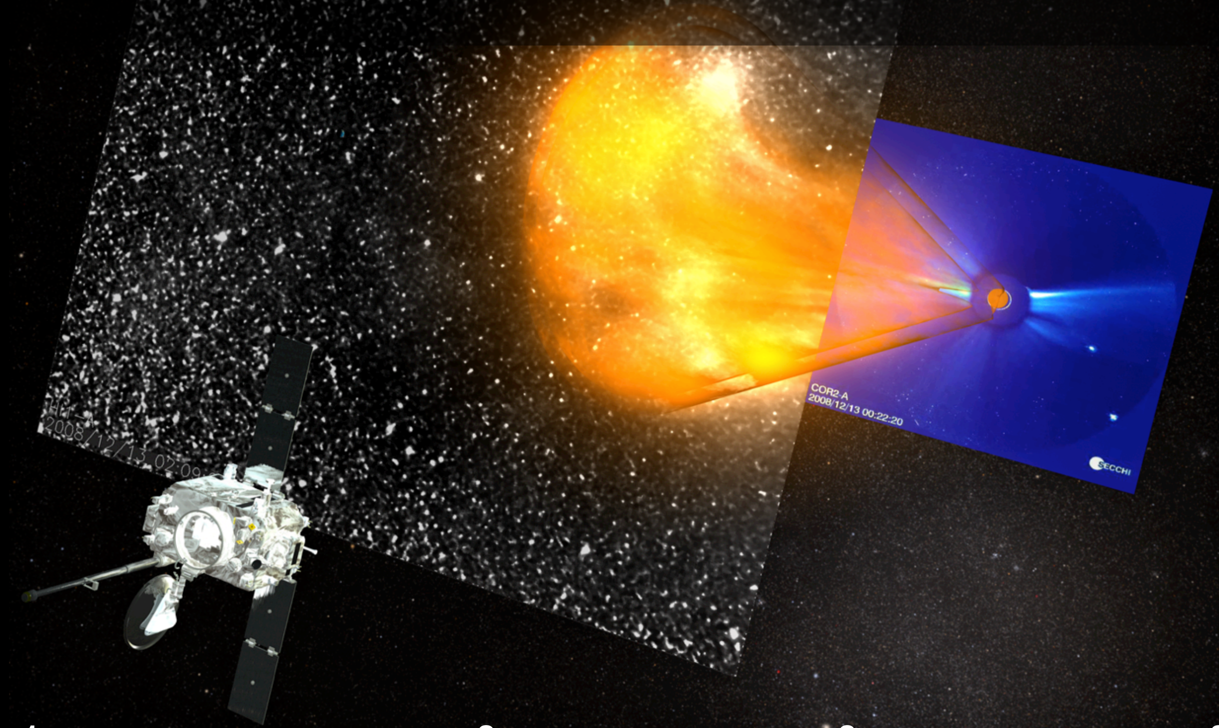
THE MOST GENERIC SHAPE OF ICMES

A COMPARISON OF MODELS AND INTERPLANETARY EVENT CATALOGUES



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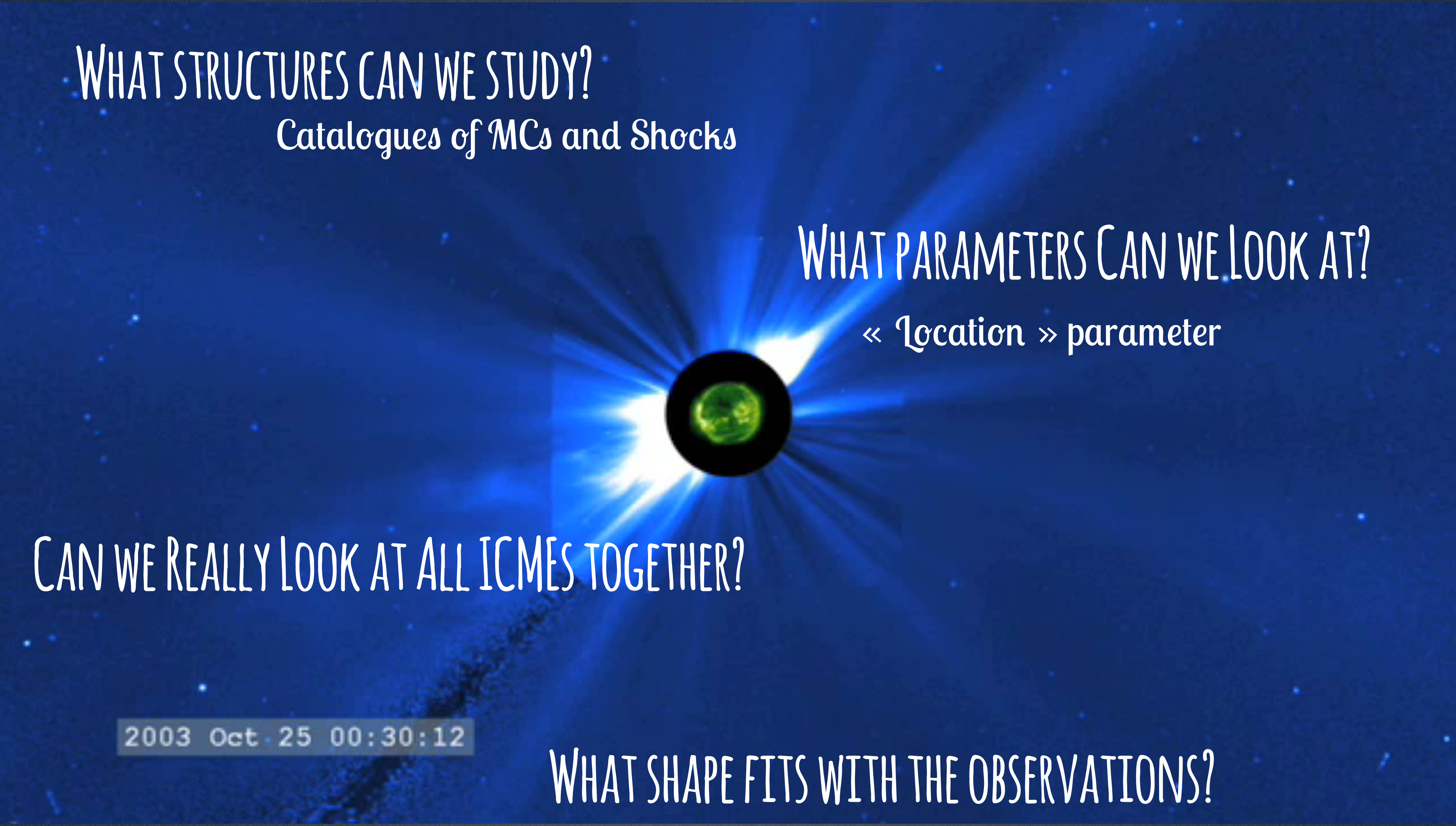
[1]University of Dundee, [2]Observatoire de Paris, [3]Universidad Buenos Aires [4]Univ. New Hampshire



What structures can we study?

Catalogues of MCs and Shocks

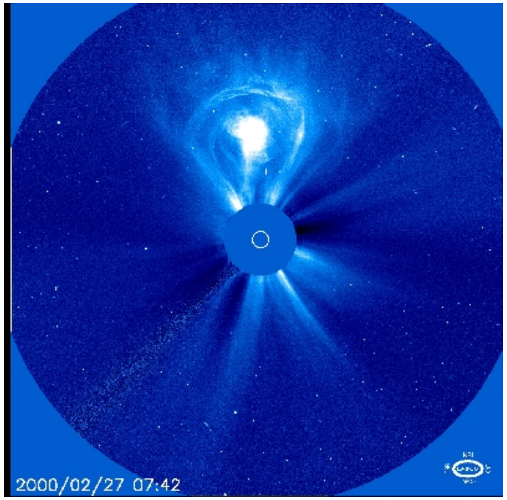
What parameters Can we Look at?

« Location » parameter

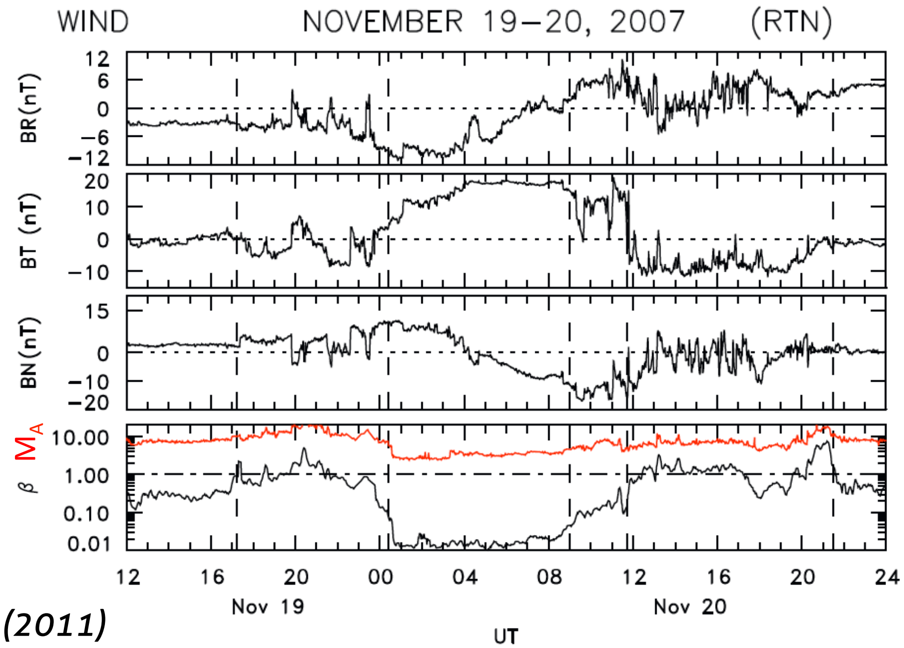
Can we Really Look at All ICMEs together?

What shape fits with the observations?

INTRODUCTION: ICMES AND MAGNETIC CLOUDS



2010 (SOHO/LASCO)



Farrugia et al. (2011)

Interplanetary CMEs criteria:

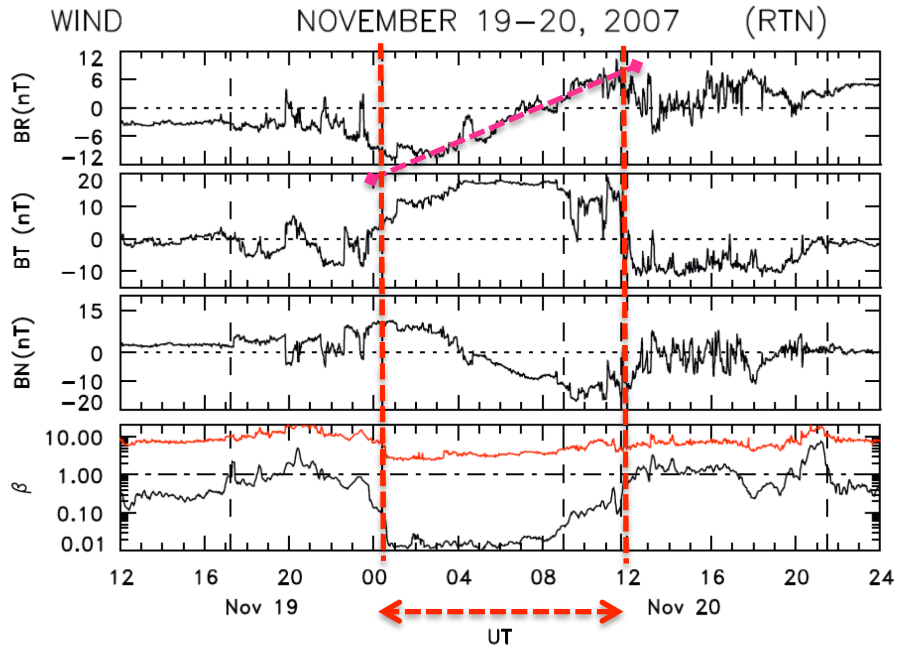
- **Stronger magnetic field than SW**
- Low proton plasma beta
- **Smooth and large rotation of MF**
- Proton temperature lower than SW
- Enhanced helium abundance
- Counter-streaming suprathermal electron beams
- Enhanced ion charge states

Wimmer-Schweingruber et al. (2006); Zurbuchen & Richardson (2006)

Magnetic clouds (MCs) criteria

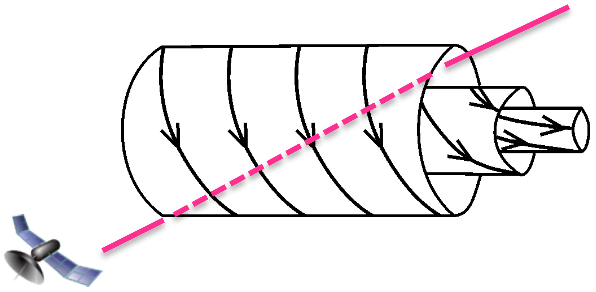
Burlaga et al. (1981)

MAGNETIC CLOUD DETECTION



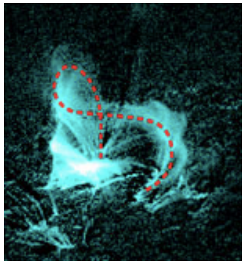
Farrugia et al. (2011)

Flux rope = twisted magnetic structure

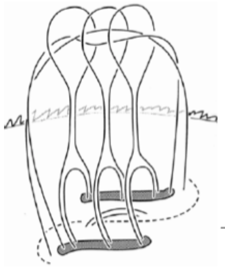


Consistent with:

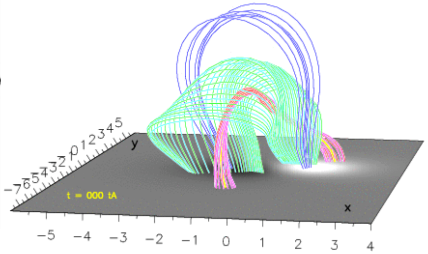
- Observations of flux ropes during eruptive flares
- Theoretical models
- 3D Numerical simulations



Zhang et al. (2012)



Moore et al. (1995)



Aulanier et al. (2010)
Janvier et al. (2013)

WHY DOES IT MATTER?

