New constraints on very light axion-like particles

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Quasar polarisation data

[*D. Hutsemékers et al.* (1998, 2001, 2005)]

Quasar polarisation vectors (in visible light)

1. are correlated in huge regions of the sky (~ 1 Gpc)
2. this effect depends on their distance.

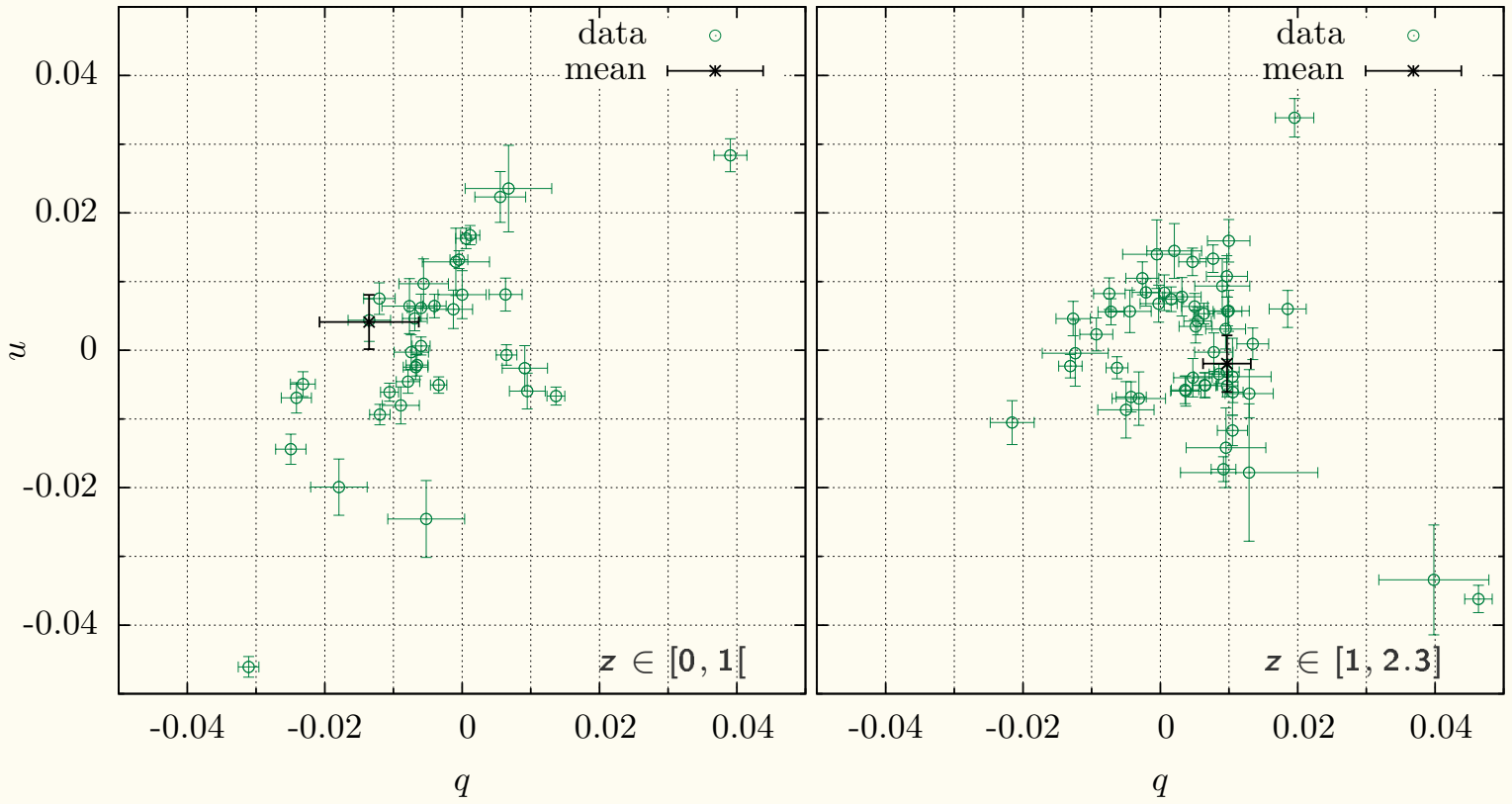
} linear pol.

Here: use these data to put constraints on ALPs

Note [*A. P., J.R. Cudell, and D. Hutsemékers* (next week on arXiv)]

Quasar data

In the space of linear polarisation parameters —a low- and a high-redshift region



(q, u) linear polarisation space

Distance from origin $\Rightarrow p_{lin} = \sqrt{q^2 + u^2}$

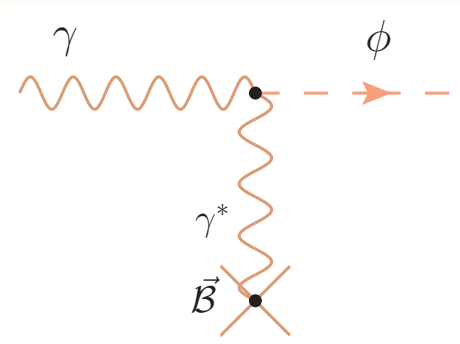
Typical linear polarisation $\sim 1\%$

How do axion-like particles change polarisation?

Axion-like particles couple to one of the two directions of polarisation in an external $\vec{\mathcal{B}}$

Pseudoscalar ϕ: $\mathcal{L}_{\phi\gamma\gamma} = \frac{1}{4}\, g\phi F_{\mu\nu}\widetilde{F}^{\mu\nu} = -g\phi(\vec{E}\cdot\vec{B}) = -g\phi(\vec{\mathcal{E}}_r\cdot\vec{\mathcal{B}}) = -g\phi(\vec{\mathcal{E}}_{r,\parallel}\cdot\vec{\mathcal{B}})$

- Dichroism: selective absorption of one component of the light.



- Birefringence: different velocities. Phase-shift between $\vec{\mathcal{E}}_{r,\parallel}$ and $\vec{\mathcal{E}}_{r,\perp}$

[*P. Sikivie* (1983)], [*G. Raffelt, L. Stodolsky* (1988)], ...

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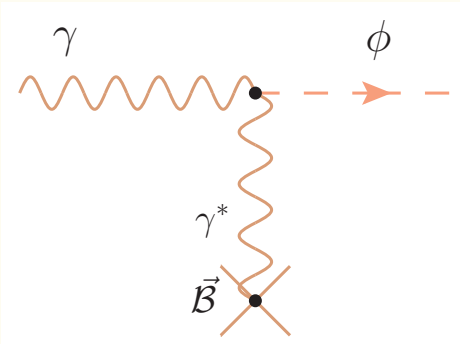

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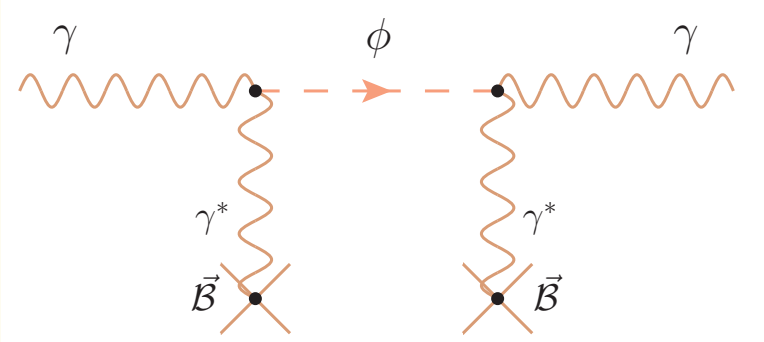

