Lille Observatory Workshop
« Dynamics and Formation of the Oort Cloud »
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Searching the Catalogue of Cometary Orbits for evidence of an impulsive component of Oort cloud flux

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Overview

The flux of observed comets coming from the outer Oort comet cloud is due to a combination of perturbations from the quasi-steady state galactic tide and from impulses.

I. We present evidence that the tidal torque dominates this process at the present epoch using 17th Catalogue class 1A orbital data.

II. A systematic approach to search the data for any component of the comet flux that is associated with a weak impulse is then described. *This approach involves a non-standard analysis of angular momentum distributions.*

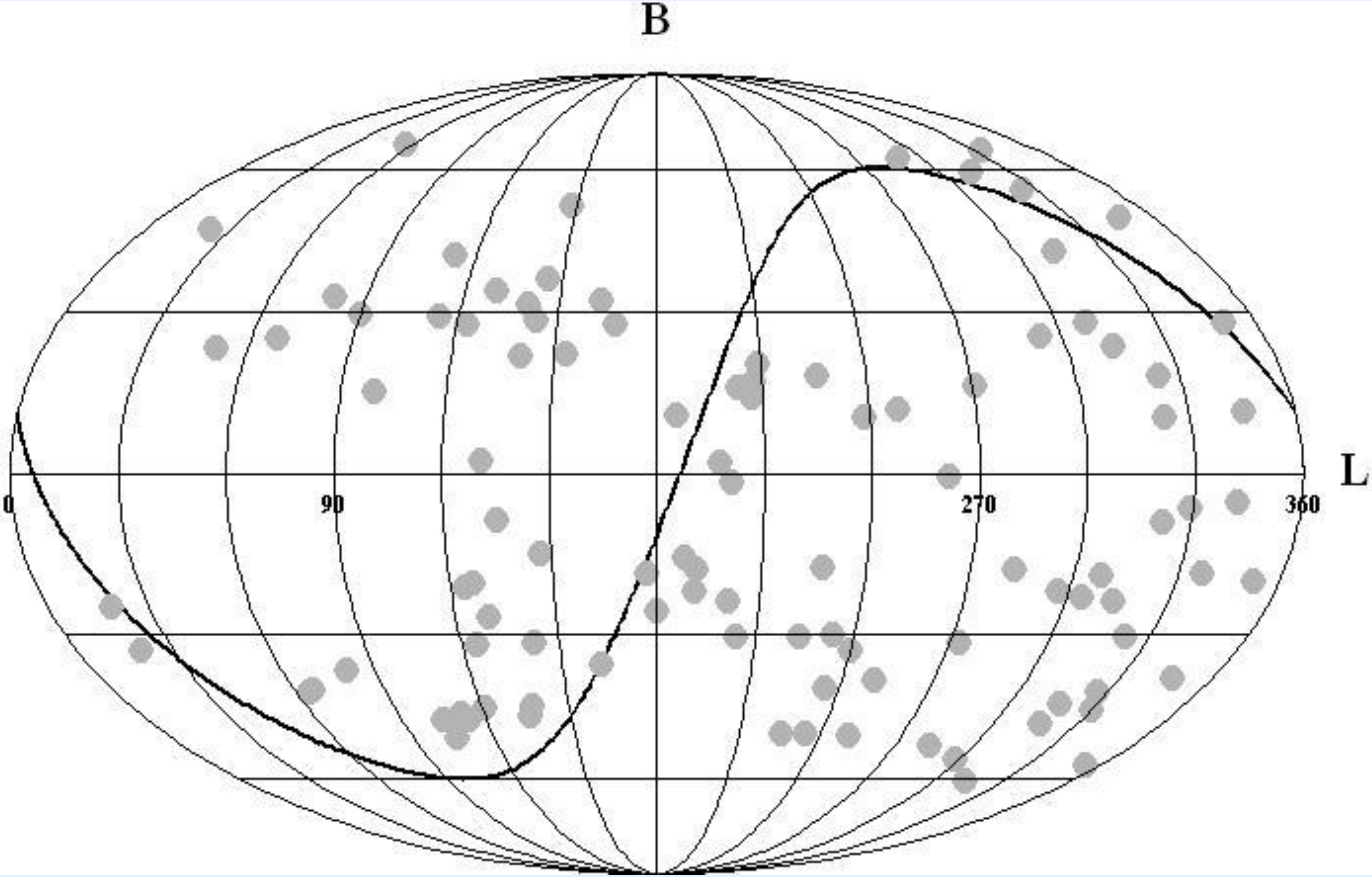
III. Finally, we discuss the possibility that such a component exists.

I. *Galactic tidal torque on comets*

- q, perihelion distance
- $\boldsymbol{H}$, specific angular momentum
- a , original semimajor axis

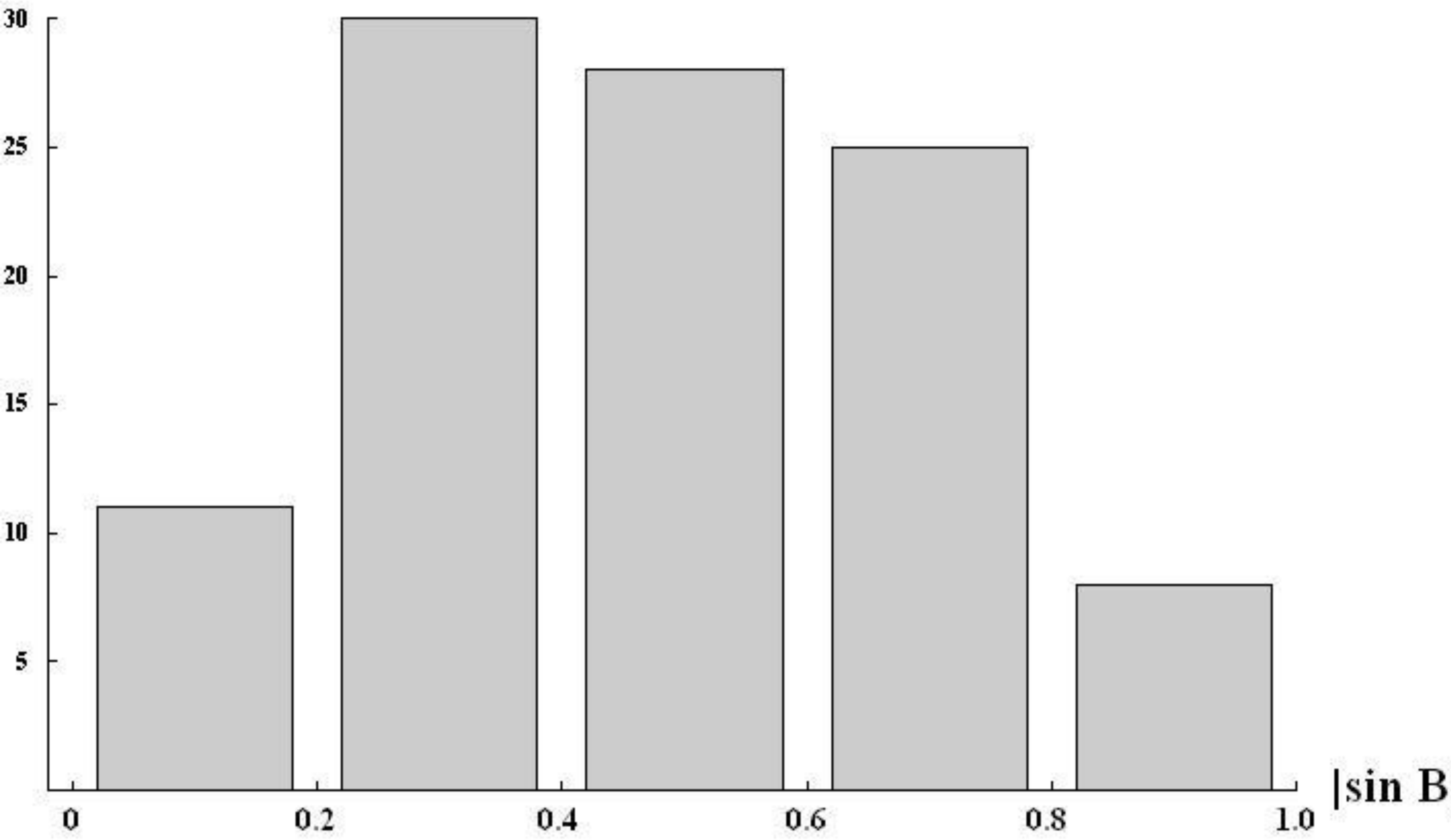
- To make a near-parabolic Oort cloud comet discernable, reduce q
- Galactic tidal change in $\boldsymbol{H}$ per orbit $\propto a^{7/2}$
- Galactic tidal torque is small at galactic poles and equator and near uniform in longitude
- So, if $\boldsymbol{H}$ is changed mainly by galactic disk tidal torque then we should see (i) deficiencies of major axes at poles and equator and (ii) a strong dependence on a

Aphelia directions of class 1A outer Oort cloud comets
Marsden's 17th Catalogue of Cometary Orbits



Aphelia distribution in galactic latitude

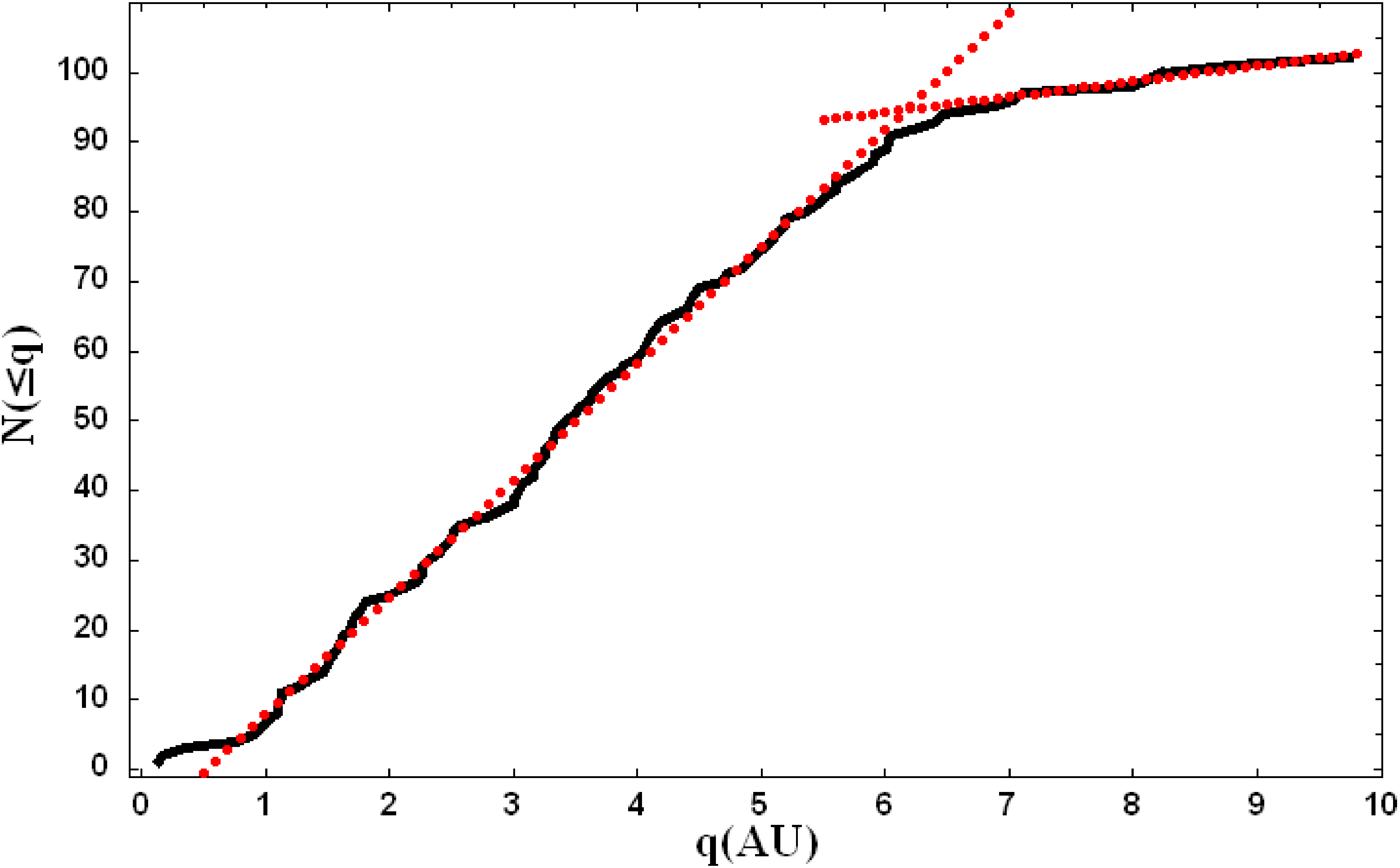
(random distribution is uniform in $\sin B$)



