Dark light in the Universe

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Our own dark matter


Dark-Disk Universe

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We point out that current constraints on dark matter imply only that the majority of dark matter is cold and collisionless. A subdominant fraction of dark matter could have much stronger interactions. In particular, it could interact in a manner that dissipates energy, thereby cooling into a rotationally supported disk, much as baryons do. We call this proposed new dark matter component double-disk dark matter (DDDM).

Why not a clef? DM
Lisa Randall and dinosaurs

864 pp.
Öpik-Oort comet home

Heavy dark disk, 30-million-year periods

Other problems, but they keep fighting
Comet bombardment

Dinos gone

Recommend the book

(Dinosaur lore, period search, physicists vs astronomers, etc.)
Theory for 1/5 of matter:
The Standard Model
Dark Sector? After 20 years?!

Discworld,
Terry Pratchett,
>40 cosmology books

Terry Pratchett:
Light thinks it travels faster than anything but it is wrong. No matter how fast light travels, it finds the darkness has always got there first, and is waiting for it.

Dark light?
Story started at AIP 2014

Elmo Tempel & DAO
BAO signature
If all or a fraction of the dark matter (DM) were coupled to a bath of dark radiation (DR) in the early Universe, we expect the combined DM-DR system to give rise to acoustic oscillations of the dark matter until it decouples from the DR. We model the interacting component as dark atoms coupled to a bath of dark photons. Interestingly, we find that at most $\sim 5\%$ of all DM can be very strongly interacting with DR.

\[
\begin{align*}
 r_{\text{DAO}} &< 3.7h^{-1}\text{Mpc} \quad (f_{\text{int}} = 100\%), \\
 r_{\text{DAO}} &< 5.3h^{-1}\text{Mpc} \quad (f_{\text{int}} = 50\%), \\
 r_{\text{DAO}} &< 15.2h^{-1}\text{Mpc} \quad (f_{\text{int}} = 10\%),
\end{align*}
\]
Border correction?

\[ \xi(s) = 0 \text{ on cube : Landy-Szalay} \]

\[ \xi(s) = \xi_{\Lambda CDM} \text{ on cube : Landy-Szalay} \]

\[ \xi(r) = \frac{DD}{RR} - \frac{2DR}{RR} + 1 = \frac{(D - R)(D - R)}{RR} \]

Unstable signal
Enn: A year later, again:

Minus-estimator

\[
\hat{\xi}_{\text{minus}}(r) = \frac{V}{V_{\text{sh}}(r)} \frac{1}{NN_{\text{int}}} \sum_{i=1}^{N_{\text{int}}} n_i(r)
\]

Volume-limited (constant-density) samples

Real space
40 Mpc to the border
SDSS DR12, trimmed groups — real space

\[ H_0 = 67.8 \text{ km/sec} \cdot \text{Mpc} \]
groups \( n \geq 10 \)
Mocks

International Virtual Observatory Alliance

www.ivoa.net
Gert: completeness problems?

DR12 completeness map
Completeness map correlation
DR10, n>=10 vollim sample
BUT?
Fig. 12. — The scale-dependence of the bias, $b(r) \equiv [\xi_{\text{gal}}(r)/\xi_{\text{dm}}(r)]^{1/2}$, predicted from our best-fit halo model and N-body simulations. The feature at a few $\text{Mpc}$ has been seen in other analyses and occurs at the transition between the 1- and 2-halo contributions (see text). Note that the bias asymptotes to a constant, $b \approx 2$, on large scales.
The clustering of galaxies in the SDSS-III Baryon Oscillation Spectroscopic Survey: the low redshift sample


Figure 10. The scale dependence of the galaxy bias, $b = \sqrt{\xi_{\text{gal}}/\xi_{\text{DM}}}$, for the LOWZ sample. The large-scale bias asymptotes to $\sim 2.0$. The strong increase toward scales below $1 h^{-1}$Mpc appears because of the strong clustering of galaxies within halos, while the bump at the few $h^{-1}$Mpc scale is due to one-halo/two-halo transition. The dashed red line shows the galaxy bias of the CMASS sample of White et al. (2011), while the dot-dashed blue line shows the LOWZ galaxy bias relative to the linear theory $\xi_{\text{DM}}$ computed with CAMB.
CMB power
Dark sector (DS)
Not much of it charged (CDM success)
Does not mean that DS is simple
Consider strange cluster collisions
(dark plasma?)
Dark neutron stars?
If you stare into the abyss, the abyss stares back at you (F.W. Nietzsche)
The right block bootstrap

\[ DD(r) = \frac{1}{N^2} \sum_i \sum_j 1(r \leq |x_i - x_j| < r + dr) = \frac{1}{N} \sum_i D_i(r) \]

- Bootstrap \( DD(r) \) - resample pair distances
- \( DR(r) \) requires bootstrapping starting points
- Solution - resample points with all their distance distributions (a marked point process)
Recipe:

1. Find $DD_i(r), DR_i(r), \forall x_i$

2. $\forall x_i$, find its block: $|x_i - x_j| \geq r_0$ ($\xi(r_0) = 1$)
   $n_i$ is # of points in the block

3. Average: $BDD_i(r) = \langle DD_j(r) \rangle, j \in$ block

4. Bootstrap $BDD_i(r), BDR_i(r)$, so as

$$\sum n_{i,\text{used}} \leq N$$
A VALID AND FAST SPATIAL BOOTSTRAP FOR CORRELATION FUNCTIONS
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RELIABILITY OF THE DETECTION OF THE BARYON ACOUSTIC PEAK
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Poisson-Voronoi process, block bootstrap