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再突入物体のレーダ観測及び予測解析

Observation and Prediction for Re-entry Objects

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低軌道のスペースデブリは、大気抵抗による減速効果で高度が下がり、いずれ大気圏に再突入する。大気圏再突入の時期やその位置を予測することは重要である。JAXA では、上齋原スペースガードセンターに設置されたレーダを用いた観測及び米国が公開している軌道情報（Two-Line Elements）を用いて、軌道把握と再突入予測解析を行っている。再突入間際のレーダ観測においては、低高度であるがゆえに、大気抵抗の予測誤差、大気密度モデル誤差の増大、及び質量面積比の不確定性などにより、観測が困難となる。そのため、多段観測と呼ぶ観測手法を確立させ、再突入直前までの観測を可能とした。
本講演においては、2011 年度に実施した 3 物体の再突入予測解析について、レーダ観測及び再突入予測解析の結果を示すとともに、得られた知見と、今度の予測精度向上に向けた取り組みを発表する。

Uncontrolled space debris re-enters atmosphere due to atmospheric drag in low altitude. The prediction of re-entry point and time window are important for space debris issues. Orbits of re-entering objects are observed by radar and also estimated using Two-Line Elements obtained from a web site for re-entry prediction analysis. However, accurate observation by radar just before re-entry is difficult due to errors in atmospheric drag prediction. We therefore established a method called the Multi-Stage Observation to solve this problem, and made much progress in observing the objects in the last hours of re-entry in visible paths.
This paper presents recent activities of space debris observation and re-entry prediction and their results obtained from three targeted satellites which re-entered in JFY 2011. In addition, means for improving prediction accuracy is further discussed.

The 5th Space Debris Workshop

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1. Introduction (1/2)

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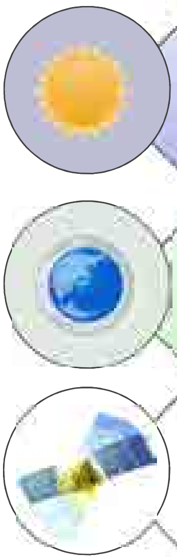
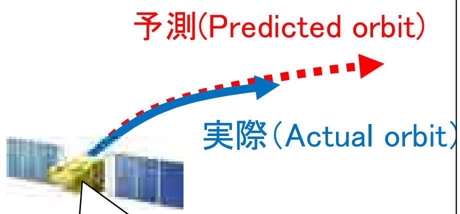
- Orbit of uncontrolled space debris is difficult to predict due to errors in atmospheric drag prediction.
- 自然落下するデブリの軌道は、大気抵抗に大きく左右され、予測が難しい。



太陽活動の将来予測の不確定性
（大気密度の変化の不確定性）
(Uncertainty 1:
Prediction of solar activity)

低高度（100～200km前後）領域における大気密度モデルの不確定性
(Uncertainty 2: Errors in atmospheric model in low attitude)

再突入物体の姿勢変動による弾道係数の変動状況の不確定性
(Uncertainty 3: Ballistic coefficient)



Most errors occur in the direction of travel of the predicted orbit.
誤差は主として軌道の進行方向に生じる

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1. Introduction (2/2)

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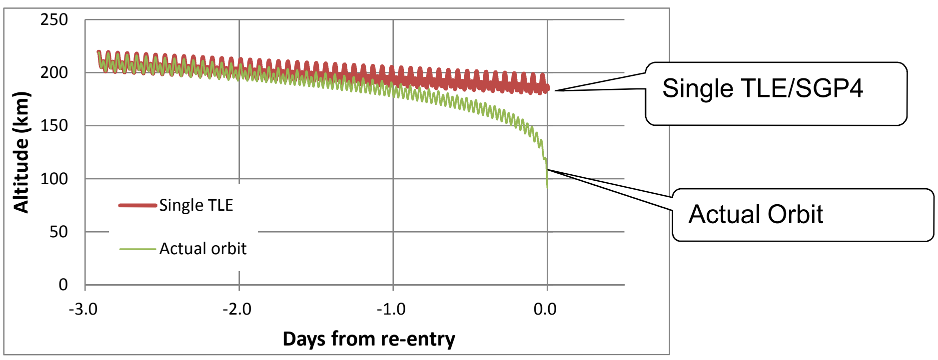
- As a first step, orbit of reentry object gets Two-line elements (TLE) from Space-Track.org.)
- However, prediction accuracy has a large error using only single TLE.
- We therefore performed observation by radar and orbit estimation using the multi-TLEs in order to improve accuracy.

