NEAT-RDS

Realistic Data Simulator

Grenoble, May 27, 2013

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moving to
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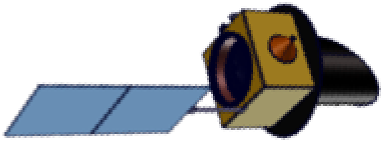
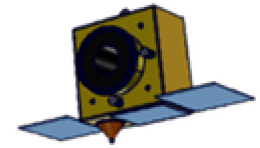
United Kingdom



NEAT-RDS



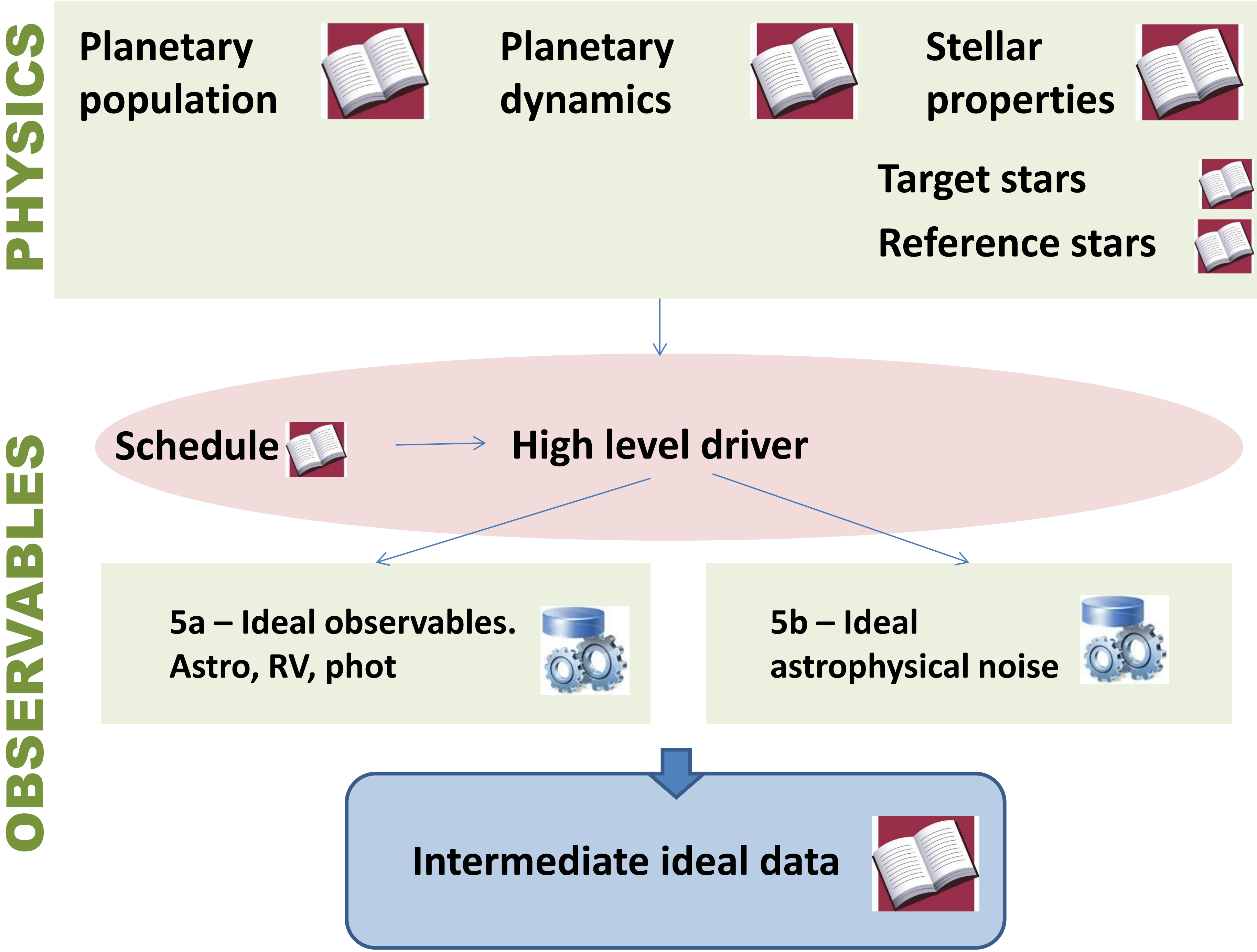
Design considerations

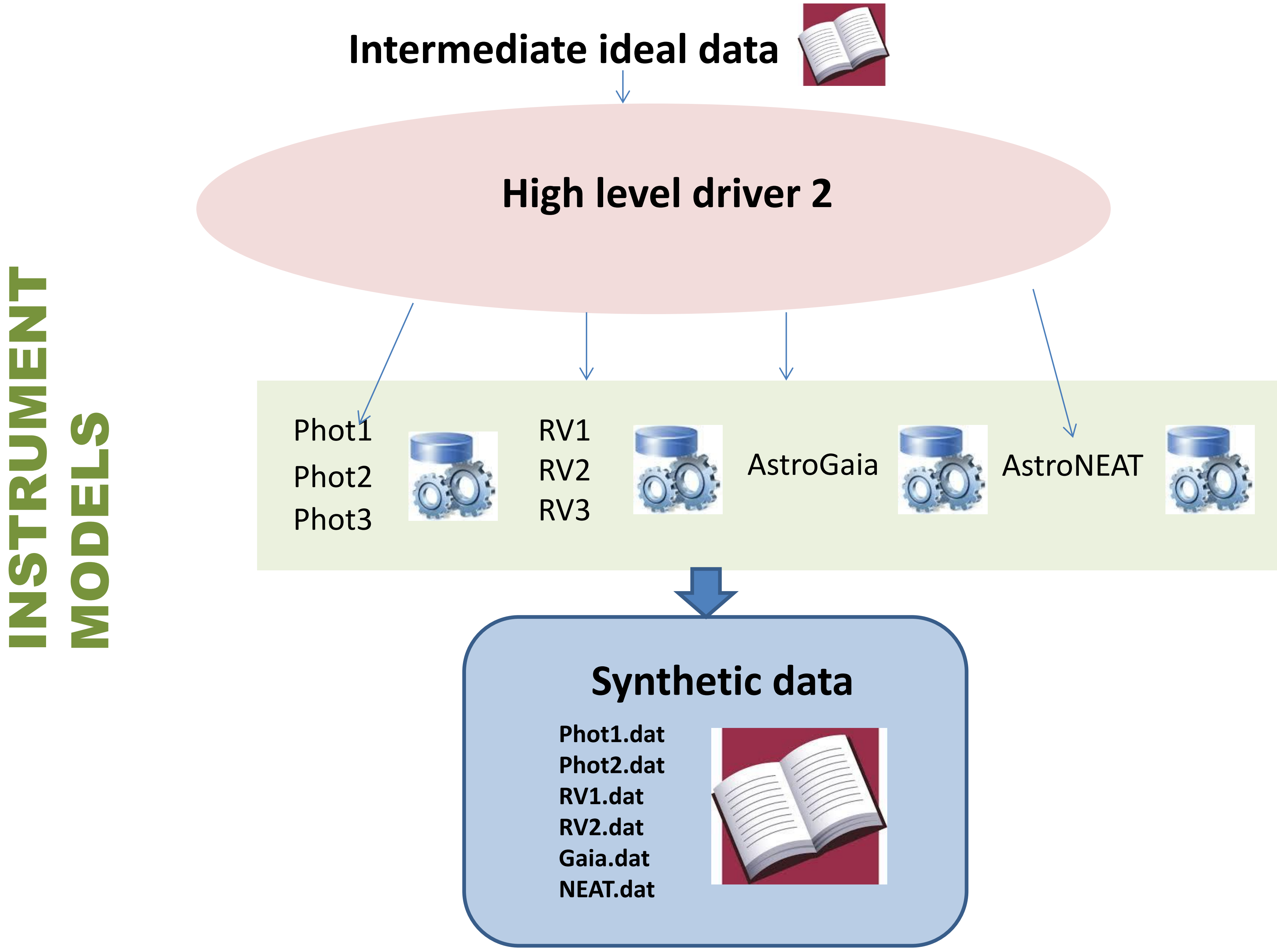
- Simple architecture
- Modular
- Portable/reusable
- Well documented
- PRECISE
- Realistic & well-defined observables

NOT critically needed

- High efficiency
- Complex data access
- User-friendly

- Realistic engineering models


PHYSICS
Planetary population
Planetary dynamics
Stellar properties
Target stars
Reference stars
OBSERVABLES
Schedule
High level driver
5a – Ideal observables. Astro, RV, phot
5b – Ideal astrophysical noise
Intermediate ideal data


