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INFINITY

The Next Generation of Binary System Modeling

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SUMMARY

INFINITY is a new program for modeling binary systems. [illegible] physics [illegible] Roche geometry with [illegible] rotation, including an assortment of effects like gravity and limb darkening, mutual irradiation, bright and dark spots and so on. [illegible] INFINITY [illegible] innovations in modeling accretion disks, and introduces the modeling of radial and non-radial oscillations on one or both components.

At this stage of development, INFINITY can produce light curves, [illegible] radial velocity curves; solving the inverse problem is still a work in progress. In terms of programming, INFINITY is being developed in the object-oriented language C#, and great care is taken to produce readable, easily extensible and verifiable code. INFINITY is fully optimized to take advantage of modern multi-core CPUs, and the code is thoroughly covered with unit-tests. We expect to make a public release during 2012.

MOTIVATION

Why build a new modeling package when there are so many existing already? The simplest answer to that question is: it's easier to start afresh than to modify. Our aim, to expand the capabilities of Djurasević's model by including stellar pulsations, a realistic treatment of stellar atmospheres and adding optional components, like the accretion disk, gas stream, circumstellar and circumbinary shells, was best served by laying out a code foundation that will allow seamless and easy integration of new features.

PHYSICS

The physics of INFINITY follows closely the physics of Djurasević's model. The shape and the basic temperature distribution of the stellar surface are determined by Roche potential and Von Zeipel's law; this base distribution can later be modified by various effects, like dark and bright spots, stellar pulsations and mutual irradiation. At the moment, we treat the stars as black bodies and calculate the emergent fluxes from the Plank law, but we'll make the transition to using models of stellar atmospheres in the near future. Djurasević's model can optionally include a flat or conical accretion disk; INFINITY expands on this capability by allowing the disk to assume a toroidal or an ellipsoid shape and stand at an angle in relation to the orbital plane. The other venue of expansion is towards the inclusion of stellar pulsations, which we model as perturbations in shape and temperature.

GEOMETRY

In INFINITY the stars are represented as geodesic meshes that consist of elementary triangles. The smoothness of the mesh is controlled by the level of geodesic subdivision; at level 5, there are about 20 000 triangles per mesh, and at level 6, about 80 000. (We are looking into alternative subdivision algorithms that will allow a gentler increase of the number of elementary surfaces per level.) Additional components, like the accretion disk, are also divided into elementary triangles. The visibility of a triangle in any given phase is determined by a method similar to the "Painter's algorithm" in computer graphics. A triangle is either visible (nothing in front), or invisible (some part covered) – there is no "partial" visibility. Instead, we're working on implementing an adaptive grid that will increase the level of subdivision in the region of the eclipse, allowing for arbitrary accuracy even when modeling planetary transits.

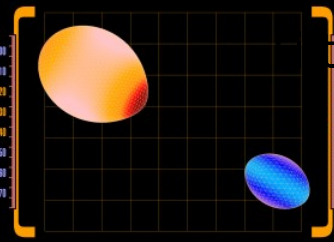
FITTING & MODE IDENTIFICATION

In addition to fitting the system and component parameters, INFINITY will be able to fit the parameters of stellar pulsations: the amplitudes and more importantly, the harmonic degrees and azimuthal orders of the modes. This method of mode identification, the so-called "direct fitting of spherical harmonics" has been tested on artificial data and a model with spherical stars, but we will attempt to apply it on distorted stars in Roche geometry. The fitting algorithm we're working on at the moment is a variation of the Nelder-Mead simplex with constraints and parameter mutations.

PROGRAMMING

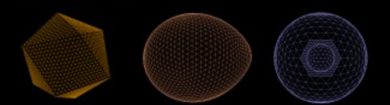
INFINITY is written in C#, an object-oriented language similar to C++. The object-oriented nature of the code allows creating very natural structures. A star is represented as an object that has mass, temperature, size and so on; the binary system is then composed of two stars and additional components. Expanding the definition so that a binary system can be composed of either single stars or other binary systems is an attractive venue for modeling multiply hierarchical systems, and well within the capabilities of INFINITY. This sort of extensibility was one of our primary goals, along with producing readable code which is easy to upgrade, maintain and verify.

GEODESIC MESH



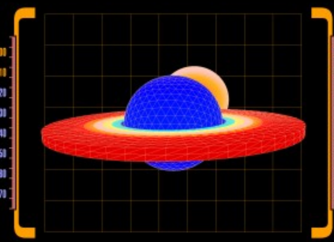
SURFACE SUBDIVISION & ADAPTIVE GRID

- Allows a very fine division into elementary surfaces, represented by flat triangles of almost the same areas.
- Triangles represent both physics and geometry: each one has its position, gradient and velocity vectors, temperature and flux.
- Adaptive subdivision in the region of eclipse makes up for lack of partial visibility and can be tuned to reproduce very fine effects.



