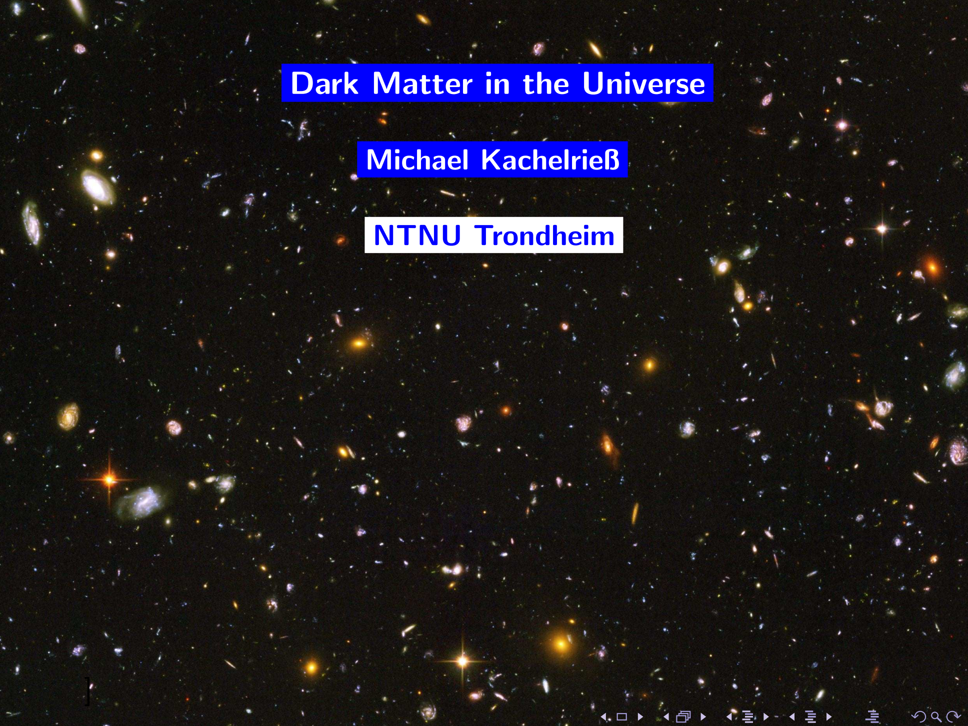
Dark Matter in the Universe

Michael Kachelrieß

NTNU Trondheim



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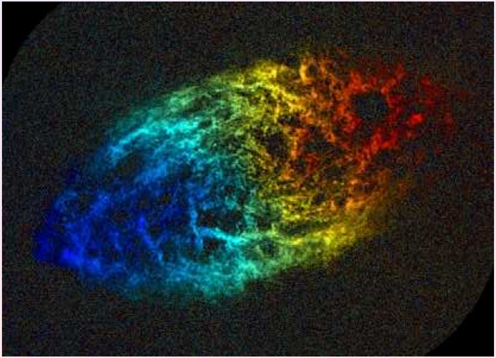

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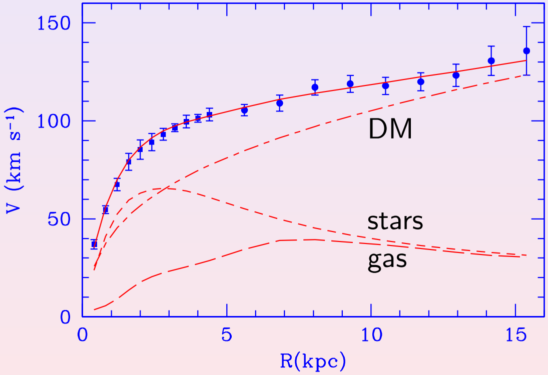

The standard lore:

- inflation suggests $\Omega \equiv \rho/\rho_{cr} = 1$

$$H^2 \equiv \left(\frac{\dot{R}}{R}\right)^2 = \frac{8\pi}{3} G\rho - \frac{k}{R^2} + \frac{\Lambda}{3}$$

with $\rho_{cr} = 3H_0^2/(8\pi G)$:

During inflation

$$|\,(\Omega_{tot} - 1)\,| = \frac{k}{\dot{R}^2} \propto \exp(-2Ht)$$

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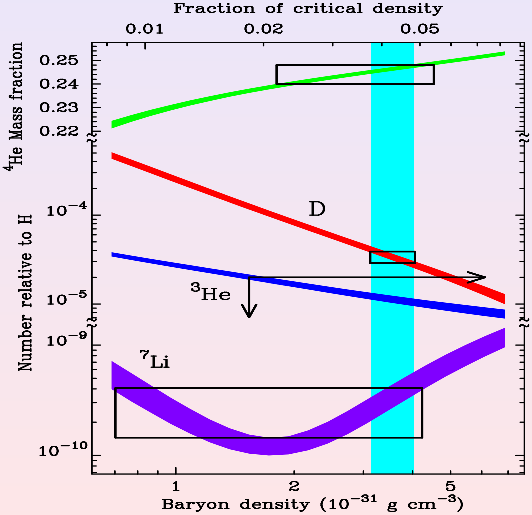

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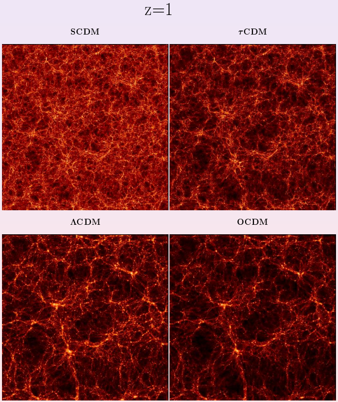

The VIRGO Collaboration 1996

Jeans criterion:

$$k_J = \left(\frac{4\pi G\rho_0}{v_s^2}\right)^{1/2}$$

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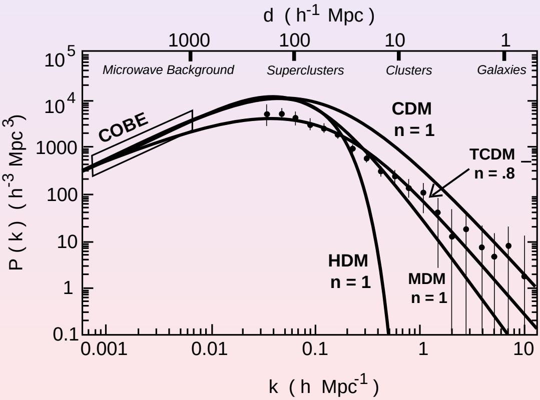
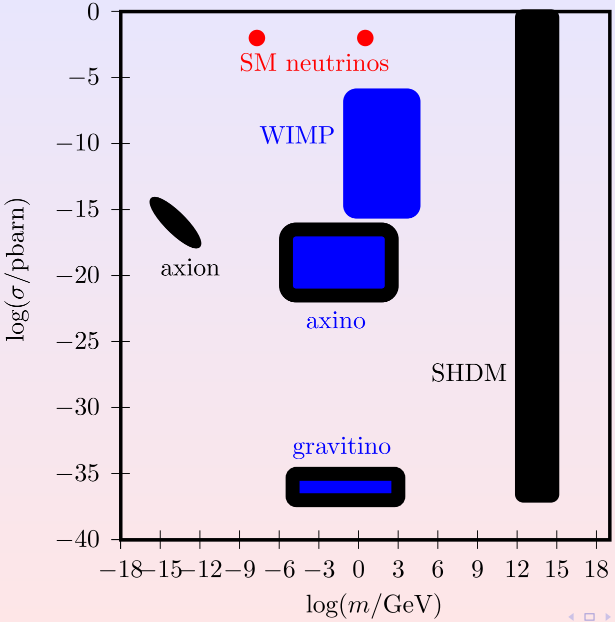


Dark matter candidates with $\Omega \sim 1$:



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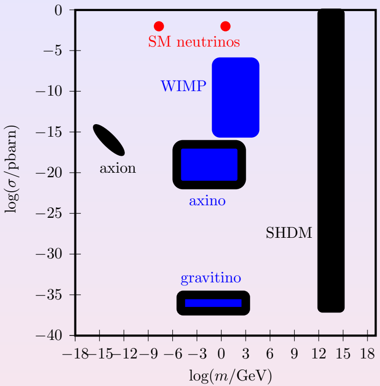

why such a large variability? Different production mechanism

- thermal relics: WIMPs
- production in phase transitions: axions
- gravitational production: superheavy dark matter (SHDM)

