Technische Universität München

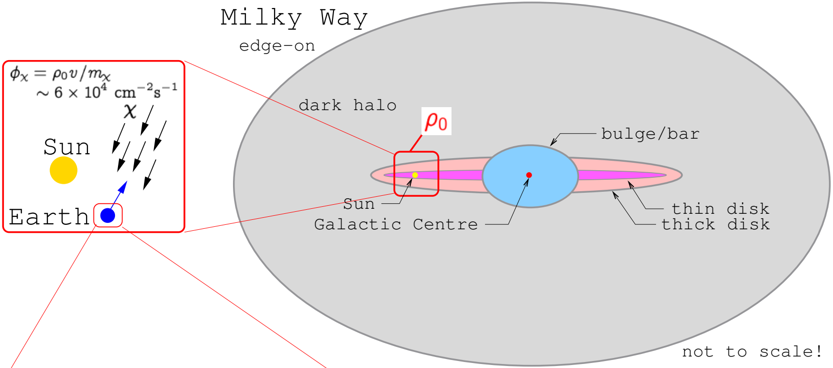
ASTROPHYSICAL UNCERTAINTIES IN DIRECT DARK MATTER SEARCHES

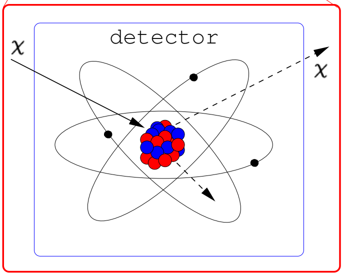
Miguel Pato

Physik-Department T30d, Technische Universität München

TUM, Garching, April 26th 2012

1. DIRECT DARK MATTER SEARCHES





driving idea: detect WIMP scattering off nuclei

$$\frac{dR}{dE_R} = \frac{1}{m_N} \int_{v_{min}}^{\infty} d^3\vec{v}\, \frac{\rho_0 v}{m_\chi} f(\vec{v} + \vec{v}_e) \frac{d\sigma_{\chi-N}}{dE_R}$$

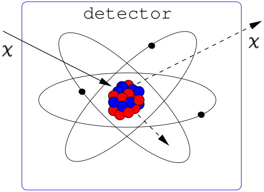
astrophysics

nuclear/particle physics

1. DIRECT DARK MATTER SEARCHES

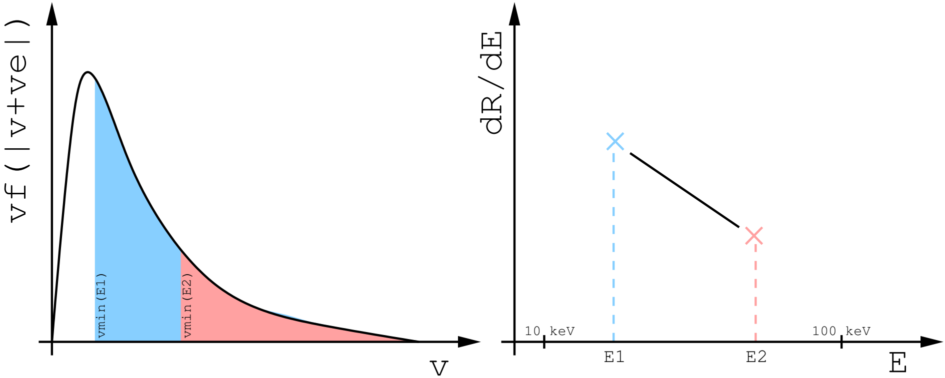
WIMP signatures

1. exponential recoil spectrum



$$v_{min} = \sqrt{\frac{m_N E_R}{2\mu_N^2}}$$

$$f(w) \propto \exp(-w^2/2\sigma^2)$$



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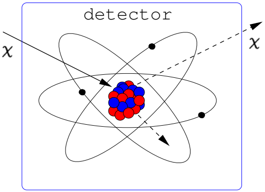
2. annual modulation



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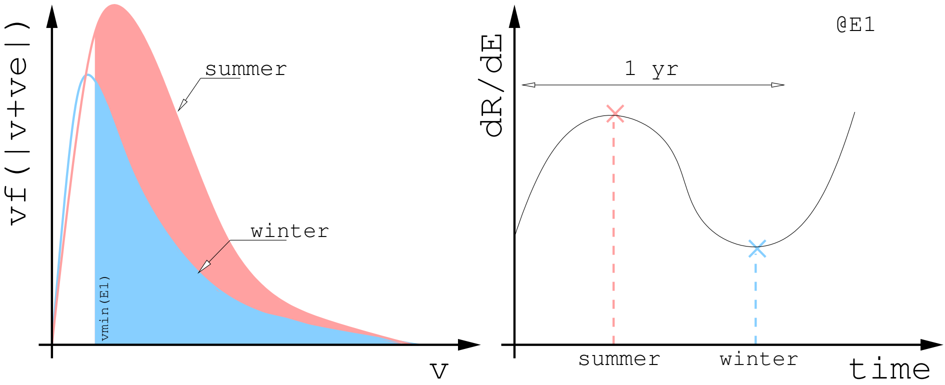

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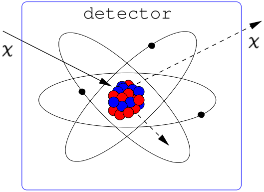
2. annual modulation
3. directional pattern