Intermediate ideal data
High level driver 2
INSTRUMENT MODELS
Phot1
Phot2
Phot3
RV1
RV2
RV3
AstroGaia
AstroNEAT
Synthetic data
Phot1.dat
Phot2.dat
RV1.dat
RV2.dat
Gaia.dat
NEAT.dat

Synthetic data

Phot1.dat
Phot2.dat
RV1.dat
RV2.dat
Gaia.dat
NEAT.dat

Detection / characterization teams

ID	Task	Prior.	Soft	Contact
PHY 1	Planet populations	High	NO	C. Beichman - W. Traub (IPAC, USA) C. Mordasini - Y. Alibert (MPIA, GE)
PHY 2	Dynamics	Med	NO	(TBD)
PHY 3a	Stellar properties. Targets	High	NO	C. Eiroa (UCM, SP), A. Crouzier (GRE)
PHY 3b	Stellar properties. Ref. stars.	Med	NO	E. Villaver (UCM, SP)
ASTRONOIS E	Astrophysical noise : Spectra & star image	High	YES	A.M. Lagrange (CNRS, FR)
MOD	Model for observables	*	NO	(TBD)
SCHED	Scheduling	High	YES	Alain Leger (IAS, FR), H. Beust (GRE)
IDEGEN	Ideal data generator	*	YES	G. Anglada (QMUL, UK)
INS 1	NEAT	High	YES	G. Duvert/A. Crouzier (GREN, FR)
INS 2	Gaia	Med	YES	X. Luri/H. Voss (UB, SP)
INS 3	RV instruments	Med	YES	T. Forveille (GREN, FR)
INS 4	Photometers	Low		?
SYNGEN	Synthetic data generator	*	YES	G. Anglada (QMUL, UK)
ANABEN	Benchmark Analysis team	High	YES	Johannes Salhman/D. Segrasan (OGE, SW)
ANA 1	Analysis team 1	Med	YES	M. Shao (SIM-LITE)
ANA …	Analysis team 2	Med	YES	A. Sozzetti (IN

PHY 1
PHY 2
PHY 3a
PHY 3b
ASTRONOISE
IDEGEN
SCHED
MODEL

INS 1
INS 2
INS 3
INS 4
SYNGEN

ANABEN
ANA 1
ANA 2

PHY 1 – Planet populations

Delivery : ASCII files – one row/one system -> thousands of them

Example :

`STARMASS NPLANETS PLANETID MASS1 RADIUS1 A1 T1 E1 W1 I1 …`

Ω and Inclination of reference plane will be randomly assigned

High priority : SIM-Double blind test sample?

Medium priority : Theoretical and Kepler generated sample

PHY 1
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PHY 3a
PHY 3b
ASTRONOISE
IDEGEN
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ANABEN
ANA 1
ANA 2

PHY 2 – Planetary Dynamics

Delivery : Interact with PHY1 to check for long term stability (10 Myrs?). Propose exotic dynamically peculiar systems (~20% of the sample?).

Medium priority : Important for data analysis teams

PHY 3 – Stellar properties

Delivery : ASCII files, interact with ASTRONOISE to agree on what is needed.

PHY 3a - Targets starts from the 15 pc sample. (High priority)

PHY 3b – Reference stars (Medium priority)

Example :

```
STARID RA DEC MURA MUDEC PAR BRV STARMASS TEFF AGE PROT LOGR FEH (INC)
```

INC should be given if known, otherwise, will be assumed random between 0 and 90.

Example reference :

```
STARID TARGETLING RA DEC MURA MUDEC PAR BRV STARMASS TEFF AGE PROT LOGR FEH INC
```

PHY 1
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PHY 3b
ASTRONOISE
IDEGEN
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ANABEN
ANA 1
ANA 2

ASTRONOISE – Astrophysical noise : spectra and star imaging

Delivery : **SOFTWARE** – Input from PHY3 to generate realistic snapshots of the star at a given T_{obs}.

High priority : Mean line profile and disk image of star with dark spots.
Corresponding activity indices (S at least)
Medium priority : Full spectrum (from 400 to 1500 nm) of the spotted star.
Effective temperature map of stellar surface. Emission lines.

