Giant Monopoles as a Dark Matter Candidate

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WIMPs and Their Weak Interactions

CDM WIMPs are the most successful dark matter model to date.

The dark matter consists of nonrelativistic particles which interact weakly at short distances and gravitationally at large distances.

Searching for weak interactions of WIMPs via direct and indirect detection is a major industry

For example the dedicated SNOWMASS indirect (direct) detection groups reported upon 8 (20) experiments which are in progress (or completed)

Nonetheless so far no compelling evidence for weak interactions of dark matter has been found

At the same time their theoretical motivation, as a generic feature of electroweak scale SUSY models, has been compromised by the failure to observe evidence for such models at the LHC

WIMPs and Their Successes in the Gravitational Sector

On the contrary, in the gravitational sector WIMP phenomenology has met with astonishing success

Some of its most successful predictions are:

I) The bullet cluster mass is separated from the ionized gas

II) Galaxy cluster density profiles (at least far from their cores)

III) The CMB power spectrum scaling and peaks at $l < 3000$

IV) Large scale structure and in particular the BAO peak (at least at redshifts $z < 1$)

These successes are all at very large scales (10+ Mpc today)

Testing WIMPs at short distances

The smallest scales at which dark matter has been confirmed are those of dwarf spheroidal galaxies (dSphs) and galactic nuclei.

What predictions do WIMPs make on these scales?

Simulations of *pure* dark matter structure formation yield two generic results:

1) About 10,000 $10^{4-5}\ M_\odot$ satellites around the Milky Way
(Klypin et al., 1999; Moore et al., 1999)

2) A cusped density profile in galactic cores
(Dubinski and Carlberg, 1991; Navarro et al., 1996 and 1997).
CDM suggests that if Milky Way satellite galaxies are cored, many should have been ripped apart by tidal forces (Peñarrubia et al., 2010)

Both claims are naively contradiction with observations

... But the universe isn't made of pure dark matter

Evading short distances WIMP problems

How can these problems be evaded?

1) Missing satellite problem:

Uninhabited halo solution: Perhaps the missing satellites are there but are not observed because they have no stars?

For example ultraviolet radiation from reionization (Couchman and Rees, 1986; Efstathiou, 1992), supernova feedback (Larson, 1974) or cosmic ray pressure (Wadepuhl and Springel, 2010) blew all of the gas out of the shallow gravitational potentials of light dark matter halos before many stars could form.

Shortcomings of the uninhabited halo solution

a) There are also missing heavier satellites: (Boylan-Kolchin et al., 2011) 10+ with mass between Fornax and the SMC in each Aquarius (Springel et al., 2008) and Via Lactae II (Diemand et al., 2008) simulation.

To eliminate the missing heavy satellites from simulations the Milky Way mass should be reduced to $8 \times 10^{11}\ M_{\odot}$ (Vera-Ciro, 2012) but it may be sufficient to reduce it to $10^{12}\ M_{\odot}$ (Wang, Frenk et al, 2012).

An $8 \times 10^{11}\ M_{\odot}$ mass is strongly disfavored by global fits (McMillan, 2010) and 95% disfavored if Leo I is a satellite (Li and White, 2008) and also suggests that the Magellanic clouds are unbound (Besla et al., 2007). If they are unbound, it is difficult to explain why they happen to be so nearby.

It is consistent with the orbits of very distant (80+ kpc) objects (Battaglia et al., 2005; Deason et al., 2012). But many of these have not had time to orbit the Milky Way once, and so such distributions are likely to be dominated by substructure rendering them unreliable.

Shortcomings of the uninhabited halo solution

b) Such solutions rely heavily upon unproven and disputed (Penarrubia et al., 2012;Garrison-Kimmel at al., 2013) assumptions concerning the efficiencies of the process considered, such as the fraction of the supernova energy which is transfered to a gas.

c) Of the thousand or so nearby globular clusters, none appear to inhabit dark matter halos. Which may be problematic because:

This seems to defy a minimum dark halo mass requirement.

It leads one to wonder how likely it is that in none of these cases has a globular cluster merged with an uninhabited dark halo.

d) Simulations with baryons typically do not have sufficient resolution to identify light uninhabited halos, for example the baryonic particle size is $2 \times 10^6\ M_\odot$ in Sawala, Frenk et al., 2012.

2) Cusp problem:

Perhaps baryonic physics smooths out the cusps?

