Retrieval of Martian dust particle size, shape, and optical depth during the 2018/MY34 global dust storm *with* MSL rover Navigation Cameras

H. Chen-Chen (hao.chen@ehu.eus), S. Pérez-Hoyos, and A. Sánchez-Lavega

**Dept. Física Aplicada I, Escuela de Ingeniería de Bilbao, Universidad del País Vasco (UPV/EHU), 48013, Bilbao, Spain.*

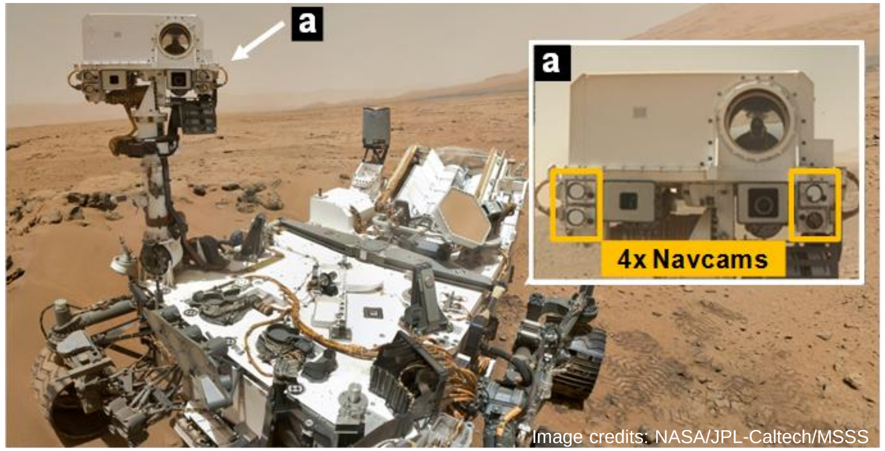
Chen-Chen, H., Pérez-Hoyos, S., and Sánchez-Lavega, A. Dust particle size, shape and optical depth during the 2018/MY34 Martian global dust storm retrieved by MSL Curiosity rover Navigation Cameras, *Icarus,* (2020). *Under review.*

Brief abstract:

- Martian global dust storms (GDS) are uncommon phenomena, have significant impact on the energy budget and global circulation.
- Intensive atmospheric-science campaign by MSL *Curiosity* rover during the 2018/MY34 GDS (initiated: 30-31 May 2018, Ls = 185º).
- We contribute to previous studies with independent retrievals of dust aerosol particle properties by comparing the sky radiance observed by MSL Navigation Cameras (Navcams) to radiative transfer simulations.
- Results show a steep rise in dust opacity, from τ of 1.2 to >9, correlated to particle size variations from 1 to 4 μm.
- Single scattering phase function: mean asymmetry parameter of g = 0.60 ± 0.11 during the storm, compared to values around 0.71 ± 0.06 for previous years.
- Best fitting particle shape: mixtures of spheroids with a log-normal distribution of aspect ratios centred around 2.8, in contrast to aspect ratios of 1.8 after the storm. More irregular particle shapes in high-opacity sols.

2. Research context

Dust in the Martian atmosphere
- By absorbing and scattering the incoming solar radiation, it has a direct impact on the thermal structure and dynamics (Gierasch and Goody, 1972)
- **Global dust storms (GDS)**: Result from rapid expansion and combined influence of multiple local and regional storms, produce a substantial rise in dust opacity ($\tau > 3$) over large portions of the planet, lasting for weeks to months, and have significant effects on pressure, temperature, atmospheric heating, and global circulation (e.g., Zurek and Martin, 1993)
- GDS are **stochastic** phenomena, with an **average frequency of approx. every 3-4 Martian Years** (Smith, 2008): 1971/MY9, 1977/MY12, 2001/MY25, 2007/MY28, and 2018/MY34

