Ground observation of asteroids at mission ETA

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Outline

- NASA emphasis for ground-based support of spacecraft missions to small bodies
- LUCY mission and LBT observations
- derive Lucy targeted asteroids information for best ground-based observation at mission estimated time of arrival (ETA) through JPL Horizons repository
- preliminary data extraction
- future work and SPICE SPK
- conclusions

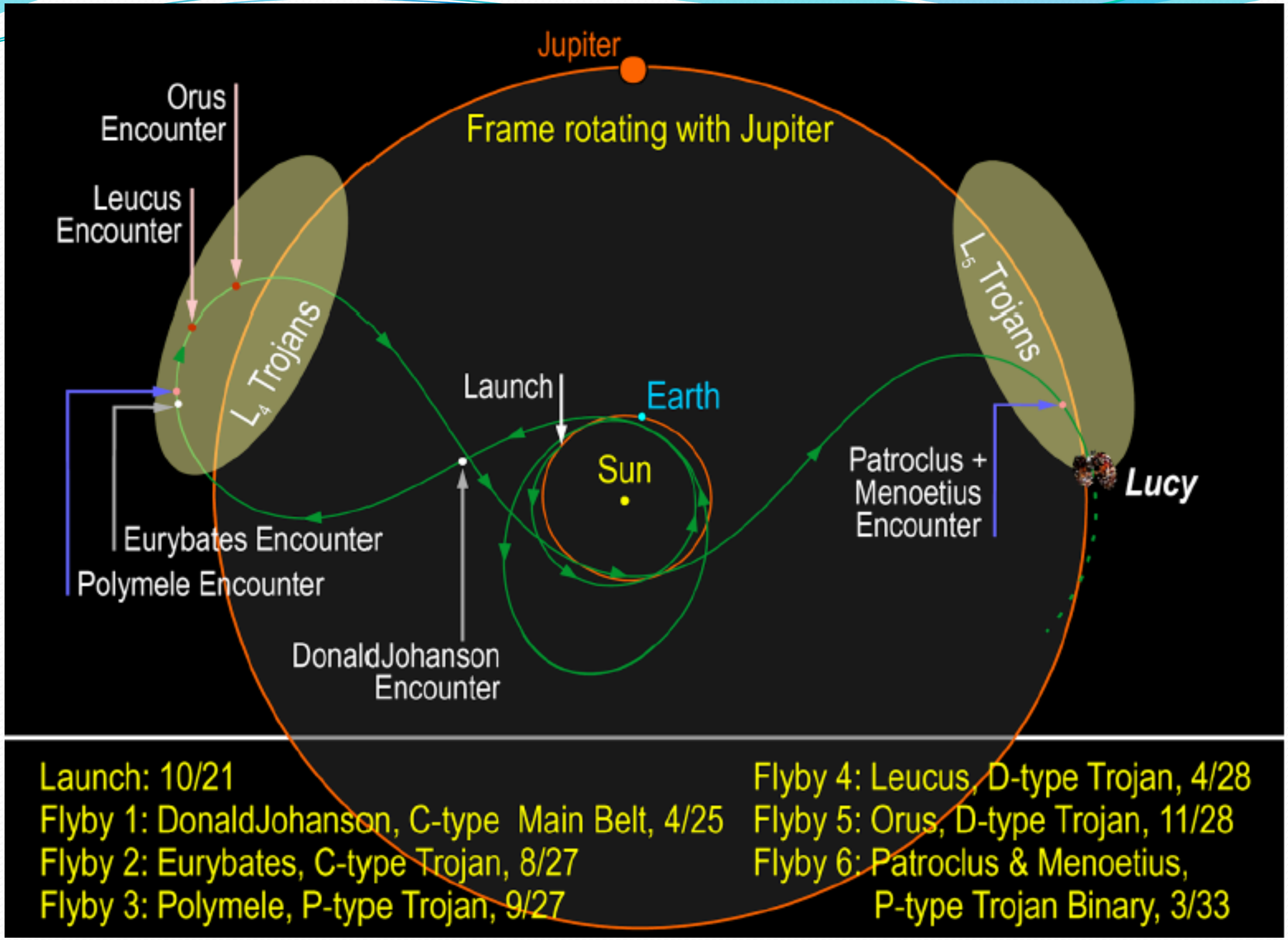
Emphasis for ground-based support of asteroids at ETA

- NASA funding for ground-based support of spacecraft missions to small bodies has increased to enhance data science return

Future Missions

Mission	Target	V mag	Size (mas)
DAWN	*Adeona*	11.0-13.6	56-133
DESTINY	*Phaeton*	10.2-19.1	4-101
PSYCHE	*Psyche*	10.9-12.2	85-156
LUCY	*Eurybates*	16.8-17.7	13-20
	Orus	16.9-17.9	11-16
	Patroclus	15.9-16.5	33-39

Lucy mission



The planned orbits and asteroid encounters for the Lucy mission. Credit: SwRI
(http://futureplanets.blogspot.com/2017/01/lucy-and-psyche-asteroid-missions.html)

Lucy instruments

Lucy, an SwRI mission proposal to study Primitive asteroids orbiting near Jupiter, is a funded/selected mission within NASA Discovery Program.

Science payload/instrumentation includes:

- **Ralph** - Panchromatic and color visible imager and Infrared spectroscopic mapper (400nm -2.5μm). L'Ralph is based on the Ralph instrument on New Horizons and will be built at Goddard Space Flight Center.

- **LORRI** - high-resolution visible imager. L'LORRI is derived from the LORRI instrument on New Horizons((350-850 nm) and will be built at the Johns Hopkins University Applied Physics Laboratory.

Source: http://www.swri.org/press-release/swri-awarded-3-million-nasa-contract-develop-mission-jupiter%E2%80%99s-trojan-asteroids#.ViEGTvBdgnc

Lucy instruments

-**TES** - thermal infrared spectrometer.
L'TES is similar to OTES on the OSIRIS-REx Mission (spectral range 5.71–100 μm) and will be built at Arizona State University.

- The **radio science** investigation will determine the mass of the Trojans by using the spacecraft radio telecommunications hardware to measure Doppler shifts.

