Light curve modeling of eclipsing binary stars

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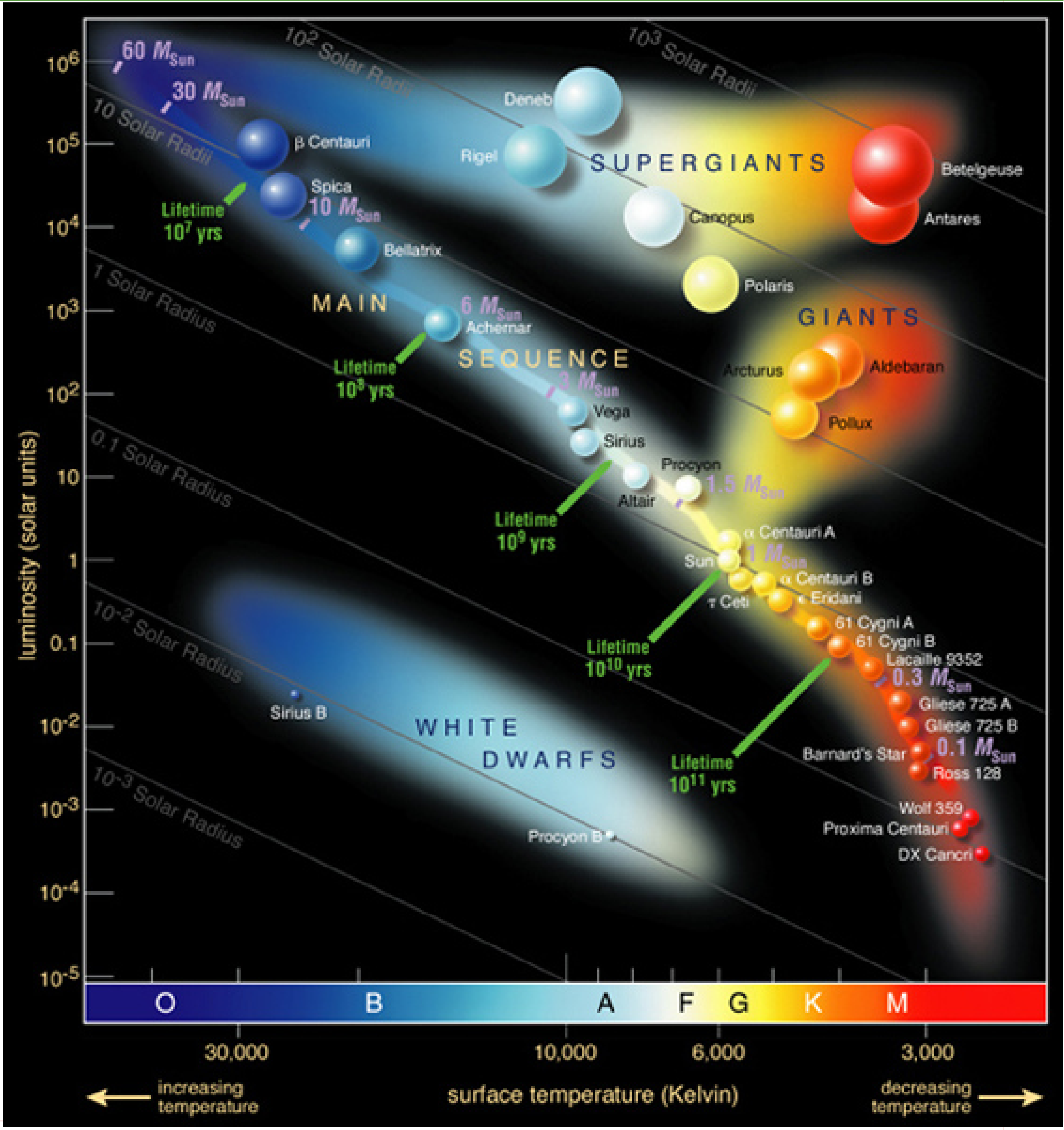
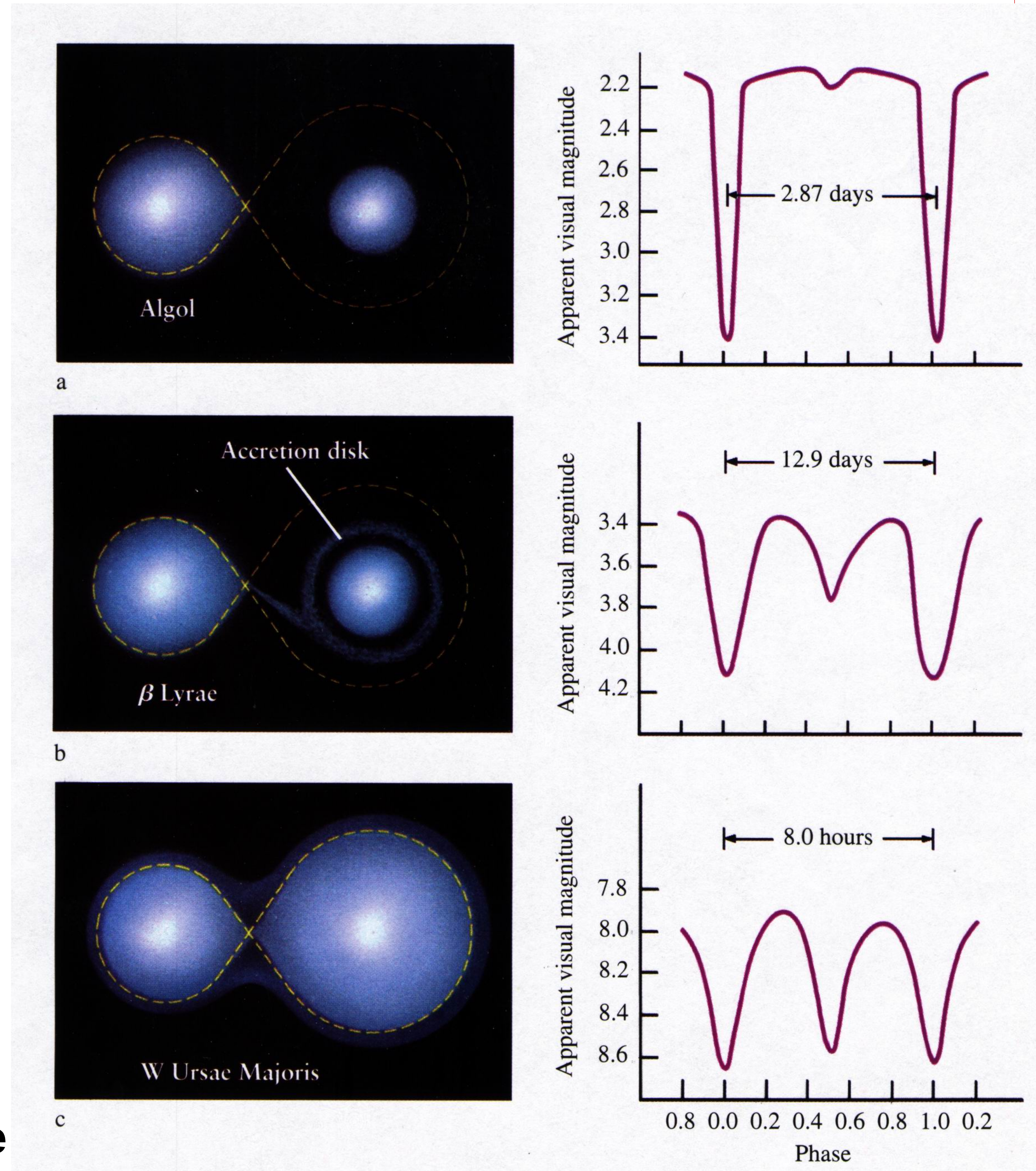
Binary stars

