

The background of the slide is a deep space scene featuring a vibrant nebula with orange and blue hues, and a satellite with solar panels extending from the right side. The title text is centered in a yellow rectangular box.

Modelling Young Stellar Disks using Genetic Algorithms

Annibal Hetem Jr.

FAFIL

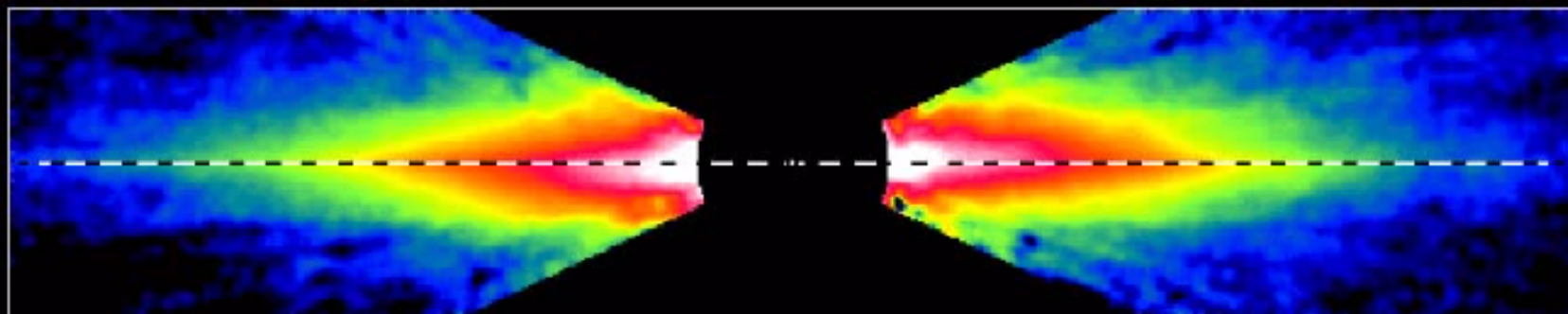
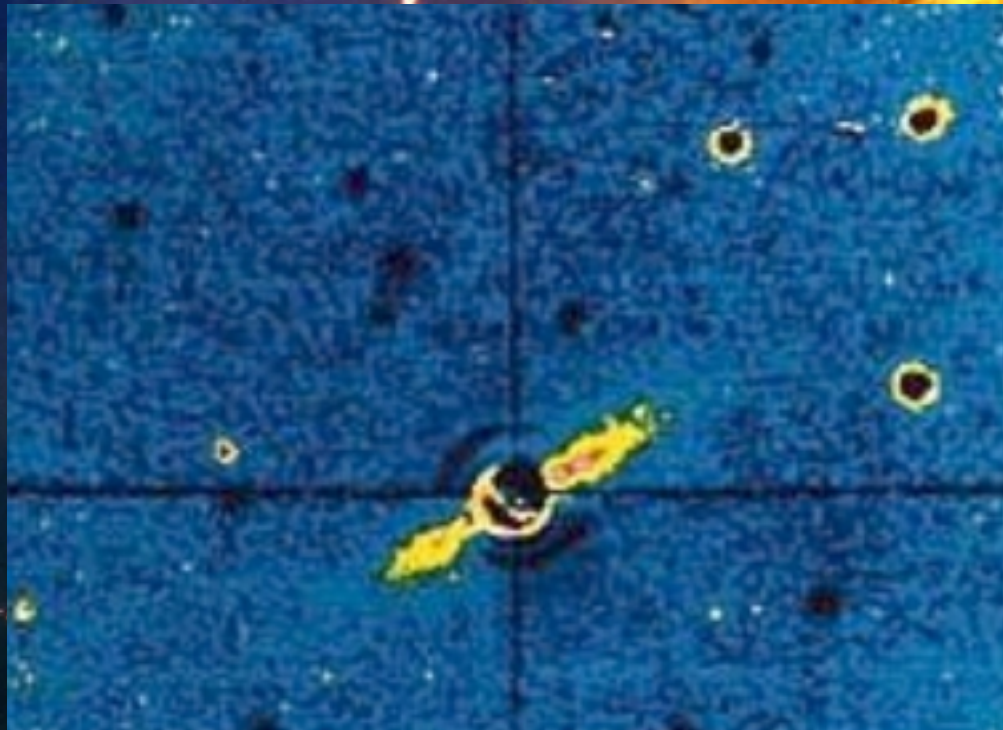
Fundação Santo André

São Paulo / Brazil

Motivation

- Young circumstellar structures are interesting targets to search for protoplanetary systems.
- Central cavities, condensations and radial gaps are believed to be associated with the disk disappearance, which is related to planetary formation.

