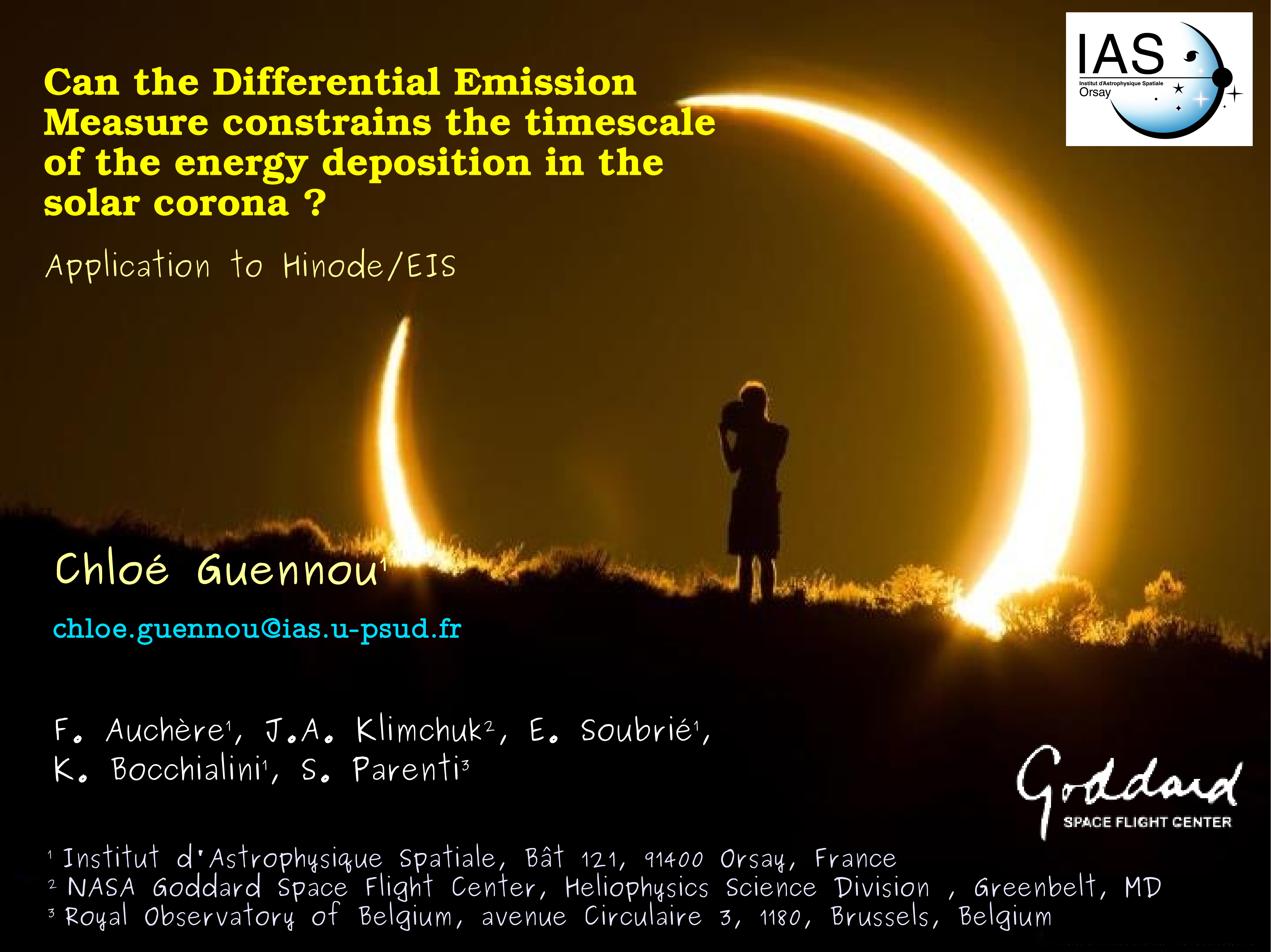

Can the Differential Emission Measure constrains the timescale of the energy deposition in the solar corona ?

Application to Hinode/EIS

Chloé Guennou[1]

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F. Auchère[1], J.A. Klimchuk[2], E. Soubrié[1], K. Bocchialini[1], S. Parenti[3]

[1] Institut d'Astrophysique Spatiale, Bât 121, 91400 Orsay, France
[2] NASA Goddard Space Flight Center, Heliophysics Science Division , Greenbelt, MD
[3] Royal Observatory of Belgium, avenue Circulaire 3, 1180, Brussels, Belgium

Why ?

↳ DEM → Information about thermal structure

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

Why ?

DEM → Information about thermal structure

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

Temperature Response function

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- 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

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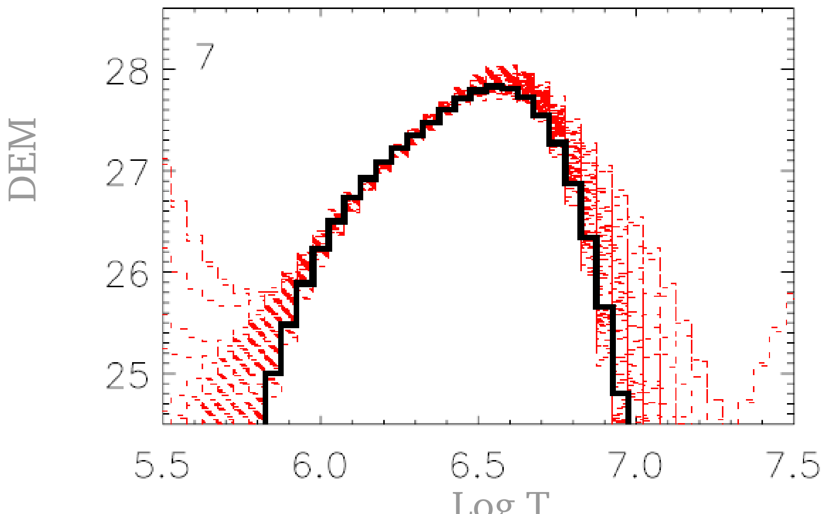

