The Inert Doublet Model low mass regime and the Galactic centre excess

GDR - Terascale, 25/11/2016

Based on work in progress, in collaboration with B. Eiteneuer, J. Heisig

LABORATOIRE DE PHYSIQUE THEORIQUE ET HAUTES ENERGIES

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The Inert Doublet Model

Desphande, Ma (1978)
Barbieri, Hall, Rychkov(2006)
Honorez, Nezri, Oliver, Tytgat (2006)
...

· Gauge + spacetime symmetries : as in the SM.

· Particle content : SM + a Z_2 – odd SU(2) doublet of complex scalar fields.

$$H = \begin{pmatrix} G^+ \\ \frac{1}{\sqrt{2}}\left(v + h^0 + \mathrm{i}G^0\right) \end{pmatrix}, \quad \Phi = \begin{pmatrix} H^+ \\ \frac{1}{\sqrt{2}}\left(H^0 + \mathrm{i}A^0\right) \end{pmatrix}$$

· Lagrangian : $\mathcal{L}_{\mathrm{IDM}} = \mathcal{L}_{\mathrm{SM}} + \mathcal{L}_{\mathrm{cov},0} - V_0$

$$\mathcal{L}_{\mathrm{cov},0} = (D_\mu H)^\dagger (D^\mu H) + (D_\mu \Phi)^\dagger (D^\mu \Phi)$$

$$V_0 = \mu_1^2 |H|^2 + \mu_2^2 |\Phi|^2 + \lambda_1 |H|^4 + \lambda_2 |\Phi|^4 + \lambda_3 |H|^2 |\Phi|^2 + \lambda_4 |H^\dagger \Phi|^2 + \frac{\lambda_5}{2}\left[(H^\dagger \Phi)^2 + \mathrm{h.c.}\right]$$

· Parameters : $m_h, \quad m_{H^0}, \quad m_{A^0}, \quad m_{H^\pm}, \quad \lambda_L, \quad \lambda_2$

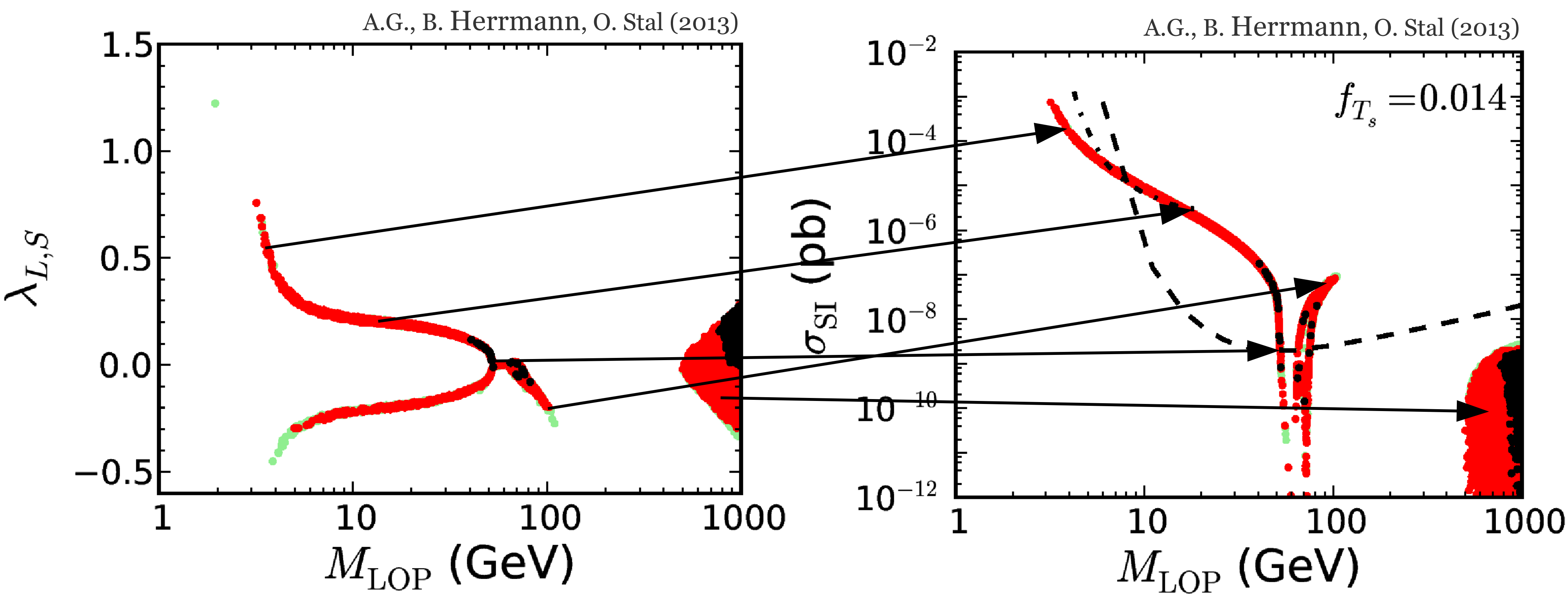
- m_h → h mass
- $m_{H^0}, m_{A^0}, m_{H^\pm}$ → inert scalar masses
- λ_L → $H^0 - H^0 - h$ coupling
- λ_2 → H^0 self-coupling

· The Z_2 symmetry ensures the stability of the lightest component of Φ → H^0/A^0 are dark matter candidates.

