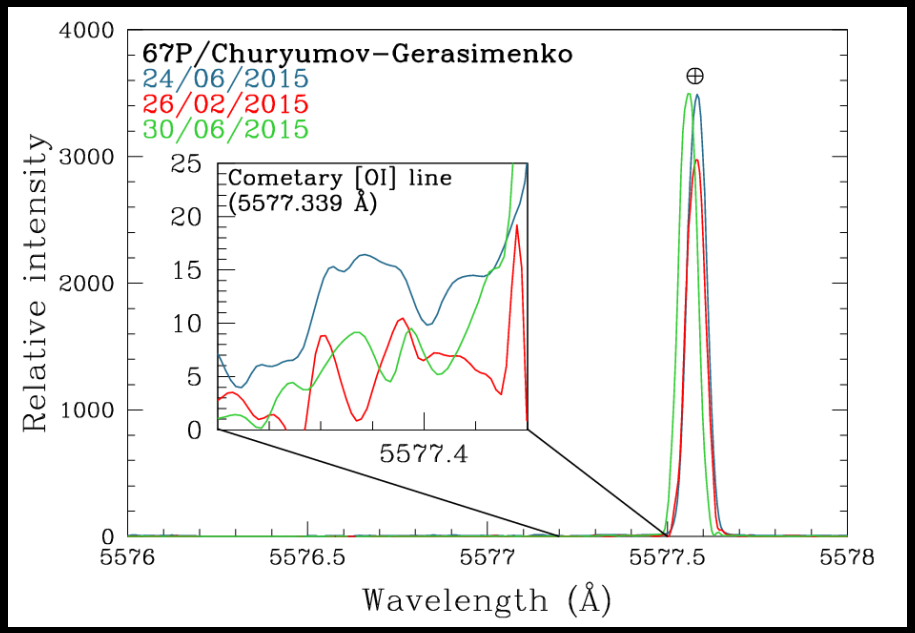
■ OC = Oort Could Comets (11)
▲ JFC = Jupiter Family Comets (5)
● HT = Halley type (3)

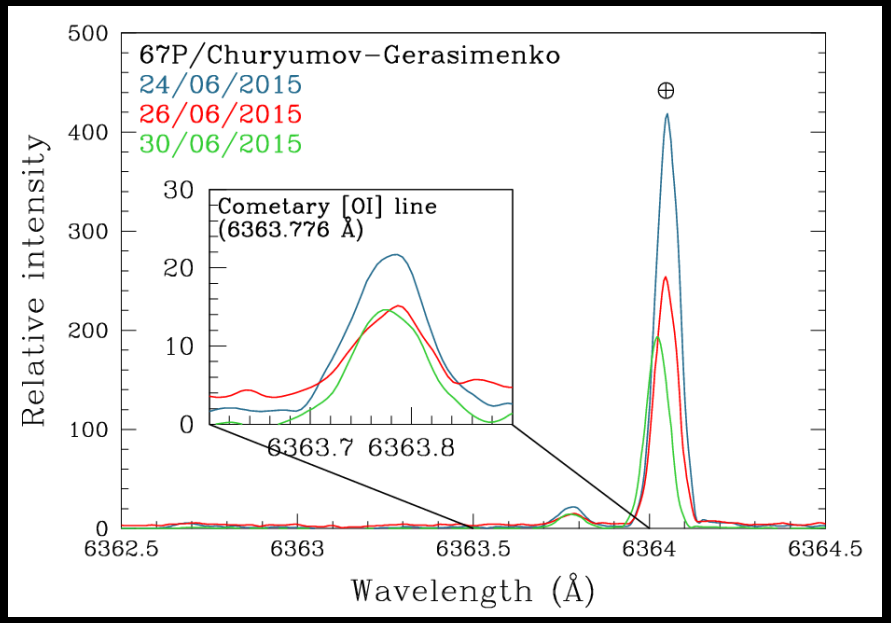
19 Comets
(25 measurements)

Jehin et al. 2016

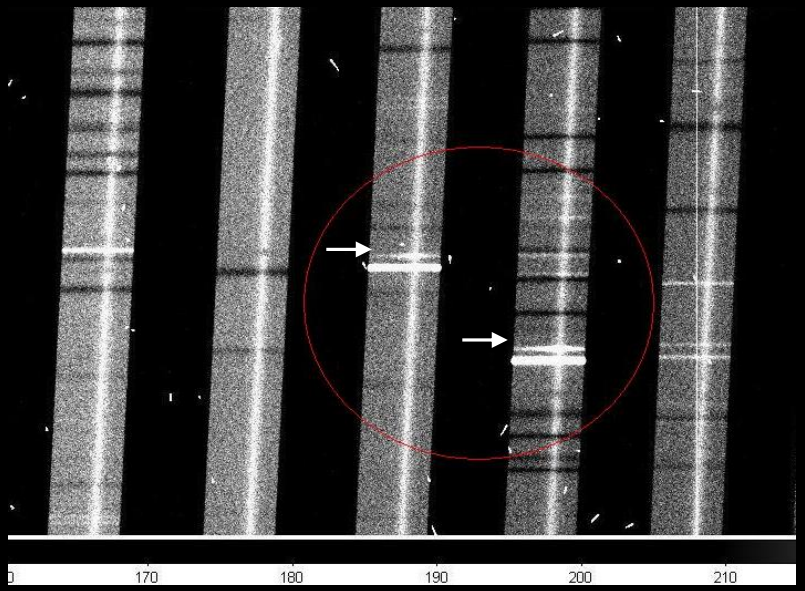
The [OI] lines : ratios and widths







[OI] red doublet 630nm



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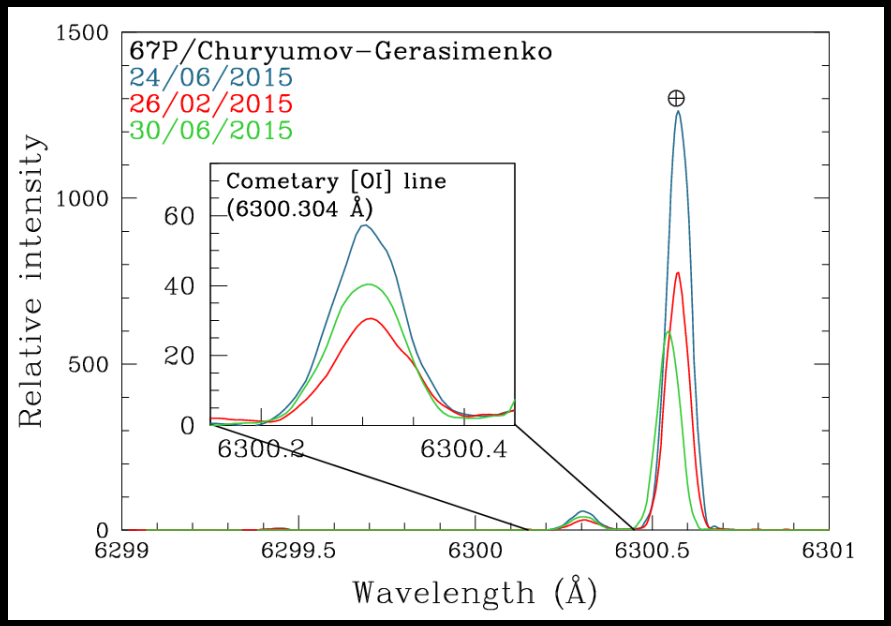

