The 4th International Workshop
on Space Debris Re-entry

PMO Progress in Re-entry Prediction

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OUTLINE

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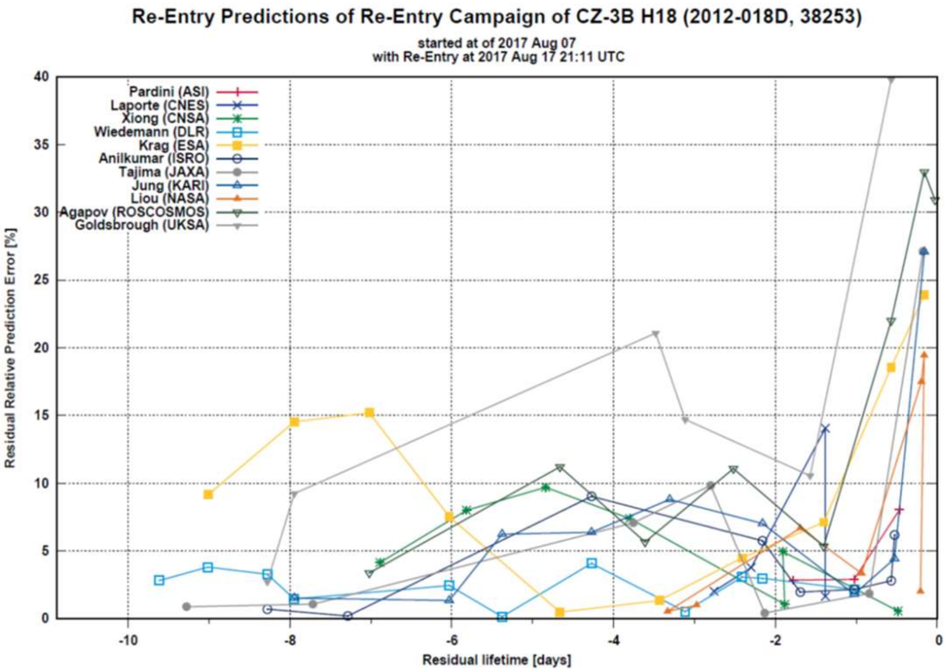
Previous Work

PMO has participated in IADC Re-entry Prediction Campaigns since 1998（Representing CNSA).

inspector(1998), GFZ-1(1999), … , VEGA AVUM (2016-2),CZ-3B(2017-1)



7 inputs in total (Xiong,CNSA)

Prediction err:
Mean : about 5%
MAX: about 10%
MIN: about 1%

Last campaign 2017-1（from ESA report）

Re-entry Prediction Method

Two methods: TLE and our observation data

- Based on TLE (semi-analytical)
  - DATA preprocessing (more than 50 TLEs)
    - Smooth the perigee
    - Determine the Mean area-mass ratio(AMR) (DNDT & MSIS 1990)
  - Mean element prediction
    - Predict by Chebyshev polynomials(above 120km)
    - Predict by numerical integration (below 120km)
  - Dynamical model
    - Gravity: JGM 50×50 ; Atmosphere: MSIS 1990
    - Solar radiation pressure; luni-solar gravity; solid earth tide

Re-entry Prediction Method

- Based on our observations(numerical integration)
  - Obtain observation data through the optical telescopes of CAS
  - Orbit determination
    - Determination variable: R ,V,Cd(AMR)
    - Numerical integration: Adams-Cowell
  - Dynamical model
    - Gravity: JGM 50×50 ; Atmosphere: MSIS 1990
    - Solar radiation pressure; luni-solar gravity; solid earth tide; sea tide
  - Osculating element prediction
    - Numerical integration
    - Stop until z<0KM

Re-entry Prediction Method

We choose the prediction method according to the data availability.

We find that if we choose the same atmospheric model and AMR value , the prediction results of the two different methods are basically the same, while the semi-analytical method is faster.

