

# The Chinese Space Program



Where are they headed?  
Why are they going?  
How will they get there?  
What does it matter?

James Oberg



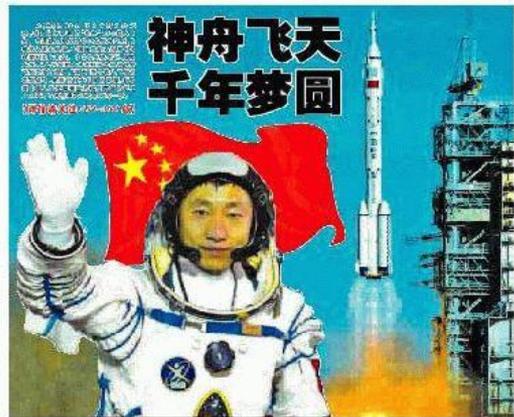
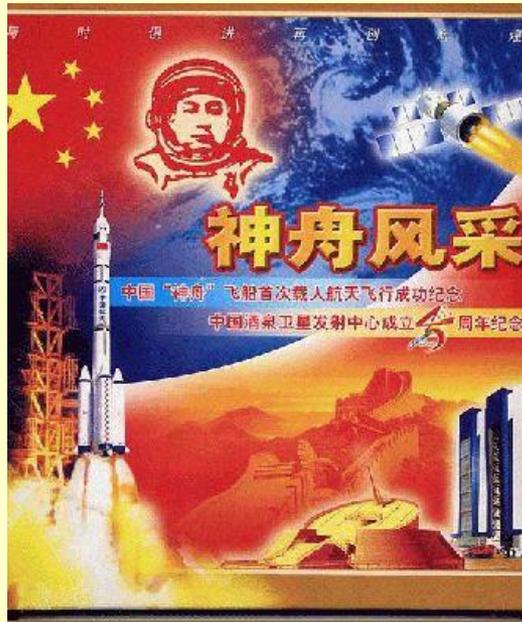
According to legend, the first man to try to ride a rocket was Wan Hu (XIVth century AD)



Yang Liwei

Shenzhou-5

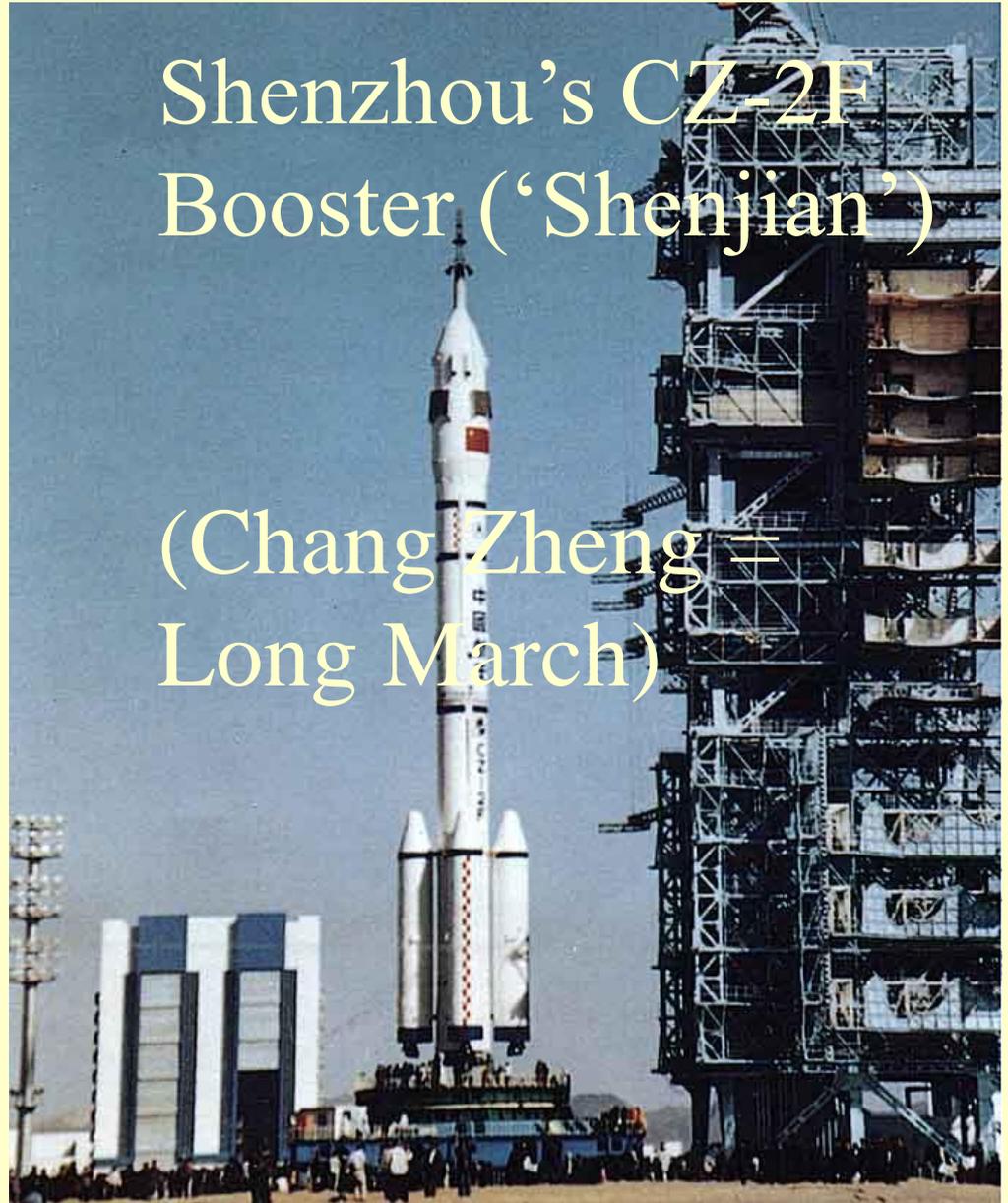
Oct 15-16, 2003



# Shen-Zhou (Heavenly Vessel)



Unmanned flight tests began in Dec 1999



Shenzhou's CZ-2F  
Booster ('Shenjian')

(Chang Zheng =  
Long March)

9 tons to LEO (more power than Russian 'Soyuz') <sup>5</sup>

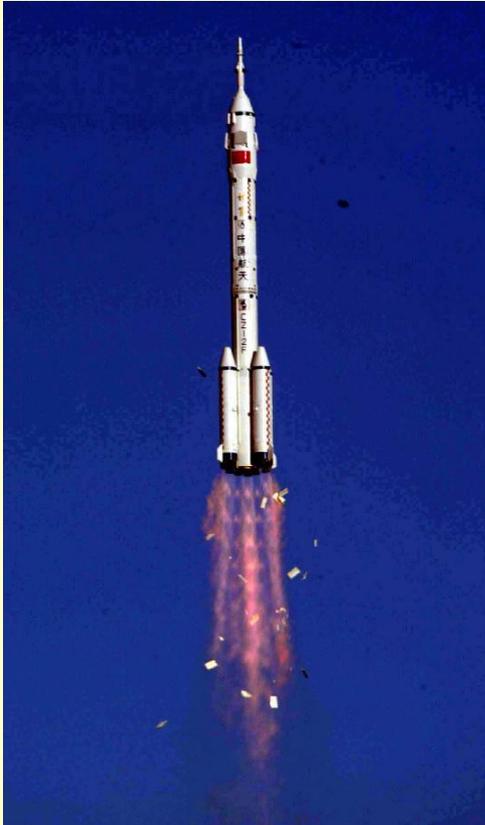
# Preparing for the breakthrough trip



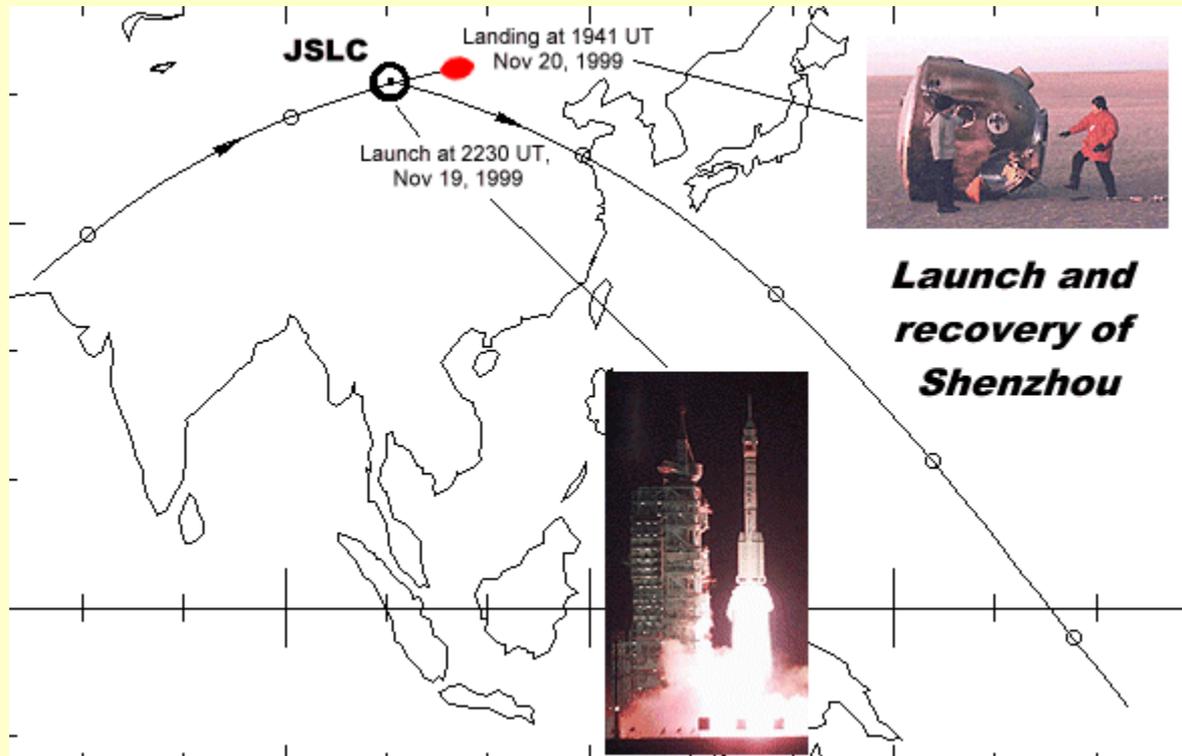
‘Yuhangyuan’ – not official  
‘Hangtianyuan’ – used in industry  
‘Taikongren’ – commonly used  
TAIKONAUT – Anglicized term

# The Launching – Never ‘Routine’

Some unusual images: jettisoning protective covers; reddish smoke

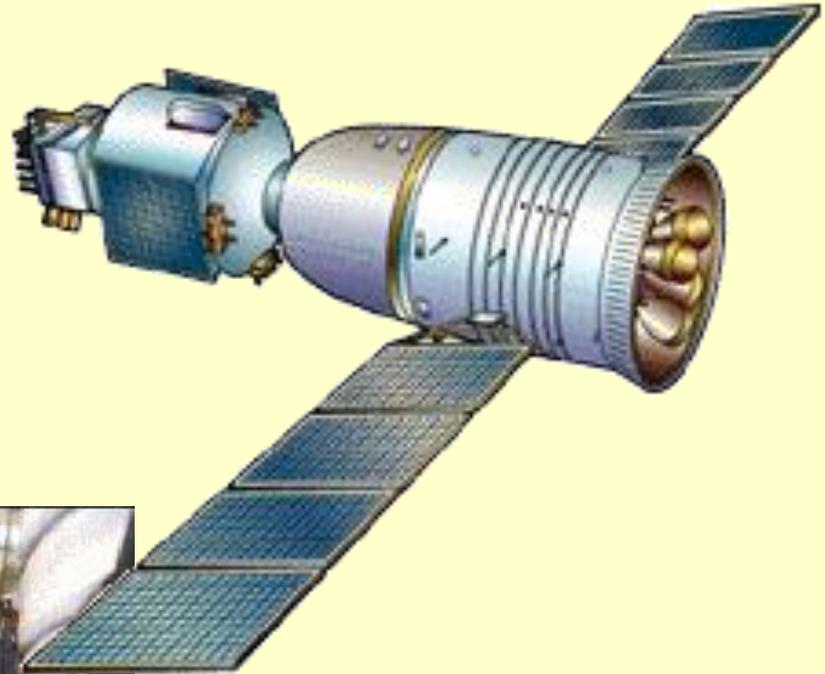


# Shenzhou ascent and landing tracks



Orbit = 42 degree inclination

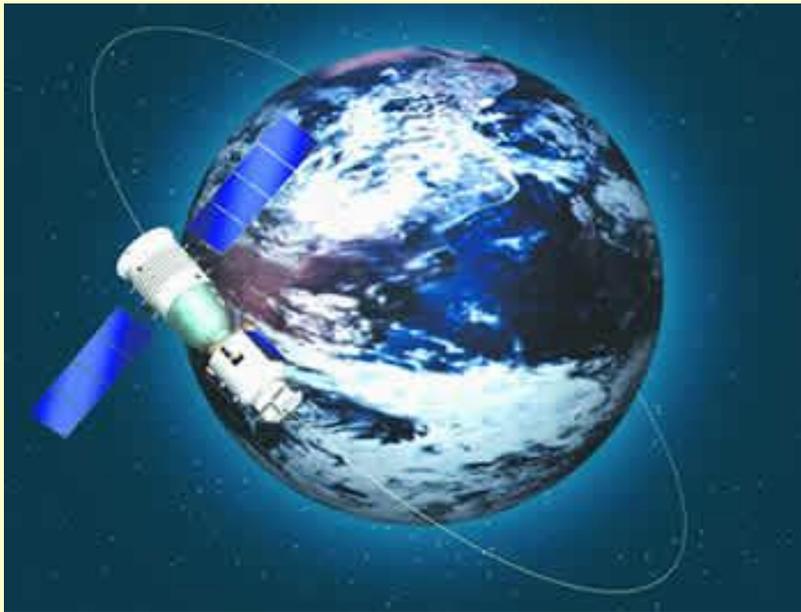
# Amazing Openness About Spacecraft



It took many years before the USSR released this level of technical detail about 'Vostok' and 'Soyuz'

