Modelling Young Stellar Disks using Genetic Algorithms

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FAFIL

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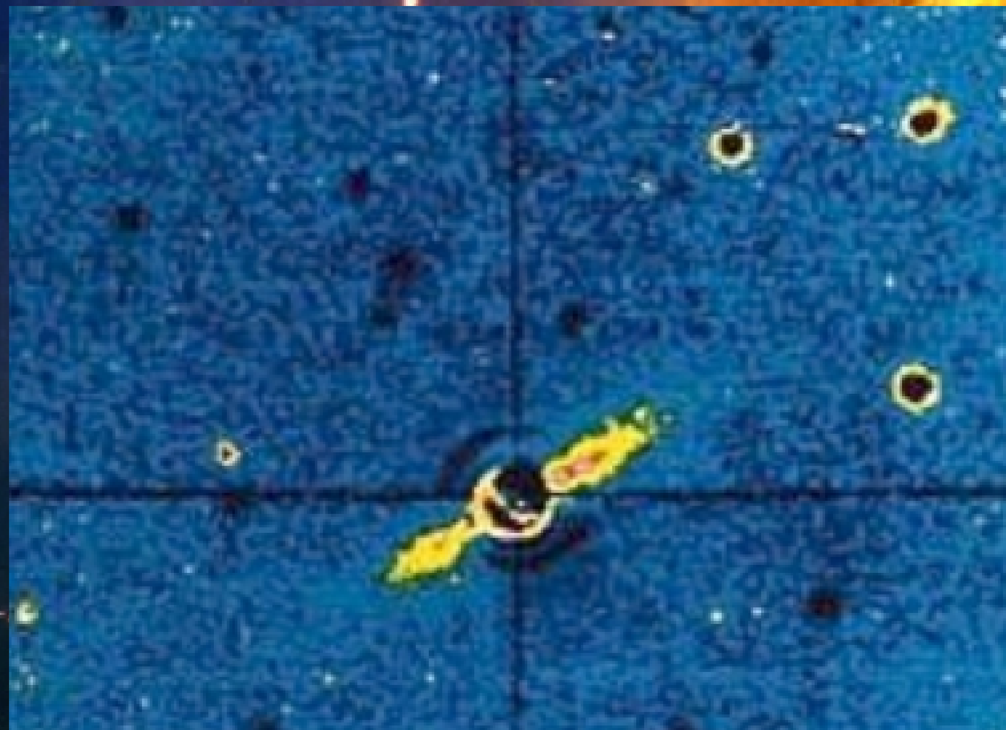
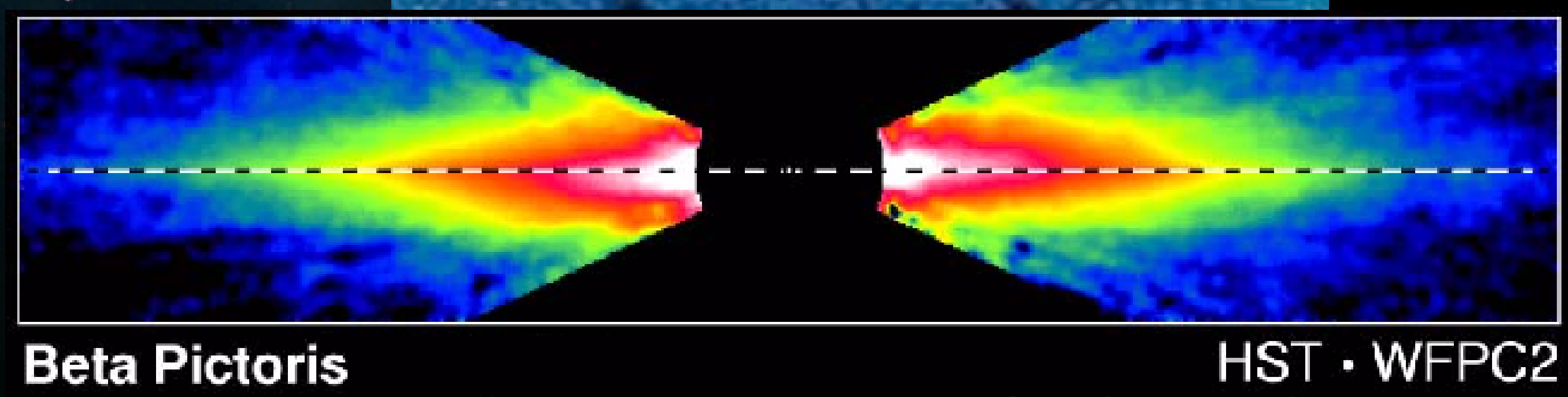
Motivation

- 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.

