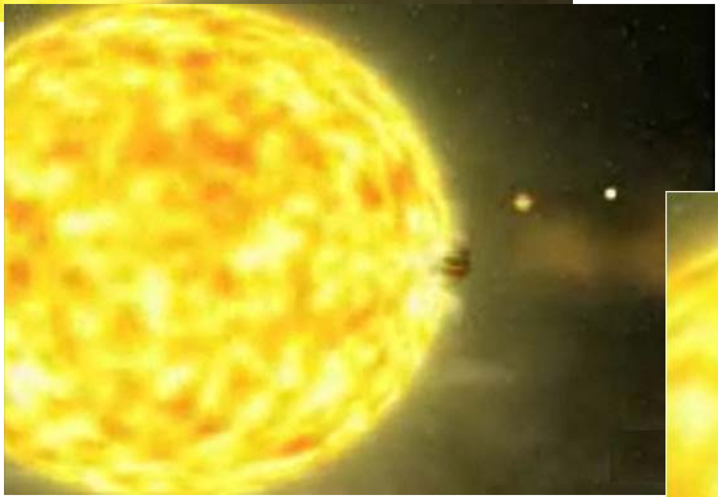
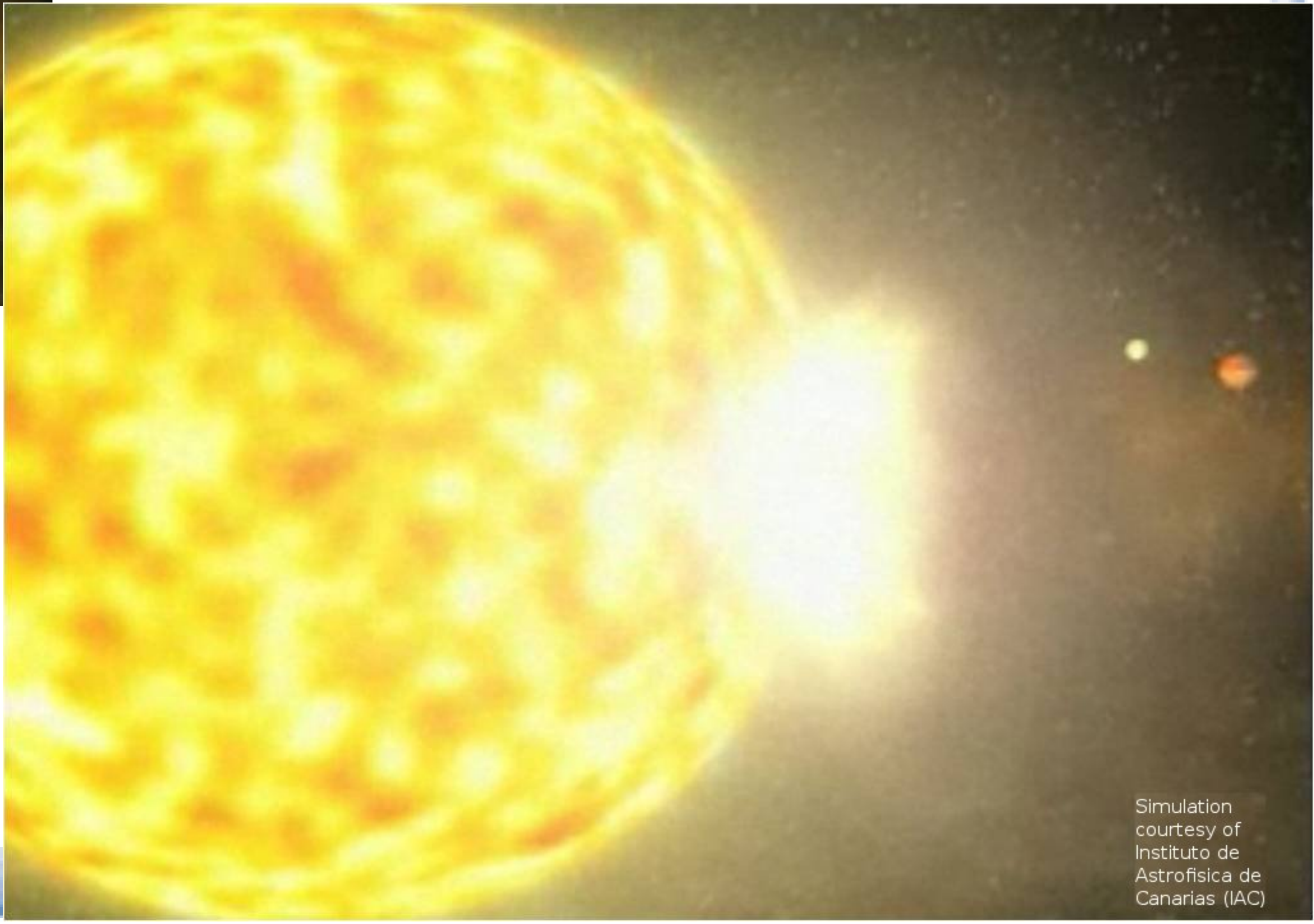


