EuroGDR Supersymmetry - 4th meeting

– Frascati 25 November 2004 –

Recent developments in Astroparticle physics

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OUTLINE

1. News from the observational front:

– Dark matter: CDMS

– Some γ rays puzzles from our galaxy...

– CMB polarization: CAPMAP, CBI, DASI

– Large Scale Structure: SDSS Lyα data

2. News from the theory side:

– Running spectral index or not ?

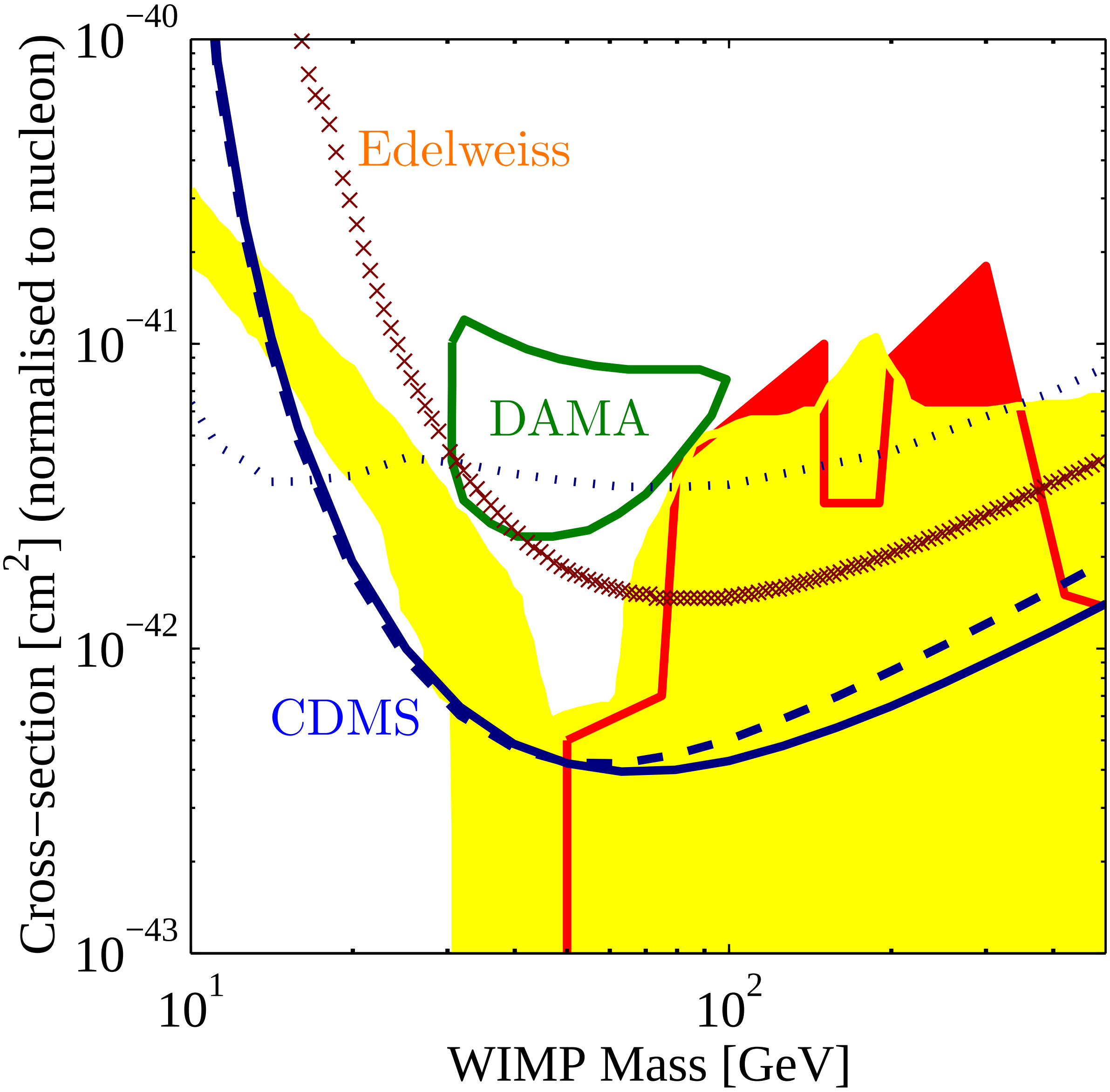
– Cosmology meets String theory

– Beyond the classical neutralino DM scenarios

3. Outlook

DARK MATTER:

New limit spin-independent cross-section from CDMS ! [astro-ph/0405033]



DAMA region excluded...
BUT: a spin-dependent cross section could still explain all data, for mass window $\simeq$ 5-13 GeV

[Savage, Gondolo & Freese '04]

$\rightarrow$ most of the SUSY parameter space still available

more in the talks tomorrow afternoon !

