SPACE MANIFOLD DYNAMICS: THE PRAGMATIC POINT OF VIEW

Ettore Perozzi

Telespazio, Roma (Italy)

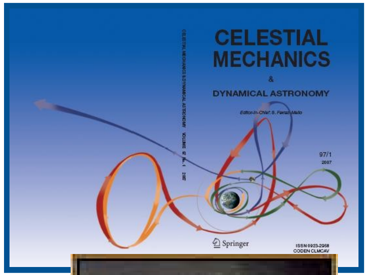
Workshop on Stability and Instabilit
Mechanical Systems
Barcellona, 1-5 December 2008

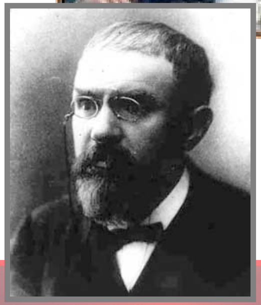
SPACE OPS ACADEMY
flight dynamics
and ground system
management

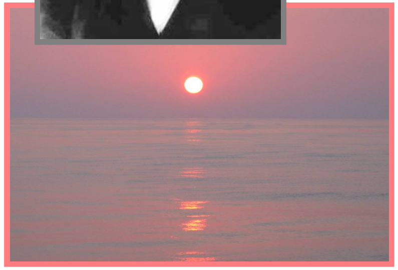
TELESPAZIO
A Finmeccanica / Thales Company

Being Pragmatic: Kaguya HDTV

contents







- **SMD - Space Manifold Dynamics**
  - back to the roots
  - from ISEE-3 to SOHO
  - Where do we go from here?
- **Tisserand and SMD**
  - temporary satellite capture of comets
  - ballistic capture
- **The Accessibility of the Moon**
  - Hohmann vs SMD
  - STK modelling
- **Case studies**
  - Lunar Eploration issues
  - Lagrangian surface drifters

The terminology “*Space Manifold Dynamics*” (SMD) is adopted for referring to the dynamical systems approach to spaceflight dynamics, thus encompassing more specific definitions (stable/unstable manifolds, lagrange trajectories, weak stability boundary, etc.);

There is the need of establishing a ***strong and continuous link*** among the research, the industrial communities and the space agencies, even at a basic level (e.g. regular organization of workshops and schools).

CELESTIAL MECHANICS

H. Poincaré : *Les Methodes Nouvelles de la Mechanique Celeste* (pag 82, section 36, Chapter III) 1889

↓

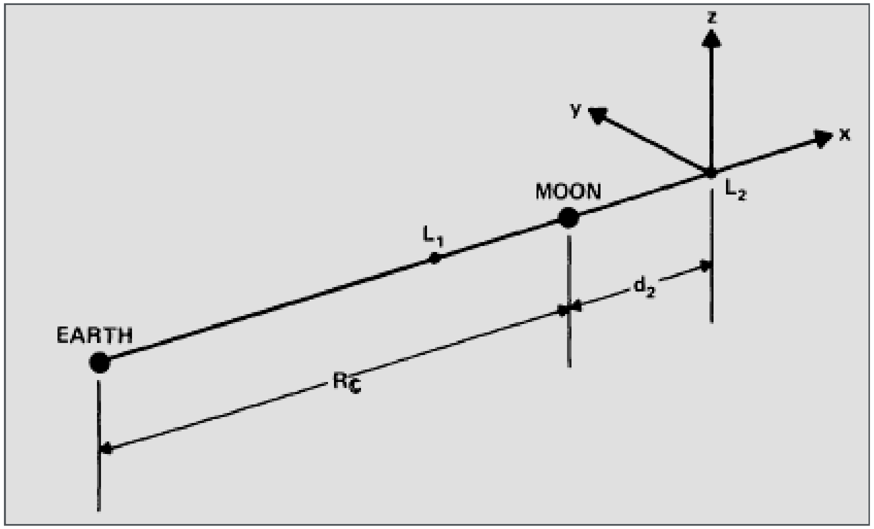
That which makes periodic solutions so valuable is that they are, so to speak, the only breach through which we can attempt to penetrate what was previously thought impregnable.

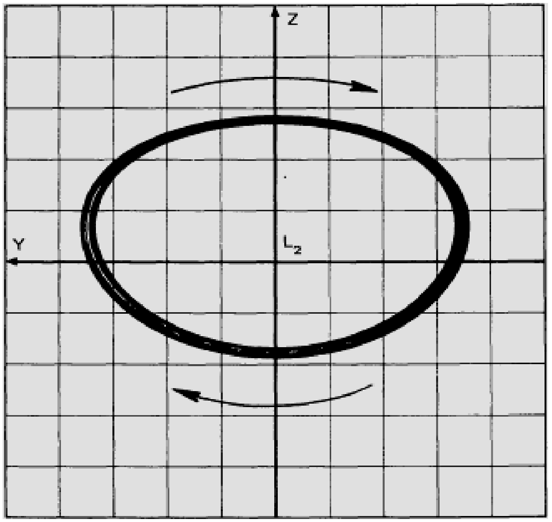
ASTRODYNAMICS

R.W. Farquhar & A. A. Kamel. *Quasi-periodic Orbits about the Translunar Libration Point*. Cel Mech 7, 1972

CELESTIAL MECHANICS

H. Poincaré : *Les Methodes Nouvelles de la Mechanique Celeste* (pag 82, section 36, Chapter III) 1889





ASTRODYNAMICS

R.W. Farquhar & A.A. Kamel. *Quasi-periodic Orbits about the translunar libration point*, Cel. Mech 7, 1972

CELESTIAL MECHANICS

H. Poincaré: *Les Methodes Nouvelles de la Mechanique Celeste* (pag 82, section 36, Chapter III) 1889

C.C. Conley: : Low Energy Transit Orbit in the Restricted Three-Body Problem. SIAM J Appl. Math, 16, 4, 1968.

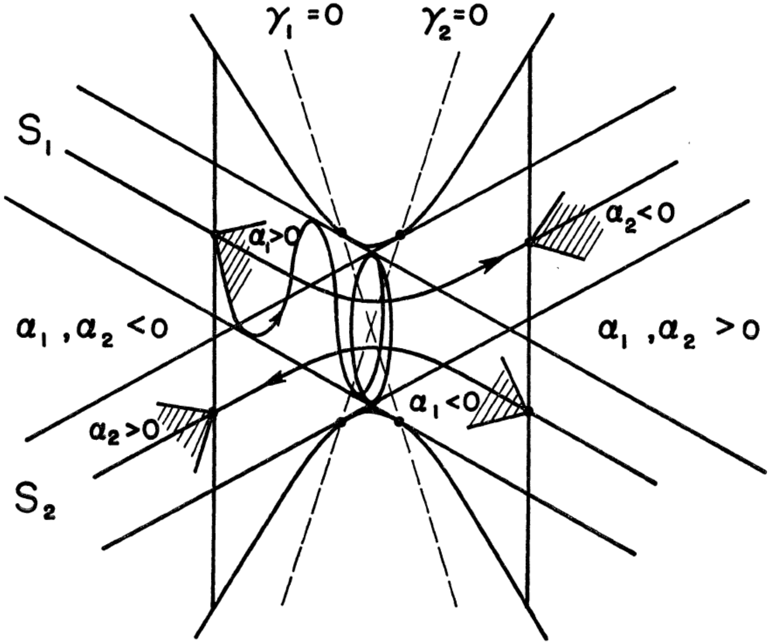


FIG. 1. *The flow in the equilibrium region. Shown are the periodic orbit, a typical asymptotic orbit (coming from the boundary of a wedge) and the two optimal crossing orbits.*

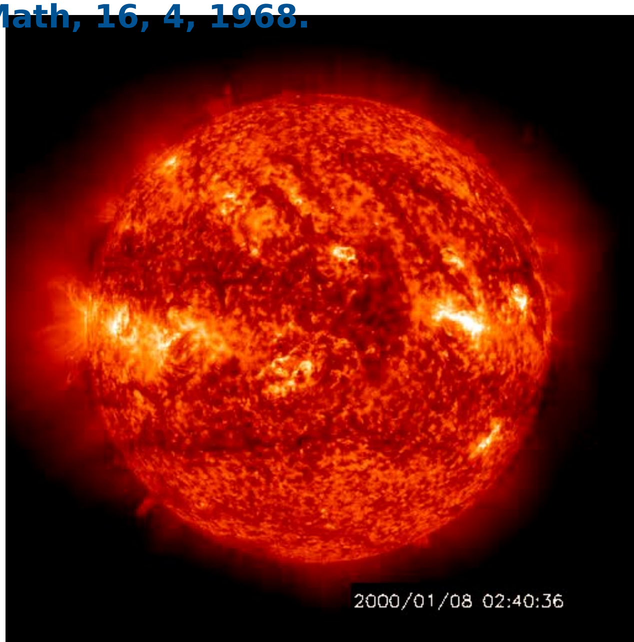
ASTRODYNAMICS

R.W. Farquhar & A.A. Kamel. *Quasi-periodic Orbits about the translunar libration point*. Cel. Mech. 7, 1972..

