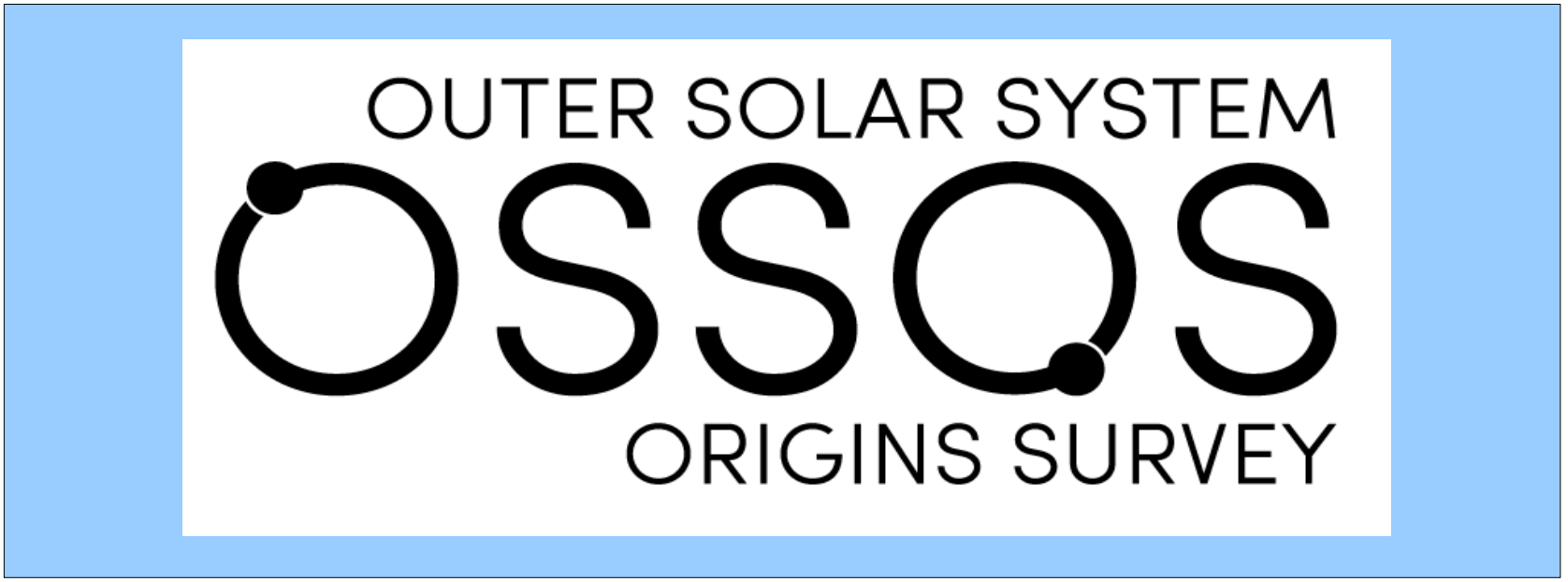


11th tri-annual CFHT User's Meeting

Brett Gladman, UBC, for the OSSOS collaboration

The OSSOS award

- Top-ranked LP from the 2nd 4-year round.
- Awarded 560 hours, evenly spread (70h/semseter) over 2013A-2016B
  - 100% Megacam
  - 45% Canada, 45% France, 10% Taiwan
  - UVic/HIA Besançon ASIAA

    UBC Marseille NCU

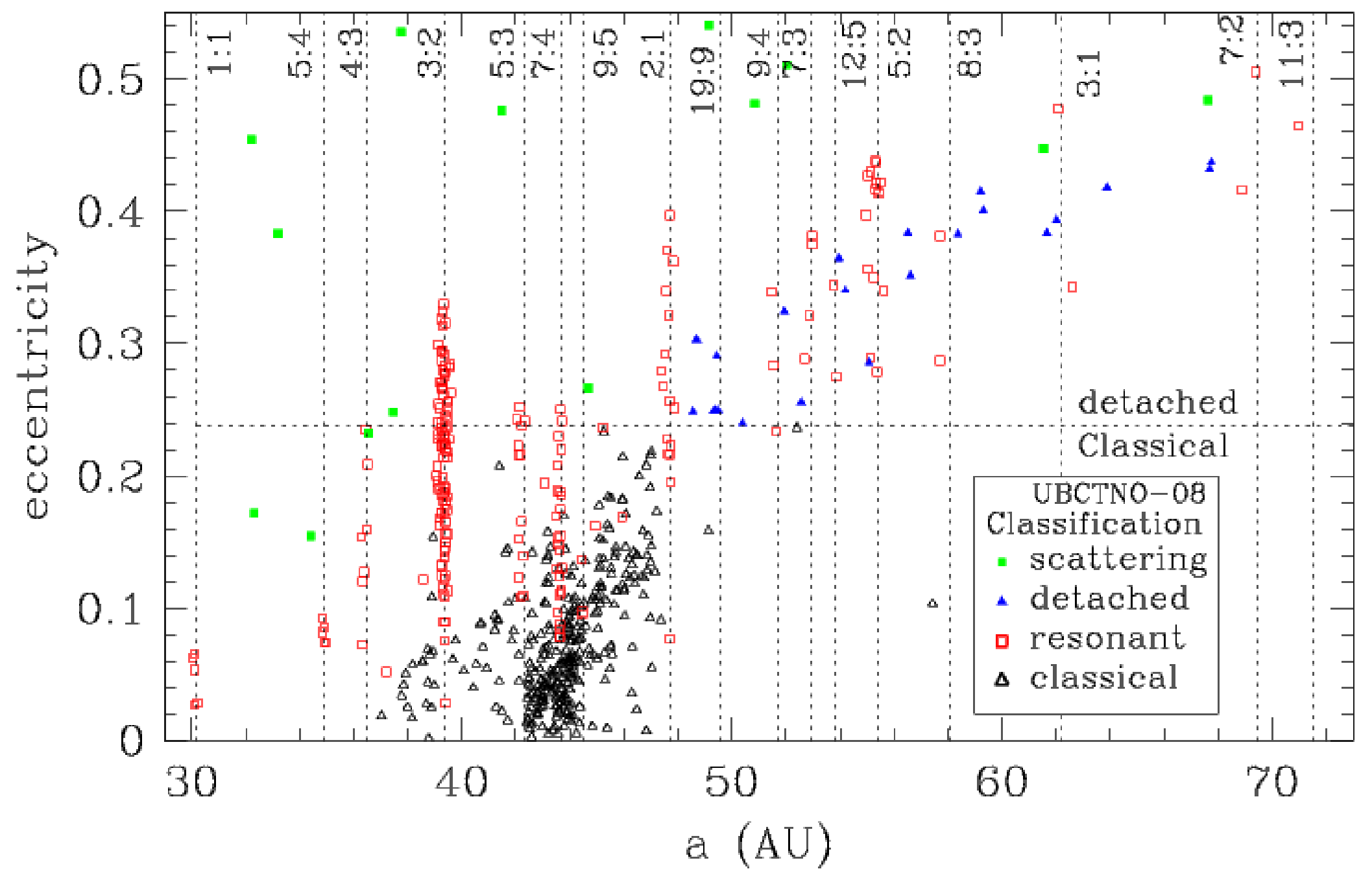
    Paris

    +USA (SWRI, Arizona, Santa Barbara, LCOGT, STSci, U Washington)

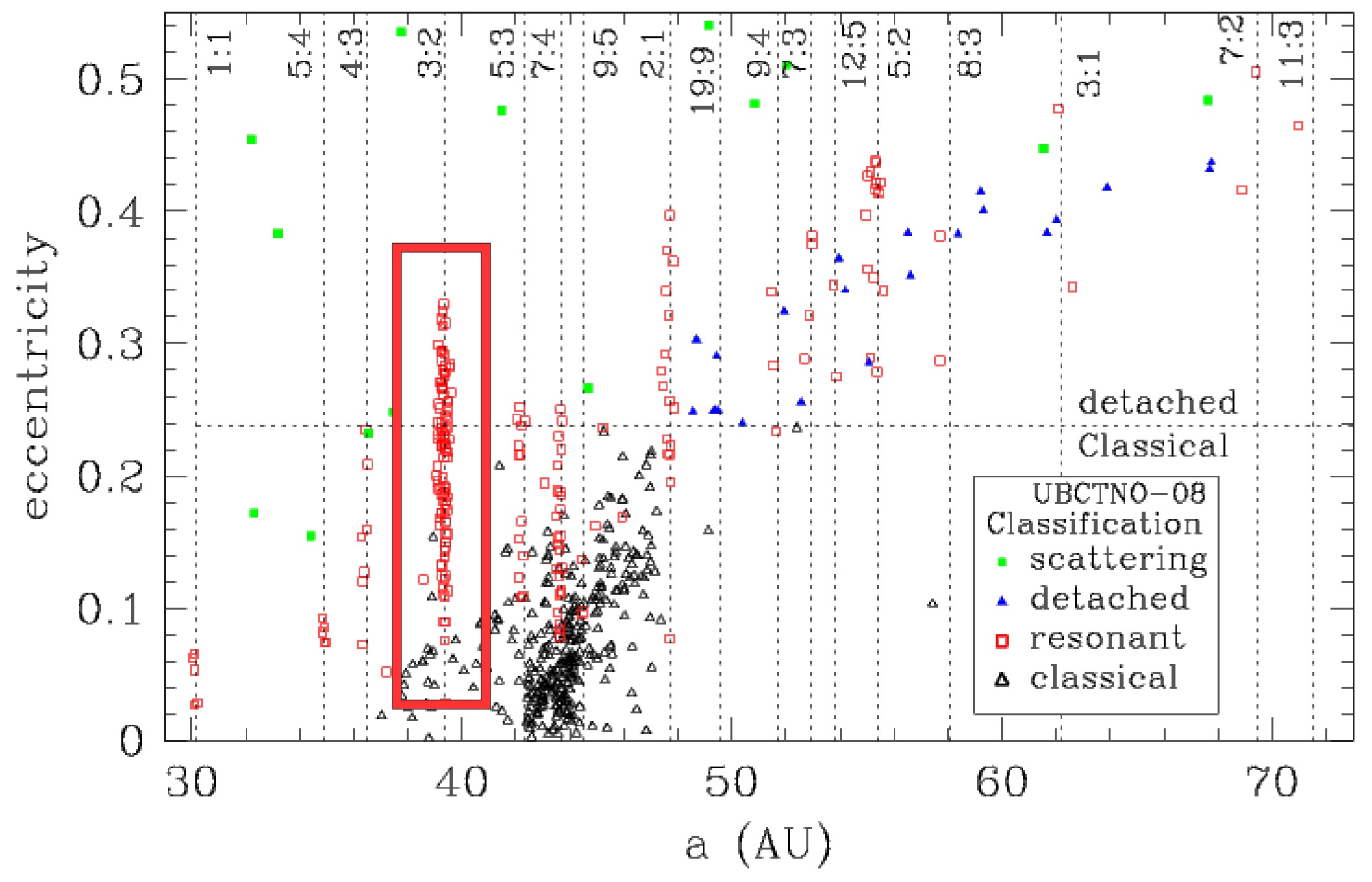
OSSOS Objectives

- Probe Kuiper Belt at interesting longitudes (resonant objects) at depths past what even LSST will achieve
- Use detected outer Solar System objects to constrain planet formation/migration via:
  - Orbits
  - Physical properties (sizes, colours, binarity, etc)
- A factor of >4 increase of *high-precision, well-characterized orbits*
  - That means targets discovered in calibrated conditions and tracked to high-precision orbits

A complex orbital structure

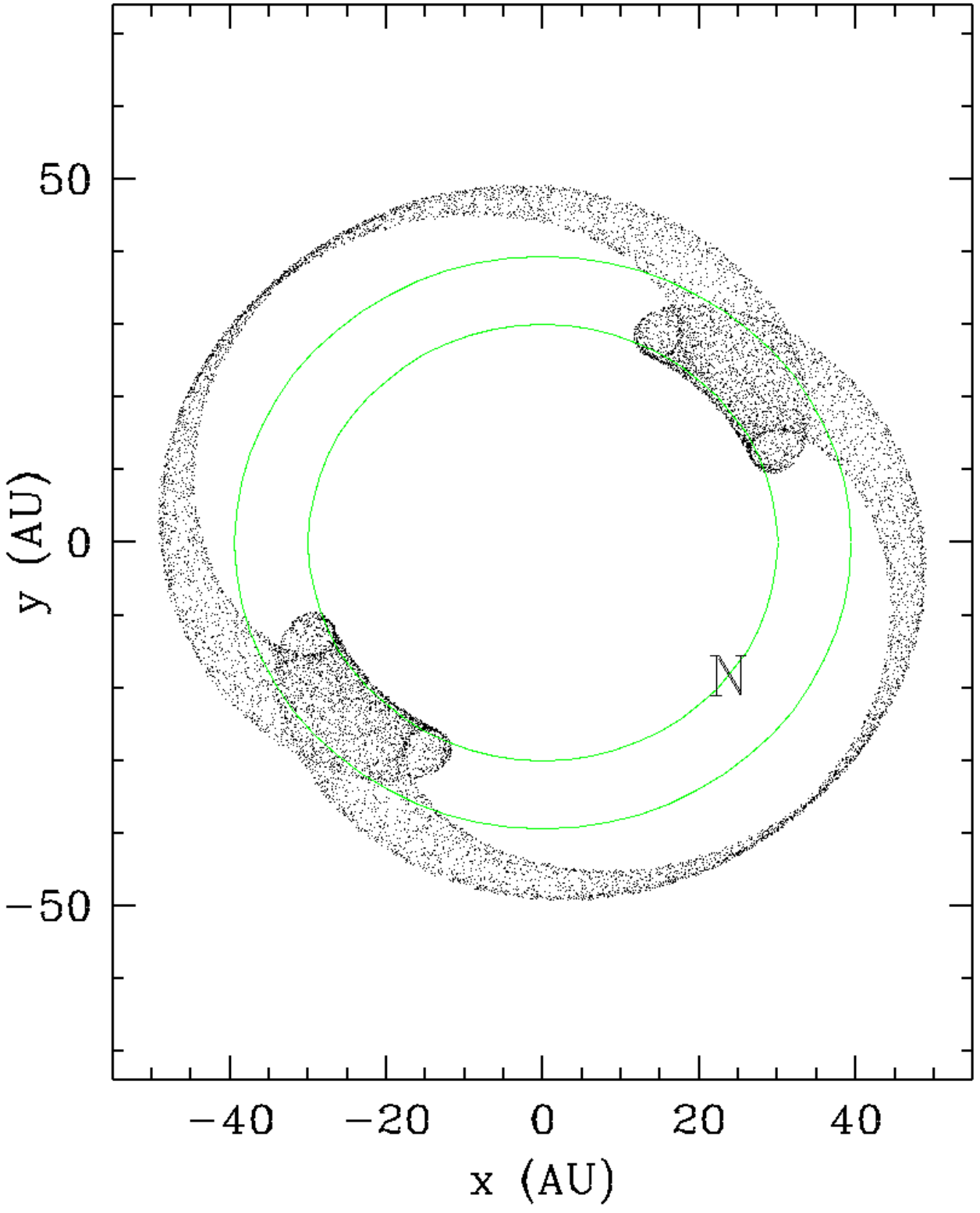


A complex orbital structure

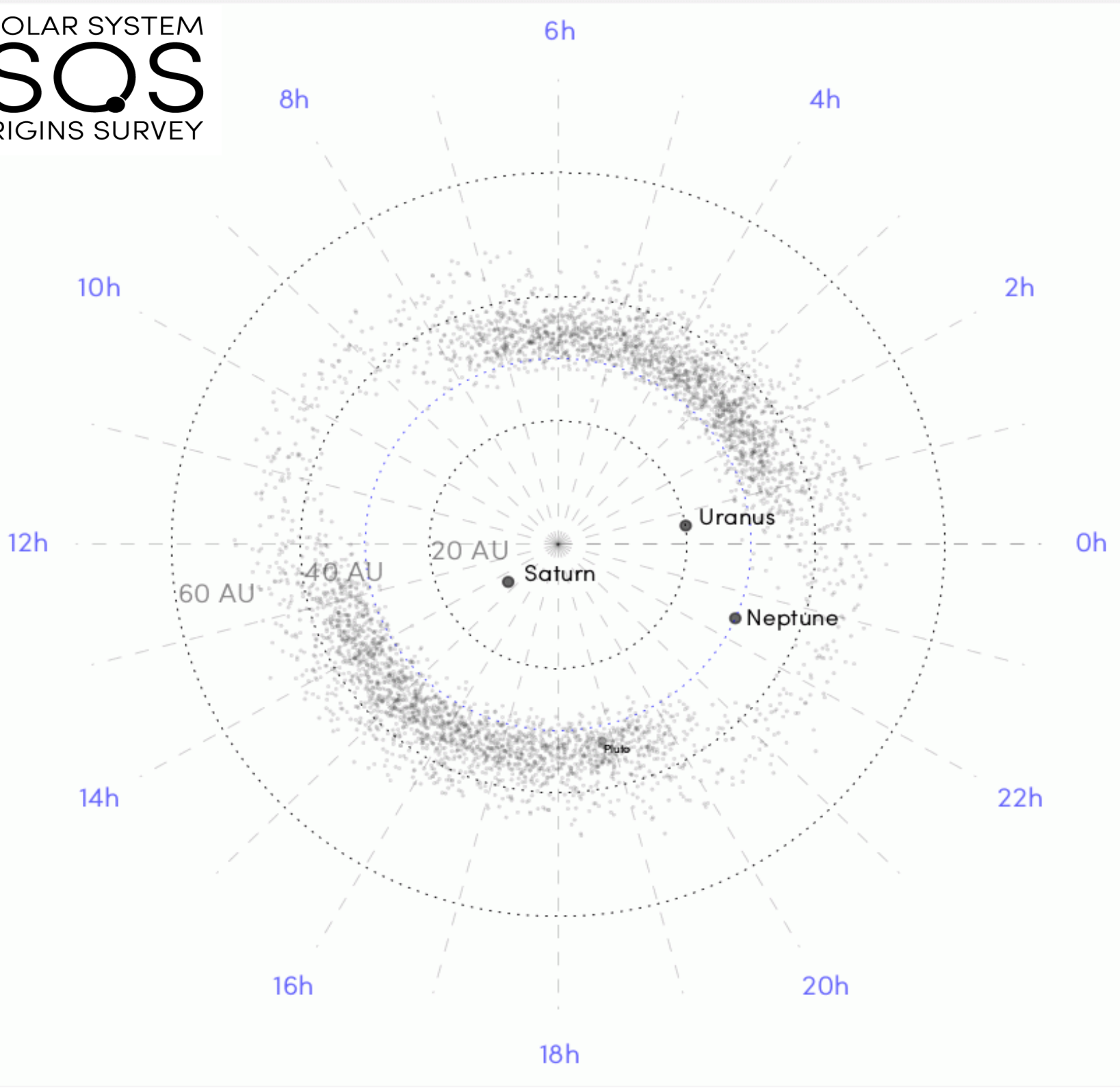


Resonance libration

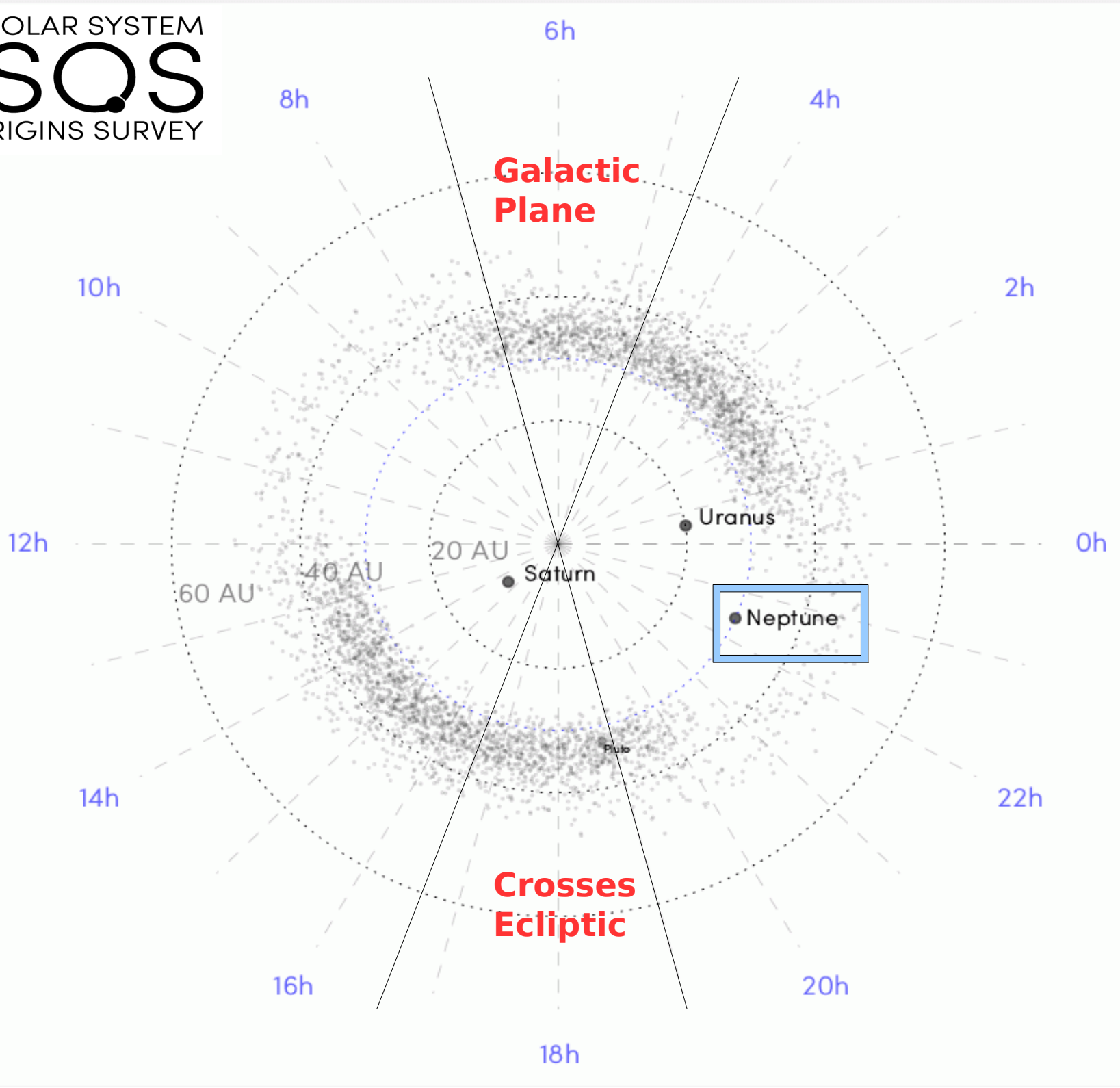
- The resonance locking results in the a specific object (over many orbits) avoiding Neptune

