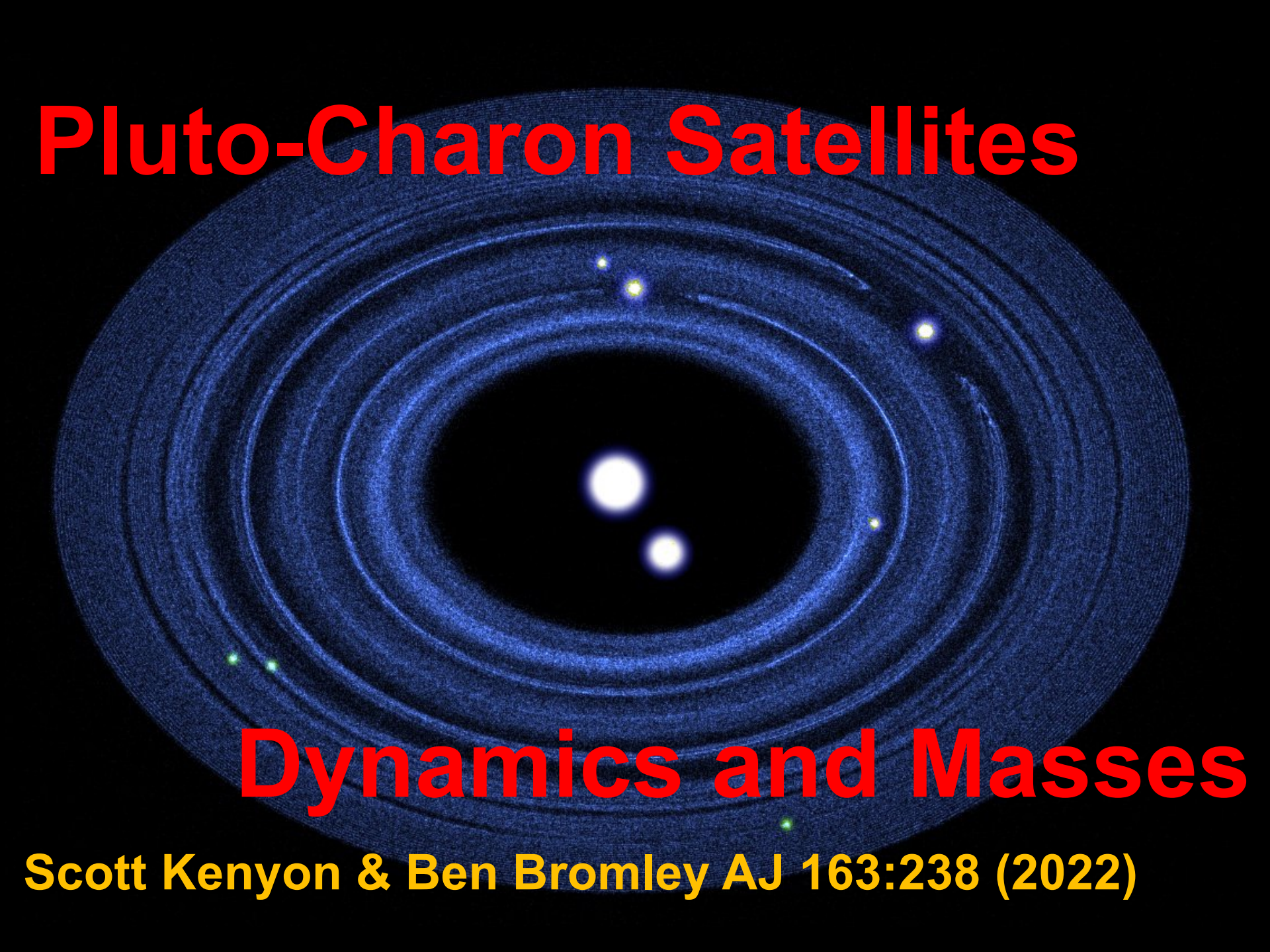


Pluto-Charon Satellites

Dynamics and Masses

Scott Kenyon & Ben Bromley AJ 163:238 (2022)

Project Goals

- Satellite masses & orbital stability
- Circumbinary dynamics
- Formation models

N-Body Calculations

- Brozovic+ state vector from HST

  initial positions and velocities
- Symplectic integrator
- Vary satellite masses
- Identify stable systems (4.5 Gyr)

  257 billion P-C orbits
- Lifetimes for unstable systems

Nominal (adopted) masses

- $M_{\{S,N,K,H\}}$ (units of 10^{18} grams)

- Styx: 0.6 ($\rho \sim 1$ gcm^{-3})
- Nix: 45 (Brozovic, $\rho \sim 1.5$ gcm^{-3})
- Kerberos: 0.9 ($\rho \sim 1$ gcm^{-3})
- Hydra: 48 (Brozovic, $\rho \sim 1.25$ gcm^{-3})

