Could a γ line

betray the mass of

Light Dark Matter?

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Cern, Clermont, Annecy

astro-ph/0607437

Outline

- Why Dark Matter?
  Why not Light DM?
- 511 keV signal from Galactic Center:
  Why LDM?
- Cross check: monochromatic γ line at m_{dm}
- Detectability

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Short: (googling Dark Matter 2007) ask Meryl Streep!

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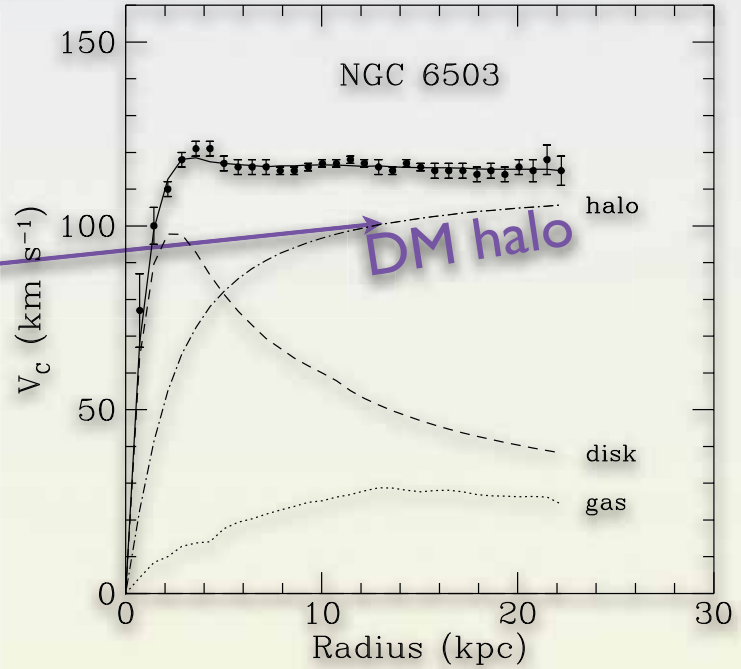

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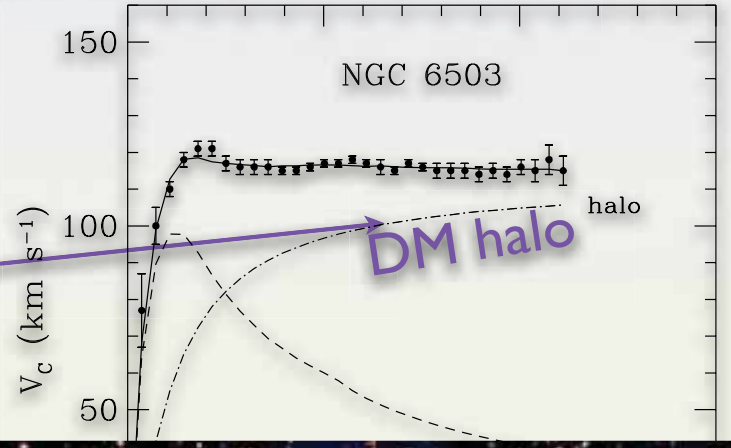
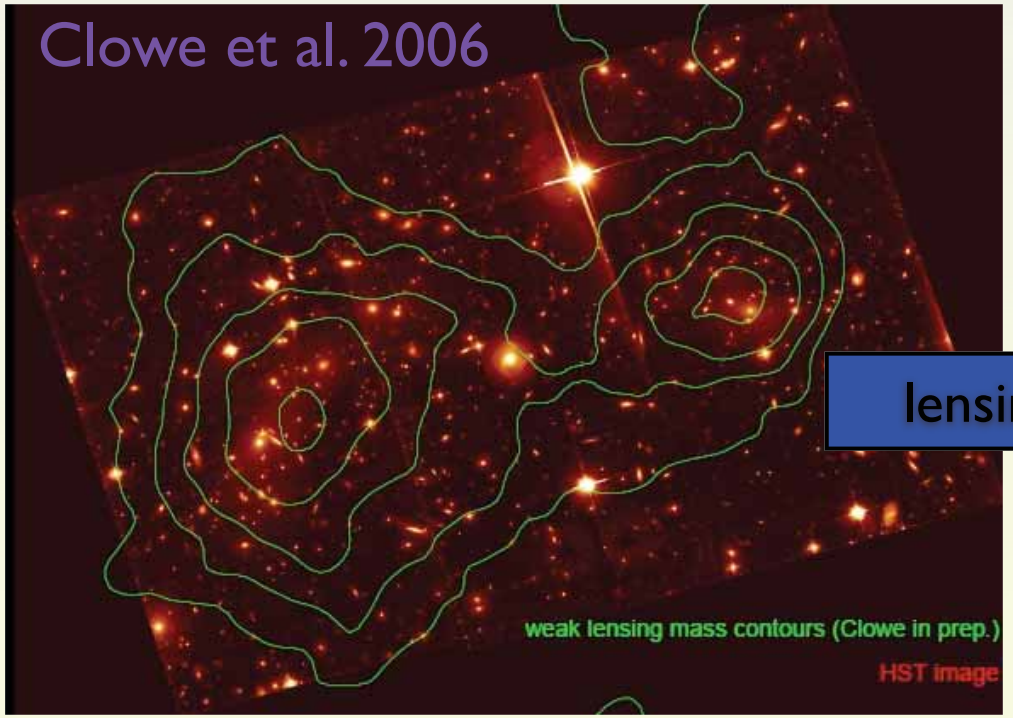
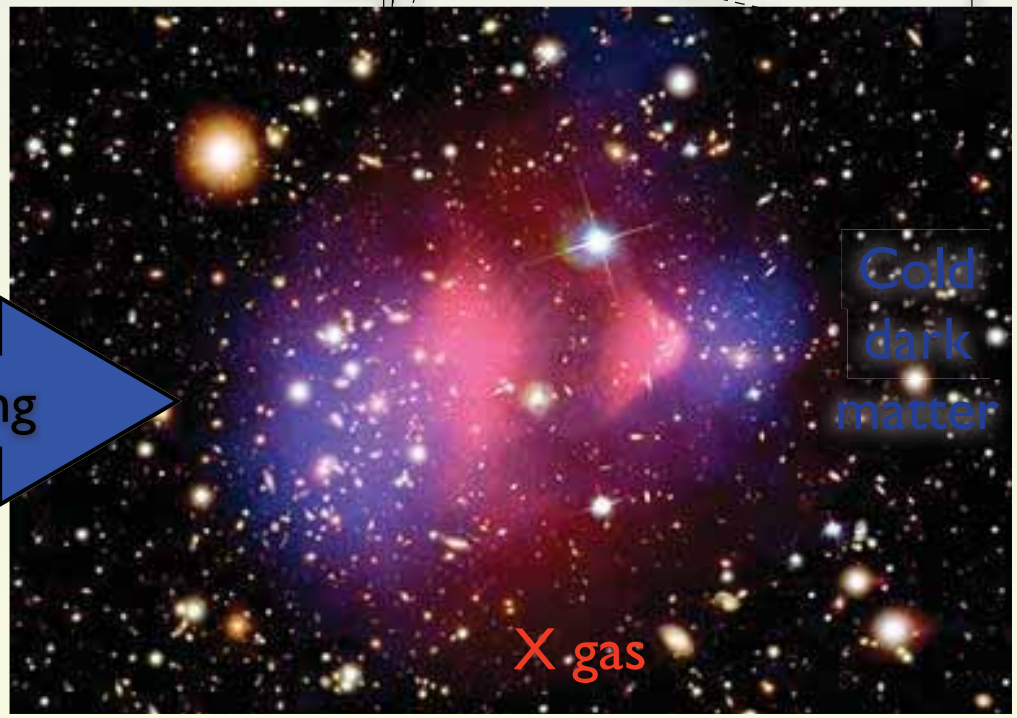