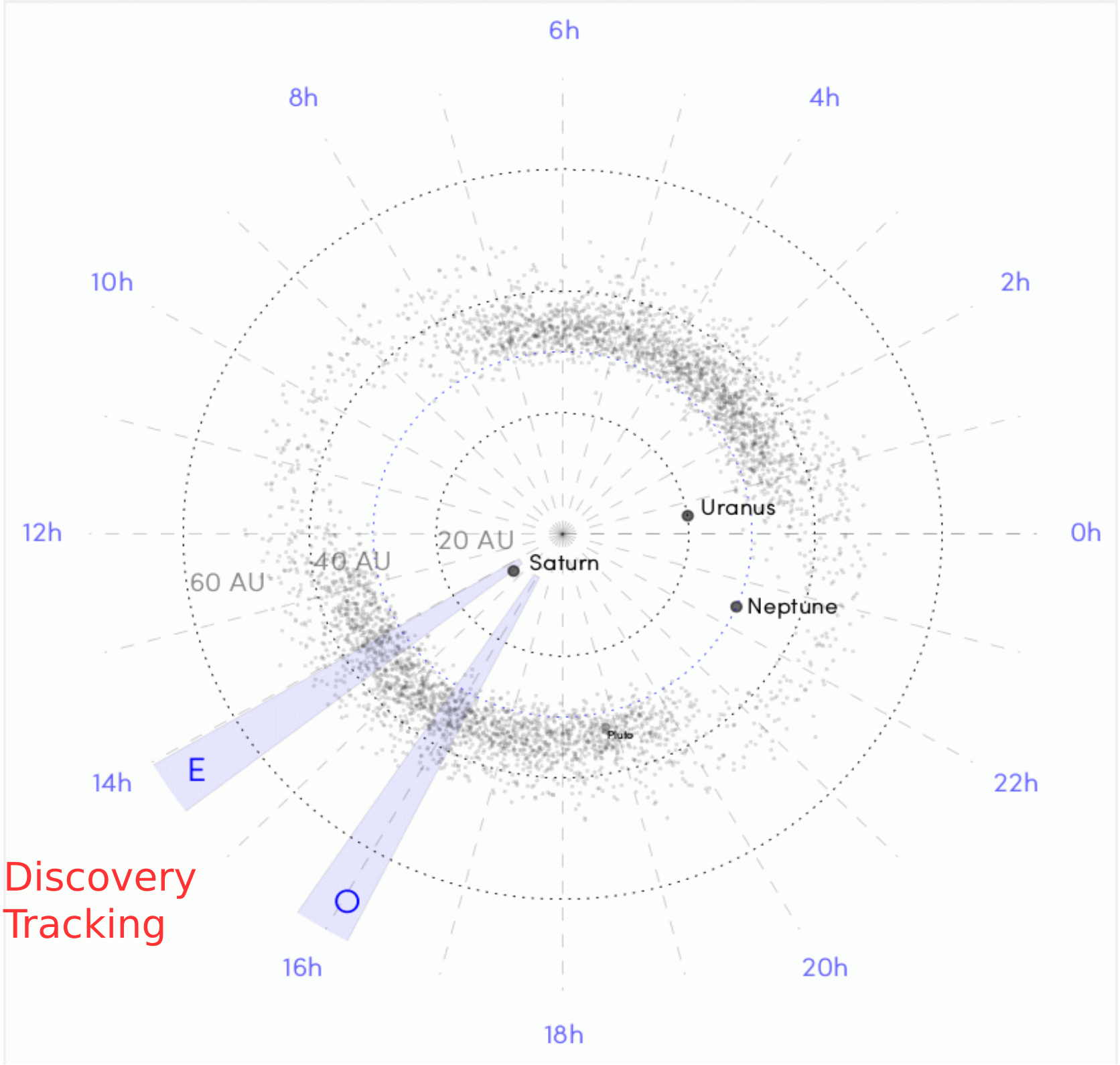


OUTER SOLAR SYSTEM
OSSOS
ORIGINS SURVEY

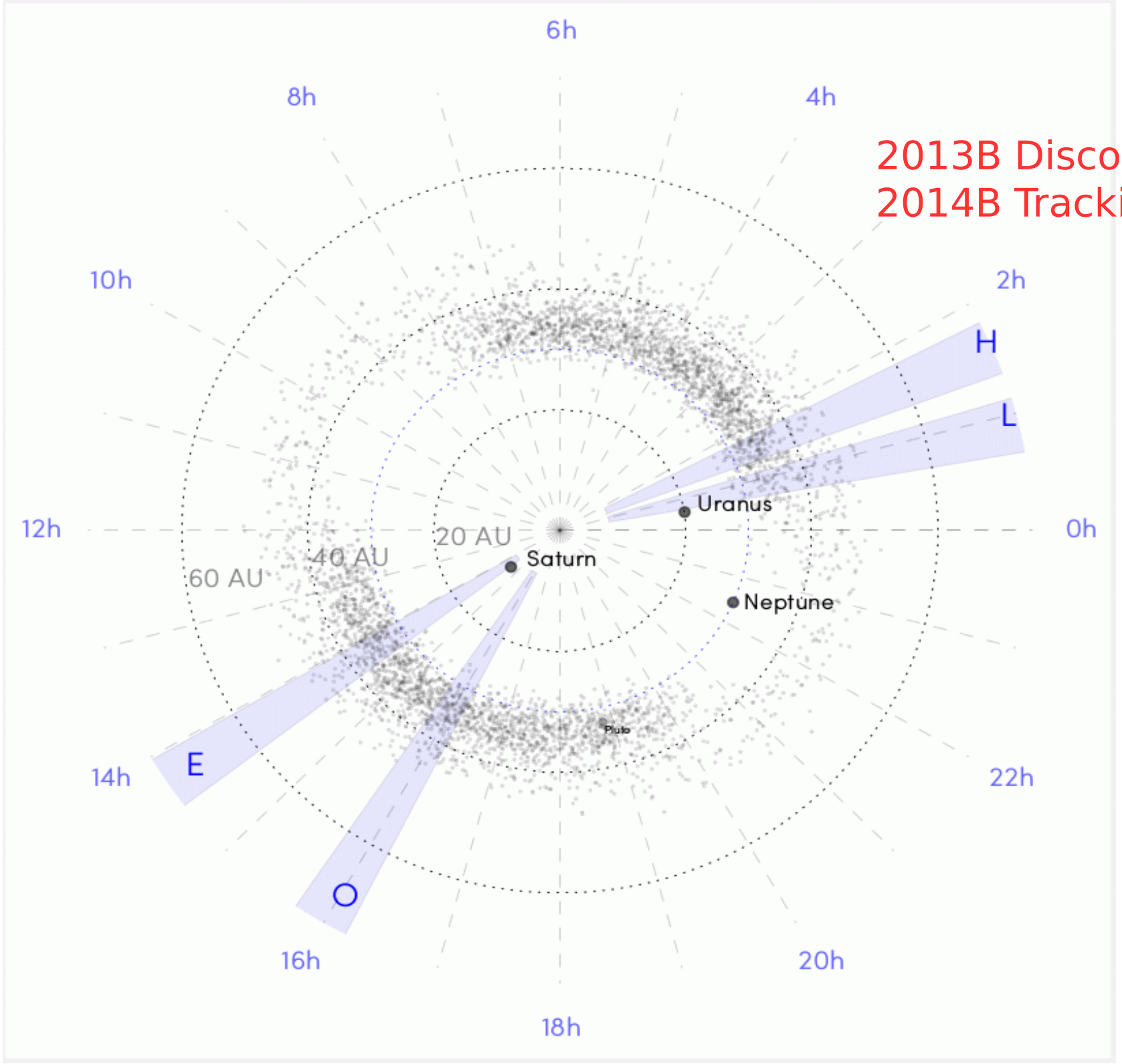


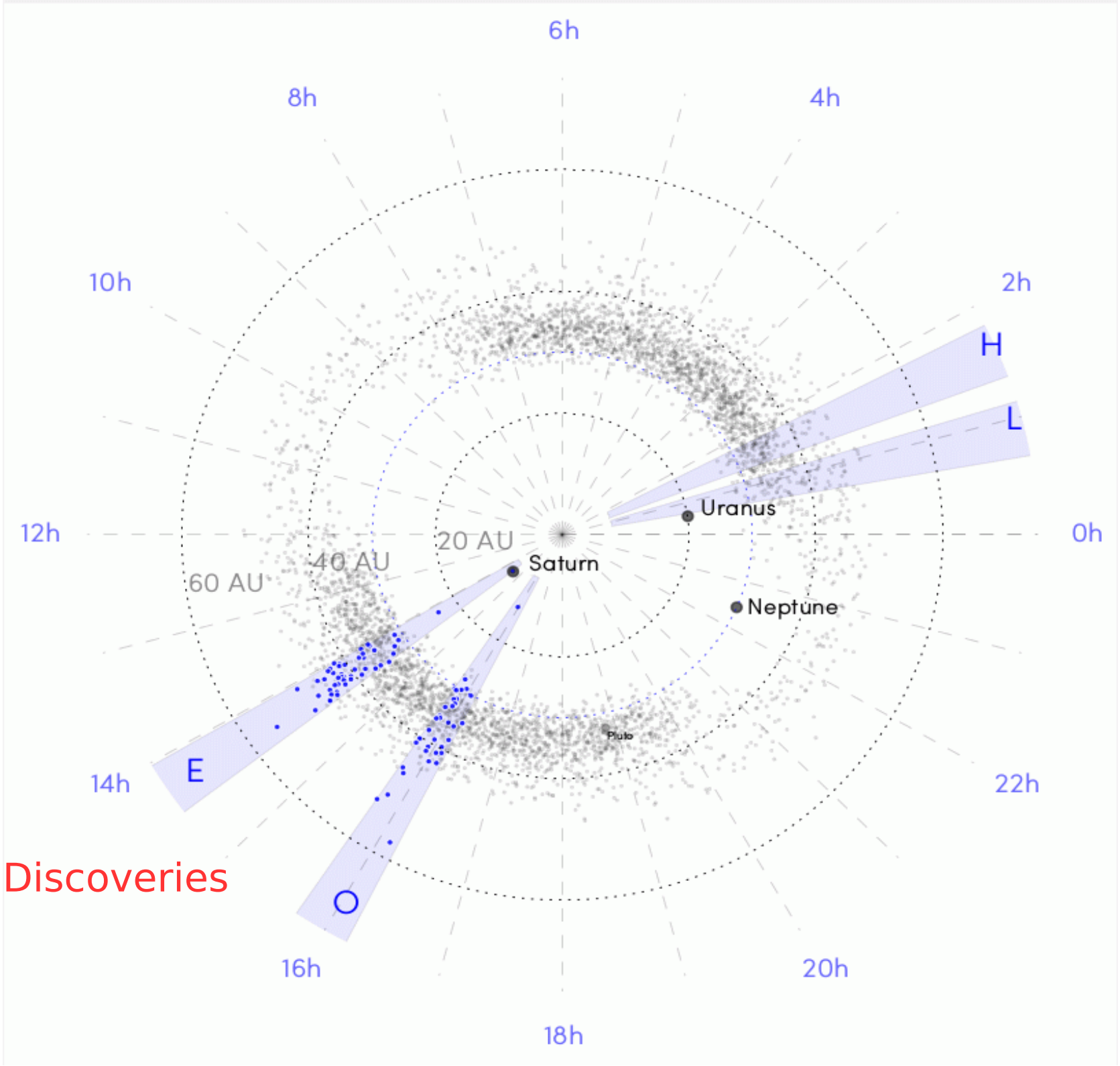
OUTER SOLAR SYSTEM
OSSOS
ORIGINS SURVEY



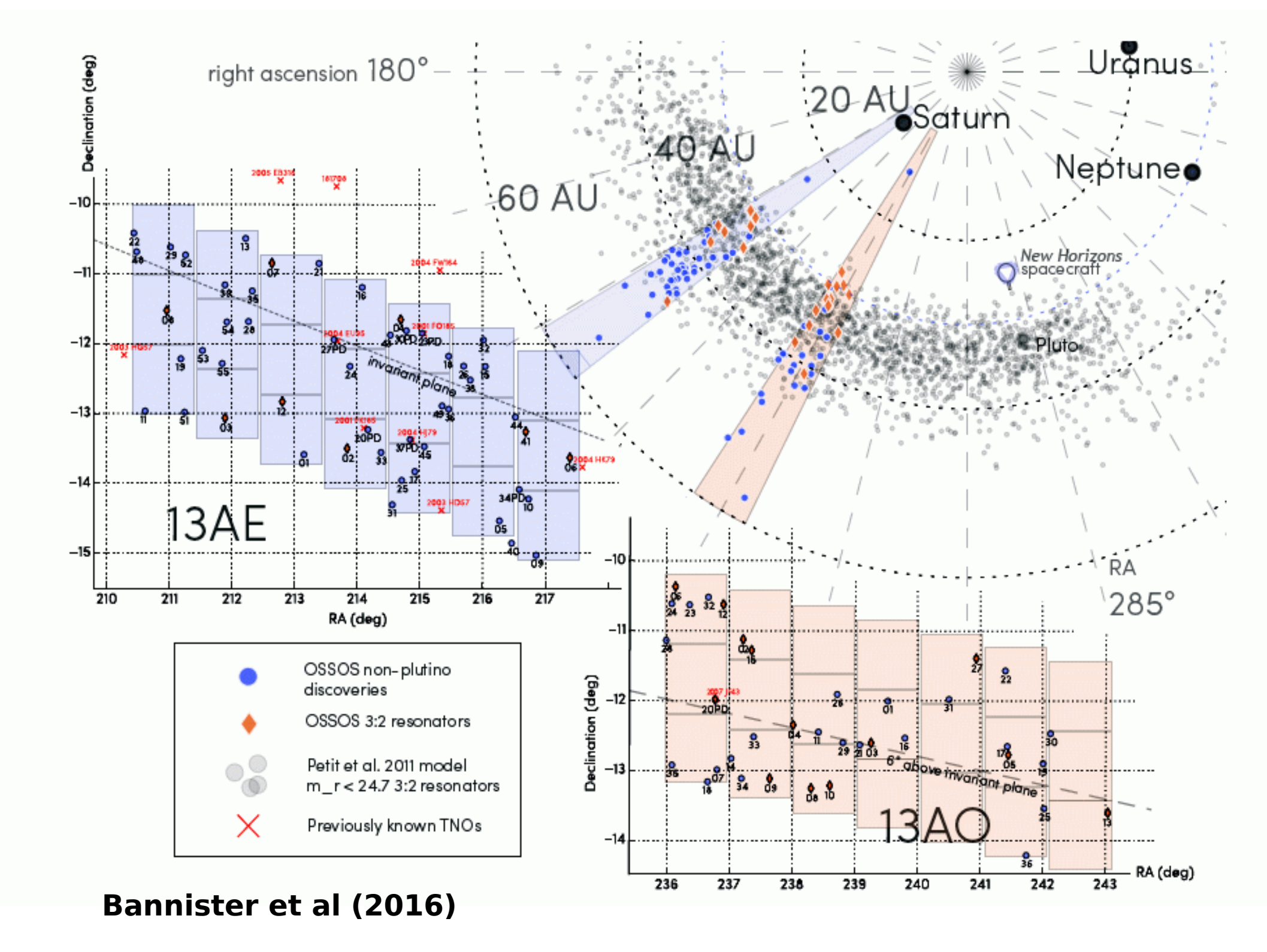


2013A Discovery
2014A Tracking

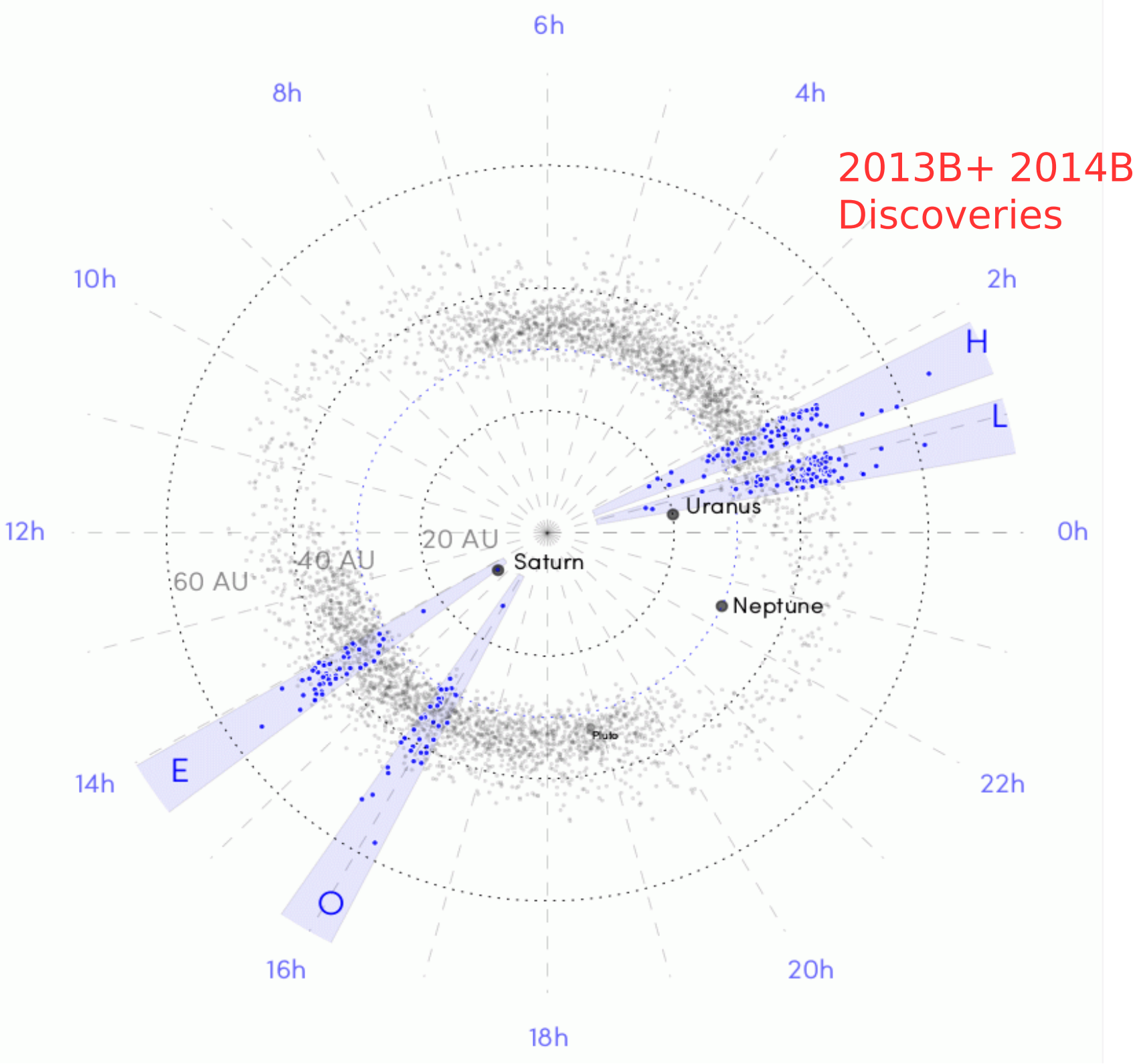

2013B Discovery
2014B Tracking
6h
8h
4h
10h
2h
12h
0h
14h
22h
16h
20h
18h
20 AU
40 AU
60 AU
Uranus
Saturn
Neptune
Pluto
H
L
E
O

