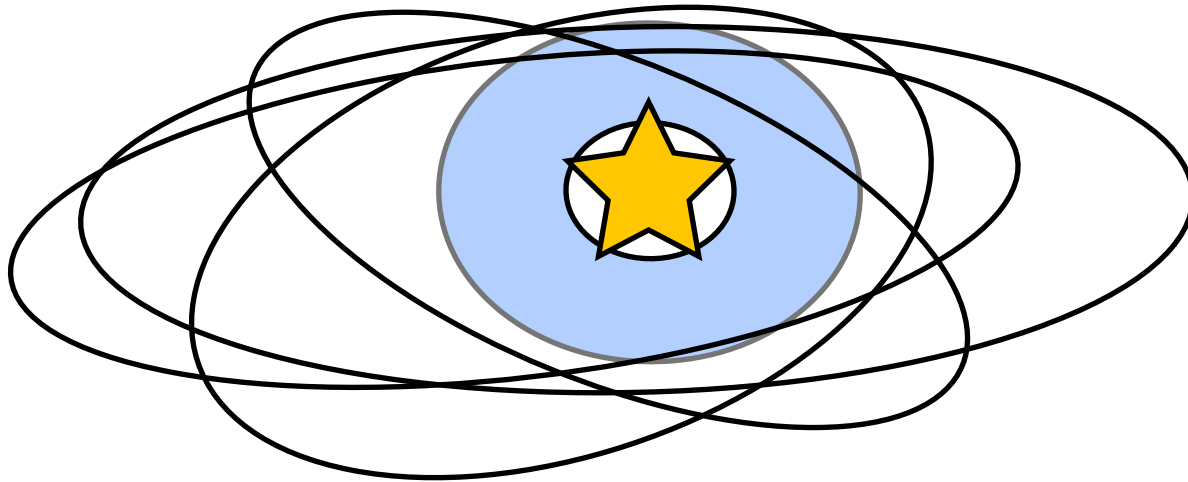


Scattering and Migration: Constraints on the Dynamical History of the Solar System



or **NEPTUNE'S WILD DAYS**

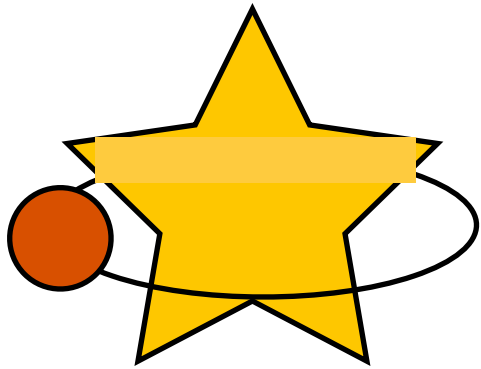
Bekki Dawson

Ruth Murray-Clay

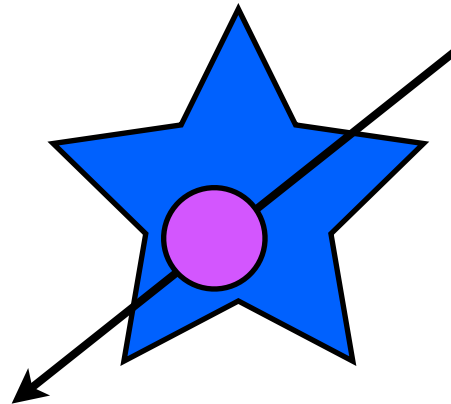
Harvard-Smithsonian CfA

EXOMENAGERIE

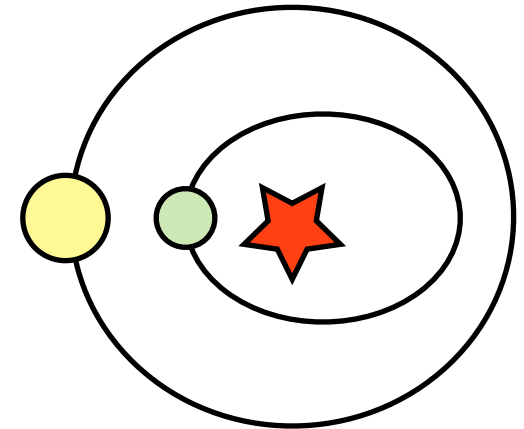
Scattering and/or Migration?



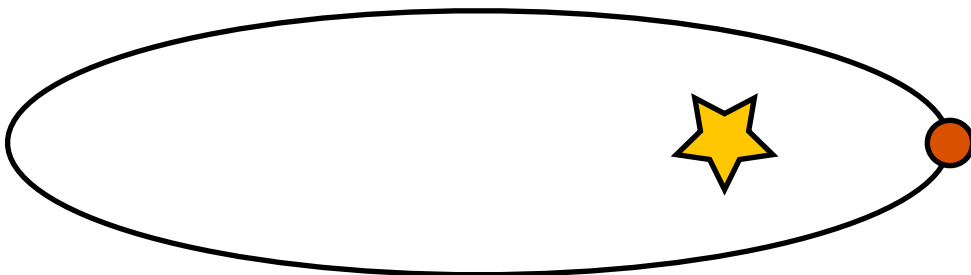
Hot Jupiters and
hot Super-Earths!



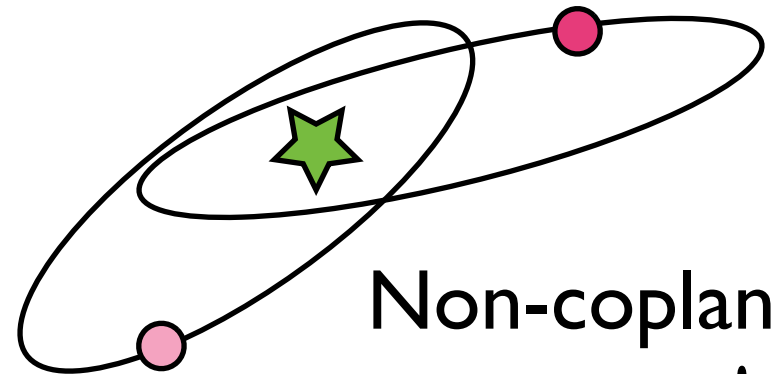
Misaligned orbits!



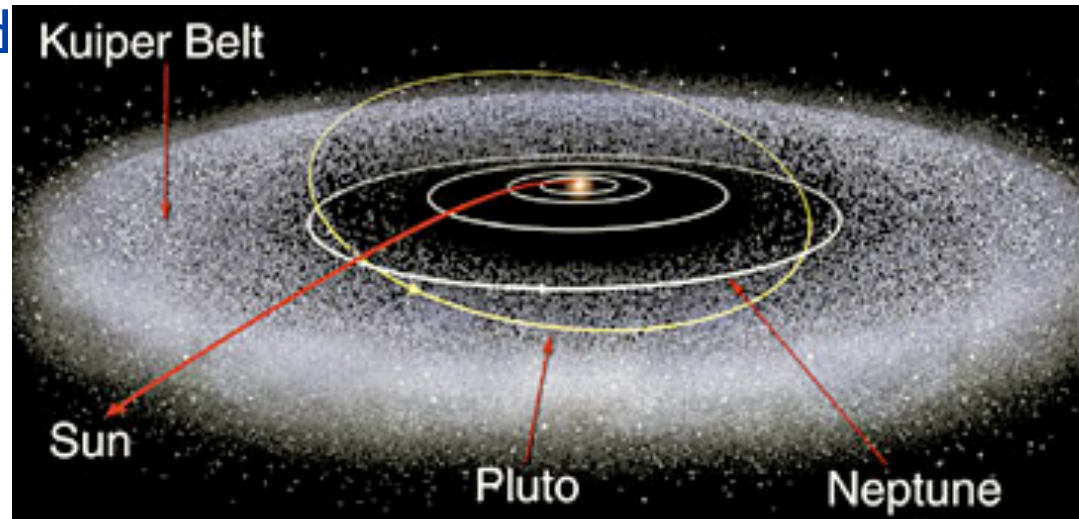
Mean motion
resonances!



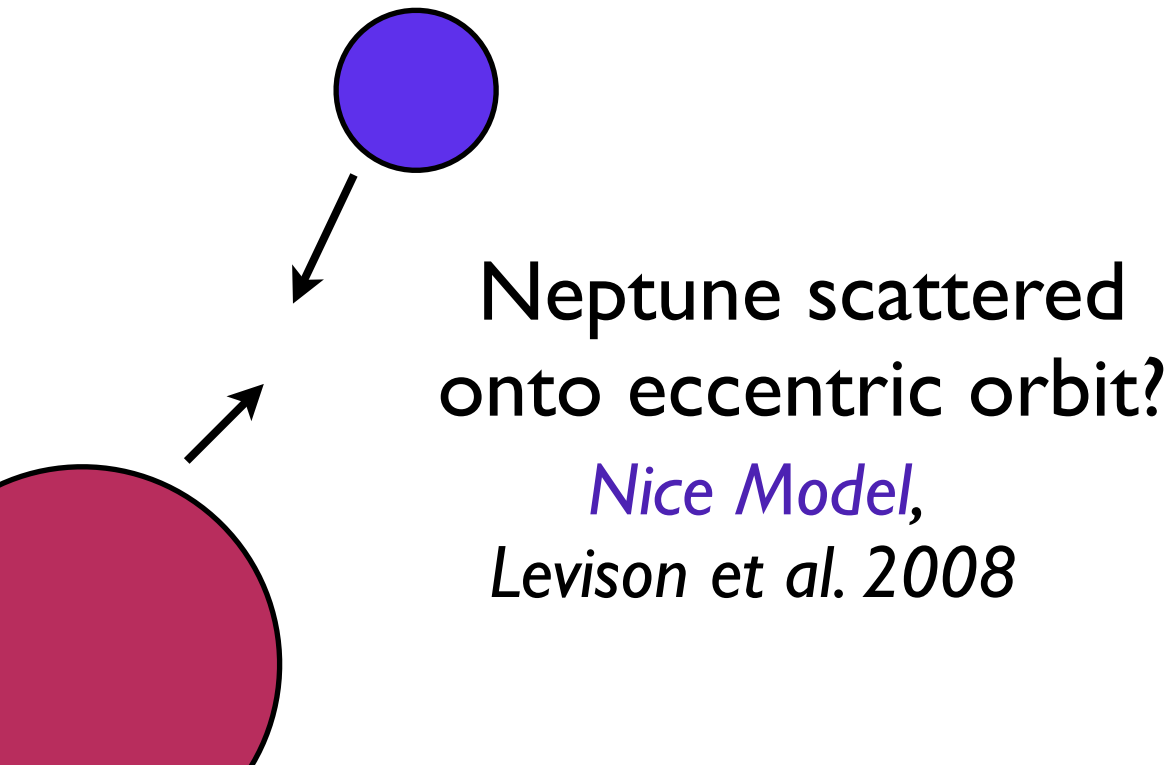
Eccentric orbits!



