Can the Differential Emission Measure constrain the timescale of the energy deposition in the solar corona ?

Application to Hinode/EIS

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Why ?

- Active Region → **DEM α T^{α}**

  (Warren et al. 2011, Winebarger et al. 2012, Schmelz 2012 ...)

- **Slope** determination :

  → Indication of the **cold/warm** material ratio

  → **Timescale** of the energy deposition in the solar corona

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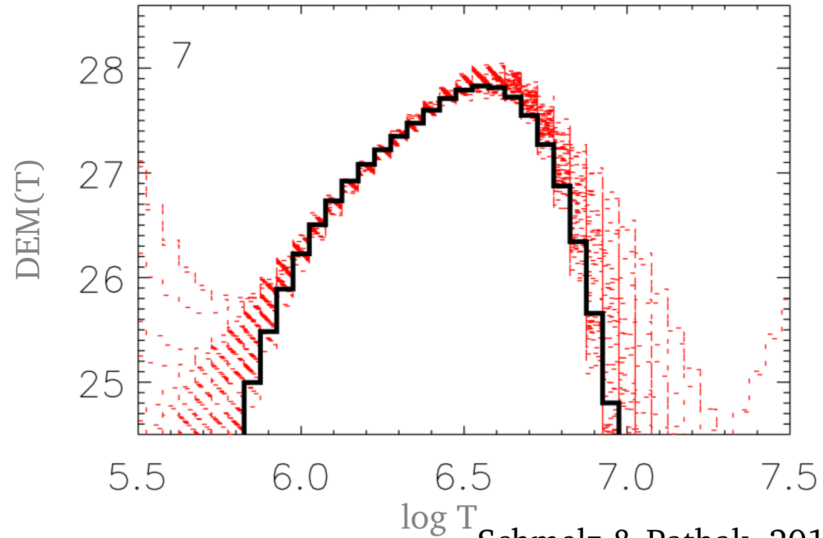

Schmelz & Pathak, 2012

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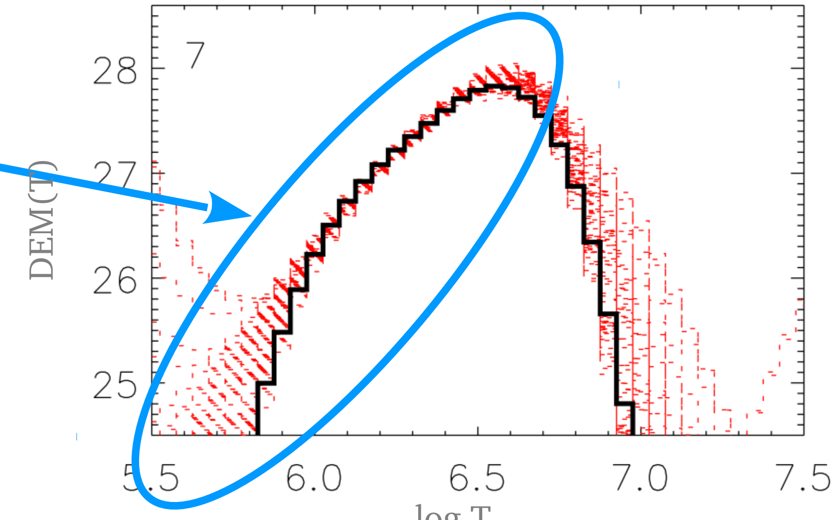

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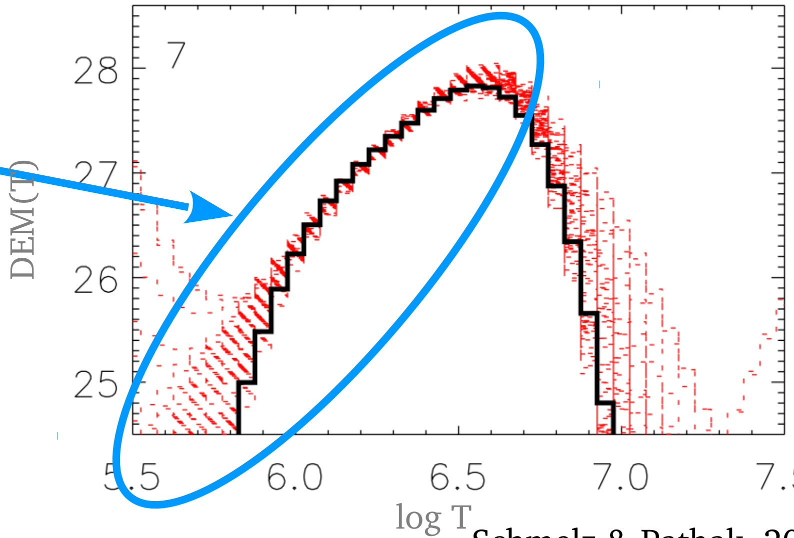

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DEM → Inverse problem

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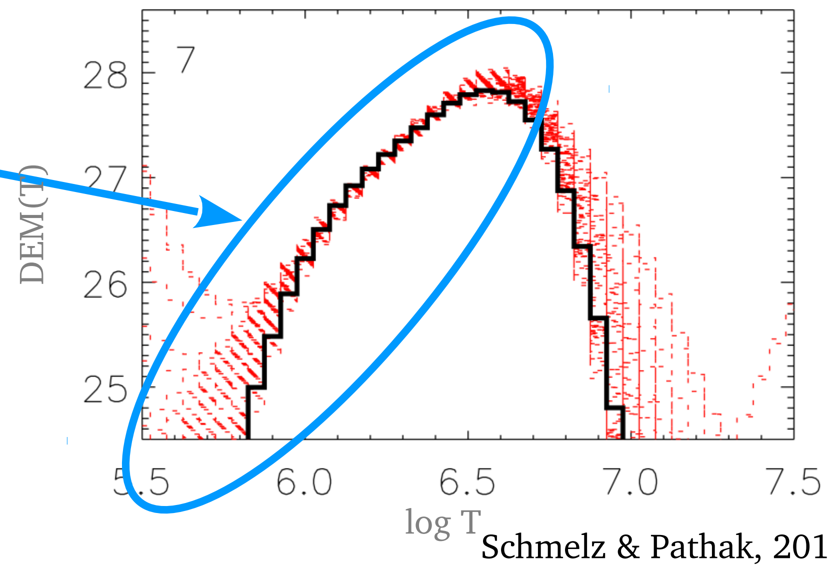

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$$I_b = \frac{1}{4\pi} \int_0^{\infty} R_b(T_e)\ \xi(T_e)\ dT_e$$

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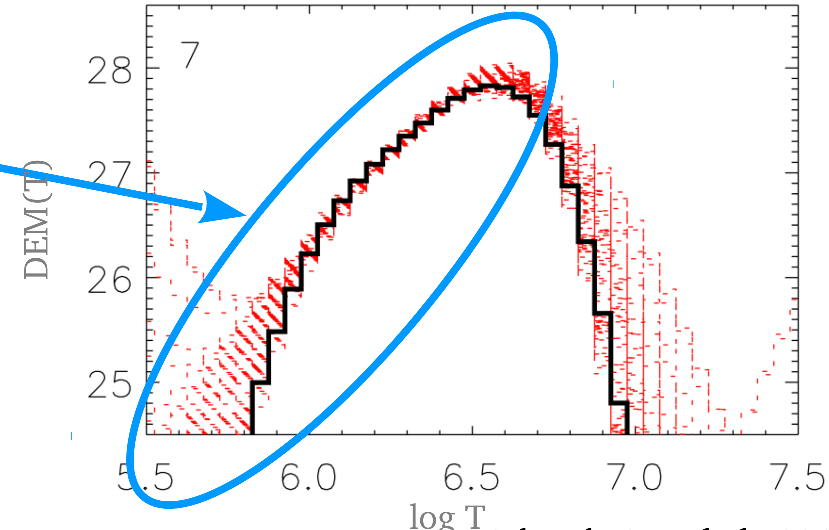

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Temperature Response function

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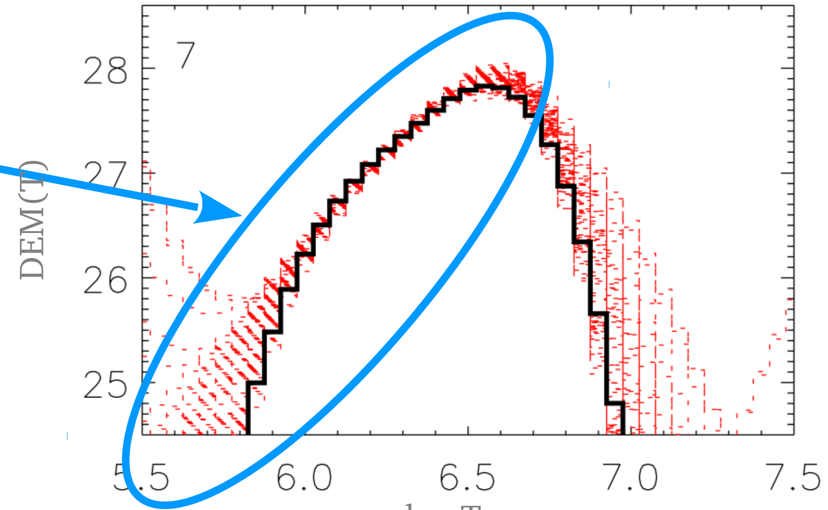

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DEM function

$$\xi(T_e) = \overline{n_e^2}(T_e)\,dp/d(\log T_e),$$

Craig & Brown (1976)

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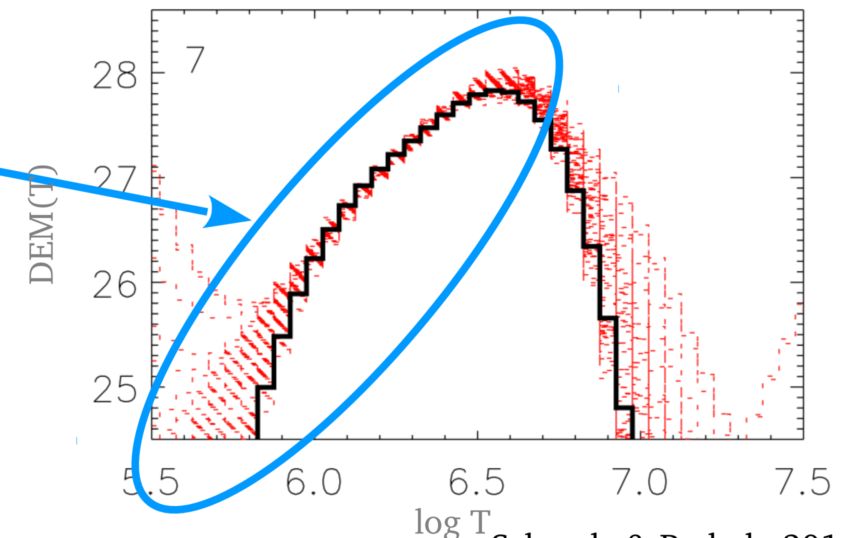

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What is the confidence level on the reconstructed slope ?

How ?