Observing Planet Falling Through Increased Stellar Luminosity

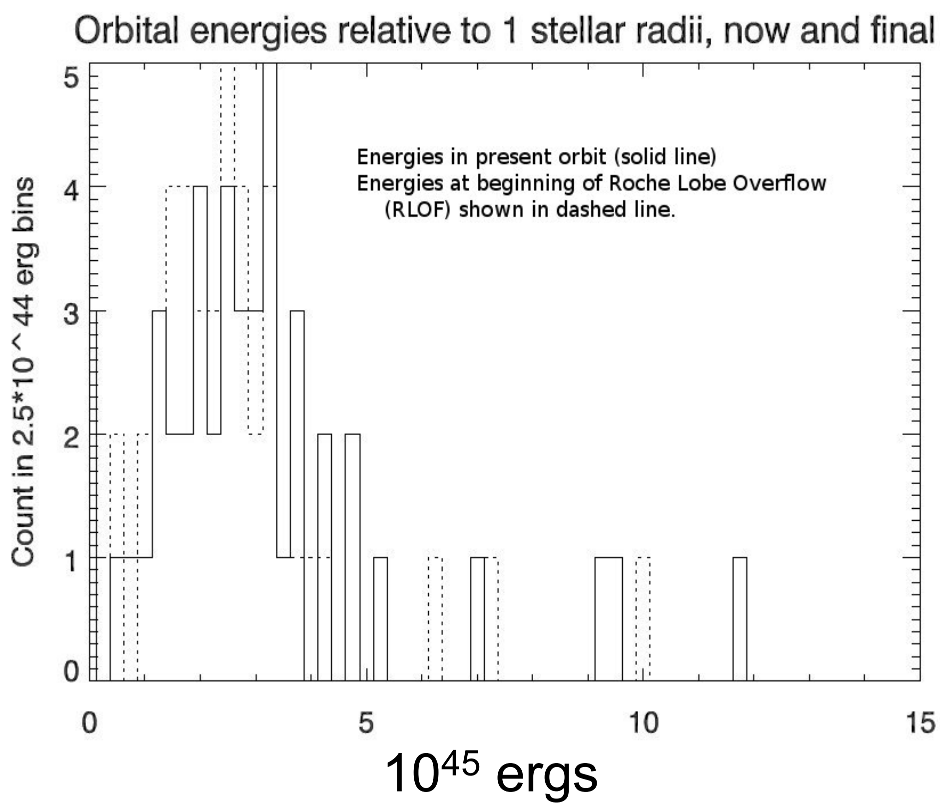
Stuart Taylor

National Speaking Tour / Global Telescope Science



Total Available Energy is HUGE!

