

# Calcoli e calcolatori che ci han portato sulla Luna

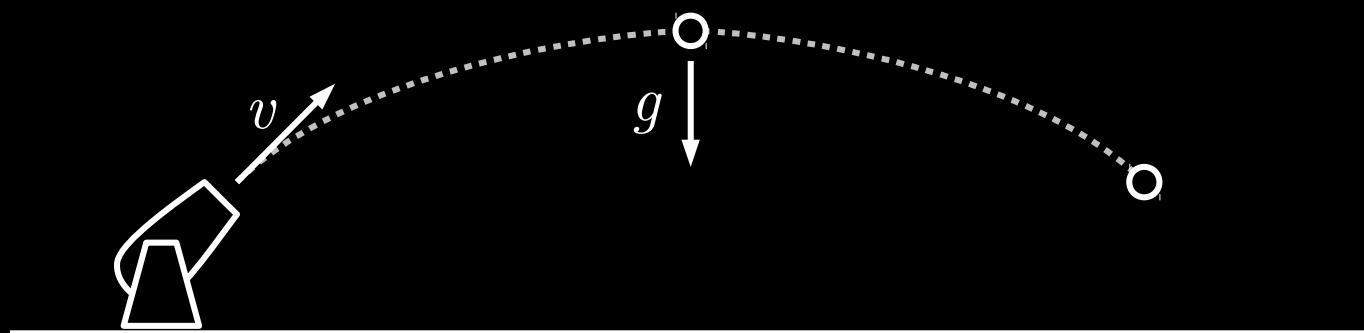
2015-05-04 Il Mondo della Luna  
*I giovedì alla Cittadella Galileiana  
Ludoteca scientifica & La Nuova Limonaia*

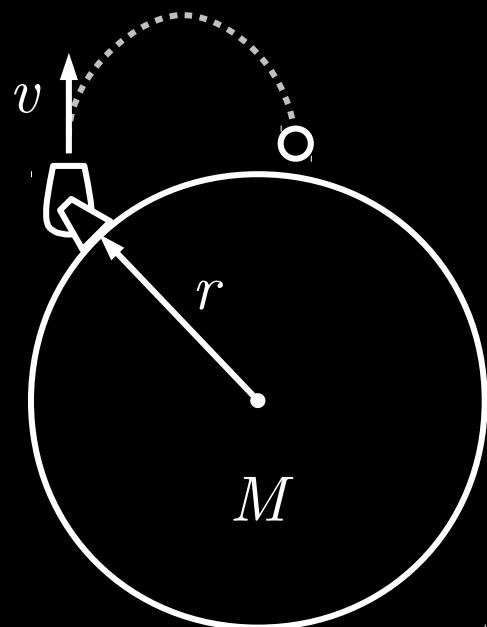


# Capitolo 1

## Velocità di fuga

- Kopernik, Kepler, Galilei, Newton
  - 1543 *De revolutionibus orbium cœlestium*
  - 1609 *Astronomia Nova*, 1619 *Armonice Mundi*
  - 1610 *Sidereus Nuncius*
  - 1687 *Philosophiæ Naturalis Principia Mathematica*
- Si comincia a sapere davvero come funziona