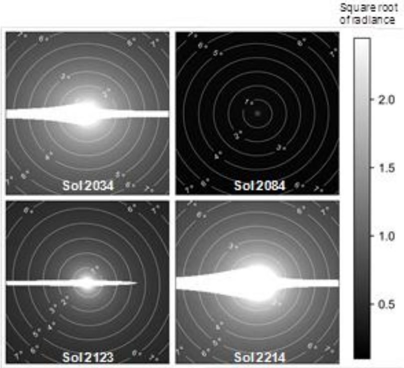


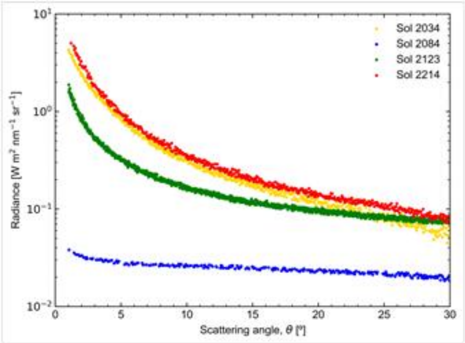
2018/MY34 Global Dust Storm
- **Initiated**: 30-31 May, Ls = 185º, **MSL sol 2067**, with precursor storms at Acidalia and Utopia regions (30-60ºN) (e.g. Guzewich et al., 2019; Sánchez-Lavega et al. 2019)
- Intensive atmospheric campaign by MSL rover Curiosity, e.g.: Lemmon et al., 2019; Víudez-Moreiras et al., 2019; Smith et al., 2019)
- **Opacity from 0.6 to 8.5 in 10 sols**, particle size from 1.5 to > 4 μm (Lemmon et al., 2019)

Motivation:
- MSL Engineering Cameras: contribute to Martian dust aerosol studies with surface-based observations, and to provide additional source of data.

Aim:
- Characterise the dust aerosol particle properties during the 2018/MY34 global dust event and study its variability with respect to previous MY's.

Objectives:
- MSL Navigation Cameras **image-data review** and **processing** (calibration)
- **Radiative transfer** modelling of Mars' atmosphere
- Retrieval of **atmospheric dust loading** and **particles' properties**





3. Methodology

Angular distribution of sky brightness observed by MSL Navcam compared with radiative transfer simulations:
- **Size**: variation of sky brightness at small scattering angles (< 30º)
- **Shape**, **phase function**: evaluated at large scattering angles (110-180º)

See:
- Chen-Chen, H., Pérez-Hoyos, S., and Sánchez-Lavega, A. (2019). Dust particle size and optical depth on Mars retrieved by the MSL Navigation Cameras, *Icarus*, **319**, 43-57. https://doi.org/10.1016/j.icarus.2018.09.010
- Chen-Chen, H., Pérez-Hoyos, S., and Sánchez-Lavega, A. (2019). Characterisation of Martian dust aerosol phase function from sky radiance measurements by MSL Engineering Cameras, *Icarus*, **330**, 16-29. https://doi.org/10.1016/j.icarus.2019.04.004

Radiative transfer model
DISORT (Stamnes et al., 1988)
Atmos. Struct.: **LMD Mars Climate Database** (Forget et al., 1999; Millour et al., 2015)
Gas Opacities: **HITRAN** (Rothman et al., 2013)

Aerosol model
Dust refractive indices: Wolff et al. 2009
Particle size distribution: **log-normal**, $\mathbf{v_{eff}}$ = 0.3, $\mathbf{r_{eff}}$ (*free*)
Column opacity: **tau** (*free*)
Radiative properties:
- **MOPSMAP** aerosol database (Gasteiger and Wiegner, 2018)
- **Double Henyey-Greenstein** phase functions

