Atomic probes of subGeV new physics

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Work in progress with

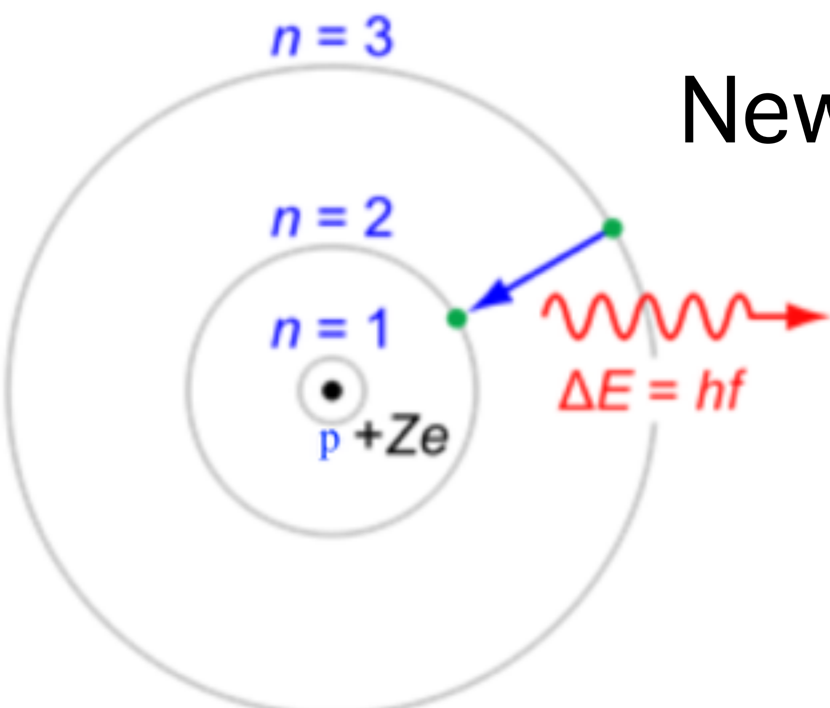
Delaunay, Fuchs, Grojean, Harnik, Ozeri,Perez, Soreq

NPKI workshop

Korea University

Atomic Probes of new physics

Consider transitions between energy levels



New forces (long or short range) change the frequency

$$V_{NP}(r) = \frac{g_e\, g_A\, e^{-M\, r}}{4\pi\, r}$$

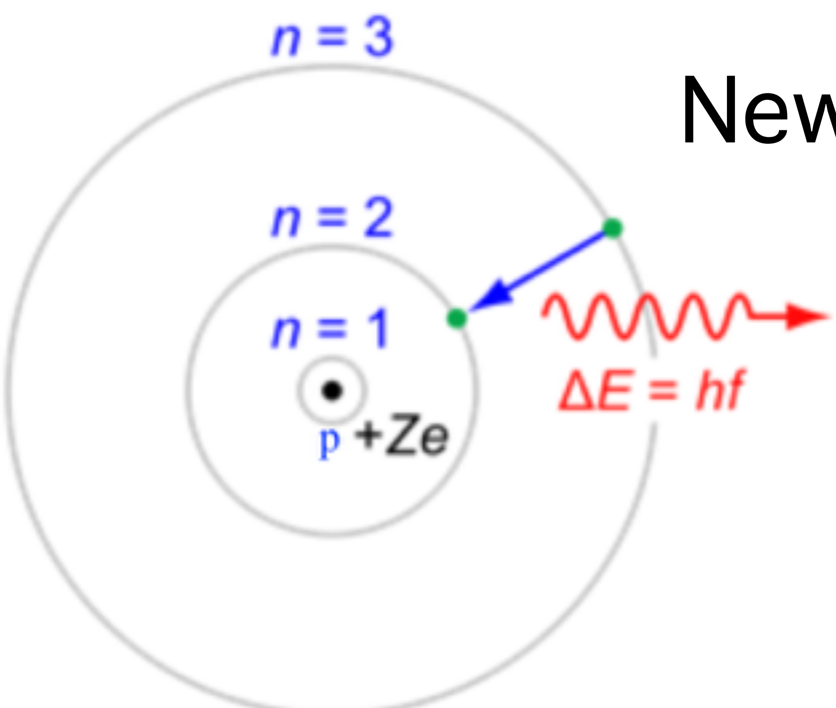
$$r > a_0 \; V_{NP} \propto 1/r \text{ massless limit}$$

$$\delta E_{nlm} = \langle \psi_{nlm} | V_{NP} | \psi_{nlm} >= 4\pi \int_0^\infty dr\, r^2\, V_{NP}(r) |\psi_{nlm}(r)|^2$$

However we can't determine the absolute frequency shift!

Atomic Probes of new physics

Consider transitions between energy levels



New forces (long or short range) change the frequency

$$V_{NP}(r) = \frac{g_e\, g_A\, e^{-M\, r}}{4\pi\, r}$$

δE_{n} ... $r)|^2$

We can measure the difference in isotope frequency shift (IS)

However we can't determine the absolute frequency shift!

ISOTOPE SHIFT

consider

- 2 atomic level transitions with frequencies ν^1, ν^2
- 2 isotopes A, A' of the same atom/ion that have transitions 1,2

frequency shift of the same transition i in A, A': **factorisation** [King '63]

$$\delta\nu_i^{AA'} \equiv \nu_i^A - \nu_i^{A'} = K_i\,\mu_{AA'} + F_i\,\delta\langle r^2\rangle_{AA'}$$
$$\mu_{AA'} = 1/m_A - 1/m_{A'}$$

