

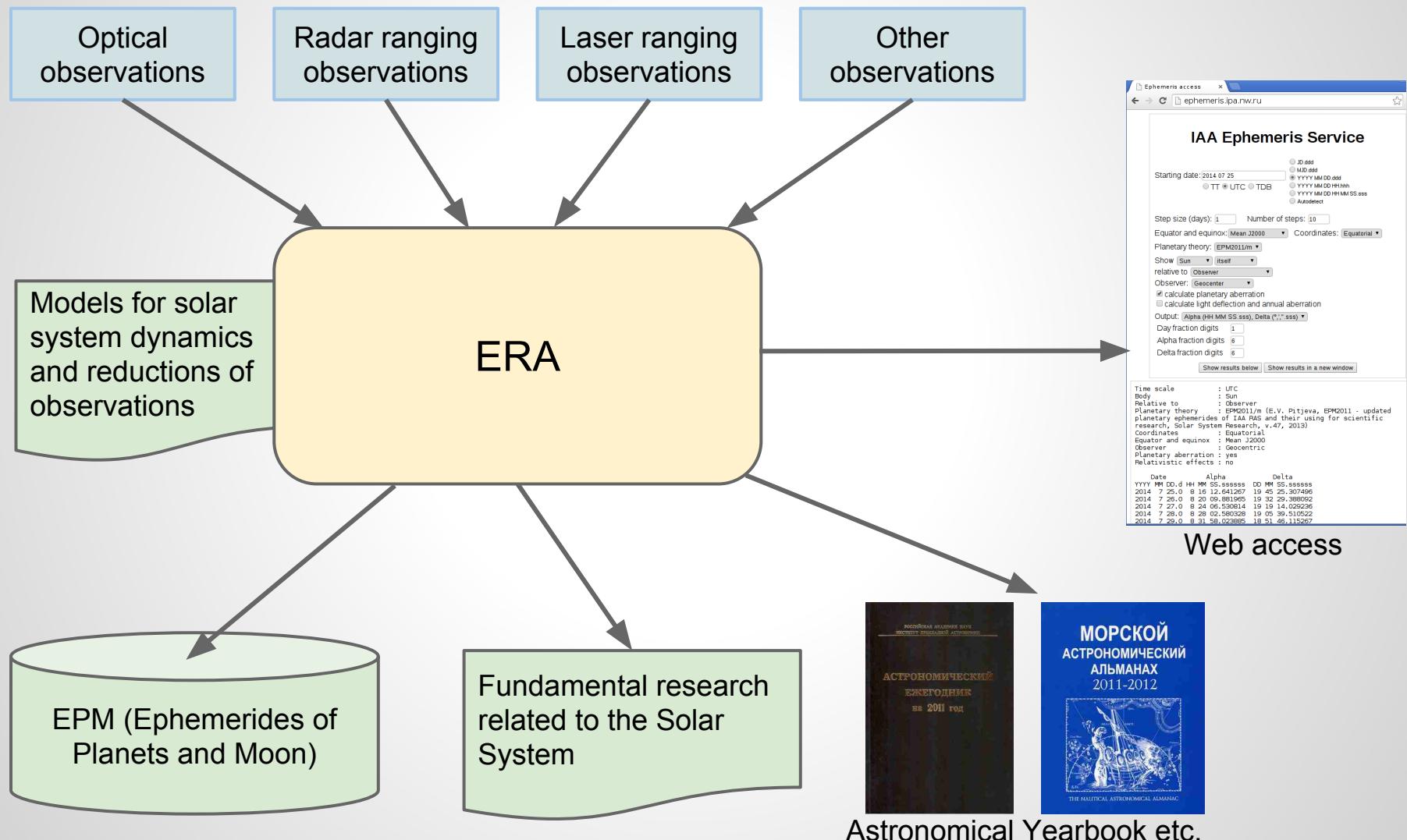
Rework of the ERA software system: ERA-8

D. Pavlov, V. Skripnichenko
Institute of Applied Astronomy RAS



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Pulkovo Observatory, St. Petersburg, Russia
24 September 2014

ERA: Ephemeris Research in Astronomy



Components of ERA

Integrated development environment (IDE): text editor, debugger, interactive prompt, graph plotter

```

File Edit View Language Racket Insert Tabs Help
ocassini.slon [define ...]
1:ocassini.slon [2: dsn-stations.slon] [3: obs-cassini.slon] [4: table-editor-main.rkt]

#lang slon
[!$m]cassini<= // file / "cassini" /* * / units / "m" //
[!$m]cassini<=
// observation_object, observer, time_scale, object_info,
ranging, Saturn_satellite, rectangular, utc, barycentric,
// cx, o_cx[0:1], dx, delx, dx[3], flag / *, *, -, 0, -, - // *
// SOLAR_CORONA, SOLAR_CORONA[1], wave_length / 0.0, 0.0, 0.0 // *
// x_site, y_site, z_site, x_site[2], y_site[2], z_site[2] /
// x_site, y_site, z_site, x_site[2], y_site[2], z_site[2] /
// theory, observer_theory / ".//theory-old/satnit7", ".//theory-old/
[observations]/cassini * 
[observations]/cassini begin o_cx = o_cx / m(1) only(date, o_cx) end "points";
> PLOT [!$m]/cassini begin o_cx = o_cx / m(1) only(date, o_cx) end "points";
read_table("data/dsn-stations" k[1], x_site, y_site, z_site, x_site[2],
x_site = km_to_distance(x_site + x_site[2]) * (DATE - fraday(20030101, 0),
y_site = km_to_distance(y_site + y_site[2]) * (DATE - fraday(20030101, 0),
z_site = km_to_distance(z_site + z_site[2]) * (DATE - fraday(20030101, 0,
if (date < fraday(20090917)) then
  dx = m(20)
else
  dx = m(60)
compute
read_table("data/obs-cassini" k[1], date, o_cx, dx, delx, cx[1:6], cx[13:18], cx[30], jx[1:6]
CX = CX(1, 0, 0, 0, 0, 0)
O_CX = OX - CX
write(1:3, " ", k[1], date:calend:16:6, " ", o_cx:m:10:3, " + ", dx:m:4
flag = abs(O_CX) > m(400)
if flag then
  write("#[deleted]")
writeln("")
select(#flag)
only(k[1], date, o_cx[0:1], dx, delx, cx[1:6], cx[13:18], cx[30], jx[1:6]
only(k[1], date, o_cx[0:1], dx, delx, cx[1:6], cx[13:18], cx[30], jx[1:6]
end;
> PLOT [!$m]/cassini begin o_cx = o_cx / m(1) only(date, o_cx) end "points";
Determine language from source

