Interaction Energy between a Charged Medium and its Electromagnetic Field as a Dark Matter Candidate

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INITIAL MOTIVATION

Was independent of dark matter. Was to develop a consistent electrodynamics in an alternative theory of gravity: "Scalar ether theory" or SET.

SET is a preferred-frame theory based on a scalar field only (MA, Braz. J. Phys. **36** (2006), 177–189). It reduces to special relativity (SR) when the gravitational field vanishes.

In GR, the eqs. of electrodynamics rewrite those of SR by using the "comma goes to semicolon" rule: $_{,\nu} \rightarrow {}_{;\nu}$

Not possible in SET, for the Dynamical Equation isn't generally $T^{\lambda\nu}_{;\nu} = 0$ (which rewrites $T^{\lambda\nu}_{,\nu} = 0$ valid in SR).

NECESSITY OF THE INTERACTION TENSOR IN SET (1)

In SET, first Maxwell group unchanged. Second group was got by applying the Dynamical Eqn of SET to a charged medium in the presence of Lorentz force, assuming that (as is the case in GR):

(A) Total energy tensor $\boldsymbol{T} = \boldsymbol{T}_{\text{charged medium}} + \boldsymbol{T}_{\text{field}}$.

The additivity (A) leads to a form of Maxwell's 2nd group in SET. (MA, Open Physics **14** (2016), 395–409)

NECESSITY OF THE INTERACTION TENSOR IN SET (2)

But that form of Maxwell's 2nd group in SET predicts charge production/destruction at untenable rates ⇒ *discarded.*
(MA, Open Physics **15** (2017), 877–890)

The additivity assumption (A) is contingent and may be abandoned. Means introducing "interaction" energy tensor $\boldsymbol{T}_{\text{inter}}$ such that

$$\boldsymbol{T}_{(\text{total})} = \boldsymbol{T}_{\text{charged medium}} + \boldsymbol{T}_{\text{field}} \underline{+\boldsymbol{T}_{\text{inter}}}\,. \qquad (1)$$

One then has to constrain the form of $\boldsymbol{T}_{\text{inter}}$ and derive eqs for it.

FORM OF THE INTERACTION TENSOR (1)

In SR, the additivity assumption (A) holds, thus $\boldsymbol{T}_{\text{inter}} = 0$.

In SET we may impose that $\boldsymbol{T}_{\text{inter}}$ should be Lorentz-invariant in the situation of SR, i.e. when the metric $\boldsymbol{\gamma}$ is Minkowski's metric $\boldsymbol{\gamma}^0$ ($\gamma^0_{\mu\nu} = \eta_{\mu\nu}$ in Cartesian coordinates).

This is true if *and only if* we have:

$$T_{\text{inter}\ \mu\nu} = p\,\gamma^0_{\mu\nu} \qquad \text{(situation of SR)}, \tag{2}$$

with some scalar field p. (MA, J. Geom. Sym. Phys. **50** (2018), 1–10)

Form of the interaction tensor (2)

This is equivalent to:

$$T_{\text{inter}\ \ \nu}^{\mu} = p\, \delta_{\nu}^{\mu} \qquad \text{(situation of SR).} \tag{3}$$

The definition

$$T_{\text{inter}\ \ \nu}^{\mu} := p\, \delta_{\nu}^{\mu}, \qquad \text{or} \quad (T_{\text{inter}})_{\mu\nu} := p\, \gamma_{\mu\nu}, \tag{4}$$

thus got in a Minkowski spacetime, is in fact generally-covariant. Hence, we adopt (4) for the general case.

SET ELECTRODYNAMICS WITH $\boldsymbol{T}_{\text{inter}}$ (1)

With the additivity assumption (A) of energy tensors, i.e., $\boldsymbol{T}_{\text{inter}} = 0$, the system of eqs of electrodynamics of SET is closed, but violates charge conservation.

With the interaction energy tensor (4) we have just one unknown more: the scalar field p. So we need just one scalar eqn more.

We may add *charge conservation* as the new scalar eqn. Then the system of eqs of electrodynamics of SET is again closed, and satisfies charge conservation.

SET ELECTRODYNAMICS WITH T_{inter} (2)

Based on that closed system, eqs. were derived that determine the field p in a given general EM field $(\mathbf{E}, \mathbf{B})$ and in a given weak gravitational field with Newtonian potential U (MA, Open Physics **16** (2018), 488–498):

p obeys an advection equation with given source S and given characteristic curves.
Thus p obtains by integrating S along those curves.

