Evolution of mass determination in Pluto's system

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Plan

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Introduction

- Pluto's system :
  - Distance from the Sun : ~ 33 AU in 2013
  - 4 objects :
    - Pluto (R=1170 km, V=15.1, D~100 mas)
    - Charon (R=603 km, V=16.8, D~55 mas)
    - Nix (R=44 km, V=23.7, D~4 mas)
    - Hydra (R=36 km, V=23.3, D~3 mas)

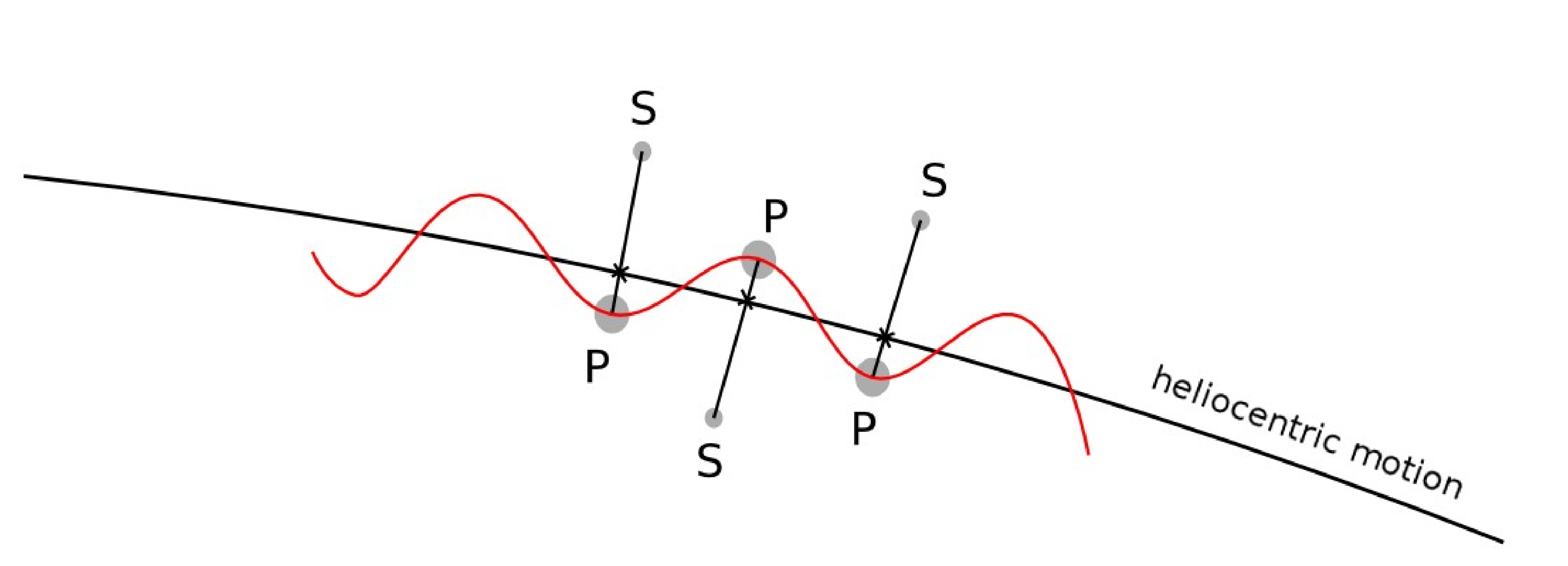
- Mission New Horizons, arrival in Pluto's system in 2015

- Previous results : no detection of polar oblateness even with New Horizons

Dynamical model

- Binary object → center of mass not within the primary

Coupling between heliocentric motion of the primary and orbital motion of the satellites



→ solution : fitting the motion of every object around the Sun

- Numerical integration of four objects' motion around the Sun
- Planetary and Sun perturbations using DE406
- Initial conditions and masses from DE406 and Tholen (2008)
- No spherical harmonics included

$$\ddot{\vec{r}}_i = \sum_{j=1}^{\mathcal{N}} -\frac{GM_j(\vec{r}_i - \vec{r}_j)}{r_{ij}^3} + \sum_{l=1,\ l\neq i}^{4} -\frac{Gm_l(\vec{r}_i - \vec{r}_l)}{r_{il}^3}$$

