SPECTRAL ENERGY DENSITY IN A GALAXY: PREDICTIONS OF A MODEL OF THE INTERSTELLAR RADIATION FIELD AS AN EXACT MAXWELL FIELD

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MOTIVATION

According to an alternative theory of gravity based on a scalar field:

In the presence of both a gravitational field & an electromagnetic (EM) field, there must appear some exotic "interaction energy", which should be distributed in space, and be gravitationally active (MA, Open Phys. **16**, 488, 2018).

That energy E_{inter} could thus possibly contribute to the dark matter.

To check if E_{inter} might indeed build a "dark halo", we must have the Interstellar Radiation Field in a galaxy (ISRF) as a solution of the Maxwell equations.

Motivation (continued)

The existing models for the ISRF do not consider the full EM field with its six components coupled through the Maxwell equations:

These models consider the stellar emissivity, the dust opacity, the light intensity,... They follow paths of photons or rays, focusing on the *radiative transfer.* Therefore:

- They do not produce an EM field $(\mathbf{E}, \mathbf{B})$, even less an exact solution of the Maxwell eqs (as is needed to check the "interaction energy" as a dark matter candidate).
- They do not account for the nature of the ISRF of being a field over space & time, subjected to those specific PDE's.
- It is interesting to check the predictions of a model that does produce an exact Maxwell field.

Maxwell model of the ISRF: Main assumptions

Axial symmetry: relevant approximation for many galaxies. (z axis)

Primary source of the ISRF: the stars. We want to describe the ISRF at a galactic scale, not in the stars or in their neighborhood $\Rightarrow$ *source-free* Maxwell eqs.

Theorem: any time-harmonic, axisymmetric, source-free Maxwell field is the sum of two Maxwell fields of that same kind:

- **1**) one deriving from a vector potential $\mathbf{A}$ having just $A_z \neq 0$;
- **2**) one deduced from a field of the form (**1**) by EM duality

(MA, Open Physics **18** (2020), 255–263).

Maxwell model of the ISRF: Form of the model

Consider a finite set of frequencies (ω_j) $(j = 1, ..., N_\omega)$. Using the Theorem above, the EM field is generated by potentials A_{jz}, A'_{jz}.

In the relevant "totally propagating" case, the potential A_{jz} for frequency ω_j is given explicitly in terms of a spectrum function $S_j(k)$, with $-K_j \leq k \leq K_j$ $\quad (K_j := \frac{\omega_j}{c})$: $A_{jz} = \psi_{\omega_j\, S_j}$, with

$$\psi_{\omega_j\ S_j}(t, \rho, z) := e^{-\,\mathrm{i}\,\omega_j t} \int_{-K_j}^{K_j} J_0\left(\rho\sqrt{K_j^2 - k^2}\right)\ e^{\mathrm{i}\,k\,z}\, S_j(k)\,\mathrm{d}\,k. \tag{1}$$

(J_0: Bessel function of order 0.)

MAXWELL MODEL OF THE ISRF: MODEL OF A GALAXY

Axisymmetric galaxy $\leftrightarrow$ Finite set $\{\mathrm{x}_i\}$ $(i = 1, ..., i_{\mathrm{max}})$ of point-like "stars", the azimuthal distribution of which is uniform.

Obtained by pseudo-random generation of their cylindrical coordinates ρ, ϕ, z with specific probability laws, ensuring that

- the distribution of ρ and z is approximately that valid for the star distribution in the galaxy considered;
- the set $\{\mathrm{x}_i\}$ is approximately invariant under azimuthal rotations of any angle ϕ.