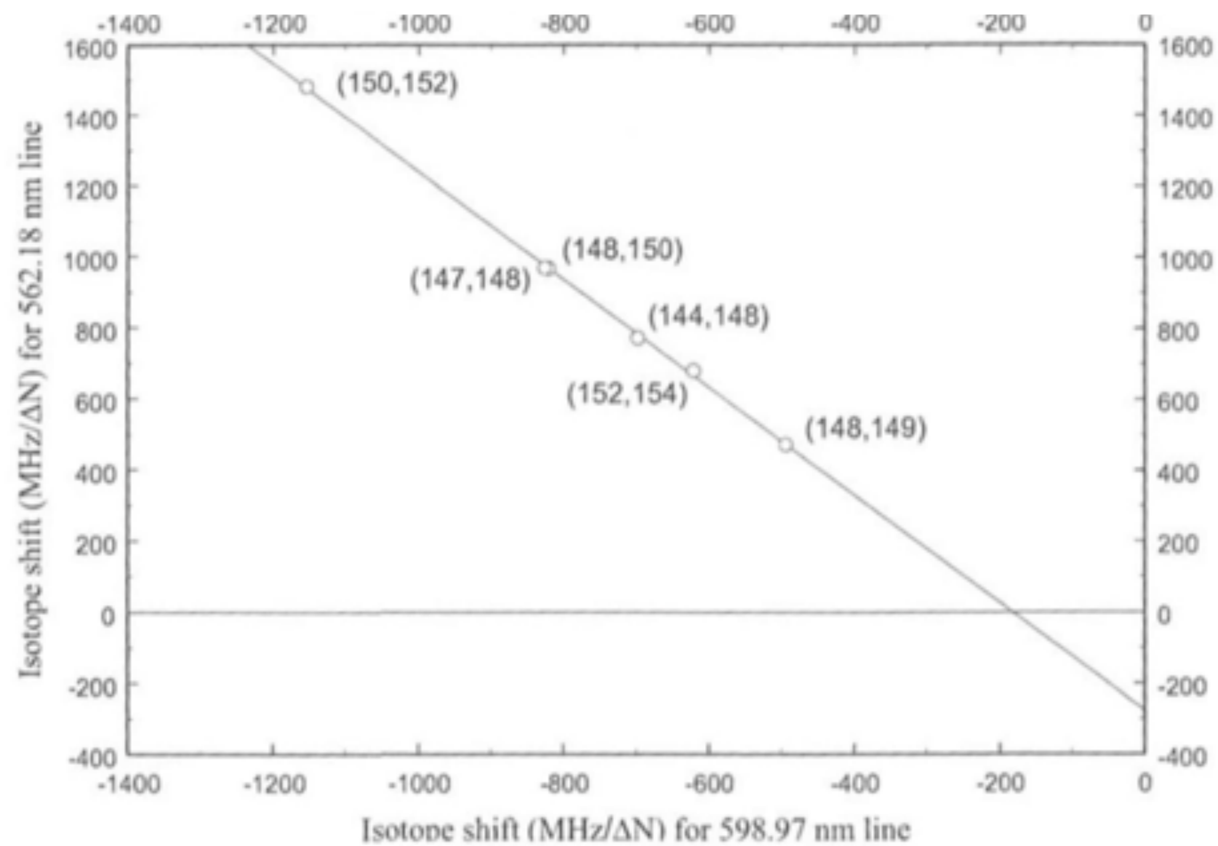
- (normal) mass shift: changed electron reduced mass
- field/volume shift: point charge approximation for nucleus breaks

Absolute frequencies difficult, but frequency shifts more precise

- eliminate unknown AA'-difference of charge distribution variance $\delta\langle r^2\rangle_{AA'}$, normalise $\delta\nu/\mu \equiv \tilde{\delta}\nu$
- express frequency shift $\tilde{\delta}\nu^2_{AA'}$ in terms of $\tilde{\delta}\nu^1_{AA'}$ $\Rightarrow$ linear relation

$$\tilde{\delta}\nu^2_{AA'} = F \cdot \tilde{\delta}\nu^1_{AA'} + K$$

classical King plot



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Now if we add the NP contribution..