- 再突入物体は、まずSpace-TrackのTLEを用いて軌道を把握する。
- しかし、TLE単体では、再突入予測の精度が満たせない。
- 「レーダー観測」と「複数のTLEsから軌道を求める」ことで再突入予測で使用できる軌道精度向上を図っている。



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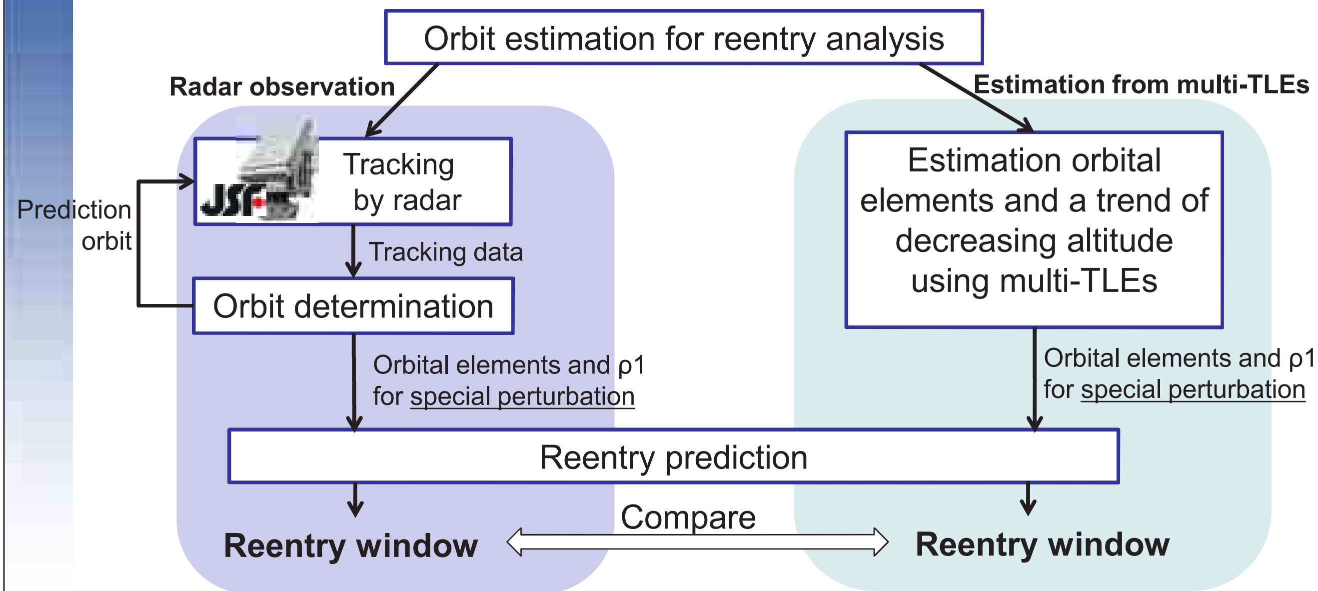
2. Method of orbit estimation

- Accuracy in orbit prediction is improved using special perturbation method.
  - Reentry objects are observed for orbit determination by KSGC radar using TLE.
  - On the other hand, orbital elements are also estimate from multi-TLEs.



