Light Dark Matter

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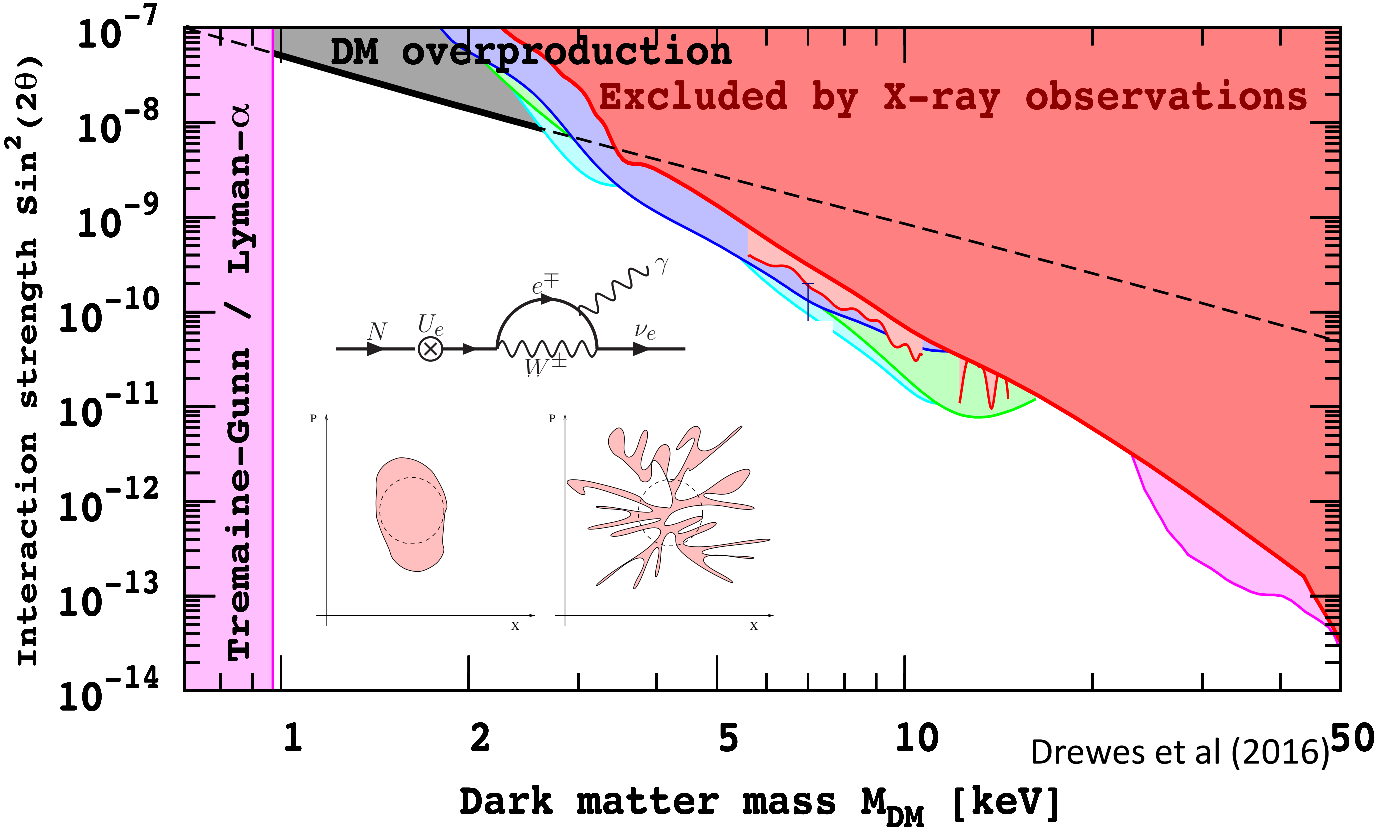
- Two concrete examples
  - ✓ Sterile neutrino DM
    - Production mechanism
  - ✓ Axion(-like) Particle
    - Radio (SKA-like) survey
- Conclusion