- Technique → ***Monte-carlo treatment*** of uncertainties

Hinode/EIS set of 30 lines of *Fe, Si, Mg, S, Ca, Ar*
→ temperature range [$10^{5.2}$: $10^{6.9}$] K

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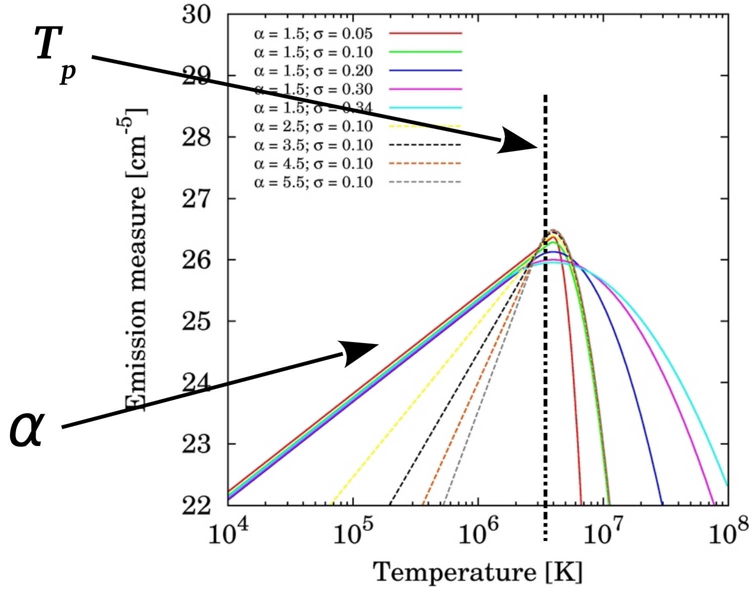
Active Regions DEMs



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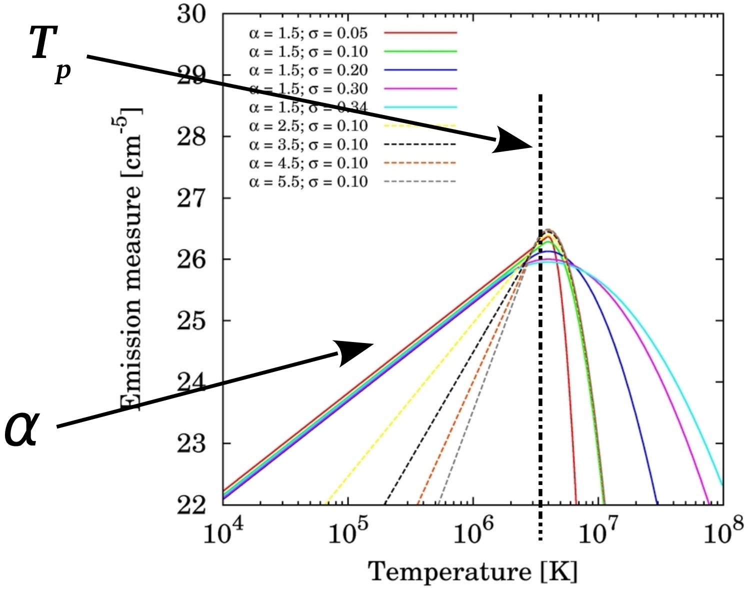

+

$$\xi^I = \arg\min \left[\sum_{b=1}^{N_b} \left(\frac{I_b^{obs}(\xi^P) - I_b^{th}(\xi)}{\sigma_b^u} \right)^2 \right]$$

(Guennou et al. 2012, part I and II)

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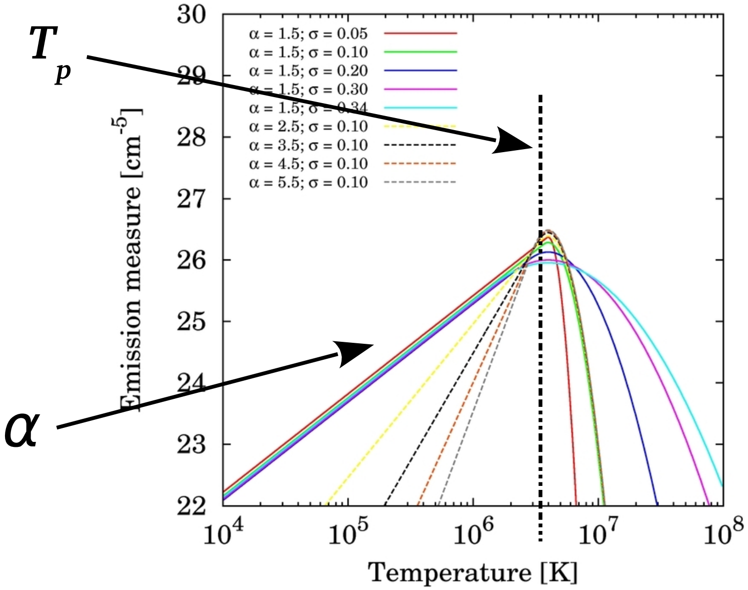

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measurement noises

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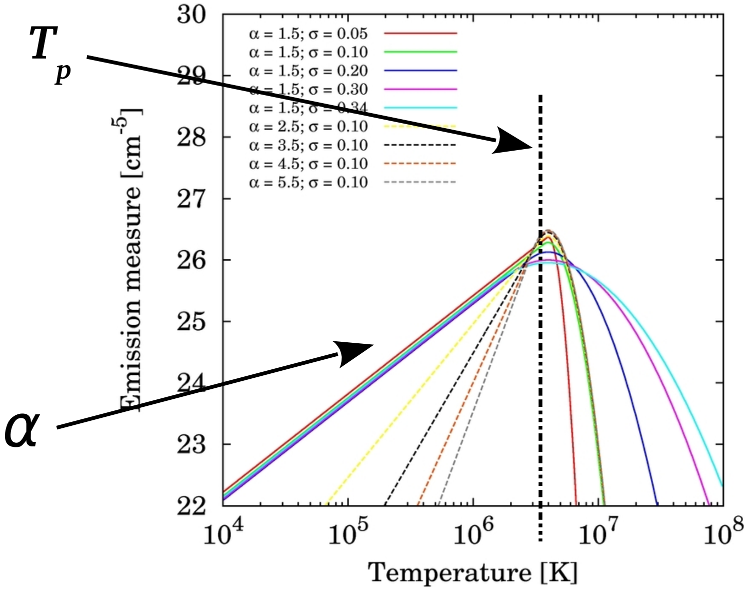

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measurement noises

systematic errors

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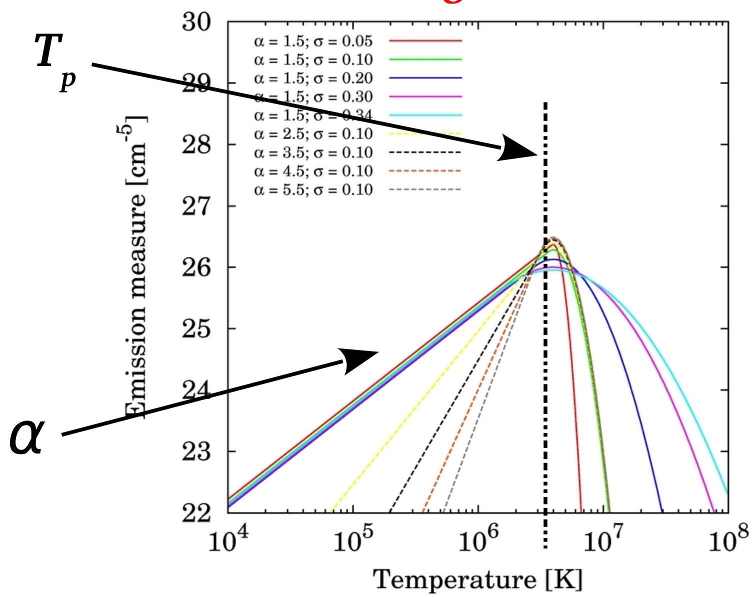

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systematic errors

~25-30%
total uncertainty

(Guennou et al. 2012, part I and II)

Thanks to H. Mason, E. Landi, G. DelZanna, J. Schmelz, H. Warren, P. Young, G. Doschek

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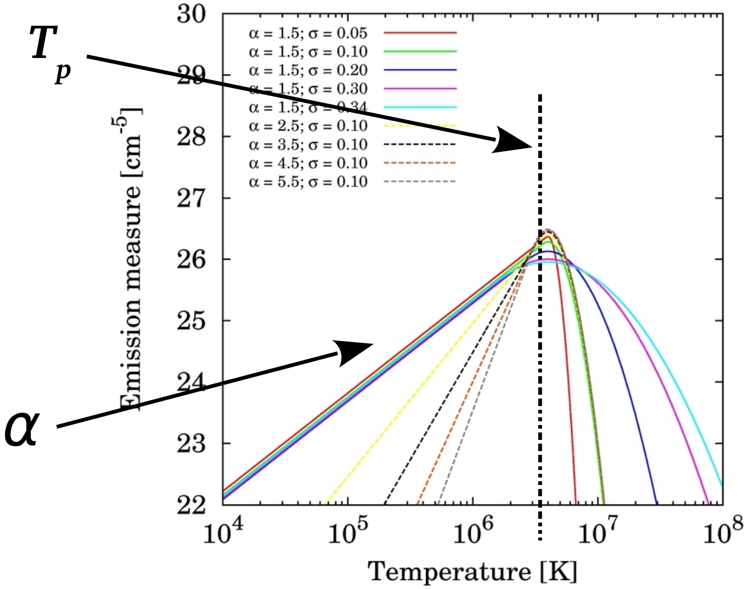

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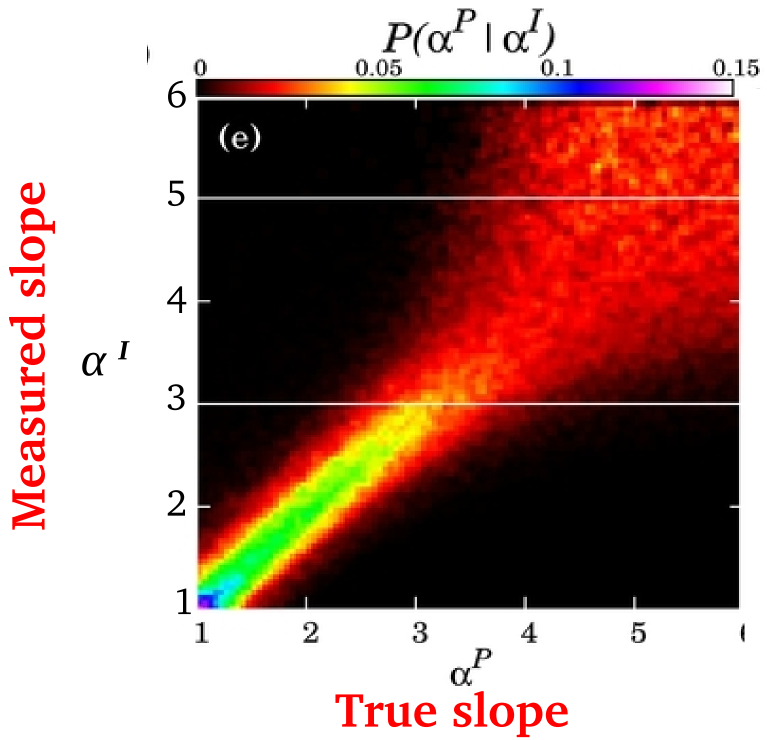
Compute *all the solutions consistent with the data*
+ associated probabilities