Example: β Pictoris

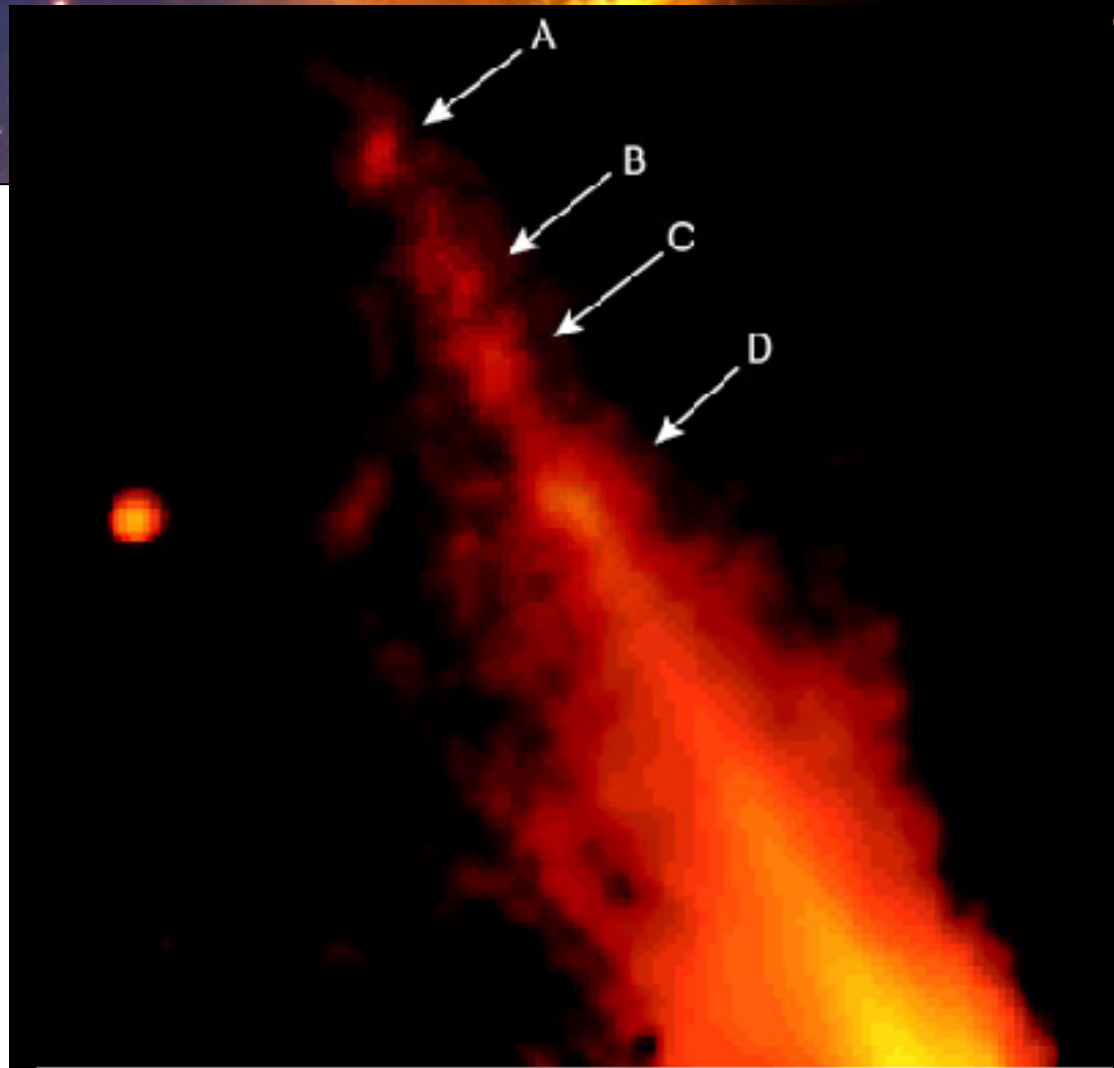


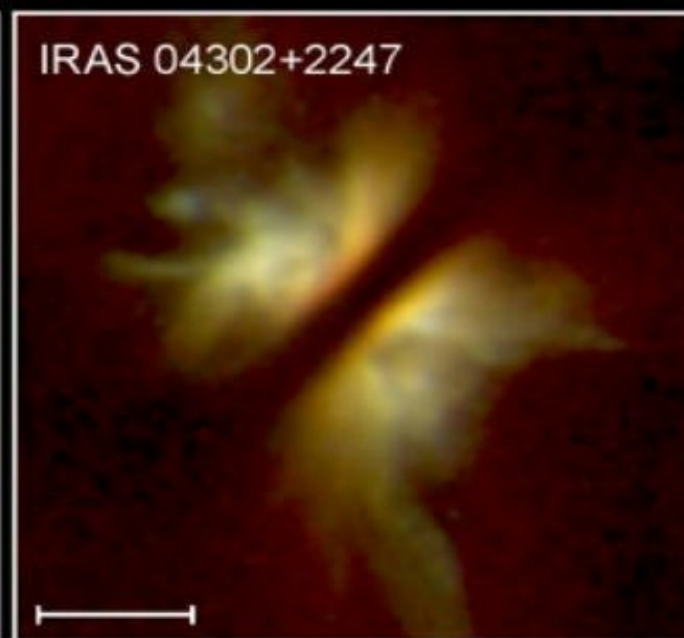
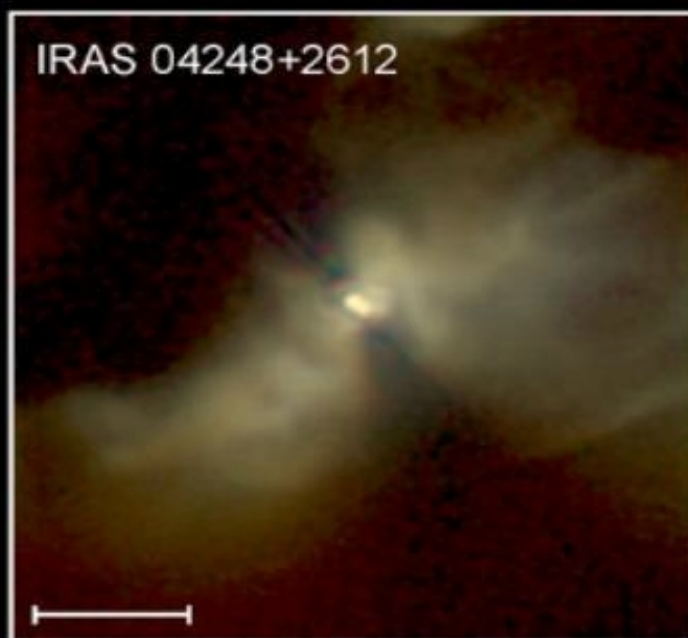
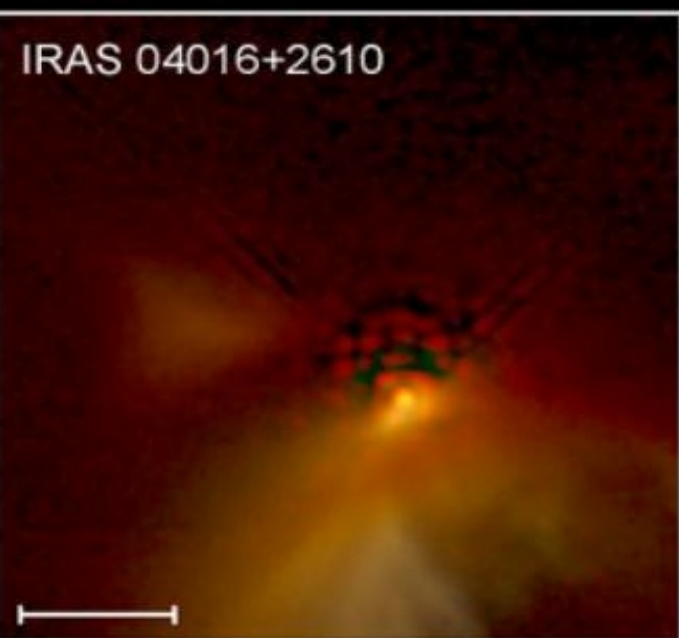
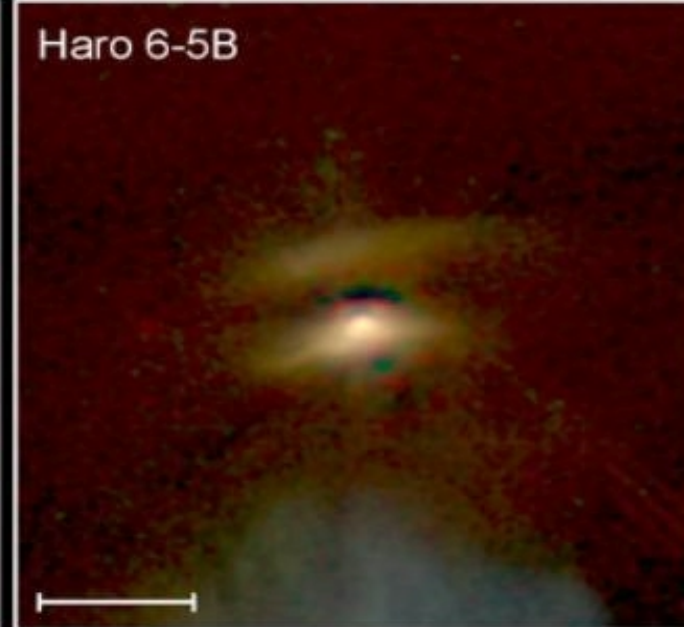
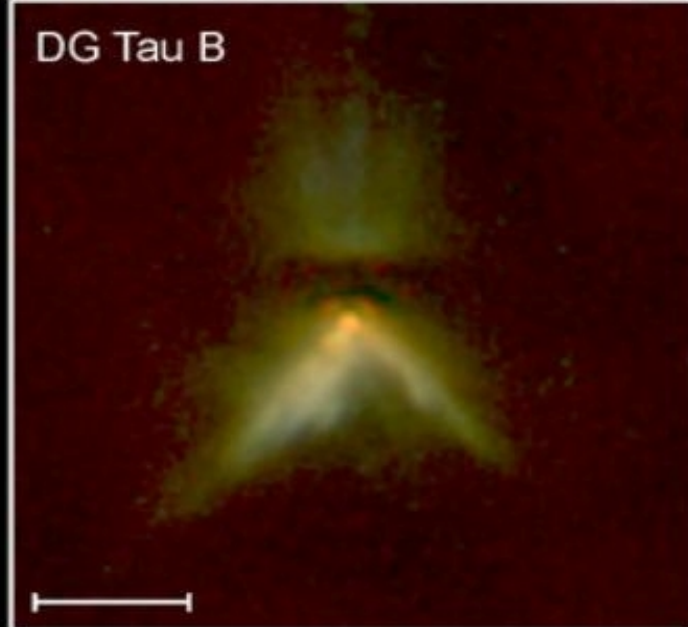
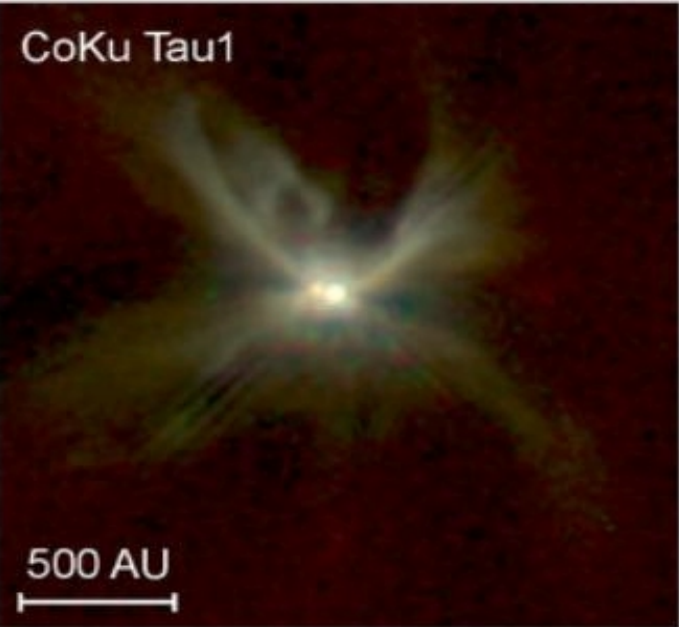
Beta Pictoris

HST • WFPC2

Example: β Pictoris

- Direct disk observations shows sub-structures, like the asymmetries in β Pictoris disk.
- Simple geometry models do not reproduce details of the spectral energy distribution.





Young Stellar Disks in Infrared

HST • NICMOS

PRC99-05a • STScI OPO

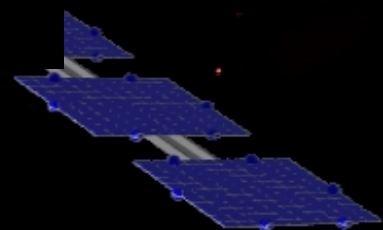
D. Padgett (IPAC/Caltech), W. Brandner (IPAC), K. Stapelfeldt (JPL) and NASA

A “flared” disk model

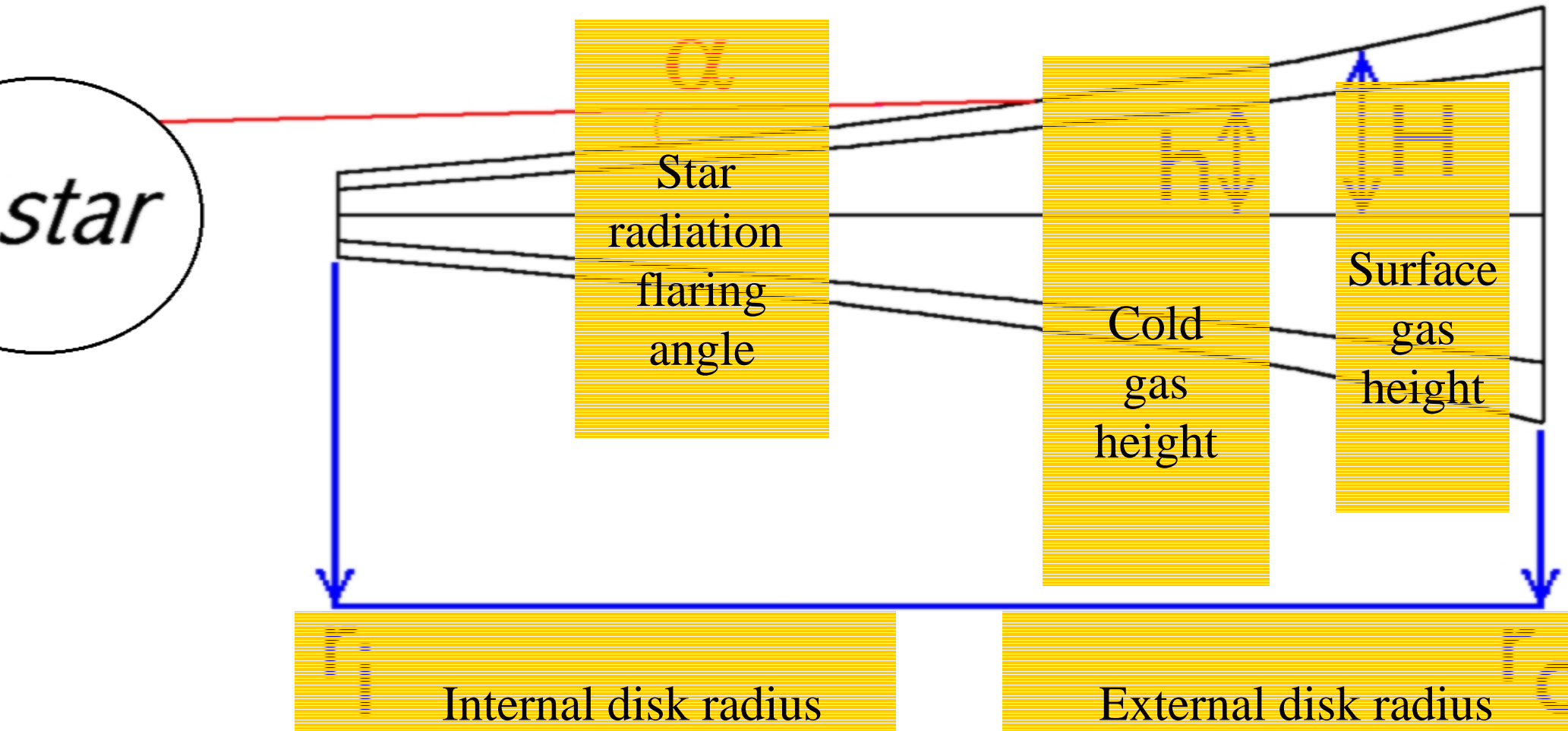
Chiang & Goldreich (1997 and 1999)

- Passive disk in hydrostatic radiative equilibrium.
- Disk presents variable height as a function of radius. The surface grains are exposed to stellar radiation.
- The inner part of disk is heated by diffusion.

