Clues from the first Covid-19 wave and recommendations for social measures in the future

R. Schlickeiser[1,2,*] and M. Kröger[3,*]

1 Institut für Theoretische Physik, Lehrstuhl IV: Weltraum- und Astrophysik,
Ruhr-Universität Bochum, D-44780 Bochum, Germany, ORCID 0000-0003-3171-5079
2 Institut für Theoretische Physik und Astrophysik,
Christian-Albrechts-Universität zu Kiel, Leibnizstr. 15, D-24118 Kiel, Germany
3 Polymer Physics, Department of Materials, ETH Zurich,
Zurich CH-8093, Switzerland, ORCID 0000-0003-1402-6714
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The Gauss model for the time evolution of the first corona pandemic wave allows to draw conclusions on the dark number of infections, the amount of heard immunization, the used maximum capacity of breathing apparati and the effectiveness of various non-pharmaceutical interventions in different countries. In Germany, Switzerland and Sweden the dark numbers are 7.4 ± 6.1, 11.1 ± 8.5 and 25.0 ± 25.0, respectively. Our method of estimating dark numbers from modeling both, infection and death rates simultaneously spares these countries the laborious, time-consuming and costly medical testing for antibodies of large portions of the population. In Germany the total number of infected persons, including the dark number of infections by the first wave is estimated to be 1.06 ± 0.60 million, corresponding to 1.28 ± 0.72 percent of the German population. We work out direct implications from these predictions for managing the 2nd and further corona waves.

Keywords: coronavirus; statistical analysis; extrapolation; parameter estimation; pandemic spreading

I. INTRODUCTION

The progression of the first Covid-19 wave is different in the countries over the world. In some countries such as Austria, Switzerland and Italy the peak infection and death rates have already occurred, whereas other countries such as the United Kingdom and India are still in the rising phase of the first wave.

Recently[1,2] (hereafter referred to as SSSK), we demonstrated that the proposed[4] Gaussian time (t) distribution functions for the daily fatalities

$$d(t) = d_{\max} e^{-\left(\frac{t - t_{d,\max}}{w_d}\right)^2} \qquad (1)$$

and the daily reported infections

$$i(t) = i_{\max} e^{-\left(\frac{t - t_{i,\max}}{w_i}\right)^2} \qquad (2)$$

provide a quantitatively correct description for the monitored rates in 25 different countries (more countries and federal states were subsequently investigated online[3] using real-time data). The Gauss model (GM) is capable to reproduce reasonably well the monitored time evolution of the Covid-19 disease, and even more important to make realistic predictions for the future evolution of the first wave in different countries. Therefore, the GM allows us already now to draw important clues from the first Covid-19 wave, which is the subject of this manuscript.

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* rsch@tp4.rub.de, mk@mat.ethz.ch

II. GAUSS MODEL (GM)

From equations (1) and (2) we find for the corresponding cumulative numbers of deaths and infections

$$D(t) = \int_{-\infty}^{t} dt'\, d(t') = \frac{D_{\text{tot}}}{2}\left[1 + \text{erf}\left(\frac{t - t_{d,\max}}{w_d}\right)\right],$$

$$I(t) = \int_{-\infty}^{t} dt'\, i(t') = \frac{I_{\text{tot}}}{2}\left[1 + \text{erf}\left(\frac{t - t_{i,\max}}{w_i}\right)\right], \quad (3)$$

respectively, in terms of the error function, where

$$D_{\text{tot}} = \sqrt{\pi}\, d_{\max} w_d, \quad I_{\text{tot}} = \sqrt{\pi}\, i_{\max} w_i \qquad (4)$$

denote the respective total number of deaths and infections due to the first pandemic wave of the Sars-Cov-2 virus.

