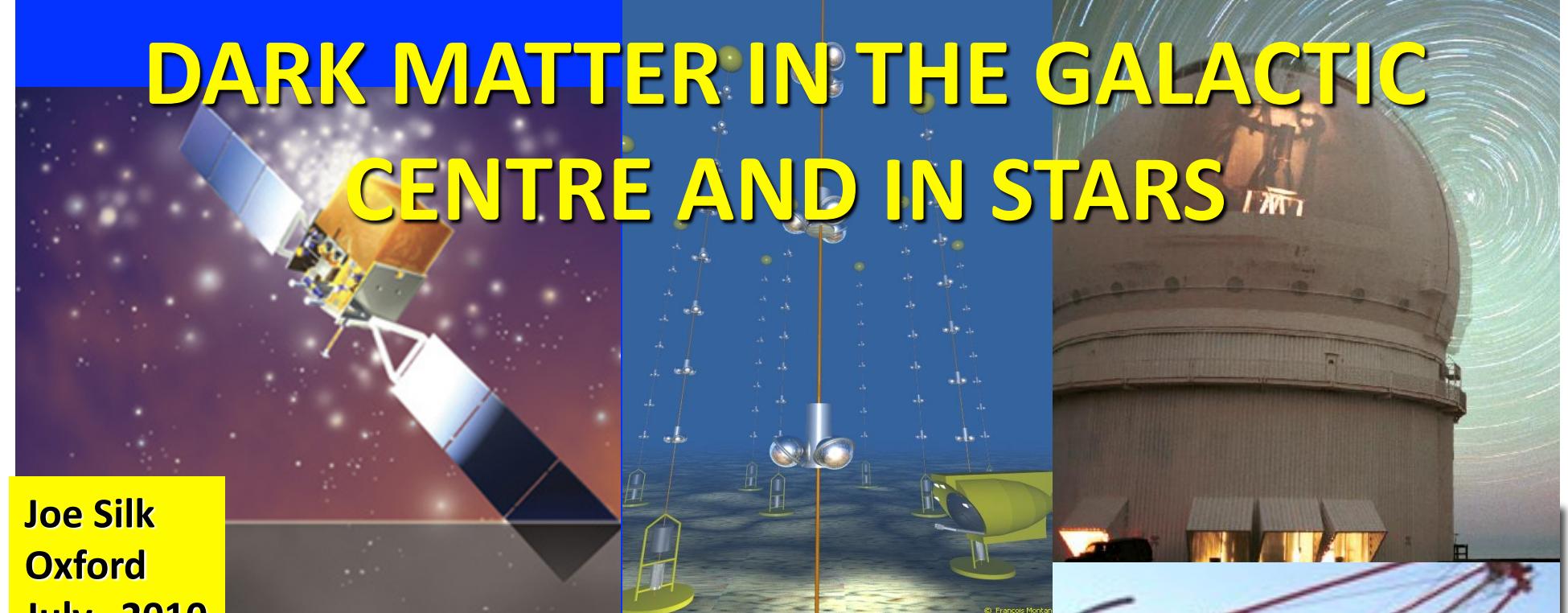


DARK MATTER IN THE GALACTIC CENTRE AND IN STARS

Joe Silk
Oxford
July, 2010



Indirect detection: The Galactic Centre

The Sun

Neutron stars

Favoured SUSY candidate: Weakly Interacting Massive Particle or WIMP

Relic abundance obtained if $\langle\sigma v\rangle \sim 3 \times 10^{-26} \text{ cm}^3/\text{s} \sim 1/\Omega_x$ for 0.1-10 TeV

1. WIMP Annihilation

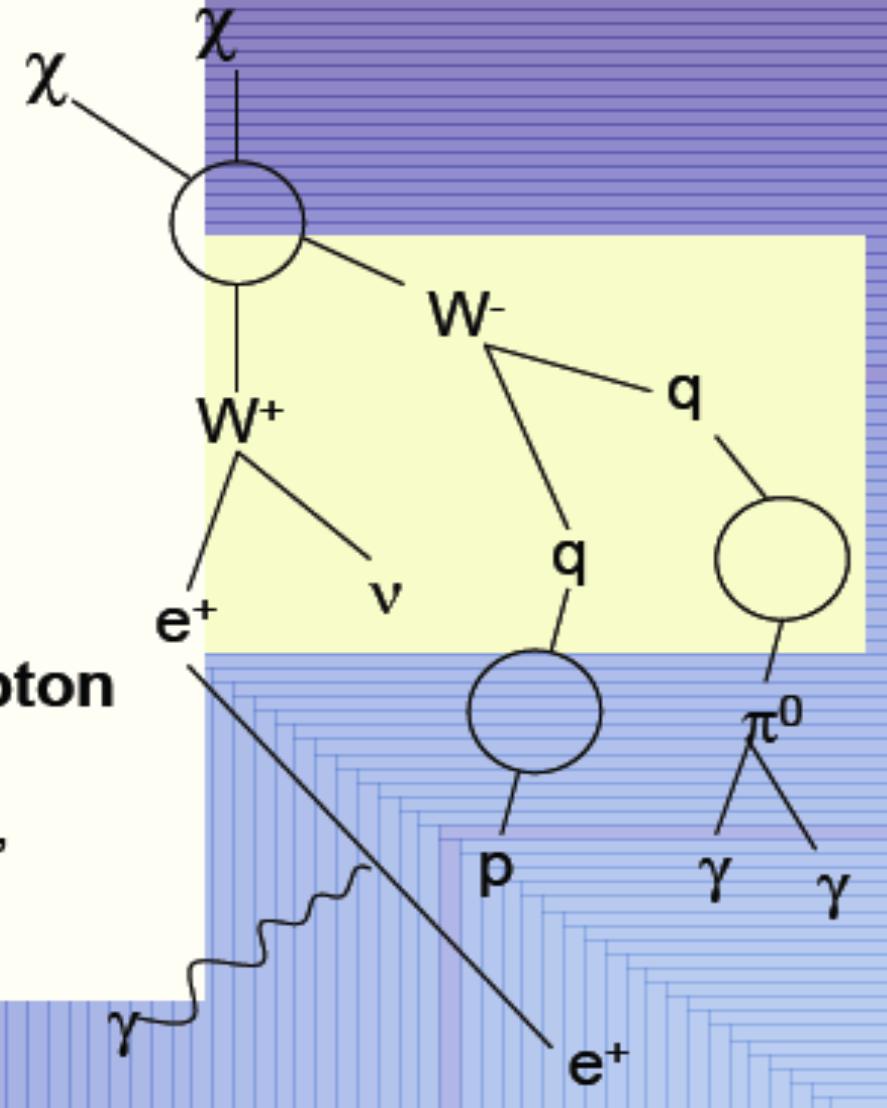
Typical final states include heavy fermions, gauge or Higgs bosons

2. Fragmentation/Decay

Annihilation products decay and/or fragment into combinations of electrons, protons, deuterium, neutrinos and gamma-rays

3. Synchrotron and Inverse Compton

Relativistic electrons up-scatter starlight/CMB to MeV-GeV energies, and emit synchrotron photons via interactions with magnetic fields



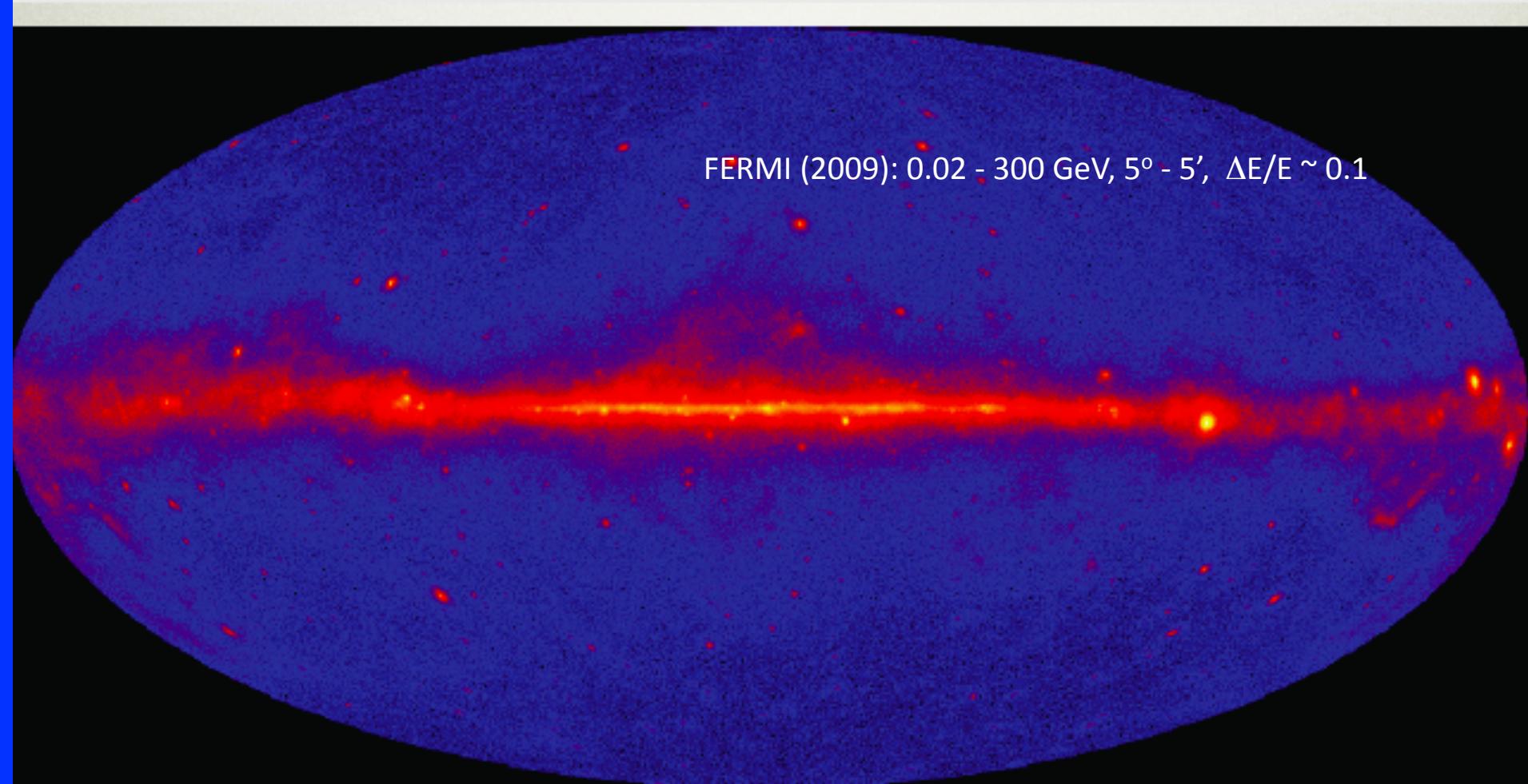
**ASTROPHYSICAL PROBES OF DARK MATTER
COMPLEMENT FUTURE COLLIDER EXPERIMENTS**

annihilation γ -rays from the centre of the Galaxy

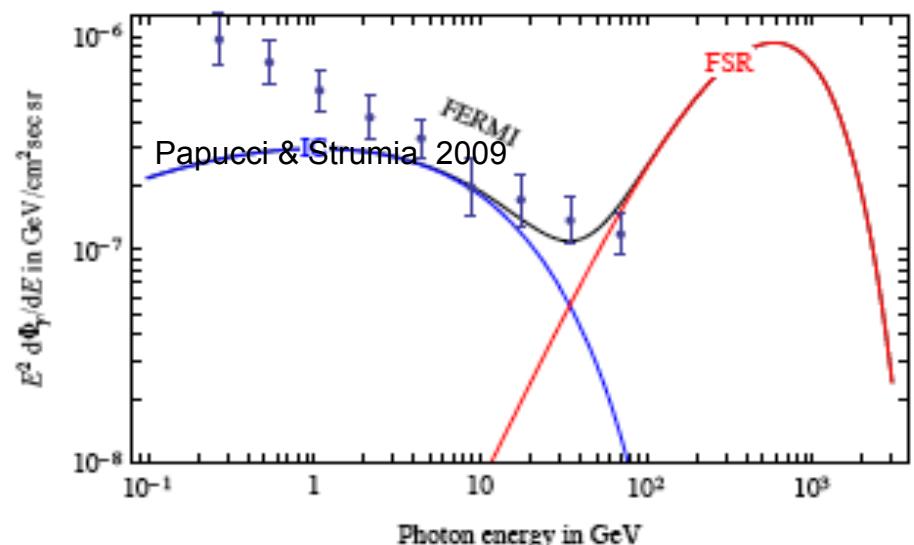
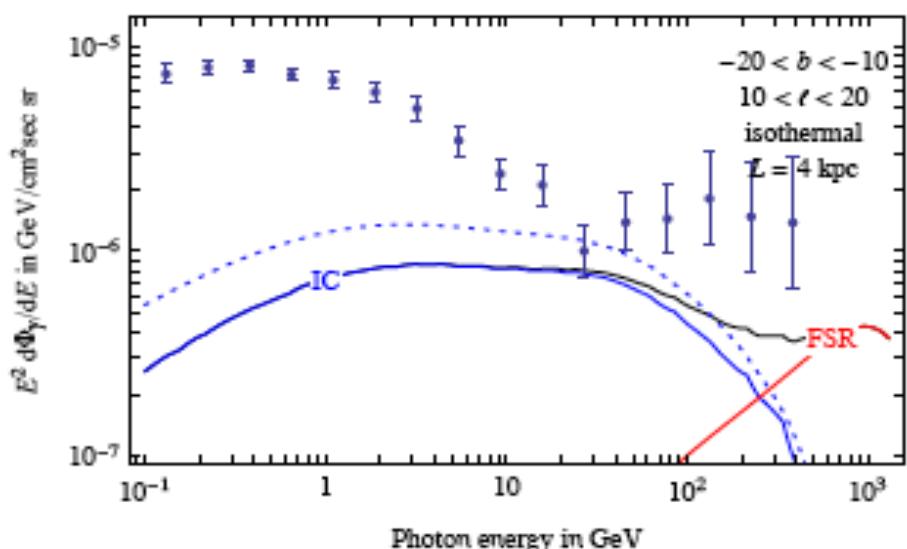
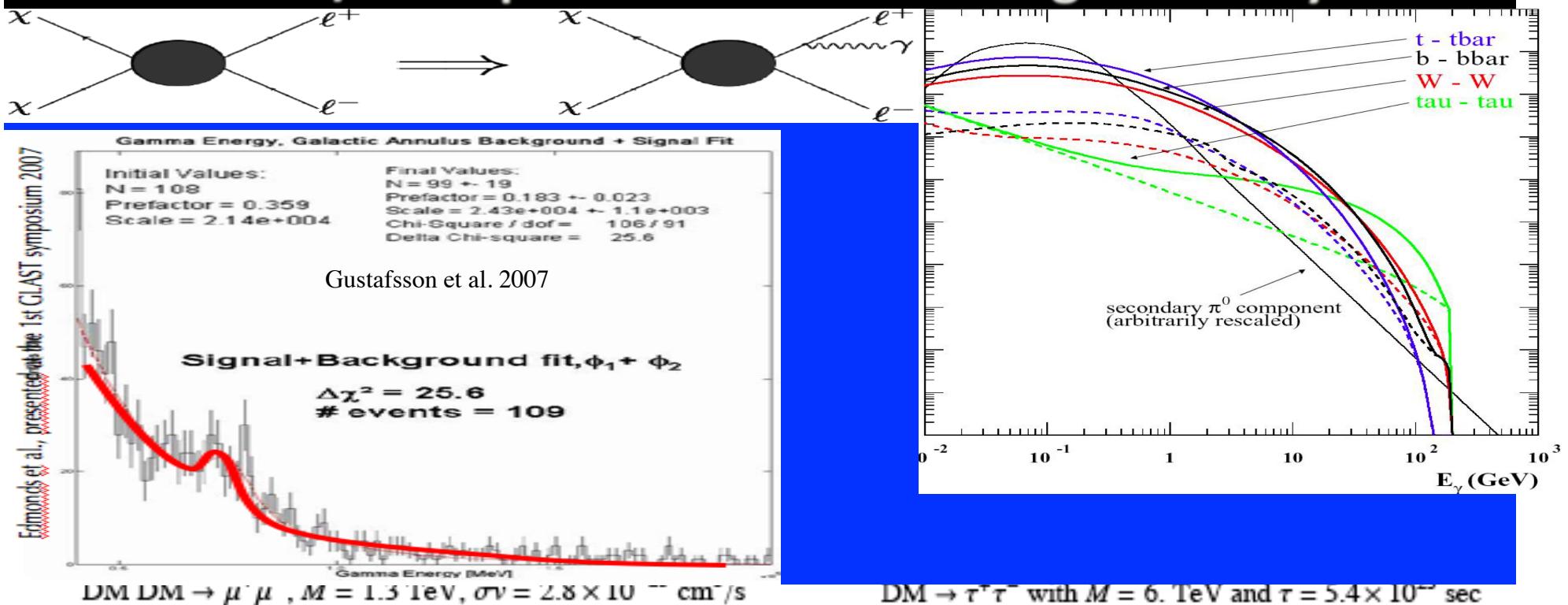
predict γ ray “smoking guns”: hard spectrum annihilation line