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- expansion of universe freezes out annihilation reactions, when

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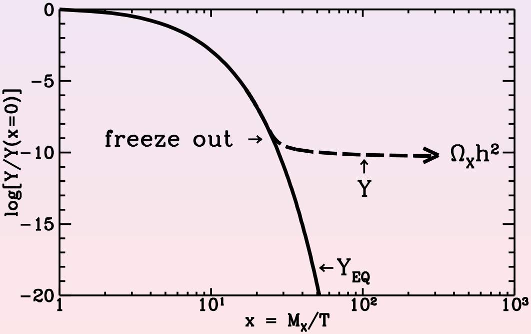

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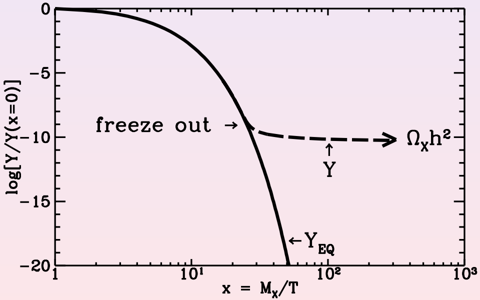

$$\Omega_X h^2 \sim \frac{3\times 10^{-26}\text{cm}^3/\text{s}}{\langle\sigma_{\text{ann}} v\rangle}$$

⇒ suggests weakly interacting DM particle with mass $m \sim m_Z$

Connection of Ω_X and $\langle\sigma_{\rm ann}v\rangle$

- Gamov criterion

$$\Gamma_{\rm ann} = n\langle\sigma_{\rm ann}v\rangle \stackrel{!}{=} H = 1.66 g_*^{1/2}\frac{T^2}{M_{\rm Pl}}$$

fixes n_X at freeze-out

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$$\begin{aligned}\langle\sigma_{\rm ann} v\rangle &= \sigma_0 + \sigma_1 v^2 + \sigma_2 v^4 + \ldots \\ &= \sigma_0 + \tilde\sigma_1 T/m + \tilde\sigma_2 (T/m)^2 + \ldots\end{aligned}$$

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Unitarity induces upper limit on thermal M_X

- Unitarity of S-matrix restricts annihilations into ℓ.th partial wave,

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- observed $\Omega_{\text{CDM}} h^2 = 0.105 \propto 1/\langle\sigma_{\text{ann}} v\rangle \Rightarrow$

$$M_X \lesssim 35\,\text{TeV}$$

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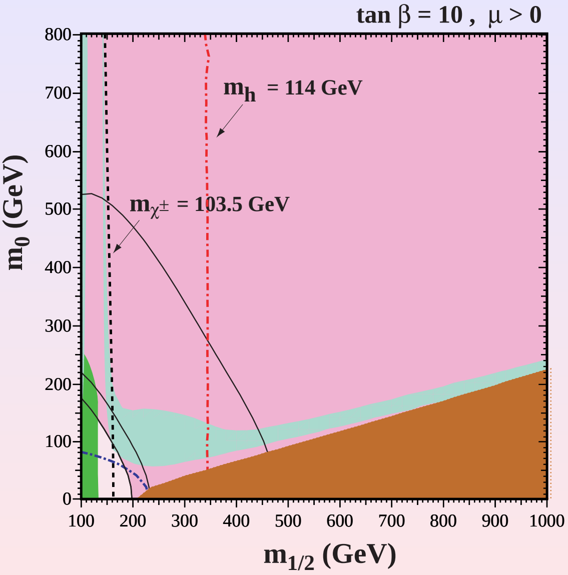
$$\chi = Z_{11}\tilde{B} + Z_{12}\tilde{W} + Z_{13}\tilde{H}_1 + Z_{14}\tilde{H}_2$$

possible WIMP candidate

Status of neutralino DM after LEPII:



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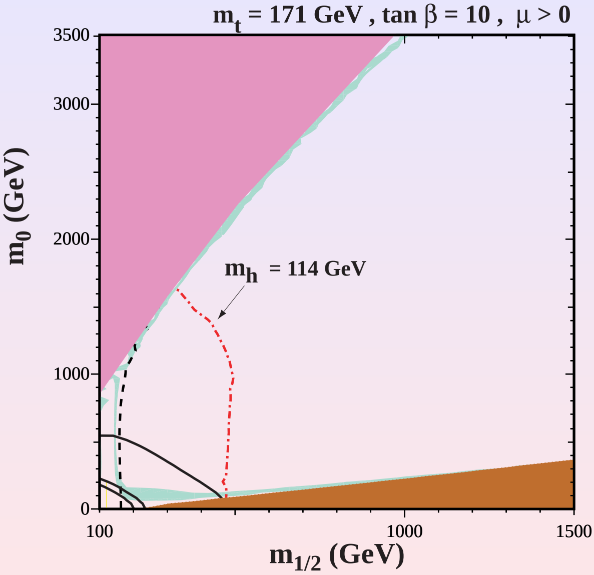

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- accelerator searches:
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  - test couplings, . . .
  - probes only short lifetimes

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$\Rightarrow$ axions are "like" pions, thus

$$m_a = m_\pi \frac{f_\pi}{f_a} \sim 0.6\text{eV} \; \frac{10^7\text{GeV}}{f_a}$$

i.e. light axions decouple

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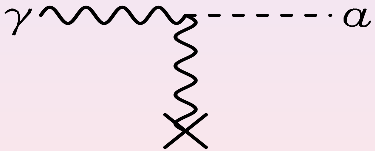
- Primakoff effect:



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- axionic strings form during the PQ phase transition and emit axions later on.

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- virial theorem:

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$\Rightarrow$ star has negative specific heat

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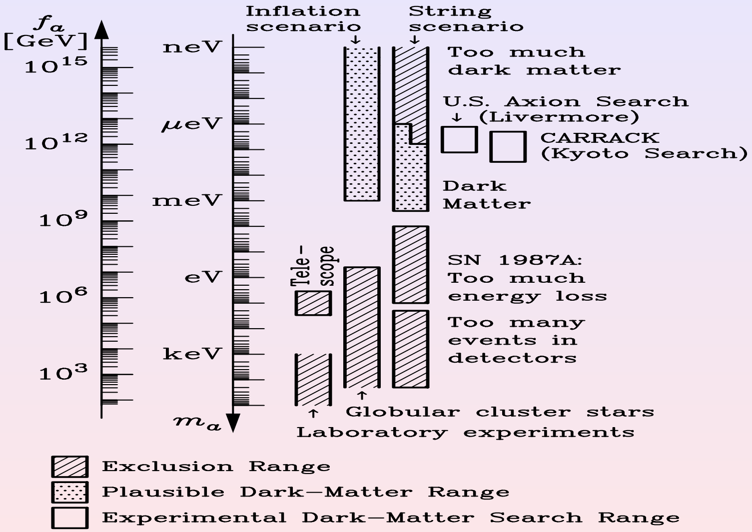
- reduction of stellar lifetime:

$$\frac{\delta\tau}{\tau} \sim \frac{L_a}{L_\gamma} \lesssim 1$$

  $\Rightarrow$ upper limit on $g_{a\gamma}$, m_a; lower limit on f_a

Summary of (old) axion limits:



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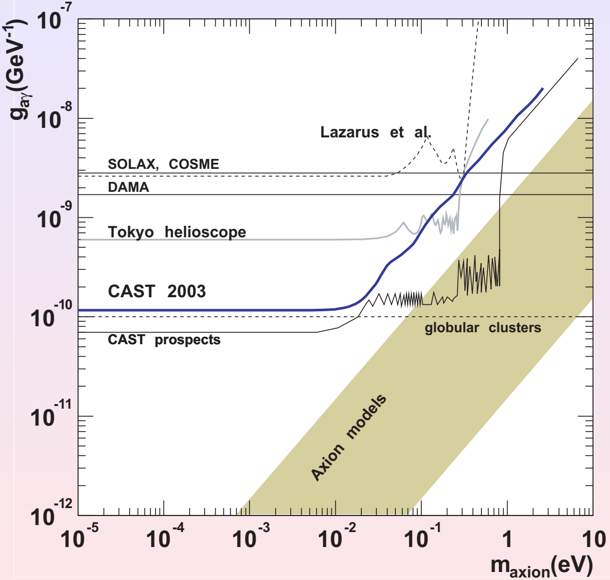