The most popular candidate is an outflow of the bulk gas caused by supernova (Mashchenko et al., 2006; Governato et al., 2010)

This mechanism appears to have two shortcomings:

a) It only works if the threshold density for star formation is at least 10 atoms per cubic centimeter (Ceverino and Klypin, 2009) which is about 1,000 times higher than the traditional threshold (Navarro and White, 1993).

New simulations replace this hard threshold with equivalent assumptions linking star formation to molecular hydrogen abundance (Governato et al, 2012).
Nonetheless the amount of energy transfer from the supernovae in these simulations is controversial (Revaz and Jablonka, 2012)

b) Galaxies with stellar masses below about $10^8\ M_\odot$ do not have enough baryons for such mechanisms to be effective (Governato et al., 2012), although the limit could be as low as $10^6\ M_\odot$ (Onorbe et al., 2015).

So CDM predicts that galaxies lighter than $10^{6-8}\ M_\odot$ have cusps, is this consistent with observations?

They are dispersion supported $\Rightarrow$ The Jeans equation with only line of sight velocities does not allow for an unambiguous determination of their density profiles, one needs to also know the velocity anistropy (Binney and Mamon, 1982).

Problems with cusped dwarfs

The hypothesis that the density profiles of the smallest dwarfs are cusped is in tension with observations for several reasons:

Cuspy profiles lead to large tidal forces which destroy substructure and pull it to the center of the halo.
This may be incompatible with the existence of old substructure in the Fornax (Goerdt et al., 2006; Cole et al., 2012), Ursa Minor (Kleyna et al., 2003) and Sextans (Lora et al., 2013) spheroidal dwarf galaxies.

Each chemically distinct component of stars allows the dark matter density to be determined within a given radius. A dynamically inconsistent analysis of distinct stellar populations in the Fornax (Walker and Peñarrubia, 2011; but maybe recently experienced a merger: Amorisco and Evans, 2012) and Sculptor dwarfs (Battaglia, 2008; Amorisco and Evans, 2011;Walker and Peñarrubia, 2011) $\Rightarrow$ both have cored density profiles.

A dynamically consistent analysis (Strigari, Frenk and White, 2014) shows that Sculptor *can* have a cusp.

Dwarf Satellite Galaxy Associations

Depending on merger histories, simulations of galaxy formation generally may lead to isotropic and uncorrelated distributions of satellite galaxies in phase space, essentially because the satellites are so light that they do not interact with each other.

Some claim that this is in contradiction with the distribution of satellite galaxies in our local group because:

a) The orbits of most of the known Milky Way satellites lie on a single (thick) disk (Kroupa et al., 2005;Metz et al, 2007)

b) About half of the Andromeda galaxy's satellites are corotating in a thin disk (Ibata et al., 2013)

c) The local group contains many more binary systems of satellites (30%) than are found in simulations (4%) (Fattahi et al, 2013)

Goal of this Talk

The goal of this talk:

I will present an extension of the standard model containing a dark matter candidate which:

a) Shares the successes of cold dark matter particles.

b) Evades the problems described above.

Necessary Conditions for a Dark Matter Model

An alternative model of dark matter needs to share the large scale success of CDM WIMPs, but at small scales and in environments with few baryons:

1) Halos should have a minimum mass.

2) Halos should have three regions:
A constant density core, a $\rho \sim 1/r^2$ intermediate region and an outer region in which the density falls faster.

3) The density profiles should be sufficiently smooth so as to satisfy lensing, wide binary and dynamical friction bounds on MACHOs.

4) The amount of dark matter should be roughly unchanged since at least $z = 10,000$.

Giant monopoles

A dark matter candidate with all of these properties is a giant, non-BPS, 't Hooft-Polyakov monopole ('t Hooft, 1974;Polyakov, 1974) in an SU(2) gauge theory with an adjoint Higgs field:

The proposal:

Extend the standard model by adding an SU(2) gauge field and an adjoint scalar Higgs, later we will see that we also need fundamental fermions

Each dark matter halo consists of a *single* monopole.

Each monopole, in the absence of baryons and in a steady state, is completely characterized by a single integer: its charge Q

Note that in such models no signature is expected at direct and indirect searches except for:

Higgs portal interactions (observable at colliders?)

