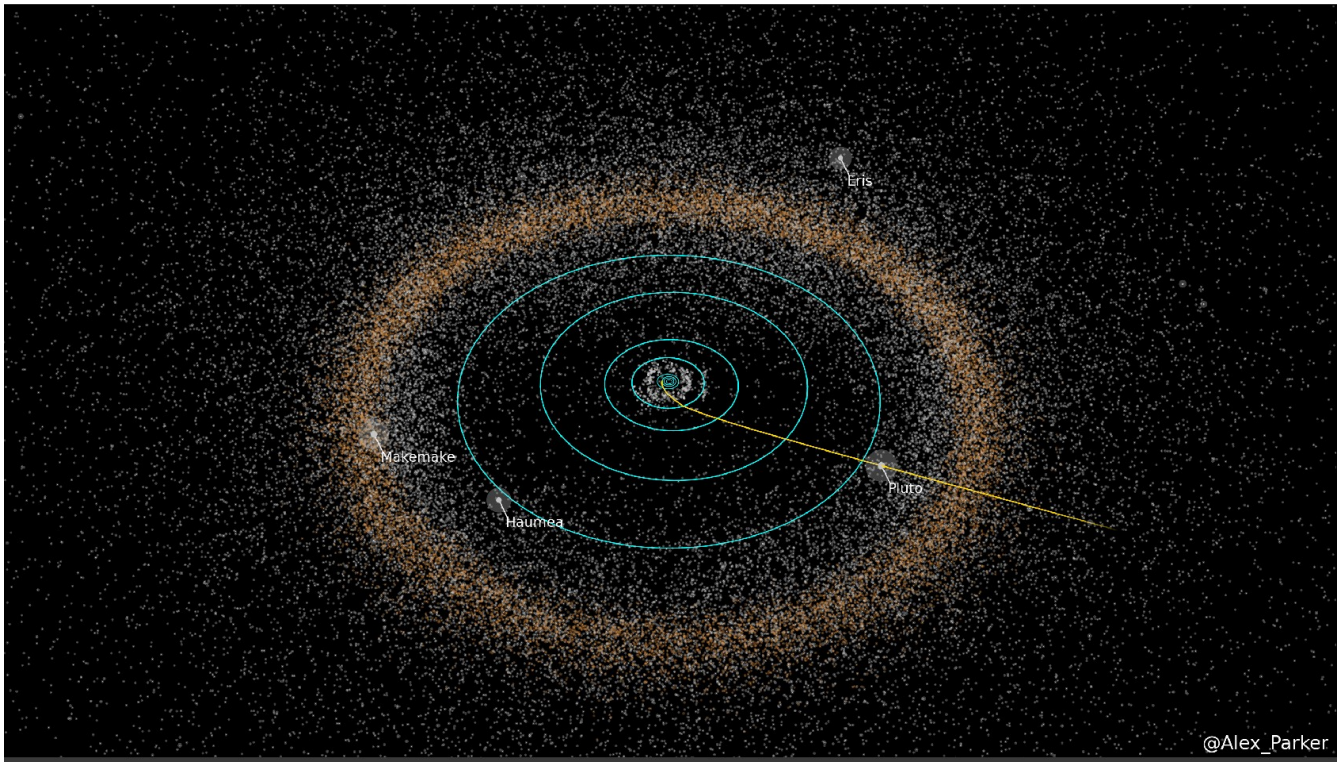
# *TNOs: astrometry, photometry, dynamics, survey modelling*

Jean-Marc Petit (UTINAM / Besançon)