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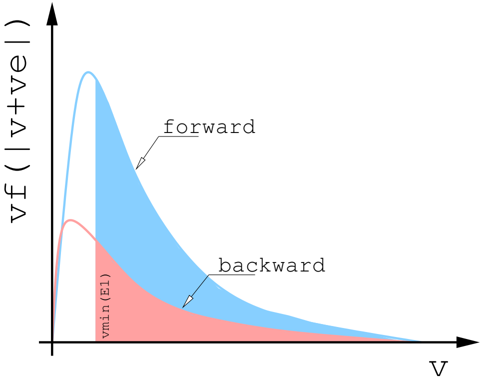

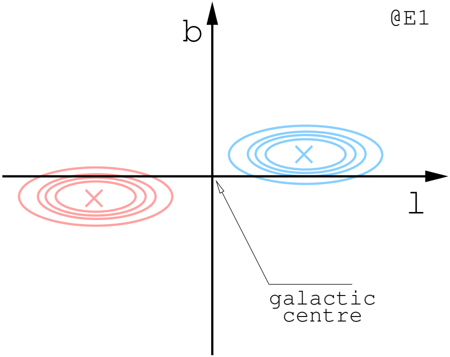

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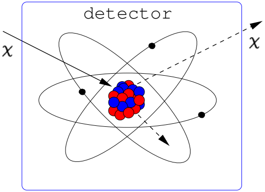

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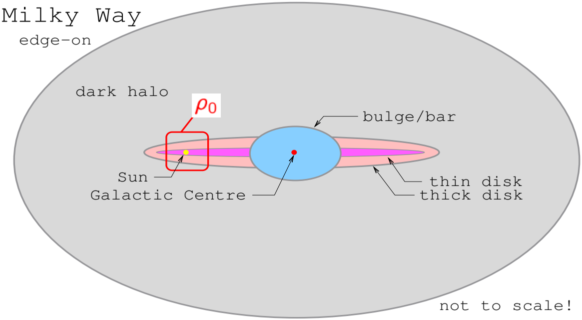
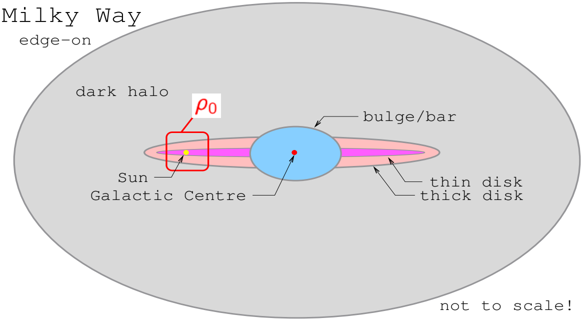


assuming we know well the dark matter distribution... but do we?

2. MILKY WAY MASS MODELLING

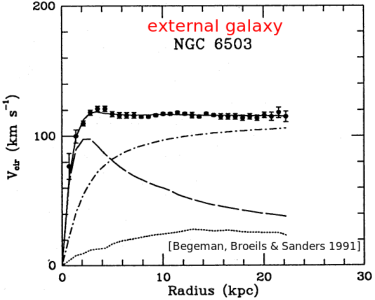
bulge(+bar)	$\lesssim$ 3 kpc	
disk	$\lesssim$ 10 kpc	
dark halo	$\lesssim$ 200 kpc	$\rho_{DM} \propto \rho_0 \, r^{-\alpha}(1 + r/r_s)^{-3+\alpha}$
+gas...		



how can we constrain the parameters of a MW mass model?

2. MILKY WAY MASS MODELLING

rotation curve   traces total potential



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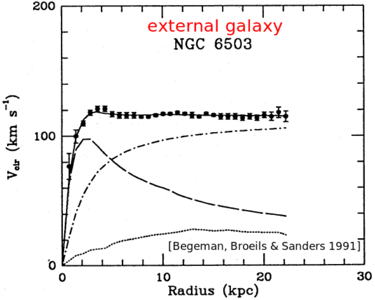

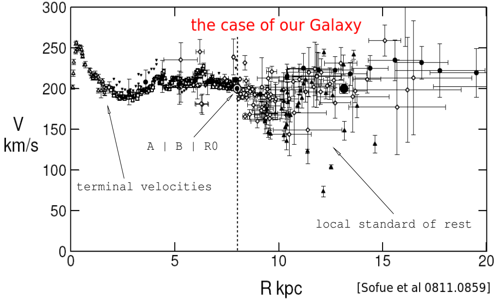

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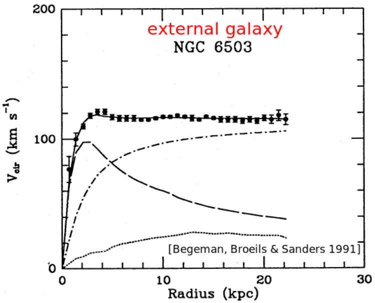