Giant Monopoles Satisfy the Conditions Above

Giant monopoles satisfy the four necessary conditions described above:

1) Dirac quantization yields a minimum mass.
The smallest dwarfs are charge $Q = 1$ (Dirac, 1931).

2) Non-BPS 't Hooft-Polykov monopoles solutions have precisely these three regimes:
A core $(r < r_1)$ where all fields are off, an intermediate region $(r_1 < r < r_2)$ with a Higgs field winding about its vacuum manifold and a far region $(r > r_2)$ with nontrivial gauge fields.

3) The density varies on scales of order the halo size, easily satisfying the lensing, dynamical friction and wide binary MACHO bounds.

4) The monopoles form when the scalar field potential is larger than Hubble damping, which occurs around $z = 50,000$.

Charge Q monopole solutions

The potential of the Higgs field is minimized on a vacuum manifold, which is a 2-sphere of points with norm v.

In the core $(r < r_1)$ the gauge field and Higgs field are essentially zero. The density is the Higgs field potential energy.

The distance r_1 is proportional to the Compton wavelength of the Higgs field.

In the intermediate region $(r_1 < r < r_2)$ the gauge field essentially vanishes and the Higgs field winds Q times around the S^2.

The distance r_2 is essentially the Compton wavelength of the gauge field.

The distant region $(r > r_2)$ is dominated by the gauge field.

Building an approximate solution from cones

There is no spherically symmetric map $S^2 \longrightarrow S^2$ of degree greater than one.

Therefore monopoles of charge $Q > 1$ can never be spherically symmetric (Weinberg and Guth, 1976).

We construct approximate monopole solutions by dividing spacetime into cones, whose tips are the origin.

The fields are taken to be trivial between the cones. In each

cross-section of each cone the Higgs field will yield a map of degree one

$$h : D^2 \longrightarrow S^2$$

Such that the boundary of the disc is mapped to zero. Therefore, quotienting by the boundary, this induces a degree one map $S^2 \longrightarrow S^2$.

The Factorization Ansatz

$$\Phi = h(z)\left[F(\eta)\left(c\, t^1 + s\, t^2\right) + \epsilon\sqrt{1 - F^2(\eta)}\, t^3\right]$$

for the Higgs field and

$$A_1 = \frac{\alpha(z)}{z}\left(cs\left[J(\eta) - G(\eta)\right] t^1 + \left[c^2 G(\eta) + s^2 J(\eta)\right] t^2 - sH(\eta)\, t^3\right) \ ,$$

$$A_2 = \frac{\alpha(z)}{z}\left(-\left[c^2 J(\eta) + s^2 G(\eta)\right] t^1 - cs\left[J(\eta) - G(\eta)\right] t^2 + cH(\eta)\, t^3\right) \ ,$$

$$A_3 = \frac{\alpha(z)}{nz} I(\eta)\left(s\, t^1 - c\, t^2\right) \ ,$$

for the $SU(2)$ gauge field A_i where we have defined the variables

$$\eta \equiv \frac{n\rho}{z} \in [0, \sigma] \ , \quad \epsilon \equiv \mathrm{sign}(F'(\eta)) \ , \quad c \equiv \cos\psi \ , \quad s \equiv \sin\psi \ ,$$

Free parameters

This nonabelian Higgs theory has 3 parameters.

1) λ is the Higgs scalar quartic interaction strength

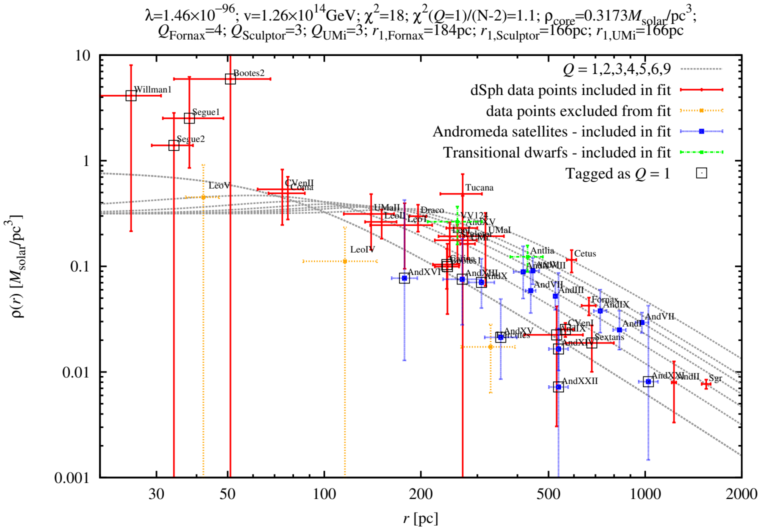
2) v is the magnitude of the Higgs VEV.

