New Window into Neutrino Astronomy with Dark Matter Experiments

Supernova Forecast and Origin of Supermassive Black Holes

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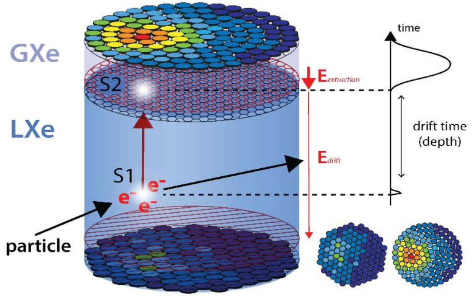
Large Direct Dark Matter Detection Experiments

- Look for particle DM interactions in detector → nuclear (electron) recoils

- Typical setup:
  - heavy target material (A ~ 40-130)
  - very low threshold (~ keV)
  - potentially scalable (Argon, Xenon)



XENON1T

- Generation-2: ton-scale

  → Generation-3: multi-ton scale

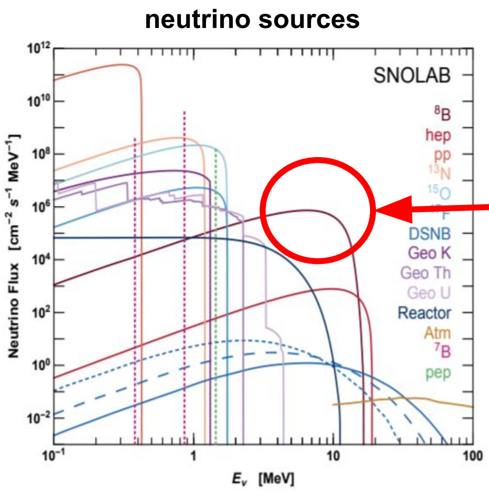
forward-looking benchmarks

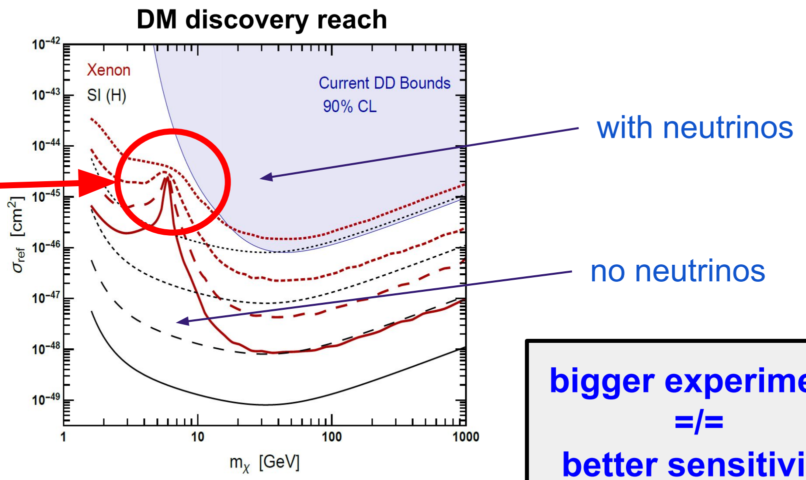
Target	Mass (tons)	Threshold (keV)	Reference
Ar	300	0.6	ARGO
Xe	50	0.7	DARWIN

Neutrino-DM Connection

- Probing DM deeper, experiments will encounter irreducible neutrino background
  → "neutrino floor" [Strigari, Figueroa-Feliciano, ...]

[Gelmini, **VT**, Witte, JCAP, 1804.01638]



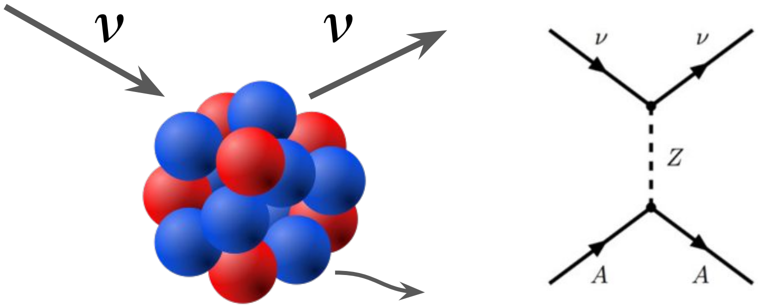


bigger experiment
=/=
better sensitivity

- Important to consider target complementarity and different DM interactions

Magnificent CEνNS

- Coherent elastic neutrino-nucleus scattering (CEνNS) - interaction with a whole nucleus
- Proposed 40+ years ago [Freedman] → recently observed [Akimov+ (COHERENT), *Science*, 2017]
- Dominant neutrino interaction for E$\nu \lesssim$ 50 MeV
- **Features:**
  - all neutrino-flavor sensitivity
  - x-section scales as $\sigma \sim N^2$



