

# Capture of Dark Matter in Compact Stars

[2004.14888 ] + [2010.13257] + [2012.08918] + [2104.14367] +  
[2108.02525]

G. Busoni

Max Planck Institute for Nuclear Physics

PANIC 2021, 5 Sept 2021

## 1 Why Compact Stars?

- Searching for DM collisions: Direct Detection
- Searching for DM collisions: DM Capture in the Sun
- Searching for DM collisions: DM Capture in Neutron Stars
- Advantages of NS

## 2 From capture in the Sun to NS and WD

- Key differences
- Leptons: highlights and results
- Baryons: highlights and results

## 3 Conclusions

- Summary

## 1 Why Compact Stars?

- Searching for DM collisions: Direct Detection
- Searching for DM collisions: DM Capture in the Sun
- Searching for DM collisions: DM Capture in Neutron Stars
- Advantages of NS

## 2 From capture in the Sun to NS and WD

- Key differences
- Leptons: highlights and results
- Baryons: highlights and results

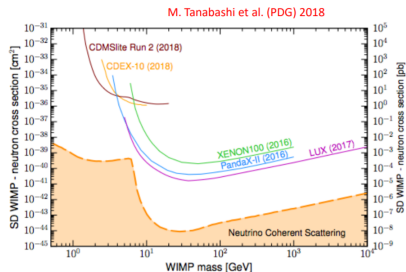
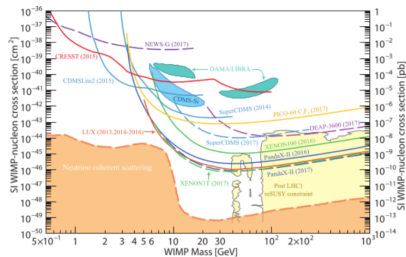
## 3 Conclusions

- Summary

# Searching for DM collisions

## Direct Detection

## Direct Detection



SI interaction give much stronger bounds that SD ones

# Searching for DM collisions

## Direct Detection

- Constraints depend strongly on interaction type
- Strong target dependence
- Some operators are suppressed by kinematics (momentum/velocity suppressed)
- Recoil energy is small, nonrelativistic kinematics
- Experimental detectors have recoil energy thresholds

## 1 Why Compact Stars?

- Searching for DM collisions: Direct Detection
- Searching for DM collisions: DM Capture in the Sun
- Searching for DM collisions: DM Capture in Neutron Stars
- Advantages of NS

## 2 From capture in the Sun to NS and WD

- Key differences
- Leptons: highlights and results
- Baryons: highlights and results

## 3 Conclusions

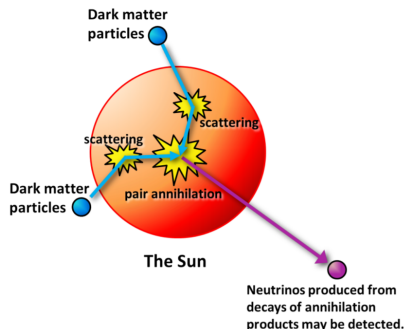
- Summary

# Searching for DM collisions

## DM Capture in the Sun

### DM Capture in Stars

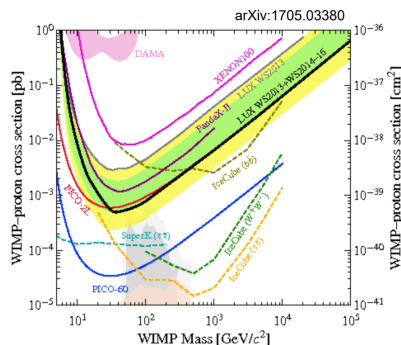
- DM can be captured and accumulate in Stars
- Dark matter scatters, loses energy, becomes gravitationally bound to star
- Accumulates in centre of Sun
- Can potentially annihilate at the center
- At equilibrium  
Capture=Annihilation
- Probes same observables as DD



# Searching for DM collisions

## DM Capture in the Sun

- SI: DD wins
- SD: DM in Sun wins
- DM in Sun requires some few more assumptions, like that it annihilates, and the annihilation channel



Some other ways to infer indirectly DM presence in the Sun: modified energy transport (see 1411.6626 , 1703.07784)



## 1 Why Compact Stars?

- Searching for DM collisions: Direct Detection
- Searching for DM collisions: DM Capture in the Sun
- Searching for DM collisions: DM Capture in Neutron Stars
- Advantages of NS

## 2 From capture in the Sun to NS and WD

- Key differences
- Leptons: highlights and results
- Baryons: highlights and results

## 3 Conclusions

- Summary

# Searching for DM collisions

## DM Capture in NS

- Very large density means very efficient capture
- Whole DM flux can be captured already for  $\sigma \sim 10^{-45} \text{ cm}^2$



