



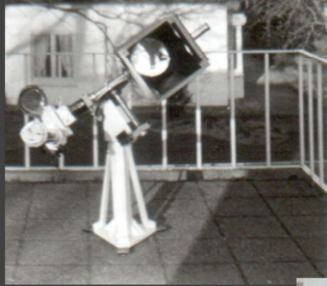
Kometes = langharige
van groot belang voor het begrip van onze ontstaansgeschiedenis

Johan van Dorp

1972-1980: Studie Natuurkunde
(kandidaats Sterrenkunde)

1981-2016: Werkzaam in industrie
als ingenieur

NKV sinds 1989



1968: 11 cm Kutter
& 18 cm Richfield

1992: CG11
(Californië)



2004: 20" Obsession (Oman)

21-okt-25

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Studie Natuur- en Sterrenkunde

Bijvangst tijdens het maken
van een Sterren Atlas voor
practicum sterrenkunde:
Komeet Bradfield 1974b

Construct programma
berekenen baanelementen
(met Rob van Gent)



Inhoud

- Geschiedenis
- Wat zijn kometen?
- Kometen zijn groen
- Komeetbanen
- Helderheidsverloop
- Desintegratie
- Komeetstaarten
- Verstrooiing
- Uitbarstingen
- Kreuz sungrazers
- Great comets
- Ruimte missies
- Fotomateriaal

Geschiedenis

- Aristoteles, 4^e v.Chr.
- L. Annaeus Seneca (A.D. -1-69)
- Petrus Appianus (1532)
- René Descartes (1596-1650)
- Georg Samuel Dörffel (1682)
- Edmund Halley (1705)



De Grote Komeet van 1680/81 gezien vanuit
Alkmaar op 22 december 1680
(Lambert Doomer, Rijksprentenkabinet
Amsterdam)
Dörffel berekende parabolische baan

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Aristoteles: hoogste regionen van het ondermaanse

Lucius Annaeus Seneca: planeten met onbekende banen

Petrus Appianus: staart wijst van zon af

René Descartes: oorsprong in interstellaire ruimte

Dörffel: baanberekening

Edmund Halley: *Astronomiæ Cometicæ Synopsis* catalogus komeetbanen

Morphology

- Een komeet is een ongerept overblijfsel uit de geboorte van ons zonnestelsel
- Kometen zijn een fragiel conglomeraat van verschillende soorten ijs, stof en steengruis (carbonaceous & silicate)
- Waarschijnlijk verdreven uit hun geboorteplaats door de zwaartekracht van de gasreuzen
- Ze zijn miljarden jaren in koude opslag gebleven
- Laag albedo (~4%), korst van donker materiaal aan oppervlak (?)
- Tonen meestal onvoorspelbaar gedrag (Whipple)
- De meteorieten die wij zien, ontstaan uit het puin dat achterblijft rond de komeetbaan (en wanneer de aarde deze baan doorkruist)

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Whipple: "Predicting the behaviour of a comet is like picking the winner of a horse race"

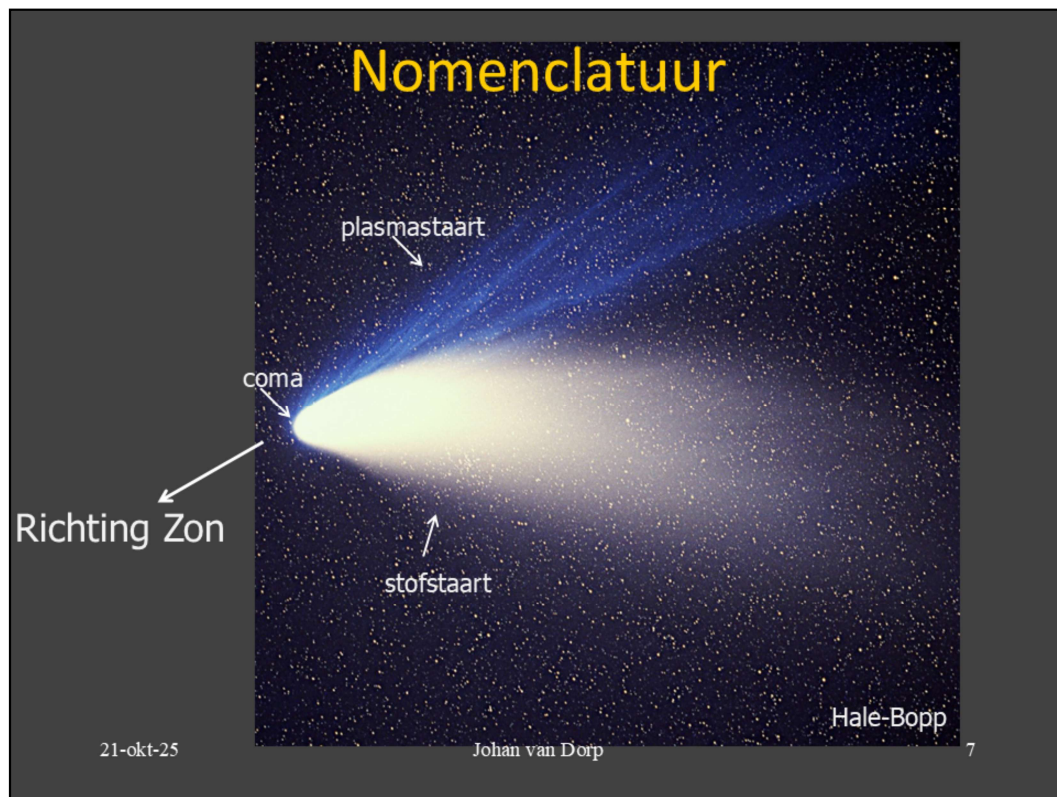
Carbonaceous and silicate refractory material = rock (baked by lithifaction, driven by ^{26}Al decay heating $<150\text{ C}$). ^{26}Al half-life 0.7 m.y., generated from Si + cosmic rays

Comets are pristine remnants of protoplanetary disk. Genetic link with **chondrites**

Chondrites: chondrules, CA-AL rich refractory inclusions, fine grained matrix.

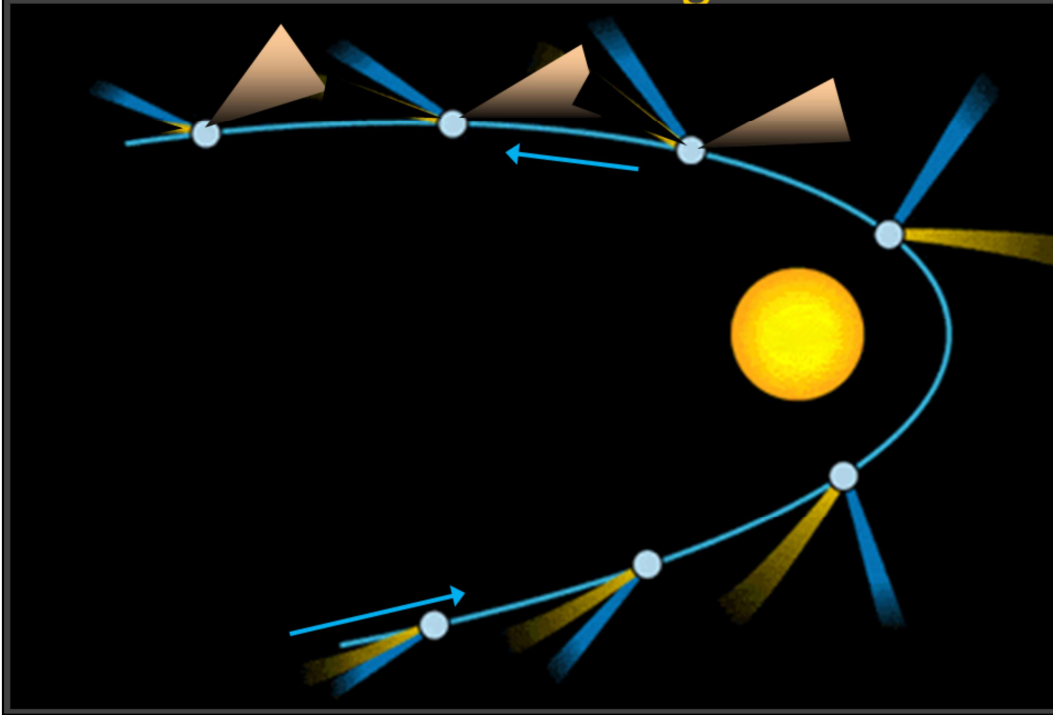
Chondrule were molten

Meteorites contain no ice and are born in the inner solar system (asteroid)

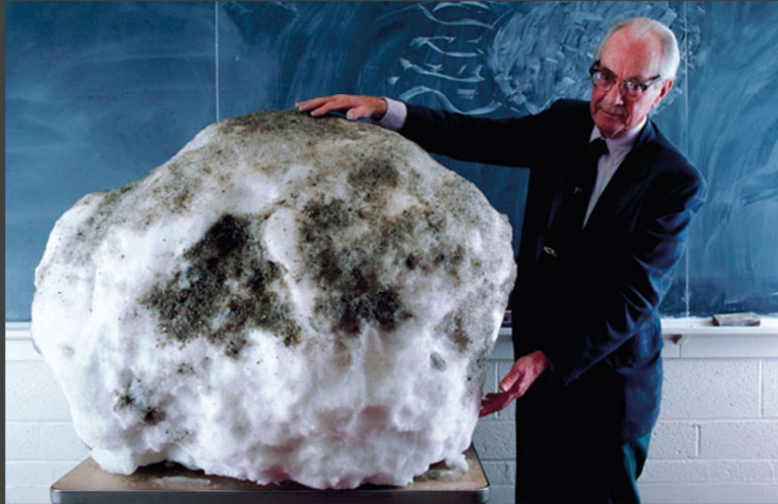


Soms ook nog een Natrium staart

Staart richting



Fred Whipple (1951) "Dirty Snowball"



gruis
 CO_2
 CH_4
 H_2O

67P H_2O bevat 3x zoveel HDO als op aarde

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H_2O : waterijs / CO_2 : droog ijs / CH_4 : methaan / NH_3 : ammoniak / CO : koolmonoxyde

$\text{D}/\text{H} = 1.5\text{-}2 \text{ E-}5$ interstellar in interstellar medium, but much higher in cold gas clouds+

Jup = $2.2\text{-}2.6 \text{ E-}5$

Earth = $15.6 \text{ E-}5$

Comets = $16.6\text{-}20 \text{ E-}5$

67P = 3x earth

Primordial $2.7 \text{ E-}5$

Classification

Periodiek

- Main-belt comets = active asteroids 133P/Elst-Pizarro
- Jupiter Family Comets (JFCs)
 $\frac{1}{2} < P_{\text{J}} < 3$ (of $P < 20$ yrs, $i < 30^\circ$) 6P/d'Arrest, 67P/Churyumov-Gerasimenko
- Vaak baan-resonantie met Jupiter
- Kort-periodiek 20-200 jaar 1P/Halley, D/Shoemaker-Levy 9
- Lang-periodiek > 200 jaar TNO's, Kuiper belt (30 – 50/100 AE)
 Baan $\sim$ in vlak van zonestelsel

Zonnescheerders

Kreuz group, C/1965 S1 Ikeya-Seki

Niet-periodiek

- $P > 1000$ jaar Oort cloud (2000 – 200,000 AE)
- (sub)Parabool, $e \sim 1$ C/1995 O1 Hale-Bopp

Interstellair (Hyperbool)

1I/Oumuamua, 2I Borisov, 3I/ATLAS

$$P_{\text{J}} = 11.86 \text{ yr}$$

$$a_{\Psi} = 30 \text{ AE}$$

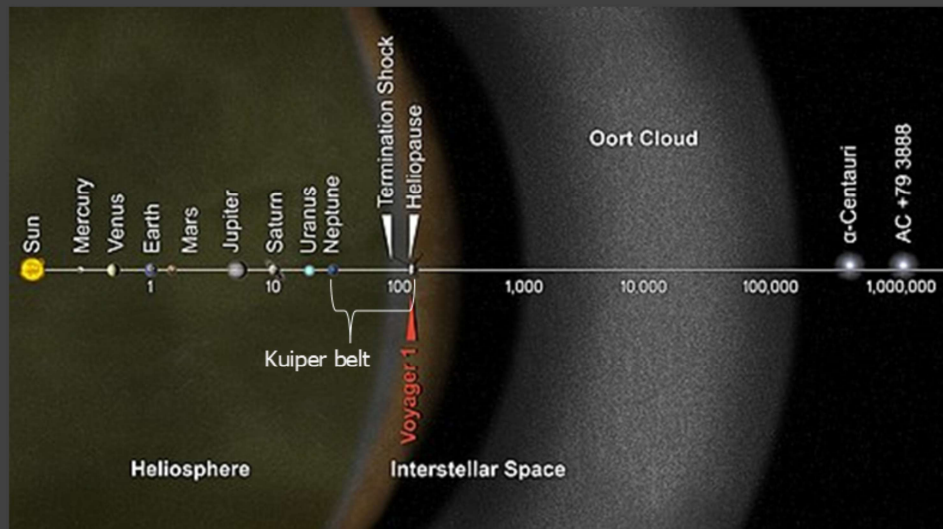
Hale-Bopp komt pas weer in 4385 voorbij

Zonnescheerders: ontstaan uit

Notable main belt comets (since 2006):

324P/La Sagra, P/2012 T1 (Pan-STARRS), 133P/Elst-Pizarro, and P/2010 A2 (LINEAR).

Oort Cloud & Kuiper belt



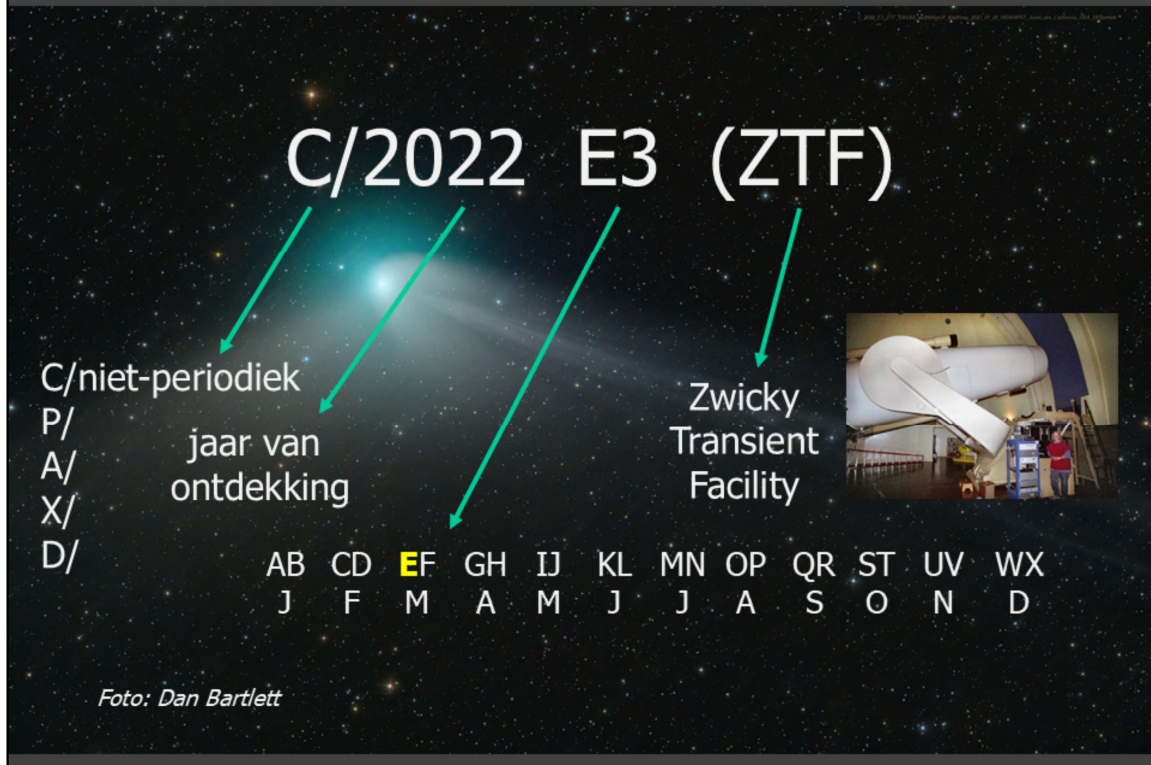
Logaritmische afstand schaal
1 lichtjaar $\approx$ 63,000 Astronomische Eenheden

Hale-Bopp komt pas weer in 4385 voorbij ($a=177$ AU)

Zonnescheerders: ontstaan uit

Edgeworth-Kuiper belt

Designation (1995)



2 maart 2022. ZTF: mount Palomar, 1.2m Schmidt, 606MP, 7x7graden, Ontdekker van o.a. Sedna, Eris, Orcus en Quaorar (Kuiperbelt-objecten)

P/ periodic comet orbital period of less than 200 years or confirmed observations at more than one perihelion passage.

C/ non-periodic comet

X/ indicates a comet for which no reliable orbit could be calculated (generally, historical comets).

D/ indicates a periodic comet that has disappeared, broken up, or been lost

A/ mistakenly identified as a comet, but actually a minor planet

I/ interstellar

De groene komeet

UV: ionisatie $\text{CO} \rightarrow \text{CO}^+$ $\Rightarrow$ (blauwe) ionenstaart

Kern warmt op, verschillende soorten ijs smelten:
diffuse atmosfeer van
(geïoniseerd) gas & stofdeeltjes $\Rightarrow$ coma

Zonnewind + coma: $\Rightarrow$ (wit/gele) stofstaart
gereflecteerd zonlicht

In coma ook gas(ionen): H, O, C, N, CN en C_2
UV $\rightsquigarrow$ + CN en C_2 : $\Rightarrow$ groene coma

CN	390 nm
Swan band (C_2)	430-620 nm

Foto: Juanjo Gonzalez

De electronen van CN + C_2 komen in een hogere energietoestand terecht en vallen weer terug: groene emissie

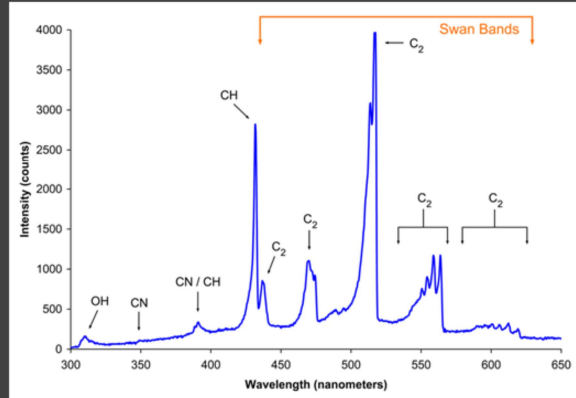
CN = Cyanide

Verdampingscyclus

CO en H₂O geschat in ongeveer gelijke hoeveelheden

Afstand | Verdampend molecuul

~7 AE	CO, CO ₂ , methaan
< 3 AE	H ₂ O, CN (388.9 nm) coma groeit met ~ 1 km/s
2-3 AE	NH ₂ , C ₃
< 2 AE	C ₂ (Swan band) OH
< 1 AE	Na
Kreuz	Metalen (silicaten)



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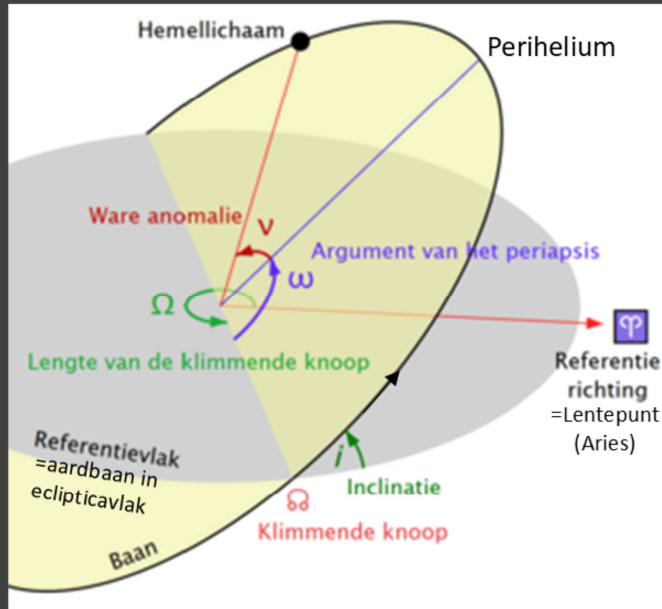
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Orbital elements

3 hoeken bepalen de baanorientatie in de ruimte ten opzichte van zon en aardbaan als referentievlak

Astrometrie geeft posities komeet aan hemelbol



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Middelbare anomalie $M = 2\pi t (t-t_0)/P = E - e \sin E$

Excentriche anomalie $E =$ ware anomalie (ν) geprojecteerd op omsluitende cirkel

$\tan(\nu / 2) = \sqrt{(1+e)/(1-e)} \tan(E/2)$

6 Orbital Elements

1x tijd referentie

T = datum periheliumdoorgang

2x vorm en grootte baan

q = periheliumafstand (au)

e = excentriciteit (parabolische banen $e = 1.0$)

$$q = a(1-e)$$

$$P^2 = a^3 \text{ (3e Keppler)}$$

3x hoeken

i = baanhelling t.o.v. de ecliptica

Ω = lengte klimmende knoop

ω = lengte perihelium

(meestal geteld vanaf de klimmende knoop)

Kan hiermee positie berekenen voor elk willekeurig tijdstip

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$P^2=a^3$ derde wet Keppler

Perturbations

Osculating elements bepaald m.b.v. astrometrische posities tegen de tijd. Zijn slechts geldig rond de *epoche* wanneer de elementen zijn berekend

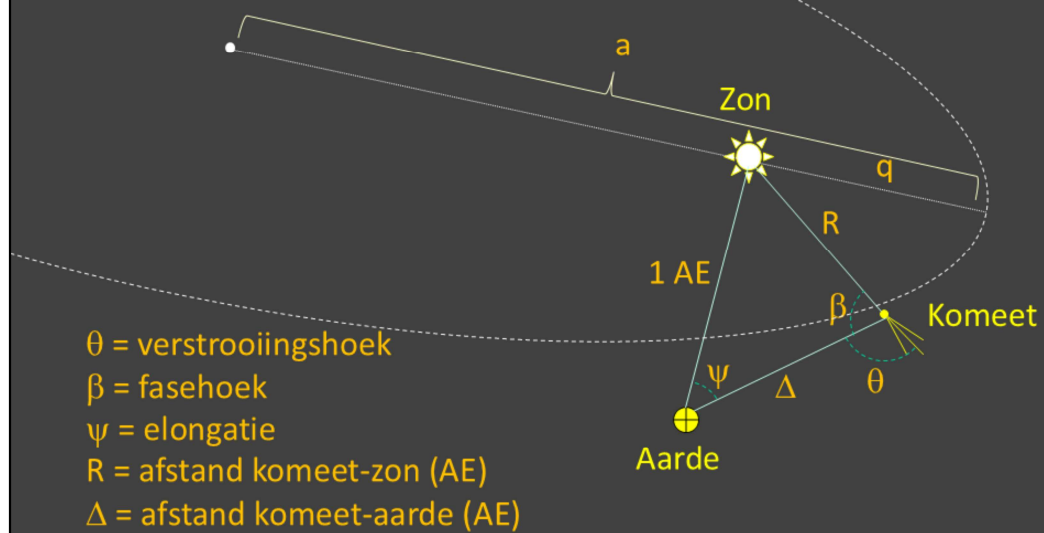
Perturbaties door “close encounters” met een (zware) planeet kunnen significante afwijkingen geven in het verloop van de komeetbaan

Komeet kan ook in *resonantie* komen met planeet. 55P/Tempel-Tuttle is in 5:14 resonantie met Jupiter (11.86 : 33 jaar)

Niet-gravitationele effecten (thrust van jets). Factoren:

- A_1 beschrijft kracht radiaal van de zon af
- A_2 beschrijft tangentele kracht langs de baan

Geometrie



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Helderheid

Magnitude-schaal is logaritmisch $m = -2.5 \log (F/F_0)$

Van belang is de **totale helderheid, inclusief coma**

(kern is aan het zicht onttrokken)

Formule van Holetscheck voor nieuwe kometen (long period comet)

$$m_1 = H_{10} + 10 \log R + 5 \log \Delta$$

Formule met "Activity index" n

$$m_1 = H_0 + 2.5n \log R + 5 \log \Delta$$

Heliocentrische magnitude

$$m_h = m_1 - 5 \log \Delta = H_0 + 2.5n \log R$$

Grafiek m_h tegen $\log R$ geeft H_0 en n

Asteroiden geven $n = 2$ (inverse square law) $m \sim 2.5(\log R^2 + \log \Delta^2)$

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Helderheid kern kan worden gerelateerd aan effectieve doorsnede komeet na aanname van albedo ($\sim 5\%$).