lensing



"Bullet" cluster 1E 0657-56

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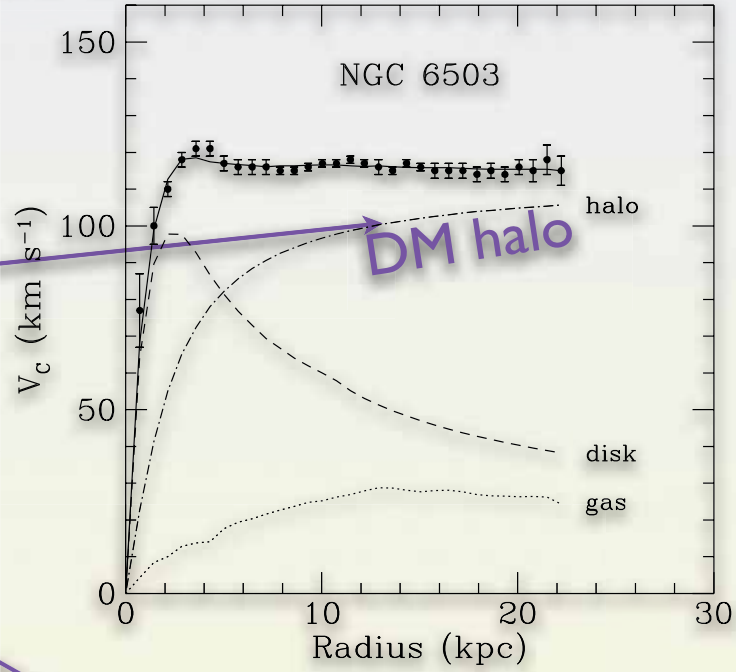

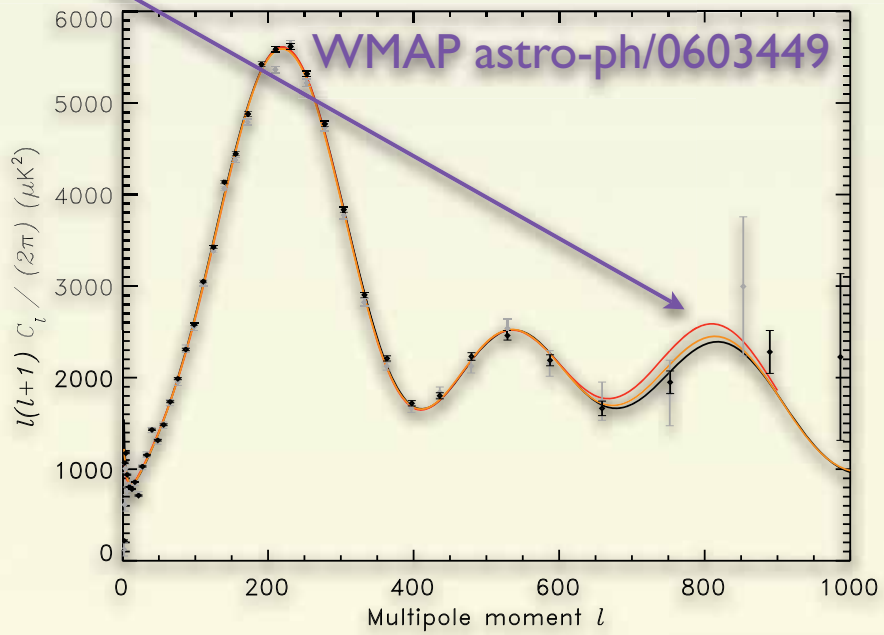

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  $\Omega_b = 0.04 \ll \Omega_{DM}$
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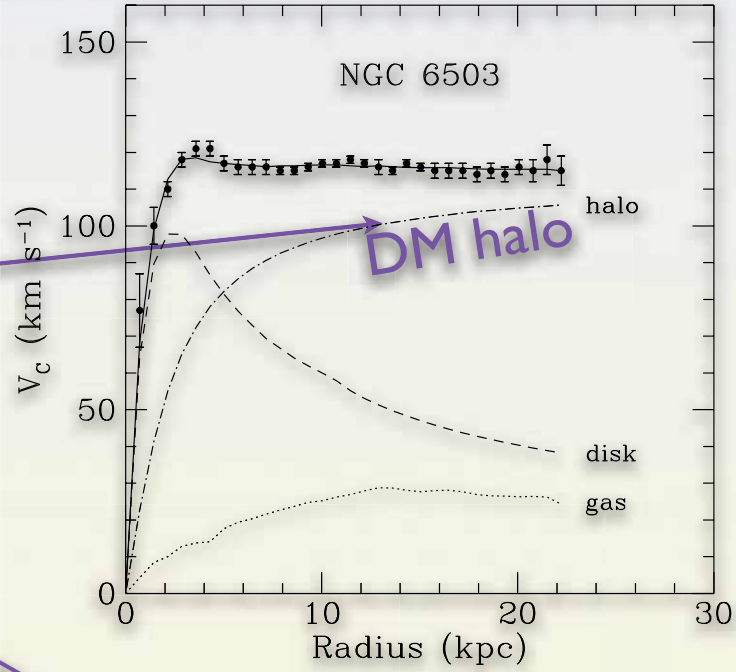

