The Diffuse radio emission and Dark Matter

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(Torino)
The ARCADE excess

As we heard in previous talks, quite difficult to get rid of it!

Possible explanations:

I) Observations: issues on calibration of zero level for the low-frequency maps? disfavoured → Al Kogut, Dale Fixsen’s talks

II) Galactic foreground: rather peculiar underhanded aspects? disfavoured → Nicolao Fornengo’s talk

III) Extragalactic sources

faint (<μJy), diffuse (Mpc scale) and/or exceptionally numerous population (or truly diffuse/high-z cosmological sources)
Proposed interpretations

“New” radio source population taking over in the number counts at $\mu$Jy level
(Singal+ 2010, Ysard&Lagache 2012, ...)

Galaxies would violate FIR-radio relation.

Some “exotic” solutions:
- late decay of metastable particle (Cline&Vincent 2013)
- ultracompact minihalos (Yang+ 2013)
- quark nugget dark matter (Lawson&Zhitnitsky 2013)
- cluster mergers (Fang&Linden 2015)
- fast radio transient (Kehayias+ 2015)
Dark matter interpretation

Synchrotron emission induced by WIMP annihilations is a viable solution

\[ \rightarrow \text{see also Tim Linden’s talk} \]

Requires significant substructure contributions and large-scale magnetic fields.

Constraints from other probes (such as the local \( e^+e^- \) flux that would be injected by DM)
Synchrotron radiation from DM

It is an indirect method to probe particle DM: source + propagation + radiation.

Energy corresponding to the peak of synchrotron power (in the monochromatic approximation):

\[ E \simeq 15 \sqrt{\nu_{\text{GHz}} / B_{\mu G}} \text{ GeV} \]

It is an indirect \(^3\) method to probe particle DM: source + propagation + radiation.

Annihilations (or decays) of WIMP DM particles in astrophysical structures inject fluxes of electrons and positrons (at GeV-TeV energy).

If emitted in a medium with magnetic field → radio continuum diffuse emission associated to synchrotron radiation.
**DM source of e⁻/e⁺**

**Morphology**
- Halo profile and concentration
- Substructure distribution
- Halo/subhalo mass function at small scales

**e.g. the so called “clumping factor”:**

\[
\Delta^2(z) = \frac{\left\langle \rho_{\text{DM}}^2 \right\rangle}{\bar{\rho}_{\text{DM}}^2} = \int_{M_{\text{min}}}^{M_{\text{max}}} dM \frac{dn}{dM}(M, z) \left[ 1 + b_{\text{sub}}(M, z) \right] \int d^3x \frac{\rho_h^2(x | M, z)}{\bar{\rho}_{\text{DM}}^2}
\]

**Spectrum of injection**

- Energy in units of DM mass

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Transport of $\text{e}^-/\text{e}^+$

- Confinement length $\ll$ halo size → morphology following DM
- Confinement length $\sim$ halo size → morphology reshaped
- Confinement length $\gg$ halo size → significant fraction of power carried away

$\bullet$ = WIMP annihilation

Graph showing:
- X-axis: $\theta$ [arcmin]
- Y-axis: $S$ [a.u.]

For Fornax NSFW

Graph showing:
- X-axis: $v$ [GHz]
- Y-axis: $I/I_{\text{BACK}}$

Legend:
- $\text{e}^\pm$
- $\gamma$

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Synchrotron emission

DM main halo and subhalos

non-thermal population of galactic electrons

Image credit: NASA, ESA, and T. Brown and J. Tumlinson (STScI)

Dark structure

Magnetic field

It affects both SED and morphology of the synchrotron emission

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Promising cases

“Traditional” structure
with non-quiescent baryonic distribution
but large scale magnetic field
Awkward cases

“Traditional” structure with non-quiescent baryonic distribution and with magnetic field following baryons

Dark structure with very feeble magnetic field (e.g. only cosmological one)
How to test the DM source

Digging into the unresolved radio background:
- 1-point statistics: $P(D)$
- 2-point statistics: auto and cross correlation

Deep observations of individual sources:
- Dwarf spheroidal galaxies
- Clusters of galaxies
- Big (and edge-on) galaxies
- Filaments?
Observations by (Vernstrom+ 2015) suggest a contribution due to diffuse emission above the point-like contribution (at the level of about 40% of the unresolved background).
Auto and cross correlations

Auto Correlation

CROSS CORRELATION

with tracers of the DM distribution

Synchrotron signal from particle DM is concentrated at low $z$

→ see Gil Holder’s talk

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EMU is a deep (~10 μJy/beam rms) radio continuum survey of the entire Southern Sky (below +30 deg) at 1.4 GHz, with a 10 arcsec resolution and sensitive to scales up to ~15 arcmin.

