

Encyclopædia Inflationaris: testing inflation after Planck

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Outline

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Purpose

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Bayesian model comparison

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Bayes factor for hundred of models

Data constraining power

And the winners are...

Narrowing down the simplest with complexity

Conclusion

J. Martin, CR and V. Vennin in arXiv:1303.3787

J. Martin, CR, R. Trotta and V. Vennin in arXiv:1312.3529

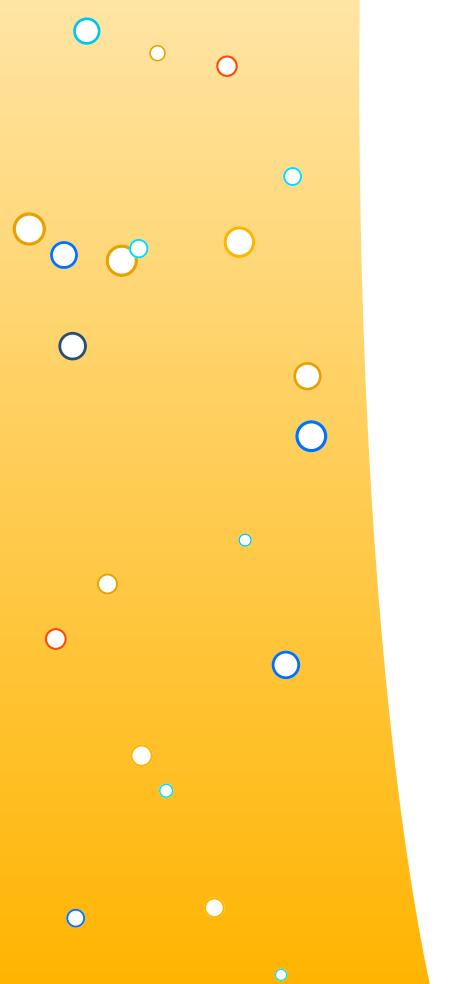
J. Martin, CR, R. Trotta and V. Vennin in preparation

The Case for Inflation

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Planck 2013 results

The Case for Inflation

❖ Planck 2013 results

❖ Bicep2 2014 results

❖ Single field inflation

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Conclusion

● Unexplained measurements

- ◆ **Flatness** ($\Omega_K = 0$) is instable during decelerated expansion

$$\Omega_K = 1 - \Omega_{dm} - \Omega_b - \Omega_\Lambda = 0.000^{+0.0066}_{-0.0067} \quad (\text{PLANCK+WP+BAO})$$

- ◆ **Adiabatic** initial conditions: isocurvature modes are constrained

$$\forall X \quad P_X(k) = P(k)$$

- ◆ **Quasi** scale invariance

$$k^3 P(k) = A \left(\frac{k}{k_*} \right)^{n_s - 1} \Rightarrow n_s = 0.9619 \pm 0.0073$$

- ◆ **Gaussianity** of the CMB anisotropies

$$f_{NL}^{\text{loc}} = 2.7 \pm 5.8, \quad f_{NL}^{\text{eq}} = -42 \pm 75, \quad f_{NL}^{\text{orth}} = -25 \pm 39$$

● The simplest answer: single-field inflation

- ◆ Makes extra-predictions: $f_{NL}^{\text{loc}} = \mathcal{O}(n_s - 1)$ and $\exists r > 0$

Bicep2 2014 results

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❖ Planck 2013 results

❖ Bicep2 2014 results

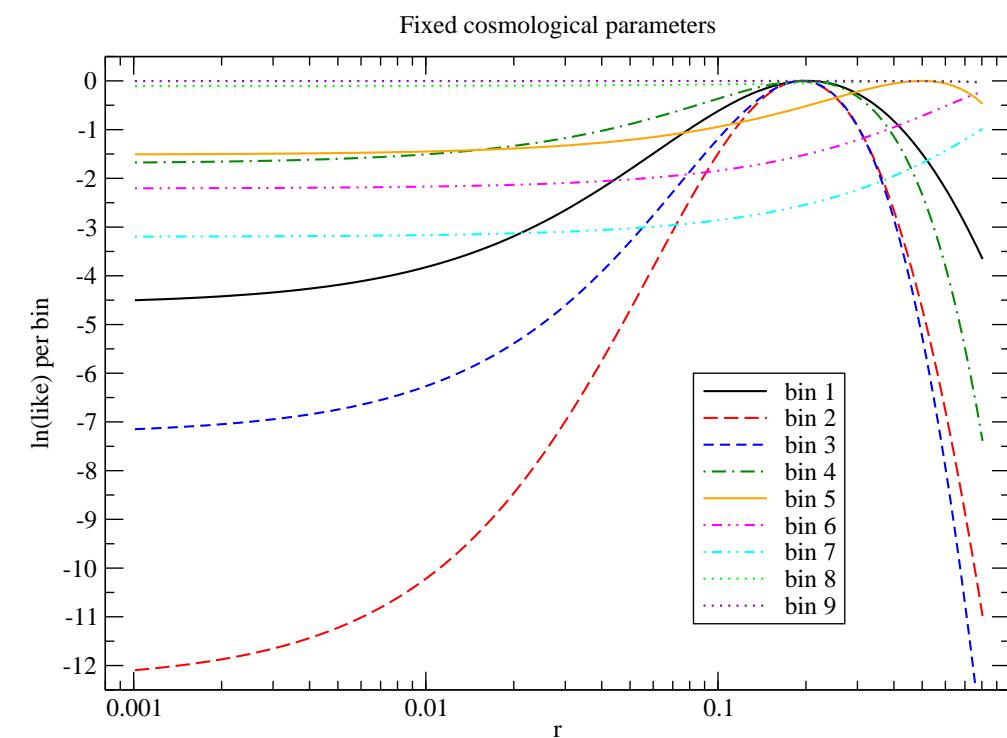
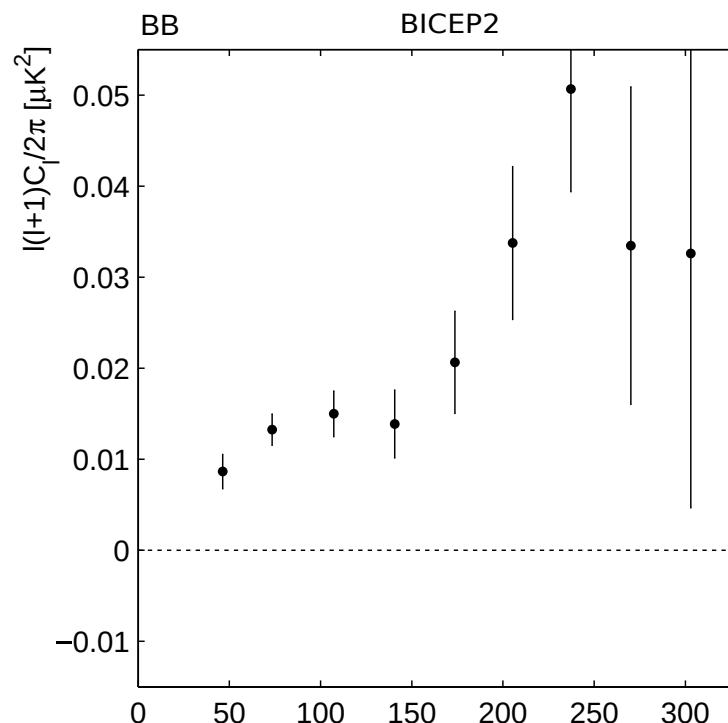
❖ Single field inflation

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Conclusion

- $\exists C_\ell^{\text{BB}}$ on large scales
- Is it due to primordial tensor modes?



- Compatible with $r = 0.2$ only on 4 bins (otherwise favours $r > 1$!?)
- Very strong statistical weight carried by the bin 2

Single field inflation

The Case for Inflation

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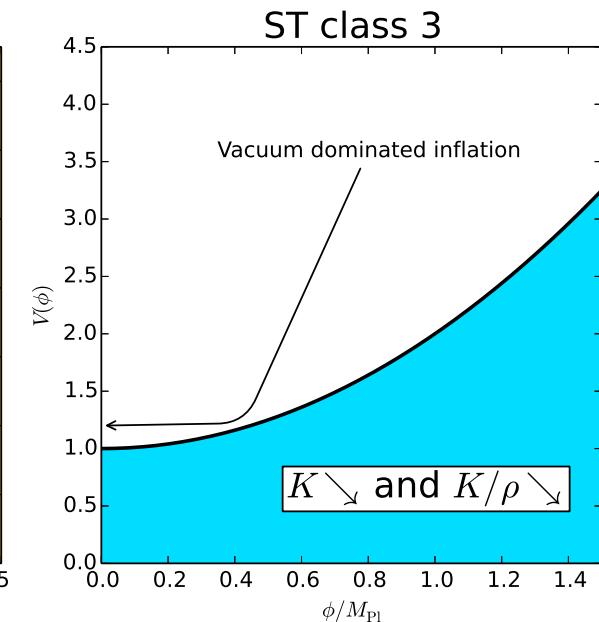
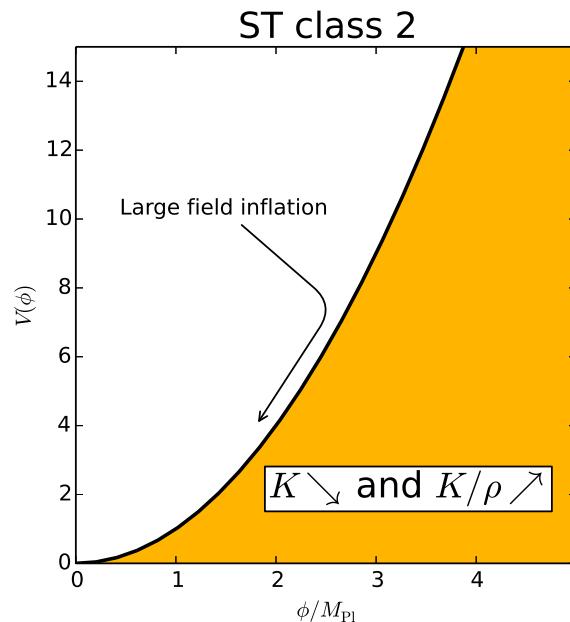
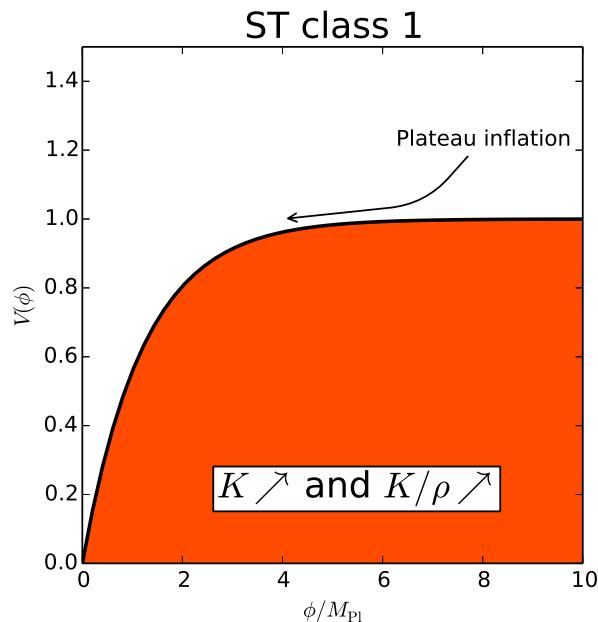
The Good, The Bad and The Ugly

Conclusion

- Universe dominated by a slow-rolling scalar field in $V(\phi)$
- Triggers acceleration for $\dot{\phi}^2 \ll 1$

$$K = \frac{1}{2}\dot{\phi}^2 \quad \rho = K + V \quad P = K - V \simeq -\rho$$

- Schwarz and Terrero-Escalante classification



- Field-metric quantum fluctuations $\Rightarrow P(k)$



Primordial power spectra

- Slow-roll inflation predicts [arXiv:1303.2120, arXiv:1303.2788]

$$\mathcal{P}_\zeta = \frac{H_*^2}{8\pi^2 M_{\text{Pl}}^2 \epsilon_{1*} c_{s*}} \left\{ 1 - 2(1+C)\epsilon_{1*} - C\epsilon_{2*} + (2+C)\delta_{1*} + \left(\frac{\pi^2}{2} - 3 + 2C + 2C^2\right) \epsilon_{1*}^2 \right. \\ + \left(\frac{7\pi^2}{12} - 6 - C + C^2 \right) \epsilon_{1*} \epsilon_{2*} + \left(\frac{\pi^2}{8} - 1 + \frac{C^2}{2} \right) \epsilon_{2*}^2 + \left(\frac{\pi^2}{24} - \frac{C^2}{2} \right) \epsilon_{2*} \epsilon_{3*} \\ + \left(\frac{\pi^2}{8} - 1 + C + \frac{C^2}{2} \right) \delta_{1*}^2 + \left(-\frac{\pi^2}{24} + 2 + 2C + \frac{C^2}{2} \right) \delta_{1*} \delta_{2*} + \left(-\frac{\pi^2}{2} + 4 - 3C - 2C^2 \right) \delta_{1*} \epsilon_{1*} \\ + \left(-\frac{\pi^2}{4} + 3 - C - C^2 \right) \delta_{1*} \epsilon_{2*} + \left[-2\epsilon_{1*} - \epsilon_{2*} + \delta_{1*} + (2+4C)\epsilon_{1*}^2 \right. \\ + (-1+2C)\epsilon_{1*} \epsilon_{2*} + C\epsilon_{2*}^2 - C\epsilon_{2*} \epsilon_{3*} + (1+C)\delta_{1*}^2 + (2+C)\delta_{1*} \delta_{2*} - (3+4C)\delta_{1*} \epsilon_{1*} \\ \left. - (1+2C)\delta_{1*} \epsilon_{2*} \right] \ln \left(\frac{k}{k_*} \right) \\ + \left[2\epsilon_{1*}^2 + \epsilon_{1*} \epsilon_{2*} + \frac{1}{2} \epsilon_{2*}^2 - \frac{1}{2} \epsilon_{2*} \epsilon_{3*} + \frac{1}{2} \delta_{1*}^2 + \frac{1}{2} \delta_{1*} \delta_{2*} - 2\delta_{1*} \epsilon_{1*} - \delta_{1*} \epsilon_{2*} \right] \ln^2 \left(\frac{k}{k_*} \right) \Big\},$$

$$\mathcal{P}_h = \frac{2H_*^2}{\pi^2 M_{\text{Pl}}^2} \left\{ 1 - 2(1+C - \ln c_{s*})\epsilon_{1*} + \left[-3 + \frac{\pi^2}{2} + 2C + 2C^2 + 2\ln^2 c_{s*} - 2(1+2C)\ln c_{s*} \right] \epsilon_{1*}^2 \right. \\ + \left[-2 + \frac{\pi^2}{12} - 2C - C^2 + 2(1+C)\ln c_{s*} - \ln^2 c_{s*} \right] \epsilon_{1*} \epsilon_{2*} + \left[-2\epsilon_{1*} + (2+4C-4\ln c_{s*})\epsilon_{1*}^2 \right. \\ \left. + (-2-2C+2\ln c_{s*})\epsilon_{1*} \epsilon_{2*} \right] \ln \left(\frac{k}{k_*} \right) + \left(2\epsilon_{1*}^2 - \epsilon_{1*} \epsilon_{1*} \right) \ln^2 \left(\frac{k}{k_*} \right) \Big\}$$

