Ground-based imaging of volcanic plumes for mass flux

Sébastien Valade[1,(2)]
A. Harris[2], F. Donnadieu[2], M. Cerminara[3], M. Gouhier[2]

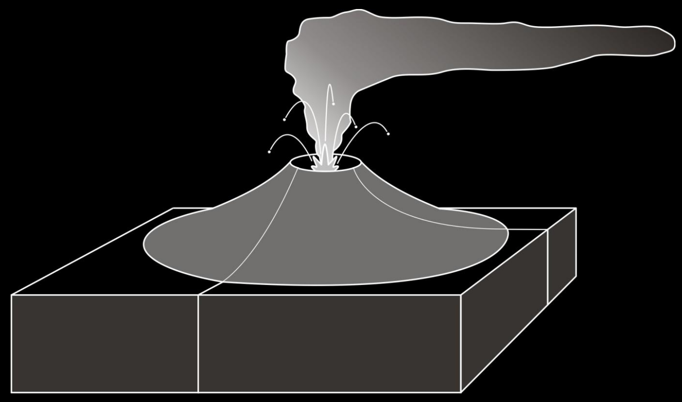
[1] ***University of Florence*** (Laboratorio di Geofisica Sperimentale, Italy)
[2] ***University Blaise Pascal*** (Laboratoire Magmas et Volcans, France)
[3] ***INGV & Scuola Normale di Pisa*** (Italy)

IUGG-WMO 2nd workshop

Geneva (Switzerland), Nov. 18-20, 2013

AIM

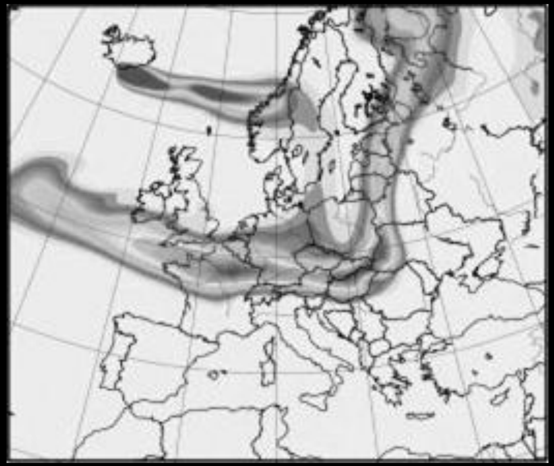
source eruptive parameters



- mass eruption rate (MER)
- particle size distribution (PSD)
- exit velocities

Mastin et al. (2009), Bonadonna et al. (2011)

ash dispersal model



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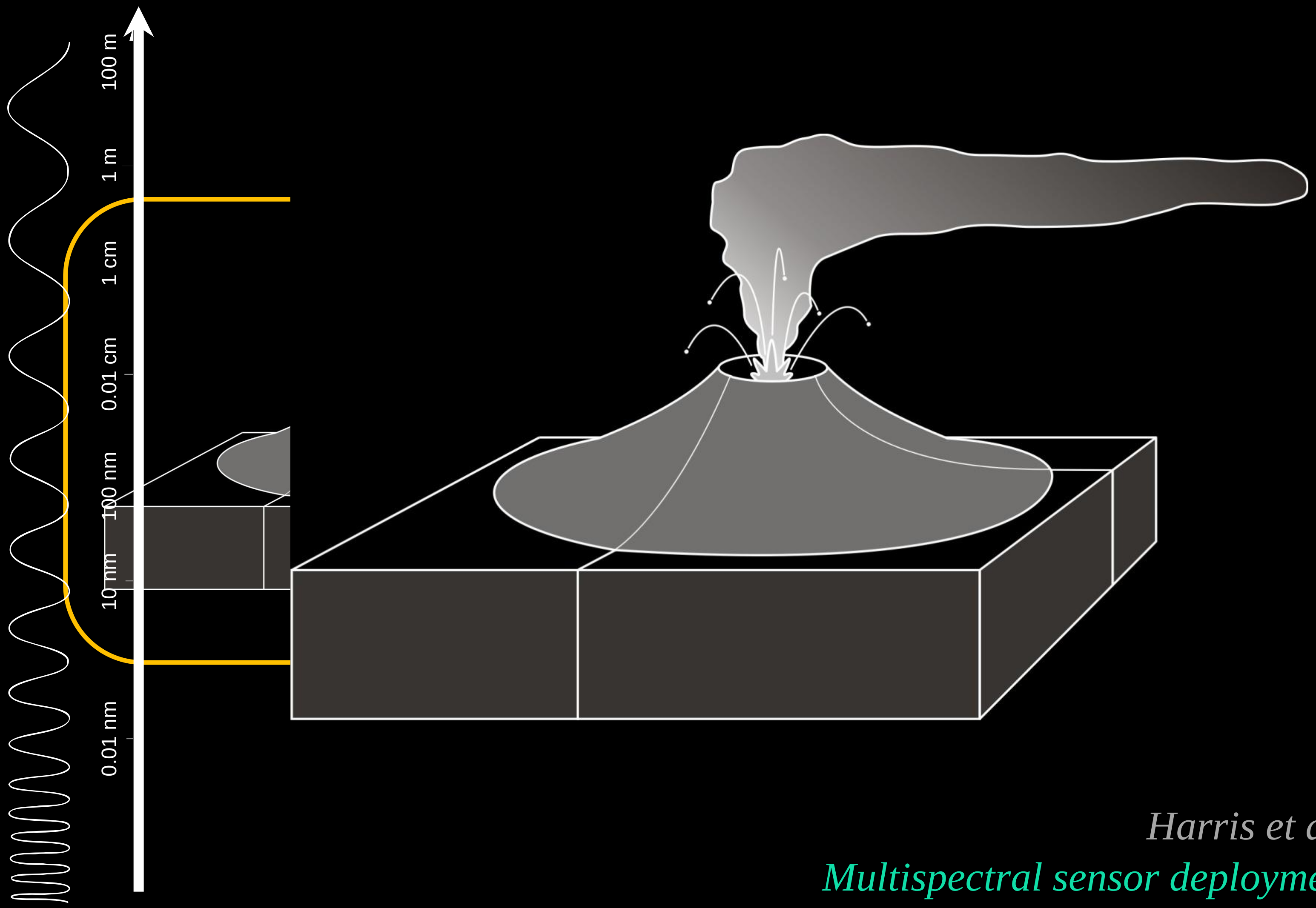
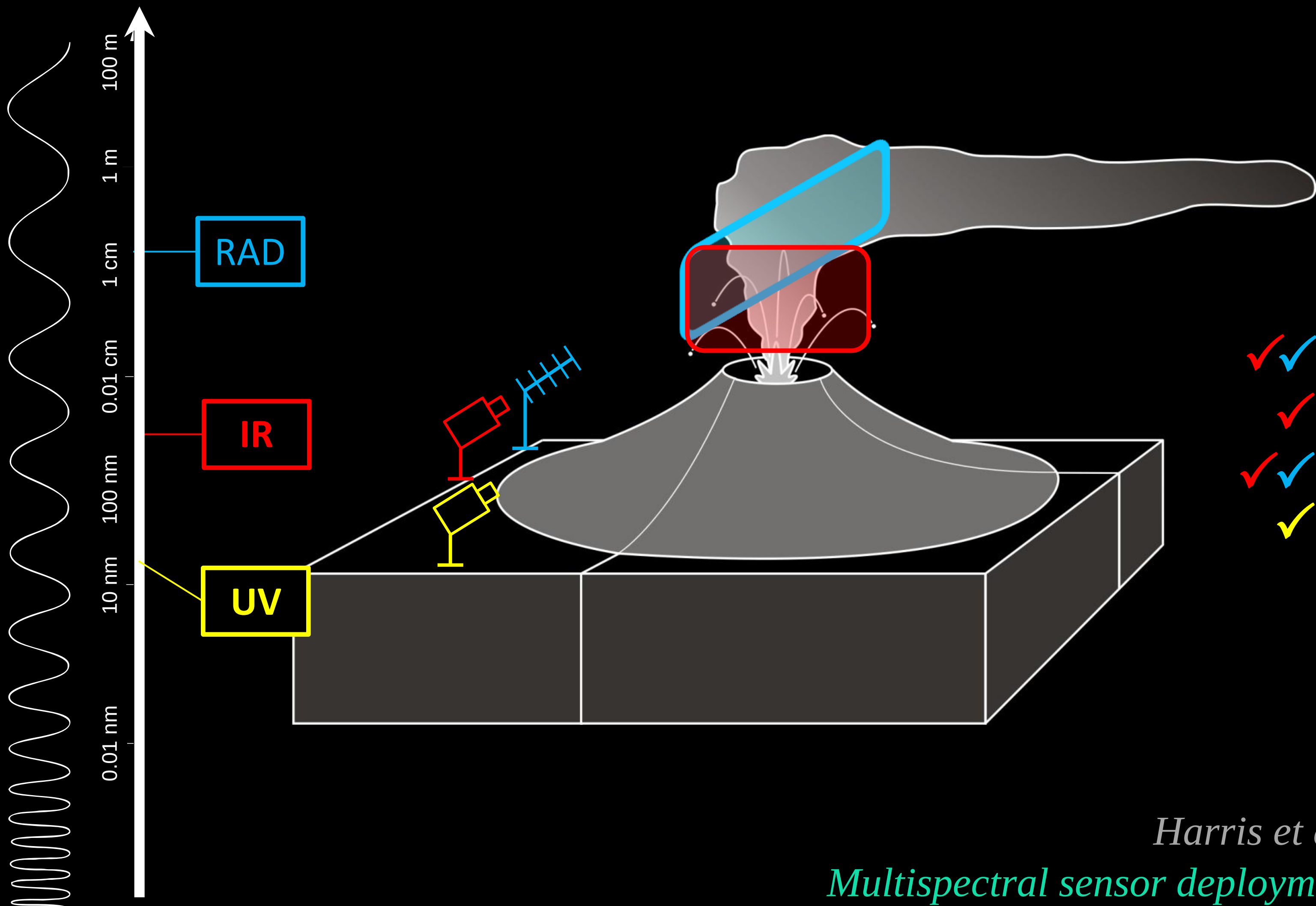


