Supernova Forecast, Echoes of Supermassive Black Holes and Axion Star Explosions

with Dark Matter Experiments

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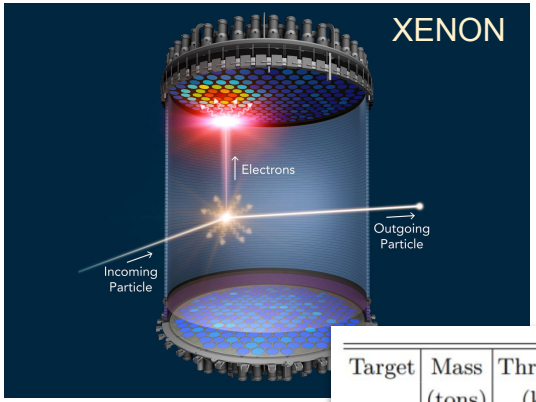
Direct Dark Matter Detection

- Look for interactions of halo DM in detector → nuclear (and electron) recoils

- Typical setup:
  - heavy target (A ~ 30-130)
  - low threshold (~ keV)
  - potentially scalable (Argon, Xenon...)

- Generations: ton-scale → multi-ton



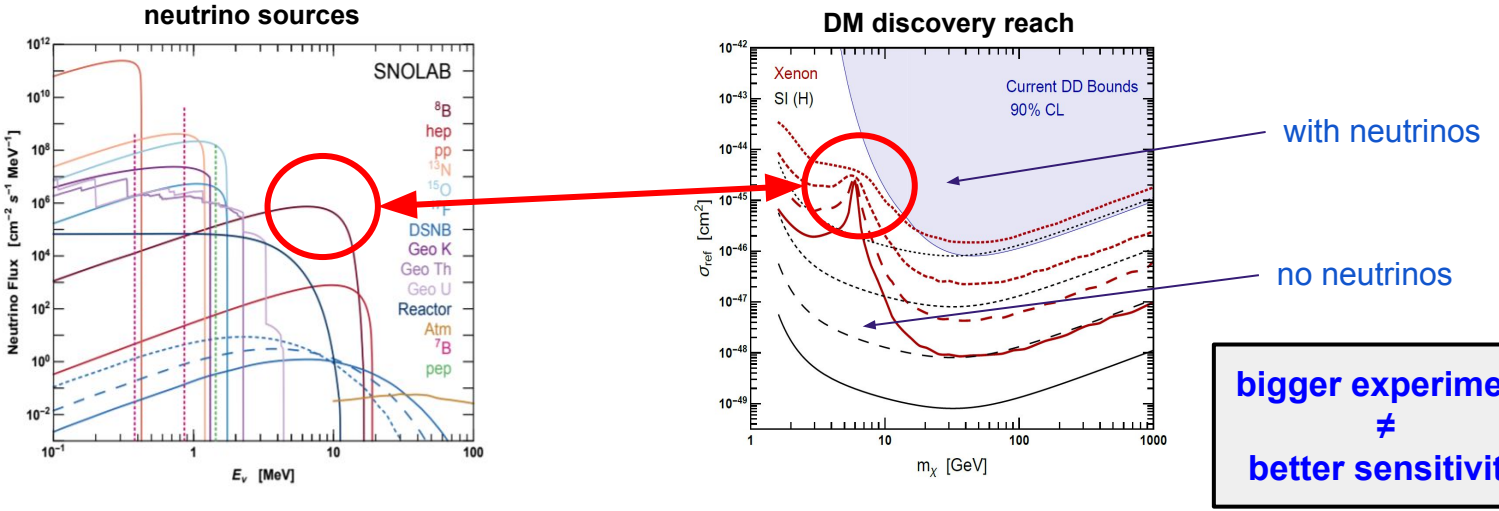
Target	Mass (tons)	Threshold (keV)	Reference
Ar	300	0.6	ARGO
Xe	50	0.7	DARWIN
Pb	2.4	1.0	RES-NOVA

** detection will allow inferring local DM halo properties*
→ first application of "halo independent" analysis to electron-scattering