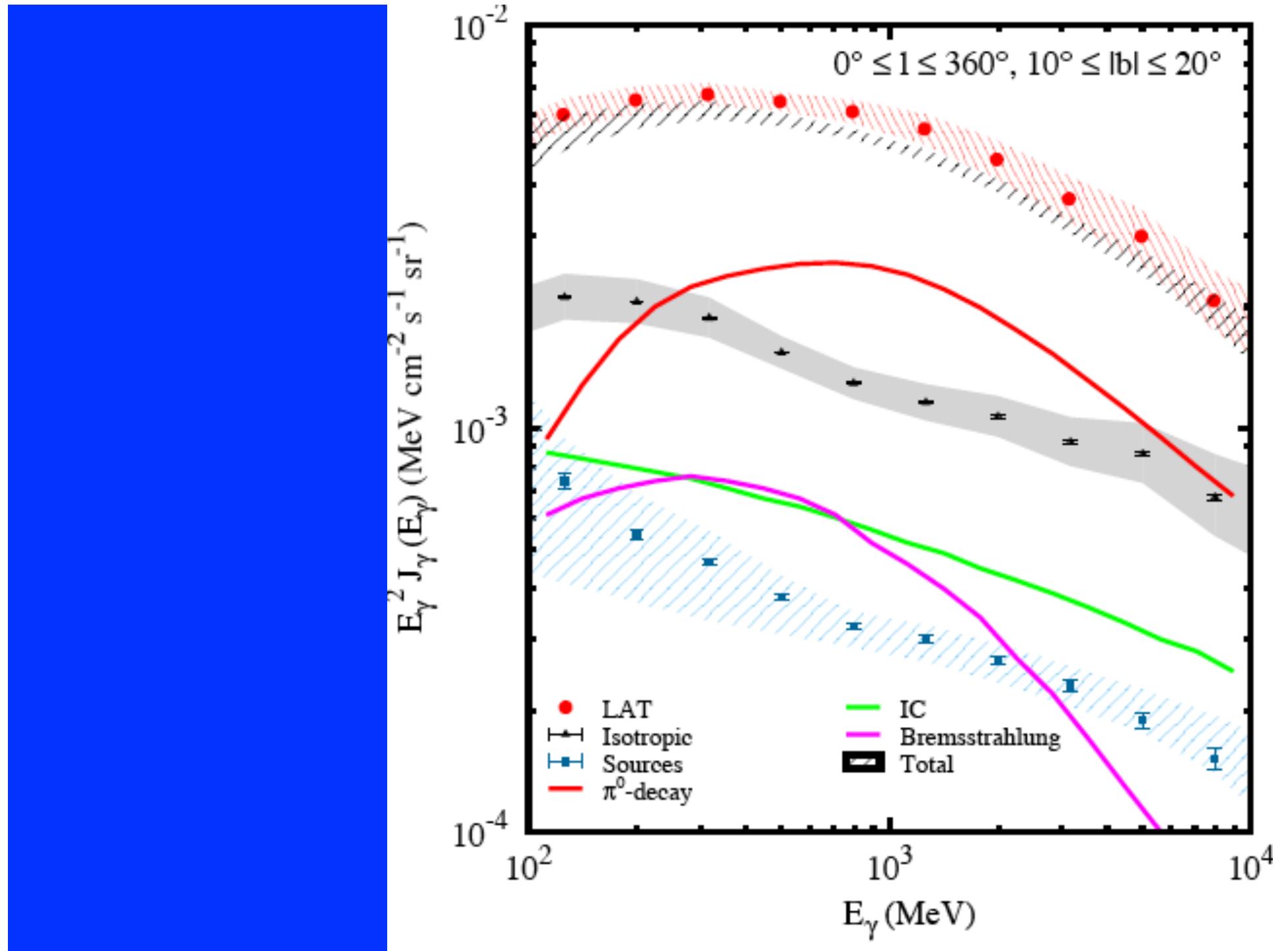
Fermi 1 year sky

FERMI (2009): 0.02 - 300 GeV, $5^\circ - 5'$, $\Delta E/E \sim 0.1$



FERMI/HESS prediction: final state gamma rays

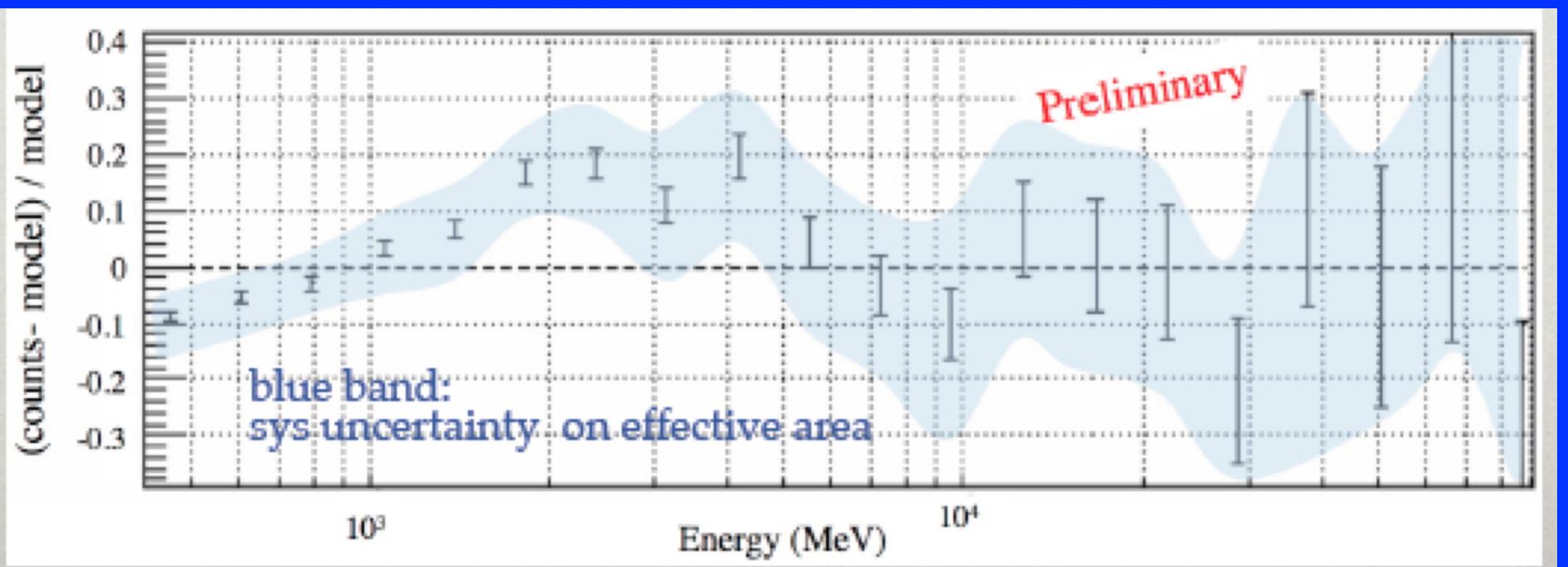




Fermi LAT (from TeVPA 2010)

SEARCH FOR DM IN THE GC

7x7 degrees



Did we prematurely abandon a dark matter contribution in the GC?

CDM cusp steepens by adiabatic growth of IMBH: $\rho \propto r^{-\gamma} \Rightarrow \rho \propto r^{-\gamma'}$, with $\gamma' = \frac{9-2\gamma}{4-\gamma}$

Annihilation rate is amplified within a radius $GM_{bh}/\sigma^2 \sim 0.003(M_{BH}/10^5 M_\odot) \text{pc}$

a local boost is natural in gravitationally bound spike around Sag A* black hole $4 \times 10^6 M_{\text{sun}}$

Dynamical heating reduces peak density

DM predicts exponential cut-off + no variability

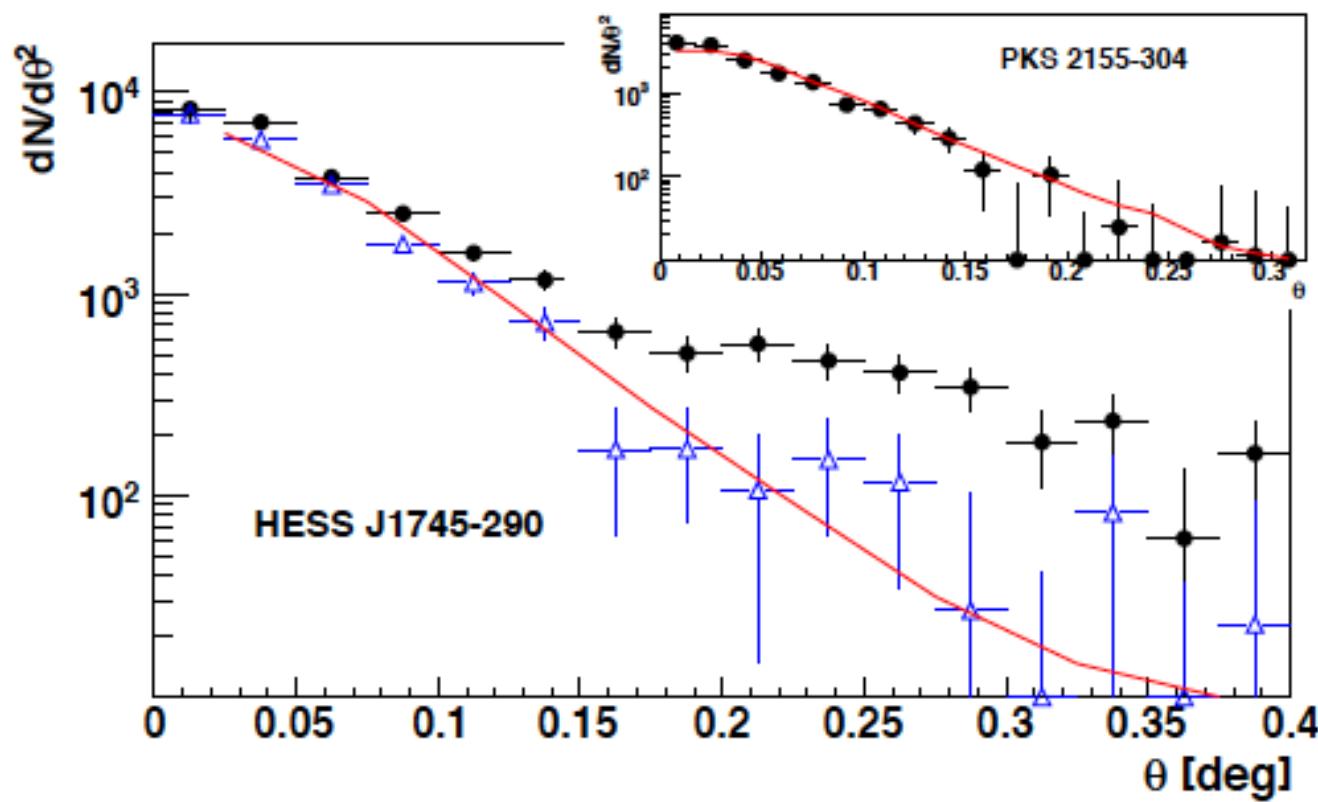
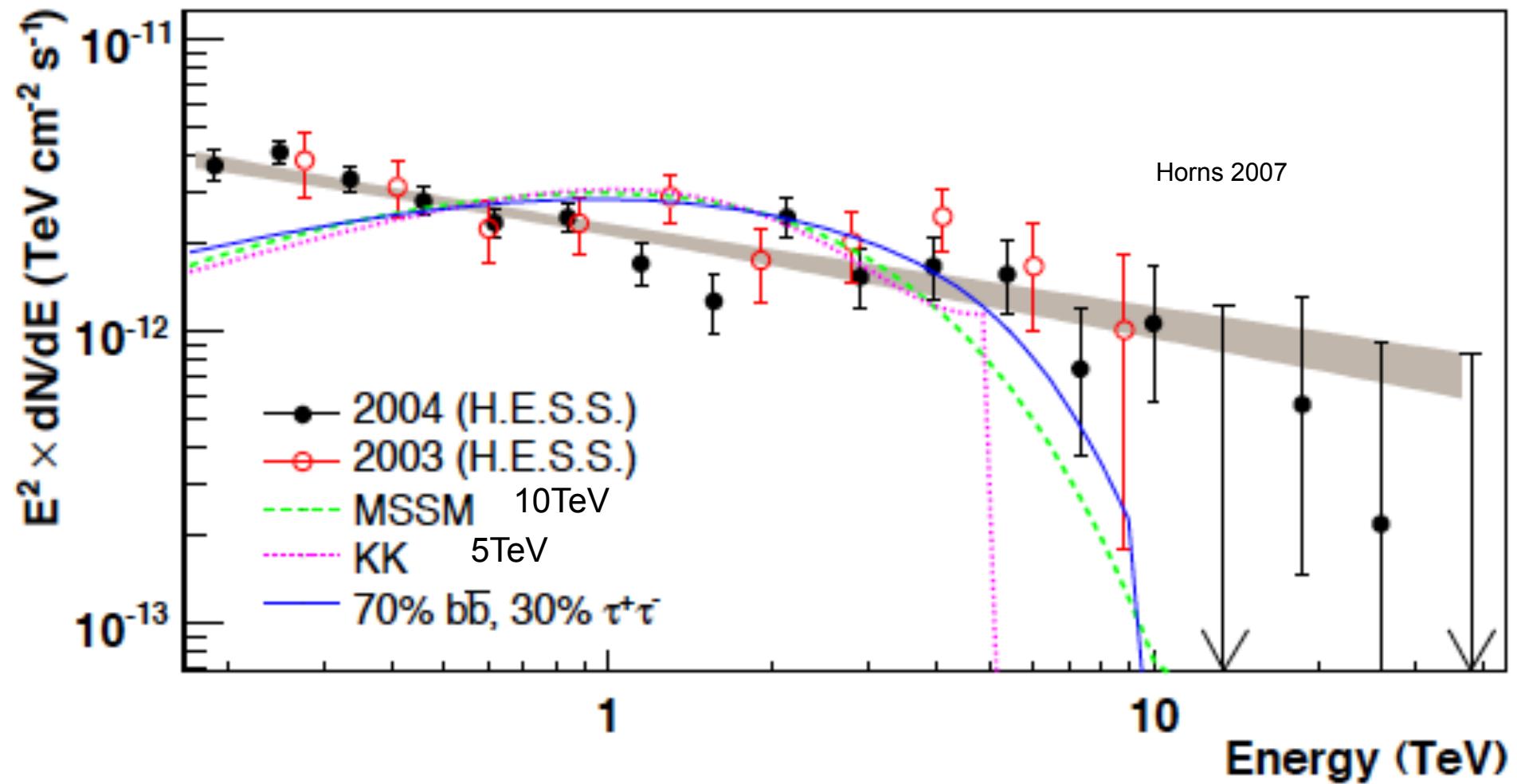


Fig. 2. Radial surface brightness profile of the gamma-ray emission (number of gamma-ray events per solid angle) from the Galactic center: The solid points indicate the number of gamma-ray events detected from the Galactic center and the environment up to an angular separation of $\theta = 0.4^\circ$ while the open points show the surface brightness after subtracting off the diffuse emission from the Galactic ridge. The solid line represents the expected distribution of gamma-rays for a point-like source taking into account varying zenith angles of the observation. As an example for an observation of a point-like source, the signal obtained from the Active Galactic Nucleus PKS 2155-304 is shown in the inlaid figure.