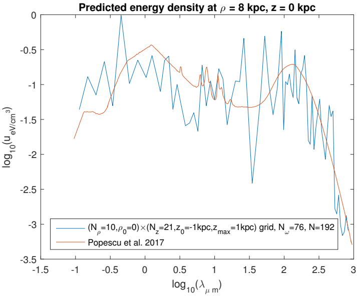
Maxwell model of the ISRF: Determining the potentials

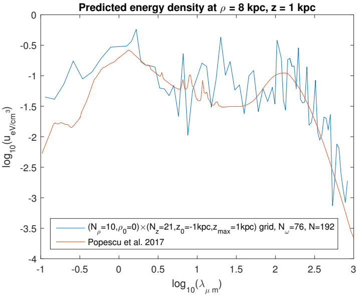
For each frequency ω_j and for each "star" at point x_i, we consider a spherical scalar potential emanating from the "star" at x_i:
$\phi_{\mathrm{x}_i\,\omega_j}(t,\mathrm{x}) = \frac{e^{\mathrm{i}(K_j r_i - \omega_j t)}}{K_j r_i}$, with $K_j := \frac{\omega_j}{c}, \quad r_i := |\mathrm{x} - \mathrm{x}_i|$.

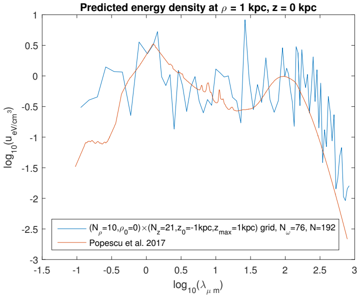
For each j, we fit the sum on stars by the unknown potential $A_{jz} = \psi_{\omega_j\,S_j}$: $\quad \sum_{i=1}^{i_{\mathrm{max}}} \phi_{\mathrm{x}_i\,\omega_j} \cong \psi_{\omega_j\ S_j} \quad \text{on } G \qquad (j = 1, ..., N_\omega)$.
($\cong$ means least-squares, evaluated on some spatial grid G.)

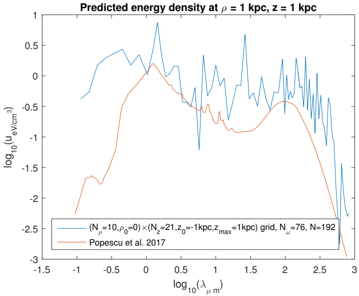
This determines the spectrum function $S_j(k)$ $(j = 1, ..., N_\omega)$.

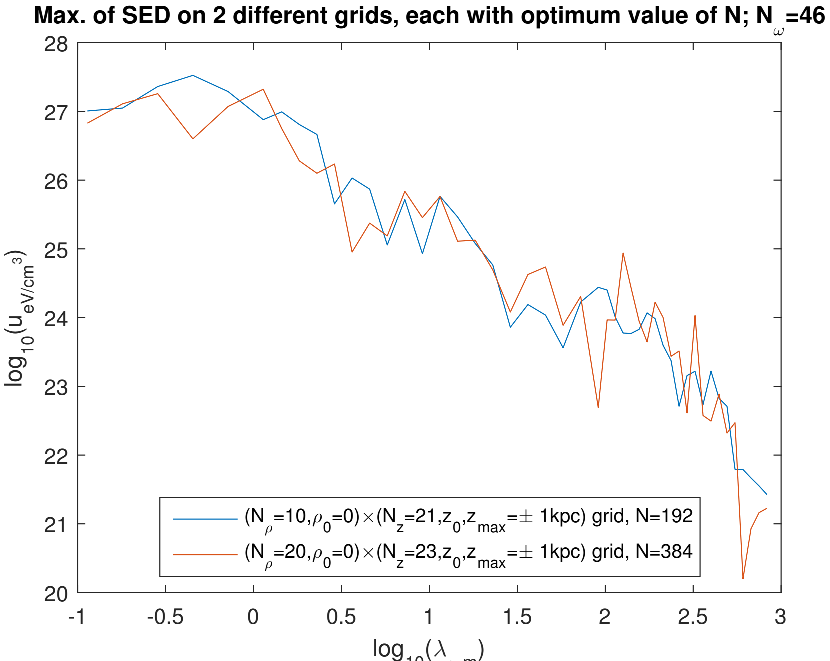
Application to spatial variation of spectral energy density (SED) in Galaxy: We impose that the SED measured at our local position $\mathrm{x}_{\mathrm{loc}}$ in the Galaxy coincides with the calculated values $u_j(\mathrm{x}_{\mathrm{loc}})$.