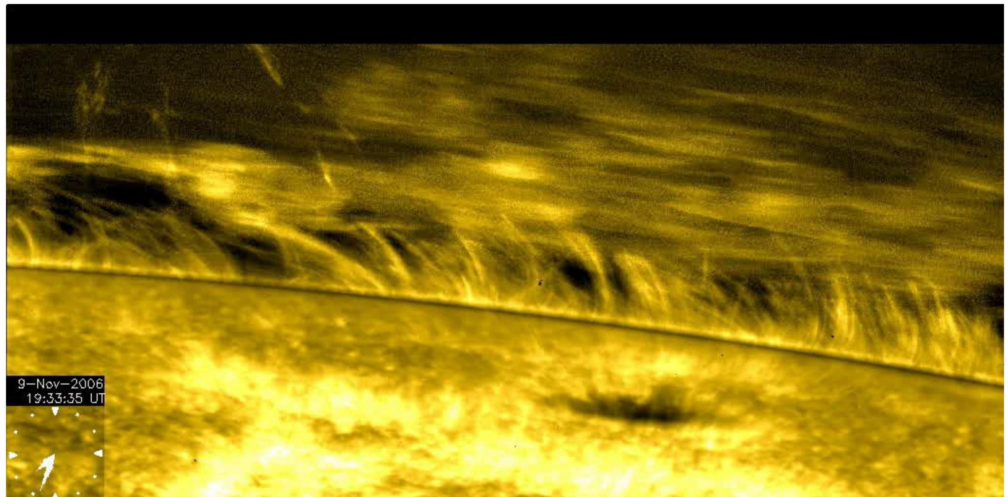
CELESTIAL MECHANICS

H. Poincaré: *Les Methodes Nouvelles de la Mechanique Celeste* (pag 82, section 36, Chapter III) 1889

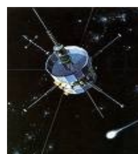
C.C. Conley: *Low Energy Transit Orbit in the Restricted Three-Body Problem*. SIAM J Appl. Math, 16, 4, 1968.



SOHO



HINODE



ISEE-3

↑ **ASTRODYNAMICS**

D.L. Richardson: A *Note on a Lagrangian Formulation for Motion around the Collinear Points*. Cel. Mech. 22, 1980.

R.W. Farquhar & A.A. Kamel. *Quasi-periodic Orbits about the translunar libration point*. Cel. Mech. 7, 1972..

Space Manifold Dynamics

Simo'. Gomez, Masdemont, Jorba Llibre,,
Marchal *et al.*

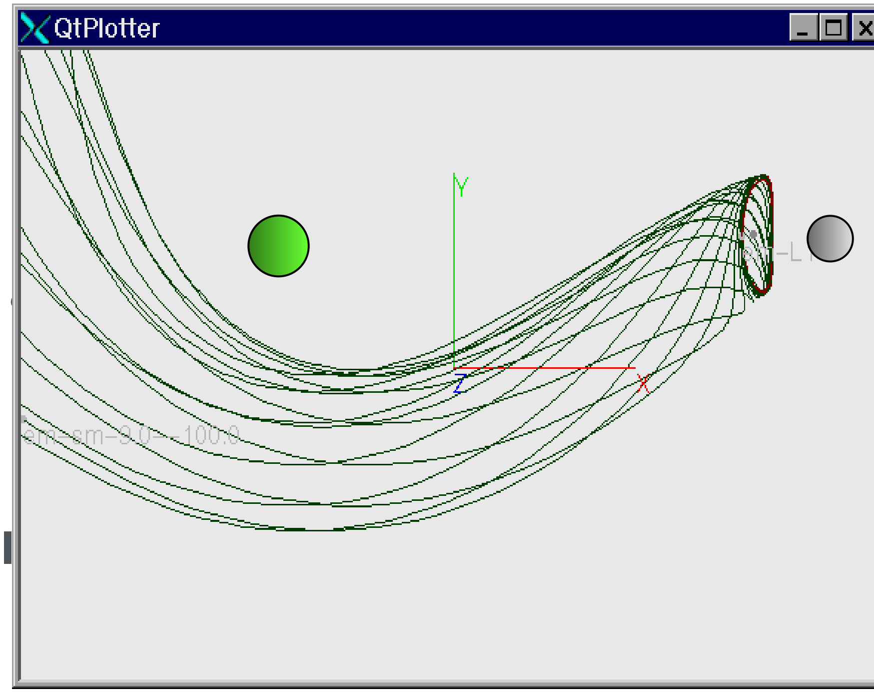
stable/unstable manifolds

halo orbits, lissajous orbits

Belbruno, Miller, Carrico, Teofilatto *et*

weak stability boundary (WSB)
ballistic capture

Lo, Ross, Marsden, Parker, Campagnol
lagrangian trajectories
interplanetay superhighways



Exploiting stability / instability

Where do we go from here?

- **EL1 EL2 mission profiles well established for scientific missions**
- **Exploration missions?**
- **BepiColombo ballistic capture / outer planets satellite tour design**
- **Moon? Mars?** *(the Vision for Solar System Exploration)*
- **Innovation is not always welcome** *(safety and cost of operations)*
- **Communication problems** *(needs different thinking)*
- **Merging scientific and technological constraints/requirements is a key issue**
- **ESA ITT “Interplanetary Trajectory Design”**

Exploration missions

TELESPAZIO
A Finmeccanica / Thales Company

LOW ENERGY TRANSIT ORBITS IN THE RESTRICTED THREE-BODY PROBLEM*

C. C. CONLEY†

CELESTIAL MECHANICS

The specific interest here is the behavior of orbits near those three critical points corresponding to the collinear Lagrangian points and particularly those orbits whose Jacobi constant is just above that of the critical point.

The second purpose is to outline a scheme for designing low-energy earth-moon orbits. Numerical work on this problem has been initiated and will be described in a later paper; for the present only the general scheme is described (§4).

ASTRODYNAMICS

SIAM J. Appl. Math.
Vol. 16, No. 4, July 1968

Tisserand and SMD

In the R3BP Sun-Jupiter-Comet when far from close encounters the Jacobian integral reduces to the so-called Tisserand invariant, which (in normalized units) can be expressed as:

$$T = \frac{1}{a} + 2\sqrt{a(1-e^2)}\cos i$$

This quantity is related to the unperturbed relative velocity of a comet (in units of the orbital velocity of the planet) at close encounter with Jupiter

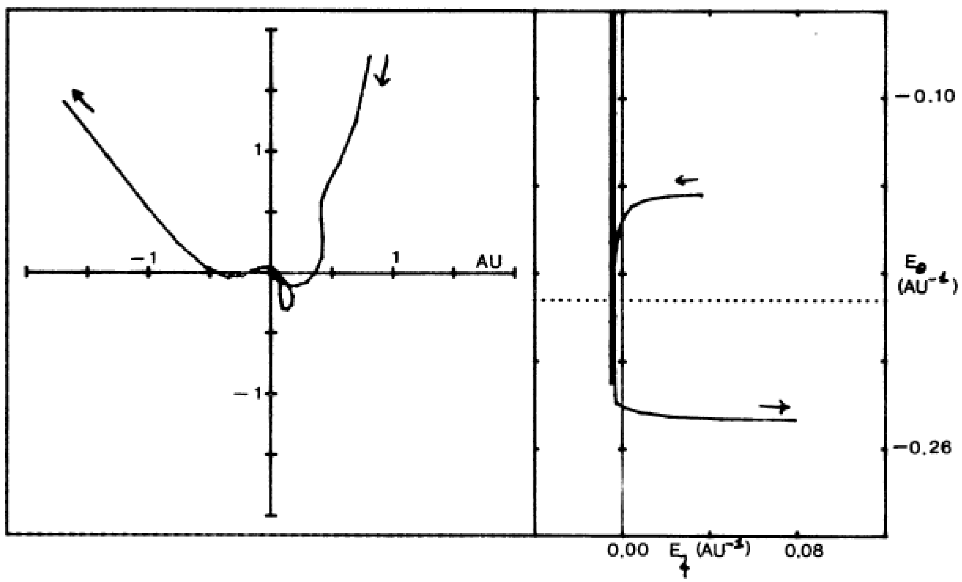
$$U = \sqrt{3-T}$$

Õpik, E.J.: 1976, "Interplanetary Encounters: Close Range Gravitational Interactions", Elsevier, New York, p. 23.