→ to derive confidence level on the estimated slopes

Reconstruction of the slope

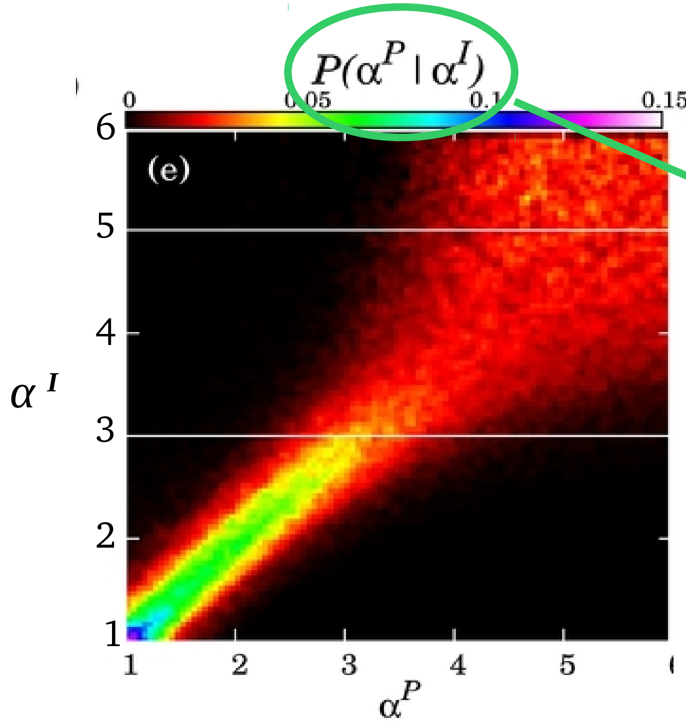
$\log T_c^P = 6.8$



Reconstruction of the slope

$\log T_c^P = 6.8$

Measured slope



True slope

Probability of the *true slope* knowing the *measured* **one**

Reconstruction of the slope

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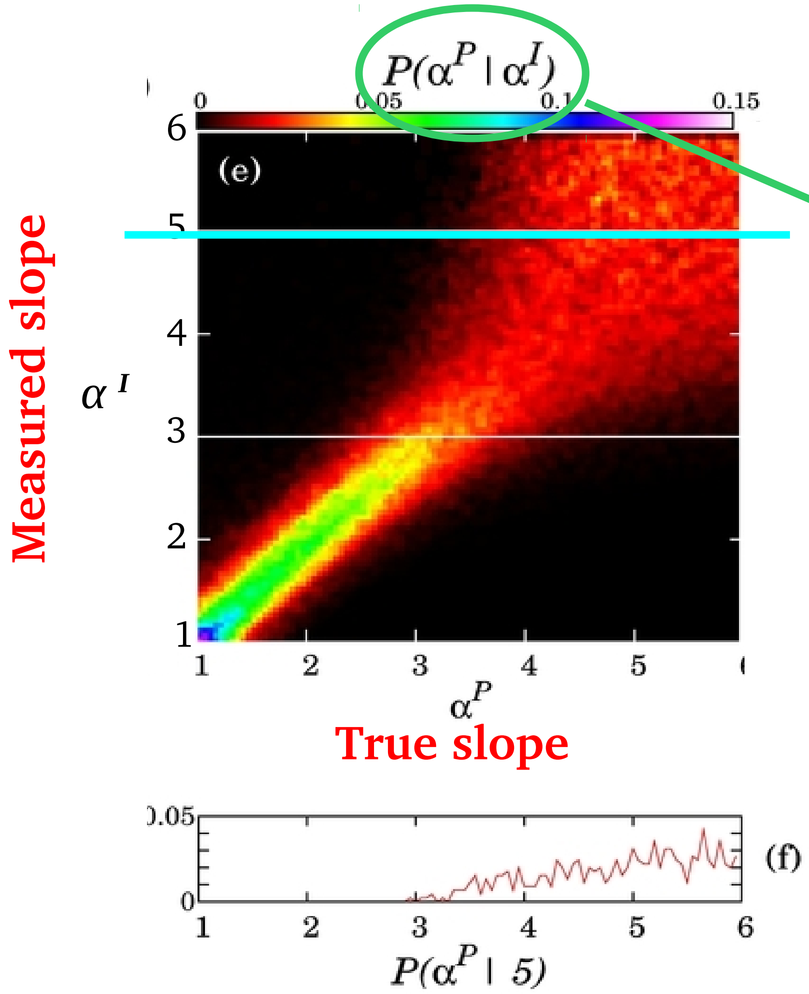

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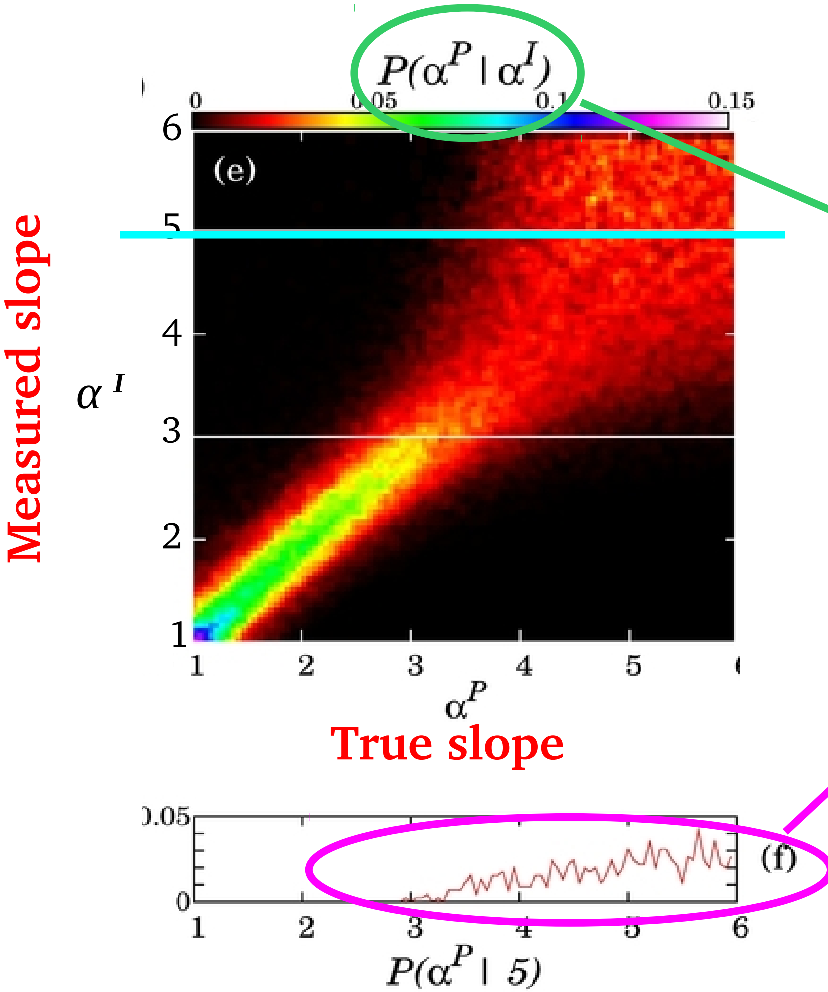

Probability of the *true slope* knowing the *measured* **one**

Probability distribution of the solutions

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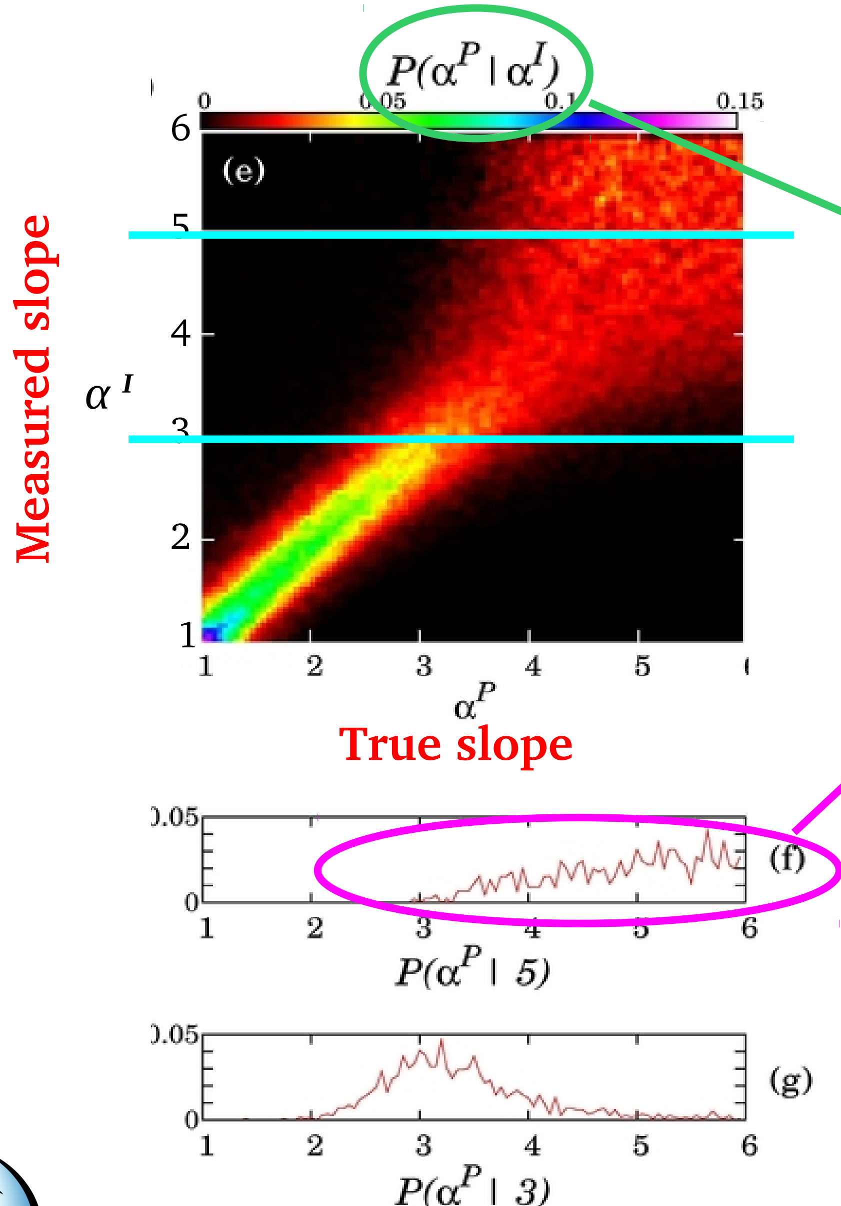