Source: http://www.swri.org/press-release/swri-awarded-3-million-nasa-contract-develop-mission-jupiter%E2%80%99s-trojan-asteroids#.ViEGTvBdgnc

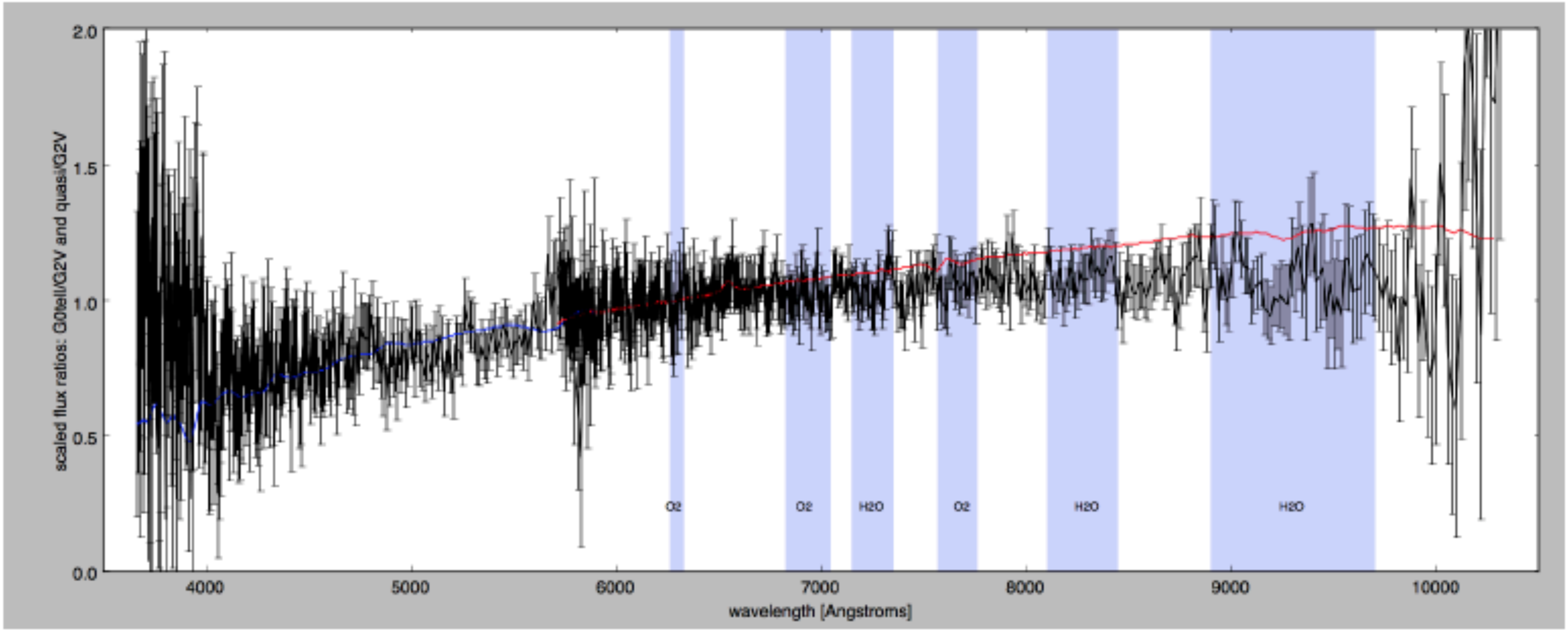
LUCY mission and LBT observations

- Importance - some Eurybates members spectra show a drop off in reflectance shortward of 0.52µm - similar features are seen in main belt C-type asteroids and commonly attributed to the intervalence charge transfer transition in oxidized iron (Fornasier et al. 2013).

- Observations - LBT Multi-Object Double Spectrographs (MODS 1) - Imager and spectrograph covering 0.32-1.1 microns with a 6'x6' FOV.

Example LBT MODS observation

(469219) 2015 HO3 Visible Spectra Acquired with MODS



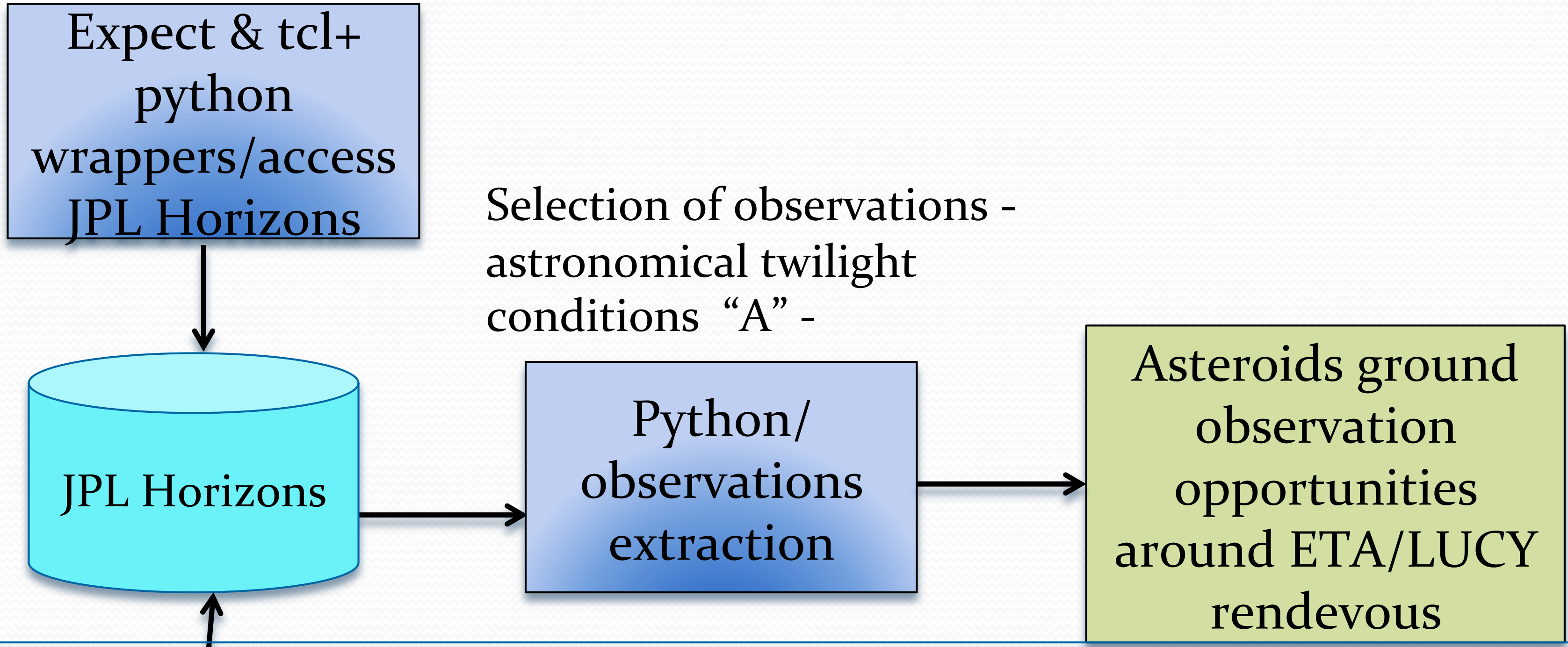
Credit: Vishnu Reddy (AAS/DPS 2017, Provo)