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ANA 1
ANA 2

IDEGEN – Ideal data generator

Delivery :

SOFTWARE releases – Generates ideal snapshots of the stars and references at the observing epochs (decided by a 'SCHED').

Ideal data sets – As realistic as possible

High priority : Coordinates physical inputs and output formats for instrument models

Medium priority : Make the ideal data as realistic as possible

PHY 1
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PHY 3b
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SCHED – Observations scheduling

Delivery :

SOFTWARE or ASCII– List of timed observations on a given target (Astro, Phot, RV). Must follow visibility and availability constraints

High priority : NEAT astrometric scheduling

Medium priority : Realistic Doppler cadence

Low priority : Photometric data points

PHY 1
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ANA 2

INS 1– NEAT astrometry simulator

Delivery :

SOFTWARE – From ideal observation to NEAT calibrated centroid or arcs between target and reference stars (to be decided).

High priority : Local plane model

Medium priority : Arc model

PHY 1
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ANA 2

INS 2– Gaia astrometry

Delivery :

SOFTWARE – Get a nominal sequence of Gaia observations with realistic noise model.

Medium priority : necessary to solve for long period gas giants

Medium priority : reference star contamination rate

Suggested format

Projected residual in the scanning direction (also across?) with respect to a static model (unit direction).

```
TOBS1  RES_ALONG  ERR_ALONG  RES_ACROSS  ERR_ACROSS  PHOT P_RA P_DE P_LOS
```

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ANA 2

INS 3– RV instrument

Delivery :

SOFTWARE – Produce Doppler measurement + line profile diagnostics for a given input mean line profile.

Suggested format

```
TOBS1  RV ERR_RV BIS FWHM (SINDEX? and +)
```

PHY 1
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ANA 2

INS 4– Photometry

Delivery :

SOFTWARE – Produce photometric measurement in one or more photometric bands

Suggested format

```
TOBS1   FLUX1  ERRFLUX   FLUX2  ERRFLUX2  ...
```

PHY 1
PHY 2
PHY 3a
PHY 3b
ASTRONOISE
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MODEL

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INS 2
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SYNGEN

ANABEN
ANA 1
ANA 2

SYNGEN - Synthetic data generator

Delivery :

SOFTWARE releases : Sends ideal data into instrument models and produces the final output of the simulator

Data releases : Preliminary ones to test and debug. Double blind test ones

High priority : coordinate input and output formats

(Need to agree on data products -> see MODEL)

PHY 1
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ANABEN
ANA 1
ANA 2

ANABEN – Benchmark analysis team

Delivery : **Data analysis pipeline that incorporates as much data as possible and reproduce simulated systems**

High priority : verify that systems are recovered correctly (noiseless data) and assist debugging simulator.
Medium priority : prepare benchmark data analysis pipeline

PHY 1
PHY 2
PHY 3a
PHY 3b
ASTRONOISE
IDEGEN
SCHED
MODEL

INS 1
INS 2
INS 3
INS 4
SYNGEN

ANABEN
ANA 1
ANA 2

ANA 1, 2 – Data analysis teams

Delivery : **Try to recover as many planets as possible. Freely choose their statistical tools and confidence levels.**

