The Nature of Prediction (and the Prediction of Nature)

Jason Frank

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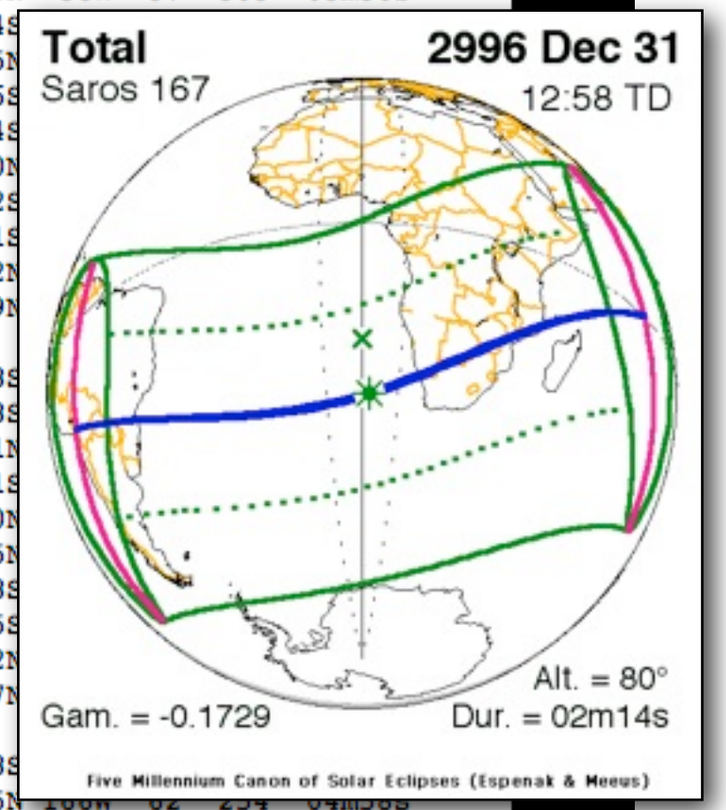
Stichting voor Hoger Onderwijs in de Toegepaste Wiskunde

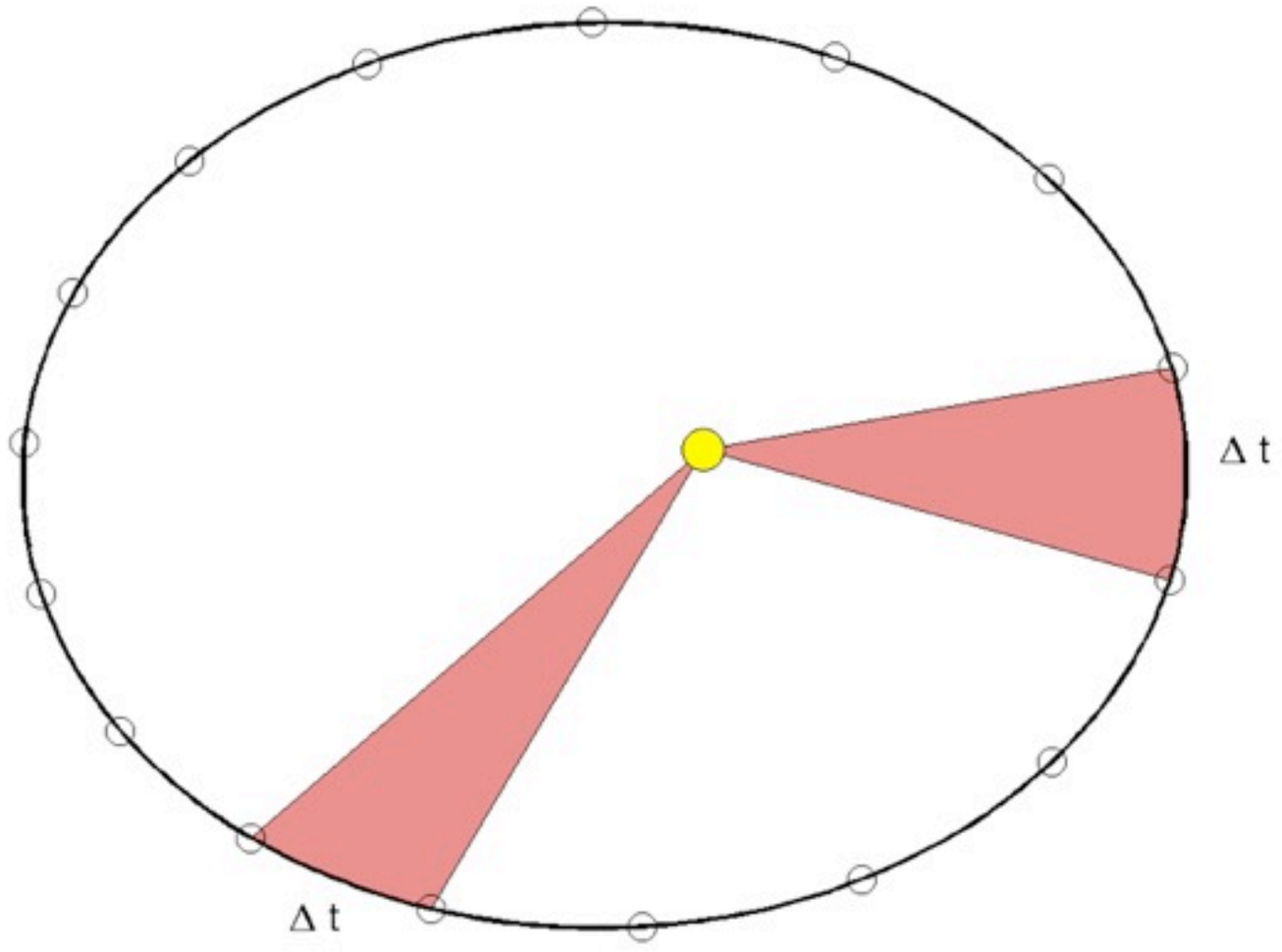
Catalog of Solar Eclipses: 2901 to 3000

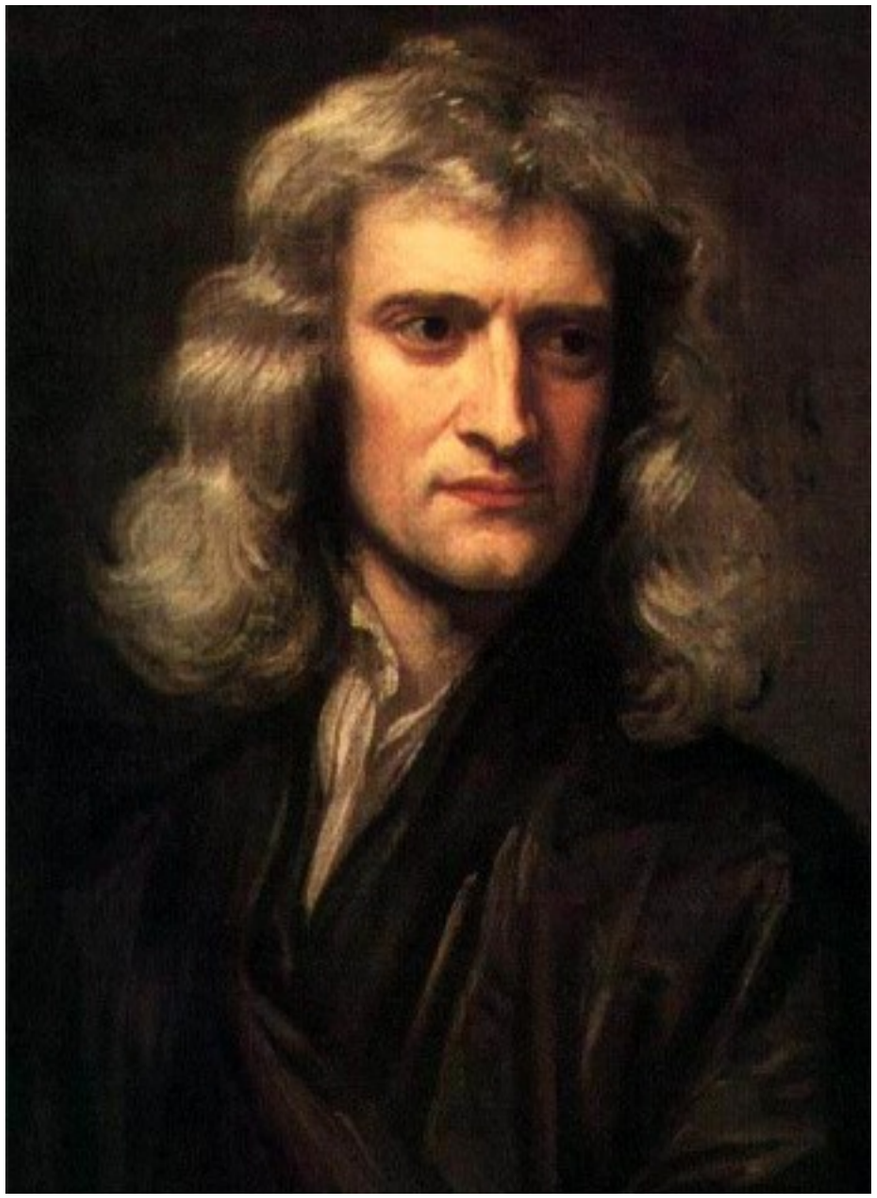
Catalog Number	Calendar Date	TD of Greatest Eclipse	ΔT s	Luna Num	Saros Num	Ecl. Type	QLE	Gamma	Ecl. Mag.	Lat °	Long °	Sun Alt °	Path Width km	Central Dur.
11851	2981 Apr 25	15:22:39	4282	12137	154	T	-p	0.7917	1.0560	63N	58W	37	303	03m36s
11852	2981 Oct 19	02:08:17	4286	12143	159	A	-p	-0.9600	0.9400	74S				
11853	2982 Apr 15	06:21:40	4289	12149	164	T	nn	0.0890	1.0223	15N				
11854	2982 Oct 08	08:26:58	4293	12155	169	H	nn	-0.1838	1.0047	16S				
11855	2983 Apr 04	15:25:41	4296	12161	174	A	p-	-0.6666	0.9599	34S				
11856	2983 Sep 27	21:47:41	4300	12167	179	T	p-	0.5531	1.0547	30N				
11857	2984 Mar 23	17:14:44	4304	12173	184	P	t-	-1.4059	0.2730	72S				
11858	2984 Aug 18	07:08:25	4307	12178	151	P	-t	-1.2800	0.4810	71S				
11859	2984 Sep 16	14:34:20	4307	12179	189	P	t-	1.2556	0.5277	72N				
11860	2985 Feb 11	00:00:02	4310	12184	156	A	-p	0.9028	0.9444	49N				
11861	2985 Aug 07	20:31:50	4314	12190	161	H	-p	-0.5686	1.0097	18S				
11862	2986 Jan 31	08:22:37	4317	12196	166	H	-n	0.1669	1.0075	8S				
11863	2986 Jul 28	02:58:21	4321	12202	171	A	nn	0.2064	0.9630	31N				
11864	2987 Jan 20	22:33:24	4325	12208	176	T	p-	-0.5111	1.0427	51S				
11865	2987 Jul 17	03:54:36	4328	12214	181	A	t-	0.9751	0.9372	80N				
11866	2987 Dec 12	02:50:04	4331	12219	148	Pe	-t	1.5396	0.0074	65N				
11867	2988 Jan 10	14:12:58	4332	12220	186	P	t-	-1.1806	0.6671	68S				
11868	2988 Jun 05	18:28:53	4335	12225	153	P	-t	-1.0476	0.9018	65S				
11869	2988 Nov 30	12:11:10	4339	12231	158	A	-t	0.9066	0.9538	42N				
11870	2989 May 26	06:52:44	4342	12237	163	T	-n	-0.2555	1.0525	7N				
11871	2989 Nov 19	14:25:04	4346	12243	168	A	nn	0.2155	0.9283	8S				
11872	2990 May 15	23:22:03	4349	12249	173	T	p-	0.4710	1.0689	45N				
11873	2990 Nov 08	13:59:19	4353	12255	178	A	p-	-0.4905	0.9360	43S	31W	60	272	06m19s
11874	2991 Apr 06	04:43:03	4356	12260	145	P	-t	-1.4726	0.1346	61S	154W	0		
11875	2991 May 05	15:20:42	4357	12261	183	P	t-	1.2116	0.6100	63N	157W	0		
11876	2991 Sep 29	06:52:19	4360	12266	150	Pe	-t	1.5333	0.0156	61N	178E	0		
11877	2991 Oct 28	18:23:00	4360	12267	188	P	t-	-1.1802	0.6604	62S	162E	0		
11878	2992 Mar 25	11:34:16	4363	12272	155	A	-p	-0.8128	0.9419	44S	59E	35	358	05m17s
11890	2996 Dec 31	12:58:17	4399	12331	167	T	-n	-0.1729	1.0249	33S	6E	80	86	02m14s
11881	2993 Sep 07	14:40:11	4374	12290	170	T	nn	0.0387	1.0673	7N	21W	88	220	05m33s
11882	2994 Mar 03	12:17:48	4378	12296	175	A	p-	0.5777	0.9422	25N	1W	55	256	06m06s
11883	2994 Aug 28	05:05:38	4381	12302	180	T	p-	-0.7327	1.0176	33S	99E	43	87	01m31s
11884	2995 Jan 22	06:39:24	4384	12307	147	P	-t	-1.5225	0.0363	63S	124W	0		
11885	2995 Feb 20	19:02:58	4385	12308	185	P	t-	1.2366	0.5608	62N	154W	0		
11886	2995 Jul 18	23:11:40	4388	12313	152	P	-t	1.2531	0.5297	64N	8W	0		
11887	2995 Aug 17	13:03:11	4389	12314	190	Pb	t-	-1.5542	0.0036	62S	60W	0		
11888	2996 Jan 11	21:44:38	4392	12319	157	T	-p	-0.8345	1.0397	73S	81W	33	243	02m20s
11889	2996 Jul 06	23:44:03	4395	12325	162	A	-p	0.5013	0.9508	52N	146W	60	208	04m44s
11890	2996 Dec 31	12:58:17	4399	12331	167	T	-n	-0.1729	1.0249	33S	6E	80	86	02m14s
11891	2997 Jun 26	03:41:44	4403	12337	172	A	p-	-0.2793	0.9916	7N	142E	74	31	01m00s
11892	2997 Dec 20	23:45:15	4406	12343	177	A	p-	0.5449	0.9696	10N	162W	57	130	03m40s



Johannes Kepler
(1571-1630)

Kepler's 2nd law of planetary motion





Sir Isaac Newton (1643-1727)

Newtonian gravity:

- A body moves in a straight line unless attracted by gravity
- A gravitational force changes the body's velocity vector
- The gravitational force is inversely proportional to the square of the separation, and acts along the line between the bodies.

$$|F| \propto \frac{1}{r^2}$$

Method A

Method B

Method C

The nature of prediction (part 1):

Given:

- A model governing the evolution of the system (Newton's equations), and
- Sufficient information about the system at time $t = 0$

Predict:

- The state of the system at future time T

Time:

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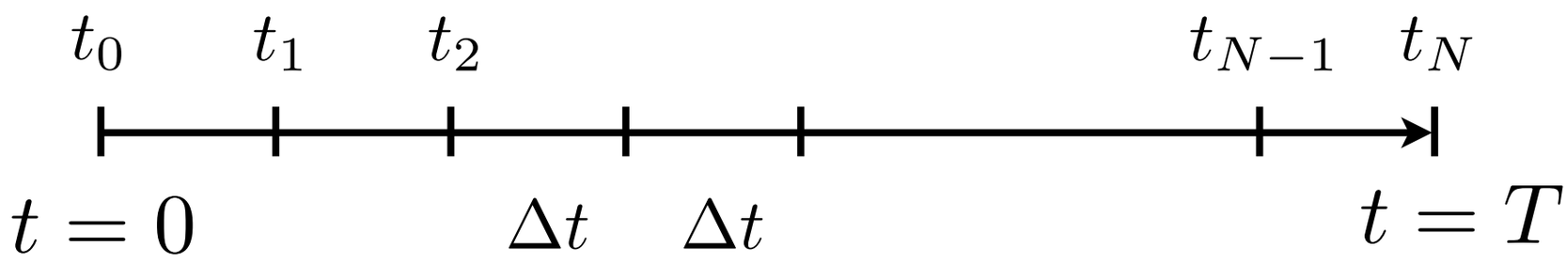

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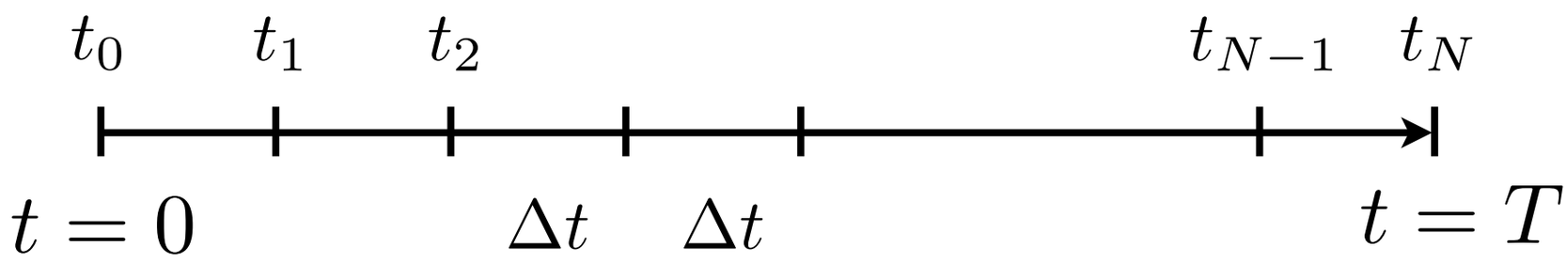
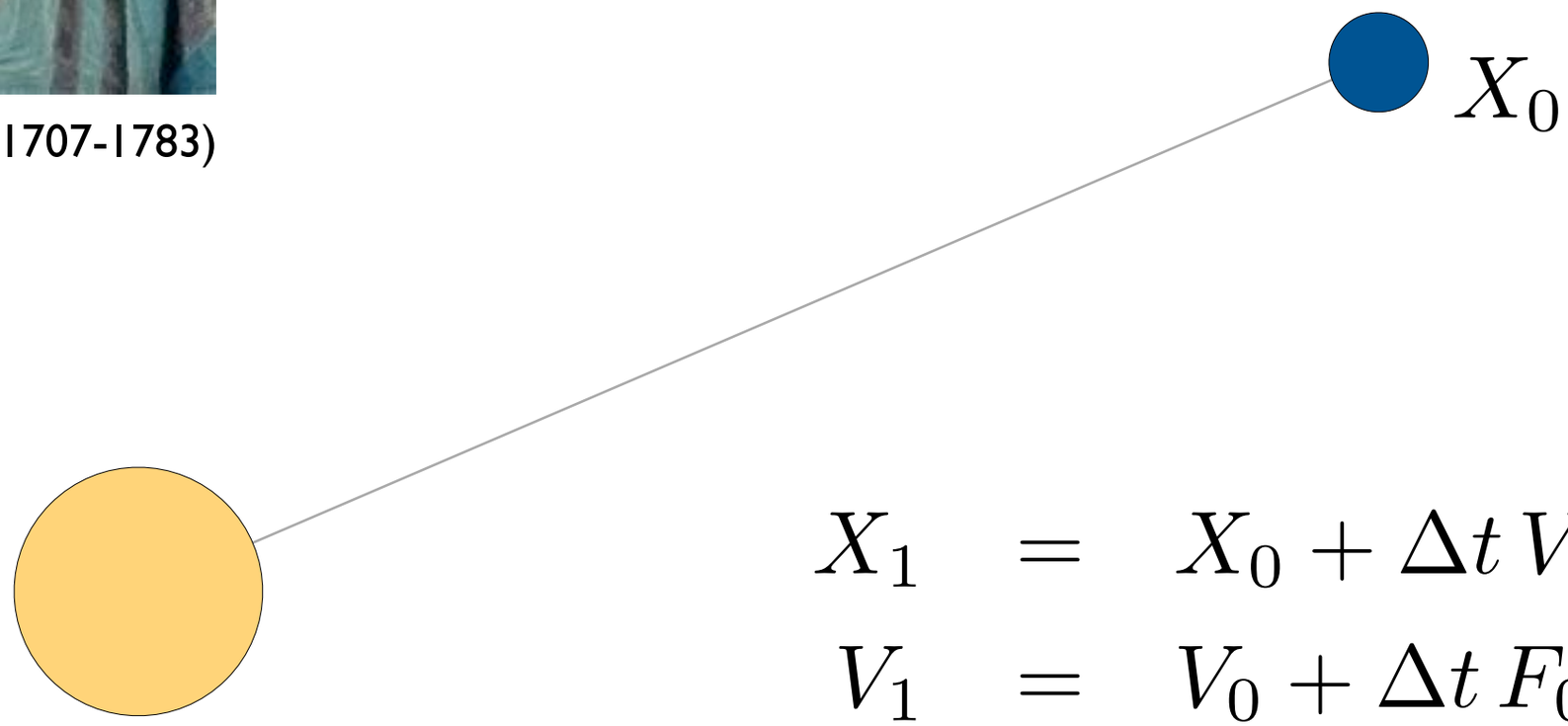