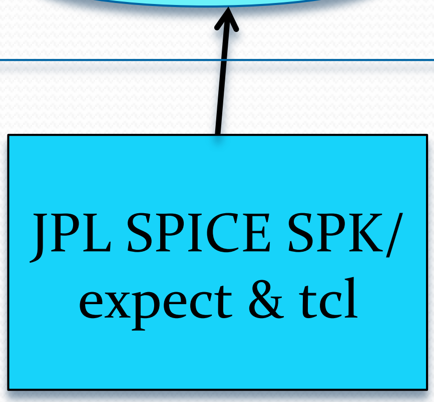
Lucy targeted asteroids

Mission	Number	Target	Vmag	Size (mas)	Albedo (μm)
Lucy	3548	Eurybates	16.8 to 17.7	13 to 20	0.052
	15094	Polymele	18.9 to 19.8	5 to 7	0.091
	11351	Leucus	17.8 to 18.8	7 to 11	0.079
	21900	Orus	16.9 to 17.9	11 to 16	0.075
	617	Patroclus	15.9 to 16.5	33 to 39	0.047
	52246	Donaldjohanson	18.3 to 20.1	2 to 4	

Lucy Mission	Encounter date	Location	Diameter (km)	Spectral type	**ETA targets**
Launch	Oct. 2021				
DonaldJohanson	April 2025	Main belt	3.9	C	
Eurybates	Aug. 2027	Greeks	64	C	12 Aug 2027
Polymele	Sept. 2027	Greeks	21	P	15 Sep 2027
Leucus	April 2028	Greeks	34	D	18 Apr 2028
Orus	Nov. 2028	Greeks	51	D	11 Nov 2028
Patroclus/Menoetius	March 2033	Trojans	113/ 104	P	02 Mar 2033

JPL Horizons repository and SPICE workflow





- can be used for observational trajectories
- uses SPK-expect & tcl
- however, info for LUCY are not yet there
- so implementation should hold till 2025

- ***…or perhaps just after I’ll take the SPICE training☺***

SPICE SPK

- JPL SPICE SPK - which stands for S(pacecraft) and P(lanet) Kernel file allows ephemerides for any collection of solar system bodies to be combined under a common file format to be used in NAIF and JPL Horizons

- JPL NAIF – science planning kernel within NAvigation InFormation system is used for mission data planning and is based on/use SPICE SPK

- scripts provided for SPK processing enable interaction with JPL Horizons (ftp://ssd.jpl.nasa.gov/pub/ssd/Horizons_doc.pdf, (https://ssd.jpl.nasa.gov/x/spk.html)

- SPK commented scripts written in the Expect programming language requires both Expect and Tcl languages be installed and can be easily used through python wrappers

- Lucy SPK is not yet part of JPL SPICE SPK - the mission has not been launched yet...

Expect + Tcl & Python scripts

```
#!/usr/bin/python3.5
#
#  Invoke JPL Horizons ephem search from python
#
#
#
import os

print( "Call to JPL horizons" )

os.system(  \
   "/usr/bin/expect nsQueryEngine.tcl Eurybates 2027-Aug-01 00:00:01 2027-Aug-31 23:59:00 1h Eurybates.txt" )

os.system(  \
   "/usr/bin/expect nsQueryEngine.tcl Polymele 2027-Sep-01 00:00:01 2027-Sep-30 23:59:00 1h Polymele.txt" )
os.system(  \
   "/usr/bin/expect nsQueryEngine.tcl Leucus 2028-Apr-01 00:00:01 2028-Apr-30 23:59:00 1h Leucus.txt" )

os.system(  \
   "/usr/bin/expect nsQueryEngine.tcl Orus 2028-Nov-01 00:00:01 2028-Nov-30 23:59:00 1h Orus.txt" )

os.system(  \
   "/usr/bin/expect nsQueryEngine.tcl Patroclus 2033-Mar-01 00:00:01 2033-Mar-31 23:59:00 1h Patroclus.txt" )

# Menoetius not found in system JPL Horizons
```

- call to JPL Horizons through Tcl to extract asteroids info during month of ETA

Expect +Tcl & Python scripts

- ETA observation extraction from JPL Horizons derived files- use “Astronomical twilight condition”

```
#!/usr/bin/python3.5
#
#   Code to look LBT ground observations for Eurybates, Polymele, Leucusdata, Orus, Patroclus
#
#   SSFA - Flora paganelli - 170731
#

#
import numpy as np
import matplotlib
import scipy
from scipy import ndimage
import astropy

#path= '/home/fpaganel/day02/exEphem/Eurybates.txt'

myfile = open('output_LUCY-ast.txt', 'w')

asteroid = ["Eurybates","Polymele", "Leucus", "Orus", "Patroclus"]

i=0

while i < len(asteroid):
    searchfile = open("/home/fpaganel/day02/exEphem/" + asteroid[i] + ".txt","r")
    print (asteroid[i], "Date_UT_HR:MM:SS", " Date_JDUT ", " A/", " R.A._(ICRF/J2000.0)_DEC", " dRA*cosD", " d(DEC)/dt
    myfile.write(asteroid[i] + '\n')
    myfile.write(" Date___UT___HR:MM:SS " + "Date____JDUT " + "     A/ " + " R.A.___(ICRF/J2000.0)___DEC" + " dRA*cosD

    count=0

    for line in searchfile:
        if (" A ") in line:
            count +=1
            print (line)
            myfile.write(line)

    i += 1

    searchfile.close()
    print ("Observation days for " + asteroid[i-1] + " are " + str(count))
    myfile.write("Observation days for " + asteroid[i-1] + " are " + str(count) + '\n')
myfile.close()
```