- physical variables
  - pulsating stars
  - mass, radius, temperature
- optical variables
  - binary stars (↔ visual binaries)
  - multiple stellar systems
  - (exoplanets)

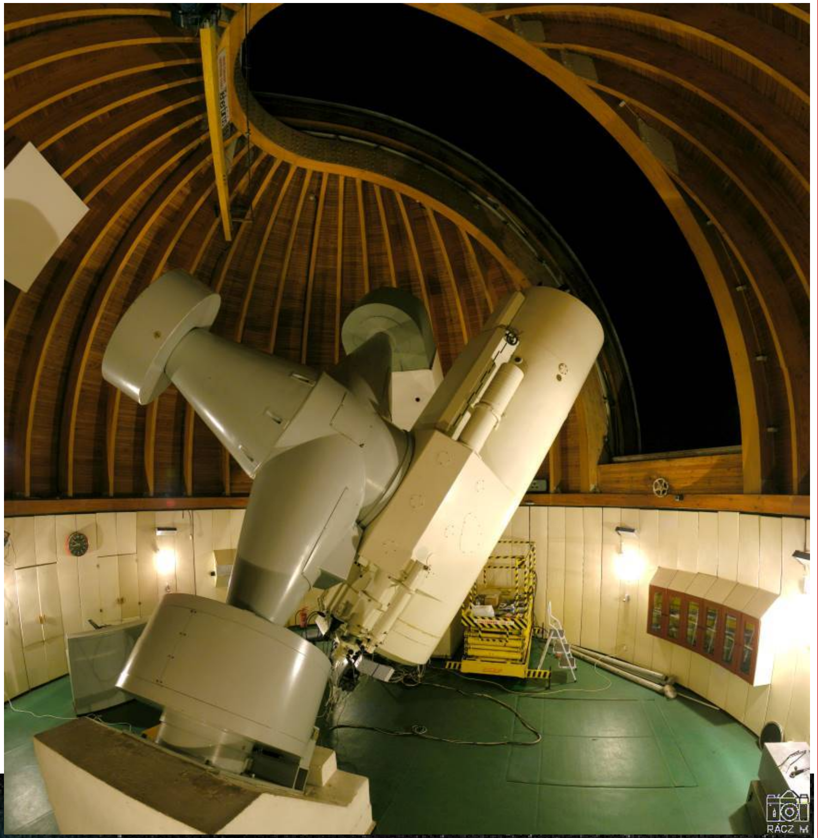


Binary stars

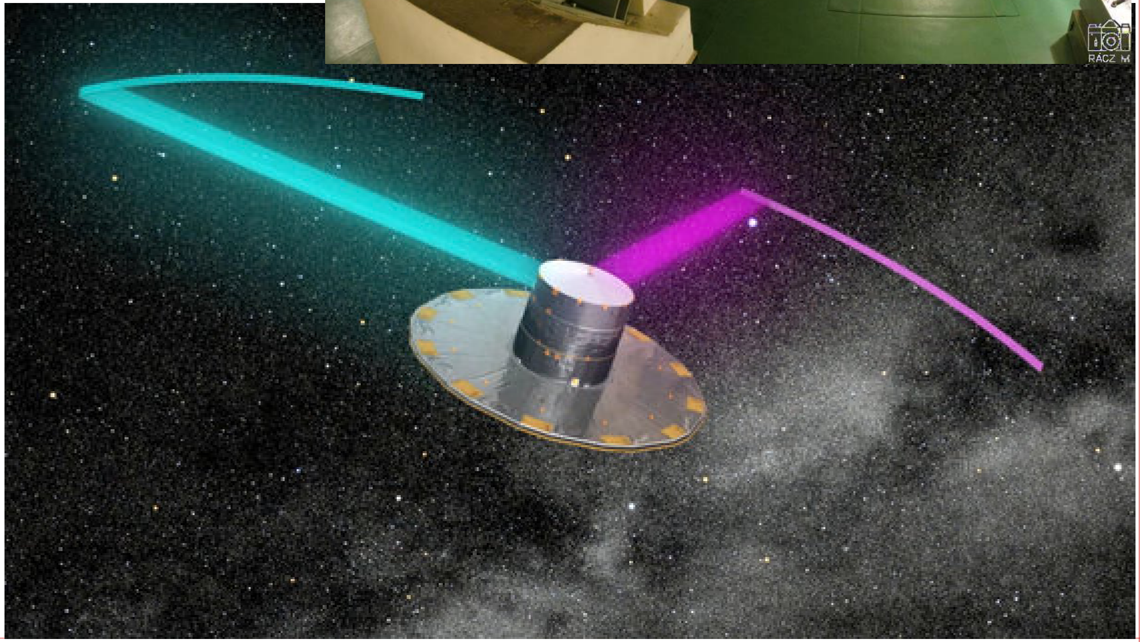
- primary
  - star, minimum
- secondary
  - star, minimum
- orbits
  - circular
  - eccentric
- distance
  - close
  - detached
  - semi-detached
- physical parameters
  - mass, radius, temperature



Observing binaries

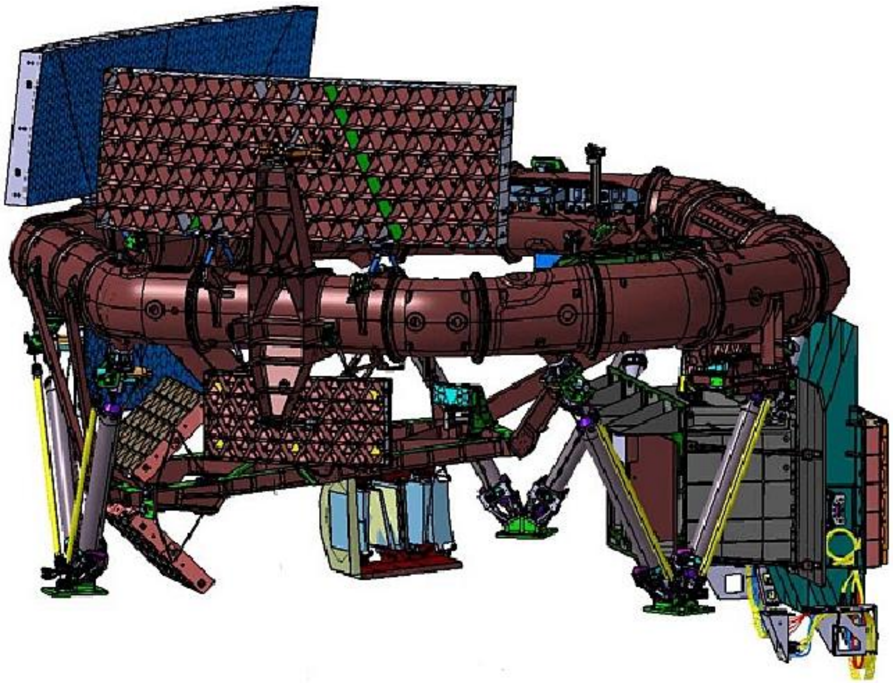


- **ground based observations**
  - **MTA CSFK KTM CSI – Piszkéstető**
  - **ELTE GAO – Szombathely**
  - **Baja Observatory – Baja**
- **space missions**
  - **GAIA (petabytes of data during 5 years operational period)**
  - **Kepler (K2)**
  - **CoRoT**