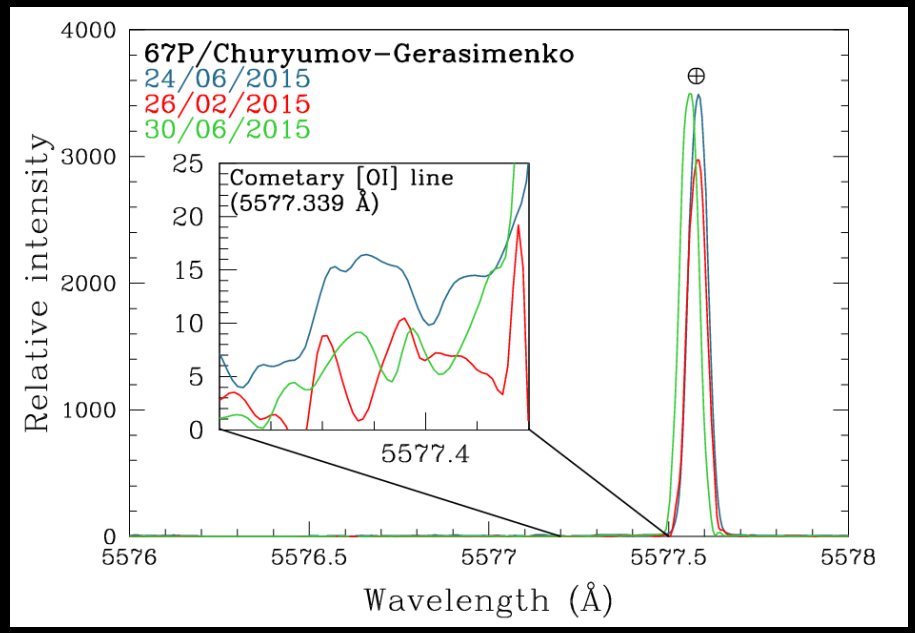

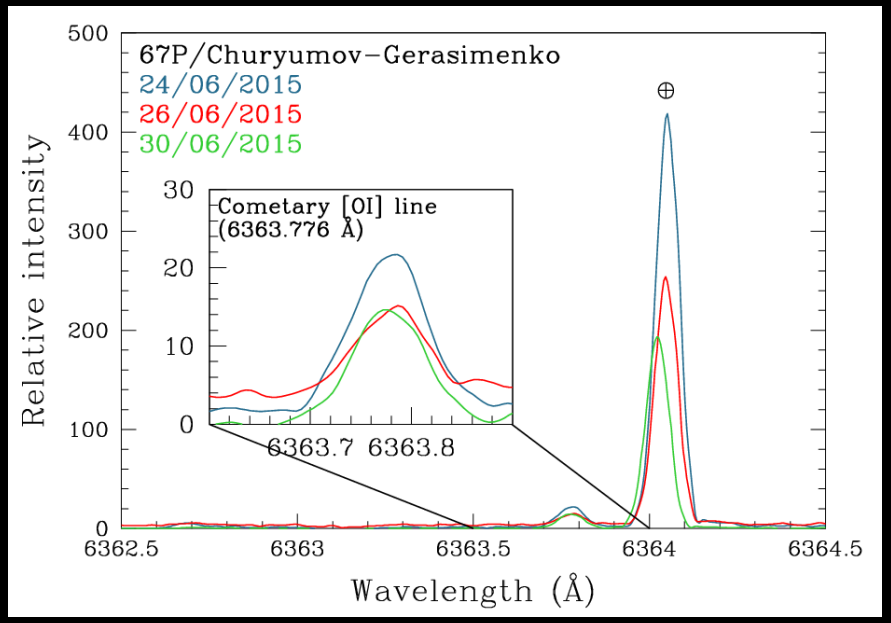

$H_2O + h\nu \rightarrow H_2 + O^*(1D)$
$H_2O + h\nu \rightarrow H_2 + O^*(1S)$

Parents	$^1S/^1D$
H_2O	0.040
CO_2	1.371
CO	0.667

Raghuram & Bhardwaj (2013)
Decock et al. (2013)
Decock et al. (2015)

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- 1x month provide Q(mol/s) to the community (IAU Circular and CBET)

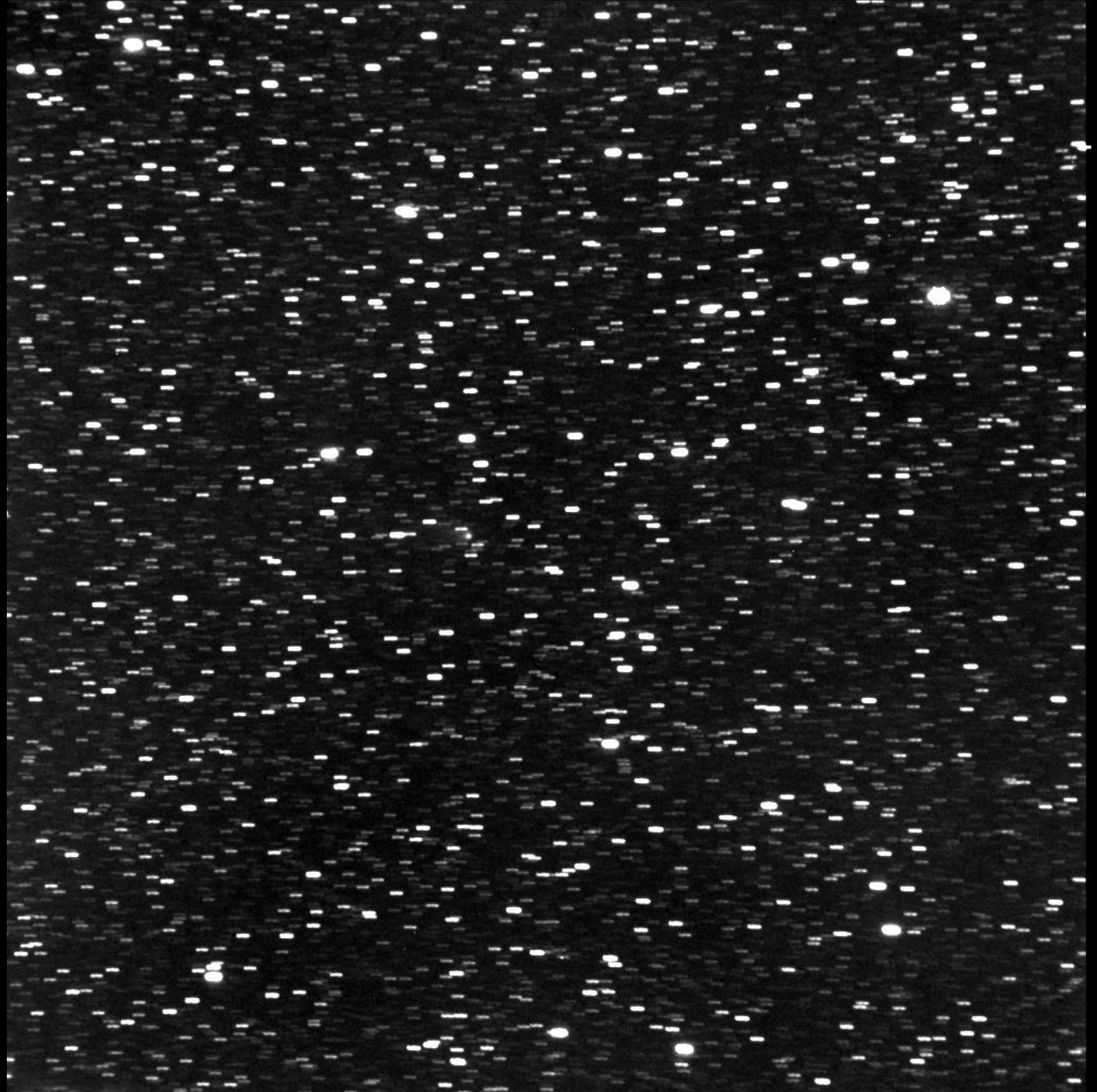
Comet C/2012 V2 (LINEAR)
11 September 2013 (r=1.50 AU)


```
Q(OH)  :  2.3E28 +/- 0.4E28 mol/s
Q(CN)  :  9.8E25 +/- 0.4E27 mol/s
Q(C3)  :  4.1E25 +/- 0.3E25 mol/s
Q(C2)  :  1.5E26 +/- 0.1E26 mol/s

Afrho(BC)  :  2600 +/- 78 cm
Afrho(GC)  :  2610 +/- 46 cm
```