Superheavy matter

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- In inflationary cosmology

$$\Omega_X h^2 \sim \left(\frac{M_X}{10^{12}\mathrm{GeV}}\right)^2 \frac{T_{RH}}{10^9\mathrm{GeV}}$$

independent of details of particle physics, for any $M_X \lesssim H_I$

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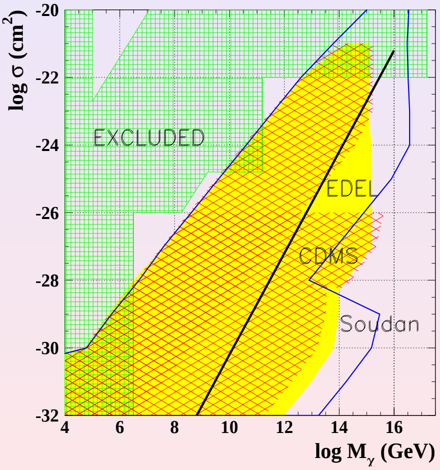
lifetime:

- metastable $\tau \gtrsim T_0$ or
- stable due to some (gauged) R symmetry

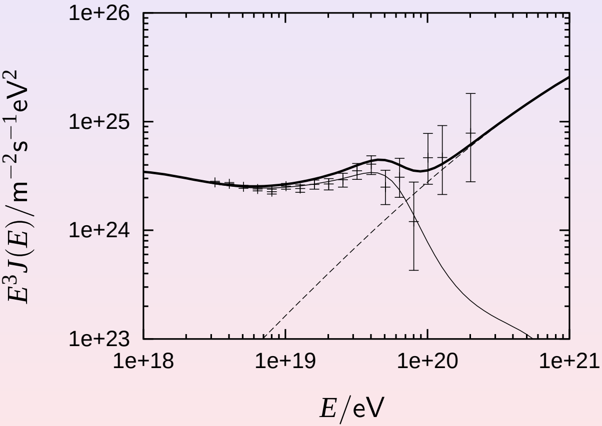
Detection of superheavy matter:

- direct detection: density $1/M_X$, recoil energy is constant
  $\Rightarrow$ large σ_{XN} required



Connection SHDM and UHECRs:

- UHECR above the GZK cutoff via photon, nucleon secondaries



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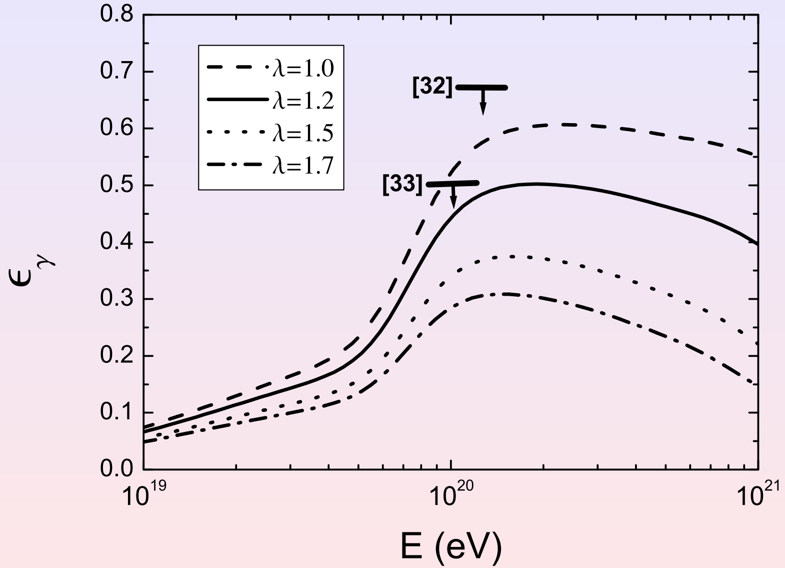

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