Aerosol model parameters for radiative transfer simulations

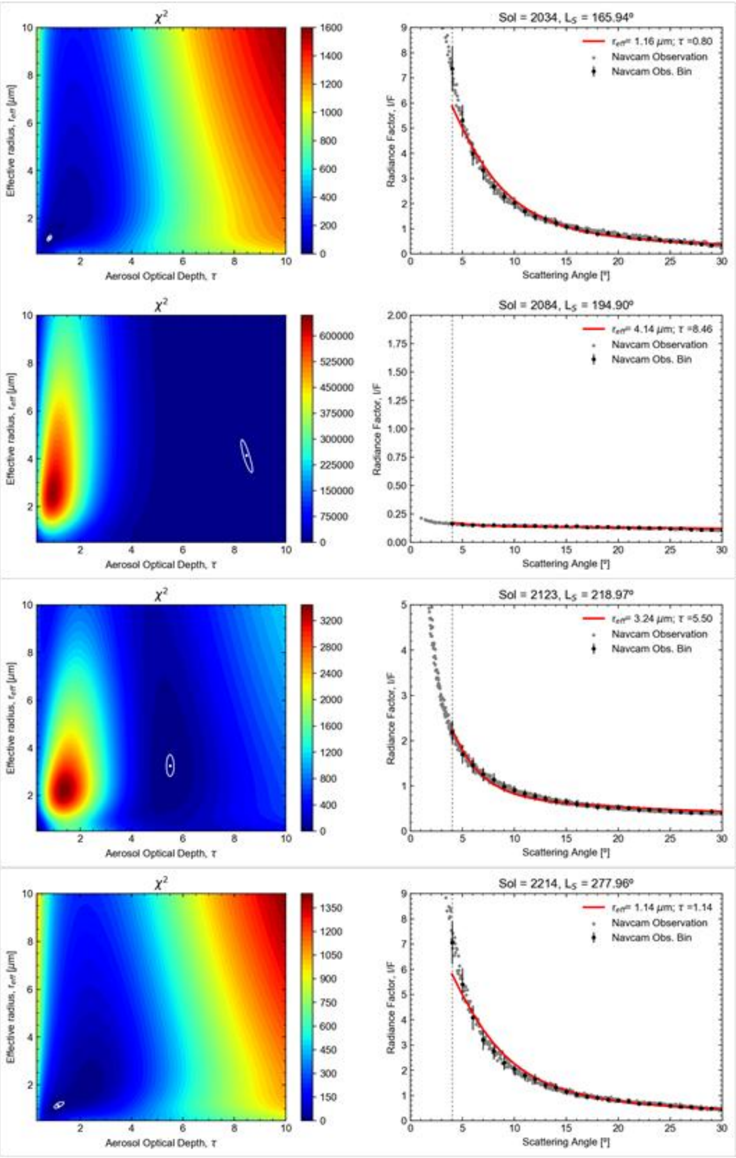
Observation	Aerosol model	Single scat. albedo, ω_0	Phase function, P(θ): Free parameters	Phase function, P(θ): Range
Sun-pointing	MOPSMAP	Calculated	*Size* r_{eff}, Dust column opacity τ	r_{eff}: 0.5 to 10.0 µm τ: 0.3 to 10.0
Backward scattering region	MOPSMAP	Calculated	Aspect ratio ε'_0, Size r_{eff}, Dust column opacity τ	ε'_0: 1.2 to 4.5. r_{eff}: 0.5 to 2.0 times r_{eff} from Sun-pointing output. τ: 0.5 to 1.5 times τ from Sun-pointing output.
	Double Henyey-Greenstein	Fixed	Forward scattering (g_1), backward scattering (g_2), and ratio (α)	g_1: 0.5 to 1.0 g_2: $-g_1$ to $+g_1$ α: 0.5 to 1.0

Retrieval procedure
Brute-force iterative retrieval scheme based in the comparison of the observed and modelled sky radiance as a function of the parameters characterising the airborne dust particles.
- Outputs: parameter-values generating the best fitting curve under a lowest mean quadratic deviation χ^2 criterion.
- Uncertainties: evaluated around the best-fitting location in the free parameter space for 68.3% confidence region (1-σ error)