A concrete example for the warm dark matter: Sterile Neutrinos

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

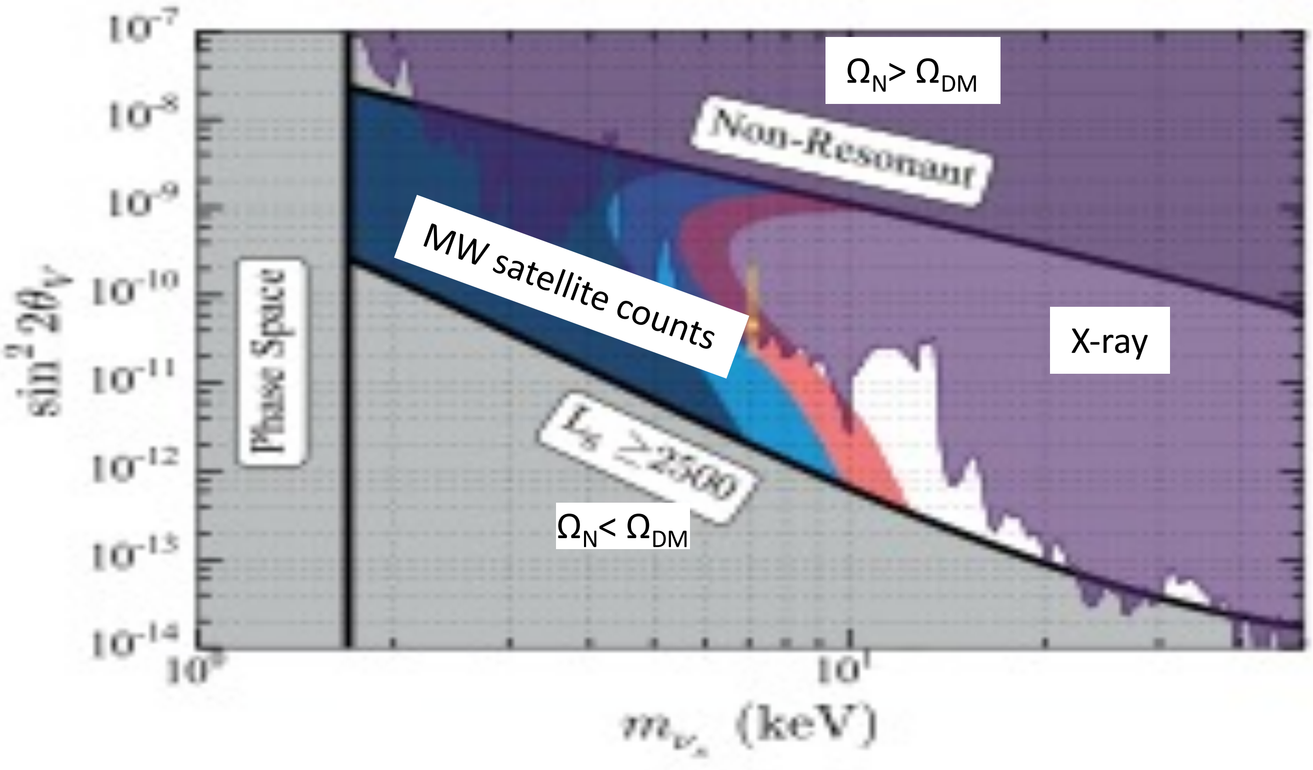
$$L = -yNLH - \frac{1}{2}MNN$$

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



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 (2017))

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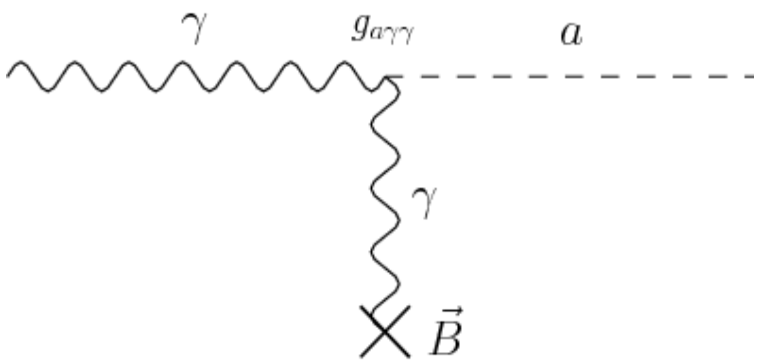
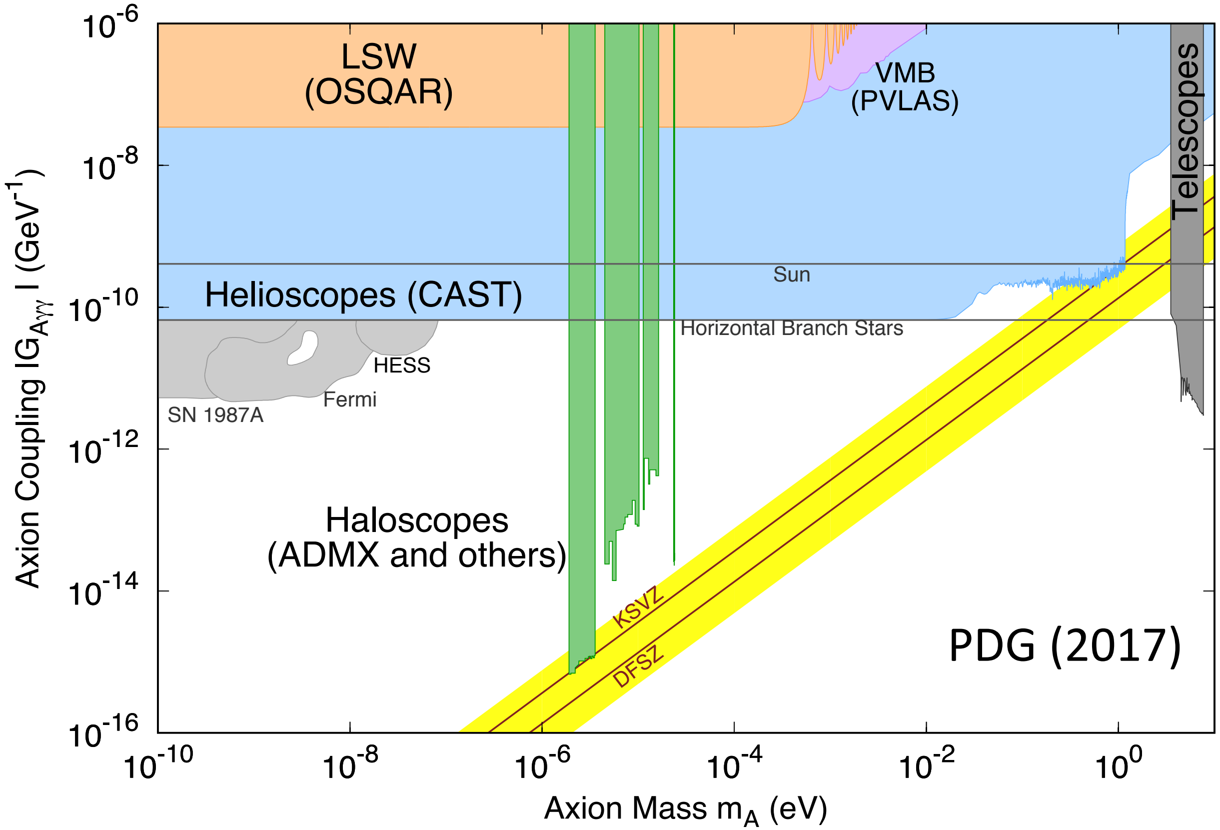
$$\frac{g_{a\gamma\gamma}}{4} aF\tilde{F} = -g_{a\gamma\gamma} a\boldsymbol{E}\cdot\boldsymbol{B}$$