[Chen, Gelmini, **Takhistov**, 2021]

Neutrino-DM Connection

- Probing deeper, big DM experiments will encounter contamination from neutrinos (Sun, supernovae, Earth, cosmic rays…) → *"neutrino floor"* via coherent scattering (CEνNS)



- **Problem for DM searches, but opportunity for neutrinos**

[Gelmini, **Takhistov**, Witte, 2018]

(also [Billard, Strigari, Figueroa-Feliciano, 2013; others])

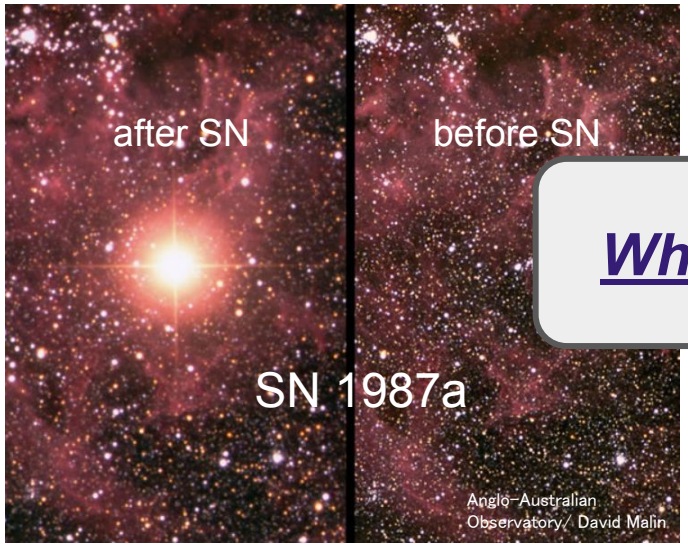
New Window into Astronomy with Dark Matter Labs

Supernova Forecast

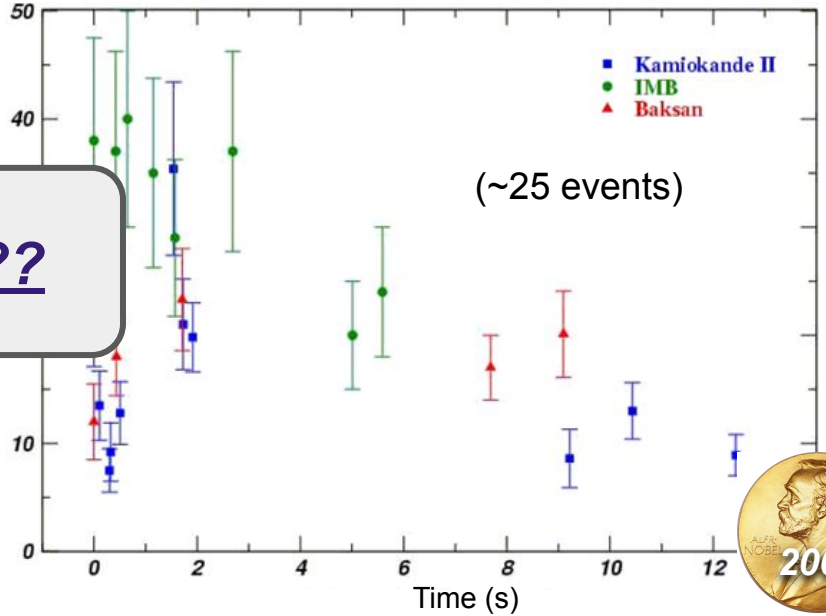
Historic ν-Astronomy Breakthrough: SN 1987a

- Core-collapse SN: most energy released as neutrinos → mechanism confirmed by SN1987a

Optical



Neutrinos

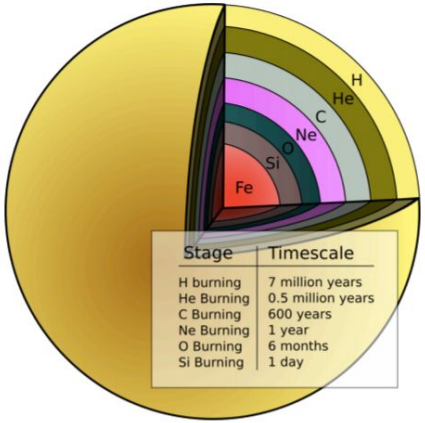


When ???