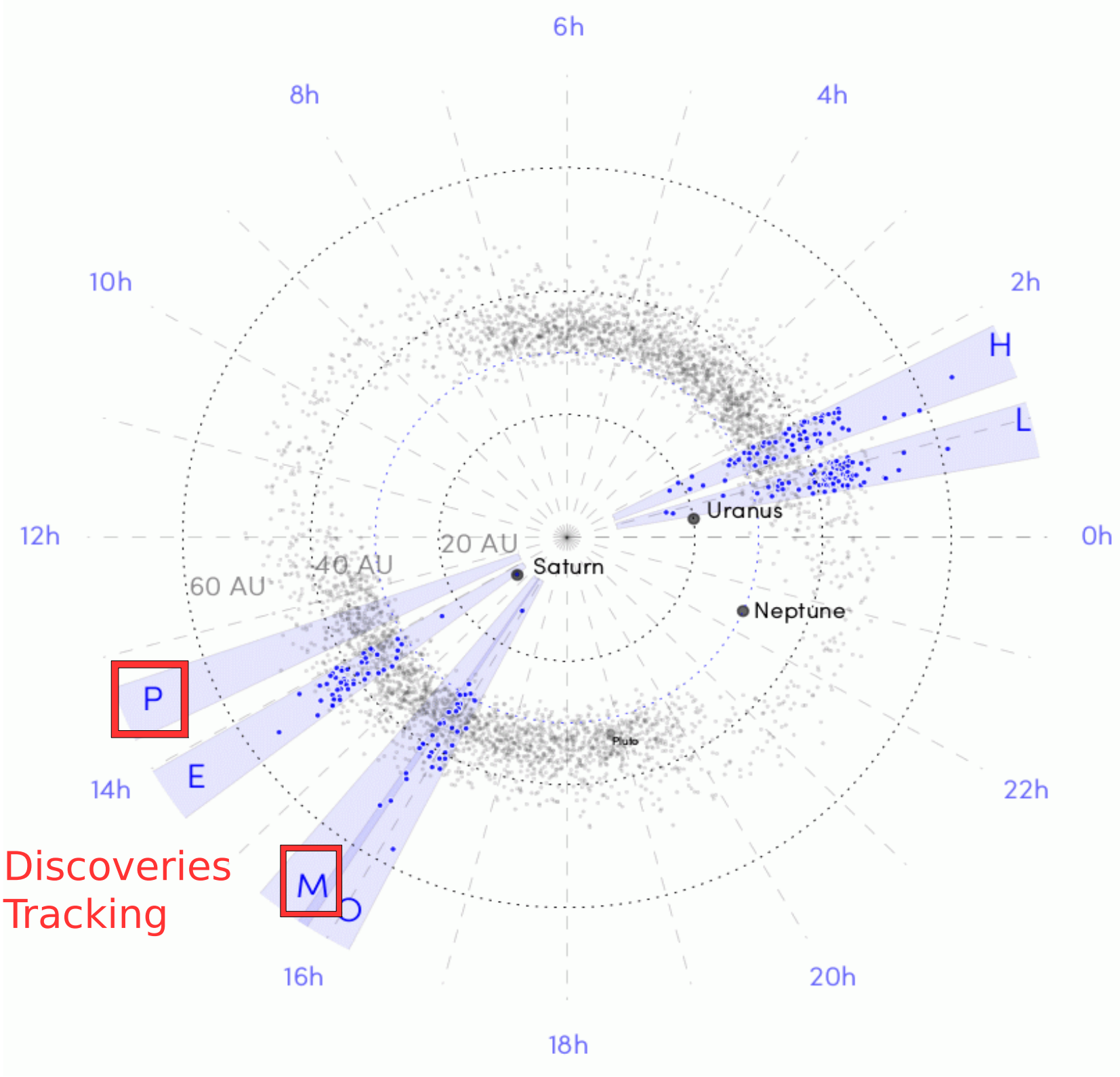


2013A Discoveries

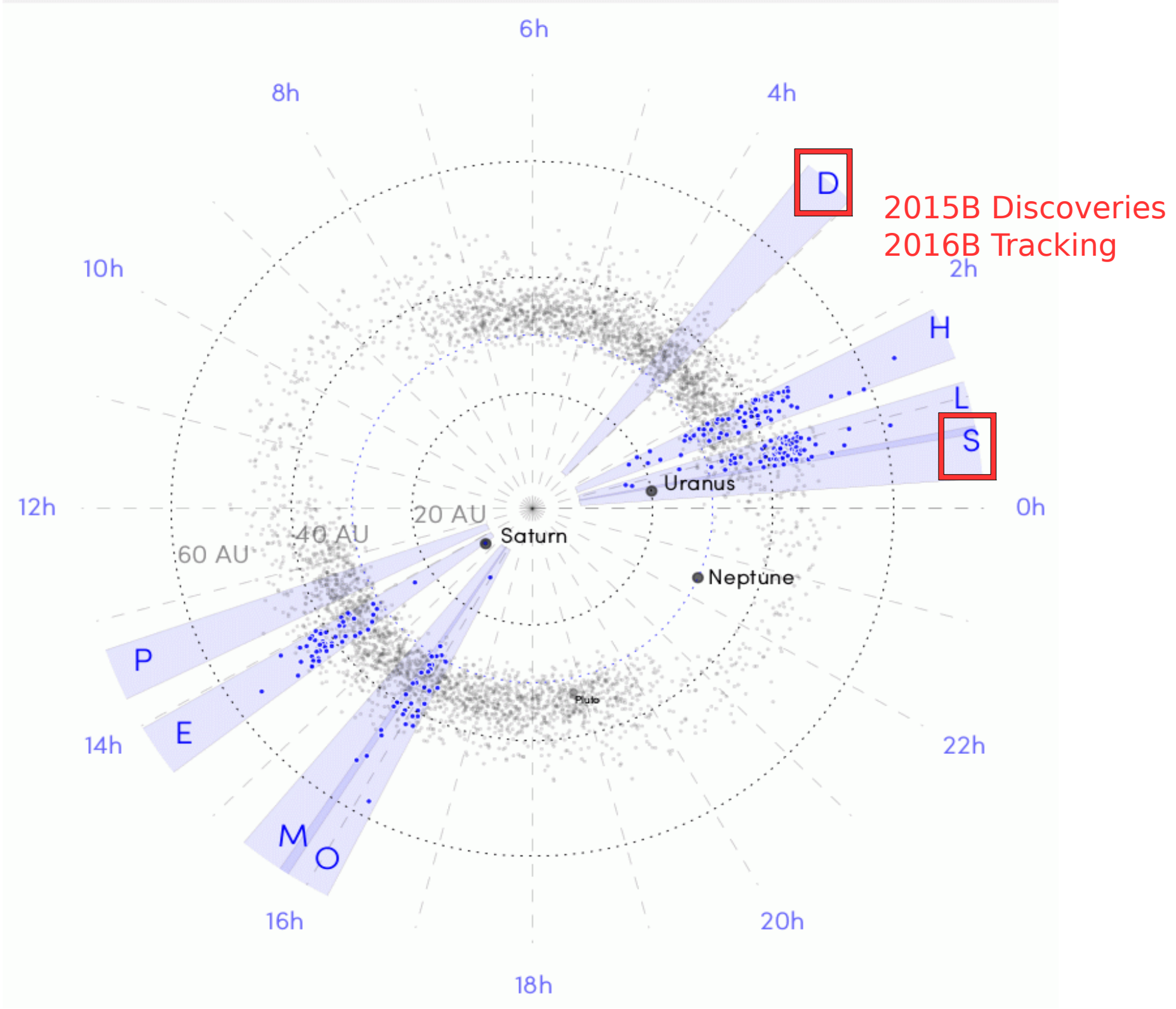


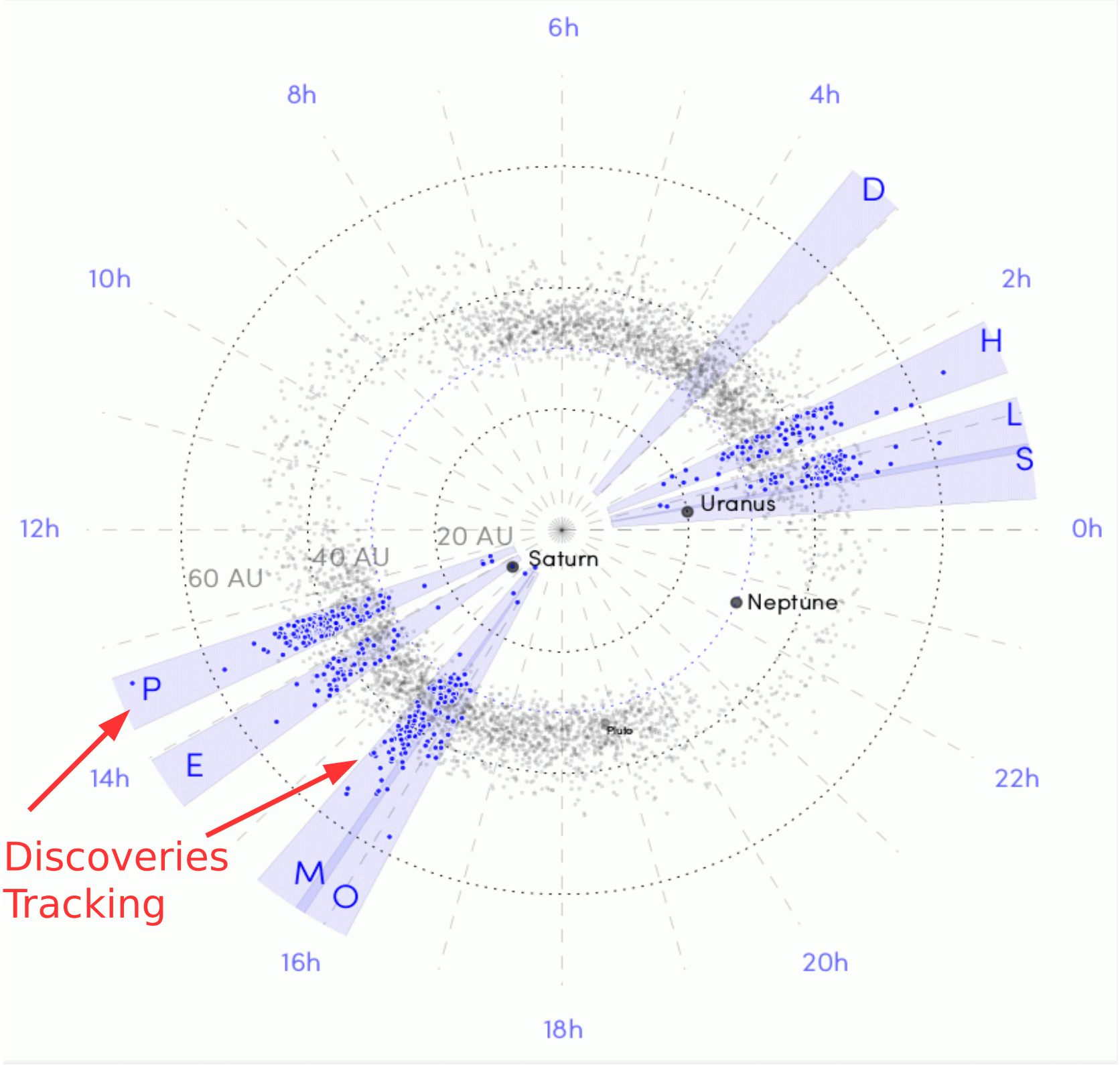
Bannister et al (2016)

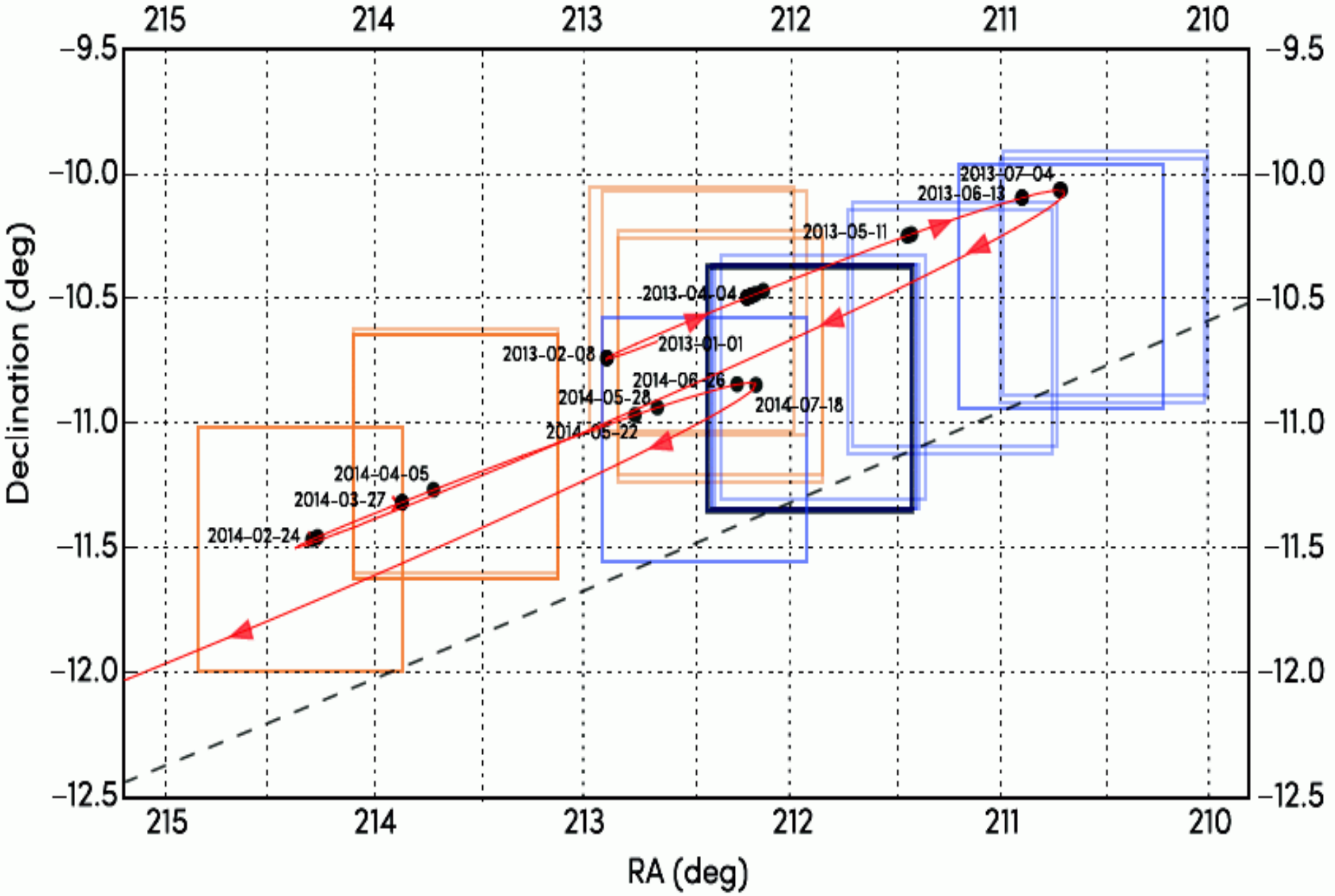

2013B+ 2014B
Discoveries
6h
8h
4h
10h
2h
12h
0h
14h
22h
16h
20h
18h
20 AU
40 AU
60 AU
Saturn
Uranus
Neptune
Pluto
H
L
E
O

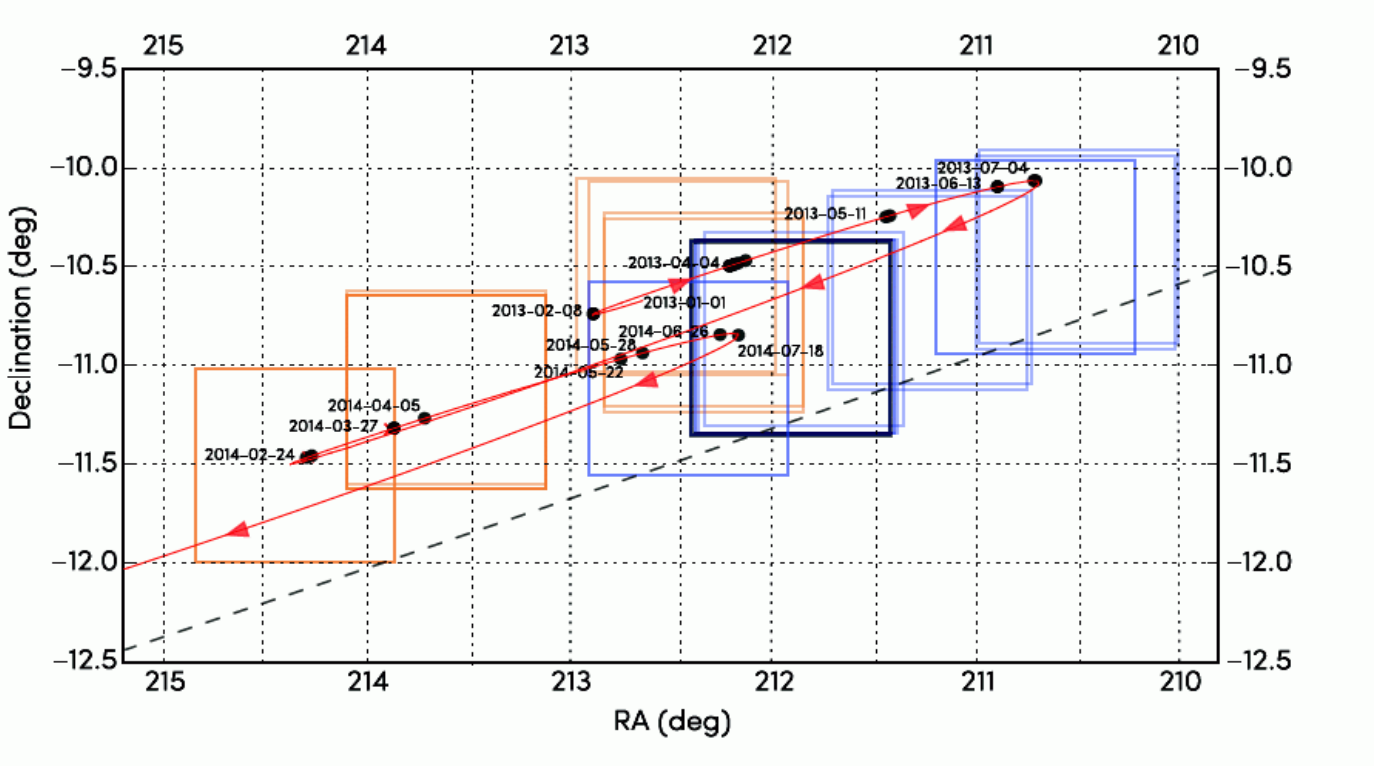


2015A Discoveries
2016A Tracking


6h
8h
4h
10h
2h
12h
0h
14h
22h
16h
20h
18h
D
H
L
S
P
E
M
O
2015B Discoveries
2016B Tracking
Uranus
Saturn
Neptune
Pluto
20 AU
40 AU
60 AU

