Low Frequency Constraints on Dark Matter Annihilation in Small Scale Galaxies

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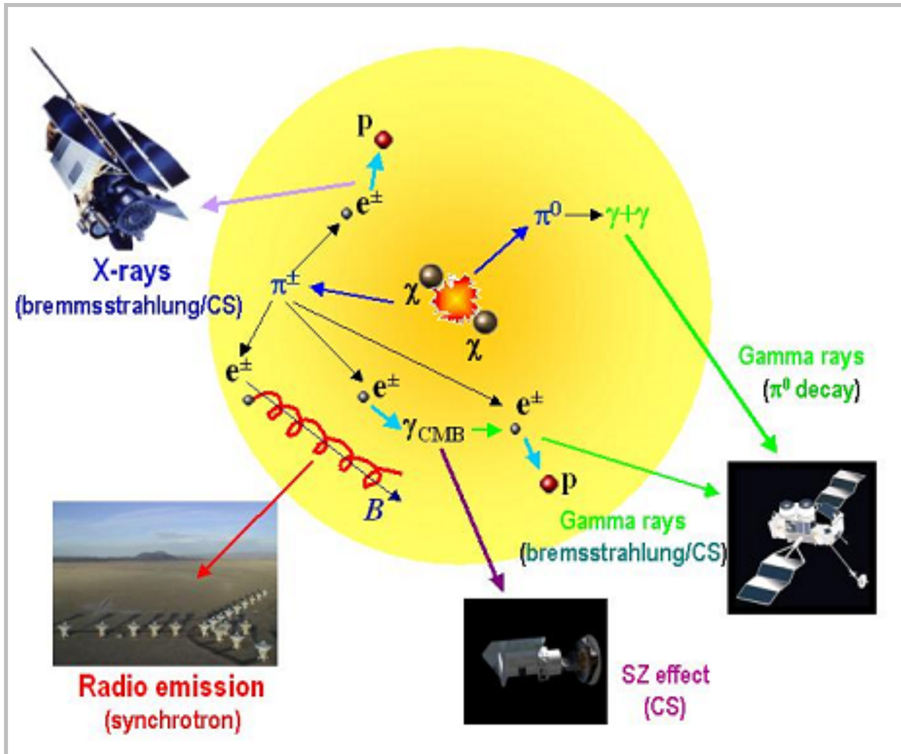
Multi-wavelength?

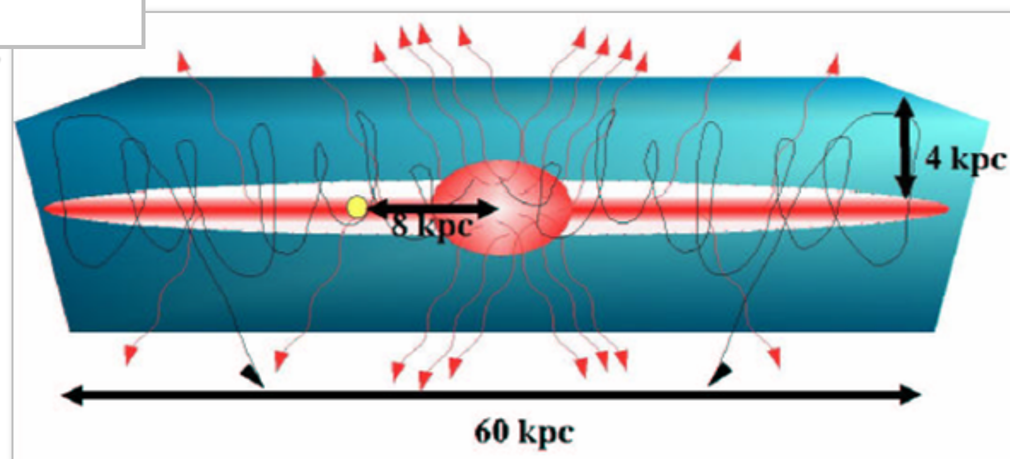
dwarf galaxies

$$q_e(E,r) = \frac{1}{2\,M_\chi^2} \sum_f \frac{dN_e^f}{dE_e}(E) B_f\, \rho^2(r)$$



Colafrancesco, IoP/RAS Meeting 2007

e^+-:
- SZ effect
- ICS emission
- Synchrotron emission



How to model
the transport process

Stationary transport equation:

$$q_e(E,r) = \frac{1}{2\,M_\chi^2}\sum_f \frac{dN_e^f}{dE_e}(E)B_f\;\rho^2(r)$$

$$\frac{\partial}{\partial t}\frac{dn_e}{dE_e} = \nabla\left[D(E,r)\nabla\frac{dn_e}{dE_e}\right] + \frac{\partial}{\partial E}\left[b(E,r)\frac{dn_e}{dE_e}\right] + q_e(E,r)$$

$$\frac{dn_e}{dE}(r,E) = \frac{1}{b(E)}\int_E^{M_\chi} dE'\;\widehat{G}\,(r, v-v')\,Q_e(r,E')$$

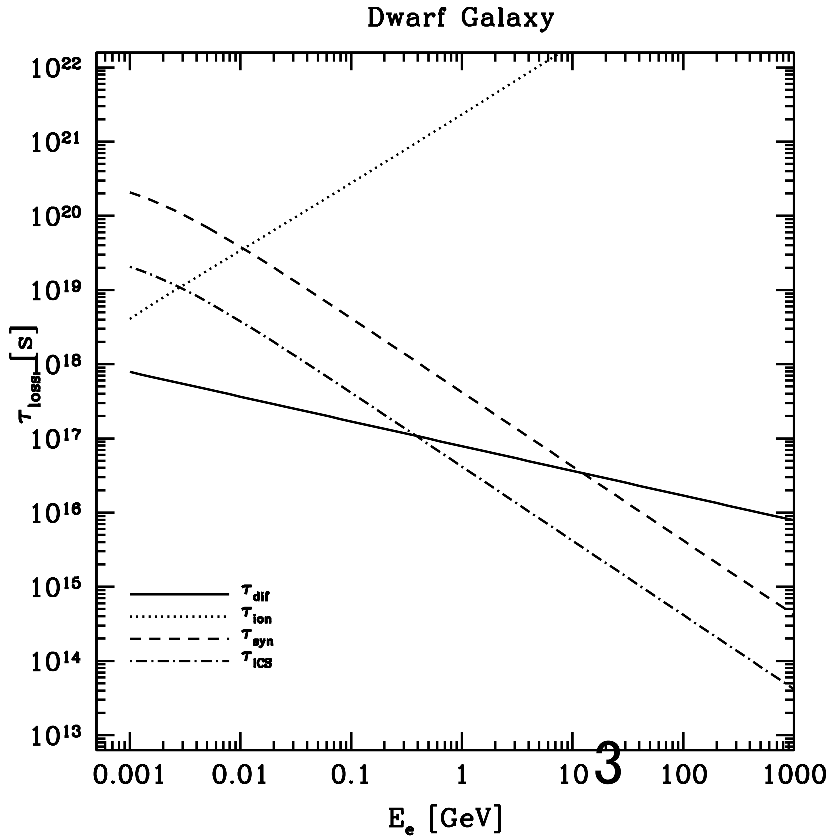
$$\widehat{G}\,(r,\Delta v) = \frac{1}{[4\pi(\Delta v)]^{1/2}}\sum_{n=-\infty}^{+\infty}(-1)^n\int_0^{r_h} dr'\frac{r'}{r_n}\left[\exp\left(-\frac{(r'-r_n)^2}{4\,\Delta v}\right)-\exp\left(-\frac{(r'+r_n)^2}{4\,\Delta v}\right)\right]\frac{\rho^2(r')}{\rho^2(r)}$$

$$b(E) = b_{Syn} + b_{ICS} + b_{Coul}$$

$$D(E) = D_0(E/B)^\delta$$

$$\tau_{loss} = E/b(E)$$

$$\tau_D = R_{halo}{}^2 / D(E)$$



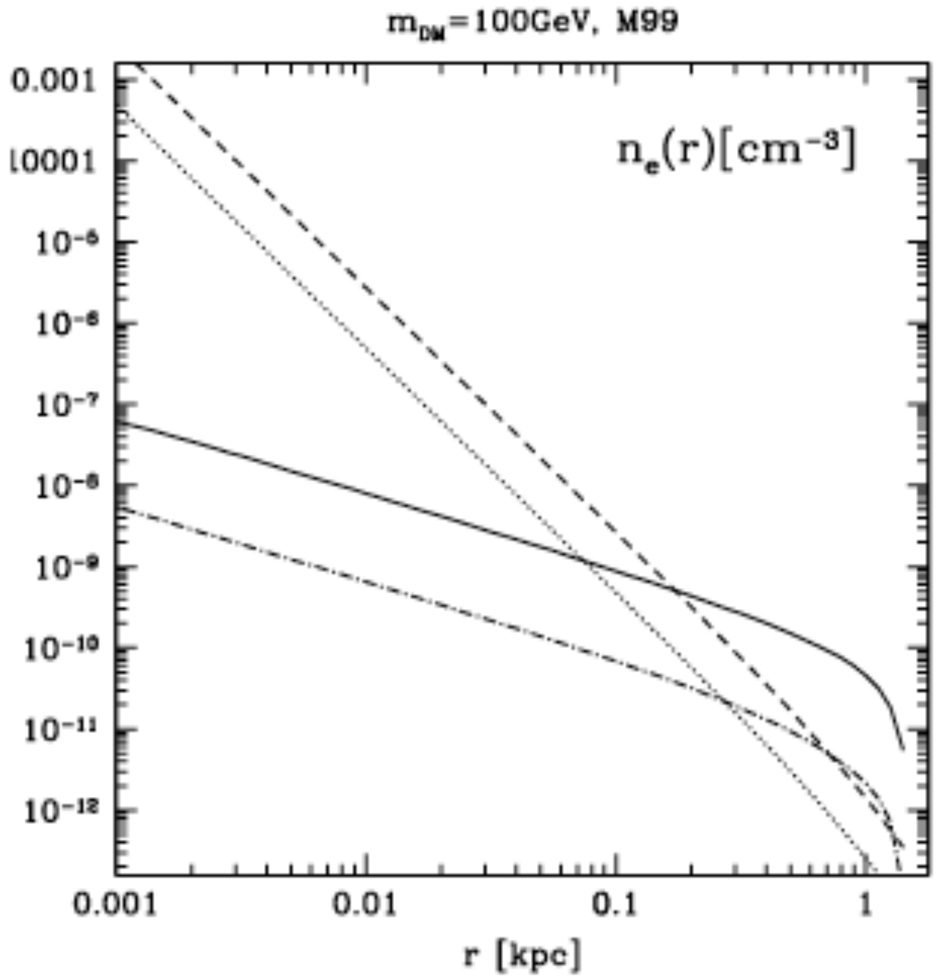


Figure 4: The $e^{\pm}$ density $n_e(r)$ from neutralino annihilations in the Draco dSph. The solid and dot-dashed curves are our full solutions with $E_{\rm min} = m_e$ and $0.01 m_{\rm DM}$ respectively. The dotted curve is the result of the "approximate solution", and the dashed curve is the result of the "no-diffusion solution" as described in Eq. (3.2).

Table 1: The dSphs parameters used in this paper. The distance and virial mass data are mostly taken from Ref. [24], other parameters are calculated as outlined below. For Ursa Minor, which was not included in Ref. [24], we take the mass as to be the same as that of Draco.