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Flared Disk Model



Model geometry



Formalism

Column density

$$\Sigma = a_{AU}^{-3/2} \Sigma_0$$

Volume density

$$\rho = \rho_0 e^{-\frac{z^2}{2h^2}}$$

Emissivity

$$\epsilon_\lambda = \left(\frac{2\pi r_p}{\lambda} \right)^\beta$$

Gravitational potential

$$T_c = \frac{GM_* \mu_g}{kR_*}$$

Outer disk temperature

$$T_s = \frac{1}{\epsilon_s} \left(\frac{R_*}{2r} \right)^{1/2} T_*$$

Inner disk temperature

$$T_i = \left(\frac{\alpha}{4} \right)^{1/4} \left(\frac{R_*}{r} \right)^{1/2} T_*$$

Formalism

Flaring angle

$$\alpha = \frac{2 R_*}{5 r} + r \frac{\partial}{\partial r} \left(\frac{H}{r} \right)$$

$$\alpha = \frac{2 R_*}{5 r} + \frac{8}{7} \frac{r}{R_*} \left(\frac{T_*}{T_c} \right)^{8/7}$$

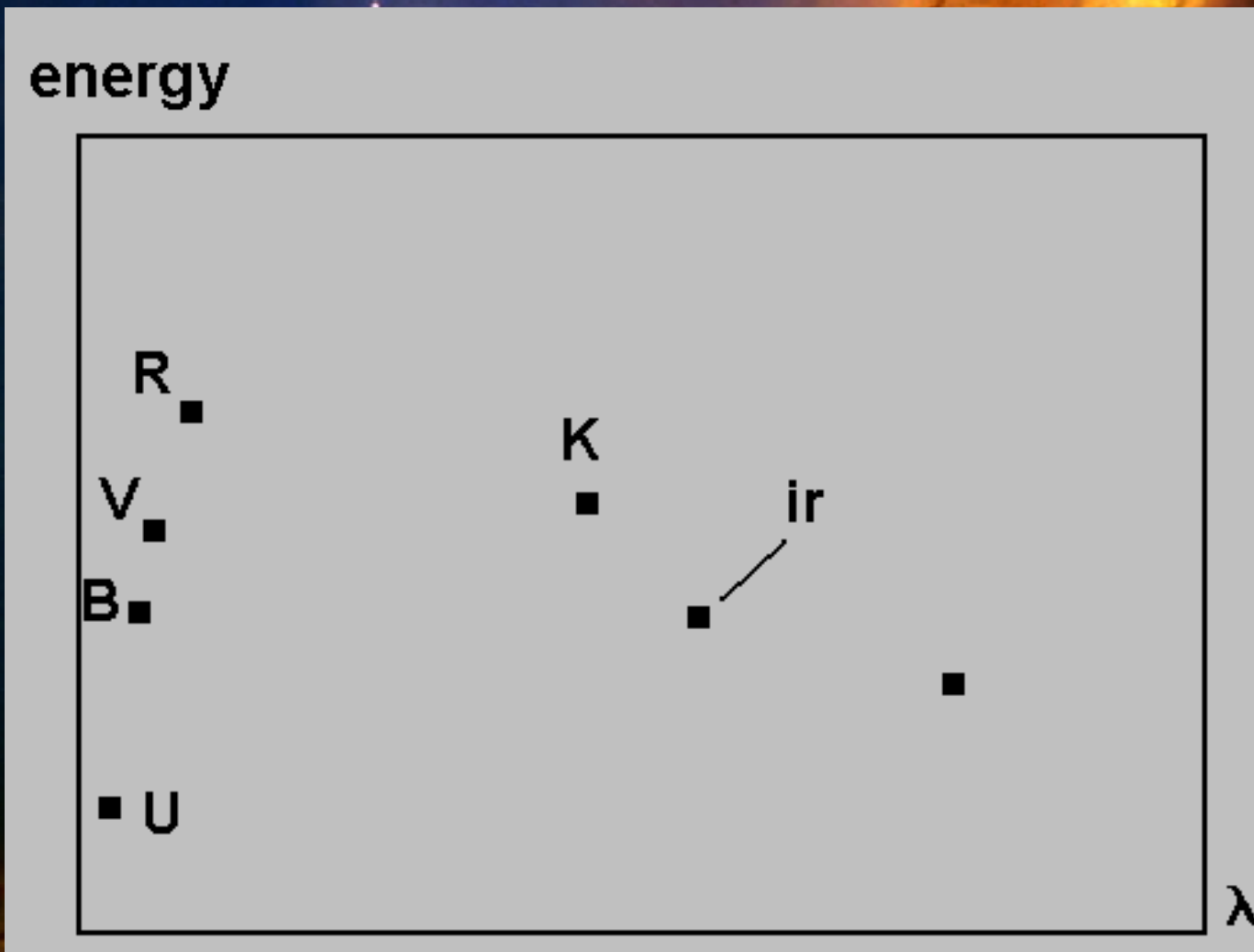
Disk height

$$\frac{H}{r} = 4 \left(\frac{T_*}{T_c} \right)^{4/7} \left(\frac{r}{R_*} \right)^{2/7}$$

Energy distribution

$$L_\lambda = 8\pi^2 \frac{c}{\lambda} \int_{r_i}^{r_o} r dr \int_{-\infty}^{\infty} \frac{\partial \tau_\lambda}{\partial z} e^{-\tau_\lambda} B_\lambda(T) dz$$

From models to reality

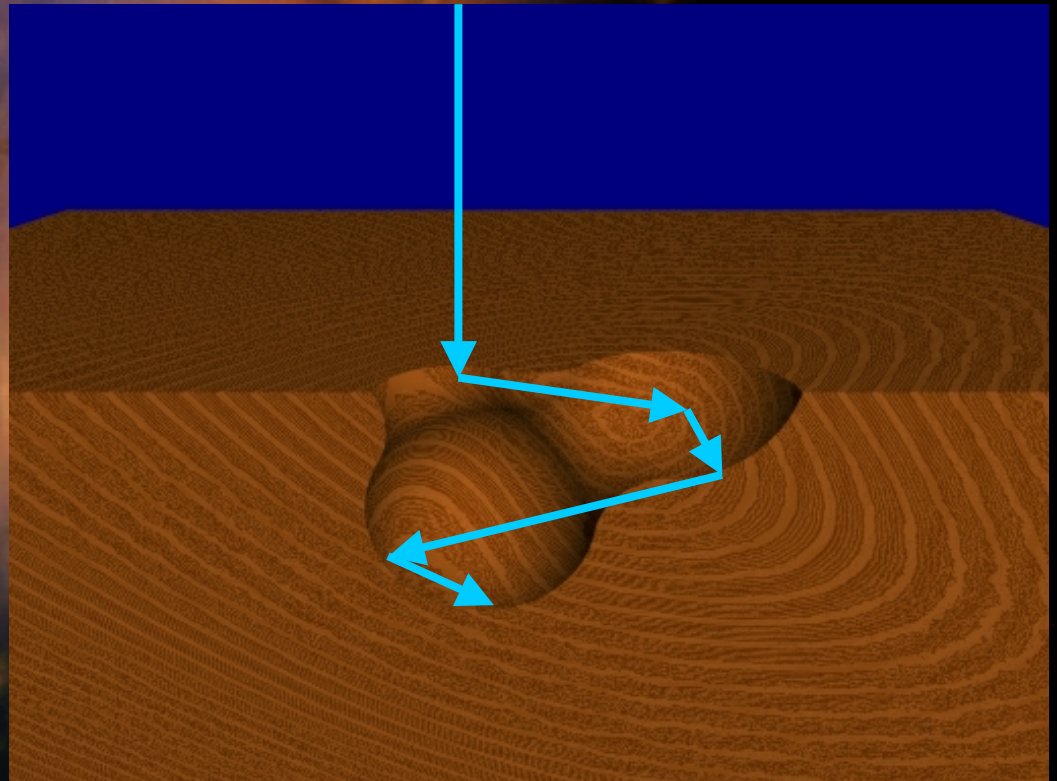


Classical fitting method

- Least squares method

$$\chi^2(\mathbf{a}) \equiv \sum_{j=1}^N \frac{[q_j - q(\mathbf{a})]^2}{\sigma_j^2}$$

$$\mathbf{a}_{n+1} = \mathbf{a}_n - k \times \nabla \chi^2(\mathbf{a}_n)$$



Classical method problems

1. When the functions present discontinuities

Disk radius:

$$r_{\text{effective}} = |r_{\text{obtained}}|$$

$$\mathbf{a}_{n+1} = \mathbf{a}_n - k \times \nabla \chi^2(\mathbf{a}_n)$$

Discontinuities in derivatives
or
artificial functions

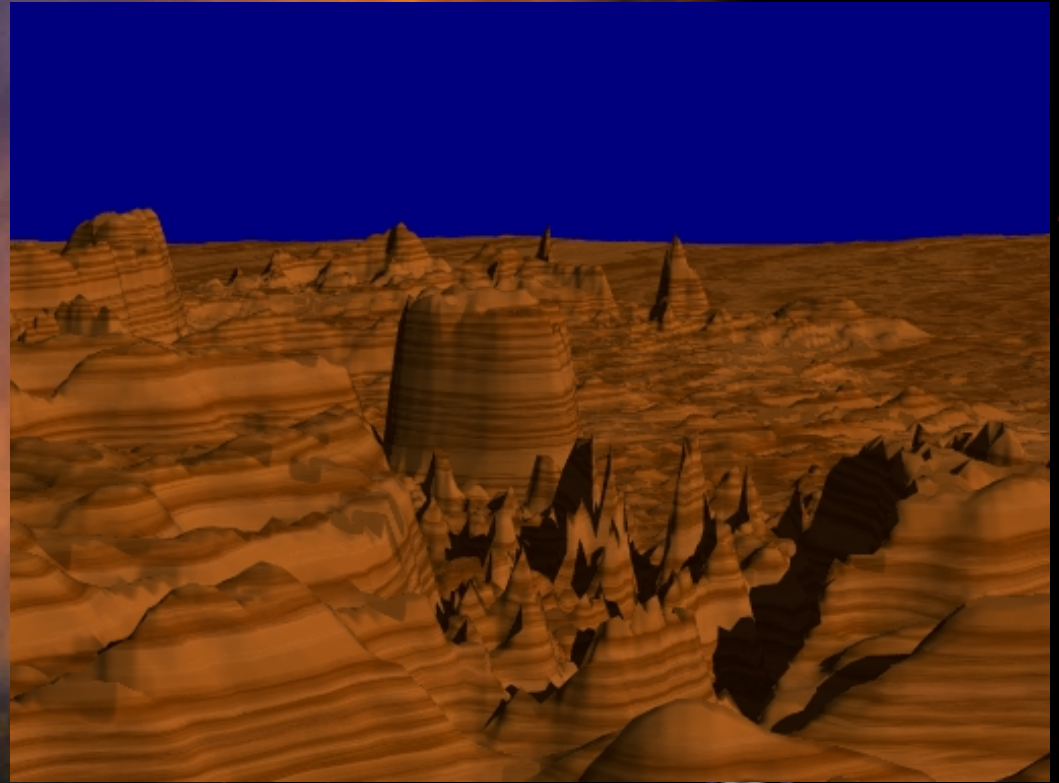
Optical depth:

$$\tau_\lambda \begin{cases} \propto 1/\lambda, & \text{if } \lambda > 1 \mu\text{m} \\ = 1, & \text{if } \lambda \leq 1 \mu\text{m} \end{cases}$$

