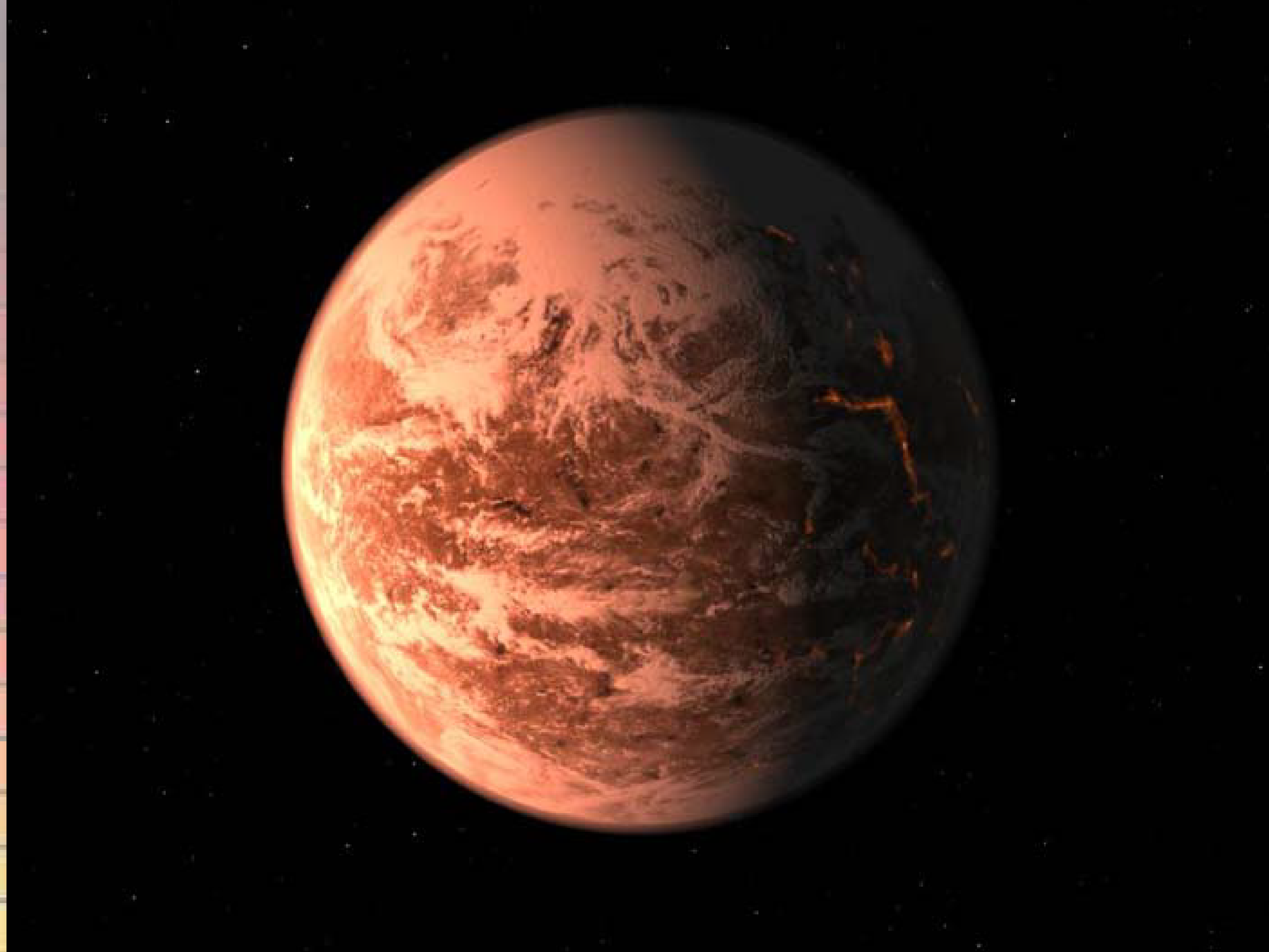

Background Image Credits:
HIRES Echelleogram: http://exoplanets.org/gl876_web/gl876_tech.html
Above: Gliese 876d Artist Rendition: http://exoplanets.org/gl876_web/gl876_graphics.html