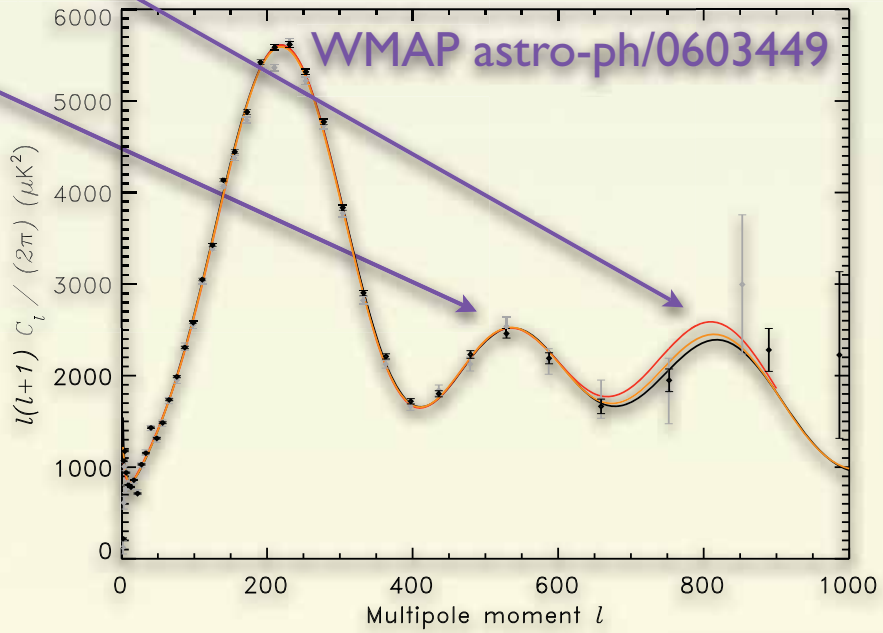

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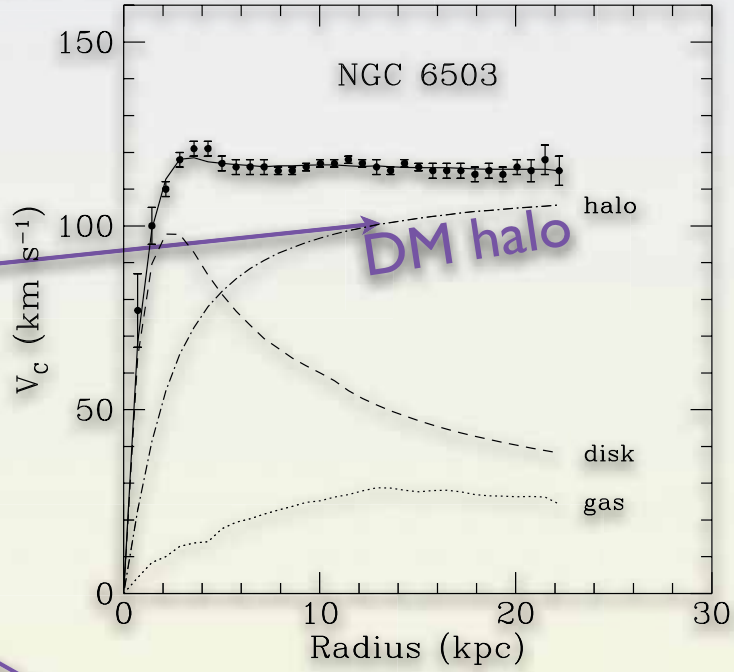