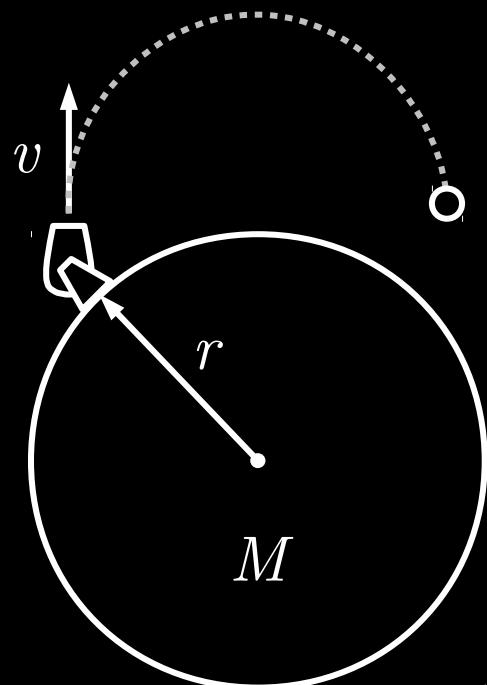
$$r = 6.371 \times 10^6 \text{ m}$$

$$M = 5.97219 \times 10^{24} \text{ kg}$$

$$G \approx 6.67408 \times 10^{-11}$$

$$g = \frac{G M}{r^2} = 9.80665 \text{ m/s}^2$$



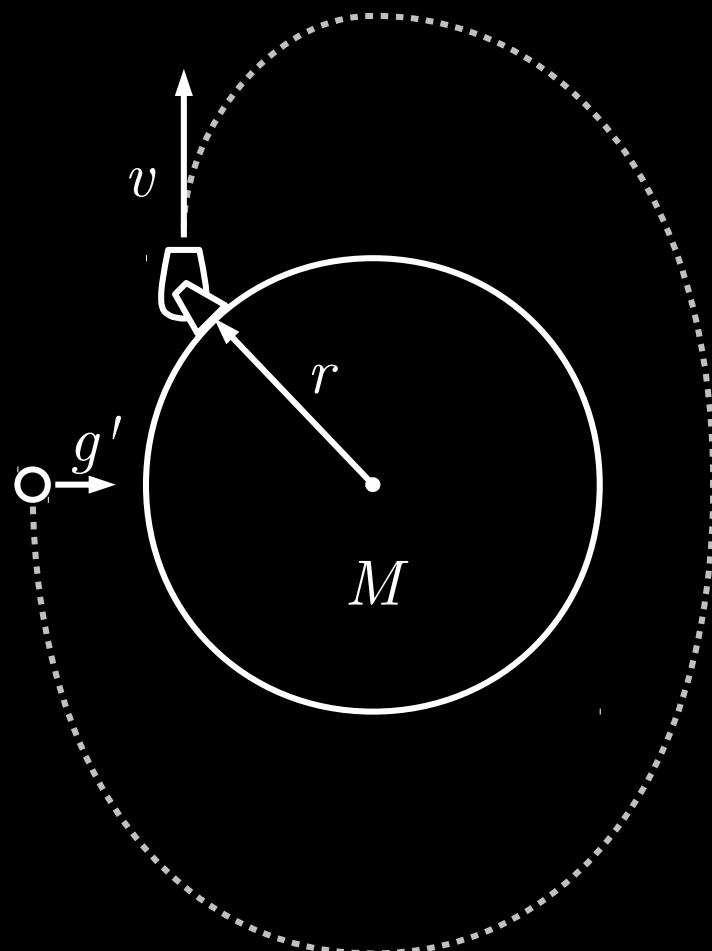


$$r = 6.371 \times 10^6 \text{ m}$$

$$M = 5.97219 \times 10^{24} \text{ kg}$$

$$G \approx 6.67408 \times 10^{-11}$$

$$g = \frac{G M}{r^2} = 9.80665 \text{ m/s}^2$$

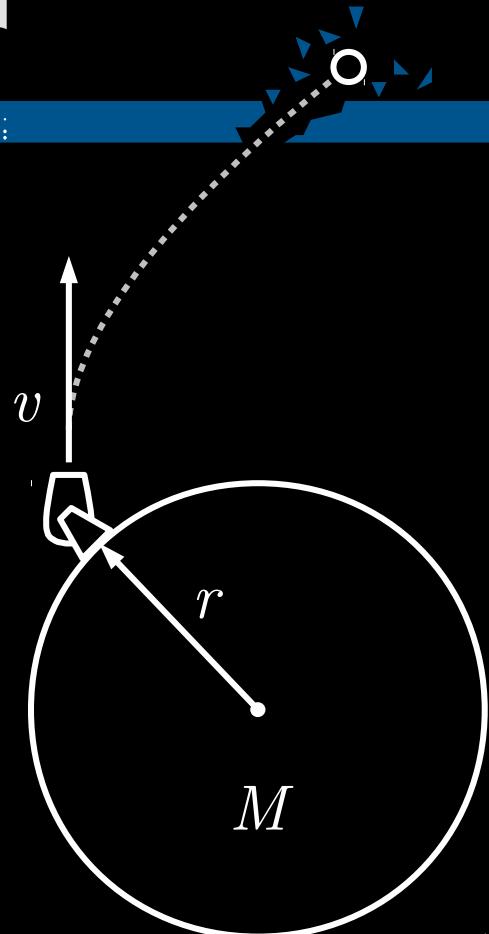


$$r = 6.371 \times 10^6 \text{ m}$$

$$M = 5.97219 \times 10^{24} \text{ kg}$$

$$G \approx 6.67408 \times 10^{-11}$$

$$g = \frac{G M}{r^2} = 9.80665 \text{ m/s}^2$$



$$r = 6.371 \times 10^6 \text{ m}$$

$$M = 5.97219 \times 10^{24} \text{ kg}$$

$$G \approx 6.67408 \times 10^{-11}$$

$$g = \frac{G M}{r^2} = 9.80665 \text{ m/s}^2$$

$$v_e = \sqrt{2 g r} = 11.2 \text{ km/s}$$

## □ Jules Verne

- 1865 De la terre à la Lune
- 1869 Autour de la Lune

## □ Racconto tecnologico

- Ricerca del plausibile
- Molti dati quasi giusti (97 vs 102)

## □ Tuttavia

- Accelerazione insopportabile
- 275 m di canna,  
(Gustav 32.5, HARP 40)



## □ HARP Project

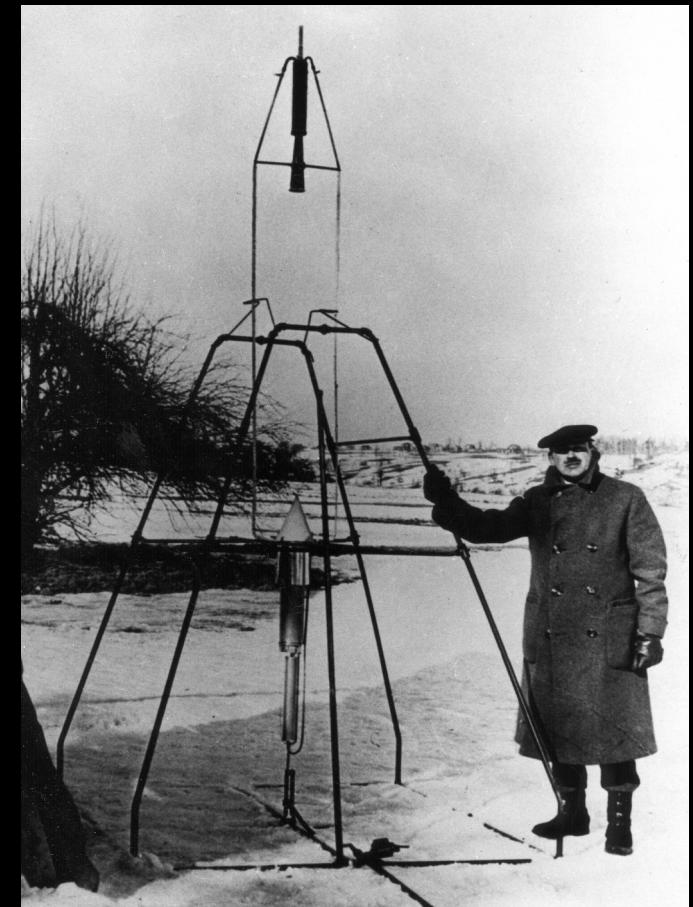
- USA-Canada, 1961-66, Barbados, Yuma (Az)
- 3.2 km/s, 180 km

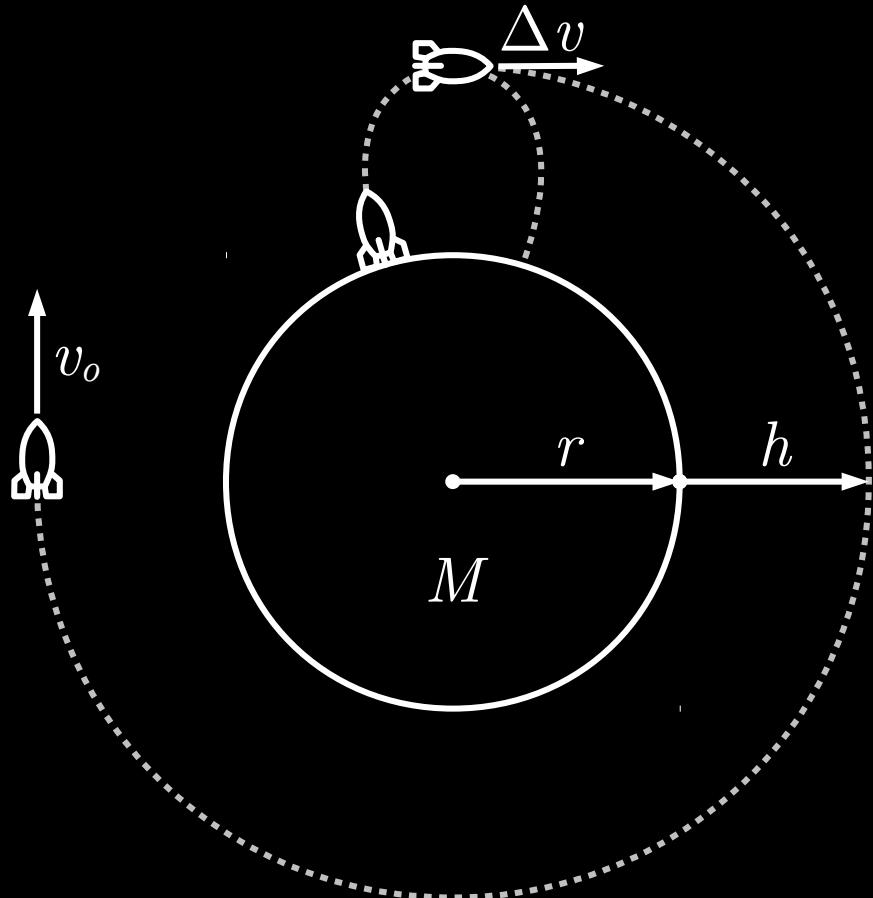


## Capitolo 2

### Equazioni e manovre

- Konstantin Tsiolkovsky
  - Razzi per lo spazio (1903)
  - Stadi, stazioni, ascensori
- Robert Goddard
  - 214 brevetti
  - Combustibile liquido (1914)
- Perché i razzi
  - Accelerano progressivamente
  - Funzionano a reazione
  - Hanno con sé il comburente