WHY we want to know MCs structures:

- ✧ Role of the field line length in time delay of energetic particles detection

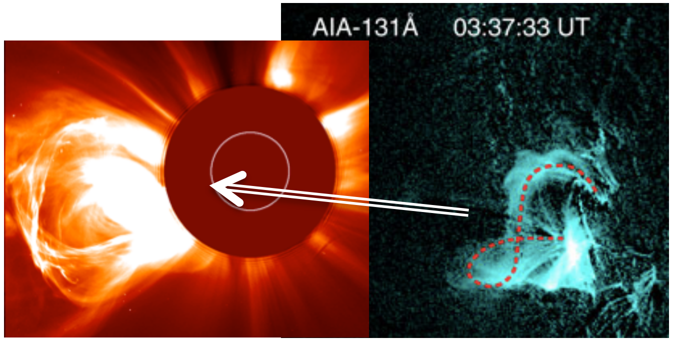
Larson et al. (1997), Masson et al. (2012)

- ✧ Link with 3D configuration of associated solar source

Nakwacki et al. (2011)

- ✧ Useful for magnetic helicity, energy, flux budget

Démoulin et al. (2002), Dasso et al. (2005)



Zhang et al. (2012)

WHY it is difficult to derive 3D MCs structures:

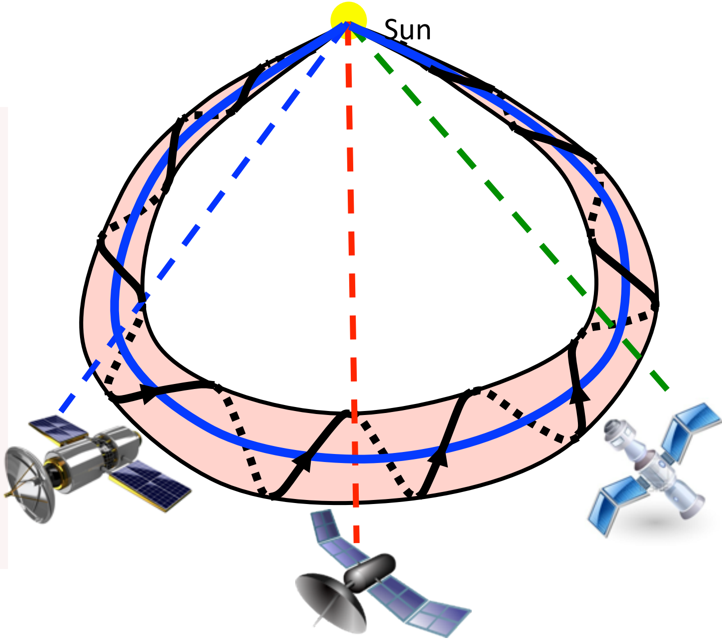
- ✧ Detection only in one direction (spacecraft crossing)

- ✧ Fitting models: only a local view

Vandas & Romashets (2003), Sonnerup et al. (2006)

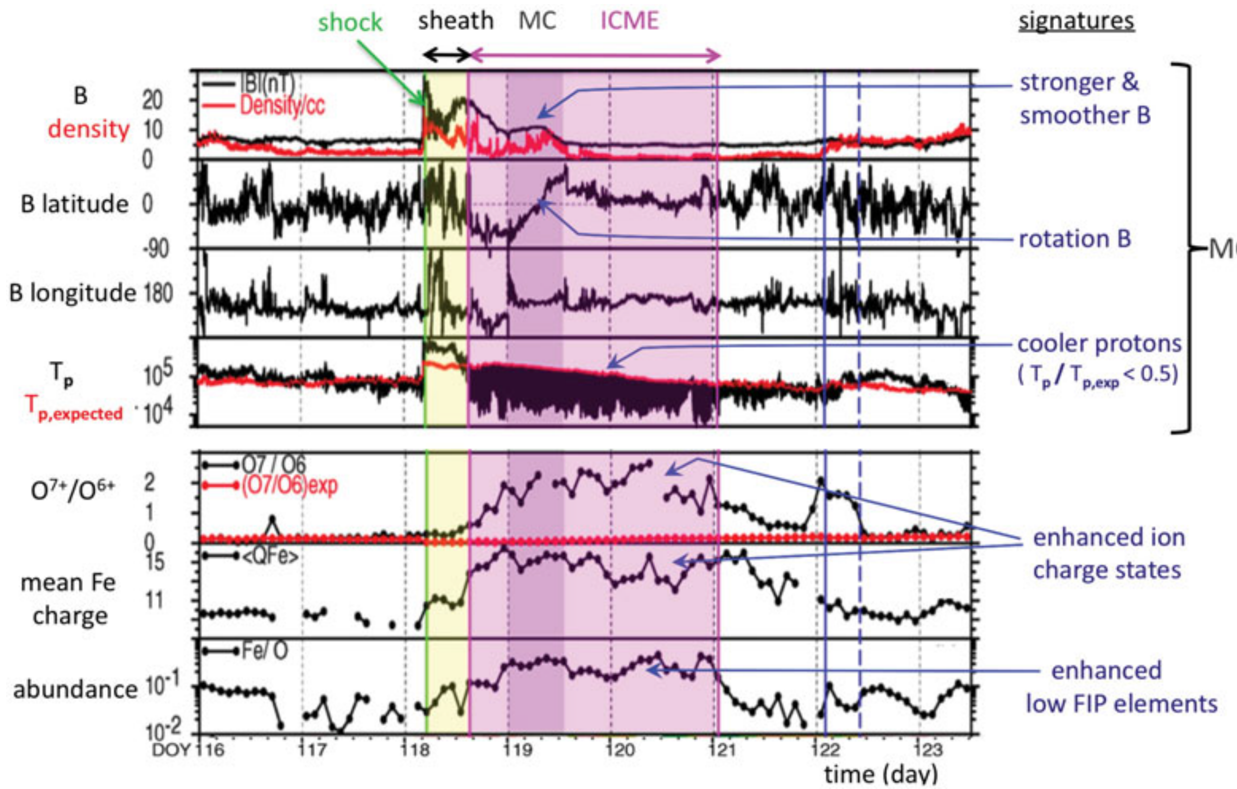
- ✧ Multiple spacecraft crossing: rare occurrences

Ruffenach et al. (2012)

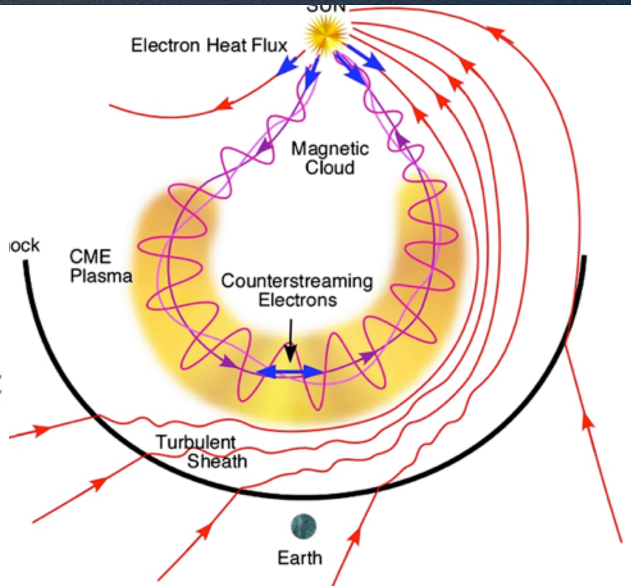


SHOCKS IN THE INTERPLANETARY MEDIUM

With in situ data, it is also possible to define a shock:



Richardson et Cane (2010)



Zurbuchen et Richardson (2006)

Shocks are geo-effective:

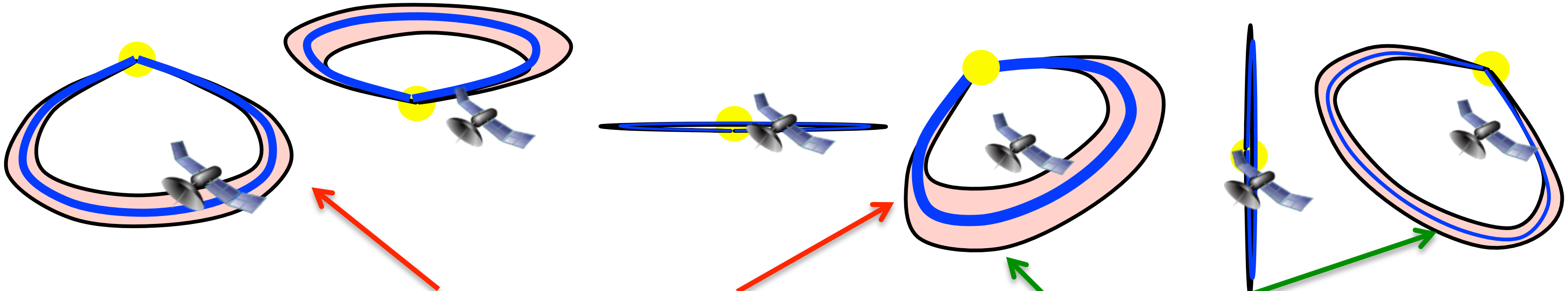
- ✧ Direct interaction with the Earth's environment
- ✧ Particle acceleration
- ✧ Decrease of high-energy particle flux (Forbush decrease)

Cane (2000)

OUR METHOD: STATISTICAL STUDIES

Statistical analysis of magnetic clouds and shocks observed by one interplanetary probe

⇒ *Analysis of samples to obtain the mean axis of MCs / shock shell*



⇒ BUT: can we analyze MCs altogether?
(effects from different orientations? speeds? MCs sizes?)

⇒ **BUT: can we analyze all shocks altogether?**
(Differences in speed? Intensity?)

⇒ What happens when we reproduce the same method on different catalogues of events?

OUTLINE

A. Introduction

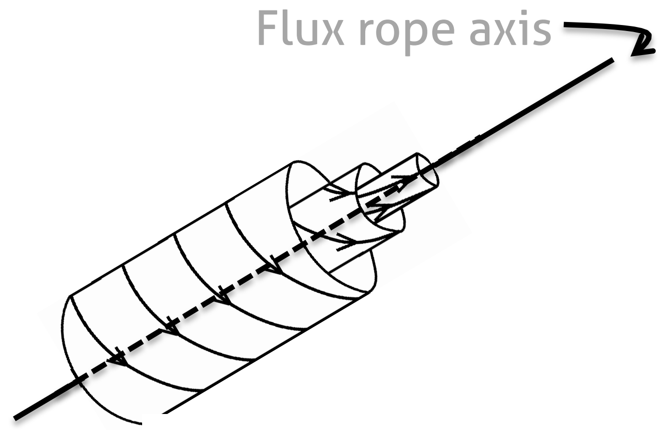
B. Data Sets And Definitions

THE DATA SETS

Lynch et al. (2005)	132 MCs	Wind and Ace	1995 - 2003
Feng et al. (2010)	62 MCs+shocks	Wind	1995 - 2007
Wang et al. (2010)	216 Shocks	ACE	1998- 2008
Lepping & Wu (2010)	121 MCs	Wind	1995 - 2009

Fitted w/ Lundquist's model *Lundquist (1950)*

circular
force-free model
straight axis



Lundquist's model gives 7 parameters, of which:

- ⇒ **longitude (ϕ)**
- ⇒ **latitude (θ)**
- ⇒ **magnetic field strength on the FR axis**
- ⇒ **FR radius (from impact parameter)**

ΔT [a] (Hr)	ϕ_A [b] (°)	θ_A [b] (°)	V [c] km/s	$2R_o$ [d] (AU)	B_o [e] (nT)
19.0	100	18	410	0.216	15.2
17.0	205	−76	443	0.165	14.9
27.0	96	−22	301	0.303	13.3
10.5	149	58	334	0.083	14.8

THE DATA SETS

Lynch et al. (2005)	132 MCs	Wind and Ace	1995 - 2003
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Lepping & Wu (2010)	121 MCs	Wind	1995 - 2009

Fitted w/ Rankine-Hugoniot *See also Lin et al. (2006)*

One fluid

Anisotropic

Study of shock + Rankine-Hugoniot's model gives :

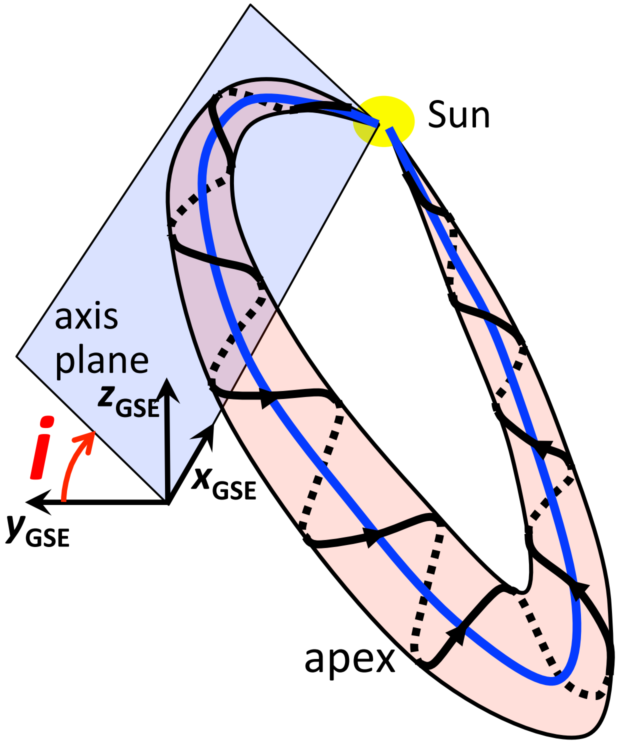
⇒ **shock normal**

⇒ **upstream/downstream density**

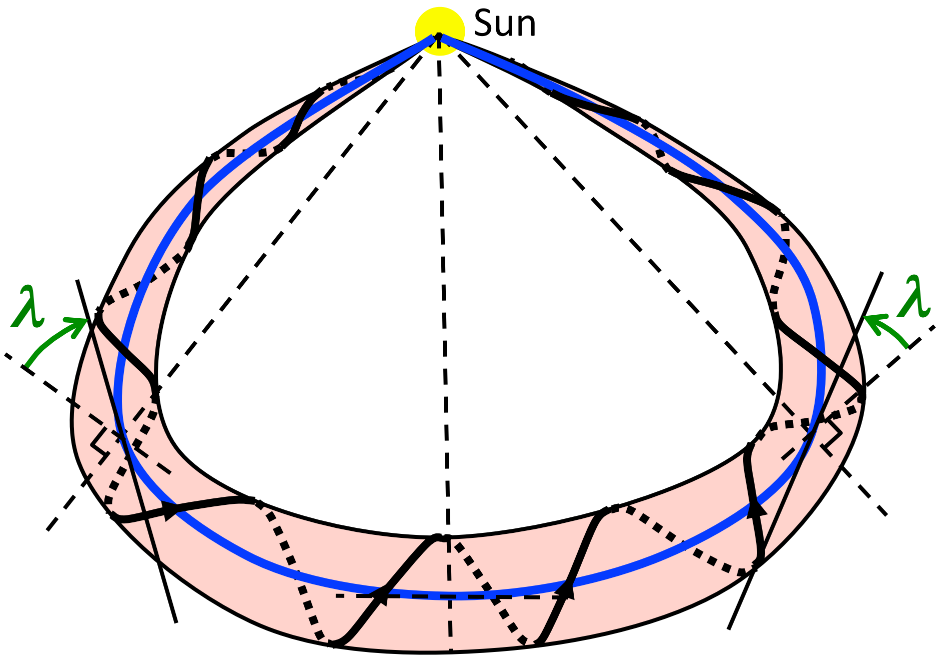
⇒ **upstream/downstream Mach number**

Shock Normal	ρ_1/ρ_2	V_{sn}	M_{f1}	M_{f2}
(−0.805, 0.152, −0.574)	0.79	383.6	0.93	0.66
(−0.919, 0.044, 0.392)	0.67	450.1	1.55	0.87
(−0.729, 0.017, −0.684)	0.51	325.9	1.29	0.46
(−0.978, −0.025, −0.209)	0.35	388.2	1.79	0.45
(−0.772, −0.421, 0.476)	0.19	330.8	5.19	0.53
(−0.793, 0.280, −0.541)	0.30	520.2	1.65	0.31
(−0.790, 0.600, −0.123)	0.36	435.2	2.75	0.58
(−0.767, 0.640, −0.033)	0.47	582.5	1.25	0.47