Results Eurybates, Polymele

Eurybates

Date___UT___HR:MM:SS	Date____JDUT	A/	R.A.___(ICRF/J2000.0)___DEC		dRA*cosD	d(DEC)/dt	APmag	S-brt	Azi_(a-appr)_Elev	
2027-Aug-01 11:00:01	2461618.958344907	A	14 49 35.1223	-18 08 21.983	7.420133	-2.87667	17.81	8.58	283.6621	-53.1648
2027-Aug-20 03:00:01	2461637.625011574	A	14 55 08.4702	-18 37 45.543	13.60701	-4.74606	17.92	8.57	221.8841	26.3718
2027-Aug-21 03:00:01	2461638.625011574	A	14 55 32.1487	-18 39 42.802	13.93981	-4.83303	17.92	8.57	222.6124	25.8441
2027-Aug-22 03:00:01	2461639.625011574	A	14 55 56.3843	-18 41 42.179	14.26970	-4.91880	17.93	8.57	223.3289	25.3105
2027-Aug-23 03:00:01	2461640.625011574	A	14 56 21.1722	-18 43 43.645	14.59672	-5.00338	17.93	8.57	224.0337	24.7713
2027-Aug-24 03:00:01	2461641.625011574	A	14 56 46.5080	-18 45 47.172	14.92091	-5.08677	17.94	8.57	224.7270	24.2267
2027-Aug-25 03:00:01	2461642.625011574	A	14 57 12.3872	-18 47 52.729	15.24230	-5.16895	17.94	8.57	225.4091	23.6768
2027-Aug-26 03:00:01	2461643.625011574	A	14 57 38.8053	-18 50 00.288	15.56090	-5.24991	17.95	8.57	226.0801	23.1220
2027-Aug-27 03:00:01	2461644.625011574	A	14 58 05.7579	-18 52 09.818	15.87669	-5.32963	17.95	8.56	226.7403	22.5625
2027-Aug-28 03:00:01	2461645.625011574	A	14 58 33.2405	-18 54 21.289	16.18961	-5.40808	17.95	8.56	227.3899	21.9983
2027-Aug-29 03:00:01	2461646.625011574	A	14 59 01.2485	-18 56 34.668	16.49954	-5.48520	17.96	8.56	228.0291	21.4297
2027-Aug-30 03:00:01	2461647.625011574	A	14 59 29.7769	-18 58 49.924	16.80634	-5.56095	17.96	8.56	228.6581	20.8569
2027-Aug-31 03:00:01	2461648.625011574	A	14 59 58.8207	-19 01 07.021	17.10981	-5.63525	17.96	8.56	229.2773	20.2801

Observation days for Eurybates are 13

Polymele

Date___UT___HR:MM:SS	Date____JDUT	A/	R.A.___(ICRF/J2000.0)___DEC		dRA*cosD	d(DEC)/dt	APmag	S-brt	Azi_(a-appr)_Elev	
2027-Sep-01 03:00:01	2461649.625011574	A	14 57 13.8582	-18 18 40.607	17.11405	-6.78336	19.98	8.15	231.0237	19.7142
2027-Sep-02 03:00:01	2461650.625011574	A	14 57 43.2741	-18 21 26.937	17.40953	-6.85008	19.99	8.15	231.6162	19.1142
2027-Sep-02 12:00:01	2461651.000011574	A	14 57 54.5114	-18 22 29.100	18.04313	-6.96741	19.99	8.15	24.4436	-74.5770
2027-Sep-03 03:00:01	2461651.625011574	A	14 58 13.1853	-18 24 14.888	17.70114	-6.91526	19.99	8.15	232.1993	18.5108
2027-Sep-03 12:00:01	2461652.000011574	A	14 58 24.6087	-18 25 17.655	18.32756	-7.03449	19.99	8.14	27.3144	-74.3039
2027-Sep-04 12:00:01	2461653.000011574	A	14 58 55.1926	-18 28 07.780	18.60798	-7.09999	19.99	8.14	30.0826	-73.9996
2027-Sep-05 12:00:01	2461654.000011574	A	14 59 26.2569	-18 30 59.437	18.88438	-7.16392	20.00	8.14	32.7447	-73.6661
2027-Sep-06 12:00:01	2461655.000011574	A	14 59 57.7952	-18 33 52.589	19.15680	-7.22631	20.00	8.14	35.2991	-73.3055
2027-Sep-07 12:00:01	2461656.000011574	A	15 00 29.8014	-18 36 47.199	19.42530	-7.28718	20.00	8.13	37.7455	-72.9196
2027-Sep-08 12:00:01	2461657.000011574	A	15 01 02.2693	-18 39 43.231	19.68994	-7.34655	20.00	8.13	40.0852	-72.5105
2027-Sep-09 12:00:01	2461658.000011574	A	15 01 35.1930	-18 42 40.650	19.95079	-7.40445	20.00	8.13	42.3204	-72.0799
2027-Sep-10 12:00:01	2461659.000011574	A	15 02 08.5666	-18 45 39.420	20.20792	-7.46089	20.01	8.13	44.4541	-71.6297
2027-Sep-11 12:00:01	2461660.000011574	A	15 02 42.3842	-18 48 39.507	20.46141	-7.51591	20.01	8.12	46.4899	-71.1615
2027-Sep-12 12:00:01	2461661.000011574	A	15 03 16.6403	-18 51 40.876	20.71132	-7.56952	20.01	8.12	48.4319	-70.6767
2027-Sep-13 12:00:01	2461662.000011574	A	15 03 51.3294	-18 54 43.496	20.95774	-7.62174	20.01	8.12	50.2843	-70.1769
2027-Sep-14 12:00:01	2461663.000011574	A	15 04 26.4459	-18 57 47.331	21.20074	-7.67260	20.01	8.11	52.0515	-69.6634
2027-Sep-29 12:00:01	2461678.000011574	A	15 14 01.1699	-19 45 49.626	24.47430	-8.27947	20.02	8.05	71.0915	-60.9449
2027-Sep-30 02:00:01	2461678.583344907	A	15 14 25.1053	-19 47 46.202	24.16667	-8.15526	20.02	8.05	236.2489	12.4217
2027-Sep-30 12:00:01	2461679.000011574	A	15 14 42.4670	-19 49 08.686	24.66677	-8.30914	20.01	8.05	72.0109	-60.3247