Schmelz & Pathak 2012

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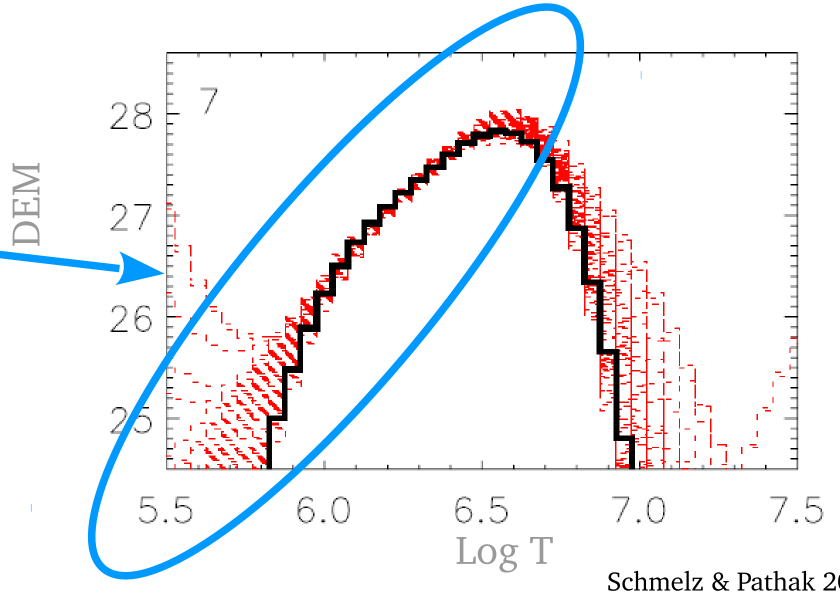

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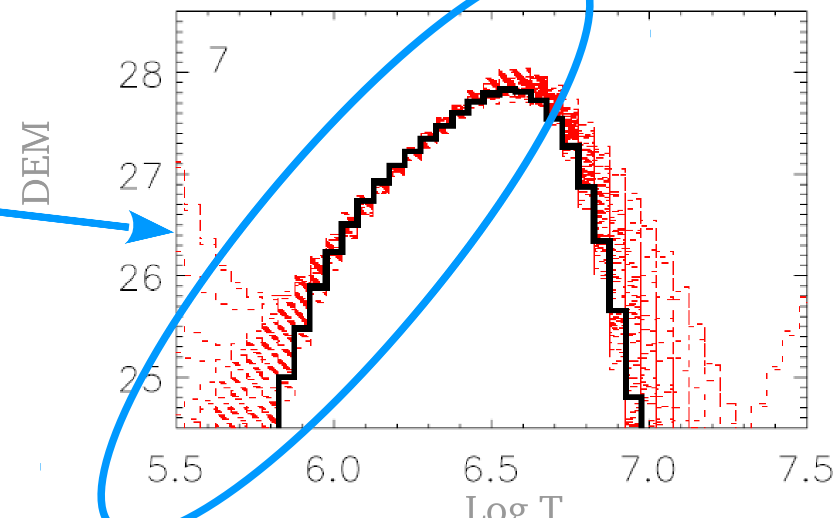

Schmelz & Pathak 2012

What is the confidence level of the reconstructed slope ?

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How ?

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

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

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

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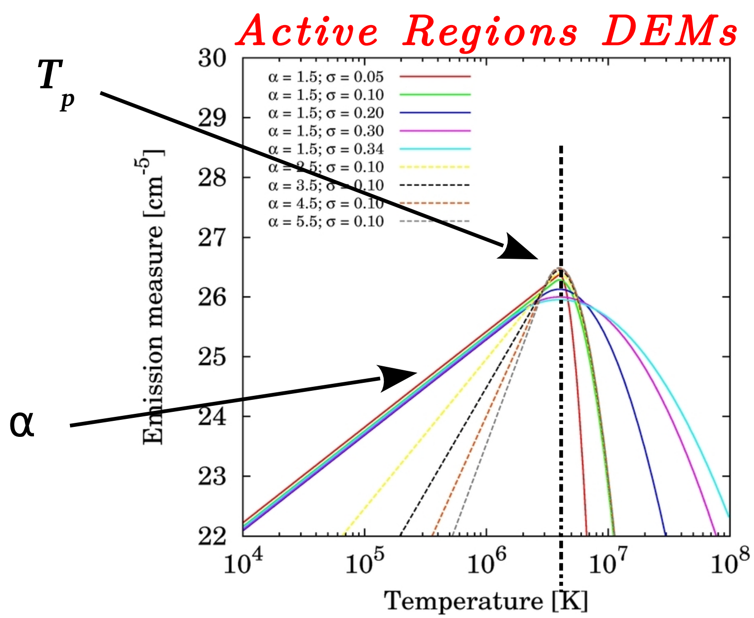