High priority : we need to be sure we have at least 2 of them

Medium priority : Open it to the participation of external groups/individuals

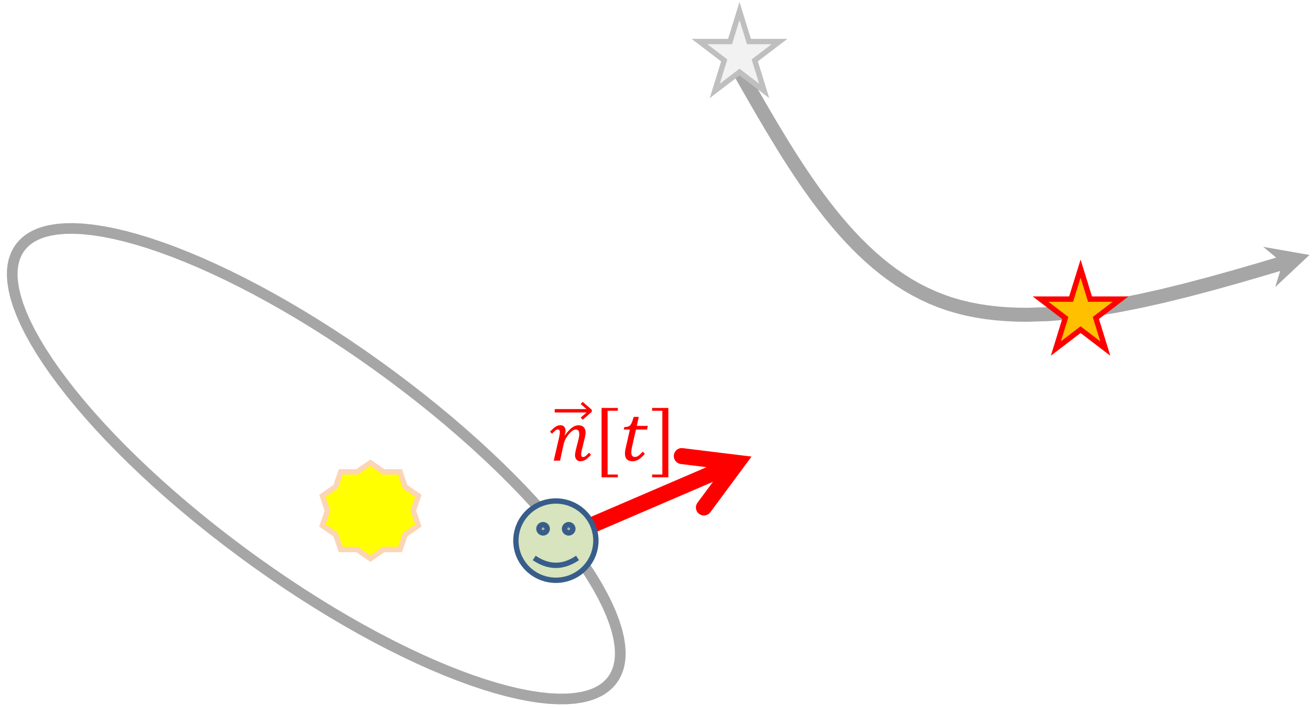
Model for observables

We need a model better than 0.1 micro-arcseconds

$1'' = 4.84 \times 10^{-6}$ rad

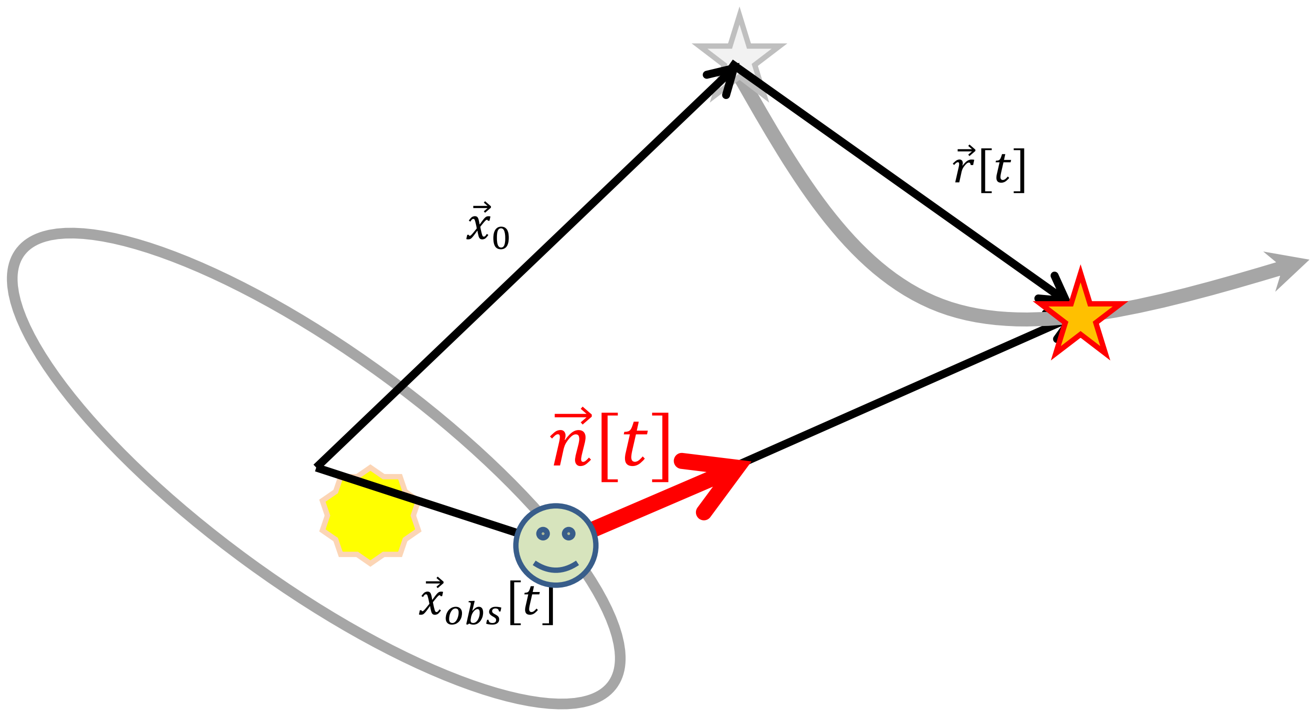
$0.1\ \mu as = 4.84 \times 10^{-13}$ rad