Observation days for Polymele are 19

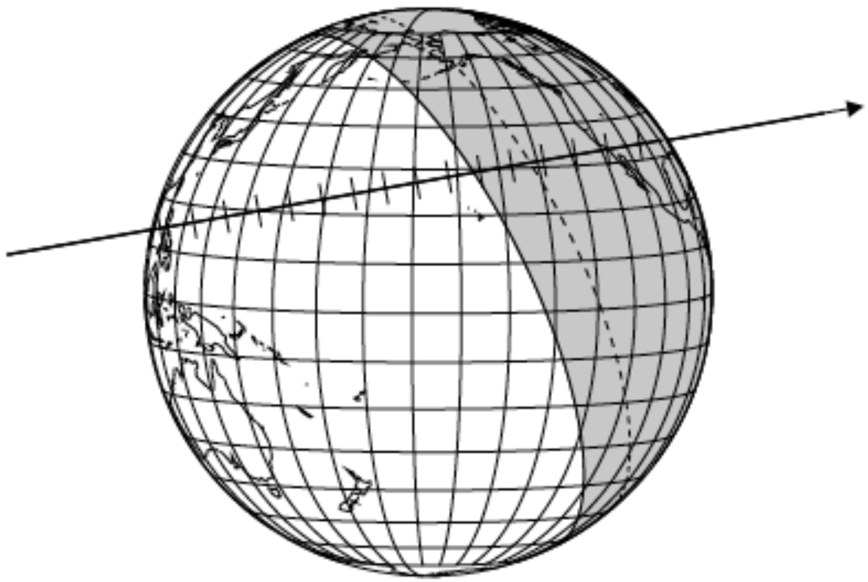
Results Leucus, Orus, Patroclus

```
Leucus
 Date___UT___HR:MM:SS Date____JDUT      A/  R.A.___(ICRF/J2000.0)___DEC dRA*cosD  d(DEC)/dt  APmag S-brt Azi_(a-appr)_Elev
 2028-Apr-01 12:00:01 2461863.000011574 A   16 48 05.3186 -23 52 34.935 -2.03708  1.967876  18.61   8.16 188.7451  32.8560
 2028-Apr-02 12:00:01 2461864.000011574 A   16 48 02.0368 -23 51 47.257 -2.47764  2.039883  18.60   8.16 189.8220  32.7334
 2028-Apr-03 12:00:01 2461865.000011574 A   16 47 57.9864 -23 50 57.883 -2.91644  2.112077  18.59   8.15 190.8982  32.5952
 2028-Apr-04 12:00:01 2461866.000011574 A   16 47 53.1706 -23 50 06.809 -3.35331  2.184463  18.58   8.15 191.9734  32.4413
 2028-Apr-05 12:00:01 2461867.000011574 A   16 47 47.5929 -23 49 14.030 -3.78812  2.257043  18.57   8.15 193.0469  32.2716
 2028-Apr-06 12:00:01 2461868.000011574 A   16 47 41.2569 -23 48 19.543 -4.22079  2.329823  18.56   8.14 194.1184  32.0863
 2028-Apr-07 12:00:01 2461869.000011574 A   16 47 34.1662 -23 47 23.343 -4.65131  2.402808  18.55   8.14 195.1872  31.8853
 2028-Apr-11 03:00:01 2461872.625011574 A   16 47 02.3258 -23 43 44.342 -5.64235  2.480793  18.51   8.12  97.9176 -34.7549
 2028-Apr-12 03:00:01 2461873.625011574 A   16 46 51.7975 -23 42 40.171 -6.06957  2.550339  18.50   8.12  98.3705 -33.8900
 2028-Apr-13 03:00:01 2461874.625011574 A   16 46 40.5368 -23 41 34.262 -6.49439  2.620069  18.49   8.11  98.8227 -33.0234
 2028-Apr-14 03:00:01 2461875.625011574 A   16 46 28.5486 -23 40 26.614 -6.91652  2.689957  18.48   8.11  99.2744 -32.1550
 2028-Apr-15 03:00:01 2461876.625011574 A   16 46 15.8382 -23 39 17.225 -7.33564  2.759975  18.47   8.10  99.7260 -31.2850
 2028-Apr-16 03:00:01 2461877.625011574 A   16 46 02.4117 -23 38 06.092 -7.75140  2.830090  18.46   8.10 100.1776 -30.4134
 2028-Apr-17 03:00:01 2461878.625011574 A   16 45 48.2757 -23 36 53.215 -8.16346  2.900269  18.44   8.09 100.6294 -29.5403
 2028-Apr-18 03:00:01 2461879.625011574 A   16 45 33.4374 -23 35 38.595 -8.57145  2.970479  18.43   8.08 101.0817 -28.6658
 2028-Apr-19 03:00:01 2461880.625011574 A   16 45 17.9047 -23 34 22.233 -8.97501  3.040684  18.42   8.08 101.5347 -27.7899
 2028-Apr-20 03:00:01 2461881.625011574 A   16 45 01.6862 -23 33 04.131 -9.37380  3.110844  18.41   8.07 101.9885 -26.9129
 2028-Apr-21 03:00:01 2461882.625011574 A   16 44 44.7908 -23 31 44.293 -9.76743  3.180921  18.40   8.07 102.4433 -26.0347
 2028-Apr-22 03:00:01 2461883.625011574 A   16 44 27.2284 -23 30 22.723 -10.1555  3.250870  18.39   8.06 102.8995 -25.1554
 2028-Apr-23 03:00:01 2461884.625011574 A   16 44 09.0094 -23 28 59.426 -10.5377  3.320647  18.38   8.05 103.3570 -24.2752
 2028-Apr-24 03:00:01 2461885.625011574 A   16 43 50.1450 -23 27 34.408 -10.9136  3.390205  18.37   8.05 103.8162 -23.3941
 2028-Apr-25 03:00:01 2461886.625011574 A   16 43 30.6468 -23 26 07.678 -11.2828  3.459496  18.35   8.04 104.2773 -22.5123
Observation days for Leucus are 22
Orus
 Date___UT___HR:MM:SS Date____JDUT      A/  R.A.___(ICRF/J2000.0)___DEC dRA*cosD  d(DEC)/dt  APmag S-brt Azi_(a-appr)_Elev
 2028-Nov-23 13:00:01 2462099.041678241 A   16 46 06.3650 -22 46 56.186 33.38001 -2.73018  17.86   7.84 103.0616 -23.2567
 2028-Nov-24 13:00:01 2462100.041678241 A   16 47 04.1979 -22 48 00.686 33.42631 -2.68640  17.85   7.83 103.4198 -22.6548
 2028-Nov-25 13:00:01 2462101.041678241 A   16 48 02.1228 -22 49 04.123 33.46925 -2.64177  17.84   7.82 103.7775 -22.0540
 2028-Nov-26 13:00:01 2462102.041678241 A   16 49 00.1339 -22 50 06.477 33.50889 -2.59631  17.83   7.81 104.1350 -21.4543
 2028-Nov-27 13:00:01 2462103.041678241 A   16 49 58.2256 -22 51 07.729 33.54530 -2.55005  17.82   7.79 104.4924 -20.8558
 2028-Nov-28 13:00:01 2462104.041678241 A   16 50 56.3920 -22 52 07.859 33.57853 -2.50300  17.81   7.78 104.8496 -20.2583
 2028-Nov-29 13:00:01 2462105.041678241 A   16 51 54.6277 -22 53 06.849 33.60866 -2.45518  17.80   7.77 105.2068 -19.6620
 2028-Nov-30 13:00:01 2462106.041678241 A   16 52 52.9272 -22 54 04.681 33.63574 -2.40662  17.78   7.76 105.5641 -19.0668
Observation days for Orus are 8
Patroclus
 Date___UT___HR:MM:SS Date____JDUT      A/  R.A.___(ICRF/J2000.0)___DEC dRA*cosD  d(DEC)/dt  APmag S-brt Azi_(a-appr)_Elev
 2033-Mar-29 03:00:01 2463685.625011574 A   16 34 28.6378 -29 43 37.757 -2.04082 -7.97173  15.88   8.63 101.0218 -45.2283
 2033-Mar-29 12:00:01 2463686.000011574 A   16 34 26.8673 -29 44 49.126 -2.86266 -7.76526  15.88   8.63 187.9653  27.0081
 2033-Mar-30 03:00:01 2463686.625011574 A   16 34 23.9382 -29 46 44.460 -2.52316 -7.92387  15.87   8.62 101.4705 -44.4149
 2033-Mar-30 12:00:01 2463687.000011574 A   16 34 21.8332 -29 47 55.348 -3.34016 -7.71018  15.87   8.62 188.9260  26.8325
 2033-Mar-31 03:00:01 2463687.625011574 A   16 34 18.3564 -29 49 49.883 -3.00516 -7.87405  15.86   8.62 101.9174 -43.5999
 2033-Mar-31 12:00:01 2463688.000011574 A   16 34 15.9170 -29 51 00.270 -3.81686 -7.65312  15.86   8.62 189.8850  26.6428
Observation days for Patroclus are 6
```