Δt = the small time upon which we can solve the model

initial condition = the "sufficient information" needed for prediction

Euler's method (A)

Leonhard Euler (1707-1783)



$$
\begin{aligned}
X_1 &= X_0 + \Delta t\, V_0 \\
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\end{aligned}
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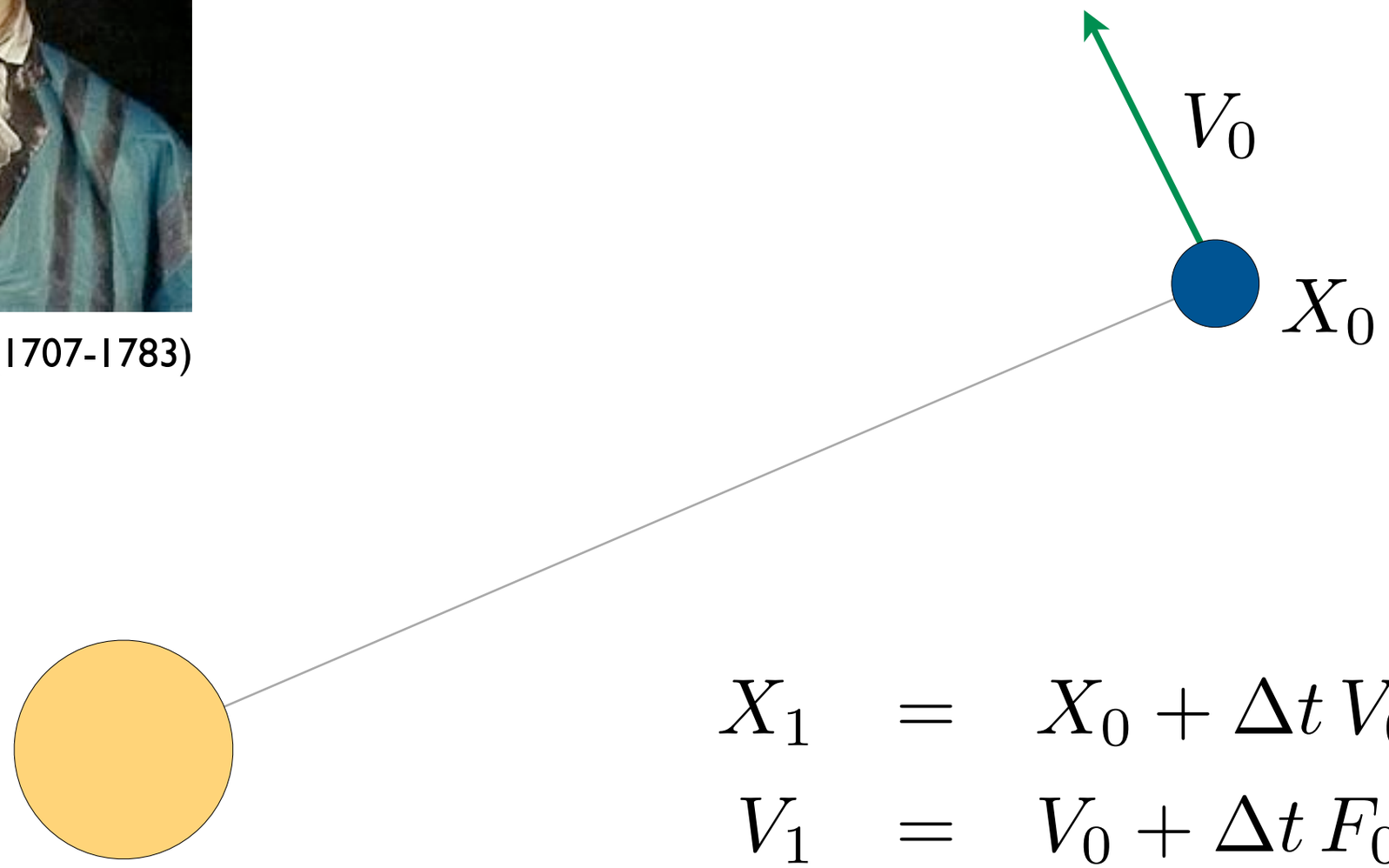

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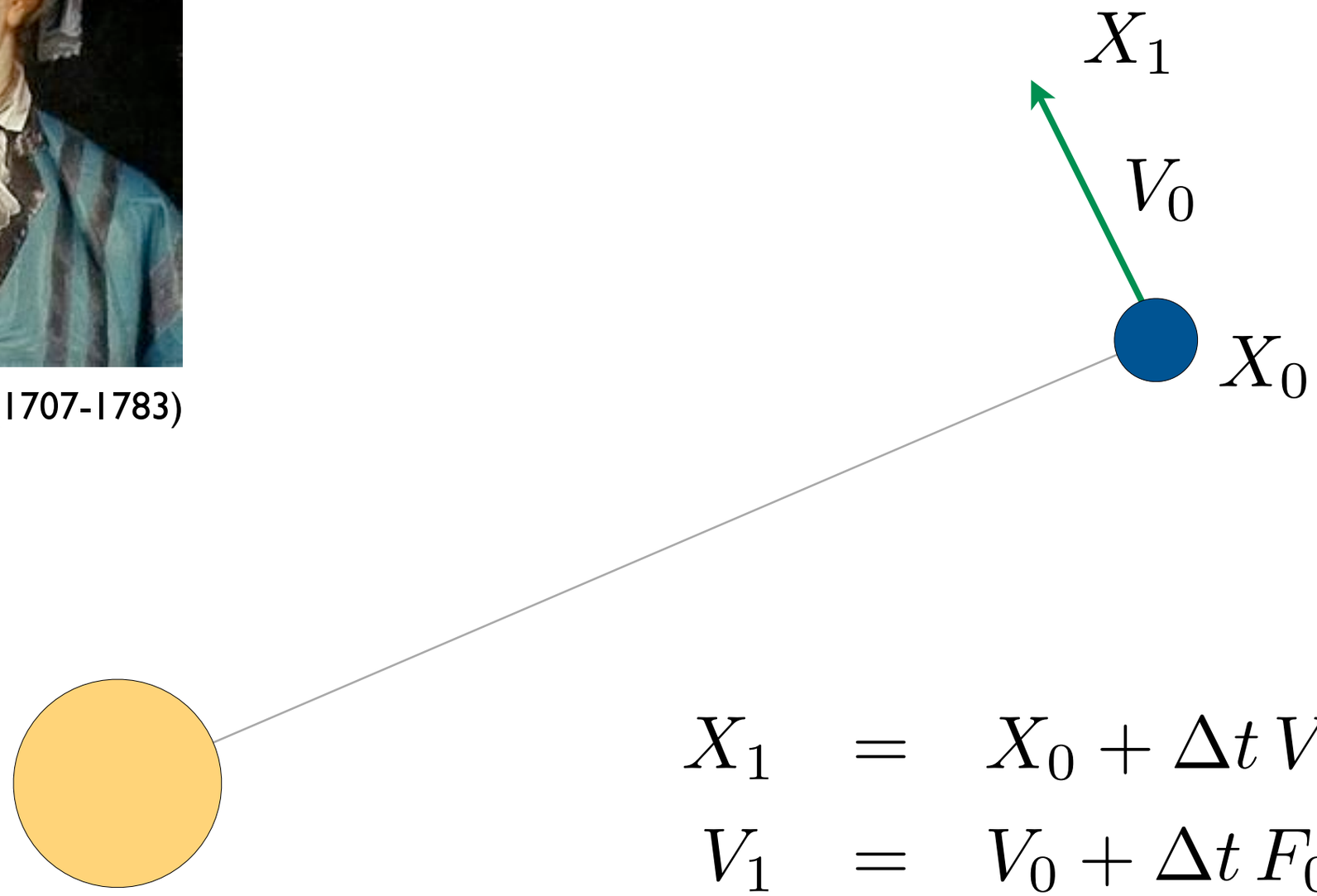

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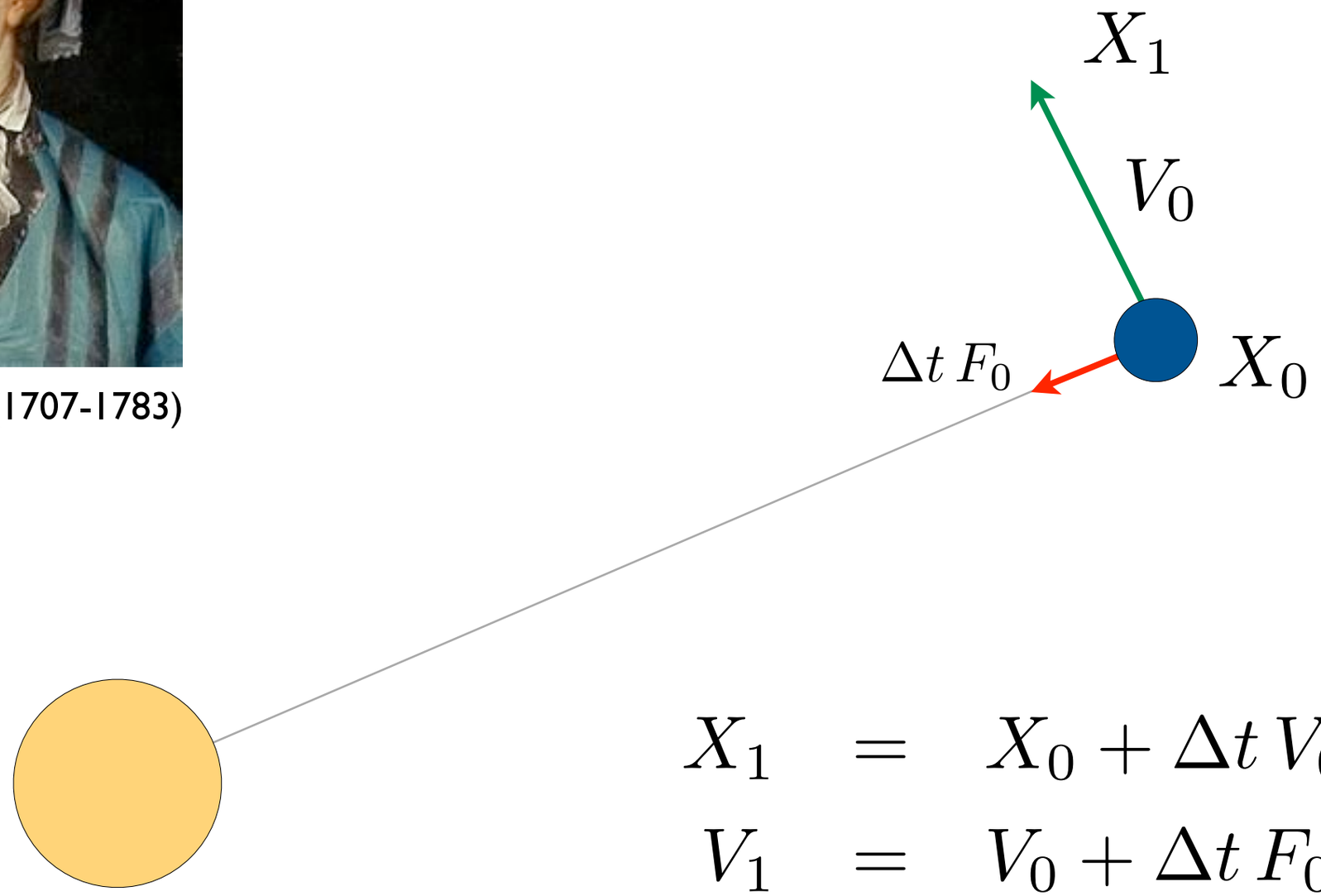

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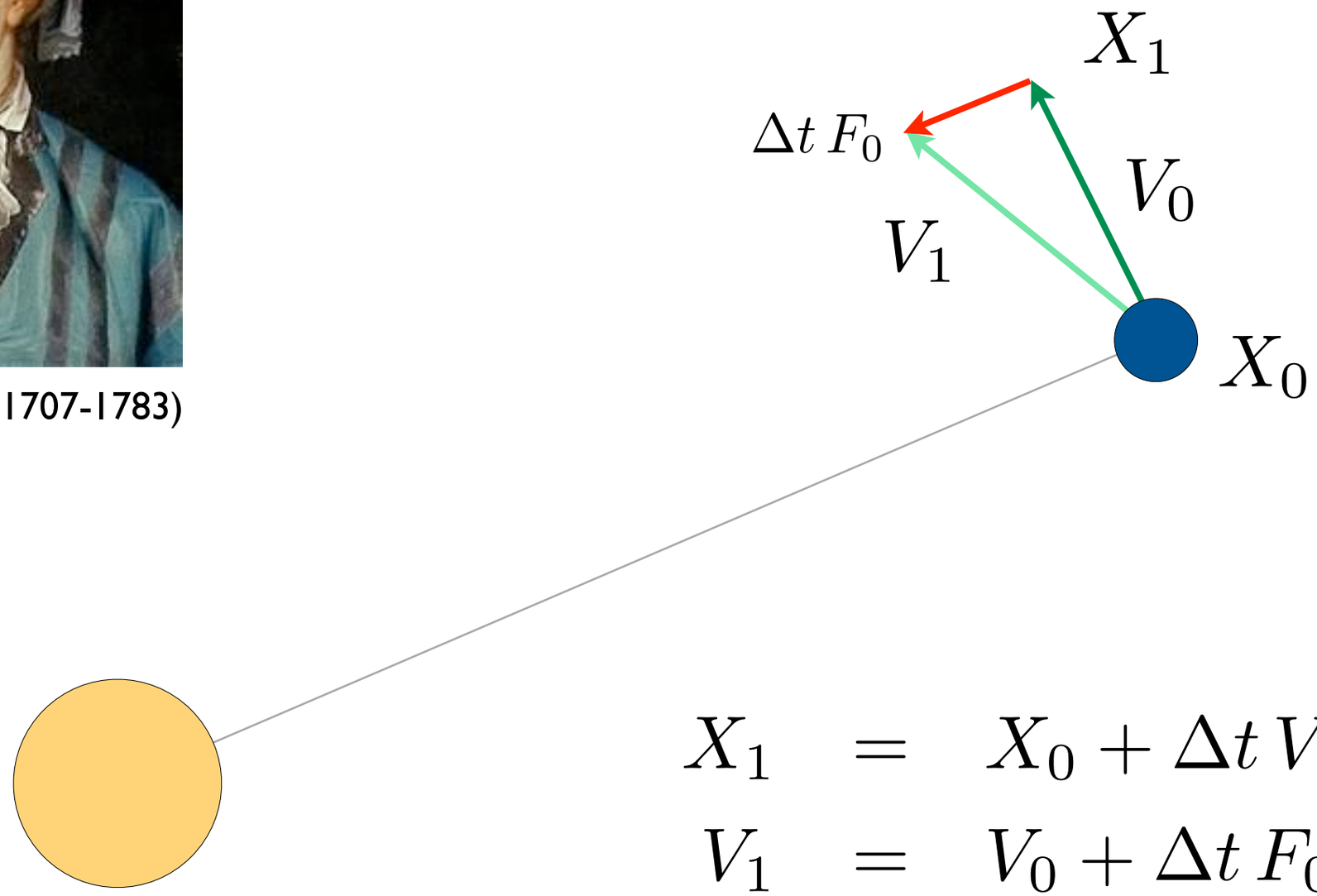

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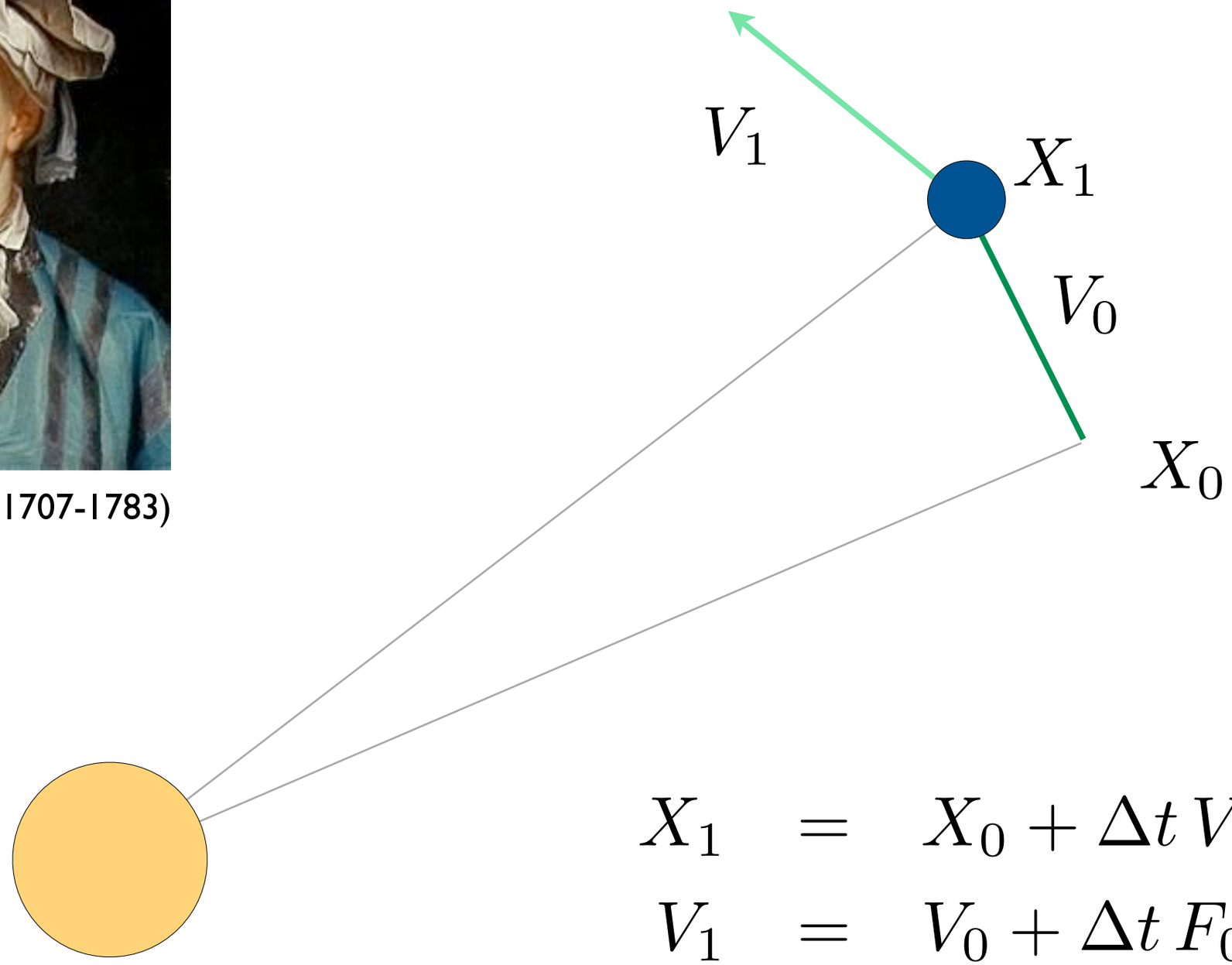

