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ひさき衛星を用いた 長周期彗星の大気の化学特性の研究

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要旨 – abstract

彗星は**地球の水の起源の候補天体**として注目されているほか、C/2013 A_1 (Siding Spring) やC/2021 A_1 (Leonard)等の惑星近傍を通過する彗星の**惑星大気への物質供給**等の観点からも重要である。これまで、様々な彗星のガス放出率の傾向や化学特性に関する研究が行われてきた。しかし、特に**長周期彗星の水放出率の日心距離依存性**の傾向と軌道要素の関係性等は未だ分かっていない。

そこで本研究では、**ひさき衛星の紫外線分光観測**データを用いて、4つの長周期彗星について核からの**水等の気体分子の放出率**を算出し、他の観測データと比較した。

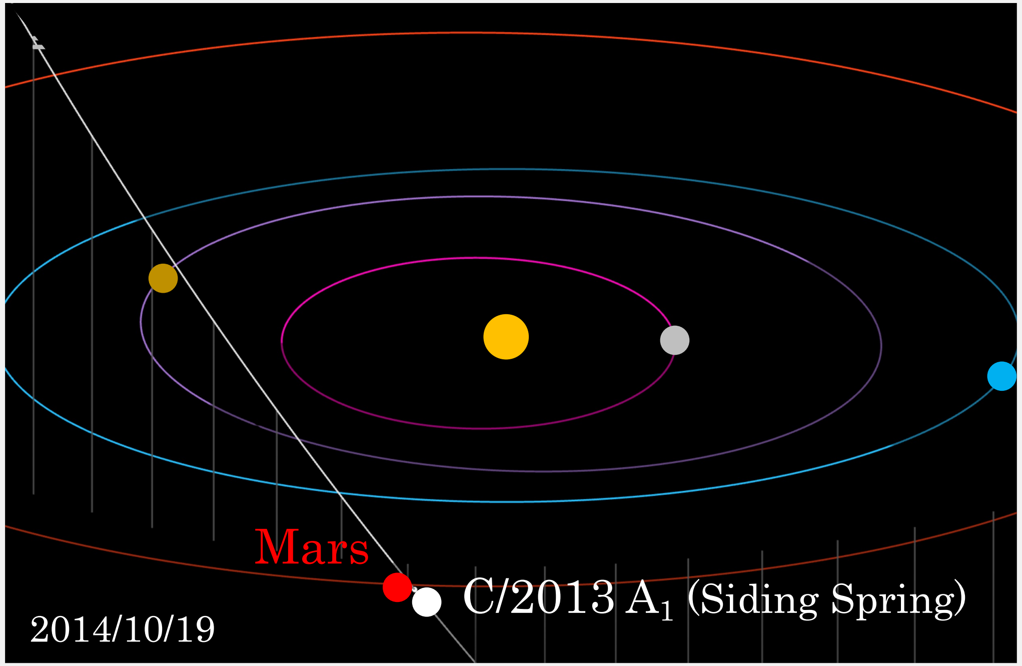
まず、ひさき衛星のジオコロナの観測データを用いて、経年変化した**検出器の感度較正**を行った。続いて水素のLy-αの放射輝度の分布と自ら構築した彗星大気（コマ）のモデルの比較から、核からの水分子の放出量を見積もった。その結果、他の観測機器を用いた先行研究と整合的な水放出率を得た。特にC/2015 ER_{61} (PanSTARRS) において、**赤外線による水分子の観測**（Saki et al., 2021）と**紫外線による水素原子の観測**（本研究）**で整合的な結果が得られた**ことは注目に値する。

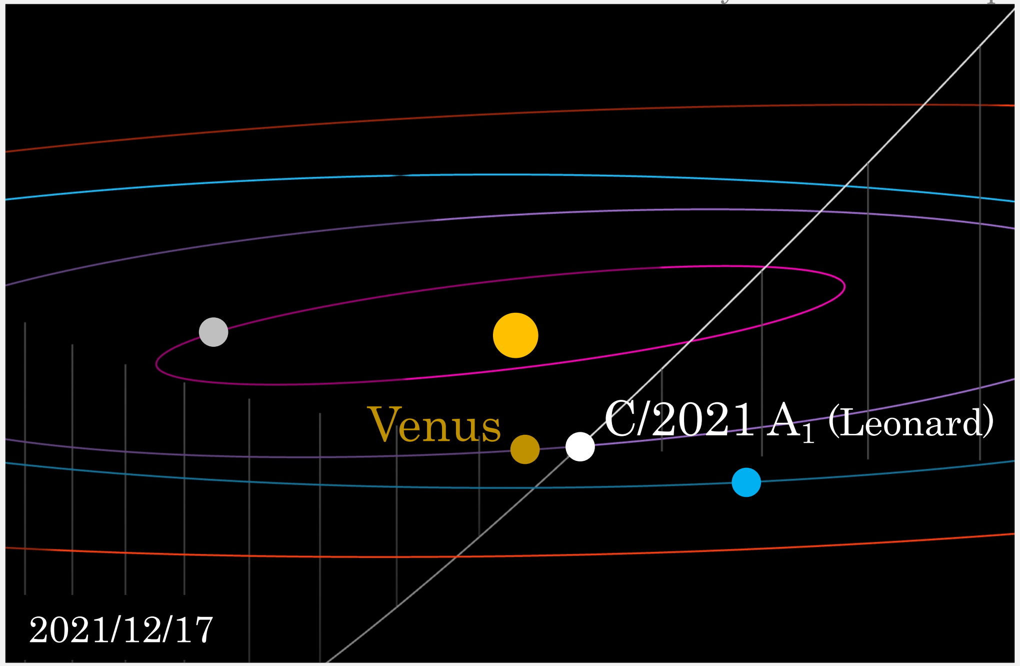
観測データの詳細な解釈のためには、**核付近での気体分子・原子同士の衝突や多重散乱に伴う減光の影響を考慮する必要**があると考えられる。今後はより詳細な彗星大気モデルを構築するとともに、核付近の大気の数密度分布や速度分布を観測するために**Comet Interceptor探査機搭載のHydrogen Imagerの開発**を進める。

1.1. Comets affect the environment of planets?

- C/2013 A_1 (Siding Spring) approached Mars within 140,000 km
  - ~2×10^4 kg of gas is estimated to impact Martian upper atmosphere, which is expected to be unobservable in the MAVEN/IUVS atmospheric data （Crismani et al., 2015. *GRL.*）
- How about C/2021 A_1 (Leonard)?

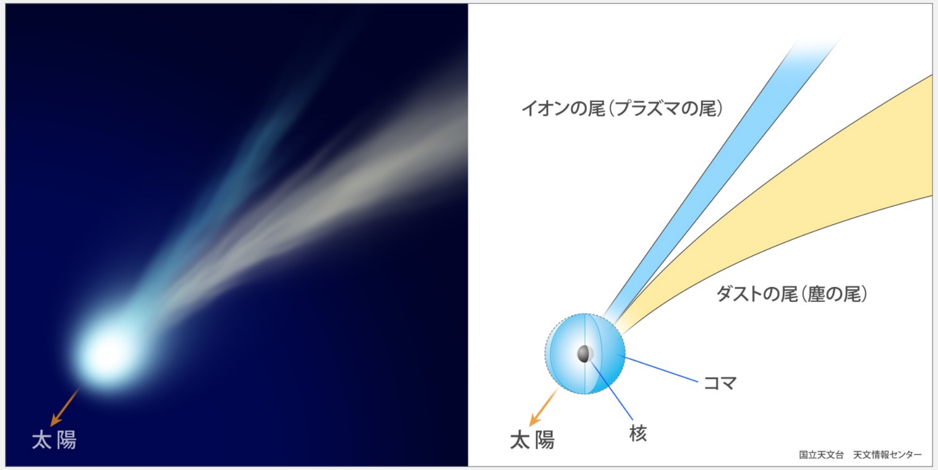
Modified from Small-Body Database Lookup