Results Leucus

TYC2 0572-01240-1 by 11351 Leucus
2019/12/29 03:30:24

RA: 22 53 00.1199 DEC: +04 20 35.612
Ephemeris corrections: 0.0000s 0.000as
Asteroid V: 18.53 Computed B: 19.33 Star V: 11.21 Drop in V: 0.999
Diam: 17.8 = 0.005as Max Duration: 0.7s Q: 43.4
Solar elongation: 69.8
Lunar elongation: 37.3 Illuminated: 8.9%
Sun altitude at -12.0 shown dotted
Ticks from: 03:26:30 to 03:34:00 every 30 sec



Thoughts on process involved

- understanding JPL Horizons parameters and retrieved data meaning for data extraction
- Tcl scripts using Expect and Tcl language environment
- understand/use Expect and .Tcl scripts and parameters
- use of python as wrappers processing in combination with Expect and Tcl
- use of python as processing language in use of list vs. arrays formats

Future work

- Lucy SPK is not yet part of JPL SPICE SPK - the mission has not been launched yet…

- tested configuration for Eurybates close approach SPK using approximate values – results simply returned no close approach between 2000-2050

- further work with SPICE SPK and training

- Other resources and documentation:

ftp://ssd.jpl.nasa.gov/pub/ssd/Horizons_doc.pdf

- sites for SPK calculation/estimates

https://naif.jpl.nasa.gov/pub/naif/toolkit_docs/C/req/spk.html#Purpose

- Asteroid & Comet SPK File Generation Request

https://ssd.jpl.nasa.gov/x/spk.html

- Spicey.py on GitHub - SPICE toolkit wrapper in Python –

https://github.com/AndrewAnnex/SpiceyPy

Expect + Tcl & Python scripts

```python
#!/usr/bin/python3.5
#
#   Invoke JPL Horizons ephem search from python
#
#   SSFA - Flora paganelli - 170801
#
import os

print( "Call to JPL horizons" )

os.system(  \
   "/usr/bin/expect close_approach_tbl.tcl Eurybates")

os.system(  \
   "/usr/bin/expect close_approach_tbl.tcl Polymele")

os.system(  \
   "/usr/bin/expect close_approach_tbl.tcl Leucus")

os.system(  \
   "/usr/bin/expect close_approach_tbl.tcl Orus")
```

- test with close-approach-tbl.tcl SPK script using close_approach_tbl.inp to derive close approach at ETA….