```

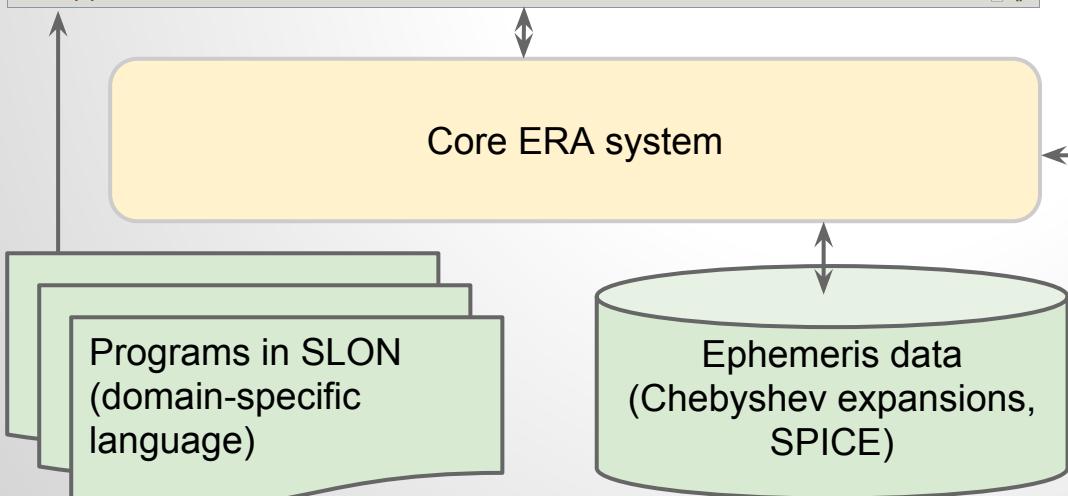


Table editor

1: OBJECT	2: km3_sec2(GM)	3: km(RADIUS)	4: K2	5: H2
1 SUN	132712440042.002	696000.000	0	0
2 MOON	4902.800	1737.400	0.025	-0.131
3 MERCURY	22031.855	2439.716	0	0
4 VENUS	324858.592	6049.805	0	0
5 MARS	42828.375	3392.384	0	0
6 JUPITER	126712764.798	71492.000	0	0
7 SATURN	37940585.199	60268.000	0	0
8 URANUS	5794548.600	25559.000	0	0
9 NEPTUNE	6836535.000	25269.000	0	0
10 PLUTO	971.799	1162.000	0	0
11 STAR	0.000	0.000	0	0
12 SATURN_SATELLITE	0.000	0.000	0	0
13 EARTH	398600.433	6378.136	0.300	0.609
14 PLANET	14.031	0.000	0	0
15 MARS_SATELLITE	0.000	0.000	0	0
16 PHOBOS	0.001	11.200	0	0
17 DEIMOS	0.000	6.100	0	0
18 IO	5930.158	1821.300	0	0
19 EUROPA	3193.162	1565.000	0	0
20 GANYMEDE	9883.596	2634.000	0	0
21 CALLISTO	7171.943	2403.000	0	0
22 EARTH_SATELLITE	0.000	0.000	0	0
23 LUNAR_SATELLITE	0.000	0.000	0	0
24 URANUS_SATELLITE	0.000	0.000	0	0

Table-organized observations and other data (SQLite)