On the Stability of the Gliese 876 System of Planets and the Importance of the Inner Planet

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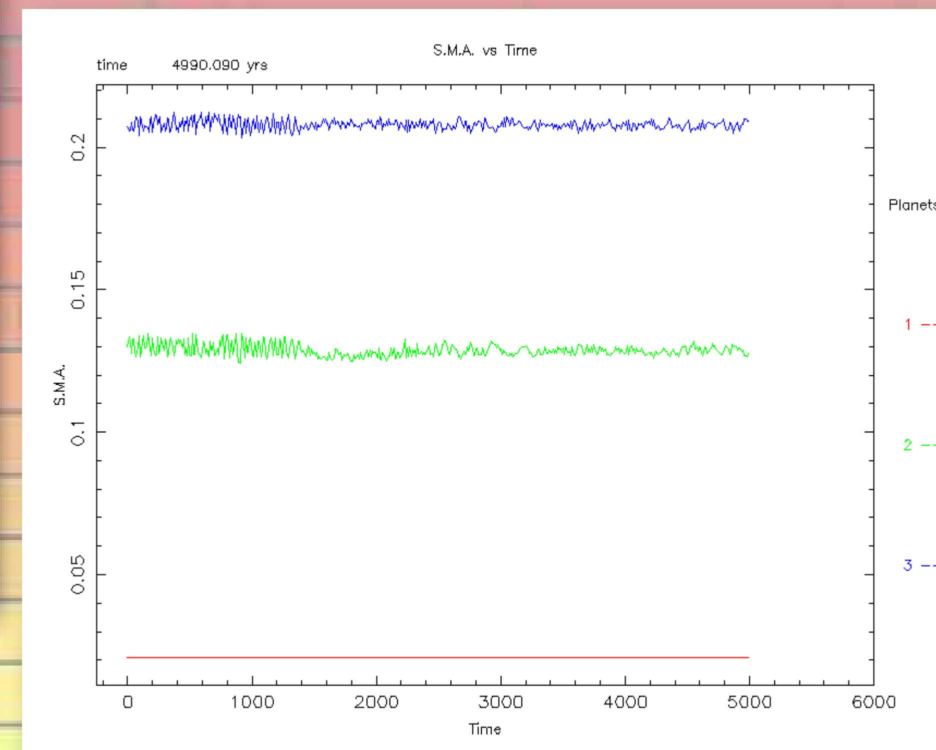