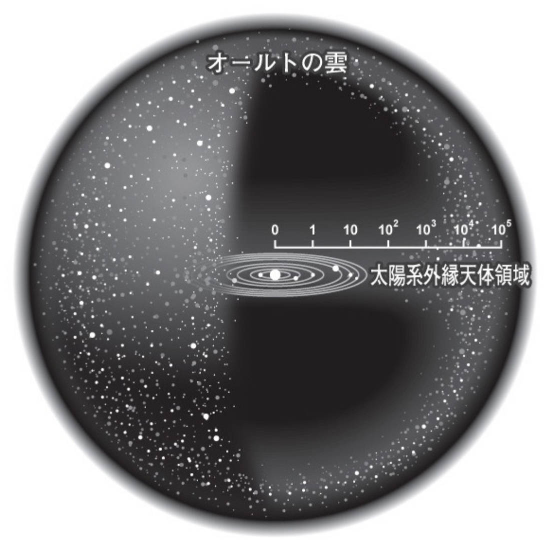


1.2. What is a Comet?

- Consists of nucleus, coma (thin atmosphere ejected from the nucleus), tail (dust, ion, Na)
- Divided into three types according to the orbital period
  - Short period comets: originated from the Edgeworth-Kuiper-belt
  - Long period comets: originated from the Oort cloud
    - Some comets have never approached the Sun = “dynamically new comets”
  - Intersteller comets: born outside our solar system
    - Only 2I/Borizov so far



credit: 国立天文台 天文情報センター



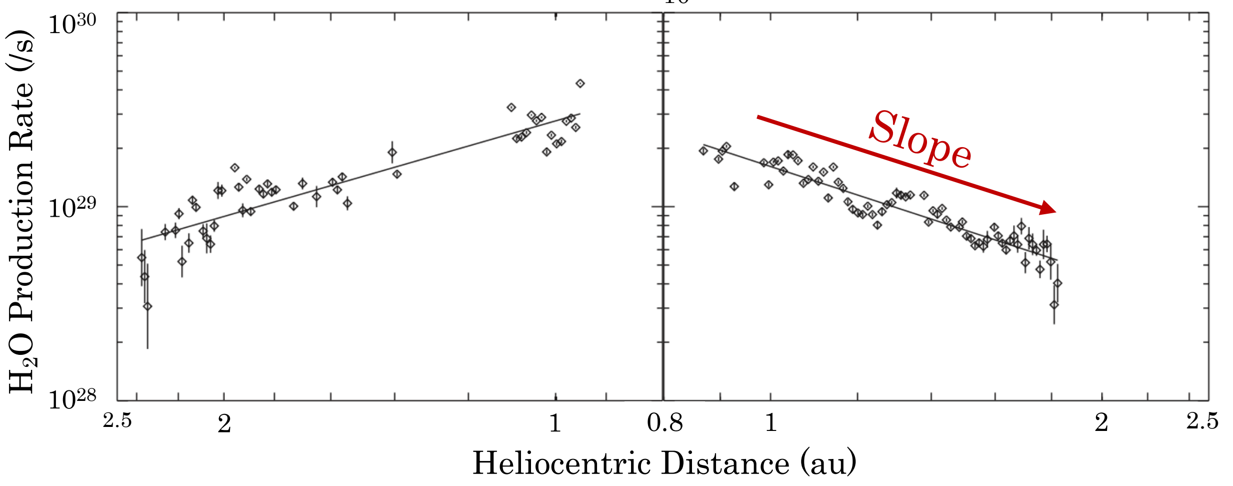
「理科年表オフィシャルサイト」より引用
http://www.rikanenpyo.jp/kaisetsu/tenmon/tenmon_011.html

1.3. Previous Study – Observation of Comets' Coma

Telescope, Spacecraft	Wavelength	Observation Period	Objects	Major Achievements
Subaru telescope	IR, Vis	2000 –	21P/Gicobini-Zinner etc.	Discovery of icy grain in the coma, Estimation of CO_2/H_2O ratio
Akari satellite	IR	2006 – 2011	67P/Churyumov-Gerasimenko etc.	Evaluation of the production rate of a variety of molecules
SOFIA (Stratospheric Observatory for Infrared Astronomy)	IR	2018	46P/Wirtanen	Derivation of HDO/H_2O ratio
FUSE space telescope	UV	1999 – 2007	C/1999 T_1 (McNaught-Hartley) etc.	Detection of CO emission line
SOHO satellite	UV	1995 –	C/2006 (SWAN) etc.	Estimation of H_2O production rate of many comets
Rosetta spacecraft	UV	2015	67P/Churyumov-Gerasimenko	Clarification of the coma's emission process in the vicinity of the nucleus

1.3. Previous Study – Estimation of H_2O Production Rate

- Many comets' water production rate is estimated through the Ly-α observations of the coma using SOHO/SWAN
  (Combi et al., 2018. *Icarus*; Combi et al., 2019. *Icarus* etc.)
  - Long period comets (LPCs) have, generally, larger H_2O production rate than short period comets (SPCs)
  - Heliocentric distance dependance slope of H_2O production rate of LPCs is flatter than that of SPCs
  - H_2O production rate of LPCs tends to fluctuate in the post-perihelion phase

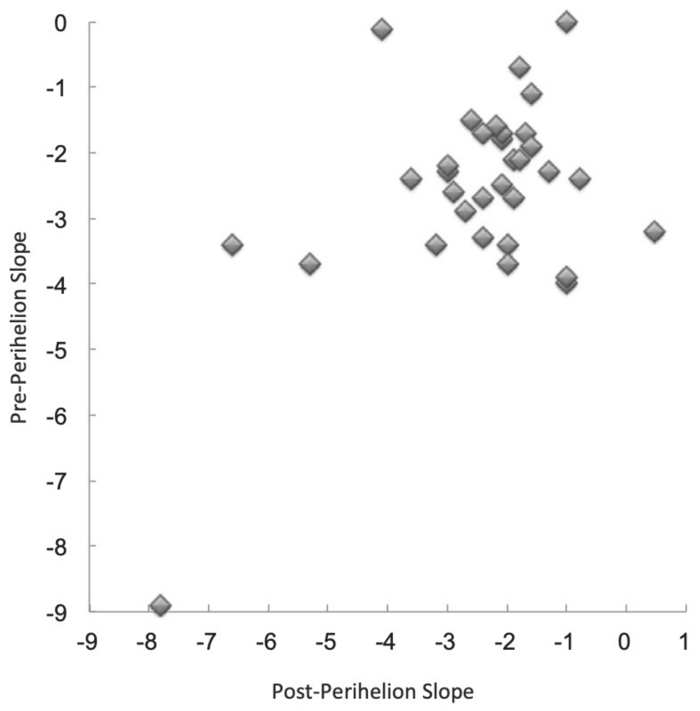


Combi et al., 2018. *Icarus*

1.3. Previous Study – Estimation of Water Production Rate

- Many comets' H_2O production rate is estimated through the Ly-α observations of the coma using SOHO/SWAN
  (Combi et al., 2018. *Icarus* ; Combi et al., 2019. *Icarus* etc.)
  - No clear tendency due to comets' period and origin?
  - Much more comets should be observed
    - Observation opportunity is quite limited

Power index of the dependence of H_2O production rate on the heliocentric distance