JACOBIAN INTEGRAL AS A CLASSIFICATIONAL AND EVOLUTIONARY PARAMETER OF INTERPLANETARY BODIES
Ľ. Kresák, Astronomical Institute of the Slovak Academy of Sciences, Bratislava Vol. 23 (1972), No. 1

CELESTIAL MECHANICS: temporary satellite capture of comets T > 2.9

Chebotarev (1964), Kazmirchak-Polonskaya (1972), Everhart (1973), Rickman (1979), Carusi & Valsecchi (198[illegible])

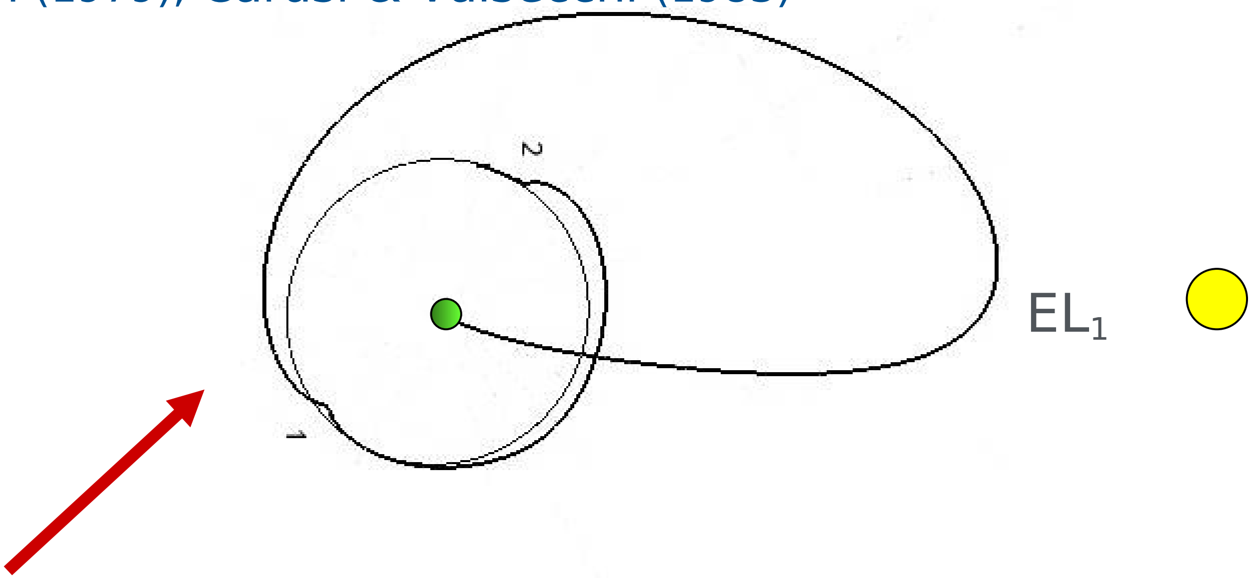


ASTRODYNAMICS: lunar ballistic capture T = 2.95

Belbruno & Miller (1990), Parker (2006)

CELESTIAL MECHANICS: temporary satellite capture of comets T > 2.9

Chebotarev (1964), Kazmirchak-Polonskaya (1972), Everhart (1973), Rickman (1979), Carusi & Valsecchi (1983)

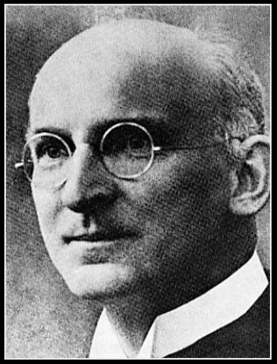


ASTRODYNAMICS: lunar ballistic capture T = 2.95

Belbruno & Miller (1990), Parker (2006)

Accessibility

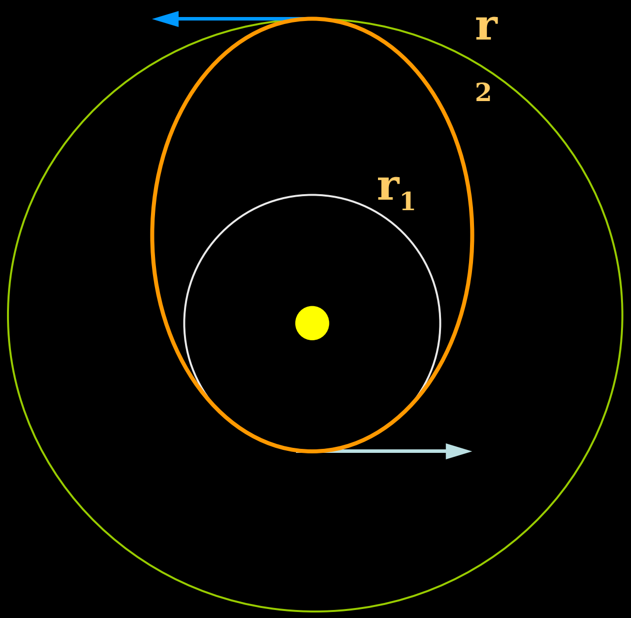
In his book **DIE ERREICHBARKEIT DER HIMMELSKORPER** *(The Attainability of Celestial Bodies),* published in 1925, Walter Hohmann gives the basis of interplanetary travelling.



Here he introduces the concept of **ΔV** change in velocity of a spacecraft as a measure of **accessibility**

$$\Delta V1 = \mu^{1/2} \left[\left(2/r_1 - 1/a \right)^{1/2} - \left(1/r_1 \right)^{1/2} \right]$$

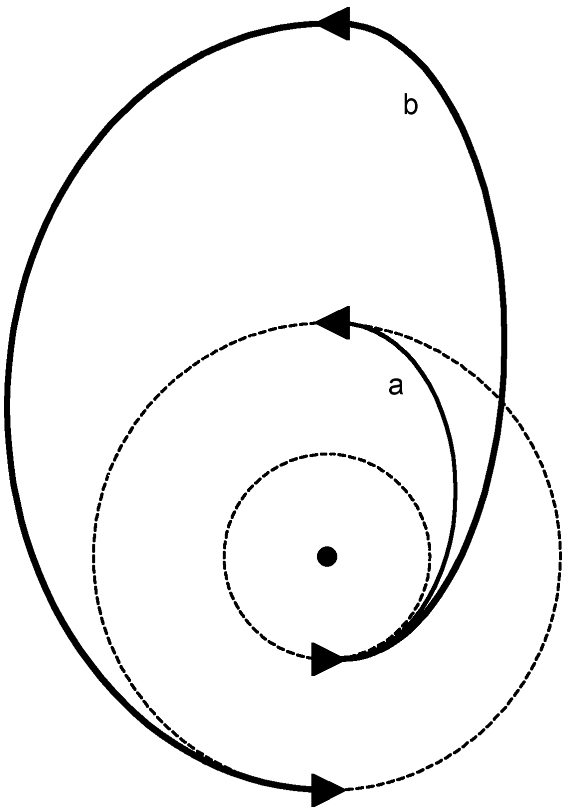
$$\Delta V2 = \mu^{1/2} \left[\left(1/r_2 \right)^{1/2} - \left(2/r_2 - 1/a \right)^{1/2} \right]$$



astronautical progress was the discovery of a new use for an old object: the ellipse."

W.I.McLaughlin: 'Walter Hohmann's Roads in Space', JSMA 2, 2000.