Classical method problems

2. When the function $\chi^2(\mathbf{a})$ has a “hard minimum”

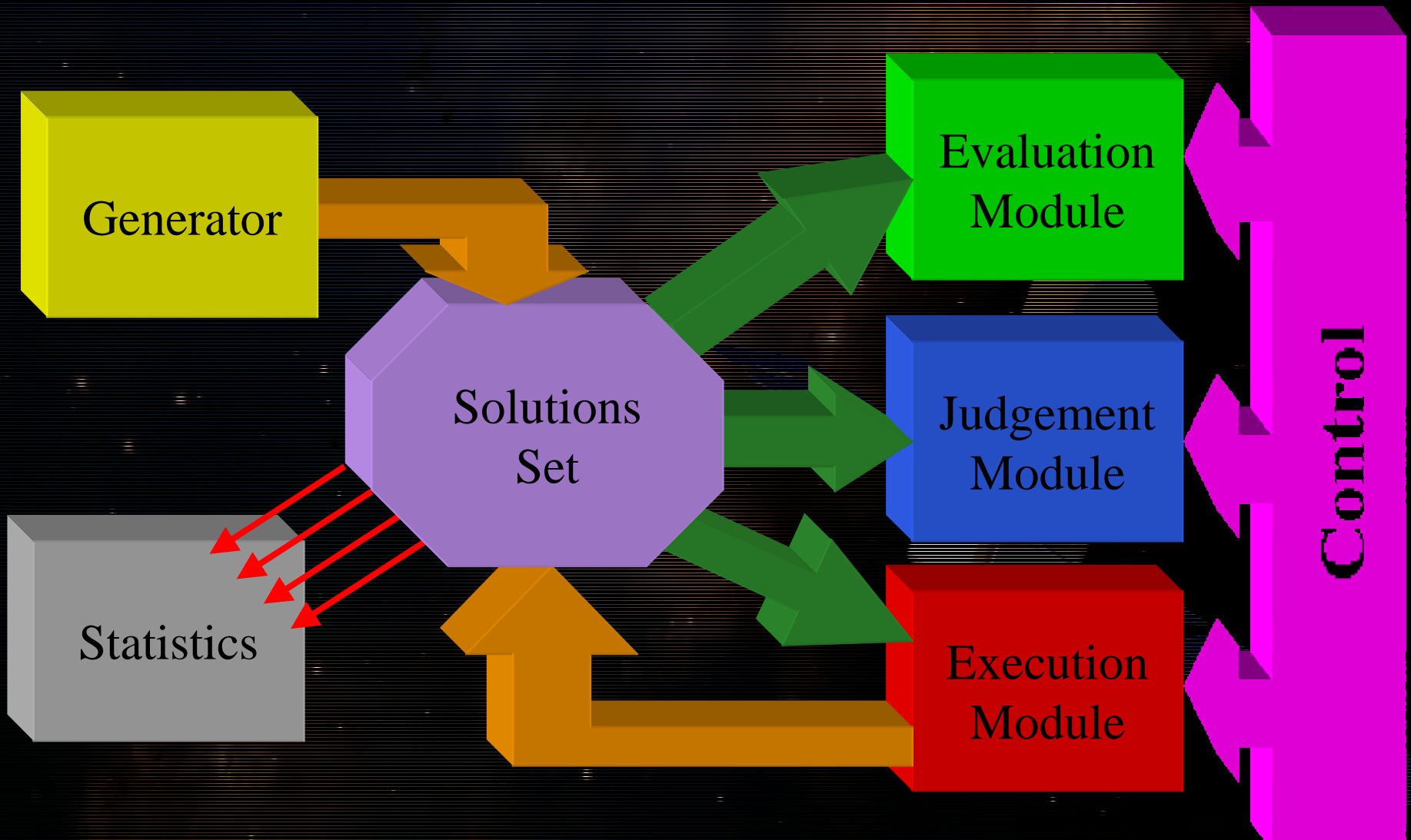
$$\chi^2(\mathbf{a}) \equiv \sum_{j=1}^N \frac{[q_j - q(\mathbf{a})]^2}{\sigma_j^2}$$



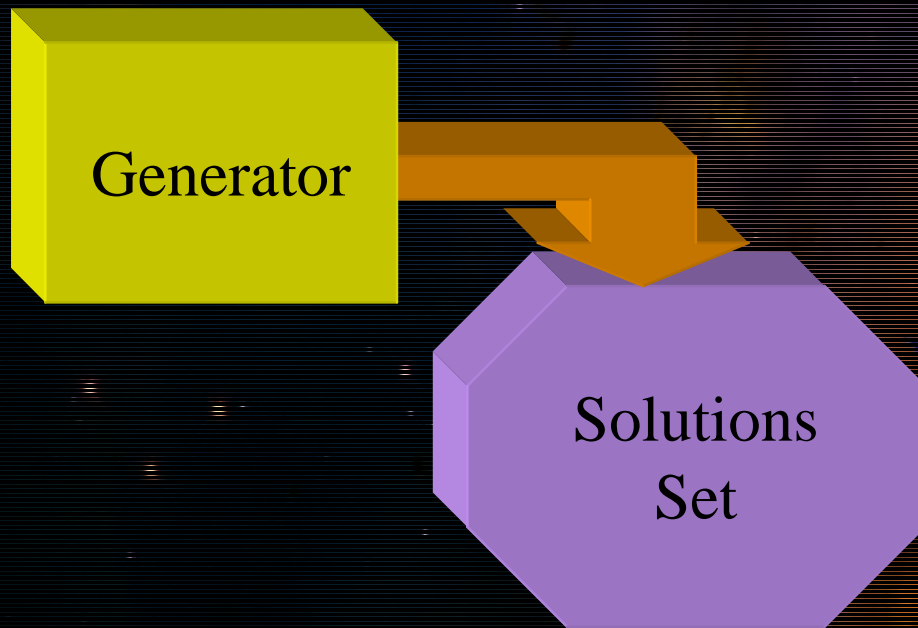
Genetic Algorithm

- Supports several parameters.
- Not affected by model complexity.
- Suggested by Koza (1992)
- Adopted version by Bentley & Corne (2002)

Implementation

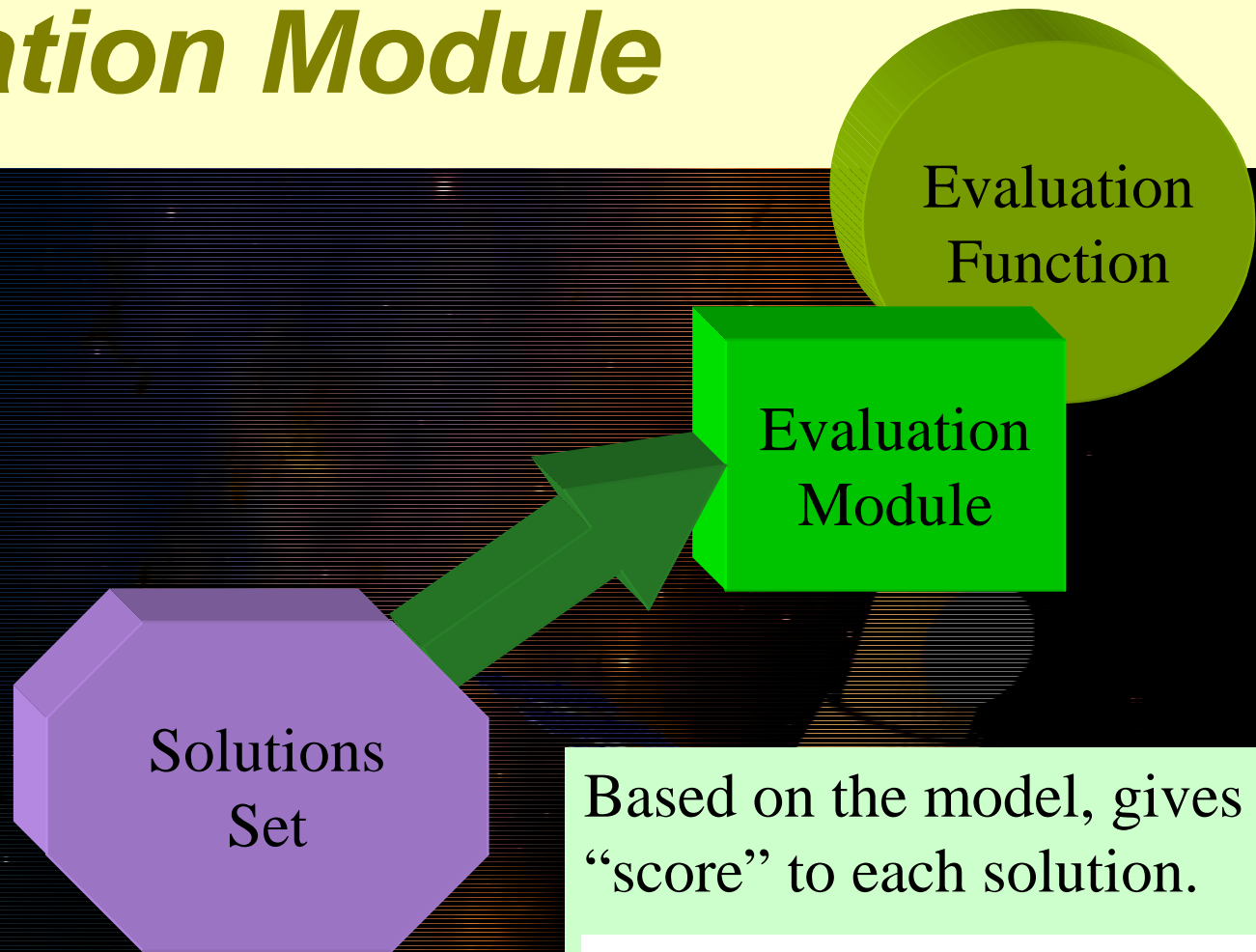


Generator



Generates the first Solution Set based on pre-established ranges for each model parameter.