- MER
- PSD
- exit velocities
- gas flux (SO_2)

Harris et al. 2013, (EOS):

Multispectral sensor deployment at Stromboli

AIM



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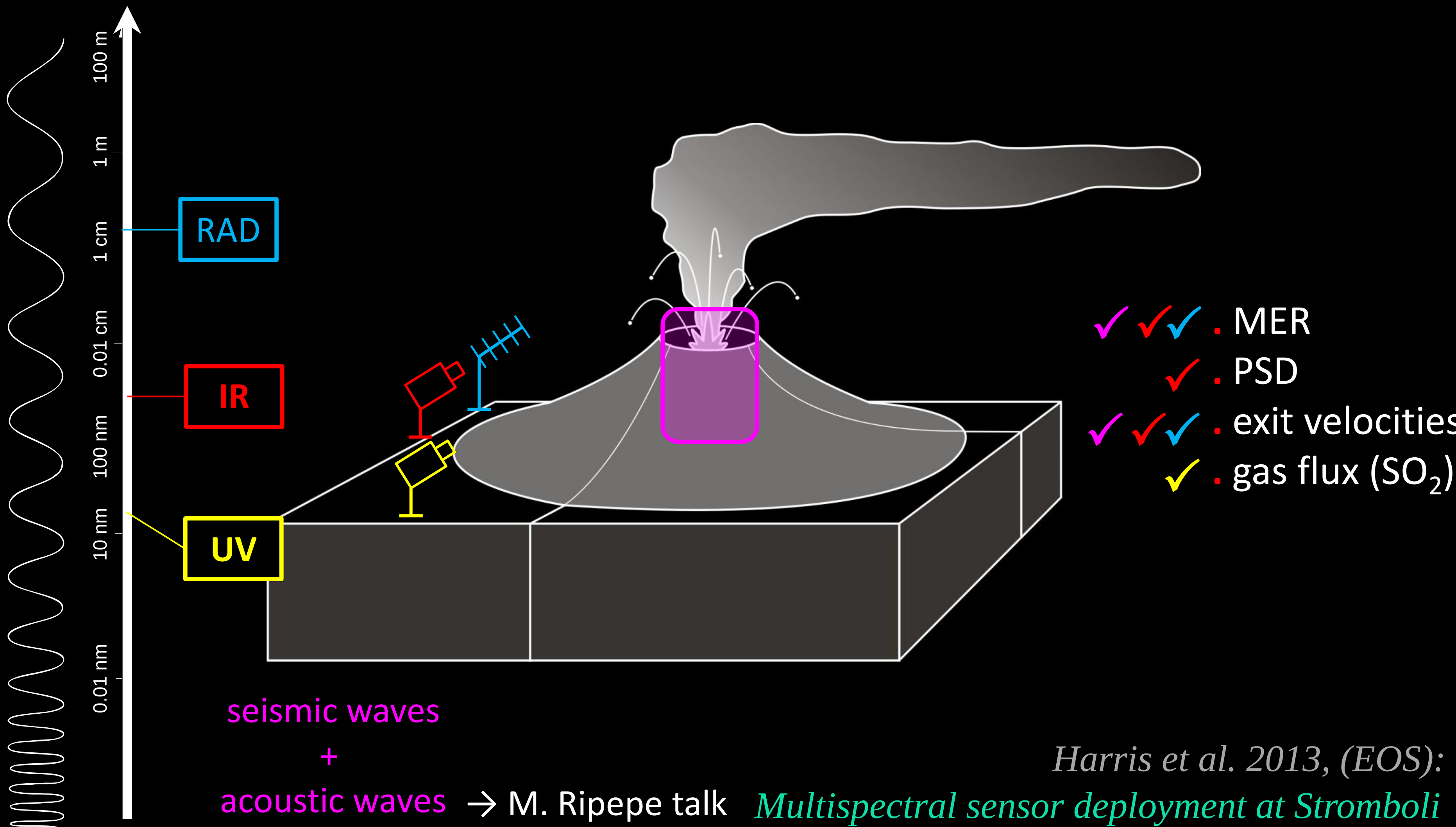

seismic waves
+
acoustic waves → M. Ripepe talk

Harris et al. 2013, (EOS):
Multispectral sensor deployment at Stromboli

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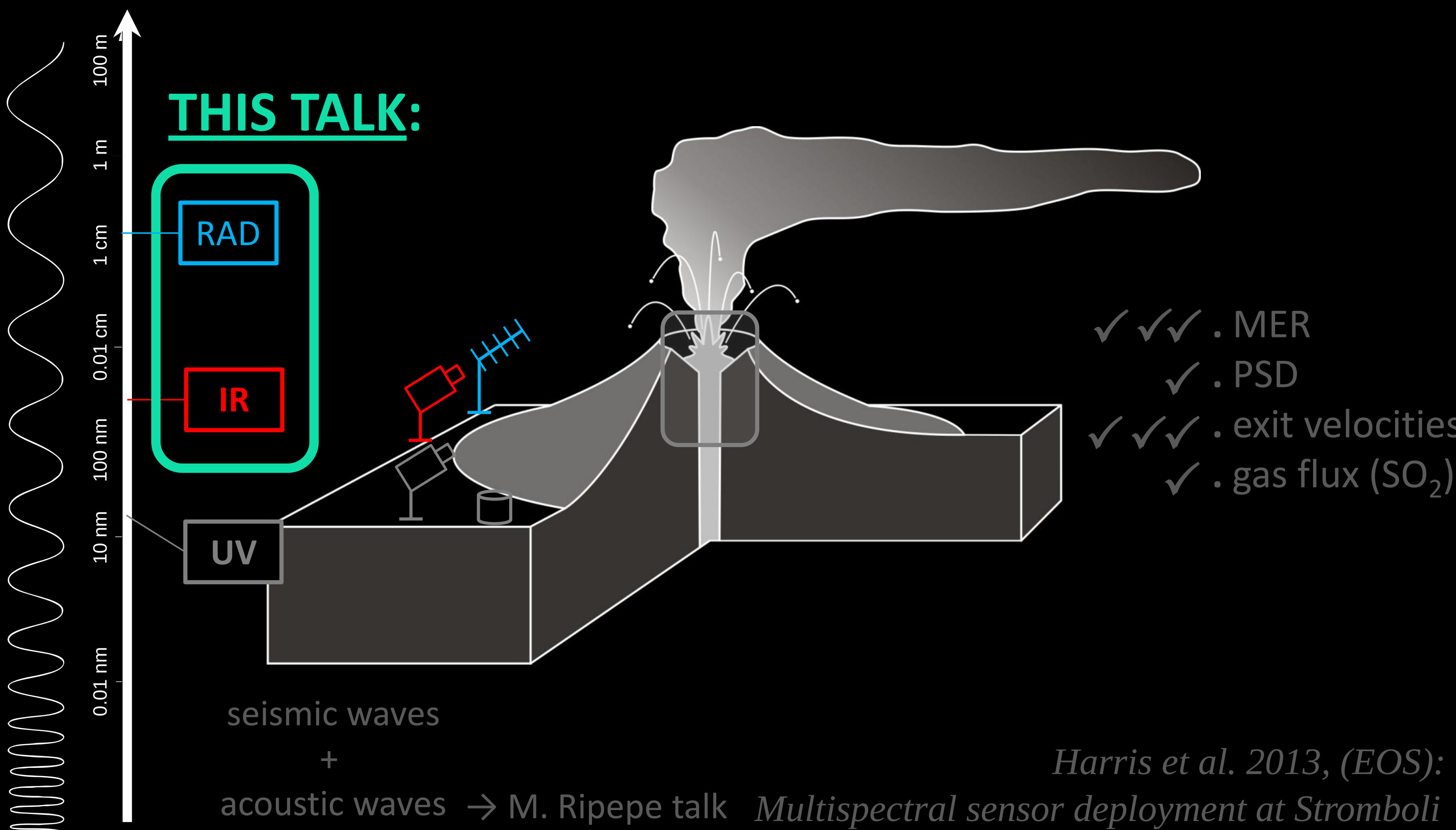


Harris et al. 2013, (EOS): Multispectral sensor deployment at Stromboli

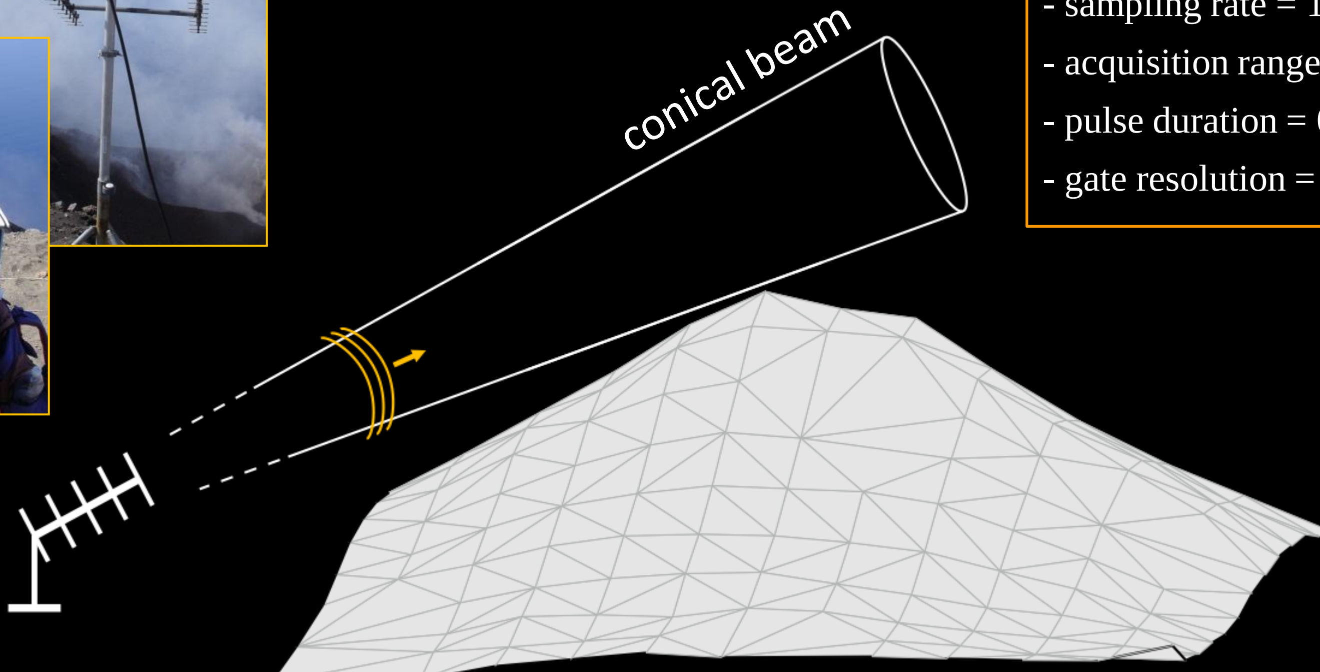
RADAR

AIM

VOLDORAD

(VOLcano DOppler RADar)