Observing and modeling binaries

- there are a lot of space missions
- there are a lot of binary and multiple system
- → we get a lot of data
- this requires automated light curve modelling and analysing packages
  - Phoebe (Wilson-Devinney code)
  - binary → multiple systems
  - paralelization (CPU, GPU).



Complex Analysis of Today's and Future Space Photometry of Multiple Stellar and Planetary Systems

- **PI: Dr. Tamás Borkovits**
  - **15 years development (binary and triple stellar systems)**
- **Dr. Emese Forgács-Dajka, senior researcher**
  - **N-body on GPU, CPU/GPU development**
- **János Sztakovics**
- **Tamás Hajdu**

Modelling binary stellar systems

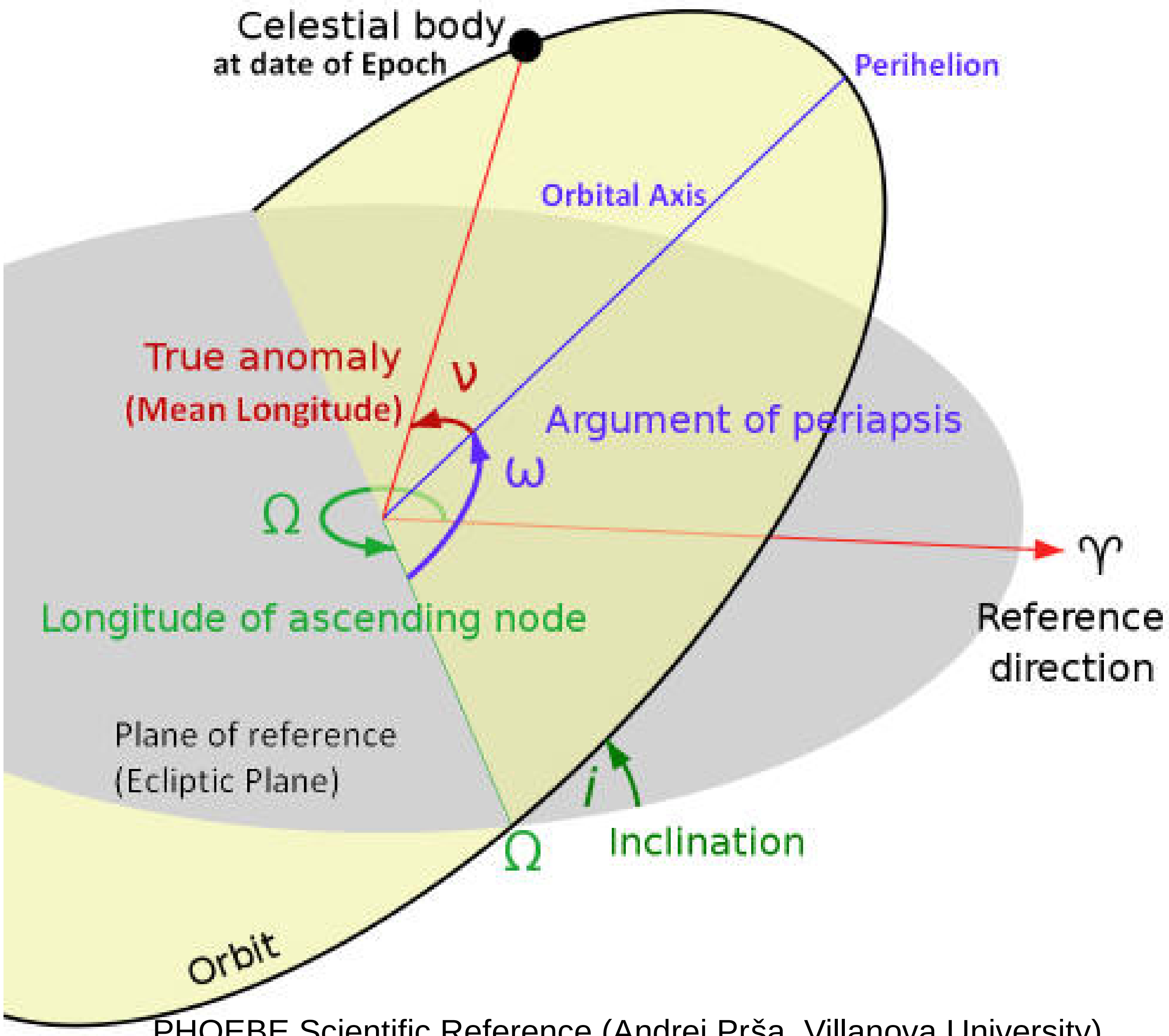
- **Now we have Tamás Borkovits's code for modelling binary and triple, hierarchical triple stellar systems and two gravitationally bound binary systems and also exoplanetary systems.**
  - **We would like to**
    - **refine some parts of it**
    - **change some algorithms for more accurate ones**
    - **standardize, modularize the different parts of the code for mutual interoperability**
    - **accelerate computation by means of GPU paralelization**
    - **involving multiple stellar systems and exoplanet systems also**

Modelling binary stellar systems

- Why it is useful to modelling binary and multiple stellar systems?
  - to determine the stars' physical parameters
    - masses (generally only an upper limit of them)
  - potential field → inner structure of the star
    - star evolution
  - orbital elements (like as semi-major axis) and stellar type define the habitable zone