Name	$\frac{D}{[\mathrm{kpc}]}$	$\frac{M_{vir}}{[10^8 M_\odot]}$	$\frac{\rho_s}{[10^8 M_\odot/\mathrm{kpc}^3]}$	$\frac{r_s}{[\mathrm{kpc}]}$	$\frac{r_t}{[\mathrm{kpc}]}$
Draco	80	40	0.82	1.2	9.9
LeoI	250	10	1.2	0.64	16.7
Fornax	138	10	1.2	0.64	10.3
LeoII	205	4	1.5	0.43	10.6
Carina	101	2	1.8	0.32	4.8
Sculptor	79	10	1.2	0.64	6.5
Sextans	86	3	1.6	0.38	4.8
Ursa Minor	66	40	0.82	1.2	8.6

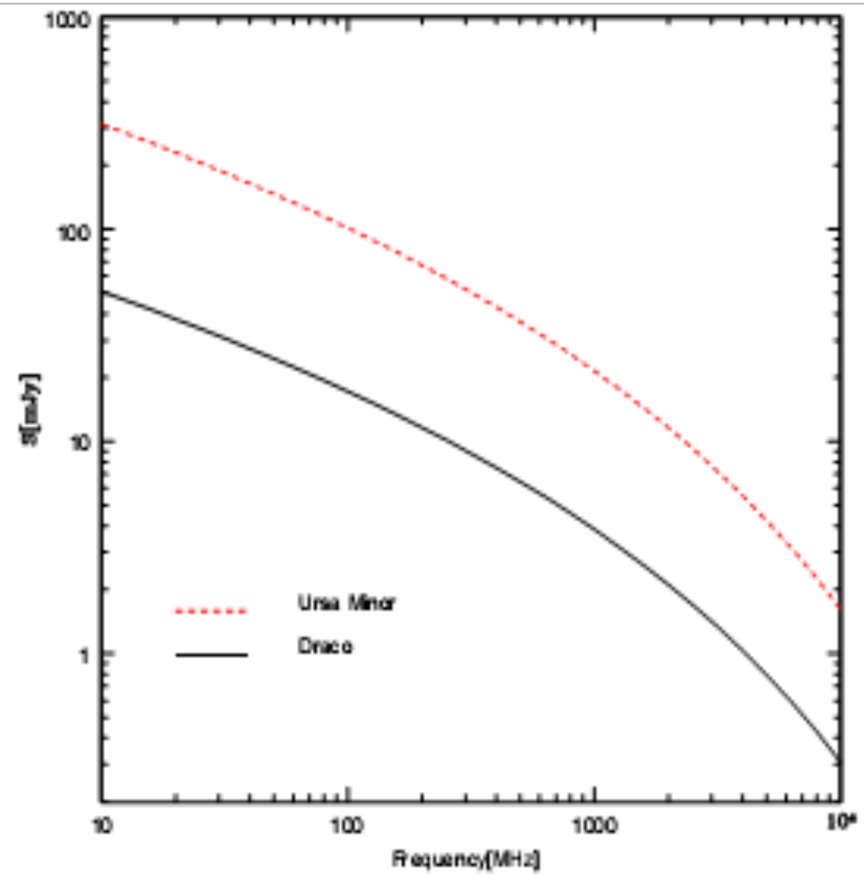
SZ-effect

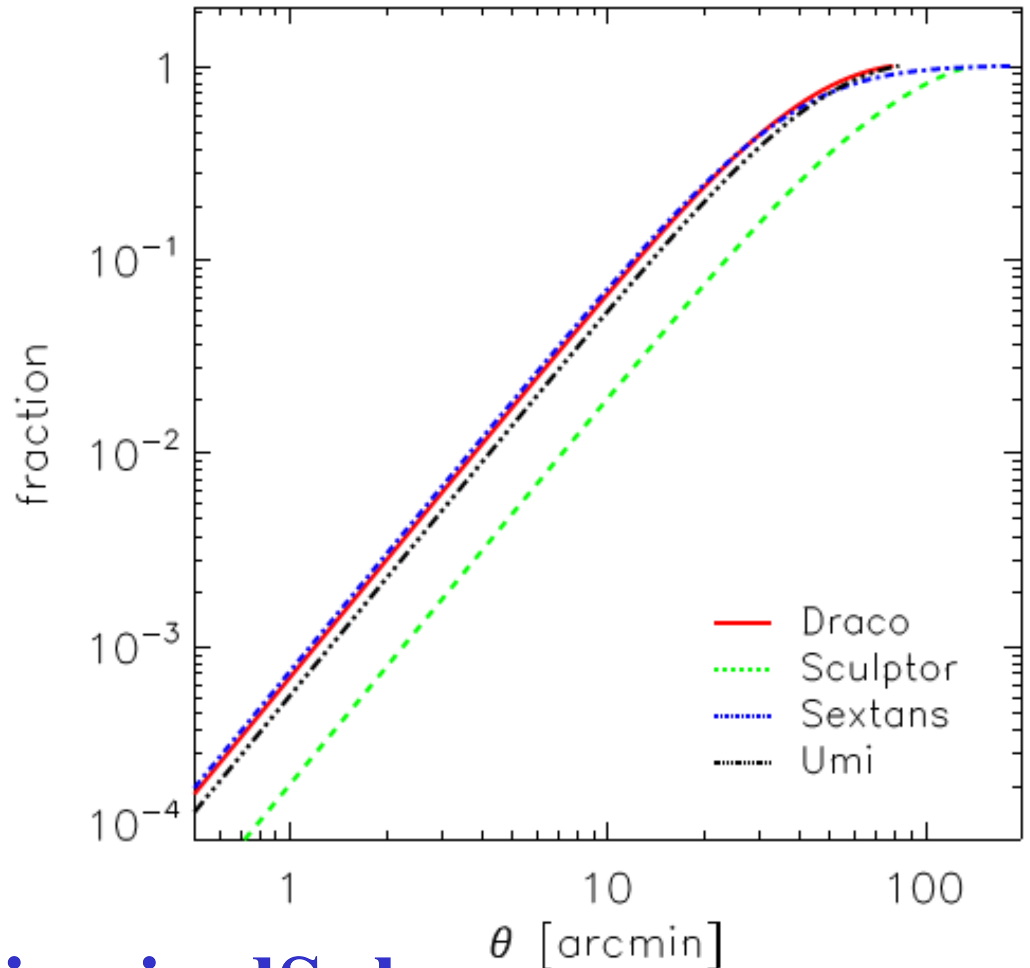
Table 2: WIMP DM induced SZ effect (in units of K) for Local Group luminous dSphs. We assume $m_\chi = 100$ GeV, $\langle\sigma v\rangle = 3.0 \times 10^{-26}\mathrm{cm^3 s^{-1}}$, M99 profile, and $\theta = 1''$.

dSph	r_h(kpc)	$M_{\rm vir}(M_\odot)$	35GHz ($x = 0.616$)	1000GHz ($x = 17.46$)
Ursa Minor	1.6	4×10^9	-5.44×10^{-12}	2.43×10^{-10}
Draco[a]	1.6	4×10^9	-5.39×10^{-12}	2.32×10^{-10}
Leo I	1.6	1×10^9	-6.88×10^{-13}	5.37×10^{-12}
Fornax	5.4	1×10^9	-5.12×10^{-13}	1.91×10^{-10}
Leo II	1.04	4×10^8	-5.45×10^{-15}	3.35×10^{-11}
Carina	1.7	2×10^8	-2.37×10^{-13}	8.97×10^{-13}
Sculptor	3.26	1×10^9	-2.61×10^{-12}	9.72×10^{-11}
Sextans[b]	4.8	3×10^8	-1.61×10^{-12}	5.89×10^{-11}

[a] $r_{\rm steller}$ is around 0.93 kpc, which give a slightly large r_h as 1.86 kpc. In the calculation, we just use the $r_h = 1.6$ kpc as the diffusion zone for consistency with previous results.
[b] $r_{\rm steller}$ is around 4 kpc, which give a really large r_h as 8 kpc. In the real calculation, we use r_t as the diffusion zone.

Radio Emission





Synchrotron emission in dSphs: diffuse and weak

Radio Observation Requirement

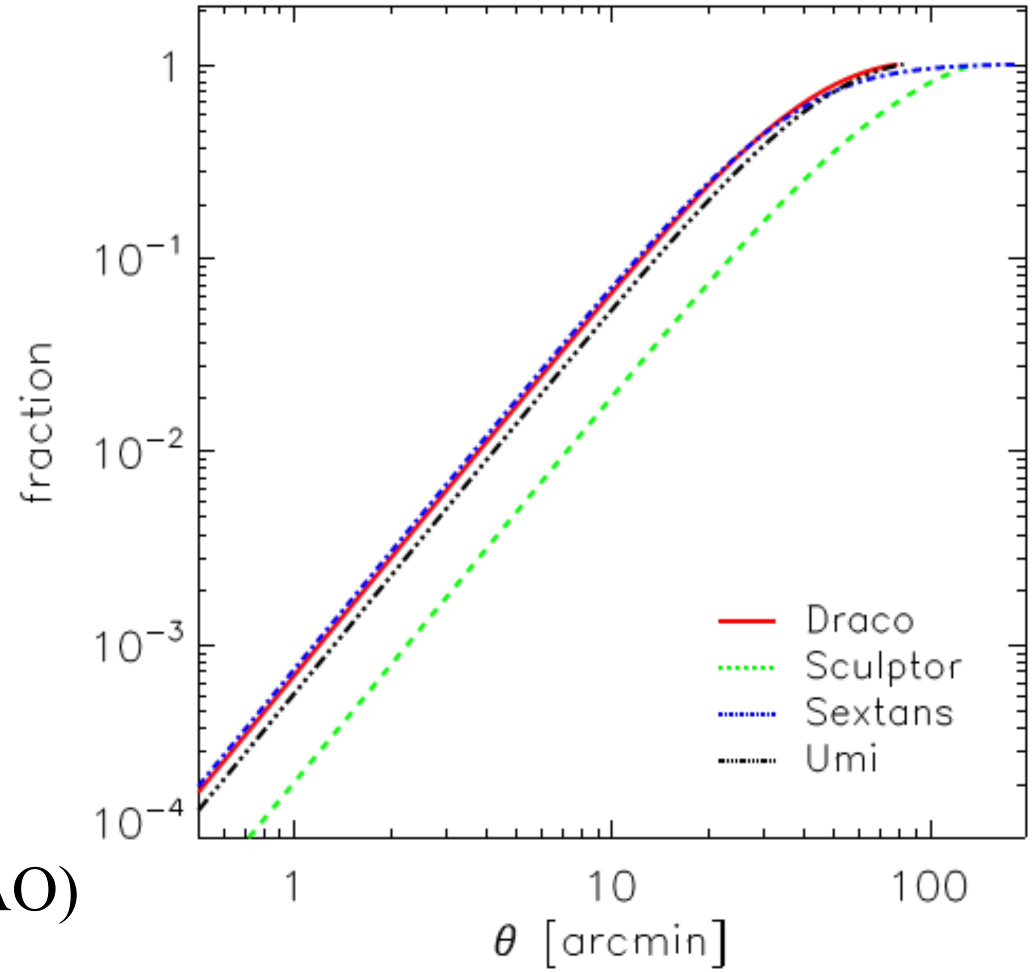
Fomalont *et. al*. with VLA at 4.885GHz in 1979

very center region (within 4arcmin)
no detectable radio emission (<2mJy)