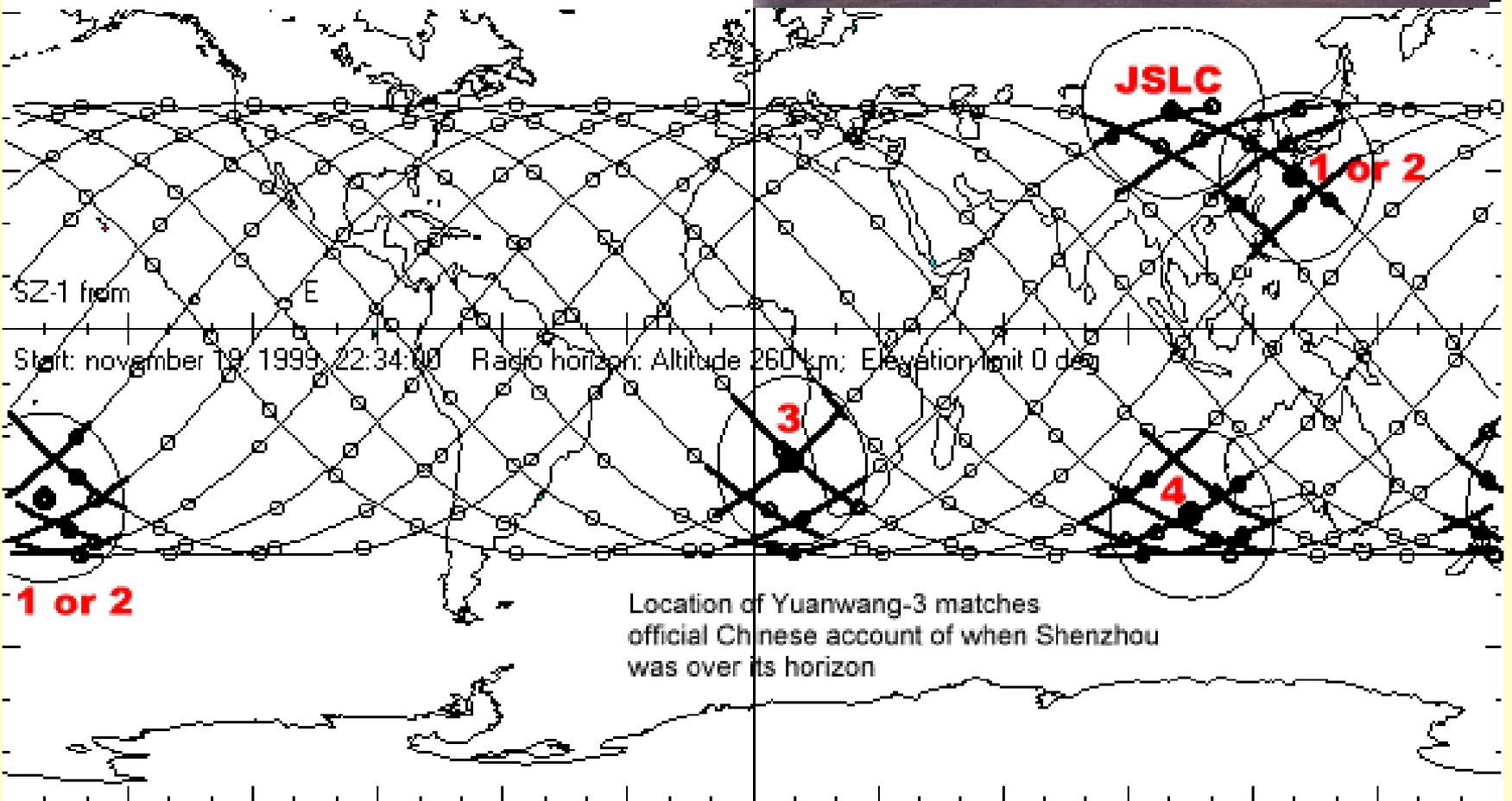
# On Orbit

Yang remained in his seat the whole flight, radioed greetings, showed the Chinese and UN flags, tried space food and took space naps, looked out the window, and above all – made manned spaceflight REAL to China.



余海里，在浩瀚的太平洋上，为我国航天事业的发展，乘风破浪，追星揽月。

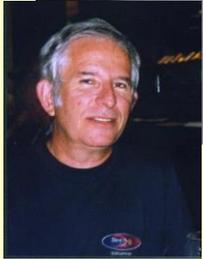
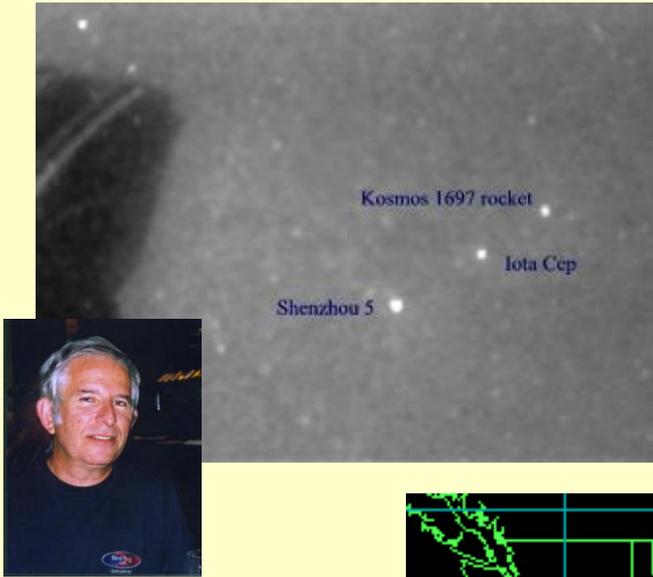
## Approximate locations of Yuanwang ships



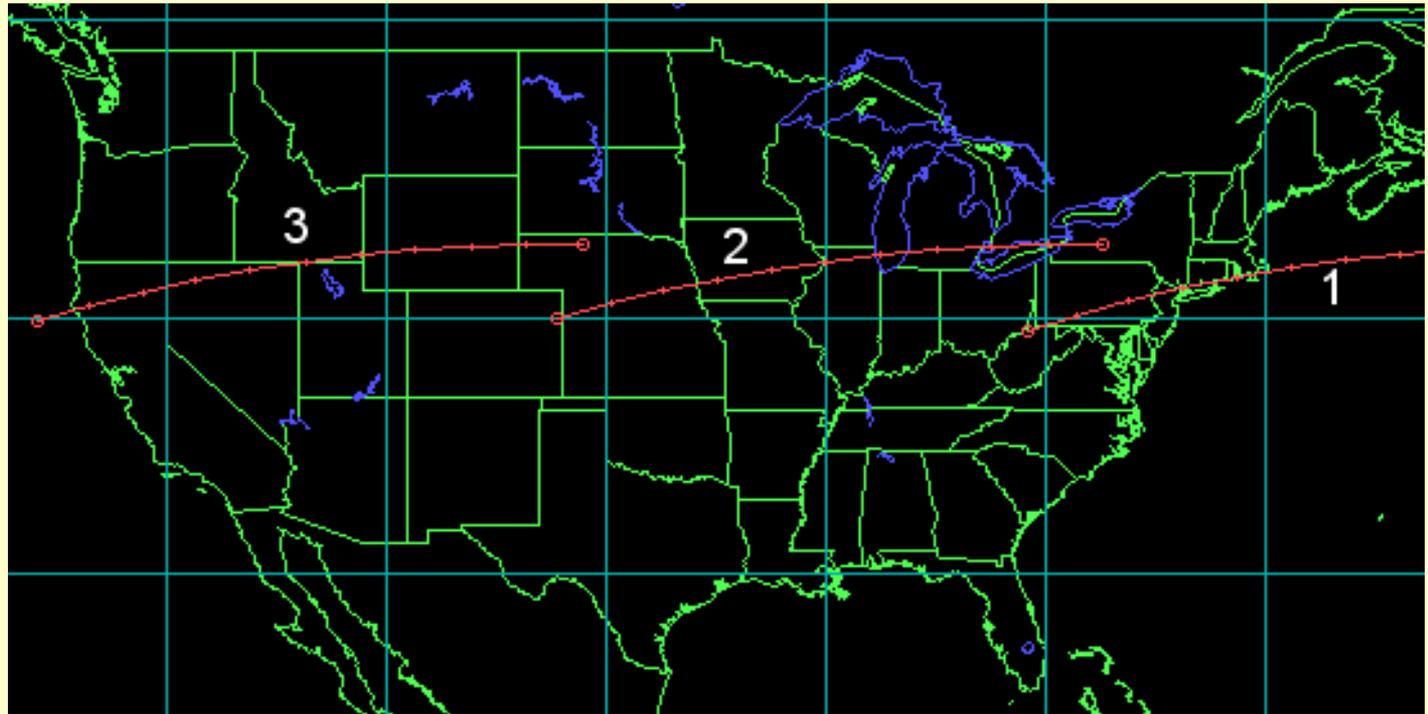
# Shenzhou Orbits and Tracking Ships

# Visually tracking Shenzhou-5

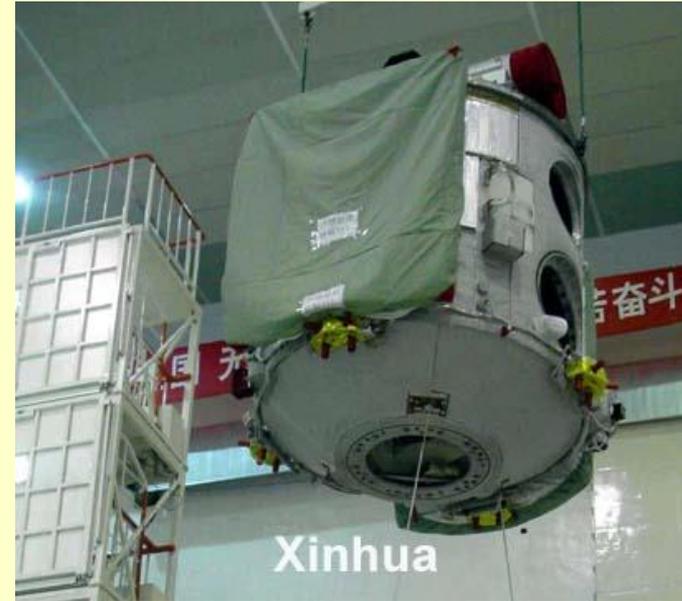
A fortuitous coincidence of orbital plane and sunlight allowed Shenzhou to appear as a moving star in the predawn sky along arcs across the northern hemisphere (below).



CCD image (top) was made by Paul Maley, one of the world's most avid amateur satellite observers, after an all-night car chase across the midwest. Such observations often give critical information on the space missions.

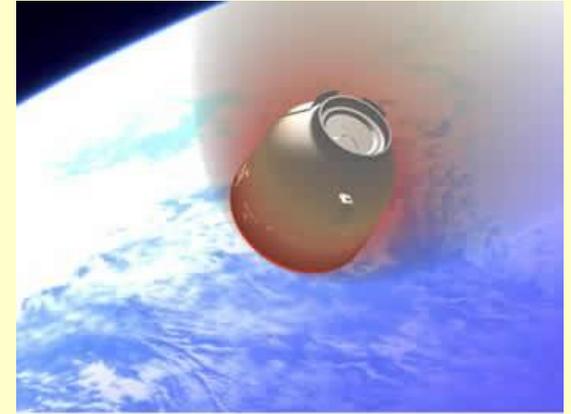


# Shenzhou 'Orbital Module' Free Flight



With its own solar panels, the OM can continue in space for research or for re-docking by later missions.

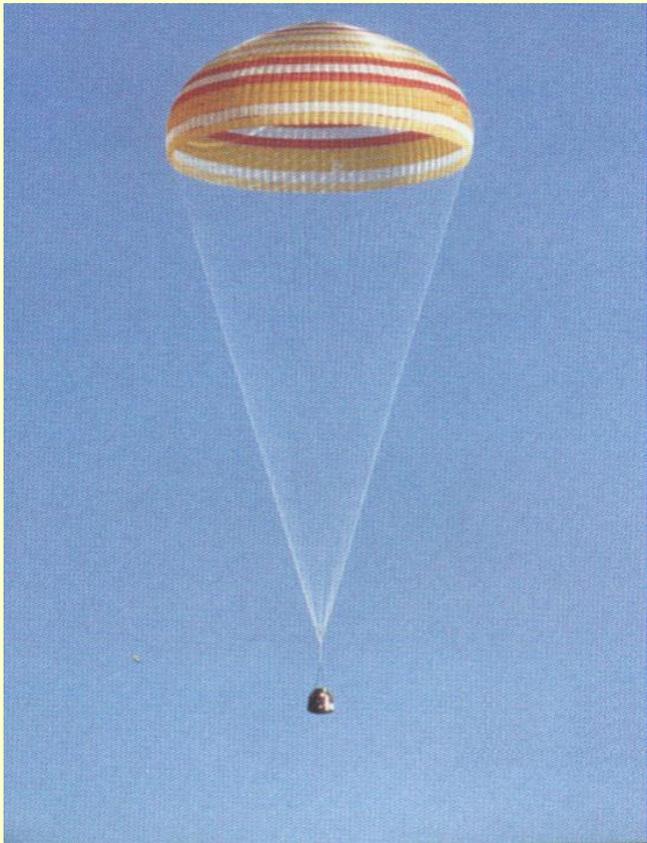
# Returning to Earth. . . .