Data simulation

- Goal : estimate the uncertainty we will obtain with a set of observations

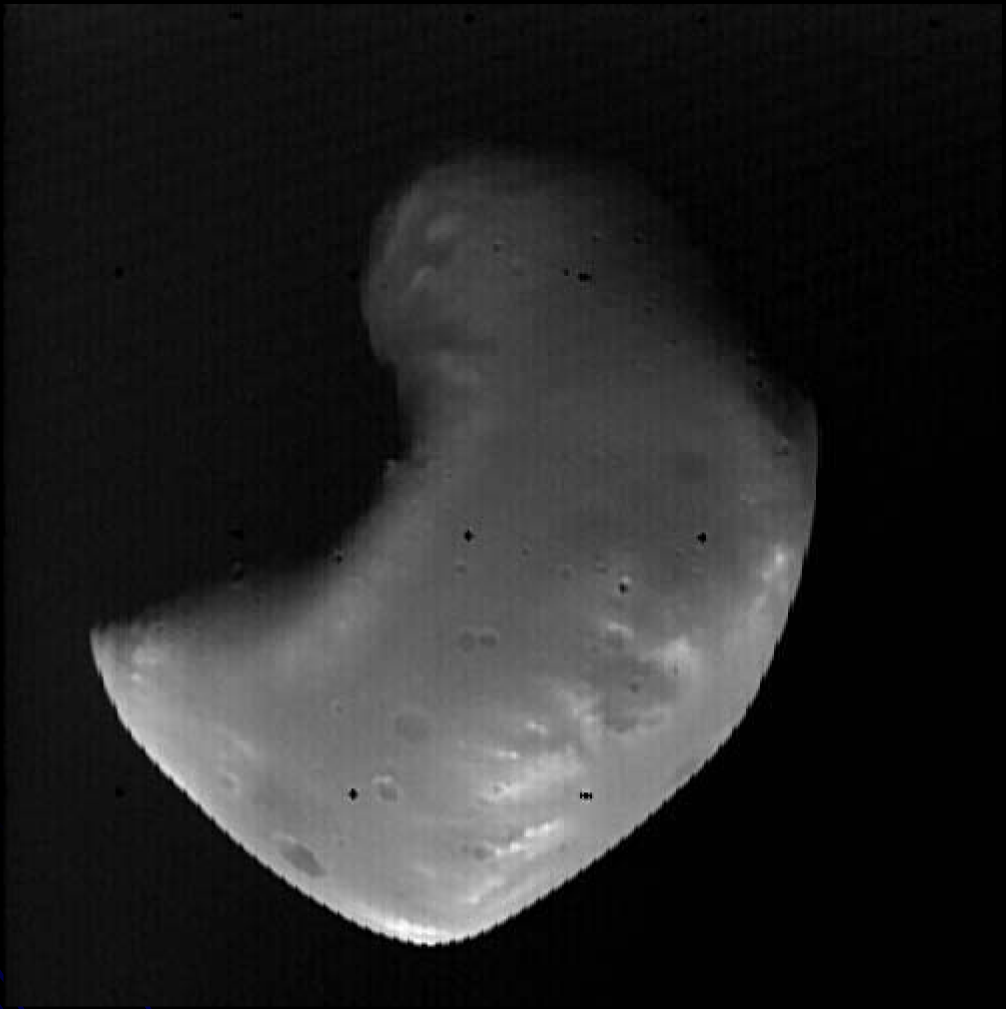
- Method :
  - Simulation of observations according to the tested schedule
  - Fitting of the model to the simulations, fitted parameters : initial positions and velocities, and masses
  - Extraction of the 1-σ uncertainty from the least-square procedure