Updated observation required

Diffuse emission -------- large field view
weak emission -------- high sensitivity

2011-07-GMRT: http://gmrt.ncra.tifr.res.in/



Feng Huang(XMU)
Xuelei Chen(NAOC)
Zhiqiang Shen, Yu Wang(SHAO)

F.o.V at 150MHz: 67 arcmint

rms: 0.02mJy/beam 10 hours, BW: 16MHz

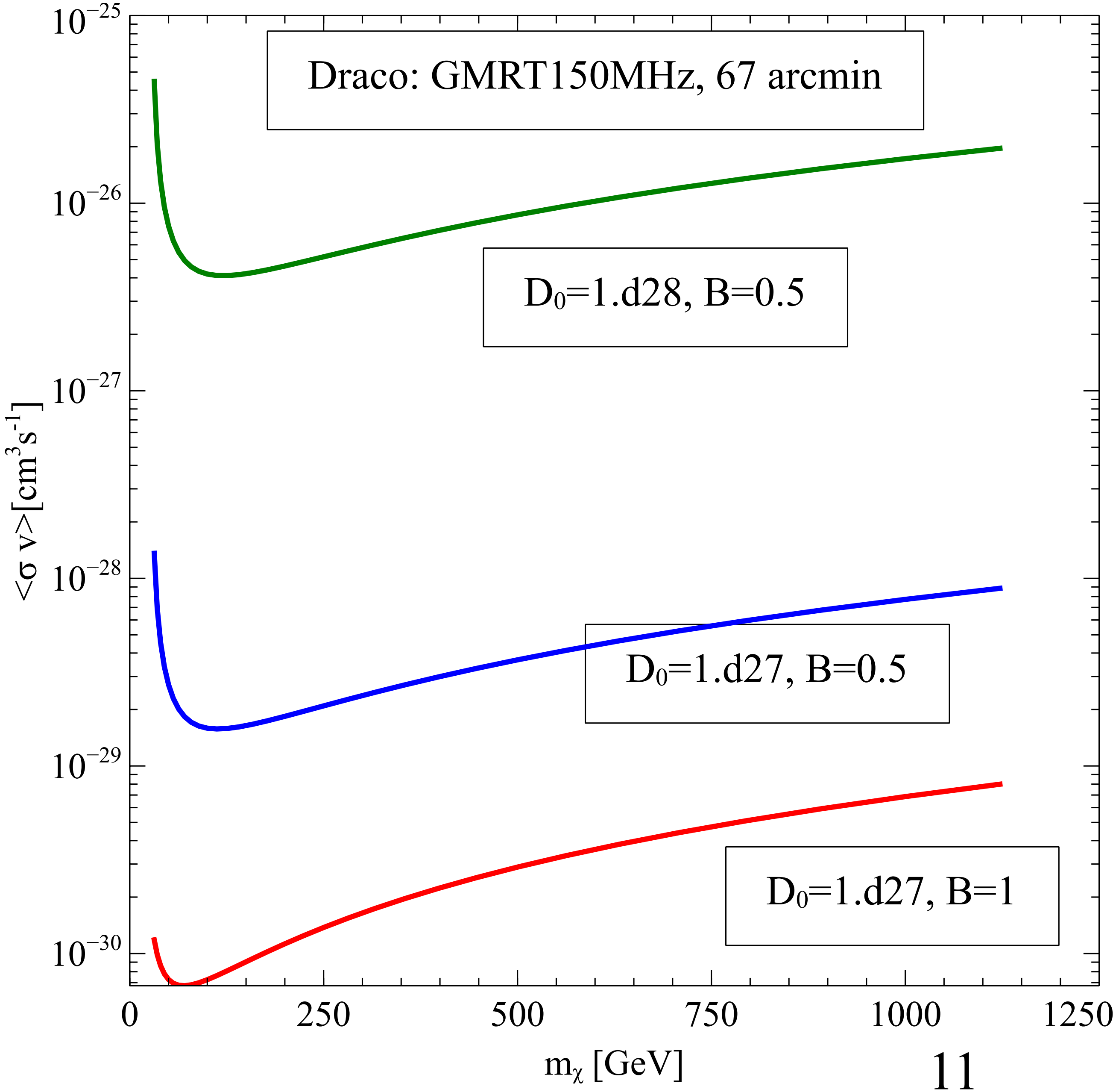
arXiv:1301.5306 K. Spekkens et al

TABLE 2
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, $57°53'$	$3° \times 4°$	$6.8'' \times 5.3''$

TABLE 3
NOISE PROPERTIES OF THE GBT MAPS

Field (1)	σ_{usub} (mJy/bm) (2)	σ_{sub} (mJy/bm) (3)	σ_{map} (mJy/bm) (4)	σ_{ast} (mJy/bm) (5)	DR (6)
Draco	33	6.6	3.4	5.7	88
UMaII	50	6.3	5.1	3.7	142
Coma	34	3.6	1.3	3.3	87
Will1	14	2.3	1.5	1.8	37


Draco: GMRT150MHz, 67 arcmin
D0=1.d28, B=0.5
D0=1.d27, B=0.5
D0=1.d27, B=1
<σ v>[cm3s-1]
10-25
10-26
10-27
10-28
10-29
10-30
0
250
500
750
1000
1250
mχ [GeV]

Dwarf Galaxies

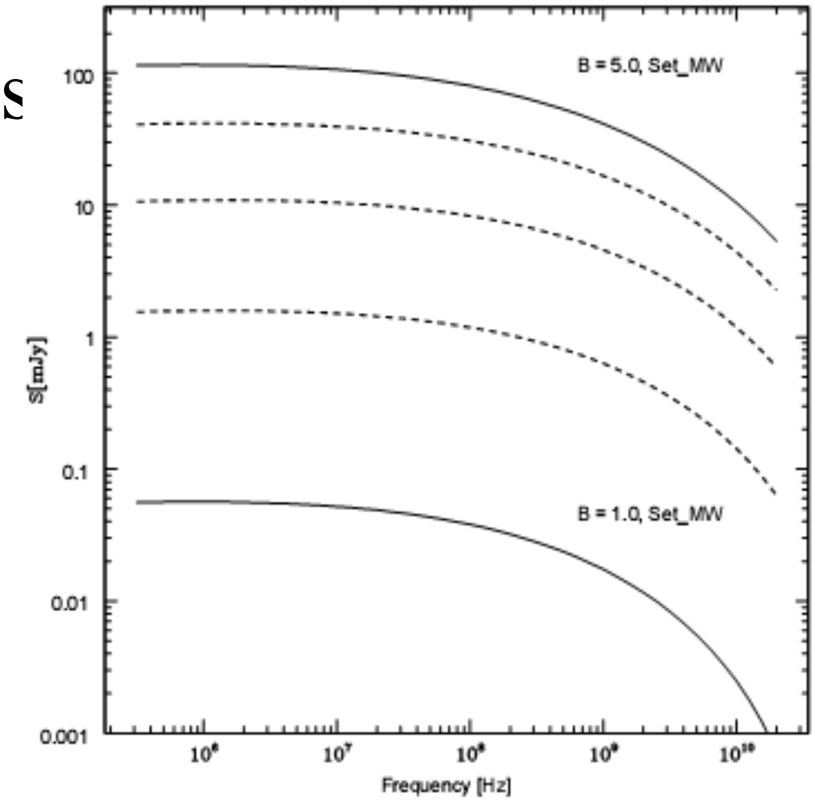
Radio Signals
(Synchrotron Emission)

Dwarf Spheroidal Galaxies
(eg: Draco; Ursa minor)

Dark Matter annihilation

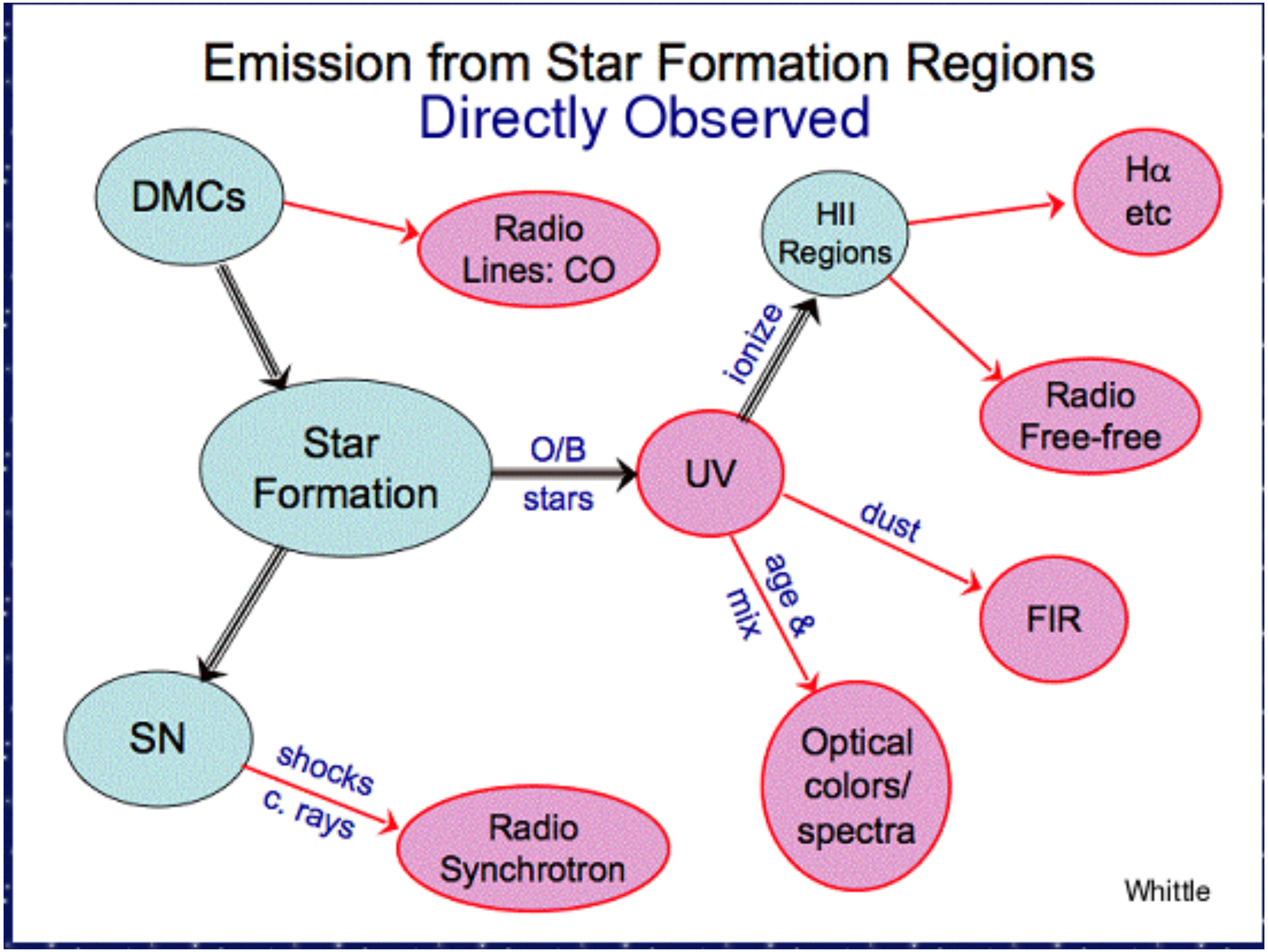
Dwarf Irregular Galaxies
(eg: LMC)