Helderheid

Dynamisch nieuw $e \geq 1$ $a \geq 20,000$ AE: $n = 2.4 \pm 0.3$
(vroeg actief, stagnerende helderheidsontwikkeling)

Terugkerend uit Oort wolk $e \leq 1$, $a \leq 20,000$ AE: $n \approx 3.2$

“Oude” periodieke kometen (gebruik H_{15}): $n = 6$

Vaak is helderheids-maximum verschoven tot na perihelium
(soms ook voor)

Correctie termen van Öpik voor optisch instrument

Helderheid Schattingen

Visueel (totale helderheid):

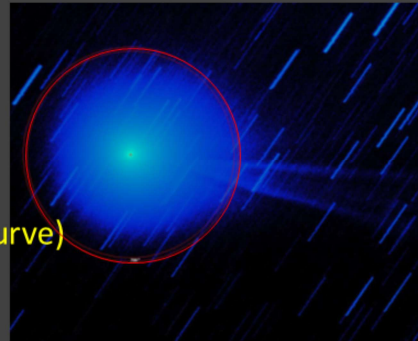
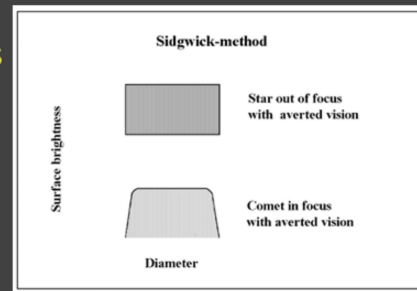
- Morris (uit-focus komeet en uit-focus vergelijkings-sterren)
- Bobrovnikoff “uit-uit” (coma en sterren ong. zelfde doorsnee)
- Sedgwick “in-uit” (Coma in-focus, sterren uit-focus, averted vision)

Fotometrisch:

Kalibreer CCD/CMOS opname
Bepaal achtergrond
Groene band (UBVR-I filters –
Visual Equivalent Magnitude)
Integreer inclusief coma
(Photometric aperture – growth curve)
corrigeer voor sterlicht

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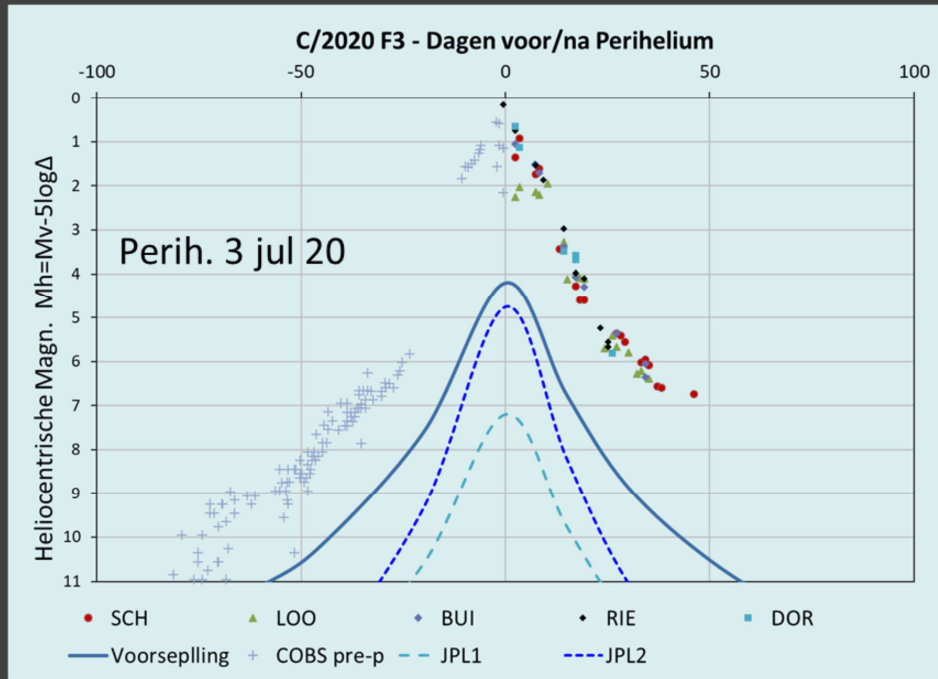
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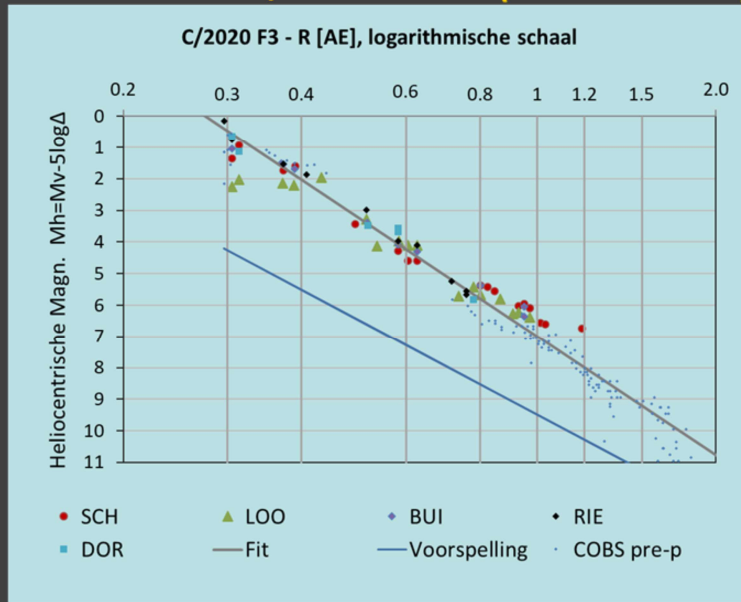
De **Bobrovnikoff**-methode is de zogenaamde “Uit-Uit” methode, waarbij het oculair zover uit het focus wordt gedraaid totdat de coma van de komeet en de vergelijkingssterren vrijwel dezelfde diameter lijken te hebben. (Door Bobrovnikoff beschreven in publicatie No. 15 van 1941 maar niet door hem gebruikt). Een komeet met een $DC=3$ wordt bij het gebruik van de Bobrovnikoff-methode ca. 0,7 magnitude zwakker waargenomen t.o.v. de Sidgwick-methode.

Bij de **Morris**-methode wordt de in het geheugen opgeslagen helderheid van een 'iets' uit focus staande komeet vergeleken met onscherp gestelde sterbeeldjes die net zover uit focus zijn gedraaid als de comadiameter van de 'iets' uit focus staande komeet.

C/2020 F3 (NEOWISE)



C/2020 F3 (NEOWISE)



Voorspelling (ini)

$H_0 = 11.9$

$n = 5.4$

Voorspelling (SY)

$H_0 = 7$

$n = 4.8$

Fit

$H_0 = 7$

$n = 5$

C/2020 F3 (NEOWISE)

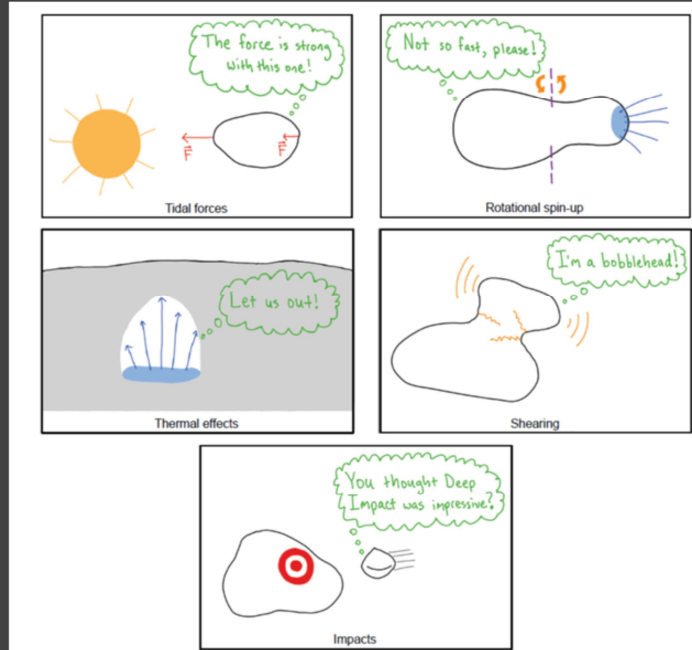


DOR 20 jul 20 25x2 sec 70mm f/4.8



DOR 21 jul 21 29x30 sec 50mm f/2

Fragmentatie



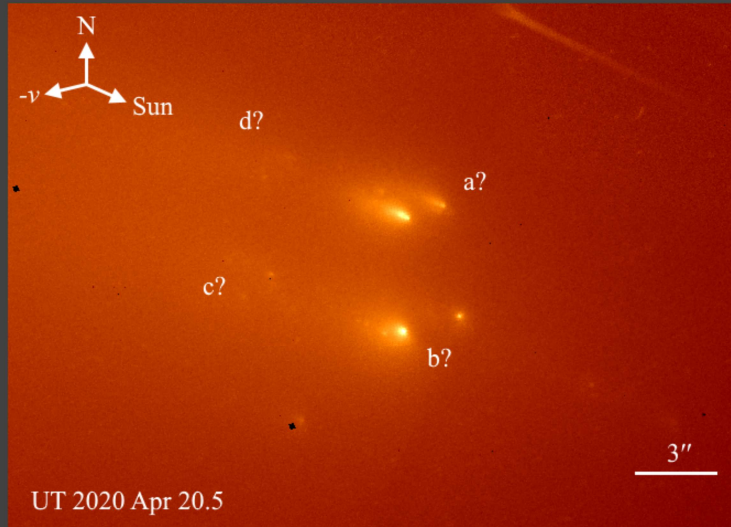
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Causes of fragmentation (see text for additional details).

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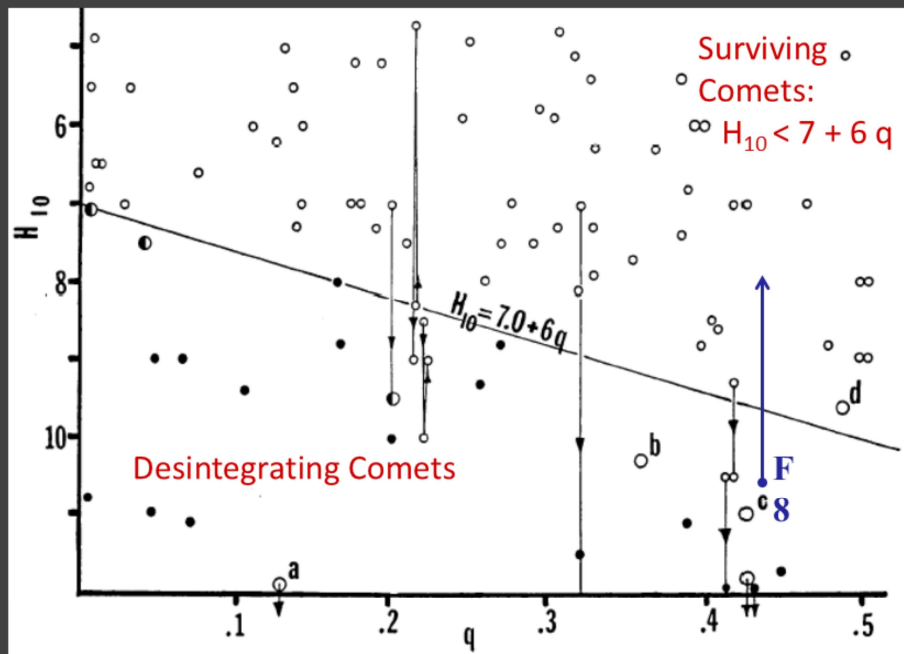
Bortle limit

Onder invloed van getijdenkrachten, kan de kern van een komeet (fragiel conglomeraat) gedeeltelijk of geheel desintegreren (verwijderingssnelheid brokken 1 - 10 m/s)



C/2019 Y4 (Atlas)

Bortle limiet

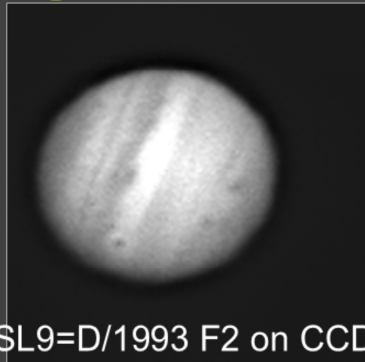


Bortle limiet

- SL9 vormde een trein van brokstukken, die uiteindelijk insloegen op Jupiter.
- 73P/SW3 nucleus split in sep 1995 en gaf een geweldige uitbarsting



CCD of P-SW3
25 oct '95



SL9=D/1993 F2 on CCD
16-22 jul 1994

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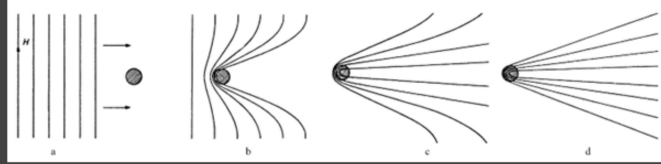
Jupiter (2x) on CCD (<1 sec), SL9 impact on Jupiter(CCD)

CCD image of comet P-Schwassmann Wachmann - III at "flare-up"

Gas- of plasma staart (Type 1)

De zonnewind is vaak turbulent met windvlagen

De staart van gas-ionen fungeert als een soort windzak en informeren ons over de zonnewind.



De CO^+ en C^+ ionen ontstaan onder invloed van hoog energetisch UV licht en geven de plasma staart. De staart straalt vnl. blauw licht en de ionen worden meegevoerd met de zonnewind, dat zelf een plasma is met vrije elektronen. De magnetische veldlijnen van de zon staan $\perp$ op de stroom van de zonnewind (250 – 700 km/s) en wikkelen zich om de komeet. De ionen in de staart spiraliseren om de veldlijnen (Lorentz). Soms vind ontkoppeling van de staart plaats (N-S).

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Gas staart C/2021 A1 (Leonard)

Perihelium op 3 jan 2022



8 dec 2021
Michael Jaeger

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Gas staart C/2021 A1 (Leonard)



21 dec 2021

M. Mattiazzo

180 sec C11Reza F/2.2 Canon 6D

Beeldveld 3 graden

C/2021 A1 Leonard, 2021 December 21 at 11:15UT, C11 RASA f/2.2 + Canon 6D, 3 mins, FOV 3 deg, North up, M. Mattiazzo, Swan Hill, Victoria

Gas staart C/2021 A1 (Leonard)



21 dec 2021

M. Jaeger - Hakos Namibia

Duidelijk is de structuur in de gasstaart

Gas staart C/2021 A1 (Leonard)



21 dec 2021

R. Ligustri

Beeldveld 3 graden

Gas staart C/2021 A1 (Leonard)



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Gas staart C/2021 A1 (Leonard)



25 dec 2021
G. Rehman

21-okt-25

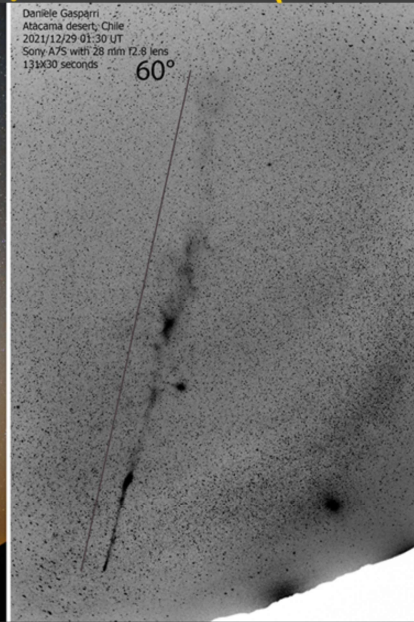
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Gas staart C/2021 A1 (Leonard)



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29 dec 2021
Gasparri
Atacama woestijn

Gas staart C/2021 A1 (Leonard)



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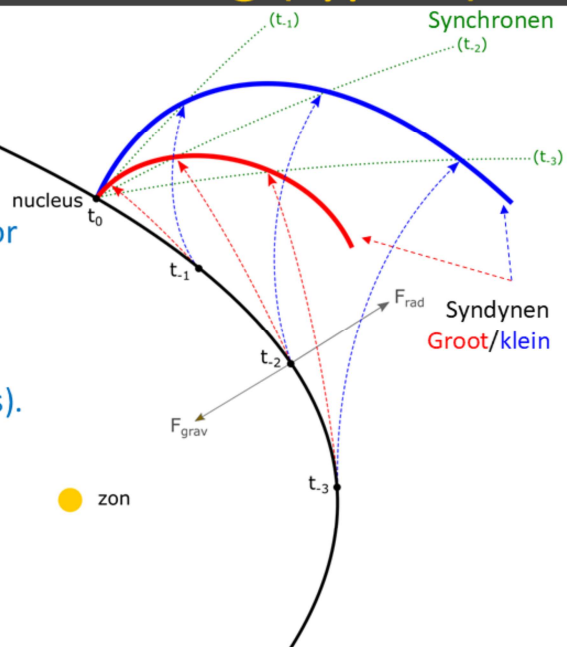
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1 jan 22
Gerald Rehman
12 inch telescoop
Tivoli, Namibië³⁷

Stofstaart ontwikkeling (type-2)

Stofstaart is wit/geel door reflecterend zonlicht.
Deeltjes worden gesorteerd in Syndynes naar grootte (μm - mm 's).
 $\beta = F_{\text{rad}}/F_{\text{grav}}$

- $\rightarrow$ traject klein deeltje ($\beta > 1$)
- $\rightarrow$ traject groot deeltje ($\beta < 1$)
- syndyne kleine deeltjes ($\beta > 1$)
- syndyne grote deeltjes ($\beta < 1$)
- synchrone



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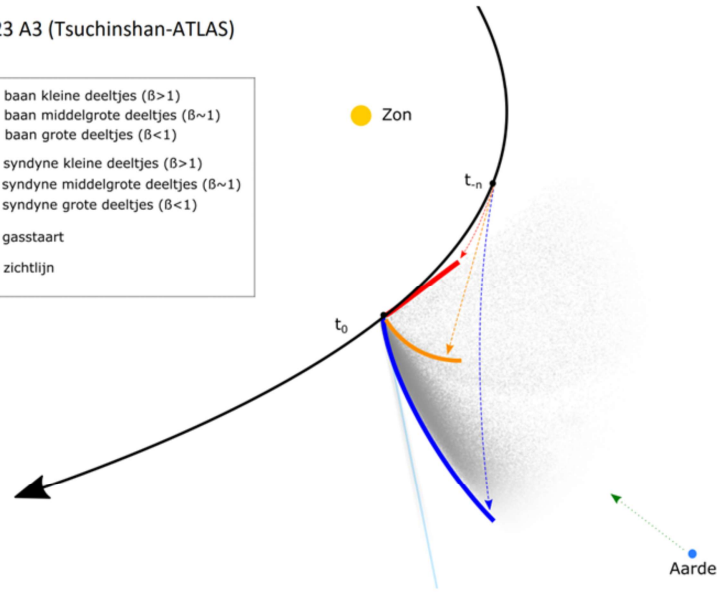


Perihelium 0,171 AE 12 jan 2007, S.Derries/ESO Paranal observatory, late january 2007 (~20)

Antitail

C/2023 A3 (Tsuchinshan-ATLAS)

-> baan kleine deeltjes ($\beta > 1$)
-> baan middelgrote deeltjes ($\beta \sim 1$)
-> baan grote deeltjes ($\beta < 1$)
- syndyne kleine deeltjes ($\beta > 1$)
- syndyne middelgrote deeltjes ($\beta \sim 1$)
- syndyne grote deeltjes ($\beta < 1$)
- gasstaart
-> zichtlijn



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Antitail C/2023 A3 (Ts.-Atlas)

C/2023 A3 (Tsuchinshan Atlas)
Adam Block 14 okt 24

10 x 2 sec Nikon D90 135 mm f/2

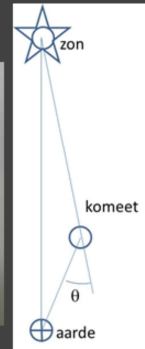
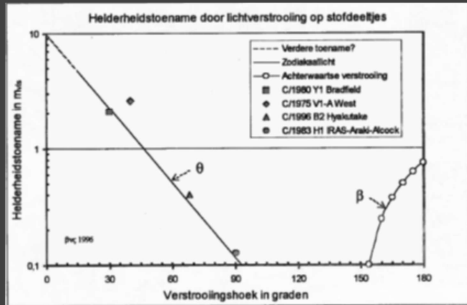
an van Dorp

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Voorwaartse verstrooiing

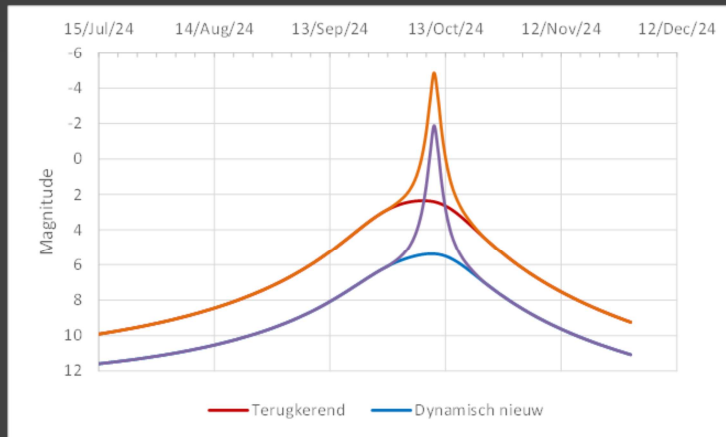
Als een komeet tussen aarde en zon door beweegt, is de verstrooiings-hoek klein.

Voorwaartse verstrooiing aan kleine deeltjes versterkt het licht vele malen als $\text{particle size} \approx \text{wave length}$.



Greenberg interstellar dust comet model of mm size particles embedded in ices.

Voorspelling C/2023 A3 (Tsuchinshan-Atlas)



Voorwaartse
verstrooiing



Perihelium 28 sep 24 @ 0,391 AE

Voorspelling Dynamisch Nieuw ($a > 20.000$ AE) $H_0 = 8,7$ $n = 2,4$

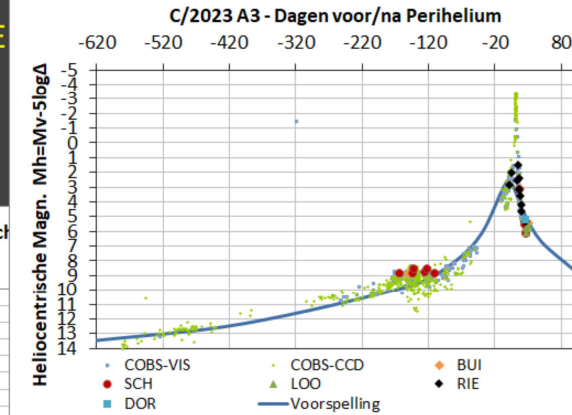
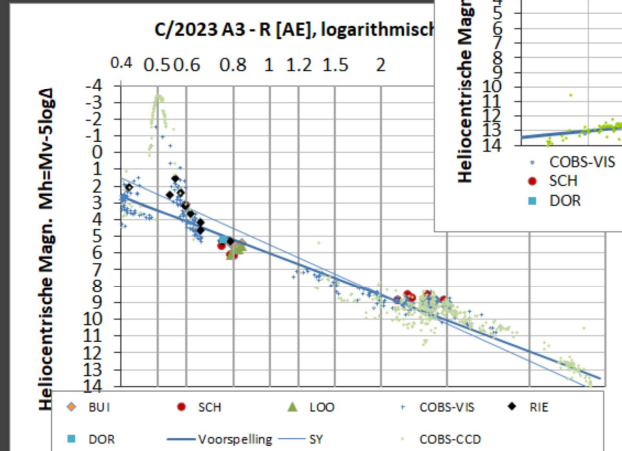
Voorspelling Terugkerend uit Oort wolk $H_0 = 6,5$ $n = 3,4$

$$m_h = m_1 - 5 \log \Delta = H_0 + 2.5n \log R$$

Twee helderheidsvoorspellingen, inclusief het effect van voorwaartse verstrooiing. Een voor dynamisch nieuw uit de Oort wolk (meest waarschijnlijk) en een voor een terugkerende komeet.

C/2023 A3 (Tsuchinshan-Atlas)

Perihelium 27 sep 24 @ 0,4 AE
 Laatste Voorspelling
 $H_0 = 6$ $n = 3,4$
 (Seiichi Yoshida 5.5 & 4)



Grootste helderheid
 $M_v = -4,9$

Forward Scattering

$$\Phi(\theta) = \frac{\delta_{90}}{1 + \delta_{90}} \left[k \left(\frac{1 + g_f^2}{1 + g_f^2 - 2g_f \cos \theta} \right)^{3/2} + (1 - k) \left(\frac{1 + g_b^2}{1 + g_b^2 - 2g_b \cos \theta} \right)^{3/2} + \frac{1}{\delta_{90}} \right]$$

Model uses Henyey-Greenstein function

$\theta = 180^\circ - \text{phase angle}$

$\delta_{90} = 1 = \text{dust to gas light ratio in coma (10 for dusty comet)}$

$k = 0.95 = \text{partitioning coefficient}$

$g_f = 0.9 = \text{forward scattering asymmetry factor}$

$g_b = -0.6 = \text{backward scattering asymmetry factor}$

Calibration:

$$m_{\Phi(\theta)} = -2.5 \log \Phi(\theta)$$

ICQ142 p39-46 Forward-Scattering Enhancement of Comet Brightness. I. Background and Model

ICQ144 p119-129 Forward-Scattering Enhancement of Comet Brightness. II. The light curve of C/2006 P1 (McNaught)

Joseph N. Marcus

21-okt-25

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Uitbarstingen

Veroorzakers van onvoorspelbaar gedrag van komeen

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12P/Pons-Brooks (Halley type)

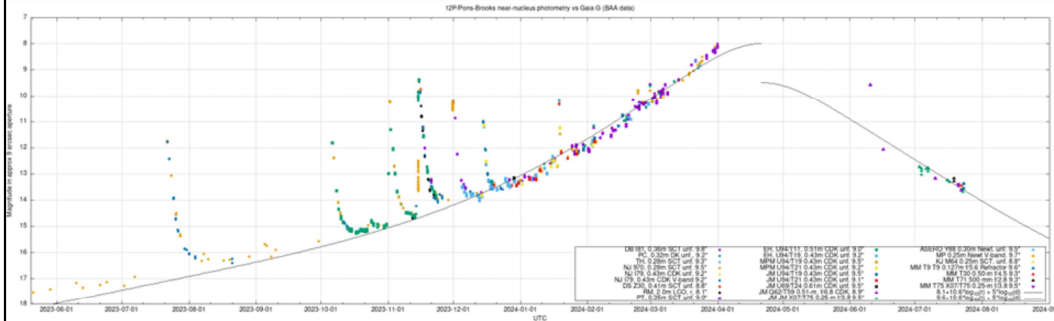
Periheliumdoorgang: 21 apr '24

Periheliumafstand q: 0.78 AE

Maximale helderheid: $M_v = 4.4$

Dichtste nadering tot de Aarde: 3 jun 2024: 1.546 AE

Vaak uitbarstingen



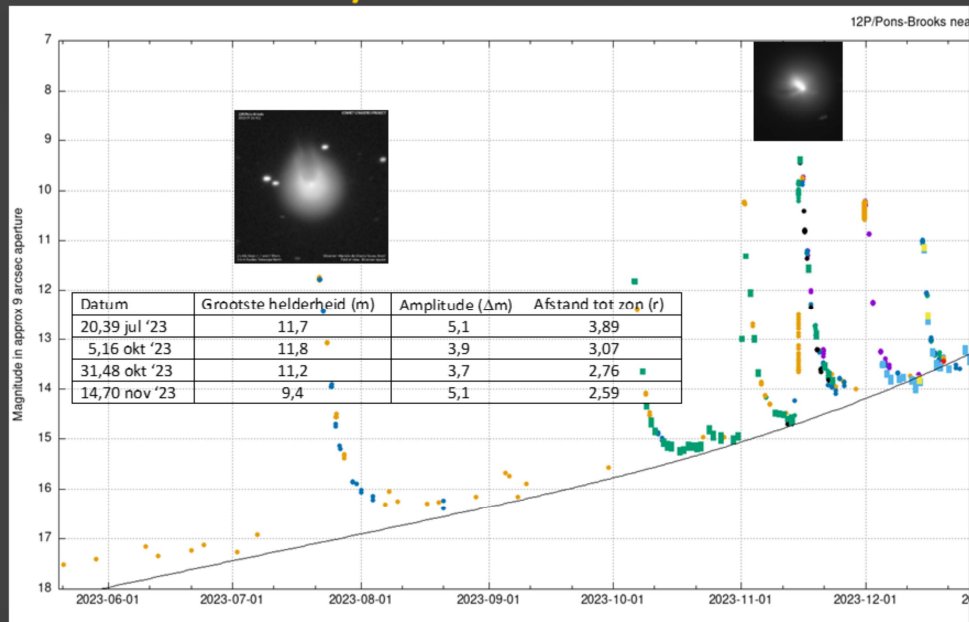
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P = 70 y

