Particle Dark Matter

Manuel Drees
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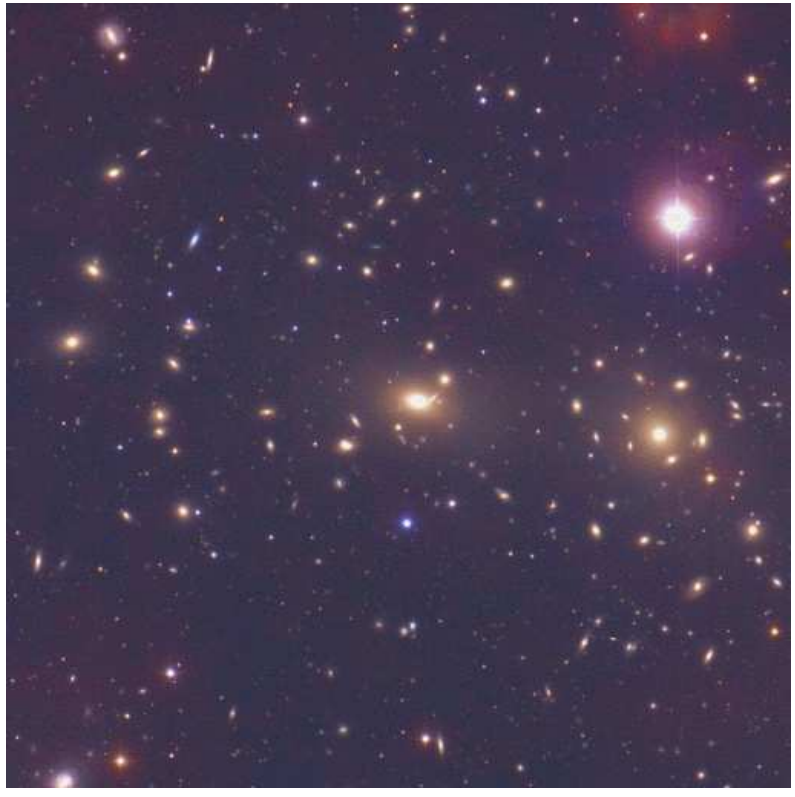

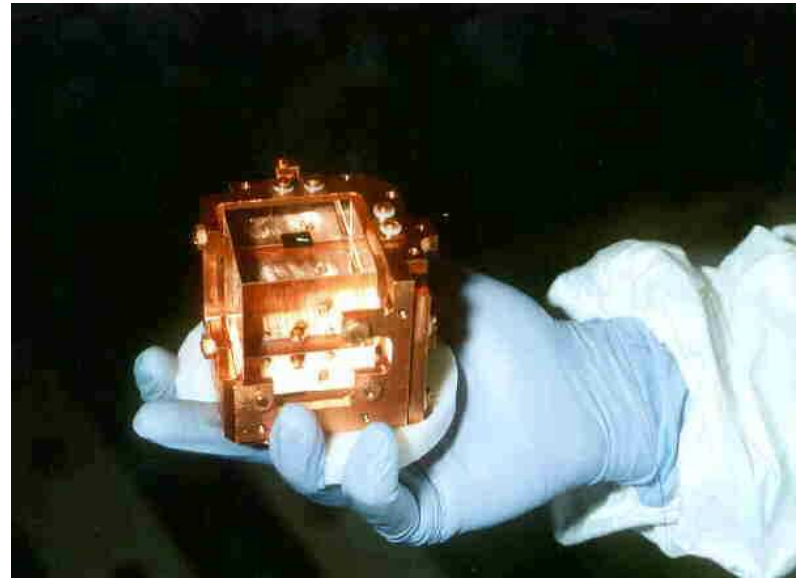

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- Spiral galaxies rotate

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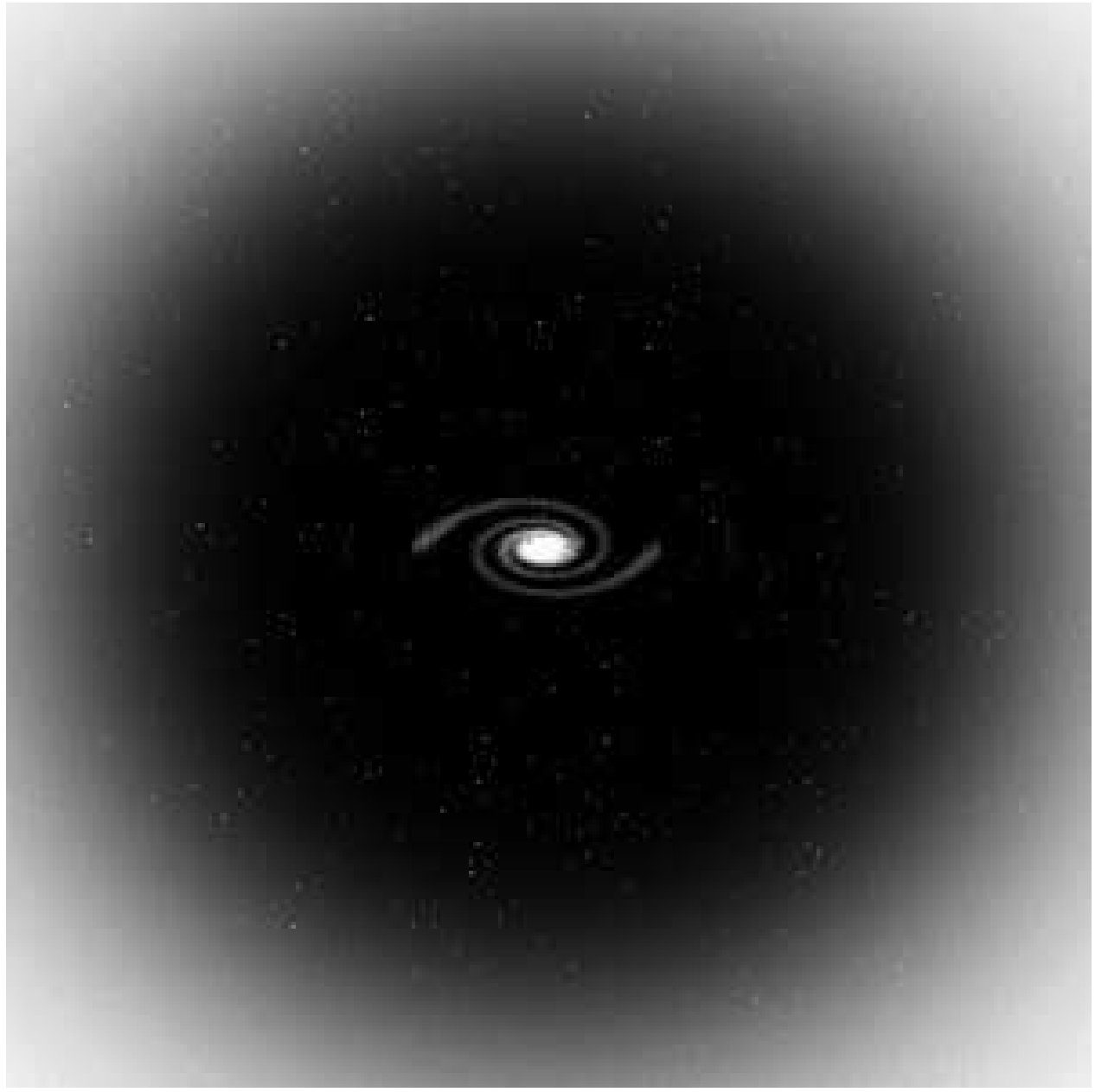
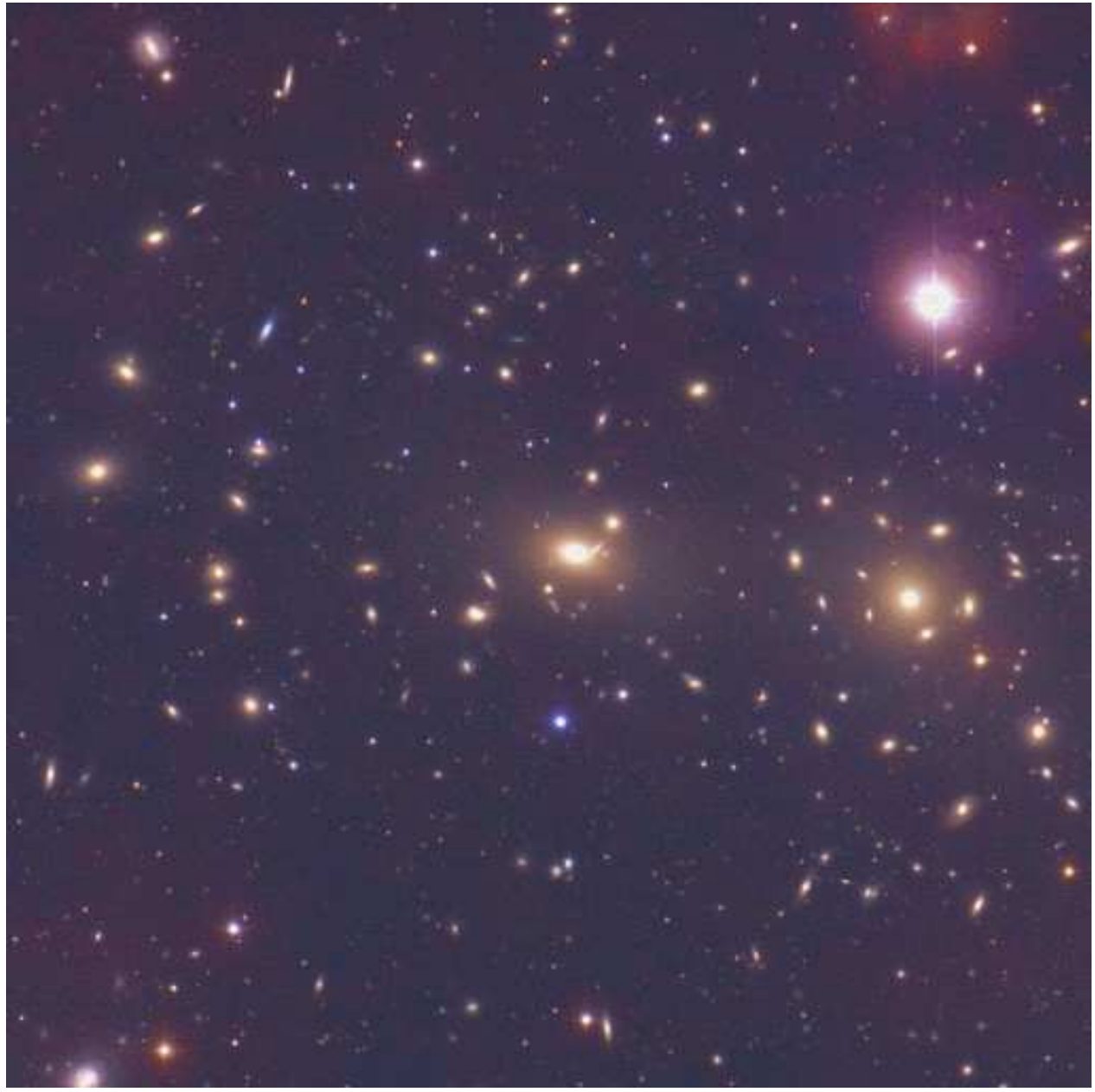
- $\Longrightarrow M(R) \propto R$: Invisible, "Dark" Matter forms halo around visible galaxy