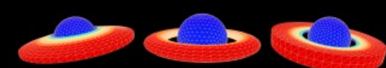
ICOSAHEDRON: the first step in modeling the shape. | PUSH TO SURFACE: the vertices are pushed to the given surface (Roche potential). | ADAPTIVE SUBDIVISION: resolve finer detail around the edges of the eclipse.

ACCRETION DISKS



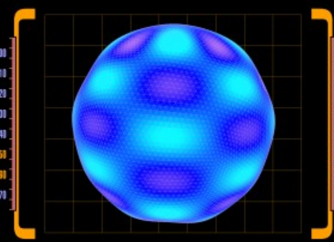
MODELING DISKS

- Various shapes: conical, toroidal, ellipsoid, inclined, non-continuous. The shape is defined by a cross-section and can be arbitrarily scaled, translated and rotated by a simple matrix operation.
- The temperature distribution is an arbitrary function of position.
- The dependence of rotation velocity with position is an arbitrary function of position.
- WIP: Bright spots standing for the active regions (like the hot spot), and in the future, disks with spiral structure and gas streams



CONICAL, CONVEX DISK. | TOROIDAL DISK. | CONICAL, CONCAVE DISK.

STELLAR PULSATIONS



MODELING PULSATIONS

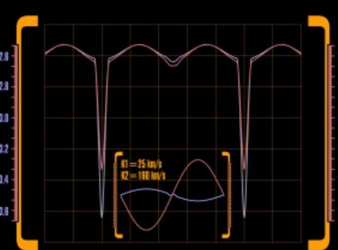
- Radial or non-radial, on one or both components, on spherical and Roche-distorted stars.
- Modes are approximated by spherical harmonics, described with frequency, harmonic degree and azimuthal order, amplitudes and phases of displacement and temperature perturbation.
- Modes can have a symmetry axis inclined to the rotation axis.
- As many simultaneous modes as needed.

SINGLE MODE: l = 5, m = 5. | SINGLE MODE: l = 4, m = 2. | TWO MODES: l = 5, m = 5 and l = 4, m = 2.

EXAMPLES OF SYNTHETIC DATA

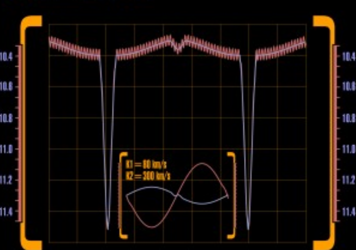
A SYSTEM SIMILAR TO AU MON

- No disk
- Large, conical, slightly concave disk
- Subdivision levels: 5 for the smaller, 6 for the larger star



A SYSTEM SIMILAR TO NY VIR

- No pulsation
- One mode with l = 2, m = 0, small displacement, large temperature amplitude
- Subdivision levels: 4 for both stars



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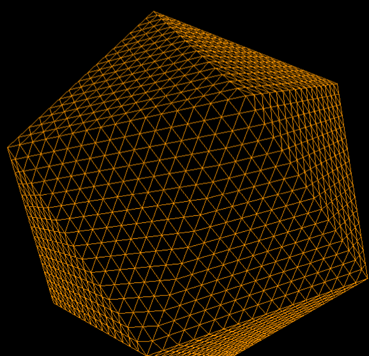

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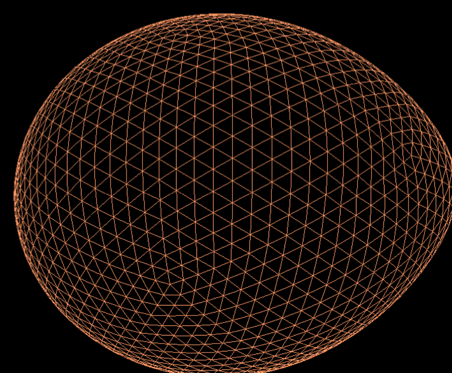

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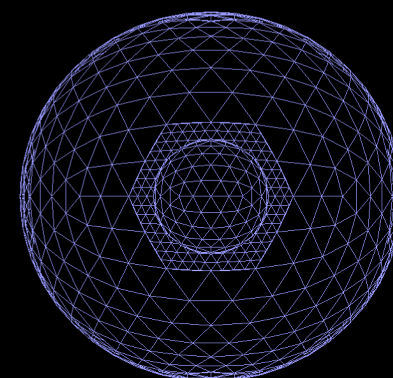

ADAPTIVE SUBDIVISION: resolve finer detail around the edges of the eclipse.