Hohmann vs Bi-elliptic

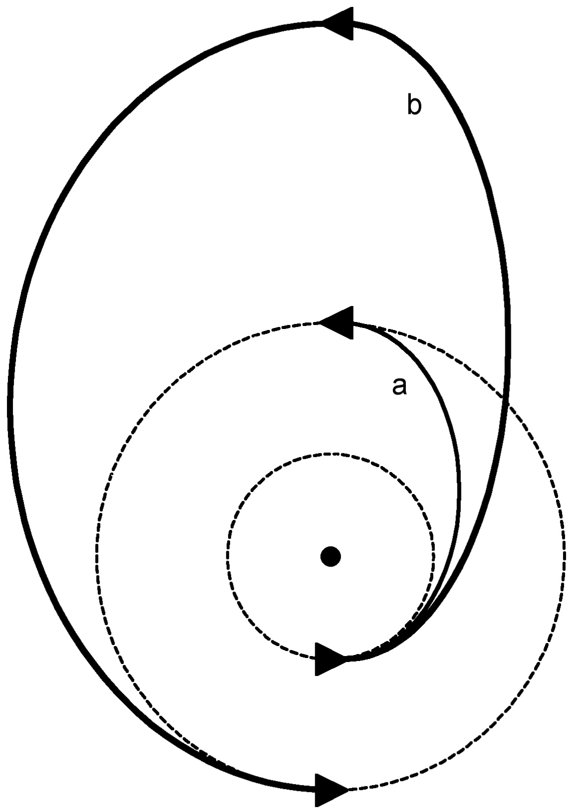


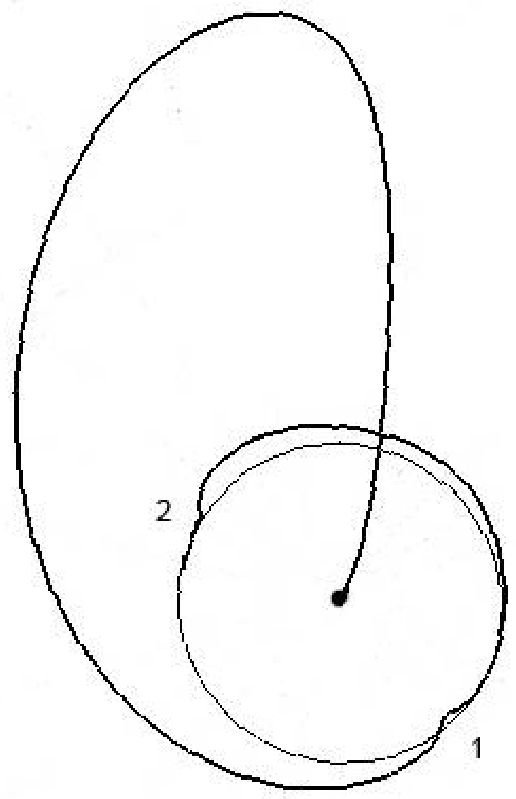
- the Hohmann transfer represents an **optimal** strategy only if the ratio between the radius of the target and that of the departure orbits is less than 11.94.

- Exceeding this value the choice of a suitable **bi-elliptic** transfer is more convenient, while if $\mathbf{r_2=r_1>15:58}$ any bi-elliptic transfer is favourable in terms of ΔV expenditure

- A bi-elliptic transfer is a three-impulse strategy which foresees an intermediate orbit with an apocenter distance larger than the target orbit, and this implies **long transfer times**

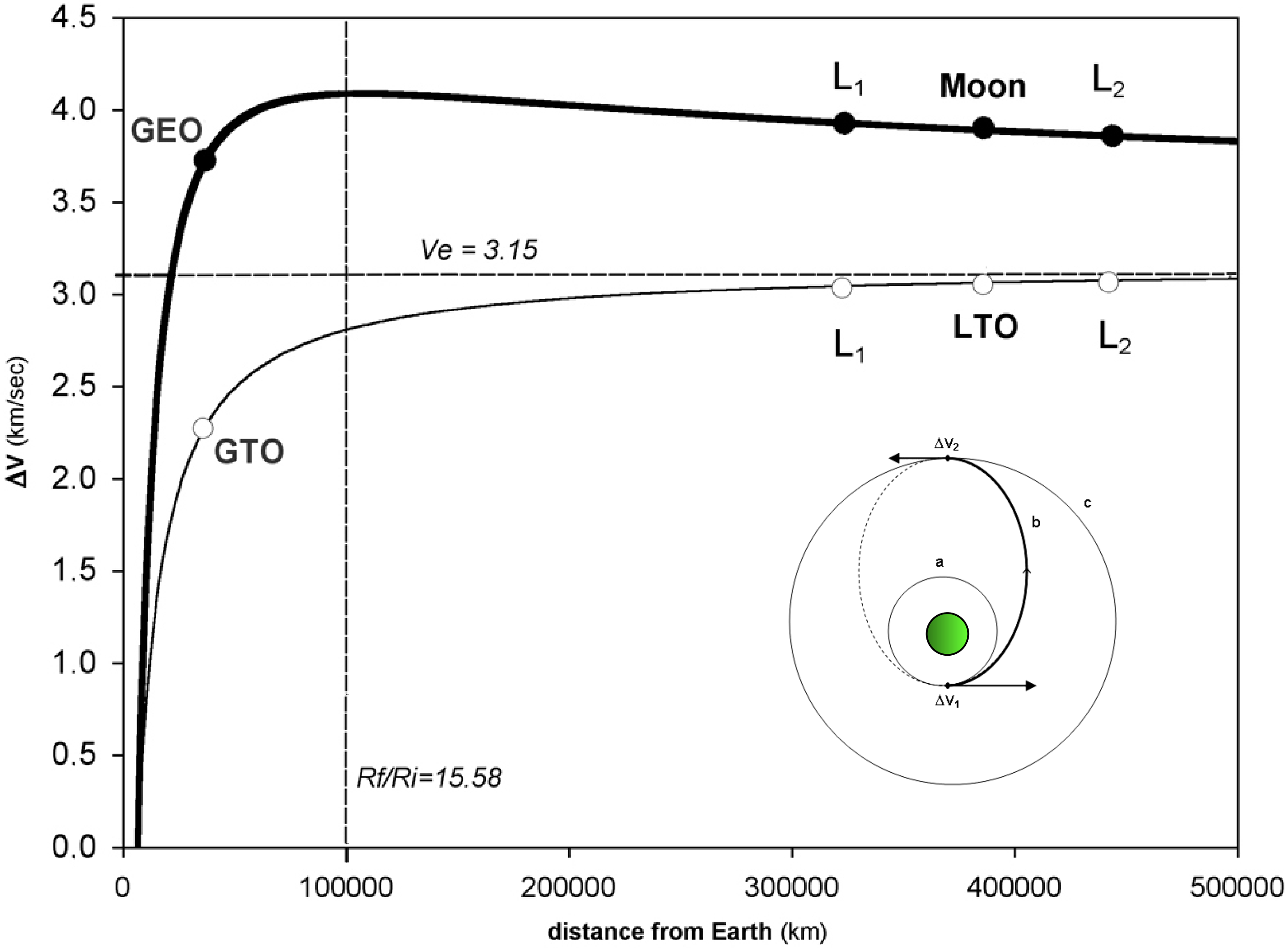
Bi-elliptic vs WSB



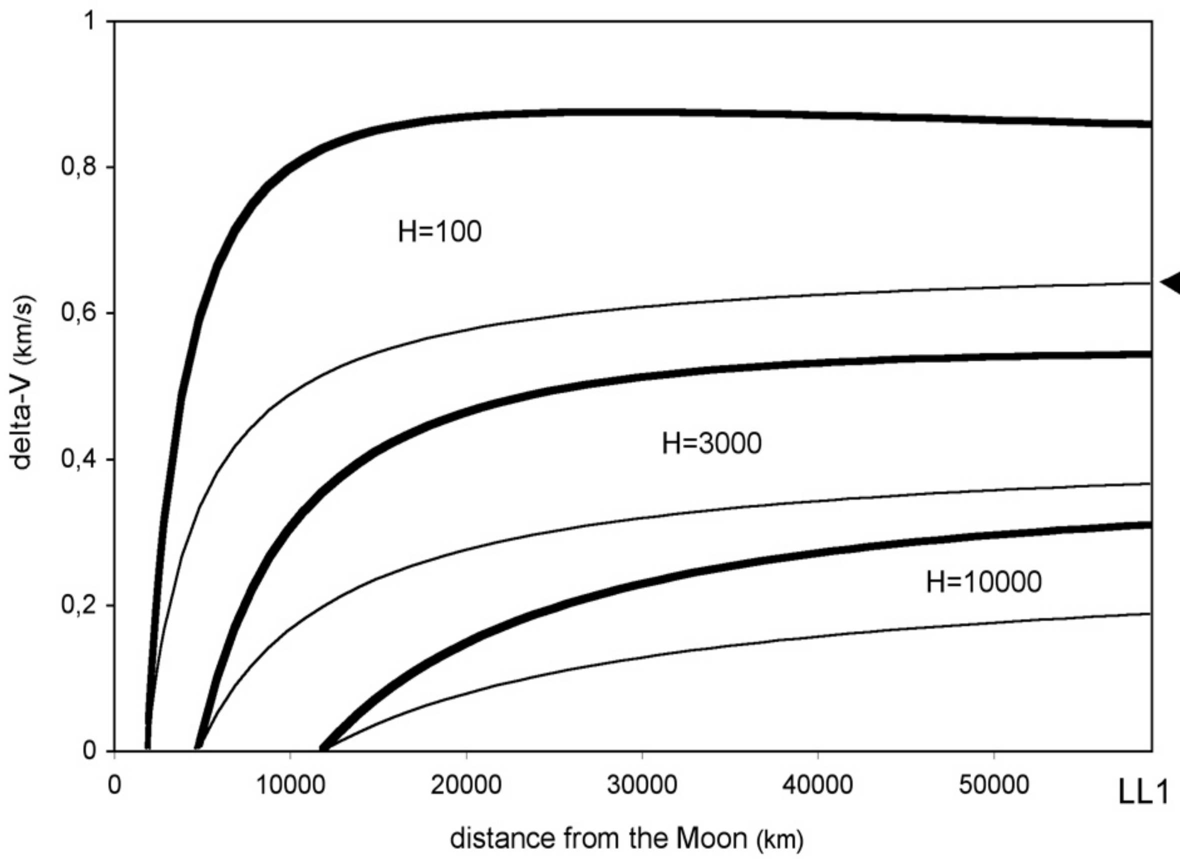


rozzi and A. Di Salvo: ***Novel Spaceways for Reaching the Moon: an Assessment for Exploration.*** **Cel Mech Dyn Astr 102, 207–218 (2**