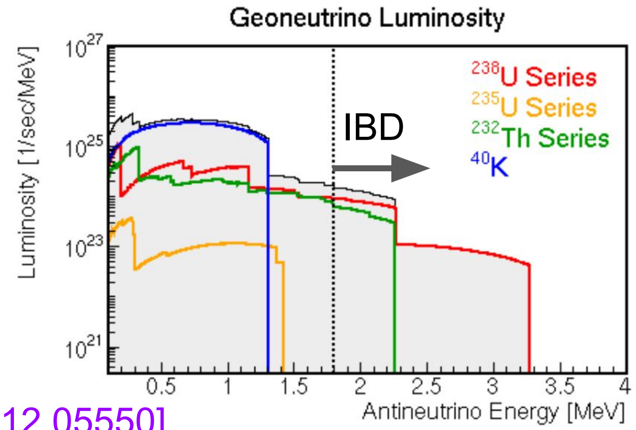
→ a new window into neutrinos and new physics

[Machado, Kopp, Lindner, Scholberg, Strigari, Dutta, Shoemaker, Denton…]

DM Experiments as Neutrino Telescopes

- *CEνNS a problem for DM, but an opportunity for neutrinos*
  → DM experiments as **"effective neutrino telescopes"** (see also [Tamborra, Strigari, Horiuchi...])

- Complementarity with conventional neutrino experiments
  - enhanced coherent scattering
    → bypass IBD ($\overline{\nu}_e + p \rightarrow n + e^+$) threshold
    → probe all ν-flavors
  - very low energy threshold



→ **gain access to unexplored regimes**
Example: geo-neutrinos [Gelmini, **VT**, Witte, PRD, 1812.05550]

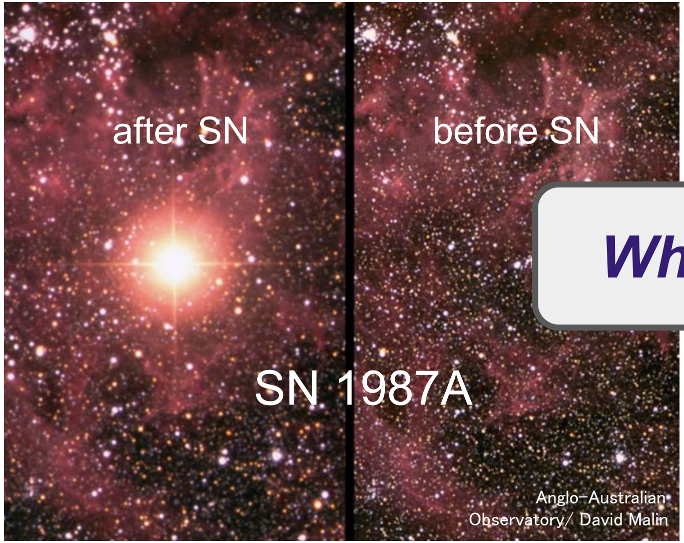
New Astronomy Window from Dark Labs

Supernova Forecast

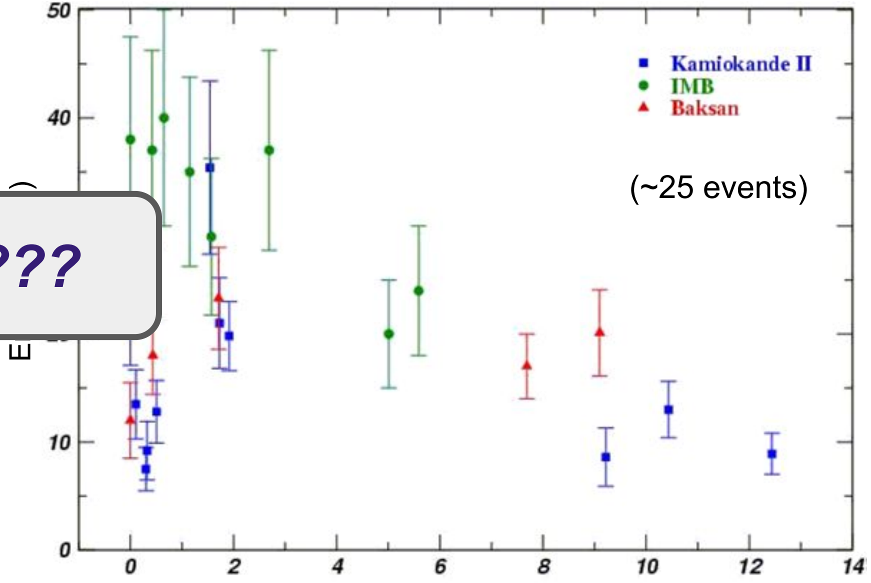
Historic ν-Astronomy Breakthrough: Supernova 1987A