- pulsed Doppler radar
- frequency = 1.274 GHz
- wavelength = 23.5 cm
- beam width = 9
- sampling rate = 10 Hz
- acquisition range = 0.3-12 km
- pulse duration = 0.4 – 1.5 µs
- gate resolution = 60 – 225 m



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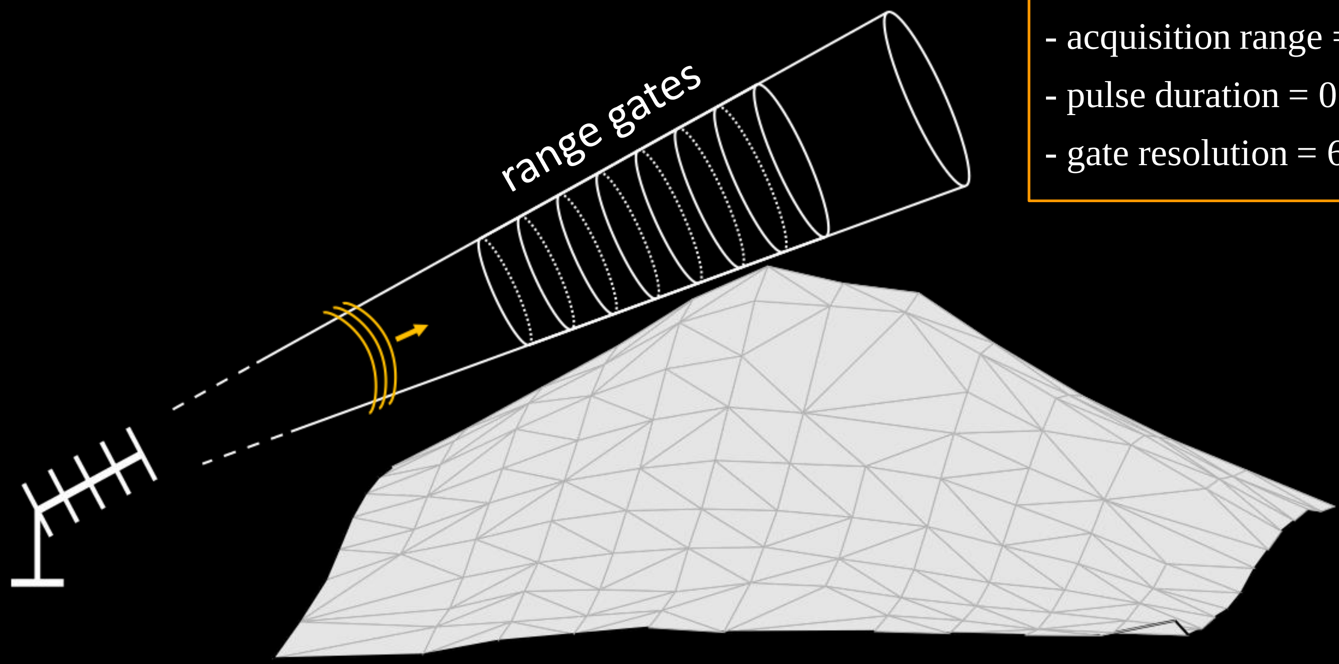

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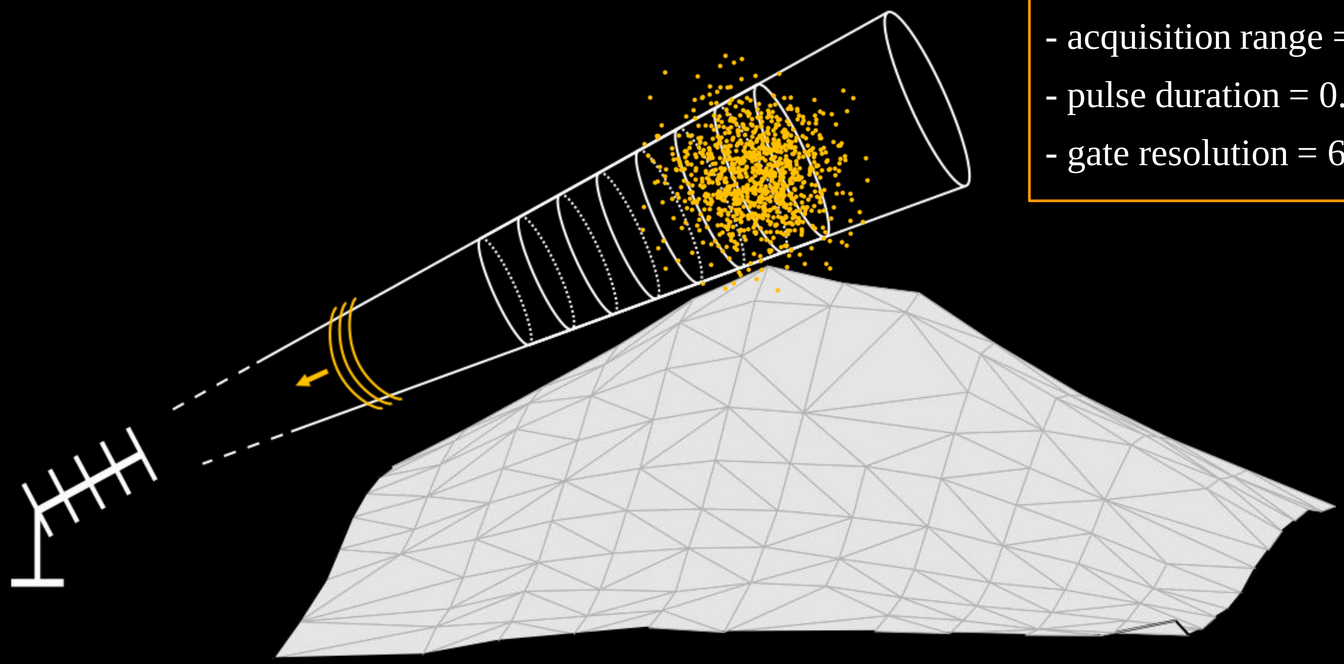
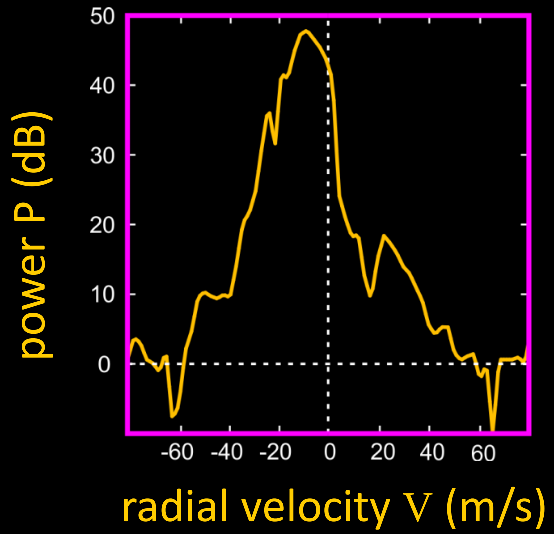
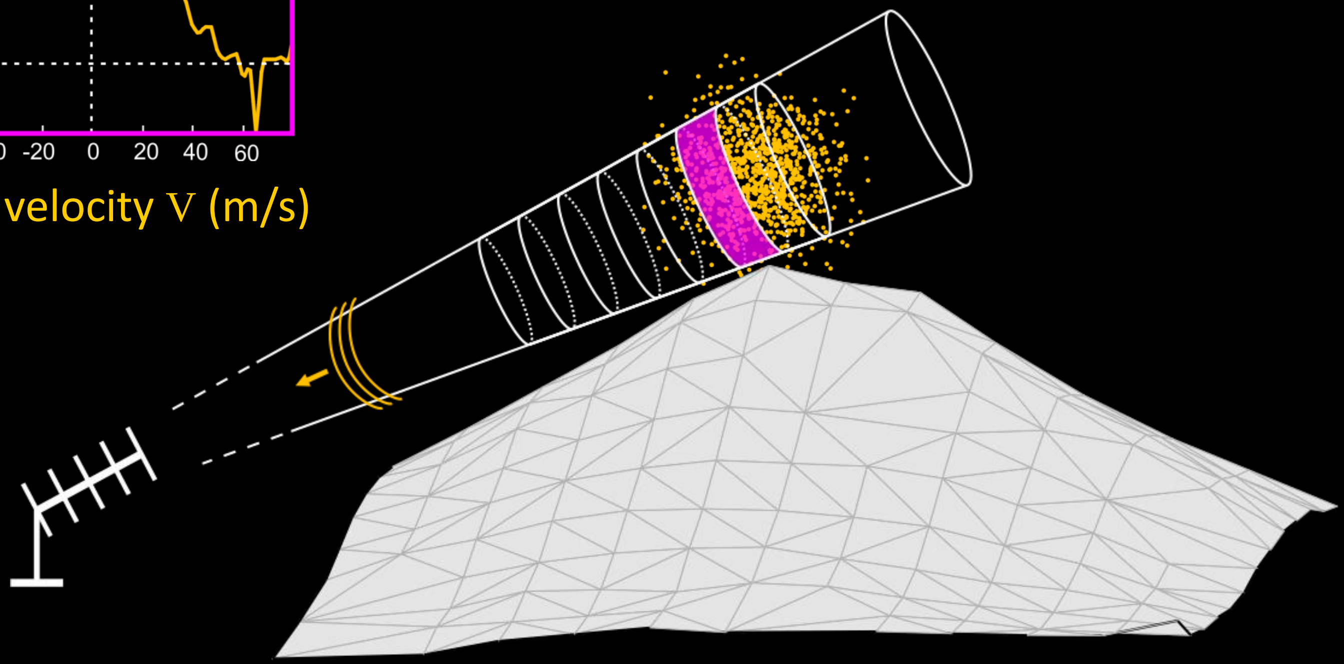