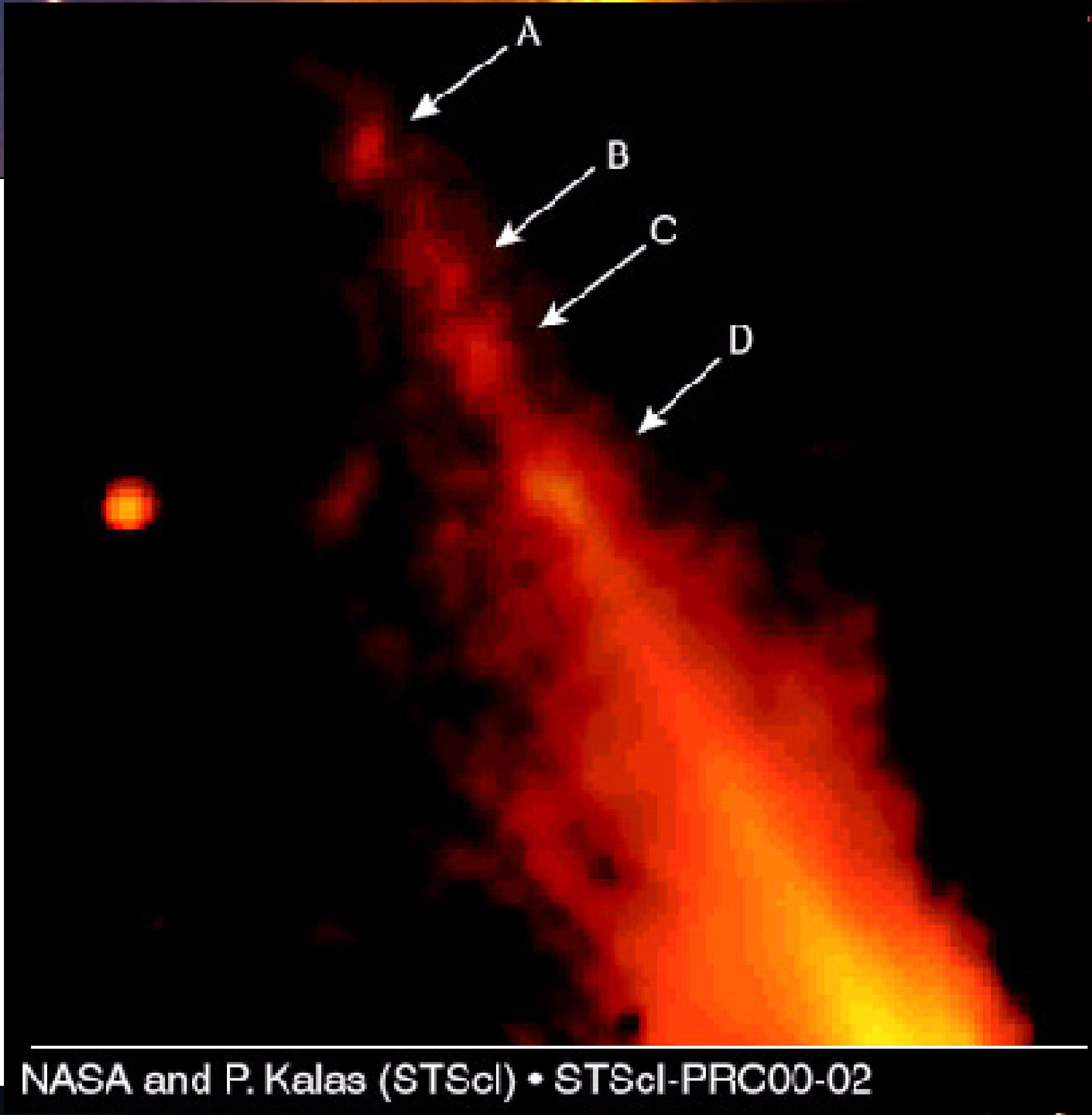
Example: β Pictoris

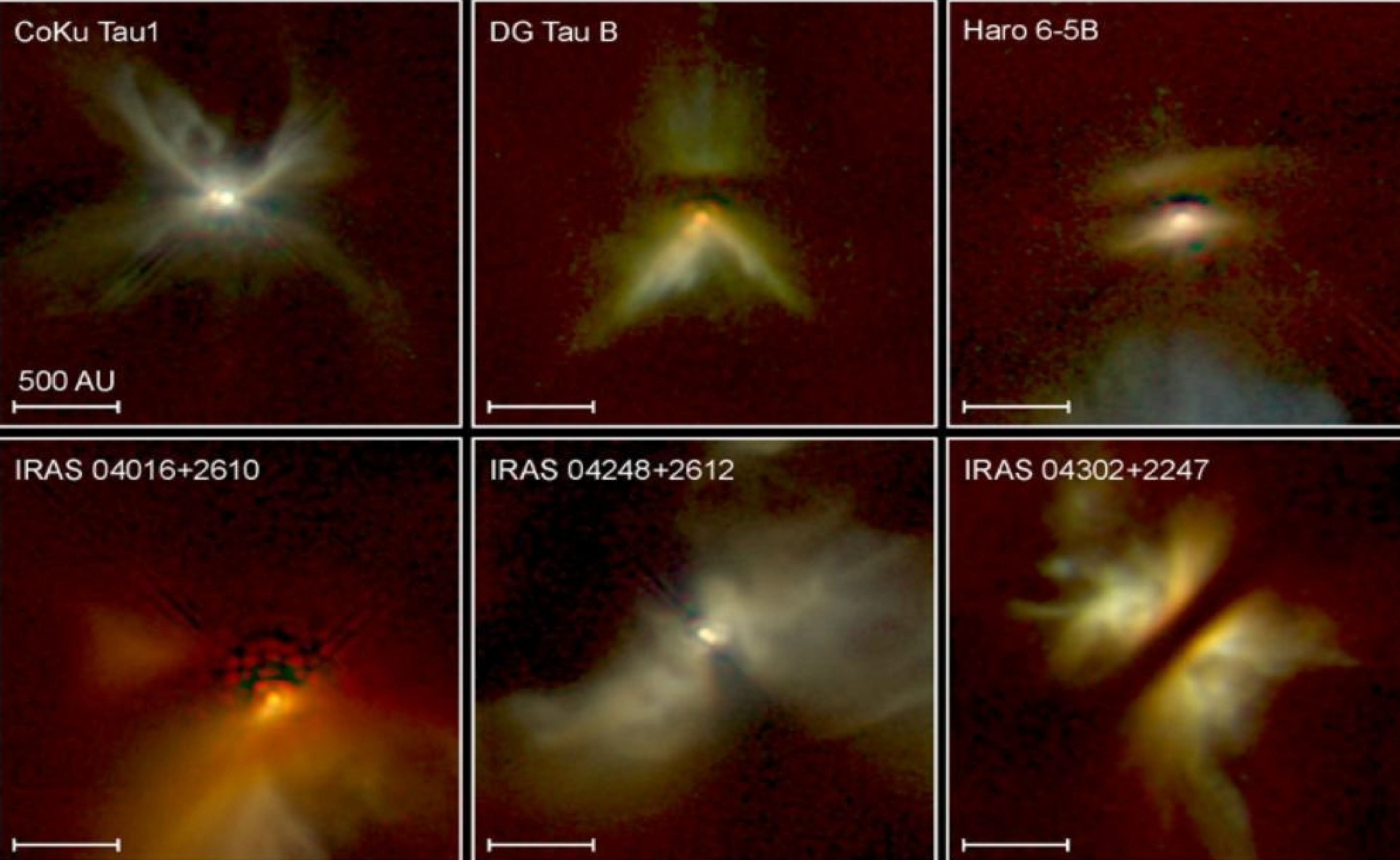




Example: β Pictoris

- 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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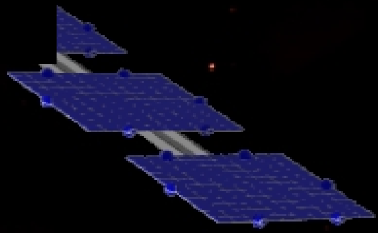
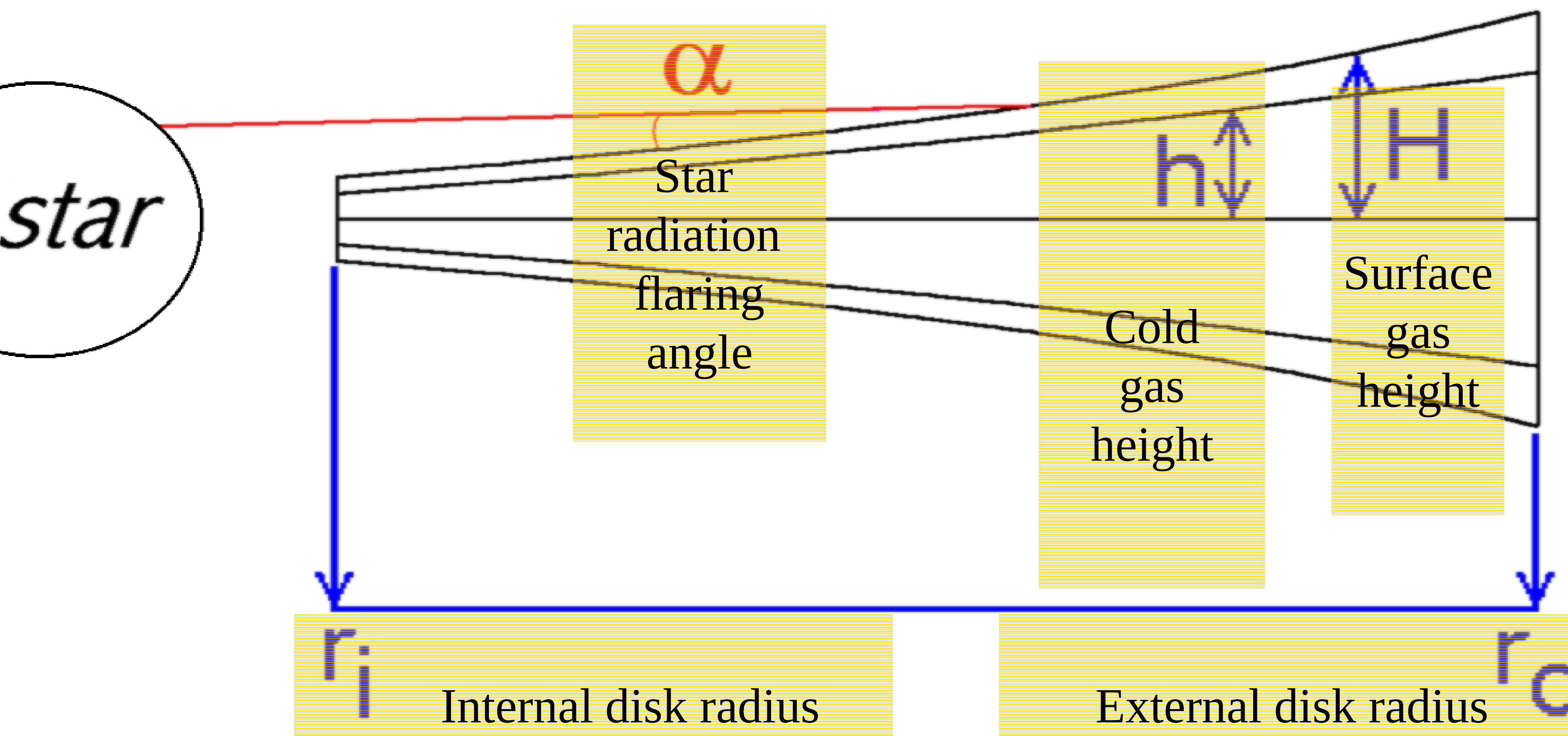
Flared Disk Model



Model geometry



Formalism

Column density

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

Volume density

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

Emissivity

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

Gravitacional potencial

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

Outer disk temperature

$$T_s = \frac{1}{\varepsilon_s}\left(\frac{R_*}{2r}\right)^{½} T_*$$

Inner disk temperature

$$T_i = \left(\frac{\alpha}{4}\right)^{¼}\left(\frac{R_*}{r}\right)^{½} T_*$$

Formalism

Flaring angle

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

Disk height

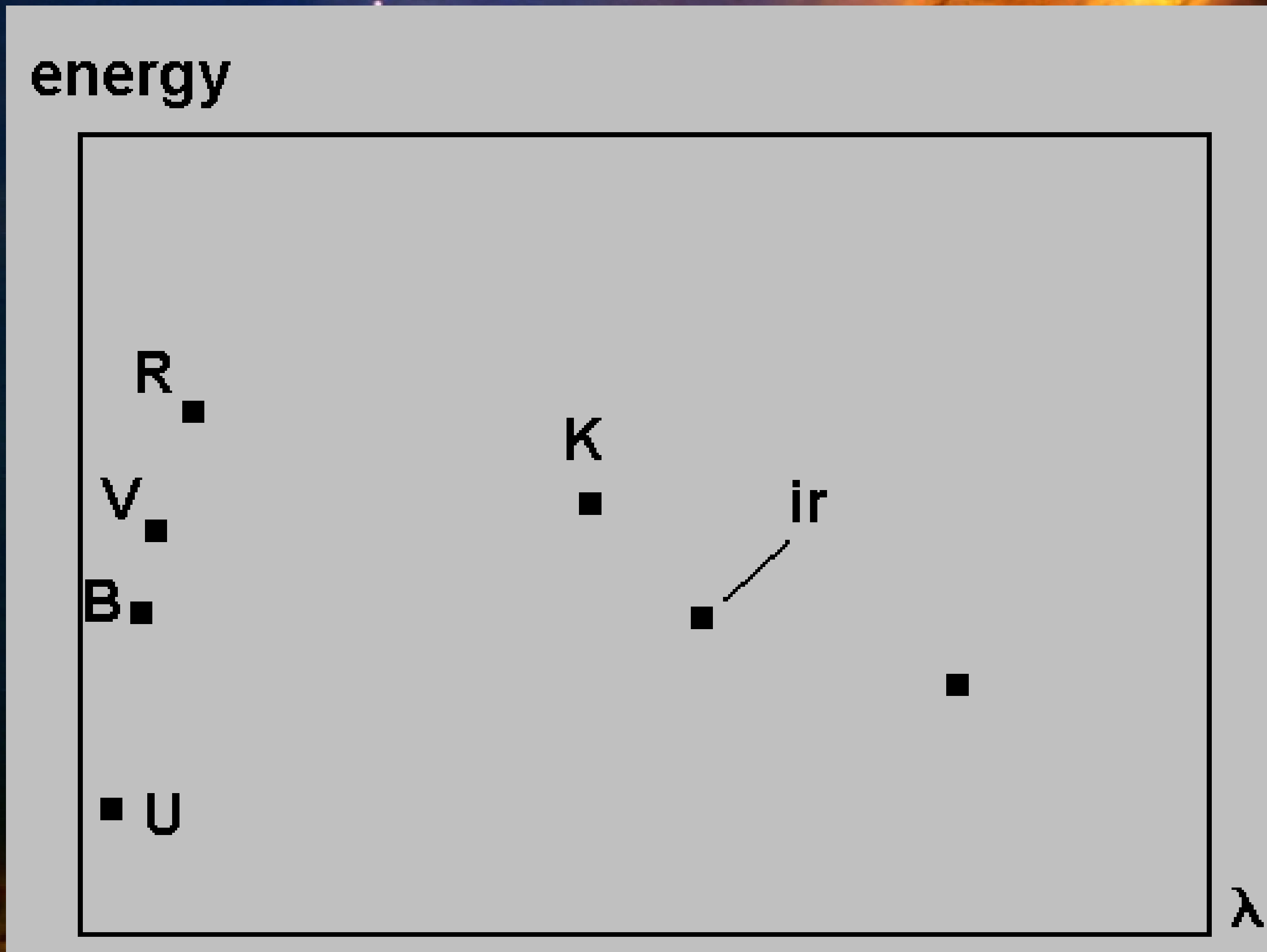
$$\frac{H}{r} = 4\left(\frac{T_*}{T_c}\right)^{4/7}\left(\frac{r}{R_*}\right)^{2/7}$$

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

Energy distribution

$$L_\lambda = 8\pi^2\frac{c}{\lambda}\int_{r_i}^{r_0} r\,dr\int_{-\infty}^{\infty}\frac{\partial\tau_\lambda}{\partial z}e^{-\tau_\lambda}B_\lambda(T)\,dz$$