It is expected to detect about 70 million galaxies.
Correlations with EMU

First ASKAP early science data have been recently released
EMU early science cosmology should start this summer
Full-project: 1.5 years of telescope time
**Dwarf spheroidal galaxies**

Hot and rapidly evolving field:

**SDSS** has **more than doubled** the known Local Group dSphs (25 new discoveries)

A dozen of new **ultrafaint** satellites, mostly coming from **DES** observations, were discovered in the past couple of years

**Many more to come** from near-future surveys.

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**Low level of star formation**

*Hernandez et al., 2000*

**Carina dSph**

Inferred from colour-magnitude diagram

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**Metal-poor stellar systems**

*McConnachie, 2013*

→ **The non-thermal emission** related to star-formation is expected to be **extremely low**.

**Why to perform radio observations?**
Very large mass-to-light ratio $\rightarrow$ Mass budget largely dominated by DM

Promising target for particle DM searches!

- **long baselines** to map background sources
- **short baselines** for the diffuse emission search

See also works from Spekkens et al. for similar searches but with a single dish (Green Bank Telescope)
→ Source subtraction is necessary to bring the noise down from its confusion level
WIMP hunt

![Observed field](image1)

![Observed field plus simulated dark matter](image2)
Limits on diffuse emission

No significant detection of an extended (few arcmin) emission.

Bounds are far from the expected non-thermal emission related to star formation (which is in some cases possibly achievable by the SKA)
Within the next 5-10 years and regardless of the astrophysical assumptions, it should be possible to **progressively close in on the full parameter space of WIMPs**.
Summary

IF dark matter is made of **WIMPs**, a synchrotron emission from DM is **unavoidable**, potentially relevant for the ARCADE excess and in general under the reach of current/near-future radio telescopes.
Backup slides
DM-induced e$^+$$^-$$^-$ source:

\[ Q_e^a(E, r) = \langle \sigma_a v \rangle \frac{\rho(r)^2}{2 M_\chi^2} \times \frac{dN_e^a}{dE}(E) \]

\[ Q_e(r, E)dE = 4\pi p^2 q_e(r, p)dp \]

Transport equation for e$^+$$^-$$^-$:

\[ -\frac{1}{r^2} \frac{\partial}{\partial r} \left[ r^2 D \frac{\partial f_e}{\partial r} \right] + \frac{1}{p^2} \frac{\partial}{\partial p} (\dot{p} p^2 f_e) = q_e(r, p) \]

**Synchrotron signal**

\[ j_{\text{synch}}(\nu, r) = \int dE P_{\text{syn}}(r, E, \nu) n_e(r, E) \]

\[ n_e(r, E)dE = 4\pi p^2 f_e(r, p)dp \]

\[ S_{\text{th}}(\nu, \theta_0) = \int d\phi d\theta \sin \theta \mathcal{G}(\theta, \phi, \theta_0) \int_{l.o.s.} ds \frac{j_{\text{synch}}(\nu, r(s, \theta, \phi))}{4\pi} \]
Magnetic field

dSph name | $D$ [kpc] | $r_h$ [''] | $B_{SFR}$ [$\mu$G] | $B_{SFR0}$ [$\mu$G] | $B_{MW}$ [$\mu$G] | $\langle B_{eq}^{obs} \rangle$ [$\mu$G] | $\langle U_{el}^{SFR0} \rangle$ [$10^{-16}$ GeV/cm$^3$] | $\langle B_{eq}^{SFR0} \rangle$ [$\mu$G]
---|---|---|---|---|---|---|---|---
Carina | 105 | 8.2 | 0.9 | 0.7 | 0.5 | $< 3.8$ (2.5) | 2.7 | 0.03
Fornax | 147 | 16.6 | 2.0 | 1.2 | 0.3 | $< 4.2$ (2.0) | 96 | 0.2
Sculptor | 86 | 11.3 | 1.6 | 1.2 | 0.6 | $< 6.7$ (2.9) | 23 | 0.1
BootesII | 42 | 4.2 | 0.4 | 0.4 | 1.2 | $< 6.3$ (6.6) | 0.45 | 0.01
Hercules | 132 | 8.6 | 0.4 | 0.4 | 0.4 | $< 4.6$ (2.6) | 0.45 | 0.01
Segue2 | 35 | 3.4 | 0.4 | 0.4 | 1.4 | $< 7.3$ (10.6) | 0.45 | 0.01

![Graph](image1.png)

![Graph](image2.png)