Kenyon & Bromley 2019

Varying Satellite Masses

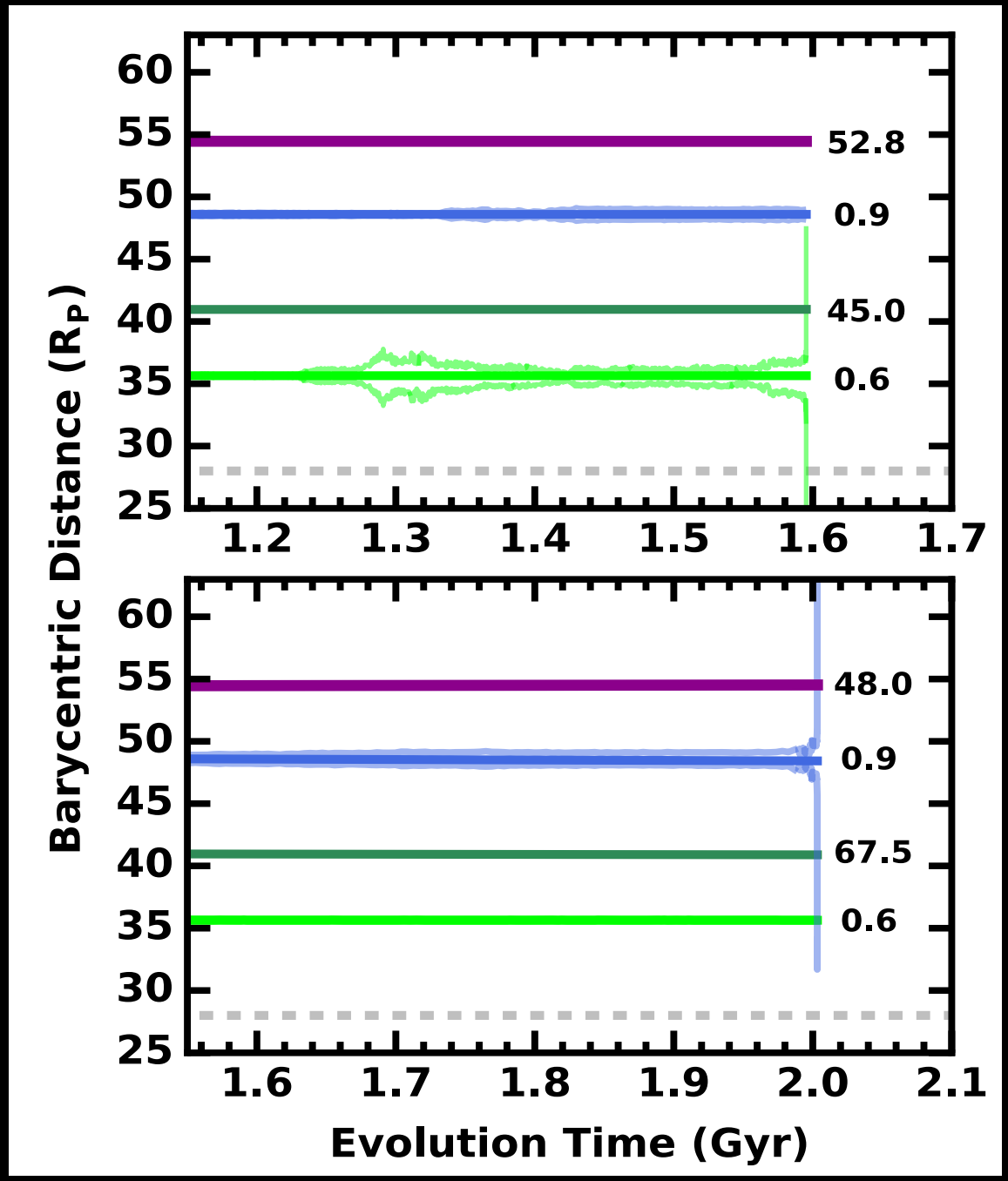
- For all satellites

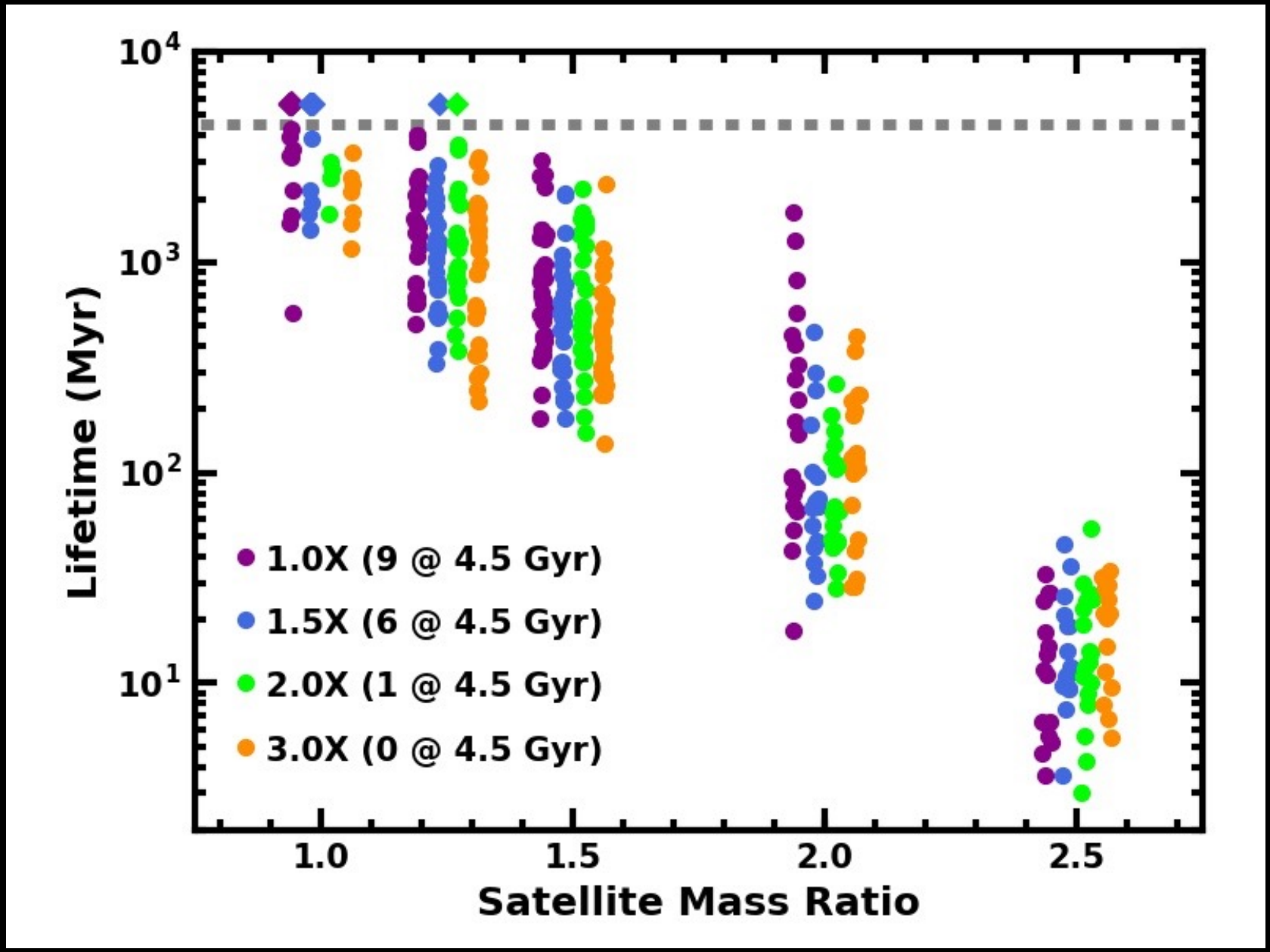
  $mass = f * m_{\{S,N,K,H\}}$

- For one satellite (sometimes two)

  $mass = f_{\{S,N,K,H\}} * m_{\{S,N,K,H\}}$

  others have their adopted mass


Barycentric Distance (R_P)
60
55
50
45
40
35
30
25
52.8
0.9
45.0
0.6
1.2
1.3
1.4
1.5
1.6
1.7
48.0
0.9
67.5
0.6
1.6
1.7
1.8
1.9
2.0
2.1
Evolution Time (Gyr)


10^4
10^3
10^2
10^1
Lifetime (Myr)
1.0X (9 @ 4.5 Gyr)
1.5X (6 @ 4.5 Gyr)
2.0X (1 @ 4.5 Gyr)
3.0X (0 @ 4.5 Gyr)
1.0
1.5
2.0
2.5
Satellite Mass Ratio

Latest Mass Estimates

- Nix, Hydra
  - <= nominal mass
- Styx, Kerberos
  - <= 1.5X nominal mass
- System mass < 9.5×10^{19} g
  - <= sum of nominal masses
- Bulk density < 1.4 gcm^{-3}