Previous work:

Relativistic axion converted into photon in presence of B.

Non-relativistic axion decay into two photons for CDM axion.

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

SKA 50MHz-14 GHz, $S\sim\mu$Jy , Axion mass: $0.2\sim60\ \mu eV$

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

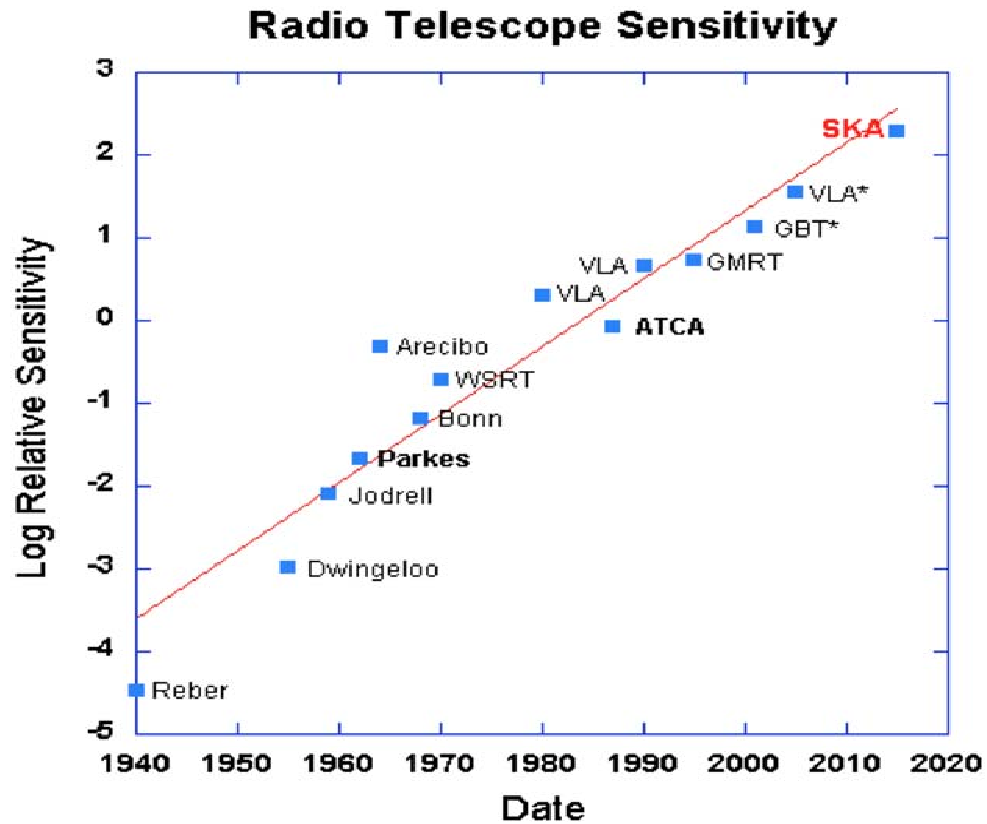
Non-resonant conversion: Kelley and Quinn (2017), Sigl (2017)