Lucy close-approach test

```
*******************************************************************************
Close-approach / PORT_LOGIN Wed Aug  2 01:01:06 2017   Pasadena, USA / Horizons
*******************************************************************************
Object name     : 3548 Eurybates (1973 SO)        {source: JPL#52-DASTCOM}
Start time      : A.D. 2000-Jan-27 00:00:00.0 TDB
Stop  time      : A.D. 2050-Jan-01 00:00:00.0 TDB
Planetary model : DE-0431LE-0431
Small body model: SB431-N16
Small-body perts: Yes                             {source: SB431-N16}
Cut-off, TCA3Sg : 14400 minutes
Cut-off, planets: .1, .1, .1, .1, 1., 1., 1., 1., .1, .003 (au)
Cut-off,asteroid: .05 au
Units conversion: 1 au= 149597870.700 km, c= 299792.458 km/s, 1 day= 86400.0 s
*******************************************************************************
Initial IAU76/J2000 heliocentric ecliptic osculating elements (au, days, deg.):
  EPOCH=  2455974.5 ! 2012-Feb-17.00 (TDB)         Residual RMS= .25157
   EC= .0909488607811488   QR= 4.704444289522097   TP= 2455351.2375611397
   OM= 43.54663408449642   W=  26.97429921064895   IN= 8.0716342051452
  Equivalent ICRF heliocentric equatorial cartesian coordinates (au, au/d):
   X=-3.224371380361148E+00  Y= 3.070340101325552E+00  Z= 2.082948741405054E+00
  VX=-2.022619942249653E+00 VY= 9.904390105006868E-01 VZ= 7.814301394607658E-01
Asteroid physical parameters (km, seconds, rotational period in hours):
   GM= n.a.                RAD= 31.9425            ROTPER= 8.711
   H= 9.7                  G= .150                 B-V= n.a.
                           ALBEDO= .052            STYP= n.a.
Orbit solution square-root covariance at EPOCH:
    SRC= -2.241866898206947E-8    5.404689536354237E-8  -2.874250115676994E-7
         -3.495202338790118E-8    2.024588521252358E-7  -6.920262029775376E-5
          1.765407016663855E-9   -4.200685741614337E-8  -.0003497435272009936
         -5.080575602021683E-7    1.667728928670612E-9  -4.25685270082072E-8
         -.0003618533614555864    4.934955272016075E-7  -1.008755279000129E-6
         -5.093475504159477E-11  -4.12260139073405E-12   3.098308774240254E-6
          1.205427107083226E-7   -1.150400978235163E-7  -1.287184371583664E-7
******************************************************************************************
 Close-approach results:

  No close-approaches detected (within specified time and distance limits).

******************************************************************************************
```

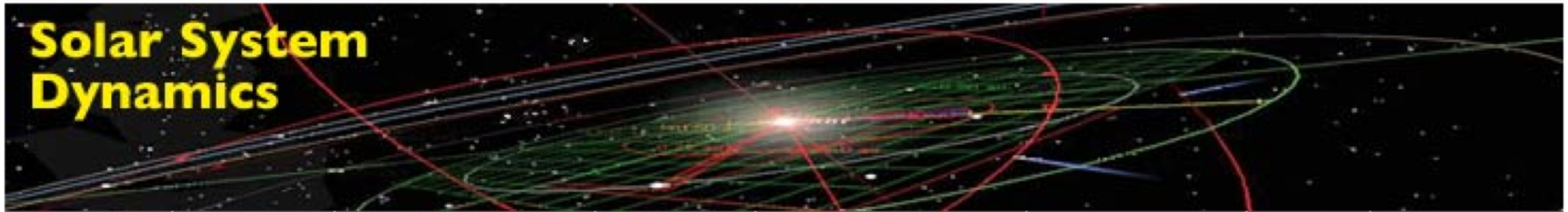
SPK quest

https://ssd.jpl.nasa.gov/?targets

Jet Propulsion Laboratory
California Institute of Technology

+ View the NASA Portal
+ Center for Near-Earth Object Studies

JPL HOME | EARTH | SOLAR SYSTEM | STARS & GALAXIES | TECHNOLOGY



BODIES | ORBITS | EPHEMERIDES | TOOLS | PHYSICAL DATA | DISCOVERY | FAQ | SITE MAP

Asteroid and Comet Spacecraft Missions

Over the years, NASA and other space agencies have targeted asteroids and comets in their spacecraft missions. Some missions were designed specifically to learn more about physical characteristics of asteroids and comets while others were able to view asteroids on their way to other planetary destinations (such as JPL's Galileo mission).

The following table shows specific asteroids and comets which have been, or will be, the targets of selected spacecraft missions. Each row represents an "encounter" event. Data are sorted by event-date. Past missions are shown with a dark-gray background, past events of current missions are shown with a blue background, future events are highlighted in green, and events of missions yet to be launched are shown in dark green.

Target Body	Event		Mission Details		
	type	date	name	launch	status
16 Psyche	arrival	2026	Psyche	2022	pre-launch
101955 Bennu (1999 RQ36)	sample-return	2023	OSIRIS-REx	2016-Sep-08	cruise
101955 Bennu (1999 RQ36)	departure	2021-Aug	OSIRIS-REx	2016-Sep-08	cruise
101955 Bennu (1999 RQ36)	arrival	2018-Aug	OSIRIS-REx	2016-Sep-08	cruise

SPK quest

SPK example Bennu

https://ssd.jpl.nasa.gov/sbdb.cgi?sstr=101955

JPL Small-Body Database Browser

Search: [help]

101955 Bennu (1999 RQ36)

Classification: Apollo [NEO, PHA] **SPK-ID:** 2101955

[Ephemeris | Orbit Diagram | Orbital Elements | Physical Parameters | Discovery Circumstances | Close-Approach Data]

[show orbit diagram]

Orbital Elements at Epoch 2455562.5 (2011-Jan-01.0) TDB
Reference: JPL 94 (heliocentric ecliptic J2000)

Element	Value	Uncertainty (1-sigma)	Units
e	.2037451091367535	2.2237e-08	
a	1.126391026023651	4.0315e-11	au
q	.8968943634958026	2.5034e-08	au
i	6.034939464618096	2.8409e-06	deg
node	2.060867873490002	3.9515e-06	deg
peri	66.22306795569258	6.096e-06	deg
M	101.7039479901095	2.6659e-06	deg
t_p	2455439.141945718134 (2010-Aug-30.64194572)	3.2307e-06	JED
period	436.6487281869375	2.3442e-08	d
	1.20	6.418e-11	yr
n	.8244613501905753	4.4263e-11	deg/d
Q	1.3558876885515	4.8529e-11	au

Orbit Determination Parameters

# obs. used (total)	511
# delay obs. used	22
# Doppler obs. used	7
data-arc span	6534 days (17.89 yr)
first obs. used	1999-09-11
last obs. used	2017-08-01
planetary ephem.	DE431
SB-pert. ephem.	SB431-N16
condition code	0
fit RMS	.26546
data source	ORB
producer	Otto Matic
solution date	2017-Aug-02 06:20:40

Additional Model Parameters

Parameter	Value	Uncertainty (1-sigma)
A2 [EST]	-4.541976335336753E-14	2.535E-16
ALN [SET]	1.	n/a
AMRAT [SET]	3.07E-6	n/a
NK [SET]	0.	n/a
NM [SET]	2.25	n/a
NN [SET]	0.	n/a
R0 [SET]	1.	n/a

Additional Information

Earth MOID = .0032228 au
Jupiter MOID = 3.87795 au
T_jup = 5.525
Nongravitational accels. using nonstandard g(r) = (1 AU/ r)^2.25

[show covariance matrix]

[Ephemeris | Orbit Diagram | Orbital Elements | Physical Parameters | Discovery Circumstances | Close-Approach Data]

SPK quest

https://ssd.jpl.nasa.gov/x/spk.html

Advanced Horizons **Asteroid & Comet SPK File Generation Request**

Fill in all necessary data and submit to produce a heliocentric small-body SPK file on your system.
For general information on this program, click here.

