Supernova 1987A Constraints on Low-Mass Dark Sectors

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Collaboration with Rouven Essig and Samuel McDermott

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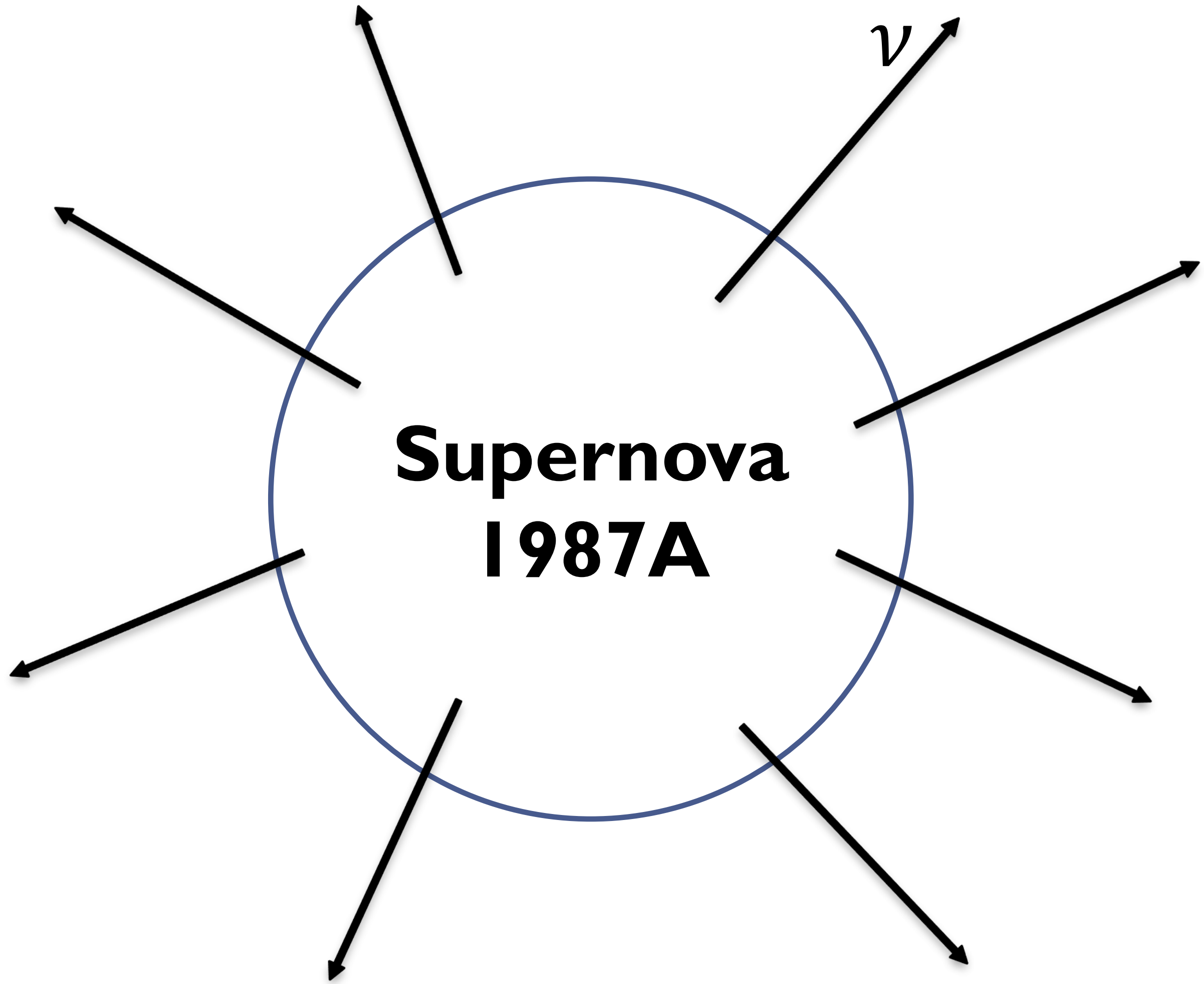
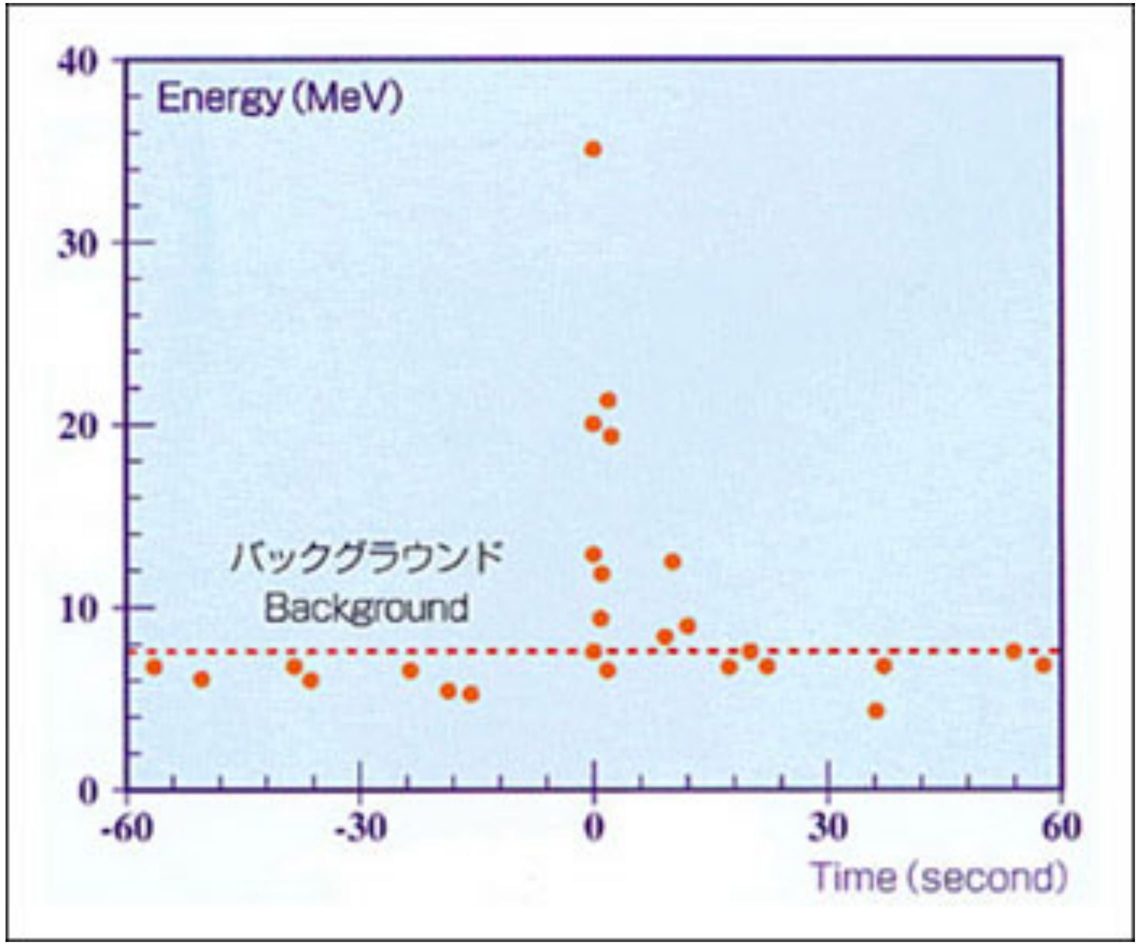
Supernova 1987A

