LECTURE 12

Final projects: more details

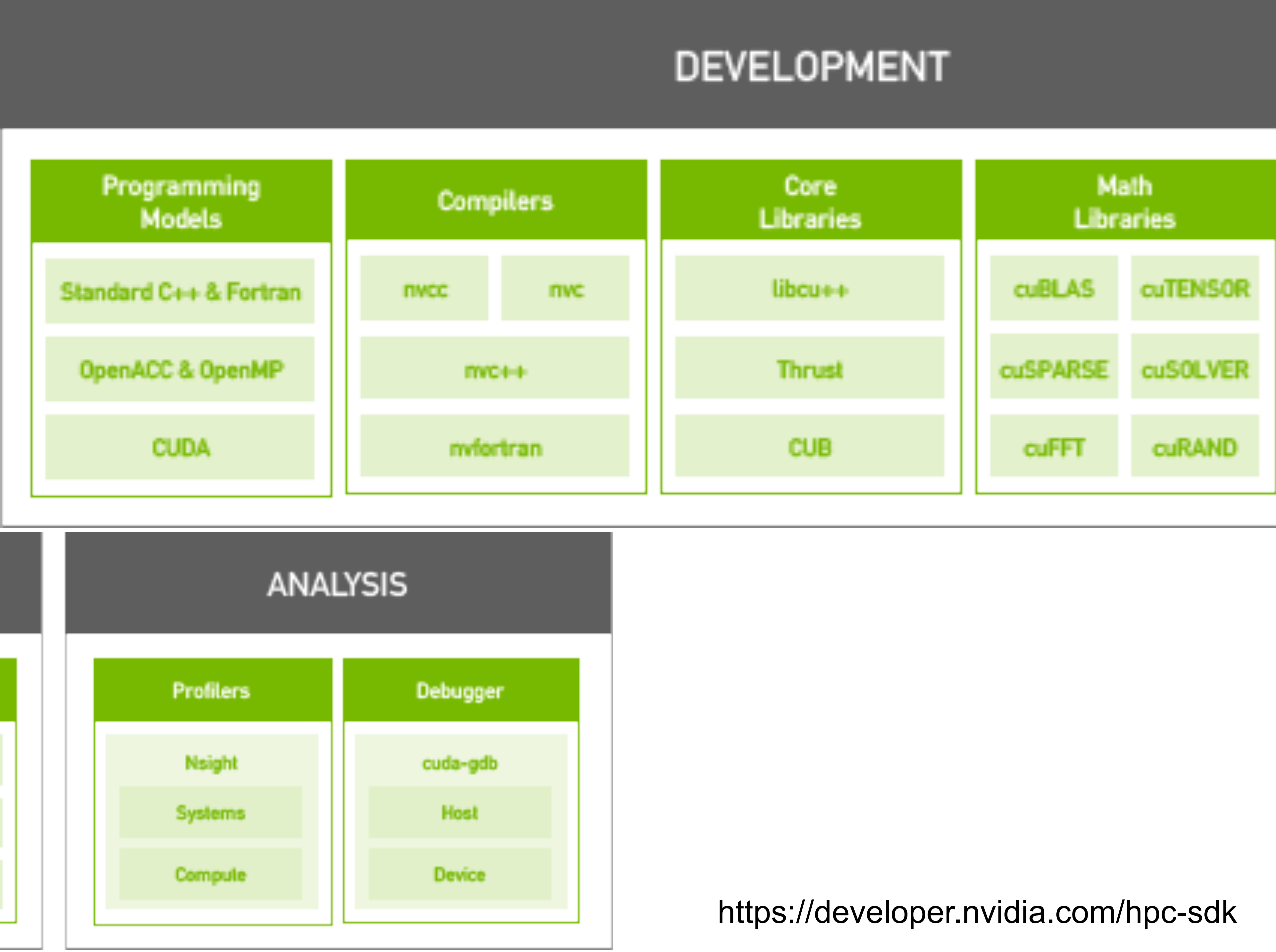
1. Practical programming of dynamics (tutorial). Project Trappist-1

3. Summary of Lagrangian hydrodynamics method for the protoplanetary disk project. How SPH works to simulate gas , and how to set up a problem (initial settling time, gradual introduction of a softened-gravity planet). What parameters of the system to vary in your simulations.

2. Details of N-body study of a sinking satellite. Rotation curve of the system and the corresponding density-potential pair of a galaxy.