Resonant conversion: Huang, KK, Sekiguchi and Tashiro to appear

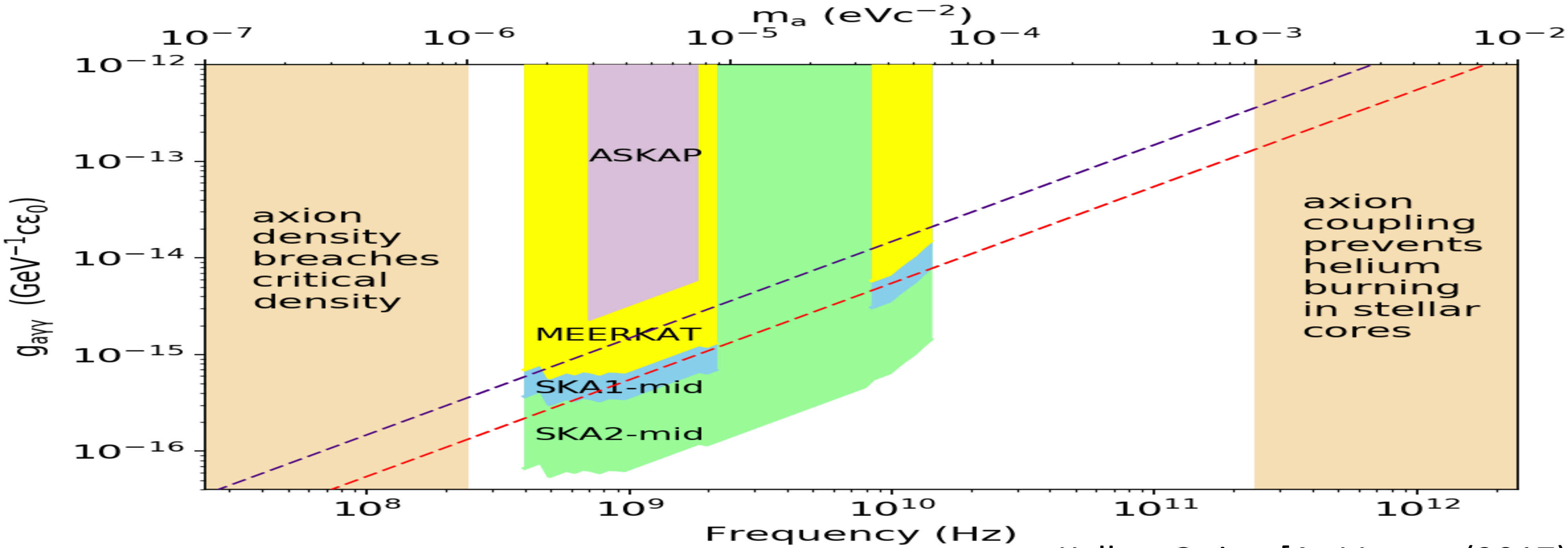
Square Kilometer Array

South Africa- Karoo
Australia- Western Outback

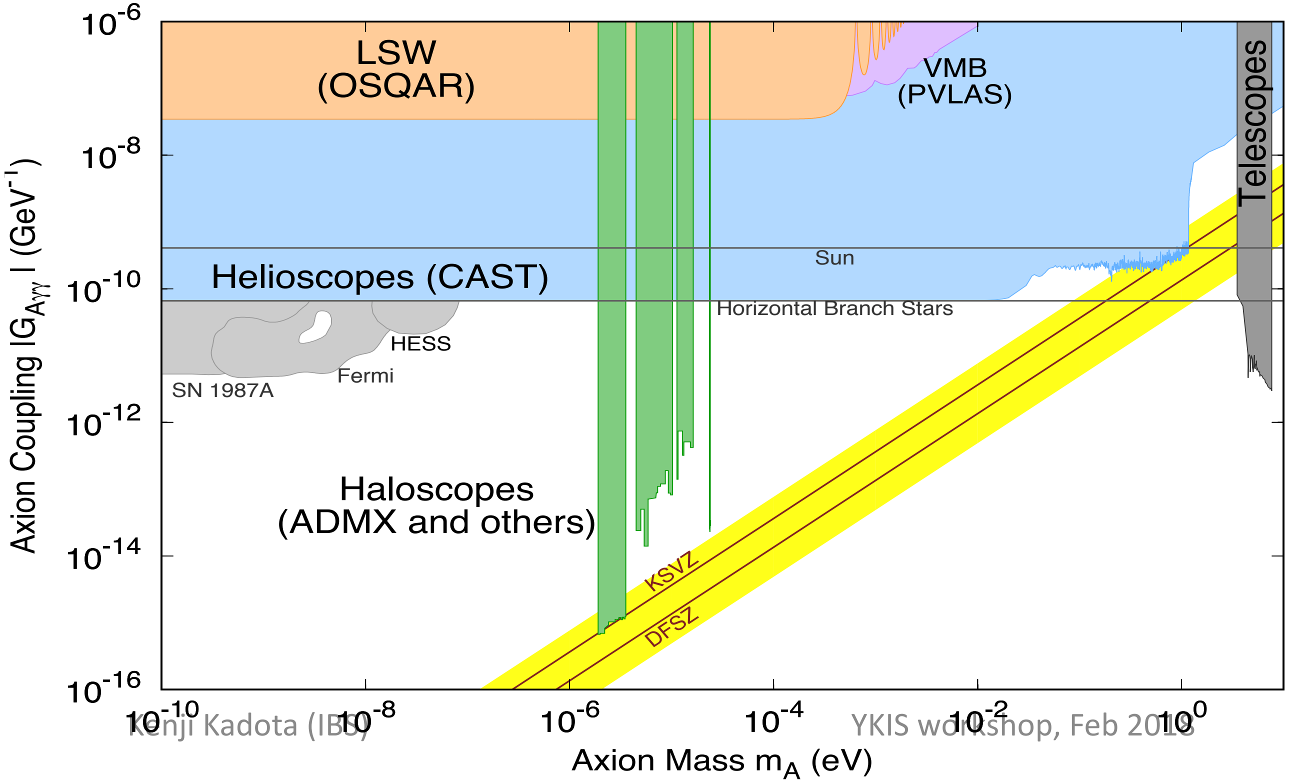
Construction 2019-2025, Early Science 2022-, Full Science 2025-2030
Cost: ~650 M Euros, Operation ~ 50 M Euros per year.