From models to reality

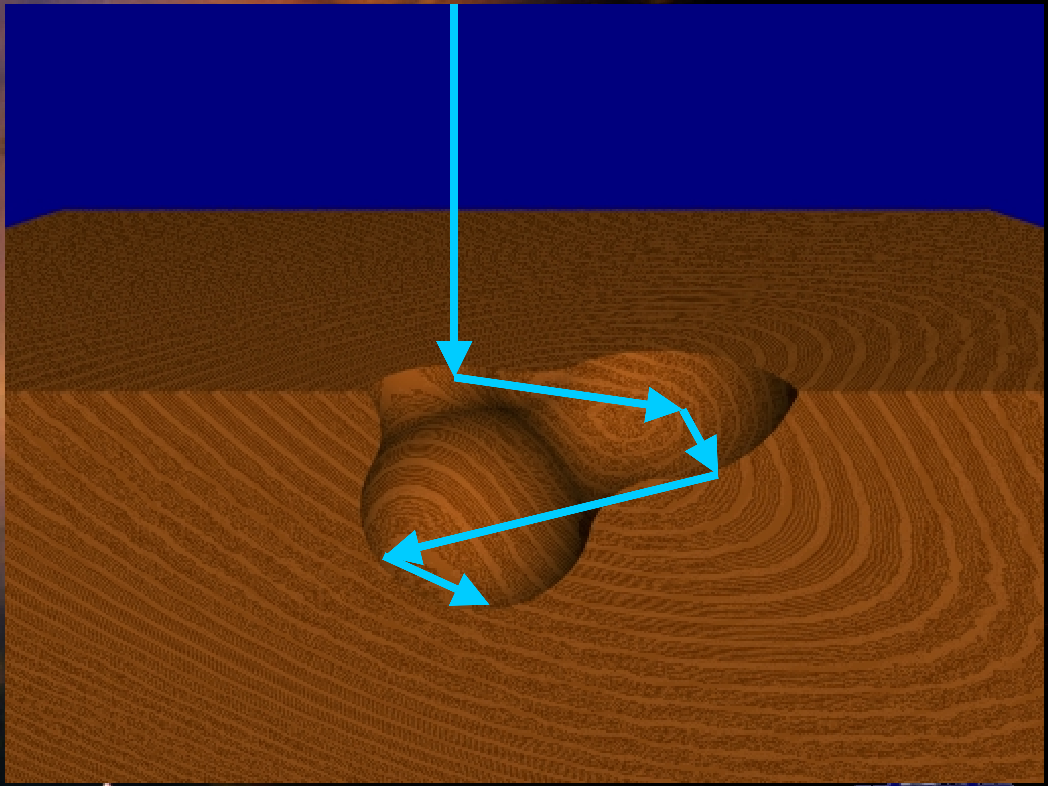


Classical fitting method

- Least squares method

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

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



Classical method problems

1. When the functions present discontinuities

Disk radius:

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

Optical depth:

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

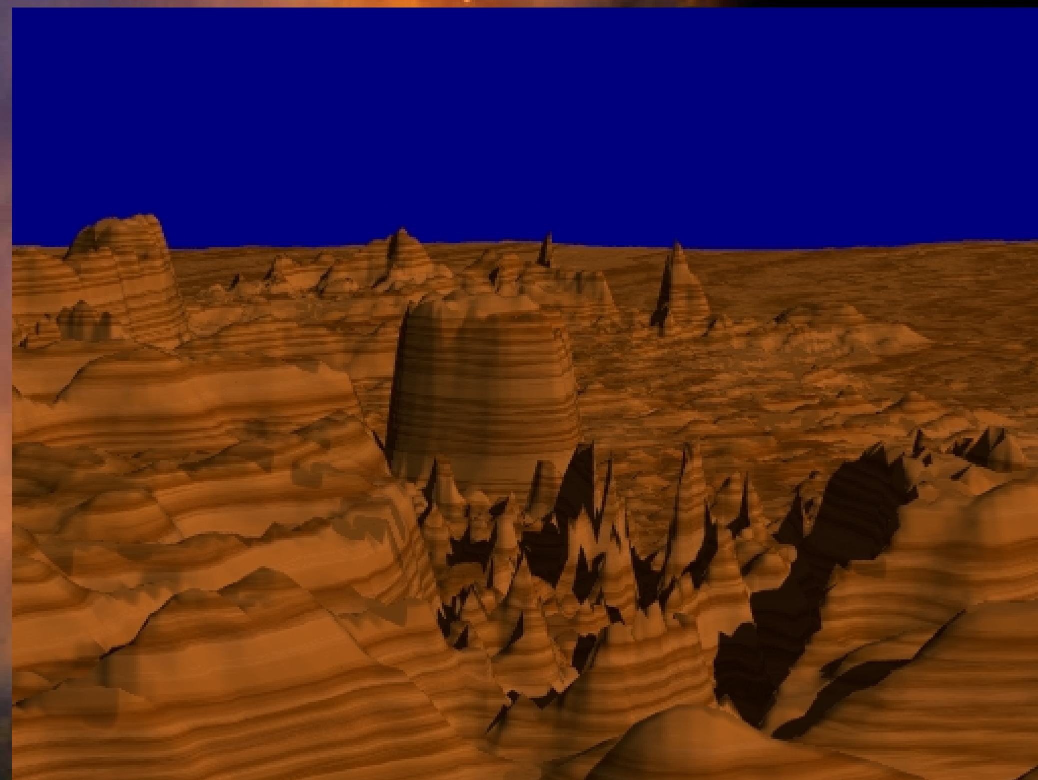
$$\mathbf{a}_{n+1} = \mathbf{a}_n - k \times \nabla\chi^2(\mathbf{a}_n)$$

Discontinuities in derivatives
or
artificial functions

Classical method problems

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

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

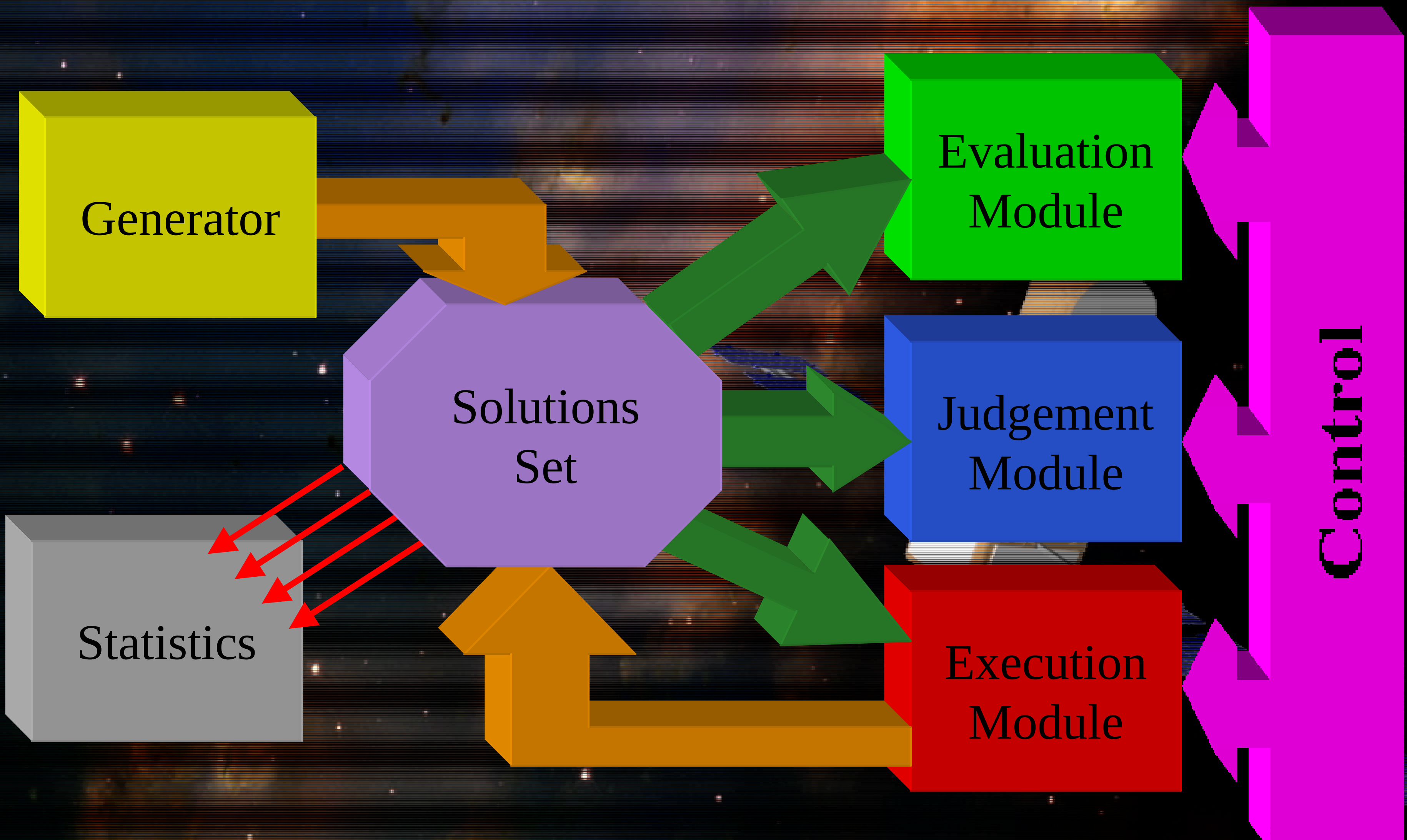


Genetic Algorithm

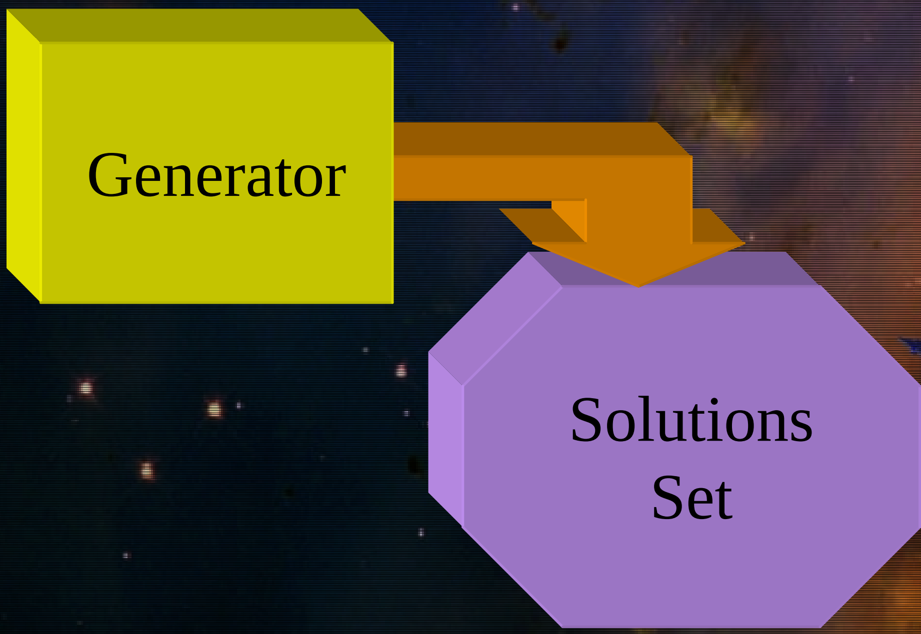
- Supports several parameters.
- Not affected by model complexity.