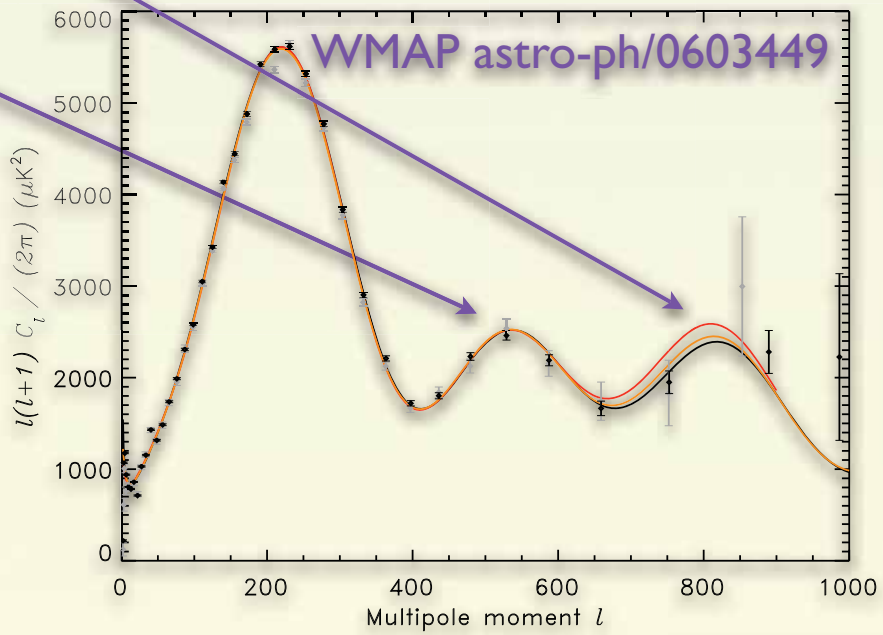

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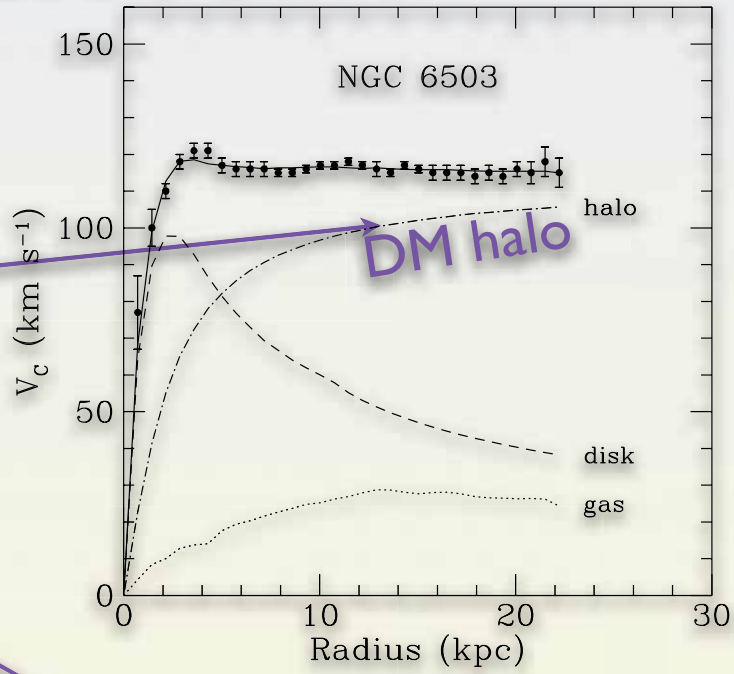
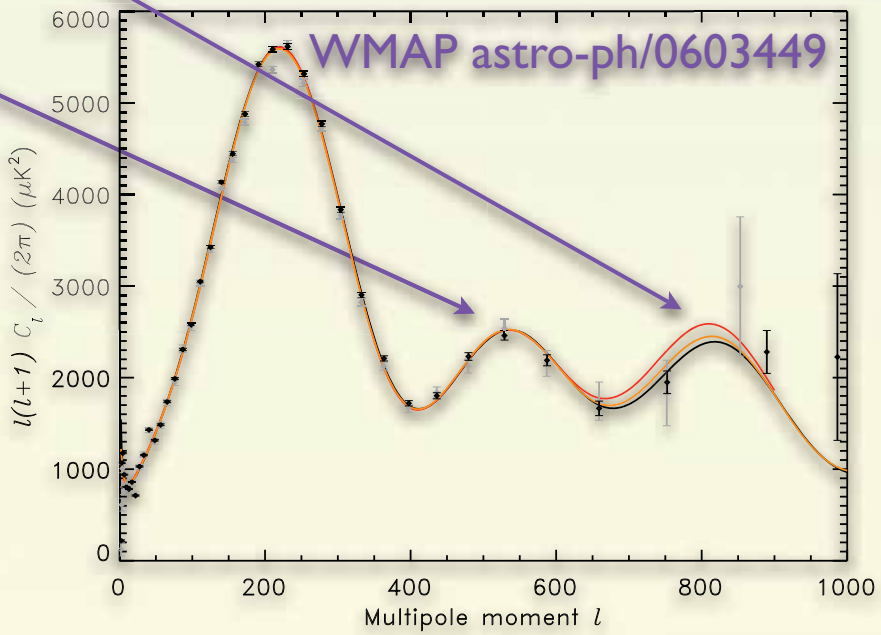
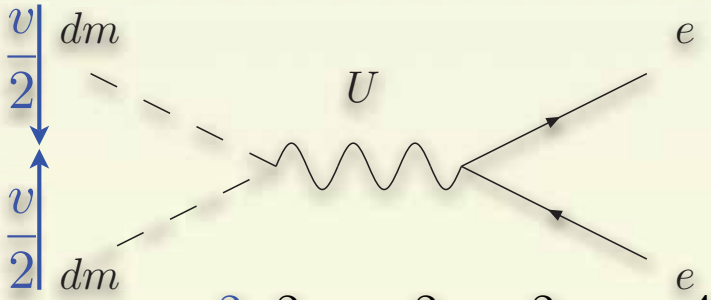
- Gravity modifications?
  Even less conservative! (& contrived)





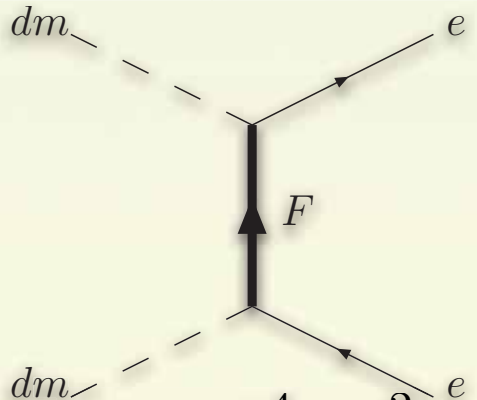
Why not Light DM?

- Honest poll in this room: *"Who would order new MeV particles?"*
- More serious: Lee-Weinberg bound $\Omega_{dm} < 1 \Rightarrow m_{dm} > 2\mathrm{GeV}$?
  Only holds for weak-like cross-sections: $\sigma_{ann} v \sim m_{dm}^2 G_F^2 (\sim 1/\Omega)$
- For other behaviors or G_F, relic density can be OK for **scalar DM** with:
  - m_{dm} > 1MeV (otherwise nucleosynthesis problems)
  - m_{dm} < 100 MeV (otherwise unseen γ's from π^0)
- Involves **light gauge boson U**, or **mirror fermions F**, or both



$\sigma v \sim v^2 q_{U\,dm}^2 q_{U\,e}^2 m_{dm}^2 / m_U^4$

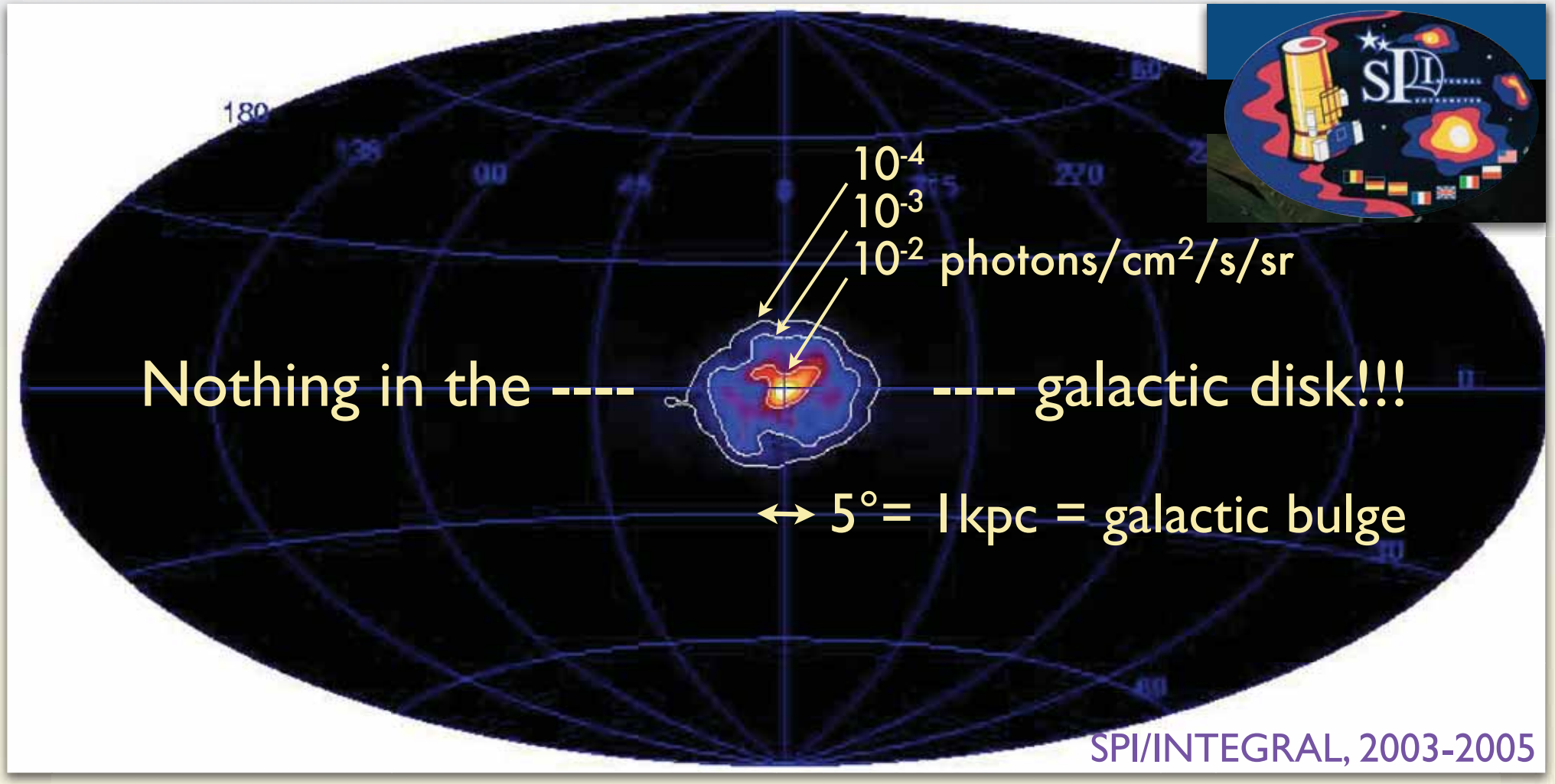
and/or



$\sigma v \sim C^4 m_F^{-2}$

⇒Intriguing possibility (Boehm, Fayet hep-ph/0305261)