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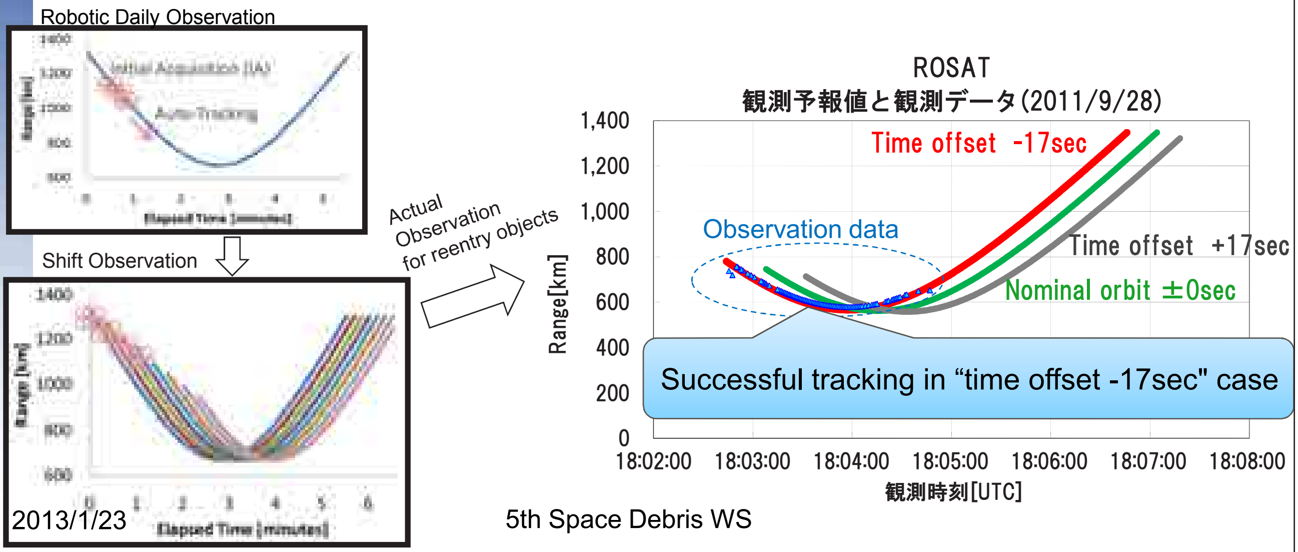
2.1. Radar observation

- Accurate observation by radar just before re-entry is difficult due to errors in atmospheric drag prediction.
- A prediction error is covered only 3 seconds if a method of robotic daily observation use.
- We therefore established a method called the Shift Observation to extend covering error span more than 20 seconds.



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2.2. Orbit estimation using multi-TLEs

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- A propagate of TLE is used general perturbation such as SGP4.
- A prediction accuracy has a large error using SGP4. It isn't available to use reentry prediction.

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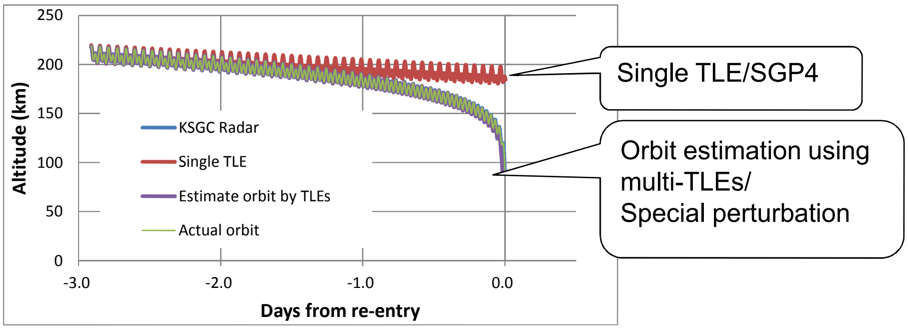
- Improved orbital elements and a trend of altitude decreasing rate are estimated using multi-TLEs for several days.
- Accuracy in prediction orbit is improved using special perturbation after estimation from multi-TLEs.



