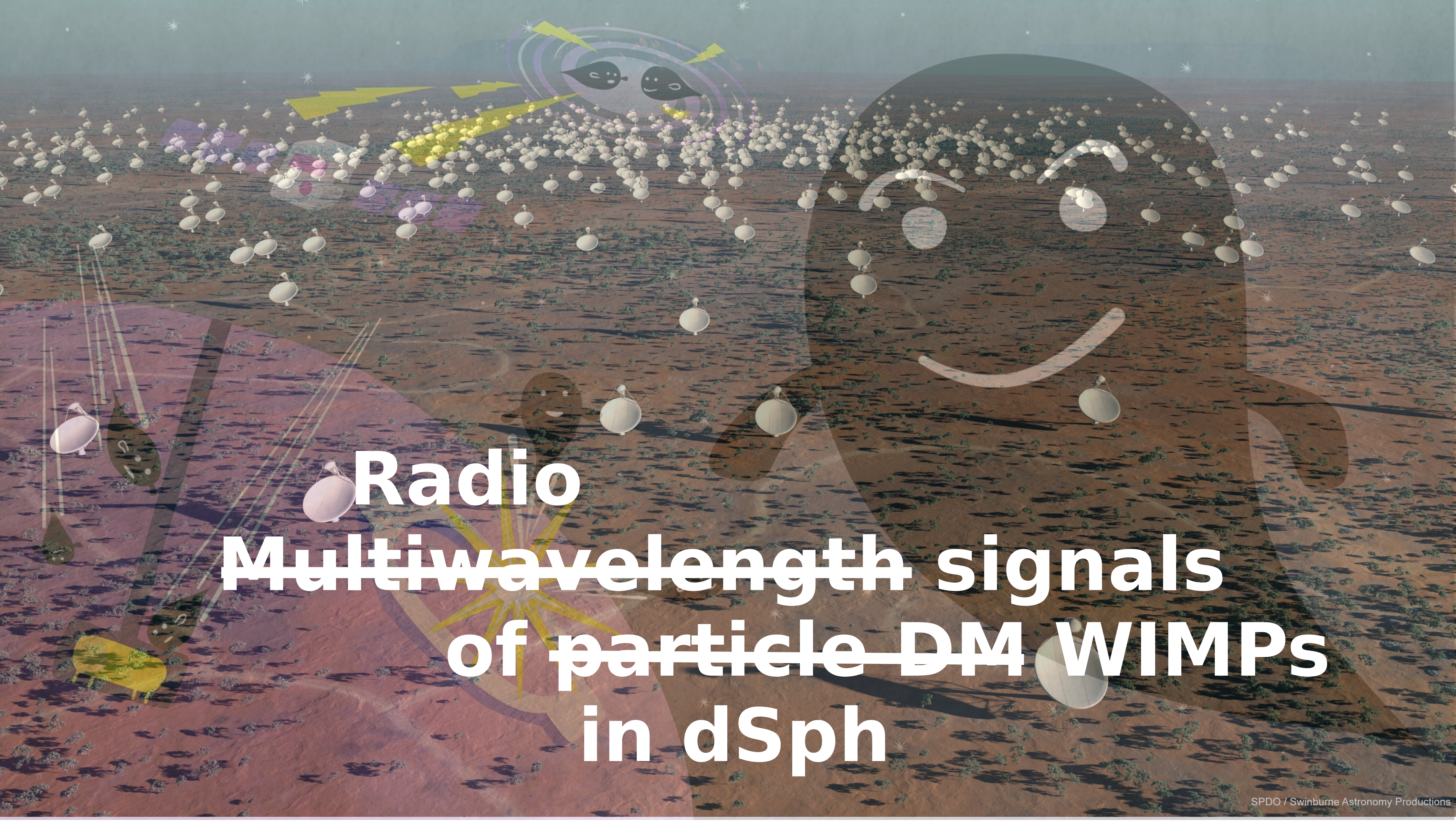

Radio ~~Multiwavelength~~ signals of ~~particle DM~~ WIMPs in dSph

UNIVERSITÀ DEGLI STUDI DI TORINO

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&

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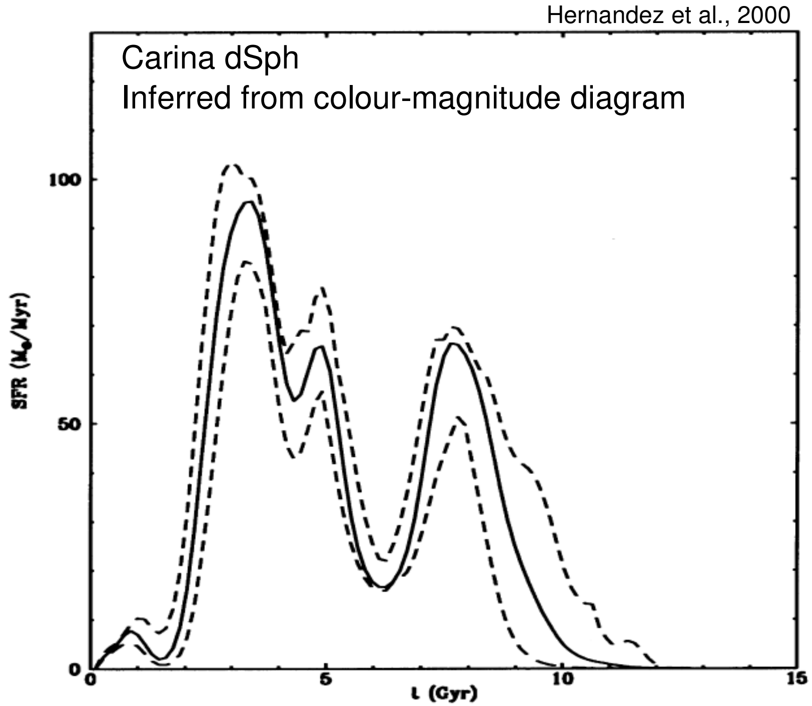
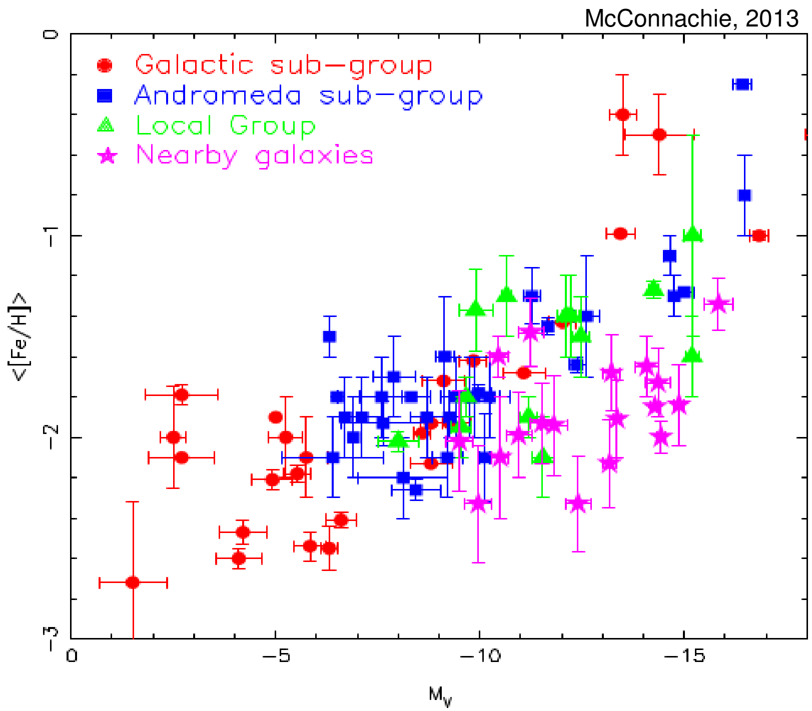
Istituto Nazionale di Fisica Nucleare