Combi et al., 2019. *Icarus*

1.4. Purpose of the Study

Study on the tendency of the H_2O production rate and coma's composition due to comets' origin

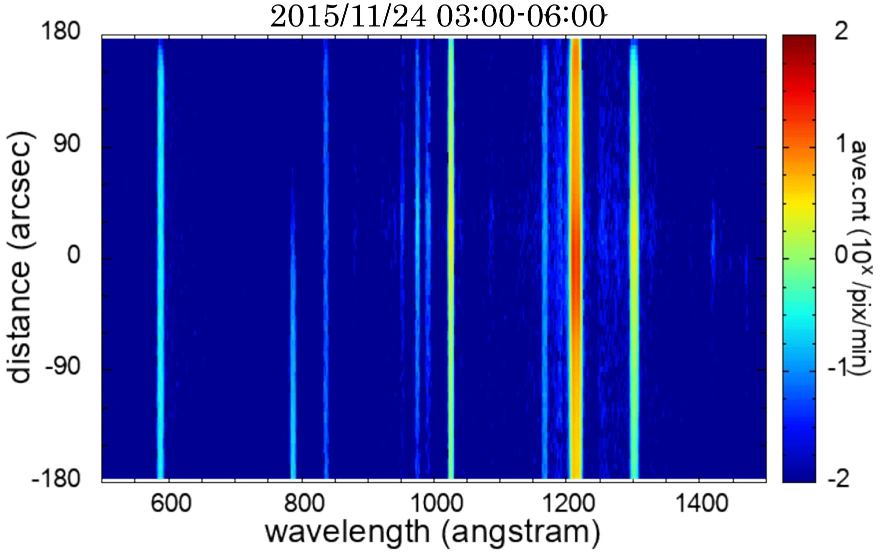
In this study, we evaluate the H_2O production rate of four comets from the distribution of Ly-α emission obtained by the Hisaki satellite

2.1. Hisaki Satellite

- Space telescope
  - Launched in Sep. 2013 (still active!)
  - Orbiting the Earth at an altitude of ~1,000 km
- UV spectroscope: EXCEED
  - Wavelength: 52nm-148nm
  - Spatial distribution in the slit direction (1D) can be obtained
- Eight comets were observed (following page)
  - However, the sensitivity of the detector around Ly-α (121.6 nm) region decreases due to degradation

credit: JAXA

Data obtained by Hisaki/EXCEED

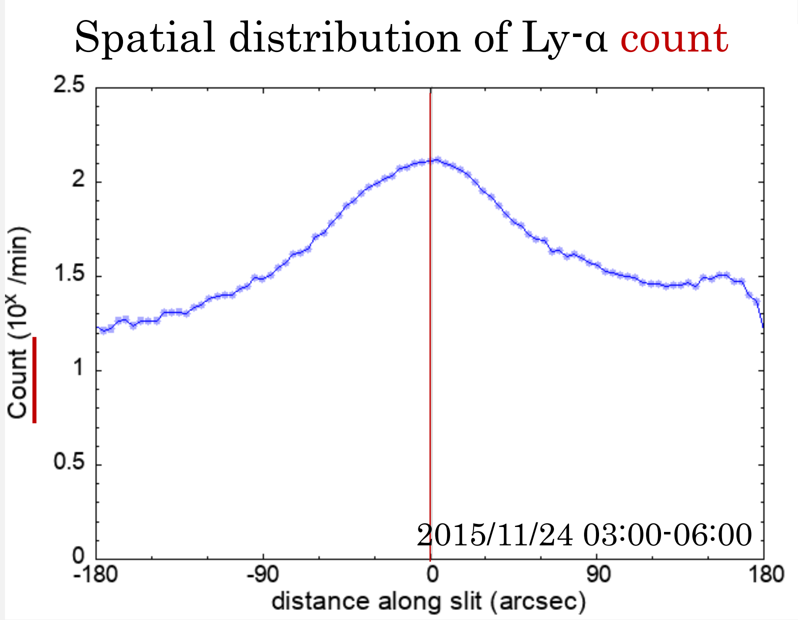


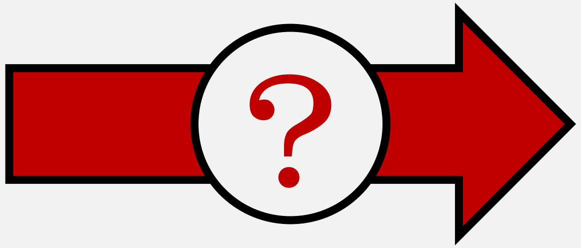
2.2. Comets Observed by Hisaki Satellite

Name	Orbital Period	Observation Period	Total Observation Time	Notes
67P/Churyumov-Gerasimenko	Short	2015/11/22 – 2015/11/30	~ 20 h	Emission lines derived from coma are not well detected
C/2013 US_{10} (Catalina)	Long	2015/11/22 – 2015/11/30	~ 39 h	Used in analysis
C/2013 X_1 (PanSTARRS)	Long	2016/05/30 – 2016/06/02	~ 13 h	Used in analysis
C/2015 ER_{61} (PanSTARRS)	Long	2017/06/02 – 2017/06/03	~ 14 h	Used in analysis
C/2015 V_2 (Johnson)	Long	2017/06/25	~ 8 h	Used in analysis
21P/Giacobini-Zinner	Short	2018/09/14	~ 8 h	No sky data
46P/Witanen	Short	2018/12/13 – 2018/12/25	~ 68 h	No sky data
C/2021 A_1 (Leonard)	Long	2021/12/17 – 2021/12/21	~ 50 h	Under analysis

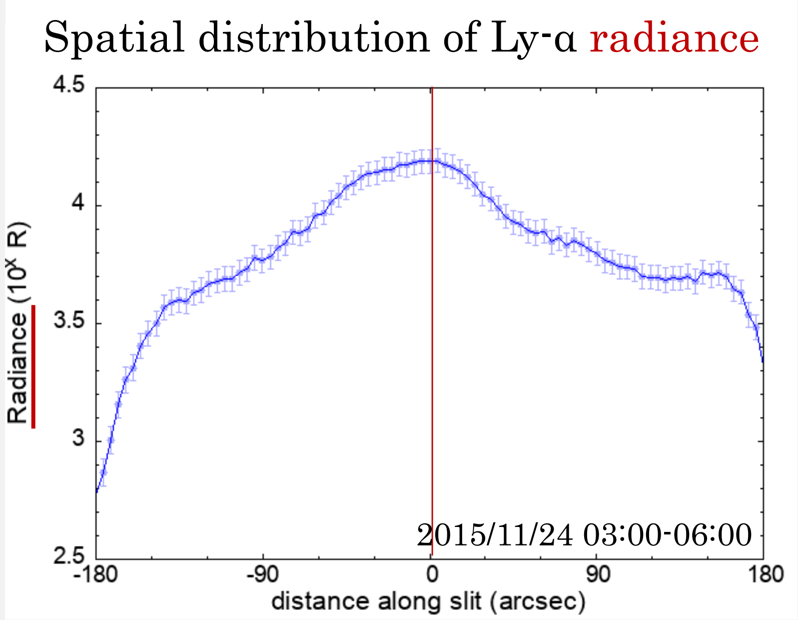
3. Estimation of the Sensitivity Using Sky Observation Data

- Conversion from count (obtained data) to radiance
  - Sensitivity of the detector around Ly-α (121.6 nm) region decreases due to degradation