Command-line interface for batch programs

```

dpavlov@dp:~/work/era/epa2014-1er95$ dpavlov@dp:~/work/era/epa2014-1er95$ racket octebib.slon
5 19900912 23099999 -0.0028 0.0014 -0.0033 0.0014 vev1117
5 19910812 18030000 -0.0028 0.0014 -0.0033 0.0014 vev1117
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Features of ERA

- System part
 - Compiler and IDE for the SLON language
 - Access to tabular astronomical data stored in plain text or internal binary formats
 - Math library including 80-bit extended precision floating point numbers
- Scientific part
 - Precession and nutation models, EOP, solid earth tides, plate motion
 - Time transformations, atmospheric refraction, relativistic effects
 - Models of natural satellites (TASS, GUST, etc) and rotation of planets
 - Numerical integrator by Gauss-Everhart algorithm (Avdushev, 2006)
 - Equations of solar system dynamics for: planets, Sun, Moon, lunar libration, minor planets, spacecraft, natural satellites, TT-TDB
 - Calculation of residuals (O-C) and partials by observations: optical, radar ranging, LLR, SLR, pseudorange, VLBI
 - Refinement of initial parameters and constants via the LSM

What has been reworked in ERA-8

- Source code rewritten from Pascal to: C for intensive calculations; Racket for logic, SLON language parser/compiler, and the GUI
- Racket's IDE DrRacket serves as IDE for ERA-8
- Portable across Windows/Linux, 32- and 64-bit
- Improved stability and diagnostics, revoked legacy limitations
- Table storage format has been changed to SQLite
- SLON language improved (new syntactic features, easier configuration)
- Acceptance of the international ephemeris file formats SPK (independent libraries for access: JPL SPICE, IMCCE Calceph)
- Unified access to all major ephemerides: EPM (IAA), DE (JPL), and INPOP (IMCCE)

Why Racket?

- Flexible programming language (dynamic typing, garbage collector, most advanced macro system, JIT compiler, interfacing to/from C)
- Most advanced tools for DSL creation
- Cross-platform
- Open-source (allowed us to implement 80-bit arithmetics, now in upstream)

Examples of ERA applications

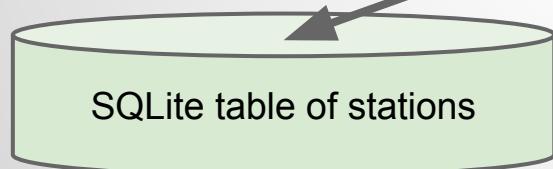
1. Correction of the orbit of Saturn by fitting to Cassini range measurements (2004-2014)
see *slides 7-13*

2. Checking the precision of the numerical integrator
see *slides 14-16*



Cassini ranging: reading DSN stations

DSN STATION COORDINATES							
Station locations used for planetary spacecraft tracking, with identifying numbers assigned by the NASA Deep Space Network.							
Locations are in ITRF 2005 reference frame at epoch 2003.0.							
#	x(m)	y(m)	z(m)	vx(m/yr)	vy(m/yr)	vz(m/yr)	
11	-2351429.1573	-4645078.8462	3673764.1469	-0.017	0.005	-0.005	
12*	-2350442.8774	-4651978.5701	3665629.1568	-0.017	0.005	-0.005	
12	-2350443.9994	-4651980.7901	3665630.9178	-0.017	0.005	-0.005	
13	-2351112.6524	-4655530.6640	3660912.7137	-0.017	0.005	-0.005	
14	-2353621.3873	-4641341.4492	3677052.2629	-0.017	0.005	-0.005	
15	-2353538.9453	-4641649.4462	3676669.9609	-0.017	0.005	-0.005	
16	-2354763.3193	-4646787.4121	3669386.9959	-0.017	0.005	-0.005	
17	-2354730.5183	-4646751.7261	3669440.5859	-0.017	0.005	-0.005	
23	-2354757.7273	-4646934.6251	3669270.7509	-0.017	0.005	-0.005	
24	-2354906.7043	-4646840.1231	3669242.3109	-0.017	0.005	-0.005	
25	-2355022.0073	-4646953.2321	3669040.5529	-0.017	0.005	-0.005	
26	-2354890.7903	-4647166.3561	3668871.7409	-0.017	0.005	-0.005	
27	-2349915.4204	-4656756.4340	3660096.4547	-0.017	0.005	-0.005	
28	-2350102.0104	-4656673.3970	3660103.5037	-0.017	0.005	-0.005	
33	-4461083.8842	2682281.7581	-3674569.9078	-0.035	0.000	0.045	
34	-4461147.1342	2682439.3011	-3674393.0678	-0.035	0.000	0.045	
41	-3978720.5639	3724850.9534	-3302171.0387	-0.034	0.000	0.045	
42	-4460981.3872	2682413.5301	-3674581.5874	-0.035	0.000	0.045	
43	-4460894.9092	2682361.5401	-3674748.0458	-0.035	0.000	0.045	
44	-4451074.3413	2676823.9203	-3691346.7139	-0.035	0.000	0.045	
45	-4460935.6092	2682765.7171	-3674380.9088	-0.035	0.000	0.045	
46	-4460828.9882	2682129.5691	-3674975.0228	-0.035	0.000	0.045	
49	-4554232.2327	2816758.9761	-3454035.5754	-0.035	0.000	0.045	
53	4849330.0413	-3603337.9005	4114758.8930	-0.007	0.019	0.011	
54	4849434.5133	-360723.9325	4114618.8160	-0.007	0.019	0.011	
55	4849525.2813	-360606.1255	4114495.0650	-0.007	0.019	0.011	

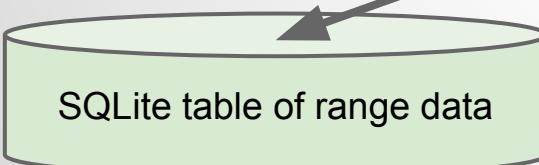


Cassini ranging: reading observations

Reduction of the round-trip light time requires knowledge of the position and velocity of the spacecraft with respect to the Saturn system barycenter. The spacecraft trajectories were estimated using radio Doppler data and on-board optical observations of the Saturnian satellites. The spacecraft position and velocity are given for each measurement at the TDB time to an integer number of microseconds near the time the signal transmitted by the DSN station was received by the spacecraft. The spacecraft position and velocity are given in Cartesian coordinates aligned with the ICRF axes.

Description of columns:

Bytes	Format	Units	Label	Explanations
1- 4	I4	---	yyyy	Year of measurement time (UTC)
6- 7	I2	---	mm	Month of measurement time (UTC)
9- 10	I2	---	dd	Day of measurement time (UTC)
12- 13	I2	h	hh	Hour of measurement time (UTC)
15- 16	I2	min	mm	Minute of measurement time (UTC)
18- 19	I2	sec	ss	Second of measurement time (UTC)
21- 22	I2	---	nsta	DSN station number
24- 43	F20.12	s	rttl	Round trip light time
45- 49	F5.2	us	Delay	Delay between arrival of the spacecraft signal at the station and the time of the measurement. TDB time of spacecraft position and velocity in second past the TDB epoch J2000.0
51- 70	F20.12	s	t2	X coordinate of Cassini spacecraft with respect to Saturn System Barycenter
72- 91	F20.12	km	x	Y coordinate of Cassini spacecraft with respect to Saturn System Barycenter
93-112	F20.12	km	y	Z coordinate of Cassini spacecraft with respect to Saturn System Barycenter
114-133	F20.12	km	z	X velocity of Cassini spacecraft with respect to Saturn System Barycenter
135-144	F10.6	km/s	vx	Y velocity of Cassini spacecraft with respect to Saturn System Barycenter
146-155	F10.6	km/s	vy	Z velocity of Cassini spacecraft with respect to Saturn System Barycenter
157-166	F10.6	km/s	vz	X velocity of Cassini spacecraft with respect to Saturn System Barycenter



```

obs-cassini.slon - DrRacket*
File Edit View Language Racket Insert Tabs Help
obs-cassini.slon ▾ (define ...) ▾ Debug Check Syntax Macro Stepper Run Stop
1: occassini.slon | 2: dsn-stations.slon ★ 3: obs-cassini.slon | 4: table-editor-main.rkt
#lang slon