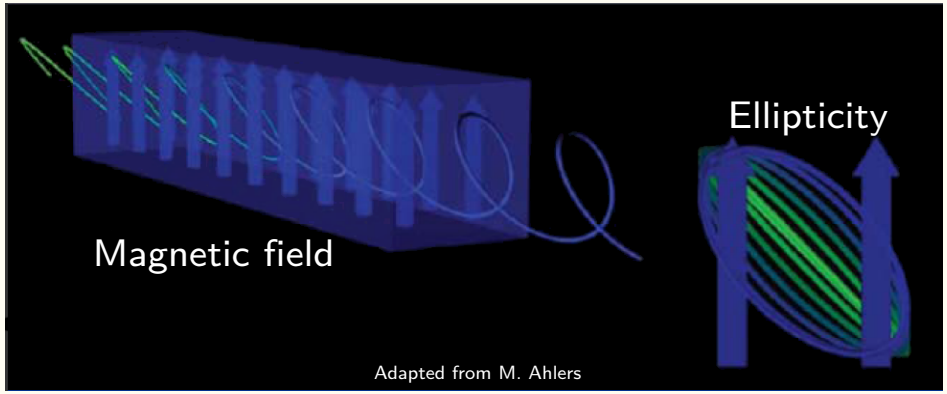

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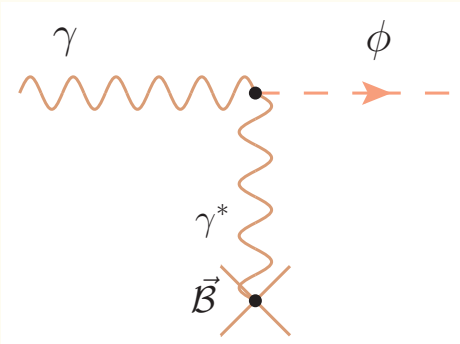
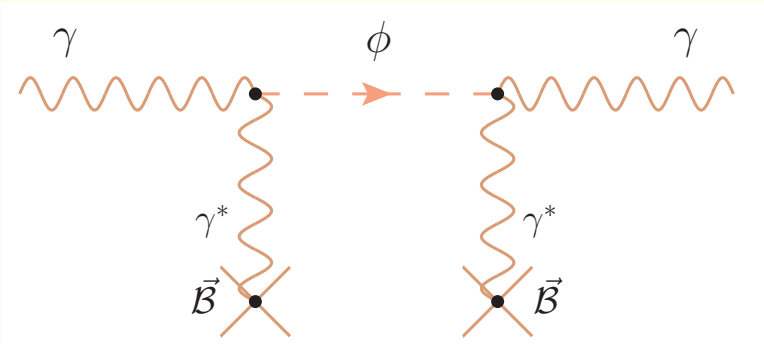
- Dichroism:
  ⇒ Changes linear polarisation



modifies linear polarisation
unpolarised beams will be linearly polarised

- Birefringence:
  ⇒ Changes circular polarisation



$p_{lin} \neq 0 \Leftrightarrow$ circ. pol $\neq 0$ (in general)

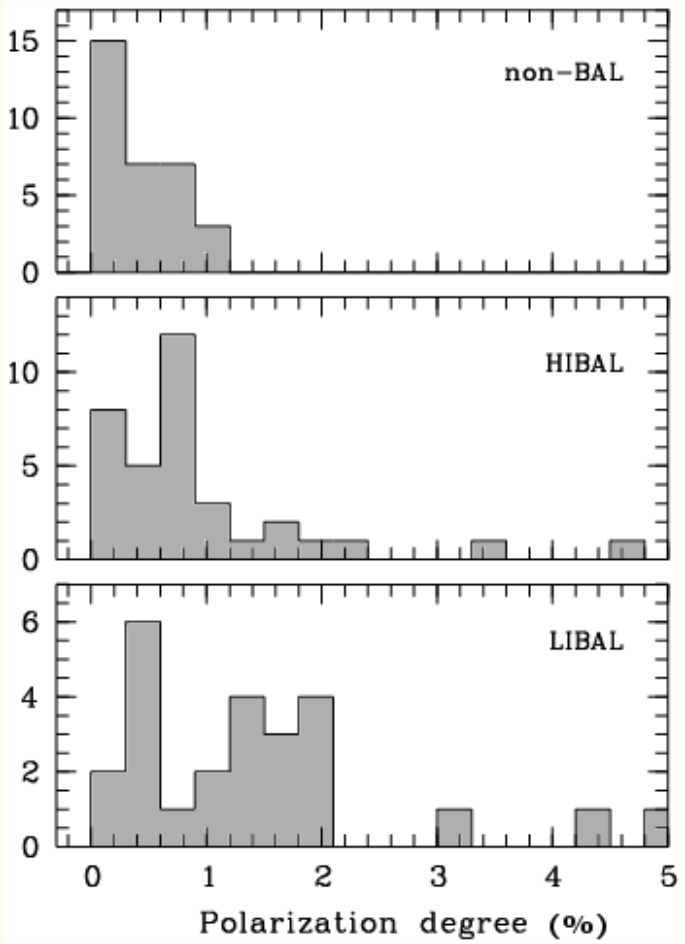
[*P. Sikivie* (1983)], [*G. Raffelt, L. Stodolsky* (1988)], ...

Quasar data: expected polarisation preserved

2 quasar populations: BAL and non-BAL

Reproduce alignments with systematic $p_{lin} \geq 0.5\%$

Sample: both BAL & non-BAL
Expected polarisation preserved



ALPs can produce much more $\Rightarrow$ constraints.

No circular polarisation reported for quasars in the sample

Pseudoscalar-photon mixing disfavoured

[*D. Hutsemékers et al.* (2010)] "All but 2 objects* have null circular polarisation"

*highly linearly polarised *blazars*, $p_{lin} > 20\%$

No circ. pol? $\Rightarrow$ additional constraint on ALPs from polarimetry.

New limits on very light pseudoscalars

Using constraints from what is known about quasar polarisation

- Quasars are intrinsically polarised
  But distribution = ?
- Δp_{lin} (BAL - non-BAL) $< 2\%$;
- Observed circ. pol compatible with 0.

1. Start with unpolarised light to avoid overestimation (esp. circ.);
2. We allow systematic p_{lin} up to 2%;
3. 3σ: final circ. pol $\in [-0.16, 0.13]\%$
   ($\hookrightarrow$ applied only if $p_{lin} \gtrsim 0.6\%$).

Conservative approach

ALPs leading to more polarisation than this for quasars contradict observations.

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New limits on very light pseudoscalars
Observational input

Quasars located in the direction of Virgo.
Last relevant magnetic field (size & field strength): our local supercluster (LSC)

- morphology and field strength:

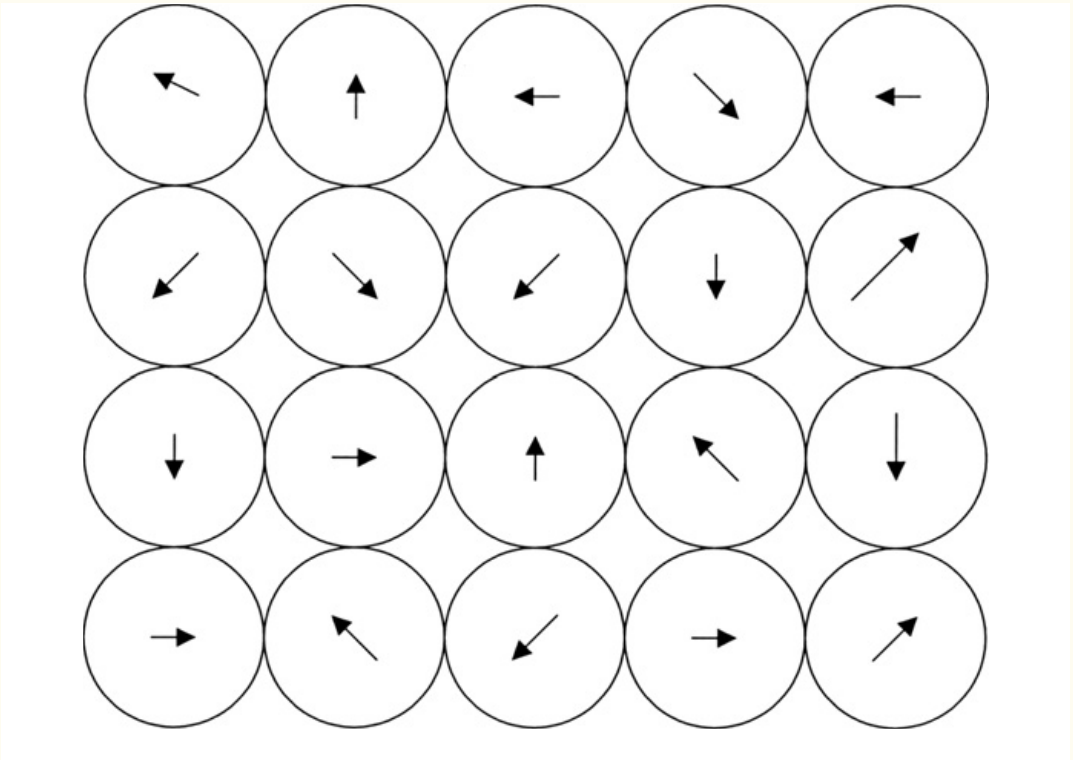


Fig. 53. A cellular magnetic field model, for cells in a supercluster of galaxies, or inside a cluster of galaxies.