12P/Pons-Brooks



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12P/Pons-Brooks



M. Mattiazzo 30 april 2024, 10x30s

12P Pons-Brooks, 2024 April 30 at 09:00UT, C11 RASA V2.2 + Canon 6D, iso1600 10x30sec, FOV 3 deg, North up, M. Mattiazzo, Swan Hill, Victoria, Aus

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Kreuz Sungrazers

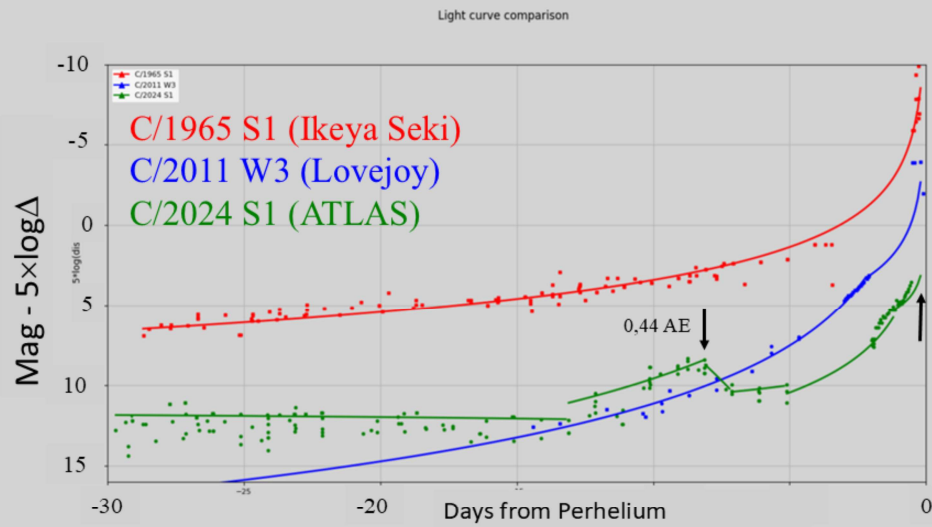
Perihelium = 0.0055-0.0077 AE
(one solar diameter = 0.0046 AE)

$a = 75\text{-}100$ AE

$P = 500\text{-}1000$ yrs

C/2011 W3 (Lovejoy) 16 dec 2011 perihelium, desintegreerd 20 dec

C/2014 A1 (Atlas)



Vergelijking helderheidscurve met bekende Kreuz kometen
C/1965 S1 (Ikeya-Seki) en C/2011 W3 (Lovejoy)

Kreuz Sungrazers

Elements Equinox J2000.0	Sekanina 2004			q	e	P (yr)	ω	Ω	i	lp	Bp	Q	e
Comet	T (UT)												
C/-314-315 progenitor	-314												
6-10 m/s, at 50 AE, 30 y before Perih	326	Mar	28										
C/356, Superfragment II	356	Mar	28.91	0.008387	0.9998986	752.2	68.416	345.914	141.659			165.42	
C/356, Superfragment I	356	Apr	4.47	0.005710	0.9999306	746.1	76.367	355.650	143.417			164.55	
C/1100 not observed	1100	Mar	27.99	0.005219	0.9999386	784.4	80.183	0.420	143.972				
8 m/s, 127 d after Perih	1100	Aug	2										
6.6 m/s, at 10.9 AU, 3 y after Perih	1102	Dec											
X/1106 C1 Great Comet 1106	1106	Jan	26.50	0.007979	0.9999065	787.8	68.200	345.805	141.703	xxx	xxx	170.67	
7 m/s, 0.75 AE, 18 days after Perih	1106	Feb	13.5										
C/1668 E1	1668	Feb	28.08	0.066604	1	784	109.810	2.520	144.38	248.61	+33.23	170	0.999217
C/1689 X1	1689	Dec	2	0.060000									
C/1695 U1	1695	Oct	23.1										
7 m/s, at 160 AE	1700												
C/1702 D1	1702	Feb	15.1										
at 150 AU	1749												
C/1843 D1 (I) Great March Comet	1843	Feb	27.91434	0.0054897	0.9999363	800	82.8063	3.7283	144.3893	282.58	+35.29	172.36	
10 m/s at 112 AU	1847	Feb											
C/1880 C1 (I) Great Southern Comet	1880	Jan	28.09679	0.0055355	0.99993442	775.5	85.1084	6.4987	144.5229	282.38	+35.25		-1
X/1882 K1 Tewfik Eclipse Comet	1882	May	17.5										
C/1882 R1 (II) Great September Comet	1882	Sep	17.72410	0.0077508	0.99991034	803.7	69.5851	347.6559	142.0109	282.94	+35.23	172.89	
C/1887 B1 (I) Great Southern Comet	1887	Jan	11.934	0.004833	0.9999473	878.7	83.597	4.410	144.396	280.24	+41.79		-1
C/1945 X1 (VIII) duToit	1945	Dec	27.98358	0.0074191	0.99992309	947.4	69.684	347.7075	142.1129	289.73	+31.96		-1
Fragment Ile, not observed	1963	Jul/Aug											
C/1963 R1 (V) Pereyra	1963	Aug	23.95638	0.0050461	0.9999439	852.8	86.07839	8.0816	144.5819	282.65	+35.33	179.89	
C/1965 S1 (VIII) ikeya-Seki	1965	Oct	20.47270	0.0082968	0.99990405	804.1	70.47194	348.6998	142.3421	282.95	+35.22	172.93	
C/1970 K1 White-Ortiz-Bolelli	1970	May	14.48735	0.0088966	0.9999084	956	61.3335	337.0267	139.0824	282.95	+35.07	194.24	
Fragment IIf	1979	Jul											
C/2011 W3 Lovejoy	2011	Dec	16.012	0.005554	0.999929	622	53.5092	326.3691	134.3558	282.98	+35.09	157.36	
Superfragment I	Superfragment II												
C/2024 S1 (ATLAS), voorlopig A11bP71	2024	Oct	28.45981	0.008313	1.000625		68.81055	347.1123	141.8853				

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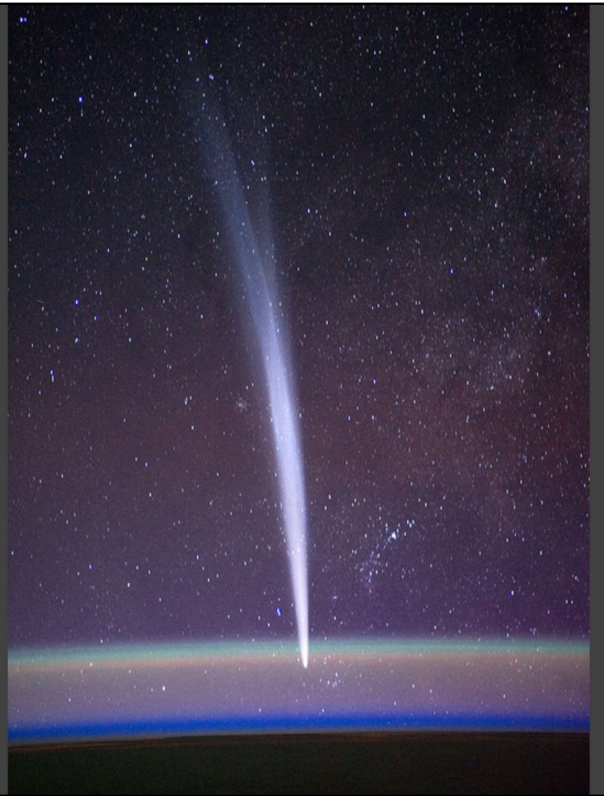
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C/2011 W3 (Lovejoy)

Enkele dagen na
perihelium (15 dec 11)
gedesintegreerd

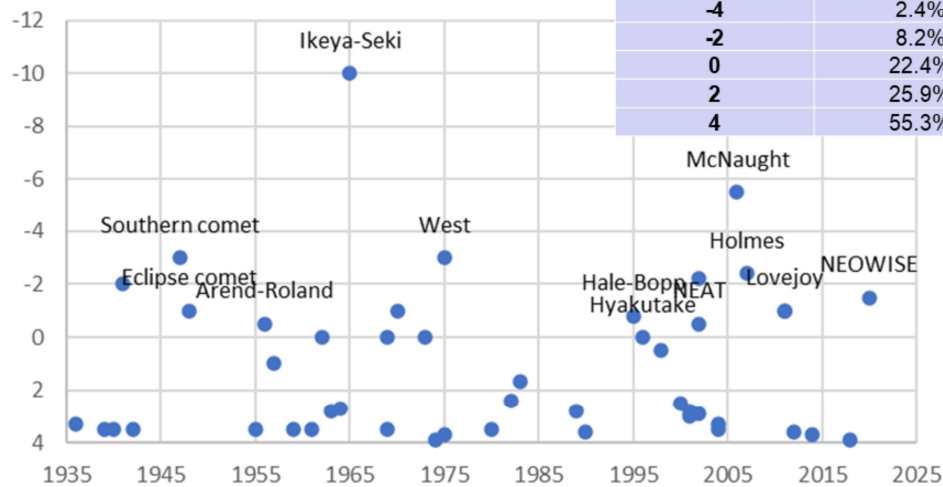
C/2011 W3 (Lovejoy)
Kreuz sungrazer
0,005 AE
21 dec 11
(Dan Burbank / ISS)



C/2011 W3 (Lovejoy) – Kreutz. We hopen allemaal op een nieuwe Kreutz komeet met zeer korte periheliumafstand en daardoor grote stof en gas productie. P=15dec2011, desintegrated 20dec2011

Great comets

Occurance Comets Brighter than $m=4$

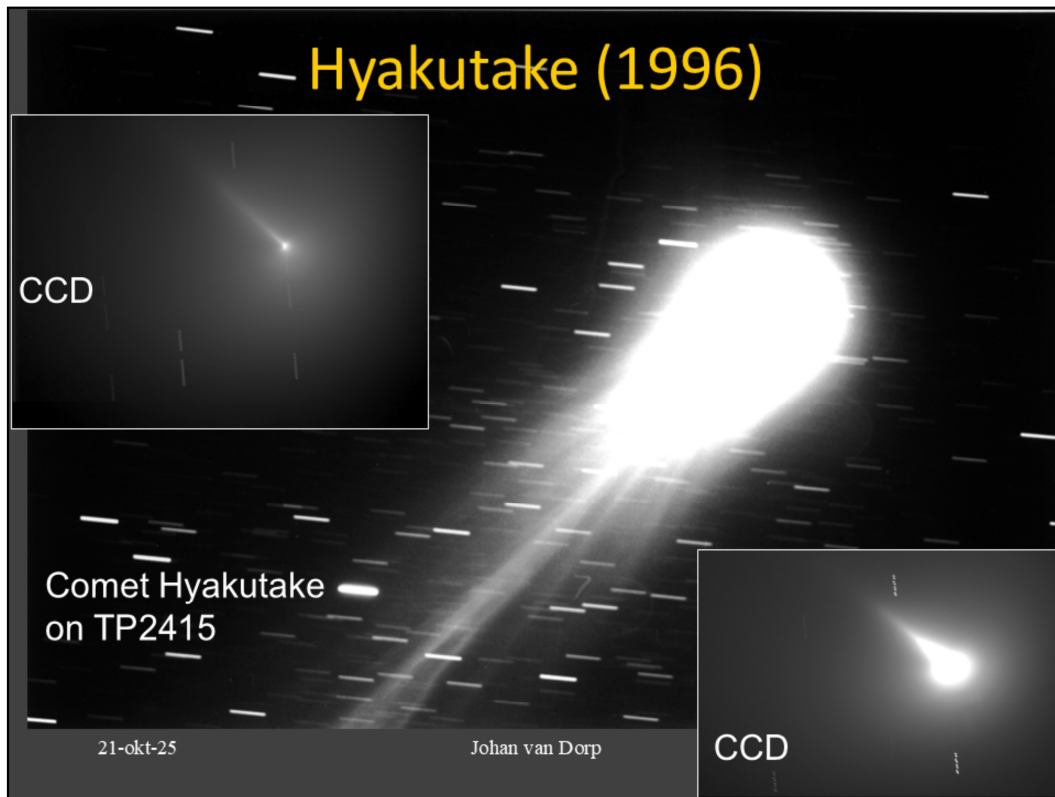


Komeet helderder dan magnitude	Kans per jaar op een dergelijke verschijning
-6	1.2%
-4	2.4%
-2	8.2%
0	22.4%
2	25.9%
4	55.3%

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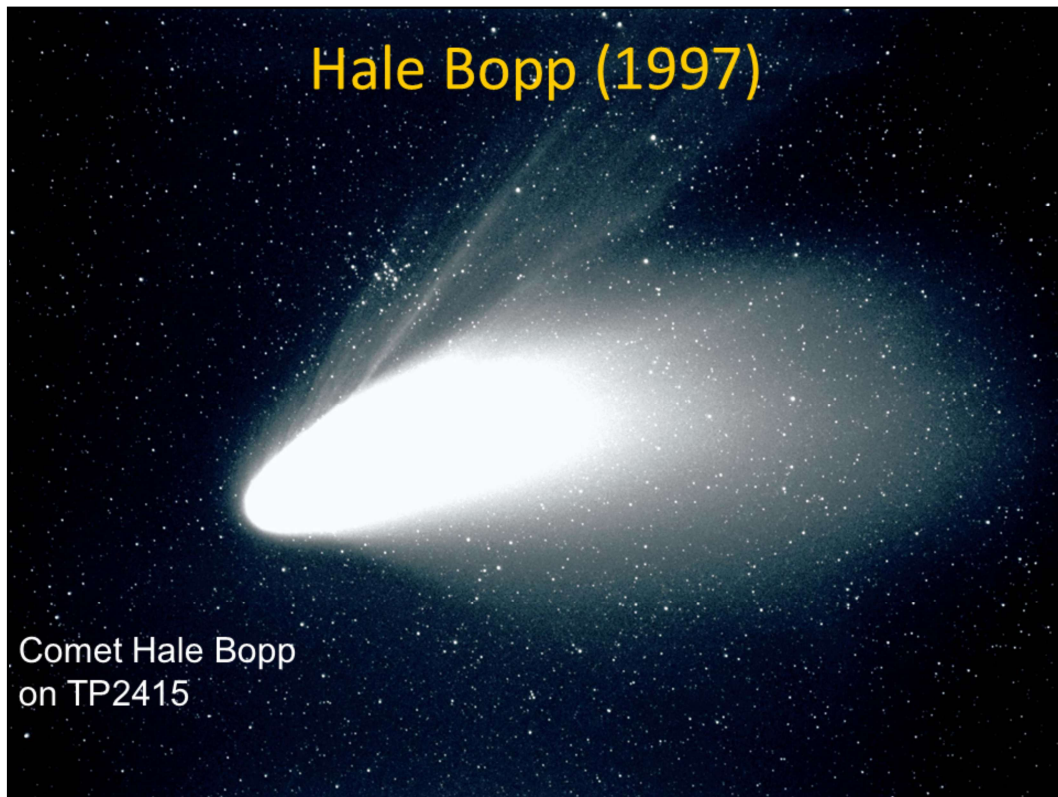
54



Hyakutake on film (20 min on TP2415, 300 mm f/2.8, 23/3/96) and CCD (2x stack of several prime focus images at CG11)



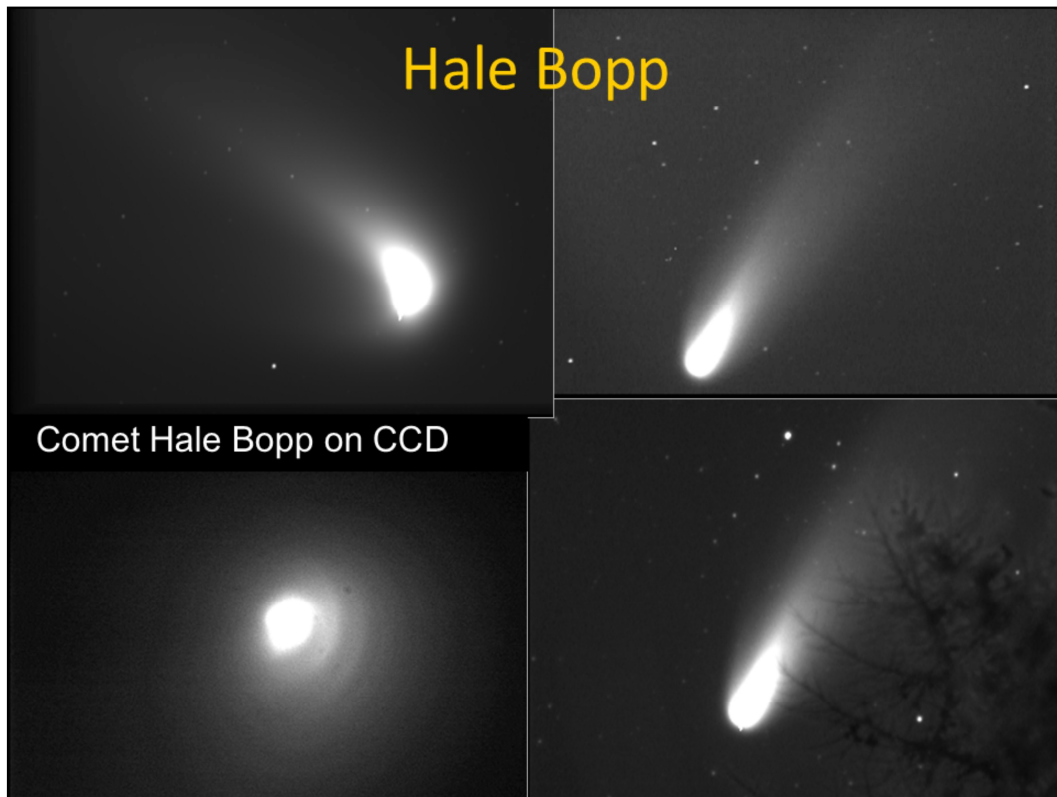
Comet Hyakutake in color (300 mm f/2.8, 20 min, HG8000 23/3/96)



Comet Hale-Bopp on TP2415. 300 mm, f/2.8 12 min, 6/4/97, 50-60 km doorsnede



Come Hale Bopp, Kodak Pro400 color film, 135 mm, f/2.8, 8 min on Beyers
Camtrack, 30/3/97



Comet Hale Bopp on CCD.

CG11 Prime focus image (lower left) shows “rotating shock waves”



Sodium tail

Connectie Meteoren

meteoren zwerm

=

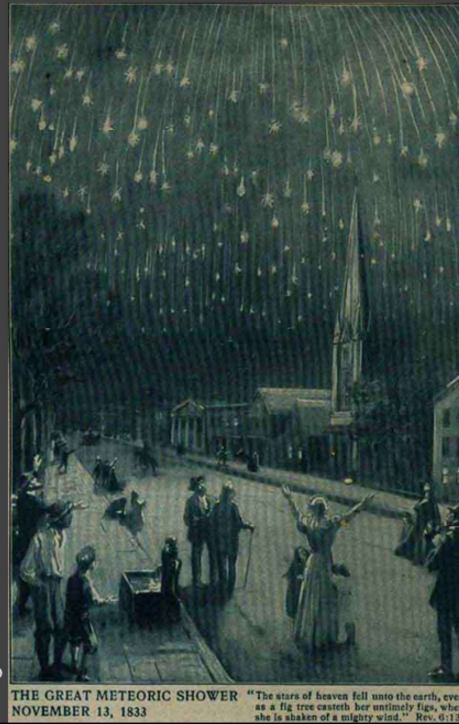
“trails” in baan komeet
Meteoren als aarde de
baan doorkruist

1835, Denison Olmsted:
Kosmische oorsprong meteoren

1862 Giovanni Schiaparelli
Demonstreerde connectie met
kometen

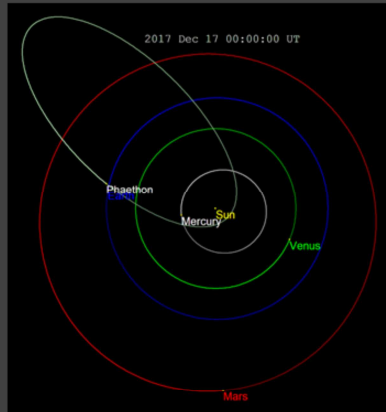
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Leoniden 1833

3200 Phaeton



1982 TP – ontdekt door IRAS
Periode: 523.5 dagen / 1.43 jr
Perihelium: 0.14 AE
Aphelium: 2.4 AE
Doorsnede: 6.25 km



Rotskomeet

Potentially Hazardous Asteroid (PHA)

PHA: <0.05 AE

3200 Phaethon: 0.019 AE

Bron Geminiden meteorenzwerm

Extinct comet

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Perihelium Mercurius: 0,30-0,46 AE.

Apollo: halve lange as groter dan Aarde (kan Aarde kruisen), Pallas: vanwege hoge inclinatie

$0.05 \text{ AE} = 7.500.000 \text{ km}$

$0.019 \text{ AE} = 2.850.000 \text{ km}$

Val frequentie meteorieten

Erwt	10 per uur
Walnoot	1 per uur
Appel	1 per 10 uur
Voetbal	1 per maand
50 meter	1 per eeuw
1 km	1 per 100.000 jaar
2 km	1 per 500.000 jaar
10 km	1 per 100.000.000 jaar

Totaal 80.000 ton materiaal per jaar

Meteoor zwermen

Meteoor zwerm	Periode	Progenitor komeet	ZHR
Lyriden	22/23 april	C/1861 G1 (Thatcher)	18
δ Aquariden	30/31 juli	96P/Machholz	16
α Capricorniden	30/31 juli	169P/NEAT	5
Perseïden	12/13 aug.	109P/Swift-Tuttle	100
Orioniden	20/21 okt.	1P/Halley	20
Leoniden	17/18 nov.	55P/Tempel-Tuttle	15
Geminiden	13/14 dec.	3200 Phaethon	150

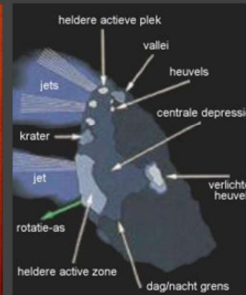
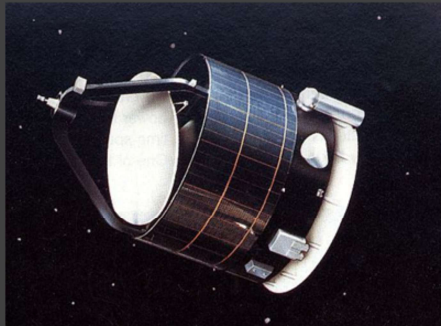
Ruimte missies

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Giotto (1986) 1P/Halley



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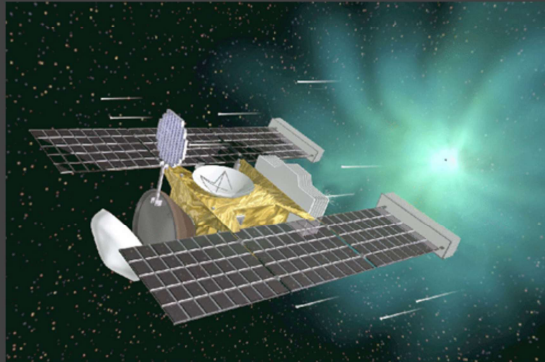
Images showed Halley's nucleus to be a dark peanut-shaped body, 15 km long, 7 km to 10 km wide. Only 10 % of the surface was active, with at least three outgassing jets seen on the sunlit side. Analysis showed the comet formed 4.5×10^9 years ago from volatiles (mainly ice) that had condensed onto interstellar dust particles. It had remained practically unaltered since its formation.

Measured volume of material ejected by Halley: 80 % water, 10 % carbon monoxide, 2.5 % A mix of methane and ammonia.

Other hydrocarbons, iron, and sodium were detected in trace amounts.

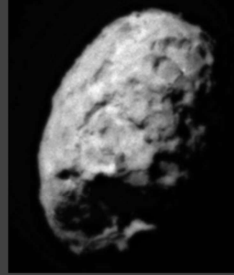
Giotto found Halley's nucleus was blacker than coal, which suggested a thick covering of dust.

Stardust (2004) 81P/Wild-2



Stardust

1999 – lancering
2004 – Wild
2006 – terugkeer



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Verwacht waren zeer kleine deeltjes (stardust) maar deeltjes waren veel groter dan verwacht.

Daarom ook diepe impact sporen in de aerogel.

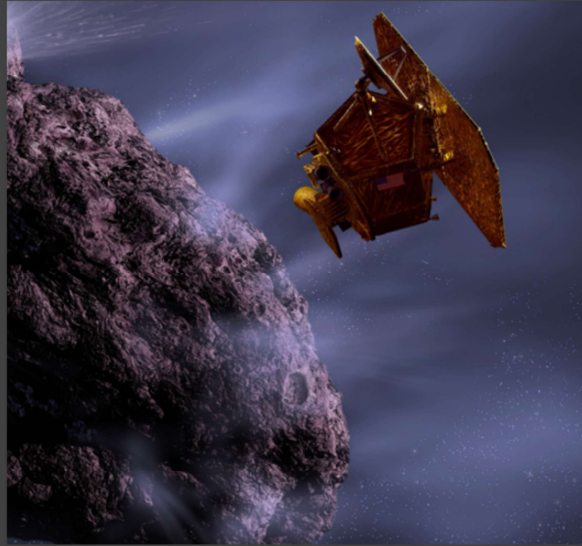
Meeste deeltjes gevormd onder zeer hete omstandigheden waarschijnlijk tijdens de vorming van het jonge zonnestelsel

en daarna pas naar buitenste delen zonnestelsel getransporteerd

Deep Impact (2005) 9P/Tempel-1

Deep Impact

2005/01 – launching
2005/07 – Tempel 1



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Deep Impact is a NASA space probe launched on January 12, 2005. It was designed to study the composition of the comet interior of 9P/Tempel, by releasing an impactor into the comet. At 5:52 UTC on July 4, 2005, the impactor successfully collided with the comet's nucleus. The impact excavated debris from the interior of the nucleus, allowing photographs of the impact crater. The photographs showed the comet to be more dusty and less icy than had been expected. The impact generated a large and bright dust cloud, which unexpectedly obscured the view of the impact crater. On November 4, 2010, the Deep Impact extended mission (EPOXI) returned images from comet Hartley 2.[59] EPOXI came within 700 kilometers (430 mi) of the comet, returning detailed photographs of the "peanut" shaped cometary nucleus and several bright jets. The probe's medium-resolution instrument captured the photographs.[59]

Rosetta (& Philae) (2014) 67P/Churyumov-Gerasimenko

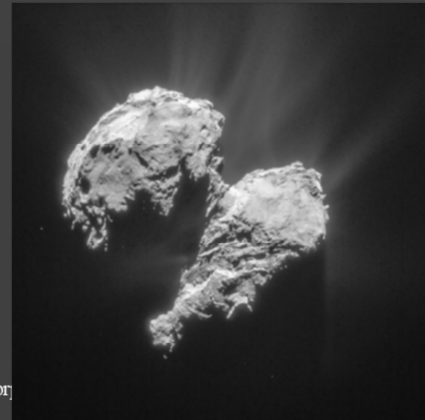
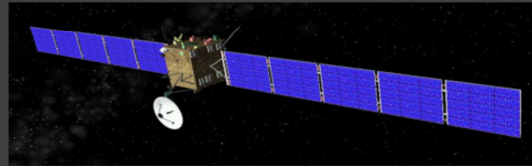


Mei 2014:
67P/Churyumov-
Gerasimenko

November 2014:
landing Philae

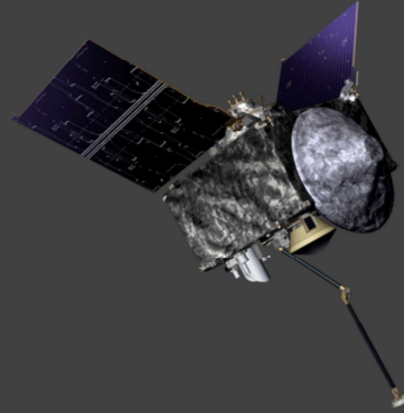
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The nucleus of Comet 67P/Churyumov-Gerasimenko as imaged by the Rosetta spacecraft on 2015 March 22.

