

# Tasa de Producción de Agua en los Cometas

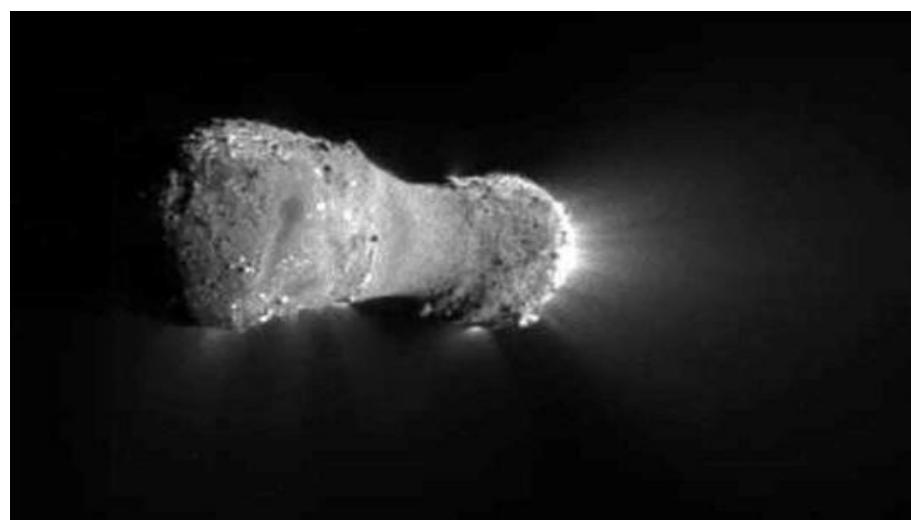
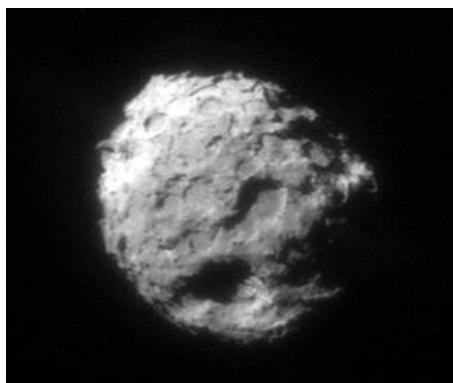
*Pedro Ignacio Deaza*



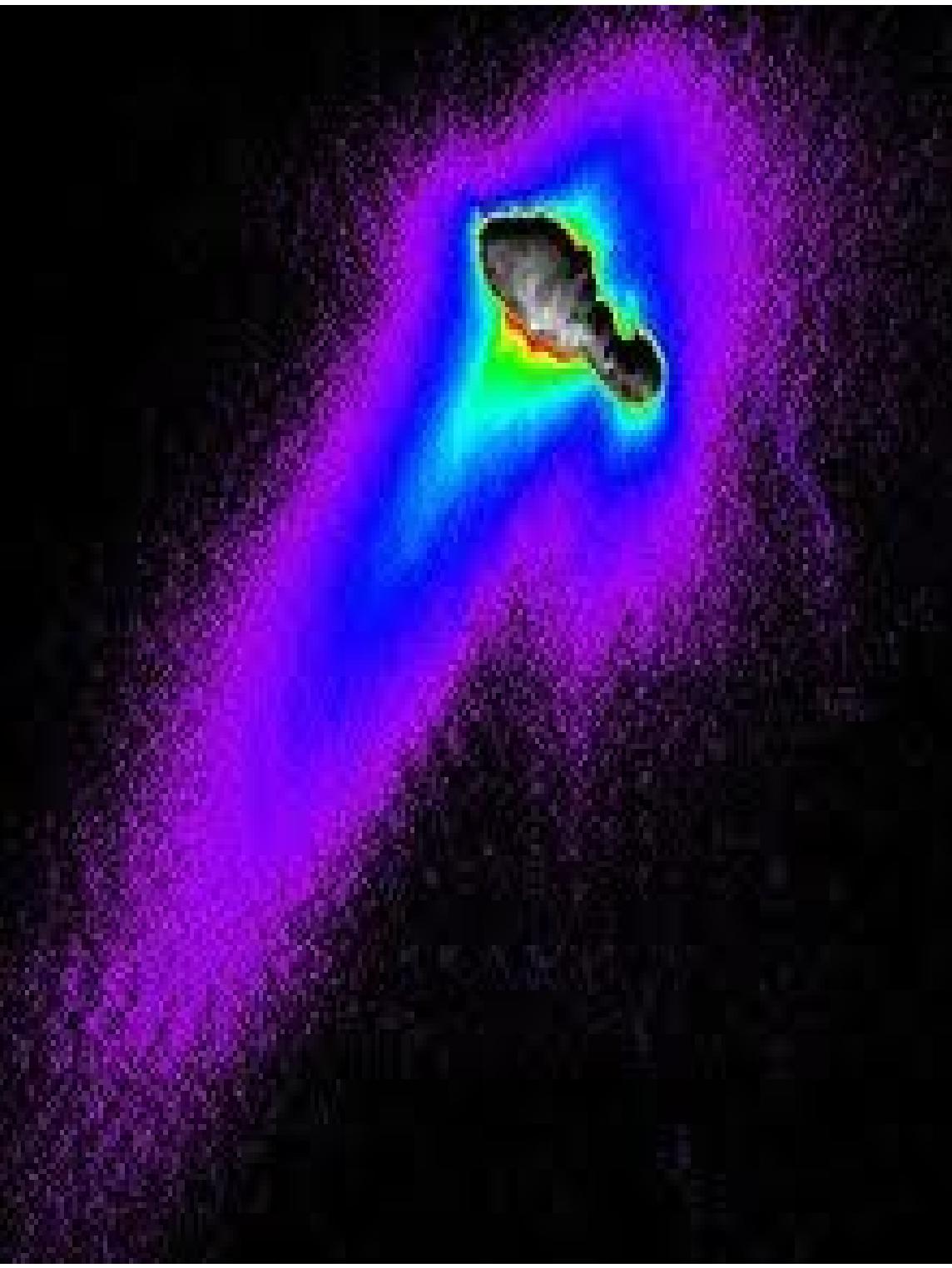
C/2012 S1 (ISON)  
2013-11-15 12:08 UTC



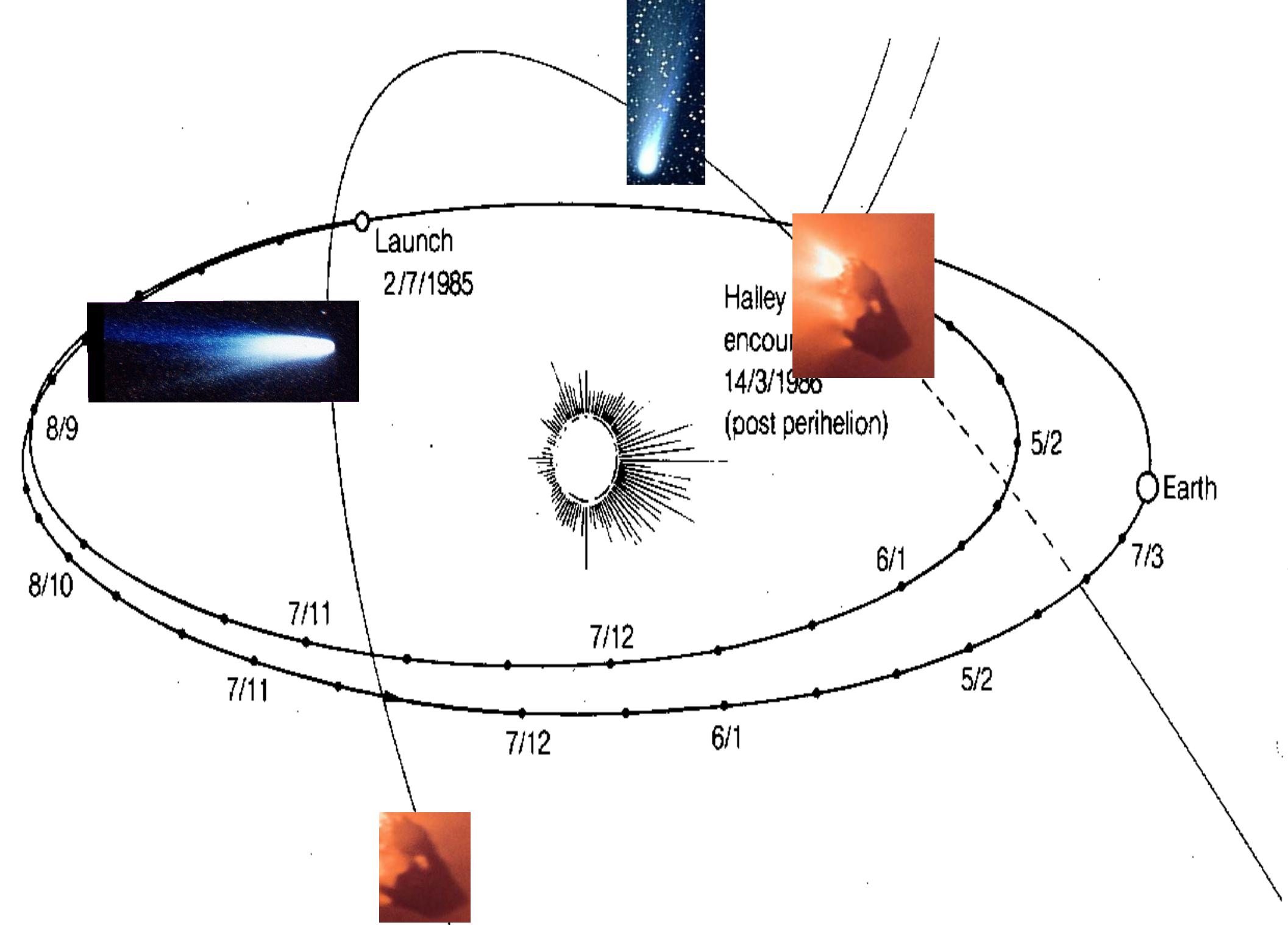
# Que son los cometas ?



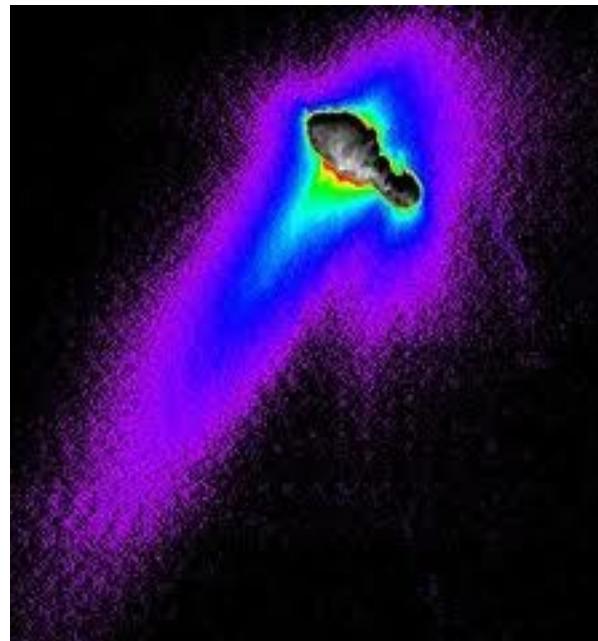
Uno o varios fragmentos rocosos de silicatos de Hierro, estructuras de Magnesio y manganeso Inmersos en una envoltura volátil cuya mezcla esta compuesta por Agua, Monóxido de Carbono, Dióxido de Carbono, Metano, Propano, Etanol, Metanol, Cianuro de Hidrógeno, Sulfido de Hidrógeno, Amoniaco, Acetileno y abundante polvo.



Las características físicas de los cometas se originan, desarrollan y se constituyen en fenómenos observables cuando el núcleo cometario ingresa al interior del sistema solar e interactúa con el viento solar.