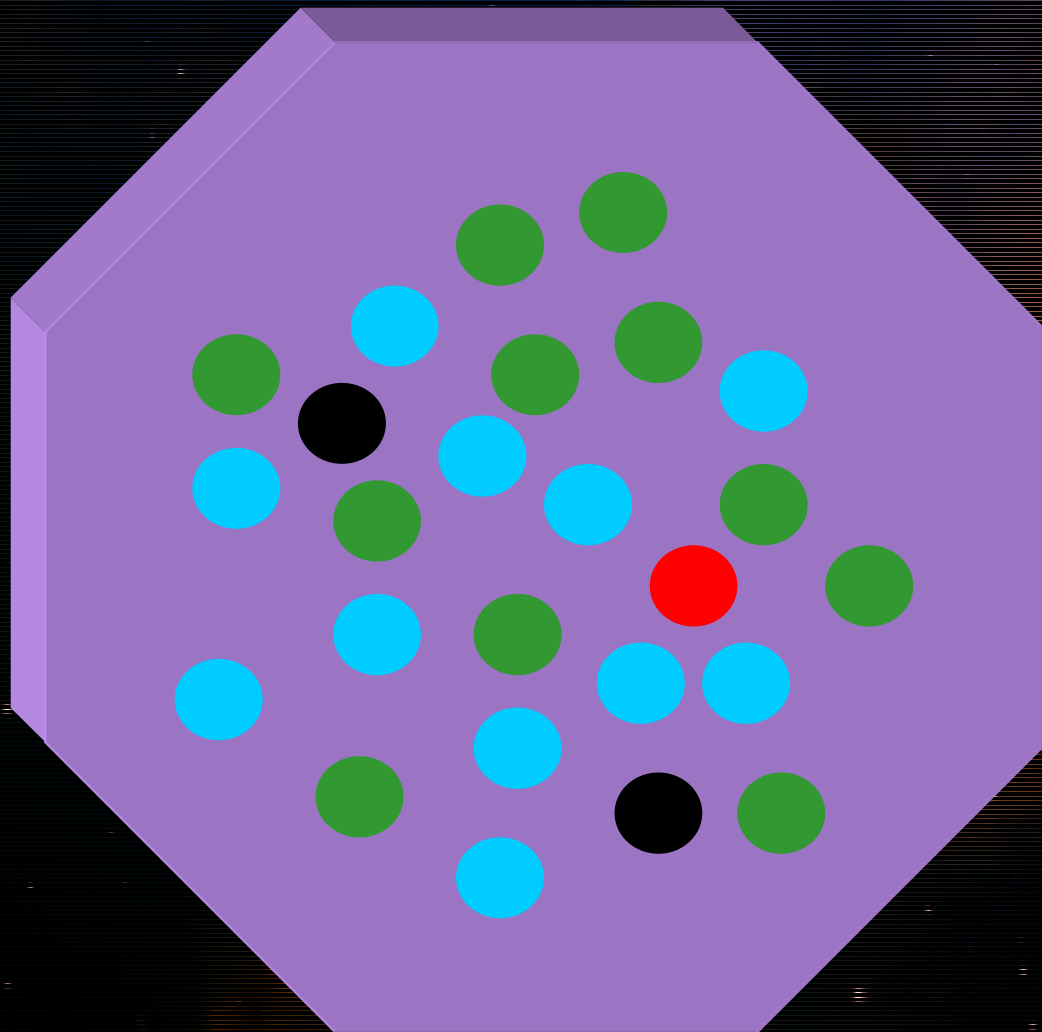
Evaluation Module



Based on the model, gives a “score” to each solution.

$$\chi^2(\mathbf{a}) \equiv \sum_{j=1}^N \frac{[q_j - q(\mathbf{a})]^2}{\sigma_j^2}$$

Judgement Module



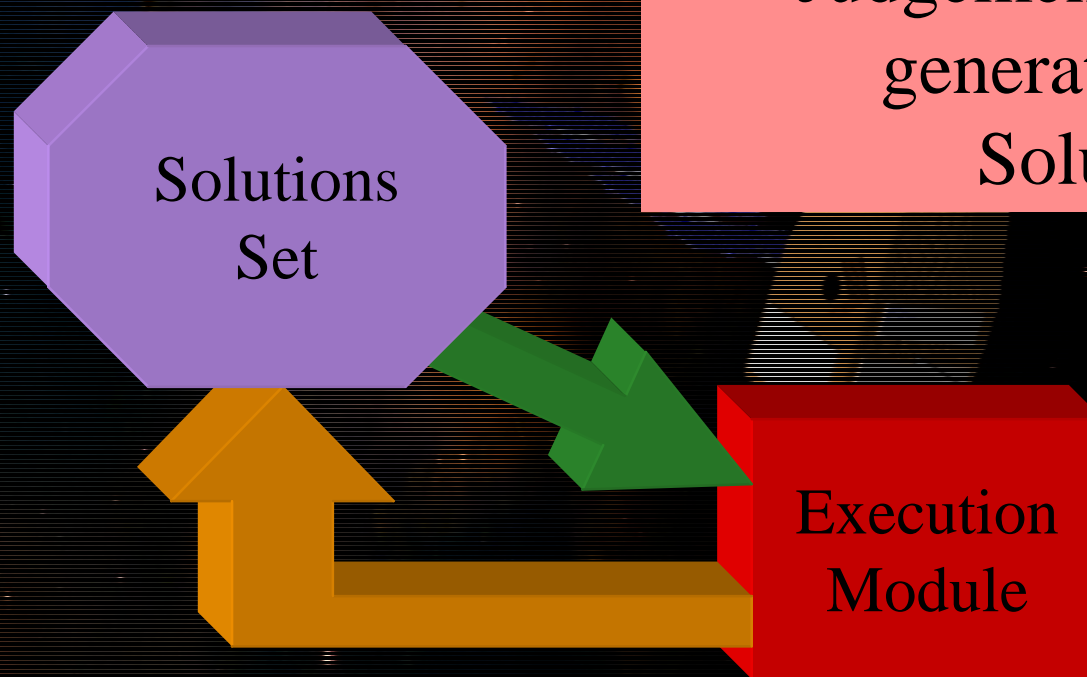
Defines which action shall be applied to each solution, according to scores.

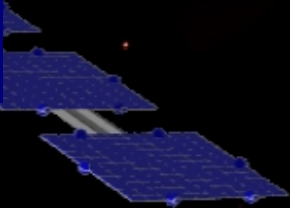
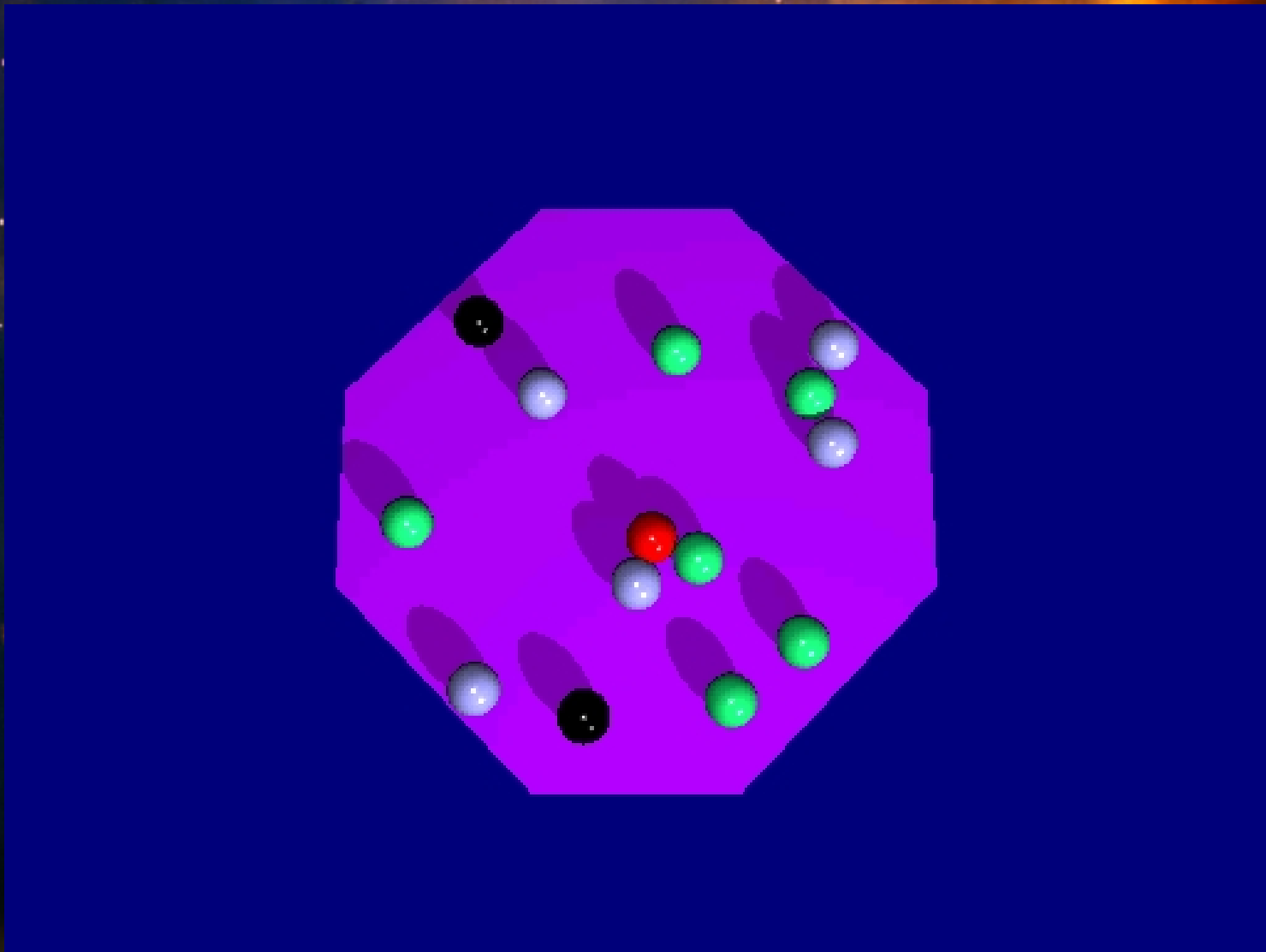
Judgement
Module