4. Results (1): Sun-Pointing

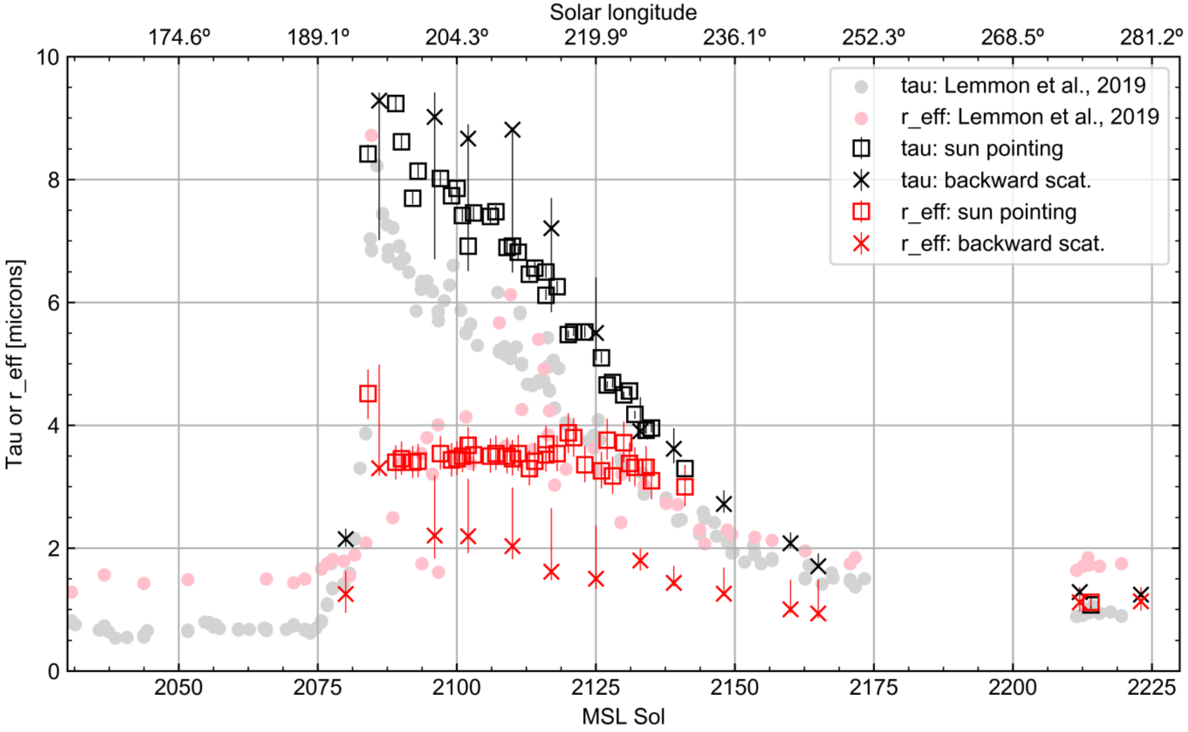
Grupo de Ciencias Planetarias

Universidad del País Vasco / Euskal Herriko Unibertsitatea



Left: Sun-pointing observations and model comparisons for sols 2034, 2084, 2123, and 2214 for different opacity scenarios. Left panels show comparisons in the τ-r_{eff} space. The point of minimum X^2 and the contour of the 68% confidence interval limit are indicated. On the right, Navcam measured sky radiance and the resulting best fitting curve.

Bottom: Dust optical depth and particle size during 2018/MY34 GDS retrieved with MSL Navcam Sun-pointing (squares) and backward-scattering (crosses) observations. For comparison purposes, MSL Mastcam retrievals reported in Lemmon et al. (2019) are also shown.