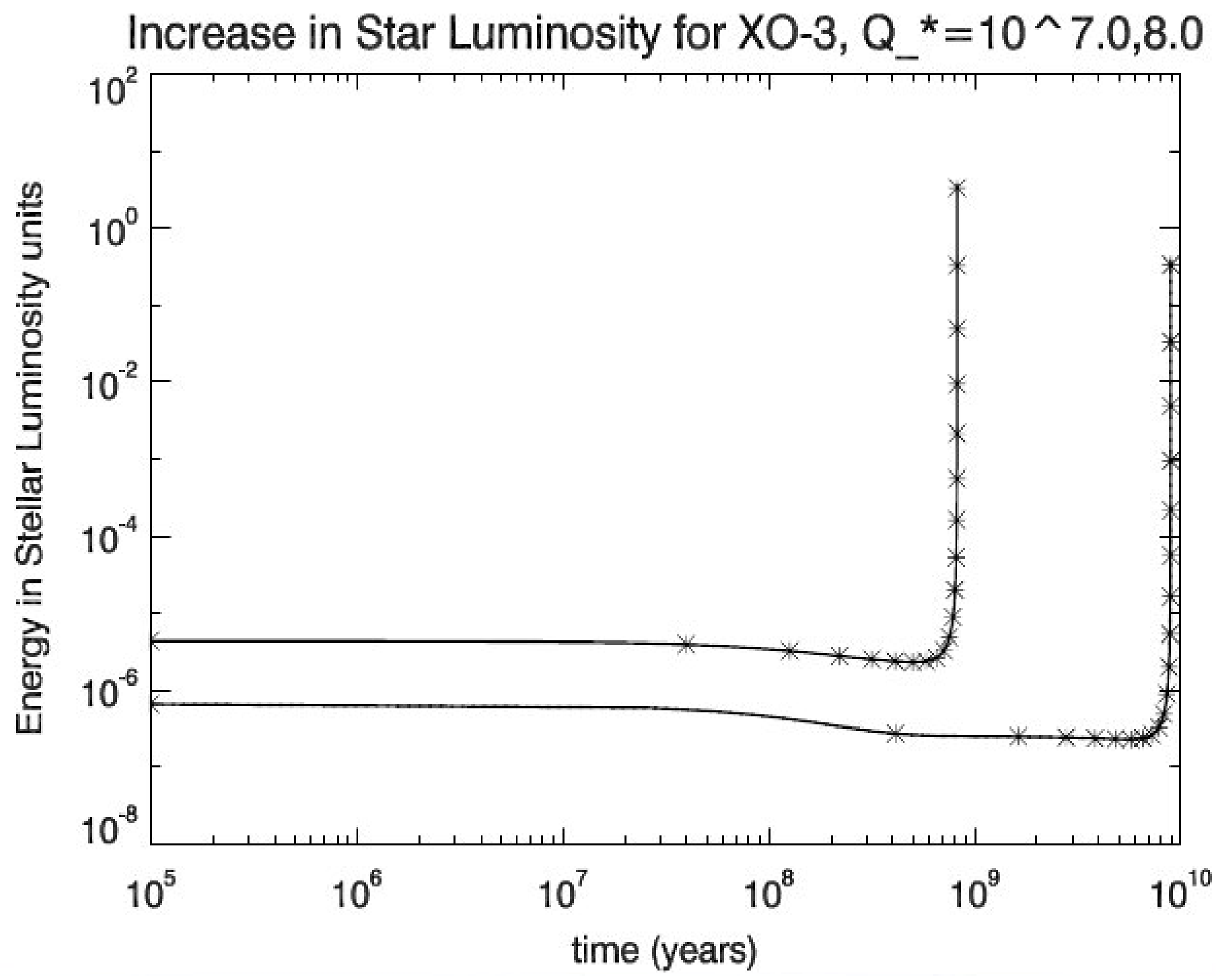
- Orbital energy relative to stellar photosphere (1 R_*) on order of small nova
- Major part of energy remains at start of planet destruction



Available Energy is Huge!
1. Tidal Migration

Energy input relative to star, even before “destruction” phase.

Dependent on star not synchronizing



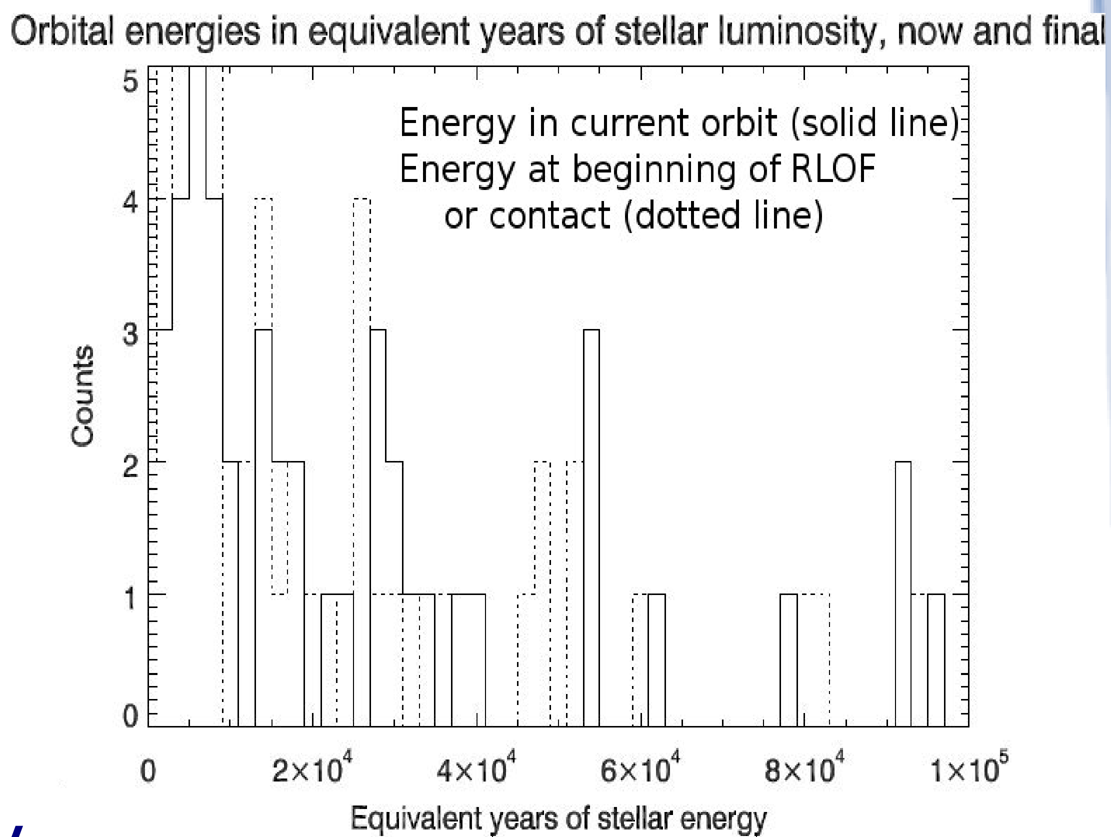
Definition: Two Phases of "End-State"