{ Cassini data: http://iau-comm4.jpl.nasa.gov/plan-eph-data/cassini_range_av

[observations/cassini <=
(196 // date, ox, satellite_date, j[1:6], k[1], x[1:2],
 satellite_x[0:1], satellite_y[0:1], satellite_z[0:1] /
 , , , , , , , , - //)
begin
  readln("cassini-jul2014.txt", j[1]:4, j[2]:3, j[3]:3, j[4]:3, j[5]:3, j[6]
  ox:21, x[1]:6, x[2]:21, satellite_x:21, satellite_y:21, satellite
  satellite_z[1]:11, satellite_y[1]:11, satellite_z[1]:11)

date = fracday(j[1] * 10000 + j[2] * 100 + j[3])
date = date + j[4] / 24.0 + j[5] / (24.0 * 60) + j[6] / (24.0 * 3600)

satellite_date = MJD(51544.5) + x[2] / 86400.0

date = date - (x[1]/1000000)/86400.0
ox = ox - 2.0 * (x[1]/1000000)
ox = km_to_distance(ox * 299792.458)
satellite_x = km_to_distance(satellite_x)
satellite_y = km_to_distance(satellite_y)
satellite_z = km_to_distance(satellite_z)
satellite_x[1] = km_s_to_velocity(satellite_x[1])
satellite_y[1] = km_s_to_velocity(satellite_y[1])
satellite_z[1] = km_s_to_velocity(satellite_z[1])
only(date, ox, satellite_date, k[1], satellite_x[0:1], satellite_y[0:1], s
end.

Determine language from source▼ 8:0 206.31 MB □ ●

```

Cassini ranging: O-C and partials

occassini.slon - DrRacket

```

File Edit View Language Racket Insert Tabs Help
occassini.slon ▾ (define ...) ▾
1: occassini.slon | 2: dsn-stations.slon | 3: obs-cassini.slon | 4: table-editor-main.rkt
#lang slon

$$\begin{array}{llllll} 161 & 14 & 20121109.230543 & -139.432 & +- & 60.0 \text{ m} \\ 162 & 45 & 20121120.013941 & 9.119 & +- & 60.0 \text{ m} \\ 163 & 45 & 20121127.041856 & -17.786 & +- & 60.0 \text{ m} \\ 164 & 14 & 20130129.180440 & 31.916 & +- & 60.0 \text{ m} \\ 165 & 63 & 20130212.093554 & -24.199 & +- & 60.0 \text{ m} \\ 166 & 55 & 20130217.092923 & 113.501 & +- & 60.0 \text{ m} \\ 167 & 34 & 20130309.205543 & 26.378 & +- & 60.0 \text{ m} \\ 168 & 14 & 20130407.080939 & 1.372 & +- & 60.0 \text{ m} \\ 169 & 14 & 20130512.110903 & -33.384 & +- & 60.0 \text{ m} \\ 170 & 63 & 20130523.025501 & -52.767 & +- & 60.0 \text{ m} \\ 171 & 45 & 20130603.155140 & -55.295 & +- & 60.0 \text{ m} \\ 172 & 34 & 20130609.152251 & -71.454 & +- & 60.0 \text{ m} \\ 173 & 43 & 20130619.081949 & -75.112 & +- & 60.0 \text{ m} \\ 174 & 54 & 20130705.235355 & -100.246 & +- & 60.0 \text{ m} \\ 175 & 15 & 20130714.065060 & -59.720 & +- & 60.0 \text{ m} \\ 176 & 43 & 20130721.123805 & -85.553 & +- & 60.0 \text{ m} \\ 177 & 34 & 20130729.120509 & -98.920 & +- & 60.0 \text{ m} \\ 178 & 43 & 20130818.092529 & -92.626 & +- & 60.0 \text{ m} \\ 179 & 34 & 20130910.093559 & -21.461 & +- & 60.0 \text{ m} \\ 180 & 45 & 20130916.090720 & -55.581 & +- & 60.0 \text{ m} \\ 181 & 45 & 20130929.065952 & -37.040 & +- & 60.0 \text{ m} \\ 182 & 14 & 20131007.013545 & -43.094 & +- & 60.0 \text{ m} \\ 183 & 34 & 20131011.073604 & 174.963 & +- & 60.0 \text{ m} \\ 184 & 14 & 20131017.011142 & 69.292 & +- & 60.0 \text{ m} \\ 185 & 43 & 20131027.055244 & 105.255 & +- & 60.0 \text{ m} \\ 186 & 63 & 20131101.162258 & 219.540 & +- & 60.0 \text{ m} \\ 187 & 26 & 20131120.230718 & 95.735 & +- & 60.0 \text{ m} \\ 188 & 14 & 20131207.220545 & 84.432 & +- & 60.0 \text{ m} \\ 189 & 14 & 20131220.211843 & 57.770 & +- & 60.0 \text{ m} \\ 190 & 43 & 20131229.030654 & 87.781 & +- & 60.0 \text{ m} \\ 191 & 63 & 20140120.102155 & 95.264 & +- & 60.0 \text{ m} \\ 192 & 43 & 20140220.235317 & 95.704 & +- & 60.0 \text{ m} \\ 193 & 25 & 20140403.141816 & 127.411 & +- & 60.0 \text{ m} \\ 194 & 25 & 20140416.134548 & 72.169 & +- & 60.0 \text{ m} \\ 195 & 25 & 20140425.130536 & 61.682 & +- & 60.0 \text{ m} \\ 196 & 54 & 20140518.230520 & 45.262 & +- & 60.0 \text{ m} \end{array}$$

begin
read_table("data/dsn-stations", k[1], x_site, y_site, z_site, x_site[2],
x_site = km_to_distance(x_site + x_site[2] * (DATE - fracday(20030101.0)
y_site = km_to_distance(y_site + y_site[2] * (DATE - fracday(20030101.0)
z_site = km_to_distance(z_site + z_site[2] * (DATE - fracday(20030101.0)
if (date < fracday(20090917)) then
  dx = m(20)
else
  dx = m(60)
compute

read_table("parameters-old/AUREMlt7",1,dx[3])  {AU}
CX = CX*(1.0+2.0*dx[3])
O_CX = OX - CX
write(i:3, " ", k[1], date:calend:16:6, " ", o_cx:m:10:3, " +- ", dx:m:4
flag = abs(O_CX) > m(400)
if flag then
  write(" [deleted]")
writeln("")
select(#flag)
only(k[1], date, o_cx[0:1], dx, delx, cx[1:6], cx[13:18], cx[30], jx[1:6]
end;

```

Determine language from source ▾

16:32 206.31 MB

Already adjusted to the delay due to: solar plasma,
 Earth troposphere and ionosphere, and spacecraft transponder.
 Reductions made to account for: light delay, time transformations.

SQLite table of residuals and partials

Cassini ranging: LSM

Screenshot of DrRacket IDE showing Racket code for calculating corrections and formal errors for the six Lagrangian elements of Saturn.