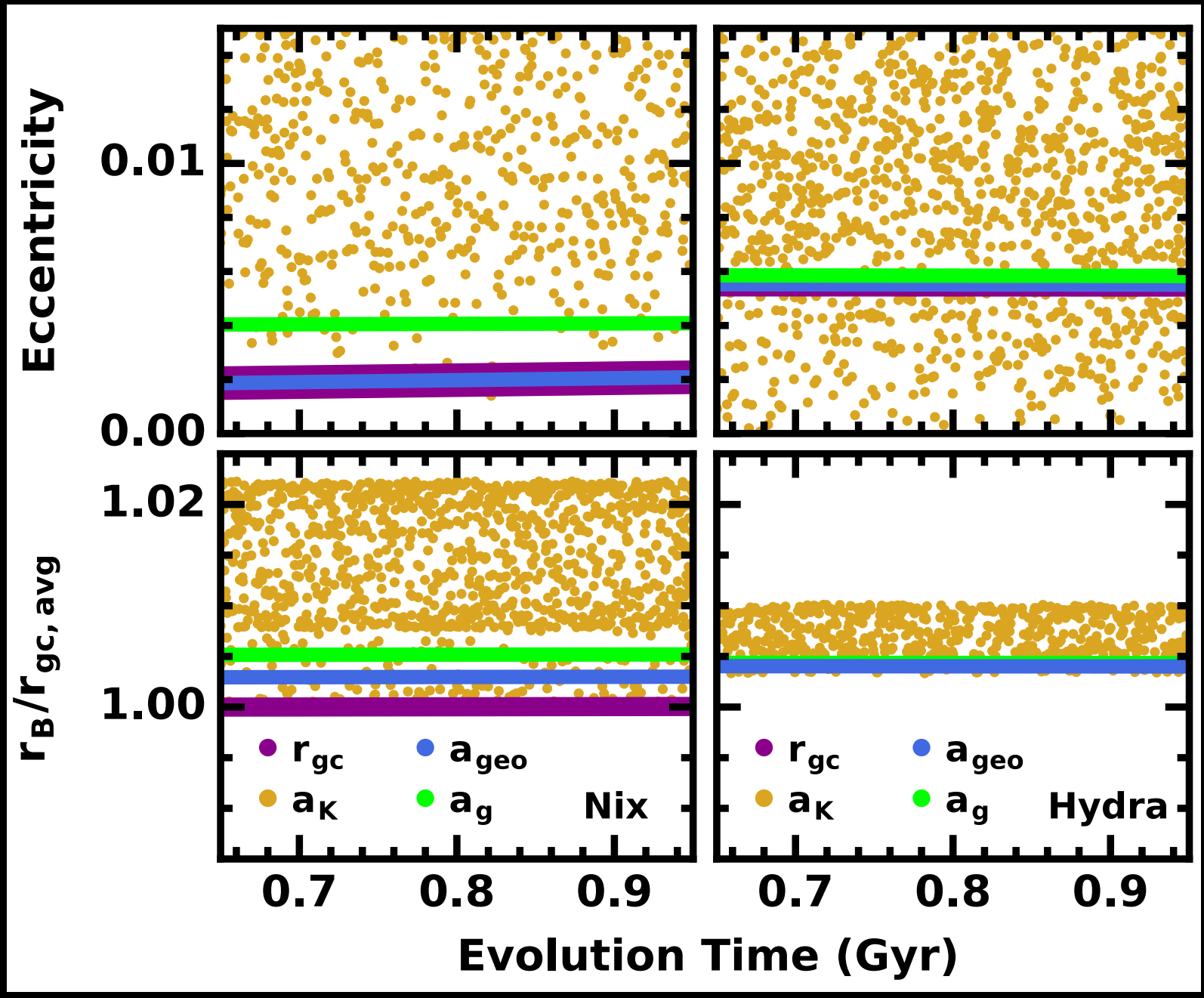
Eccentricity

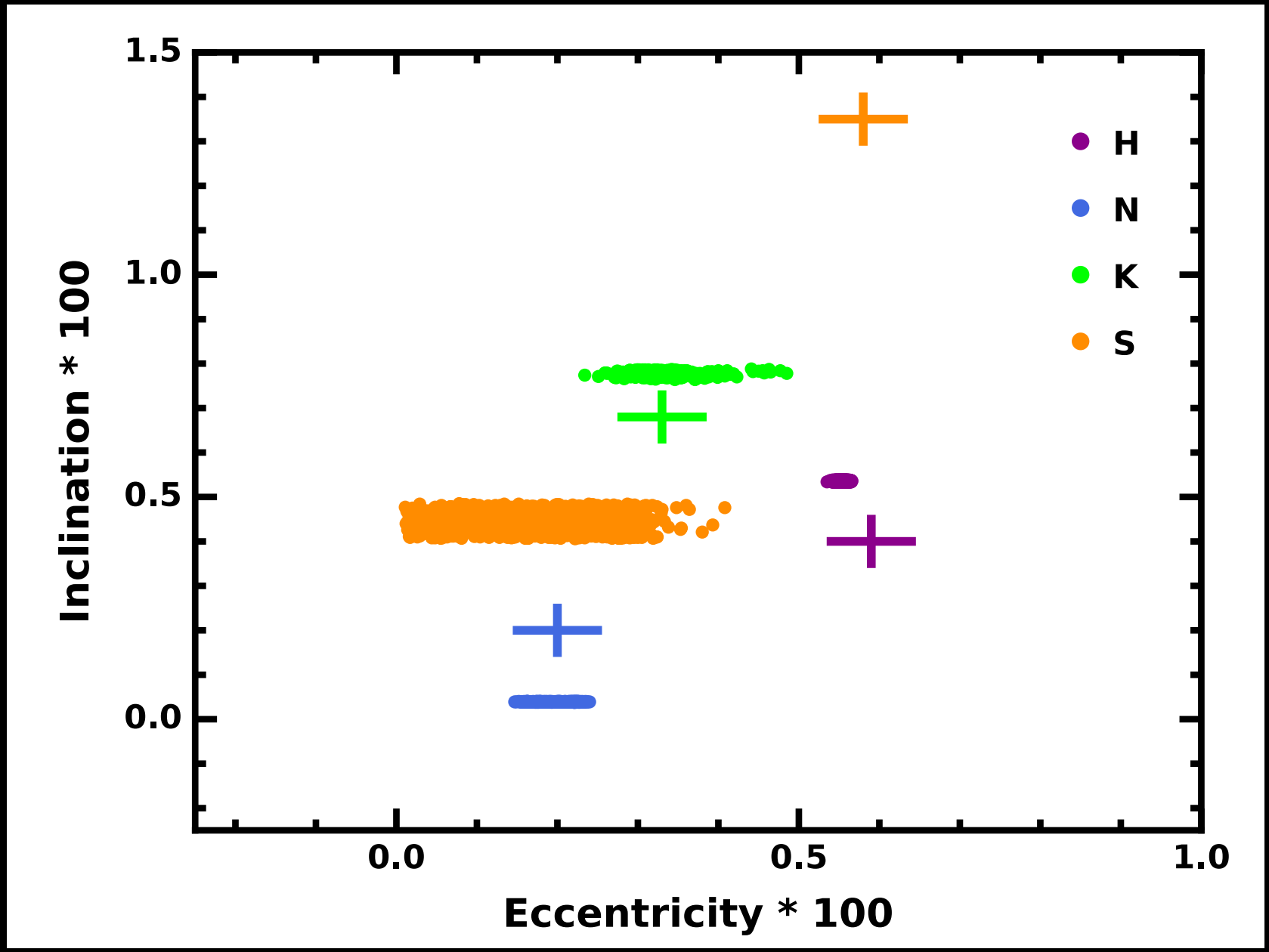
- Measurement from state vectors