- Type II Supernova observed in 1987
- Closest supernova since Kepler (~50 kpc)
- The only supernova that neutrinos from supernova explosion were detected
- Can be used to constrain new particles

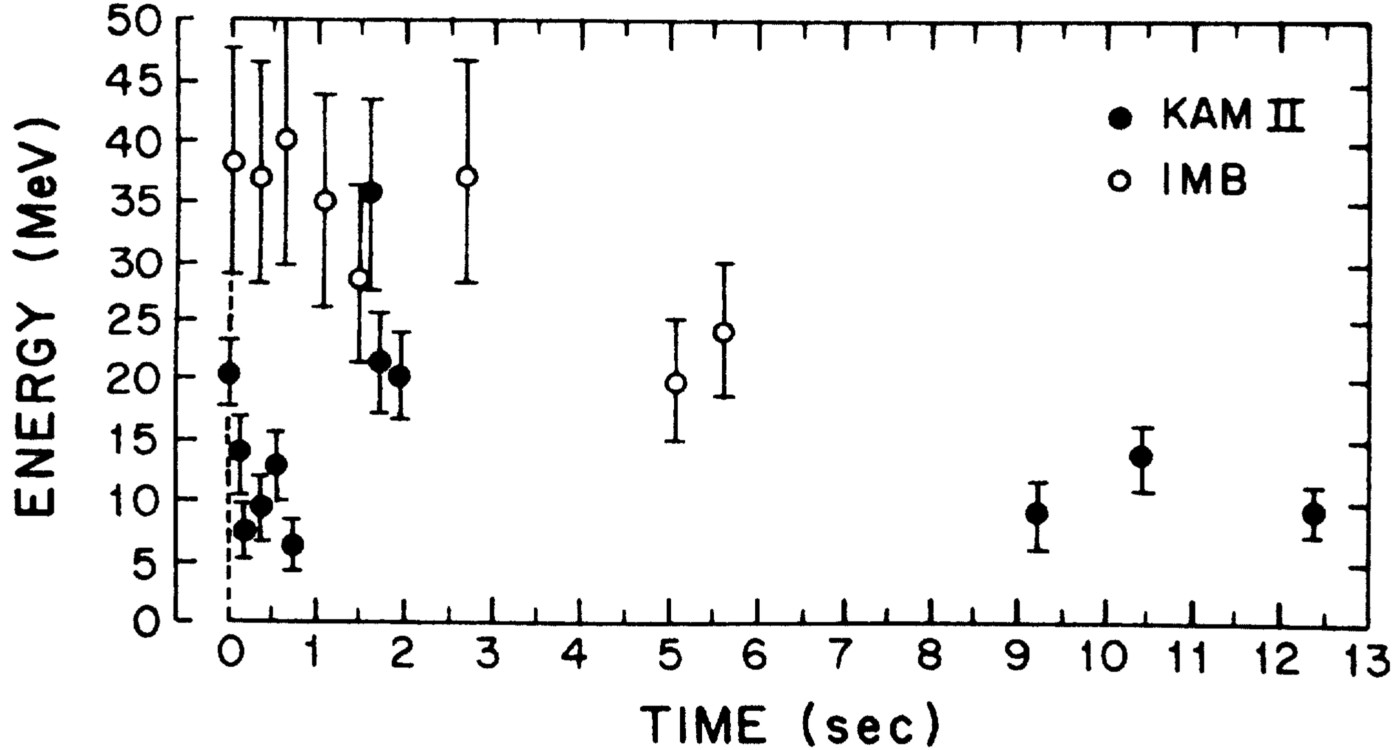


- When the supernova was exploded, 99% of energy is carried by neutrinos

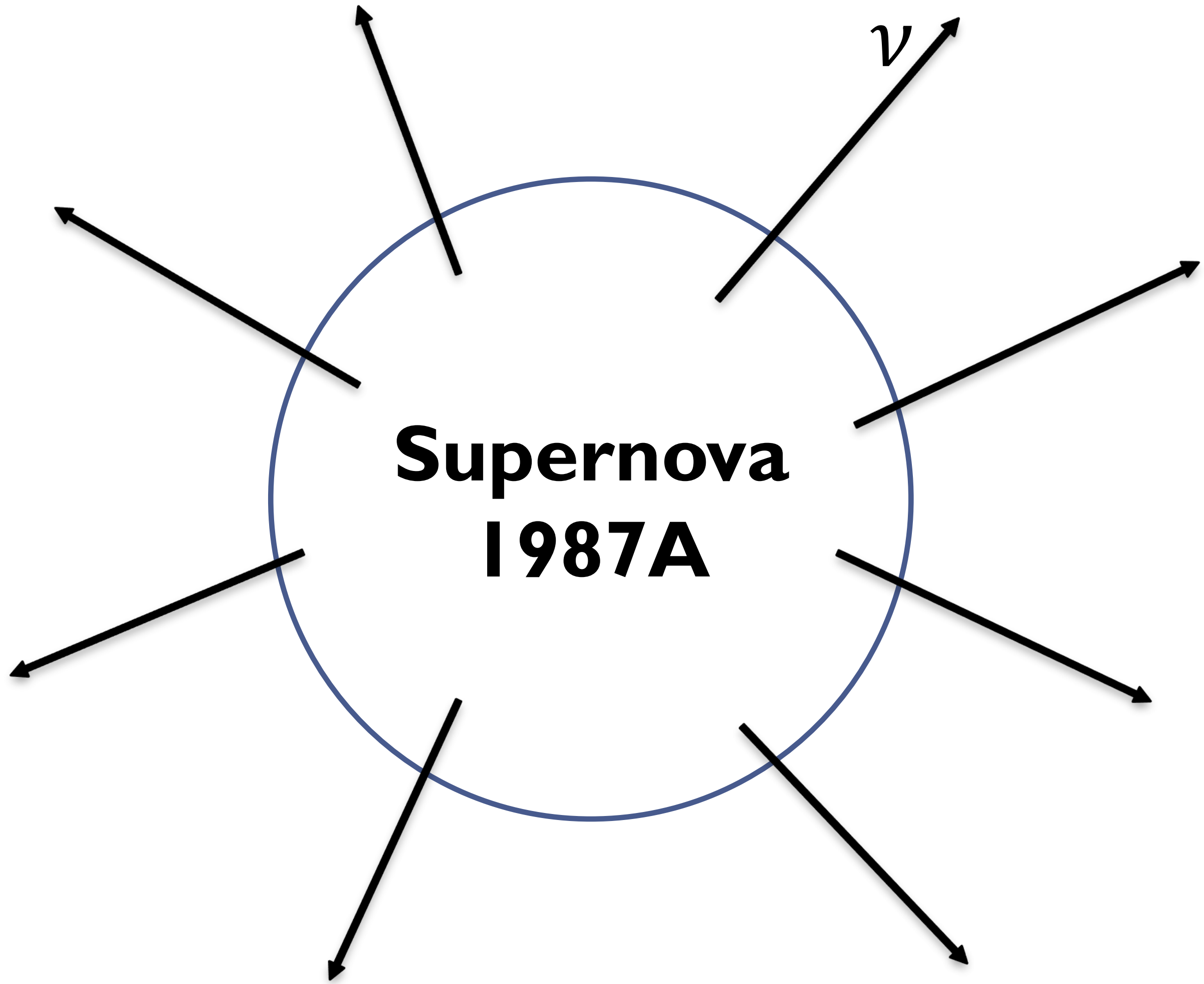


- Kamiokande II, IMB, and Baksan detected the neutrinos at the same time

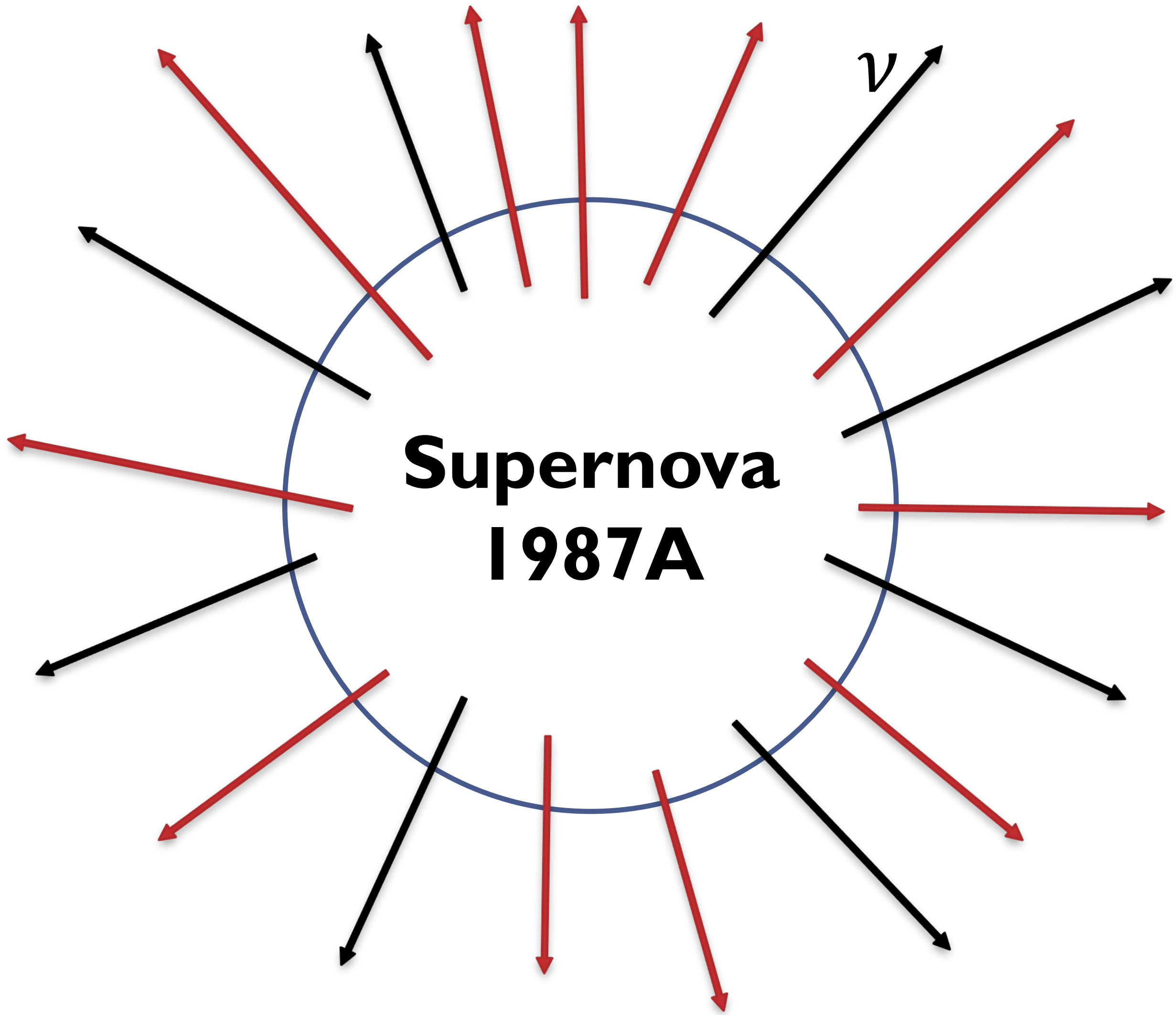
Hirata et al, 1988



- Cooling time : ~10 seconds
- Consistent with the SM prediction



- If a new particle exists