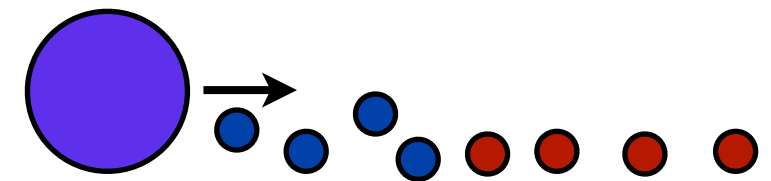
Non-coplanar
systems!



Inclined, eccentric, resonant orbits of Kuiper Belt Objects imply early dynamical upheaval



Neptune migrated through planetesimal disk?



Malhotra 1993, 1995,
Hahn and Malhotra 2005

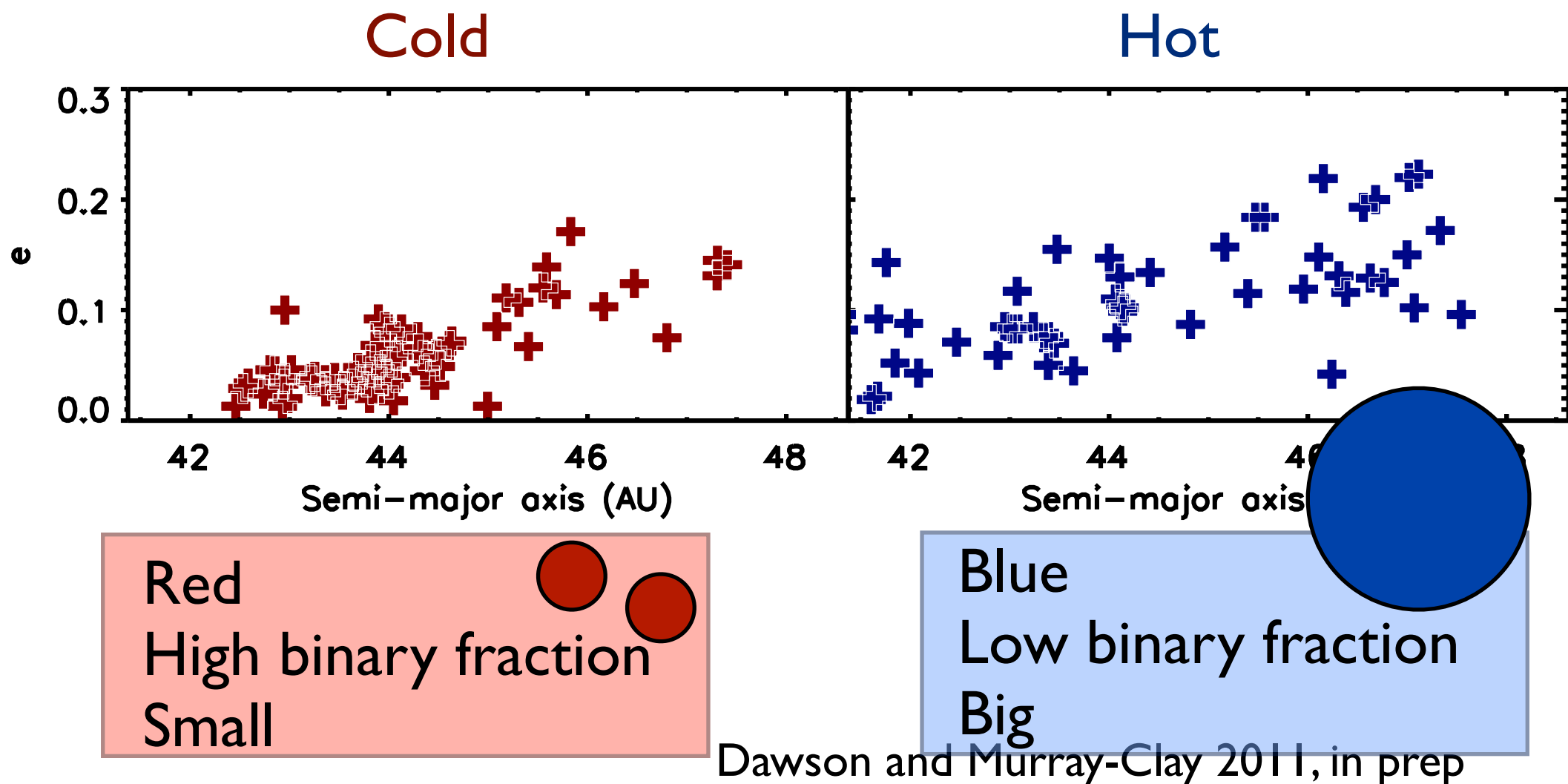
NEPTUNE'S WILD DAYS

From the sculpted orbits of Kuiper Belt Objects we can determine

- Was Neptune scattered to a high-eccentricity orbit?
- If so, how quickly did dynamical friction damp Neptune's eccentricity?
- How far did Neptune migrate in the proto-planetary disk?
- What were the relative timescales of damping and migration?

Solar system case study for migration and scattering

Neptune's history sculpted population of dynamically **cold** and **hot** Kuiper Belt Objects with different physical properties

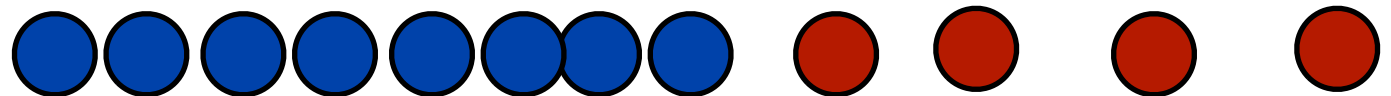
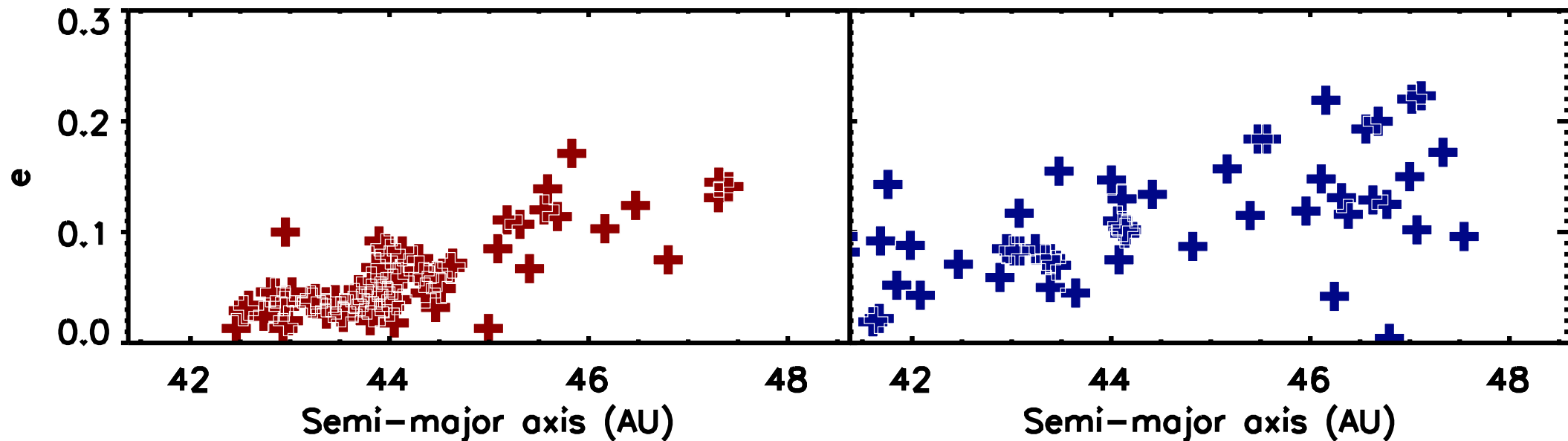