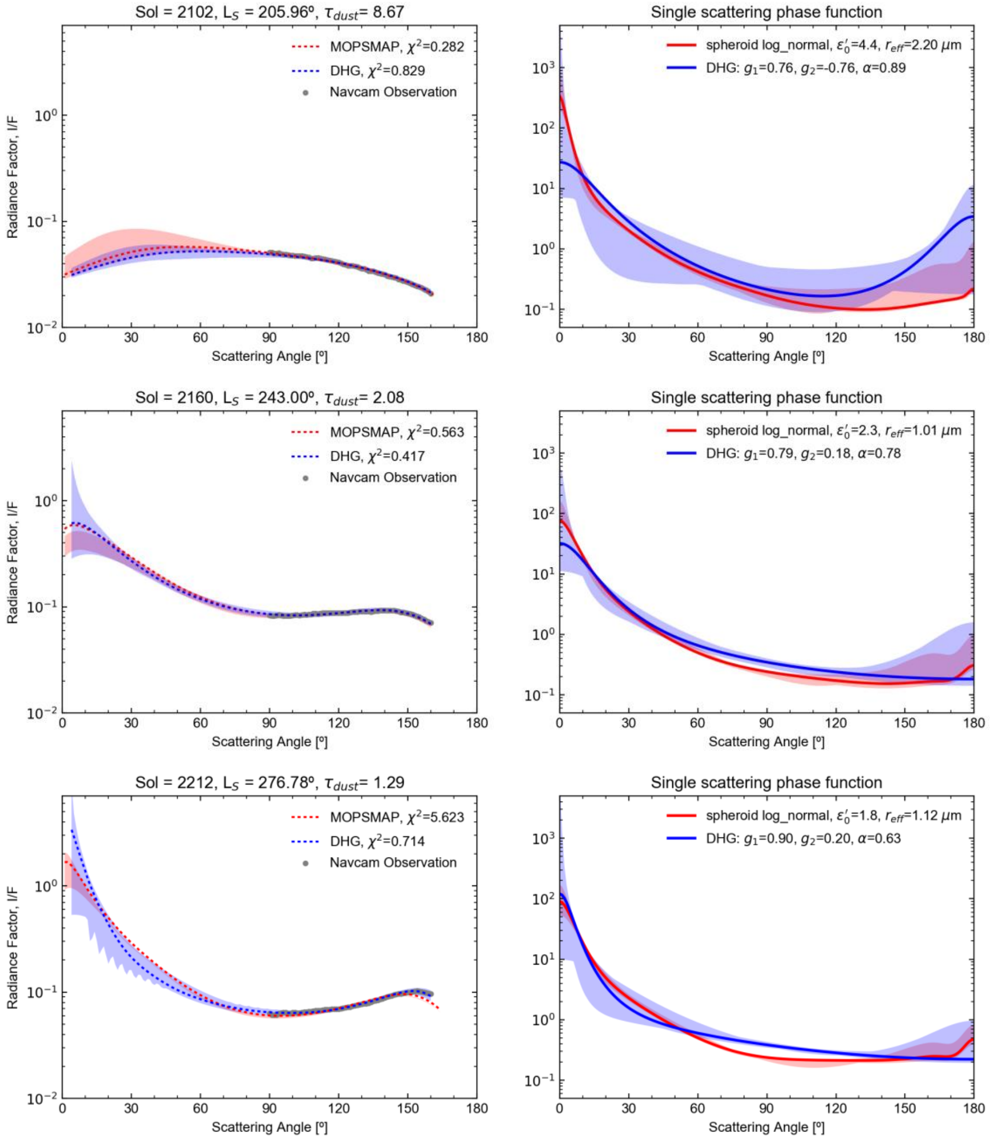


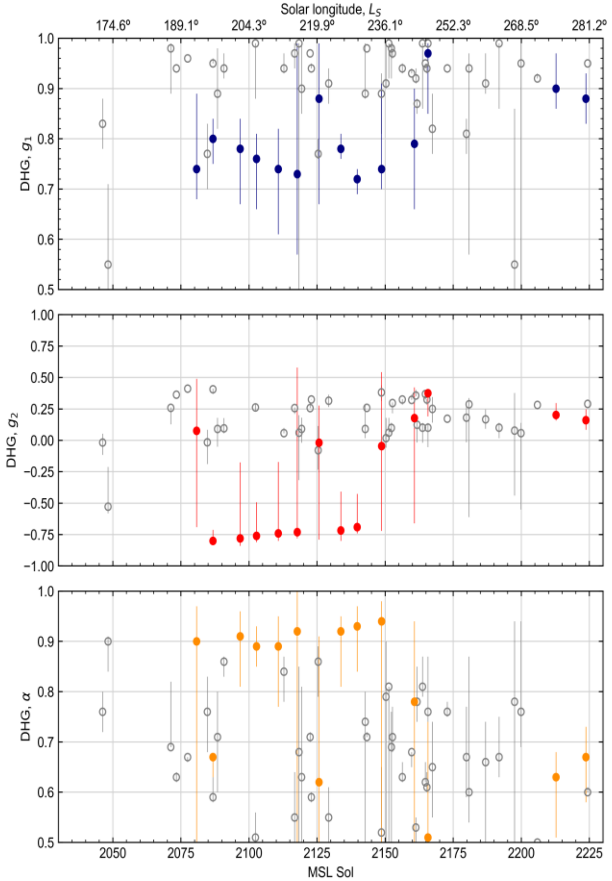
Size: Positive correlation between particle size and column dust opacity during the GDS

