STARDUST

Incredulous DREAM To Incredible RETURN

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October 19, 2006 Venice Italy

From an Incredulous Dream to an Incredible Return of a Life Time

- **Jet Propulsion Laboratory** - Caltech CIT
- **Solar System** - Very small part of the Universe
- **Comets** - Water & Life on Earth?
- **Get Pieces of a Comet** - Incredulous Dream
- **Strategy** - Technology, Proposals, Flights
- **STARDUST** - Launch, Encounter, Return
- **Samples** - Incredible Return of a Life Time
- **Significance** - Science, Career, Achievements
- **Space Concrete** - Silica Aerogel
- **Team Work** - Emotional Quotient, EQ

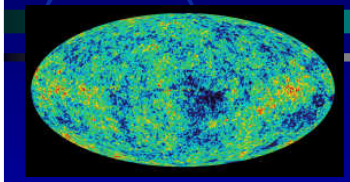
Jet Propulsion Laboratory
California Institute of Technology

- Pasadena California
- NASA Funded
- Caltech Managed
- Robotic Exploration
- 5000 People
- First Instrumented Satellite
- Visited all Planets
- 26 Spacecraft in Space
- 2 Rovers/3 Orbiters on Mars

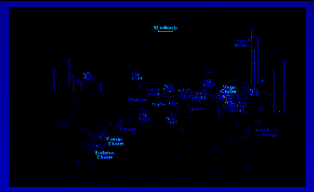
Why Explorations?

- Curiosity
- Knowledge Progression
- Technology Demonstration
- Human Pride
- Desire to Visit

Universe?



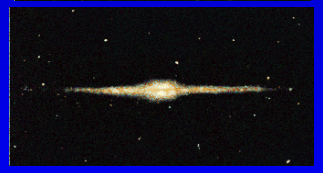
Known Universe = 13,000,000,000 - 78,000,000,000 ly