Comet C/2013 R1 (Lovejoy)
12 September 2013 (r=1.93 AU)


```
Q(OH)  =  7.8E27 +/- 1.0E27 mol/s
Q(CN)  =  3.1E25 +/- 0.1E25 mol/s
Q(C3)  =  7.4E24 +/- 0.4E24 mol/s
Q(C2)  =  3.2E25 +/- 0.1E25 mol/s

Afrho(GC)  =  160 +/- 8 cm
```

➔ MPC circular (ejehin@ulg.ac.be)



2. The TRAPPIST survey of faint Comets

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

BVRI images database

Comet	N	n
0002P	4	1
0009P	260	24
0010P	83	11
0017P	143	22
0026P	60	12
0027P	47	9
0029P	1196	139
0037P	39	5
0043P	96	8
0045P	127	10
0048P	27	5
0049P	226	31
0063P	201	30
0065P	78	13
0067P	7	1
0071P	137	19
0073P	36	3
0078P	167	23
0091P	21	3
0096P	99	13
0097P	51	9
0098P	21	3
0102P	7	1
0103P	630	71
0105P	67	11
0111P	14	2
0114P	16	2
0117P	114	17
0119P	3	1
0123P	133	17
0125P	97	13
0130P	58	9
0133P	108	17
0152P	136	18
0154P	68	8
0160P	55	7
0163P	6	1
0164P	73	11
0165P	7	1
0168P	557	28

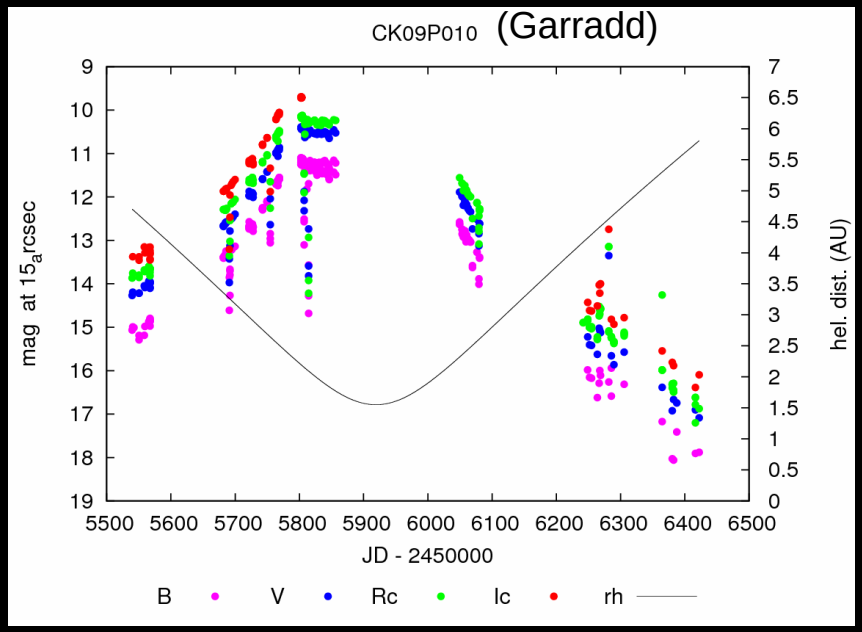
Comet	N	n
0174P	43	7
0175P	40	7
0176P	7	1
0184P	12	2
0189P	23	4
0197P	6	1
0198P	6	1
0213P	199	25
0238P	7	1
0240P	12	2
0244P	8	2
0246P	464	68
0257P	11	2
0260P	142	16
0261P	72	7
0262P	61	10
0270P	7	1
0273P	5	2
PK04A010	7	1
PK04FE0Y	23	2
PK04R030	7	1
PK05K030	15	3
PK05L010	11	2
PK05T020	15	3
PK06T010	6	1
PK10R020	15	2
PK11A020	16	1
PK11W020	6	1
PK12B010	88	13
PK12F050	22	3
PK12N00J	594	4
PK12O030	24	3
PK12T010	13	3
PK12U27S	14	2
PK12W32X	7	1
PK13CC9U	23	4
PK13J020	62	11

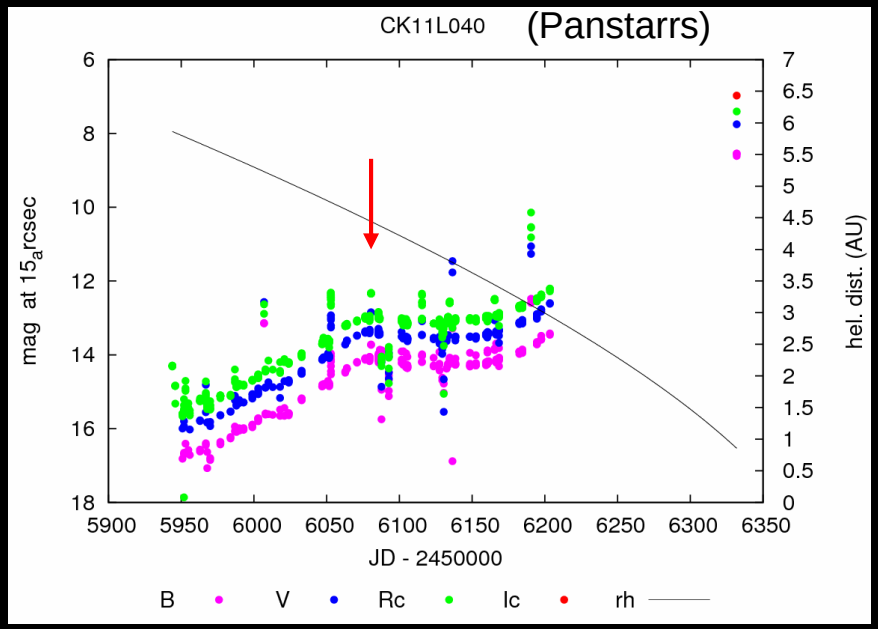
Comet	N	n
CK06S030	176	25
CK06W030	113	12
CK09F040	868	107
CK09K030	12	1
CK09P010	629	86
CK10B010	101	9
CK10F87B	89	7
CK10G020	363	40
CK10M010	12	1
CK10R010	35	5
CK10S010	39	6
CK10X010	374	28
CK11A030	33	4
CK11C010	173	30
CK11C030	44	3
CK11F010	130	27
CK11J020	13	2
CK11L020	15	4
CK11L040	950	73
CK11M010	4	1
CK11O010	209	28
CK11Q020	7	1
CK11Q040	30	5
CK11R010	397	56
CK11UU5F	35	5
CK11W030	4	1
CK12C010	140	22
CK12F030	7	1
CK12F060	401	46
CK12J010	55	10
CK12K010	149	24
CK12K050	124	15
CK12K060	91	14
CK12S010	213	30
CK12T050	101	15
CK12V010	14	2
CK12V020	4	1
CK13A010	21	3
CK13E020	150	30
CK13F030	14	2