Osiris-REx (2016-23) 101955 Bennu



20 Oct 2020 touch down on Bennu
24 Sep 2023 sample return

Organic compounds

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Fotomateriaal bijzondere kometen

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17P/Holmes (2007)

The 2007 mega-burst of 17P is unrivalled as the most powerful event of this kind on record

29 Oct 2007
Jery Lodriguess

False nucleus and inner coma
10 x 10-sec exposures
07:51 UT 29 Oct 2007.
N is up

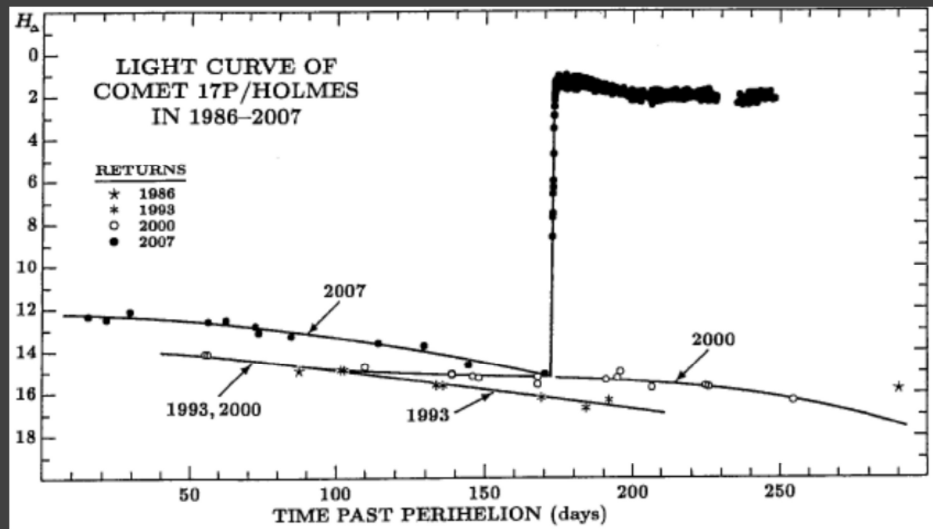
© 2007 Jerry Lodriguess / AstroPix.com

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17P/Holmes Explosion



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17P/Holmes (2007)

Spectacular outburst
Oct 24th

17th to 2.5th
magnitude

29 Oct 2007
Jerry Lodriguss

21-okt-25

Johan van Dorp

3 x 600-sec exposures
01:11 UT 31 Oct 2007
N is up

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17P/Holmes (2007)

Comet 17P/Holmes began a spectacular outburst on October 24th, going from 17th magnitude to 2.5th magnitude, an increase of more than 1 million times in brightness, to become an unaided-eye object in the constellation of Perseus.

30 Oct 2007
Jerry Lodriguess

21-oct-25

The faintest hint of a blue ion tail is visible to the lower right of the brilliant coma of Comet 17P/Holmes, seen here in a composite of 3 x 600-second exposures starting at 01:11 UT on 31 October 2007. North is to the top in this image.

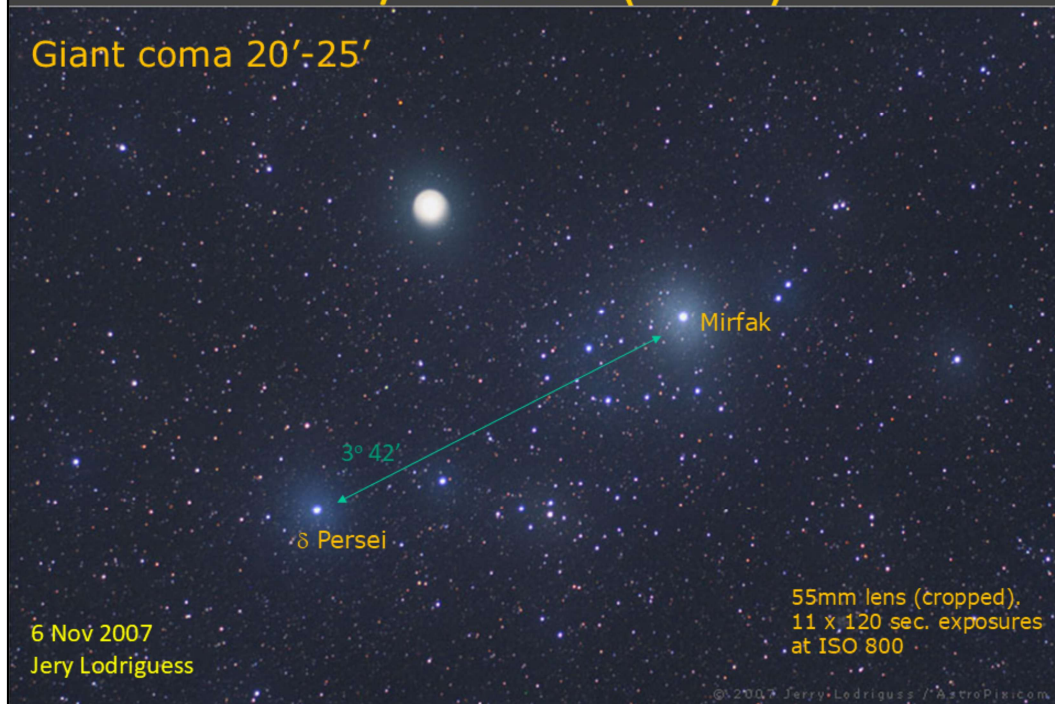
Johan van Dorp

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© 2007 Jerry Lodriguess / AstroPix.com

17P/Holmes (2007)

Giant coma 20'-25'



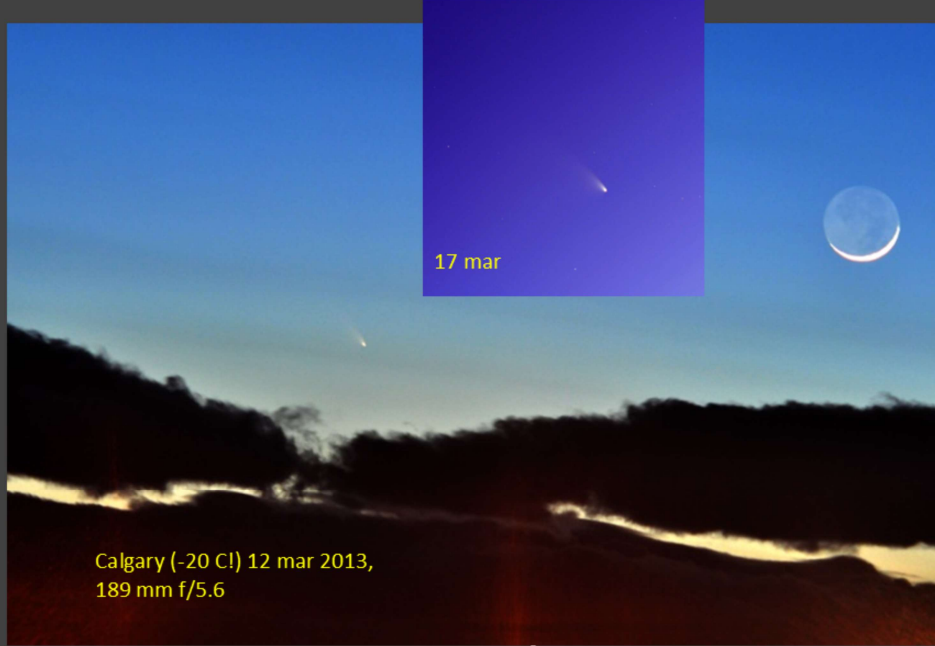
C/2014 UN271 (Bernardinelli-Bernstein)



28 mar 22 Hubble

Ontdekt in 2021 op
beeldmateriaal uit 2014.
Toen op 29 AE; actief door
CO/CO₂ verdamping
doorsnede ~100-200km,
(based on 5% albedo)
perihelium 28/1/31 at 10.9 AE

C/2011 L4 (PanSTARRS)



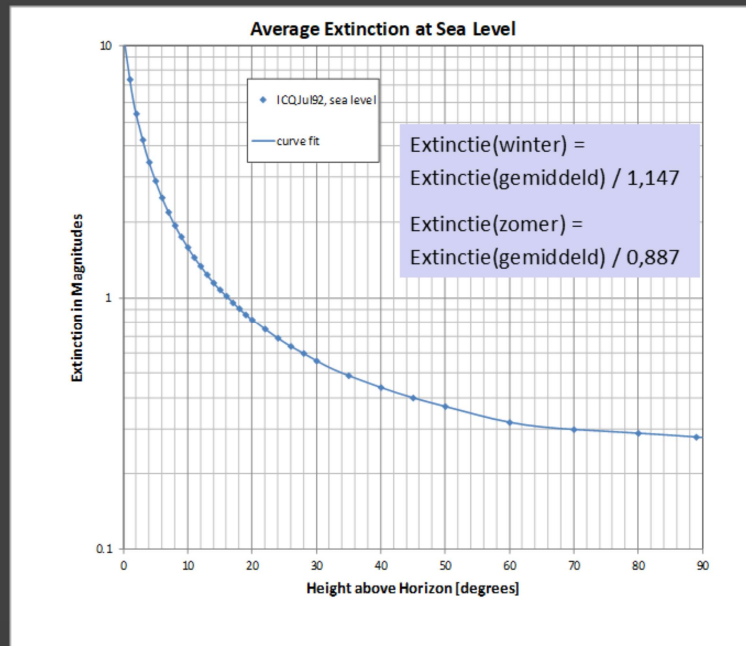
Back-up

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Extinctie



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Water Production [mol/s]

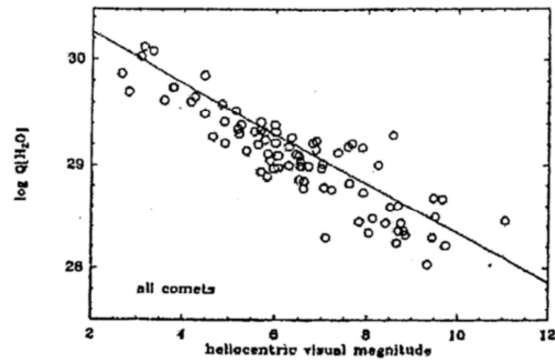


Figure 1. The correlation between heliocentric visual magnitudes and the water-production rates observed in 13 comets. From Jorda *et al.* (1992).

Bron:
Comets III

Afρ

Why Use the Afρ Quantity?

The Afρ quantity was introduced by A'Hearn *et al.* (1984) with the aim of comparing photometric data obtained with different instruments and geometric circumstances. At that time, this quantity proved useful for observations performed with photoelectric photometers, but nowadays it is commonly derived also from the analysis of CCD images. There are several advantages in using this quantity, chiefly:

- It is simple and affordable for amateur astronomers.
- The Afρ quantity refers to the “stationary coma” model, where it is assumed that dust expands at constant speed, and, if this condition is satisfied, it is independent of the measuring window used for photometry. This greatly reduces instrumental errors, as it is much less sensitive to the size of the photometric window.
- It allows amateur astronomers to obtain sets of data that are comparable with those obtained with professional equipment.

¹ The parameter introduced by A'Hearn and colleagues in the 1980s that is intended to be independent of the size of the aperture through which the dust is observed. Their quantity Afρ is given by $A(\theta)f\rho = qr^2\Delta F_\lambda/d$, where A is the Bond albedo for the particular scattering angle (θ); f is the so-called “filling factor” of the grains in the field-of-view, ρ is the radius of the assumed-circular field-of-view; Δ and r are given in AU; the mean cometary continuum flux averaged over the filter bandpass (F_λ) is given in erg cm⁻² s⁻¹ Å⁻¹; d is the diameter of the field-of-view in arcsec; and q is a coefficient that is a function of solar flux (tabulated by A'Hearn *et al.* 1995, *Icarus* 118, 223). The filling factor is the number of grains per unit area, divided by the area of the field-of-view, times their mean cross-section. As a crude estimate, the value of Afρ in 1000 cm roughly equals the production of dust in metric tons per second. There are many assumptions used in this quantity, however, assuming a static picture for size distribution and physical nature of the scattering particles and for expansion velocity (thus somewhat analogous to the situation with the Haser model). – Ed.

Bron:
Comets III

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Saturation Vapour Pressure

Bron:
Comets III

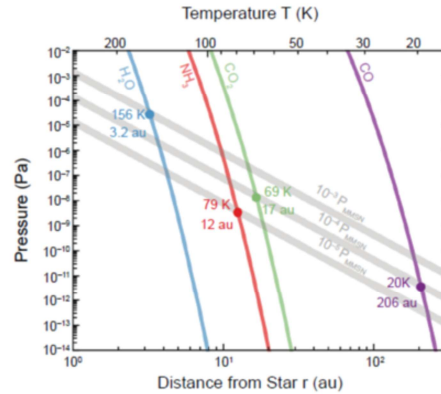


Fig. 2. Saturation vapor pressures for pure CO, CO₂, NH₃, and H₂O ices (thin lines) as a function of temperature T (indicated on the top edge). For reference, the thick lines show how the temperature and 0.1, 0.01, and 0.001% of the total midplane gas pressure vary with orbital radius (indicated on the bottom edge) in a radially extended version of the classical, optically thin minimum-mass solar nebula (Hayashi, 1981). The circles mark the locations of the snowlines.

MMSN = minimum mass solar nebula.

Tisserand Criterion Periodic

OCCs → HTC's drawn in by gas giants

OCCs → detached objects → SDOs (scattered disk objects)

SDOs belong to TNOs, e.g. Sedna = SDO.

SDOs are scattered by gas giants and are origin of most periodic comets

SDO = $\{e \in [0-0.8]; i < 40^\circ; q > 30 \text{ AU}\}$

SDO → Centaurs (e.g. 29P/SW-1, 2060 Chiron) with orbit between Jupiter & Neptune [5-30 AU]

Centaurs have erratic, unstable orbits

Centaurs → JFCs migration to inner solar system

Tisserand parameter w.r.t. Jupiter

$$T_J = \frac{a_J}{a} + 2 \sqrt{\frac{a}{a_J} (1 - e^2) \cos i}$$

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SPCs short period comets <200j. $T_J=2-3$ for JFCs. $T_J<2$ for HTC's (scattered disk origin?). $T_J>3$ for ETCs.

Orbital dynamics of comets

OCCs → HTC drawn in by gas giants

OCCs → detached objects → SDOs (scattered disk objects)

SDO belong to TNOs, e.g. Sedna = SDO.

SDOs are scattered by gas giants and are origin of most periodic comets

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SDO → Centaurs (e.g. 29P/SW-1, 2060 Chiron) with orbit between Jupiter & Neptune [5-30 AU]

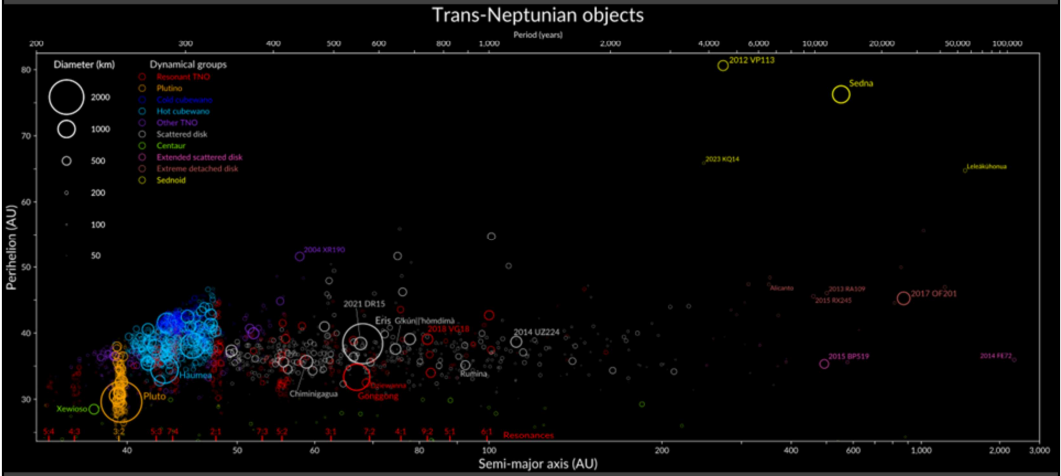
Centaurs have erratic, unstable orbits

Centaurs → JFCs migration to inner solar system

OCC = Oort Cloud Comet; HTC = Halley type comet

JFC = Jupiter family comet; SDO = Scattered disk object

TNOs

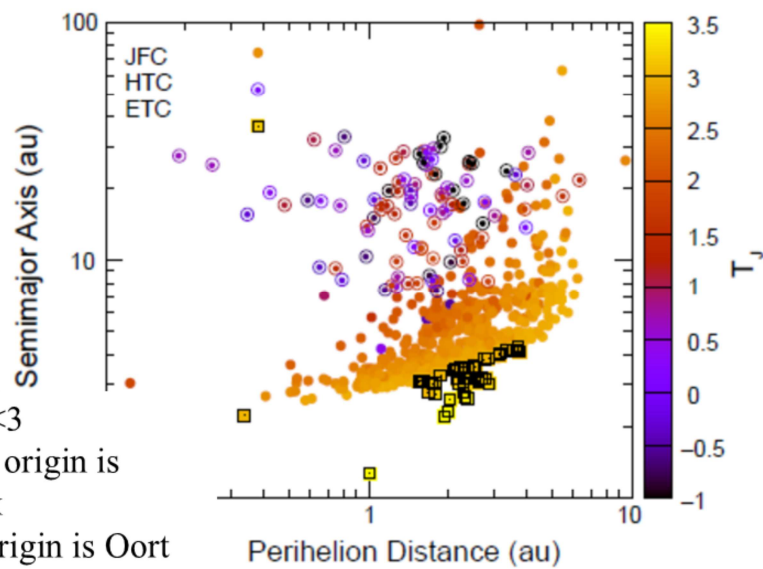


Tisserand Criterion Periodic

Bron:
Comets III

Most SPCs $T_J \sim < 3$

- JFCs $2 < T_J < 3$ origin is scattered disk
- HTC $T_J < 2$ origin is Oort cloud
- ETCs $T_J > 3$ after $1.5 \cdot 10^5$ revolutions



han van Dorp

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SPCs short period comets $< 200j$. $T_J = 2-3$ for JFCs. $T_J < 2$ for HTCs (scattered disk origin?). $T_J > 3$ for ETCs.

Oort Cloud & Scattered disk

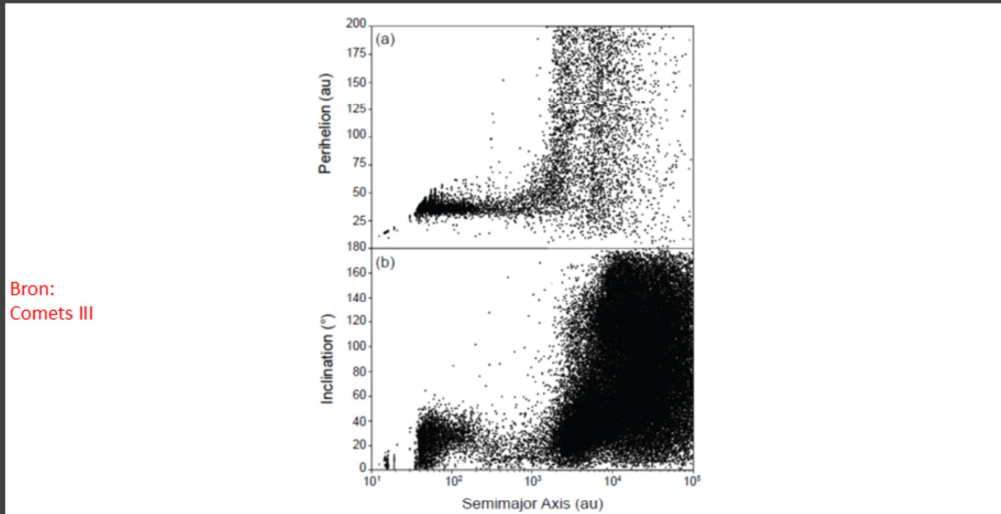


Fig. 9. Perihelia (upper panel) and inclinations (lower panel) vs. semimajor axes of particles at $t = 4$ G.y. in a simulation forming the Oort cloud and scattered disk concurrently. Plot is generated from the “OC” simulation of *Kaib et al. (2019)*.

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Discovery by surveys

Survey	Location*	SPCs†	LPCs†	Total
Catalina	G96, 703, I52	200	193	393
Pan-STARRS	F51, F52	112	142	254
LINEAR	704	91	128	219
NEAT	566,644	39	16	55
ATLAS	T05, T07, T08	16	35	51
NEOWISE	C51	16	23	39
Spacewatch	291,691	16	12	28
LONEOS	699	17	5	22
ZTF/PTF	I41	2	16	18
SOHO/SWAN‡	249	12	1466	1478
STEREO‡	C49	1	8	9

* The Minor Planet Center Observatory Code contributors.

† Short-period comets (SPCs) with orbital periods <200 years and long-period comets (LPCs) with orbital periods ≥ 200 years.

‡ Sun-looking survey total.

Note that the count of SOHO-discovered comets includes only those contributions with additional non-SOHO observations (see text).

Bron:
Comets III

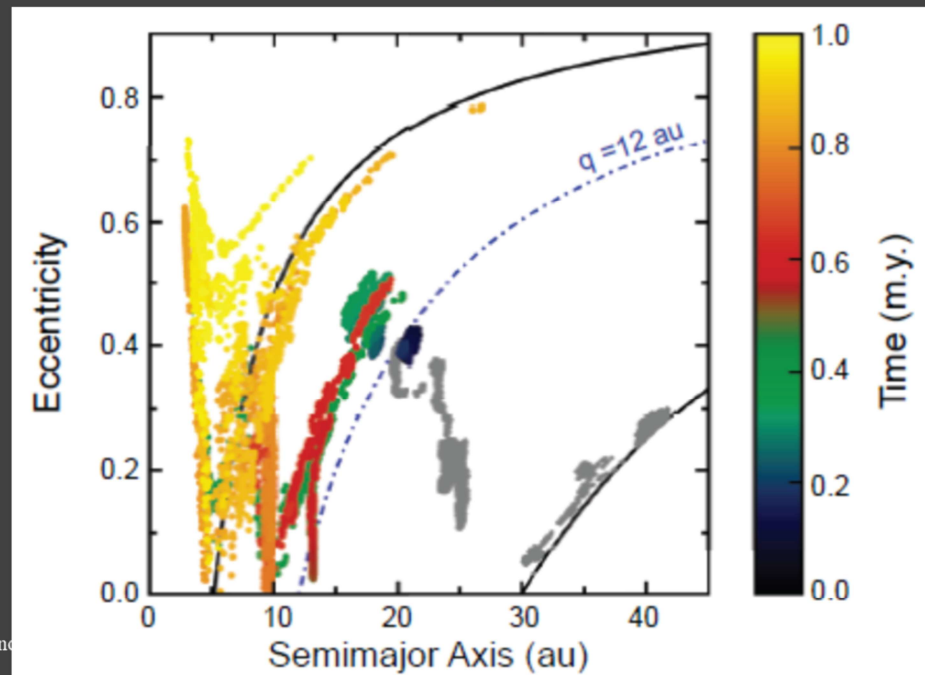
21-ok

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Back-up

Bron:
Comets III

3-110



Example of one possible orbit evolution from TNO region in e-versus-a plane. 100yr per data point. Prior 1 m.y. in gray.

Black lines 5.2-30 AU.