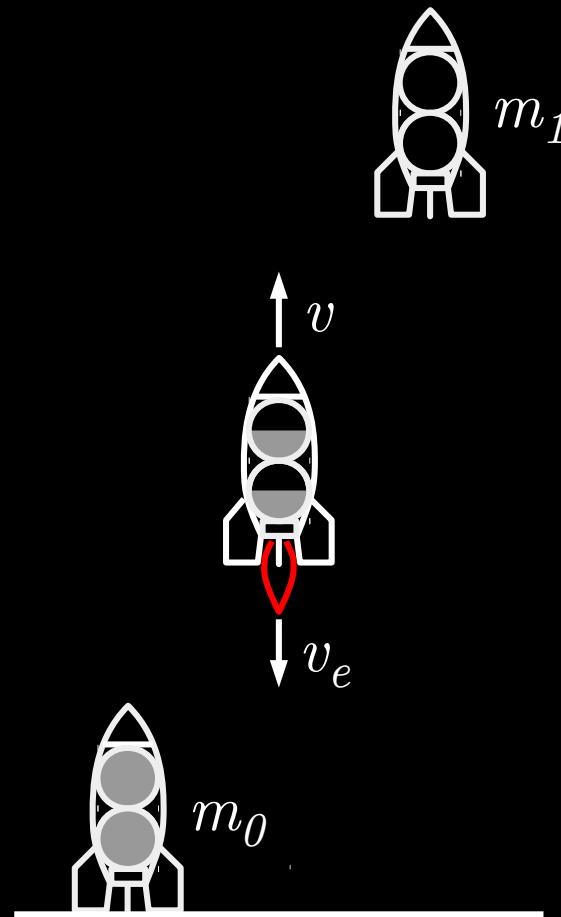
$$h = 200 \times 10^3 \text{ m}$$

$$r = 6.371 \times 10^6 \text{ m}$$

$$M = 5.97219 \times 10^{24} \text{ kg}$$

$$G \approx 6.67408 \times 10^{-11}$$

$$v_o \approx \sqrt{\frac{GM}{r+h}} = 7.788 \text{ km/s}$$



$m_0$ =massa iniziale, propellente incluso

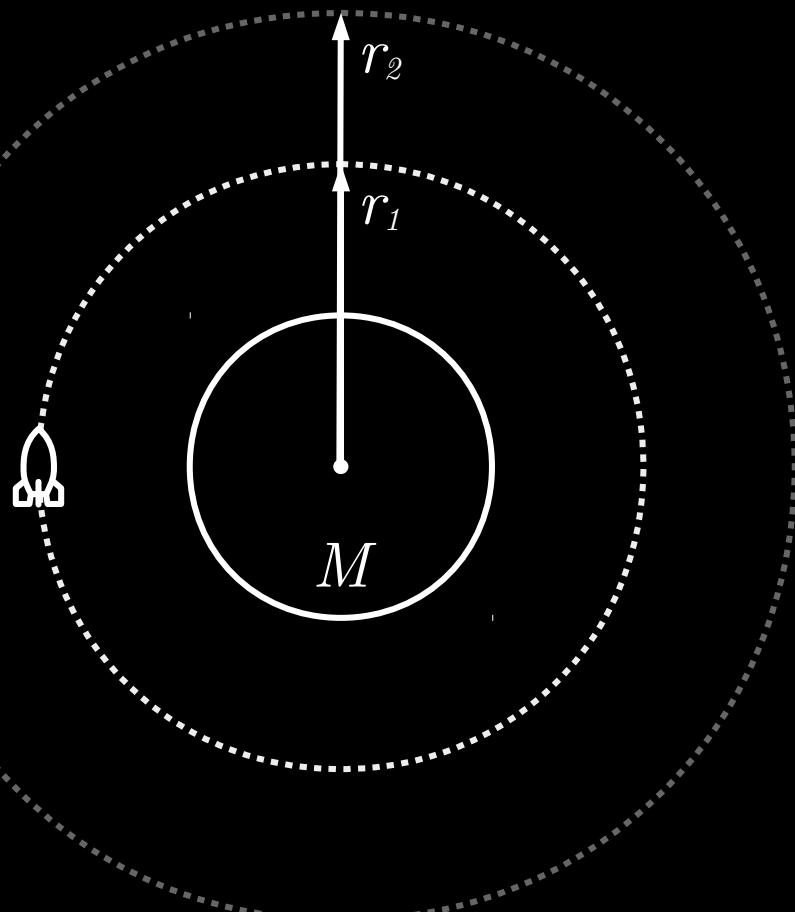
$m_1$ =massa finale , struttura e carico utile

$v_e$ = spinta effettiva

$$\Delta v = v_e \ln\left(\frac{m_0}{m_1}\right)$$

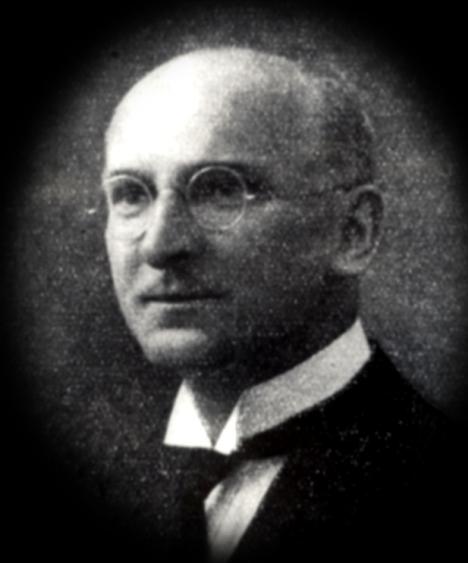


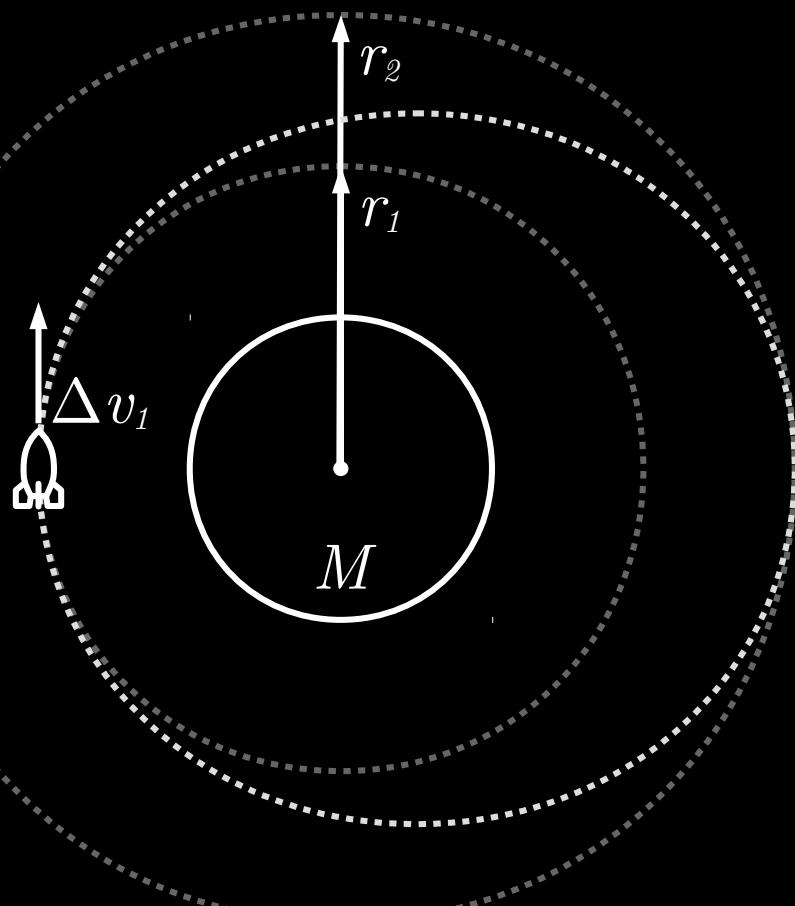
# Walter Hohmann (1925)