3) g is the gauge field strength. It is only relevant at $r \gtrsim r_2$ and beyond. Here there are few stars, and so it is only weakly constrained.

We will fit λ and v using the density profiles of dwarf spheroidal galaxies (dSph's) as these are the most dark matter dominated objects in the universe.

While in general the Jeans equation does not allow a determination of the mass enclosed within an arbitrary radius, it does allow a determination of the density within the half-light radius under fairly general conditions (Walker et al., 2009;Wolf et al., 2010).
We now plot this for all known dSph's and dwarf transitional galaxies and use the plot to fit λ and v.

Fitting using dSph's and transition dwarfs



Do v and λ satisfy other constraints?

Note that $\lambda \sim 10^{-96}$. Is it small enough to easily satisfy bullet cluster bounds on dark matter scattering cross-sections (Randall et al., 2008) and the slightly tighter bounds from 72 other such systems (Harvey et al., 2015)?

$v \sim 10^{14}\ GeV$ is determined using only inputs on galactic scales and miraculously the result is a particle physics scale (about the leptogenesis scale).
Had it been bigger than M_{pl} then quantum gravity corrections would have been large, had it been smaller than $1\ eV$ then dark matter would not have formed in time to seed perturbations.

If the relationship between λ and v had been slightly different, v would not have fallen in this window.

r_1 is just large enough to be consistent with substructure in the Fornax, Ursa Minor and Sextans dwarfs

Other kinds of galaxies?

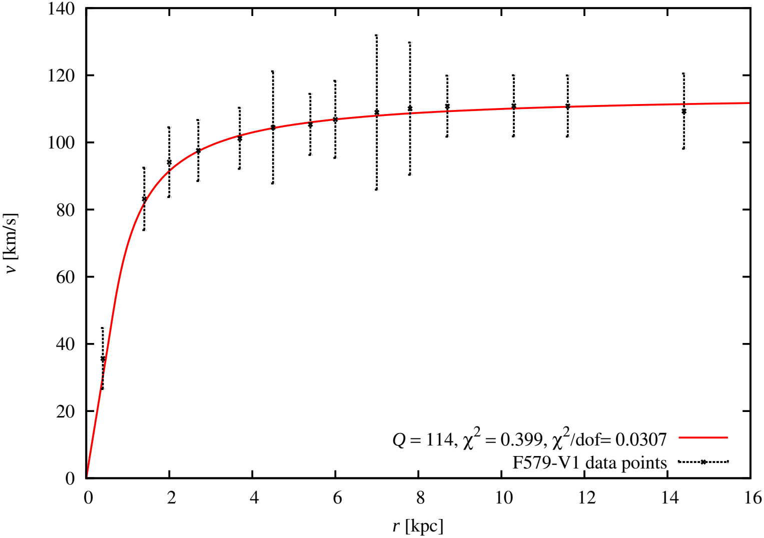
Using just dSph's and dwarf transitional galaxies we have fixed all of the relevant parameters of the theory.

Now that no parameters are left, there are many very nontrivial checks.

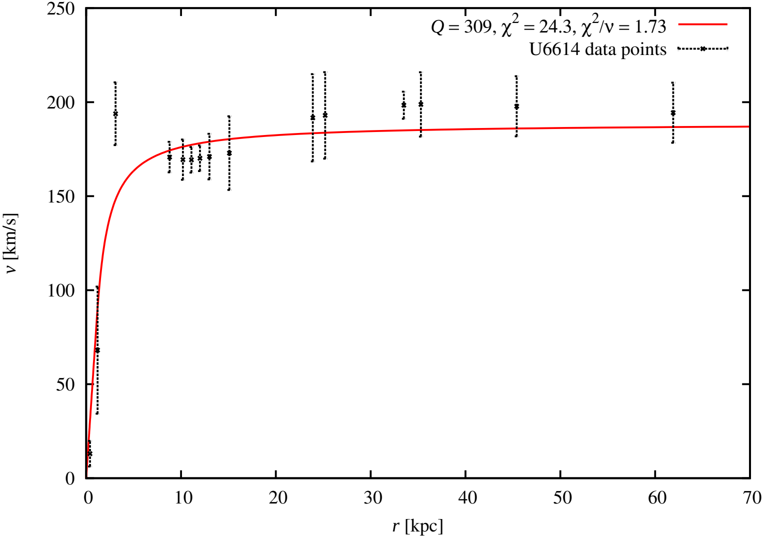
For example, the rotation curves of all other dark matter dominated galaxies should now be determined by a *single* discrete parameter Q.