NB: H^0/A^0 practically interchangeable, take H^0 LOP for concreteness

The IDM as a dark matter model

· Considering all constraints modulo direct detection, the IDM can reproduce the observed DM abundance in the Universe in two distinct H^o mass ranges

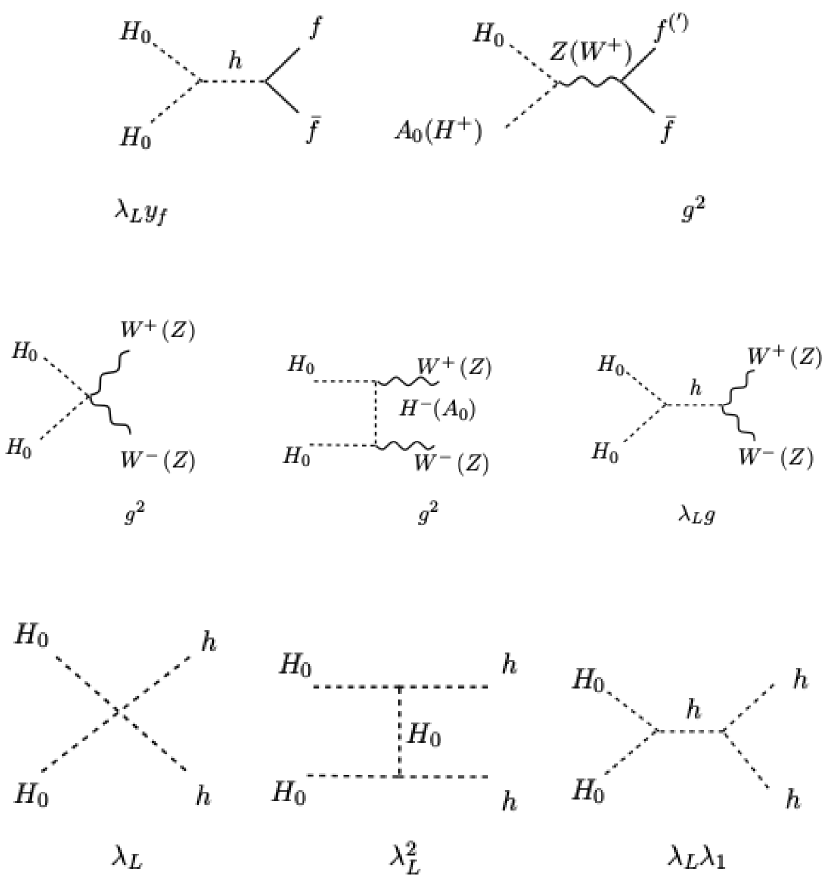


· The high – mass region of the IDM is pretty hard to probe. Partial coverage with direct/indirect detection. In the following, focus on the low – mass region.

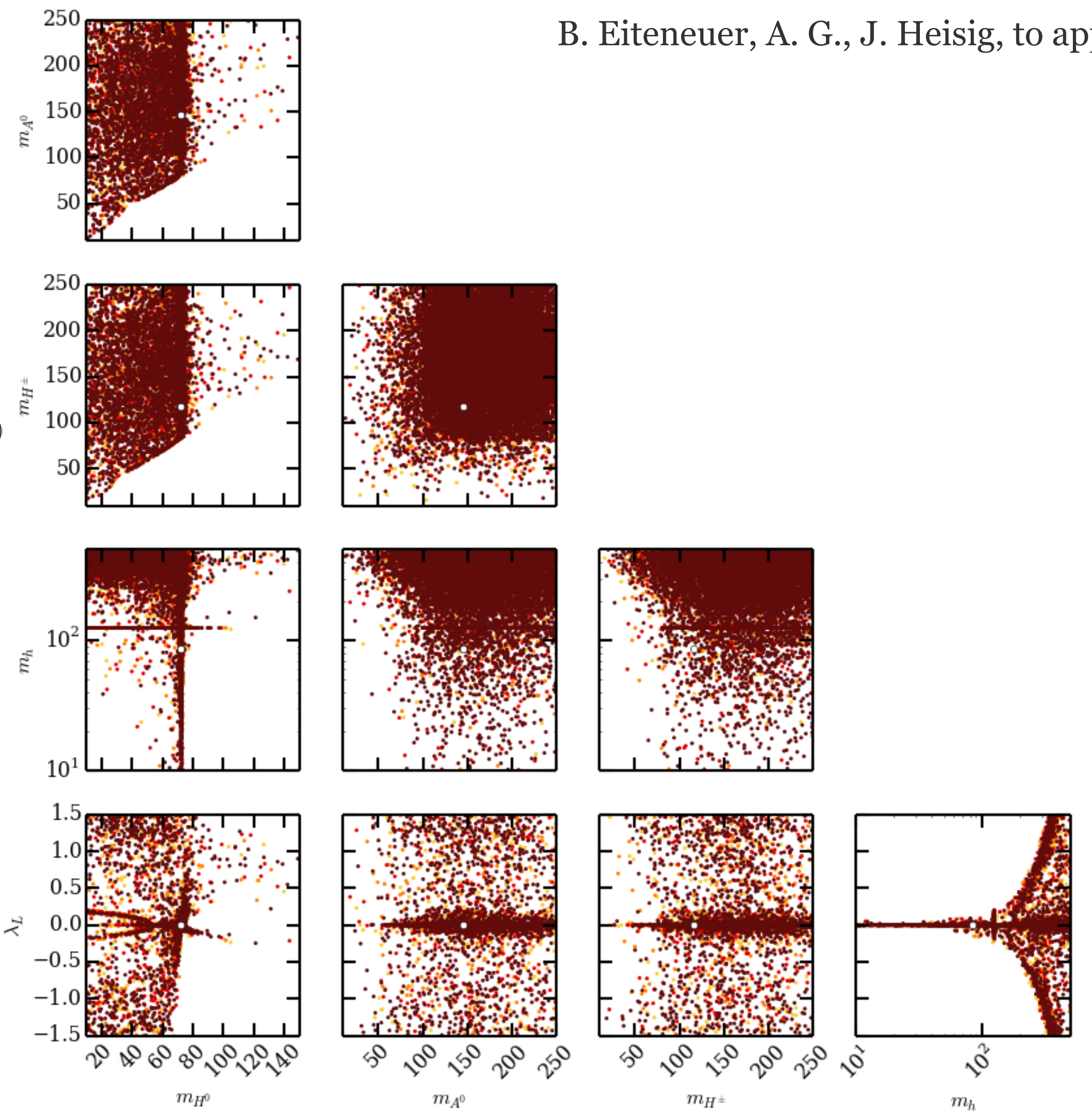
· Most of its features can be understood by imposing: relic abundance, LEP-II bounds on the heavier Z_2 – odd masses and Higgs mass.