- Supernova cools faster

Supernova Constraints

- **Any type of light novel particles** coupled to the SM can be constrained

$$m \lesssim \mathcal{O}(T_c) \approx 100\ MeV$$

- The new particle doesn't need to be relic dark matter

- Provides reasonable lower bounds for experiment searches

Supernova Constraints

- Pure dark photons
- Dark sector fermions
- Inelastic dark matter
- Millicharged particles
- QCD Axions
- Axion-like particles

Novelties in this Work

- Varying temperature and density profiles
- Novel treatment for the upper bounds
- Included the thermal effects to the supernova environment for the first time

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Thermal Effects

- High temperature and high electron density in SN change photon behaviors
- Many dark sector models contain interactions with photons
- Thermal effects are important

Photons in Supernova

- Photons have a different dispersion relation
  - Photon gets a plasma mass
  - Photon has a longitudinal polarization

- Photons can be produced/absorbed from/into the plasma

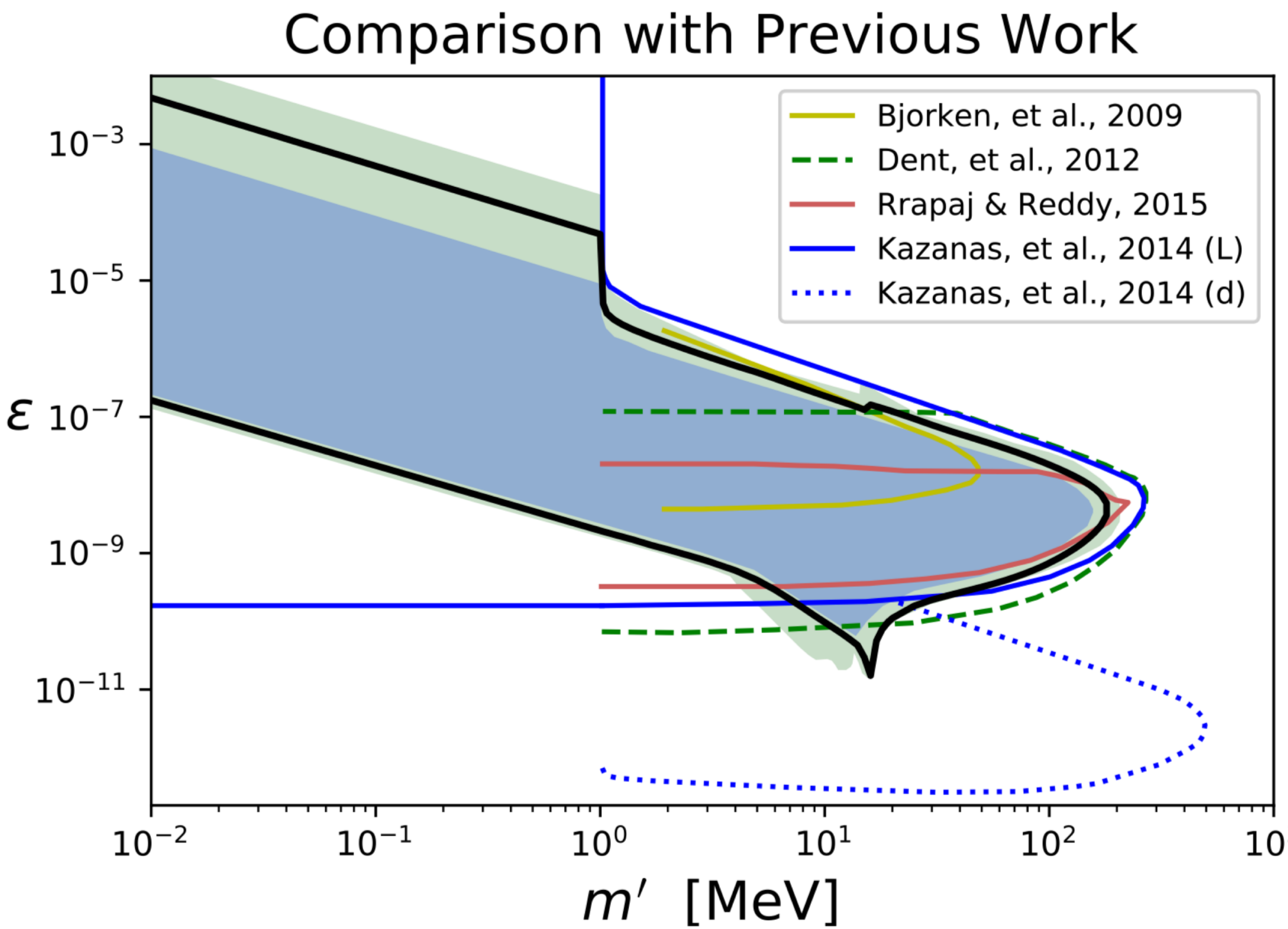
- Can be described with polarization tensors