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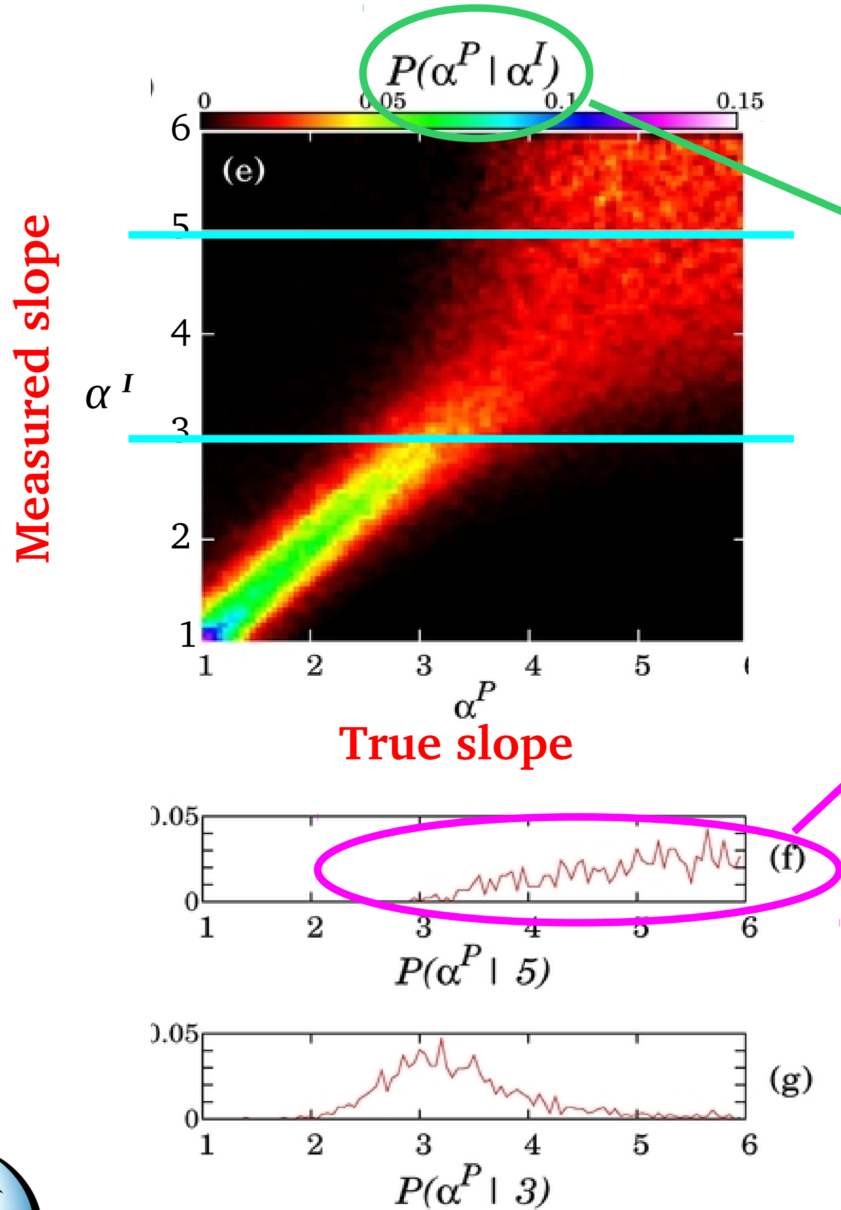


Probability of the *true slope* knowing the *measured* **one**

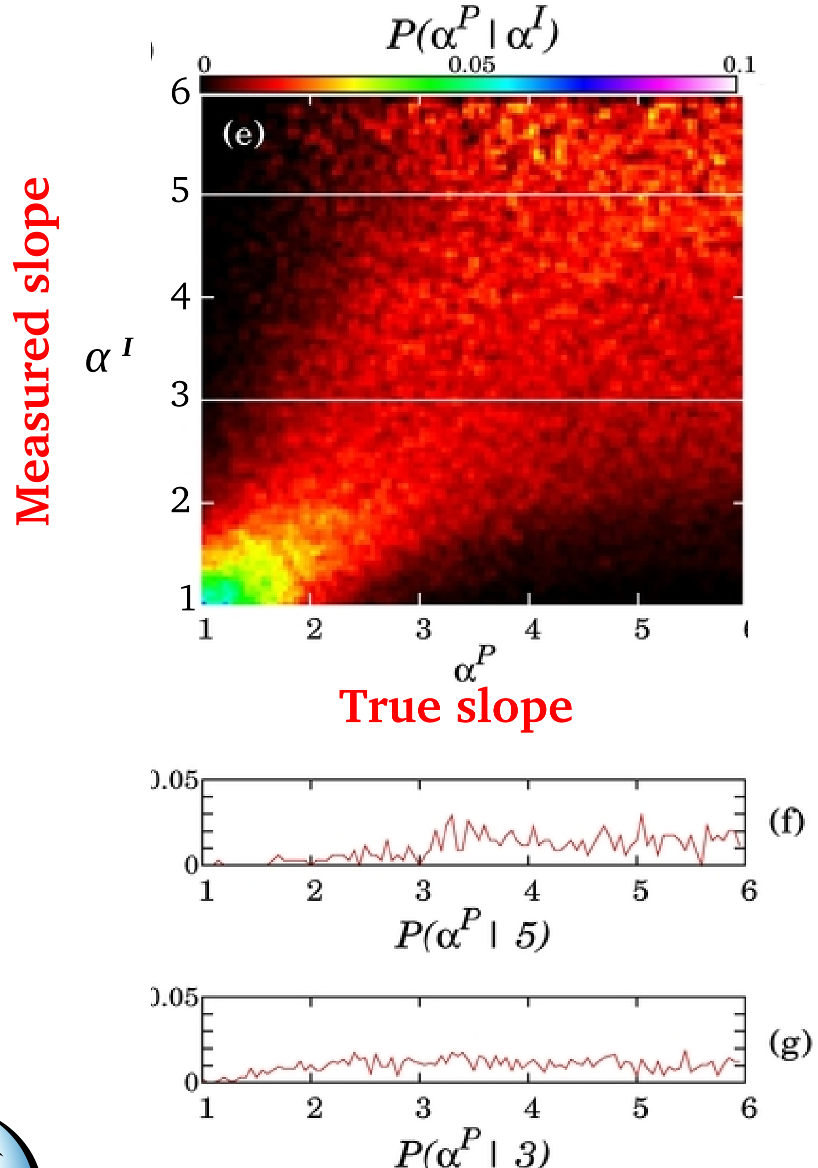
Probability distribution of the solutions

$\alpha^P = 4.9 \pm 0.7$

$\alpha^P = 3.2 \pm 0.6$

Reconstruction of the slope

$log\ T_c^P = 6.5$



Reconstruction of the slope

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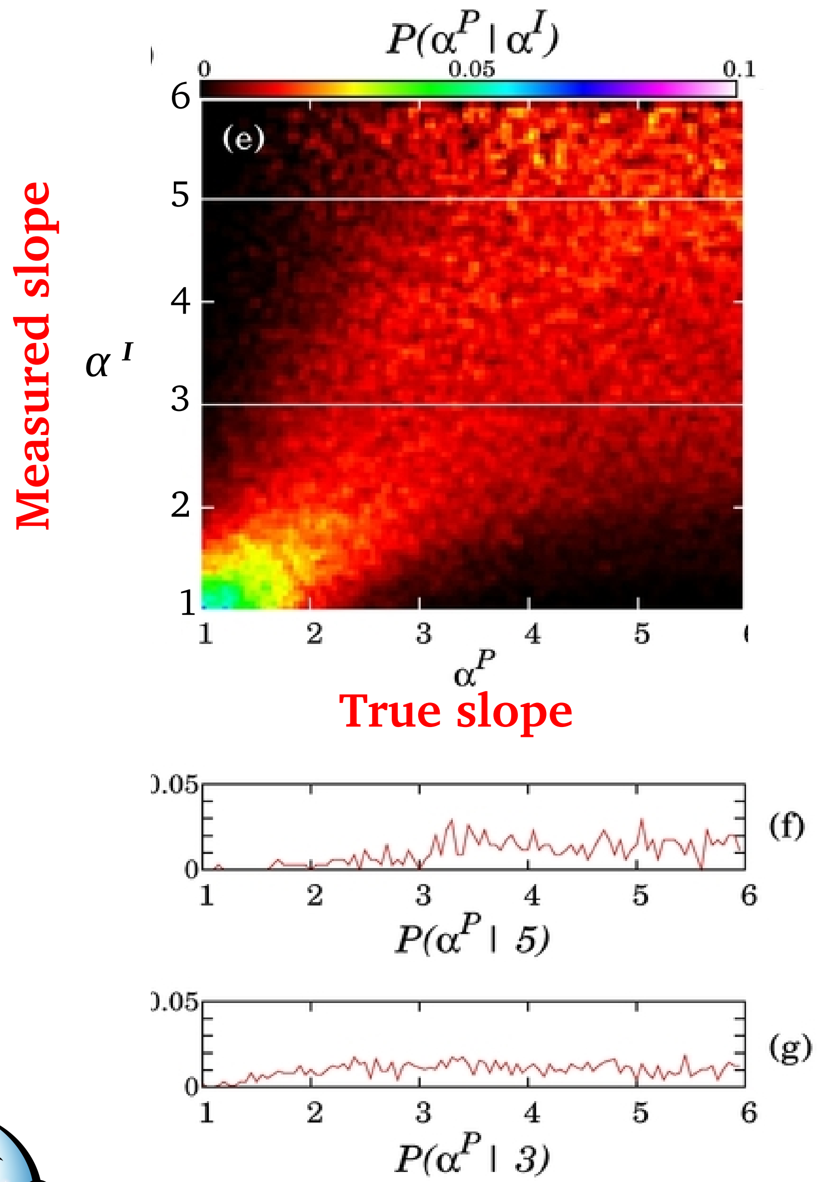

$\alpha^P = 5 \pm 1.1$

$\alpha^P = 3.8 \pm 1.2$

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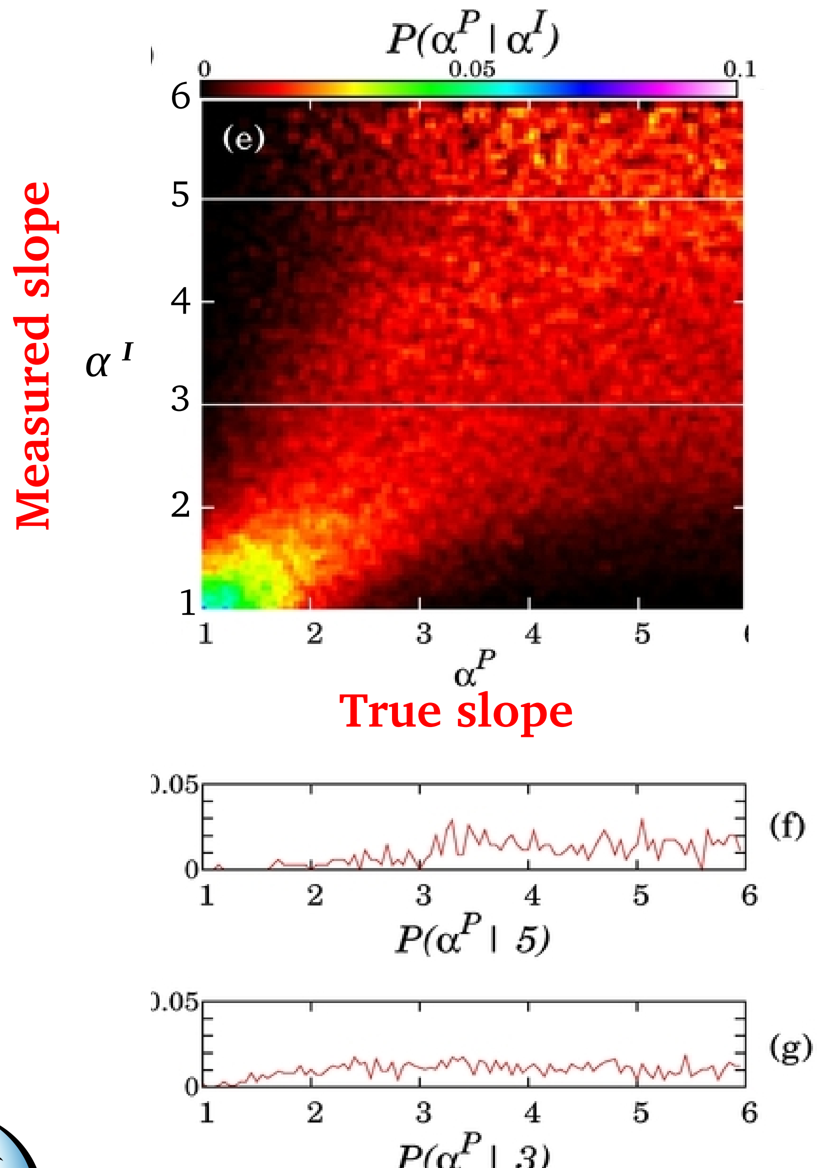