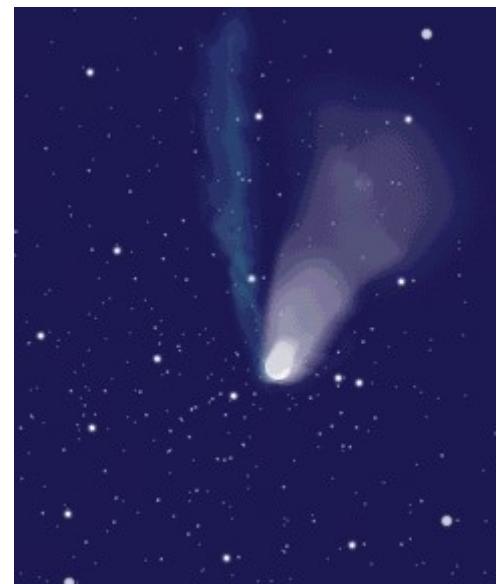


# Cuando el núcleo desnudo ingresa al sistema solar interior . . .



Inician los procesos de sublimación, se genera la coma, la cola de polvo, la cola iónica

La cola iónica se desconecta a causa de su interacción con el campo magnético solar



# 2P/Encke

alternate orbits: [epoch=2017-Feb-16.0] K173/3 (default) ▾

Orbital Elements at Epoch 2457800.5 (2017-Feb-16.0) TDB  
Reference: JPL K173/3 (heliocentric ecliptic J2000)

| Element        | Value  | Uncertainty (1-sigma)  | Units   |
|----------------|--|------------------------|---------|
| e              | .8483344648805893                              | 8.7798e-08             |         |
| a              | 2.214708946332168                              | 1.1514e-06             | au      |
| q              | .3358950174792145                              | 1.3726e-07             | au      |
| i              | 11.7782345748081                               | 9.2259e-06             | deg     |
| node           | 334.560002251314                               | 4.4579e-05             | deg     |
| peri           | 186.5634749500582                              | 4.5186e-05             | deg     |
| M              | 353.3934800530336                              | 2.7866e-05             | deg     |
| t <sub>p</sub> | 2457822.592439109404<br>(2017-Mar-10.09243911) | 0.00010078             | JED     |
| period         | 1203.85288218761<br>3.30                       | 0.00093877<br>2.57e-06 | d<br>yr |
| n              | .2990398622012829                              | 2.3319e-07             | deg/d   |
| Q              | 4.093522875185121                              | 2.1281e-06             | au      |

## Additional Model Parameters

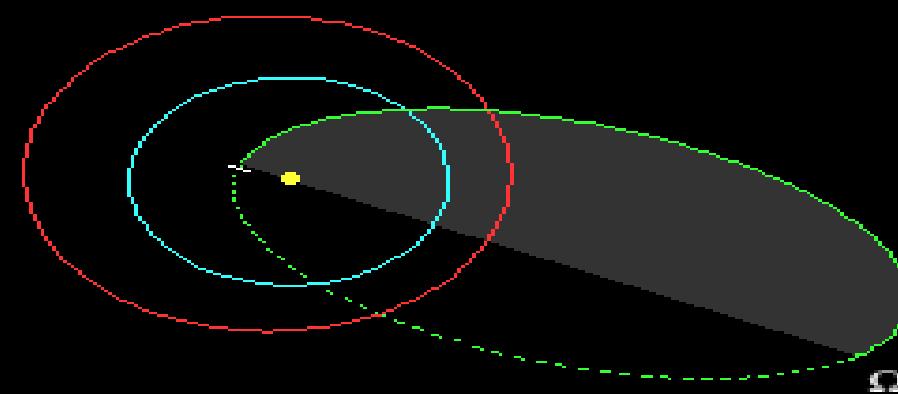
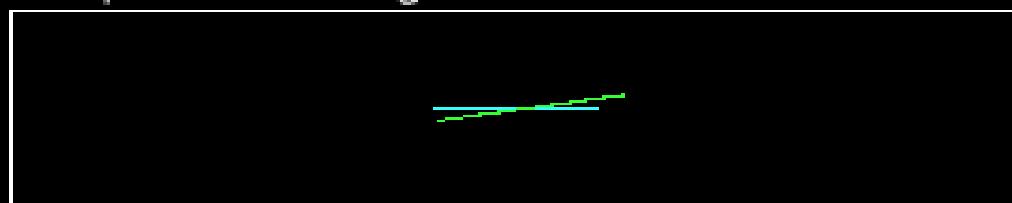
| Parameter | Value                  | Uncertainty (1-sigma) |
|-----------|------------------------|-----------------------|
| A1 [EST]  | 1.571586396593935E-13  | 3.164E-11             |
| A2 [EST]  | -1.222860693694846E-12 | 5.15E-13              |

| Orbit Determination Parameters |                      |
|--------------------------------|----------------------|
| # obs. used (total)            | 1909                 |
| data-arc span                  | 2704 days (7.40 yr)  |
| first obs. used                | 2009-08-15           |
| last obs. used                 | 2017-01-09           |
| planetary ephem.               | DE431                |
| SB-pert. ephem.                | SB431-BIG16          |
| condition code                 | 2                    |
| fit RMS                        | .71135               |
| data source                    | ORB                  |
| producer                       | Davide Farnocchia    |
| solution date                  | 2017-Jan-19 13:23:32 |

## Additional Information

Earth MOID = .172886 au  
Jupiter MOID = .921271 au  
T<sub>Jup</sub> = 3.026

## Ecliptic View Along The Asc.-Desc. Nodal Line

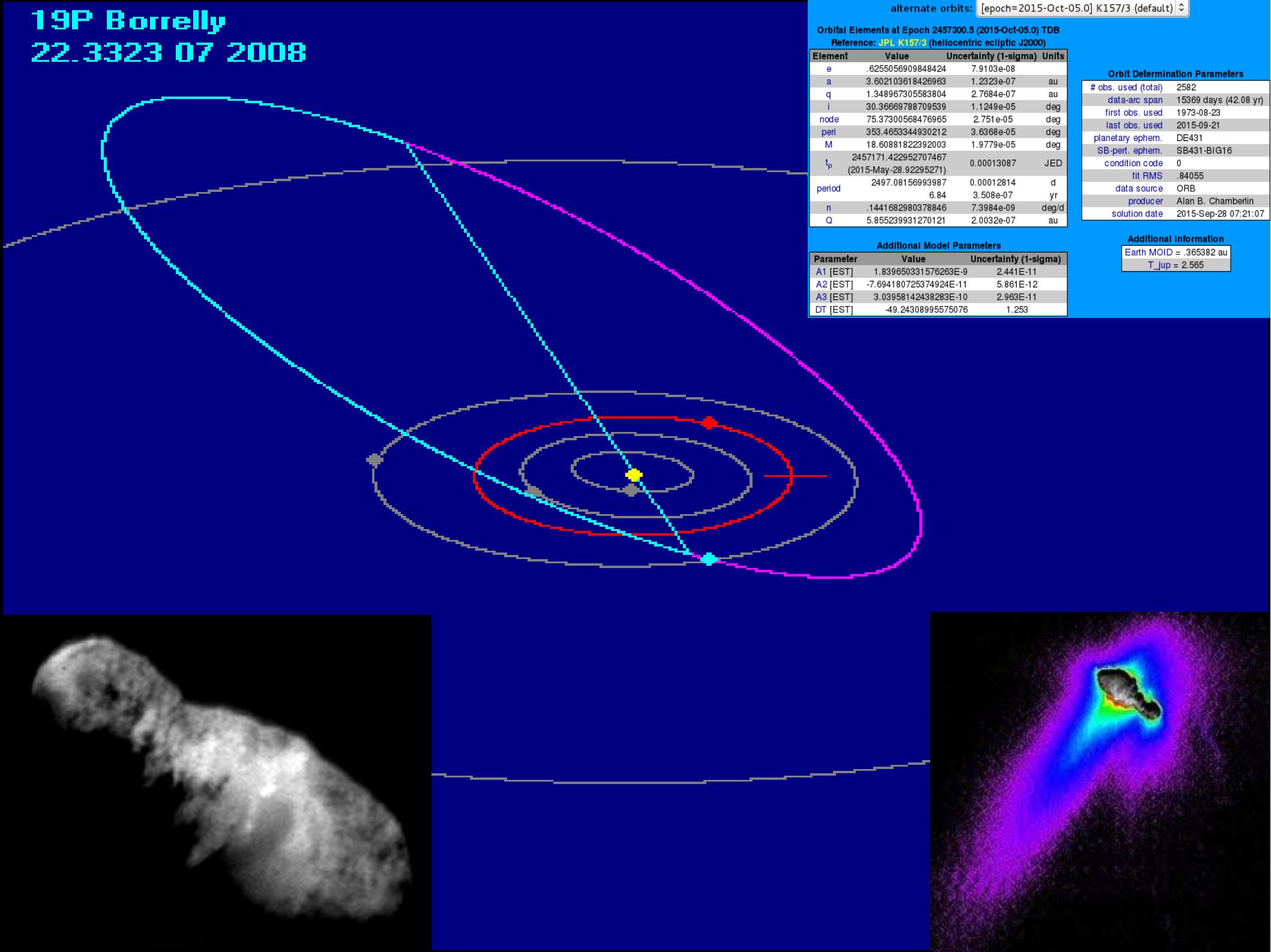


Y →  
Vernal  
Equinox

Mars — Comet  
Earth — Jupiter

# 19P Borrelly

22.3323 07 2008



alternate orbits: [epoch=2015-Oct-05.0] K157/3 (default) ▾

Orbital Elements at Epoch 2457300.5 (2015-Oct-05.0) TDB

Reference: JPL K157/3 (heliocentric ecliptic J2000)

| Element        | Value  | Uncertainty (1-sigma) | Units |
|----------------|--|-----------------------|-------|
| e              | .6255056909848424                              | 7.9103e-08            |       |
| a              | 3.602103618426963                              | 1.2323e-07            | au    |
| q              | 1.348967305583804                              | 2.7684e-07            | au    |
| i              | 30.36669788709539                              | 1.1249e-05            | deg   |
| node           | 75.37300568476965                              | 2.751e-05             | deg   |
| peri           | 353.4653344930212                              | 3.6368e-05            | deg   |
| M              | 18.60881822392003                              | 1.9779e-05            | deg   |
| t <sub>p</sub> | 2457171.422952707467<br>(2015-May-28.92295271) | 0.00013087            | JED   |
| period         | 2497.08156993987                               | 0.00012814            | d     |
|                | 6.84   | 3.508e-07             | yr    |
| n              | .1441682980378846                              | 7.3984e-09            | deg/d |
| Q              | 5.855239931270121                              | 2.0032e-07            | au    |

## Orbit Determination Parameters

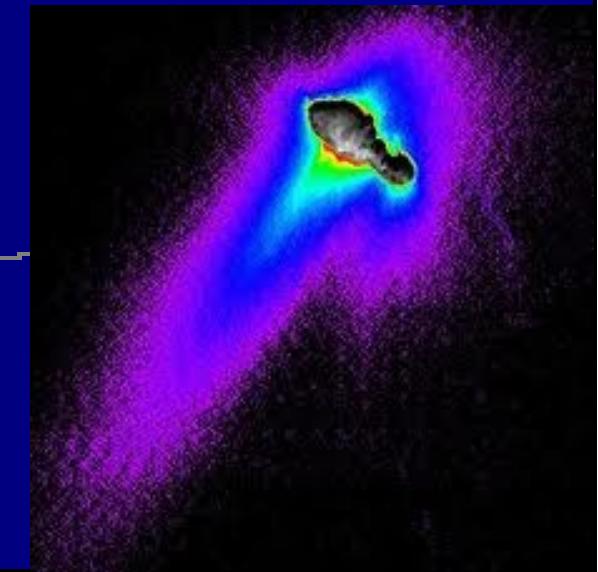
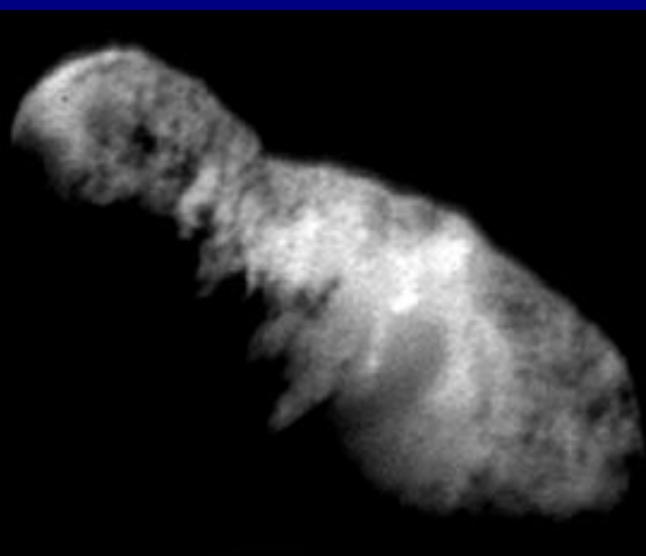
|                     |                       |
|---------------------|-----------------------|
| # obs. used (total) | 2582                  |
| data-arc span       | 15369 days (42.08 yr) |
| first obs. used     | 1973-08-23            |
| last obs. used      | 2015-09-21            |
| planetary ephem.    | DE431                 |
| SB-pert. ephem.     | SB431-BIG16           |
| condition code      | 0                     |
| fit RMS             | .84055                |
| data source         | ORB                   |
| producer            | Alan B. Chamberlin    |
| solution date       | 2015-Sep-28 07:21:07  |

## Additional Model Parameters

| Parameter | Value                  | Uncertainty (1-sigma) |
|-----------|------------------------|-----------------------|
| A1 [EST]  | 1.839650331576263E-9   | 2.441E-11             |
| A2 [EST]  | -7.694180725374924E-11 | 5.861E-12             |
| A3 [EST]  | 3.03958142438283E-10   | 2.963E-11             |
| DT [EST]  | -49.24308995575076     | 1.253                 |

## Additional Information

|                          |
|--------------------------|
| Earth MOID = .365382 au  |
| T <sub>Jup</sub> = 2.565 |



# PASSAGE OF COMET HYAKUTAKE IN MARCH-APRIL 1996



Orbital Elements at Epoch 2450158.5 (1996-Mar-16.0) TDB  
Reference: JPL 72 (heliocentric ecliptic J2000)

| Element        | Value  | Uncertainty (1-sigma) | Units |
|----------------|--|-----------------------|-------|
| e              | .9998986702212276                              | 9.2685e-07            |       |
| a              | 2272.079439771763                              | 20.789                | au    |
| q              | .2302293069854339                              | 7.6629e-07            | au    |
| i              | 124.9226625944912                              | 5.013e-05             | deg   |
| node           | 188.0452284985425                              | 9.9117e-06            | deg   |
| peri           | 130.1740835084622                              | 0.00013771            | deg   |
| M              | 359.9995777871475                              | 5.7949e-06            | deg   |
| t <sub>p</sub> | 2450204.894088137433<br>(1996-May-01.39408814) | 1.4391e-05            | JED   |
| period         | 39557942.46665863                              | 5.4293e+05            | d     |
|                | 108303.74                                      | 1486                  | yr    |
| n              | 9.100574437192371E-6                           | 1.249e-07             | deg/d |
| Q              | 4543.92865023654                               | 41.577                | au    |