Photon Propagator in Plasma

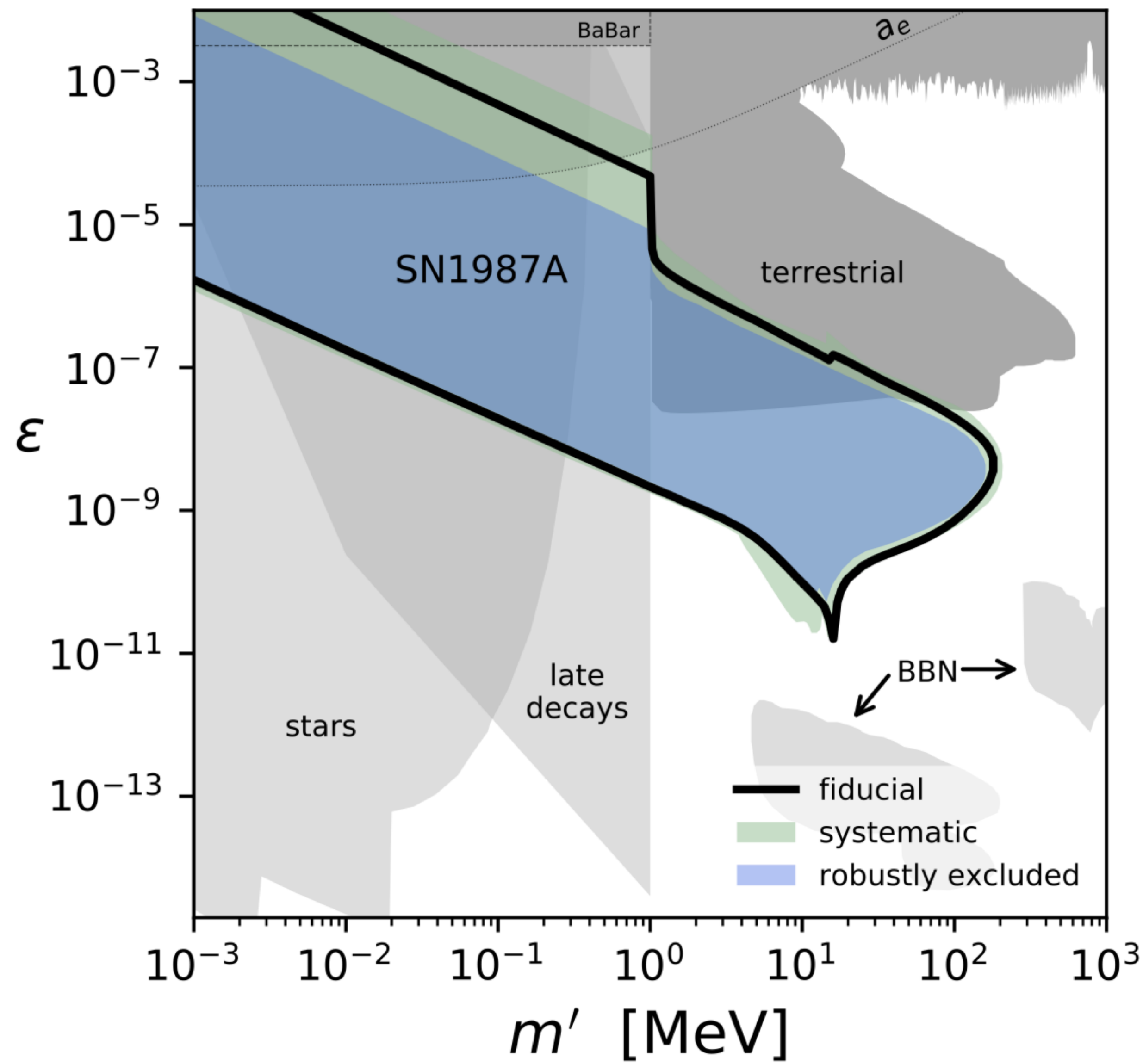
$$\frac{ig_{\mu\nu}}{q^2} \to \frac{ig_{\mu\nu}}{q^2 - \Pi}$$