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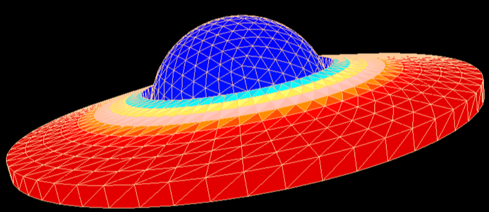

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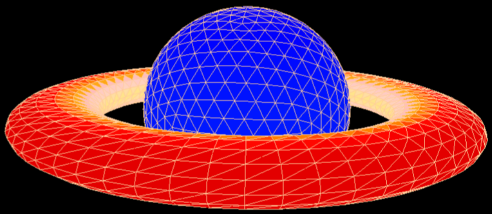
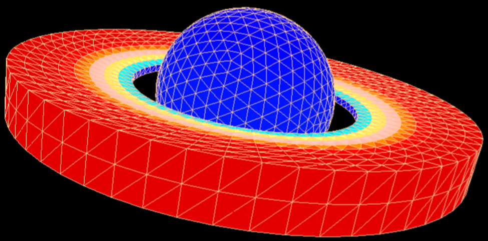


TOROIDAL DISK.



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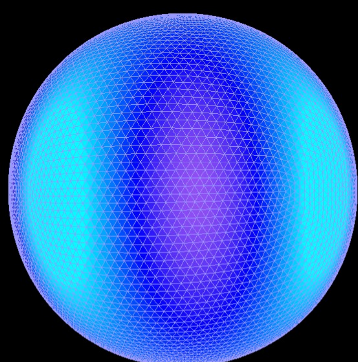

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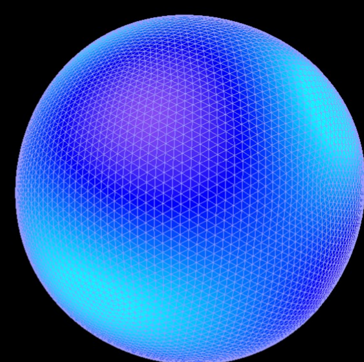
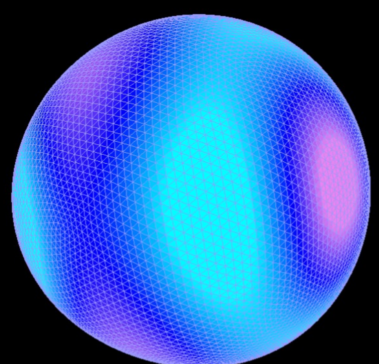


SINGLE MODE: $l = 4$, $m = 2$.



TWO MODES: $l = 5$, $m = 5$ and $l = 4$, $m = 2$.

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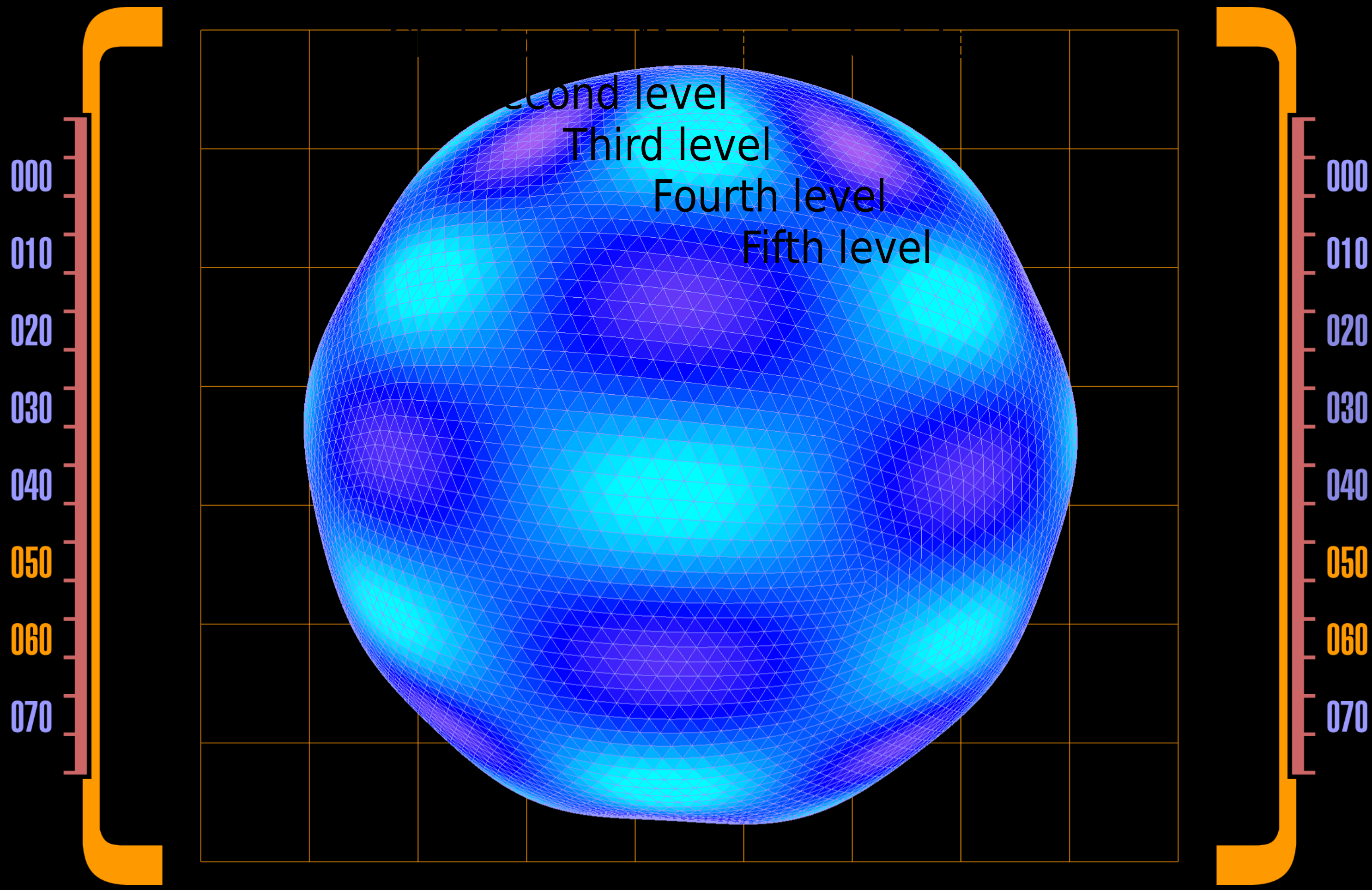