Focus on the low mass region

· Processes contributing to DM depletion :



B. Eiteneuer, A. G., J. Heisig, to appear



· Without imposing any constraint, most λ_L values allowed regardless of H^o mass.

Focus on the low mass regime

· Impose LEP-II bounds on the heavy Z_2 – odd masses :

→ Coannilation becomes essentially irrelevant.

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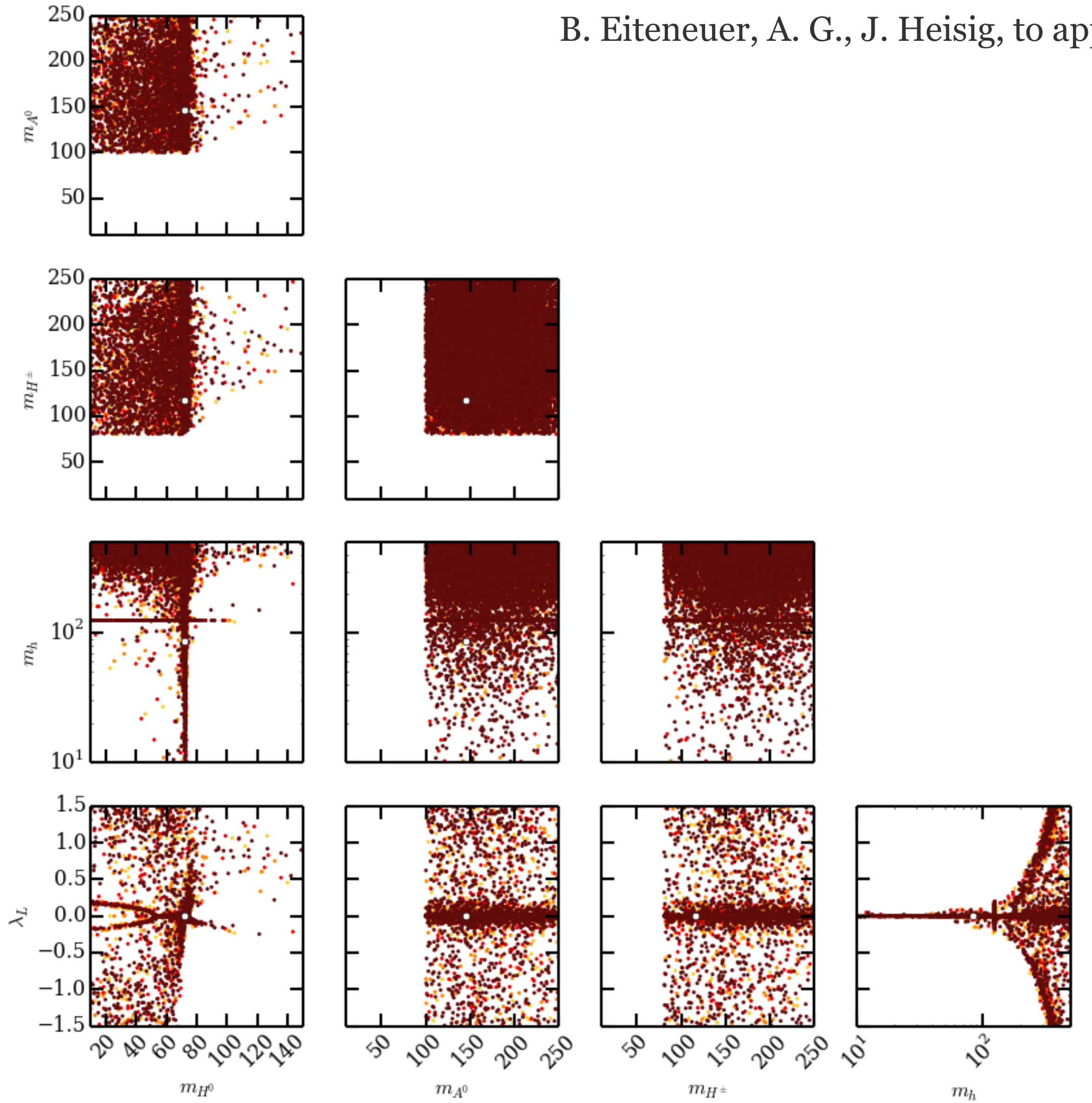

Focus on the low mass regime

· Impose LEP-II bounds on the heavy Z_2 – odd masses :

→ Coannilation becomes essentially irrelevant.