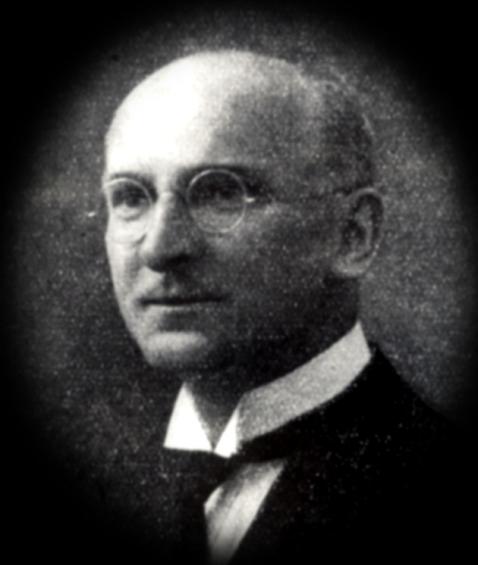
$r_1$ =orbita iniziale

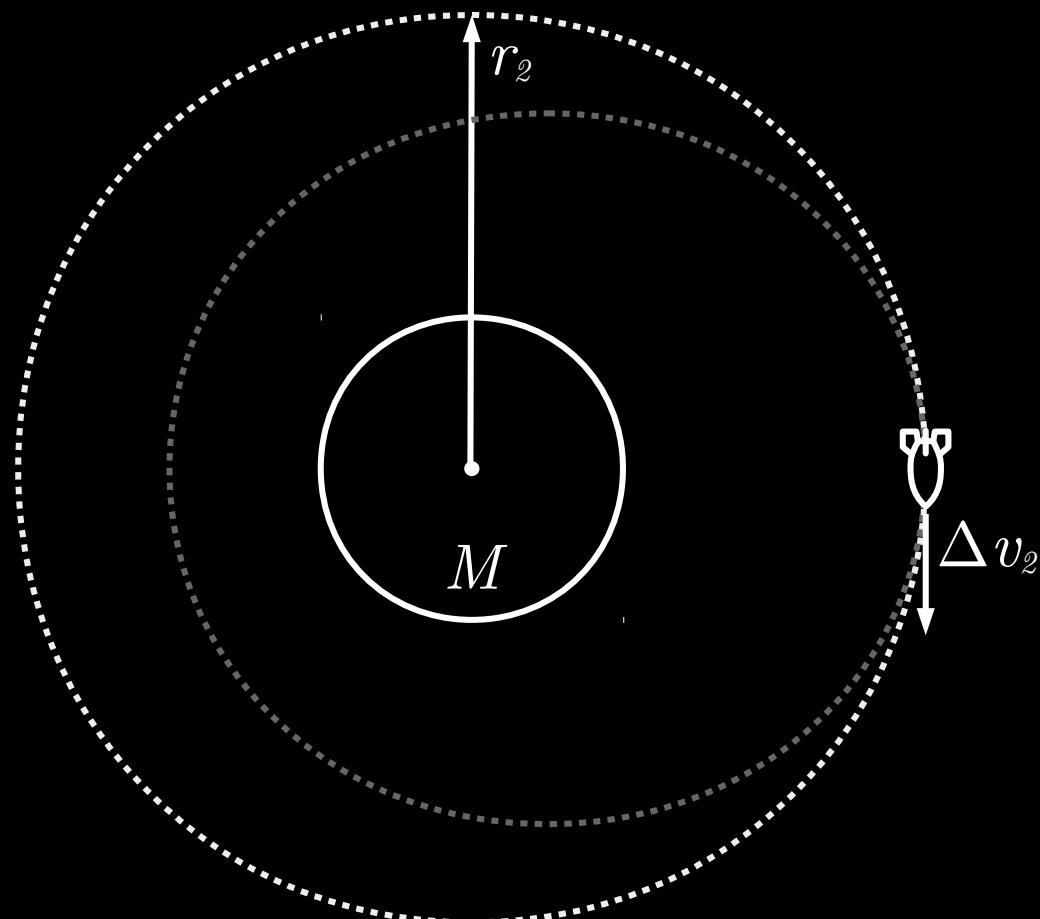
$r_2$ =orbita finale





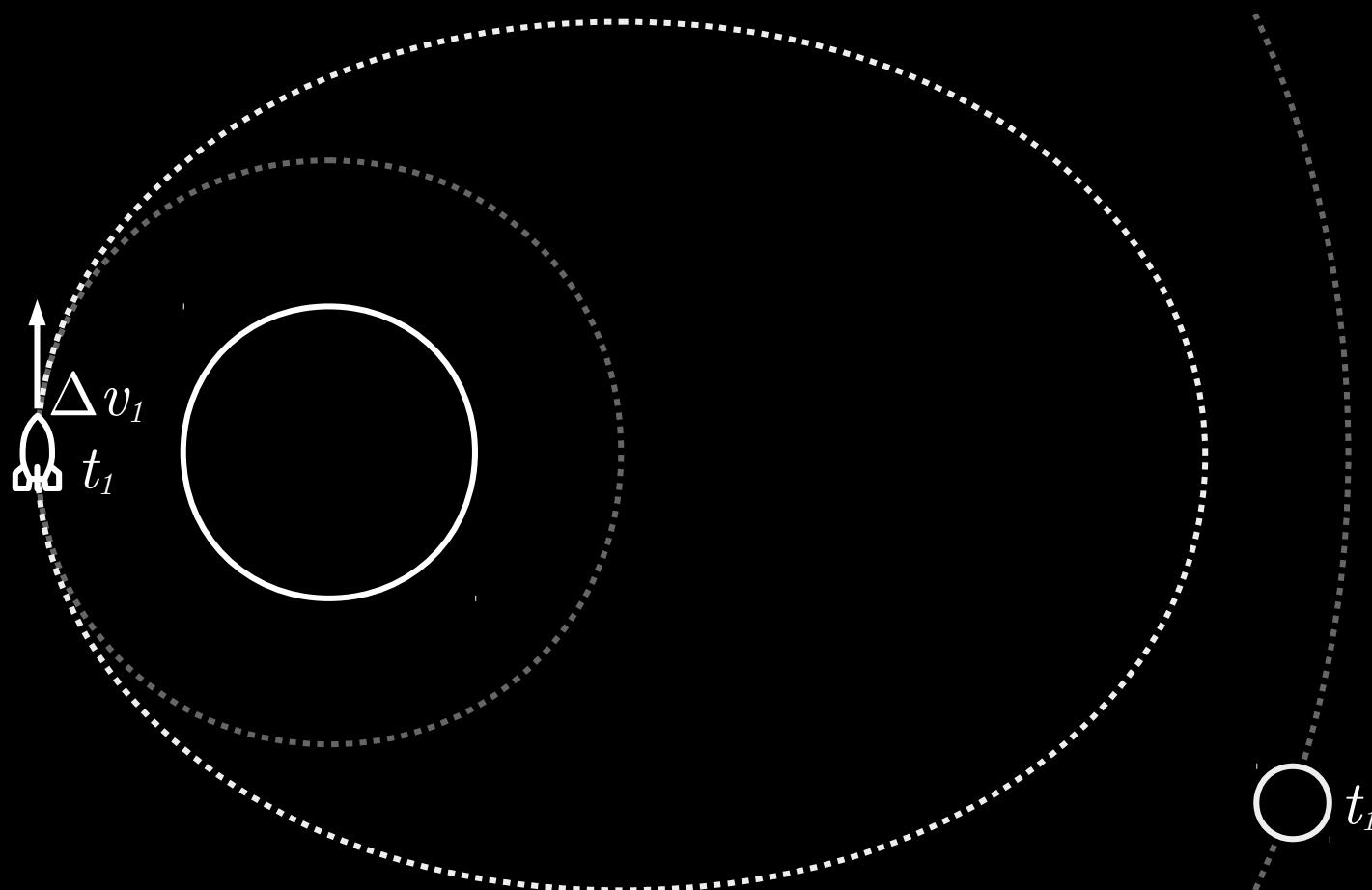
$$\Delta v_1 = \sqrt{\frac{GM}{r_1}} \left( \sqrt{\frac{2r_2}{r_1 + r_2}} - 1 \right)$$