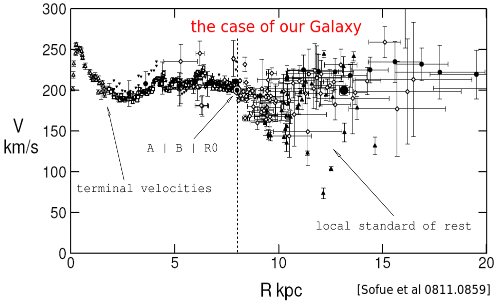

satellite dynamics traces total mass enclosed at $R \sim \mathcal{O}(100)$ kpc

star counts and dynamics

.. σ_v in tracers: traces total potential at $R \sim \mathcal{O}(50)$ kpc

.. Oort's limit: traces local total surface density

.. local luminosity: traces local visible surface density

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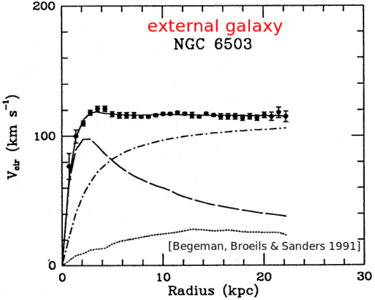

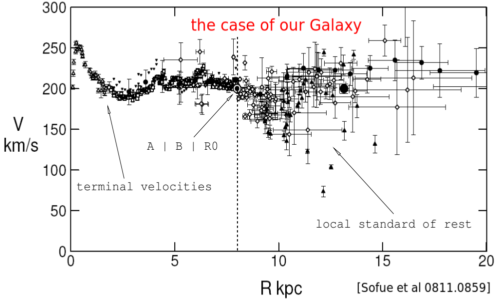

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gravitational microlensing

traces the density of lenses along l.o.s.

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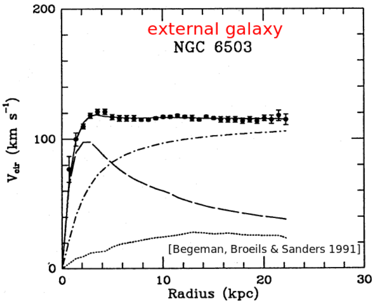

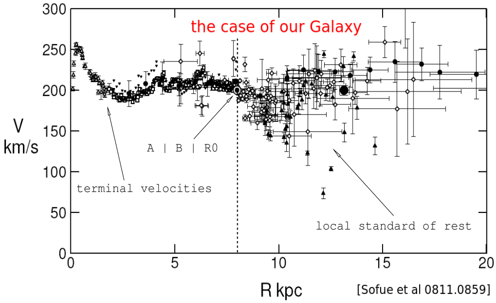

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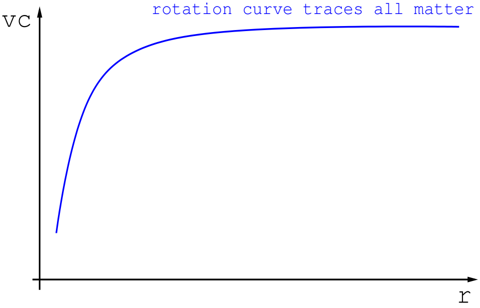

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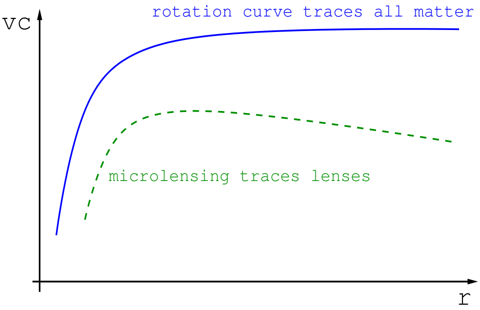

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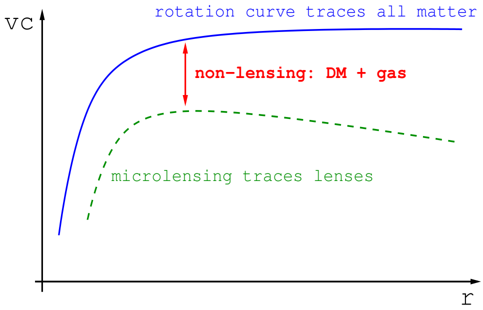

bottomline rotation curve + microlensing constrain DM profile

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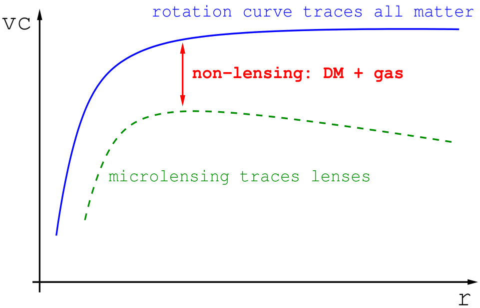


bottomline rotation curve + microlensing constrain DM profile

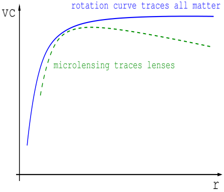
Binney & Evans 2001

conclude that cuspy profiles are inconsistent (!!)

but: .. new microlensing data released

.. poor v_c treatment

.. simplified MW mass modelling



[**Iocco, MP, Bertone & Jetzer, arXiv:1107.5810, JCAP11(2011)029**]

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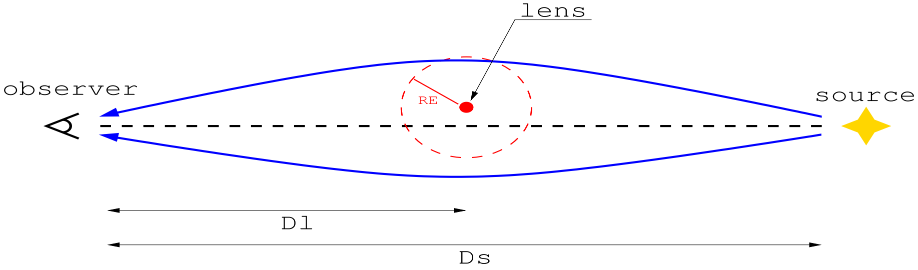
microlensing is a direct consequence of GR