Galaxy γ ray puzzles:

- SPI/INTEGRAL has (again) evidence for a 0.511 MeV emission line from the centre of the galaxy: e^+e^- annihilation *at rest !*

  ??? Annihilating/decaying CDM ???

  $\rightarrow$ see P. Fayet talk tomorrow

- EGRET excess of γ rays at about 1-10 GeV

  $\rightarrow$ see W. de Boer and A. Morselli talks

- also some γ ray emission seen around TeV by VERITAS, CANGAROO and H.E.S.S., but the position and energy spectra do not match...: different sources ???

  Possible explanation from annihilating DM requires very heavy masses $M_\chi > 12$ TeV

Astrophysical explanations probably more plausible... more data needed !

CMB polarization

New measurements of the E-mode by DASI, CAPMAP and CBI [astro-ph/0409357,380,569]

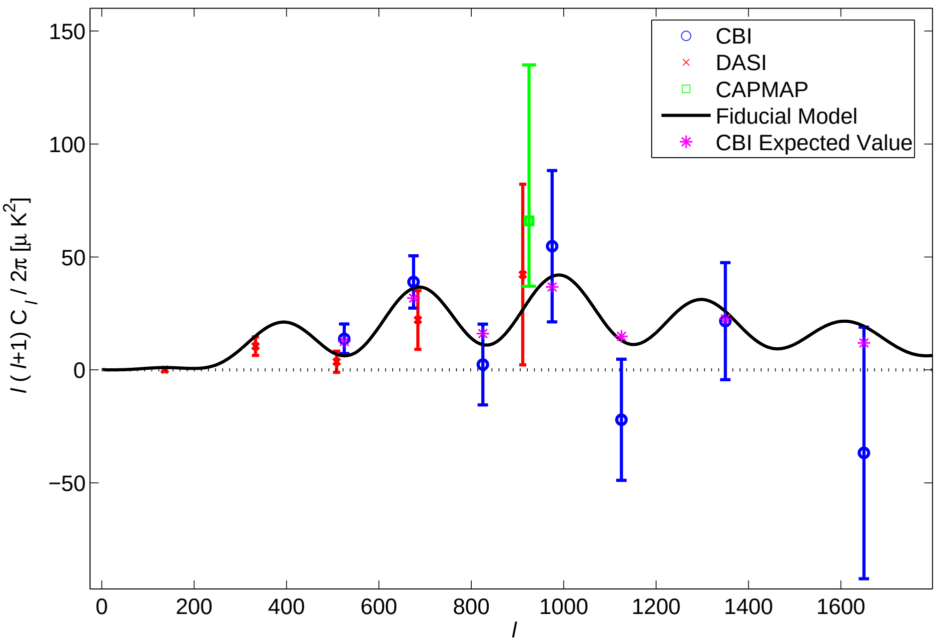


Figure from CBI [astro-ph/0409569]

7σ detection, consistent with WMAP and scalar perturbations, but error bars still very large !

No evidence for the B-mode.

WMAP 2nd release and other polarization measurements (Boomerang...) still to come...

Large Scale Structure: the Sloan Digital Sky Survey

New determination of the power spectrum at small scales from Ly α data [astro-ph/0405013,07377]

