Title: Particle Dark Matter: What Comes Next?

Date: Jun 02, 2008 11:50 AM

URL: http://pirsa.org/08060029

Abstract: After a brief introduction, where I review the properties of the \'good Dark Matter candidate\' and the status of accelerator, direct and indirect Dark Matter searches, I will show that a conclusive identification of DM particles can most likely be achieved only through a \'multidisciplinary\' approach, that combines together different detection techniques. I will place special emphasis on the upcoming Large Hadron Collider, and on the gamma-ray satellite GLAST (scheduled for launch on June 3, i.e. the day after the talk...)

Particle Dark Matter: WHAT COMES NEXT?

Gianfranco Bertone
Institut d'Astrophysique de Paris

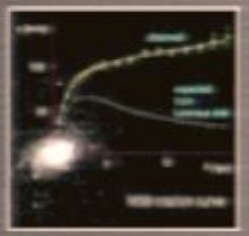
Summary

- Introduction
  - Evidence for DM
  - Properties of the "Good DM Candidate"
- DM searches @ accelerators
  - Principle & Status
  - What can we learn?
- DM Direct Detection
  - Principle & Status
  - What can we learn?
- DM Indirect Detection
  - Strategies
  - How to convince a particle physicist
- Conclusions

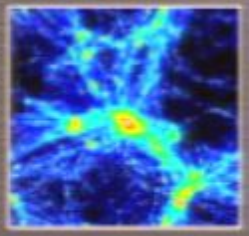
Evidence for Dark Matter

Evidence for the existence of an unseen, "dark", component in the energy density of the Universe comes from several independent observations at different length scales

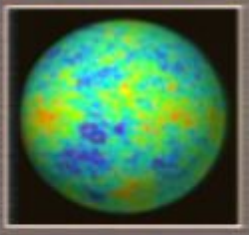
Cosmological observations



• Rotation Curves

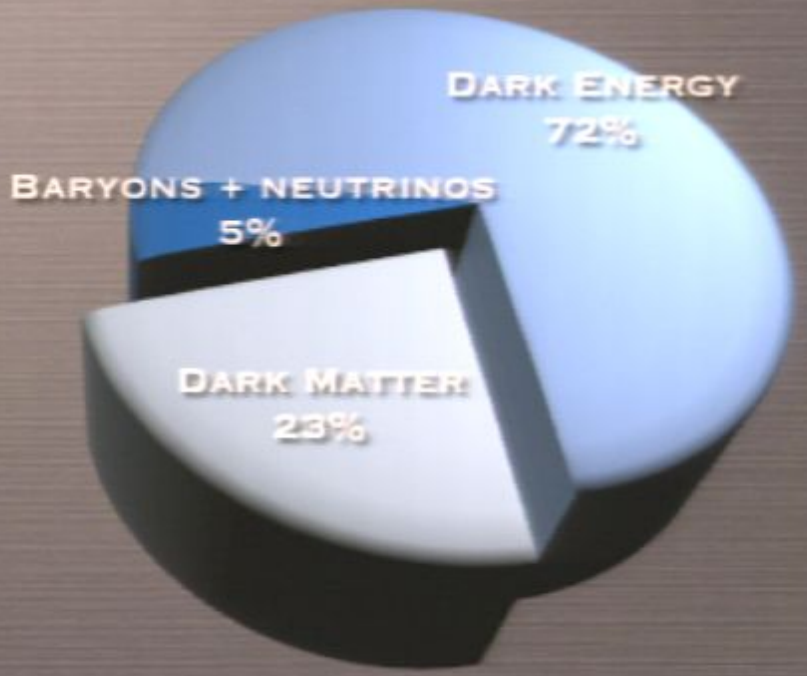


• Clusters of galaxies



•CMB

•Type Ia Supernovae



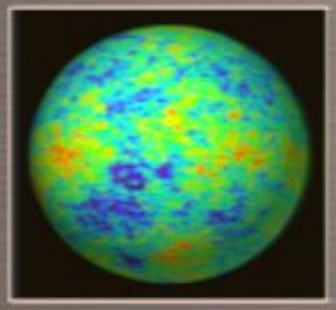
For recent reviews see e.g.:

GB, Hooper & Silk, hep-ph/0404175, Bergstrom, hep-ph/0002126

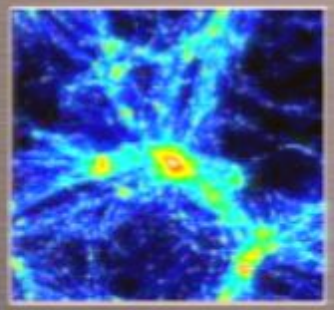
What do we know?

An extraordinarily rich zoo of non-baryonic Dark Matter candidates has been proposed over the last three decades. In order to be considered a viable DM candidate, a new particle has to pass the following 10-point test

1) Ωh^2 OK?

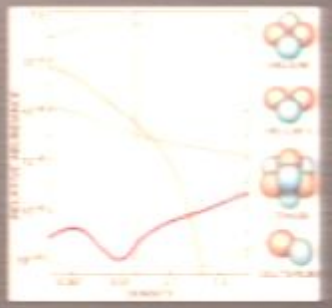


2) Is it cold?

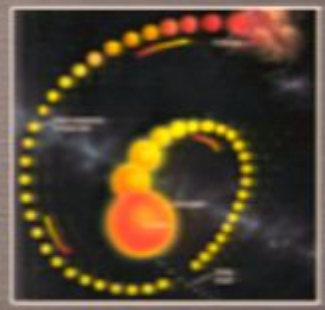


3) Is it neutral?

4) Is BBN ok?

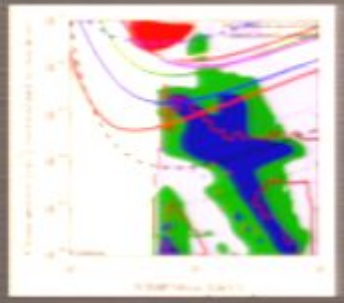


5) Stars OK?

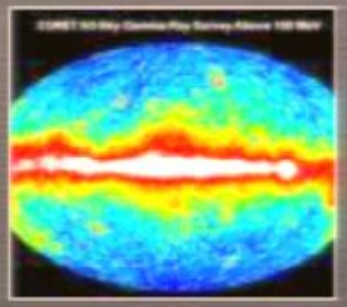


6) Collisionless?

7) Couplings OK?



8) γ-rays OK?



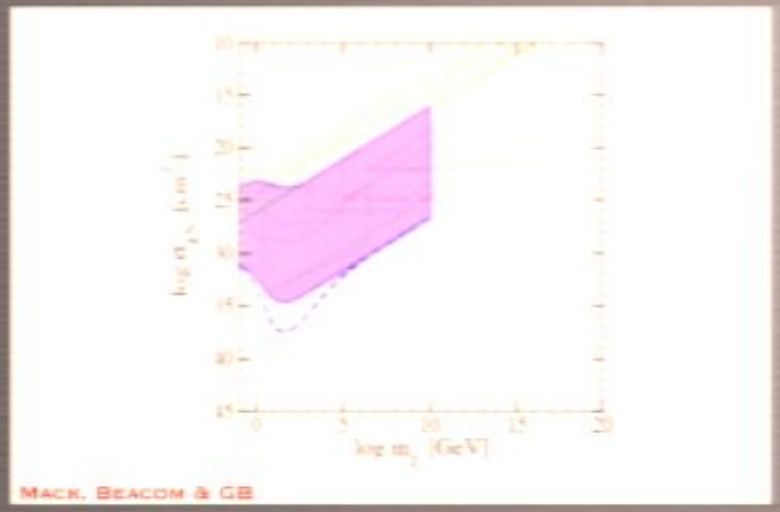
9) Astro bounds?

10) Can probe it?

Taoso, GB & Masiero 2007

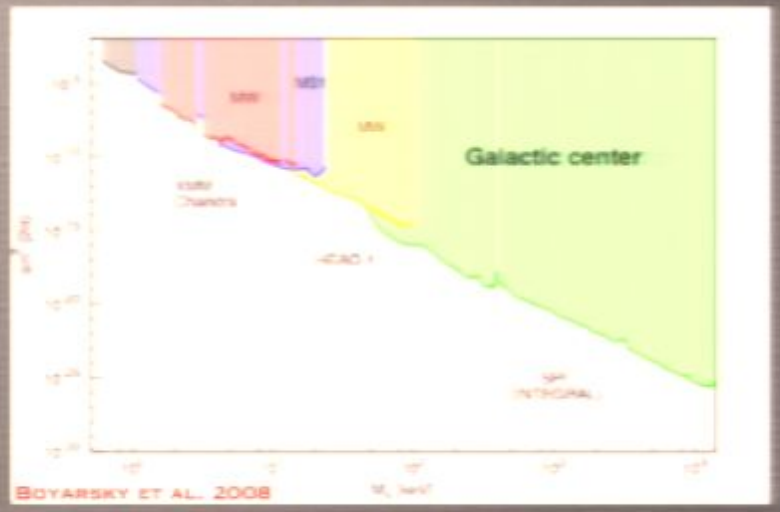
Cosmology and Astrophysics constrain the properties of DM

Scattering cross-section



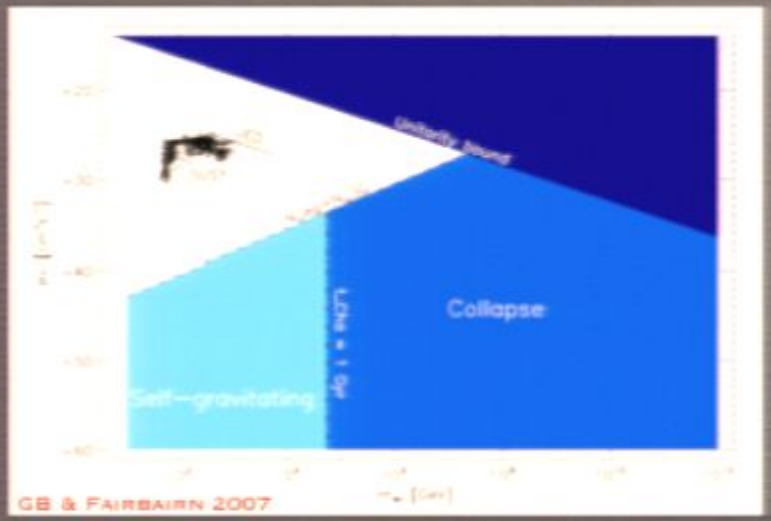
Mack, Beacom & GB

Mixing angle (Sterile neutrinos)



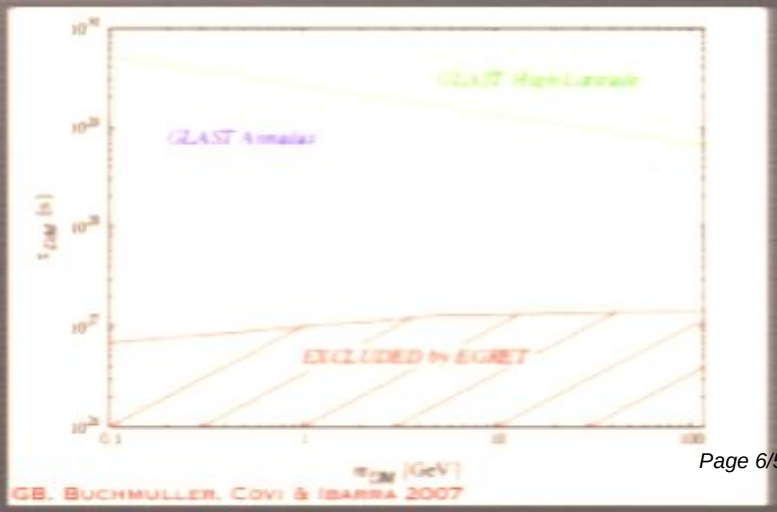
Boyarsky et al. 2008

Annihilation cross-section



GB & Fairbairn 2007

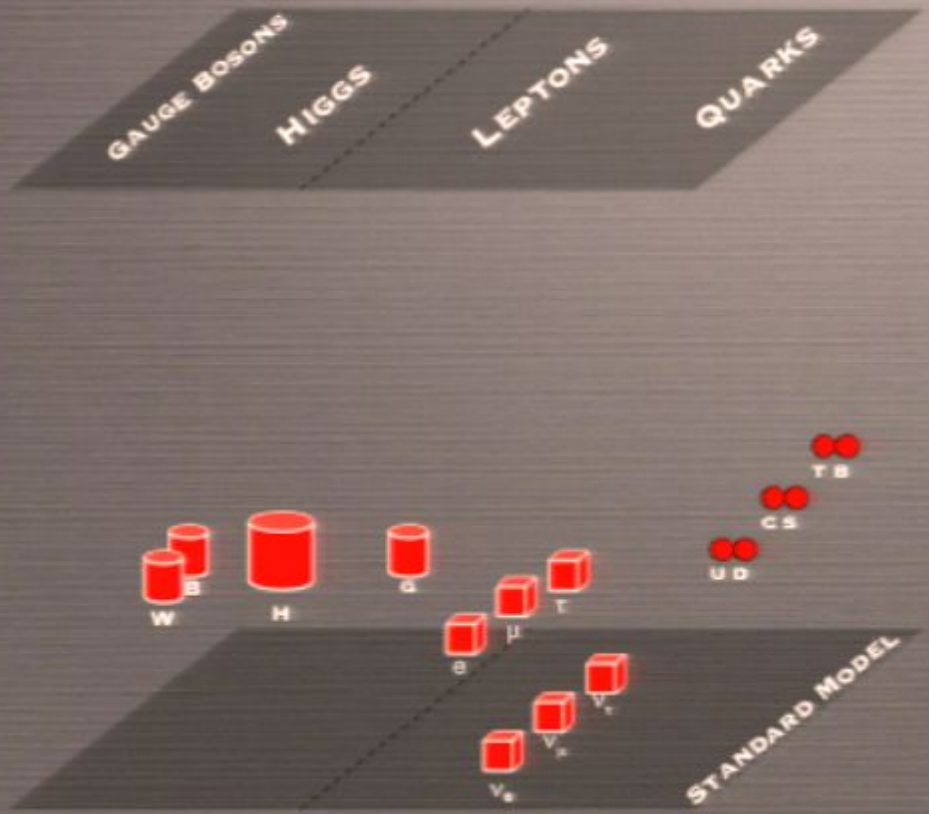
Decay Time



GB, Buchmuller, Covi & Ibarra 2007

Beyond the Standard Model

The Standard Model provides an accurate description of all known particles and interactions, however there are good reasons to believe that the Standard model is a low-energy limit of a more fundamental theory



Standard Model Particles

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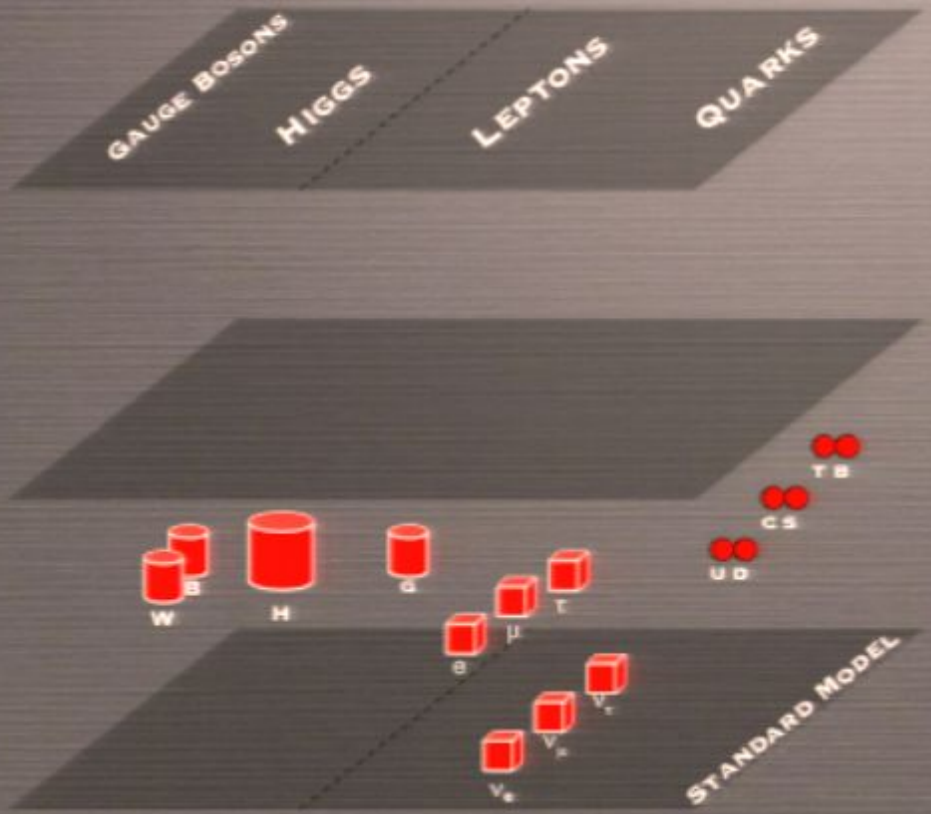

New theory
(SUSY, Extra-dim, etc.)