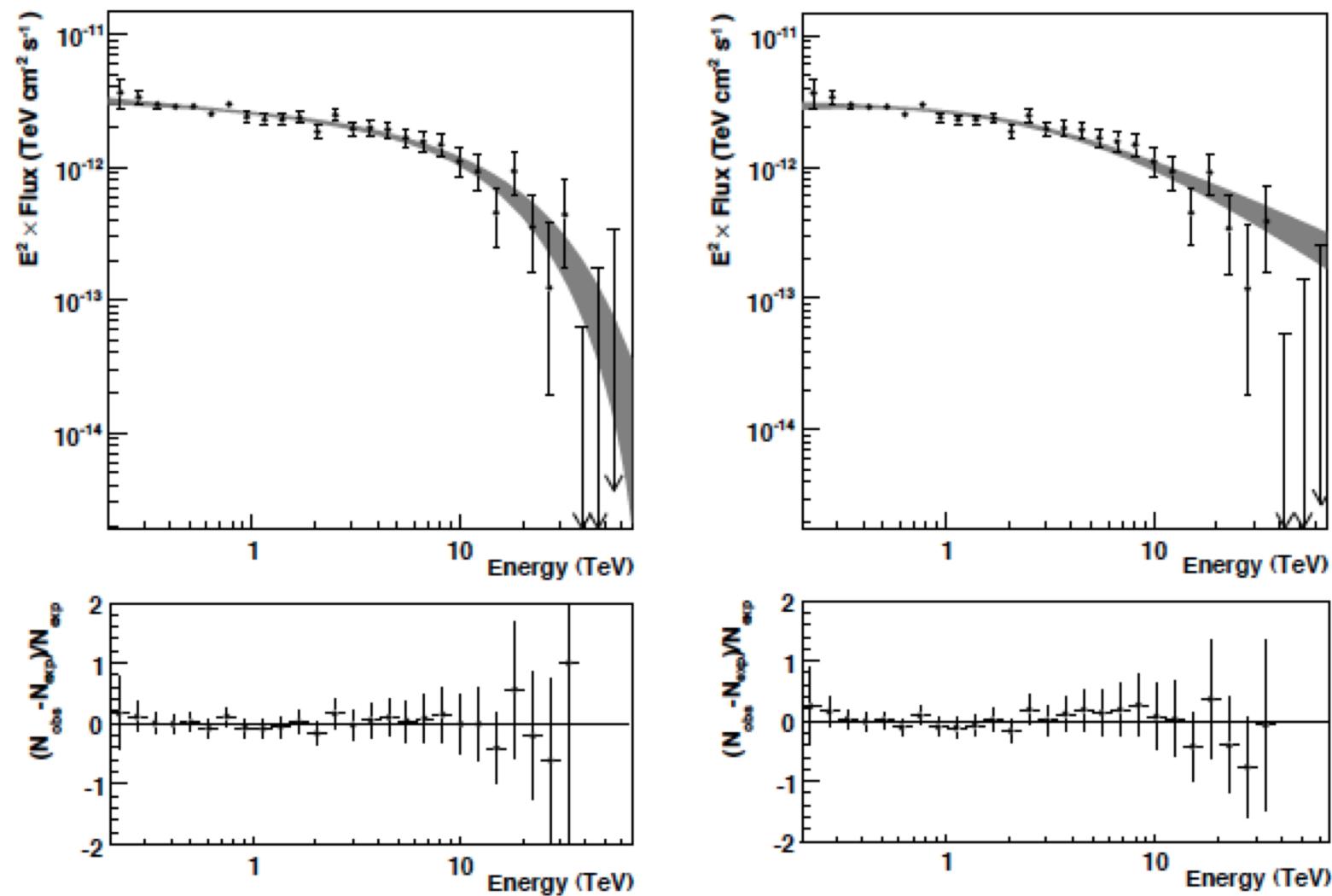
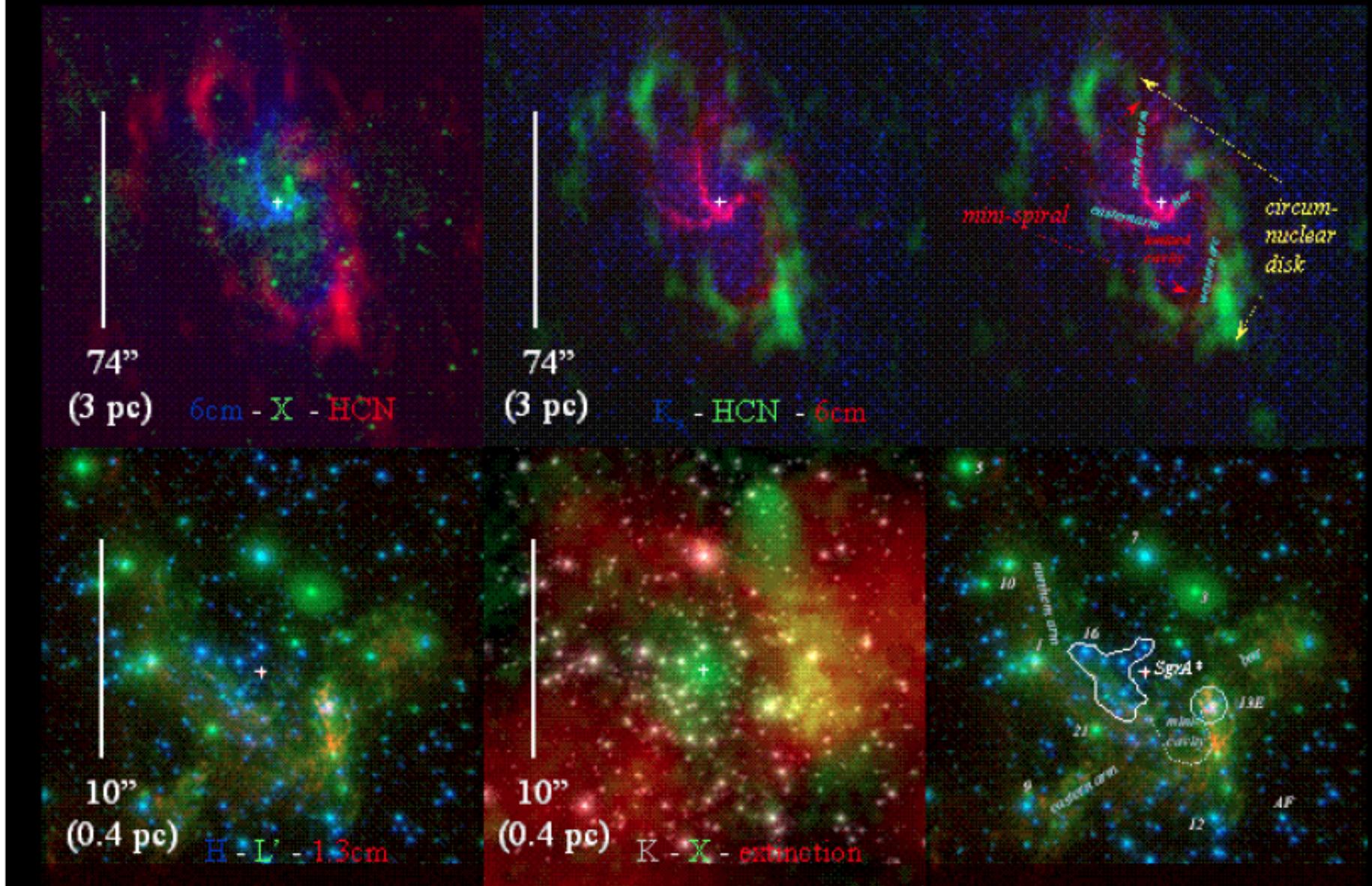
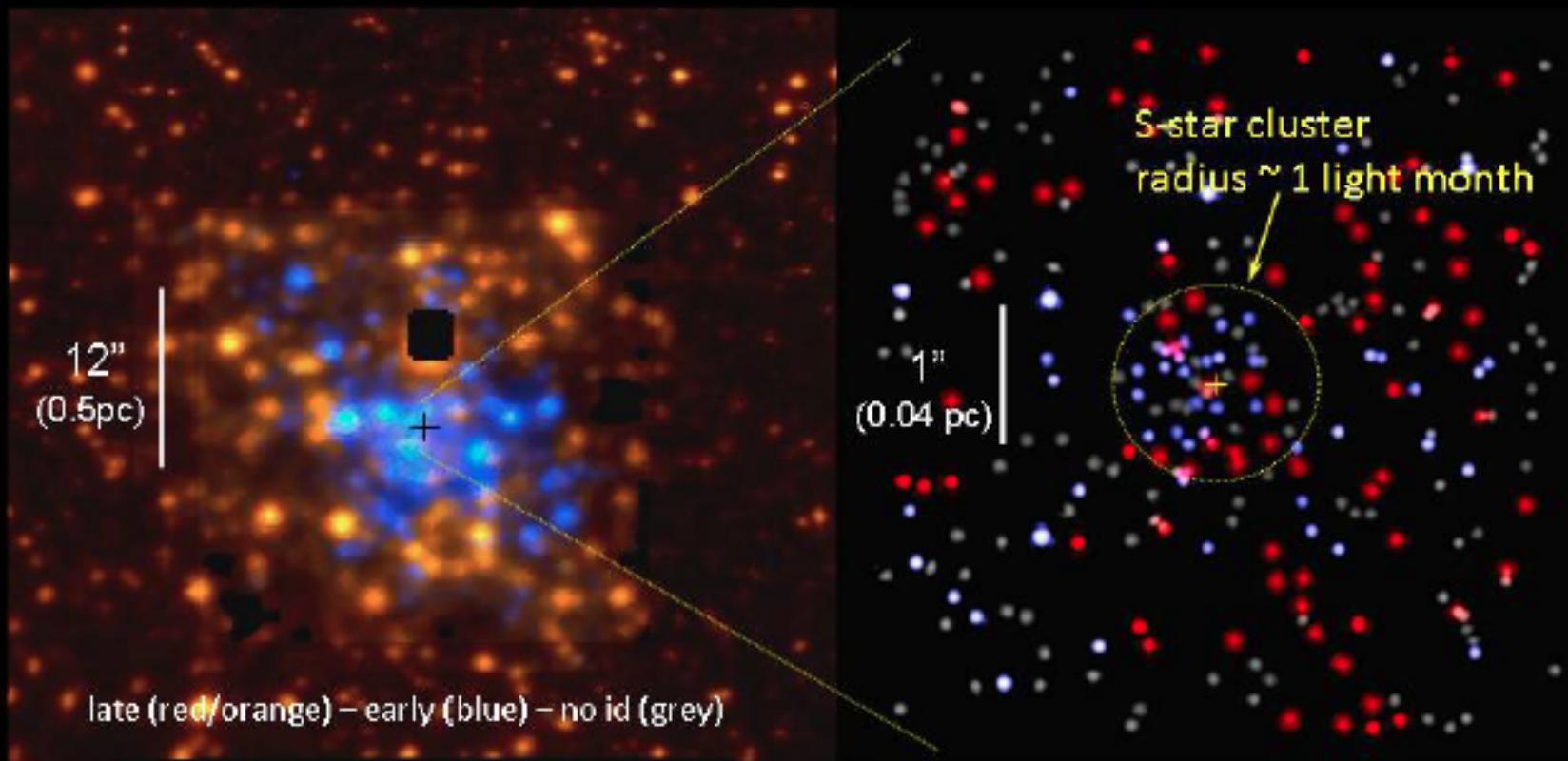


Fig. 2. HESS J1745–290 spectra derived with the combined Hillas/Model analysis for the whole H.E.S.S. GC dataset covering the three years 2004, 2005 and 2006. The shaded areas are the 1σ confidence intervals for the power law with an exponential cut-off fit (left) and the smoothed broken power law fit (right). The last points represent 95% confidence level upper limits on the flux. The fit residuals corresponding to the respective fits are shown on the lower panels.





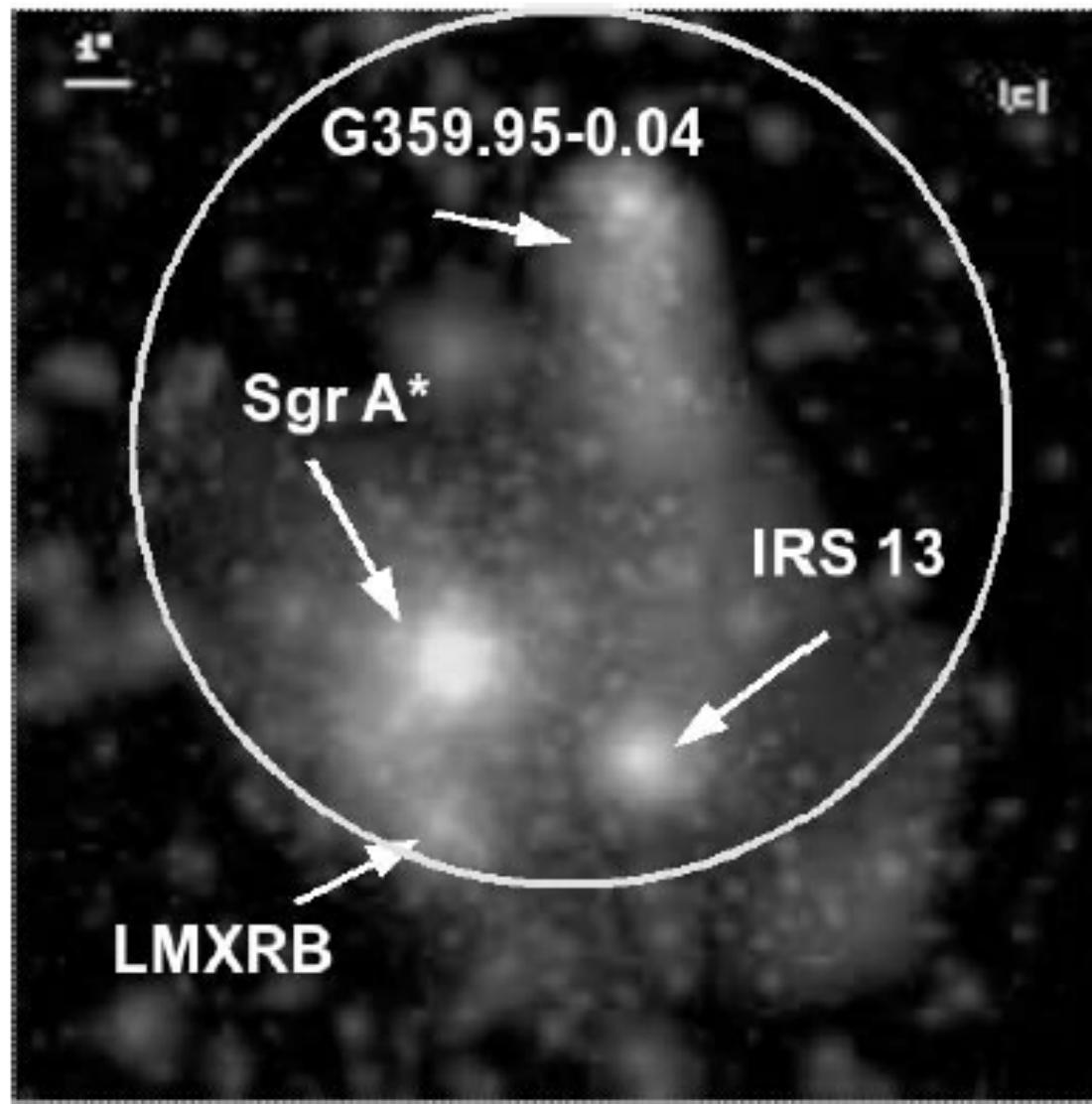
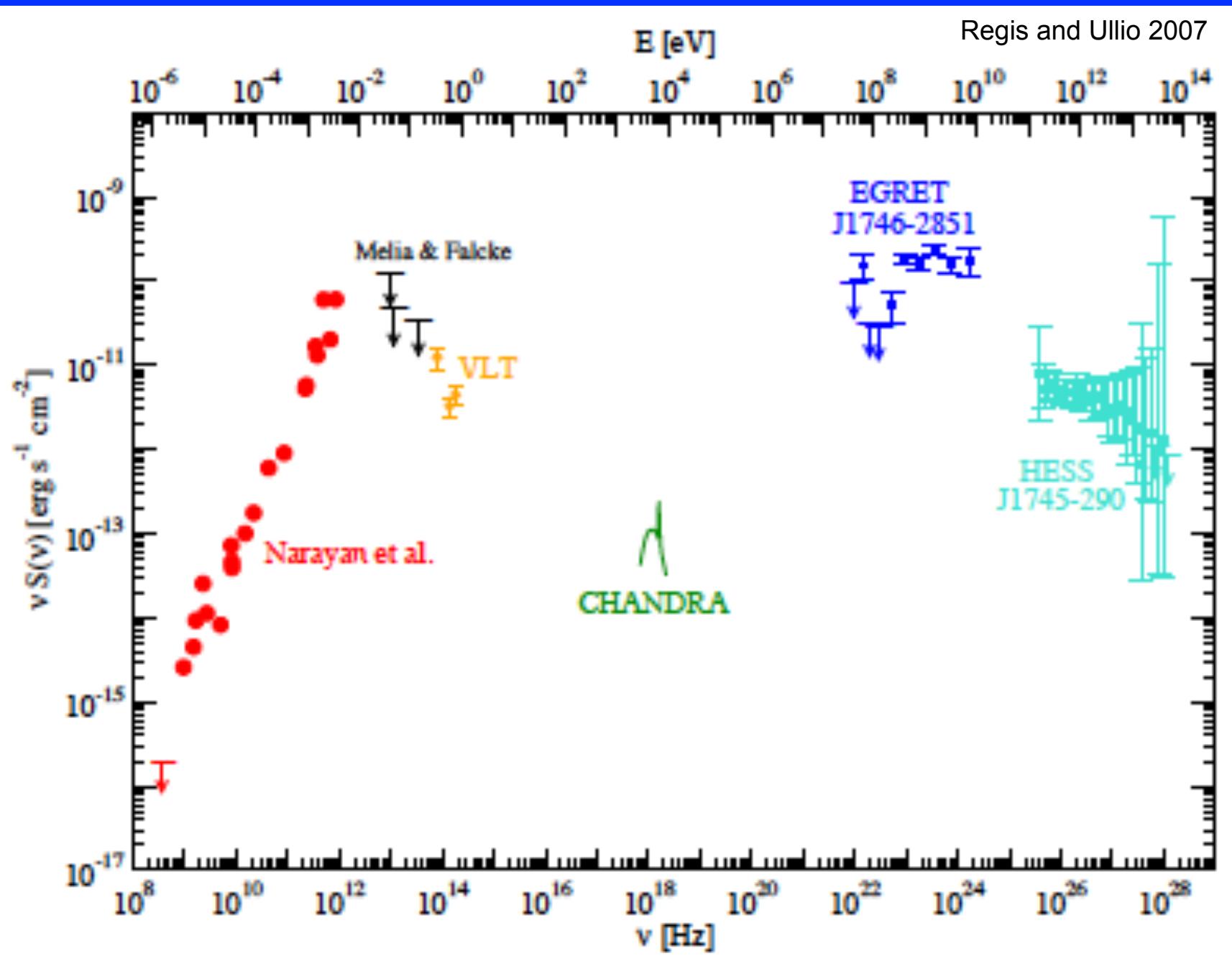
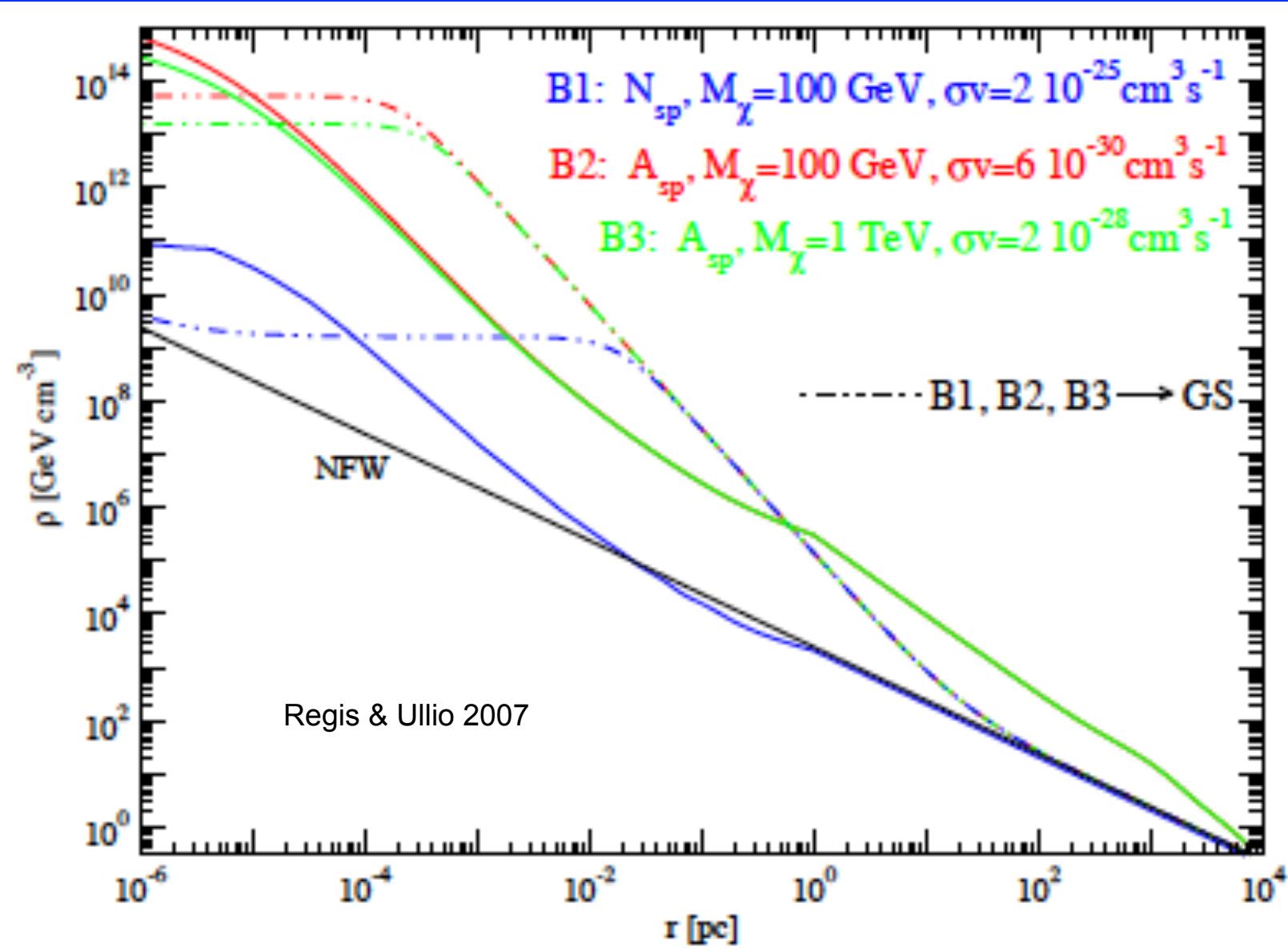
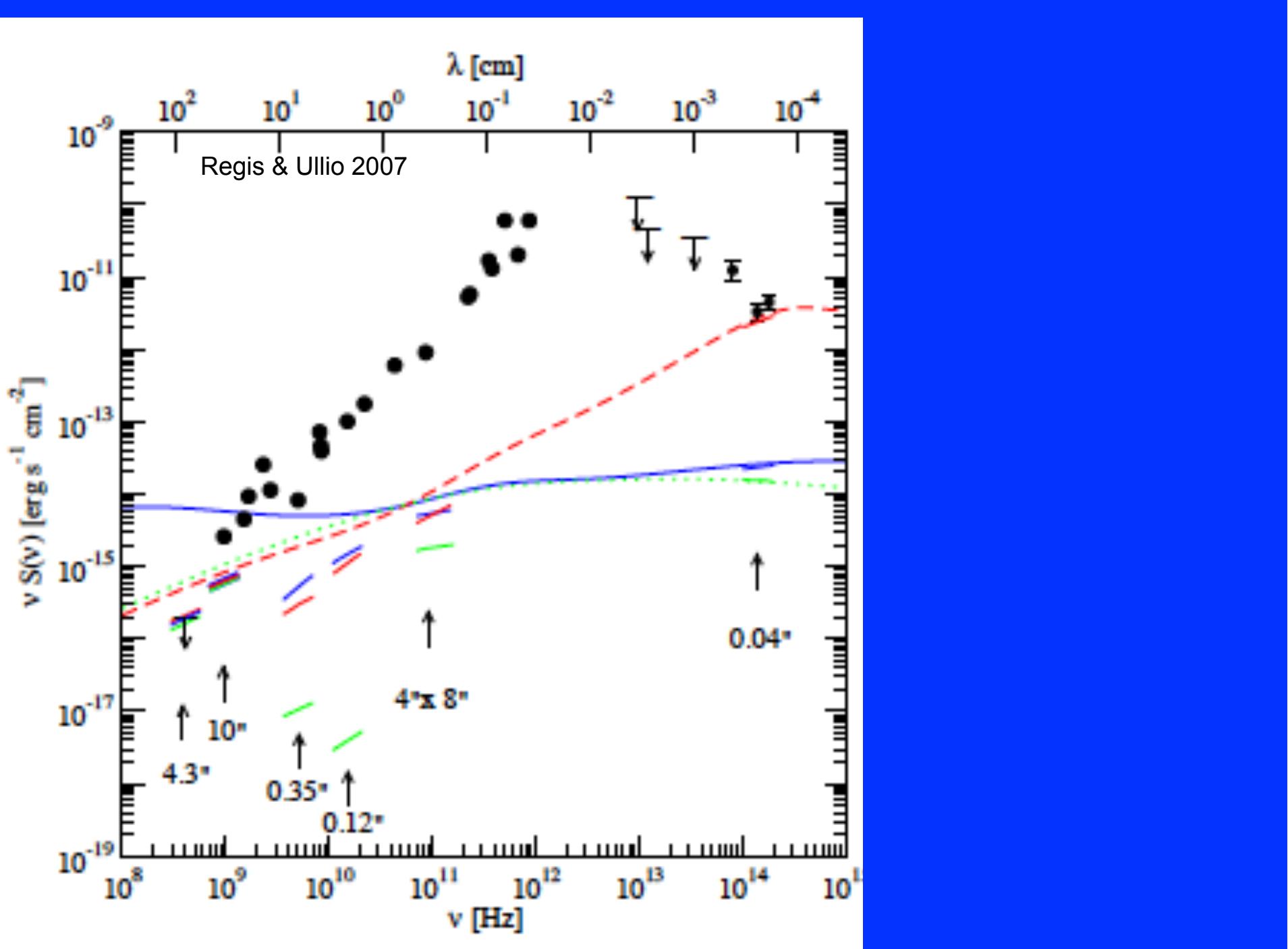
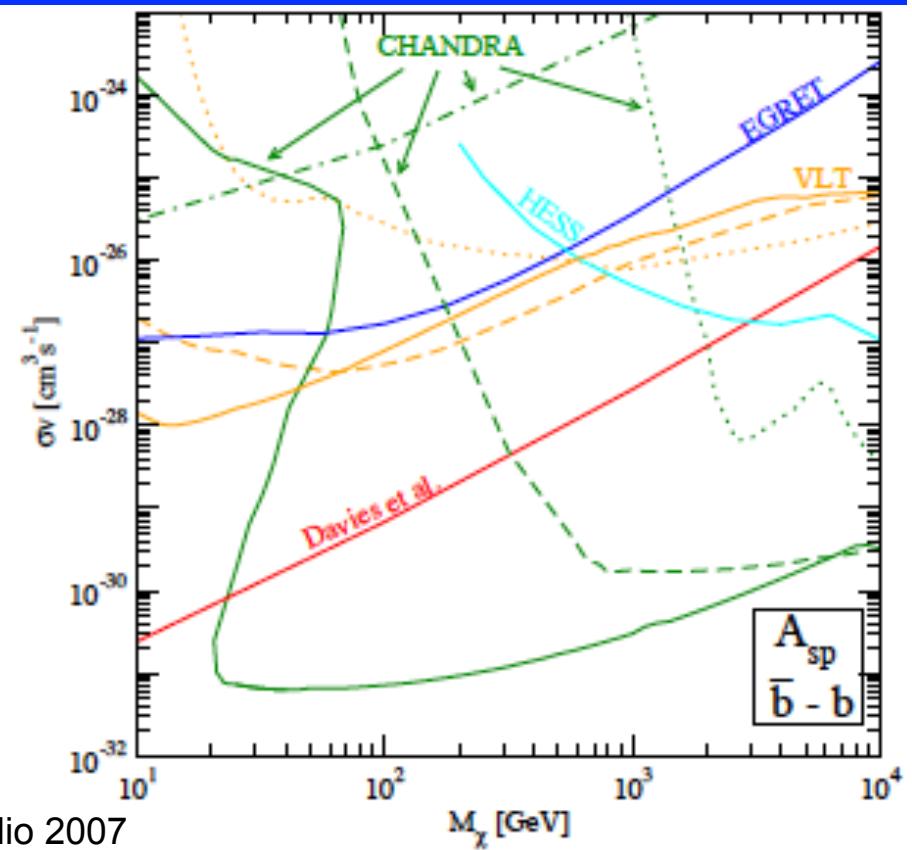
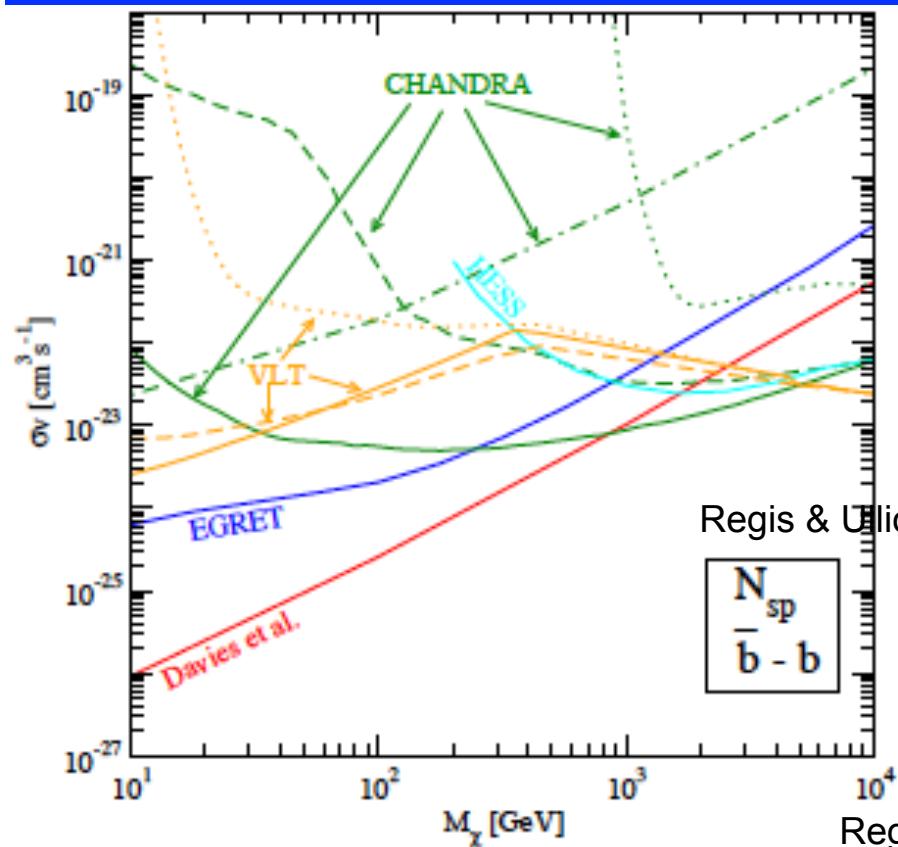