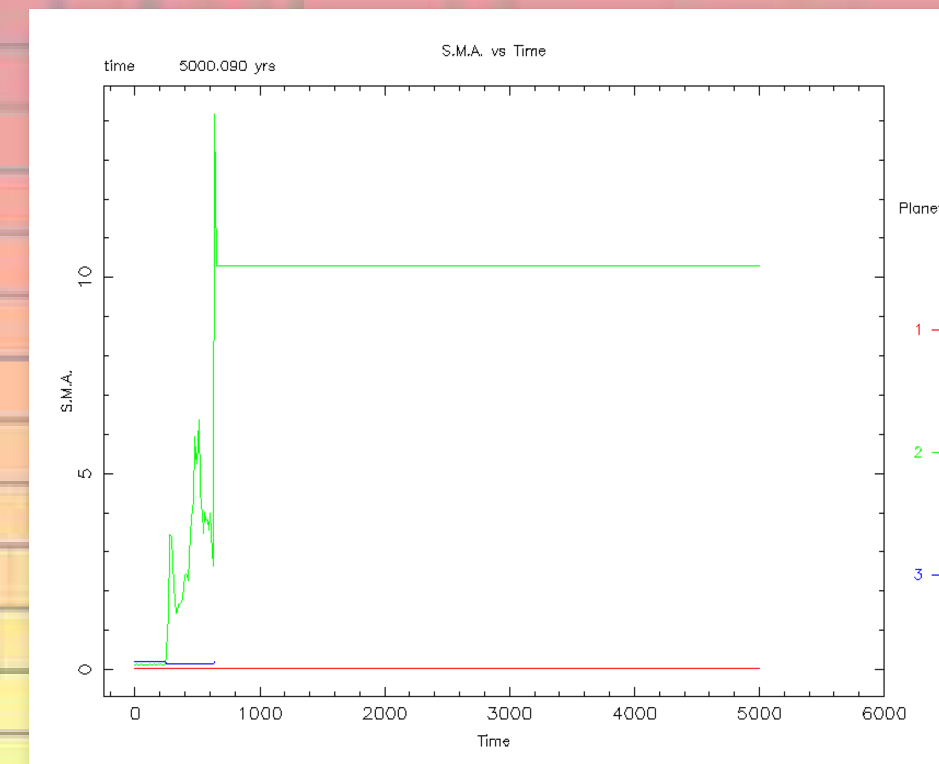
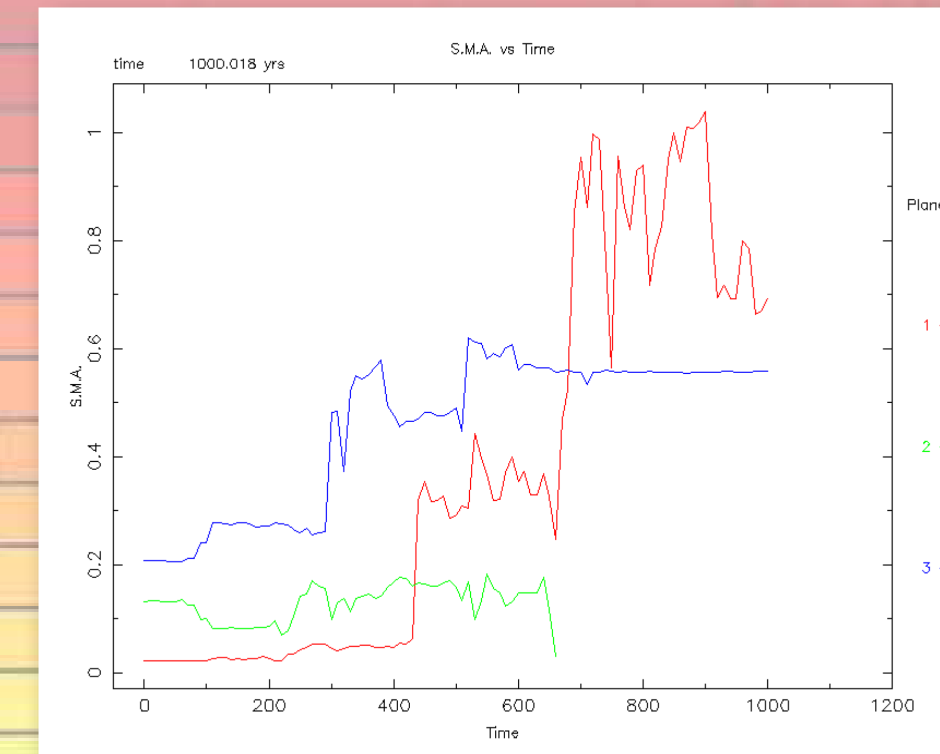
Major Project – HET617 – Computational Astrophysics S2 – 2005 | Supervisor: Professor James Murray