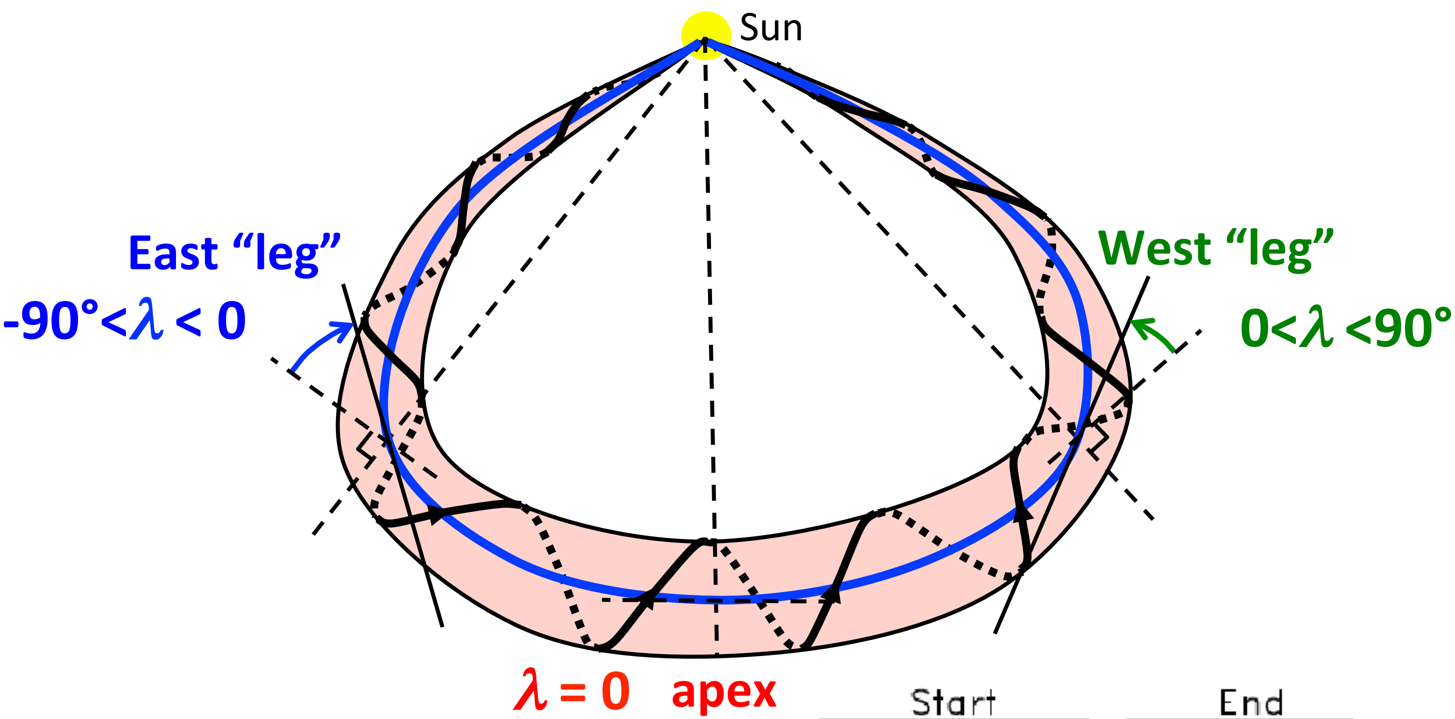
Inclination angle *i*



Location angle λ



Location angle λ



We can deduce i and λ with the latitude and longitude angles

	Start				End									
Yr	Mon	Day	DOY	Hr	Mon	Day	DOY	Hr	ΔT [a] (Hr)	ϕ_A [b] (°)	θ_A [b] (°)	V [c] km/s	2Ro [d] (AU)	B_o [e] (nT)
95	02	8	039	5.8	02	9	040	0.8	19.0	100	18	410	0.216	15.2
95	03	4	063	10.8	03	5	064	3.8	17.0	205	−76	443	0.165	14.9
95	04	3	093	7.8	04	4	094	10.8	27.0	96	−22	301	0.303	13.3
95	04	6	096	7.3	04	6	096	17.8	10.5	149	58	334	0.083	14.8

NEW REFERENTIAL: LOCATION ANGLE

YY	MM	DD	hh	mm	Flag	Shock Normal	ρ_1/ρ_2	V_{sn}	M_{f1}	M_{f2}
1998	2	17	22	25	0	(−0.8[illegible]5, 0.152, −0.574)	0.79	383.6	0.93	0.66
1998	2	18	7	52	1	(−0.919, 0.044, 0.392)	0.67	450.1	1.55	0.87
1998	3	4	10	57	1	(−0.729, 0.017, −0.684)	0.51	325.9	1.29	0.46
1998	4	23	17	30	1	(−0.978, −0.025, −0.209)	0.35	388.2	1.79	0.45
1998	4	30	8	48	1	(−0.772, −0.421, 0.476)	0.19	330.8	5.19	0.53
1998	5	1	21	20	1	(−0.793, 0.280, −0.541)	0.30	520.2	1.65	0.31
1998	5	3	16	58	1	(−0.790, 0.600, −0.123)	0.36	435.2	2.75	0.58
1998	5	8	9	20	1	(−0.767, 0.640, −0.033)	0.47	582.5	1.25	0.47

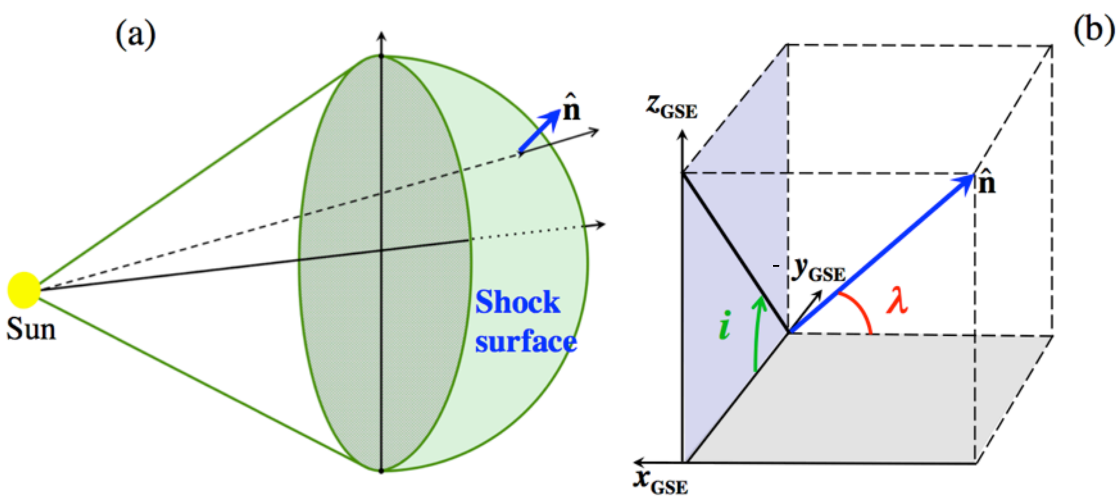
(...)

Shock normal (Rankine-Hugoniot method)

With the normal orientation, we have:

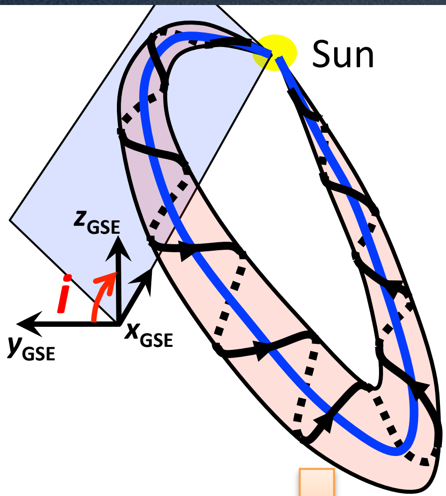
✧ Inclination angle *i*

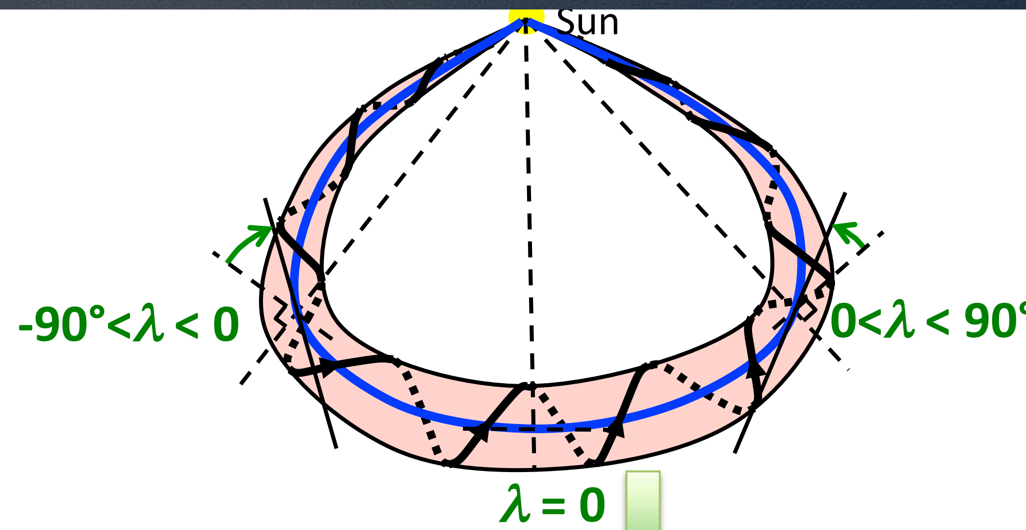
✧ Localisation angle λ



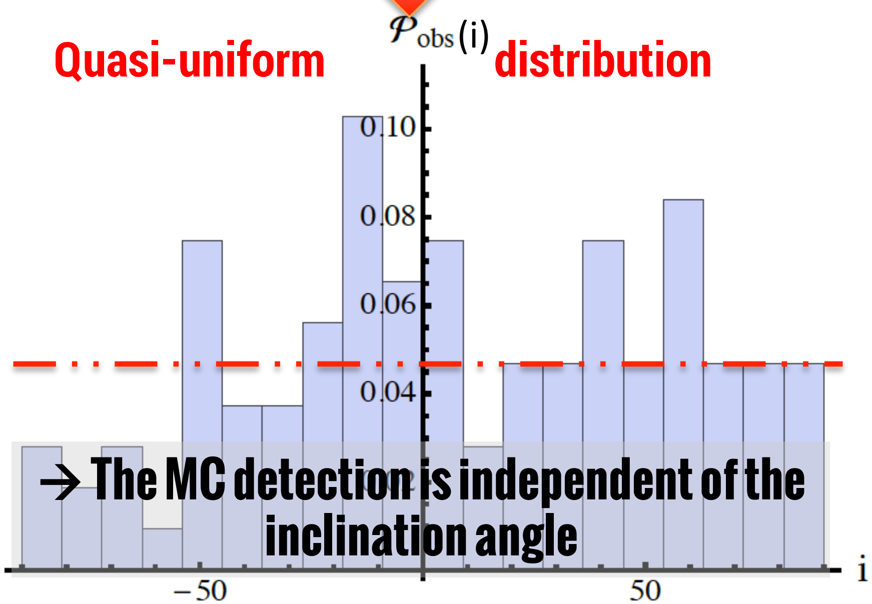
DISTRIBUTIONS OF OBSERVED PARAMETERS (MCs)

Lepping & Wu (2010)



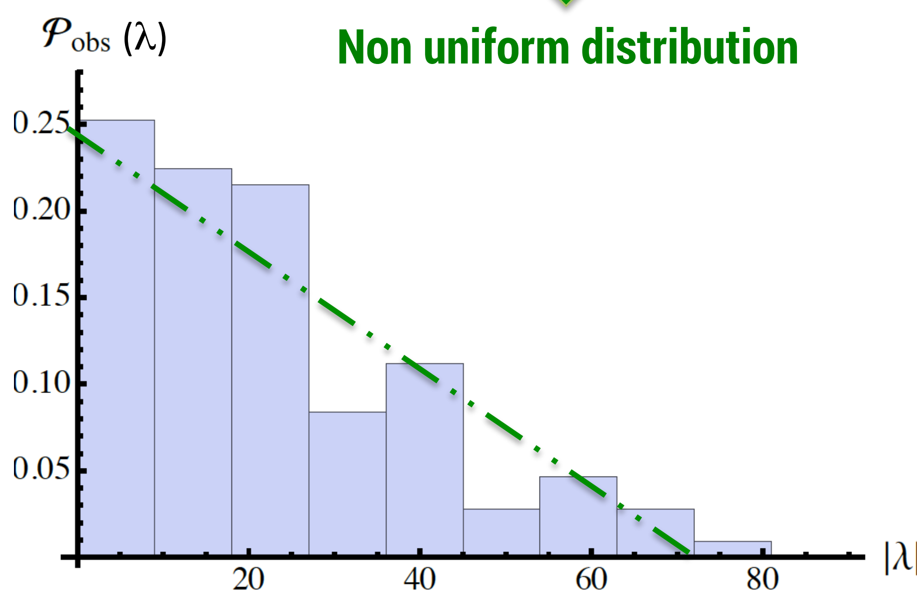


Quasi-uniform distribution



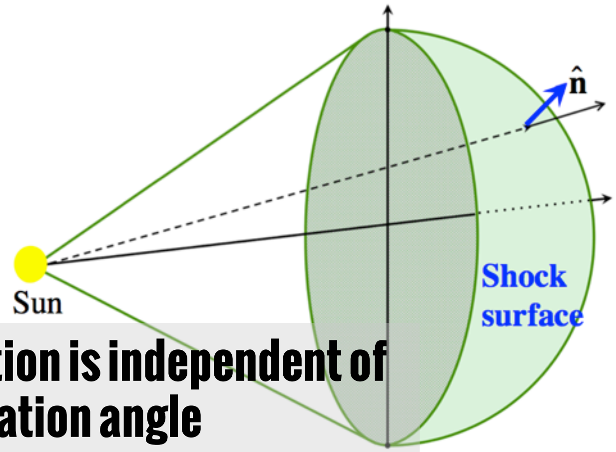
→ **The MC detection is independent of the inclination angle**