For information about each input, click on its title -- a window will open.

Object	Eurybates
SPK start date (TDB)	2027-Aug-12 00:00:01
SPK stop date (TDB)	2027-Aug-12 23:59:00
E-mail contact address	fpaganelli@nccc.edu
SPK file format	(•) ASCII ( ) Binary

[Look up] [Make SPK] [Clear Form]

After clicking "Make SPK", please wait until the integration is complete.
It could take a minute or so to generate and stream data, depending on system load.

Optional (below): define your own object by supplying heliocentric J2000 ecliptic osculating elements.

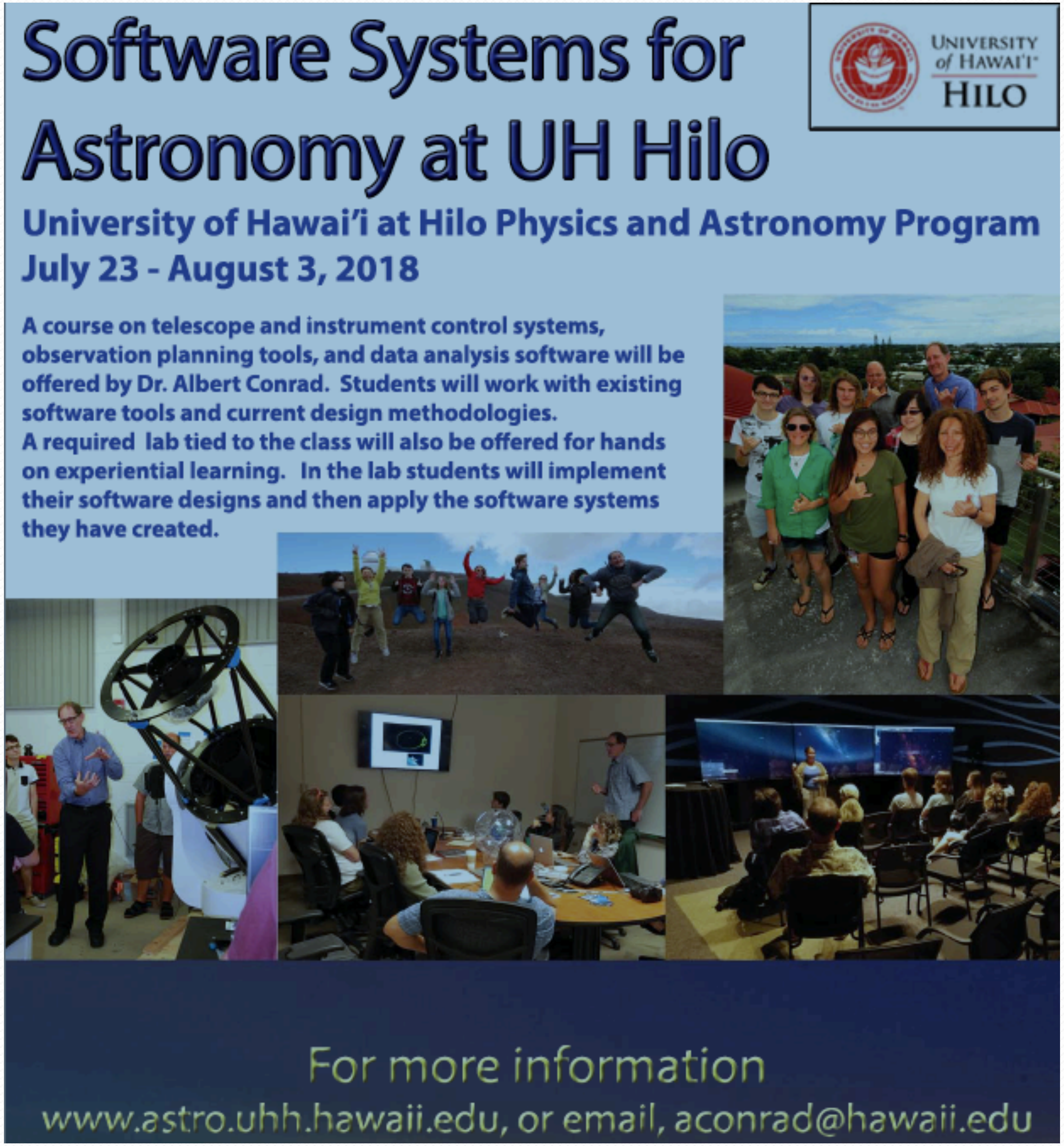
Epoch (Julian Day Number, TDB)	2455974.5
Eccentricity	.0909488607811488
Perihelion distance (au)	2455351.2375611397
Perihelion Julian date (JDTDB)	
Longitude of Ascending Node (deg)	
Argument of Perihelion (deg)	
Inclination (deg)	8.0716342051452
Optional cometary values:	
A1 radial non-grav (au/d^2)	
A2 transverse non-grav (au/d^2)	
A3 normal non-grav (au/d^2)	
DT delay time (days)	

Contact: Webmaster (webmaster@ssd.jpl.nasa.gov) JPL Solar System Dynamics Group

Conclusions

- we have developed software and procedures to extract data from JPL Horizons
- this information will be used to plan observations, for example, like the LBT MODS spectra shown earlier
- we are working to use the SPK information at JPL that is currently available for this mission

SSFA-UH Hilo 23-Jul to 03-Aug, 2018



Thank you!

Questions?