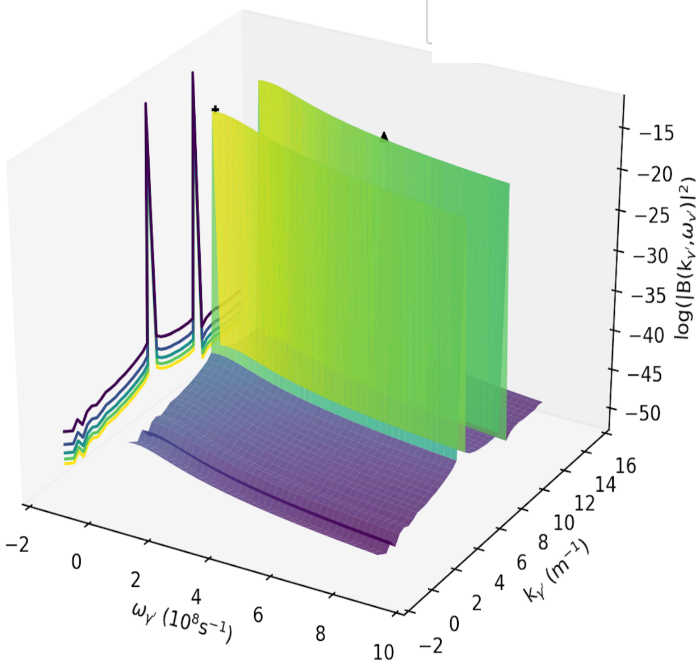


CERN-SKA Big data co-operation agreement



Kelley, Quinn [ApJ Letter (2017)]





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

- Ultra-light mass :

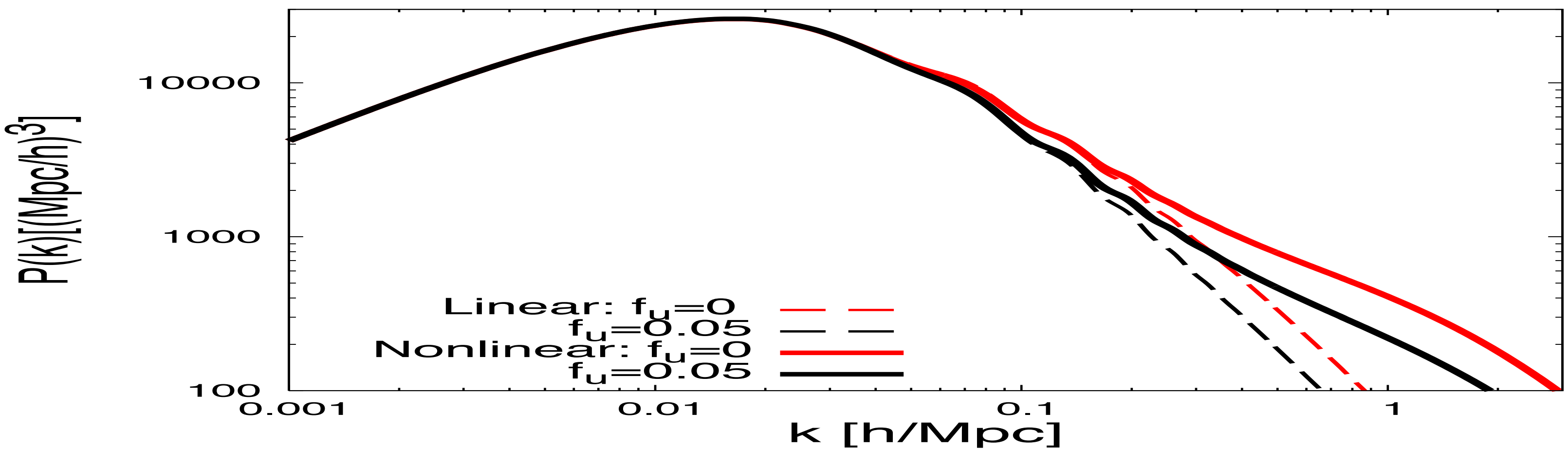
$m_u \sim H_0 \sim 10^{-33} eV$ DE (Barbieri et al (2005),...)