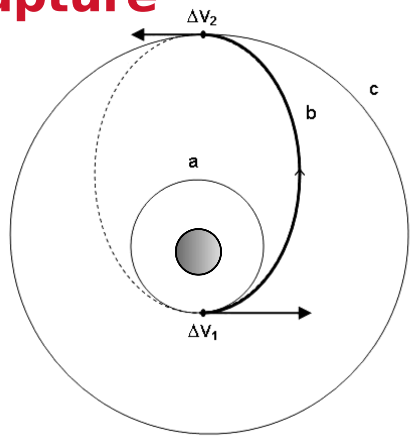
Earth centered H-plot



Moon centered H-plot

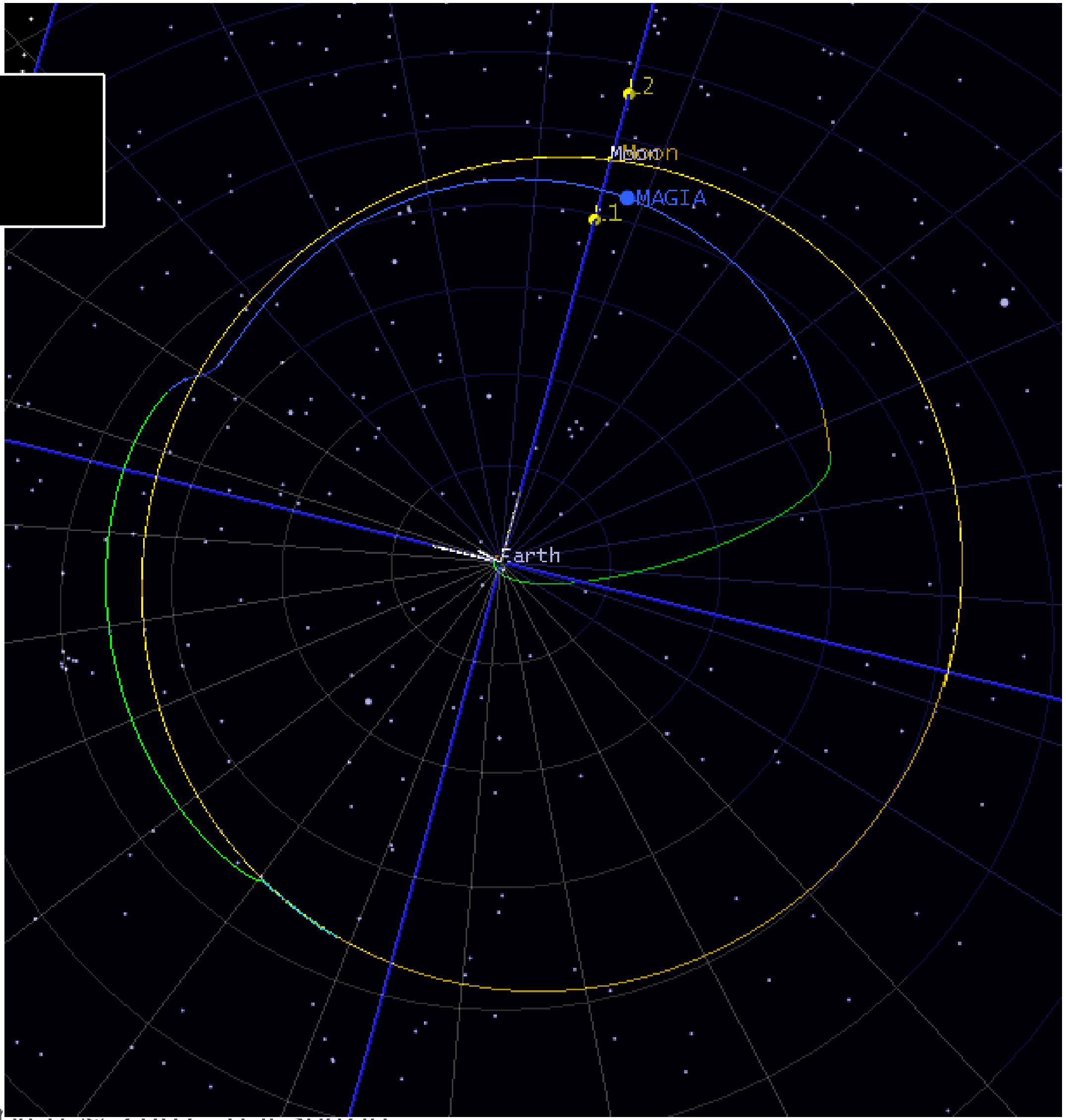


ballistic capture



STK modelling

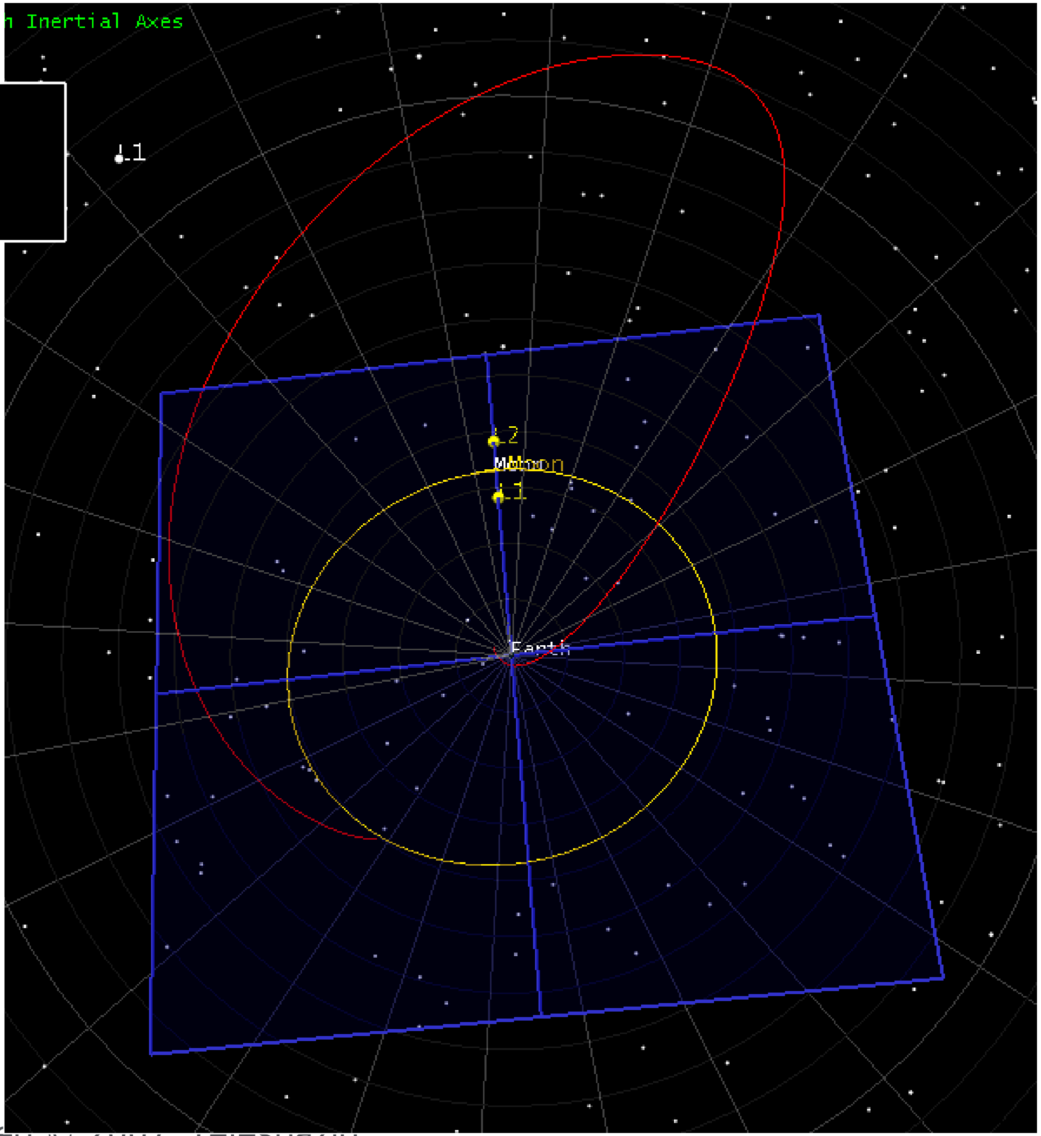
SMD internal



Satellite ToolKit (STK) is a commercial software for near-Earth mission design, recently upgraded to treat interplanetary mission analysis.