Dwarf spheroidal galaxies

Low level of star formation

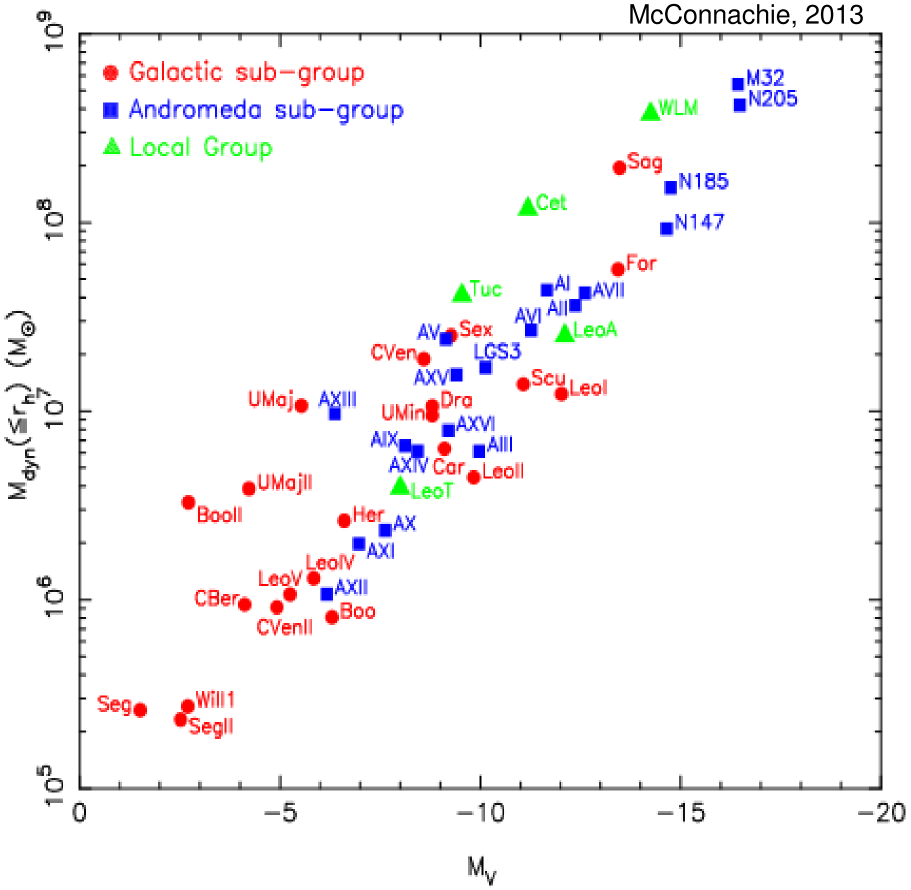


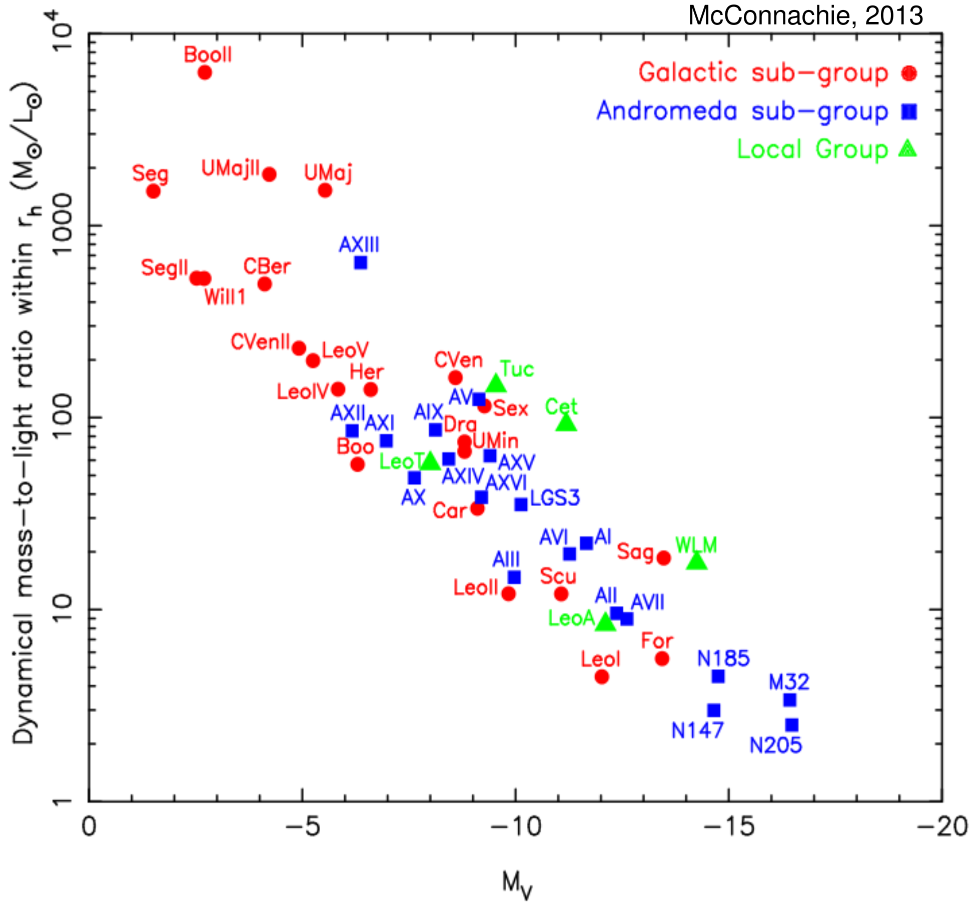
Metal-poor stellar systems



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

Local Group dSph

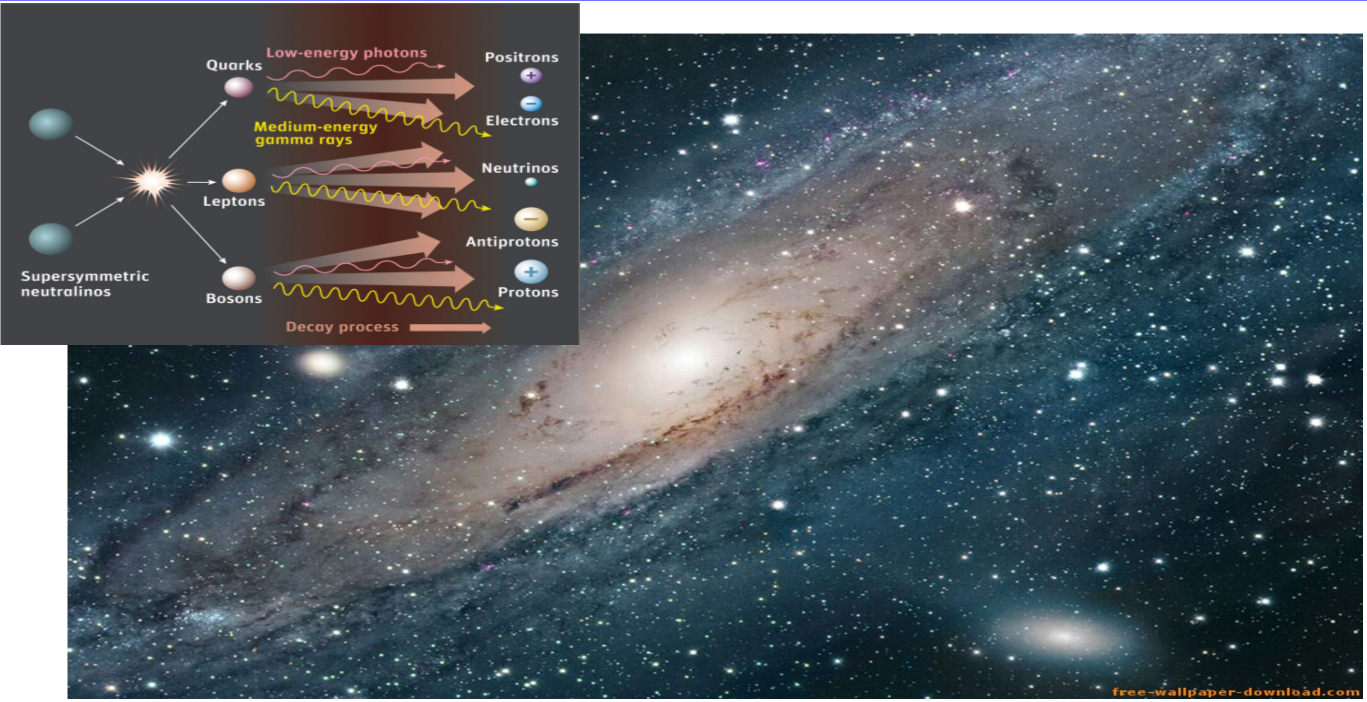




Very large mass-to-light ratio → Mass budget largely dominated by DM

Promising target for particle DM searches!

Synchrotron radiation from DM



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

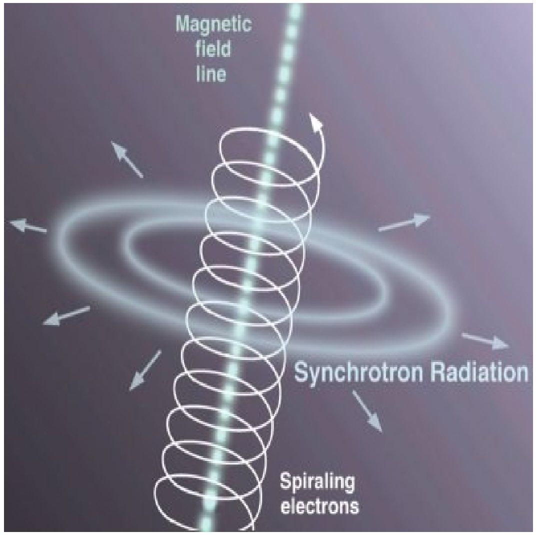
If emitted in a medium with **magnetic field** → radio continuum diffuse emission associated to synchrotron radiation.

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

$$E \simeq 15\sqrt{\nu_{GHz}/B_{\mu G}}\ \mathbf{GeV}$$

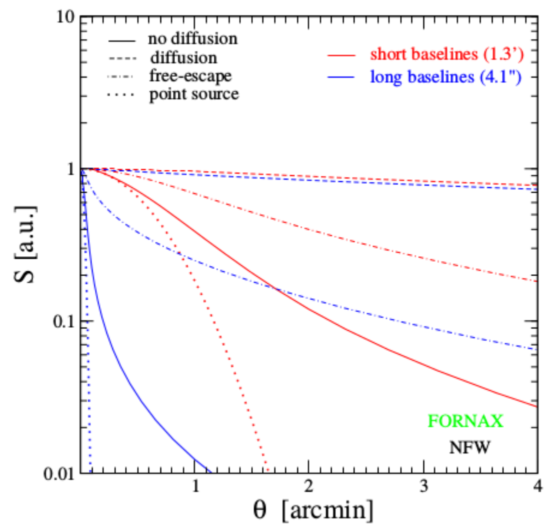
It is an indirect^3 method to probe particle DM:

source+propagation+radiation



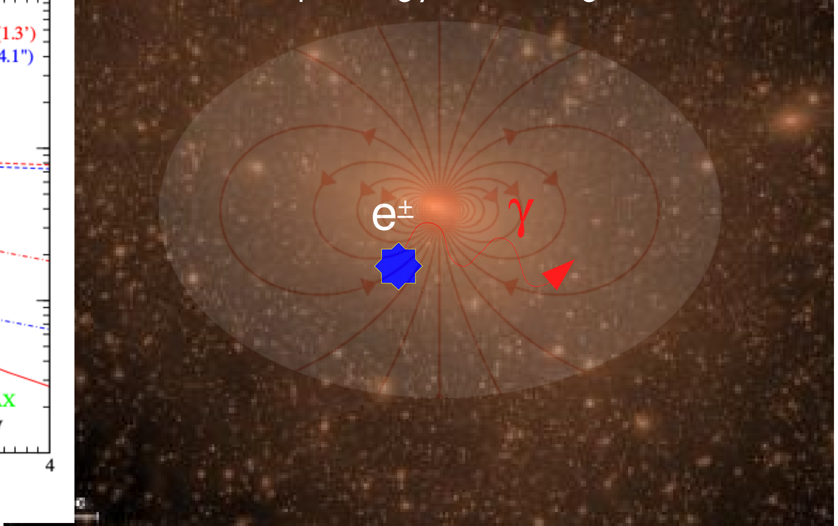
Transport of e⁻/e⁺

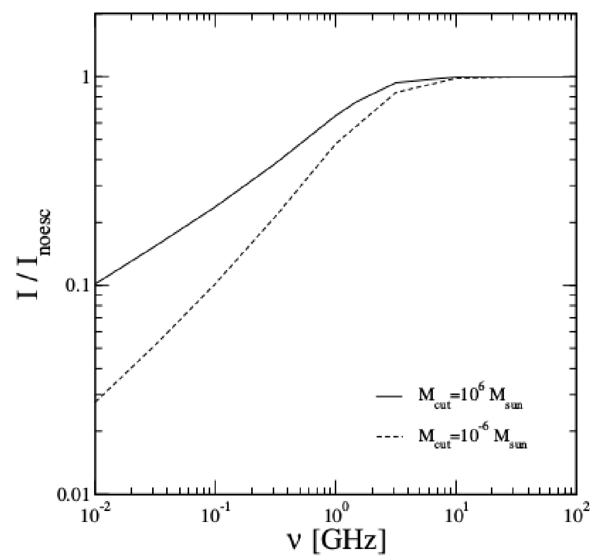
= WIMP annihilation



Confinement length << halo size

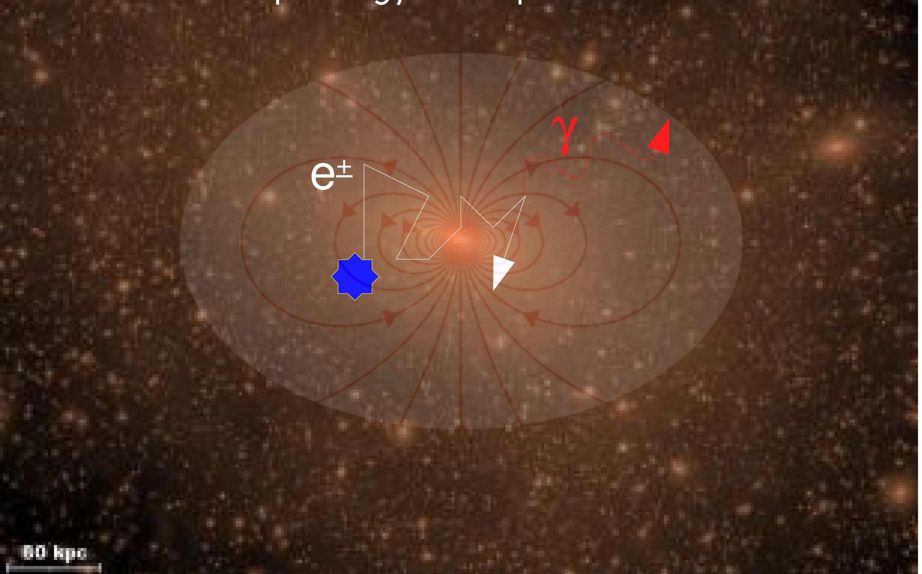
→ morphology following DM





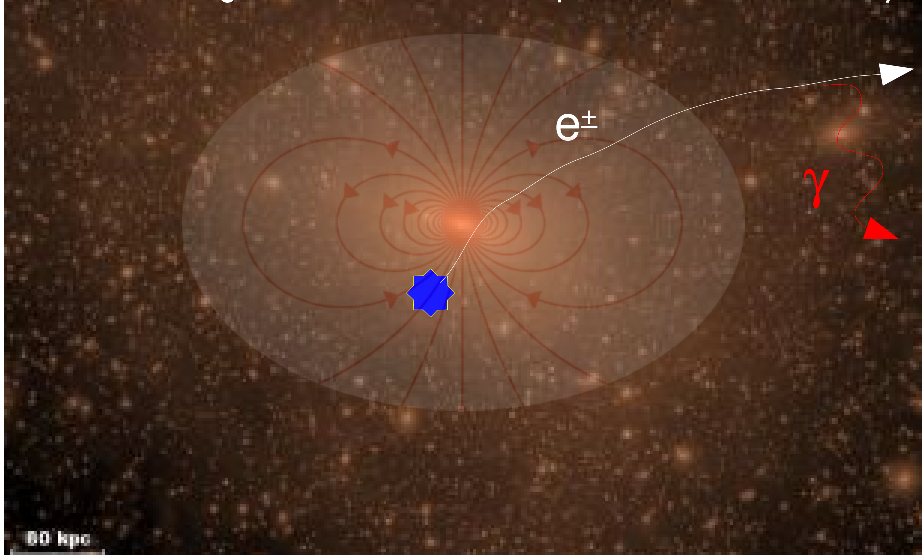
Confinement length ~ halo size

→ morphology reshaped

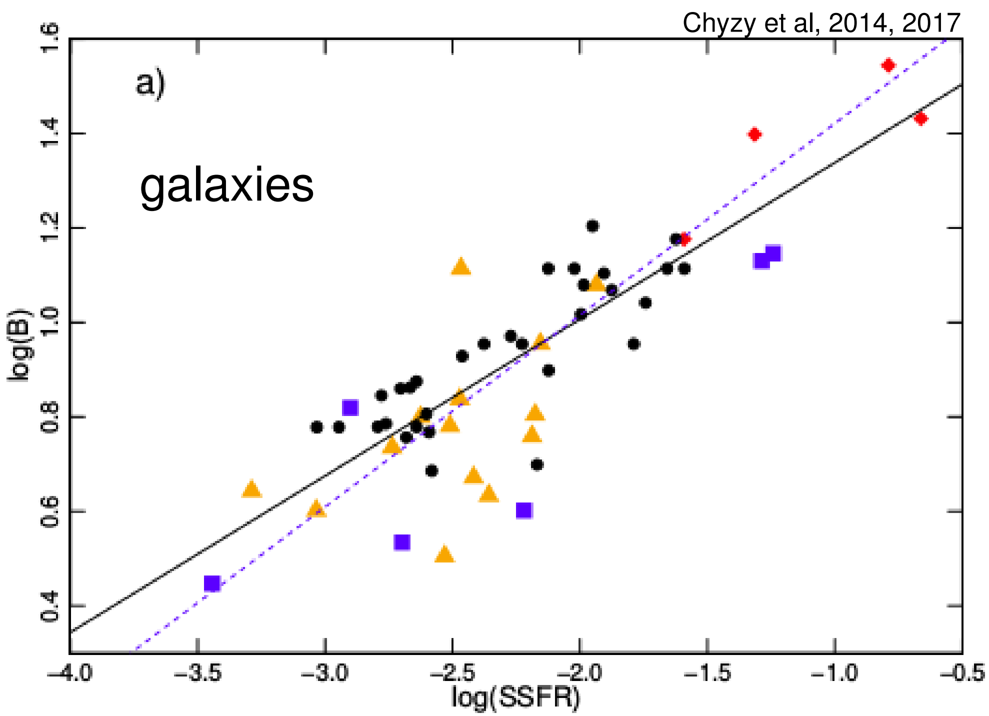


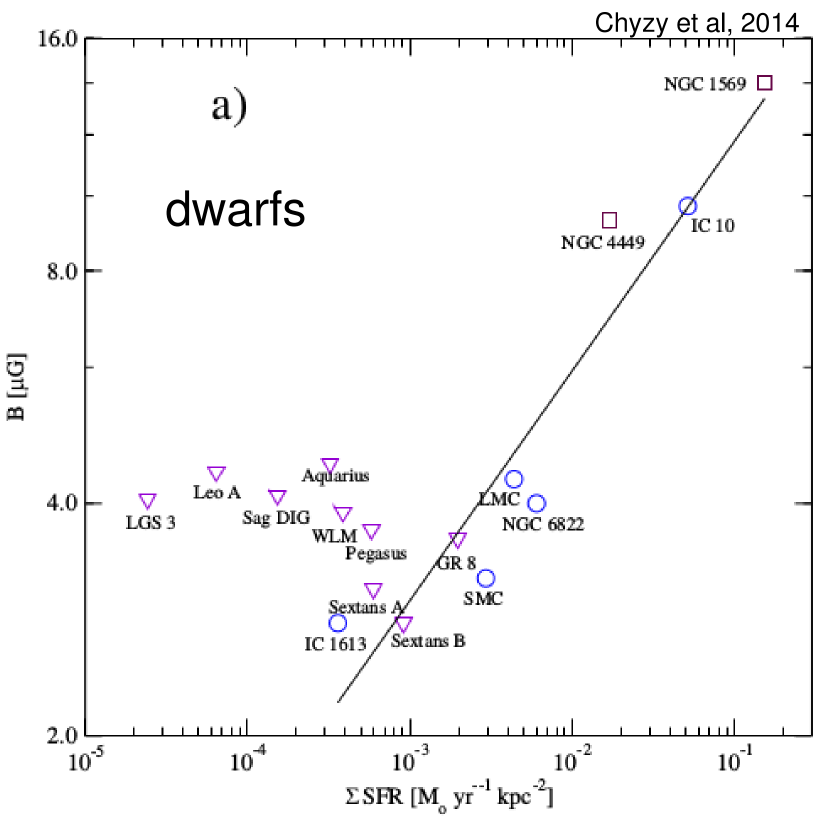
Confinement length >> halo size

→ significant fraction of power carried away



Magnetic field

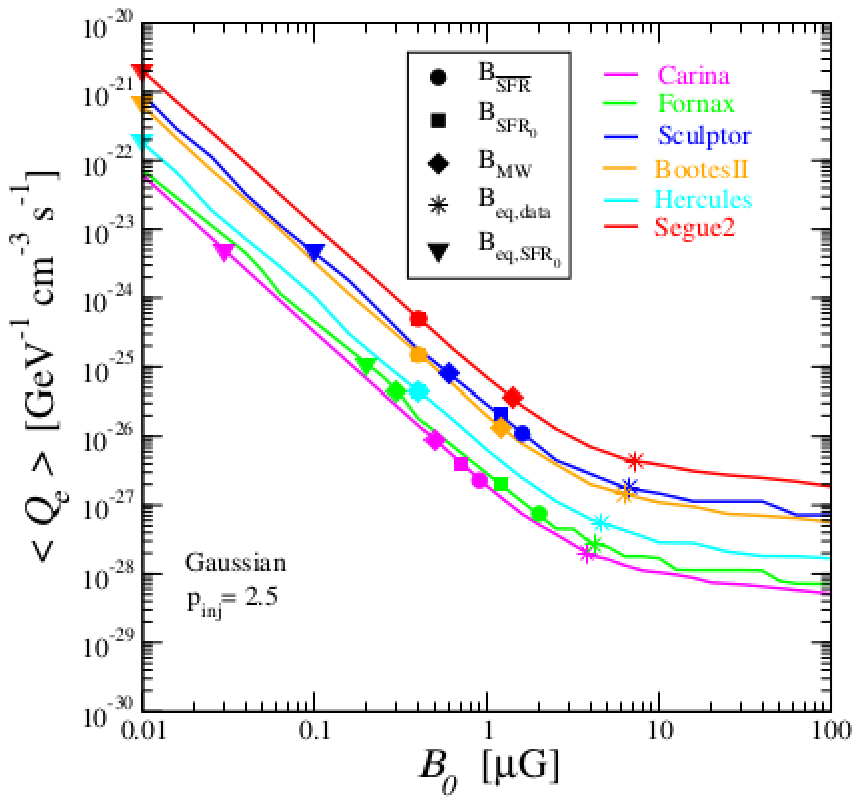


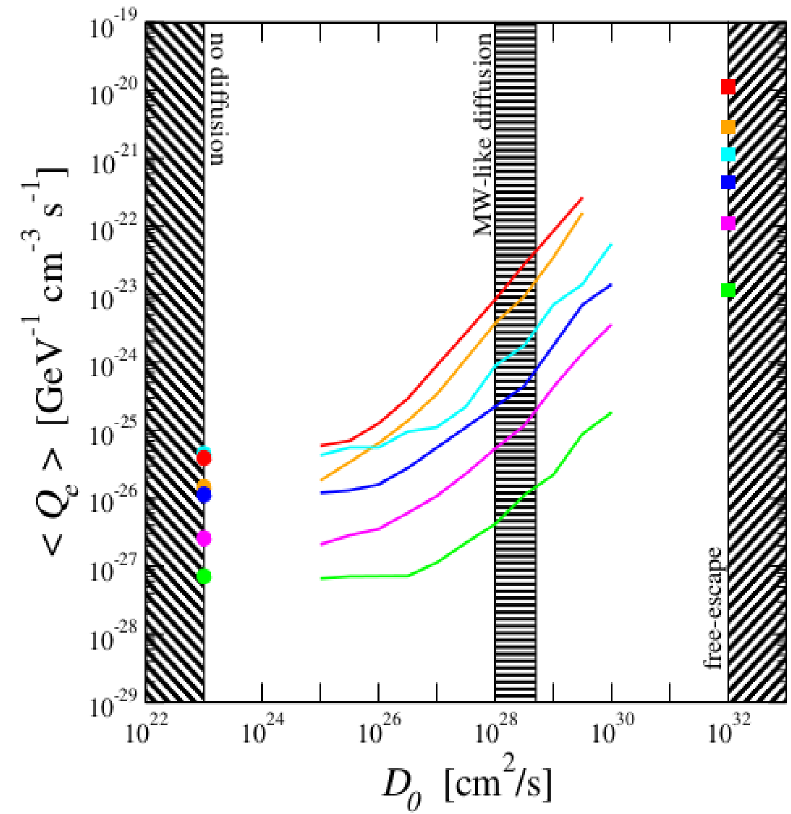