$$\delta\nu^i_{AA'} = K_i \mu_{AA'} + F_i\, \delta r^2_{AA'} + H_i (A - A')$$

classical King plot

Isotope shift (MHz/ΔN) for 598.97 nm line

$$H_{21} = H_2 - F_{21} H_1$$

$$m\delta\nu^2_{AA'} = F_{21} m\delta\nu^1_{AA'} + K_{21} - AA' H_{21}$$

new physics can violate King's linearity

Light mediators

F_i contact interaction $F_i \propto |\psi(0)|^2$

For short range interactions $H_i \propto F_i$

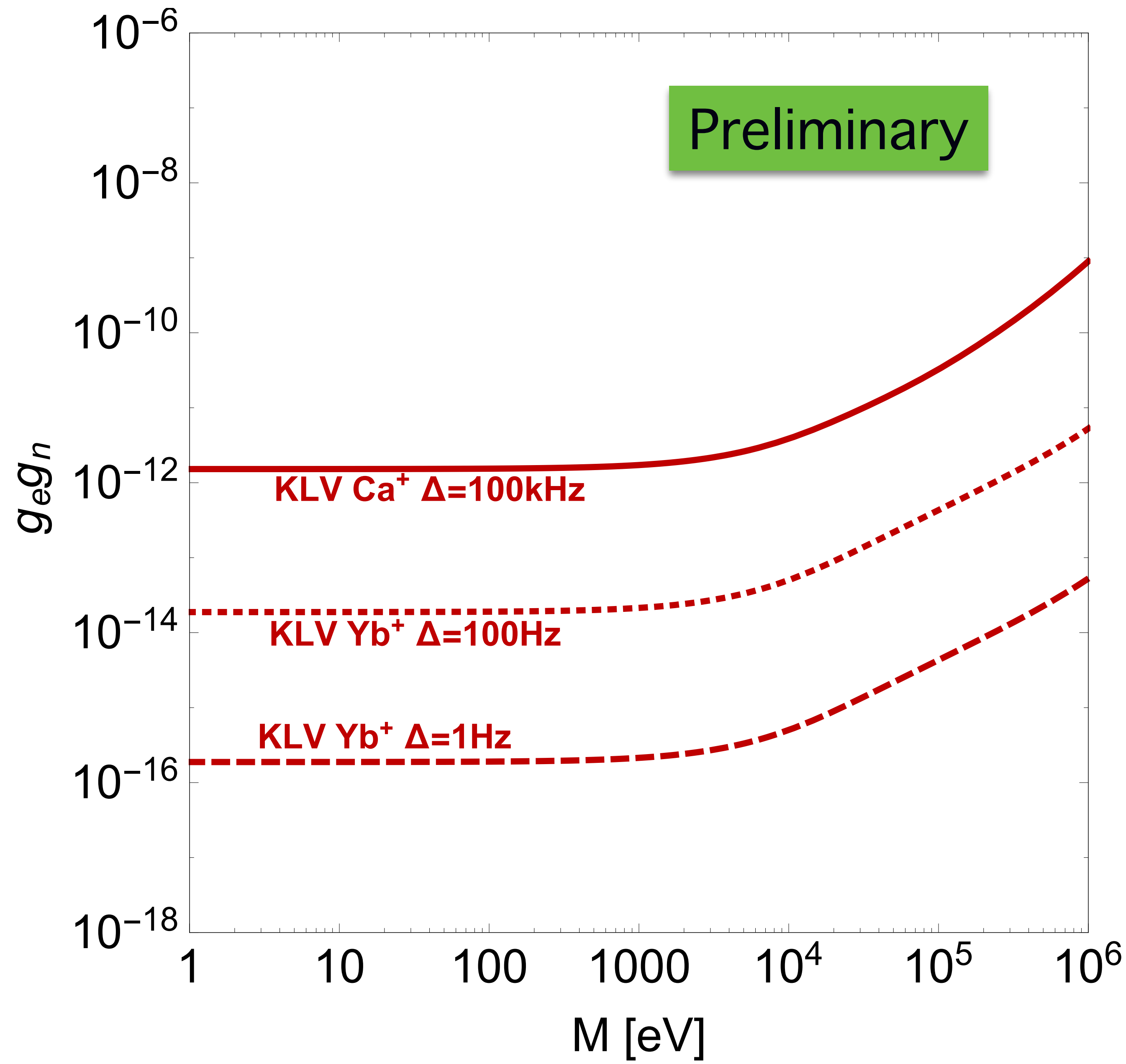
for long range interactions we probe instead a sizeable region of electronic wave function

→ Breaking of Kings linearity

$$m\delta\nu^2_{AA'} = F_{21} m\delta\nu^1_{AA'} + K_{21} - AA' H_{21}$$

Probe of new light particles (scalar or vector) coupled to neutrons and electrons (spin independent interaction only)

KLV sensitivity to light mediators



Non linearity supposed to hold up to 1 Hz

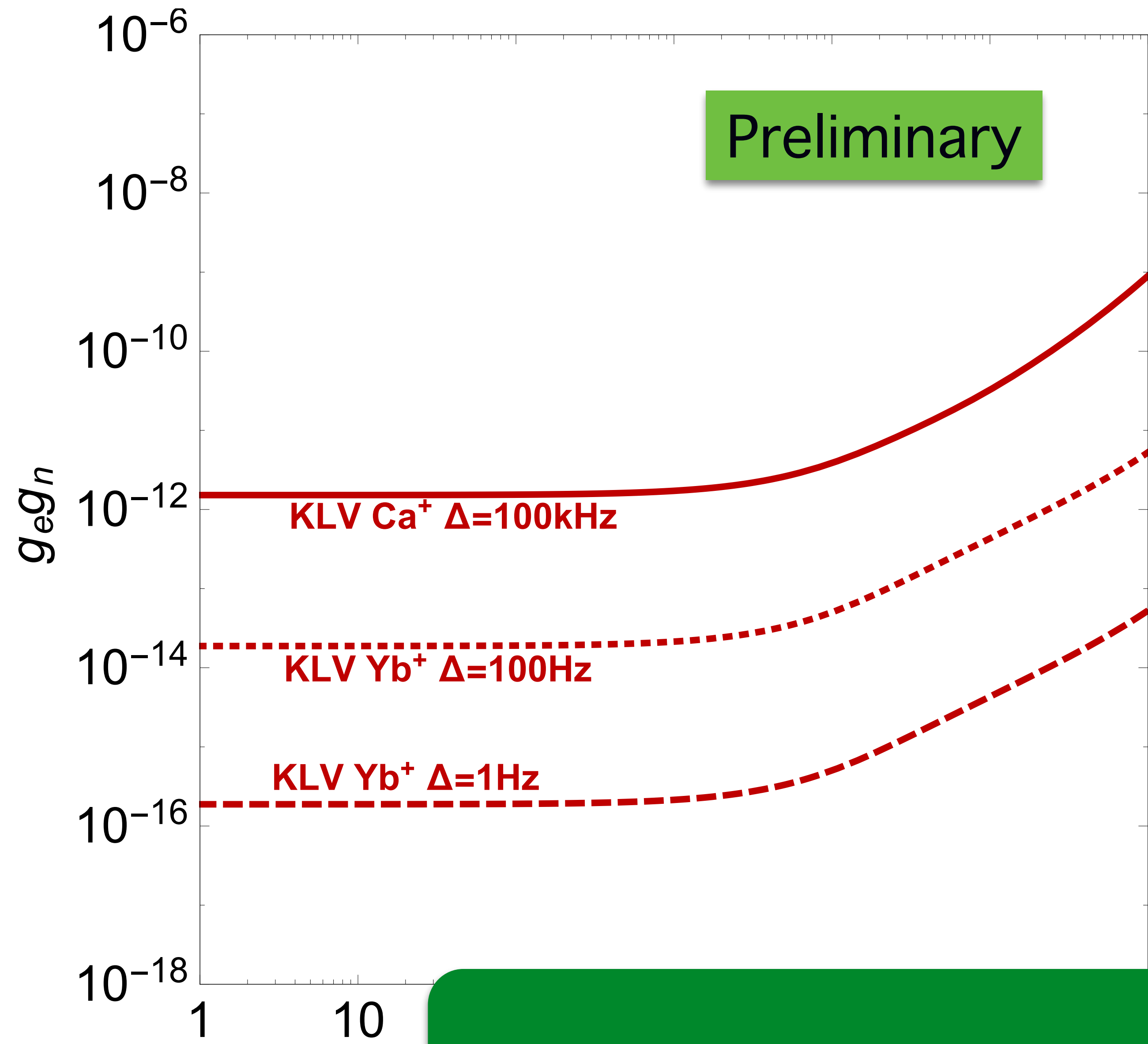
g_e coupling to the electron

g_N coupling to the neutron

work in progress

Focus on region below 1 MeV to be safe- potential good sensitivity up few tens of MeV