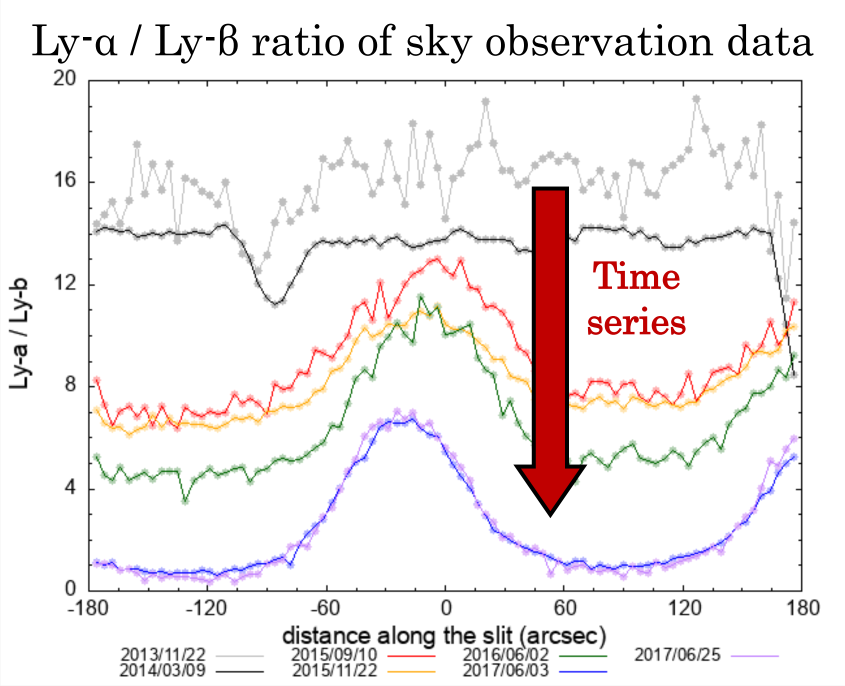


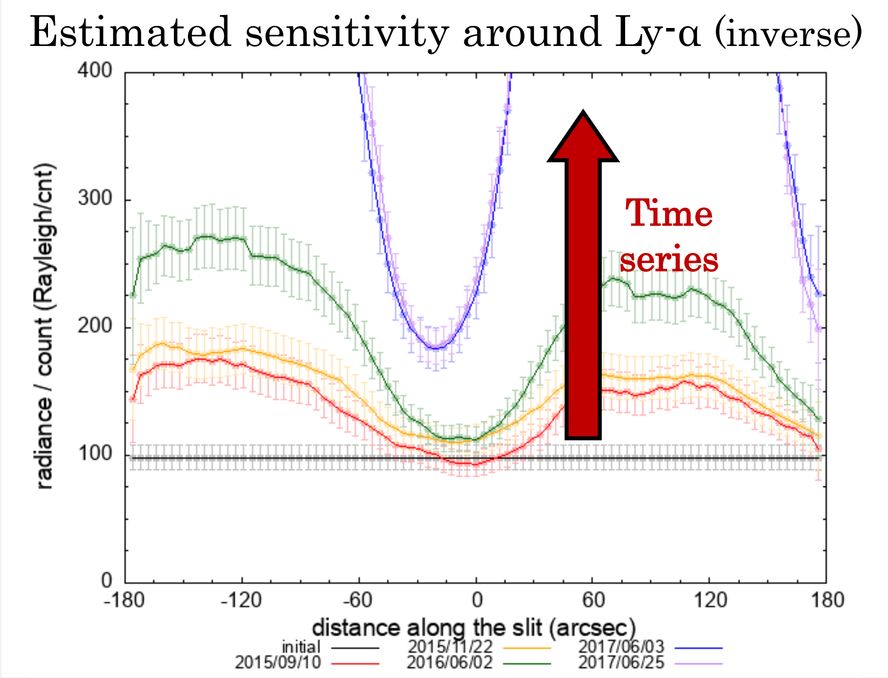
We need to estimate the sensitivity of the instrument



3. Estimation of the Sensitivity Using Sky Observation Data

- Evaluate the sensitivity around Ly-α at the time of comet observation using Ly-α / Ly-β ratio of the sky observation data (assumed to be spatially uniform)
  - Assuming that the sensitivity in the vicinity of Ly-β is constant
  - Ground calibration test data are used for the initial absolute sensitivity

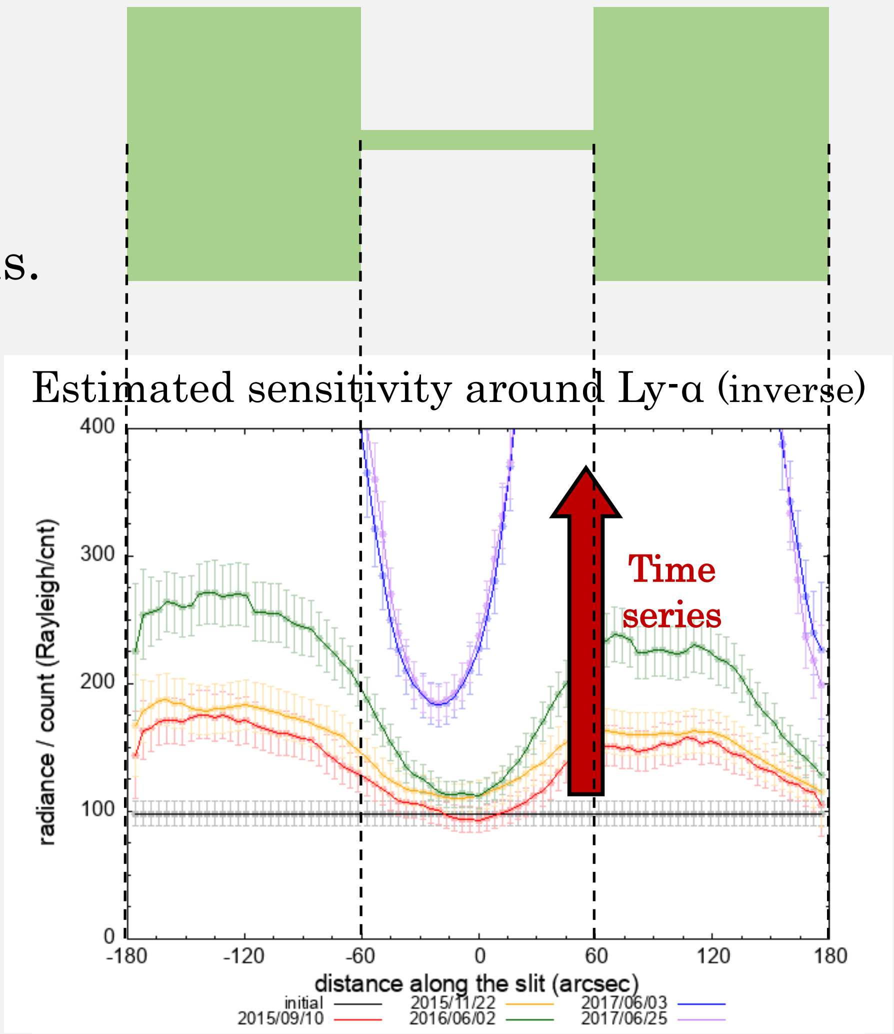




3. Estimation of the Sensitivity Using Sky Observation Data

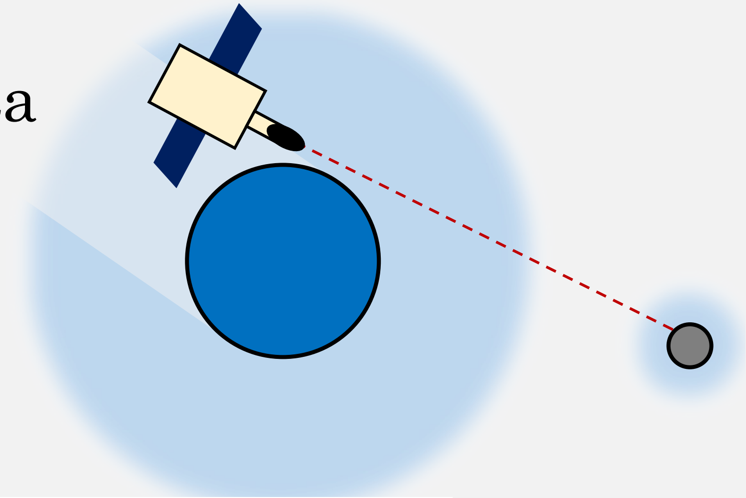
- Sensitivity has a large non-uniformity
  - Hisaki often uses dumbbell-shaped slit (width varies depending on location) for observations of Jupiter and the Io-plasma torus.
  - More photons enter the detector through wide part than through narrow part -> degradation has progressed faster