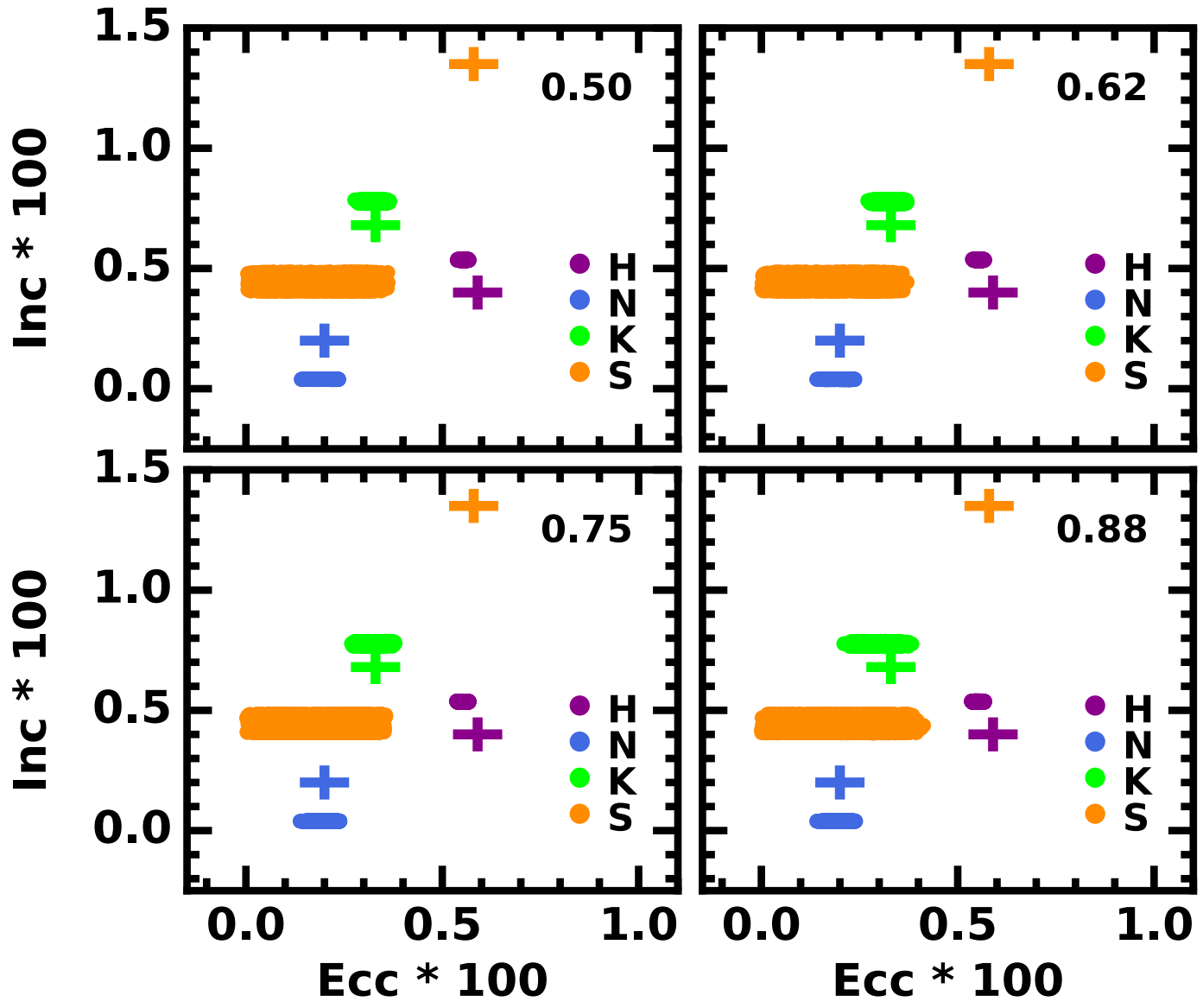
- Keplerian (single: v, R, and L)
- Numerically (many: R_{min} and R_{max})
- Restricted Three Body Problem