In paper SSSM we have applied the GM, described by the time evolutions (1)–(3), to the monitored death and infection rates in 25 countries. In fact, we fitted $\ln d(t)$ and $\ln i(t)$ to the monitored data, as both quantities are simple polynomials of grade 2 in time, i.e.

$$\ln d(t) = d_0 + d_1 t - d_2 t^2, \quad \ln i(t) = i_0 + i_1 t - i_2 t^2 \quad (5)$$

with

$$d_0 = \ln d_{\max} - \frac{t_{d,\max}^2}{w_d^2}, \ d_1 = \frac{2t_{d,\max}}{w_d^2}, \ d_2 = \frac{1}{w_d^2}, \quad (6)$$

and similarly for the infections providing immediately

$$d_{\max} = e^{d_0 + d_1^2/4d_2}, \quad t_{d,\max} = \frac{d_1}{2d_2}, \quad w_d = \frac{1}{\sqrt{d_2}},$$
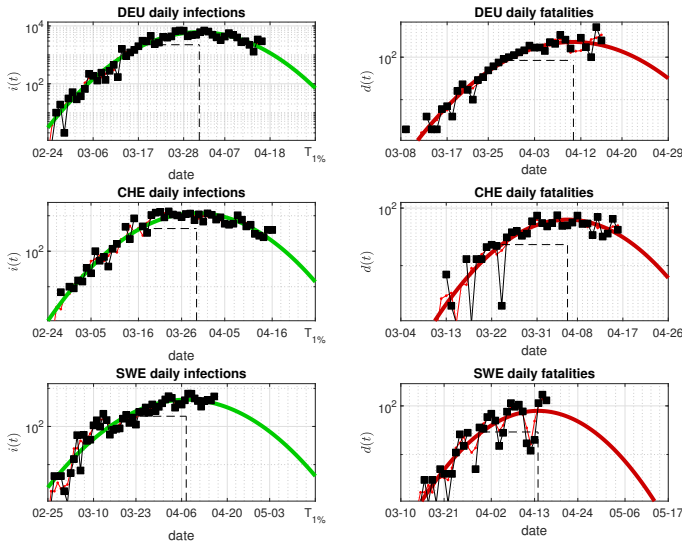
FIG. 1. Reported daily infection (left) and daily death (right) rates in Germany, Switzerland and Sweden in comparison with the best fit from the Gauss model. Fit from April 18, 2020. The dashed vertical lines indicate the peak times.
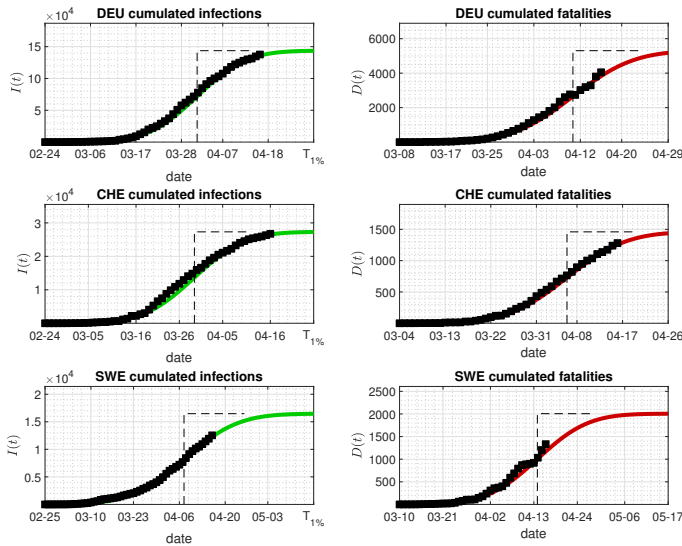

FIG. 2. Cumulative number of reported infection (left) and cumulative number of deaths (right) in Germany, Switzerland and Sweden in comparison with the best fit from the Gauss model. Fit from April 18, 2020. The dashed vertical lines indicate the peak times.

$$i_{\max} = e^{i_0 + i_1^2/4i_2}, \quad t_{i,\max} = \frac{i_1}{2i_2}, \quad w_i = \frac{1}{\sqrt{i_2}}, \quad (7)$$

In 14 countries the monitored death and infections rates were of sufficient quality by April 2 to determine with a statistics package[1] the values of the six coefficients (6) with 95 percent confidence for each country. From these coefficients we readily inferred according to equation (7) the best values and their 95 percent confidence errors of the only three parameters $(d_{\max}, t_{d,\max}, w_d)$ and

$(i_{\max}, t_{i,\max}, w_i)$ determining the Gauss functions (1) and (2). The upper table in Fig. 4 of ref.[1] lists the respective death rate parameters $(d_{\max}, t_{d,\max}, w_d)$, determined on April 2, 2020, but omits the corresponding values of the reported infections rate parameters $(i_{\max}, t_{i,\max}, w_i)$.

