Light Dark Matter

Kenji Kadota
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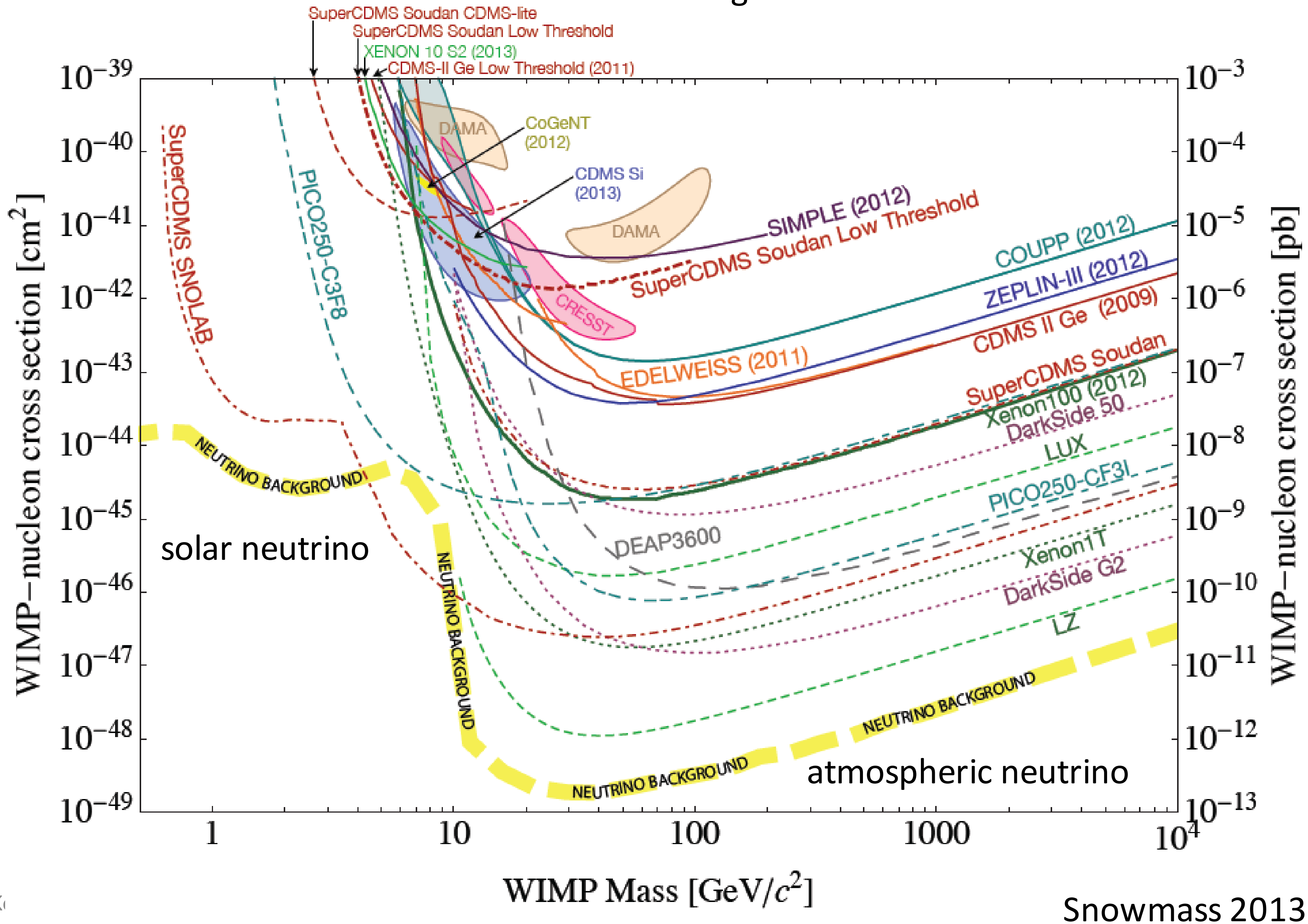
- Two concrete examples
  - ✓ Sterile neutrino DM
    - Production mechanism
  - ✓ Axion(-like) Particle
    - Radio (SKA-like) survey
- Conclusion

A wide mass range

Direct detection experiments

Light: < GeV



Snowmass 2013

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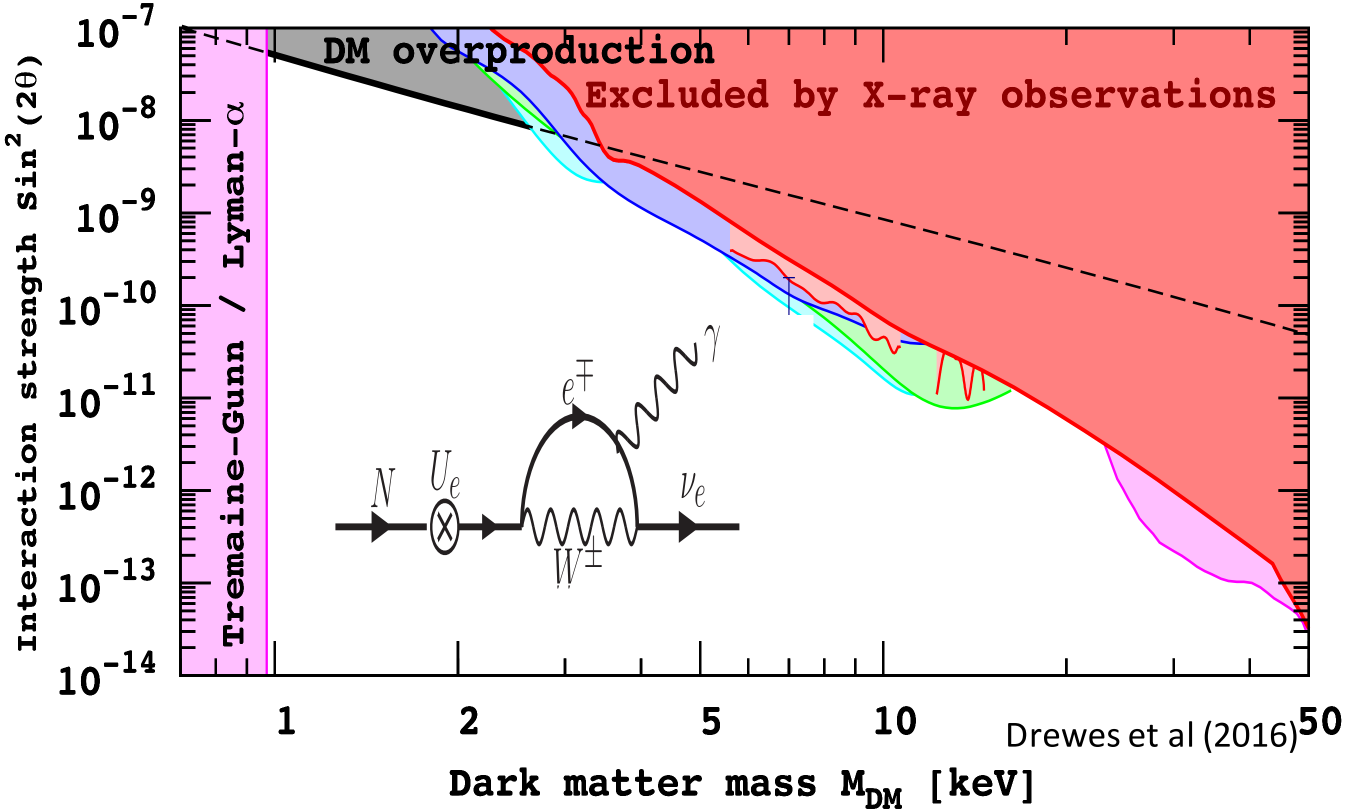
A concrete example for the warm dark matter: Sterile Neutrinos