- Schedules used :
  - Currently available observations of the satellites (Buie 2006, Weaver et al. 2005, Sicardy et al. 2006, Tholen 1997)
  - Simulation of future observations between 2010 and 2014, 10 per year
  - New Horizons schedule and uncertainty
  - GAIA schedule simulation

- New Horizons : short period observations, varying precision with the distance of the probe, observations of the four objects of the system

- GAIA : observations simulated from 2013 to 2017, 1 mas constant precision, only Pluto and Charon observed

Center of mass determination



- Center of mass determination at best at 1/8 of Nix's and Hydra's diameter

Results

set of simulated observations	1-σ error bars on the masses ($km^3 s^{-2}$) number of simulated observations			
	Pluto	Charon	Nix	Hydra
1992-2006	1.28	0.51	0.024	0.036
		72	16	17
1992-2014	0.82	0.28	0.010	0.019
		125	68	69
1992-2006+NH	0.27	0.072	0.012	0.0028
		129	106	124
1992-2014+NH	0.25	0.045	0.0076	0.0026
		181	158	176
1992-2014+extended NH	0.19	0.039	0.0070	0.0024
		181	186	233
1992-2014+NH+GAIA	0.17	0.017	0.0054	0.0024
	66	247	158	176

1-σ error bars on the masses given by least square method using different sets of simulated observations, with m1 = 870.3 $km^3.s^{-2}$, m2 = 101.4 $km^3.s^{-2}$, m3 = 0.039 $km^3.s^{-2}$ and m4 = 0.021 $km^3.s^{-2}$.

Orbit enhancement thanks to GAIA before New Horizons arrival

set of simulated observations	1-σ error bars on the masses ($km^3.s^{-2}$) number of simulated observations			
	Pluto	Charon	Nix	Hydra
2002-2013	0.95	0.24	0.010	0.022
		125	68	69
2002-2013+GAIA before 2015	0.45	0.035	0.0086	0.016
	41	166	68	69

set of simulated observations	1-σ error bars on the semi-major axis (km)		
	Charon	Nix	Hydra
2002-2013	5.8	23	155
2002-2013+GAIA before 2015	3.25	10	43

Fitting to real observations

- Problem : scale unconstitancy between the different HST sets → uncertainties increasing
- Uncertainty on the masses greater than in our previous study

Fitting to real observations

	Charon		Nix		Hydra	
	ΔRA	ΔDec	ΔRA	ΔDec	ΔRA	ΔDec
Mean value of the residuals (mas)	1.1	0.12	-5.2	-2.5	0.8	3.0
Standard deviation of the residuals (mas)	5.8	3.9	18.3	16.5	11.4	9.0

Table 1 : statistics of the post-fit residuals for Pluto's satellites

	Pluton	Charon	Nix	Hydra
GM ($km^3.s^{-2}$)	872.8±1.8	100.6±0.3	0.046± 0.026	0.011± 0.036

Table 2 : fitted masses and errors for Pluto and its satellites

Conclusion

- Precise mass determination will have to wait for New Horizons
- GAIA will be able to improve the orbit of Pluto's satellites, even before New Horizons arrival
- GAIA will improve the uncertainties on the system's masses
- Though GAIA does not observe Nix and Hydra, the constraints put on Pluto and Charon are expected to lower the uncertainties on Nix's and Hydra's dynamical parameters