- Many unknowns → ***hunt for ν's from next Galactic SN (rate ~1/30 yrs) a major target***

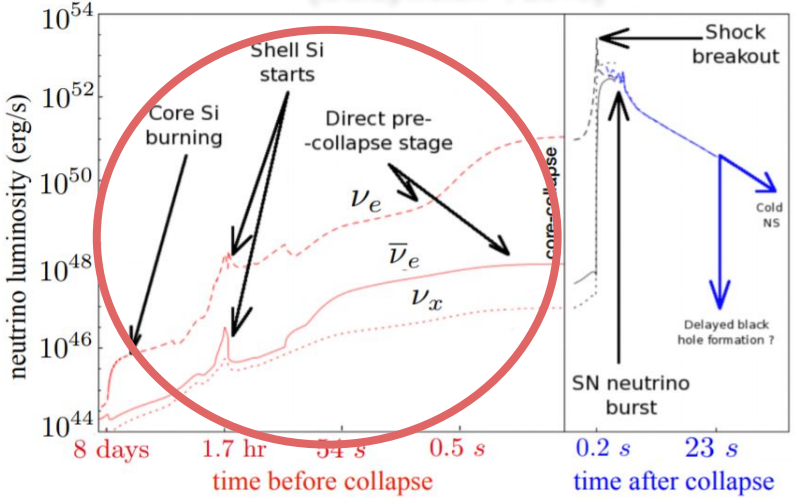
Last Stages of Stellar Evolution

- Dying star rapidly changes composition → ⬆️ density/temperature → ⬆️ ν-emission



A. C. Phillips, *The Physics of Stars, 2nd Edition* (Wiley, 1999)

[Odrzywolek+, 2010]



- Pre-SN neutrinos are low-energy (~ few MeV) → **opportunity for dark matter labs**

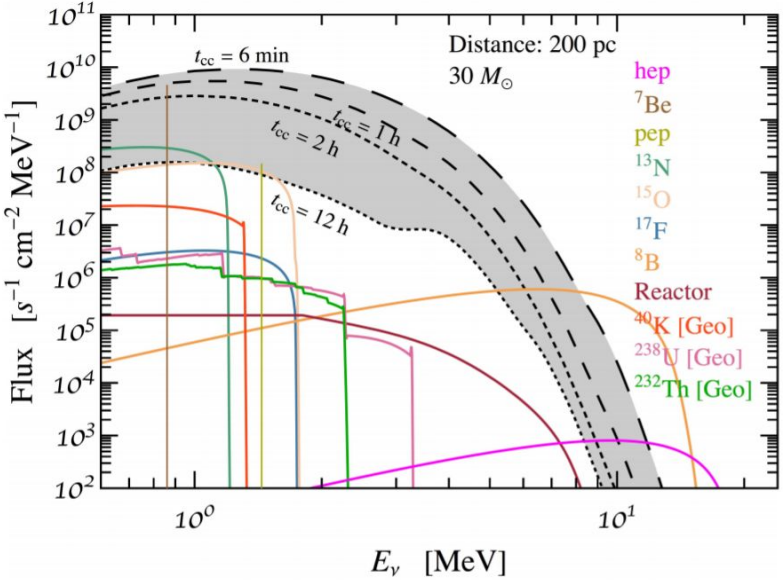
** Super-Kamiokande will see hundreds of events from Betelgeuse before SN*