[*Vallée 2011*]

New limits on very light pseudoscalars

Observational input

Quasars located in the direction of Virgo.
Last relevant magnetic field (size & field strength): our local supercluster (LSC)

- morphology and field strength:

  - patchy field: $\approx$100-kpc cells with random 2 μG, over $\approx$ 10 Mpc

Reviews: see, *e.g.* [*Giovannini* (2004)], [*Vallée* (2011)]

Check that our constraints on m and g are stable w.r.t. changes in parameters.

New limits on very light pseudoscalars
Observational input

Quasars located in the direction of Virgo.
Last relevant magnetic field (size & field strength): our local supercluster (LSC)

- morphology and field strength:
  - patchy field: ≈100-kpc cells with random 2 μG, over ≈ 10 Mpc

Reviews: see, *e.g.* [*Giovannini* (2004)], [*Vallée* (2011)]

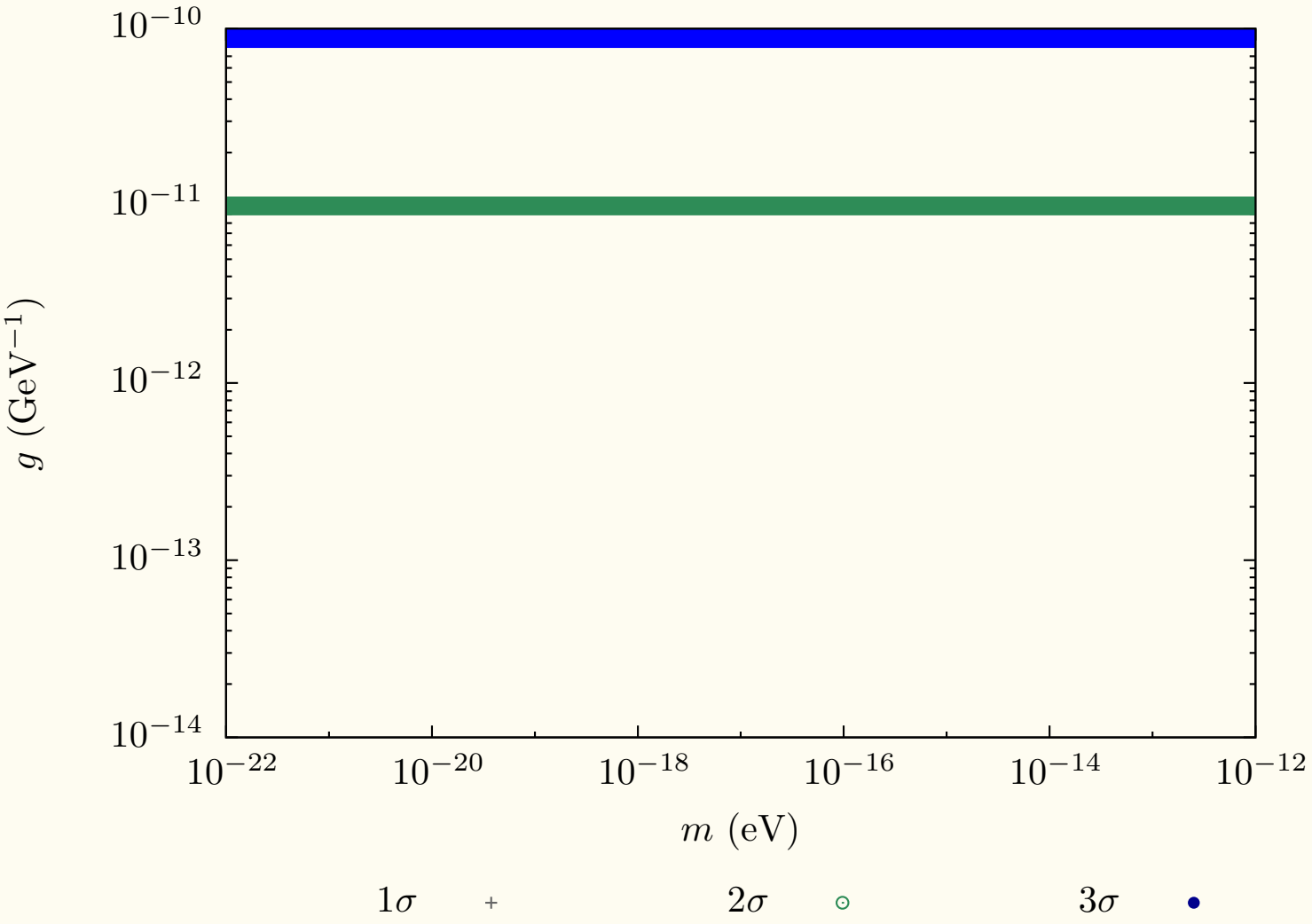
- plasma frequency:

$$\omega_p \simeq 3.7\ 10^{-14}\ \mathrm{eV}; \quad \omega_p \propto \sqrt{n_e}$$

Check that our constraints on m and g are stable w.r.t. changes in parameters.

Limits
Exclusion plot

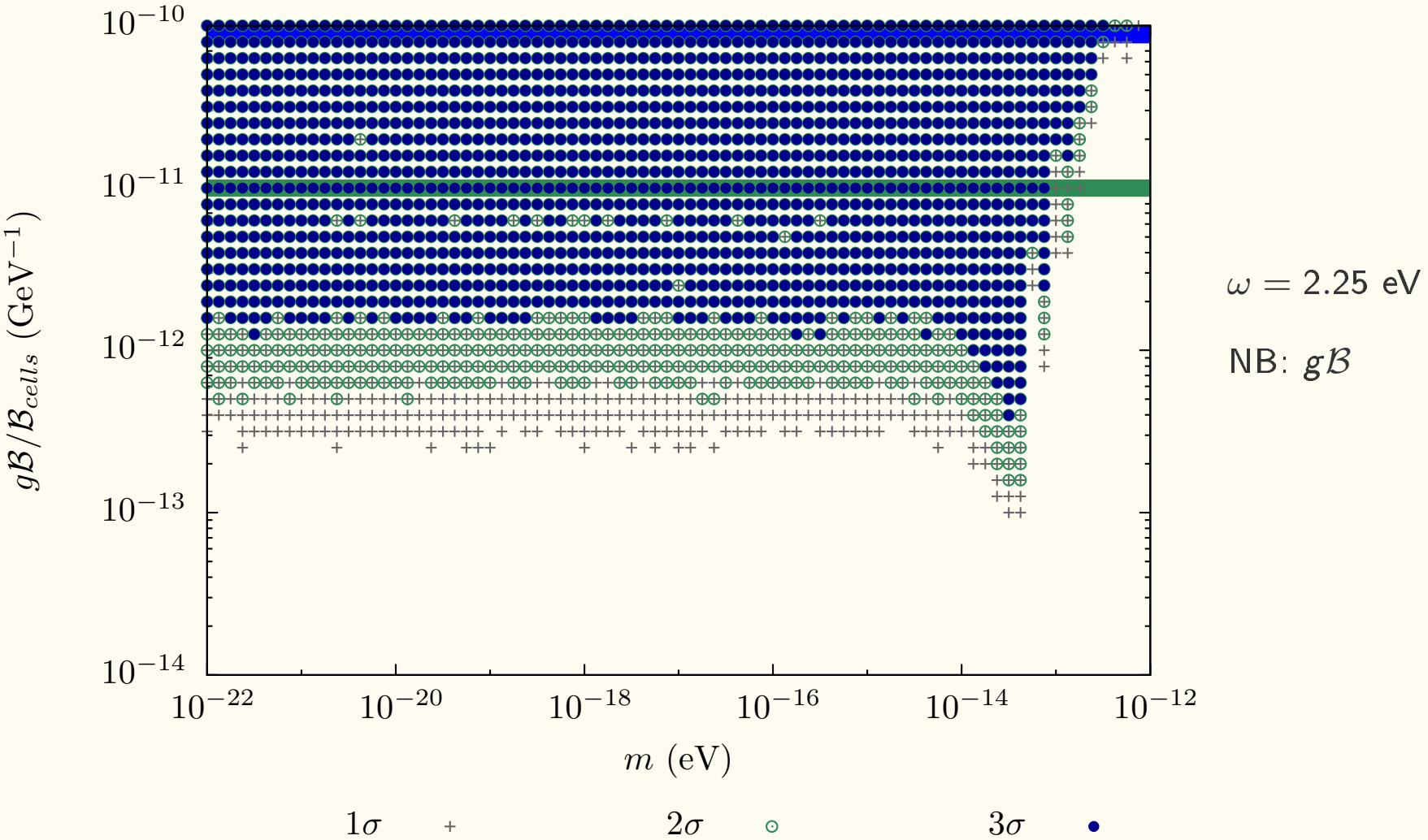
95% CL limits on nearly massless ALPs from CAST and SN1987A.