Energy Scale
New Physics

Standard Model
Particles

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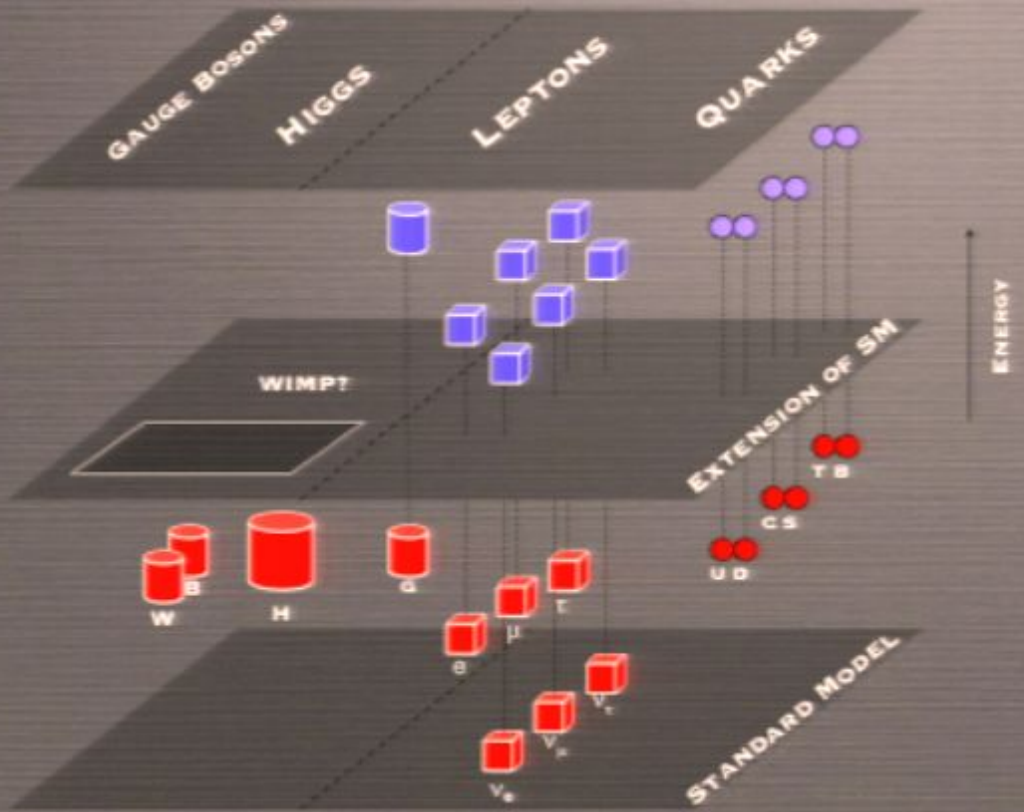

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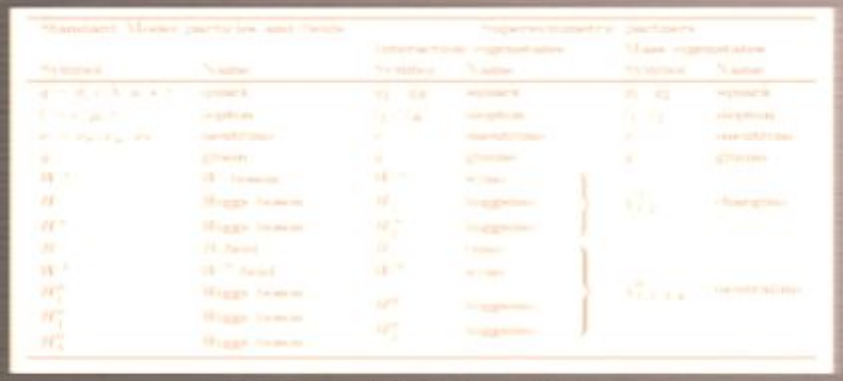
Beyond the Standard Model

2 examples

Minimal Supersymmetry



E.G. GB, Hooper & Silk 2005

E.G. Nezri et al. 2001

WIMP: Neutralino

Alternatives: Gravitino, axino, Sneutrino...

Universal Extra-Dimensions

Cheng, Matchev & Schmaltz 2002

Servant and Tait 2002

WIMP: B^1

Alternatives: Z^1, H^1, γ^H...

In both cases: viable DM candidate, with mass ~ TeV and weak cross sections

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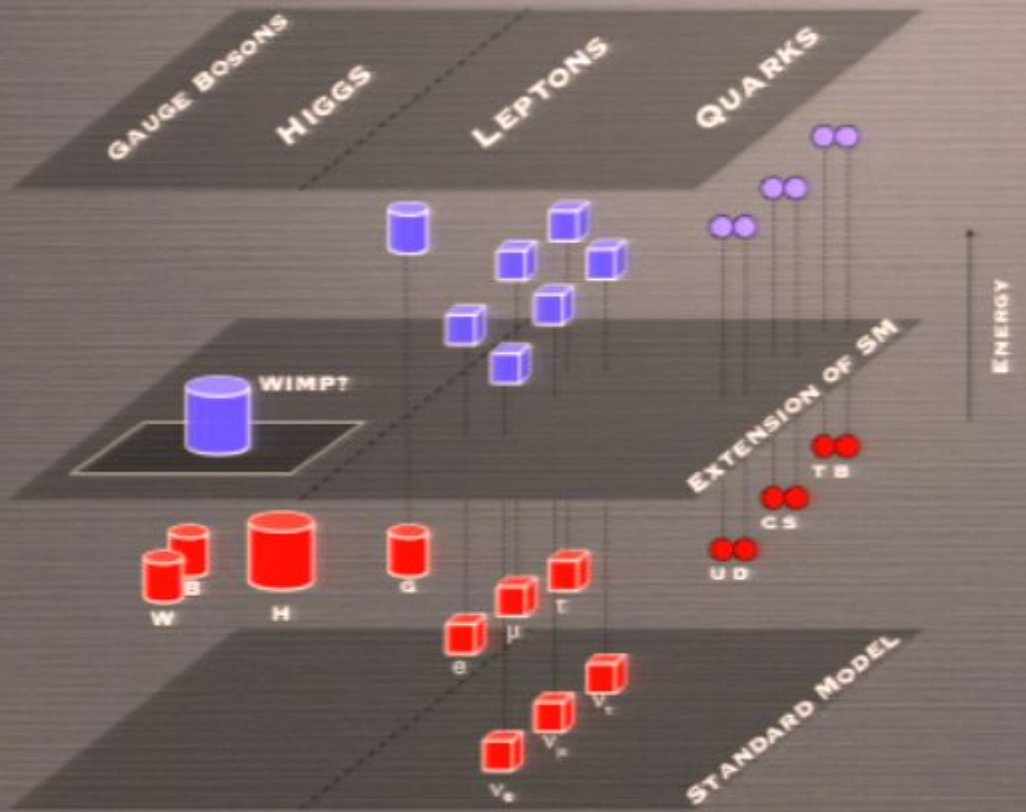
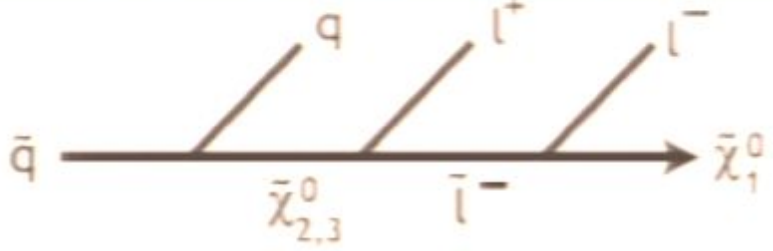


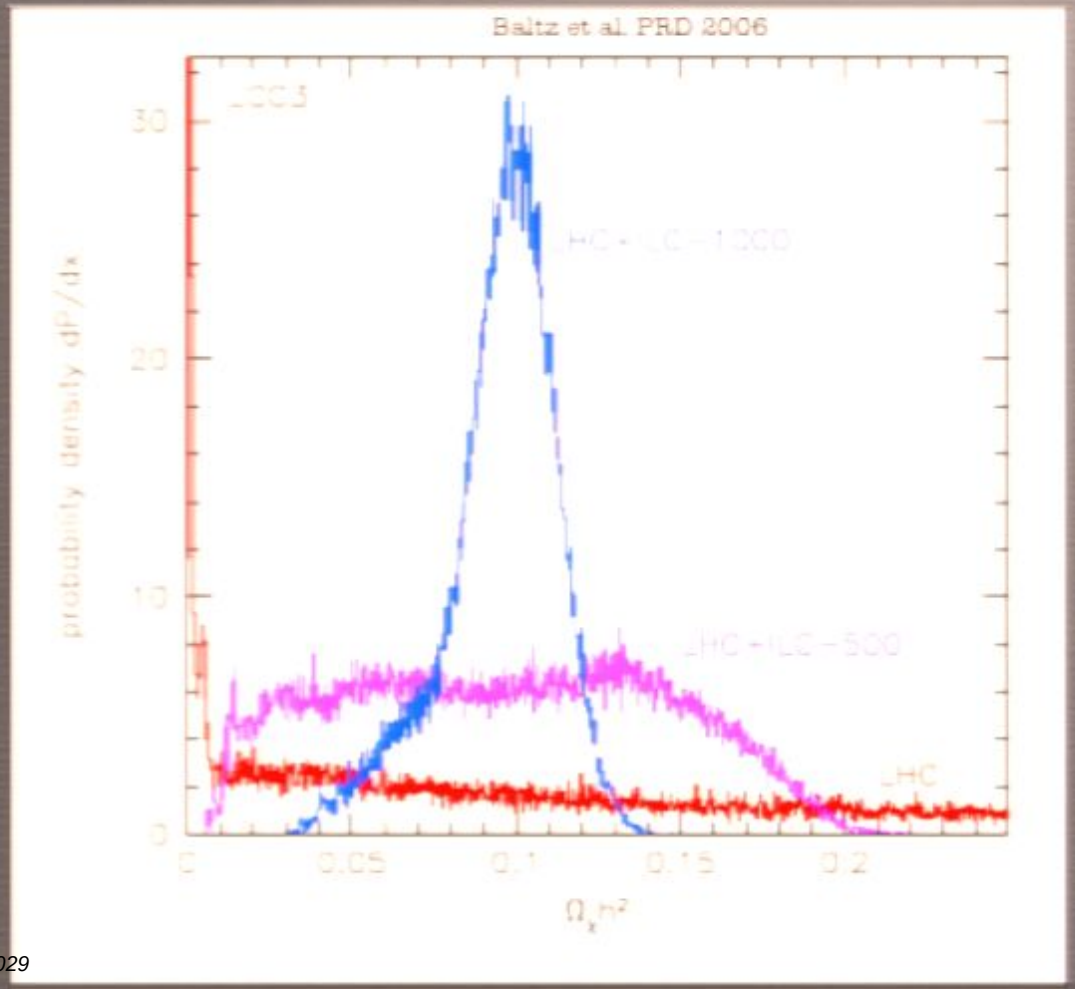
Search at LHC for processes like



See e.g. Baltz et al. hep-ph/0602187

Search for DM at LHC

Warning n. 1: LHC may not necessarily allow us to infer the relic density (thus the DM nature) of newly discovered particles



Even if SUSY particles are discovered, it will be challenging to determine $\Omega_\chi h^2$ with good accuracy!

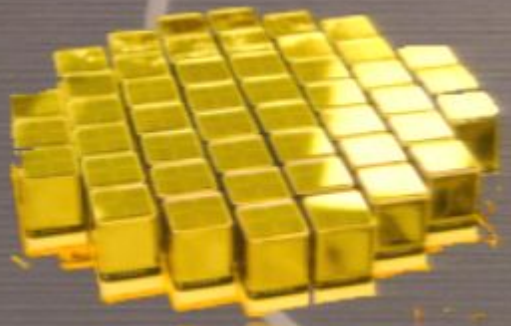
	Ωh^2	LHC
LCC1	0.192	7.2%
LCC2	0.109	82.%
LCC3	0.101	167%
LCC4	0.114	405%

New particles may then turn out to be too abundant (decaying DM?) or not enough (multi-component DM)...

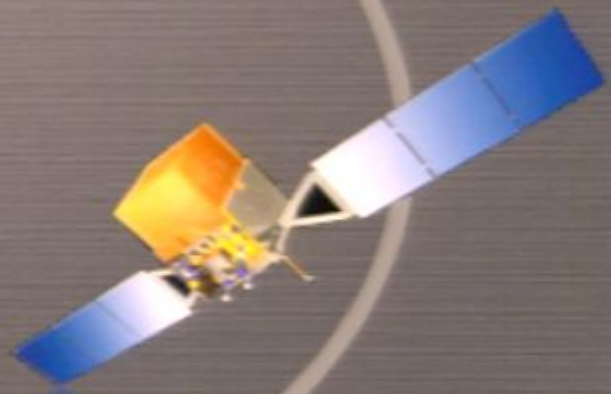
Need particle astrophysics (direct/indirect) experiments to prove that new particles = DM !!

Particle Dark Matter: A multidisciplinary approach

Colliders



Direct Detection



Indirect Detection

Dark Matter-related Experiments circa 2008

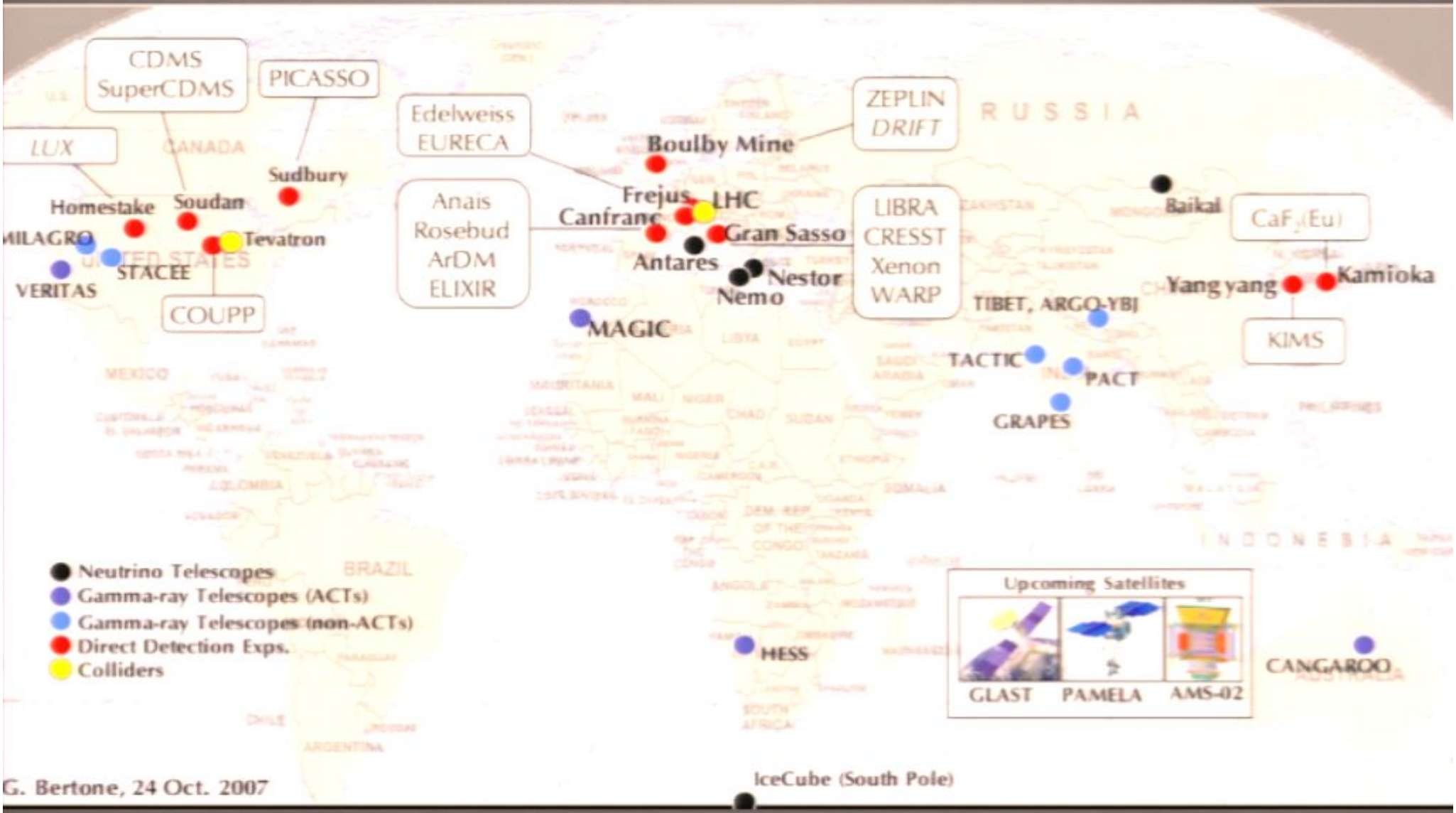
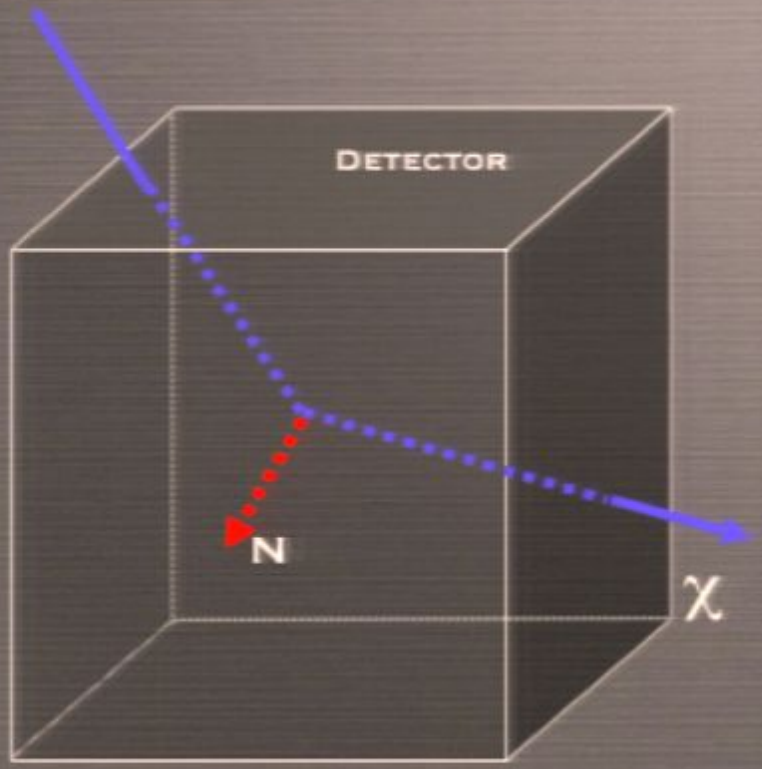


Figure available for download at: http://www2.iap.fr/users/bertone/

Direct Detection

Principle and Detection Techniques

DM Scatters off nuclei in the detector



Differential Event Rate

$$\frac{dR}{dE}(E) = \frac{\sigma_p \rho_\chi}{2\mu_{p\chi}^2 m_\chi} A^2 F^2(E) \int_{v_{min}}^{\infty} \frac{f^E(v,t)}{v} dv$$