Extrapolation of empirical relations suggests a magnetic field strength around μG.

Magnetic field

dSph name	D [kpc]	r_h [$'$]	$B_{\overline{SFR}}$ [μG]	B_{SFR_0} [μG]	B_{MW} [μG]	$\langle B_{eq}^{obs} \rangle$ [μG]	$\langle U_{el}^{SFR_0} \rangle$ [10^{-16}GeV/cm^3]	$\langle B_{eq}^{SFR_0} \rangle$ [μG]
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





Single dish observations

dSph observations with the **Green Bank Telescope**

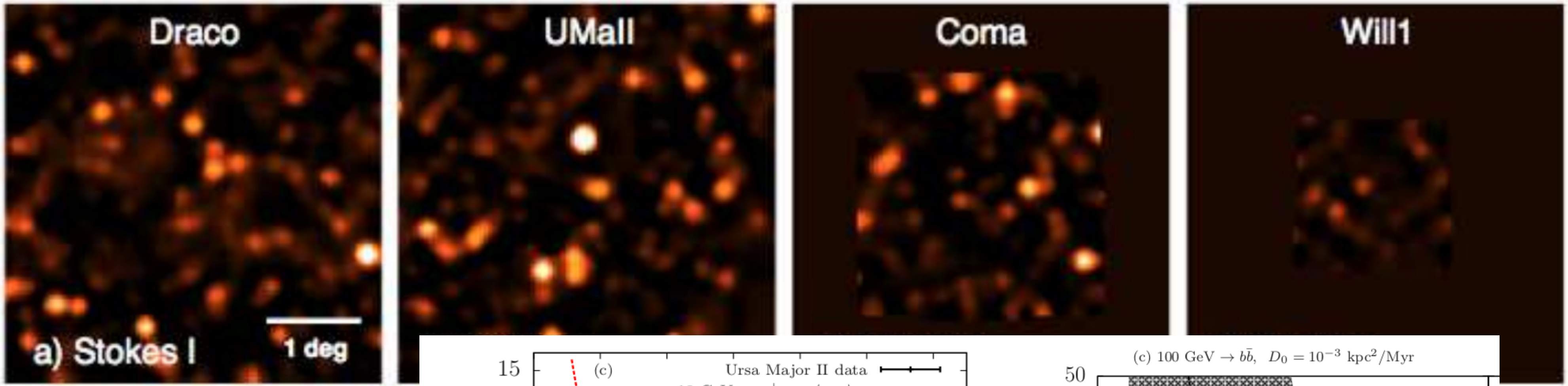
(9.1 arcmin FWHM beam)

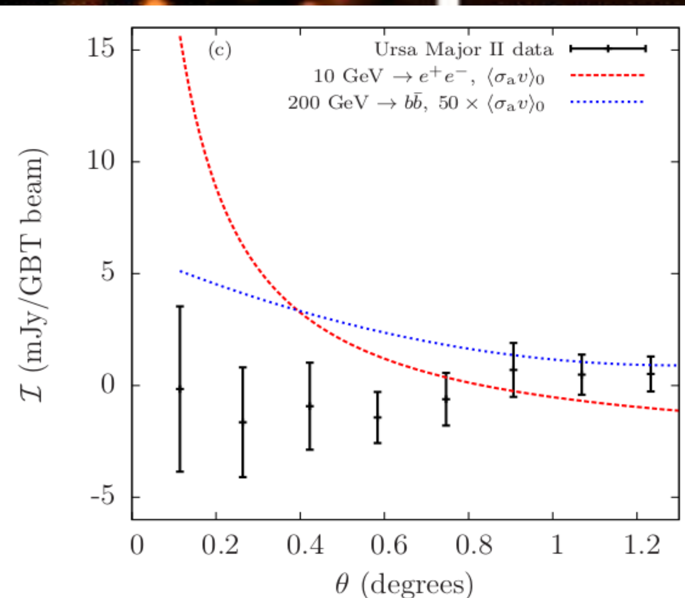
GBT v.1.0

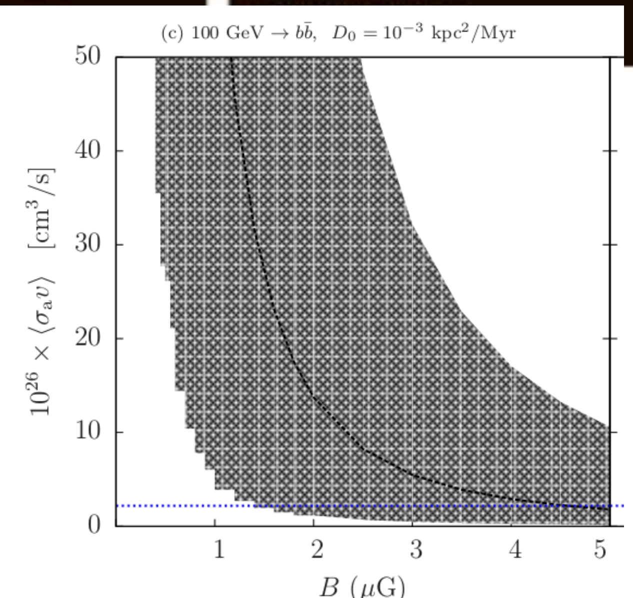
TABLE 2
OBSERVATION AND MAP PROPERTIES

[Spekkens et al. 2013]