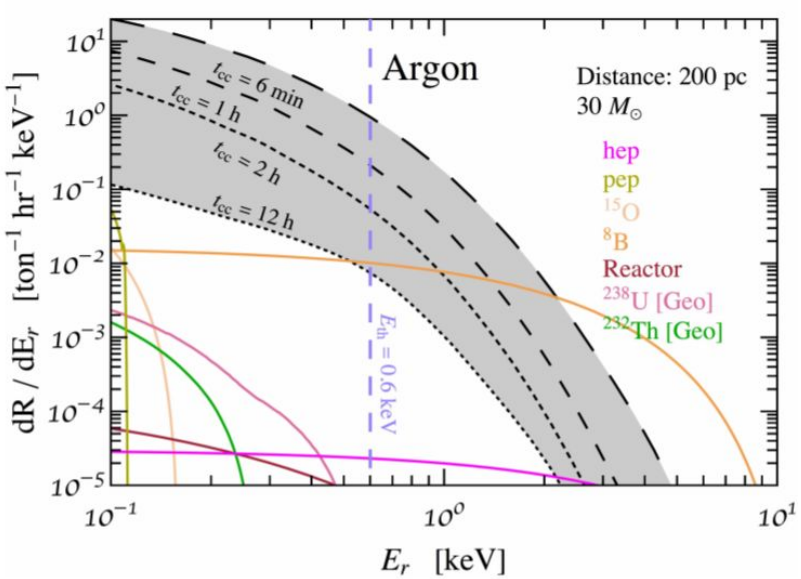
Supernova Forecast with Pre-Supernova Neutrinos

neutrino flux

@ Betelgeuse (0.2 kpc)

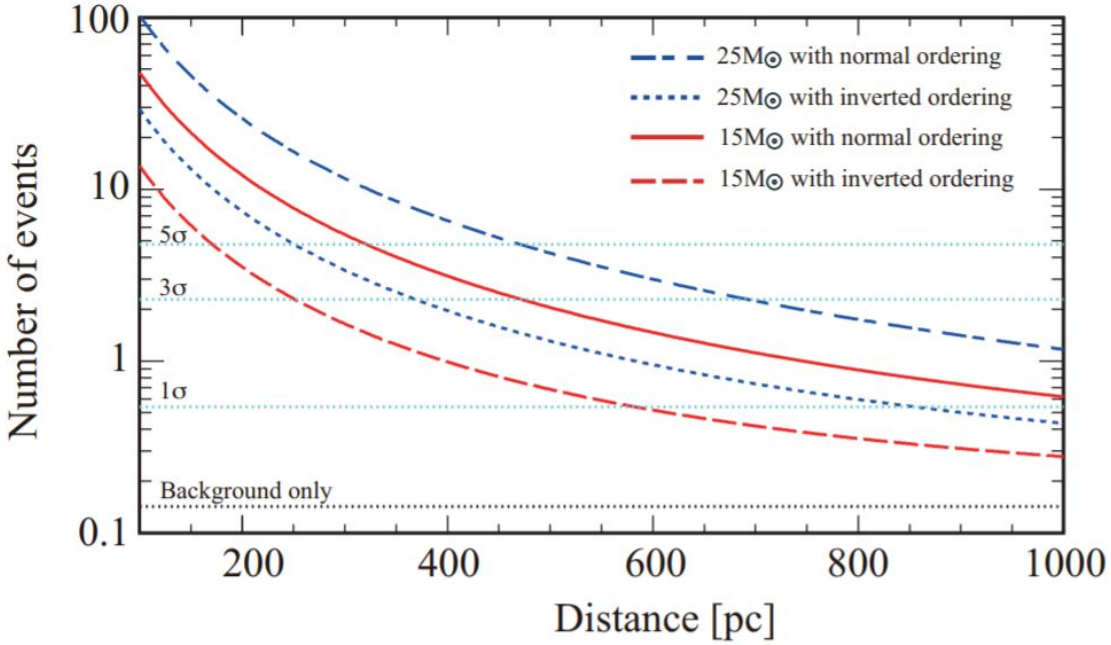
nuclear recoils





[Raj, **VT**, Witte, 2019]

Do Not Suffer Oscillation Effects



[Asakura+ (KamLAND), 2015]