Non uniform distribution

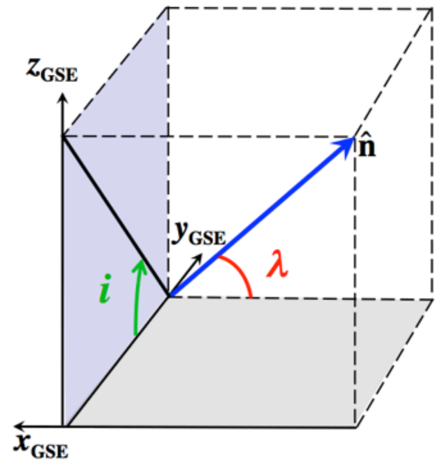


DISTRIBUTIONS OF OBSERVED PARAMETERS (SHOCKS)

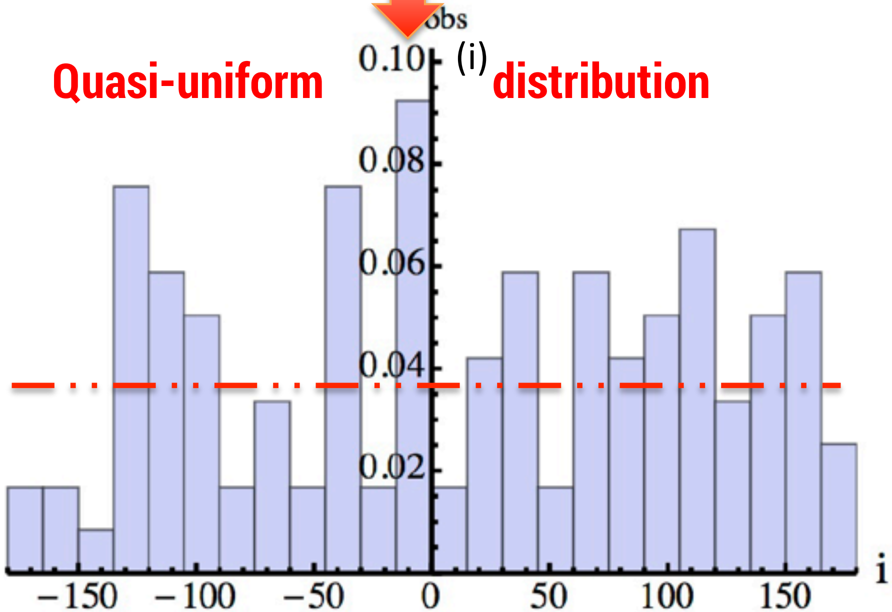
Wang et al. (2010)



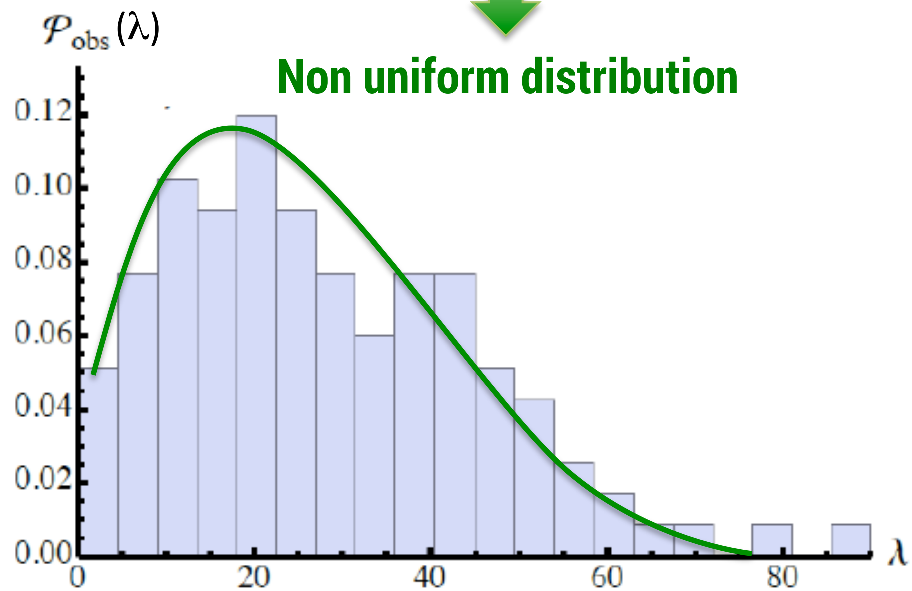
→ **The shock detection is independent of the inclination angle**



Quasi-uniform distribution



Non uniform distribution



COMPARING DIFFERENT CATALOGUES

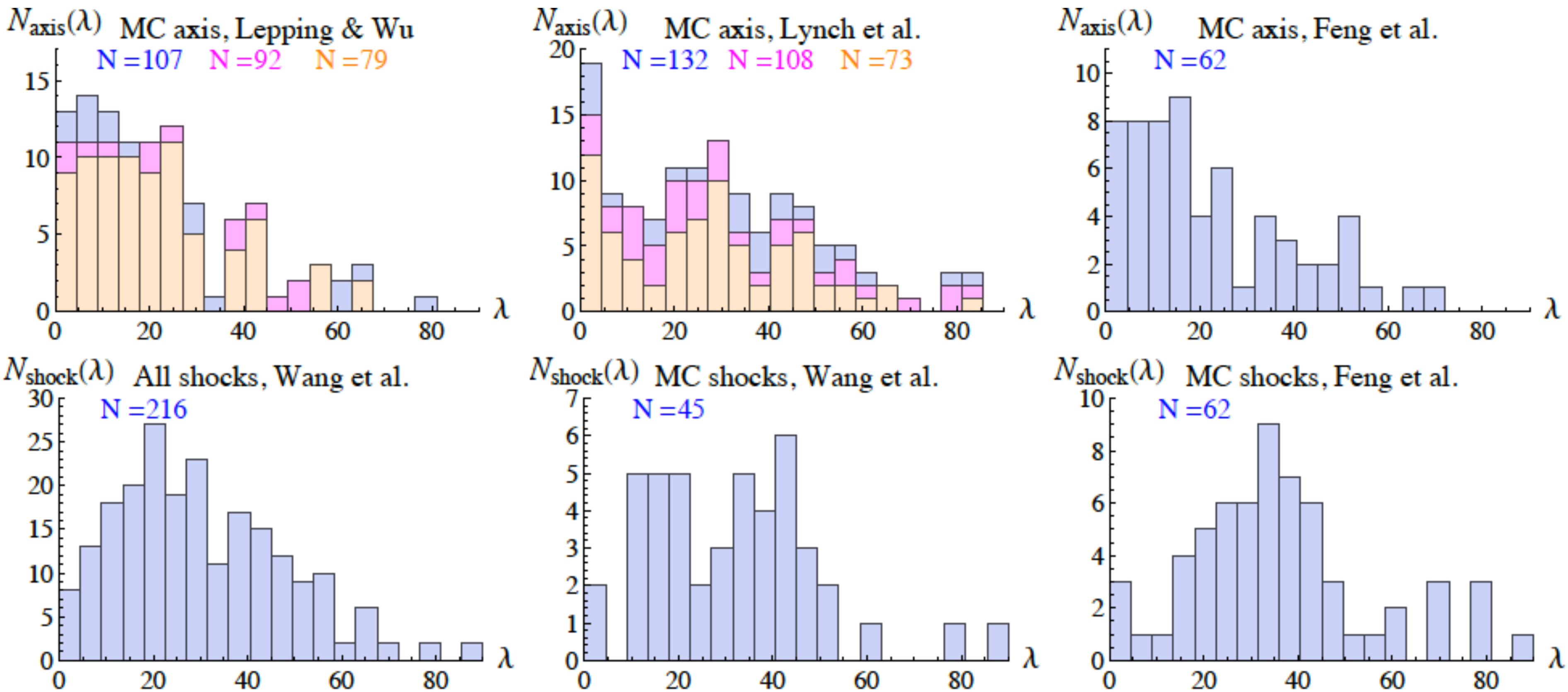
Lynch et al. (2005)	132 MCs
Feng et al. (2010)	62 MCs+shocks
Wang et al. (2010)	216 Shocks
Lepping & Wu (2010)	121 MCs

Only took similar events···

Why such a discrepancy
in the λ data?

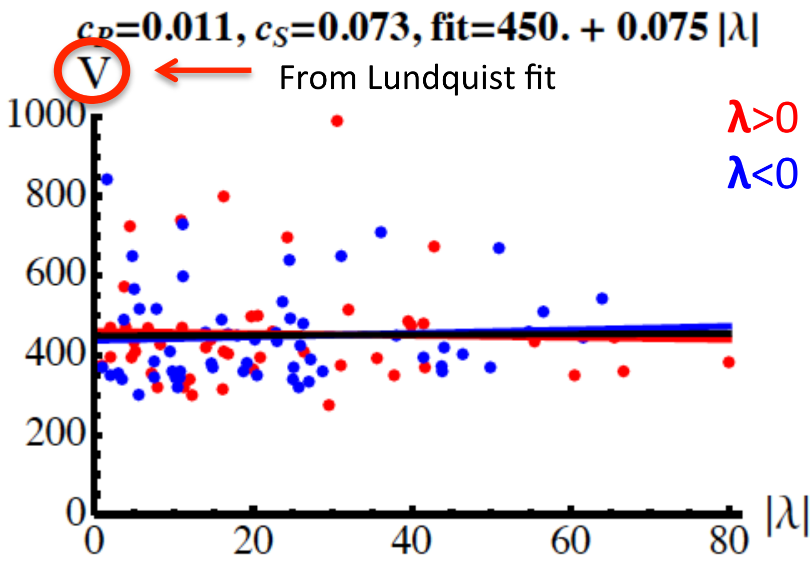
(frontier definition?)

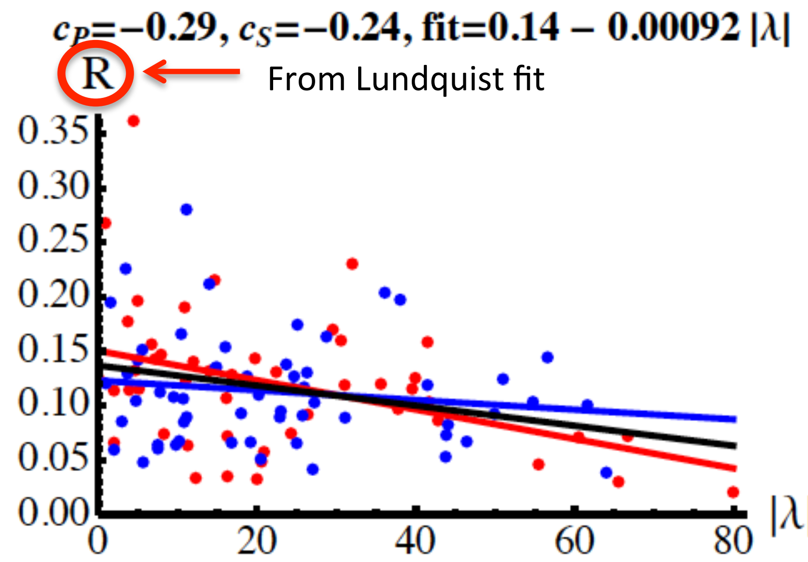
COMPARING DIFFERENT CATALOGUES



→ Distributions are actually similar!

Correlation between λ – other parameters:





- ✧ λ >0 and λ <0 give similar results: independent of the "legs"
- ✧ λ is weakly correlated with other MC parameters

DEPENDENCE OF λ WITH OTHER PARAMETERS (SHOCKS)

Correlation between λ – other parameters:

Correlation?

