Searching for Dark Matter through Radio Observations: Present and Future

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Kavli IPMU Seminar,
Tokyo, Dec 12, 2013

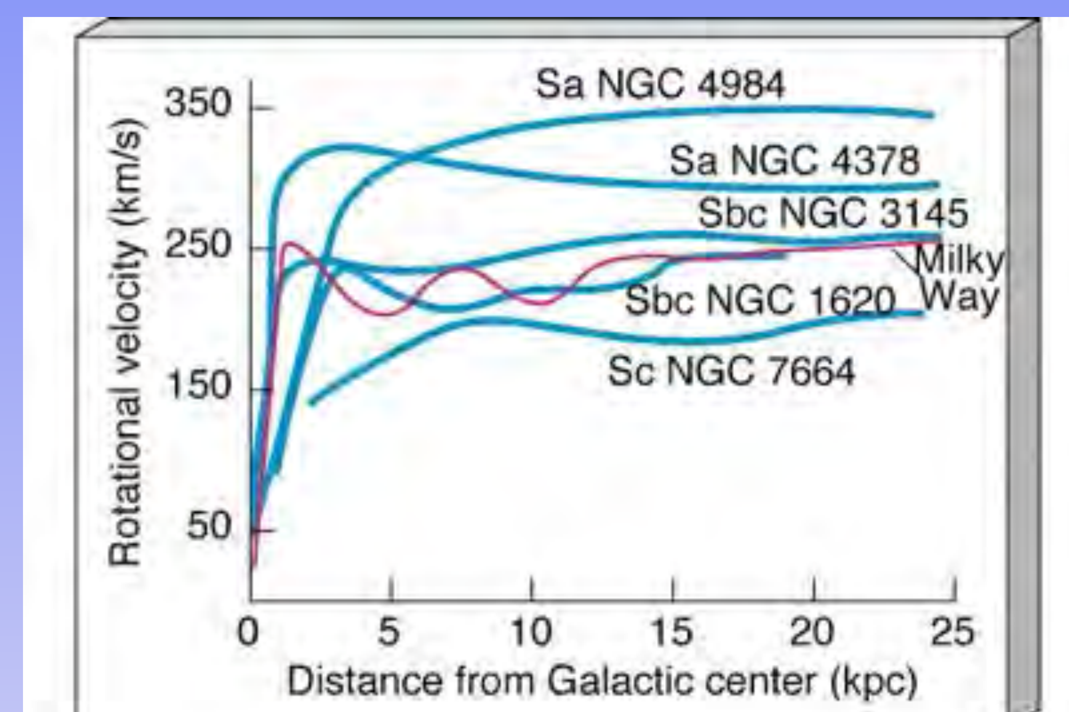
Early evidence for dark matter

Fritz Zwicky and the Coma Cluster
1933 Helvetica Physica Acta

gr/cm³. Es ist natürlich möglich, dass leuchtende plus dunkle (kalte) Materie zusammengenommen eine bedeutend höhere Dichte ergeben, und der Wert $\varrho \sim 10^{-28}$ gr/cm³ erscheint daher nicht

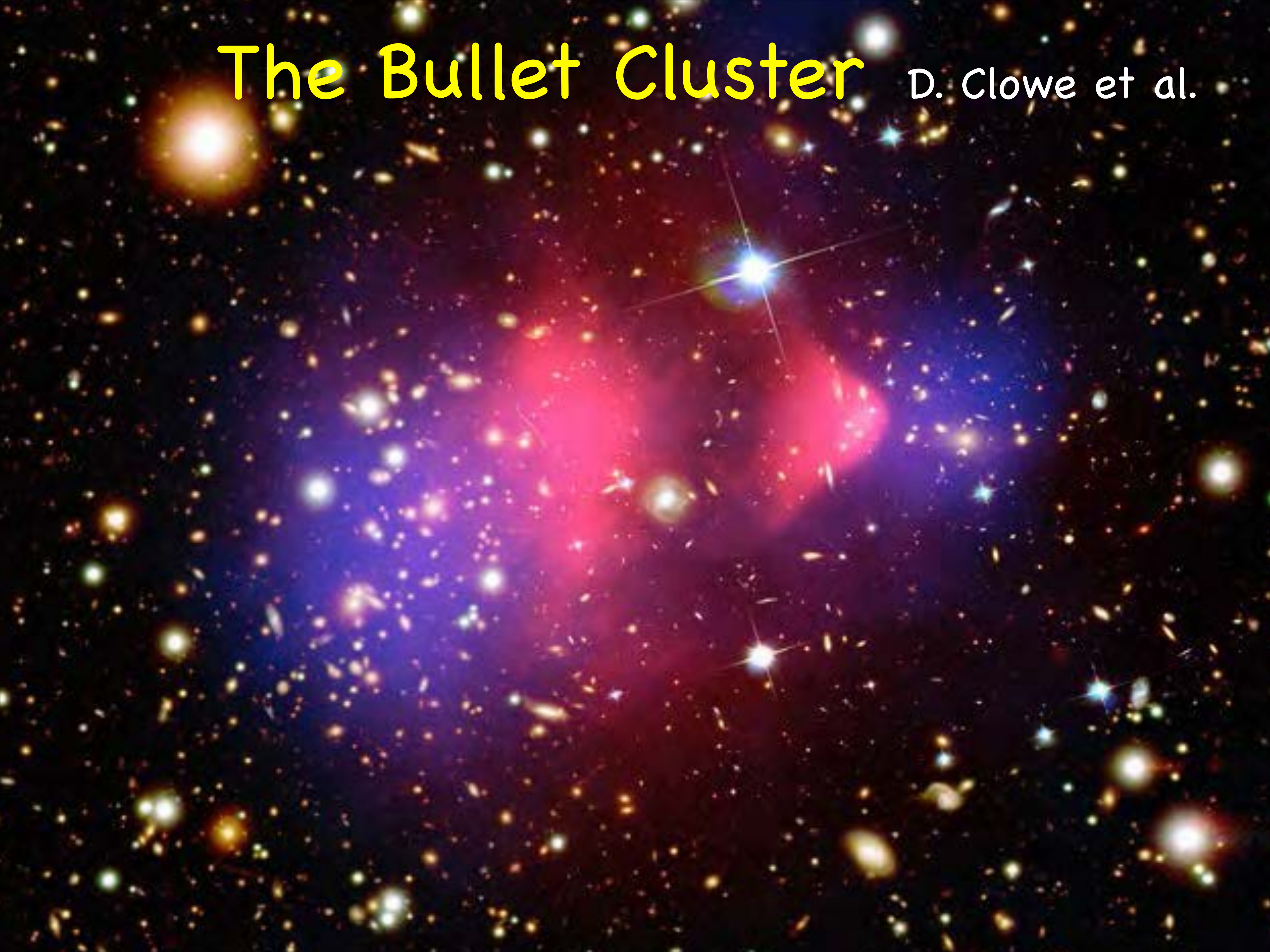
Dark Matter or Modified Gravity?

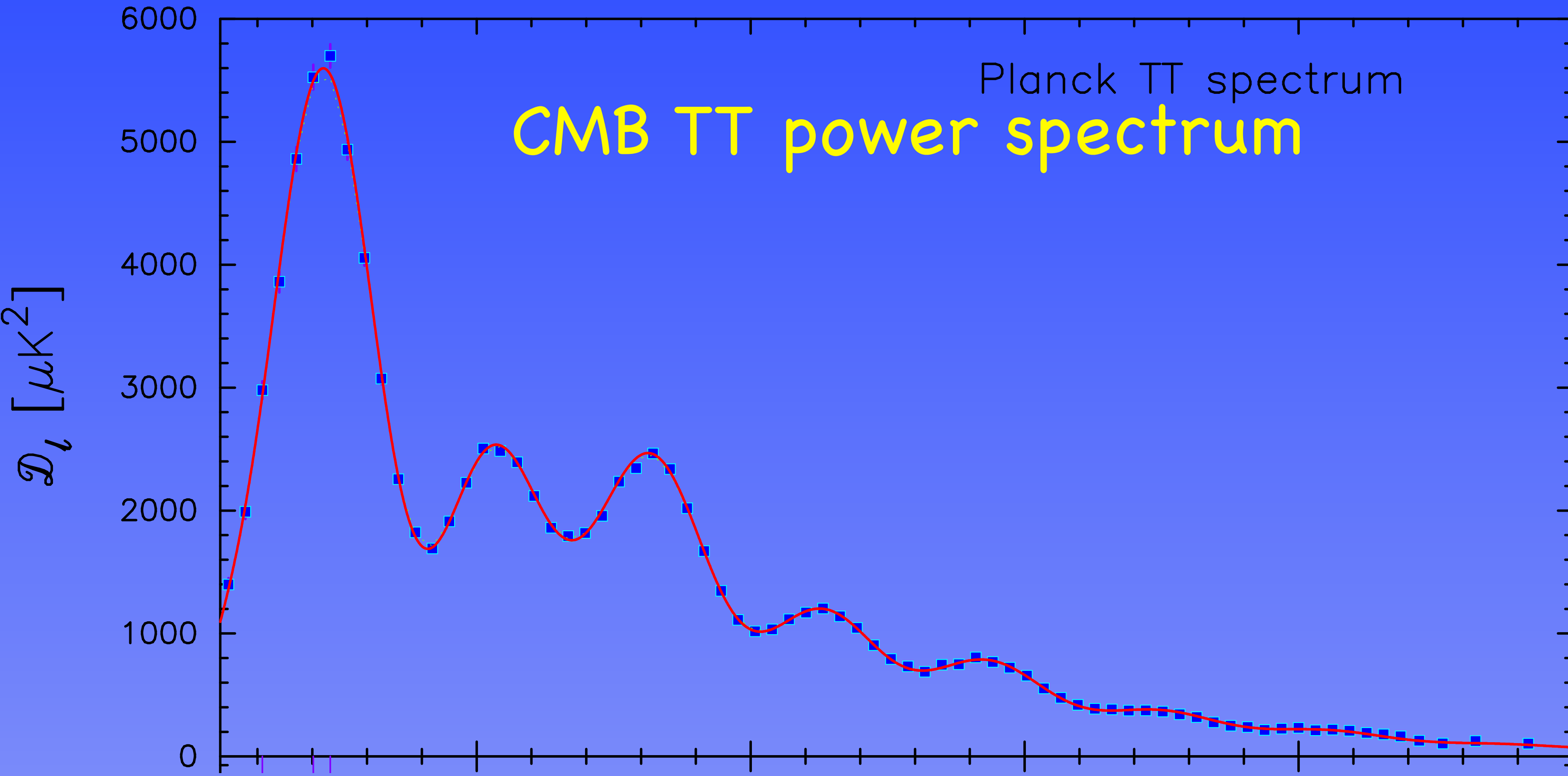
Vera Rubin - Flat rotation curves
1970's