True picture of a galaxy



A typical galaxy cluster



Dark matter in clusters of galaxies

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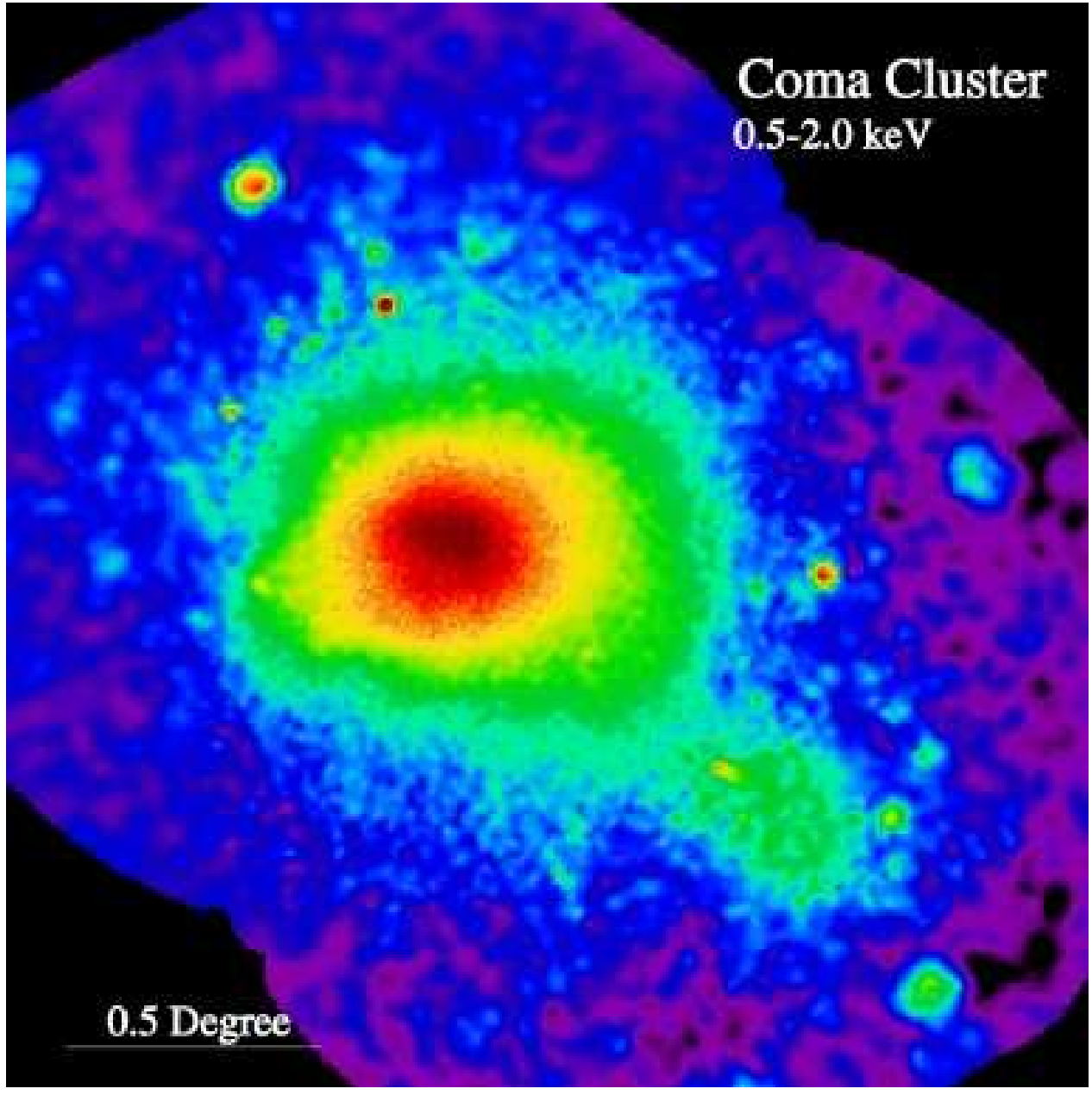
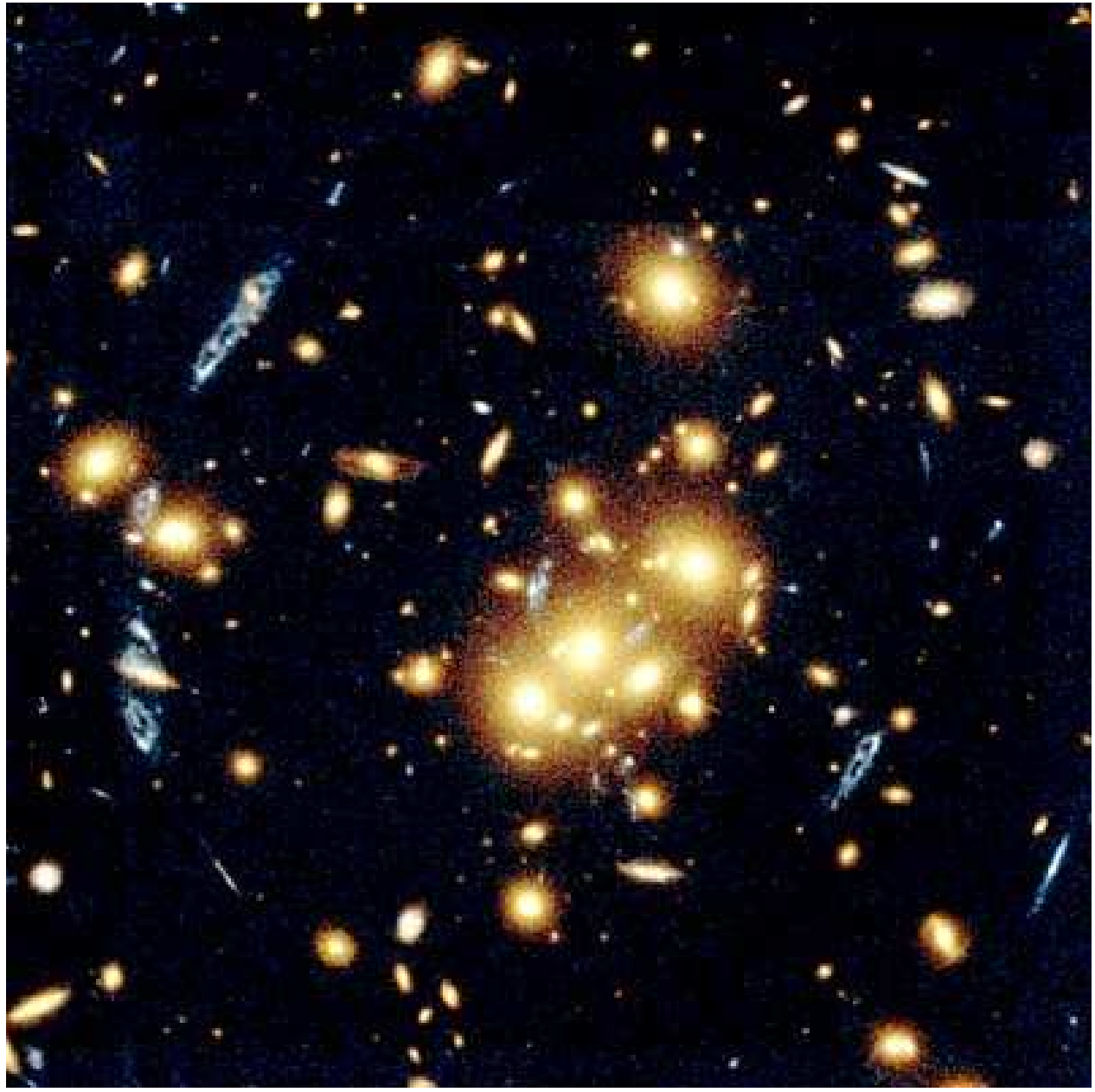
  Temperature of gas in cluster $\propto M_{\rm cluster}$!
  Gives consistent result.