- Core-collapse SN: most energy released as neutrinos → confirmed by SN1987A

optical



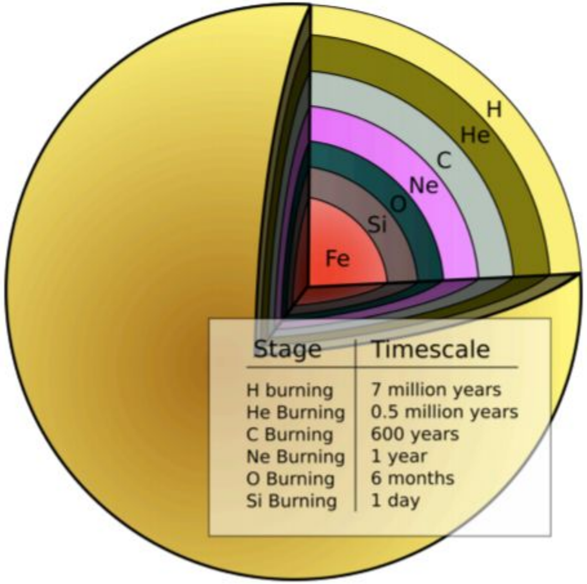
neutrinos



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

Last Stages of Stellar Evolution

- Fast changes in composition
- Increase of density/temperature
- Increase of neutrino emission



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

Supernova Forecast with Pre-Supernova ν's

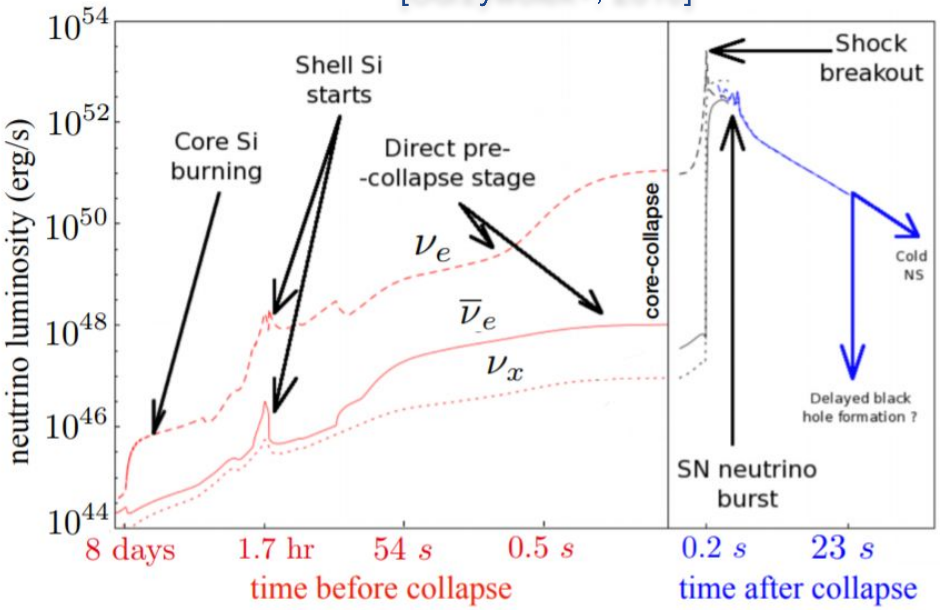
Super-K-Gd will see hundreds ν's within ~day before SN @ Betelgeuse (0.2 kpc)

(...also KamLAND)

[Simpson+ (Super-K), 2019]

→ *complementarity*

[Odrzywolek+, 2010]