Cold and hot eccentricity distributions

➔ **Cold formed in situ in outer disk
and hot delivered from inner disk?**

Cold

Hot

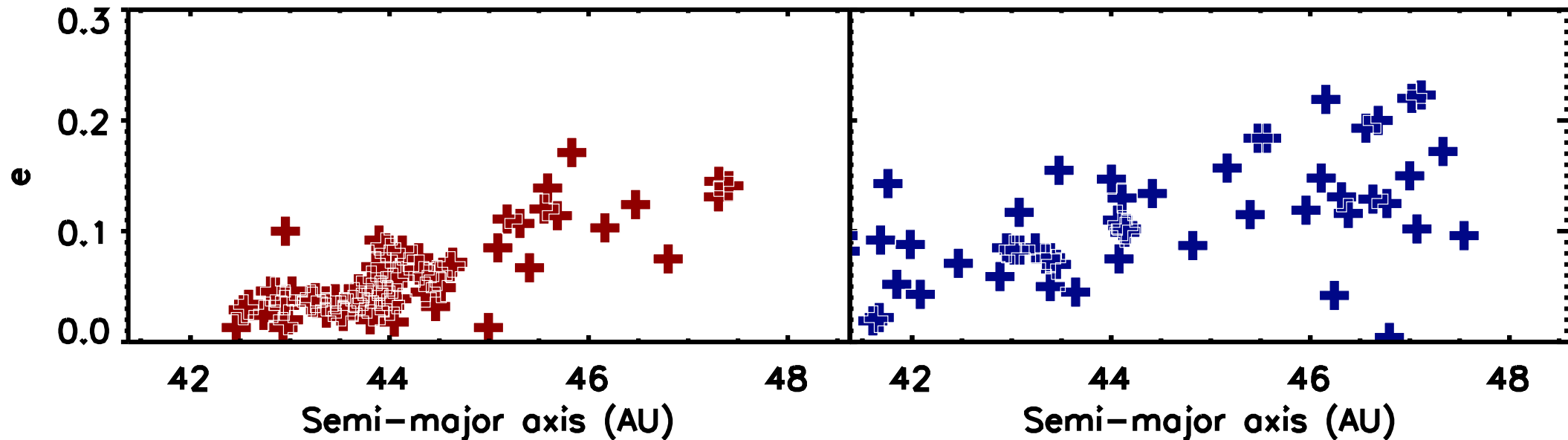


Cold and hot eccentricity distributions

➔ **Neither model (4 Gyr N-body integrations) produces both populations**

Cold

Hot



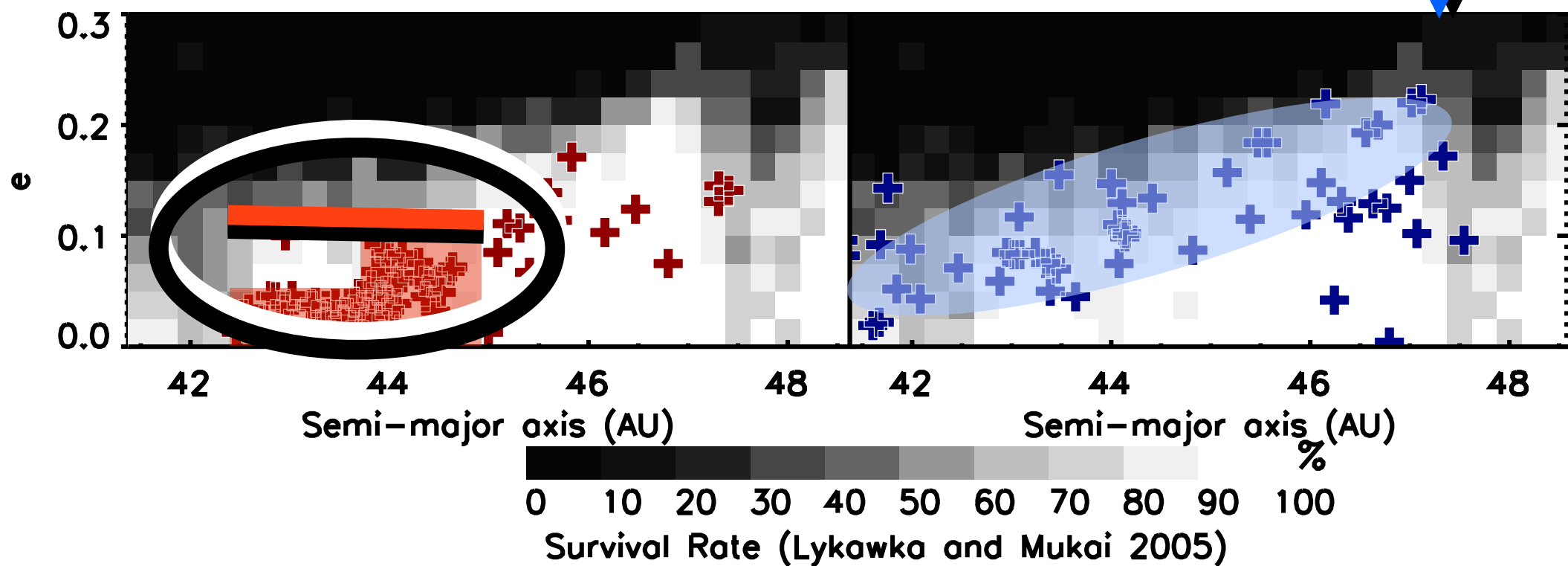
Constraints from eccentricities:

conservative criteria to match

Cold : $e < 0.1$ in
 $42.5 < a < 45$ AU
Cold

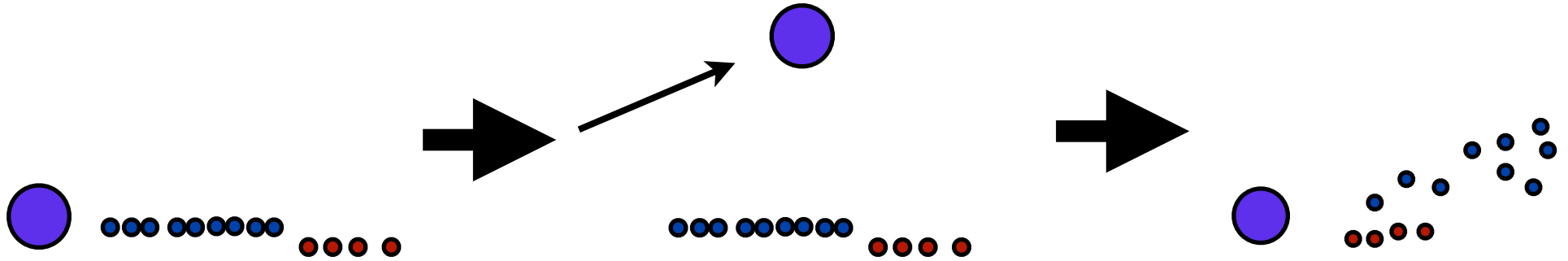
Hot: $e < .3$ at 47.5

Hot

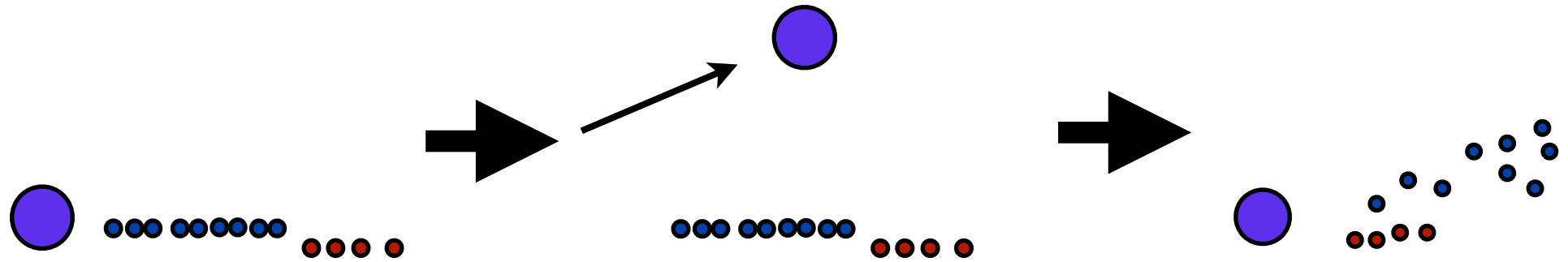


Lykawka and Mukai 2005

Dawson and Murray-Clay 2011, in prep



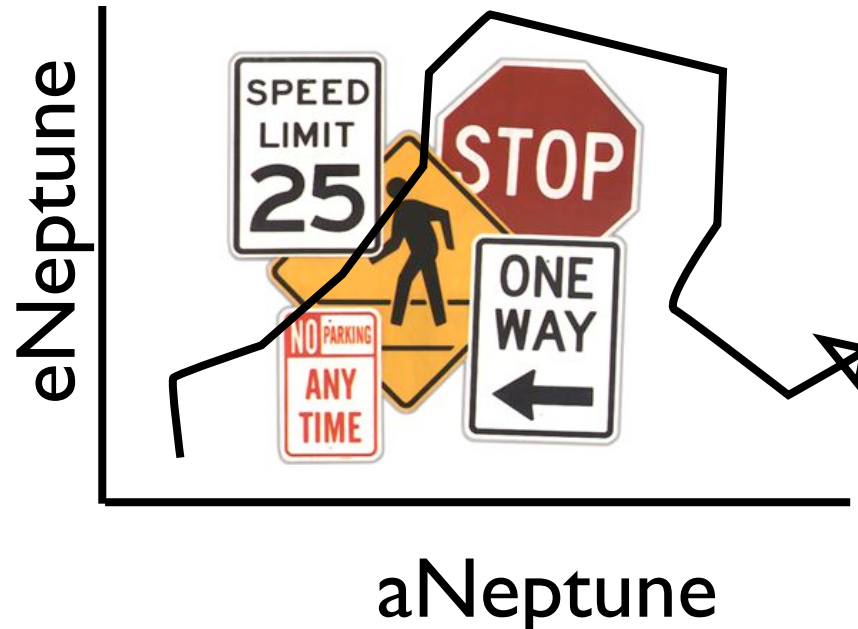
Parameter space exploration: What dynamical histories of Neptune deliver **hot** classicals from inner disk without disrupting **colds**?