Shenzhou performs de-orbit burn (left), separation, and entry (right); as viewed from launch site, SM disintegrates while CM fireballs home



# Shenzhou Parachute Landing



[top] Russian  
Soyuz landing

[left] Chinese Shenzhou spacecraft descending on parachute  
[upper center] Firing of soft-landing engines prior to impact  
[lower center] Shenzhou parachute spread out on ground

# Astronaut extraction – Shenzhou vs. Soyuz



Once recovery forces arrive at landing point, Shenzhou command module (left) is fitted with platform/slide like the design used for Soyuz (right)



Note how Shenzhou appears to be a bit larger than Soyuz – and it is.



# Shenzhou vs. Soyuz

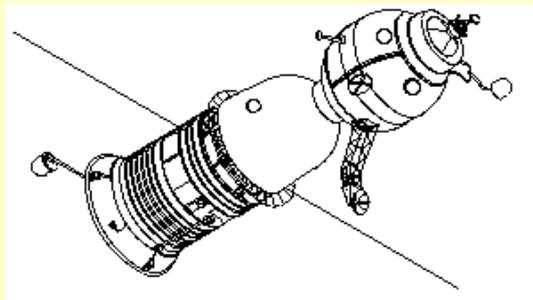
## A Family Resemblance??



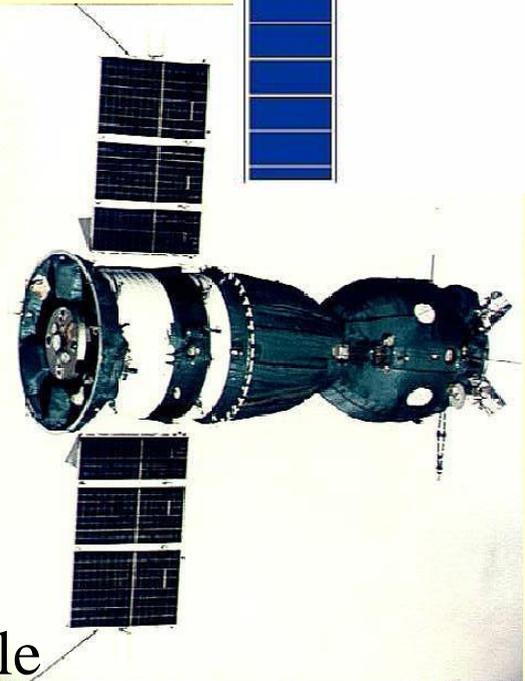
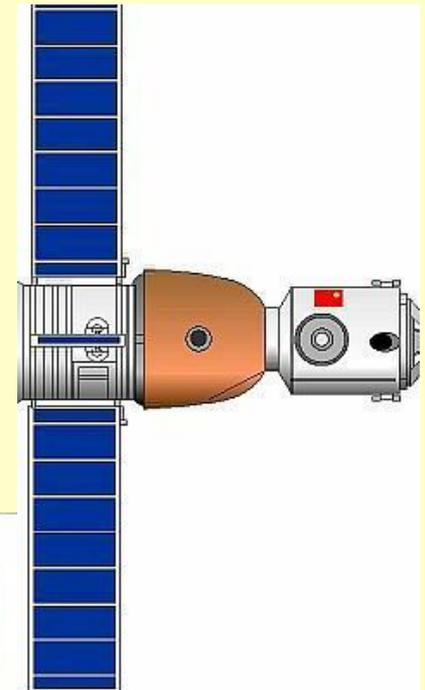
Shenzhou (Chinese) vehicle (top L, R)

NY Times (Jan 3, 2003):  
“The Shenzhou spacecraft are converted Soviet capsules from the 1960s....”

Agence France Presse:  
“Little more than a slightly modified version of the old Soviet workhorse of space, the Soyuz.”



Soyuz (Russian) vehicle (lower left, lower right)



Some systems clearly were 100% Derivative:  
E.G., In-cabin pressure suits



Shenzhou

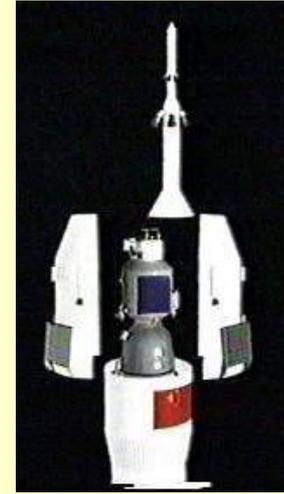


Soyuz

Some were very similar:  
e.g., Launch-Escape-Tower



Test firing of Shenzhou  
launch escape tower



[Top] Spacecraft with aero shroud and ‘escape tower’: left, Russian Soyuz; center & right, Chinese Shenzhou.

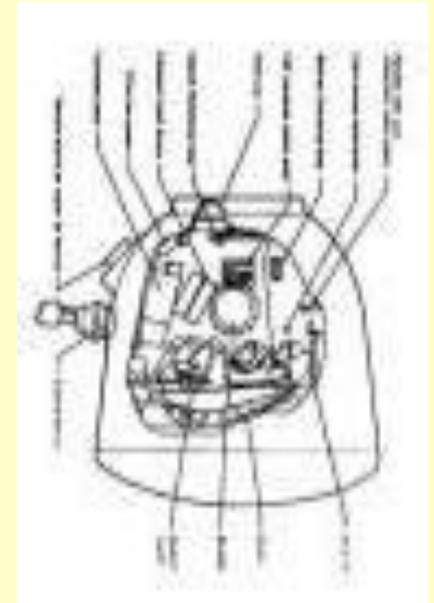
Huang Chunping on stabilization flaps: *“This is the most difficult part of the escape system. We once wanted to inquire about it from Russian experts, but they set the price at \$10 million. Finally we solved the problem on our own.”*



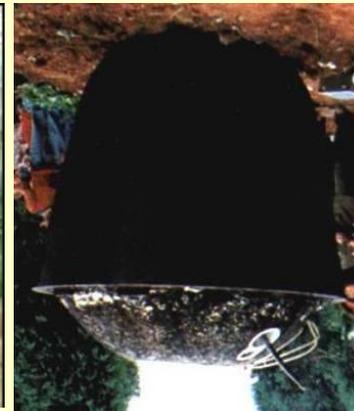
# Shenzhou, Soyuz CM shape similarities



Shenzhou (left top/bottom),  
Soyuz cutaway (right),



Chinese small recoverable  
satellite (below right)



# Shenzhou-Soyuz Parachute Compartment



Parachute compartments of Russian 'Soyuz' (left) and Chinese 'Shenzhou' (right).

# Close-up of 'recoverable satellite' recently when it hit a house



# Moscow Cosmonaut Training (1996-7)



Li Qinglong and Wu Jie learn what Russia has to teach about human space flight. They graduate (below) with full certificates.



@Neil Costa

# Russian space tradition: autograph the guest-room door

Since the very first flight, cosmonauts autographed the door of their quarters at the launch site (left); aware of the tradition, Yang Liwei did the same (right). It remains unclear whether he also repeated the Gagarin tradition about the tire on the bus to the launch pad (below).



# Open credit to Russian help

*Liaowang* magazine (Xinhua News Agency), 2002:  
“After China and Russia signed a space cooperation agreement in 1996, the two countries carried out very fruitful cooperation in docking system installations, model spaceships, flight control, and means of life support and other areas of manned space flight. **Russia’s experience in space technology development was and is of momentous significance as enlightenment to China.**”

[For perspective, it should also be pointed out that the docking mechanism on American space shuttles is also based on this same Russian design]

# Technology Acquisition Issues

- Commercially purchased
- Cooperatively learned
- Openly researched
- Surreptitiously obtained
- Domestic transfers
- Specific R&D

# How Do We 'Find Out' About Chinese Space?

- Official announcements
- Press Accounts
- Personal conversations
- Implications of released information
- Non-Chinese government statements/leaks
- Non-Chinese private observations
- Analogies with Soviet 'space race'



# Significant openness about personnel

Luan Enjie, Director, China National Aerospace Administration

Qi Faren, 'General Designer' of Shenzhou spacecraft

Yuan Jiajun, 'Chief Director' of Shenzhou program operations

Zhang Qingwei, 'General Manager' of 'whole manned space industry'

Wang Yongzhi, 'Chief Designer' of entire manned program

Li Jinai, 'Commander-in-Chief' of manned spacecraft project

Yuan Jie, Director, Shanghai Aerospace Bureau (builds the Shenzhou)

Su Shuangning, 'Chief Director/Designer' of astronaut systems

Gu Yidong, 'Commander and Chief Designer', application systems

Zhao Jun, 'Commander and Chief Designer', landing systems

Huang Chunping, Commander-in-Chief of SZ-2F booster program

Liu Zhusheng, 'Chief Designer' of Shenzhou carrier rocket system

Zhou Jianping, 'Chief Designer' of the 'launch system'

Xie Guangxuan, 'Chief Designer' of CZ3 booster

Sun Baosheng, 'Deputy Chief Designer', telecommunication system

Ouyang Ziyuan, 'Chief Scientist' of lunar projects

Much more information  
than Soviet-style  
'Space Race' secrecy  
(EG, names of candidate  
astronauts available)



Leaked to press in mid-2003:

*Chen Quan, Deng Qingming, Fei Junlong, Jing  
Haipen, Li Buoming, Li Qinlong, Li Wang, Nie  
Haishen, Pan Zhanchun, Wu Jie, Yang Liwei, Zhai  
Zhigang, Zhang Xiaoguang, Zhao Chuandong*

## *Nov 2000: 12-page SPACE 'WHITE PAPER'*

**\*\*** “The continuous development and application of space technology has become an important endeavor in the modernization drive of countries all over the world.”

**\*\*** “The Chinese government has all along regarded the space industry as an integral part of the state's comprehensive development strategy.”

**\*\*** “A number of satellite application systems have been established and have yielded remarkable social and economic benefits.”

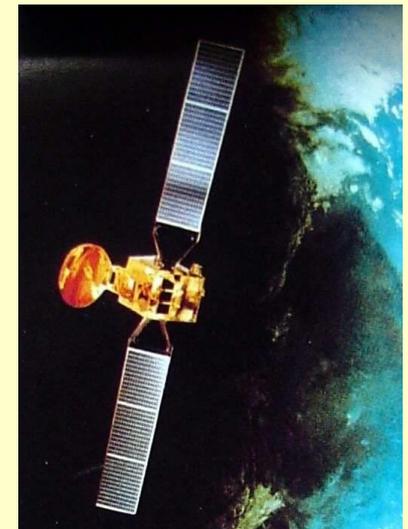
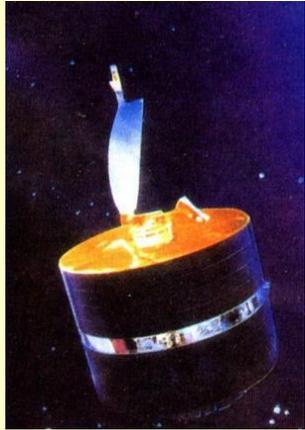
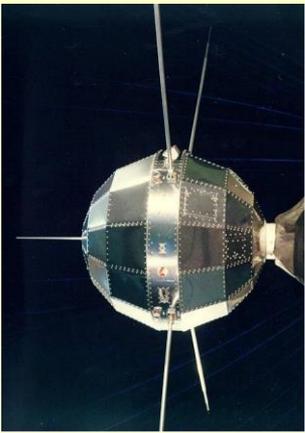
# Applications satellites

(left) DFH-1 (top), -2 (center), -3 (bottom) commsats (Dongfanghong = 'East-is-Red')

(right top) Zi-Yuan Chinese-Brazilian Earth Resources Survey Satellite (two launched)

(right bottom) Bei-Dou navigation sat

(below) Feng Yun (FY-2A) "Wind-Cloud" geosync metsat, launched 1997 to 105° E



## **‘Space White Paper’ on Central Control**

"The state guides the development of space activities through macro-control, makes overall plans for the development of space technology, space applications, and space science, promotes the R&D and system integration of important space technologies and the application of space science and technology in the fields of economy, science and technology, culture, and defense."

***“The state's supervision over space activities is being continuously strengthened.”***

# Dependence on Omniscience ‘At The Top’

“China's various types of artificial satellites, in their research and manufacture, are all under unified national leadership...” that will “correctly select technological paths, strengthen advanced research, and constantly initiate technical advances. We must constantly select development paths where the technological leaps are the greatest.” Strict funding constraints require selecting “limited goals and focus[ing] on developing the ... satellites urgently required by our country,” and on determining which satellites “are most crucial to national development.”

-- Xu Fuxiang (February 2001)

## *Ideological Idiom:*

“Concentrating superior forces to fight the tough battle and persisting in accomplishing something while putting some other things aside.”

# Skepticism of tightly-focused control

Dr. Joan Johnson-Freese:

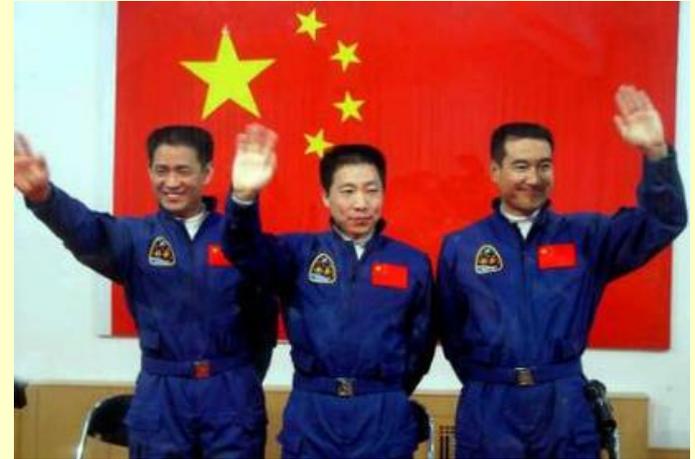
“They are not building the science/technology infrastructure necessary for a broad program,” a “critical” issue.