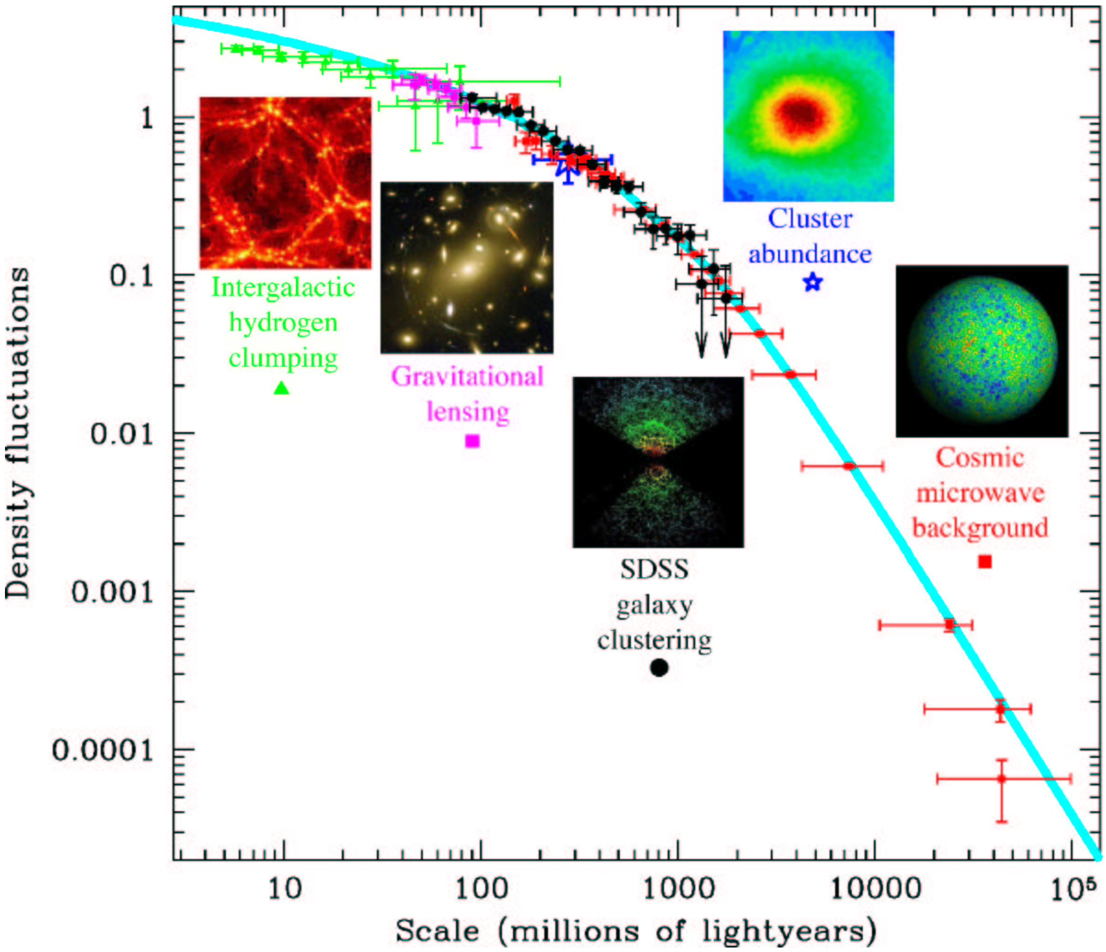


Figure by M. Tegmark

$\longrightarrow$ better control of systematics

$\longrightarrow$ longer lever arm in scale

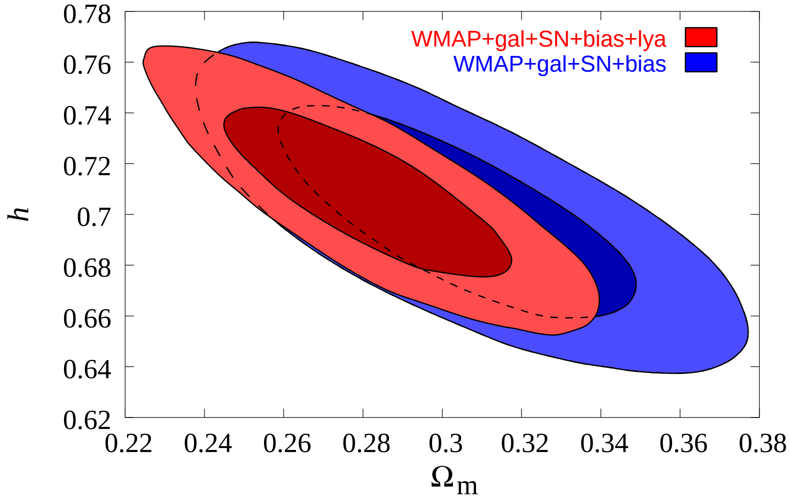
$$\Downarrow$$

NEW determination of the cosmological parameters from WMAP data, SDSS galaxy clustering, bias and Lyman α data, SN Ia data.