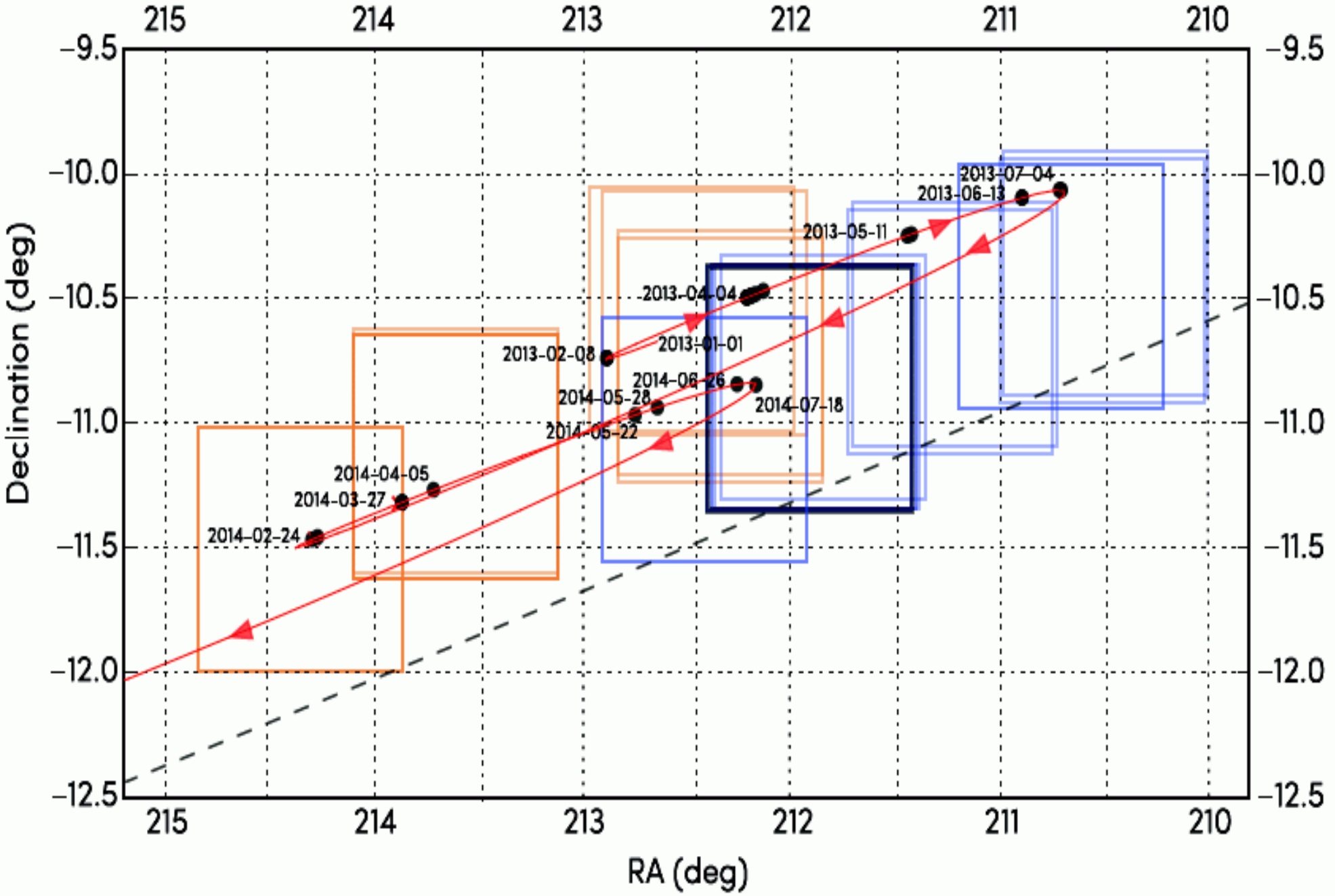

6h
8h
4h
10h
2h
12h
0h
14h
22h
16h
20h
18h
20 AU
40 AU
60 AU
Saturn
Uranus
Neptune
Pluto
D
H
L
S
P
E
M
O
2015A Discoveries
2016A Tracking

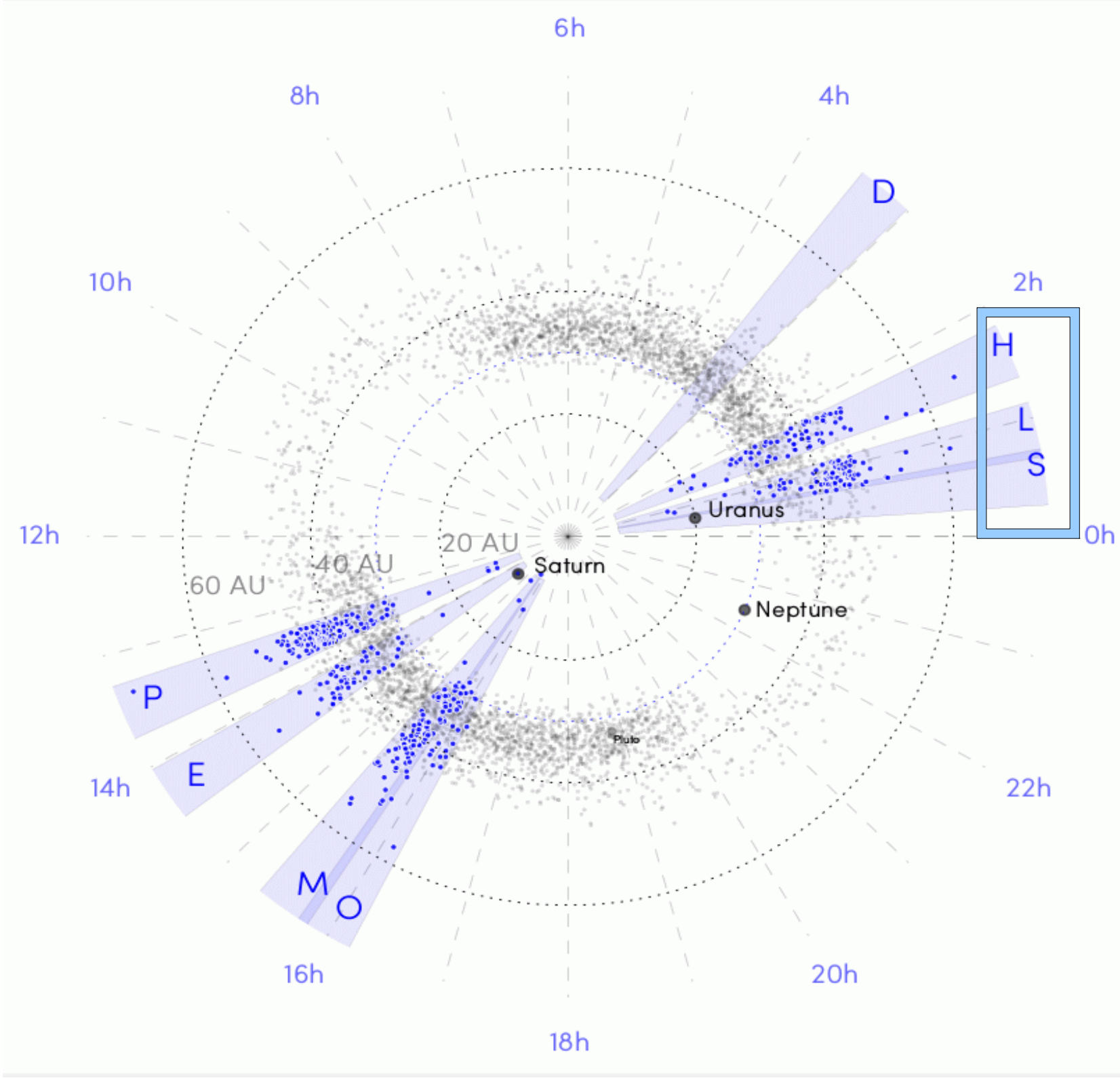

215
214
213
212
211
210
−9.5
−10.0
−10.5
−11.0
−11.5
−12.0
−12.5
Declination (deg)
RA (deg)
2013-07-04
2013-06-13
2013-05-11
2013-04-04
2013-01-01
2013-02-08
2014-06-26
2014-05-28
2014-05-22
2014-07-18
2014-04-05
2014-03-27
2014-02-24

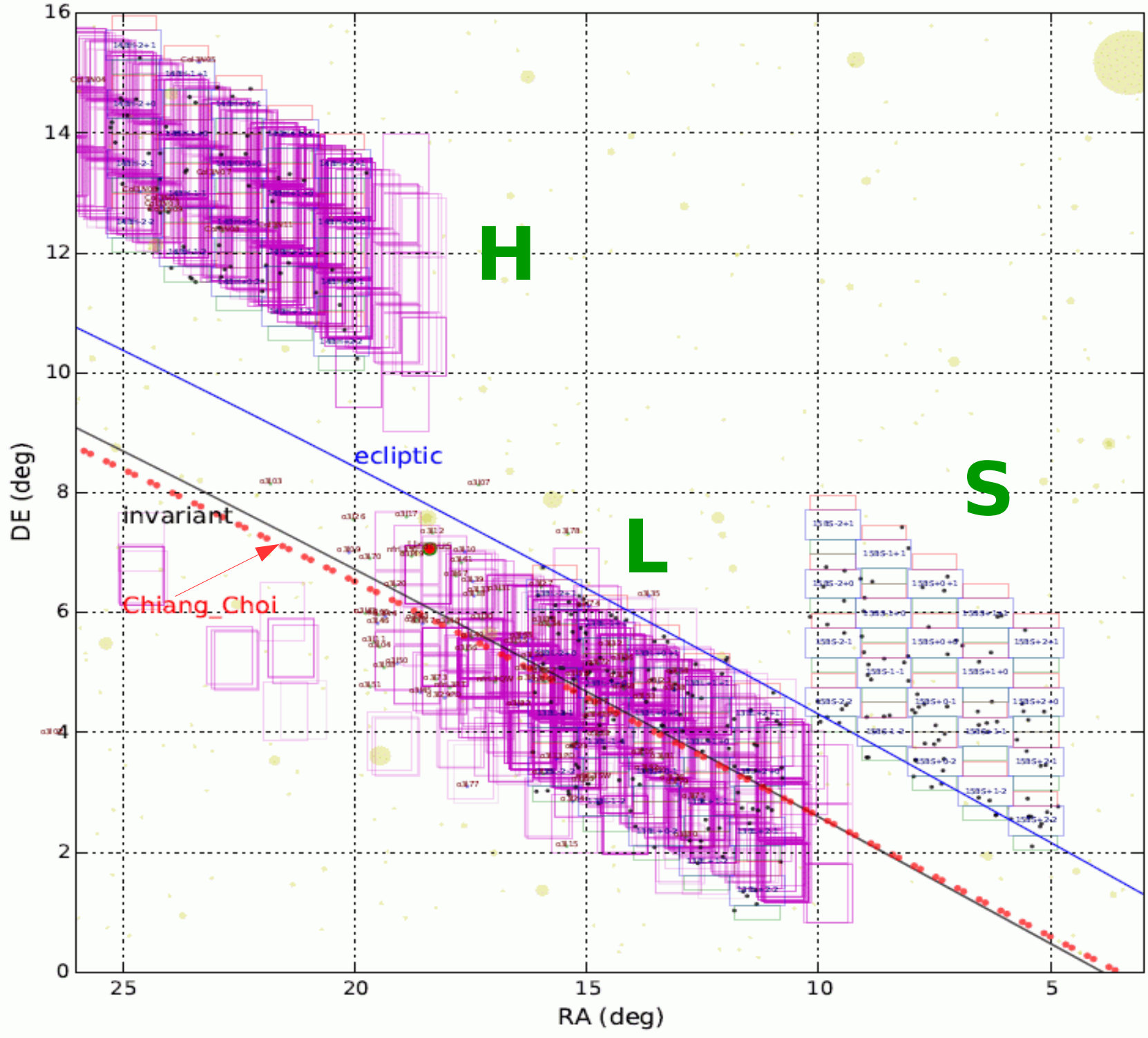


OSSOS Data acquisition Strategy

- Discovery year
  - Blind pointings shearing at mean on-sky rate of Kuiper Belt
  - Critical 'discovery triple' in opposition dark run
- Tracking year
  - Hand-chosen recovery pointings

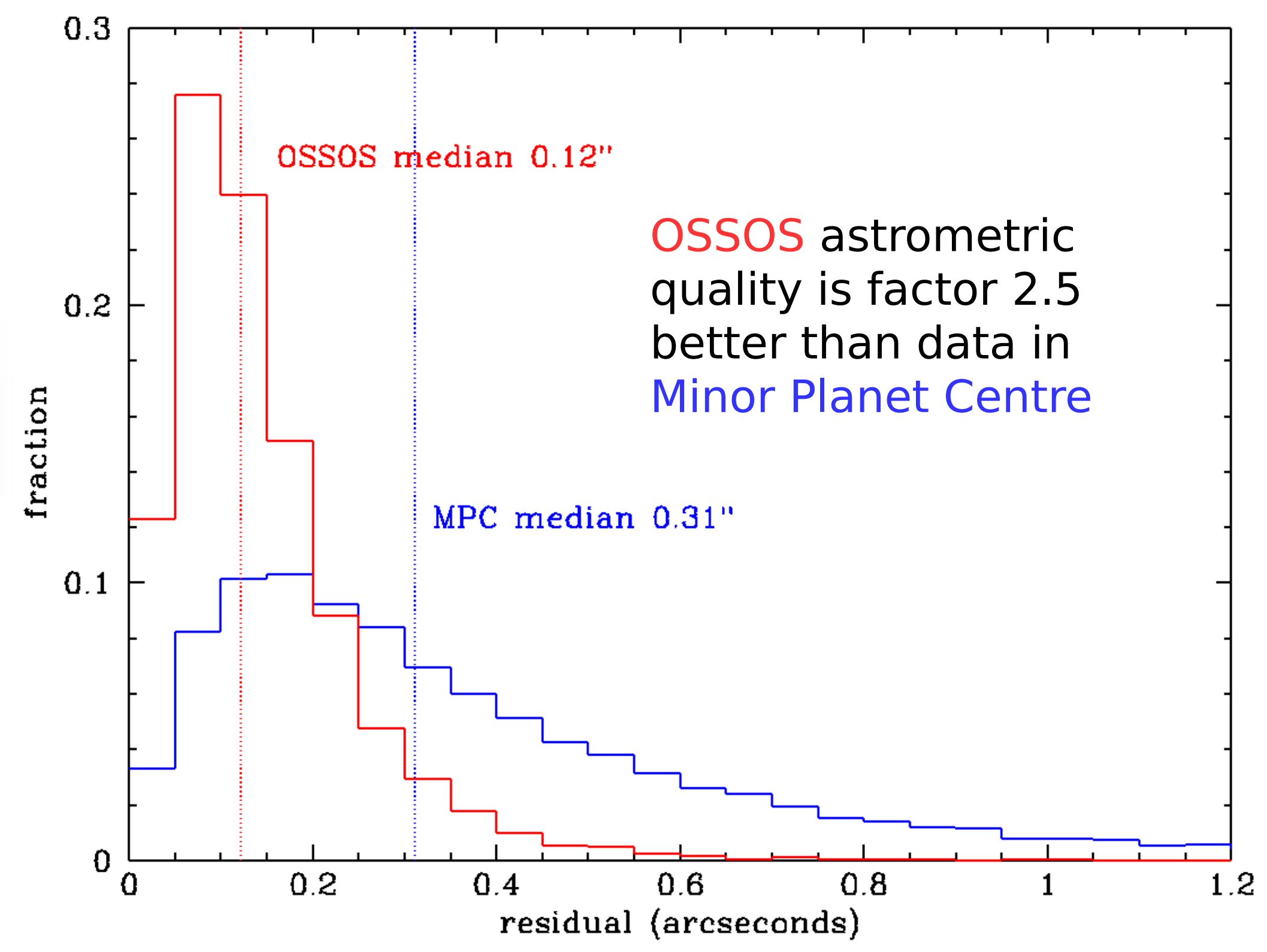

215
214
213
212
211
210
−9.5
−10.0
−10.5
−11.0
−11.5
−12.0
−12.5
Declination (deg)
RA (deg)
2013-07-04
2013-06-13
2013-05-11
2013-04-04
2013-01-01
2013-02-08
2014-06-26
2014-05-28
2014-05-22
2014-07-18
2014-04-05
2014-03-27
2014-02-24

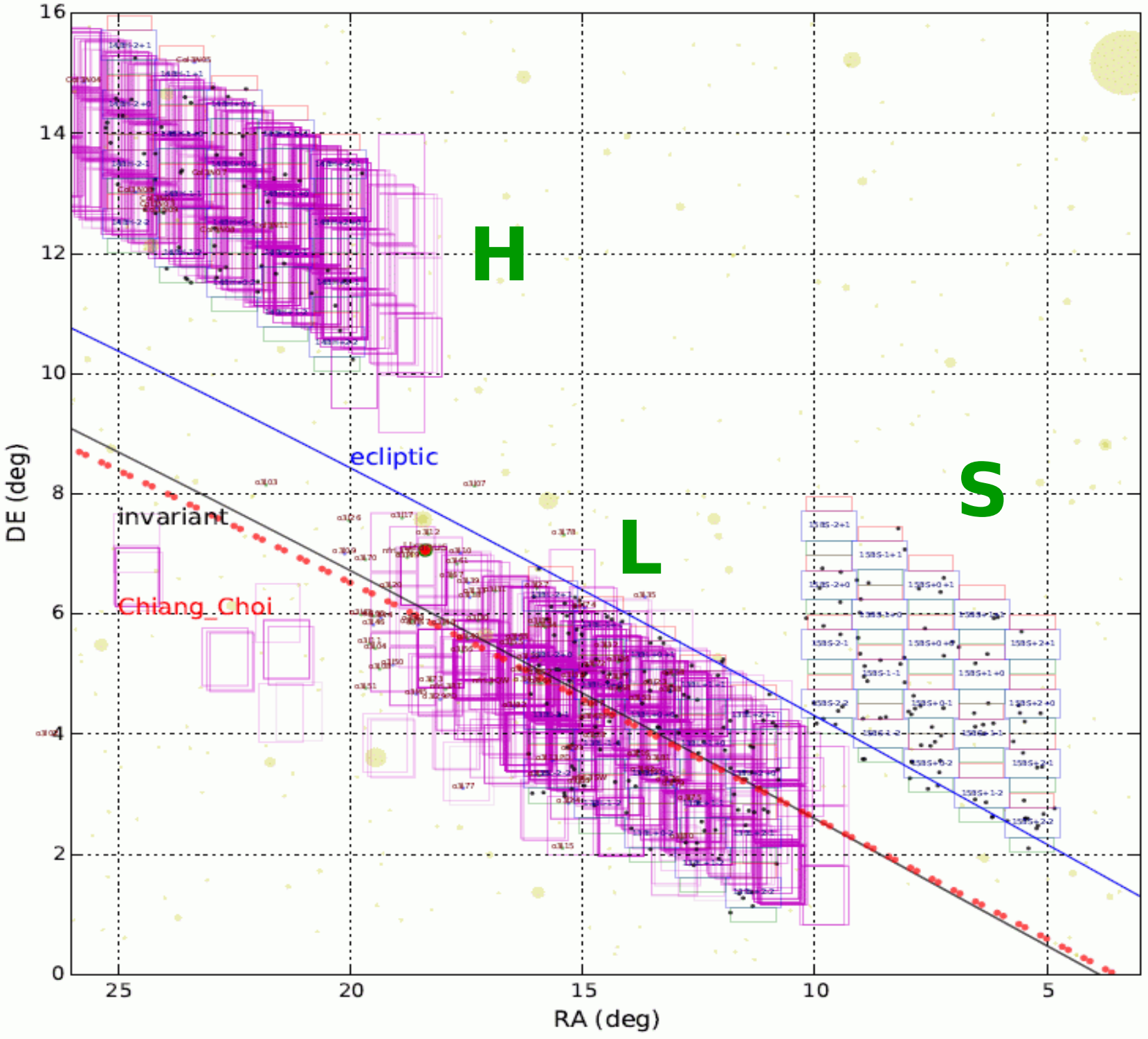

6h
8h
4h
10h
2h
12h
0h
14h
22h
16h
20h
18h
D
H
L
S
Uranus
20 AU
40 AU
60 AU
Saturn
Neptune
Pluto
P
E
M
O