RADAR

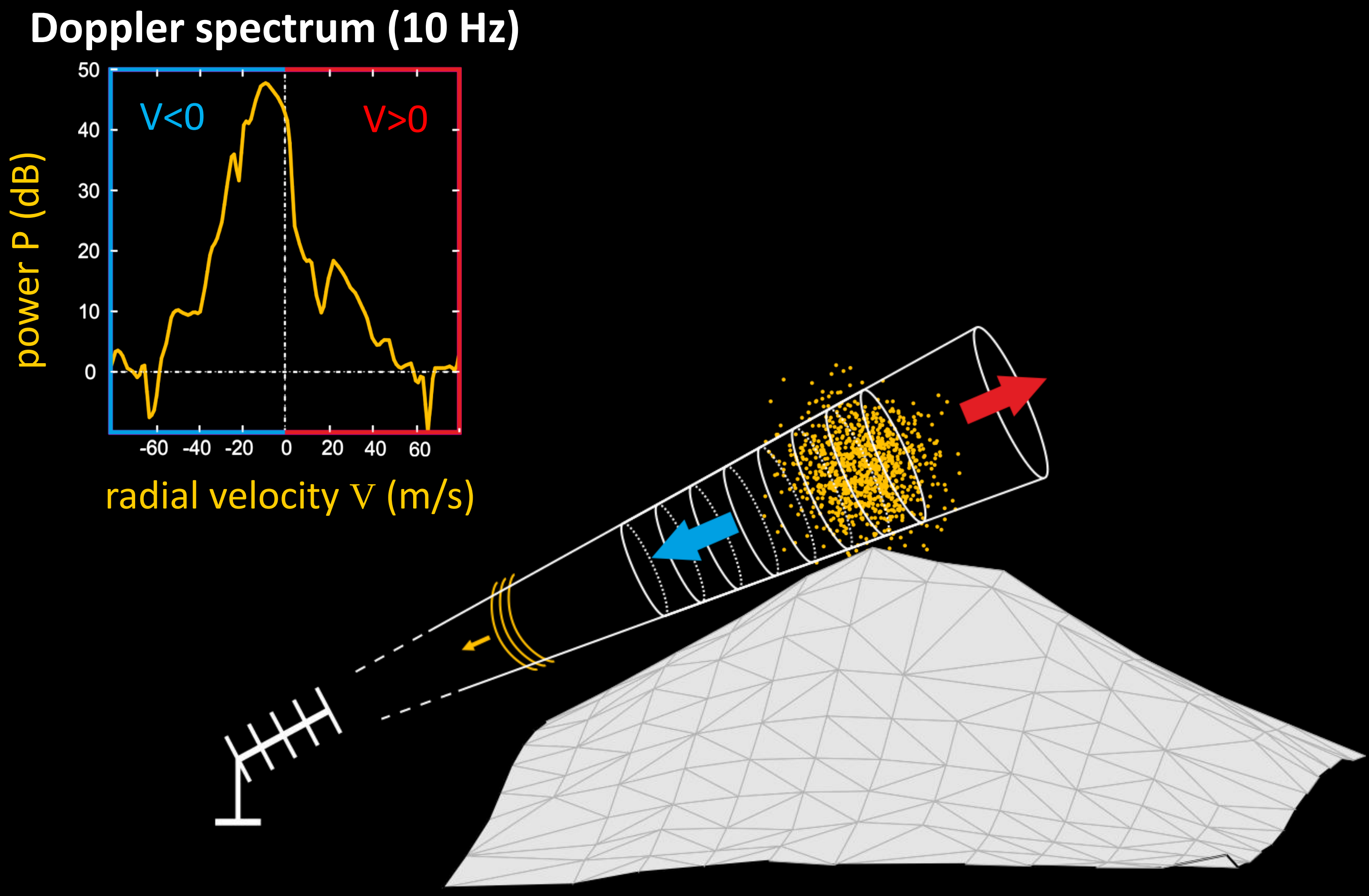
Doppler spectrum (10 Hz)



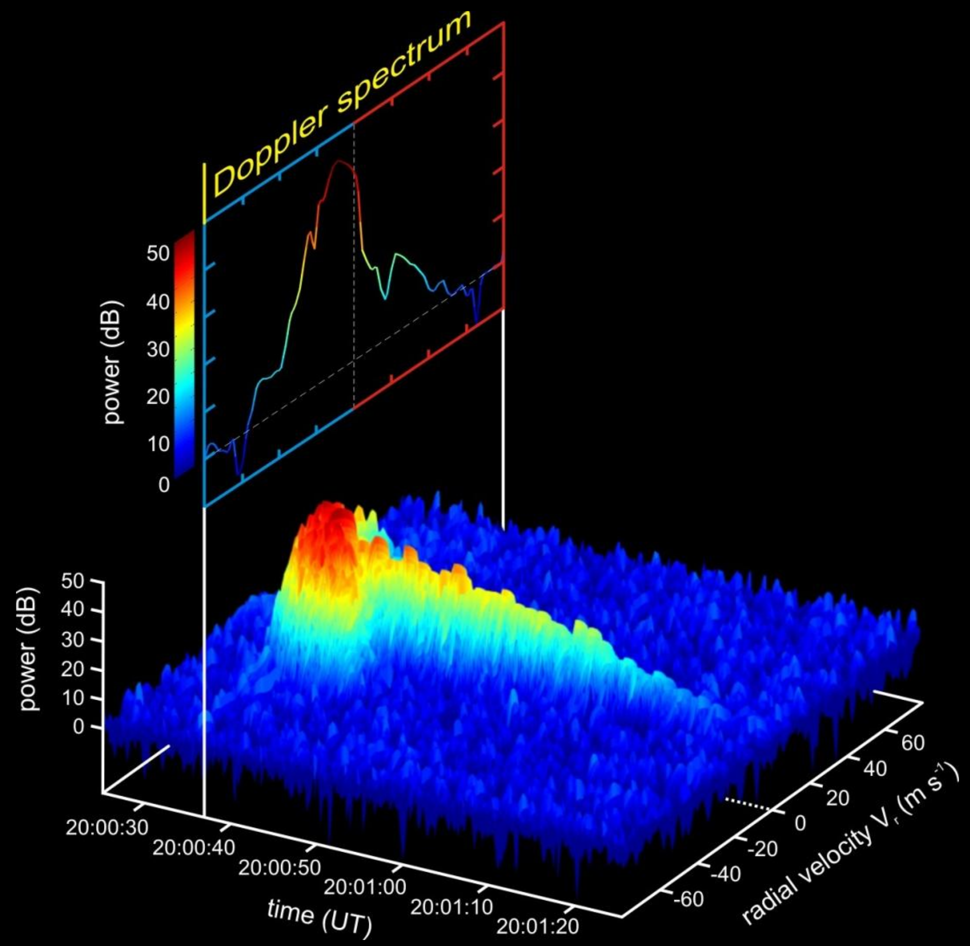
- **backscattered POWER** *(P)*
  ⇨ **number / size** of particles
- radial **VELOCITY** *(V)*
  (velocity along on beam axis)



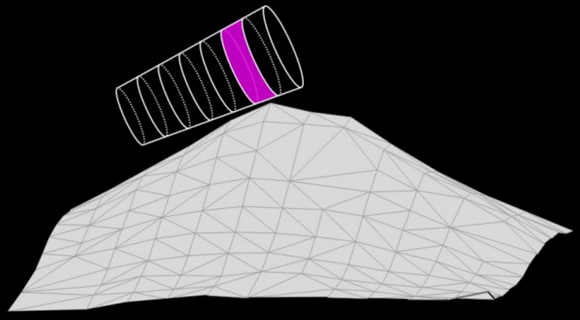
RADAR


Doppler spectrum (10 Hz)
V<0
V>0
50
40
30
20
10
0
-60
-40
-20
0
20
40
60
power P (dB)
radial velocity V (m/s)