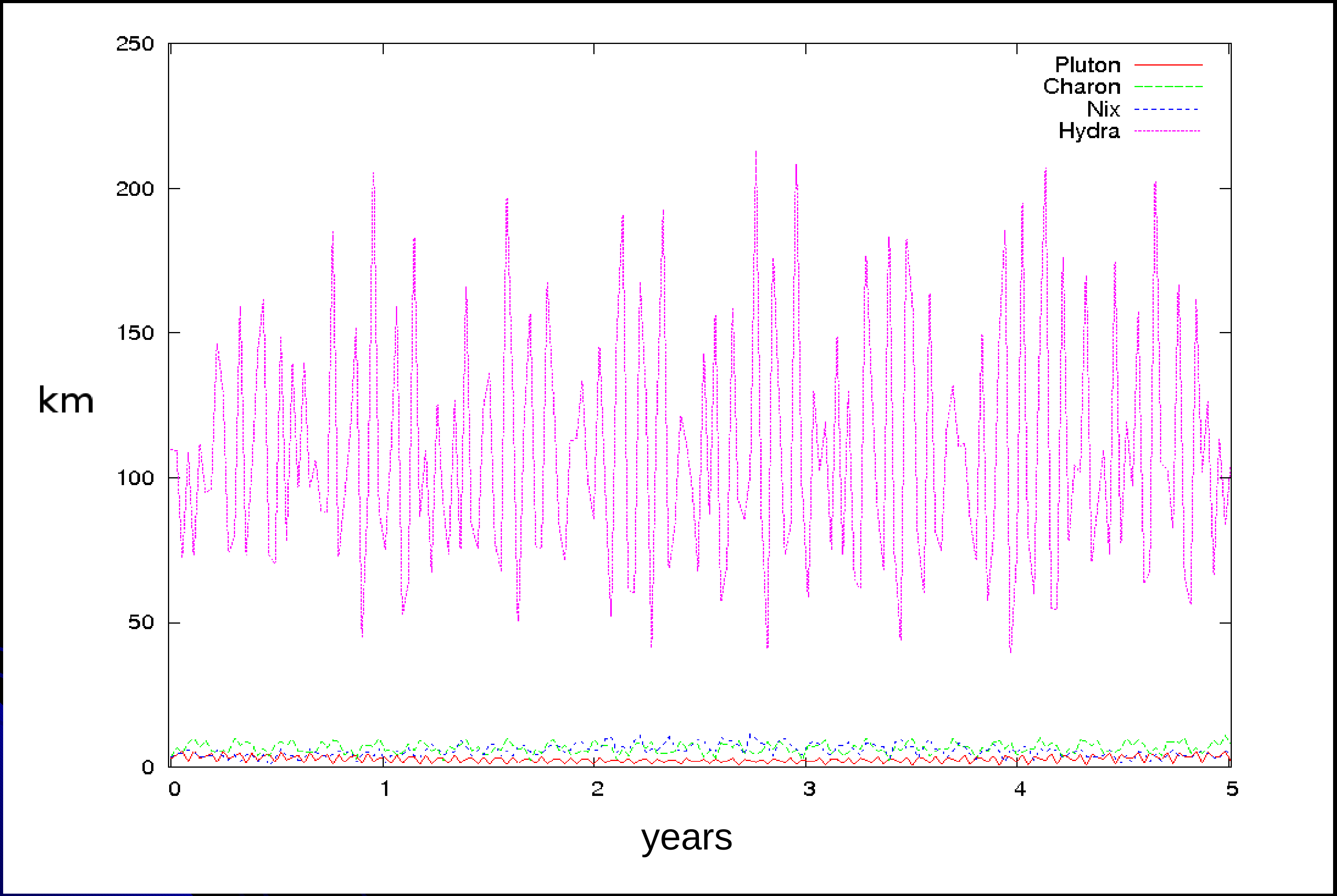
Why constraining Pluto and Charon helps ?

- What influences Nix's and Hydra's orbit :
  - Masses
  - Positions of Pluto and Charon
- When adjusting the orbit, the residuals are reduced by adjusting parameters
- If a parameter which has a strong influence on Pluto and Charon motion is fixed, it can no longer absorb the residuals