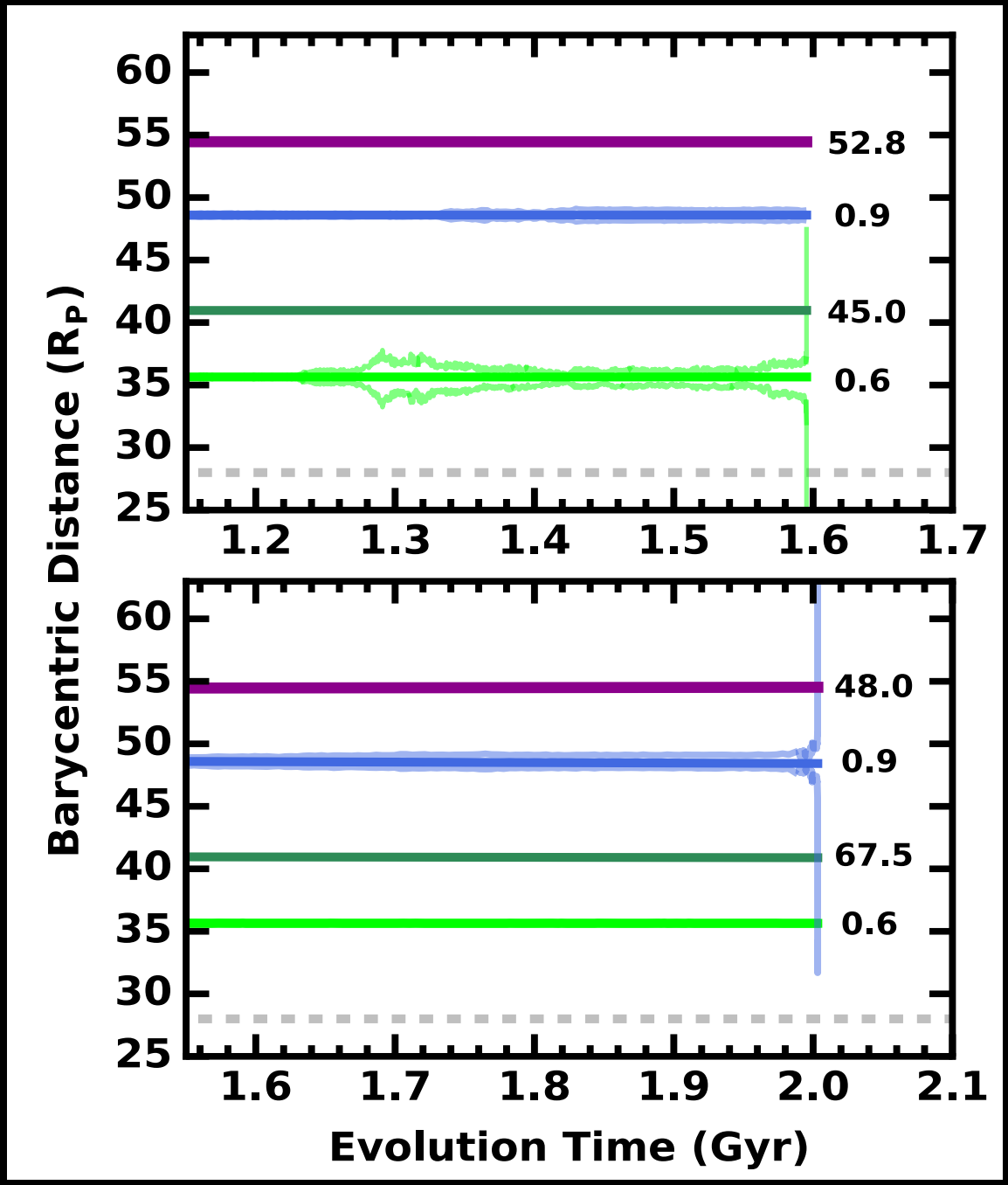
  Lee & Peale (2006)