Preliminary

Exclusion plots —check the stability

100 cells of 100-kpc (10 Mpc); $\omega = 2.25$ eV (average ω of V-filter).



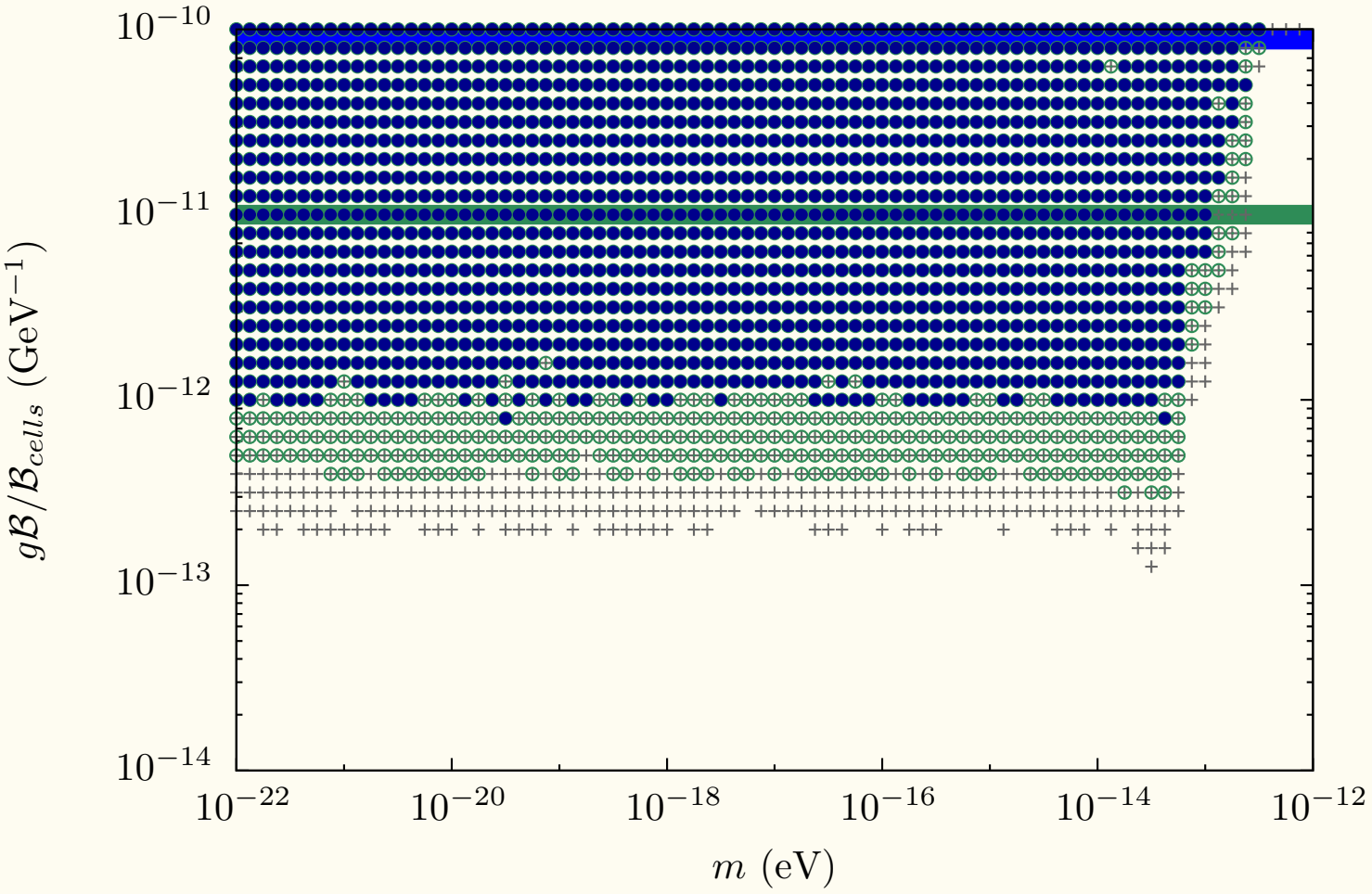
$\omega = 2.25$ eV

NB: $g\mathcal{B}$

Preliminary

Exclusion plots —check the stability

100 cells of 50-kpc (5 Mpc).