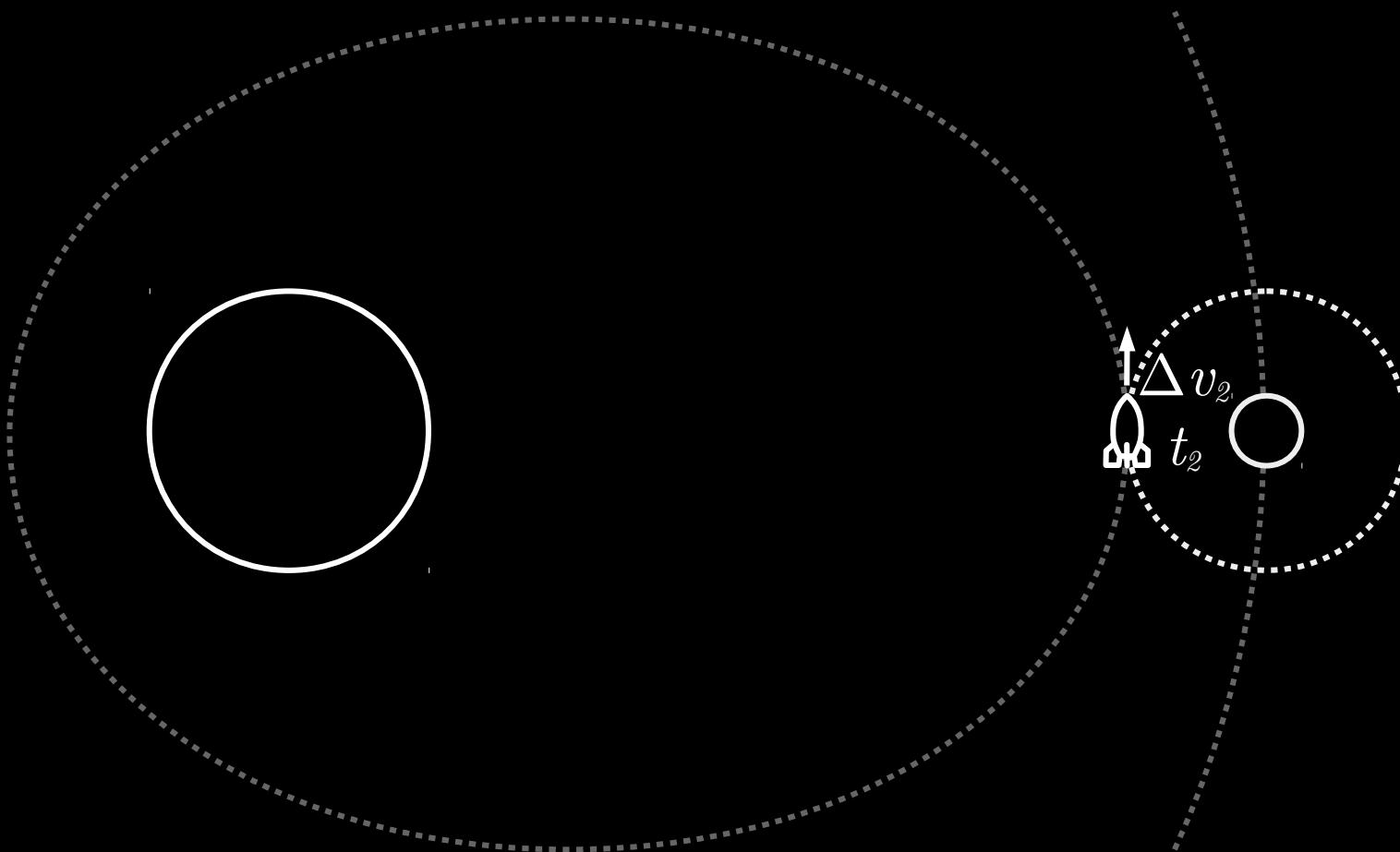




$$\Delta v_2 = \sqrt{\frac{GM}{r_2}} \left( 1 - \sqrt{\frac{2r_1}{r_1 + r_2}} \right)$$

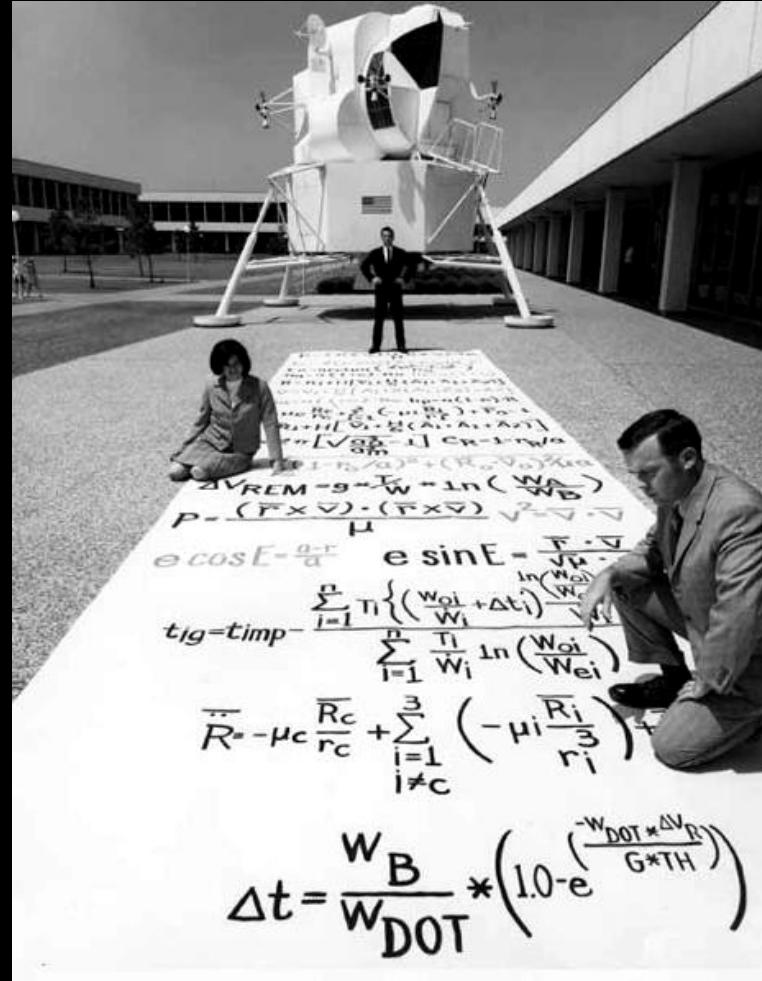






## Capitolo 3

### Calcolatori per i calcoli



- Pianificazione del volo
  - Moti dei corpi celesti, traiettorie e velocità
  - Vettori e tempi delle manovre
  - Verifica e validazione del piano di volo
- Progettazione e prova dei sistemi
- Simulazione
  - Addestramento sui moduli di comando e lunare
  - Controllo di missione in tempo reale
- Calcolatori di bordo, avionica e controllo
- Elaborazione/archiviazione dei dati di missione

