Astronomy in the Lab

Supernova Forecast and

Origin of Supermassive Black Holes

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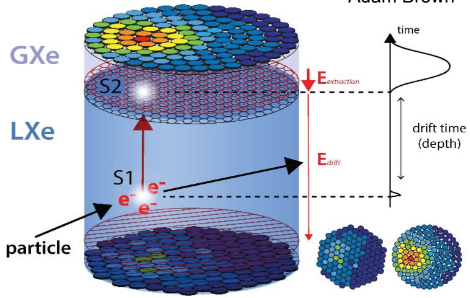
Large Direct Dark Matter Detection Experiments

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

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

Adam Brown



Xenon1T

- Generation-2: ton-scale

  → Generation-3: multi-ton scale

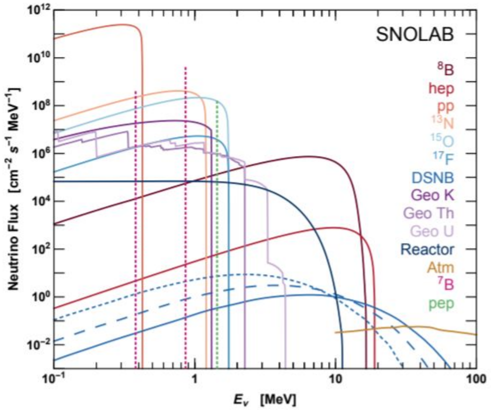
benchmark

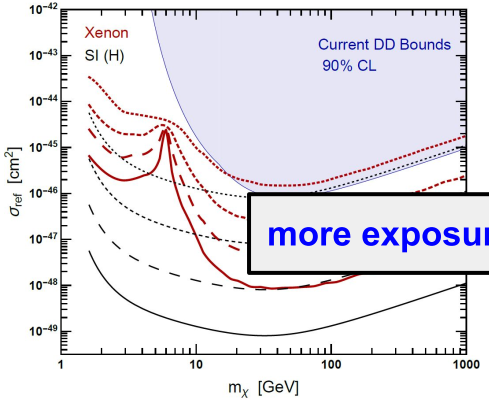
Target	Mass (tons)	Threshold (keV)	Reference
Ar	300	0.6	ARGO
Xe	50	0.7	DARWIN

Neutrino Floor

- No convincing signs of DM yet → probe further   ** exciting excesses keep community vigorous*

- Eventually will encounter irreducible neutrino-background from CEνNS
  → *"neutrino floor"*





more exposure =/= good sensitivity

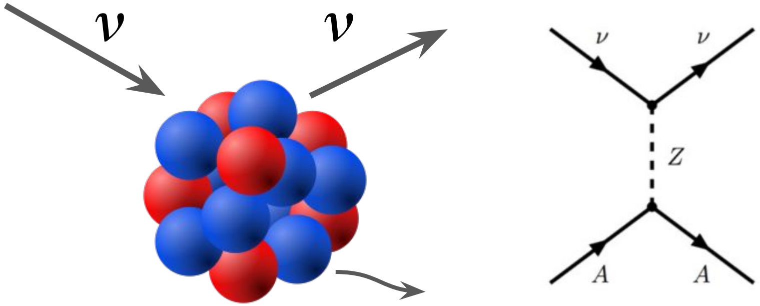
- Important to consider target complementarity and different DM interactions

[Gelmini, **VT**, Witte, 2018]

see [Strigari, Dutta, Dent, Lang, Billard, O'Hare...]

Magnificent CEνNS

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



→ big "*new*" window into ν's as well as new physics

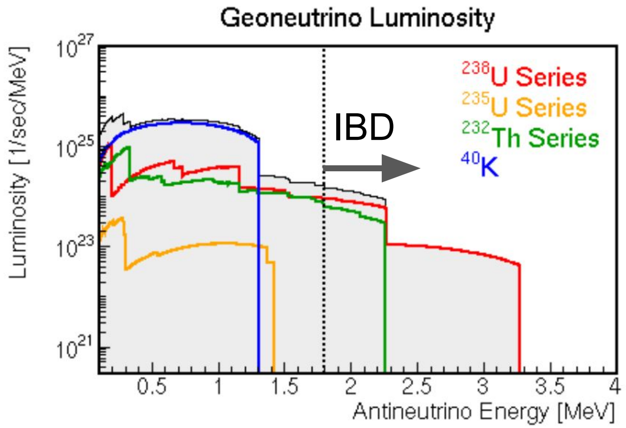
[Scholberg, Dent, Strigari, Dutta, Lindner, Shoemaker, Denton, Kim, Newstead…]