# Searching for DM collisions

## DM Capture in NS

### Possible observable signals

- NS to BH collapse (more likely for bosonic DM)
- Gravitational waves: DM increases tidal deformability (1803.03266)
- Kinetic Heating (M. Baryakhtar et al. PRL 119, 131801 (2017) arXiv:1704.01577)
- Kinetic + Annihilation heating (Bramante, Delgado and Martin 1704.01577)

# Searching for DM collisions

## DM Capture in NS

### NS temperature evolution

- NS have no known large heating sources
- Lose energy by neutrino and photon emission
- Neutrino dominates early stages of NS life, photon the late stages
- In absence of other heating sources, one expects  $T \sim 1000K$  after  $10Myr$  and  $T \sim 100K$  after  $1Gyr$
- Kinetic heating: sets an equilibrium temperature of  $T_{eq,th} \sim 1700K$  if whole DM flux is captured
- Kin+Ann heating: equilibrium temperature is raised to  $T_{eq,th} \sim 2400K$

## 1 Why Compact Stars?

- Searching for DM collisions: Direct Detection
- Searching for DM collisions: DM Capture in the Sun
- Searching for DM collisions: DM Capture in Neutron Stars
- **Advantages of NS**

## 2 From capture in the Sun to NS and WD

- Key differences
- Leptons: highlights and results
- Baryons: highlights and results

## 3 Conclusions

- Summary

# Searching for DM collisions

## Advantages of NS

- High capture probability
- DM particles accelerated to  $\mathcal{O}(0.5)c$  means no momentum/velocity suppression
- Cross section of  $\sigma_{th} = 10^{-45} \text{ cm}^2$  enough to reach maximum capture
- No threshold recoil energy
- Similar sensitivity for SI and SD interaction
- Similar sensitivity for momentum/velocity suppressed interactions comparing to unsuppressed ones
- Observation of old cold NS of temperature  $T < T_{eq,th}$ :

$$\sigma \leq \sigma_{th} \left( \frac{T}{T_{eq,th}} \right)^4 \quad (1)$$

## 1 Why Compact Stars?

- Searching for DM collisions: Direct Detection
- Searching for DM collisions: DM Capture in the Sun
- Searching for DM collisions: DM Capture in Neutron Stars
- Advantages of NS

## 2 From capture in the Sun to NS and WD

- Key differences
- Leptons: highlights and results
- Baryons: highlights and results

## 3 Conclusions

- Summary

# From capture in the Sun to NS and WD

## Key differences

- DM Capture in the Sun formalism developed by Gould in the '80
- We adapted this formalism to NS

Sun/Gould+Extensions	NS/Our
Newtonian gravity	GR
Sun structure from Standard Solar Model	NS structure from EOS
Non-relativistic kinematics	Relativistic kinematics
Atomic Nuclei Targets	Baryon and Lepton targets
Non-relativistic matrix element	Relativistic matrix element
MB distribution for targets	FD distribution for targets
Capture probability $\neq 1$	Capture probability $= 1^*$
Star opacity	Star Opacity
MS requires MC approach	MS can be treated analytically
Targets have FF	Targets have FF
Fixed Target mass	Density-dependent Target mass

\* for some masses



# From capture in the Sun to NS and WD

## Key differences

### Our Papers

- 2004.14888 Basics of NS formalism, including GR, EOS, relativistic kinematics/matrix elements/interaction rates, Pauli Blocking effects, Star opacity, Multiple Scattering, for Neutron targets
- 2010.13257 Extension to lepton targets, interaction rates generalised for all Dim 6 EFT operators
- 2012.08918 Baryon Targets have structure and cannot be approximated by free gas
- 2108.02525 Full treatment of baryonic targets, including the above effects
- 2104.14367 Application of formalism to WD (electrons are fully degenerate)

## 1 Why Compact Stars?

- Searching for DM collisions: Direct Detection
- Searching for DM collisions: DM Capture in the Sun
- Searching for DM collisions: DM Capture in Neutron Stars
- Advantages of NS

## 2 From capture in the Sun to NS and WD

- Key differences
- **Leptons: highlights and results**
- Baryons: highlights and results