- Suggested by Koza (1992)
- Adopted version by Bentley & Corne (2002)

Implementation

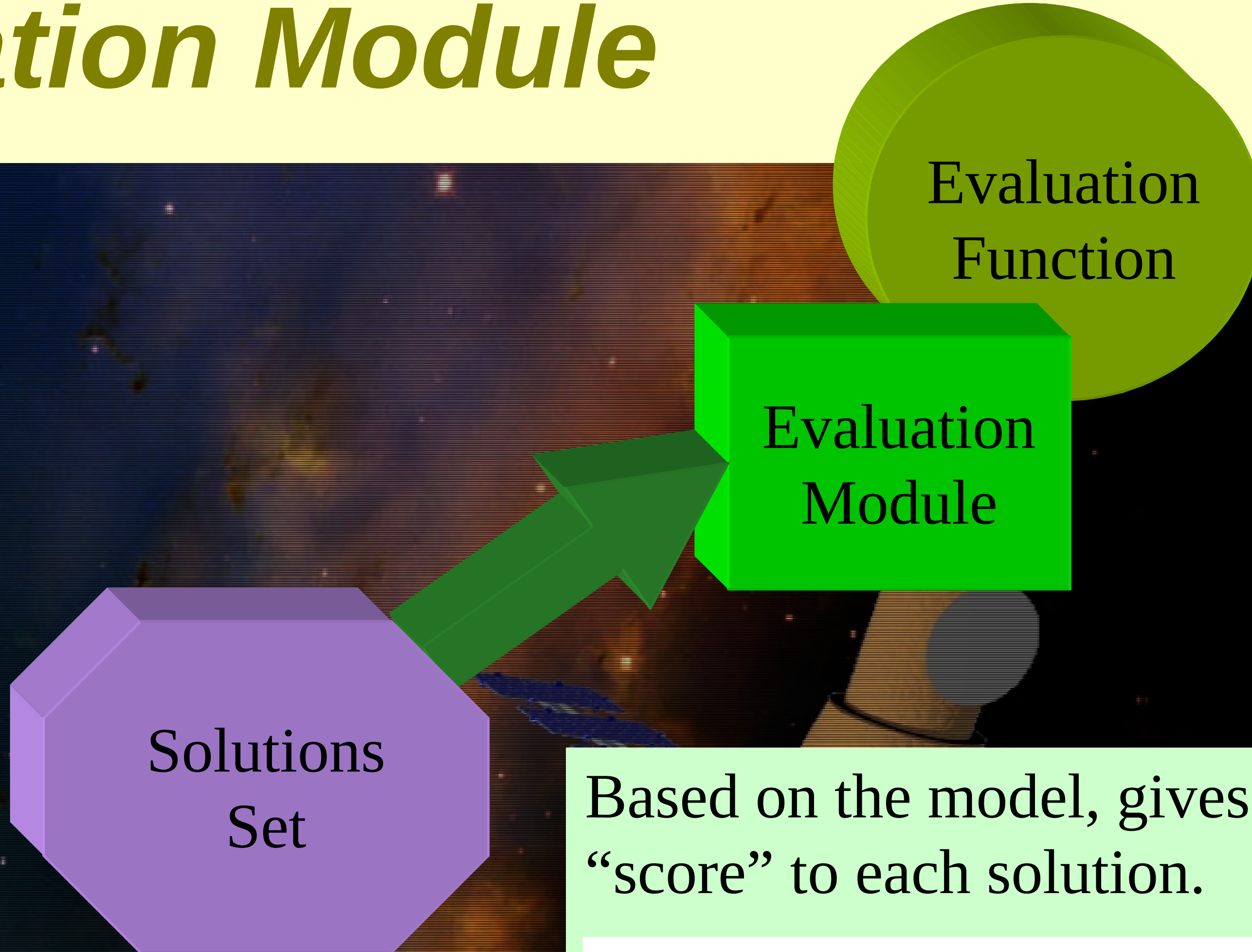


Generator



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

Evaluation Module

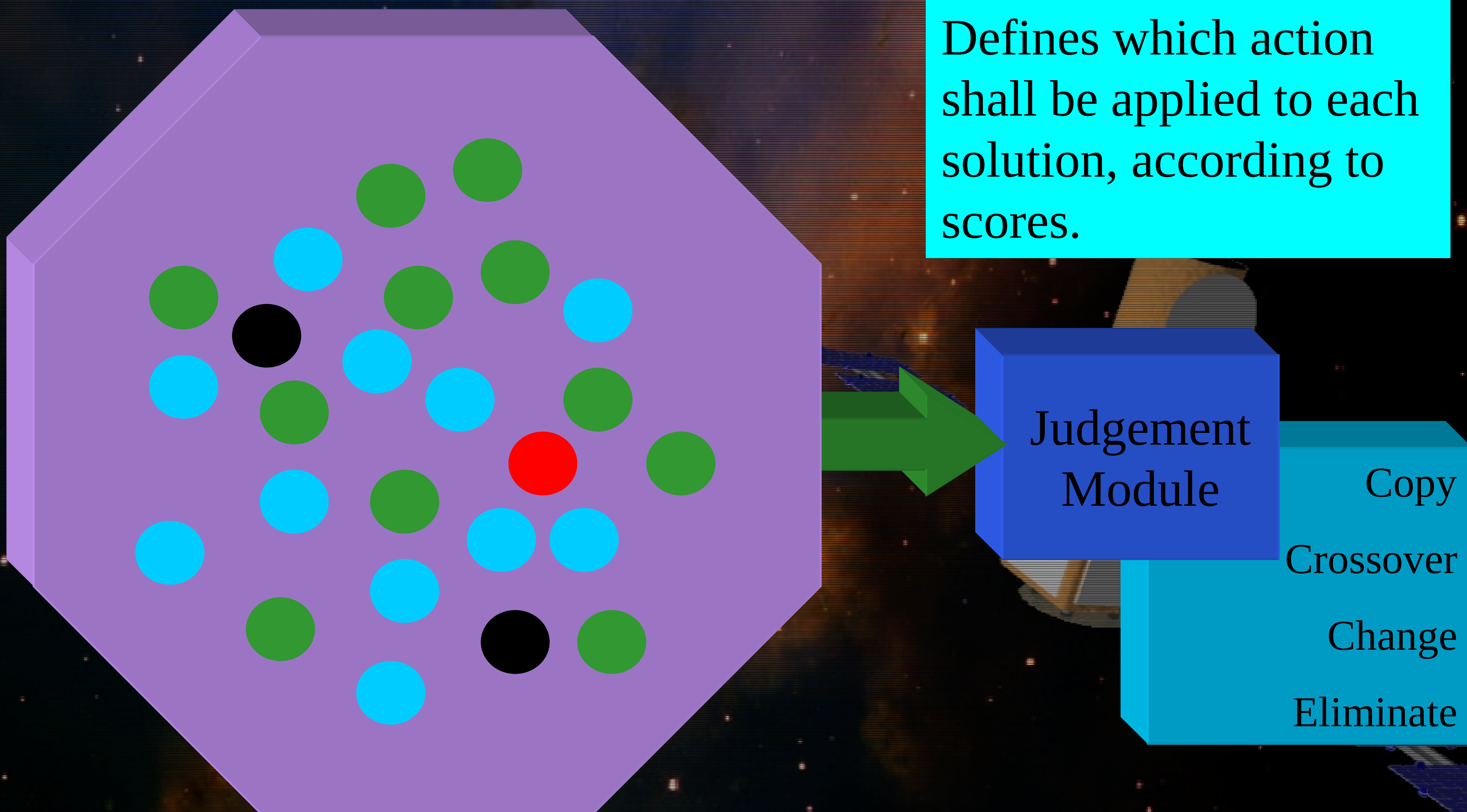


Based on the model, gives a "score" to each solution.