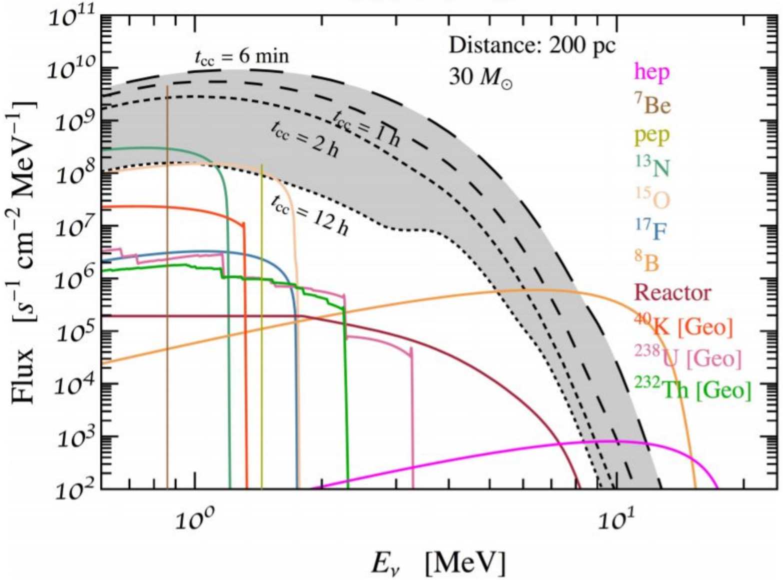


- Pre-SN neutrinos are low-energy (~ few MeV) → ***new opportunity for CEνNS!***

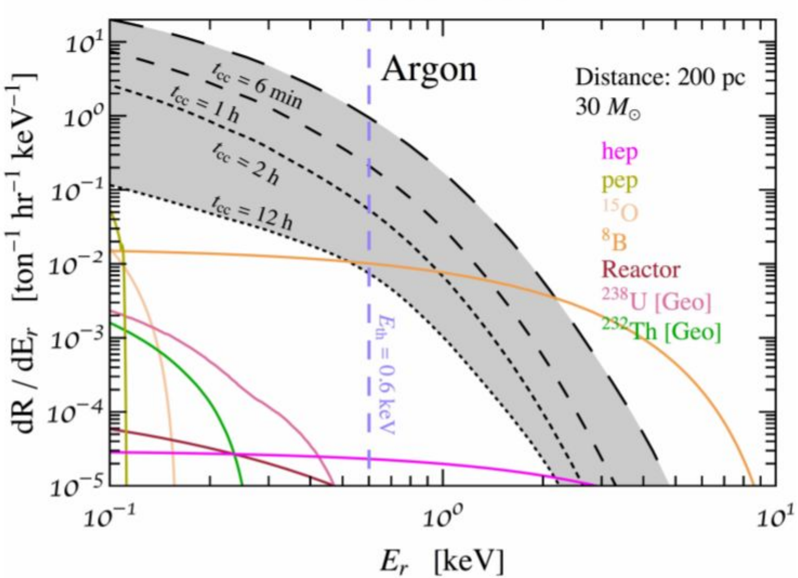
Pre-SN ν's in DM Labs: Signal

@ Betelgeuse (0.2 kpc)