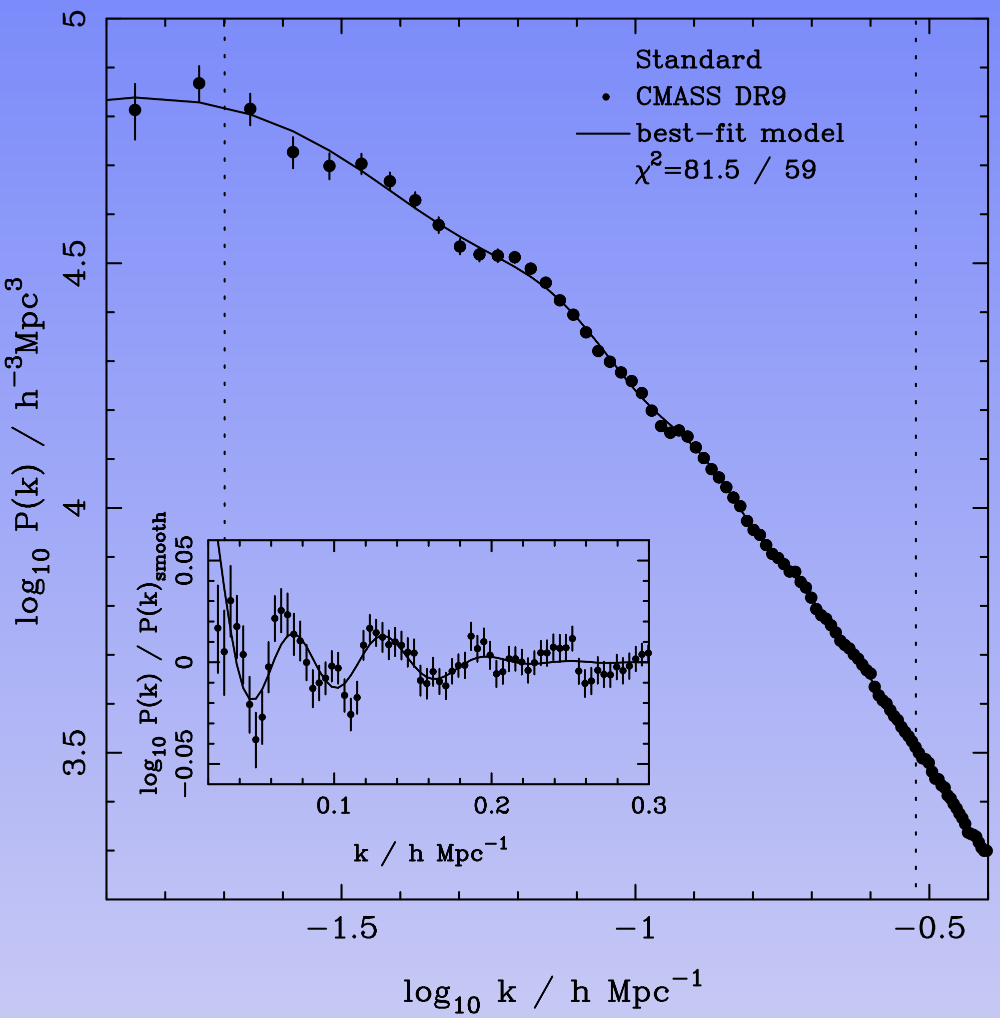


The Bullet Cluster

D. Clowe et al.







Matter power spectrum
SDSS

Outline

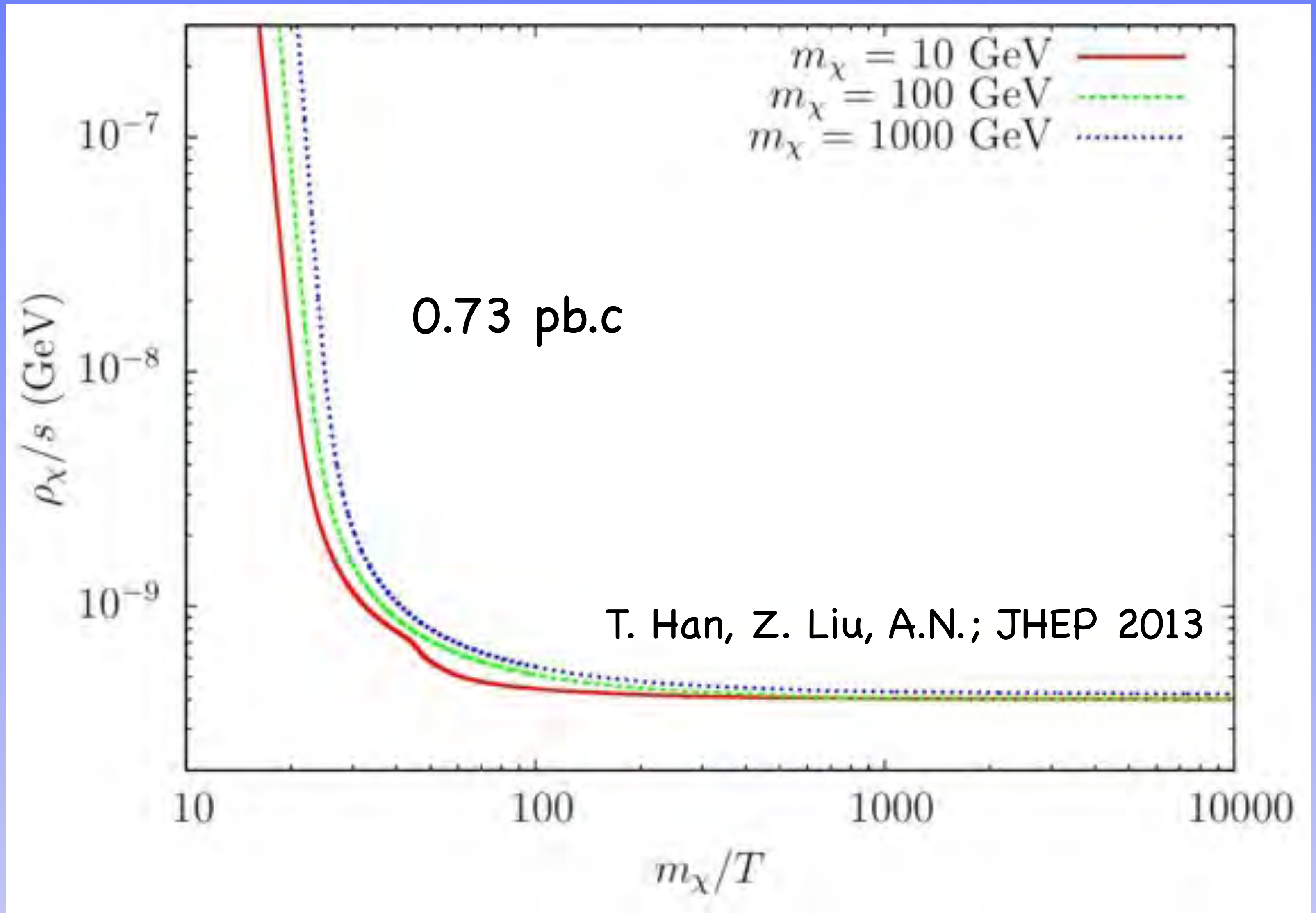
Dark Matter: Is it light and weakly interacting?
DAMA, CoGeNT, CRESST, and CDMS think so.
LUX, Xenon, etc do not.

If the dark matter is light, we could search for it through indirect means:

1. The CMB is well understood. Experiments are sensitive. We can use the CMB anisotropies to study dark matter.
2. Dwarf galaxies are dark matter dominated: High M/L Probing dark matter through radio observations.
3. The redshifted neutral 21cm observations are sensitive to the IGM - and hence to WIMP dark matter annihilation.

Why consider WIMPs ?

1. They were suggested to solve problems in particle physics unrelated to dark matter.
2. They predict the correct relic density independent of mass.
3. Presence of weak interactions allows us to make observable predictions.

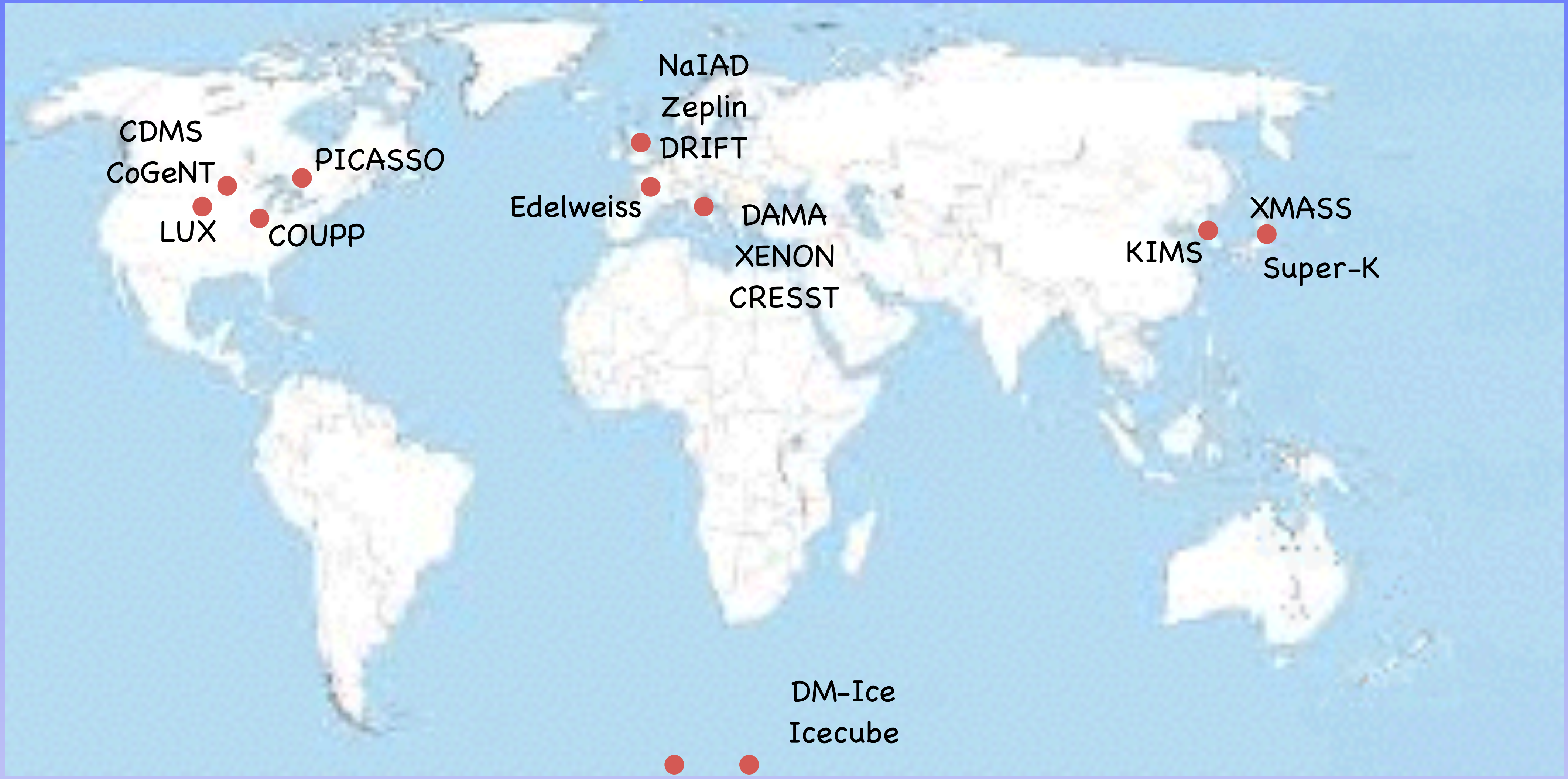


"Join the dark side"