Dark Matter Experiments as Neutrino Telescopes

- CEvNS a curse for DM detection, but a blessing for neutrino physics!
  → big DM experiments as "effective neutrino telescopes"

- Complementarity with conventional neutrino experiments
  - enhanced coherent scattering
    → bypass IBD threshold
    → probe all ν's flavors
  - very low energy threshold

→ **gain access to unexplored regimes**
Example: geo-neutrinos [Gelmini, **VT**, Witte, 2018]



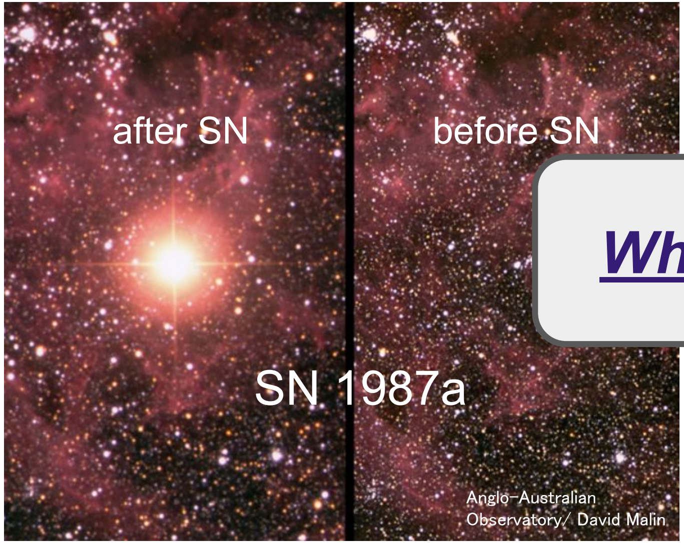
Astronomy in the Lab

Supernova Forecast

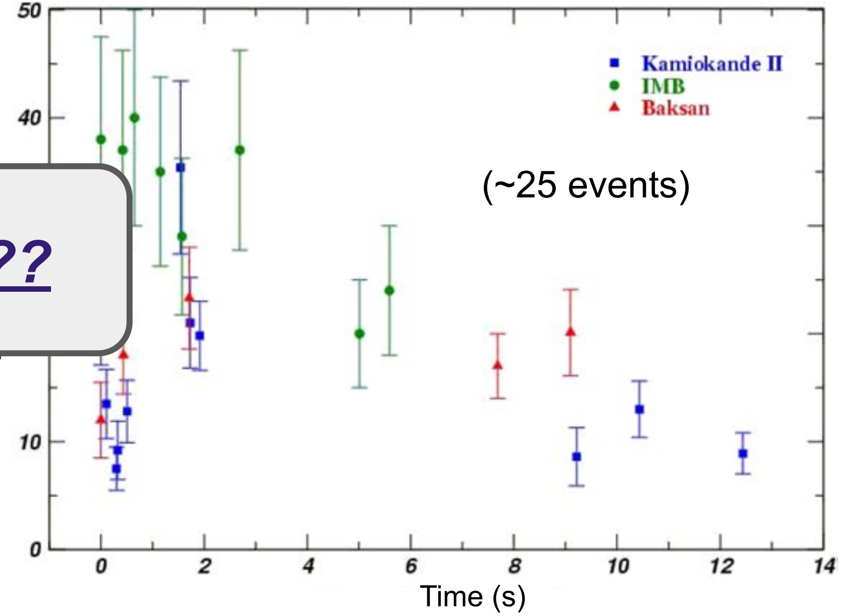
Historic ν-Astronomy Breakthrough: SN 1987a

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

Optical



Neutrinos

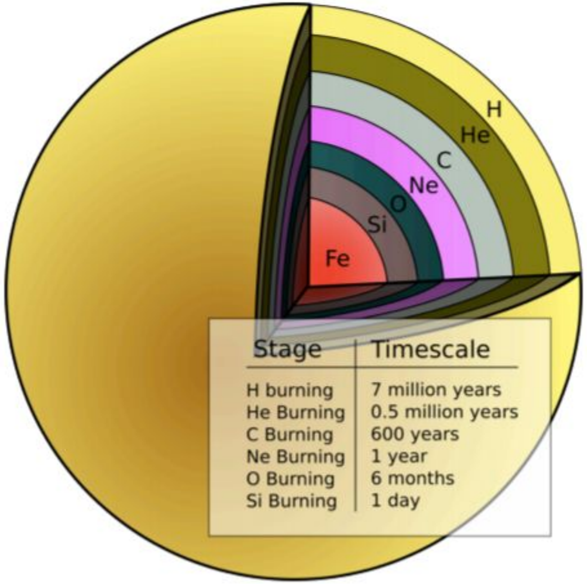


When ???