[Paczynski '86]



$$R_E^2 = \frac{4GM_l}{c^2} D_l \left(1 - \frac{D_l}{D_s}\right)$$

unresolved images $\quad A(t) = \frac{u^2+2}{u\sqrt{u^2+4}}$

$M_l \sim [10^{-6}, 10^2]$ $M_\odot$: $t_E \sim$ hr − days

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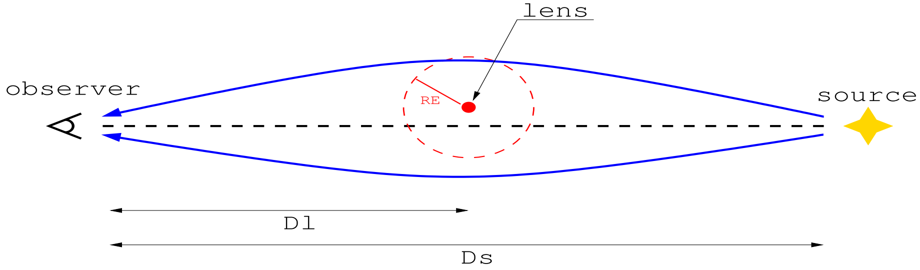

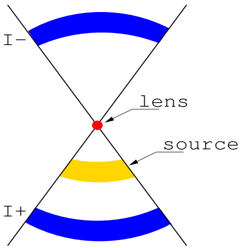

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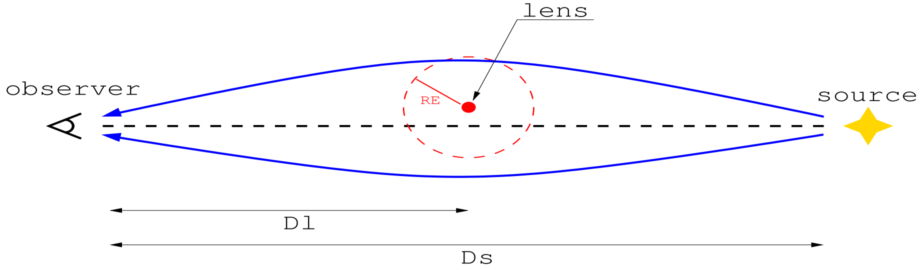

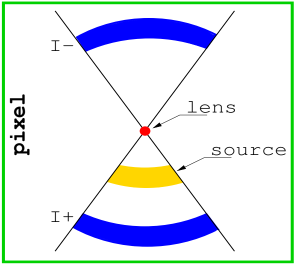

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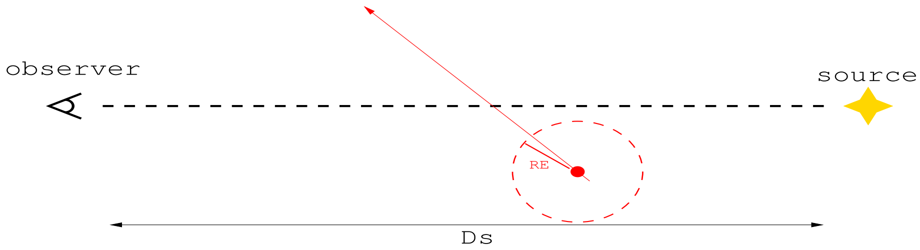

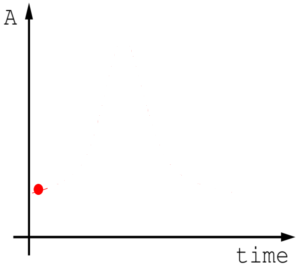

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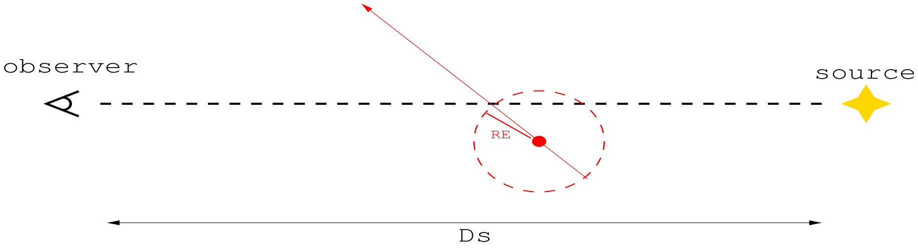

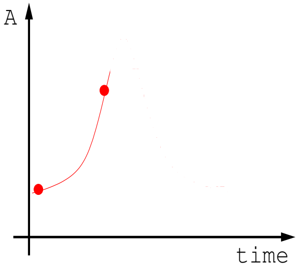

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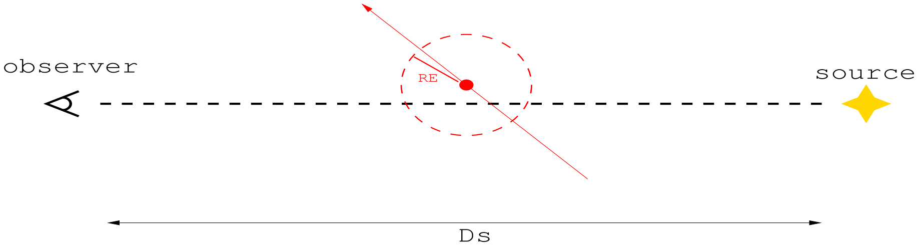