Above:
Using the SWIFT simulator code, a 5,000 year simulation of the current Gliese 876 system was performed (Monte Carlo simulations - to determine the best Cartesian coordinates). The result is a system that is stable. These parameters will be used for the remaining simulations of Gliese 876.



Above:
Changing the mass of the inner body has resulted in the middle planet to take on a more distant orbit. The eccentricity of this body was very high, so the mass of the inner body was not available to ensure system stability. The mass of the inner body was changed to 0.000000001 M_J.



Above:
In addition to mass, the eccentricity of the inner body also severely affects system stability. Here the mass of the inner body is the same as the stable system (0.023M_J) with a change in the orbital eccentricity from 0 to 0.1. None of the planets are able to hold their orbits.

Abstract:

A third planet with a mass of 0.023 M_J was found orbiting the star Gliese 876. The initial two body system was found to have a perfect orbital resonance of 2/1. This paper will demonstrate the orbital stability to maintain this ratio is highly dependant on the presence of the small, inner planet. In addition, any change in orbital eccentricity of the inner planet as well as initial planetary set-up will also severely alter the orbital dynamics of the remaining two bodies. In addition to this demonstration, methods of detecting the planetary system will be covered as well as the theories and techniques used to plot the orbits of these bodies.

Gliese 876 System Data (Rivera et al., 2005):

Star:	
Class:	M4
Mass:	0.32M_{Sun}
Distance:	15 light years
Gliese 876d (GJ876d): Discovered in 2005	
Mass:	0.023 M_J
Semi-major Axis:	0.0208067 A.U.
Orbital Period:	1.94 Days
Eccentricity:	0
Gliese 876c (GJ876c): Discovered in 2001	
Mass:	0.619M_J
Semi-major Axis:	0.1303 A.U.
Orbital Period:	30.34 Days
Eccentricity:	0.2243
Gliese 876b (GJ876b): Discovered in 1998	
Mass:	1.935M_J
Semi-major Axis:	0.20783 A.U.
Orbital Period:	60.94 Days
Eccentricity:	0.0249

Discussion:

The works of Duncan & Quinn (1993) and Innanen et al. (1998) indicate our Solar System is very stable. However, Innanen et al. (1998) was able to determine that the Solar System minus the Earth-Moon dynamic as well as without the inner Solar System resulted in a system with eccentic orbits. While our Solar System has the benefit of large and widely spaced bodies, the Gliese 876 system does not have that luxury. Using Innanen et al. (1998) as a base, the simulations of Gliese 876 indicate that without the inner planet, and with changes to the inner planet's eccentricity, the overall system is chaotic.

While the Solar Nebula Hypothesis model seems to support our own system's formation, the Gravitational Instability model seems to be the best way to understand exoplanetary systems (Zhou et al., 2005). This model also explains the resonant orbits of exoplanets as well: if two high mass planets are formed close to each other, they can lock together in resonance and maintain the same orbital dynamics for millions of years. In the case of Gliese 876, the large bodies exhibit a 2/1 resonance – that is the middle planet – GJ876c - orbits at 30.3 days while the outer planet - GJ876b - rotates at 61 days.

For the "perfect" 2/1 resonance to occur, the Gravitational Instability model was probably working as the large bodies began their migration - migration is the key to this model. The inner planet could have forced the eccentricity required for GJ876c to allow GJ876b and GJ876c to be captured in a co-rotational resonance. Once resonance occurred, it should be noted that there will be certain liberation to this resonance – in other words, each orbit may speed up or slow down as each mass acts on each other – similar to the action of a pendulum.

Summary:

The lack of the Earth-Moon mass as well as the inner Solar System greatly affects the orbit of Pluto in our simulations. With the benefit of the gas giant planets of Jupiter, Saturn, Uranus and Neptune, the residual bodies of the Solar System are still in check. The planetary system of Gliese 876 does not have the luxury of multiple large bodies to keep the system stable. In fact, the orbital resonance of the two large bodies at such close proximity relies heavily on the presence of the inner planet. There is enough mass within the inner body to provide the counter-resonance required to keep this system in check. It is difficult to say if the 15/1 ratio of the inner two bodies is required for the 2/1 ratio of the outer two bodies - only with further computer simulation can we determine this to be true – but the simulation results seems to support this idea.

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