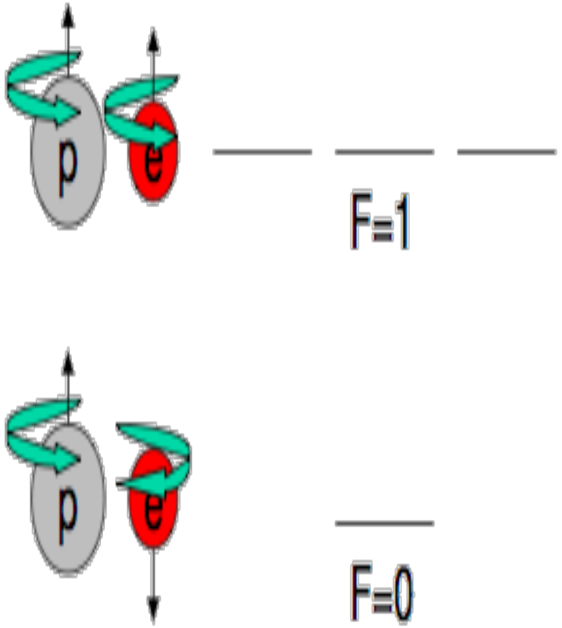
$m_u \sim 10^{-22} eV$ Fuzzy DM (Hu (2000),...)

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

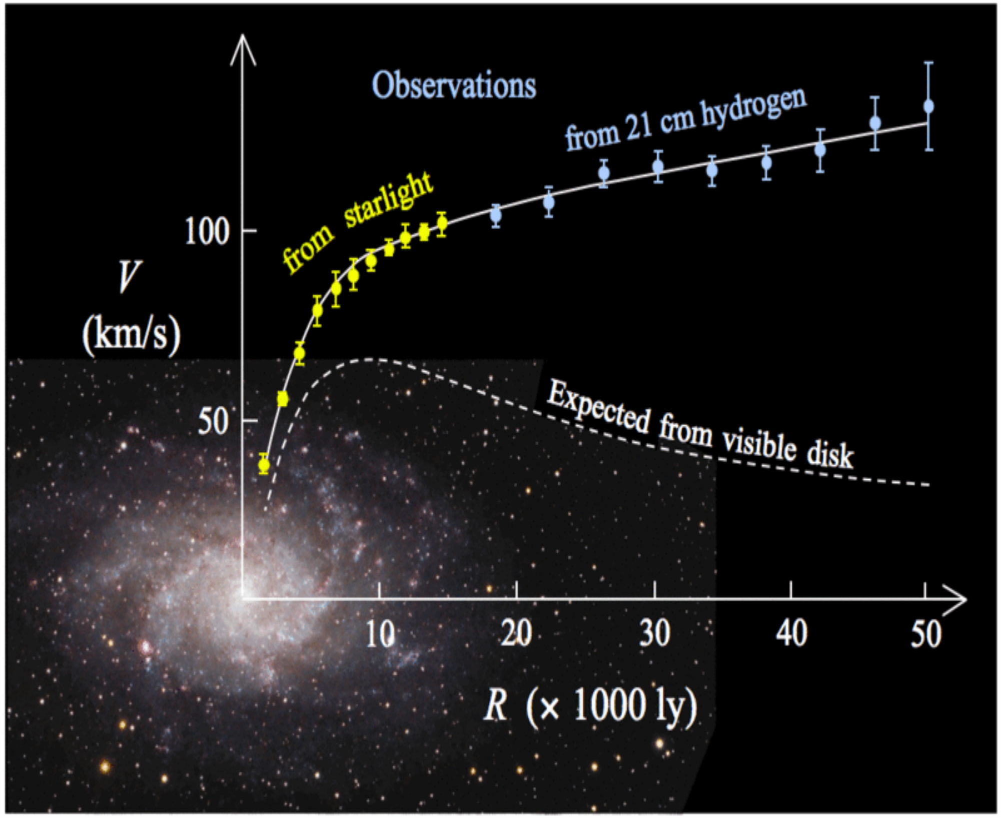
$$m_u, f_u = \Omega_u / \Omega_m \sim O(0.01)$$
$$m_u \leq H(t) : \rho_u = const$$
$$m_u > H(t) : \rho_u \propto 1/a^3$$

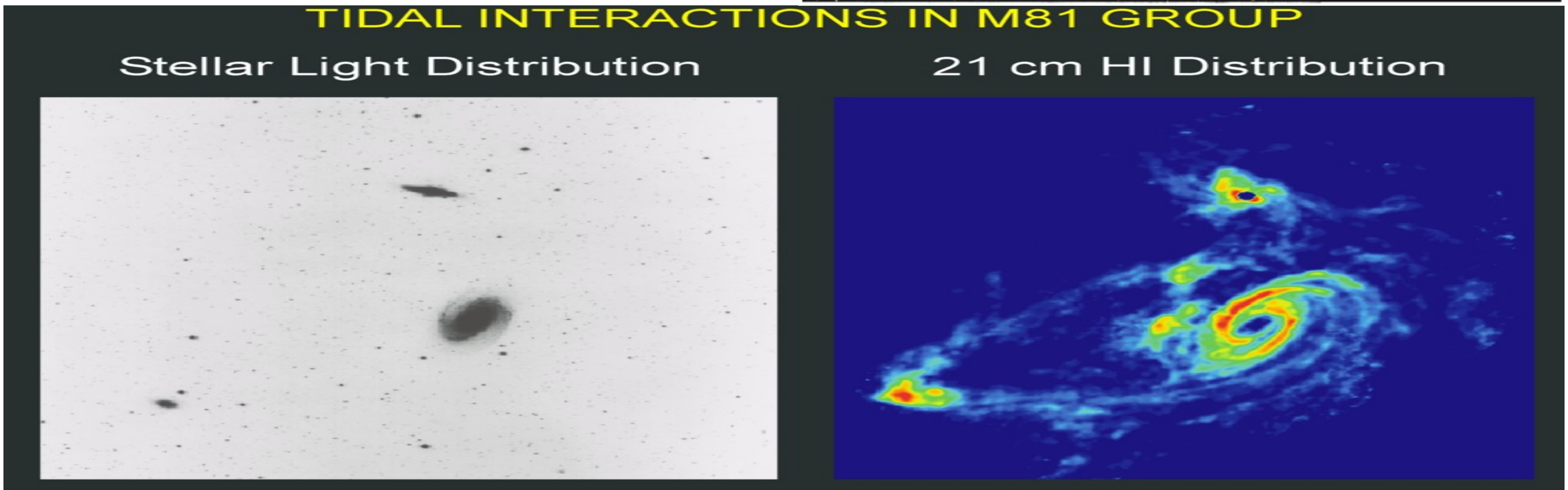
KK, Mao, Ichiki, Silk (2014)





