# Exact radiative transfer: code ARTY and VO

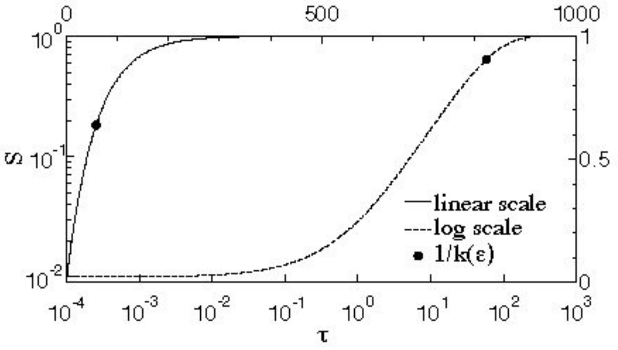
Loïc Chevallier, Bernard Rutily

# Outline

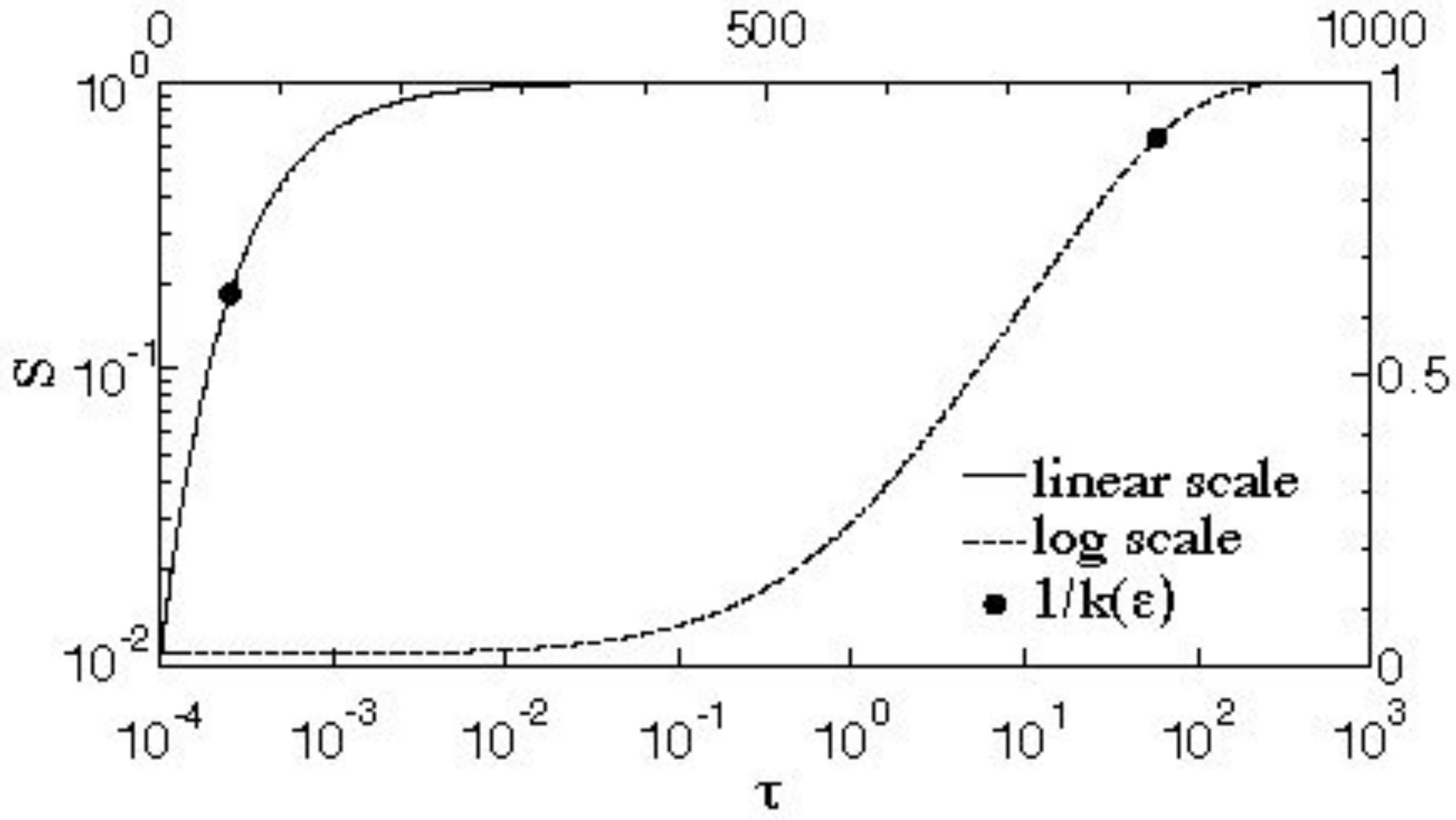
- Exact results: ARTY
- One test: stellar atmosphere (ALI)
- VO: reference solution tables
- VO: application to exoplanets