We also perform the long-term orbital lifetime estimation by simplifying the dynamical model.

Progress in Improving the Prediction Accuracy

According to the atmospheric dynamical equation :

$$\vec{F_s} = -\frac{1}{2} C_d \frac{S}{m} \rho V^2 \left(\frac{\vec{V}}{V}\right)$$

Two factors that influence the prediction accuracy are:

- **Atmospheric model error**

  During orbit determination, part of atmospheric model errors may be offset by AMR estimation. However, the atmospheric model errors at different altitudes are not the same.

- **AMR(S/m) error**

  For some irregularly shaped debris, their rotation may cause long-term changes in the AMR. In fact, we have observed some long-term AMR changes of space debris. The changes come from atmospheric model error and rotational state.

Progress in Improving the Prediction Accuracy

- **Atmospheric model building**
  - **coefficient correction**

Atmospheric model structure:(similar DTM)

$$\rho = k\sum m_i n_i(z)$$

$$n_i(z) = A_{i1}e^{G_i(L)-1} f_i(z)$$

$$\begin{aligned}
G(L) = 1 & \\
& + A_2 P_2^0 + A_3 P_4^0 \\
& + A_4(F-\bar{F}) + A_5(F-\bar{F})^2 + A_6(\bar{F}-150) \\
& + (A_7 + A_8 P_2^{\,0})K_p \\
& + \beta\{(A_9 + A_{10}P_2^{\,0})\cos[\Omega(d - A_{11})] \\
& + (A_{12} + A_{13}P_2^{\,0}) \times \cos[2\Omega(d - A_{14})] \\
& + (A_{15}P_1^{\,0} + A_{16}P_3^{\,0} + A_{17}P_5^{\,0}) \cdot \cos[\Omega(d - A_{18})] \\
& + A_{19}P_1^0 \cdot \cos[2\Omega(d - A_{20})]\} \\
& + \beta(A_{37}\cos\psi + A_{38}\cos 2\psi)
\end{aligned}$$

coefficient correction equation:

$$\dot{a}_o - \dot{a}_c = \sum \frac{\partial \dot{a}_c}{\partial \varepsilon_i}\Delta \varepsilon_i$$

$\dot{a}_o$ **: come from drag data**

$\dot{a}_c$ **: come from atmospheric model**

$$\frac{\partial \dot{a}_c}{\partial \varepsilon_i} = \frac{1}{2\pi}\int_0^{2\pi} \frac{2}{n\sqrt{1-e^2}}\left(Se\sin f + \frac{P}{r}T\right)\frac{1}{\rho}\frac{\partial \rho_c}{\partial \varepsilon_i}dM$$

ε_i **: coefficient Aij**

Progress in Improving the Prediction Accuracy

- **Atmospheric model building**

Use drag data:

Space debris number(R/B): > 40

Drag data time span: > 22 years

Perigee: <400km, mainly >200km

Correction result:

coefficient number: 44

inner coincidence(RMS): ~15%

Progress in Improving the Prediction Accuracy

- **Atmospheric density correction (champ accelerometer)**

Density correction equation:

$$\rho_{\text{true}} = \rho_{\text{model}} + \Delta\rho = \rho_{\text{model}}\left(1 + \frac{\Delta\rho}{\rho_{\text{model}}}\right) = \rho_{\text{model}}(1+\varepsilon)$$

$$\varepsilon = \varepsilon_1(\varphi) + \varepsilon_2(t) + \varepsilon_3(h) + \varepsilon_4(F_{10.7})$$

