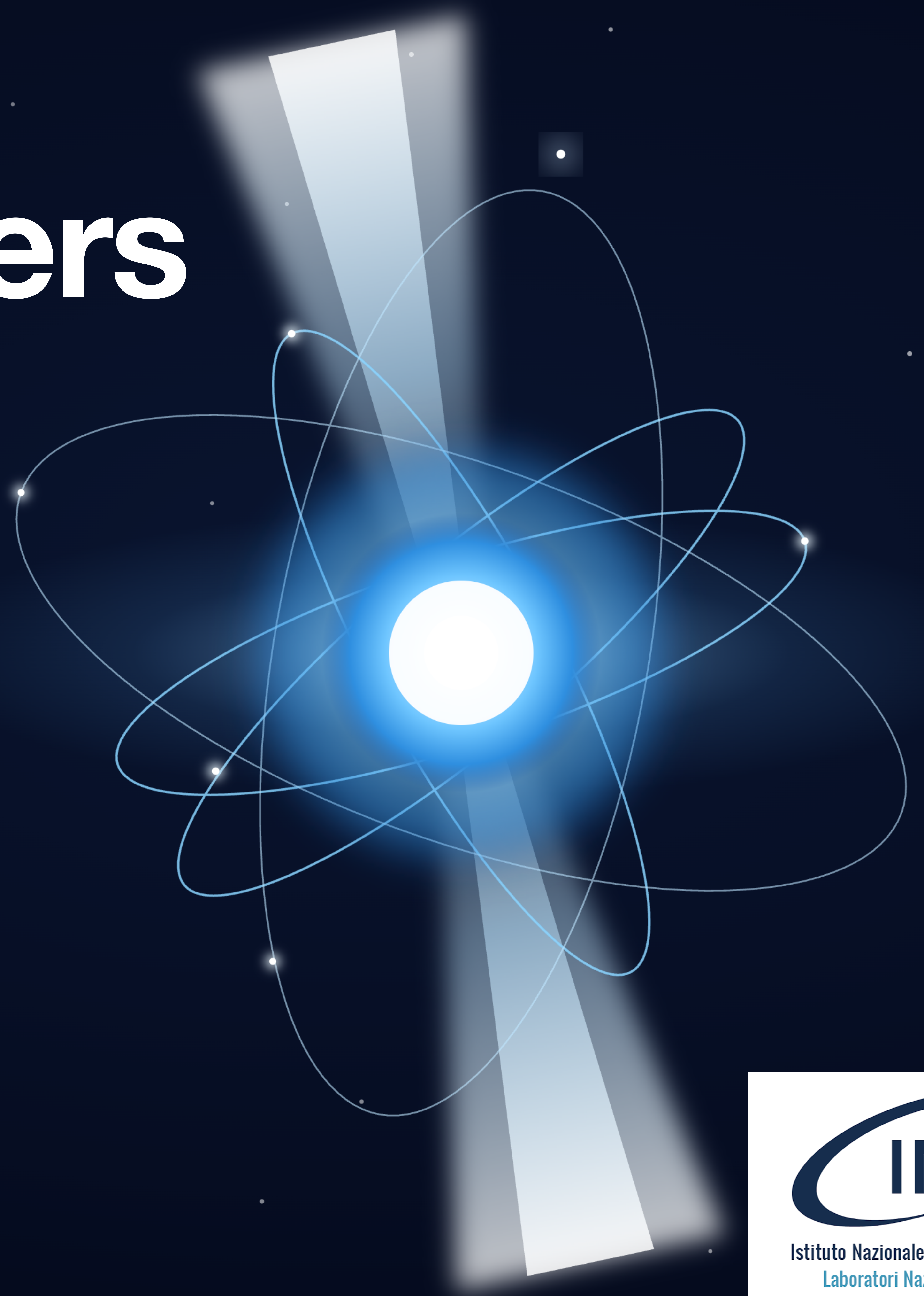
Light nuclear clusters

In warm magnetised stellar matter



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Light clusters in strong magnetic fields

Neutron stars can have extremely strong magnetic fields, which might have an effect on the properties of matter in their interior

Especially at finite temperature, in the inner crust of neutron stars, light nuclear clusters (deuteron, tritons, helions and alphas) should be present