Cosmic Ray
Dark Matter annihilation



Assumption on Magnetic Field B

Comic Ray:



$\xi(M) = c\ M^{-(1+x)}$

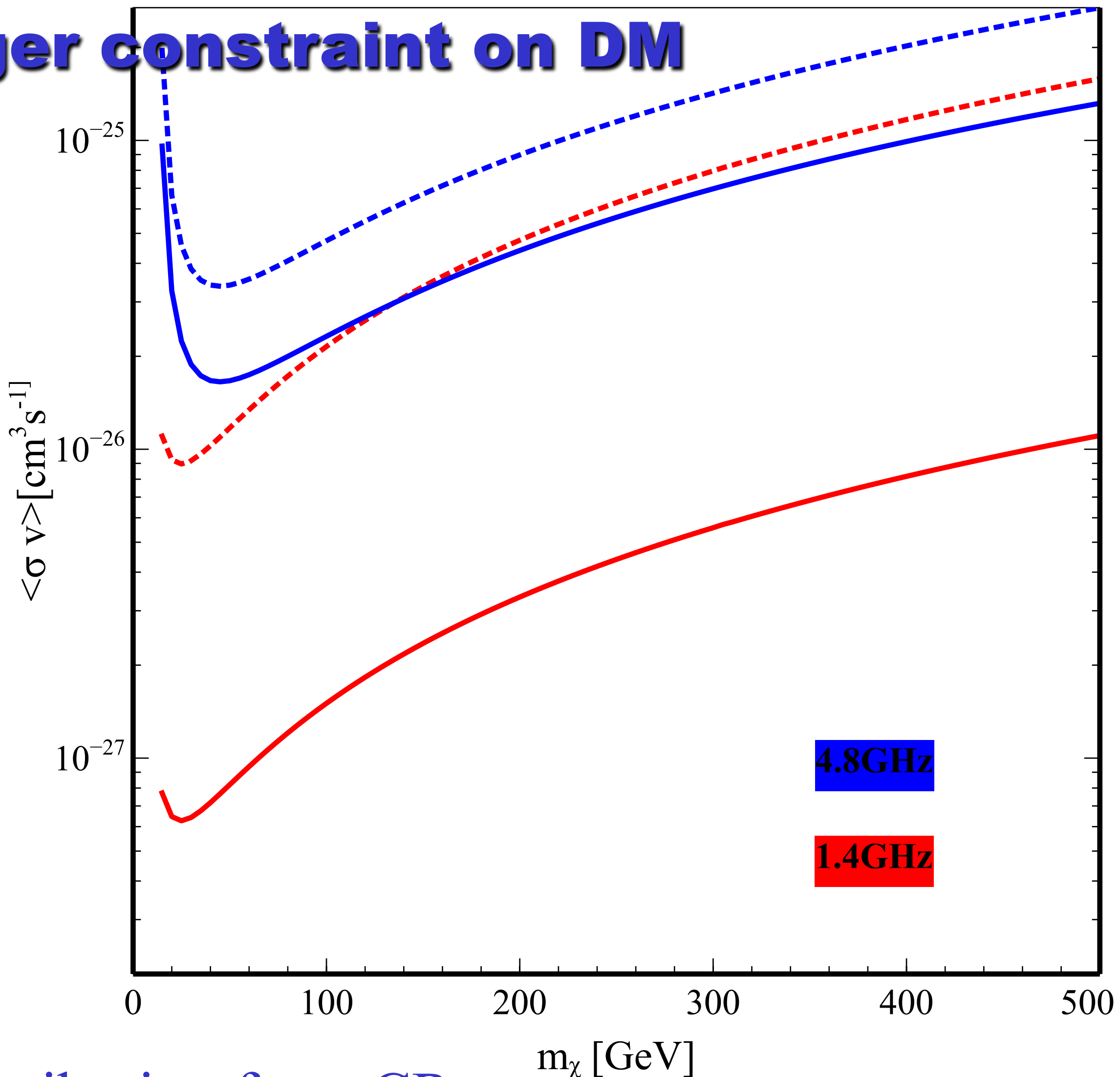
Observables produced by massive stars (short-lived population) although low mass stars dominate the mass.

radio	1. 4GHz	4. 8GHz
observation	529Jy	363Jy
Cosmic ray	492Jy	185Jy
excess	37Jy	178Jy

FIR → SFR → Contribution from CR

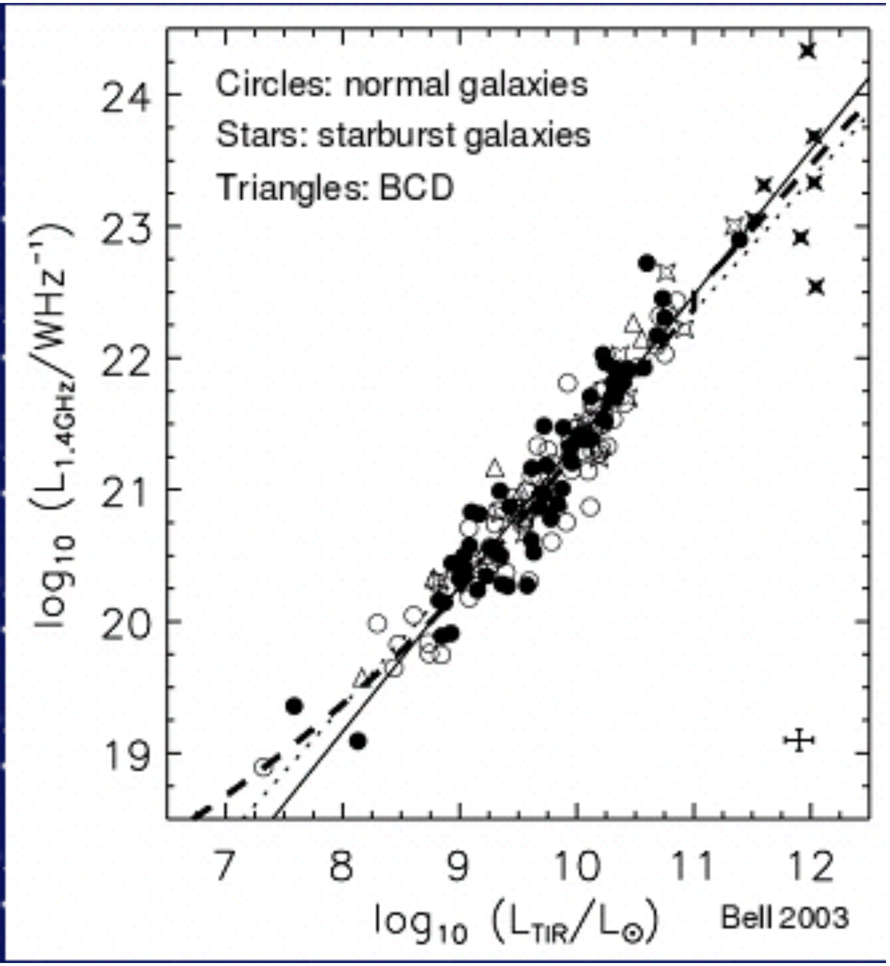
“excess” as the upper limit from DM

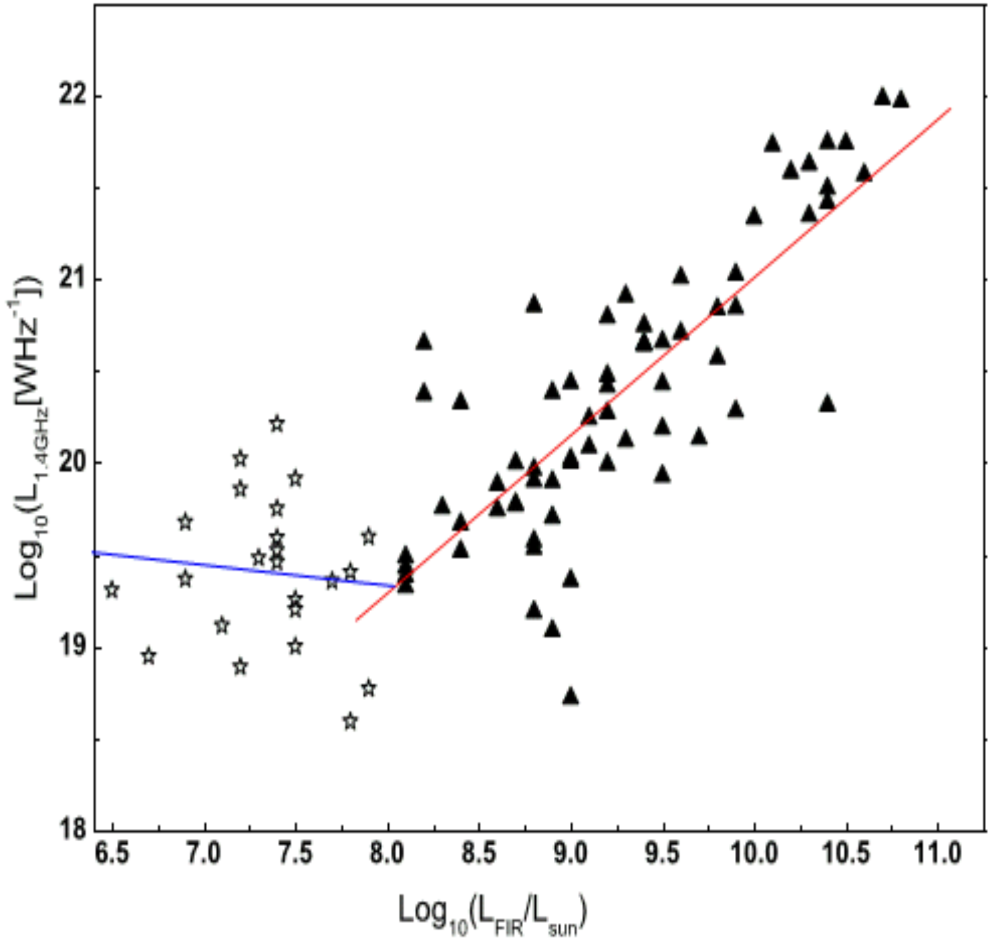
Lower frequency put stronger constraint on DM



Subtract contribution from CR,
constraints on DM are comparable to gamma-ray window