4. Glory/Brocken Specter. Mie theory routine. art-2, subdirectory phyd57/mie

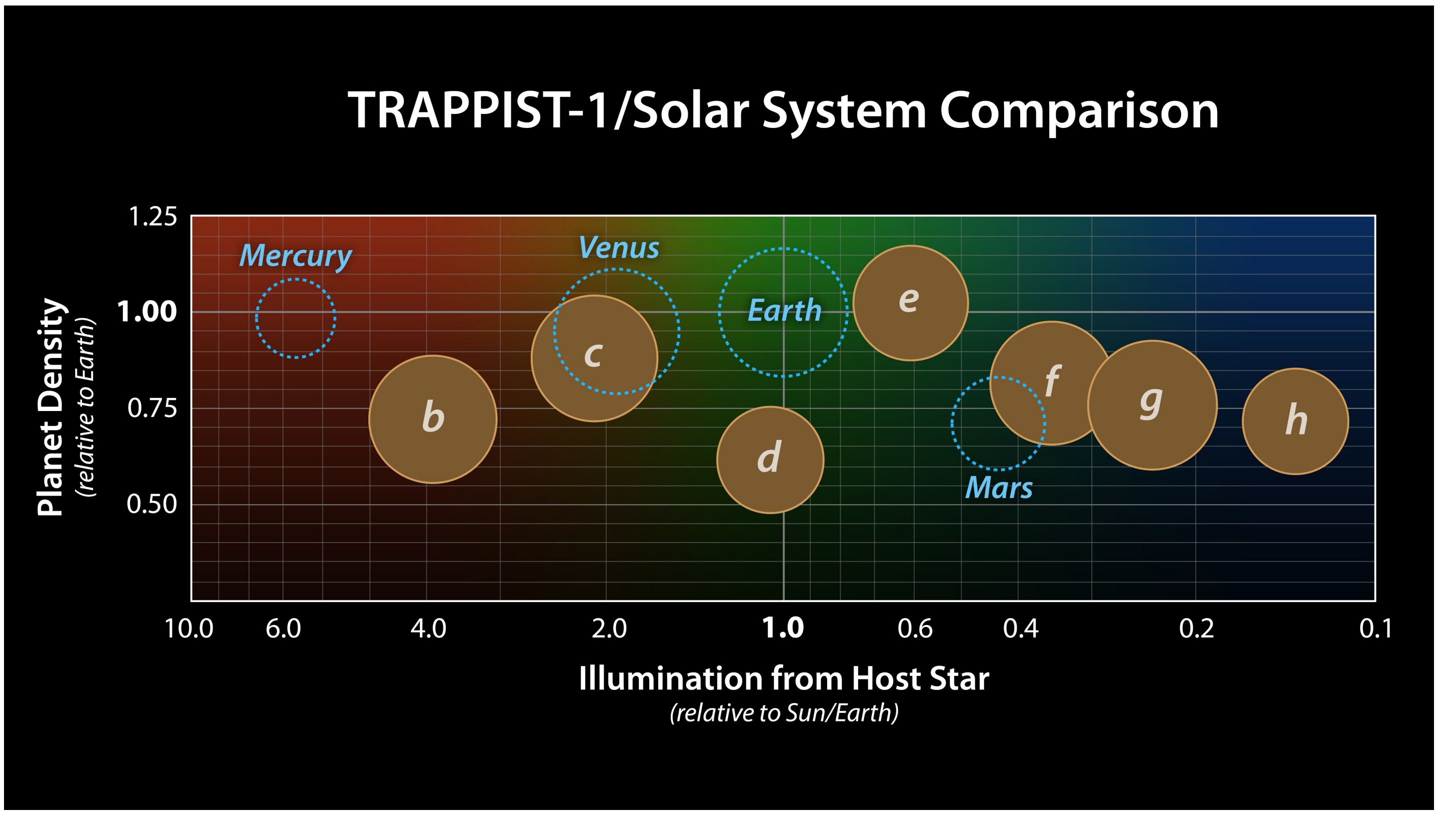
Neural networks and multi-dimensional optimization: ML ≠ AI



https://developer.nvidia.com/hpc-sdk

Project on N-body planetary system stability:
Trappist-1 system of 7 planets discovered in 2016-2017

Many processors (all of their cores) compute one problem: but this system of one star and 7 Earth-like planets does not offer enough parallelism to expose the power of the GPU



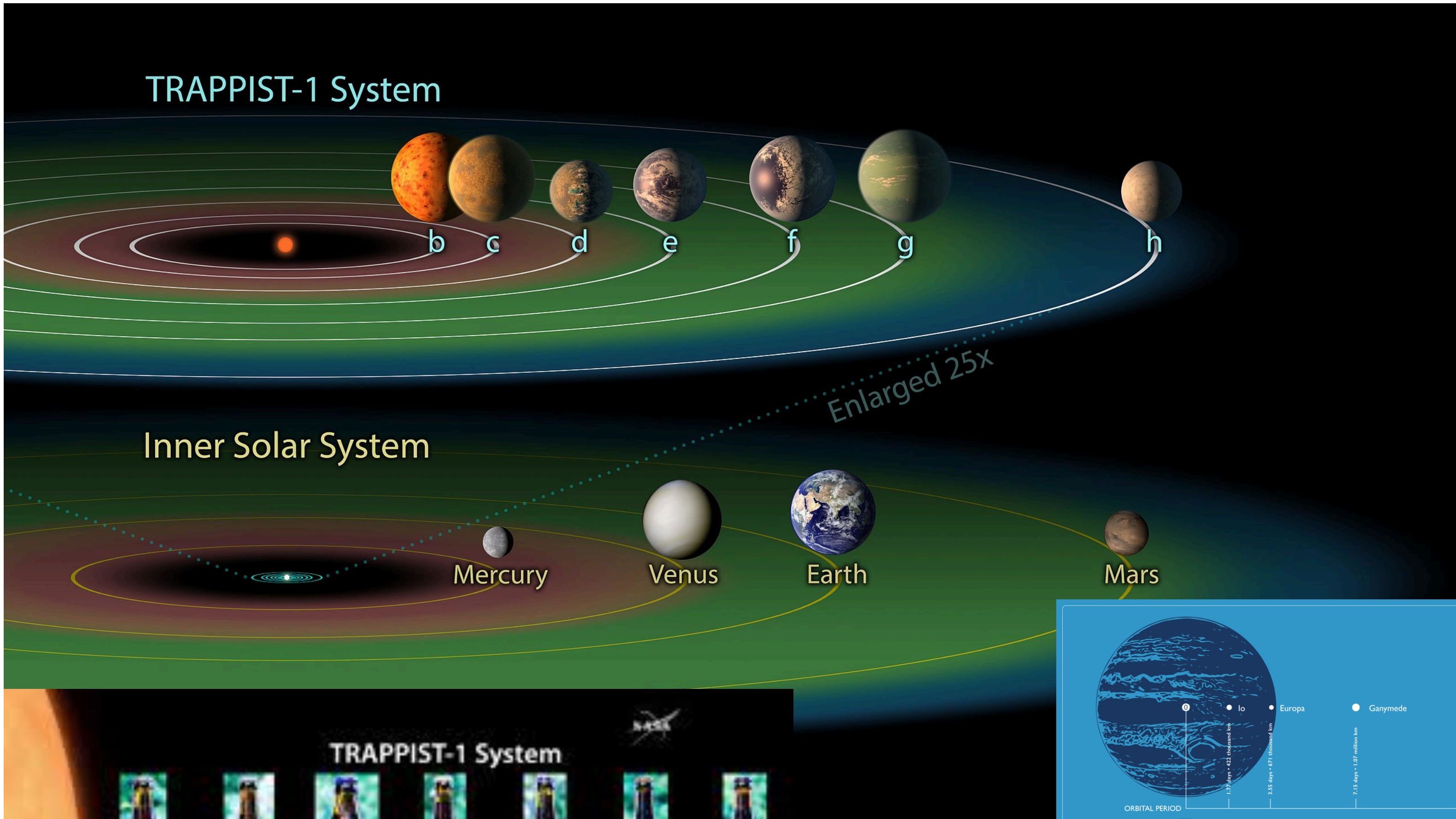
Use another type of parallelism: same algorithm run in many variants