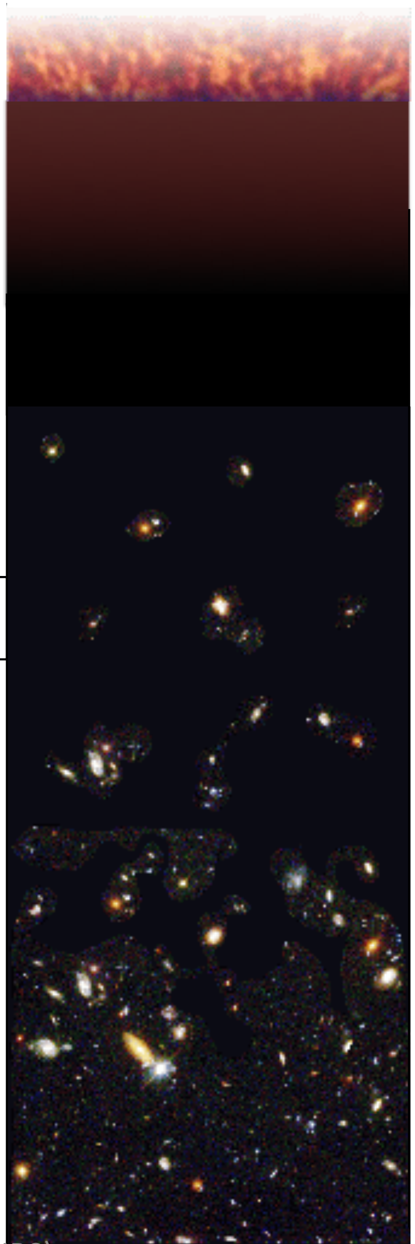
21 cm signals
1420 MHz





Brief History of Universe

Years since the Big Bang



← Big Bang:
the Universe is filled with ionized gas

~300000 (z~1000)

← Recombination: The gas cools and becomes neutral

Dark Ages

~100 million (z~20-40)

← The first structures begin to form.

Reionization starts (z ~12)

Reionization

~1 billion (z~6)

← Reionization is complete

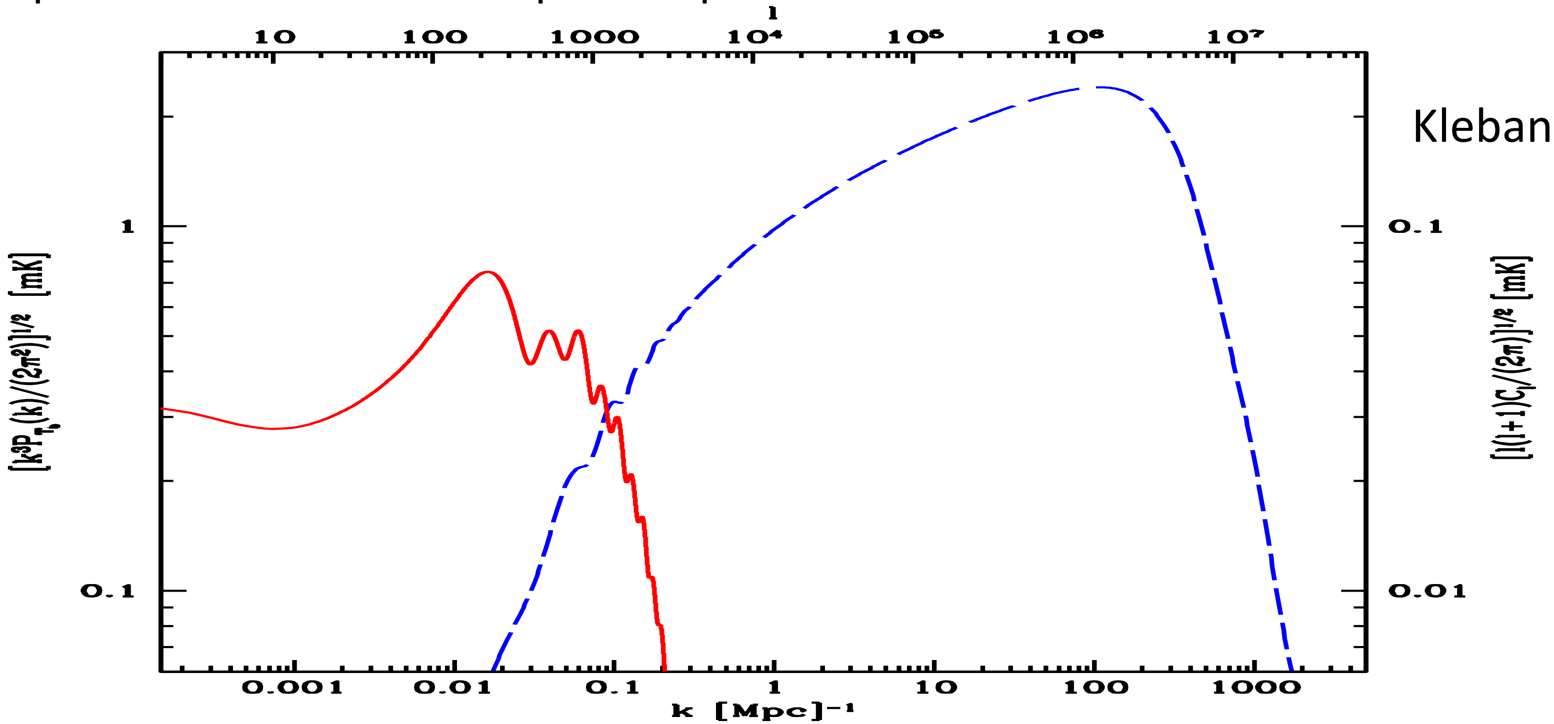
~13 billion (z=0)