- "Gravitational lensing": Mass deflects light, by angle $\propto$ mass: Most direct way to measure
  $M_{\rm cluster} \geq 10 \times M_{\rm visible}$!

Same cluster in $X-$ray light



Example of gravitational lensing



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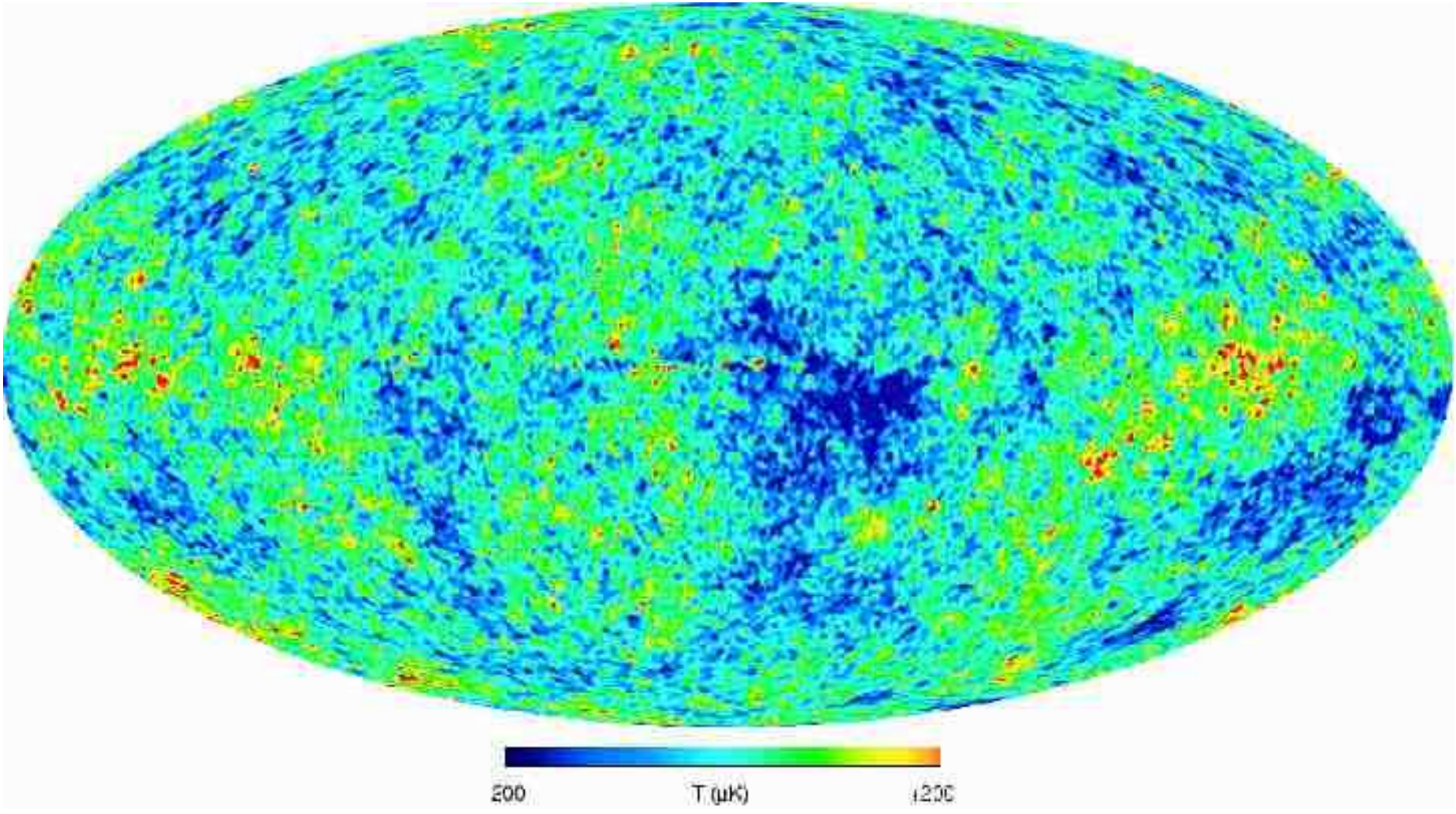
- From angular distribution and size of these variations: can determine cosmological parameters!