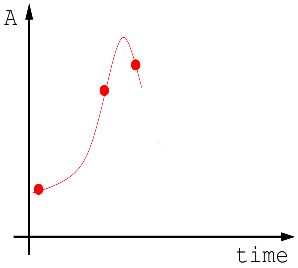

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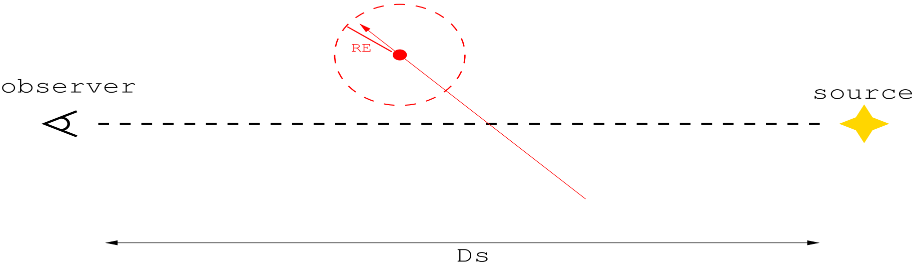

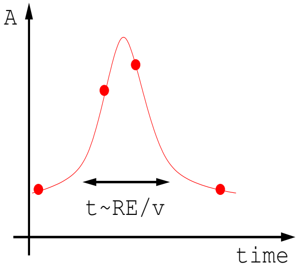

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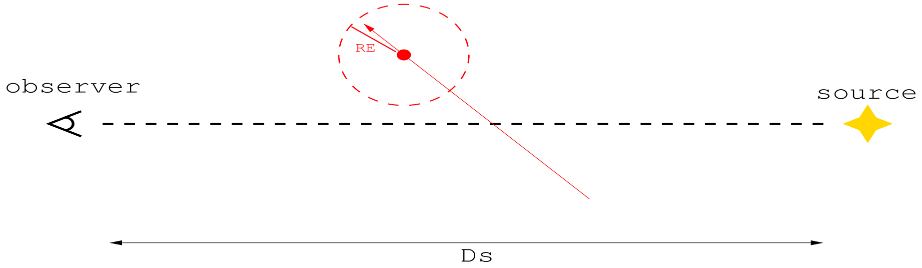

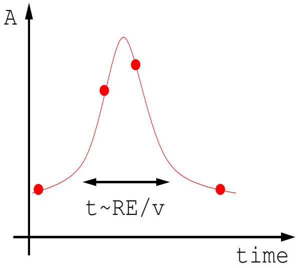

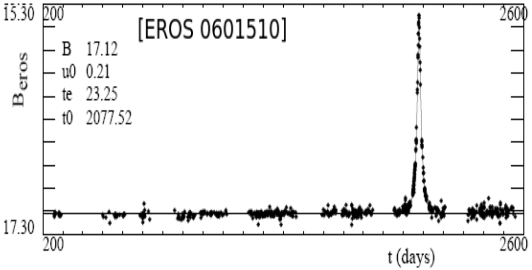

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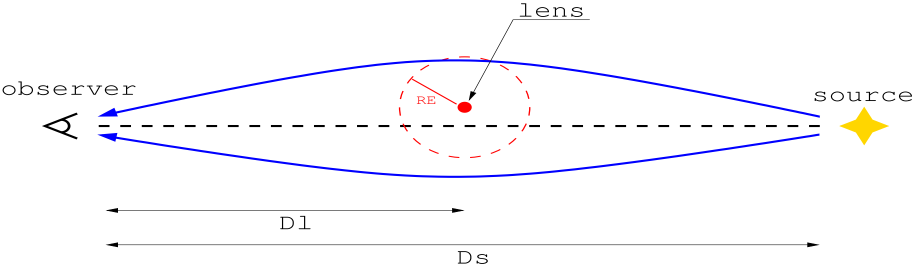

optical depth   probability for observing a microlensing event

$$\tau = \int_0^{D_s} dD_l \int dM_l \, \left(\pi R_E^2\right) \times \left(\frac{d^2 N_l}{dV dM_l}\right) = \frac{4\pi G}{c^2} \int_0^{D_s} dD_l \, \rho_l D_l \left(1 - \frac{D_l}{D_s}\right)$$

just depends on ρ_l, not on M_l!

[Iocco, MP, Bertone & Jetzer, arXiv:1107.5810]

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1. fix $\rho_{0,b}$ to match MACHO '05 $\langle\tau\rangle = 2.17^{+0.47}_{-0.38} \times 10^{-6}$

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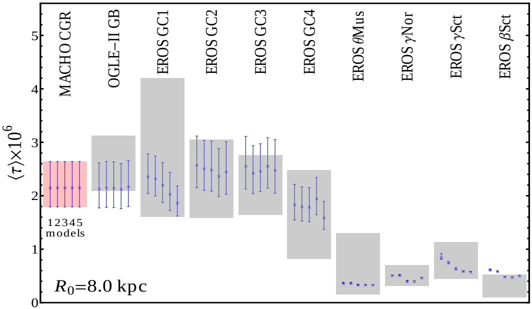