Shock Normal	ρ_1/ρ_2	V_{sn}	M_{f1}	M_{f2}
(−0.805, 0.152, −0.574)	0.79	383.6	0.93	0.66
(−0.919, 0.044, 0.392)	0.67	450.1	1.55	0.87
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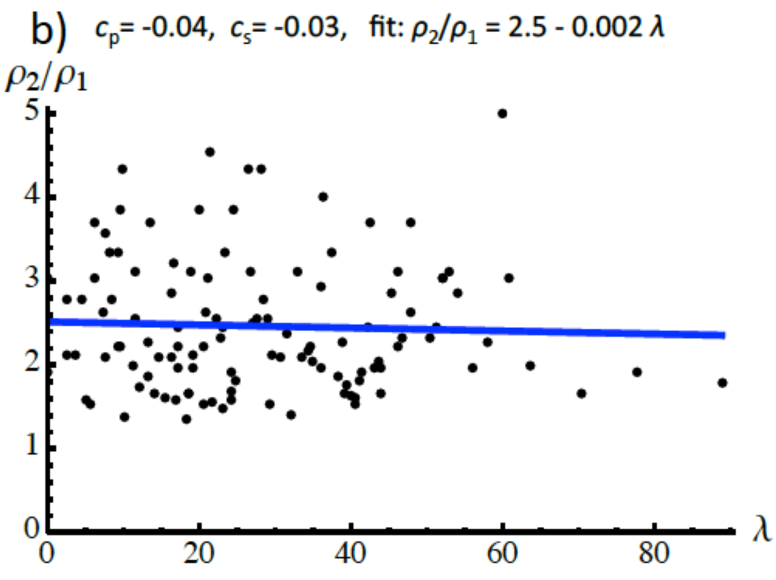
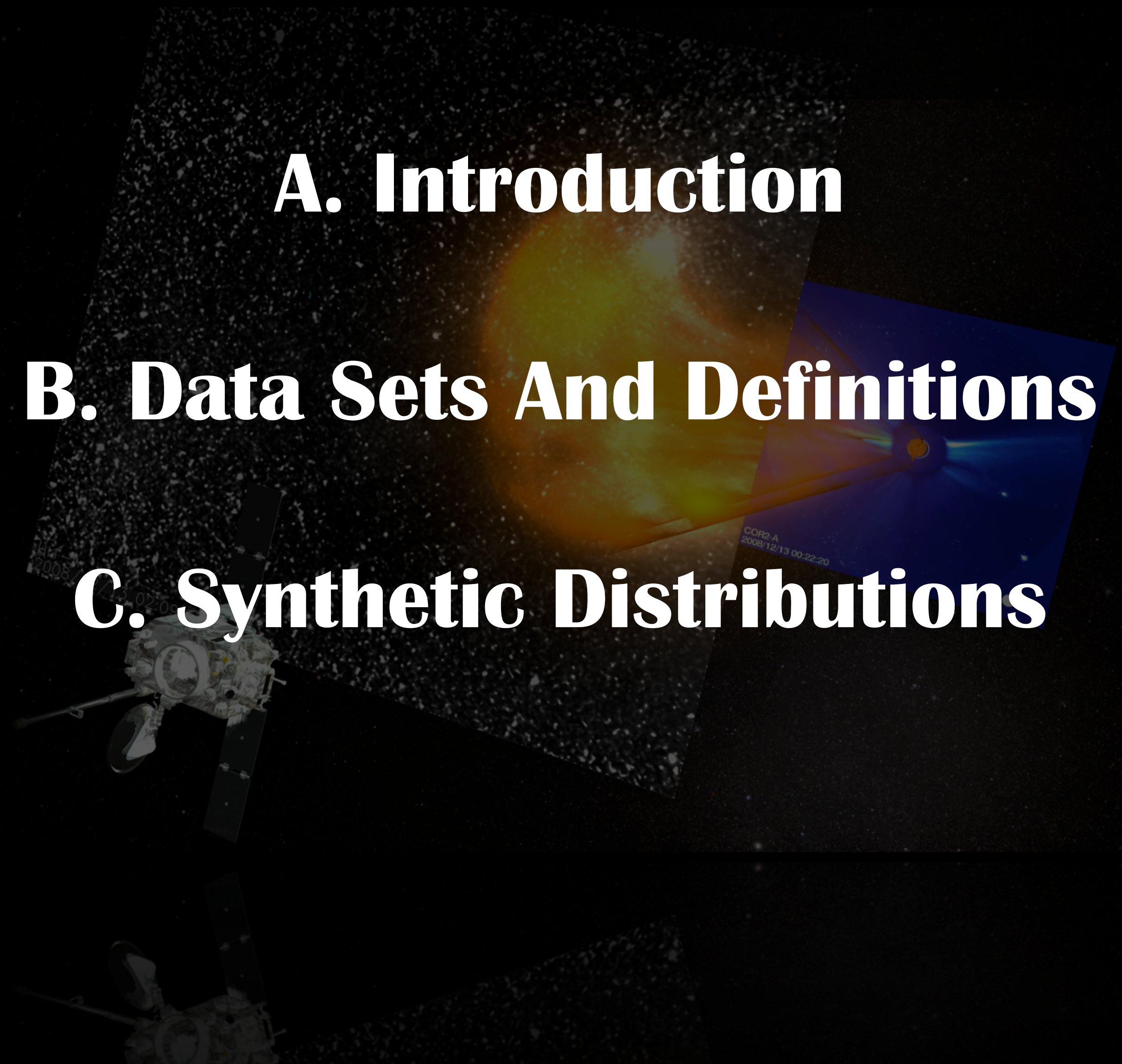
No correlation!



⇛ λ parameter independent of the other MC/shock caracteristics

- We can therefore perform a statistical analysis
- It *seems* that there is a similar shape for all the MCs/shocks

OUTLINE



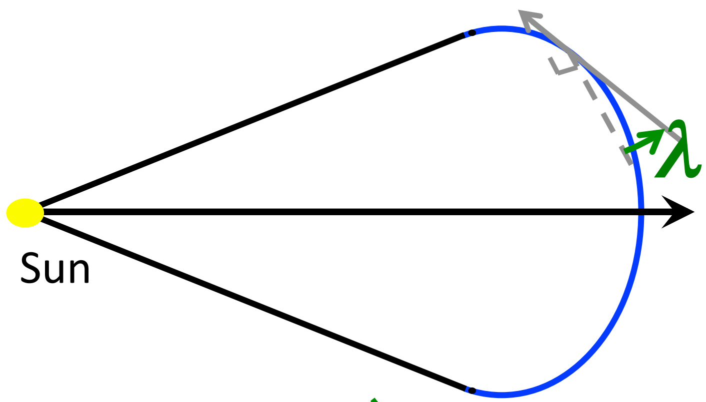
A. Introduction

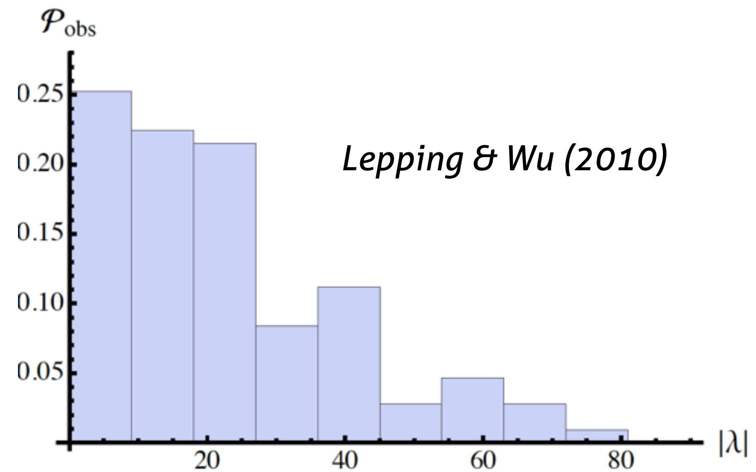
B. Data Sets And Definitions

C. Synthetic Distributions

THE IDEA: SYNTHETIC PROBABILITY DISTRIBUTION FROM A MODEL

How does the geometry of the MC axis change the λ distribution?



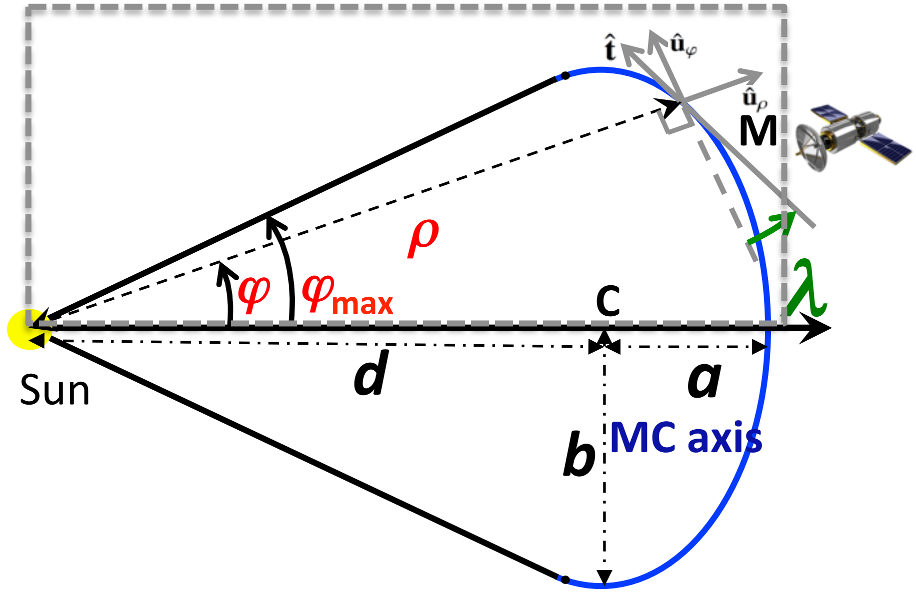


Comparison between synthetic distributions where the axis shape is **given**

✪ SAME SHAPE FOR DIFFERENT CATALOGUES?

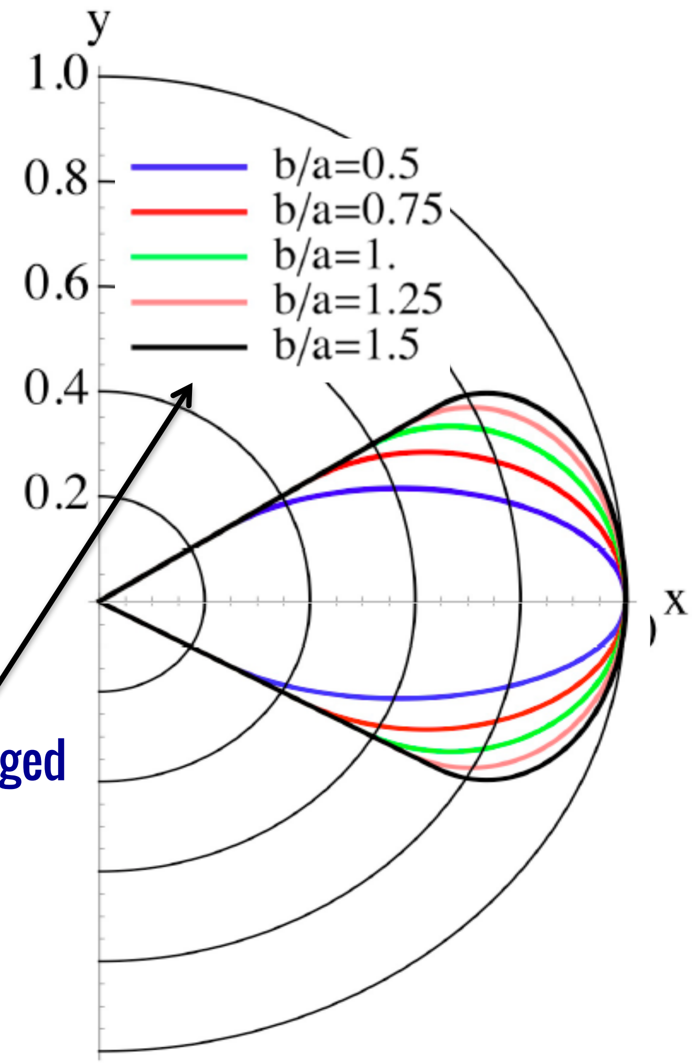
Janvier, Démoulin, Dasso (2013)

THE ELLIPSOID MODEL (MC CASE)

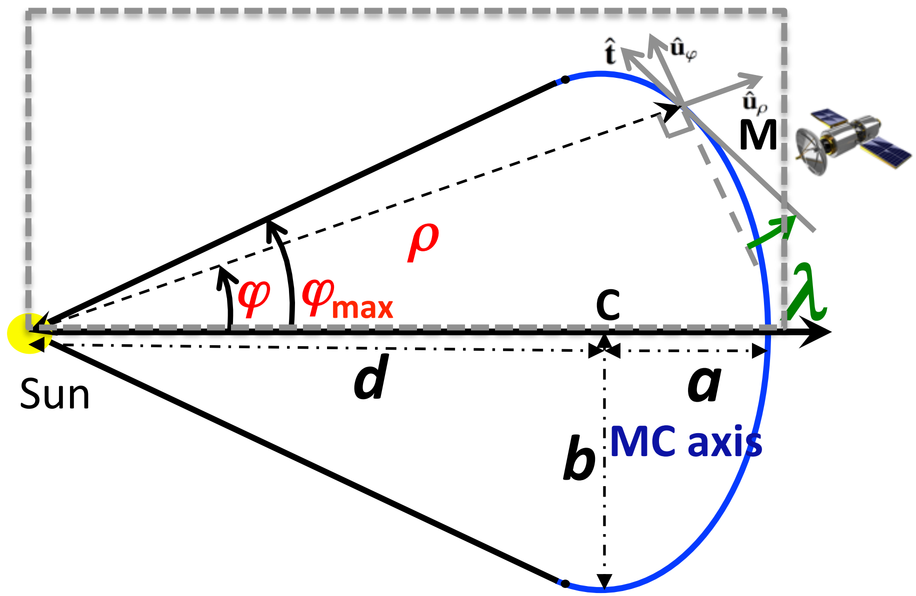


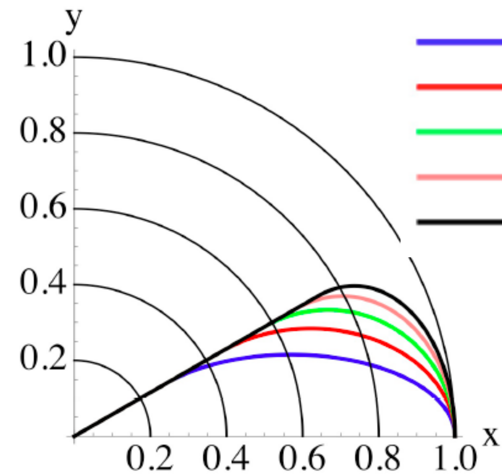
The MC axis is given as an ellipse

The aspect ratio can be changed



THE ELLIPSOID MODEL (MC CASE)





Synthetic distribution:

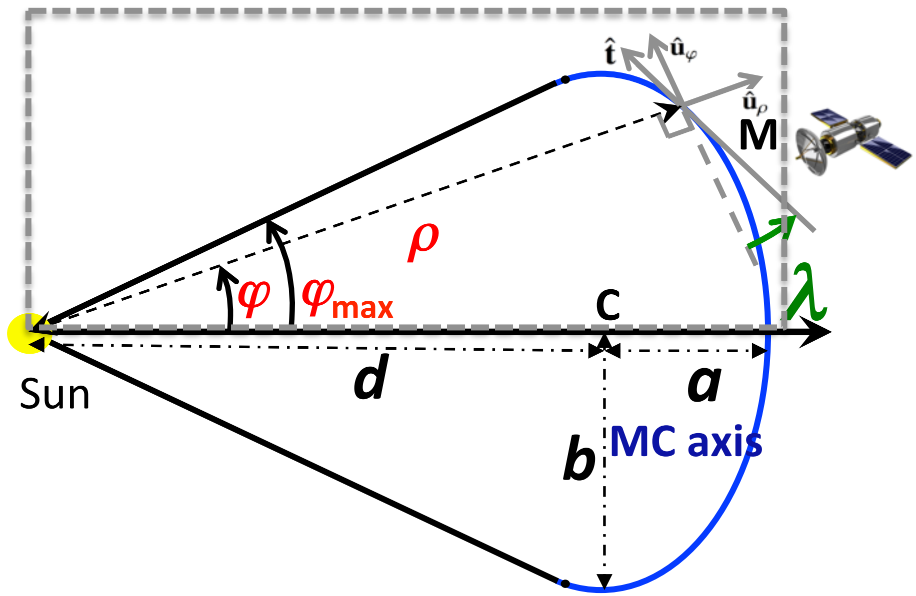
$$\mathcal{P}(\lambda) = \mathcal{P}_\varphi \, |\mathrm{d}\varphi/\mathrm{d}\lambda|$$