Copy
Crossover
Change
Eliminate

Execution Module

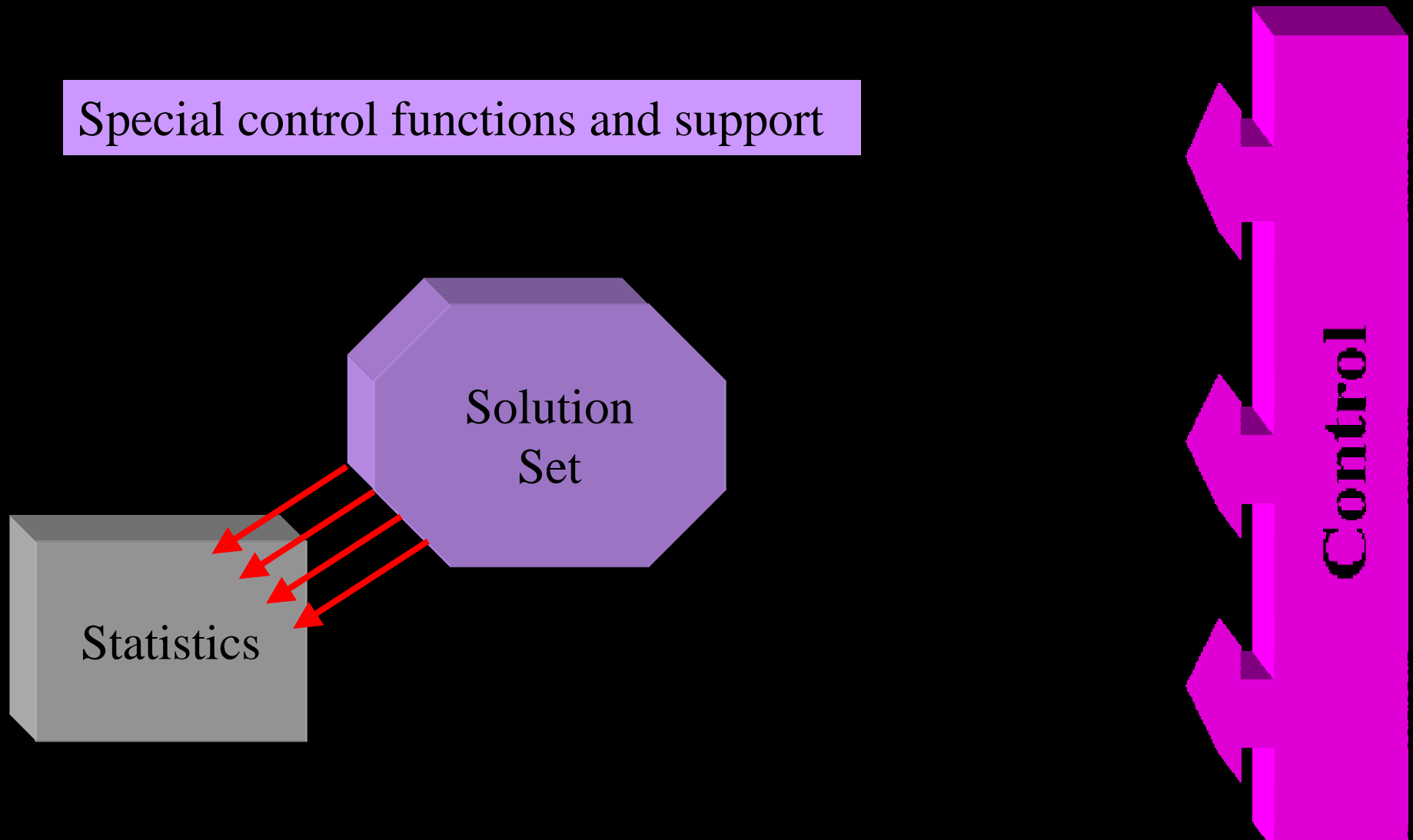
The Execution Module applies the actions defined by the Judgement Module, generating a new Solutions Set.





Statistics and Control

Special control functions and support



Evaluation Function

- Associates a numerical value (score) indicating the goodness of fit for given set of parameters.
- Contains the physics of the problem.
- Must be fast.

Software

Automatic functions

The screenshot displays the TTDisk Project software interface. The main window is titled "TTDisk Project" and contains a menu bar with "Arquivo" and "Perfil". Below the menu bar is a text field for the file path: "Fonte C:\ahj\Projetos\Sab2001\dados\HD98922.txt".

The central plot area shows a spectral energy distribution (SED) plot. The x-axis is labeled with spectral types: U, V, R, I, J, H, K, L, M, f12, f25, f50, f100. The y-axis represents flux density. The plot contains several data series: "Observational data" (represented by open circles and squares), "Model Results" (represented by solid lines), and "Geometry visualization" (represented by a dashed line). A red box labeled "Geometry visualization" points to the dashed line. A red box labeled "Observational data" points to the open circles and squares. A red box labeled "Model Results (Star, disk, envelope and sum of all components)" points to the solid lines. The plot also shows numerical values: -7.4875 at the top right and -12.8665 at the bottom right.

On the right side of the interface, there are several control panels:

- palheta:** A color palette selection area with radio buttons for "DISCO" (selected), "NUVEM", and "(vazio)".
- edição:** A yellow circle icon.
- Buttons:** "Plotar", "Ajuste 1", and "Salvar".
- Geometry Visualization:** Two circular diagrams labeled "polar log" and "cartesiano log".
- Parameters:** A list of parameters with input fields and +/- buttons:
 - TStar: 11882.5
 - RStar: 12.5753
 - Tau: 0.474249
 - RDisk: 31.0638
 - Theta: 4
 - Renv: 171204
- Other Parameters:** "gof" (17.3302), "note", "step" (0), "dTStar", "dRStar", "dTau", "dRDisk", "dTheta", "dRenv".

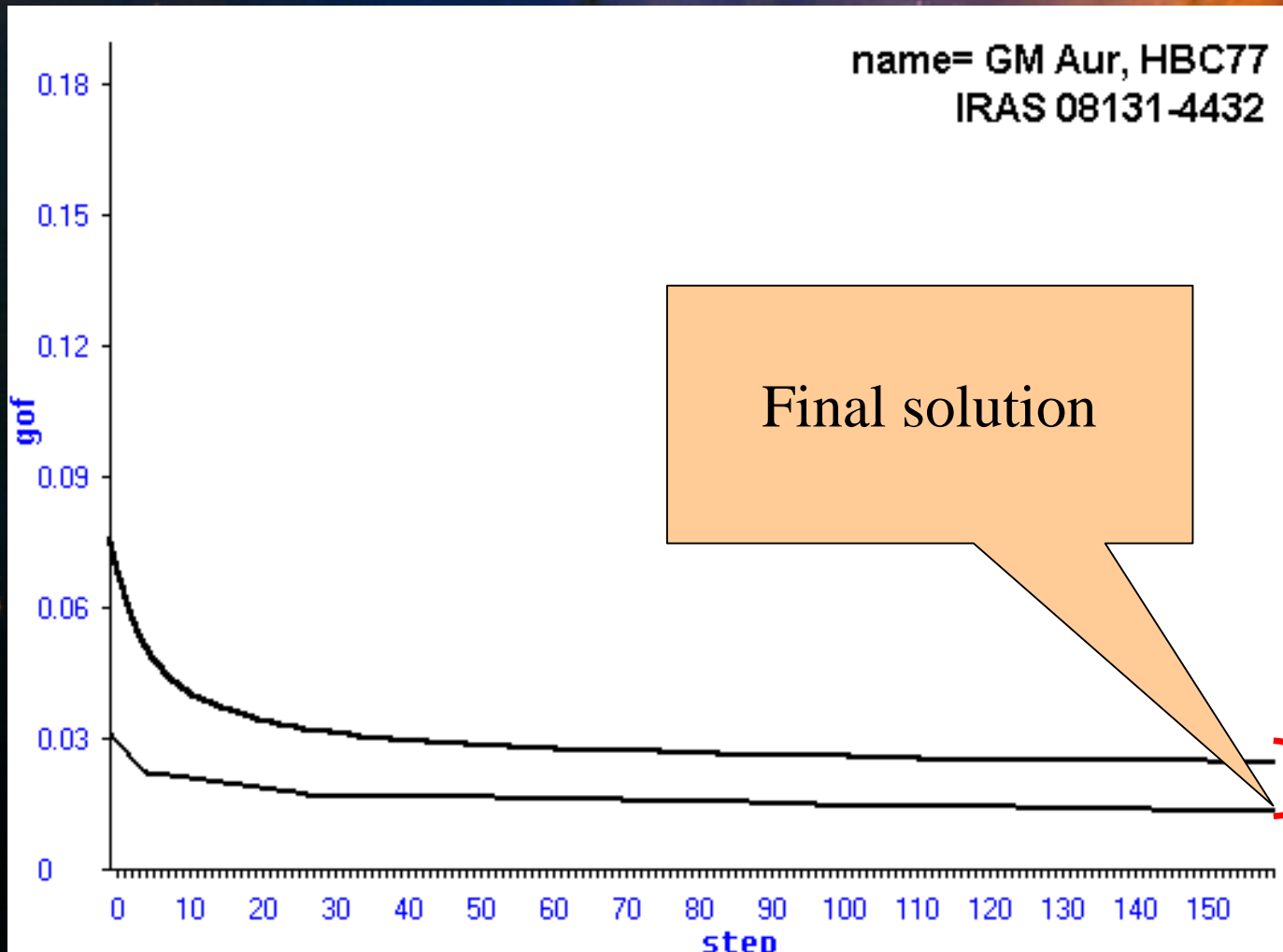
Geometry visualization

Observational data

Model Results
(Star, disk, envelope
and sum of all
components)