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Primordial power spectra

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- Slow-roll inflation (with $c_{S*} = 1$) predicts [arXiv:1303.2120, arXiv:1303.2788]

$$\begin{aligned}\mathcal{P}_\zeta &= \frac{H_*^2}{8\pi^2 M_{\text{Pl}}^2 \epsilon_{1*}} \left\{ 1 - 2(1+C)\epsilon_{1*} - C\epsilon_{2*} + \left(\frac{\pi^2}{2} - 3 + 2C + 2C^2 \right) \epsilon_{1*}^2 + \left(\frac{7\pi^2}{12} - 6 - C + C^2 \right) \epsilon_{1*}\epsilon_{2*} \right. \\ &\quad + \left(\frac{\pi^2}{8} - 1 + \frac{C^2}{2} \right) \epsilon_{2*}^2 + \left(\frac{\pi^2}{24} - \frac{C^2}{2} \right) \epsilon_{2*}\epsilon_{3*} \\ &\quad + \left[-2\epsilon_{1*} - \epsilon_{2*} + (2+4C)\epsilon_{1*}^2 + (-1+2C)\epsilon_{1*}\epsilon_{2*} + C\epsilon_{2*}^2 - C\epsilon_{2*}\epsilon_{3*} \right] \ln \left(\frac{k}{k_*} \right) \\ &\quad \left. + \left[2\epsilon_{1*}^2 + \epsilon_{1*}\epsilon_{2*} + \frac{1}{2}\epsilon_{2*}^2 - \frac{1}{2}\epsilon_{2*}\epsilon_{3*} \right] \ln^2 \left(\frac{k}{k_*} \right) \right\}, \\ \mathcal{P}_h &= \frac{2H_*^2}{\pi^2 M_{\text{Pl}}^2} \left\{ 1 - 2(1+C)\epsilon_{1*} + \left[-3 + \frac{\pi^2}{2} + 2C + 2C^2 \right] \epsilon_{1*}^2 + \left[-2 + \frac{\pi^2}{12} - 2C - C^2 \right] \epsilon_{1*}\epsilon_{2*} \right. \\ &\quad \left. + \left[-2\epsilon_{1*} + (2+4C)\epsilon_{1*}^2 + (-2-2C)\epsilon_{1*}\epsilon_{2*} \right] \ln \left(\frac{k}{k_*} \right) + (2\epsilon_{1*}^2 - \epsilon_{1*}\epsilon_{1*}) \ln^2 \left(\frac{k}{k_*} \right) \right\}\end{aligned}$$

- Model dependence is only through H_* , $\epsilon_{i*} \dots$, evaluated at ϕ_*
 - ◆ Depends on: model + how inflation ends + reheating + data

$$\begin{aligned}-\frac{1}{M_{\text{Pl}}^2} \left[\int_{\phi_{\text{end}}}^{\phi_*} \frac{V(\psi)}{V'(\psi)} d\psi \right] &= \ln(R_{\text{rad}}) - N_0 + \frac{1}{4} \ln(8\pi^2 P_*) \\ &\quad - \frac{1}{4} \ln \left\{ \frac{9}{\epsilon_1(\phi_*)[3 - \epsilon_1(\phi_{\text{end}})]} \frac{V(\phi_{\text{end}})}{V(\phi_*)} \right\}\end{aligned}$$

Reheating effects

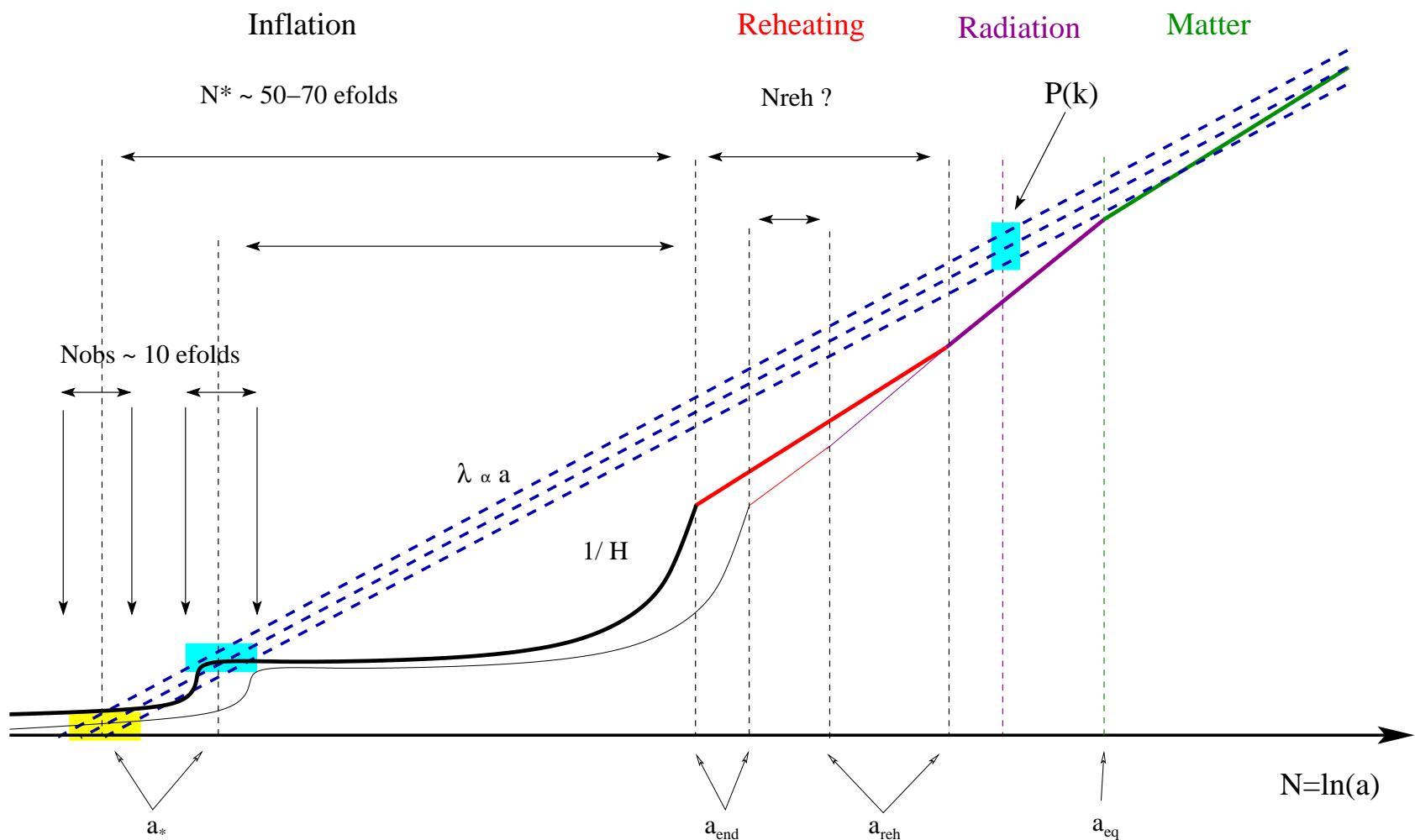
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- Model testing: reheating effects must be included!



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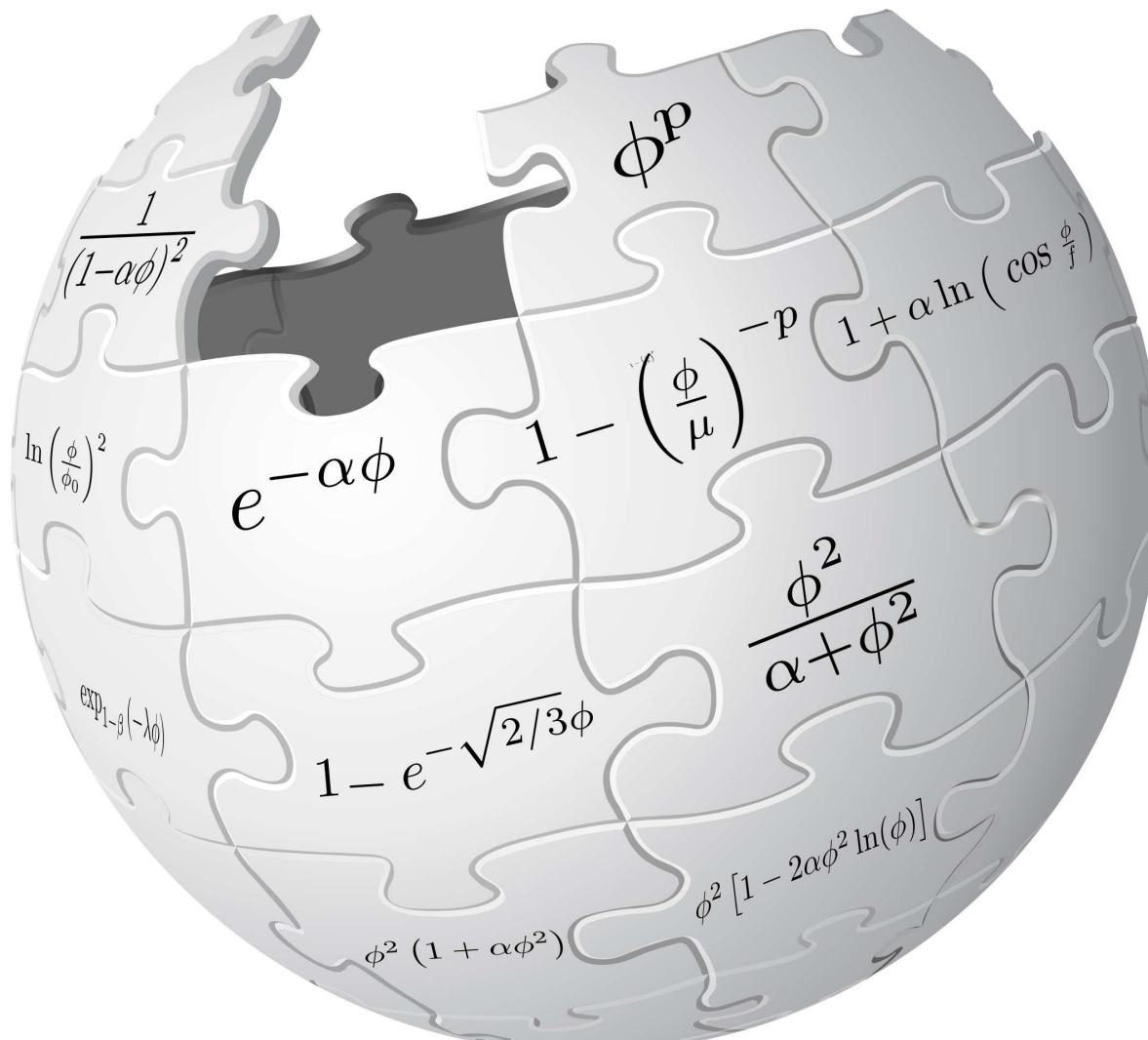
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- ❖ Purpose
- ❖ Accurate and easy comparison with data
- ❖ The ASPI^C library

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Purpose

The Case for Inflation

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Conclusion

- Aims at deriving **reheating consistent** observable predictions for **all** slow-roll single field inflationary models
- Currently supports 50 motivated classes of potential