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

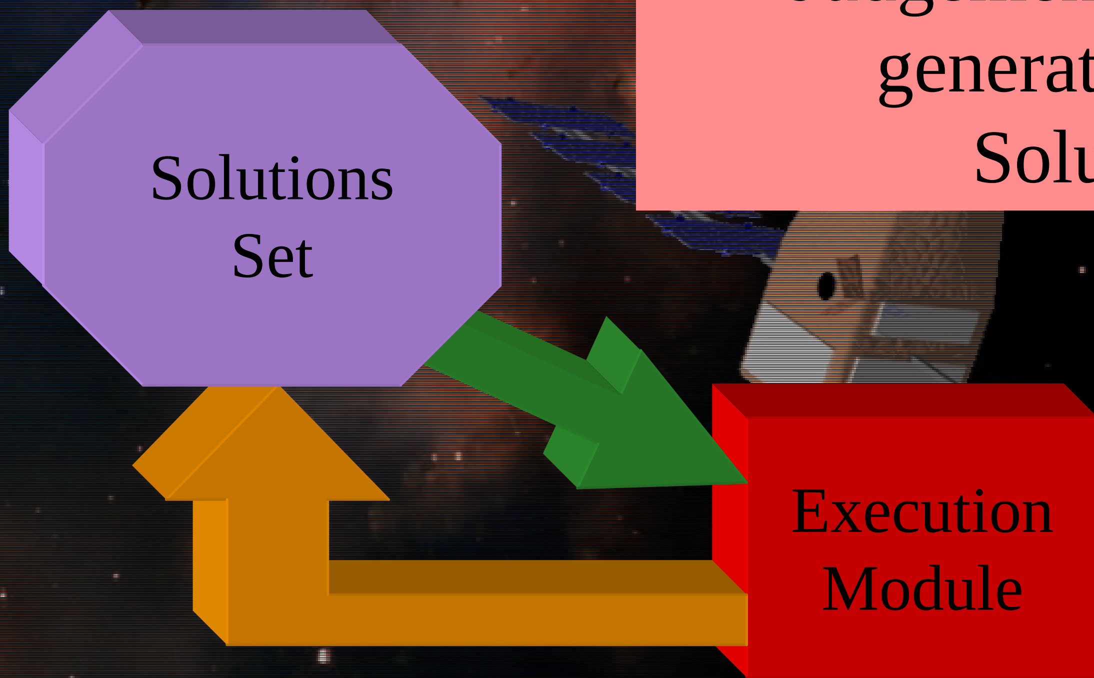
Judgement Module

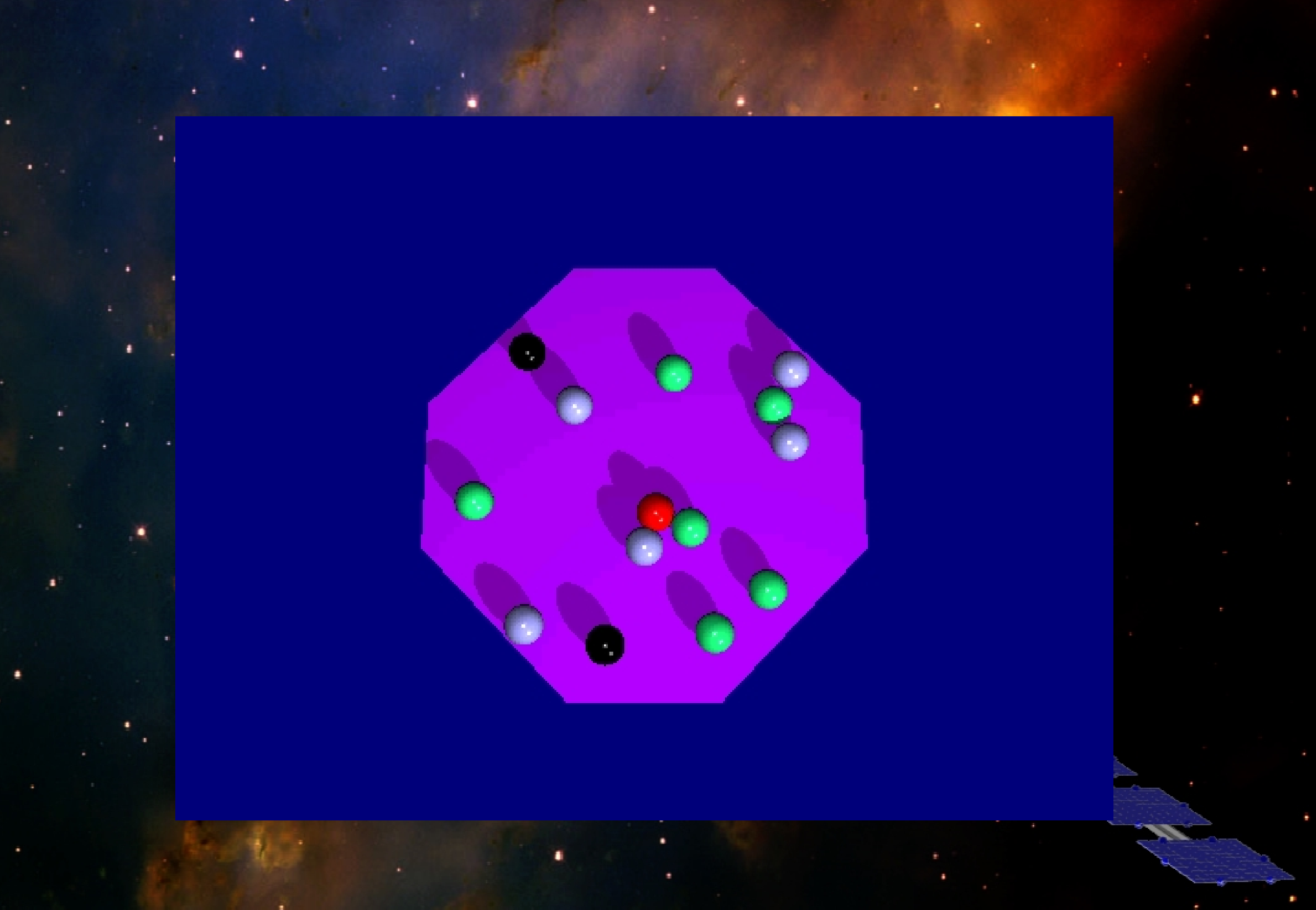
Defines which action shall be applied to each solution, according to scores.



Execution Module

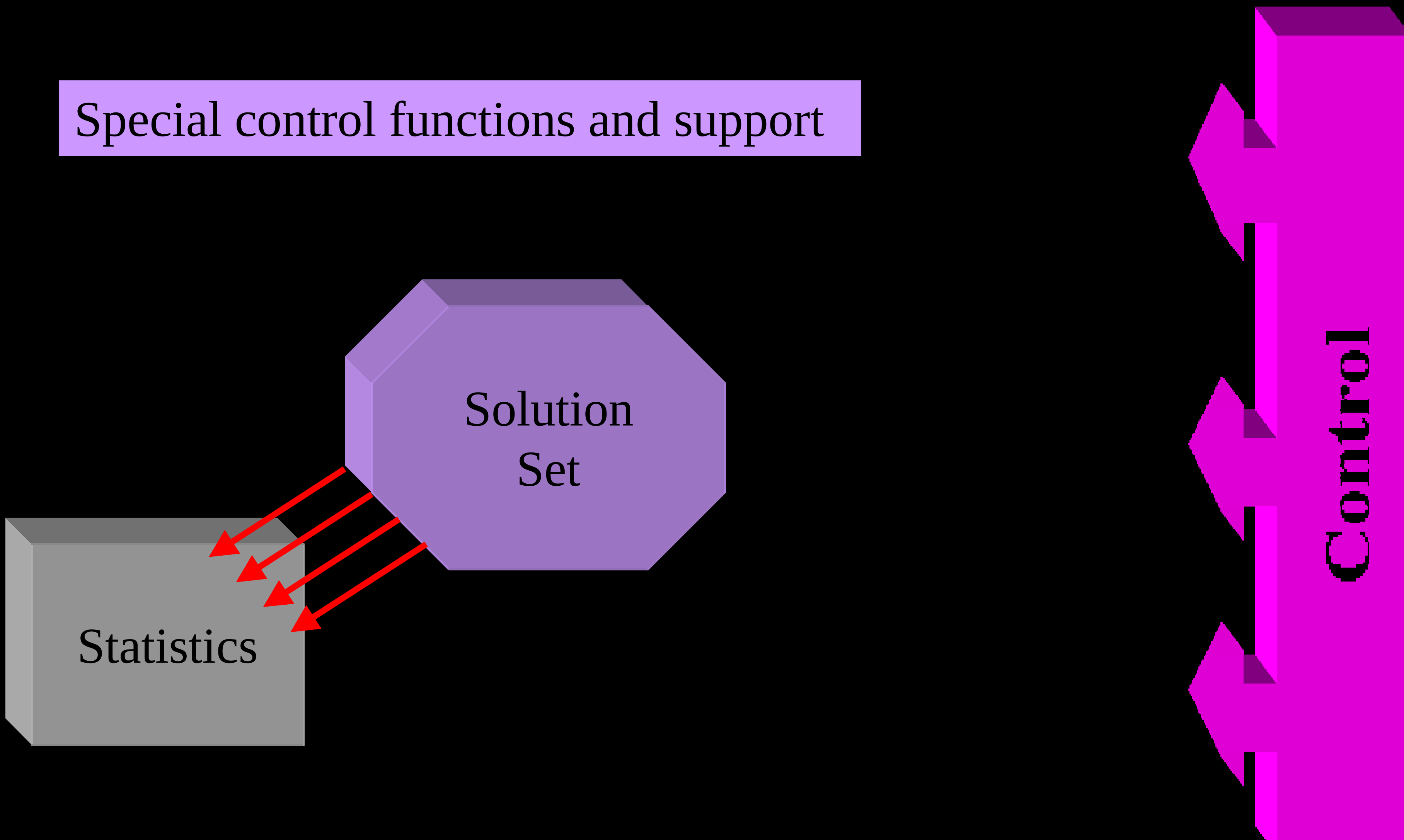
The Execution Module applies the actions defined by the Judgement Module, generating a new Solutions Set.