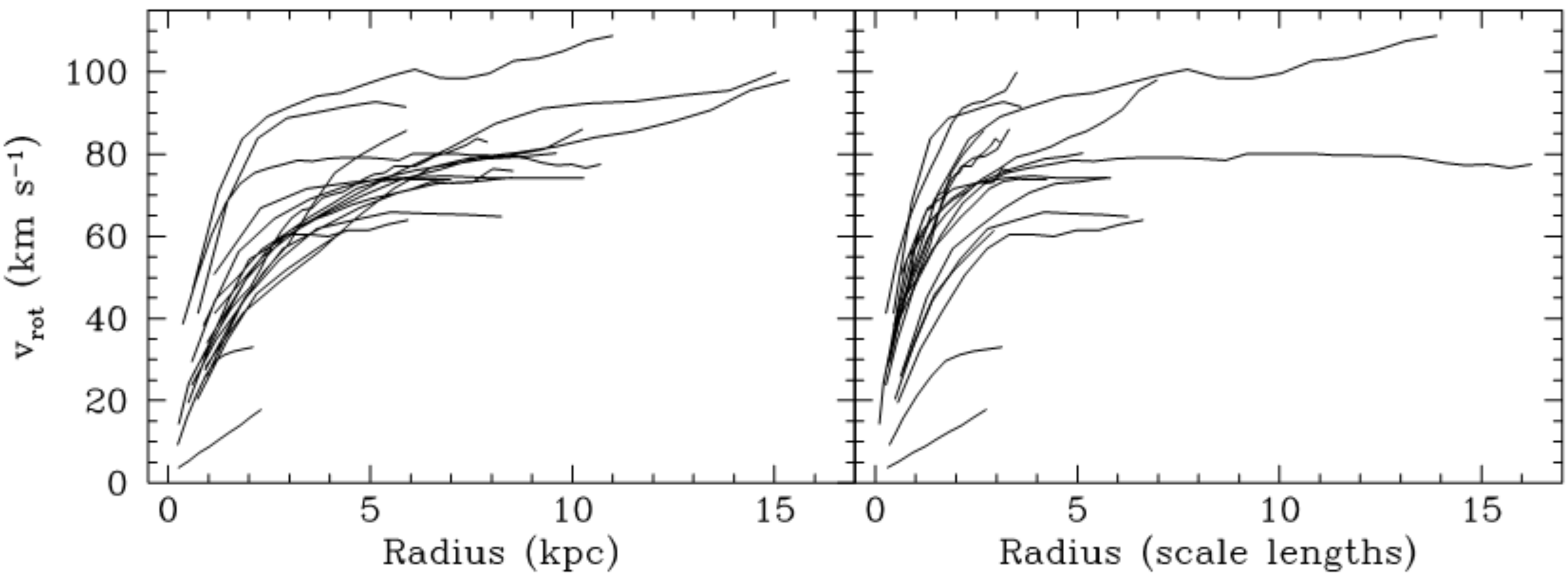
If this excess exist for other small scale galaxies

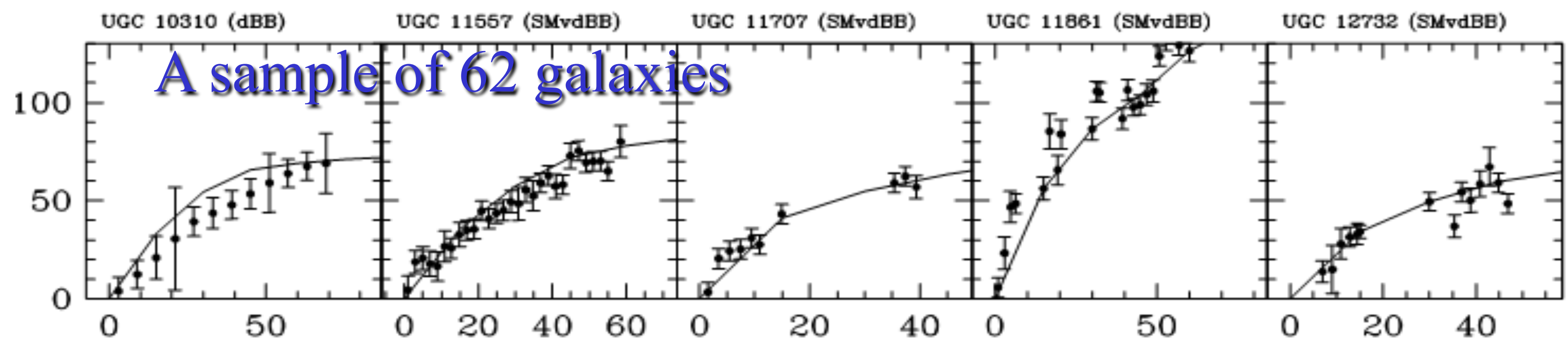




Legacy: Survey Description and Infrared Photometry(92/258)

$$(r_s, \rho_s) \longleftrightarrow (r_{vir}, M_{vir}) \longleftrightarrow (r_{max}, v_{max})$$





A sample of 62 galaxies

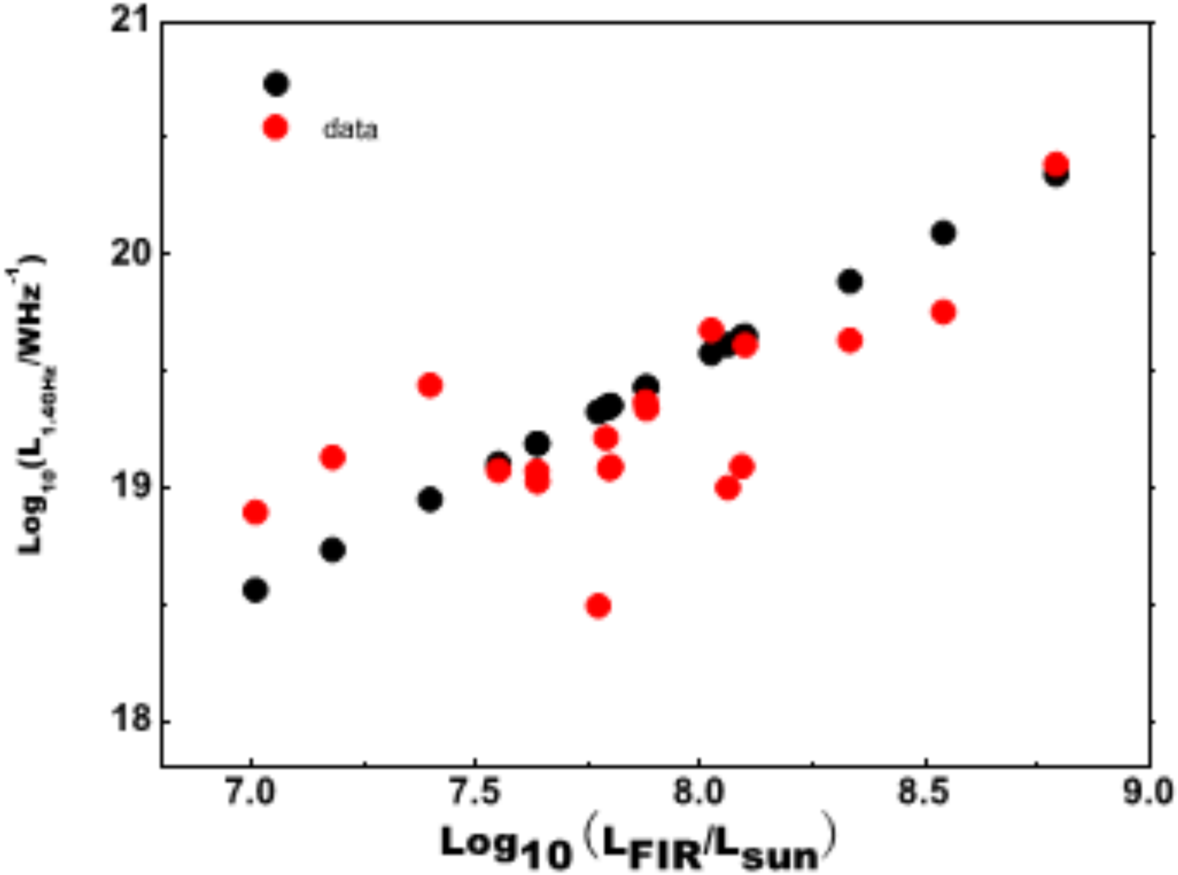
The rotation curves shapes of late-type dwarf galaxies

Arxive:0901.4222, R.A. Swaters et al

22 out of 62

UGC2033*****	0.03977
UGC2455*****	0.07284
UGC3711*****	0.19383
UGC3851*****	0.36694
UGC4305*****	0.07526
UGC4325*****	0.12908
UGC4499*****	0.04375
UGC5272*****	0.05319
UGC5414*****	0.04432
UGC5721*****	0.19589
UGC5829*****	0.07584

UGC7151*****	0.64784
UGC7232*****	0.15222
UGC7261*****	0.09583
UGC7278*****	0.767
UGC7524*****	0.71783
UGC7603*****	0.10884
UGC7690*****	0.05661
UGC8490*****	0.35408
UGC11861****	0.08045
UGC7399*****	0.29246
UGC1281*****	0.1224



Bell et al. 2005: Estimate Total IR from 24μ MIPS and combine with UV to obtain SFR:

$$SFR\ (M_{O} yr^{-1}) = 9.8 \times 10^{-11} (L_{IR} + 2.2 L_{UV})\ (erg\ s^{-1})$$

$$L_N = 1.3 \times 10^{30} \times \left(\frac{\nu}{GHz}\right)^{-\delta} \left(\frac{\nu_{SN}}{yr^{-1}}\right)$$

*f

Where & How

GALAXY: MW(GC,halo,subhalo)

Nearby Dwarf Galaxies;

Cluster of Galaxies

Extragalactic Background...

STAR: the SUN;

Pop III star;

Neutron Star

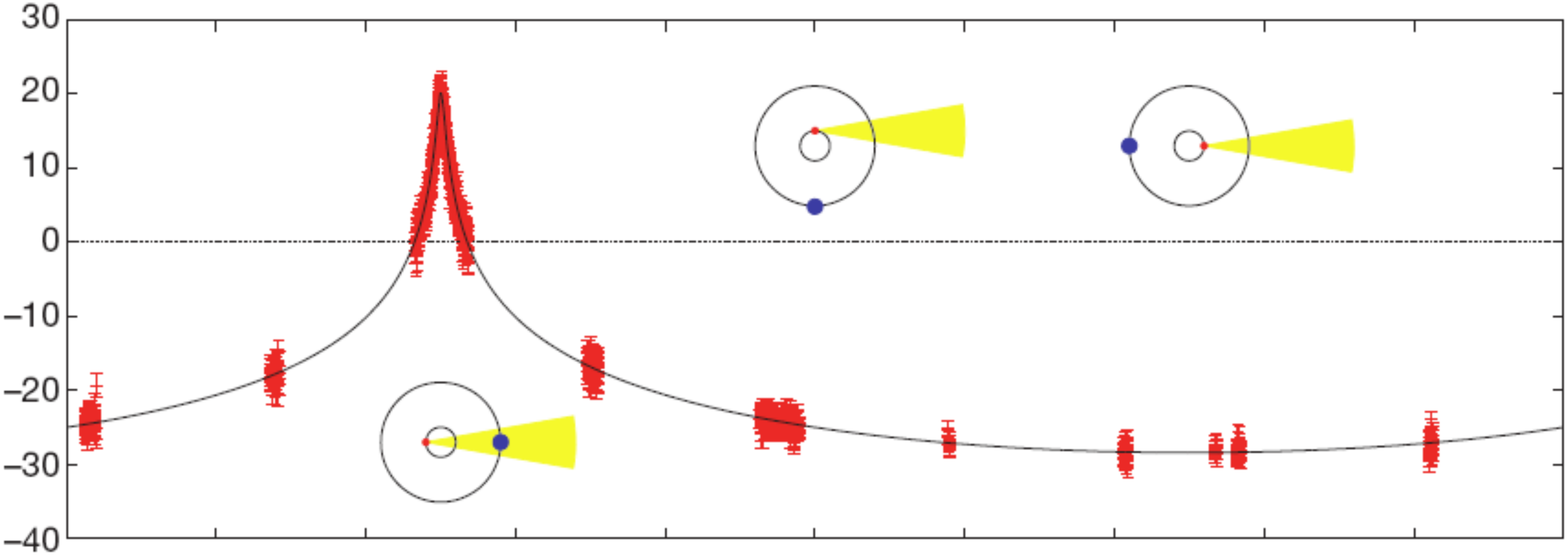
Binary System...