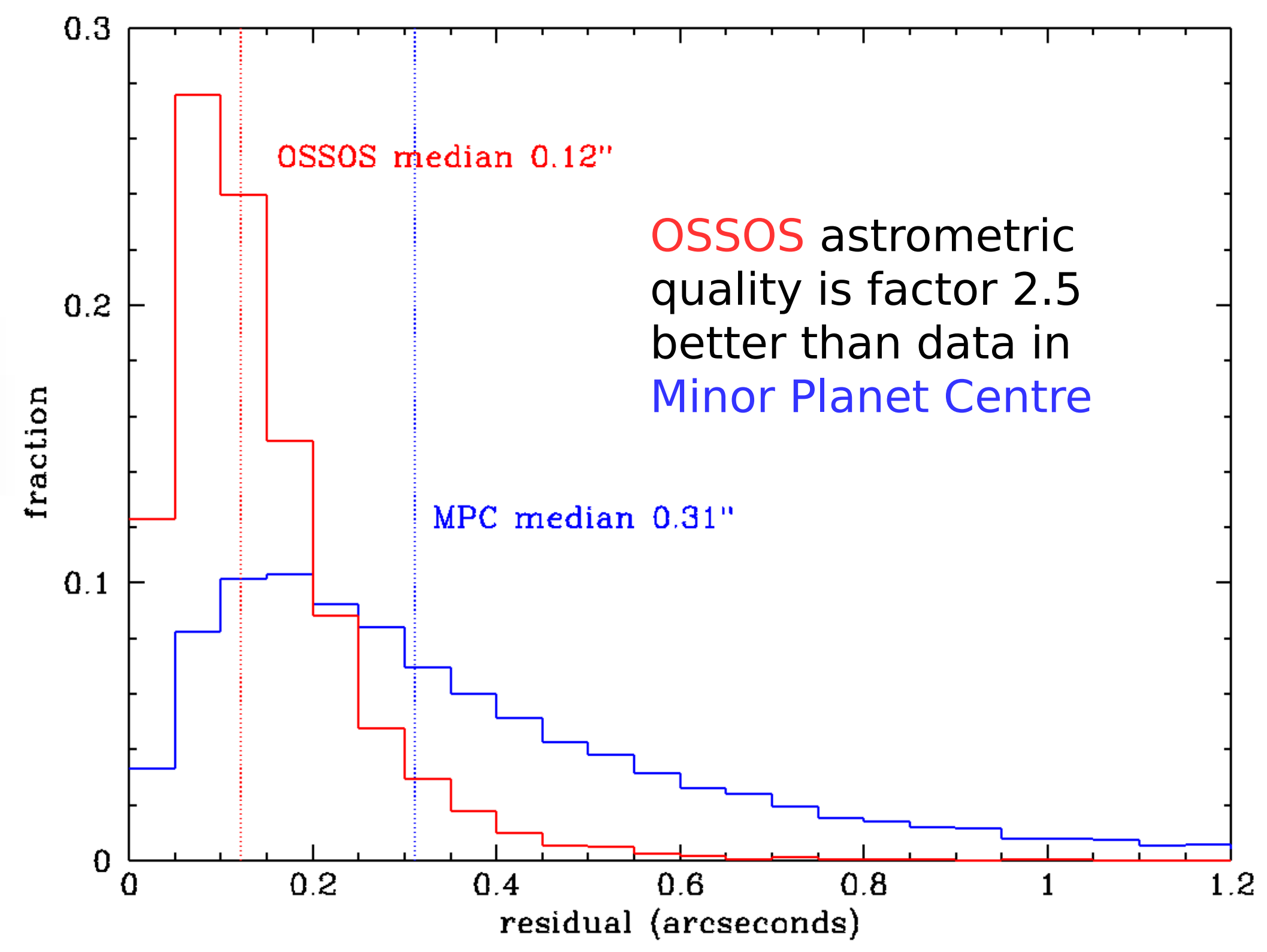

H
L
S
ecliptic
invariant
Chiang_Choi
DE (deg)
RA (deg)
16
14
12
10
8
6
4
2
0
25
20
15
10
5

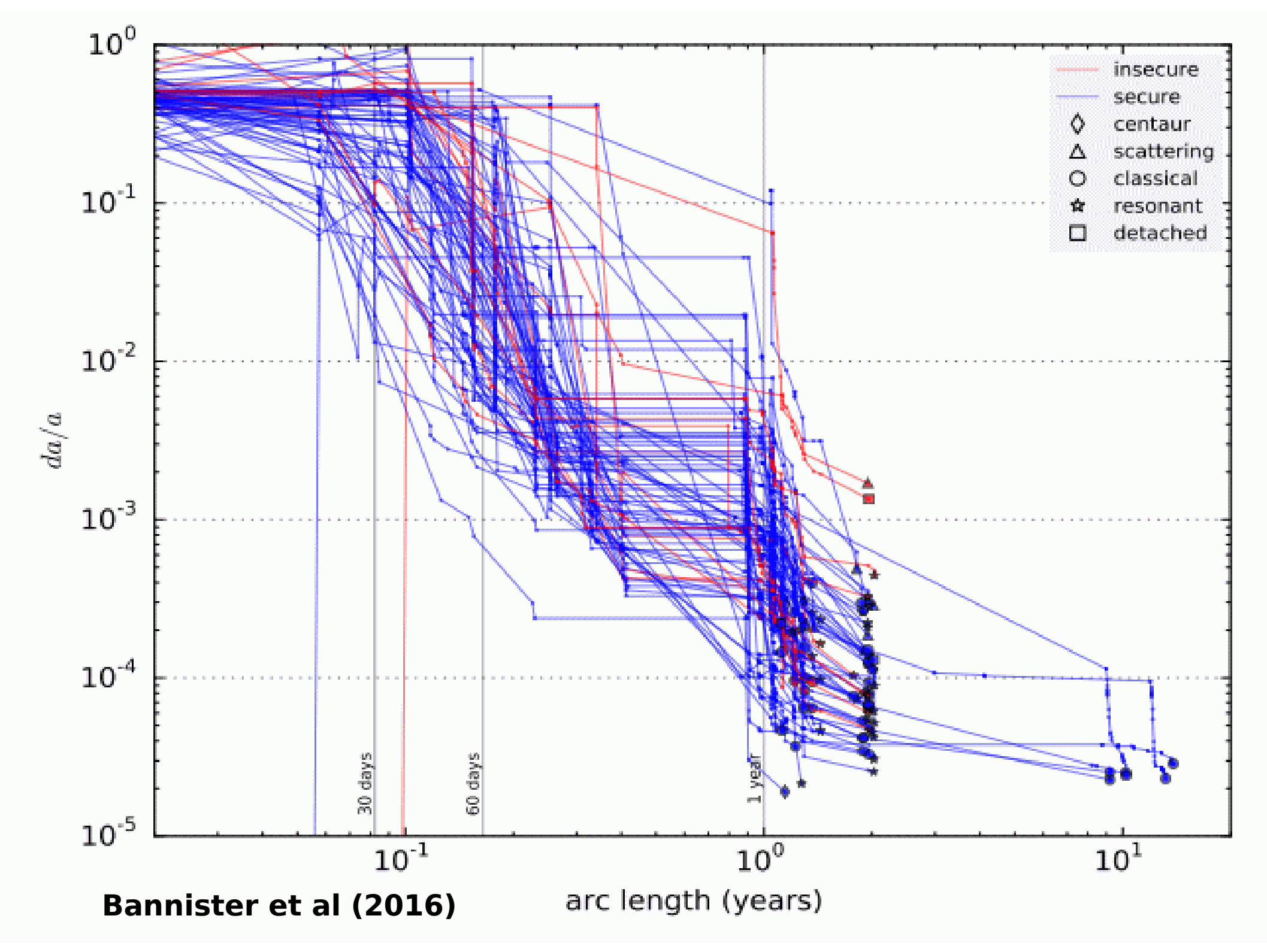
ONLY CFHT can do this!

- Combination of:
- Queue scheduled observations
- Queue programming is responsive/flexible
- Ephemeris targeting is implemented
- Seeing-dependent exposure times for tracking observations permitted
- Priority needed for time constrained observations is provided by QSO+ranking
  - RESULT: HIGH QUALITY ORBITS

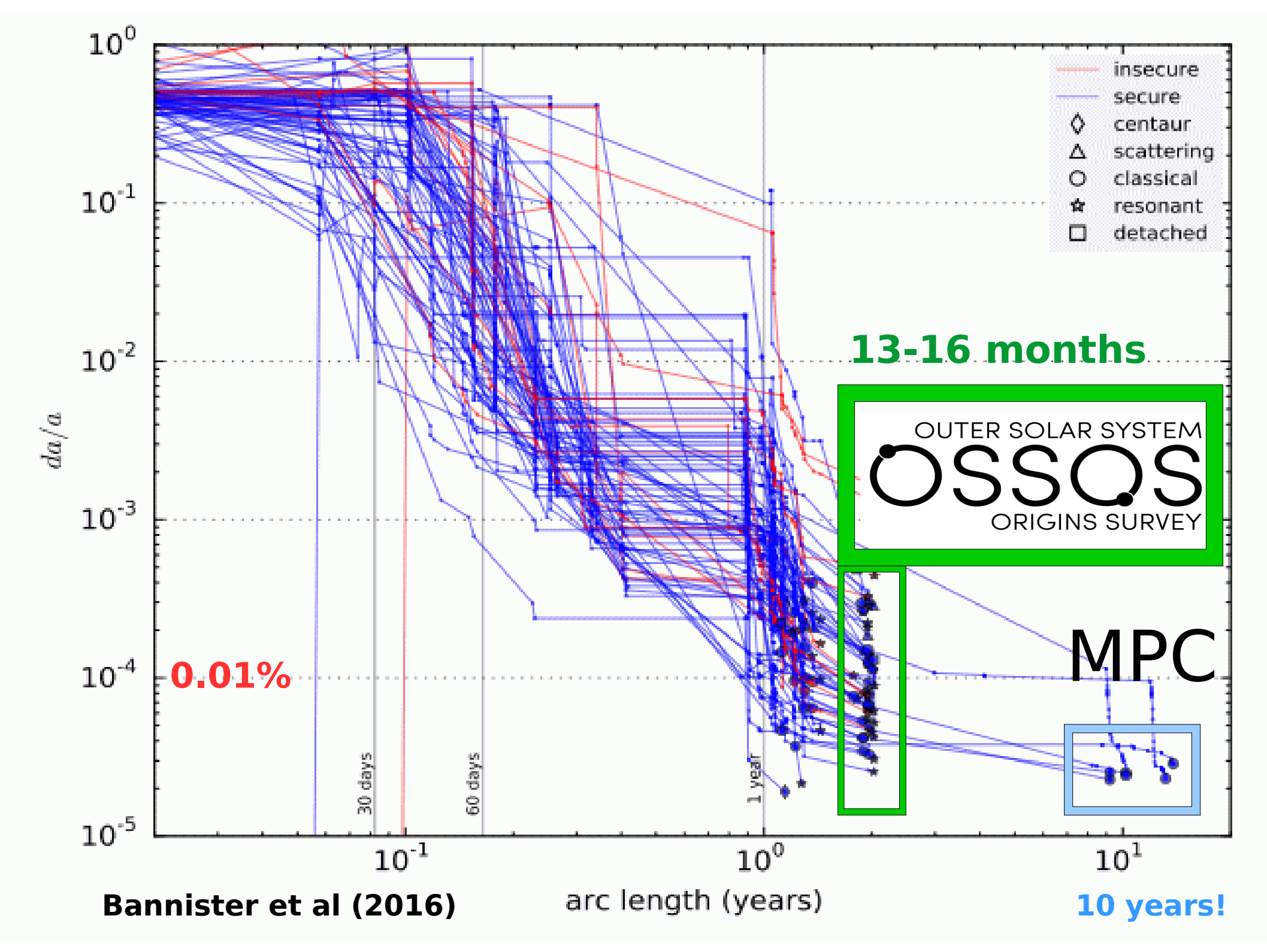

0.3
0.2
0.1
0
fraction
OSSOS median 0.12"
MPC median 0.31"
OSSOS astrometric quality is factor 2.5 better than data in Minor Planet Centre
0
0.2
0.4
0.6
0.8
1
1.2
residual (arcseconds)


H
L
S
ecliptic
invariant
Chiang_Choi
DE (deg)
RA (deg)
16
14
12
10
8
6
4
2
0
25
20
15
10
5


0.3
0.2
0.1
0
fraction
OSSOS median 0.12"
MPC median 0.31"
OSSOS astrometric quality is factor 2.5 better than data in Minor Planet Centre
0
0.2
0.4
0.6
0.8
1
1.2
residual (arcseconds)

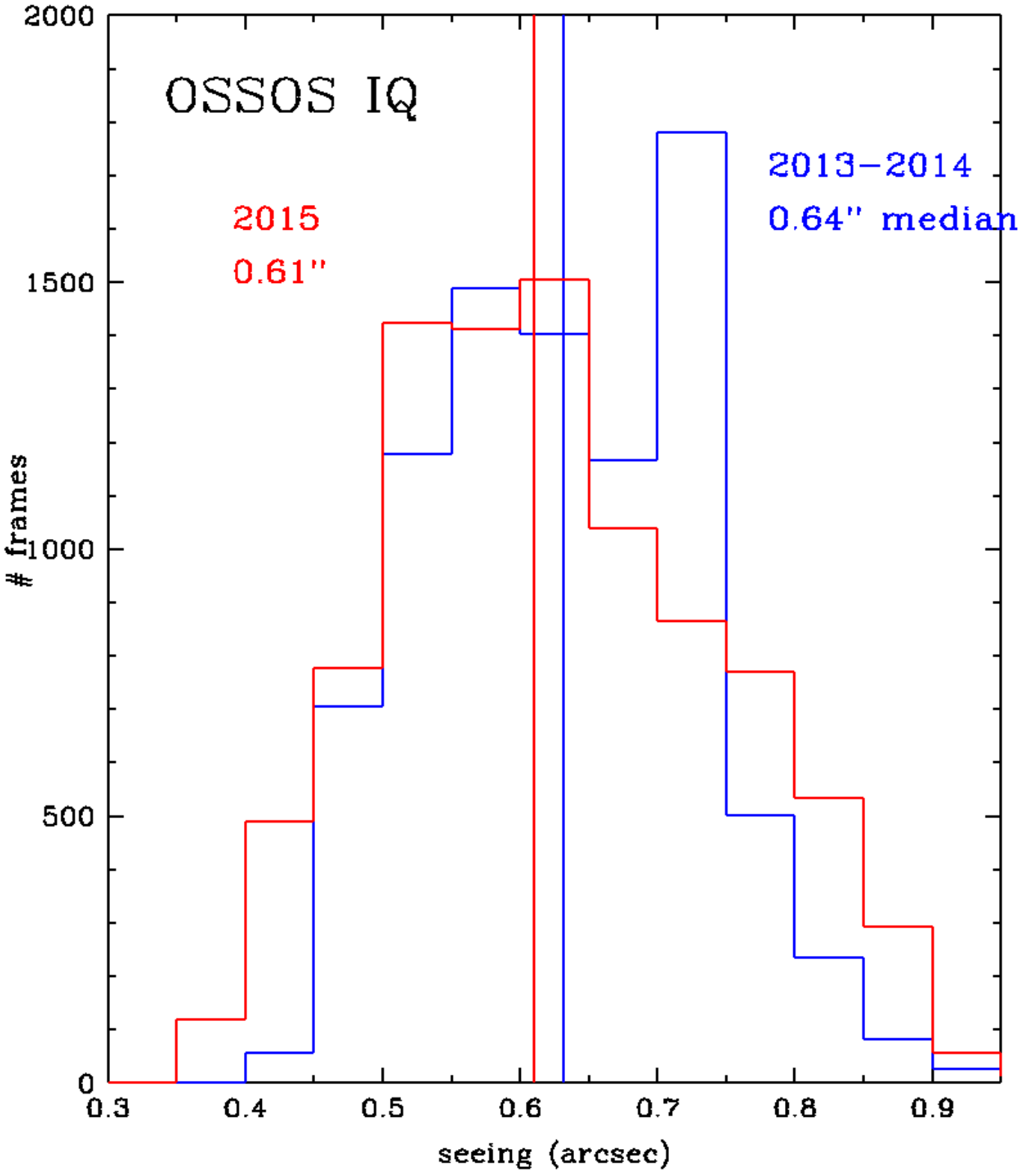


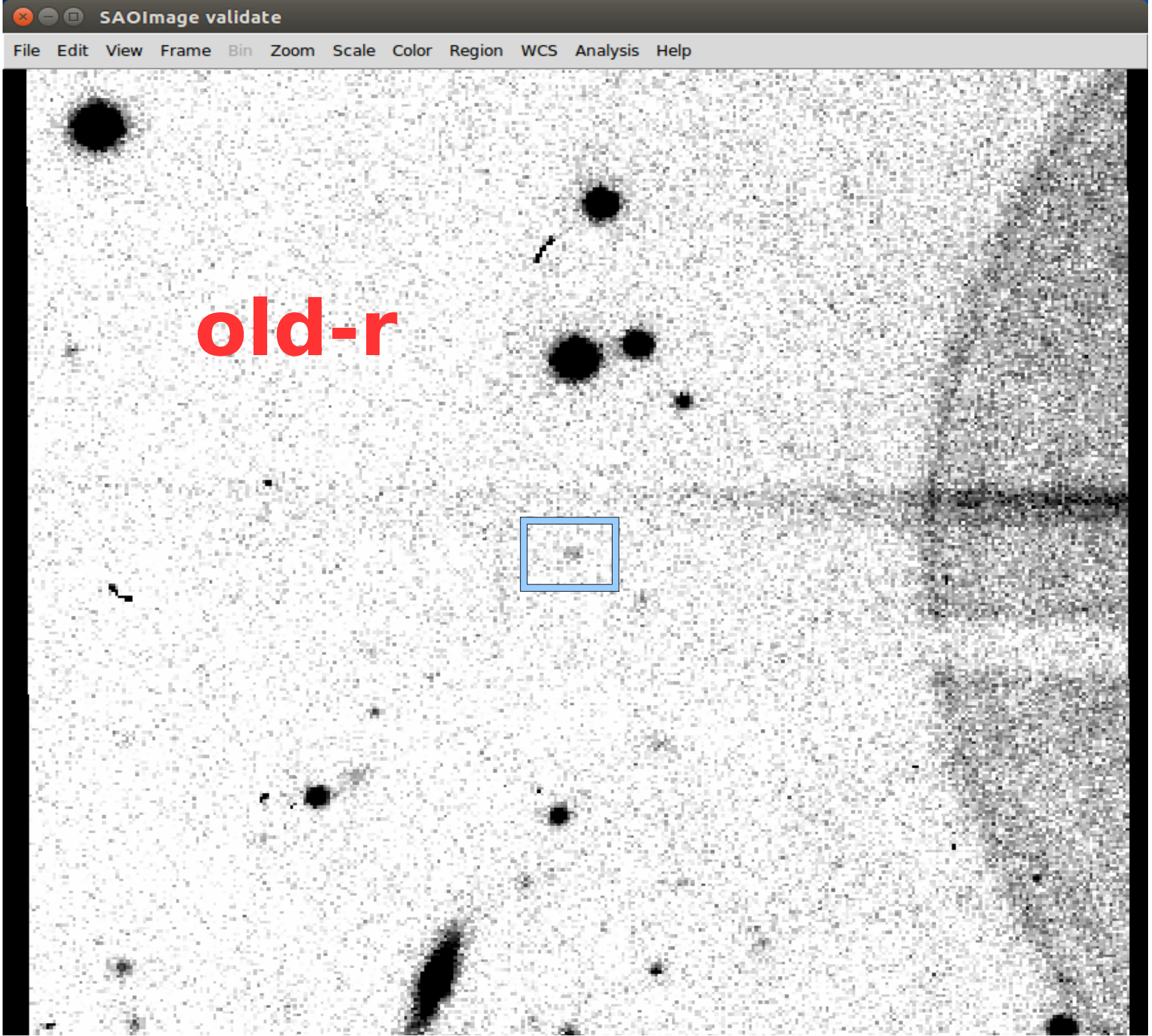
Bannister et al (2016)