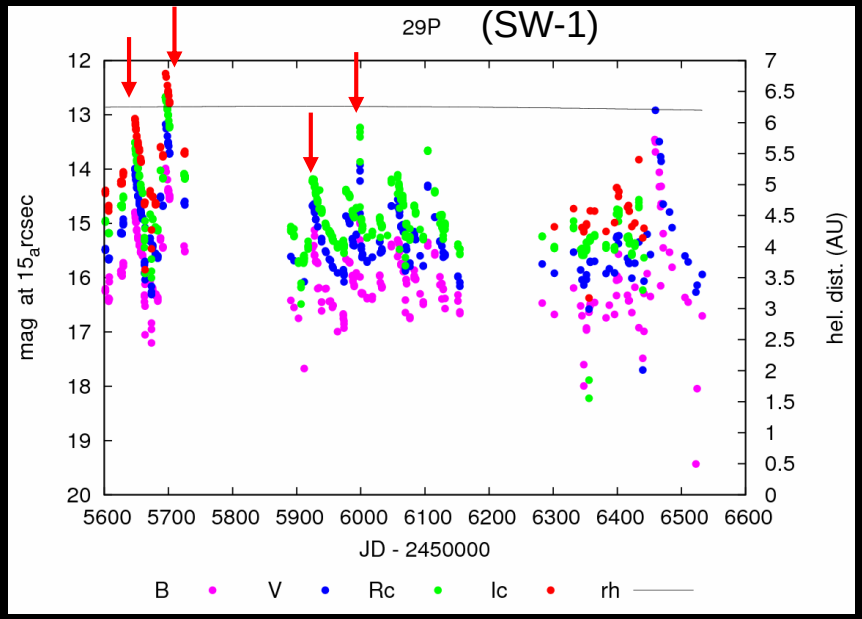
Comet	N	n
CK13G010	11	2
CK13G020	21	3
CK13G060	18	3
CK13G070	31	5
CK13J030	14	2

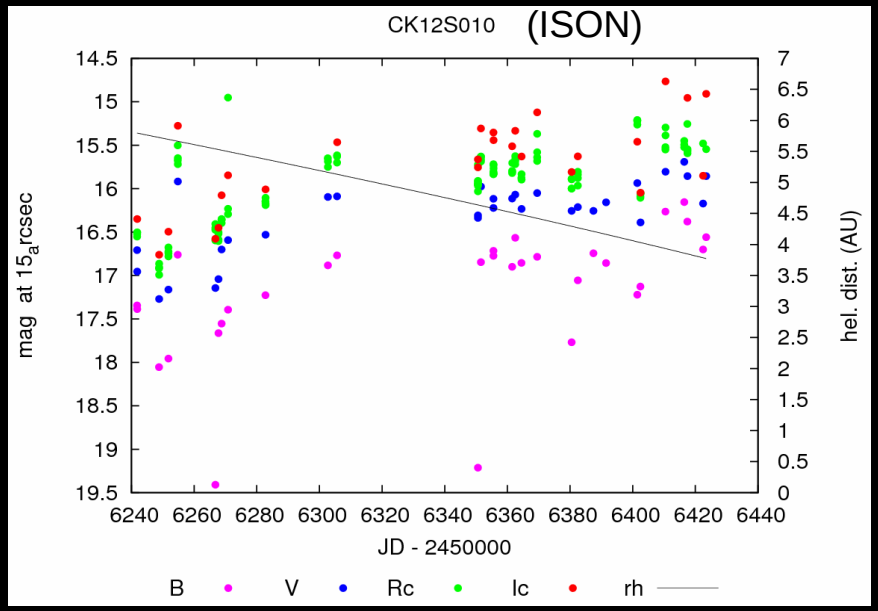
120 periodic comets
75 OC comets

BVRI monitoring (~1-2x a week)