Bulk Density

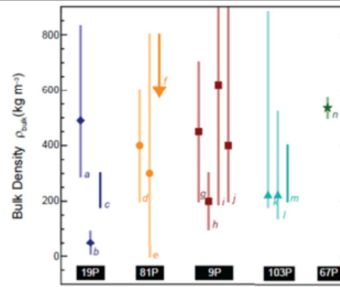


Fig. 3. Summary of bulk densities derived for comet nuclei with a volume measured by spacecraft missions. References: for 19P/Borrelly — (a) 490⁺³⁴⁰₋₂₀₀ kg m⁻³ (Farnham and Cochran, 2002), (b) 50 ± 40 kg m⁻³ (Sosa and Fernández, 2009), (c) 180–300 kg m⁻³ (Davidsson and Gutiérrez, 2004), for 81P/Wild 2 — (d) 400 ± 200 kg m⁻³ (Szutowicz et al., 2008), (e) 300⁺⁵⁰⁰₋₃₀₀ kg m⁻³ (Sosa and Fernández, 2009), (f) ≈600–800 kg m⁻³ (Davidsson and Gutiérrez, 2006), for 9P/Tempel 1 — (g) 450 ± 250 kg m⁻³ (Davidsson et al., 2007), (h) 200 ± 100 kg m⁻³ (Sosa and Fernández, 2009), (i) 620⁺⁴⁷⁰₋₃₃₀ kg m⁻³ (A'Hearn et al., 2005b), (j) 400 kg m⁻³ (200–1000 kg m⁻³) (Richardson et al., 2007), for 103P/Hartley 2 — (k) 220 kg m⁻³ (180–880 kg m⁻³) (A'Hearn et

Bron:
Comets III

21-0

Magnitude scale

The dimmer an object appears, the higher the numerical value given to its magnitude, with a difference of 5 magnitudes corresponding to a brightness factor of exactly 100. Therefore, the magnitude m , in the spectral band x , would be given by

$$m_x = -5 \log_{10} \left(\frac{F_x}{F_{x,0}} \right),$$

which is more commonly expressed in terms of common (base-10) logarithms as

$$m_x = -2.5 \log_{10} \left(\frac{F_x}{F_{x,0}} \right),$$

where F_x is the observed irradiance using spectral filter x , and $F_{x,0}$ is the reference flux (zero-point) for that photometric filter. Since an increase of 5 magnitudes corresponds to a decrease in brightness by a factor of exactly 100, each magnitude increase implies a decrease in brightness by the factor $\sqrt[5]{100} \approx 2.512$ (Pogson's ratio). Inverting the above formula, a magnitude difference $m_1 - m_2 = \Delta m$ implies a brightness factor of

$$\frac{F_2}{F_1} = 100^{\frac{\Delta m}{5}} = 10^{0.4 \Delta m} \approx 2.512^{\Delta m}.$$



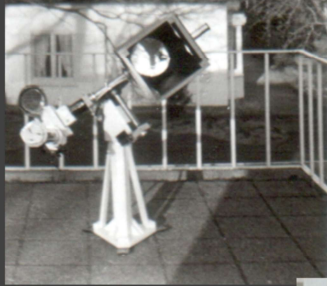
Kometes = langharige
van groot belang voor het begrip van onze ontstaansgeschiedenis

Johan van Dorp

1972-1980: Studie Natuurkunde
(kandidaats Sterrenkunde)

1981-2016: Werkzaam in industrie
als ingenieur

NKV sinds 1989



1968: 11 cm Kutter
& 18 cm Richfield

1992: CG11
(Californië)



2004: 20" Obsession (Oman)

21-okt-25

Johan van Dorp

2

Studie Natuur- en Sterrenkunde

Bijvangst tijdens het maken
van een Sterren Atlas voor
practicum sterrenkunde:
Komeet Bradfield 1974b

Construct programma
berekenen baanelementen
(met Rob van Gent)



Inhoud

- Geschiedenis
- Wat zijn kometen?
- Kometen zijn groen
- Komeetbanen
- Helderheidsverloop
- Desintegratie
- Komeetstaarten
- Verstrooiing
- Uitbarstingen
- Kreuz sungrazers
- Great comets
- Ruimte missies
- Fotomateriaal

Geschiedenis

- Aristoteles, 4^e v.Chr.
- L. Annaeus Seneca (A.D. -1-69)
- Petrus Appianus (1532)
- René Descartes (1596-1650)
- Georg Samuel Dörffel (1682)
- Edmund Halley (1705)



De Grote Komeet van 1680/81 gezien vanuit
Alkmaar op 22 december 1680
(Lambert Doomer, Rijksprentenkabinet
Amsterdam)
Dörffel berekende parabolische baan

3-nov-25

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Aristoteles: hoogste regionen van het ondermaanse

Lucius Annaeus Seneca: planeten met onbekende banen

Petrus Appianus: staart wijst van zon af

René Descartes: oorsprong in interstellaire ruimte

Dörffel: baanberekening

Edmund Halley: *Astronomiæ Cometicæ Synopsis* catalogus
komeetbanen

Morphology

- Een komeet is een ongerept overblijfsel uit de geboorte van ons zonnestelsel
- Kometen zijn een fragiel conglomeraat van verschillende soorten ijs, stof en steengruis (carbonaceous & silicate)
- Waarschijnlijk verdreven uit hun geboorteplaats door de zwaartekracht van de gasreuzen
- Ze zijn miljarden jaren in koude opslag gebleven
- Laag albedo (~4%), korst van donker materiaal aan oppervlak (?)
- Tonen meestal onvoorspelbaar gedrag (Whipple)
- De meteorieten die wij zien, ontstaan uit het puin dat achterblijft rond de komeetbaan (en wanneer de aarde deze baan doorkruist)

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6

Whipple: "Predicting the behaviour of a comet is like picking the winner of a horse race"

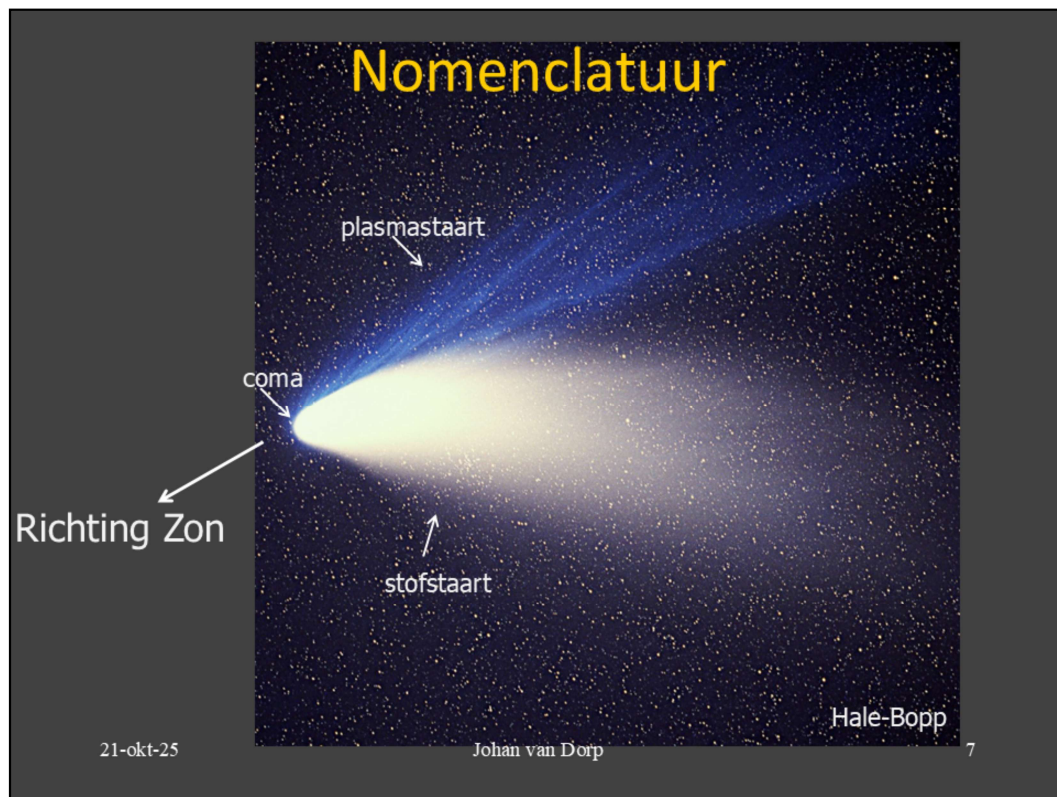
Carbonaceous and silicate refractory material = rock (baked by lithifaction, driven by ^{26}Al decay heating $<150\text{ C}$). ^{26}Al half-life 0.7 m.y., generated from Si + cosmic rays

Comets are pristine remnants of protoplanetary disk. Genetic link with **chondrites**

Chondrites: chondrules, CA-AL rich refractory inclusions, fine grained matrix.

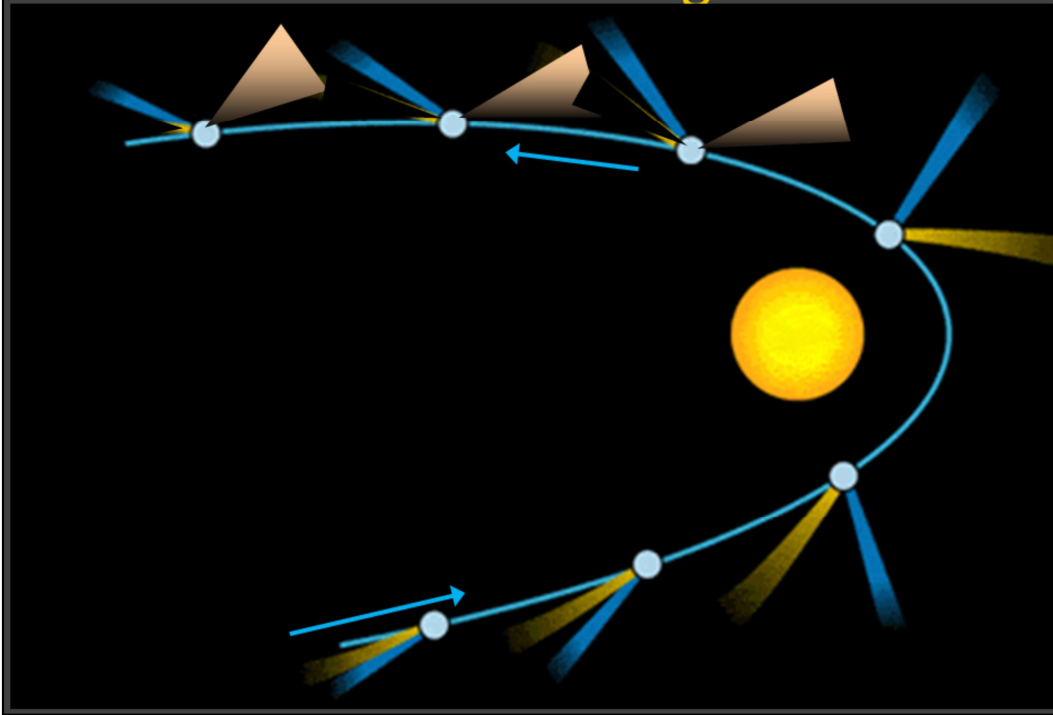
Chondrule were molten

Meteorites contain no ice and are born in the inner solar system (asteroid)

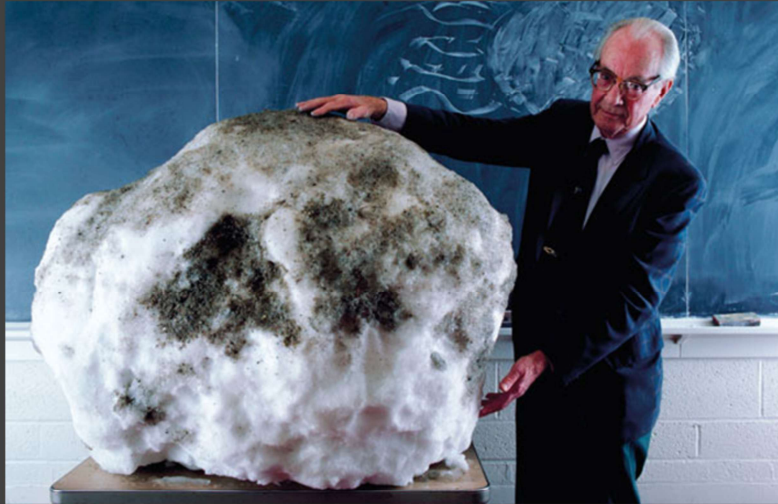


Soms ook nog een Natrium staart

Staart richting



Fred Whipple (1951) "Dirty Snowball"



gruis
 CO_2
 CH_4
 H_2O

67P H_2O bevat 3x zoveel HDO als op aarde

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H_2O : waterijs / CO_2 : droog ijs / CH_4 : methaan / NH_3 : ammoniak / CO : koolmonoxyde

$\text{D}/\text{H} = 1.5\text{-}2 \text{ E-}5$ interstellar in interstellar medium, but much higher in cold gas clouds+

Jup = $2.2\text{-}2.6 \text{ E-}5$

Earth = $15.6 \text{ E-}5$

Comets = $16.6\text{-}20 \text{ E-}5$

67P = 3x earth

Primordial $2.7 \text{ E-}5$

Classification

Periodiek

- Main-belt comets = active asteroids 133P/Elst-Pizarro
- Jupiter Family Comets (JFCs)
 $\frac{1}{2} < P_{\text{J}} < 3$ (of $P < 20$ yrs, $i < 30^\circ$) 6P/d'Arrest, 67P/Churyumov-Gerasimenko
- Vaak baan-resonantie met Jupiter
- Kort-periodiek 20-200 jaar 1P/Halley, D/Shoemaker-Levy 9
- Lang-periodiek > 200 jaar TNO's, Kuiper belt (30 – 50/100 AE)
 Baan $\sim$ in vlak van zonestelsel

Zonnescheerders

Kreuz group, C/1965 S1 Ikeya-Seki

Niet-periodiek

- $P > 1000$ jaar Oort cloud (2000 – 200,000 AE)
- (sub)Parabool, $e \sim 1$ C/1995 O1 Hale-Bopp

Interstellair (Hyperbool)

1I/Oumuamua, 2I Borisov, 3I/ATLAS

$$P_{\text{J}} = 11.86 \text{ yr}$$

$$a_{\Psi} = 30 \text{ AE}$$

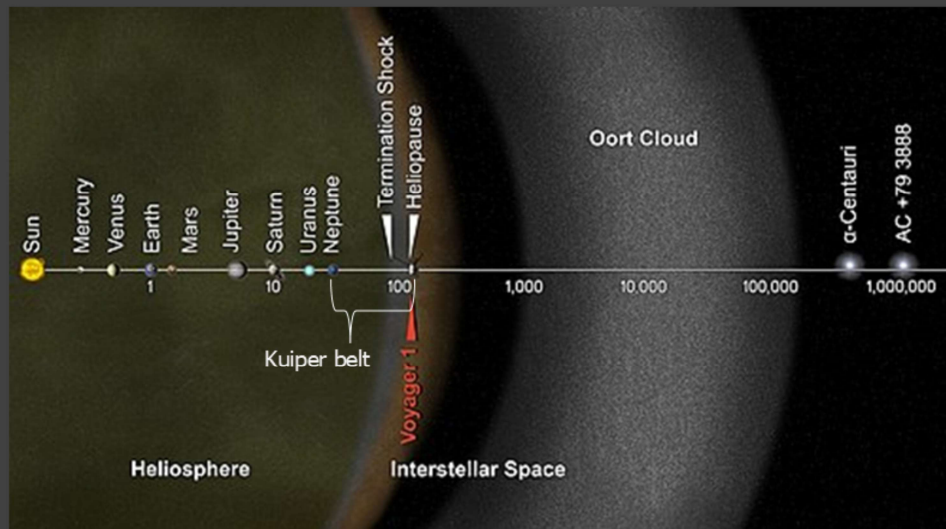
Hale-Bopp komt pas weer in 4385 voorbij

Zonnescheerders: ontstaan uit

Notable main belt comets (since 2006):

324P/La Sagra, P/2012 T1 (Pan-STARRS), 133P/Elst-Pizarro, and P/2010 A2 (LINEAR).

Oort Cloud & Kuiper belt



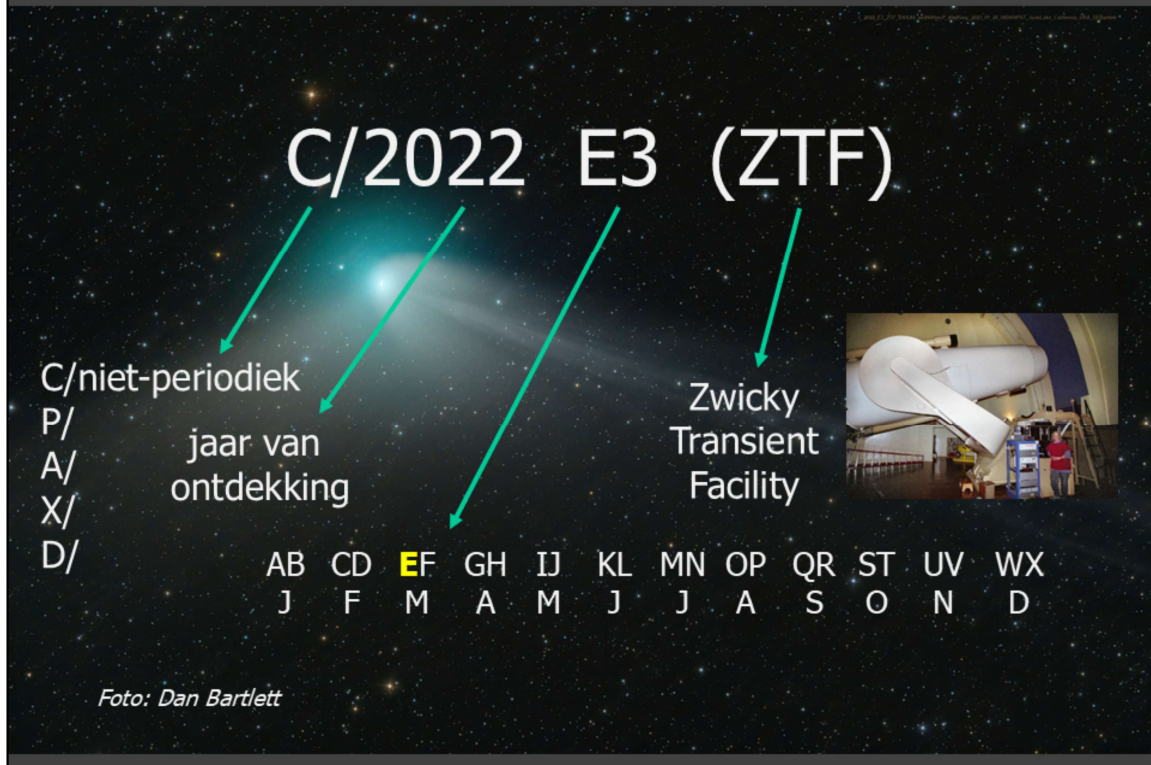
Logaritmische afstand schaal
1 lichtjaar $\approx$ 63,000 Astronomische Eenheden

Hale-Bopp komt pas weer in 4385 voorbij ($a=177$ AU)

Zonnescheerders: ontstaan uit

Edgeworth-Kuiper belt

Designation (1995)



2 maart 2022. ZTF: mount Palomar, 1.2m Schmidt, 606MP, 7x7graden, Ontdekker van o.a. Sedna, Eris, Orcus en Quaorar (Kuiperbelt-objecten)

P/ periodic comet orbital period of less than 200 years or confirmed observations at more than one perihelion passage.

C/ non-periodic comet

X/ indicates a comet for which no reliable orbit could be calculated (generally, historical comets).

D/ indicates a periodic comet that has disappeared, broken up, or been lost

A/ mistakenly identified as a comet, but actually a minor planet

I/ interstellar

De groene komeet

UV: ionisatie $\text{CO} \rightarrow \text{CO}^+$ $\Rightarrow$ (blauwe) ionenstaart

Kern warmt op, verschillende soorten ijs smelten:
diffuse atmosfeer van
(geïoniseerd) gas & stofdeeltjes $\Rightarrow$ coma

Zonnewind + coma: $\Rightarrow$ (wit/gele) stofstaart
gereflecteerd zonlicht

In coma ook gas(ionen): H, O, C, N, CN en C_2
UV $\rightsquigarrow$ + CN en C_2 : $\Rightarrow$ groene coma

CN	390 nm
Swan band (C_2)	430-620 nm

Foto: Juanjo Gonzalez

De electronen van CN + C_2 komen in een hogere energietoestand terecht en vallen weer terug: groene emissie

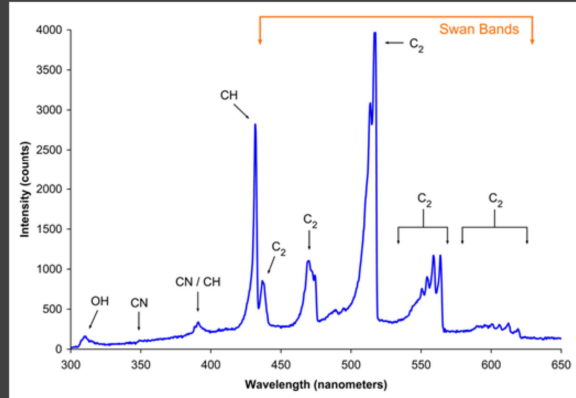
CN = Cyanide

Verdampingscyclus

CO en H₂O geschat in ongeveer gelijke hoeveelheden

Afstand | Verdampend molecuul

~7 AE	CO, CO ₂ , methaan
< 3 AE	H ₂ O, CN (388.9 nm) coma groeit met ~ 1 km/s
2-3 AE	NH ₂ , C ₃
< 2 AE	C ₂ (Swan band) OH
< 1 AE	Na
Kreuz	Metalen (silicaten)



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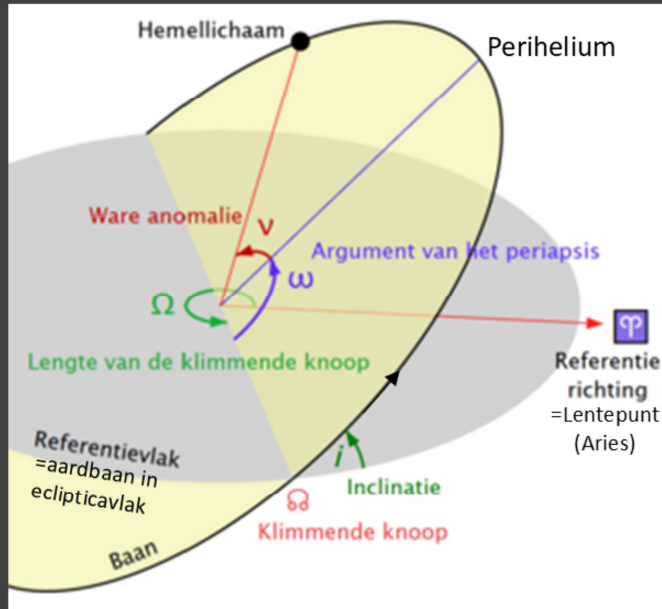
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Orbital elements

3 hoeken bepalen de baanorientatie in de ruimte ten opzichte van zon en aardbaan als referentievlak

Astrometrie geeft posities komeet aan hemelbol



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Middelbare anomalie $M = 2\pi t (t-t_0)/P = E - e \sin E$

Excentriche anomalie $E =$ ware anomalie (ν) geprojecteerd op omsluitende cirkel

$\tan(\nu / 2) = \sqrt{(1+e)/(1-e)} \tan(E/2)$

6 Orbital Elements

1x tijd referentie

T = datum periheliumdoorgang

2x vorm en grootte baan

q = periheliumafstand (au)

e = excentriciteit (parabolische banen $e = 1.0$)

$$q = a(1-e)$$

$$P^2 = a^3 \text{ (3e Keppler)}$$

3x hoeken

i = baanhelling t.o.v. de ecliptica

Ω = lengte klimmende knoop

ω = lengte perihelium

(meestal geteld vanaf de klimmende knoop)

Kan hiermee positie berekenen voor elk willekeurig tijdstip

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$P^2=a^3$ derde wet Keppler

Perturbations

Osculating elements bepaald m.b.v. astrometrische posities tegen de tijd. Zijn slechts geldig rond de *epoche* wanneer de elementen zijn berekend

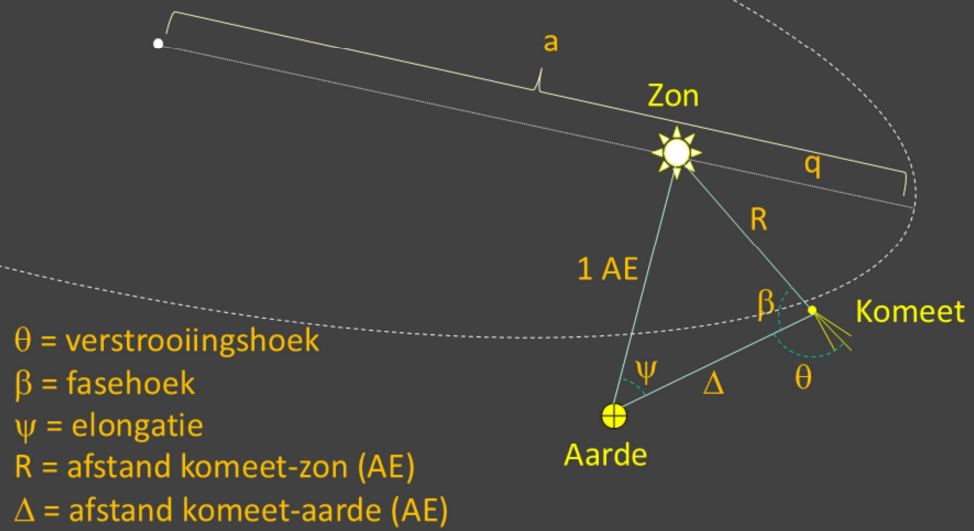
Perturbaties door “close encounters” met een (zware) planeet kunnen significante afwijkingen geven in het verloop van de komeetbaan

Komeet kan ook in *resonantie* komen met planeet. 55P/Tempel-Tuttle is in 5:14 resonantie met Jupiter (11.86 : 33 jaar)

Niet-gravitationele effecten (thrust van jets). Factoren:

- A_1 beschrijft kracht radiaal van de zon af
- A_2 beschrijft tangentele kracht langs de baan

Geometrie



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Helderheid

Magnitude-schaal is logaritmisch $m = -2.5 \log (F/F_0)$

Van belang is de **totale helderheid, inclusief coma**

(kern is aan het zicht onttrokken)

Formule van Holetscheck voor nieuwe kometen (long period comet)

$$m_1 = H_{10} + 10 \log R + 5 \log \Delta$$

Formule met "Activity index" n

$$m_1 = H_0 + 2.5n \log R + 5 \log \Delta$$

Heliocentrische magnitude

$$m_h = m_1 - 5 \log \Delta = H_0 + 2.5n \log R$$

Grafiek m_h tegen $\log R$ geeft H_0 en n

Asteroiden geven $n = 2$ (inverse square law) $m \sim 2.5(\log R^2 + \log \Delta^2)$

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Helderheid kern kan worden gerelateerd aan effectieve doorsnede komeet na aanname van albedo ($\sim 5\%$).