Here we update our statistical analysis of the GM with the available monitored data until April 18, 2020. Our best fits for selected countries Germany, Switzerland and Sweden are shown in Fig. 1 for the daily infection and death rates and in Fig. 2 for the cumulative number of infections and fatalities.

Table I lists the resulting best fit values for these three countries. We notice first that the reported Gaussian widths parameters w_i for the infections and w_d are of comparable and almost equal value. The corresponding times of maximum are shifted to each other with $t_{d,\max} = t_{i,\max} + \tau$, where the delay peak time of deaths with respect to the peak time of infections $\tau \in [7, 10]$ days in agreement with earlier estimates (SSSK).

III. DARK NUMBER AND HEARD IMMUNIZATION

From the inferred values of D_{tot} and I_{tot} we obtain an estimate of the dark number of infections with the following argument: Let $\gamma = 0.5\gamma_5$ be the fraction of seriously sick persons in the hospital, estimated to α percent of all infected persons (typically $\alpha = 1$), who die from Covid-19. The fatality rate can be smaller: the recent Gangelt study[5] suggests $\gamma = 0.37$ with a rather significant error, but we adopt the value $\gamma = 0.5\gamma_5$ here. Dividing D_{tot} by

$$f = 0.01\gamma\alpha = 5 \cdot 10^{-3}\gamma_5\alpha \qquad (8)$$

we can estimate the total true (reported plus unreported) number of infected persons as

$$I_{\mathrm{tot}}^{\mathrm{true}} = \frac{D_{\mathrm{tot}}}{f} = \frac{200 D_{\mathrm{tot}}}{\gamma_5\alpha} \qquad (9)$$

Consequently, the dark number of infections, i.e. the number of infected persons unreported for each reported, is

$$N_d = \frac{I_{\mathrm{tot}}^{\mathrm{true}}}{I_{\mathrm{tot}}} = \frac{200 D_{\mathrm{tot}}}{\gamma_5\alpha I_{\mathrm{tot}}} \qquad (10)$$

The last column of Table I lists the resulting dark numbers in these three countries. Despite the partially large 95-percent confidence errors, which will reduce with later analysis time, these determinations of the dark numbers in different countries by using the modeled infection and death rates is another strong advantage of the Gauss model. If it is applied, it spares any country the laborious, time-consuming and costly medical testing of large portions of the population.

For Germany we obtain $N_d = 7.4 \pm 6.1$. Hence, up to one of about 13 infected people had been recognized as being infected by testing. This dark number still has

TABLE I. Best Gaussian fit parameters and their 95 percent confidence range: width w_x (in days), time $t_{x,\max}$, and amplitude $x_{\max}$, calculated on April 18, 2020, for reported infected ($x = i$) and deceased ($x = d$) as well as the resulting estimates for total number of reported cases X_{tot}, fade-out time $T_{1\%}$, and dark number N_d of infections, defined in ref.[1] and equation (10), respectively.

Country	code	w_i	$t_{i,\max}$	$i_{\max}/1000$	$I_{\text{tot}}/1000$	w_d	$t_{d,\max}$	$d_{\max}$	$D_{\text{tot}}/1000$	$T_{1\%}$	N_d
Germany	DEU	13.4 ± 0.2	04-01 $\pm$ 1	6.07 ± 1.50	144 ± 38	13.1 ± 0.1	04-11 $\pm$ 3	228 ± 130	5.3 ± 3.0	04-29	7.4 ± 6.1
Switzerland	CHE	13.0 ± 0.2	03-29 $\pm$ 1	1.18 ± 0.35	27 ± 8	13.1 ± 0.1	04-06 $\pm$ 2	65 ± 30	1.5 ± 0.7	04-26	11.1 ± 8.5
Sweden	SWE	18.4 ± 0.4	04-07 $\pm$ 3	0.50 ± 0.28	16 ± 9	14.3 ± 0.3	04-14 $\pm$ 8	80 ± 40	2.0 ± 1.0	05-17	25 ± 25

a significant uncertainty, but the error will shrink with time when more precise input data are available.