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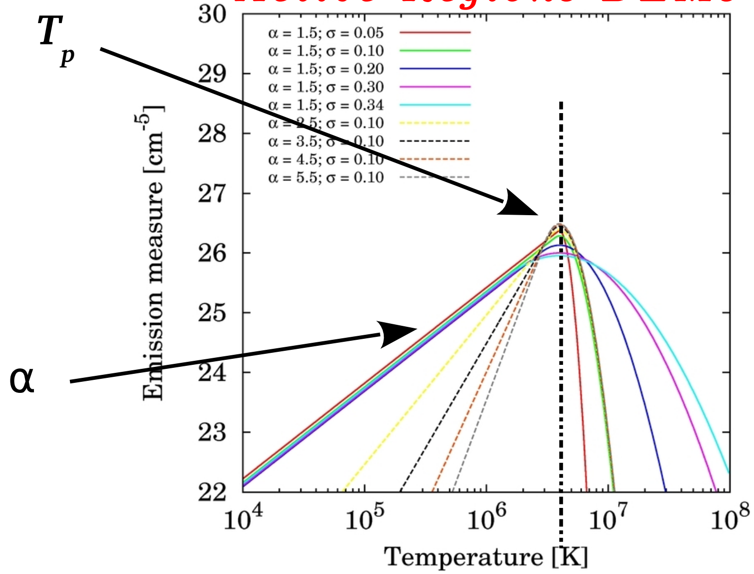
Active Regions DEMs



+

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

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

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Orsay

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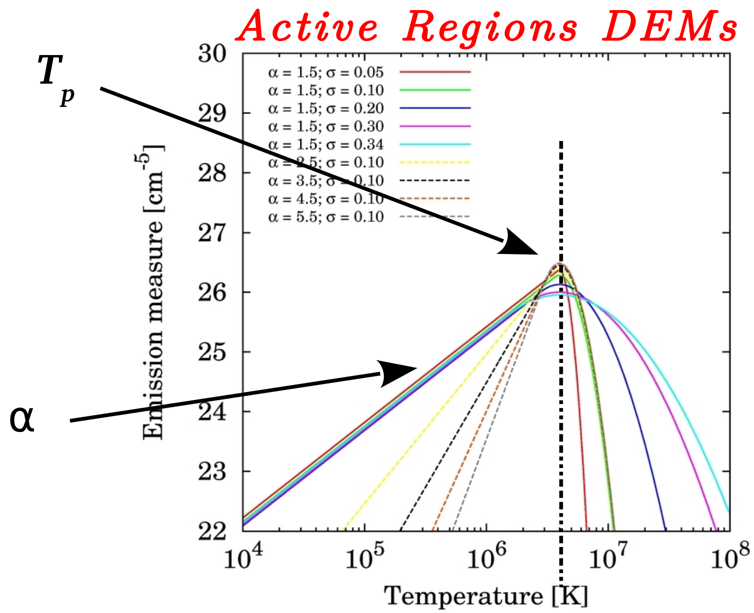

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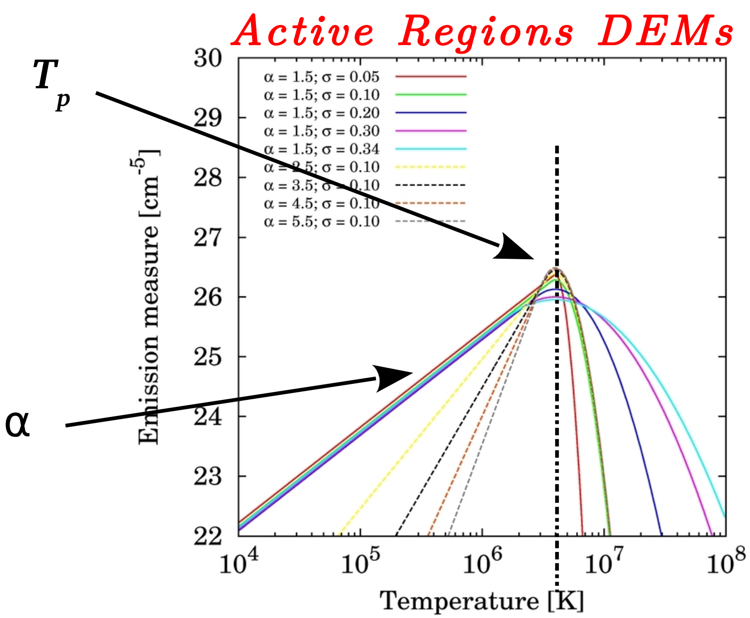

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(Guennou et al. 2012, part I and II)

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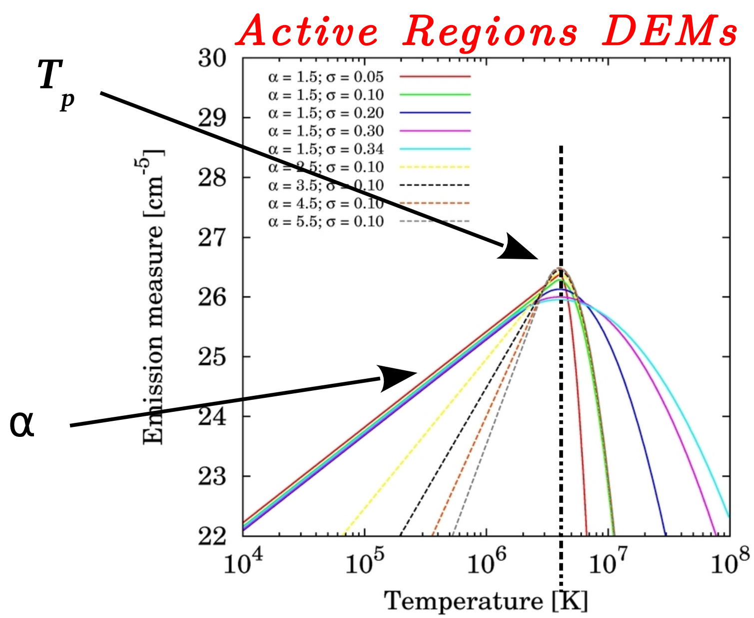