3. Re-entry analysis condition

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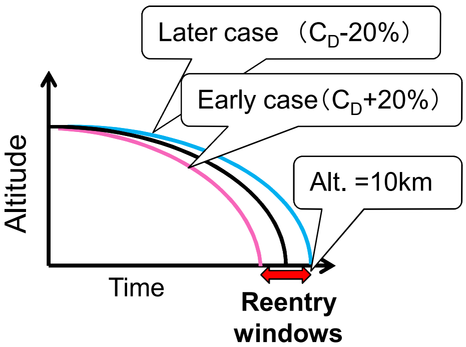
- 大気密度モデル:
  (Atmospheric density models)
  - Jacchia-Roberts（Alt. ≧90km）
  - US. Standard（Alt.＜90km）

- 再突入予測範囲:
  (Reentry windows)
  - 大気抵抗係数(C_D) ±20%
  - 過去の実績及び経験則から設定
    (Based on past results and heuristics)



- Analysis targets (satellites)

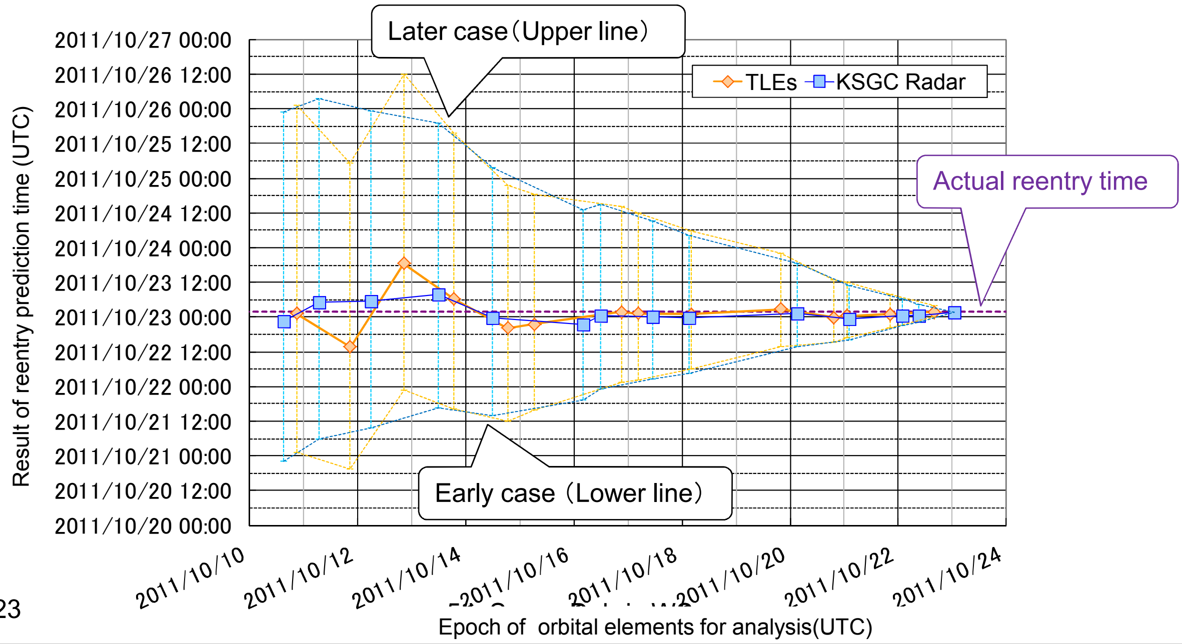
ROSAT


UARS


Phobos-Grunt (P-G)


3.1. Result of reentry prediction for ROSAT

- There is no significant difference between case of orbit estimation from multi-TLEs and case of KSGC radar.
- This analysis is shown good results because of ideal convergence.