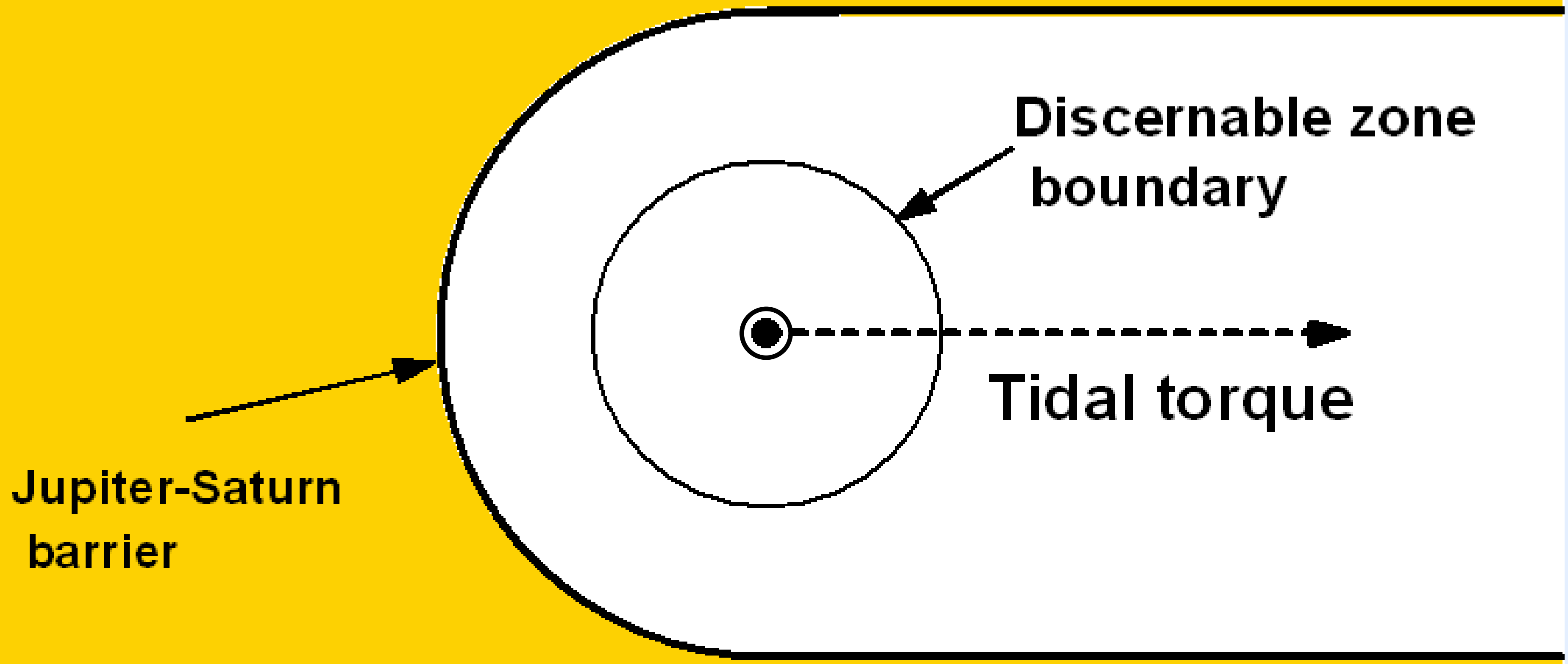
The loss cylinder (loss circle) model and the angular momentum distribution analysis

- The Jupiter-Saturn dynamical barrier concept ~ 12-15 AU
- The discernable (*i.e.* observable) zone concept ~ 5-6 AU
- As a comet leaves the planetary region on its prior orbit, specify the semimajor axis (a), the perihelion passage time, and the major axis orientation (**Q**): these four orbital properties are *essentially unchanged* by the galactic tide in the course of a single orbit as it returns to the planetary region.
- The specific angular momentum phase space just outside the barrier is asymmetrically shaped by the tide and barrier and are the only two orbital properties that *are* significantly changed when the comet returns to the planetary region.
- All points in this phase space are *uniformly displaced* by the galactic tide in a single orbit.

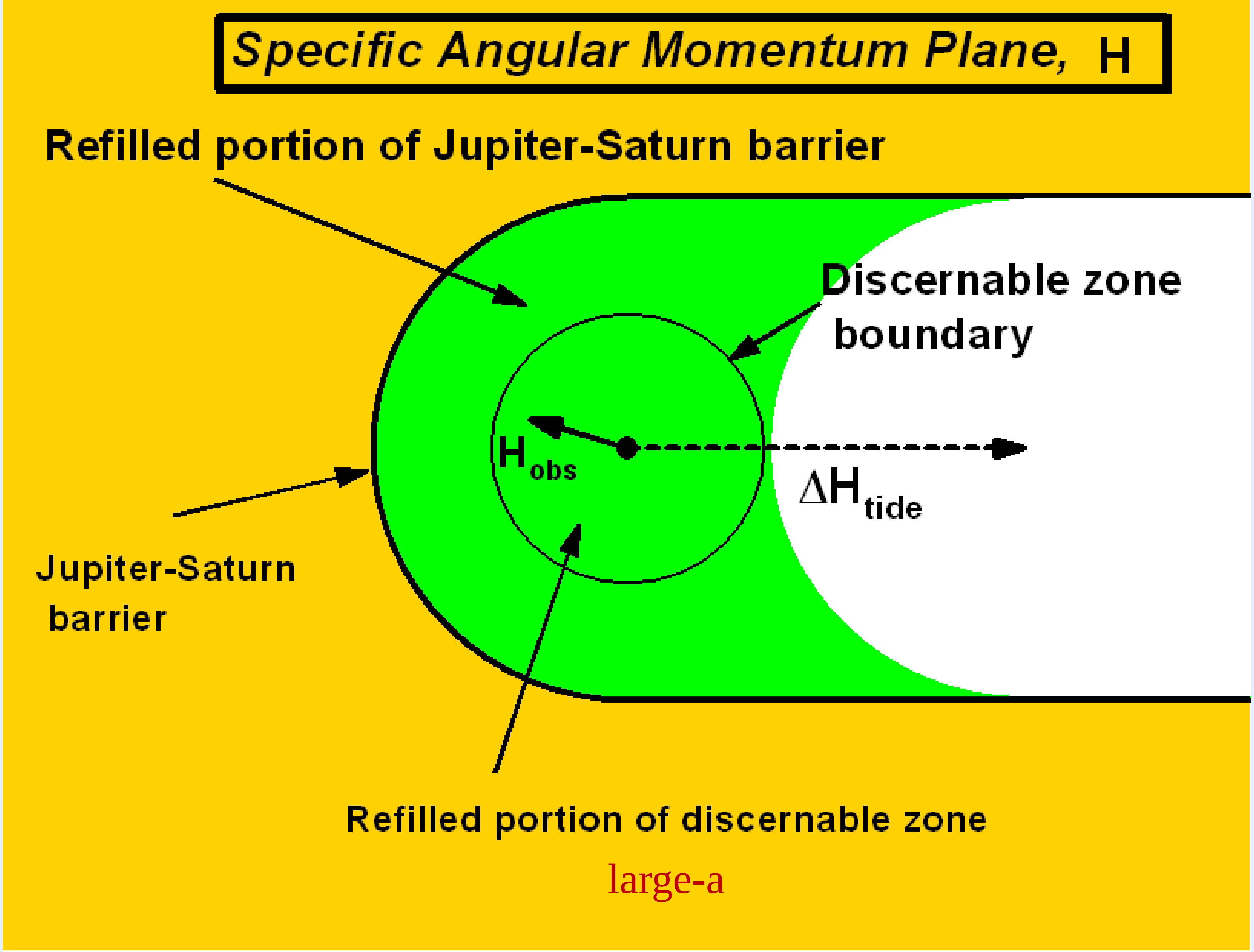
Discernable zone boundary ~ 6AU



Specific Angular Momentum Plane, H



Consider a fixed value of *a*. Orient the aphelia direction out of the plane and the tidal torque to the right. H phase space changes are then in the direction of torque. Comets with perihelia inside the barrier are removed from the OOC. Comets exterior to the barrier can be moved interior on the next perihelion passage as shown in the next slide.


Specific Angular Momentum Plane, H
Refilled portion of Jupiter-Saturn barrier
Discernable zone
boundary
H_{obs}
ΔH_{tide}
Jupiter-Saturn
barrier
Refilled portion of discernable zone
large-a

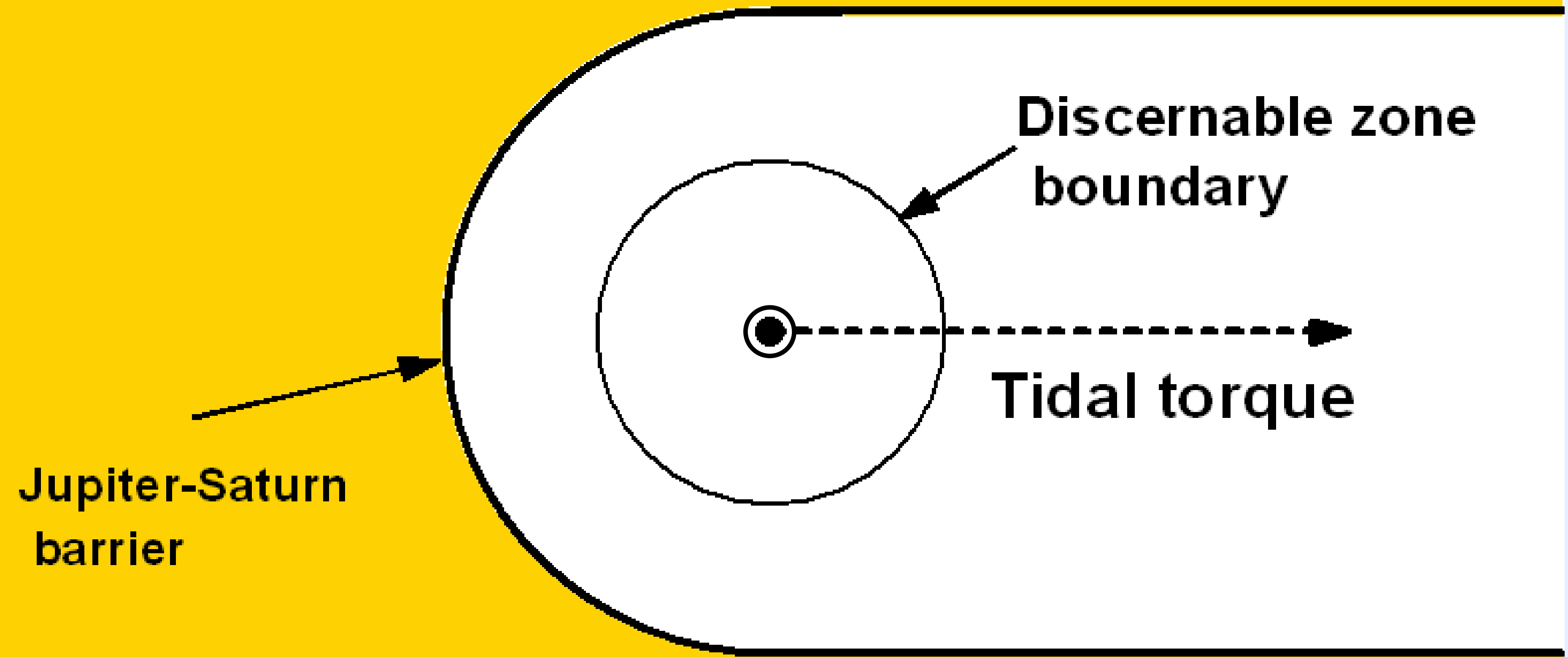
Another signature of galactic tidal dominance