Dumbbell-shaped slit

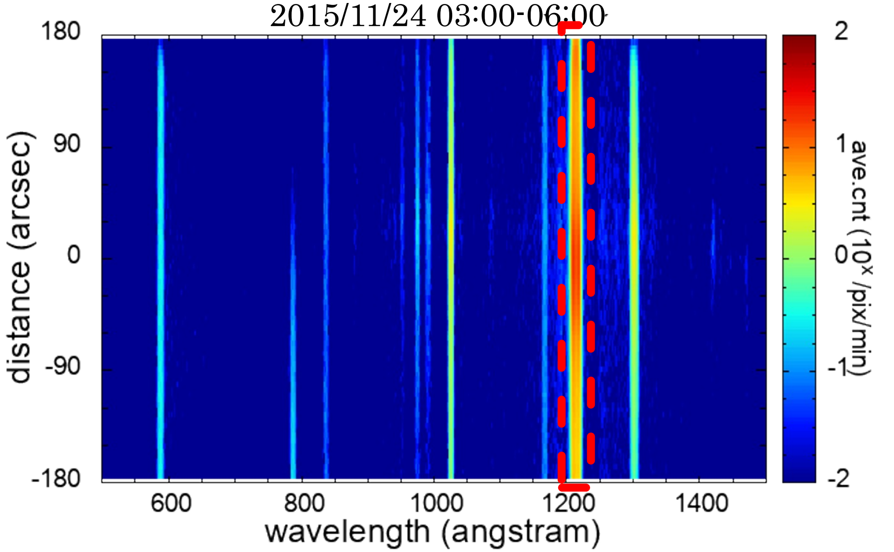


4.1. Hydrogen Distribution in the Coma

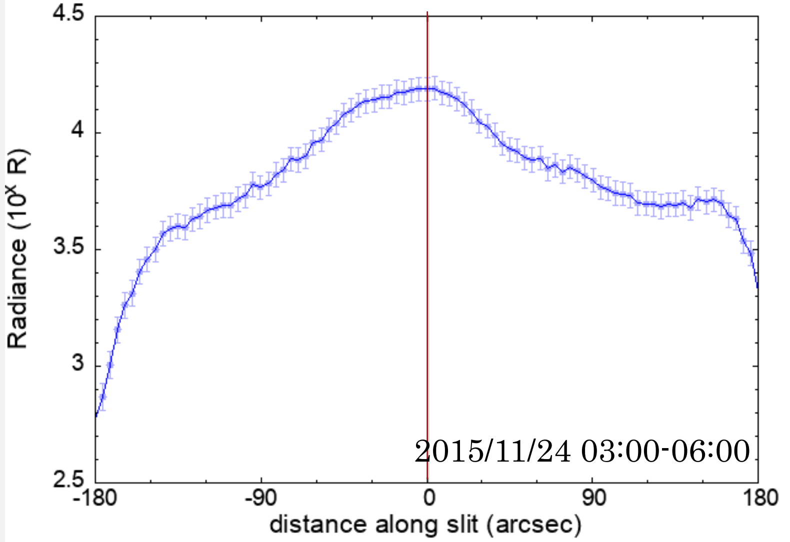
- Subtract sky observation data from comet observation data
  - Remove the influence of geocorona
  - The local time of the sky observation data used is the same as that of the observation data