We will now check this claim for the low surface brightness galaxies F579-V1, U6614 and F563-1 which were chosen only because they have good velocity data going out to high radii and good determinations of their gas profile.

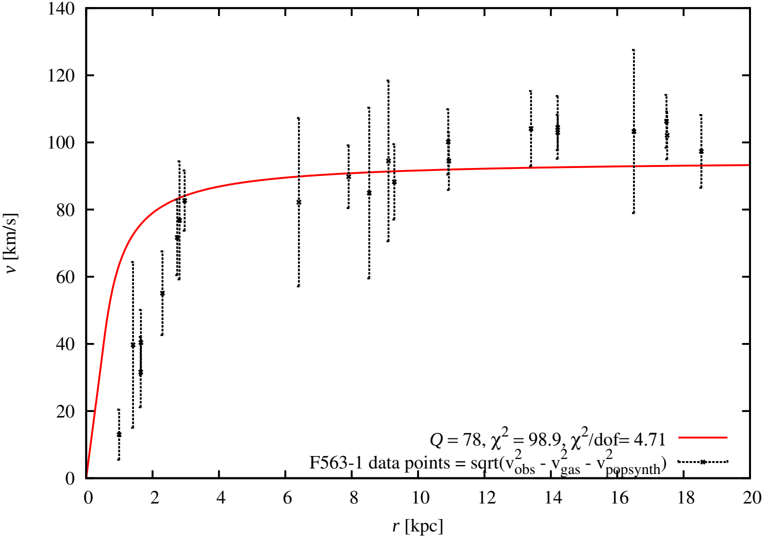
F579-V1 Rotation curve (minus gas) vs theory



U6614 Rotation curve (minus gas) vs theory



F563-1 Rotation curve (minus gas and stars) vs theory



Other checks

1) No galaxies smaller than $Q = 1$ may be found at any redshift: The three dwarf galaxies seen at high redshift via gravitational lensing (Vegetti et al., 2010 and 2012;Fadely and Keeton, 2012) appear consistent with this minimum, although the technique allows smaller galaxies to be seen.

2) Dark matter should behave as a fluid so far as $l < 1500$ oscillations are concerned.
$l = 1500$ corresponds to 5 kpc at recombination. There were over 1,000 monopoles in each such volume, and so the fluid approximation can be trusted. Had today's dark matter density been 100 times lower, the fluid approximation would have failed. Had it been 1000 times higher, the cores would have overlapped in a 5 kpc sphere and so the equation of state would have changed. This check relies on a relation between the absolute size of dwarf galaxy cores today and the Silk damping scale at recombination!

A prediction

The stability of these halos demands that r_2 be independent of Q.

This is a very strong prediction. It requires the halos of the smallest dSph's to be the same size as those of the largest LSBs. The lightest masses would be over $10^9 M_\odot$.

As the dark matter halos of satellites have a higher total mass in this proposal than ΛCDM:

a) Satellite galaxies will interact with each other more strongly, reducing the tension with observations of satellite binaries and the fact that satellites in our local group inhabit discs

b) The halos of many satellites extend beyond their tidal radii .

This would be impossible in a WIMP theory in which the halos are gravitationally bound.

Halos which extend beyond their tidal radii are a smoking gun signature of dark force models.

Evidence for extra-tidal halo radii?

In 2003 Hayashi et al. claimed that stars in dSphs do indeed in general extend somewhat beyond their tidal radius.

However the halo radii predicted by this model extend far beyond the bulk of the stars. How can one determine if the dark matter halo extends beyond the stars?

Leo IV and Leo V dwarfs orbit each other. One can use Newtonian physics to determine their total mass, finding $4-12\times10^{9}\ M_{\odot}$ (de Jong et al., 2010) or $1.6-5.4\times10^{10}\ M_{\odot}$ (Blaña et al., 2012)

This is much more than the less than $1.6\times10^{6}\ M_{\odot}$ within their half-light radii (Walker et al., 2009) but it agrees well with the mass predicted if r_2 is Q-independent.