511 keV γ's from Galactic Center



- 1.6 10^{-3} photons/cm^2/s from the bulge, with energy 511±1 keV
- ⇒ positronium at rest annihilating into 2 photons

Are these e^+ "Dark"?

"Found a 0.5 MeV radiation excess?
Do your Nuclear Physics right!"

However:

- All known potential astrophysical sources (e.g. hypernovae) more frequent in the disk than in the (quiescent, old stars) bulge.
- Known e^+ sources also have known intense gamma lines (unseen)
- Diffuse steady signal requires at least 8(?) steady(?) point sources

On the other hand, the DM density

- must increase in the bulge, and would give a steady, diffuse signal
- fits a reasonable profile: $\rho_{NFW}(r) \sim 1/r$ (Ascasibar a-ph/0507142)
- requires **both** mirror fermions F (e^+ signal) $\sigma v \sim C^4 m_F^{-2}$
  and U boson (relic density too large otherwise) $\sigma v \sim v^2 q_{U\,dm}^2 q_{U\,e}^2 m_{dm}^2 / m_U^4$

with:
$$\begin{cases} m_F > 100\mathrm{GeV} \\ m_{dm} \sim 1 \rightarrow 100\mathrm{MeV} < m_U \\ q_{dmU} q_{eU} \sim 10^{-6} \ (\text{for } m_U \sim m_{dm}) \end{cases}$$

Light DM Window

- Upper limits on m_{dm}:
  - FSR: $\phi^{\gamma}_{cont}(dm + dm \rightarrow e^{+}e^{-}\gamma) > \phi_{obs.}(.5 \rightarrow 5MeV)$
    → m_{dm} < 20 MeV (Beacom, a-ph/0409403)
    or m_{dm} < 35 MeV w. better cross-section (Boehm, hep-ph/0606058)
  - In flight annihilation: some e^{+} can annihilate before stopping and exceed
    - error bars(???) on continuum → m_{dm} < 3MeV (Beacom, a-ph/0512411),
    - continuum itself → m_{dm} < 20MeV
- Lower limits on m_{dm}:
  - Nucleosynthesis disturbed by annihilation → m_{dm} > 2MeV
    (Serpico, Raffelt, a-ph/0403417)
  - Neutrinos from SN1987A too cold (Fayet, Sigl, hep-ph/0602169)
    → m_{dm} > 10MeV if it couples to neutrinos (not necessary)

⇒2MeV < m_{dm} < 20 MeV

The story so far

- There is an intense positronium annihilation line from galactic center
- No easy astrophysical explanation
- ⇒ Imagine annihilation: LDM+LDM → e^+e^-
- Produced positrons radiate energy locally (in 1pc), then (most) find an e^- to form positronium and annihilate (25%) into 511 keV gammas.

Requires peculiar particle models, with special ingredient/parameters: what would it take to convince (and believe) this is the real story?

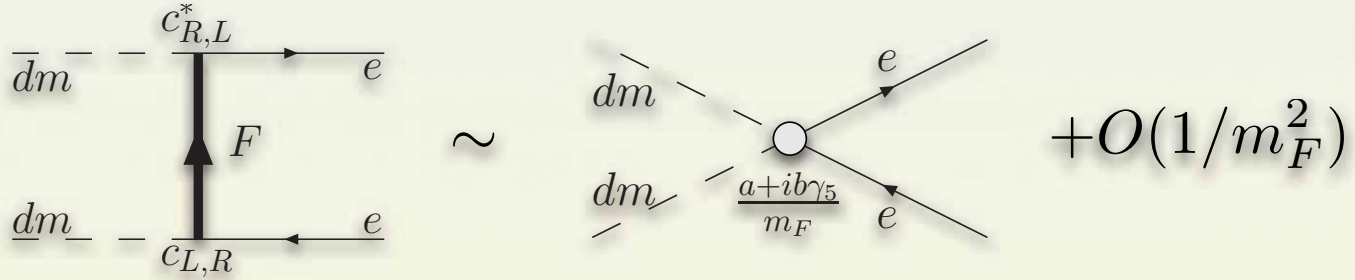
If DM annihilation produces many e^+e^- pairs, it must guarantee a minimum number of unambiguous monochromatic γ's
⇒ how much? ⇔ Is there a chance of proving this scenario?

X-check: e^+e^- production

- For heavy $m_F >> m_{dm,e}$,

$$\mathcal{L} = \bar{\psi}_F (c_R P_L + c_L P_R) \psi_e \phi_{dm} + h.c$$

heavy F exchange reduces to effective interaction



$$+O(1/m_F^2)$$

$$\mathcal{L}_{eff} = \frac{1}{m_F} \phi^*_{dm} \phi_{dm} \bar{\psi}_e (a + ib\gamma_5) \psi_e; \quad a + ib = c^*_L c_R.$$

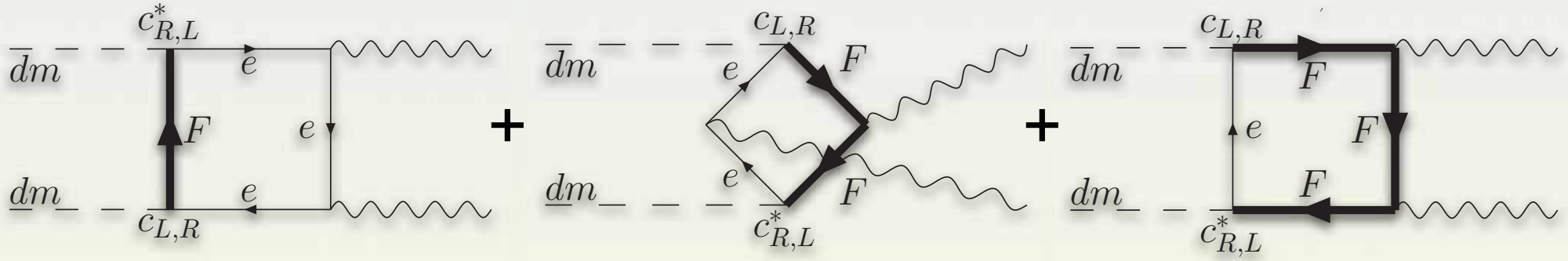
$$\Rightarrow \quad \sigma_{511} v_r = \frac{\beta_e}{4\pi m_F^2} \left(a^2 \beta_e^2 + b^2\right) = 2\ 10^{-30} \left(\frac{m_{dm}}{\mathrm{MeV}}\right)^2 \mathrm{cm}^3/\mathrm{s}$$