"Asian programs generally are weakest on the systems engineering issues, those which require 'big picture' orientation. The Japanese are at least aware of that weakness and try to compensate -- the Chinese, less so."

"It is likely that [this weakness will catch up with the Chinese] at some point."

# Shenzhou-6 – when and what?

Early expectations of rapid-fire  
sequence of missions not fulfilled  
by slow, methodical approach



China has fourteen astronauts  
in training; they plan to try a  
spacewalk (below) ‘soon’ but  
not on next mission.

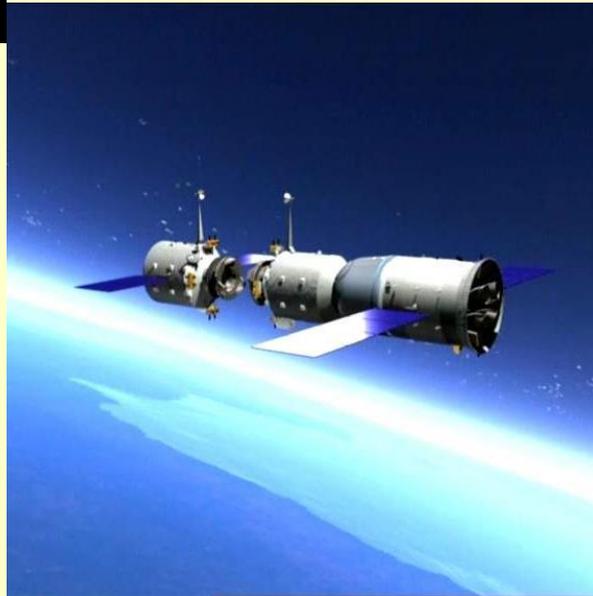


# Space Rendezvous & Docking



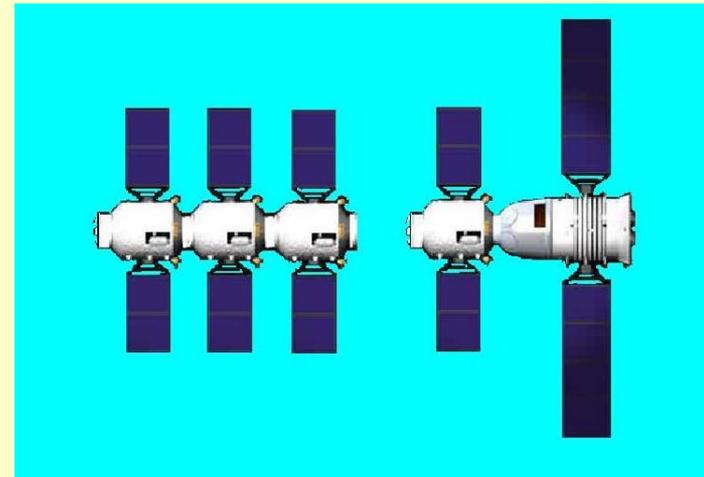
(Top) First tests will probably involve short-range redocking with detached Orbital Module

(Center) Later a test flight would chase down a module left in orbit previously.



(Right) Artist concept (unofficial) of 'module train' of small units to build up room & power in orbit for brief visits.

Rendezvous and docking is the key to space station missions, military space inspection capability, and eventually to a manned lunar landing like Apollo.



# Shenzhou Military Applications?

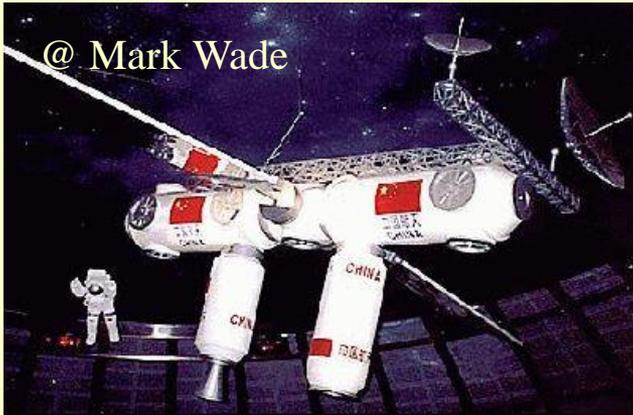
Photographs of equipment associated associated with the Orbital Module suggest usage for image & electronic reconnaissance, and maybe others.



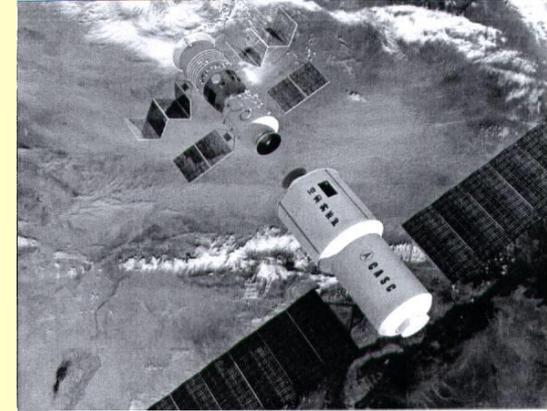
# Puzzle over forward-mounted module (sub-satellite?)



# Space Station Plans

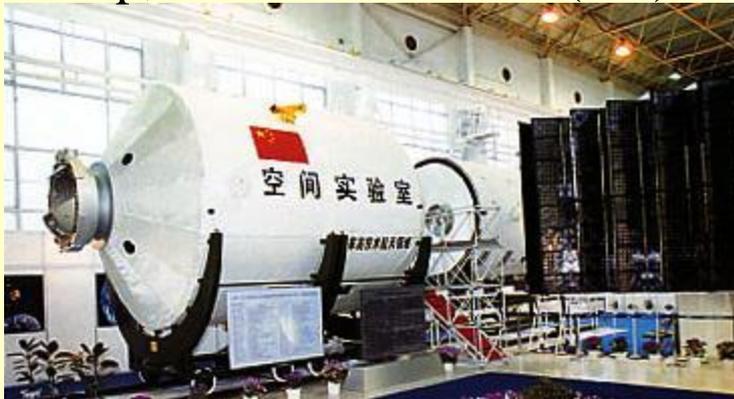


Modular concept displayed at European trade fair, 2000



Artist concepts of station (below) and Shenzhou docking (above).

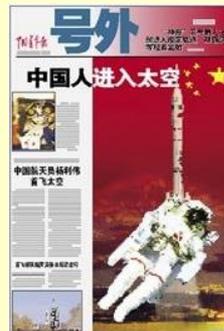
Official photograph of space station mockup, 2003. Note APAS (left).



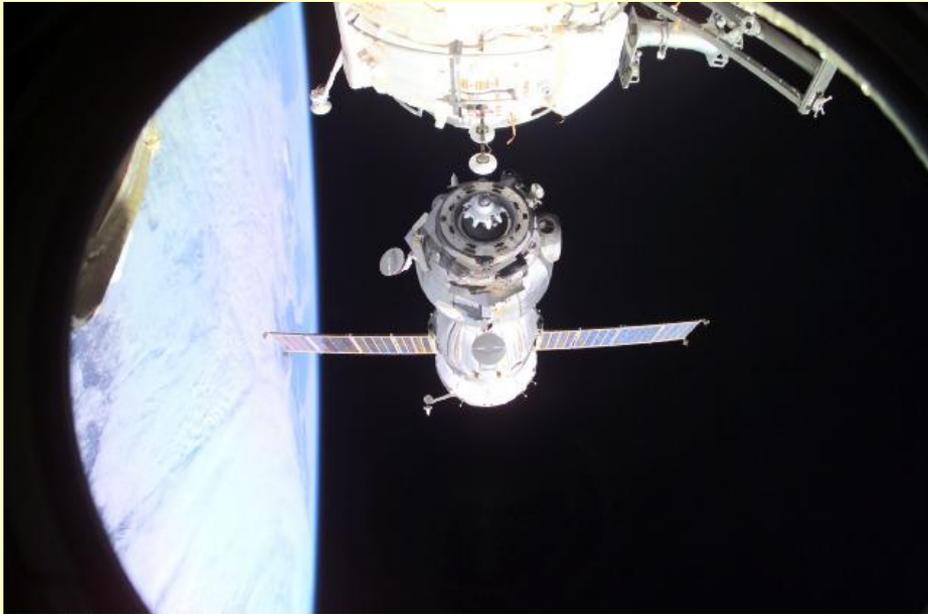


# Caution – Art Often is Direct Rip-Off

Much of the art published during recent enthusiastic press coverage is merely Western space hardware with Chinese flags painted on.



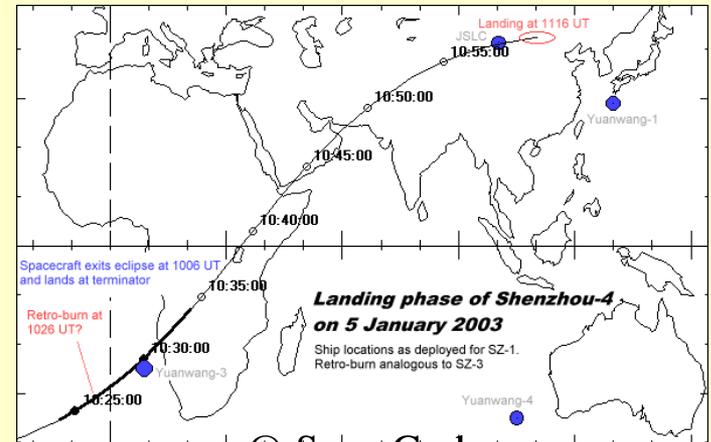
# Will China Have A Role on the International Space Station?



ISS003E7122 2001/10/31 01 43 09

Shenzhou vehicles could visit, and could ferry supplies and personnel to the ISS and back within a few years.

Tracking site recently completed in Namibia is directly below normal landing path BUT return from ISS orbit passes too far south for tracking



@ Sven Grahn



# Why the Moon?

Wu Ji (Deputy Director, Chinese Academy of Sciences' 'Center for Space Science and Applied Research', declared that Chinese Moon probes will aim at questions not addressed by previous missions, stressing the importance of doing "something unique“.

Other sources states that Chinese probes will study the geological evolution of the lunar soil, its interactions with the solar wind and will analyze its chemical composition.

Most interviews and published accounts of lunar applications appear to be derivative of the existing Western literature (e.g., 'helium-3') and not a reflection of any approved domestic program.

# Booster choice for initial lunar missions

Yu Mengjun: Research on a Chinese Lunar Probe Launcher; Aerospace China, No. 11, 2002

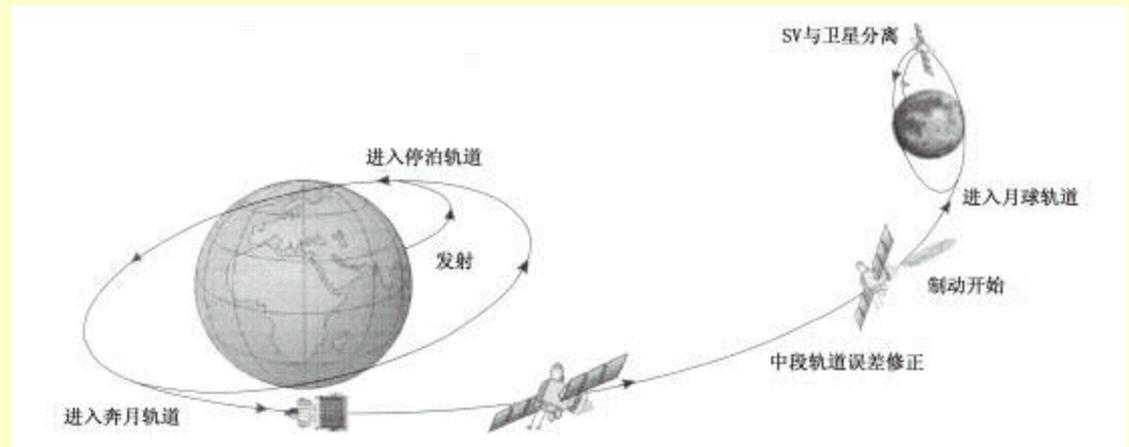
Comment: This paper reveals details on the Chinese lunar launchers. Due to its injection accuracy, it appears that a CZ-3A based launcher (i.e. a CZ-3A, -3B or -3C) would be the best choice. The paper publishes the following payload characteristics for several Chinese launchers

<b>Launcher</b>	<b>to Lunar Orbit</b>	<b>to Lunar Surface</b>
CZ-3A	1700	500
CZ-3B	3400	1250
CZ-3C	2400	800
CZ-5 "light"	4400	
CZ-5 "medium"	8100	
CZ-5 "heavy"	10600	

# Cheng-Eh Lunar Probe



Lunar orbital probe (left) is to be built on basis of DFH-3 communications satellite (lower left)



"Chang'e" is a character who flies to the Moon in the Huai Nan Zi fairy tale, 4<sup>th</sup> C. BC.

Typical trajectory of simple lunar probe shows checkout, transfer, and arrival.