- Resonances at $q^2 = \mathrm{Re}\Pi$
- Suppression for small q^2

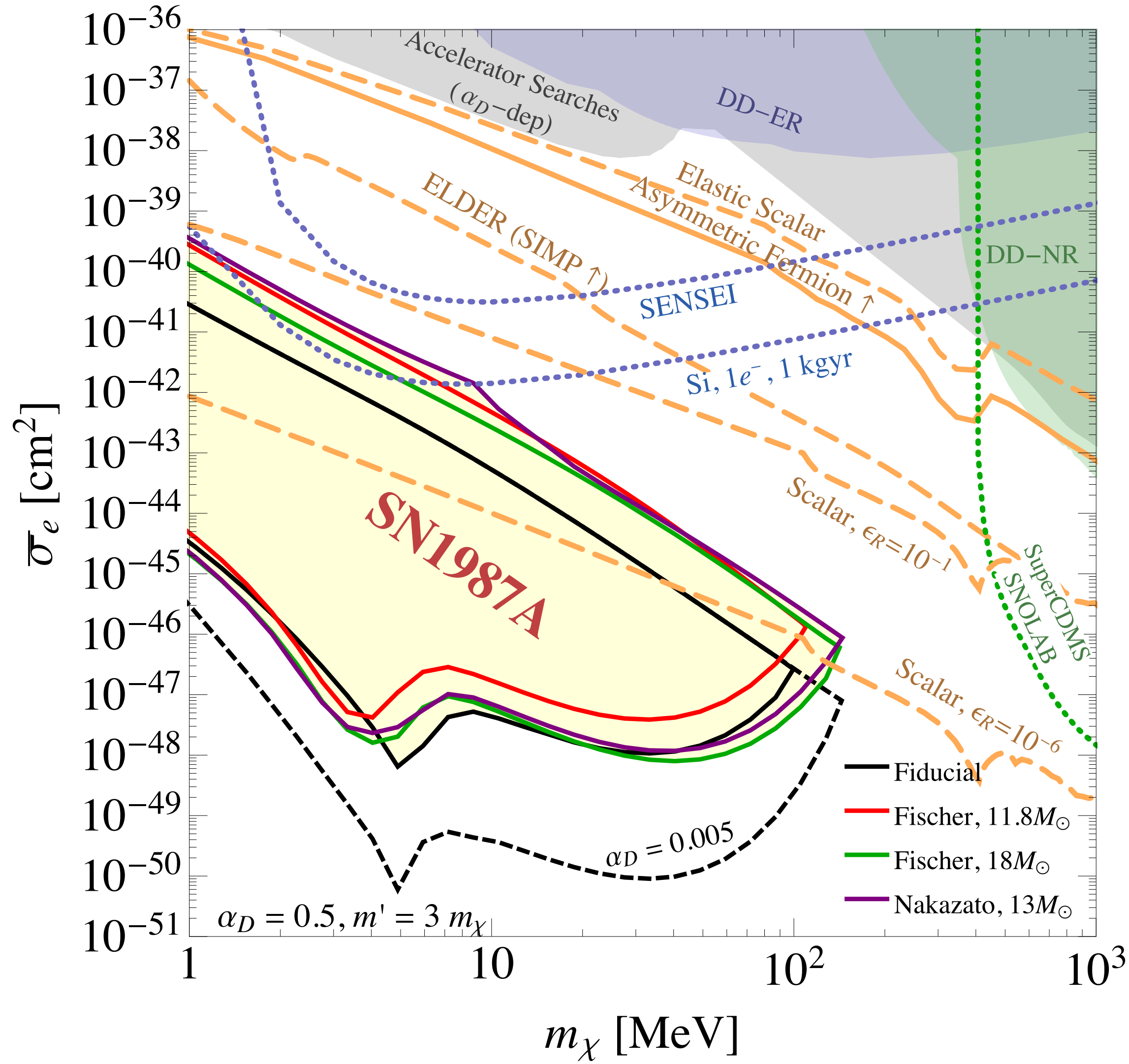
Dark Photons



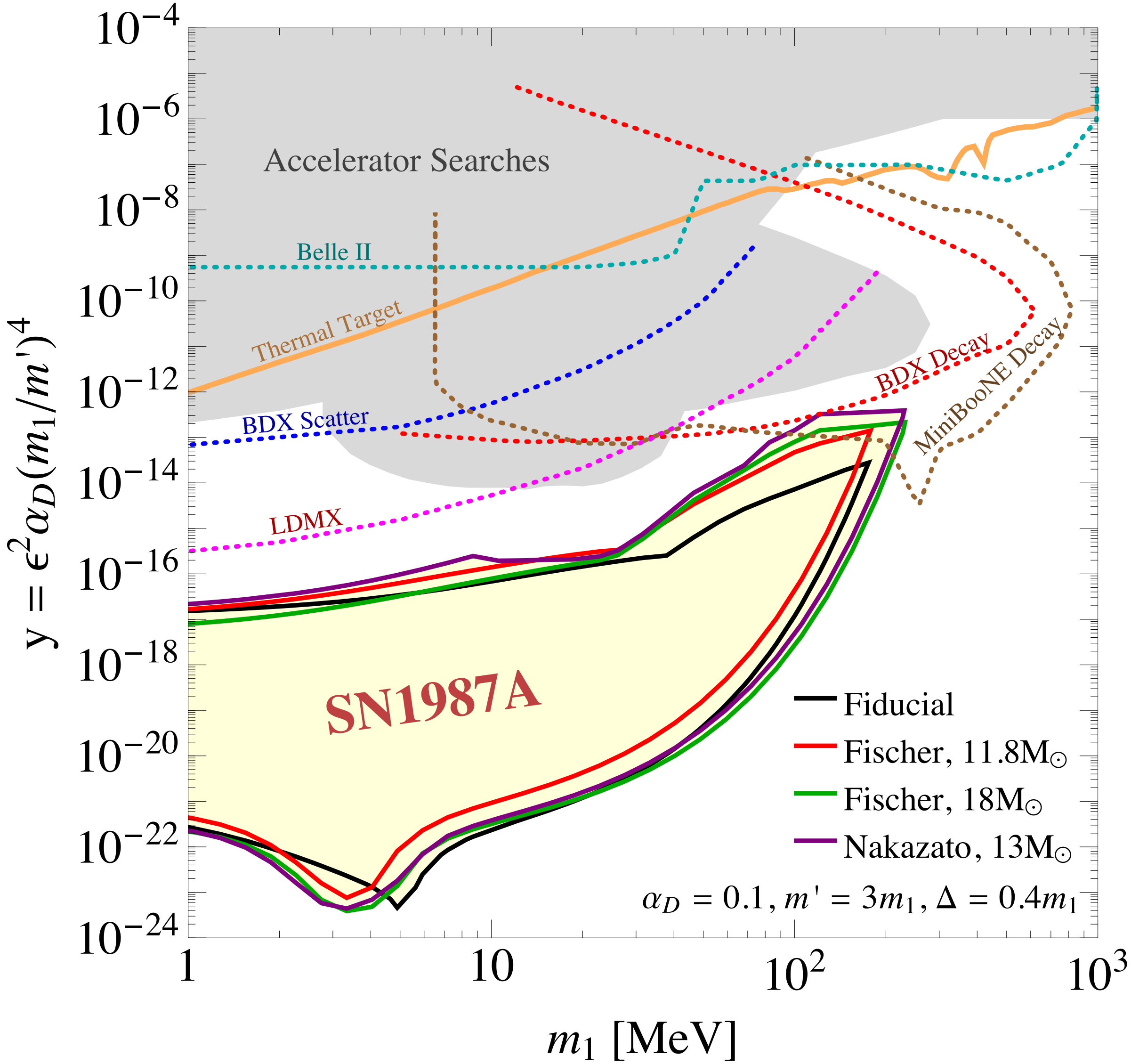
Dark Photons



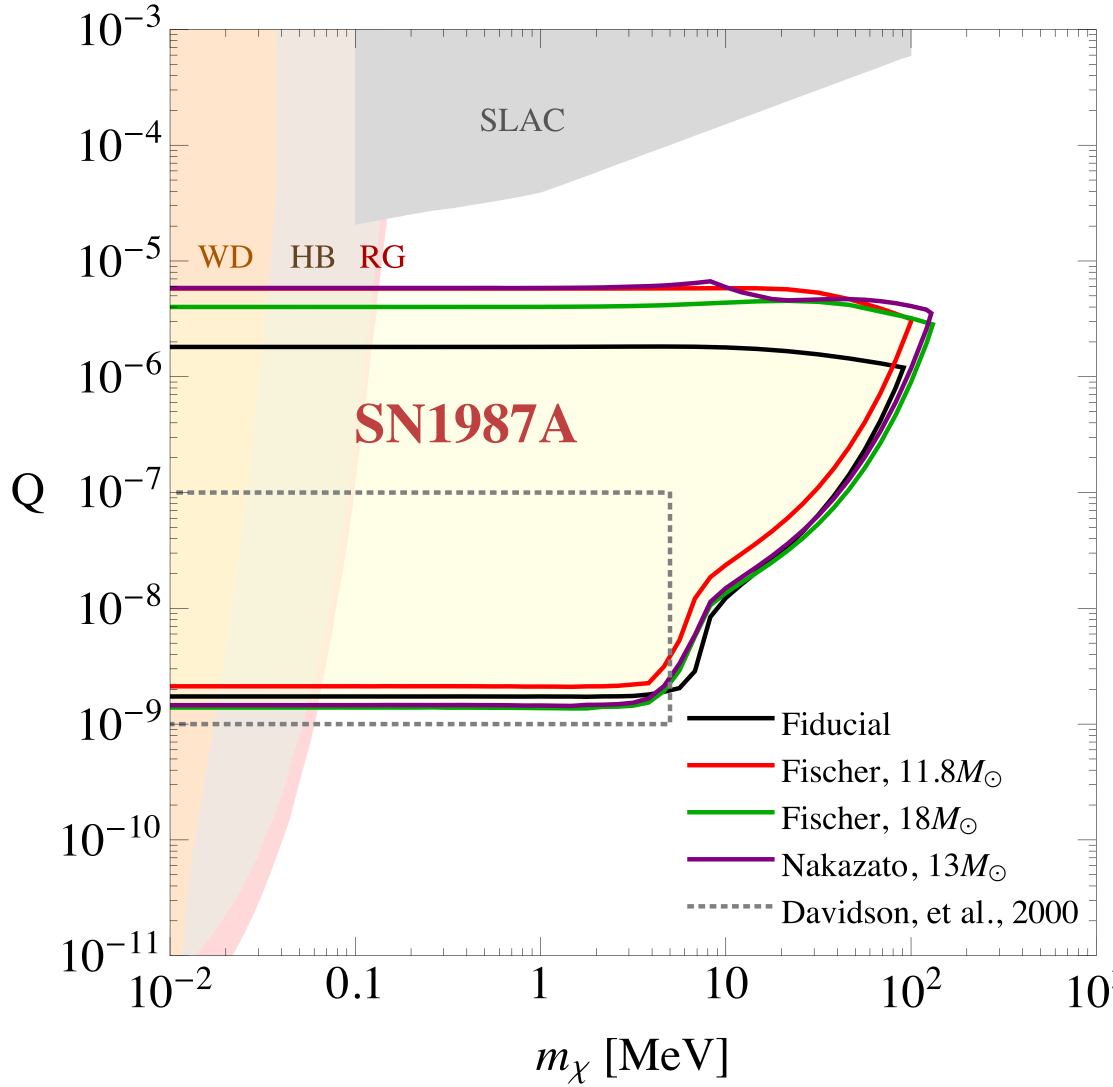
Dark Photon + Dark Matter



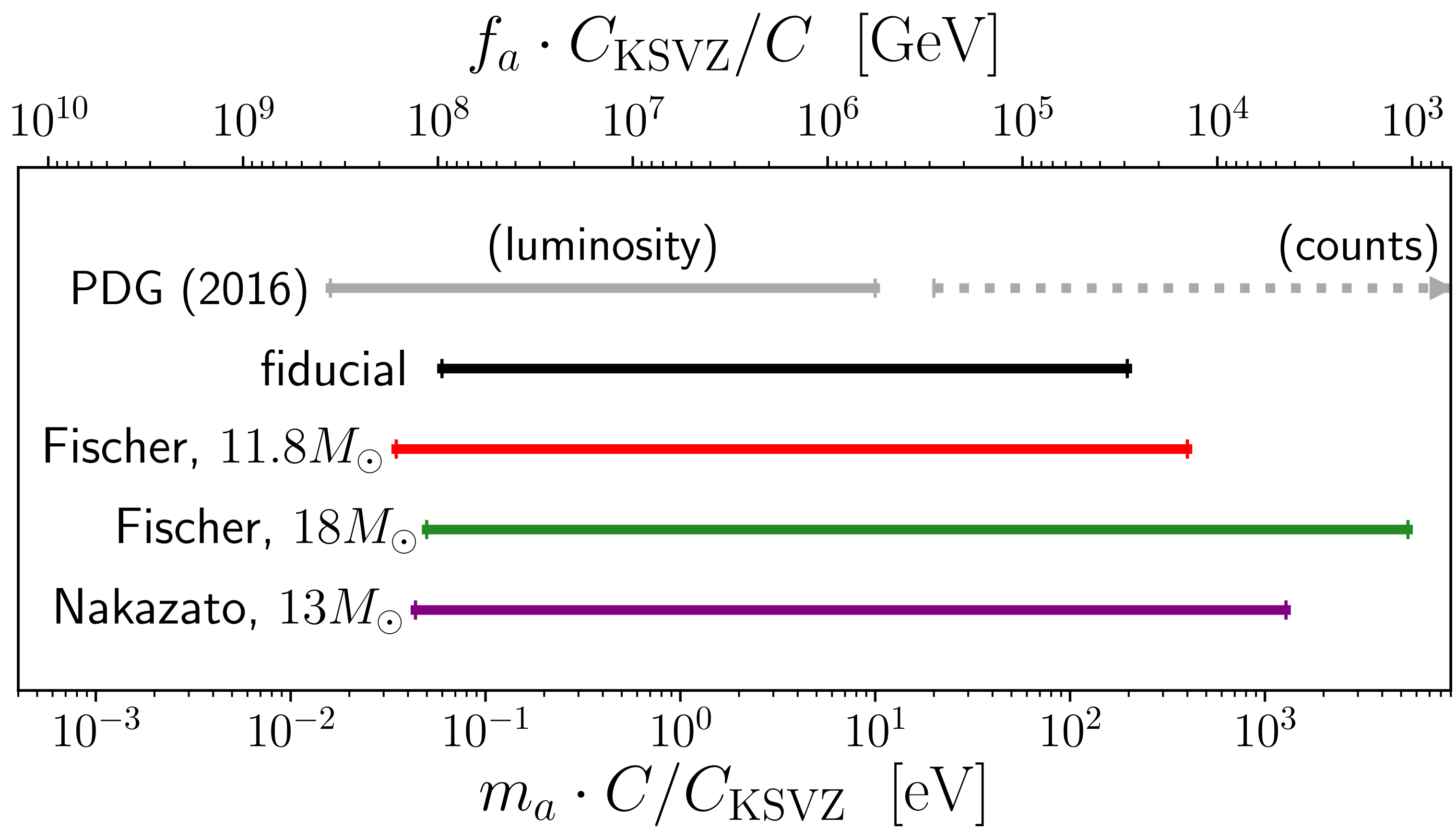
Inelastic Dark Matter



