



Sterile Neutrinos in GAMBIT

Tomás Gonzalo

Universitetet i Oslo

Spåtind 2018
Nordic Conference on Particle Physics
4th January 2018





Outline

- 1 GAMBIT
- 2 Sterile neutrinos
- 3 A peek into the future



Outline



1 GAMBIT

2 Sterile neutrinos

3 A peek into the future

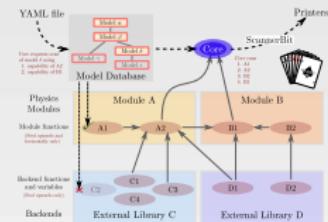




The Global And Modular BSM Inference Tool

- ~~ Framework for performing **global fits** on BSM models

[GAMBIT, Eur. Phys. J. C 77, no.11, 784 (2017)]

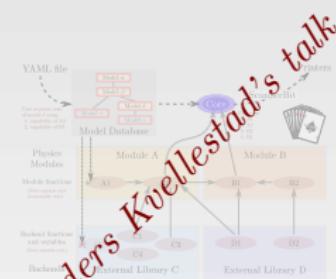


GAMBIT

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- ~~ Results:

- **GUT-scale MSSM**

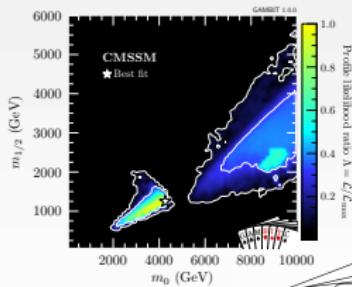
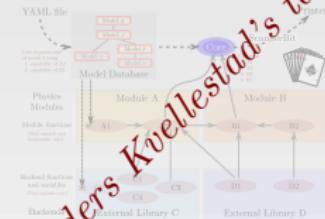
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- **Weak-scale MSSM**

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- **Scalar singlet dark matter**

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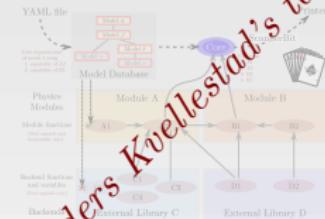
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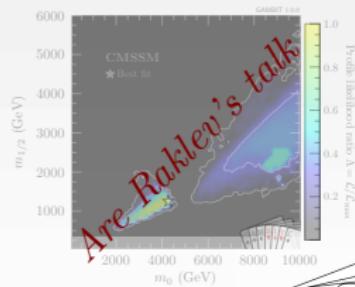
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Anders Kvællestad's talk



Are Raklev's talk



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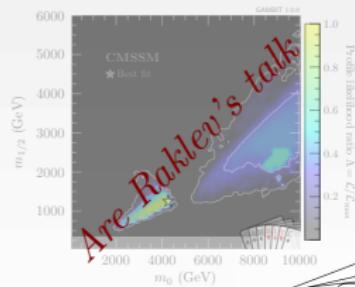
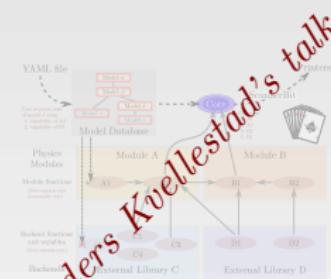
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- ~ New analyses in the pipeline



Sterile neutrinos



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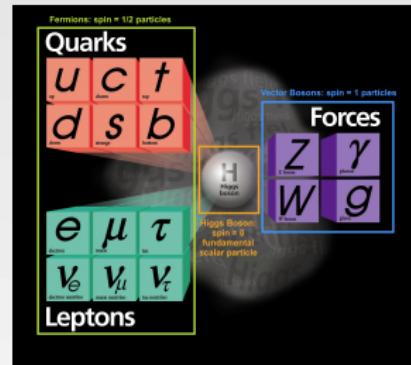




Sterile neutrinos

Active vs Sterile

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# Sterile neutrinos

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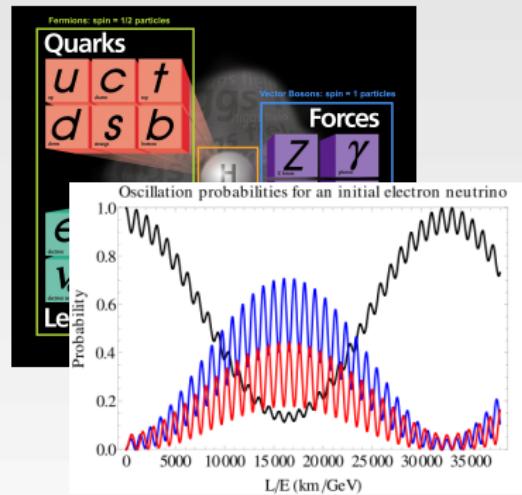
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$$\Delta m_{12}^2 \sim 7.59 \times 10^{-5} \text{ eV}^2$$