Orbital elements

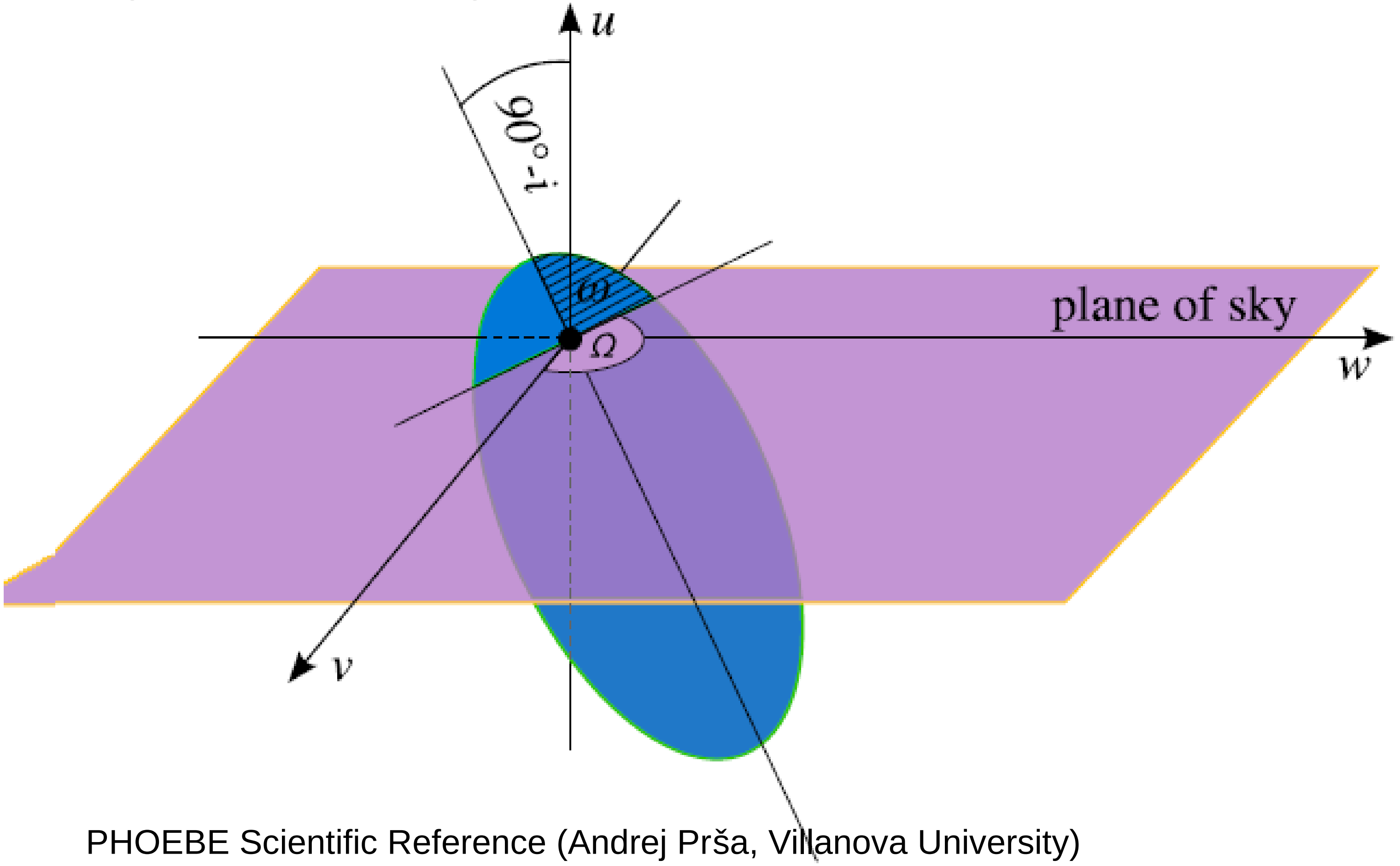
- Initial parameters:
  - orbital parameters
    - eccentricity
    - semi-major axis
    - inclination
    - argument of pericentre
    - longitude of ascending node
    - time of periastron passage
  - stellar parameters
    - radius, mass
    - effective temperature
      - based on Kurutz atmospheric model



PHOEBE Scientific Reference (Andrej Prša, Villanova University)

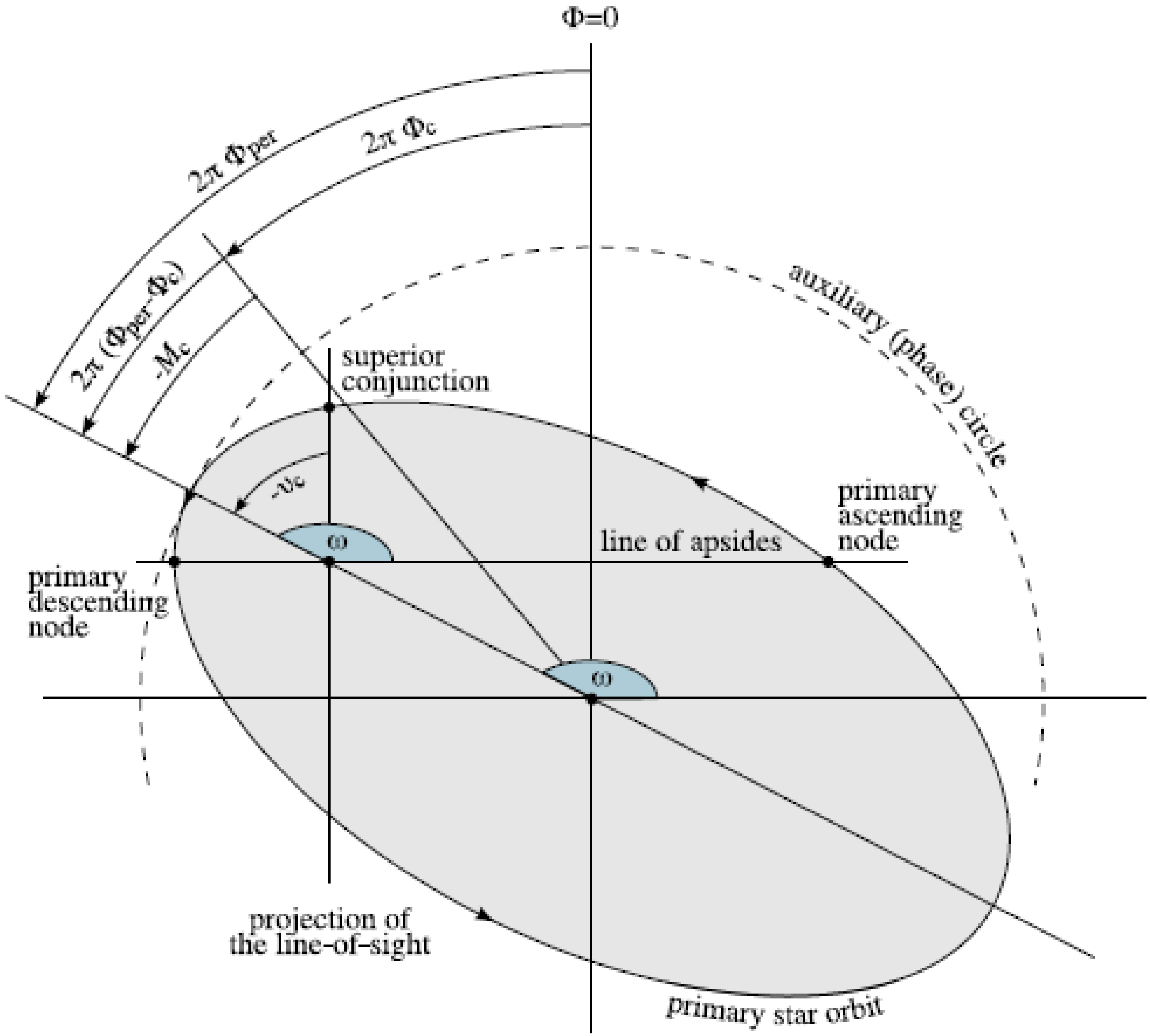
Orbital parameters

- **stellar positions are calculated by solving Kepler equation with Newton-Raphson method**
- **we using a co-rotating system in the center the primary star**