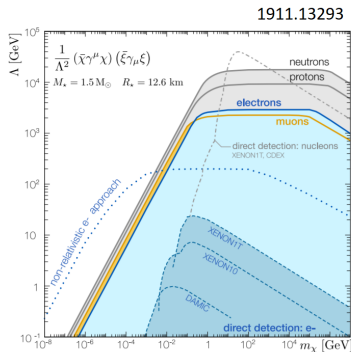
## 3 Conclusions

- Summary

# From capture in the Sun to NS and WD

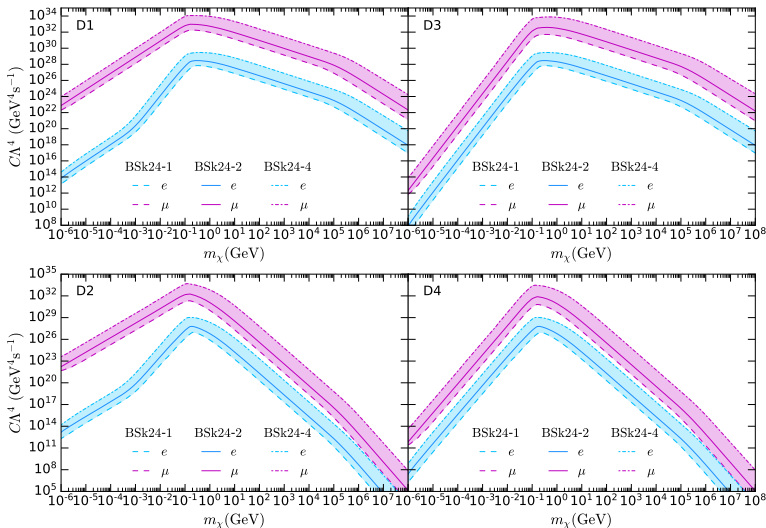
## Leptons: highlights and results

- Very degenerate and relativistic target due to their low mass
- Relativistic treatment is very important for these targets
- Muon targets: also check next talk about them



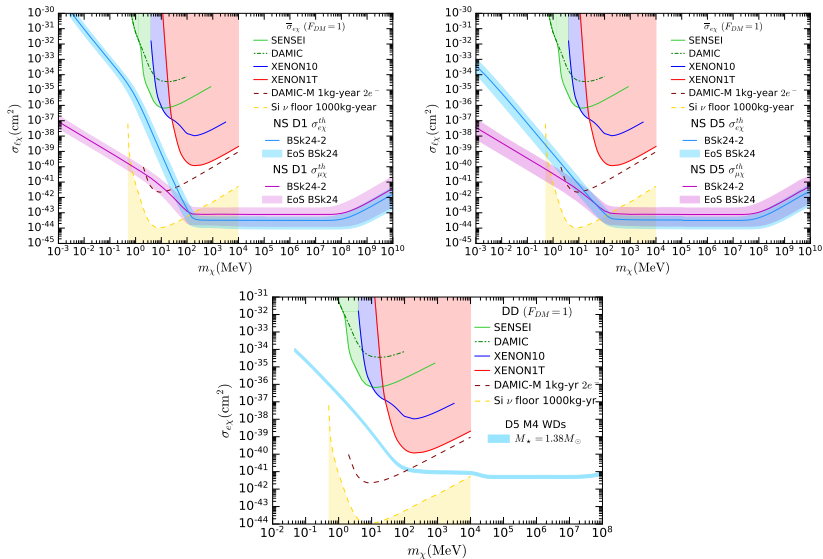
# From capture in the Sun to NS and WD

## Leptons: highlights and results



# From capture in the Sun to NS and WD

## Leptons: highlights and results



## 1 Why Compact Stars?

- Searching for DM collisions: Direct Detection
- Searching for DM collisions: DM Capture in the Sun
- Searching for DM collisions: DM Capture in Neutron Stars
- Advantages of NS

## 2 From capture in the Sun to NS and WD

- Key differences
- Leptons: highlights and results
- **Baryons: highlights and results**