KLV sensitivity to light mediators



Non linearity supposed to hold up to 1 Hz

g_e coupling to the electron

g_N coupling to the neutron

Foc

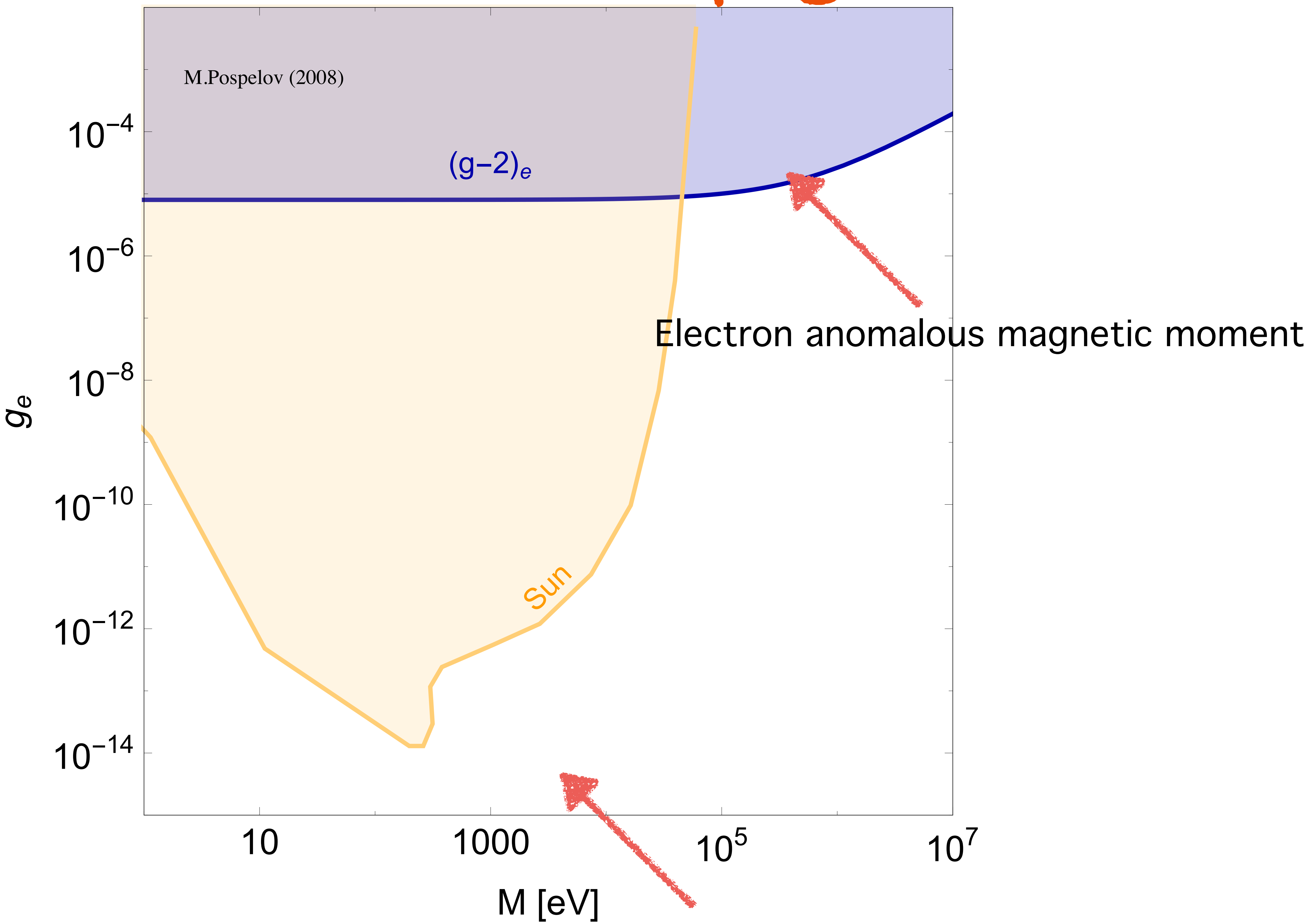
poter

V

What are the existing constraints? which frequency is necessary to set the strongest bounds?