[KAMLand, Phys.Rev.Lett. 90 (2003) 021802]

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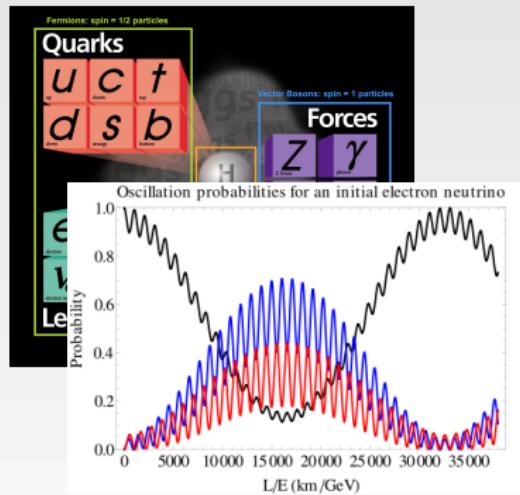
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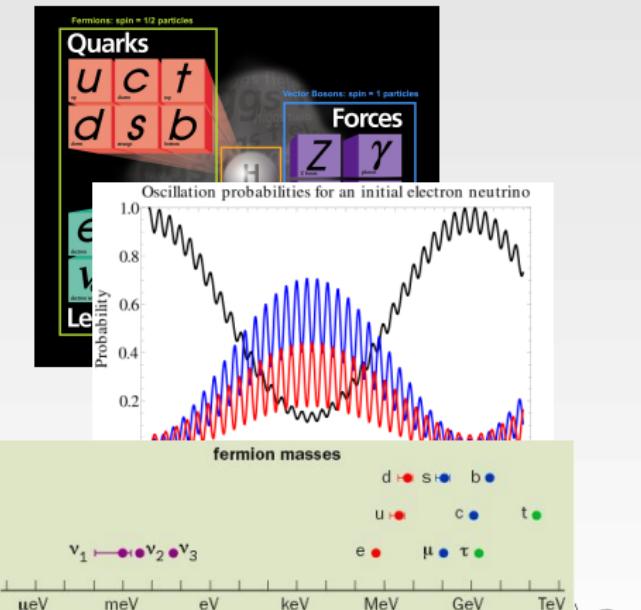
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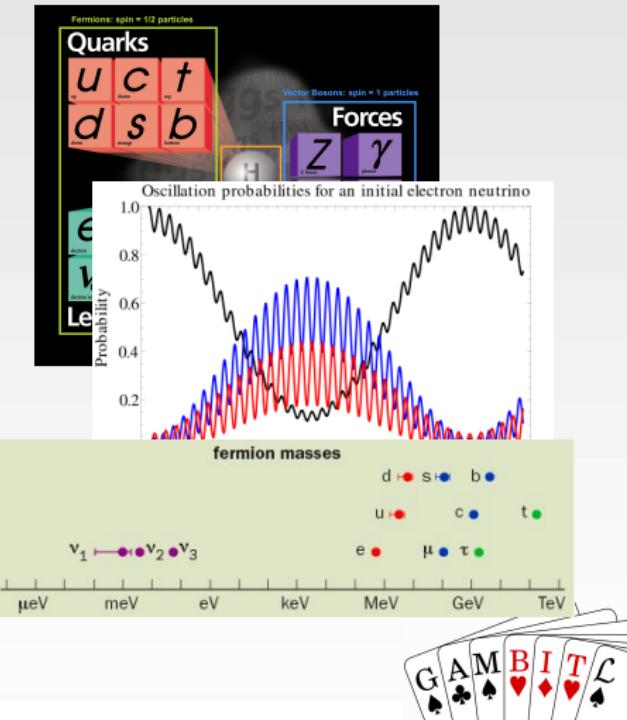
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~~ **Natural?**