· Impose Higgs mass constraint :

→ One Higgs funnel is chosen

→ H^0 lighter than ~120 GeV

→ No Higgs final states

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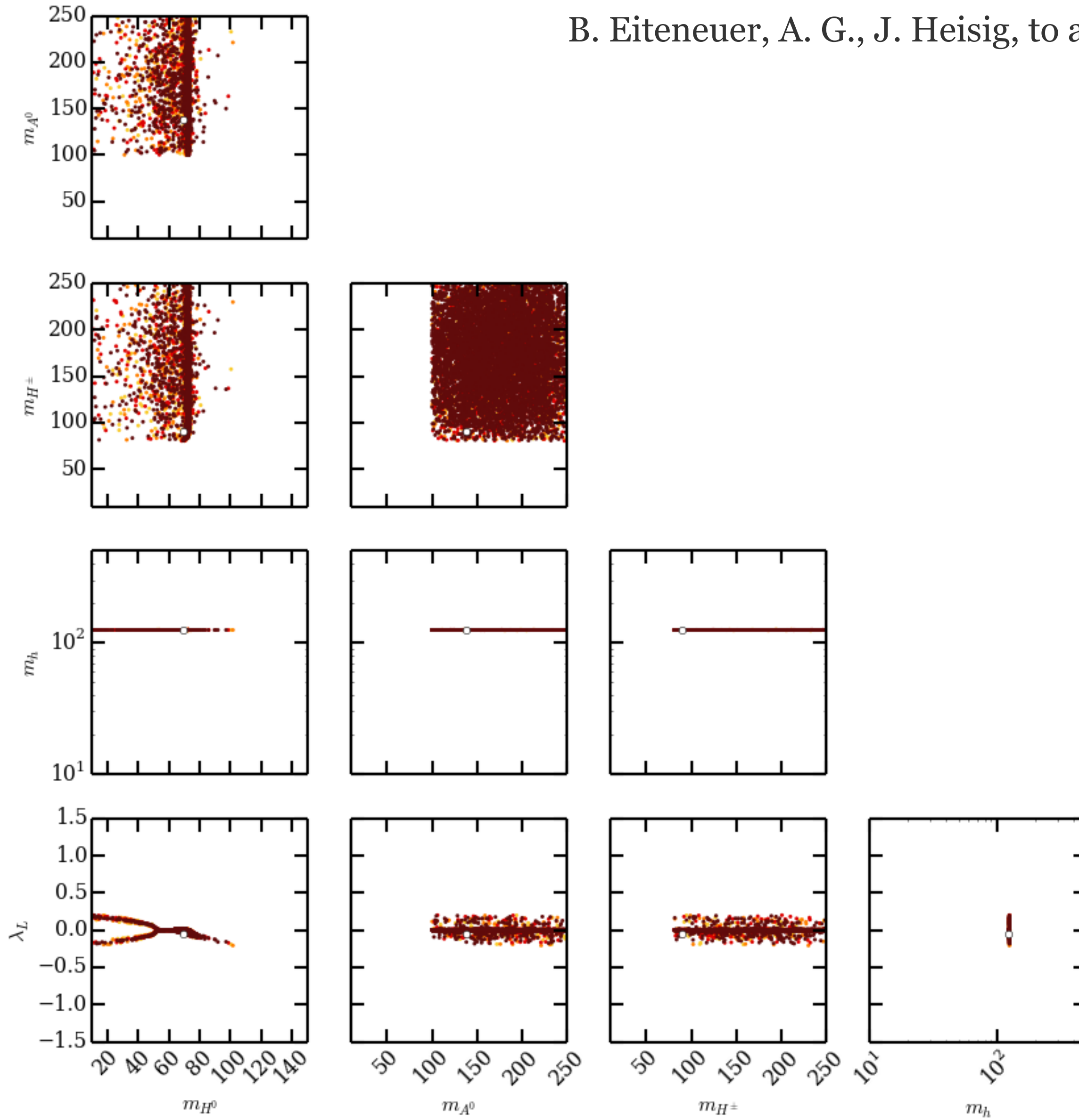

Focus on the low mass regime

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· Impose DD constraints :