work in progress

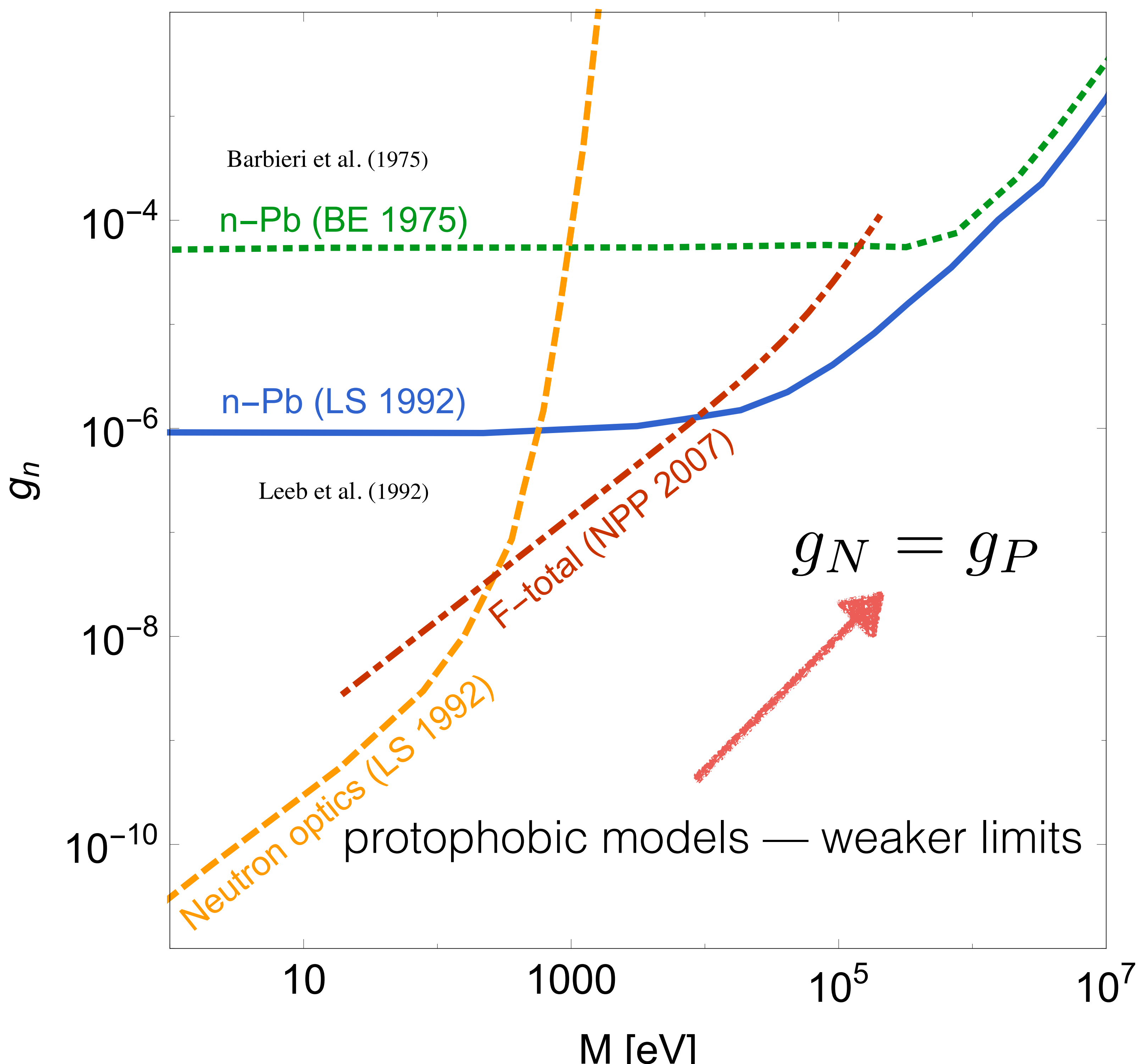
Probes of ge



Astro bounds coming from the production via thermal radiation in the sun of a new scalar or vector boson G. G. Raffelt and G. D. Starkman (1989)