5. Results (2): Backscattering

Grupo de Ciencias Planetarias

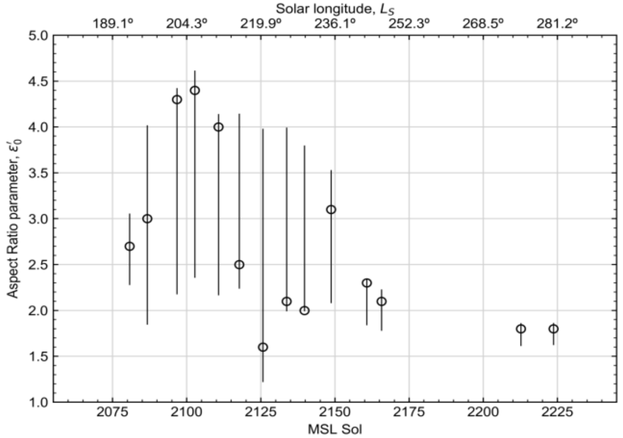
Universidad del País Vasco Euskal Herriko Unibertsitatea





Shape: more irregular particle shapes during high-opacity sols.

Phase function: DHG asymmetry parameter of g ~ 0.60 during GDS, g ~ 0.71 previous MY’s



Left: Results of DHG analytical single scattering phase function parameters

Top: Evolution of the aspect ratio parameter during the GDS.

Left: Backward scattering observations and model comparison for sols 2102, 2160, and 2212 for different dust opacity scenarios during the GDS. ON the left panel, The best fitting simulated curves with MOPSMAP (red) and DHG (blue) are plotted together with Navcam’s observation. On the right, the single scattering phase function generating the corresponding best fitting curve. Shaded area shows the 68% confidence interval

6. Future prospects

Grupo de Ciencias Planetarias

Universidad del País Vasco Euskal Herriko Unibertsitatea

Aerosol particle modelling

- Implementation of more **complex particle shapes** (e.g. tri-axial ellipsoids, aggregates) (e.g., Merikallio et al, 2013)
- Comparison with further **experimental scattering parameters** for Martian dust analogues samples (Muñoz et al., 2001)
- Implementation of **inversion algorithms for the retrieval**

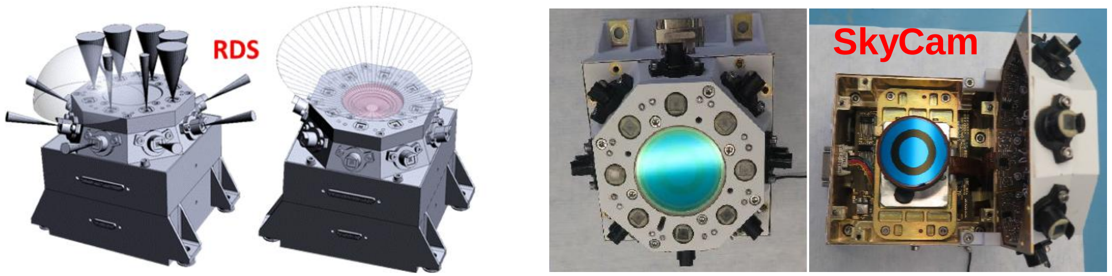
Mars 2020 rover: Mars Environmental Dynamics Analyzer (MEDA)

- Instruments: **Radiation & Dust Sensor** (RDS), **Skycam**
- Retrieval of dust column opacity, and particle size.
- Sky radiance at intermediate and large scattering angles for **characterisation of single scattering phase function**

Regional atmospheric dynamical simulations

- Study accuracy and performance of radiative transfer codes in Mars Regional Atmospheric Modeling System (**MRAMS**) (Rafkin et al., 2001)
- Mesoscale modelling of **local dust storms development**

Mars 2020 rover MEDA RDS and SkyCam instruments



Source: Rodriguez-Manfredi (2017), Arruego (2018)

Full-sky radiative transfer simulations for 2 atmospheric dust loading cases