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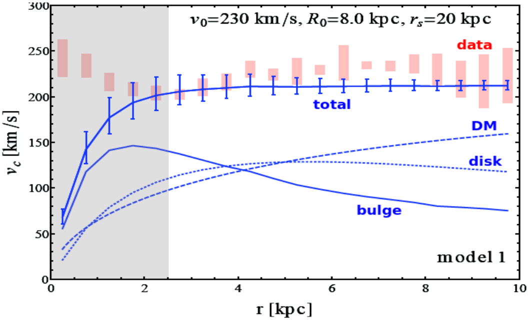

NFW with $(\rho_0, \alpha) = (0.4\ \mathrm{GeV/cm^3}, 1.0)$

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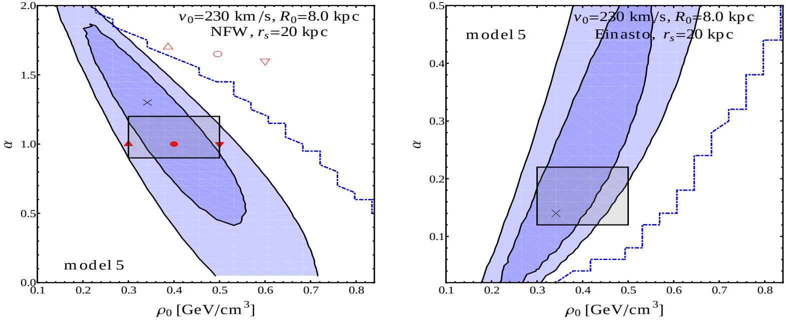

excellent agreement with findings of numerical simulations

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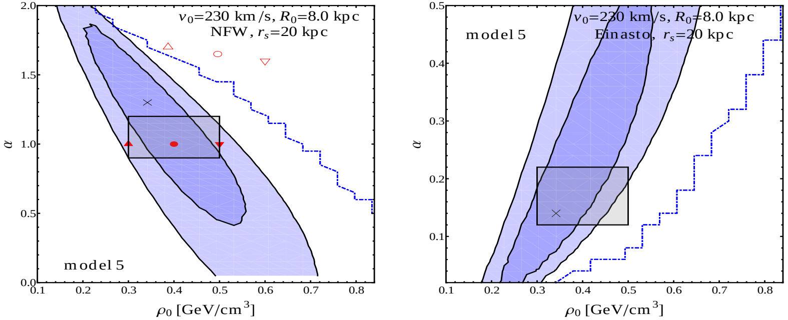
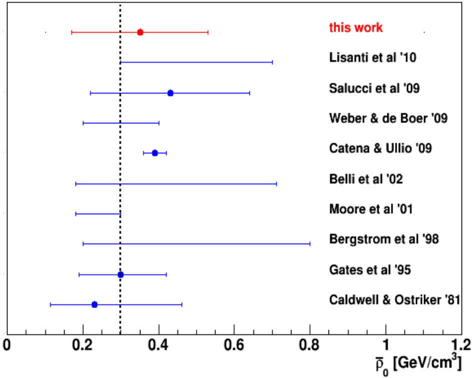


$\rho_0 = 0.20 - 0.56$ GeV/cm^3 (NFW) $\rho_0 = 0.22 - 0.55$ GeV/cm^3 (Ein)

2. MICROLENSING + DYNAMICS: SUMMARY

NFW: $\rho_0 = 0.20 - 0.56\ \mathrm{GeV/cm^3}$ $\alpha = 0.4 - 1.8$

[Iocco, MP, Bertone & Jetzer, arXiv:1107.5810]



bottomline

.. not competitive with other measurements e.g. Catena & Ullio '09

.. but complementary technique

.. huge potential: constrain local density, profile slope and shape

3. IMPACT ON DIRECT SEARCHES

spin-independent scattering rate

$$\frac{dR}{dE_R} = \frac{\rho_0 \sigma_{SI}^p}{2 m_\chi \mu_{p\chi}^2} \times \underbrace{\mathbf{A}^2 F^2(E_R, \mathbf{A})}_{\text{nuclear physics}} \times \underbrace{\mathcal{F}\left(v_{min}(E_R, \mathbf{A}, m_\chi)\right)}_{\text{astrophysics}}$$

$$\mathcal{F} \equiv \int_{v > v_{min}} d^3\vec{v}\, \frac{f\left(\vec{v} + \vec{v_e}\right)}{v} \qquad v_{min}(E_R) = \frac{1}{\sqrt{2 m_N E_R}} \left(\frac{m_N E_R}{\mu_N} + \delta \right)$$

standard halo model

$$\rho_0 = 0.3\ \mathrm{GeV/cm^3}$$

$$f(w) \propto \begin{cases} \exp(-w^2/v_0^2) & \text{for } w \leq v_{esc} \\ 0 & \text{for } w > v_{esc} \end{cases}$$

$$v_0 \equiv 2\sqrt{\sigma_{1d}} = v_c^0 \simeq 220\ \mathrm{km/s}$$

$$v_{esc} \simeq 600\ \mathrm{km/s}$$

good starting point but huge uncertainties on the parameters ρ_0, v_c^0, v_{esc}

3. IMPACT ON DIRECT SEARCHES

spin-independent scattering rate

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our approach

$$f(w) \propto \begin{cases} \left[\exp\left(\frac{v_{esc}^2 - w^2}{k v_0^2}\right) - 1\right]^k & \text{for } w \leq v_{esc} \\ 0 & \text{for } w > v_{esc} \end{cases} \quad \text{(see Lisanti et al 2010)}$$