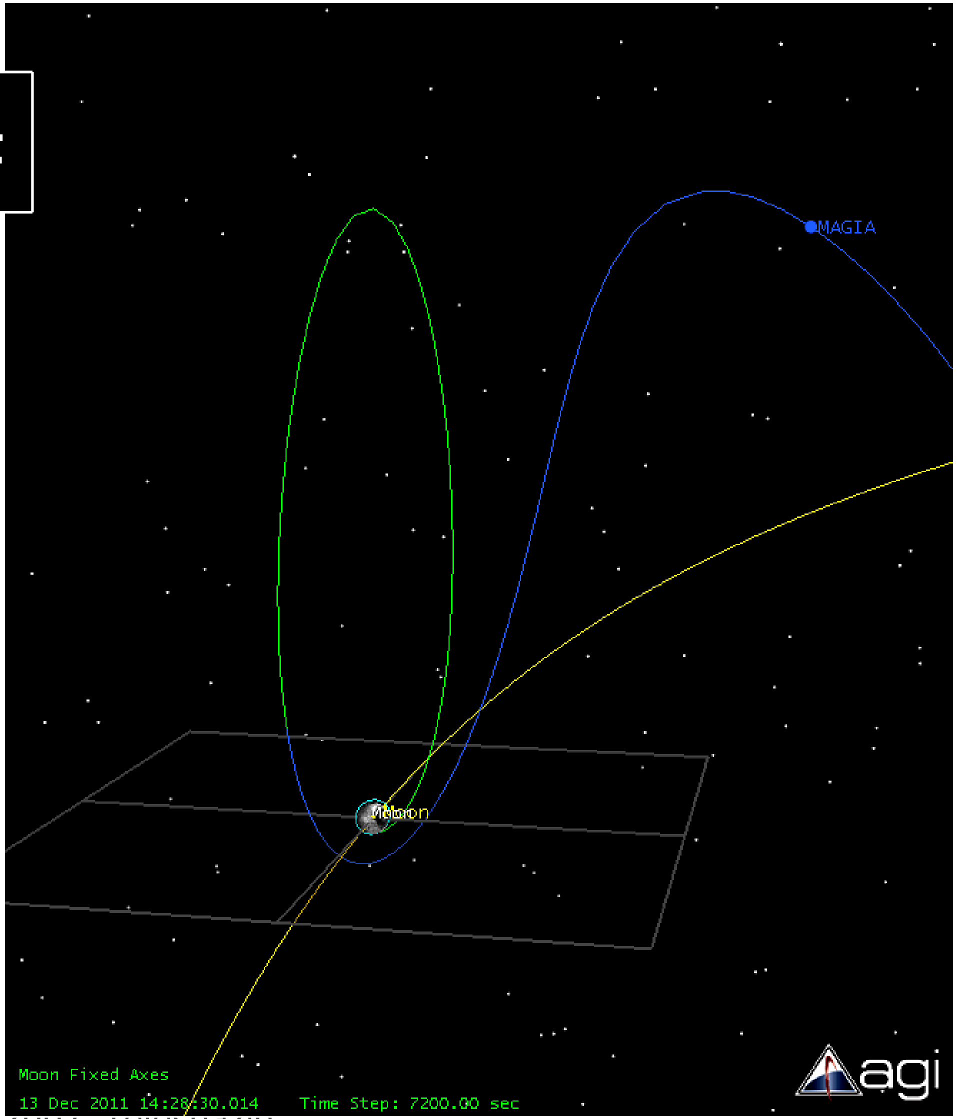
STK modelling

SMD external



STK modelling

ballistic capture event



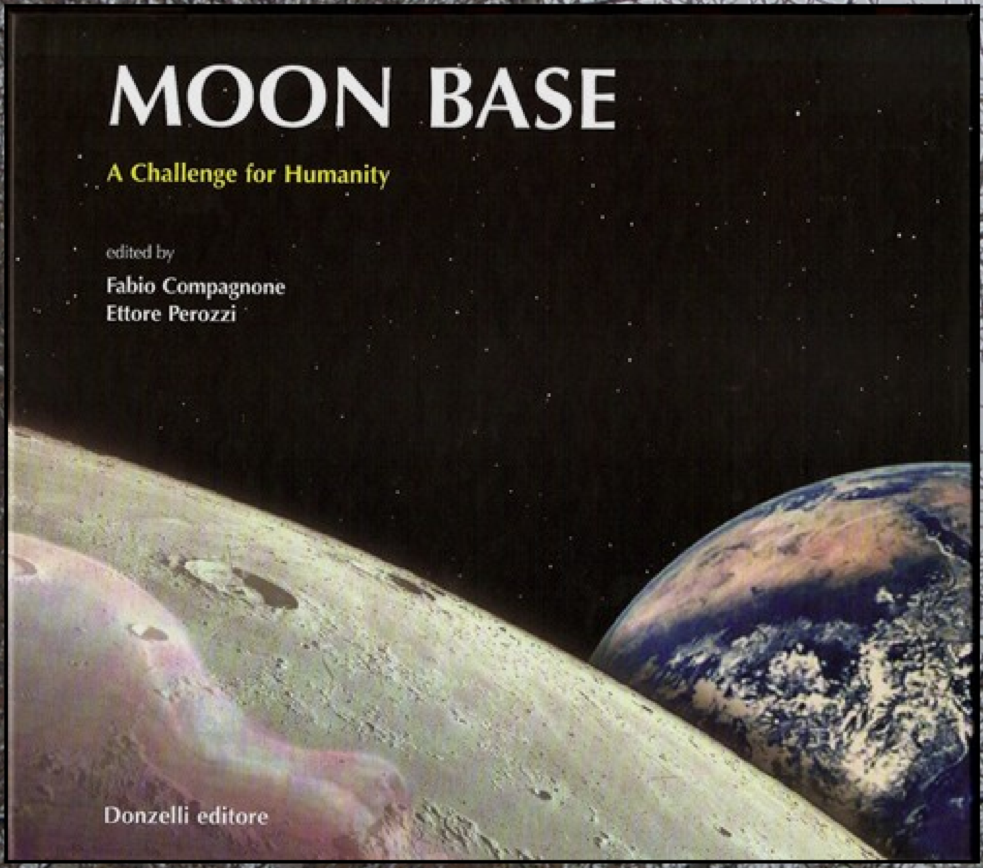
MAGIA study

Hohmann	SMD internal	SMD external
Transfer Time: 4 days	Transfer Time: 18 days	Transfer Time: 90 days
Total delta-V = 3.9 km/s	Total delta-V = 4.2 km/s	Total delta-V = 3.8 km/s
2 manoeuvres: TLI, LOI	3 manoeuvres: BOI, TLI, LOI	2 manoeuvres: TLI, LOI
TLI=3.1; **LOI=0.8**	BOI=2.9; TLI=0.7; **LOI=0.0**; NOI=0.6	TLI=3.2; **LOI=0.0**; NOI=0.6
Elliptic trajectory (high LOI)	BLT trajectory (low LOI)	WSB trajectory (low LOI)
LOI critical	Ballistic Capture (LOI non-critical)	Ballistic Capture (LOI non-critical)
consolidated guidance	innovative guidance	innovative guidance
Needs quick reaction time	Allows slow reaction time	Allows slow reaction time
-	Possible E-M cruise science	Possible E-M-S cruise
Apollo-like	Science & Exploration precursor	Science & Exploration precursor