Field (1)	Observing Dates (2)	Integ.Time (3)	Map Centre (4)	Dimensions (5)	Resolution (6)
Draco (GBT)	2007 October – December[a]	14.8 h	17^h20^m, 57°55′	4° × 4°	9.12′ × 9.12′
UMaII (GBT)	2009 February – March[b]	18.8 h	8^h52^m, 63°08′	4° × 4°	9.12′ × 9.12′
Coma (GBT)	2009 February – March	8.6 h	12^h27^m, 23°54′	2°.5 × 2°.5	9.12′ × 9.12′
Will1 (GBT)	2009 February[c]	1.8 h	10^h49^m, 51°03′	1°.5 × 1°.5	9.12′ × 9.12′
Draco (VLA)	2007 November 4	5.4 h	17^h18^m, 57°53′	3° × 4°	6.8″ × 5.3″







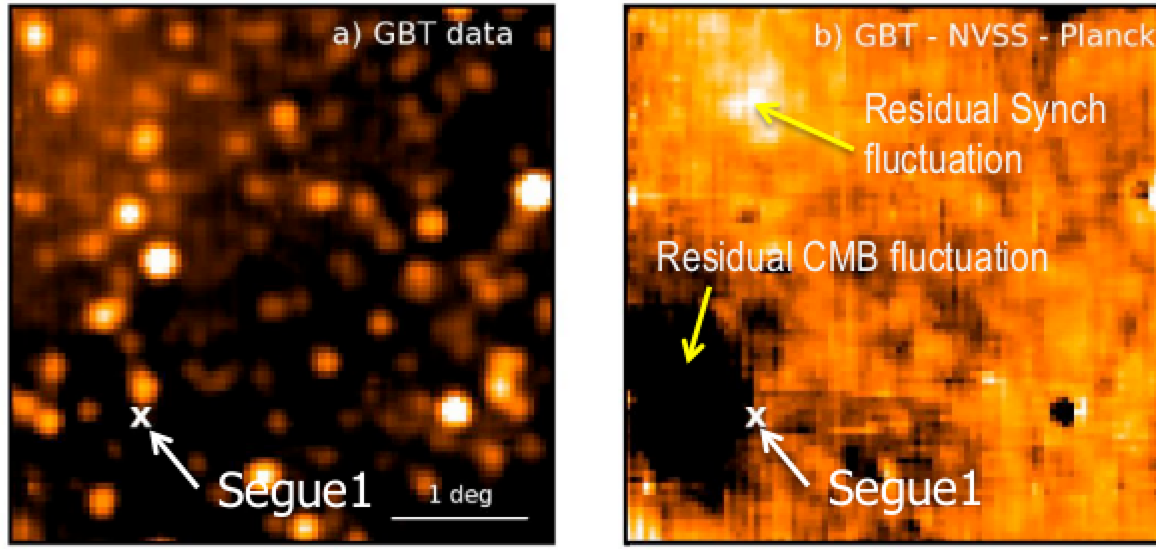
Single dish observations

Single dishes

Target: Segue1

[Natarajan et al. 2015]

GBT v.1.2

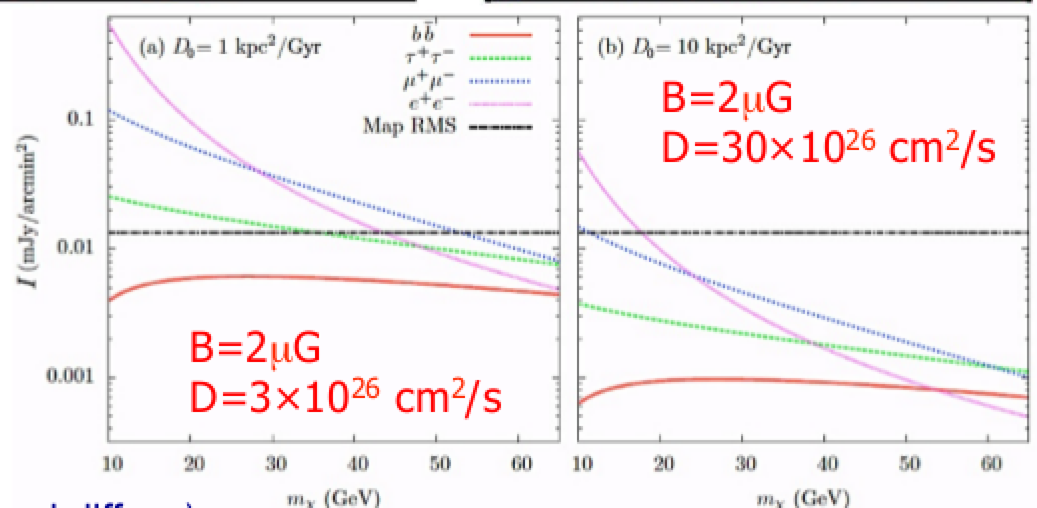


Data: GBT + NVSS + PLANCK

(9.1′) (45″) (32.24′)

Assumptions:

- $B = 2\mu G$
  ($\langle B_{ran} \rangle \sim 1\mu G$; $\sigma \sim 0.4\ \mu G$)
  uniform through the halo
- $D = (3\text{-}30) \times 10^{26}\ cm^2/s$
  ($\ll D_{MW} \approx 10^{28\text{-}29}\ cm^2/s$)



Problems:

- Confusion limited at ~ 0.26 mJy/arcmin^2
- Difficult to control foregrounds (point-like and diffuse)
- Difficult to prove DM signal at scales <10′ where it is stronger

ATCA campaigns

Program of observations performed in five campaigns with the

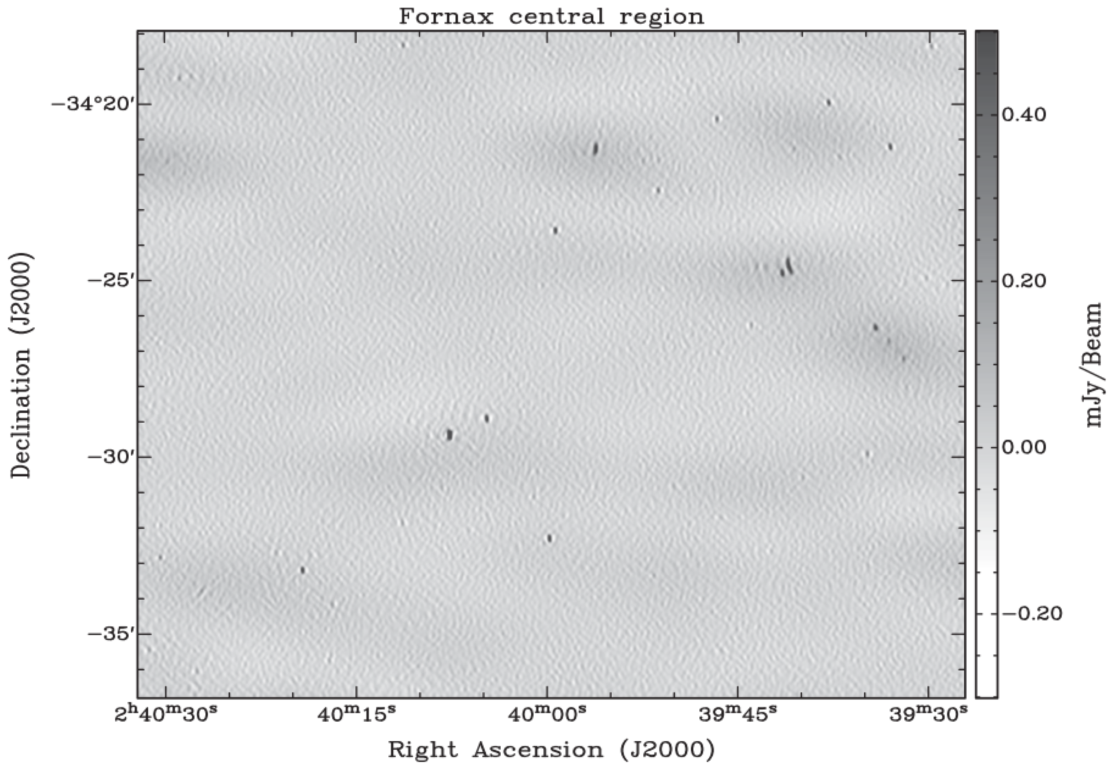
Australia Compact Telescope Array

(and KAT7)

16 cm band, 20-30 hours on each dSph

BootesII, Carina, Fornax, Hercules, ReticulumII, Sculptor, Segue2

(MR et al., MNRAS 2015a, MNRAS2015b JCAP2014, JCAP 2017)



Long baselines

to map background sources

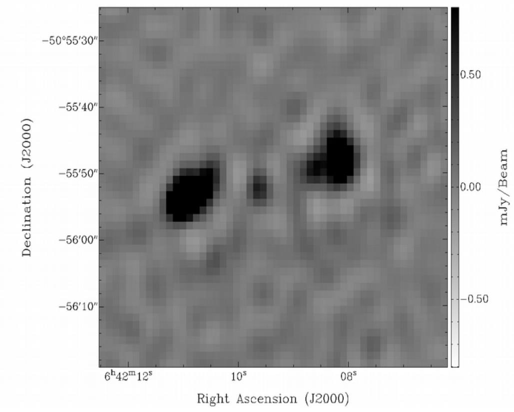
Short baselines

to search for diffuse emission

Background sources

More than 2000 sources in the catalogue (> 5σ)