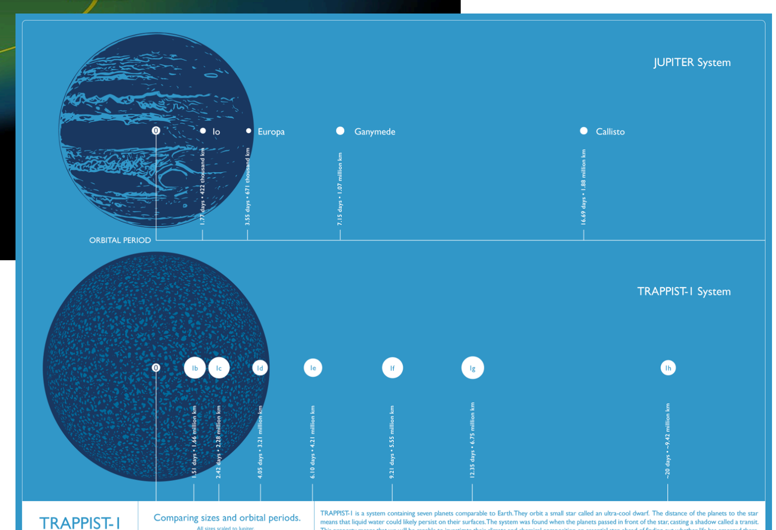
K x N-body

K > 1000,   N <10 (planetary system)   (final project 1) http://exoplanet.eu/catalog/

+ search for “trappist-1” on that page,

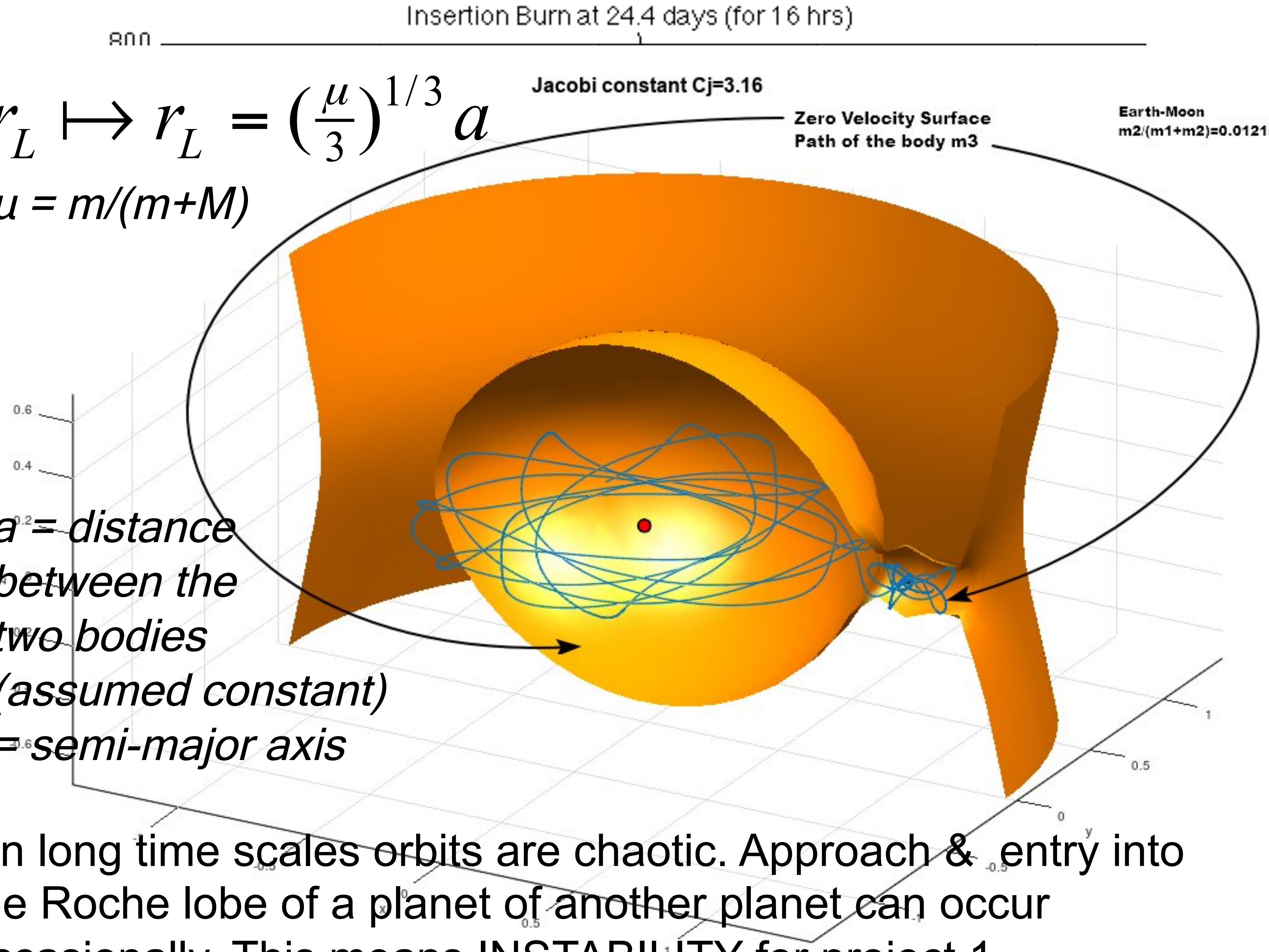
also: https://fr.wikipedia.org/wiki/TRAPPIST-1