→ only tiny values of λ_L allowed

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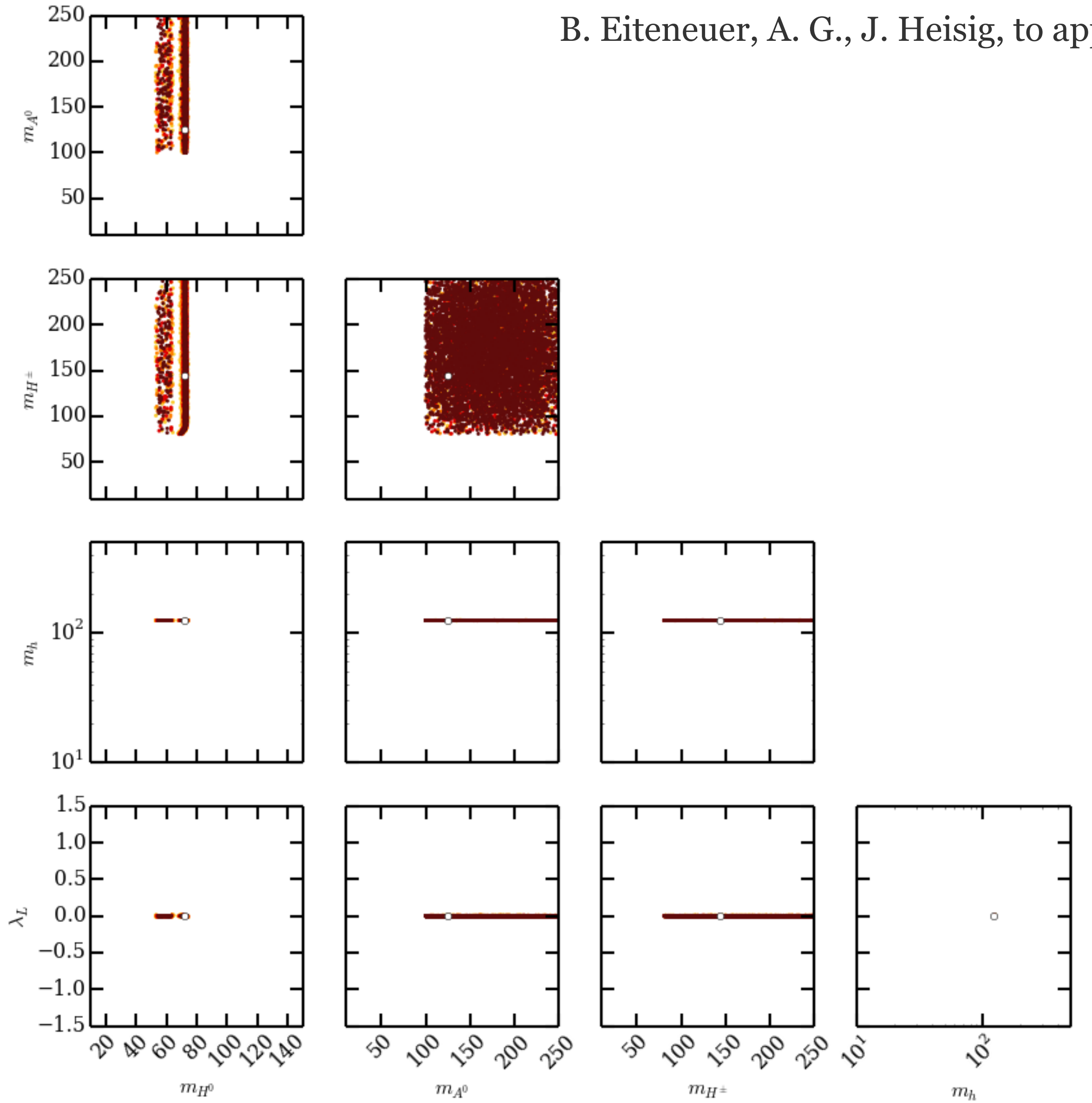
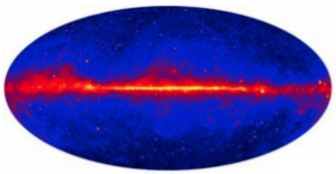


The Galactic centre excess

· Once all known contributions to the Fermi gamma-ray sky are subtracted, one is left with an excessive emission :



Data

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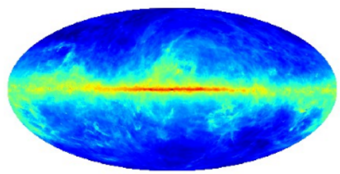
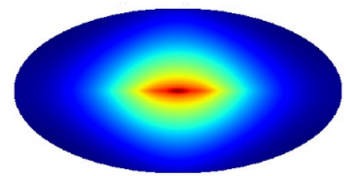


π- decay

-



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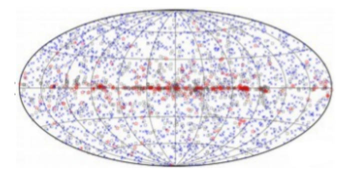

PS's

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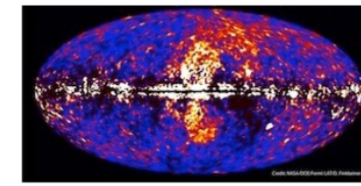

Fermi bubbles

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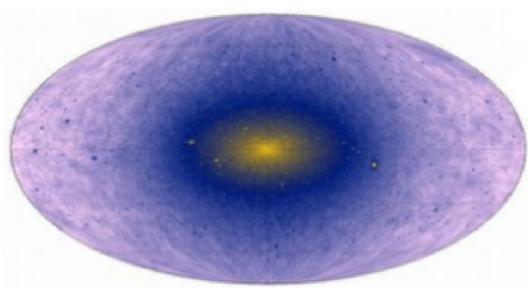


Galactic bulge emission ("excess")

Numerous references, excess confirmed by Fermi Collaboration (2015)

· Some apparent characteristics:
- roughly spherical morphology
- extends up to more than 10^{o} away from the Galactic centre
- is rather cusped towards the GC
- peaks at a few GeV in E^2 x (Flux).

Daylan *et al* (2014)
Calore, Cholis, Weniger (2014)

Fitting the CGE with dark matter - 1

· Several explanations have been proposed, most of which involve astrophysical effects.