New analysis by Seljak *et al* [astro-ph/0407372]

What has changed ???

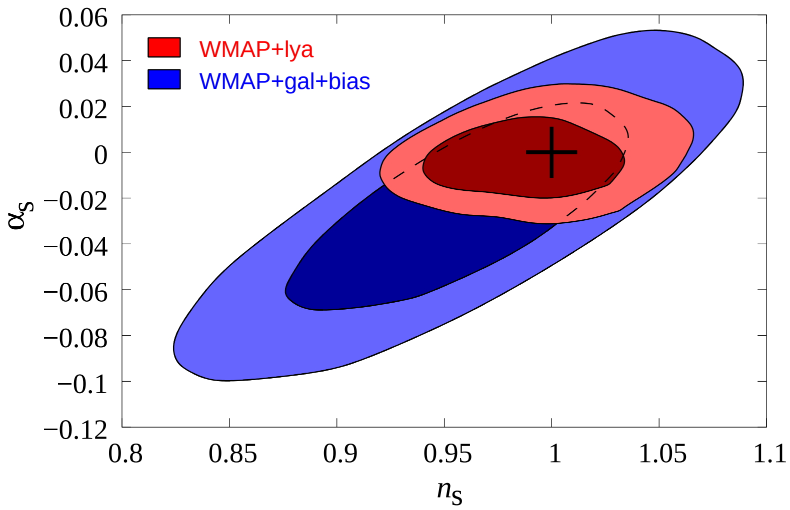
- Improved accuracy on all parameters, e.g.



- More stringent bound on neutrino masses

$$\sum m_\nu \leq 0.66 \text{ eV } (3\nu) \quad \text{or } m_\nu \leq 0.79 \text{ eV } (3+1\nu)$$

- Spectral index $n_s = 0.977^{+0.025}_{-0.021}$ and $\alpha_s = n_s' = -0.003 \pm 0.010$: NO RUNNING !



Also bound on the tensors as $r \leq 0.45$ at 1σ.

What can we say about inflation then ?

In single field inflation with $V(\phi)$ the scalar power spectrum is

$$\mathcal{P}_{\mathcal{R}}(k) = \frac{1}{12\pi^2 M_P^6} \frac{V^3}{V'^2}\bigg|_{k=aH} \qquad \propto k^{n-1}$$

and the spectral index:

$$n(k) - 1 = \frac{d\log(\mathcal{P}_{\mathcal{R}})}{d\log(k)}\bigg|_{k=aH} = 2\eta - 6\epsilon + \ldots$$

So $n'(k_0)$ arises only at second order:

$$n'(k) = \frac{2}{3}\left((n-1)^2 - 4\eta^2\right) + 2\xi$$

where

$$\epsilon = \frac{M_P^2}{16\pi}\frac{(V')^2}{V^2} \qquad \eta = \frac{M_P^2}{8\pi}\frac{V''}{V} \qquad \xi = \frac{M_P^4}{64\pi^2}\frac{V'V'''}{V^2}$$

so we expect $n' \propto (n-1)^2$ (or ξ must be large).

The new result is consistent with this !

Lyman α data give stronger constraints for models with substantial running, e.g. $\rightarrow$ running mass models !

Running mass model(s) [Stewart '96,'97]

$\phi \longrightarrow$ flat direction of the SUSY potential $\qquad V'_{SUSY}(\phi) = 0$

Break supersymmetry explicitly in a hidden sector and obtain a soft mass for the inflaton field:

$$V(\phi) = V_0 \left(1 + \frac{\mu^2 \phi^2}{2M_P^2}\right) + ... \text{ for } \phi < M_P.$$

At tree level, for a generic scalar field one has naturally $|\mu^2| \simeq 1$ $\qquad$ η problem !

$\rightarrow V(\phi)$ is NOT flat at high scale

Assume that the inflaton field interacts not so weakly and add one loop corrections to the potential by substituting

$$\mu^2 \rightarrow \mu^2(Q = \phi) \quad \text{running mass}$$

The running of the mass can flatten the potential somewhere in the region $\phi < M_P$.

