Dark Matter Burners

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Abstract

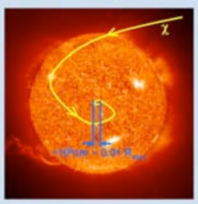
We show that a star orbiting close enough to an adiabatically grown supermassive black hole can capture a large number of weakly interacting massive particles (WIMPs) during its lifetime. WIMP annihilation energy release in low- to medium-mass stars is comparable with or even exceeds the luminosity of such stars due to thermonuclear burning. The excessive energy release in the stellar core may result in an evolution scenario different from what is expected for a regular star. The model thus predicts the existence of unusual stars within the central parsec of galactic nuclei. If found, such stars would provide evidence for the existence of particle dark matter. White dwarfs seem to be the most promising candidates to look for. A signature of a white dwarf burning WIMPs would be a very hot star with mass and radius characteristic for a white dwarf, but with the luminosity exceeding its typical luminosity by orders of magnitude ($<50\,L_\odot$). A white dwarf with a highly eccentric orbit around the central black hole may exhibit variations in brightness correlated with the orbital phase.

direction

Basic idea

- Extremely high dark matter density possibly exists near the supermassive black hole in the Galactic center
- WIMP pair annihilation creates an additional energy source in the star
- Effects of heating are largest for stars with $<M_{sun}$ (Salati & Silk 1989): predict red giant population
- A white dwarf in an orbit around the Galactic center is the best candidate (Moskalenko & Wai 2006)

WIMP-nucleon scattering leads to gravitational capture and allows WIMP accumulation in a star



WIMP accumulation

WIMP accumulation during different burning stages

M_{init}^H $M_\odot$	M_* $M_\odot$	R_* $R_\odot$	T_c 10^8 K	ρ_c g cm^{-3}	C s^{-1}	r_{th} 10^8 cm	τ_{eq} s	τ_* s	N_χ	n_χ^c cm^{-3}
Hydrogen Stage										
1	1	1	0.157	153	2.85 × 10^[illegible]	7.55	5.29 × 10^8	3.47 × 10^[illegible]	1.51 × 10^[illegible]	6.30 × 10^[illegible]
13	12.8	6.24	0.344	6.06	6.89 × 10^[illegible]	53.5	2.04 × 10^9	4.28 × 10^[illegible]	1.40 × 10^[illegible]	1.64 × 10^[illegible]
25	24.5	6.17	0.381	3.81	1.65 × 10^[illegible]	74.5	2.16 × 10^9	2.11 × 10^[illegible]	3.56 × 10^[illegible]	1.55 × 10^[illegible]
75	67.3	21.3	0.426	1.99	5.30 × 10^[illegible]	109	2.13 × 10^9	9.97 × 10^[illegible]	1.13 × 10^[illegible]	1.56 × 10^[illegible]
75*	75	9.36	0.760	10.6	1.44 × 10^[illegible]	63.1	5.69 × 10^8	1.09 × 10^[illegible]	8.19 × 10^[illegible]	5.85 × 10^[illegible]
Helium Stage										
1	0.71	19	1.25	20000	3.13 × 10^[illegible]	1.86	6.19 × 10^8	3.47 × 10^[illegible]	1.94 × 10^[illegible]	5.30 × 10^[illegible]
13	12.4	359	1.72	1730	4.80 × 10^[illegible]	7.43	1.26 × 10^[illegible]	8.43 × 10^[illegible]	6.05 × 10^[illegible]	2.65 × 10^[illegible]
25	19.6	1030	1.96	762	7.14 × 10^[illegible]	11.9	2.11 × 10^[illegible]	2.65 × 10^[illegible]	1.50 × 10^[illegible]	1.58 × 10^[illegible]
75	16.1	1.17	2.10	490	3.35 × 10^[illegible]	15.4	4.51 × 10^9	1.51 × 10^[illegible]	1.51 × 10^[illegible]	7.40 × 10^[illegible]
75*	74.4	702	2.25	319	3.67 × 10^[illegible]	19.8	1.98 × 10^[illegible]	1.05 × 10^[illegible]	7.27 × 10^[illegible]	1.68 × 10^[illegible]
Carbon Stage — white dwarf										
~3	1.0	0.01	10	1.00 × 10^6	4.03 × 10^[illegible]	0.745	1.38 × 10^7	…	5.56 × 10^[illegible]	2.41 × 10^[illegible]
13	11.4	665	6.15	3.13 × 10^5	1.11 × 10^[illegible]	1.20	1.70 × 10^8	8.90 × 10^[illegible]	1.89 × 10^[illegible]	1.96 × 10^{17}
25	12.5	1390	8.41	1.29 × 10^5	1.18 × 10^[illegible]	1.90	3.29 × 10^8	1.65 × 10^[illegible]	3.88 × 10^[illegible]	1.01 × 10^{17}
75	6.37	0.644	8.68	1.39 × 10^5	2.59 × 10^[illegible]	1.86	6.80 × 10^7	3.38 × 10^[illegible]	1.76 × 10^[illegible]	4.90 × 10^{17}
75*	74.0	714	10.4	7.45 × 10^4	9.79 × 10^[illegible]	2.78	2.02 × 10^8	8.52 × 10^8	1.98 × 10^[illegible]	1.65 × 10^{17}

Note. — M_{init}^H is the initial hydrogen star mass.
*Stellar model with 10^{-4} solar metallicity.