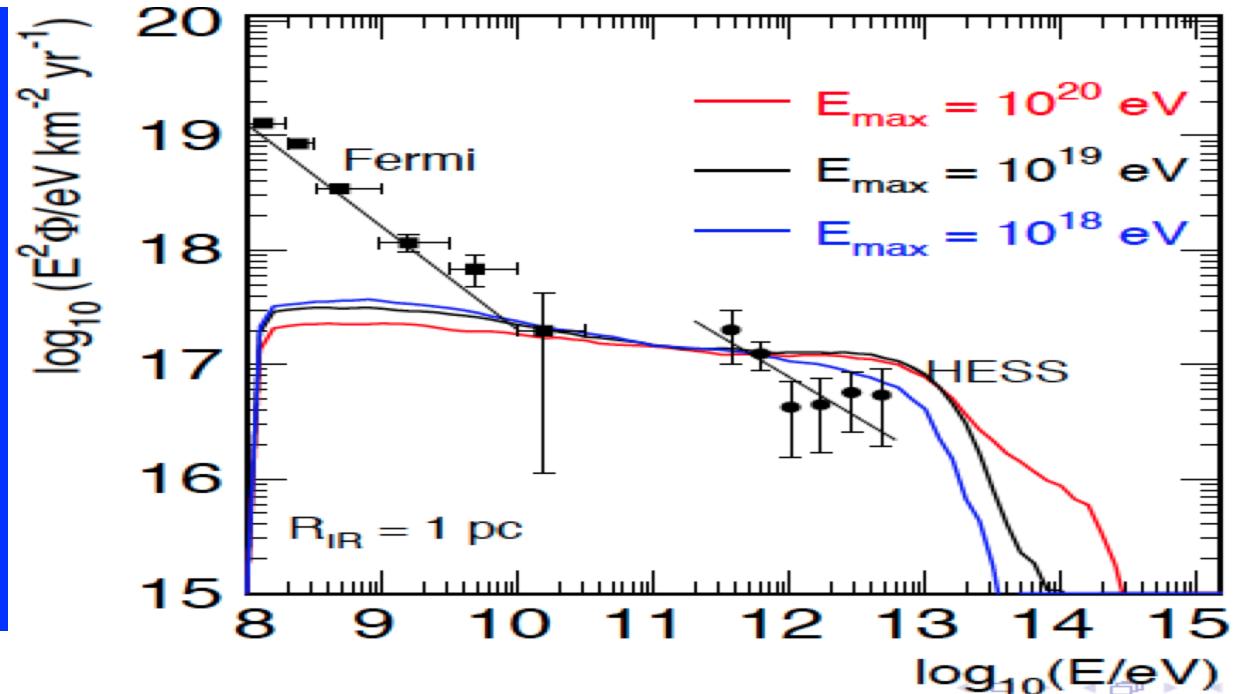
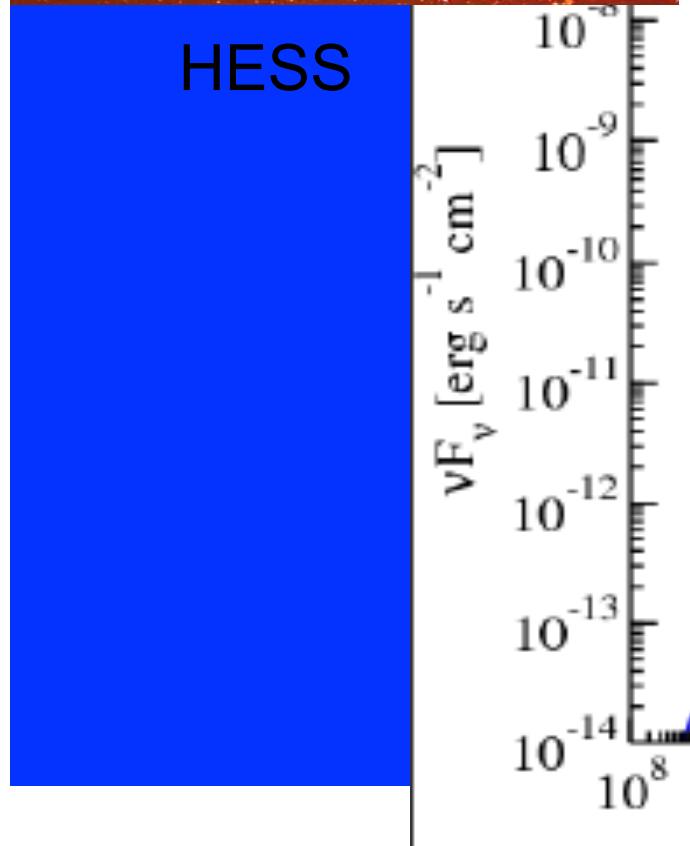
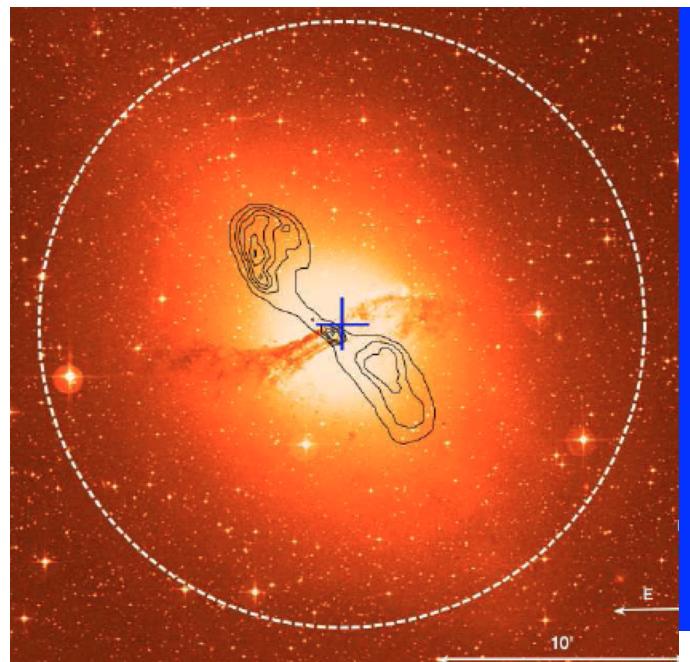
FIGURE 1. Chandra X-ray and NACO Near-infrared Composite of the Galactic center region [4]. The circle marks the systematic (and therefore irreducible) H.E.S.S. uncertainty region of 6''.