Earth: Direct Detection...

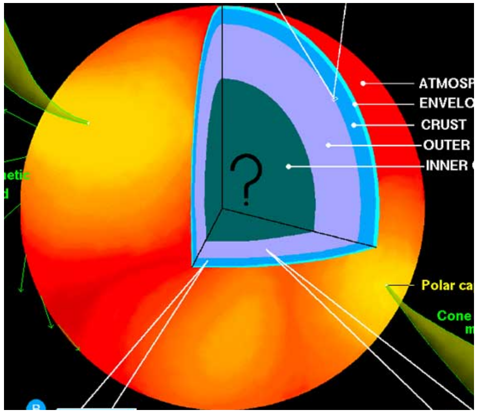
Too massive neutron stars: The role of dark matter?

Ang Li, Feng Huang(XMU)
Renxin Xu(PKU)

A two-solar-mass neutron star (NS) measured using Shapiro delay

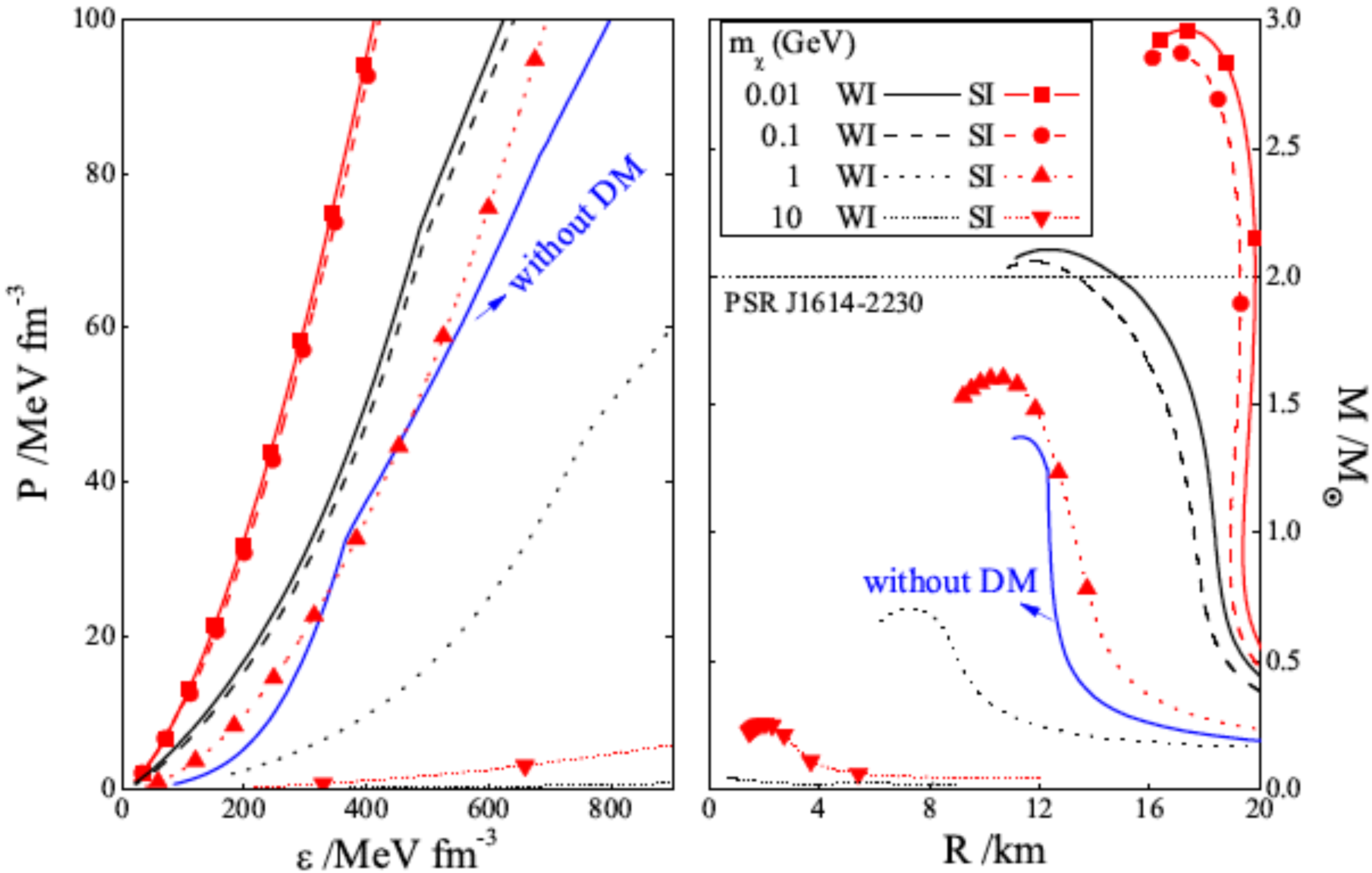


$1.97 \pm 0.04\ M_{\odot}$



- Large companion star: $0.5M_{\odot}$
- Remarkably edge-on: 89.17±0.02°

Demorest P., et al,.Nature, 2010,467: 1081



$$\mathcal{E}_\chi = \frac{m_\chi^4}{\pi^2}\int_0^{k_F/m_\chi} x^2\sqrt{1+x^2}\,dx + \left(\frac{1}{3\pi^2}\right)^2 \frac{k_F^6}{m_\mathcal{I}^2}$$

$$P_\chi = \frac{m_\chi^4}{3\pi^2}\int_0^{k_F/m_\chi} \frac{x^4}{\sqrt{1+x^2}}\,dx + \left(\frac{1}{3\pi^2}\right)^2 \frac{k_F^6}{m_\mathcal{I}^2}$$

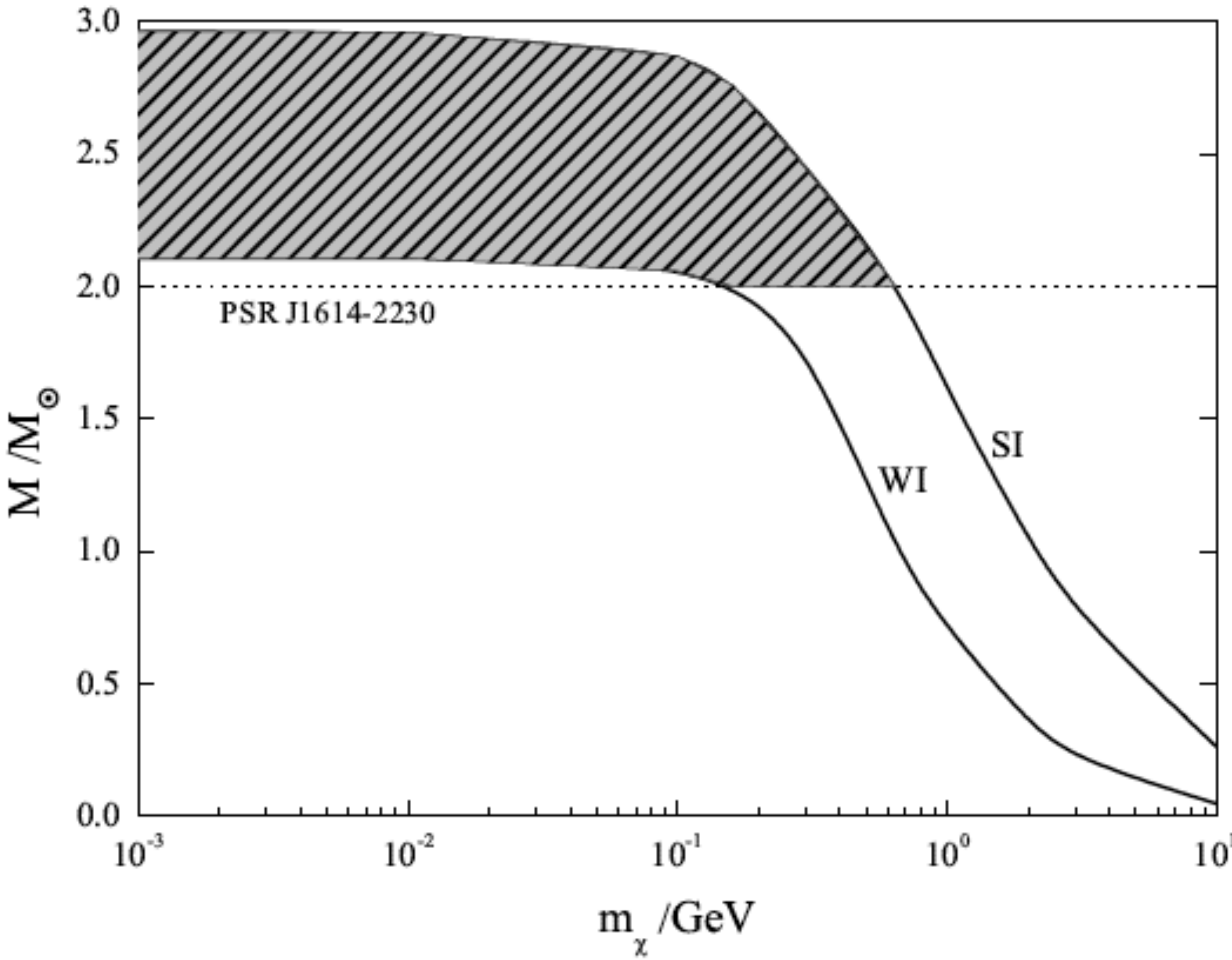
$$\frac{dP(r)}{dr} = -\frac{Gm(r)\mathcal{E}(r)}{r^2}\,\frac{\left[1+\frac{P(r)}{\mathcal{E}(r)}\right]\left[1+\frac{4\pi r^3 P(r)}{m(r)}\right]}{1-\frac{2Gm(r)}{r}},$$

$$\frac{dm(r)}{dr} = 4\pi r^2 \mathcal{E}(r)$$

Table 1
Characteristics of the maximum mass configurations (maximum masses M, corresponding radii R and central number densities ρ_c) for different DM mass m_χ and composition.

m_χ (GeV)		SI			WI		
		$M(M_\odot)$	R (km)	ρ_c (fm^{-3})	$M(M_\odot)$	R (km)	ρ_c (fm^{-3})
0.01	NS	2.96	17.3	0.35	2.11	12.4	0.77
	HS	2.96	17.3	0.35	2.11	12.4	0.77
0.1	NS	2.88	16.8	0.36	2.06	11.7	0.82
	HS	2.88	16.8	0.36	2.06	11.7	0.82
1	NS	1.67	9.85	0.68	1.34	6.61	1.39
	HS	1.61	10.5	0.61	0.71	7.39	1.32
10	NS	0.39	2.16	2.61	0.34	1.74	4.12
	HS	0.26	1.99	3.62	0.05	0.65	40.9

$$M_\chi = \frac{4}{3}\pi R^3 \bar{\rho_\chi} \qquad R = \frac{0.49(M_1/M_2)^{2/3}}{0.6(M_1/M_2)^{2/3} + ln[1 + (M_1/M_2)^{1/3}]}\, a$$



$$\mathcal{E}_\chi = \frac{m_\chi^4}{\pi^2}\int_0^{k_F/m_\chi} x^2\sqrt{1+x^2}dx + \left(\frac{1}{3\pi^2}\right)^2 \frac{k_F^6}{m_{\mathcal{I}}^2}$$

$$P_\chi = \frac{m_\chi^4}{3\pi^2}\int_0^{k_F/m_\chi} \frac{x^4}{\sqrt{1+x^2}}dx + \left(\frac{1}{3\pi^2}\right)^2 \frac{k_F^6}{m_{\mathcal{I}}^2}$$