## Additional Model Parameters

| Parameter | Value                 | Uncertainty (1-sigma) |
|-----------|-----------------------|-----------------------|
| A1 [EST]  | 2.303845253882055E-8  | 4.706E-10             |
| A2 [EST]  | 3.621508865039903E-10 | 8.391E-11             |

## Orbit Determination Parameters

|                     |                      |
|---------------------|----------------------|
| # obs. used (total) | 978                  |
| data-arc span       | 306 days             |
| first obs. used     | 1996-01-01           |
| last obs. used      | 1996-11-02           |
| planetary ephem.    | DE431                |
| SB-pert. ephem.     | SB431-BIG16          |
| fit RMS             | .88913               |
| data source         | ORB                  |
| producer            | Otto Matic           |
| solution date       | 2014-Jun-13 19:42:31 |

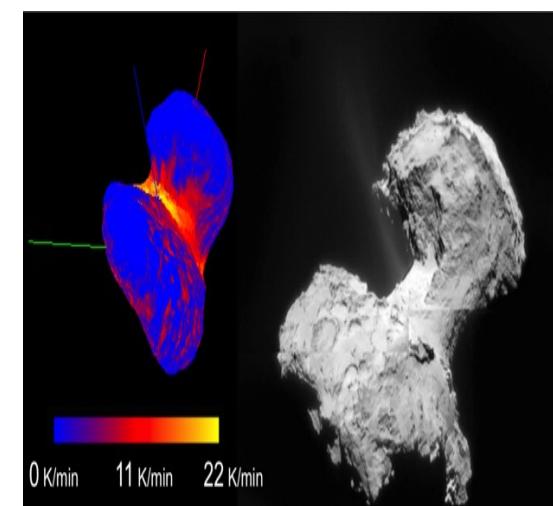
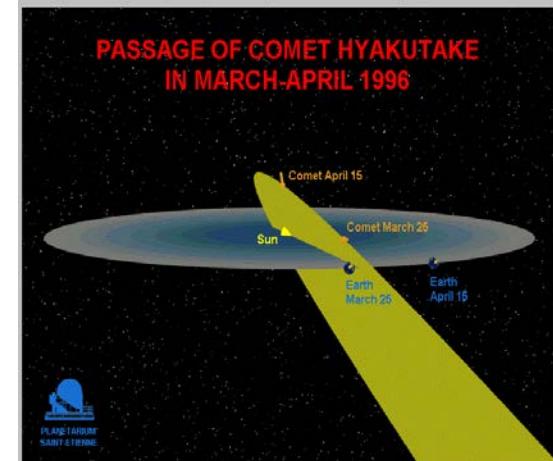
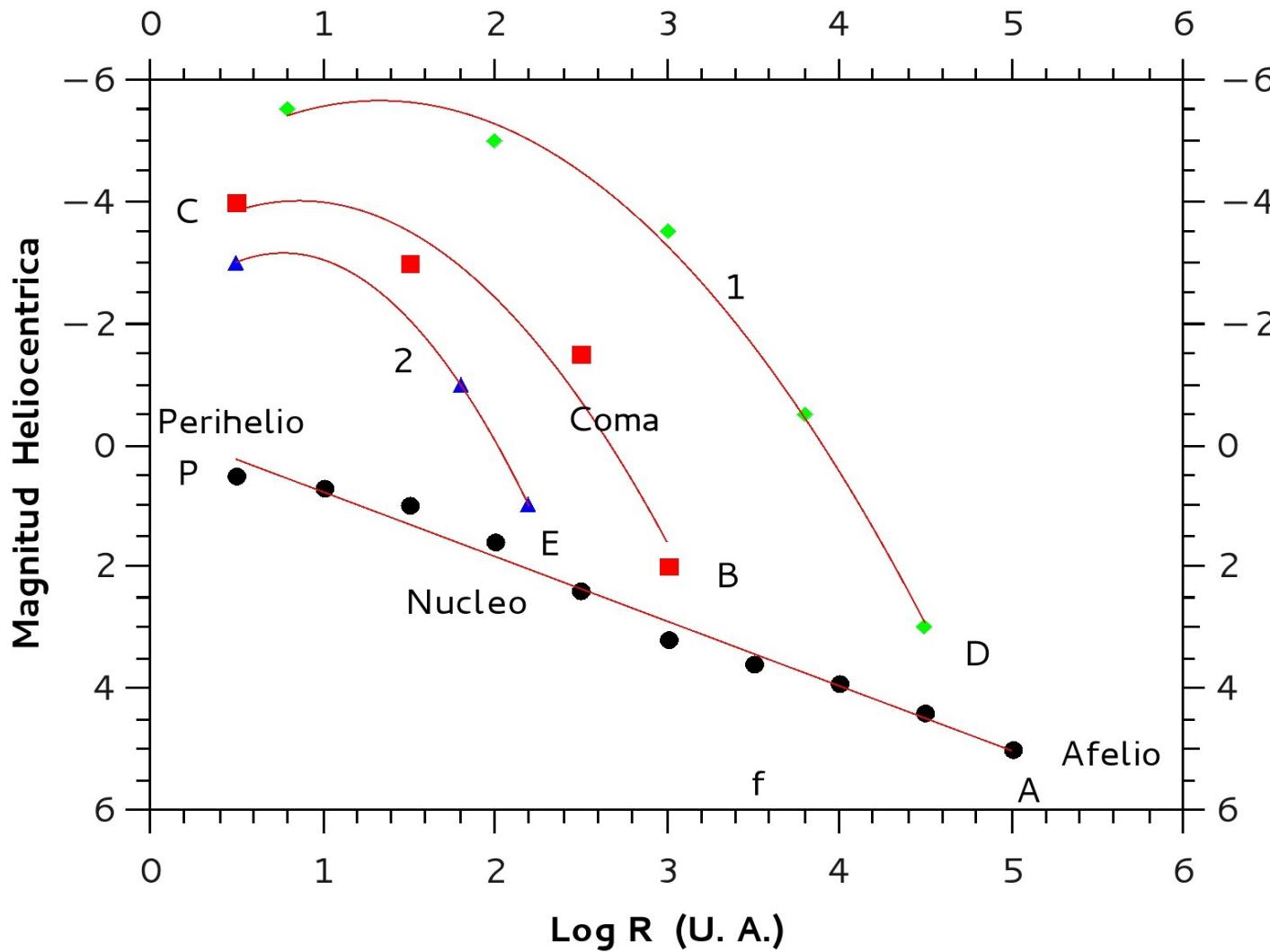
## Additional Information

Earth MOID = .100969 au  
T<sub>Jup</sub> = -0.338

$$m_h = 2,5 n \log R + m_o$$

En la que:  $m_h = m_o - 5 \log \Delta$

**Curva de Luz de un Cometa**



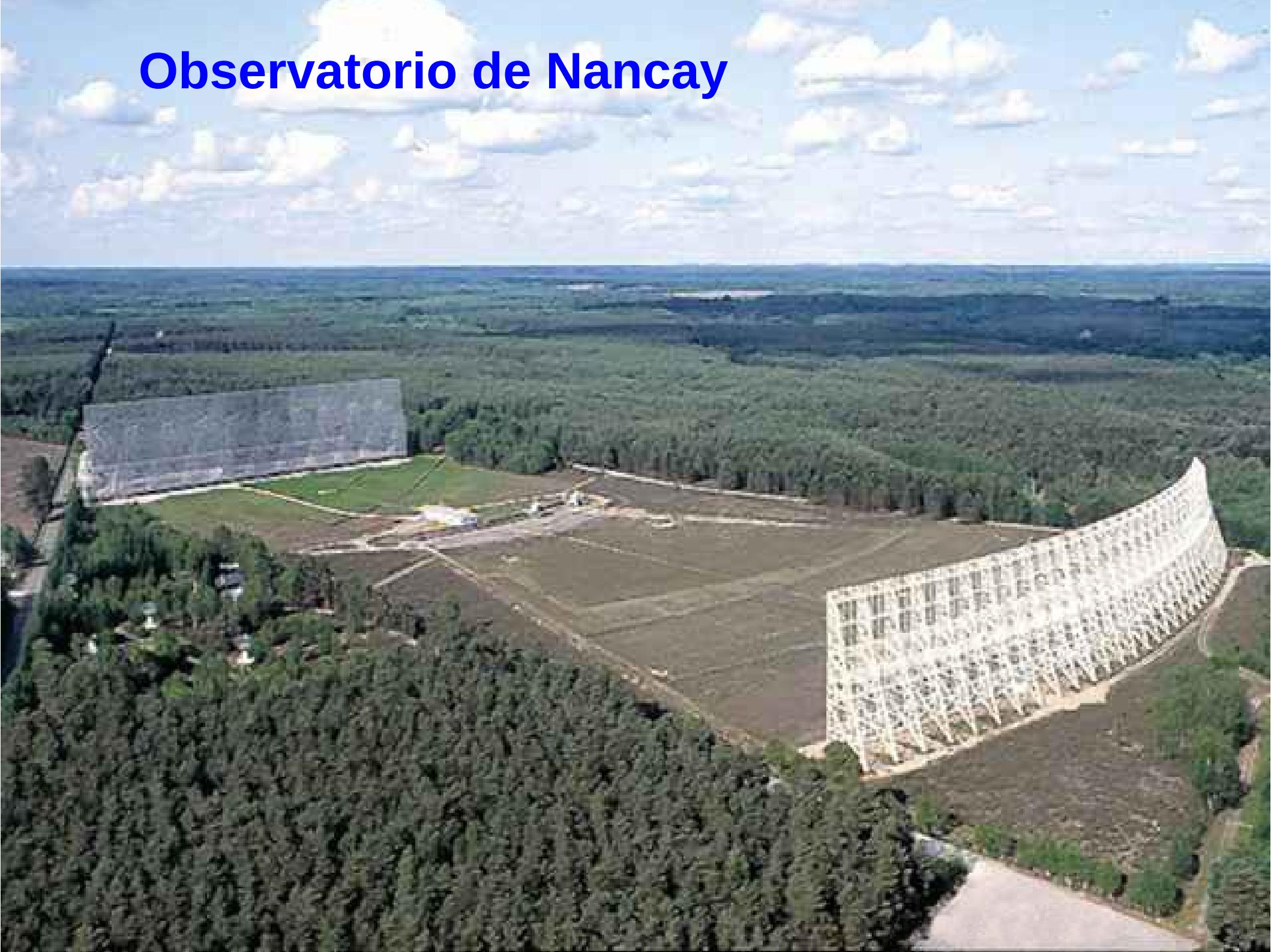


Como se observa  
En la longitud de onda  
De 18 centímetros?