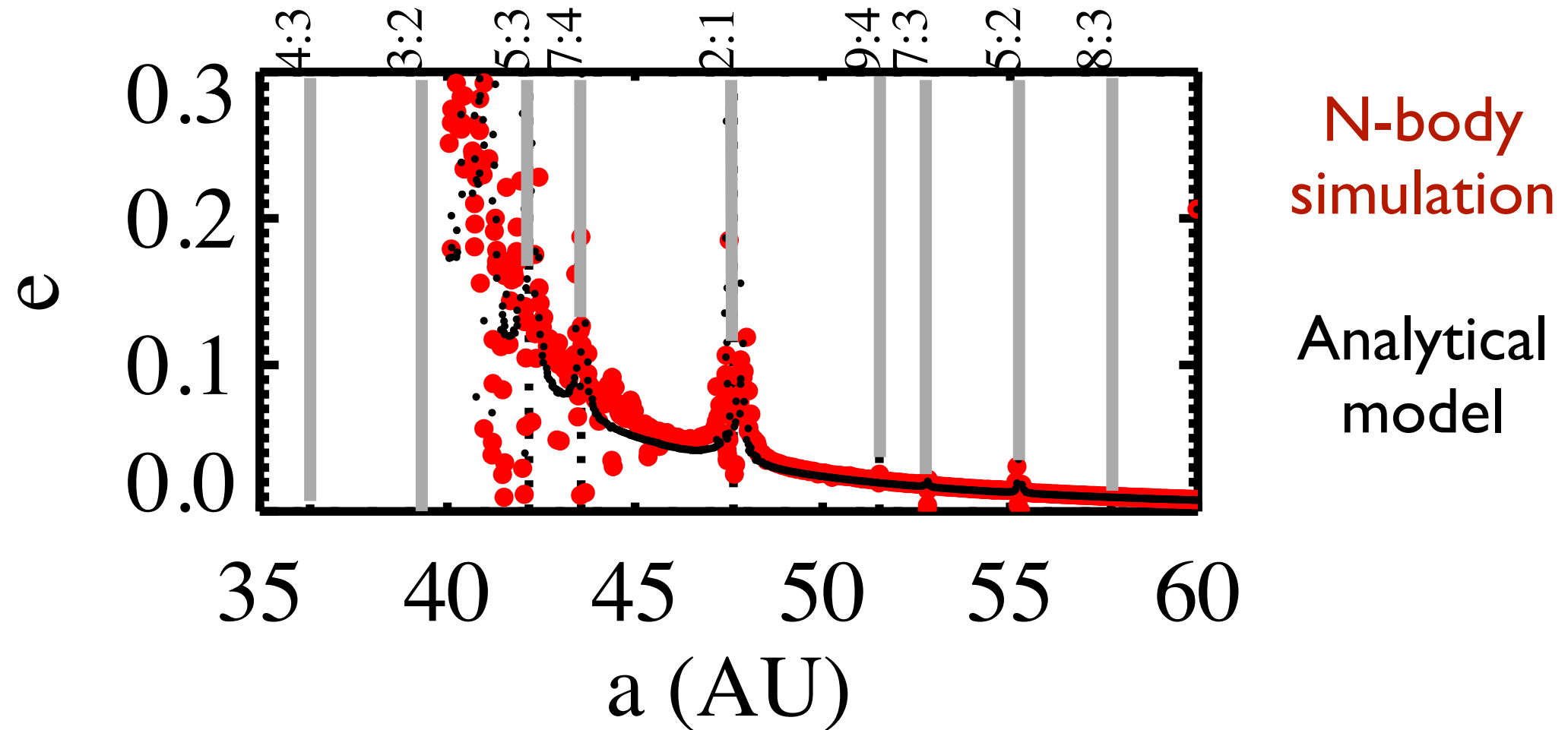
conservative criteria
from observations

analytical expressions
validated by numerical
integrations

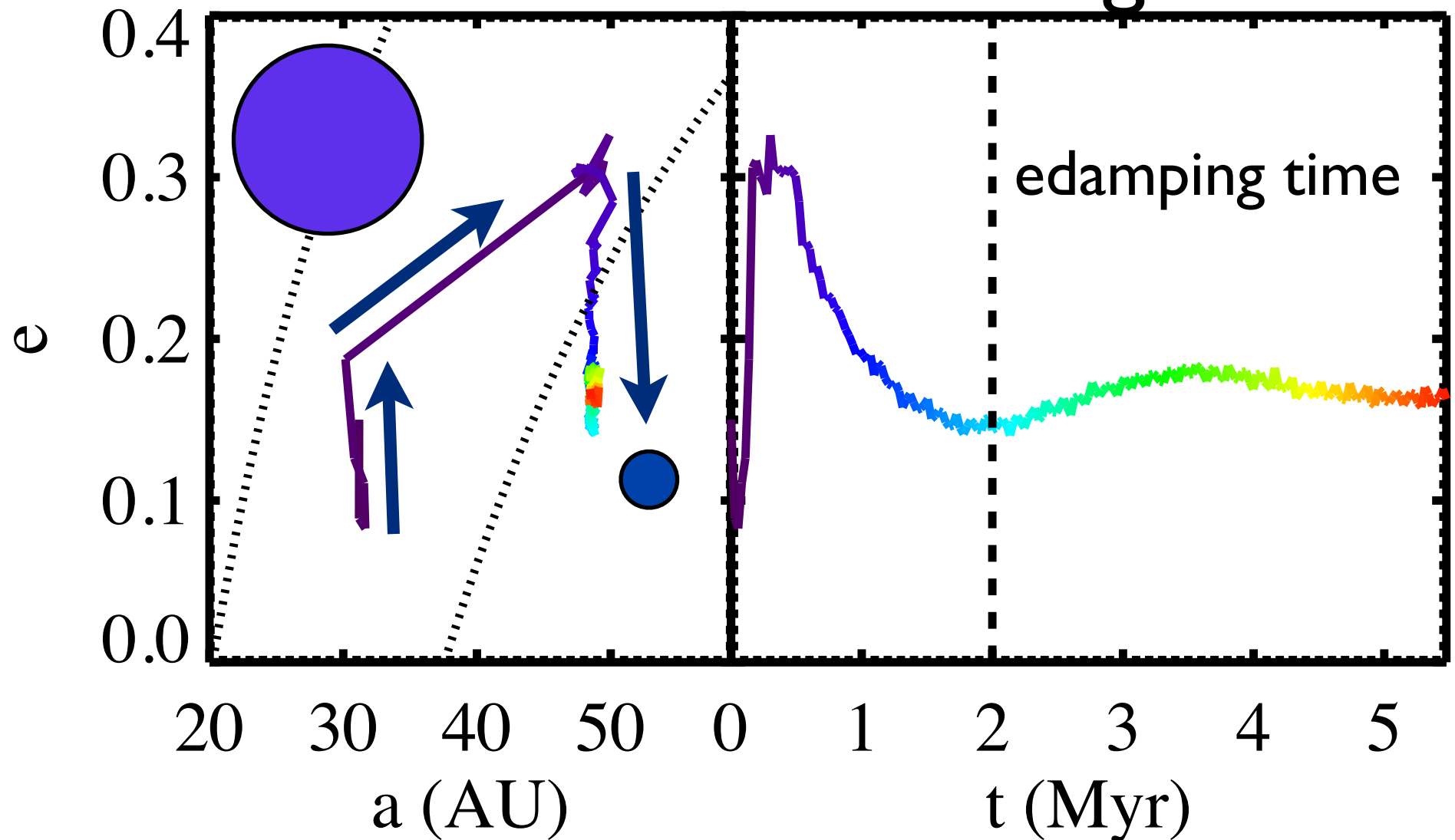
Constraints on
Neptune's path
and timescales