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“Backward” Euler (B)

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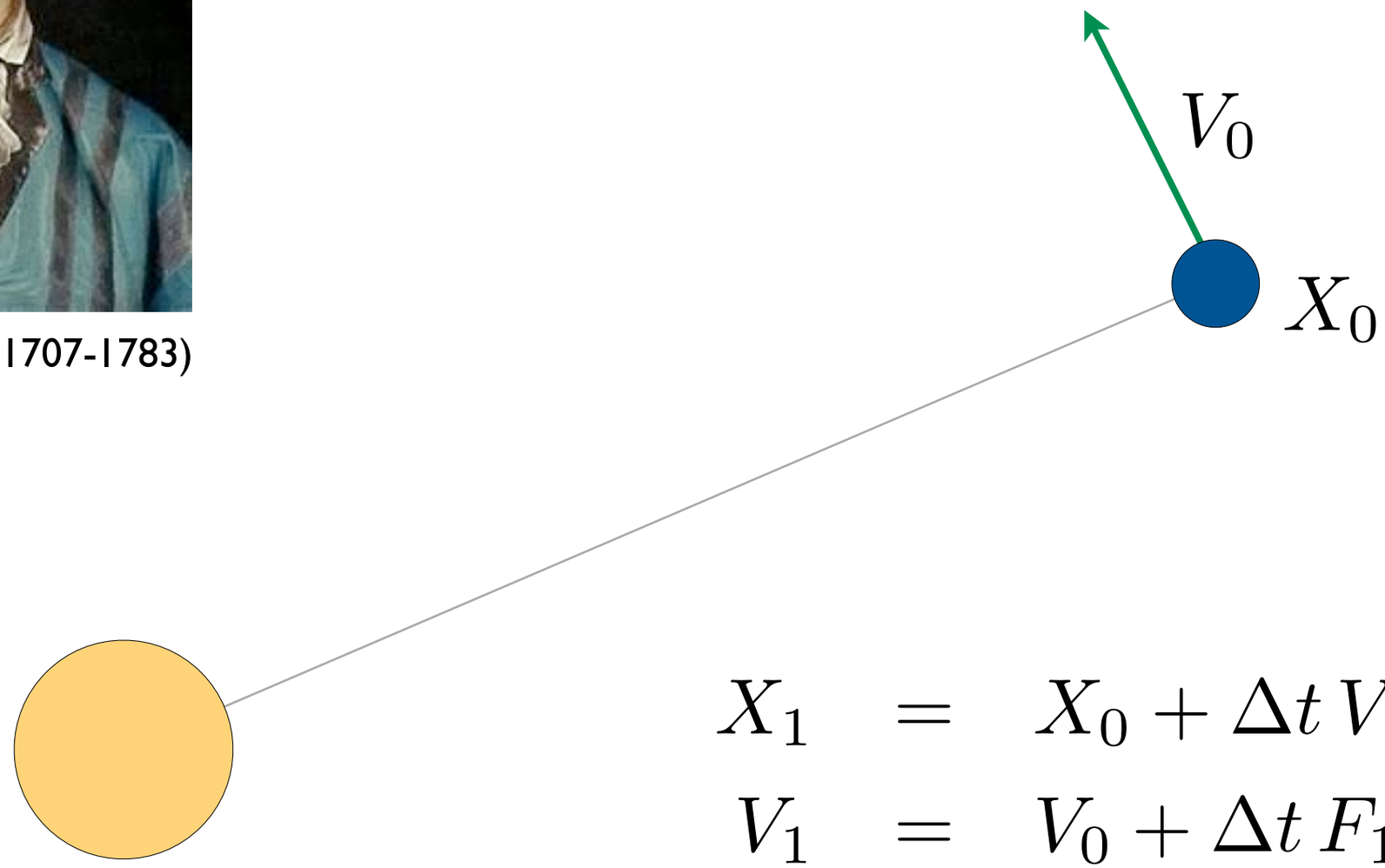

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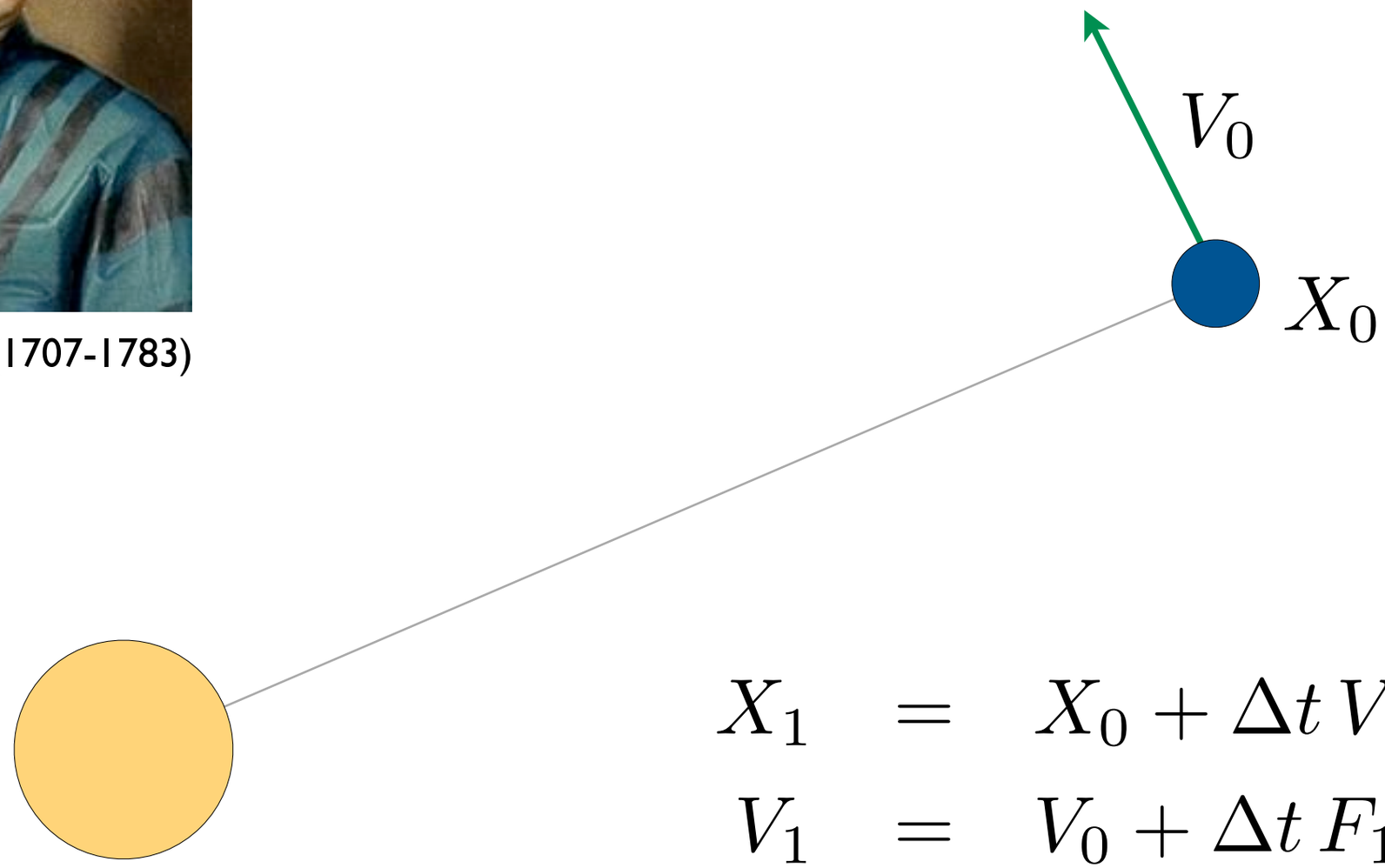

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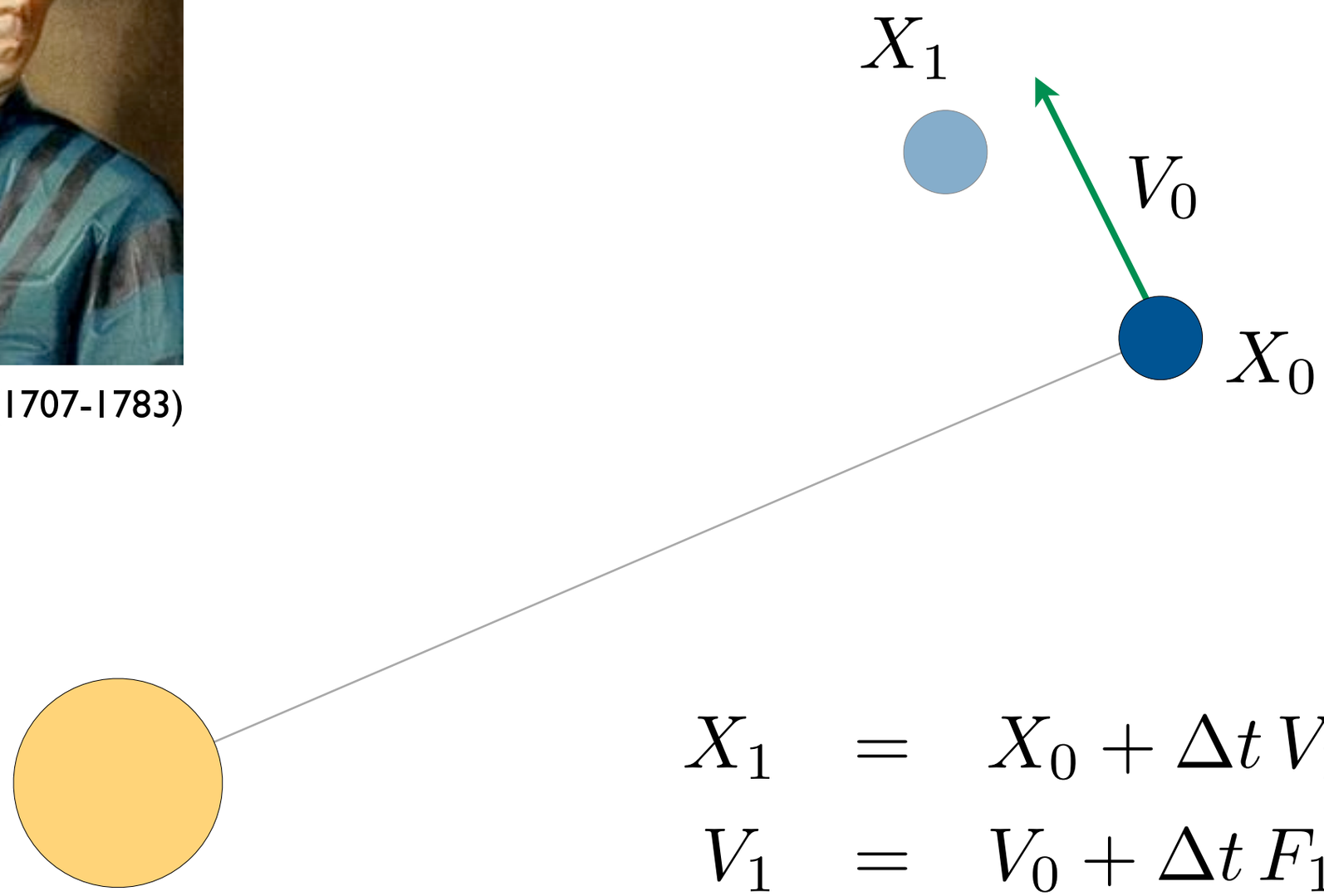

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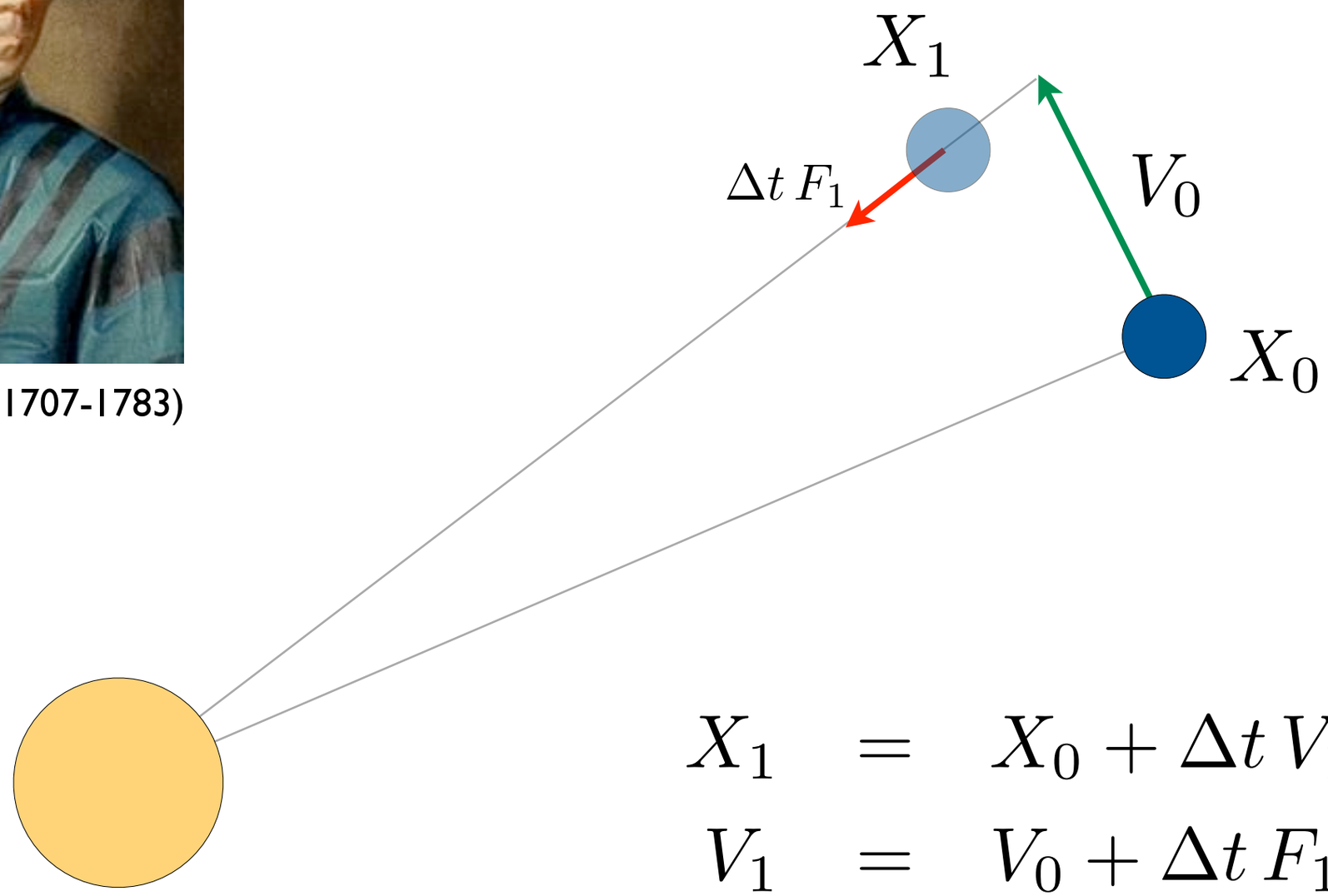

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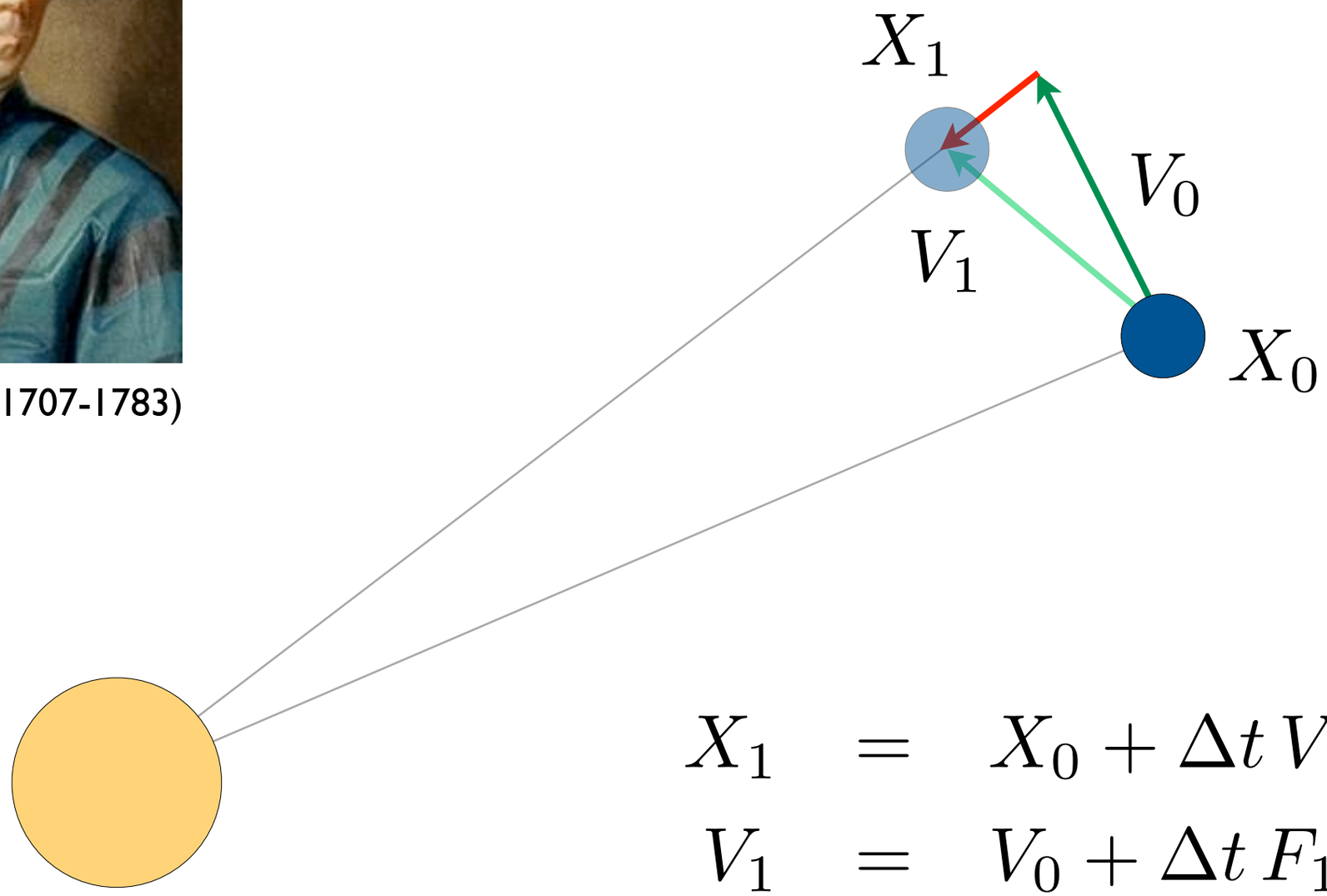