Sky in microwaves



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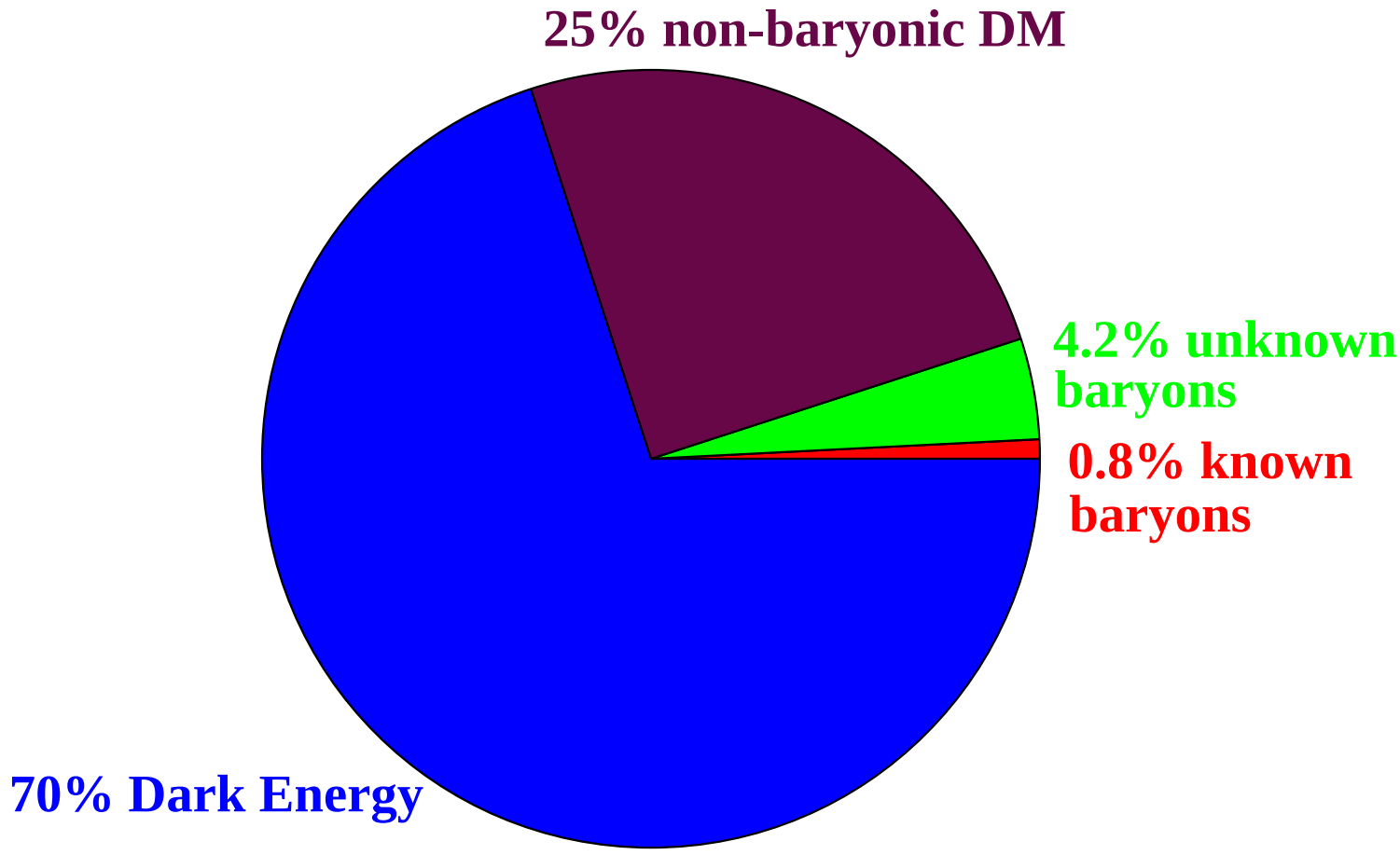
- Expansion of Universe is accelarating: Dark Energy has "negative pressure"!

Composition of the Universe



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- Particle physicists have suggested many candidates

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- For bh's to form "fluid": need $M_{\rm bh} \lesssim 10^3 M_\odot$

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- and has (strongly) suppressed coupling to elm radiation

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  E.g. Ferreras, Sakellariadou, Yusaf, arXiv:0709.3189 [astro-ph]: Strong lensing implies that even MOND needs galactic DM!

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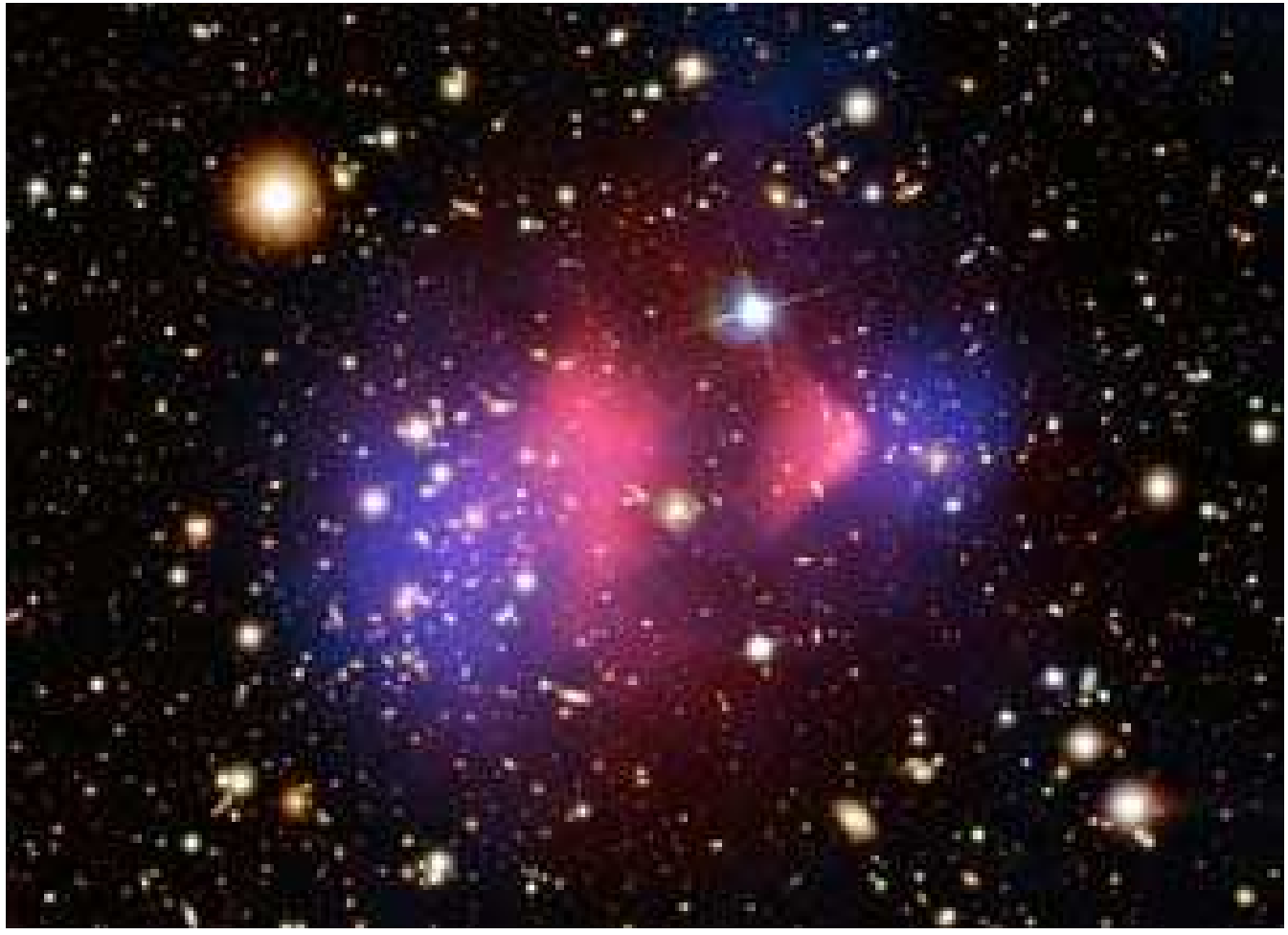
Resulting bound on DM–DM scattering cross section constrains models of interacting DM! Markevitch et al., astro–ph/0309303