Tidal characteristic, $S \equiv Sign[\Delta H_{tide} \bullet H_{observed}]$

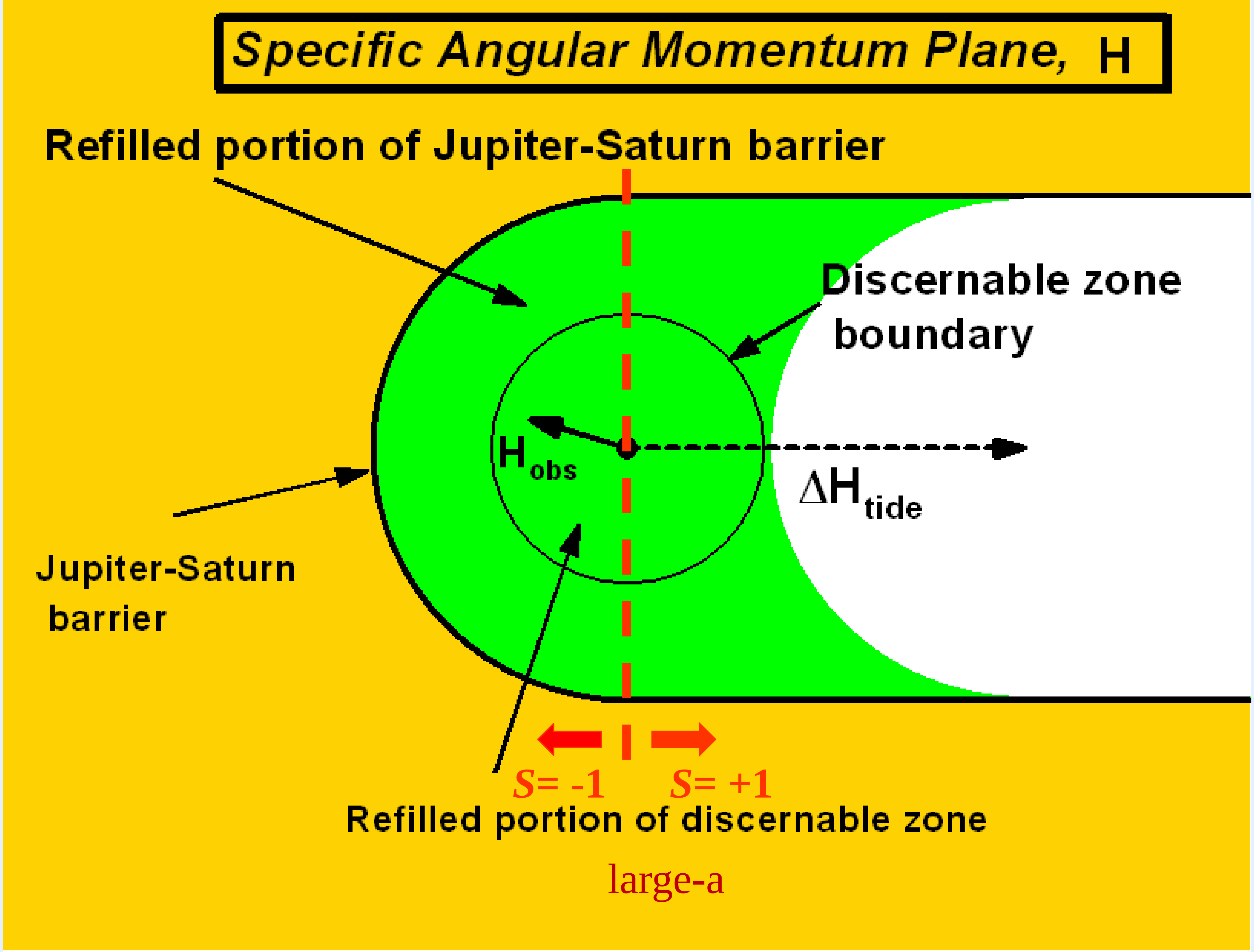
Galactic tidal change in H per orbit $\propto a^{7/2}$. If making Oort cloud comets discernable at the present epoch is indeed dominated by the galactic tidal interaction then we can expect three things to be true, two of which are observationally verifiable

- large-*a* comets ($\Delta H_{\mathrm{tide}} > H_{\mathrm{JSB}} + H_{\mathrm{DZB}}$) would equally likely have S = -1 or S = +1
- intermediate-*a* comets would more likely have S = -1 than S = +1
- ○ small-*a* comets ($\Delta H_{\mathrm{tide}} < H_{\mathrm{JSB}} - H_{\mathrm{DZB}}$) are unlikely to be both truly new comets and due to the galactic tide

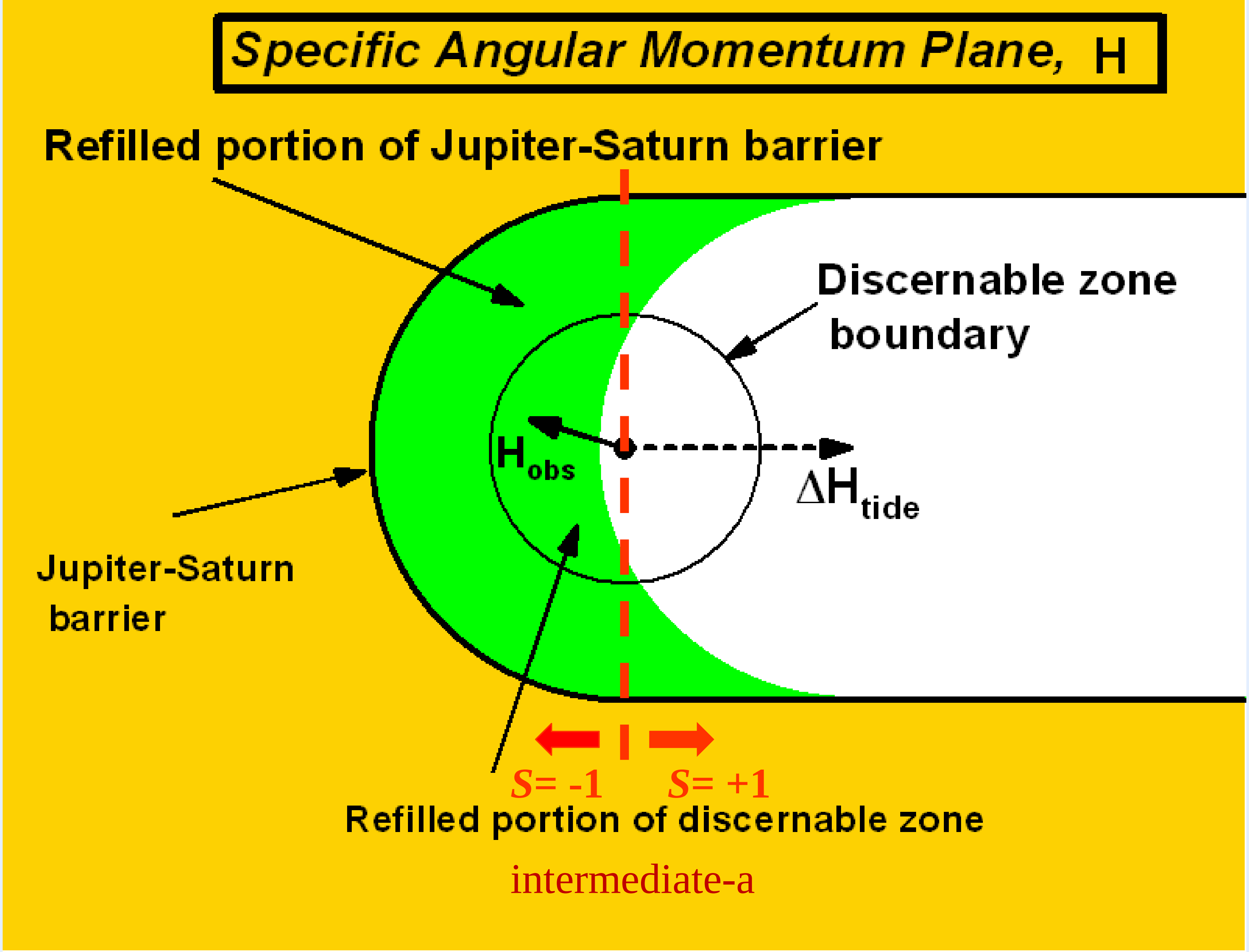
Specific Angular Momentum Plane, H

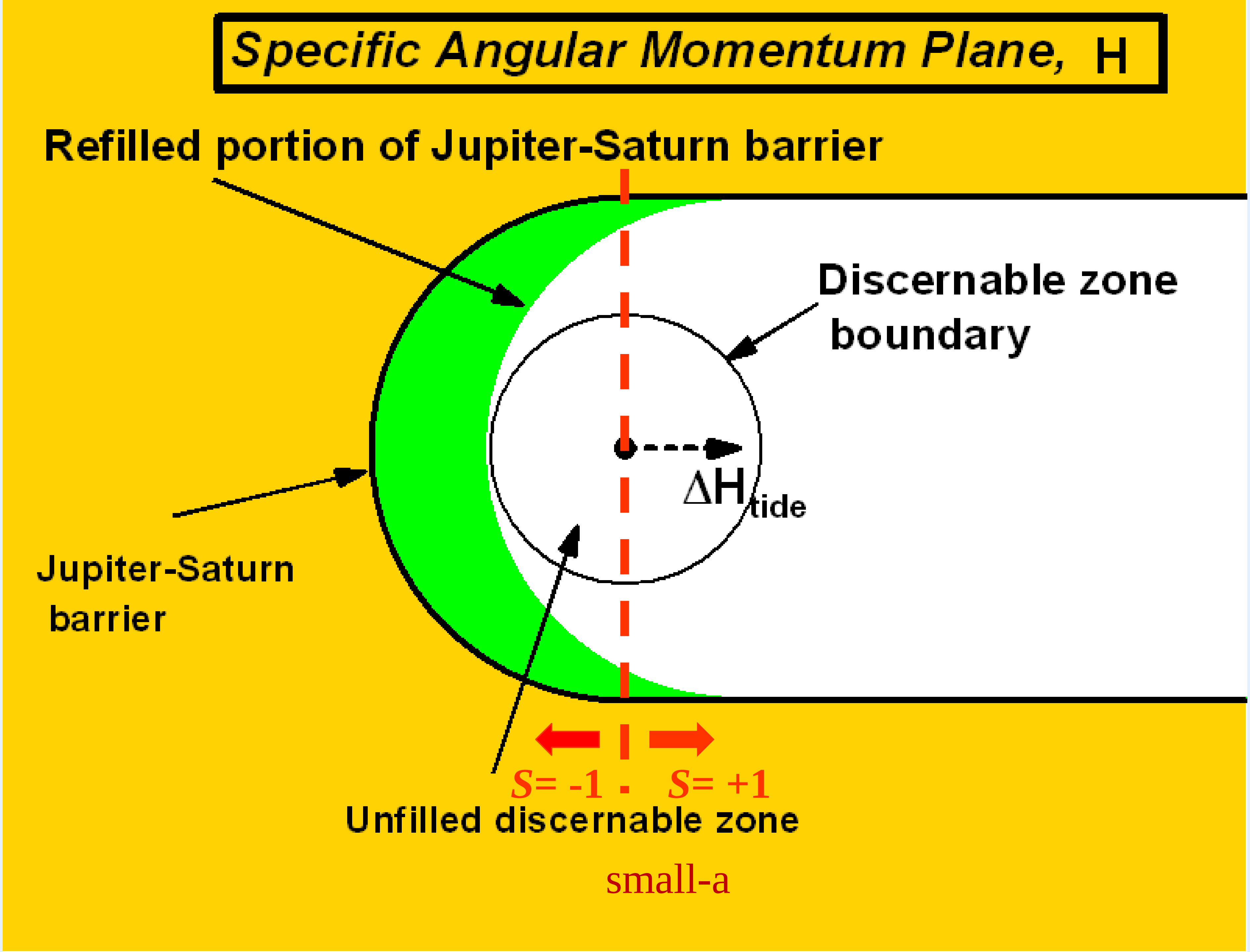


Orient major axis out of the plane, and tidal torque to the right. H phase space changes are then in the direction of torque. Comets with perihelia inside the barrier are removed from the OOC. Comets exterior to the barrier can be moved interior on the next perihelion passage as shown in next sets of slides.