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measurement noises

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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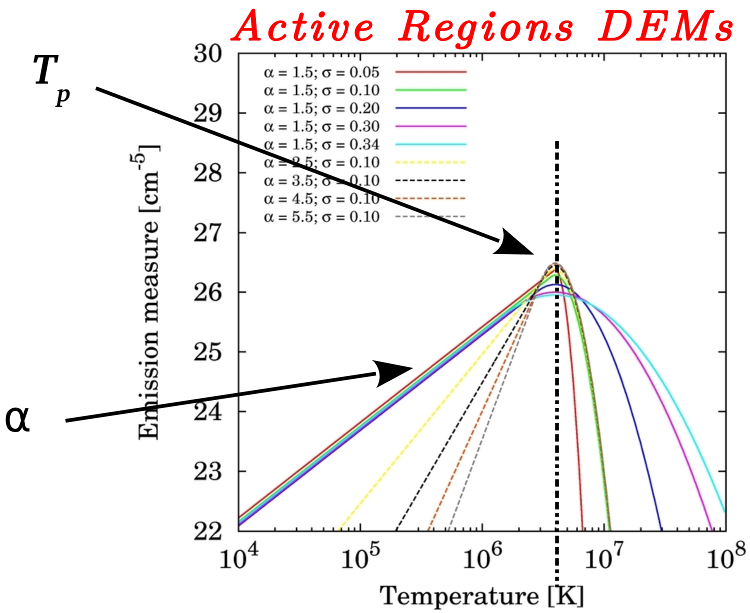

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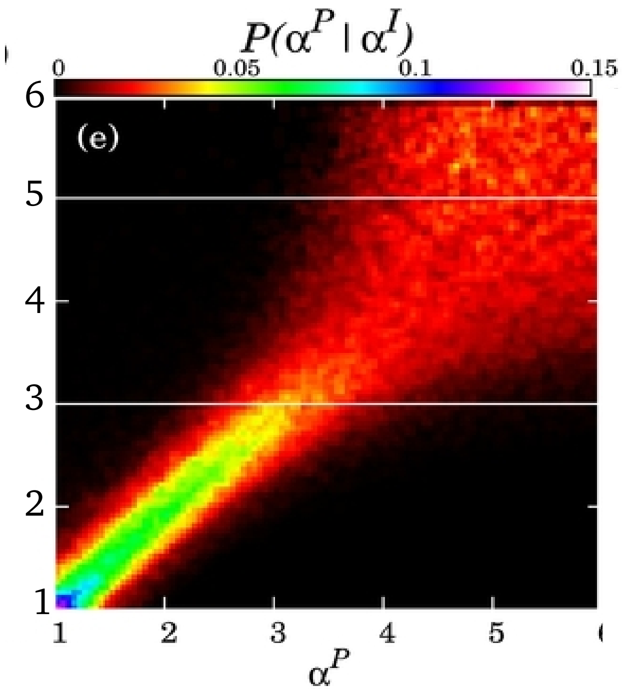
Compute *all the solutions consistent with the data* + associated probabilities

→ *to derive confidence level* on the estimated DEM slopes

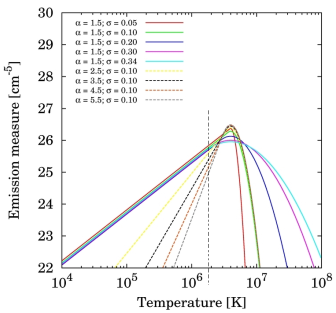
Reconstruction of the slope



Measured slope

True Plasma slope

$Log\ T_c^P = 6.8$



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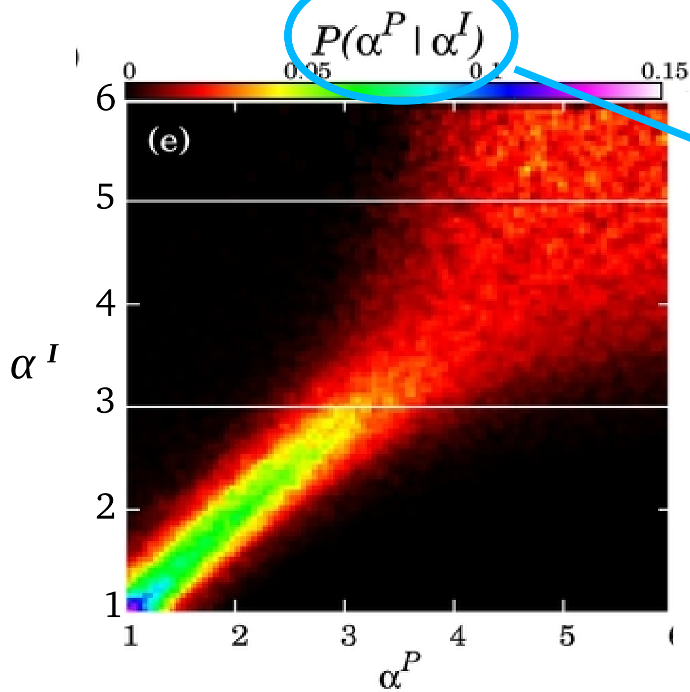
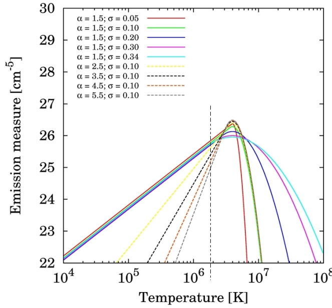