Data obtained by Hisaki/EXCEED

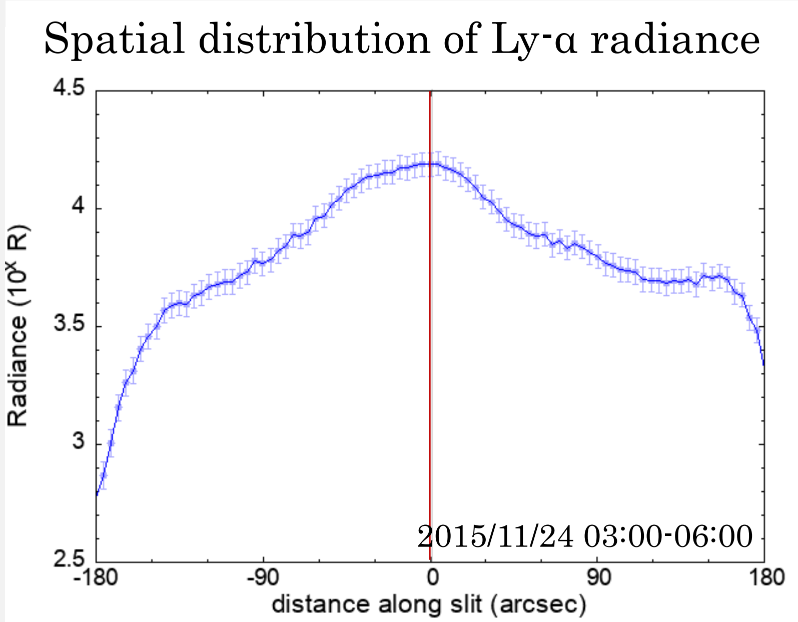


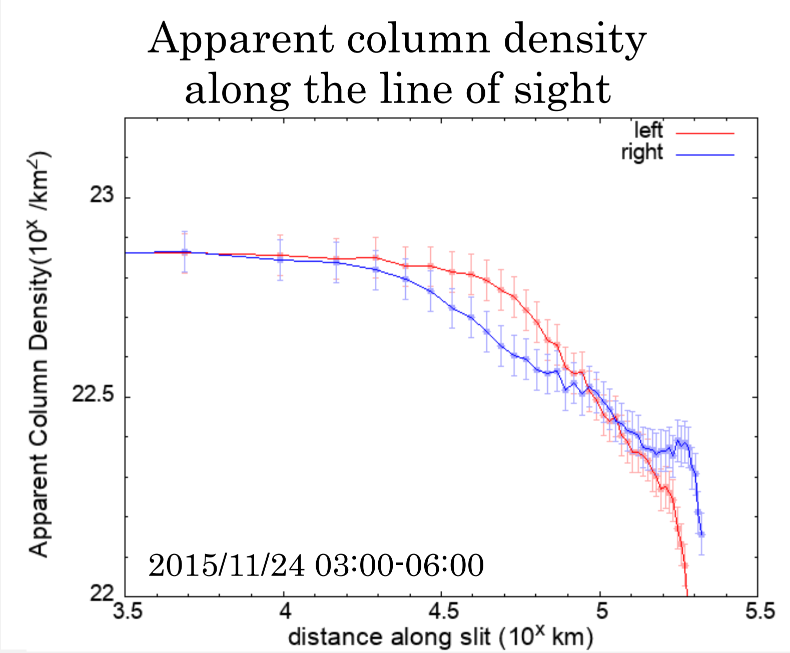
Spatial distribution of Ly-α radiance



4.1. Hydrogen Distribution in the Coma

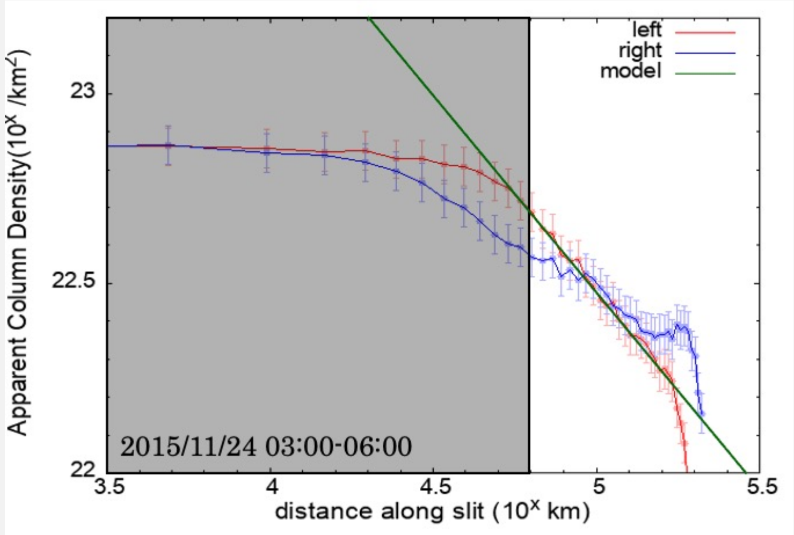
- Vertical profile is made assuming the brightest part along the slit is the nucleus
- Ly-α radiance is devided by emission efficiency (g-factor) and is converted to the apparent column density
  - g-factor is assumed not to depend on the velocity of the comets and atoms



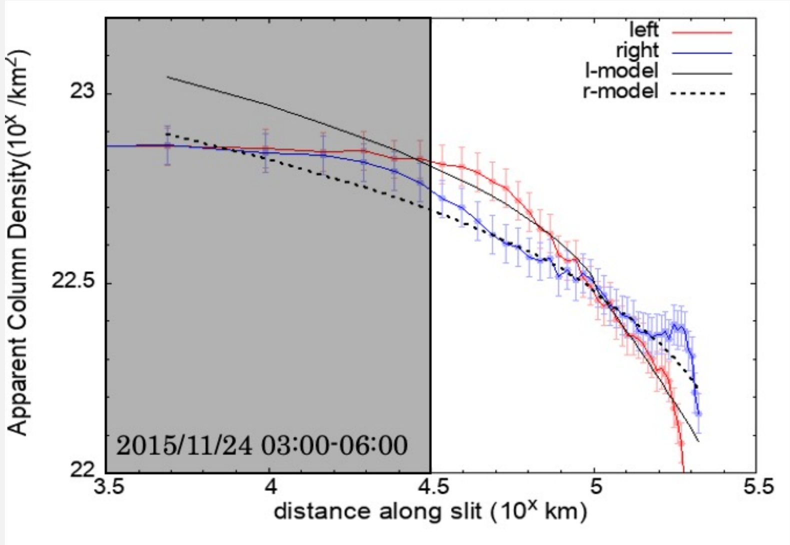


4.2. Evaluation of the Water Production Rate

- Analytical 1-D vertical profile model
  (Kaneda et al., 1986, *Nature*)
  - Fitting parameter is H_2O production rate
  - Motion of H_2O and OH is not considered



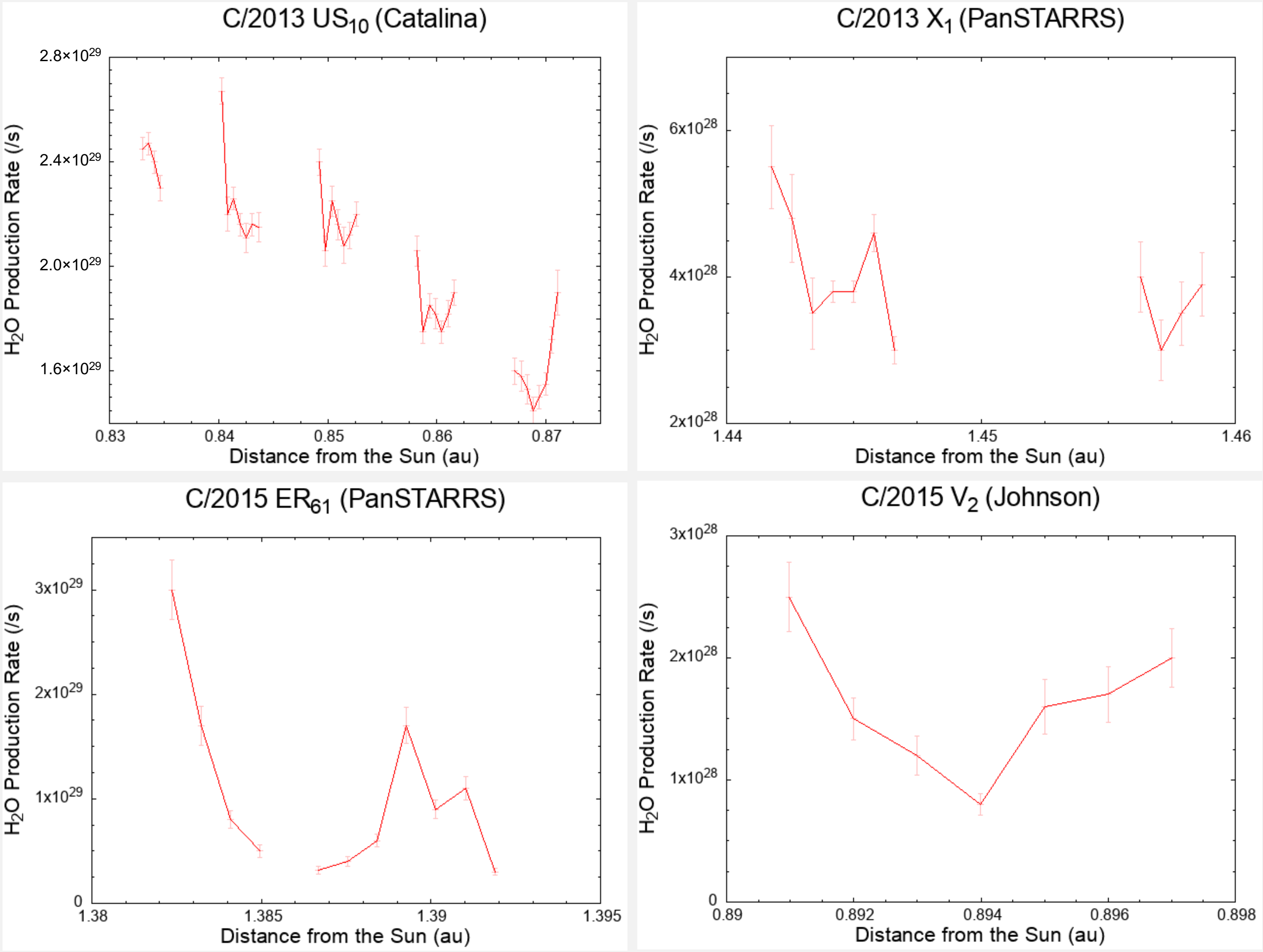
- Numerical 1-D vertical profile model
  - Solving Boltzman's eq.
  - V_{H2O}, V_{OH} is assumed to be 1.0 km/s