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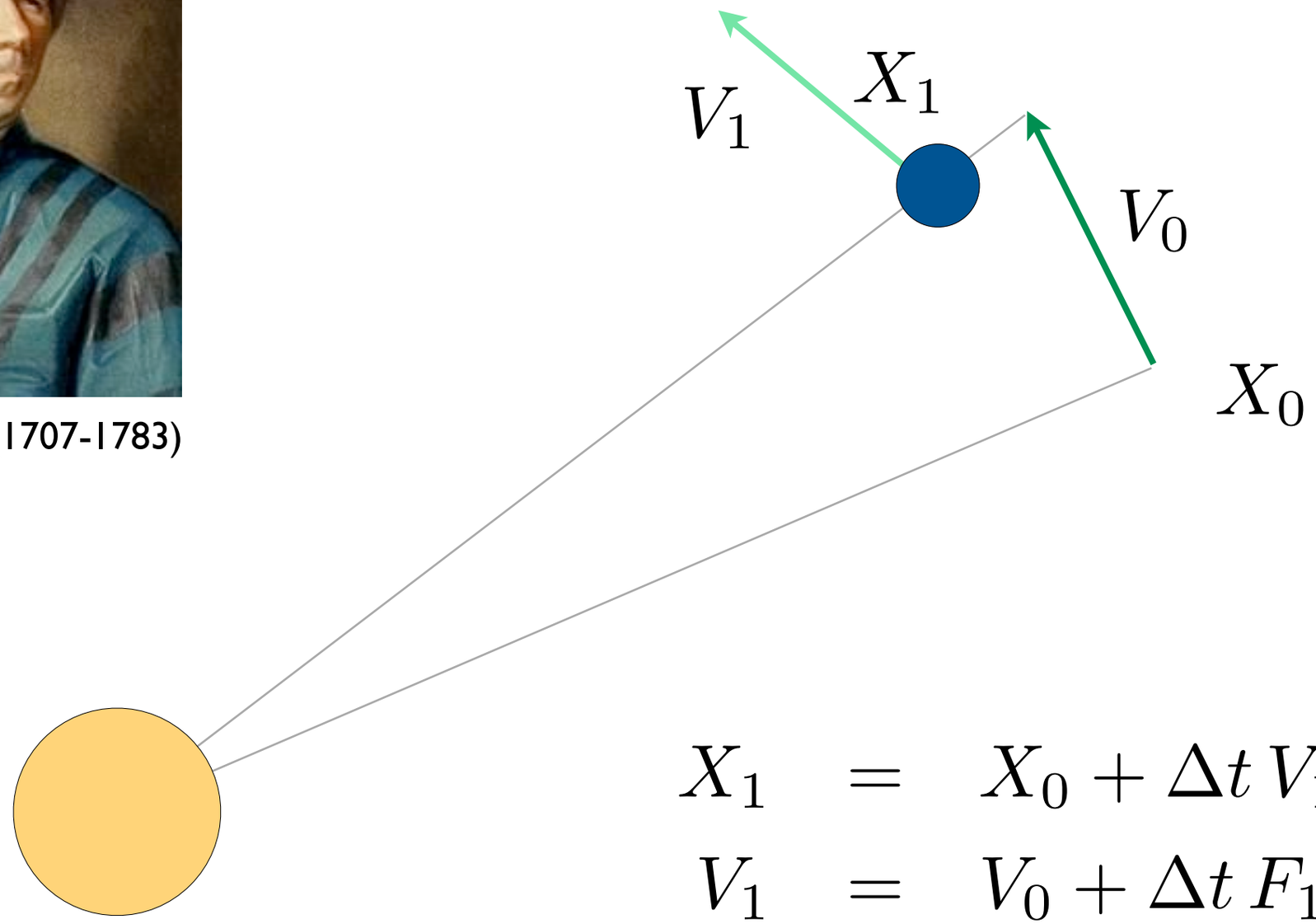

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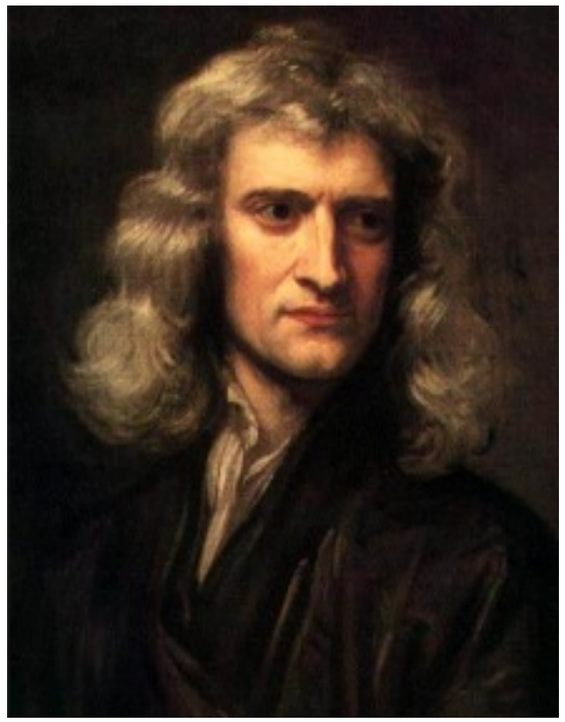

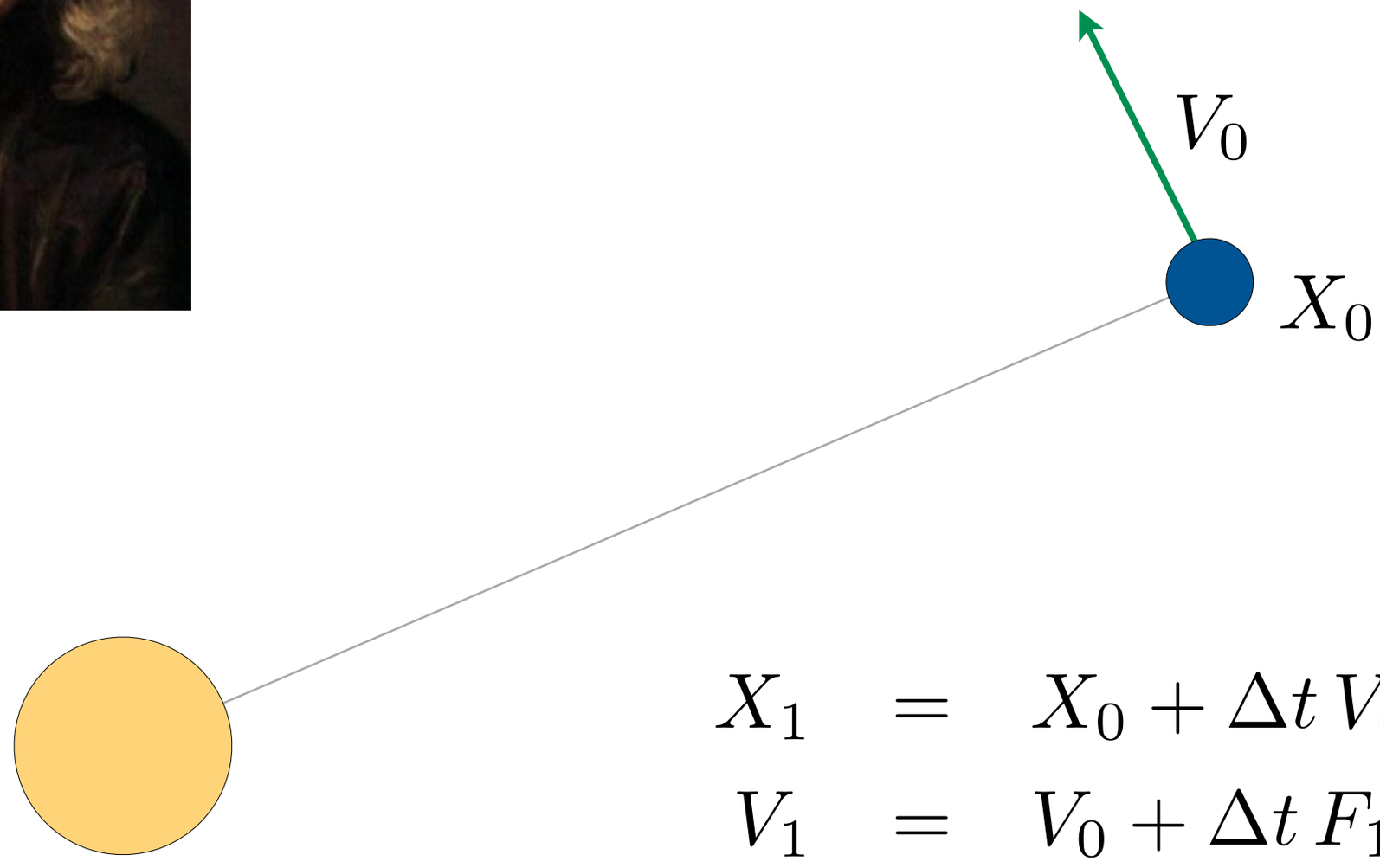

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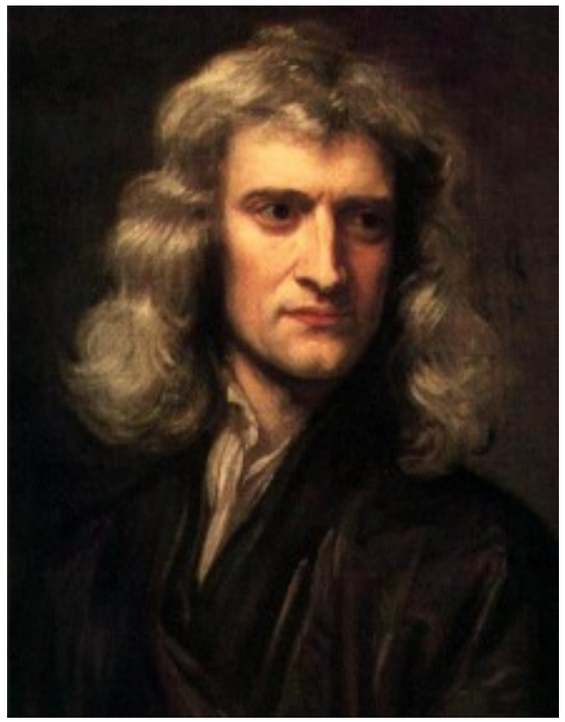

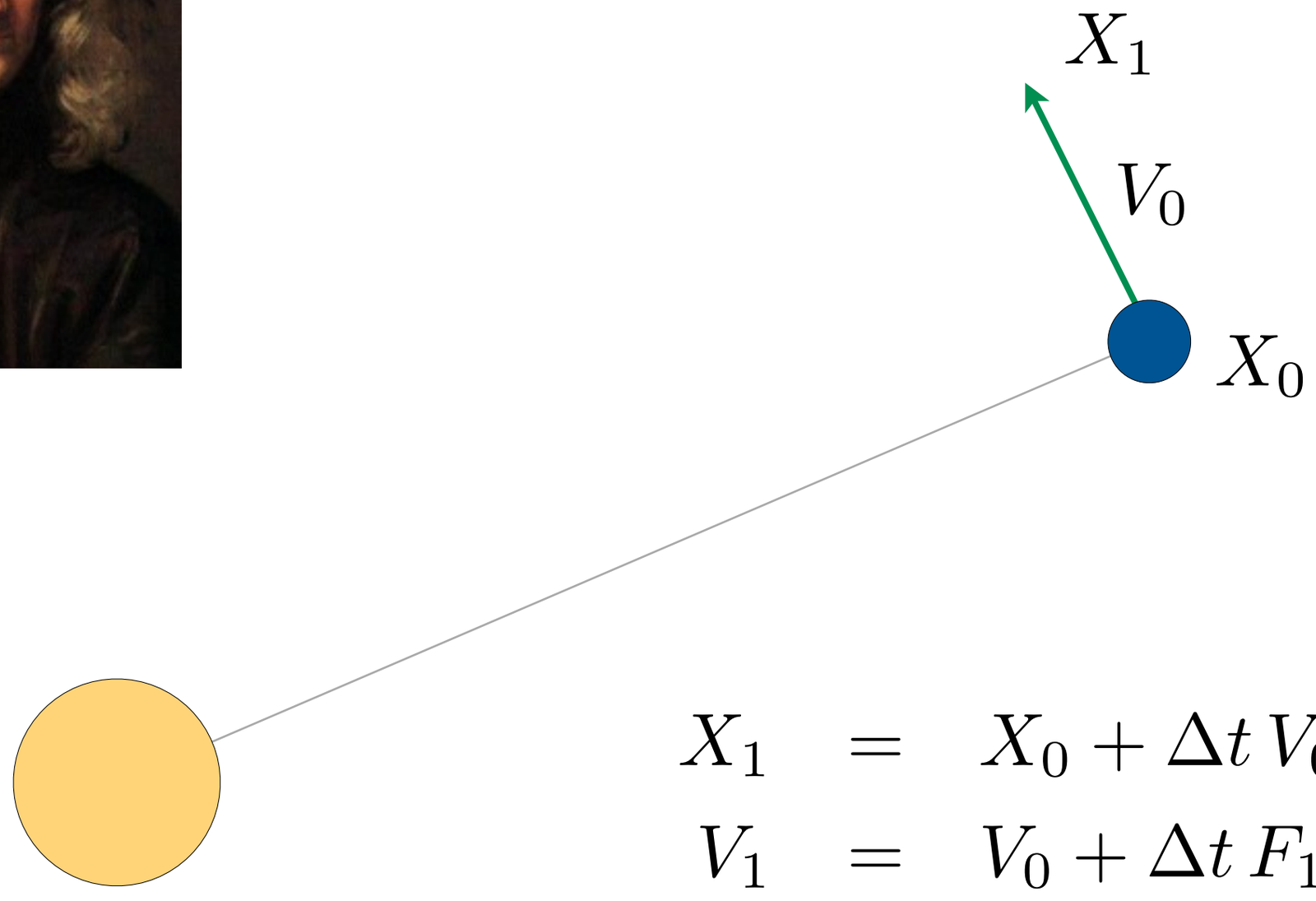

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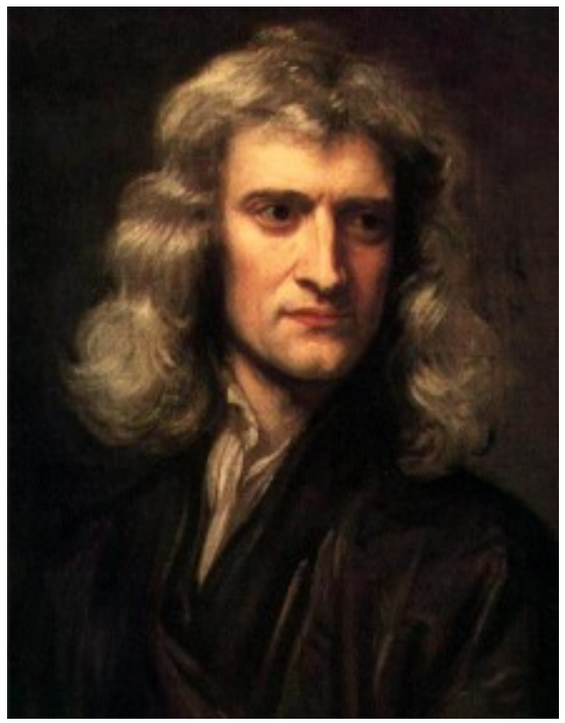

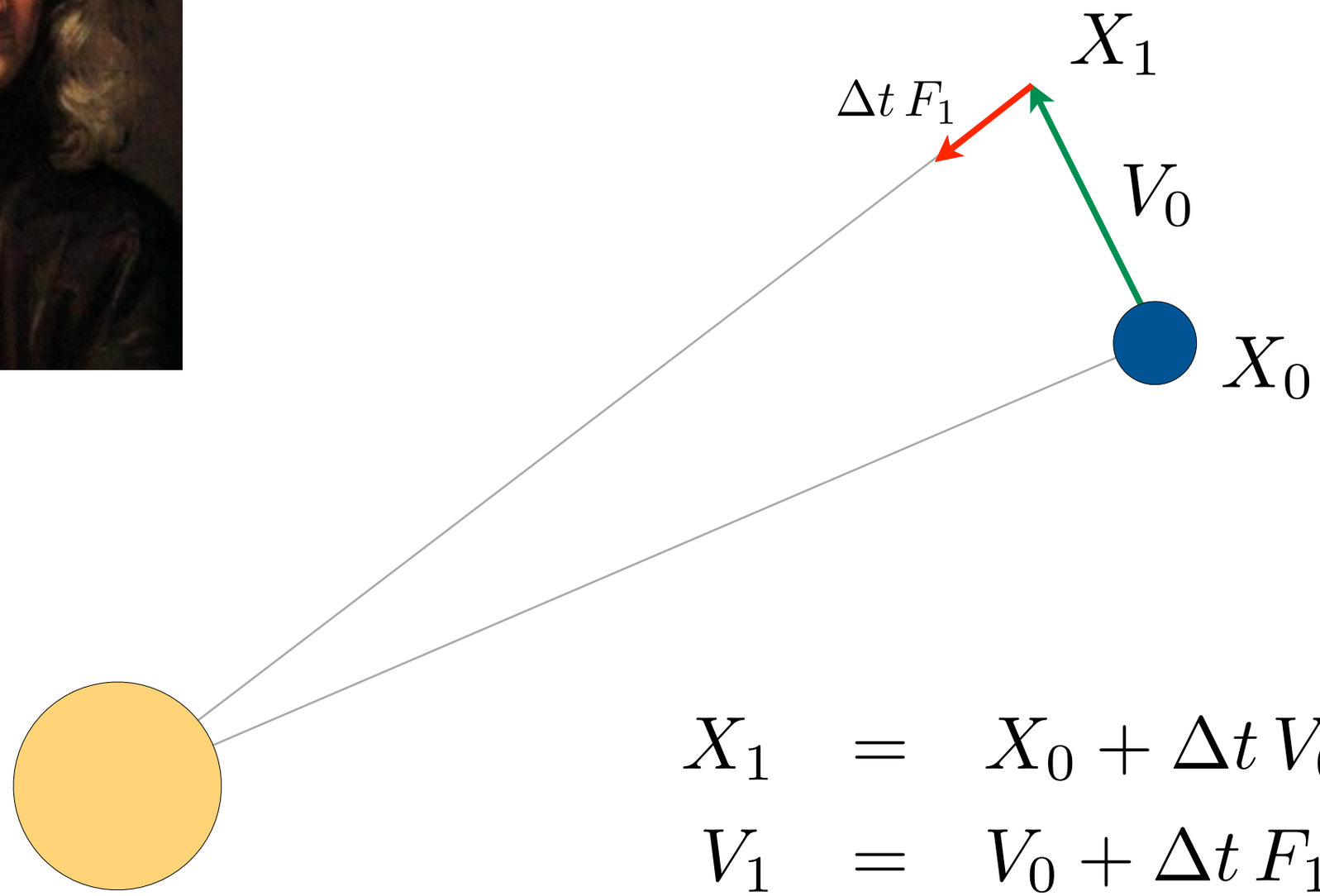

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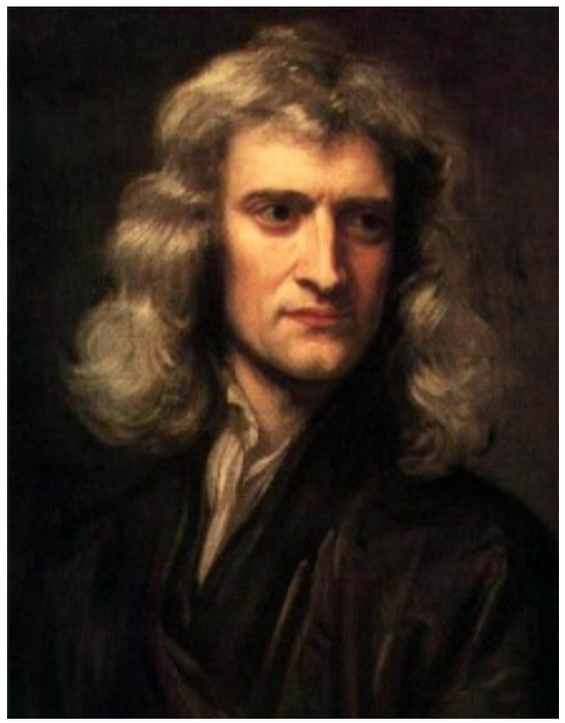