PHOEBE Scientific Reference (Andrej Prša, Villanova University)

Orbital parameters



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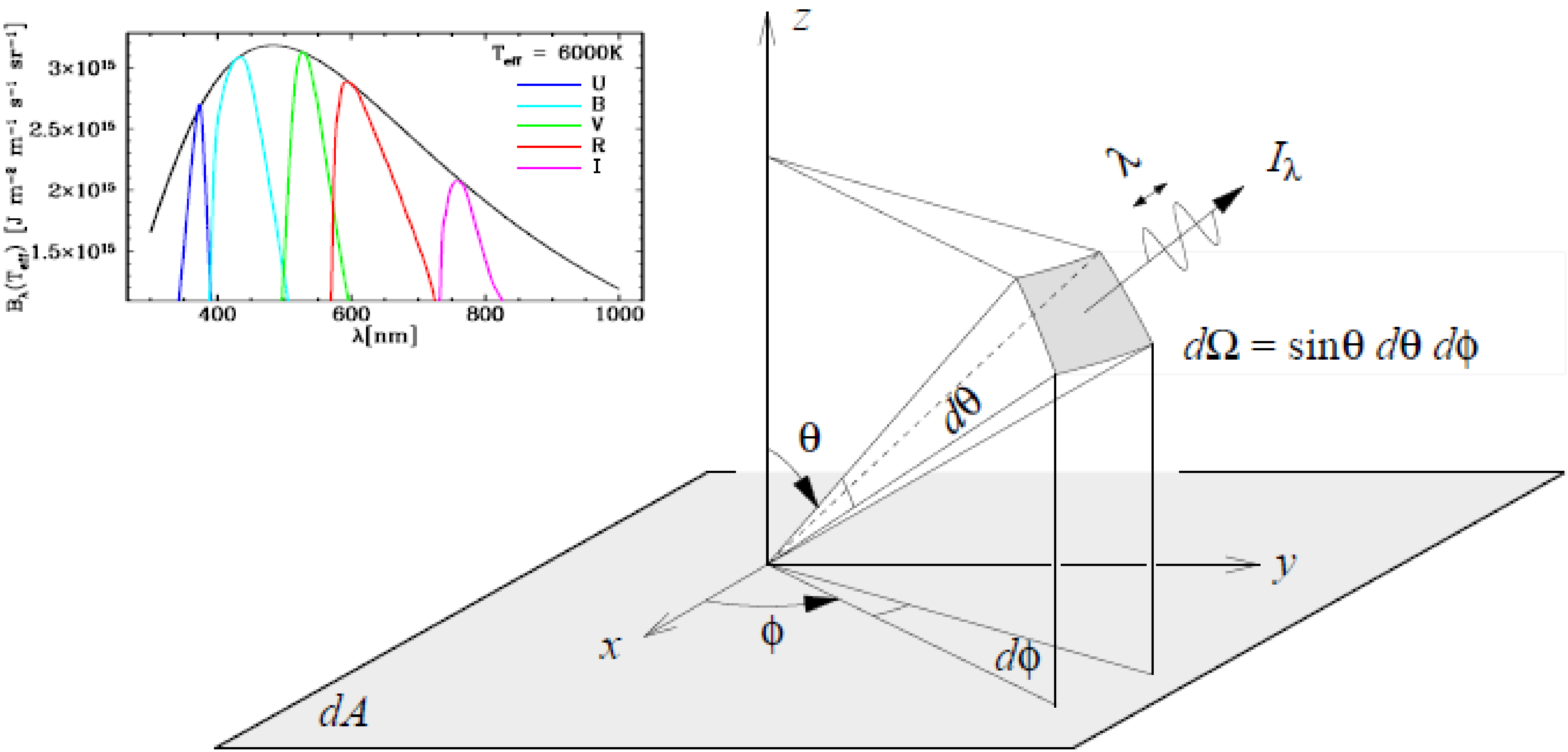
Radiative properties

- **we can calculate the emitted intensity for every surface element**



PHOEBE Scientific Reference (Andrej Prša, Villanova University)

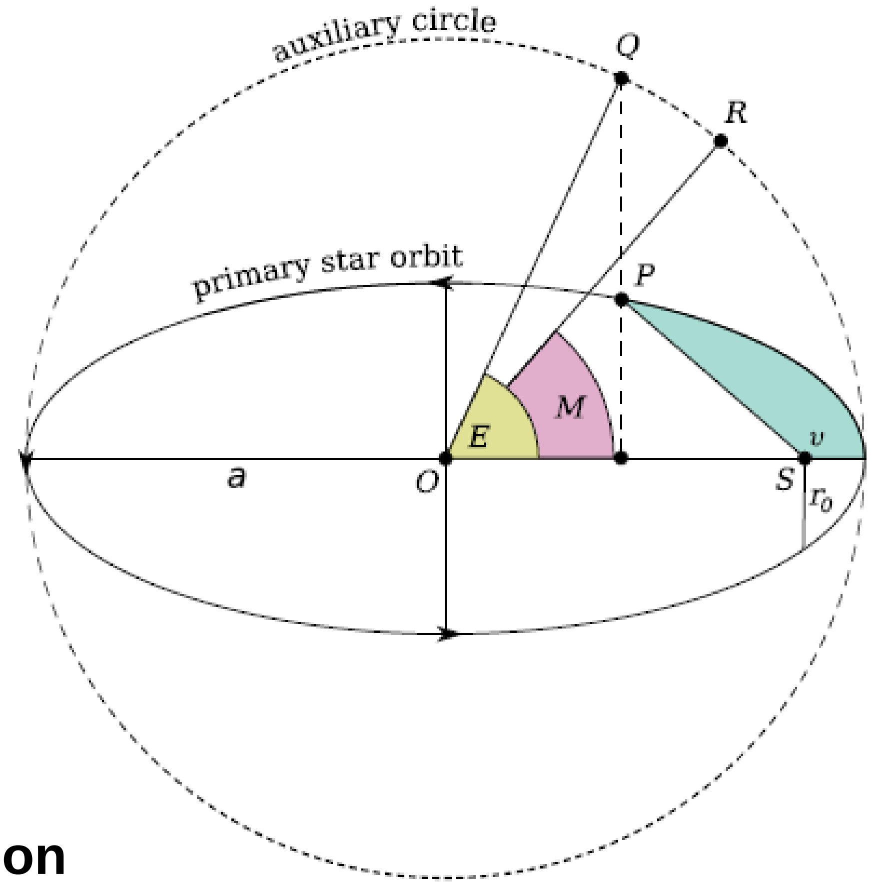
The old version

init_gpu

- **load parameters**
- **calculate surface grid**
- **solve Kepler equation with Newton-Raphson method**

$$M = E - e\sin(E)$$

- **calculate initial surface element positions in the plane of orbit**
- **and in the plane of sky.**



calc surface br.