neutrino flux

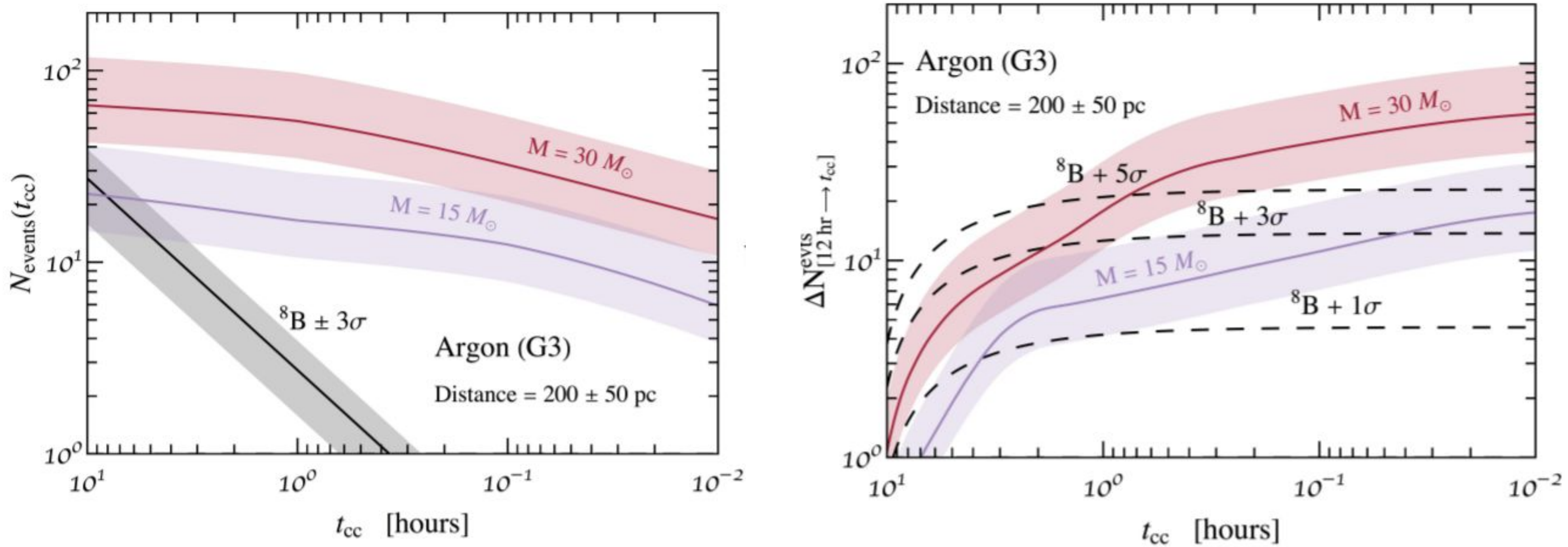


nuclear recoils



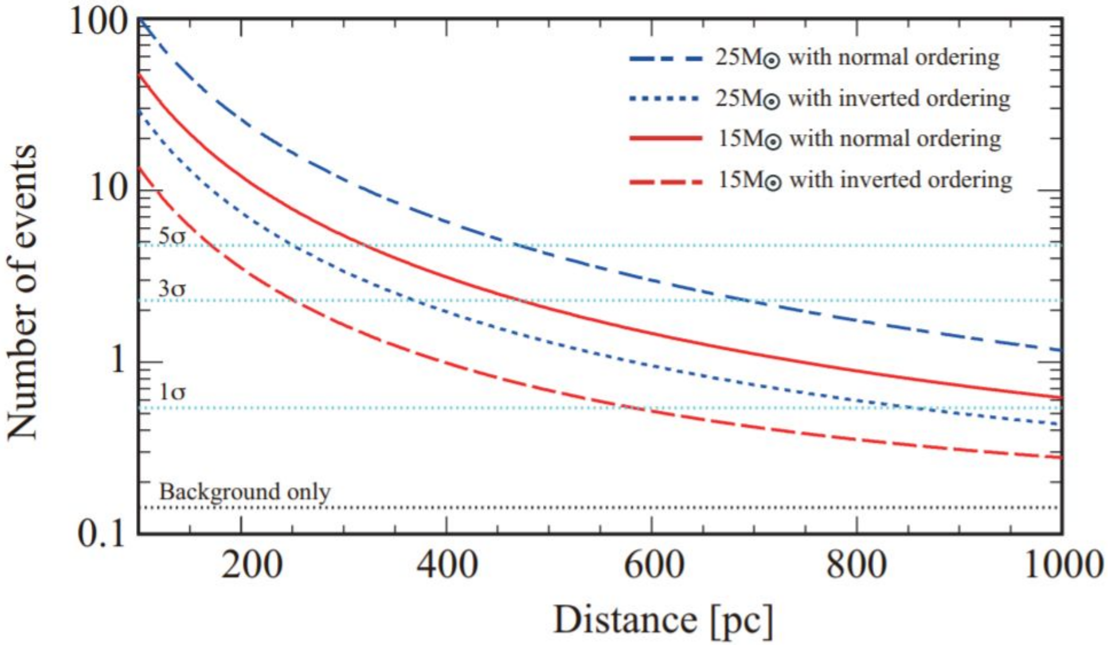
[Raj, **VT**, Witte, PRD, 1905.09283]

Pre-SN ν's in DM Labs: Detection



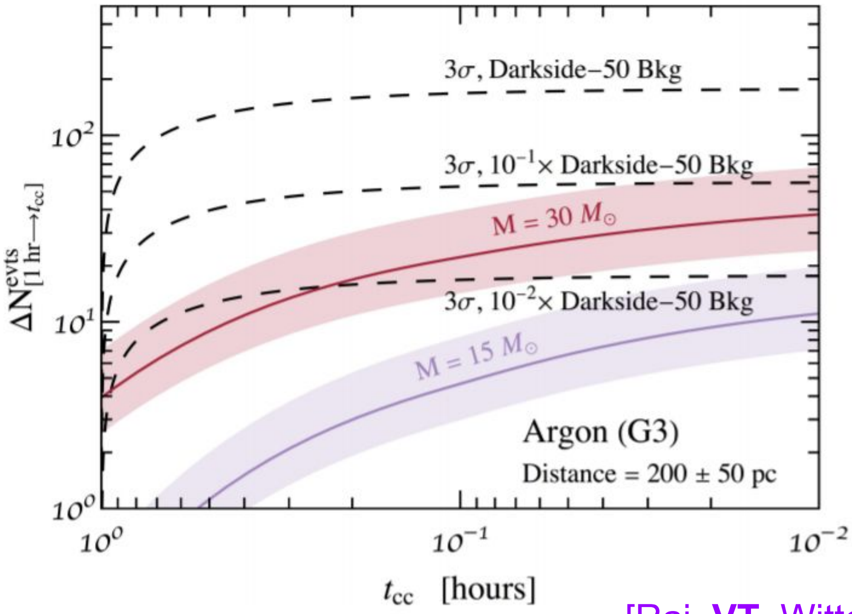
[Raj, **VT**, Witte, PRD, 1905.09283]