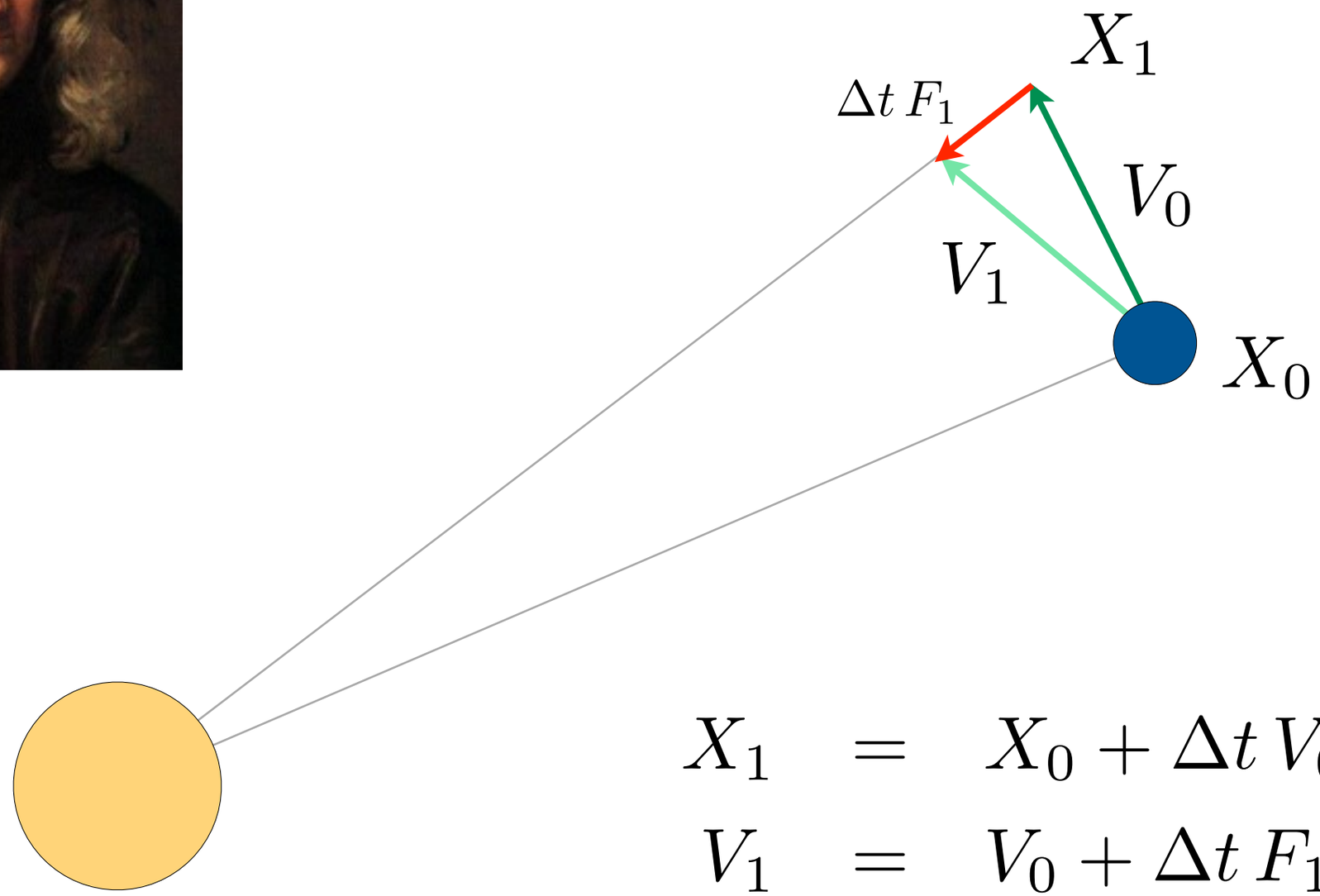

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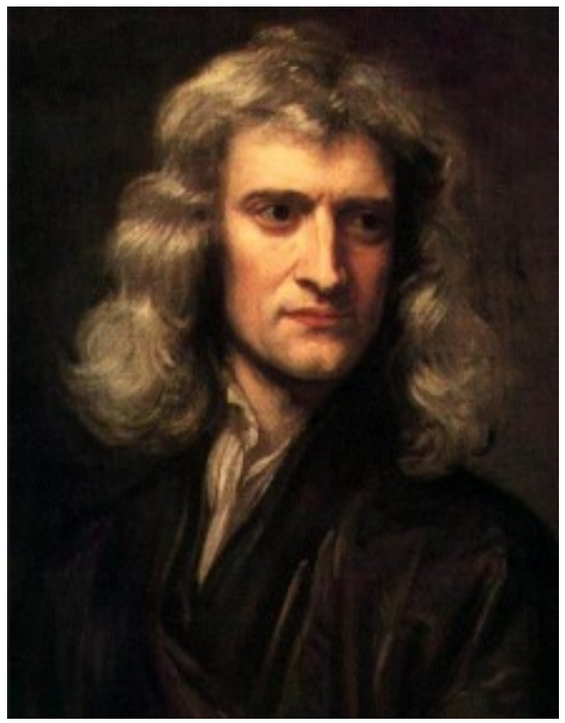

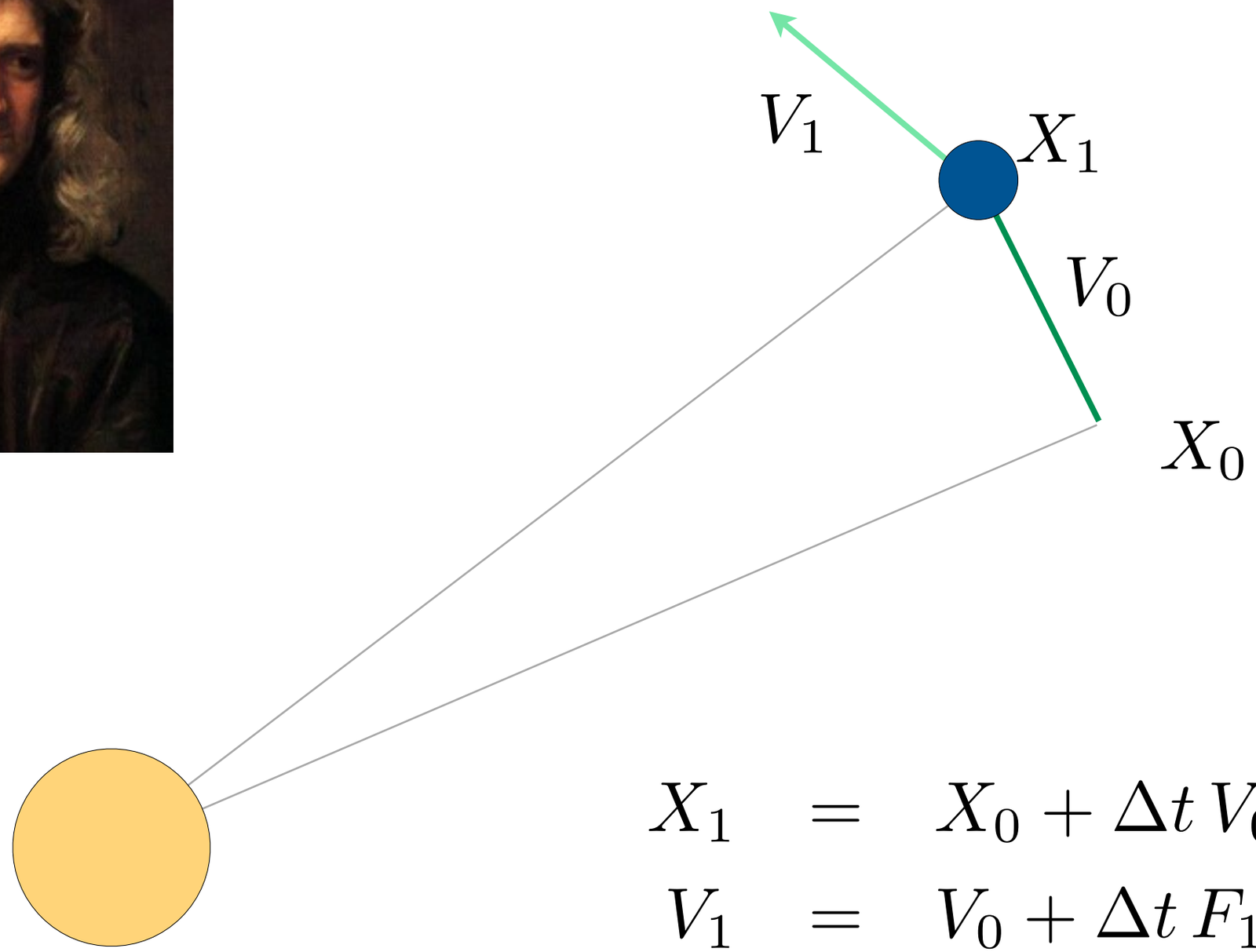

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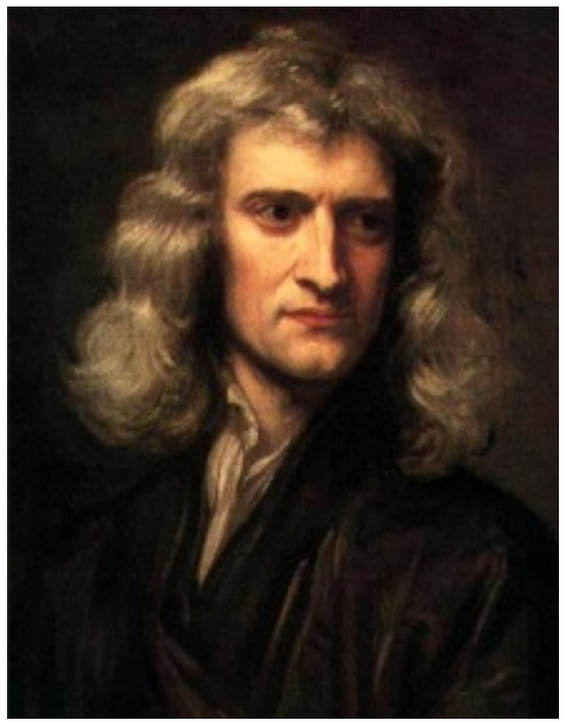

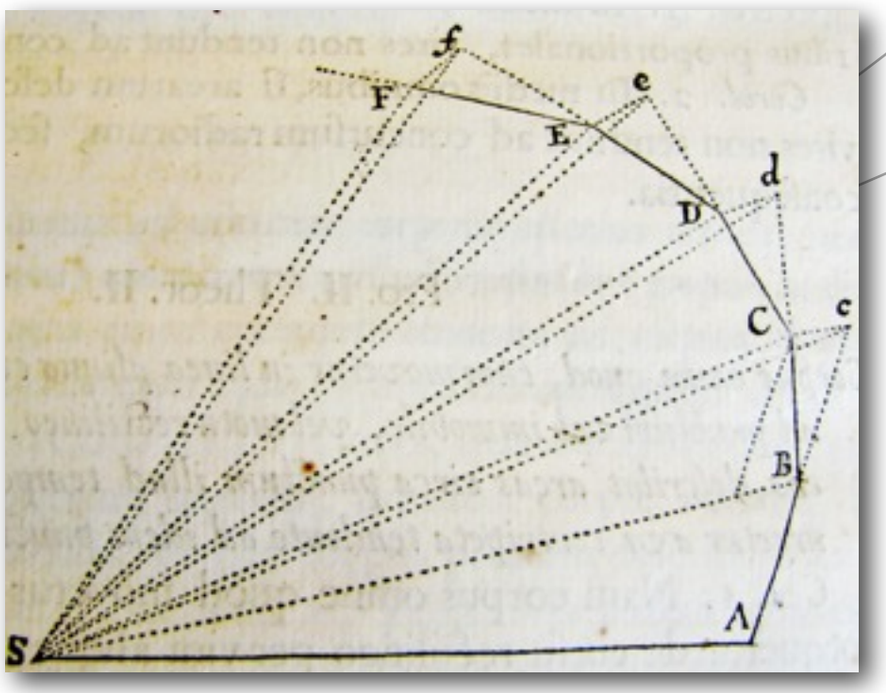

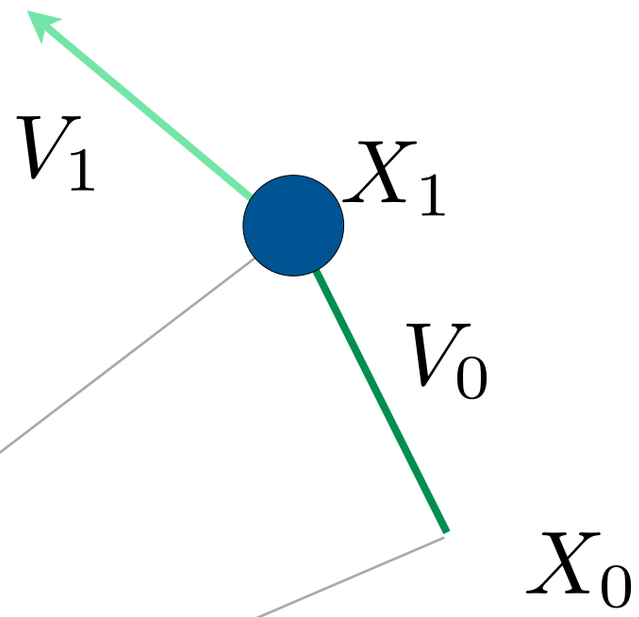

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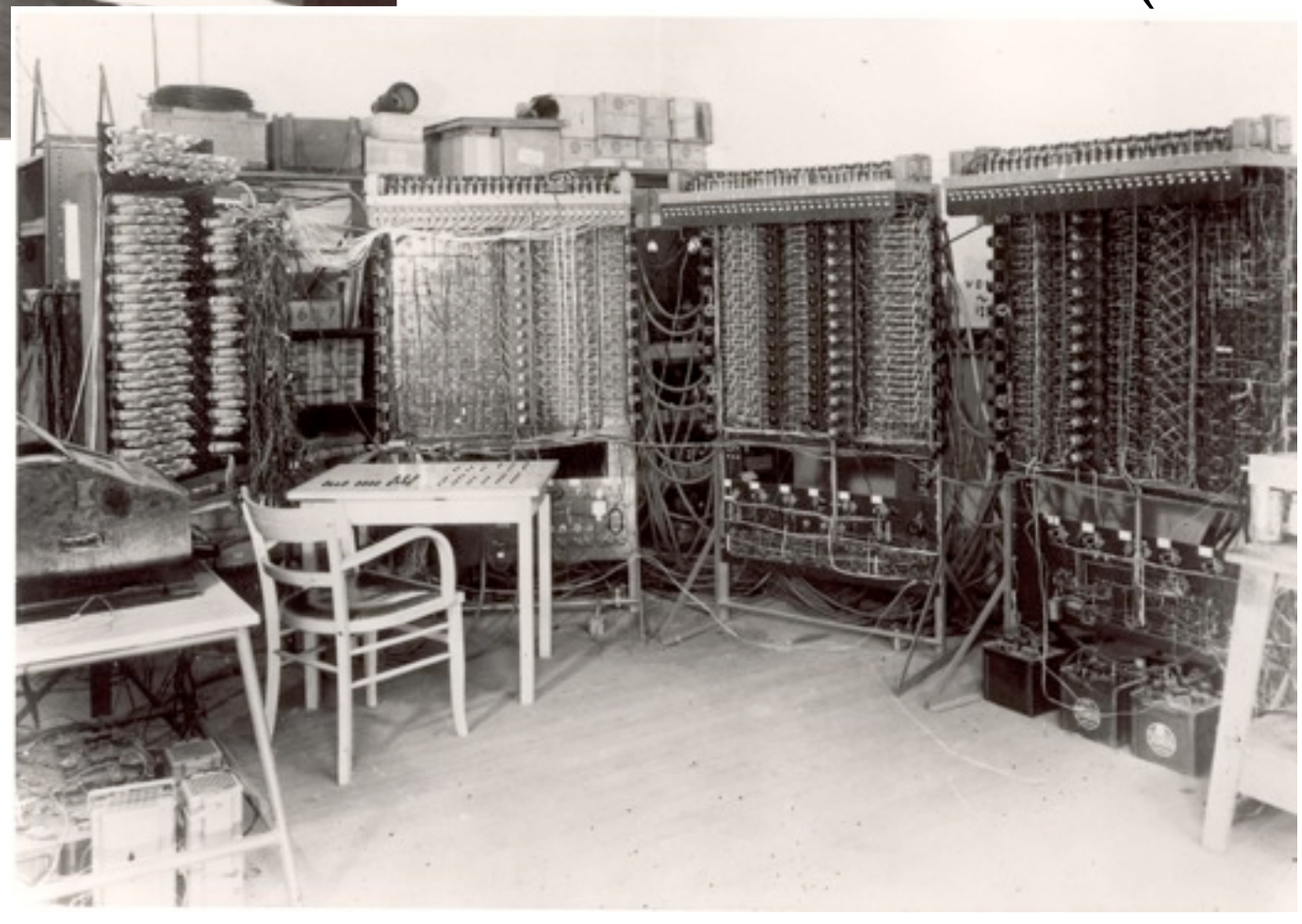
Obeys Kepler's 2nd Law (*Principia*)

Computing room of the Mathematisch Centrum (1951)

A. van Wijngaarden

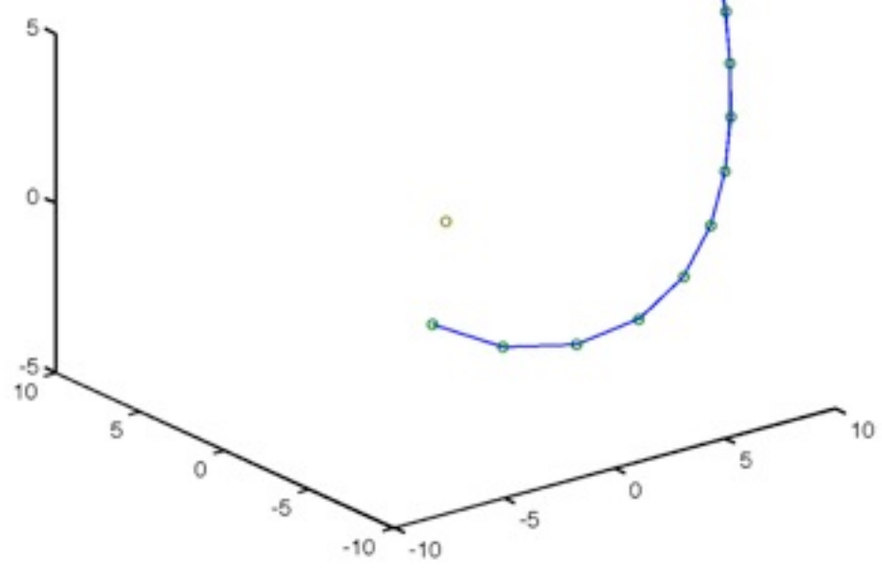
ARRA 1 - the first computer of the Netherlands (1952)