Name	Parameters	Sub-models	$V(\phi)$
HI	0	1	$M^4 \left(1 - e^{-\sqrt{2/3}\phi/M_{\text{Pl}}}\right)$
RCHI	1	1	$M^4 \left(1 - 2e^{-\sqrt{2/3}\phi/M_{\text{Pl}}} + \frac{A_1}{16\pi^2} \frac{\phi}{\sqrt{6}M_{\text{Pl}}}\right)$
LFI	1	1	$M^4 \left(\frac{\phi}{M_{\text{Pl}}}\right)^p$
MLFI	1	1	$M^4 \frac{\phi^2}{M_{\text{Pl}}^2} \left[1 + \alpha \frac{\phi^2}{M_{\text{Pl}}^2}\right]$
RCMI	1	1	$M^4 \left(\frac{\phi}{M_{\text{Pl}}}\right)^2 \left[1 - 2\alpha \frac{\phi^2}{M_{\text{Pl}}^2} \ln \left(\frac{\phi}{M_{\text{Pl}}}\right)\right]$
RCQI	1	1	$M^4 \left(\frac{\phi}{M_{\text{Pl}}}\right)^4 \left[1 - \alpha \ln \left(\frac{\phi}{M_{\text{Pl}}}\right)\right]$
NI	1	1	$M^4 \left[1 + \cos \left(\frac{\phi}{f}\right)\right]$
ESI	1	1	$M^4 \left(1 - e^{-q\phi/M_{\text{Pl}}}\right)$
PLI	1	1	$M^4 e^{-\alpha\phi/M_{\text{Pl}}}$
KMII	1	2	$M^4 \left(1 - \alpha \frac{\phi}{M_{\text{Pl}}} e^{-\phi/M_{\text{Pl}}}\right)$
HFII	1	1	$M^4 \left(1 + A_1 \frac{\phi}{M_{\text{Pl}}}\right)^2 \left[1 - \frac{2}{3} \left(\frac{A_1}{1+A_1\phi/M_{\text{Pl}}}\right)^2\right]$
CWI	1	1	$M^4 \left[1 + \alpha \left(\frac{\phi}{Q}\right)^4 \ln \left(\frac{\phi}{Q}\right)\right]$
LI	1	2	$M^4 \left[1 + \alpha \ln \left(\frac{\phi}{M_{\text{Pl}}}\right)\right]$
RpI	1	3	$M^4 e^{-2\sqrt{2/3}\phi/M_{\text{Pl}}} \left[e^{\sqrt{2/3}\phi/M_{\text{Pl}}} - 1\right]^{2p/(2p-1)}$
DWI	1	1	$M^4 \left[\left(\frac{\phi}{\phi_0}\right)^2 - 1\right]^2$
MHI	1	1	$M^4 \left[1 - \operatorname{sech}^2 \left(\frac{\phi}{\mu}\right)\right]$
RGI	1	1	$M^4 \frac{(\phi/M_{\text{Pl}})^2}{\alpha + (\phi/M_{\text{Pl}})^2}$
MSSMI	1	1	$M^4 \left[\left(\frac{\phi}{\phi_0}\right)^2 - \frac{2}{3} \left(\frac{\phi}{\phi_0}\right)^3 + \frac{1}{5} \left(\frac{\phi}{\phi_0}\right)^{10}\right]$
RIPI	1	1	$M^4 \left[\left(\frac{\phi}{\phi_0}\right)^2 - \frac{1}{3} \left(\frac{\phi}{\phi_0}\right)^3 + \frac{1}{2} \left(\frac{\phi}{\phi_0}\right)^4\right]$
AI	1	1	$M^4 \left[1 - \frac{2}{\pi} \arctan \left(\frac{\phi}{\mu}\right)\right]$
CNAI	1	1	$M^4 \left[3 - (3 + \alpha^2) \tan^2 \left(\frac{\phi}{\sqrt{2}M_{\text{Pl}}}\right)\right]$
CNBI	1	1	$M^4 \left[(3 - \alpha^2) \tan^2 \left(\frac{\phi}{\sqrt{2}M_{\text{Pl}}}\right) - 3\right]$
OSTI	1	1	$-M^4 \left(\frac{\phi}{\phi_0}\right)^2 \ln \left(\frac{\phi}{\phi_0}\right)^2$
WRI	1	1	$M^4 \ln \left(\frac{\phi}{\phi_0}\right)^2$
SFI	2	1	$M^4 \left[1 - \left(\frac{\phi}{\mu}\right)^p\right]$

II	2	1	$M^4 \left(\frac{\phi - \phi_0}{M_{\text{Pl}}}\right)^{-\beta} - M^4 \frac{\beta^2}{6} \left(\frac{\phi - \phi_0}{M_{\text{Pl}}}\right)^{-\beta-2}$
KMIII	2	1	$M^4 \left[1 - \alpha \frac{\phi}{M_{\text{Pl}}} \exp \left(-\beta \frac{\phi}{M_{\text{Pl}}}\right)\right]$
LMI	2	2	$M^4 \left(\frac{\phi}{M_{\text{Pl}}}\right)^{\alpha} \exp \left[-\beta \left(\phi/M_{\text{Pl}}\right)^{\gamma}\right]$
TWI	2	1	$M^4 \left[1 - A \left(\frac{\phi}{\phi_0}\right)^2 e^{-\phi/\phi_0}\right]$
GMSSMI	2	2	$M^4 \left[\left(\frac{\phi}{\phi_0}\right)^2 - \frac{2}{3} \alpha \left(\frac{\phi}{\phi_0}\right)^6 + \frac{\alpha}{5} \left(\frac{\phi}{\phi_0}\right)^{10}\right]$
GRIP	2	2	$M^4 \left[\left(\frac{\phi}{\phi_0}\right)^2 - \frac{4}{3} \alpha \left(\frac{\phi}{\phi_0}\right)^3 + \frac{\alpha}{2} \left(\frac{\phi}{\phi_0}\right)^4\right]$
BSUSYBI	2	1	$M^4 \left(e^{\sqrt{\frac{\phi}{M_{\text{Pl}}}}} + e^{\sqrt{6}\gamma \frac{\phi}{M_{\text{Pl}}}}\right)$
TI	2	3	$M^4 \left(1 + \cos \frac{\phi}{\mu} + \alpha \sin^2 \frac{\phi}{\mu}\right)$
BEI	2	1	$M^4 \exp_{1-\beta} \left(-\lambda \frac{\phi}{M_{\text{Pl}}}\right)$
PSNI	2	1	$M^4 \left[1 + \alpha \ln \left(\cos \frac{\phi}{f}\right)\right]$
NCKI	2	2	$M^4 \left[1 + \alpha \ln \left(\frac{\phi}{M_{\text{Pl}}}\right) + \beta \left(\frac{\phi}{M_{\text{Pl}}}\right)^2\right]$
CSI	2	1	$\frac{M^4}{\left(1 - \alpha \frac{\phi}{M_{\text{Pl}}}\right)^2}$
OI	2	1	$M^4 \left(\frac{\phi}{\phi_0}\right)^4 \left[\left(\ln \frac{\phi}{\phi_0}\right)^2 - \alpha\right]$
CNCI	2	1	$M^4 \left(3 + \alpha^2\right) \coth^2 \left(\frac{\alpha}{\sqrt{2}} \frac{\phi}{M_{\text{Pl}}}\right) - 3$
SBI	2	2	$M^4 \left\{1 + \left[-\alpha + \beta \ln \left(\frac{\phi}{M_{\text{Pl}}}\right)\right] \left(\frac{\phi}{M_{\text{Pl}}}\right)^4\right\}$
SSBI	2	6	$M^4 \left[1 + \alpha \left(\frac{\phi}{M_{\text{Pl}}}\right)^2 + \beta \left(\frac{\phi}{M_{\text{Pl}}}\right)^4\right]$
IMI	2	1	$M^4 \left(\frac{\phi}{M_{\text{Pl}}}\right)^{-p}$
BI	2	2	$M^4 \left[1 - \left(\frac{\phi}{\mu}\right)^{-p}\right]$
RMI	3	4	$M^4 \left[1 - \frac{\kappa}{2} \left(-\frac{1}{2} + \ln \frac{\phi}{\phi_0}\right) \frac{\phi^2}{M_{\text{Pl}}^2}\right]$
VHI	3	1	$M^4 \left[1 + \left(\frac{\phi}{\mu}\right)^p\right]$
DSI	3	1	$M^4 \left[1 + \left(\frac{\phi}{\mu}\right)^{-p}\right]$
GMLFI	3	1	$M^4 \left(\frac{\phi}{M_{\text{Pl}}}\right)^p \left[1 + \alpha \left(\frac{\phi}{M_{\text{Pl}}}\right)^q\right]$
LPI	3	3	$M^4 \left(\frac{\phi}{\phi_0}\right)^p \left(\ln \frac{\phi}{\phi_0}\right)^q$
CNDI	3	3	$\frac{M^4}{\left\{1 + \beta \cos \left[\alpha \left(\frac{\phi - \phi_0}{M_{\text{Pl}}}\right)\right]\right\}^2}$

The ASPIC library

[The Case for Inflation](#)

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❖ Purpose

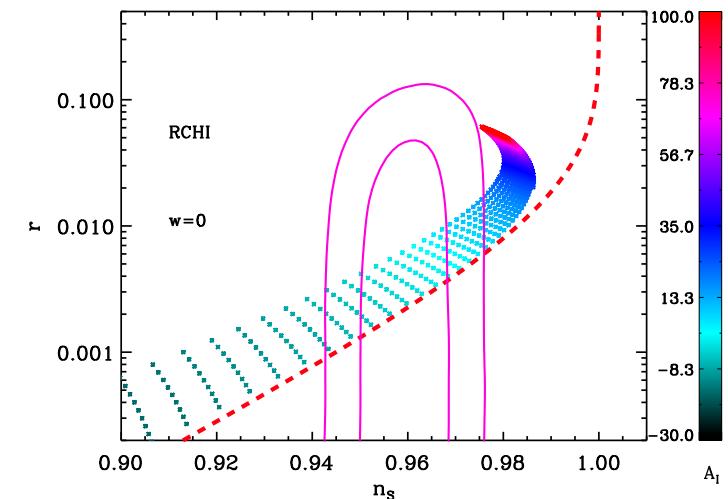
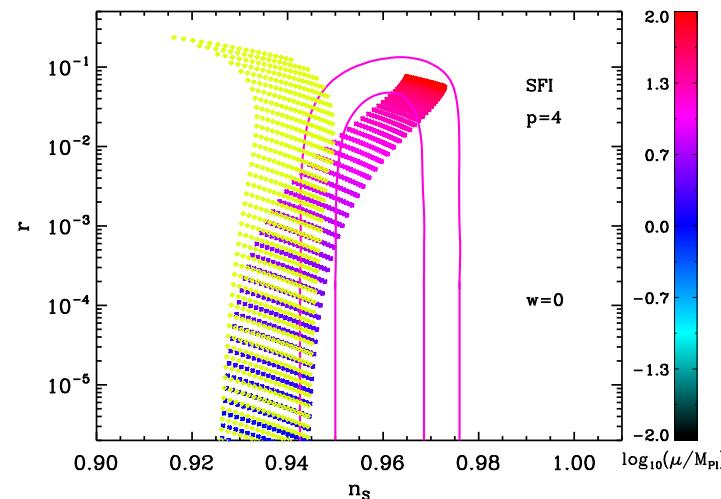
❖ Accurate and easy comparison with data

❖ The ASPIC library

[The Good, The Bad and The Ugly](#)

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- Slow-roll equations cannot always be solved analytically
- ASPIC: public code solving, **without any other approximation**:
 - ◆ Slow-roll field evolution + post-inflationary history
 - ◆ Hubble flow functions at Hubble crossing : ϵ_{i*} or n_s , r , $\alpha \dots$
 - ◆ <http://cp3.irmp.ucl.ac.be/~ringeal/aspic.html>
- Commonly used approximations on top of slow-roll = **DANGER**



- ◆ Planck's accuracy will give you what you deserve...

Accurate and easy comparison with data

- WMAP9, PLANCK, PLANCK + BICEP2 in the plane $(n_s, \log r)$
 - ◆ Mind the **Jeffreys'** prior on ϵ_{1*}

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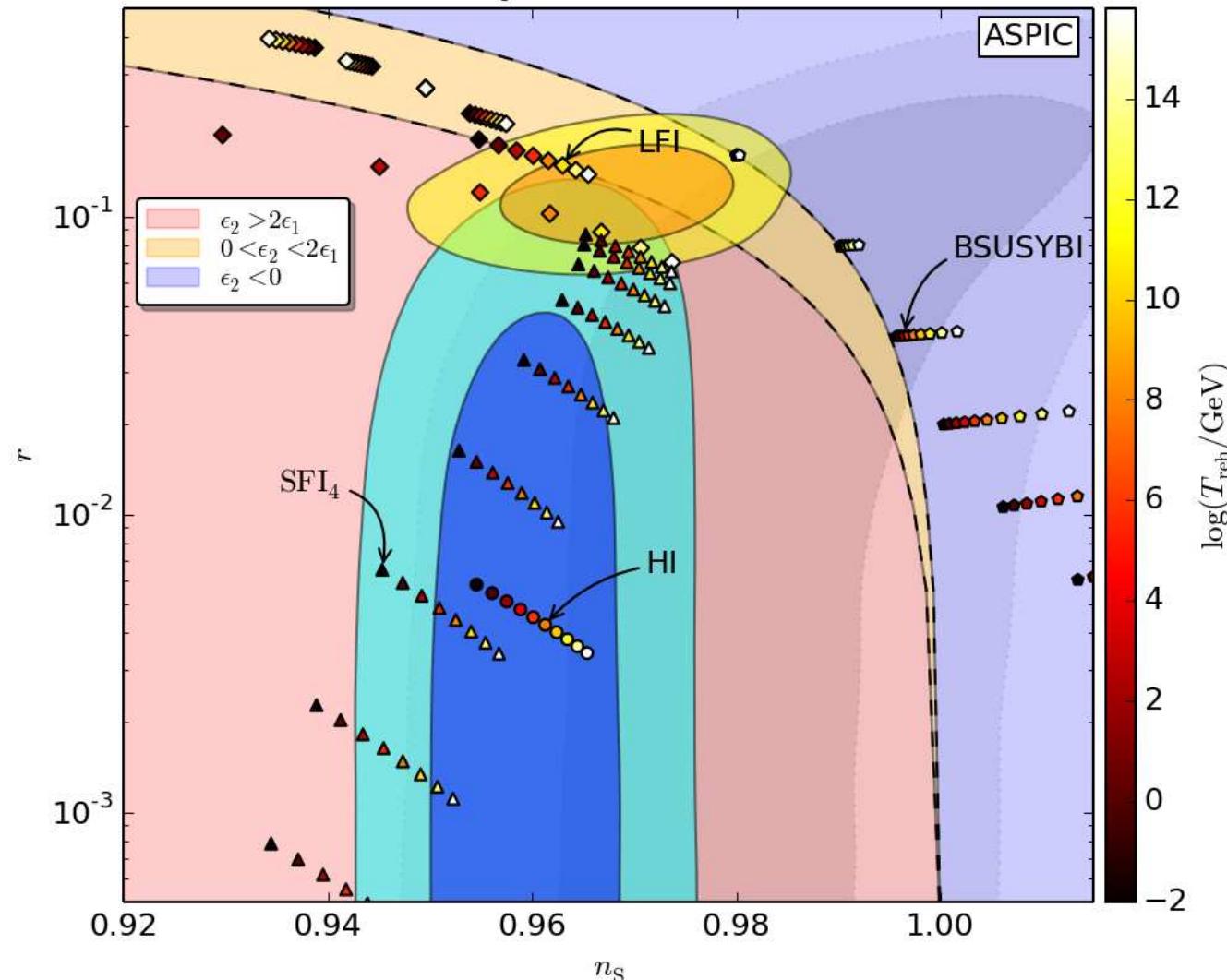
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Martin, Ringeval, Vennin (arXiv:1303.3787)