SUSY: squarks and Higgs exchange

UED: 1st level quarks and Higgs exchange

Direct Detection

Principle and Detection Techniques

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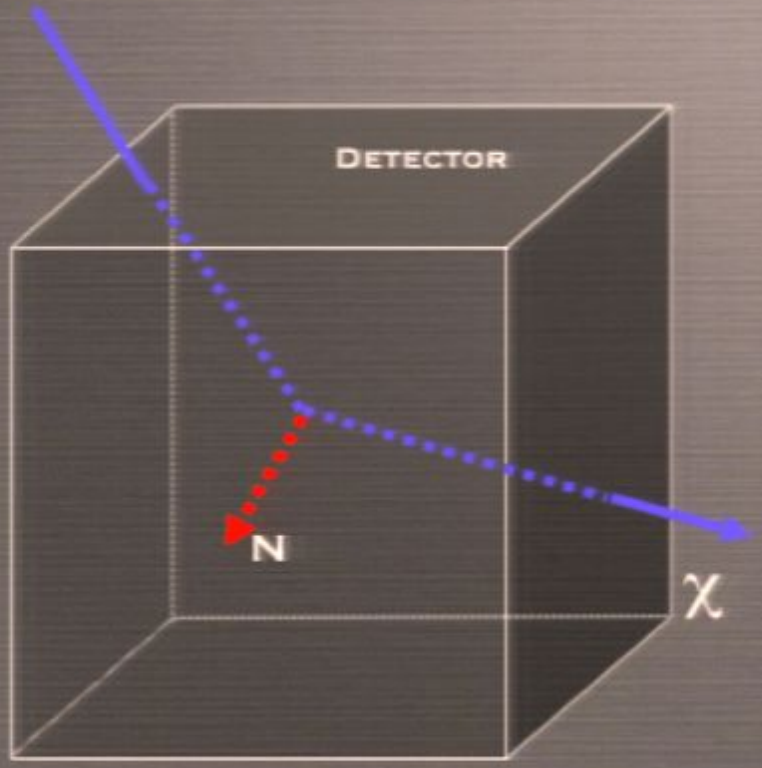
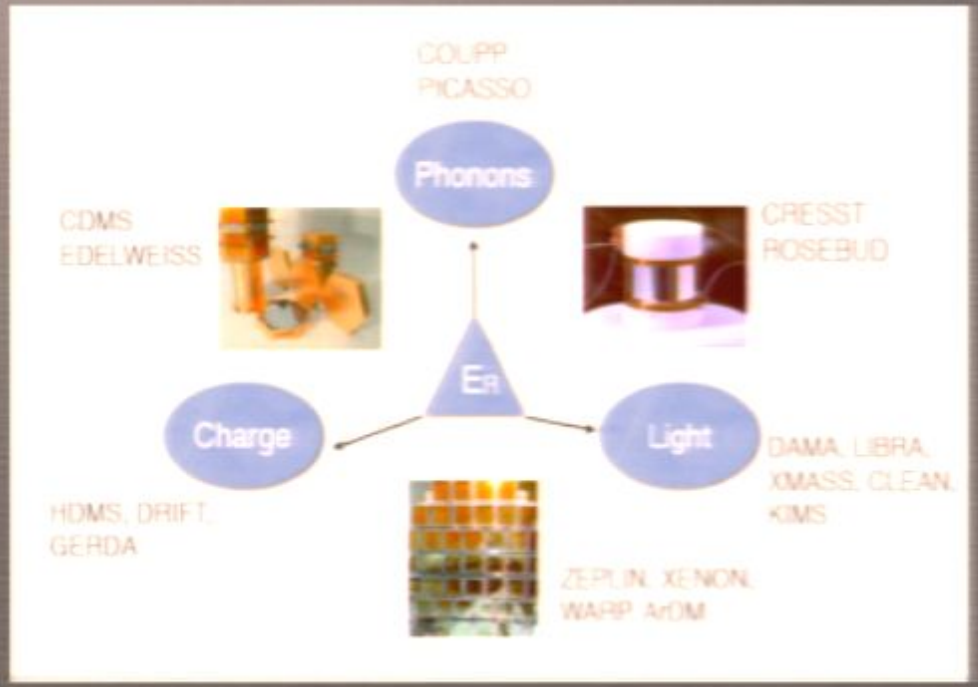
Detection of recoil energy via ionization (charges), scintillation (light) and heat (phonons)





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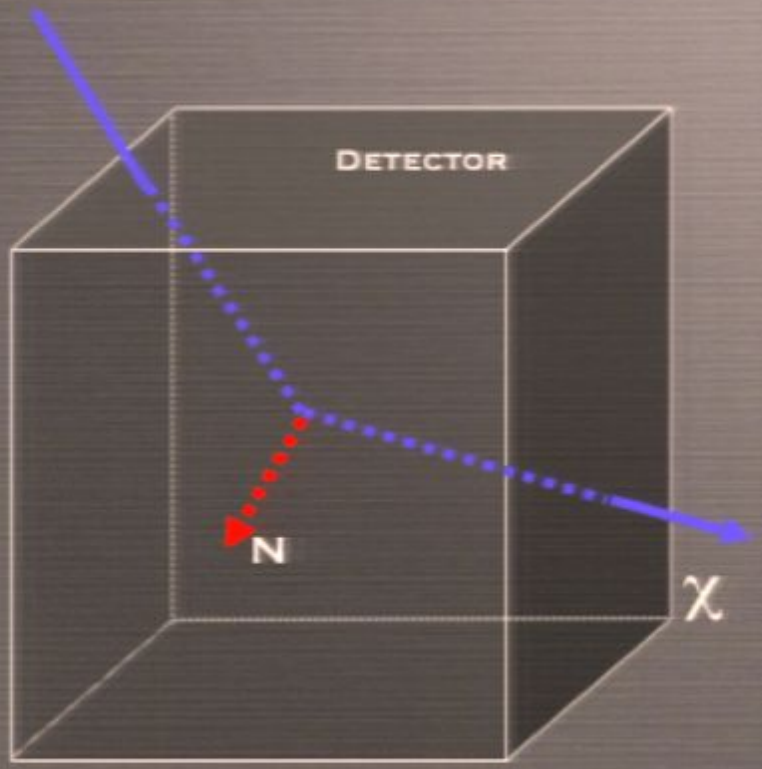

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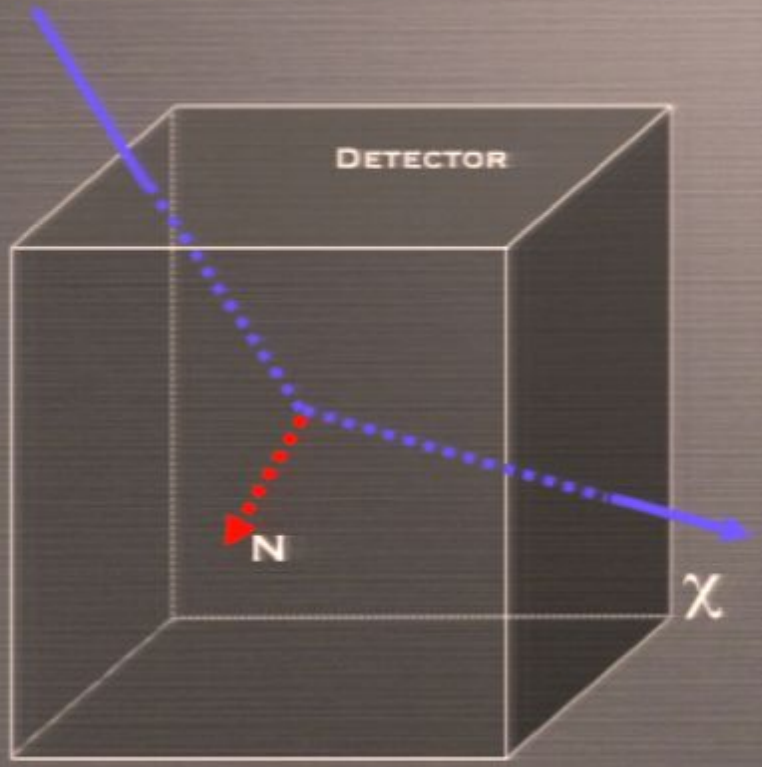
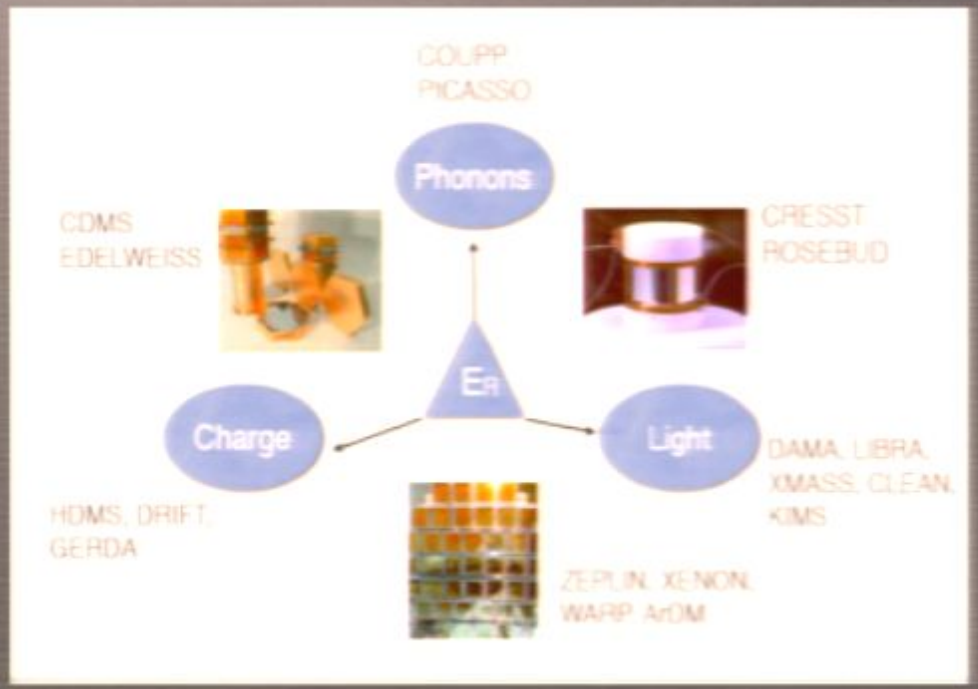
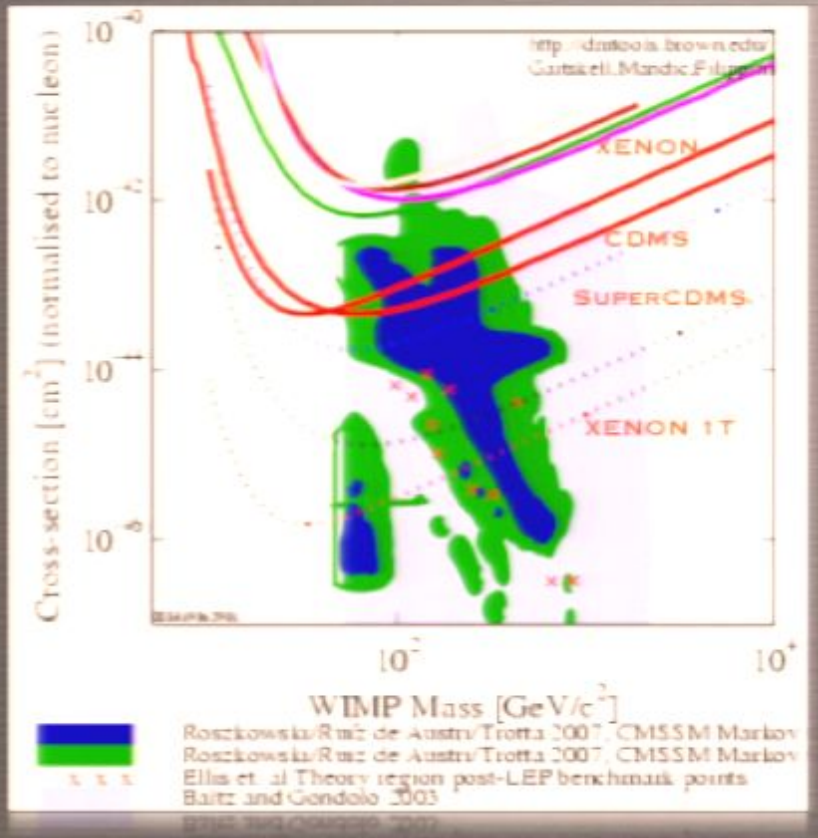




Direct Detection

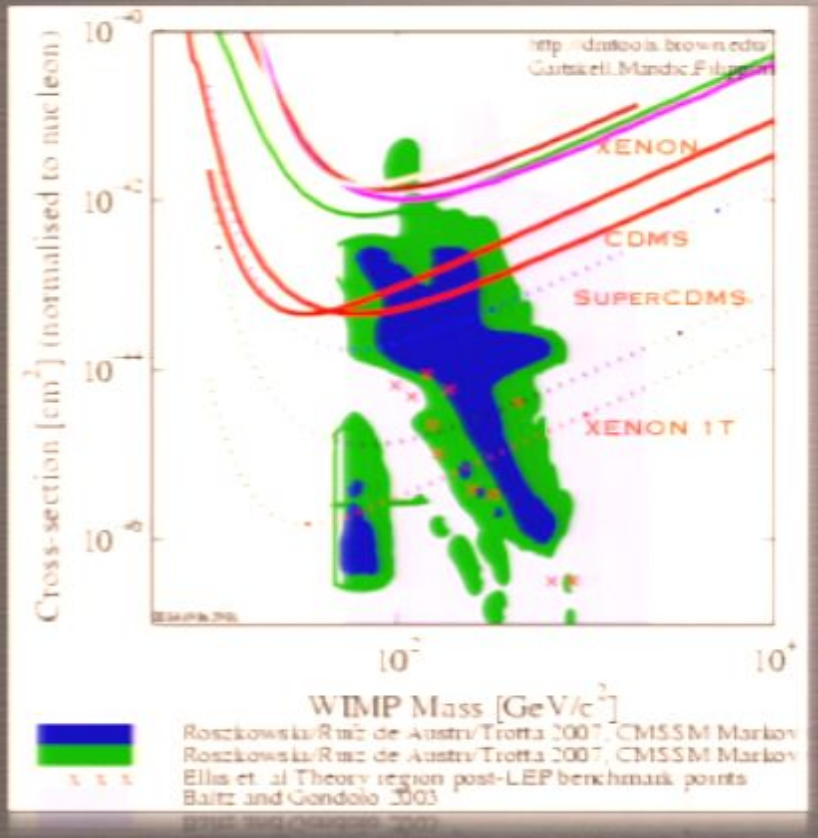
status



- Xenon and CDMS are the current leaders on spin-independent cross-sections
- Future reach should cover large portion (but not all) of the SUSY parameter space

Direct Detection

status



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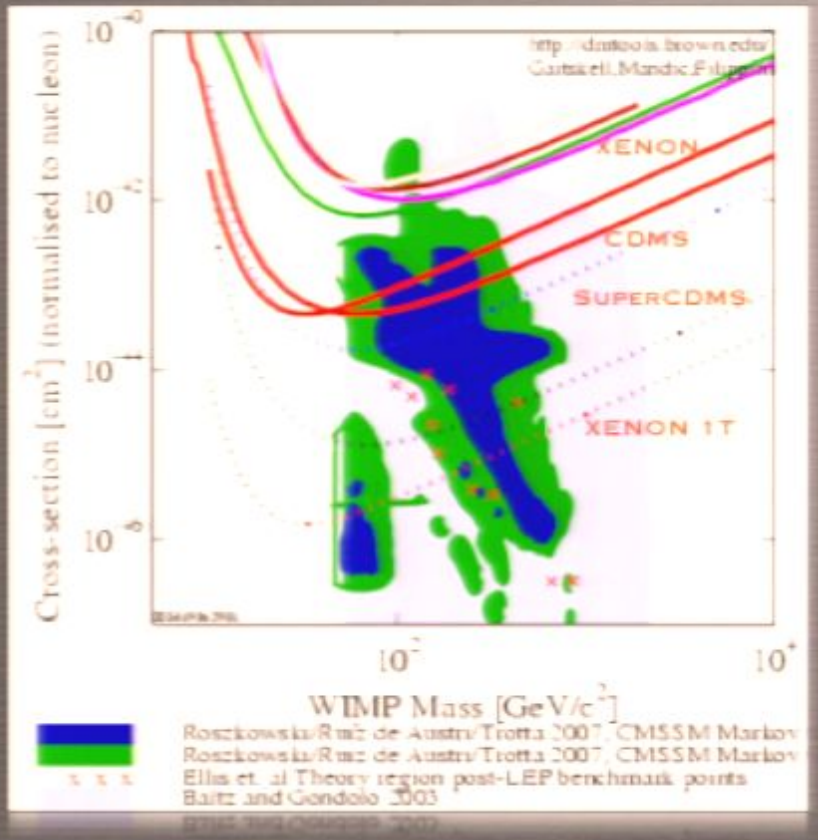

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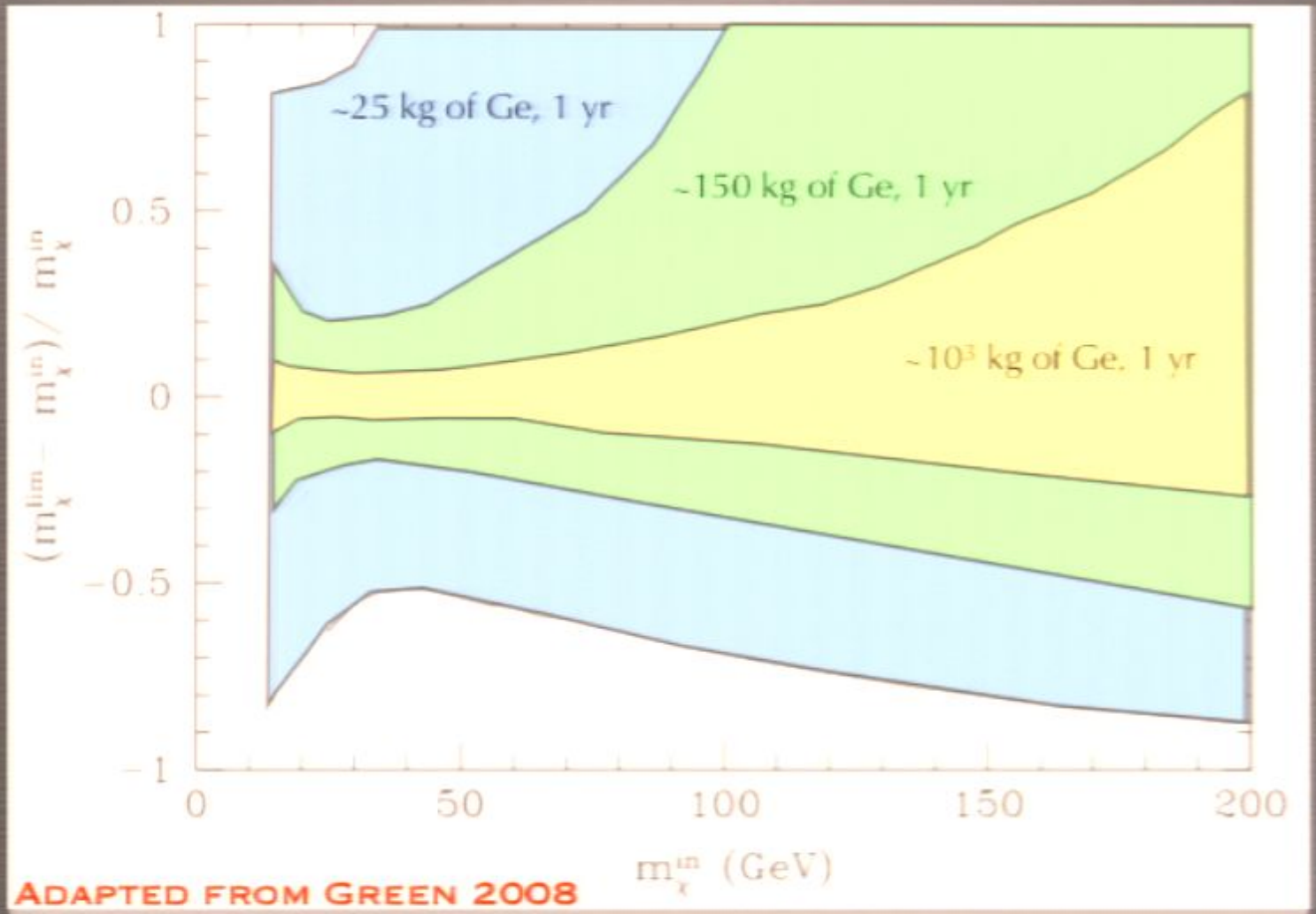
Direct Detection