Main parameter edition

Finding a solution

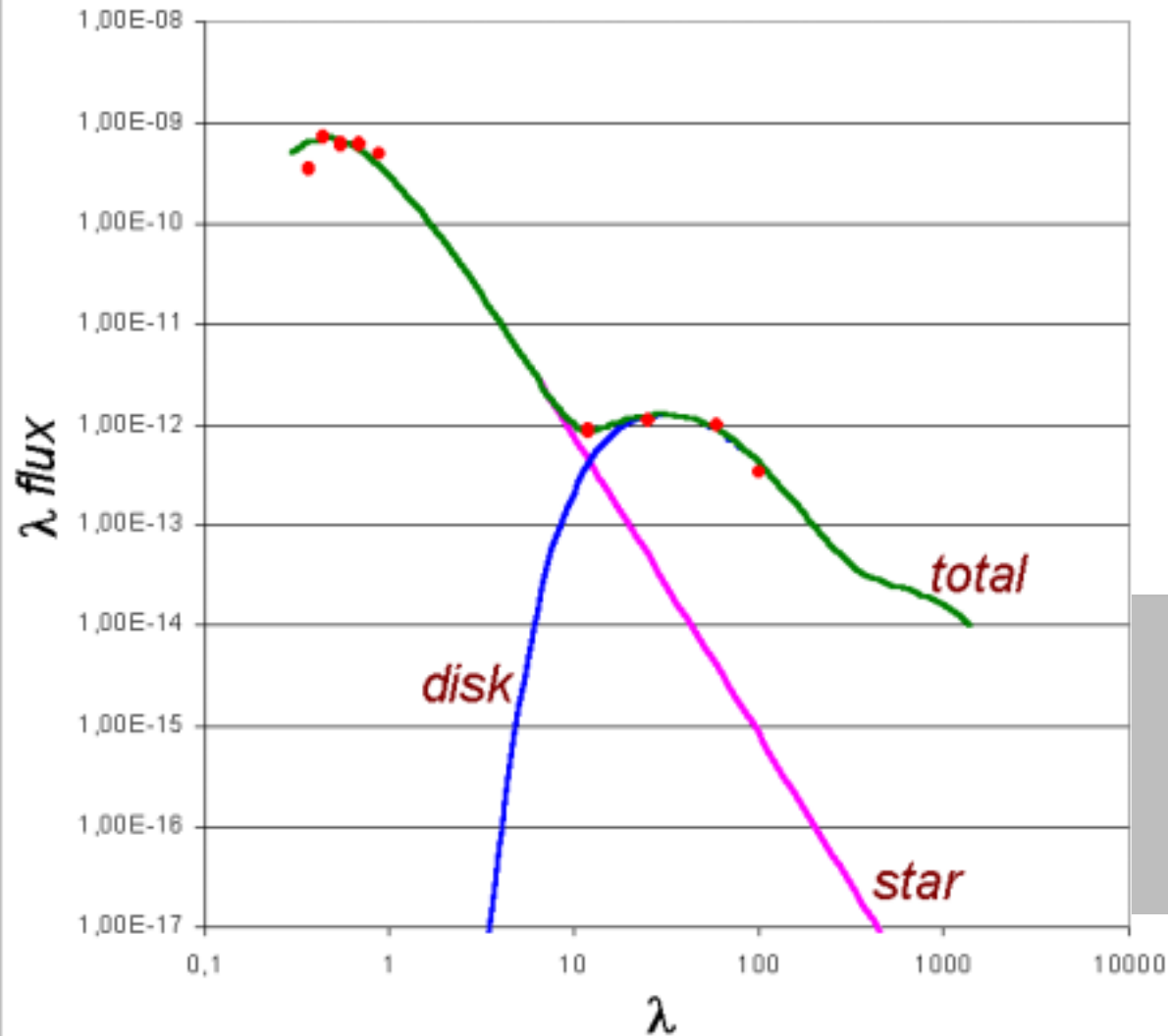


**Solution set with
 10^2 individuals.**

**Execution time:
200 s.**

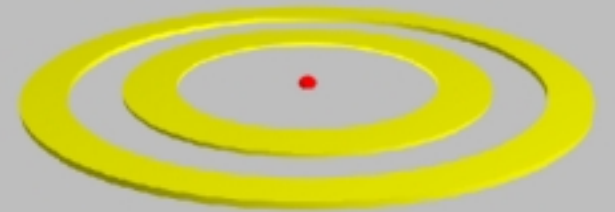
**Error bar
estimative**

Results: β Pictoris



Disk radii = 0.99 - 7.8 AU
62 - 350 AU

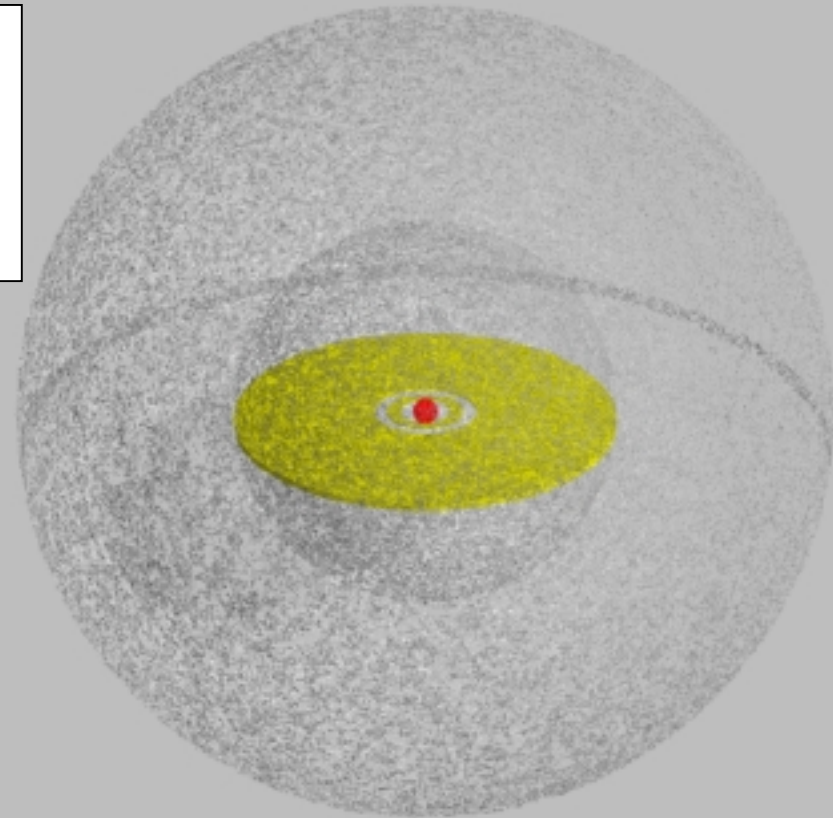
Height = 6 AU



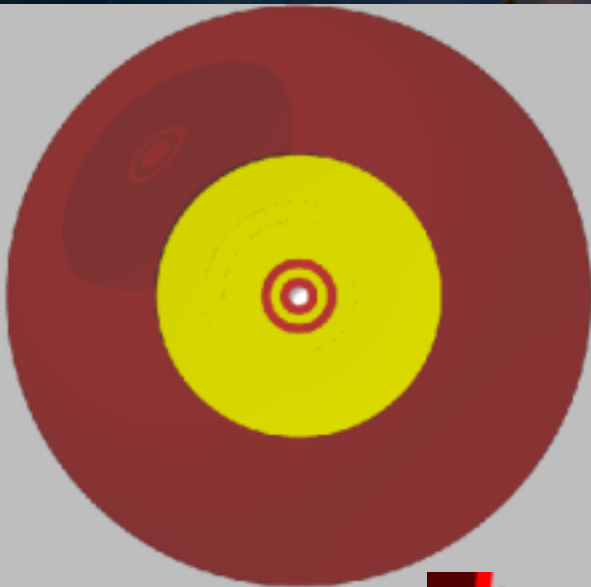
Results: TW Hydra

Disk radii = 0.014 - 0.029 AU
0.060 - 78 AU

Height = 0.033 AU



axial
view

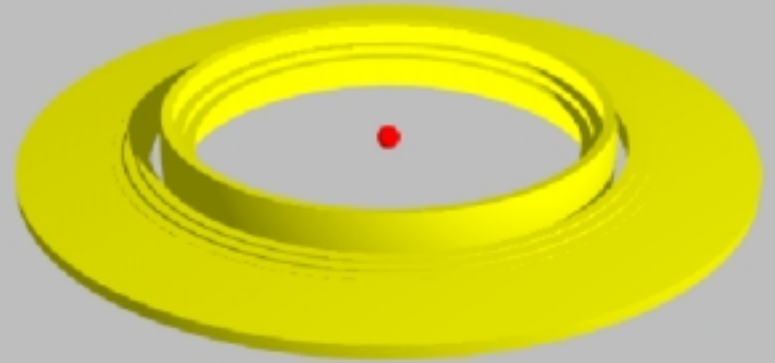
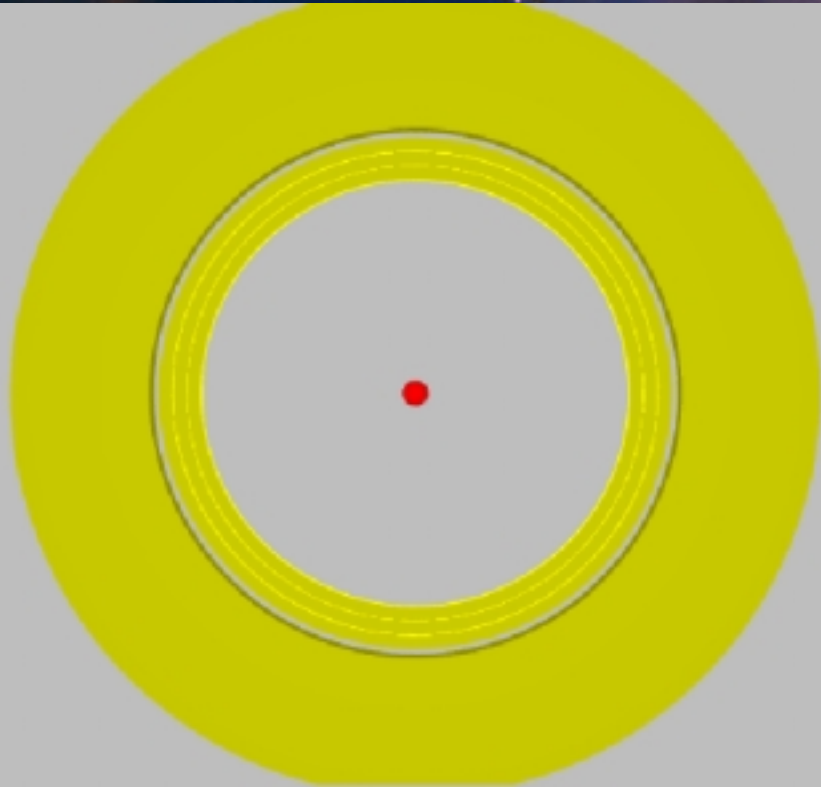