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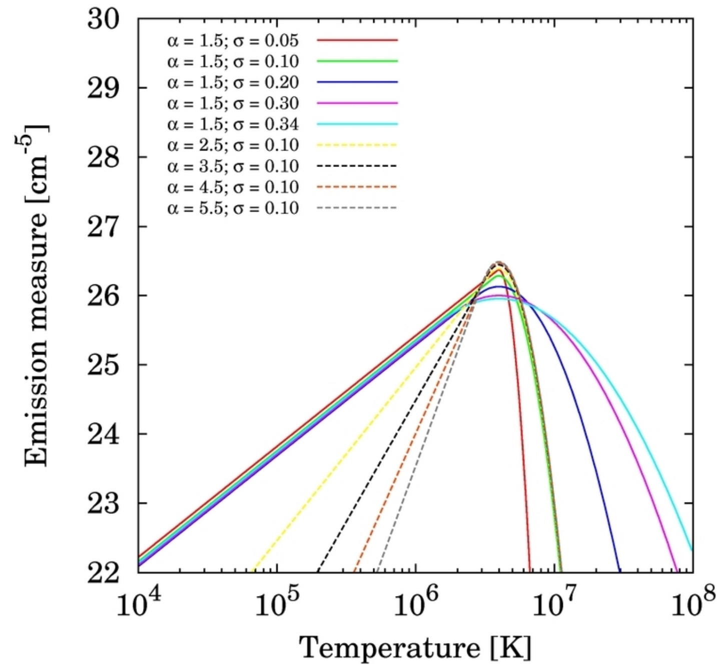
Dégradation of the quality of the reconstruction

List of used lines

Ions	Wavelength (Å)	$\log(T[K])$
Mg V	276.579	5.45
Mg VI	268.991	5.65
Mg VI	270.391	5.65
Si VII	275.354	5.80
Mg VII^b	278.404	5.80
Mg VII	280.745	5.80
Fe IX	188.497	5.85
Fe IX	197.865	5.85
Fe X	184.357	6.05
Si IX	258.082	6.05
Fe XI	180.408	6.15
Fe XI	188.232	6.15
Si X	258.371	6.15
Si X	261.044	6.15
S X	264.231	6.15
Fe XII	192.394	6.20
Fe XII	195.119	6.20
Fe XIII	202.044	6.25
Fe XIII	203.828	6.25
Fe XIV	264.790	6.30
Fe XIV	270.522	6.30
Fe XIV^b	274.204	6.30
Fe XV	284.163	6.35
S XIII^b	256.685	6.40
Fe XVI	262.976	6.45
Ca XIV	193.866	6.55
Ca XV	200.972	6.65
Ca XVI	208.604	6.70
Ca XVII^b	192.853	6.75



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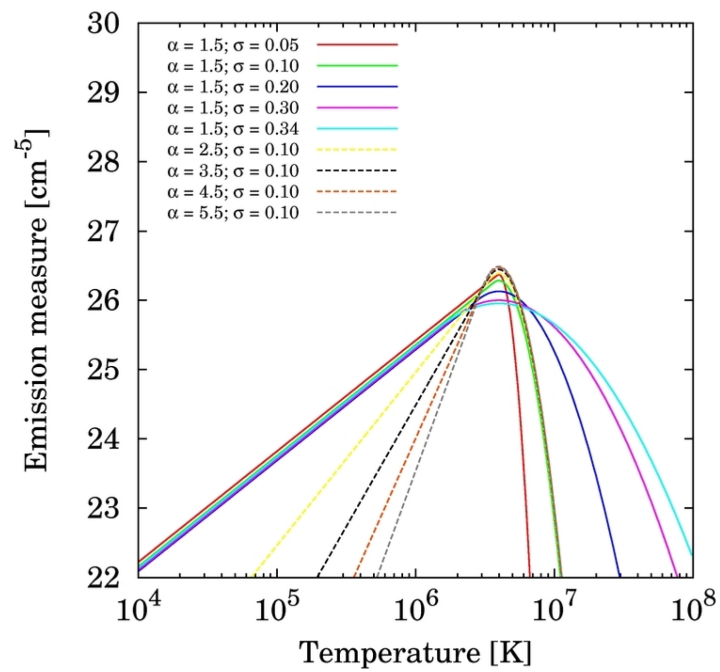

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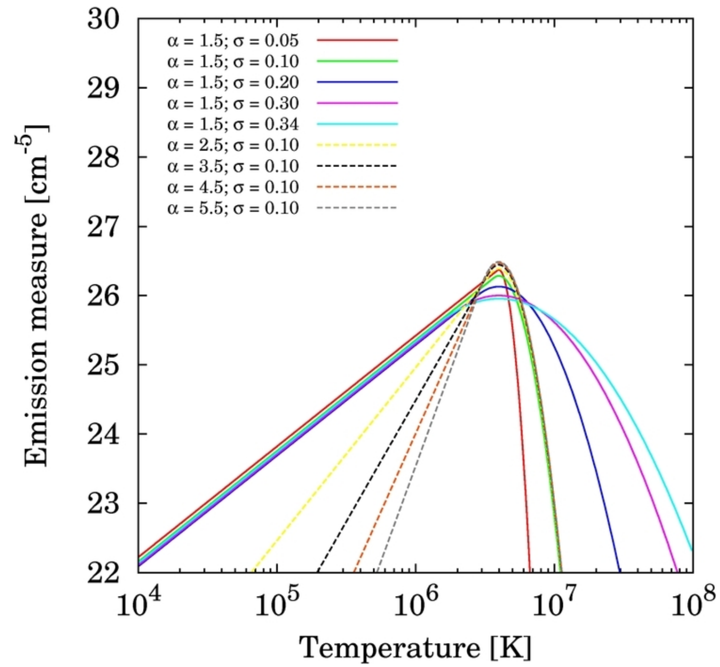
$T_p = 10^{6.8}$ K



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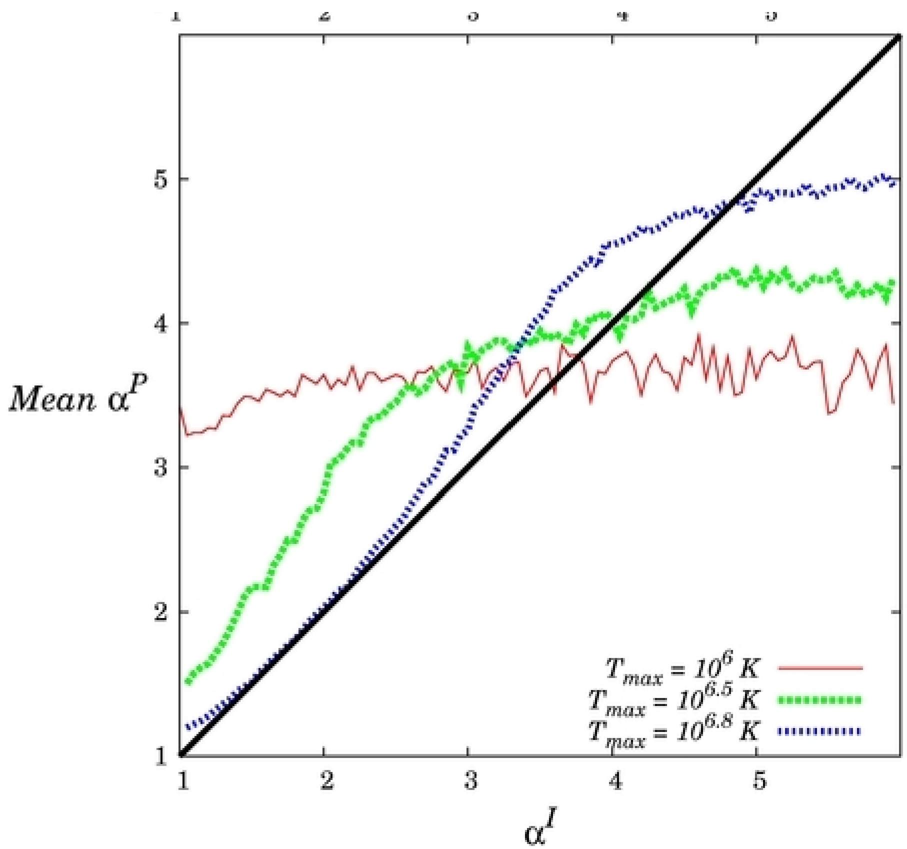
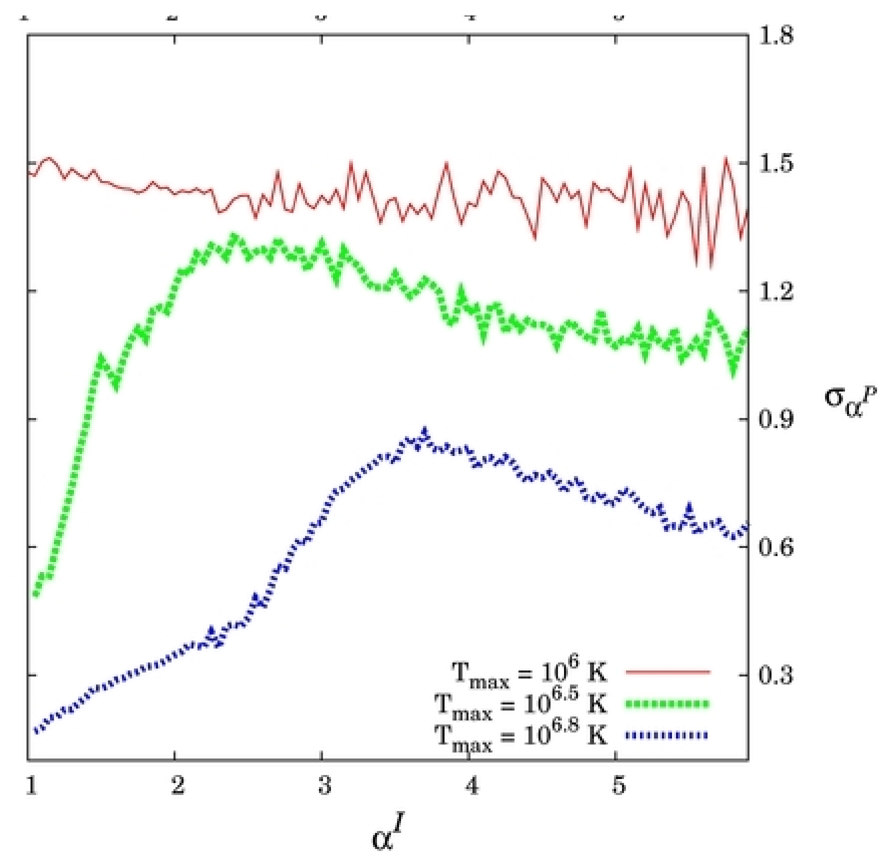
Providing confidence level on the DEM slope