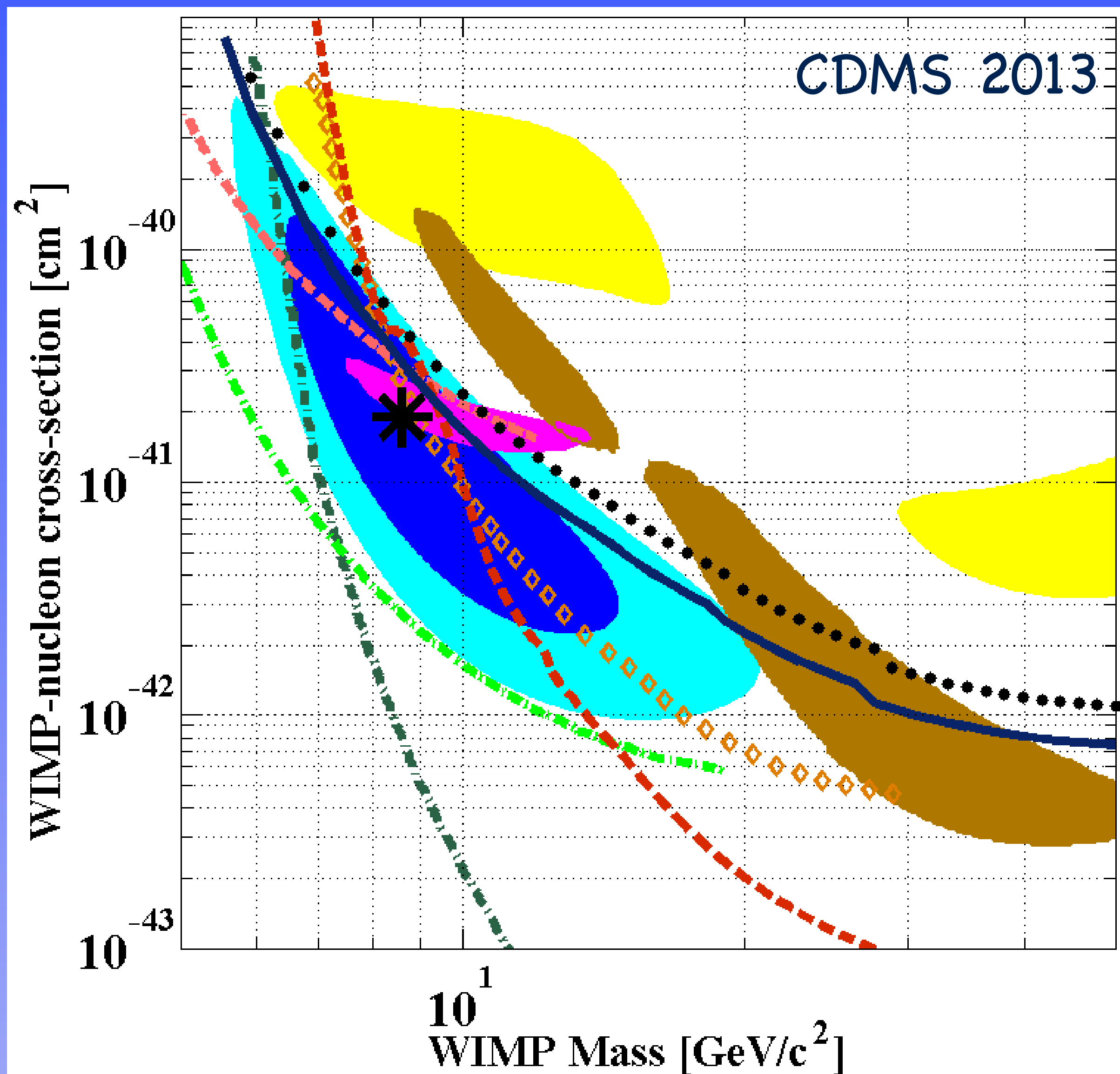
Dark matter detection expts worldwide

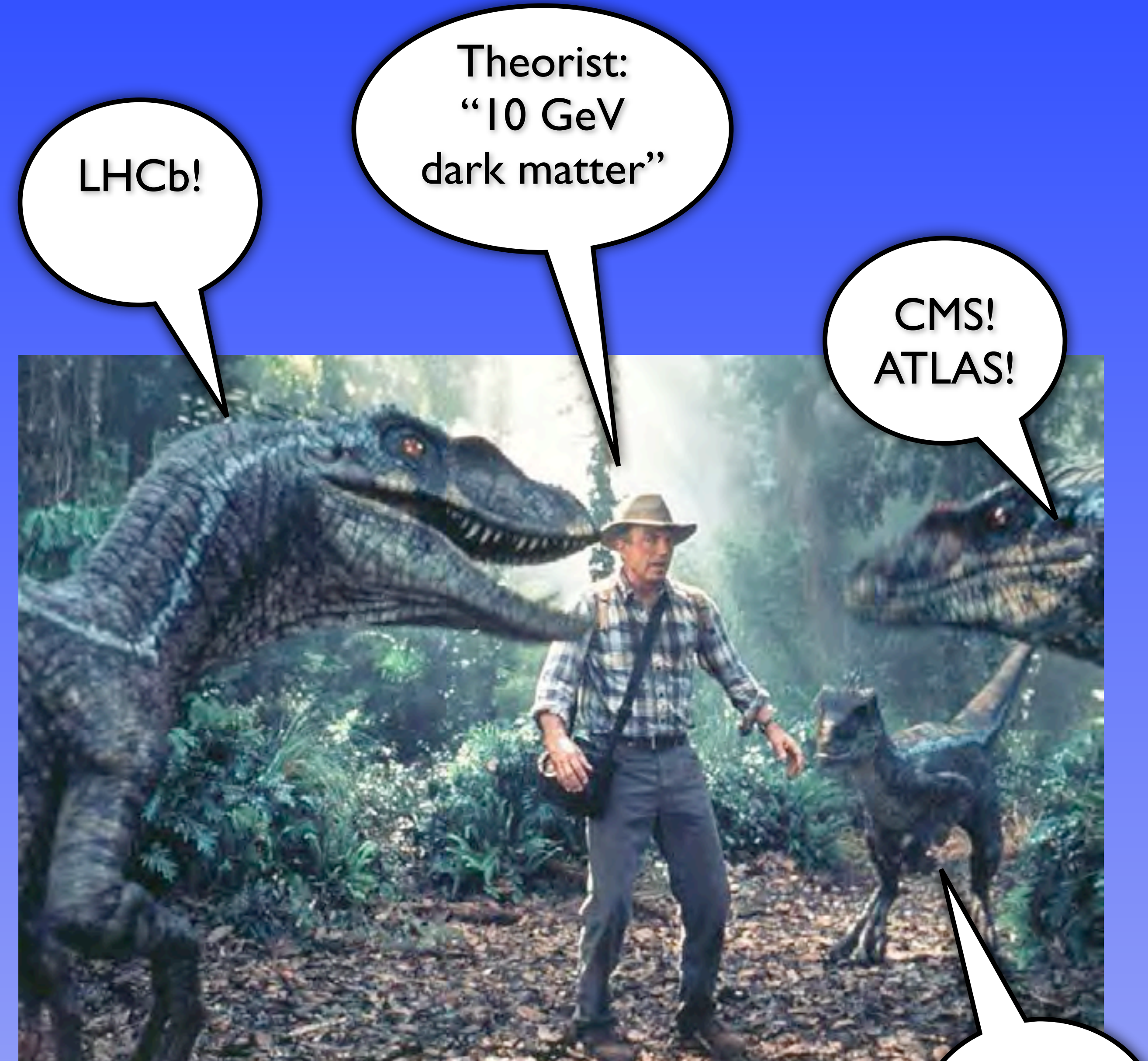
Fermi Telescope

Large Hadron Collider



Direct detection experiments





A healthy field :)

Theory has to pass the expt. tests

B_s decay branching ratio

No sign of CP-odd Higgs

LUX sees no sign of DM

Direct Detection Expts: mass 8-15 GeV

Indirect detection experiments can test this!