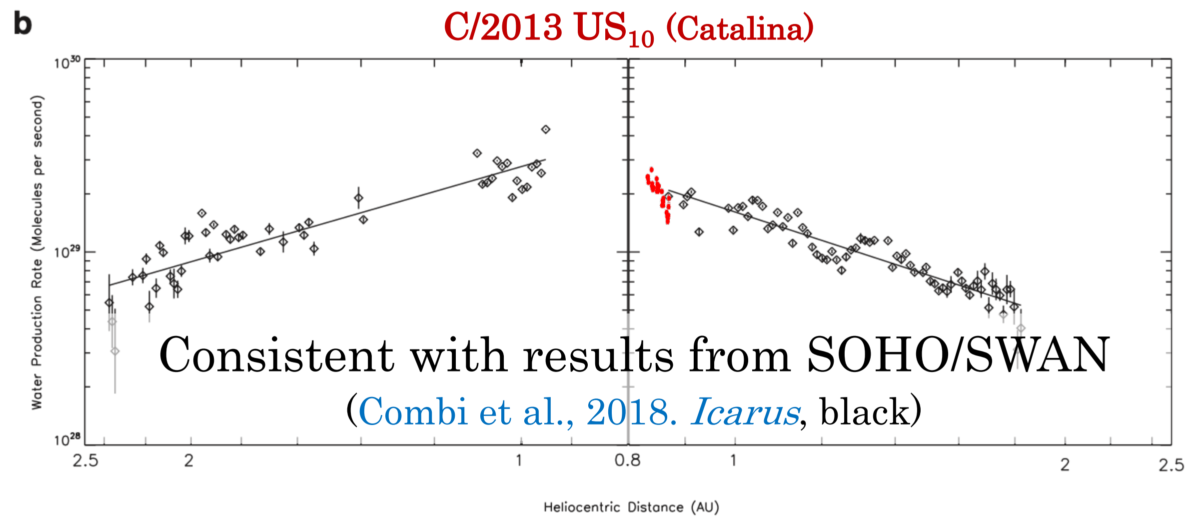
Collision of molecules or multiple scattering in the innner coma?

4.3. Comparison of Comets' H_2O Production Rate

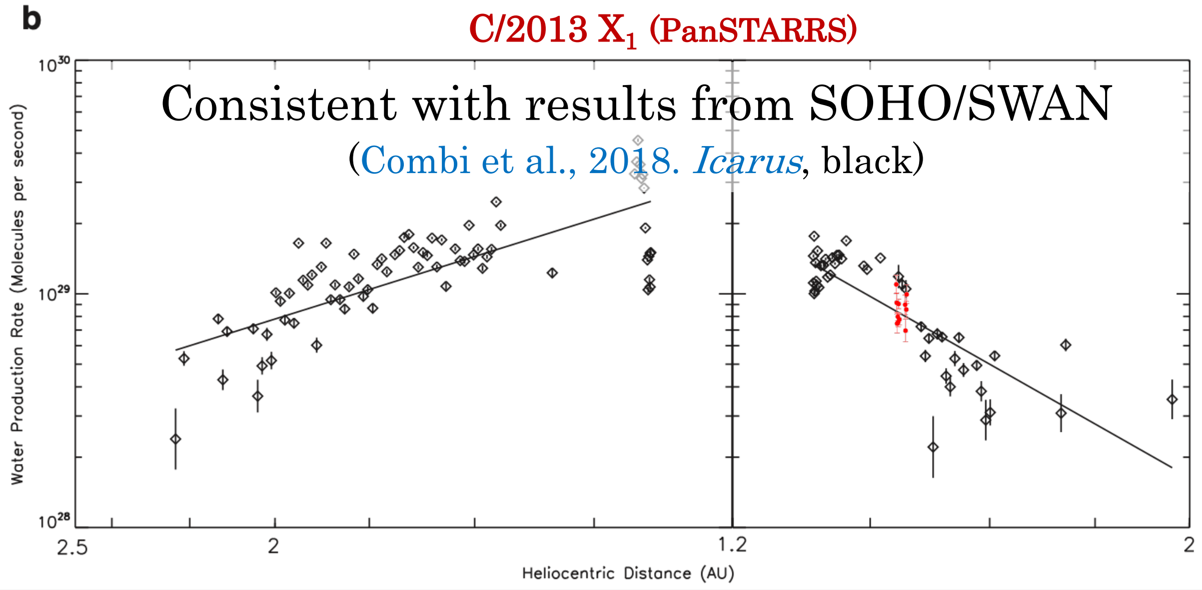
- Dependence of four comets' water production rate on the heliocentric distance ->
  - All the observations were held after comets passed the perihelion



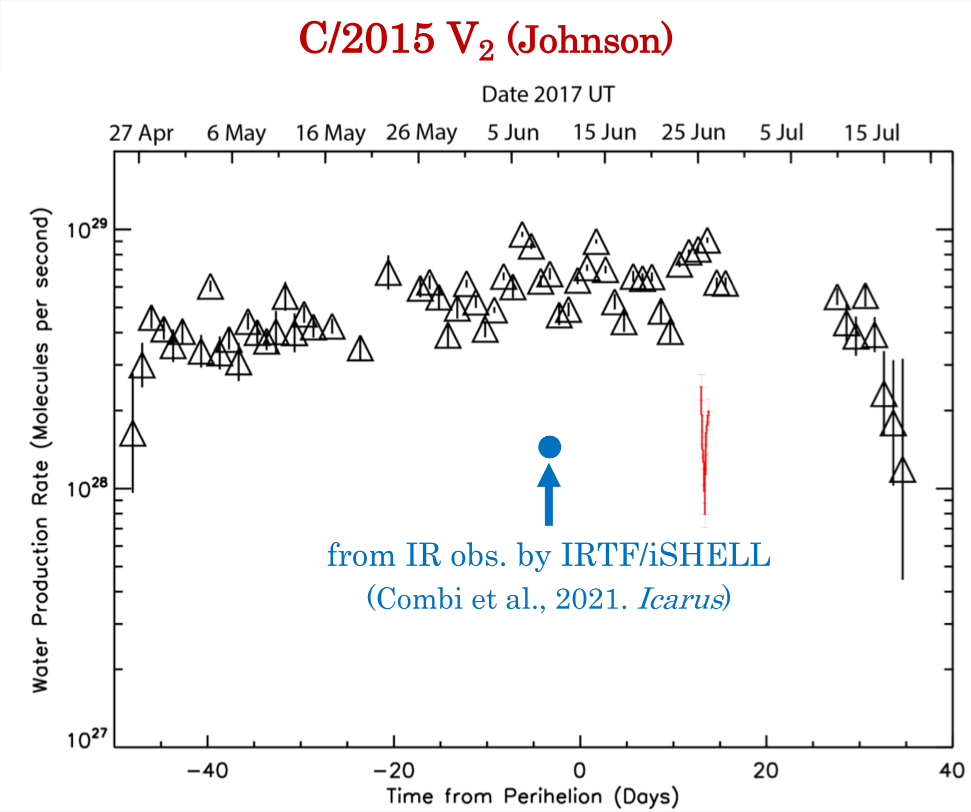
4.3. Comparison of Comets' H_2O Production Rate



Consistent with results from SOHO/SWAN
(Combi et al., 2018. *Icarus*, black)



Consistent with results from SOHO/SWAN
(Combi et al., 2018. *Icarus*, black)



Inconsitent with the results from SOHO/SWAN
(Combi et al., 2021. *Icarus*, black)