Statistics and Control

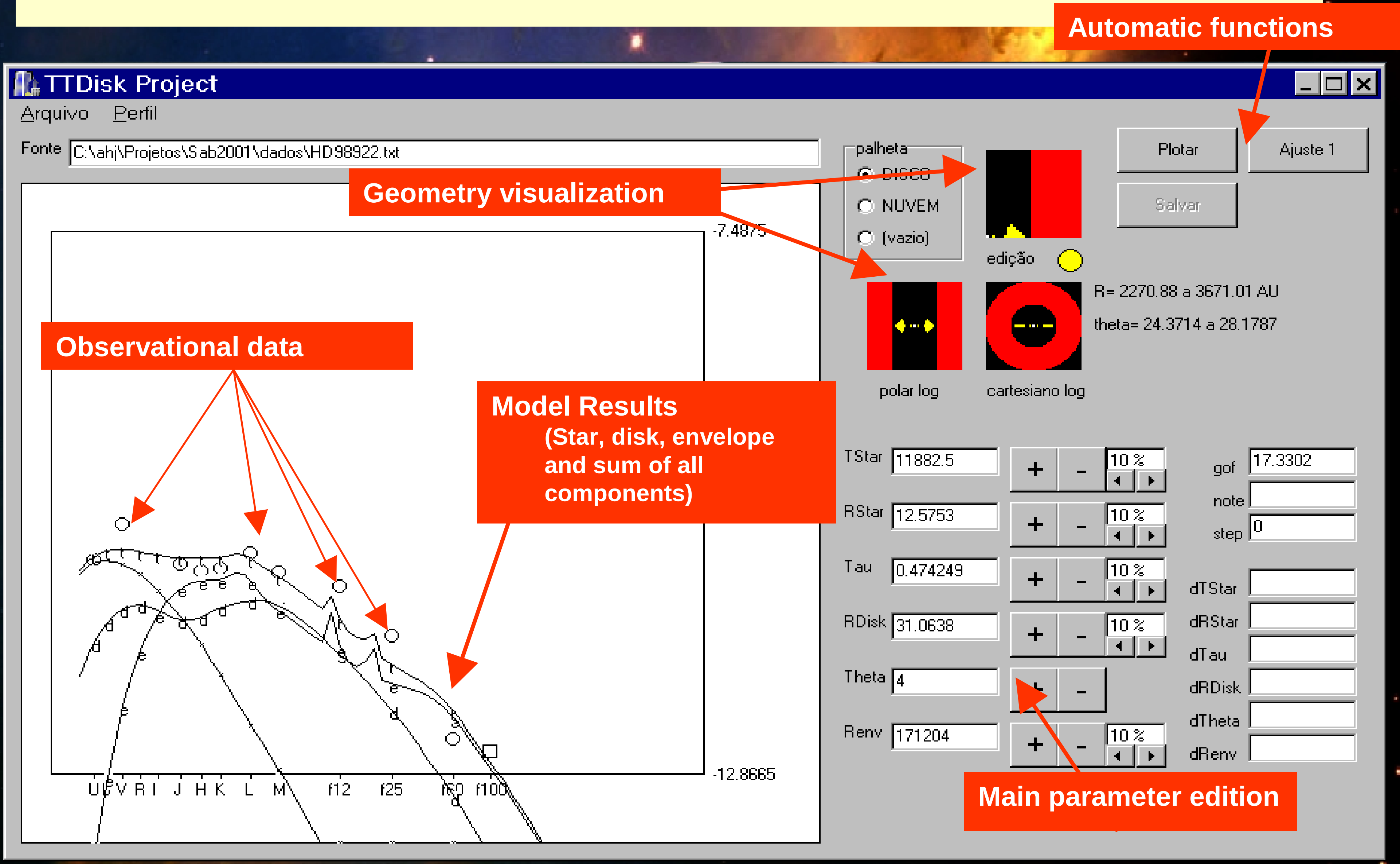
Special control functions and support



Evaluation Function

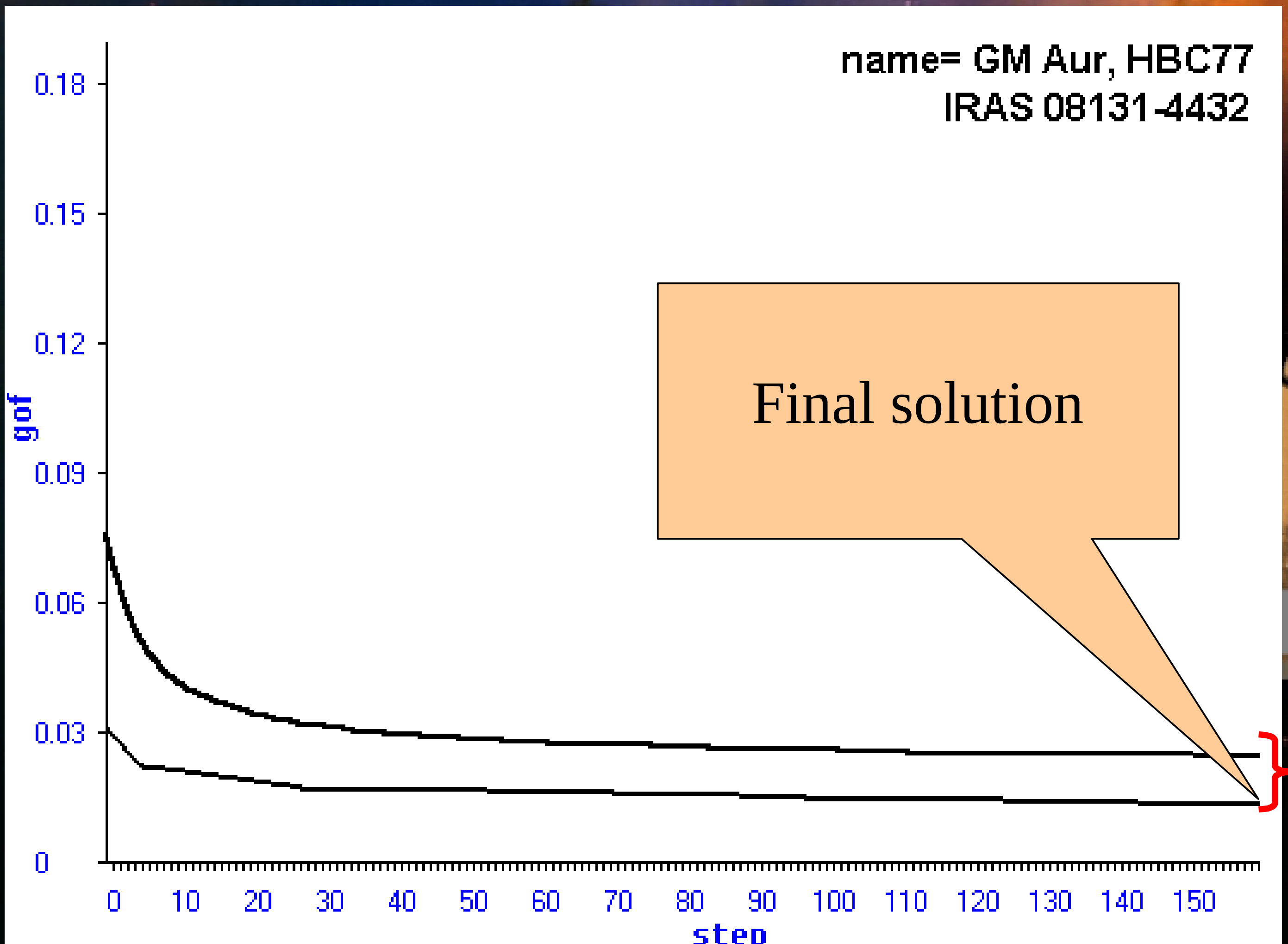
- Associates a numerical value (score) indicating the goodness of fit for given set of parameters.
- Contains the physics of the problem.
- Must be fast.

Software



Automatic functions
TTDisk Project
Arquivo
Perfil
Fonte
C:\ahj\Projetos\Sab2001\dados\HD98922.txt
palheta
DISCO
NUVEM
(vazio)
Plotar
Ajuste 1
Salvar
Geometry visualization
edição
-7.4875
polar log
cartesiano log
R= 2270.88 a 3671.01 AU
theta= 24.3714 a 28.1787
Observational data
Model Results
(Star, disk, envelope and sum of all components)
TStar
11882.5
RStar
12.5753
Tau
0.474249
RDisk
31.0638
Theta
4
Renv
171204
10 %
gof
17.3302
note
step
0
dTStar
dRStar
dTau
dRDisk
dTheta
dRenv
-12.8665
U B V R I J H K L M f12 f25 f60 f100
Main parameter edition

Finding a solution

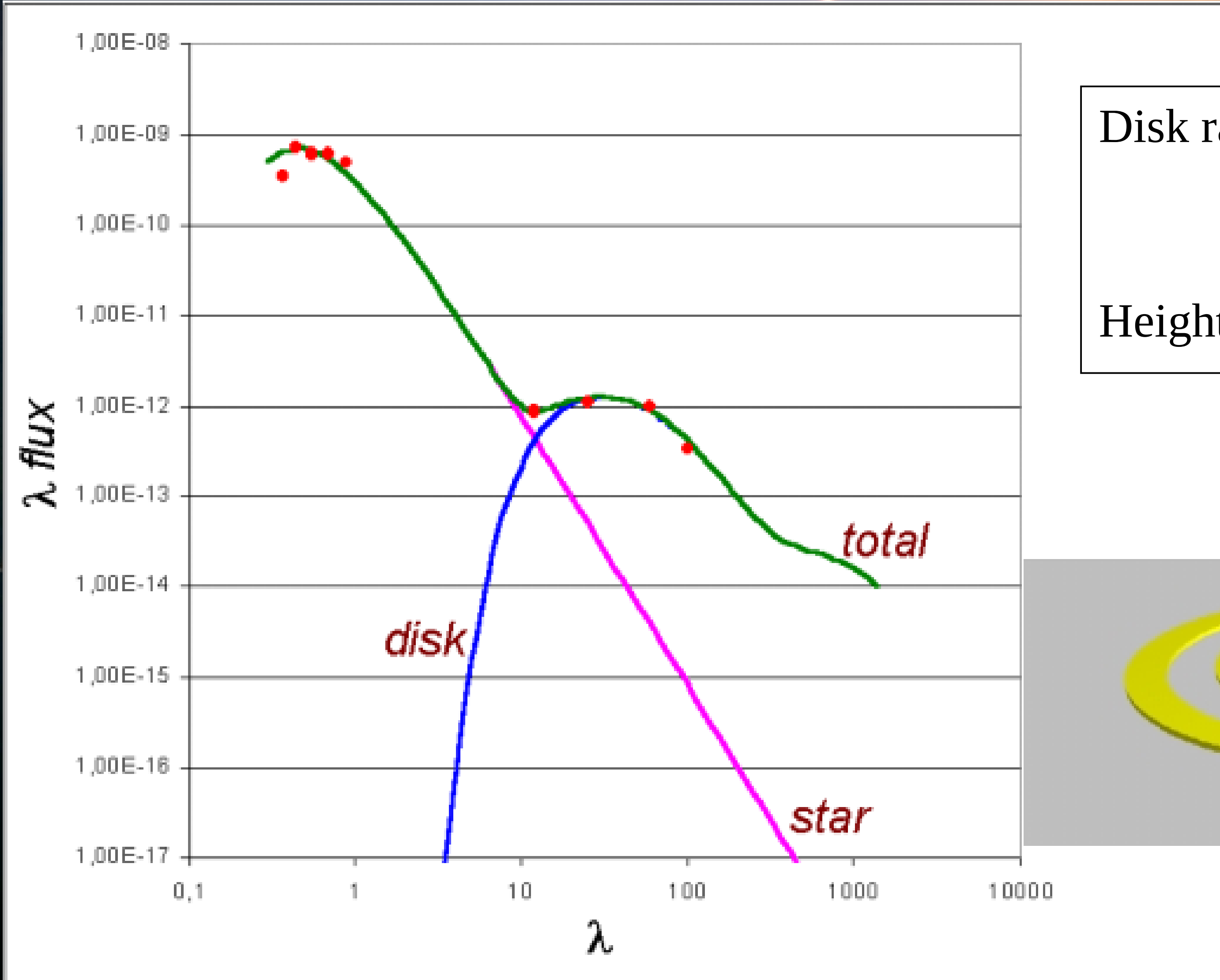


Solution set with 10^2 individuals.

Execution time: 200 s.