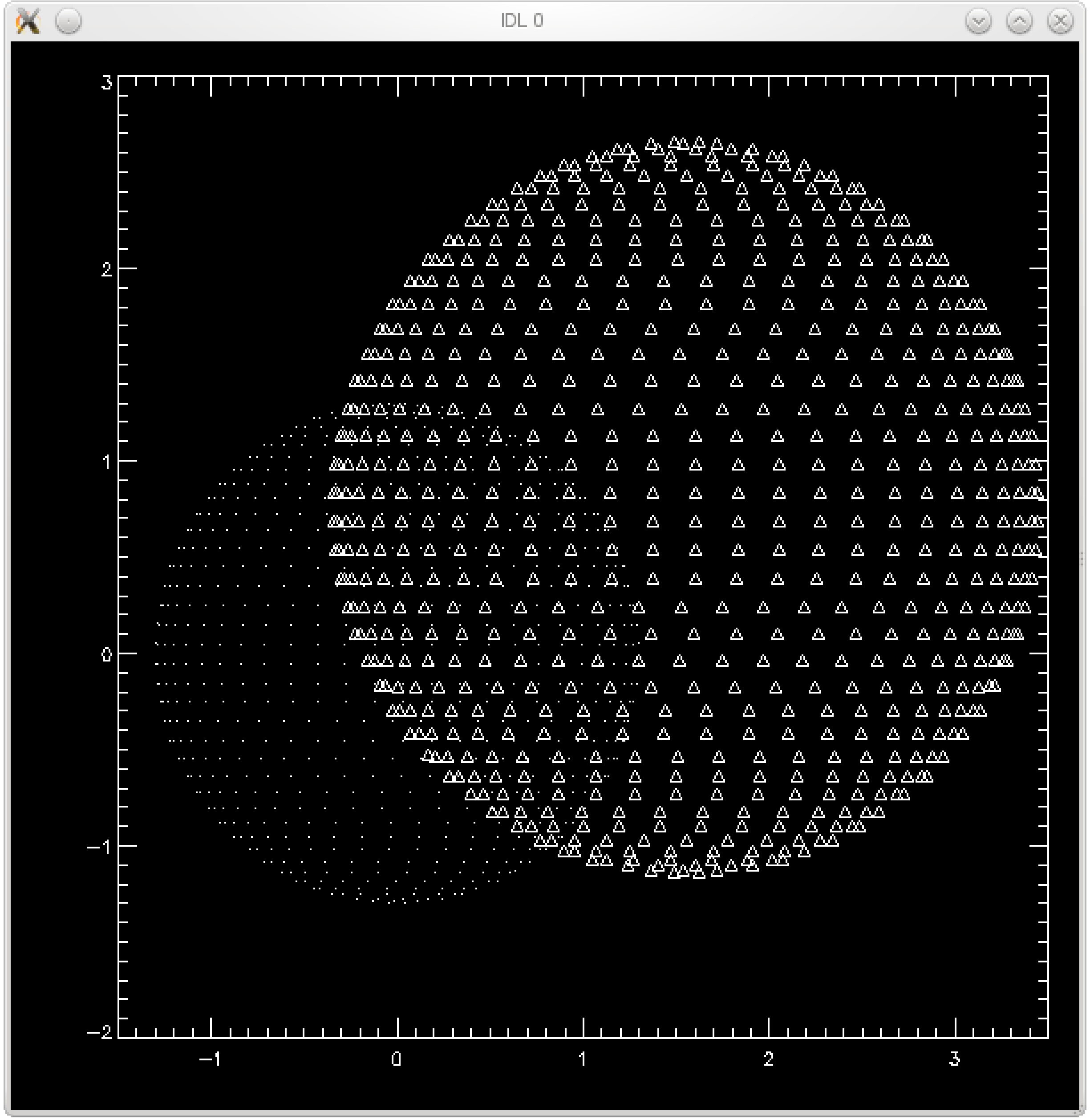
- **calculate:**
  - **norm vector**
  - **surface area**
  - **cos(gamma)**
  - **temperature**
  - **gravity acceleration**

PHOEBE Scientific Reference (Andrej Prša, Villanova University)