```

#lang slon
params_u4 := // n / 265 / 266 / 267 / 268 / 269 / 270 //;
params_n1 := // n / 271 / 272 / 273 / 274 / 275 / 276 //;

[lsm/]params <= ;
[lsm/]params <= (params_earth +
  params_mars + params_mars_ext +
  params_vik1 + params_vik2 + params_pfnd + params_odys +
  params_venus +
  params_mercury + params_mercury_legendre +
  params_jupiter + params_j1 + params_j2 + params_j3 + params_j4 +
  params_saturn + params_s3 + params_s4 + params_s5 + params_s6 + params_s7 + params_s8 + params_s9 +
  params_urans + params_u1 + params_u2 + params_u3 + params_u4 +
  params_neptune + params_n1 +
  params_pluto +
  params_masses +
  params_corona +
  params_common
) * // dx[0:1] / - //;
:= // iterations,n_sigma / 3, 3 //

begin
lsm_processor lsm/names", "lsm/params", "lsm/corr", "lsm/rms")
end;

:= [lsm/]names
begin
writeln(&"result.txt", "File ", file:8, " before solving", "           File ", file:8, " after solving")
writeln(&"result.txt", " first parameter (" + units + ")")
if units = "arcs" then begin
  writeln(&"result.txt", " A = ", mean_o_c[0]:arcs:13:6, "           A = ", mean_o_c[1]:arcs:13:6)
  writeln(&"result.txt", " DA = ", d_mean_o_c[0]:arcs:13:6, "           DA = ", d_mean_o_c[1]:arcs:13:6)
  writeln(&"result.txt", " RMS = ", rms[0]:arcs:13:6, "           RMS = ", rms[1]:arcs:13:6)
end else begin if units = "m" then begin
  writeln(&"result.txt", " A = ", mean_o_c[0]:m:13:6, "           A = ", mean_o_c[1]:m:13:6)
  writeln(&"result.txt", " DA = ", d_mean_o_c[0]:m:13:6, "           DA = ", d_mean_o_c[1]:m:13:6)
  writeln(&"result.txt", " RMS = ", rms[0]:m:13:6, "           RMS = ", rms[1]:m:13:6)
end else begin if units = "mcs" then begin
  writeln(&"result.txt", " A = ", mean_o_c[0]:mcs:13:6, "           A = ", mean_o_c[1]:mcs:13:6)
  writeln(&"result.txt", " DA = ", d_mean_o_c[0]:mcs:13:6, "           DA = ", d_mean_o_c[1]:mcs:13:6)
  writeln(&"result.txt", " RMS = ", rms[0]:mcs:13:6, "           RMS = ", rms[1]:mcs:13:6)
end

```

Determine language from source ▾ 123:0 206.31 MB

Calculating corrections and formal errors for the six Lagrangian elements of Saturn

SQLLite table of corrections

Cassini ranging: applying the corrections

thenlt7b.slon - DrRacket