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

Last Stages of Stellar Evolution

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

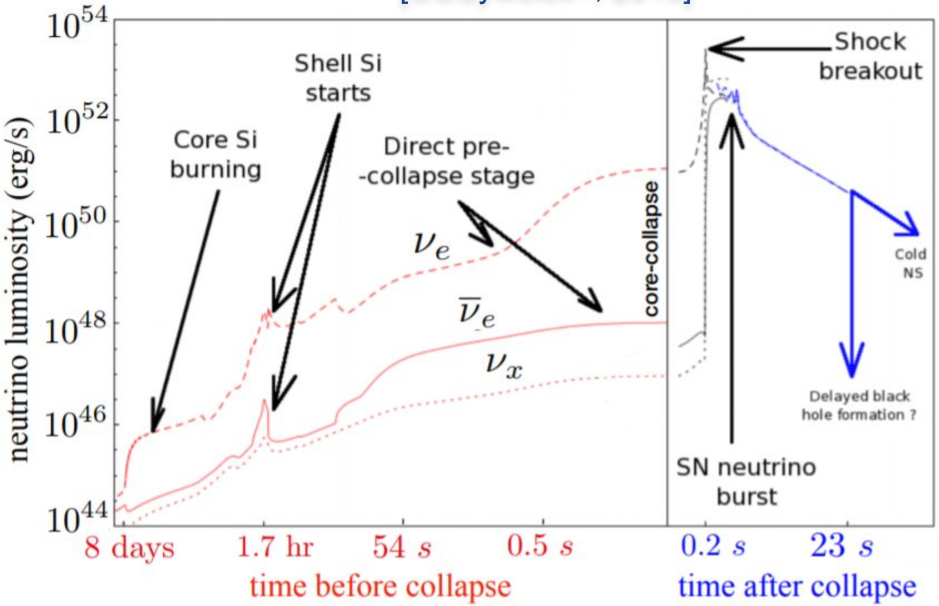


A. C. Phillips, *The Physics of Stars, 2nd Edition* (Wiley, 1999)

Supernova Forecast with Pre-Supernova Neutrinos

Super-K-GD *(2020)*, besides likely first DSNB observation, will see hundreds pre-SN ν's within ~day before SN explosion @ Betelgeuse (0.2 kpc)

[Odrzywolek+, 2010]

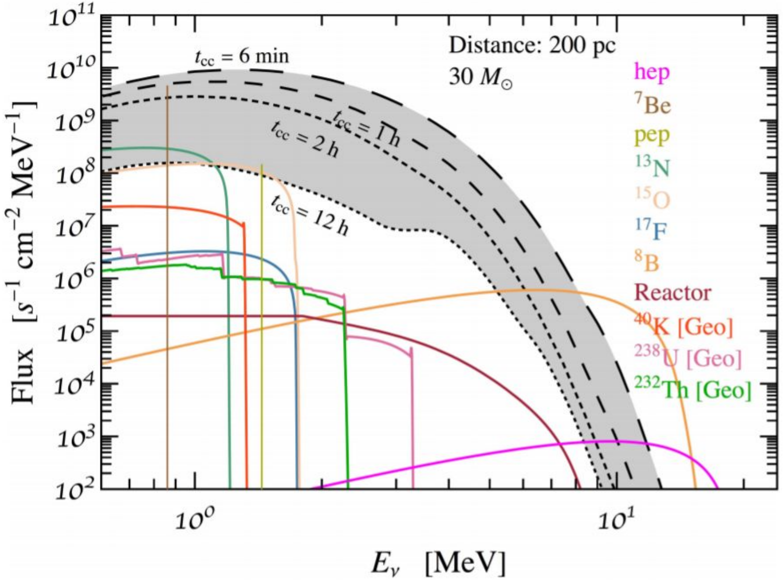


- Pre-SN neutrinos are low-energy (~ few MeV) → ***a new opportunity for CEvNS!***