ρ_{ture} :　**from champ**

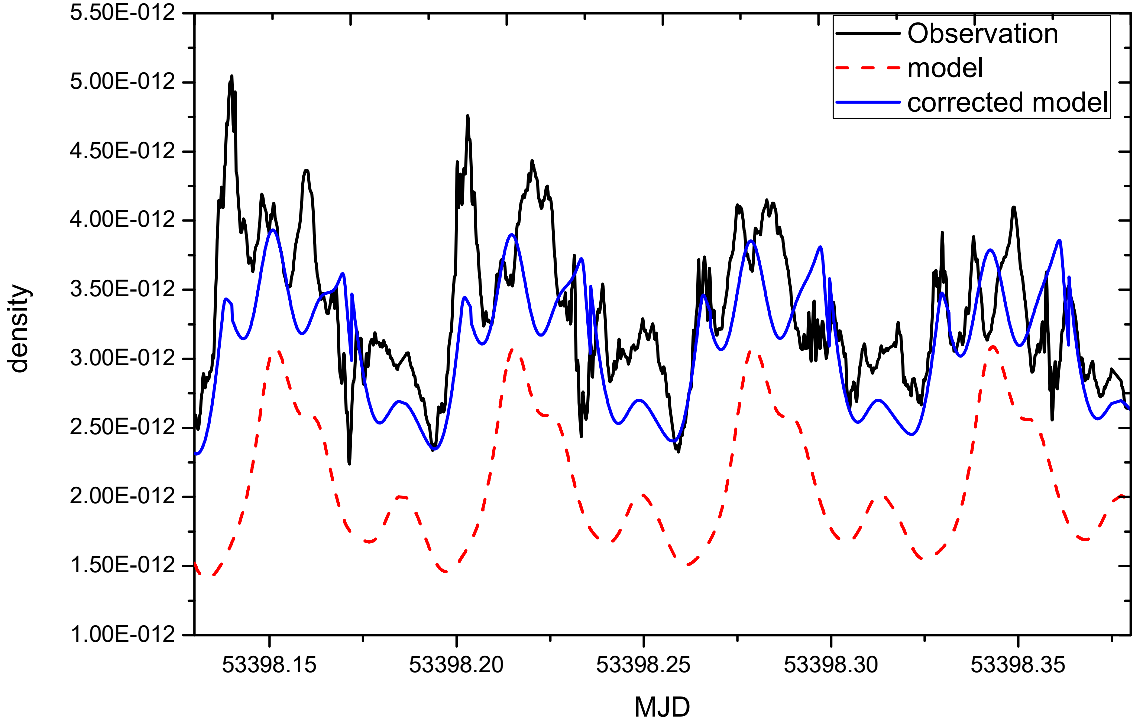
Calculate the correction function:

ε1, ε2, ε3, ε4

Progress in Improving the Prediction Accuracy

- **Atmospheric density correction (champ accelerometer)**

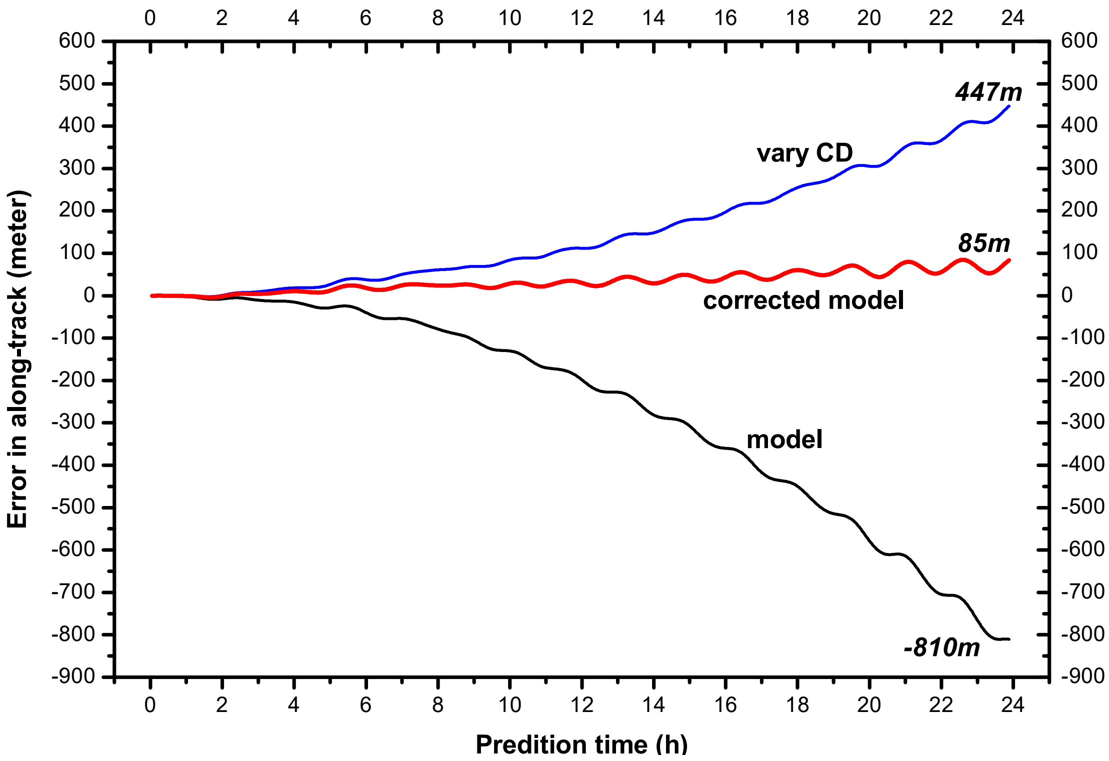
The corrected density is better than the original model



Progress in Improving the Prediction Accuracy

- Atmospheric density correction (champ accelerometer)

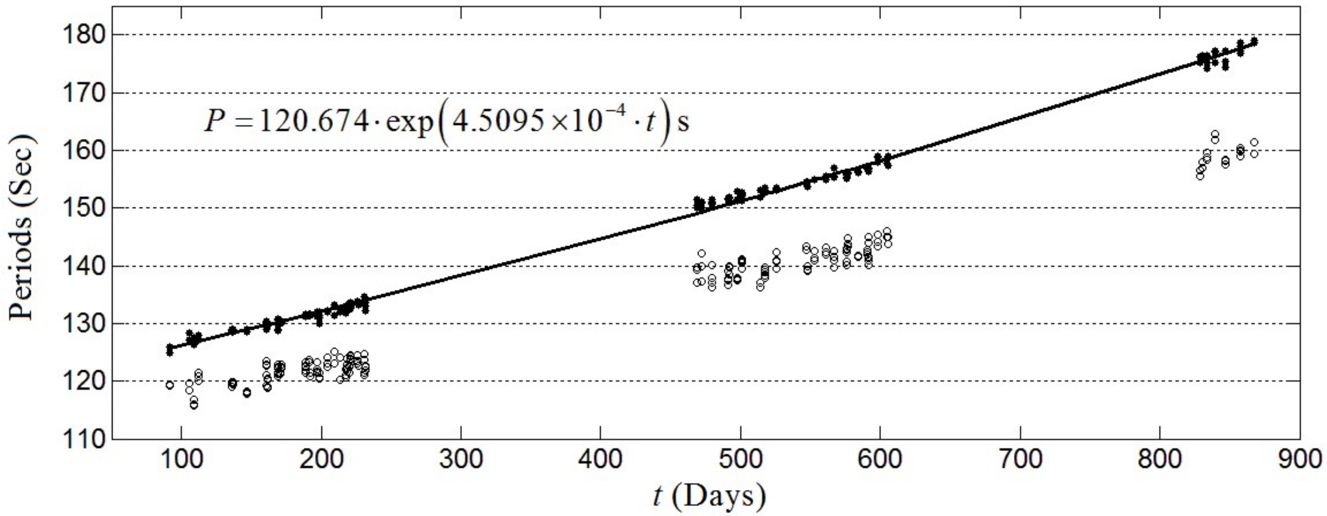
In the 24-h prediction, champ's position error is minimum using the corrected density model.