1. Tidal Migration
2. "Destruction" defined to be whichever a falling planet reaches first: Roche lobe overflow ("RLOF") or orbiting at less than 1 R_* (orbiting below the stellar "surface")

Larger part of energy released during "destruction phase" but energy released into star during last of tidal migration is still on order of that of star

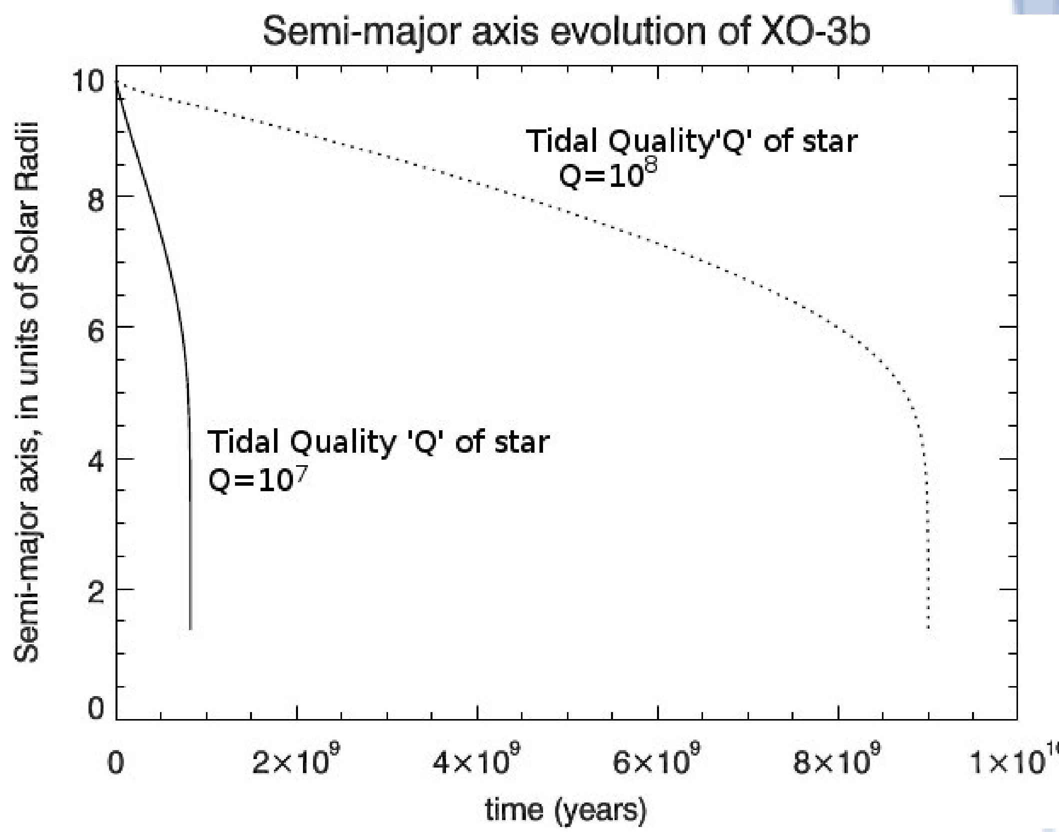
Available Energy Significant Relative to Star's Luminosity

- Tens of thousands of years worth of stellar luminosity now (solid histogram)
- Still tens of thousands of years luminosity of energy even at destruction (dashed histogram)