Accurate and easy comparison with data

- WMAP9, PLANCK, PLANCK + BICEP2 in the plane (n_s, r)
 - ◆ Mind the flat prior on ϵ_{1*}

The Case for Inflation

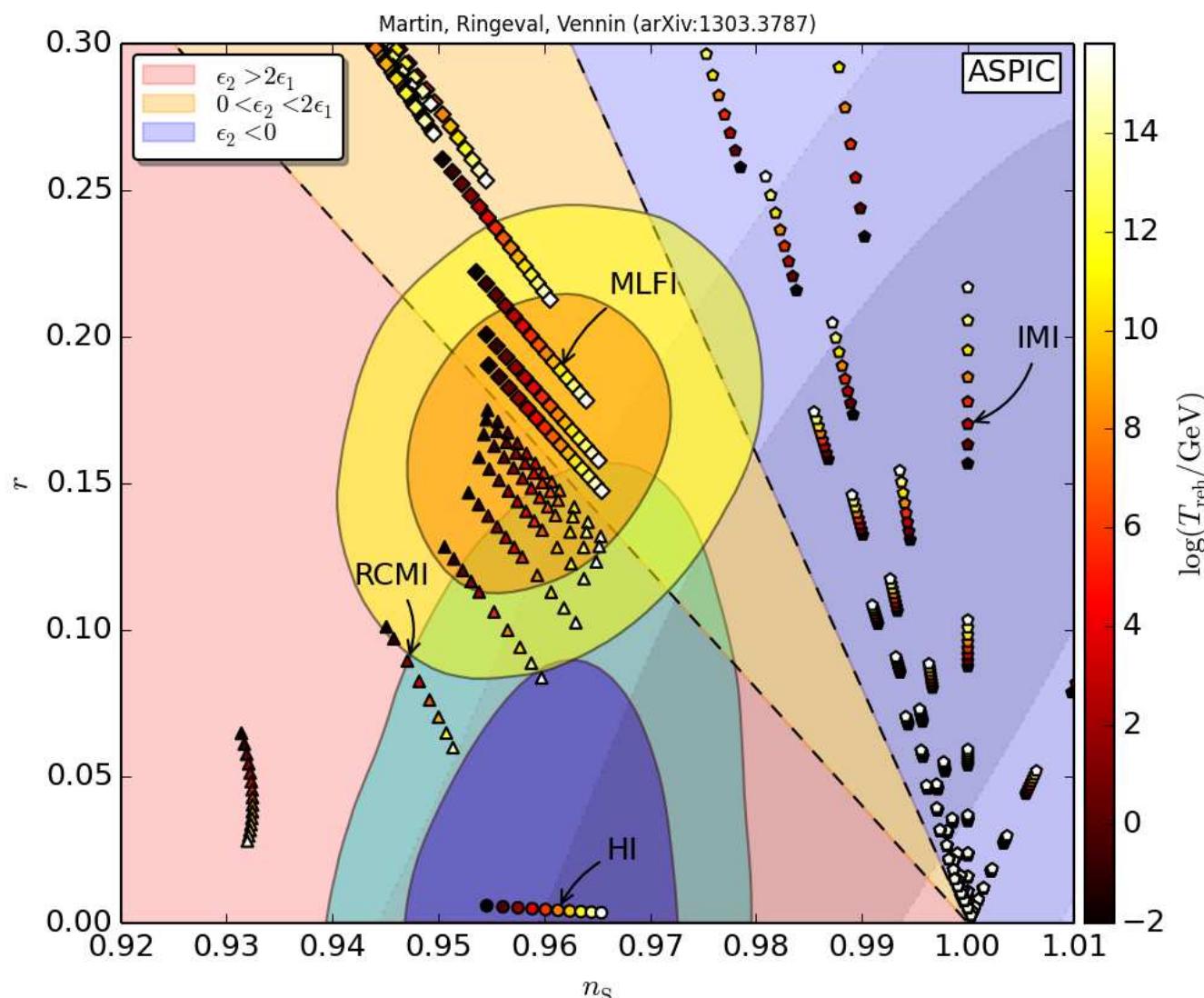
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Digging deeper...

The Case for Inflation

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- ❖ Bayesian model comparison
- ❖ Speeding up evidence calculation
- ❖ Bayes factor for hundred of models
- ❖ Data constraining power
- ❖ And the winners are...
- ❖ Narrowing down the simplest with complexity

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Bayesian model comparison

- Bayesian evidence

- ◆ For each model \mathcal{M} , marginalisation over **all** parameters

$$\mathcal{E}(D|\mathcal{M}) = \int d\boldsymbol{\theta} \mathcal{L}(\boldsymbol{\theta})\pi(\boldsymbol{\theta}|\mathcal{M})$$

- ◆ Gives the posterior probability of \mathcal{M} to explain the data D

$$p(\mathcal{M}|D) = \frac{\mathcal{E}(D|\mathcal{M})\pi(\mathcal{M})}{p(D)} \quad \text{where} \quad p(D) = \sum_i \mathcal{E}(\mathcal{M}_i|D)\pi(\mathcal{M}_i)$$

- Bayes' factor

- ◆ Gives the posterior odds between \mathcal{M} and a reference model \mathcal{M}_0

$$\frac{p(\mathcal{M}|D)}{p(\mathcal{M}_0|D)} = B \frac{\pi(\mathcal{M})}{\pi(\mathcal{M}_0)} \Rightarrow B = \frac{\mathcal{E}(D|\mathcal{M})}{\mathcal{E}(D|\mathcal{M}_0)}$$

- ◆ Measure of how much the prior information has been updated

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Jeffreys' scale

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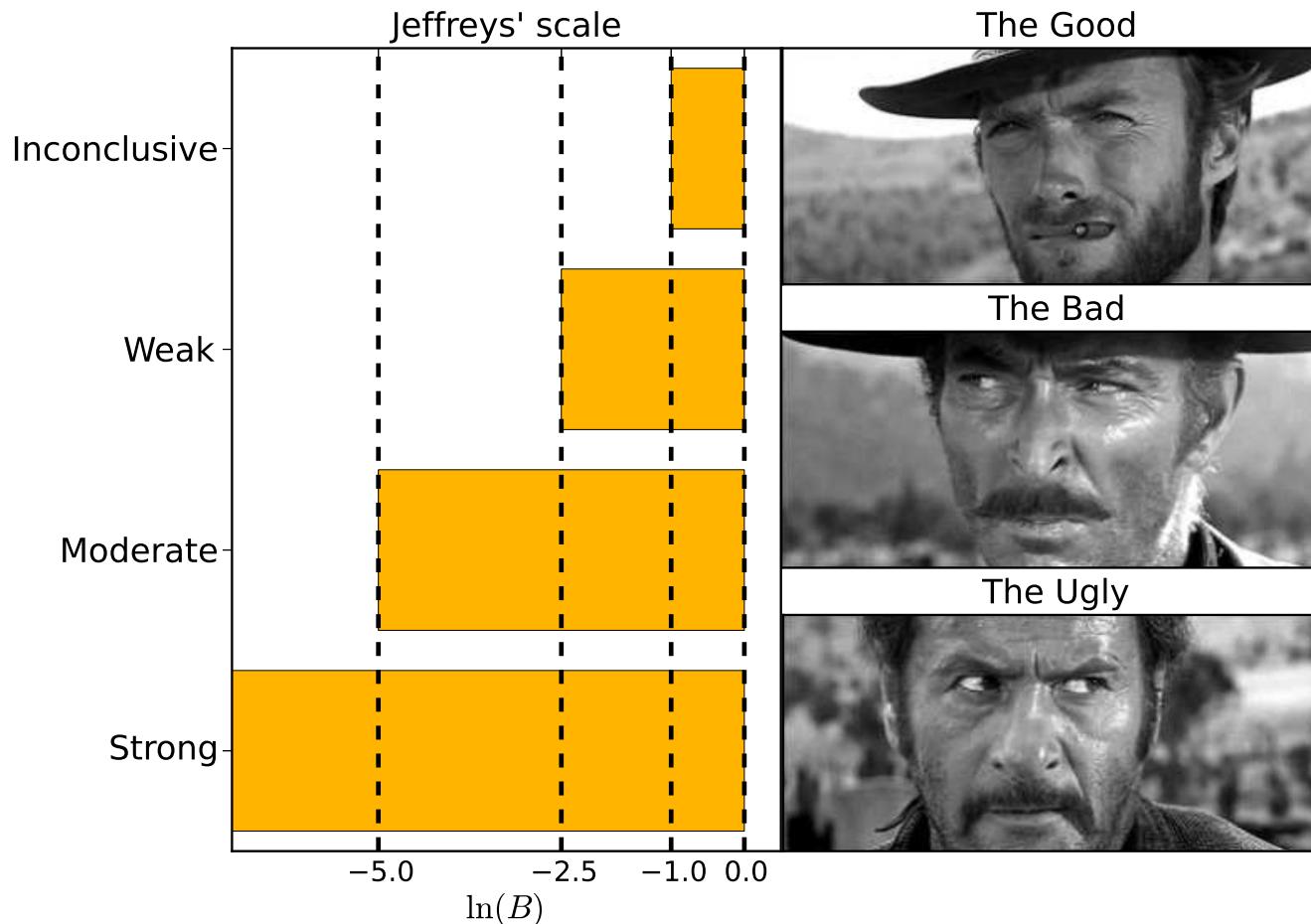
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- Strength of evidence of \mathcal{M} compared to \mathcal{M}_0



- Can we do that for all models of the Encyclopaedia?



Speeding up evidence calculation

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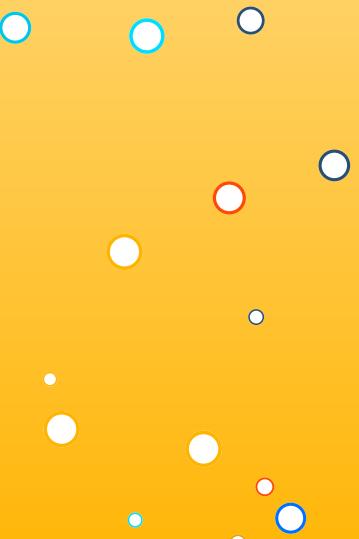
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Conclusion



- Marginalisation over all parameters is numerically challenging!
- Effective likelihood for slow-roll inflation
 - ◆ Requires only one complete data analysis to get

$$\mathcal{L}_{\text{eff}}(D|P_*, \epsilon_{i*}) = \int p(D|\boldsymbol{\theta}_{\text{cosmo}}, P_*, \epsilon_{i*})\pi(\boldsymbol{\theta}_{\text{cosmo}})d\boldsymbol{\theta}_{\text{cosmo}}$$

- ◆ Use machine-learning algorithm to fit its multidimensional shape
- ◆ For each model \mathcal{M} and their parameter $\boldsymbol{\theta}_{\text{prim}}$

$$p(\boldsymbol{\theta}_{\text{prim}}|D, \mathcal{M}) = \frac{\mathcal{L}_{\text{eff}}[D|P_*(\boldsymbol{\theta}_{\text{prim}}), \epsilon_{i*}(\boldsymbol{\theta}_{\text{prim}})]\pi(\boldsymbol{\theta}_{\text{prim}}|\mathcal{M})}{p(D|\mathcal{M})}$$

- All evidences can be obtained by integrating \mathcal{L}_{eff}
 - ◆ In practice: ASPIC + MultiNest + \mathcal{L}_{eff} = 1 hour per model

Is it accurate enough for Planck?