True slope mean value



Measured slope

True slope standard deviation



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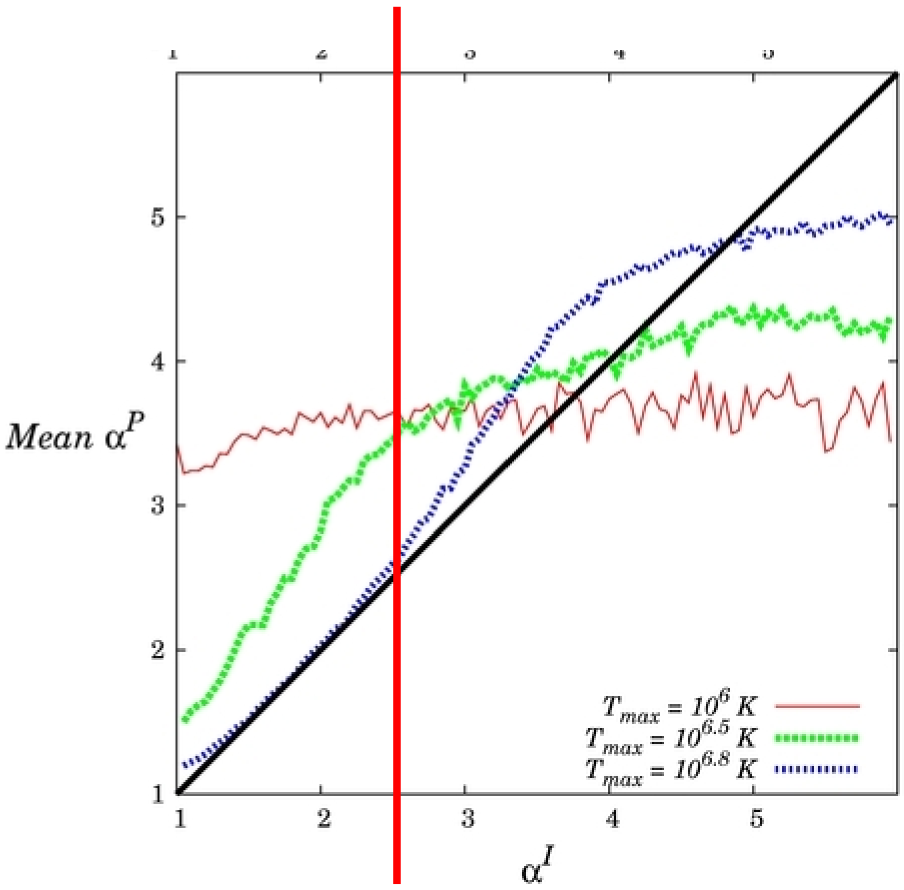

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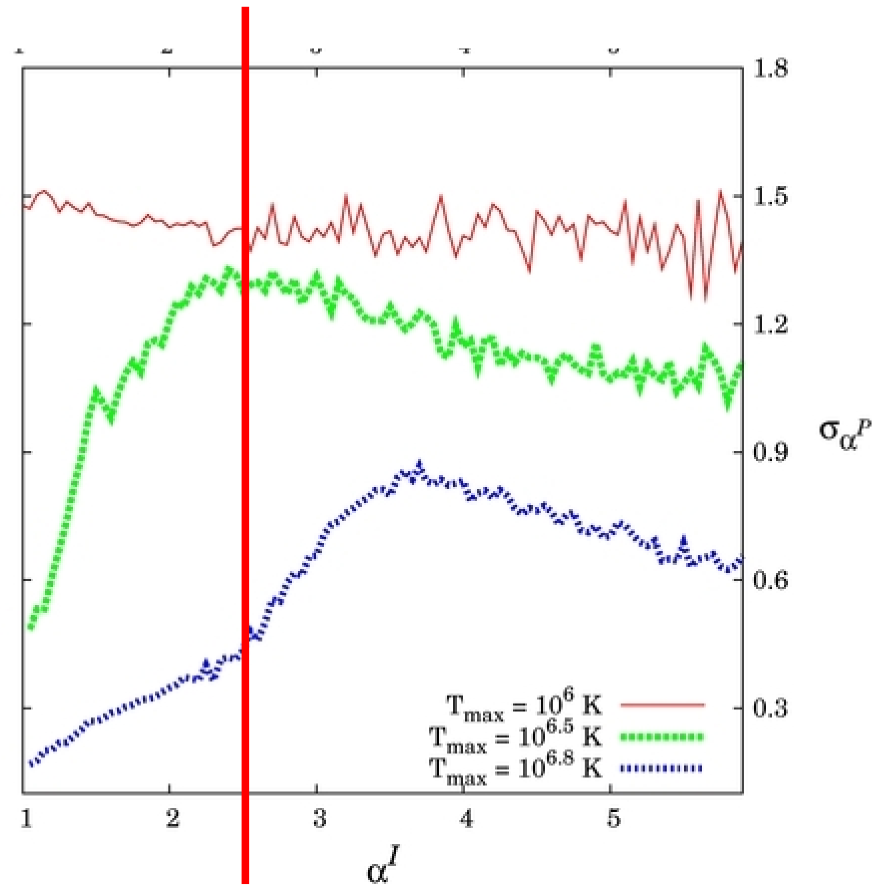

Measured slope

EIS capabilities

→ *Difficulty to constrain the timescale of heating event* :

22 Active Region Cores (inter-moss regions)

Bradshaw et al. (2012)

	$\alpha \leq 2.0$	$2.0 < \alpha \leq 2.5$	$2.5 < \alpha \leq 3.0$	$3.0 < \alpha \leq 3.5$	$\alpha > 3.5$
α	3	5	3	6	5

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Schmelz & Pathak (2012)
Tripathi, Klimchuk, & Mason (2011)
Warren, Brooks, & Winebarger (2011)
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Model of low frequency nanoflares → **$0.81 \leq \alpha \leq 2.56$**

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Δα = ± 1.0

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α	3	5	3	6	5

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Bradshaw et al. (2012)

$\Delta\alpha = \pm 1.0$

	$\alpha \leq 2.0$	$2.0 < \alpha \leq 2.5$	$2.5 < \alpha \leq 3.0$	$3.0 < \alpha \leq 3.5$	$\alpha > 3.5$	
α	3	5	3	6	5	**36% consistent**
$\alpha - \Delta\alpha$	11	6	2	2	1	77% consistent

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Schmelz & Pathak (2012)
Tripathi, Klimchuk, & Mason (2011)
Warren, Brooks, & Winebarger (2011)
Warren, Winebarger, & Brooks (2012)
Winebarger et al. (2011)

EIS capabilities

→ ***Difficulty to constrain the timescale of heating event*** :

22 Active Region Cores (inter-moss regions)

Bradshaw et al. (2012)

$\Delta\alpha = \pm 1.0$

	$\alpha \leq 2.0$	$2.0 < \alpha \leq 2.5$	$2.5 < \alpha \leq 3.0$	$3.0 < \alpha \leq 3.5$	$\alpha > 3.5$	
α	3	5	3	6	5	**36% consistent**
$\alpha - \Delta\alpha$	11	6	2	2	1	**77% consistent**
$\alpha + \Delta\alpha$			3	5	14	**0% consistent**

Model of low frequency nanoflares → **$0.81 \leq \alpha \leq 2.56$**

Schmelz & Pathak (2012)
Tripathi, Klimchuk, & Mason (2011)
Warren, Brooks, & Winebarger (2011)
Warren, Winebarger, & Brooks (2012)
Winebarger et al. (2011)

Thank you !

List of used lines

Ion	Wavelength (Å)	$\log_{10}$ T (K)
Mg V	276.579	5.45
Mg VI	268.991	5.65
Mg VI	270.391	5.65
Si VII	275.354	5.80
Mg VII	278.404	5.80
Mg VII	280.745	5.80
Fe IX	188.497	5.85
Fe IX	197.865	5.85
Si IX	258.082	6.05
Fe X	184.357	6.05
Fe XI	180.408	6.15
Fe XI	188.232	6.15
Si X	258.371	6.15
Si X	261.044	6.15
S X	264.231	6.15

Ion	Wavelength (Å)	$\log_{10}$ T (K)
S X	264.231	6.15
Fe XII	192.394	6.20
Fe XII	195.119	6.20
Fe XIII	202.044	6.25
Fe XIII	203.828	6.25
Fe XIV	264.790	6.30
Fe XIV	270.522	6.30
Fe XIV	274.204	6.30
Fe XV	284.163	6.35
S XIII	256.685	6.40
Fe XVI	262.976	6.45
Ca XIV	193.866	6.55
Ca XV	200.972	6.65
Ca XVI	208.604	6.70
Ca XVII	192.853	6.75
Fe XVII	269.494	6.75

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Random and systematics errors are taken into account

Random n_b	Systematics s_b
Read noise	Calibration
Photon noise	Atomic physics

- Abundance of each element : 30%
- Ionization balance : 30%
- combined radiative + excitation rates + atomic structure calculations uncertainties : 20%
- FIP effect → 30% on low FIP elements

Thanks to H. Mason, E. Landi, G. DelZanna, J. Schmelz.