$$r_L \mapsto r_L = \left(\frac{\mu}{3}\right)^{1/3} a$$

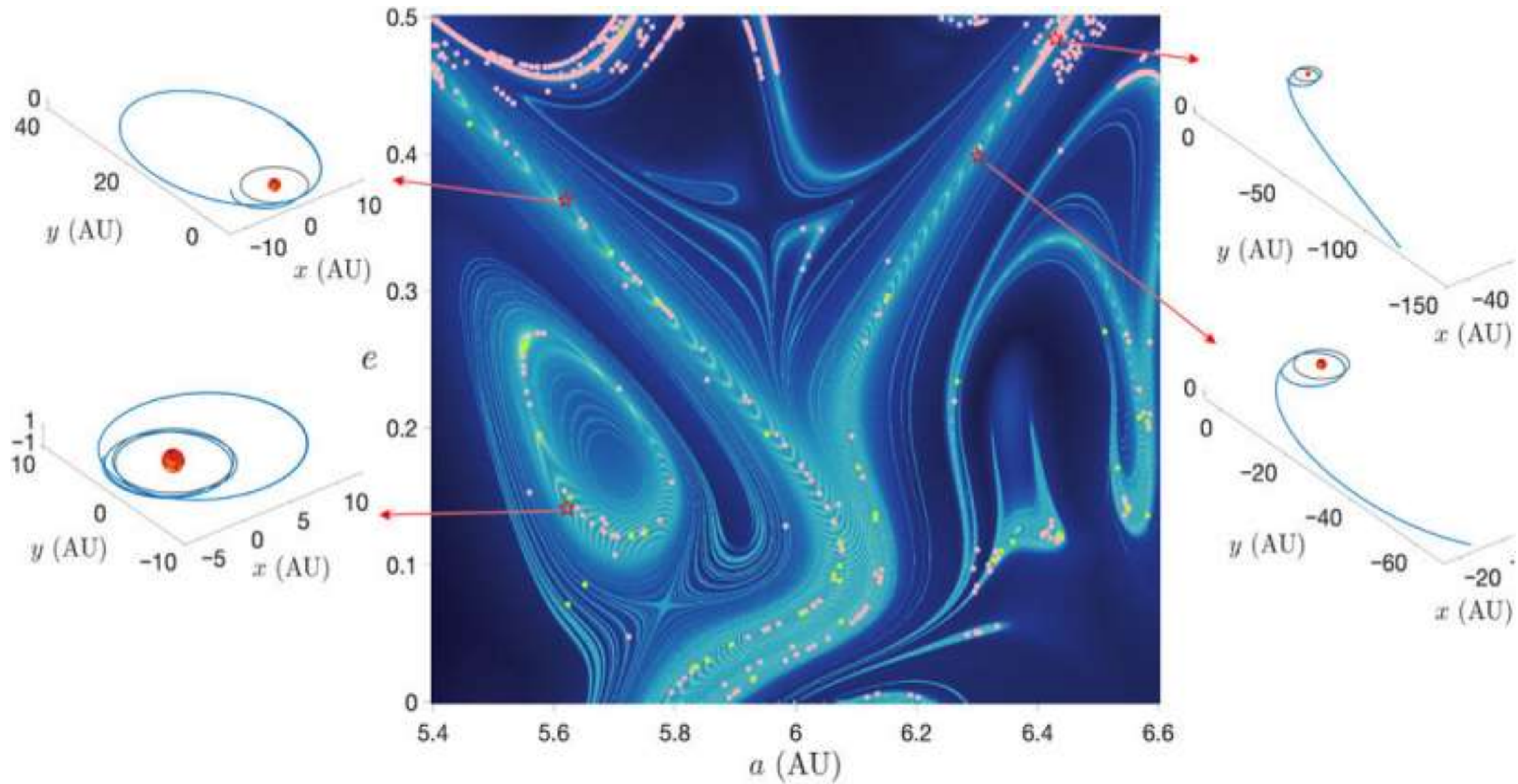
$\mu = m/(m+M)$



a = distance between the two bodies (assumed constant) = semi-major axis

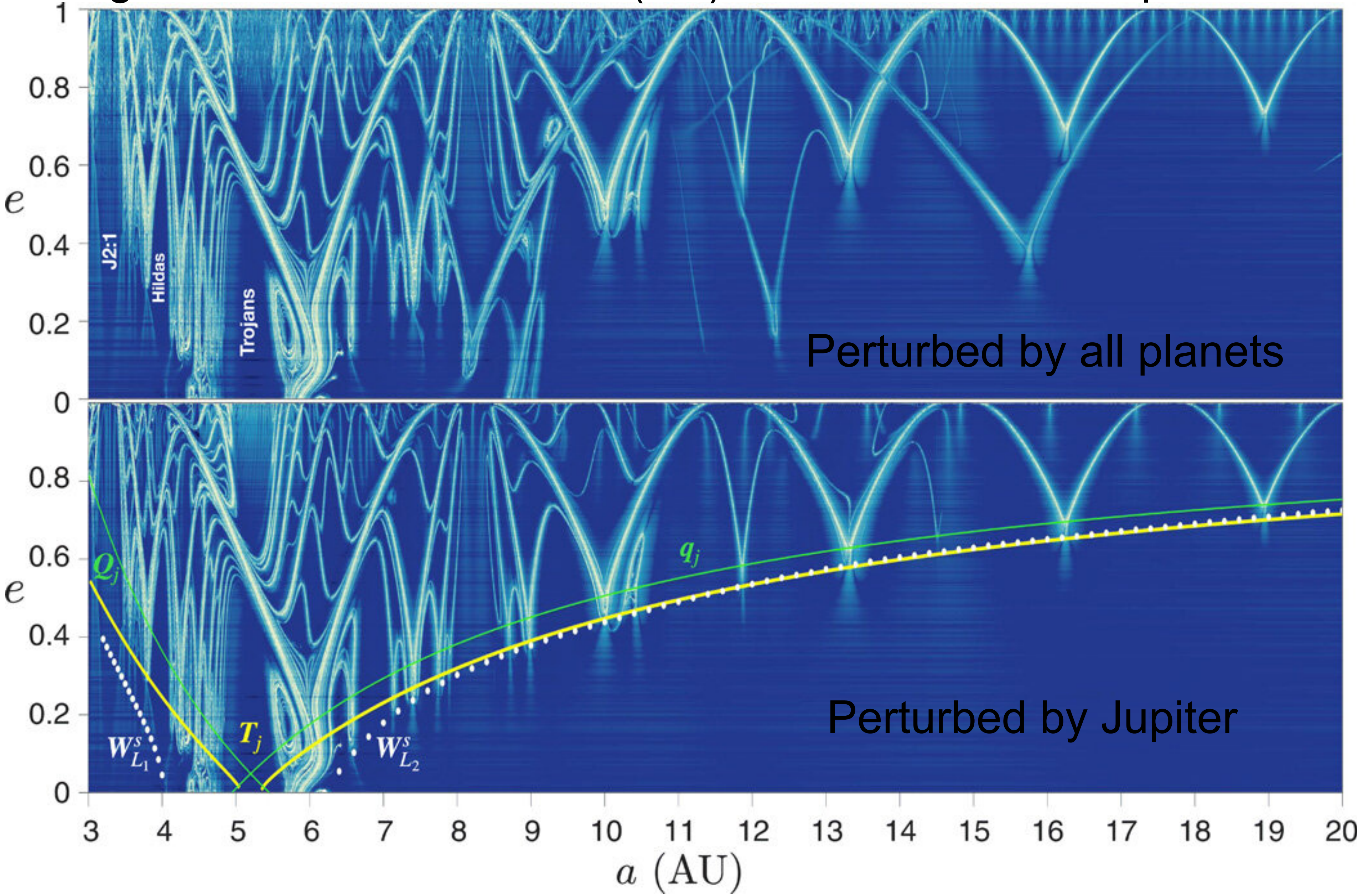
On long time scales orbits are chaotic. Approach & entry into the Roche lobe of a planet of another planet can occur occasionally. This means INSTABILITY for project 1.