The Case for Inflation

The Encyclopædia

The Good, The Bad and
The Ugly

❖ Bayesian model
comparison

❖ Speeding up evidence
calculation

❖ Bayes factor for hundred
of models

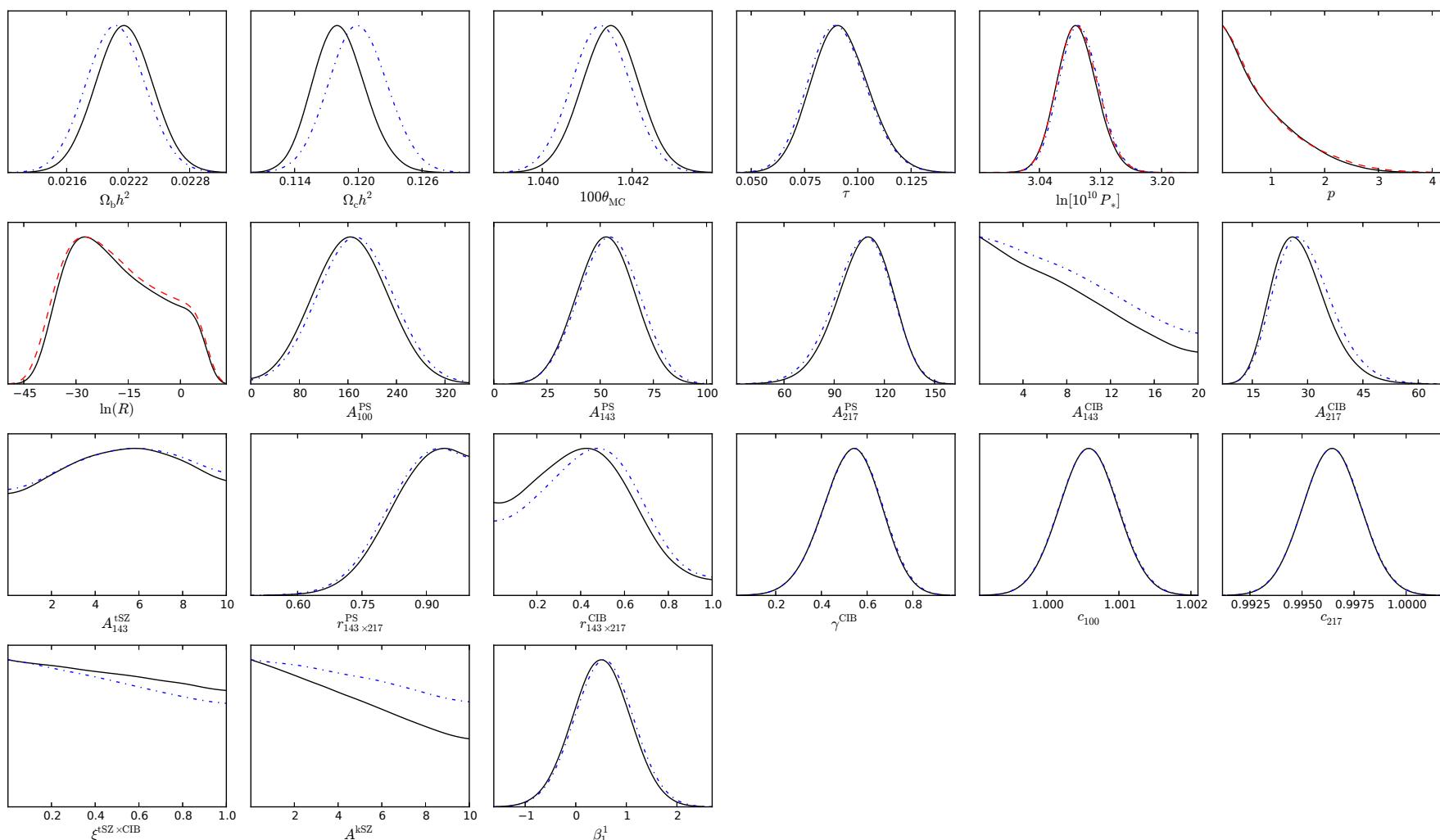
❖ Data constraining power

❖ And the winners are...

❖ Narrowing down the
simplest with complexity

Conclusion

— All exact: large field power spectra (FieldInf) + Planck likelihood (CamSpec)
- - Fast: slow roll power spectra + large field Hubble flow functions (aspic) + \mathcal{L}_{eff}
--- figure 1





Bayes factor for hundred of models

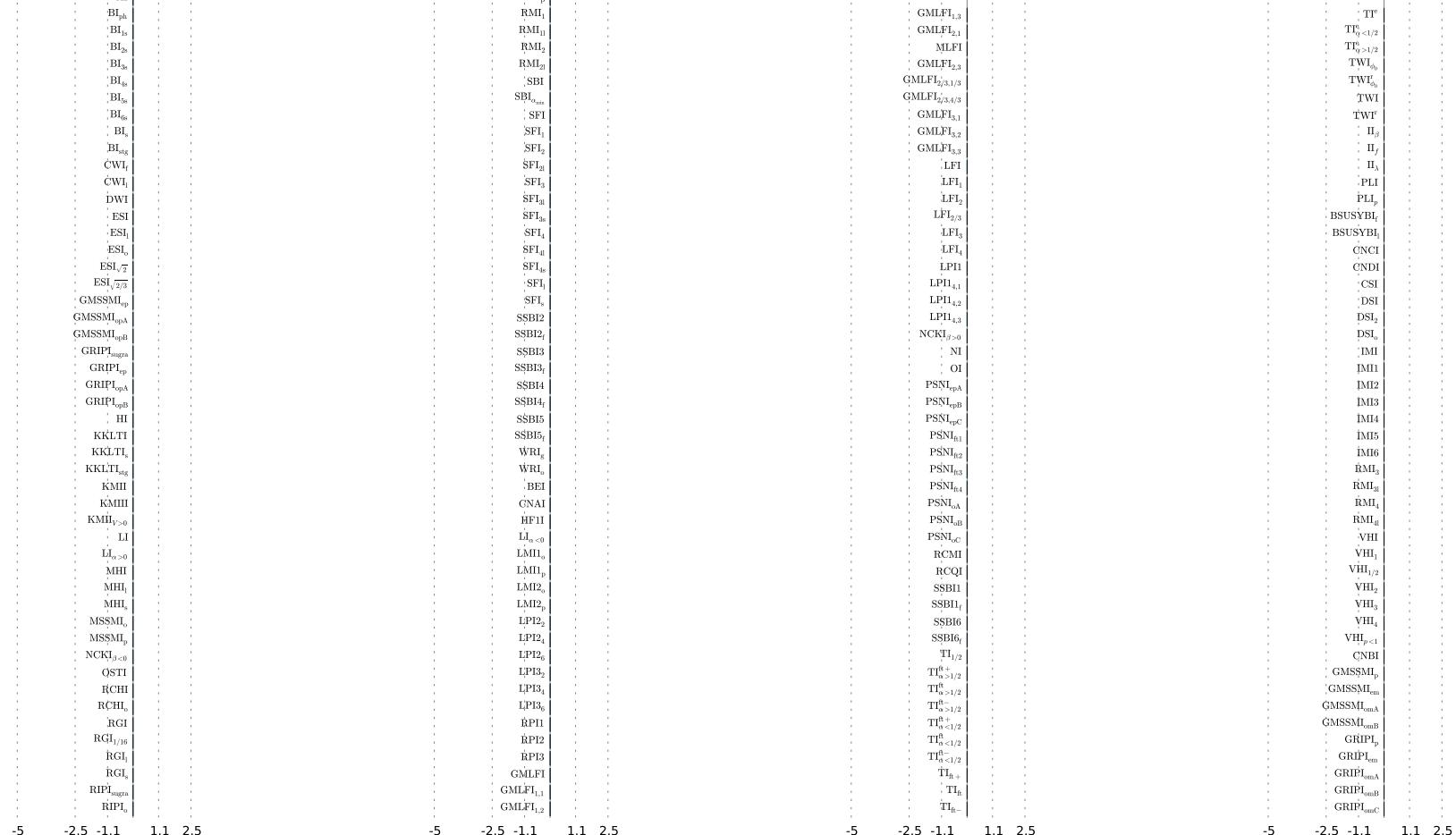
The Case for Inflation

The Encyclopædia

The Good, The Bad and The Ugly

- ❖ Bayesian model comparison
 - ❖ Speeding up evidence calculation
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Conclusion



J.Martin, C.Ringeval, R.Trotta, V.Venni
ASPIIC project

Displayed Evidences: 0



Bayes factor for hundred of models

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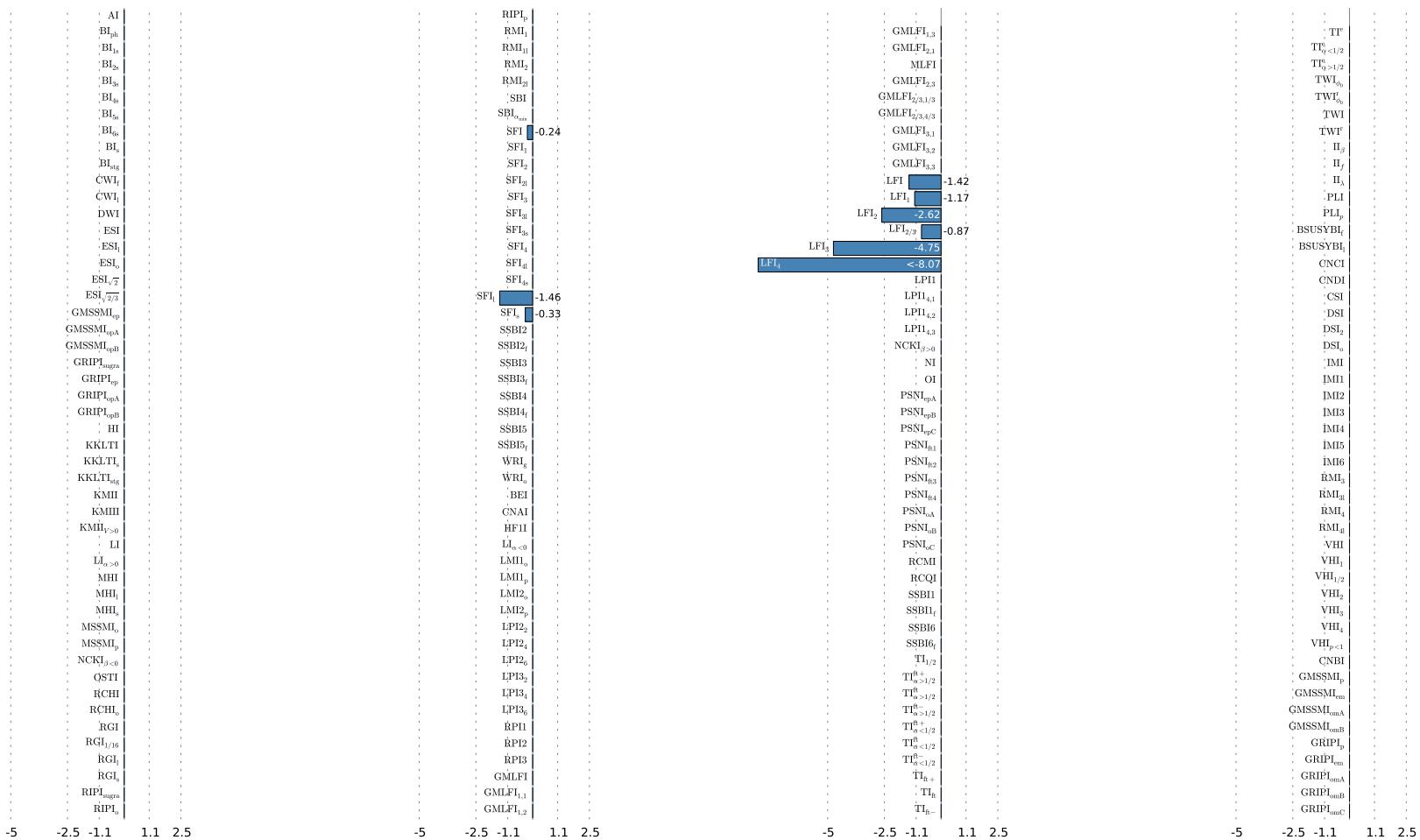
The Good, The Bad and The Ugly

- ❖ Bayesian model comparison
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Conclusion



WMAP7: Martin, Ringeval & Trotta
arXiv:1009.4157



J.Martin, C.Ringeval, R.Trotta, V.Venni
ASPIC project

Displayed Evidences: 9



Bayes factor for hundred of models

The Case for Inflation

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The Good, The Bad and
The Ugly