Petrovic, Serpico, Zaharijas (2014) x2
Cholis *et al* (2015)
Gaggero, Taoso, Urbano, Valli, Ullio (2015)

· Or, we could entertain the possibility that it is due to dark matter.

Calore, Cholis, Weniger (2014)
cf however concerns in Calore *et al* (2016)

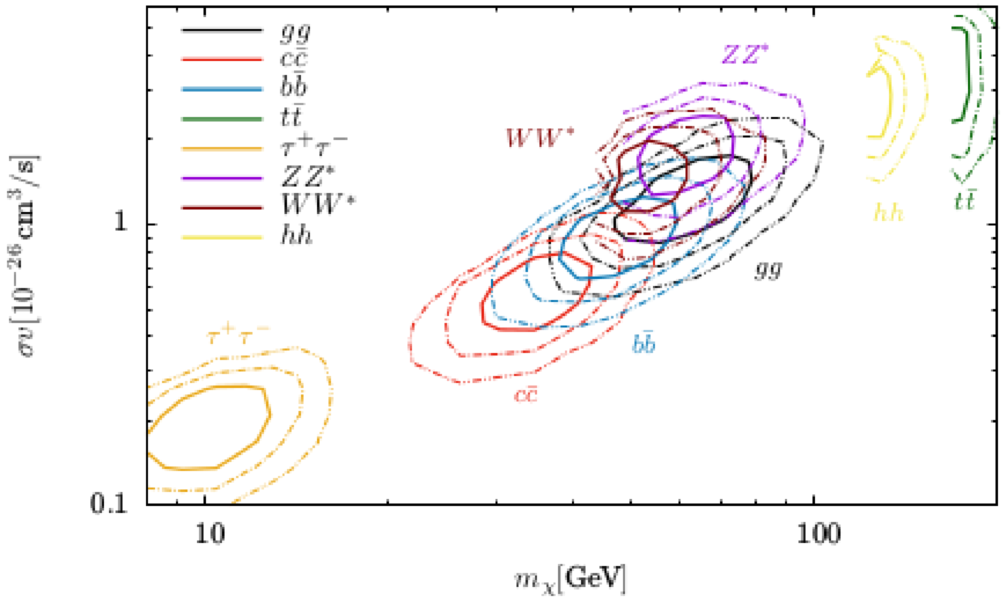
· Interesting point: at least when fitting the GCE with individual annihilation channels…

Eiteneuer (2016)
cf also Calore, Cholis, Weniger (2014)

The required cross section is (roughly) thermal!

(actually, slightly lower, but $\langle\sigma v\rangle_{today} \neq \langle\sigma v\rangle_{freeze\text{-}out}$ in the general case!)

What about concrete dark matter models ?



Fitting the CGE with dark matter - 2

· Get a decent fit of the excess itself : spectrum measured in 24 energy bins, covariance matrix taken from Calore, Cholis, Weniger (2014). Consider O(10%) additional uncertainty on the spectrum.

· Take into account astrophysical uncertainties (J-factors/spatial distribution of γ-ray flux) : generalised NFW

$$\rho(r) = \rho_s \left(\frac{r}{r_s}\right)^{-\gamma} \left(1 + \frac{r}{r_s}\right)^{-3+\gamma}$$

Vary central slope around Calore, Cholis, Weniger (2014) best fit values + ρ_s, r_s (correlated, from rotation curves).

Consider 40^o x 40^o region around GC masking inner 2^o x 2^o stripe along GP

· When working within concrete models (if actually interested in explaining dark matter abundance) : Consider the possibility that we're dealing with a subleading component of dark matter.

· When working within concrete models : consider all relevant experimental + theoretical constraints.

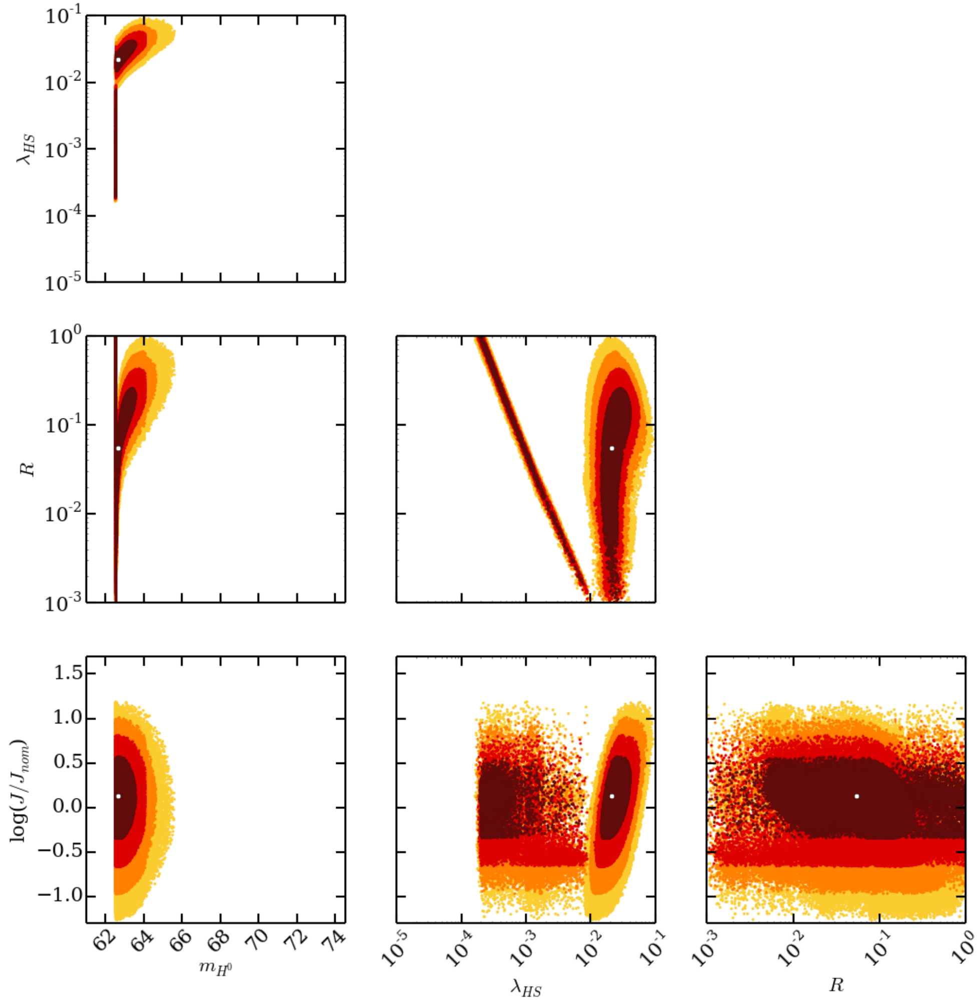
Global fit, parameter space scanned with MultiNest.