# Observatorio de Arecibo



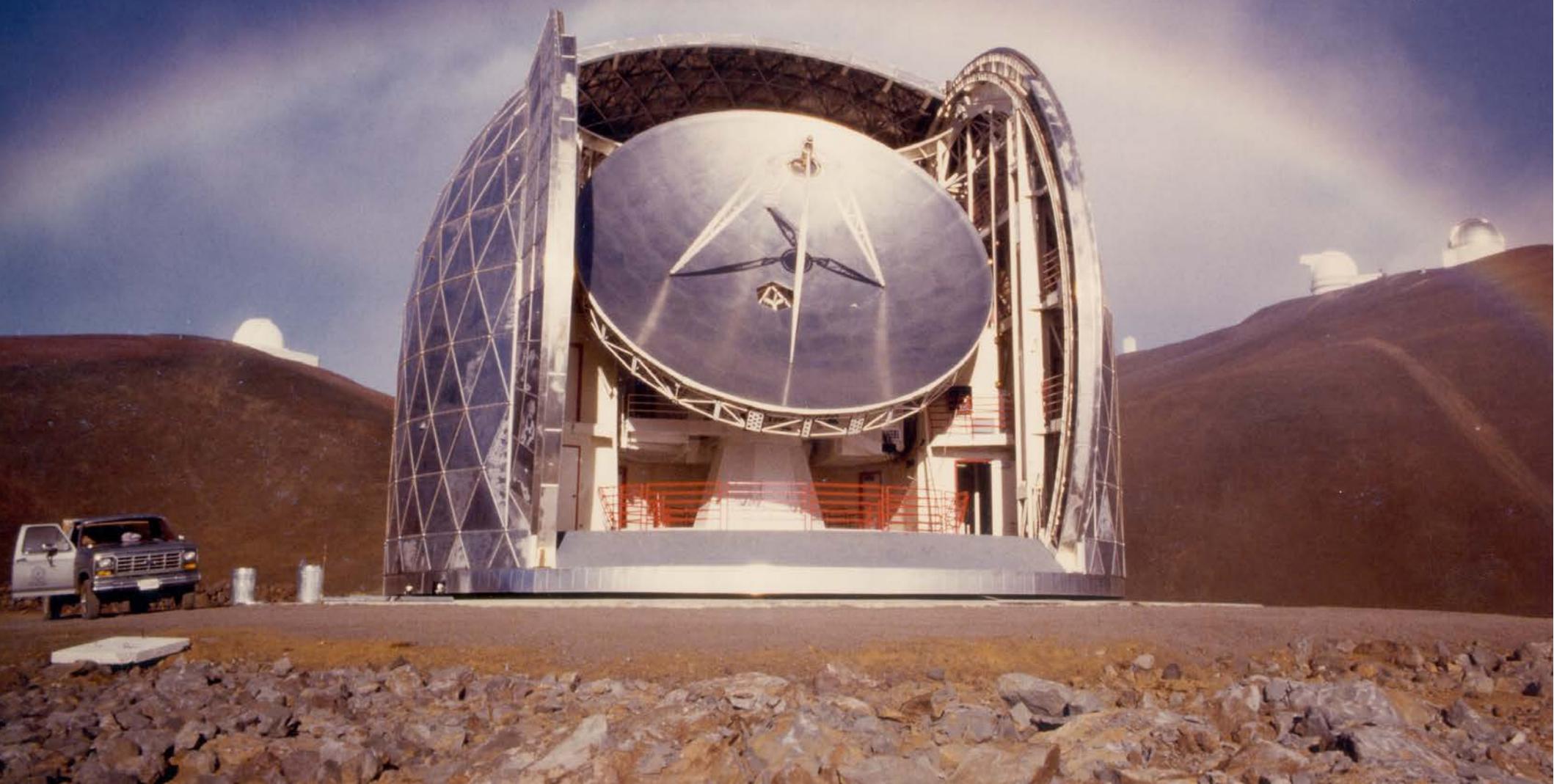
# Observatorio de Nancay



# Observatorio James Clerk Maxwell



# Observatorio Sub Milimetrico de Caltech

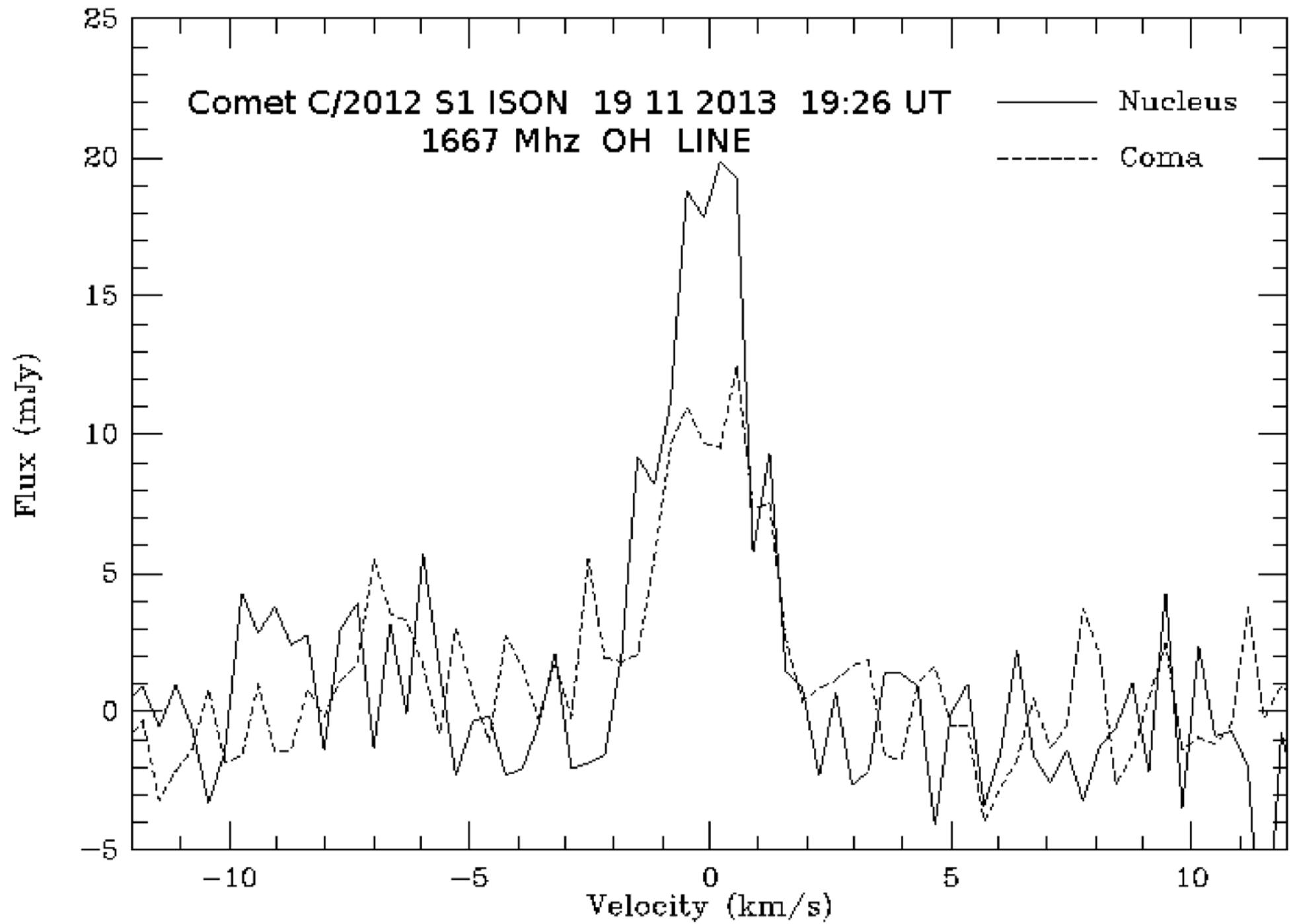


# Observatorio Arreglo Compacto de Telescopios Australianos



# Observatorio ALMA





# Densidad de Flujo de Energía Promedio

$$S_{\nu} = \frac{A_{\mu l} i k T_{BG}}{4 \pi \Delta^2} \frac{c}{2V_{Max} \nu} \frac{2F_{\mu} + 1}{8} Q_{OH} \tau_{OH}$$

en la que:

$A_{\mu l}$  Coeficiente de Einstein

$V_{Max}$  Velocidad Máxima de Expansión del Gas en la Coma

$i$  Inversión del Estado Fundamental  
De Niveles del Doblete  $\wedge$

$\nu$  Frecuencia de la Radiación Electromagnética

$k$  Constante de Boltzman

$F_{\mu}$  Peso Estadístico del Nivel Superior

$T_{BG}$  Temperatura de Fondo Cometario

$Q_{OH}$  Tasa de Producción de OH

$\Delta$  Distancia Cometa-Tierra

$\tau_{OH}$  Tiempo de Vida Media de la Molécula OH

$c$  Rapidez de las Ondas Electromagnéticas en el Vacío

## Tasa de Producción de OH

$$Q_{OH} = \frac{7,06 \times 10^{25}}{i} \frac{3,3 K}{T_{GB}} \frac{10^5 s}{\tau_{OH}} \left( \frac{\Delta}{1 UA} \right)^2 \frac{2V_{Max} S_\nu}{1 \text{mJykm s}^{-1}} \frac{\text{moleculas}}{s}$$

**En promedio una de cada 555 moléculas de agua se disocia, entonces:**

$$Q_{H_2O} = 555 Q_{OH} 3 \times 10^{-26} \frac{kg}{molecula} \quad \text{en} \quad \frac{kg}{s}$$

**y organizando las observaciones en una tabla de datos**



# Comet C/2012 S1 ISON

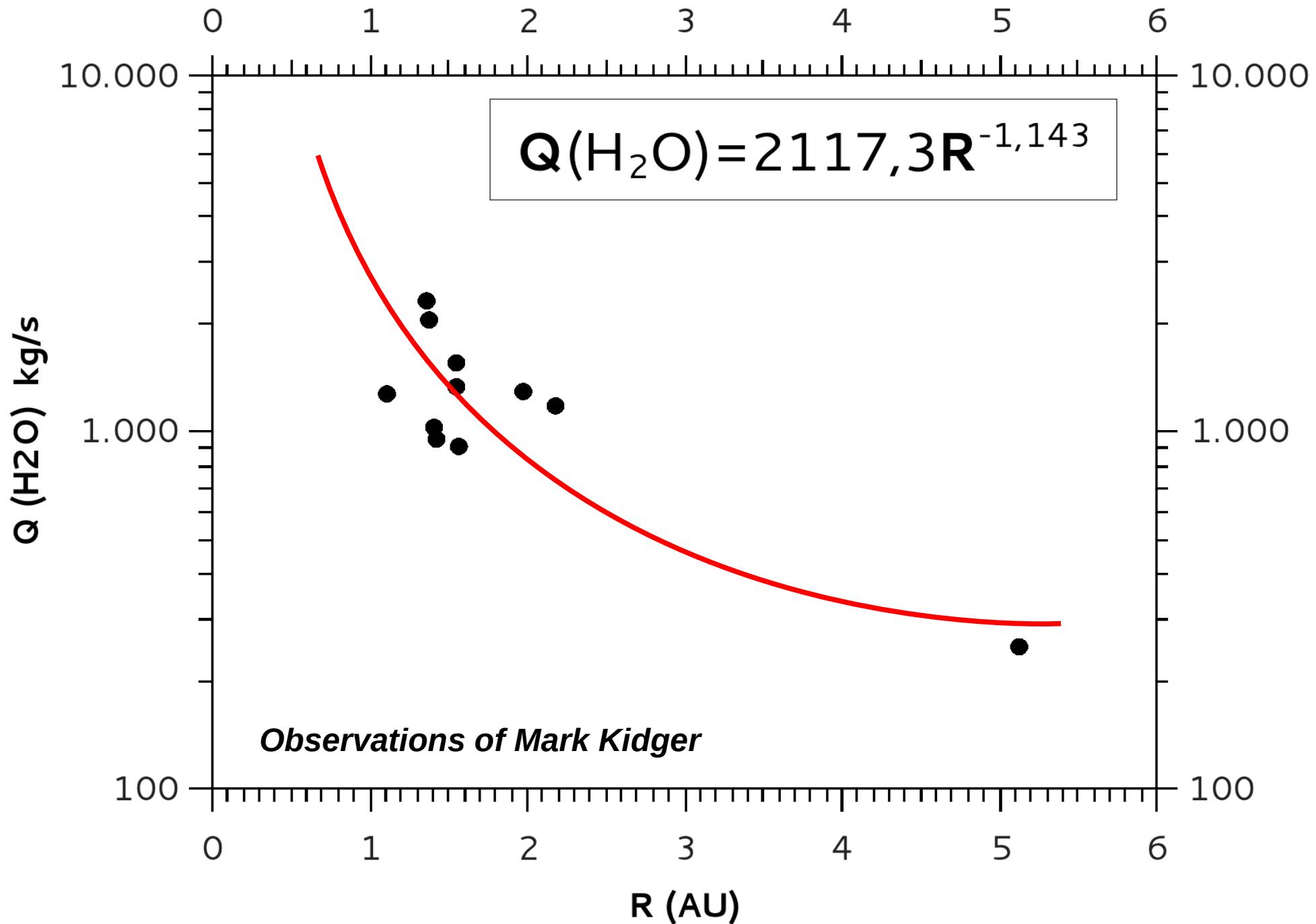
## Water Production Rate

| R Distance Comet – Sun A.U. | $Q_{H_2O}$ | Water Production Rate | $kg\ s$ |
|-----------------------------|------------|-----------------------|---------|
| 1,10                        |            | 1288,25               |         |
| 1,36                        |            | 2344,23               |         |
| 1,37                        |            | 2089,30               |         |
| 1,40                        |            | 1047,13               |         |
| 1,41                        |            | 955,00                |         |
| 1,54                        |            | 1584,90               |         |
| 1,55                        |            | 1348,96               |         |
| 1,56                        |            | 912,00                |         |
| 1,97                        |            | 1318,25               |         |
| 2,18                        |            | 1202,26               |         |
| 5,12                        |            | 251,19                |         |