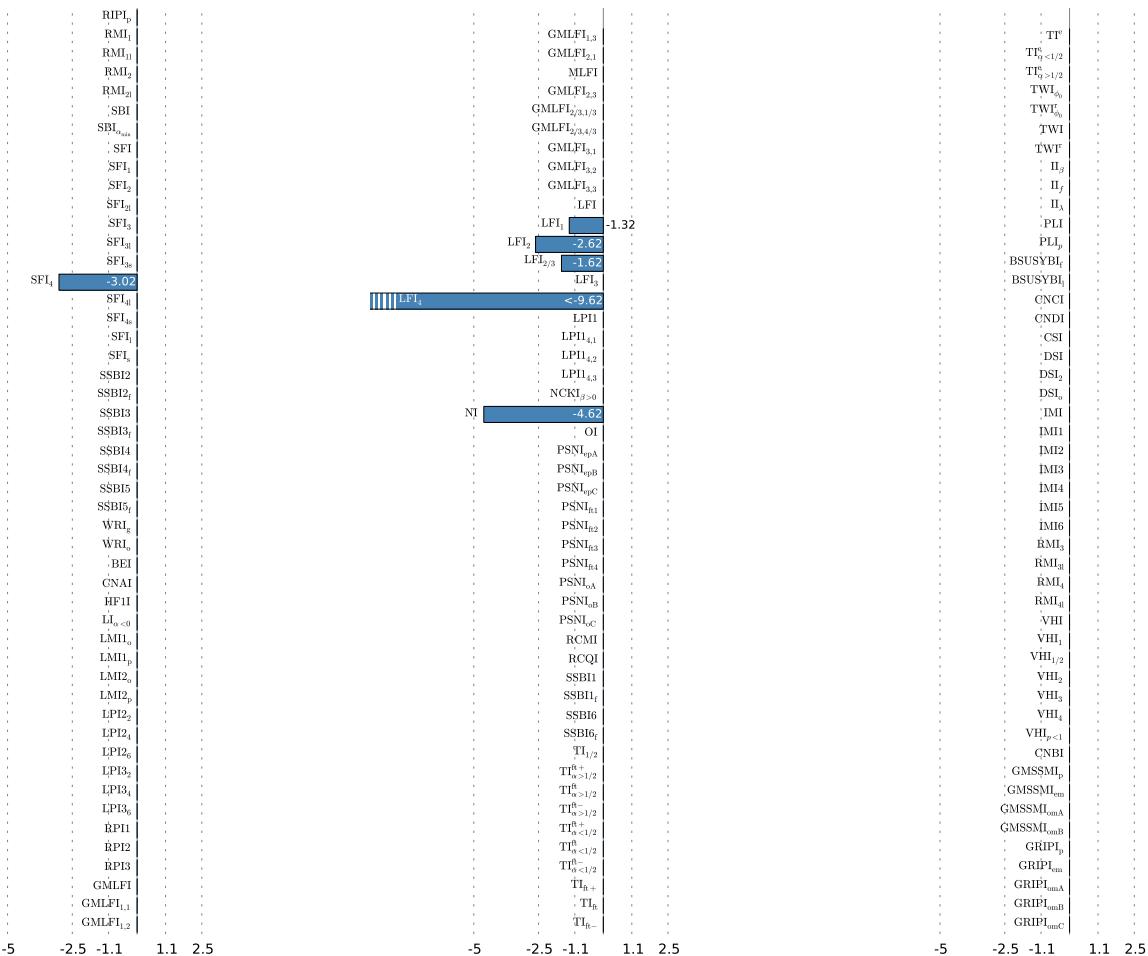
- ❖ Bayesian model comparison
- ❖ Speeding up evidence calculation
- ❖ Bayes factor for hundred of models
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Conclusion

PLANCK

Bayesian Evidences $\ln(\mathcal{E}/\mathcal{E}_{HI})$

Planck collaboration
arXiv:1303.5082



J.Martin, C.Ringeval, R.Trotta, V.Vennin
ASPIC project

Displayed Evidences: 5



Bayes factor for hundred of models

The Case for Inflation

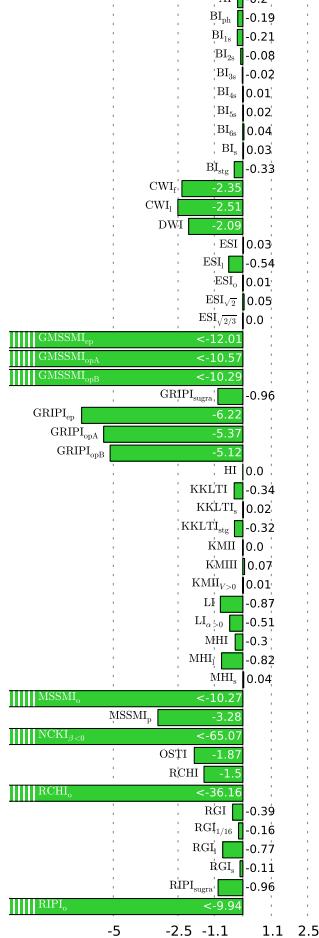
The Encyclopædia

The Good, The Bad and The Ugly

- ❖ Bayesian model comparison
- ❖ Speeding up evidence calculation
- ❖ Bayes factor for hundred of models
- ❖ Data constraining power
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Conclusion

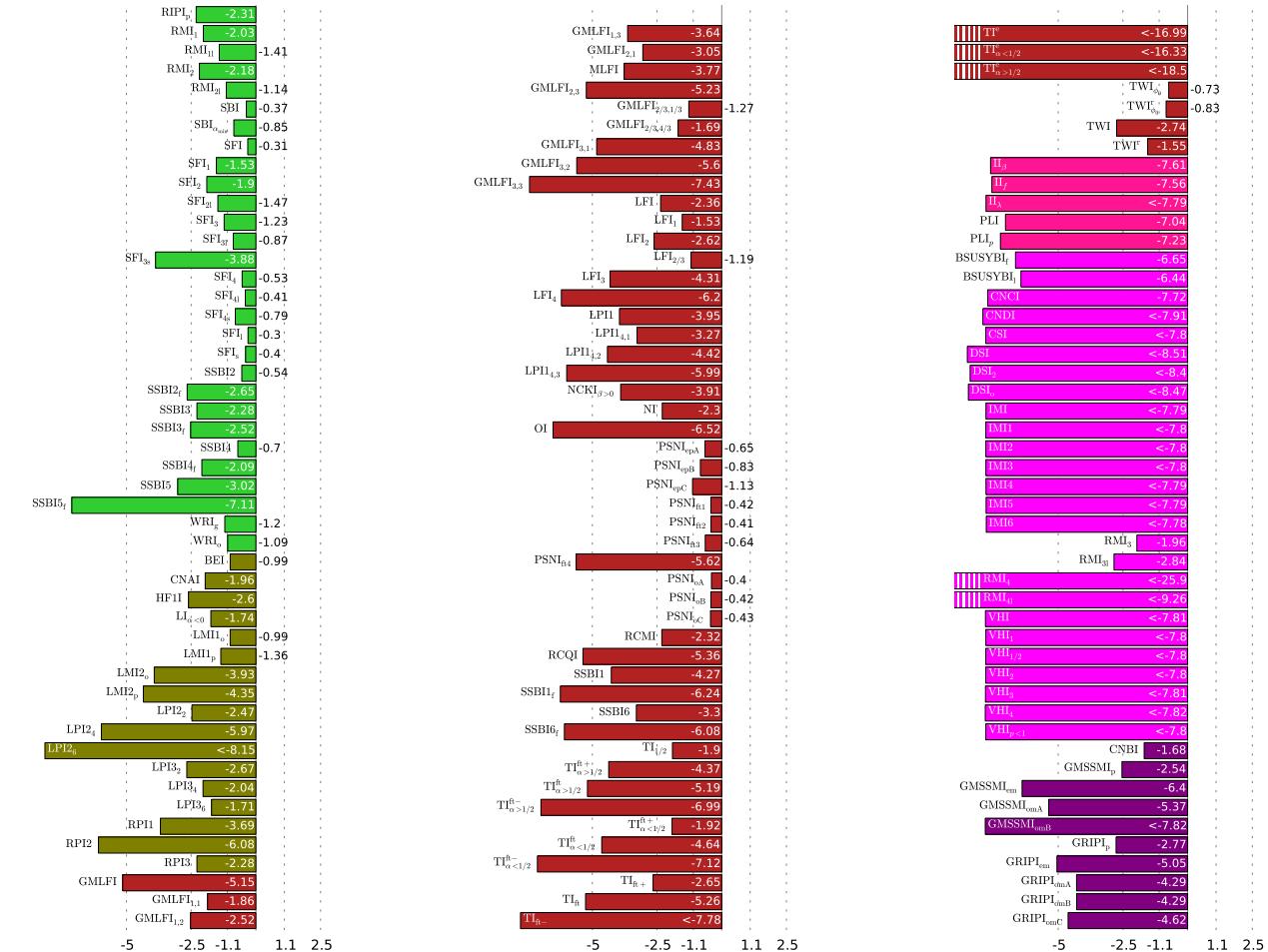
PLANCK



Schwarz-Terrero-Escalante Classification:

- 1
- 1-2
- 2
- 2-3
- 3
- 1-2-3

Bayesian Evidences $\ln(\mathcal{E}/\mathcal{E}_{HI})$



J.Martin, C.Ringeval, R.Trotta, V.Vennin
ASPIC project

Displayed Evidences: 194

Bayes factor for hundred of models

The Case for Inflation

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The Good, The Bad and The Ugly

❖ Bayesian model comparison

❖ Speeding up evidence calculation

❖ Bayes factor for hundred of models

❖ Data constraining power

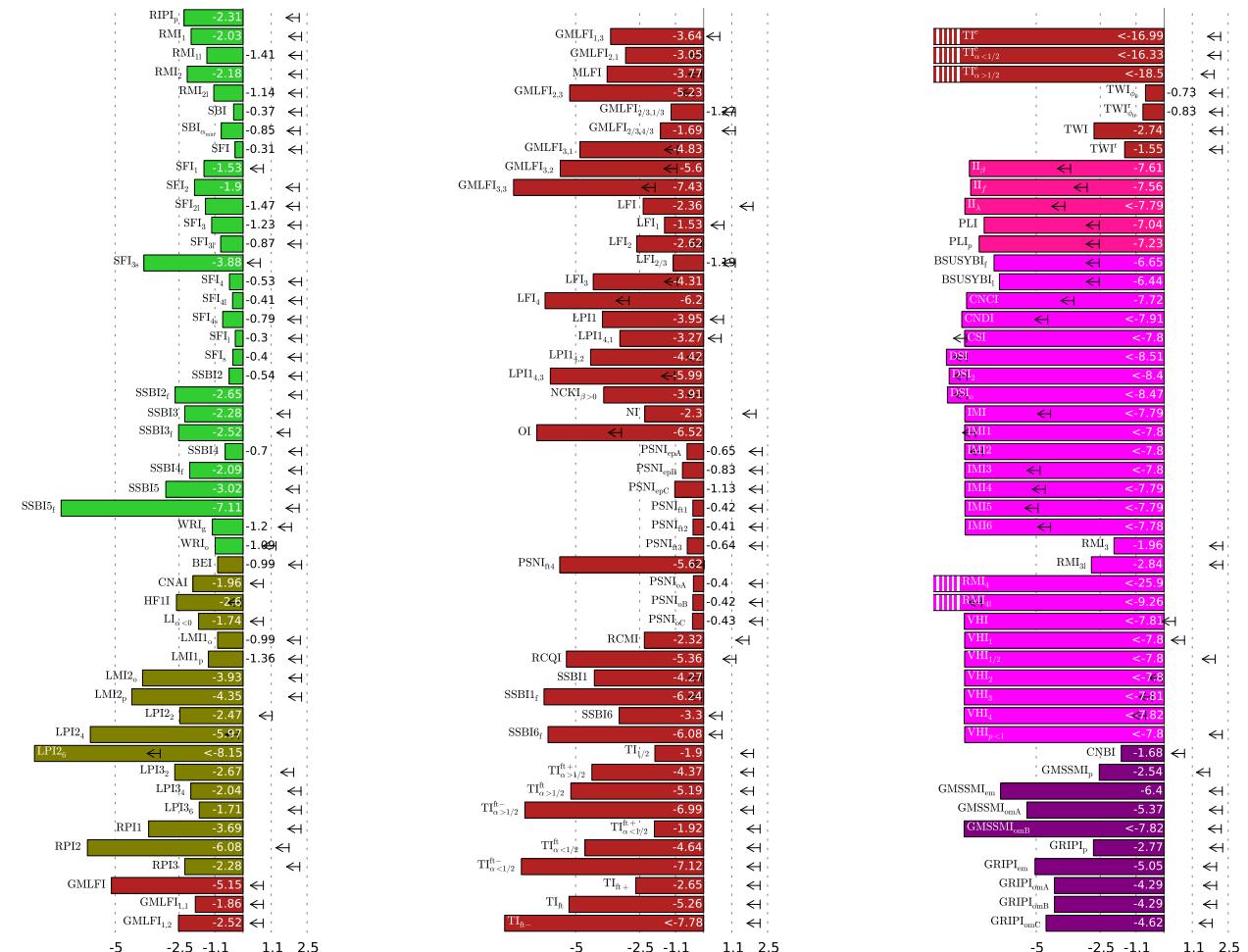
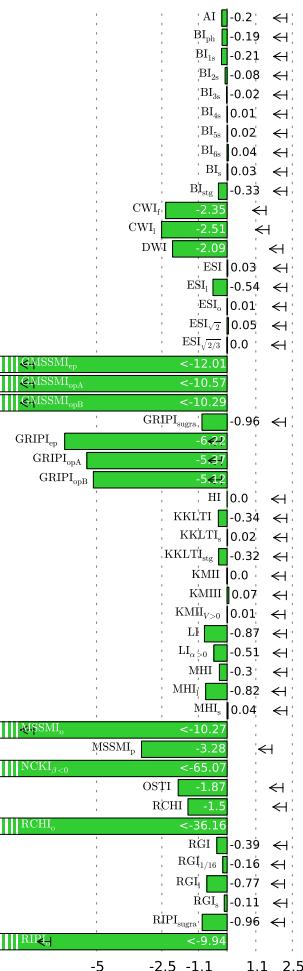
❖ And the winners are...