# A variety of informations/data

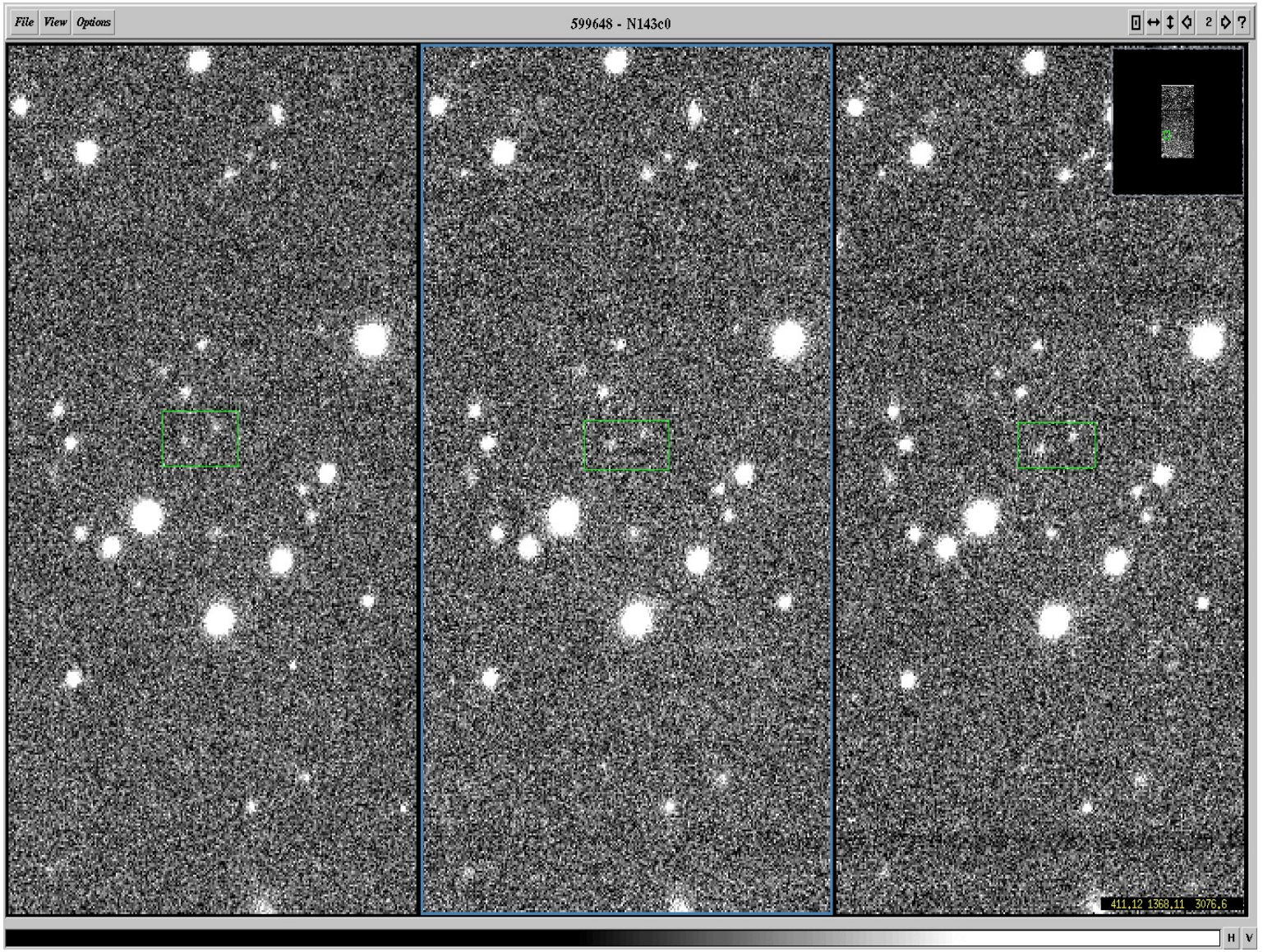
- Photometry: time series, …
- Astrometry: time series, …
- Dynamics
- Survey description

# How do we get them ?

- Large scale Surveys : OSSOS, ...

- Image detrending
  - By telescope team
  - By PI

# Search the images...



# Process the data ...

- Determine (X, Y) position of object
  - Use in-house software
  - Human processing
  - Circular trust construction
  - Limited possibility of reprocessing
- Find reference stars
  - Catalog(s) used ?
  - Proper motions ?
  - Photometry included ?

# Process the data ...

- Determine plate solution
  - Which formula used ?
- Determine the efficiency of detection
  - Depends on photometric calibration
  - On all frames
  - Pointing history

# Photometry

- Derived data: periods, lightcurve amplitude, shape

| Informations disponibles concernant la courbe de lumière : | | | |
|---|---|---|---|
| **Période (heures)** | **Amplitude (mag.)** | **Référence pour la période** | **Référence pour l'amplitude** |
| 26.802 hr (double peak assumed) | 0.24 (R) | P. Rousselot, J.M. Petit, F. Poulet, A. Sergeev, 2005, ``Photometric study of Centaur (60558) 2000~EC$_{98}$ and Trans-Neptunian Object (55637) 2002 UX25 at different phase angles', Icarus 176, 478-491 | P. Rousselot, J.M. Petit, F. Poulet, A. Sergeev, 2005, ``Photometric study of Centaur (60558) 2000~EC$_{98}$ and Trans-Neptunian Object (55637) 2002 UX25 at different phase angles', Icarus 176, 478-491 |

- Provenance

| Ref. Obs. | Observateur | Mesureur | Observatoire | Télescope | Instrument | Article(s) scientifique(s) | Commentaires |
|---|---|---|---|---|---|---|---|
| 2 | Rousselot P. / Poulet F. | Rousselot P. | 809 (La Silla) | 1.54-m (Danish) / T3.60-m / NTT | DFOSC / EFOSC 2 / SUSI 2 | Rousselot P., Petit J.-M., Poulet F., Sergeev A., 2005, Photometry study of Centaur (60558) 2000EC98 and trans-neptunian object (55637) 2002 UX25 at different phase angles, Icarus 176, 478-491 | |
| 17 | Bauer et al. | Bauer et al. | 568 (Mauna Kea) | 2.2-m | Tek 2048 CCD camera | Bauer, J.M., Meech, K.J., Fernandez, Y.R., Pittichova, J., Hainaut, O.R., Boehnhardt, H., Delsanti, A.C., 2003, "Physical survey of 24 Centaurs with visible photometry", Icarus 166, 195-211 | |

# Photometry

- External data
  - Can only reference the paper describing the data
  - Possibly link to any provenance data from the paper

- Our data
  - Reference catalog used for calibration
  - Color correction
  - Any internal processing

# Astrometry

- From astrometric positions to orbit
  - Program used
  - Ephemerides used
  - Type of orbital elements: heliocentric, barycentric, Jacobi ?