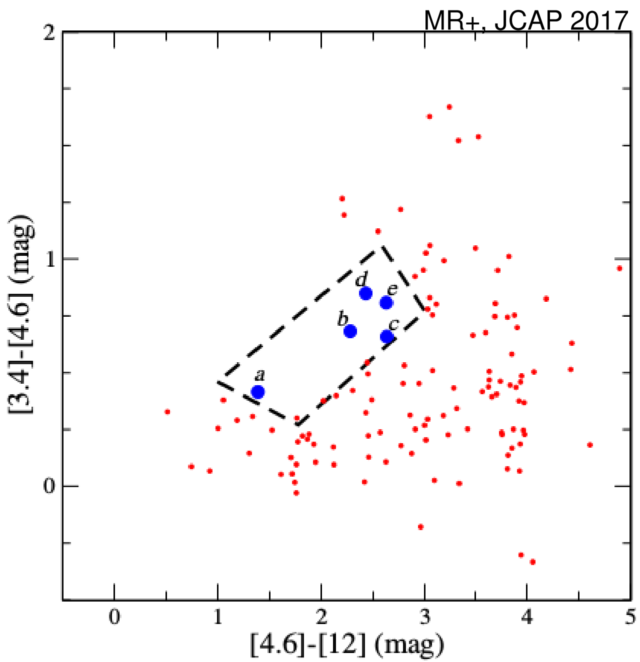
Good agreement with FIRST/NVSS/SUMSS and with theoretical models of number counts



The case of Reticulum II and counterpart for possible γ-ray excess

id	J2000 RA			J2000 DEC			Distance arcmin	Flux density mJy
a^*	03	34	46.0	−54	08	43.7	9.9	1.26 ± 0.07
b	03	34	29.6	−53	54	44.4	13.3	0.59 ± 0.04
c^*	03	35	49.4	−53	52	52.6	10.2	2.39 ± 0.15
d	03	34	52.5	−53	50	19.4	14.5	0.53 ± 0.04
e	03	35	32.4	−54	04	12.1	1.7	0.89 ± 0.05

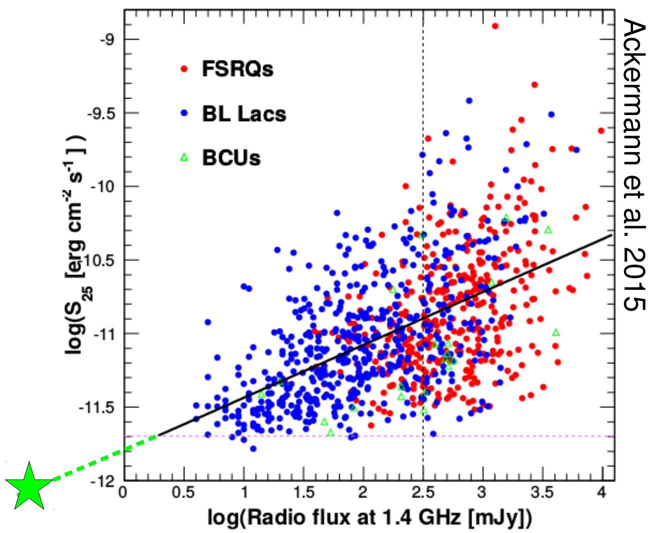
$\beta > -1$



γ-rays:

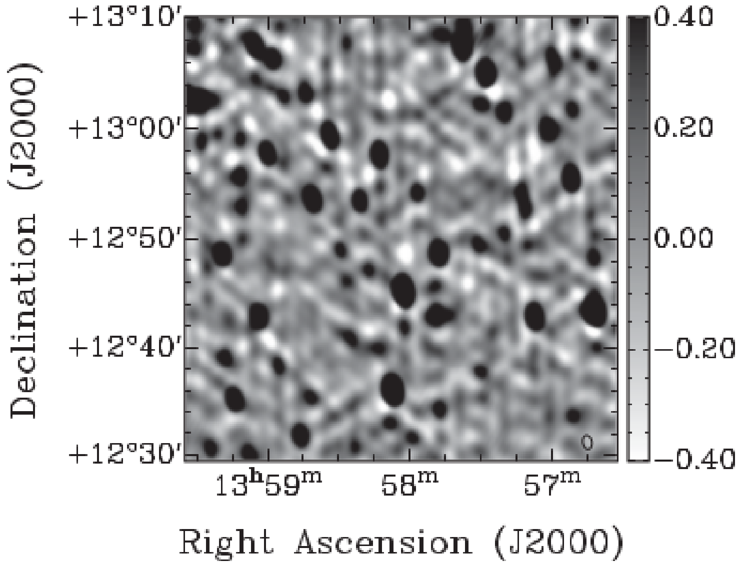
$\Gamma \sim 1.5 \rightarrow$ BL Lac?