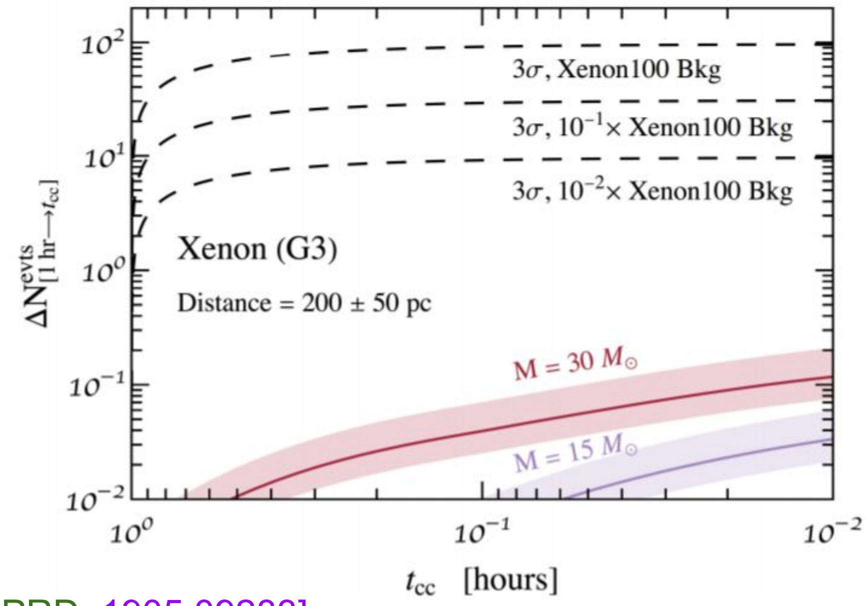
Do Not Suffer Oscillation Effects



[Asakura+ (KamLAND), 2015]

Work on Non-neutrino Background Essential





[Raj, **VT**, Witte, PRD, 1905.09283]

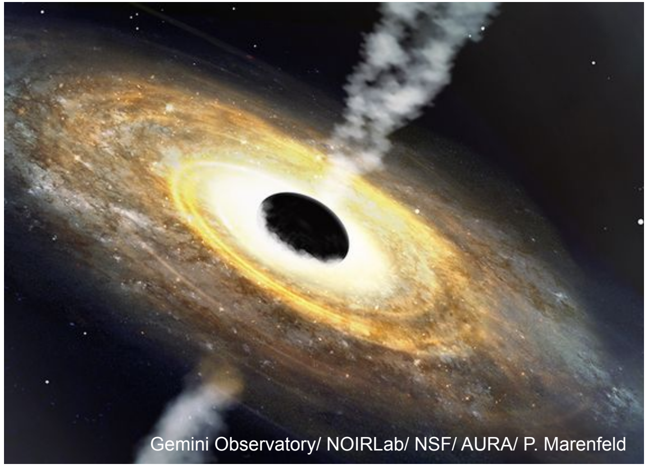
New Astronomy Window from Dark Labs

Unravelling Origin of Supermassive Black Holes

Supermassive Black Holes

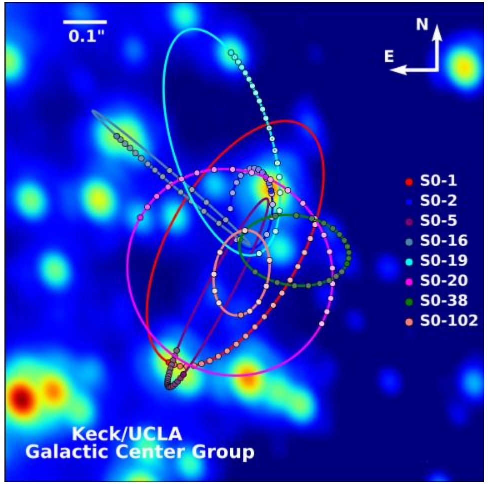
quasars

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



galactic centers

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



Milky Way

Where do huge BHs come from?

→ **<u>major problem</u>**

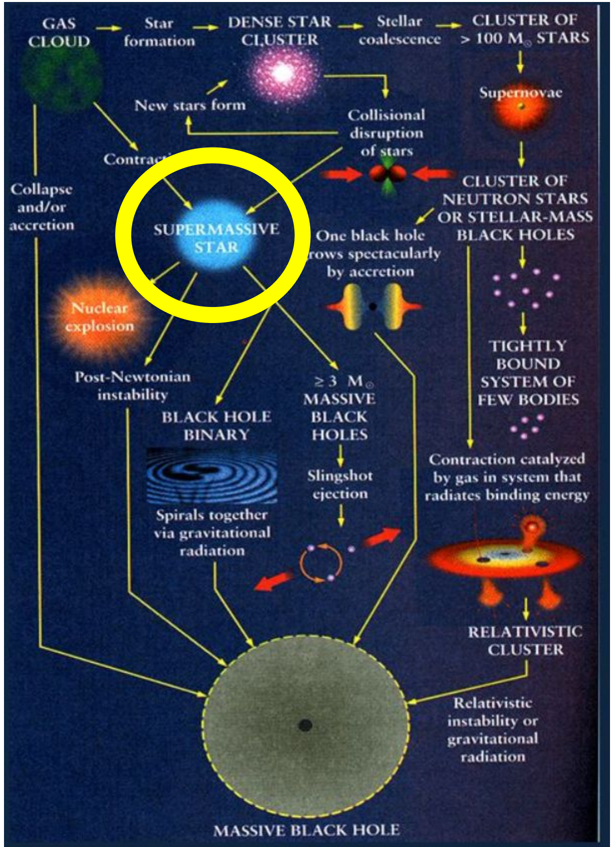
Supermassive Black Holes from Supermassive Stars (SMS)

- 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 ?