Y elaborando una gráfica



# Water Production Rate Comet C/2012 S1

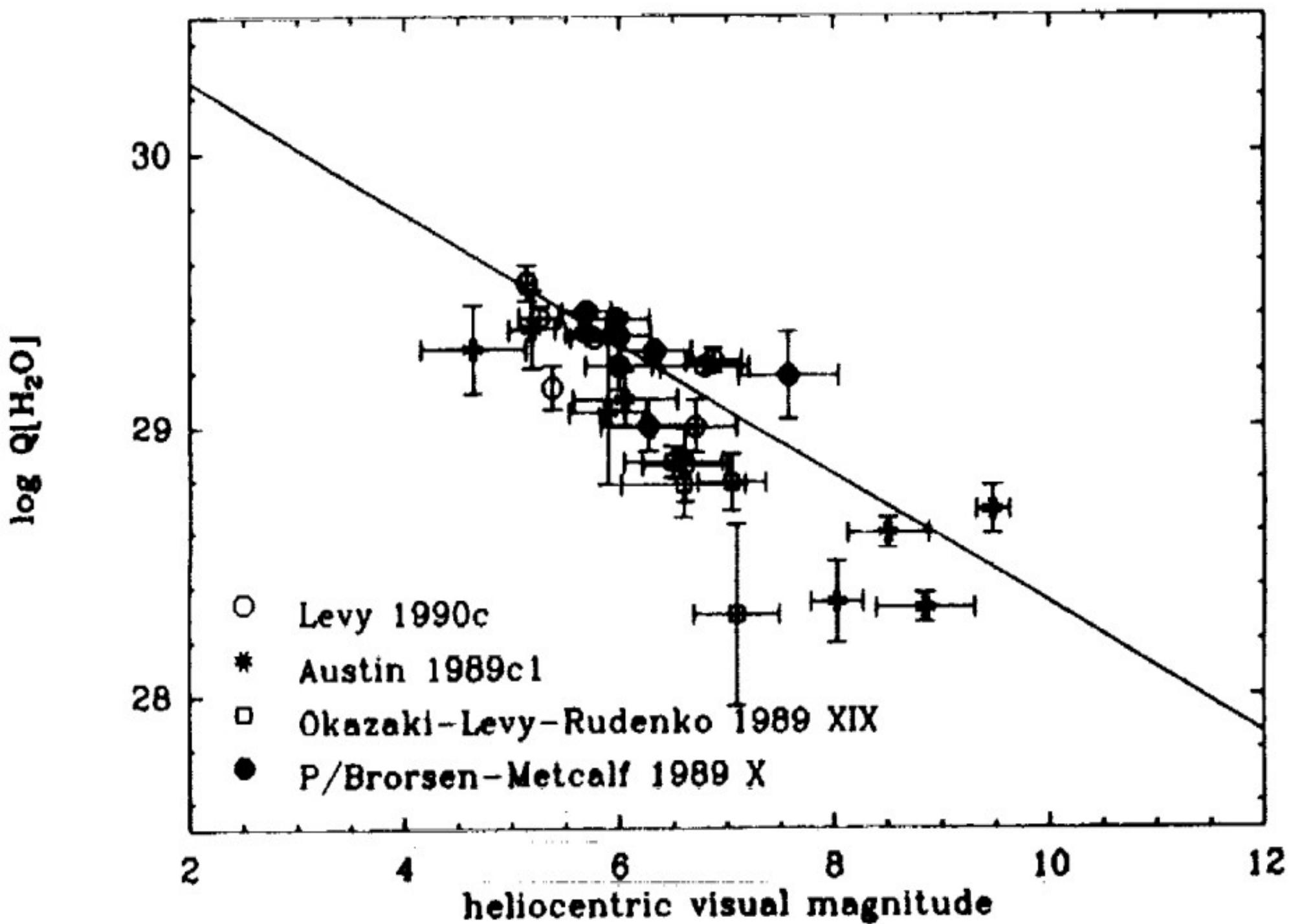


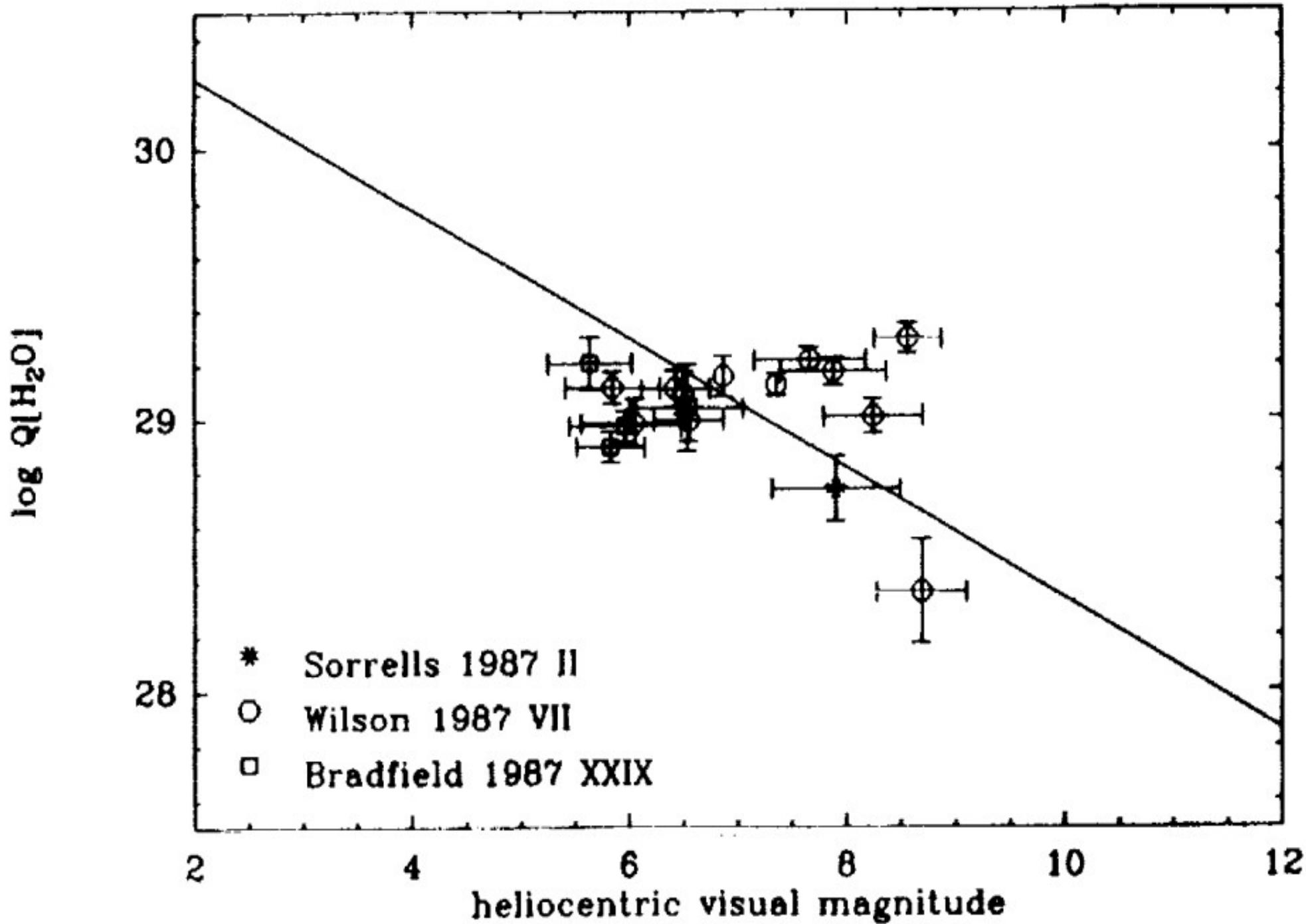
**L. Jorda, . Crovisieier, y D.W.E. Green en un articulo publicado en Asteroids, Comets, Meteors 1991, pp 285-288 con el titulo THE CORRELATION BETWEEN WATER PRODUCTION RATE AND VISUAL MAGNITUDES IN COMETS, resultados confirmados en una decena de trabajos posteriores y que hoy constituye la curva de calibración que correlaciona la tasa de producción de agua y la curva de luz de un cometa.**

$$\log Q_{H_2O} = 30,78 - 0,265 [2,5 n \log R + m_o]$$

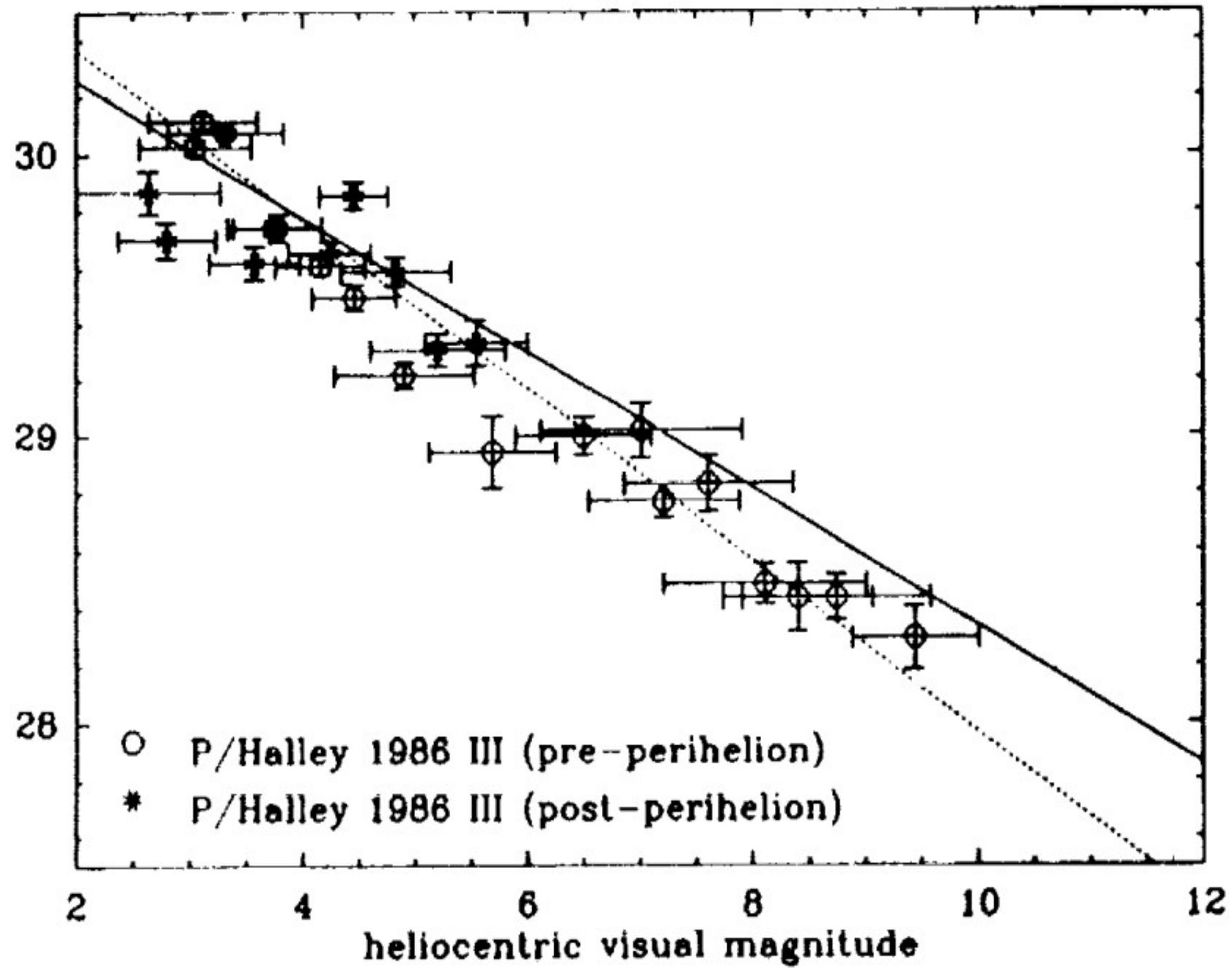
***Observaciones que condujeron al anterior resultado:***