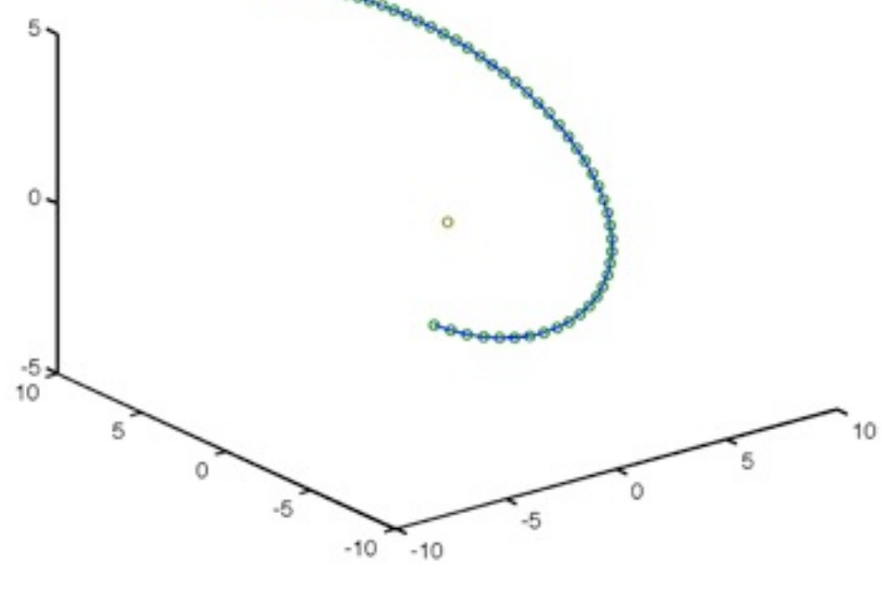
The nature of prediction (part 2): error

"a day without error is a day without mathematics" - J.G. Verwer

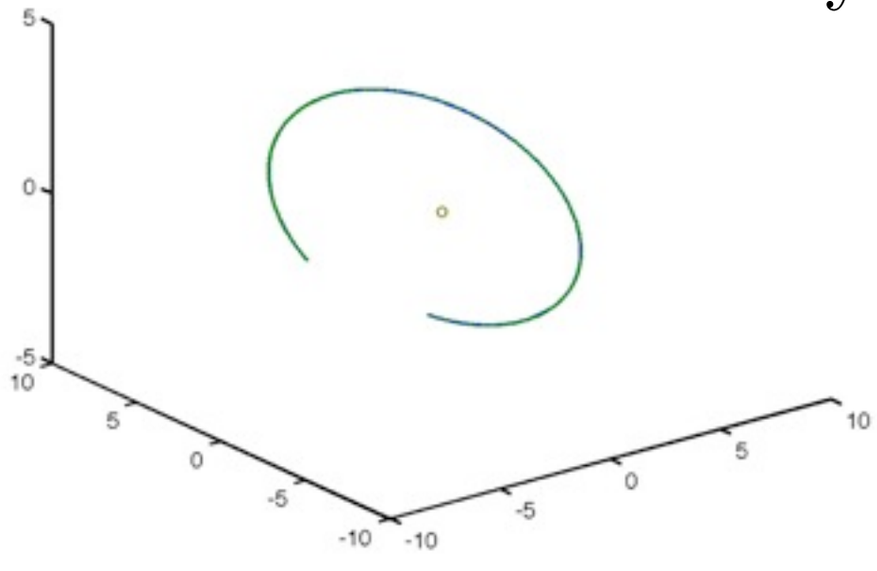
$\Delta t = 1$ month



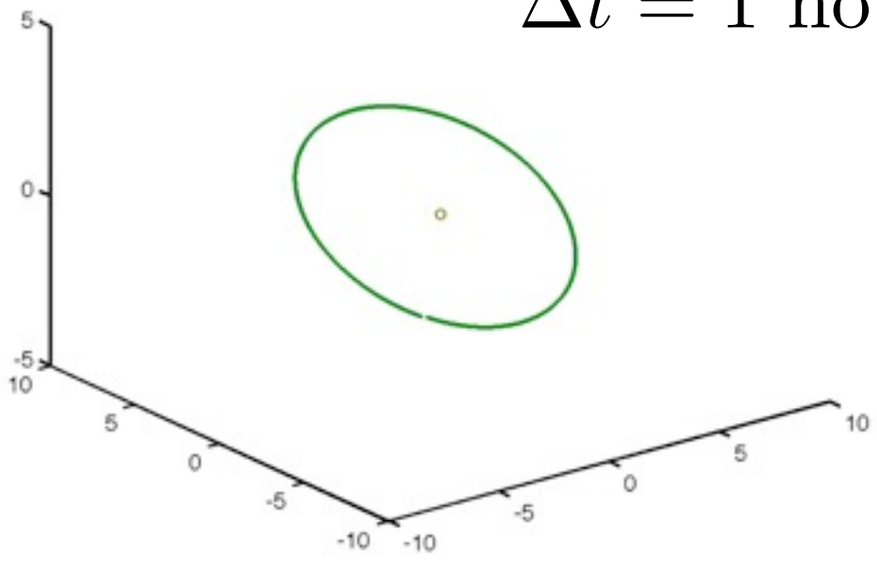
$\Delta t = 1$ week



$\Delta t = 1$ day



$\Delta t = 1$ hour



Chair “Numerical Analysis and Dynamical Systems”

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A. van Wijngaarden

H.A. Lauwerier

P.J. van der Houwen

J. G. Verwer

B.L. van der Waerden ('48-'50)
A. van Wijngaarden ('52-'58)
H.A. Lauwerier ('59-'63)
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The nature of prediction (part 3): uncertainty

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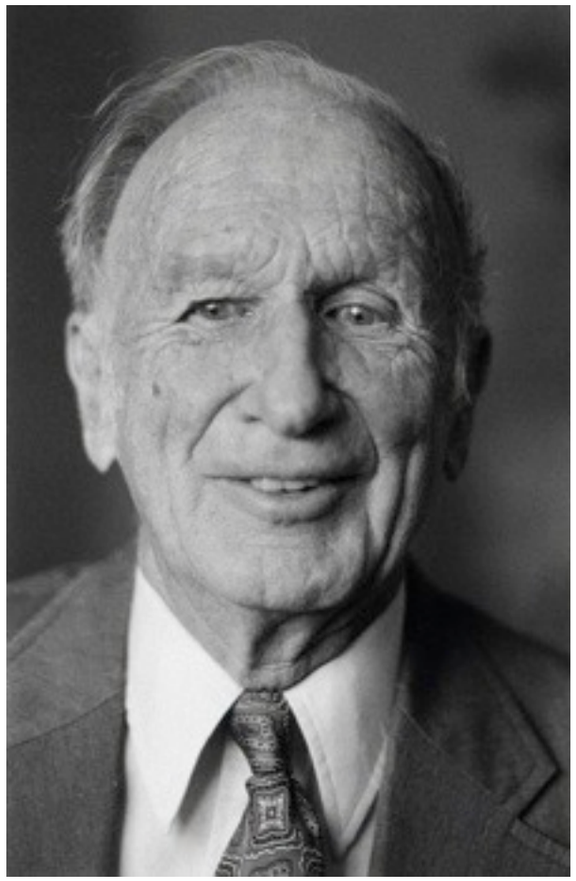
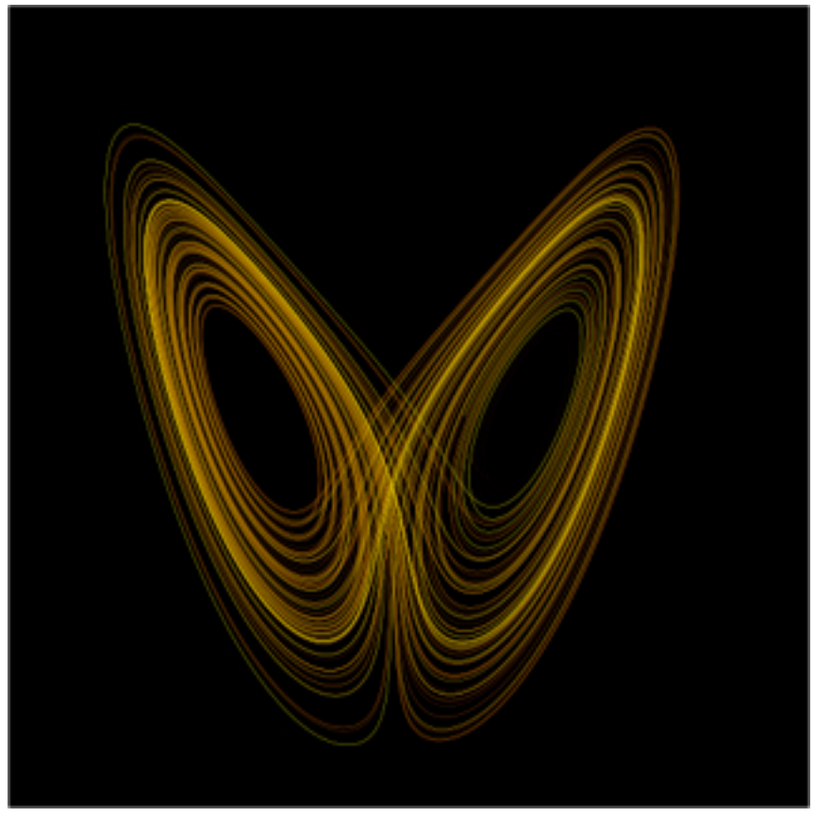


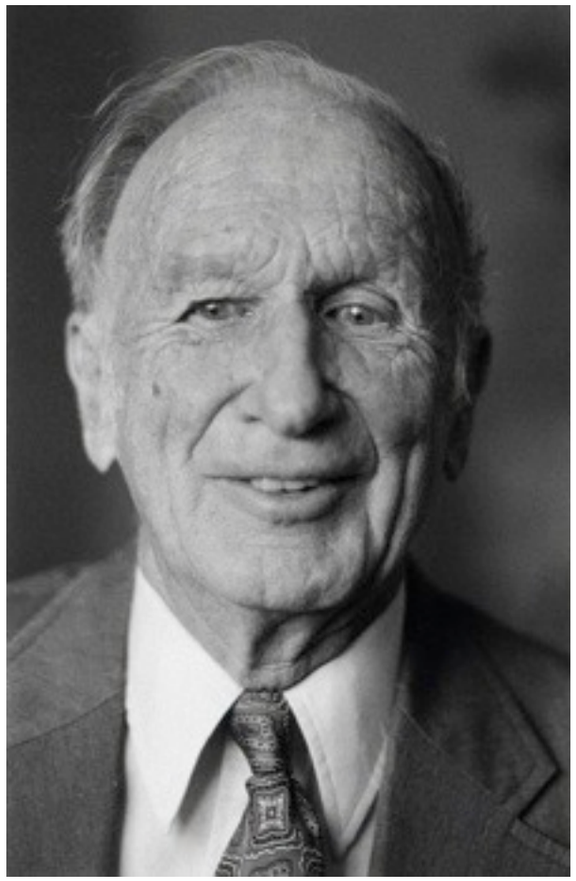
Lorenz Attractor



$$
\begin{aligned}
X_1 &= X_0 + \Delta t\, s(Y_0 - X_0) \\
Y_1 &= Y_0 + \Delta t\, (rX_0 - X_0 Z_0 - Y_n) \\
Z_1 &= D_0 + \Delta t\, (X_0 Y_0 - bZ_0)
\end{aligned}
$$

$r = 28 \quad b = 8/3 \quad s = 10$

The nature of prediction (part 3): uncertainty



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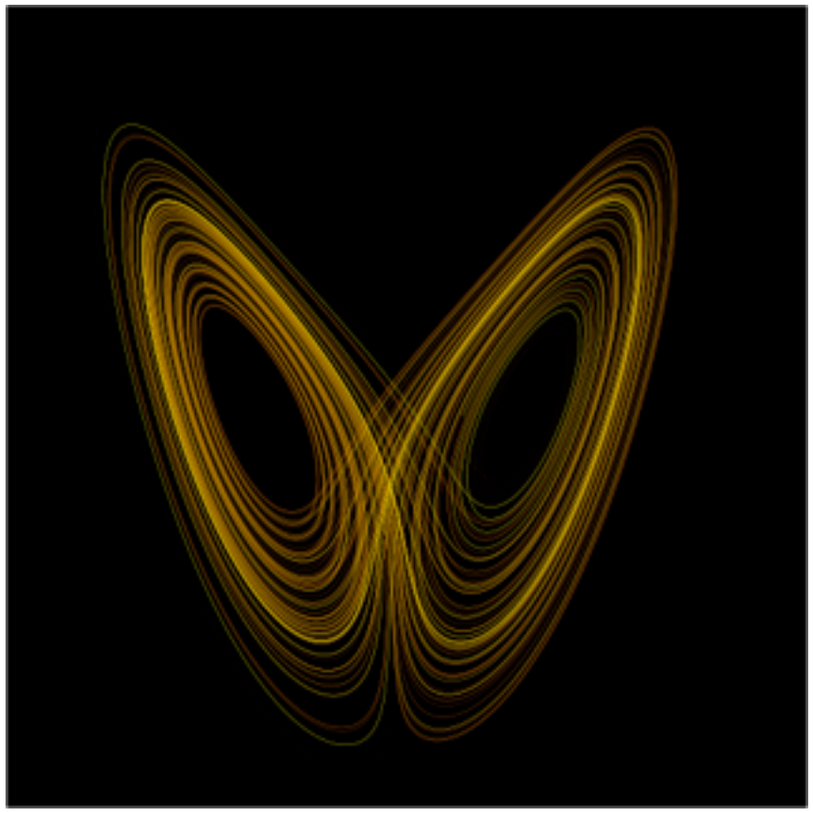

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Ten simulations of the Lorenz system with tiny errors in the initial condition:

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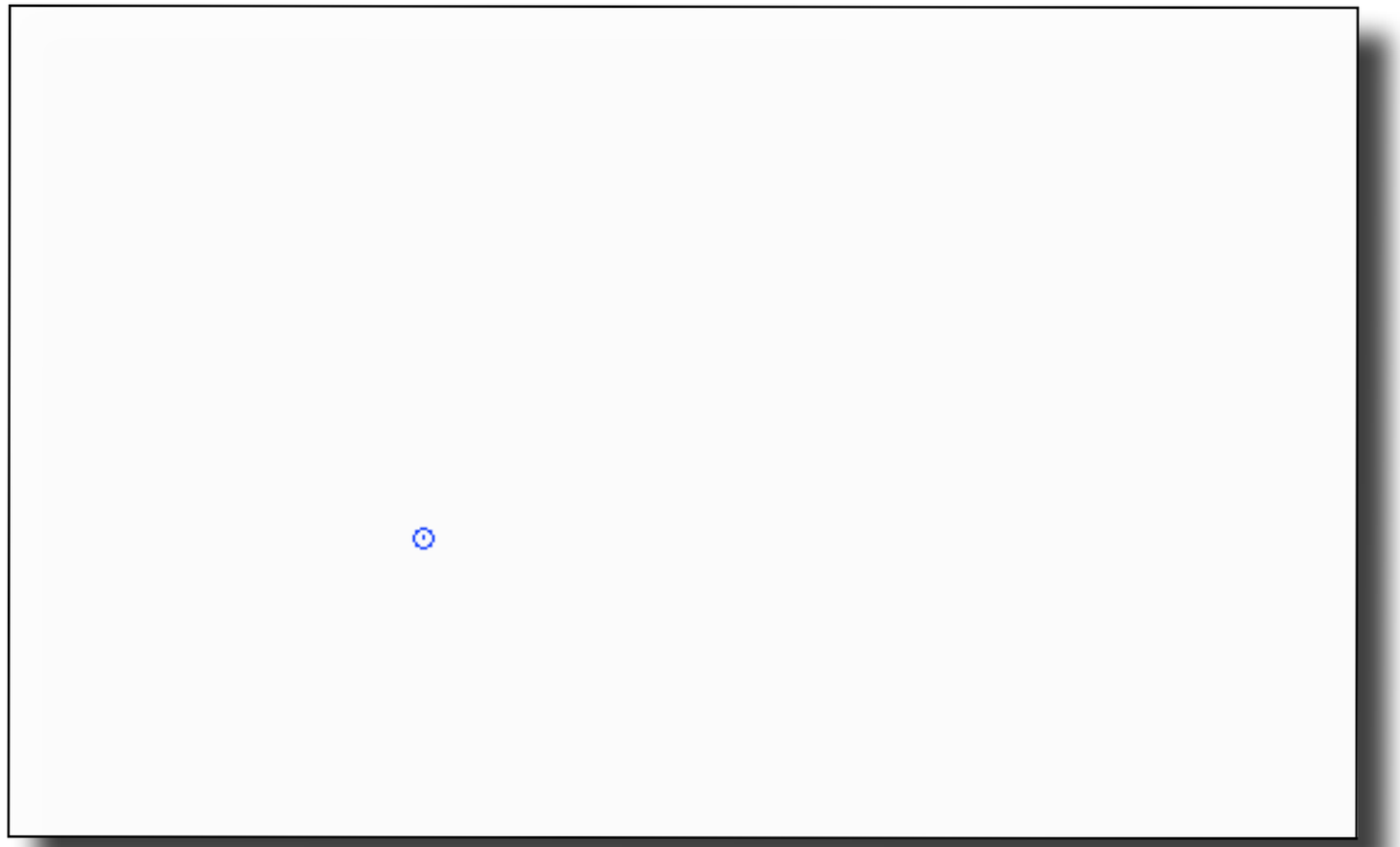

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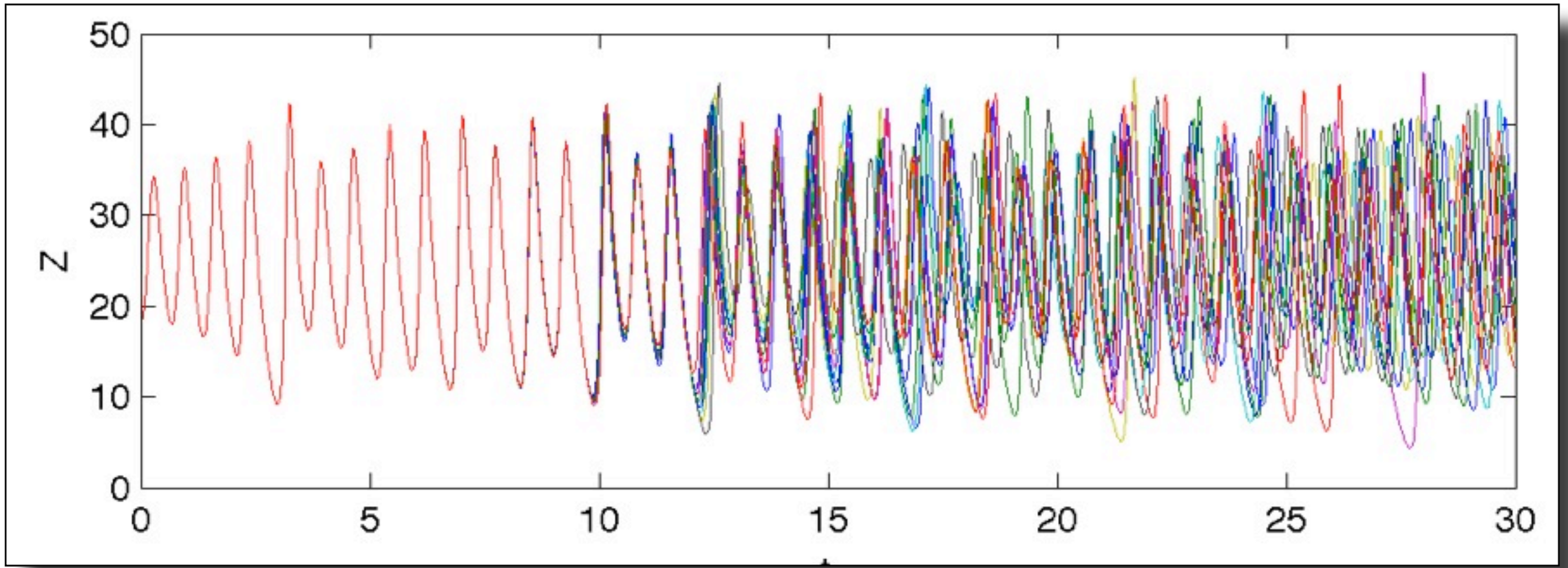

Just the variable ‘Z’ as a function of time.