True Plasma slope

Probability that the **plasma** has a given slope knowing the **result of the inversion**



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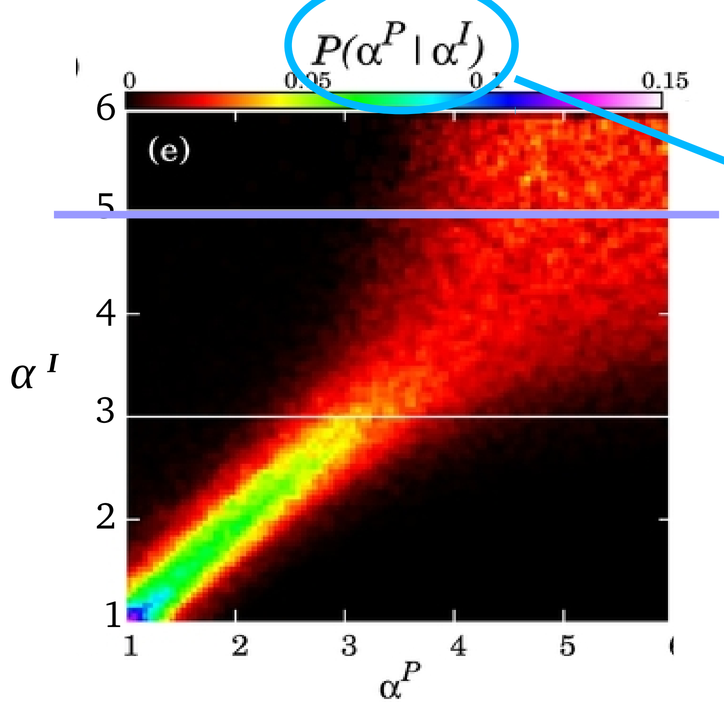

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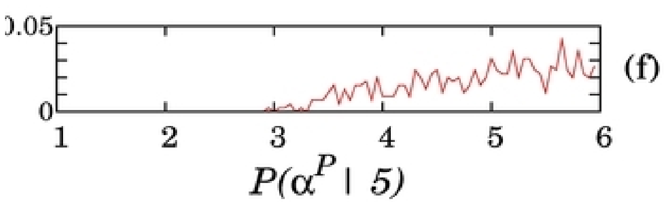

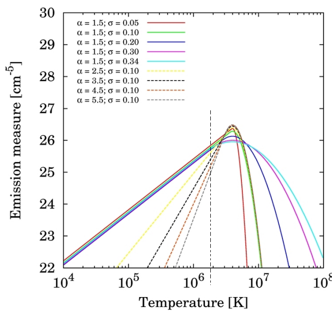

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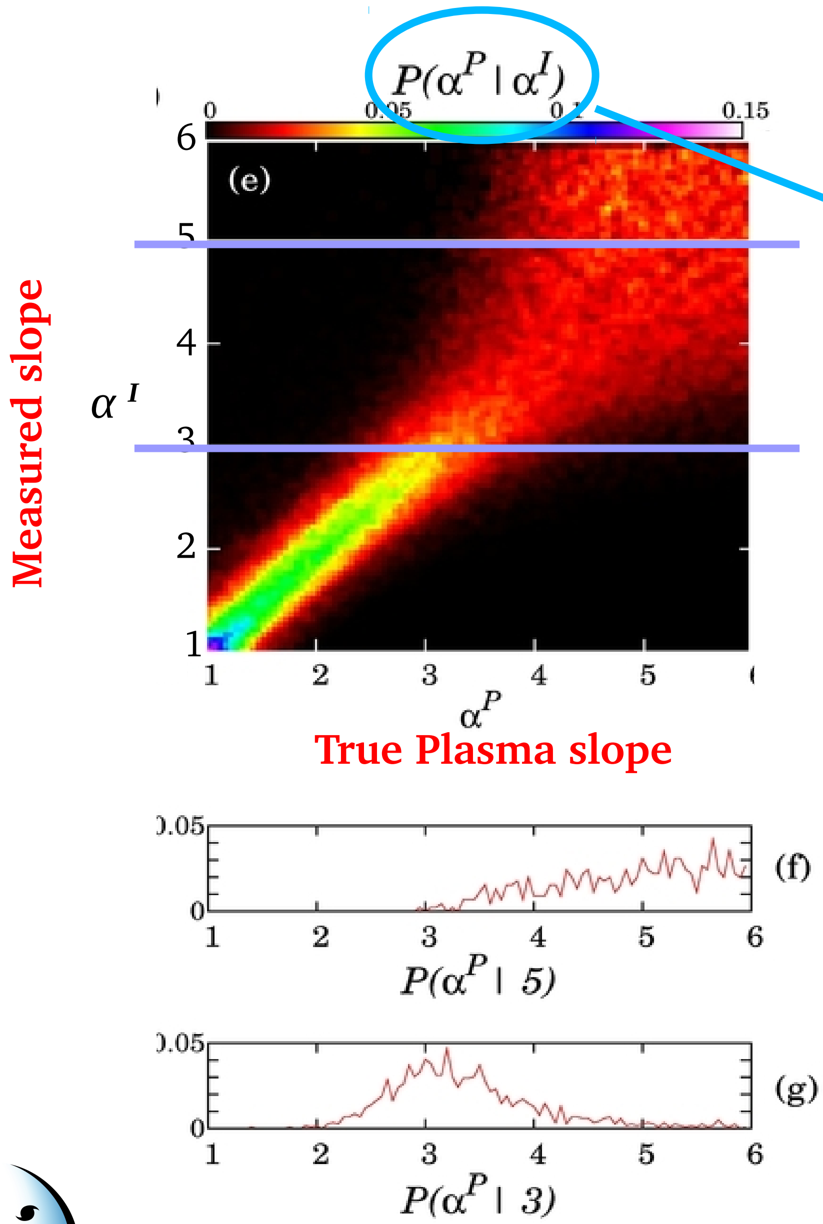