```

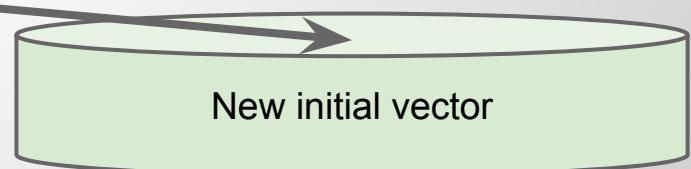
File Edit View Language Racket Insert Tabs Help
thenlt7b.slon (define ...) ▾ Debug Check Syntax Macro Stepper Run Stop
1: occassini.slon | 2: dsn-stations.slon | 3: obs-cassini.slon | 4: table-editor-main.rkt | 5: allnl7_conv.slon | 6: allnl7_lsm.slon | 7: thenlt7a.slon | 8: thenlt7b.slon
#lang slon
repeat
if l=1 then begin object=Mercury j=37 end
if l=2 then begin object=Venus j=31 end
if l=3 then begin object=Earth j=1 end
if l=4 then begin object=Mars j=7 end
if l=5 then begin object=Jupiter j=5 end
if l=6 then begin object=Saturn i=301 end
if l=7 then begin object=Uranus j=307 end
if l=8 then begin object=Neptune j=313 end
if l=9 then begin object=Pluto j=319 end
k=1
repeat
x[k]=x[1*6+k]-x[k+66]
cy[k]=cx[j-1+k]
k=k+1
until k=9
coordinates_to_elements(object,x[1:6],flag)
writeln("corrections.txt"," Keplerian elements of ",OBJECT:8," and correction for JD:",date)
writeln("corrections.txt"," Semimajor axis, ", X[1]:18:14," CY[1]=",CY[1]:m:10:3)
writeln("corrections.txt"," sin(I) * cos(omega) ", X[2]:18:14," CY[2]=",CY[2]*1000.0:arcs:10:5)
writeln("corrections.txt"," sin(I) * sin(omega) ", X[3]:18:14," CY[3]=",CY[3]*1000.0:arcs:10:5)
writeln("corrections.txt"," e * cos(p) ", X[4]:18:14," CY[4]=",CY[4]*1000.0:arcs:10:5)