$S_{25} \sim 10^{-12}$ erg cm^{-2}s^{-1}

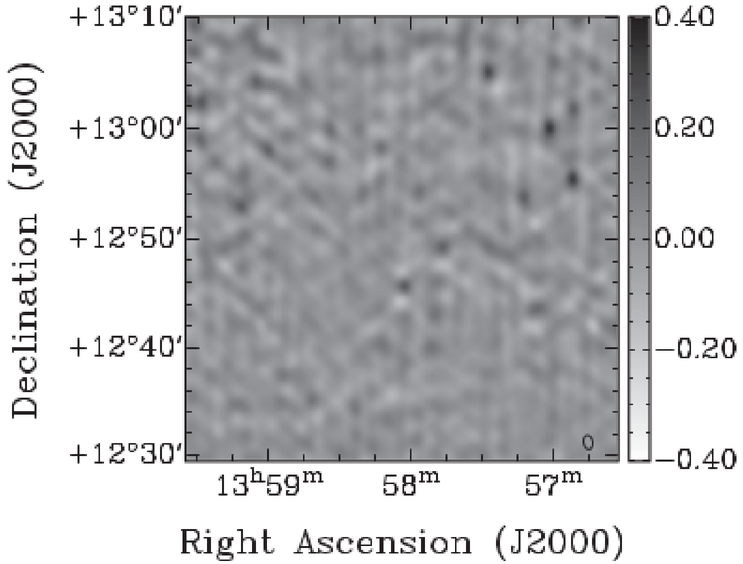


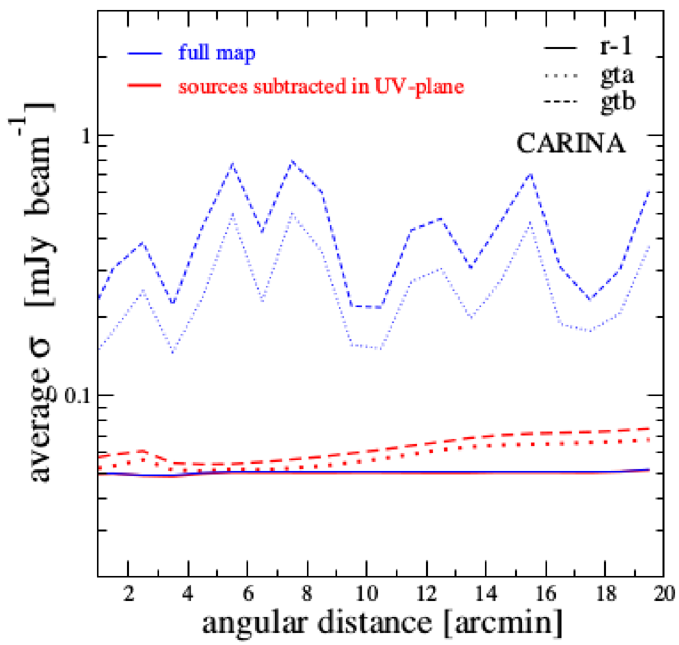
Source subtraction

Short-baseline map



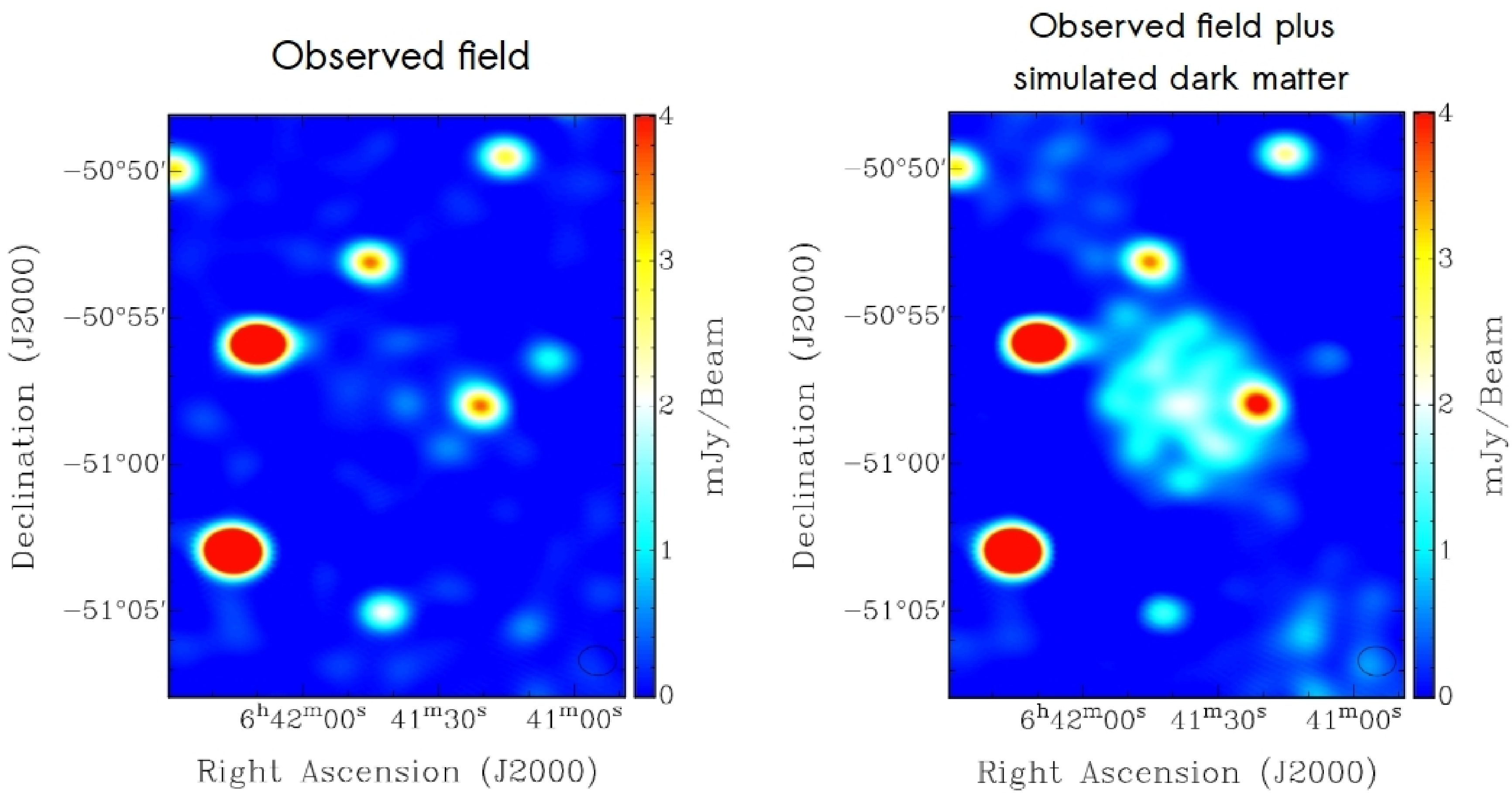
Source subtraction in UV-plane





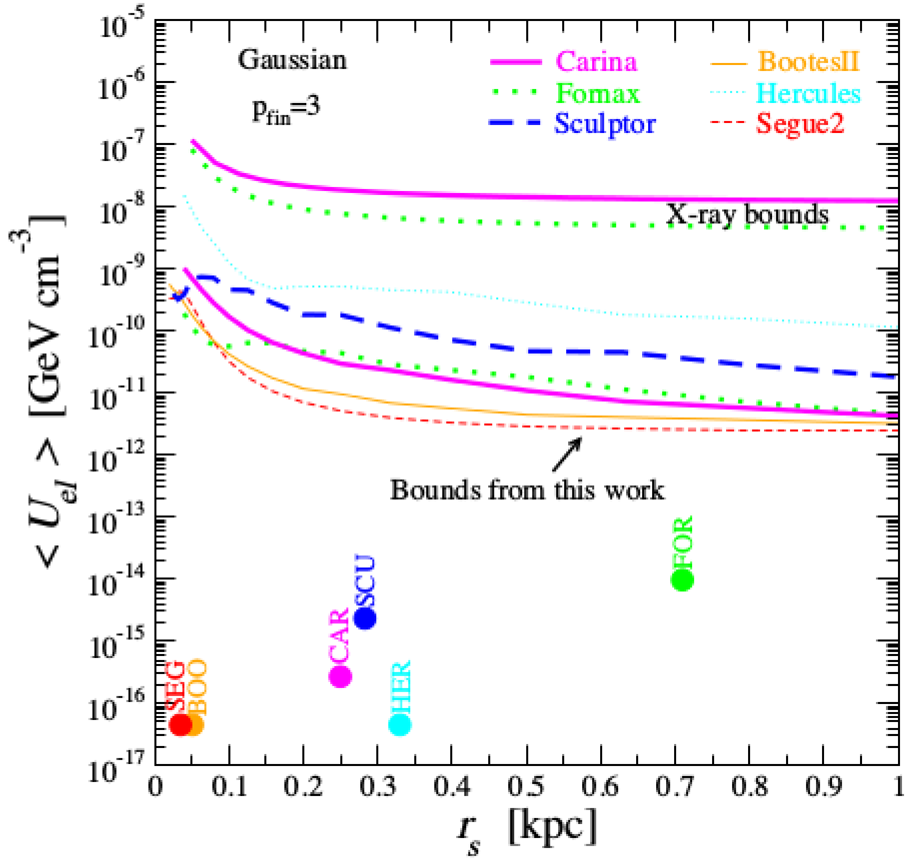
→ **Source subtraction is necessary** to bring the noise down from its confusion level

WIMP hunt


Observed field
Observed field plus
simulated dark matter
−50°50′
−50°55′
−51°00′
−51°05′
Declination (J2000)
6h42m00s 41m30s 41m00s
Right Ascension (J2000)
mJy/Beam
0
1
2
3
4

Limits on diffuse emission

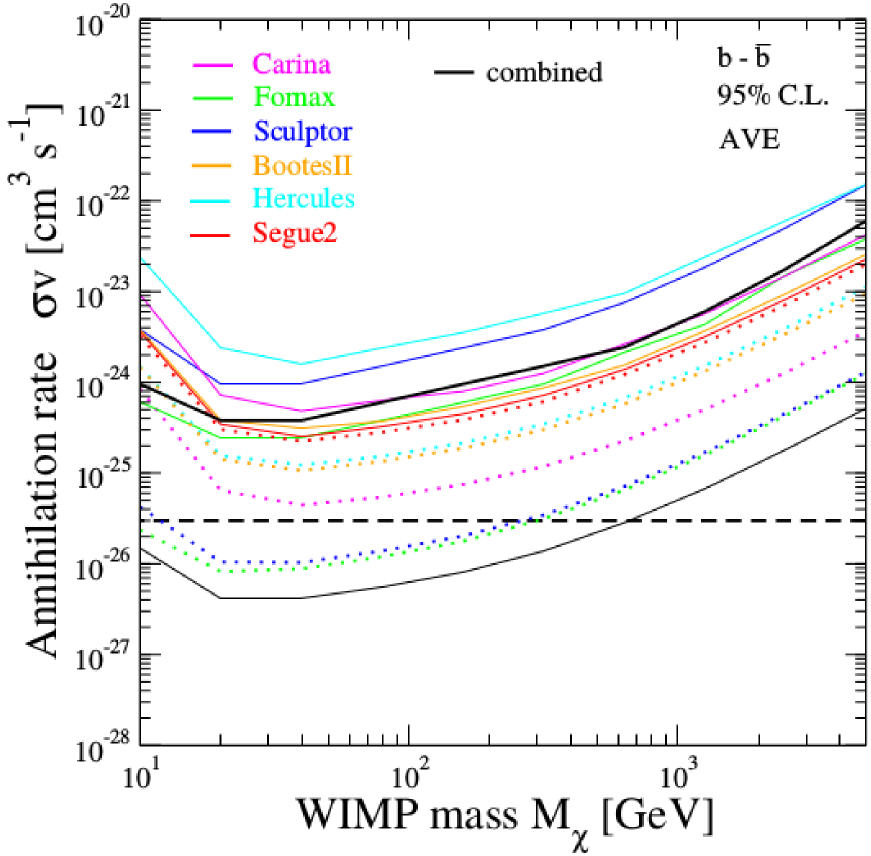
No significant detection of an extended (few arcmin) emission.