Feroz *et al* (2013)

The CGE in the singlet scalar model

- A recent attempt to fit the GCE : singlet scalar dark matter model.

Cuocco, Eiteneuer, Heisig, Krämer (2016)



Model – specific constraints :

- BR(h → inv)
- Direct detection (LUX 2013)
- γ-ray searches in dSphs (Fermi 2015)
- γ-ray line searches at the GC (Fermi 2015)
- Dark matter abundance (Planck 2013)

Fit parameters :

- 2 model parameters
- Dark matter abundance $R = \rho_{model}/\rho_{DM}$
- J-factor

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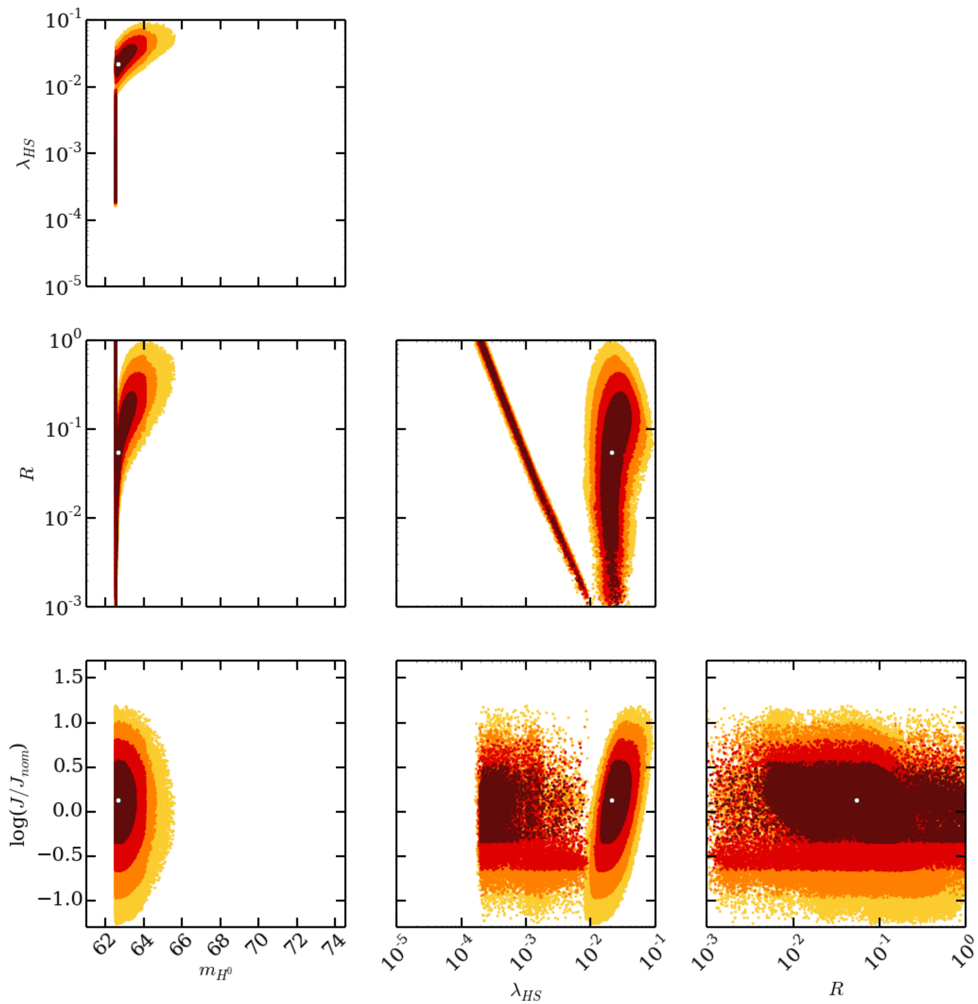

Findings :

· A decent fit of the GCE is possible within the singlet scalar model

· Dark matter tends to be underabundant

· For not-too underabundant DM, favoured regions clearly concentrated around the Higgs resonance

$$\sigma v \sim \frac{1/m_h^2}{(\delta^2 - v_{\rm rel})^2 - \Gamma_h^2}, \delta^2 \equiv \frac{m_h^2 - 4m_s^2}{m_h^2}$$

i.e. substantial velocity dependence of σv

The CGE in the Inert Doublet Model

- In the IDM, the situation changes quite a bit!