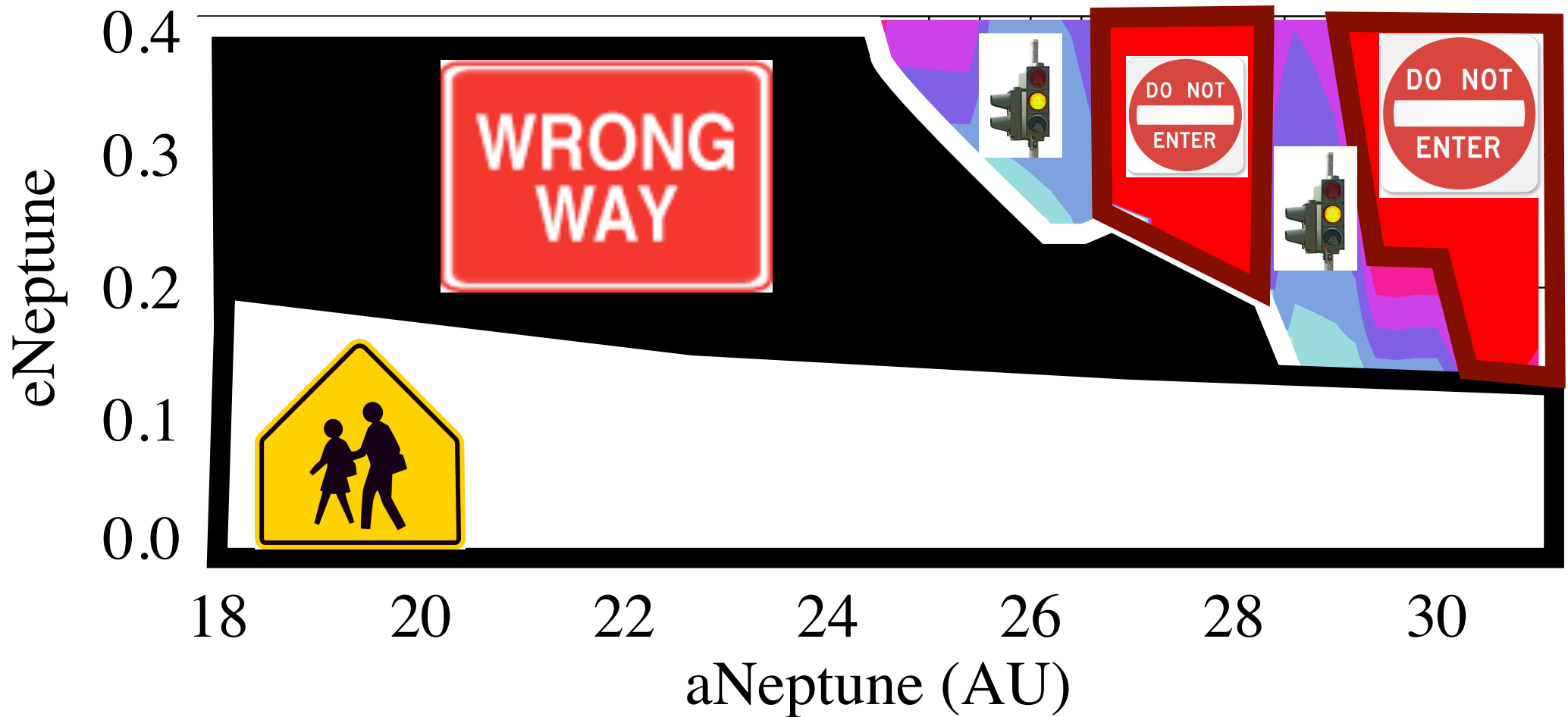
Cold objects cannot be secularly excited above $e = 0.1$



Hot objects must be delivered to the cold classical region



Analytical constraints on Neptune's history validated by short N-body simulations