Dodelson-Widrow mechanism: Thermal active neutrinos conversion to sterile neutrinos

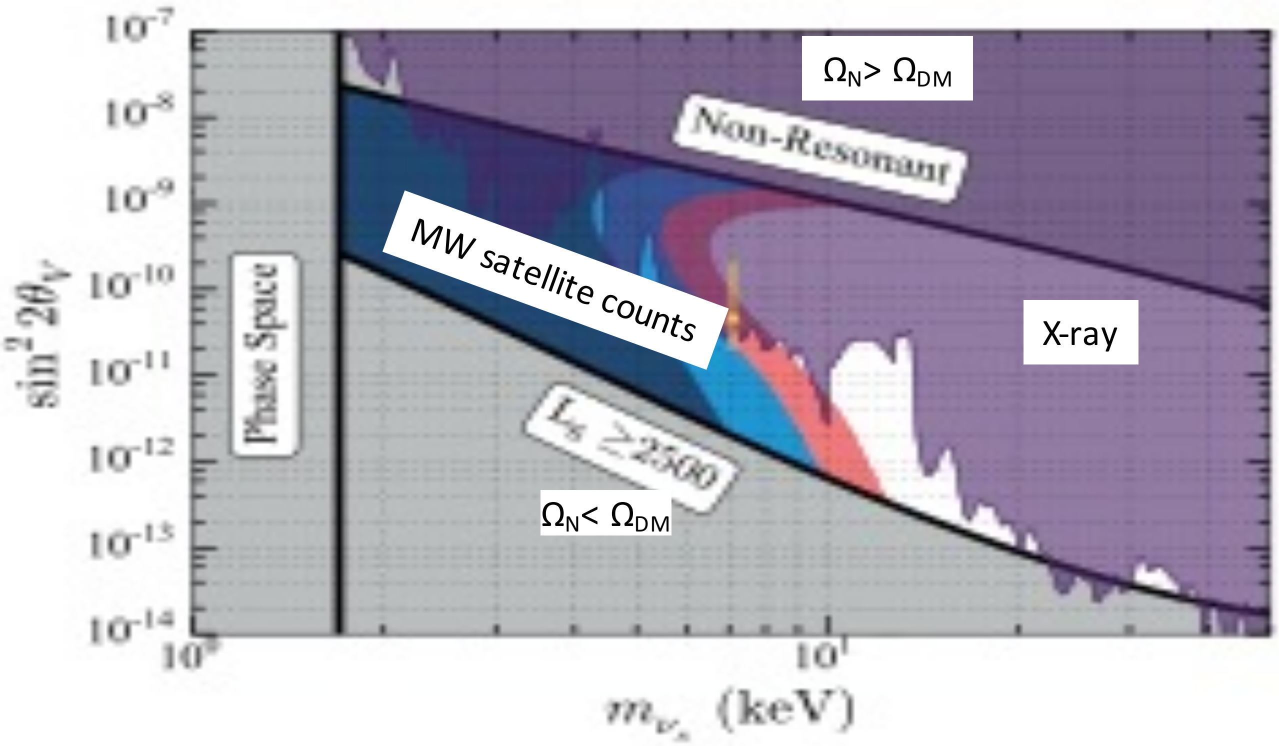
$$L = -yNLH - \frac{1}{2}MNN$$

$$\theta = \frac{y\langle H \rangle}{M}$$



Drewes et al (2016)

Production from (active-sterile) neutrino oscillation



Cherry,Horiuch(2017)

DM constraints heavily depend on the production mechanism!

1) Active-Sterile neutrino oscillation (e.g. Dodelson-Widrow)

2) Active-Sterile neutrino oscillation with the resonance (e.g. Shi-Fuller)

3) Decay of a heavier particle, Thermal freeze-out, variable mixing angle, ...
(e.g. Kusenko, Petraki, Asaka, Shaposhnikov, Merle, Schneider ,Berlin, Hooper,..)

4) Sterile-sterile oscillation! (KK and Kaneta (2018))

Also the left-handed neutrino masses via the seesaw mechanism!

$$\mathcal{L} = \mathcal{L}_{\rm SM} + \mathcal{L}_N,$$

$$\mathcal{L}_N = \overline{\nu}_R i \partial\!\!\!/ \nu_R - \left[{\nu_R^c}^T y_\nu L H - \frac{1}{2} {\nu_R^c}^T \mathcal{M}_N \nu_R^c + h.c. \right]$$

$$\Omega_{N1} h^2 \propto \sin^2 2\theta_N M_1 (y_\nu y_\nu^+)_{22}$$

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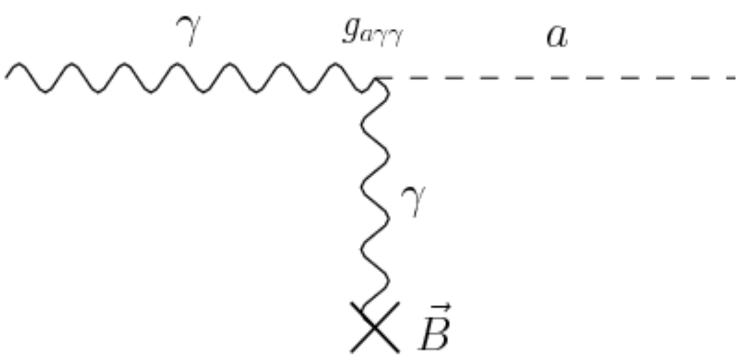
Primakoff effect

$$\frac{g_{a\gamma\gamma}}{4} a F\tilde{F} = -g_{a\gamma\gamma}\, a\, \boldsymbol{E}\cdot\boldsymbol{B}$$