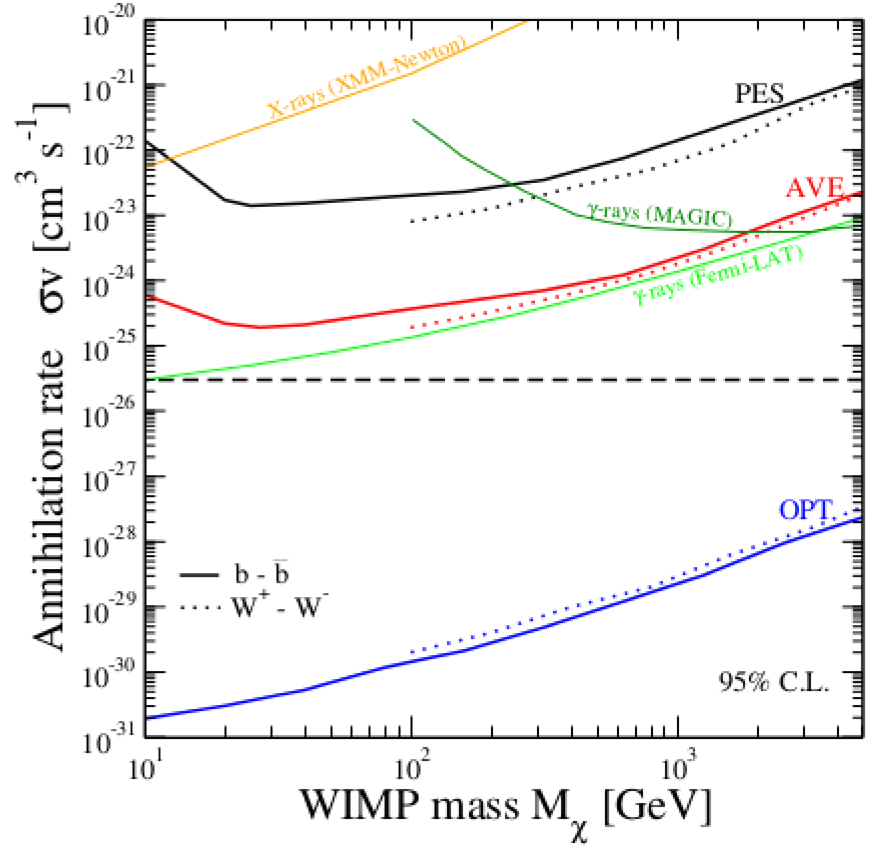


Bounds are far from the expected non-thermal emission related to star formation

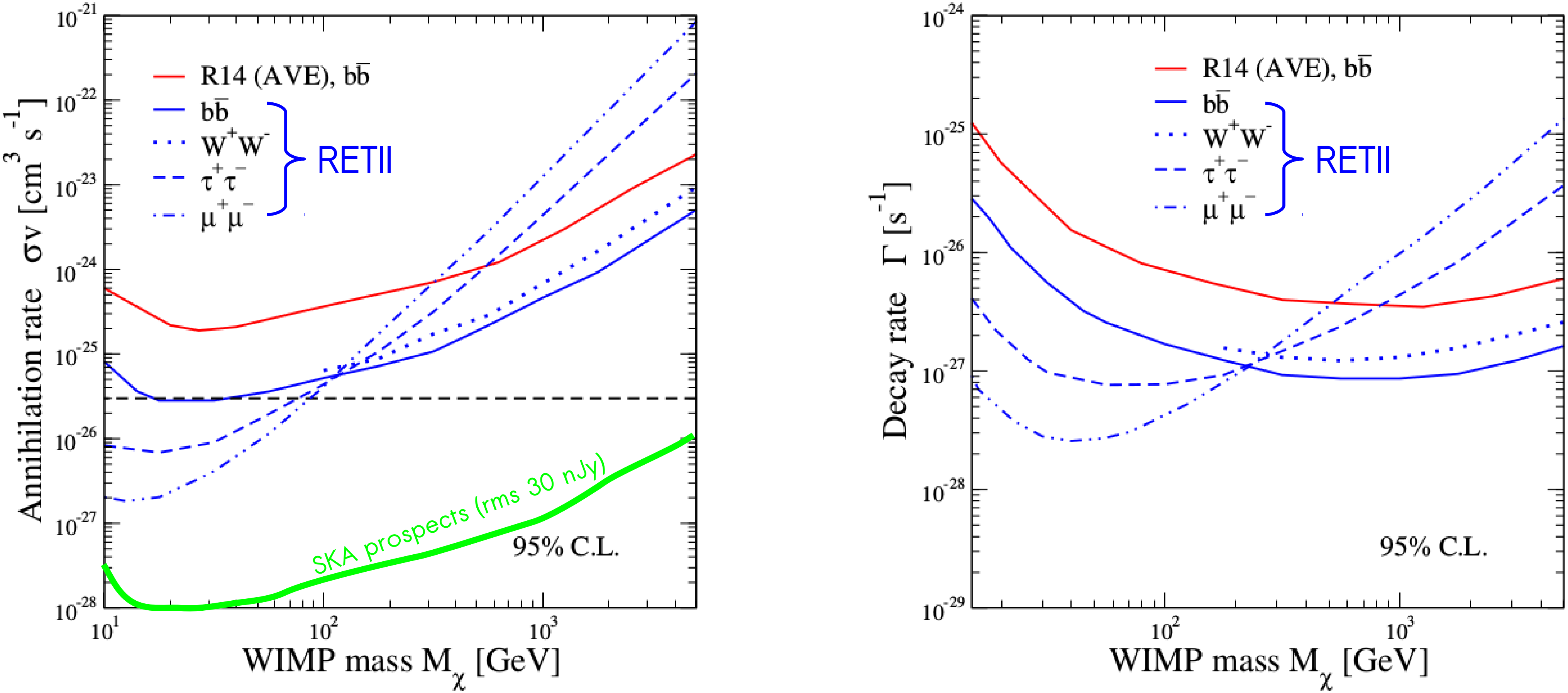
DM bounds

Name	magnetic field	diffusion scheme	DM profile
OPT	B_{eq}^{obs}	loss-at-injection	Einasto
AVE	$\max(B_{\overline{SFR}}, 1\,\mu G)$	$D = 3 \cdot 10^{28}\,(E/\mathrm{GeV})^{0.3} \exp(r/r_*)\,\mathrm{cm}^2/\mathrm{s}$	NFW
PES	B_{SFR_0}	$D = 10^{30}\,(E/\mathrm{GeV})^{0.3} \exp(r/r_*)\,\mathrm{cm}^2/\mathrm{s}$	Burkert





Impact on WIMP parameter space

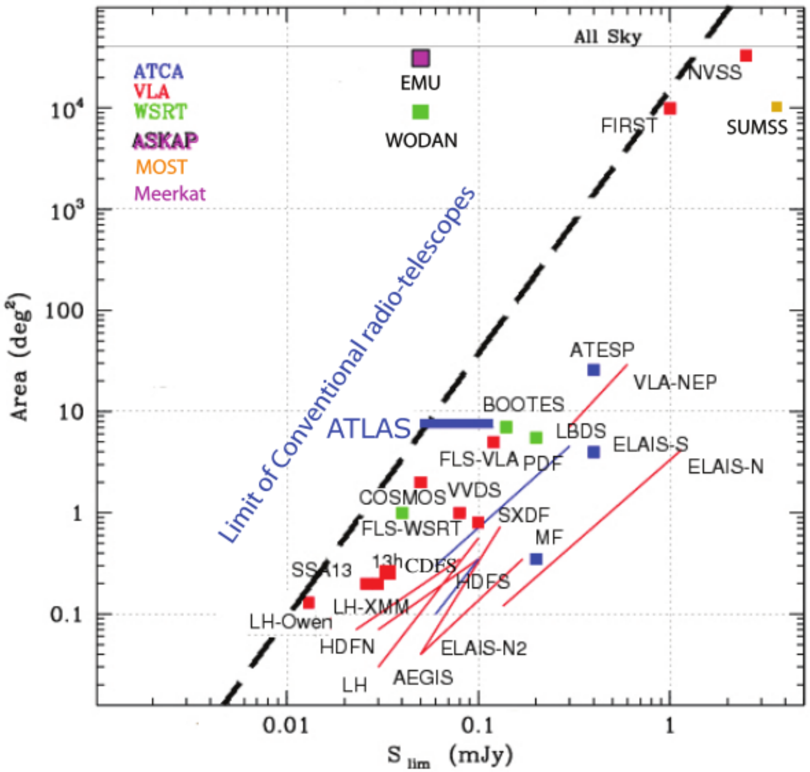


Within the next 10 years and regardless of the astrophysical assumptions,
it should be possible to **progressively close in on the full parameter space of WIMPs**.

EMU

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**



What can SKA tell us ?

There is one serious problem with current radio observations

$$F_{radio} \sim n_{e,DM} \cdot B^{(s_{DM}+1)/2} \cdot \nu^{-(s_{DM}-1)/2}$$

difficulty to estimate the magnetic field simultaneously with DM particle density

SKA can measure B independently of DM-produced secondary electrons

Faraday Rotation

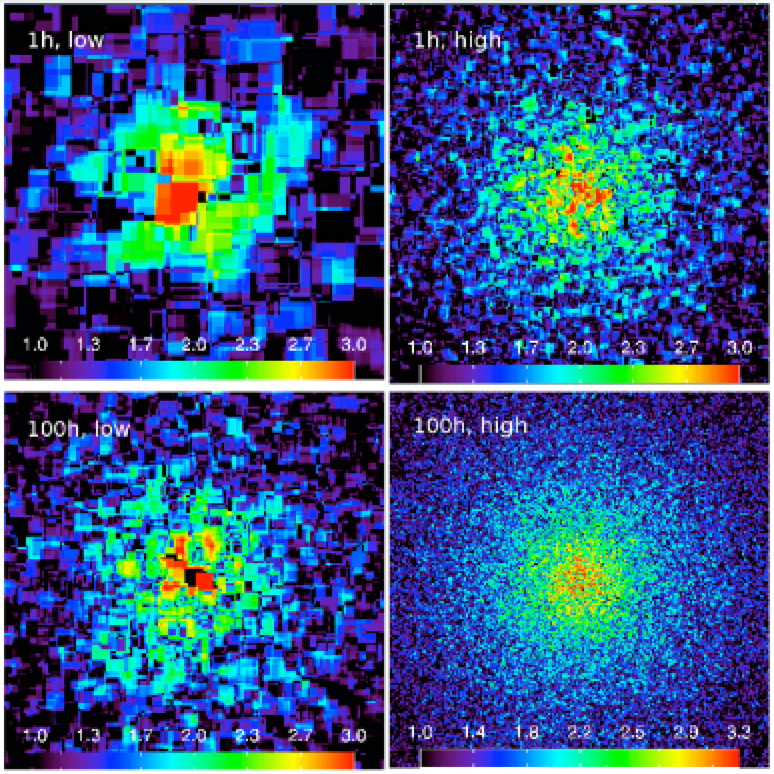
$$\mathrm{RM} = \frac{e^3}{2\pi m^2 c^4} \int_0^d n_e(s) B_{\parallel}(s)\, \mathrm{d}s,$$

Polarization synchrotron

$$p = \frac{P}{I} = p_0 \frac{B_{u,\perp}^2}{B_{t,\perp}^2},$$

Nearby objects: SKA will measure 300 RMs per deg2 with z=0-0.2

Distant objects: SKA will measure 10 RMs per deg2 with z=0.5-1



[SKA FR maps: Bogdanovic et al. 2011]

Summary

IF dark matter is made of WIMPs

and

IF magnetic field in dSph is non-negligible

→ radio signal under the reach of current/near-future radio telescopes