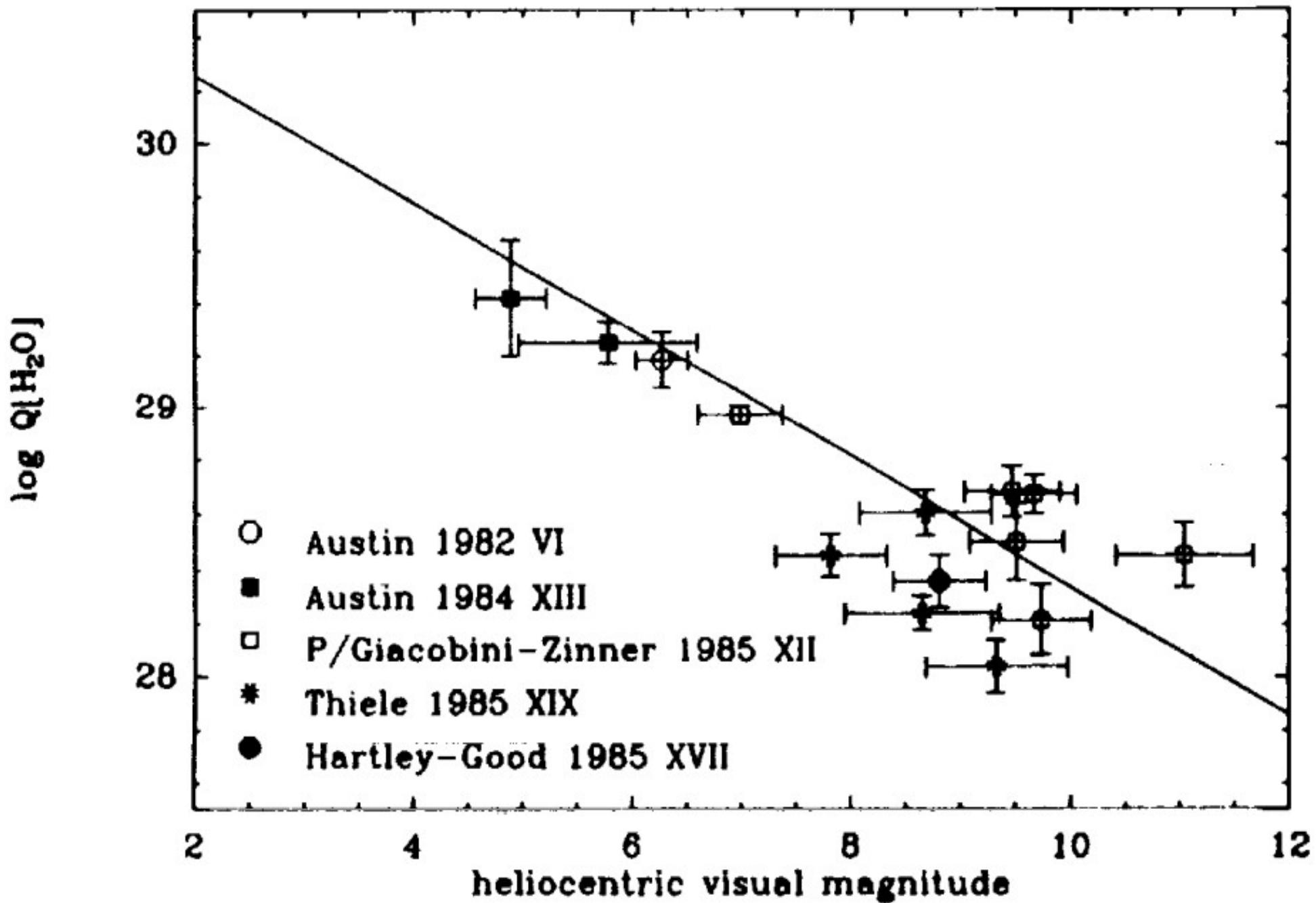


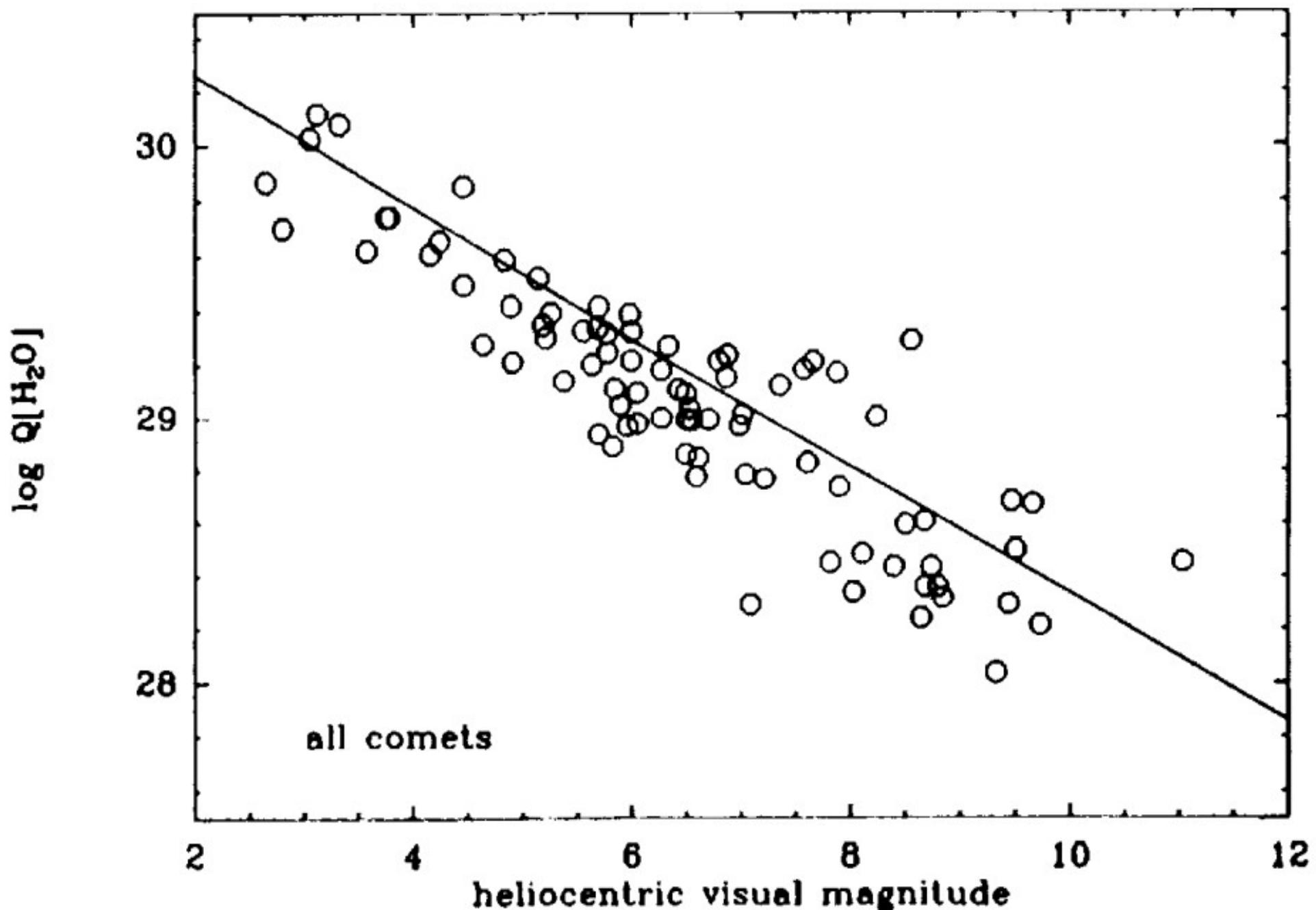




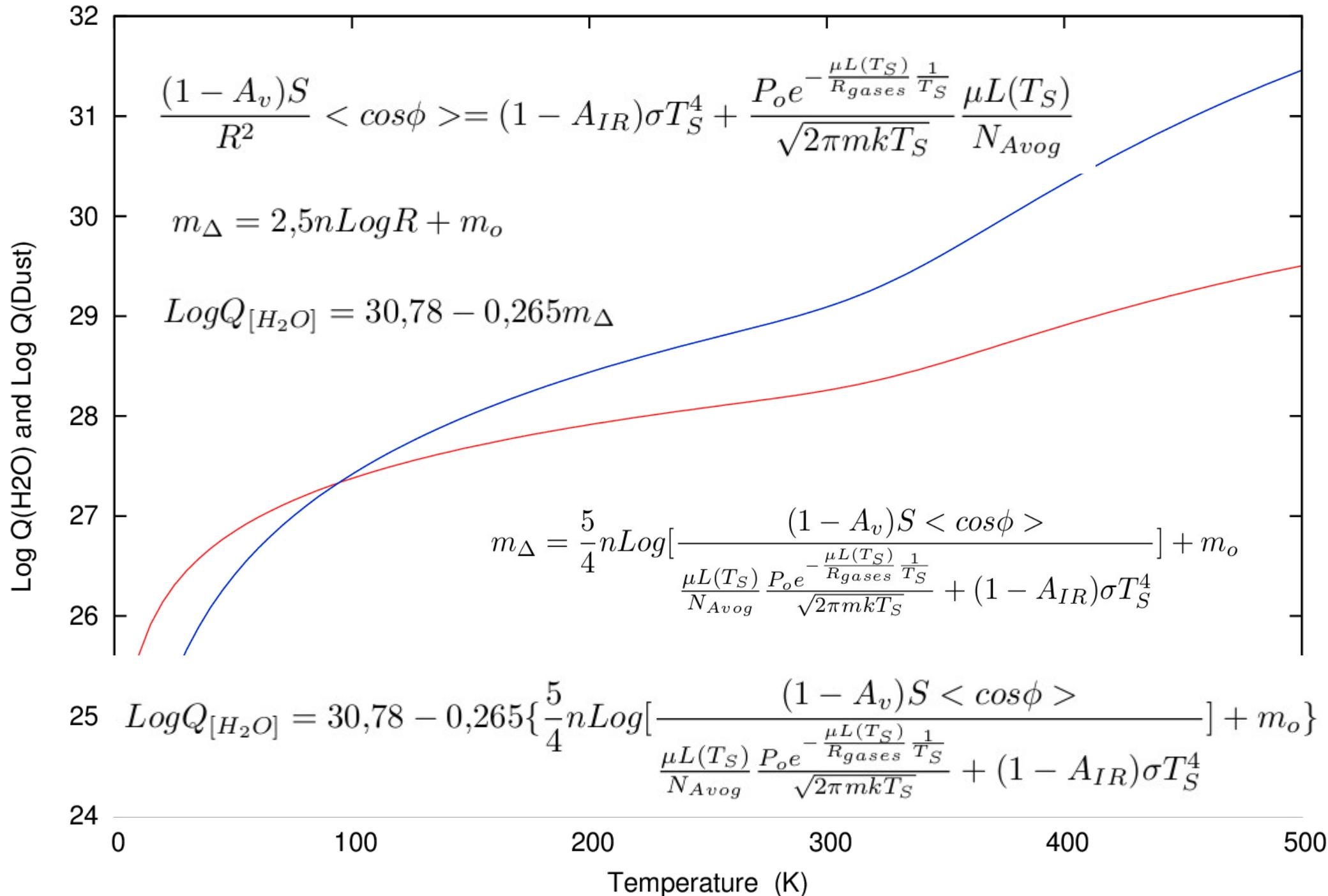
log Q[H<sub>2</sub>O]