Bullet cluster



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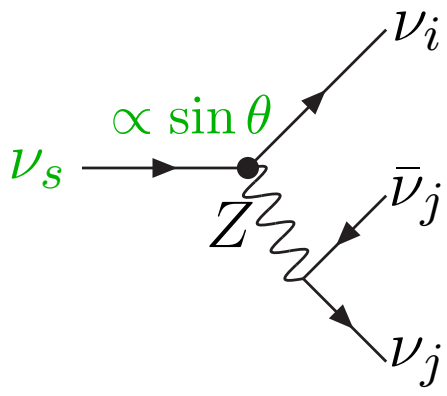
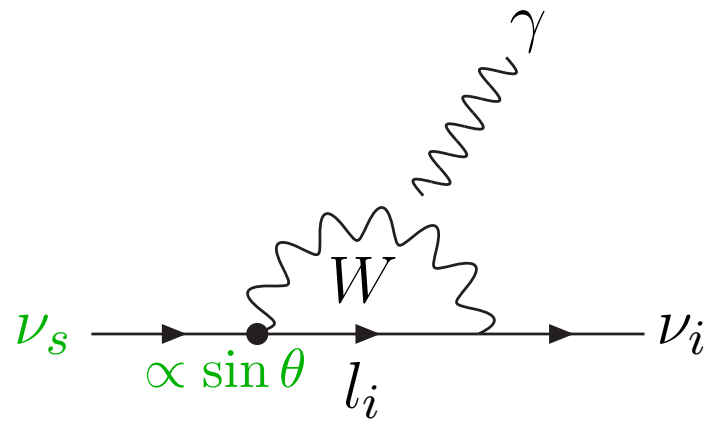
- Are unstable!

Decays of “sterile” neutrinos





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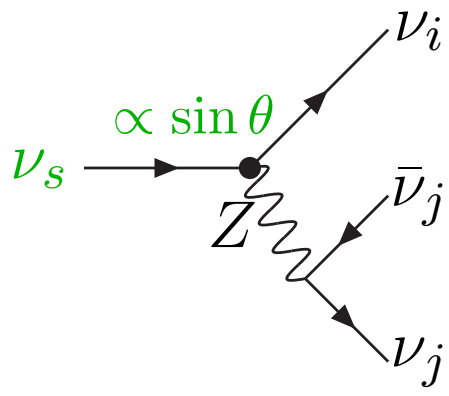

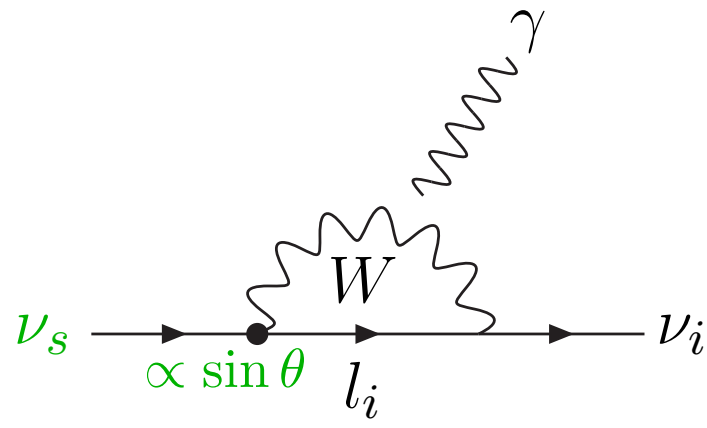

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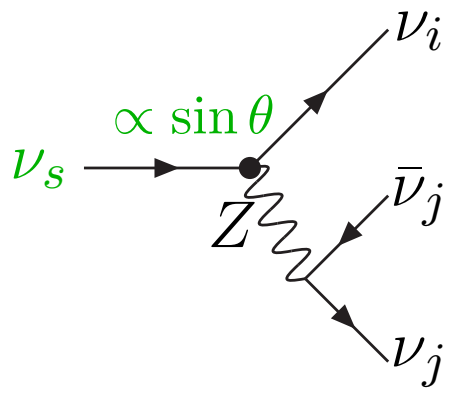