SPI

$$\beta_e = \sqrt{1 - m_e^2/m_{dm}^2}$$

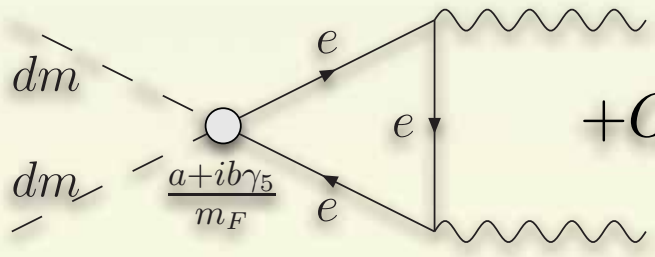
X-check: γ line at m_{dm}

- 2x3 box diagrams:



- Each superficially $\int d^4k/k^4$ but gauge invariance requires 2 external momenta $\Rightarrow \int_{m_F} d^4k/k^6 < 1/m_F^2$ and $1/m_F$ expansion OK

- $\sim$



$+O(1/m_F^2)$

$$C_0(q_1^2=0,(q_1+q_2)^2=4m_{dm}^2,q_2^2=0,m_e^2,m_e^2,m_e^2)$$

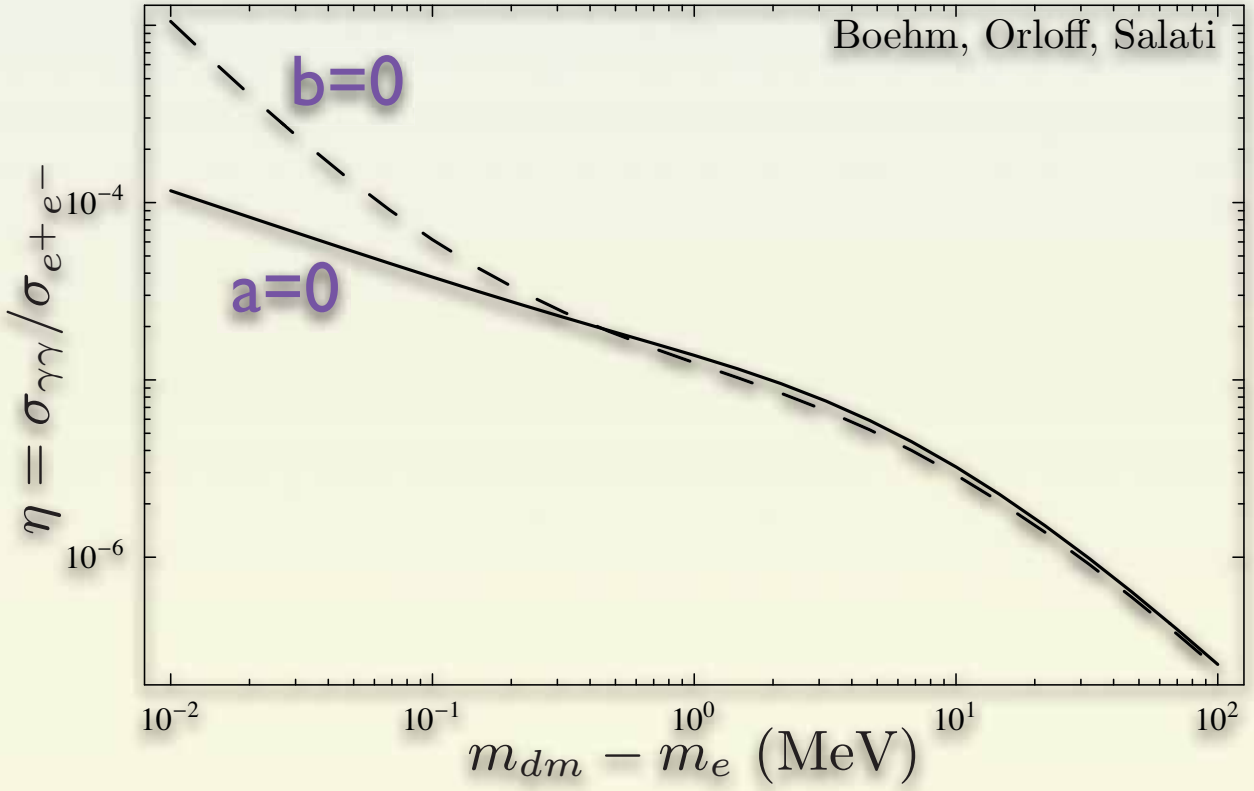
$$=\int \frac{d^4k}{i\pi^2}\frac{1}{((k+q_1)^2-m_e^2)\,(k^2-m_e^2)\,((k-q_2)^2-m_e^2)}$$

$$=\frac{1}{4m_{dm}^2}\int_0^1\frac{dx}{x}\ln(1-x(1-x)4m_{dm}^2/m_e^2-i\varepsilon_F)$$

$$\sigma_{\gamma\gamma}v_r=\frac{\alpha^2}{(2\pi)^3}\frac{m_e^2}{m_F^2}\frac{m_e^2}{m_{dm}^2}\times\left[b^2|2C_0m_{dm}^2|^2+a^2|1+2C_0(m_e^2-m_{dm}^2)|^2\right]$$

X-check: γ line /e^+e^-

$$\eta \doteq \frac{\sigma_{\gamma\gamma}}{\sigma_{511}} = \frac{\alpha^2}{2\pi^2\,\beta_e}\,\frac{m_e^2}{m_{dm}^2}\,\frac{a^2|1+2\,(m_e^2-m_{dm}^2)C_0|^2+b^2|2m_{dm}^2C_0|^2}{a^2\beta_e^2+b^2}$$