Model for observables



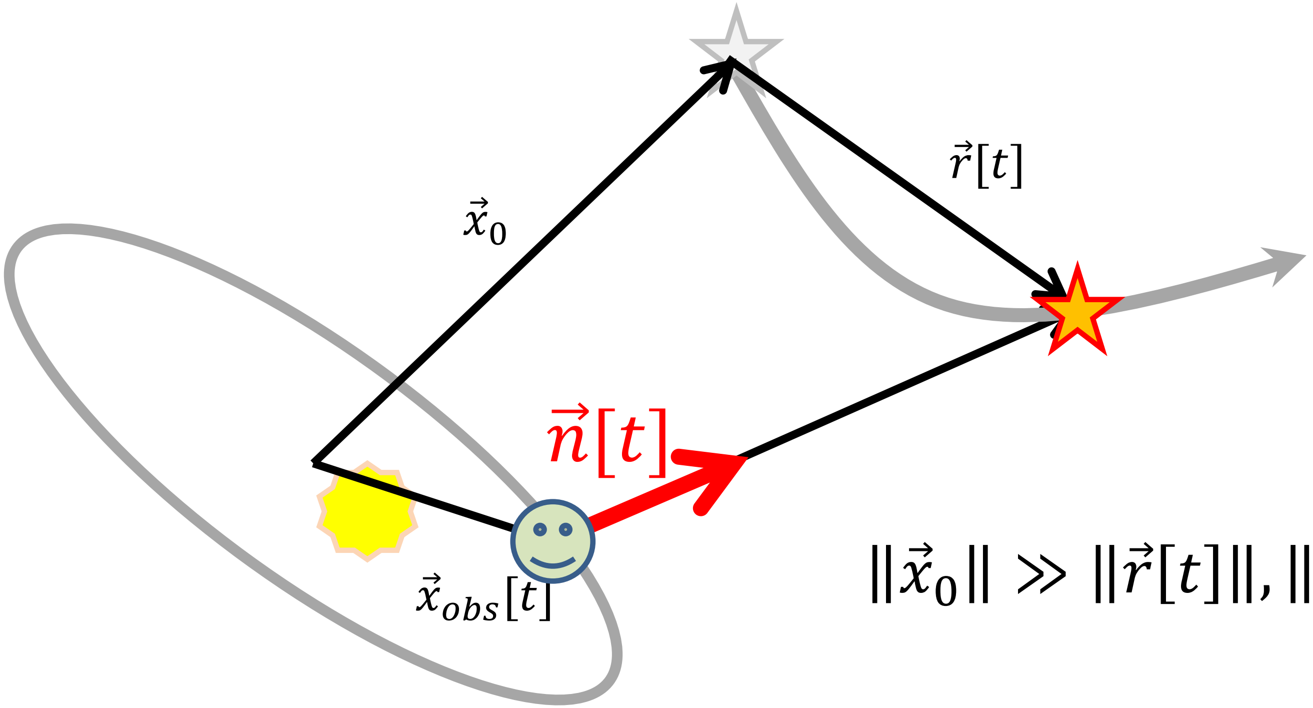
Back to basics…

Model for observables



Back to basics…

Model for observables



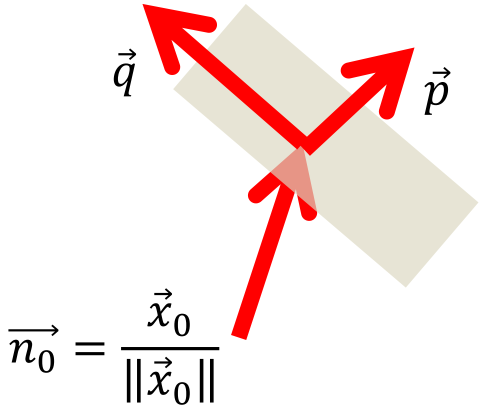
$$\|\vec{x}_0\| \gg \|\vec{r}[t]\|, \|\vec{x}_{obs}\|$$