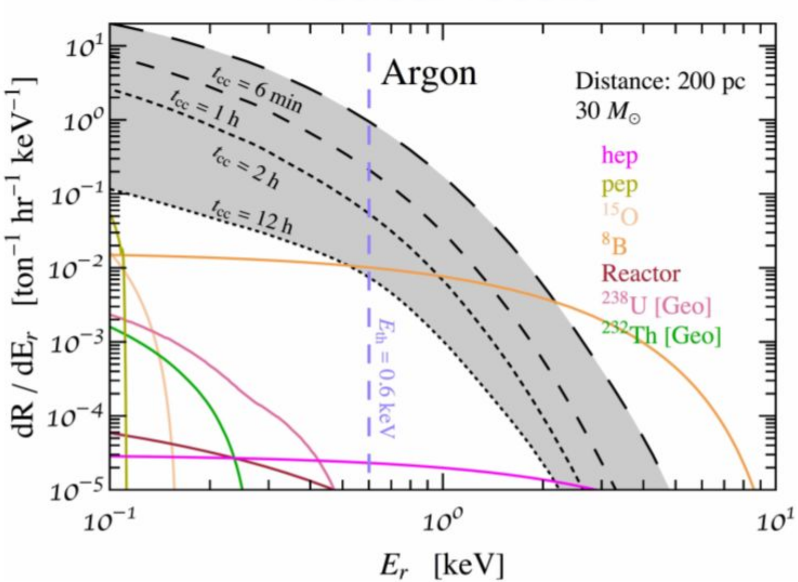
Pre-SN ν's in DM experiments: signal

@ Betelgeuse (0.2 kpc)

