Interest of old data for the determination of the heliocentric distance of Pluto

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Plan

Introduction

- Pluto discovered in 1930, revolution period : 248 years
- Never explored in situ

$\rightarrow$ heliocentric distance subject to caution

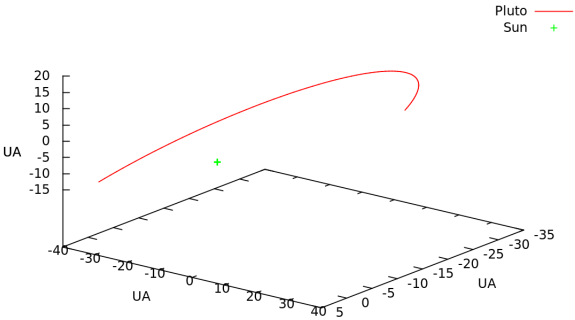
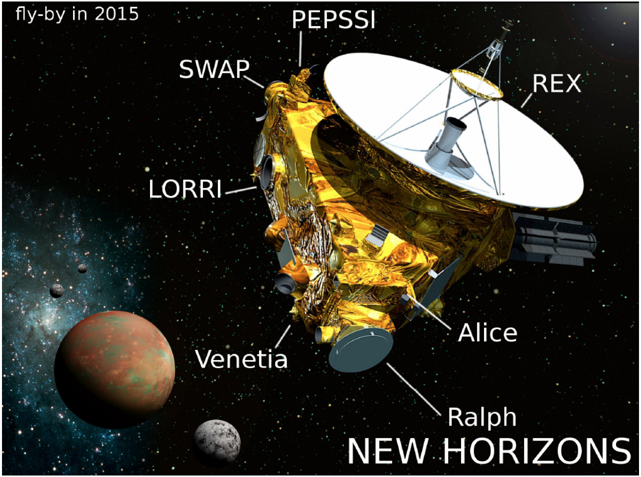


FIGURE: Trajectory of Pluto around the Sun since its discovery.

New Horizons



Ephemeris internal precision and observations

Precision

Internal precision : precision of the modelization, depends on the neglected terms and the estimated accuracy of the observations. It is the precision we would have if the error on observations were strictly gaussian

How to obtain this precision :

- fitting of a numerical model to observations with the least-square method
- 1-σ precision estimated alongside the fitting

System Observations

2 kinds of observations :

- unresolved observations :
  - photographic observations from 1914 to 1993
  - CCD observations since 1995
- resolved observations :
  - HST observations 1992-1993 and 2002-2003
  - discovery observations of Nix and Hydra in 2005
  - precovery observations of Nix and Hydra in 2002-2003
  - VLT observation in2006
  - stellar occultations since 2005

Two-step fitting :

- fitting of the satellites motion
- fitting of the heliocentric motion

Equations of motion

Numerical model developped : ODIN (Orbite, Dynamique et Intégration Numérique)

- **reference frame** : solar system barycentric
- Integration of Pluto and its satellites' equations of motion
- Perturbations from the sun and the planets
- No polar oblateness included (negligible effect)

Equation of motion of the i body :

$$\ddot{\vec{r}}_i = \underbrace{-\sum_{j=1}^{\mathcal{N}} GM_j \frac{\vec{r}_j - \vec{r}_i}{r_{ij}^3}}_{\text{interactions with the Sun and the planets}} + \underbrace{\sum_{l=1, l\neq i}^{4} -Gm_l \frac{\vec{r}_l - \vec{r}_i}{r_{il}^3}}_{\text{interactions between the objects of Pluto's system}} \quad (1)$$

Fitting and variationnal equations

Simple relation between obtained residuals and the error on the parameters of the model

$$\Delta \overrightarrow{r_{li}} = \sum_{k=1}^{6N+N'} \left. \frac{\partial f^i}{\partial c_k} \right|_{t_l, c_k} \Delta c_k \qquad (2)$$

To get the coefficients $\left. \frac{\partial \mathbf{f}^i}{\partial c_k} \right|_{t_l, c_k}$, we use Newton's second law :

$$\frac{d^2 \overrightarrow{r_{li}}}{dt^2}(t_l) = \frac{\overrightarrow{F}}{m_i}(t_l, \overrightarrow{r_{l1}}, \dot{\overrightarrow{r_{l1}}}, \ldots, \overrightarrow{r_{lN}}, \dot{\overrightarrow{r_{lN}}}, \mathbf{p}) \qquad (3)$$

from which we obtain :

$$\frac{d^2}{dt^2} \left(\left. \frac{\partial \mathbf{f}^i}{\partial c_k} \right|_{t_l, c_k} \right) = \frac{1}{m_i} \left[\sum_{j=1}^{N} \left(\frac{\partial \overrightarrow{F}}{\partial \overrightarrow{r_{lj}}} \frac{\partial \mathbf{f}^j(t_l)}{\partial c_k} + \frac{\partial \overrightarrow{F}}{\partial \dot{\overrightarrow{r_{lj}}}} \frac{\partial \dot{\overrightarrow{r_{lj}}}}{\partial c_k} \right) + \frac{\partial \overrightarrow{F}}{\partial \mathbf{p}} \frac{\partial \mathbf{p}}{\partial c_k} \right] \qquad (4)$$

We integrate numerically these equations alongside the equations of motion.