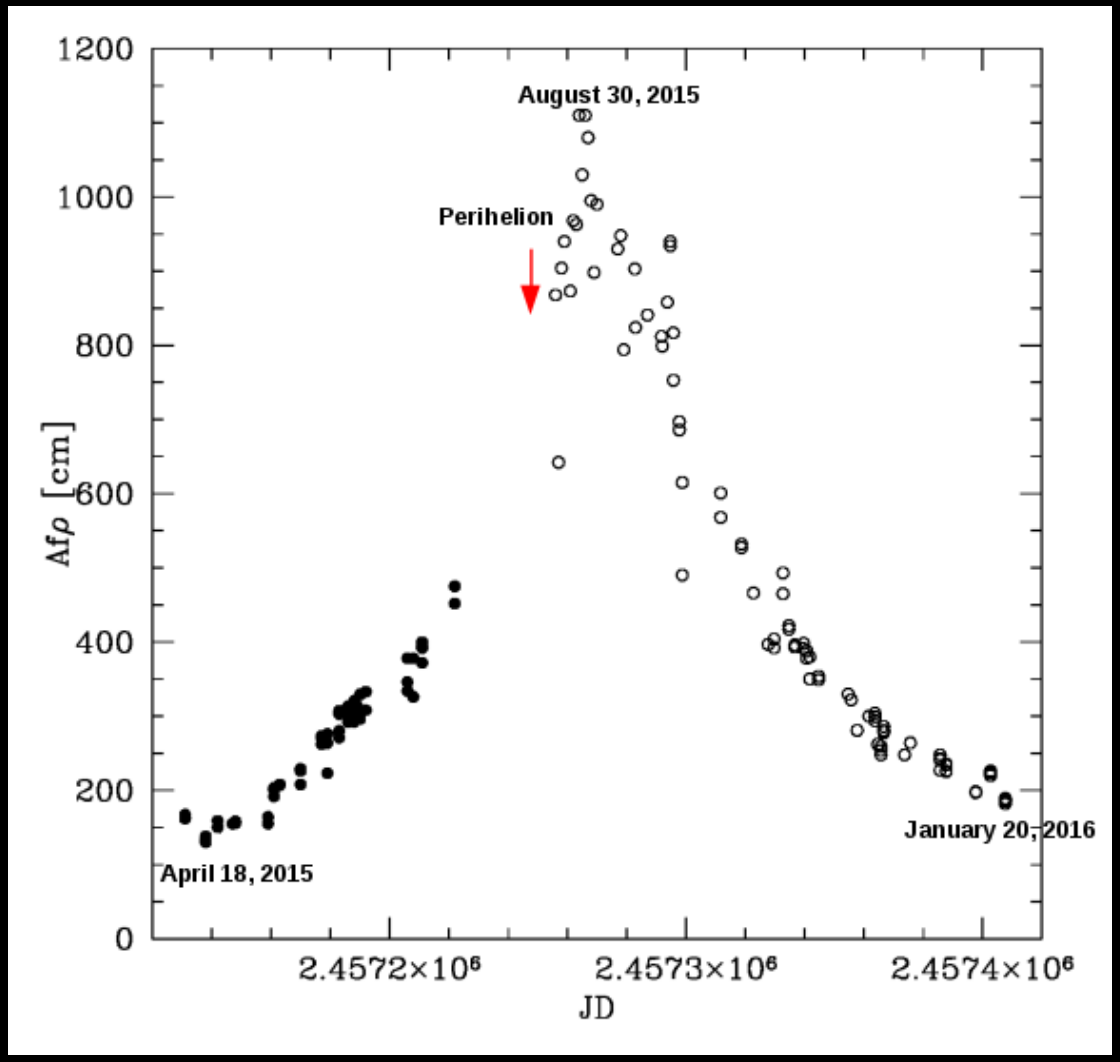






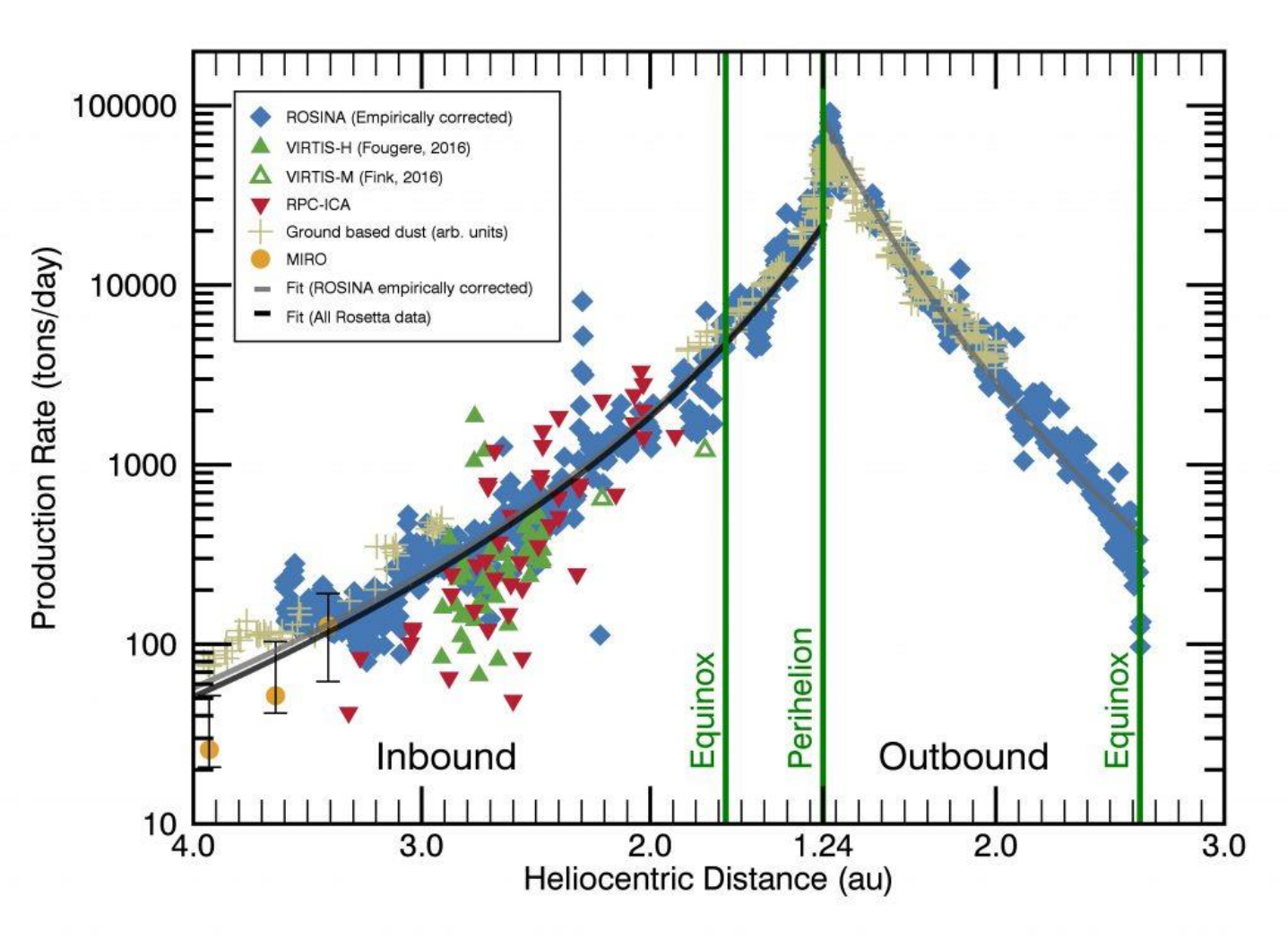


67P Churyumov-Gerasimenko activity monitoring



ROSETTA dust production rate (Jehin et al. 2016)