← Today's structures

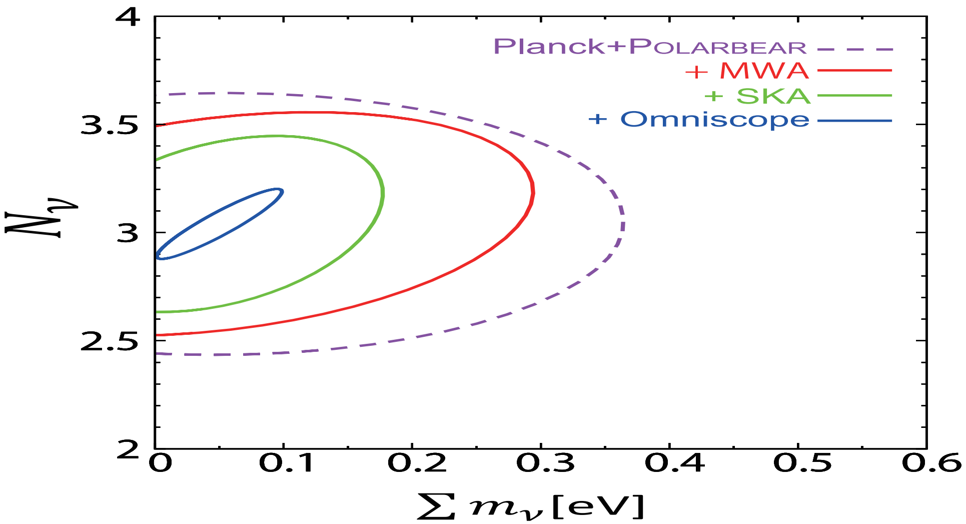
What can we do with 21cm?

High precision on small-scale power spectrum

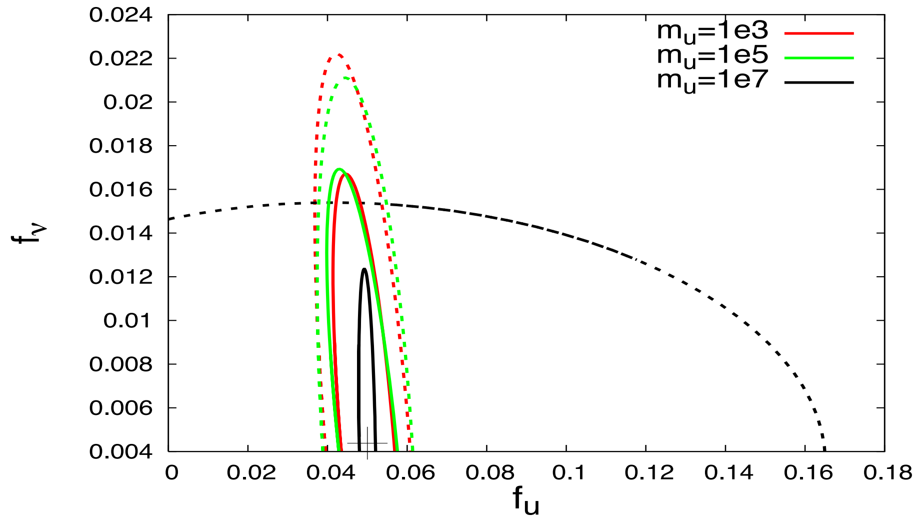
$$\Delta P / P \sim 1 / \sqrt{N}$$



Kleban+(2007)



Oyama+(2013)



KK, Mao, Ichiki, Silk (2014)

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Let us be open minded.
Complimentarity between particle physics and cosmology.