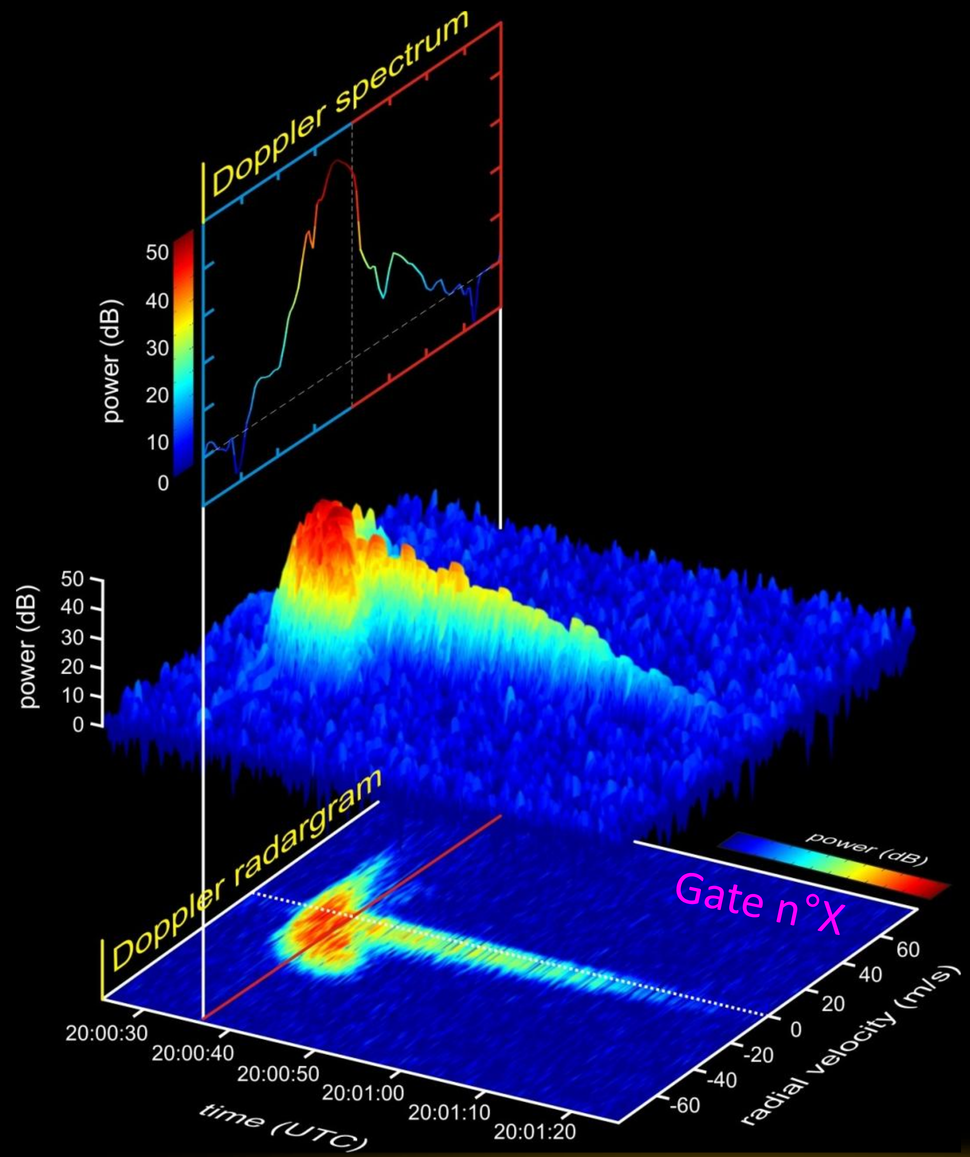
RADAR



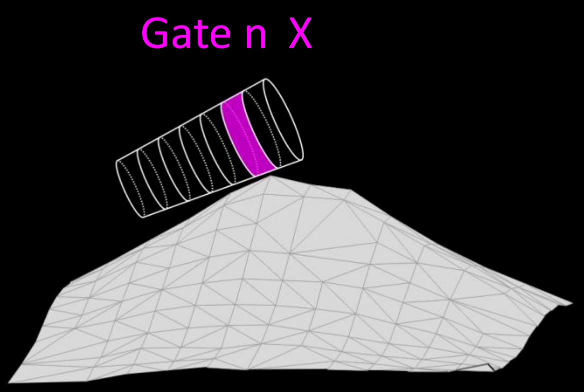
Gate n X



RADAR

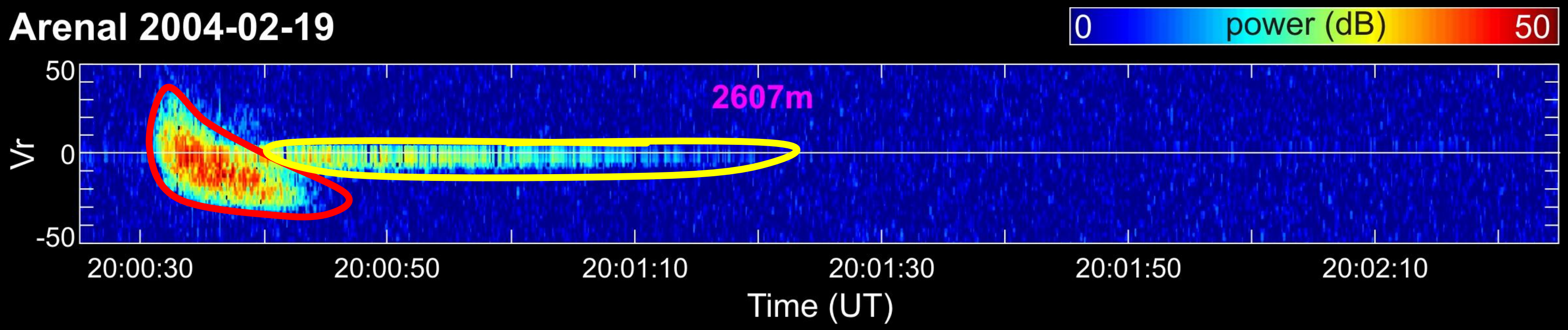


Doppler spectrum
power (dB)
50
40
30
20
10
0
power (dB)
50
40
30
20
10
0
Doppler radargram
power (dB)
Gate n°X
60
40
20
0
-20
-40
-60
radial velocity (m/s)
20:00:30
20:00:40
20:00:50
20:01:00
20:01:10
20:01:20
time (UTC)



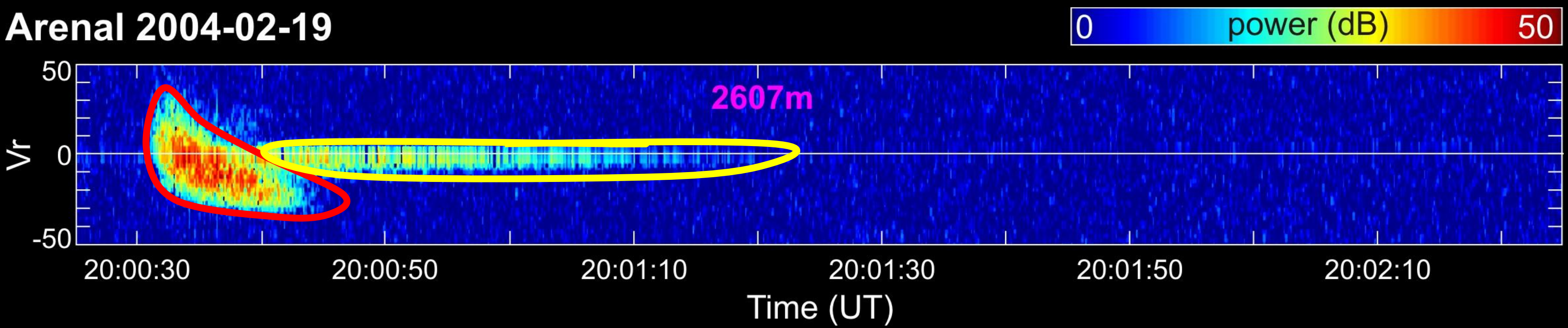
Gate n X

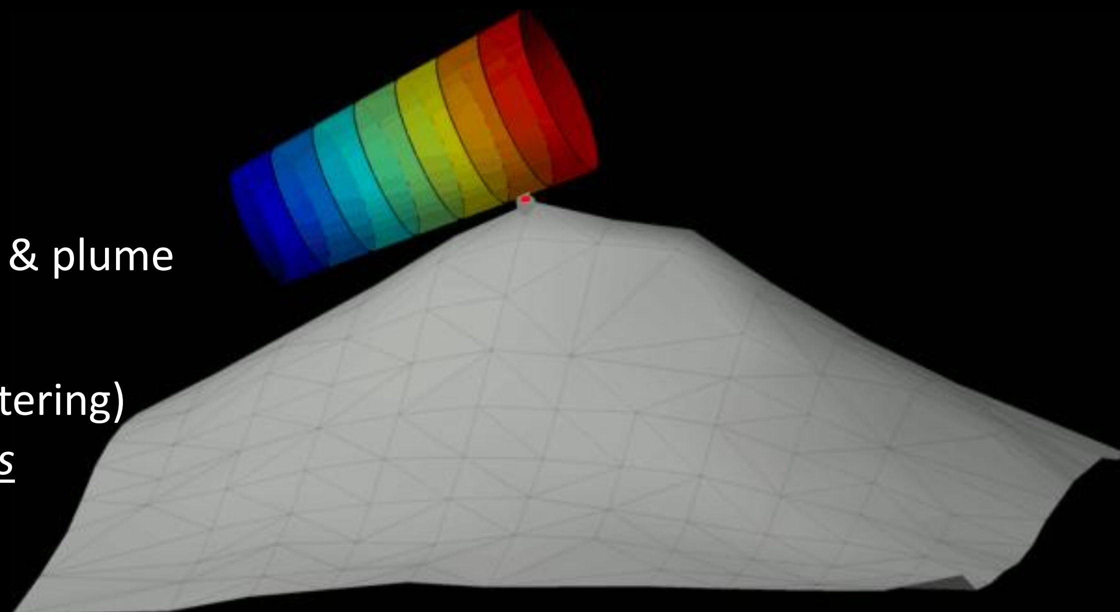
RADAR



Arenal 2004-02-19
0
power (dB)
50
2607m
50
0
-50
Vr
20:00:30
20:00:50
20:01:10
20:01:30
20:01:50
20:02:10
Time (UT)