Nucleon Spin Structure ann its impact on Dark Matter Direct Search

Feng Huang(XMU)
Shaoyang Jia(St. W&M, USA)

DM interact with quarks through… $\tilde{q}$ h Z

$$L = f_q(\bar{\chi}\chi)\cdot(\bar{q}q) + d_q(\bar{\chi}\gamma^{\mu}\gamma^5\chi)\cdot(\bar{q}\gamma_{\mu}\gamma^5 q) + \ldots.$$

quark content

quark spin

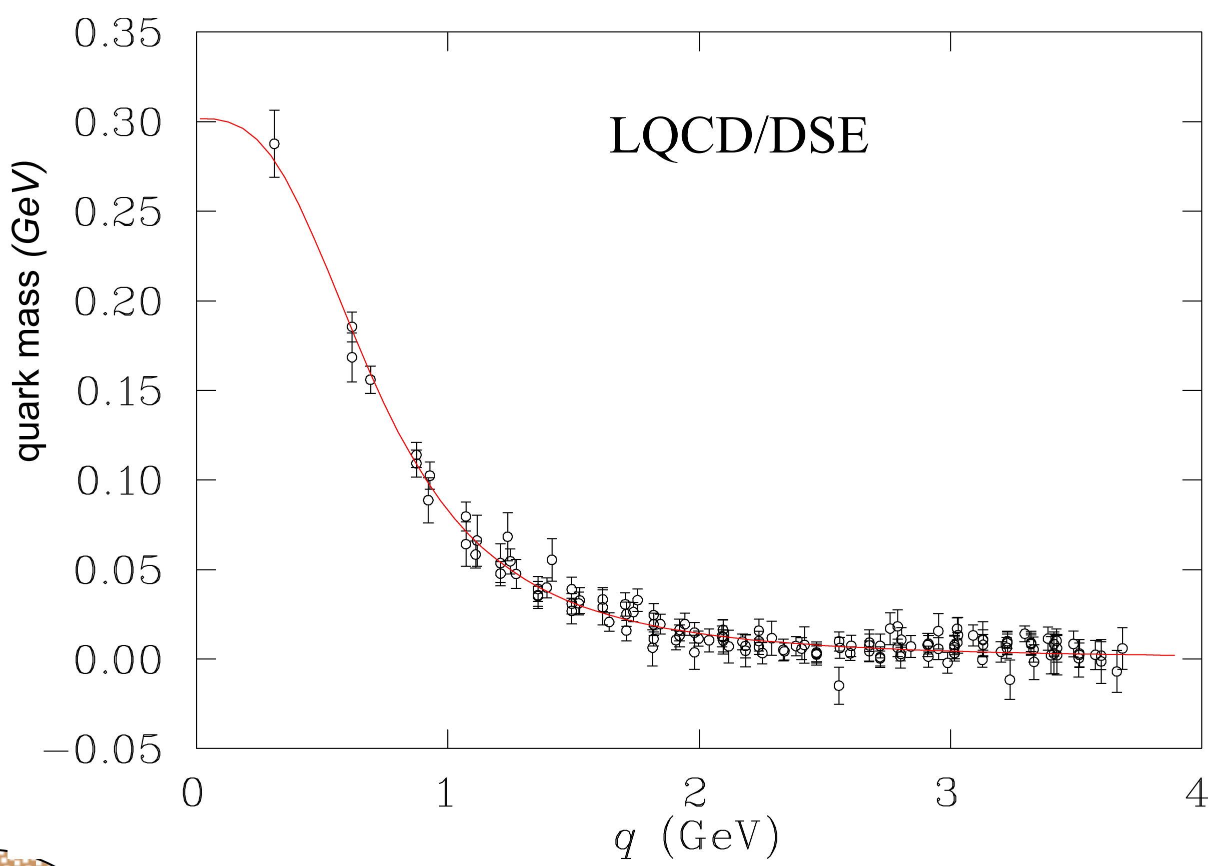
$\tilde{q}$, h, Z → $f_q; d_q$

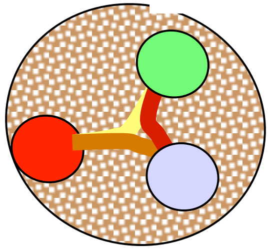
m_u/m_d	0.553 ± 0.043	[4]
m_d	5 ± 2 MeV	[5]
m_s/m_d	18.9 ± 0.8	[4]
m_c	1.25 ± 0.09 GeV	[5]
m_b	4.20 ± 0.07 GeV	[5]
m_t	171.4 ± 2.1 GeV	[6]
σ_0	36 ± 7 MeV	[7]
$\Sigma_{\pi N}$	64 ± 8 MeV	[8, 9]
$a_3^{(p)}$	1.2695 ± 0.0029	[5]
$a_8^{(p)}$	0.585 ± 0.025	[10, 11]
$\Delta_s^{(p)}$	-0.09 ± 0.03	[12]

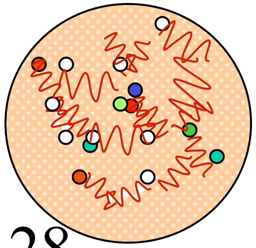
Strange quark

Arxiv:[hep-ph]0801.3656

Eg: the scale dependency of quark mass







the scale of $m_s^{\ 2} \approx 0.01 GeV^2$

Nucleon Structure in low energy???

- Lattice QCD
- Phenomenological model
- Experiment data

Due to the divergeny of α_s
Results confined to the scale of GeV

↓

The scale dependency?

the scale of $m_s{}^2 \approx 0.01 GeV^2$

Our Model:

- Step1: Expand the Nucleon property in α_s

- Step2: Find the scale dependency of α_s

Converge in the low energy region

QCD coupling constant α_s

$$\beta(\alpha_s) = -\alpha_s^2(\beta_0 + \beta_1\alpha_s + \beta_2\alpha_s^2 + \ldots)$$

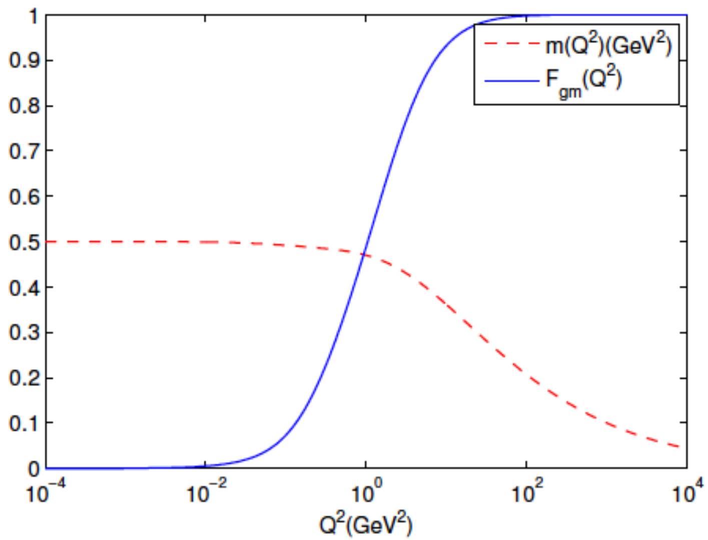


FIG. 2. Scale Dependence of m and F_{gm}; Solid line for correction factor, and dashed line for effective gluon mass in unit of GeV.

$$Q^2 \frac{d\alpha_s}{dQ^2} = \beta(\alpha_s).$$

$$Q^2 \frac{d\alpha_s}{dQ^2} = \beta_{ptb}(\alpha_s) F_{gm}(Q^2),$$

$$F_{gm}(Q^2) = \frac{Q^2}{4m^2(Q^2) + Q^2}\left(1 + 4\frac{dm^2(Q^2)}{dQ^2}\right)$$

$$m^2(Q^2) = \frac{m_0^4}{Q^2 + m_0^2}\left[\ln\left(\frac{Q^2 + 2m_0^2}{\Lambda_{\rm QCD}}\right) / \ln\left(\frac{2m_0^2}{\Lambda_{\rm QCD}^2}\right)\right]^3$$

$$Q^2 \frac{d\alpha_s}{dQ^2} = \beta_{ptb}(\alpha_s) F_{gm}(Q^2),$$

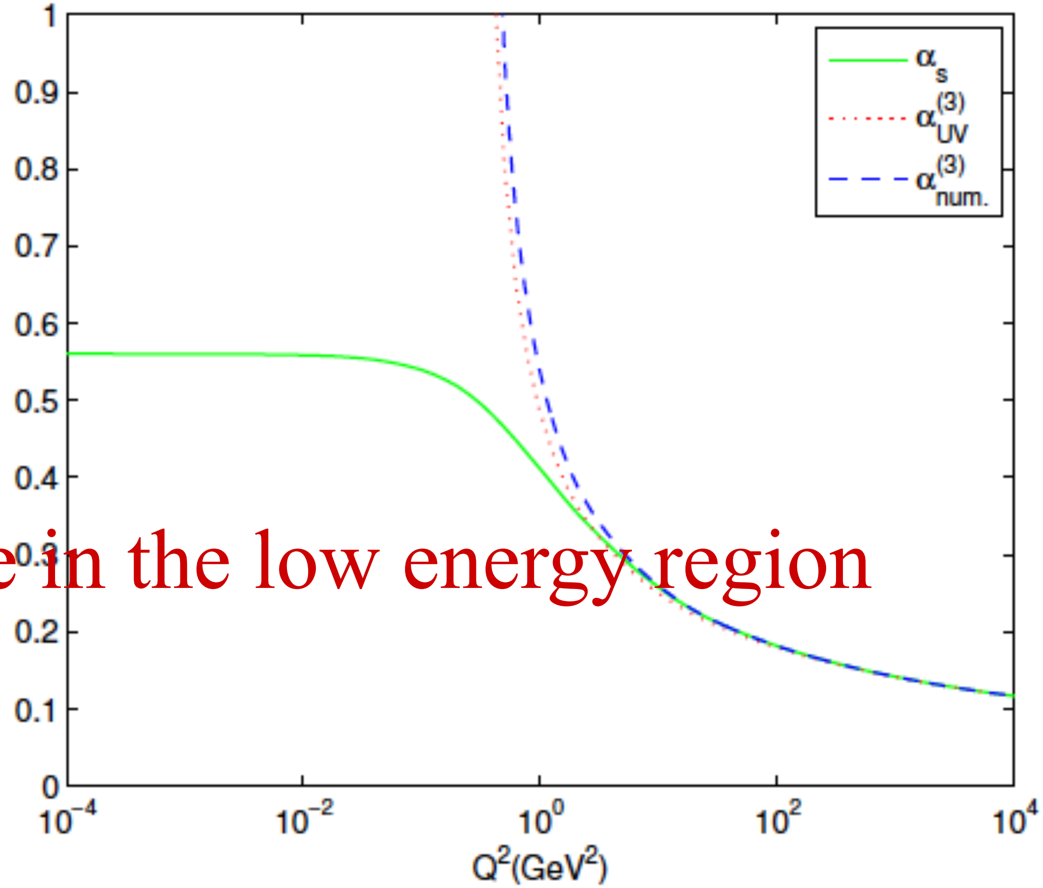
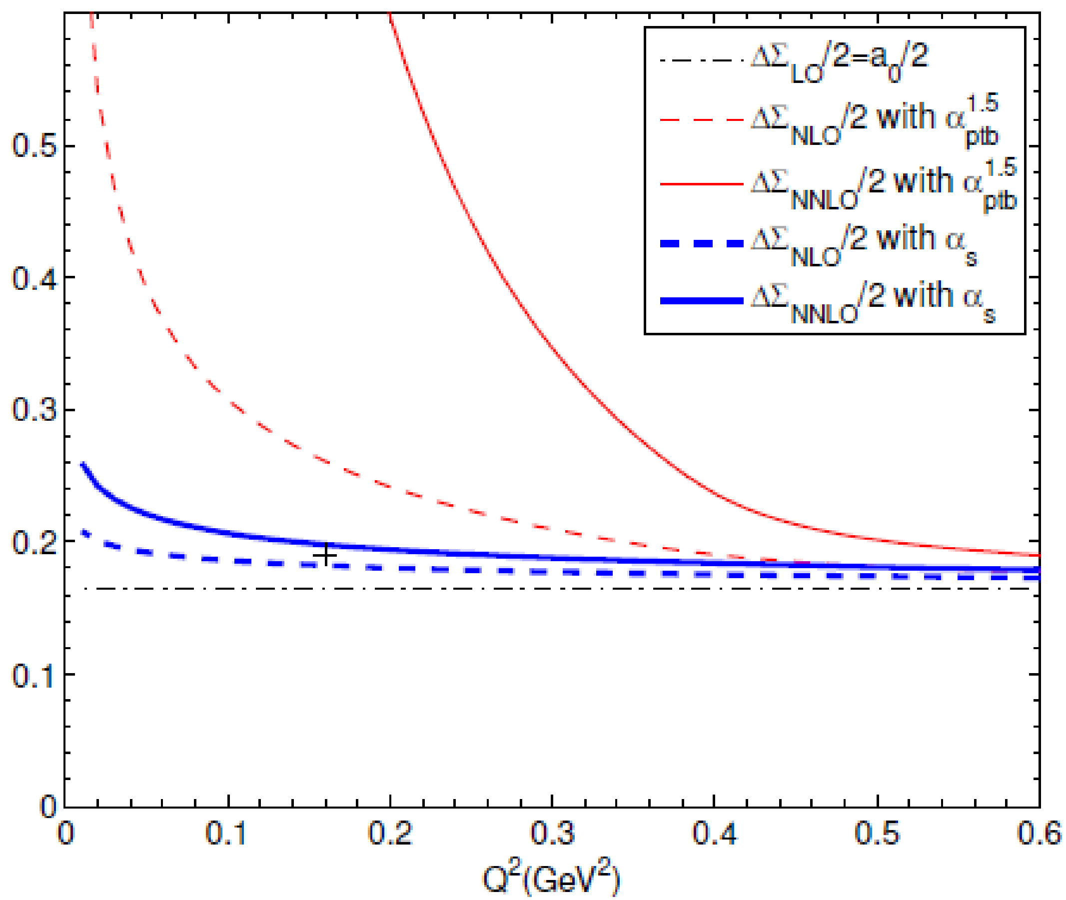