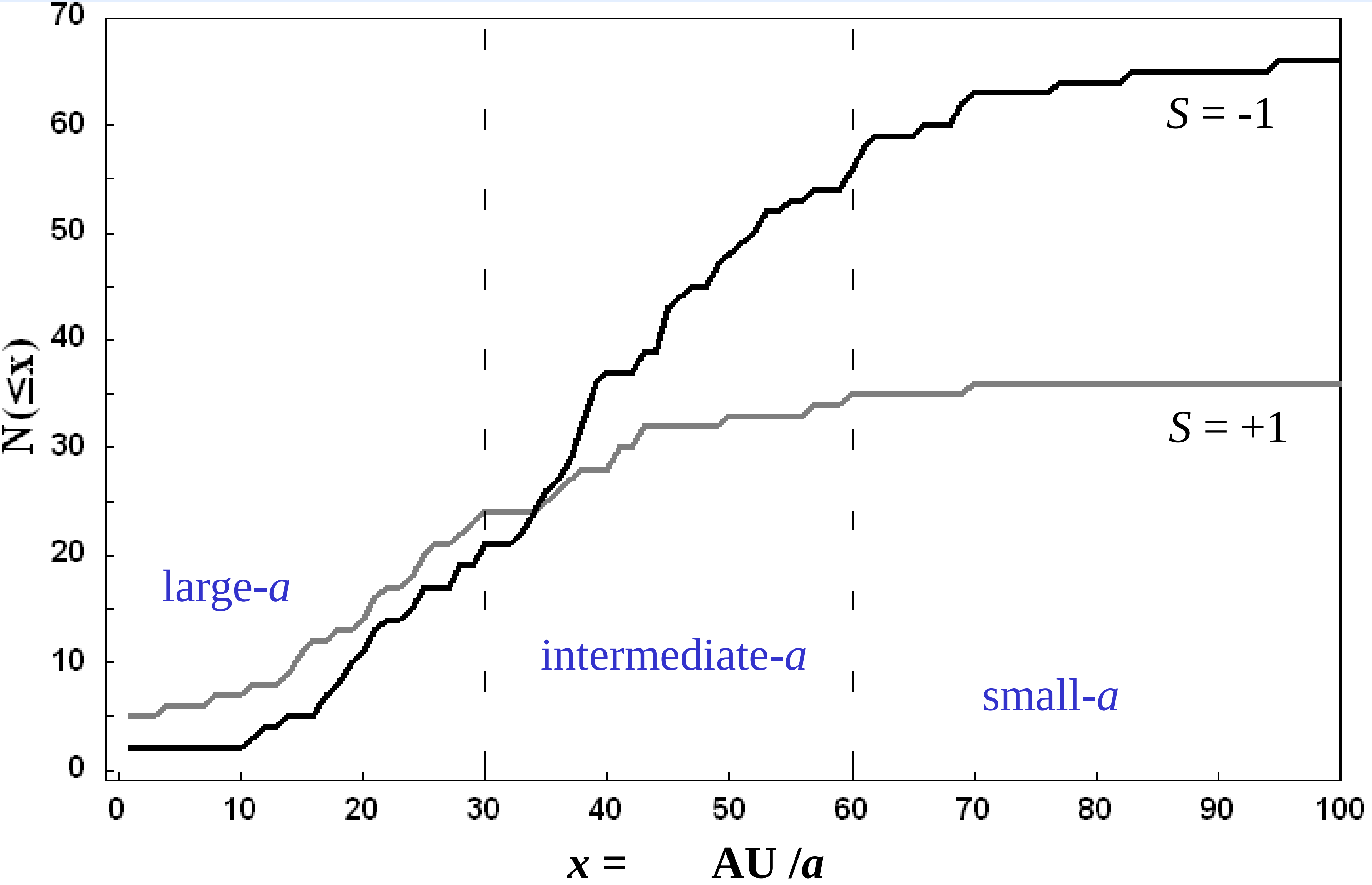


Specific Angular Momentum Plane, H
Refilled portion of Jupiter-Saturn barrier
Discernable zone
boundary
H_{obs}
ΔH_{tide}
Jupiter-Saturn
barrier
S= -1
S= +1
Refilled portion of discernable zone
large-a

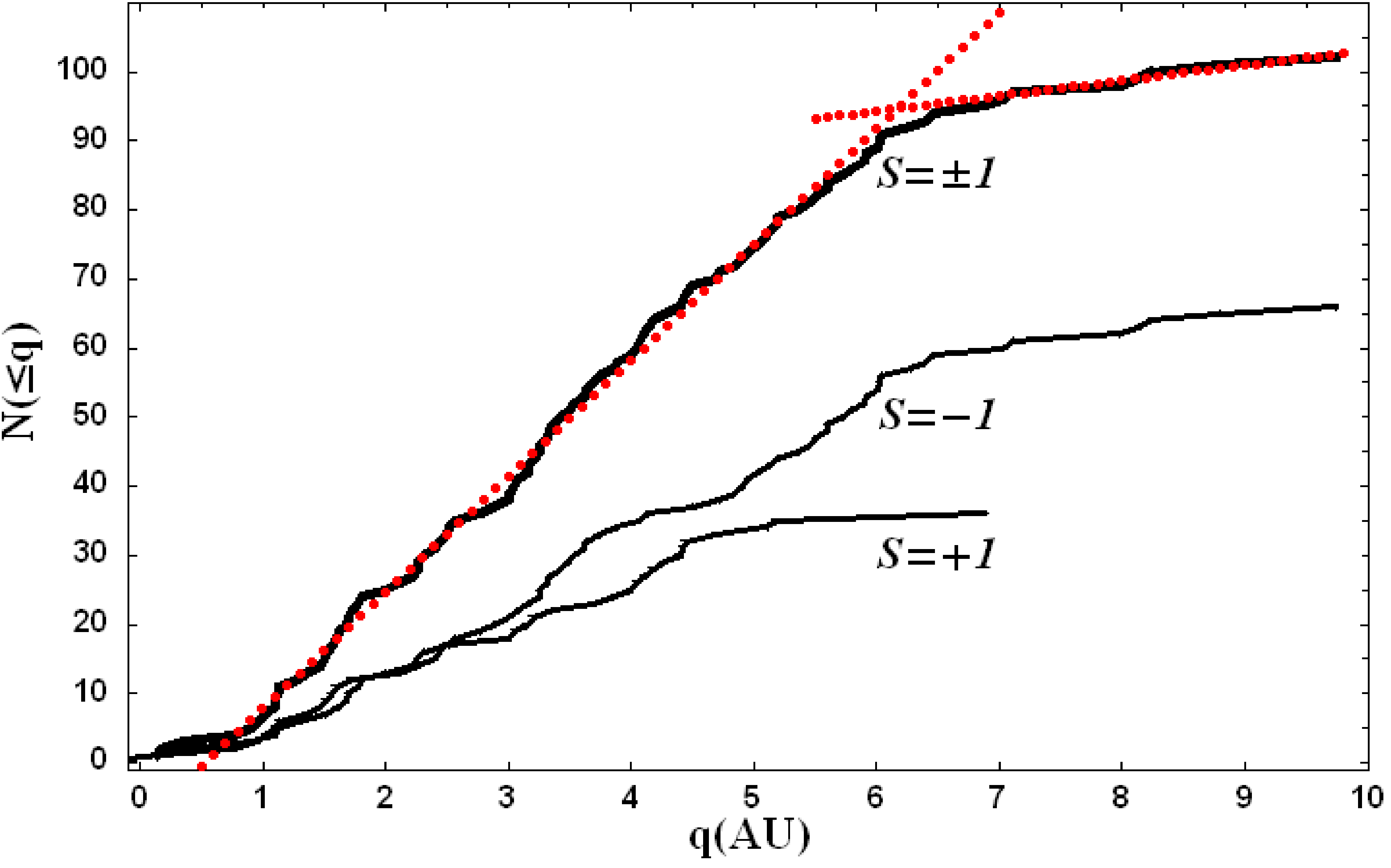

Specific Angular Momentum Plane, H
Refilled portion of Jupiter-Saturn barrier
Discernable zone
boundary
H_{obs}
ΔH_{tide}
Jupiter-Saturn
barrier
S= -1
S= +1
Refilled portion of discernable zone
intermediate-a

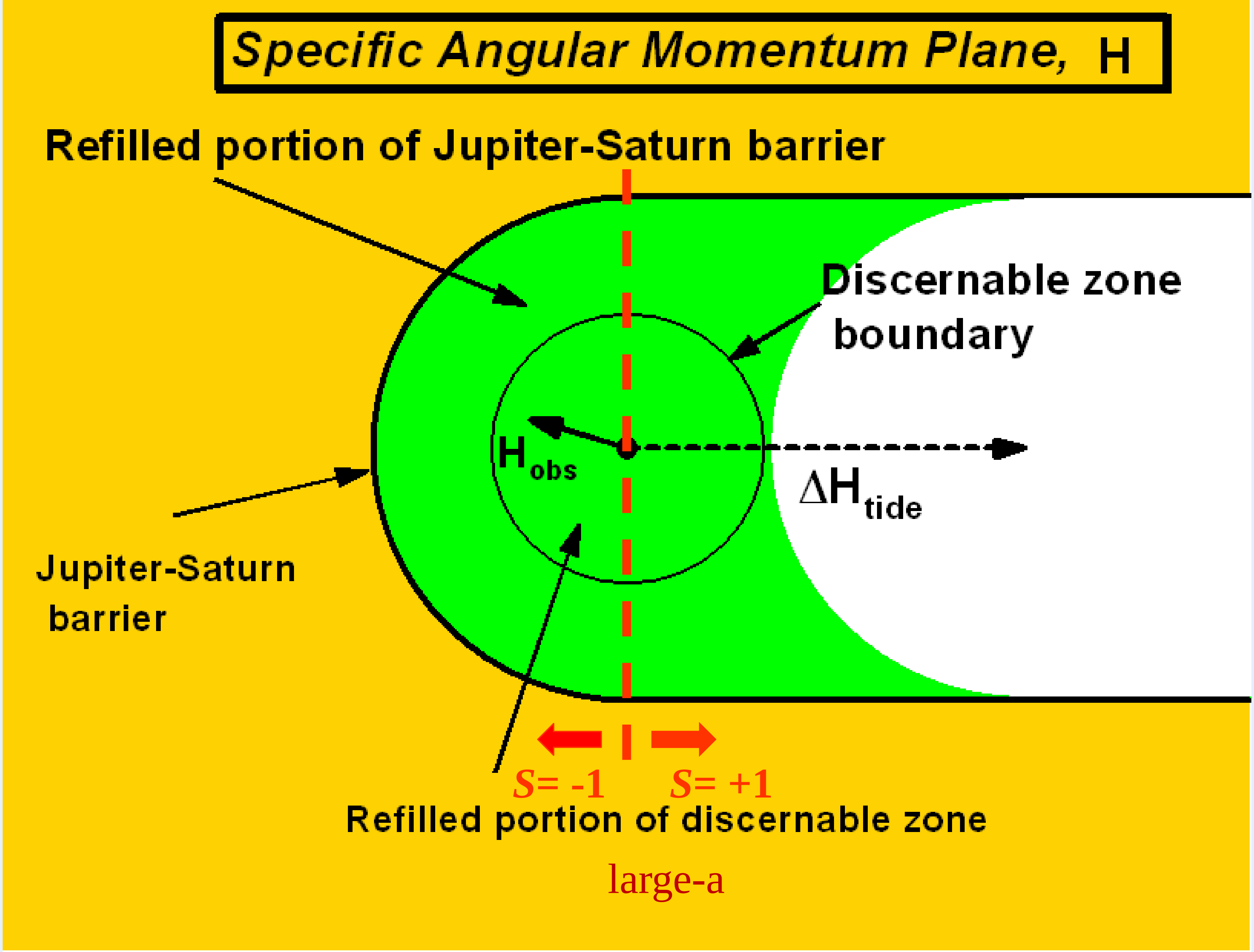

Specific Angular Momentum Plane, H
Refilled portion of Jupiter-Saturn barrier
Discernable zone boundary
ΔH tide
Jupiter-Saturn barrier
S= -1
S= +1
Unfilled discernable zone
small-a