67P Churyumov-Gerasimenko activity monitoring

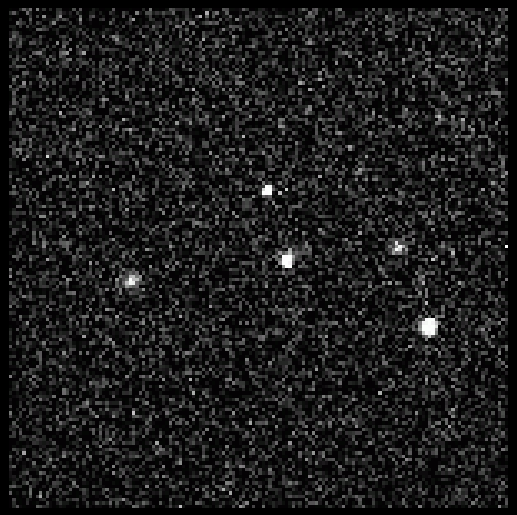


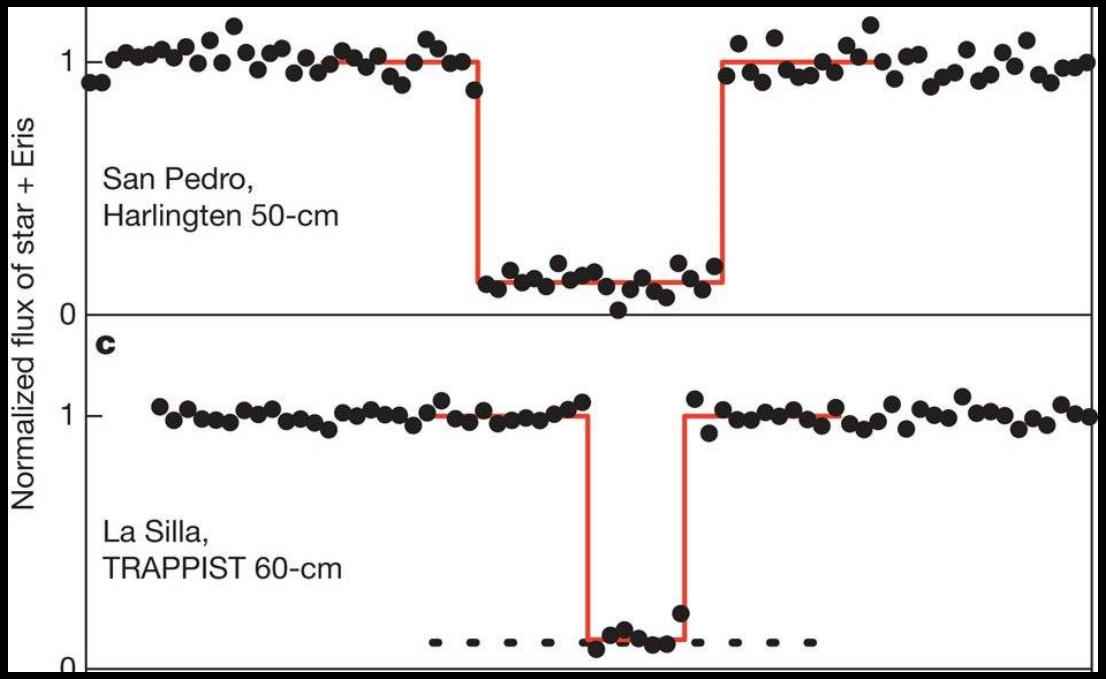
ROSETTA water production rate (Hansen et al. 2016)

3. Stellar Occultations by TNO: the case of Eris

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)





Sicardy et al. Nature 2011

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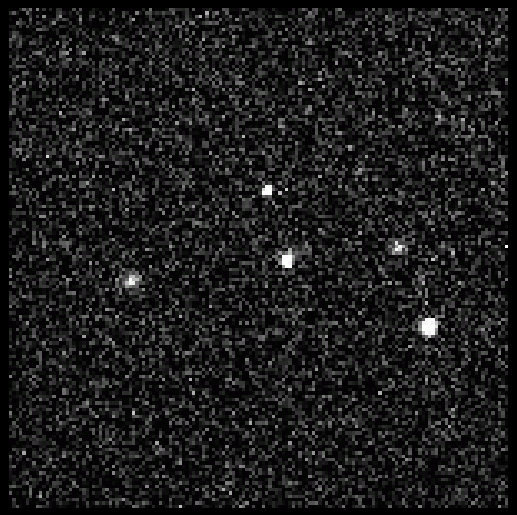
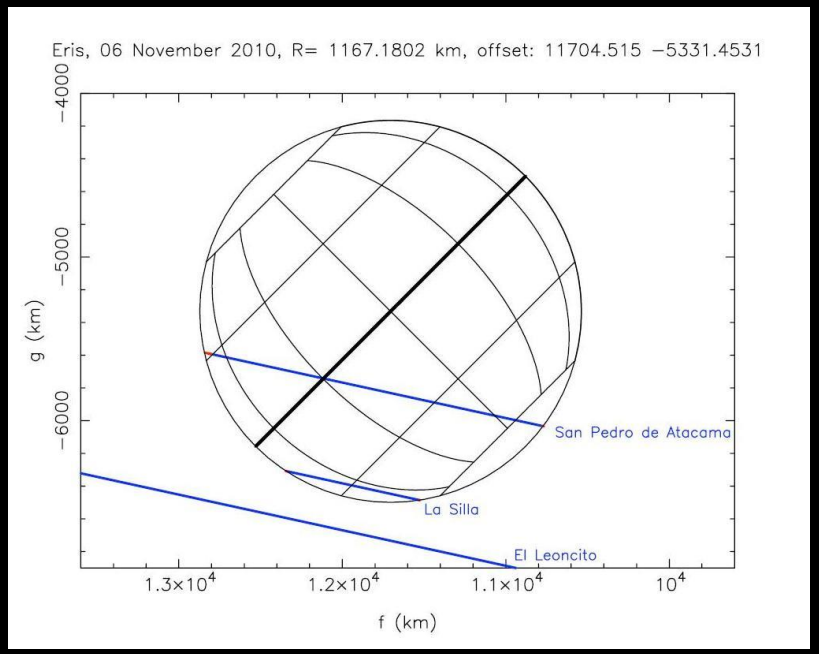