FIG. 1. Green solid line: numerical solution to Eq. (8) with four-loop β_{ptb}. Red dotted line: running coupling obtained by three-loop version of Eq. (B1). Blue dashed line: numerical solution to three-loop QCD beta function. All curves are normalized at $Q^2 = M_{Z_0}^2$.

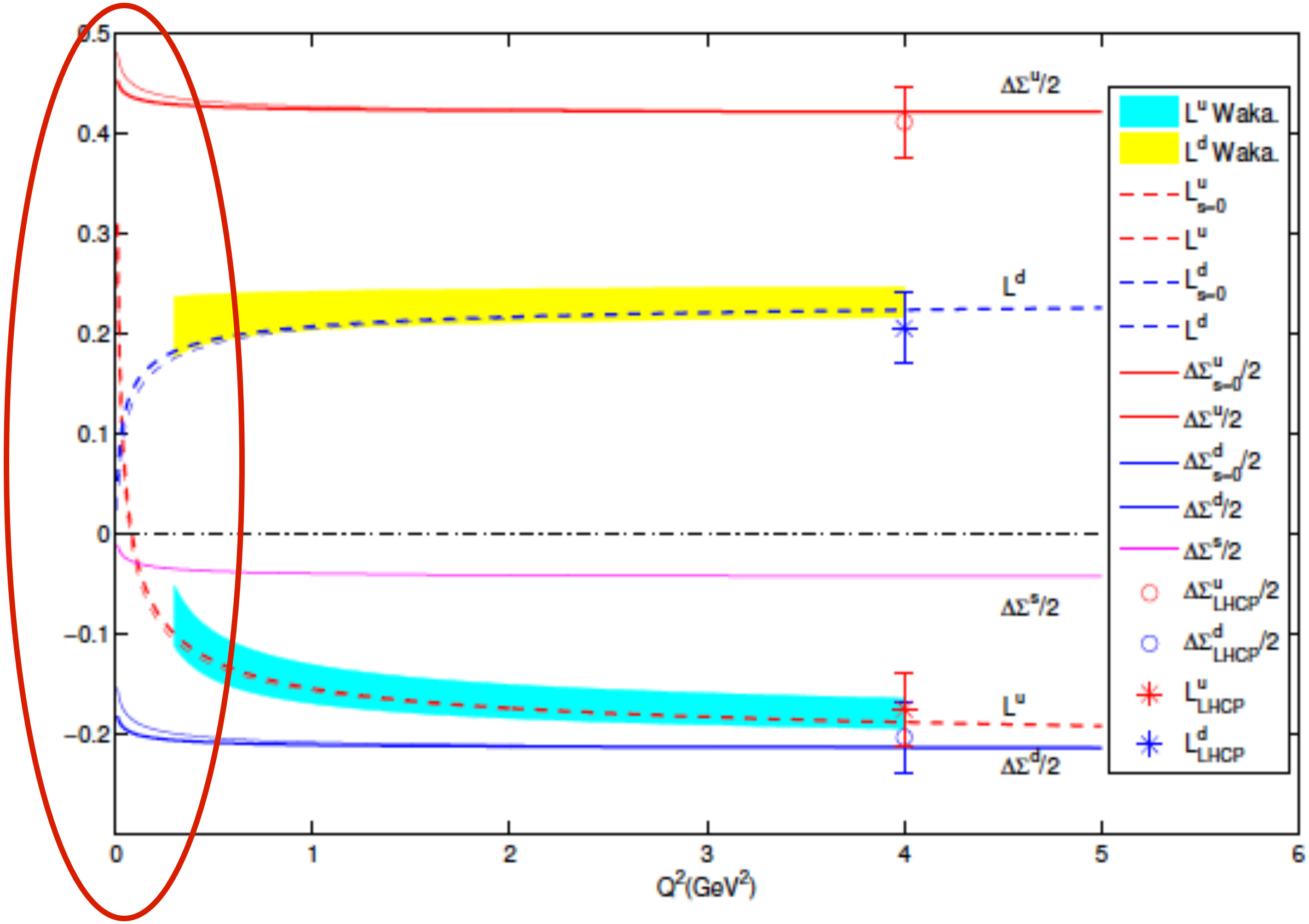
$$\Delta\Sigma(Q^2) = \Delta\Sigma(\mu^2) exp\left\{\int_{Q^2}^{\mu^2}\left(8n_f\left(\frac{\alpha_s(Q^2)}{4\pi}\right)^2 + \left(200n_f - \frac{16}{9}n_f^2\right)\left(\frac{\alpha_s(Q^2)}{4\pi}\right)^3\right)\frac{dQ^2}{Q^2}\right\}. \tag{10}$$



(1): perturbatively expand to what kind of order

(2): How does the coupling constant evolve with the energy scale Q^2

$$\frac{1}{2} = \frac{1}{2}\underbrace{(\Delta u + \Delta d + \Delta s)}_{\Delta\Sigma} + \Delta G + L$$



$\Delta_s{}^p = \Delta_s{}^n = -0.022$ @$Q^2 = 0.01 GeV^2$

Spin-dependent DM-N cross-section

$$\sigma_{\chi p,n} = \frac{32}{\pi} G_F{}^2 m_r{}^2 \Lambda^2 J(J+1) \qquad m_r = \frac{m_\chi m_p}{m_\chi + m_p}$$

where $\Lambda = \dfrac{a_{p,n}}{J}$ (J : the spin of the nucleon)

$$a_{p,n} = \sum_{q=u,d,s} \frac{d_q}{\sqrt{2}G_F} \Delta_q{}^{(p,n)} \qquad d_q = -\frac{g^2 T_{3q}}{8M_W^2}\left(|N_{13}|^2 - |N_{14}|^2\right) + \ldots$$

$\Delta_q{}^{(p,n)}$: the quark spin content of the nucleon

Our results:

$$\Delta_s{}^p = \Delta_s{}^n = \text{-}0.022 \ @\mathrm{Q}^2 = 0.01 GeV^2$$

$$\Delta_s{}^p = \Delta_s{}^n = \text{-}0.084 \ @\mathrm{Q}^2 = 3 GeV^2$$

		$Q^2 = 0.01\ GeV^2$	
		σ^{d}_{px}/Pb	σ^{d}_{nx}/Pb
Mx=（GeV）	73.33	1.96E-06	1.84E-06
	78.27	2.88E-03	2.70E-03
	92.25	3.79E-04	3.56E-04
	151.57	4.97E-05	4.70E-05
	165.02	4.54E-04	4.25E-04
	377.32	5.73E-07	5.36E-07
	988.44	9.78E-04	9.16E-04
	1016.83	9.67E-04	9.10E-04

		$Q^2 = 1.00\ GeV^2$	
		σ^{d}_{px}/Pb	σ^{d}_{nx}/Pb
Mx=（GeV）	73.33	2.34E-06	1.46E-06
	78.27	3.44E-03	2.14E-03
	92.25	4.53E-04	2.81E-04
	151.57	5.95E-05	3.71E-05
	165.02	5.41E-04	3.37E-04
	377.32	6.83E-07	4.25E-07
	988.44	1.17E-03	7.25E-04
	1016.83	1.16E-03	7.19E-04

表格七：为在自旋$Q^2 = 0.01GeV^2$下各物质的弹性散射截面

$Q^2 = 0.01GeV^2$	σ_{Ax}^{d}/Pb					
Mx/GeV	a=1，z=0	a=1，z=1	a=7，z=3	a=23，z=11	a=73，z=32	a=127，z=53
78.27	2.70E-03	2.88E-03	3.94E-02	0.106778814	0.755063204	0.716975714
151.57	4.70E-05	4.97E-05	7.63E-04	2.70E-03	3.45E-02	4.80E-02
1016.83	9.10E-04	9.67E-04	1.33E-02	3.68E-02	0.270643779	0.259847102

表格八：为在自旋$Q^2 = 0.10GeV^2$下各物质的弹性散射截面

$Q^2 = 0.10GeV^2$	σ_{Ax}^{d}					
Mx/GeV	a=1，z=0	a=1，z=1	a=7，z=3	a=23，z=11	a=73，z=32	a=127，z=53
78.27	2.54E-03	3.04E-03	4.16E-02	0.113787152	0.705147425	0.782515072
151.57	4.44E-05	5.25E-05	8.07E-04	2.88E-03	3.22E-02	5.25E-02
1016.83	8.58E-04	1.02E-03	1.41E-02	3.93E-02	0.252621582	0.283863118

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