Outer Oort cloud binding energy distribution



Outer Oort cloud perihelion distribution

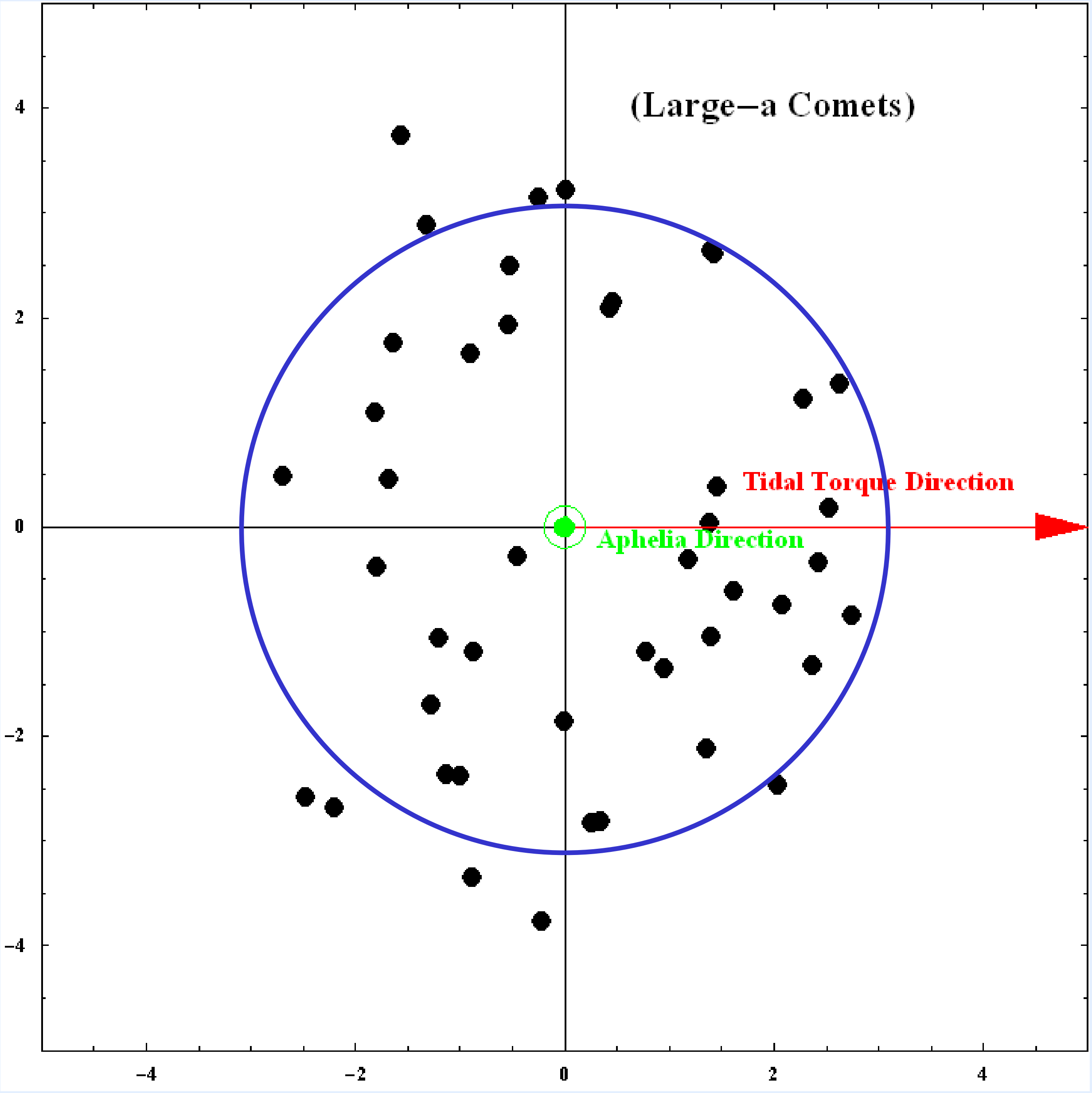


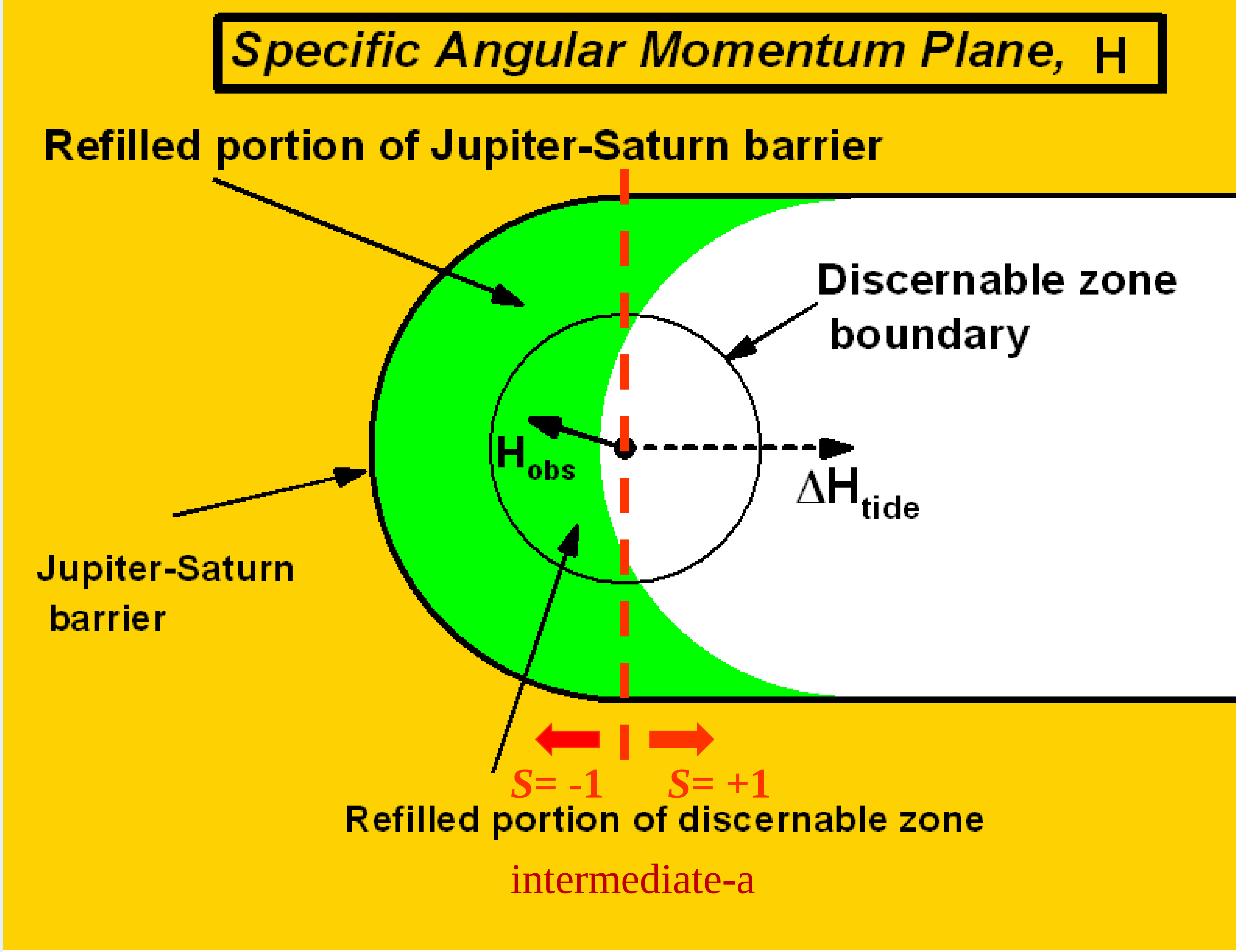


Specific Angular Momentum Plane, H
Refilled portion of Jupiter-Saturn barrier
Discernable zone boundary
H obs
ΔH tide
Jupiter-Saturn barrier
S= -1
S= +1
Refilled portion of discernable zone
large-a

Scaled angular momentum scatter observations

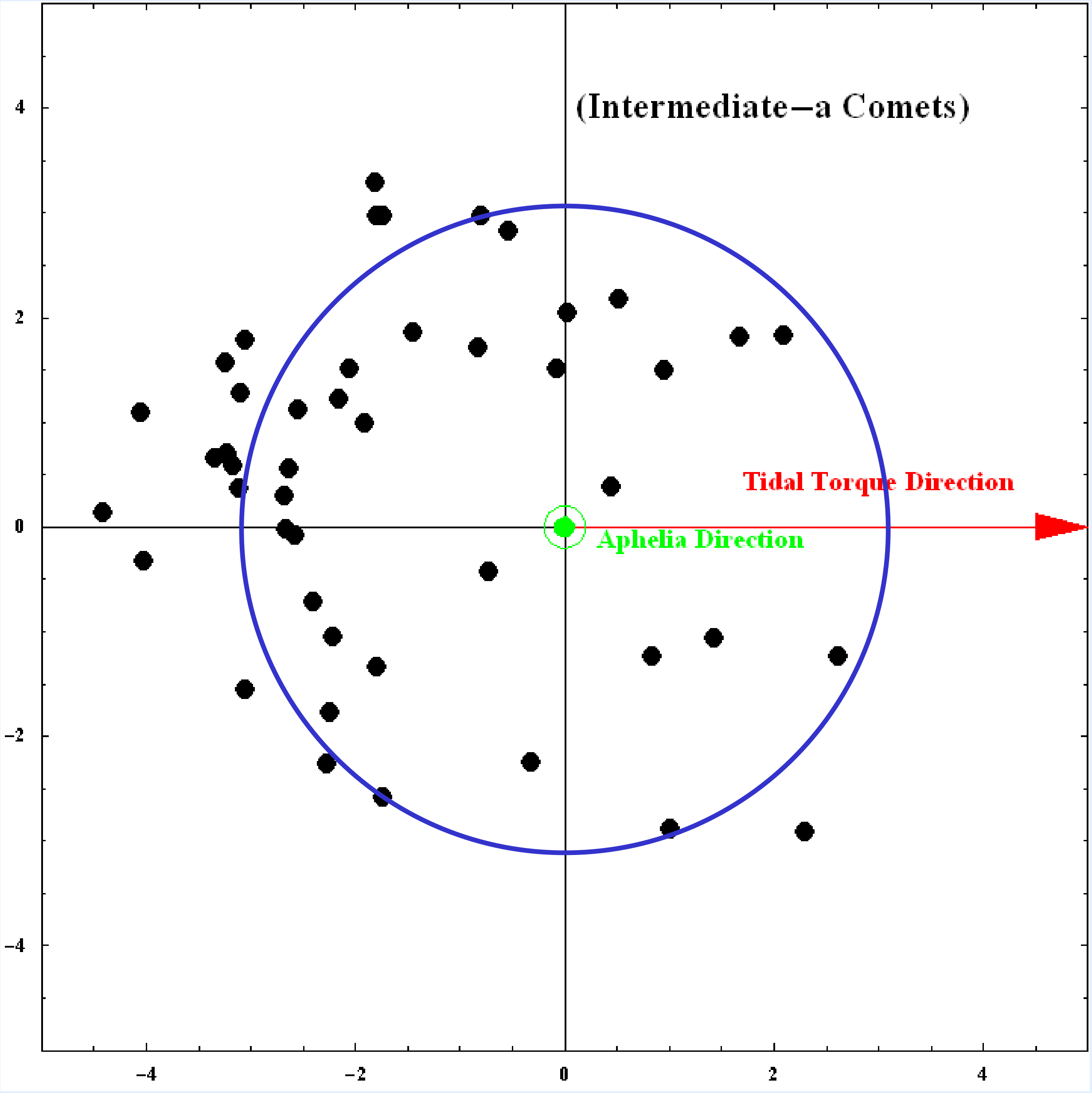
$$\frac{H}{\sqrt{G\,M_{solar}\,(AU)}}$$




Specific Angular Momentum Plane, H
Refilled portion of Jupiter-Saturn barrier
Discernable zone boundary
H obs
ΔH tide
Jupiter-Saturn barrier
S= -1
S= +1
Refilled portion of discernable zone
intermediate-a

Scaled angular momentum scatter observations

$$\frac{H}{\sqrt{G\, M_{solar}\,(AU)}}$$



Summary of assertion I.