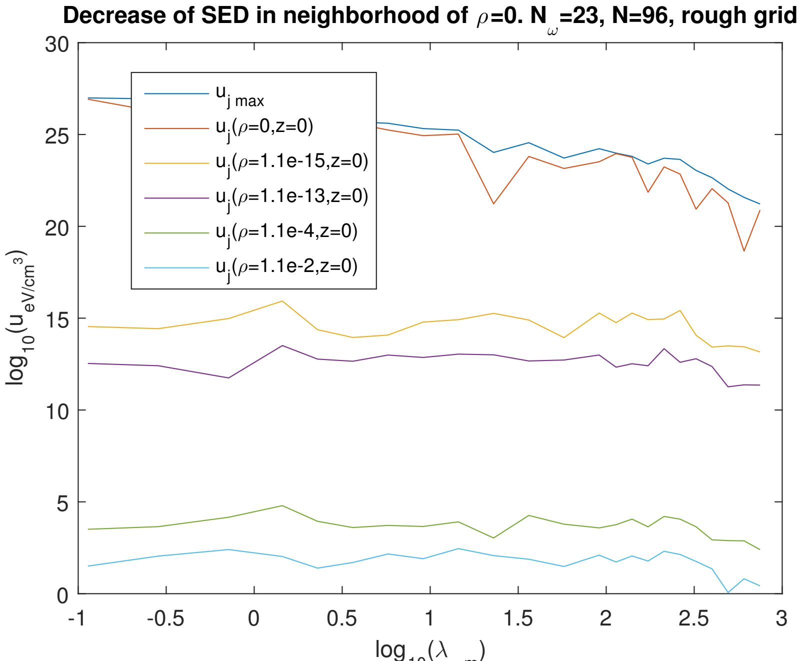

Predicted energy density at ρ = 8 kpc, z = 0 kpc
log10(u_eV/cm^3)
log10(λ_μm)
(N_ρ=10,ρ_0=0)×(N_z=21,z_0=-1kpc,z_max=1kpc) grid, N_ω=76, N=192
Popescu et al. 2017


Predicted energy density at ρ = 8 kpc, z = 1 kpc
log10(u_eV/cm^3)
log10(λ_μm)
(N_ρ=10,ρ_0=0)×(N_z=21,z_0=-1kpc,z_max=1kpc) grid, N_ω=76, N=192
Popescu et al. 2017


Predicted energy density at ρ = 1 kpc, z = 0 kpc
log10(u_eV/cm^3)
log10(λ_μm)
(N_ρ=10,ρ_0=0)×(N_z=21,z_0=-1kpc,z_max=1kpc) grid, N_ω=76, N=192
Popescu et al. 2017


Predicted energy density at ρ = 1 kpc, z = 1 kpc
log10(u_eV/cm^3)
log10(λ_μm)
(N_ρ=10,ρ_0=0)×(N_z=21,z_0=-1kpc,z_max=1kpc) grid, N_ω=76, N=192
Popescu et al. 2017


Max. of SED on 2 different grids, each with optimum value of N; N_ω=46
$\log_{10}(u_{eV/cm^3})$
$\log_{10}(\lambda_{\mu m})$
$(N_\rho=10,\rho_0=0)\times(N_z=21,z_0,z_{max}=\pm$ 1kpc) grid, N=192
$(N_\rho=20,\rho_0=0)\times(N_z=23,z_0,z_{max}=\pm$ 1kpc) grid, N=384
28
27
26
25
24
23
22
21
20
-1
-0.5
0
0.5
1
1.5
2
2.5
3


Decrease of SED in neighborhood of ρ=0. N_ω=23, N=96, rough grid
u_j max
u_j(ρ=0,z=0)
u_j(ρ=1.1e-15,z=0)
u_j(ρ=1.1e-13,z=0)
u_j(ρ=1.1e-4,z=0)
u_j(ρ=1.1e-2,z=0)
log_10(u_eV/cm^3)
30
25
20
15
10
5
0
-1
-0.5
0
0.5
1
1.5
2
2.5
3

CONCLUSION

Built a model providing the interstellar radiation field in a galaxy as an exact Maxwell field. Axial symmetry is assumed.