Capture rate — Total # of WIMPs

Signatures… I

Temperature:

- Black-body spectrum: $(L/L_{sun}) \sim (R/R_{sun})^2\,(T/T_{sun})^4$
- A dwarf WIMP burner $R \sim 0.01R_{sun} \rightarrow L \sim 20L_{sun}$
- This implies T~100,000 K! Probably *not inconsistent* with K-band measurements, and considering optical & UV extinction

Rotational velocity:

- Absorption line widths of S0-2 imply rotational velocity of ~220km/s (Ghez, et.al 2003); consistent with dwarf

Experimental inputs

- Spin-independent scattering limits
  - ★ CDMS II: $s_{SI} < 10^{-43}$cm^2
- Spin-dependent scattering limits
  - ★ SuperK: $s_{SD} < 10^{-38}$cm^2
- Annihilation cross-section estimate (actual value not important to results)
  - ★ $\langle\sigma v\rangle \sim 3\times10^{-26}$cm^{3}s^{-1}
- Infrared observations of galactic center stars

The "paradox of youth" for Sgr A* stars (e.g. Ghez, et.al. 2005)

- K-band measurements of Sgr A* stars indicate that they are hot
  - ★ imply that they are young stars
- Difficult to see how they could have formed in situ:
  - ★ given the lack / low density of gas
  - ★ extreme gravitational forces near the supermassive BH
- Difficult to see how they could have efficiently migrated in given the short time since birth
- Conventional hypotheses discussed are:
  - ★ "old stars masquerading as young" or
  - ★ "hot dwarfs - stripped cores of red giants"

Signatures… II

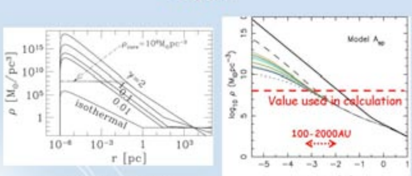
Gravitational redshift:

- Radial velocity measured for S0-2 is ~500 km/s ±10%
- Gravitational redshift is ~50 km/s equivalent… may be measurable!
- If the mass is ~Msun then it would be a "smoking gun" (given high T)

DM density gradient:

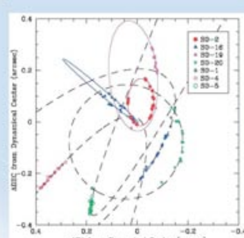
- Variability with orbital phase (dark matter density gradients

Dark matter density near the supermassive black hole at the Galactic center



Gondolo & Silk (1999) — Bertone & Merritt (2005)

Galactic center stars in near-infrared



Ghez et al. 2005

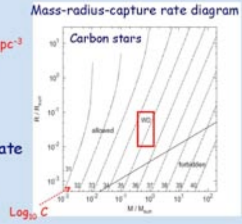
Summary

- Could any of the "paradoxically young" stars near Sgr A* be white dwarfs burning dark matter?
  - Answer: yes
- How can we demonstrate that any of these stars are white dwarfs burning dark matter?
  - Answer: by measuring the gravitational redshift and temperature (or luminosity)
- If found, a population of dwarf dark matter burners near Sgr A*, would trace the dark matter distribution
- Such tracer of dark matter would be complementary to gamma ray searches for WIMP annihilation at the galactic center

Back of the envelope calculations

- Assume:
  - ★ DM density of 10^8M_{sun} pc^{-3}
  - ★ WIMP mass 100 GeV
  - ★ white dwarf radius $\sim 0.01R_{sun}$
  - ★ dwarf mass $\sim M_{sun}$
- Obtain the capture rate & luminosity:
  - $C \sim 4\times10^{35}$ χ/s
  - $L_\chi \sim 7\times10^{34}$ erg/s
  - $L_\chi \sim 20\,L_{sun}$

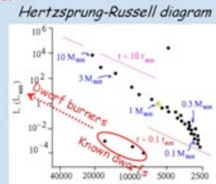
Mass-radius-capture rate diagram



The white dwarf WIMP burner hypothesis

- White dwarfs are everywhere! *Some just happen* to fall into the high density dark matter region near the black hole where they appear as WIMP burners
- Compact structure: more stable against extreme gravitational conditions near the supermassive black hole
- What are the spectral or other signatures?

Hertzsprung-Russell diagram



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