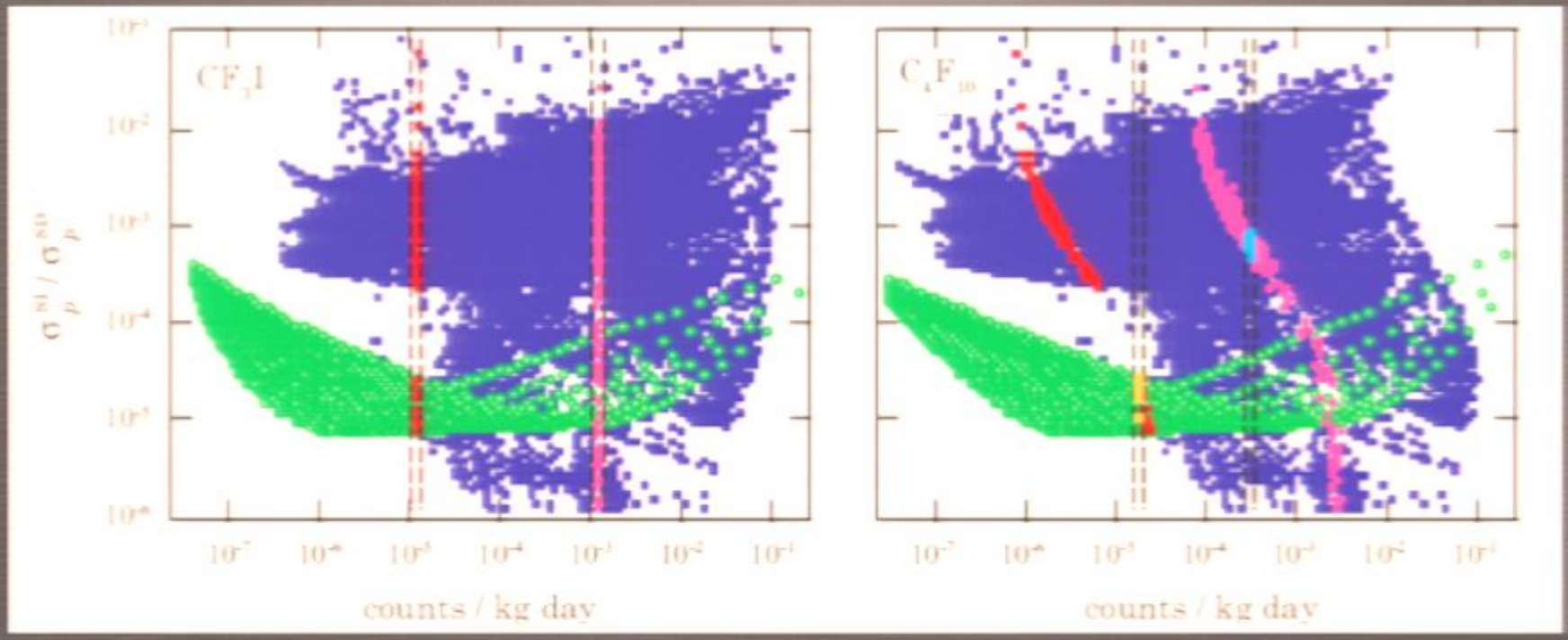
95% C.L. constraint on the reconstructed DM mass



Adapted from Green 2008

Direct Detection

Better constraints when combining results from different targets

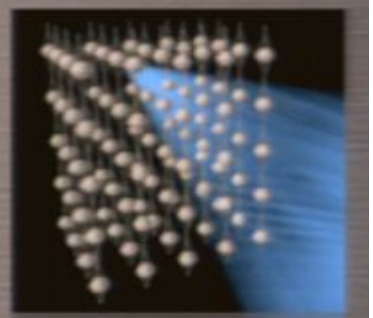


The case of COUPP. GB, Cerdeno, Collar & Odom 2007

See also Drees & Shan 2008

Indirect Detection



Gamma-ray telescopes

- Ground Based (CANGAROO, HESS, MAGIC, MILAGRO, VERITAS)
- Space satellite GLAST
- Plans for a future Cherenkov Telescope Array

Neutrino Telescopes

- Amanda, IceCube
- Antares, Nemo, Nestor
- Km3

Anti-matter Satellites

- PAMELA
- AMS-02

Other

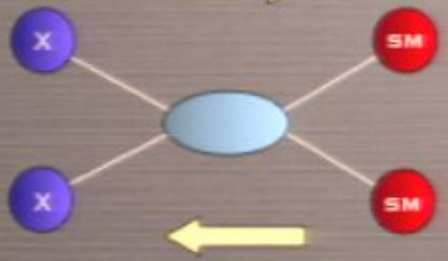
- Synchrotron Emission
- SZ effect
- Effect on Stars

INDIRECT DETECTION

WHY "ANNIHILATIONS"?

X = DARK MATTER SM = STANDARD MODEL PARTICLE

EARLY UNIVERSE



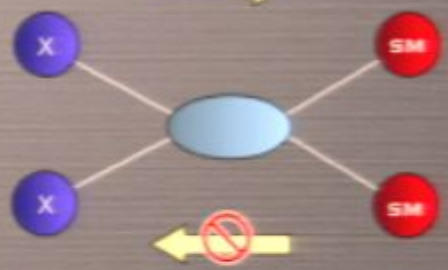
$$\frac{dn_\chi}{dt} + 3Hn_\chi = -\langle\sigma v\rangle\left[n_\chi^2 - (n_\chi^{eq})^2\right]$$

ROUGH ESTIMATE OF THE RELIC DENSITY:

$$\Omega_\chi h^2 \approx \frac{3\times 10^{-27}\,\mathrm{cm^3 s^{-1}}}{\langle\sigma v\rangle}$$

ELECTROWEAK-SCALE CROSS SECTIONS CAN REPRODUCE CORRECT RELIC DENSITY. LSP IN SUSY SCENARIOS KK DM IN UED SCENARIOS ARE OK!!

TODAY



$$\dot{n}_\chi(r,t) = -\sigma v\, n_\chi^2$$

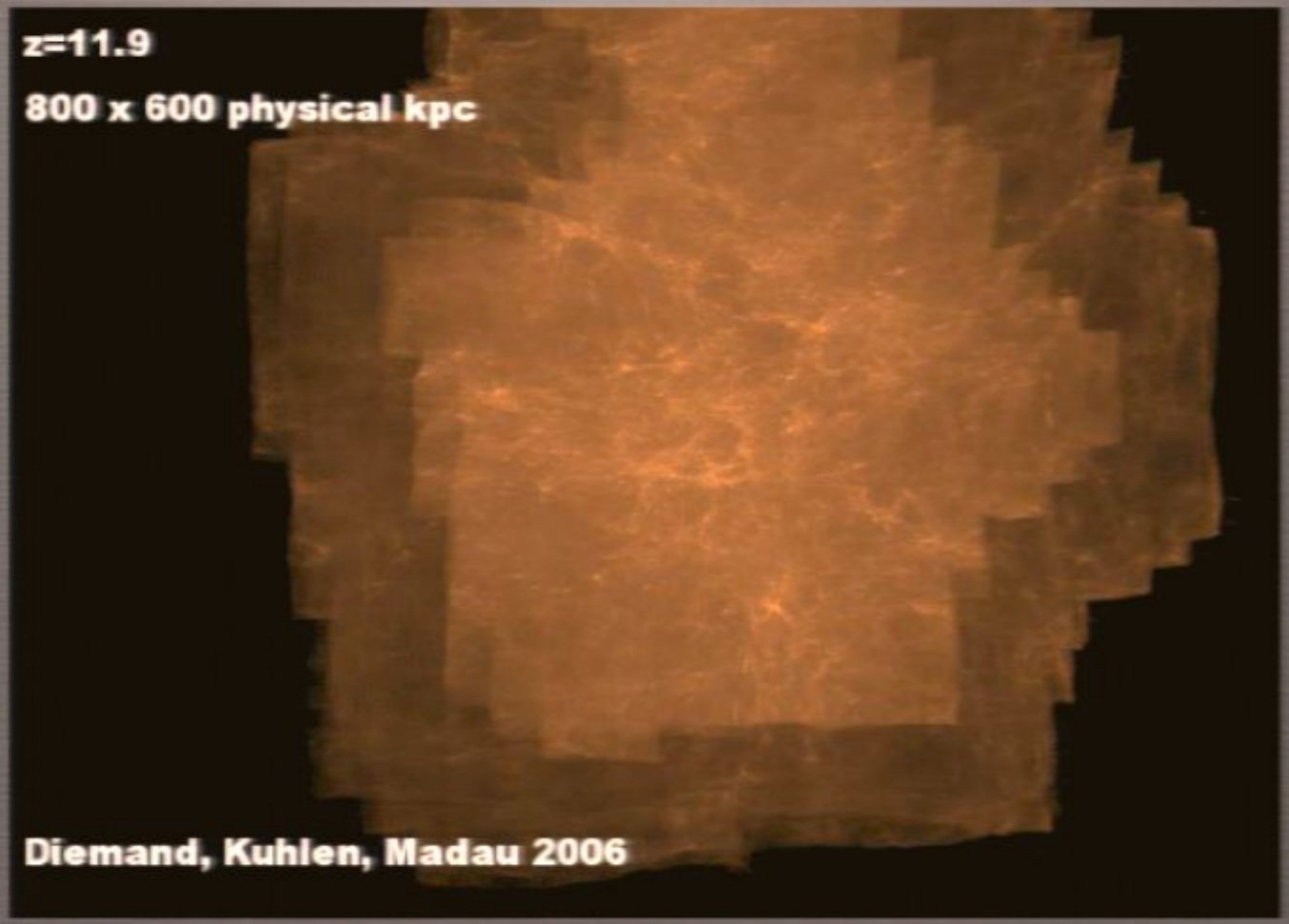
FLUX OF SECONDARY PARTICLES FROM DM ANN.

$$\Phi(\Delta\Omega, E) = \Delta\Omega \frac{dN}{dE}\frac{\langle\sigma v\rangle}{4\pi m^2}\bar{J}_{\Delta\Omega}$$

PARTICLE PHYSICS INPUT FROM EXTENSIONS OF THE STANDARD MODEL. NEED TO SPECIFY DISTRIBUTION OF DM ALONG THE LINE OF SIGHT

N-BODY SIMULATIONS

PROJECTED DARK MATTER DENSITY-SQUARE MAPS OF THE SIMULATED MILKY WAY-SIZE HALO VIA LACTEA. ENTIRE FORMATION HISTORY (Z=11.9->0), PLUS ROTATION AND ZOOM AT Z=0. DIEMAND, KUHLEN & MADAU 2006



HTTP://WWW.UCOLICK.ORG/~DIEMAND/VL/

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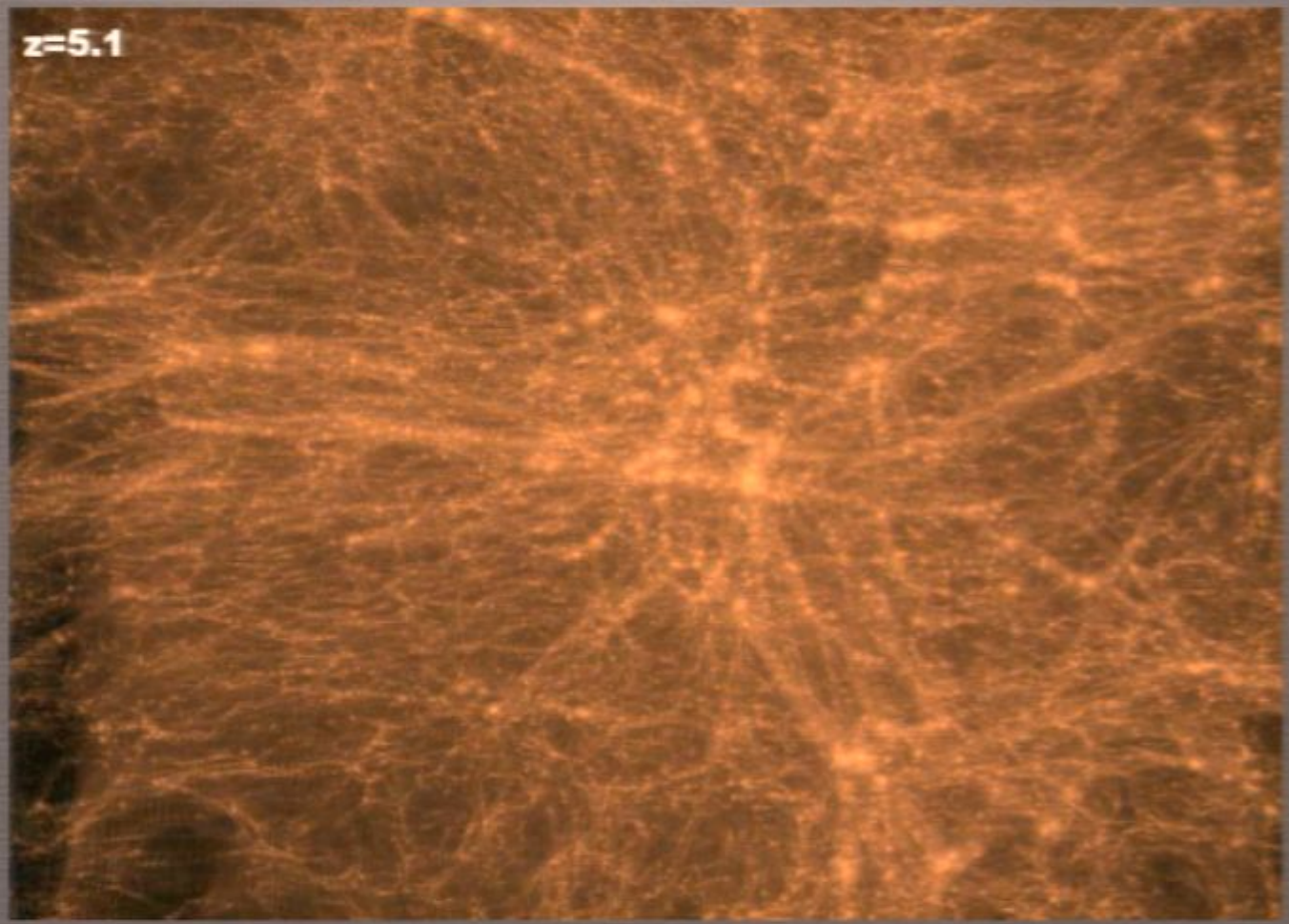

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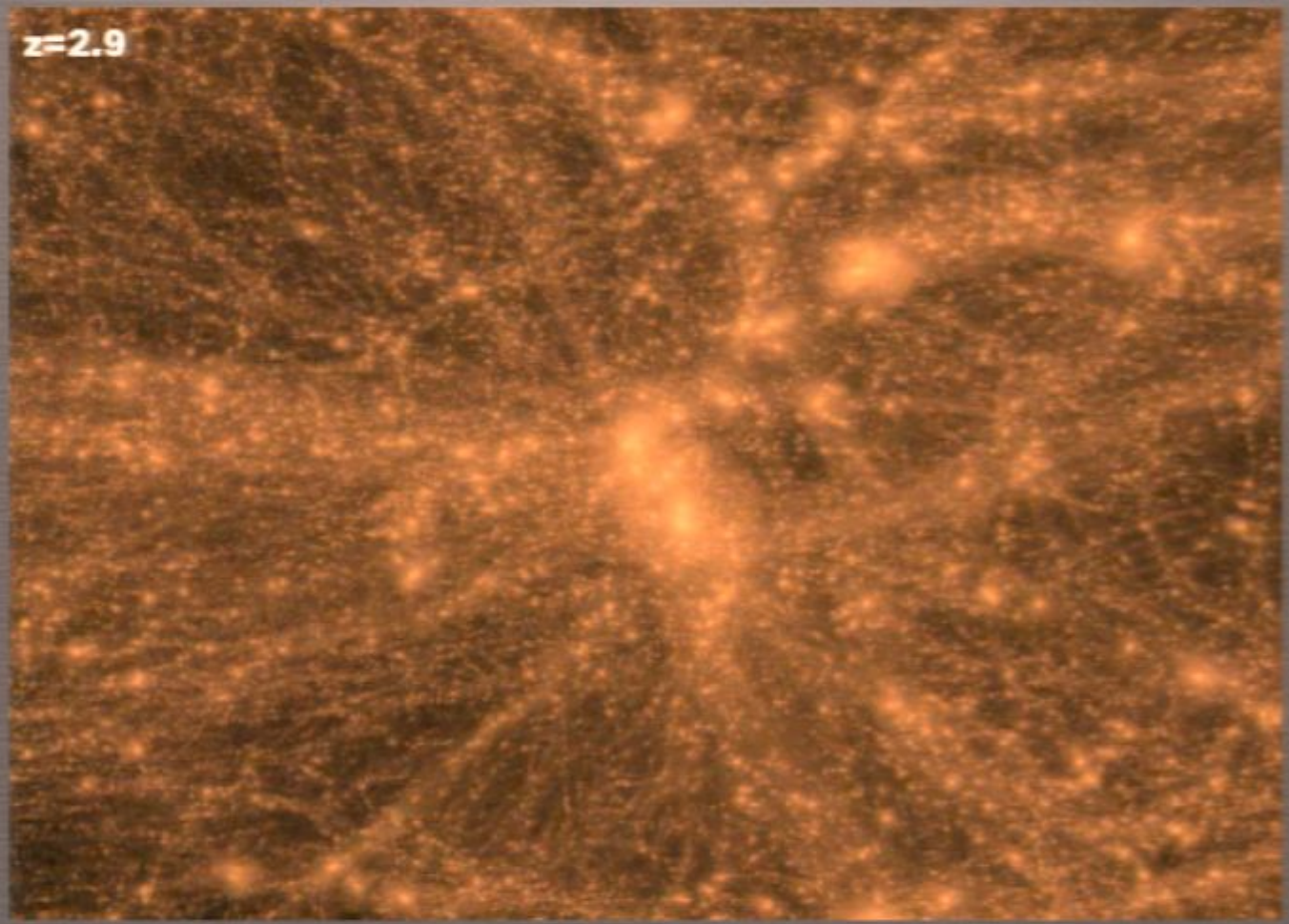