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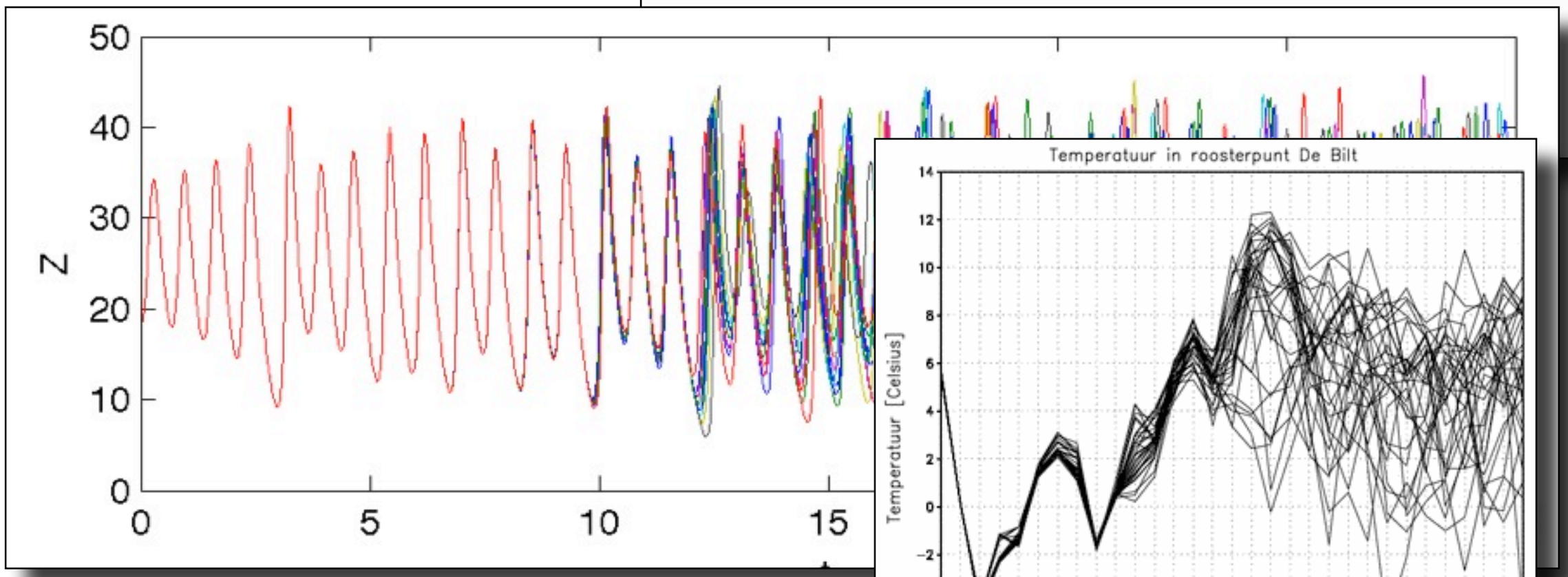
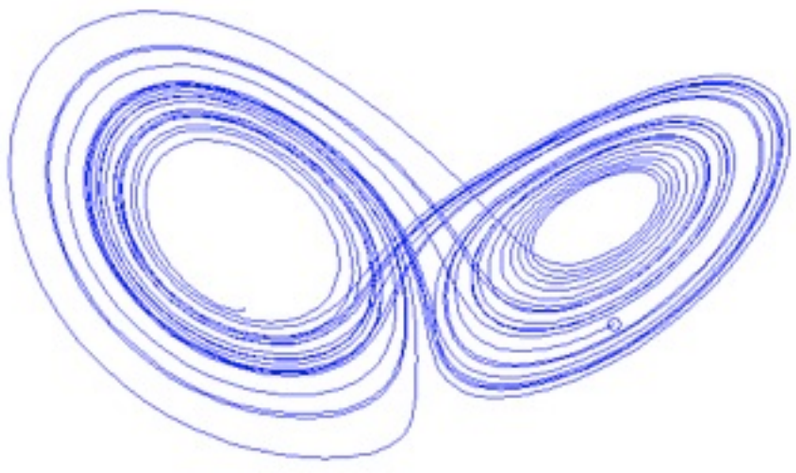
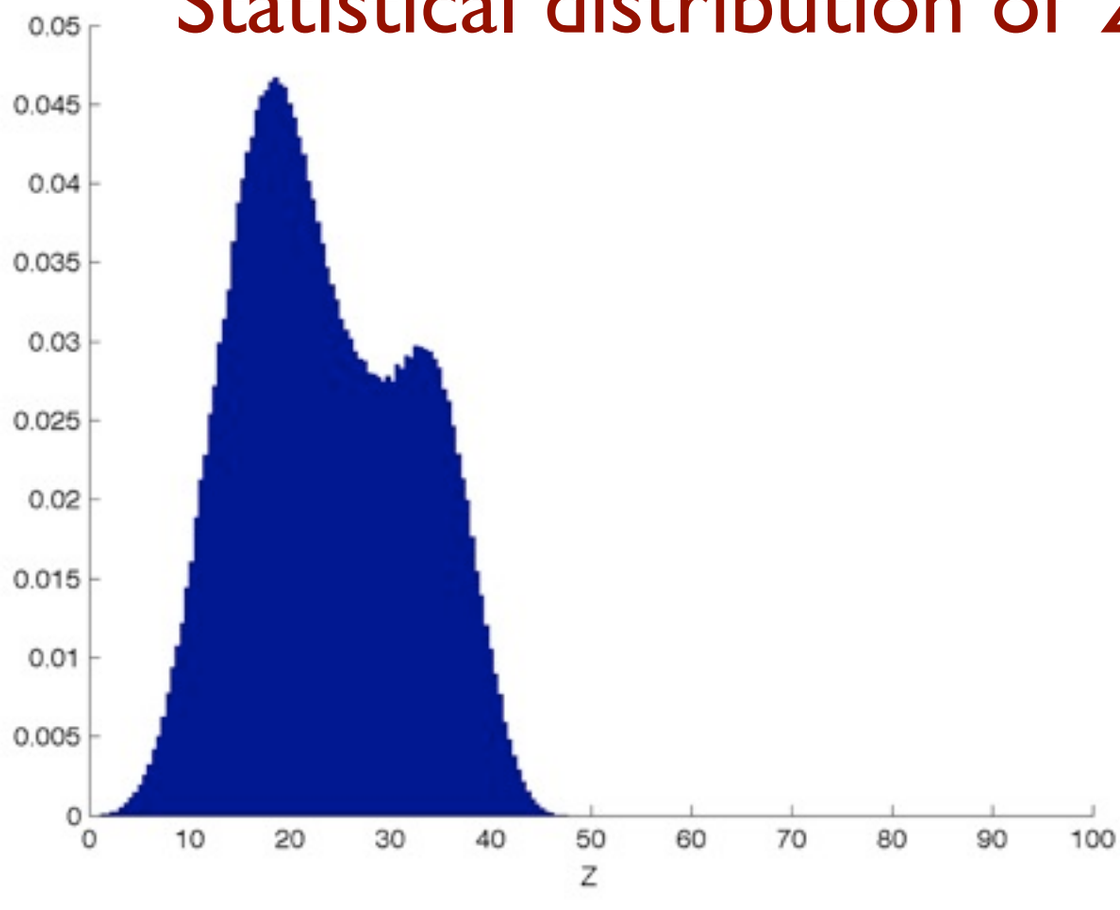


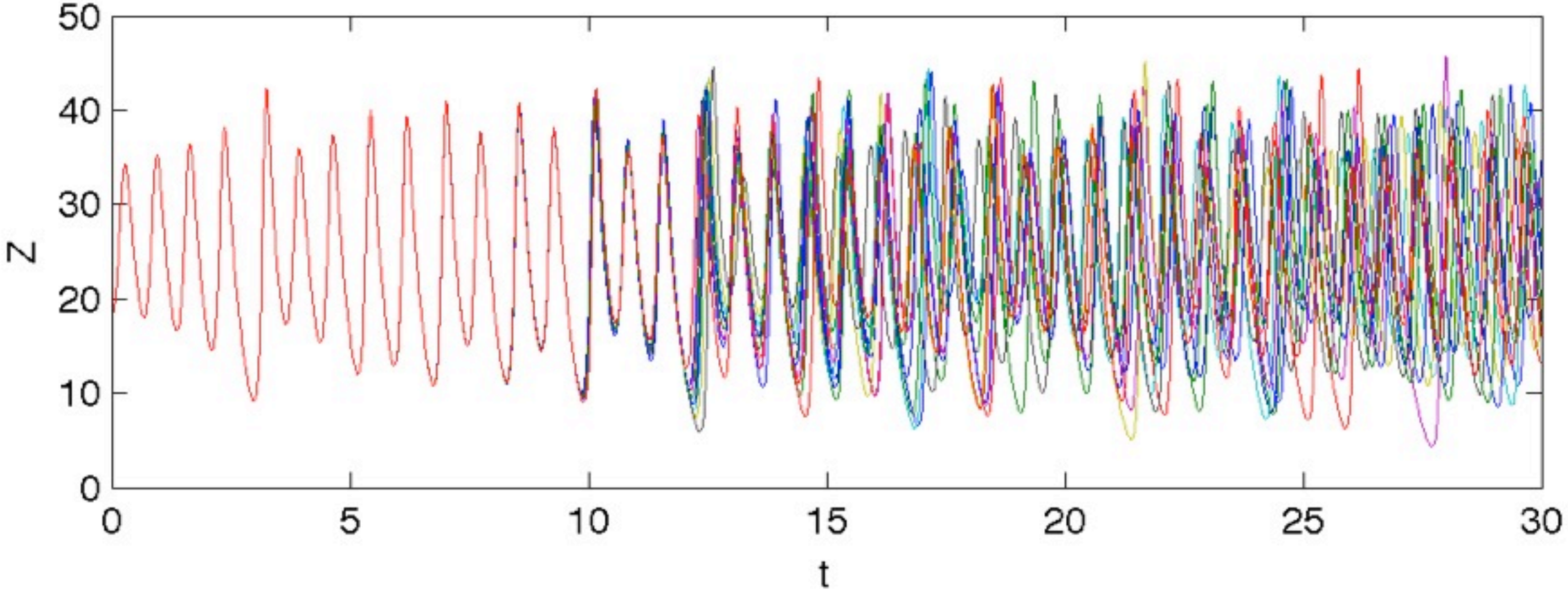
Just the variable ‘Z’ as a function of time.

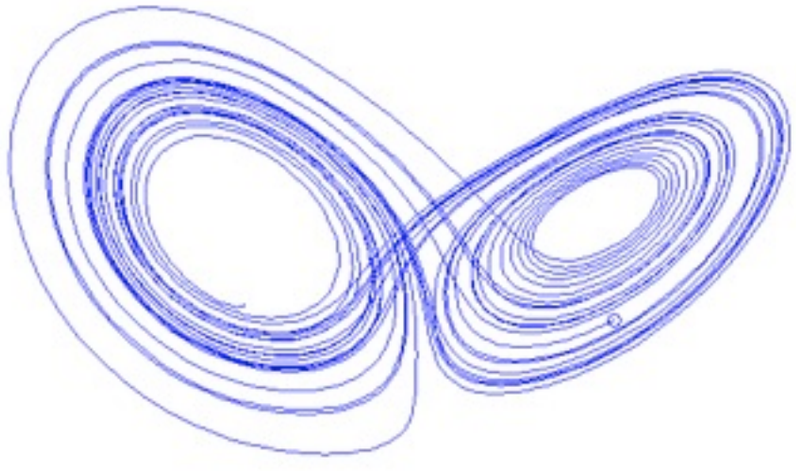
The same effect in a real climate simulation



Statistical distribution of ‘Z’







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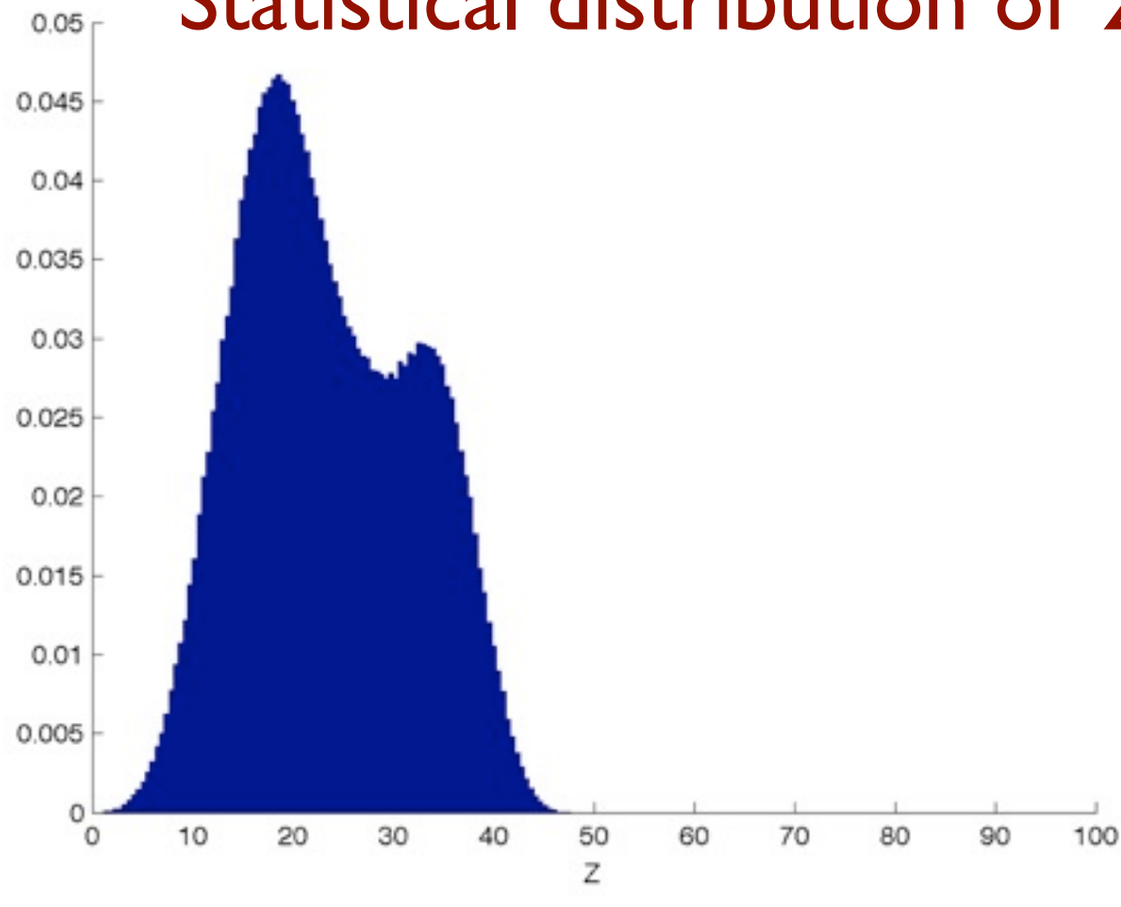

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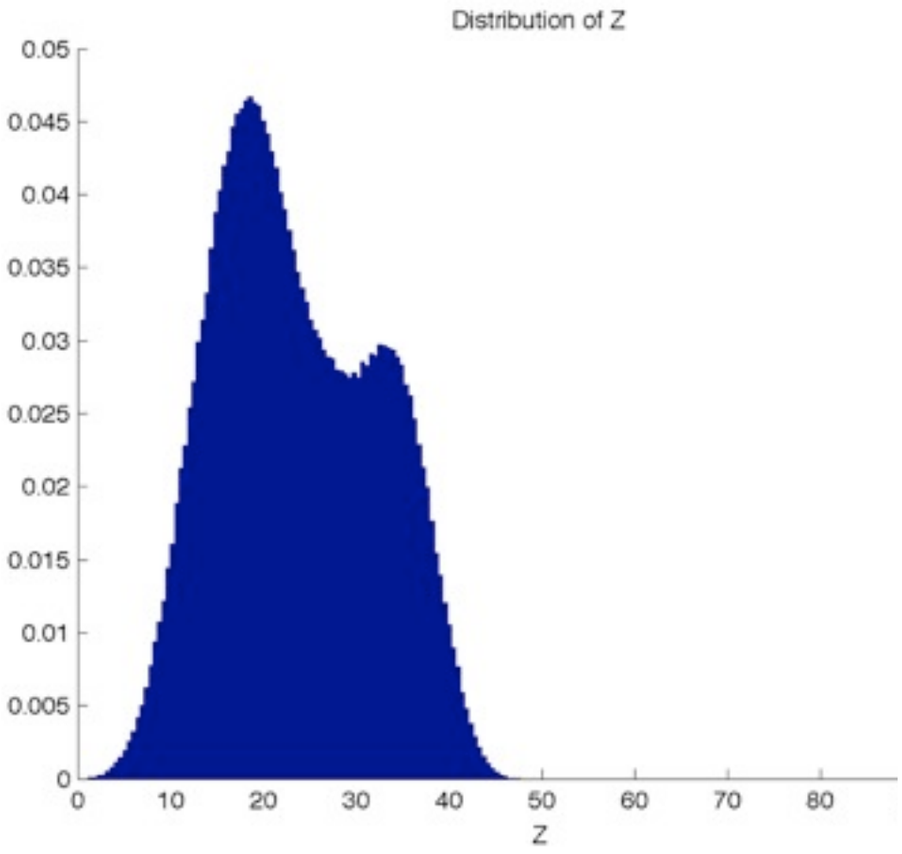
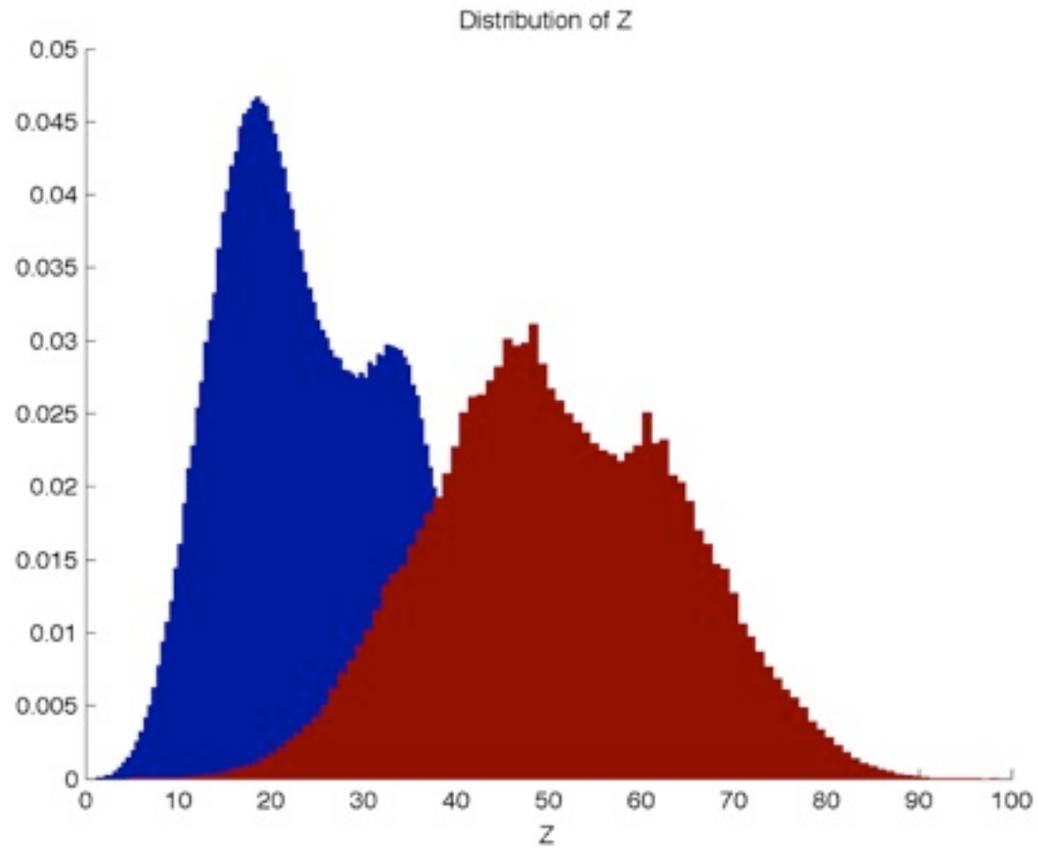