$$v_e \sim v_c^0 \qquad v_0 = v_c^0$$

fiducial: $\rho_0 = 0.4 \text{ GeV/cm}^3, k = 1, v_{esc} = 544 \text{ km/s}, v_0 = 230 \text{ km/s}$

crucial point: huge uncertainties on ρ_0, v_c^0, v_{esc}, k

3. IMPACT ON DIRECT SEARCHES

local DM density $\boxed{\rho_0 = 0.4 \pm 0.1 \text{ GeV/cm}^3 \quad (1\sigma)}$

(Catena & Ullio + systematics)

circular velocity $\boxed{v_0 = v_c^0 = 230 \pm 30 \text{ km/s} \quad (1\sigma)}$

(perhaps optimistic!)

escape velocity $\boxed{v_{esc} = 544 \pm 33 \text{ km/s} \quad (1\sigma)}$

(Smith et al 2006, RAVE survey)

shape parameter $\boxed{k = 0.5 - 3.5 \quad (\text{flat})}$

(Lisanti et al 2010 $\oplus$ k=1)

key question: how do these uncertainties impact direct searches?

[MP, Baudis, Bertone, de Austri, Strigari & Trotta '11]

3. IMPACT ON DIRECT SEARCHES

fast forward to $\sim$2020

MP, Baudis, Bertone, de Austri, Strigari & Trotta, PRD 2011

.. use next generation of experiments Xe, Ge, Ar

.. study the complementarity of targets

.. include astrophysical uncertainties

3. IMPACT ON DIRECT SEARCHES

fast forward to ∼2020

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.. use next generation of experiments Xe, Ge, Ar
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.. include astrophysical uncertainties

upcoming experimental capabilities

noble liquids

DARWIN $\sigma^p_{SI} < 10^{-47}$ cm^2 (2016)

cryogenic

EURECA $\sigma^p_{SI} > 10^{-46}$ cm^2 (2018)

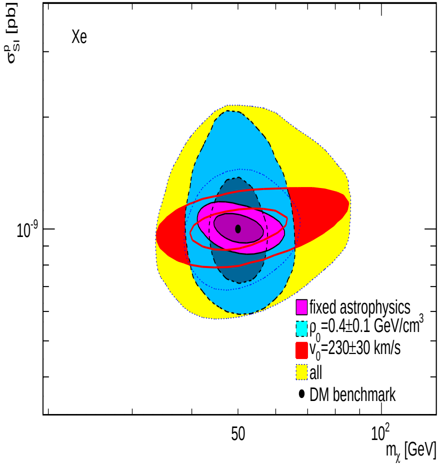
10 yr from now

target	ϵ [ton×yr]	η_{cut}	A_{NR}	ϵ_{eff} [ton×yr]	E_{thr} [keV]	$\sigma(E)$ [keV]	background events/ϵ_{eff}
Xe	5.0	0.8	0.5	2.00	10	Eq. (7)	< 1
Ge	3.0	0.8	0.9	2.16	10	Eq. (6)	< 1
Ar	10.0	0.8	0.8	6.40	30	Eq. (8)	< 1

[MP, Baudis, Bertone, de Austri, Strigari & Trotta '11]

3. IMPACT ON DIRECT SEARCHES

varying astrophysics



$$\rho_0 = 0.4 \pm 0.1 \text{ GeV}/\text{cm}^3$$
$$v_0 = 230 \pm 30 \text{ km}/\text{s}$$
$$v_{esc} = 544 \pm 33 \text{ km}/\text{s}$$
$$k = 0.5 - 3.5$$

most relevant are ρ_0 and v_0:

ρ_0: deg. with σ^p_{SI}, $\frac{dR}{dE_R} \propto \rho_0 \sigma^p_{SI}$

v_0: deg. with m_χ, $\frac{dR}{dE_R} \propto \frac{1}{m_\chi v_0}$

[MP, Baudis, Bertone, de Austri, Strigari & Trotta '11]

3. IMPACT ON DIRECT SEARCHES

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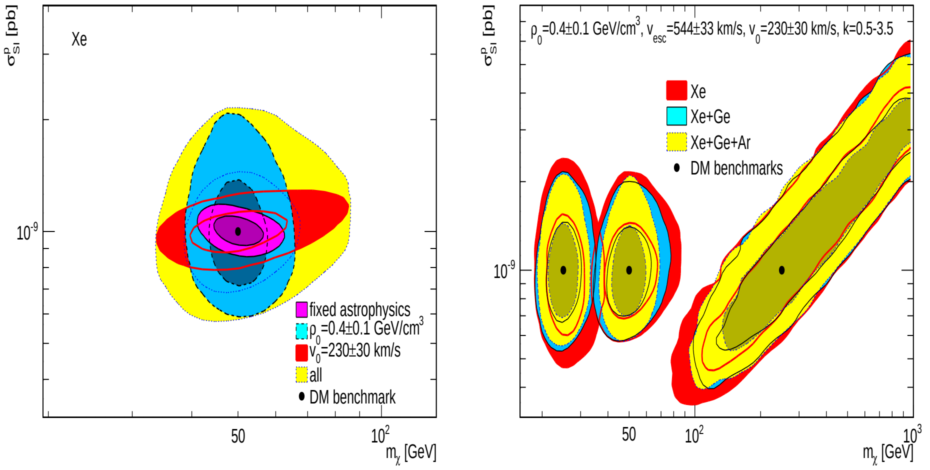
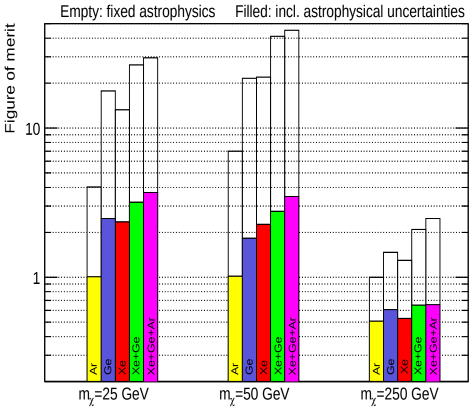