Local Supercluster = 200,000,000 ly

Local Group = 10,000,000 ly

Light Year [ly] = 9,460,000,000,000 km

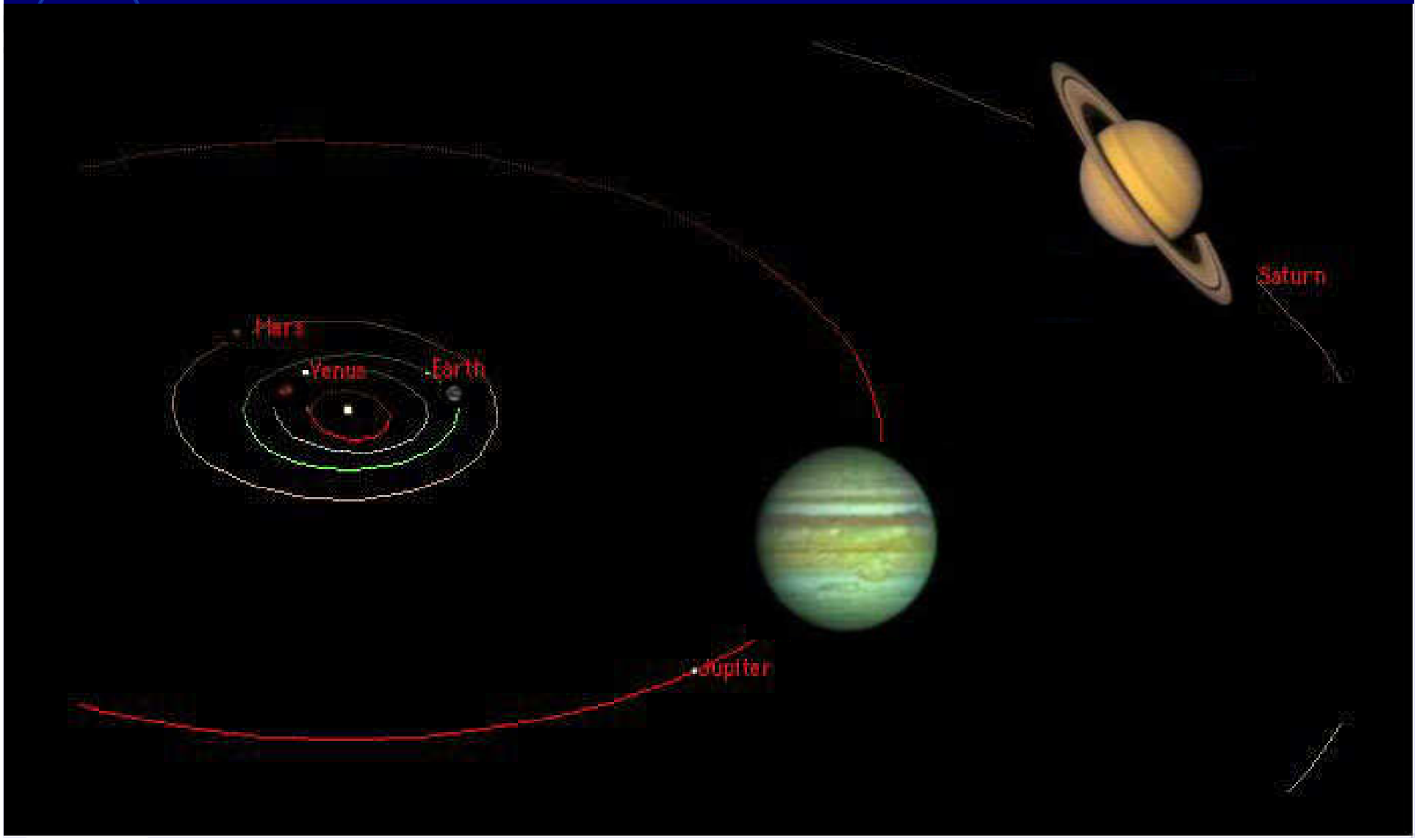


Milky Way = 100,000 ly

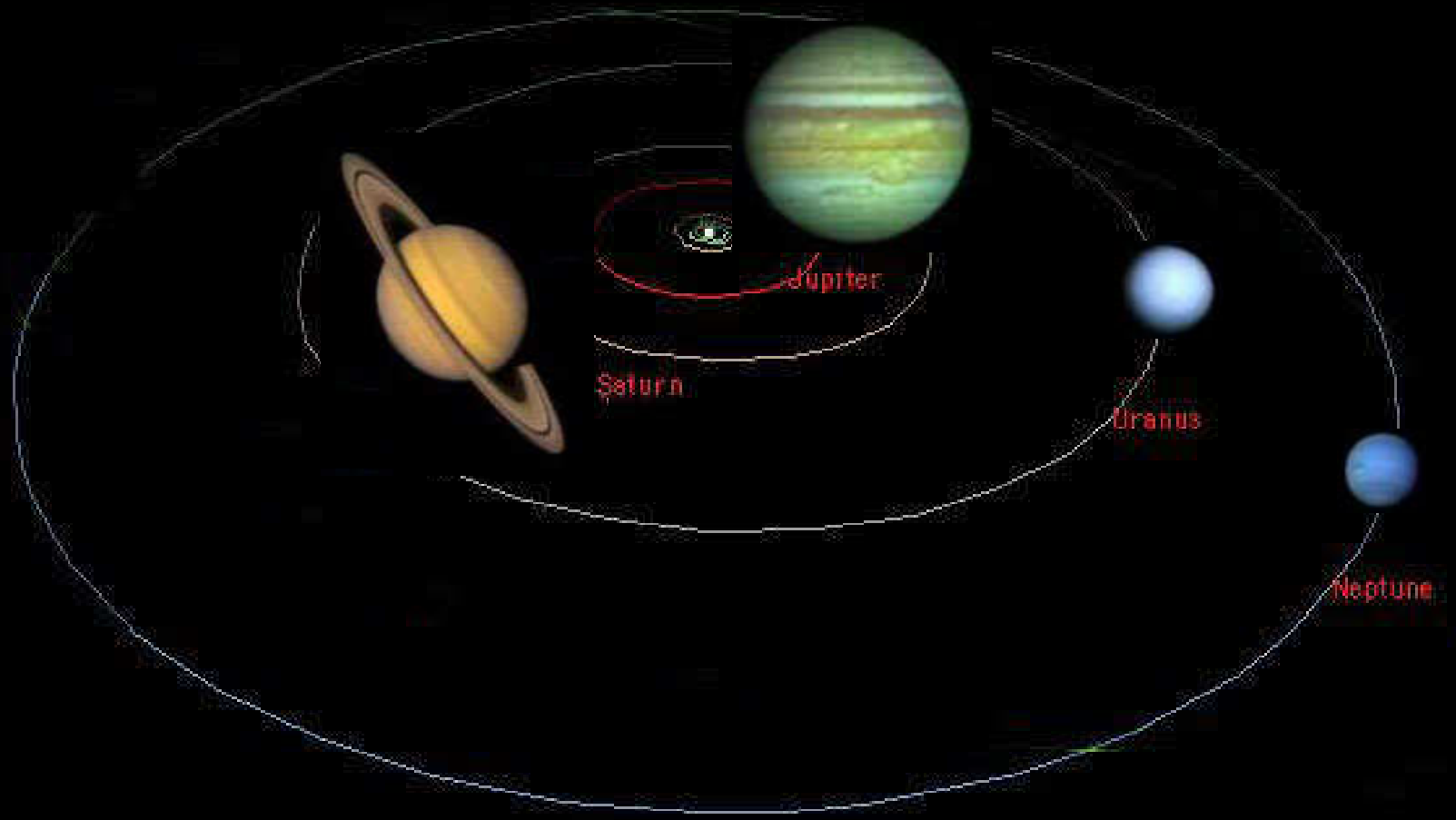
Solar System = 9 10^9 km 0.00085 ly

Earth = 1.3 10^4 km 0.0000000013 ly

INNER
SOLAR SYSTEMS



OUTER
SOLAR SYSTEMS



Solar System Explorations

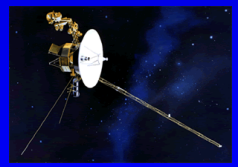
- Sun: Ulysses, Genesis
- Mercury: Mariner 10

- Venus: Mariner 1,5,10, Magellan