longitudinal view



Results: HD98800

axial
view



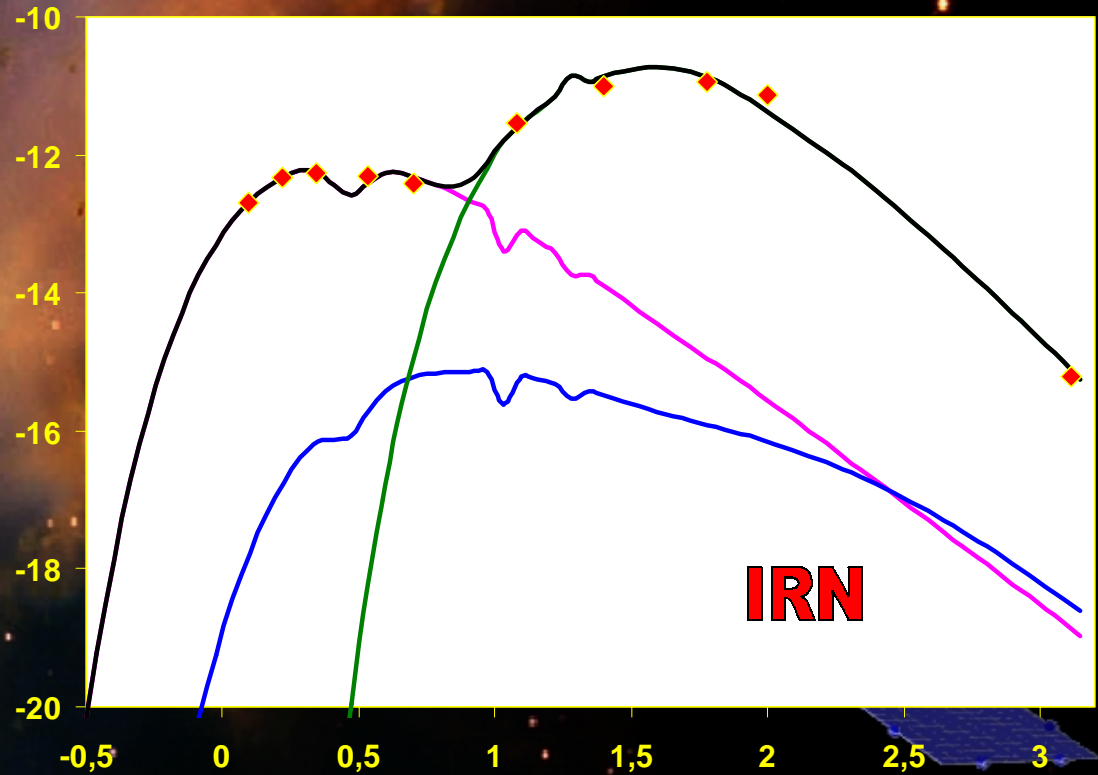
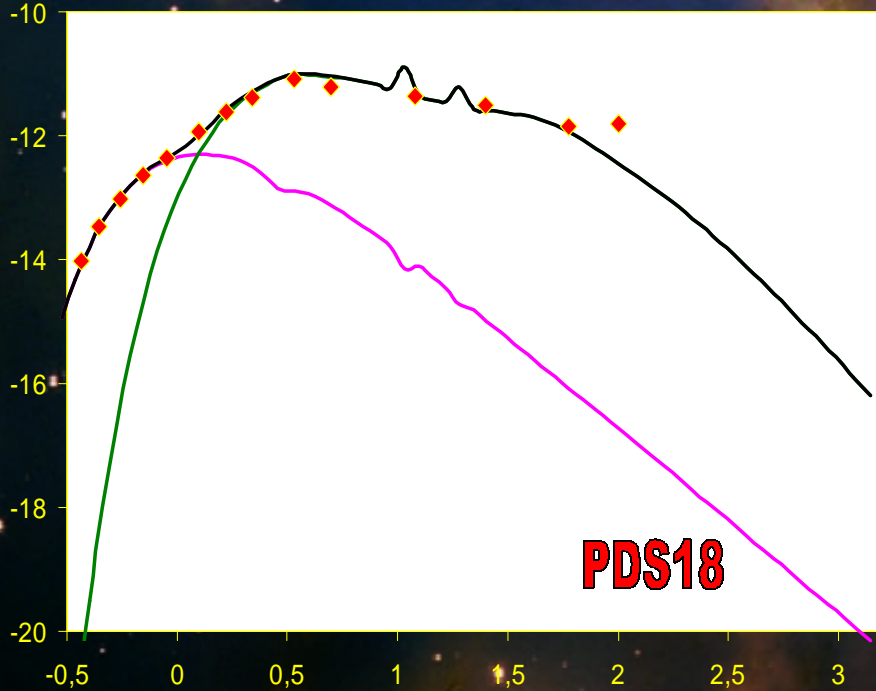
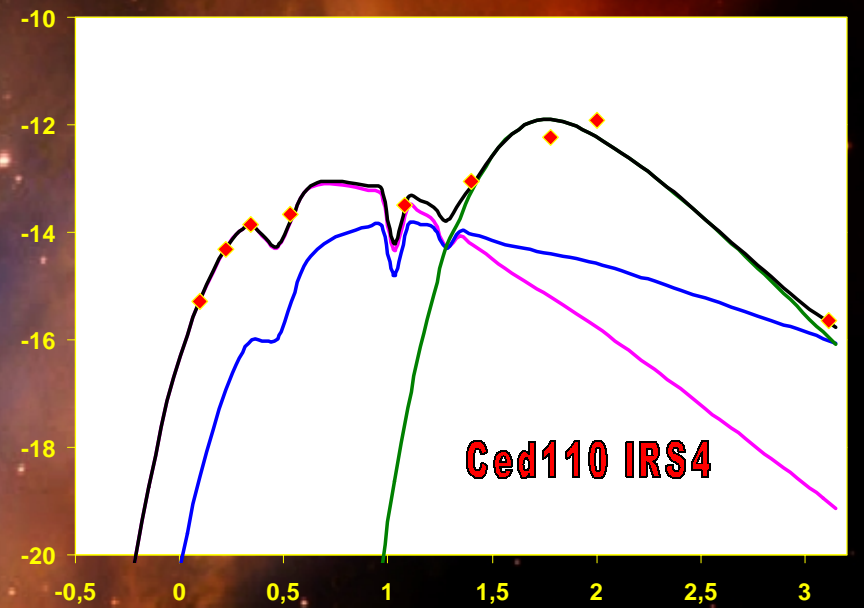
Disk radii = 0.48 - 1.02 AU
1.3 - 20 AU

Height = 0.17 AU

longitudinal view



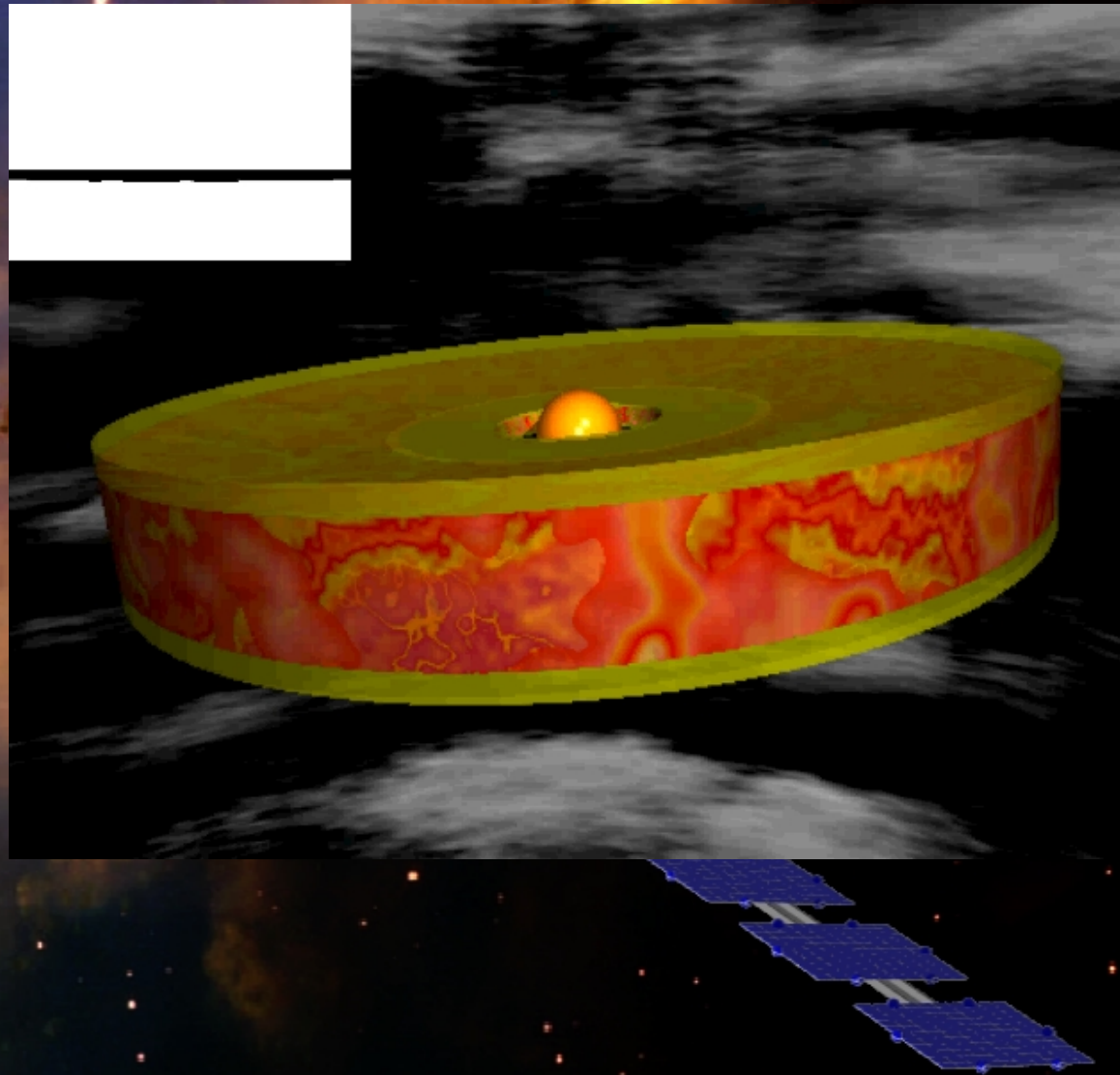
Other results



Disk transits

Circumstellar asymmetries can generate photometric variations similar to planet transits.

- View angle
- Accretion episodes
- Periodic eclipses



Current research

1. Judgement Module parameters optimisation.
2. Test new crossover modalities.
3. Porting the code for parallel machines / clusters.
4. Enhance portability for new models and contexts.

Conclusion

- The method is efficient to search solutions, even if the model is complex or presents high number of parameters.
- The final solutions present quality similar to those obtained by traditional methods.

References

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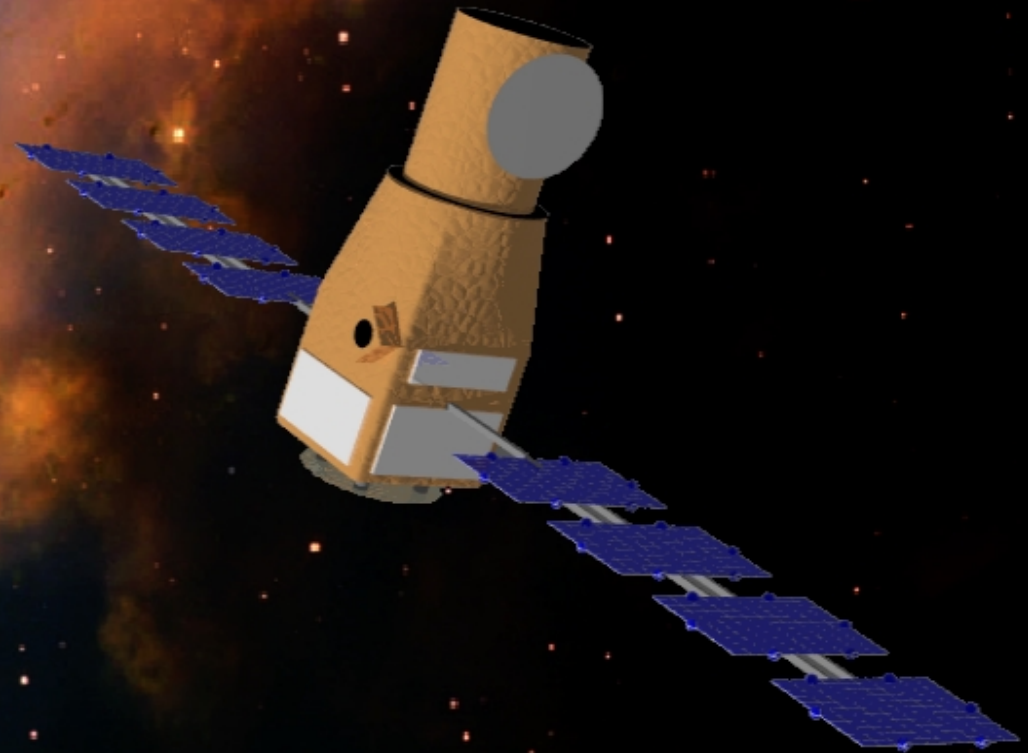
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Thank you!



annibal.hetem.jr@usa.net