After inserting the estimated number of D_{tot} for a specific country we obtain the total true number of infected persons according to equation (9), allowing us clues on the amount of heard immunization from the first wave. In Germany with $D_{\text{tot}} = 5300 \pm 3000$ we obtain

$$I^{\text{true}}_{\text{tot,Germany}} = \frac{(1.06 \pm 0.6)}{\gamma_5 \alpha} \text{ million people}, \qquad (11)$$

which includes the dark number of infections. The estimate (11) implies that only 1.28 ± 0.72 percent of the German population ($P = 83$ million persons) will be infected in total by the first pandemic wave, leaving more than 98 percent of the German population to be potentially infected by the second and future pandemic waves.

If these future waves infect a similar percentage of the population under the same strict social distancing measures, we expect more than about 27 waves to occur over the next years until 2/3 of the total population in Germany are immunized, unless an efficient anti-Covid-19 vaccine is available soon. This is a frightening prospect, and optimized strategies for the manageing of future pandemic waves have to be developed urgently. We address this further below more quantitatively in section VI.

IV. BREATHING APPARATI CAPACITY IN GERMANY

With the estimated total death toll in Germany of $D_{\text{tot}}/\text{MP} = (5300 \pm 3000)/83 = 64 \pm 36$ per million people (MP) we calculate the total number of seriously sick persons by dividing by the fatality rate $\gamma = 0.5\gamma_5$ to obtain $(128 \pm 72)/\gamma_5$ per million people. According to the first equation (4) with $w_d = 13.1 \pm 0.1$ we then find for the maximum number of seriously sick persons per day (NSSPs) per million people

$$\frac{\text{NSSPs}}{\text{MP}} = \frac{(128 \pm 72)}{\sqrt{\pi} w_d \gamma_5} = \frac{5.5 \pm 3.1}{\gamma_5} \qquad (12)$$

On the other hand in Germany currently there are approximately 40000 breathing apparati in total available, corresponding with $P = 83$ MP to 482/MP. With a typical breathing time of $10w_{10}$ days or less, German hospitals have the capacity of handling $48w_{10}^{-1}/\text{MP}$ NSSPs at

the peak time of the first wave, which is more than a factor 6 greater than the maximum value (12). Fortunately, only about 17 percent of the German breathing apparati capacity had to be used to treat the maximum number of NSSPs during the peak day of the first wave.

V. QUARANTINE FACTOR

In the earlier analysis[4] the quarantine factor $q \leq 1$ had been introduced to account for the non-pharmaceutical interventions (NPIs), i.e. political actions and social measures in order to reduce the number of infections, such as quarantining of elder and infected people, social distancing actions, mask obligations as well as the closure of schools and daycare facilities. If none of these actions are applied then $q = 1$ and the canonical fraction $2/3 \simeq 0.67$ of the total population in Germany are infected.

Scaling the total population in units of MP we then note that $0.67q$ MP are infected during the whole duration of the first wave. Then with the fatality rate $0.5\gamma_5$ and the percentage $\alpha = 1$ of NSSPs we note that the expected total number of fatalities is

$$\frac{D_{\text{tot,exp}}}{\text{MP}} = 0.5\gamma_5 0.01\alpha \cdot 6.7q10^5 = 3333\gamma_5\alpha q \qquad (13)$$

By equating this expectation value with the predictions for different countries we obtain an estimate of the corresponding values of the quarantine factor. For the standard values $\gamma_5 = 1$ and $\alpha = 1$ we obtain:

(i) for Germany ($P = 83$) with the predicted value $D_{\text{tot}}/\text{MP} = 64 \pm 8$ we obtain $q_{\text{DEU}} = (1.9 \pm 1.15) \cdot 10^{-2}$,

(ii) for Switzerland ($P = 8.5$) the predicted value $D_{\text{tot}}/\text{MP} = 176 \pm 82$ leads to $q_{\text{CHE}} = (5.3 \pm 2.5) \cdot 10^{-2}$,

(iii) for Sweden ($P = 10.5$) the predicted value ($D_{\text{tot}}/\text{MP} = 200 \pm 100$) we find the slightly higher value $q_{\text{SWE}} = (6.0 \pm 3.0) \cdot 10^{-2}$. It can be expected that the q value for Sweden is going to rise further, as the pandemic in Sweden was mainly focused on Stockholm so far.