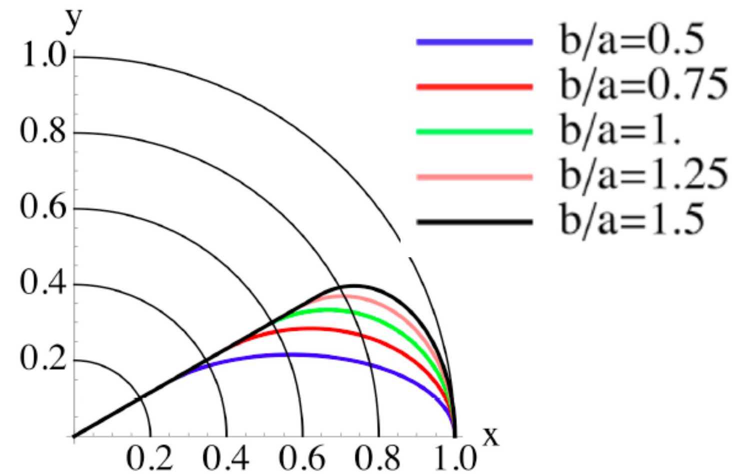
$1/(2\,\varphi_{\max})$

Equiprobability in φ

Calculated from the geometrical model

THE ELLIPSOID MODEL (MC CASE)

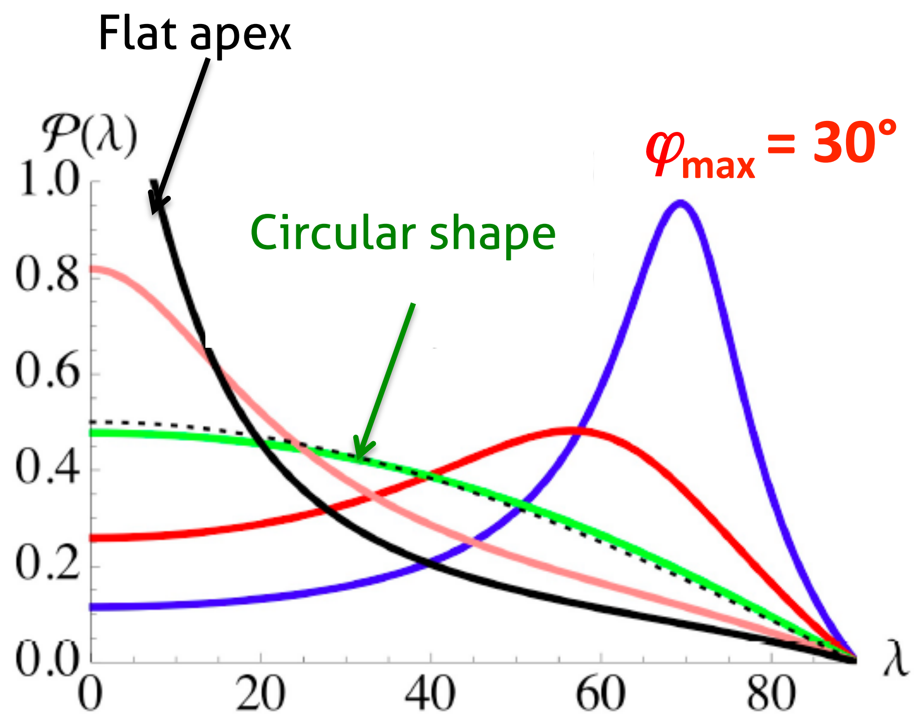




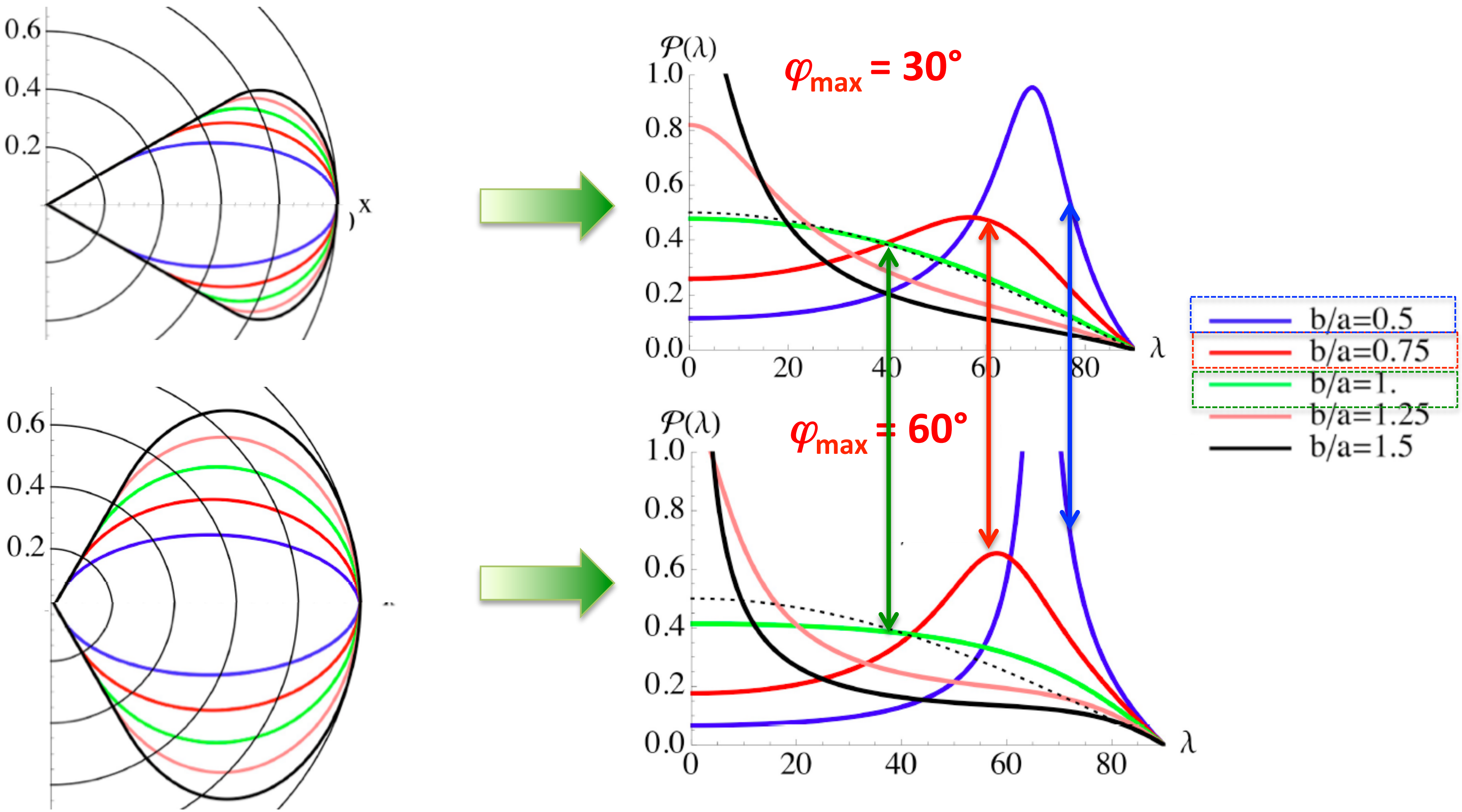
Synthetic distribution:

$$\mathcal{P}(\lambda) = \mathcal{P}_\varphi \, |\mathrm{d}\varphi/\mathrm{d}\lambda|$$

$1/(2\,\varphi_{\max})$

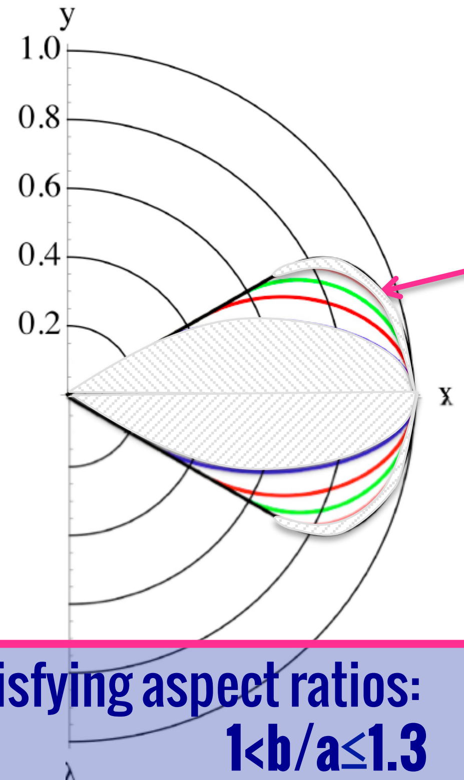


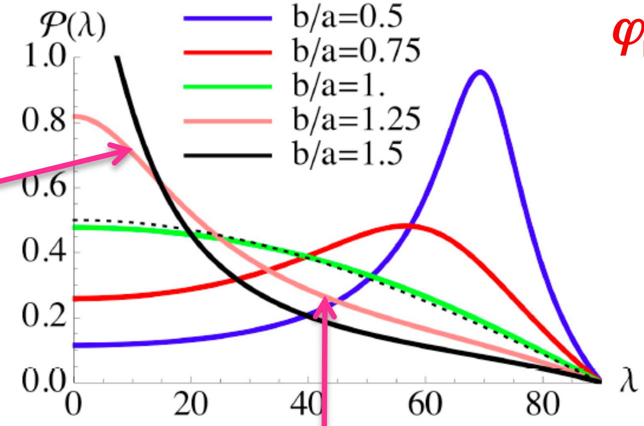
THE ELLIPSOID MODEL (MC CASE)



The elongation parameter φ_{max} has a weak effect, contrary to the aspect ratio **b/a**

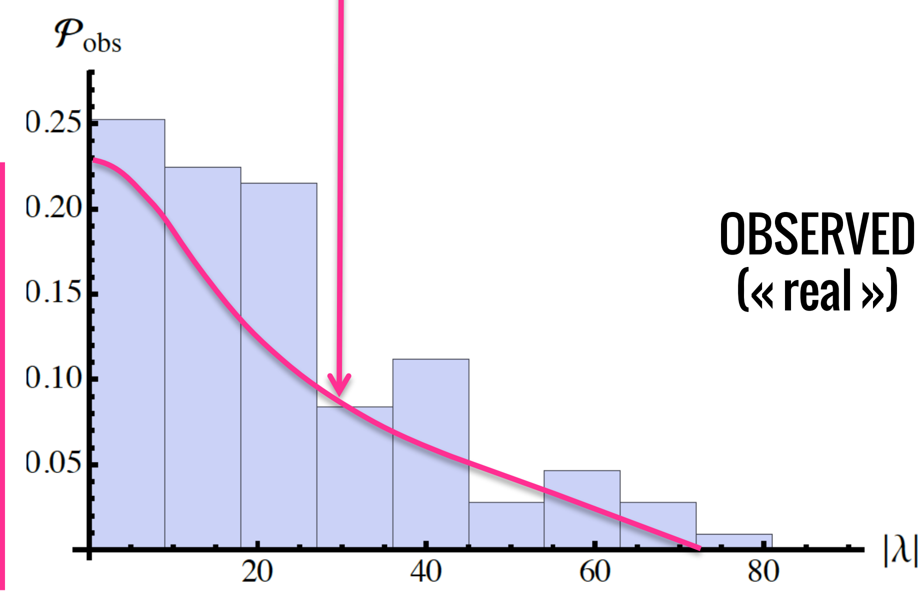
THE ELLIPSOID MODEL (MC CASE)





φ_{max} = 30°

SYNTHETIC

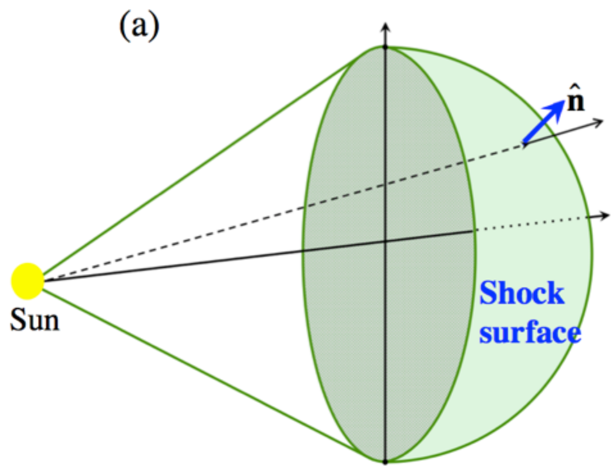


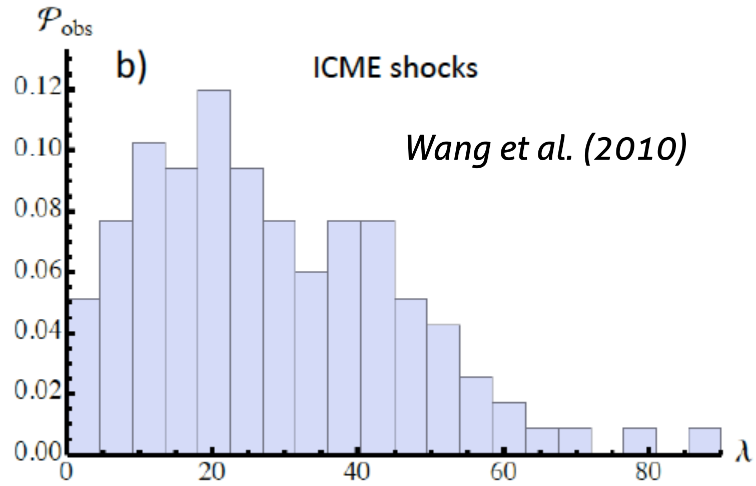
OBSERVED
(« real »)

Satisfying aspect ratios:
1<b/a≤1.3
(➽only a small interval of possible shapes)
<u>We have found the most probable MC shapes</u>

THE COSINE MODEL (SHOCK CASE)

How does the geometry of the shock shell change the λ distribution?