$$\Phi = \frac{\langle \sigma_{\rm a} v \rangle}{m_\chi} \; \rho_\chi^2$$

The electromagnetic spectrum

< 10-30 MHz
Opaque

70 MHz
HI at z = 20

1420 MHz
HI at z = 0

143 GHz
CMB Sky

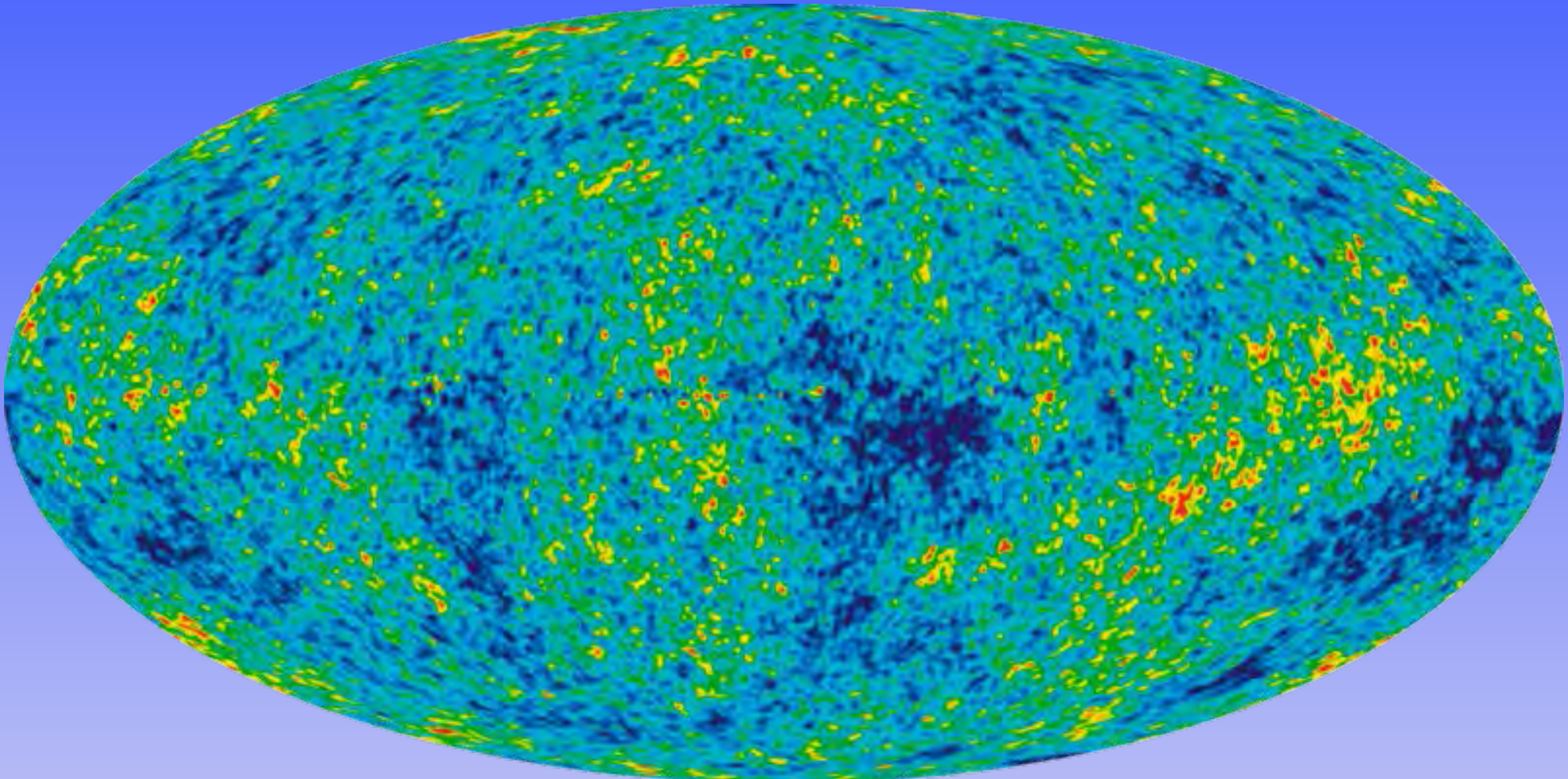
X-rays,
Gamma rays

SCI-HI
21cm experiment

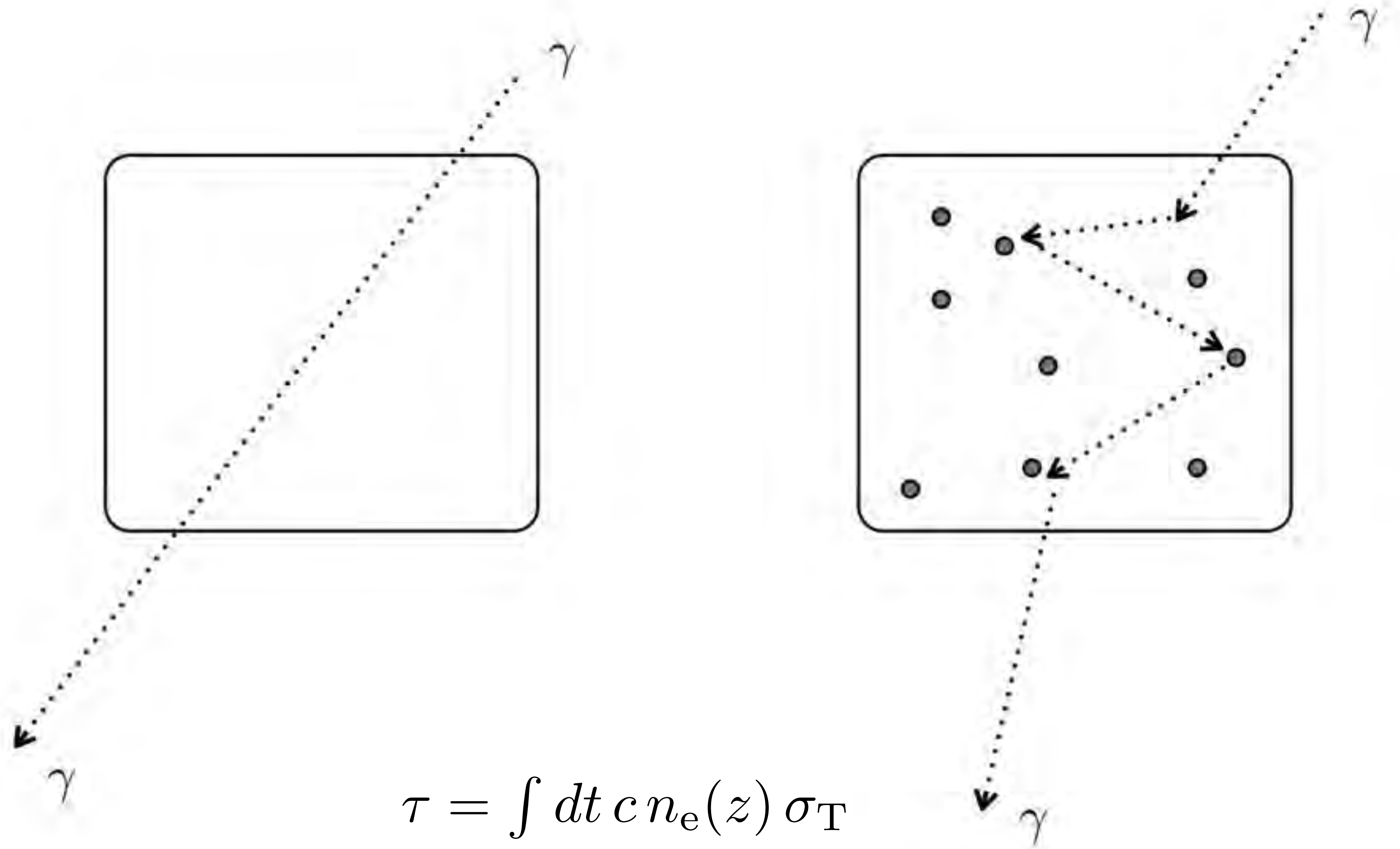
Radio obs. of
dwarf galaxies

Planck, ACT, SPT, etc

I. Using the CMB to probe dark matter.

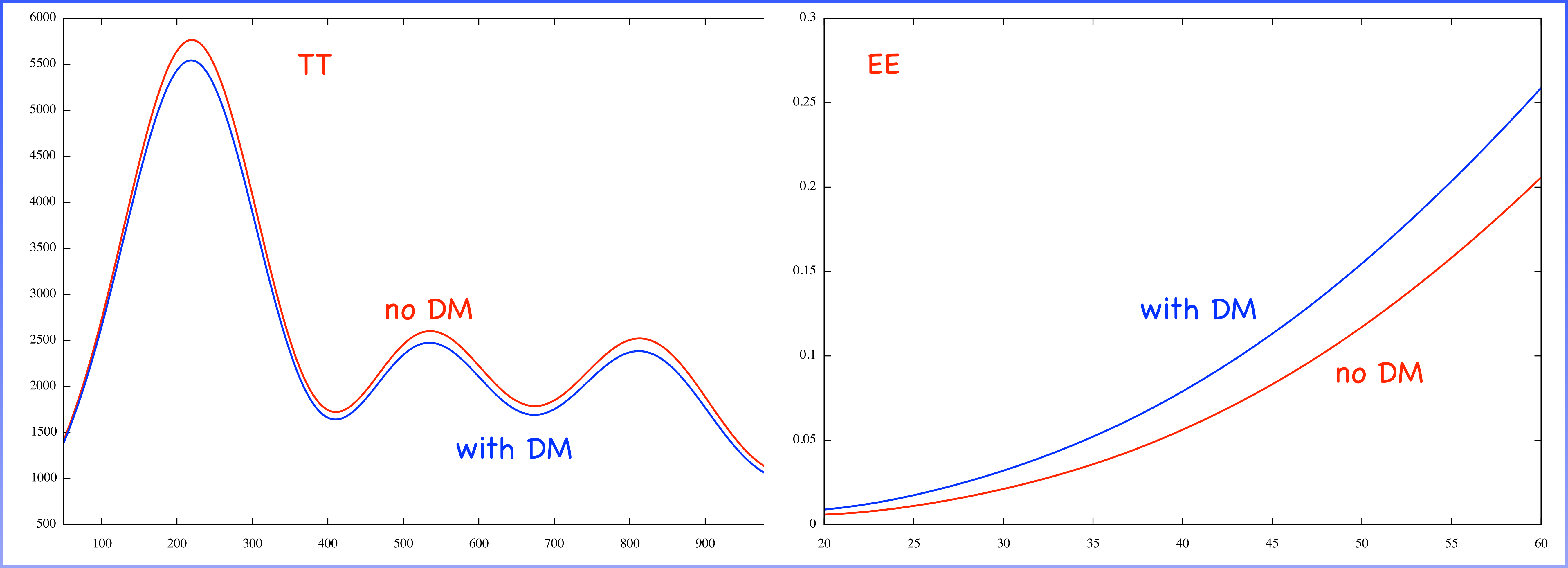


DM annihilation to standard model particles



$$\tau = \int dt\, c\, n_{\rm e}(z)\, \sigma_{\rm T}$$

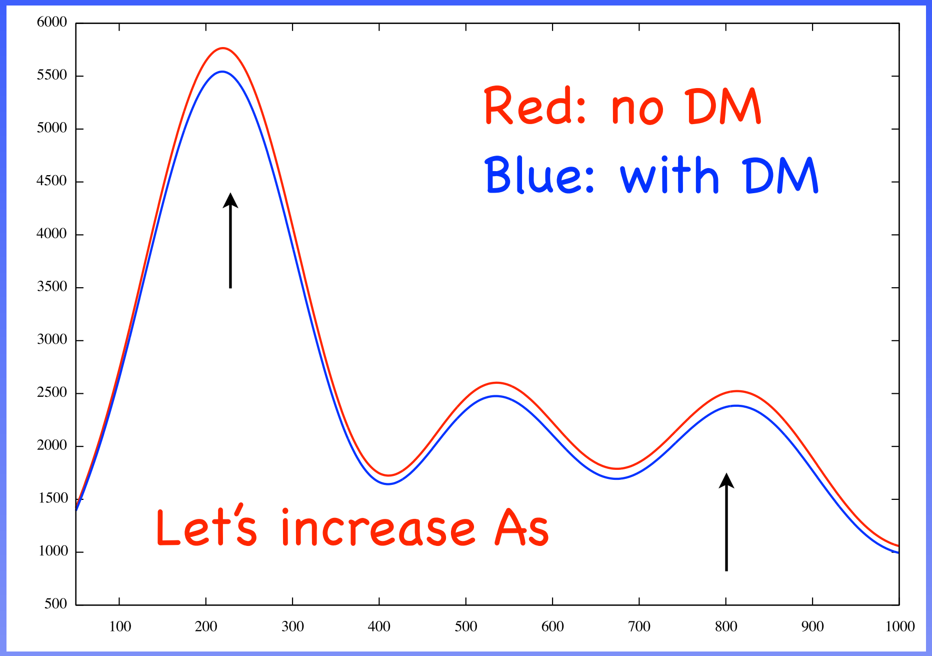
TT damped on small scales
EE boosted on large scales

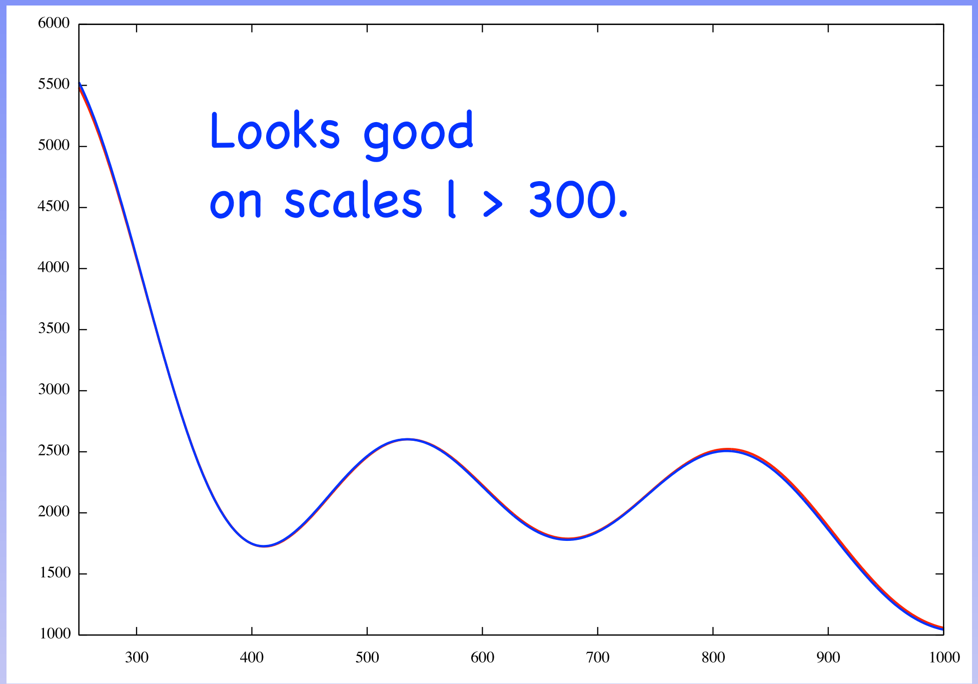


Degeneracies with other CMB parameters.

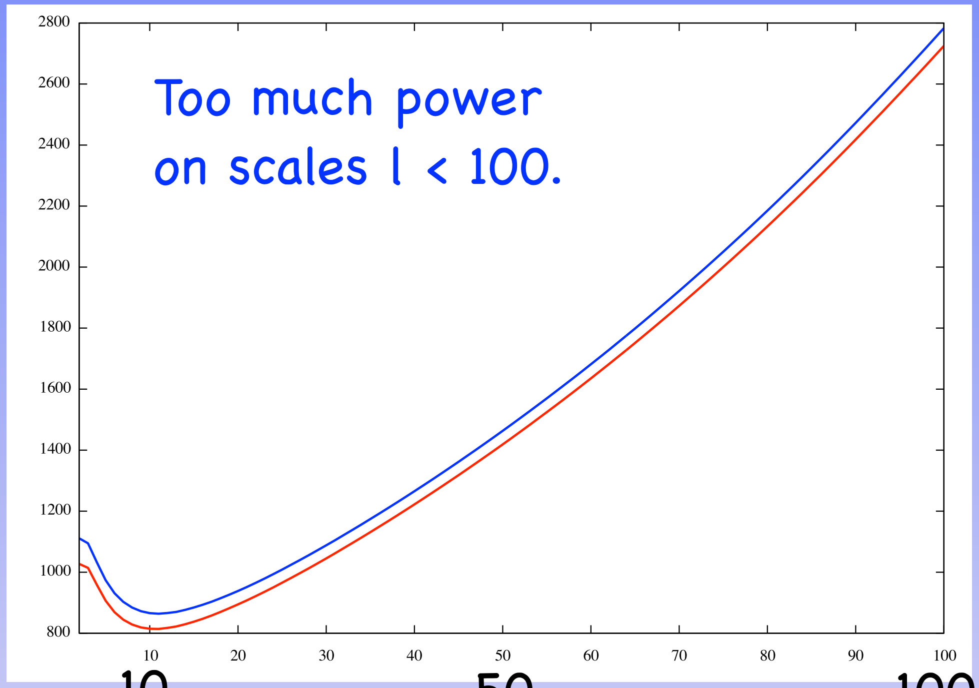
$$C_l \propto A_{s0} \, (k/k_*)^{n_s - 1} \, e^{-2\tau}$$

Let's keep n_s fixed, but increase As





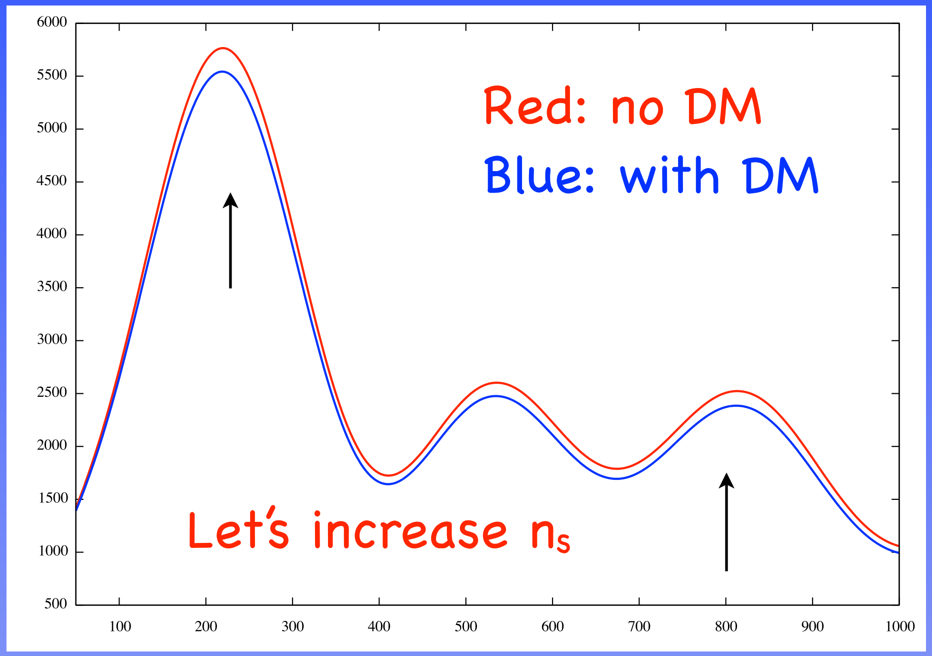
BUT

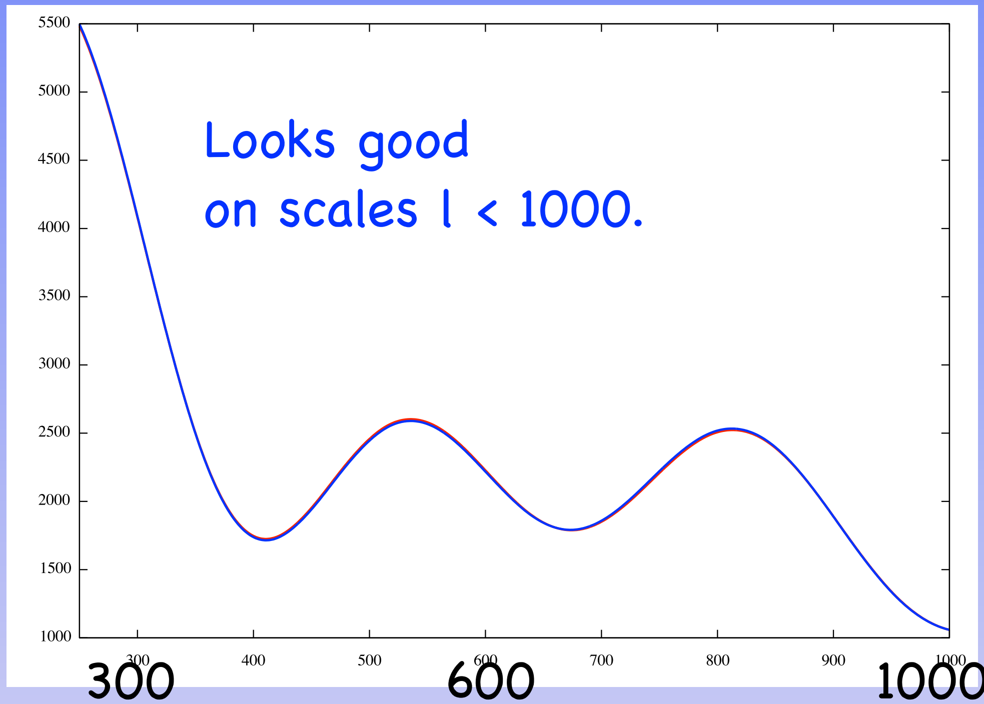


Degeneracies with other CMB parameters.

$$C_l \propto A_{\mathrm{s}0}\,(k/k_*)^{n_\mathrm{s}-1}\,e^{-2\tau}$$

Let's keep As fixed,
but increase n_s





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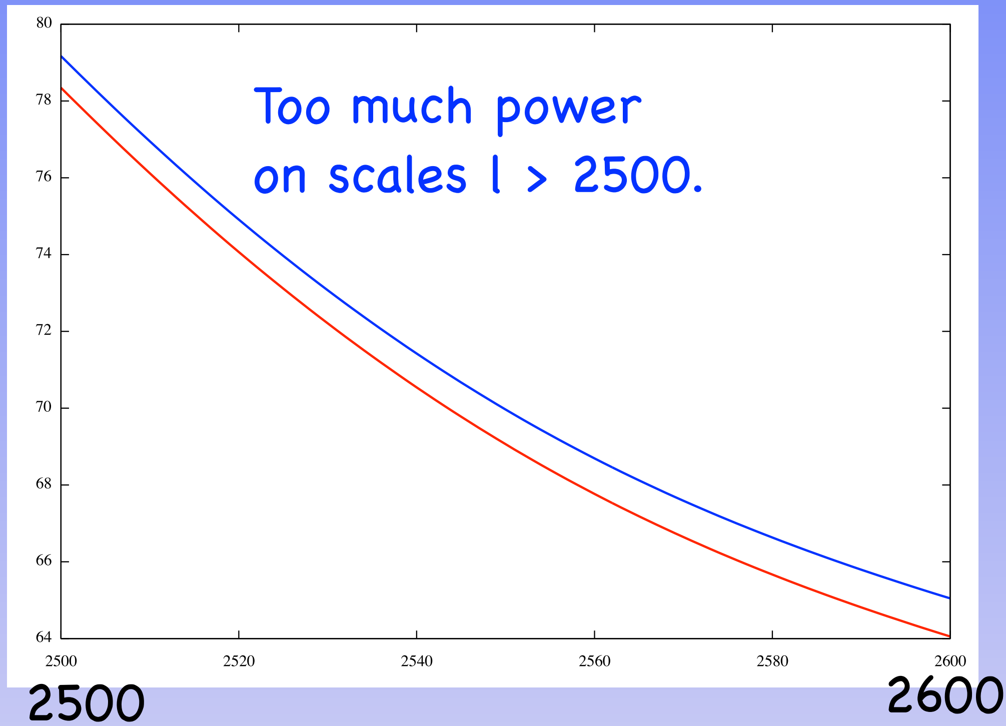


CMB Data & Variables: MCMC with MontePython

A.N. et al., in prep.