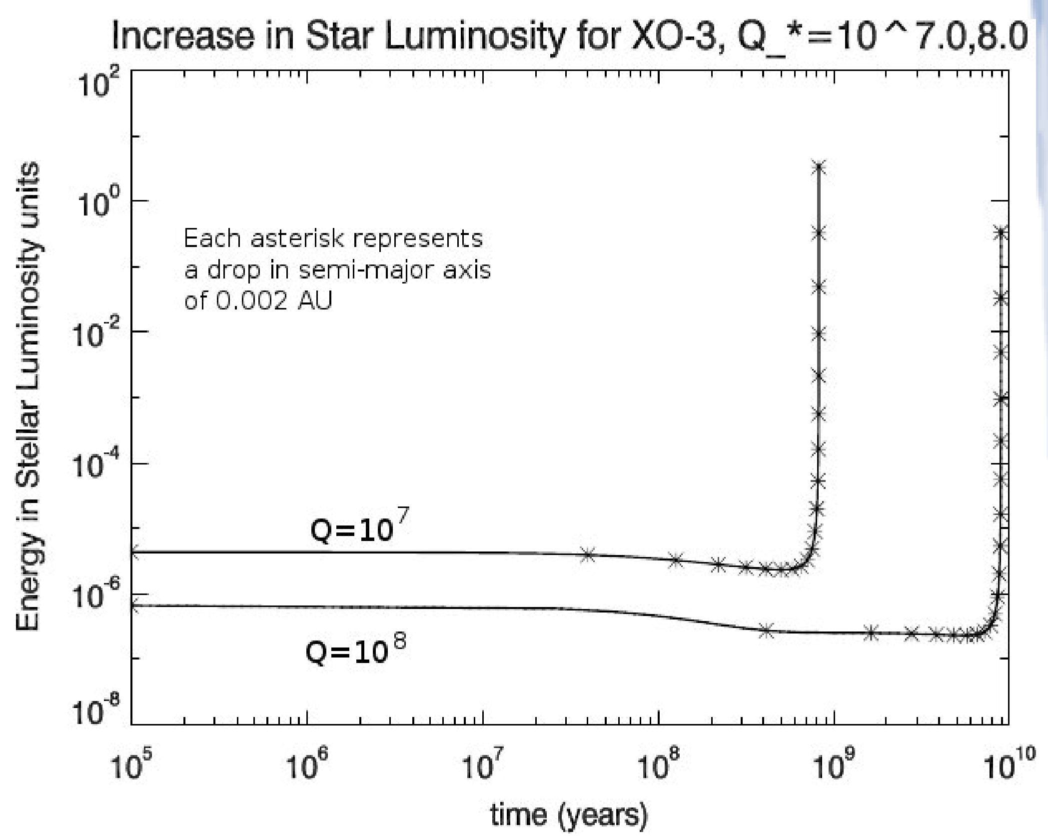
Migration stage: Infall steady, then rapid

- Very stiff function of semi-major axis
- Not well recognized until recently: Planet destruction newly recognized in 2008 by Jackson et al., and early 2009 by Levrard et al.
- Recognized tides created by planet on star become significant
- Dependant on Tidal Dissipation Parameter Q_*' , the main unknown parameter



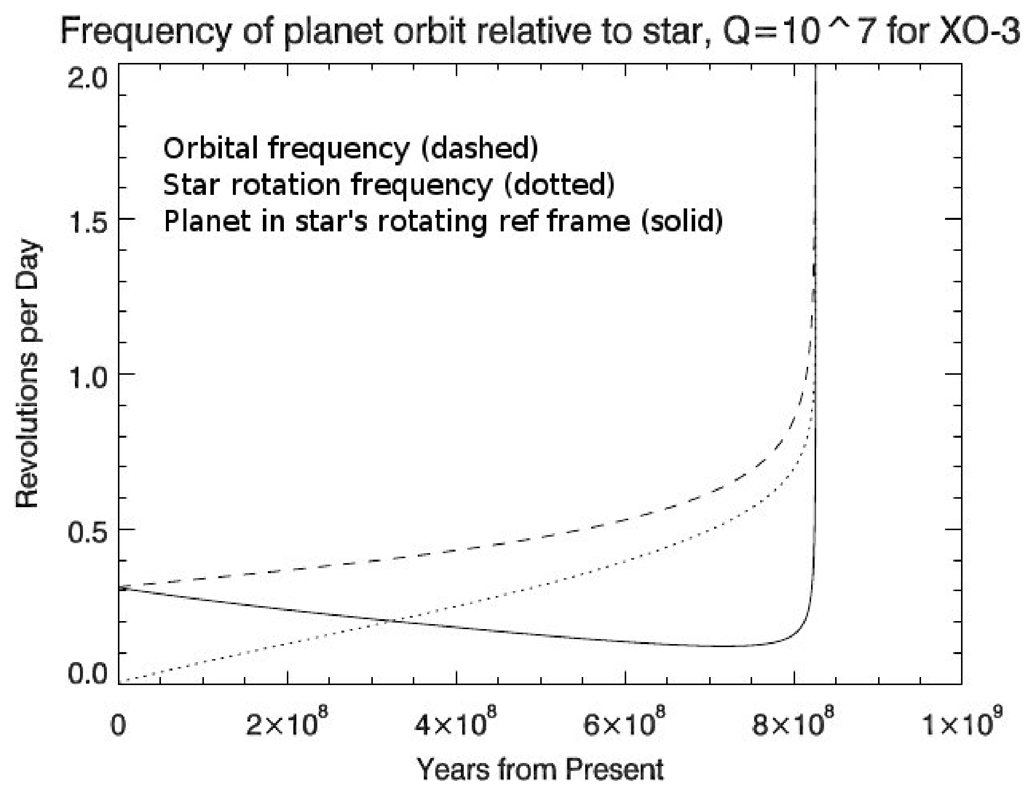
Tidal energy input into star significant!