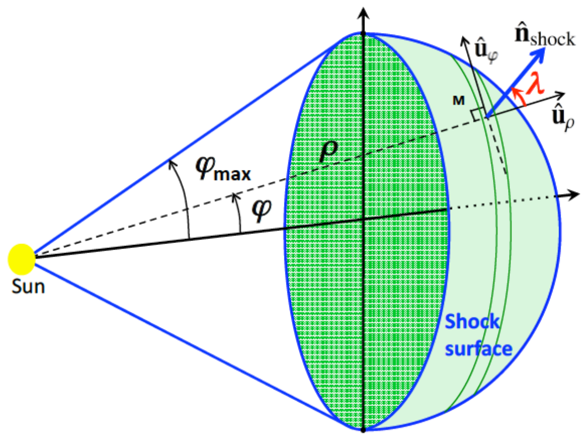


Comparison between synthetic distributions where the shock shape is **given**

✪ We suppose that the shock has a Symmetry around the Sun-Apex direction

Janvier, Démoulin, Dasso (2014)

THE COSINE MODEL (SHOCK CASE)



Given shock geometry in cylindrical coordinates:

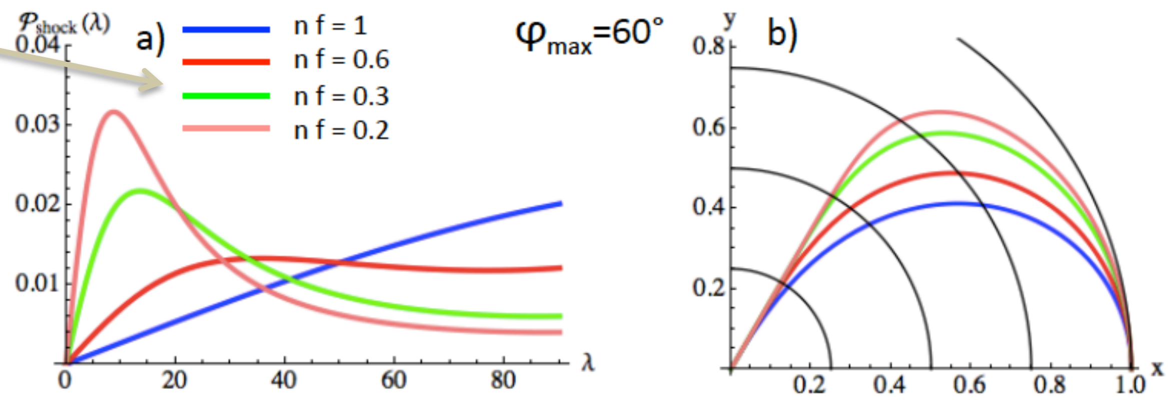
⇛ The λ distribution can be expressed as:

$$\mathcal{P}(\lambda) = \frac{\sin\varphi}{1-\cos\varphi_{max}} \frac{1}{\cos^2\lambda\,(-d^2\ln\rho/d\varphi^2)}$$

For example, if we take the following function: $\rho(\varphi) = \rho_{max}\cos^n(f\varphi)$ we get:

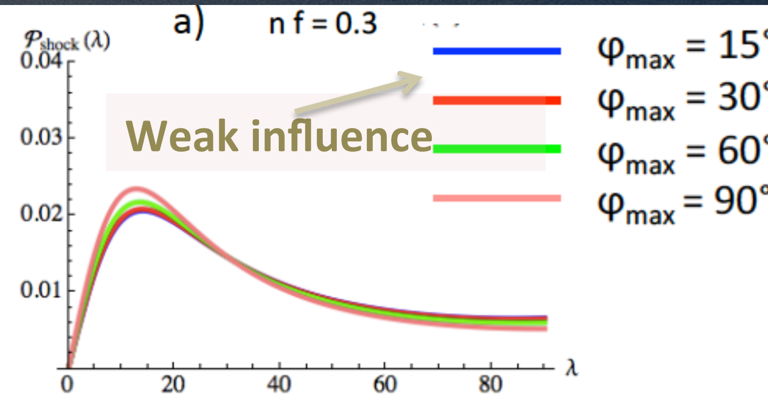
$$\mathcal{P}(\lambda) = \frac{\sin\varphi}{1-\cos\varphi_{max}} \overbrace{\frac{n\,(1+\tan^2\lambda)}{(nf)^2+\tan^2\lambda}}^{\text{(correlation)}}$$

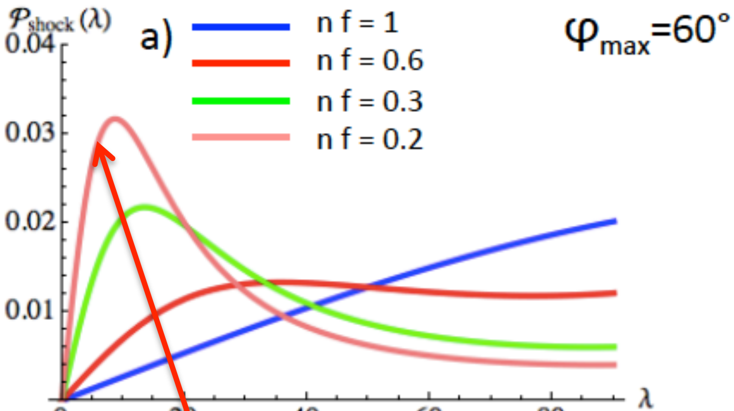
Parameter having an effect on the shapes

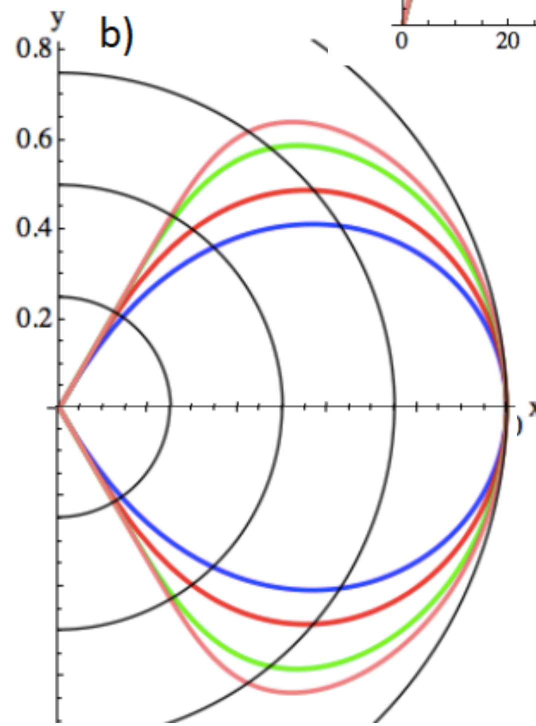


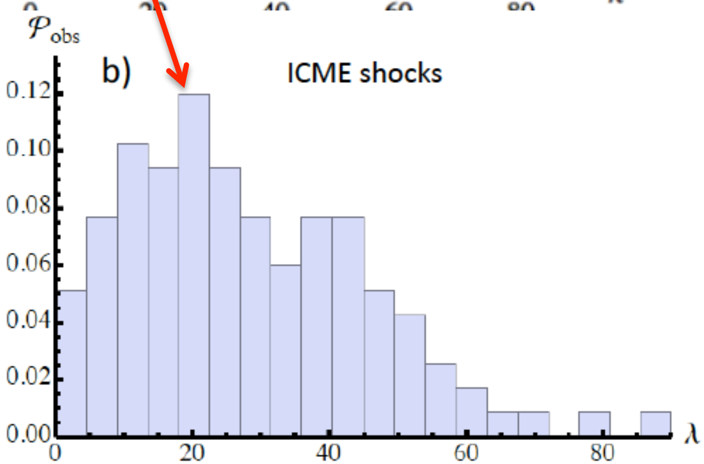
THE COSINE MODEL (SHOCK CASE)

Elongation angle has a weak effect on the distribution functions





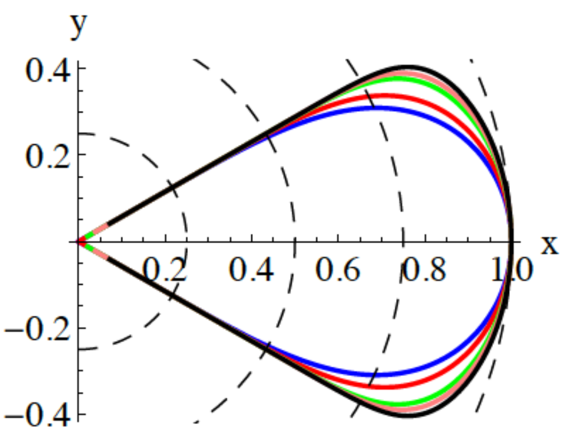




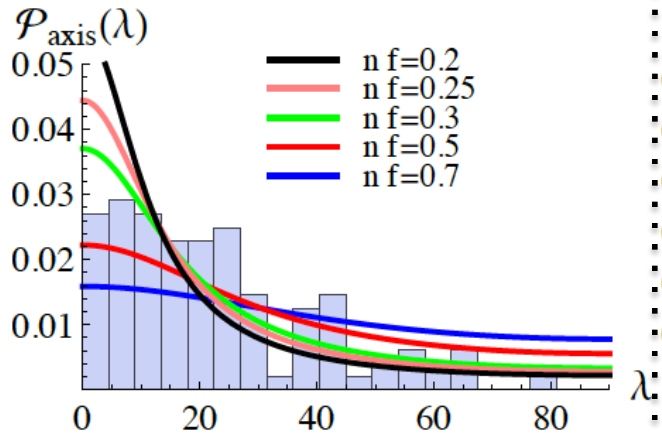
We found the most probable shapes (nf between 0.17 et 0.45)

SYNTHETIC DISTRIBUTION FITTING: SUMMARY

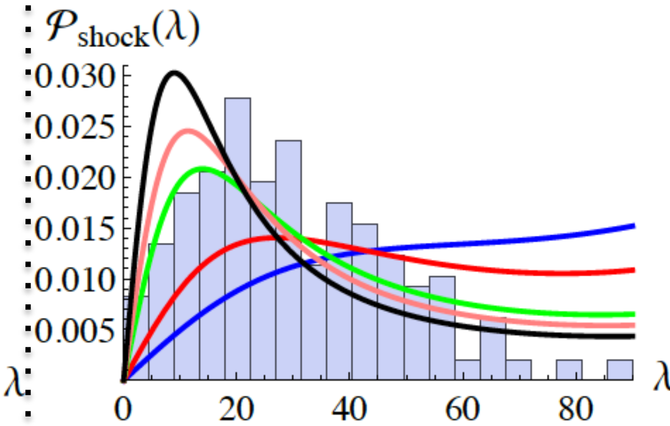
Cosine model



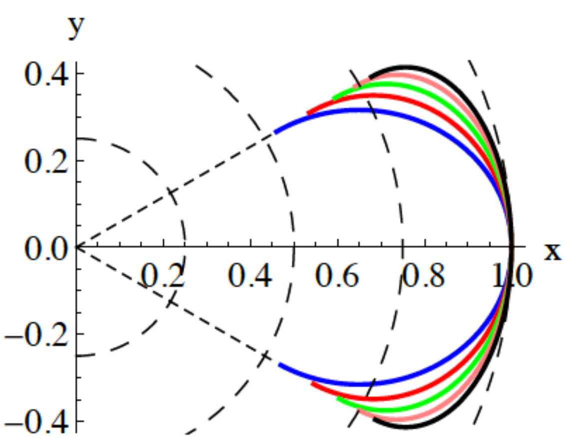
MC AXIS

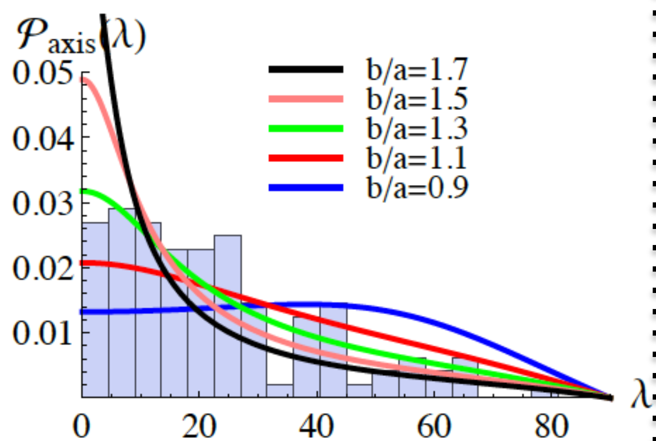


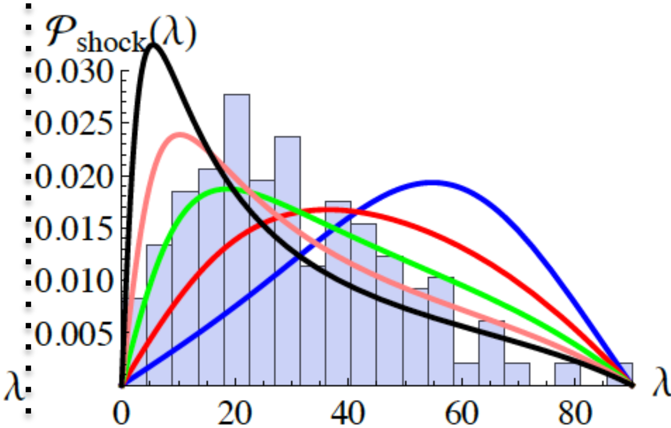
SHOCK



Ellipsoidal model

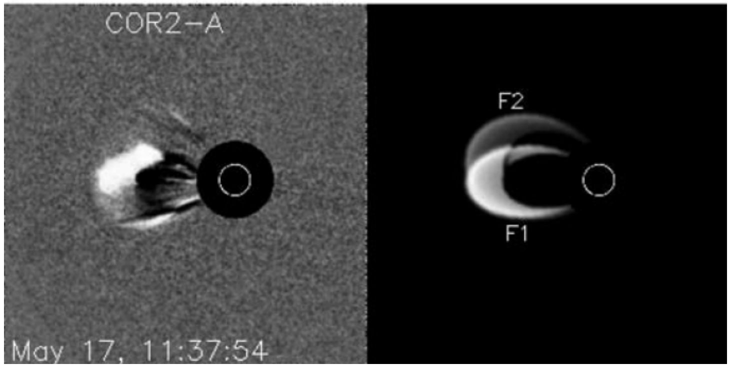






SYNTHETIC DISTRIBUTION FITTING: SUMMARY

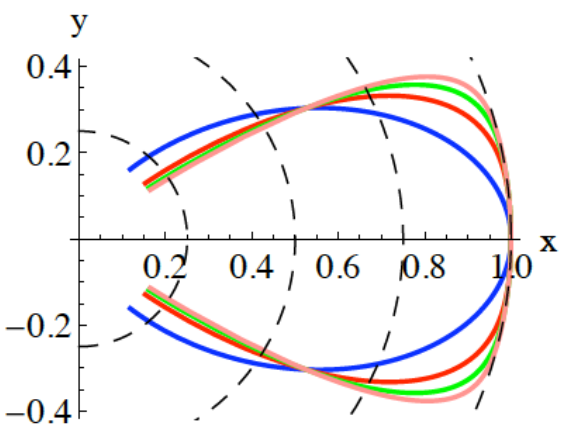
Wood model



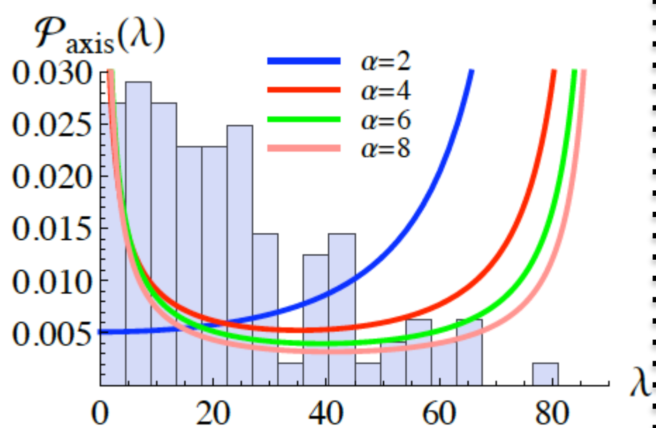
Wood et al. (2009-2012)