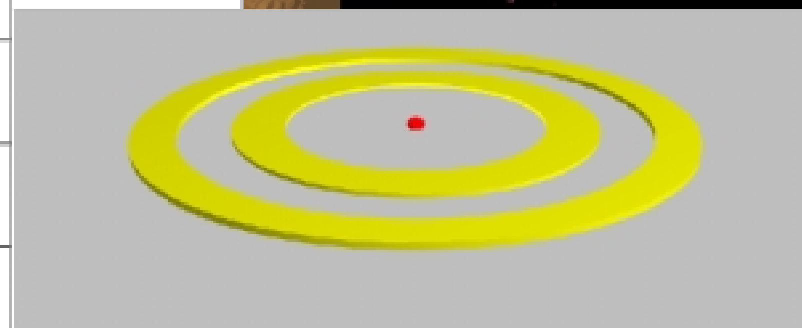
Error bar estimative

Results: β Pictoris



Disk radii = 0.99 - 7.8 AU
62 - 350 AU

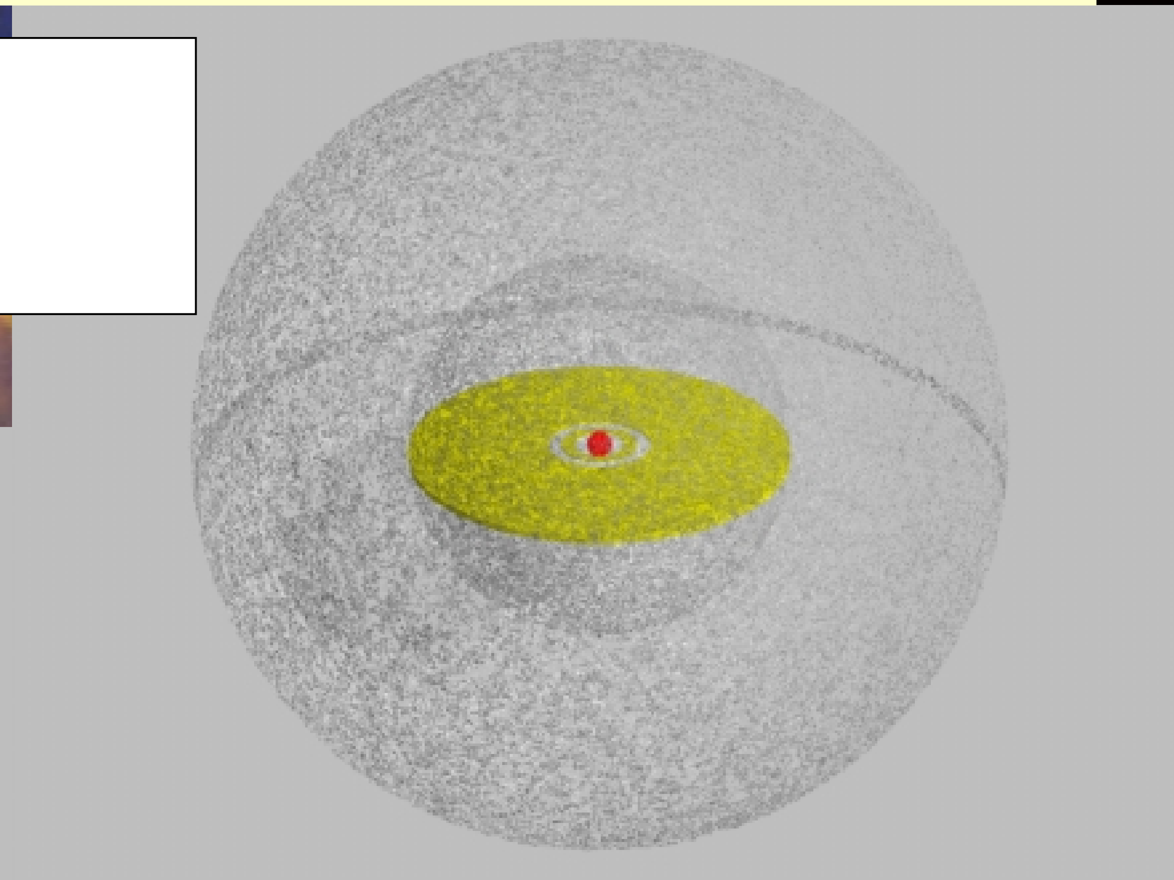
Height = 6 AU

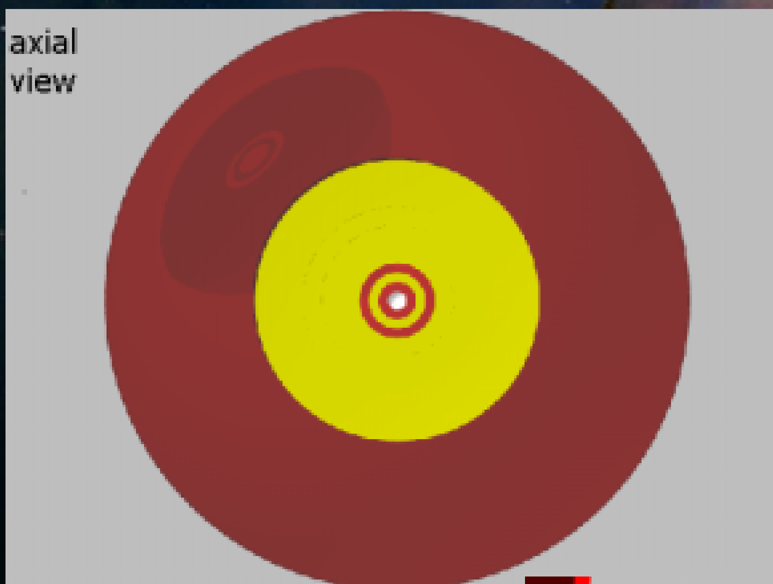


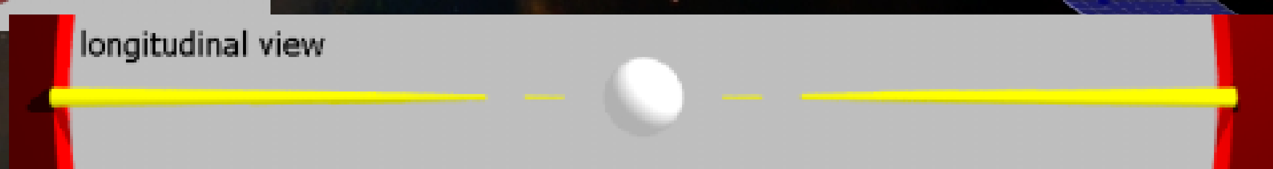
Results: TW Hydra

Disk radii = 0.014 - 0.029 AU
0.060 - 78 AU

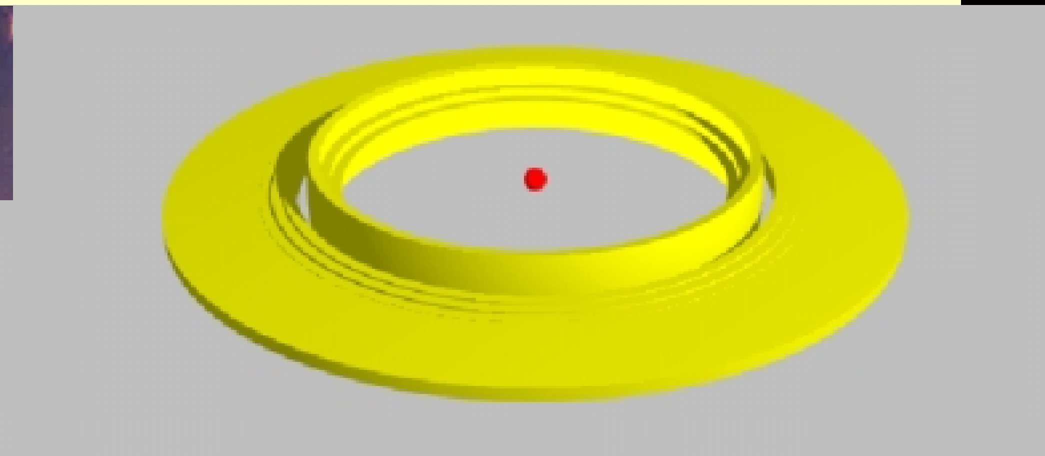
Height = 0.033 AU

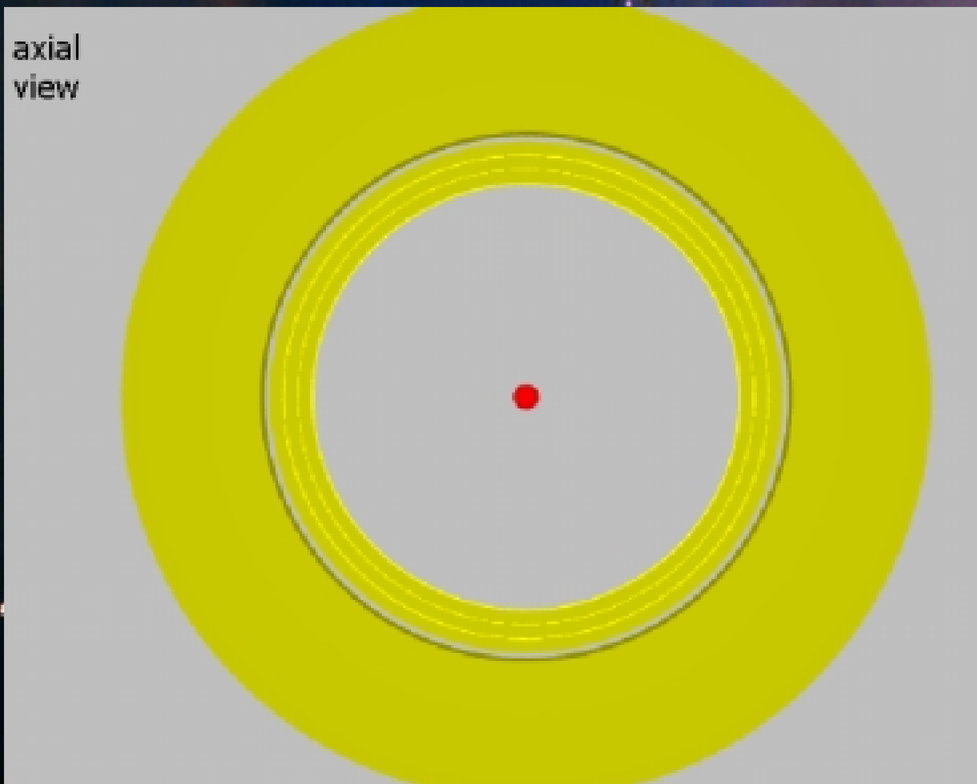






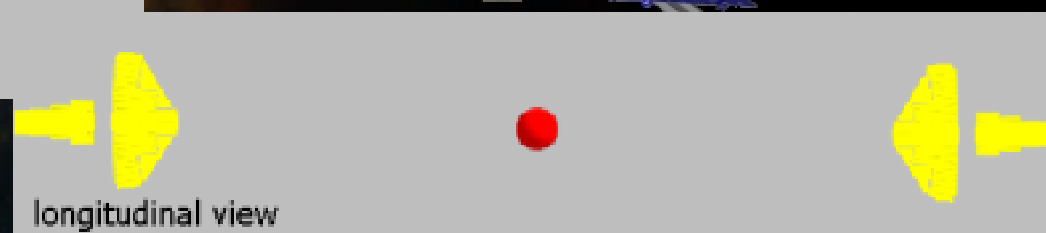
Results: HD98800



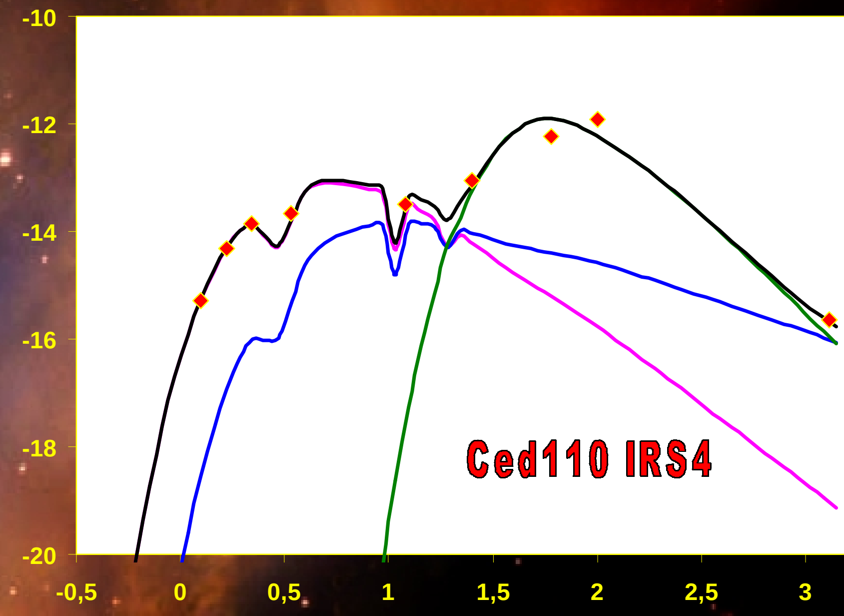


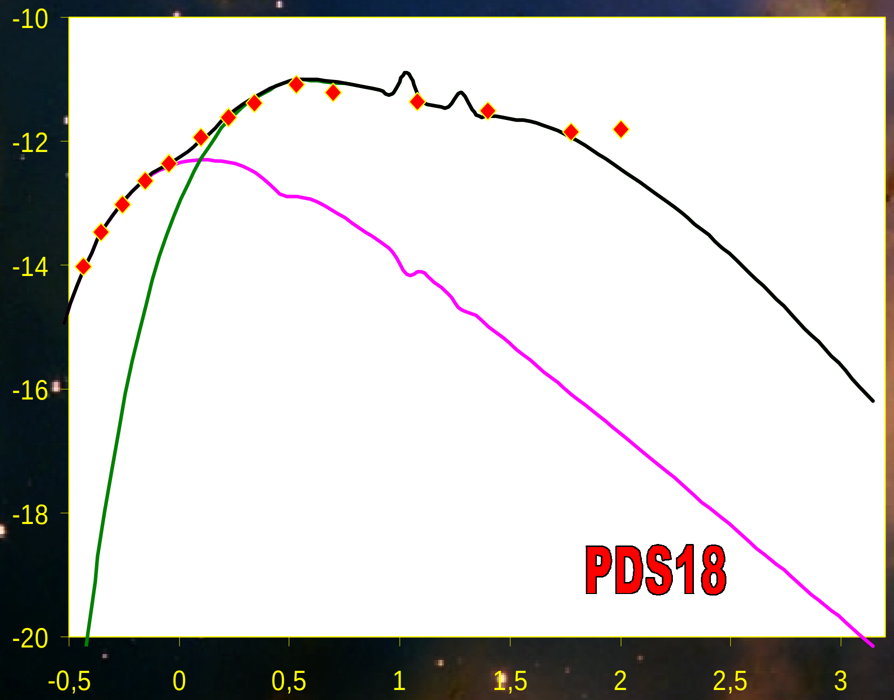
Disk radii = 0.48 - 1.02 AU
1.3 - 20 AU

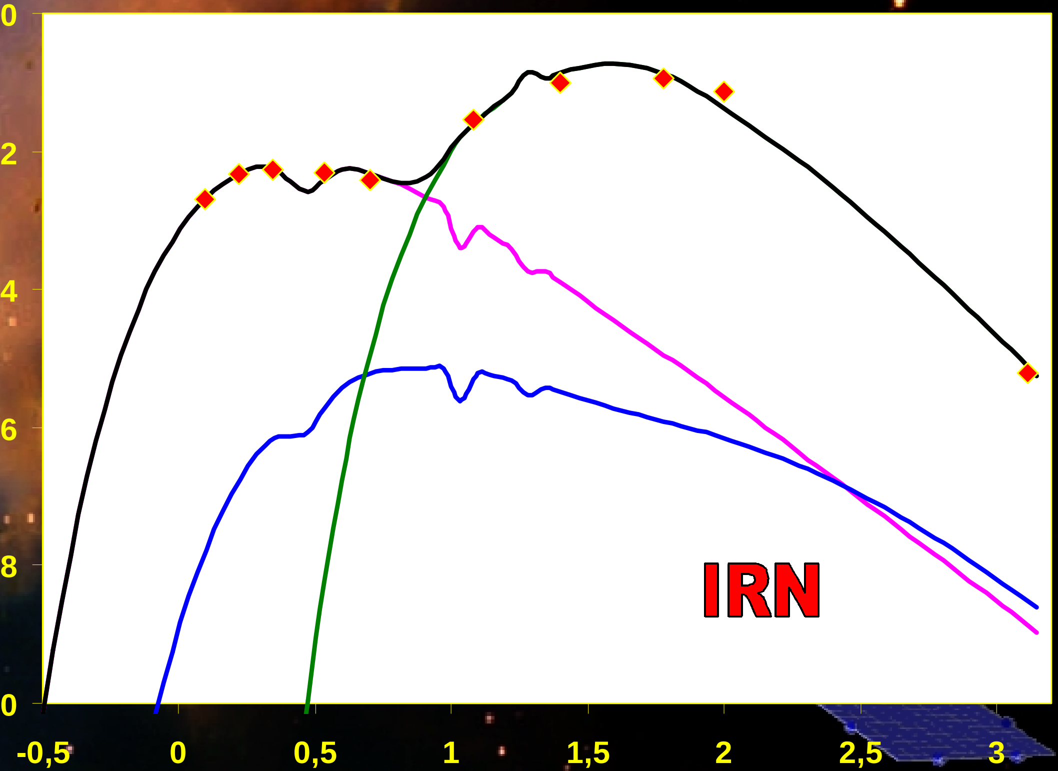
Height = 0.17 AU



Other results



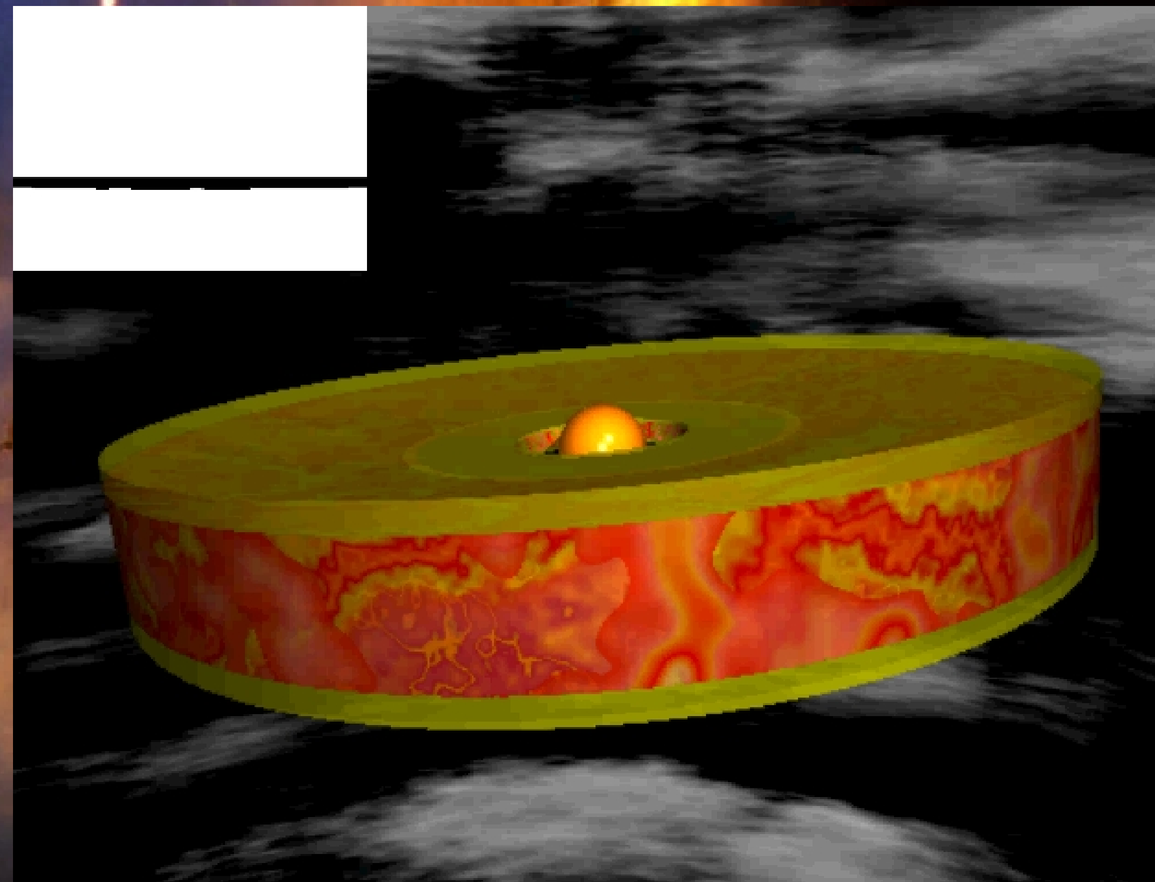




Disk transits

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