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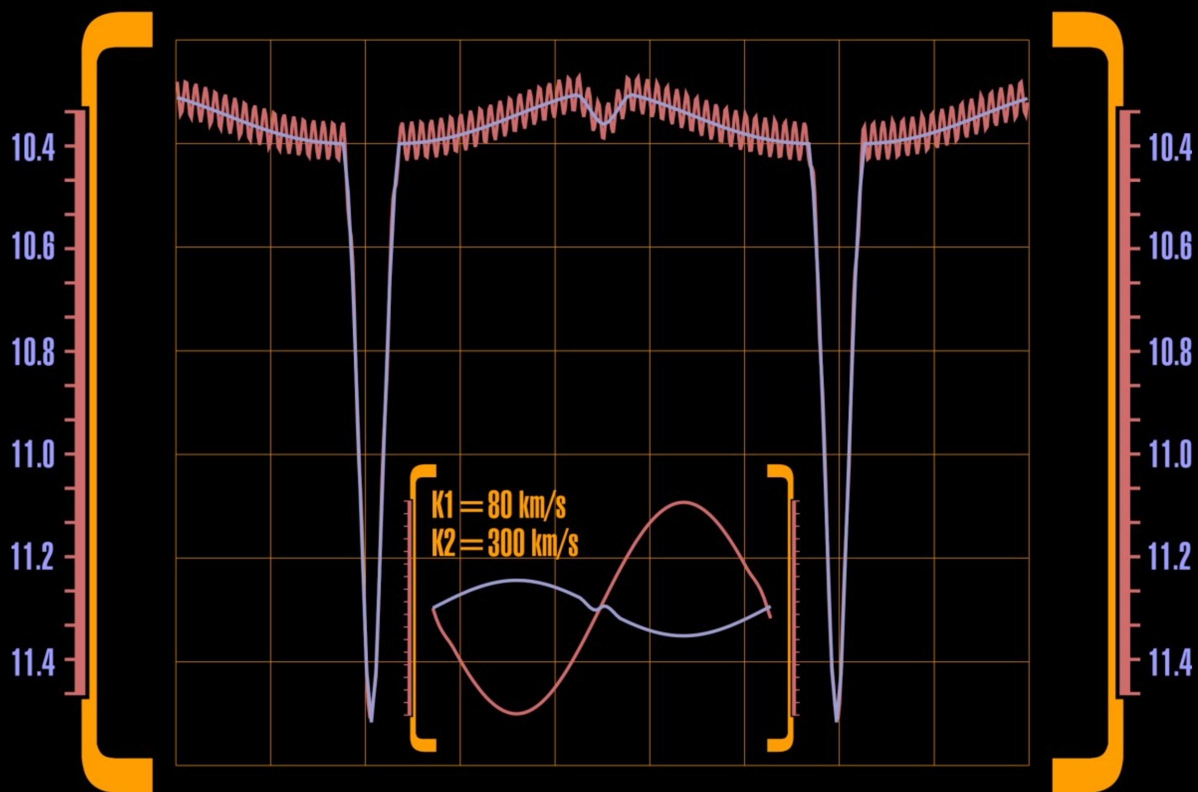

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