❖ Narrowing down the simplest with complexity

Conclusion

PLANCK

Bayesian Evidences $\ln(\mathcal{E}/\mathcal{E}_{\text{HI}})$ and $\ln(\mathcal{L}_{\text{max}}/\mathcal{E}_{\text{HI}})$



Schwarz-Terrero-Escalante Classification:

- 1
- 1-2
- 2
- 2-3
- 3
- 1-2-3

J.Martin, C.Ringeval, R.Trotta, V.Vennin
ASPIC project

Displayed Evidences: 194



Bayes factor for hundred of models

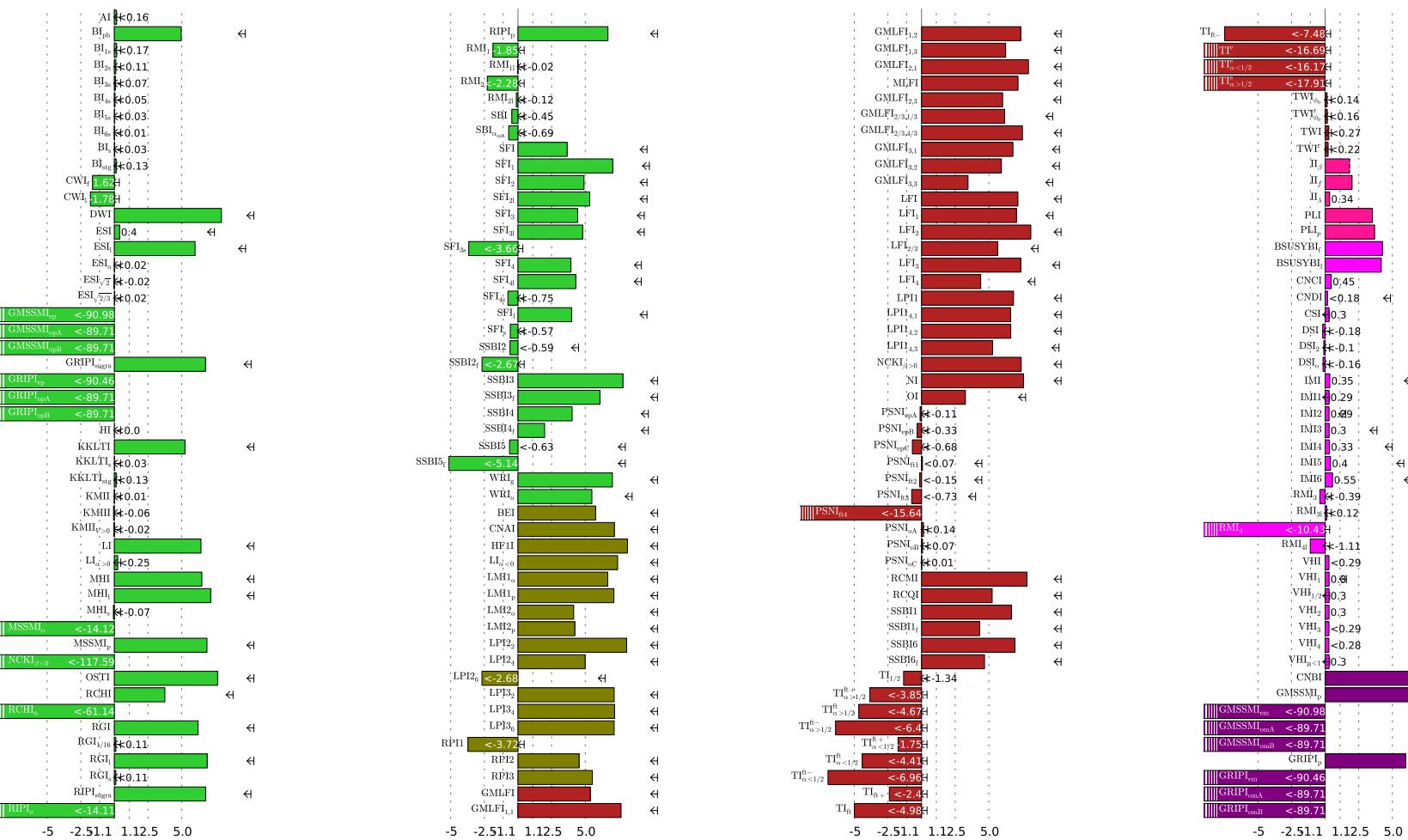
The Case for Inflation

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Schwarz-Terrero-Escalante Classification:

J.Martin, C.Ringeval, R.Trotta, V.Vennin
ASPIC project

Displayed Evidences: 193

Bayes factor for hundred of models

The Case for Inflation

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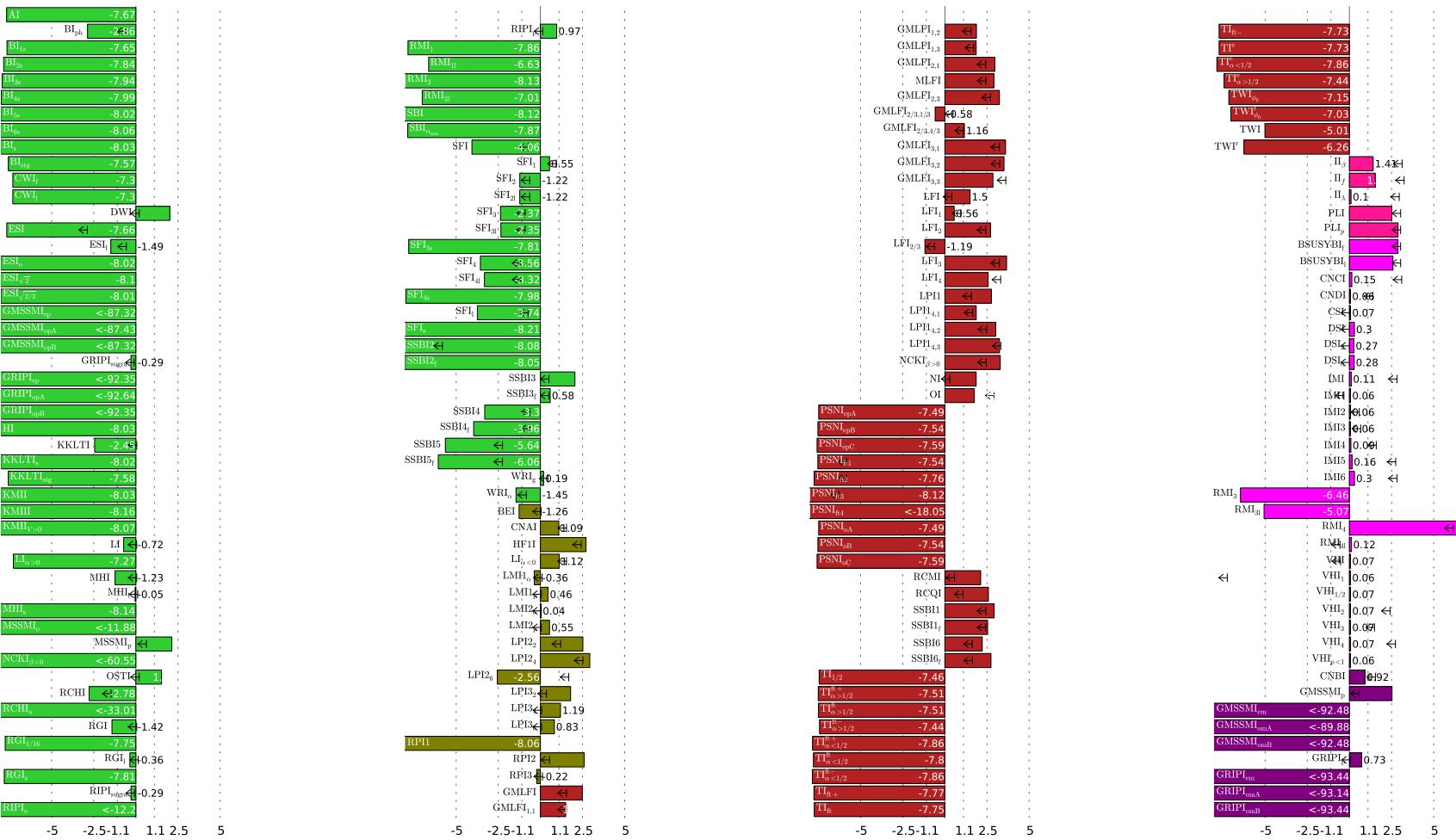
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Conclusion

DIFFERENCES

Bayesian Evidences $\ln(\mathcal{E}/\mathcal{E}_{\text{Planck}})$ and $\ln(\mathcal{L}_{\max}/\mathcal{L}_{\max, \text{Planck}})$



Schwarz-Terrero-Escalante Classification:



J. Martin, C. Ringeval, R. Trotta, V. Vennin
ASPIC project

Displayed Evidences: 193

Data constraining power

The Case for Inflation

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The Good, The Bad and
The Ugly

Bayesian model
comparison

❖ Speeding up evidence
calculation

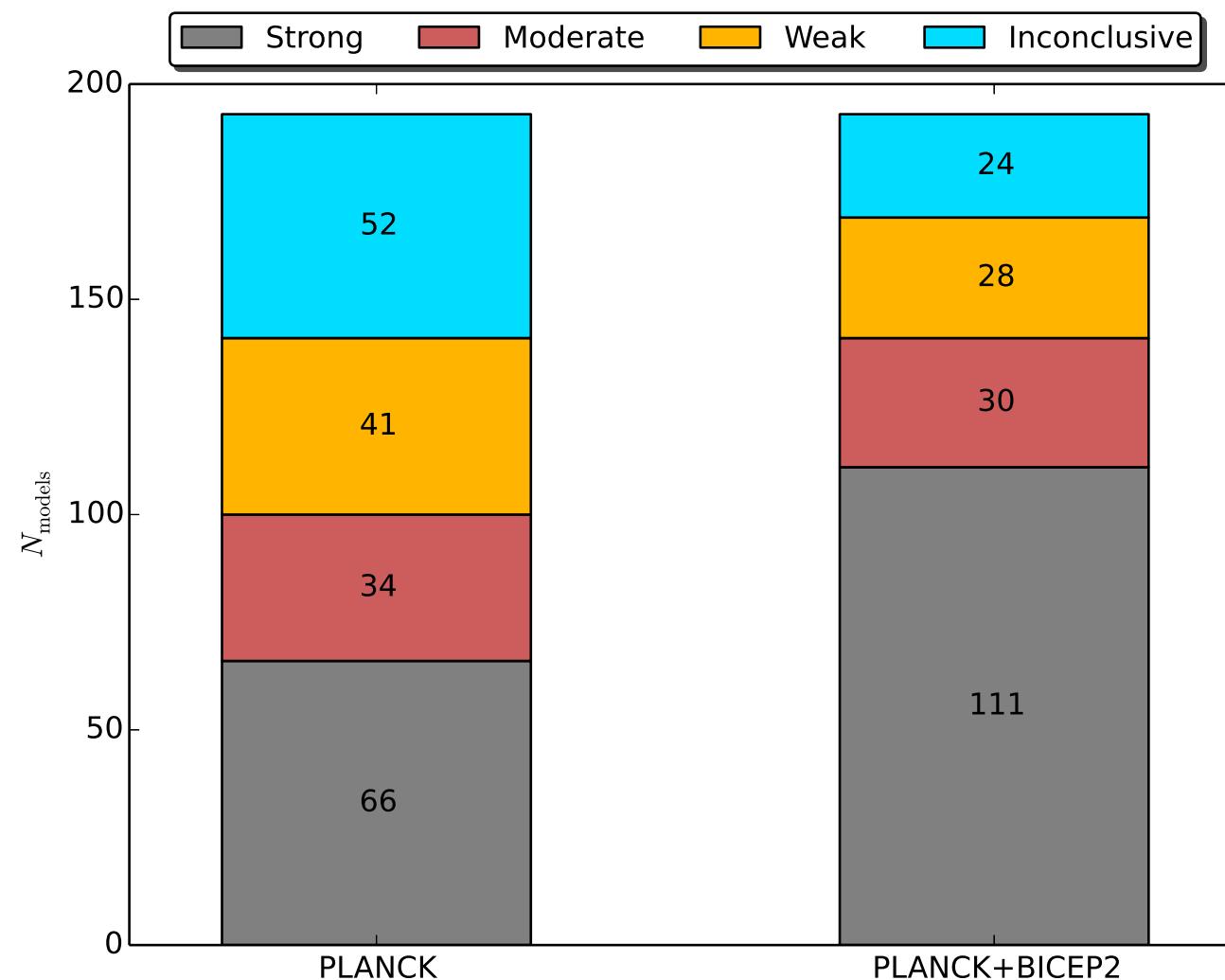
❖ Bayes factor for hundred
of models

❖ Data constraining power

❖ And the winners are...
❖ Narrowing down the
simplest with complexity

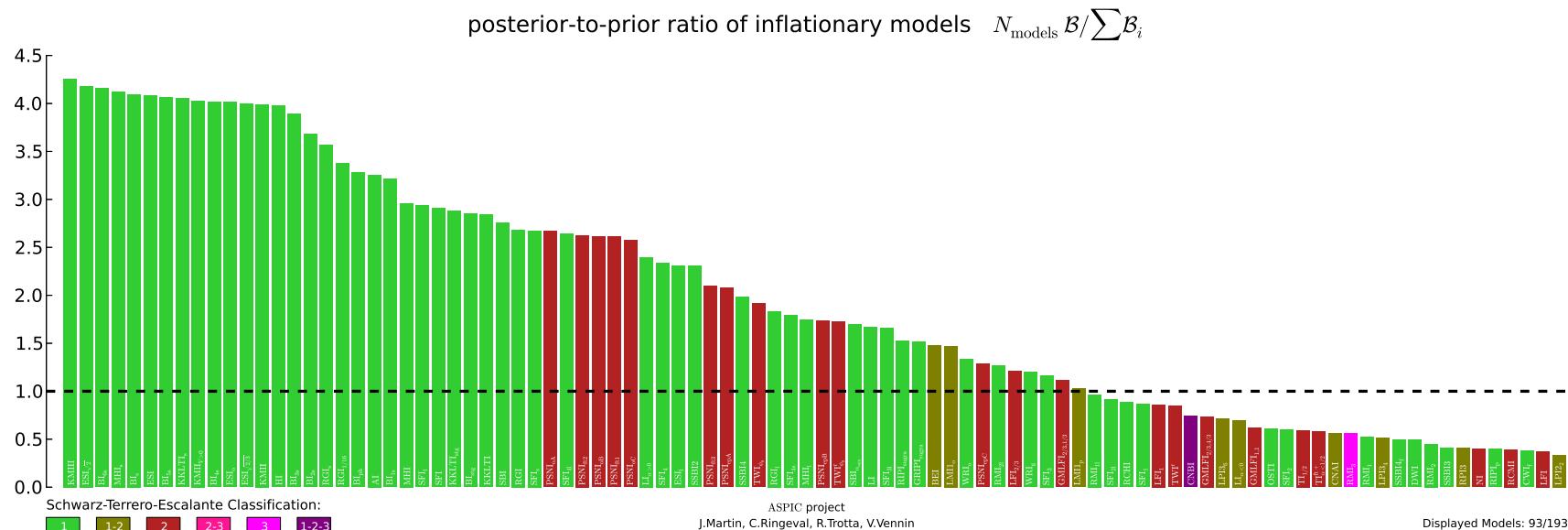
Conclusion

- Comparison between PLANCK and PLANCK + BICEP2



And the winners are...