The corresponding interaction energy $E_{\text{inter}} := T^{00}_{\text{inter}} = p\gamma^{00}$ can be counted as "dark matter", for

- it is not localized inside (usual) matter;
- it is gravitationally active;
- it is "exotic", i.e., it's not usual matter.

Maxwell model of the ISRF: Main assumptions

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

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

Primary source of the ISRF: the stars. We want to describe ISRF at 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:

- **1**) one deriving from vector potential 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

$$\psi_{\omega_j\ S_j}(t, \rho, z) = e^{-\mathrm{i}\,\omega_j t} \int_{-K_j}^{K_j} J_0\left(\rho\sqrt{K_j^2 - k^2}\right)\ e^{\mathrm{i}\,k\,z}\, S_j(k)\ \mathrm{d}\,k. \tag{5}$$

(J_0: Bessel function of order 0.)

Maxwell model of the ISRF: Model of a galaxy

Axisymmetric galaxy $\leftrightarrow$ Finite set $\{\mathrm{x}_i\}$ 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.

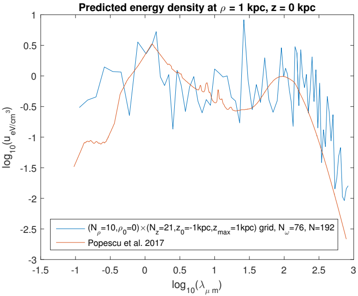
MAXWELL MODEL OF THE ISRF: DETERMINING THE POTENTIALS

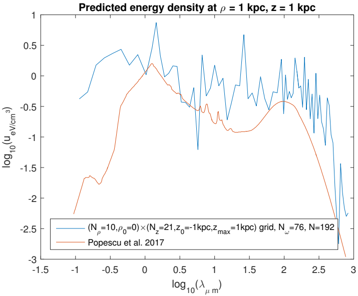
We consider a sum of spherical potentials $\varphi_{x_i \omega_j}$ emanating from the stars at points x_i.

We fit this sum by the unknown potentials $A_{jz} = \psi_{\omega_j\, S_j}$.

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

Application to spatial variation of spectral energy density in Galaxy:


Predicted energy density at ρ = 1 kpc, z = 0 kpc
$\log_{10}(u_{eV/cm^3})$
$\log_{10}(\lambda_{\mu m})$
(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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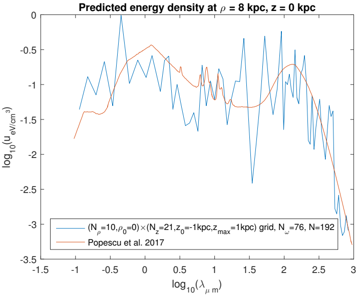
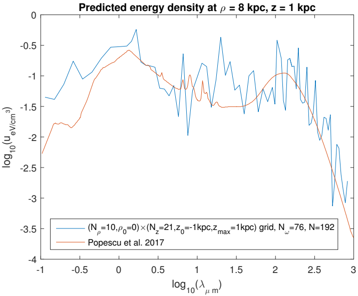

Predicted energy density at ρ = 8 kpc, z = 0 kpc
log10(u eV/cm3)
log10(λ μm)
(Nρ=10,ρ0=0)×(Nz=21,z0=-1kpc,zmax=1kpc) grid, Nω=76, N=192
Popescu et al. 2017


Predicted energy density at ρ = 8 kpc, z = 1 kpc
log10(u eV/cm3)
log10(λ μm)
(Nρ=10,ρ0=0)×(Nz=21,z0=-1kpc,zmax=1kpc) grid, Nω=76, N=192
Popescu et al. 2017

CONCLUSION

In that "ether theory" of gravity, a consistent electrodynamics in a gravitational field needs introducing an additional energy tensor: $\boldsymbol{T}_{\text{inter}}$, with $T^{\mu}_{\text{inter}\ \nu} := p\,\delta^{\mu}_{\nu}$.

This could contribute to dark matter. Not ad hoc. Can be calculated from the data of the EM field and the gravitational field.

To learn more, built a Maxwell model of the radiation field in a galaxy.

Currently checking its predictions for the variation of the spectral energy distribution in the Galaxy.

THANK YOU !