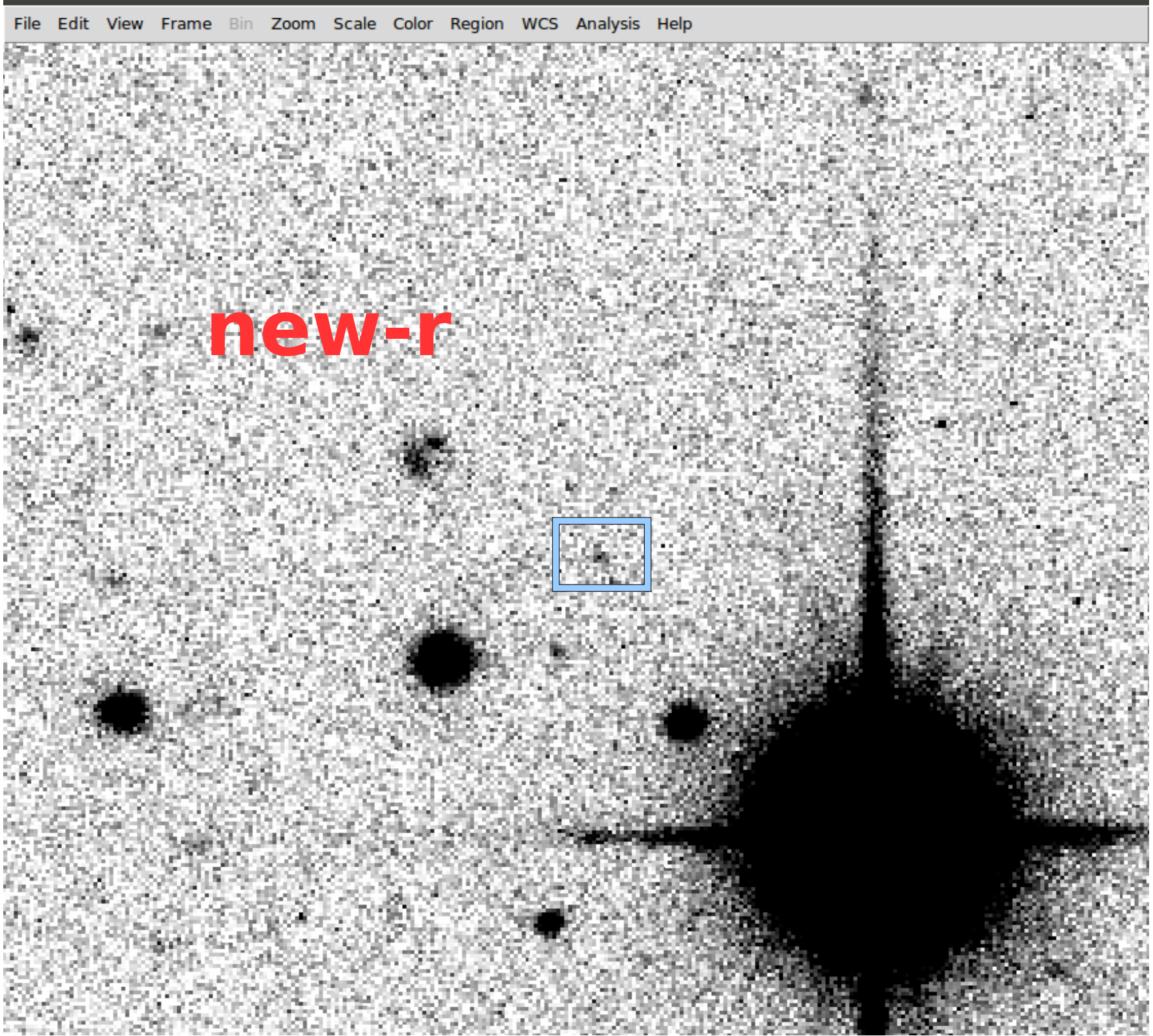

insecure
secure
centaur
scattering
classical
resonant
detached
13-16 months
OUTER SOLAR SYSTEM
OSSOS
ORIGINS SURVEY
MPC
0.01%
30 days
60 days
1 year
da/a
arc length (years)
Bannister et al (2016)
10 years!

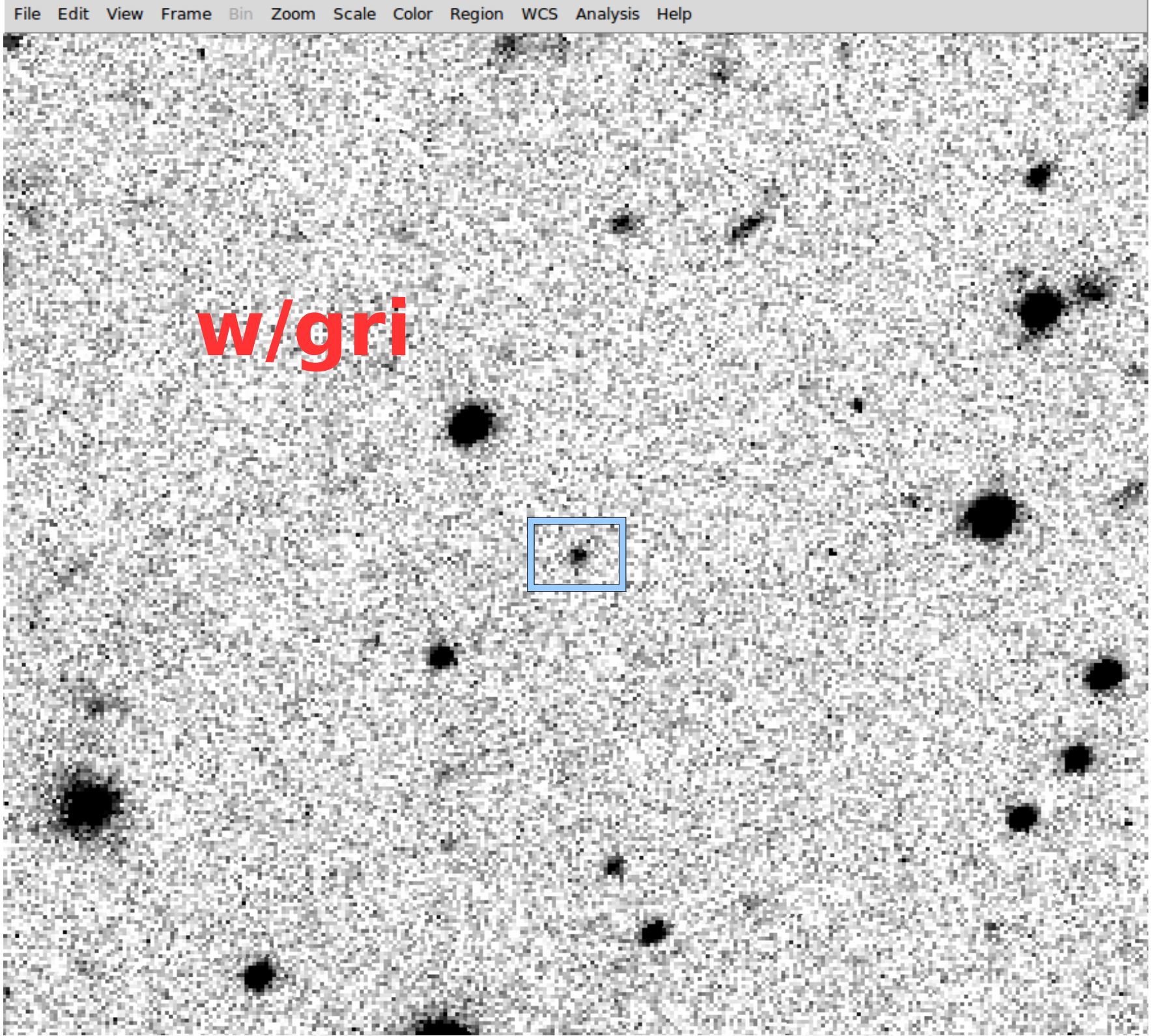
Filter and IQ evolution

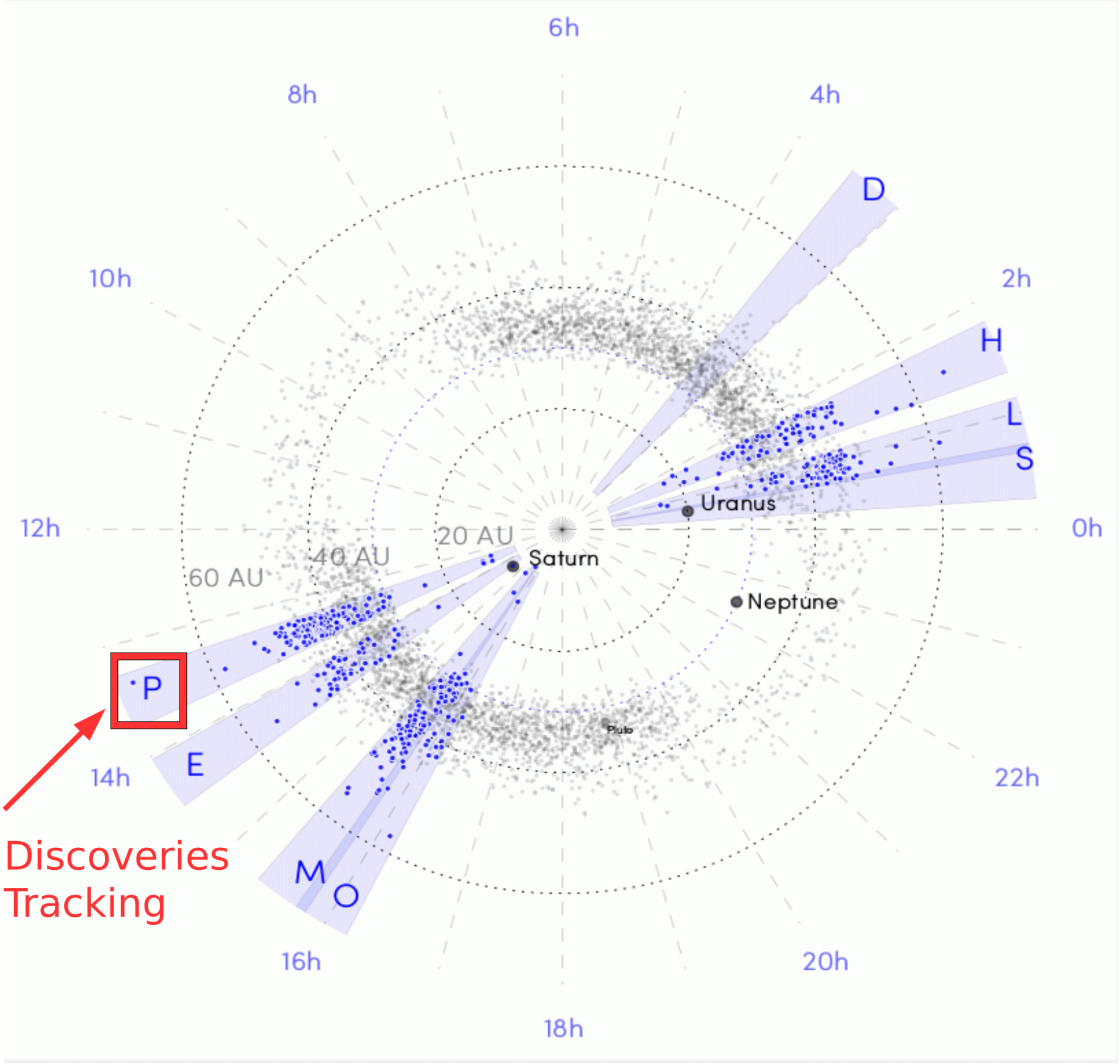
- OSSOS LP has spanned the introduction of:
  - Activation of Megacam's ears
  - New filters
  - Dome venting

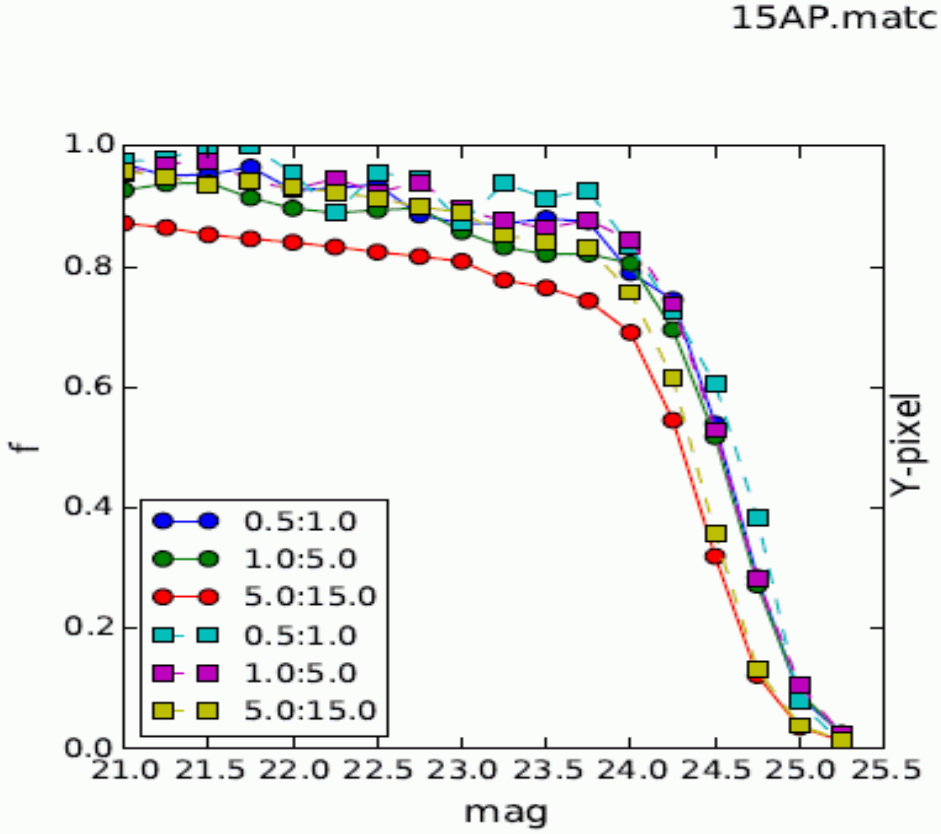

OSSOS IQ
2015
0.61"
2013–2014
0.64" median
frames
seeing (arcsec)
0
500
1000
1500
2000
0.3
0.4
0.5
0.6
0.7
0.8
0.9

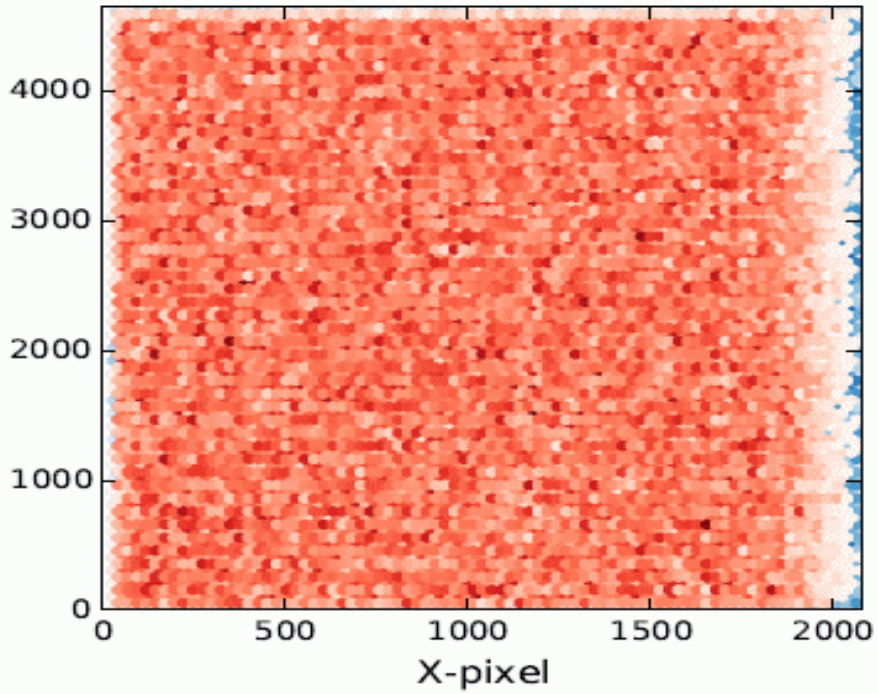

SAOImage validate
File Edit View Frame Bin Zoom Scale Color Region WCS Analysis Help
old-r