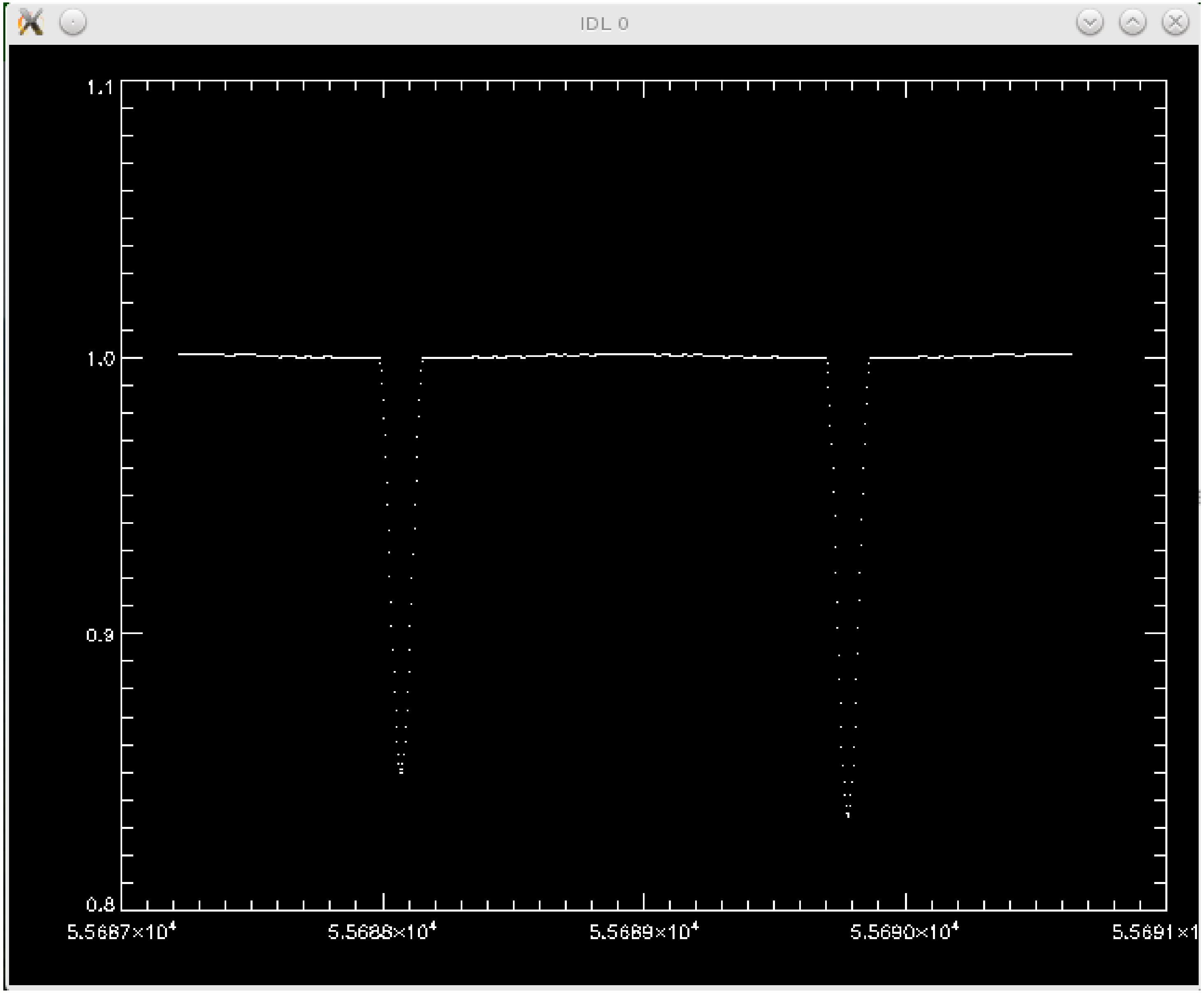
The new version

- **host functions**
  - **read data and initialize the (main) parameters**
  - **calculate orbital positions (plane of sight coordinates, angles)**
  - **calculate surface “constants” (polar radius, polar gravitational acceleration..)**
  - **copy constants between CPU and GPU**
- **device functions (they have CPU versions too)**
  - **calculate surface data (direction of normal vector, radius, gravitational acceleration, temperature, …)**
  - **calculate (surface) radiation data (the most important is brightness)**
  - **if there is an eclipse**
    - **calculate the horizon of the former star (parallelization not with surface element, but with latitudes)**
    - **calculate the eclipsed surface elements (is it eclipsed, if it is, how many percent of the area is eclipsed)**

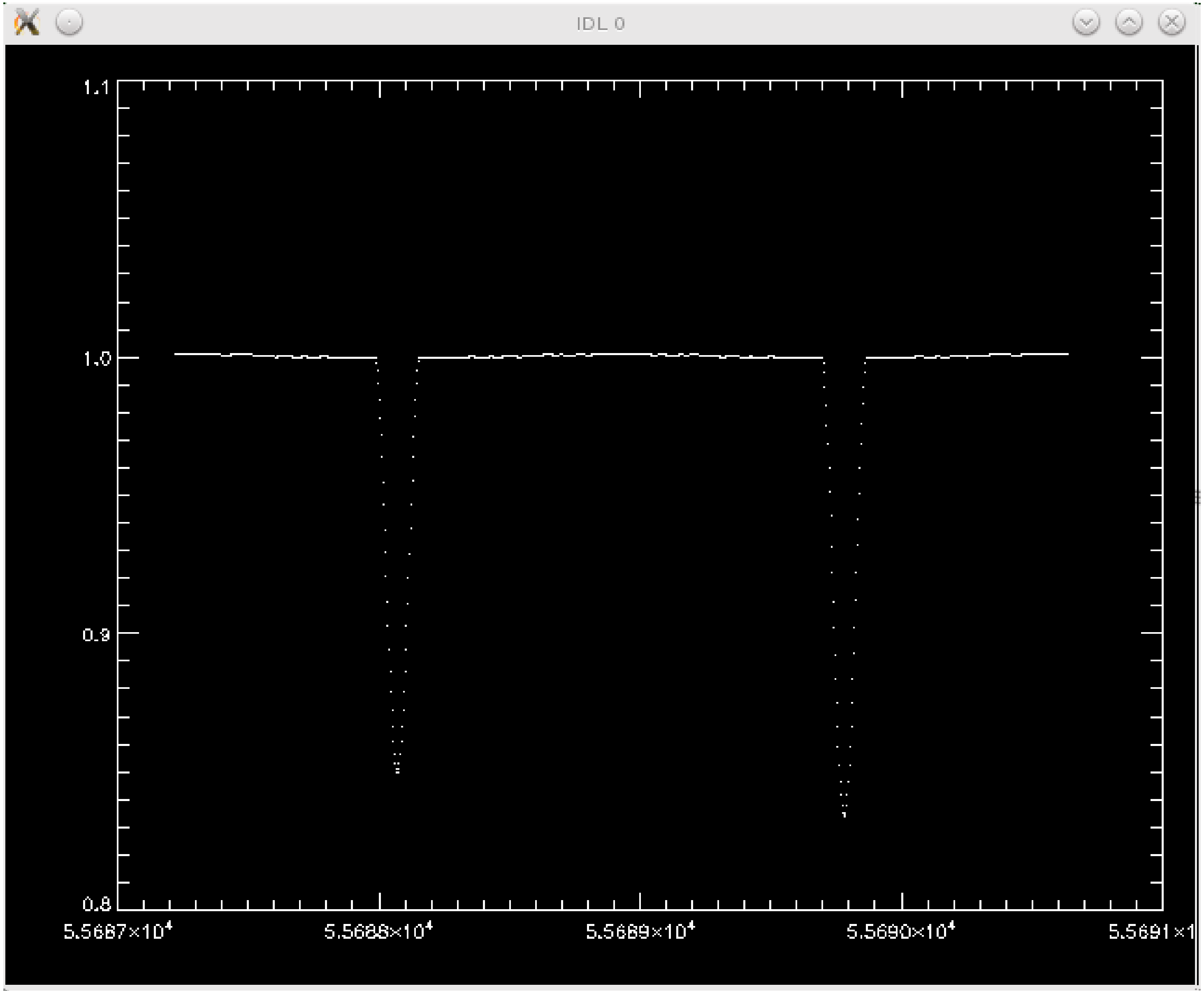
Surface grid



Lightcurve (GPU)



Lightcurve (CPU)



The old version

Computational prices

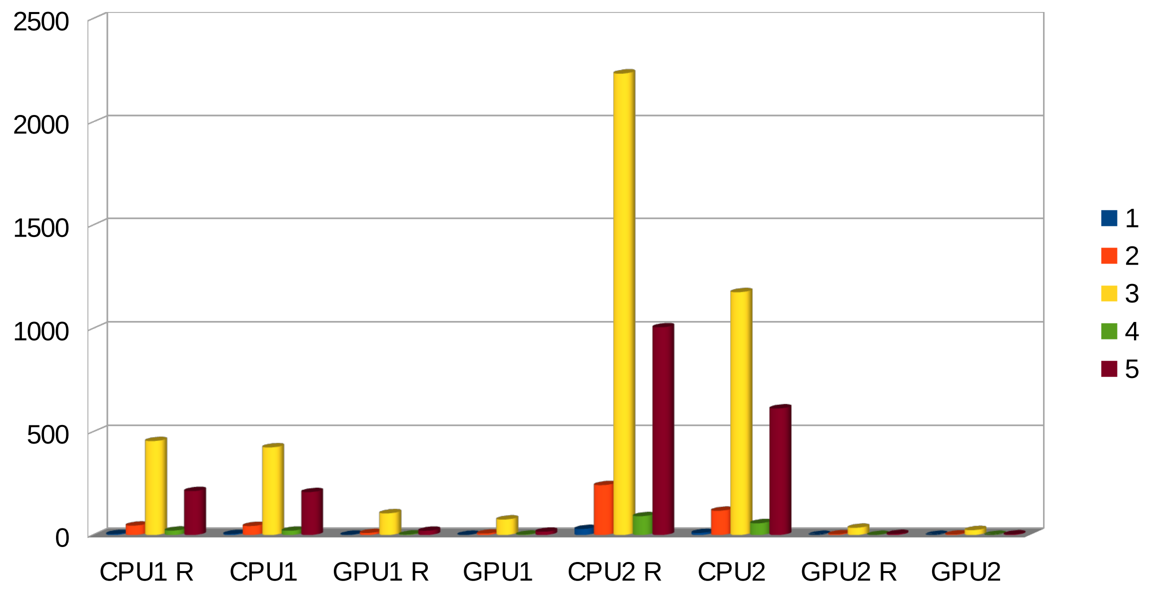
CPU 1 **Intel Core i7-4770 3.4 GHz** **4 cores, hyperthreading enabled**	**CPU 2** **Intel Core i7 920 2.67 GHz** **4 cores, hyperthreading enabled**
GPU 1 **NVIDIA GeForce GT 620** **compute capability: 2.1** **1024 threads/block**	**GPU 2** **NVIDIA GeForce GTX 980** **compute capability: 5.2** **1024 threads/block**