Sterile neutrinos

Type I Seesaw

~~~  $N_j$  are **SM singlets**     $N_j \in \{1, 1, 0\}$





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- ~~~  $N_j$  are **SM singlets**     $N_j \in \{1, 1, 0\}$
- ~~~ **Majorana** mass term for  $N_j$

$$\begin{aligned}\mathcal{L} &\supset Y_\nu^{ij} L_i N_j \phi + M^{ij} N_i N_j \\ &= M_D^{ij} \nu_i N_j + M_M^{ij} N_i N_j\end{aligned}$$





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$$M_\nu = \begin{pmatrix} \delta m_\nu^{1-loop} & M_D \\ M_D^T & M_M \end{pmatrix}$$





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- ~~ “Naturally” **light neutrino masses**

$$m_\nu \sim M_D^T M_M^{-1} M_D, \quad m_N \sim M_M$$





## Sterile neutrinos

The Casas-Ibarra parametrization~~> Flavour **mixing** matrix

[J. A. Casas &amp; A. Ibarra, Nucl. Phys. B618, (1-2), 2001]

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$$\Theta = iU_\nu \sqrt{m_\nu^{diag}} \mathcal{R} \sqrt{\tilde{M}^{diag}}^{-1}$$

$$\mathcal{R} = \mathcal{R}^{23}\mathcal{R}^{13}\mathcal{R}^{12} \quad \mathcal{R}_{ii}^{ij} = \mathcal{R}_{jj}^{ij} = \cos \omega_{ij} \quad \mathcal{R}_{ij}^{ij} = -\mathcal{R}_{ji}^{ij} = \sin \omega_{ij}$$





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~~ Scan Parameters

$$\{\Re(\omega_{ij}), \Im(\omega_{ij}), M_i, \alpha_1, \alpha_2, \delta\}$$





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Direct constraints

- ~~ Direct searches for RHN in **meson**, **tau** and **gauge boson** decays





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## Direct constraints

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- ~~ Direct searches for RHN in **meson**, **tau** and **gauge boson** decays
- ~~ **Beam dump** and **peak search** experiments
- ~~ List of used constraints

|        |                  |                                                |                                                  |
|--------|------------------|------------------------------------------------|--------------------------------------------------|
| PIENU  | 0.06 - 0.129 GeV | $\Theta_{ei}$                                  | [M. Aoki et al, Phys. Rev. D, 84(5), 2011]       |
| PS191  | 0.02 - 0.45 GeV  | $\Theta_{ei}, \Theta_{\mu i}$                  | [G. Bernardi et al, Phys. Lett. B, 203(3), 1988] |
| E949   | 0.175 - 0.3 GeV  | $\Theta_{\mu i}$                               | [A. V. Artamonov et al, Phys. Rev. D 91, 2015]   |
| CHARM  | 0.01 - 2.8 GeV   | $\Theta_{ei}, \Theta_{\mu i}, \Theta_{\tau i}$ | [CHARM, Phys. Lett. B166(4), 1986]               |
| NuTeV  | 0.25 - 2 GeV     | $\Theta_{\mu i}$                               | [FNAL-E815, Phys. Rev. Lett. 83, 1999]           |
| DELPHI | 3 - 50 GeV       | $\Theta_{ei}, \Theta_{\mu i}, \Theta_{\tau i}$ | [DELPHI, Z. Phys. C, 74(1), 1997]                |
| ATLAS  | 50 - 500 GeV     | $\Theta_{ei}, \Theta_{\mu i}$                  | [ATLAS, JHEP 07:162, 2015]                       |





## Sterile neutrinos

Indirect constraints

↔ Lepton flavour violation

$$l \rightarrow l\gamma \Rightarrow BR(\mu \rightarrow e\gamma) < 4.2 \times 10^{-13}$$

$$l \rightarrow lll \Rightarrow BR(\mu \rightarrow eee) < 1.0 \times 10^{-12}$$

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$$R_{\alpha\beta}^{X=\pi,K,\tau} = \frac{\Gamma(X^+ \rightarrow l_\alpha^+ \nu_\alpha)}{\Gamma(X^+ \rightarrow l_\beta^+ \nu_\beta)} \Rightarrow R_{e\mu}^\pi = (1.2352 \pm 0.0001) \times 10^{-4}$$