The influential Imperial College study[6] has listed the following five possible non-pharmaceutical interventions (NPIs) determining the quarantine factor: (1) CI: Case isolation in the home, (2) HQ: Voluntary home quarantine, (3) SDO: Social distancing of those over 70 years of age, (4) SD: Social distancing of entire population, and (5) PC: Closure of schools and universities. Based on

the drastic measures taken in Germany and Switzerland we like to add as sixth NIP the closure of nonessential non-food shops and industry (CSI) imposed strictly in Germany and Switzerland.

These NPIs have been differently applied in the above 3 countries which have a comparable ethnic composition and standard of living: whereas Germany has been very strict, Switzerland didn't apply SDO, SD, and PC strictly, Sweden has only applied CI, closure of universities and a mild form of SD. Therefore we are able to weight two combinations of the six NPIs actions with a quantitative number R, where

$$R_{\text{CI+SDO+SD}} \simeq 10, \quad R_{\text{HQ+PC+CSI}} = 20 \qquad (14)$$

The quarantine factor is then given approximately by the reciprocal sum

$$q \simeq \frac{1}{\sum_i R_i} \qquad (15)$$

While Germany has strictly applied all six NPIs, Switzerland has applied them in a less strict fashion, Sweden only applied three of them.

If hypothetically Germany would during the next waves only apply the mild NIPs, that Sweden has chosen for the first wave, the chosen quarantine factor would be $q_2 = 0.1$. With this value the expected total number of fatalities from the 2nd wave is

$$\frac{D_{\text{tot,exp}}}{\text{MP}} = 0.5\gamma_5 0.01\alpha \cdot 6.7q_2 10^5 = 333\gamma_5\alpha \qquad (16)$$

As in equation (12) we then find for the maximum number of seriously sick persons per day (NSSPs) per million people during the second wave

$$\frac{\text{NSSPs}}{\text{MP}} = \frac{333\gamma_5\alpha}{\sqrt{\pi}w_d\gamma_5} = 14.3\alpha, \qquad (17)$$

which German hospitals can handle even with the presently available capacity to treat up to $48w_{10}^{-1}/\text{MP}$ NSSPs. At unchanged q, the ratio NSSPs/MP is going to drop during subsequent waves, as the number of immune people will grow with each wave.

The limited breathing apparati capacity at least in Germany is no good justification to apply the additional strict NPIs, i.e. voluntary home quarantine, closure of schools and universities as well as the closure of nonessential non-food shops and industry (CSI), also to the second and future waves.

VI. SUMMARY AND CONCLUSIONS

Based on the lessons learned from the first wave of the Covid-19 pandemic disease and their analysis with the Gauss model we suggest the following recommendations for handling the 2nd and further waves.

The fraction of the total population P that has developed antibodies during the first wave is given by $I_{\text{total}}^{\text{true}}/P$. So for Germany with $P \approx 83$ million inhabitants, as noted, only $\approx 1.3 \pm 0.7\%$ will have developed antibodies. In the light of this small percentage, or the small heard immunization, first there is no compelling reason to wait for the first wave to terminate completely. We could start continuing our daily lives at another level of social distancing immediately. Or as soon as sufficient amounts of masks will be available. Masks must not be perfect. Masks from linen that can be washed, and do not pollute our environment further, should be a preferred option.

Any day ending the economical lockdown earlier is worth a thought: it would reduce the currently planned extremely high level of public indebtedness significantly, lower the risk of inflation, and save the public enormous amounts of financial resources that could be better used in improving the public health system to cope with the unavoidable 2nd and later pandemic waves.