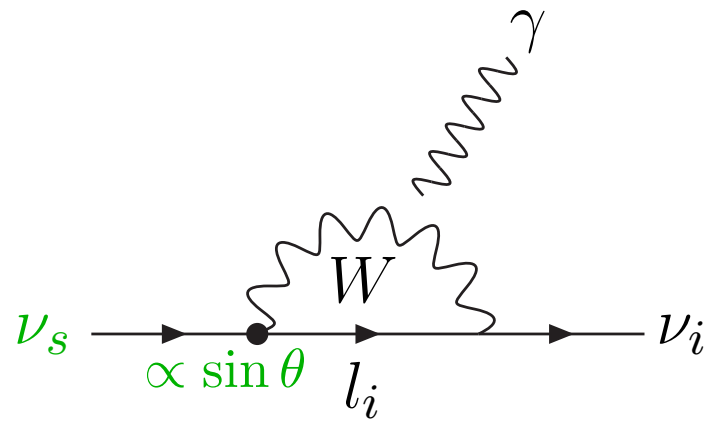

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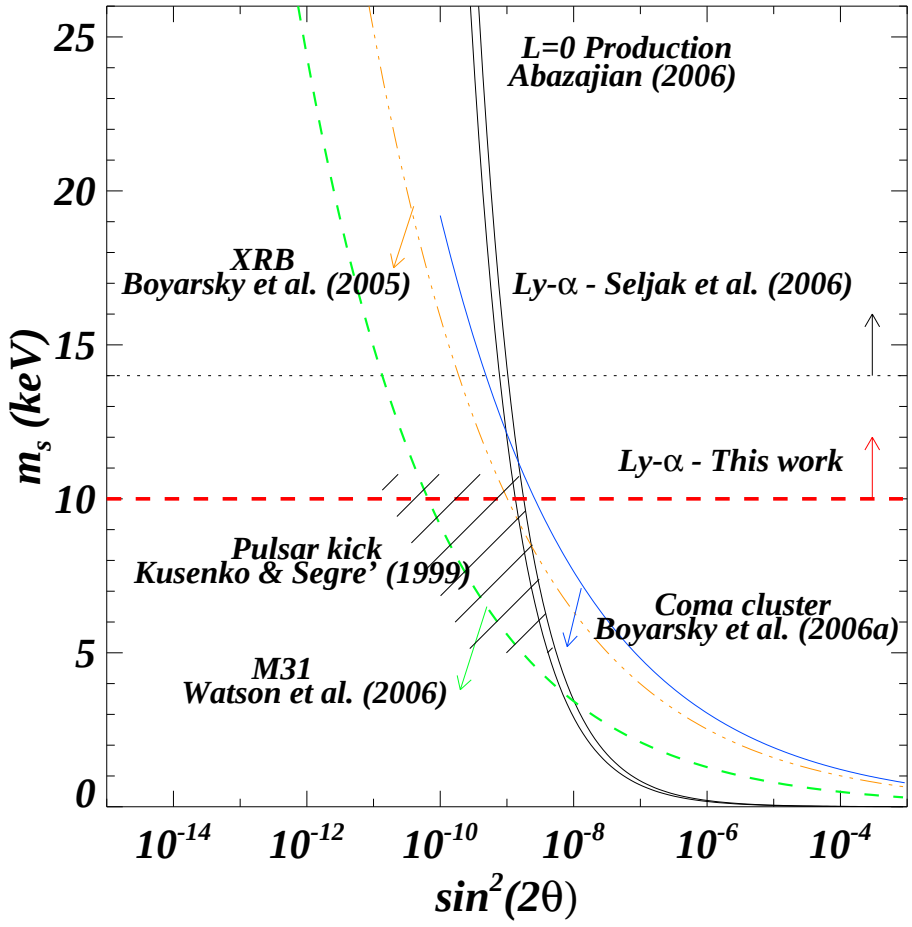
Right diagram gives only way to detect ν_s: monochromatic (X–ray) photon at $E_\gamma = m_{\nu_s}/2$.

Standard sterile neutrinos are excluded!

Viel et al., astro-ph/0605706



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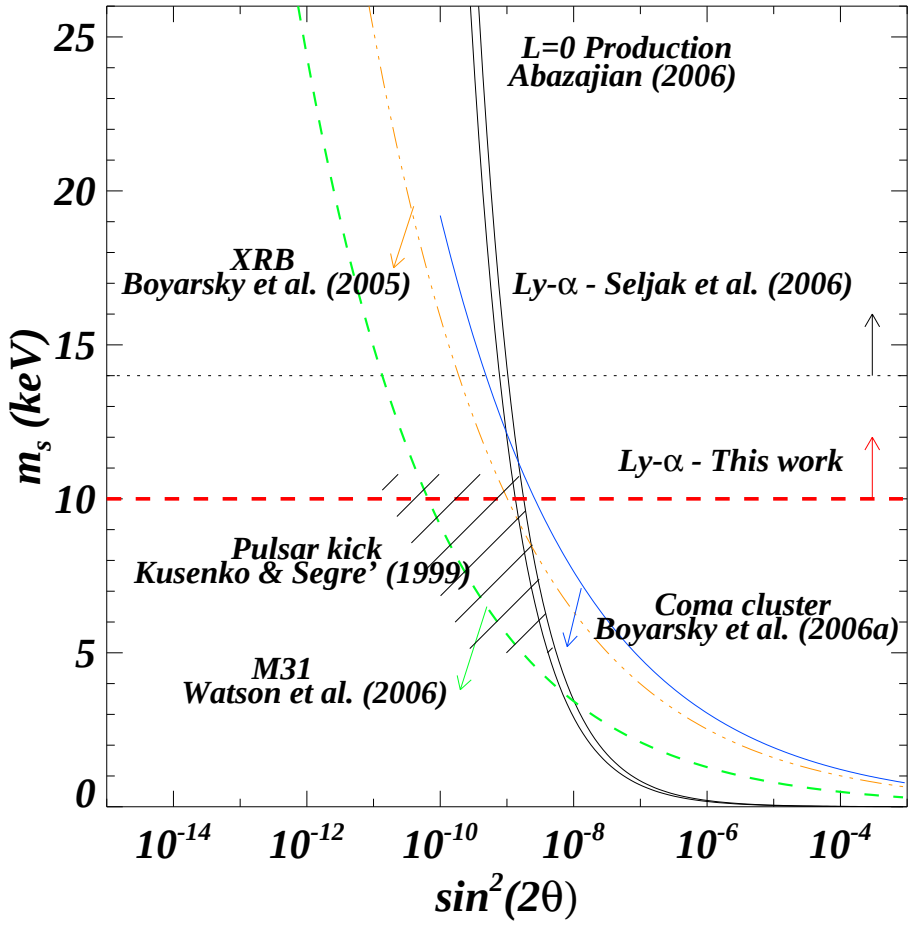

Loophole: Use non–standard production mechanism: large lepton asymmetry ($\Delta L \sim 0.1$), ν_s coupling to inflaton, . . .

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  - From NLSP decay: E.g. $\tilde{\tau}_1 \rightarrow \tau + \tilde{G} \text{ or } \tilde{a}$:

    $$\Omega_{\tilde{G} \text{ or } \tilde{a}} h^2 = \widetilde{\Omega}_{\text{NLSP}} h^2 \frac{m_{\tilde{G} \text{ or } \tilde{a}}}{m_{\text{NLSP}}}$$

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- DM Super–/E–WIMPs cannot be detected
- Allow charged NLSP, e.g. $\tilde{\tau}_1$. However, BBN requires $\tau_{\tilde{\tau}_1} < 2 \cdot 10^3$s (catalyzed Li overproduction): Can still see $\tilde{\tau}_1$ tracks, but cannot collect $\tilde{\tau}_1$.

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- Roughly weak interactions may allow both *direct* and *indirect* detection of WIMPs

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Let χ be a generic DM particle, n_χ its number density (unit: GeV^3). Assume $\chi = \bar{\chi}$, i.e. $\chi\chi \leftrightarrow$SM particles is possible, but single production of χ is forbidden by some symmetry.

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Evolution of n_χ determined by Boltzmann equation:

$$\frac{dn_\chi}{dt} + 3Hn_\chi = -\langle\sigma_{\rm ann} v\rangle \left(n_\chi^2 - n_{\chi,\,\rm eq}^2\right)$$

$H = \dot{R}/R$: Hubble parameter
$\langle \ldots \rangle$: Thermal averaging
$\sigma_{\rm ann} = \sigma(\chi\chi \to \text{SM particles})$
v : relative velocity between χ's in their cms
$n_{\chi,\,\rm eq}$: χ density in full equilibrium

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For $T < m_\chi$: $n_\chi \simeq n_{\chi,\,\rm eq} \propto T^{3/2} e^{-m_\chi/T}$, $H \propto T^2$

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$$\Omega_\chi h^2 \propto \frac{1}{\langle v \sigma_{\rm ann} \rangle} \sim 0.1 \text{ for } \sigma_{\rm ann} \sim \text{pb}$$