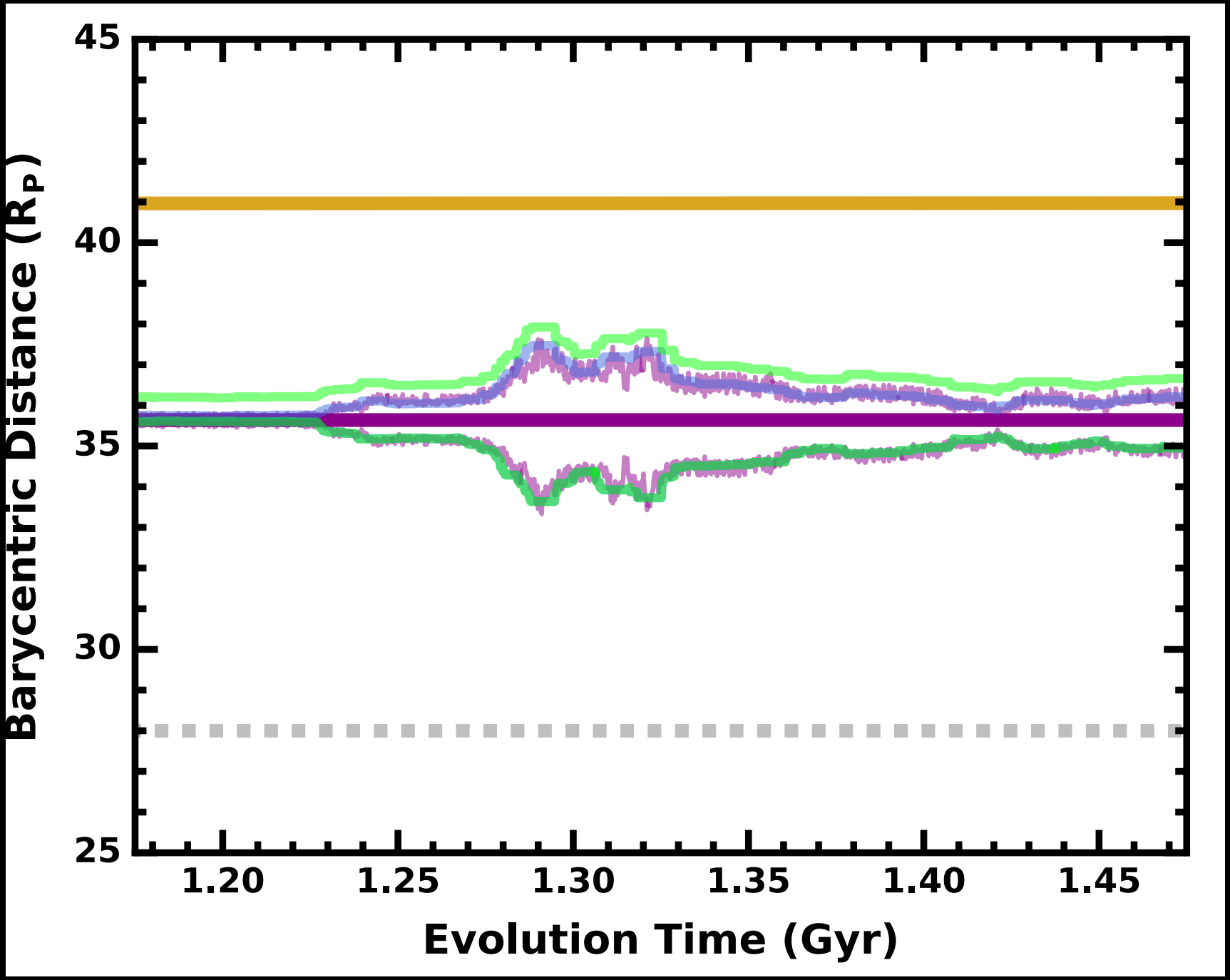
  single: Bromley & Kenyon (2021)