## **Chang-Eh Moon Satellite's Technology Base (DFH-3) Was (According to Cox Report) Largely Western**

*Cox: “DFH-3 commsat (1994) had its development time cut in half by use of a large number of Western components”:*

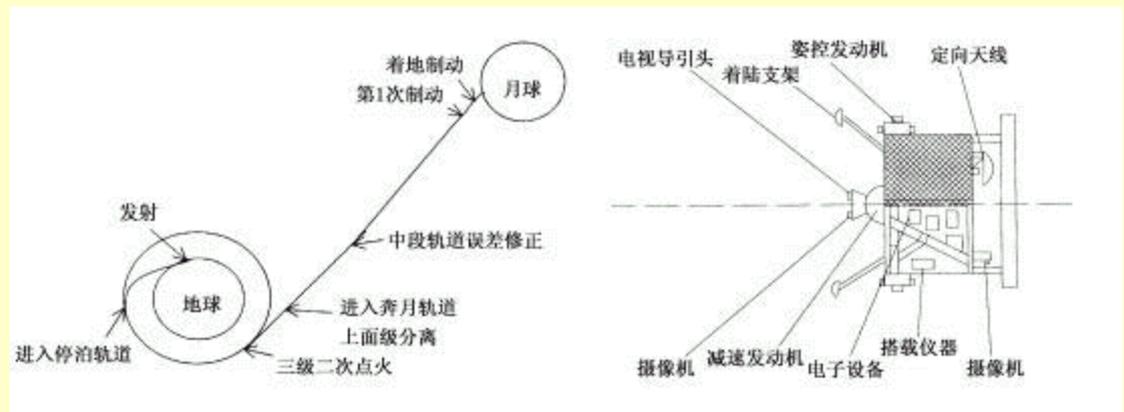
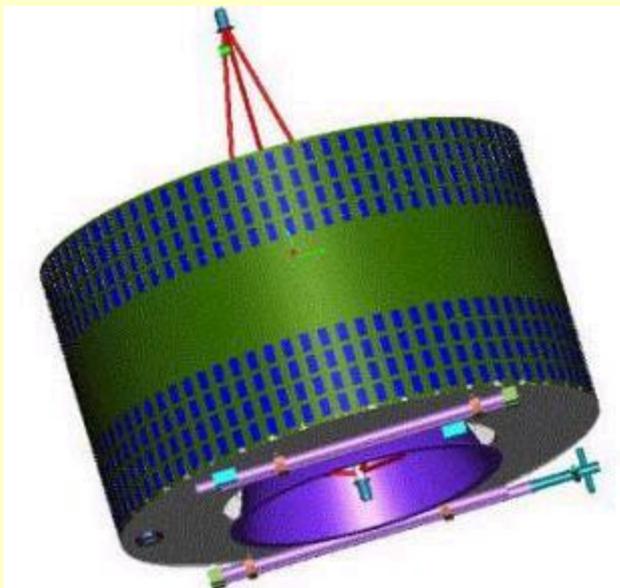
- \* Central processor was built by Matra-Marconi;
- \* The solar panel substrates provided by Messerschmitt-Boelkow-Blohm, which also performed final fabrication;
- \* The antenna assembly, consisting of a deployable dual gridded reflector, feed, and interconnecting structure, was built by Daimler Chrysler Aerospace Group
- \* IR Earth sensor (attitude control) built by Officine Galileo;
- \* Payload test equipment consisted of five racks with 80% US equipment; racks provided by German corporation.

# Other moon proposals

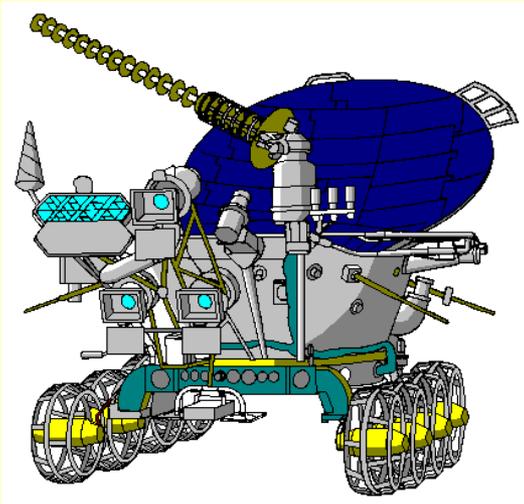
Tsinghua University's "LunarNet" -- a polar orbiter equipped with sixteen 28 kg landers, to be released in equally spaced areas on two mutually perpendicular orbital planes. The landing system, probably using airbags, would ensure surviving a landing at speeds between 12 and 22 m/s. Each lander will carry a camera, temperature sensors, cosmic ray detectors, a penetrometer, an instrument for the measurement of soil magnetic properties and other instruments. Use relay satellite for earth comm.

"Lunar Rabbit" -- This 330 kg probe will cost as little as \$ 30 million and will be launched on a geostationary transfer orbit from the Xichang space center. Insertion into a lunar transfer orbit will be carried out on the following day using the on board bipropellant engine. At the time of the third apogee the probe will be inserted in a 100 to 200 km high lunar orbit where it will split into two components. The first, apparently based on the Double Star scientific satellites, will carry out an orbital mission, using a CCD camera, an infrared camera, a radar altimeter and a radiometer. The second will head for a lunar landing. This lander, braked by a solid propellant engine, will carry only a camera and will test optimal control algorithms discussed in some length in Chinese literature. Once on the surface the lander will release a 60 sq. meters Chinese flag.

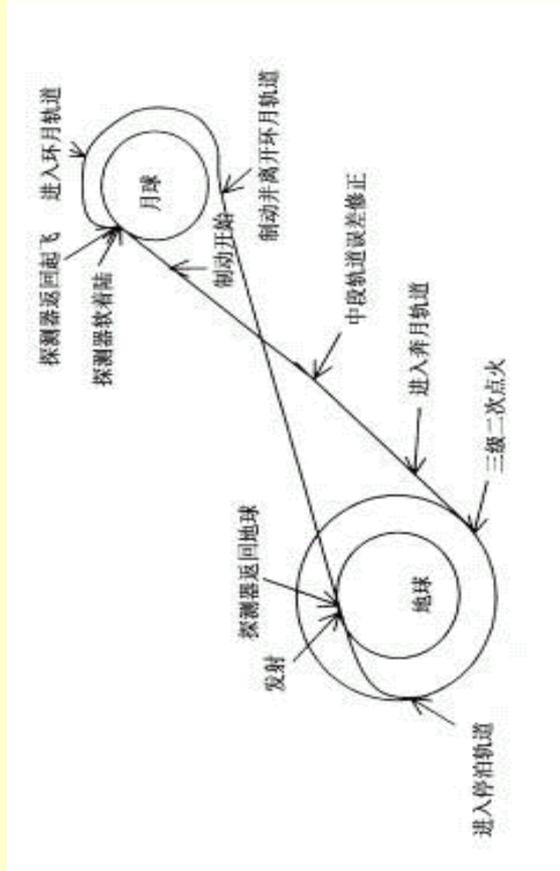
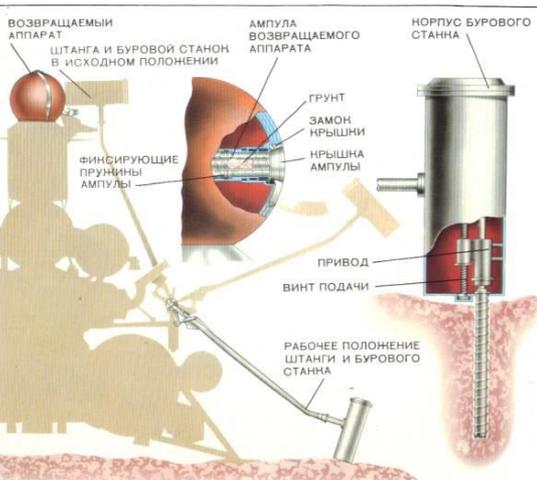
# “Moon Rabbit” small lander (based on ‘Double Star’ payload) and trajectory plans



# Lunar Rovers and Samplers



Soviet precursors such as Lunokhod (top) and sample return (bottom) show capability of CZ-5-class boosted payloads



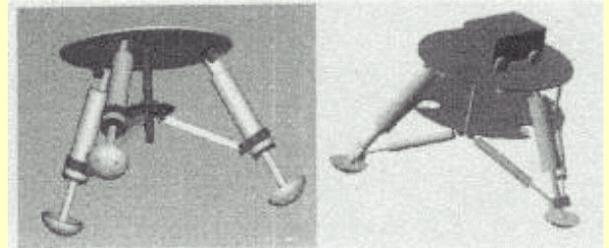
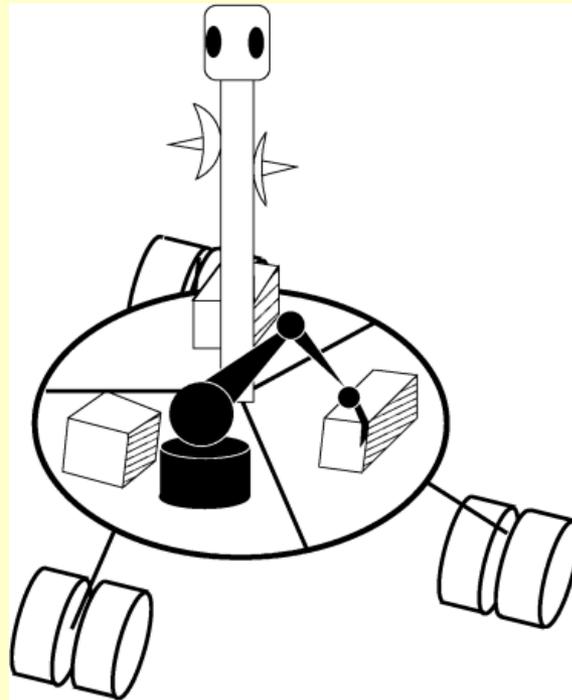
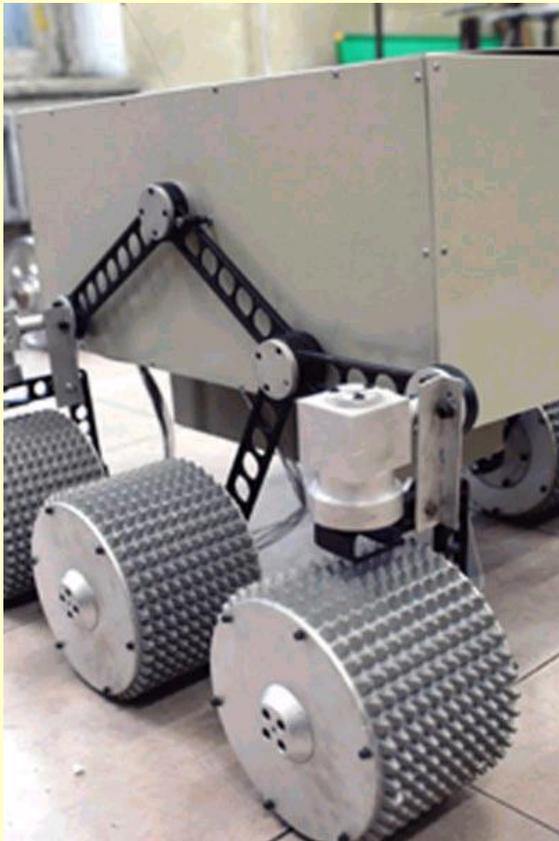
Theoretical flight path studies show interest, not intent.



Toy 'moon-buggies' (above) now are widely sold in China; but sometimes a space toy is just a space toy (below)



# Numerous 'rover' models studied in university engineering class projects



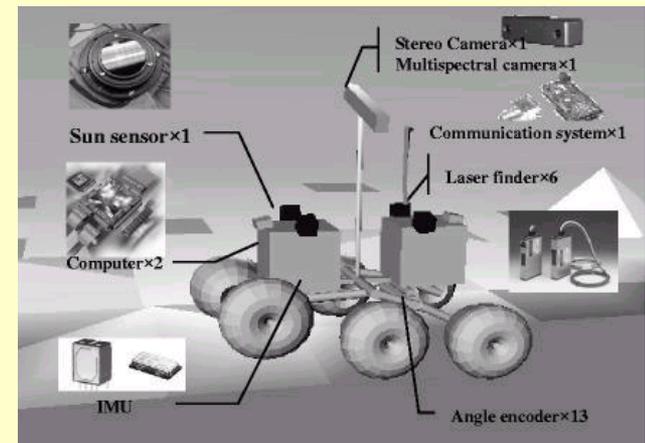
# 火星

# Mars

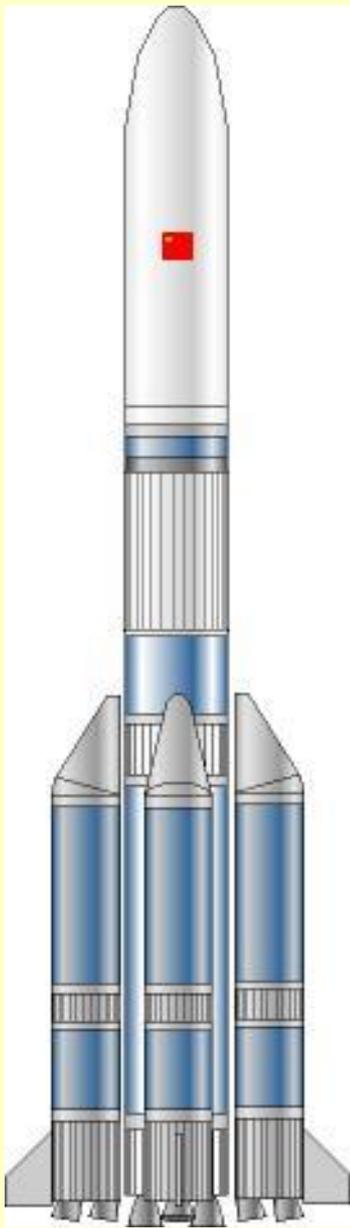


*(Above): Cui Pingyuan, director of the Deep Space Exploration Center of the 'Harbin Institute of Technology' answers questions from Chinese TV during the "5th Chinese International Exhibition of Space Technology" held in Beijing in November 2003. Behind him is a model of a Chinese Mars orbiter. Courtesy Paolo Ulivi.*

*May 2002: a prototype Mars rover unveiled at the China Sci-Tech Week held in Beijing. The "Mars Explorer" rover was said to be based on NASA's Mars Exploratory Rovers, and had six wheels, a square-shaped body and a sensor "head" weighing around 20 kg. Each of its six wheels is powered by two independent motors for redundancy. Between the rover body and wheels is a mechanical arm, able to crush stones and perform chemical analyses. See below:*