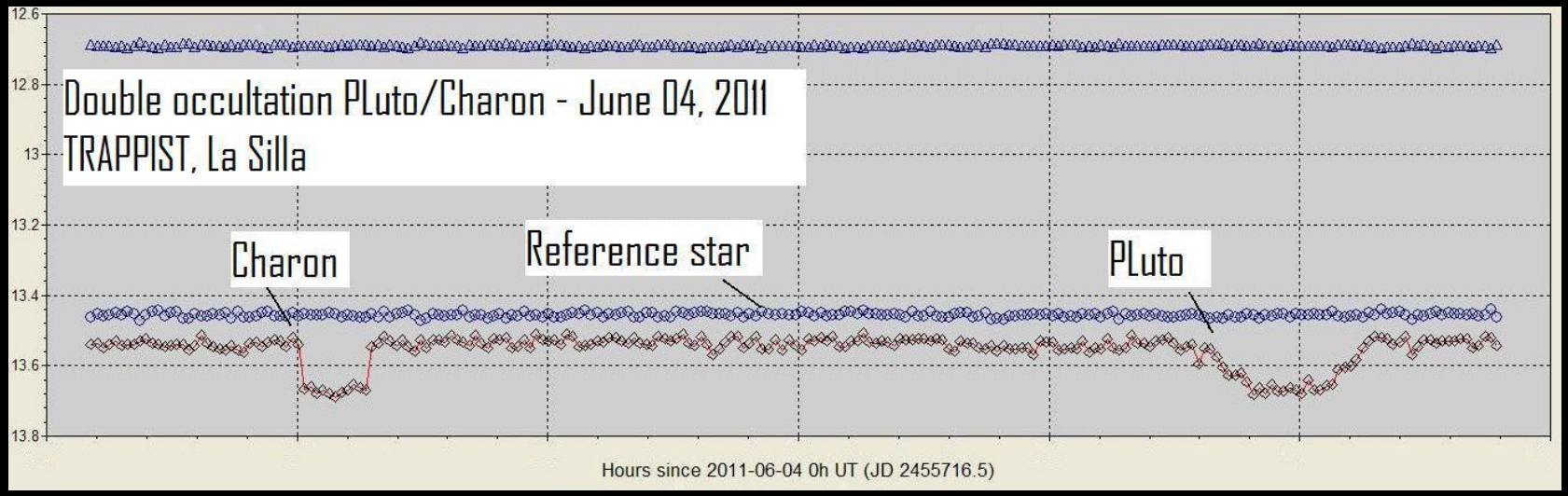


- Radius : 1163 km ± 6 km
  Pluto : 1184 ± 10 km
- No atmosphere

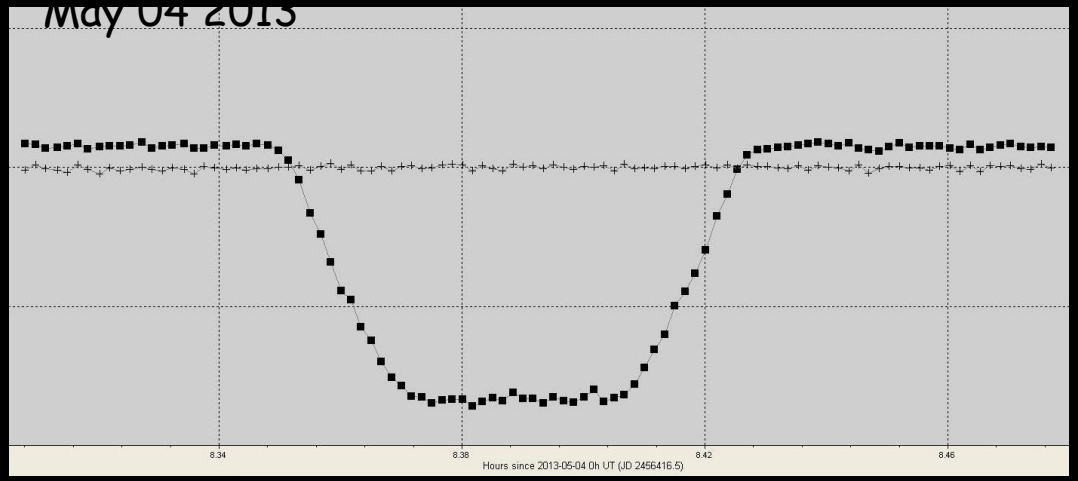
→ Density 2.5 g/cm^3 and albedo ~96% !

Sicardy et al. Nature 2011

Stellar occultations by Pluto and Charon



(Sicardy et al. 2013)

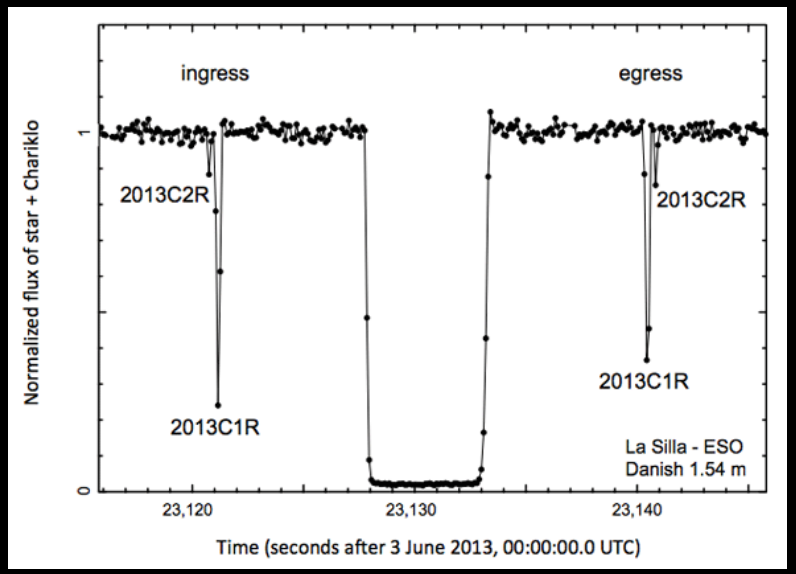


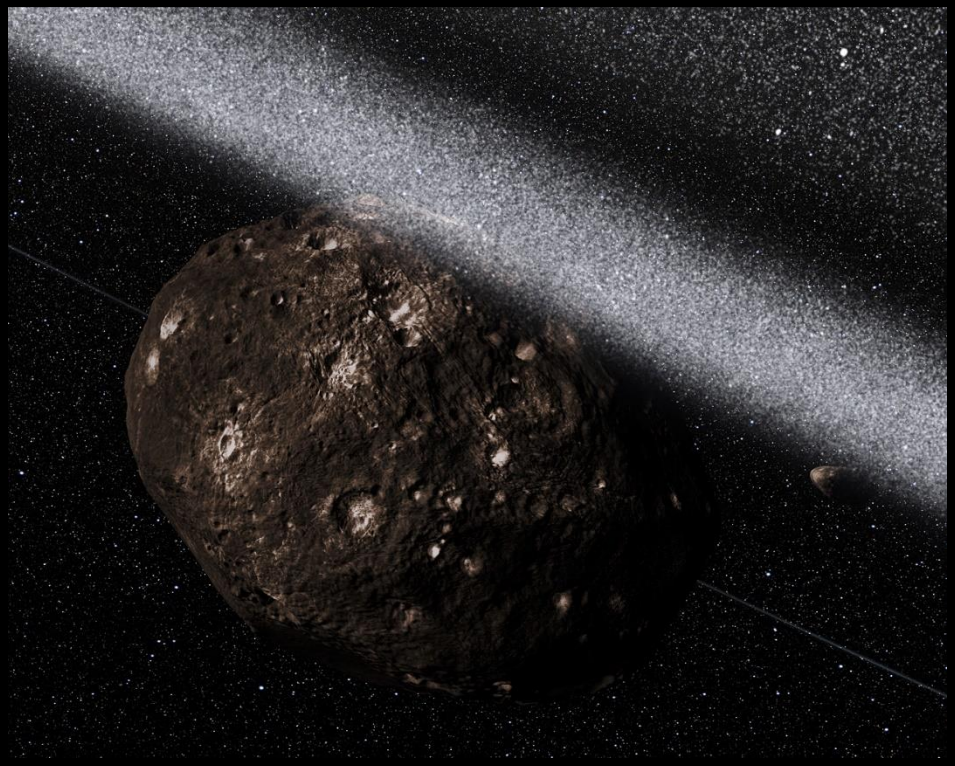
"The atmosphere of Pluto does not collapse"
(Olkin et al. 2014)

The rings of Chariklo

Chariklo, a centaur (icy asteroid) at r=2.5 10^9 km, might have cometary activity, on unstable orbit, coming from Kuiper Belt