Five Binary Pairs in the Local Group

Of the 50 or so satellite galaxies identified in our Local Group, it has been claimed that the following 5 pairs may be associated, in that they have similar positions and velocities:

1) The Magellanic clouds
2) NGC 147 and 185 (van den Bergh, 1978)
3) Leo IV and V (Belokurov, 2008)
4) Andromeda I and III (Fattahi, 2013)
5) Draco and Ursa Minor (Fattahi, 2013)

The Magellanic clouds are different from the others as their proper motions are well measured, they are very extended and they have been extensively simulated, so we will focus on the other 4 pairs.

Outline of The Next Part of the Talk

These pairs are either bound or they are not.

Assuming CDM we will argue that

1) If they are gravitationally bound then their masses are higher than is found in ΛCDM structure formation simulations

2) If they are bound and are at typical points in their orbits, then their masses may be estimated from the Virial theorem and we find that the tidal force from their host galaxy is greater than their mutual attraction, thus they are not indeed bound

3) If the pairs are not currently bound and their phase space proximity is due to their condensation from a common disrupted progenitor, then the proximities of the pairs implies that the disruption occurred within about the last 2 billion years in each case. However, the absence of pairs with a medium separation implies that no such events appear to have occurred earlier, which again is statistically unlikely.

Lower Bound on the Mass of a Bound Pair

If a pair of satellite galaxies is gravitationally bound, then Newtonian gravity yields a lower bound on their mass.

dSphs appear to have little spatial extent, so we will make the crude approximation that they are point masses of masses M_1 and M_2 with speeds v_1 and v_2 in the center of mass frame.

The total kinetic and potential energies are

$$T = \frac{v^2}{2}\frac{M_1 M_2}{M_T}, \quad U = -\frac{G_N M_1 M_2}{d}$$

where $M_T = M_1 + M_2$ and $v = v_1 + v_2$ are the total mass and relative speed, G_N is Newton's constant and d is the distance separating the two galaxies.

Therefore the assumption that the system is gravitationally bound yields a lower bound on the total mass

$$M_T > v^2 d/2G_N \geq M_{\mathrm{min}} = v_{\mathrm{los}}^2 d/2G_N$$

What are these lower bounds?

Given the separations d between the 5 known pairs and their relative line of sight velocities $v_{\rm los}$ (proper motions for the MC) one can use the previous formula to find a lower bound $M_{\rm min}$ on the total mass of each pair

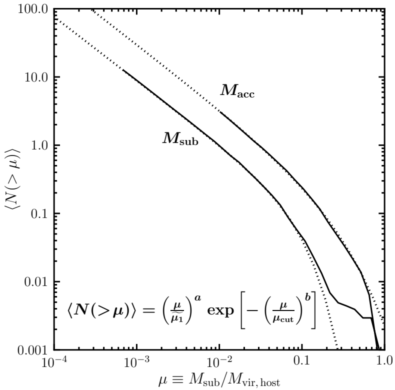
	Dr&UMi	Leo	And	NGC	MC
d	23^{+2}_{-0}	25^{+11}_{-10}	33^{+16}_{-0}	59^{+39}_{-36}	24^{+2}_{-1}
ang.	17.4°	2.8°	2.5°	1.0°	20.7°
$v_{\rm los}$	44.1 ± 0.1	41.0 ± 3.4	30.2 ± 2.3	10.7 ± 1.4	98
$M_{\rm min}$	$5.2^{+0.4}_{-0}$	$4.9^{+2.3}_{-2.1}$	$3.5^{+1.8}_{-0.5}$	0.8 ± 0.5	28

All distances are given in kpc and velocities in km/s.

$M_{\rm min}$ is given in units of $10^9\ M_\odot$.

Expected Halo Masses in ΛCDM

The expected number of subhalos with a given mass fraction, according to the Millennium-2 simulation, is (Boylan-Kolchin 2009)



The lower bounds above correspond to mass fractions μ of about 2×10^{-3} for each halo in a pair.