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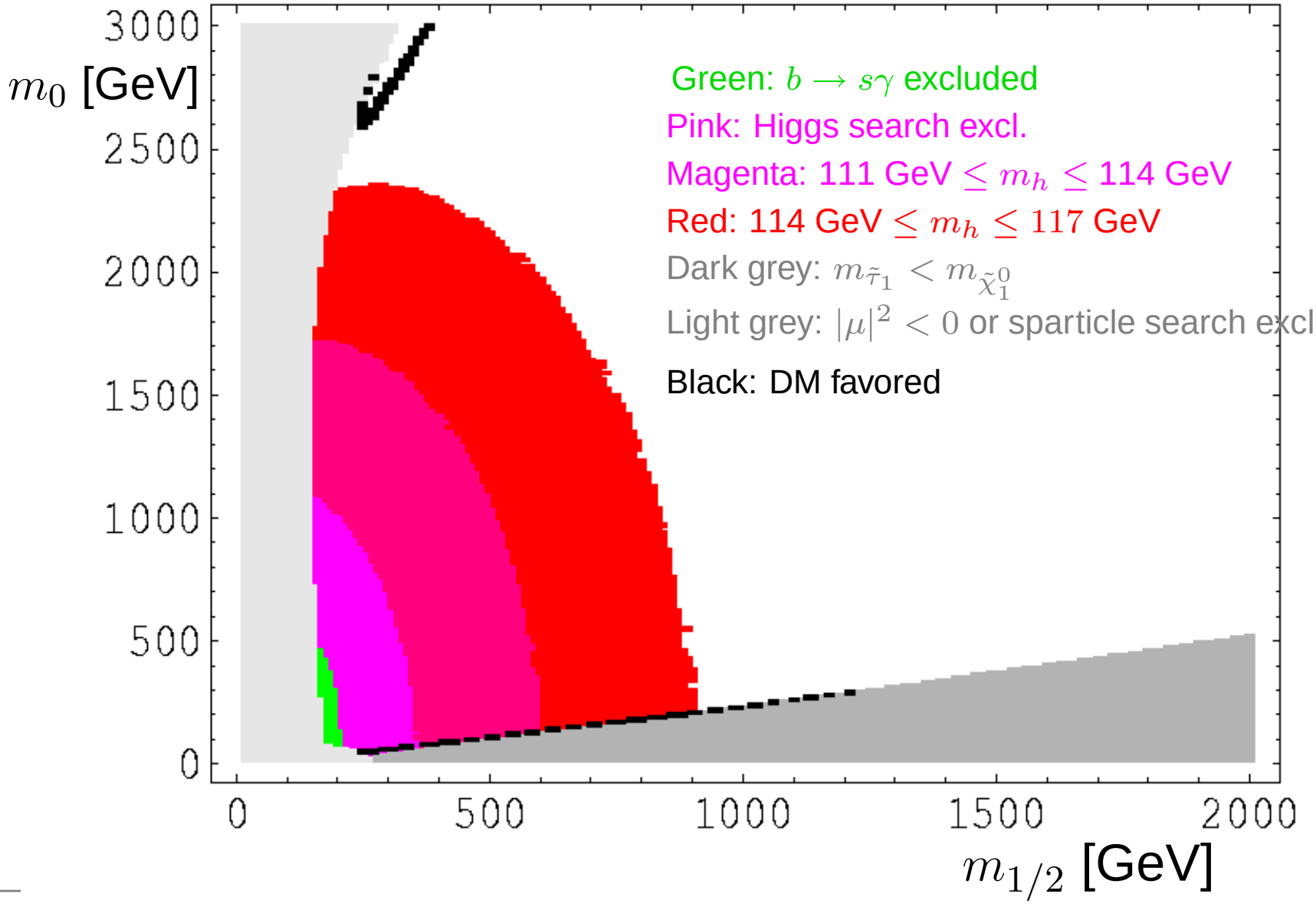
- In simplest (R_p-invariant) version: LSP is stable: can be good candidate for DM particle! (Free bonus, *not* related to original motivation.)

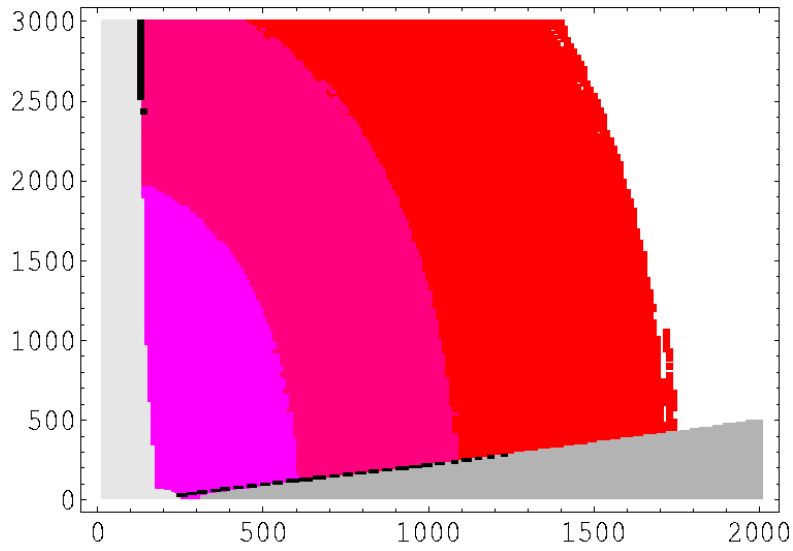
mSUGRA, $m_t = 172.7$ GeV, $\tan\beta = 10,\ A_0 = 0,\ \mu > 0$