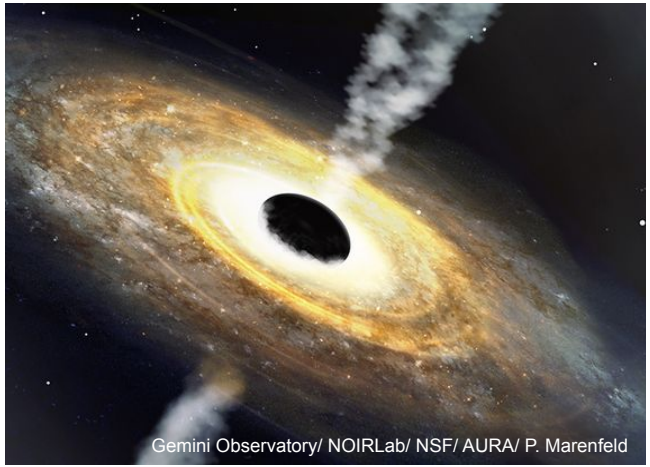
New Window into Astronomy with Dark Matter Labs

Unravelling the Origin of Supermassive Black Holes

Supermassive Black Holes

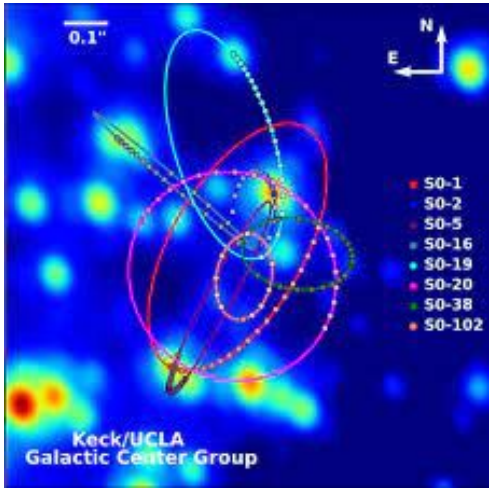
quasars

$(M_{\rm BH} \sim 10^9 M_\odot)$



galactic centers

$(M_{\rm BH} \sim 10^6 M_\odot)$



Milky Way

Where do huge BHs come from? → major problem

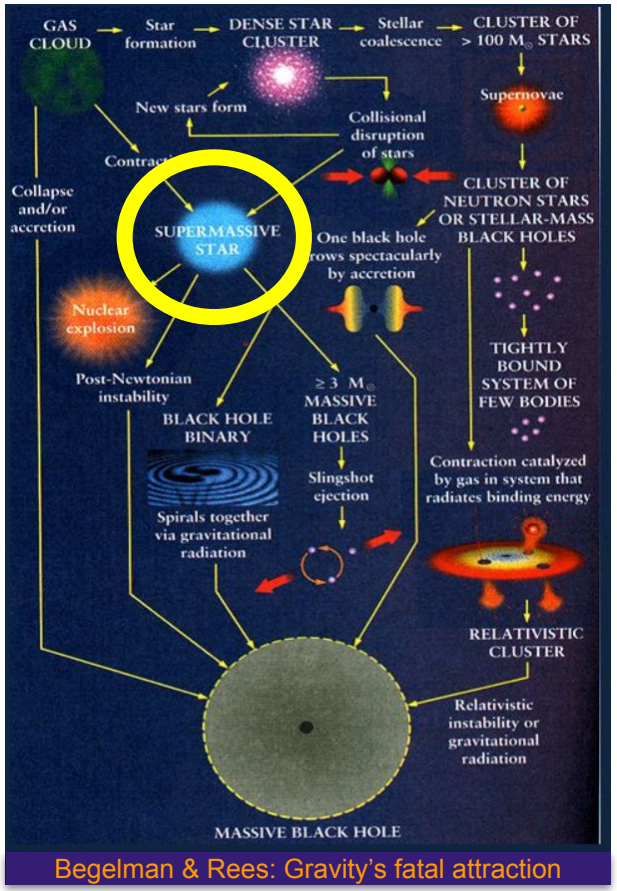
** primordial BHs?* [Kusenko, Sasaki, Sugiyama, Takada, **Takhistov**, Vitagliano, *Phys.Rev.Lett.*, 2020]