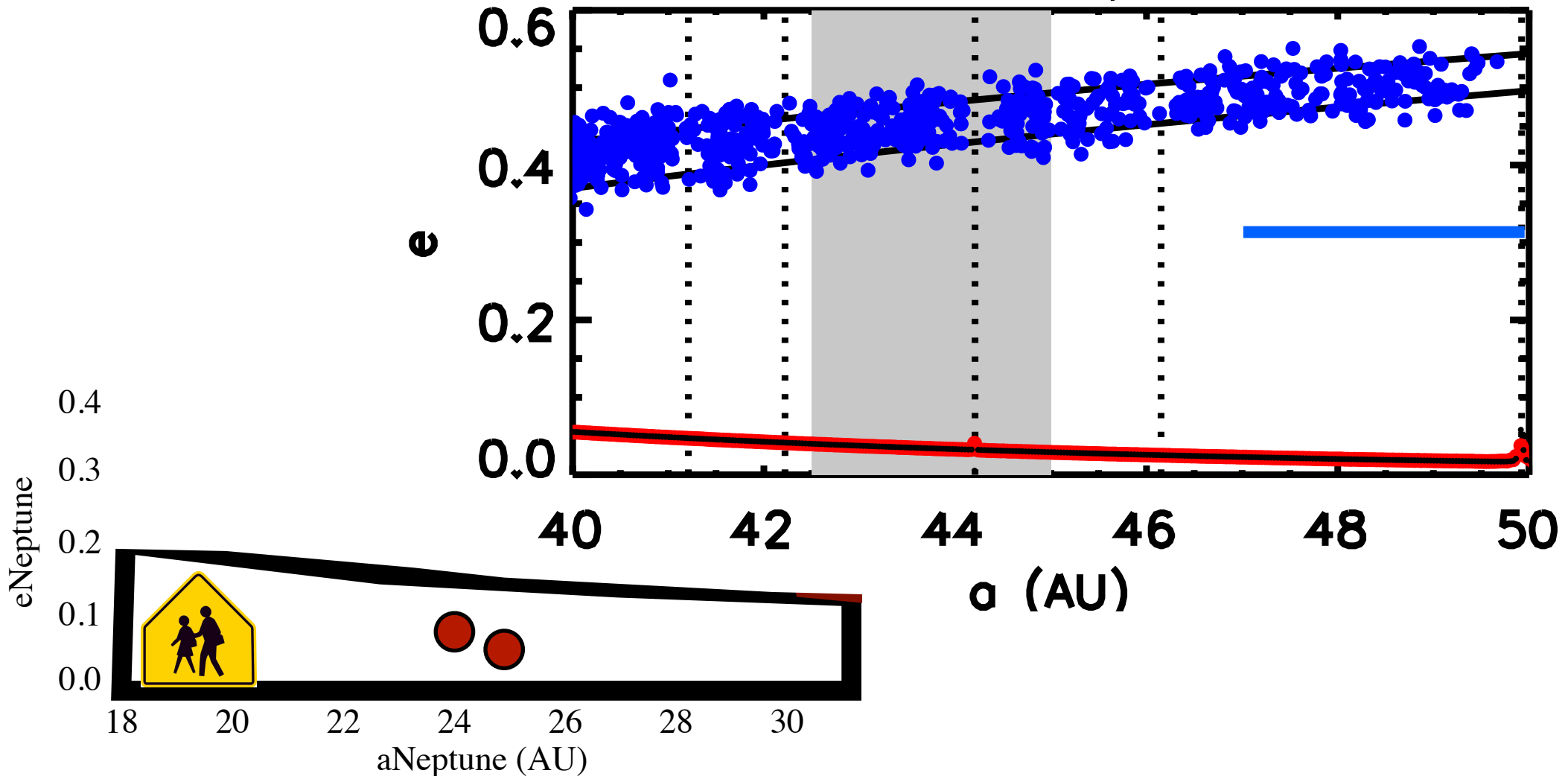




-Secular forcing by Neptune too low to disrupt the cold



-But hot population is not scattered into stable region
2.2 Myr

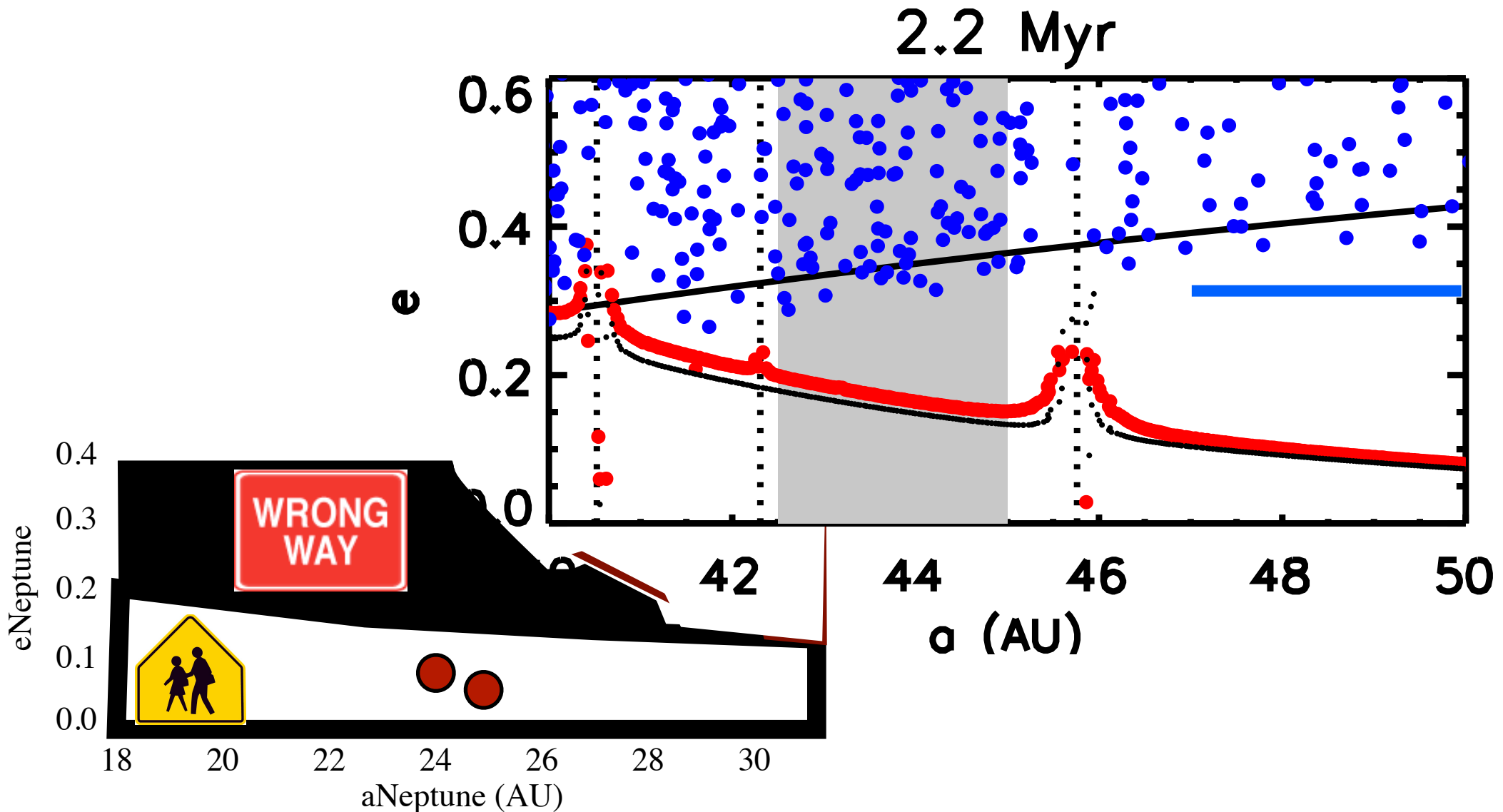


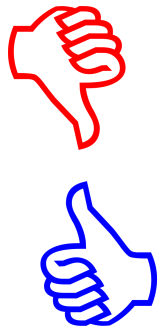


-Hot not scattered into stable region



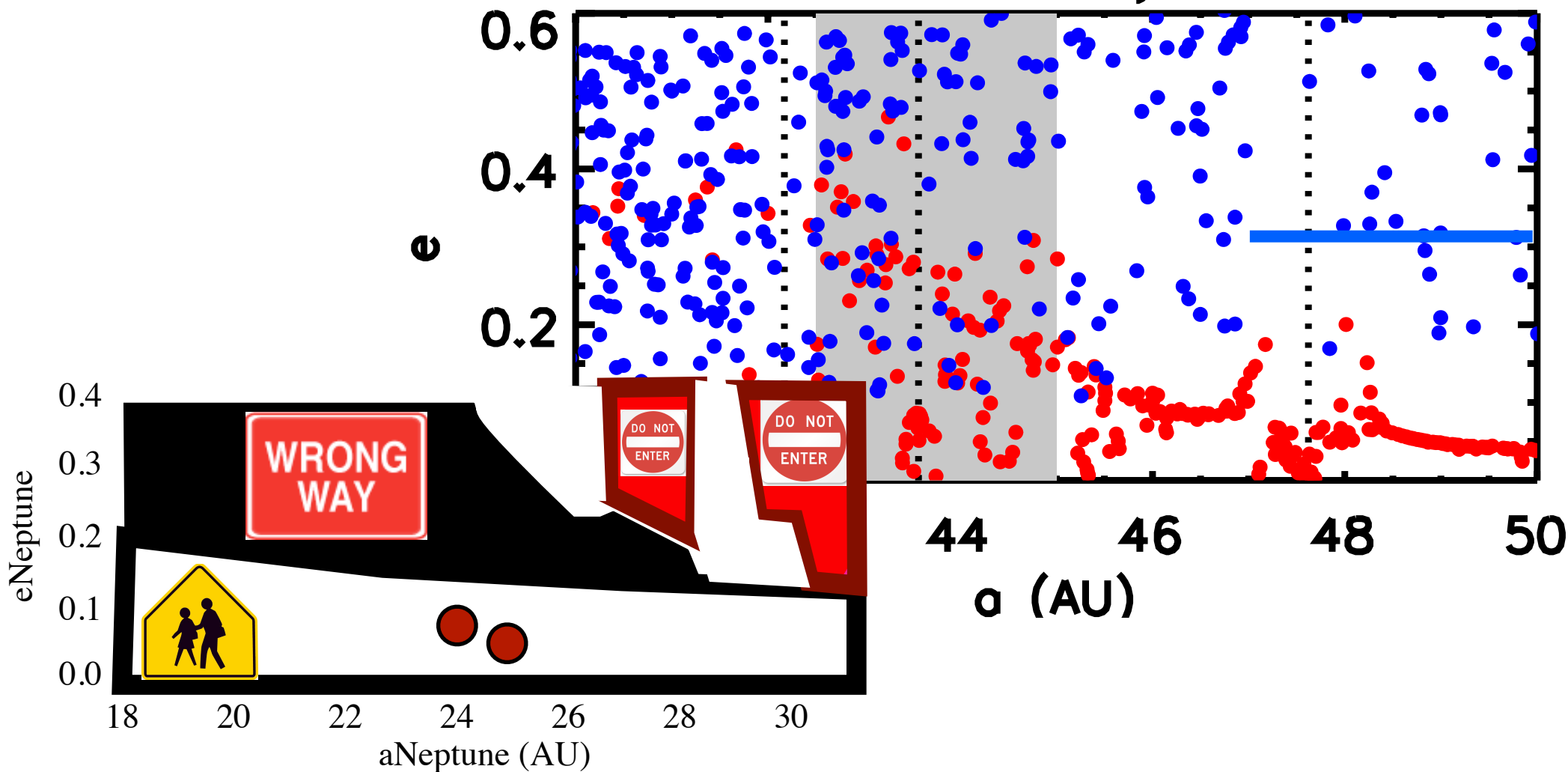
-Cold can get disrupted by Neptune's secular forcing





-Colds disrupted by
fast secular forcing near resonances
- Hots delivered

0.16 Myr



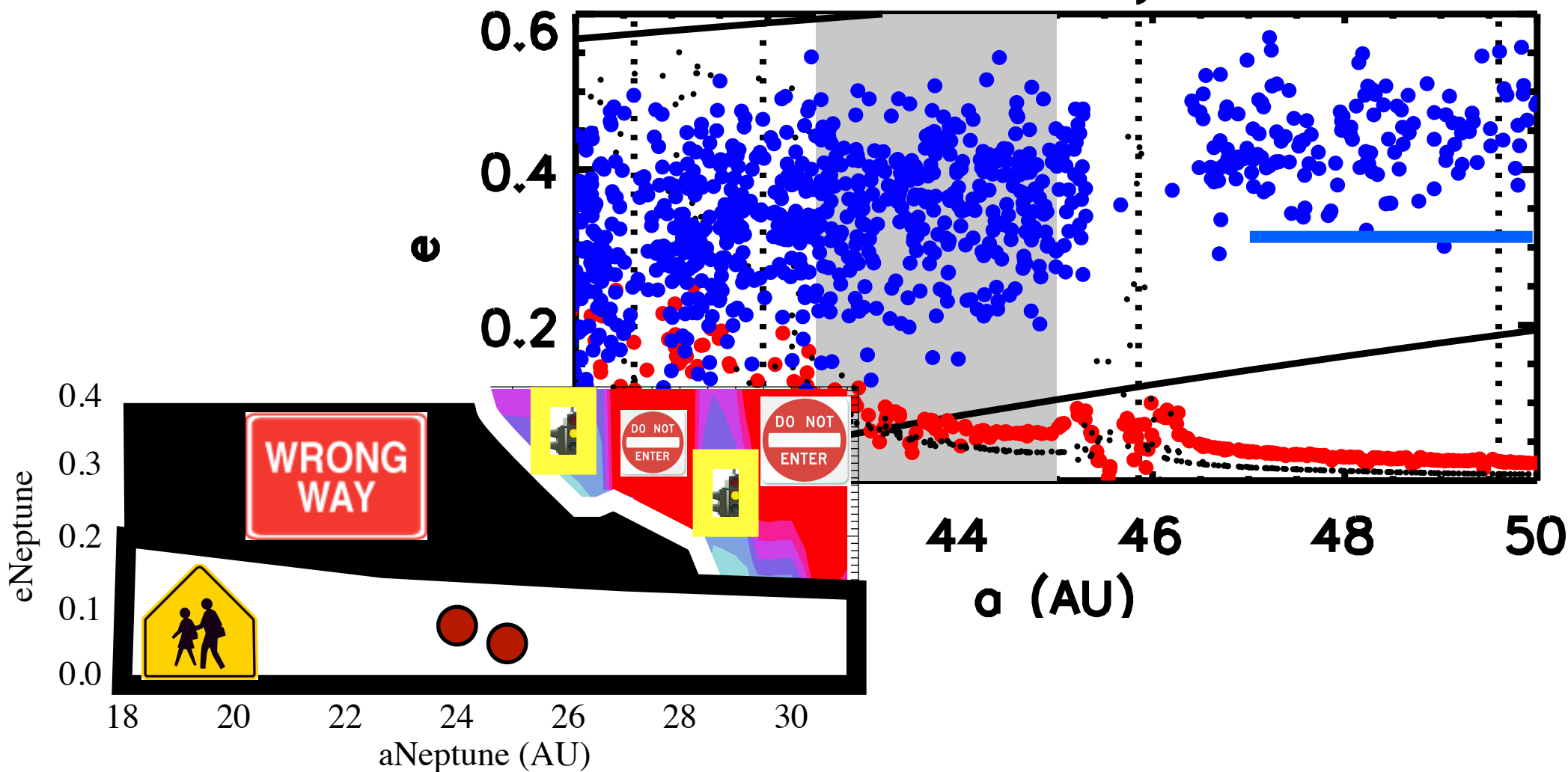


-Colds preserved **if** Neptune's eccentricity damps quickly (<0.4 Myr)