$\Downarrow$

Slow roll inflation

Parameterize $n(k)$ and $\mathcal{P}_{\mathcal{R}}(k)$:

$n(k) - 1 \ll 1$ on cosmological scales $\Rightarrow$ linear expansion around pivot ϕ_0 ($\leftrightarrow k_0$)

So take the running mass as

$$m^2(\phi) \simeq m^2(\phi_0) + c * \log\left(\frac{\phi}{\phi_0}\right)$$

where $c \propto \beta_m = \frac{dm^2}{d\log(Q)}(\phi_0) = coupling \times m^2_{loop}$.

Then defining ϕ_* by $V'_{lin}(\phi_*) = 0$ and introducing the parameter $s = c\log(\phi_*/\phi_0)$, we have

$$\frac{n(k)-1}{2} = s\left(\frac{k}{k_0}\right)^c - c$$

and

$$n'(k) = 2sc\left(\frac{k}{k_0}\right)^c$$

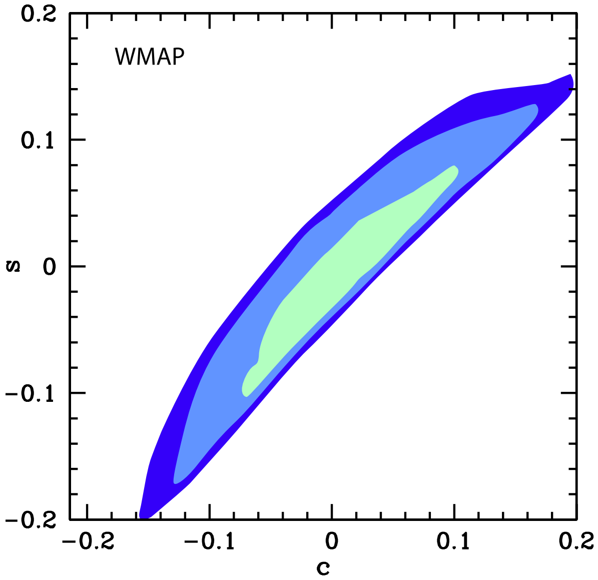
"Strong (exponential !)" scale dependence !!

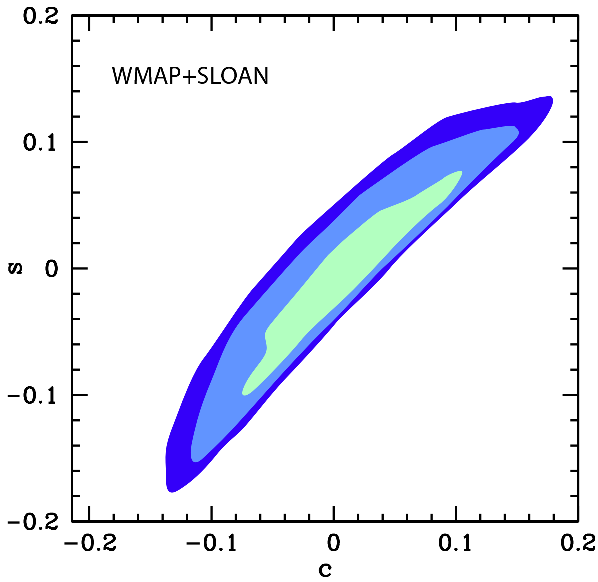
NOTE: s, c are related to physical parameters rescaled by the inflationary Hubble scale H_I^2:

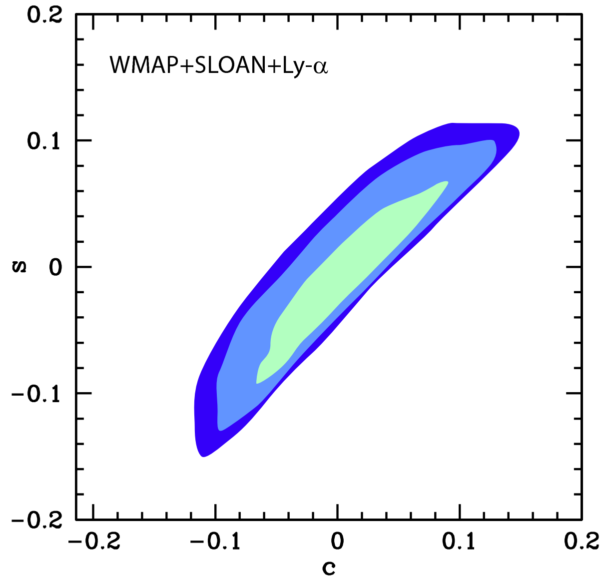
$$c \equiv -\frac{\beta_m(\phi_0)}{3H_I^2} \qquad s + \frac{1}{2}c \equiv \frac{m^2(\phi_0)}{3H_I^2}$$