# Plans for the CZ-5 Booster

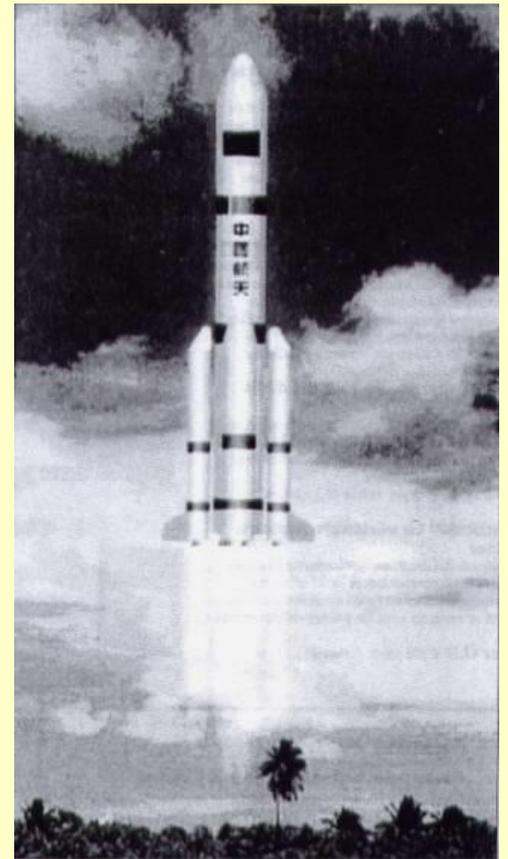


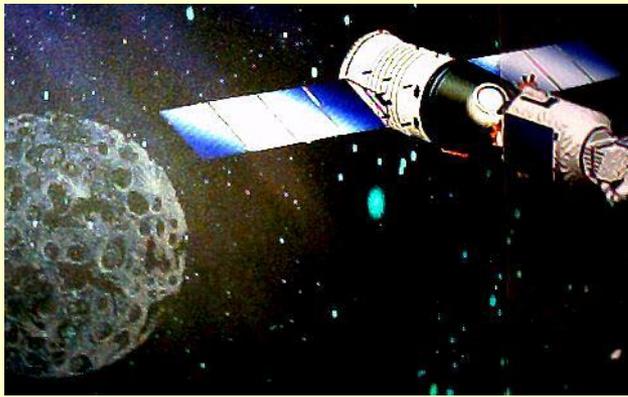
@ Mark Wade

Officially-described vehicle for heavy commsats and for large manned space station.

Ariane-5-class vehicle is a major quantum-jump in the 'Long March' family and presents very formidable engineering challenges.

Designed for sea transport and launch only from new Hainan Island site (right)

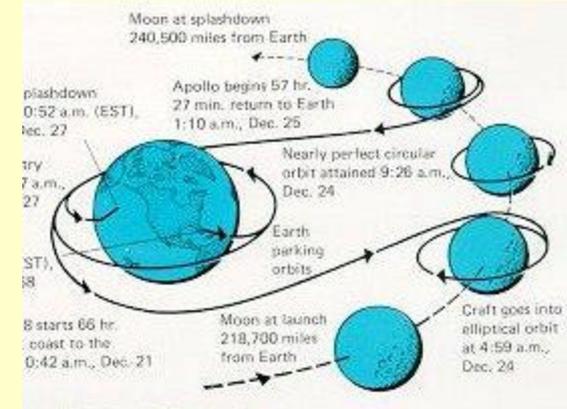
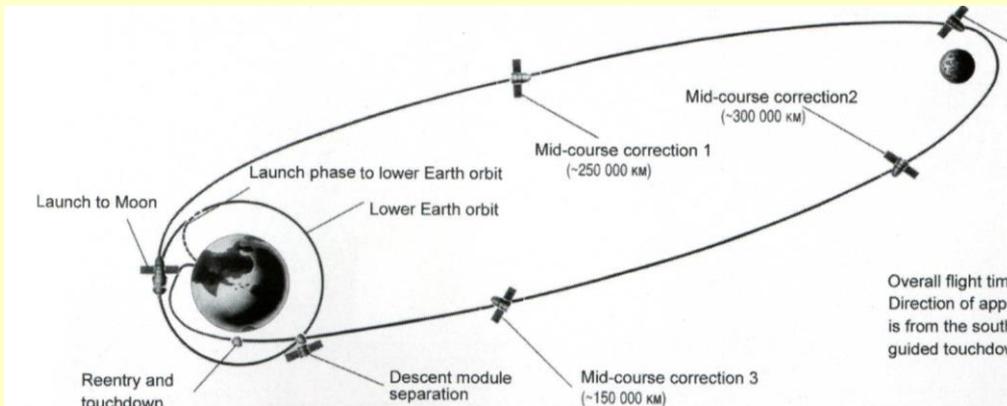




# Manned Lunar Flight?

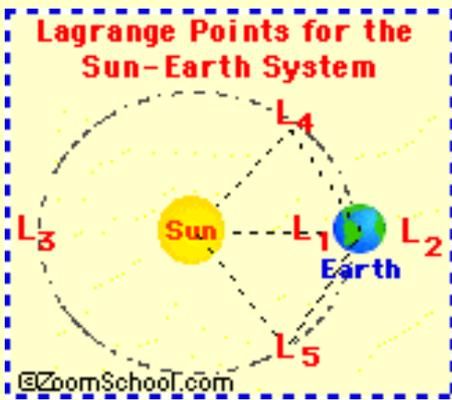
@ Mark Wade

“China intends to conduct a mission to circumnavigate the Moon in a similar manner as was carried out by Apollo-8 in 1968. This mission will apparently involve a modified Shenzhou spacecraft and will be launched around 2006.” **FUTRON Corporation**, *China and the Second Space Age*, October 15, 2003, p. 7.

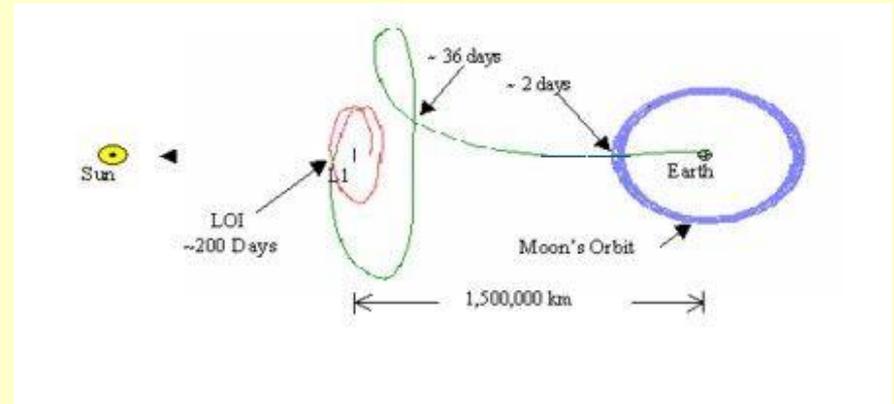


Two different possible flight plans are a simple swing-by (left, as with Soviet ‘Zond’) and orbital (right, as with Apollo-8). Simpler variant could be carried out with a single CZ-5 launching; orbital profile could require two launches.

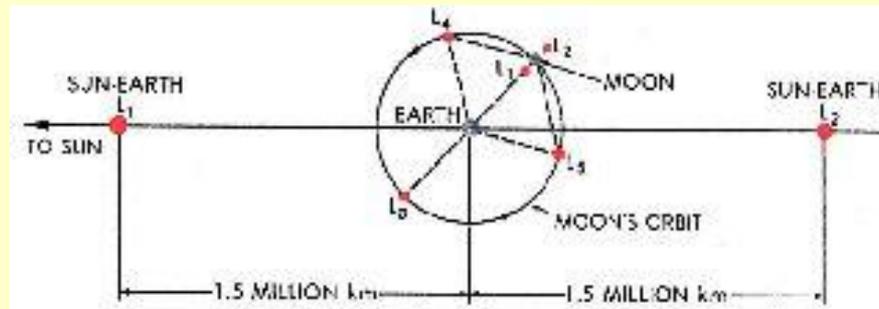
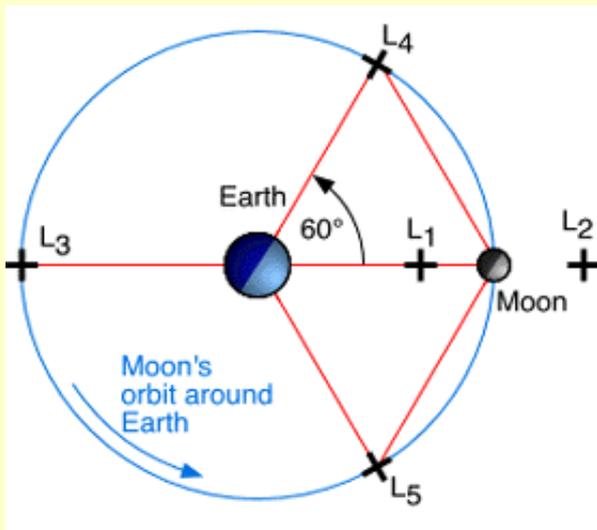
# Earth-Moon Space: Other specific 'locations of interest'



Classic 'Lagrange points' were associated with planetary orbits. Space probes make use of the Sun-Earth L1 (right) and L2.

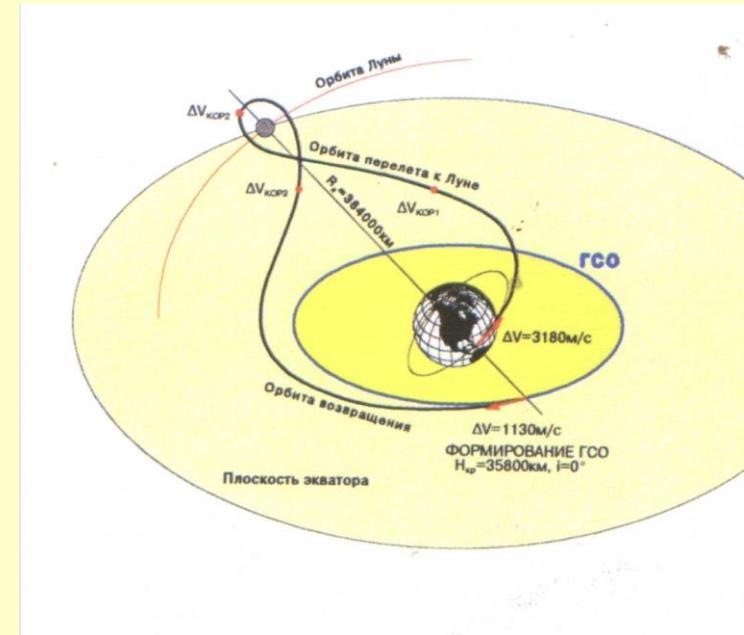
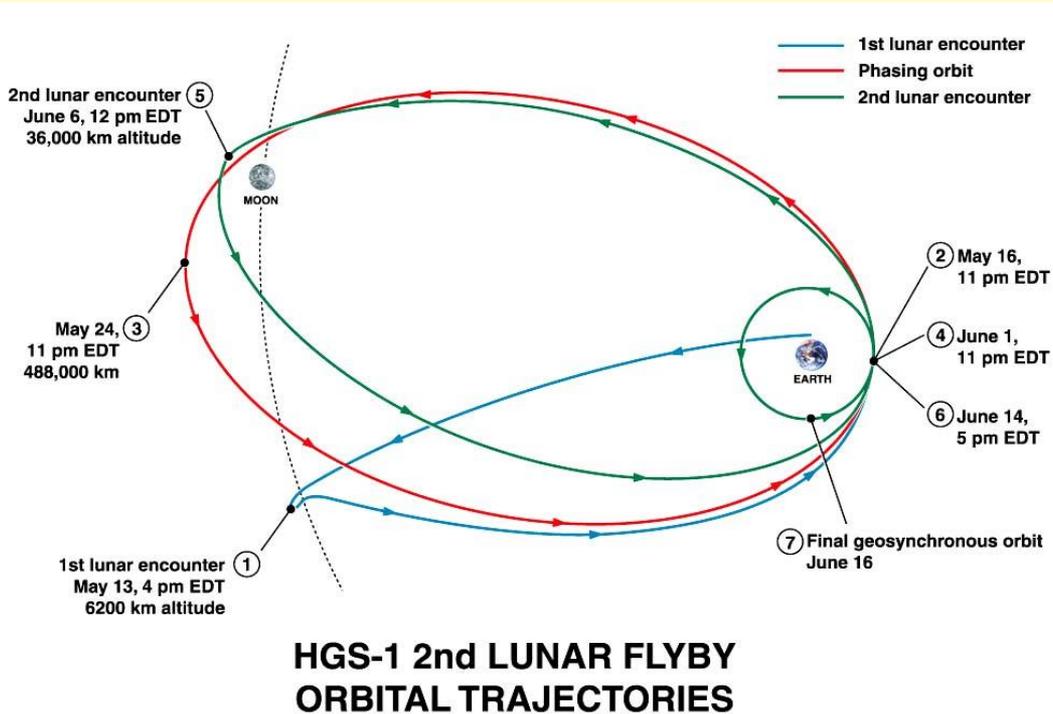


Earth-Moon system also has 'Lagrange points' (left) that have been suggested for lunar exploration support. All 'local' Lagrange points are shown below:



# Moon as a backdoor to any other orbit of interest

Case study: Hughes commsat rescue to GEO



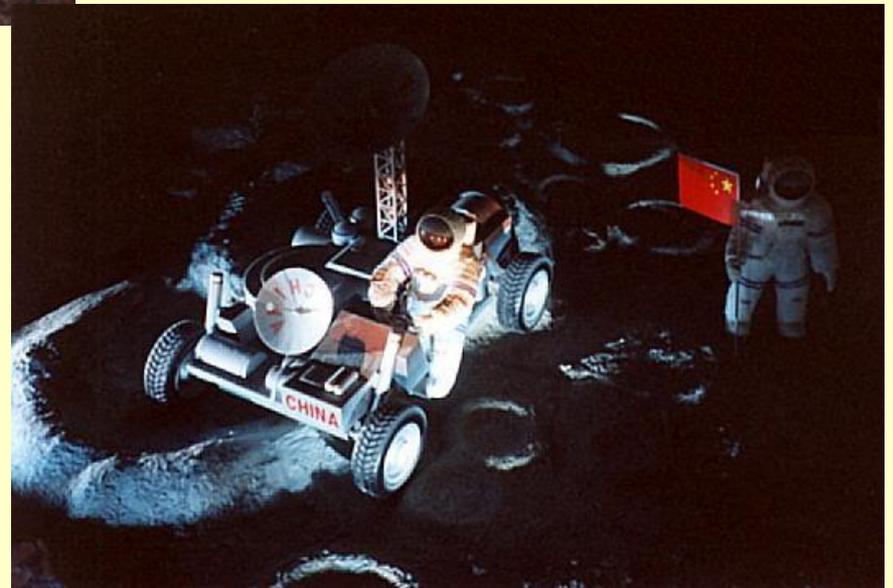
Translunar opens way to undetected access to GPS (12-hr), GEO, retro-GEO, unexpected low-altitude passes, etc. 55

# Chinese Astronauts on the Moon?



@ Mark Wade

These dioramas at a Chinese trade exhibit in Germany in 2000 seem to only be copies of US Apollo hardware with flags added. There is little if any credible evidence that such hardware is even being designed in China for actual human missions to the Moon.