RADAR



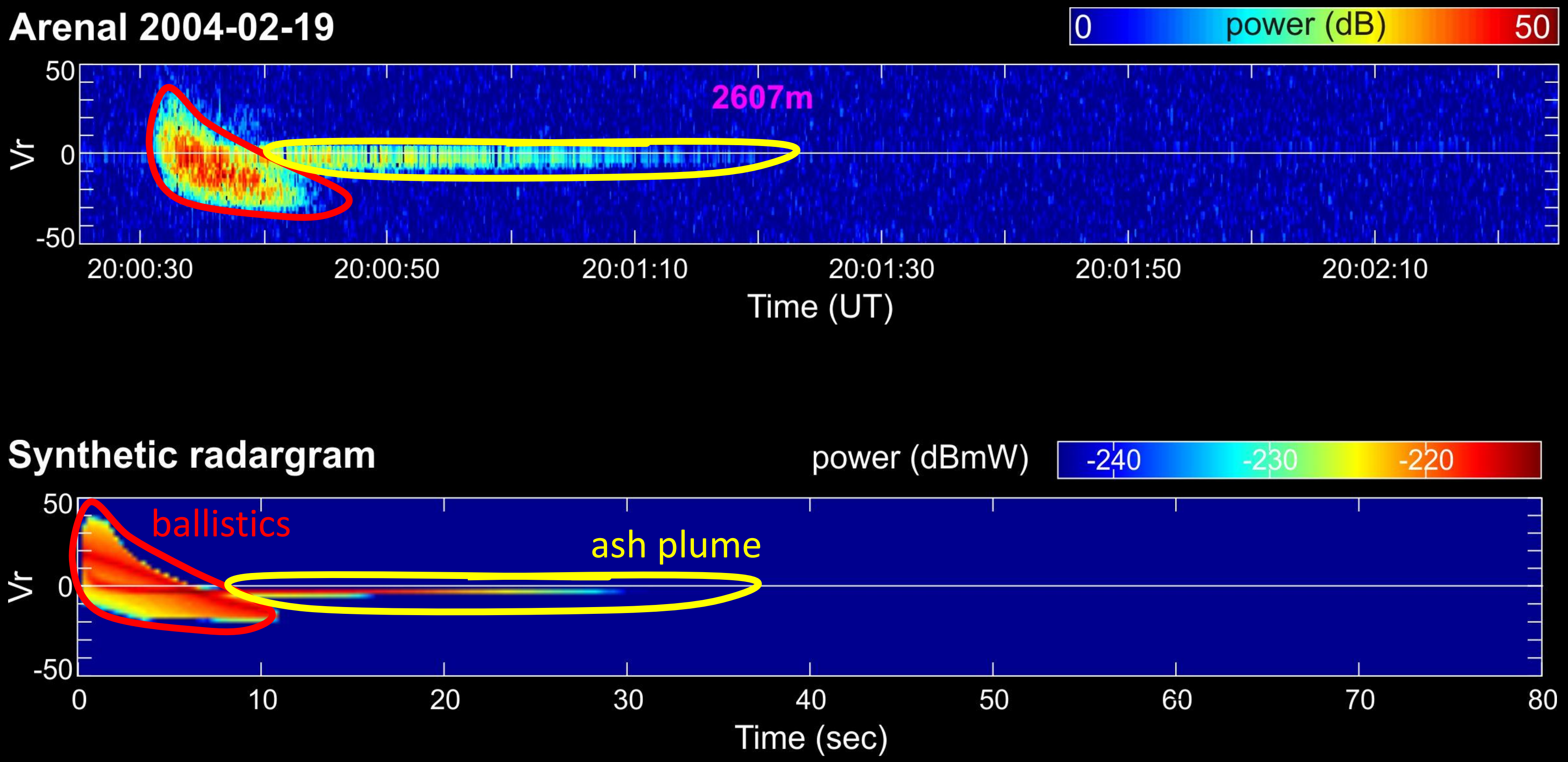


Numerical Modeling:

1. Simulate trajectories
   ⇨ 3D *particle motion* of ballistics & plume
   (Dubosclard et al., 2004)

2. Simulate radar signal (Mie scattering)
   ⇨ construct *synthetic radargrams*
   (Gouhier and Donnadieu, 2008)

RADAR

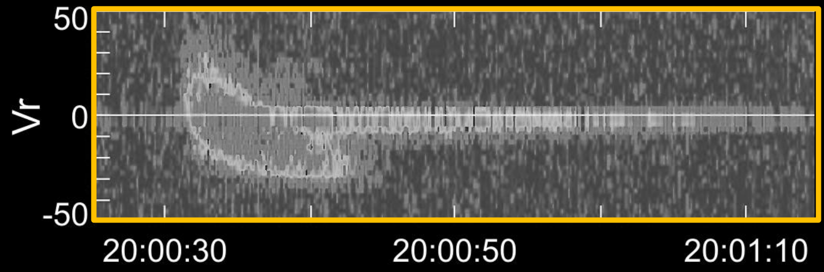


⇨ insights into **internal dynamics** of pyroclastic emissions

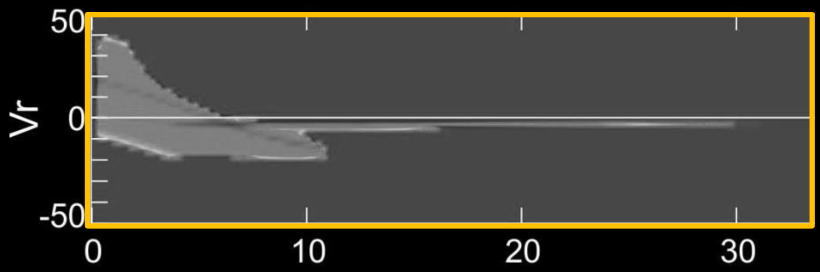
Valade and Donnadieu, 2011 (GRL)

RADAR

OBSERVED rdgrm



MODELED rdgrm



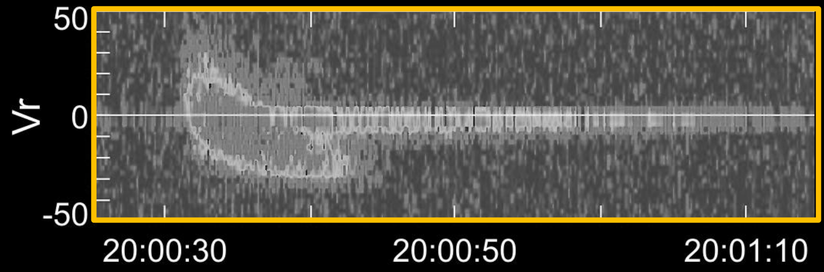
INPUTS

- initial gas velocity
- ejection angles
- PSD

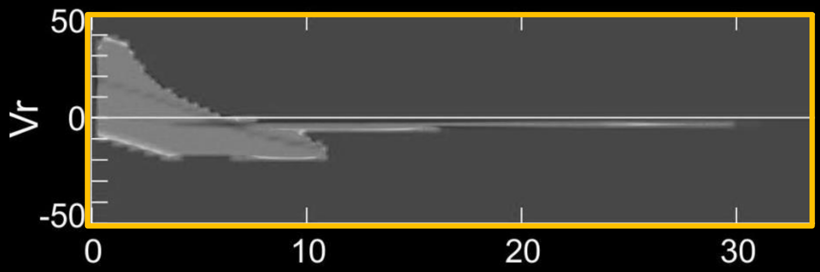
Valade, 2012 (PhD)

RADAR

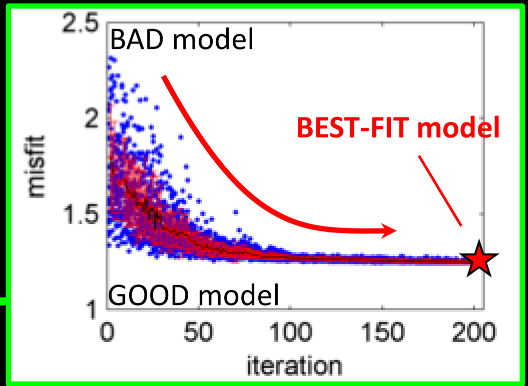
OBSERVED rdgrm



MODELED rdgrm



⇨ minimize fit criterion



INVERSION model

(Monte Carlo. NA search)

Fukushima et al. (2005), Augier (2011)

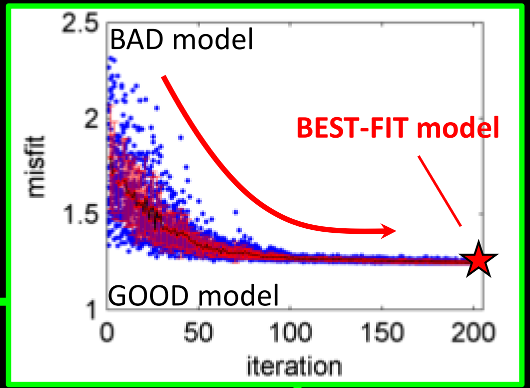
INPUTS

- initial gas velocity
- ejection angles
- PSD

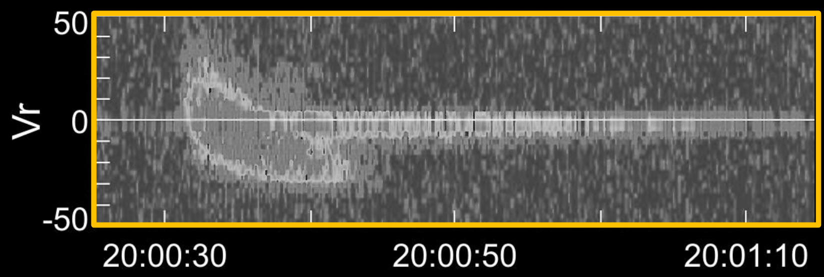
Valade, 2012 (PhD)

RADAR

⇨ minimize fit criterion



OBSERVED rdgrm



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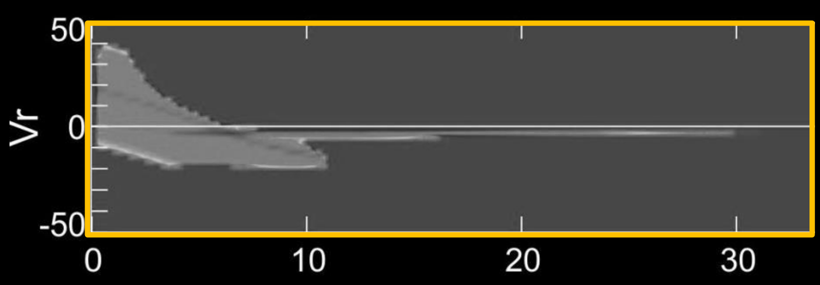


- initial gas velocity
- ejection angles
- PSD

source parameters

EX: Arenal 2004-02-19

⇒ eruptive ***velocities***	
initial *gas velocities*	~ 130 – 170 m/s
max *particle velocities* (real)	~ 65 – 85 m/s
⇒ eruptive ***particle size distribution***	~ 0.1 – 0.5 m
⇒ eruptive ***jet geometry***	
inclined	~ 10° from vertical
max *height/distance* from vent	~ 245 m / 500 m