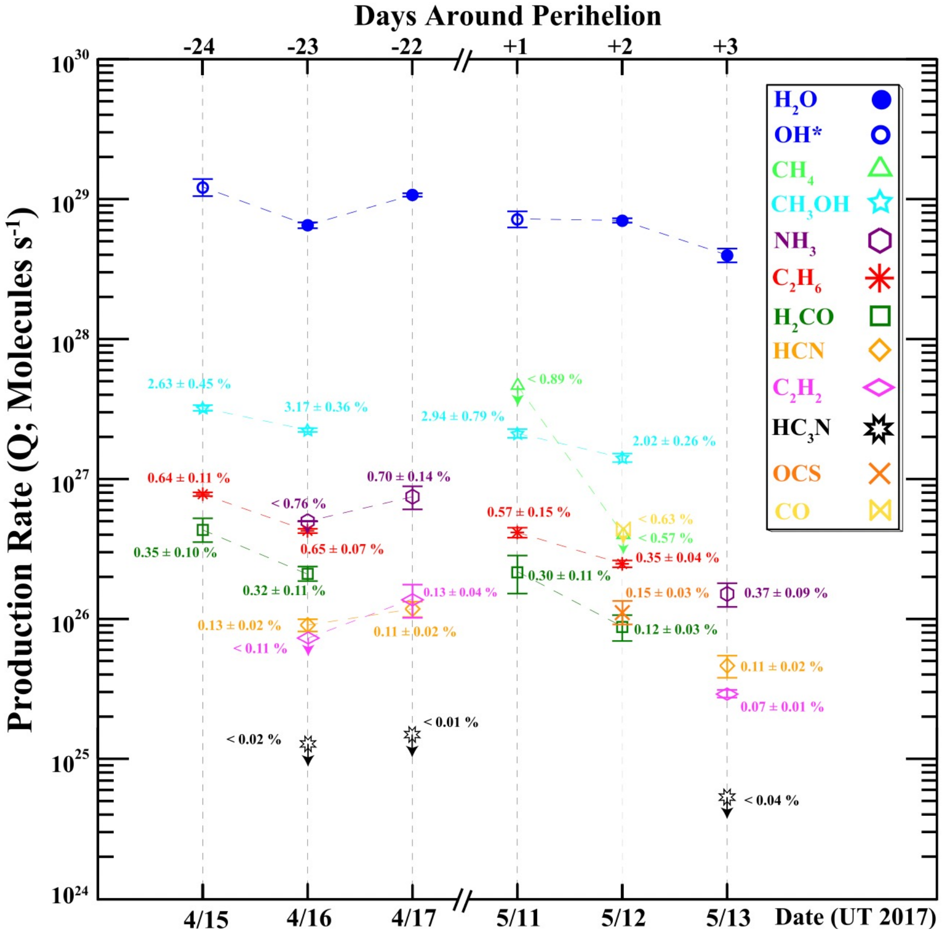
- The accuracy of Hisaki's data is possibly low due to short observation time

4.3. Comparison of Comets' Water Production Rate

- H_2O production rate of C/2015 ER_{61} (PanSTARRS)
  - Results from Hisaki (Q_{H2O}~10^{29} /s) is consistent with that from IRTF/iSHELL (Saki et al., 2021. *AnJ.*)
    - Hisaki = UV observation of H atoms
    - IRTF = IR observation of H_2O molecules

  -> Different methods show the consistent results!

- Short-period (~1 day) variation of each molecules were also detected by Hisaki.
  - Background (geocorona) variation? -> Future work



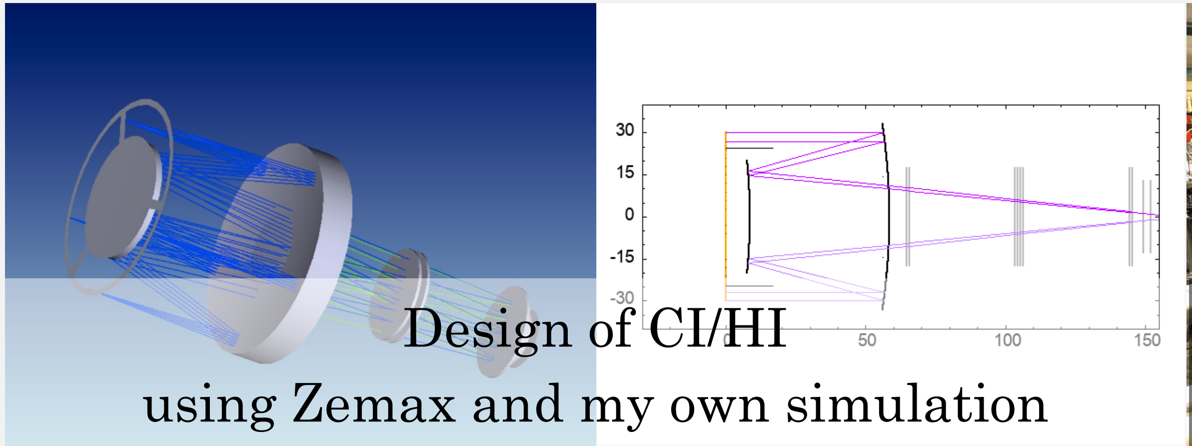
Saki et al., 2021. *AnJ.*

5.1. Summary

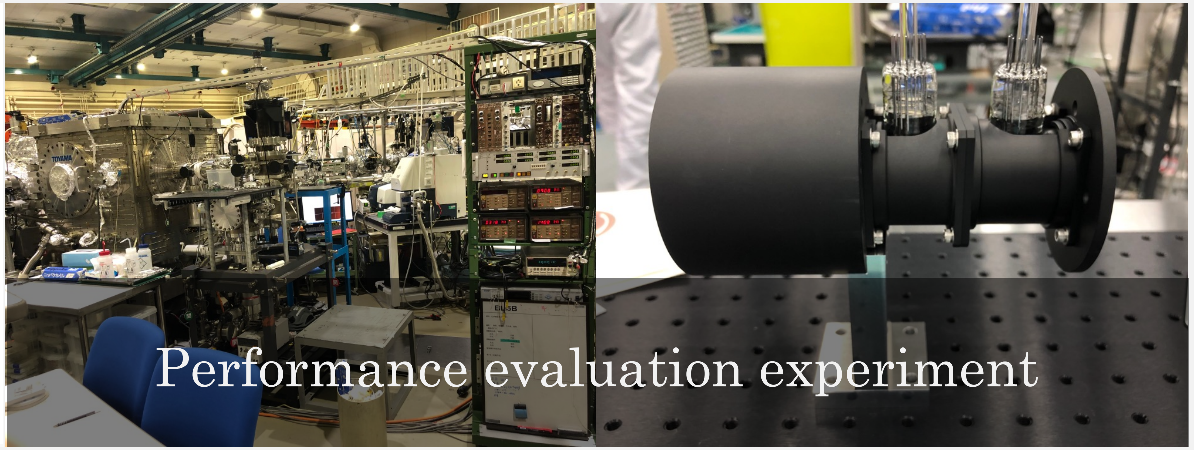
- We succeeded to estimate the H_2O production rate of four long period comets using Hisaki satellite's observation data
  - Sensitivity of the degraded detector are assumed using the Ly-α / Ly-β ratio of sky observation data
  - H_2O production rate of C/2013 US_{10} (Catalina) and C/2013 X_1 (PanSTARRS) was very consistent with the results of previous study (Combi et al., 2018. *Icarus*) using SOHO/SWAN
  - C/2015 ER_{61} (PanSTARRS): H_2O production rate obtained by UV observations of Hisaki is consistent with that by IR observations of IRTF!

5.2. Future Work

- Constructing model considering multi-scattering in the inner coma
- Detailed analysis of short-period variation of molecules in the coma
- Development of Hydroden Imager onboard Comet Interceptor spacecraft



Design of CI/HI
using Zemax and my own simulation



Performance evaluation experiment