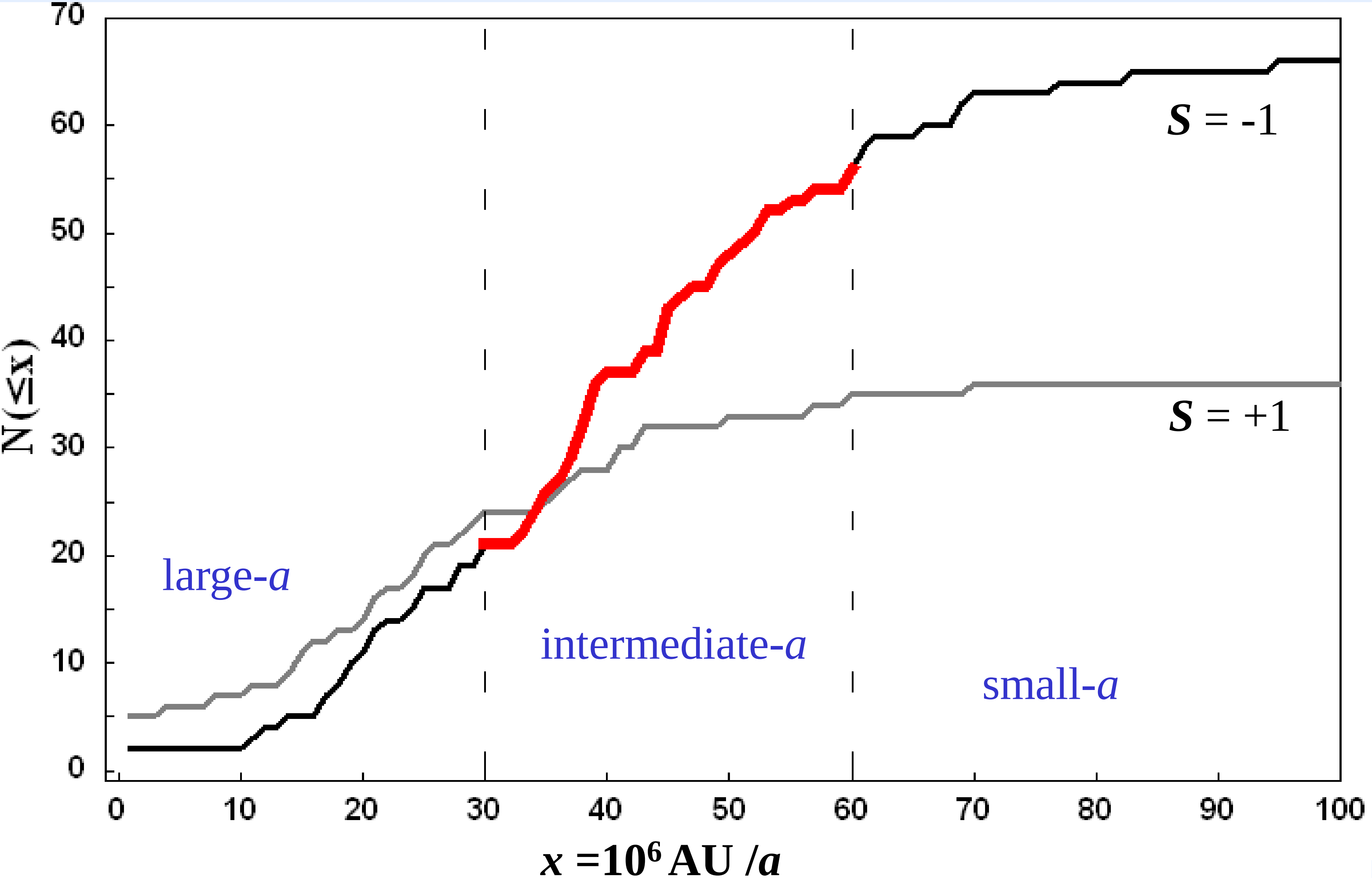
There is Catalogue evidence that the galactic tidal torque dominates in producing the flux of observed comets coming from the outer Oort cloud <u>at the present epoch</u>. This does not contradict the conclusion of Fouchard et al. (2010) and Rickman et al. (2008) that "synergy" between stellar perturbations and the galactic tide cannot be ignored <u>over long timescales</u>.

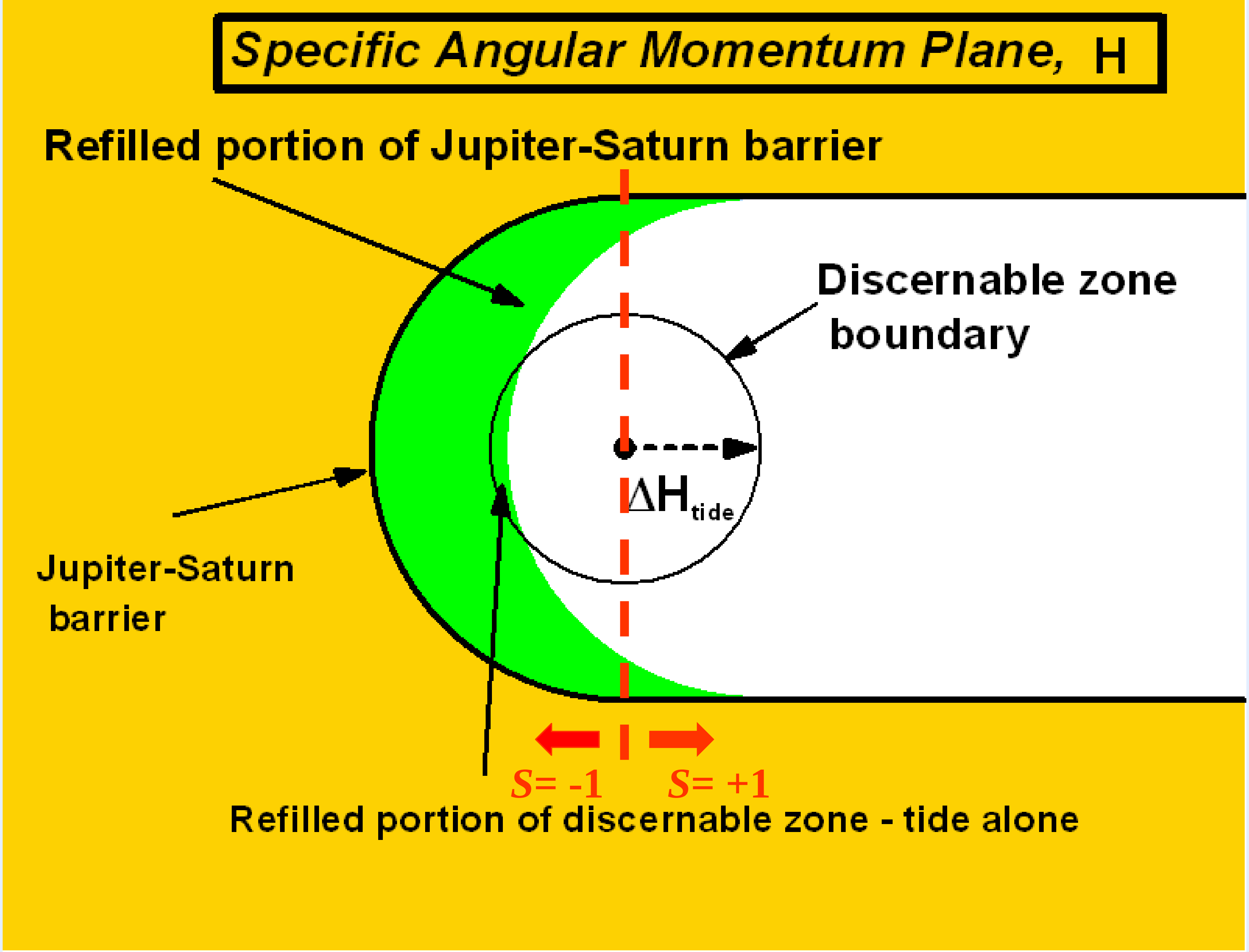
- Polar and equatorial deficiencies in aphelia latitudes are consistent with loss-circle modeling assuming tidal dominance (Matese & Lissauer 2004)
- Break in semimajor axis distributions for *S* = -1 and *S* = +1 at the boundary between large-*a* and intermediate-*a* is consistent with this modeling
- Angular momentum phase space scatter for large-*a* (symmetrically distributed) and intermediate-*a* (asymmetrically distributed) is consistent with this modeling
- Break in semimajor axis distribution at the boundary between intermediate-*a* and small-*a* is <u>not</u> consistent with this modeling, but is more nearly consistent with that found by Kaib & Quinn (2009)

II. *A systematic approach in searching the Catalogue data for a weak impulsive component of the outer Oort cloud flux.*

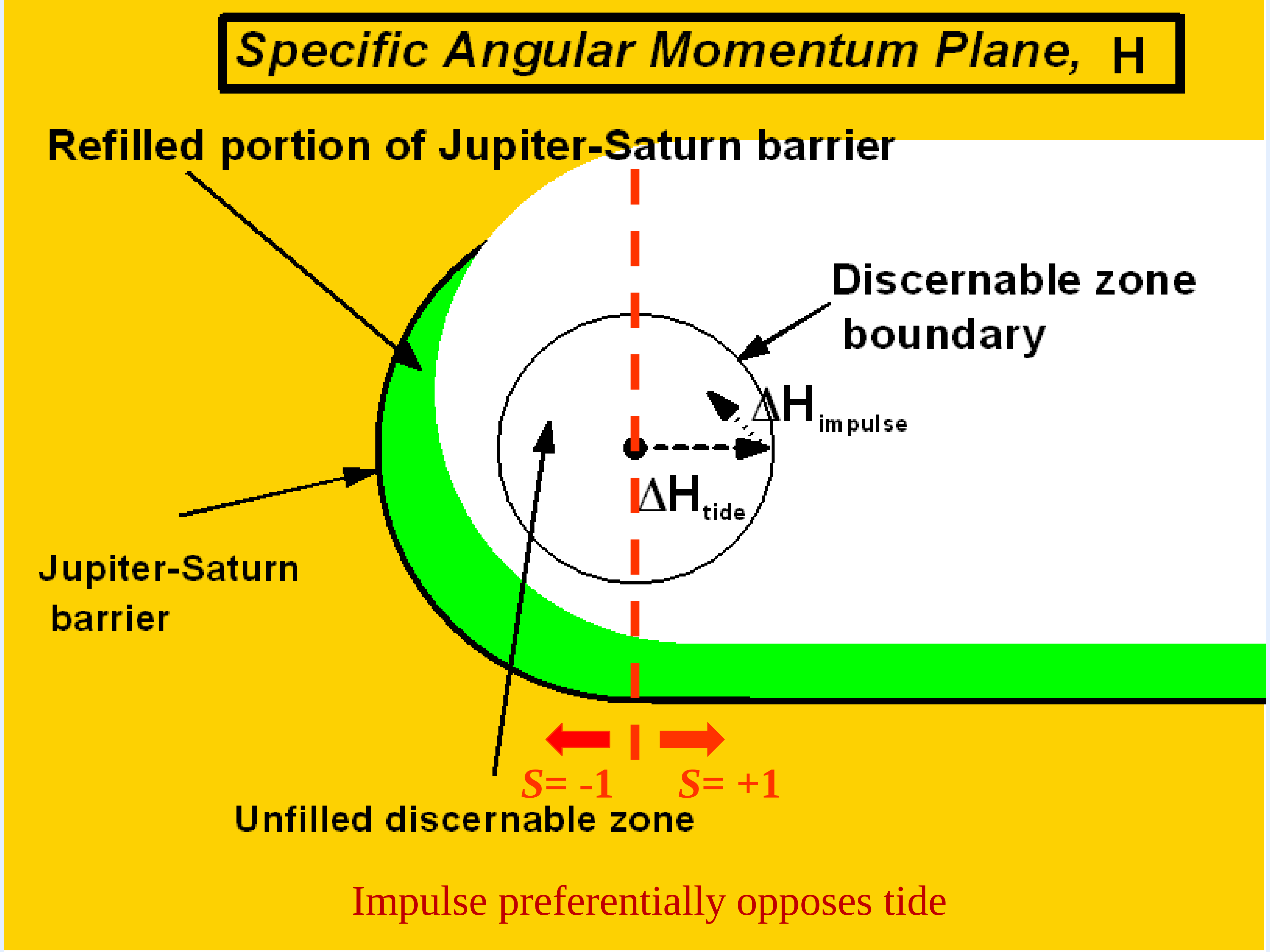
- Consider only high-quality data, class 1A
- Recognize that data where the tide clearly dominates weak impulses, *i.e.* large-*a* comets, *cannot* show evidence of an impulse!
- Conclude that one should focus on comets most likely to show evidence of a weak impulse, those that have just barely entered the discernable zone , *i.e.*, high-quality intermediate-*a* comets with S=-1