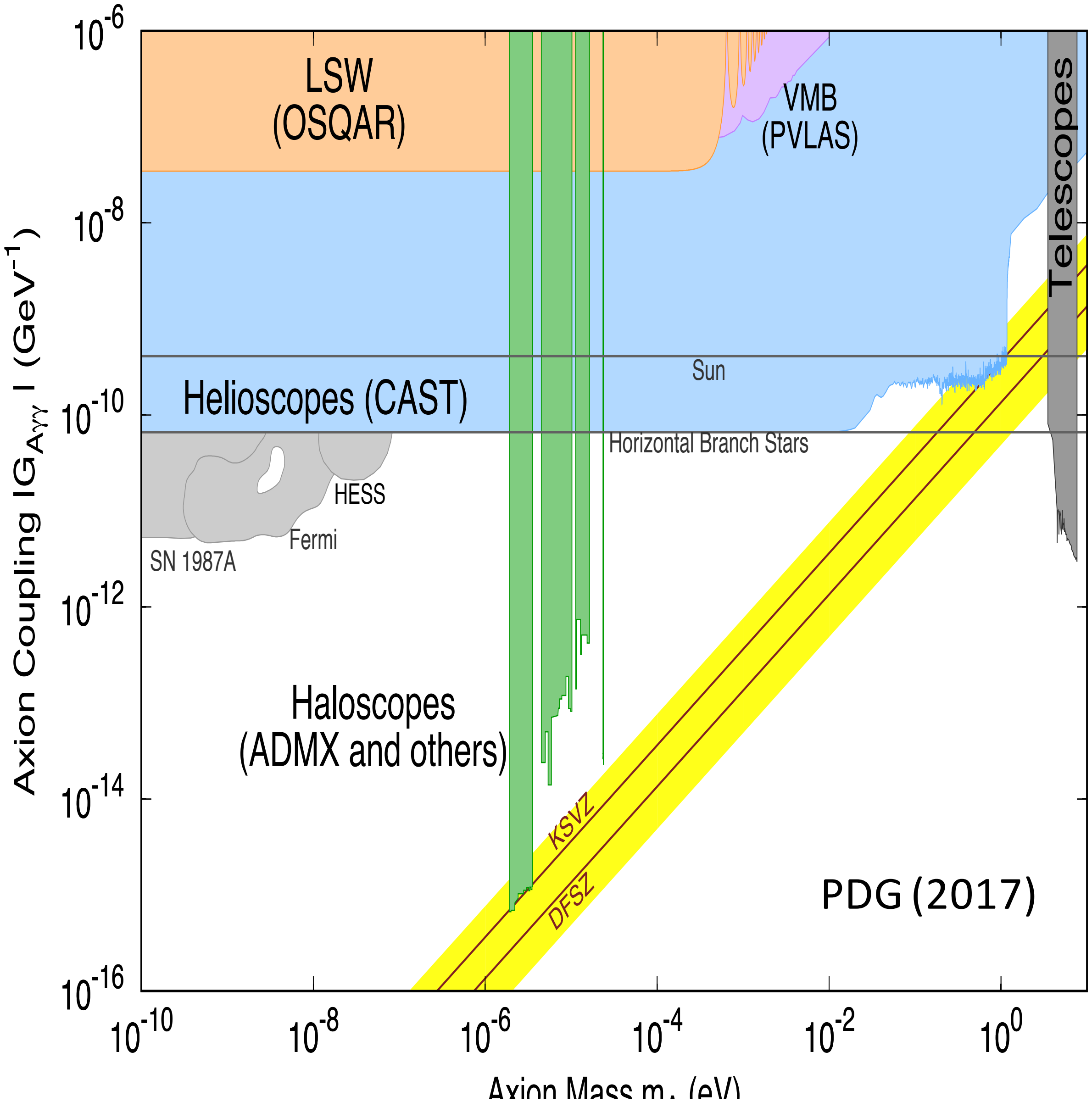
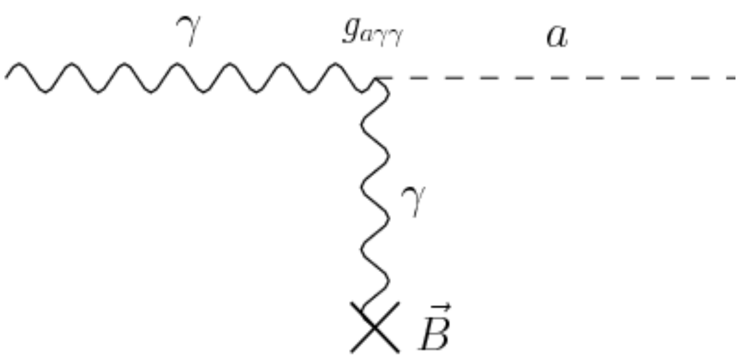
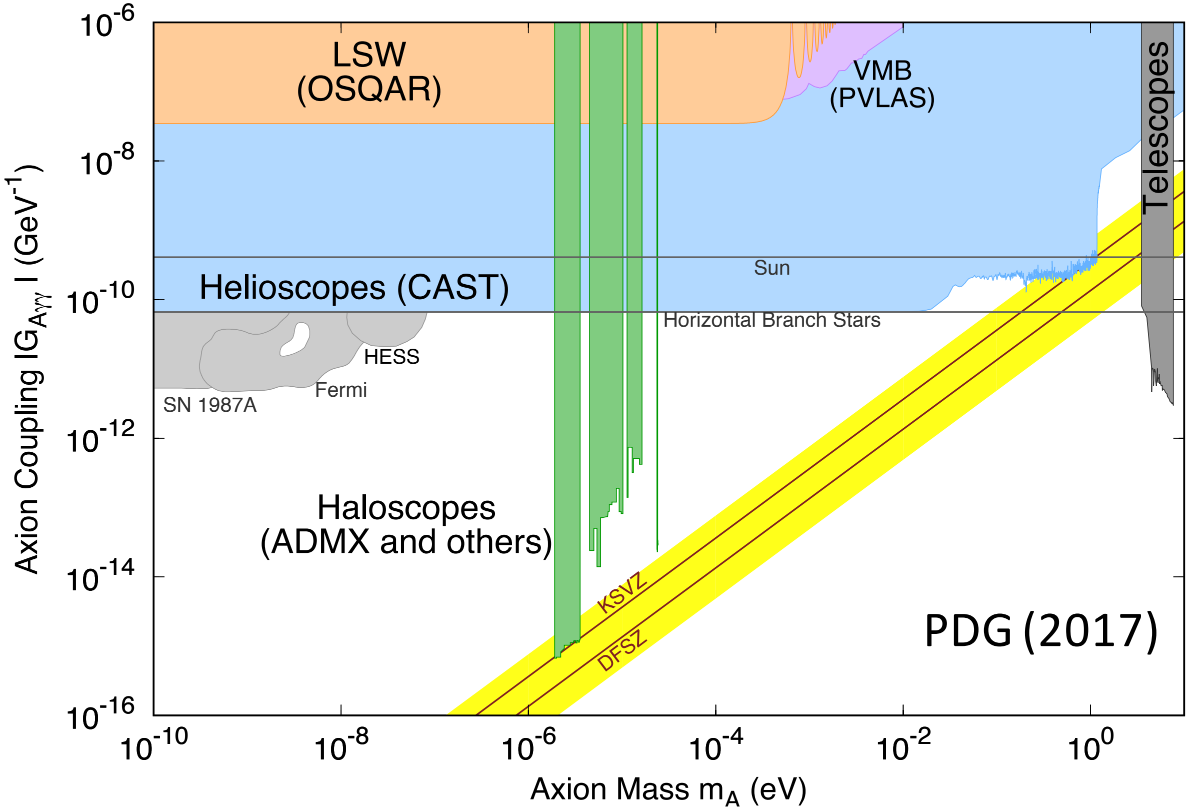


Figure 61.1: Exclusion plot for axion like particles as described in the text.