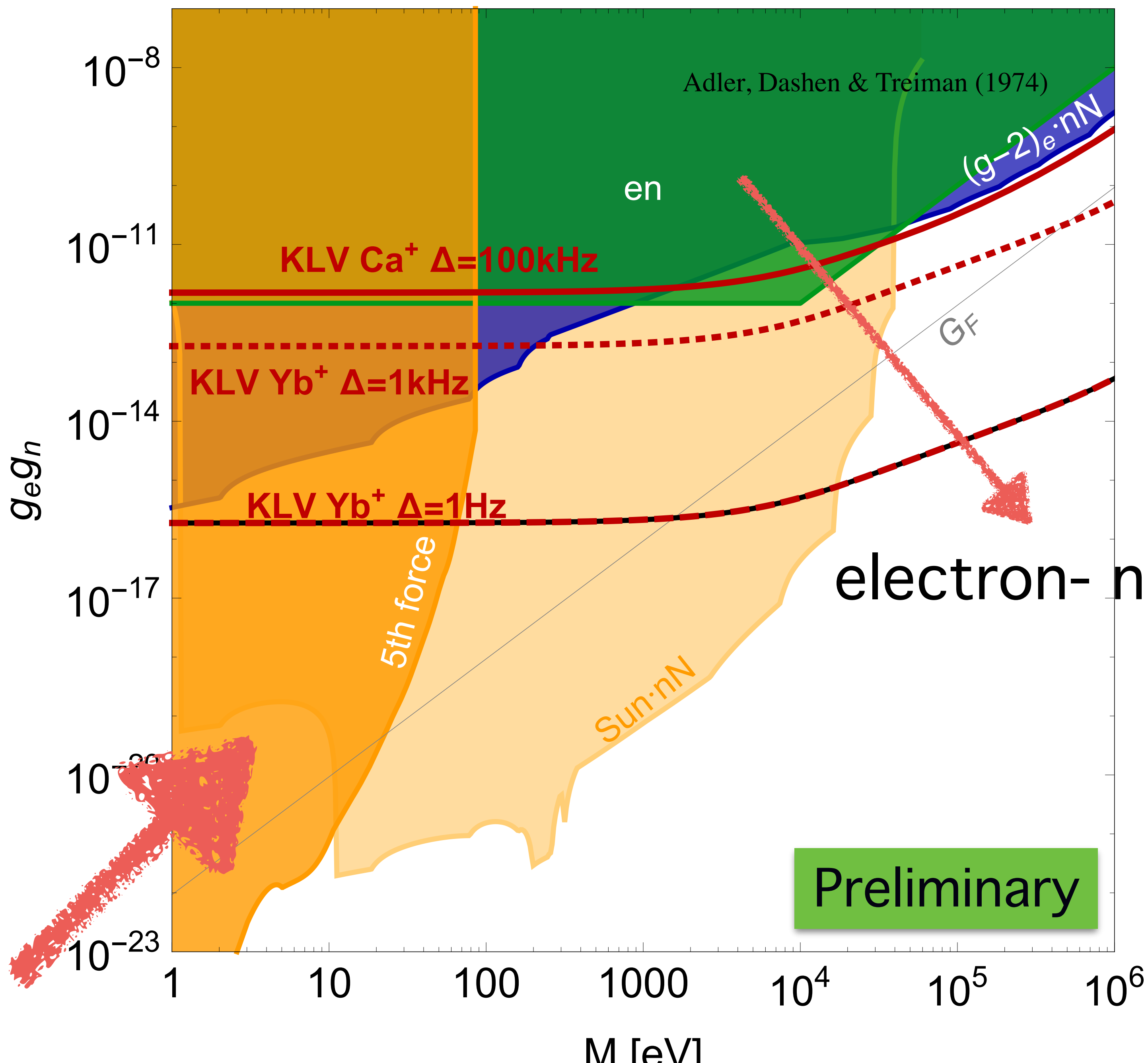
Probes of gN

Low energy neutron-nucleus scattering



ex: angular distribution measurements in low energy neutron- nucleus scattering.

Probes of gN ge

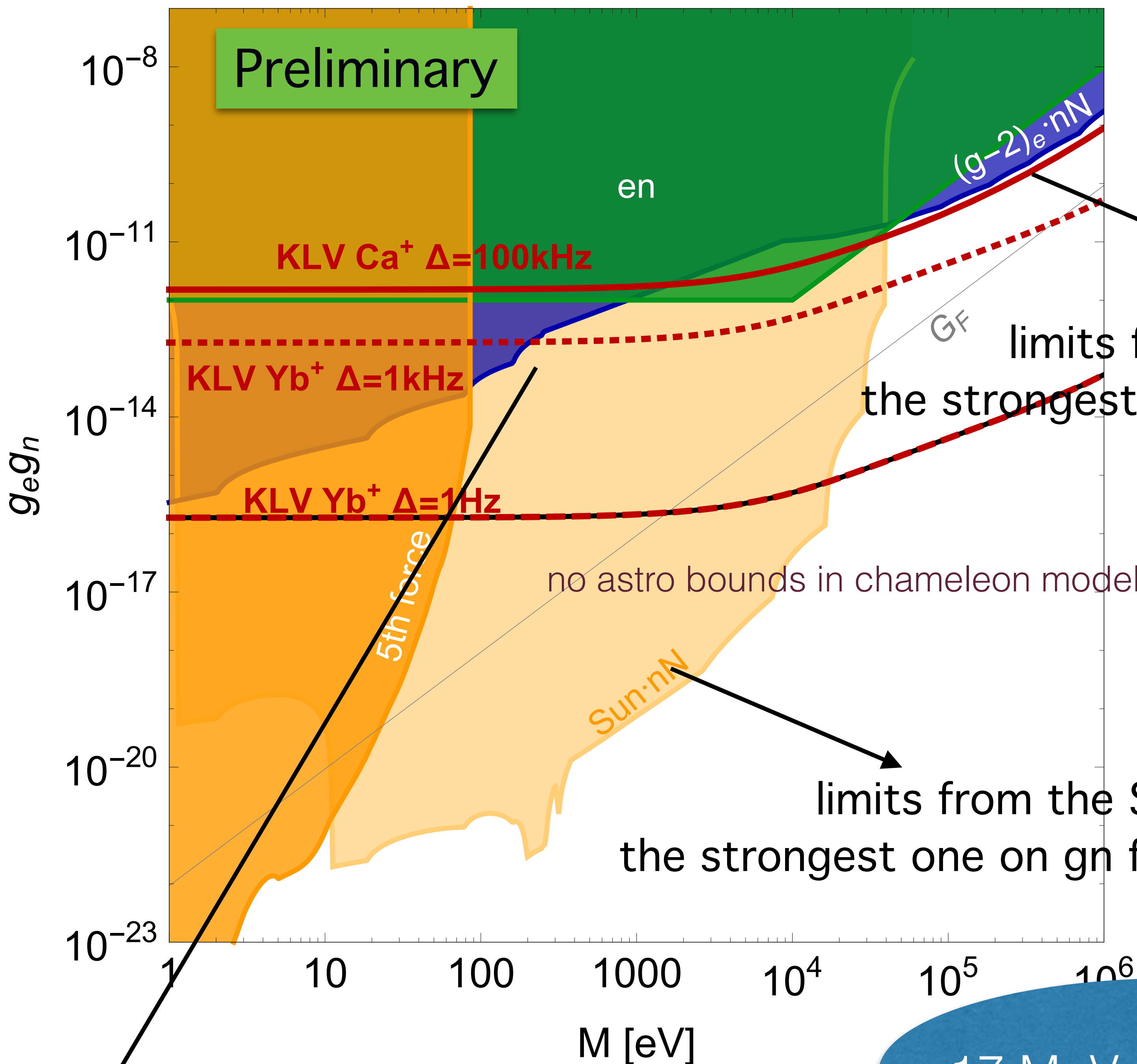


electron- neutron scattering

Fifth force experiments

too strong to compete- we focus on > 50 eV mass range

Probes of gN ge



limits from the (g-2) on ge and
the strongest gn one from neutron scattering

limits from the Sun on ge and
the strongest one on gn from neutron scattering

Stronger than Gfermi interaction

17 MeV Be anomaly

Heavier mediators: work in progress

Models?