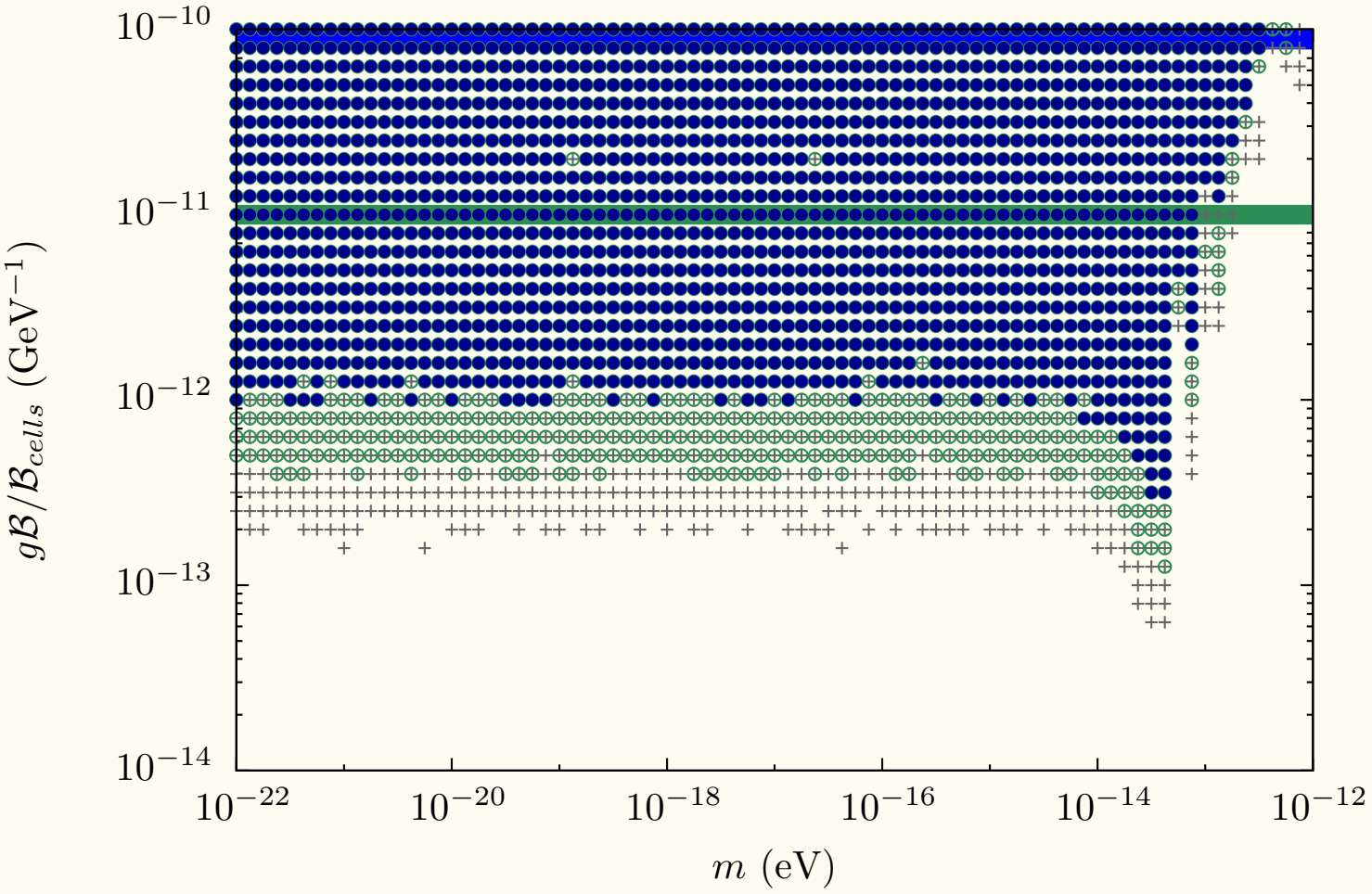
$\omega = 2.25$ eV

NB: $g\mathcal{B}$

Preliminary

Exclusion plots —check the stability

200 cells of 100-kpc (20 Mpc).



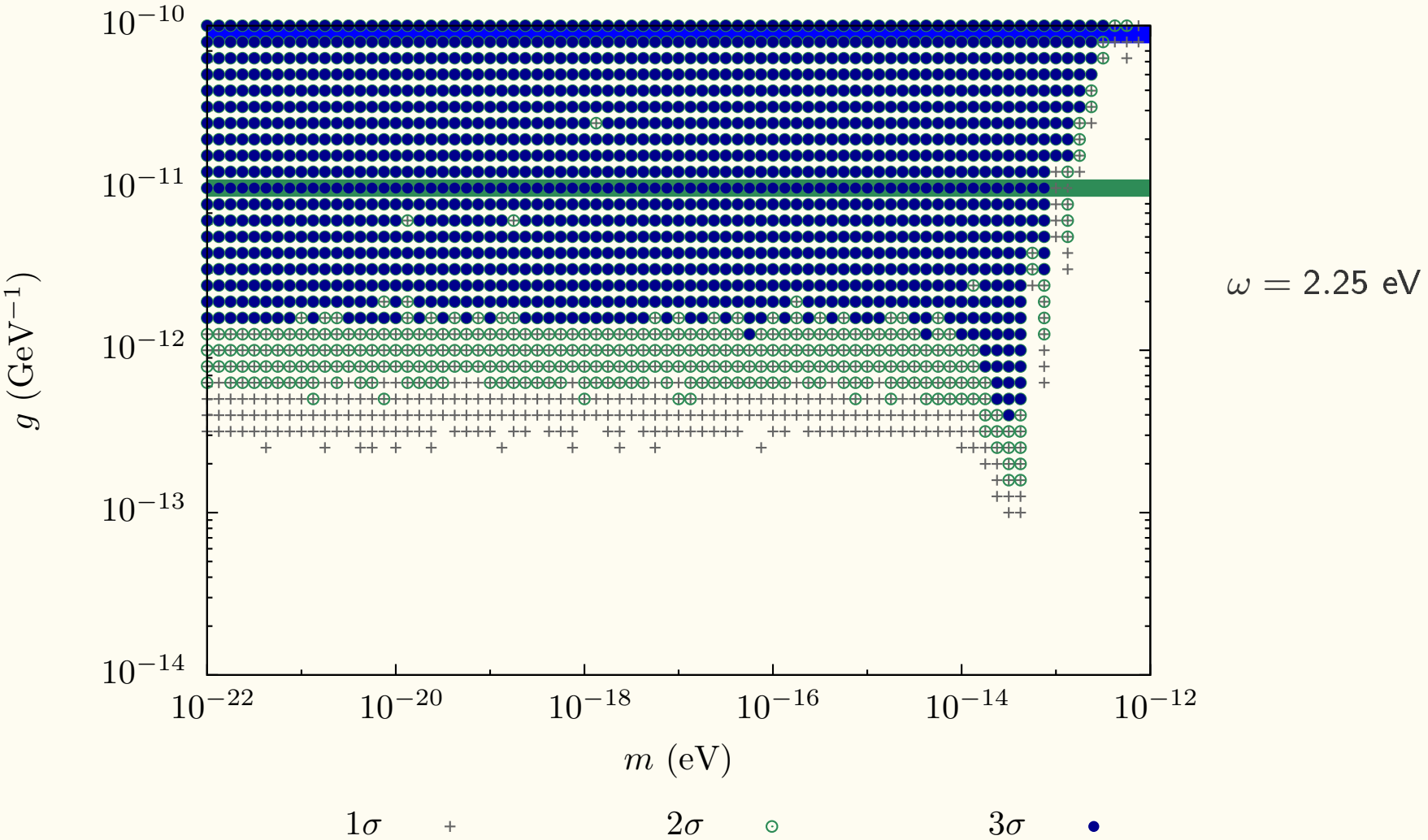
$\omega = 2.25$ eV

NB: $g\mathcal{B}$

Preliminary

Exclusion plots —check the stability

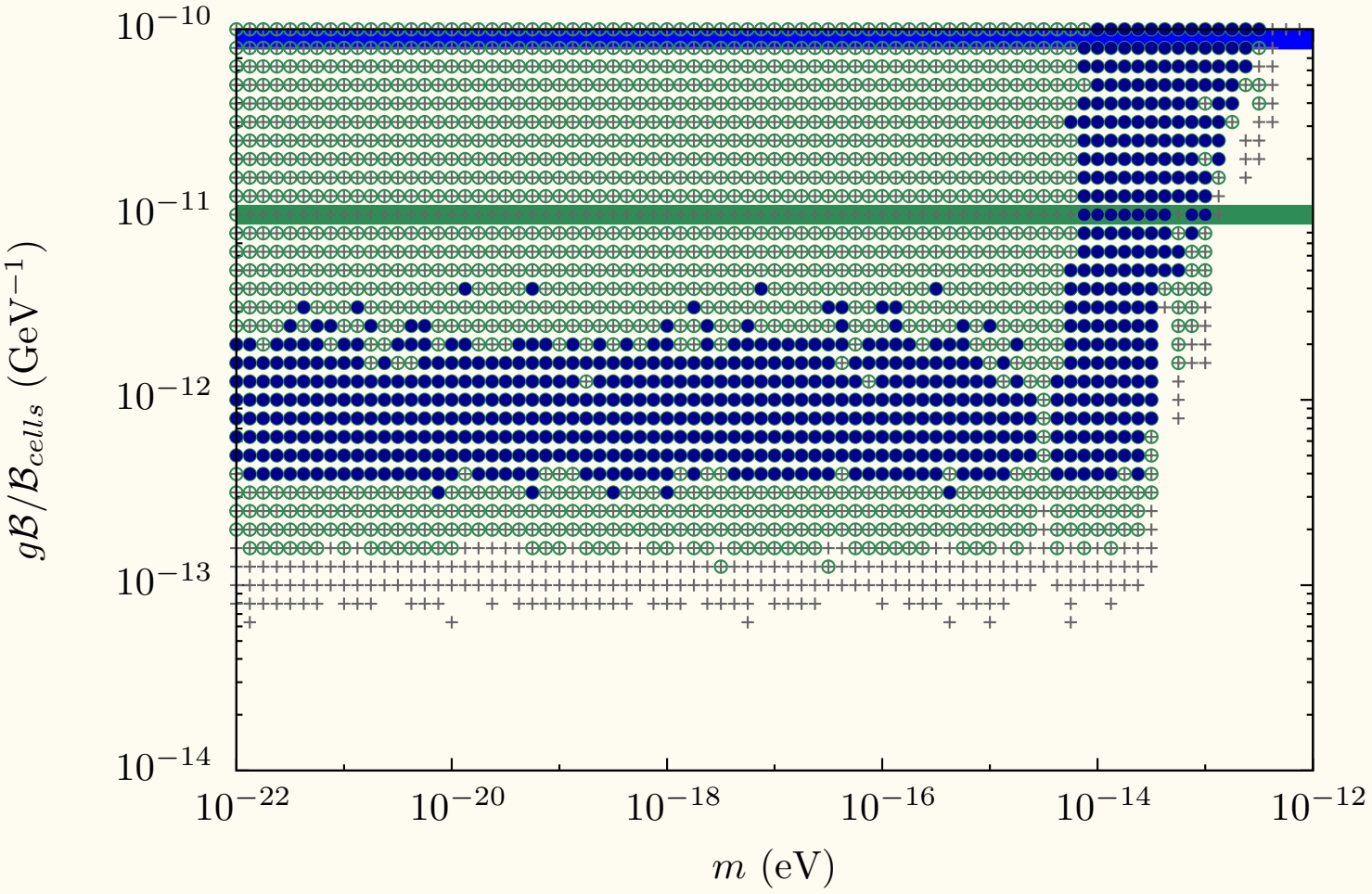
100 cells of 100-kpc (10 Mpc); patchy + uniform field (0.3 μG over $\approx$ 10 Mpc).