neutrino flux

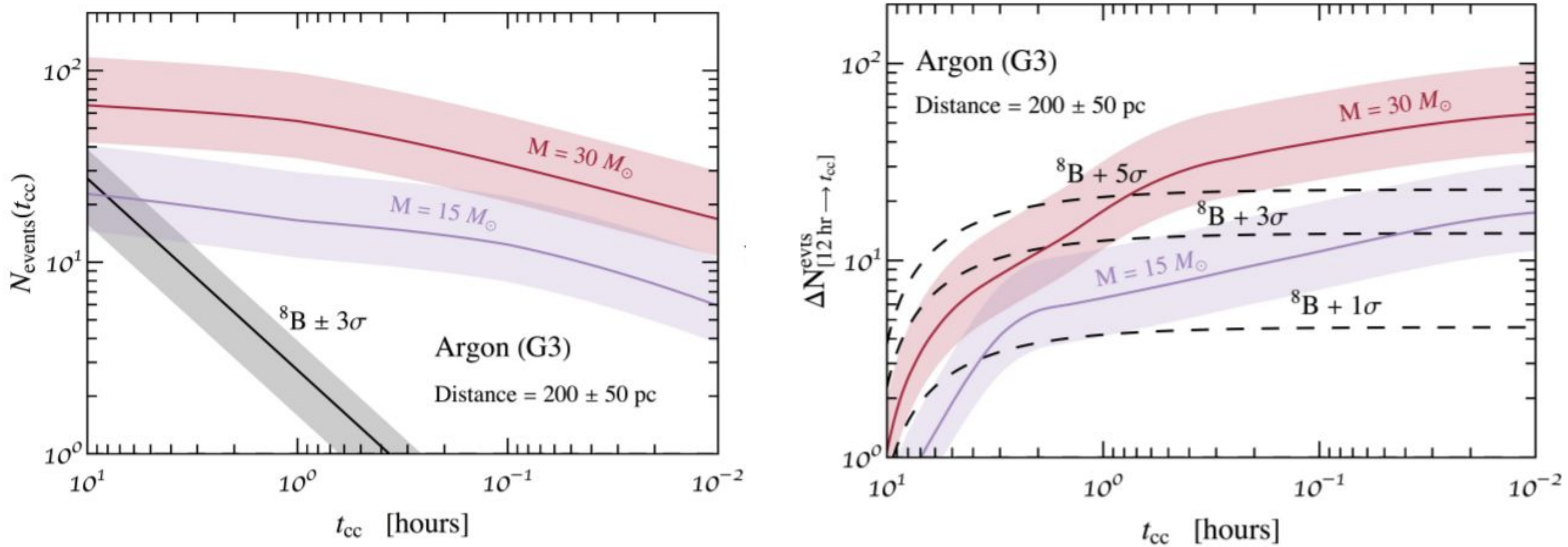


nuclear recoils



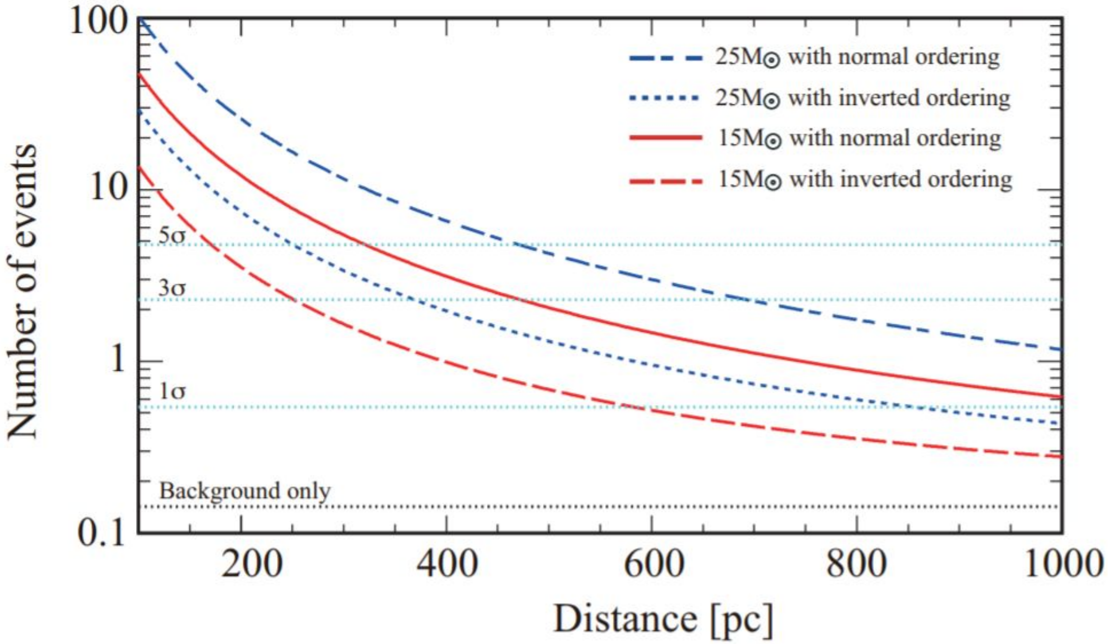
[Raj, **VT**, Witte, 2019]

Pre-SN ν's in DM experiments: detection



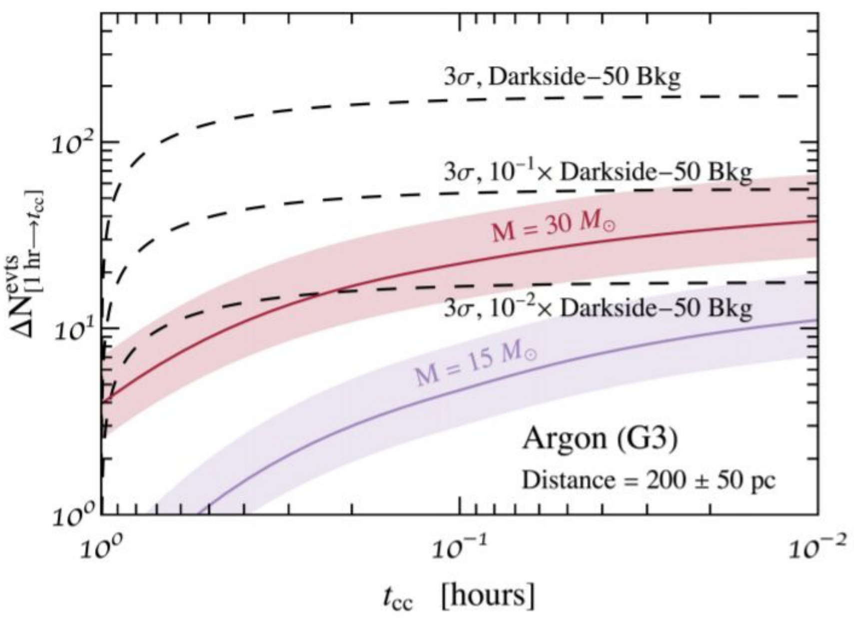
[Raj, **VT**, Witte, 2019]