## □ Programma Apollo

- SA-1 – 5, 1961-64, prove Saturn I
- A-101 – 105, 1964-65, prove Saturn I
- QTV, A-001 – 004, 1963-66, prove Little Joe
- AS-201 – 203, 1966, prove Saturn IB
- Apollo 1 (Grissom, White, Chaffee), 1967, incidente
- Apollo 4 – 6, 1967-68, prove Saturn V e CM
- Apollo 7 (Schirra, Eisele, Cunningham), 1968, orbita T
- Apollo 8 (Borman, Lovell, Anders), 1968, orbita L
- Apollo 9 (McDivitt, Scott, Schweickart), 1969, dock
- Apollo 10 (Stafford, Young, Cernan), 1969, volo L
- Apollo 11 (Armstrong, Collins, Aldrin), 1969, allunaggio
- Apollo 12 – 17, 1969-72



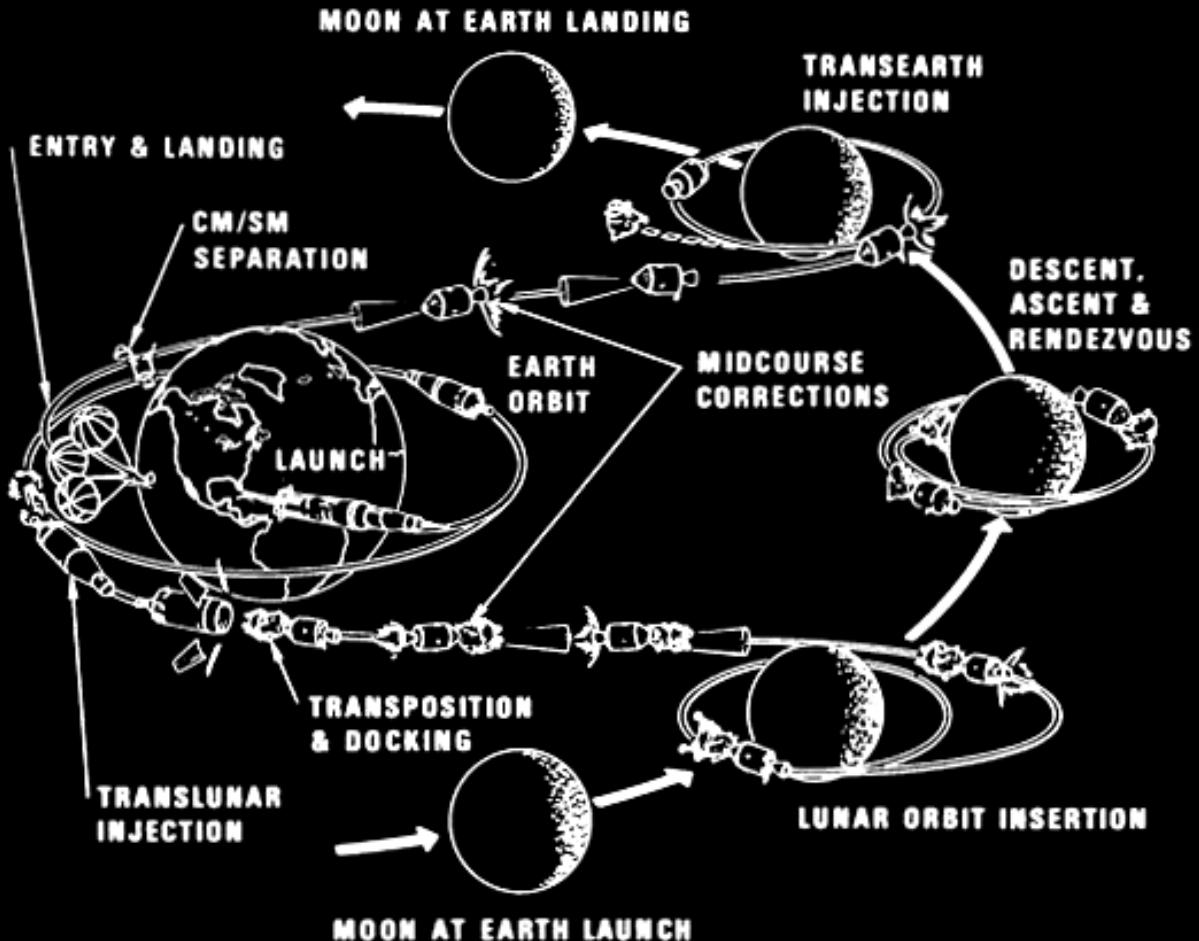
□ Tre stadi

- Evoluzione del Saturn I e IB  
con due stadi (solo inserimento in LEO)

# il piano di volo, 8 giorni

## □ Strategie

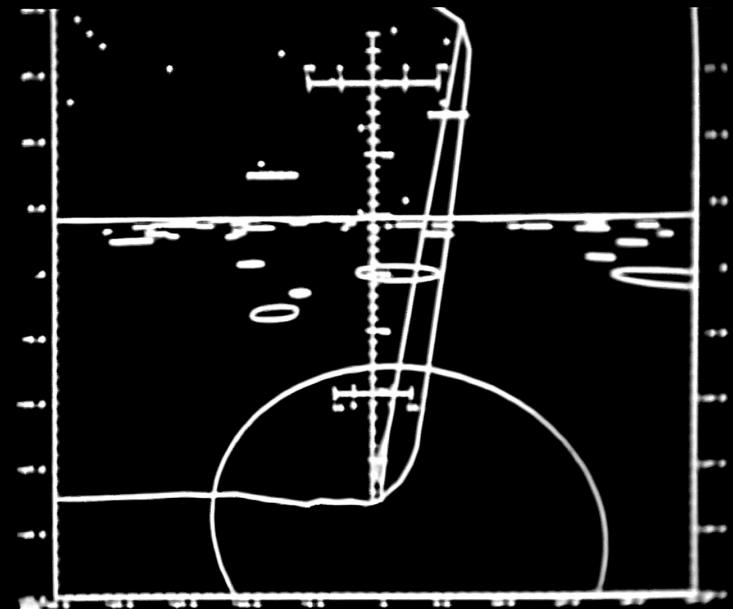
- Direct Ascend, Nova Rocket abbandonato
- Earth Orbit Rv, sperimentato nel programma Gemini
- Lunar Orbit Rv, infine adottato con il Saturno V