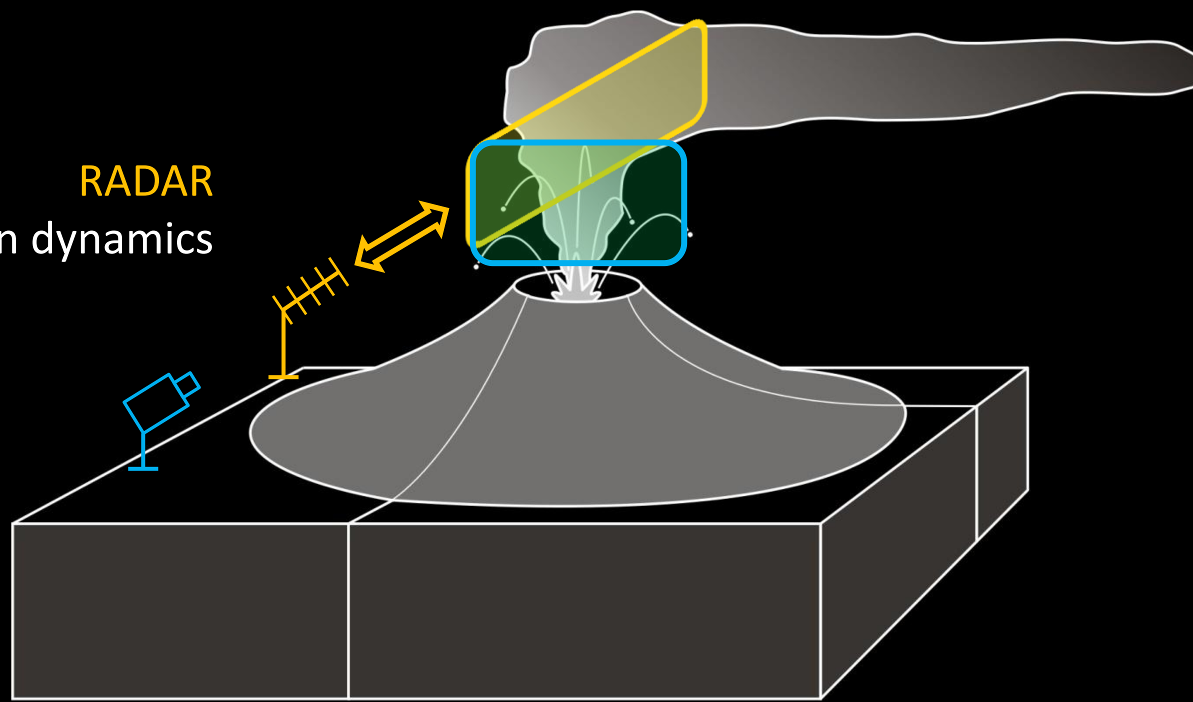
BUT: method is time consuming

IR imagery

RADAR

RADAR
internal emission dynamics

IMAGERY
synopic view of plume rise

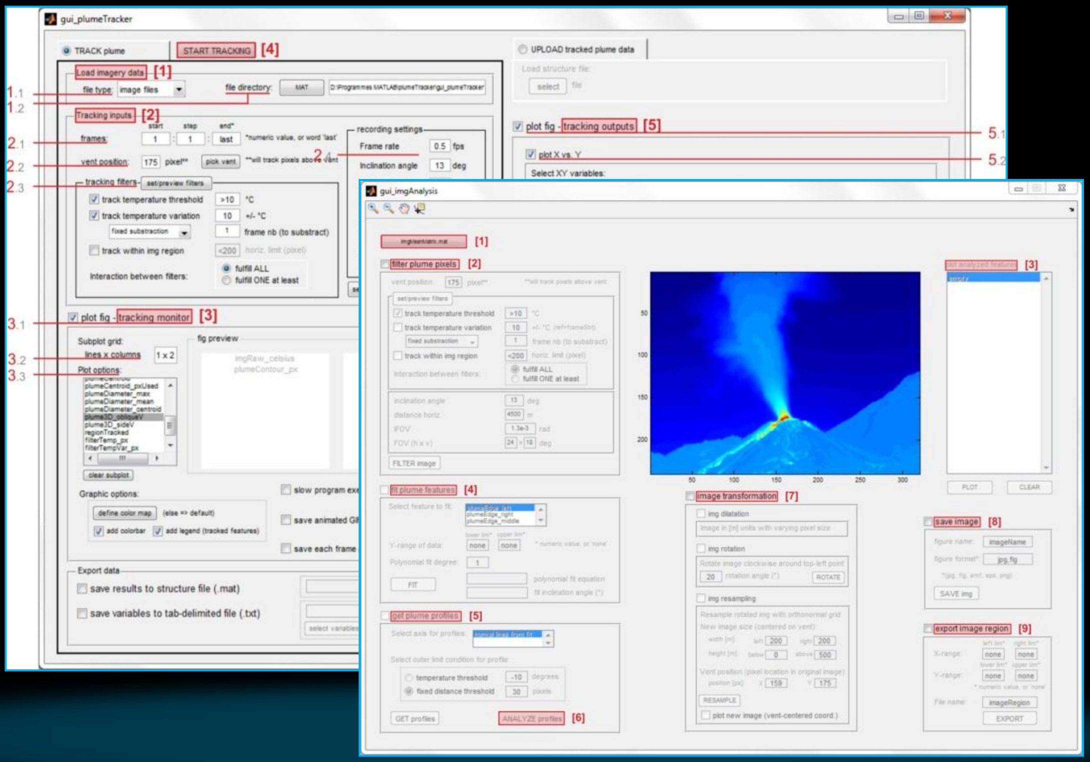


IR imagery

1. development of **tracking algorithms** to process imagery data

Plume Tracker: an interactive Matlab software to analyze volcanic emission in imagery data

Valade et al. (accepted by *Computers and Geosciences*)



IR imagery

Plume Tracker

Language: **Matlab 2012** (+ default toolboxes)

Various OS:

Various inputs:

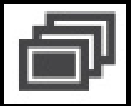
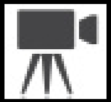


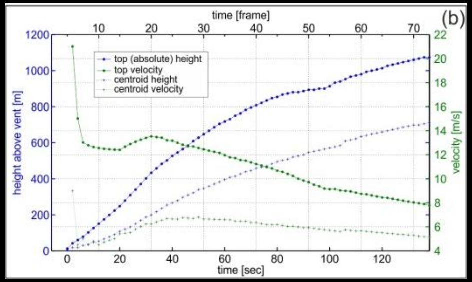
image files



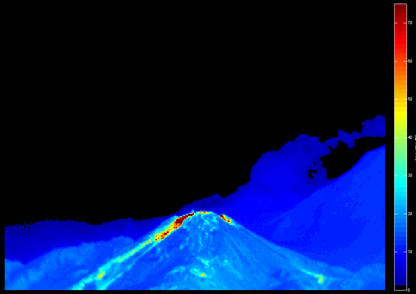
video files

webcam url

Various outputs:



graphics



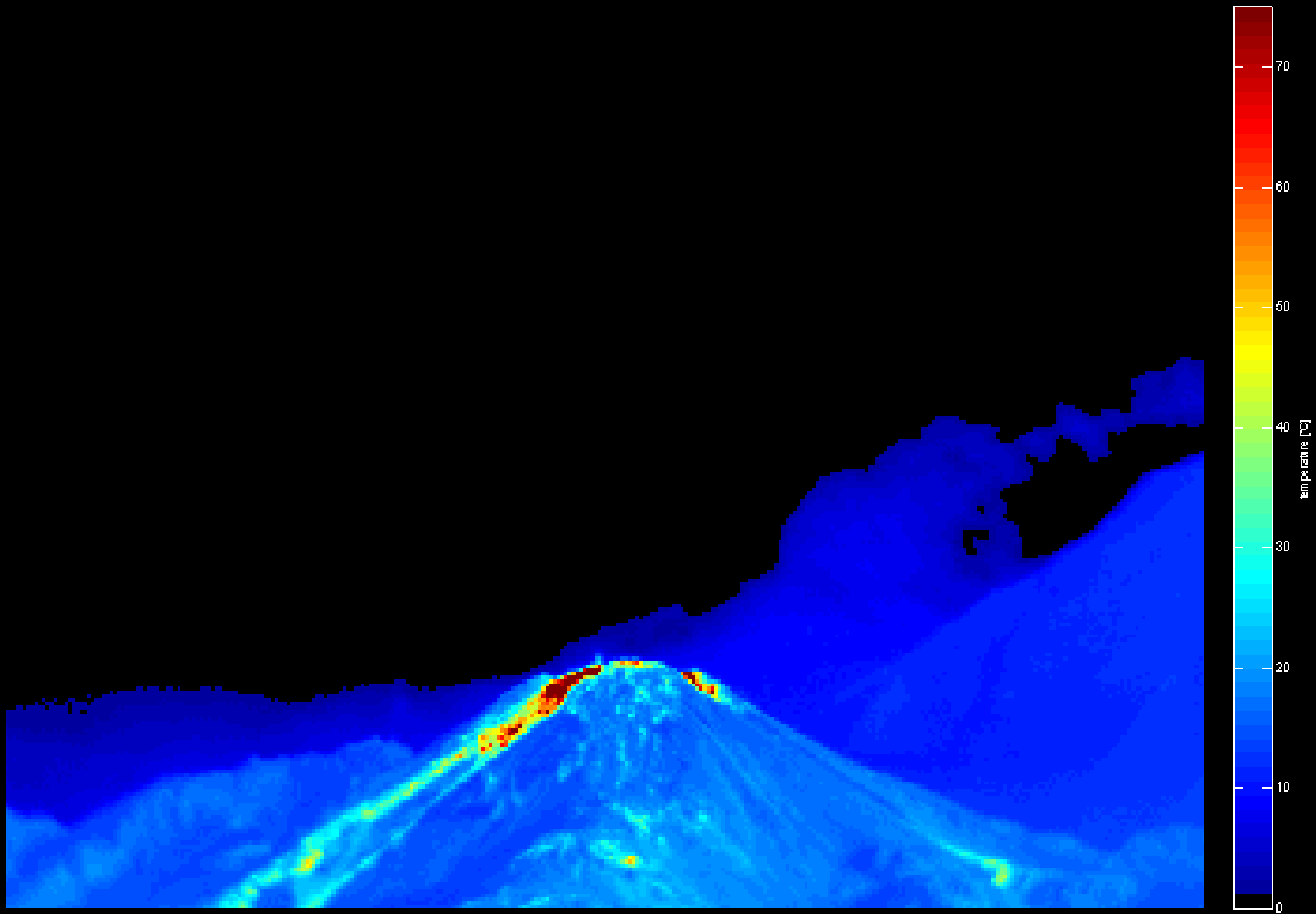
animated gif

t_sec	heightTop	velocityTop
NaN	NaN	NaN
NaN	NaN	NaN
0.00	11.99	Inf
4.00	60.07	15.02
8.00	102.27	12.78
12.00	150.67	12.56
16.00	199.26	12.45
20.00	248.06	12.40
24.00	309.36	12.89
28.00	371.03	13.25

data sheets

IR imagery

Santiaguito volcano (2005)