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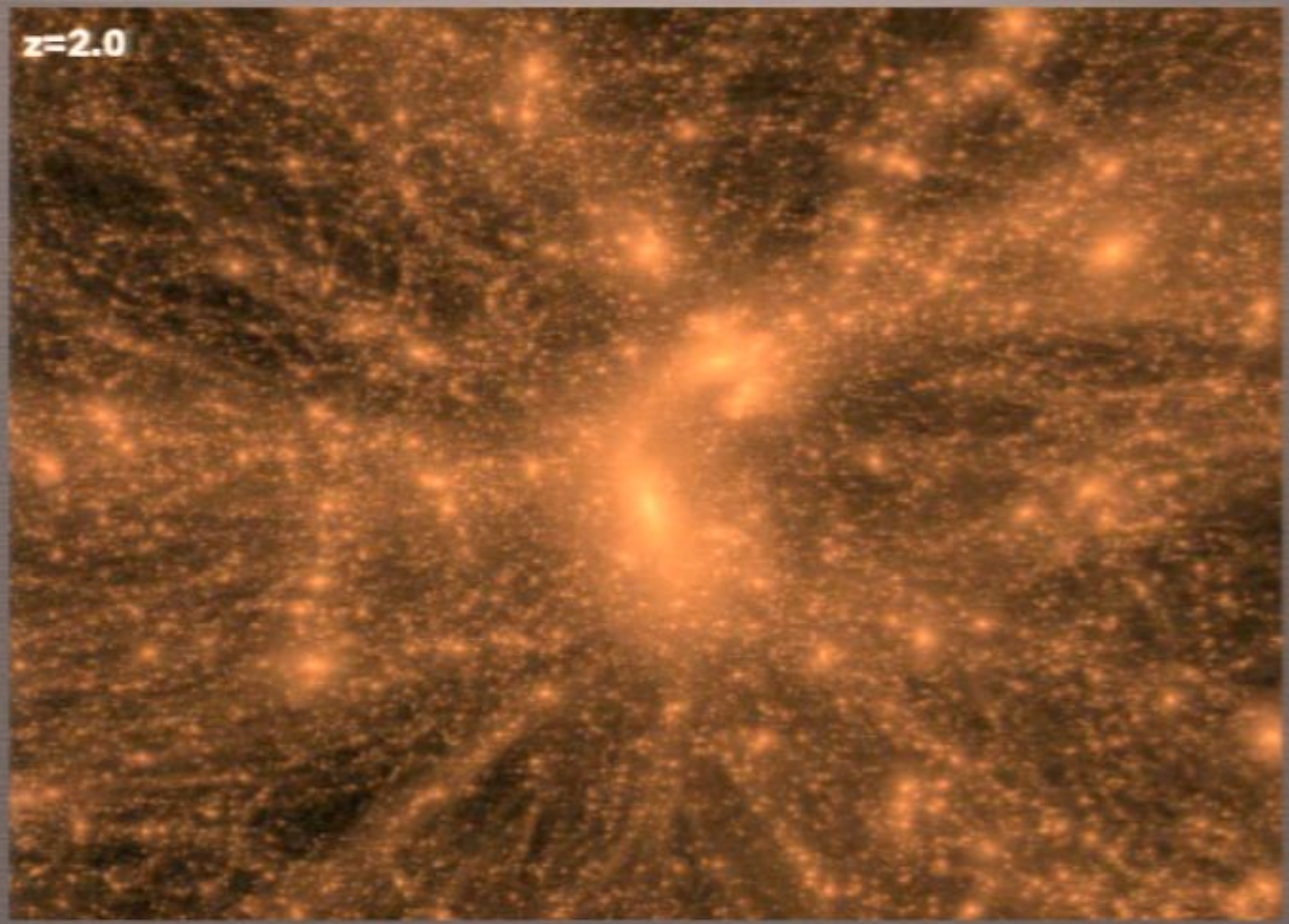

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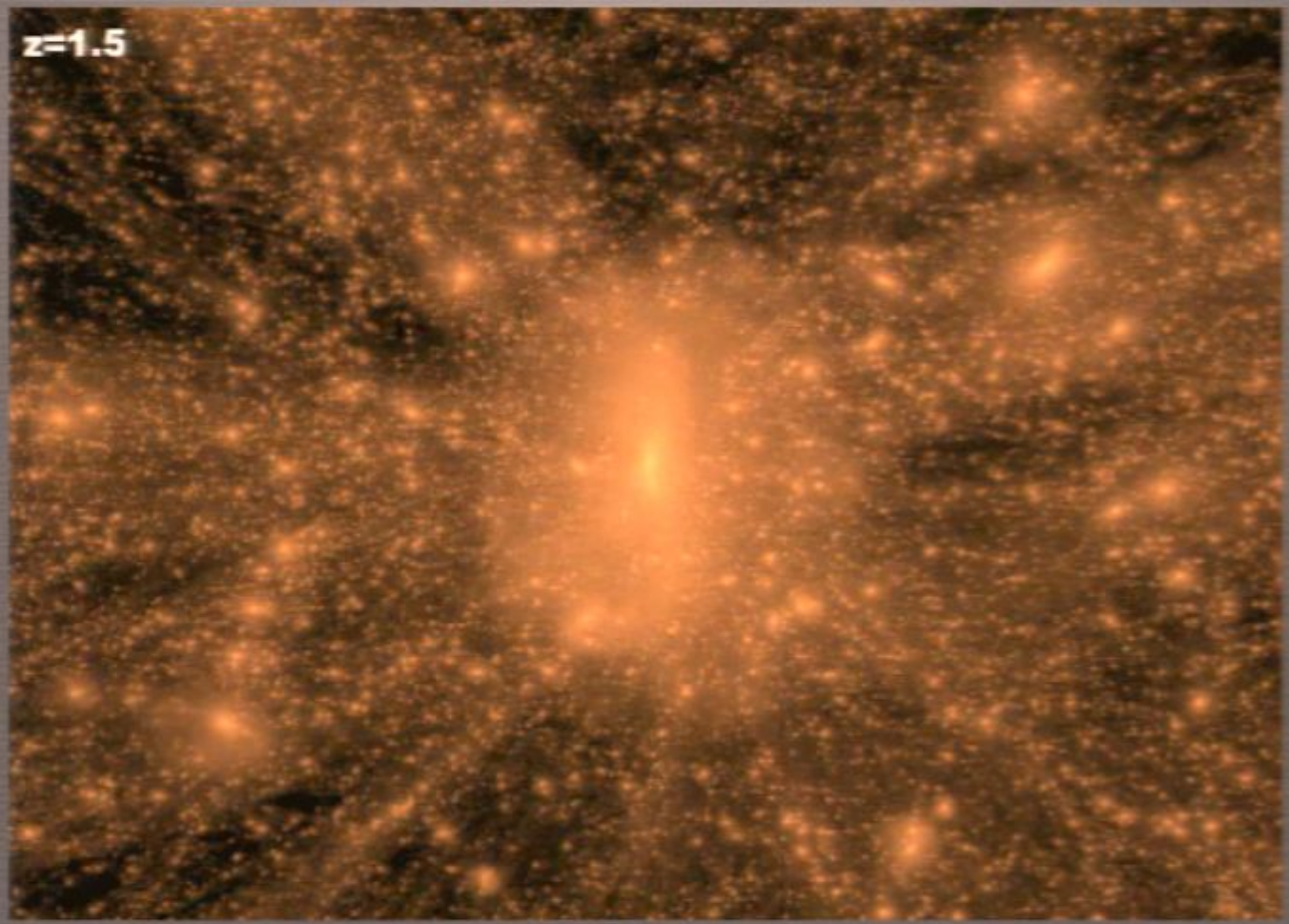

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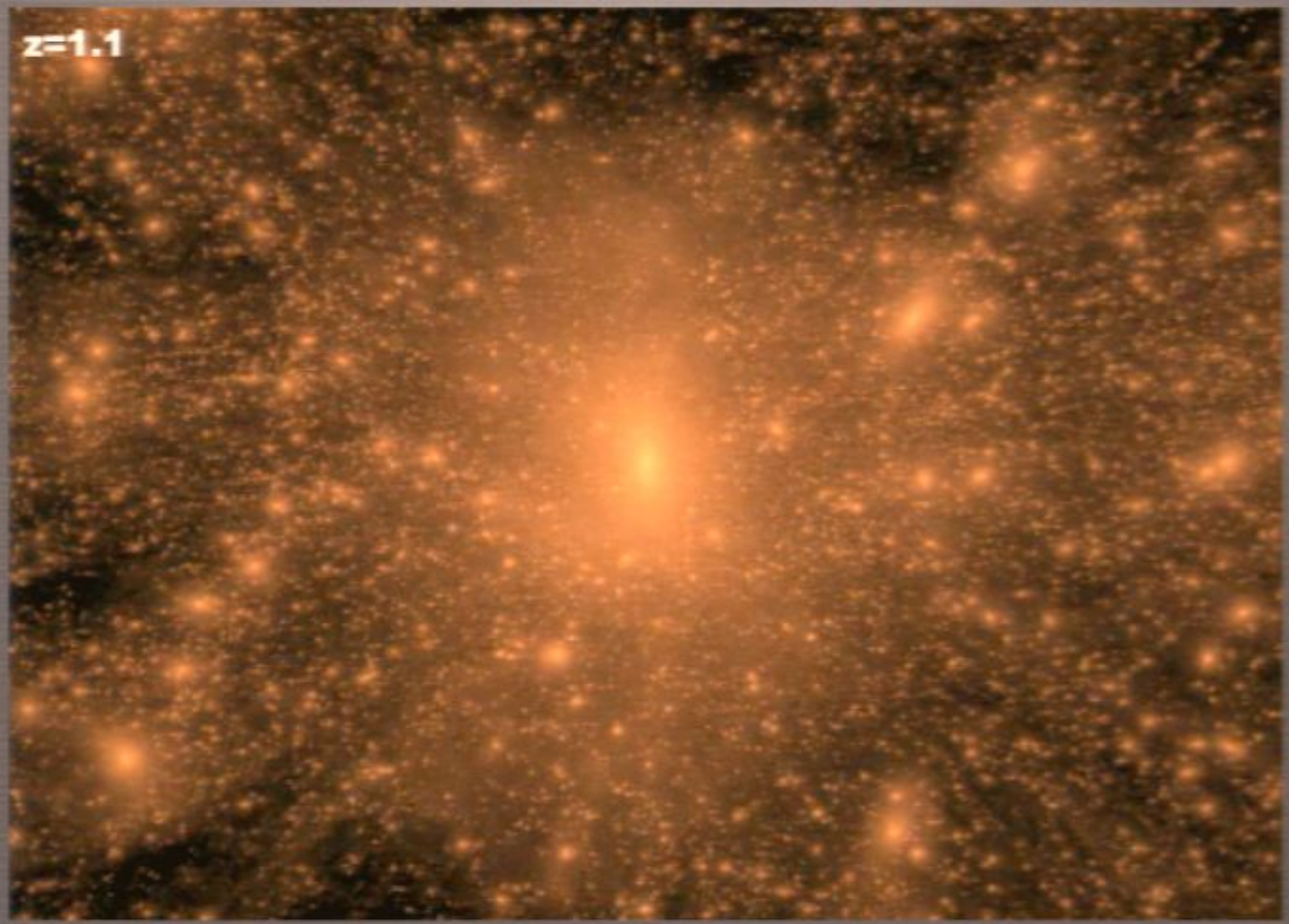

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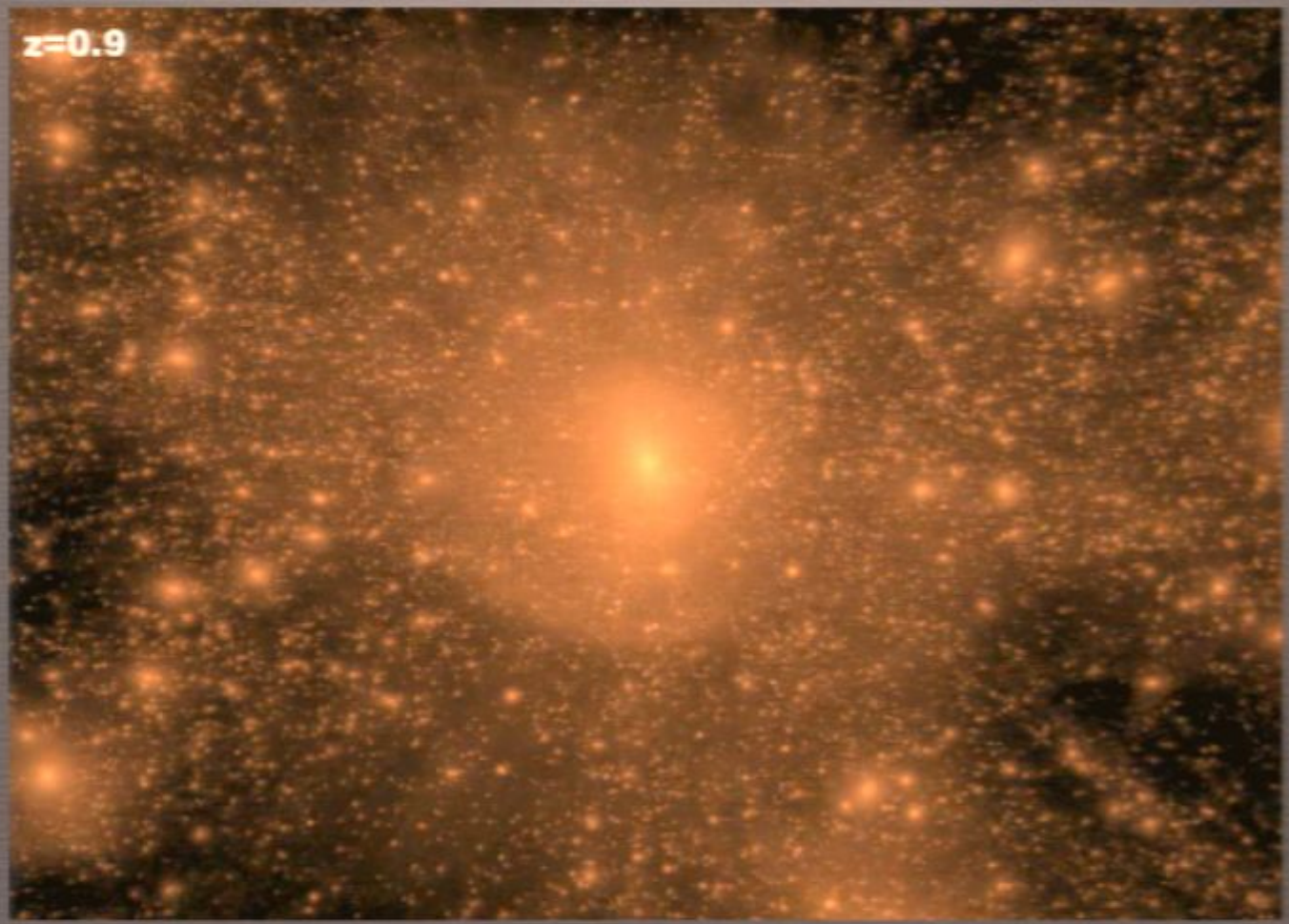

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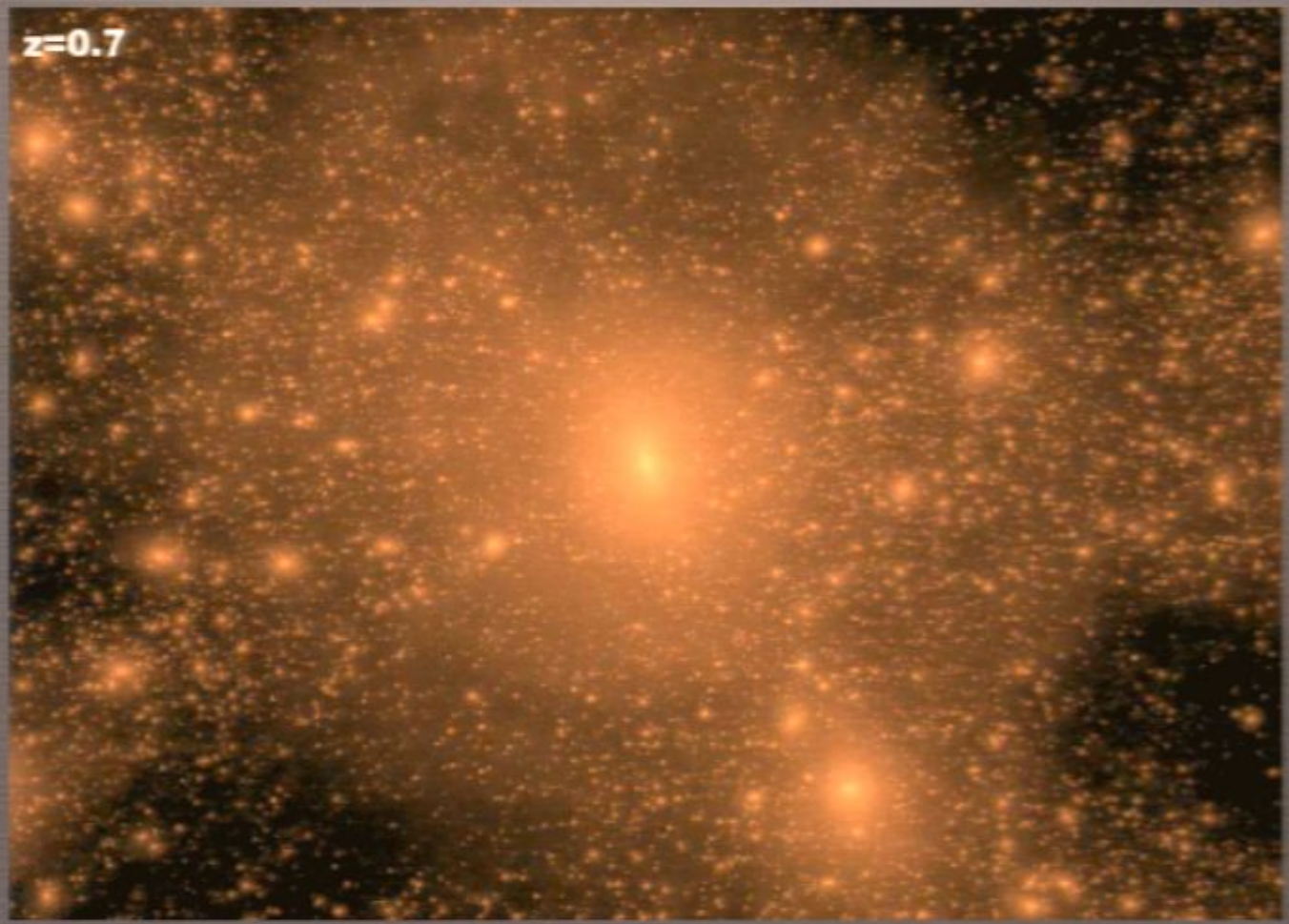