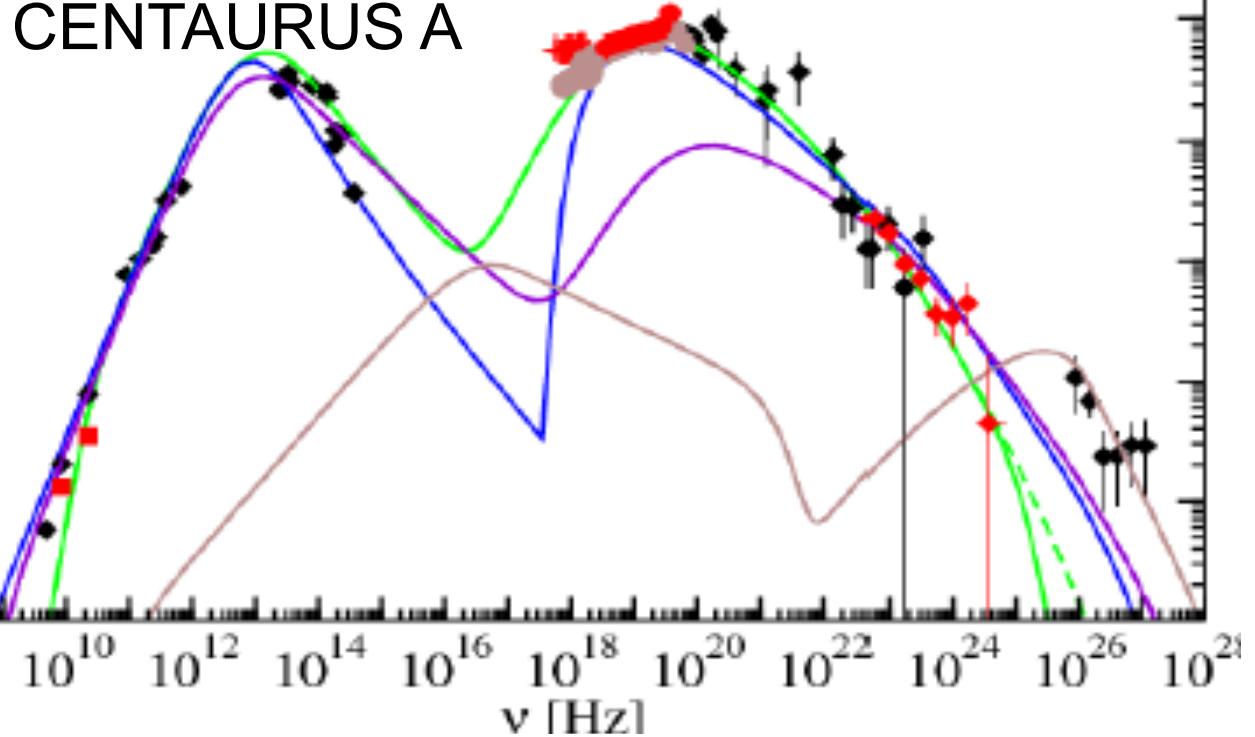








Leptonic and hadronic injection needed
CENTAURUS A

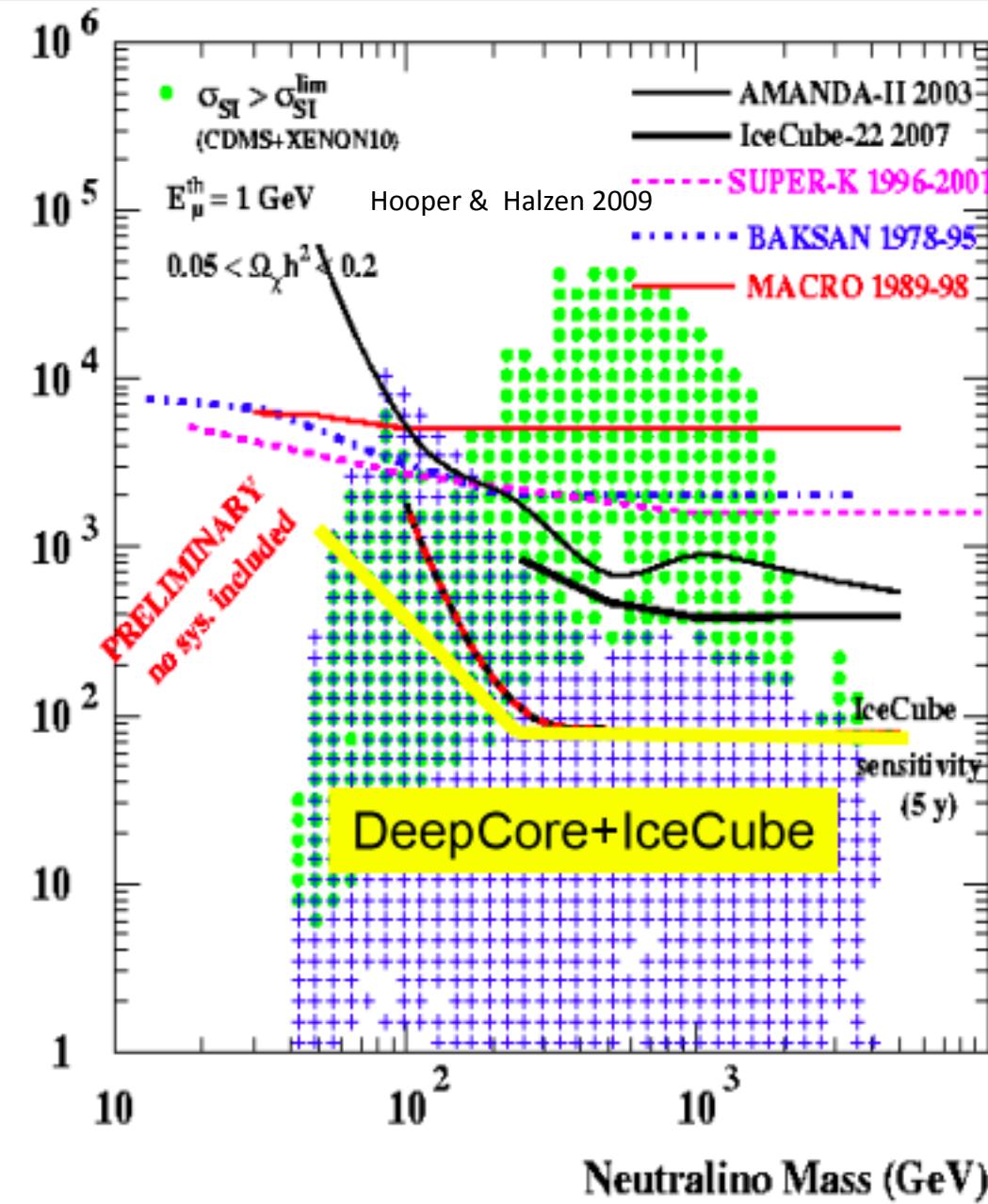
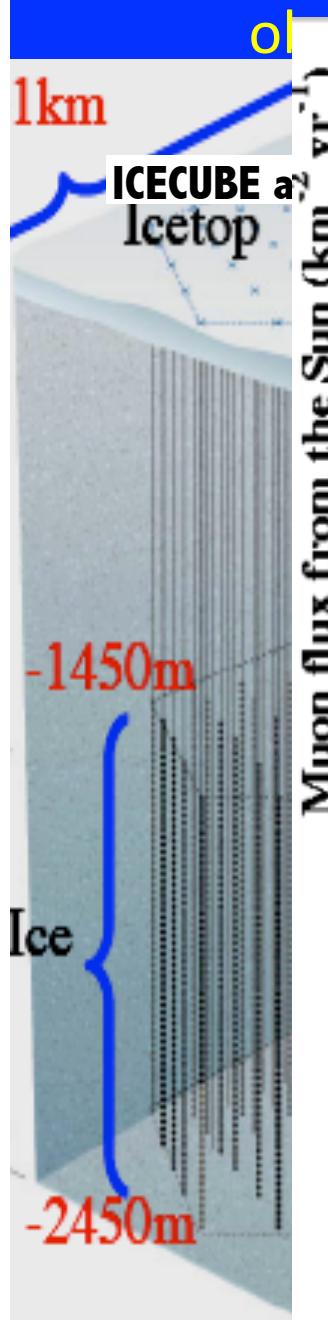


Indirect detection: The Galactic Centre

The Sun

Neutron stars

high energy neutrinos from WIMPs annihilating in the sun

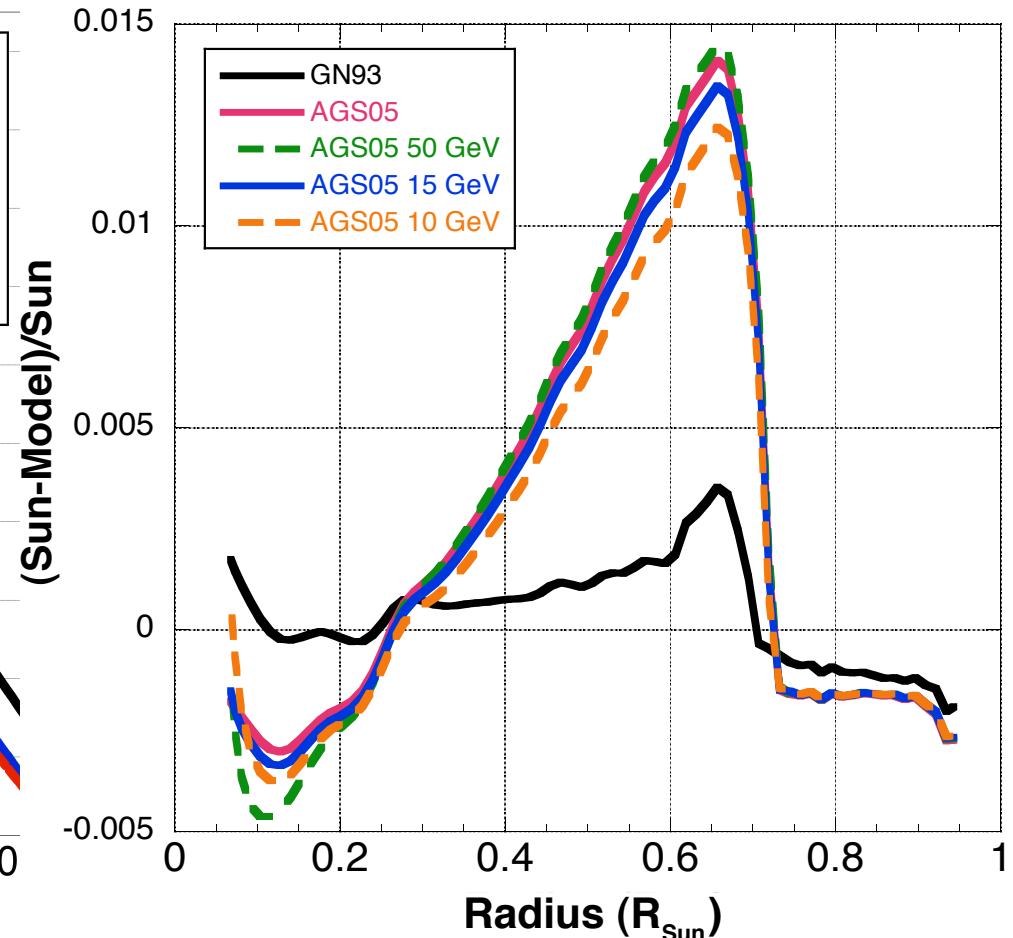
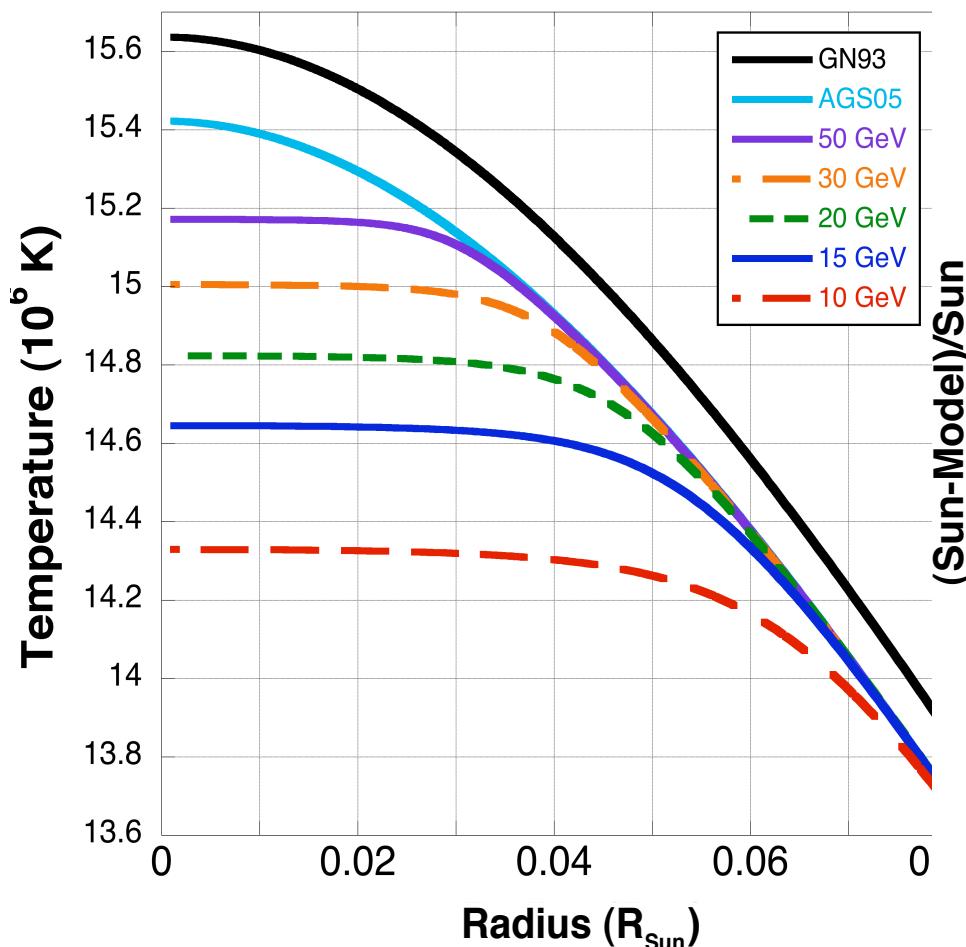


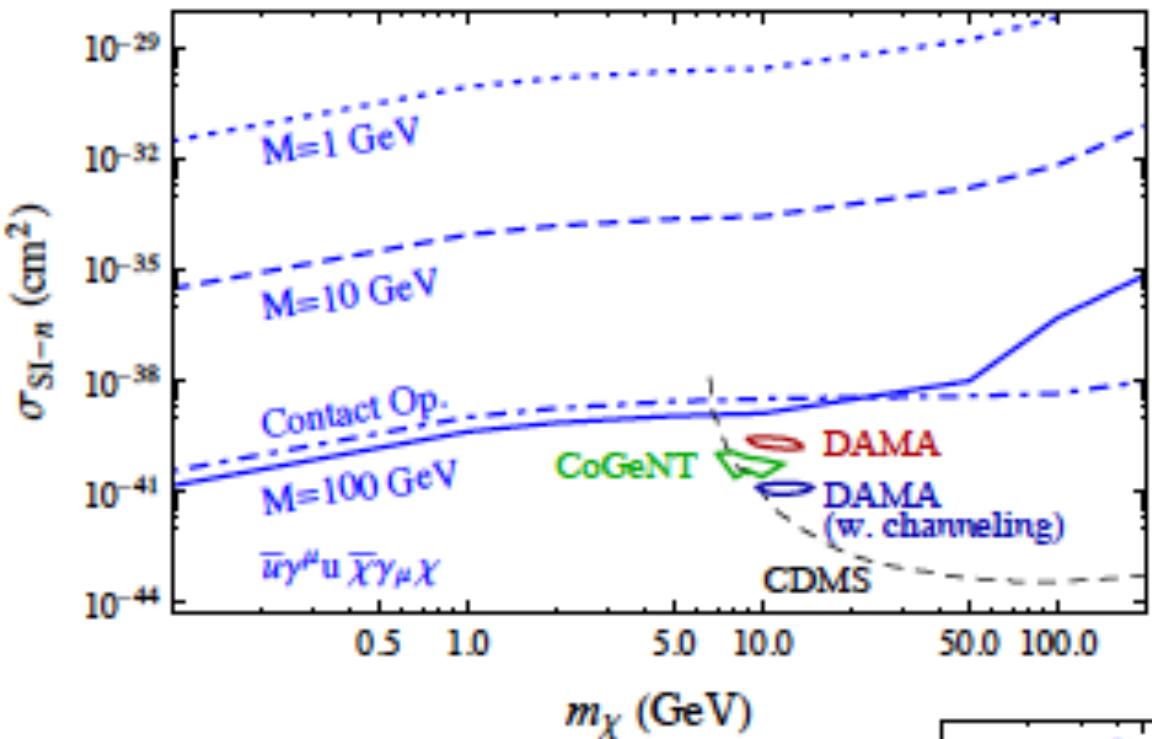
STARS AS NEUTRALINO TRAPS

For annihilating $m_x \sim 5\text{-}20 \text{ GeV}$ with large SD cross-section,
WIMPs can modify the core properties of the sun.

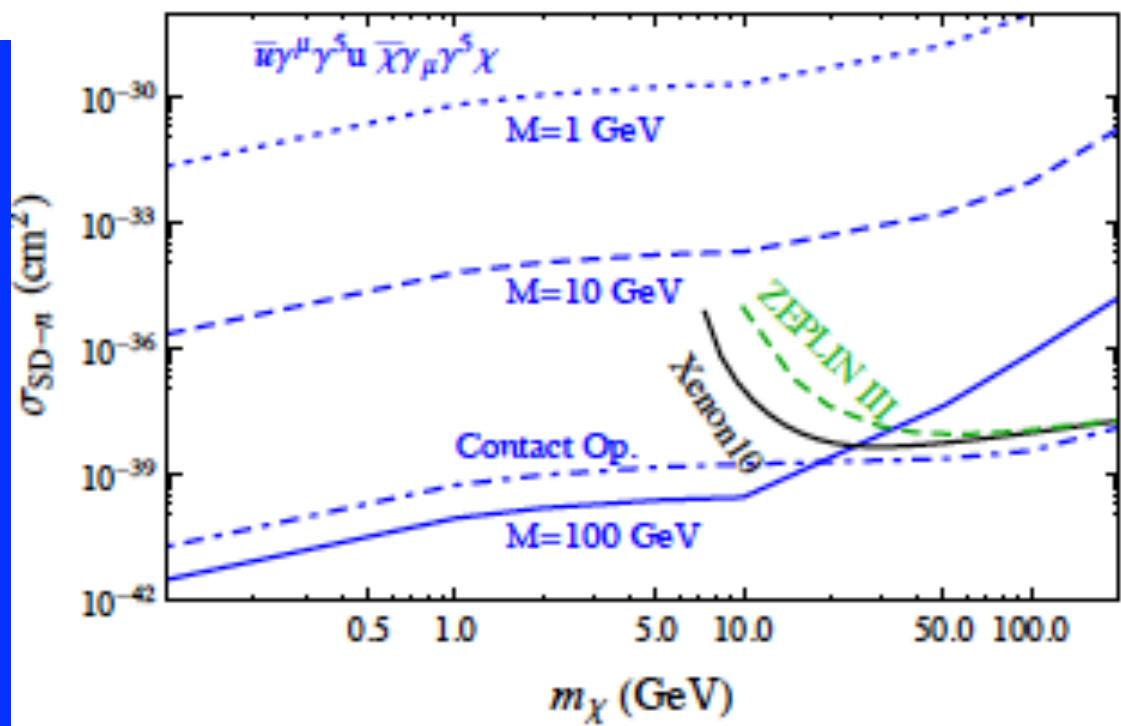
Cumberbatch et al 2010
Taoso et al 2010

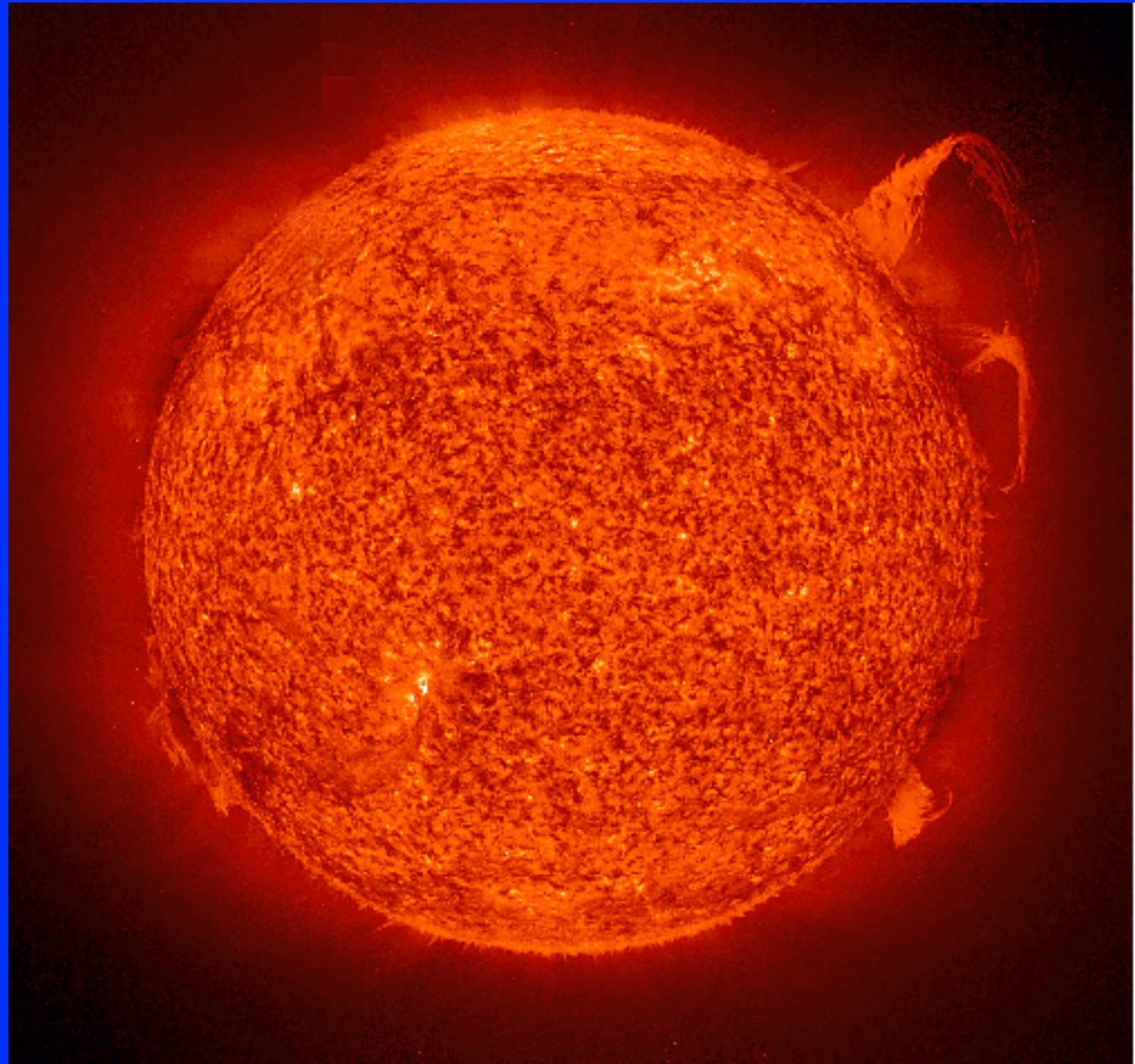
Sound speed differences!