Comparison between Ephemeris

Residuals obtained

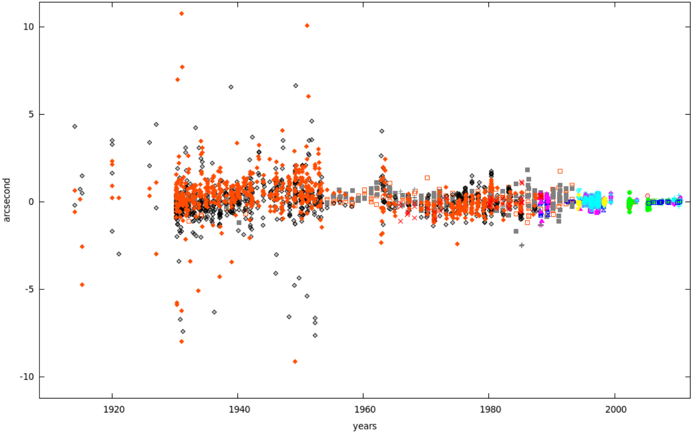


FIGURE: Post-fit residuals of Pluto's right ascension with ODIN.

Statistics on the residuals between observations and various Ephemeris

TABLE: Exemples of mean value and standard deviations of residuals for ODIN, DE421 and INPOP08, $\mu \pm \sigma$.

	ODIN		DE421 INPOP08	
	$\Delta\alpha$ ('')	$\Delta\delta$ ('')	$\Delta\alpha$ ('')	$\Delta\delta$ ('')
observations anciennes	-0.028 ± 1.16	0.0235 ± 1.56	-0.104 ± 1.163 0.754 ± 1.342	0.088 ± 1.553 0.142 ± 1.560
Pulkovo	0.027 ± 0.395	0.163 ± 0.418	-0.081 ± 0.388 0.352 ± 0.657	0.027 ± 0.414 0.035 ± 0.414
A.J. Dyer-Lick-Mink	-0.477 ± 0.958	-0.033 ± 0.480	-0.617 ± 0.932 -0.564 ± 0.990	-0.146 ± 0.500 -0.147 ± 0.523
Tokyo-Bordeaux-Flagstaff	-0.029 ± 0.100	-0.007 ± 0.097	-0.053 ± 0.0962 -0.068 ± 0.095	-0.028 ± 0.105 -0.021 ± 0.105
Gemmo-USNO	-0.076 ± 0.197	-0.022 ± 0.248	-0.110 ± 0.199 -0.129 ± 0.200	-0.014 ± 0.252 -0.004 ± 0.251
Bordeaux	-0.067 ± 0.097	-0.072 ± 0.170	-0.078 ± 0.091 -0.129 ± 0.200	-0.075 ± 0.146 -0.004 ± 0.251

Heliocentric distance

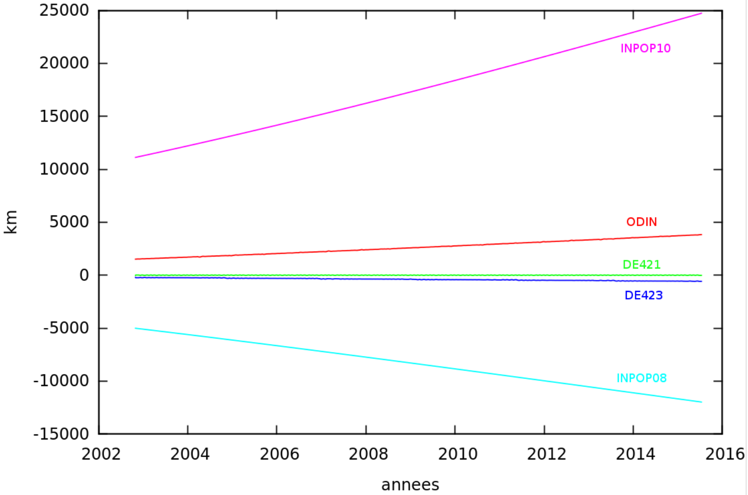


FIGURE: Comparison of heliocentric distance given by DE421 and other ephemeris

External precision of ephemeris

Different ephemeris with close residuals $\rightarrow$ very different heliocentric distance

External precision of the ephemeris : depends on the observations systematic biases, reference catalog used, ...

Problem : there is no way to predict how the external precision of the ephemeris will evolve

Possible solution : to put better constraints on the long term trajectory = to make a new reduction of the old photographic observations before the arrival of New Horizons in 2015.

Conclusion

Because of a lack of long-time accurate observations of Pluto, different models give very different heliocentric distance
$\rightarrow$ strong need of a new reduction of Pluto's old observations

Problems :

- number of photographic plates
- time : New Horizons' fly-by is in 2015

Good news : much improvement possible (old observations standard deviation 1 arcsec)