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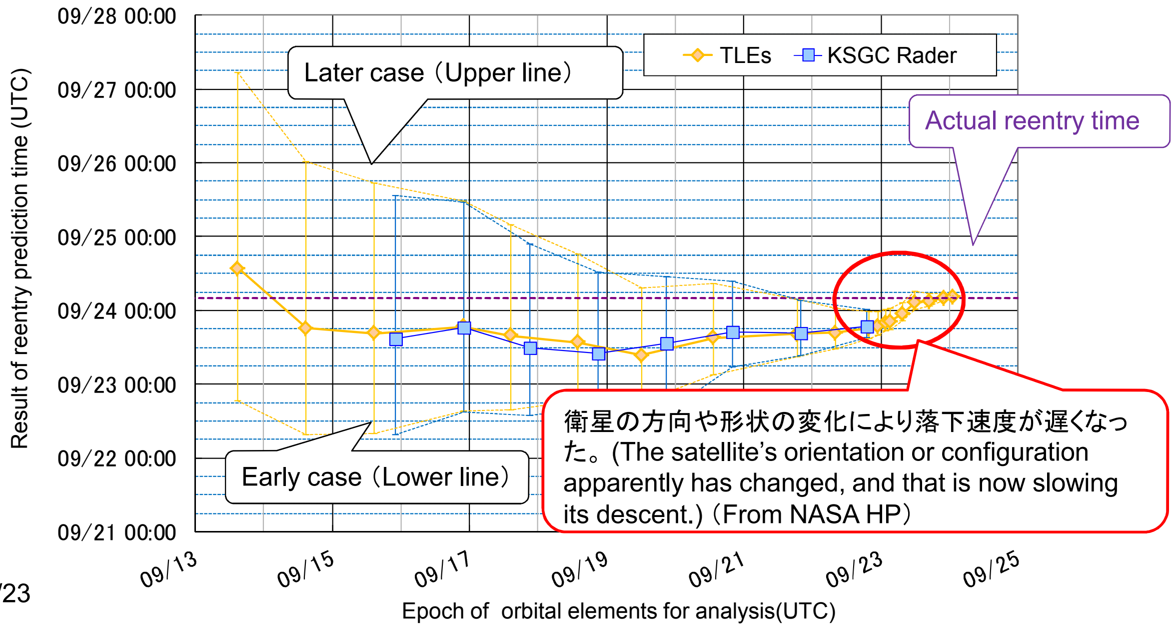
3.2. Result of reentry prediction for UARS

- Change in the satellite's orientation or configuration is apparently slowing its descent before one day from reentry.
- There is shown to be associated uncertainty 3 such as Ballistic coefficient .



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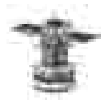
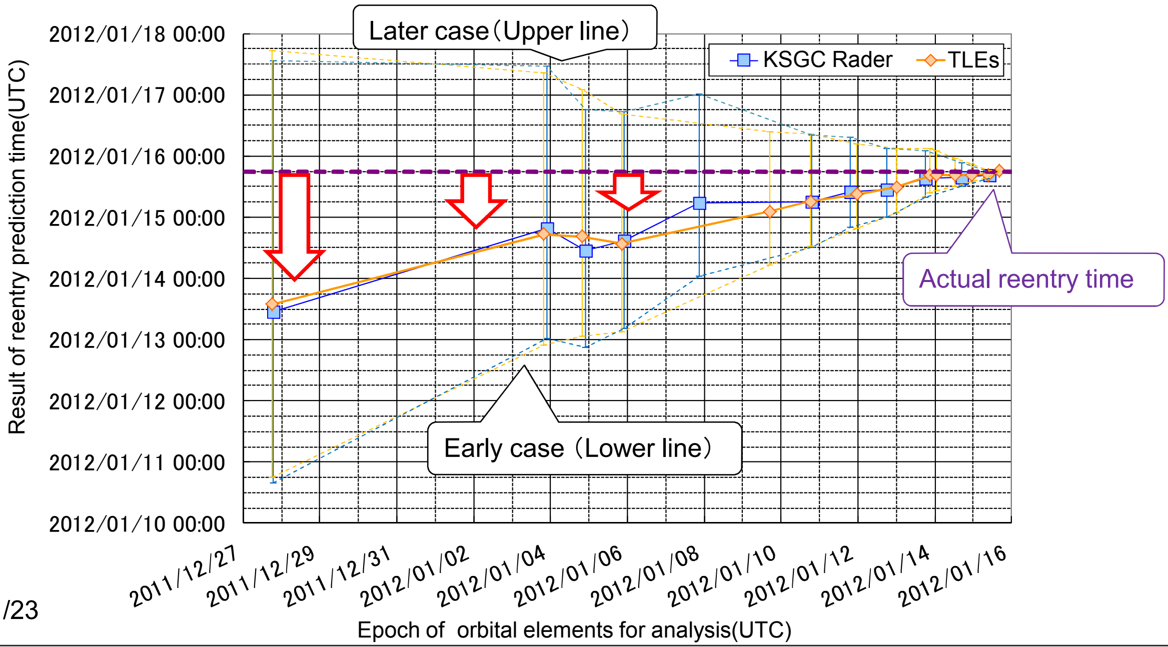
3.3. Result of reentry prediction for P-G