Helderheid

Dynamisch nieuw $e \geq 1$ $a \geq 20,000$ AE: $n = 2.4 \pm 0.3$
(vroeg actief, stagnerende helderheidsontwikkeling)

Terugkerend uit Oort wolk $e \leq 1$, $a \leq 20,000$ AE: $n \approx 3.2$

“Oude” periodieke kometen (gebruik H_{15}): $n = 6$

Vaak is helderheids-maximum verschoven tot na perihelium
(soms ook voor)

Correctie termen van Öpik voor optisch instrument

Helderheid Schattingen

Visueel (totale helderheid):

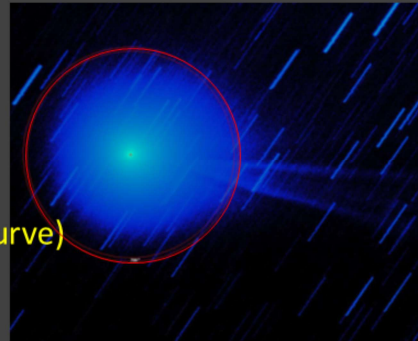
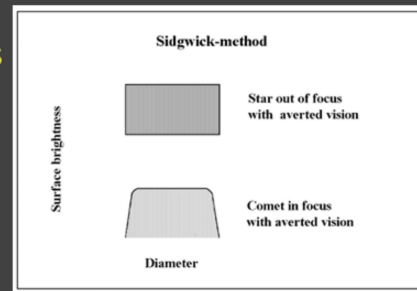
- Morris (uit-focus komeet en uit-focus vergelijkings-sterren)
- Bobrovnikoff “uit-uit” (coma en sterren ong. zelfde doorsnee)
- Sedgwick “in-uit” (Coma in-focus, sterren uit-focus, averted vision)

Fotometrisch:

Kalibreer CCD/CMOS opname
Bepaal achtergrond
Groene band (UBVR-I filters –
Visual Equivalent Magnitude)
Integreer inclusief coma
(Photometric aperture – growth curve)
corrigeer voor sterlicht

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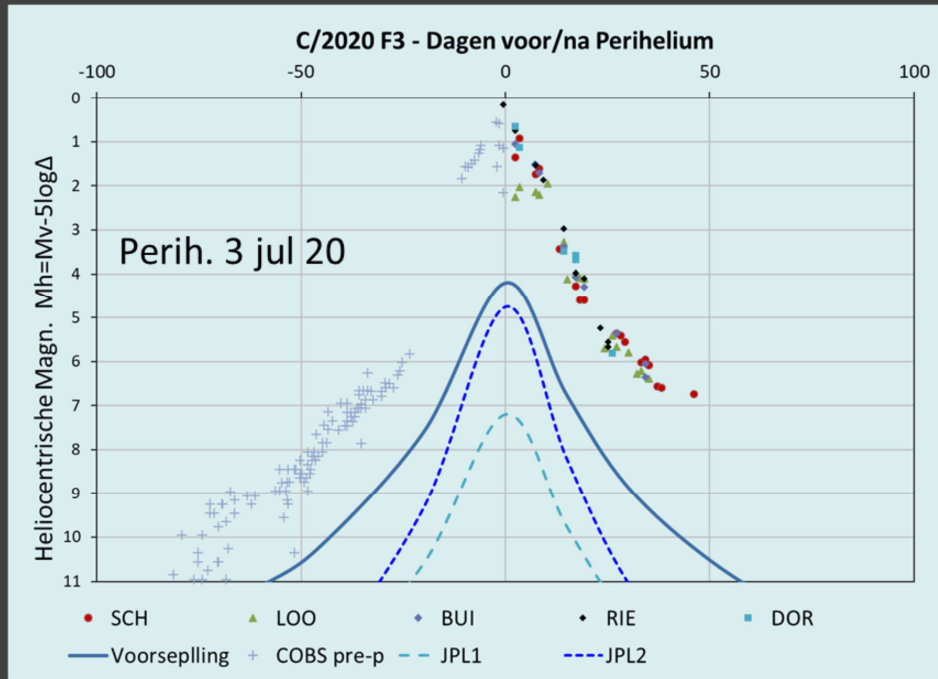
Johan van Dorp



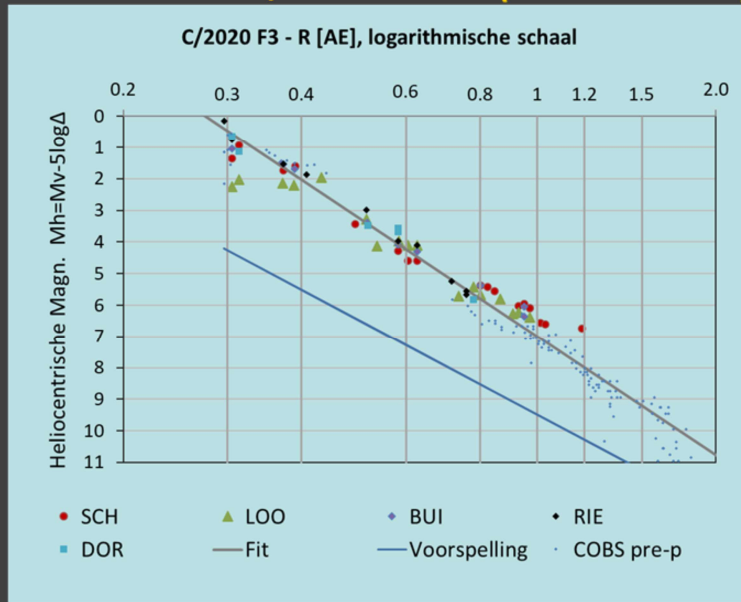
De **Bobrovnikoff**-methode is de zogenaamde “Uit-Uit” methode, waarbij het oculair zover uit het focus wordt gedraaid totdat de coma van de komeet en de vergelijkingssterren vrijwel dezelfde diameter lijken te hebben. (Door Bobrovnikoff beschreven in publicatie No. 15 van 1941 maar niet door hem gebruikt). Een komeet met een $DC=3$ wordt bij het gebruik van de Bobrovnikoff-methode ca. 0,7 magnitude zwakker waargenomen t.o.v. de Sidgwick-methode.

Bij de **Morris**-methode wordt de in het geheugen opgeslagen helderheid van een 'iets' uit focus staande komeet vergeleken met onscherp gestelde sterbeeldjes die net zover uit focus zijn gedraaid als de comadiameter van de 'iets' uit focus staande komeet.

C/2020 F3 (NEOWISE)



C/2020 F3 (NEOWISE)



Voorspelling (ini)

$H_0 = 11.9$

$n = 5.4$

Voorspelling (SY)

$H_0 = 7$

$n = 4.8$

Fit

$H_0 = 7$

$n = 5$

C/2020 F3 (NEOWISE)

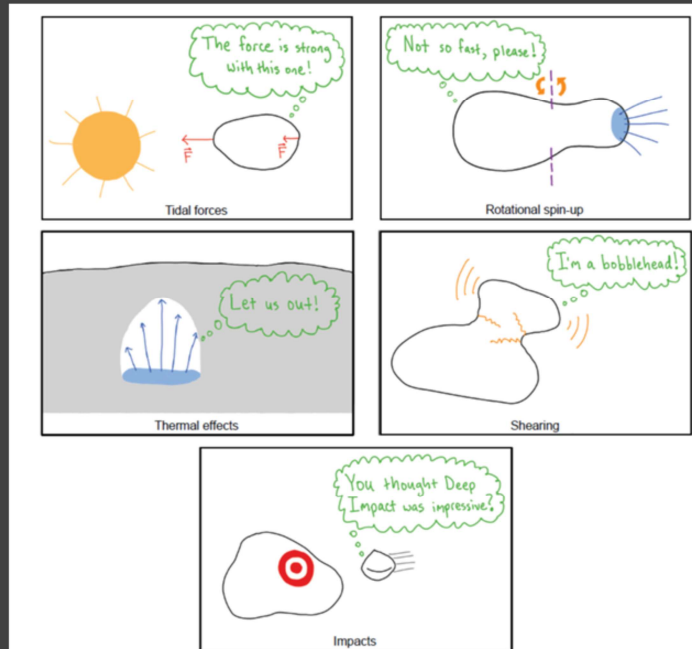


DOR 20 jul 20 25x2 sec 70mm f/4.8



DOR 21 jul 21 29x30 sec 50mm f/2

Fragmentatie



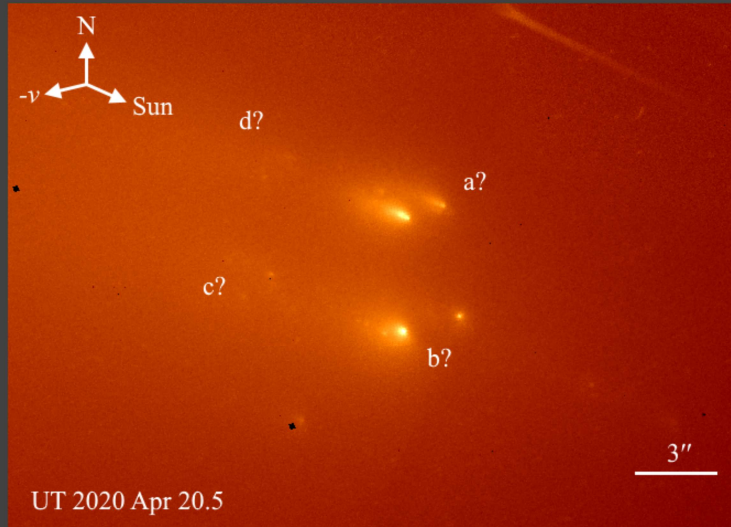
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Causes of fragmentation (see text for additional details).

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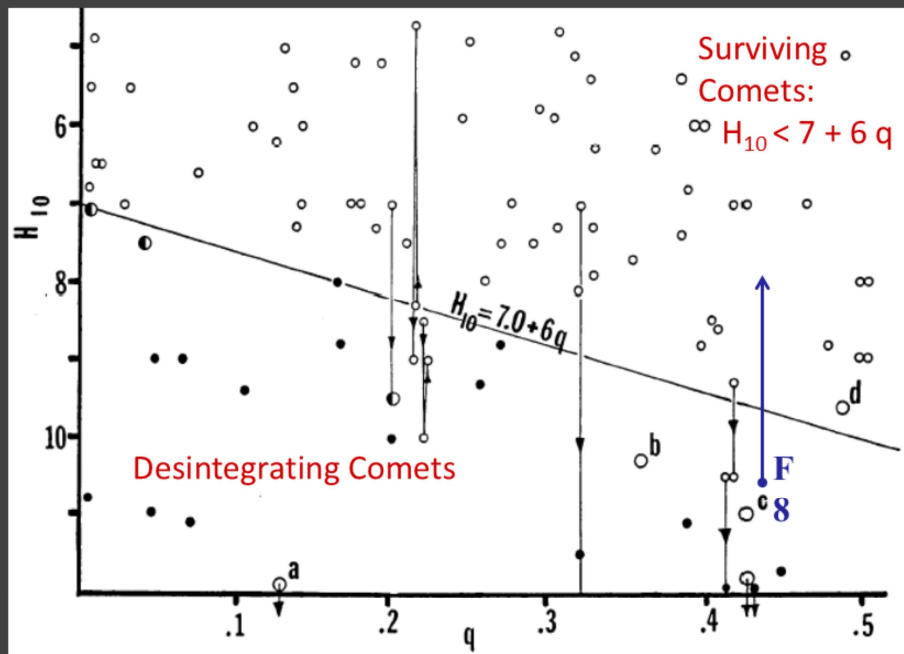
Bortle limit

Onder invloed van getijdenkrachten, kan de kern van een komeet (fragiel conglomeraat) gedeeltelijk of geheel desintegreren (verwijderingssnelheid brokken 1 - 10 m/s)



C/2019 Y4 (Atlas)

Bortle limiet

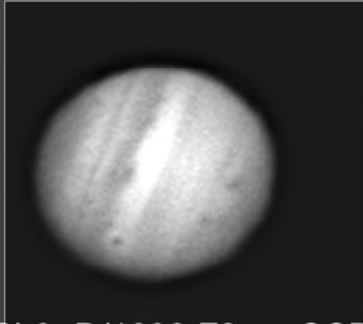


Bortle limiet

- SL9 vormde een trein van brokstukken, die uiteindelijk insloegen op Jupiter.
- 73P/SW3 nucleus split in sep 1995 en gaf een geweldige uitbarsting



CCD of P-SW3
25 oct '95



SL9=D/1993 F2 on CCD
16-22 jul 1994

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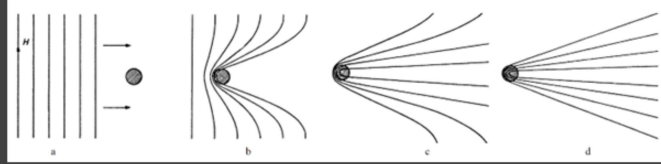
Jupiter (2x) on CCD (<1 sec), SL9 impact on Jupiter(CCD)

CCD image of comet P-Schwassmann Wachmann - III at "flare-up"

Gas- of plasma staart (Type 1)

De zonnewind is vaak turbulent met windvlagen

De staart van gas-ionen fungeert als een soort windzak en informeren ons over de zonnewind.



De CO^+ en C^+ ionen ontstaan onder invloed van hoog energetisch UV licht en geven de plasma staart. De staart straalt vnl. blauw licht en de ionen worden meegevoerd met de zonnewind, dat zelf een plasma is met vrije elektronen. De magnetische veldlijnen van de zon staan $\perp$ op de stroom van de zonnewind (250 – 700 km/s) en wikkelen zich om de komeet. De ionen in de staart spiraliseren om de veldlijnen (Lorentz). Soms vind ontkoppeling van de staart plaats (N-S).

3-nov-25

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Gas staart C/2021 A1 (Leonard)

Perihelium op 3 jan 2022



8 dec 2021
Michael Jaeger

21-okt-25

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Gas staart C/2021 A1 (Leonard)



21 dec 2021

M. Mattiazzo

180 sec C11Reza F/2.2 Canon 6D

Beeldveld 3 graden

C/2021 A1 Leonard, 2021 December 21 at 11:15UT, C11 RASA f/2.2 + Canon 6D, 3 mins, FOV 3 deg, North up, M. Mattiazzo, Swan Hill, Victoria

Gas staart C/2021 A1 (Leonard)



21 dec 2021

M. Jaeger - Hakos Namibia

Duidelijk is de structuur in de gasstaart

Gas staart C/2021 A1 (Leonard)



21 dec 2021

R. Ligustri

Beeldveld 3 graden

Gas staart C/2021 A1 (Leonard)



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Gas staart C/2021 A1 (Leonard)



25 dec 2021
G. Rehman

21-okt-25

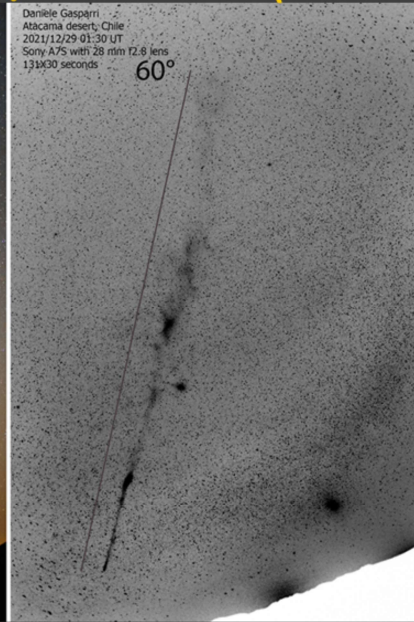
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Gas staart C/2021 A1 (Leonard)



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29 dec 2021
Gasparri
Atacama woestijn

Gas staart C/2021 A1 (Leonard)



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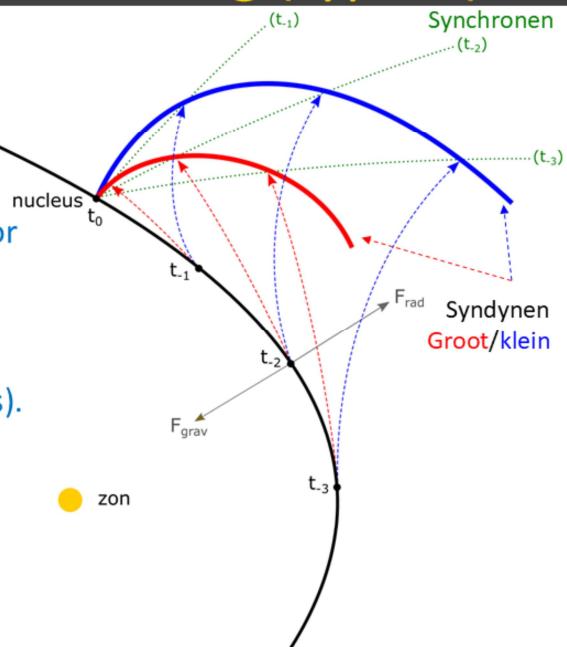
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1 jan 22
Gerald Rehman
12 inch telescoop
Tivoli, Namibië³⁷

Stofstaart ontwikkeling (type-2)

Stofstaart is wit/geel door reflecterend zonlicht.
Deeltjes worden gesorteerd in Syndynes naar grootte (μm - mm 's).
 $\beta = F_{\text{rad}}/F_{\text{grav}}$

- $\rightarrow$ traject klein deeltje ($\beta > 1$)
- $\rightarrow$ traject groot deeltje ($\beta < 1$)
- syndyne kleine deeltjes ($\beta > 1$)
- syndyne grote deeltjes ($\beta < 1$)
- synchrone



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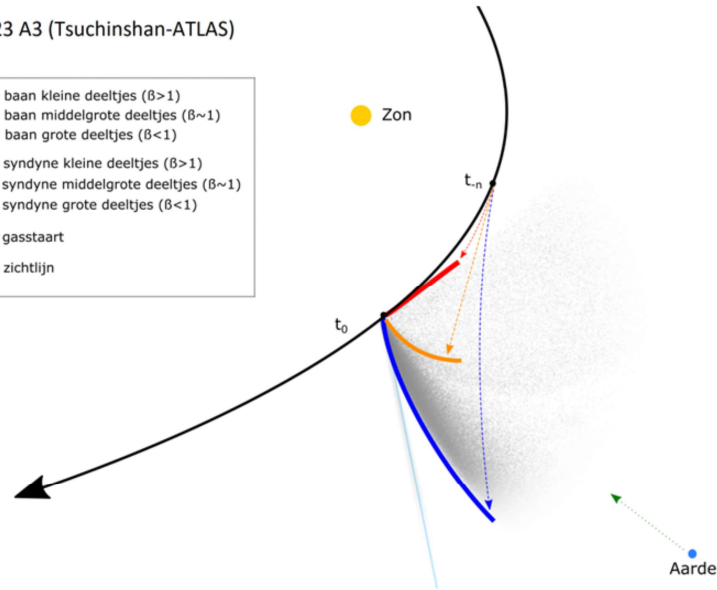


Perihelium 0,171 AE 12 jan 2007, S.Derries/ESO Paranal observatory, late january 2007 (~20)

Antitail

C/2023 A3 (Tsuchinshan-ATLAS)

- baan kleine deeltjes ($\beta > 1$)
- baan middelgrote deeltjes ($\beta \sim 1$)
- baan grote deeltjes ($\beta < 1$)
- syndyne kleine deeltjes ($\beta > 1$)
- syndyne middelgrote deeltjes ($\beta \sim 1$)
- syndyne grote deeltjes ($\beta < 1$)
- gasstaart
- zichtlijn



21-okt-25

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Antitail C/2023 A3 (Ts.-Atlas)

C/2023 A3 (Tsuchinshan Atlas)
Adam Block 14 okt 24

10 x 2 sec Nikon D90 135 mm f/2

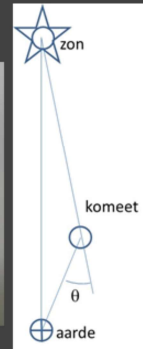
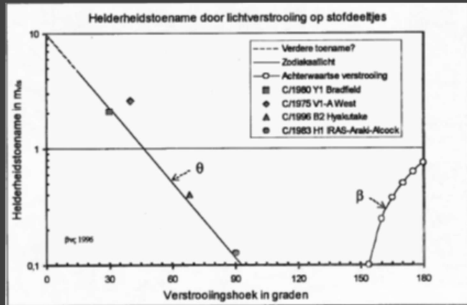
an van Dorp

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Voorwaartse verstrooiing

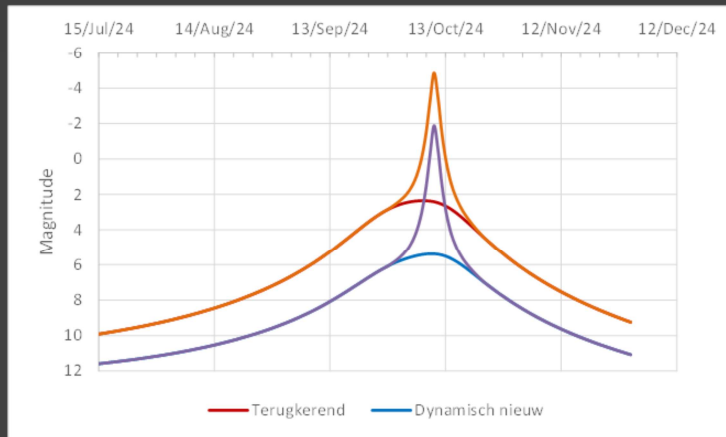
Als een komeet tussen aarde en zon door beweegt, is de verstrooiings-hoek klein.

Voorwaartse verstrooiing aan kleine deeltjes versterkt het licht vele malen als $\text{particle size} \approx \text{wave length}$.



Greenberg interstellar dust comet model of mm size particles embedded in ices.

Voorspelling C/2023 A3 (Tsuchinshan-Atlas)



Voorwaartse
verstrooiing



Perihelium 28 sep 24 @ 0,391 AE

Voorspelling Dynamisch Nieuw ($a > 20.000$ AE) $H_0 = 8,7$ $n = 2,4$

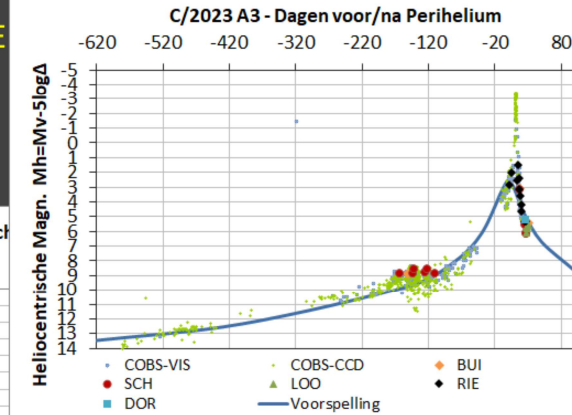
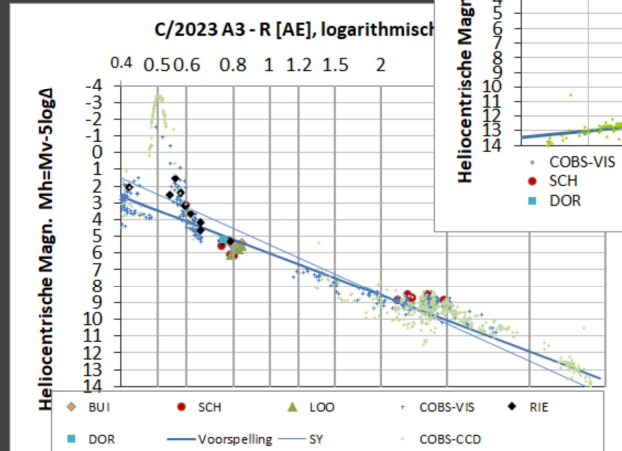
Voorspelling Terugkerend uit Oort wolk $H_0 = 6,5$ $n = 3,4$

$$m_h = m_1 - 5 \log \Delta = H_0 + 2.5n \log R$$

Twee helderheidsvoorspellingen, inclusief het effect van voorwaartse verstrooiing. Een voor dynamisch nieuw uit de Oort wolk (meest waarschijnlijk) en een voor een terugkerende komeet.

C/2023 A3 (Tsuchinshan-Atlas)

Perihelium 27 sep 24 @ 0,4 AE
 Laatste Voorspelling
 $H_0 = 6$ $n = 3,4$
 (Seiichi Yoshida 5.5 & 4)



Grootste helderheid
 $M_v = -4,9$

Forward Scattering

$$\Phi(\theta) = \frac{\delta_{90}}{1 + \delta_{90}} \left[k \left(\frac{1 + g_f^2}{1 + g_f^2 - 2g_f \cos \theta} \right)^{3/2} + (1 - k) \left(\frac{1 + g_b^2}{1 + g_b^2 - 2g_b \cos \theta} \right)^{3/2} + \frac{1}{\delta_{90}} \right]$$

Model uses Henyey-Greenstein function

$\theta = 180^\circ - \text{phase angle}$

$\delta_{90} = 1 = \text{dust to gas light ratio in coma (10 for dusty comet)}$

$k = 0.95 = \text{partitioning coefficient}$

$g_f = 0.9 = \text{forward scattering asymmetry factor}$

$g_b = -0.6 = \text{backward scattering asymmetry factor}$

Calibration:

$$m_{\Phi(\theta)} = -2.5 \log \Phi(\theta)$$

ICQ142 p39-46 Forward-Scattering Enhancement of Comet Brightness. I. Background and Model

ICQ144 p119-129 Forward-Scattering Enhancement of Comet Brightness. II. The light curve of C/2006 P1 (McNaught)

Joseph N. Marcus

21-okt-25

Johan van Dorp

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Uitbarstingen

Veroorzakers van onvoorspelbaar gedrag van komeen

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12P/Pons-Brooks (Halley type)

Periheliumdoorgang: 21 apr '24

Periheliumafstand q: 0.78 AE

Maximale helderheid: Mv = 4.4

Dichtste nadering tot de Aarde: 3 jun 2024: 1.546 AE

Vaak uitbarstingen



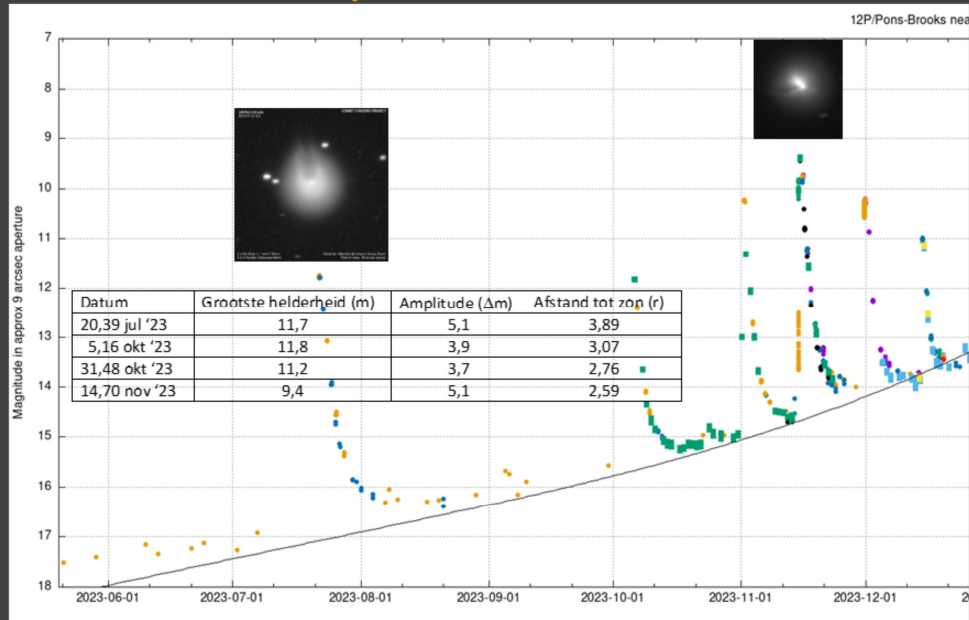
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P = 70 y

12P/Pons-Brooks



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12P/Pons-Brooks



M. Mattiazzo 30 april 2024, 10x30s

12P Pons-Brooks, 2024 April 30 at 08:00UT, C11 RASA V2.2 + Canon 6D, iso1600 10x30sec, FOV 3 deg, North up, M. Mattiazzo, Swan Hill, Victoria, Aus