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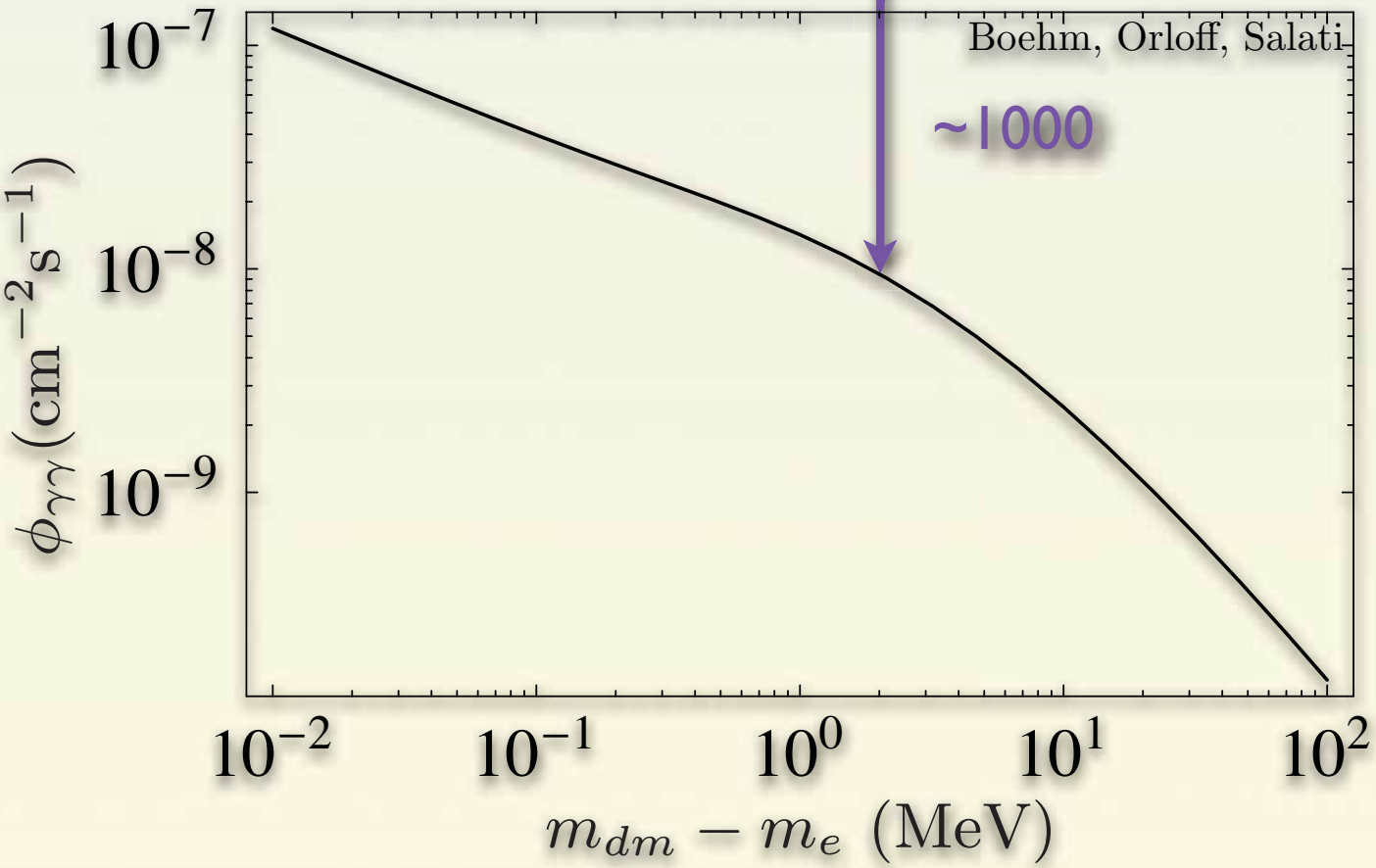
- Not vanishing ⇒ guaranteed signal, given the known e^+e^- signal
- Enhancements?
  - $m_{dm} \approx m_e \Leftrightarrow \beta_e \approx 0$? But dangerous for nucleosynthesis !
  - More heavier particles, like tau, in loop?
    Not much: $\eta(m_\tau \gg m_{dm}) \sim m_{dm}^2/(m_F^2 m_\tau^2)$
    (despite m_e^2/m_{dm}^2 prefactor)
    ⇒ will be relevant only for couplings $c_{L,R}$ scaling like Yukawas

- Kasuya (a-ph/0602296) estimate $\eta_K = \dfrac{\Gamma_{\gamma\gamma}}{\Gamma_{e^+e^-}} \approx \dfrac{\alpha^2 m_{dm}^2}{2\pi^2 m_e^2 \beta_e^3}$
  (for moduli decay):
  overestimates by 1000 (!!!) at 10MeV
  ⇒ (wrongly) concludes detectability in near future

γ line detectability: now

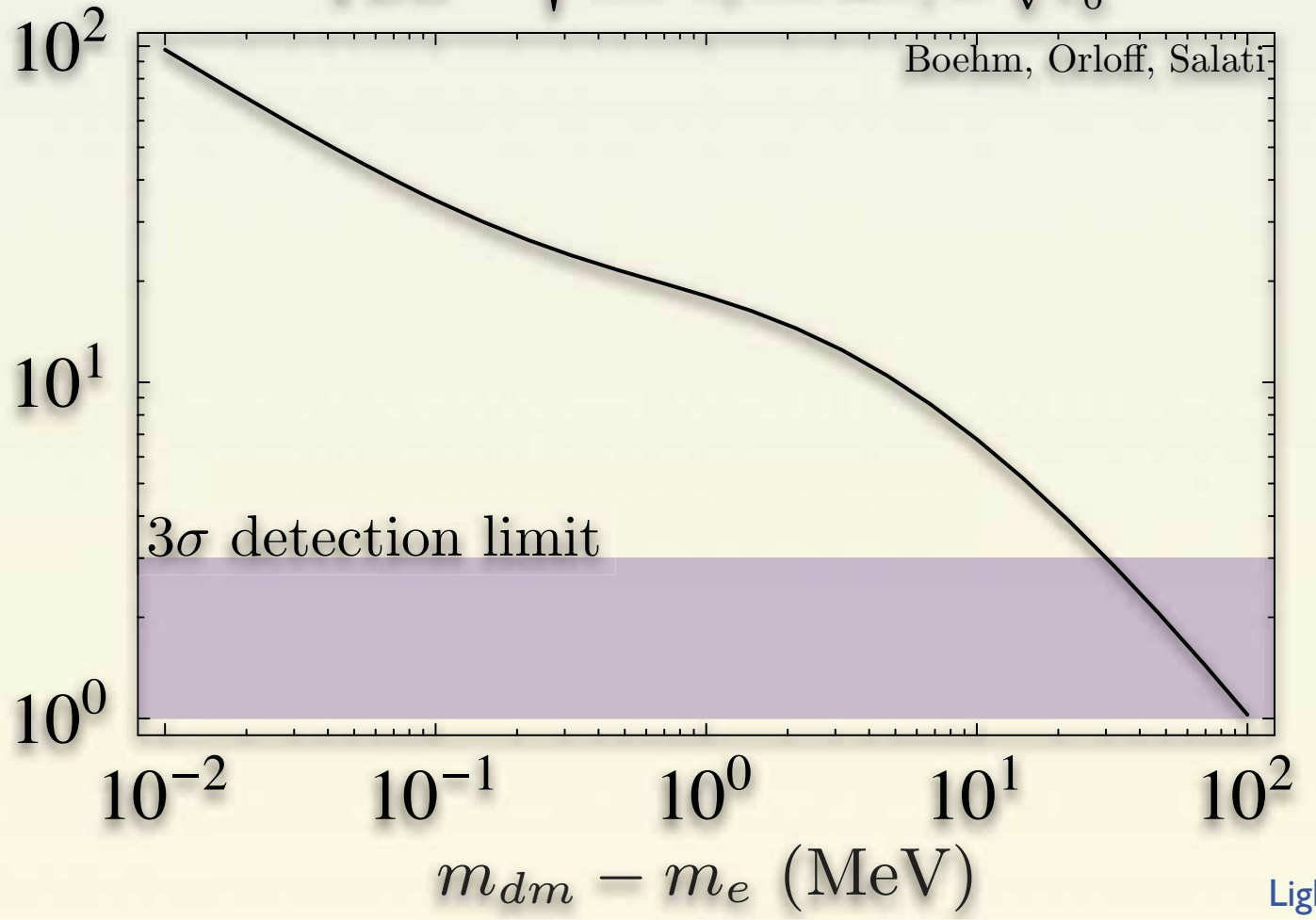
- SPI sensitivity to narrow lines from point-sources is:
  2.5 10^{-5} photons/cm^2/s, in 10^6 s at 2MeV
- The signal is at most 1000 times smaller: wait 30 years????
- Not much to be gained from angular distribution