Djouadi, MD, Kneur, hep-ph/0602001

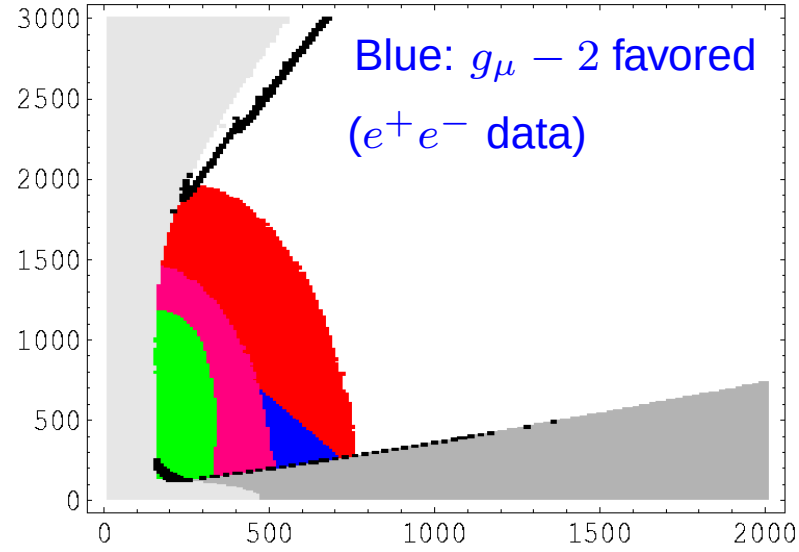


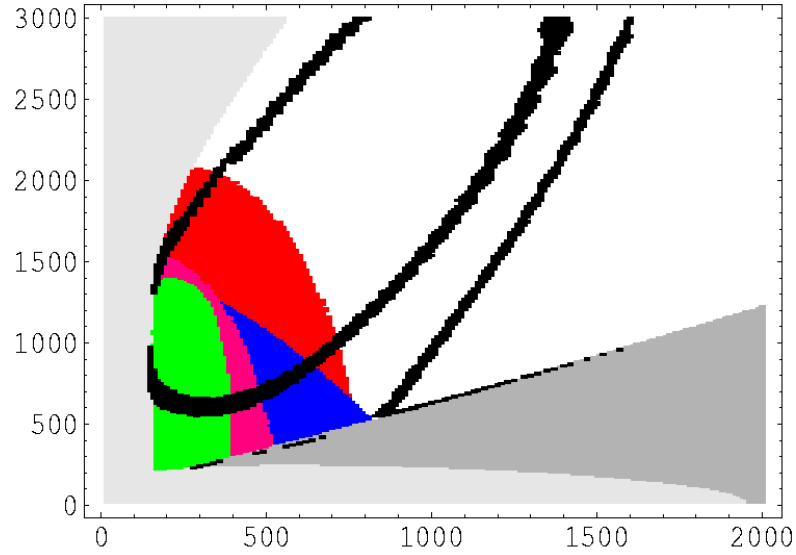
Effect of varying $\tan\beta$

$\tan\beta = 5$



$\tan\beta = 30$





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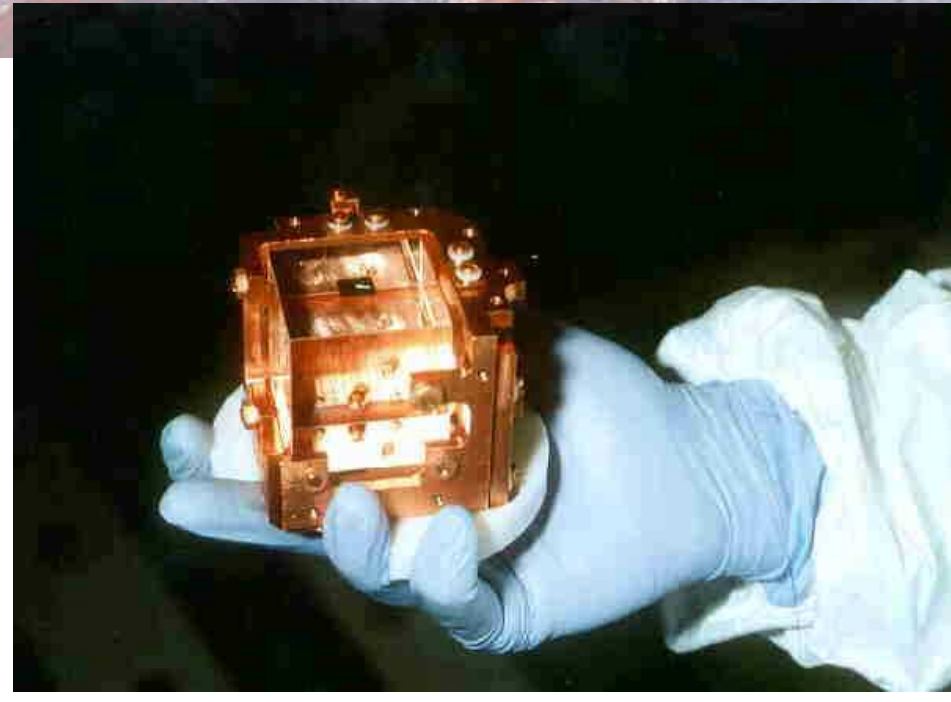

Detector

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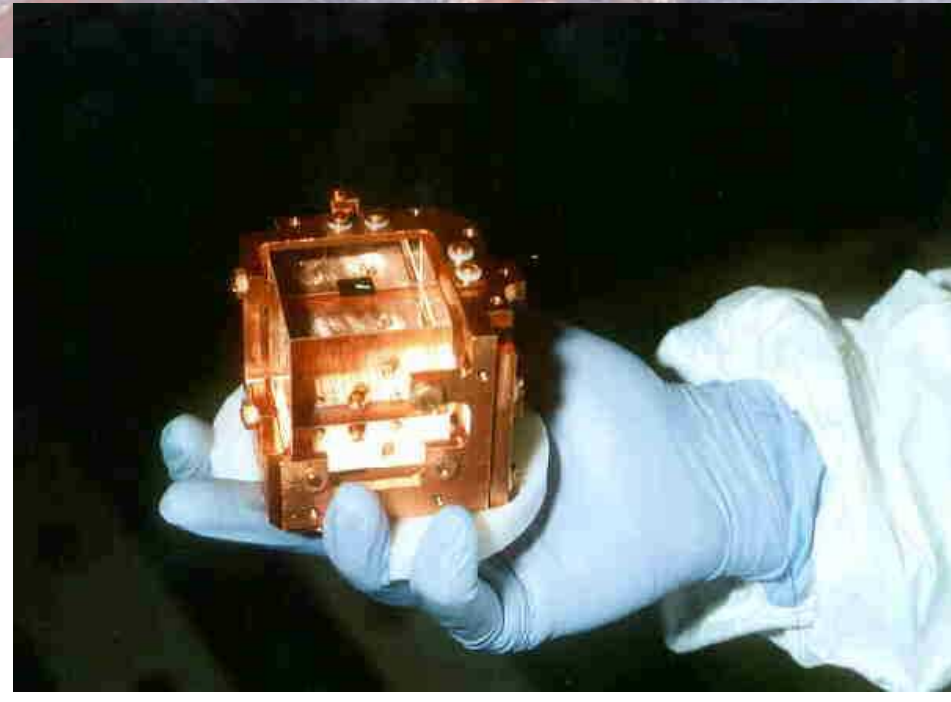
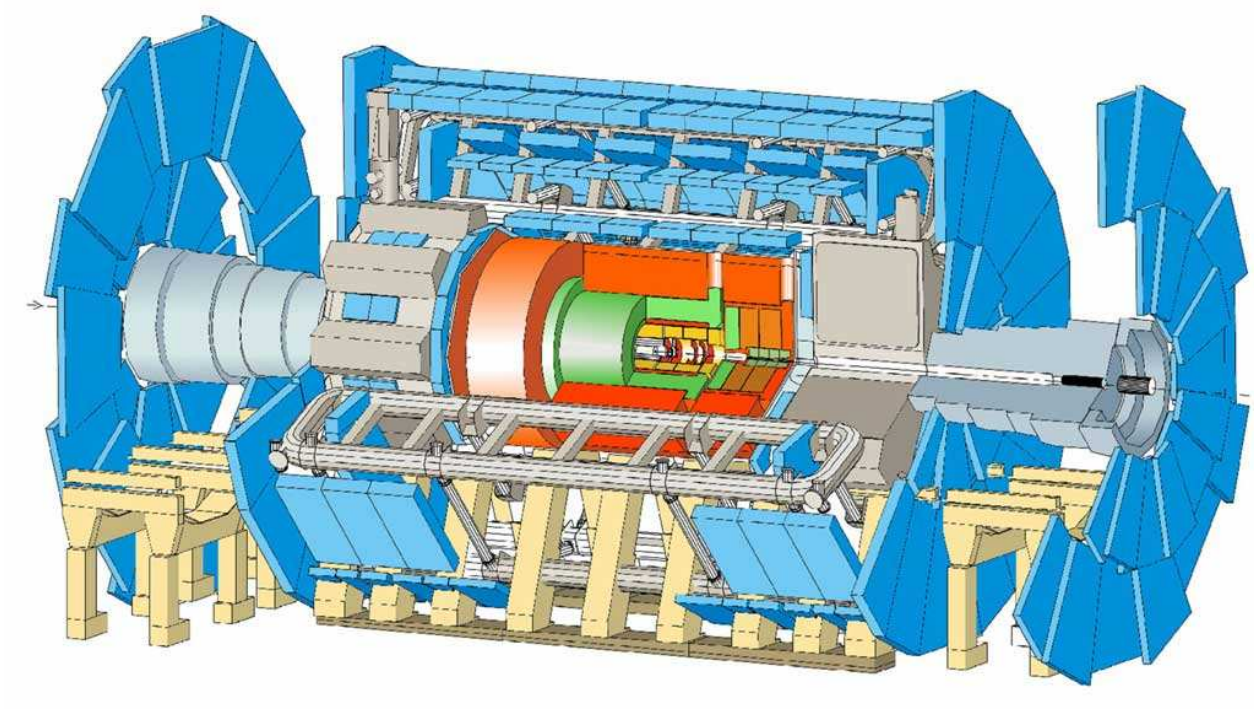


Detector

May also be testable at colliders

ATLAS detector at the LHC



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- Superheavy DM: Assumed to be unstable, with $\tau_\chi \sim 10^{17}$ yrs. Motivated by attempt to explain UHECR. Produced in very early universe, probably non–thermally. Recent UHECR data (AUGER) seem to disfavor this scenario.

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