$$\vec{n}[t] = \frac{\vec{x}_0 + \vec{r}[t] - \vec{x}_{obs}[t]}{\|\vec{x}_0 + \vec{r}[t] - \vec{x}_{obs}[t]\|}$$

Back to basics…

Model for observables

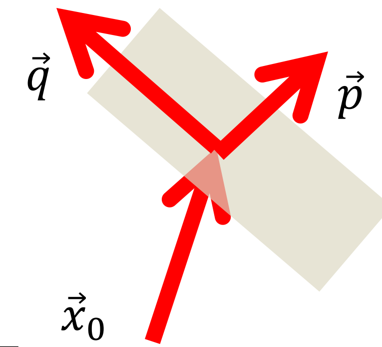
$$\vec{n}[t] = \frac{\vec{x}_0 + \vec{r}[t] - \vec{x}_{obs}[t]}{\|\vec{x}_0 + \vec{r}[t] - \vec{x}_{obs}[t]\|}$$



Astrometric model in local triad (Gaia)

Model for observables

$$\vec{n}[t] = \frac{\vec{x}_0 + \vec{r}[t] - \vec{x}_{obs}[t]}{\|\vec{x}_0 + \vec{r}[t] - \vec{x}_{obs}[t]\|}$$



$$\overrightarrow{n_0} = \frac{\vec{x}_0}{\|\vec{x}_0\|}$$

Astrometric model in local triad (Gaia)

$$\hat{u}[t] \begin{cases} \mathrm{U} = U_0 + \mu_p \Delta t(1 - \varphi \Delta t) - \pi F_p[t] \\ \mathrm{V} = V_0 + \mu_q \Delta t(1 - \varphi \Delta t) - \pi F_q[t] \end{cases}$$

$$\varphi = \frac{(\vec{n}_0 \cdot \vec{v})}{\|\vec{x}_0\|}$$

$$(\vec{n}[t] - \vec{n}_0) \cdot \vec{s} \approx \hat{u}[t] \cdot \vec{s}$$

$\vec{s} \equiv$ SCAN DIRECTION

Model for observables

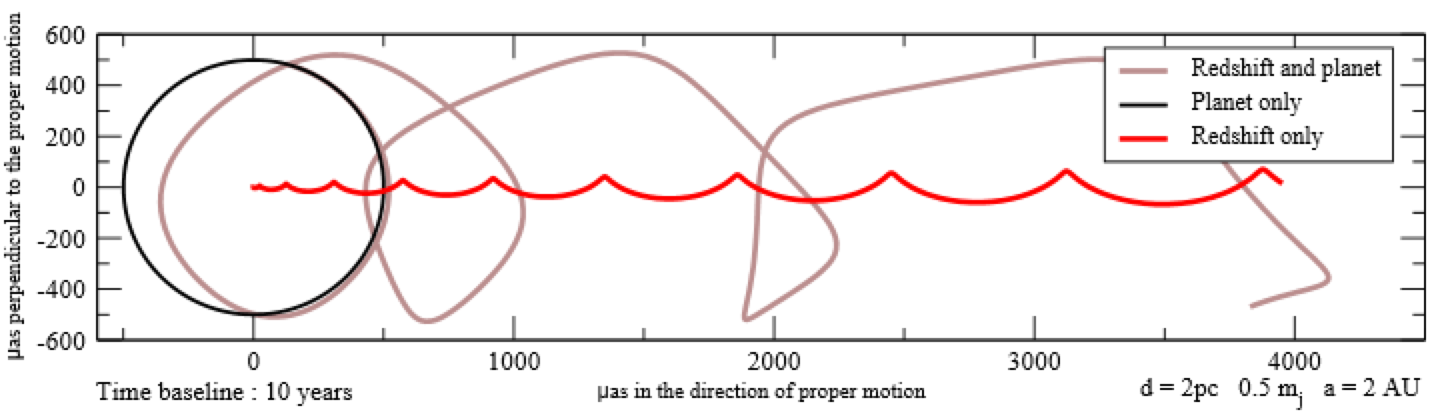
Minimal model for NEAT observables (local-frame style)