There are indicators of chaos (so-called fast Lyapunov exponents) that can map stable and unstable manifolds in parameter space *(a,e)* for asteroids like Centaurs (in Jupiter-Neptune region). Centaurs use overlapping resonances to travel fast (in a few million yr) from the outer to the inner Solar System.



Nataša Todorović et al. *The arches of chaos in the Solar System*, Science Adv. (2020).

Lighter = more stable, (a,e) of initial orbit of test particle



https://phys.org/news/2020-12-accessing-arches-chaos-solar-fast.html

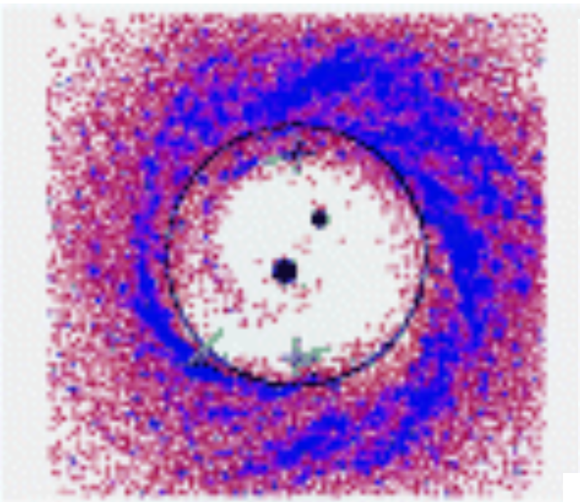
How wide a region is quickly destabilized by a planet?
(We call it **Corotational Region**)

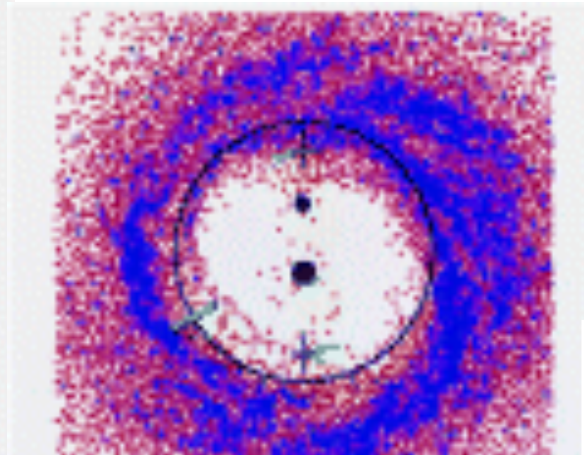
The gravitational influence of a small body (a planet around a star, for instance) dominates the motion inside its Roche lobe, so particle orbits there are circling around the planet, not the star. The circumstellar orbits (usually in a disk), in the vicinity of the planet's orbit are affected, too.

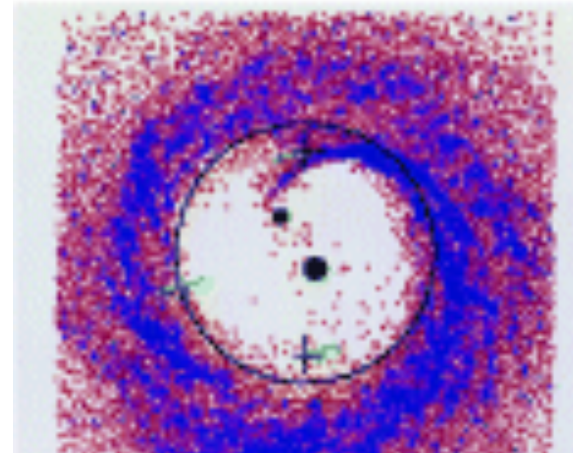
To what radial extent?

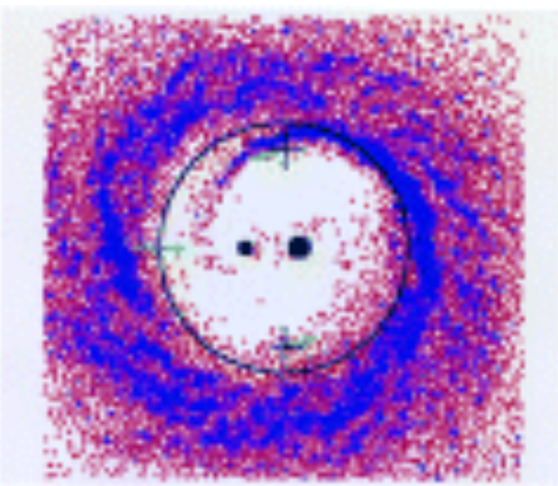
Corotational region defines the 'feeding zone' of a growing protoplanet. We will see how it is populated by tadpoles and littered by horseshoes...