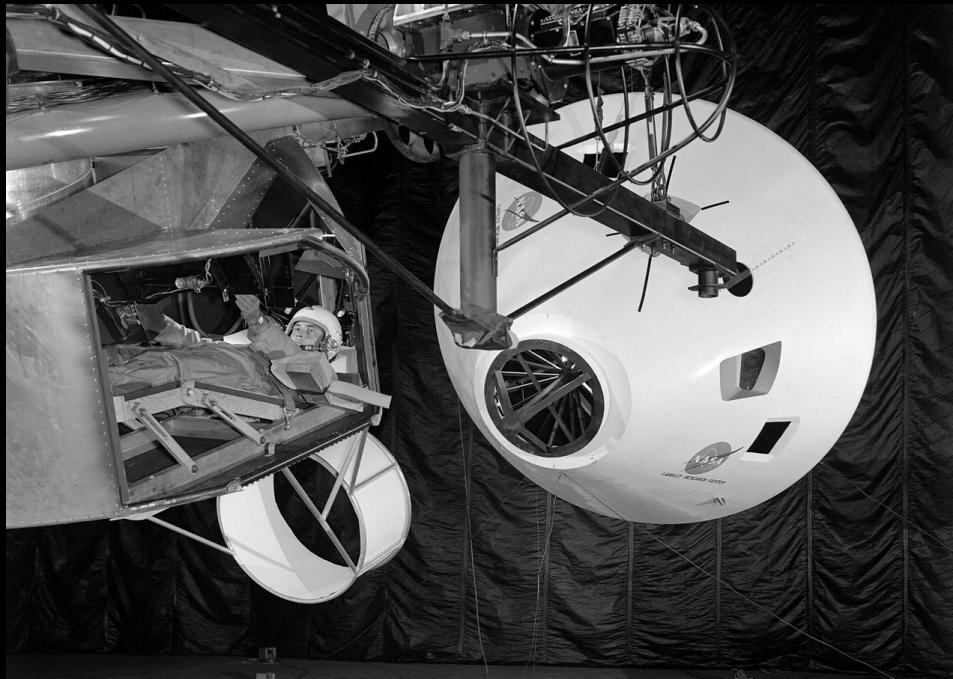
# i calcolatori, soprattutto IBM...



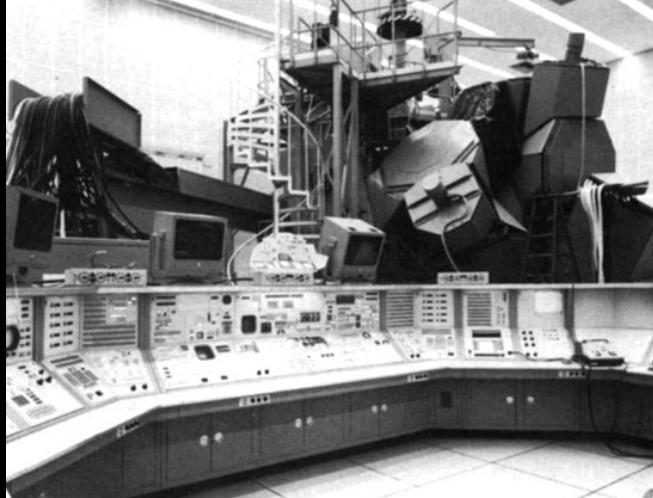
- Procedure
  - Soluzione digitale
  - Mainframe IBM 360 e 370
  
- Manovre
  - Soluzione mista
  - 3C/Honeywell DDP 224
  - 3-4-5 CMS, 3-4 LMS
  - Emulazione dell'AGS
  - In “rete” via RAM condivisa
  - 200 specialisti hardware
  - 175 specialisti software



# dal Gemini all'Apollo



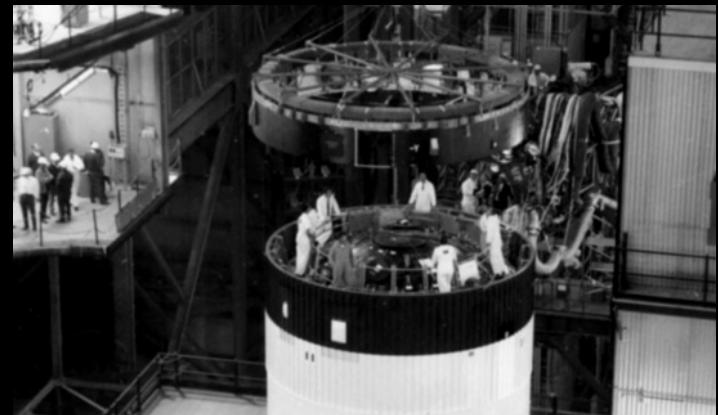
# hardware di simulazione



# Saturn V Instrument Unit

## □ Sistemi di controllo e guida

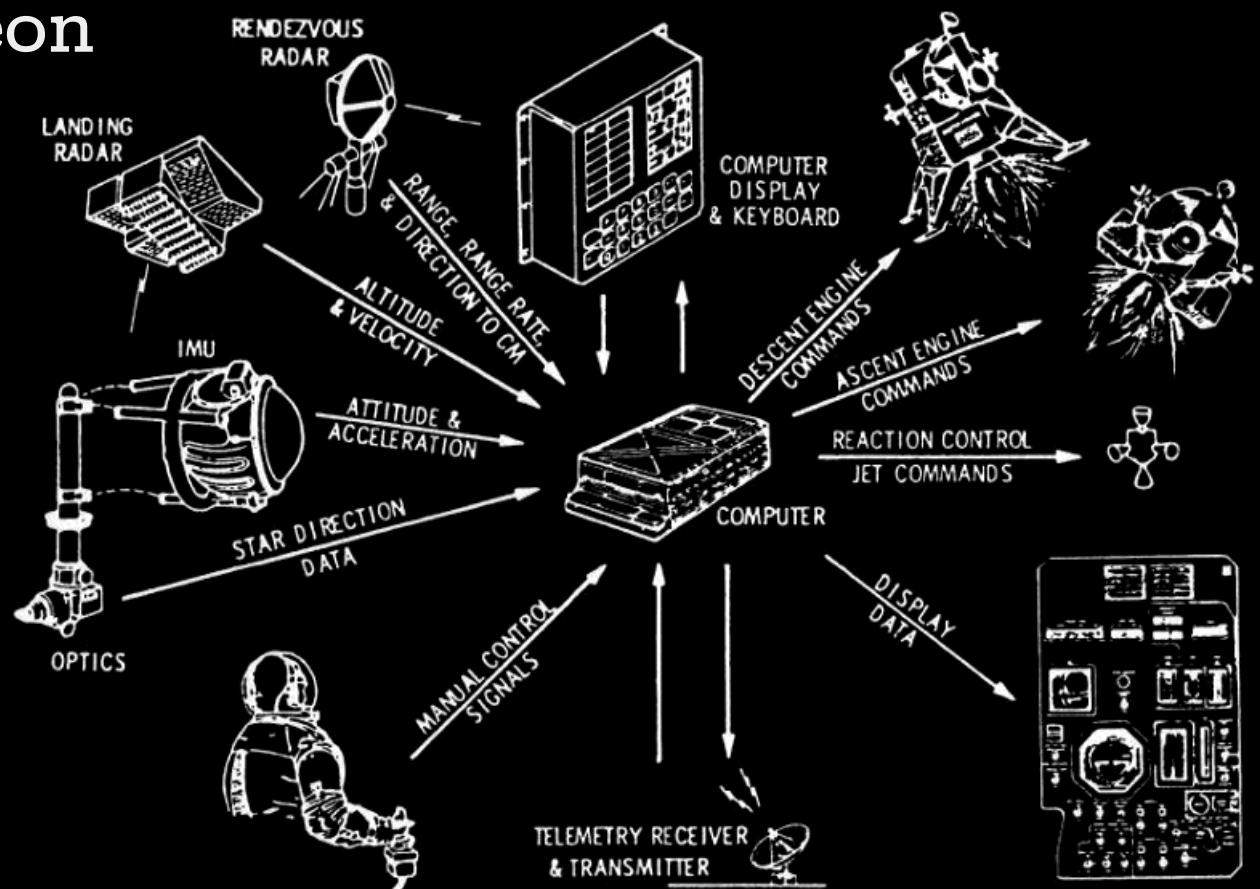
- Pilota automatico analogico
- Calcolatore di bordo
- Giroscopi
- Sensori