# Why study radiative transfer ?

- Difficult problem not yet solved in 1D
- Difficulties due to astrophysical problems (scattering problem = computation of populations)
- Source function: infinite derivative at surface
- Numerical computations MAY be accurate but slow
- Exact computations are RARE but FAST (known difficulties, derivative for grid, etc.)



# Source function (std problem) - infinite derivative at surface



# Transfer theory - The standard problem

$$\forall \nu,\ \mu \frac{\partial I}{\partial \tau}(\tau,\mu) = I(\tau,\mu) - S^*(\tau) - \frac{\varpi(\tau)}{2}\int_{-1}^{1} I(\tau,\mu')\mathrm{d}\mu$$

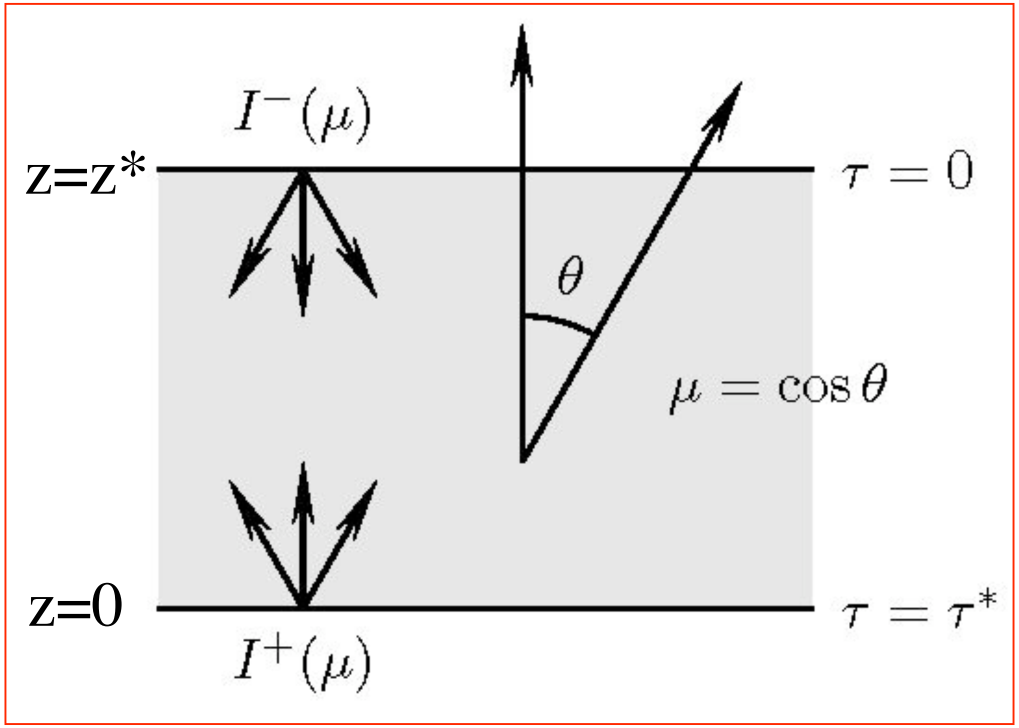
- plane-parallel,
- diffusion:
monochromatic, isotropic
- albedo ω = 1 - ε
- S*: internal source (Planck)