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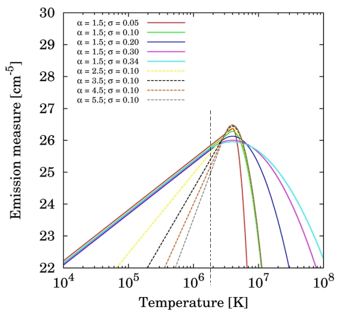

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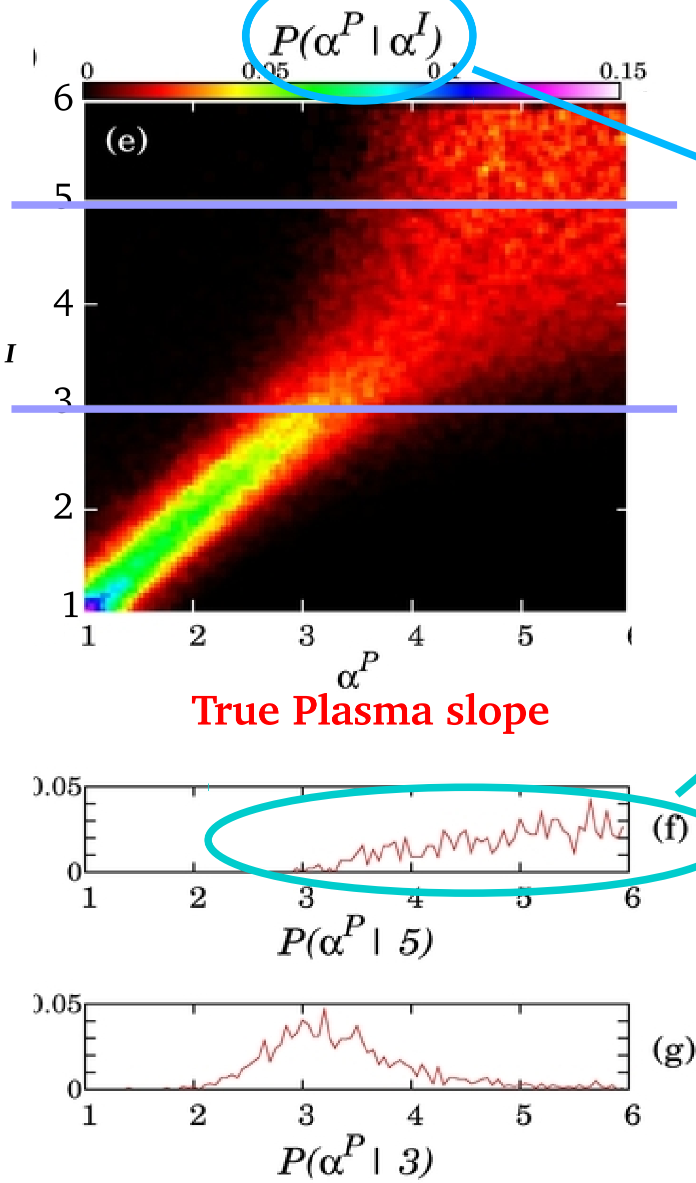

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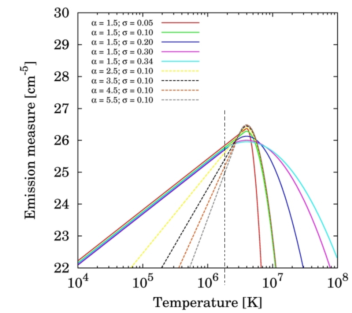
Probability distribution of the solutions