Mass Estimates

We now assume that the pairs are bound *and* at generic points in their orbits

Then isotropy and the Virial theorem yield a rough estimate (not just a bound) of the satellite masses masses, valid to within about a factor of two

Isotropy: $v^2 = 3v_{\rm los}^2$

Virial theorem: $2T = -V$

Putting this altogether yields an estimate of the total mass

$$M_T \sim \frac{v^2 d}{G_N} \sim \frac{3v_{\rm los}^2 d}{G_N} = 6M_{\rm min}.$$

What are these lower bounds?

Multiplying $M_{\rm min}$ by 6 (2 for the MC) one obtains an estimate of the total mass of each pair:

	Dr&UMi	Leo	And	NGC	MC
$M_T(10^9\ M_\odot)$	31	30	21	5	55

Thus the typical satellite/host halo mass ratio is about $\mu \sim 10^{-2}$

Recall that ΛCDM simulations imply that each host will only have 1 satellite with such a high mass

Here on the contrary we found that $\mu \sim 10^{-2}$ is the *typical* mass ratio for (bound) satellites

Tidal Force

So far we have treated satellite pairs as 2-body systems, what effect does the host galaxy have on this pair?

The host will exert a tidal force which tends to separate the pair, the pair will only be bound if their separation is less than the tidal radius

$$r_{\mathrm{tidal}} = R\left(\frac{M}{3M_g}\right)^{1/3}$$

where $M \sim M_T/2$ is the satellite mass, R is the radius of its orbit and M_g is the host galaxy mass

Due to the cuberoot, r_{tidal} is reasonably insensitive to the uncertainty in the mass

Strategy: Compare r_{tidal} to d, if $r_{\mathrm{tidal}} < d$ then the pair is not gravitationally bound

How big are the tidal radii?

The tidal radius depends on the mass model for the host galaxy, which is the Milky Way or Andromeda.

We use the mass models of McMillan (2011) and Corbelli (2010) respectively and obtain

	Dr&UMi	Leo	And	NGC	MC
d (kpc)	23^{+2}_{-0}	25^{+11}_{-10}	33^{+16}_{-0}	59^{+39}_{-36}	24^{+2}_{-1}
R (kpc)	77	167	66.5	164.5	55
$M_g(10^{11}\ M_\odot)$	7.4	12.2	6.0	10.4	5.8
$r_{\rm tidal}$ (kpc)	15	27	12	15	19

So we find that all pairs except for, just barely, Leo IV and V are separated by more than the tidal radius and so are not bound. (inconclusive for the MC)

Leo IV and V are receding quickly from the Milky Way and so their tidal radius is increasing, thus they were recently unbound

If not gravitationally bound, why are they so close?

We have seen that most or all of the pairs of Local Group satellite galaxies cannot currently be gravitationally bound.

So why are they so close together and why are their velocities so similar?

1) A coincidence? Fattahi (2013) estimated the probability, for just a subset of the pairs, at well under 1%.

   Furthermore, James and Ivory (2011) found strong position correlations between satellites in systems other than the Local Group

2) They were once part of a bound structure that has now disassociated?

   In this case we can use their relative velocities to estimate when they unbound

Time since the pairs became unbound

The pairs are separated by about 30 kpc and have relative line of sight velocities of about 30 km/sec, leading to relative proper motions of at least 30 km/sec.

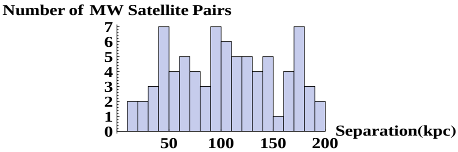
Therefore the pairs ceased to be bound within the past 1-2 billion years.

The presence of the host galaxy does not affect this conclusion without a large fine tuning of the transverse velocities (in contradiction with measurements where they exist).

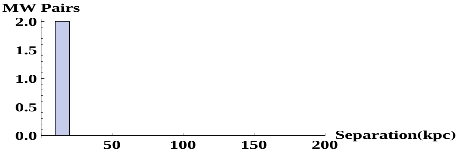
In this case one expects to observe pairs with a larger separation, which became unbound earlier. Do they exist?

Separations of Milky Way Satellites

Distribution of separations of Milky Way satellites with relative $v_{\mathrm{los}} < 90$ km/sec.



Some pairs are close to each other because both are close to the Milky Way. If we impose that the distance to the Milky Way is at least twice the separation between the pairs:

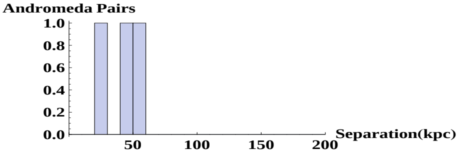


No intermediate separations/old pairs!