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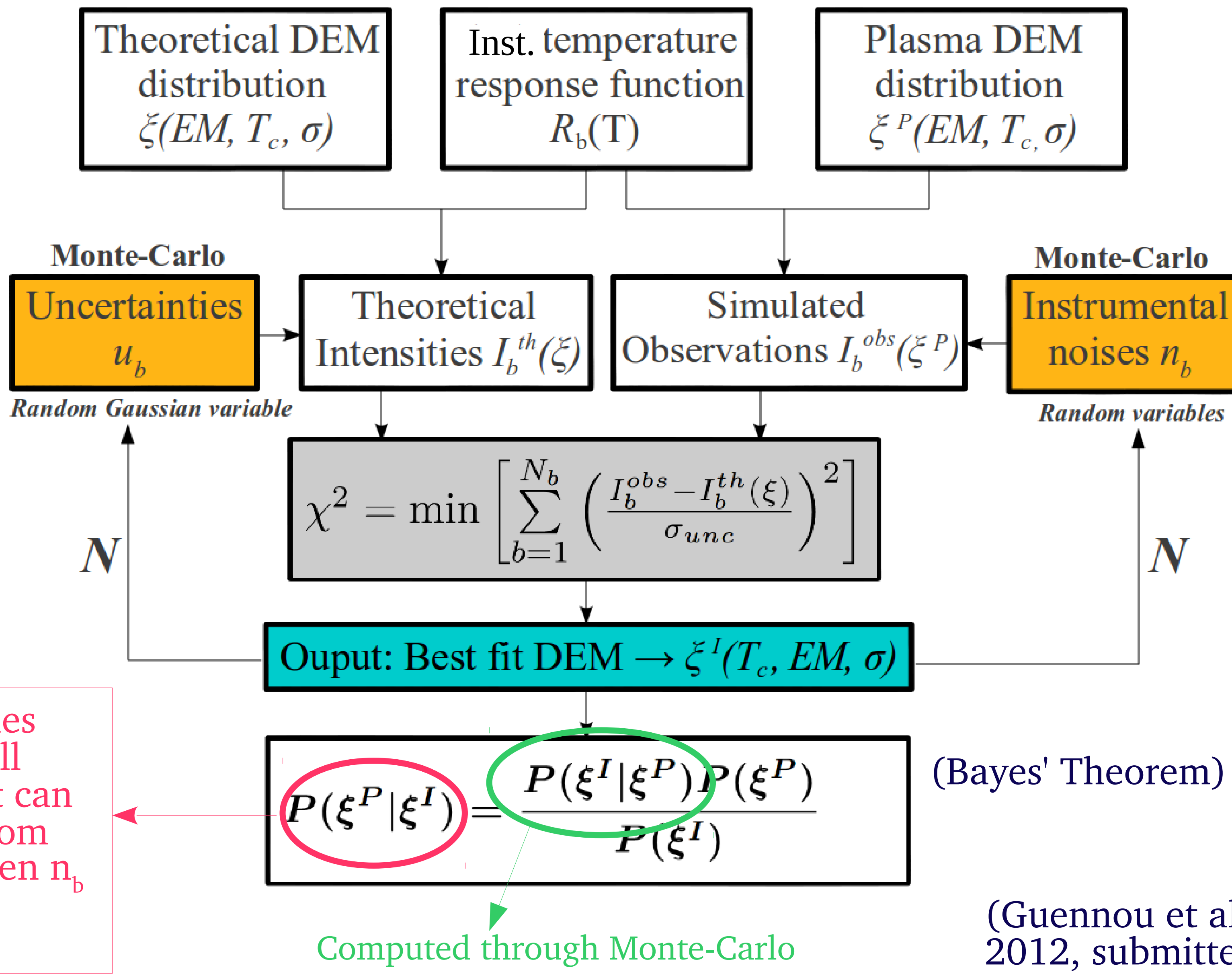


(Bayes' Theorem)

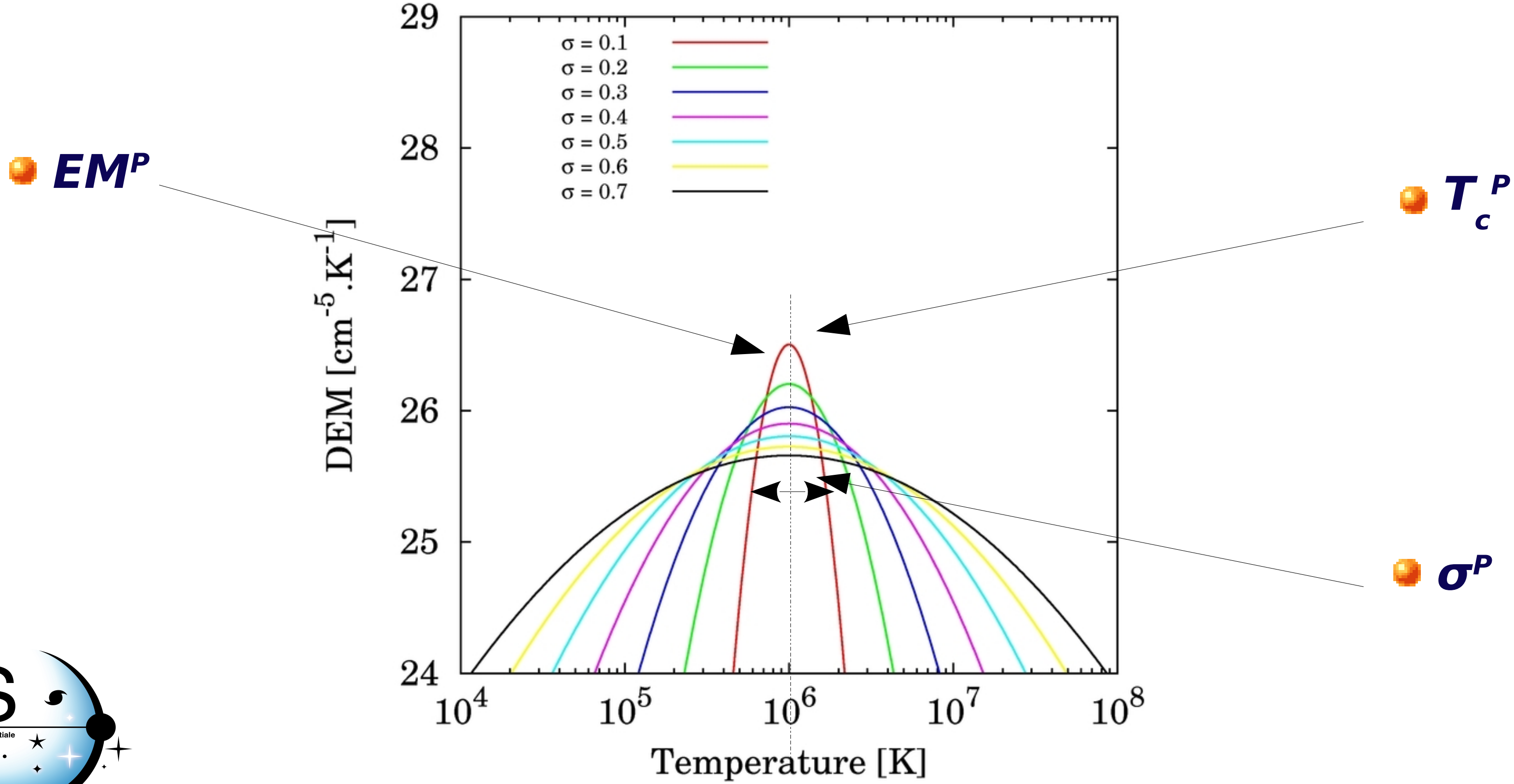
Desirable values
→ Contains all information that can be extracted from observations, given n_b and s_b

(Guennou et al., part I, 2012, submitted)

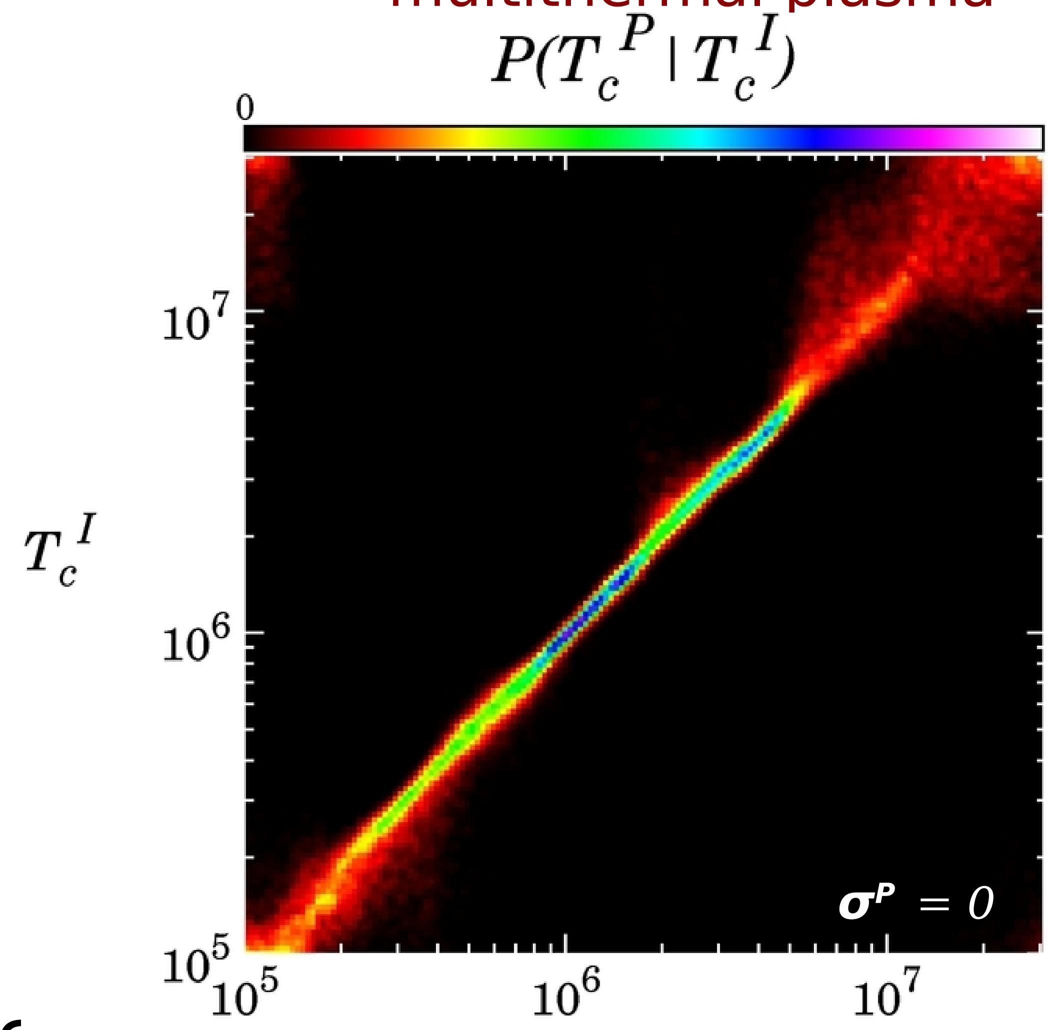
EIS capabilities to reconstruct multithermal plasma

- **Simulations using Gaussian DEMs ξ^P,**
  → Useful to represent a great class of plasma thermal condition