Progress in Improving the Prediction Accuracy

- **Rotational state research**

Estimation of Envisat's rotational state using optical observation data



Variation of rotation period from 2013 to 2015

PMO has started the rotational state research in recent years. More research is needed to determine the long-term change of AMR by estimating the rotational state.

Future Plan

- **Atmospheric model research**

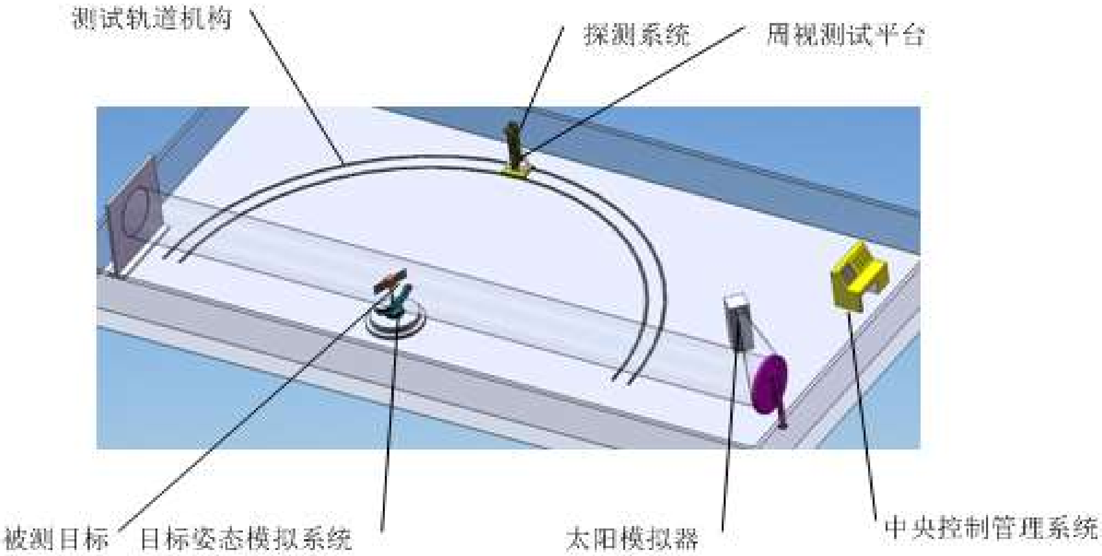
In the future, we will mainly focus on the atmospheric density corrections below 200km. Because the drag data below 200km is relatively less , the corrected density accuracy below 200km is not very good.

We will use drag data to conduct dynamic determination of atmospheric density model parameters to improve short-term (months) atmospheric density model accuracy.

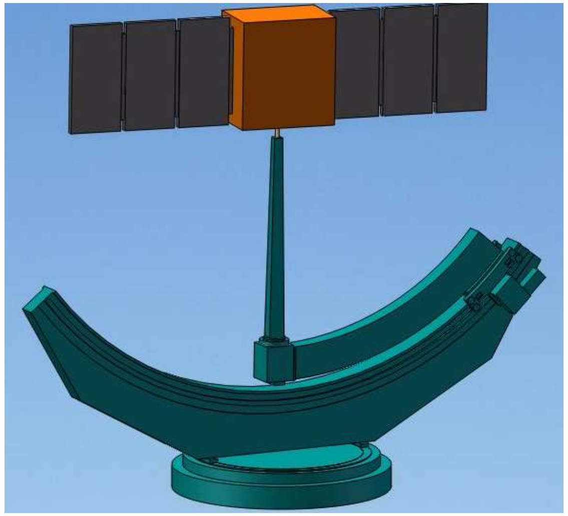
Future Plan

- **Build a lab to carry out rotational state research**

  Establish the relation between the photometry data and the rotational state by simulation



Sketch of the lab



Attitude simulation platform

Thanks for your attention