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Kreuz Sungrazers

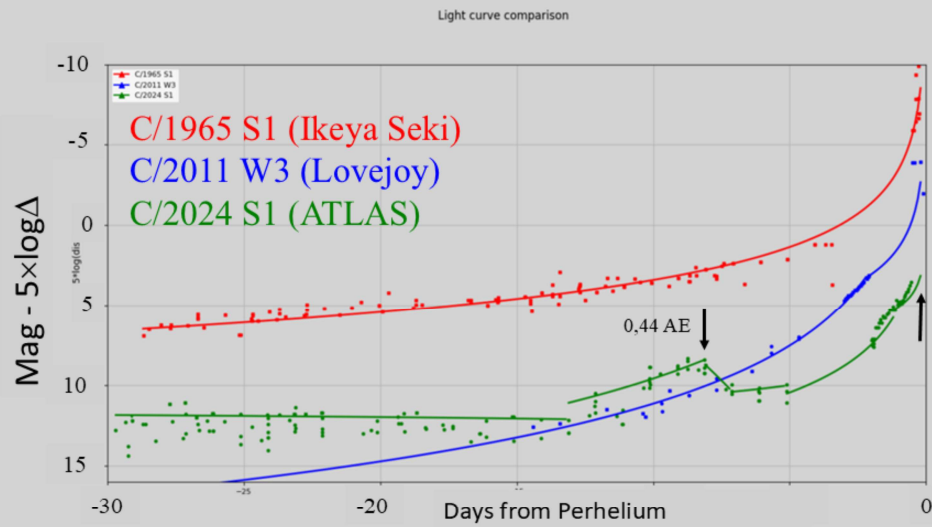
Perihelium = 0.0055-0.0077 AE
(one solar diameter = 0.0046 AE)

$a = 75-100$ AE

$P = 500-1000$ yrs

C/2011 W3 (Lovejoy) 16 dec 2011 perihelium, desintegreerd 20 dec

C/2014 A1 (Atlas)



Vergelijking helderheidscurve met bekende Kreuz kometen
C/1965 S1 (Ikeya-Seki) en C/2011 W3 (Lovejoy)

Kreuz Sungrazers

Elements Equinox J2000.0	Sekanina 2004			q	e	P (yr)	ω	Ω	i	lp	Bp	Q	e
Comet	T (UT)												
C/-314-315 progenitor	-314												
6-10 m/s, at 50 AE, 30 y before Perih	326	Mar	28										
C/356, Superfragment II	356	Mar	28.91	0.008387	0.9998986	752.2	68.416	345.914	141.659			165.42	
C/356, Superfragment I	356	Apr	4.47	0.005710	0.9999306	746.1	76.367	355.650	143.417			164.55	
C/1100 not observed	1100	Mar	27.99	0.005219	0.9999386	784.4	80.183	0.420	143.972				
8 m/s, 127 d after Perih	1100	Aug	2										
6.6 m/s, at 10.9 AU, 3 y after Perih	1102	Dec											
X/1106 C1 Great Comet 1106	1106	Jan	26.50	0.007979	0.9999065	787.8	68.200	345.805	141.703	xxx	xxx	170.67	
7 m/s, 0.75 AE, 18 days after Perih	1106	Feb	13.5										
C/1668 E1	1668	Feb	28.08	0.066604	1	784	109.810	2.520	144.38	248.61	+33.23	170	0.999217
C/1689 X1	1689	Dec	2	0.060000									
C/1695 U1	1695	Oct	23.1										
7 m/s, at 160 AE	1700												
C/1702 D1	1702	Feb	15.1										
at 150 AU	1749												
C/1843 D1 (I) Great March Comet	1843	Feb	27.91434	0.0054897	0.9999363	800	82.8063	3.7283	144.3893	282.58	+35.29	172.36	
10 m/s at 112 AU	1847	Feb											
C/1880 C1 (I) Great Southern Comet	1880	Jan	28.09679	0.0055355	0.99993442	775.5	85.1084	6.4987	144.5229	282.38	+35.25		-1
X/1882 K1 Tewfik Eclipse Comet	1882	May	17.5										
C/1882 R1 (II) Great September Comet	1882	Sep	17.72410	0.0077508	0.99991034	803.7	69.5851	347.6559	142.0109	282.94	+35.23	172.89	
C/1887 B1 (I) Great Southern Comet	1887	Jan	11.934	0.004833	0.9999473	878.7	83.597	4.410	144.396	280.24	+41.79		-1
C/1945 X1 (VIII) duToit	1945	Dec	27.98358	0.0074191	0.99992309	947.4	69.684	347.7075	142.1129	289.73	+31.96		-1
Fragment Ite, not observed	1963	Jul/Aug											
C/1963 R1 (V) Pereyra	1963	Aug	23.95638	0.0050461	0.9999439	852.8	86.07839	8.0816	144.5819	282.65	+35.33	179.89	
C/1965 S1 (VIII) ikeya-Seki	1965	Oct	20.47270	0.0082968	0.99990405	804.1	70.47194	348.6998	142.3421	282.95	+35.22	172.93	
C/1970 K1 White-Ortiz-Bolelli	1970	May	14.48735	0.0088966	0.9999084	956	61.3335	337.0267	139.0824	282.95	+35.07	194.24	
Fragment IIf	1979	Jul											
C/2011 W3 Lovejoy	2011	Dec	16.012	0.005554	0.999929	622	53.5092	326.3691	134.3558	282.98	+35.09	157.36	
Superfragment I	Superfragment II												
C/2024 S1 (ATLAS), voorlopig A11bP71	2024	Oct	28.45981	0.008313	1.000625		68.81055	347.1123	141.8853				

21-okt-25

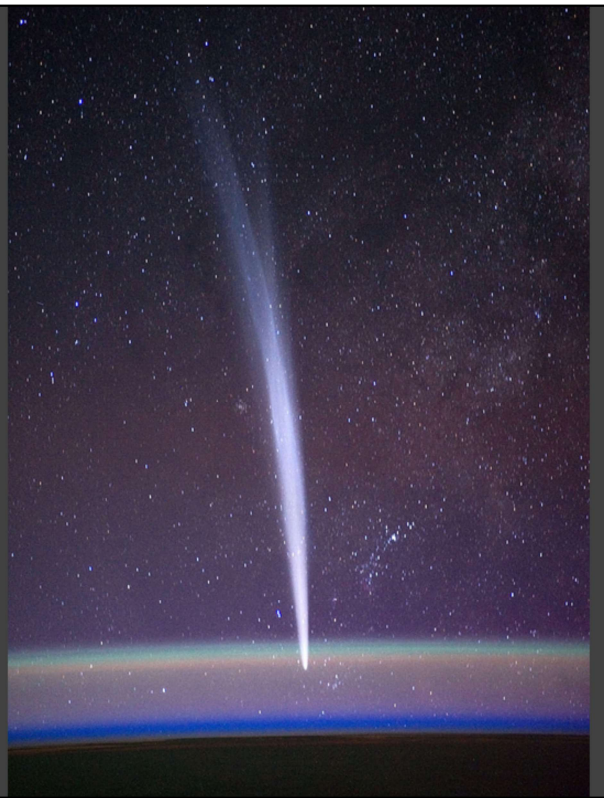
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C/2011 W3 (Lovejoy)

Enkele dagen na
perihelium (15 dec 11)
gedesintegreerd

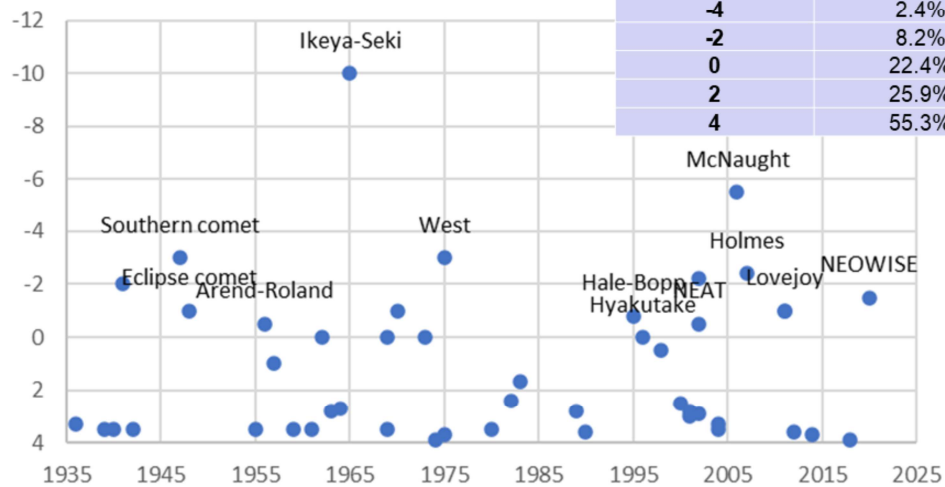
C/2011 W3 (Lovejoy)
Kreuz sungrazer
0,005 AE
21 dec 11
(Dan Burbank / ISS)



C/2011 W3 (Lovejoy) – Kreutz. We hopen allemaal op een nieuwe Kreutz komeet met zeer korte periheliumafstand en daardoor grote stof en gas productie. P=15dec2011, desintegrated 20dec2011

Great comets

Occurance Comets Brighter than $m=4$

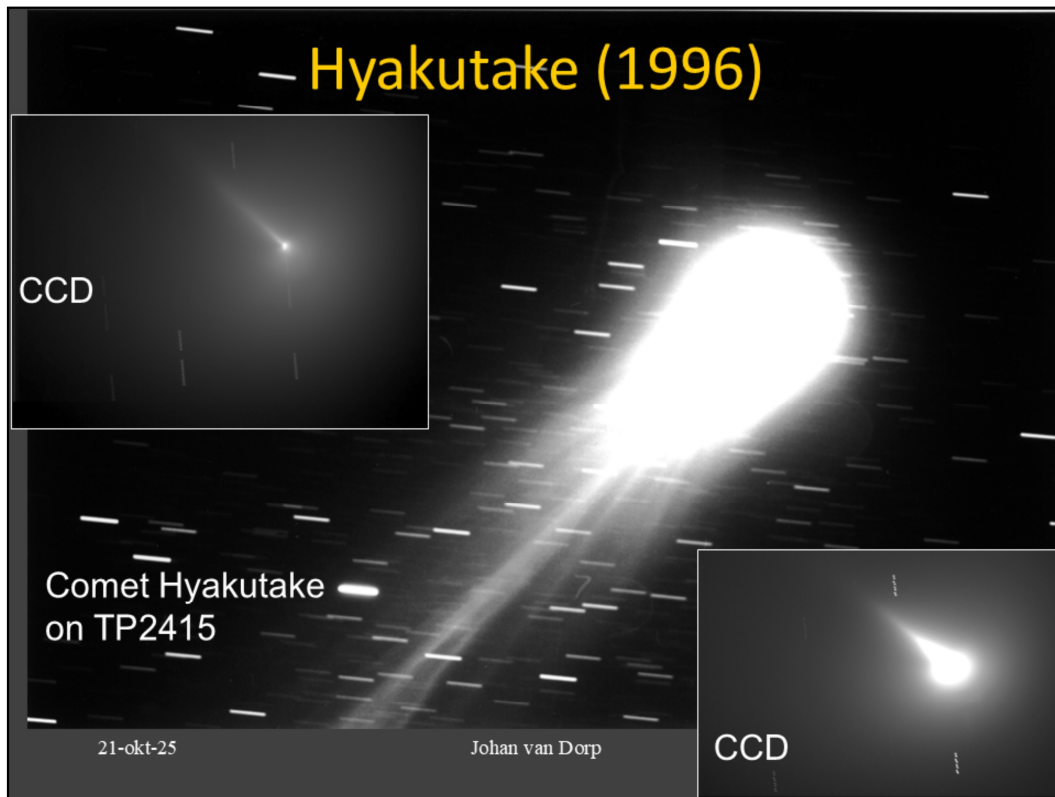


Komeet helderder dan magnitude	Kans per jaar op een dergelijke verschijning
-6	1.2%
-4	2.4%
-2	8.2%
0	22.4%
2	25.9%
4	55.3%

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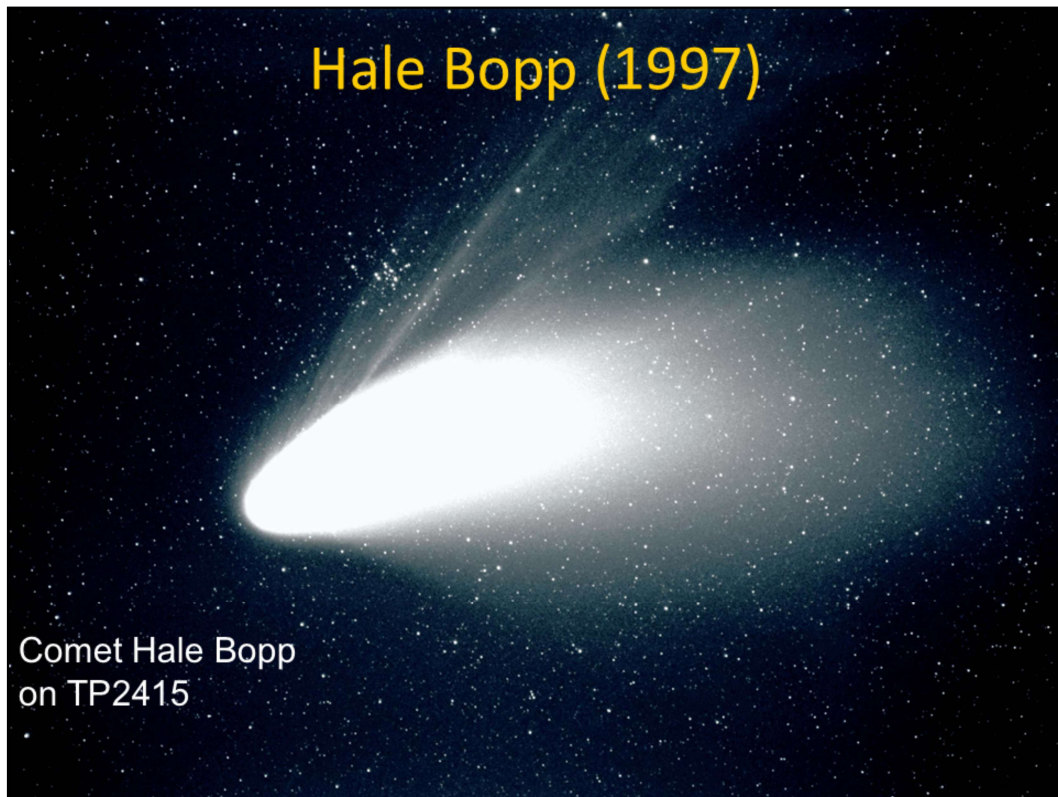
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Hyakutake on film (20 min on TP2415, 300 mm f/2.8, 23/3/96) and CCD (2x stack of several prime focus images at CG11)



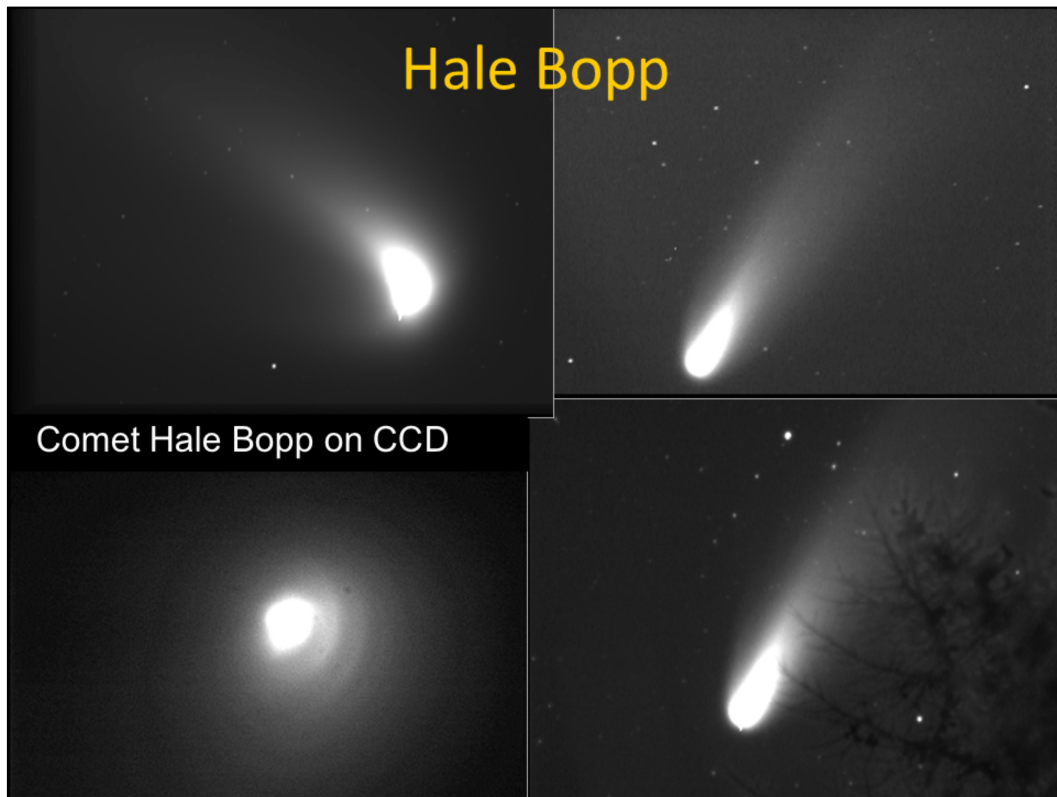
Comet Hyakutake in color (300 mm f/2.8, 20 min, HG8000 23/3/96)



Comet Hale-Bopp on TP2415. 300 mm, f/2.8 12 min, 6/4/97, 50-60 km doorsnede



Come Hale Bopp, Kodak Pro400 color film, 135 mm, f/2.8, 8 min on Beyers
Camtrack, 30/3/97



Comet Hale Bopp on CCD.

CG11 Prime focus image (lower left) shows “rotating shock waves”



Sodium tail

Connectie Meteoren

meteoren zwerm

=

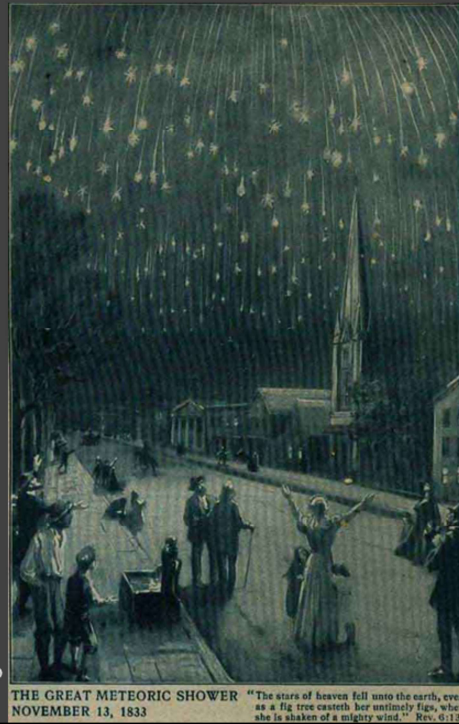
“trails” in baan komeet
Meteoren als aarde de
baan doorkruist

1835, Denison Olmsted:
Kosmische oorsprong meteoren

1862 Giovanni Schiaparelli
Demonstreerde connectie met
kometen

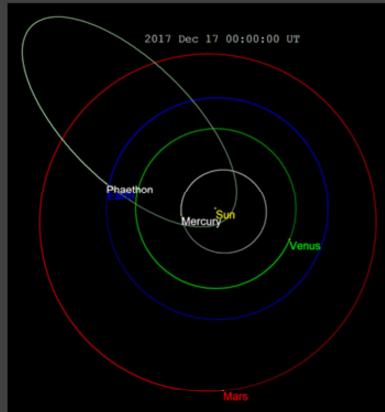
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Leoniden 1833

3200 Phaeton



1982 TP – ontdekt door IRAS
Periode: 523.5 dagen / 1.43 jr
Perihelium: 0.14 AE
Aphelium: 2.4 AE
Doorsnede: 6.25 km



Rotskomeet

Potentially Hazardous Asteroid (PHA)

PHA: <0.05 AE

3200 Phaethon: 0.019 AE

Bron Geminiden meteorenzwerm

Extinct comet

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Perihelium Mercurius: 0,30-0,46 AE.

Apollo: halve lange as groter dan Aarde (kan Aarde kruisen), Pallas: vanwege hoge inclinatie

$0.05 \text{ AE} = 7.500.000 \text{ km}$

$0.019 \text{ AE} = 2.850.000 \text{ km}$

Val frequentie meteorieten

Erwt	10 per uur
Walnoot	1 per uur
Appel	1 per 10 uur
Voetbal	1 per maand
50 meter	1 per eeuw
1 km	1 per 100.000 jaar
2 km	1 per 500.000 jaar
10 km	1 per 100.000.000 jaar

Totaal 80.000 ton materiaal per jaar

Meteoor zwermen

Meteoor zwerm	Periode	Progenitor komeet	ZHR
Lyriden	22/23 april	C/1861 G1 (Thatcher)	18
δ Aquariden	30/31 juli	96P/Machholz	16
α Capricorniden	30/31 juli	169P/NEAT	5
Perseïden	12/13 aug.	109P/Swift-Tuttle	100
Orioniden	20/21 okt.	1P/Halley	20
Leoniden	17/18 nov.	55P/Tempel-Tuttle	15
Geminiden	13/14 dec.	3200 Phaethon	150

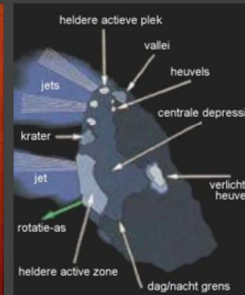
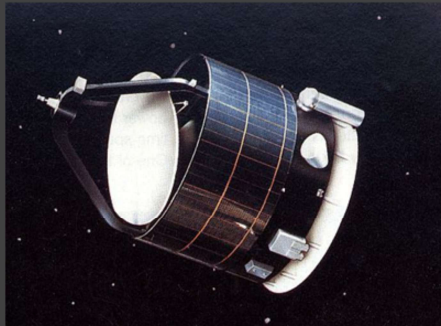
Ruimte missies

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Giotto (1986) 1P/Halley



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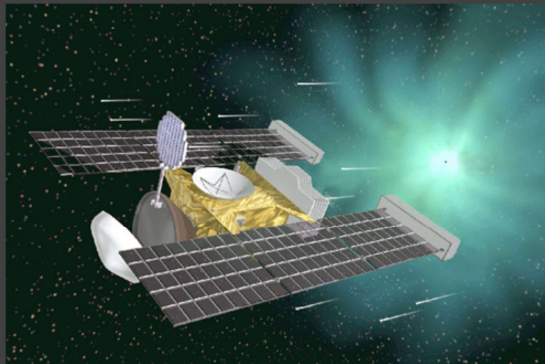
Images showed Halley's nucleus to be a dark peanut-shaped body, 15 km long, 7 km to 10 km wide. Only 10 % of the surface was active, with at least three outgassing jets seen on the sunlit side. Analysis showed the comet formed 4.5×10^9 years ago from volatiles (mainly ice) that had condensed onto interstellar dust particles. It had remained practically unaltered since its formation.

Measured volume of material ejected by Halley: 80 % water, 10 % carbon monoxide, 2.5 % A mix of methane and ammonia.

Other hydrocarbons, iron, and sodium were detected in trace amounts.

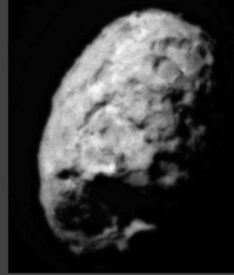
Giotto found Halley's nucleus was blacker than coal, which suggested a thick covering of dust.

Stardust (2004) 81P/Wild-2



Stardust

1999 – lancering
2004 – Wild
2006 – terugkeer



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Verwacht waren zeer kleine deeltjes (stardust) maar deeltjes waren veel groter dan verwacht.

Daarom ook diepe impact sporen in de aerogel.

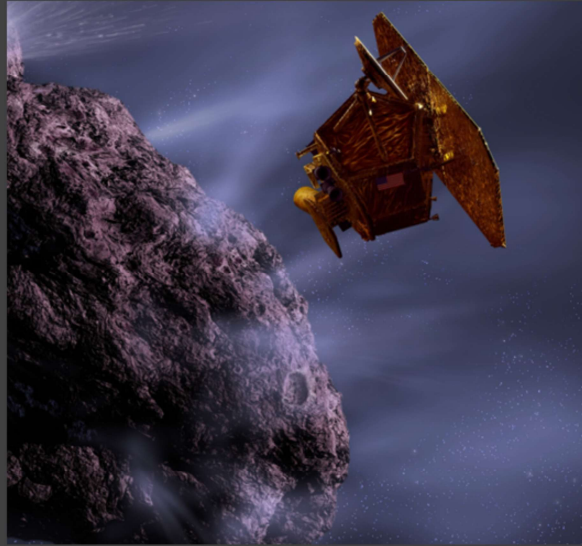
Meeste deeltjes gevormd onder zeer hete omstandigheden waarschijnlijk tijdens de vorming van het jonge zonnestelsel

en daarna pas naar buitenste delen zonnestelsel getransporteerd

Deep Impact (2005) 9P/Tempel-1

Deep Impact

2005/01 – launching
2005/07 – Tempel 1



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Deep Impact is a NASA space probe launched on January 12, 2005. It was designed to study the composition of the comet interior of 9P/Tempel, by releasing an impactor into the comet. At 5:52 UTC on July 4, 2005, the impactor successfully collided with the comet's nucleus. The impact excavated debris from the interior of the nucleus, allowing photographs of the impact crater. The photographs showed the comet to be more dusty and less icy than had been expected. The impact generated a large and bright dust cloud, which unexpectedly obscured the view of the impact crater. On November 4, 2010, the Deep Impact extended mission (EPOXI) returned images from comet Hartley 2.[59] EPOXI came within 700 kilometers (430 mi) of the comet, returning detailed photographs of the "peanut" shaped cometary nucleus and several bright jets. The probe's medium-resolution instrument captured the photographs.[59]

Rosetta (& Philae) (2014) 67P/Churyumov-Gerasimenko

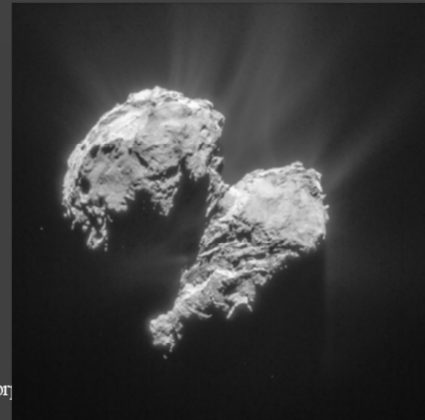
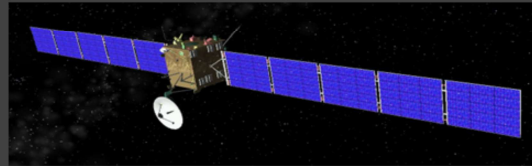


Mei 2014:
67P/Churyumov-
Gerasimenko

November 2014:
landing Philae

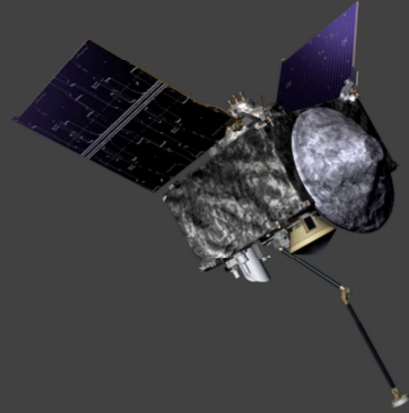
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The nucleus of Comet 67P/Churyumov-Gerasimenko as imaged by the Rosetta spacecraft on 2015 March 22.