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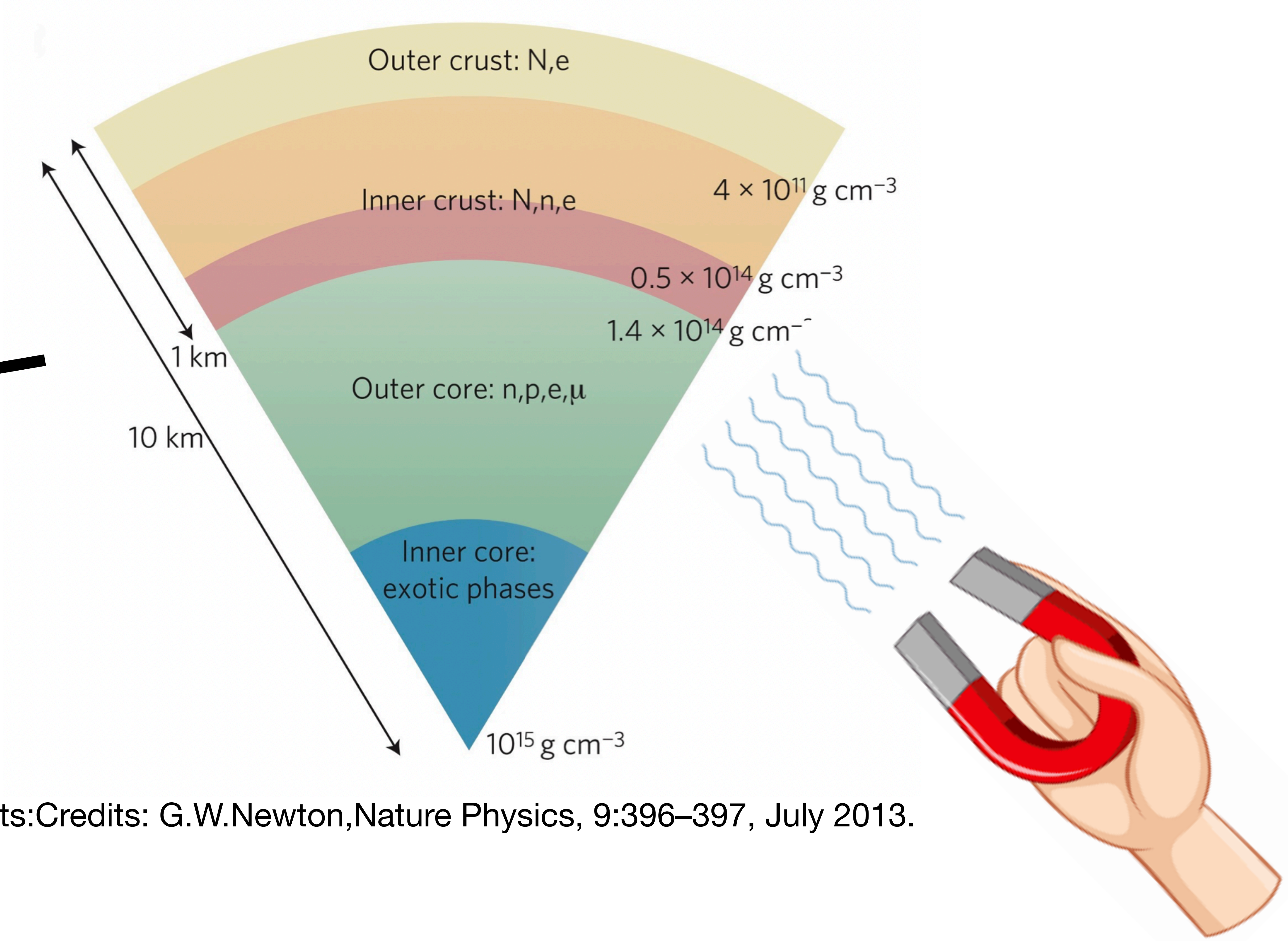
They are all charged, so they should feel the magnetic field



Credits:Credits: G.W.Newton,Nature Physics, 9:396–397, July 2013.