What about Andromeda's Satellites?

In the case of the satellite galaxies of the Andromeda galaxy, the uncertainties in the distances are much larger.

An analysis similar to that above yields



Only one new (intermediate separation) pair, Andromeda XI and XIV, although these have a high relative speed of 61 km/s.

Although the errors are larger, this system seems consistent with the thesis that all pairs became unbound within the past 2-3 Gyrs.

Thus even if the pairs did become unbound only recently, one needs to understand why no observed pairs have unbound earlier.

Future Observations

The Gaia satellite will provide precise proper motions for the Ursa Minor/Draco pair and a rough proper motion for Leo IV and V in the next 3 to 5 years.

In the next decade, the Thirty Meter Telescope should be able to provide proper motions for the Andromeda satellites.

If their transverse motions are very different, then we will learn that these associations are in fact coincidental.

In any case, the proper motions will allow 3d simulations of the histories of these systems, revealing for example whether they are separating from a common origin and whether Andromeda's thin disk arose from a single merger event.

What next?

With the Gaia mission, these puzzles (the pair multiplicity, the existence of disks, etc) will either disappear or become much sharper.

Gaia and TMT may find that the pairs are currently bound (similar 3d velocities and no evidence for a progenitor) but, using their proper stellar dispersions to find their dark matter profiles, that they are too light to be bound gravitationally.

What then?

This would imply that dark matter interacts with a long range force (light particle) besides gravity.

Small scale structure formation

The cores of monopoles are already fully formed before recombination.

Therefore one expects small galaxies to form much earlier than in WIMP cosmologies - a prediction which soon may be tested by 21 cm observations.

It has been claimed that supermassive black holes (SMBHs) appear fully formed at the highest redshifts at which they can be observed.

This would be natural if SMBHs are part of the Einstein-Higgs-Yang Mills solution, at least at high Q and possibly with some baryons.

In this case gravitational consumption of stars, gas and dark matter may not be the main mechanism driving SMBH growth, it may be a dark interaction.

The big problem

Monopoles interact with each other via their scalar and gauge fields.

The gauge fields mediate a repulsive interaction and the scalars an attractive interactions.

In the BPS case these cancel.

In this case the scalar field is massive, and so the gauge field dominates at $r >> r_2$

As a result these monopoles repel!

Needless to say this would be a disaster ...

Analogy with protons

There is a similar problem in the baryonic sector.

Visible matter is dominated by protons, which repel.

The long range repulsion is screened by electrons, the short range by neutrons.

In the case at hand there is no short range repulsion, so let's focus on the long range.

The long range repulsion is screened by electrons.

The electrons do not annihilate with protons because they carry a different conserved flavor charge (and $m_n > m_p + m_e$).

Jackiw-Rebbi and monopole screening

How can we create a new conserved flavor charge for monopoles?

The Jackiw-Rebbi mechanism (Jackiw and Rebbi, 1976)

If there are N flavors of fundamental fermions, then there will be 2^N charges of monopole.

We will consider, for simplicity, 2 flavors of fermions.

Of the 4 kinds of monopole, 2 will be heavy and 2 very light.

This is a generic situation in $\mathcal{N} = 2$ supersymmetric gauge theories which are softly broken to $\mathcal{N} = 1$ (Argyres, Plesser and Seiberg, 1996).

We consider a universe filled with heavy monopoles of one flavor (the dark matter) and the light antimonopoles which screen them.

Another solution: Monopoles are trapped together inside of skyrmions (Gudnason et al., 2015)

Conclusions

1) The successes of WIMPs are all at very large length scales.
2) At kpc scales CDM WIMPs face challeges with dwarf galactic abundances and density profiles.
3) Giant monopoles behave like WIMPs at large scales, but solve these problems at small scales.
4) There are only 2 relevant parameters, which can be fit by dwarf galaxy data and then satisfy a number of nontrivial constraints.
5) This model predicts that dwarf galaxy halos extend for 10s of kpc, with only the central cores occupied by stars. This increases the masses of dSph's by 2-3 orders of magnitude. These masses can be determined for binary dwarfs or with lensing.
6) It also predicts that small galaxies form much sooner than in WIMP cosmologies.