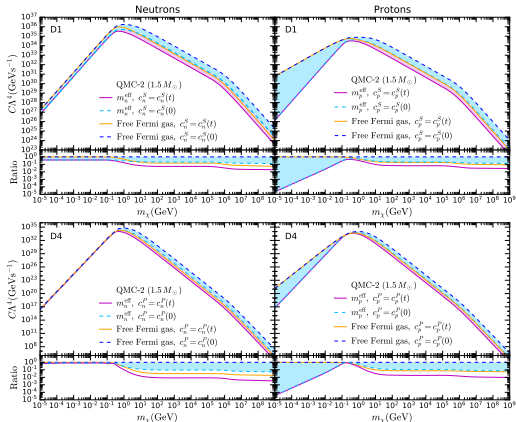
## 3 Conclusions

- Summary

# From capture in the Sun to NS and WD

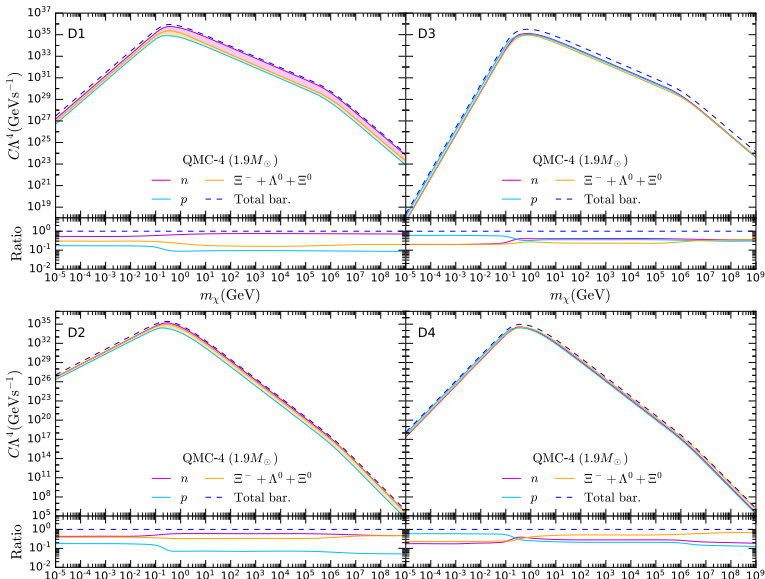
## Baryons: highlights and results

- Baryons are composite particles
- Strong force mean field effects require treatment beyond free Fermi gas



# From capture in the Sun to NS and WD

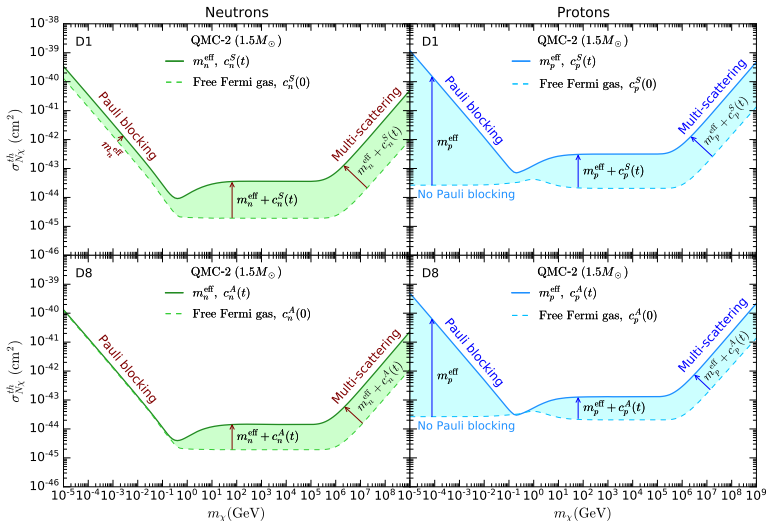
## Baryons: highlights and results





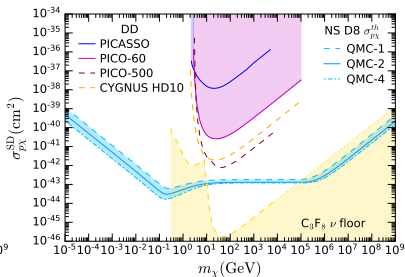
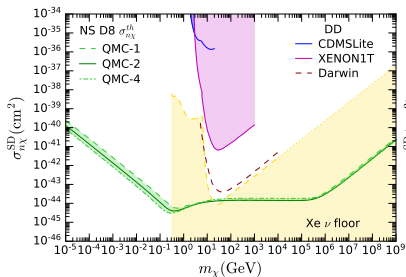
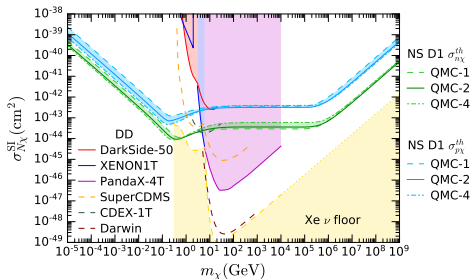
# From capture in the Sun to NS and WD

## Baryons: highlights and results



# From capture in the Sun to NS and WD

## Baryons: highlights and results



## 1 Why Compact Stars?

- Searching for DM collisions: Direct Detection
- Searching for DM collisions: DM Capture in the Sun
- Searching for DM collisions: DM Capture in Neutron Stars
- Advantages of NS

## 2 From capture in the Sun to NS and WD

- Key differences
- Leptons: highlights and results
- Baryons: highlights and results

## 3 Conclusions

- Summary

# Conclusions

## Summary

- Neutron Stars: cosmic laboratory to probe DM scattering interactions
- Completely different kinematic regime to direct detection experiments
- High energy scattering washes away momentum suppression
- Higher reach on inelastic scattering [1807.02840]
- Can probe a very large mass range
- Very sensitive for all interactions, including momentum-suppressed and leptons
- Current coolest NS of  $\mathcal{O}(10^4)K$
- Prospects for observation in the coming decade