- Most results were earlier than reference reentry time.
- There are one of the factors that effects of prediction of solar activity. (Relation with uncertainty 1)



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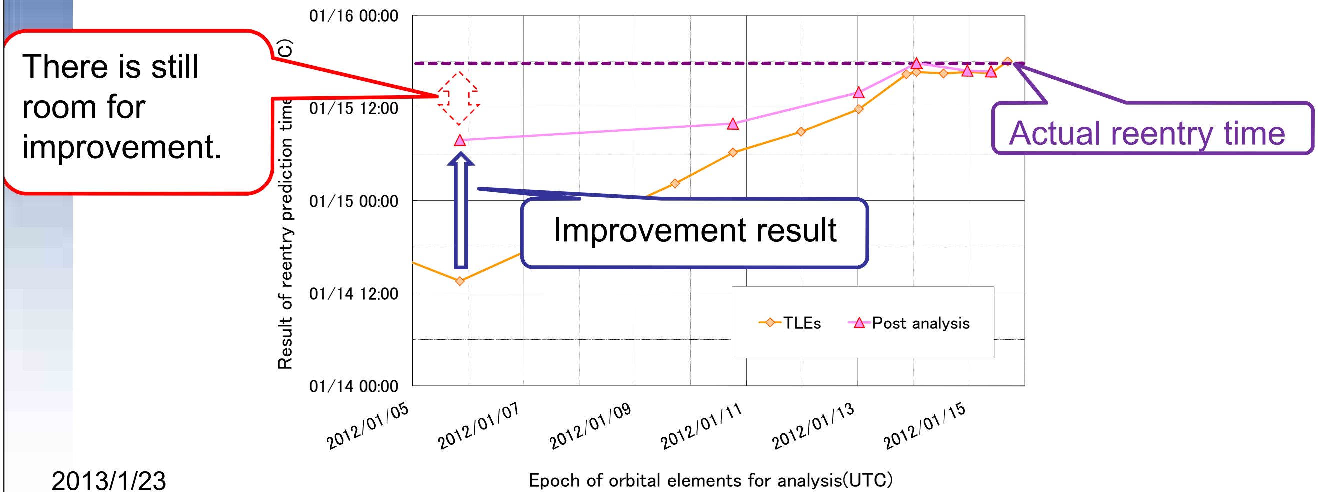
3.4. Effects of prediction of solar activity

- Prediction of solar activity refers solar flux (F10.7cm) and geomagnetic index value from NOAA site.
- The solar activity is updated from perdition to actual value several days later.
- Post analysis : conducted by replacing the solar activity prediction to its actual value.



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5. Conclusion

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- We were successful in continual prediction of reentry window through establishing the method of initial acquisition for radar observation and orbit estimation based on multi-TLEs for accuracy improvement.
- We performed estimation of orbits and prediction of reentry windows for three satellites in FY2011. The errors in these results were almost within 20 percent, as we had expected.

- レーダー観測における捕捉方法の確立、複数TLEからの精度向上を行うことで、継続的な再突入予測解析が実施できた。
- 2011年度に再突入した3衛星について、再突入予測解析を行い、概ね誤差20%の予測範囲内の結果であった。

Future Works(今後の課題)
- We will further study the physics of a situation just before re-entry, in order to improve the accuracy of prediction.)
- 再突入物体の挙動から物理的現象の分析を深掘りし、精度向上に向けた研究を実施していきたい。

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ご清聴ありがとうございました。
Thank you for your attention!

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