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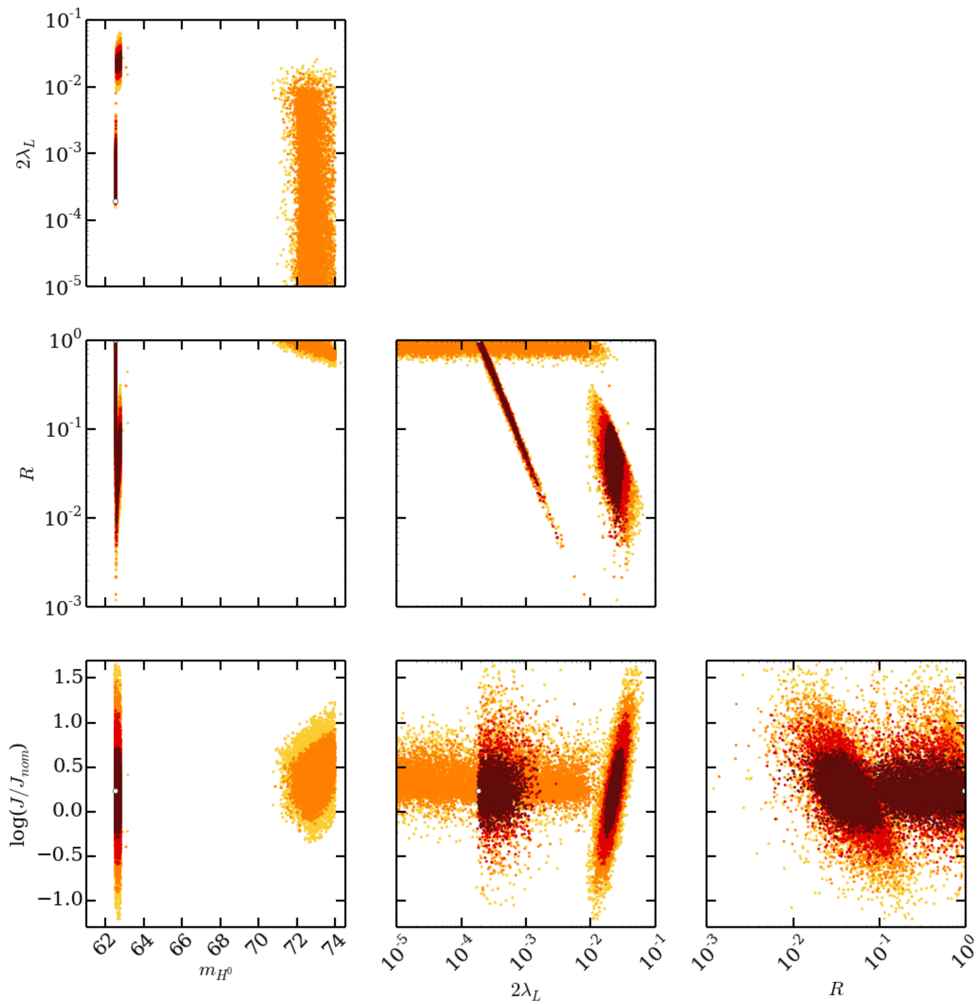


Differences :

- Included theoretical + oblique parameter constraints

With 2HDMC
Eriksson, Rathsman, Stal (2009)

- Included LUX 2016 data

Findings :

- A decent fit of the GCE is still possible in the IDM
- Contrary to the singlet scalar model, in the IDM we can have R = 1 !
- A new region appears towards the WW* threshold (2-3σ – compatible)
- Better parameter space coverage on the way

Conclusions and outlook

· The nature of the Galactic Centre Excess remains unclear, especially given the numerous associated astrophysical uncertainties.

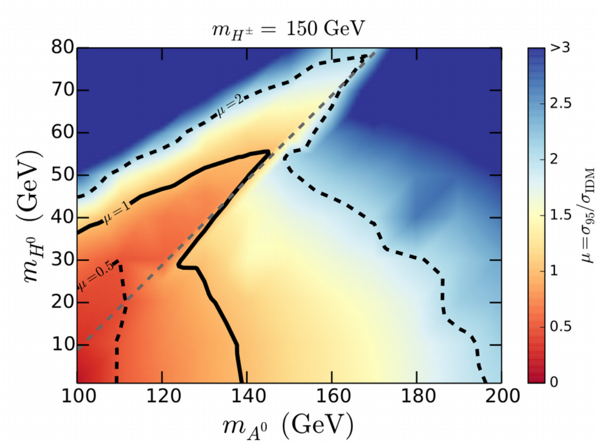
· Dark matter interpretations of the GCE are under pressure but remain attractive.

Or wishful thinking, depending on your perspective!

· The Inert Doublet Model does provide such an interpretation, whilst being able to explain the dark matter abundance in the Universe. Preferred DM masses around Higgs resonance and/or close to the WW* threshold (σv velocity-dependent).

· It is also a testable interpretation, through a combination of direct/indirect detection and LHC searches for the heavier Z_2 – odd states.

· Interesting interplay between the IDM GCE intepretation and the LHC!



G. Bélanger *et al*, arXiv:1503.07367

Thank you!