Distribution of Z
0.05
0.045
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
0
10
20
30
40
50
60
70
80
Z

r = 56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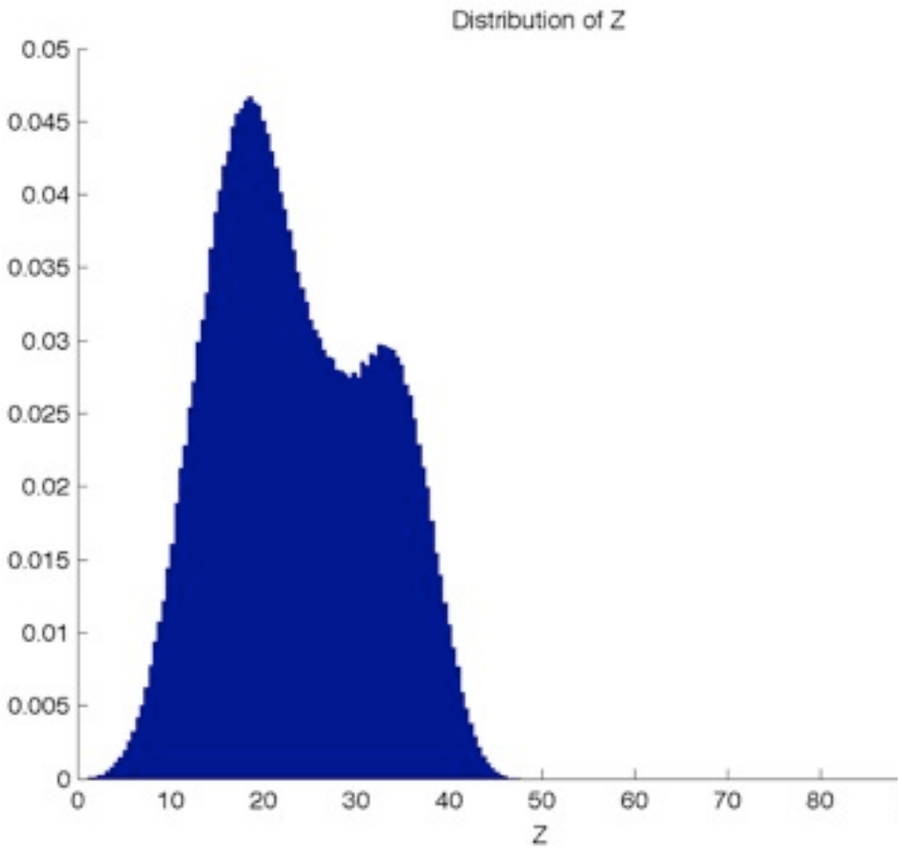

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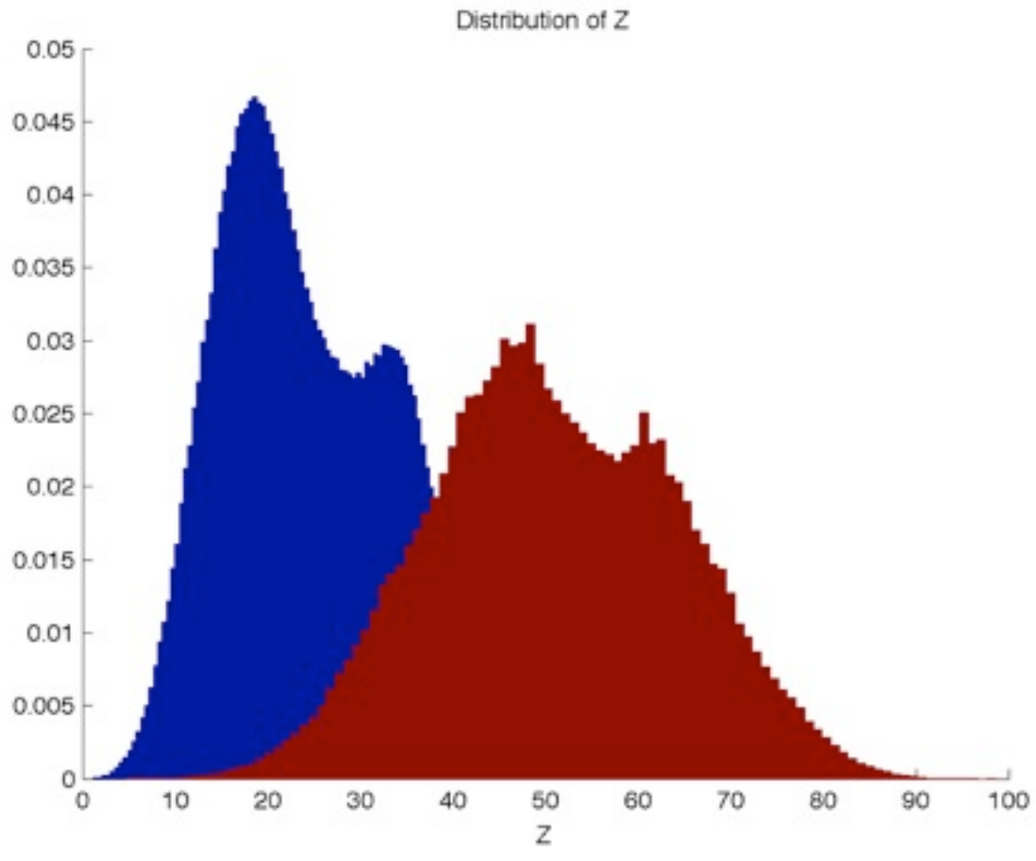

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1995, 2001, 2007.

June 4, 2007

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Predictions of climate

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Even if there were, the projections are based on model results that provide differences of the future climate relative to that today. None of the models used by IPCC are initialized to the observed state and none of the climate states in the models correspond even remotely to the current observed climate. In particular, the state of the oceans, sea ice, and soil moisture has no relationship to the observed state at any recent time in any of the IPCC models. There is neither an El Niño sequence nor any Pacific Decadal Oscillation that replicates the recent past; yet these are critical modes of variability that affect Pacific rim countries and beyond. The Atlantic Multidecadal Oscillation, that may depend on the thermohaline circulation and thus ocean currents in the Atlantic, is not set up to match today's state, but it is a critical component of the Atlantic hurricanes and it undoubtedly affects forecasts for the next decade from Brazil to Europe. Moreover, the starting climate state in several of the models may depart significantly from the real climate owing to model errors. I postulate that regional climate change is impossible to deal with properly unless the models are initialized.

The current projection method works to the extent it does because it utilizes differences from one time to another and the main model bias and systematic errors are thereby subtracted out. This assumes linearity. It works for global forced variations, but it can not work for many aspects of climate, especially those related to the water cycle. For instance, if the current state is one of drought then it is unlikely to get drier, but unrealistic model states and model biases can easily violate such constraints and project drier conditions. Of course one can initialize a climate model, but a biased model will immediately drift back to the model climate and the predicted trends will then be wrong. Therefore the problem of overcoming this shortcoming, and facing up to initializing climate models means not only obtaining sufficient reliable observations of all aspects of the climate system, but also overcoming model biases. So this is a major challenge.

The IPCC report makes it clear that there is a substantial future commitment to further climate change even if we could stabilize atmospheric concentrations of greenhouse gases. And the commitment is even greater given that the best we can realistically hope for in the near term is to perhaps stabilize emissions, which means increases in concentrations of long-lived greenhouse gases indefinitely into the future. Thus future climate change is guaranteed.

So if the science is settled, then what are we planning for and adapting to? A consensus has emerged that "warming of the climate system is unequivocal" to quote the 2007 IPCC Fourth Assessment Working Group I Summary for Policy Makers (pdf) and the science is convincing that humans are the cause. Hence mitigation of the problem: stopping or slowing greenhouse gas emissions into the atmosphere is essential. The science is clear in this respect.

However, the science is not done because we do not have reliable or regional predictions of climate. But we need them. Indeed it is an imperative! So the science is just beginning. Beginning, that is, to face up to the challenge of building a climate information system that tracks the current climate and the agents of change, that initializes models and makes predictions, and that provides useful climate information on many time scales regionally and tailored to many sectoral needs.

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Climate Analysis Section, NCAR

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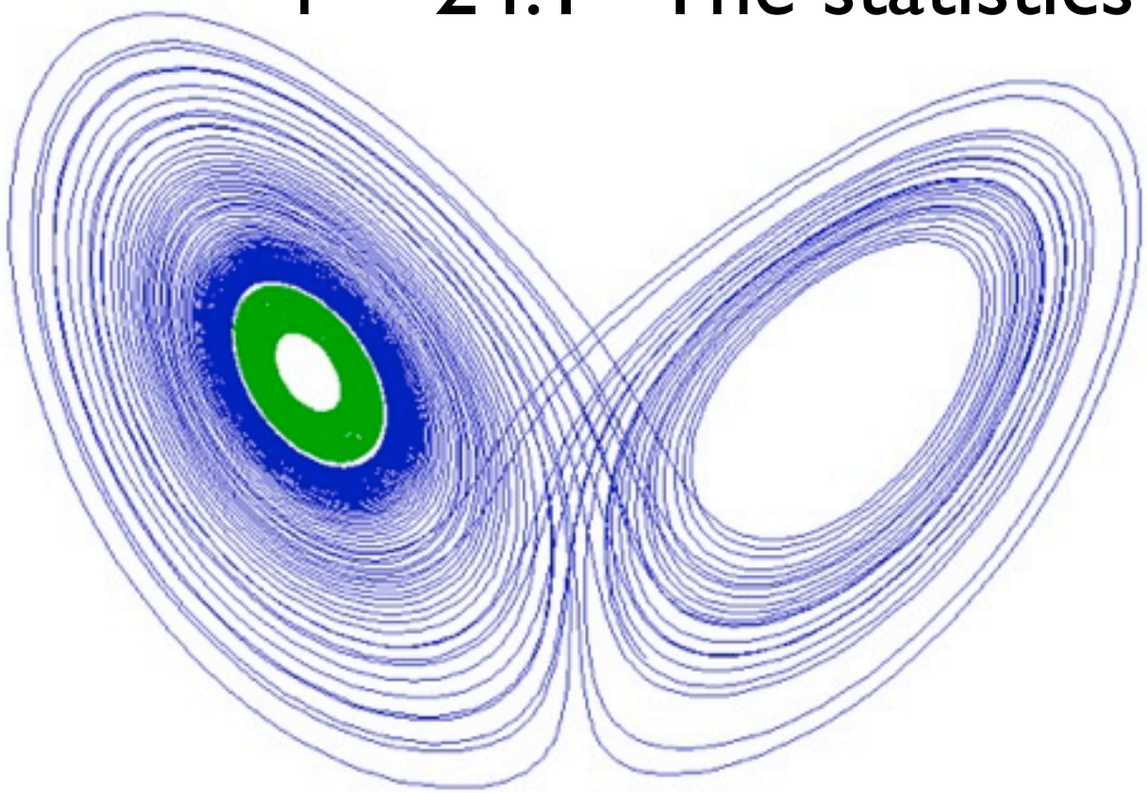
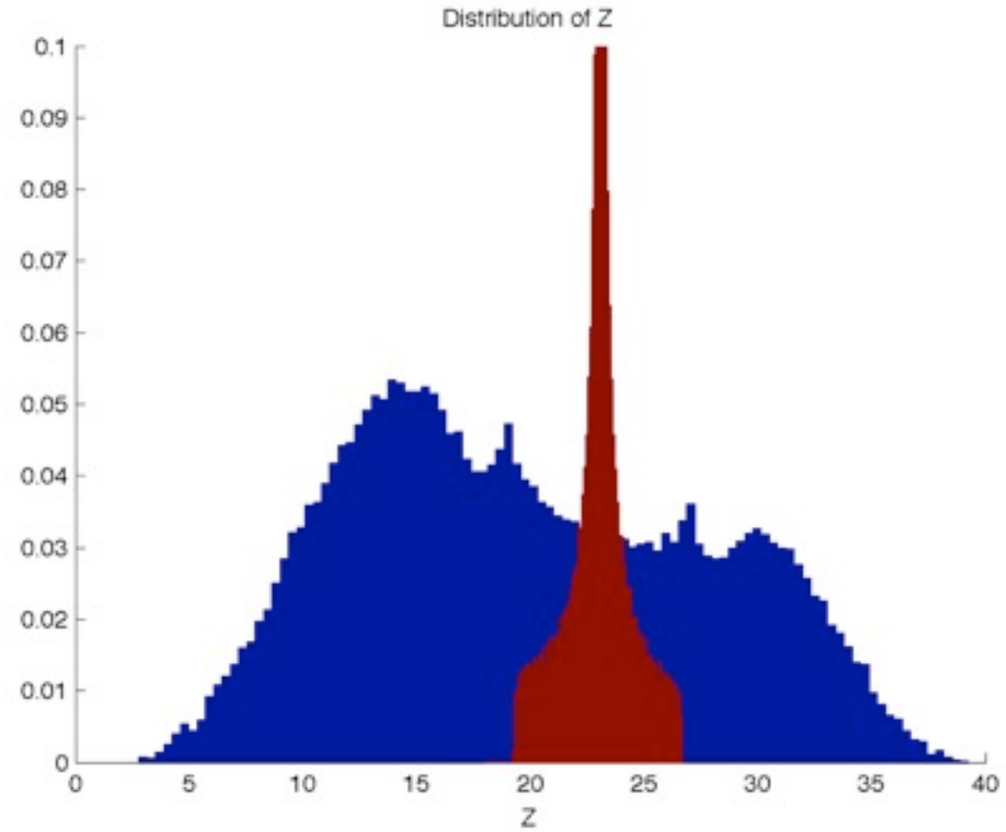
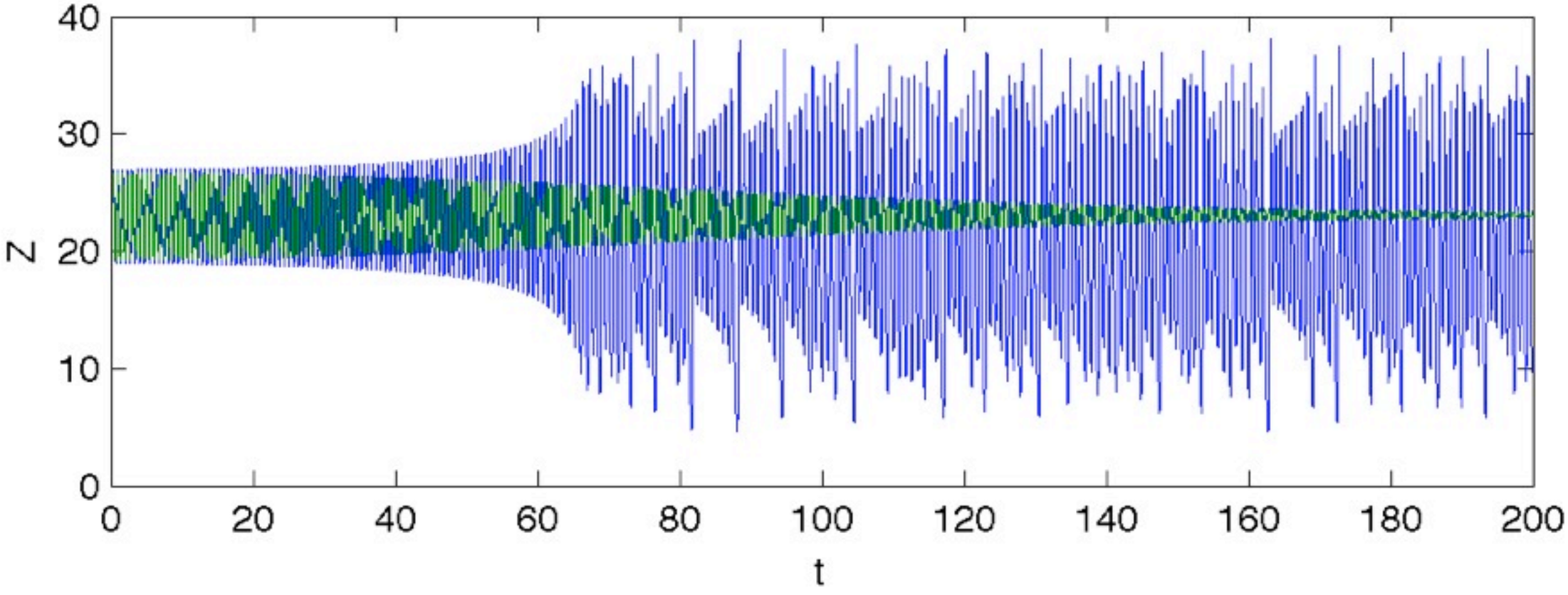
r = 24.1 The statistics depends on the initial condition







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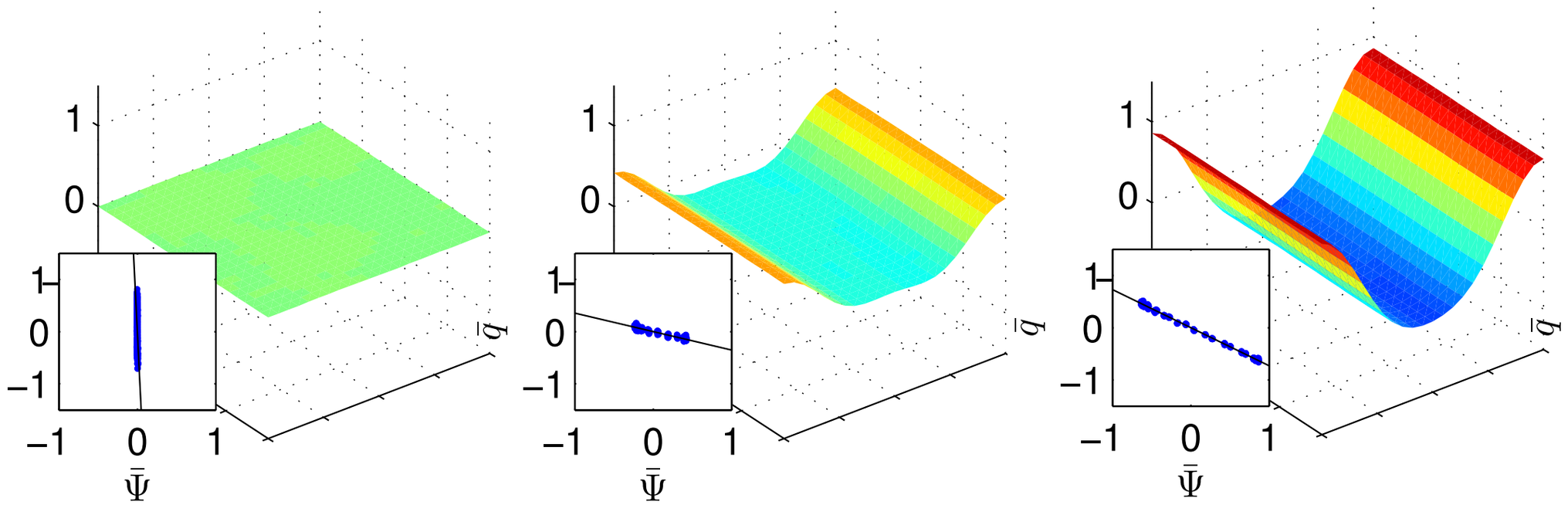
... Overcoming model biases

Energy law

Enstrophy law

Both



Mean pressure surface response to topography

“Those who have knowledge, don't predict. Those who predict, don't have knowledge” - Lao Tsu