γ line detectability: future

- More sensitive future ideal detector: more background (a-ph/0405441)
- Rejected by energy resolution (not angular)

$$\sigma = \frac{S}{\sqrt{BG}} \sim \sqrt{\frac{S_0}{1\mathrm{m}^2}\frac{T_0}{1\mathrm{year}}\frac{10^{-3}}{\Delta E/E}\frac{\theta_0}{\sqrt{\theta_0^2}}}$$



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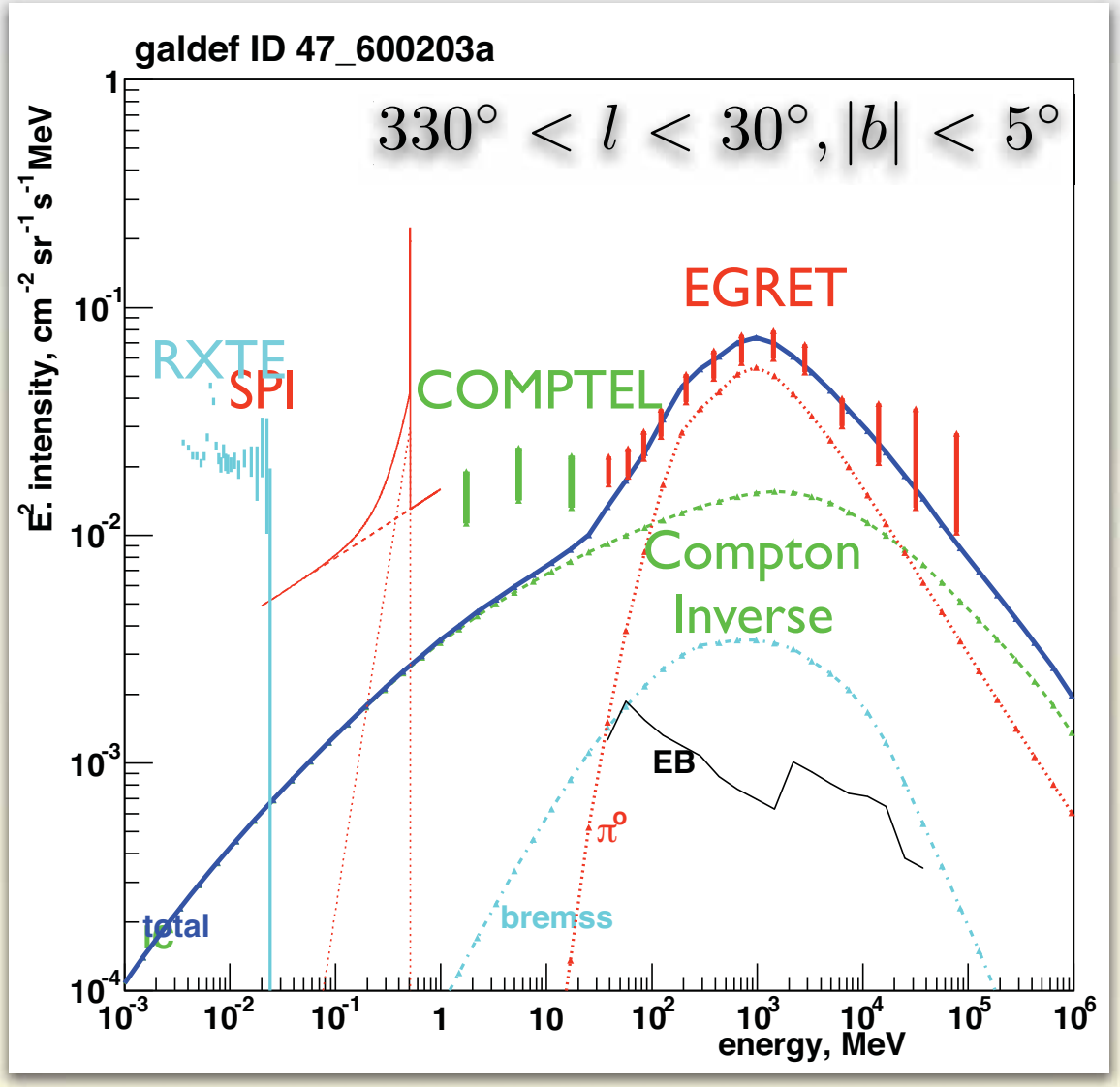
- Requires deep (anti-unifying) rethinking of usual BSM ideas
- We have computed the minimal monochromatic γ flux allowing to unambiguously establish the existence and mass of LDM
- Theorists are not immediately forced to take this possibility into account
  (until experimentalists reach the sensitivity/significance mentioned above)

Continuum Background

Strong et al., a-ph/0509290



Underlying Models

Not completely compelling but not impossible:

- N=2 SUSY inspiration: (Fayet '70 ⇒ ...ph/0702176)
  - Extra U(1) = gauged R-sym (why so light? Sssmall gauge coupling???)
  - Mirror fermions needed for anomaly cancellations
  - LDM?
- Extra-dimensions:
  - Scalar DM = 5th gauge component
  - F= KK fermions

- Different moduli story (Takahashi hep-ph/0512296) unifies DE and DM:
  Quintessence=Im(S) (pseudo NG boson)
  scalar DM= Re(S) (other piece of chiral field)
  - out-of equilibrium production (also breaks link between relic and 511)
  - slowly decays instead of annihilating at rest