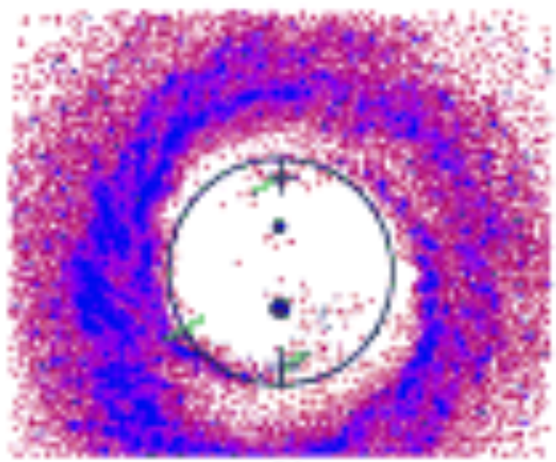
Binary-disk interaction

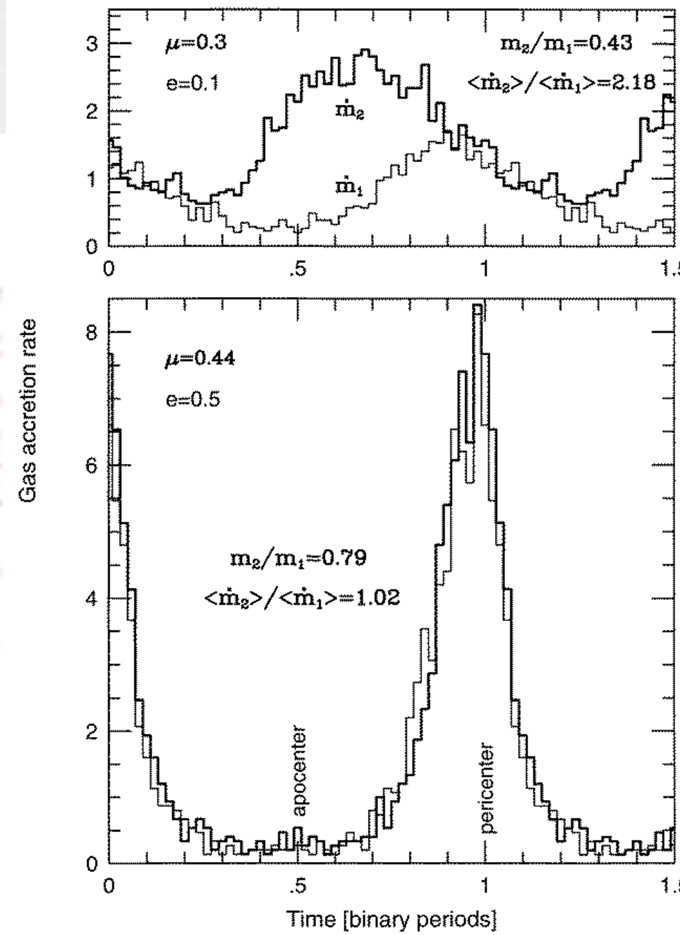












SPH = smoothed hydrodynamics: cf. wiki

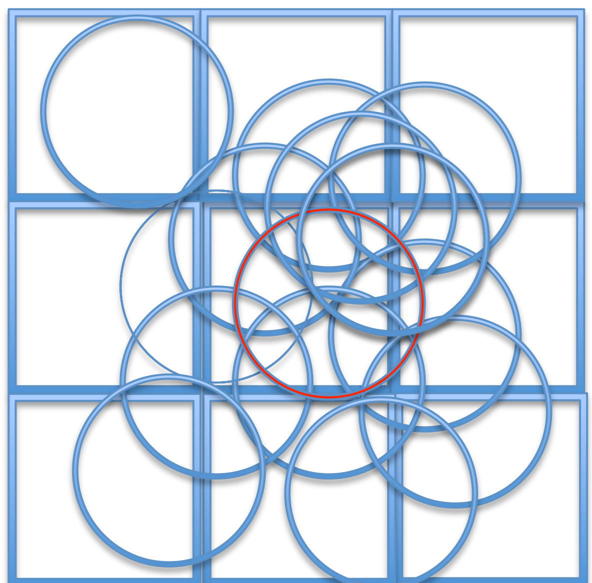
Smoothed Particle Hydrodynamics

A method of representing fluid parcels as fuzzy **clouds** a.k.a. particles

Monaghan(1977) – smoothing kernel $W(|r_i - r_j|, h)$ = *e.g., Gaussian*

Fast finding of nearest neighbors: a rough grid with mesh size 2h allows to locate an SPH pa

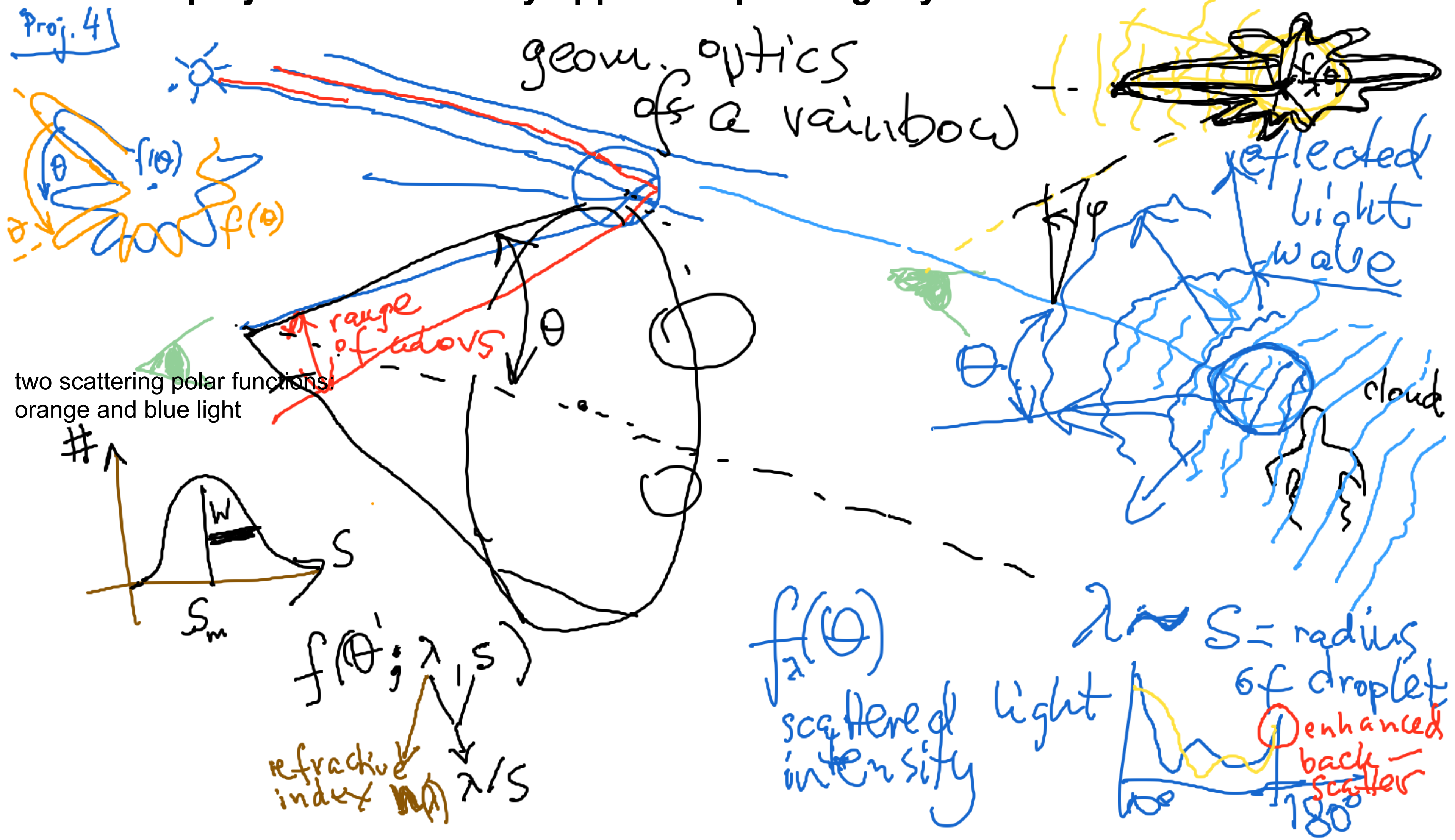
The trick is that you only need to search 9 cells for all the neighbors