writeln("corrections.txt"," e * sin(p) ", X[5]:18:14," CY[5]=",CY[5]*1000.0:arcs:10:5)
writeln("corrections.txt"," mean longitude ", X[6]:18:14," CY[6]=",CY[6]*1000.0:arcs:10:5)
x[1]=x[1]*(1+CY[1])
x[2]=x[2]+CY[2]
x[3]=x[3]+CY[3]
x[4]=x[4]+CY[4]
x[5]=x[5]+CY[5]
x[6]=x[6]+CY[6]
elements_to_coordinates(object,x[1:6],flag)
k=1
repeat
x[k]=x[k]+x[k+66]

```

resnl7d.sln Next Prev 1/60 Matches corrections.txt Replace Skip Hide Replace

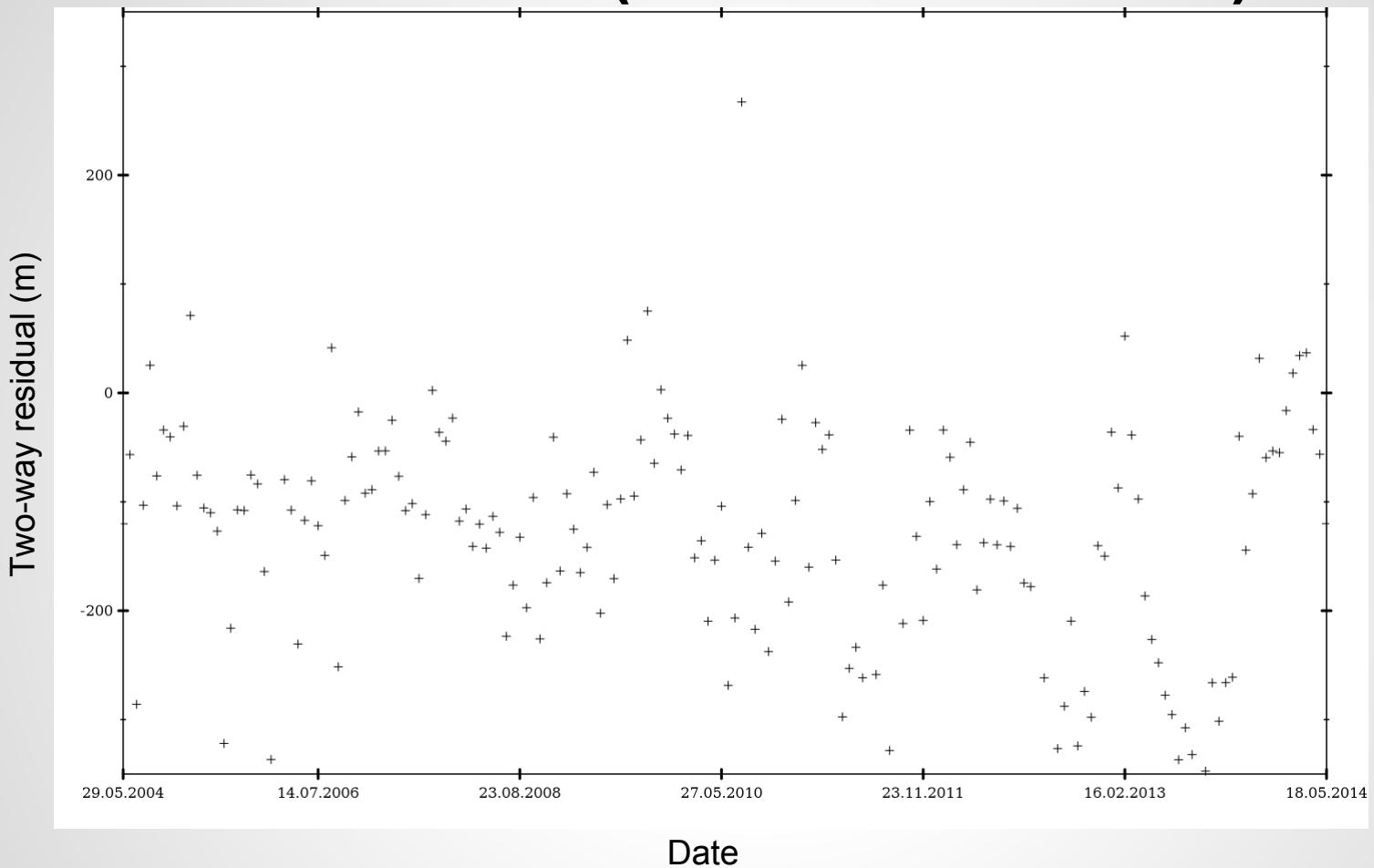
Determine language from source ▾ 35:0 206.31 MB

coordinates → elements;
 apply corrections to the elements;
 refined elements → refined coordinates.

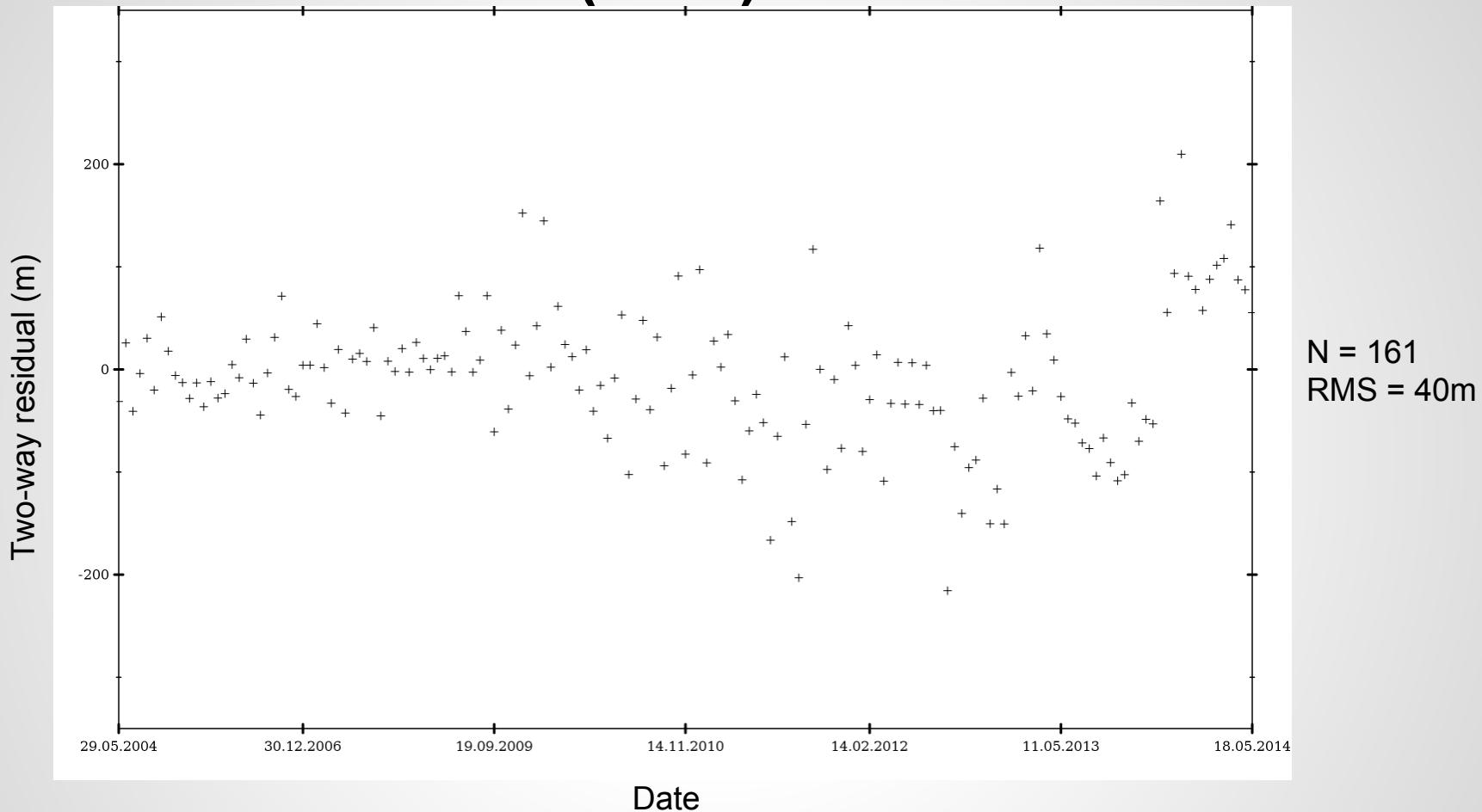


New initial vector

Cassini residuals (before correction)



Cassini residuals (final)



Ephemeris	Planet	a [m]	$\sin i \cos \Omega$ [mas]	$\sin i \sin \Omega$ [mas]	$e \cos \pi$ [mas]	$e \sin \pi$ [mas]	λ [mas]
EPM2004	Saturn	4222	3.237	4.085	3.858	2.975	3.474
EPM2008		12.026	0.09448	0.09246	0.00161	0.00135	0.02477
EPM2011		70.519	0.10792	0.12023	0.01093	0.00327	0.03434
EPM2013		67.973	0.09517	0.10313	0.01021	0.00276	0.02885
EPM2014		4.828	0.08065	0.05726	0.00097	0.00035	0.01239

source: Elena Pitjeva, "Evolution of ephemerides EPM of IAA RAS"

Two-way integration

integrator-precision.slon - DrRacket