Case ID	Number of orbital positions	Number of theta grid points	number of surface elements
1	360	40	1348
2	3 600	40	1348
3	36 000	40	1348
4	360	60	3012
5	3600	60	3012

The old version

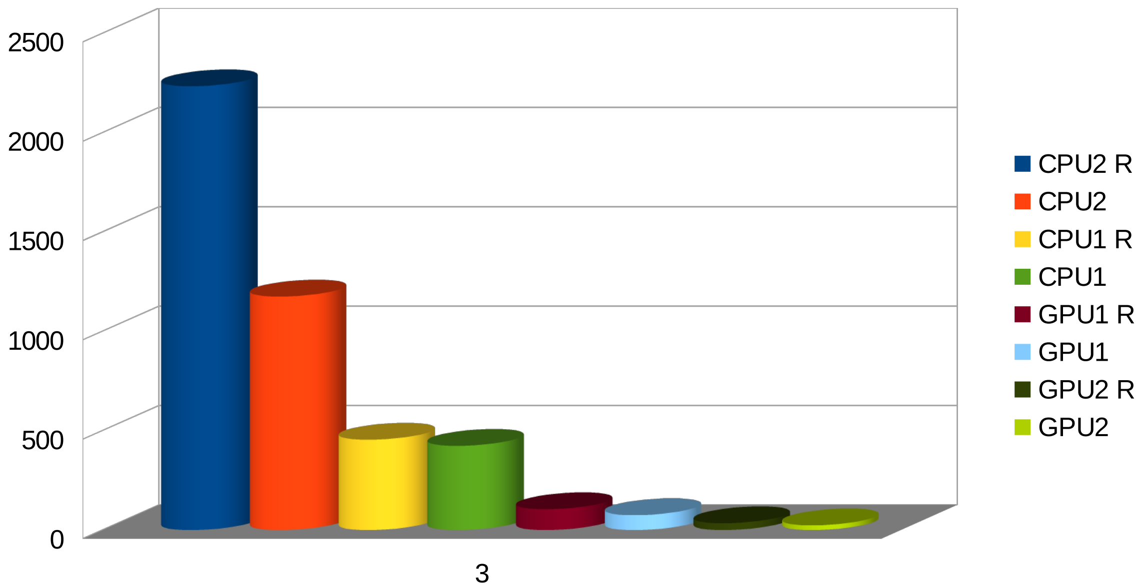
Computational prices

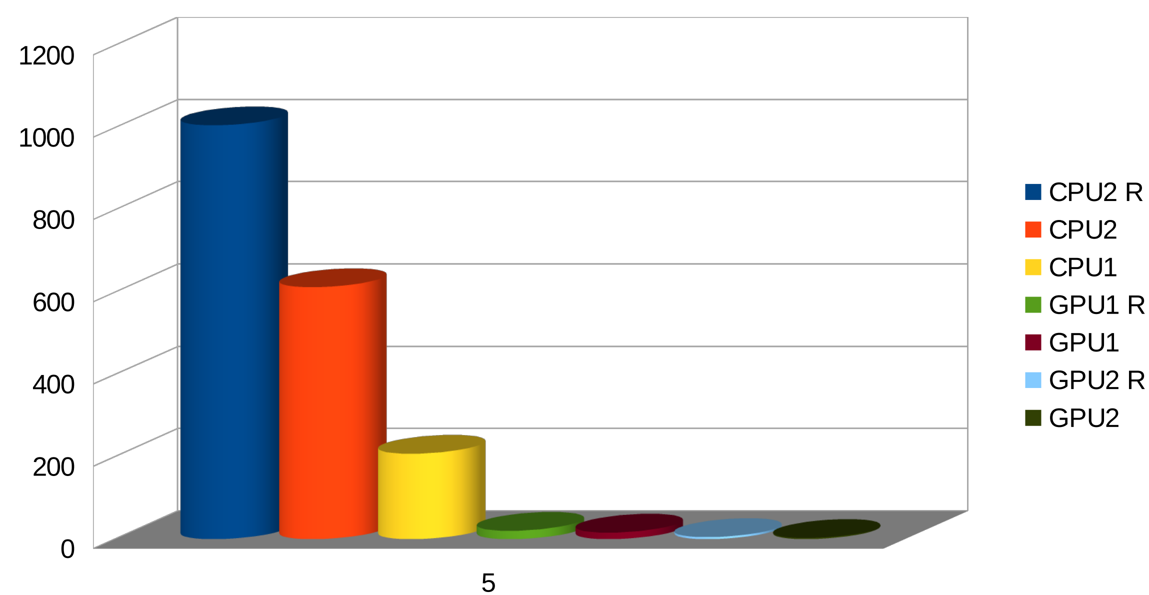
configuration	CPU1		GPU1		CPU2		GPU2	
With Roche- model	√	X	√	X	√	X	√	X
1	4,42	4,37	0,959	0,733	28,98	9,92	0,363	0,276
2	45,43	43,33	9,575	6,953	241,16	117,37	3,389	2,402
3	454,82	424,12	104,82	74,826	2234,2	1175,5	34,659	23,597
4	21,17	20,65	2,042	1,792	91,01	56,92	0,518	0,354
5	212,94	207,67	20,373	15,949	1005,8	612,42	4,955	2,880



Computational prices

The old version





New code performance test

CPU 1 Intel Core i7-4770 3.4 GHz 4 cores, hyperthreading enabled	? (password)
GPU 1 NVIDIA GeForce GT 620 compute capability: 2.1 1024 threads/block	? (problem)

Case ID	Number of orbital positions	Number of theta grid points	number of surface elements
1	1000	10/20	1348
2	1000	20/40	1348

Computational prices

	CPU1	GPU1
1.	19,3	12,5
2.	51,2	25,9

WIth Nvidia GeForce GTX 1080 Ti it will be surely much faster.

Other features

- tidal distortions of close binaries (Roche - model)
- gravity darkening
- limb darkening
- reflection
- light-time variation
- the inverse problem
  - orbital and stellar parameters from the light (and radial velocity) curve
  - using Markov chain Monte Carlo
  - multiple stellar system and exoplanet modelling (only in host)
  - GUI for setting initial parameters

Acknowledgements

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- **Máté Ferenc Nagy-Egri**
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- **Tamás Hajdu**
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Thank You for Your Attention