Highlighted comets are most likely to reveal weak impulse

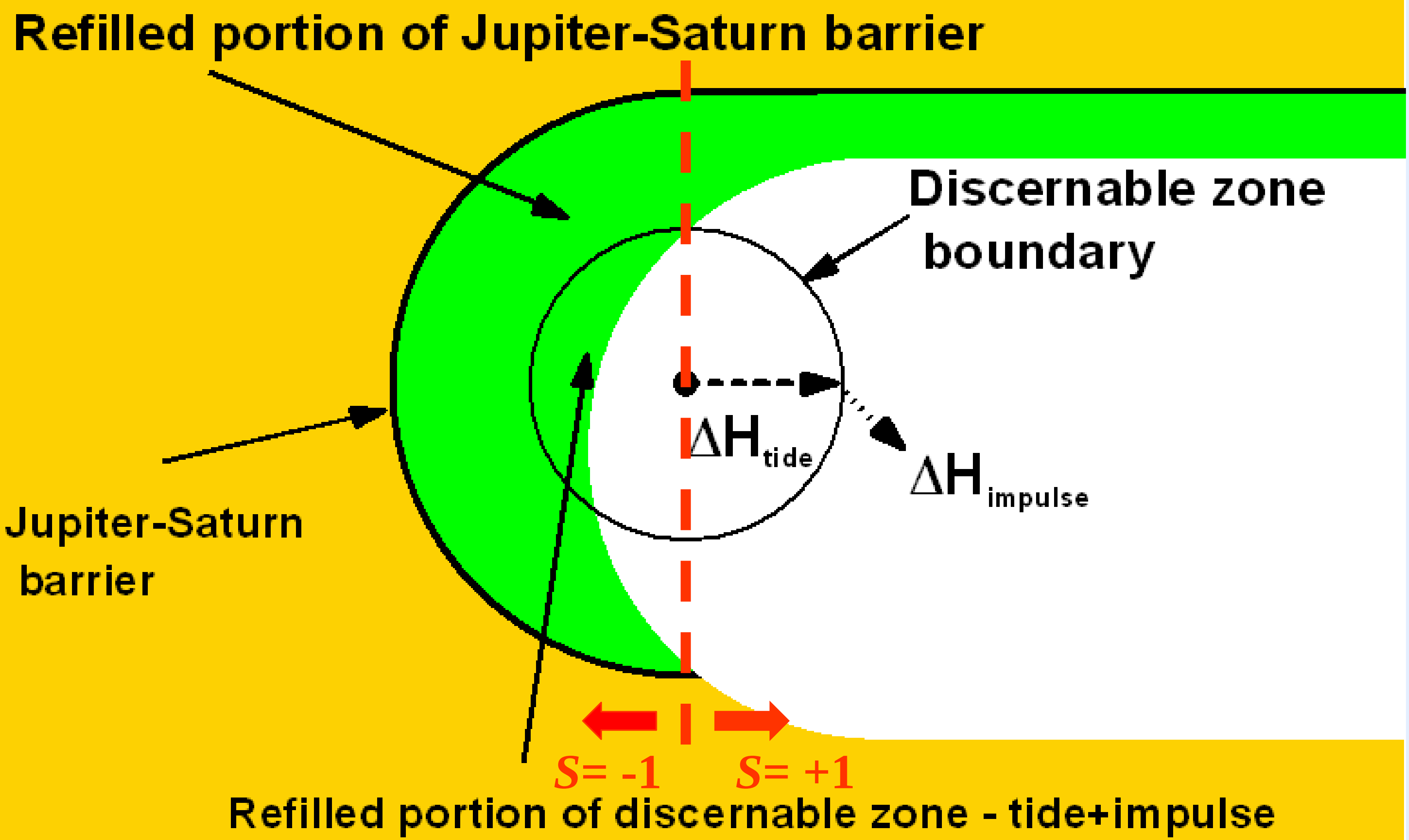




Specific Angular Momentum Plane, H
Refilled portion of Jupiter-Saturn barrier
Discernable zone boundary
ΔH tide
Jupiter-Saturn barrier
S= -1
S= +1
Refilled portion of discernable zone - tide alone


Specific Angular Momentum Plane, H
Refilled portion of Jupiter-Saturn barrier
Discernable zone
boundary
ΔH impulse
ΔH tide
Jupiter-Saturn
barrier
S= -1
S= +1
Unfilled discernable zone
Impulse preferentially opposes tide

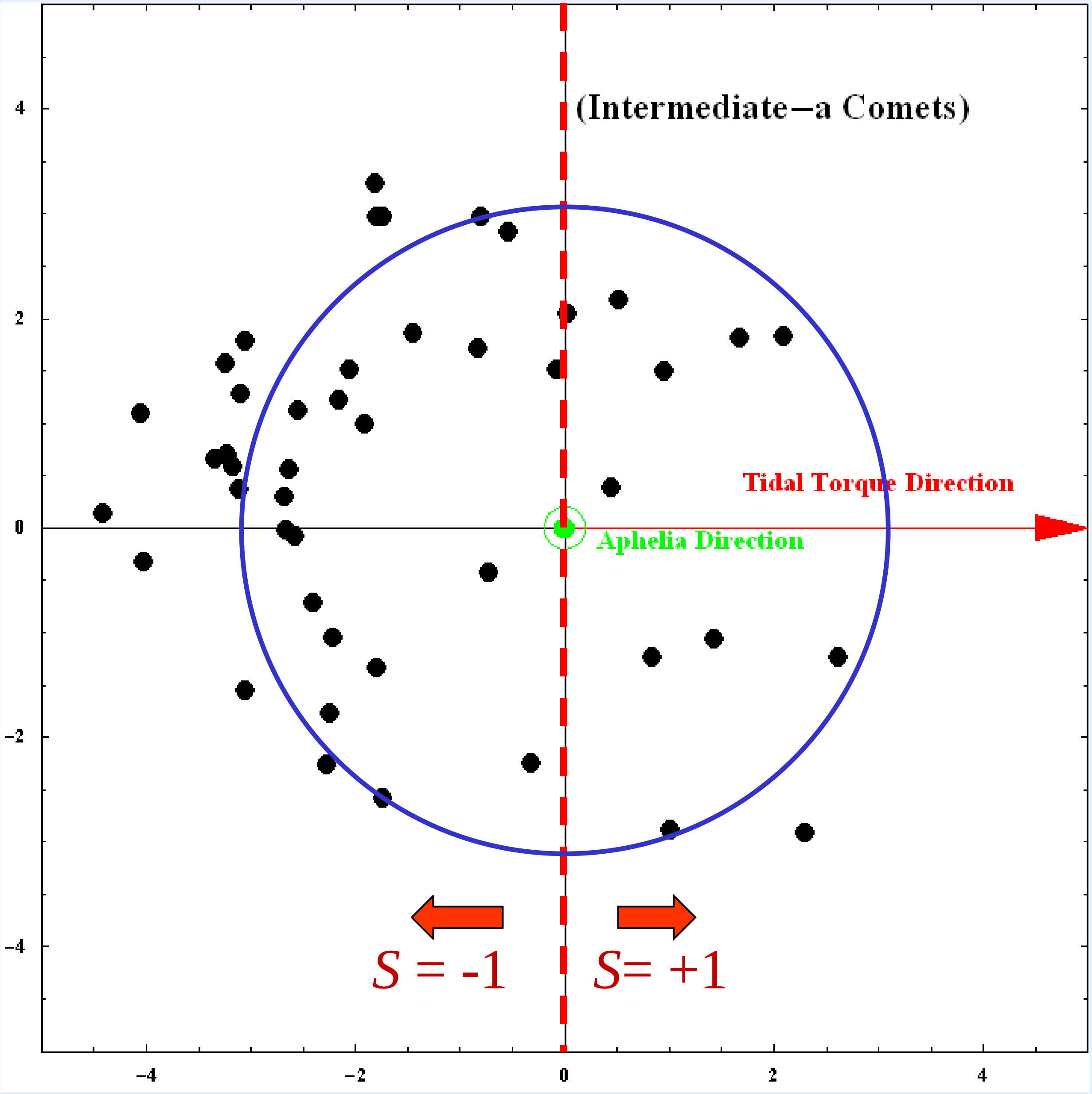
Specific Angular Momentum Plane, H



Synergy in action! Impulse preferentially aids tide

H scatter most likely to reveal impulse? S = -1 !