- We can't set limits on dark photon kinetic mixing since it is aligned with QED

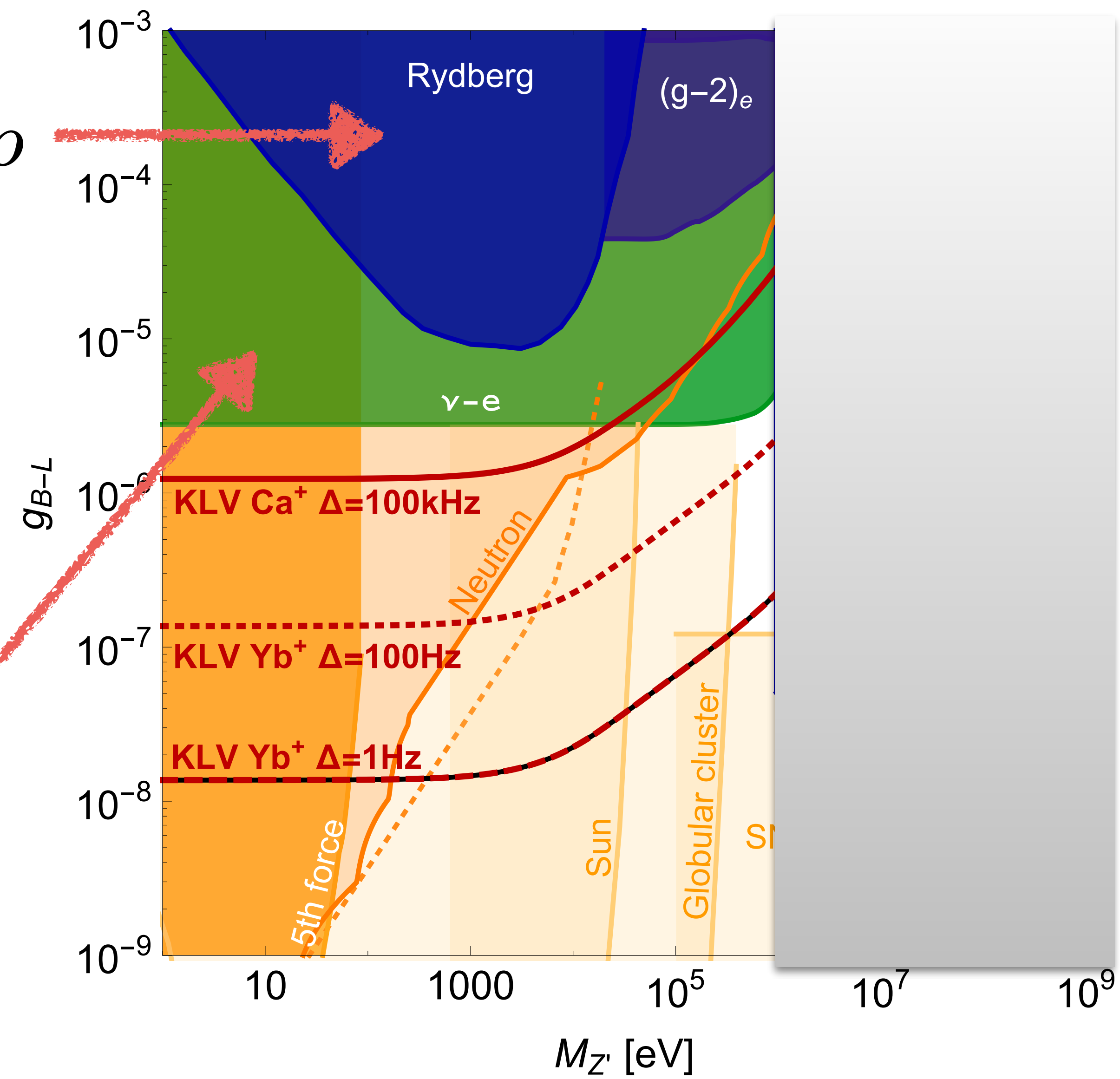
- Benchmark model B-L or the Higgs portal

limits weakened by the smallness of electron yukawa coupling

Constraints on B-L

Preliminary

Probe of $g_e \times g_p$



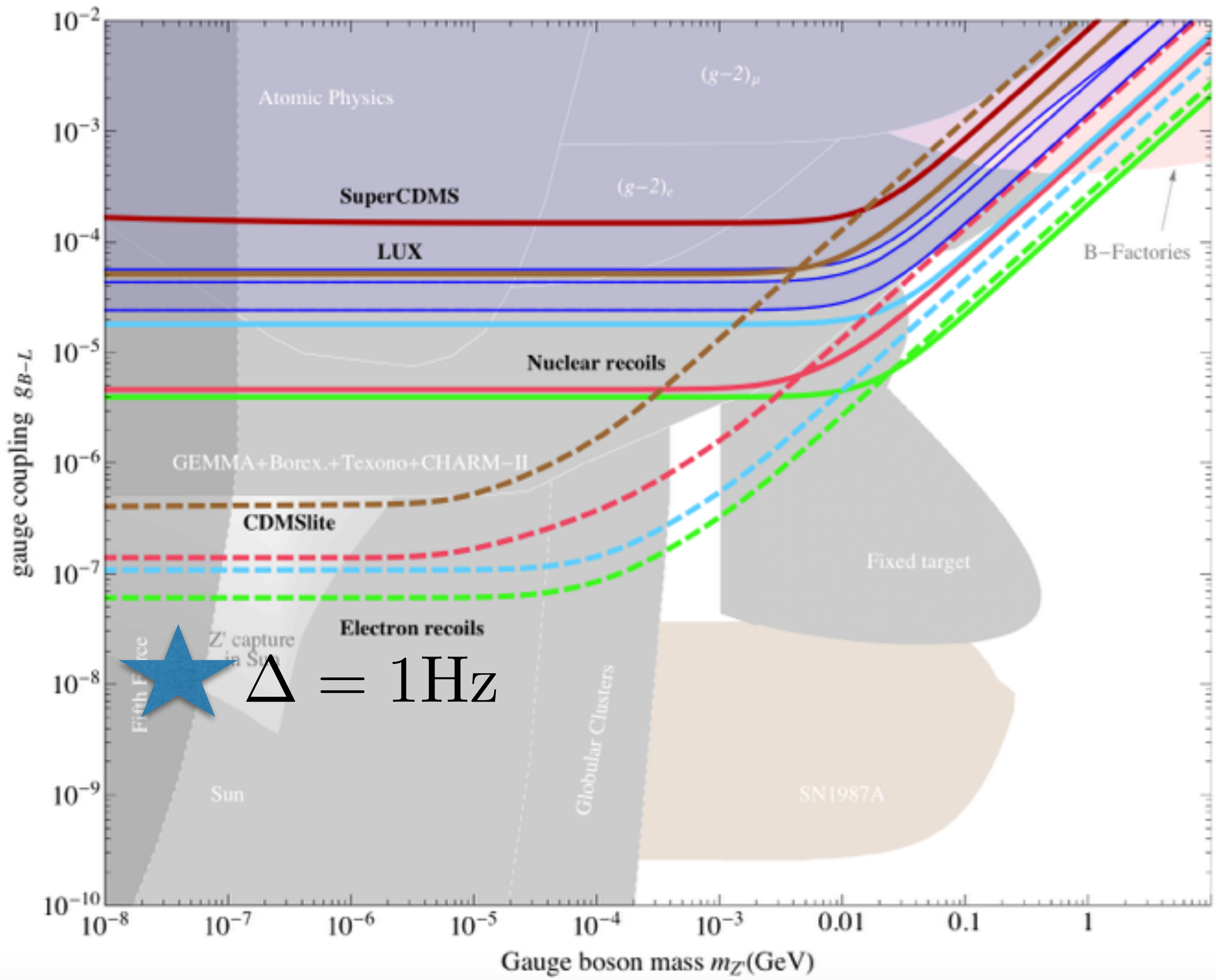
bounds on (solar or reactor) neutrinos- electron scattering