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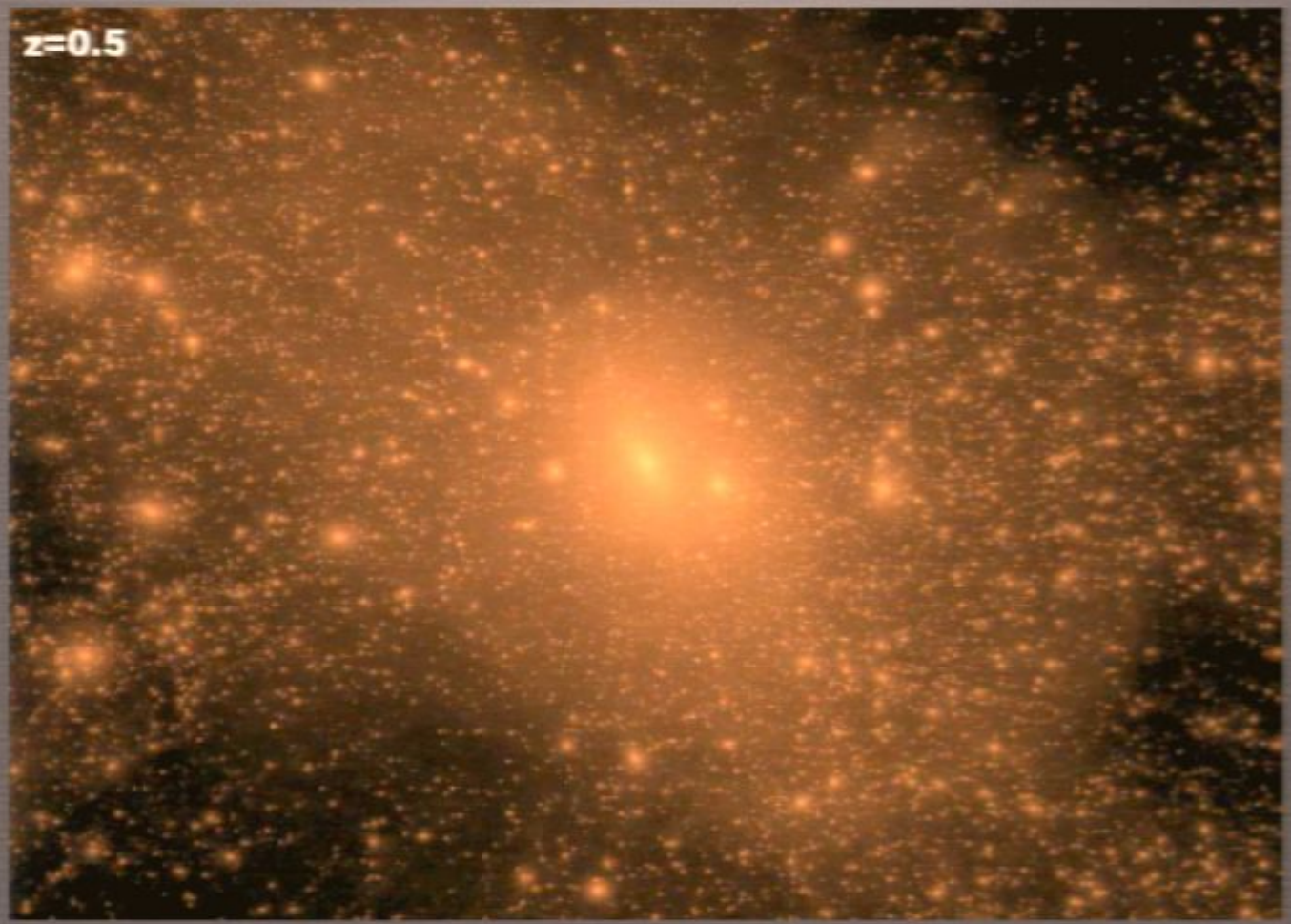

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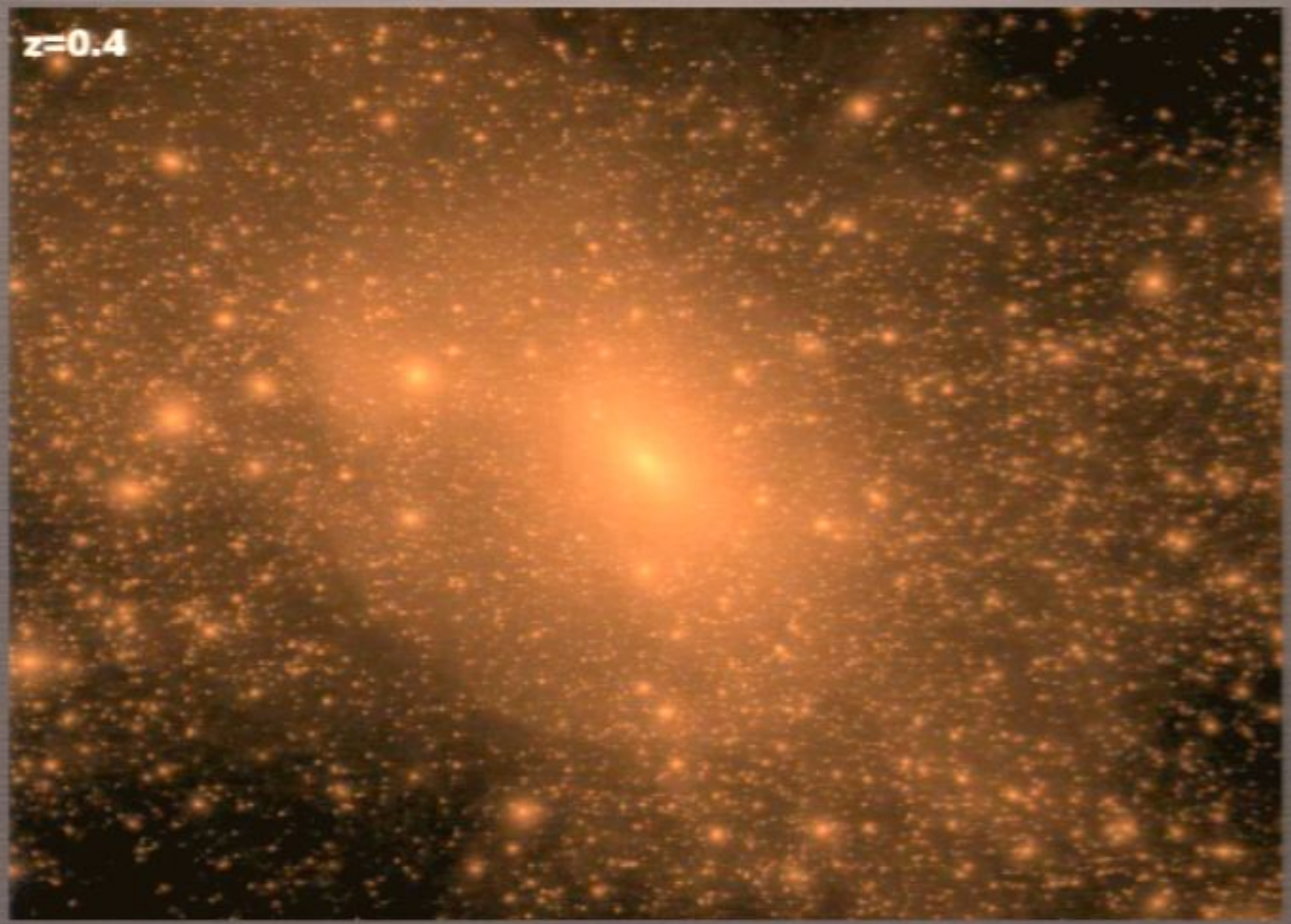

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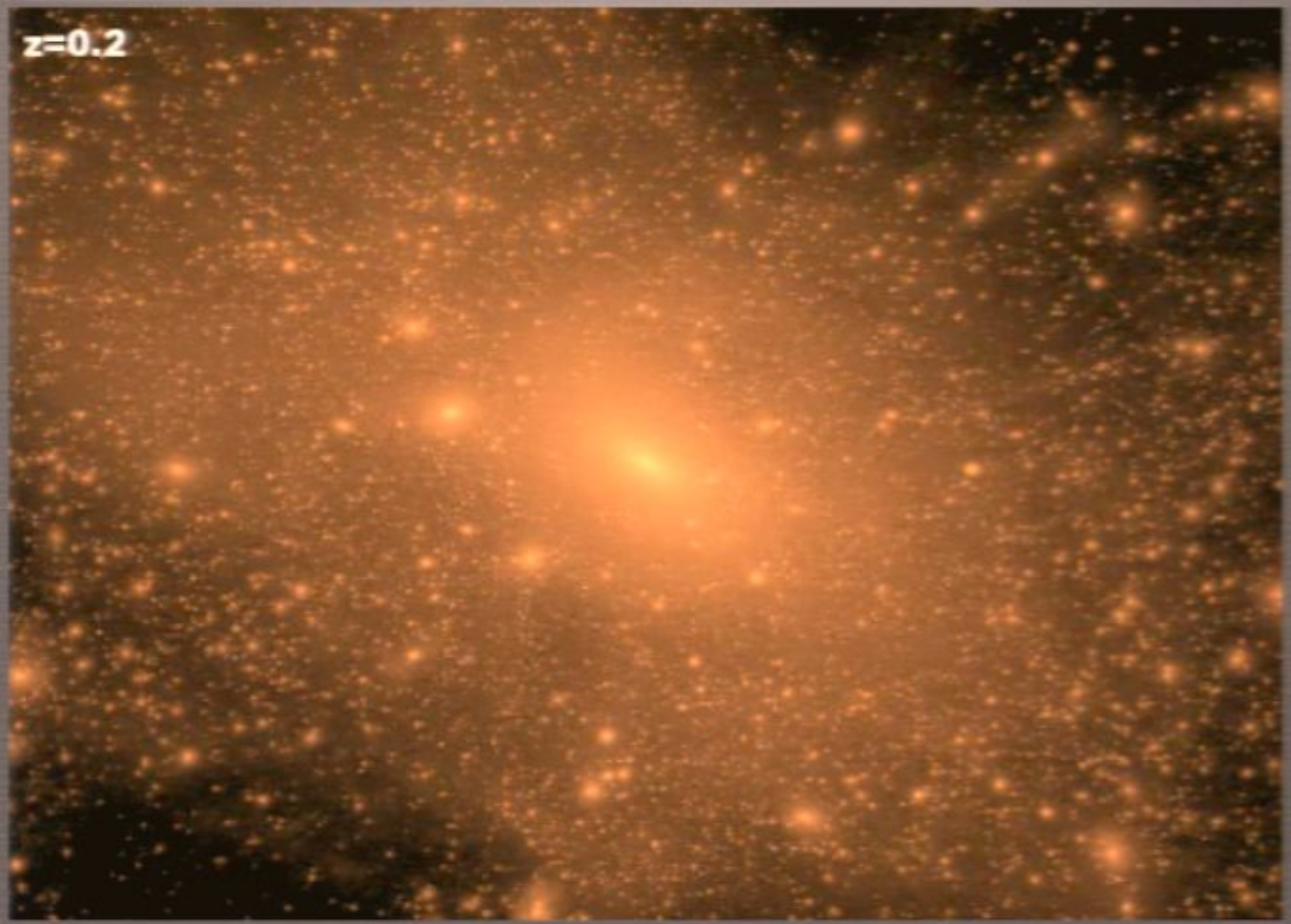

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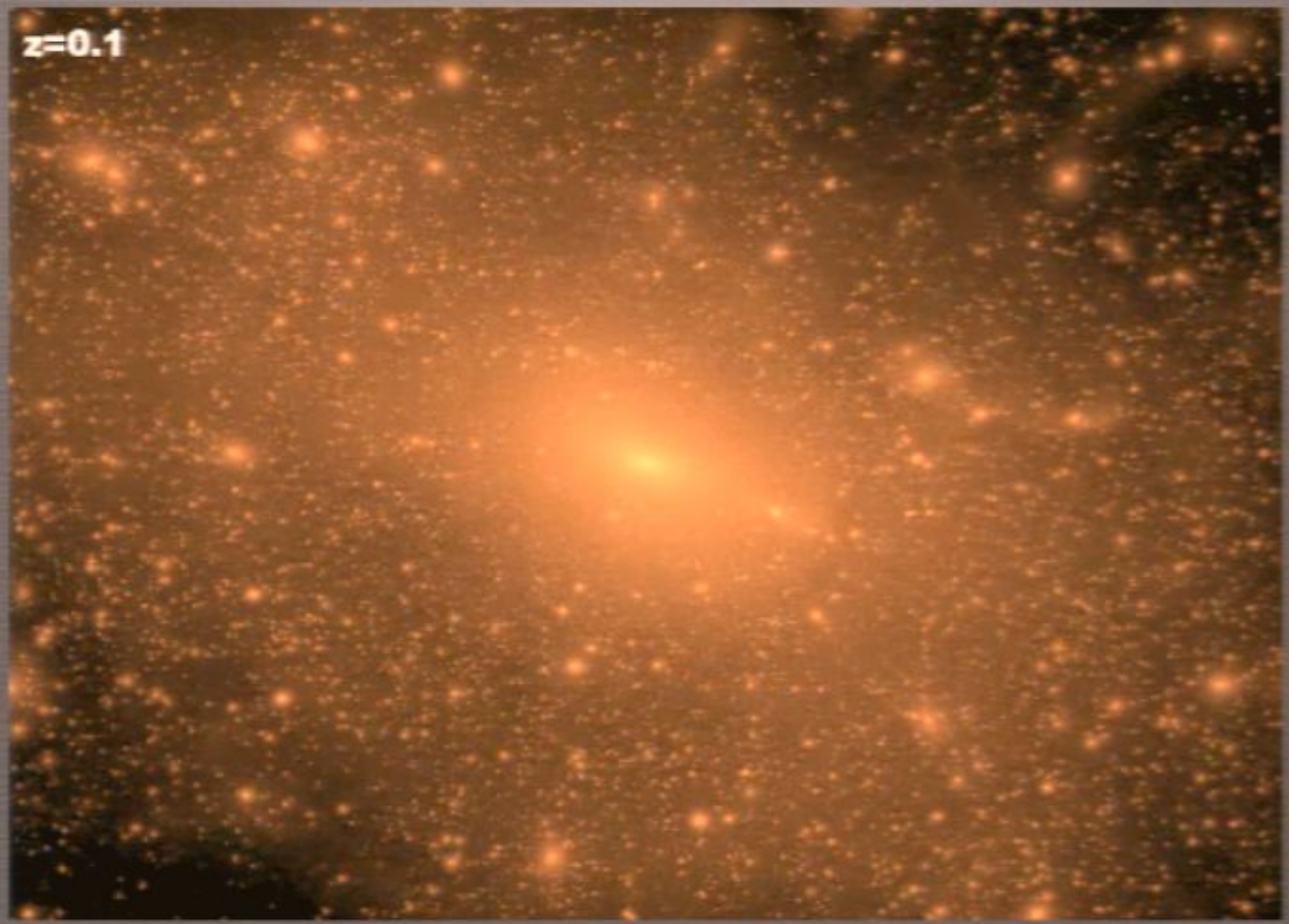

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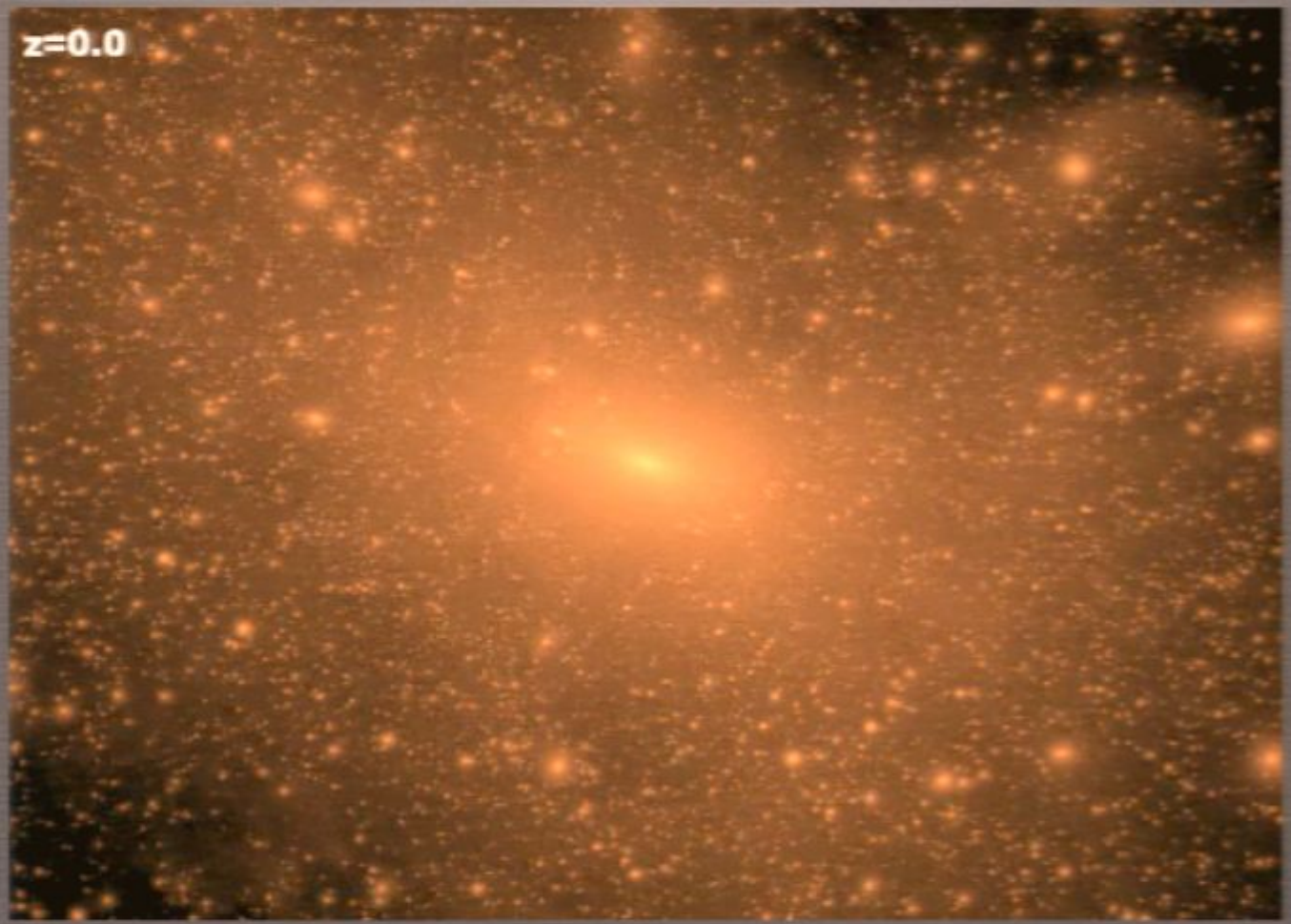