=Trans Lunar Injection; BOI = Bridging Orbit Insertion; LOI = Lunar Orbit Insertion; NOI = Nominal Orbit Insertion

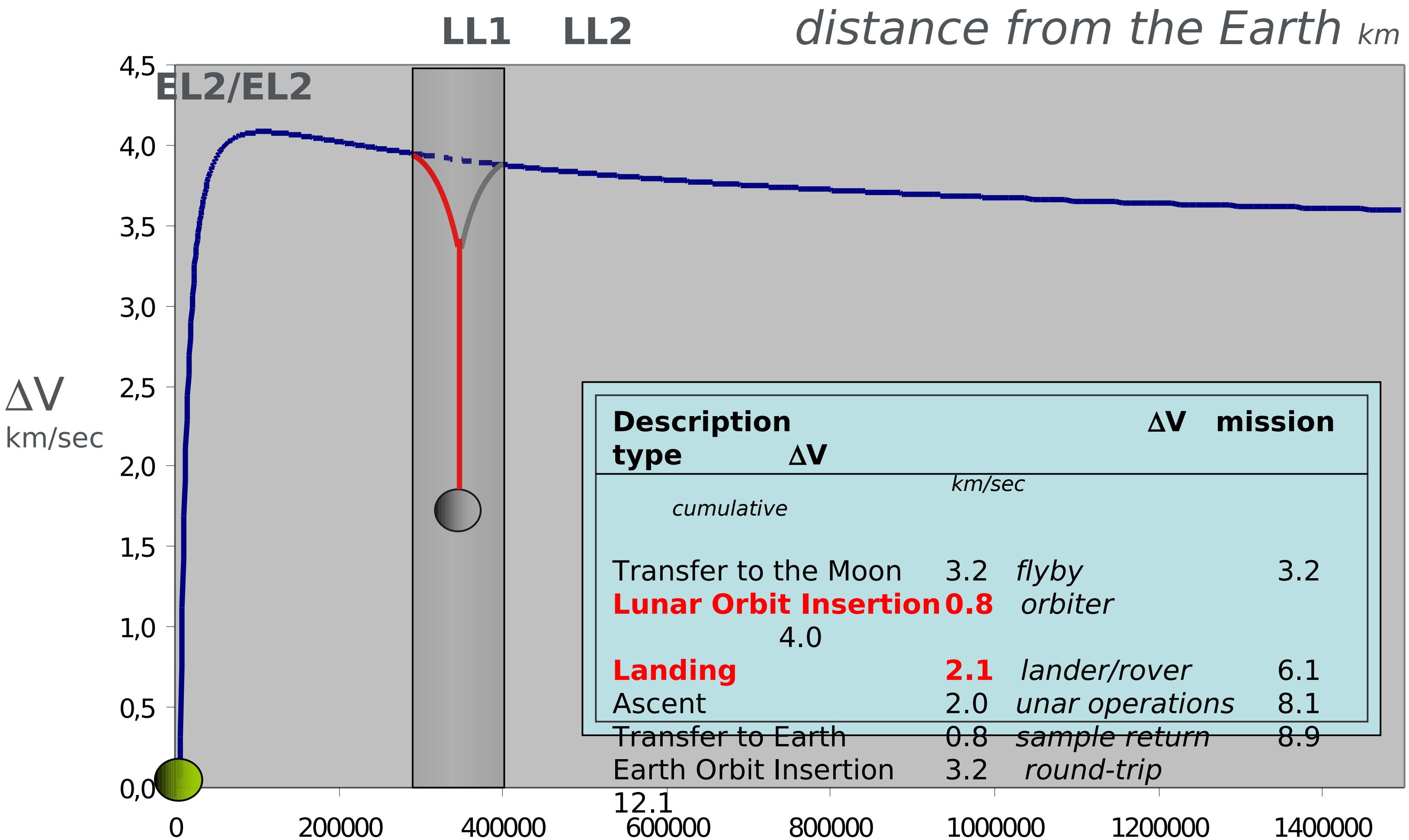
Moon Base Conference

Being Pragmatic: Moon Base proceedings



Information is not knowledge, knowledge is not wisdom

The Accessibility of the Moon



SMD lunar applications

Moon harbor: a LL1 halo orbiting infrastructure for manned / unmanned missions support (e.g refurbishing space relescopes, space elevator)

Low altitude lunar orbiters / landers

High altitude lunar constellations for satellite navigation

High eccentricity orbits / halo orbiters for telecommunications

Operations safety (avoiding critical events)

Flexibility of mission profile (e.g. different launch scenario)

Long transfers: cruise science (e.g. gravitational redshift, solar/magnetosphere interactions)

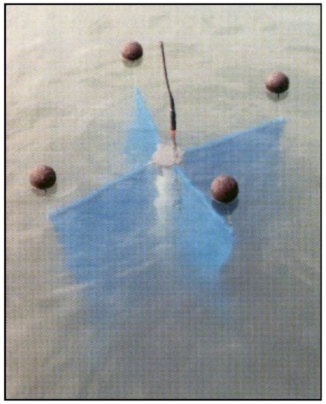
Manned vs unmanned missions (radiation issue, non–critical cargo delivery)

SPACE OPS ACADEMY
flight dynamics
and ground system
management

Workshop recommendation:

focus on the effect of ***dissipative systems*** **on SMD in terms of outcomes, methods and applications (e.g. low-thrust engines, non-gravitational forces, tethered systems etc.);**

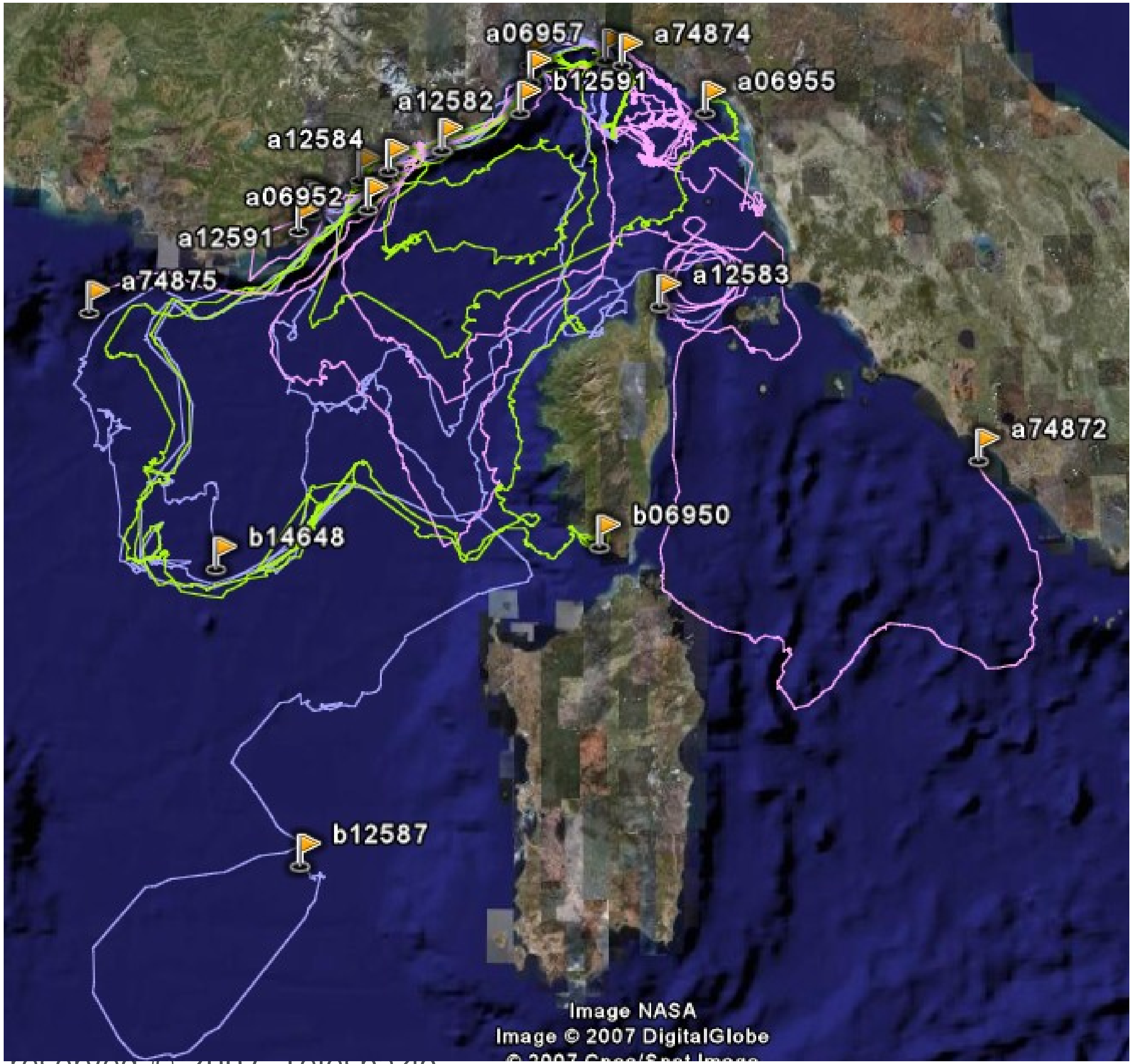
surface drifters dynamics



Dispersione nel Mare Ligure

14 maggio 25 settembre 2007

Source:



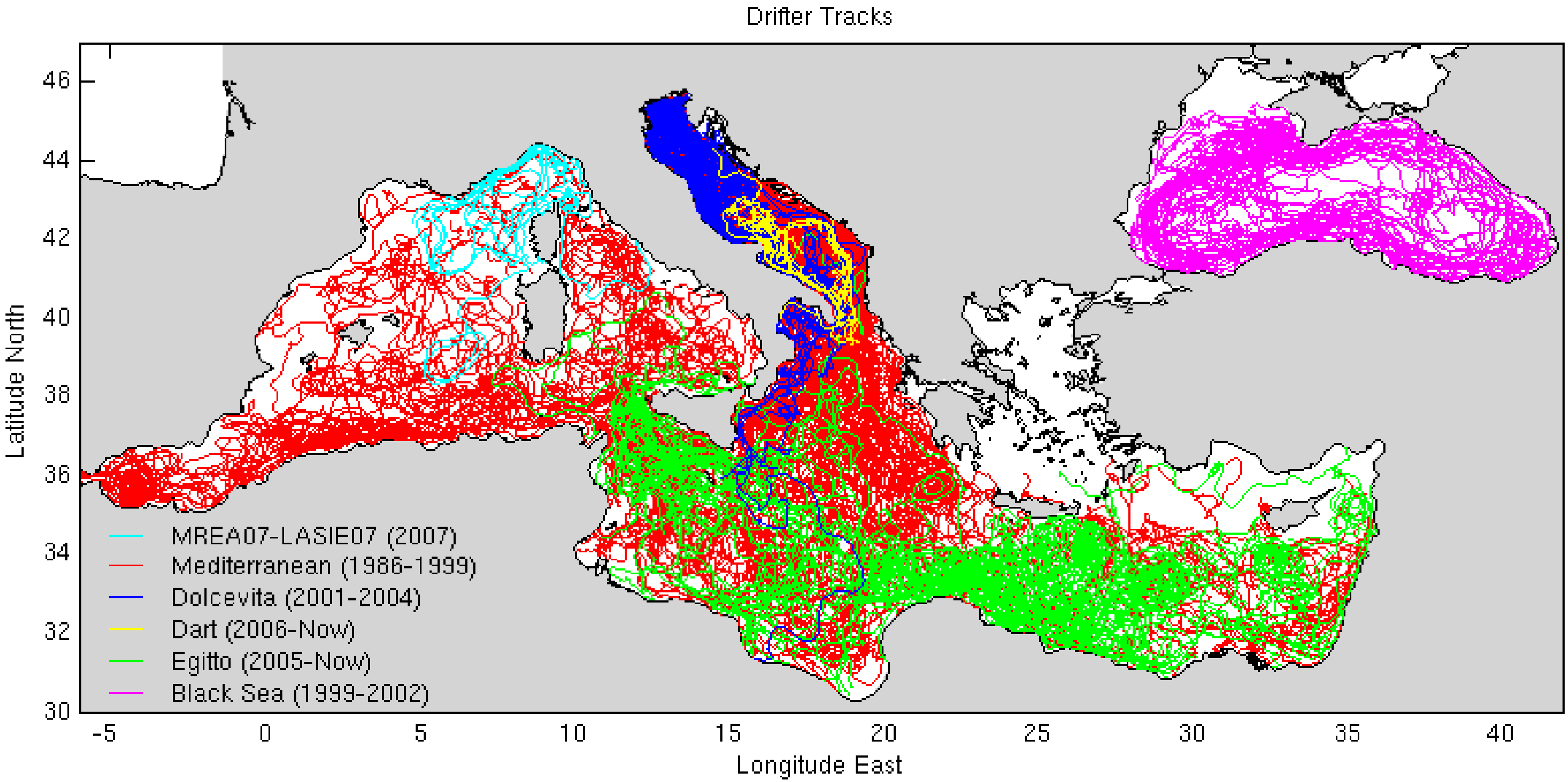
surface drifters dynamics

TELESPAZIO
A Finmeccanica / Thales Company

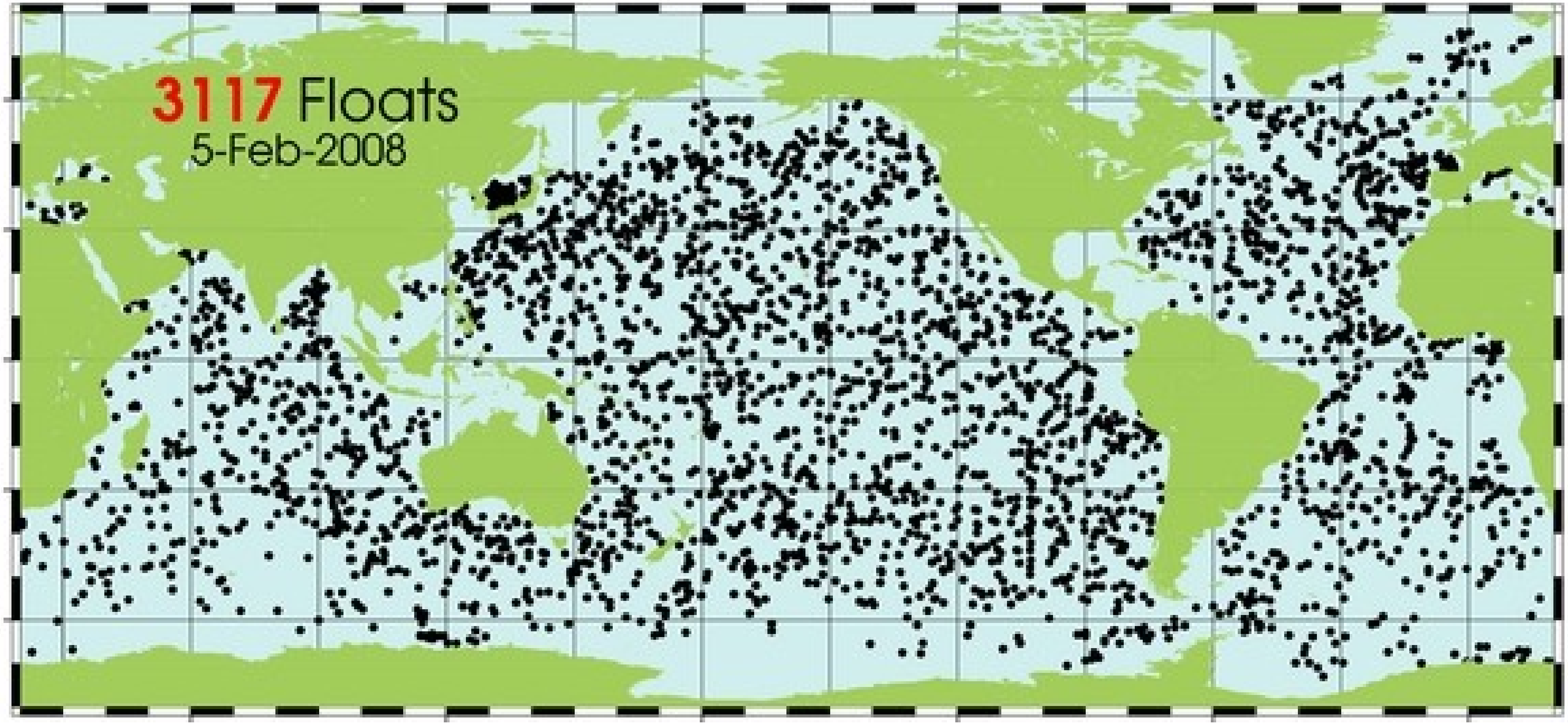
Source:

OGS · GNOO GRUPPO NAZIONALE di OCEANOGRAFIA OPERATIVA · MOON

Traiettorie nel Mar Mediterraneo (1986 – 2008)



surface drifters dynamics



Source:

thank you