Cosmological: $h, \tau, n_{\rm s}, A_{\rm s}, \Omega_{\rm b}h^2, \Omega_{\rm c}h^2$

Particle: m_χ

Nuisance: A_tSZ, A_kSZ, A_PS(100), A_PS(143),
A_PS(217), A_CIB(143), A_CIB(217) [Planck]
+ A_SZ, A_CIB_cl, A_CIB_ps [SPT]

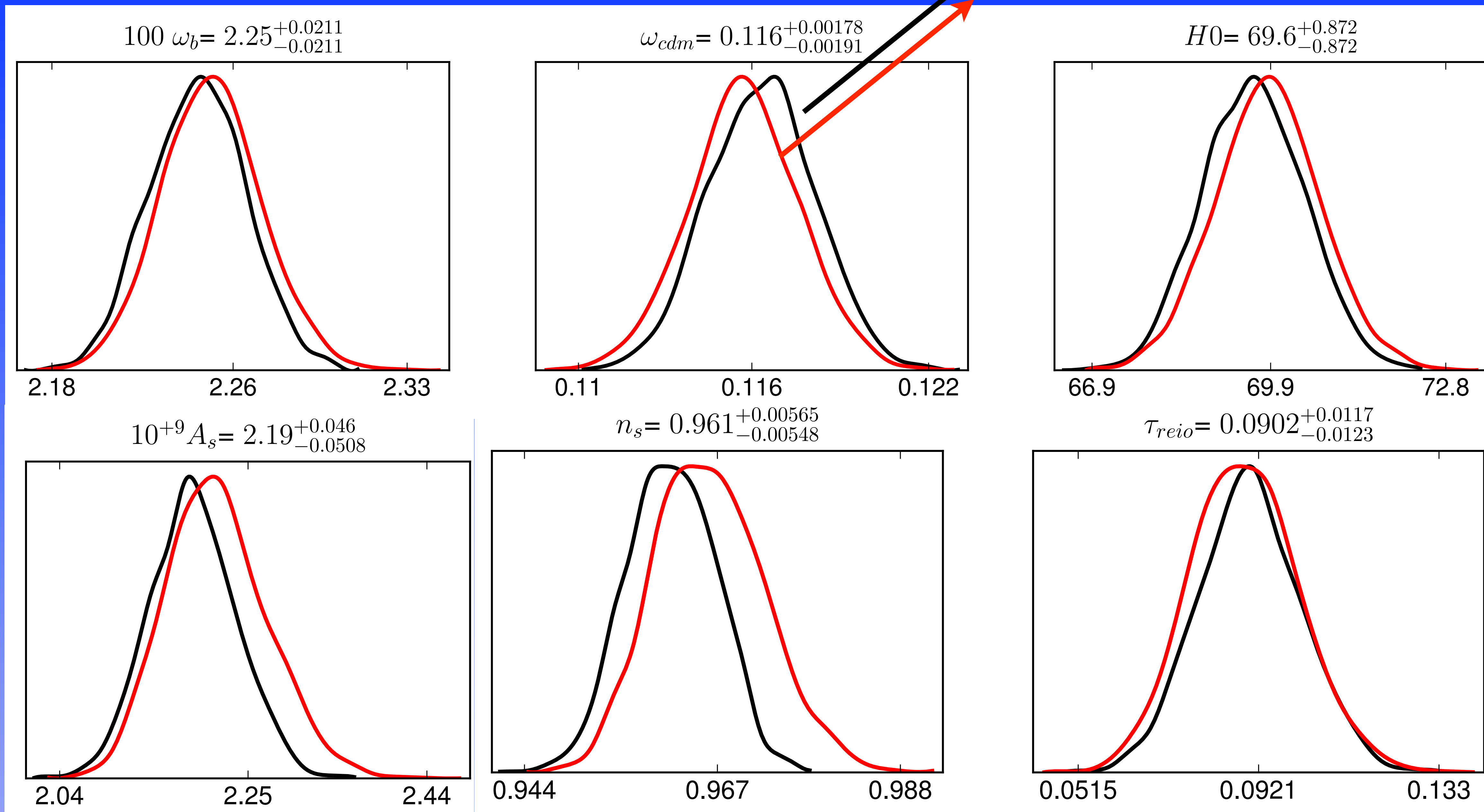
Data:

Planck (for TT)
+ WMAP (for TT, EE and TE)
+ SPT (high ell TT)
+ ACT (high ell TT)

Planck + WMAP + SPT + ACT

no DM annihilation

with DM annihilation



A.N. et al., in prep.

	without DM	with DM
100 x ombh2:	2.25 \pm 0.021	2.25 \pm 0.022
omch2:	0.116 \pm 0.0018	0.116 \pm 0.0019
H0:	69.6 \pm 0.87	69.8 \pm 0.89
10^9 As:	2.19 \pm 0.048	2.21 \pm 0.056
ns:	0.961 \pm 0.006	0.966 \pm 0.007
\tau:	0.090 \pm 0.01	0.089 \pm 0.01

Bounds on the WIMP mass (95% CL):

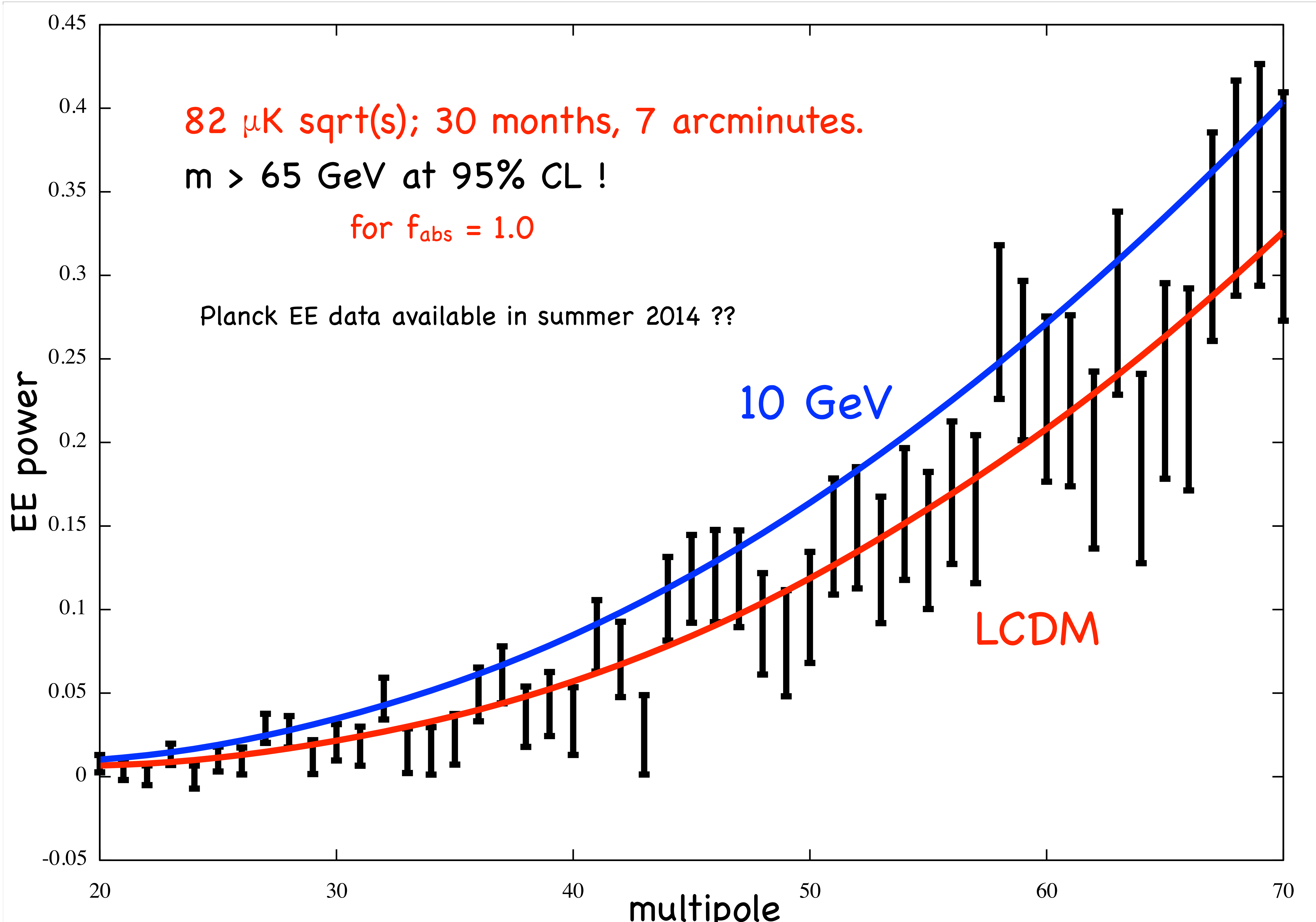
$$\xi = \frac{1\ \mathrm{pb}}{m_\chi}\ \frac{f_{\mathrm{abs}}}{1.0}$$

Planck + WMAP + SPT + ACT	m > 19.7 GeV
Planck + WMAP + SPT	m > 23.0 GeV
Planck + WMAP + ACT	m > 17.4 GeV

for f_{abs} = 1.0

A.N. PRD 2012
A.N. et al., in prep.

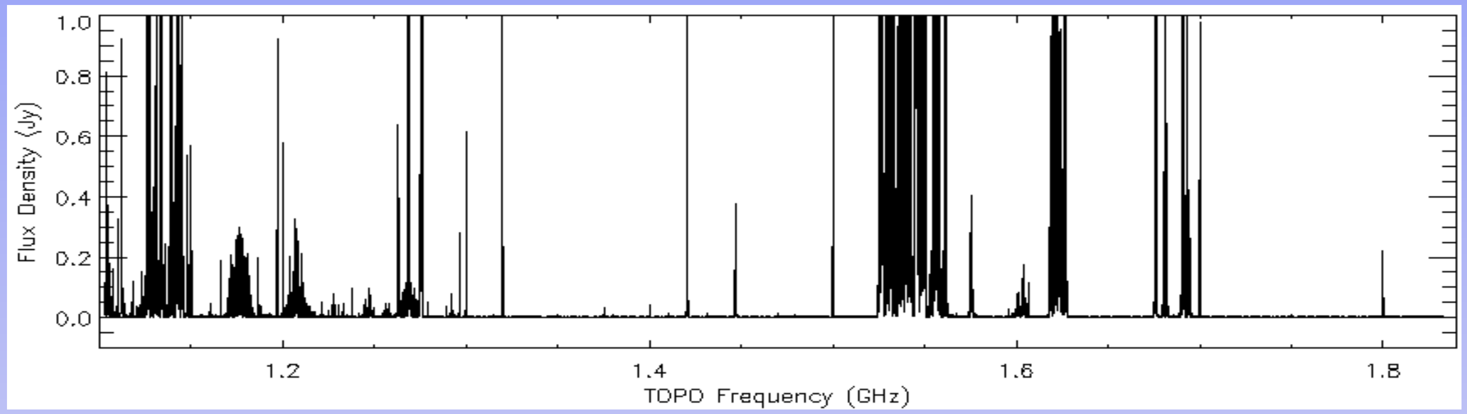
With simulated Planck Polarization data:

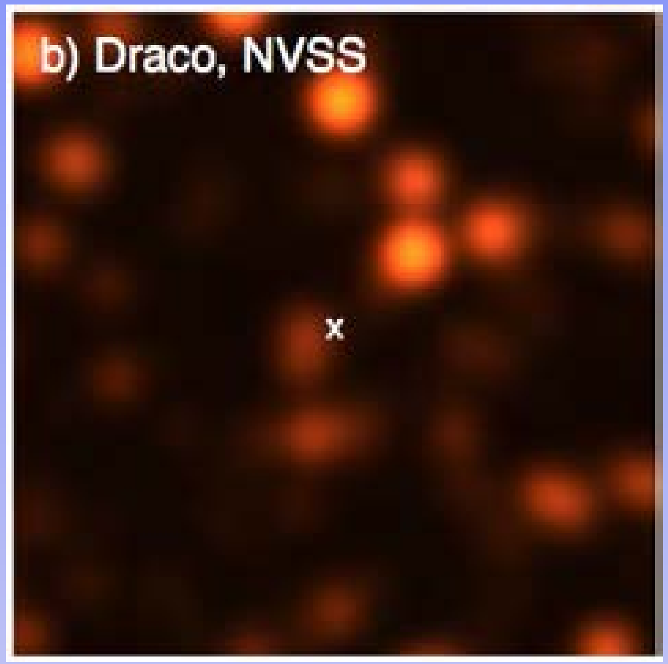


II. DM constraints from GBT observations

Radio quiet zone in WV.
Single Dish.
100m fully steerable telescope.
300 MHz - 100 GHz.

Low RFI at 1.4 GHz
NVSS catalog can be used to subtract point sources.