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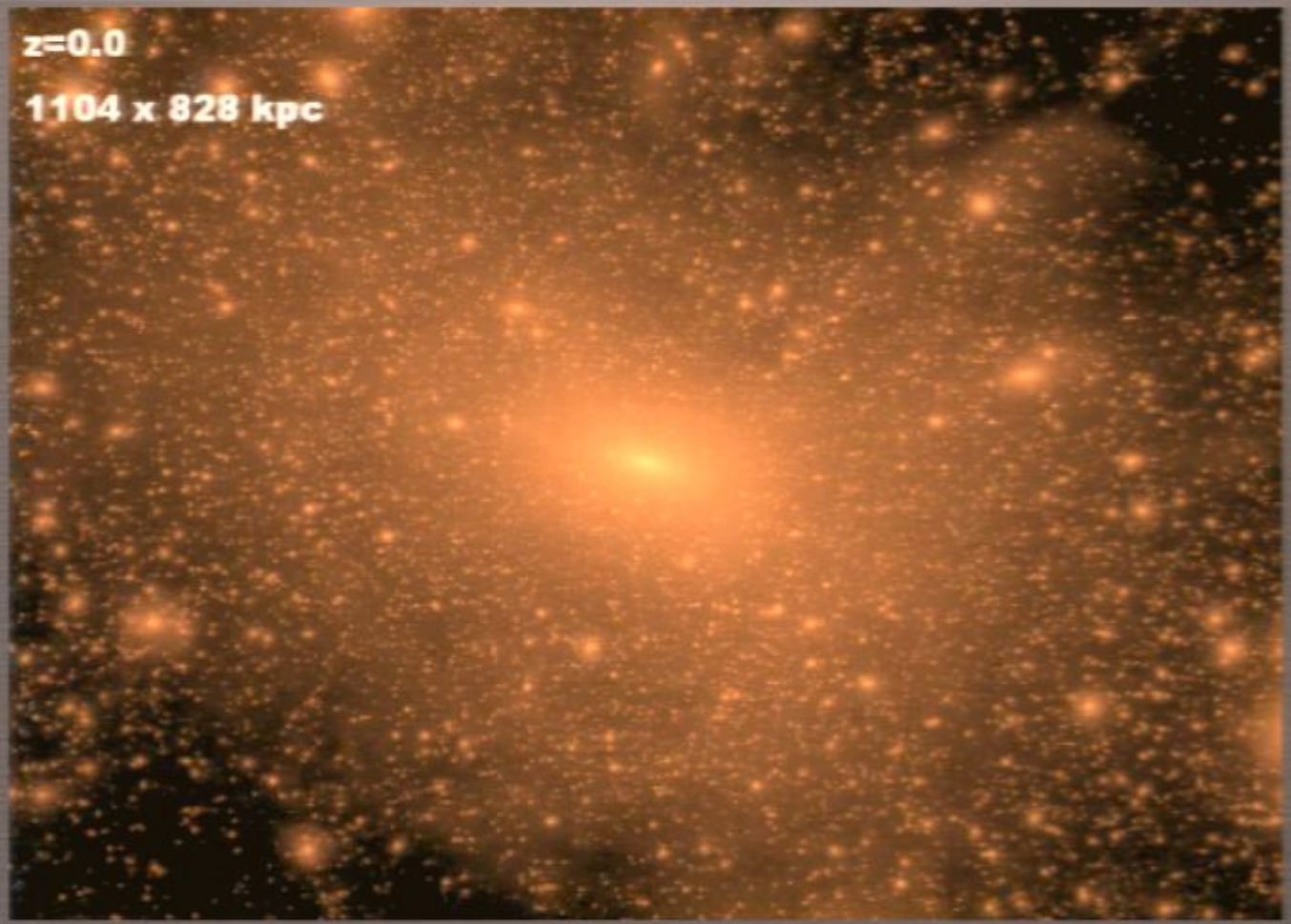

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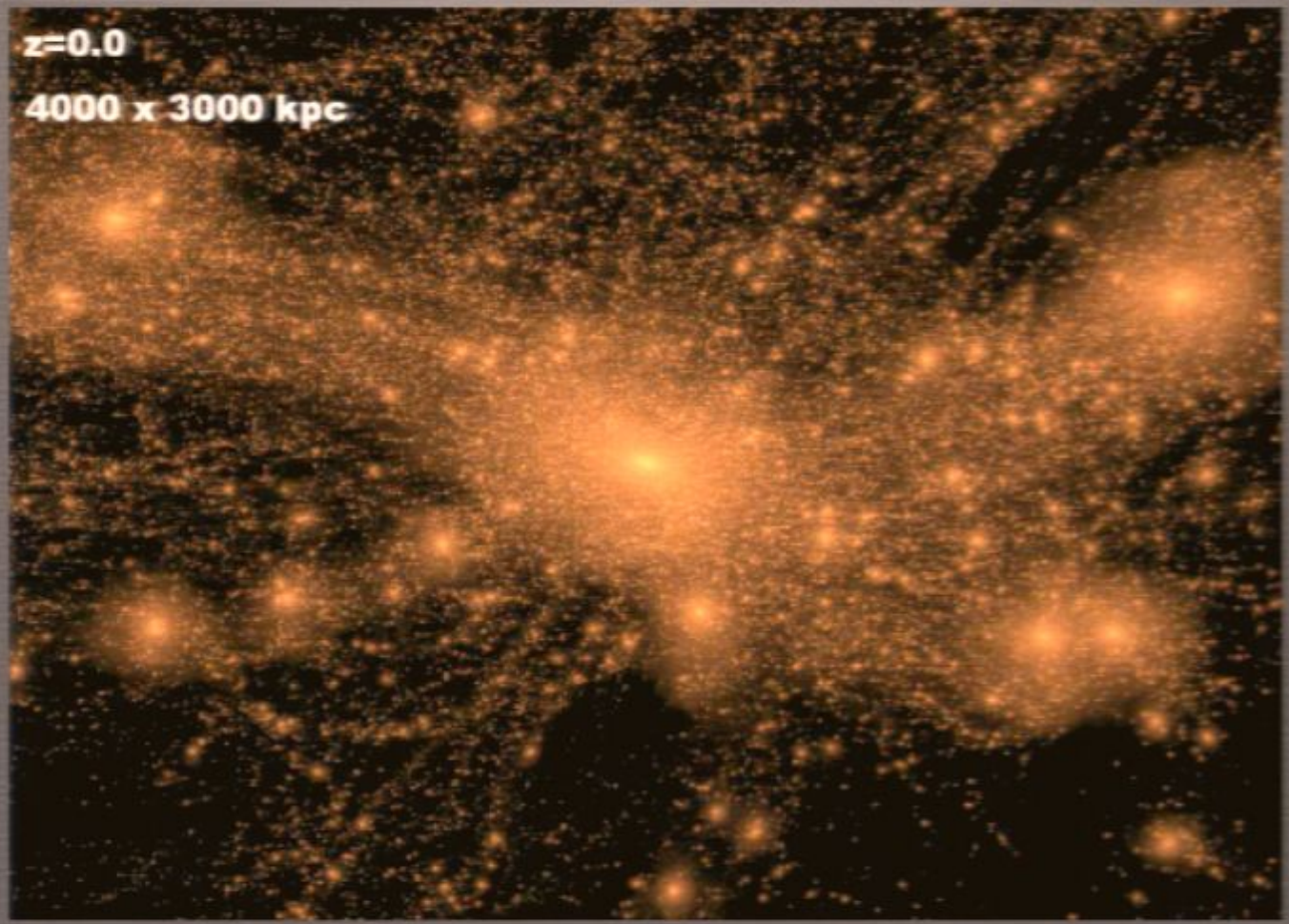

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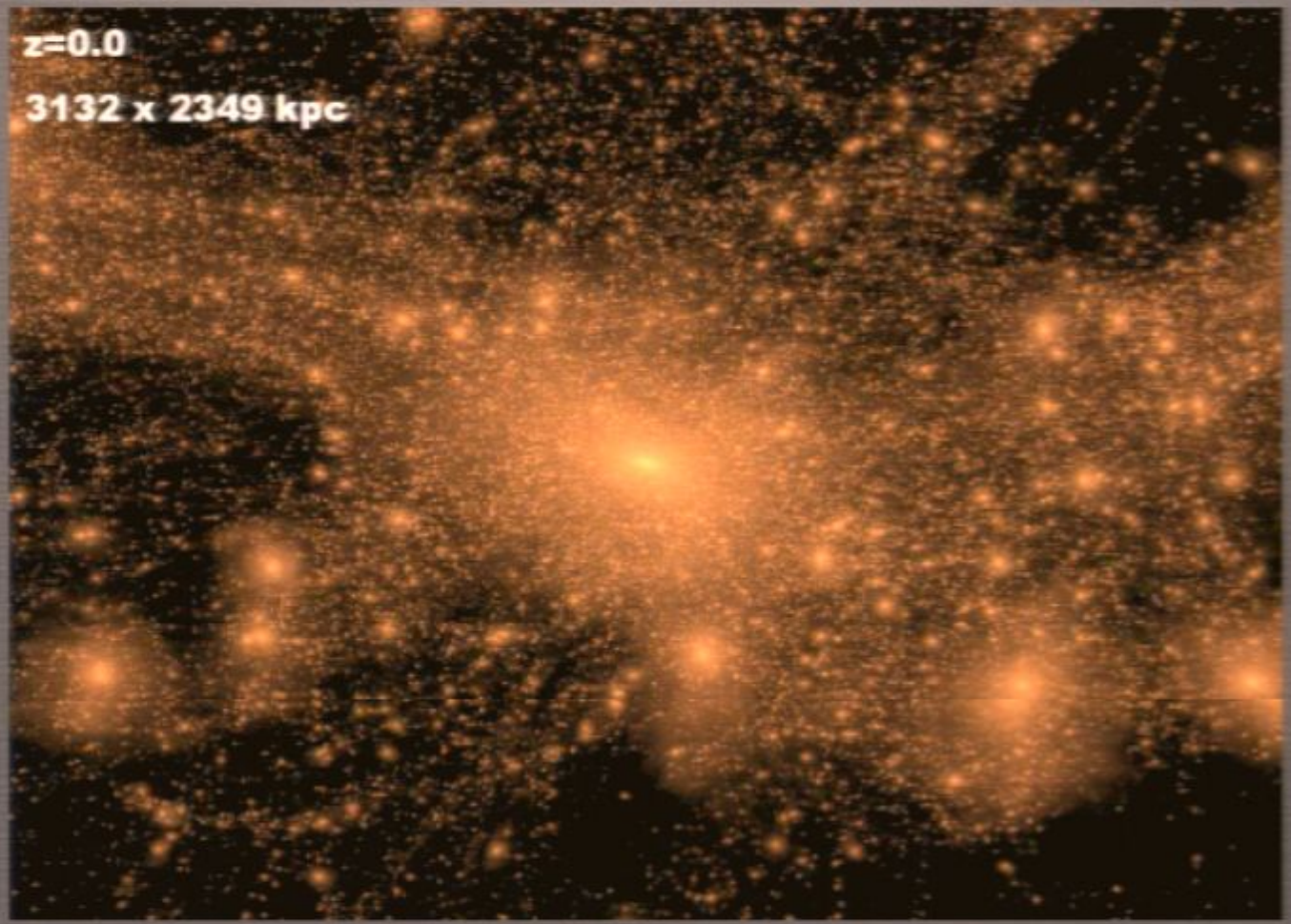

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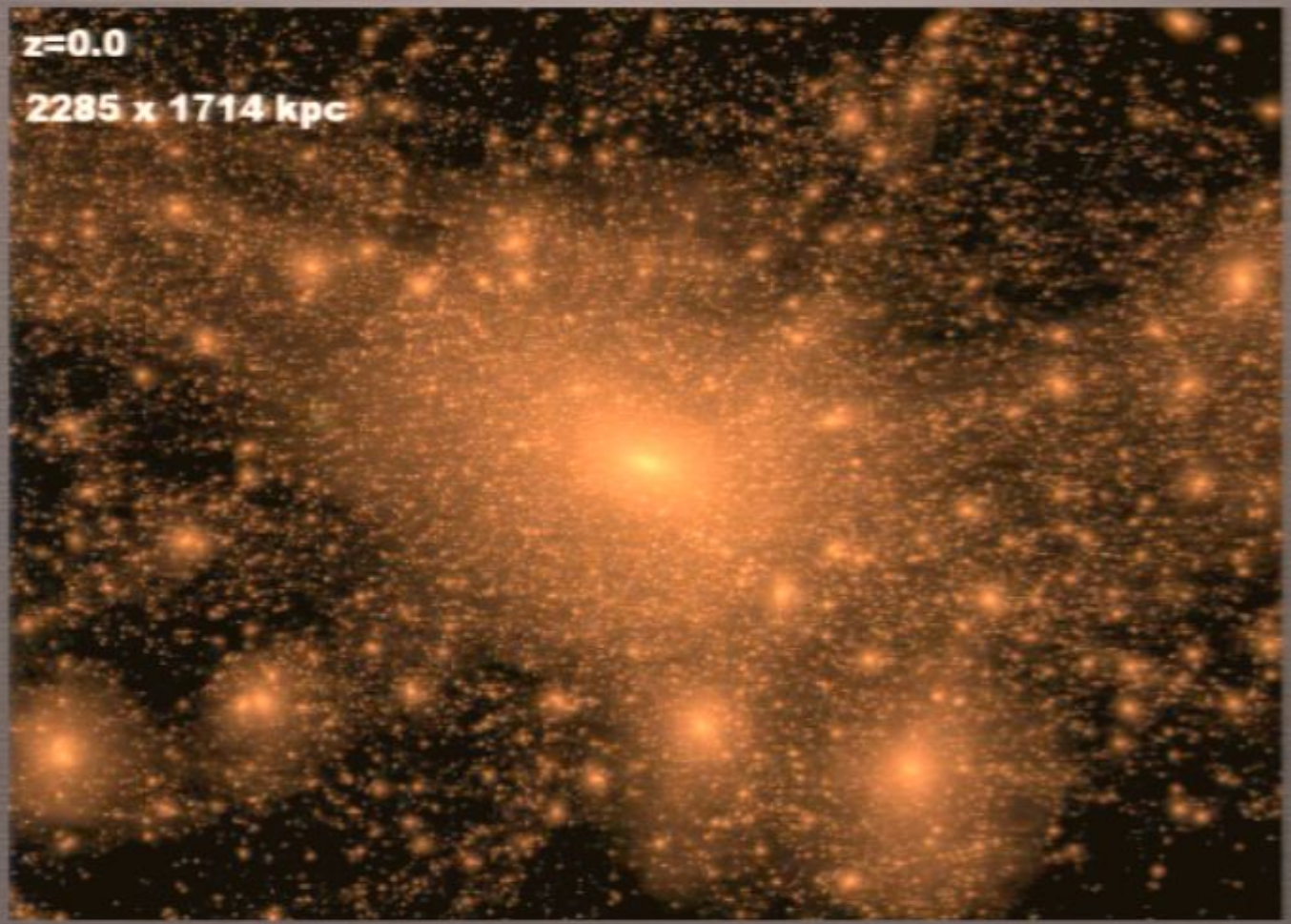

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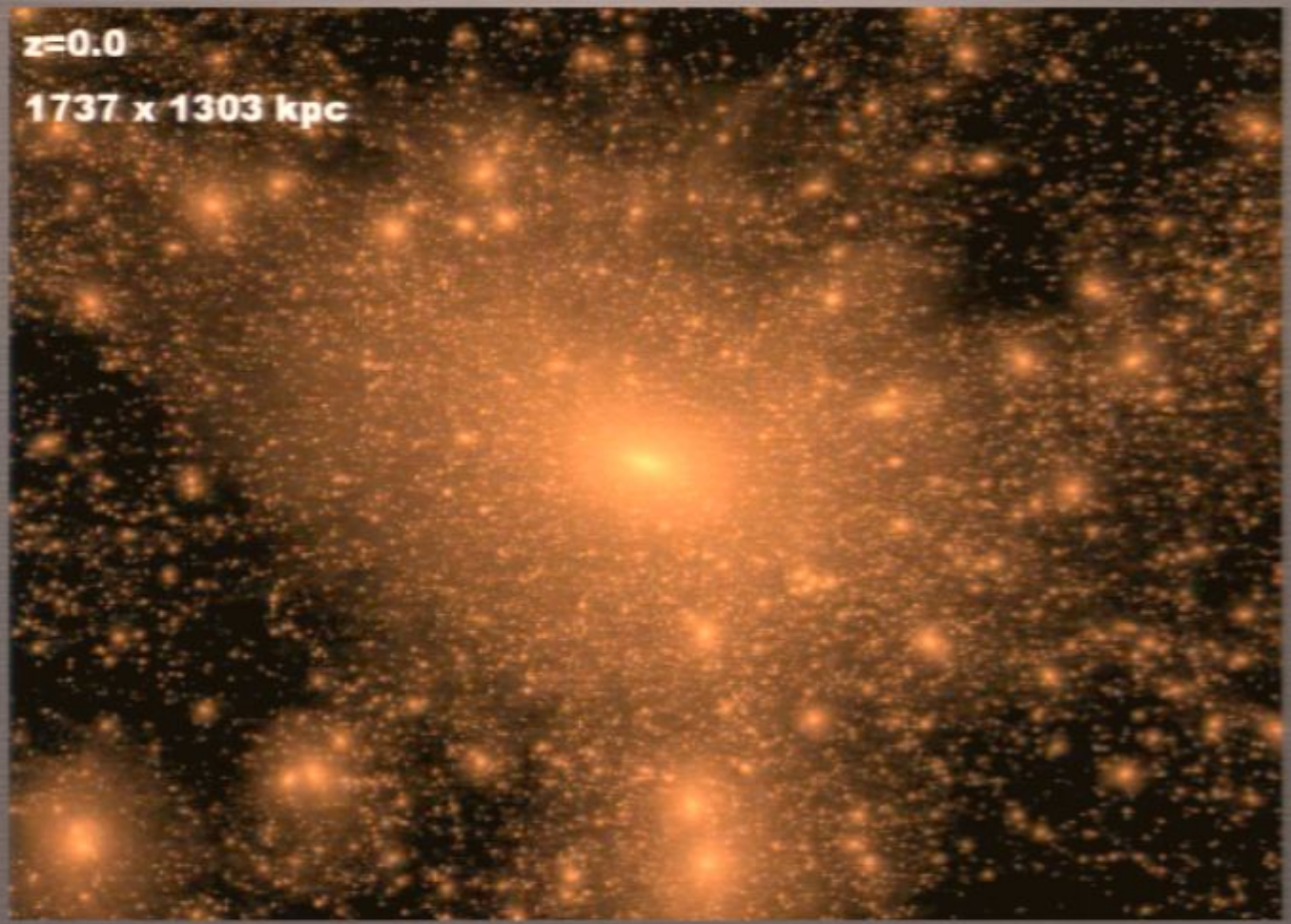