Supermassive Black Holes from Supermassive Stars (SMS)

- Even with vigorous feeding, hard to grow huge BH
  → easy if start with sizable “seed”

- Pathways predict ($\gtrsim 10^4\ M_\odot$) supermassive stars

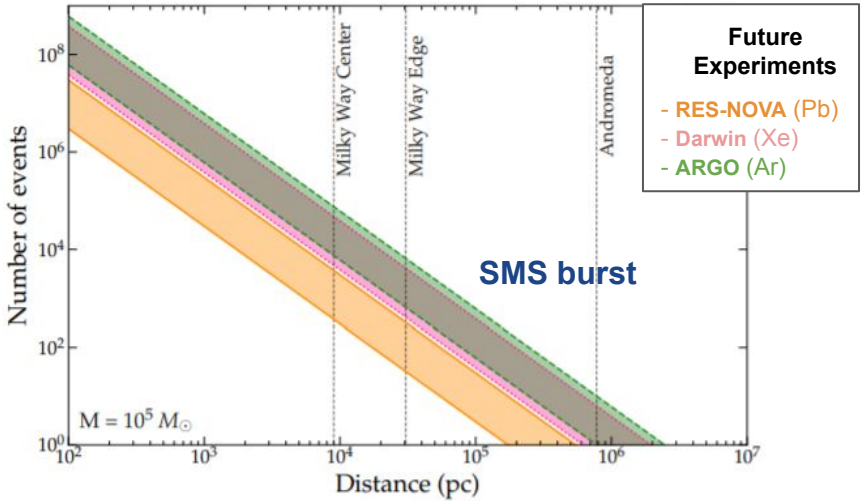
How to test ?

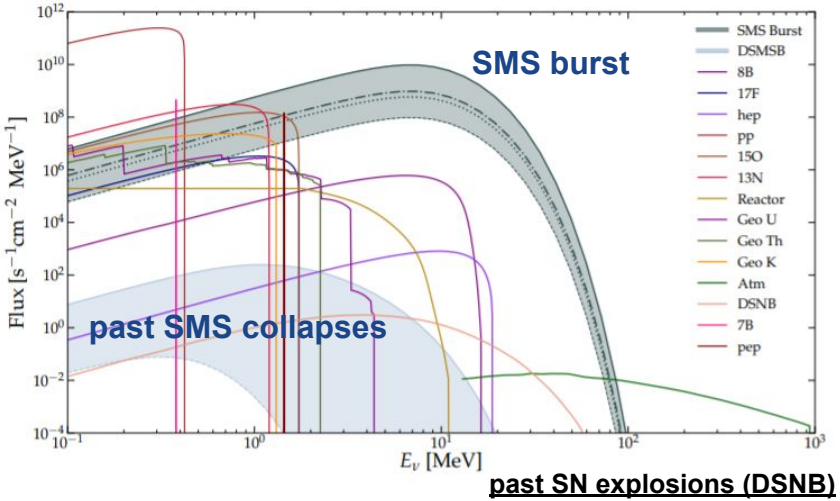


Begelman & Rees: Gravity’s fatal attraction

SMS Neutrinos in Dark Quantum Labs

- SMS collapse releases enormous total energy in neutrinos (~ 10^4 x supernova) [Shi, Fuller, 1998]
- Individual neutrinos low energy → big DM experiments can easily detect





past SN explosions (DSNB)

- **Neutrinos from past SMS collapses pose novel contamination source for DM !**

[Munoz, **Takhistov**, Witte, Fuller, 2021]