Warm magnetised matter

In the Relativistic Mean Field (RMF) framework

$$\mathscr{L} = \sum_{i=n,p,t,h} \mathscr{L}_i + \mathscr{L}_d + \mathscr{L}_\alpha + \mathscr{L}_l + \mathscr{L}_\sigma + \mathscr{L}_\omega + \mathscr{L}_\rho + \mathscr{L}_A$$

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$$\mathscr{L}_i = \bar{\psi}_i \left(\gamma_\mu i D_i^\mu - M_i^* \right) \psi_i$$

Nucleons, tritons and helions

Warm magnetised matter

In the Relativistic Mean Field (RMF) framework

$$\mathscr{L} = \boxed{\sum_{i=n,p,t,h} \mathscr{L}_i} + \boxed{\mathscr{L}_d + \mathscr{L}_\alpha} + \mathscr{L}_l + \mathscr{L}_\sigma + \mathscr{L}_\omega + \mathscr{L}_\rho + \mathscr{L}_A$$

$$\mathscr{L}_i = \bar{\psi}_i \left(\gamma_\mu i D_i^\mu - M_i^* \right) \psi_i$$

Nucleons, tritons and helions

$$\mathscr{L}_\alpha = \frac{1}{2} \left(i D_\alpha^\mu \phi_\alpha \right)^* \left(i D_{\alpha\mu} \phi_\alpha \right) - \frac{1}{2} M_\alpha^{*2} \, \phi_\alpha^* \phi_\alpha \, .$$

$$\mathscr{L}_d = \frac{1}{4} \left(i D_d^\mu \phi_d^\nu - i D_d^\nu \phi_d^\mu \right)^* \left(i D_{d\mu} \phi_{d\nu} - i D_{d\nu} \phi_{d\mu} \right) - \frac{1}{2} M_d^{*2} \, \phi_d^{\mu *} \phi_{d\mu}$$

Deuterons and alphas

Warm magnetised matter

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Nucleons, tritons and helions

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Deuterons and alphas

$$\mathscr{L}_l = \mathscr{L}_e + \mathscr{L}_{\nu_e}$$
$$= \bar{\psi}_e \left[\gamma_\mu \left(i\partial^\mu + eA^\mu \right) - m_e \right] \psi_e + \bar{\psi}_{\nu_e} i \gamma_\mu \partial^\mu \psi_{\nu_e}$$

Leptons

Warm magnetised matter

In the Relativistic Mean Field (RMF) framework

$$\mathscr{L} = \boxed{\sum_{i=n,p,t,h} \mathscr{L}_i} + \boxed{\mathscr{L}_d + \mathscr{L}_\alpha} + \boxed{\mathscr{L}_l} + \boxed{\mathscr{L}_\sigma + \mathscr{L}_\omega + \mathscr{L}_\rho} + \mathscr{L}_A$$

Mesons that mediate interaction

$$\mathscr{L}_i = \bar{\psi}_i \left(\gamma_\mu i D_i^\mu - M_i^* \right) \psi_i$$

Nucleons, tritons and helions

$$\mathscr{L}_\alpha = \frac{1}{2} \left(i D_\alpha^\mu \phi_\alpha \right)^* \left(i D_{\alpha\mu} \phi_\alpha \right) - \frac{1}{2} M_\alpha^{*2} \phi_\alpha^* \phi_\alpha \,.$$

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Deuterons and alphas

$$\begin{aligned} \mathscr{L}_l &= \mathscr{L}_e + \mathscr{L}_{\nu_e} \\ &= \bar{\psi}_e \left[\gamma_\mu \left(i \partial^\mu + e A^\mu \right) - m_e \right] \psi_e + \bar{\psi}_{\nu_e} i \gamma_\mu \partial^\mu \psi_{\nu_e} \end{aligned}$$

Leptons

Warm magnetised matter

In the Relativistic Mean Field (RMF) framework

$$\mathscr{L} = \boxed{\sum_{i=n,p,t,h} \mathscr{L}_i} + \boxed{\mathscr{L}_d + \mathscr{L}_\alpha} + \boxed{\mathscr{L}_l} + \boxed{\mathscr{L}_\sigma + \mathscr{L}_\omega + \mathscr{L}_\rho} + \boxed{\mathscr{L}_A}$$

Mesons that mediate interaction

$$\mathscr{L}_A = -\frac{1}{4} F_{\mu\nu} F^{\mu\nu},$$

Magnetic field

$$\mathscr{L}_i = \bar{\psi}_i \left(\gamma_\mu i D_i^\mu - M_i^* \right) \psi_i$$