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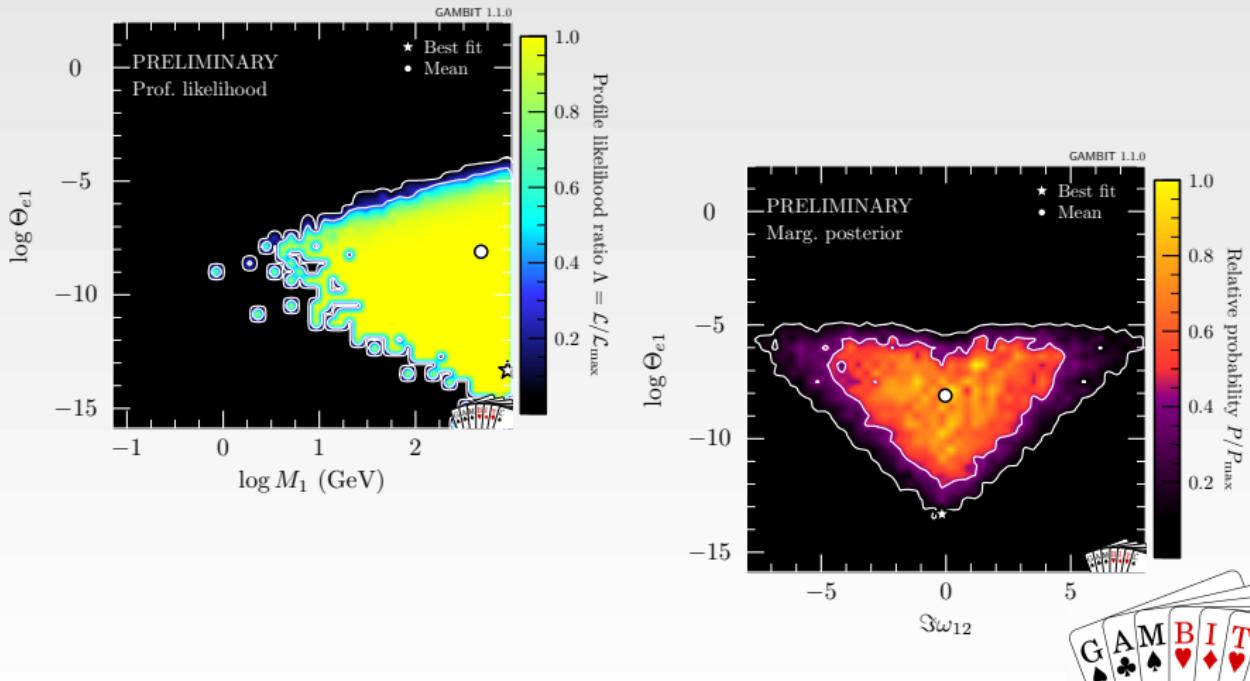
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~~~ CKM Unitarity  $|V_{us}^{CKM}|^2 + |V_{ud}^{CKM}|^2 = 1$



Sterile neutrinos

Preliminary Results





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A peek into the future

GAMBIT v1.1

~~~ Latest release - published as an **addendum** to core paper





## A peek into the future

## GAMBIT v1.1

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- ~~ Latest release - published as an **addendum** to core paper
  - ~~ Compatibility with DDCalc v1.1 (<http://ddcalc.hepforge.org/>)
    - Calculates SI and SD likelihoods for Xenon1T and PICO-60

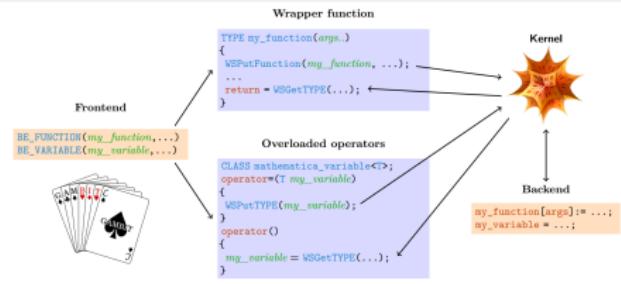




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  - Calculates SI and SD likelihoods for Xenon1T and PICO-60
- ~~~ Enabled use of **Mathematica** backends
  - Wolfram Symbolic Transfer Protocol (WSTP)  $\leftrightarrow$  Kernel



- Interface same as with C/C++/Fortran backends
- Alternative Higgs mass calculation  $\rightarrow$  **SUSYHD**