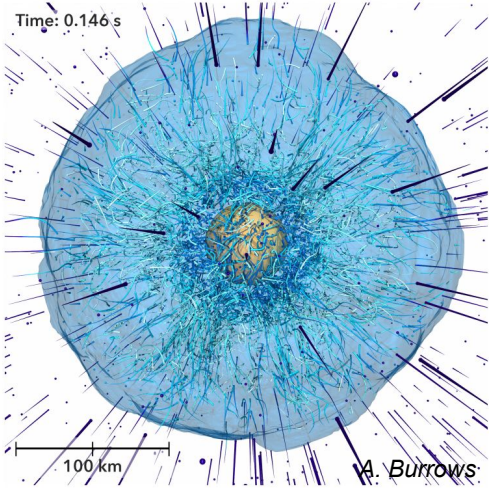
Neutrinos are Wonderful Teachers …

Axion Astronomy, a Neutrino Analogy

Higgstan.com

- Axions well motivated (CP, fundamental theory…see [Ellis+, 2021] review)
  → usual experiments focus on non-relativistic axion DM

- Novel direction: **axion astronomy with transients**… *take lessons from neutrinos*

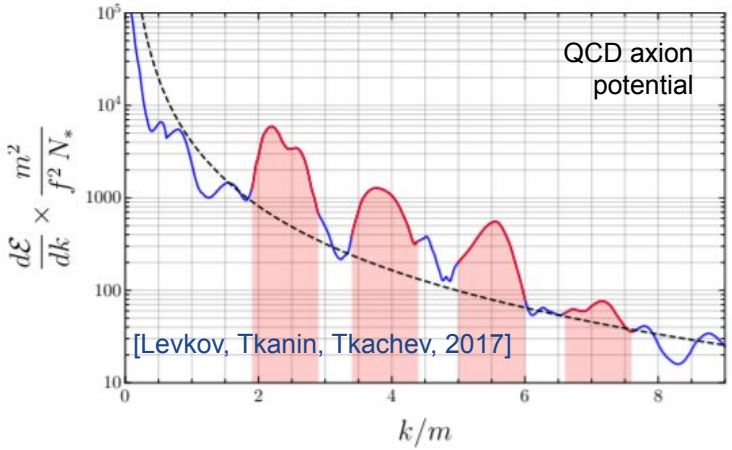


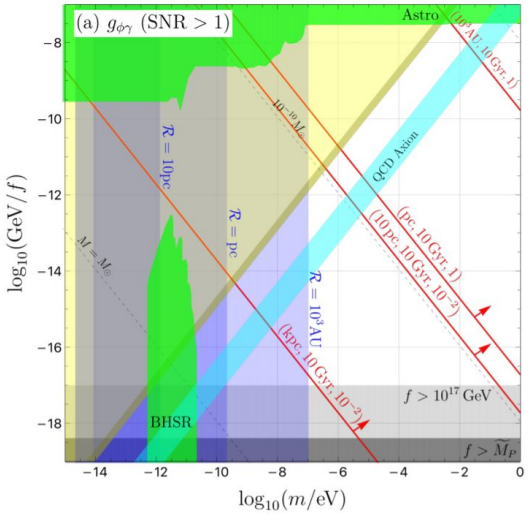
Neutrino Burst (transients: SN, SMS, mergers...)	⟷	**Axion Burst** (transients: axion star explosion, BH bombs, mergers...)
Diffuse Neutrino Background (historic transients)	⟷	**Diffuse Axion Background** (historic transients)

[Eby, Shirai, Stadnik, **Takhistov**, 2021]

Axion Star Explosions

- Axion stars can arise within e.g. minicluster “clouds” [Kolb, Tkachev, 1993]
- With self-interactions, collapsing stars burst in relativistic axions (bosenova)





- **New signatures, could lead to insights into the fundamental axion potential !**

[Eby, Shirai, Stadnik, **Takhistov**, 2021] * *axion star collapse also* [Fairbairn+, 2019] *…microlensing signals* [Fairbairn+, 2017]

Concluding Remarks

- Tackling **Big multi-faceted questions** requires broad perspective and exploiting connections between historically distinct fields (cosmology, particle physics, astrophysics…)

- Interplay and complementarity between dark matter and neutrino experiments

→ Neutrinos serve as a guiding ghostly light for discoveries in multi-messenger era !