# hmr Block II Apollo Guidance System

## MIT & Raytheon

- 1×LM+AbGS
- 2×CM
- 2.048 MHz
- 16 bit
- 2 Kiw RAM
- 32 Kiw ROM
- DSKY



## Capitolo 4

# Programmi per i calcolatori

- Margaret Hamilton
  - NASA SwEng Director
  - MIT Instrumentation Lab
- Colossus & Luminary
- Sistema operativo
  - Multitasking
  - Tempo reale
  - Gestione del carico
  - Priorità



GAP: ASSEMBLE REVISION 055 OF AGC PROGRAM COMANCHE BY NASA 2021113-051 10:29 APR. 1, 1969 (MAIN) PAGE 1  
L ASSEMBLY AND OPERATION INFORMATION USER'S PAGE NO. 1 EO

R00001  
R00002 \*  
R00003 \*  
R00004 \* THIS AGC PROGRAM SHALL ALSO BE REFERRED TO AS:  
R00005 \*  
R00006 \*  
R00007 \* COLOSSUS-2A  
R00008 \*  
R00009 \*  
R00010 \* THIS PROGRAM IS INTENDED FOR USE IN THE CM AS SPECIFIED  
IN REPORT R-577. THIS PROGRAM WAS PREPARED UNDER DSR  
PROJECT 55-23870, SPONSORED BY THE MANNED SPACECRAFT  
CENTER OF THE NATIONAL AERONAUTICS AND SPACE  
ADMINISTRATION THROUGH CONTRACT NAS 9-4065 WITH THE  
INSTRUMENTATION LABORATORY, MASSACHUSETTS INSTITUTE OF  
TECHNOLOGY, CAMBRIDGE, MASS.  
R00011 \*  
R00012 \*  
R00013 \*  
R00014 \*  
R00015 \*  
R00016 \*  
R00017 \*  
R00018 \*\*\*\*\*

R00019 SUBMITTED: MARGARET H. HAMILTON DATE: 28 MAR 69  
R00020 M.H.HAMILTON, COLOSSUS PROGRAMMING LEADER  
R00021 APOLLO GUIDANCE AND NAVIGATION

R00022 APPROVED: DANIEL J. LICKLY DATE: 28 MAR 69  
R00023 D.J.LICKLY, DIRECTOR, MISSION PROGRAM DEVELOPMENT  
R00024 APOLLO GUIDANCE AND NAVIGATION PROGRAM

R00025 APPROVED: FRED H. MARTIN DATE: 28 MAR 69  
R00026 FRED H. MARTIN, COLOSSUS PROJECT MANGER  
R00027 APOLLO GUIDANCE AND NAVIGATION PROGRAM

R00028 APPROVED: NORMAN E. SEARS DATE: 28 MAR 69  
R00029 N.E. SEARS, DIRECTOR, MISSION DEVELOPMENT  
R00030 APOLLO GUIDANCE AND NAVIGATION PROGRAM

R00031 APPROVED: RICHARD H. BATTIN DATE: 28 MAR 69  
R00032 R.H. BATTIN, DIRECTOR, MISSION DEVELOPMENT  
R00033 APOLLO GUIDANCE AND NAVIGATION PROGRAM

R00034 APPROVED: DAVID G. HOAG DATE: 28 MAR 69  
R00035 D.G. HOAG, DIRECTOR  
R00036 APOLLO GUIDANCE AND NAVIGATION PROGRAM

R00038 APPROVED: RALPH R. RAGAN DATE: 28 MAR 69  
R00039 R.R. RAGAN, DEPUTY DIRECTOR  
R00040 INSTRUMENTATION LABORATORY  
R00041



GAP: ASSEMBLE REVISION 055 OF AGC PROGRAM COMANCHE BY NASA 2021113-051		10:28 APR. 1, 1969	COMAID .029	PAGE 181
L	FRESH START AND RESTART		USER'S PAGE NO.	I EO S3
R0001	PROGRAM DESCRIPTION	8 APRIL, 1967		
R0001		SUNDISK REV 120		
R0002	FUNCTIONAL DESCRIPTION			
R0003	SLAPI MAN INITIATED FRESH START			
R0004	1. EXECUTE STARTSUB			
R0005	2. TURN OFF DSKY DISCRETE-LAMPS			
R0006	3. CLEAR FAIL REGISTERS, SELF CHECK ERROR COUNTER AND RESTART			
R0007	COUNTER			
R0008	4. EXECUTE DOFSTART			
R0009	DOFSTART MACHINE INITIATED FRESH START			
R0010	1. CLEAR SELF-CHECK REGISTERS, MODE REGISTER AND CDUZ REGISTER			
R0011	2. CLEAR PHASE TABLE			
R0012	3. INITIALIZE IMU FLAGS			
R0013	4. INITIALIZE FLAGWORDS			
R0014	5. TRANSFER CONTROL TO IDLE LOOP IN DUMMYJOB			
R0015	GOPROG HARDWARE RESTART			
R0016	0. EXECUTE STARTSUB			
R0017	1. TRANSFER CONTROL TO DOFSTART IF ANY OF THE FOLLOWING CONDITIONS EXIST.			
R0018	A. RESTART OCCURRED DURING EXECUTION OF ERASCHK			
R0019	B. BOTH OSCILLATOR FAIL AND AGC WARNING ARE ON			
R0020	C. MARK REJECT AND EITHER NAV OR MAIN DSKY ERROR LIGHT RESET ARE ON.			
R0021	2. SCHEDULE A T-SRUPPT PROGRAM FOR THE DAP			
R0022	3. SET FLAGWORDS BITS FOR INTWAKE ROUTINE			
R0023	4. EXTINGUISH ALL DSKY LAMPS, EXCEPT PROGRAM ALARM, GIMBAL LOCK AND NO ATT			
R0024	5. INITIALIZE IMU FLAGS			
R0025	6. IF ENGINE COMMAND IS ON (FLAGWORDS.BIT 7), SET ENGINE ON (CHAN-NEL 11, BIT 13)			
R0026	7. TRANSFER CONTROL TO GOPROG3			
R0031	ENEMA SOFTWARE RESTART INITIATED BY MAJOR MODE CHANGE			
R0032	1. EXECUTE STARTSB2			
R0033	2. KILL PROGRAMS THAT WERE INTEGRATING OR WAITING FOR INTEGRATION ROUTINE			
R0034	3. TRANSFER CONTROL TO GOPROG3			
R0036	GOPROG3 SUBROUTINE COMMON TO GOPROG AND ENEMA			
R0037	1. TEST PHASE TABLES - IF INCORRECT, DISPLAY ALARM 1107 AND TRANSFER CONTROL TO DOFSTART			
R0038	2. DISPLAY MAJOR MODE			
R0040	3. IF ANY GROUPS WERE ACTIVE UPON RESTART, TRANSFER CONTROL TO THE			



- Moonscape Project  
<http://moonscape-project.blogspot.it>
- Virtual Apollo Guidance Computer  
<http://github.com/virtualagc>
- Project Apollo Archive  
<http://www.apolloarchive.com>
- NASA History Program Office  
<http://history.nasa.gov>