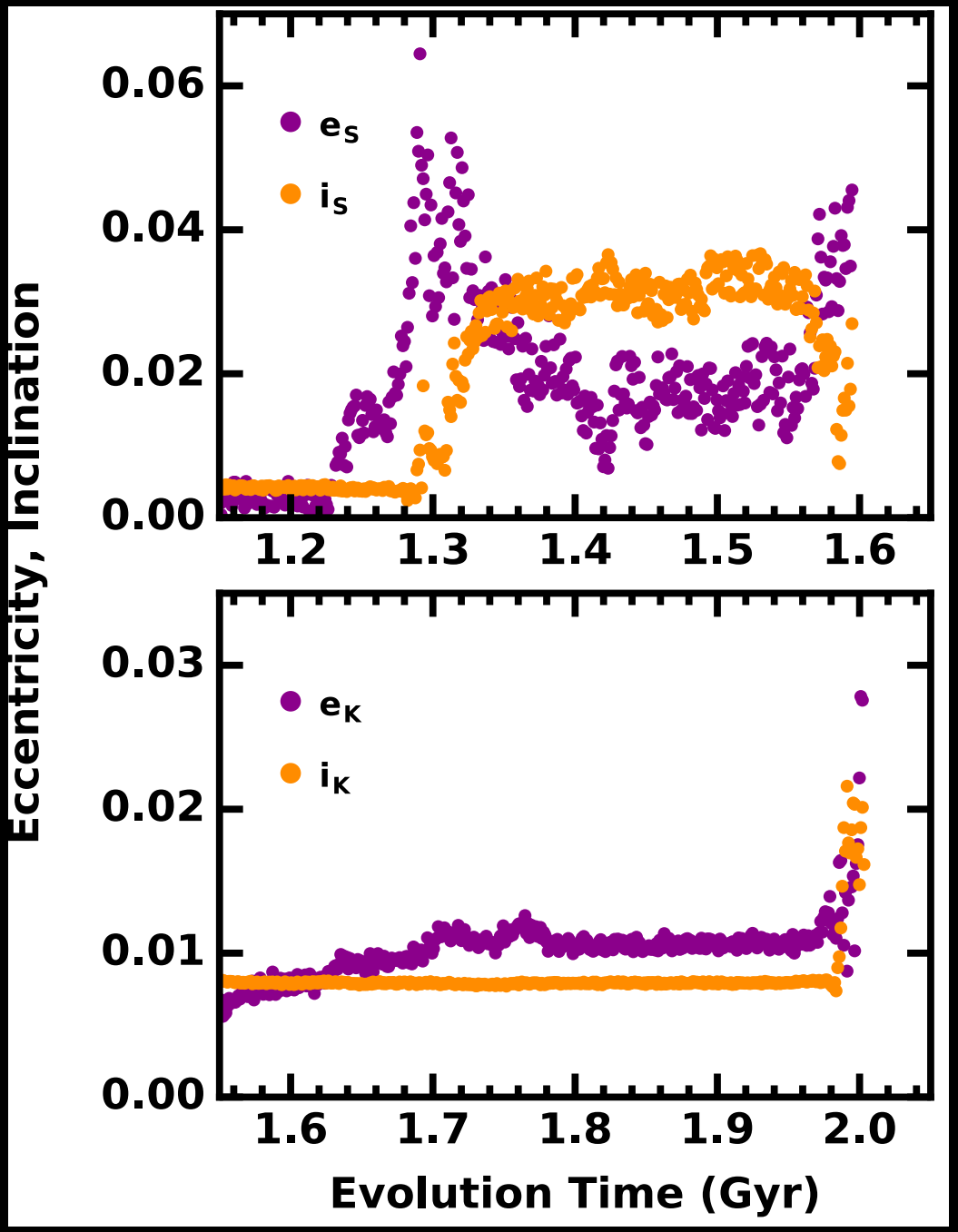

Eccentricity
0.01
0.00
$r_B/r_{gc,avg}$
1.02
1.00
r_{gc}
a_{geo}
a_K
a_g
Nix
Hydra
0.7
0.8
0.9
Evolution Time (Gyr)


1.5
1.0
0.5
0.0
Inclination * 100
0.0
0.5
1.0
Eccentricity * 100
H
N
K
S


0.50
0.62
0.75
0.88
H
N
K
S
Inc * 100
Ecc * 100
0.0
0.5
1.0
1.5


Barycentric Distance (R_P)
60
55
50
45
40
35
30
25
52.8
0.9
45.0
0.6
1.2
1.3
1.4
1.5
1.6
1.7
48.0
0.9
67.5
0.6
1.6
1.7
1.8
1.9
2.0
2.1
Evolution Time (Gyr)


45
40
35
30
25
Barycentric Distance (R_P)
1.20
1.25
1.30
1.35
1.40
1.45
Evolution Time (Gyr)


Eccentricity, Inclination
0.06
0.04
0.02
0.00
e_S
i_S
1.2
1.3
1.4
1.5
1.6
0.03
0.02
0.01
0.00
e_K
i_K
1.6
1.7
1.8
1.9
2.0
Evolution Time (Gyr)

Results

- Nix/Hydra

  <= nominal masses
- Styx/Kerberos

  <= 1.5X nominal masses
- N-Body calcs match HST e & i
- Chaotic Dynamics

Next Steps

- Limits on satellites outside Hydra
- Origin of e, i, near-resonant orbits
  Primordial or Evolutionary?