c suppressed by a coupling, s also to have slow roll...

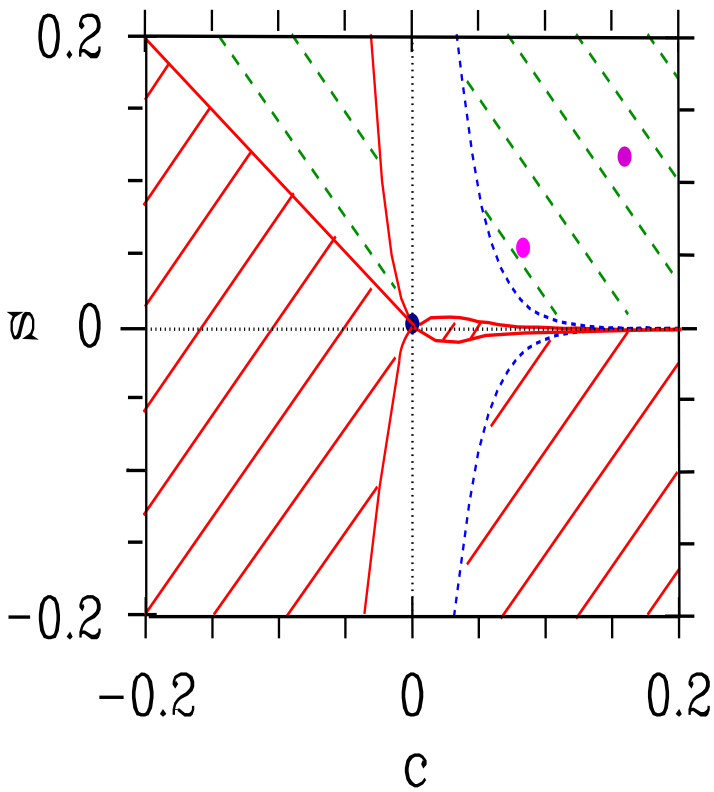
What are the constraint from the new data for s, c in such models ? [LC, Lyth, Melchiorri & Odman astro-ph/0408129]



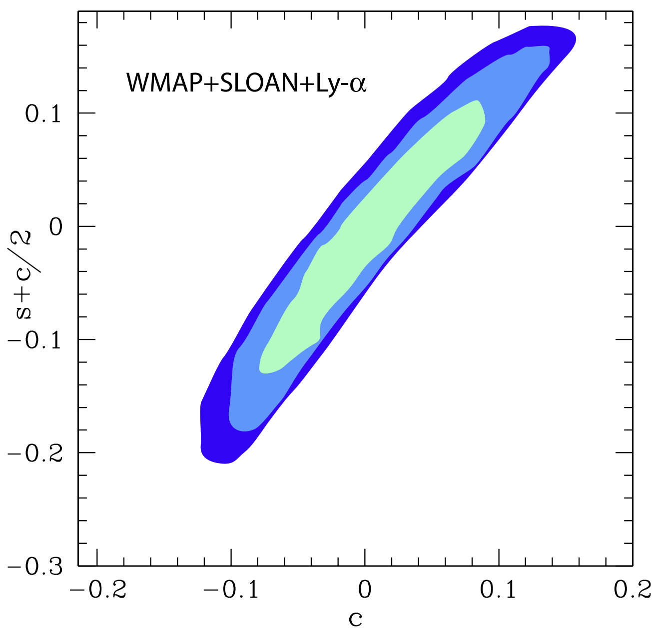




Theoretically expected region



“Physical parameters”



$c \propto$ coupling

String theory meets inflationary cosmology

Lots of activity on inflationary model building in string models, too many models to review here, but a couple of general results are:

• it is possible to have "unstable", but sufficiently long-lived de Sitter minima in string theory

→ **KKLT**

• the string inflationary potentials are pretty complex, they must include non-perturbative contributions (difficult to compute...) and in general a fine-tuning of the order $\mathcal{O}(10^{-2})$ is necessary to have slow roll...