$$I_n(\tau) = \frac{1}{2}\int_{-1}^{1} I(\tau,\mu)\mu^n \mathrm{d}\mu$$

$$J(\tau) = I_0(\tau)$$

$$F(\tau) = 4\pi I_1(\tau)$$

$$P(\tau) = \frac{4\pi}{c} I_2(\tau)$$

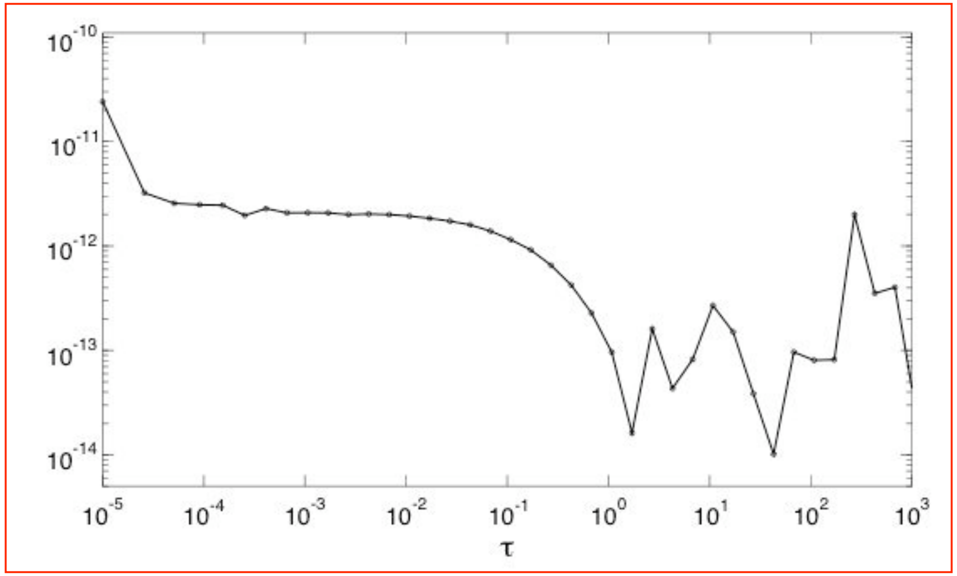


$$\tau = \int_{z}^{z*} \chi(z')\mathrm{d}z'$$

# Exact methods - ARTY

- UNIQUE
- B. Rutily (1992): exact solutions 1D (maths >16 yr, 2D, 3D possible)
- Continuum and line (Milne)
- Method:
  - Finite Laplace transform,
  - complex domain,
  - integral formulation,
  - Fredholm equations regular kernel
- Code ARTY: numerical evaluation (6 yr, 300+ routines, 50 000 lines)
- NO numerical parameters (builtin)
- Applications: Atmospheres (star, planets), Benchmark, etc.