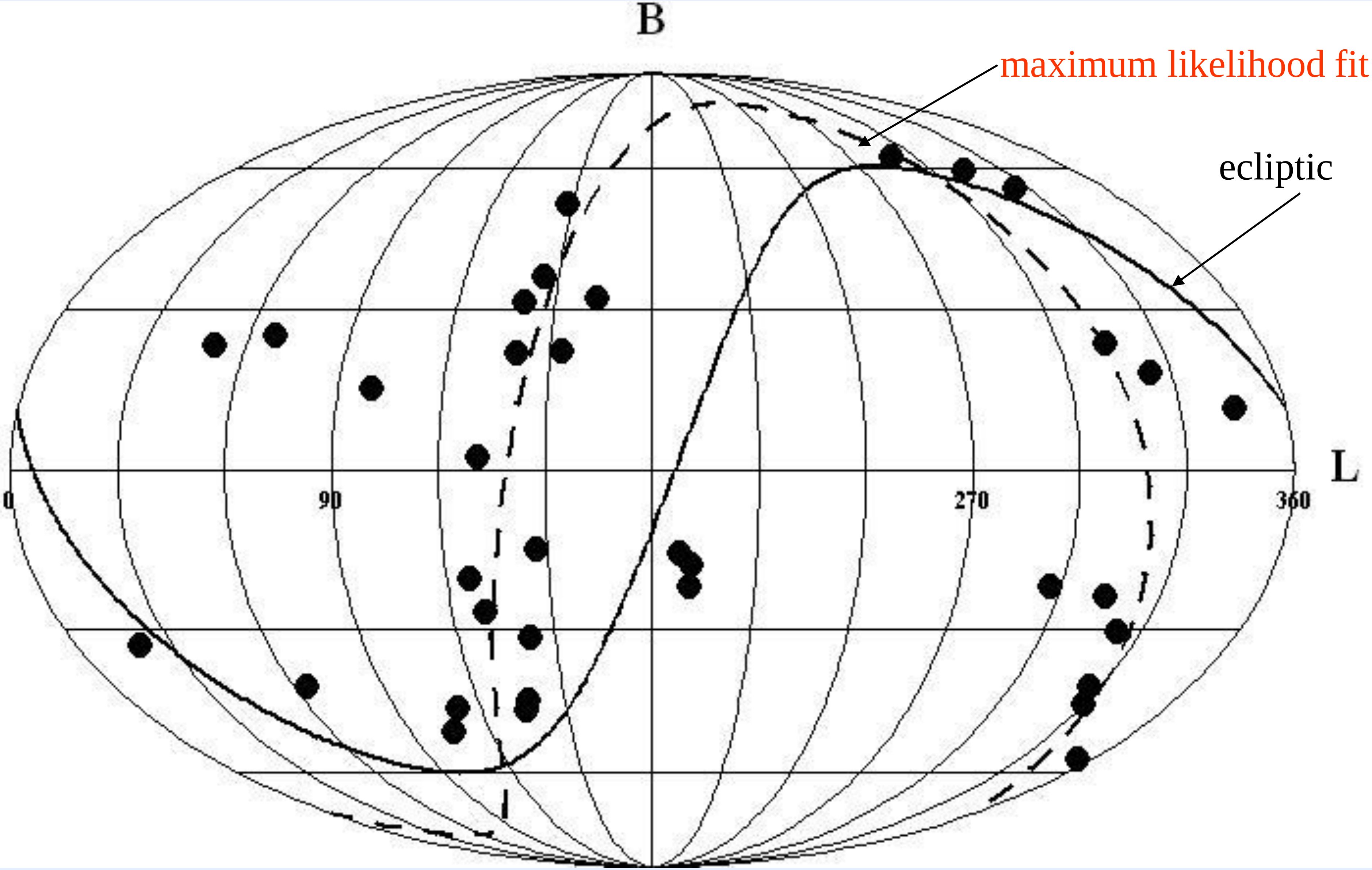
$$\frac{H}{\sqrt{G\,M_{solar}\,(AU)}}$$



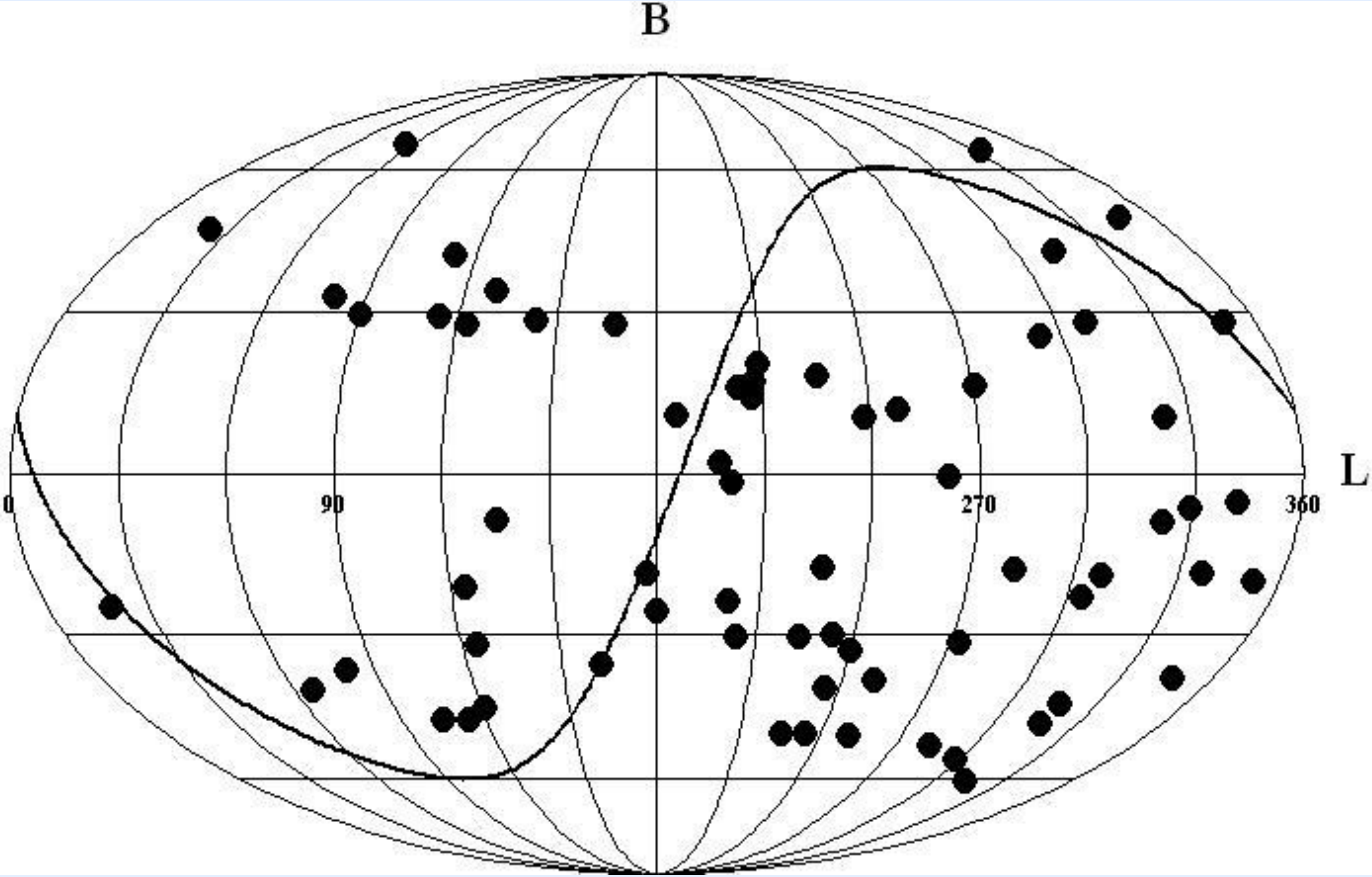
III. *Is there evidence for a weak impulse?*

- Look at the aphelia scatter of the data most likely to show the concentration that would be evidence of the short timescale "synergy" between the galactic tide and individual weak impulses (Matese & Lissauer 2002)
- When we do so, the scatter reveals a persistent concentration that is unlikely to be due to a statistical fluke (Matese & Whitmire 2011)
- It is also unlikely to be due to a weak stellar impulse
- It could be produced by a jovian mass companion orbiting in the outer Oort cloud (Matese & Whitmire 2011, Fernandez 2011)

Aphelia scatter of S = -1, intermediate-a comets

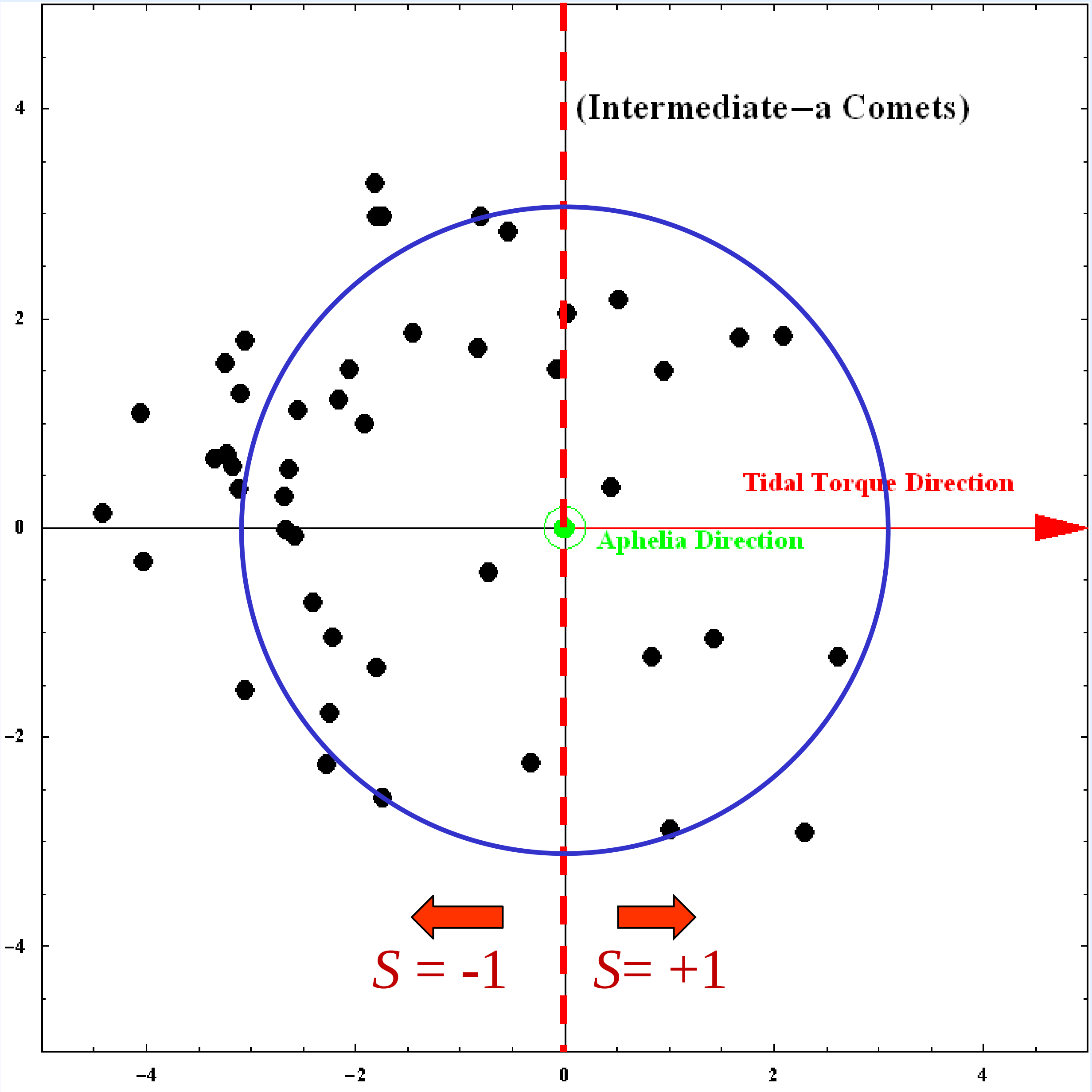


Aphelia scatter of other new comets



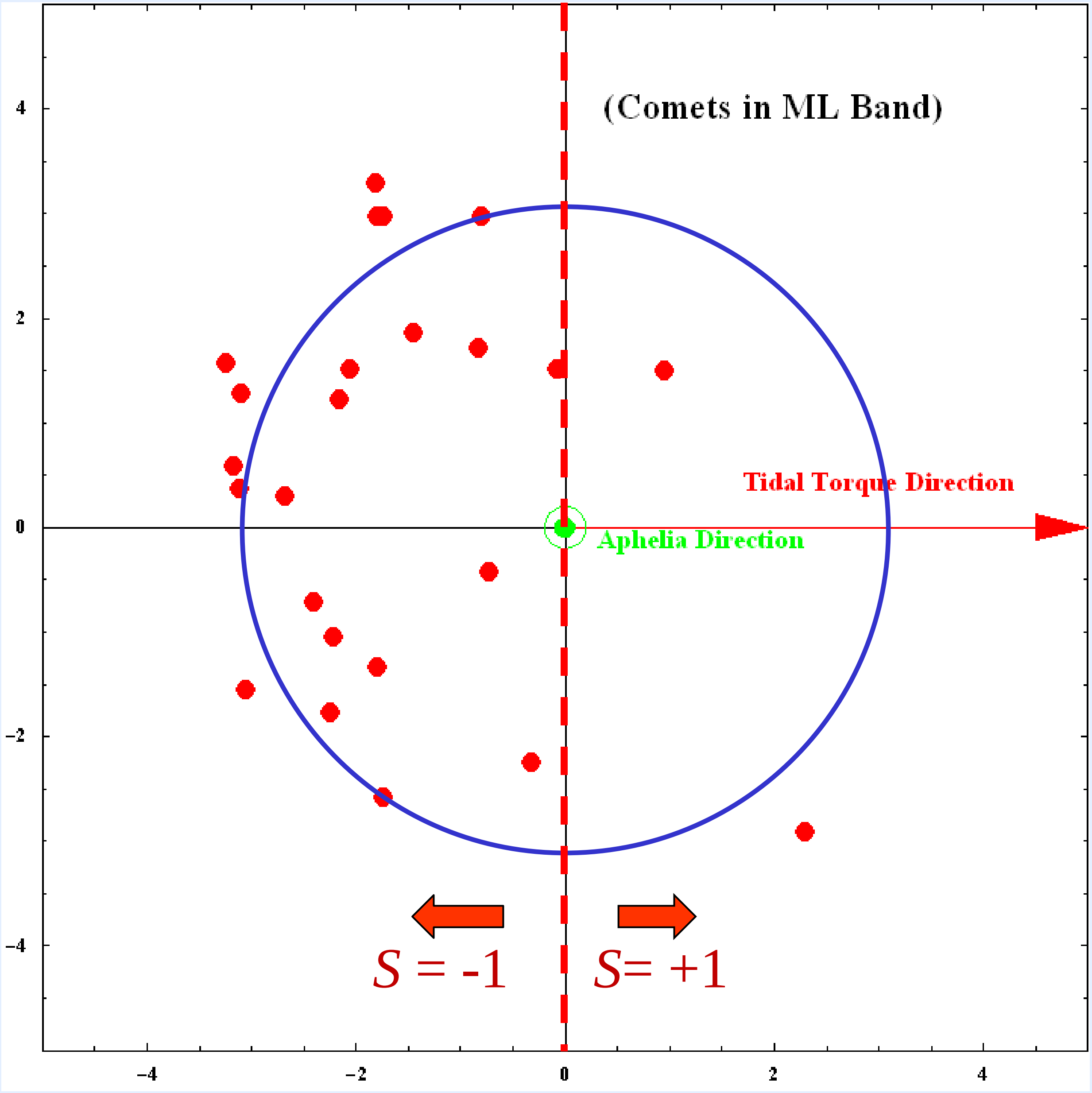
H scatter of all intermediate-a comets!

$$\frac{H}{\sqrt{G\,M_{solar}\,(AU)}}$$



H scatter inside the maximum likelihood 10º band

$$\frac{H}{\sqrt{G\,M_{solar}\,(AU)}}$$



Capture Origin for Companion?

- **Oort comet cloud may have been predominantly formed by capture of planetesimal ejecta from other stars in the dense birth cluster complex. (Zheng *et al.* 1990, Levison *et al.* 2010)**
- **Very wide binary stars may form during the star cluster dissolution phase. (Kouwenhoven *et al.* 2010)**
- **A wide-binary solar companion also could have been captured in the Sun's youth.**
- **A recent microlensing study (Sumi *et al.* 2011) suggests that a population of unbound or distant Jupiter mass objects may be more common than stars in our Galaxy.**

Wide-field Infrared Survey Explorer (WISE)

- **If the object exists, WISE will have recorded it in the 4.6 micron band (W2) and/or the 22 micron band (W4), and perhaps the 12 micron band (W3), but should have no signal in the 3.4 micron (W1) band. If it *only* has a W2 or W4 band detection, it will be difficult to confirm (Wright 2011).**
- **The claim we make? "<u>If</u> a bound object is discovered by WISE, then it likely will explain the perceived Oort cloud comet anomaly and it will be a "Goldilocks" companion ."**

  - not too small, not too big (just the right band flux and colors)

  - not too slow, not too fast (just the right proper motion)

  - not too close, not too far (just the right parallax)

  - not too little, not too much inclination (just the right orbital plane).
- **Any promising observation that is recorded in the WISE database would be sent to narrow-field IR telescopes for detailed follow up observations to falsify or verify the Goldilocks criteria. Time frame ~ 1 year.**
- **http://www.nasa.gov/mission_pages/WISE/news/wise20110218.html**

Acknowledgements

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A copy of the slideshow can be found at
http://www.ucs.louisiana.edu/~jjm9638/Lille.pdf