[MP, Baudis, Bertone, de Austri, Strigari & Trotta '11]

3. TARGET COMPLEMENTARITY

figure of merit: $(95\%$ contour area in the plane $\log_{10} m_\chi - \log_{10} \sigma^p_{SI})^{-1}$



.. astrophysical uncertainties reduce constraining power

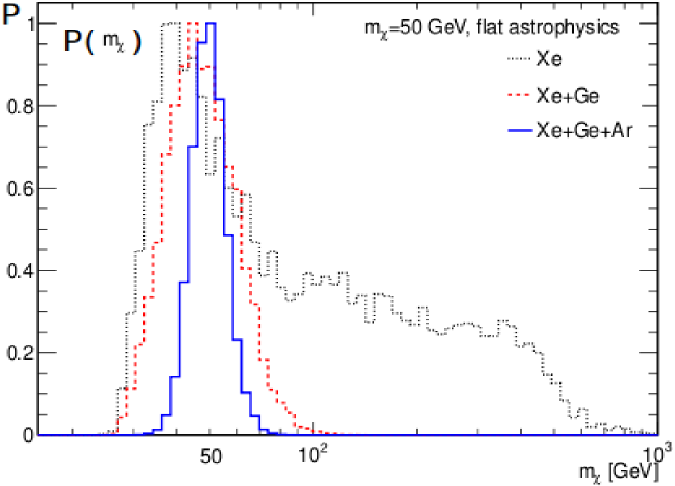
.. Ge best at $m_\chi = 25, 250$ GeV; Xe best at $m_\chi = 50$ GeV

.. astrophysical uncertainties affect target complementarity in a non-trivial way

[MP, Baudis, Bertone, de Austri, Strigari & Trotta '11]

3. TARGET COMPLEMENTARITY

let us be conservative:
what can be robustly measured irrespective of astrophysics?



.. wimp mass m_χ: within 10's GeV

[MP, Baudis, Bertone, de Austri, Strigari & Trotta '11]

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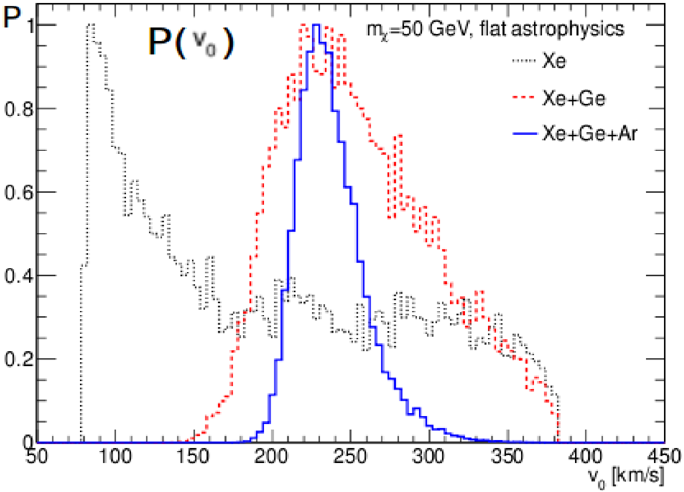

.. local circular velocity v_0: within 10's km/s

[MP, Baudis, Bertone, de Austri, Strigari & Trotta '11]

3. TARGET COMPLEMENTARITY

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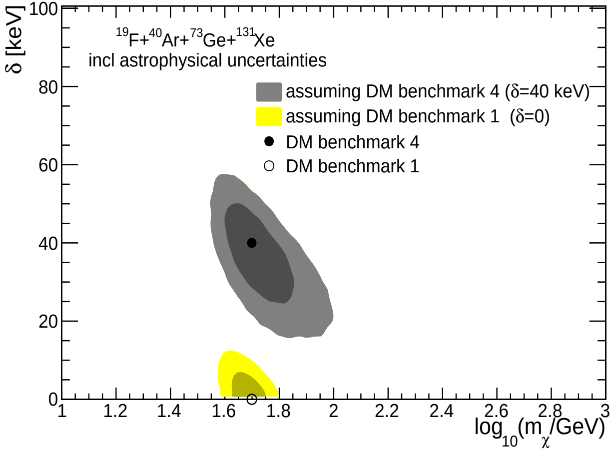

.. inelastic parameter δ: within 10's keV

[MP, arXiv:1106.0743]

4. TO WRAP UP...

dark matter distribution

.. distribution of dark matter in our Galaxy is not well-known

.. microlensing + dynamical: powerful, complementary technique

.. future data will help pinpointing astrophysical parameters

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future for dark matter searches?

complementarity direct+indirect+collider searches

accurate description of dark matter distribution