Primakoff effect

$$\frac{g_{a\gamma\gamma}}{4} aF\tilde{F} = -g_{a\gamma\gamma} a\boldsymbol{E}\cdot\boldsymbol{B}$$





QCD axion as a CDM candidate : mass range μeV ~ meV(0.1GHz ~ 100GHz)
Previous works: CDM axions converted into photons in the labs.

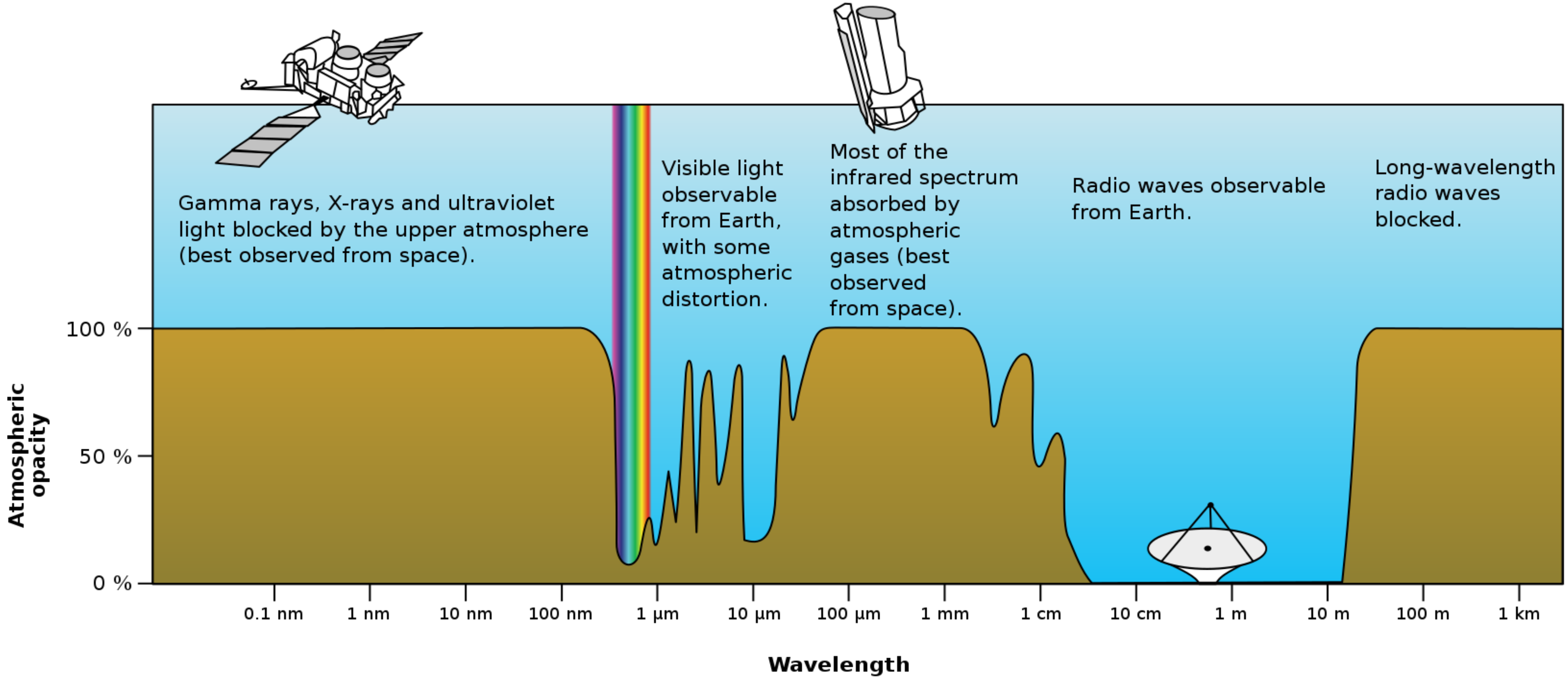
New works: How about the astrophysically sourced magnetic fields?

Non-resonant conversion: Kelley and Quinn (2017), Sigl (2017)

Resonant conversion: Huang, KK, Sekiguchi and Tashiro (2018), Hook,Kahn,Safdi and Sun(2018

Line-like radio signal for non-relativistic axion conversion:

$$f \sim \frac{m_a}{2\pi} \sim 240\left(\frac{m_a}{\mu eV}\right)\text{MHz}$$



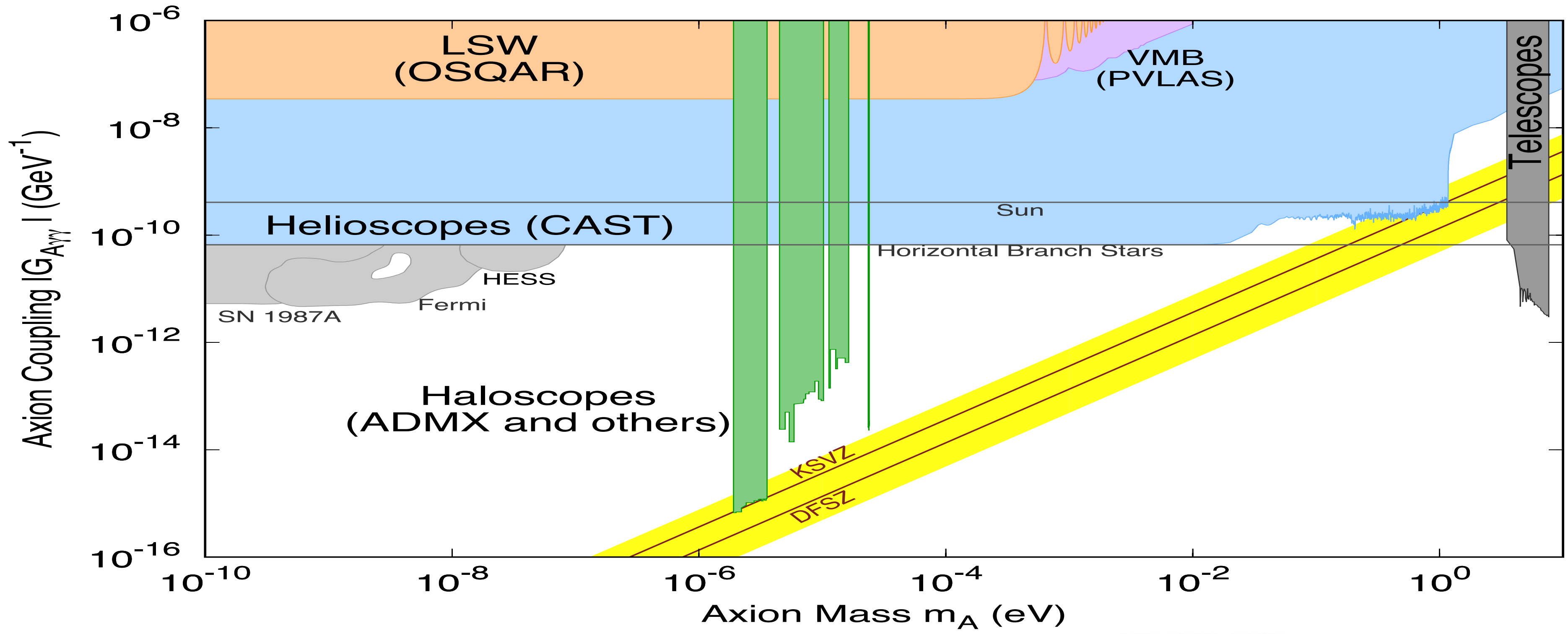
Australia: SKA low: 50-350 MHz

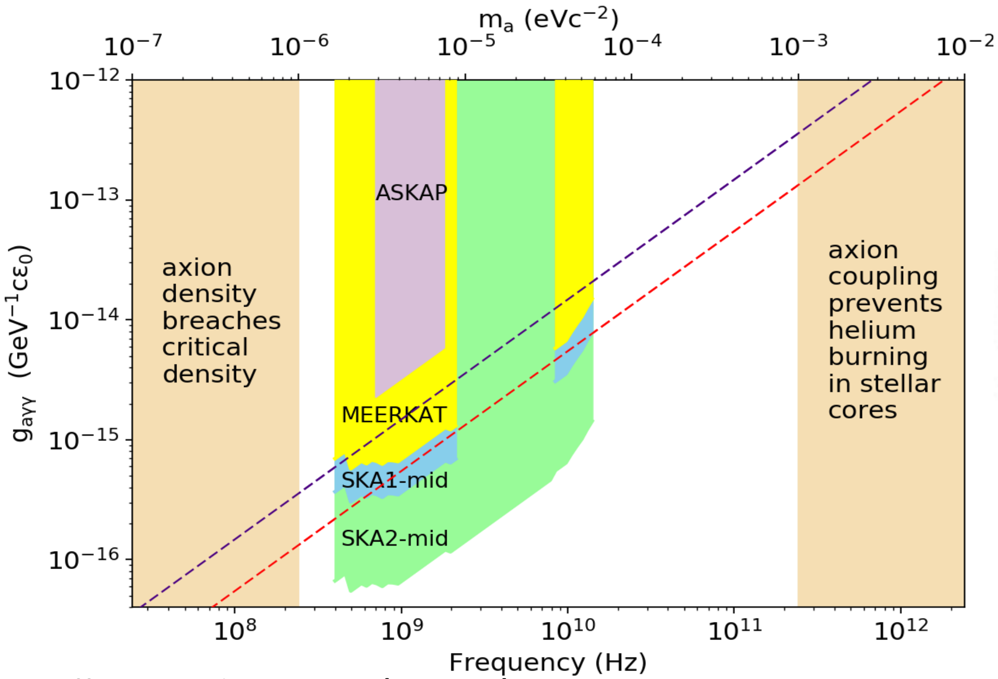
S. Africa: SKA mid: 350 MHz-14GHz

Axion mass: $0.2{\sim}60\ \mu eV$

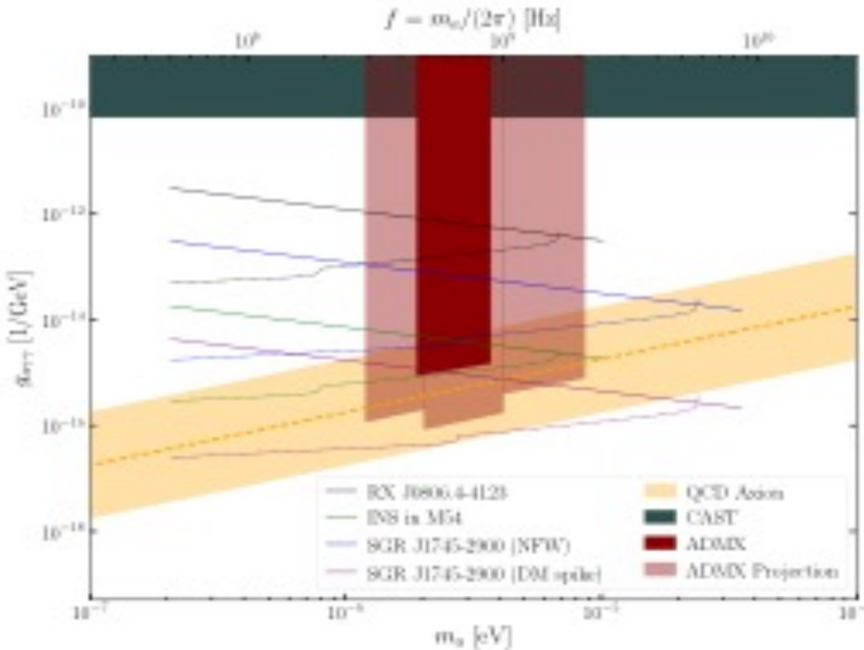
QCD axion as a CDM candidate :

Mass µeV ~ meV(0.1GHz ~ 100GHz)





Kelley and Quinn (2017)



Hook, Kahn, Safdi and Sun (2018)

Model: ALP (Axion-like particles) i.e. Ultra-light scalars

- Ultra-light mass :