- For values of Q_*' that had been commonly accepted, tides will heat star at rates comparable to luminosity
- Q_*' depends on what?
- What is value of Q_*'?
- WASP-18 perhaps too unlikely unless Q_*' larger for F star



Inward migration determined by *difference* in rotational motion between orbit and star

- All stars, and even massive planets will synchronize star's rotation with orbit.
- Most hot Jupiters unstable to infall, (Levrard et al. 2009) but for many depends on current stellar rotation and inclination
- Apparently only one star/planet with rotation synchronized by planet has been found
- τ Boo's semi-major axis is further than 4 or 5 stellar radii
- Is lack of synchronization an emerging Sign of Magnetic Braking?



Exosolar System Transients Proposing to LSST as A separate category of transients

Planet destruction can be considered to happen differently in three different stages of a star's lifetime:

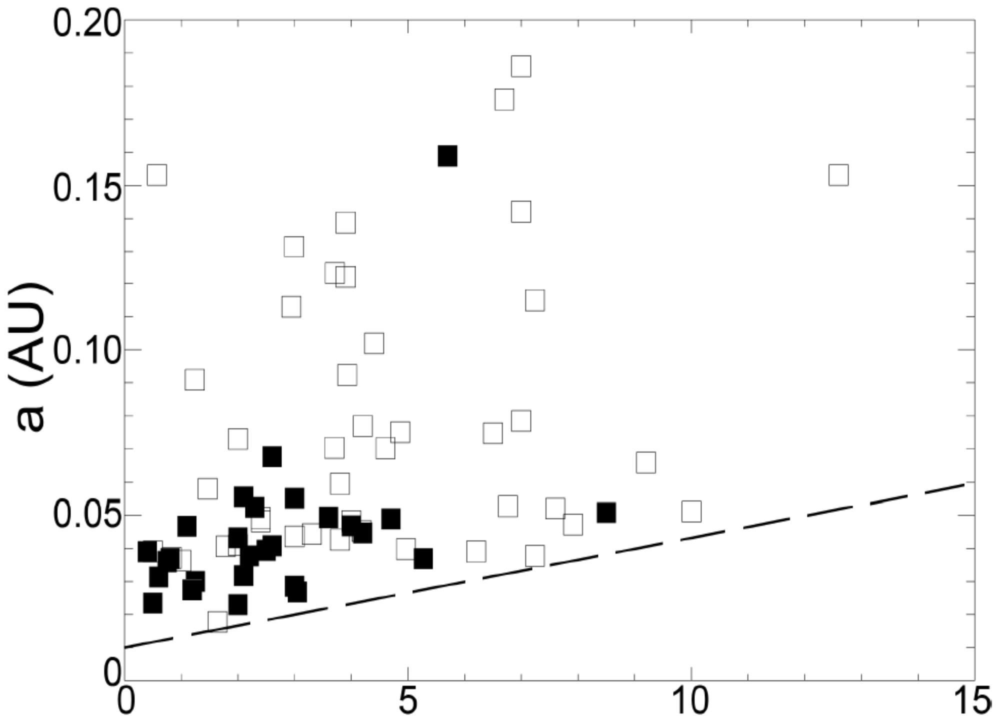
1. During formation (while circumstellar disk is present).

2. Main sequence lifetime probably least common but most bright (minimum star radius). Full range of exosolar system transients yet to be explored.

3. During stellar expansion

Could We Find Orbit Evolution Due To Migration?