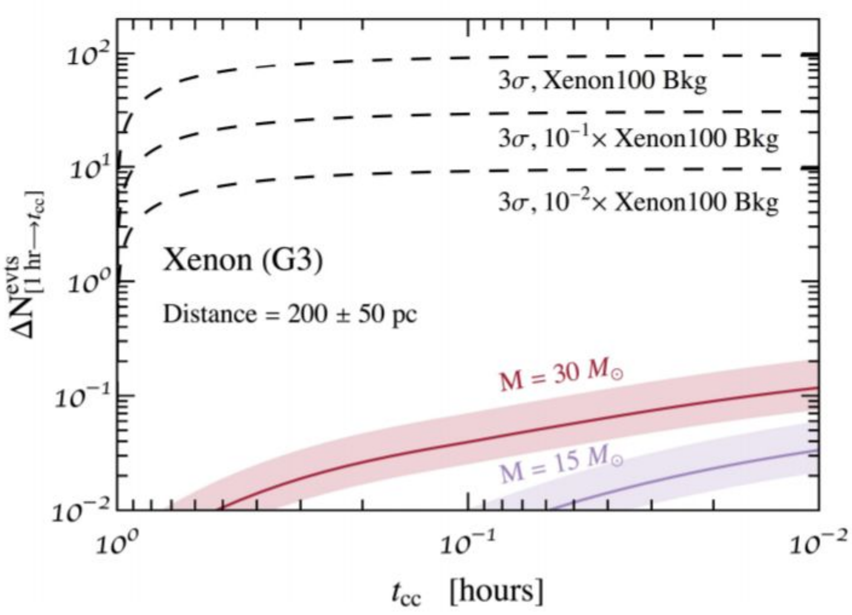
Do Not Suffer Oscillation Effects



[Asakura+ (KamLAND), 2015]

Work on Non-neutrino Background Suppression Essential





Astronomy in the Lab

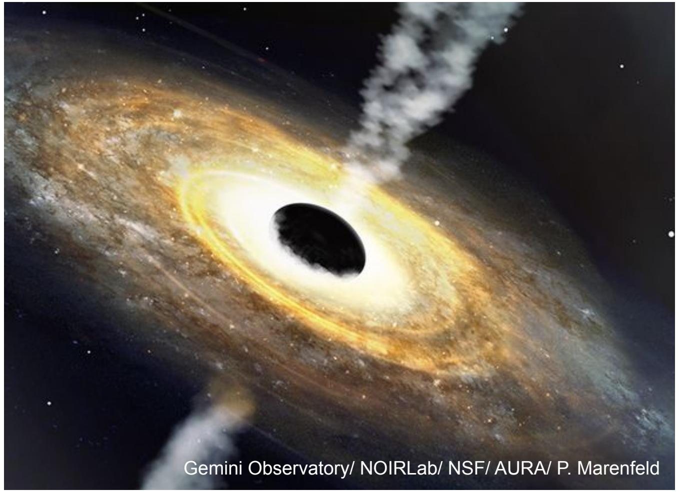
Origin of Supermassive Black Holes

Supermassive Black Holes

high redshift quasars

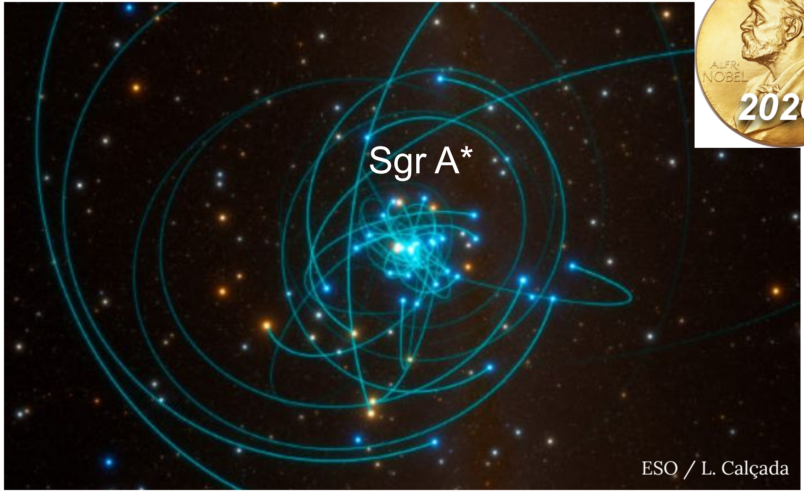
$(M \sim 10^9 M_\odot)$

[Benados+, *Nature*, 2018; Wu+, *Nature*, 2015...]