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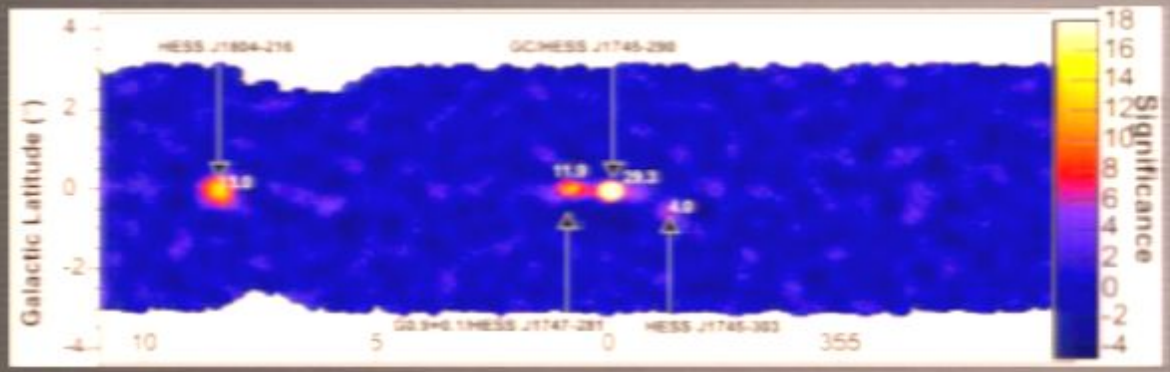
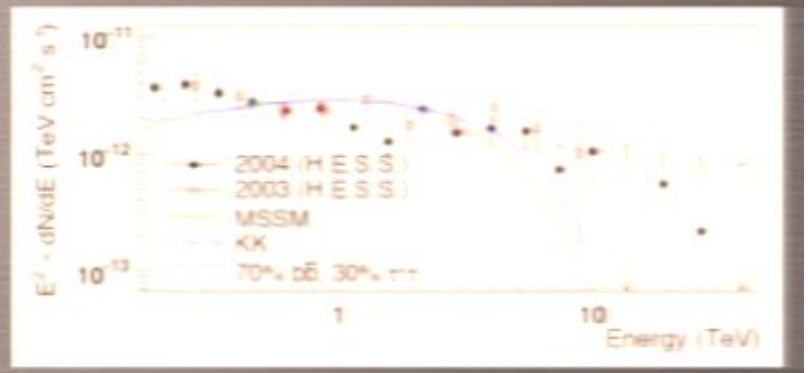
The Galactic center

bright point source detected by HESS and MAGIC



Aharonian et al. 2007



Aharonian et al. 2006

...Might be more interesting to focus on an "annulus" around the center (Stoehr et al. 2002)

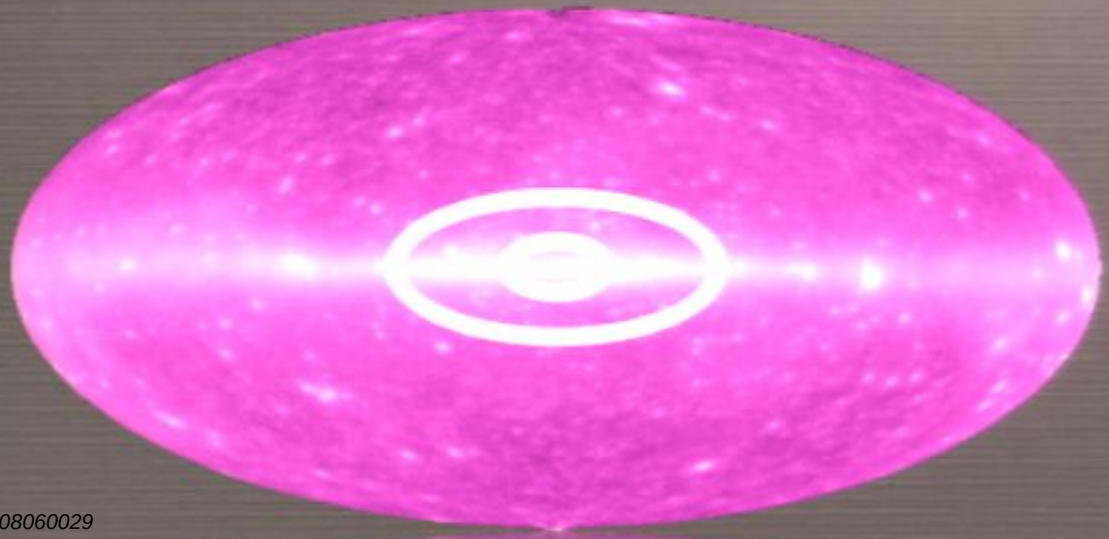
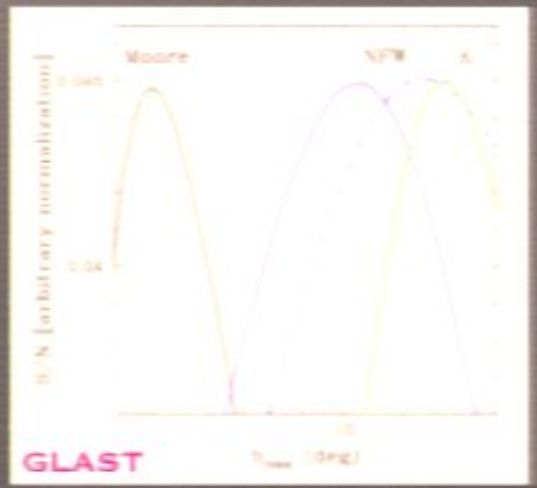
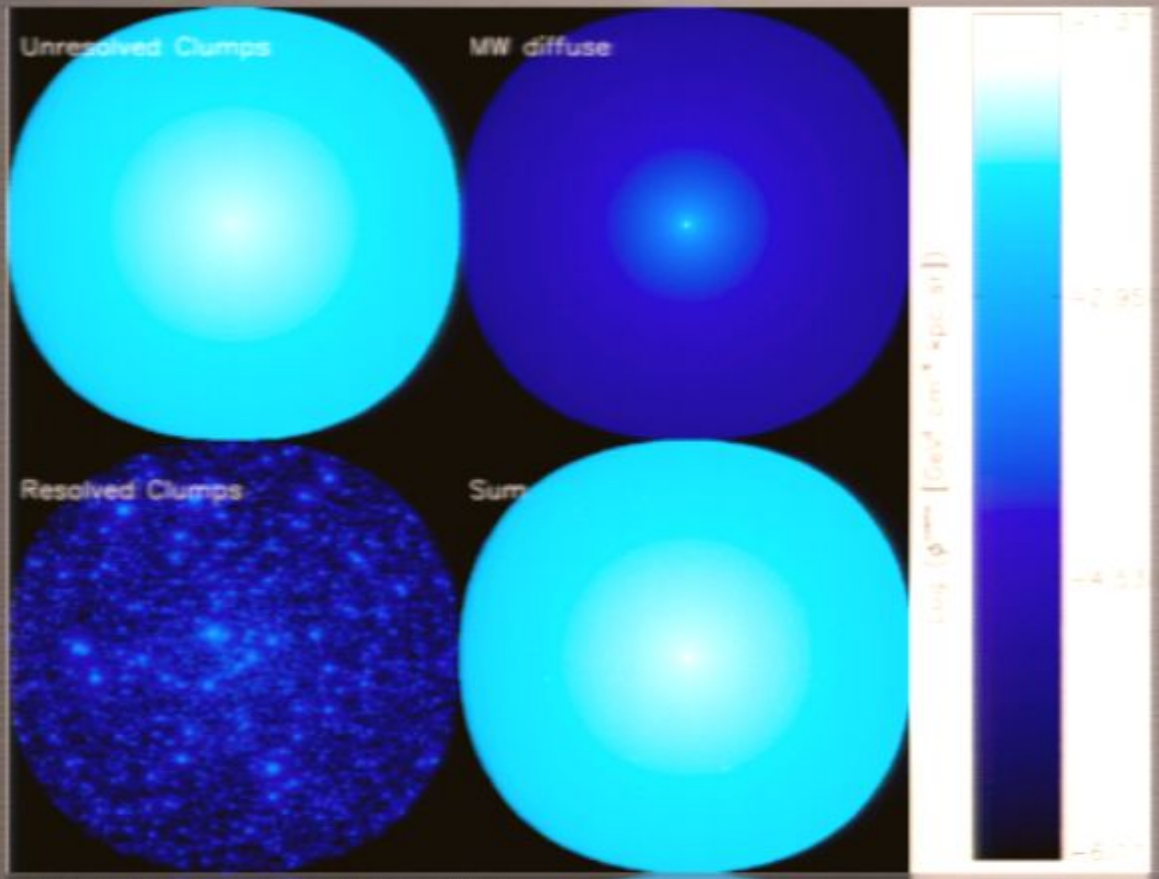


Image from http://glast.gsfc.nasa.gov



Serpico & Zaharijas 20

DM Substructures



Pieri, GB & Branchini 2008

2 effects:

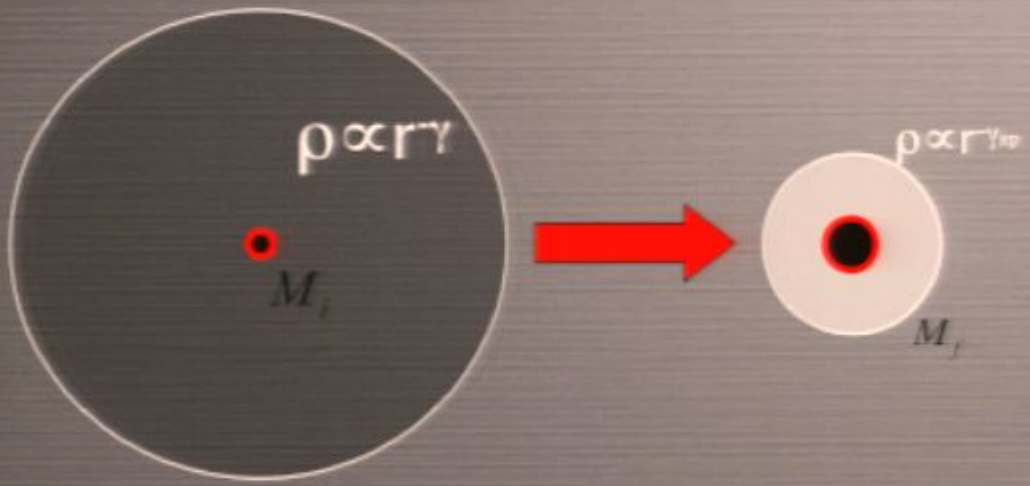
- unresolved clumps "boost" the diffuse flux
- resolved ones can be identified as (diffuse?) sources.

Depending on the particle phys. and astrophys. assumptions, up to 10/100 large mass subhalos could be detected with GLAST. See also Diemand, Kuhlen & Madau 2008 for results based on the Via Lactea simulation.

- Prospects strongly depend on astrophysical (mass function, concentration, spatial distribution, profile) and particle physics (mass, spectrum, cross section) parameters. Dedicated workshop on June 7-8.

Intermediate-Mass Black Holes

Adiabatic accretion of BHs modifies the surrounding DM distribution (Gondolo & Silk 2000)



Conserve Mass & Angular Momentum:

$$\gamma_{sp} = \frac{9-2\gamma}{4-\gamma}$$

Any overdensity at the GC likely destroyed due to gravitational scatter off the central stellar cusp (GB & Merritt 2005)

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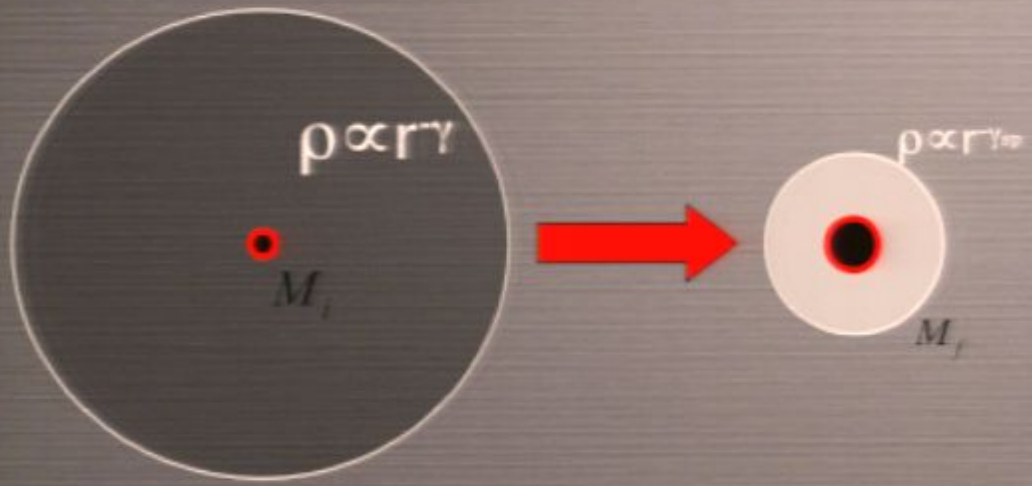

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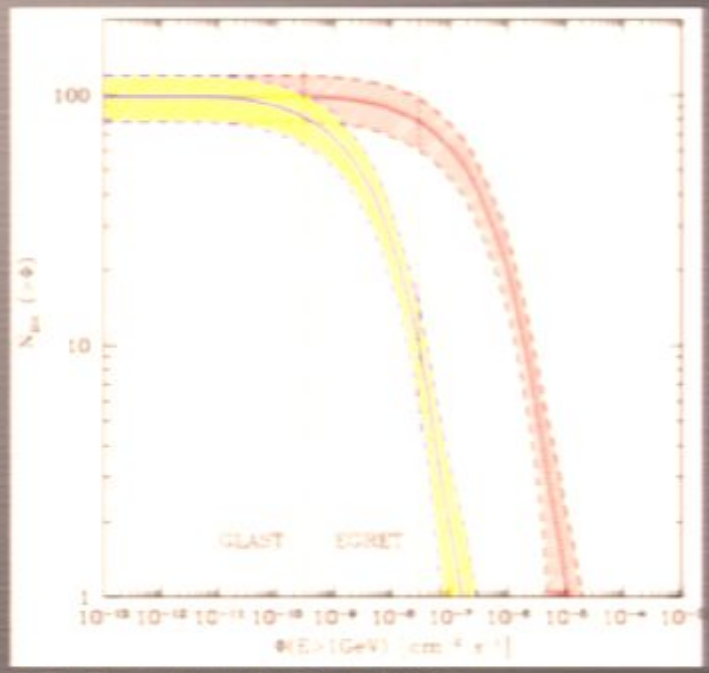
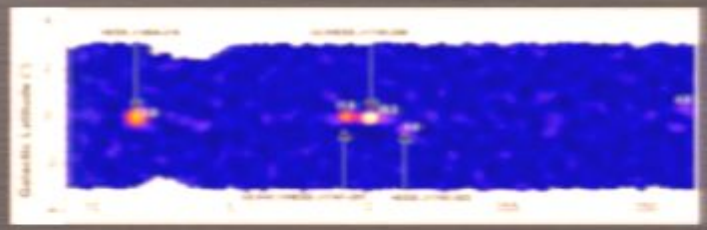
Overdensities around IMBHs likely survive , making them interesting targe



GB, Zentner & Silk 2005



Hess galactic scan constrains these models. Results soon to appear

Aharonian et al. 2008

The quest for the smoking-gun or "How to convince a particle physicist?"

Claims of discovery have been made over the years (EGRET source, HEAT excess, INTEGRAL 511 keV line, WMAP Haze). The footprint of DM could be anywhere, but how do we go from "hints" to "discovery"?

The quest for the smoking-gun or "How to convince a particle physicist?"

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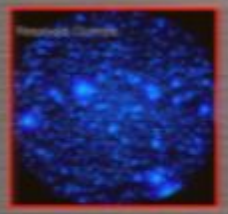
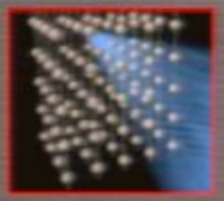
1) Annihilation Lines (or other unmistakable spectral features)

Neutralinos (e.g. Bergstrom and Ullio 1997)
KK Dark Matter in UED (Bringmann et al. 2005)
Inert Higgs DM (Gustafsson et al. 2007)
gravitinos in SUSY with R-parity violation (GB, Buchmueller, Covi & Ibarra 2008)



2) Multiple Sources with Identical spectra

e.g. DM clumps or IMBHs



3) High-Energy Neutrinos from the Sun

Icecube, Antares, km3
Fluxes proportional to SCATTERING not annihilation cross section

4) Multi-wavelength / multi-messenger approach

Bertone, Sigl & Silk 2001; Aloisio, Blasi & Olinto 2004; Colafrancesco, Profumo & Ullio 2005; Regis & Ullio 2007

5) Angular power Spectrum of EG Background

Ando & Komatsu 2006, Ando et al. 2007

Conclusions

- Huge Theoretical and experimental effort towards the identification of DM
- LHC is about to start. Exciting time ahead, but direct and indirect searches likely necessary to identify DM
- DM Direct Detection looks promising, but info from other exps. is needed to determine DM parameters
- DM Indirect Detection uncertain, but smoking-gun evidence might be found
- Let's keep our fingers Crossed!