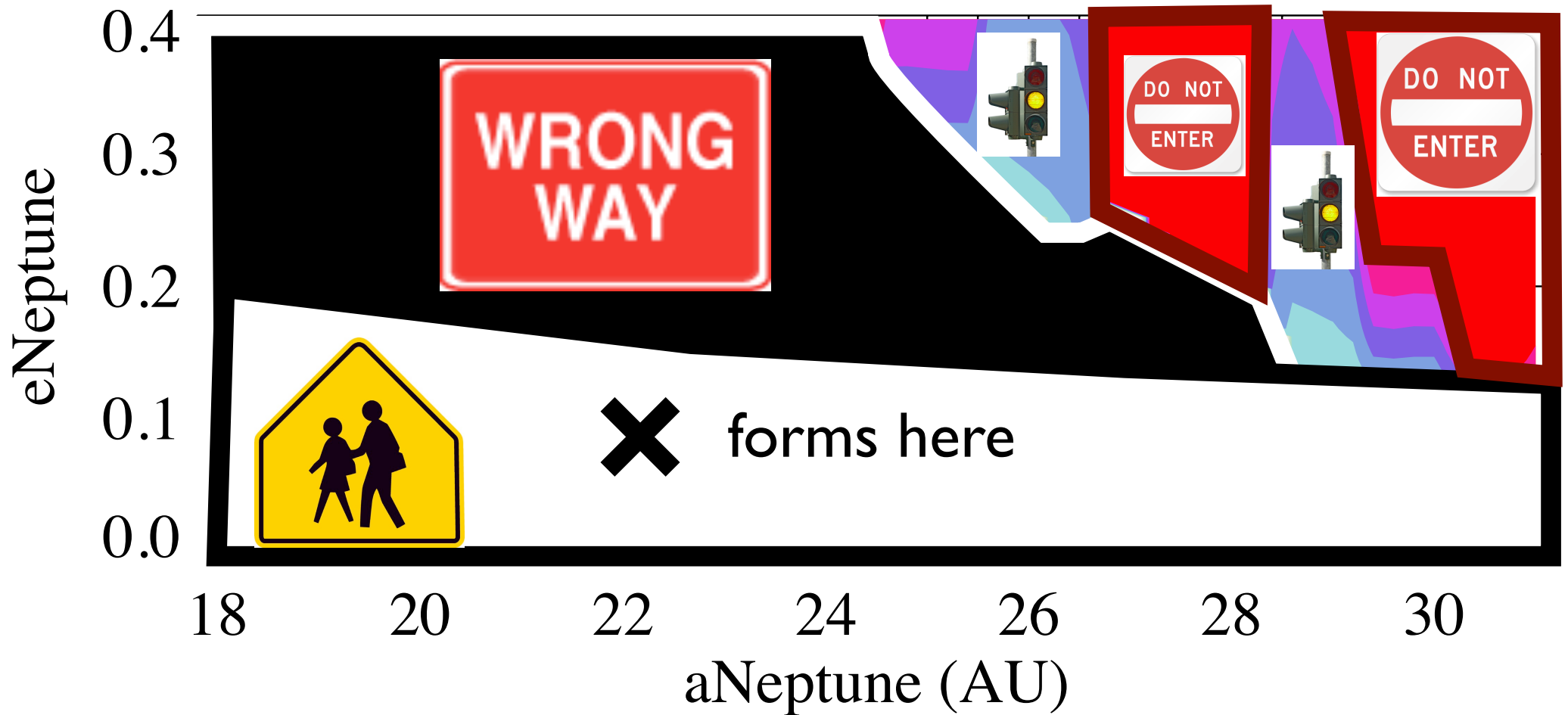


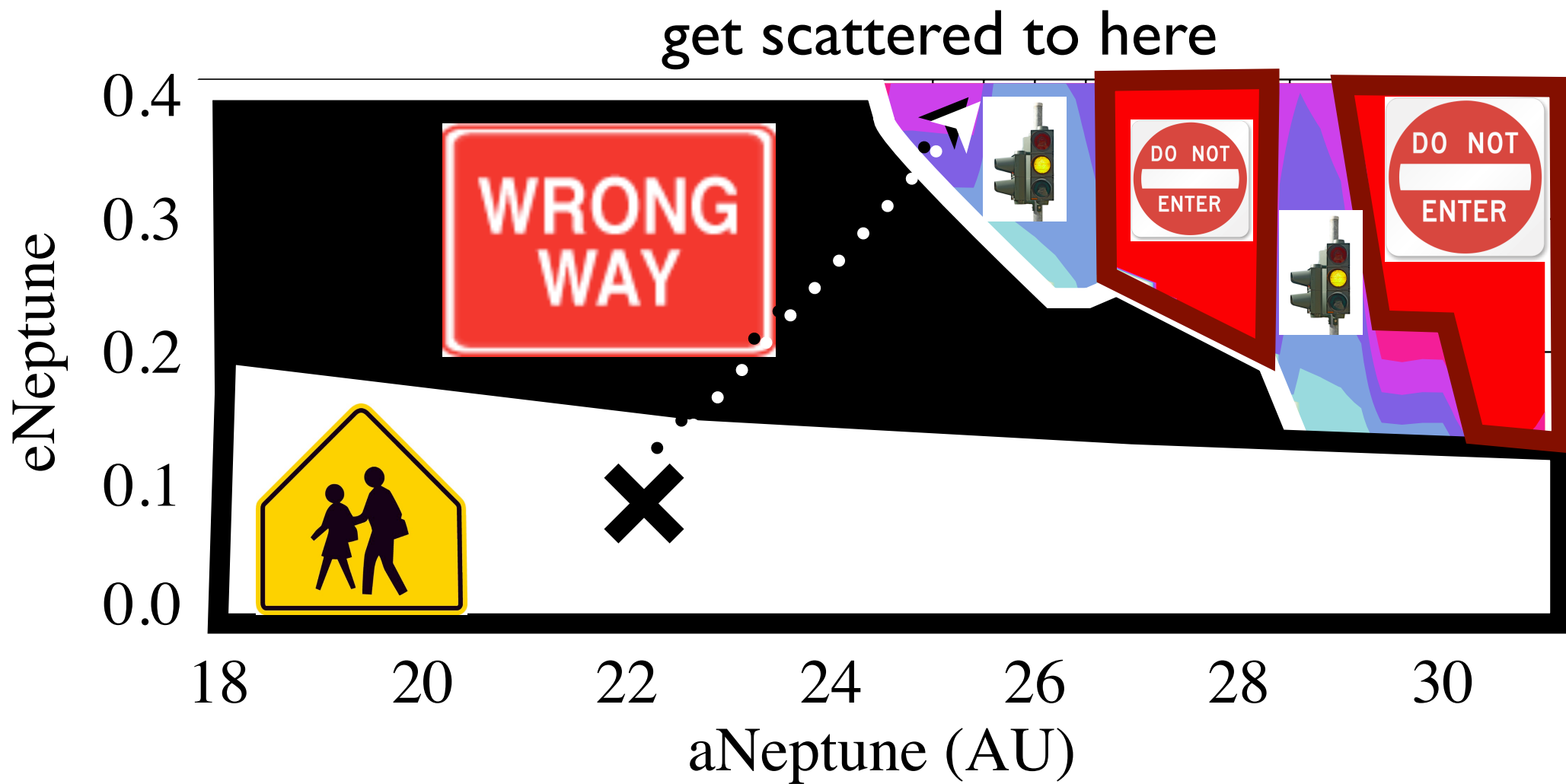
- Hots delivered

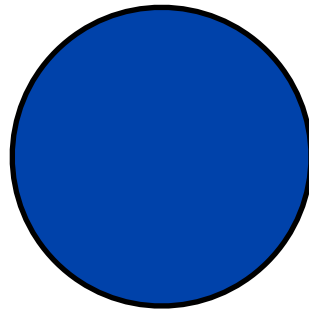
0.44 Myr



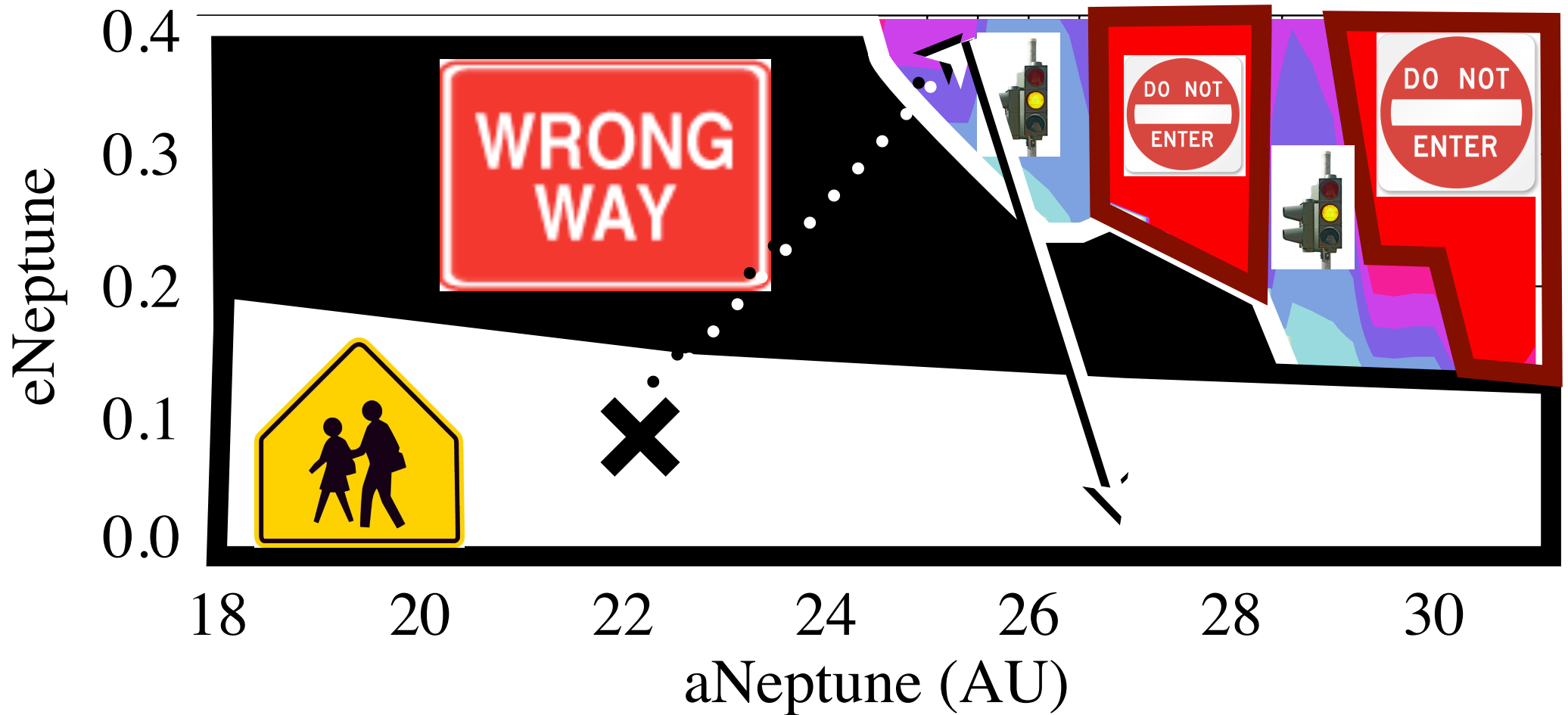
Choose your own dynamical adventure for Neptune