Preliminary

Exclusion plots —check the stability

Extreme case: 100 cells of 100-kpc (10 Mpc); $n_{e,voids}$ ($\simeq 10^{-3}$ $n_{e,LSC}$).



$\omega = 2.25$ eV

NB: $g\mathcal{B}$

Summary

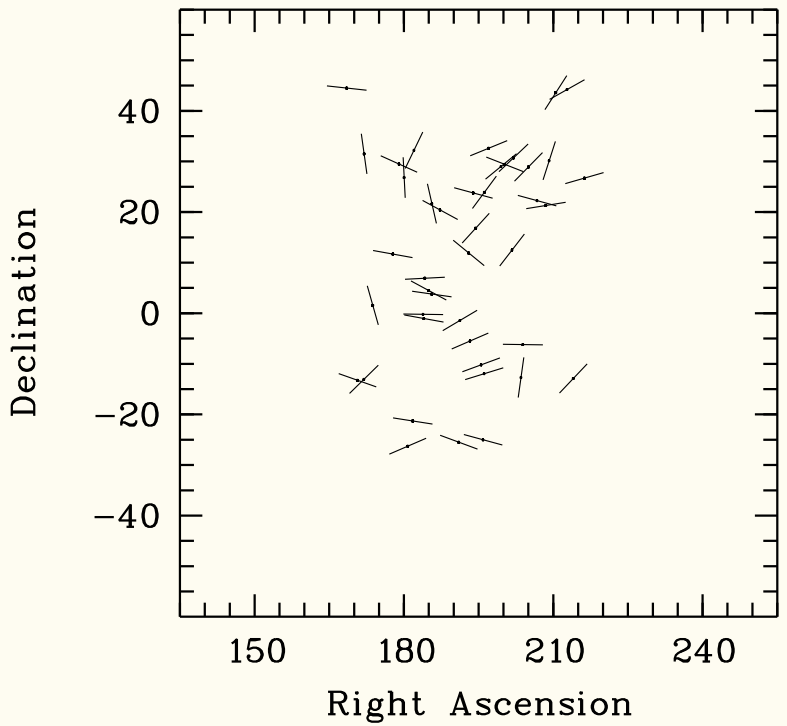
- Polarisation can be used to constrain the parameter space of (very-light) ALPs (mass, coupling)
- This can be done as axions create polarisation in magnetic fields

  $\Rightarrow$ can produce too much (& contradict observations)
- Constraints are stable w.r.t. changes in astrophysical parameters (magnetic field size & strength, plasma frequency).
- More polarisation data always welcome (note: X-ray surely looks interesting, c.f. Axel's talk).

Coherent orientation of quasar polarisation vectors

Quite a puzzling observation —a low-z region

[*D. Hutsemékers et al* (1998, 2001, 2005)]



- 43 objects with $z \in [0, 1[$
- $P_{random} = 3\ 10^{-3}$ ($\bar{\theta} = 79°$)

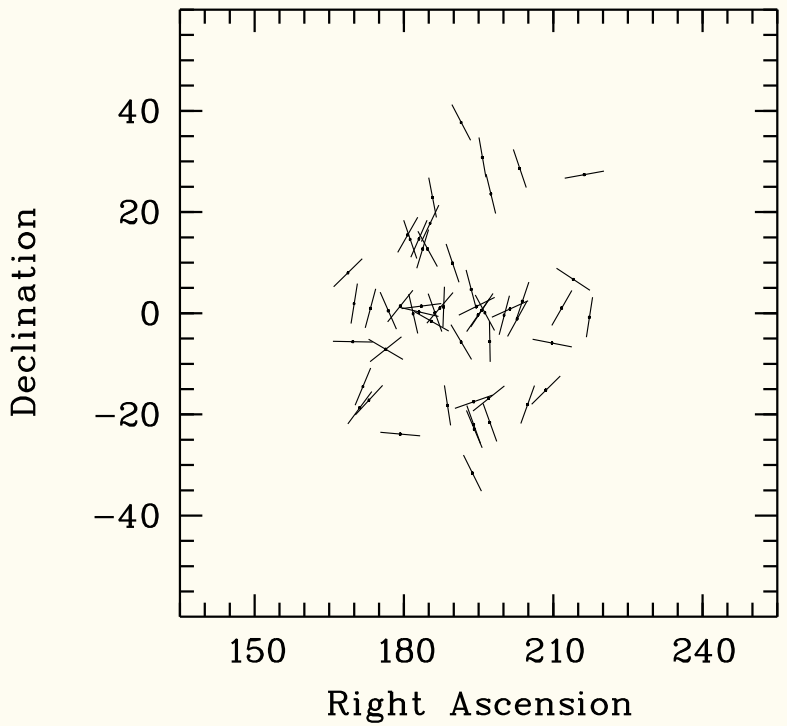
Latest all-sky sample
355 quasars

(1/2 from literature)

Coherent orientation of quasar polarisation vectors

Quite a puzzling observation —a high-z region

[*D. Hutsemékers et al* (1998, 2001, 2005)]



- 56 objects with $z \in [1, 2.3]$
- $P_{random} = 2\ 10^{-3}$ $(\bar{\theta} = 8^{\circ})$

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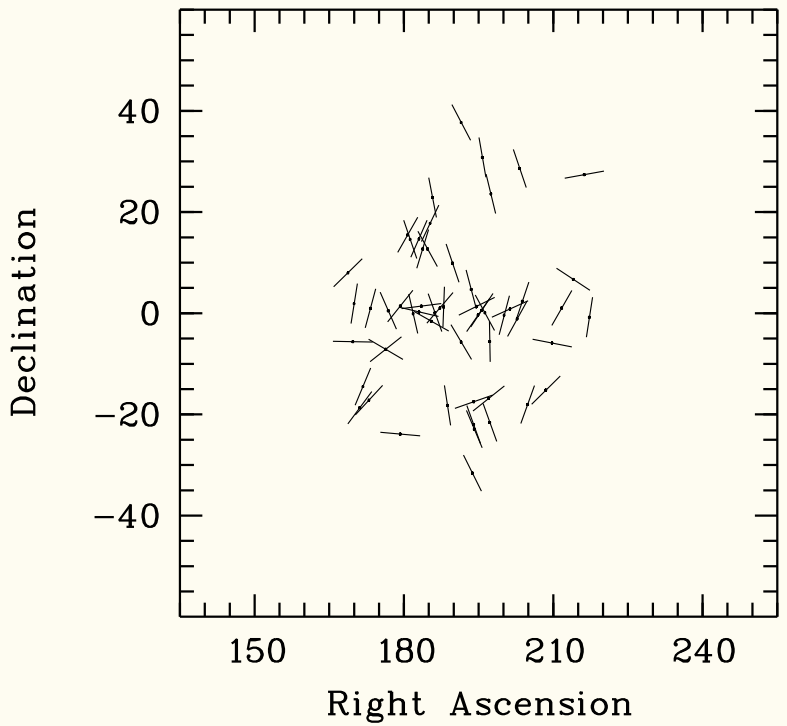