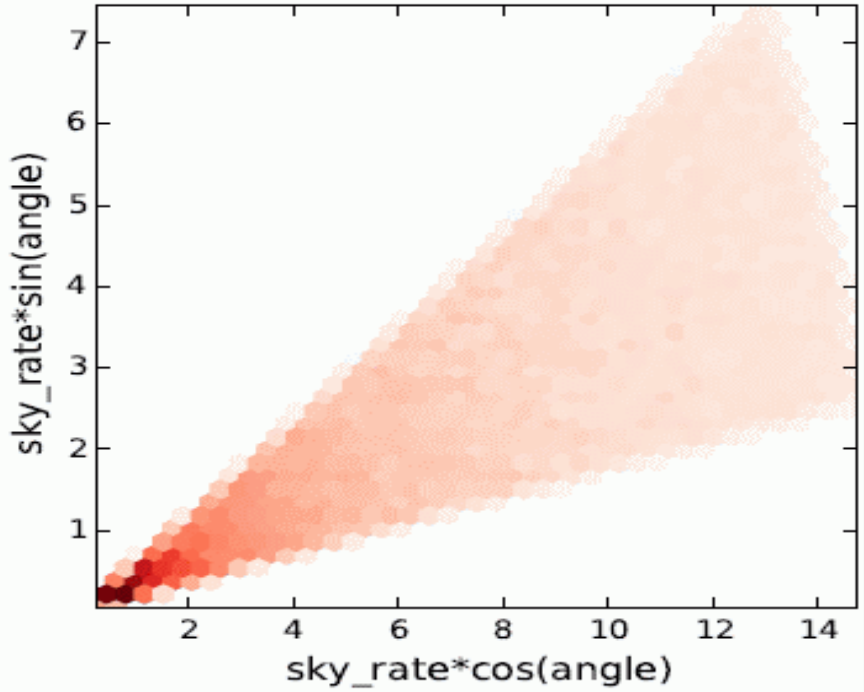

File Edit View Frame Bin Zoom Scale Color Region WCS Analysis Help
new-r


File Edit View Frame Bin Zoom Scale Color Region WCS Analysis Help
w/gri

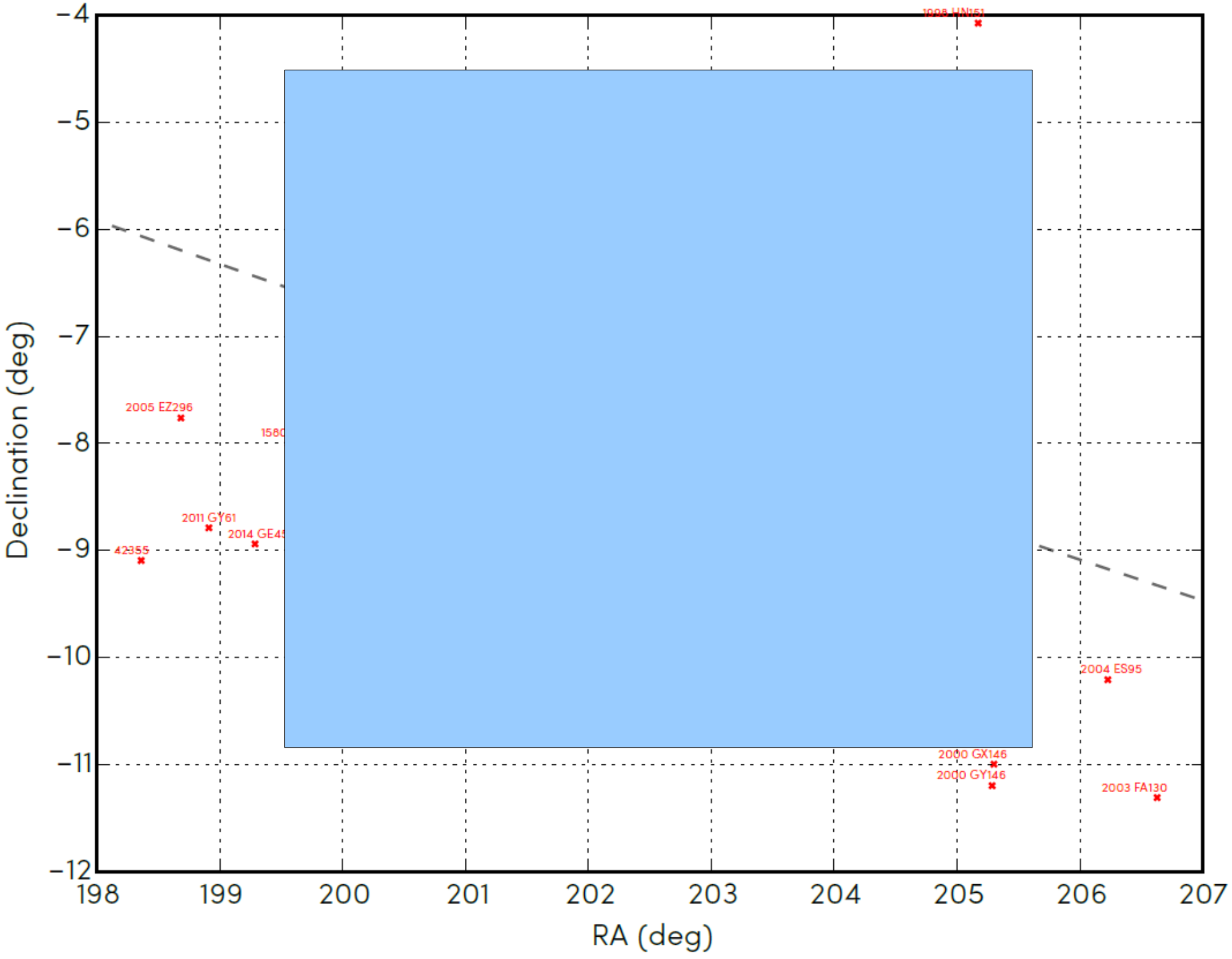

6h
8h
4h
10h
2h
12h
0h
14h
22h
16h
20h
18h
D
H
L
S
Uranus
20 AU
40 AU
60 AU
Saturn
Neptune
P
E
M
O
2015A Discoveries
2016A Tracking



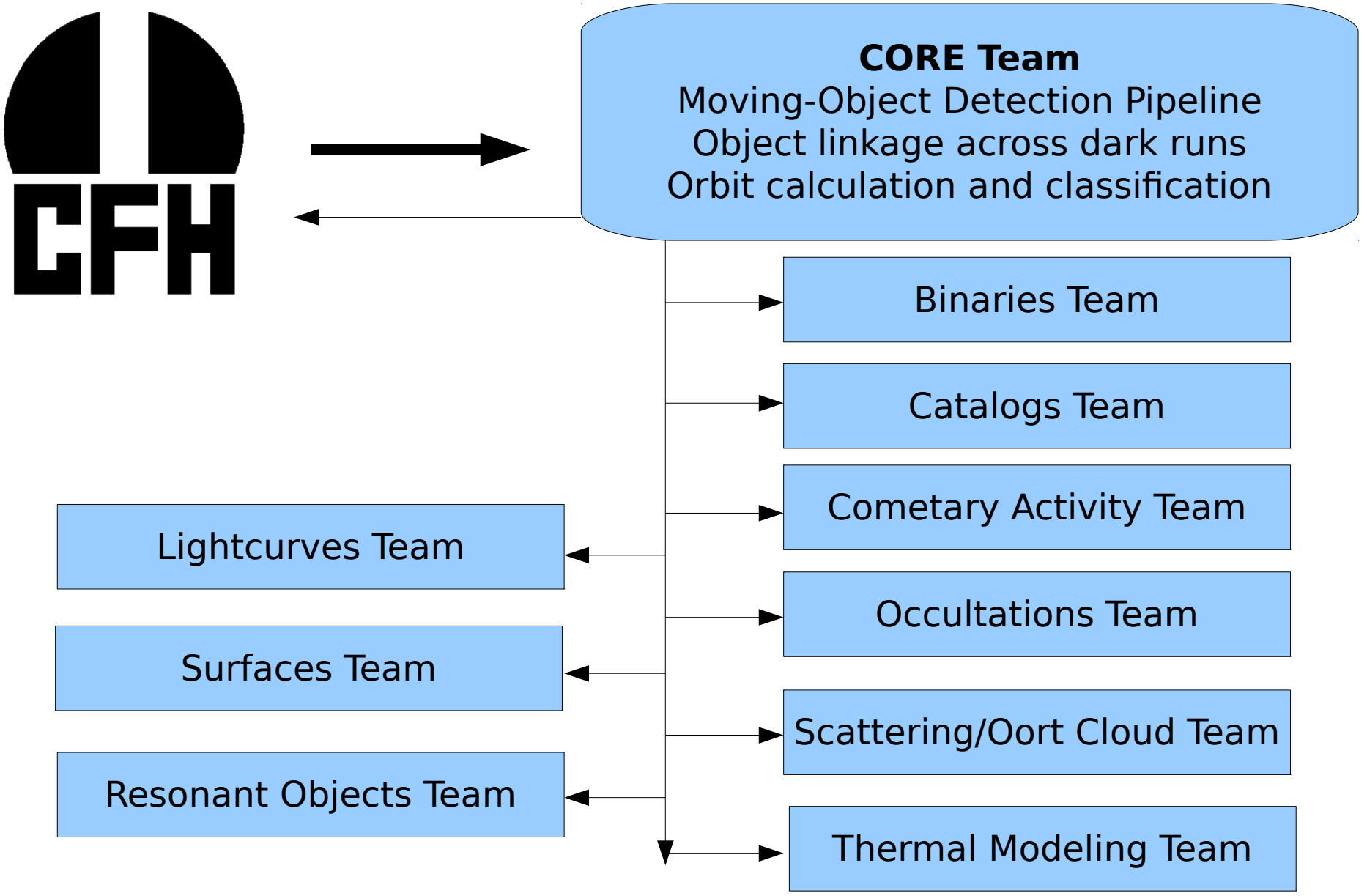




P Block characterization


−4
−5
−6
−7
−8
−9
−10
−11
−12
Declination (deg)
198
199
200
201
202
203
204
205
206
207
RA (deg)
2005 EZ296
2011 GY61
2014 GE45
42355
2004 ES95
2000 GX146
2000 GY146
2003 FA130

OSSOS Collaboration Structure



OUTER SOLAR SYSTEM

OSSOS

ORIGINS SURVEY

cometary activity

surfaces

occultations

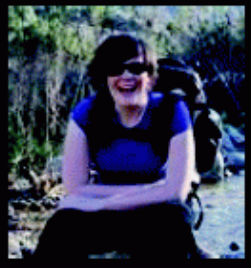
light curves

from core discovery/tracking to

collaboration

thermal modelling

binaries



mining catalogues

resonant

scattering

OSSOS Collaborators

Core : B. Gladman, J. Kavelaars, J-M. Petit, M. Bannister, S. Gwyn, M. Alexandersen, Y. Chen, M. Alexandersen

Binaries: A. Parker, S. Bennechi, W. Grundy, D. Hestroffer, E. Lin, K. Noll

Catalogs: L. Jones, S. Krughoff, E. Ashton

HST Legacy

Cometary Activity: P. Rousselot, I. Kulyk, P. Korsen

Light Curves: S. Bennechi, L. Jones, P. Lacerda, N. Peixinho, M. Lehner, S. Wang, M. Schwamb

HSC awards

Occultations: W. Fraser, A. Gulbis, B. Sicardy, T. Lister, M. Granvik, ...

Resonant objects: R. Murray-Clay, B. Gladman, W. Ip, S. Lawler, Y. Chen, P. Lykawka, K. Volk, S. Greenstreet

Scattering/Centaurs: N. Kaib, R. Brasser, S. Tremaine, C. Shankman, J. Kavelaars, C. Chen, M. Jakubik

Surfaces: A. Delsanti, M. Bannister, P. Vernazza, W. Fraser, R. Pike, A. Guilbert-Lepoutre, N. Peixhino, M. Lehner, S. Wang

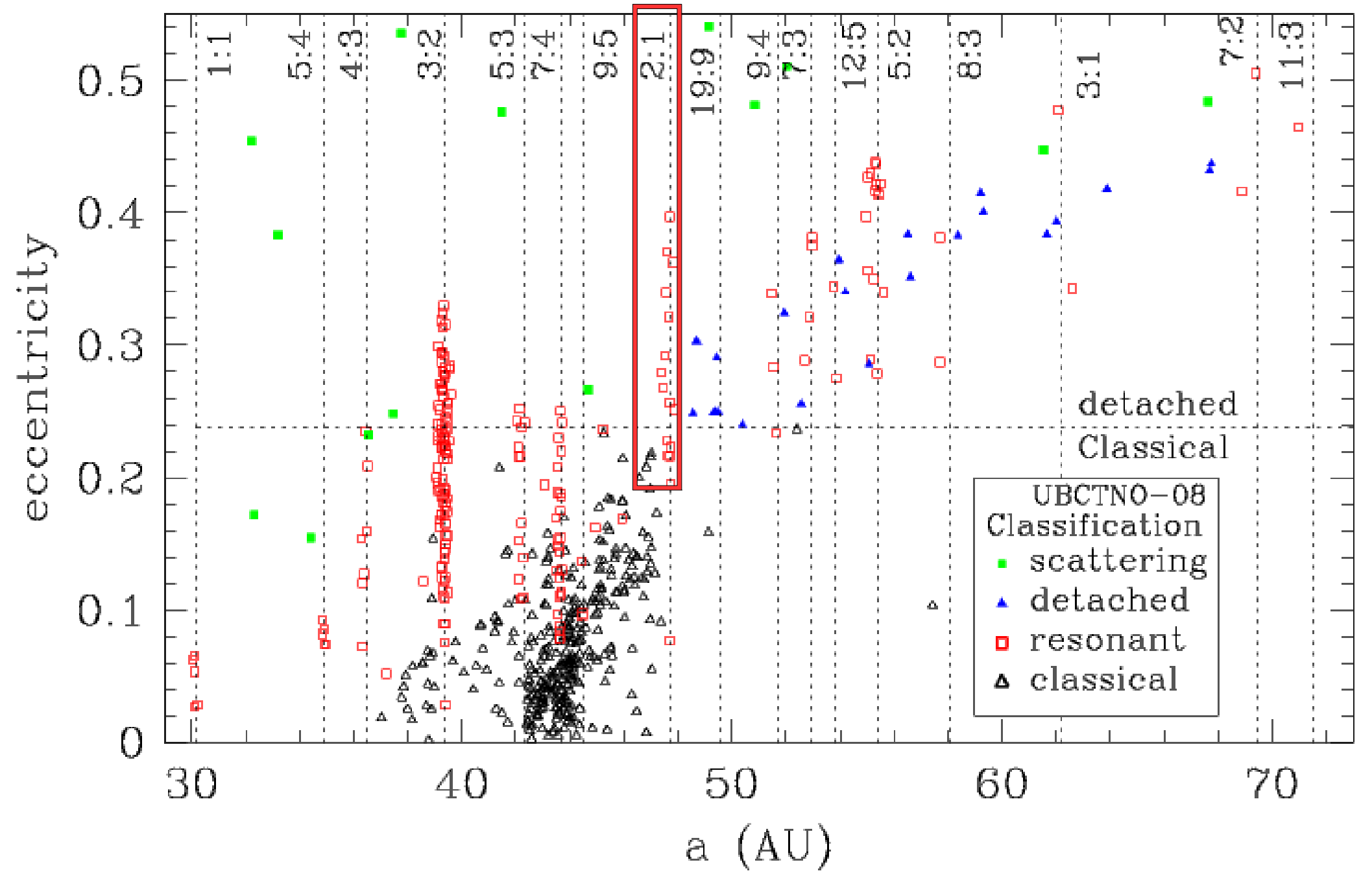
ColOSSOS

386 hr G-N

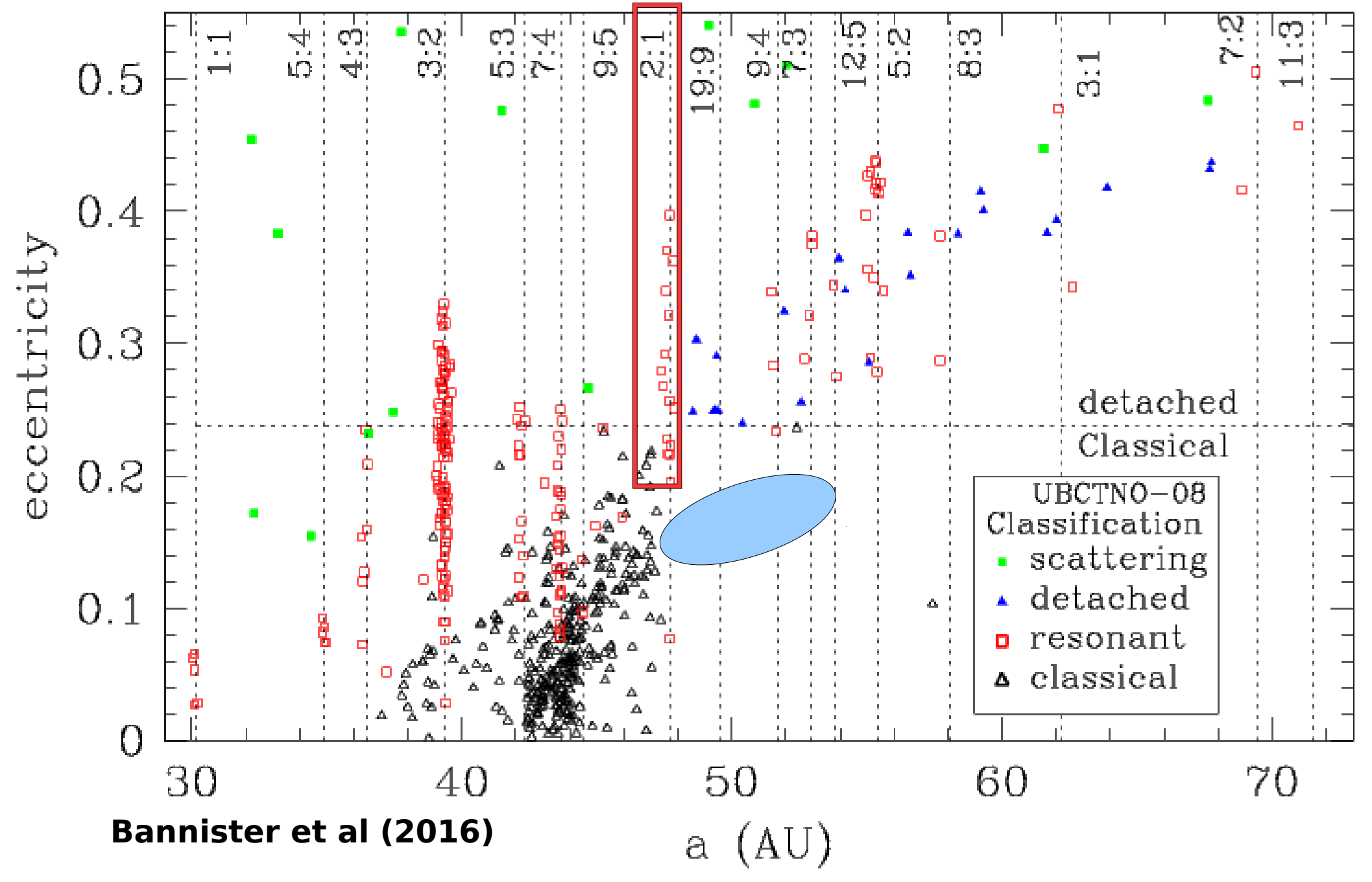
Publications already out

- Bannister et al (2016): First quarter of the survey. Overview of techniques
- Shankman et al (2016): Size distribution of small outer Solar System objects
- Volk et al (2016): Resonant populations

Extension of cold belt past 2:1



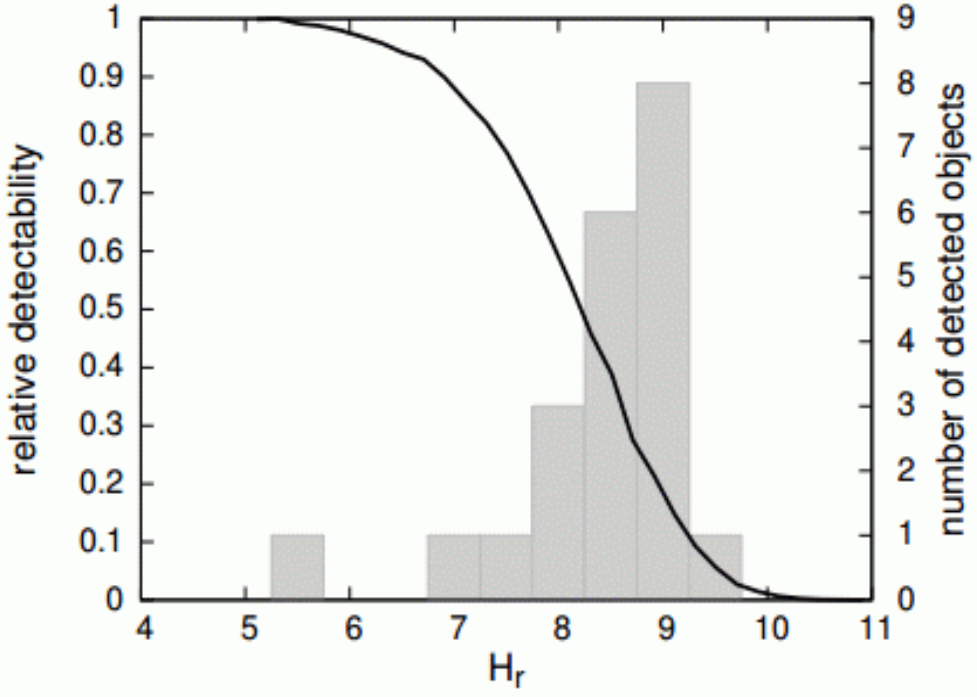
Extension of cold belt past 2:1

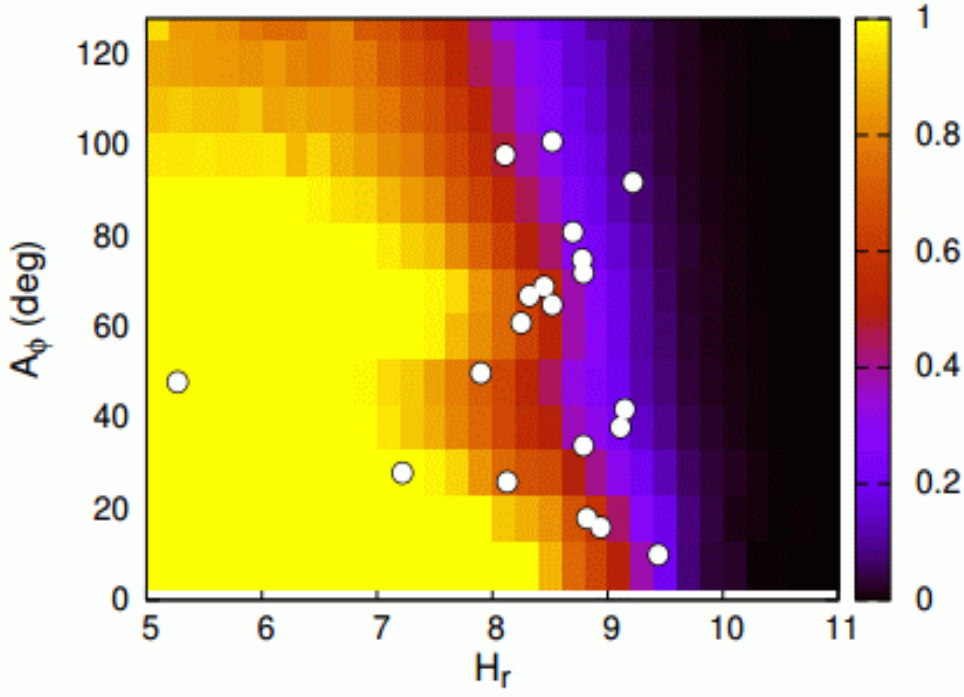


Bannister et al (2016)