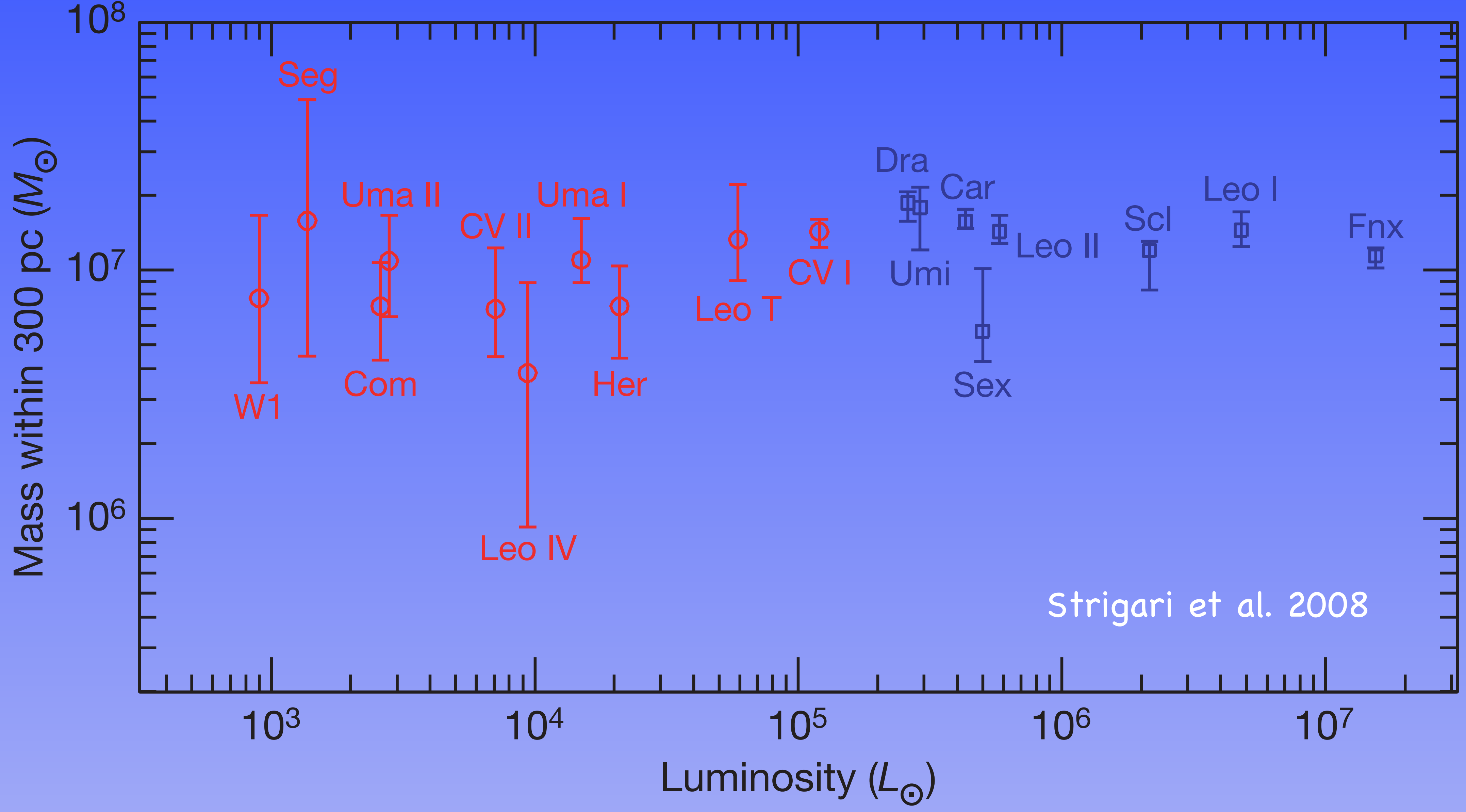
II. DM constraints from GBT observations

$$\Phi = \frac{\langle \sigma_{\rm a} v \rangle}{m_\chi} \, \rho_\chi^2$$

$$\chi\chi \to \left\{ b\bar{b},\ \tau^+\tau^-,\ W^+W^-,\ \ldots \right\} \longrightarrow e^+e^-, p\bar{p}, d\bar{d}, \nu\bar{\nu}, \gamma$$

Charged particles moving in a magnetic field emit synchrotron radiation.

The Milky Way and the 20 dwarfs



1. About 2 dozen nearby dwarf galaxies.
2. Dark matter dominated

--> Lots of WIMP annihilations.

--> No astrophysical backgrounds to worry about.

DM annihilation in a magnetic field

Colafrancesco, Profumo, Ullio '07

$$D(E)\nabla^2\psi(r,E) + \frac{\partial}{\partial E}\left[b(E)\psi(r,E)\right] + Q(r,E) = 0 \qquad \psi(r,E) = dn/dE$$

Diffusion — Energy loss — Source

Complications:

- Unlike gamma rays, charged particles don't point back to the source.
- Transport of $e^{\pm}$ is complicated due to diffusion and energy loss (synchrotron and IC losses).

What is the magnetic field? How important is diffusion?
What are the energy losses?

Magnetic field in dwarf galaxies:

- No measurements of B for the ultra faint dwarfs.

- But has been measured in the local group dwarf irregulars: Chyzy et al. 2011

$B = 2.8 \pm 0.7\ \mu G$ for IC 1613

$B = 4.0 \pm 1.0\ \mu G$ for NGC 6822

$B = 3.2 \pm 1.0\ \mu G$ for the SMC

We will assume $B \sim 1\ \mu G$ in dwarf galaxies.

Diffusion in dwarf galaxies:

- well studied only for the Milky Way!

  B/C ratio affects propagation of cosmic rays.

  D_0 = 0.01 kpc^2 / Myr for the MW galaxy.

  Donato et al. 2004

- For clusters, peaked iron abundance profiles give

  D_0 = 0.3 kpc^2 / Myr   Rebusco et al 2005, 2006

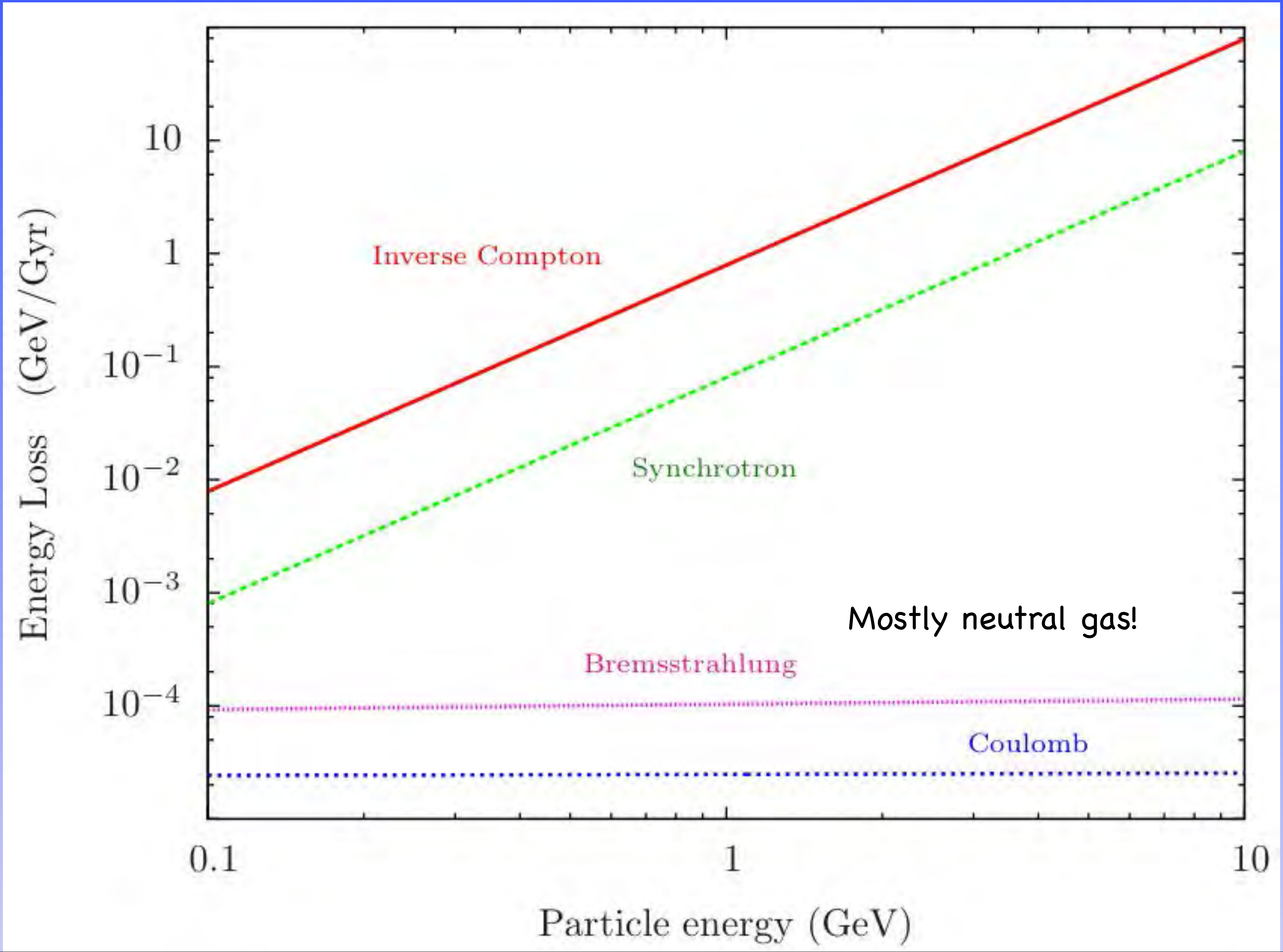
  > 2 orders of magnitude more than the MW.

- D_0 for dwarf galaxies = 0.1 MW value

  or maybe 1.0 x MW value (pessimistic)

  Jeltema & Profumo 2008

Energy loss in dwarf galaxies:

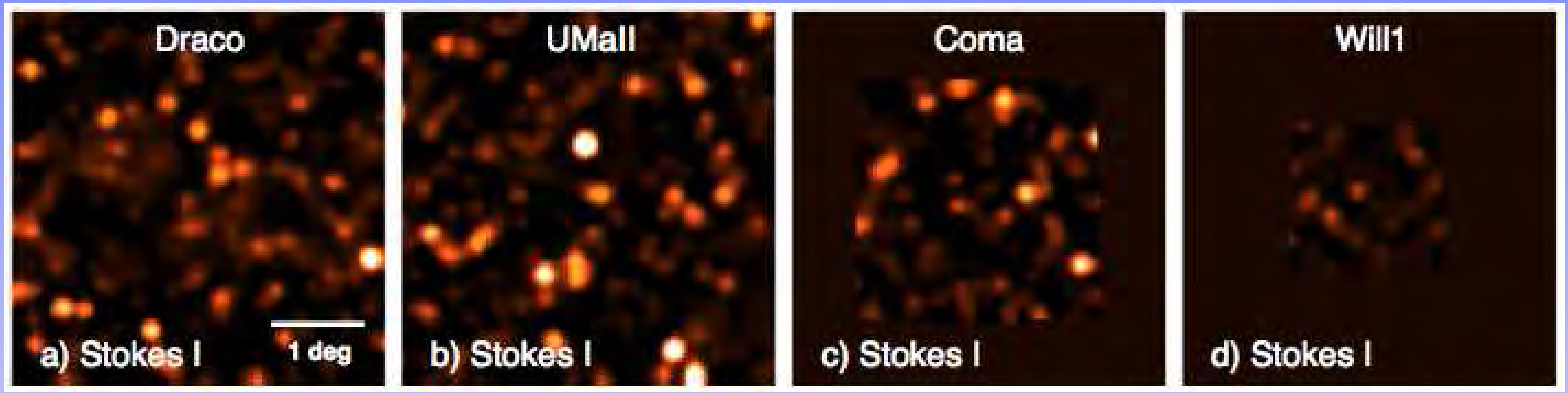


Deep radio observations of nearby dSphs.