```

File Edit View Language Racket Insert Tabs Help
integrator-precision.... ▾ (define ...) ▾ Check Syntax Macro Stepper Run Stop
8: epm2011-all-lter5/occassini.slon | simple-actors.rkt | plotting.rkt | 9: integrator-precision.slon
#lang slon

:// date_b,date_e, equations, time_scale, tolerance, integration_step /
// theory[1],subinterval[1], n_coefficients[1],
theory[2],subinterval[2], n_coefficients[2],
theory[3],subinterval[3], n_coefficients[3],
theory[4],subinterval[4], n_coefficients[4],
theory[5],subinterval[5], n_coefficients[5],
theory[6],subinterval[6], n_coefficients[6],
theory[7],subinterval[7], n_coefficients[7],
theory[8],subinterval[8], n_coefficients[8],
theory[9],subinterval[9], n_coefficients[9],
theory[10],subinterval[10], n_coefficients[10],
theory[11],subinterval[11], n_coefficients[11],
theory[12],subinterval[12], n_coefficients[12] /
"theory-new/libnlt7",      5.0, 15,
"theory-new/mernlt7",      5.0, 15,
"theory-new/vennl7",       5.0, 15,
"theory-new/earnl7",       5.0, 15,
"theory-new/marnl7",       5.0, 15,
"theory-new/jupnl7",       5.0, 15,
"theory-new/satnl7",       5.0, 15,
"theory-new/uranl7",       5.0, 15,
"theory-new/nepnl7",       5.0, 15,
"theory-new/plunl7",       5.0, 15,
"theory-new/moonl7",       4.0,
"theory-new/sunnl7",       15 //;
:=(totnl7 * integr * // cy) / 05.1, X 0 //;
begin
  date_b = date
  date_e = date + 36525 * 4
  integrator
    k = 0 repeat
      k = k + 1
      x[k] = cy[k]
    until k = 2058
  date = date_e
  k = 0 repeat
    k = k + 1
    theory[k] = theory[k] + "_back"
    writein(theory[k])
  until k = 12
  integrator

```

400 yrs

Forward

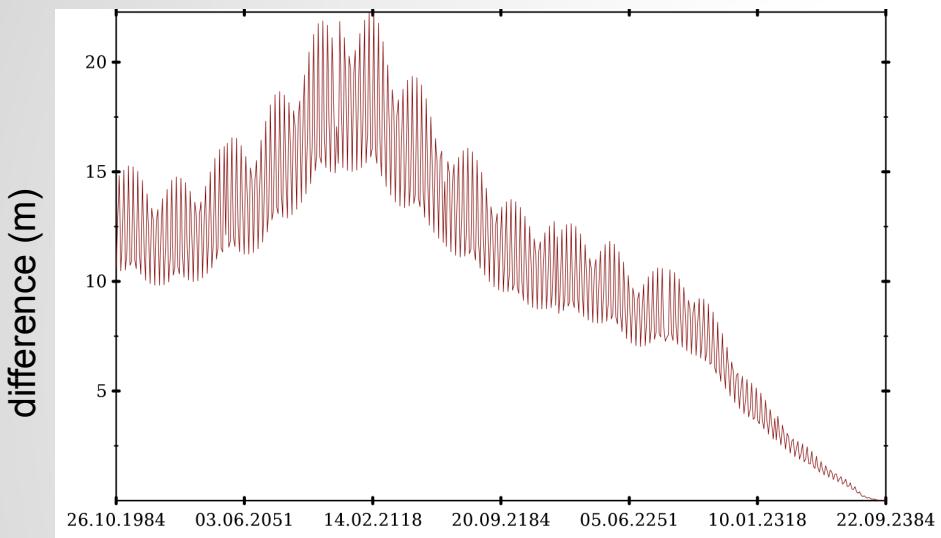
Backward

Determine language from source ▾ 17:42 206.31 MB

Idea:

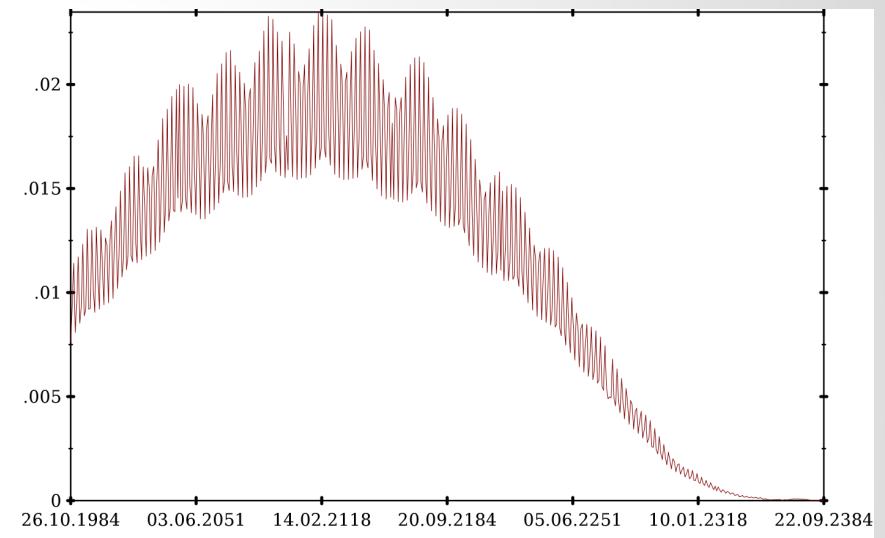
1. run the numerical integration for the timespan of 400 years;
2. save the state vector in the end;
3. run the numerical integration 400 years back (to the initial date);
4. calculate the difference between the resulting ephemeris (should be zero mathematically, non-zero difference gives an estimate of the integrator precision).

Results of two-way integration: Mercury



Date

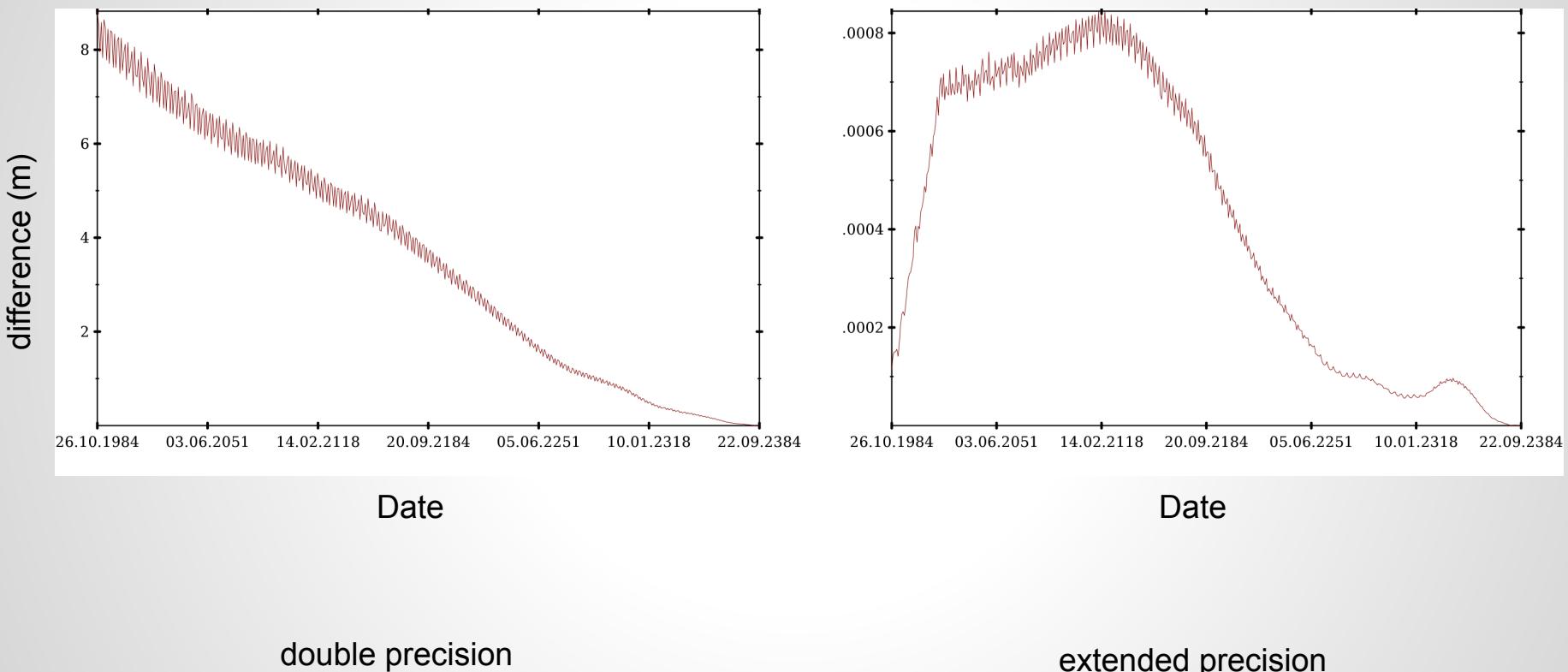
double precision



Date

extended precision

Results of two-way integration: Moon



Future plans

- Incorporation of the modern software libraries into ERA:
 - SOFA library
 - Numerical libraries?
- Incorporation of the newest models of solar system bodies:
 - GRACE (Earth gravitational potential)
 - GRAILS (Lunar gravitational potential)
- Release of EPM2014 ephemerides
- Extensibility for the users
- Public release with user documentation, including description of all underlying algorithms and reductions

For now:

- <ftp://quasar.ipa.nw.ru/incoming/EPM/> (EPM2011m ephemeris files)
- <http://ephemeris.ipa.nw.ru/> (interactive ephemerides calculation)

Thank you for your attention

Backup slides

Cassini range measurements

1. Read x/y/z positions and yearly trends of stations of the Deep Station Network
2. Read observations: UTC date, round trip time, position of the spacecraft w.r.t. Saturn system barycenter
3. Calculate residuals (O-C) and their partials w.r.t. Lagrangian orbital elements of Earth and Saturn on epoch T_0
4. Put the residuals and partials into a system of conditional equations
5. Solve the system with LSM, get the corrections for orbital elements
6. Apply the corrections
7. Re-integrate the Solar system in the time span from T_0 to observations' time
8. Repeat from step 3 until the residuals stabilize.