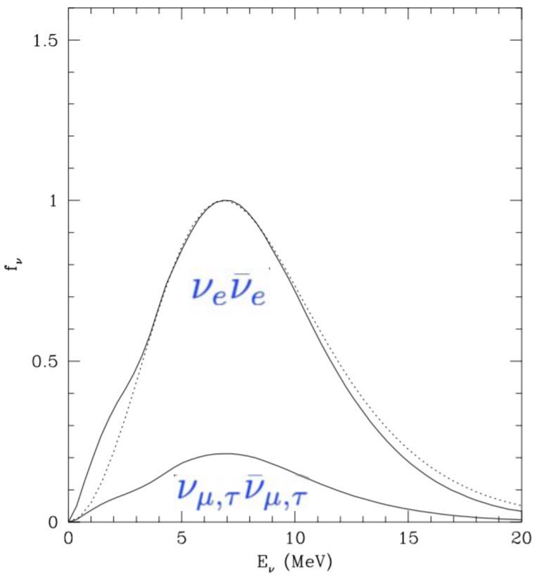
*** seed could also be primordial BH from early Universe
(e.g. [Kusenko, Sasaki, Sugiyama, Takada, **VT**, Vitagliano, PRL, 2001.09160])

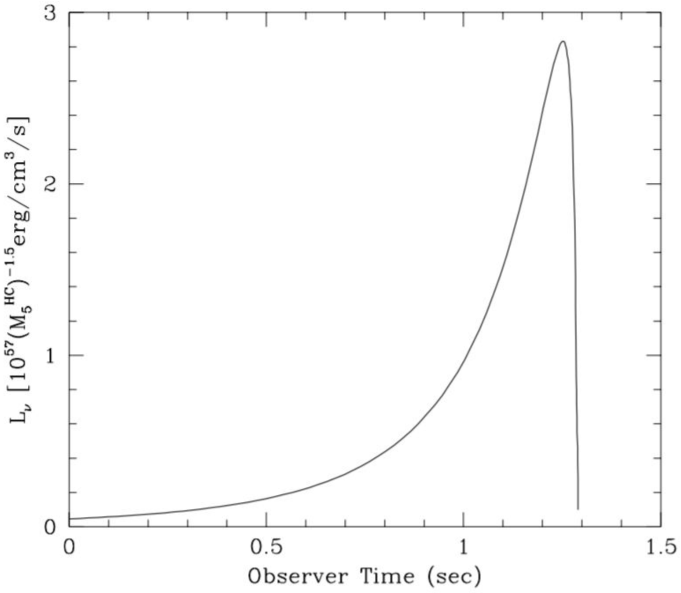


Begelman & Rees: Gravity's fatal attraction

Neutrinos from SMS Collapse

- SMS collapse releases enormous energy in neutrinos ~ (several orders x supernova)





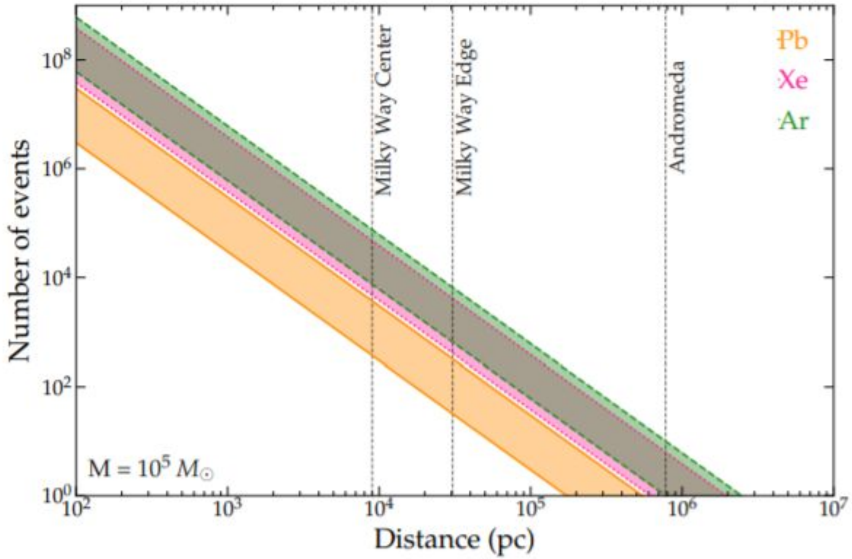
[Shi, Fuller, 1998]

...however, neutrinos are low energy, also redshifted *(unknown, follows quasars?)*