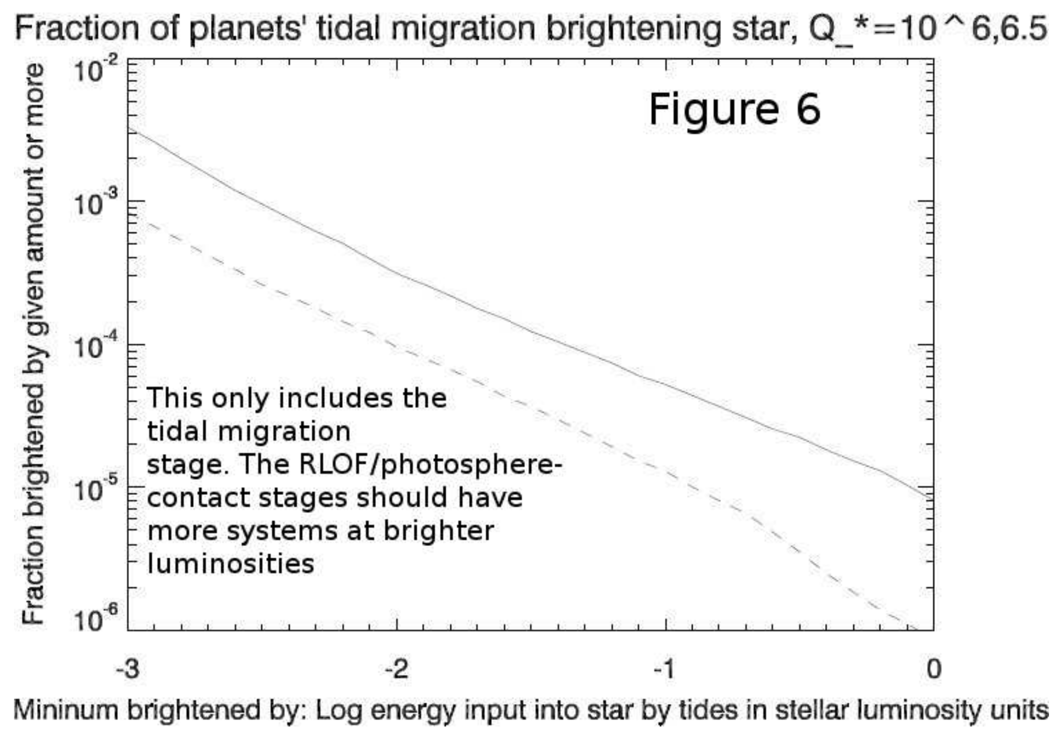
- Are planets falling in, or are stars just being synchronized?
- Semi-major axis distribution has been presented as evidence that planets are removed from semi-major axis ranges, but now Jackson et al. (2009) agree the "age" may not be correct



Proxies for Age (Gyr) that actually likely to indicate other factors

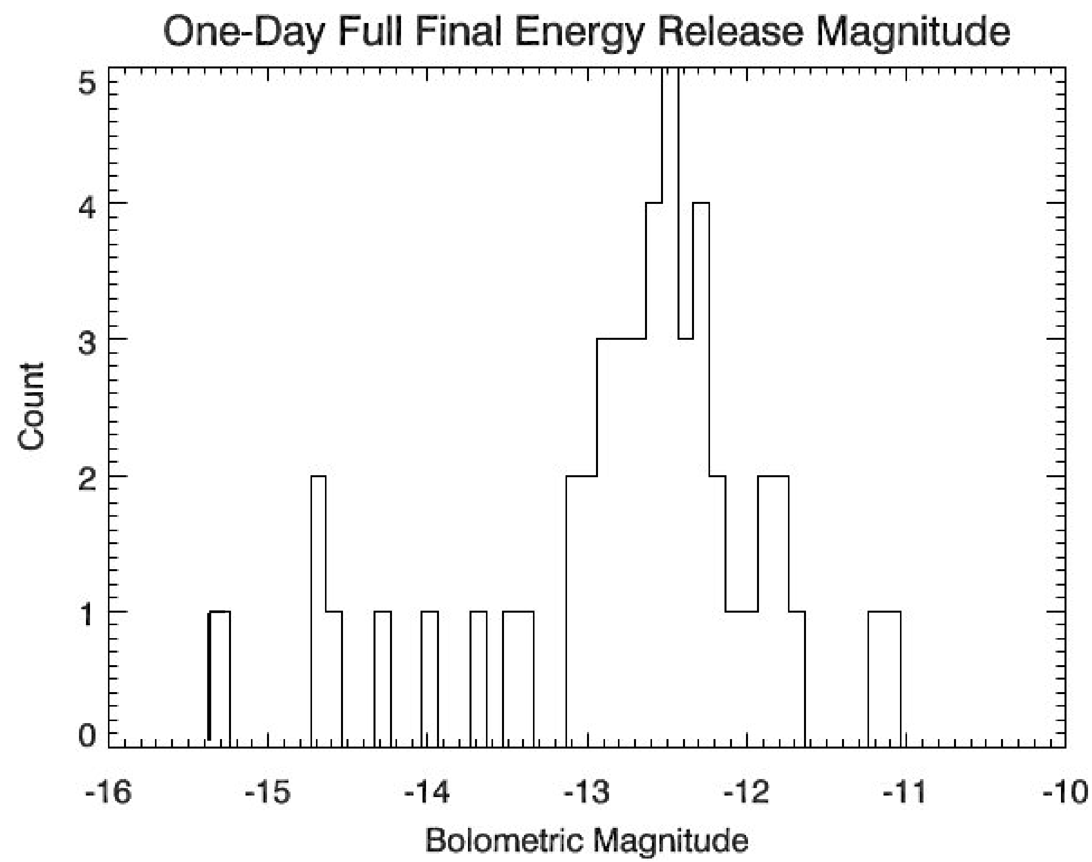
An observable luminosity increase?