Osiris-REx (2016-23) 101955 Bennu



20 Oct 2020 touch down on Bennu
24 Sep 2023 sample return

Organic compounds

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Fotomateriaal bijzondere kometen

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17P/Holmes (2007)

The 2007 mega-burst of 17P is unrivalled as the most powerful event of this kind on record

29 Oct 2007
Jery Lodriguess

False nucleus and inner coma
10 x 10-sec exposures
07:51 UT 29 Oct 2007.
N is up

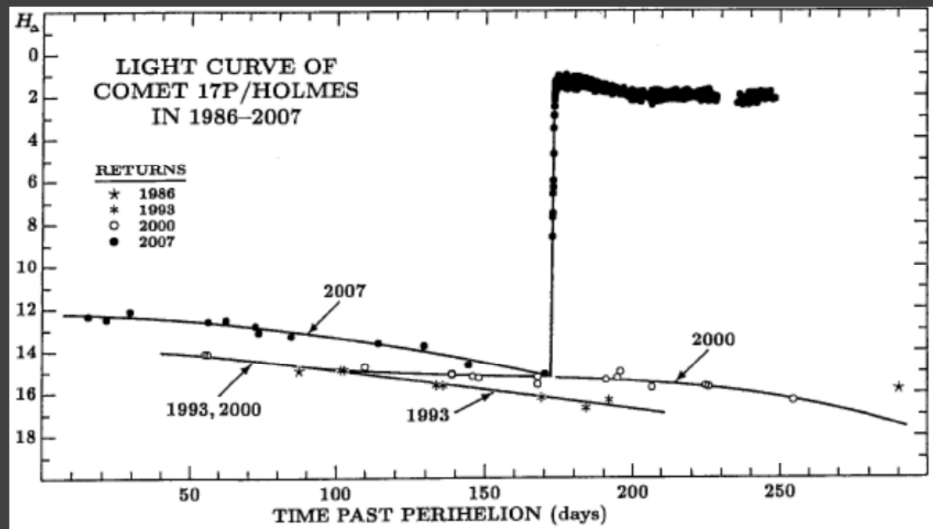
© 2007 Jerry Lodriguess / AstroPix.com

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17P/Holmes Explosion



21-okt-25

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17P/Holmes (2007)

Spectacular outburst
Oct 24th

17th to 2.5th
magnitude

29 Oct 2007
Jerry Lodriguss

21-okt-25

Johan van Dorp

3 x 600-sec exposures
01:11 UT 31 Oct 2007
N is up

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17P/Holmes (2007)

Comet 17P/Holmes began a spectacular outburst on October 24th, going from 17th magnitude to 2.5th magnitude, an increase of more than 1 million times in brightness, to become an unaided-eye object in the constellation of Perseus.

30 Oct 2007
Jerry Lodriguess

21-oct-25

The faintest hint of a blue ion tail is visible to the lower right of the brilliant coma of Comet 17P/Holmes, seen here in a composite of 3 x 600-second exposures starting at 01:11 UT on 31 October 2007. North is to the top in this image.

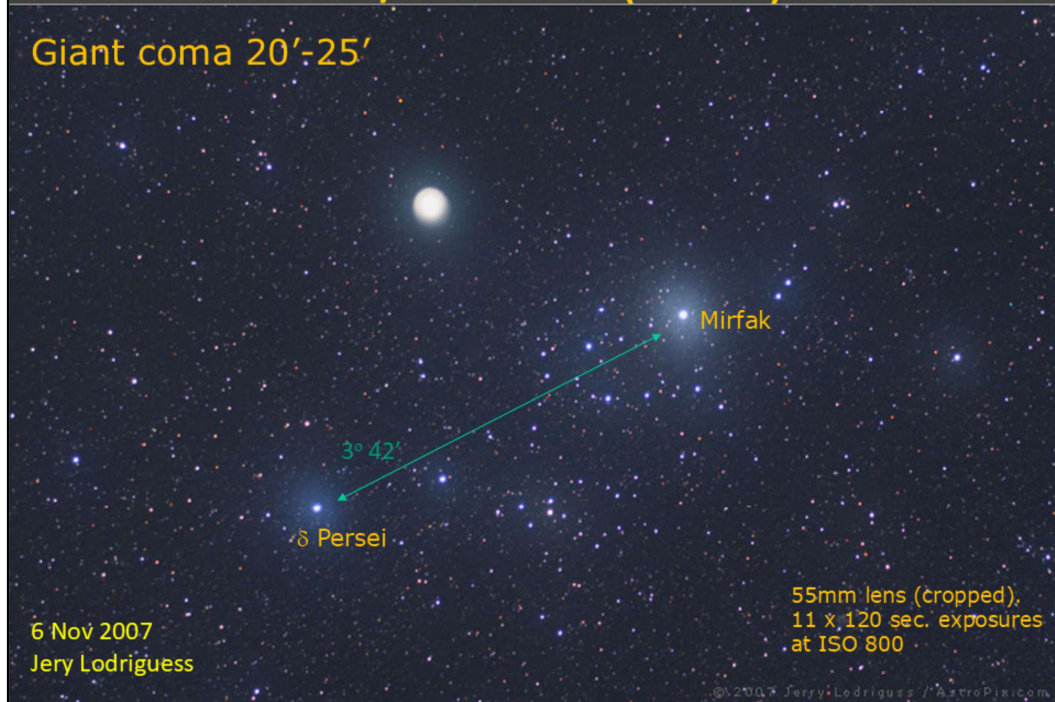
Johan van Dorp

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17P/Holmes (2007)

Giant coma 20'-25'



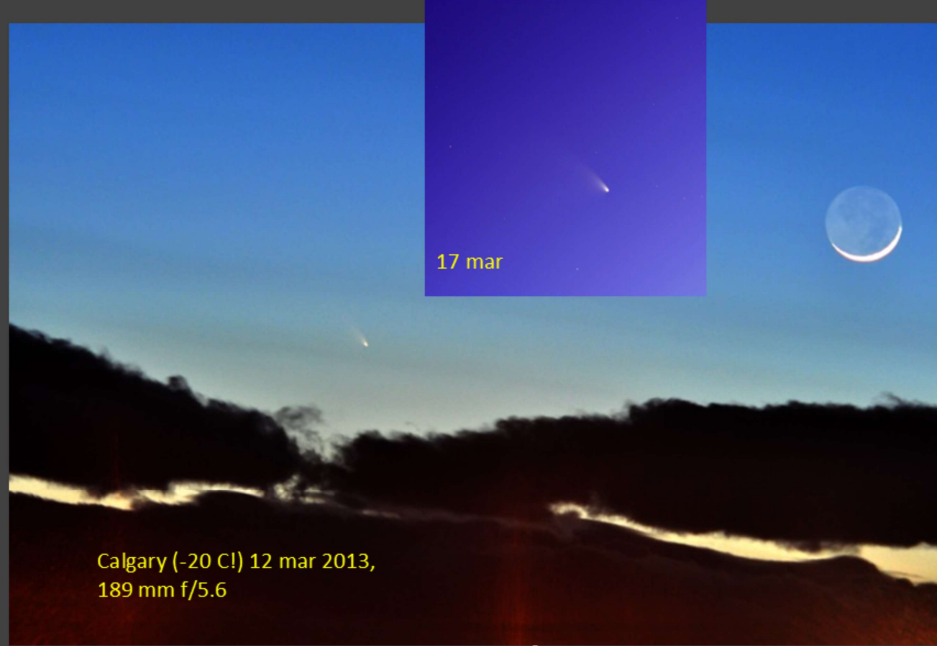
C/2014 UN271 (Bernardinelli-Bernstein)



28 mar 22 Hubble

Ontdekt in 2021 op
beeldmateriaal uit 2014.
Toen op 29 AE; actief door
CO/CO₂ verdamping
doorsnede ~100-200km,
(based on 5% albedo)
perihelium 28/1/31 at 10.9 AE

C/2011 L4 (PanSTARRS)



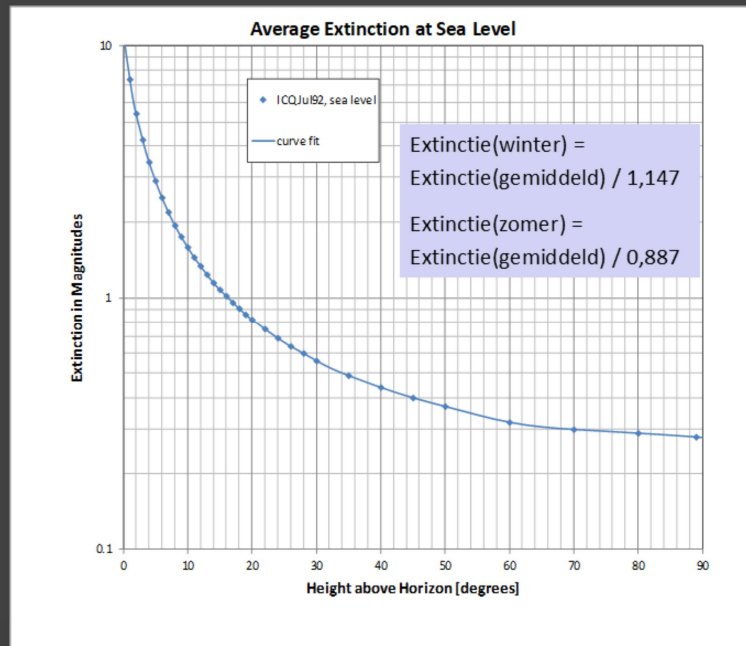
Back-up

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Extinctie



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Water Production [mol/s]

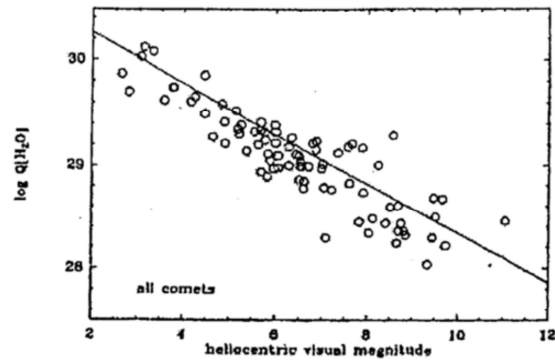


Figure 1. The correlation between heliocentric visual magnitudes and the water-production rates observed in 13 comets. From Jorda *et al.* (1992).

Bron:
Comets III

Afρ

Why Use the Afρ Quantity?

The Afρ quantity was introduced by A'Hearn *et al.* (1984) with the aim of comparing photometric data obtained with different instruments and geometric circumstances. At that time, this quantity proved useful for observations performed with photoelectric photometers, but nowadays it is commonly derived also from the analysis of CCD images. There are several advantages in using this quantity, chiefly:

- It is simple and affordable for amateur astronomers.
- The Afρ quantity refers to the “stationary coma” model, where it is assumed that dust expands at constant speed, and, if this condition is satisfied, it is independent of the measuring window used for photometry. This greatly reduces instrumental errors, as it is much less sensitive to the size of the photometric window.
- It allows amateur astronomers to obtain sets of data that are comparable with those obtained with professional equipment.

¹ The parameter introduced by A'Hearn and colleagues in the 1980s that is intended to be independent of the size of the aperture through which the dust is observed. Their quantity Afρ is given by $A(\theta)f\rho = qr^2\Delta F_\lambda/d$, where A is the Bond albedo for the particular scattering angle (θ); f is the so-called “filling factor” of the grains in the field-of-view, ρ is the radius of the assumed-circular field-of-view; Δ and r are given in AU; the mean cometary continuum flux averaged over the filter bandpass (F_λ) is given in $\text{erg cm}^{-2} \text{s}^{-1} \text{\AA}^{-1}$; d is the diameter of the field-of-view in arcsec; and q is a coefficient that is a function of solar flux (tabulated by A'Hearn *et al.* 1995, *Icarus* 118, 223). The filling factor is the number of grains per unit area, divided by the area of the field-of-view, times their mean cross-section. As a crude estimate, the value of Afρ in 1000 cm roughly equals the production of dust in metric tons per second. There are many assumptions used in this quantity, however, assuming a static picture for size distribution and physical nature of the scattering particles and for expansion velocity (thus somewhat analogous to the situation with the Haser model). – Ed.

Bron:
Comets III

Saturation Vapour Pressure

Bron:
Comets III

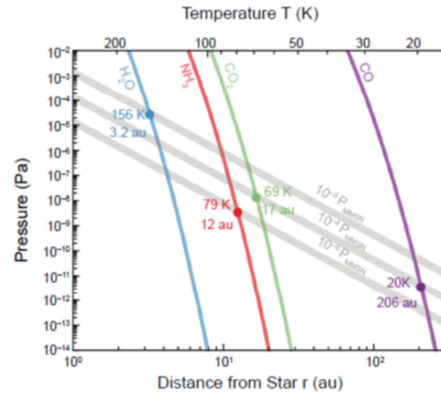


Fig. 2. Saturation vapor pressures for pure CO, CO₂, NH₃, and H₂O ices (thin lines) as a function of temperature T (indicated on the top edge). For reference, the thick lines show how the temperature and 0.1, 0.01, and 0.001% of the total midplane gas pressure vary with orbital radius (indicated on the bottom edge) in a radially extended version of the classical, optically thin minimum-mass solar nebula (Hayashi, 1981). The circles mark the locations of the snowlines.

MMSN = minimum mass solar nebula.

Tisserand Criterion Periodic

OCCs → HTC's drawn in by gas giants

OCCs → detached objects → SDOs (scattered disk objects)

SDOs belong to TNOs, e.g. Sedna = SDO.

SDOs are scattered by gas giants and are origin of most periodic comets

SDO = $\{e \in [0-0.8]; i < 40^\circ; q > 30 \text{ AU}\}$

SDO → Centaurs (e.g. 29P/SW-1, 2060 Chiron) with orbit between Jupiter & Neptune [5-30 AU]

Centaurs have erratic, unstable orbits

Centaurs → JFCs migration to inner solar system

Tisserand parameter w.r.t. Jupiter

$$T_J = \frac{a_J}{a} + 2 \sqrt{\frac{a}{a_J} (1 - e^2) \cos i}$$

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SPCs short period comets <200j. $T_J=2-3$ for JFCs. $T_J<2$ for HTC's (scattered disk origin?). $T_J>3$ for ETCs.

Orbital dynamics of comets

OCCs → HTC drawn in by gas giants

OCCs → detached objects → SDOs (scattered disk objects)

SDO belong to TNOs, e.g. Sedna = SDO.

SDOs are scattered by gas giants and are origin of most periodic comets

SDO = $\{e \in [0-0.8]; i < 40^\circ; q > 30 \text{ AU}\}$

SDO → Centaurs (e.g. 29P/SW-1, 2060 Chiron) with orbit between Jupiter & Neptune [5-30 AU]

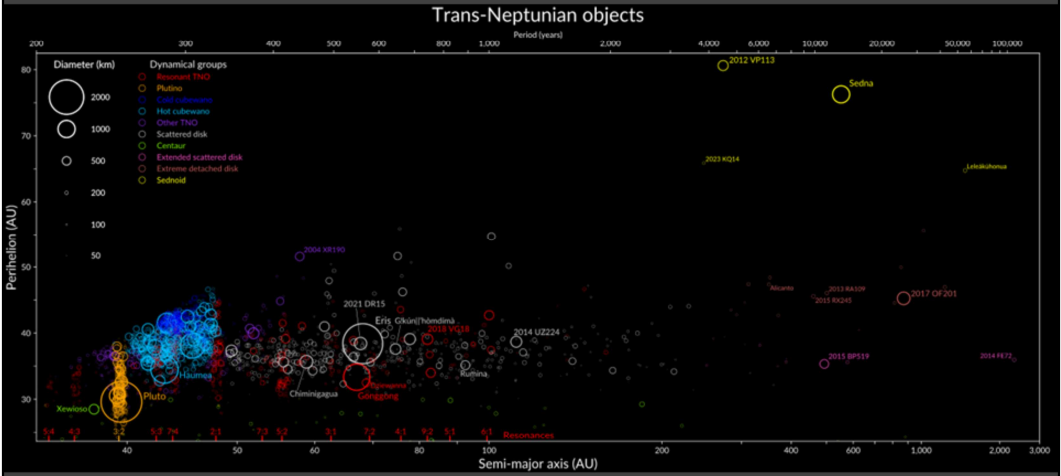
Centaurs have erratic, unstable orbits

Centaurs → JFCs migration to inner solar system

OCC = Oort Cloud Comet; HTC = Halley type comet

JFC = Jupiter family comet; SDO = Scattered disk object

TNOs

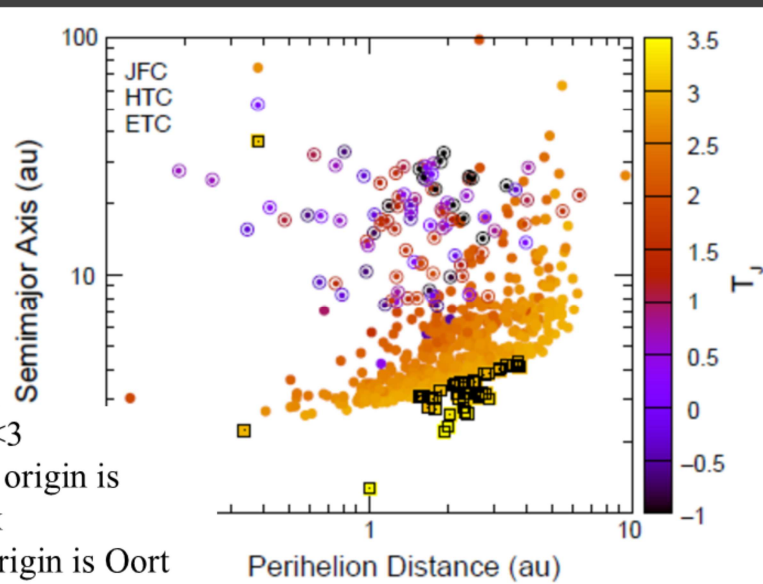


Tisserand Criterion Periodic

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Most SPCs $T_J \sim < 3$

- JFCs $2 < T_J < 3$ origin is scattered disk
- HTC $T_J < 2$ origin is Oort cloud
- ETCs $T_J > 3$ after $1.5 \cdot 10^5$ revolutions



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SPCs short period comets $< 200j$. $T_J = 2-3$ for JFCs. $T_J < 2$ for HTCs (scattered disk origin?). $T_J > 3$ for ETCs.

Oort Cloud & Scattered disk

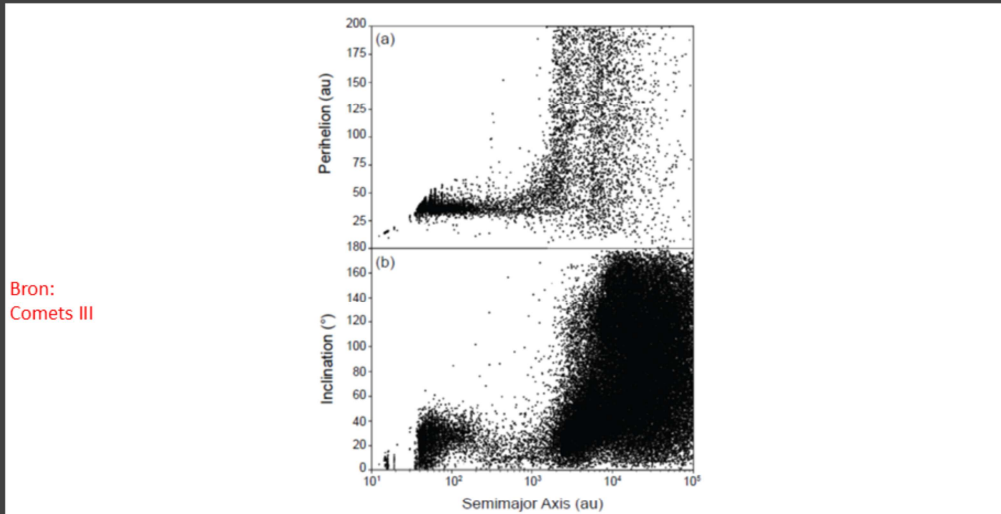


Fig. 9. Perihelia (upper panel) and inclinations (lower panel) vs. semimajor axes of particles at $t = 4$ G.y. in a simulation forming the Oort cloud and scattered disk concurrently. Plot is generated from the “OC” simulation of *Kaib et al. (2019)*.

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Discovery by surveys

Survey	Location*	SPCs†	LPCs†	Total
Catalina	G96, 703, I52	200	193	393
Pan-STARRS	F51, F52	112	142	254
LINEAR	704	91	128	219
NEAT	566,644	39	16	55
ATLAS	T05, T07, T08	16	35	51
NEOWISE	C51	16	23	39
Spacewatch	291,691	16	12	28
LONEOS	699	17	5	22
ZTF/PTF	I41	2	16	18
SOHO/SWAN‡	249	12	1466	1478
STEREO‡	C49	1	8	9

* The Minor Planet Center Observatory Code contributors.

† Short-period comets (SPCs) with orbital periods <200 years and long-period comets (LPCs) with orbital periods ≥ 200 years.

‡ Sun-looking survey total.

Note that the count of SOHO-discovered comets includes only those contributions with additional non-SOHO observations (see text).

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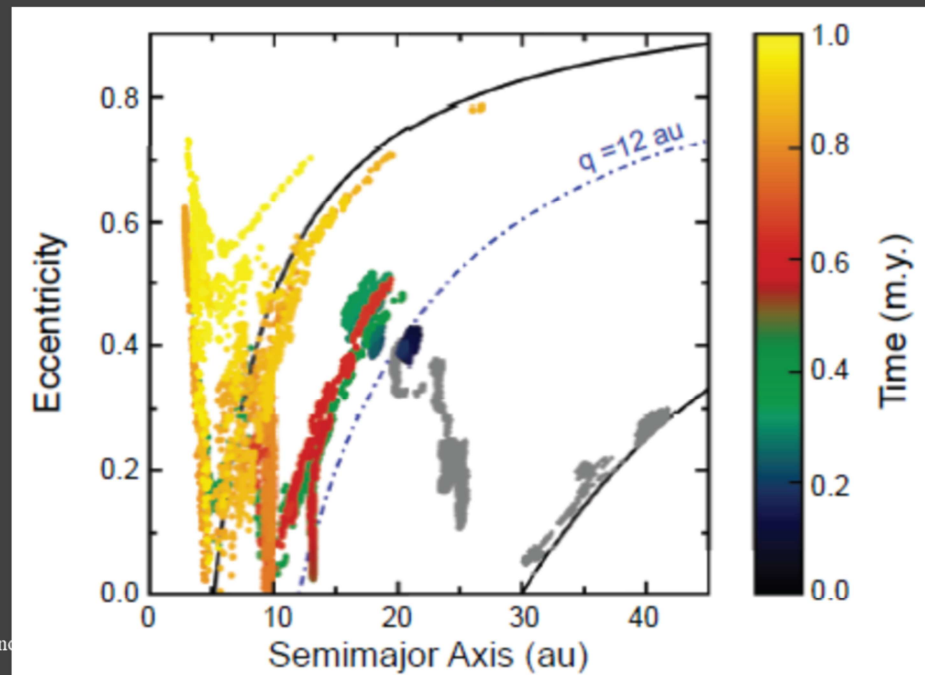
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Back-up

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Example of one possible orbit evolution from TNO region in e-versus-a plane. 100yr per data point. Prior 1 m.y. in gray.

Black lines 5.2-30 AU.

Bulk Density

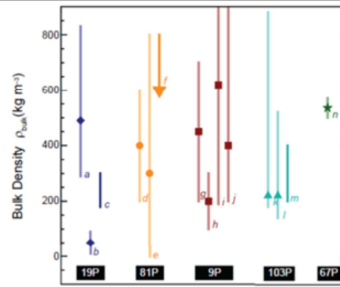


Fig. 3. Summary of bulk densities derived for comet nuclei with a volume measured by spacecraft missions. References: for 19P/Borrelly — (a) 490⁺³⁴⁰₋₂₀₀ kg m⁻³ (Farnham and Cochran, 2002), (b) 50 ± 40 kg m⁻³ (Sosa and Fernández, 2009), (c) 180–300 kg m⁻³ (Davidsson and Gutiérrez, 2004), for 81P/Wild 2 — (d) 400 ± 200 kg m⁻³ (Szutowicz et al., 2008), (e) 300⁺⁵⁰⁰₋₃₀₀ kg m⁻³ (Sosa and Fernández, 2009), (f) ≈600–800 kg m⁻³ (Davidsson and Gutiérrez, 2006), for 9P/Tempel 1 — (g) 450 ± 250 kg m⁻³ (Davidsson et al., 2007), (h) 200 ± 100 kg m⁻³ (Sosa and Fernández, 2009), (i) 620⁺⁴⁷⁰₋₃₃₀ kg m⁻³ (A'Hearn et al., 2005b), (j) 400 kg m⁻³ (200–1000 kg m⁻³) (Richardson et al., 2007), for 103P/Hartley 2 — (k) 220 kg m⁻³ (180–880 kg m⁻³) (A'Hearn et

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Magnitude scale

The dimmer an object appears, the higher the numerical value given to its magnitude, with a difference of 5 magnitudes corresponding to a brightness factor of exactly 100. Therefore, the magnitude m , in the spectral band x , would be given by

$$m_x = -5 \log_{10} \left(\frac{F_x}{F_{x,0}} \right),$$

which is more commonly expressed in terms of common (base-10) logarithms as

$$m_x = -2.5 \log_{10} \left(\frac{F_x}{F_{x,0}} \right),$$

where F_x is the observed irradiance using spectral filter x , and $F_{x,0}$ is the reference flux (zero-point) for that photometric filter. Since an increase of 5 magnitudes corresponds to a decrease in brightness by a factor of exactly 100, each magnitude increase implies a decrease in brightness by the factor $\sqrt[5]{100} \approx 2.512$ (Pogson's ratio). Inverting the above formula, a magnitude difference $m_1 - m_2 = \Delta m$ implies a brightness factor of

$$\frac{F_2}{F_1} = 100^{\frac{\Delta m}{5}} = 10^{0.4 \Delta m} \approx 2.512^{\Delta m}.$$