$P(EM^I, T_c^I, \sigma^I \mid EM^P, T_c^P, \sigma^P)$



EIS capabilities to reconstruct multithermal plasma

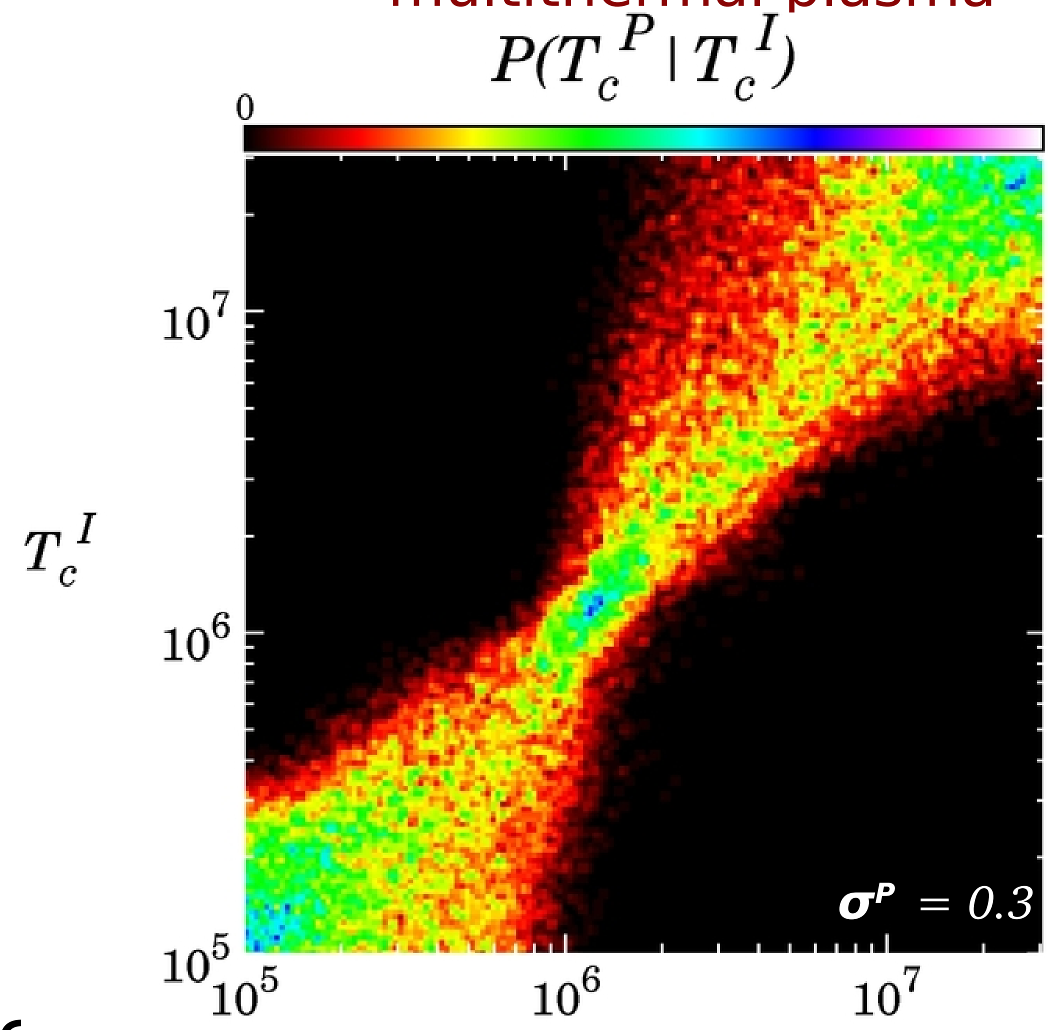


$P(\boldsymbol{EM^P}, \boldsymbol{T_c^P}, \boldsymbol{\sigma^P} \mid \boldsymbol{EM^I}, \boldsymbol{T_c^I}, \boldsymbol{\sigma^I})$

- $\boldsymbol{EM^P} = 10^{28}\ \mathrm{m}^{-5}$

$\boldsymbol{\Sigma\ (EM^I, \sigma^I)}$

EIS capabilities to reconstruct multithermal plasma

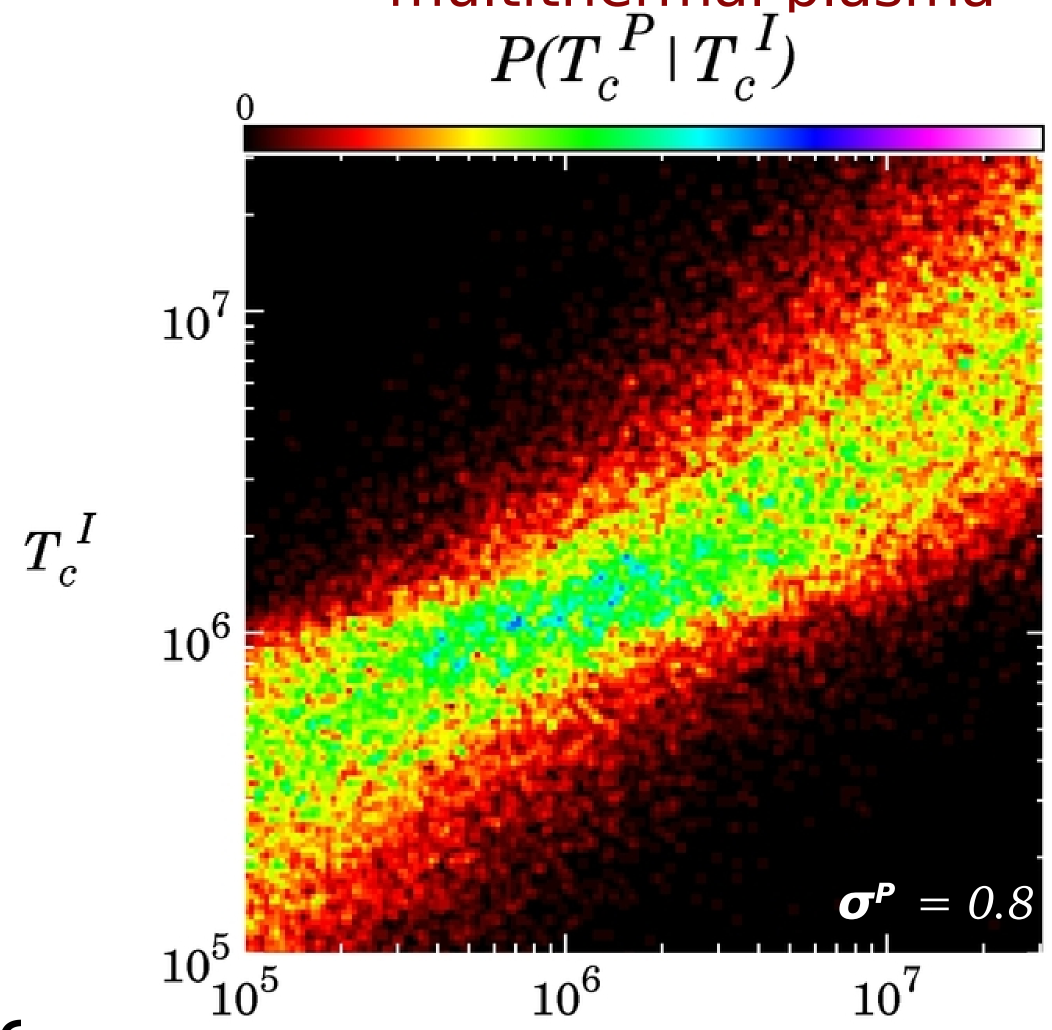


$P(EM^P, T_c^P, \sigma^P \mid EM^I, T_c^I, \sigma^I)$

- $EM^P = 10^{28}$ m^{-5}

$\Sigma\,(EM^I, \sigma^I)$

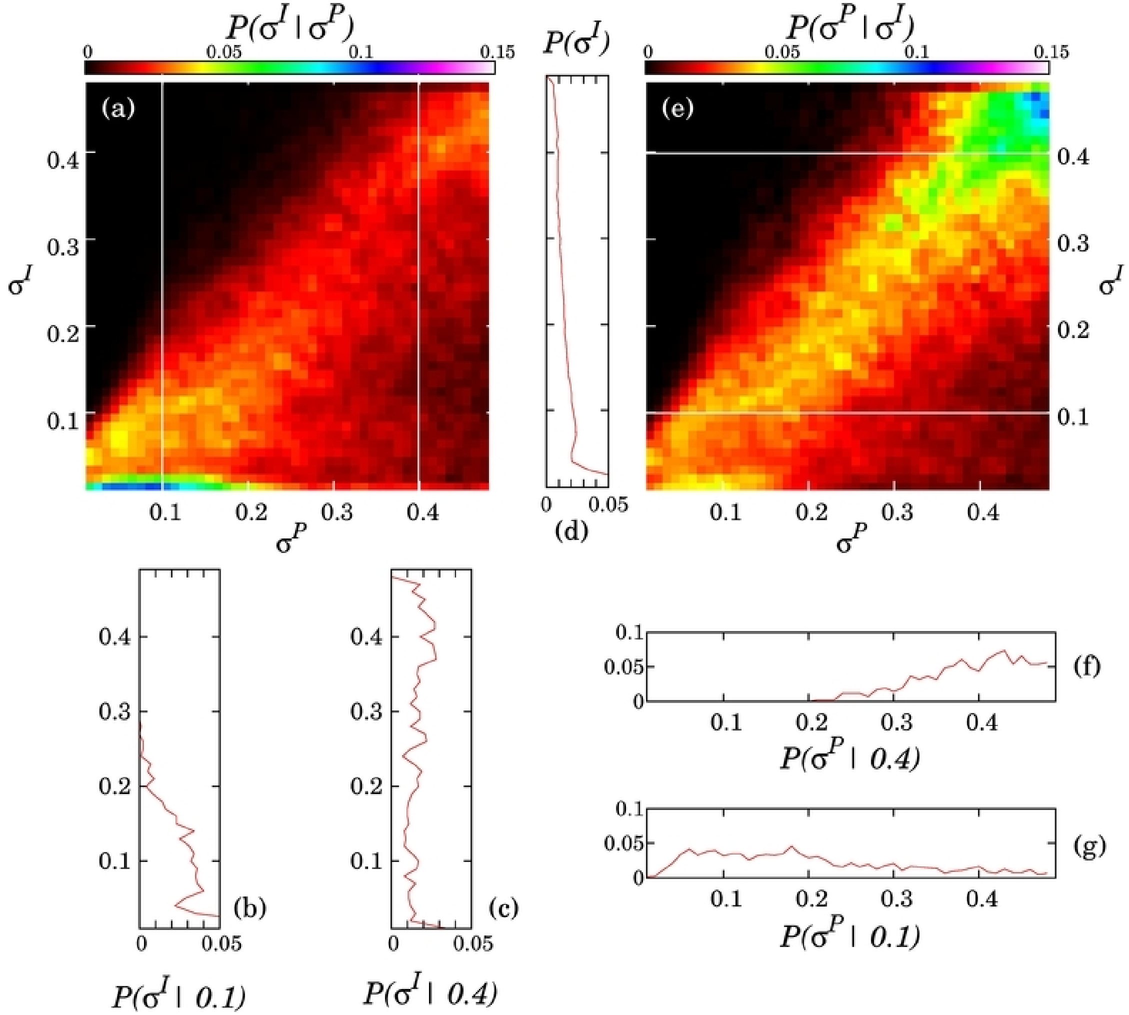
EIS capabilities to reconstruct multithermal plasma



$P(EM^P, T_c^P, \sigma^P \mid EM^I, T_c^I, \sigma^I)$

- $EM^P = 10^{28}$ m^{-5}

$\Sigma (EM^I, \sigma^I)$



$T_p = 10^6$ K

→ Only a few information about the thermal structure at high temperature can be extracted (cf Winebarger et al. 2012)