$$U = (\vec{n}[t] - \vec{n}_0) \cdot \vec{p} \qquad V = (\vec{n}[t] - \vec{n}_0) \cdot \vec{q}$$

$$\mathrm{U} \approx (U_0 + \mu_p \Delta t - \pi F_p[t])(1 - \varphi \Delta t + \pi_r F_r[t])$$

$$\mathrm{V} \approx (V_0 + \mu_q \Delta t - \pi F_q[t])(1 - \varphi \Delta t + \pi_r F_r[t])$$

(might be third order effects)



Model for observables

Minimal model for NEAT observables (local-frame style)

$$U = (\vec{n}[t] - \vec{n}_0) \cdot \vec{p} \qquad V = (\vec{n}[t] - \vec{n}_0) \cdot \vec{q}$$

$$\mathrm{U} \approx (U_0 + \mu_p \Delta t - \pi F_p[t])(1 - \varphi \Delta t + \pi_r F_r[t])$$

$$\mathrm{V} \approx (V_0 + \mu_q \Delta t - \pi F_q[t])(1 - \varphi \Delta t + \pi_r F_r[t])$$

(might be third order effects)

Alternative model for NEAT observables (interferometry style)

$$(\vec{n}[t] - \vec{n}_0) \cdot \vec{c}_k[t]$$

Need to work out the expansion… volunteers?

Different things come into play:

- O(2) effects from relative motion of target-reference,
- motion of k-reference star
- Format of observables : offsets wrt local reference frame (might be not realistic), arc between reference and target?

Model for observables

Local plane style

- Linearized expressions (almost) ready
- Natural extension of ground based optical astrometry
- Assumes perfectly calibrated, ortonormal local frame
- Easy to display

Interferometry style

- Linearized expressions not done
- Natural extension of interferometry (ask some VLBI folks to join?)
- Realistic arc measurements that account for poor reference frame
- Tricky to display (but not as bad as Gaia or HIPPARCOS –> random scan angles).

Model for observables

This is the ‘kinematic’ part only!

Thinks we will ignore for now :

- Motion of the source during integration! (Barnard’s star moves at 0.31 μas/sec)
- BINARIES!!!
- Light Travel Time
- Acceleration from galactic potential
- Relativistic “corrections” : aberration, light deflection
- NEAT ephemeris

Model for observables

and more…

- Refraction by zodiacal dust
- Interstellar refraction and scintillation
- Gravitational waves
- Differential galactic aberration
- Time-scales and synchronization
- Solar system ephemeris

<u>Be careful with rounding errors! (10^{-13} is close to double-precision floating point truncation)</u>

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PHY 2	Dynamics	Med	NO	
PHY 3a	Stellar properties. Targets	High	NO	
PHY 3b	Stellar properties. Ref. stars.	Med	NO	
ASTRONOISE	Astrophysical noise : Spectra & star image	High	YES	
MODEL	Model for observables	*	NO	
SCHED	Scheduling	High	YES	
IDEGEN	Ideal data generator	*	YES	
INS 1	NEAT	High	YES	
INS 2	Gaia	Med	YES	
INS 3	RV instruments	Med	YES	
INS 4	Photometers	Low		
SYNGEN	Synthetic data generator	*	YES	
ANABEN	Benchmark Analysis team	High	YES	
ANA 1	Analysis team 1	Med	YES	
ANA …	…			

Unassigned volunteers

- J. Lunine – Cornell/USA

- Huub Röttgering – Leiden/Netherlands

- Alain Chelli – Grenoble/France
- Frederic Arenou – Paris/France
- J. Laskar – Paris/France
- Carine Babusiaux- Paris/France

- Didier Queloz – Cambridge/UK

- Alexandre Andrei – Brazil

- Andre Moitinho de Almeida – Portugal
- Alberto Krone-Martins – Portugal

- Alexis Brandeker – Stockolm
- David Hobbs – Lund/Sweden