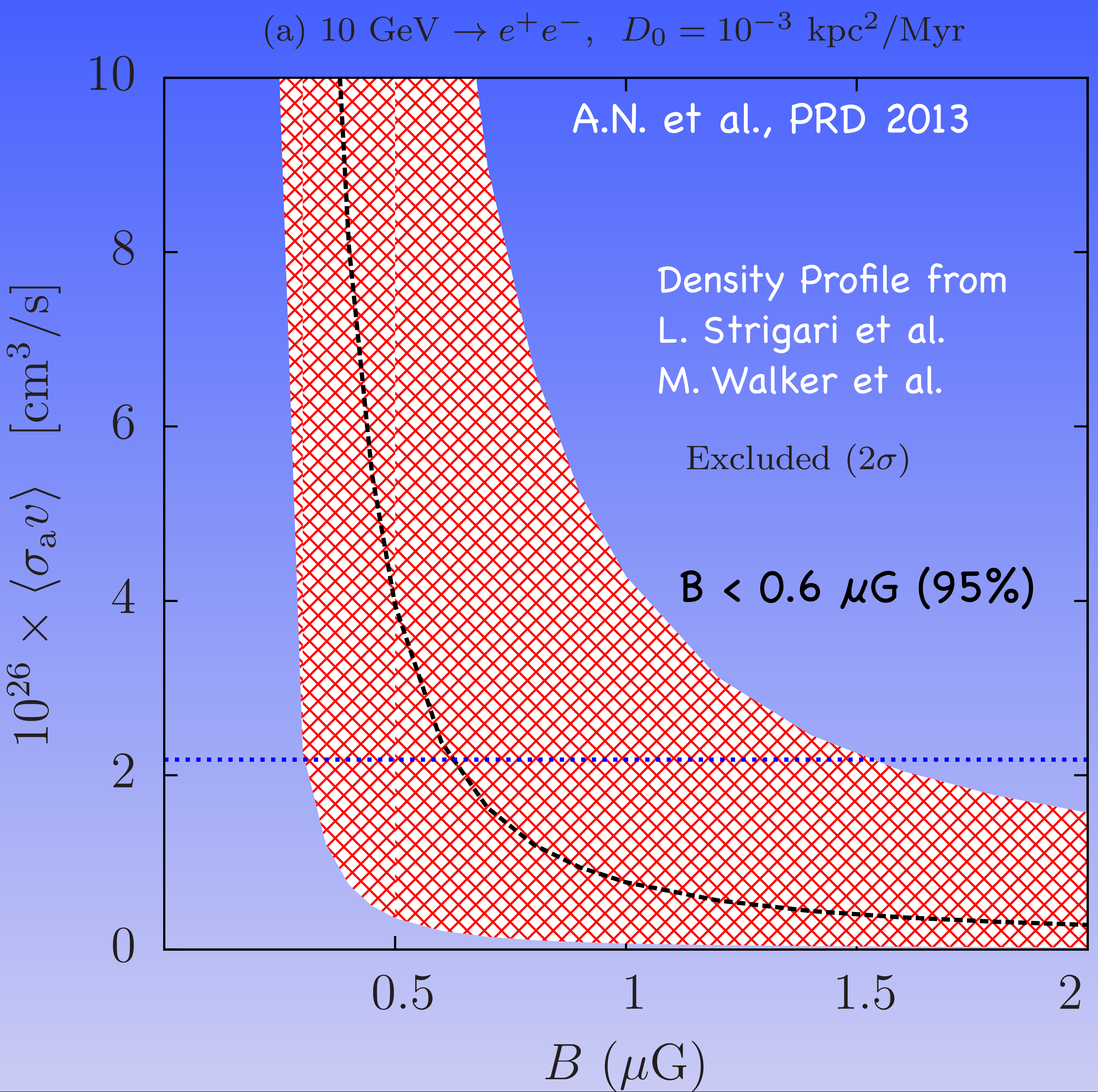
Spekkens et al., ApJ 2013

Observation and Map Properties

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, $57°55'$	$4° \times 4°$	$9.12' \times 9.12'$
UMaII (GBT)	2009 February – March[b]	18.8 h	8^h52^m, $63°08'$	$4° \times 4°$	$9.12' \times 9.12'$
Coma (GBT)	2009 February – March	8.6 h	12^h27^m, $23°54'$	$2°.5 \times 2°.5$	$9.12' \times 9.12'$
Will1 (GBT)	2009 February[c]	1.8 h	10^h49^m, $51°03'$	$1°.5 \times 1°.5$	$9.12' \times 9.12'$
Draco (VLA)	2007 November 4	5.4 h	17^h18^m, $57°53'$	$3° \times 4°$	$6.8'' \times 5.3''$



DM constraints: B and <σv>



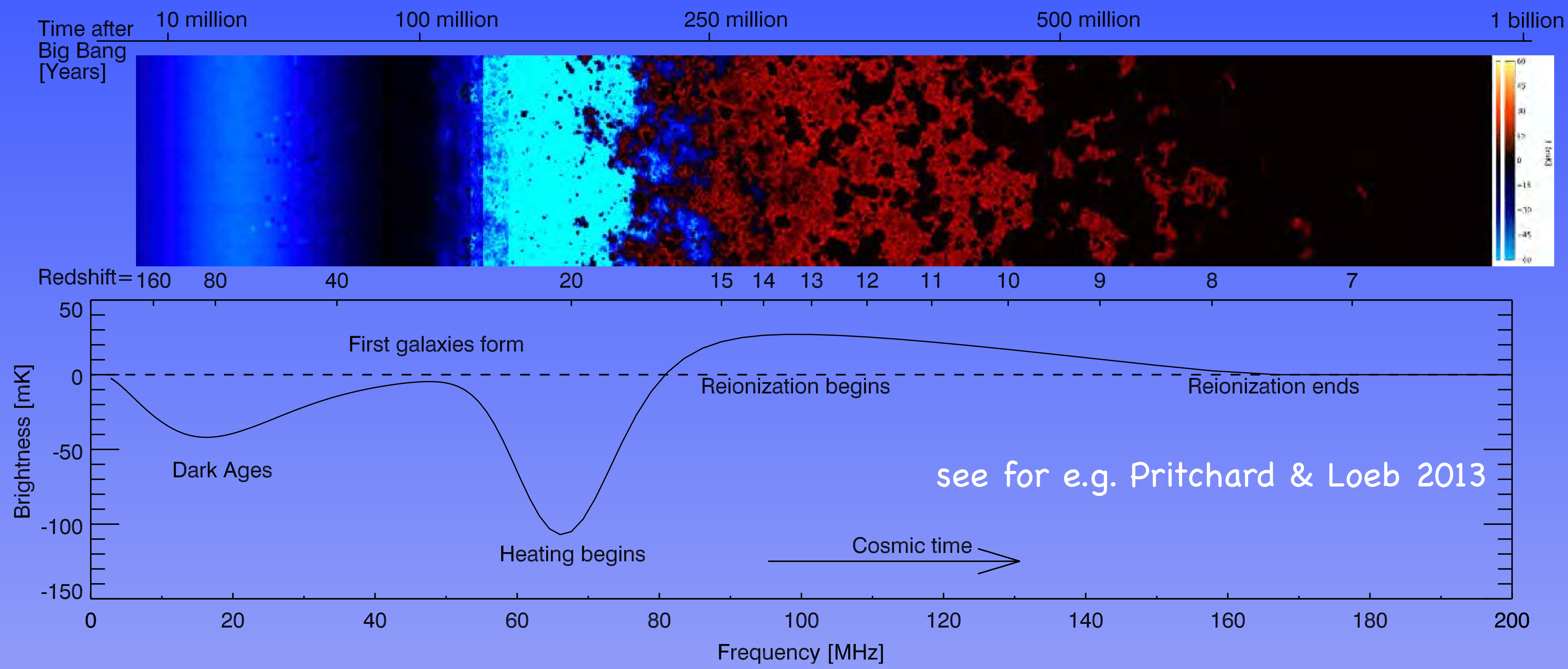
Radio observations at 1.4 GHz set constraints on light DM --> leptons.

- for the e^+e^- channel, we exclude 10 GeV annihilating at the thermal rate at 95% C.L. if B > 0.6 μG. Better results can be obtained with GBT + array such as GMRT or VLA.

- We have requested 150 hours observation time to map all the dwarf galaxies in the local group.
  Already obtained 70 hours observation time: Completed mapping Segue-I and Ursa Minor.

What is the magnetic field in the ultrafaint dwarfs?

III. The redshifted 21cm line of neutral Hydrogen

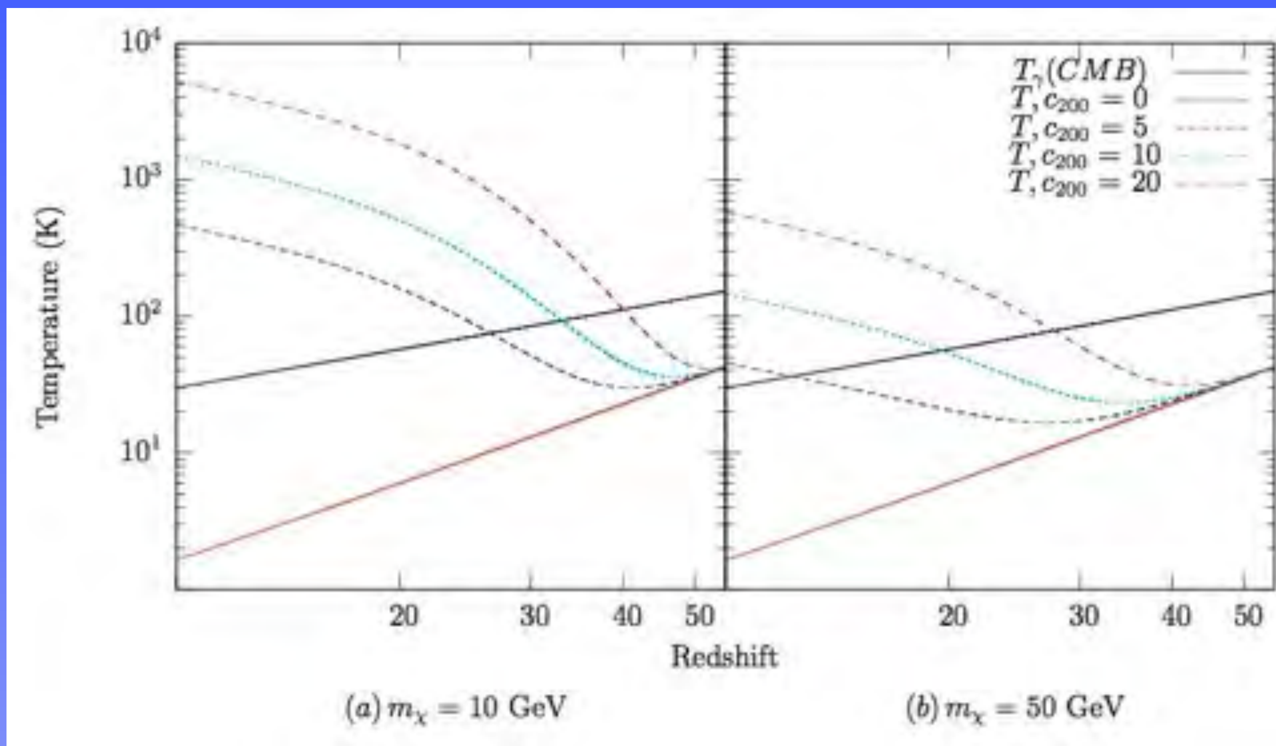


see for e.g. Pritchard & Loeb 2013

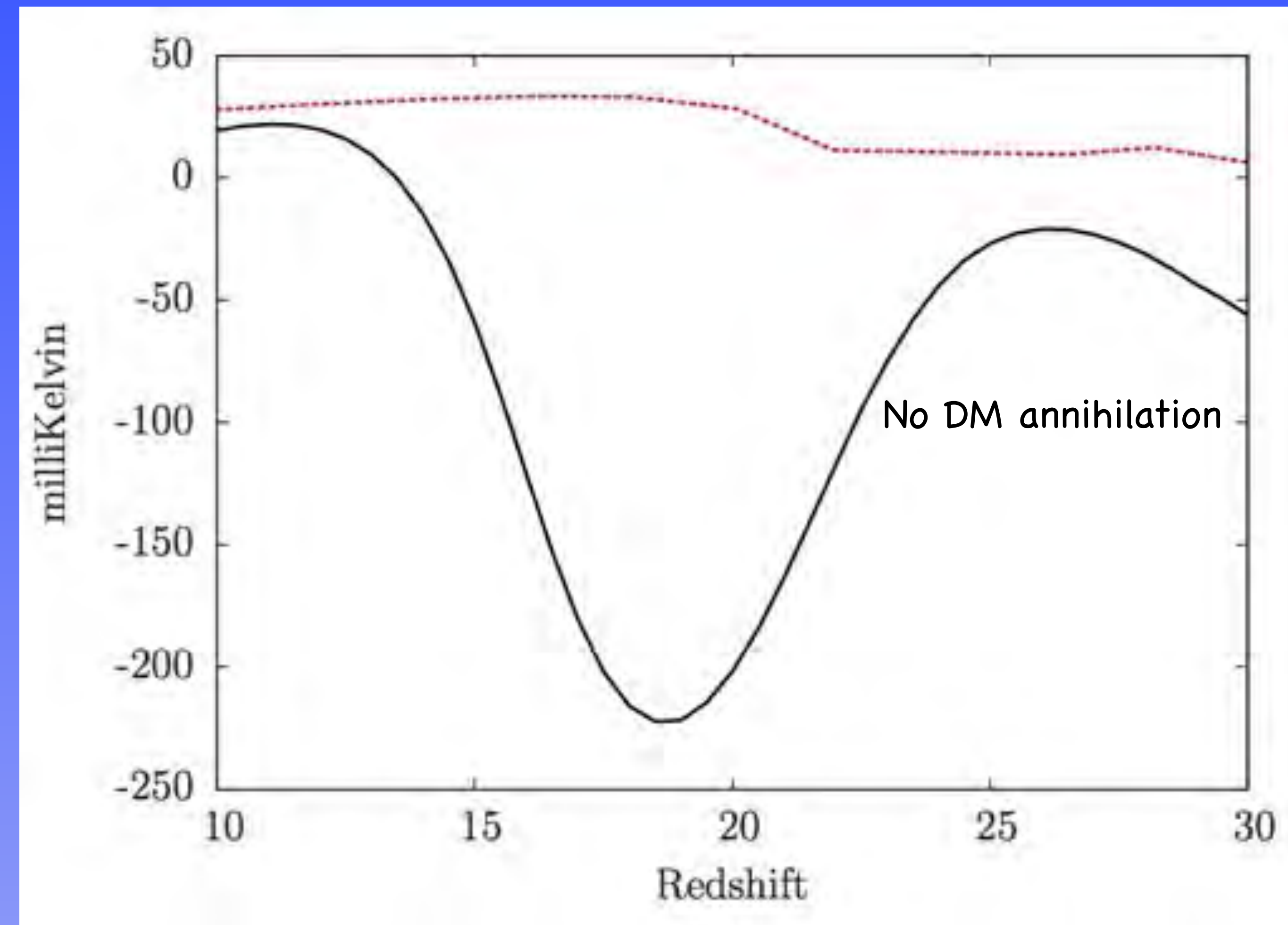
Large (negative) dip in the brightness temperature at 70 MHz!
provided the gas is colder than the CMB.

It is therefore a probe of the IGM temperature at z = 20.

DM annihilation can heat the gas



A.N. & D.J. Schwarz; PRD 2009



A.N. et al. in prep.
Valdes, Evoli, Mesinger, Ferrara, Yoshida, 2012

With heating from DM halos, the IGM can be hotter than the CMB for z < 30!