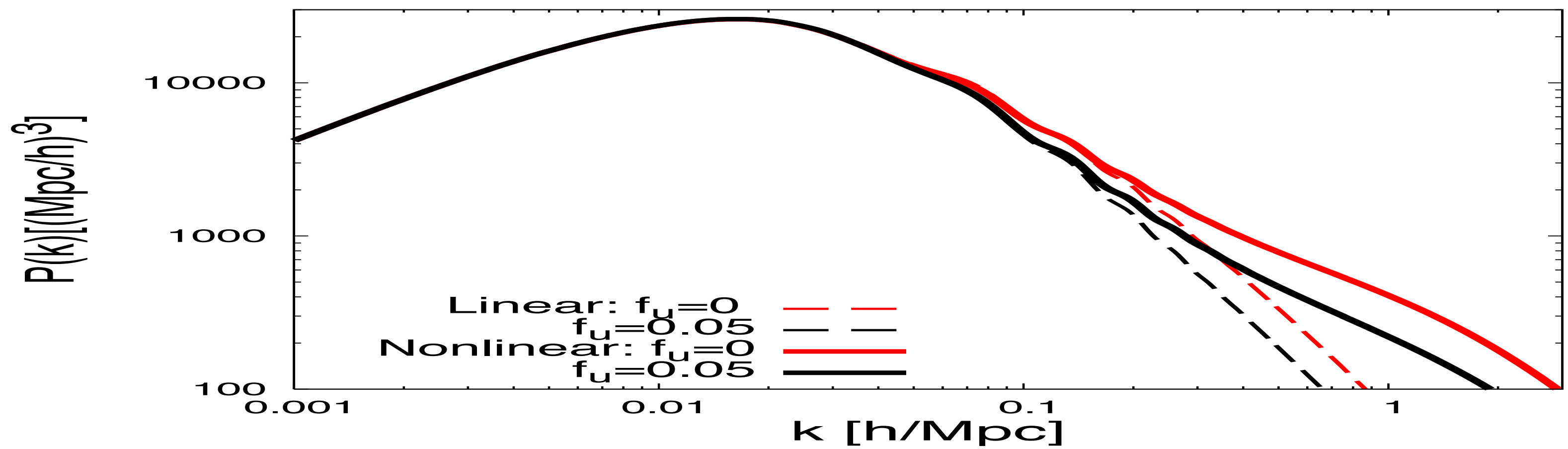
$m_u \sim H_0 \sim 10^{-33} eV$ DE (Barbieri et al (2005),...)

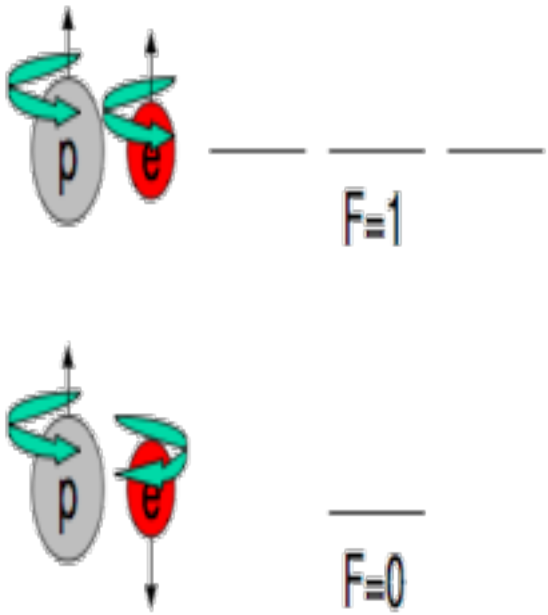
$m_u \sim 10^{-22} eV$ Fuzzy DM (Hu (2000),...)

$m_u \sim 10^{-22} eV - 10^{-10} eV$ String axiverse (Arvanitaki et al (2009),...)

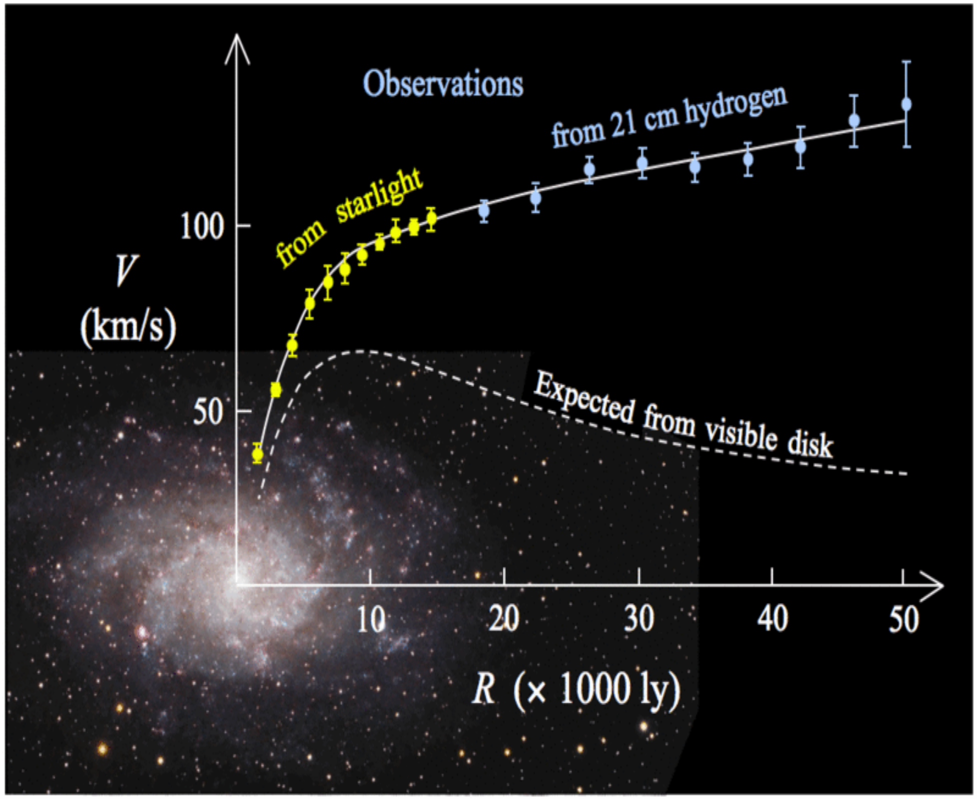
$$m_u, f_u = \Omega_u / \Omega_m \sim O(0.01)$$
$$m_u \leq H(t) : \rho_u = const$$
$$m_u > H(t) : \rho_u \propto 1/a^3$$