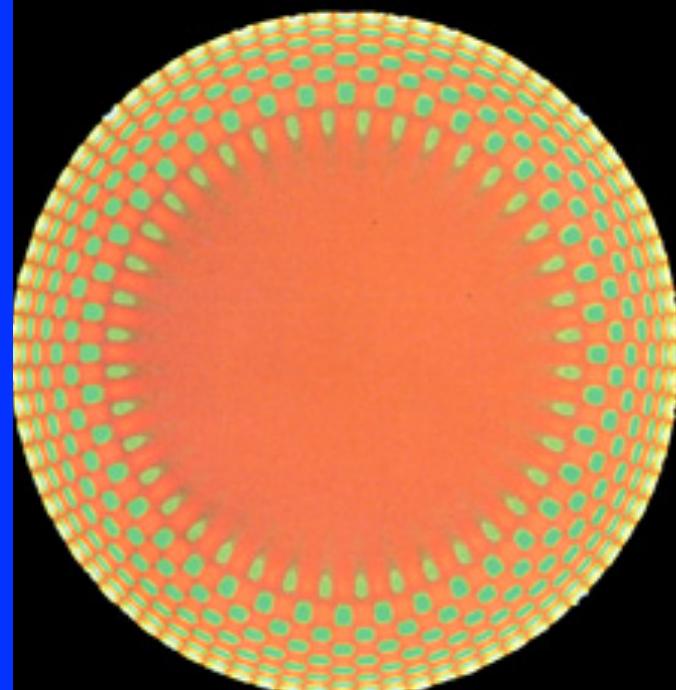
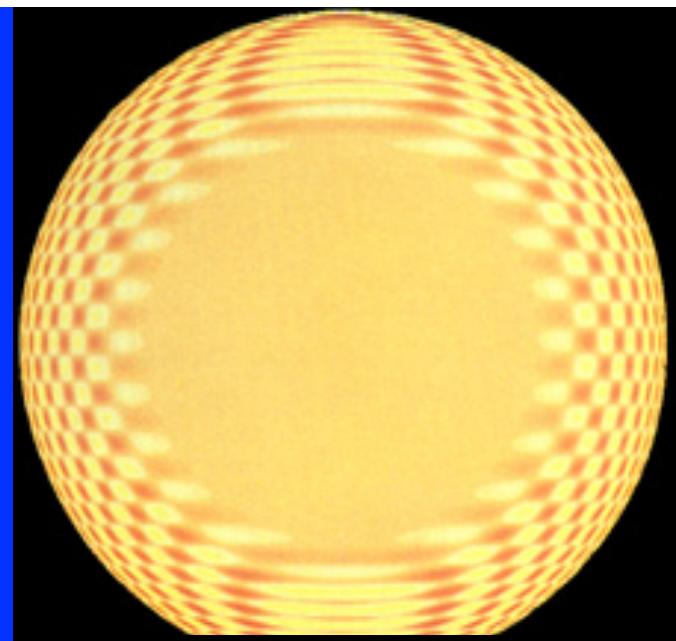
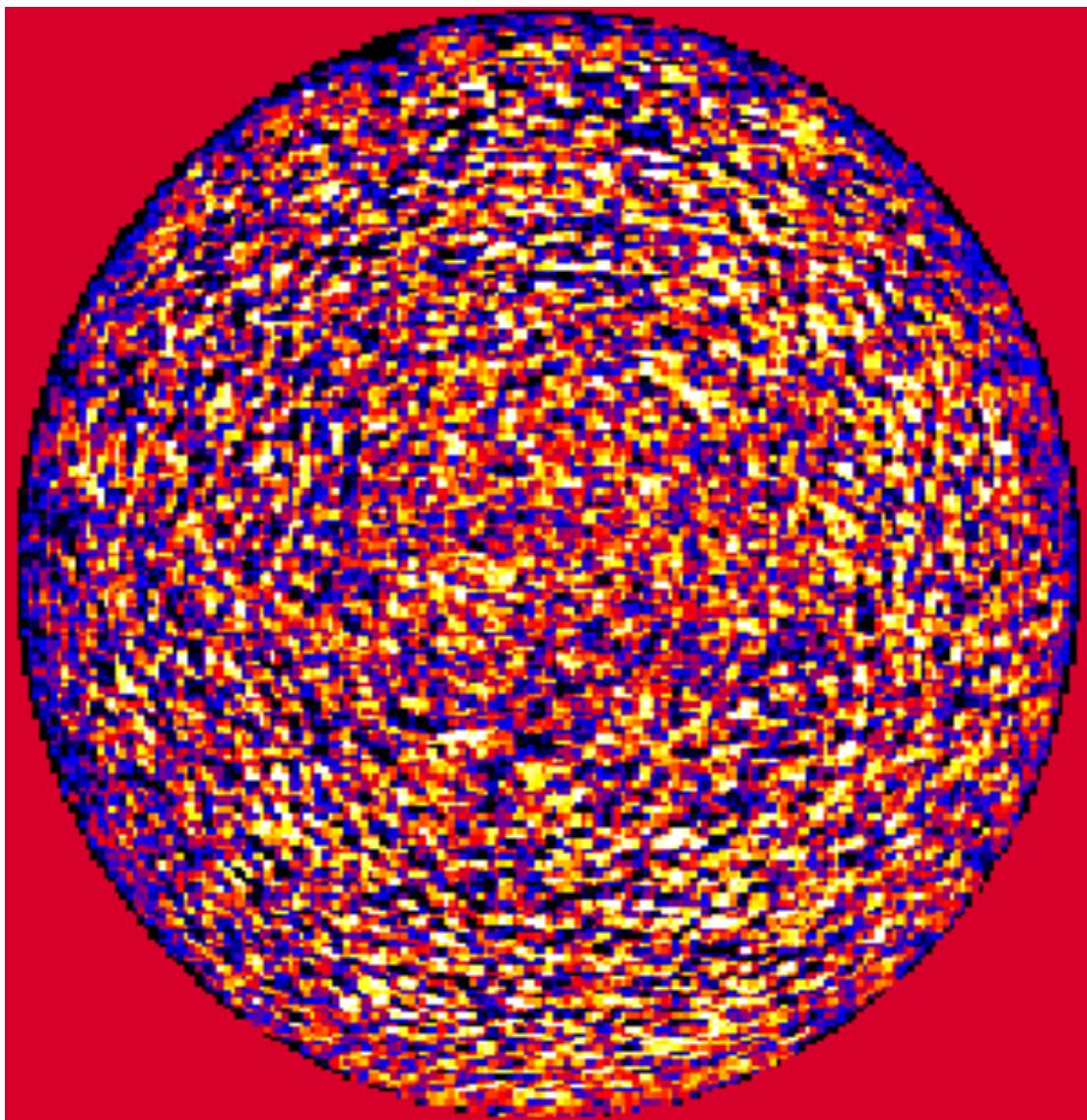




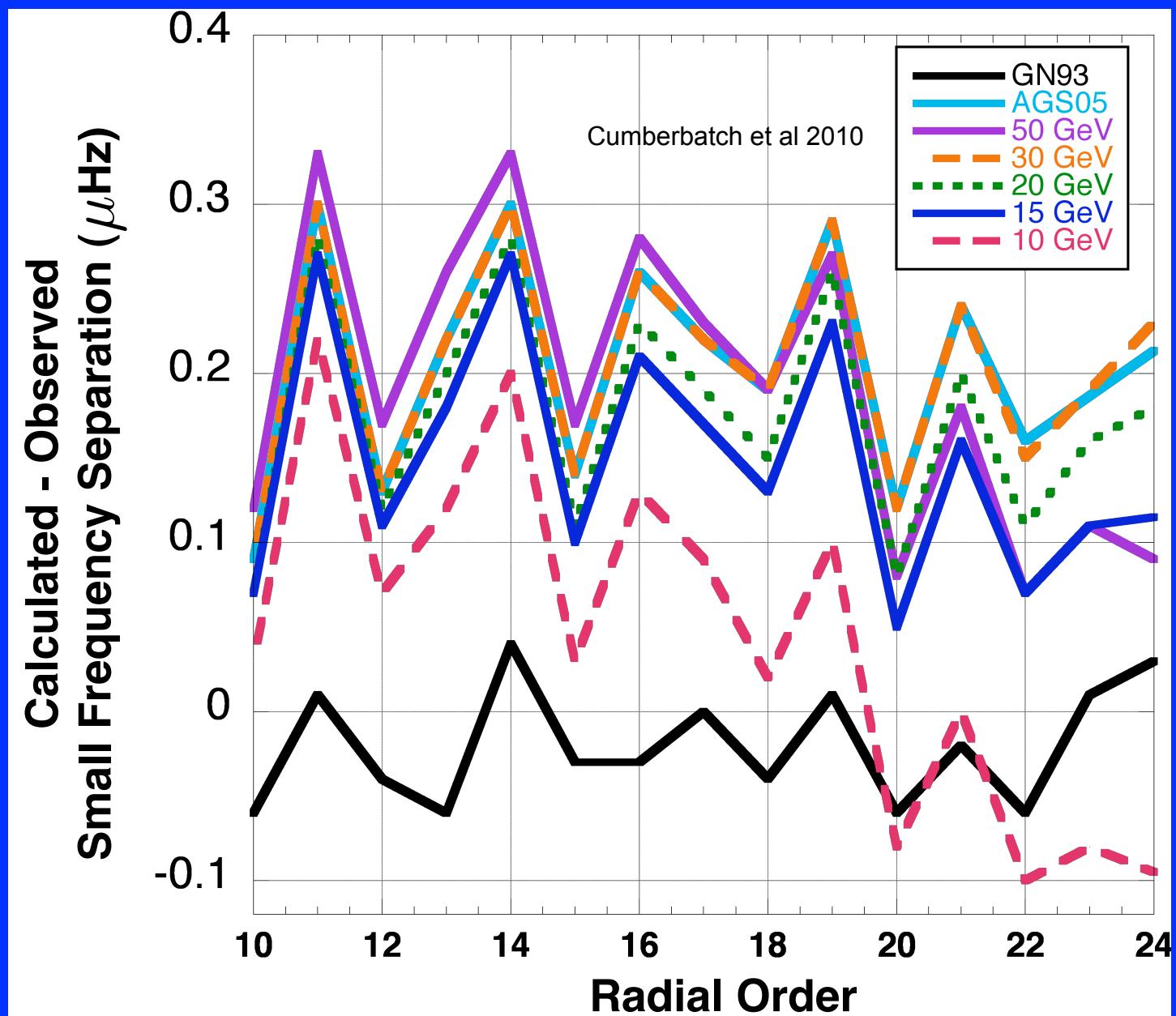
TEVATRON LIMITS
Bai et al. 2010





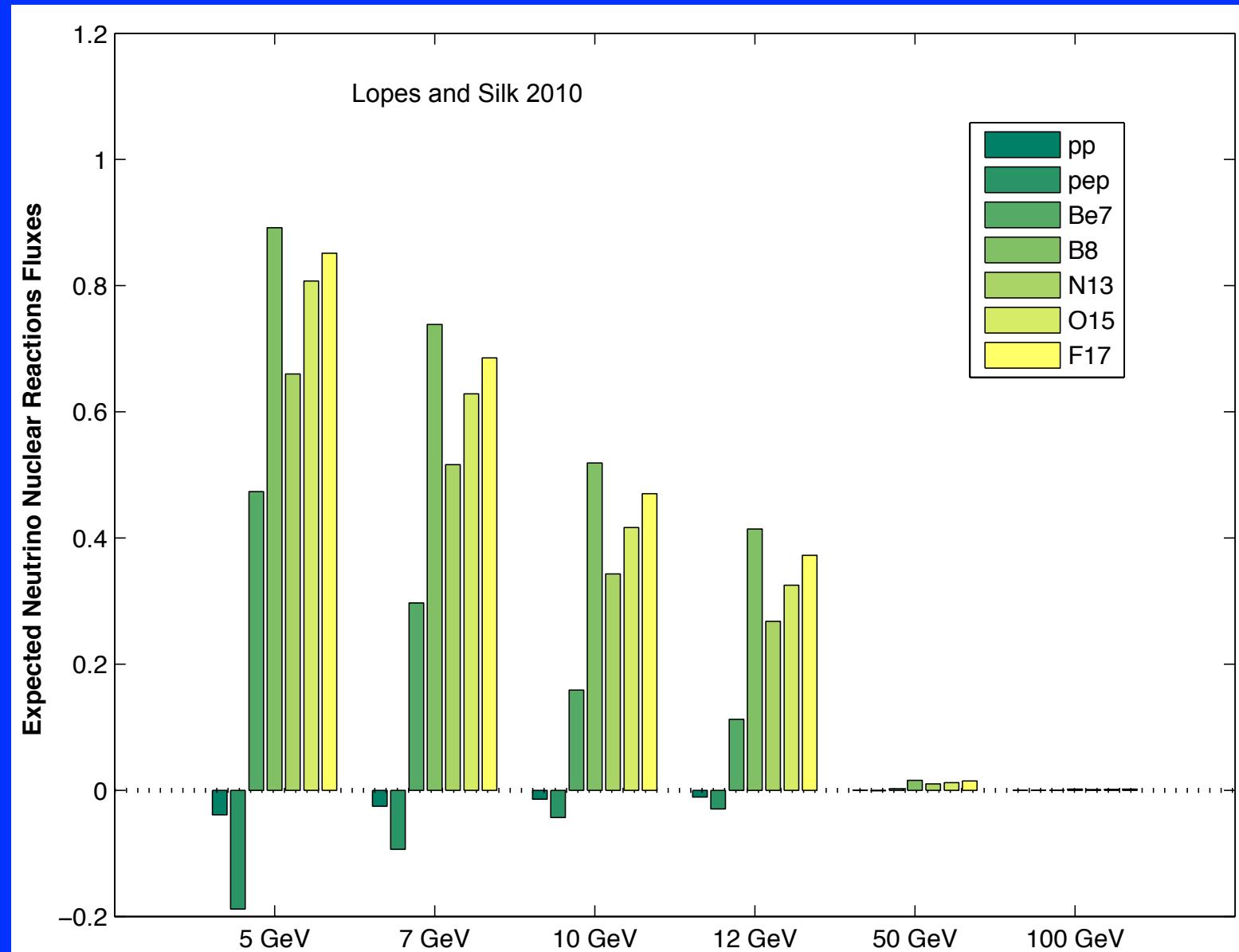


helioseismology constraints



Neutrino predictions

$$\sigma_{\text{ann}} = 10^{-36} \text{ cm}^2$$
$$\sigma_s = 10^{-35} \text{ cm}^2$$



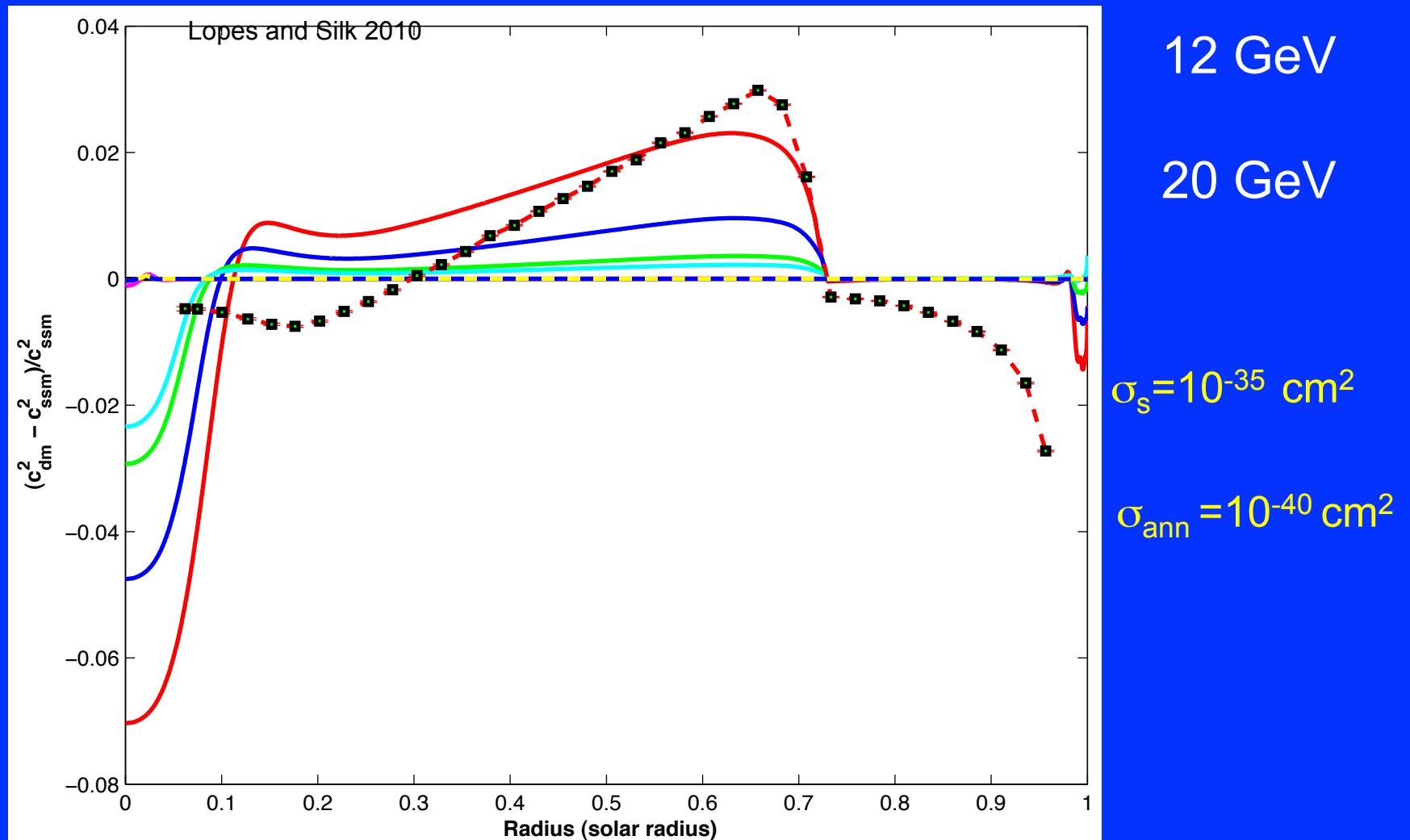
For non-annihilating $m_x \sim 5\text{-}20 \text{ GeV}$ with large SD cross-section, the effect is larger!