Detectability of 3:2 resonators

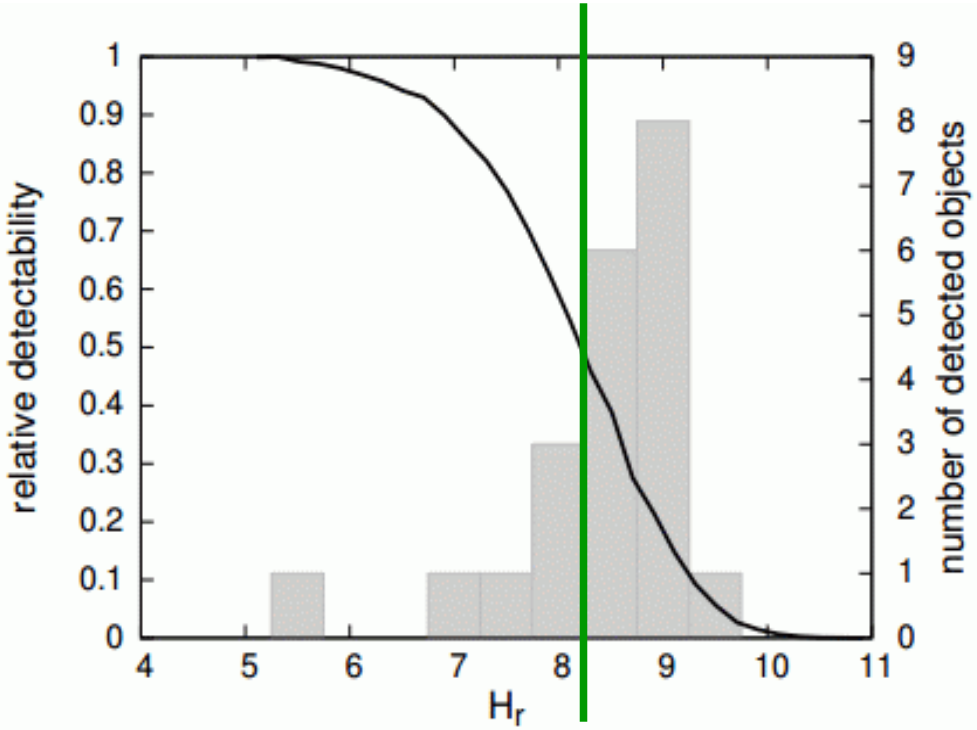
Volk et al (2016)

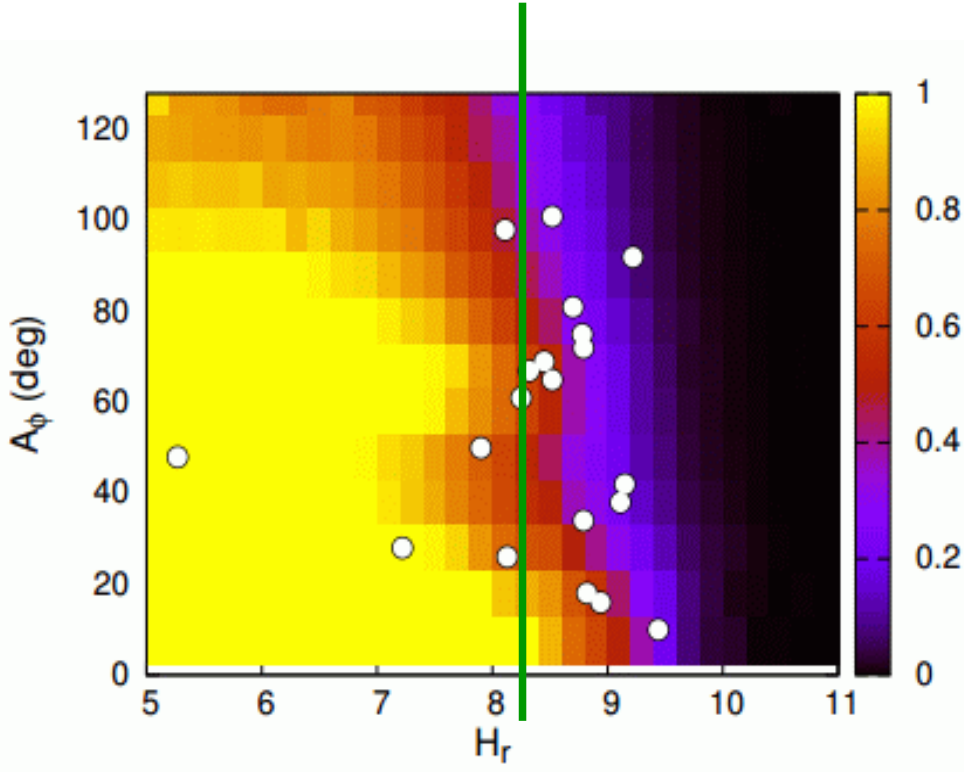




Detectability of 3:2 resonators

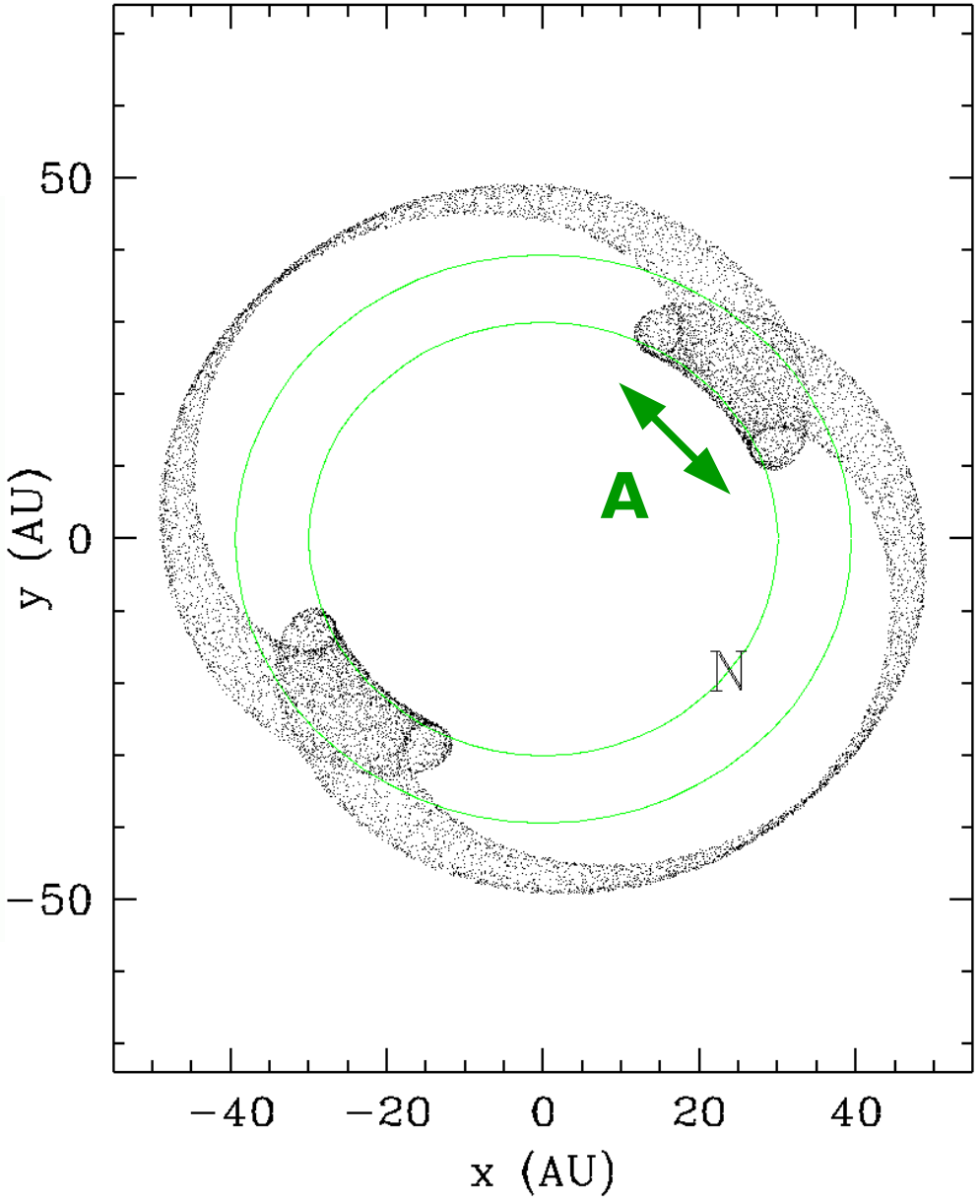
Volk et al (2016)

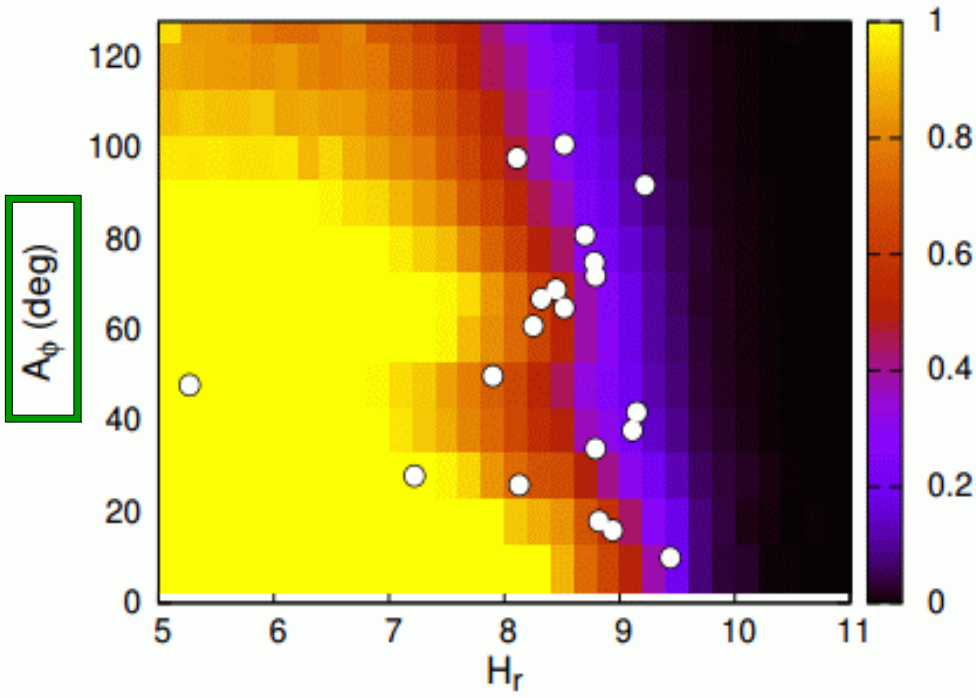




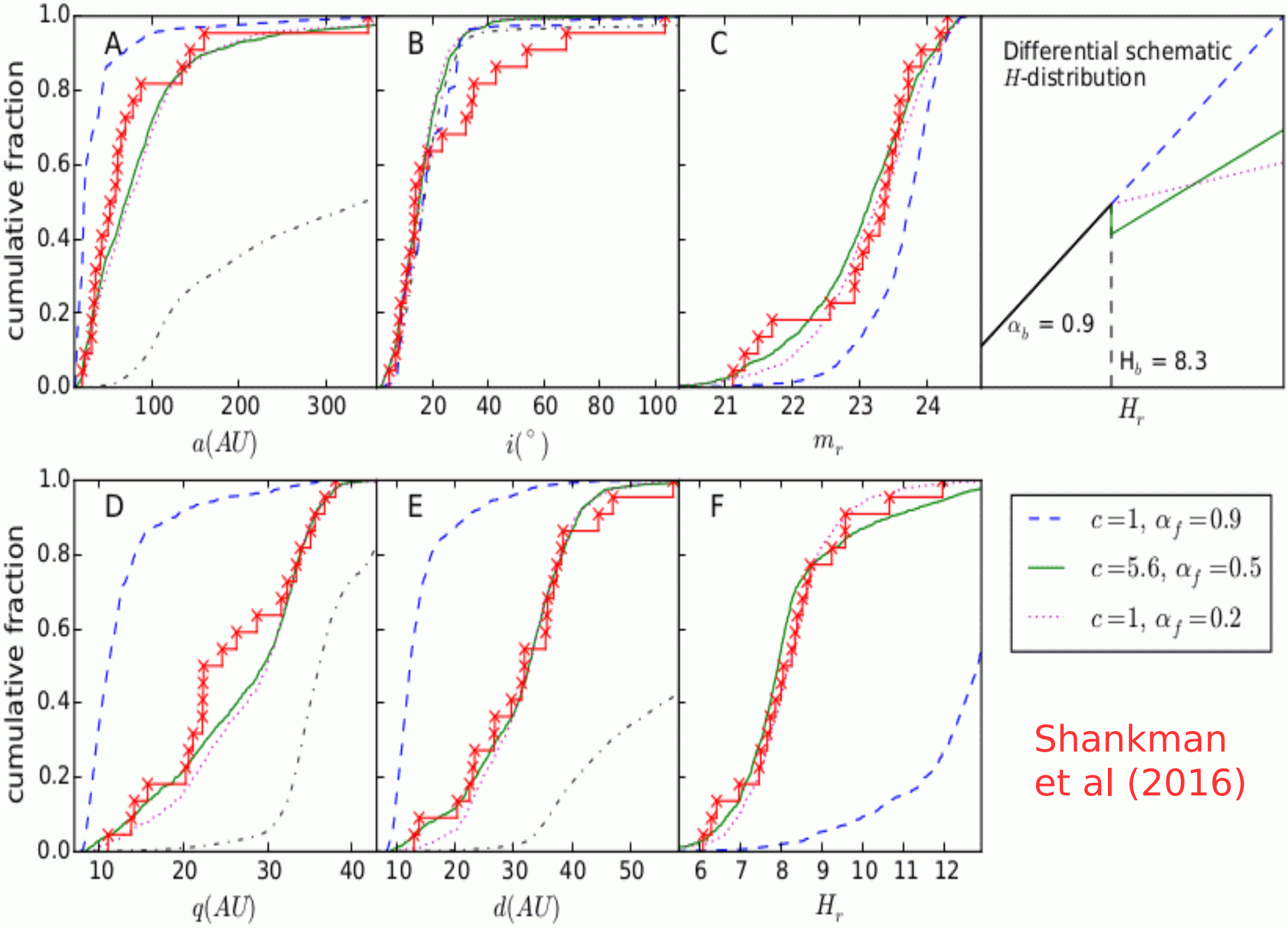
Detectability of 3:2 resonators

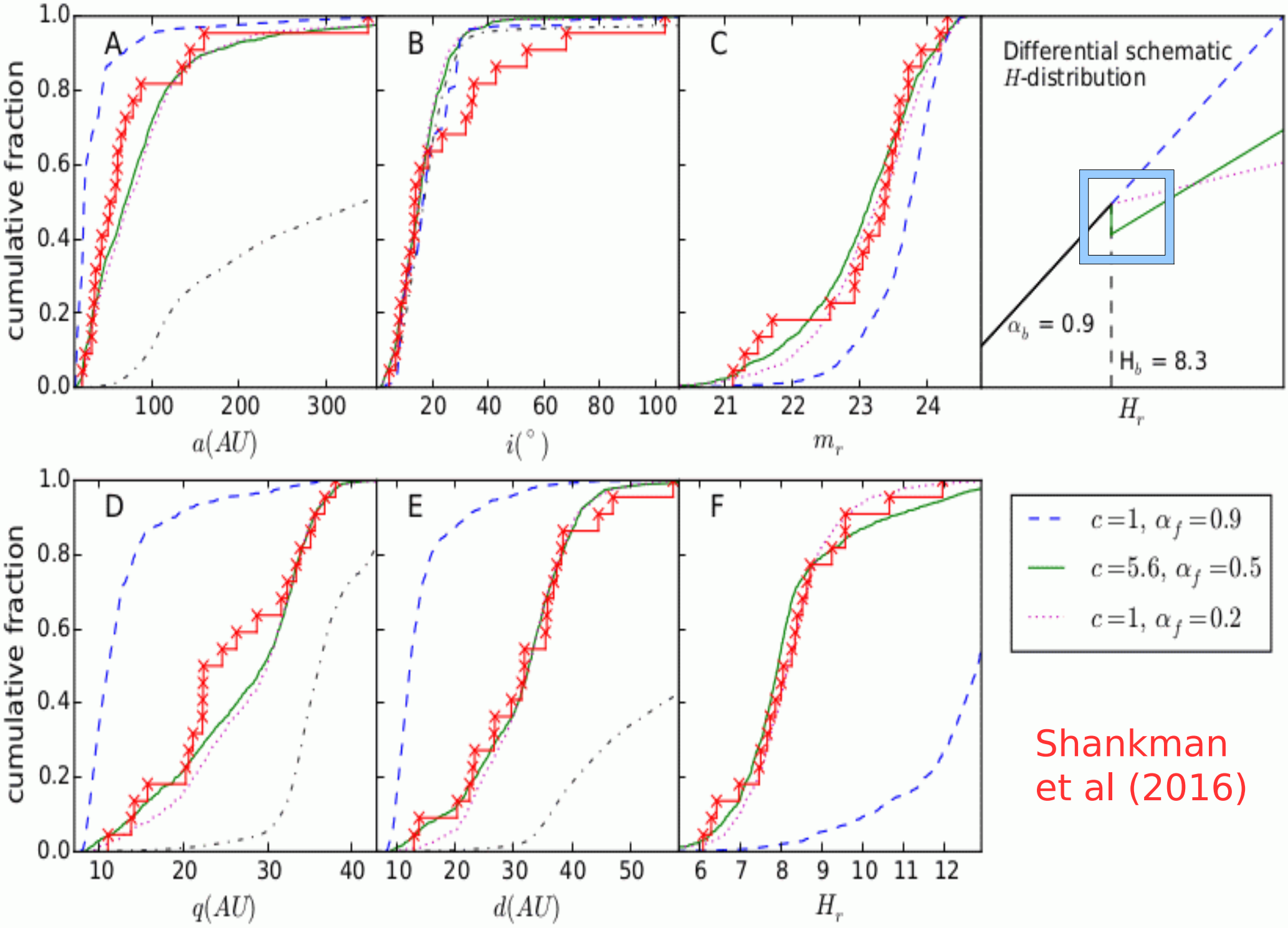
Volk et al (2016)





A distribution is diagnostic of mode of Kuiper Belt implantation during planetary migration


A
B
C
D
E
F
cumulative fraction
1.0
0.8
0.6
0.4
0.2
0.0
100
200
300
$a(AU)$
20
40
60
80
100
$i(^\circ)$
21
22
23
24
m_r
Differential schematic
H-distribution
α_b = 0.9
H_b = 8.3
H_r
10
20
30
40
$q(AU)$
10
20
30
40
50
$d(AU)$
6
7
8
9
10
11
12
H_r
$c=1,\ \alpha_f=0.9$
$c=5.6,\ \alpha_f=0.5$
$c=1,\ \alpha_f=0.2$
Shankman
et al (2016)



Shankman et al (2016)

Thank you

- Looking forward to presenting detailed results at the next CFHT UM!
  - By that time there will be a factor of 3 improvement over CFEPS