N(neighbors) ~ 20...40

Description of SPH gas dynamics implementation
is found on our main course page, cf. papers by Monaghan.
New paper, an Annual Review has been added!

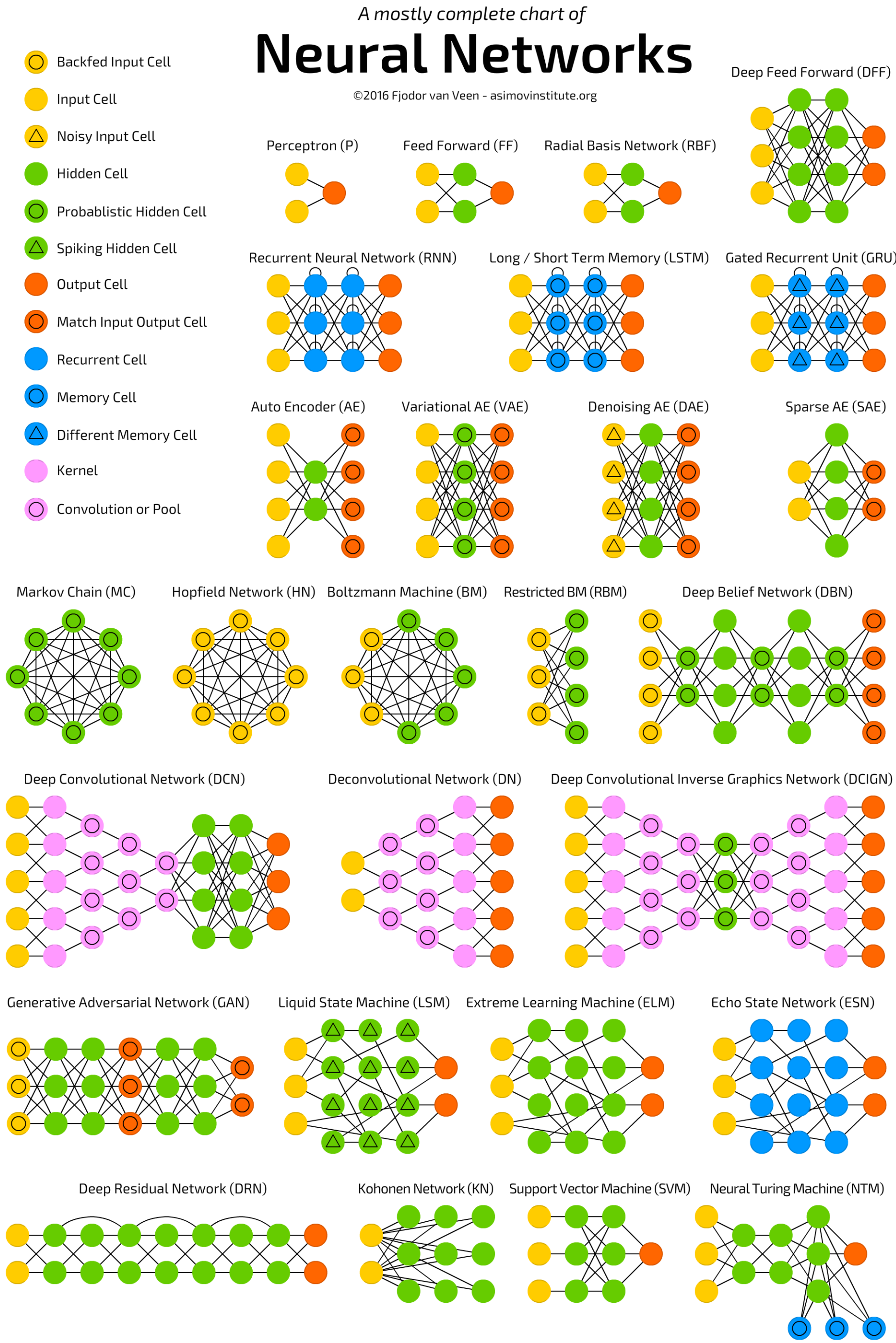
project 4: Mie theory applied to pilot’s glory



two scattering polar functions: orange and blue light

two scattering functions: yellow and blue light

Subroutine mie(...) returns array xi in which columns 2 & 3 are i1 & i2, the intensities in light linearly polarized in two different directions. For the purpose of project 4, one needs to take a square root of their squares (for unpolarized starlight).