- Stellar occultation from 7 sites on June 3, 2013



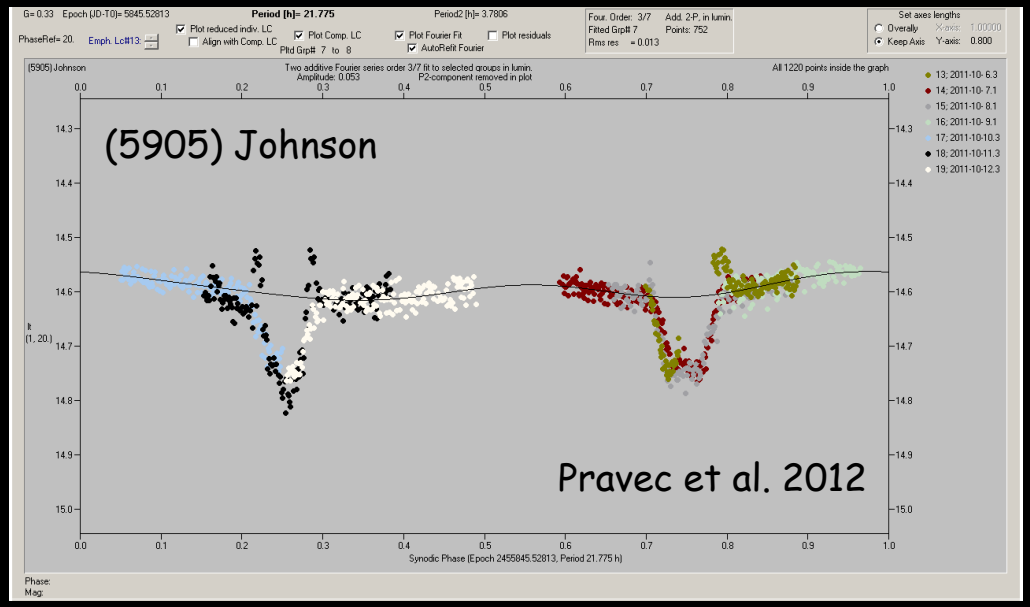


- Radius : 124 km ± 9 km
- Double ring : 3.5 km at 405 km
  6.5 km at 390 km
- Origin ? Collision, cometary activity,…

Barrigas et al. Nature 2014

4. Asteroids Light Curves (~0.01 mag)

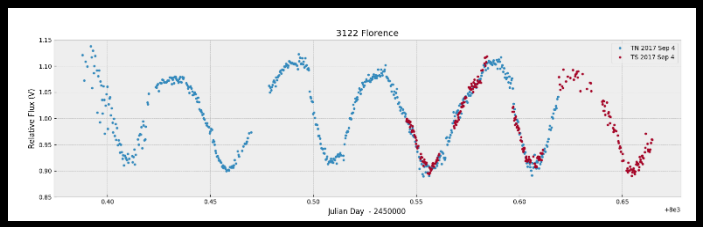
a) Eclipses of binary asteroïds



b) Light curves of NEA

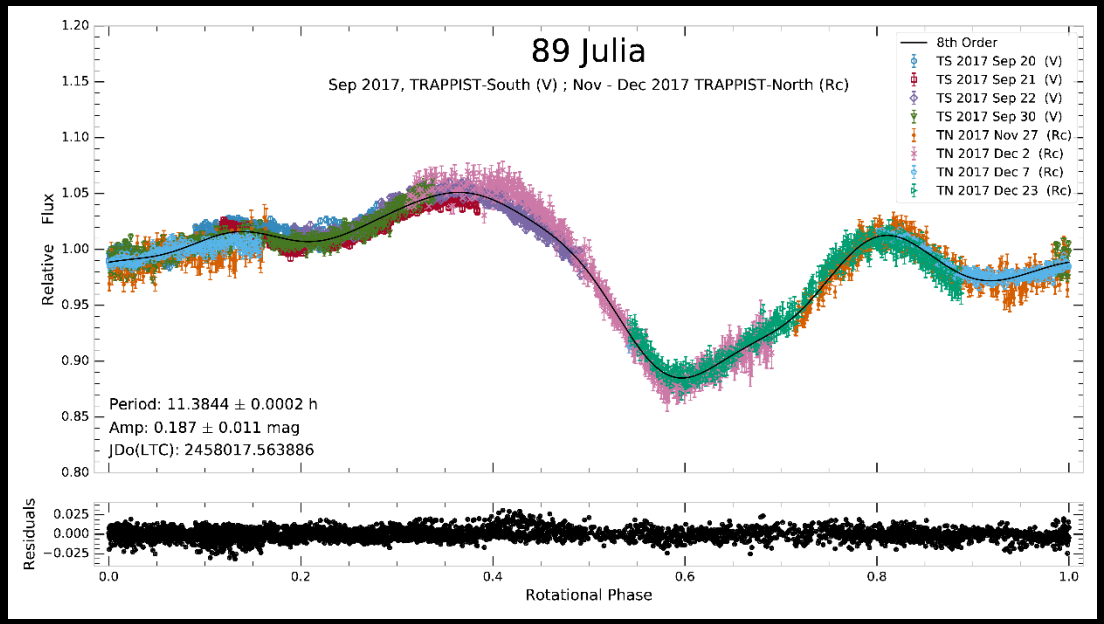
c) Light curves of large asteroïds

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



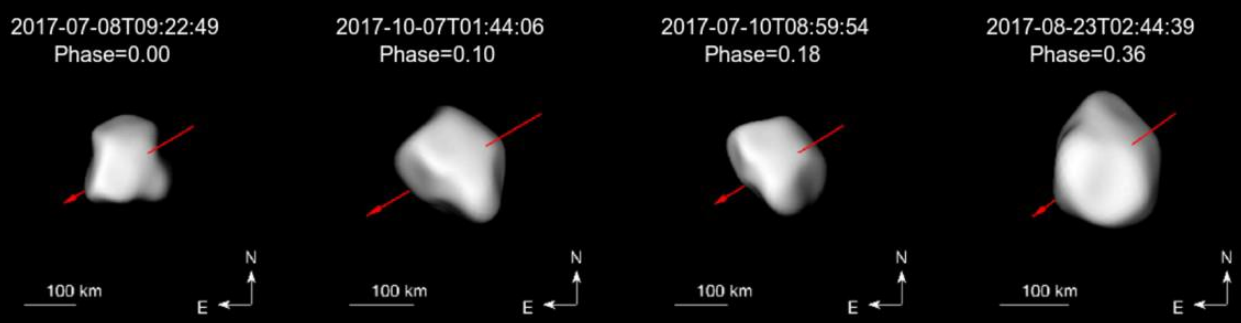
NEA 3122 (Florence) Sept 2017

Light curves of large Main Belt Asteroids

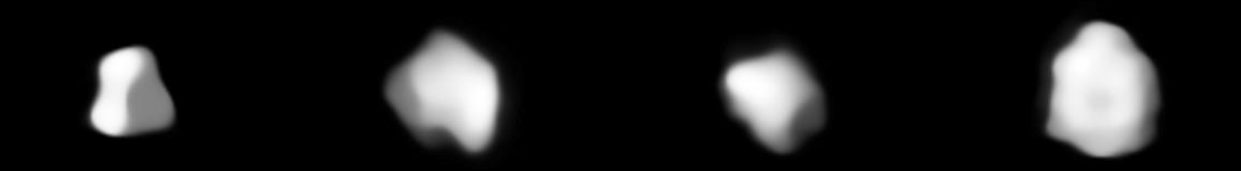


ESO Large Programme
P. Vernazza (2016-2020)
→ precise volumes from AO
→ densities for 50 MBA !

Phased light curve
TN and TS data (8 nights)
(Marin et al. 2018)



3D Shape Model



AO Observations VLT
(Vernazza et al. 2018)