Adjustment & comparison of predictions with existing models:

We can & do impose that at our local position in the Galaxy, the spectral energy distribution (SED) be equal to the measured one.

The predicted spatial variation of the SED is quite close to that predicted by a radiation transfer model, except that it oscillates with λ, and:

Extremely high values are predicted right on the Galaxy's axis. However, the SED decreases very quickly when departing from it.

The SED decreases more slowly with increasing altitude z (not shown).

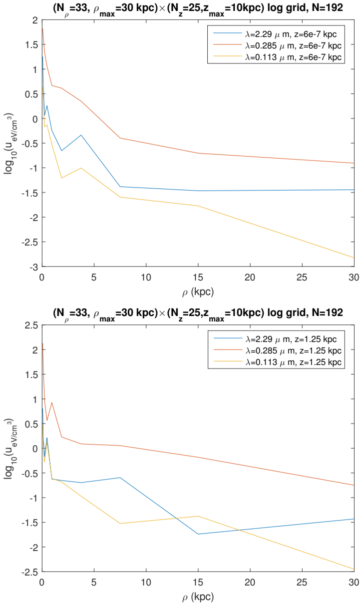


FIGURE: Radial profiles of radiation fields.

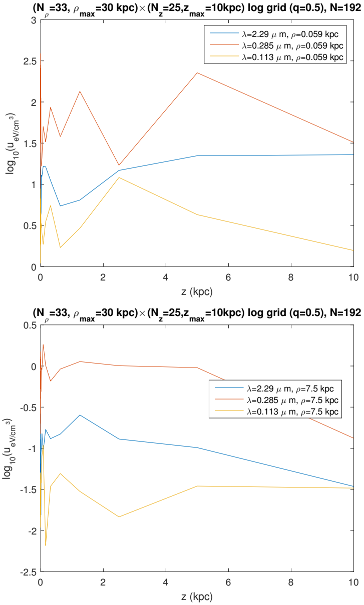
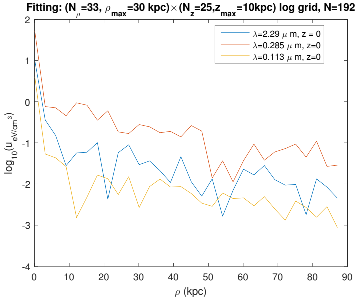


FIGURE: Vertical profiles of radiation fields.



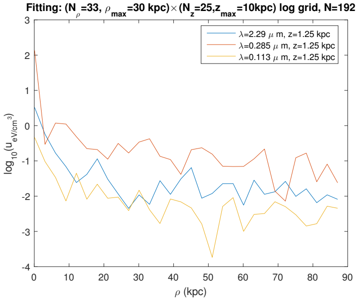


FIGURE: Radial profiles of radiation fields. Not the fitting grid

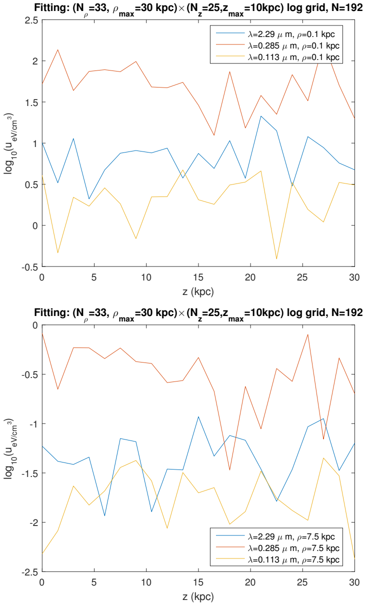


FIGURE: Vertical profiles of radiation fields. Not the fitting grid