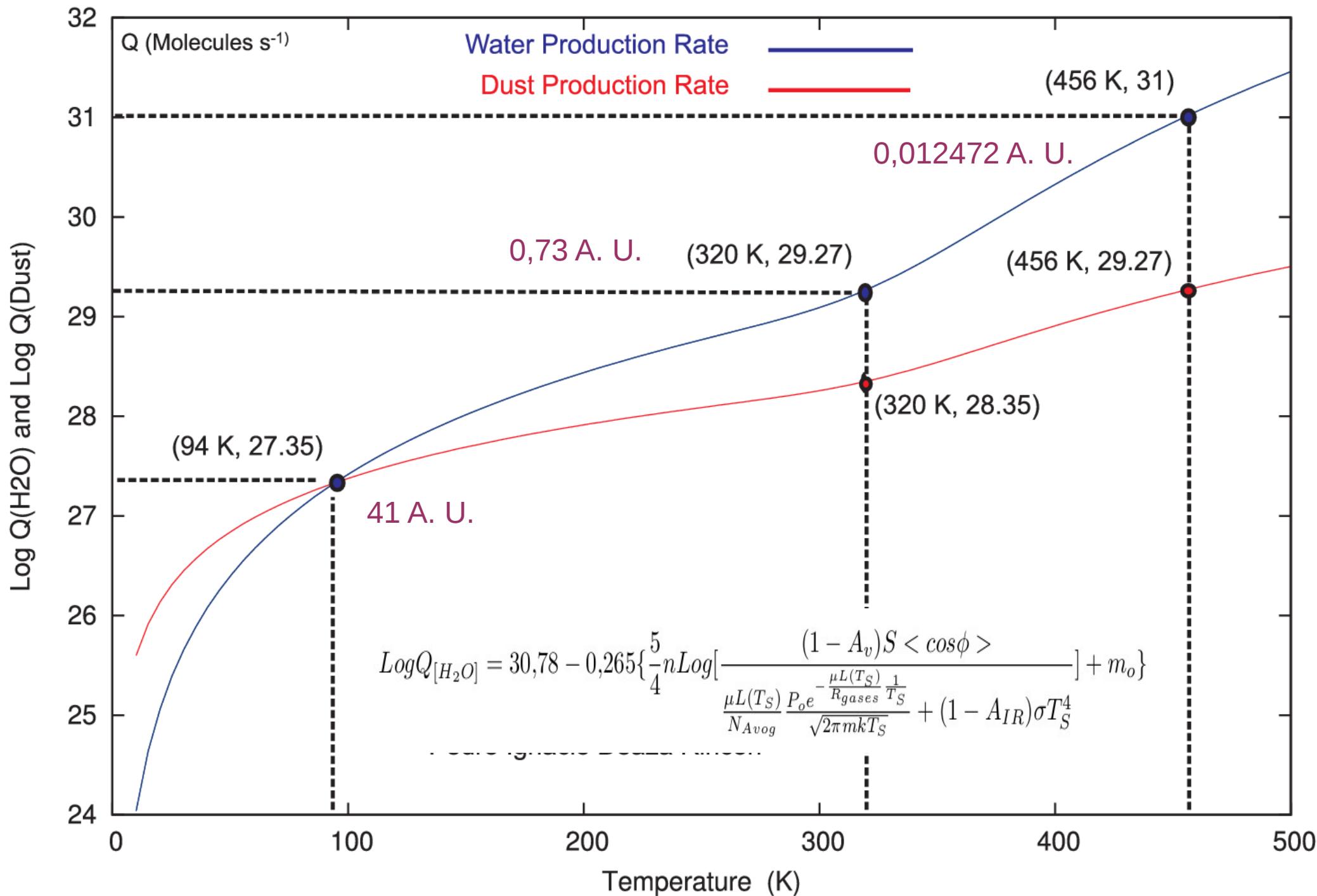




## Production Rates of Water and Dust as Function of the Temperature



# Production Rates of Water and Dust as Function of the Temperature



$$Q_{H_2O} = 2117,3 \cdot R^{-1,143} \frac{kg}{s}$$

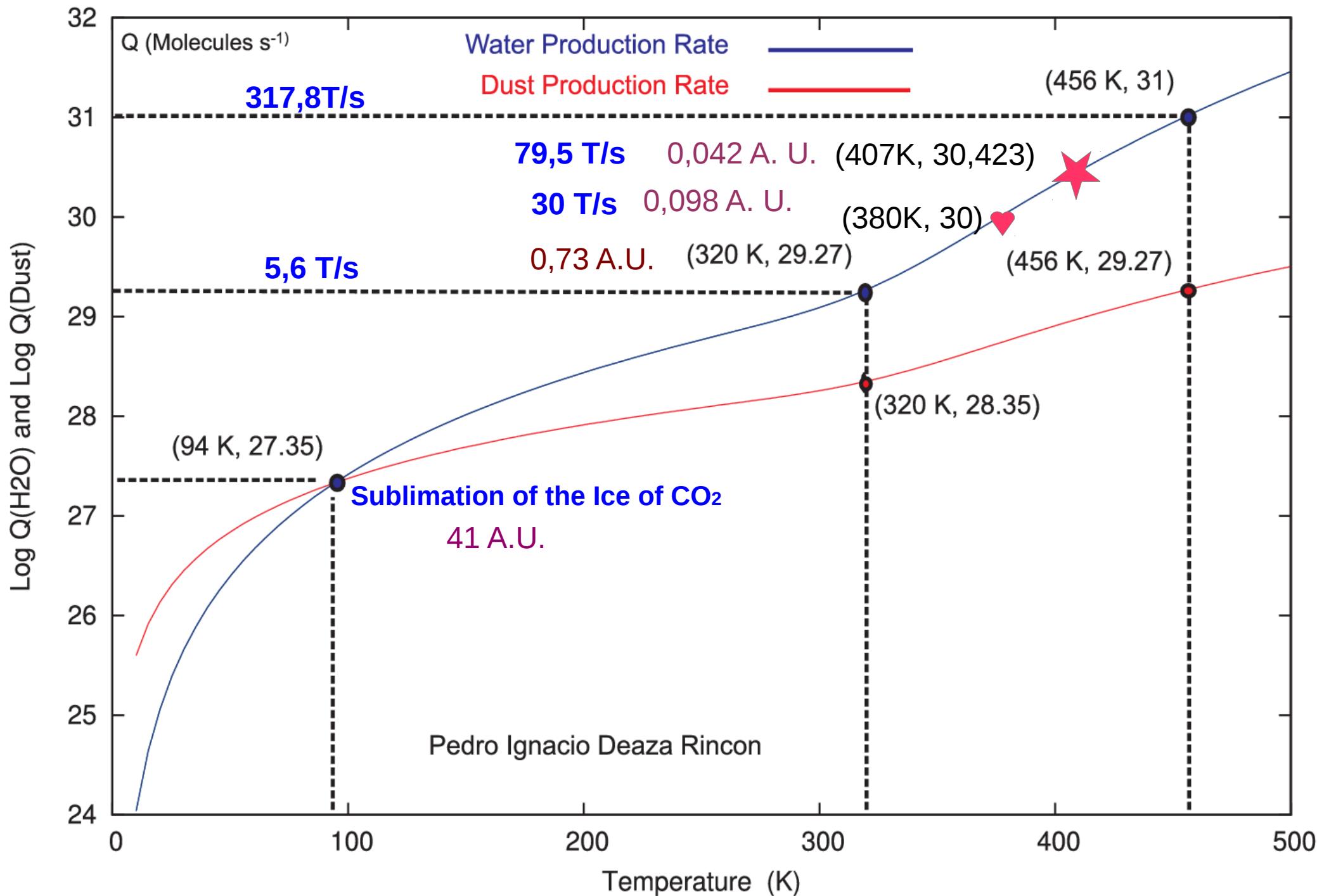
$$Q_{H_2O} = 2117,3 \cdot (0,012472)^{-1,143} \frac{kg}{s} = 317780,638 \frac{kg}{s}$$

lo que equivale a  $317,78 \frac{\text{Toneladas}}{\text{s}}$ , que comparativamente correspondería a perder cada segundo solamente entre el 0.0000043 % y el 0.0000003 % de su probable masa total.

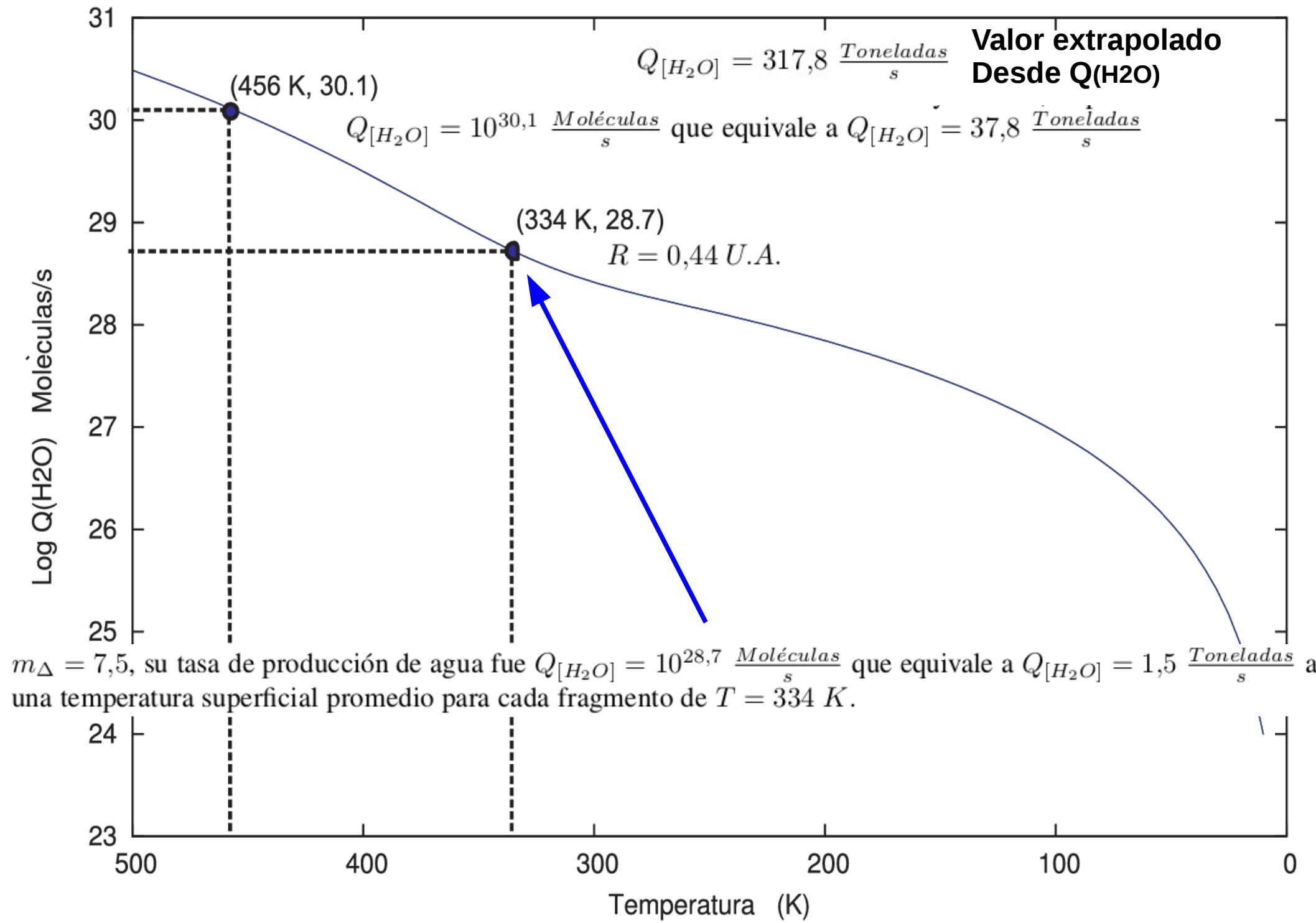
Pero a la hora de efectuar la interpolación de la temperatura, se requerirá la tasa de producción de agua en  $\frac{\text{Moleculas}}{\text{Segundo}}$ , entonces

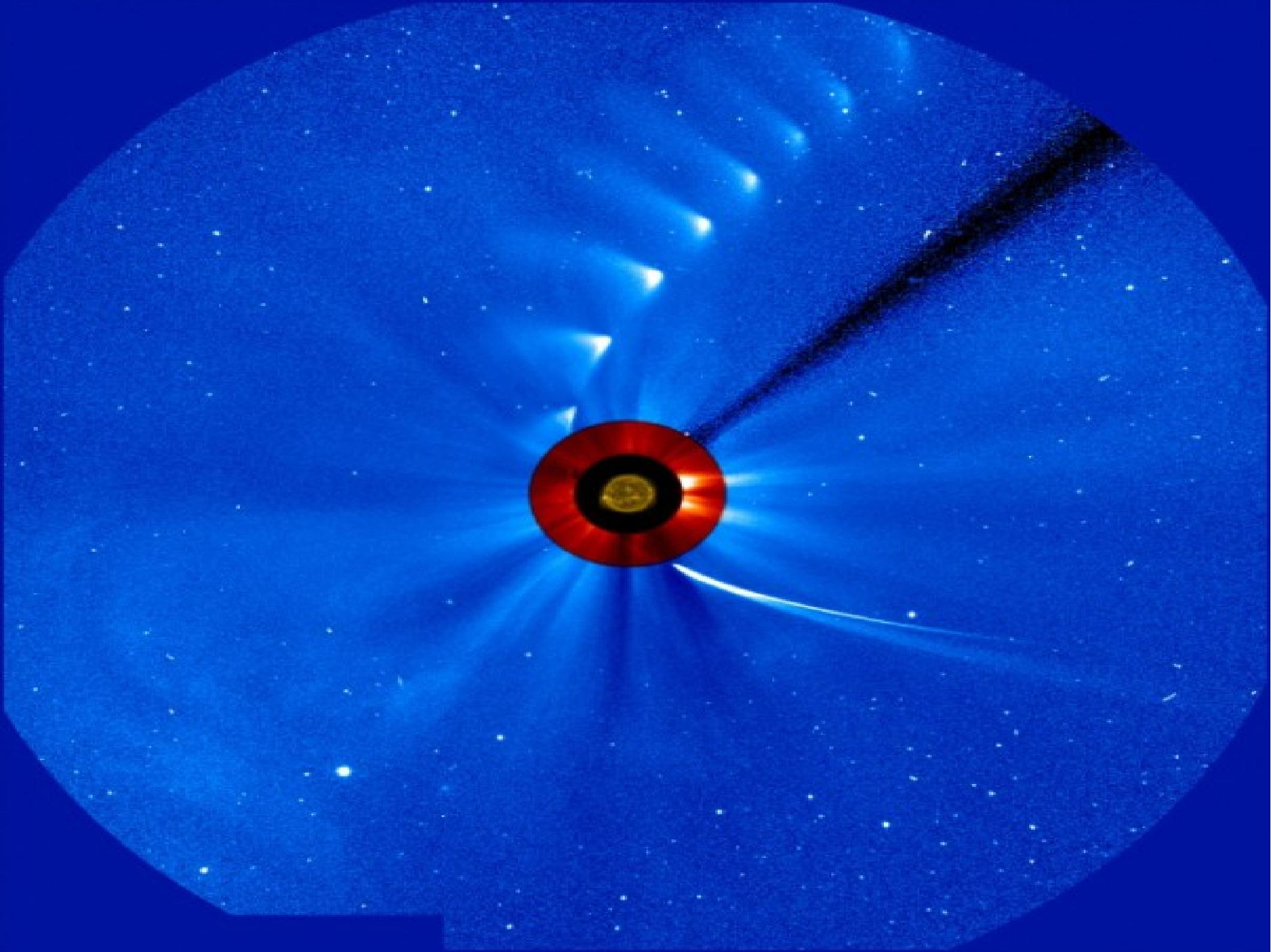
$$Q_{H_2O} = 317780,638 \frac{kg}{s} = 1,06 \cdot 10^{31} \frac{\text{Moleculas}}{s}$$

# Production Rates of Water and Dust as Function of the Temperature



## Tasa de Producción de Agua en Función de la Temperatura





# **CONCLUSION**

*La complejidad de la evolución y actividad de un núcleo cometario ha conducido a los astrónomos de la ciencia cometaria a utilizar los mas variados recursos científicos y tecnológicos, desde los mas simples, hasta los mas sofisticados. Telescopios y radiotelescopios pequeños, medianos y grandes, telescopios orbitales, naves espaciales con una variada gama de instrumentación para la medición*

*El gran cumulo de datos obtenidos en las observaciones, implica el uso de sistemas grid y cluster de computación con recursos gráficos de alto desempeño.*

*Hoy la ciencia cometaria, compite arduamente por tiempo de observación y por tiempo de utilización de sistemas computacionales con los poderosos grupos de la cosmología, astrofísica estelar, astronomía extragaláctica . . .*

*Los cometas, estos minúsculos productos de la gravitación, guardan celosamente los secretos del origen de los sistemas planetarios, los mapas de las fronteras interestelares, las respuestas a los interrogantes del origen de la vida, la estrecha relación de los núcleos activos de galaxia con el resto de la galaxia y por ende contienen incluso pistas que permitirán completar una mejor percepción del universo.*

# Referencias

L. E. Tacconi Garman, F. Peter Schloerb, M. J. Claussen. High Spectral Resolution Observation And Kinematic Modeling of the 1667 MHz Hyperfine Transition of OH in Comets Halley (1982i), Giacobini Zinner (1984e), Hartley Good (1985l), Thiele (1985m) and Wilson (1986l). Astrophysical Jornal, **364**: 672-686, 1990 December 1.

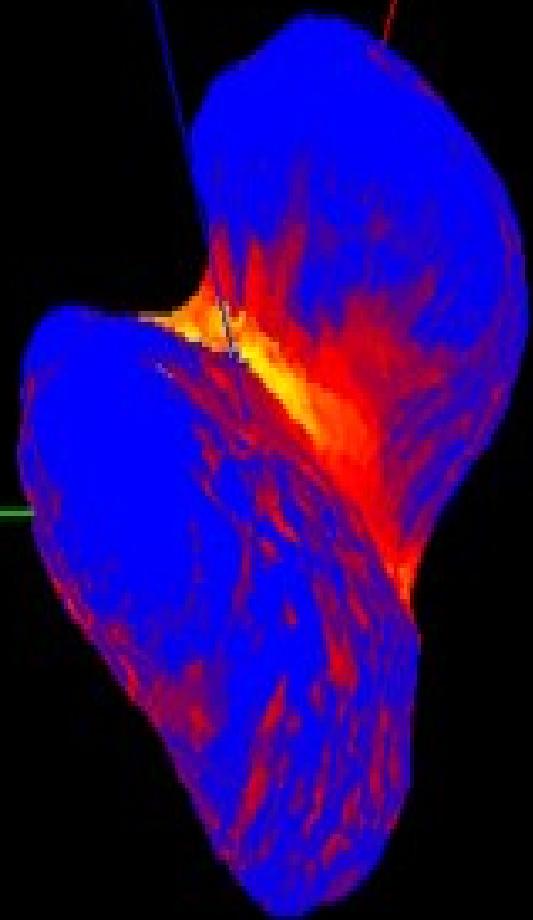
W.-L. Tseng, D. Bockelee-Morvan, J. Crovisier, P. Colom, and W.-H. Ip. Cometary Water Expansion Velocity from OH Line Shapes. Astronomy & Astrophysics, February 8, 2007.