Bilmis et al. (2015)

Kopp et al (2013)

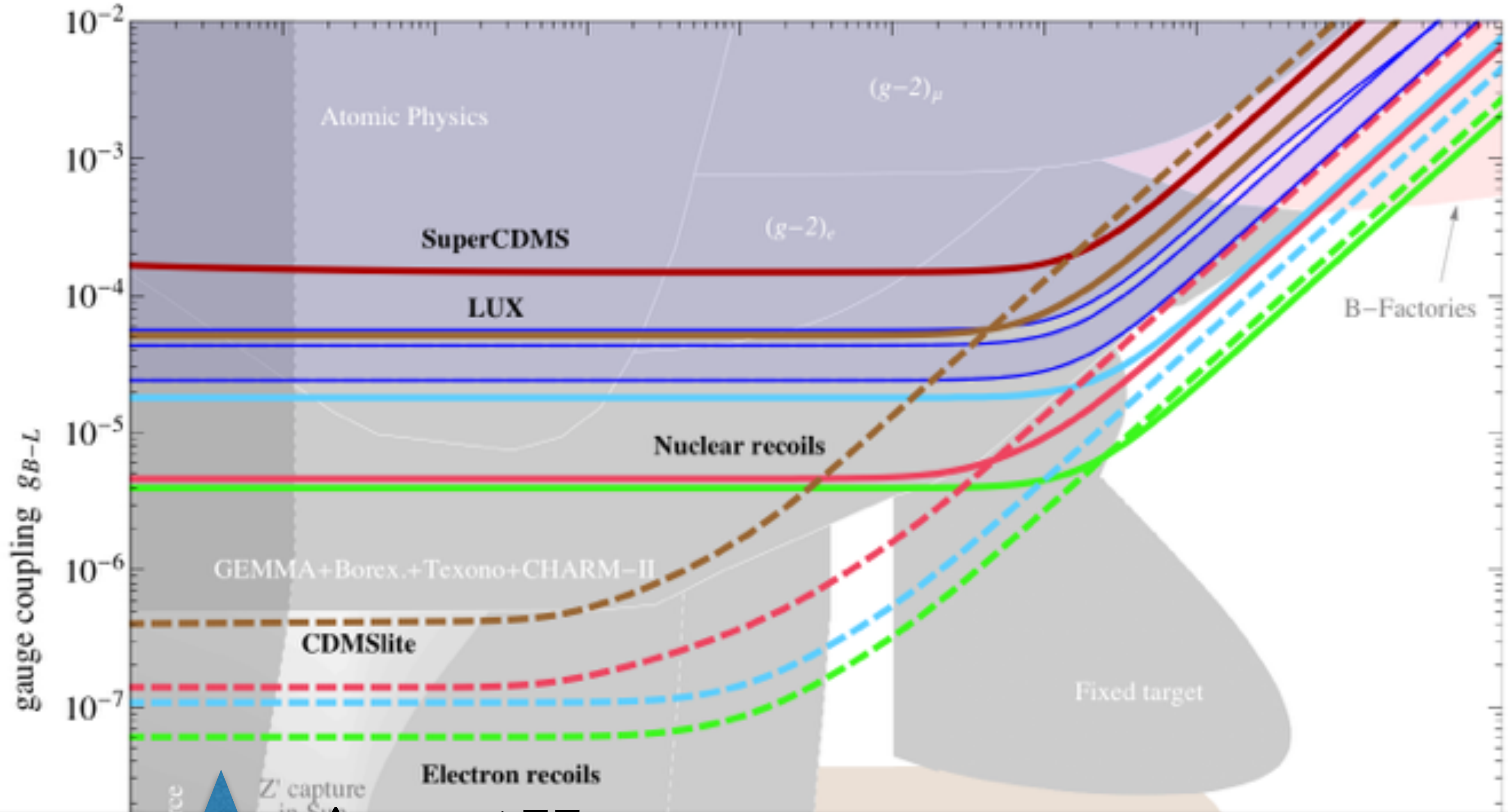
Pospelov (2013)

Neutrino signals at dark matter direct detection experiments?



Cerdeno et al. (2016)

Neutrino signals at dark matter direct detection experiments?



If a signal is detected at future DM experiments our measurements will rule out some neutrino related interpretations

Cerdeno et al. (2016)

Conclusions

- We can probe long range interactions with isotope shift measurements via kings linearity

- We can set the strongest lab limits in the 50 eV $< m <$ 1 MeV region and in some region also compete with astrophysics