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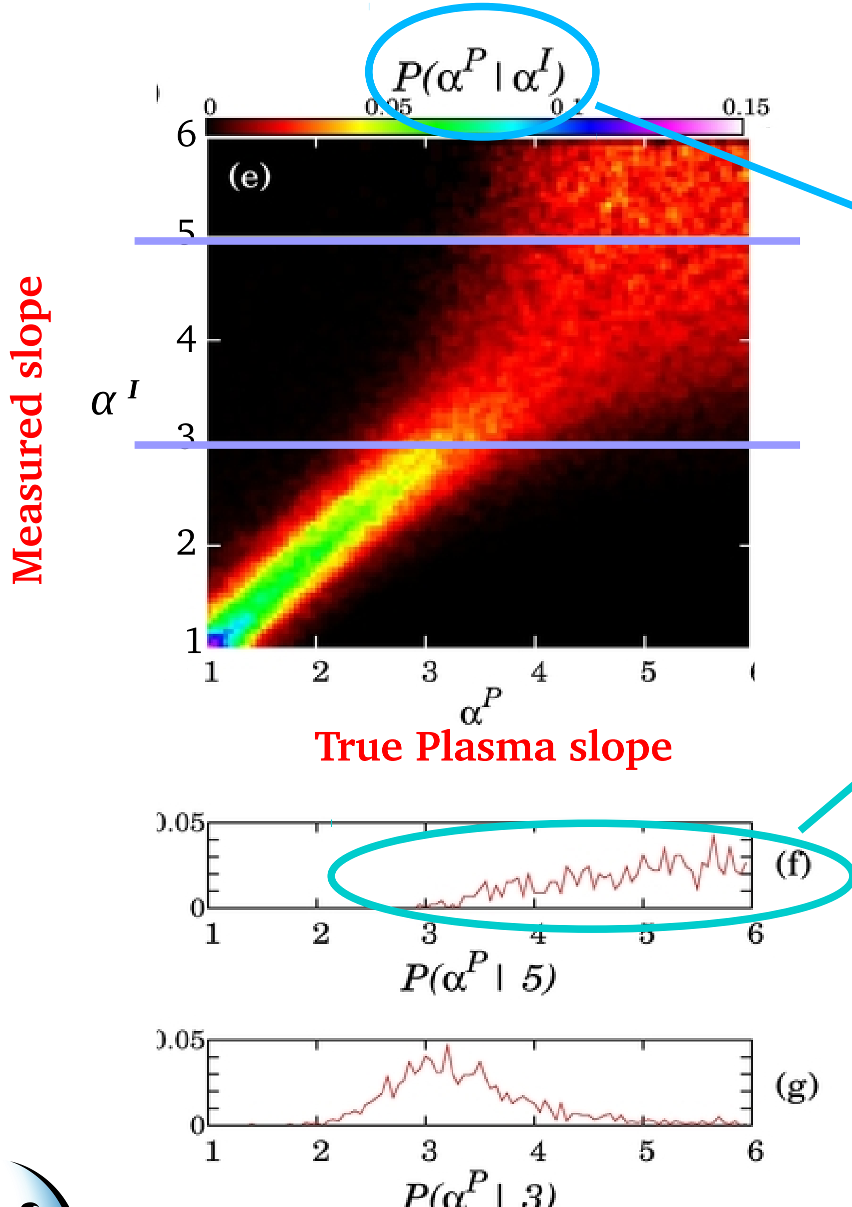

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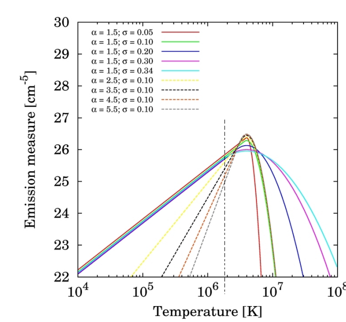
Probability that the **plasma** has a given slope knowing the **result of the inversion**

Probability distribution of the solutions

$\alpha^P = 4.47 \pm 1.07$

$\alpha^P = 3.39 \pm 0.79$



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

Schmelz & Pathak (2012)
Tripathi, Klimchuk, & Mason (2011)
Warren, Brooks, & Winebarger (2011)
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36% consistent

Model of low frequency nanoflares → $\boxed{0.81 \leq \alpha \leq 2.56}$

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$\boxed{\Delta\alpha = \pm 1.0}$

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α	3	5	3	6	5	36% consistent
$\alpha - \Delta\alpha$	11	6	2	2	1	77% consistent

$\underbrace{\hphantom{\alpha \leq 2.0 \quad 2.0 < \alpha \leq 2.5}}$

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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

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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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Ions	Wavelength (Å)	$\log(T[K])$	Total uncertainty σ_{unc}
Mg V	276.579	5.45	61.03 %
Mg VI	268.991	5.65	61.03 %
Mg VI	270.391	5.65	61.03 %
Si VII	275.354	5.80	61.03 %
Mg VII[b]	278.404	5.80	62.85 %
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S XIII[b]	256.685	6.40	55.23 %
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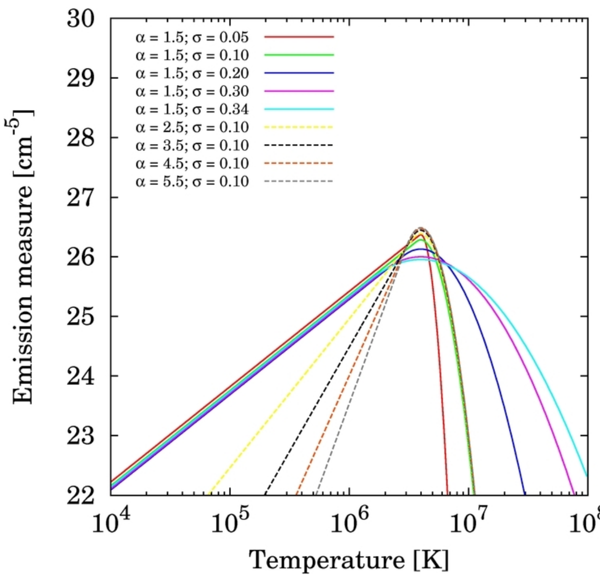
Ca XV	200.972	6.65	61.03 %
Ca XVI	208.604	6.70	61.03 %
Ca XVII[b]	192.853	6.75	62.85 %

$$T_p = 10^{6.5}\ K$$

$$T_p = 10^{6.8}\ K$$



- Probabilistic interpretation -

DEM ξ^P = DEM ξ^I ?