Millicharged Particles

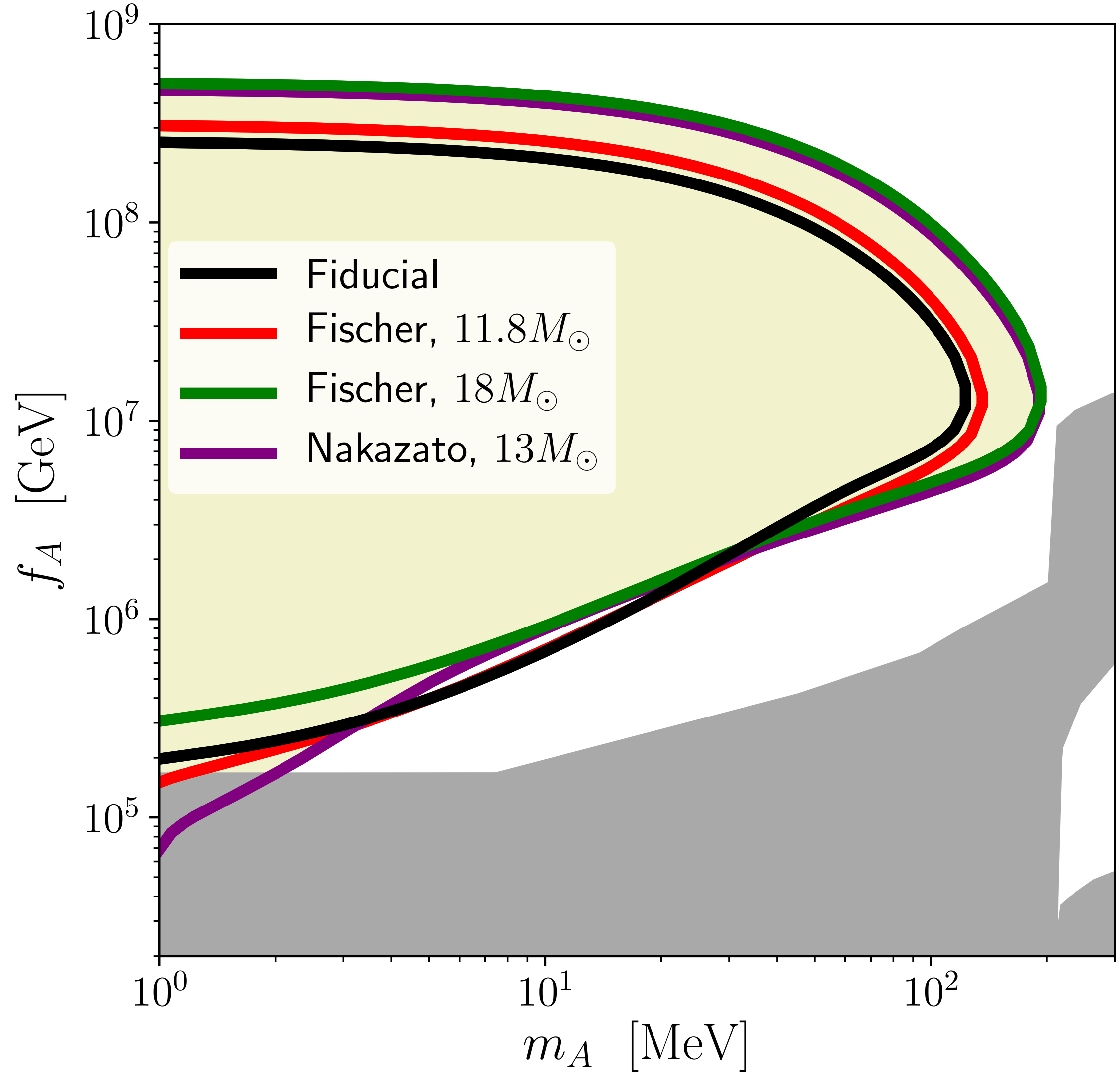


QCD Axions



$f_a \cdot C_{\rm KSVZ}/C$ [GeV]
10^{10} 10^{9} 10^{8} 10^{7} 10^{6} 10^{5} 10^{4} 10^{3}
(luminosity)
(counts)
PDG (2016)
fiducial
Fischer, $11.8 M_\odot$
Fischer, $18 M_\odot$
Nakazato, $13 M_\odot$
10^{-3} 10^{-2} 10^{-1} 10^{0} 10^{1} 10^{2} 10^{3}
$m_a \cdot C/C_{\rm KSVZ}$ [eV]

Axion-like Particles



Conclusion

- Supernova1987A can give constraints on low-mass dark sector particles

- We calculated constraints for various models with thermal effects, which provide reasonable lower bounds for experiment searches

THANK YOU