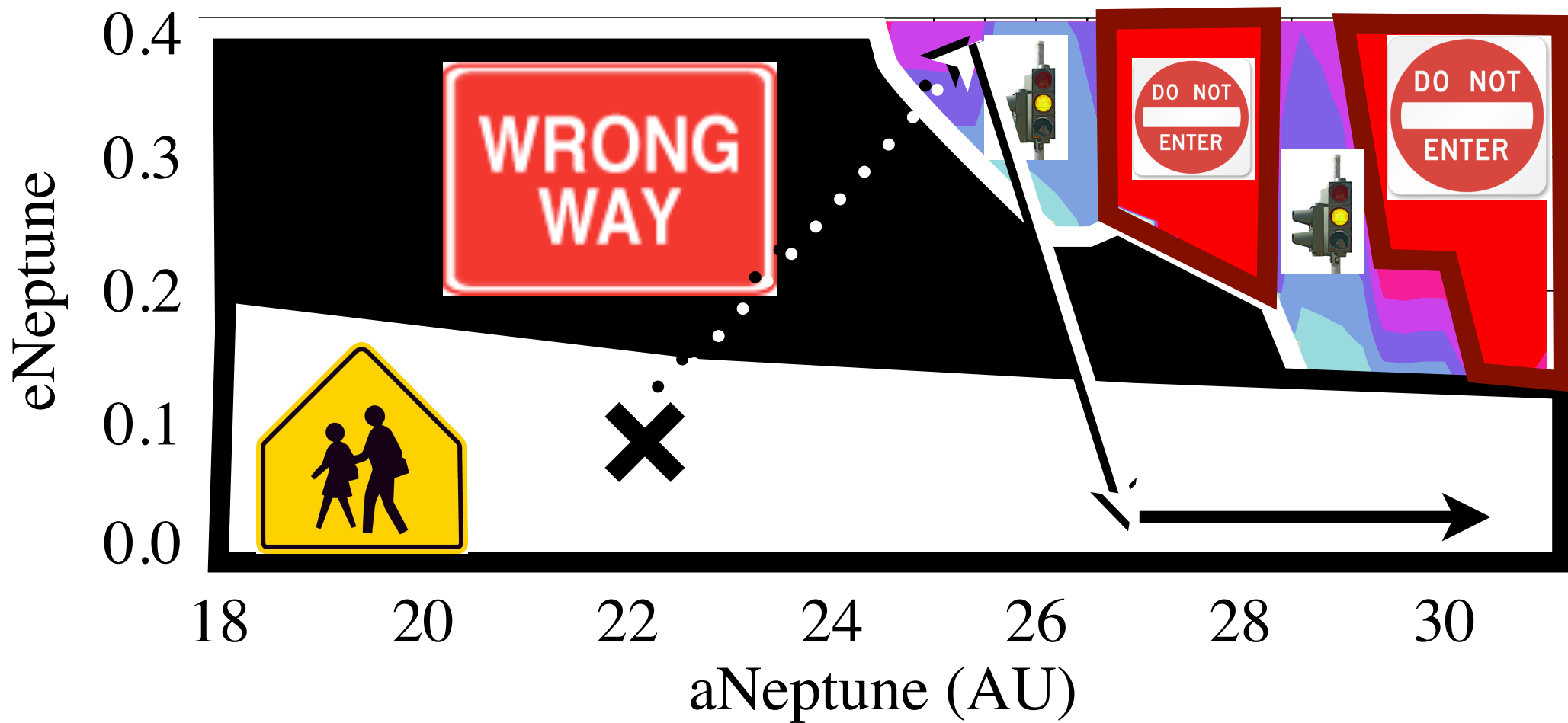




delivers hots and quickly damps



migrates to current location



NEPTUNE'S WILD DAYS

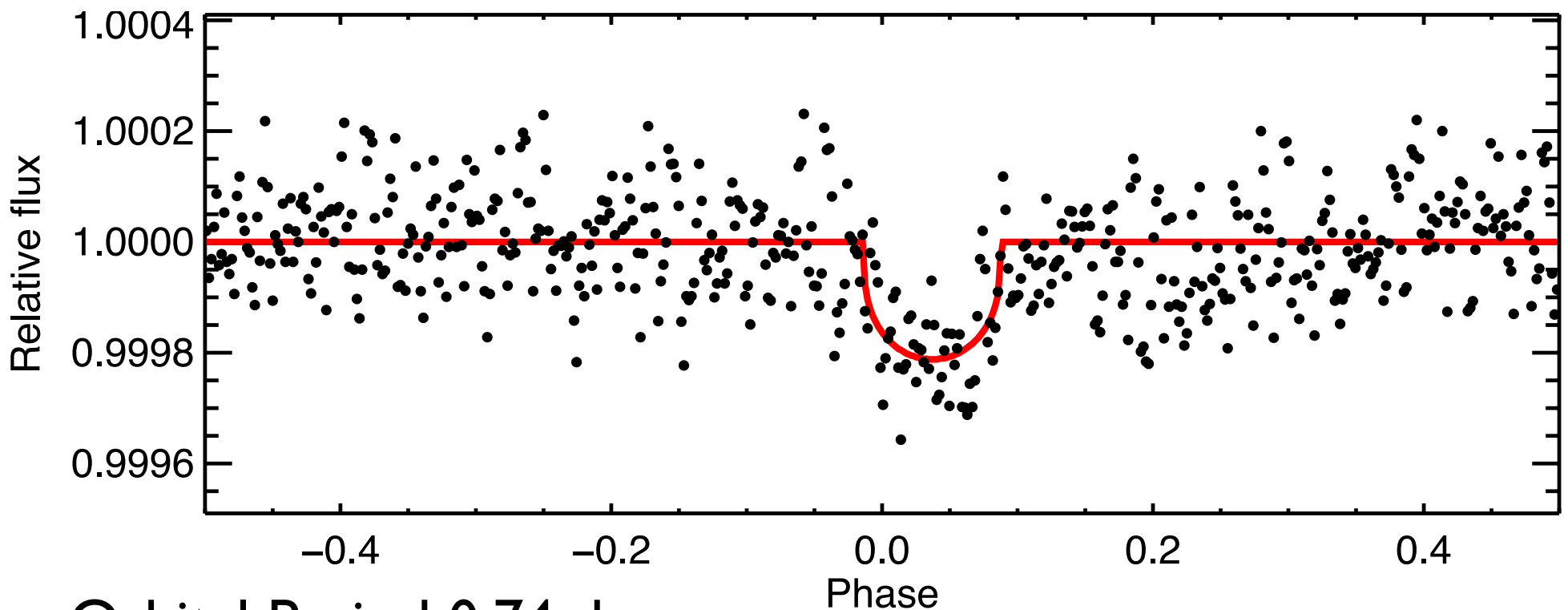
- Analytical constraints from Kuiper Belt allowed us to rule out much of parameter space: useful for extensive models
 - Neptune scattered to $e > 0.15$
 - Dynamical friction damps Neptune's eccentricity quickly (less than 0.4 Myr).
 - Neptune scattered to ~ 1 - 6 AU of its current location and migrates this short distance
 - Neptune's eccentricity damps before it undergoes substantial migration
- scattering and migration both place a role
- dense planetesimal disk

R. Dawson, May 2nd, 2011, Exploring Strange New Worlds

55 Cnc e: a super-hot super-dense Super-Earth transiting a naked eye star

$$8.57 \pm 0.64 M_{\oplus} \quad 1.63 \pm 0.16 R_{\oplus} \quad 10.9 \pm 3.1 \text{ g cm}^{-3}$$

Winn, Matthews, Dawson, Fabrycky, Holman, Kallinger, Kuschnig, Sasselov,
Dragomir, Guenther, Moffat, Rowe, Rucinski, Weiss, submitted/arXived



Orbital Period 0.74 days
(Dawson and Fabrycky 2010)

See Diana Dragomir's poster for
more about MOST transit searches