5 GeV

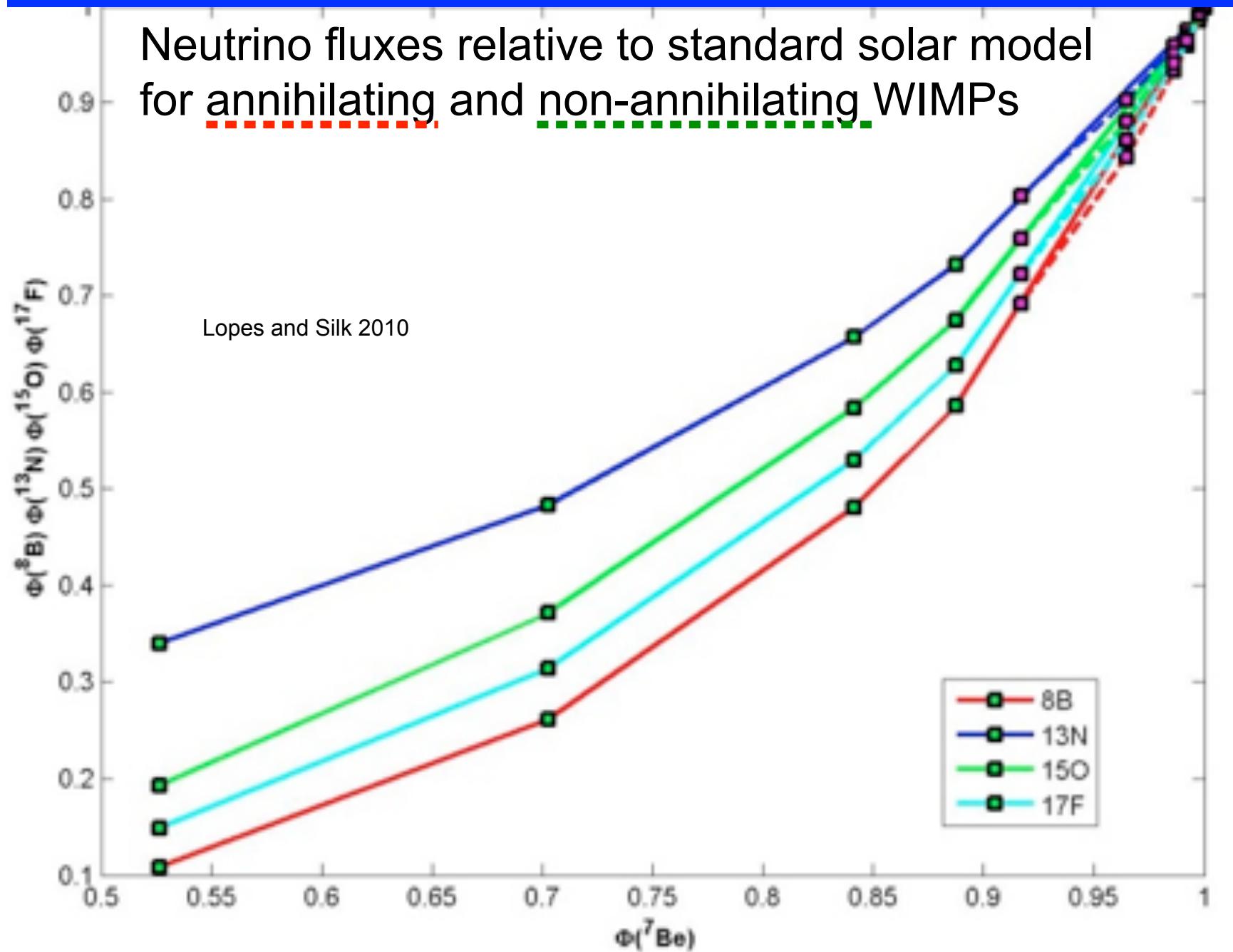
7 GeV

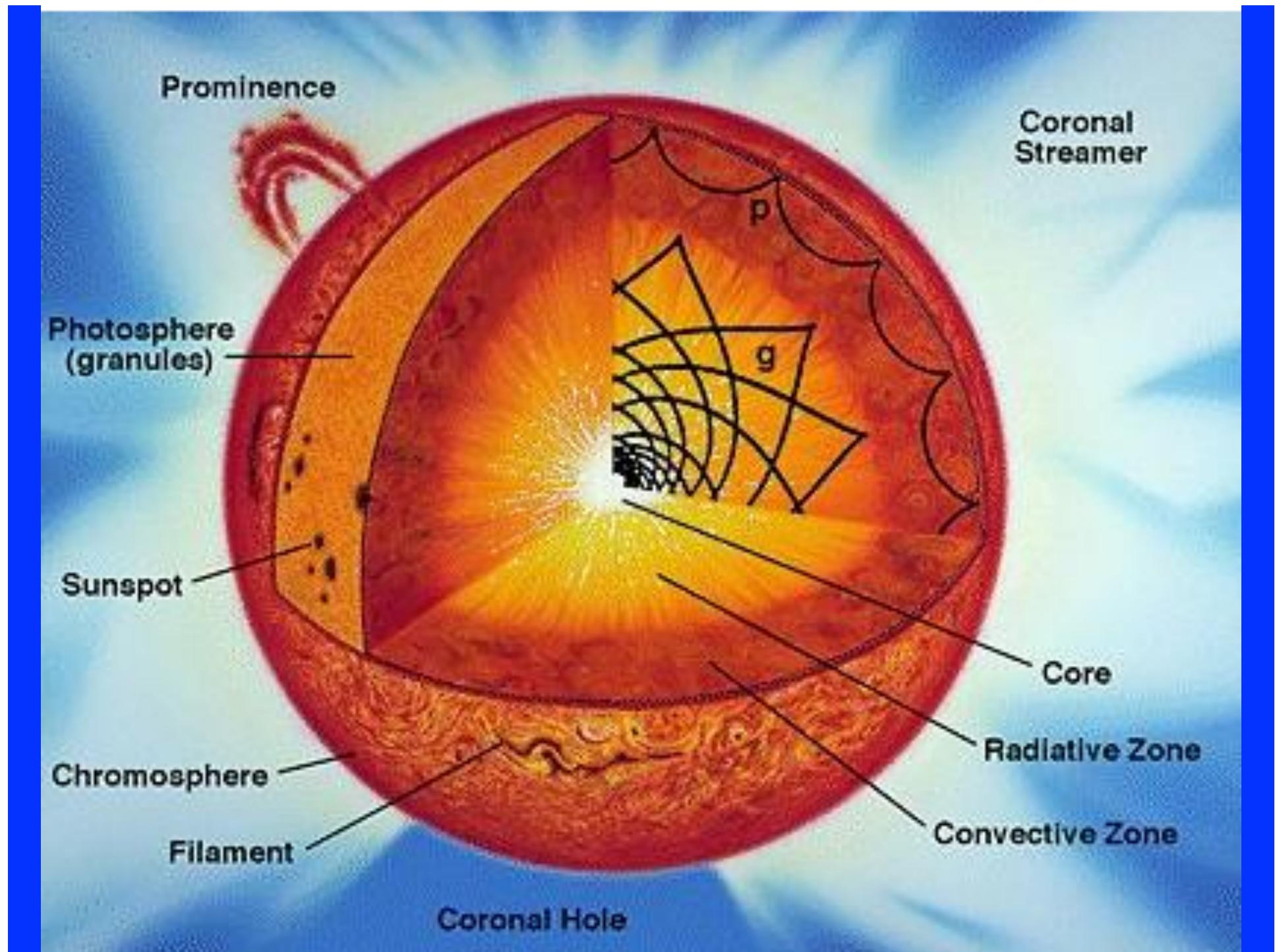
12 GeV

20 GeV

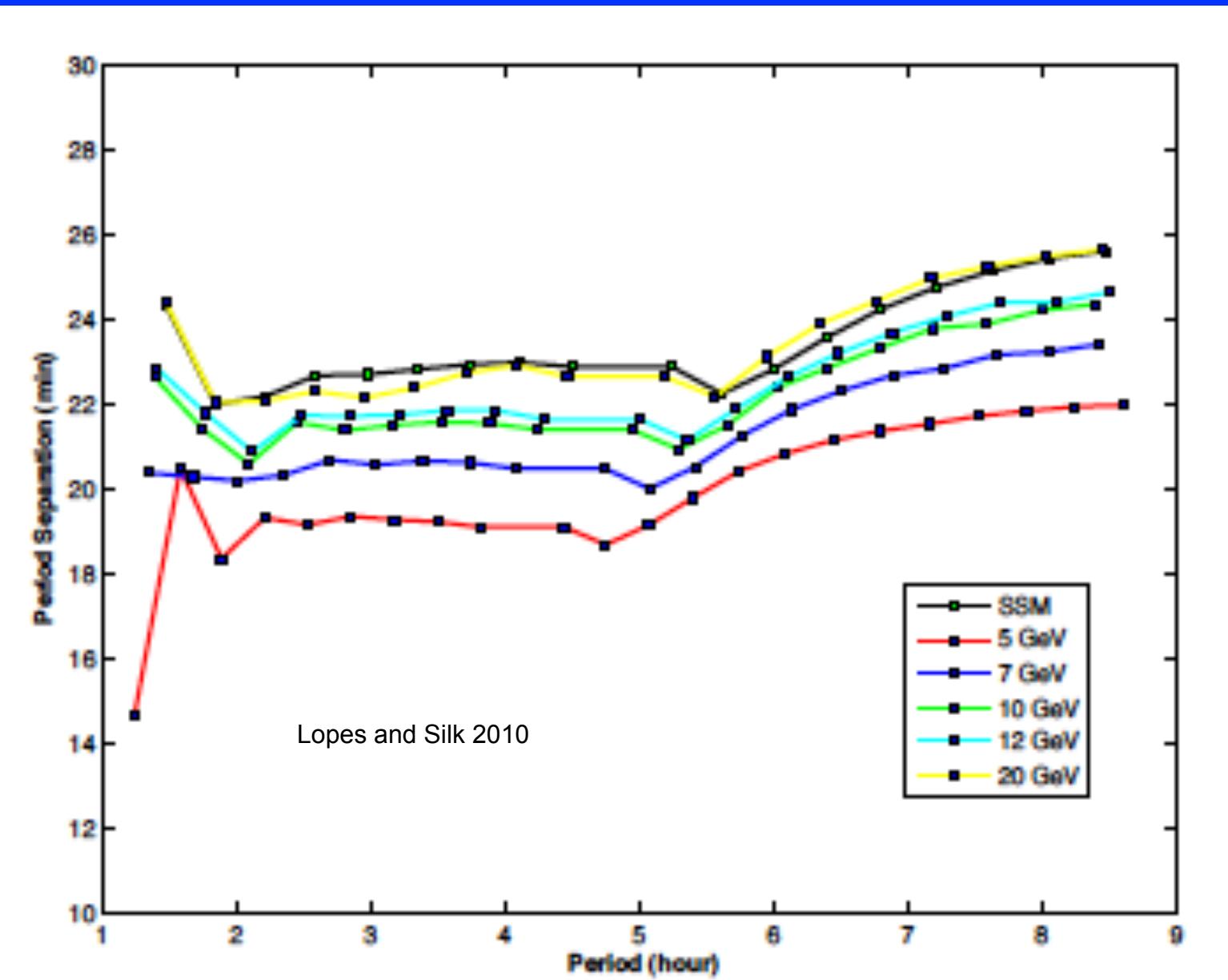


Neutrino fluxes relative to standard solar model for annihilating and non-annihilating WIMPs





Period separation for $l=1$ gravity modes



Indirect detection: The Galactic Centre

The Sun

Neutron stars

Cosmic separation of phases

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(Received 9 April 1984)

A first-order QCD phase transition that occurred reversibly in the early universe would lead to a surprisingly rich cosmological scenario. Although observable consequences would not necessarily survive, it is at least conceivable that the phase transition would concentrate most of the quark excess in dense, invisible quark nuggets, providing an explanation for the dark matter in terms of QCD effects only. This possibility is viable only if quark matter has energy per baryon less than 938 MeV. Two related issues are considered in appendices: the possibility that neutron stars generate a quark-matter component of cosmic rays, and the possibility that the QCD phase transition may have produced a detectable gravitational signal.

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Received 1986 February 14; accepted 1986 April 14

ABSTRACT

Strange matter, a form of quark matter that is postulated to be absolutely stable, may be the true ground state of the hadrons. If this hypothesis is correct, neutron stars may convert to "strange stars." The mass-radius relation for strange stars is very different from that of neutron stars; there is no minimum mass, and for mass $\lesssim 1 M_{\odot}$, $M \propto R^3$. For masses between $1 M_{\odot}$ and $2 M_{\odot}$, the radii of strange stars are ~ 10 km, as for neutron stars. Strange stars may have an exposed quark surface, which is capable of radiating at rates greatly exceeding the Eddington limit, but has a low emissivity for X-ray photons. The stars may have a thin crust with the same composition as the pre-neutron drip outer layer of a conventional neutron star crust. Strange stars cool efficiently via neutrino emission. It is not clear whether or not all neutron stars must convert into strange stars, but this seems the most likely conclusion. There may be no neutron stars, only strange stars.

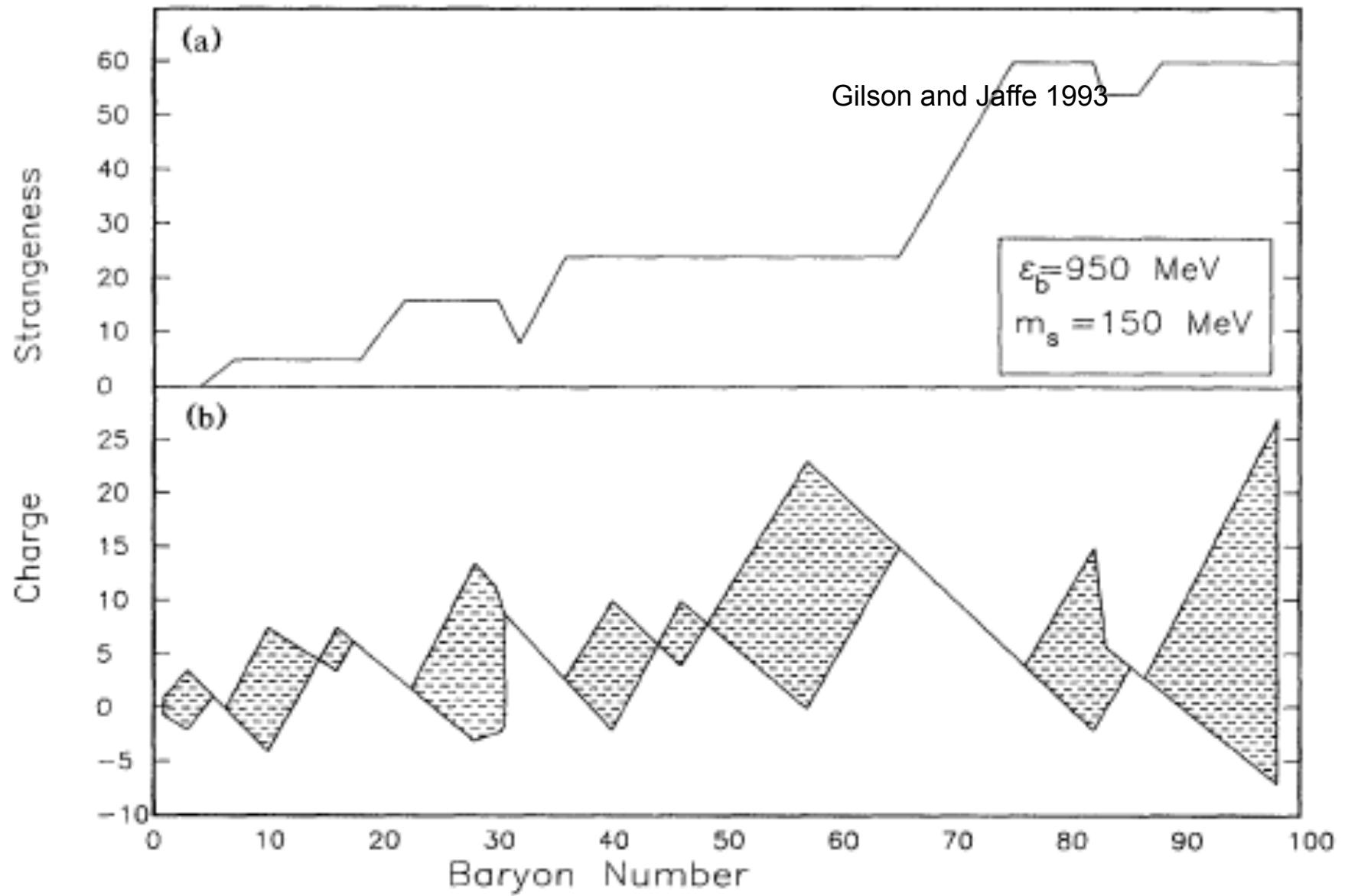


FIG. 2. (a) Strangeness as a function of A for the most stable species. (b) Strangelet charges as a function of A .