- Fraction of total transiting planets as a function of minimum luminosity increase



Destruction phase has even more energy left

- Even much slower and smaller releases visible across galaxy
- More observable events than migration, if energy release is fast enough
- RLOF not yet well modeled but work is coming out
- Reason to monitor nearby galaxies



Nearby galaxy distance moduli:
M31 24.5
M81 27.8

LSST monitor to 18.5
SDSS-II to 15.5
Pan-STARRS 15
Pan-STARRS wide 12.5

Range of Exoplanet Destruction Events

	Smaller Planets Statistics poorly known	Giant Planets Good statistics
Pre-Main Sequence Future work		Likely more events Previous publications
Pre-Main Sequence This work	Many more events likely Events fainter	1 event per over 30 or more years in Milky Way. Brightest events rare. (This work)
Post-Main Sequence Future work		Likely more events Previous publications

MS-giant planet destruction rare, but other channels more common

- Smaller planets likely more common
- Probably more planets destroyed during planet formation stage (but protostar larger so less energy out)
- Post MS expansion to consume more planets, also less bright
  - Planet consumed further out
  - But planet will fall to stellar core (but this “internally falling” energy may be released on KH timescale)

Energies From Familiar Bodies

Kinetic Energies at 2 Solar Radii

Sun outputs 1.2 x10^{41} erg/yr, has absolute magnitude of 4.75

Obviously limited in how representative of other systems

	Mass	Radius	Energy	Energy	Change	Absolute
	Earth=1	Earth=1	Years of Sun	Days of Sun	Magnitude	Magnitude
			Equivalent	Equivalent		
Mercury	0.055	0.38	1.9	475	6.7	-1.9
Venus	0.82	0.95	28	7015	9.6	-4.9
Earth	1.00	1.00	34	8600	9.8	-5.1
Mars	0.11	0.53	3.3	925	7.4	-2.7
Jupiter	318.26	11.21	6639	2736943	16.1	-11.3
Saturn	95.31	9.45	1578	819642	14.8	-10.0
Uranus	14.51	4.01	302	124747	12.7	-8.0
Neptune	17.25	3.88	393	148371	12.9	-8.2
Pluto	0.0022	0.18	0.1	19	3.2	1.5
Moon	0.012	0.27	0.4	106	5.1	-0.3
Ganymede	0.025	0.41	0.6	213	5.8	-1.1
Europa	0.0080	0.25	0.2	69	4.6	0.1
Titan	0.023	0.40	0.5	194	5.7	-1.0
Rhea	0.00039	0.12	0.008	3	1.6	3.2
Enceladus	0.00002	0.04	0.0004	0.16	0.2	4.6
Ceres	0.00016	0.08	0.004	1.4	0.9	3.8

Maximum Stellar Variability: Implications for Life?

- The largest changes in stellar luminosity will have outsized effects on habitable planets
  - May change elemental constituents on planets
  - May disrupt evolution
- Protoplanet destruction would cause the largest brightness increase, but there is little study of any unusual outliers of stellar luminosity
- "Rare maxima" of stellar luminosity not studied
- Luminosity variations of sun not looked for in geologic record. (The sun should have been less luminous, but not even this is evidenced.)

Fast moving subject

- 2008 and earlier -
  - Some “in passing” mention of planet destruction, but dismissed as disappearing into star.
  - Three day pileup almost seen as barrier
- 2008 - Solar tide recognized as important
- 2009 January - Falling planets papers
- 2009 June - WASP 18
  - Getting closer to a planet being destroyed
  - Evidence that Q_*' may be larger in F star?

Much Opportunity for Further Work

- Rates and magnitudes of pre and post main sequence events
- What is Q_*' as function of: Spectral type, rotation, frequency, metallicity
- Is there not more rotational synchronization? Why?
- Model destruction event
- Gives opportunity to do detailed study of tides
- Opportunity to study stellar and planet interiors
- Radiative dissipation
- Magnetic braking (Barker et al.)
- How does tidal energy affect star, starting with where is the tidal energy deposited?
- Destruction by RLOF
- What happens when planet orbits at stellar radius?
- Observable rates for LSST, Pan-STARRS, and nearby galaxies in form of Beatty & Gaudi 2008

National Speaking Tour 2010 September

- 2010 September hosting and support sought
- 2009 tour was 7500 driving miles