- From non-committal priors: $\pi(\mathcal{M}) = 1/N_{\text{models}}$
 - Posterior-to-prior ratio: PLANCK



- Some numbers
 - ◆ 52 models are in the inconclusive region
“Some Good”: AI, BI, ESI, HI, KKLTI, KMII, KMIII, LI, MHI, PSNI, RGI, SBI, SFI, SSBI2, TWI
 - ◆ 66 models are strongly disfavoured (some “Bad” others “Ugly”)

And the winners are... .

The Case for Inflation

The Encyclopædia

The Good, The Bad and
The Ugly

❖ Bayesian model
comparison

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calculation

❖ Bayes factor for hundred
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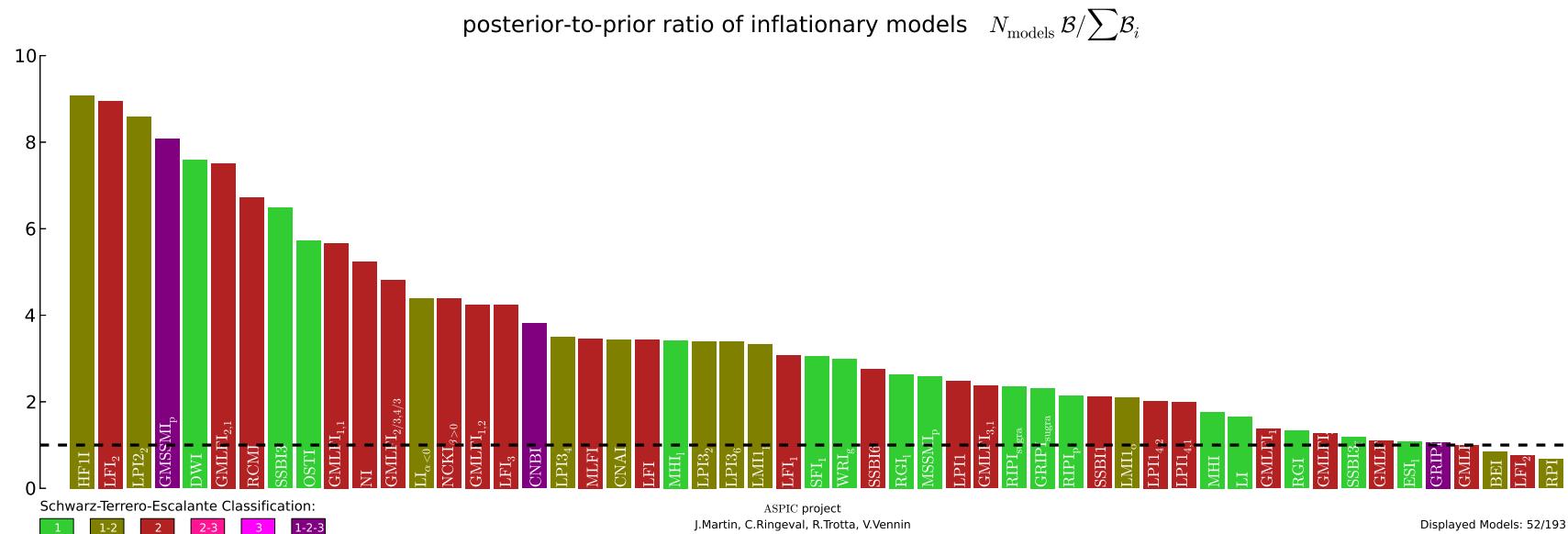
❖ Data constraining power

❖ And the winners are... .

❖ Narrowing down the
simplest with complexity

Conclusion

- From non-committal priors: $\pi(\mathcal{M}) = 1/N_{\text{model}}$
- Posterior-to-prior ratio: PLANCK+BICEP2



- Some numbers
 - ◆ 24 models are in the inconclusive region
“Some Good”: HF1I, LFI, LPI, DWI, GMLFI, RCMI, SSBI, OSTI, NI, NCKI, CN(A)BI, MHI, LMI, SFI₁, WRI, RGI, RIP_{sugra}, LI
 - ◆ 111 models are strongly disfavoured (some “Bad” others “Ugly”)

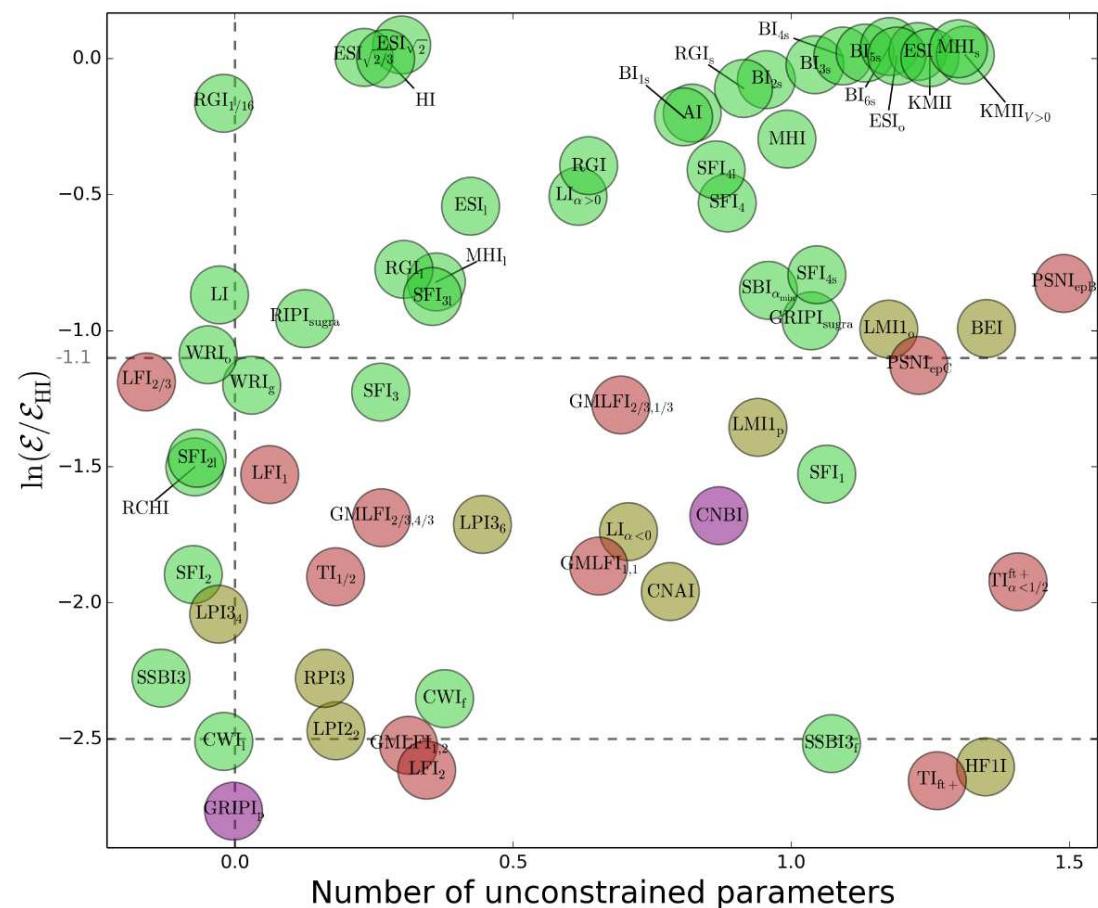
Narrowing down the simplest with complexity

- Bayesian complexity \simeq the number of constrained parameters

$$\mathcal{C} = \langle -2 \ln \mathcal{L} \rangle + 2 \ln \mathcal{L}_{\max} \quad \Rightarrow \quad N_{\text{unconstrained}} = N_{\text{param}} - \mathcal{C}$$

Displayed Models: 66/193

PLANCK



The Case for Inflation

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The Good, The Bad and
The Ugly

- ❖ Bayesian model comparison
- ❖ Speeding up evidence calculation
- ❖ Bayes factor for hundred of models
- ❖ Data constraining power
- ❖ And the winners are...
- ❖ Narrowing down the simplest with complexity

Conclusion

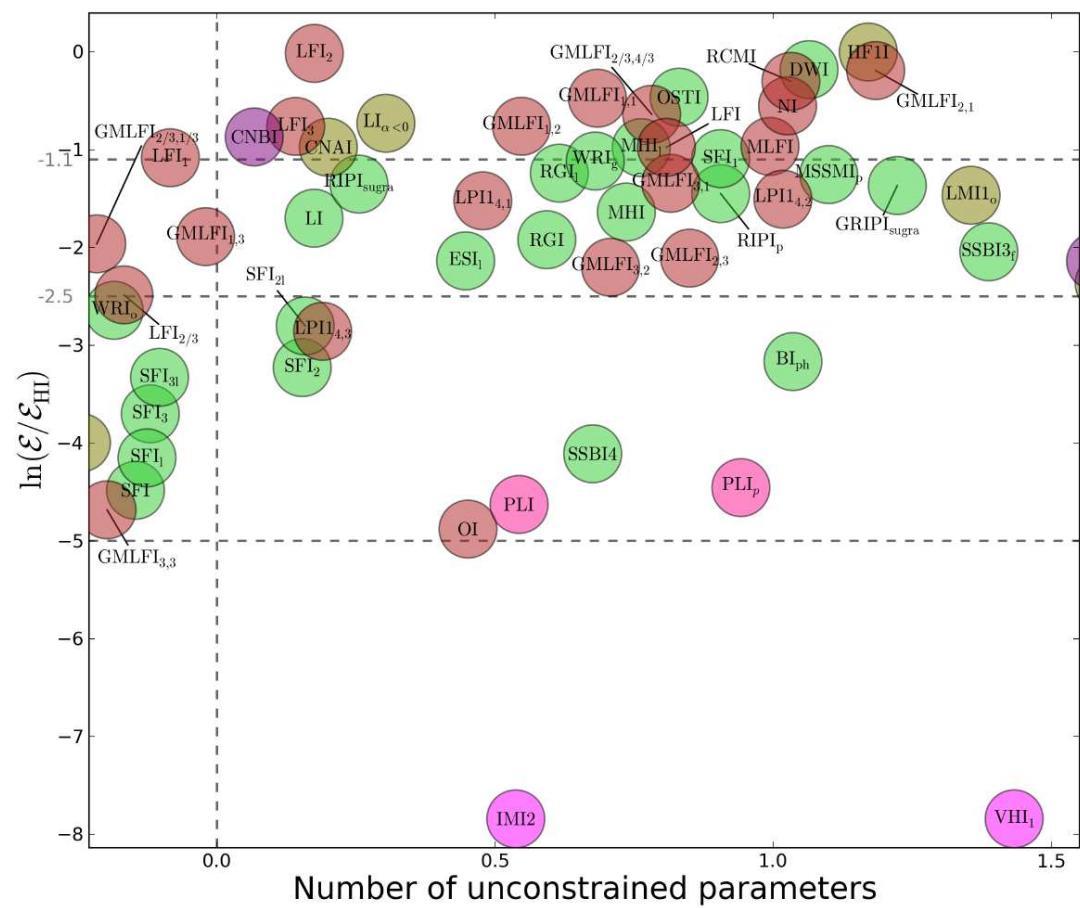
Narrowing down the simplest with complexity

- Bayesian complexity \simeq the number of constrained parameters

$$\mathcal{C} = \langle -2 \ln \mathcal{L} \rangle + 2 \ln \mathcal{L}_{\max} \quad \Rightarrow \quad N_{\text{unconstrained}} = N_{\text{param}} - \mathcal{C}$$

Displayed Models: 55/193

- PLANCK + BICEP2



The Case for Inflation

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The Good, The Bad and
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Conclusion



Conclusion

The Case for Inflation

The Encyclopædia

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The Ugly

Conclusion

- Inflationary models can and should be tested
 - ◆ Bayesian evidence provides quantitative answers
 - ◆ Planck likes ST class 1 (“plateau inflation”)
 - ◆ HI, ESI and RGI are proto-typical of **most probable** and **simplest** scenarios explaining the Planck 2013 data
- Not all models have been tested yet
 - ◆ We welcome **your** contribution: code your model in ASPIC
- Not all data have been employed yet
- The BICEP crucial question
 - ◆ Is it really **r**?
- Waiting for Planck 2014 and **polarization**



Conclusion

The Case for Inflation

The Encyclopædia

The Good, The Bad and
The Ugly

Conclusion

- Inflationary models can and should be tested
 - ◆ Bayesian evidence provides quantitative answers
 - ◆ Planck + bicep2 likes ST class 1-2
 - ◆ LFI, LI, CNA(B)I are proto-typical of **most probable** and **simplest** scenarios explaining the Planck 2013 + bicep2 data
- Not all models have been tested yet
 - ◆ We welcome **your** contribution: code your model in ASPIC
- Not all data have been employed yet
- The BICEP crucial question
 - ◆ Is it really **r**?
- Waiting for Planck 2014 and **polarization**