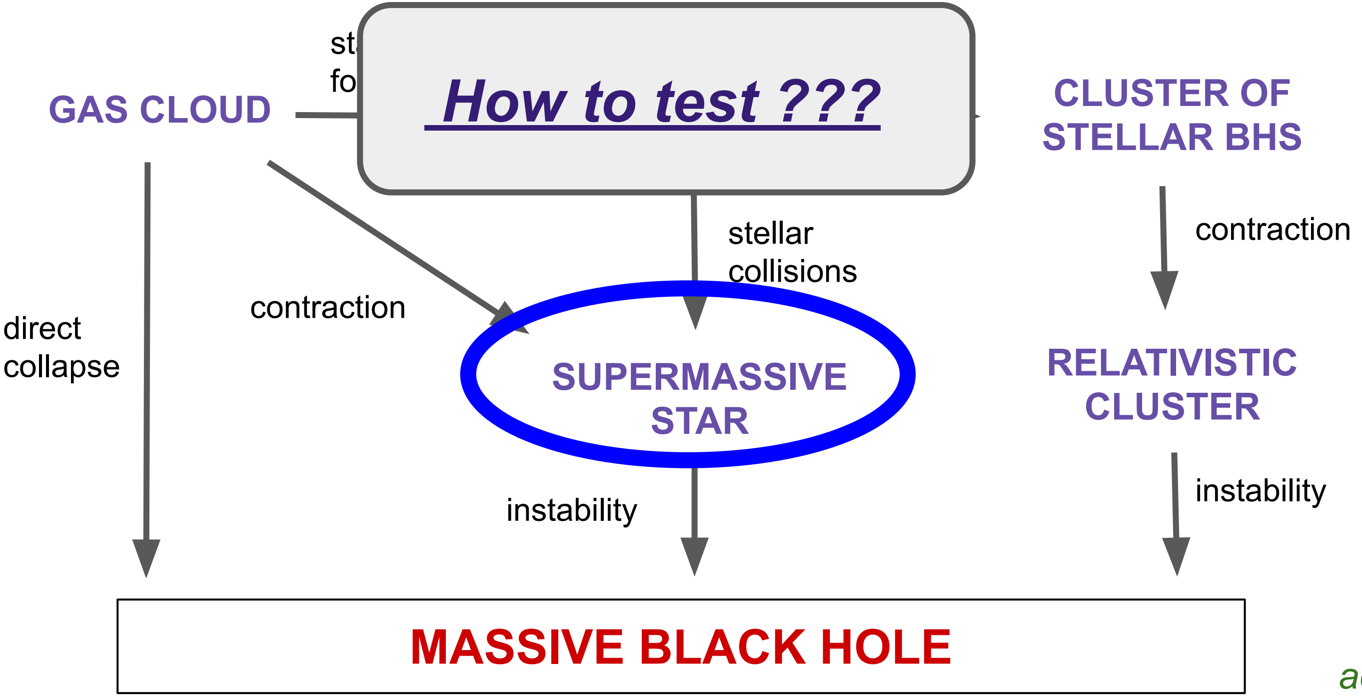
galactic centers

$(M \sim 10^6 M_\odot)$



Supermassive Black Holes from Supermassive Stars

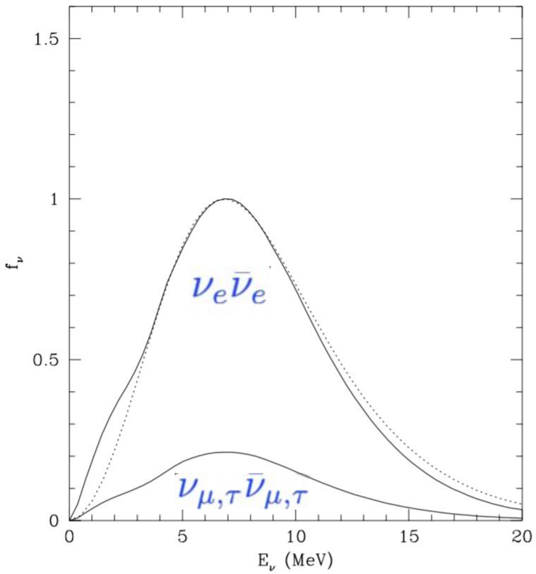
- Several formation pathways go through supermassive star ($\gtrsim 10^4\ M_\odot$) "*seeds*"

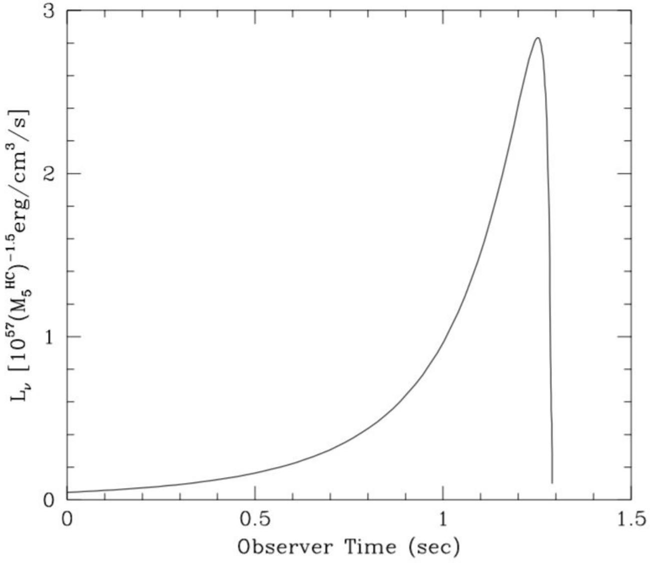


adopted from M. Volonteri

Neutrinos from Supermassive Star Collapse

- Collapse of SMS leads to huge neutrino flux ~ fraction of binding energy ~10^{59} erg