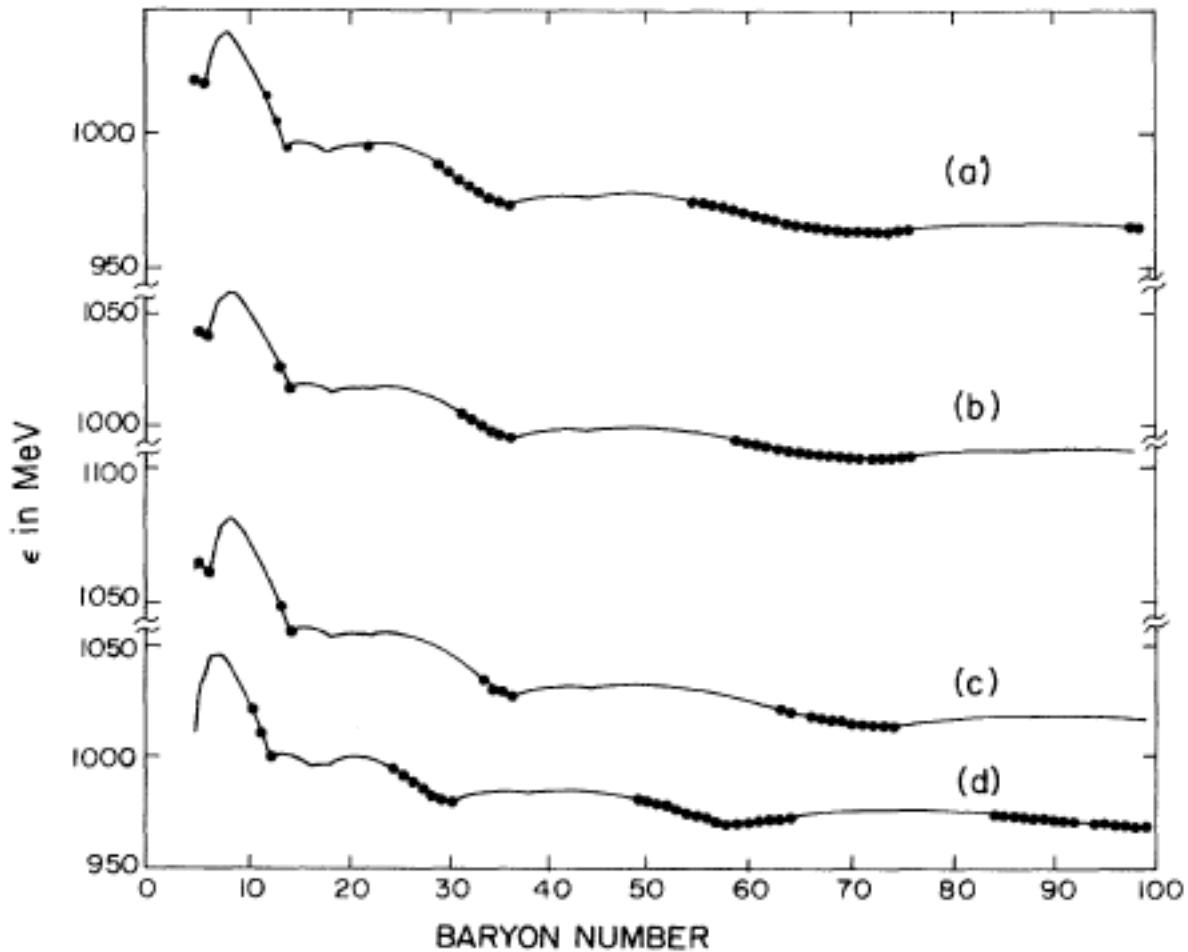


FIG. 3. Energy per baryon as a function of A . (a) $\epsilon_b = 930$ MeV, $m_s = 150$ MeV, $B^{1/4} = 154.64$ MeV. (b) $\epsilon_b = 950$ MeV, $m_s = 150$ MeV, $B^{1/4} = 158.71$ MeV. (c) $\epsilon_b = 970$ MeV, $m_s = 150$ MeV, $B^{1/4} = 162.31$ MeV. (d) $\epsilon_b = 950$ MeV, $m_s = 250$ MeV, $B^{1/4} = 151.60$ MeV.

If neutron matter is metastable, it takes \sim 300 MeV/baryon to convert neutrons into strange quark matter ($m_s = 104$ MeV).

Strangelets with A as low as 10-600 may be long-lived,
eg \sim days (Alford et al. 2006, Shaffner-Bielich et al 1997).

Hence 3 GeV to 180 GeV is the energy release deep inside a neutron star by annihilation that can catalyse conversion,
eg \sim minutes (Bhattacharyya et al 2006)

$$E^A(\mu_i, m_i, B) = \sum_i (\Omega_i + N_i \mu_i) + BV$$

$$E_{\text{coul}} = \frac{4}{3} \left(\frac{\alpha Z_Y^2}{10R} + \frac{\alpha Z^2}{2R} \right)$$

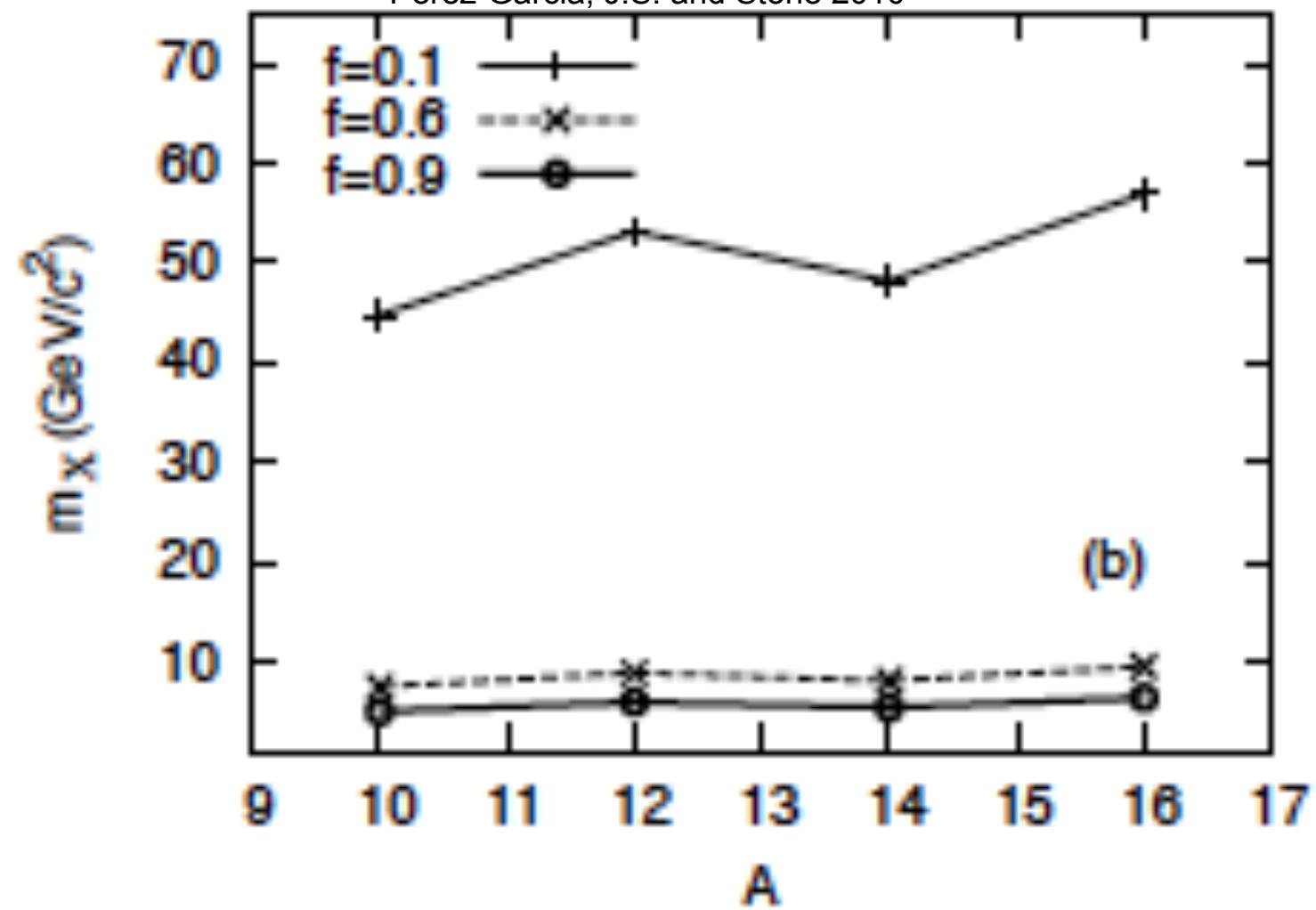
$$E_{\text{slet}}^A \approx E^A(\mu_i, m_i, B) + E_{\text{coul}}$$

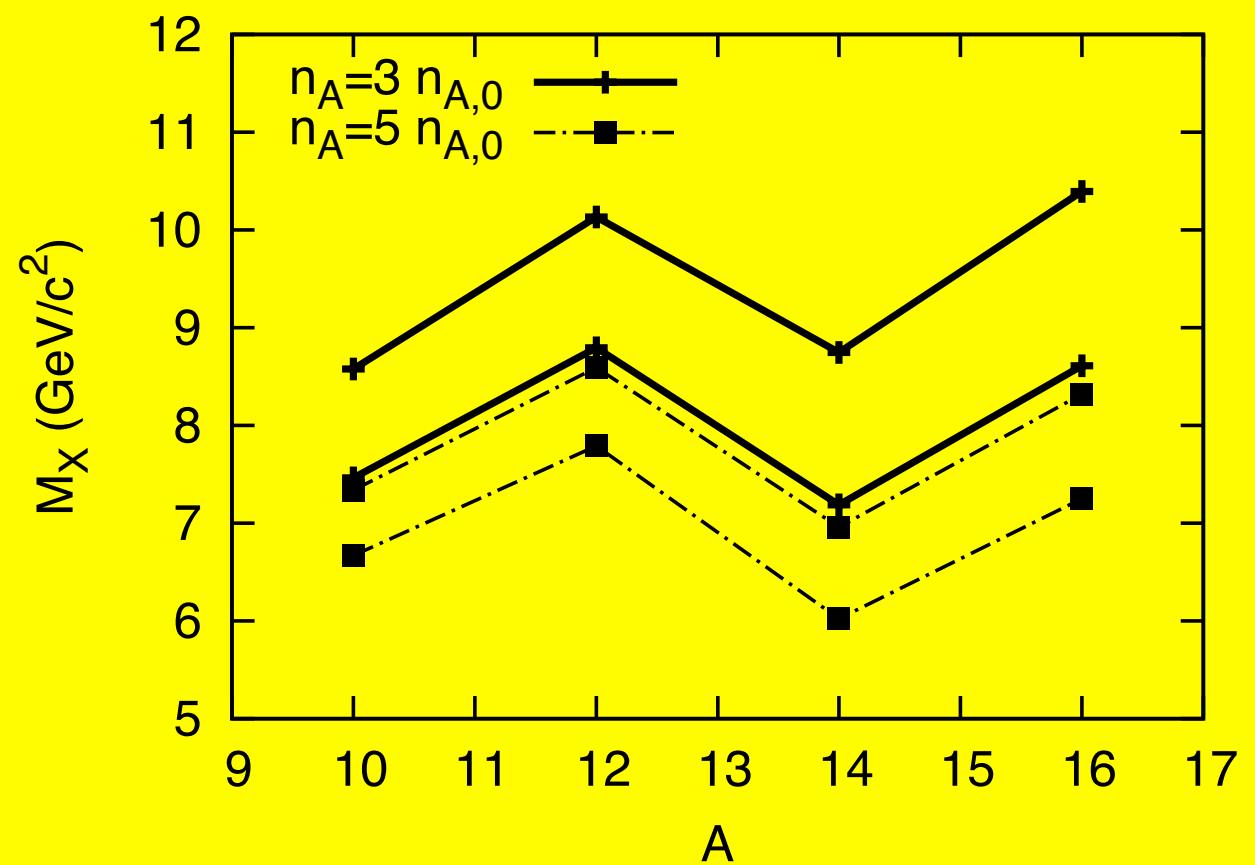
$$m_u = 2.55 \text{ MeV}, m_d = 5.04 \text{ MeV}, m_s = 104 \text{ MeV}$$

For conversion

$$2fm_\chi c^2 \geq E_{\text{slet}}^A(\mu_i(n_A), m_i, B)$$

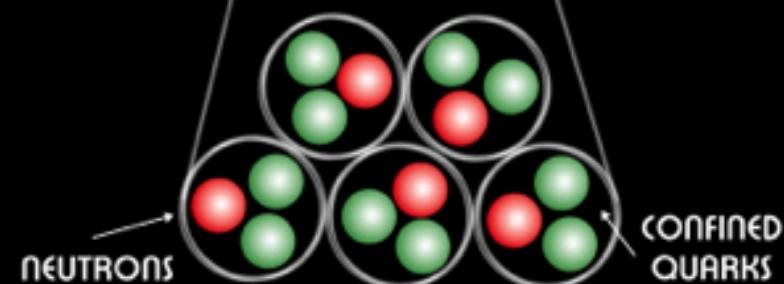
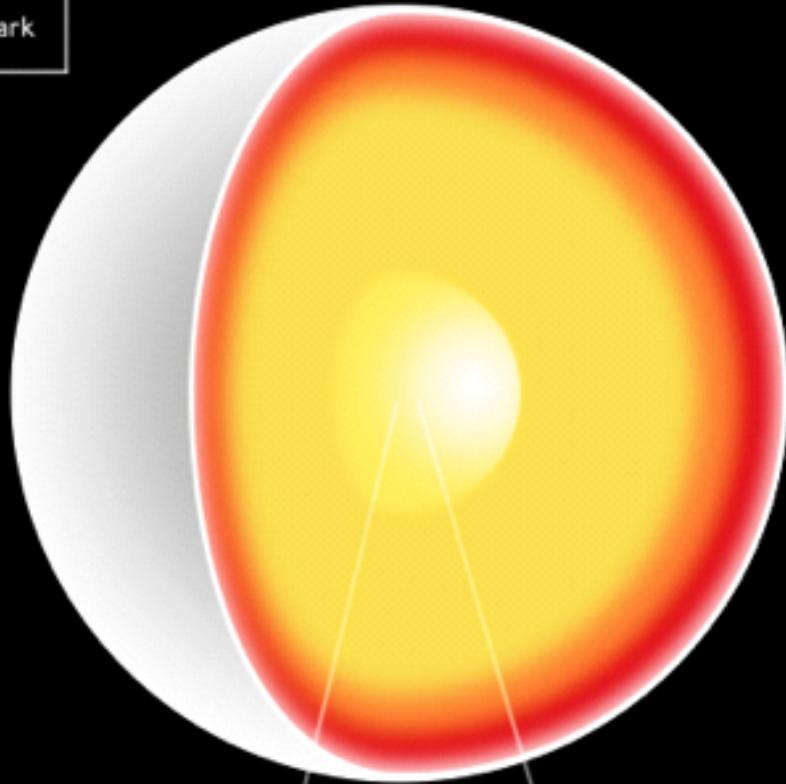
Perez-Garcia, J.S. and Stone 2010



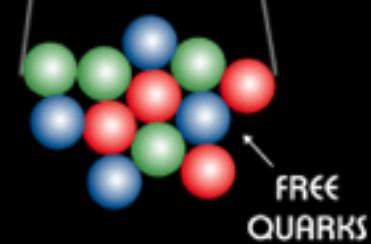
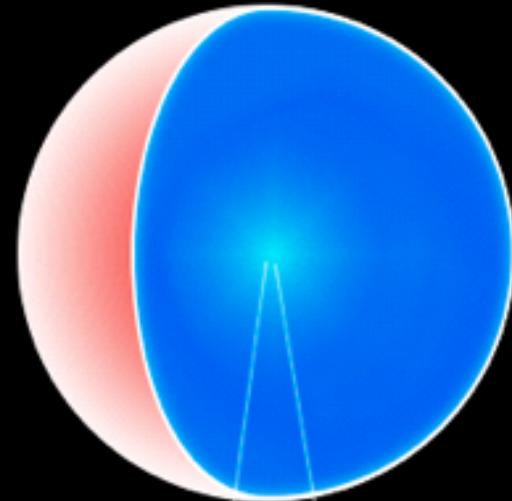


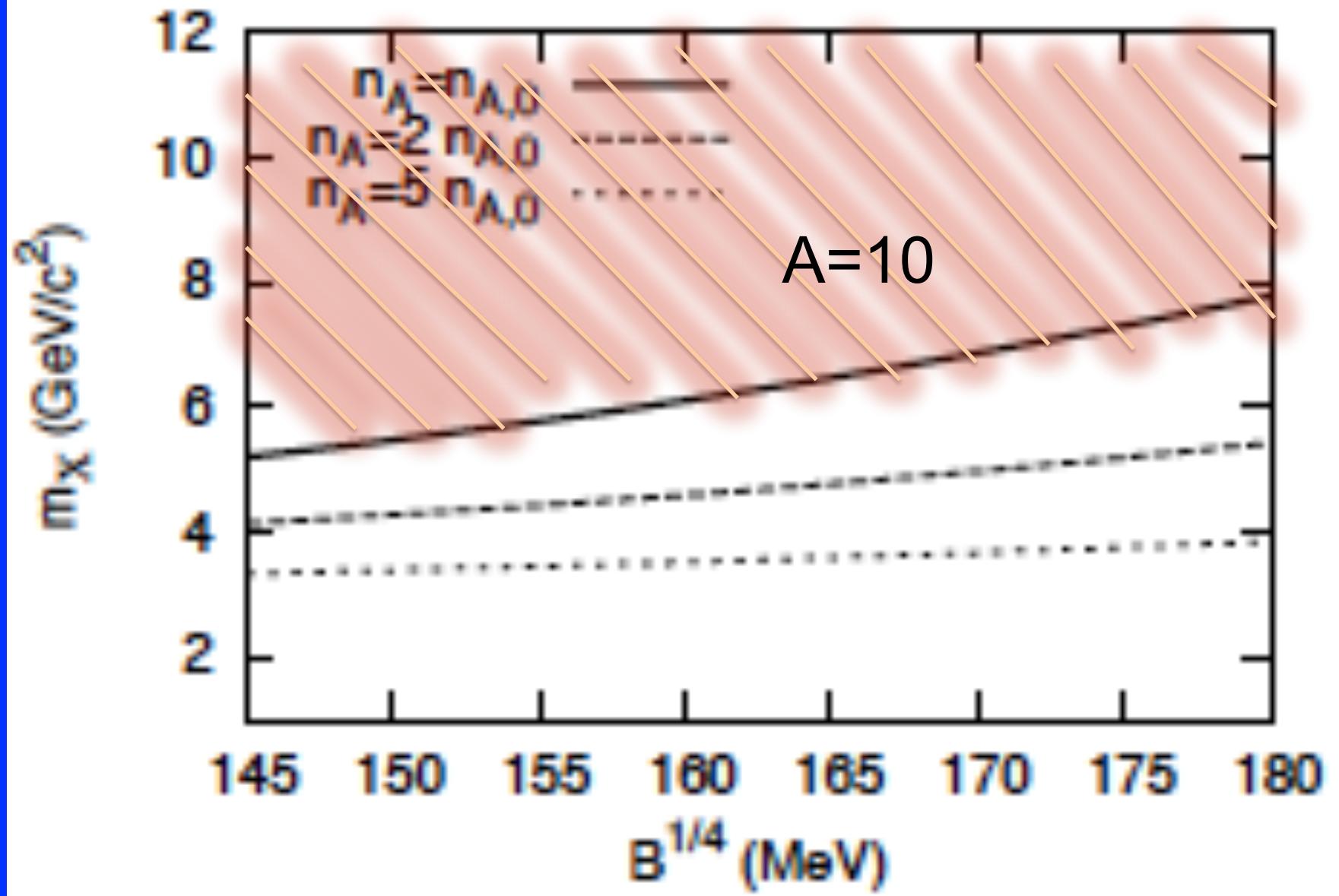
- Up Quark
- Down Quark
- Strange Quark

Neutron Star



Strange Quark Star





SUMMARY

Dark matter spikes at the Galactic Centre
and other SMBH/IMBH are possible γ sources

The Sun is a dark matter probe via
helioseismology especially with g modes

Neutron star conversion to strange quark stars
may be triggered by dark matter annihilations

extraordinary claims require extraordinary evidence.
extraordinary claims require extraordinary evidence.