L. Jorda, J. Crovisier, and D.W.E.Green. The Correlation Between Water Production Rates and Visual Magnitudes in Comets. Asteroids, Comets, Meteors, 1991, pp. 285-288. Lunar and Planetary Institute Houston, 1992.

Pedro Ignacio Deaza Rincon. Photometry and Activity of the Cometary Nuclei, IAU SYMPOSIUM 263 - ICY BODIES IN THE SOLAR SYSTEM

Pedro Ignacio Deaza Rincon, Evolución y Actividad del Núcleo del Cometa C/2012 S1 (ISON). Liga Iberoamericana de Astronomia LIADA. Seccion de Cometas, Noviembre 2013.

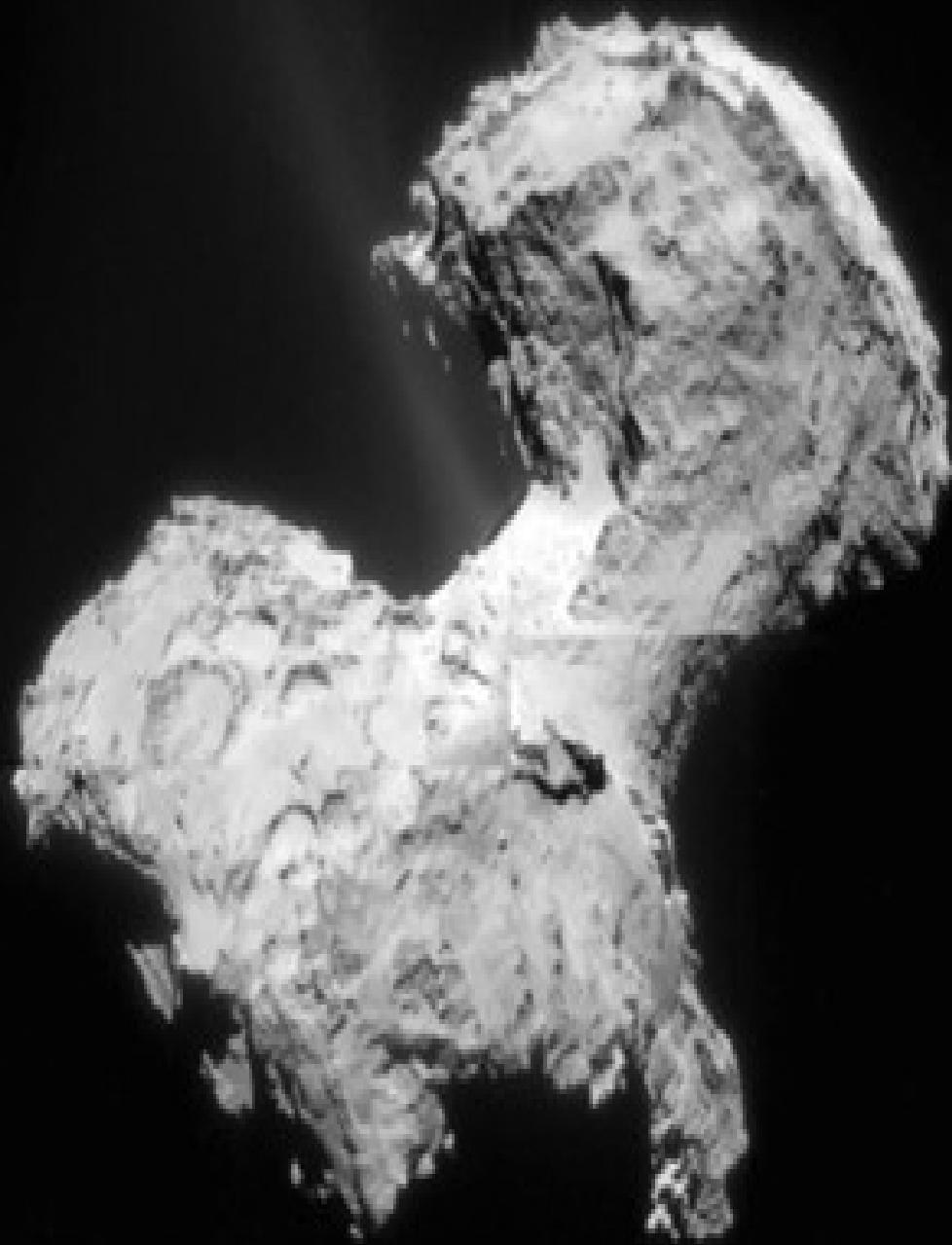


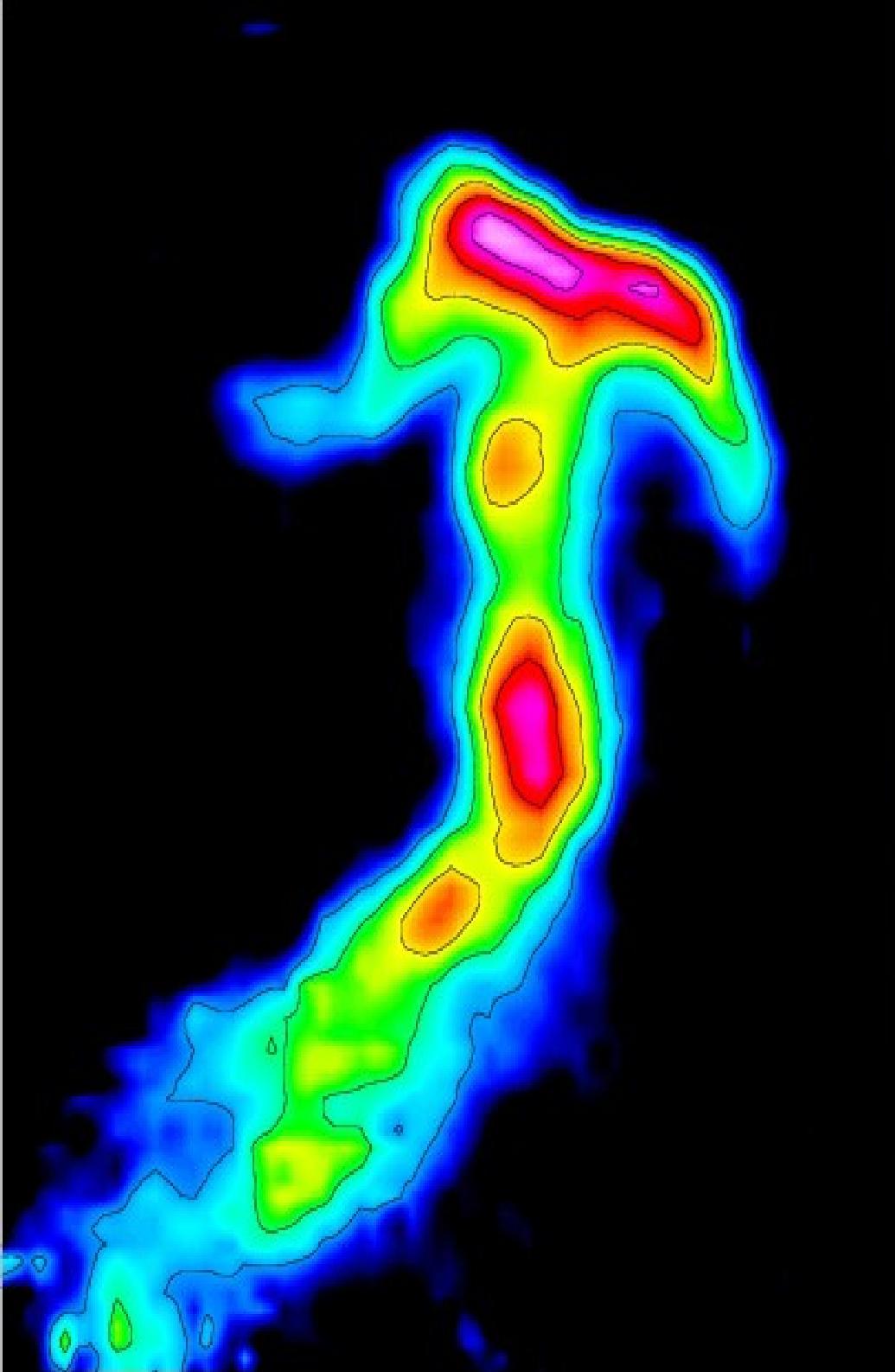


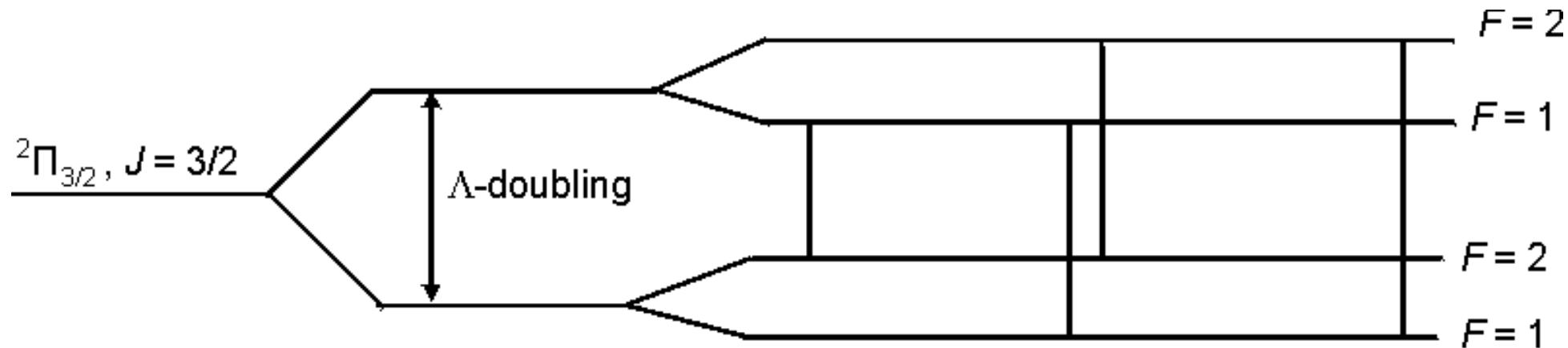
0 K/min

11 K/min

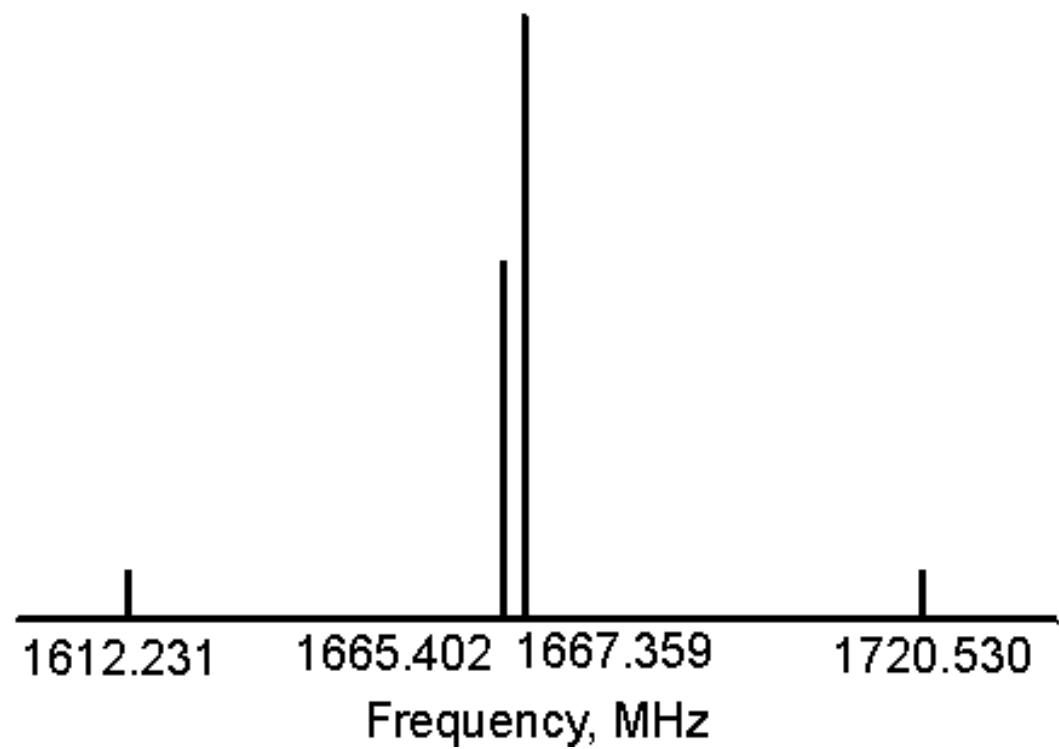
22 K/min







OH



C/2007 N3 (Lulin): HCN(3–2) at 265.9GHz: 25.04 Feb.09  $\phi=0.00$