[Shi, Fuller, 1998]

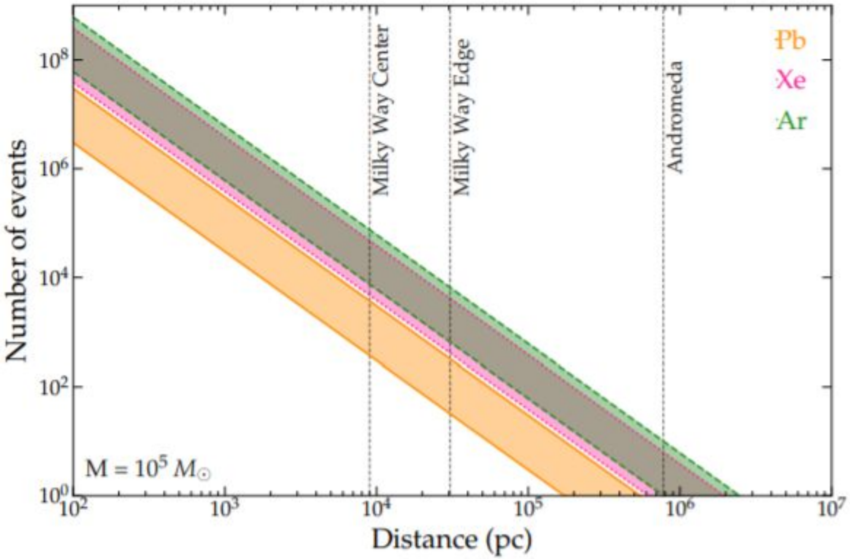
...however, neutrinos are low energy, also redshifted (unknown, follows quasars?)

→ detection via IBD in standard neutrino experiments limited [Shi, Fuller, 1998]

Neutrinos from Supermassive Star Collapse

- **Exploit CEvNS!** → catch low-energy neutrinos

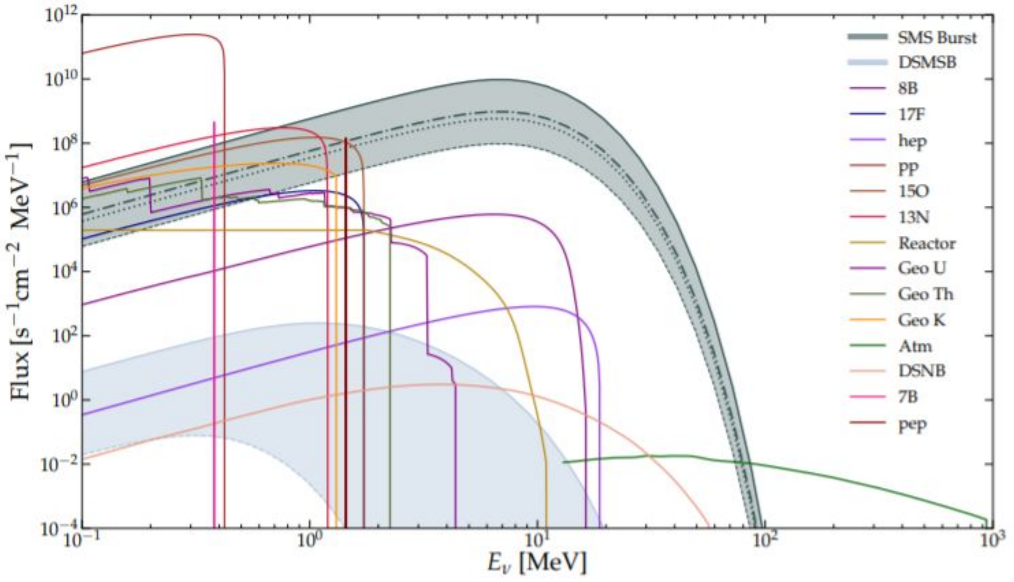
SMS burst



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

[Fuller, Munoz, **VT**, Witte, *prep.*]

New Contribution to Diffuse Neutrino Background



- Additional potential background for DM searches !

[Fuller, Munoz, **VT**, Witte, *prep.*]

Conclusions

- Magnificent CEvNS open a new exciting window for neutrino physics

- Future large DM experiments well positioned to exploit CEvNS
  → *effective neutrino telescopes*

- New opportunities to explore neutrino astronomy (and other topics) in a complementary way