A mostly complete chart of
Neural Networks
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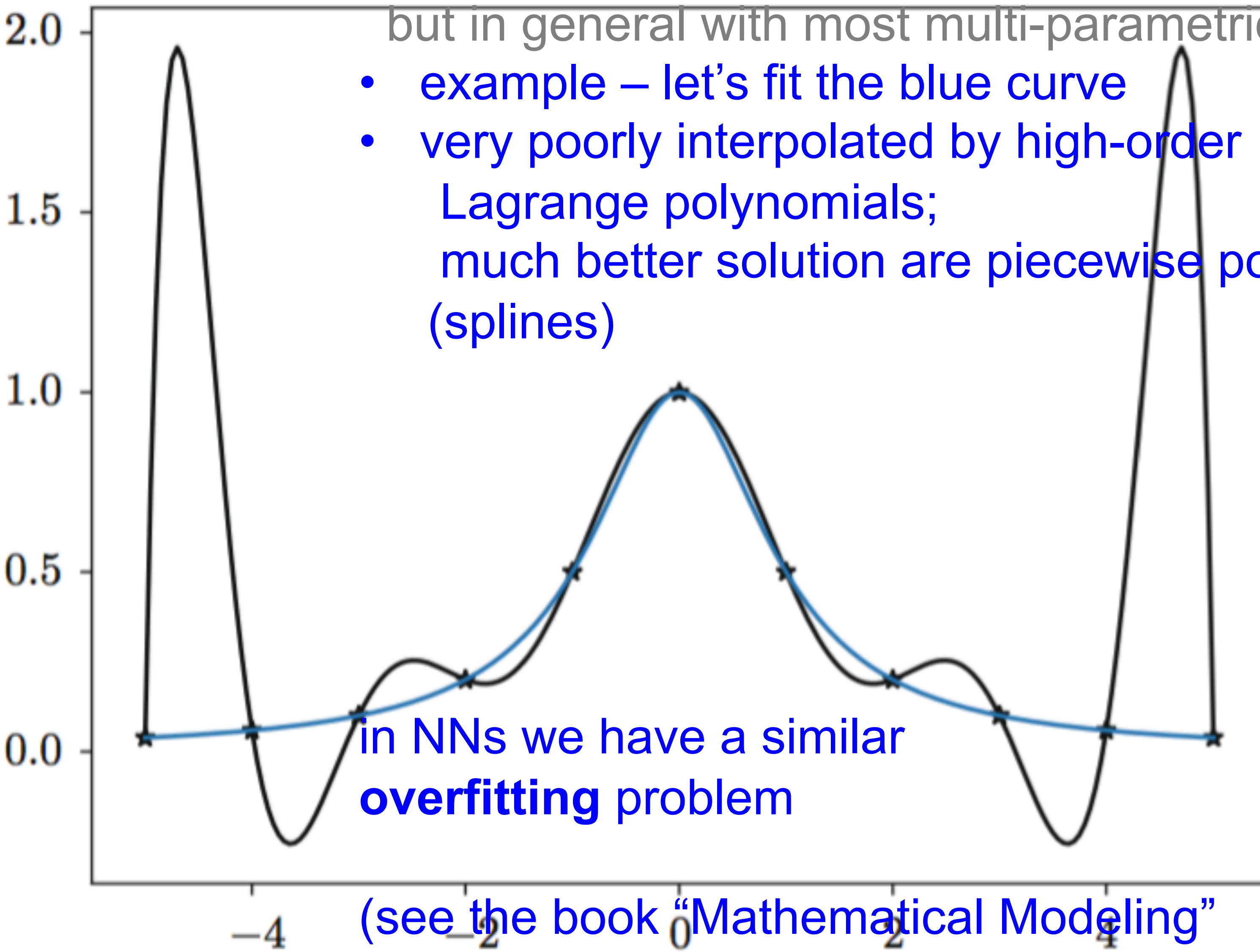
Backfed Input Cell
Input Cell
Noisy Input Cell
Hidden Cell
Probablistic Hidden Cell
Spiking Hidden Cell
Output Cell
Match Input Output Cell
Recurrent Cell
Memory Cell
Different Memory Cell
Kernel
Convolution or Pool
Perceptron (P)
Feed Forward (FF)
Radial Basis Network (RBF)
Deep Feed Forward (DFF)
Recurrent Neural Network (RNN)
Long / Short Term Memory (LSTM)
Gated Recurrent Unit (GRU)
Auto Encoder (AE)
Variational AE (VAE)
Denoising AE (DAE)
Sparse AE (SAE)
Markov Chain (MC)
Hopfield Network (HN)
Boltzmann Machine (BM)
Restricted BM (RBM)
Deep Belief Network (DBN)
Deep Convolutional Network (DCN)
Deconvolutional Network (DN)
Deep Convolutional Inverse Graphics Network (DCIGN)
Generative Adversarial Network (GAN)
Liquid State Machine (LSM)
Extreme Learning Machine (ELM)
Echo State Network (ESN)
Deep Residual Network (DRN)
Kohonen Network (KN)
Support Vector Machine (SVM)
Neural Turing Machine (NTM)

Interpolation, Extrapolation, Splines -- problems similar to the ones encountered while optimizing neural networks (NNs)

Turner et al. (2018)

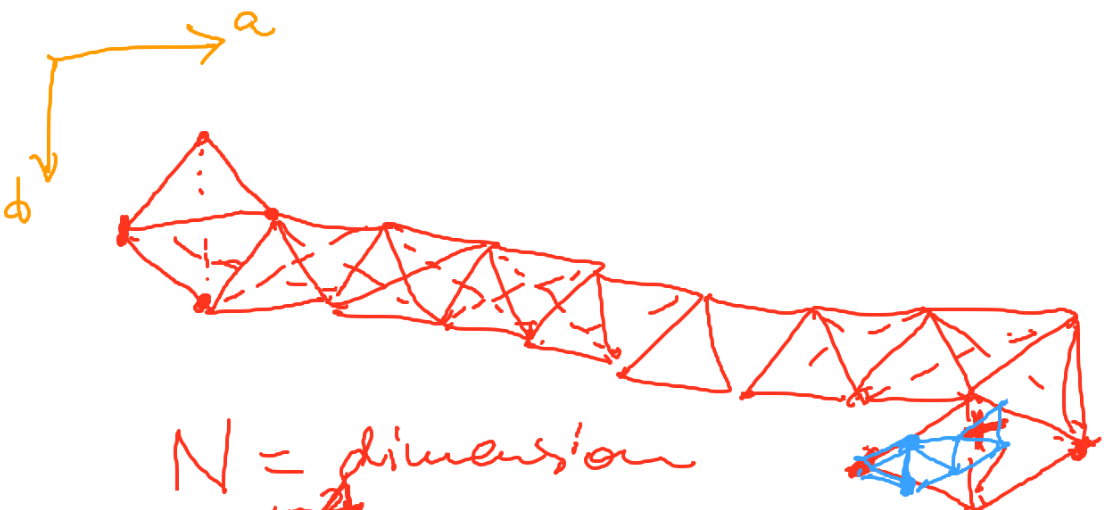
- There is a problem with polynomials in particular, but in general with most multi-parametric fits
- example – let’s fit the blue curve
- very poorly interpolated by high-order Lagrange polynomials;
  much better solution are piecewise polynomials (splines)



in NNs we have a similar **overfitting** problem

(see the book “Mathematical Modeling” by Gershenfeld)

Illustration of Nader-Mead optimization
(downhill simplex method),
described in Gershenfeld's book p. 157, sect.. 3.1 on Multidimensional Search



N = dimension

$N \sim 10^4$

1 eval. / step

rescaling