• in certain realizations with colliding branes cosmological "superstrings" could form at the end of inflation

→ similar to the old local strings, but with different scale and smaller interconnection probability $P < 1$

[Copeland *et al*, Dvali *at al*... '04]

Beyond the classical CMSSM supersymmetric DM

The CMSSM neutralino scenario appears nowadays to be a bit fine-tuned... Most of the activities lately are concentrated on less constrained scenarios:

- More general SUSY breaking schemes, e.g. → Y. Mambrini
- NMSSM, e.g. [Cerdeño *et al*, Menon *et al* '04]
- Split SUSY → A. Romanino, A. Mazumdar
- scalar/Kaluza-Klein DM → P. Fayet, G. Servant
- Super Weakly Interacting Massive Particles: gravitinos (see e.g. [W. Buchmüller *et al*..., J. Ellis *et al*, J. Feng *et al*..., Roszkowski & Ruiz de Austri, K. Hamaguchi *et al* '04])
  or axinos (e.g. [LC *et al*..., Brandenburg & Steffen '04])
  or ....

SuperWIMPs: such particles reach thermal equilibrium at very high temperatures and "freeze out" when relativistic with high number density $\Omega < 1 \rightarrow$ very light masses $\rightarrow$ Hot or Warm DM !

They can be Cold DM if $T_{RH} < T_f$. Their yield is given (at least) by two mechanisms:

– thermal scattering and decays in the plasma

$$\frac{dY_{\rm SW}}{dT} = \frac{-1}{HTs(T)} \left[\sum_{ij} \langle \sigma(i+j \rightarrow {\rm SW} + ...) v_{rel} \rangle n_i n_j \right.$$

scatterings

$$\left. \sum_{i} \langle \Gamma(i \rightarrow {\rm SW} + ...) \rangle n_i \right]$$

decays

strongly dependent on T_{RH} !

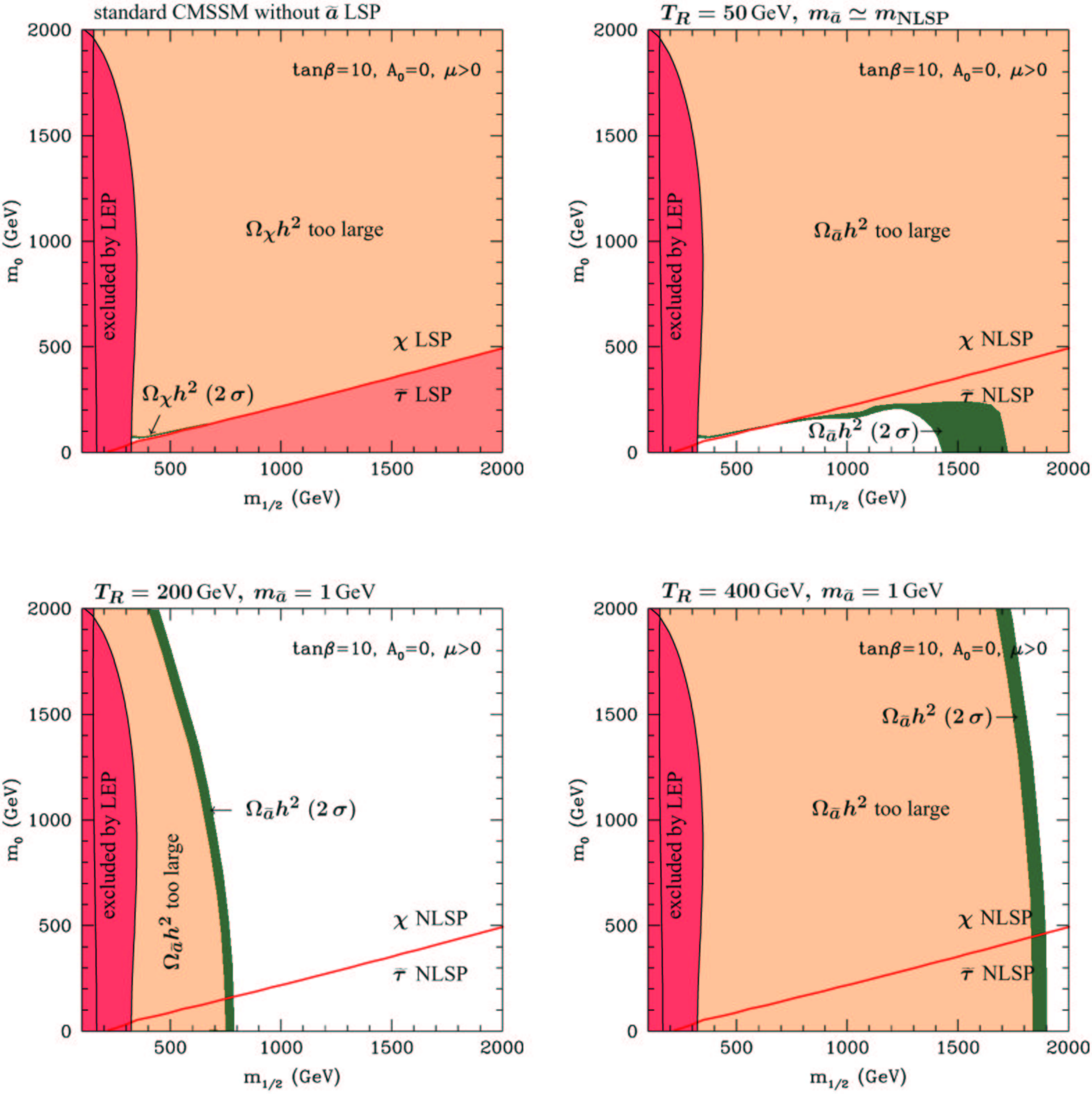
– decay *out of equilibrium* of the NLSP:

$$\Omega_{\rm SW}^{NT} = \frac{m_{\rm SW}}{m_{\rm NLSP}} \, \Omega_{\rm NLSP}$$

BEWARE of the other decay products (γs or hadrons) not spoiling Nucleosynthesis or distort the CMB !

What are the consequences for the supersymmetric parameters from SWIMP CDM ?

More parameter space allowed, especially the $\tilde{\tau}$ NLSP region. See e.g. for the axino (less constrained by BBN), [LC, Roszkowski, Ruiz de Austri & Small 04]



Collider signature: long-lived $\tilde{\tau}$ s ???

Then it will be necessary to study the $\tilde{\tau}$ decay to distinguish between the different scenarios: gravitino, axino, singlino, R-parity violation, other...

Note measuring the $\tilde{\tau}$ lifetime and mass is not enough, the main decay channel and possibly a radiative one are probably needed !

$\Rightarrow$ need to block the $\tilde{\tau}$ s and store them for a sufficient time..., but the lifetime could range from minutes to years ! [Feng *et al*, Hamaguchi *et al* 04]

If the decay is seen, the main signals are:

• SuperWIMP: main $\tilde{\tau}$ decay into SW+τ, then SW+$\tau + \gamma$...

Perhaps the angular distribution in the radiative decay could give information on the spin of the invisible particle and distinguish the gravitino if not mainly goldstino [Buchmüller *et al* 04]

• R-parity breaking: mainly 3-body decay to visible particles [Allanach *et al* 04]

• NMSSM "singlino": different topologies and shorter lifetimes due to non-negligible mixing in the neutralino sector. [Ellwanger & Hugonie 98, Martin 00]

Conclusions and Outlook

The era of precision cosmology continues:

- the new LSS data from Lyman α allow to put better constraints on the models of structure formation, e.g. $\Omega_\nu h^2$, and the scale dependence of the spectral index
- the simple single field inflationary paradigm with negligible tensor perturbation and running is sufficient to describe the data
- Dark matter bounds are becoming more stringent and starting to probe the SUSY parameter space
- still there are important open puzzles:

  - galaxy γ emissions ?

  - reionization ?

  - UHECR ?

  - Λ ?

  - ?

We are looking forward to the next year with more data from WMAP, SDSS, DM experiments, etc...