- Plasma DEM $\xi^P \rightarrow I_b^{obs}(\xi^P)$

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

- BUT I_b^{obs} are affected by **measurement noises**
  I_b^{th} are affected by **systematic errors**

Random + Systematics

➢ Inversion can yield different solutions $\boldsymbol{\xi}^I \rightarrow P(\boldsymbol{\xi}^I | \boldsymbol{\xi}^P)$

- **$P(\boldsymbol{\xi}^P | \boldsymbol{\xi}^I)$** → contains all information that can be extracted from the observations, given the n_b and s_b

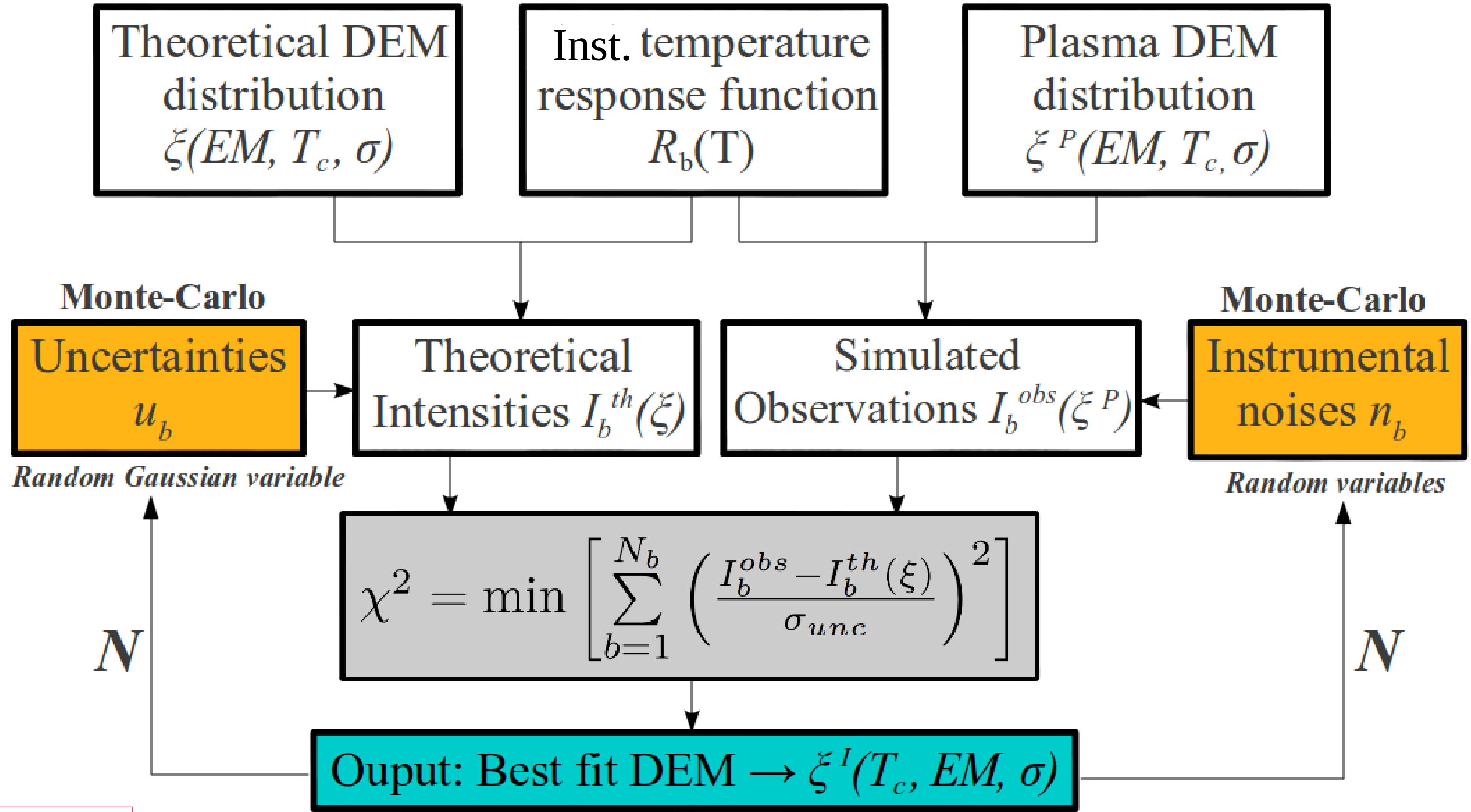
$$P(\xi^P|\xi^I) = \frac{P(\xi^I|\xi^P)P(\xi^P)}{P(\xi^I)}, \qquad \text{(Bayes' theorem)}$$

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 : 10%
- Ionization balance : 10%
- combined radiative + excitation rates + atomic structure calculations uncertainties : 10%
- FIP effect → 10% on low FIP elements

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



$$P(\xi^P|\xi^I) = \frac{P(\xi^I|\xi^P)P(\xi^P)}{P(\xi^I)}$$

(Bayes' Theorem)

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

Computed through Monte-Carlo

(Guennou et al., part I, 2012, ApJ, 25)

Providing confidence level on the DEM parameters

Slope mean value

Slope standard deviation