# ‘Shenzhou’ versus ‘Constellation’

Both China and US are now developing human space vehicles for use in low earth orbit and then eventually beyond; the Chinese vehicle already is flying, the US vehicle has more experience to support its development.



Both vehicles can carry 3 or more crew, are launched on expendable boosters, have launch-escape-systems, can rendezvous and dock in orbit, and return on dry land. Both promise to outstrip capabilities of the Russian ‘Soyuz’ vehicle, just as Russia wants to replace it.

# Strategies: Copying versus Innovating?

- a) Have any indicators appeared that China may be implementing some kind of strategic plan to "get on top of the US" in space by developing capability to operate in (or even dominate) cis-lunar space and key regions such as L points and orbits above GEO?
- b) Are there any reasons to suspect that China may be pursuing some kind of space architecture that would be fundamentally different from the "traditional" architectures developed over the years by the US and Russia?
- [E.G., a strategic shift towards networked constellations of microsats in lieu of large sats for C4ISR operations, and/or the development of some kind of highly flexible, rapid launch infrastructure.]
- c) What indicators should we be watching for that China may be pursuing these kinds of strategies (or others for that matter).

# What indicators proved helpful in forecasting (even in hindsight) 1960's Soviet space?

- Public statements
- Public silences
- Unmanned test flights
- Infrastructure construction
- Acquisitions menu for shopping abroad
- Scientific theoretical papers
- Crew training (e.g., helicopters)
- Artwork

## Rationale for >> \$1 Billion per year

"China certainly has the political will to forge ahead with its space program. It recognizes all the internal and external prestige-related benefits of space that the U.S. and the FSU did in the 1960s, as well as the technology-industrialization-economic benefits that pushed Europe into space later."

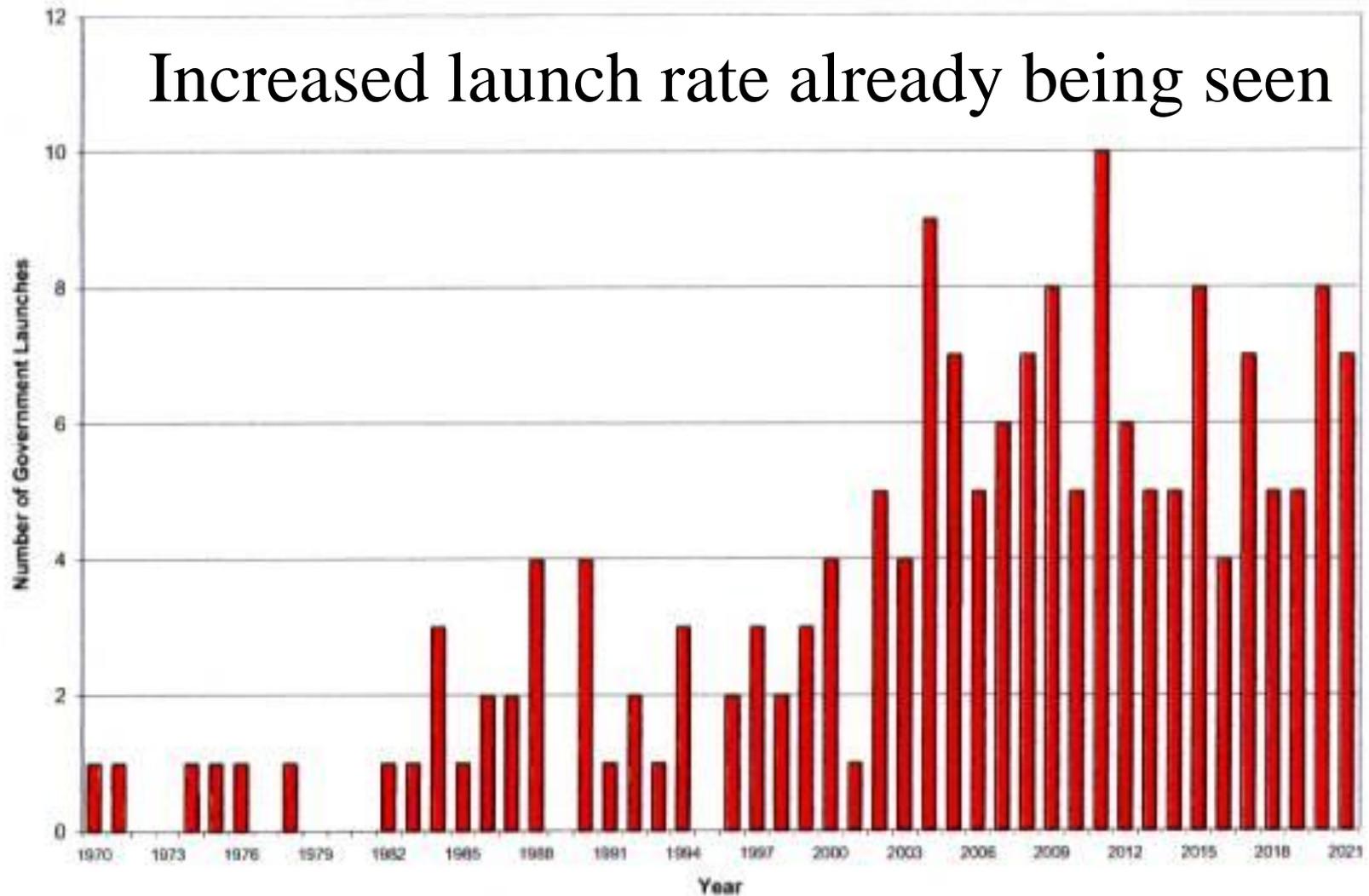
Dr. Joan Johnson-Freese, then in department of transnational security issues at Honolulu's *Asia-Pacific Center on Security Studies*, author of The Chinese Space Program: A Mystery Within A Maze (Krieger, 1998).

## Human spaceflight as a broad technology spur

"From a science & technology perspective, the experience of developing and testing a manned spacecraft will be more important to China's space effort than anything that their astronauts can actually accomplish on the new spacecraft. This is because it will raise levels in areas such as computers, space materials, manufacturing technology, electronic equipment, systems integration, and testing as well as being beneficial in the acquisition of experience in developing navigational, attitude control, propulsion, life support, and other important subsystems, all of which are vitally necessary to dual-use military/civilian projects."

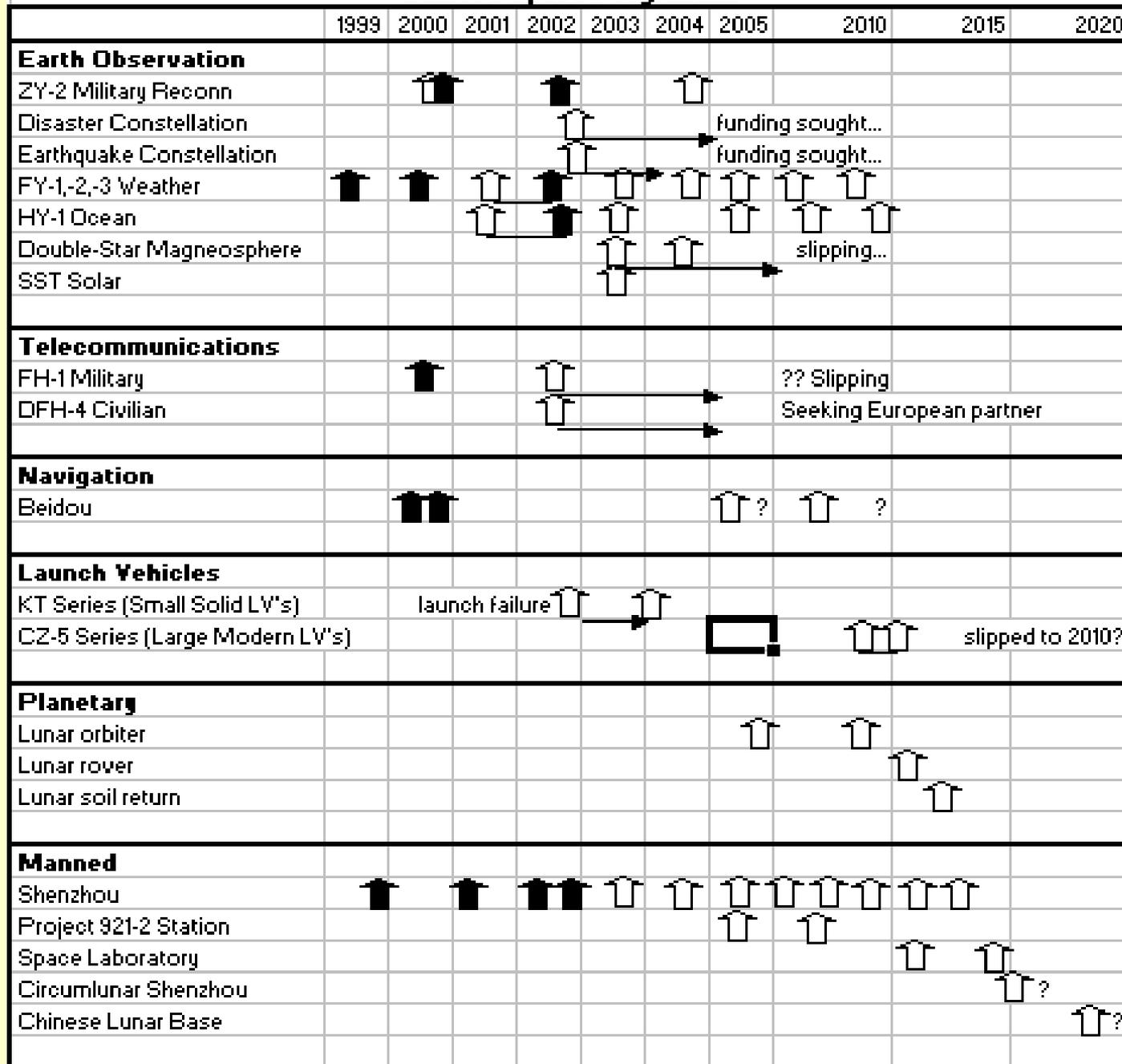
-- *Xiandai Bingqi magazine (June 2000)*

# Increased launch rate already being seen



**Figure 1: Chinese Government Launches (1970-2021).**  
*Future Launch Projection from Futron's ASCENT Study*

## Chinese Space Programme



Chinese space schedule, Mark Wade, [www.astronautix.com](http://www.astronautix.com) (late 2003)

# For China, space is the stage for the future



China's public morale has responded proudly to the news stories about space activities

# China uses 'space militarization' as diplomatic lever

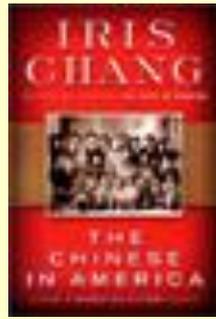
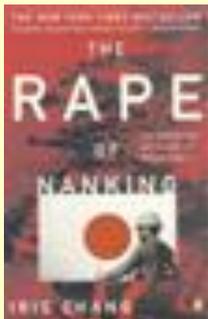
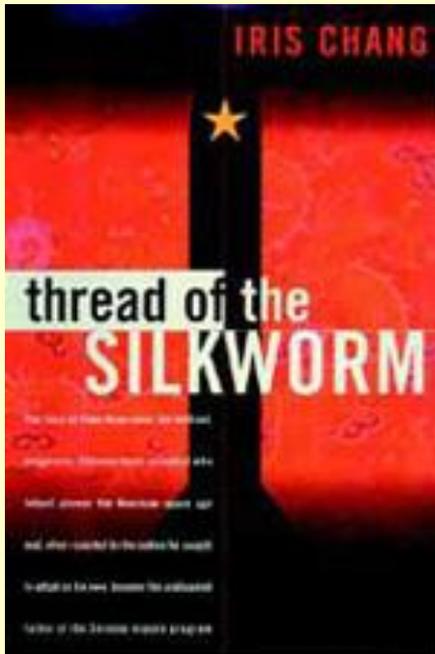