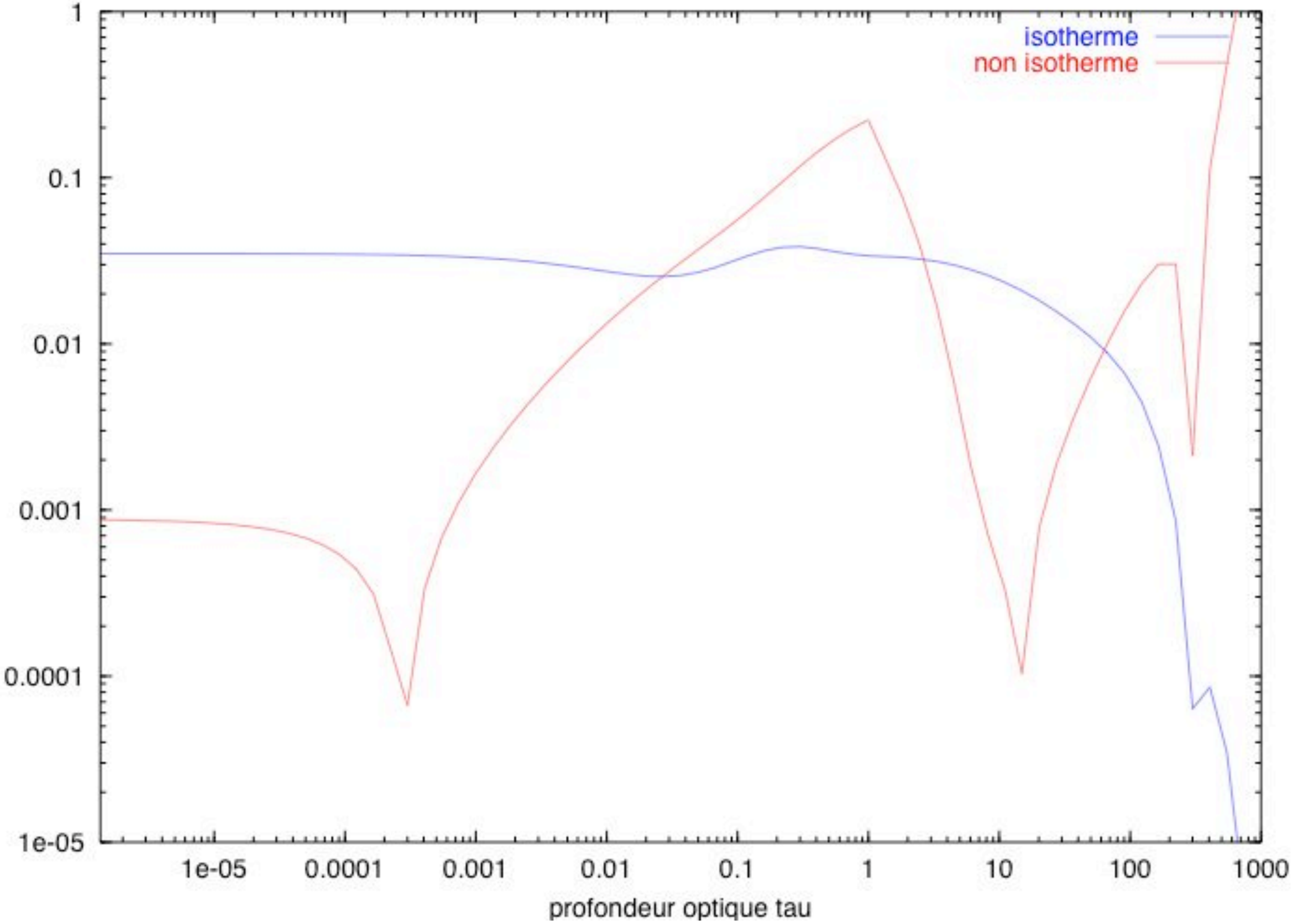
Accurate, reliable, fast



ARTY Standard relative error
Chevallier & Rutily, JQSRT (2005)

# ALI tests - summary

(stellar atmosphere code conditions)



# VO - Reference solutions - Benchmarks

- Other solutions available (60’s) not accurate,
- Solutions available (1D, one 2D case, linearity):
  - S*(tau)=1, tau^n, exp(-tau), exp(tau)
  - I+/-(mu) = mu^n, 1/mu, δ(mu)
  - w = constant (variable is correct approximation)
- Time consuming collaboration (F. Paletou, E. Audit), not supported, publication=long process
- Complex usage of ARTY
- Reference tables + easy interface to ARTY : clear problem, user can test by himself
- Why VO? Interaction between ARTY, ALI, etc.

# VO - Exoplanets (coll. J. Schneider)

- 4 publications on exact stellar and planetary atmospheres (add radiative equilibrium)
- Gray + Semi-gray cases:
  - Input: stellar flux (luminosity+distance), incident angle, Giant or telluric planet (width, surface albedo), opacity
  - Output: outward flux all directions, temperature profile, surface temperature (telluric)
- Application for COROT (V, templates, 10 000 stars in the field)
- Grid of models ARTY (Simulations portal and Exoplanets database)
- Why VO? Interaction with services (atomic data, orbit+ phase calculation tool, light curve model vs. observations fitting tool: templates)