Neutrinos from SMS Collapse

- Exploit CEνNS to catch low-energy neutrinos with DM experiments (complementary to a search in neutrino experiments [Shi, Fuller, 1998; Shi, Fuller, Halzen, 1998])

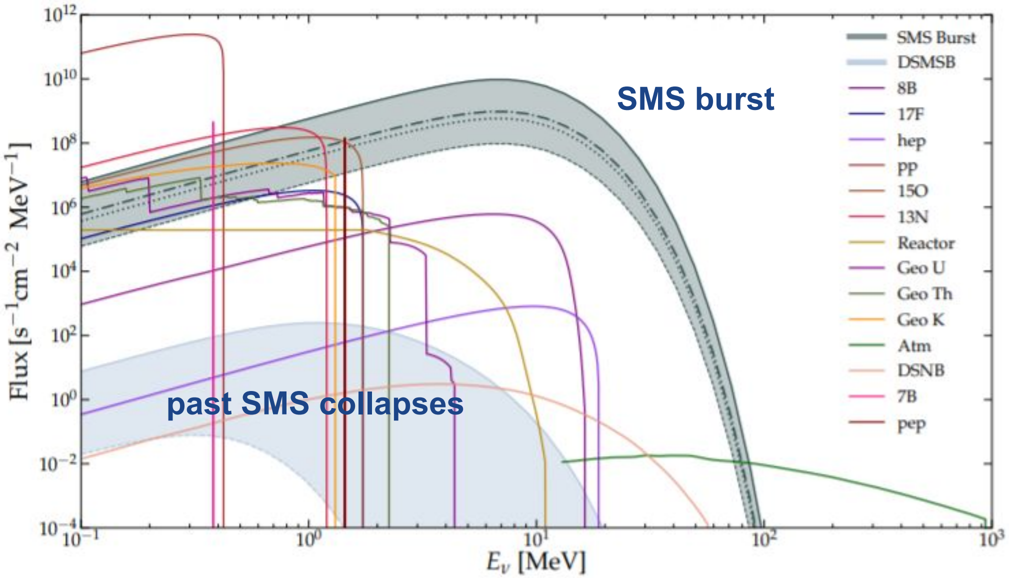
SMS burst



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

[Munoz, **VT**, Witte, Fuller, 2102.00885]

New Contribution to Diffuse Neutrino Background

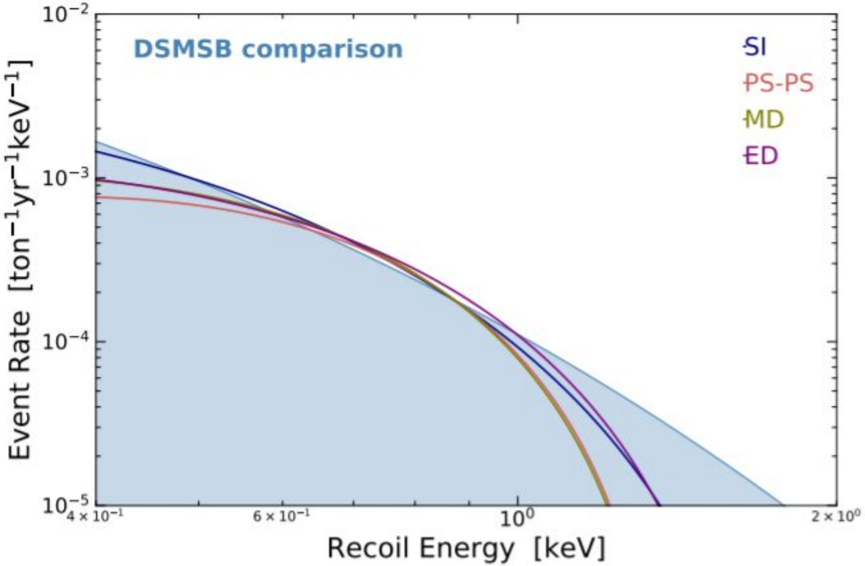


*** past SN neutrinos (DSNB)
Super-K goal
- see talk by M. Smy

- Additional potential source of background for DM searches !

[Munoz, **VT**, Witte, Fuller, 2102.00885]

New DM Background



Significant uncertainty

Model	Mass (GeV)	σ (cm^2)
SI	4.34	1.02×10^{-50}
ED	4.15	4.41×10^{-48}
MD	3.79	2.18×10^{-42}
PS	3.79	1.42×10^{-41}

[Munoz, **VT**, Witte, Fuller, 2102.00885]

Conclusions

- CEνNS open a new exciting window for neutrino astronomy
- Future large DM experiments well positioned to exploit CEνNS
  $\rightarrow$ *effective neutrino telescopes*
- New opportunities to explore fundamental astronomical problems in a complementary way with conventional neutrino experiments