$$\rho_w(\varphi) = \rho_{max} \exp(-|\varphi/\sigma|^{\alpha}/2)$$

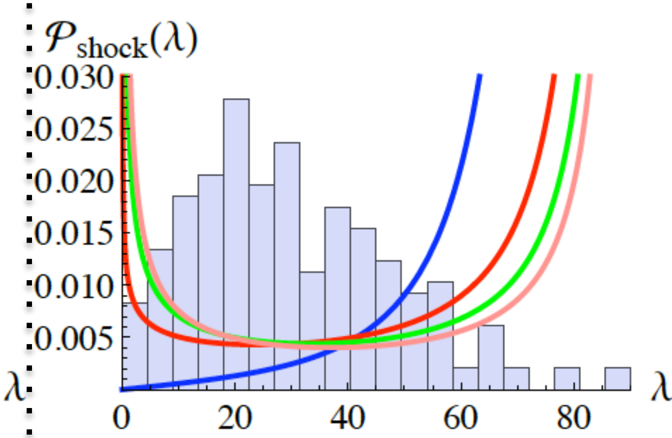
$$\mathcal{P}_w(\lambda) = \frac{\mathcal{P}_{\varphi}(\varphi_w)}{\alpha - 1} \left(\frac{2\sigma^{\alpha}}{\alpha} \sin^{2-\alpha}\lambda \cos^{-\alpha}\lambda \right)^{1/(\alpha-1)}$$



MC AXIS



SHOCK



SYNTHETIC DISTRIBUTION FITTING: SUMMARY

TAKING ALL THE CATALOGUES:

$$\mathrm{diff(obs., mod.)} = \sqrt{\frac{1}{n_b}\sum_{i=1}^{n_b}\left(\mathcal{P}_{obs}(\lambda_i) - \mathcal{P}_{bmod}(\lambda_i)\right)^2}$$

Result 1: Ellipsoidal model slightly better

Result 2:

MC AXIS: **b/a ~ 1.2**

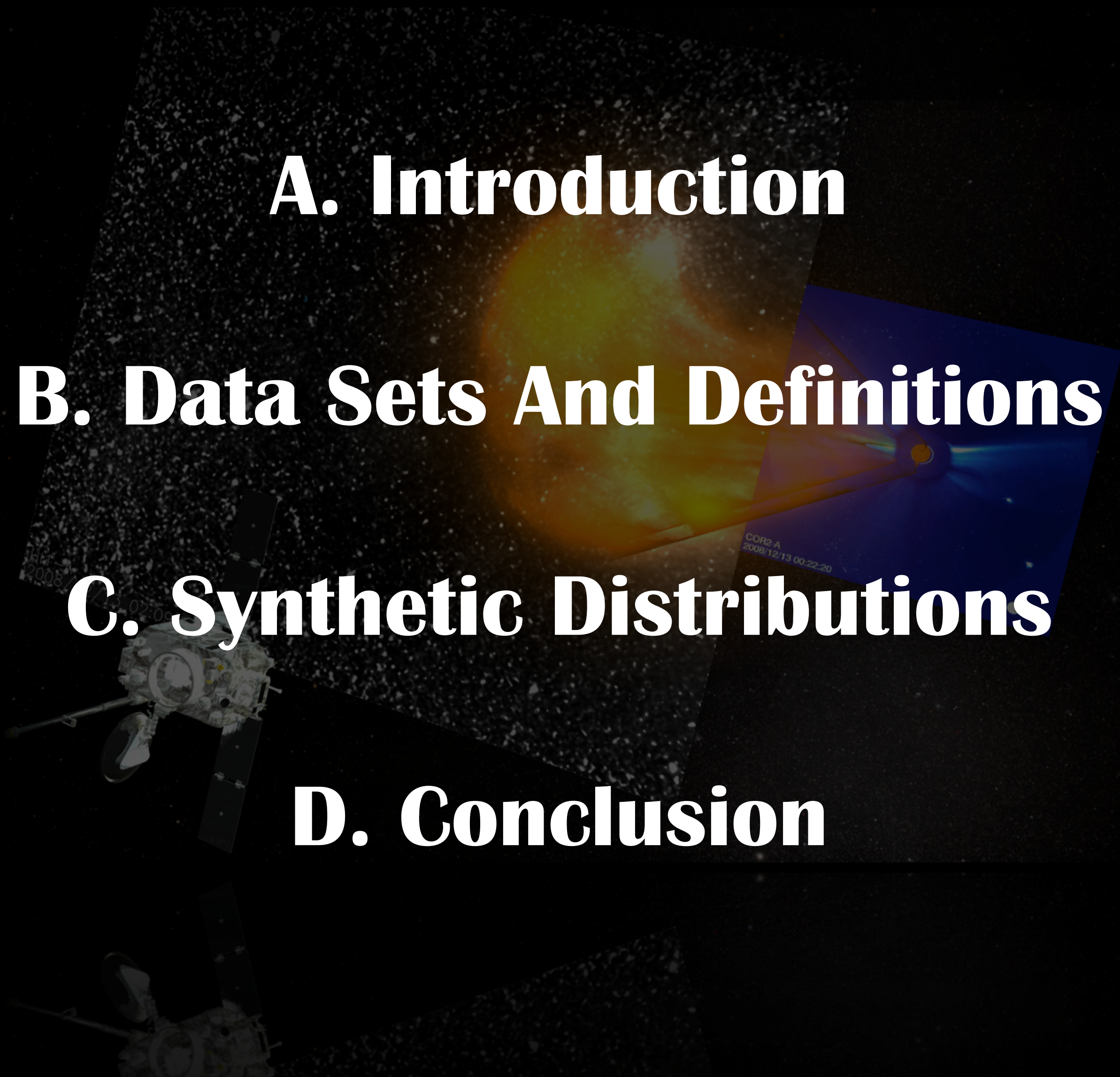
SHOCK: **b/a ~ 1.3**

Table 1. Best fitted cosine and ellipsoidal models to various data sets.

Observations	
data set	N_{case}
results with MC axis	
Lepping & Wu, all	107
Lepping & Wu, quality 1,2[b]	74
Lynch *et al.*	132
Feng *et al.* , axis	62
results with shock normal	
Feng *et al.* , shock	62
Wang , all	216
Wang , non-detected ICME[c]	99
Wang , all ICME	117
Wang , non-flux rope ICME	36
Wang , MC-like	36
Wang , MC	45

Janvier et al. (2015)

OUTLINE



A. Introduction

B. Data Sets And Definitions

C. Synthetic Distributions

D. Conclusion

CONCLUSION

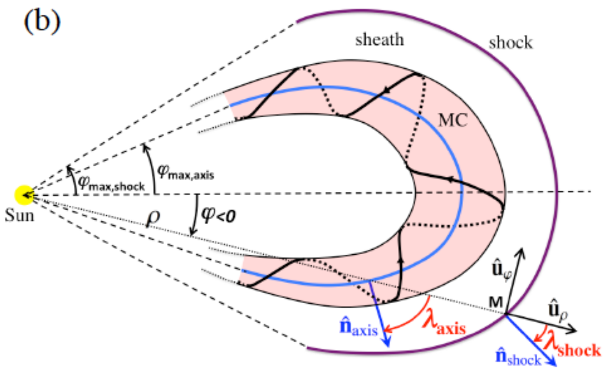
IS THERE A GENERIC SHAPE FOR ICMES? → Look at **MC** and **SHOCKS**

Introduced new parameters

Inclination angle

Location angle

LOOKED AT THEIR PROBABILITY DISTRIBUTION ←



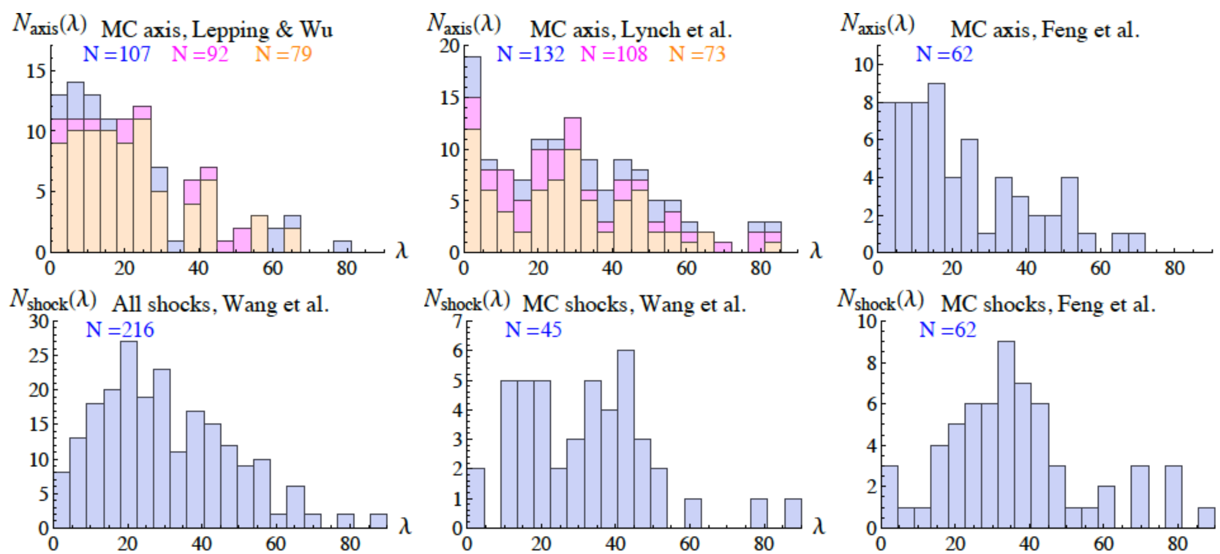
CONCLUSION

Is there a generic shape for ICMEs? → Look at **MC** and **SHOCKS**

Introduced new parameters
Inclination angle
Location angle

LOOKED AT THEIR PROBABILITY DISTRIBUTION

Particular shape
Can we deduce a shape influence on this distribution ?



CONCLUSION

IS THERE A GENERIC SHAPE FOR ICMES? → Look at **MC** and **SHOCKS**

Introduced new parameters

Inclination angle

Location angle

LOOKED AT THEIR PROBABILITY DISTRIBUTION

Particular shape

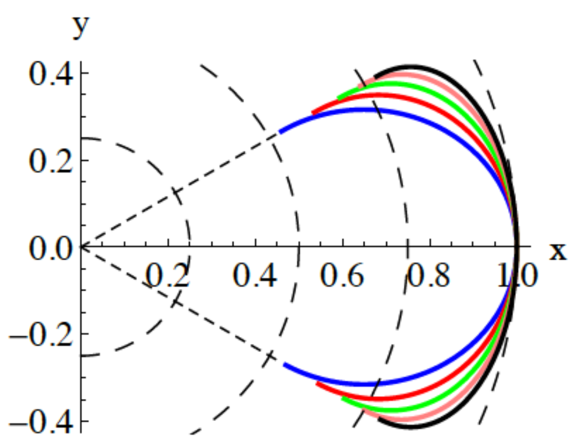
Can we deduce a shape influence on this distribution ?

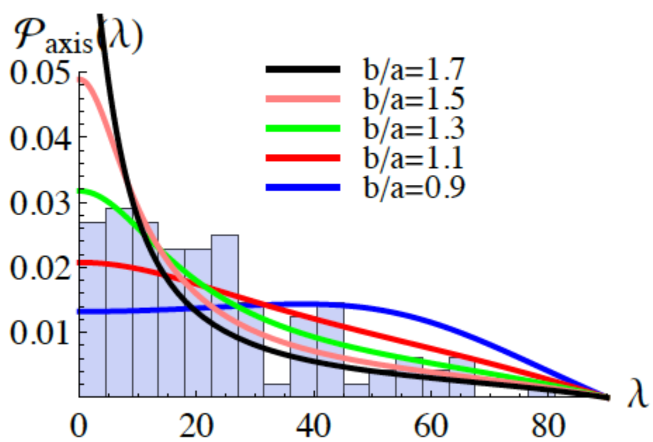
MC AXIS: **b/a ~ 1.2**

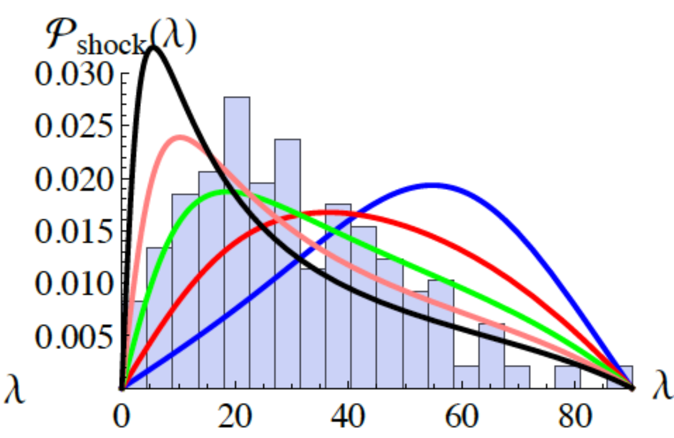
SHOCK: **b/a ~ 1.3**

CHECKED NO CORRELATIONS!

ELLIPSOIDAL MODEL







WHAT'S IN FOR HELCATS?

MORE CATALOGUES! → Test on a more extended sample

→ *Different distances?*
Understand shape changes throughout propagation of ICMEs

CONTRIBUTION FROM NUMERICAL MODELS → Currently testing ellipsoidal shape from different simulations
What parameters influence shape?

CONTRIBUTION FROM CORONAGRAPHS/HI → Models of shocks (probably the easiest)
Can we deduce similar shapes?