# A peek into the future

GAMBIT v1.2.x

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~~ New analyses

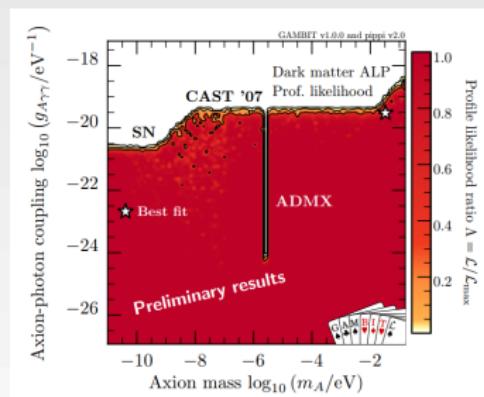


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- MSSM9
- Higgs portals
- Future Facilities in DM

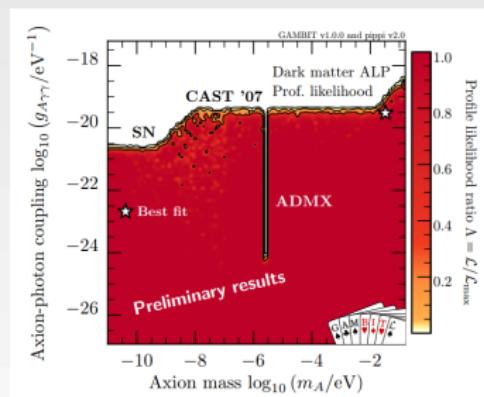


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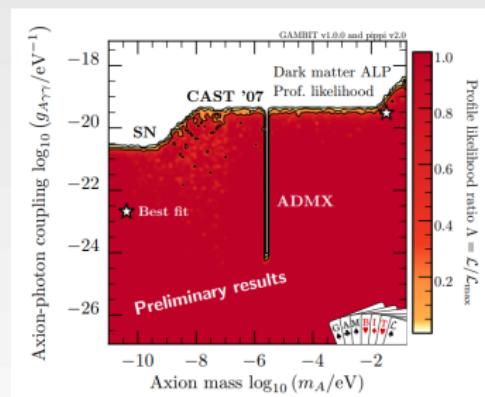


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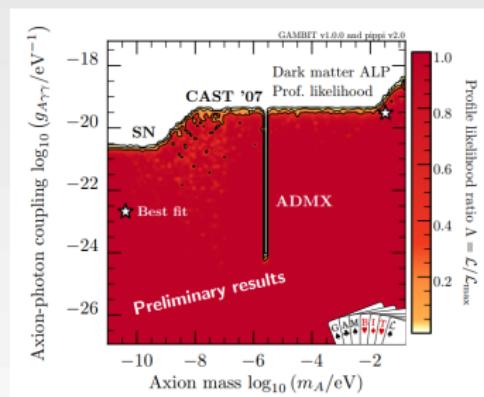


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- ~~ **Python** backends





A peek into the future

GAMBIT v2.0

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~~> GAMBIT Universal Models (**GUM**)





## A peek into the future

GAMBIT v2.0

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- ~~> GAMBIT Universal Models (**GUM**)
- ~~> Generalize model files (*.gum*)





## A peek into the future

## GAMBIT v2.0

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  - ~~> Interface with **Lagrangian-level** tools





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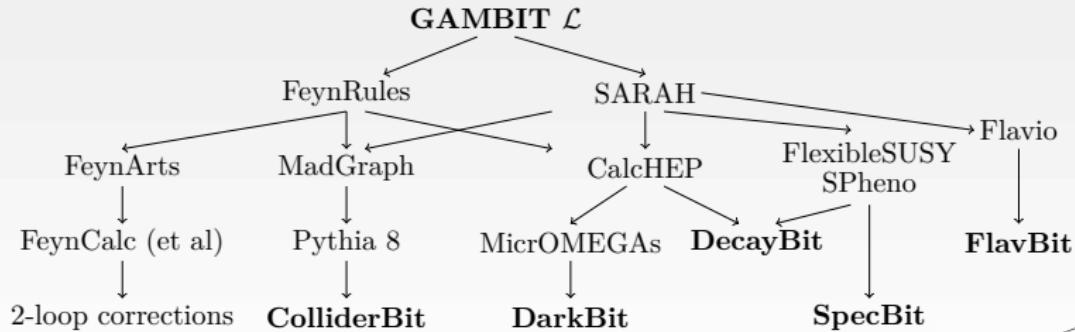




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Thanks!