Nucleons, tritons and helions

$$\mathscr{L}_\alpha = \frac{1}{2} \left(i D_\alpha^\mu \phi_\alpha \right)^* \left(i D_{\alpha\mu} \phi_\alpha \right) - \frac{1}{2} M_\alpha^{*2} \phi_\alpha^* \phi_\alpha .$$

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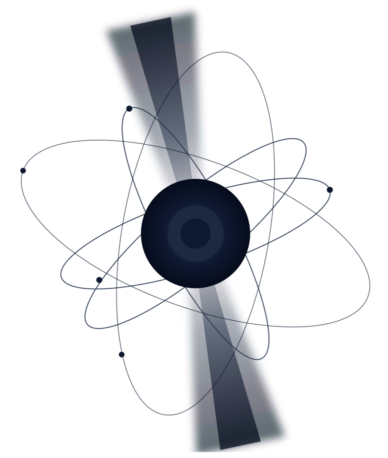
Deuterons and alphas

$$\begin{aligned} \mathscr{L}_l &= \mathscr{L}_e + \mathscr{L}_{\nu_e} \\ &= \bar{\psi}_e \left[\gamma_\mu \left(i\partial^\mu + eA^\mu \right) - m_e \right] \psi_e + \bar{\psi}_{\nu_e} i \gamma_\mu \partial^\mu \psi_{\nu_e} \end{aligned}$$