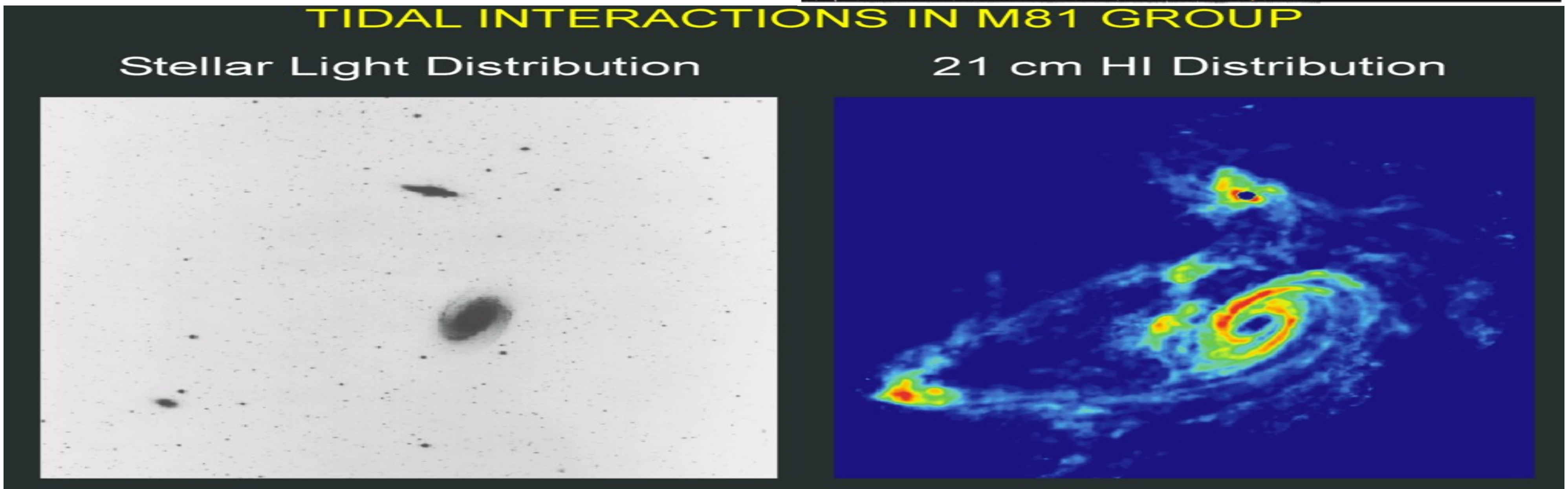
KK, Mao, Ichiki, Silk (2014)





21 cm signals
1420 MHz





Brief History of Universe

Years since the Big Bang

~300000 (z~1000)

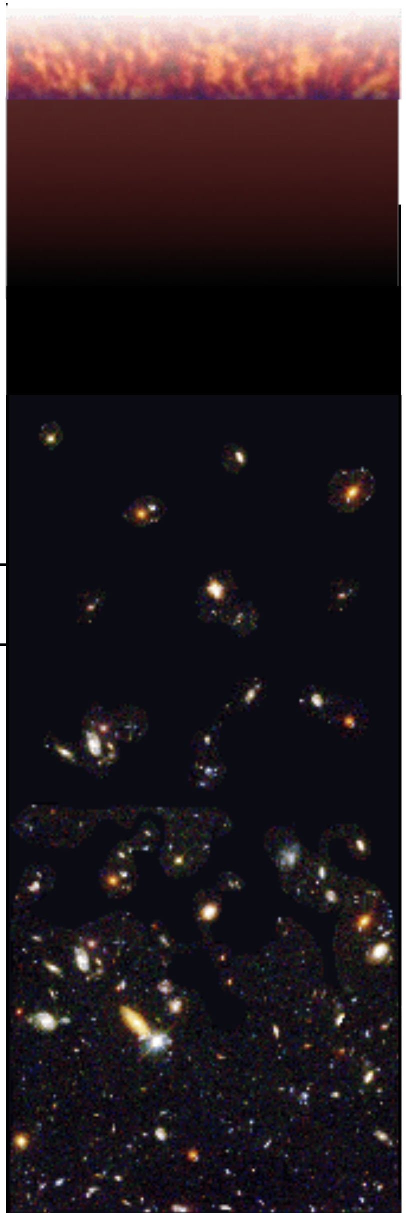
Dark Ages

~100 million (z~20-40)

Reionization

~1 billion (z~6)

~13 billion (z=0)



← Big Bang: the Universe is filled with ionized gas

← Recombination: The gas cools and becomes neutral

← The first structures begin to form.

Reionization starts (z ~12)