- all types of quasars (High-L)
- expected polarisation preserved
- high galactic latitudes ($\geq 30^\circ$)
- criterion: good quality
  ($p_{\rm lin} \geq 0.6\%$, $\Delta\theta \leq 14^\circ$)
- NB: quasars have $p_{\rm lin} \sim 1\%$

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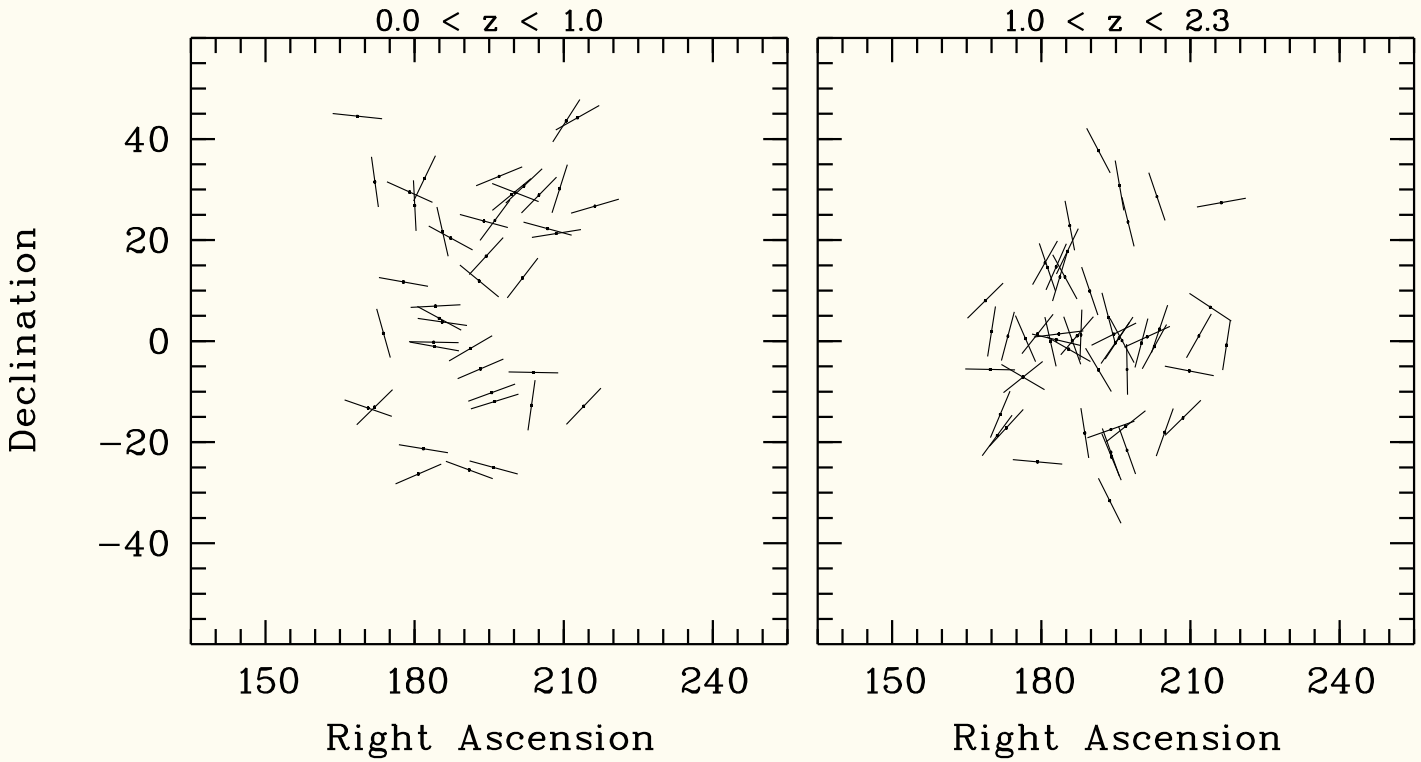
Quite a puzzling observation —non-local effect



- Different alignments for regions along the same line of sight
  $\Rightarrow$ Non-local effect

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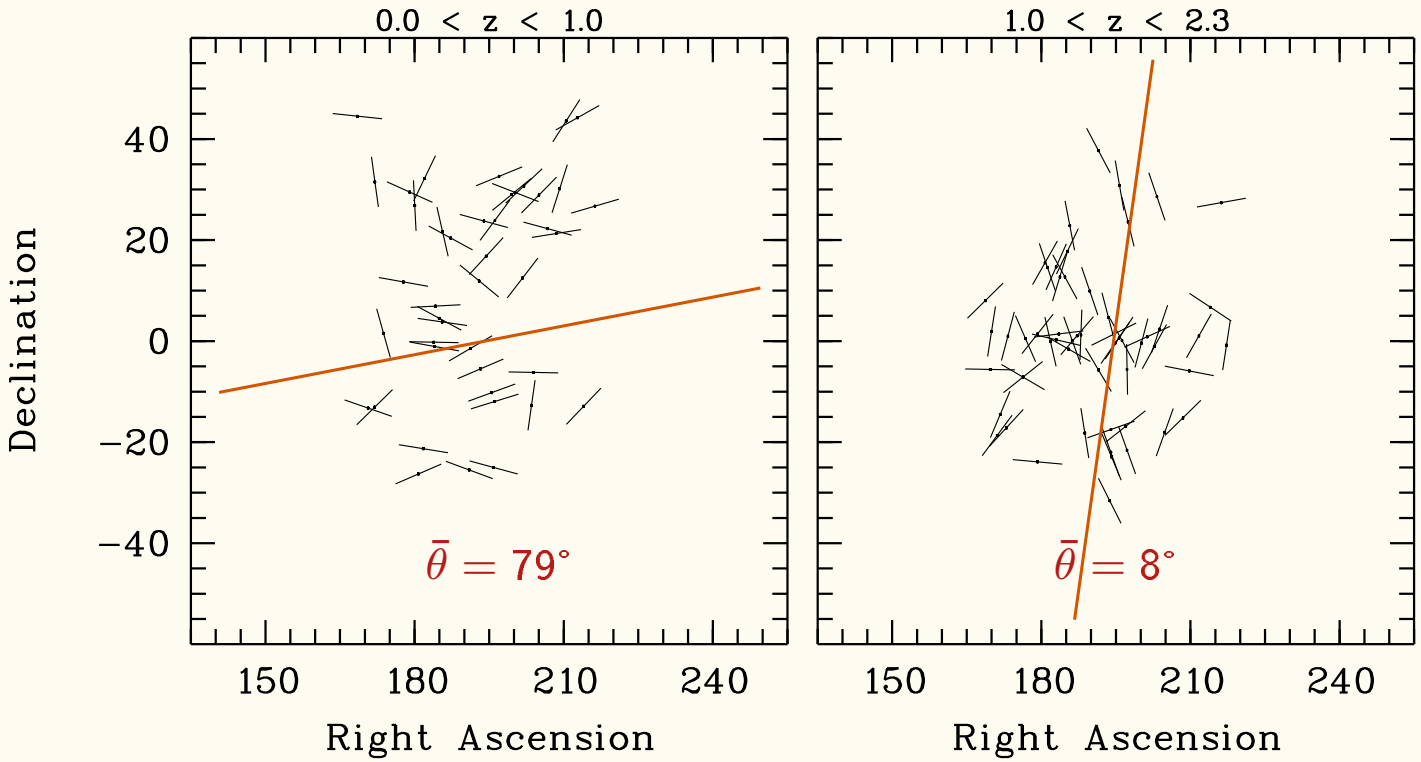