Bentley, P.J., & Corne D.W., 2002, Creative Evolutionary Systems. Morgan-Kaufmann, San Francisco.

Calvet, N. Hartmann, L., Kenyon, S.J., Whitney, B.A., 1994, ApJ, 434, 330.

Chiang, E.I., Goldreich, P., 1997, ApJ, 490, 368.

Chiang, E.I., Goldreich, P., 1999, ApJ, 519, 279.

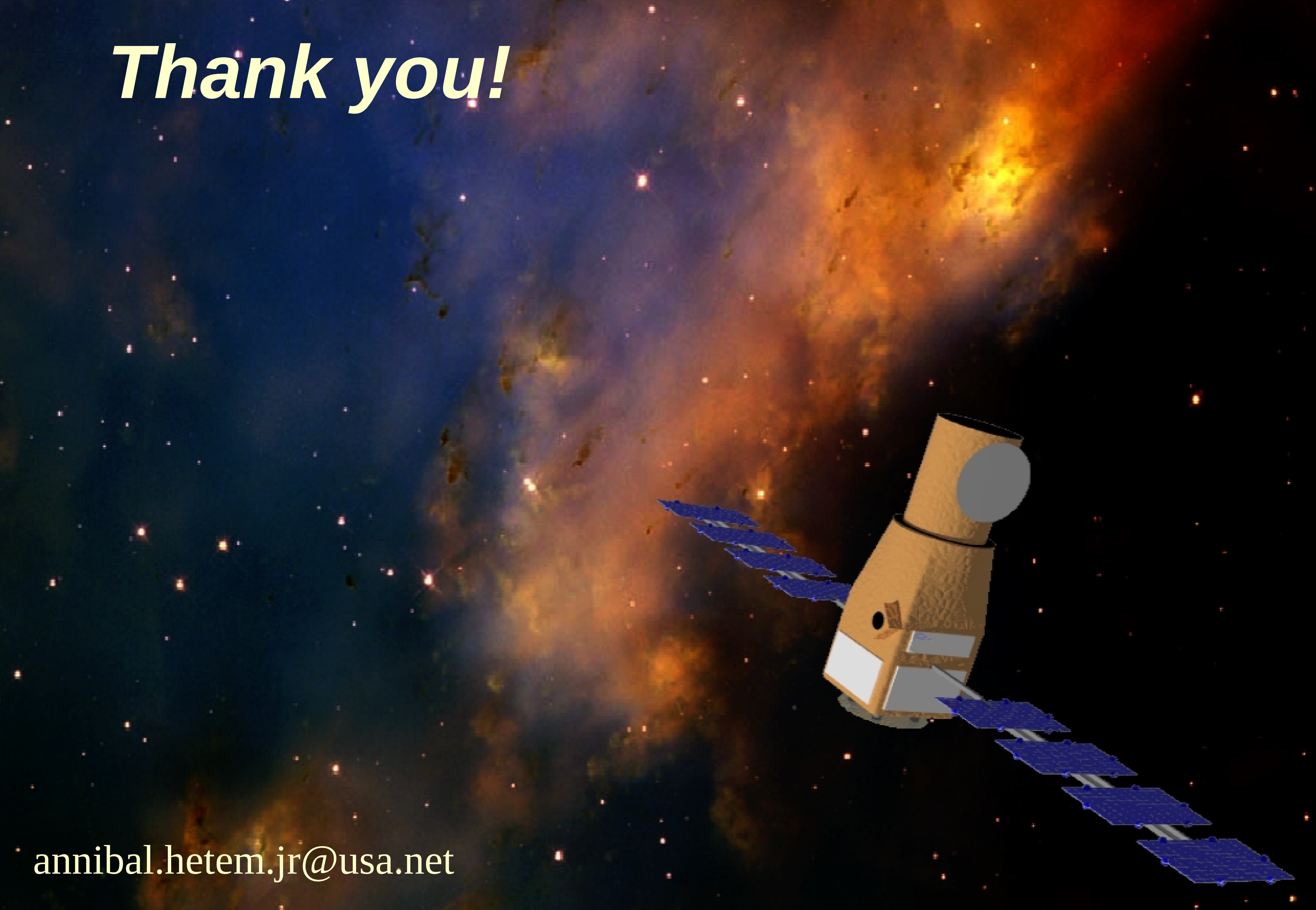
Chiang, E.I., Joung, M.K., Creech-Eakman, C. Q.I., Kesseler, J.E., Blake, G. A., van Dishoeck, E.F. 2001, ApJ 547, 1077.

D'Alessio, P., Calvet, N., Hartman, L., Lizano, S., Cantó, J., 1999, ApJ, 527, 893.

Gregorio-Hetem, J., & Hetem Jr., A., 2002, MNRAS 336, 197 Classification of a Selected Sample of Weak T Tauri stars.

Koza, J.R., 1992, Genetic Programming: On the Programming of Computers by Means of Natural Selection. MIT Press.

Natta, A., 1993, ApJ, 412, 761.


Thank you!
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