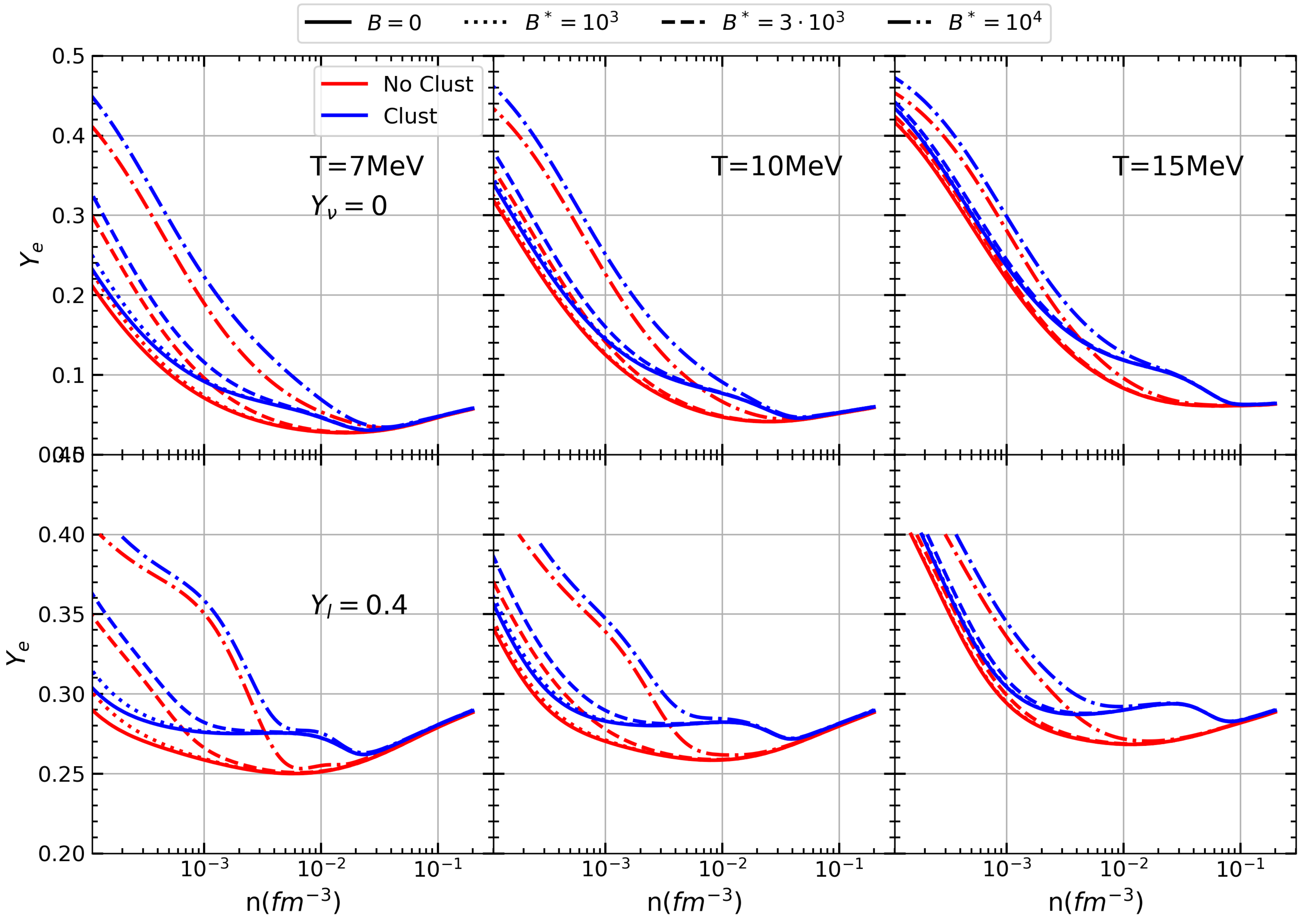
Leptons

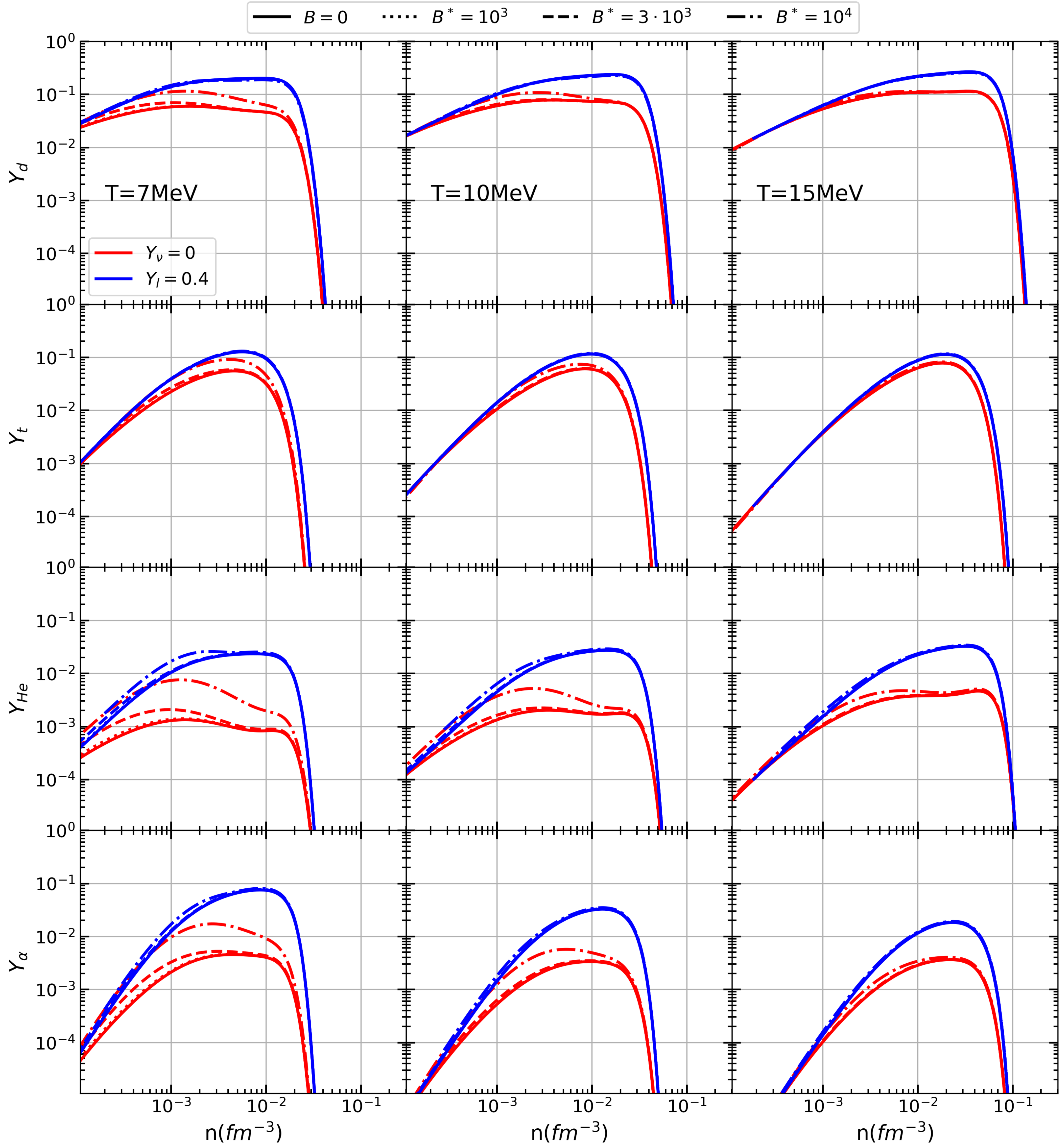
Amount of light clusters

Under strong magnetic fields



The magnetic field increases the amount of charged particles, which increases the amount of light clusters