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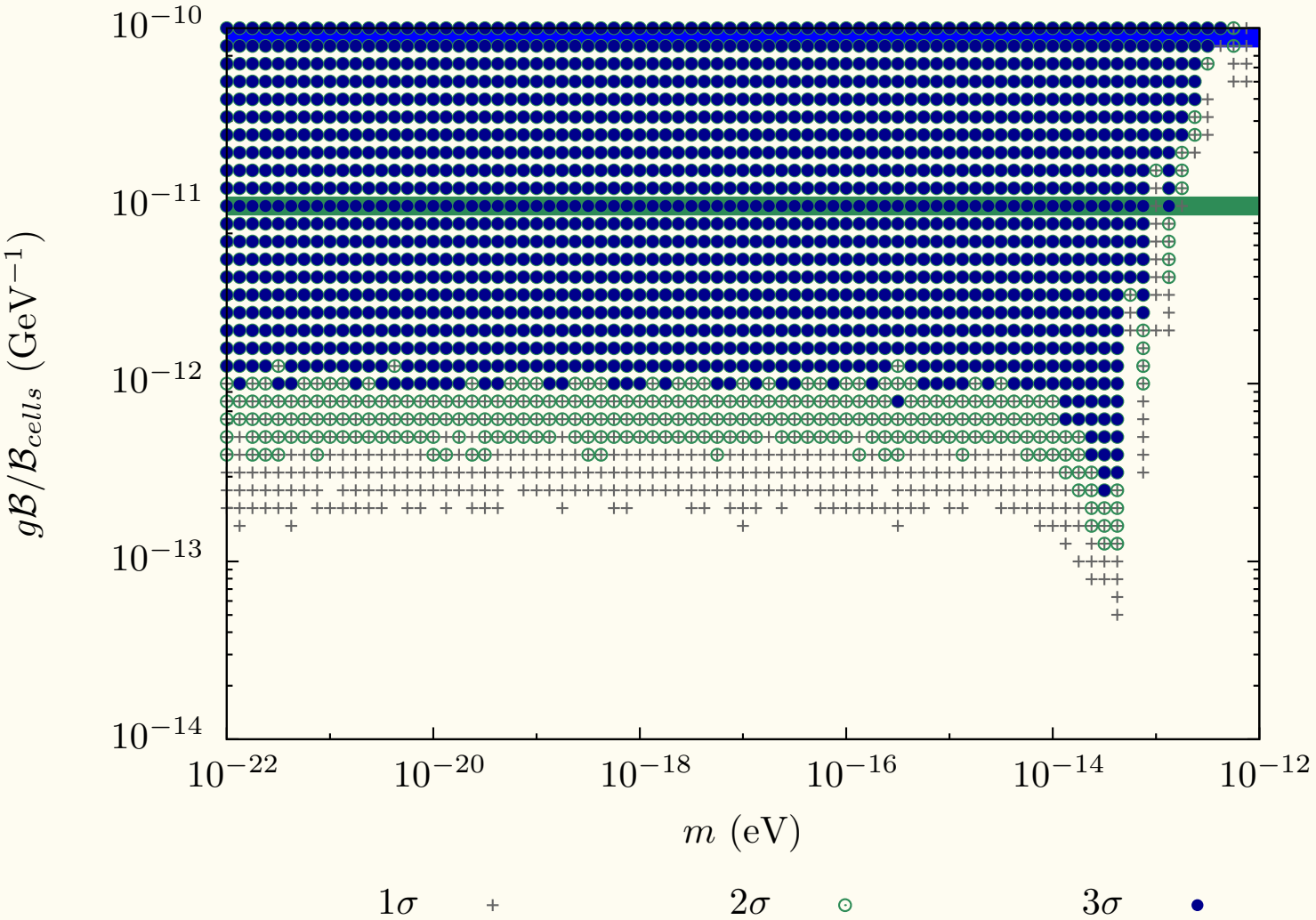
A hundred 100-kpc regions (10 Mpc); $\omega = 2.25$ eV.



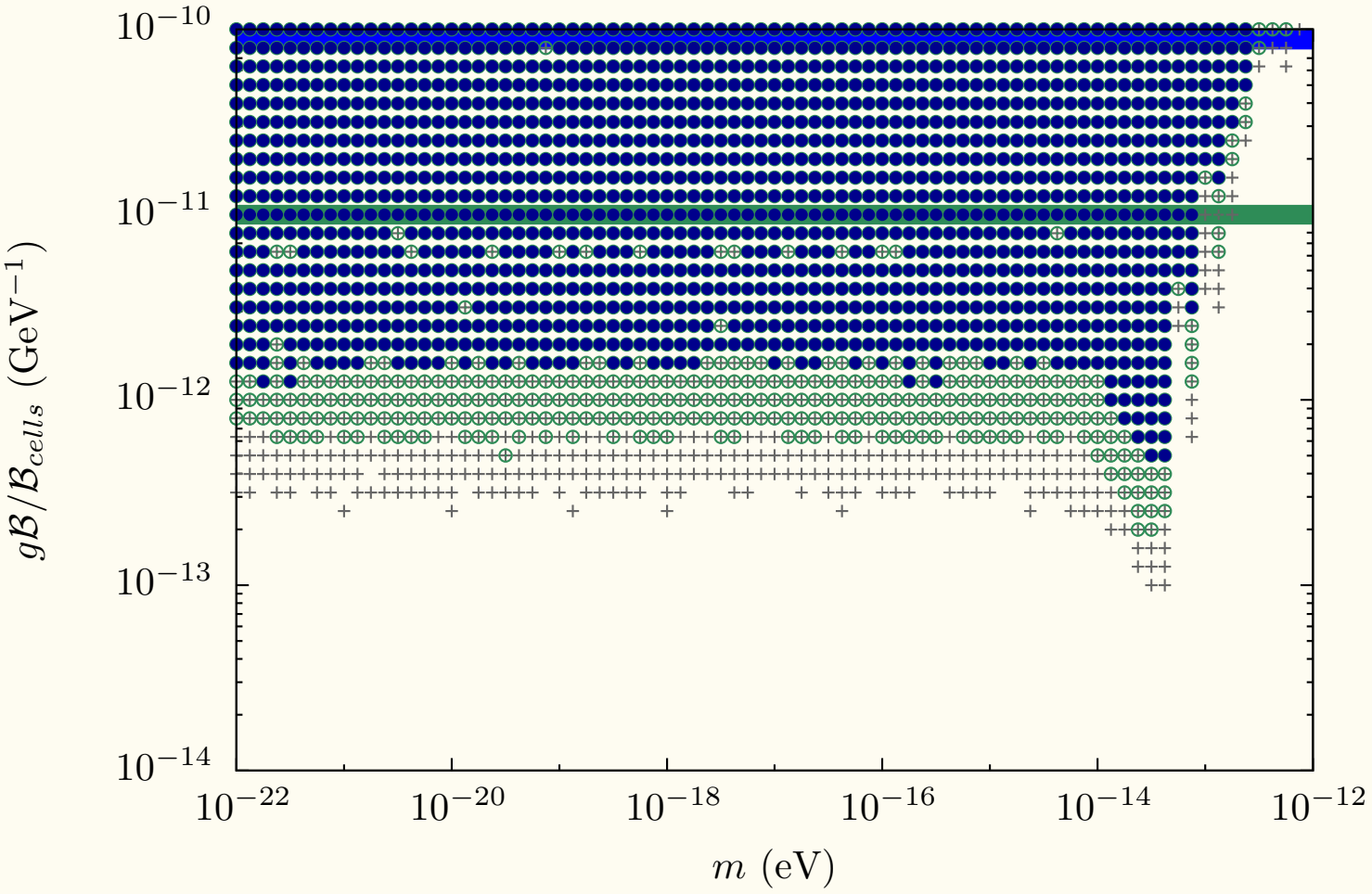
$\omega = 2.25$ eV

Magnetic field: patchy (nb: $g\mathcal{B}$)

circ. pol constraint $\forall p_{lin}$.

Preliminary
Exclusion plots —check the stability

A hundred 100-kpc regions (10 Mpc); $\omega = 2.25$ eV; + blazars for circ. pol.



$\omega = 2.25$ eV

Magnetic field: patchy (nb: $g\mathcal{B}$)

circ. pol $\in [-0.24, 0.25]\%$.