—> 21cm line is seen in emission

—> reaches saturation: 25 mK sqrt[(1+z) / 10]

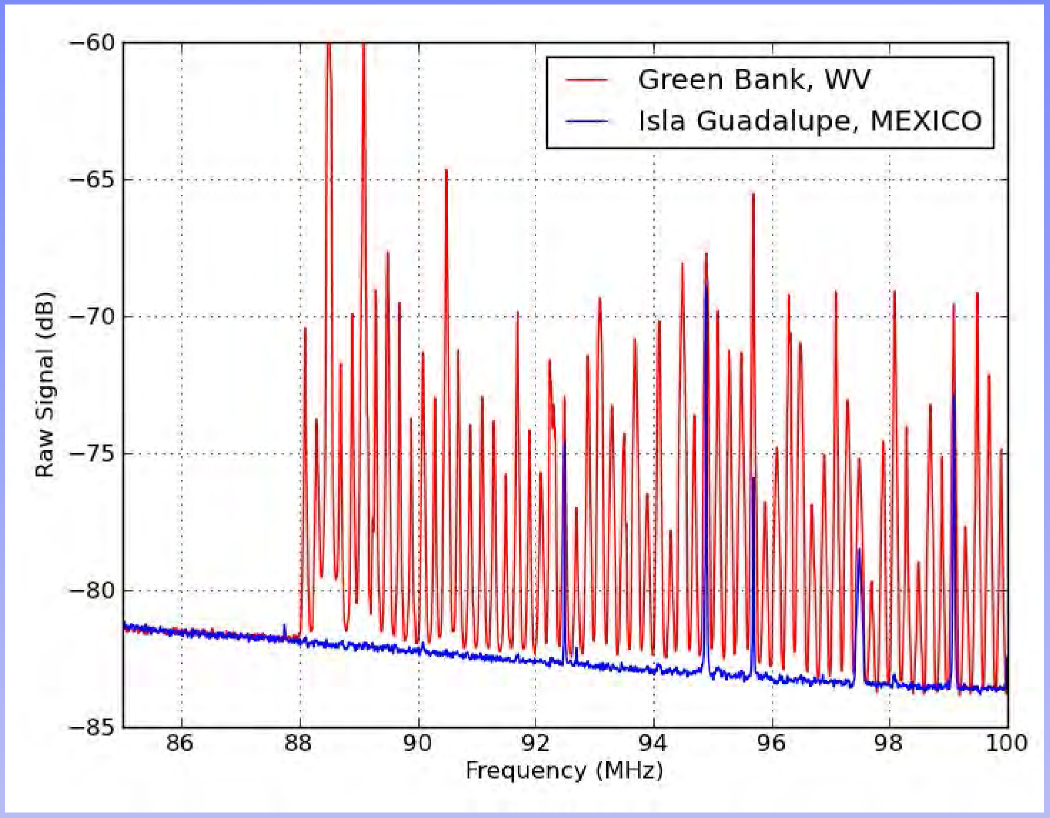
Measuring the global 21cm temperature at z = 20

SCI-HI global 21cm experiment

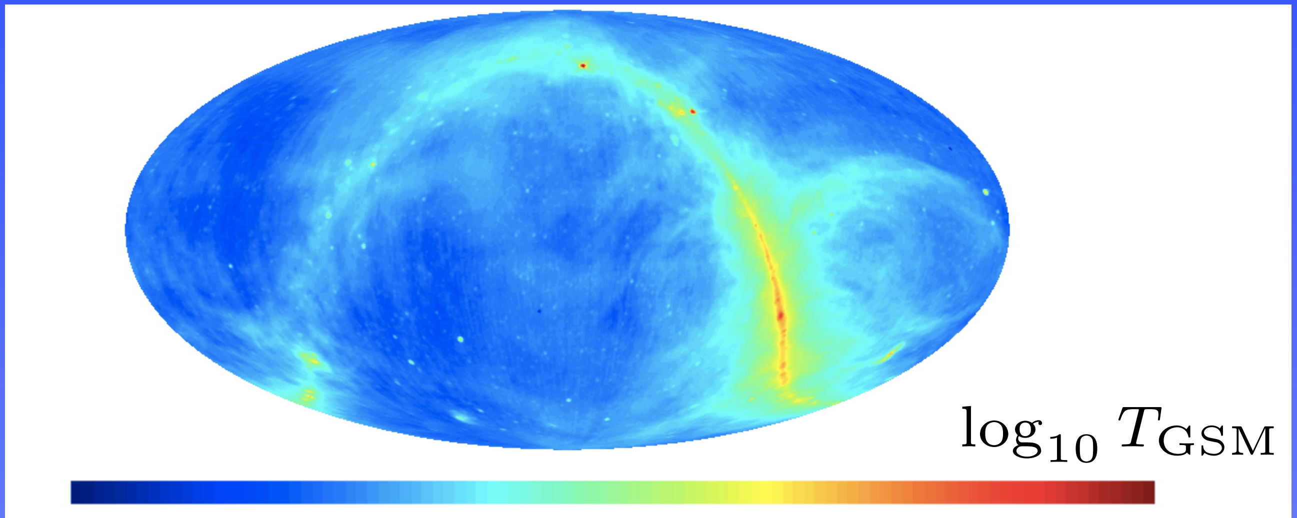
Sonda Cosmológica de las Islas para la detección de Hidrógeno neutro
Carnegie Mellon and Instituto Nacional de Astrofísica, Óptica y Electrónica

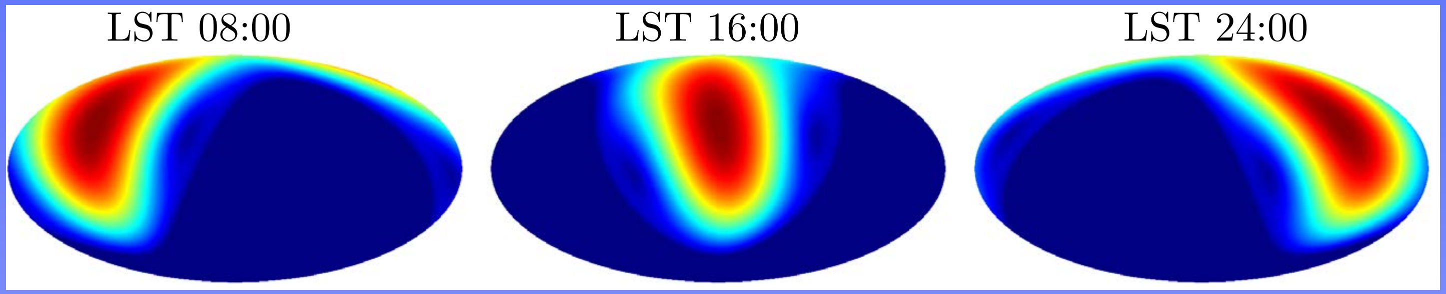
An all sky experiment to measure the global 21cm brightness temperature of HI in the frequency range 50 - 130 MHz.

RFI at Isla Guadalupe Vs Green Bank

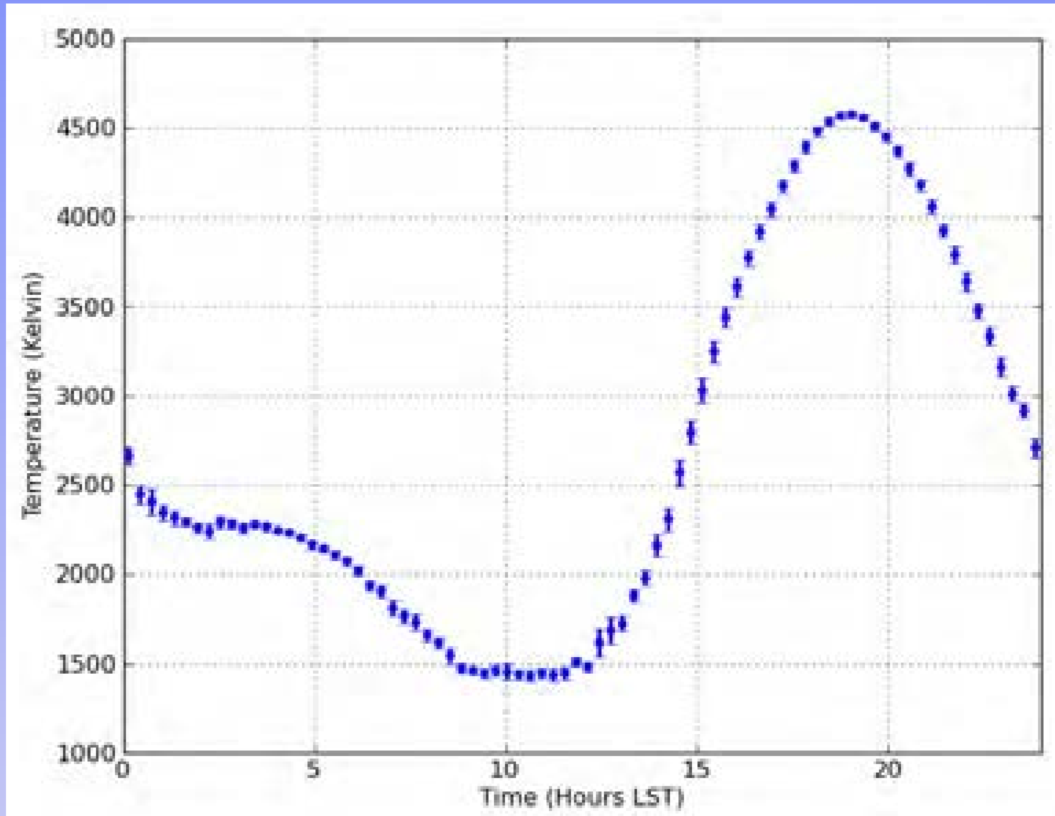


The Galaxy at 70 MHz

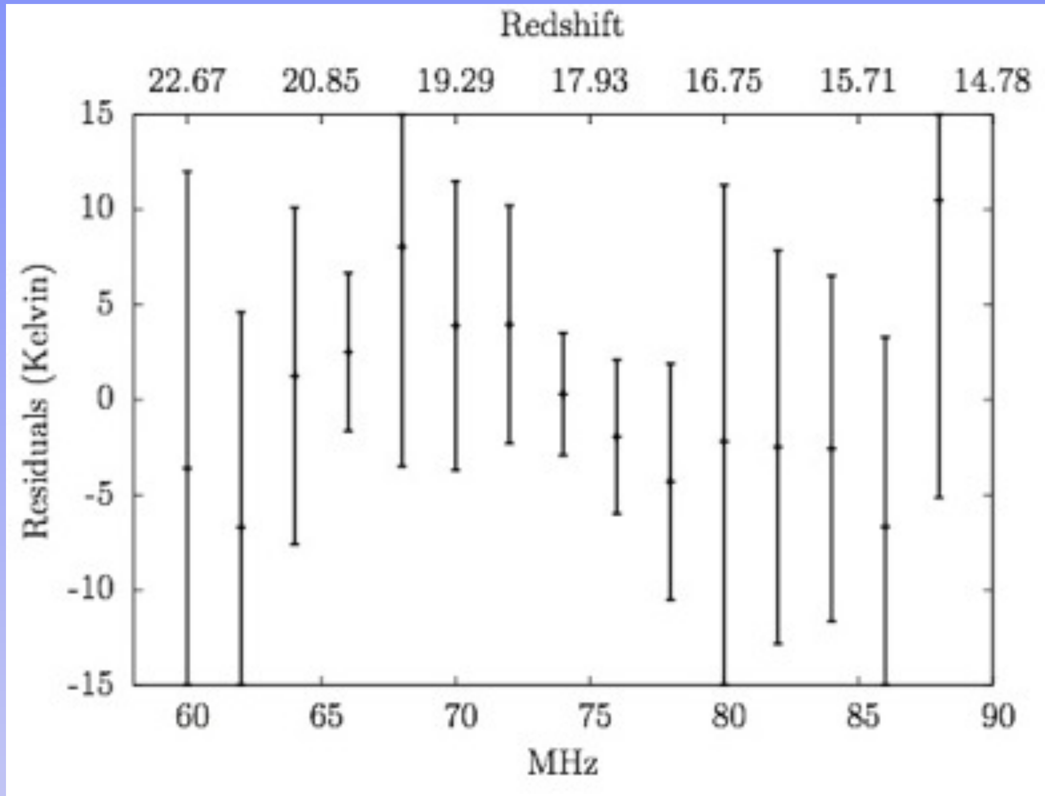




Sky brightness at 70 MHz



PRELIMINARY! Residuals at ≈ few Kelvin level.



The very quiet Isla Guadalupe is not quiet enough!

We plan to go to Isla Socorro and/or Isla Clarion in Spring 2014

We will observe continuously for 2 weeks.

—> We expect RFI in the FM band to be below the thermal level.

—> expect to obtain residuals ≈ 100 mK.

Conclusions

Direct detection experiments have obtained results consistent with light DM in the Galaxy.
--> Must test through independent experiments:

The CMB is well measured. Theory is well understood.
New expts: ACTPol, SPTPol, Plank Pol.
PIXIE can measure spectral distortions (Chluba & Sunyaev)
Combined with clusters and LSS, one can break degeneracies.

Dwarf galaxies have a lot of DM:
Observe in the radio - complementary to gamma ray obs.
Prelim. results $B < 0.6\ \mu G$ for 10 GeV DM and fid. parameters.
We have requested 150 hours of obs. time with the GBT to observe all the dwarfs in the local group

21cm observations - A new and exciting probe of physics at $z = 20$!
DM annihilations heat the IGM - 21cm line seen in emission.
Sensitive measurements can test this - see SCI-HI, LEDA, DARE.
We can study DM annihilation, effects on primordial star formation, etc.