Secondly, the 2nd and future waves could be handled with the mild NIPs that Sweden has so far successfully applied during the first wave: case isolation in the home and a mild form of social distancing. Social distancing will be the main non-pharmaceutical intervention for the majority of the population. This will not seriously affect the daily lifes of most of the populations and avoid dramatic economical consequences. These mild NPIS should be simultaneously accompanied by the running analysis with the Gauss model that provides reliable predictions for several future weeks for the effectiveness of the taken measures, and if necessary allows to implement in due time stricter social interventions.

Third, the strict and months-long lock-down seems to reflect the hope that the pandemic can be completely stopped. This appears very questionable. In view of the about 98% of the population for which the 2nd wave is basically identical with the 1st wave, and if we proceed with the current strategy, many complete lock-downs featuring unused capacities will follow. If such lock-downs are not planned, there is or was no reason to keep the present one for an extended period. A sufficient amount of social distancing can be applied immediately, also without masks and gloves. All it requires is inhabitants to overtake responsibility, and to change our daily lives. We have already proven that we are able to do so.

From the about 930000 people who died 2017 in Germany, about 344000 died from sometimes stress-related heart diseases (this annual number exceeds the total number of fatalities caused by Covid-19 without non-pharmaceutical interventions, as long as hospitals are not overloaded) about 25000 died in the 2018/2019 season from influenza.[7] The number of fatalities caused by car accidents decreased from about 20000 per annum in 1970 down to 3000 in 2019. On one hand a complete shutdown could therefore be considered to prevent fatalities in every year, on the other does it remains unclear yet, if there won't be any socioeconomic or health-related issues that diminish the efforts.

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VII. DEUTSCHE ZUSAMMENFASSUNG: DUNKELZIFFERN, HERDENIMMUNISIERUNG UND INTENSIVBETTENAUSLASTUNG WÄHREND DER ERSTEN CORONAWELLE

Die erfolgreiche Modellierung der Zeitentwicklung der ersten Covid-19 Pandemiewelle als auch die Vorhersagen für die Zukunft durch das Gauss-Modell erlaubt es schon jetzt, wichtige Erkenntnisse für verschiedene Länder abzuleiten. Diese betreffen die Dunkelziffer der Infizierten, die Herden-Immunisierung, die maximale Auslastung der Beatmungsgeräte und die Effizienz der unterschiedlichen nicht-pharmazeutischen Eingriffe in das gesellschaftliche Leben. In Deutschland, Schweiz und Schweden betragen die Dunkelziffern 7.4 ± 6.1, 11.1 ± 8.5 bzw. 25 ± 25 für die erste Welle. Unsere neuartige Methode zur Bestimmung der Dunkelziffer beruht auf der gleichzeitigen Modellierung von Infektions- und Sterberaten mit dem Gauss-Modell. Die Anwendung dieser Methode erspart den Ländern das arbeitsreiche lang-andauernde und kostspielige medizinische Testen auf Antikörper eines grossen Teils der Bevölkerung. In Deutschland werden sich durch die 1. Welle, inklusive der Dunkelziffer, insgesamt nur 1.06 ± 0.60 Millionen Personen mit dem Covid-19 Virus anstecken, was 1.3 ± 0.7 Prozent der Einwohnerzahl entspricht. Wegen dieses geringen Prozentsatzes und der geringen Herden-Immunisierung besteht kein Grund mehr, ausser den sozialen Distanzierungsmassnahmen und der Quarantäne von infizierten Personen, die weiteren sehr strikten politisch angeordneten sozialen Eingriffe in Deutschland bis ans Ende der ersten Welle beizubehalten. Für Deutschland wird empfohlen, die zweite und weitere Coronawellen mit den milden nicht-pharmazeutischen Massnahmen zu begleiten, wie sie Schweden während der ersten Coronawelle praktiziert hat: Heimisolierung von Infizierten und eine abgeschwächte Form der sozialen Distanzierung. Diese Interventionen sollten fortwährend mit dem Gauss-Modell und seinen verlässlichen Vorhersagen für mehrere Wochen begleitet und in ihrer Wirksamkeit überwacht werden.