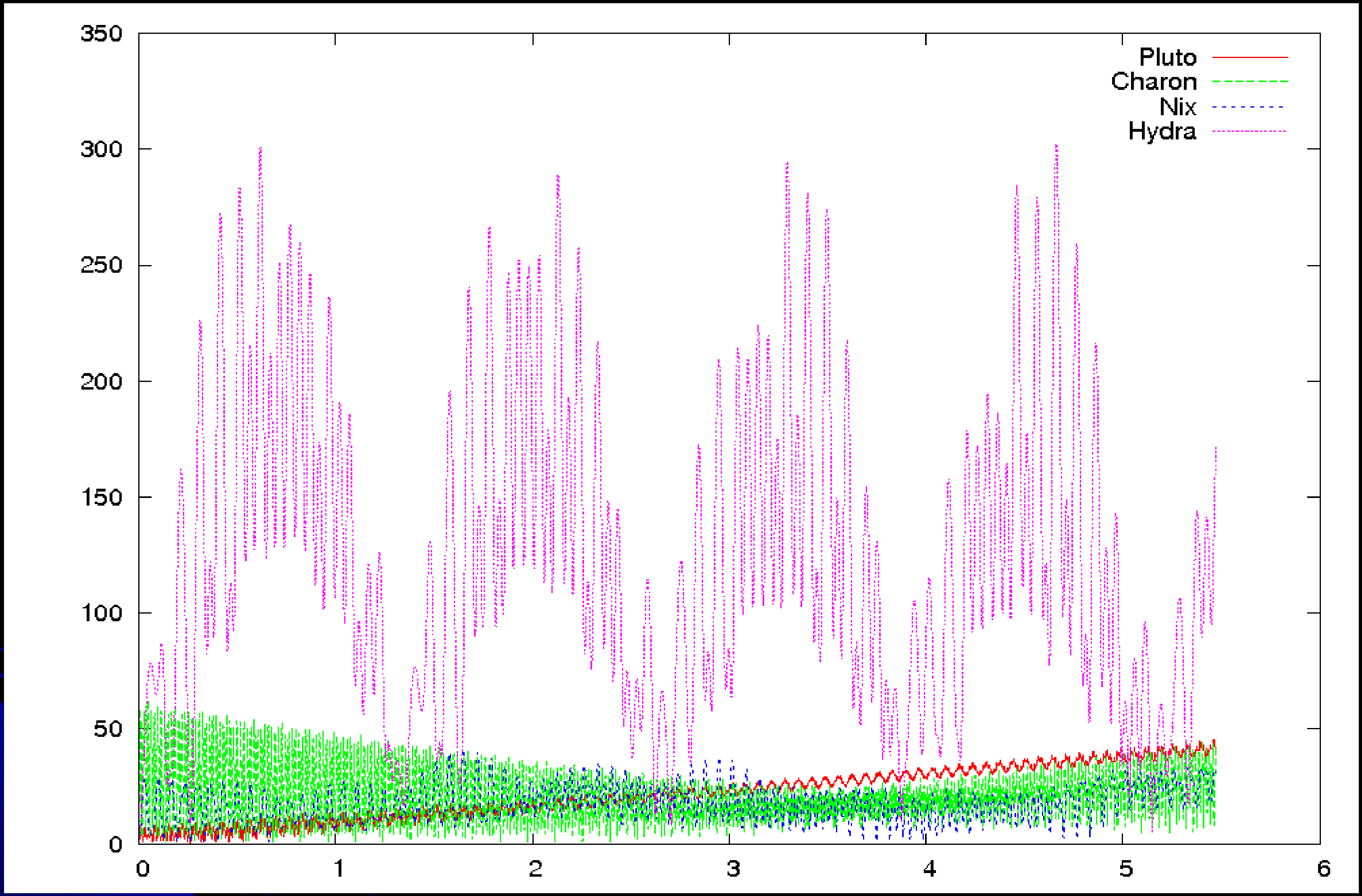
→ constraining Pluto's and Charon's dynamical parameters means higher residuals on Nix and Hydra

→ clearer effect of their dynamical parameters

→ higher precision on these parameters



Post-fit residuals of a model with a massless Nix fitted to simulated observations with GM_{Nix}=0.039 ± 0.034 $km^3.s^{-2}$



Post-fit residuals of a model with a massless Nix fitted to simulated observations with GM_{Nix}=0.039 ± 0.034 $km^3.s^{-2}$