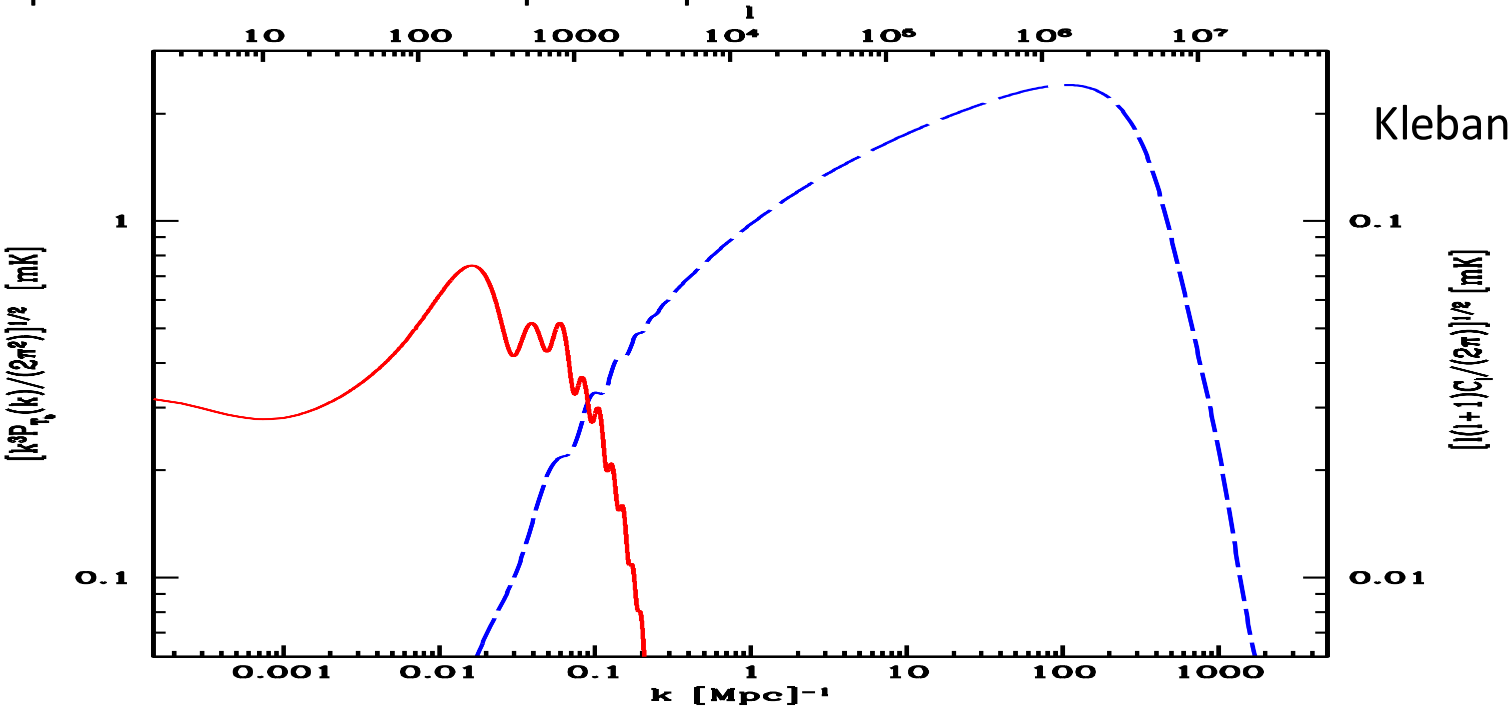
← Reionization is complete

← Today's structures

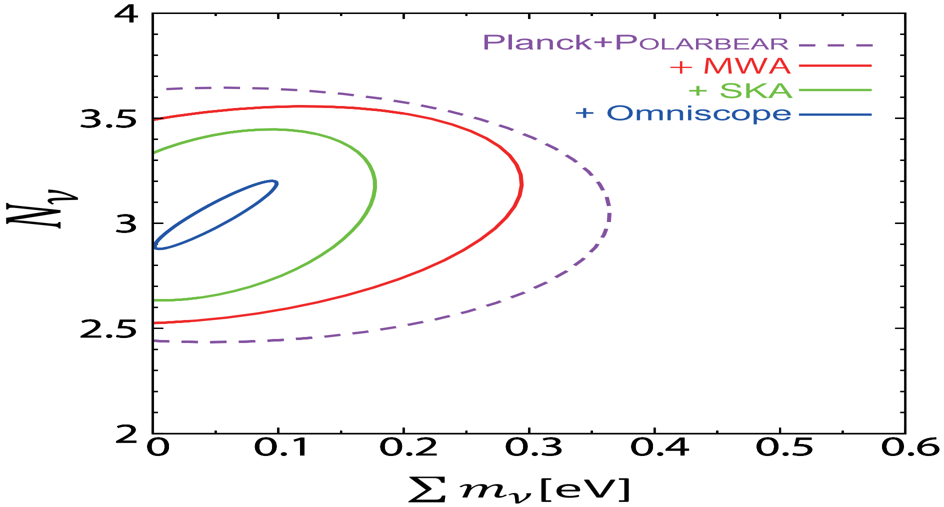
What can we do with 21cm?

High precision on small-scale power spectrum

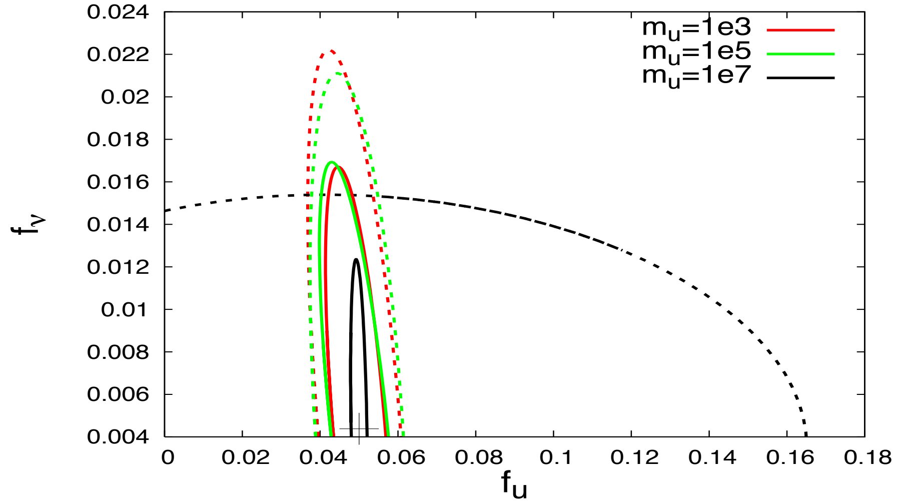
$$\Delta P / P \sim 1 / \sqrt{N}$$



Kleban+(2007)



Oyama+(2013)



KK, Mao, Ichiki, Silk (2014)

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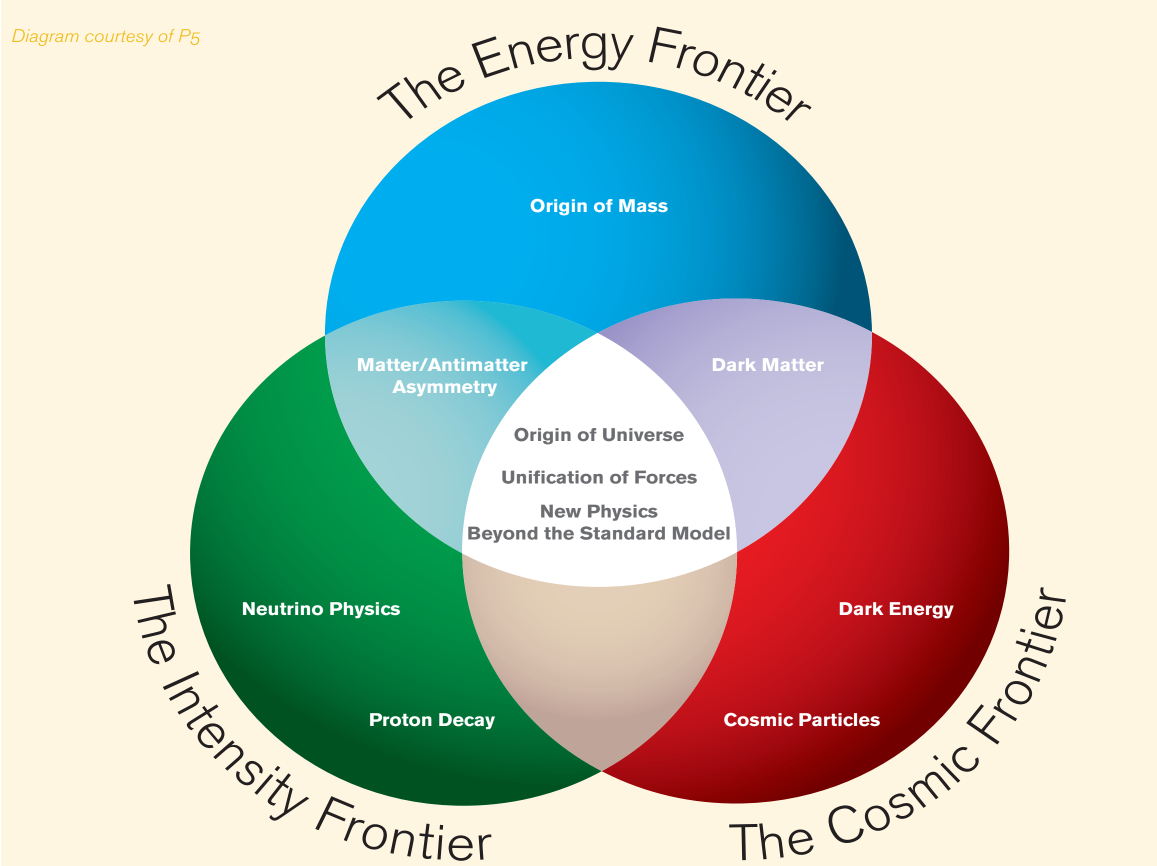

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Let us be open minded.
Can go beyond the electroweak scale dark matter mass range.
Can go beyond CDM paradigm in LambdaCDM.
Many production mechanisms, many detection methods.