# The “Treasure Fleet” of Admiral Zheng He (Cheng Ho)



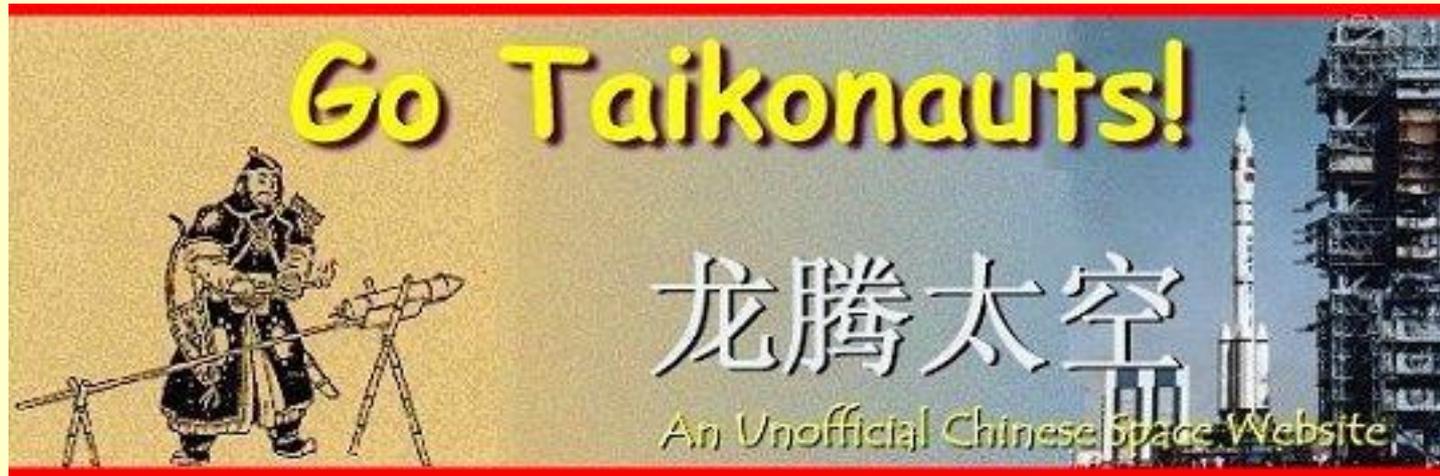
The Chinese decision to terminate these expensive voyages may have been rational in the short term but it led to half a millennium of grief.

Understanding comes through people --  
and the loss of Iris Chang diminishes our ability to understand



<http://www.irischang.net/>

# Chen Lan's Unofficial Chinese Space Website



**<http://www.geocities.com/>**

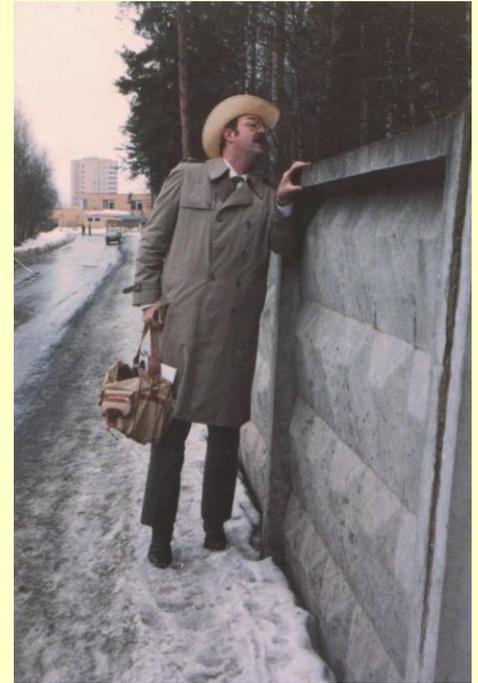
**[CapeCanaveral/Launchpad/1921/](http://www.geocities.com/CapeCanaveral/Launchpad/1921/)**

Also: [www.fas.org](http://www.fas.org) and [www.spacetoday.org](http://www.spacetoday.org)

[www.spectrum.ieee.org/WEBONLY/publicfeature/may01/china.html](http://www.spectrum.ieee.org/WEBONLY/publicfeature/may01/china.html) & [dec01/space.html](http://www.spectrum.ieee.org/WEBONLY/publicfeature/dec01/space.html) (two Oberg articles)

# Have passport, will travel

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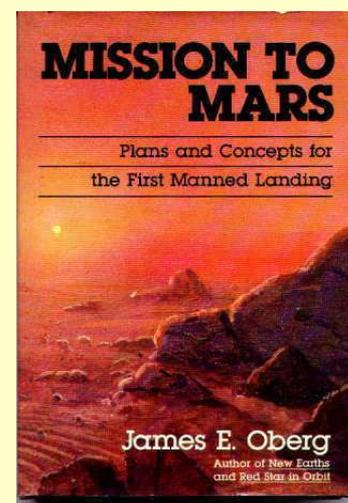
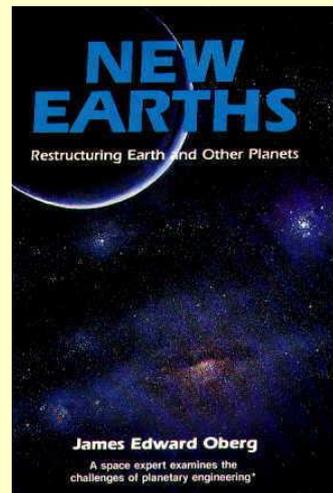
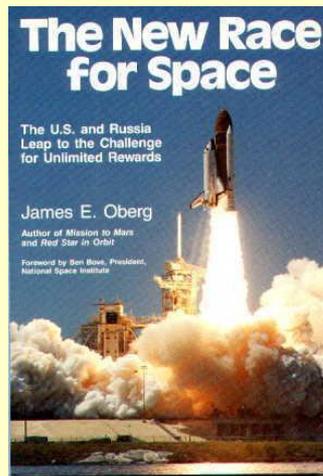
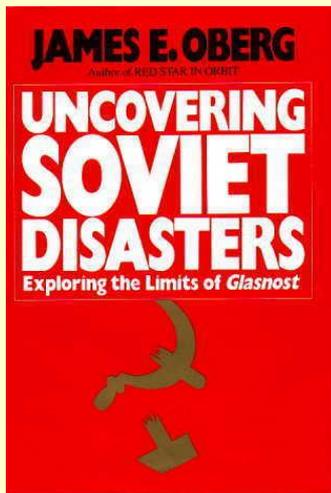
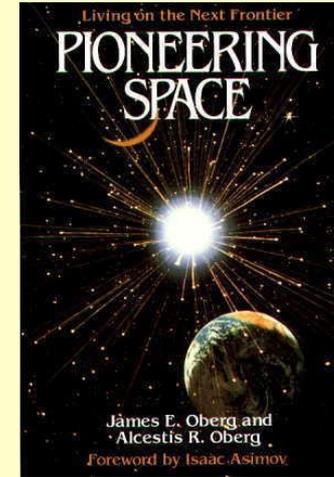
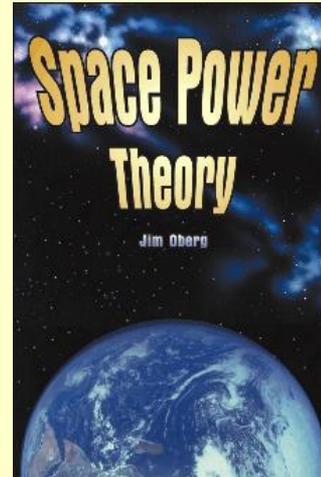
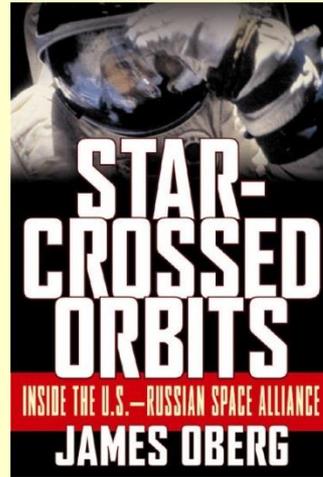
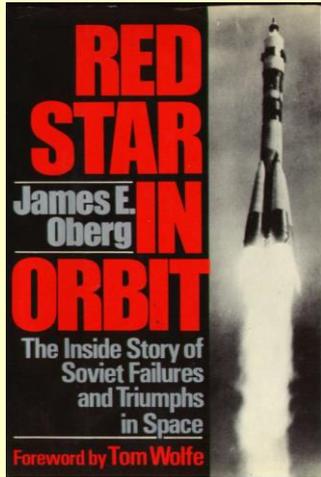


# Spaceflight Consultancies

- Launch services assessments
- Sales of specific components and supplies
- Auctions -- Authentication of Artifacts
- Technology Transfer Issues
- Operations Compatibility
- Commercial Tours
- “Space Tourism”
- Lectures and interviews



# ... And books as well



# Star-Crossed Orbits -- Inside the US-Russian Space Alliance

- Richard Truly, former astronaut and NASA Administrator: “Clear-eyed, cold-blooded look at the real costs and benefits of this joint endeavor. Don't miss this one!”
- Gene Kranz, Apollo Flight director: “A great piece of investigative journalism... A must read for program managers, engineers and scientists engaged in present and future projects with Russia. ”
- Sci-Tech Books: “Oberg combines riveting personal memoir with top-notch investigative journalism to tell the complete untold story of the U.S.-Russian space alliance. ”

(more)

## Star-Crossed Orbits (continued)

- Harrison 'Jack' Schmitt, Apollo moon walker and US Senator: "This remarkable book is must reading for anyone who wishes to understand the culture with which one must deal when attempting to cooperate with Russia "
- *American Scientist*:: "His sleuthing and storytelling abilities make this a gripping narrative"
- Walt Cunningham, Apollo astronaut: "Finally, someone is telling it like it is about the Russian manned space program - the good, the bad and the ugly. I have relied on Jim for years because no one knows it or tells it like he does."
- Gregory Bennett: "Riveting prose that grabs your attention and won't let loose"

# Jiu-Quan Space Center, Gansu Province

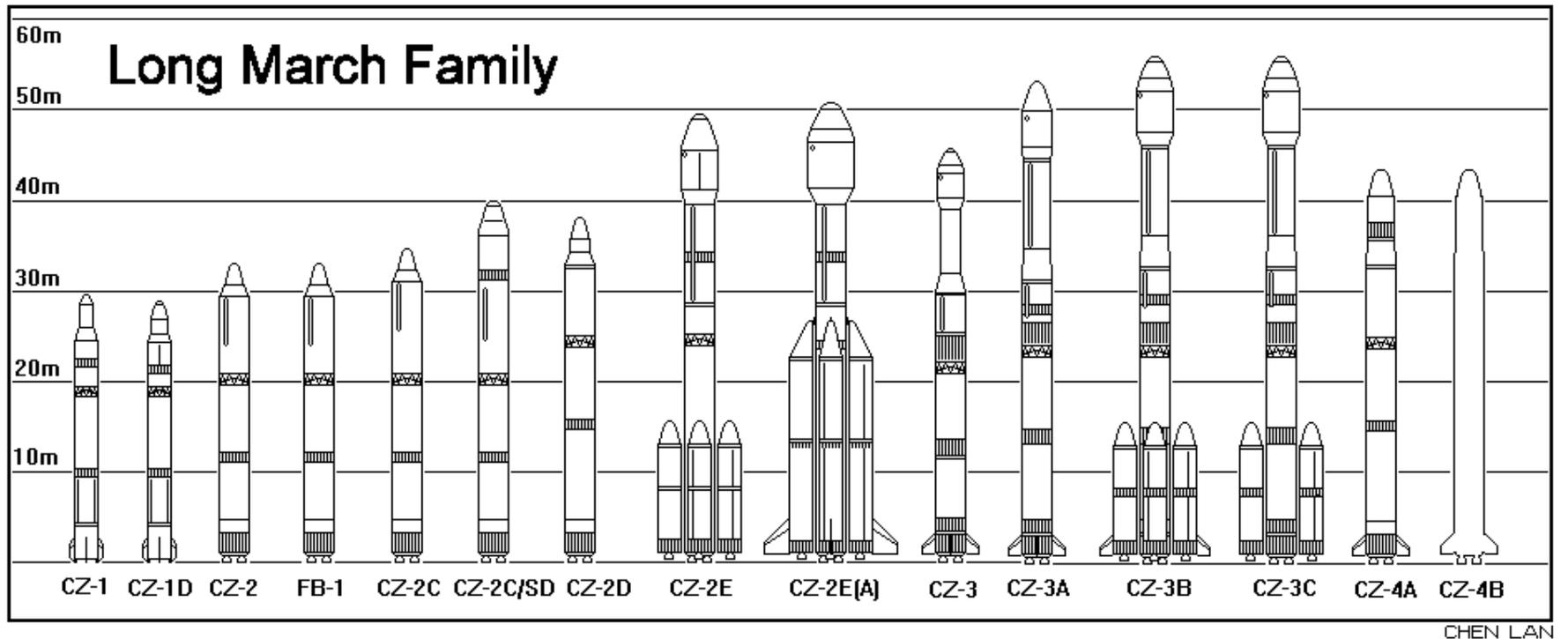


41°N, 100°E

Formerly known as  
Shuang Cheng Tzu  
First launches, 1960

Mainly to launch sci-  
entific & recoverable  
satellites into low or  
medium earth orbits  
at high inclinations.

# “Long March” (“Chang Zheng”) Boosters



Remarkably unified basic design with many varieties of strap-ons and stretches

# “Father of Chinese Missile/Space Program”, Qian Xuesen (Tsien Hsue-Shen)



(Left) In charge of  
missile program;  
(Below) Retired in  
Beijing in 2002



# Qian (Tsien) in America



Tsien with US Army V-2 inspection team in Germany (1945), working at Jet Propulsion Laboratory, teaching at Caltech (late 1940's).

# “Find the differences” – Means What?



# Future Crews