# Dynamics

```
# File: All_Surveys_v11.detections
#
# cl p   j    k sh     object   mag e_mag Filt Hsur dist   e_dist    Nobs    time   av_xres av_yres max_x   max_y       a          e_a
sca x   -1   -1 S       o3e01 21.50 0.087 r   7.73  23.291    0.000    43     2.1956   0.051   0.042   0.115   0.169   34.417216     0.0080
res N    3    2 S       o3e02 23.34 0.140 r   8.32  31.080    0.001    32     3.2522   0.047   0.052   0.187   0.134   39.440179     0.0041
res N    3    2 S       o3e03 23.72 0.109 r   8.70  31.131    0.000    29     4.1449   0.092   0.052   0.195   0.207   39.334897     0.0052
res N    3    2 S       o3e04 23.39 0.163 r   8.25  32.136    0.000    29     3.1756   0.059   0.050   0.253   0.320   39.495980     0.0043
res N    2    1 S       o3e05 22.69 0.066 r   7.42  33.001    0.001    31     2.1187   0.044   0.047   0.139   0.093   47.744356     0.0099
res N    3    2 S       o3e06 24.03 0.309 r   8.59  34.357    0.001    36     2.0422   0.110   0.103   0.432   0.463   39.258556     0.0083
res N    3    2 S       o3e07 24.06 0.162 r   8.52  35.160    0.001    25     1.3764   0.097   0.102   0.425   0.453   39.333143     0.0184
res N    3    2 S       o3e08 24.02 0.130 r   8.45  35.413    0.001    34     4.2867   0.069   0.071   0.235   0.230   39.371591     0.0028
res N    5    2 S       o3e09 22.94 0.051 r   7.32  35.765    0.001    38     2.1189   0.059   0.058   0.268   0.329   55.536335     0.0202
```

- Dynamical classification
  - Which classification ?
  - How to handle ambiguous classification ?
    - Human intervention

# Survey Simulator

```
# This is the OSSOS survey description file.
#
# All lines starting with '#' are ignored, so they are used for comments
#
# 2013B-L block
#
poly 8 00:52:55.81 +03:43:49.1 2456596.72735 0.9151 500 2013BL.eff
-3.5 -2.743222
-3.5  0.256778
 3.5  2.743222
 3.5 -0.256778
 0.5 -1.322397
 0.5 -0.322397
-0.5 -0.677603
-0.5 -1.677603
#
# 2014B-H block
#
poly 4 01:35:14.39 +13:28:25.3 2456952.77017 0.9103 500 2014BH.eff
-3.5 -2.700361
-3.5  0.299639
 3.5  2.670528
 3.5 -0.329472
#
# ma11la block
#
 4.887  1.990 01:51:08.00 +15:51:48.0 2455860.843750 0.916 500 ma11la.eff
 4.922  1.990 01:51:08.00 +13:54:00.0 2455858.963195 0.912 500 ma11la.eff
 1.993  2.984 01:41:01.70 +28:10:00.0 2456220.904167 0.907 500 ma12ha.eff
 1.993  2.984 01:49:58.30 +28:10:00.0 2456221.947917 0.907 500 ma12ha.eff
```

U:---  **pointings.list<2021>**   All (31,0)     (Text Fill)

```
# This is an efficiency file with analytic function
#
# All lines starting with '#' are ignored, so they are used for comments.
#
# The parameters are given using a "<key> = <value(s)> pair, one per line.
# Some <keys> can only appear after a previous <key> had a specific value.
#
# See README.format and/or Template.eff for a description of the format of this
# file.
#
rate_cut= 0.50   15.00   -23.00   30.00
#
mag_error= 0.03 0.11 23.5 -0.12 24.5 -0.6
#
phot_frac= 0.013 0.152 0.835
#
track_frac= 1.0 25.35 -5.00
#
filter= r
#
rates=  0.50  2.50
function= square
square_param=   0.852392793       1.68104991E-02   24.5213051      0.148857504
# Goodness of fit (reduced chi^2):   1.086
#
# Limiting magnitude of the block
mag_lim= 24.45
#
rates=  2.50  8.00
function= square
square_param=   0.888259053       1.33343311E-02   24.4792595      0.145277739
# Goodness of fit (reduced chi^2):   2.910
#
# Limiting magnitude of the block
#mag_lim= 24.45
mag_lim= 24.46
#
rates=  8.00 12.00
function= square
square_param=   0.884100020       9.23251361E-03   24.3310623      0.160950899
# Goodness of fit (reduced chi^2):   0.689
#
# Limiting magnitude of the block
#mag_lim= 24.32
mag_lim= 24.22
```

# Survey Simulator

- How to link
  - Survey description
  - Actual detections
- Can provide more derived data
  - Detection biases
    - May depend on a model

# Astrometry, dynamics

- Using provenance to improve derived data
- Reprocess data with new calibration catalogs
  - How much information to store in provenance metadata ?
    - Previous catalogs
    - Reference stars ?