FILTER image + TRACK plume

RAW image stream

IR imagery

2. Mass estimations from plume ascent dynamics *(un-sustained plumes)*

$$\beta = \frac{g - 3C_s w^2 / 8r}{g + du/dt} \cdot \alpha$$

Wilson and Self (1980)

β = plume **bulk density** for a spherical thermal ascending by buoyancy
r = plume radius
w = cloud top velocity
u = cloud center velocity
α = atmospheric density = f(altitude) *[NOAA, 1976]*
C_s = drag coefficient = 0.47 for a sphere
g = acceleration due to gravity

$$\beta = f\rho_{ash} + (1-f)\rho_{air}$$

f = fractional content of ash
ρ_{ash} = density of vesicular ash
ρ_{air} = density of the heated air in the plume $\rho_{air} = \alpha \cdot \frac{T_\alpha}{T_\beta}$

$$m_{ash} = f \cdot V_{plume} \cdot \rho_{ash}$$

V_{plume} = plume volume approximation $V_{plume} = \sum_{discs} \pi \cdot r^2 \cdot pixel_{height}$

⇨ mass estimations for Santiaguito ash plume ~ [10^4 - 10^5] kg

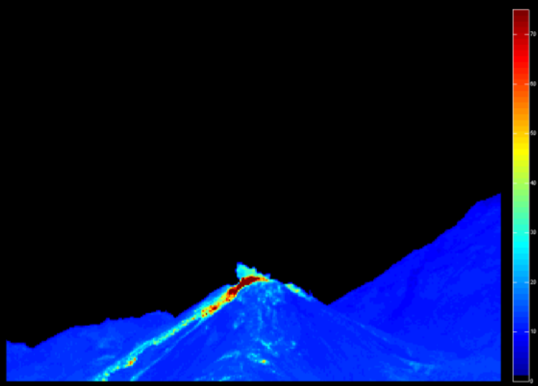
BUT: method can only be applied to
- *plumes with finite volume release (short emission duration)*
- *plumes with simple shape (minor deformation by wind)*

IR imagery

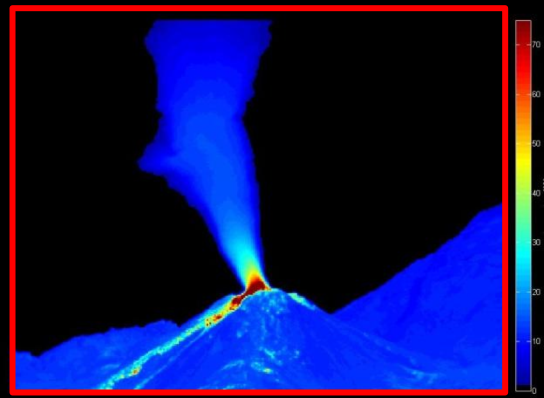
2. Mass estimations from plume modeling *(sustained plumes)*

MEAN plume behaviour

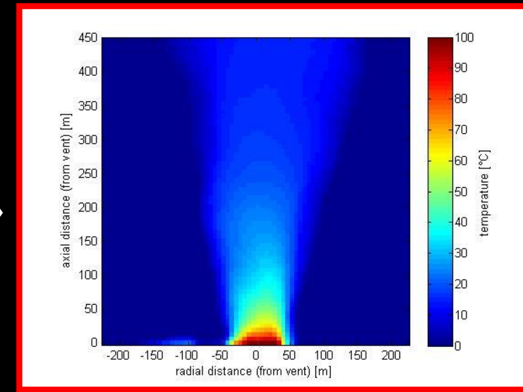
+ img transformation *(Plume Tracker)*



sustained plume

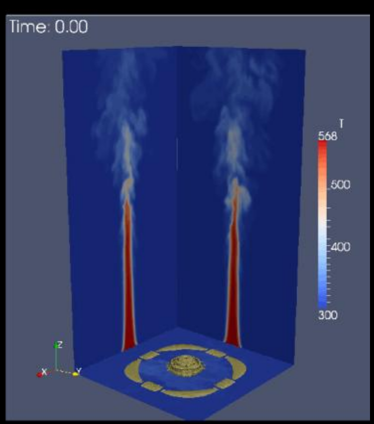


mean image
(Plume Tracker)

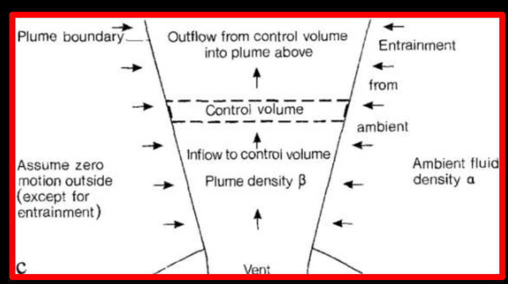


observed IR image

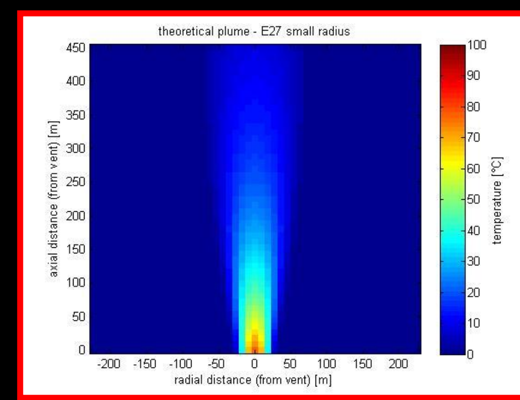
+ electro-magnetic equ. *(Schwarzschild)*



3D plume model
(Matteo Cerminara)



mean plume model
(e.g., Woods, 1981)

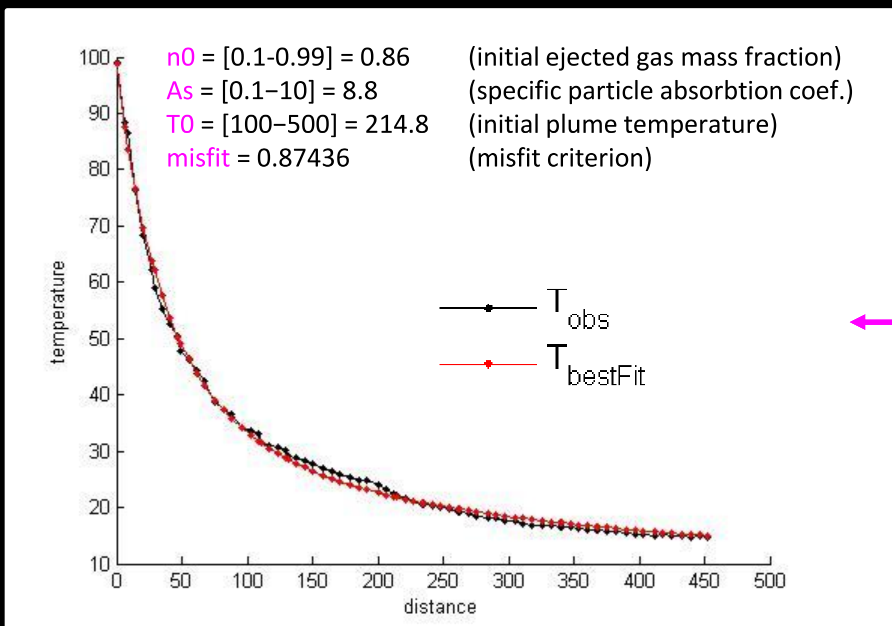


modeled IR image
(Matteo Cerminara)

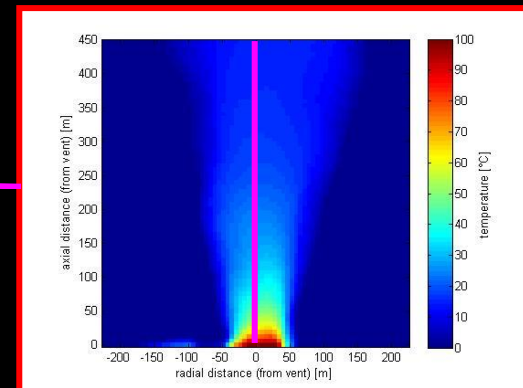
IR imagery

2. Mass estimations from plume modeling *(sustained plumes)*

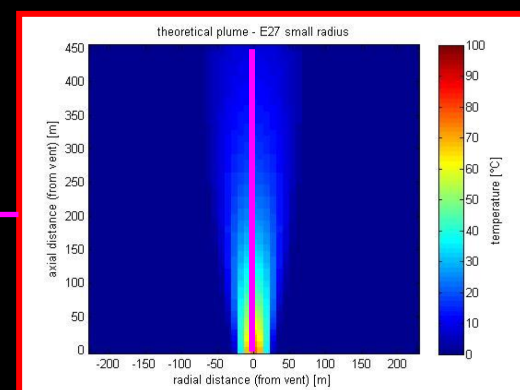
<u>The method is</u>:
- fast (analytical formulation allow calculations <1min)
- robust (strong thermodynamic constraints => little sensitivity of solid mass flow)
*➯ Potential applications to **RT estimation of solid mass flux and PSD***



inversion model



observed IR image



modeled IR image
(Matteo Cerminara)

Ejected solid mass: 1.3   0.2 x 10^5 kg ➯ mass flow = 620 kg/s
Particle size distribution: $r_{particles}$ = [0.01, 1] mm

CONCLUSIONS

- Need to provide **eruptive source terms** **for ash dispersal models**
  ⇨ requires **full bandwidth remote sensing**

- **RADAR** data processing and modeling
  ⇨ insights into the internal dynamics of volcanic emissions
  ⇨ recovery of source eruptive parameters from reconstruction of synthetic data (forward/inverse modeling)

- **INFRA-RED** imagery
  ⇨ synopic view of plume rise
  ⇨ ash mass estimation from plume ascent dynamics (*PlumeTracker*)
  ⇨ ash mass estimation from reconstruction of synthetic IR images

Thank you