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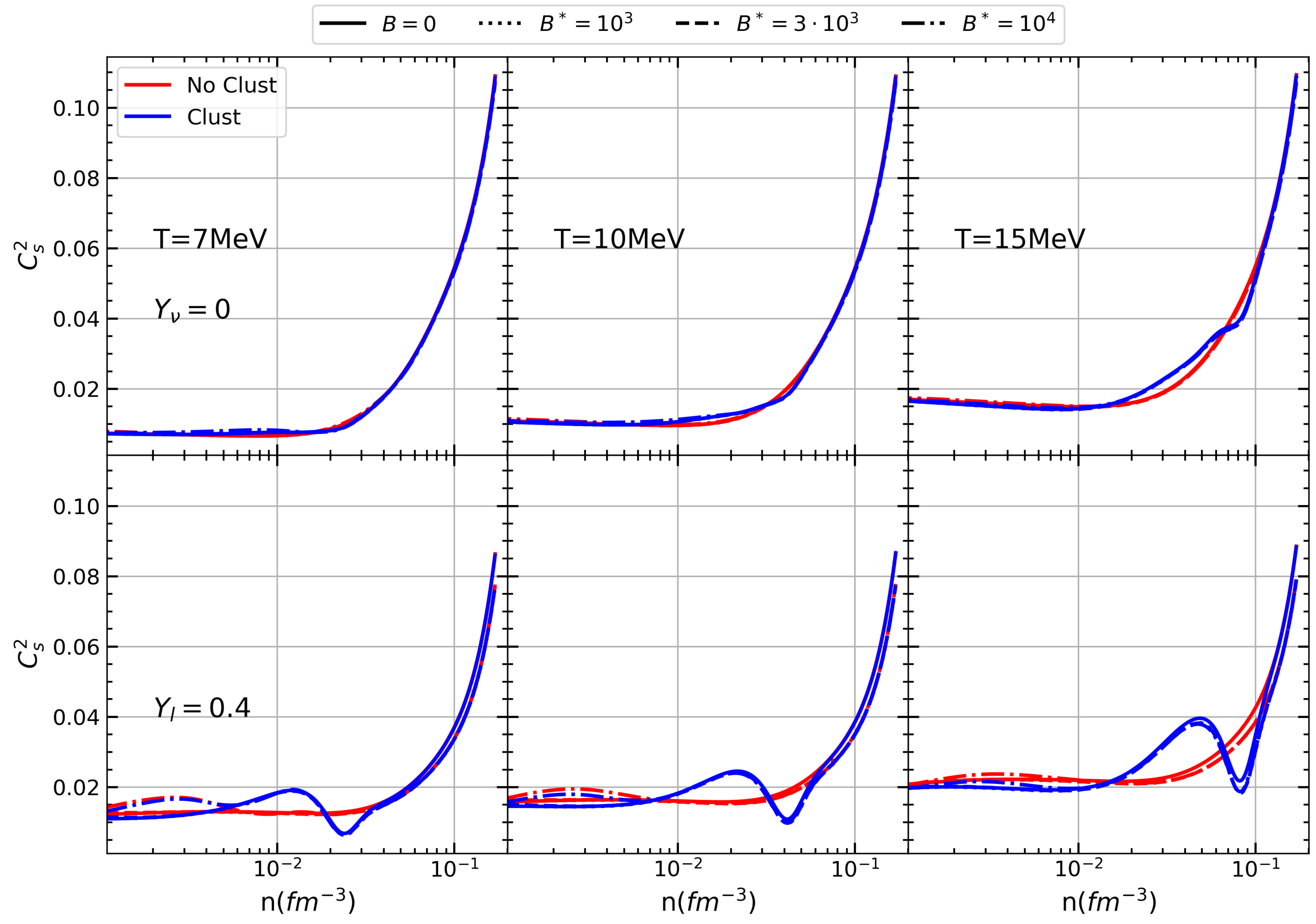
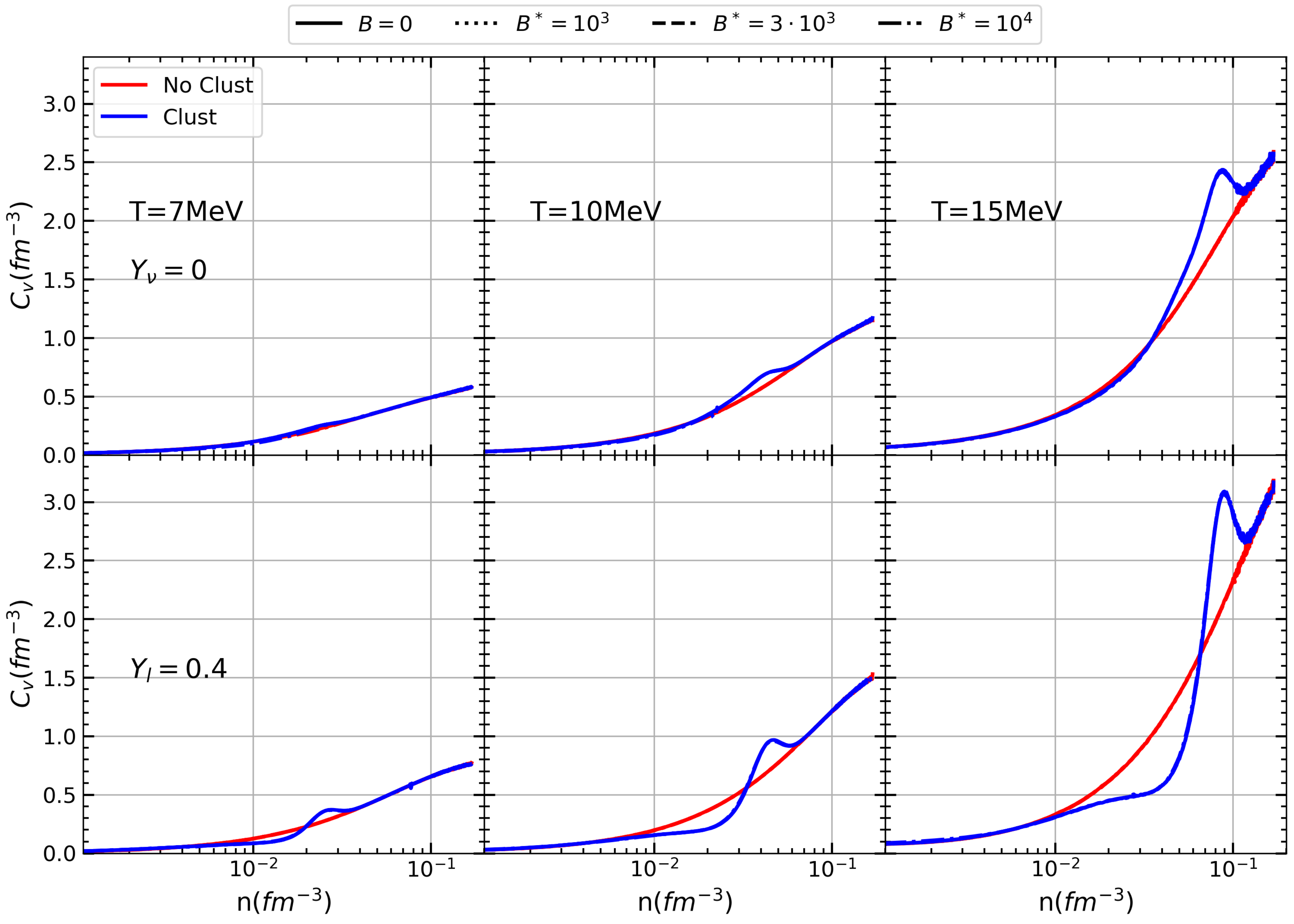
Effect on the dynamical properties

We observe that the presence of light clusters can have a strong effect on properties such as the speed of sound in our star or the specific heat





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Thank you !