- Earth: Explorer, SeaSat, SAR, Topex, Seawind, CloudSat

- Moon: Rangers, Surveyors
- Mars: Mariners, Viking, Pathfinder, MCO, MPL, MER, MRO

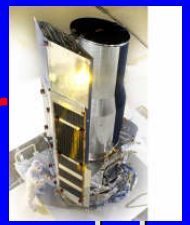
- Jupiter: Voyager, Galileo
- Saturn: Voyager, Cassini-Huygens

- Uranus: Voyager



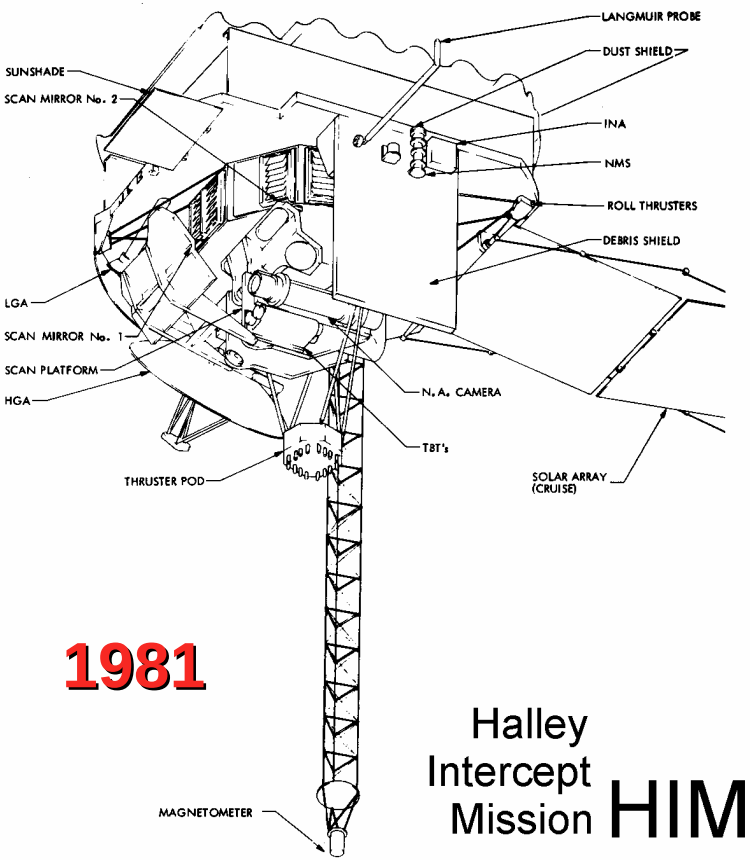
- Neptune: Voyager

- Comet: DS1, STARDUST
- Universe: IRAS, VLBI, WFPC, Galaxy EE, Spitzer



Comet Hale-Bopp

Dream
To Catch Pieces of a Comet



1981

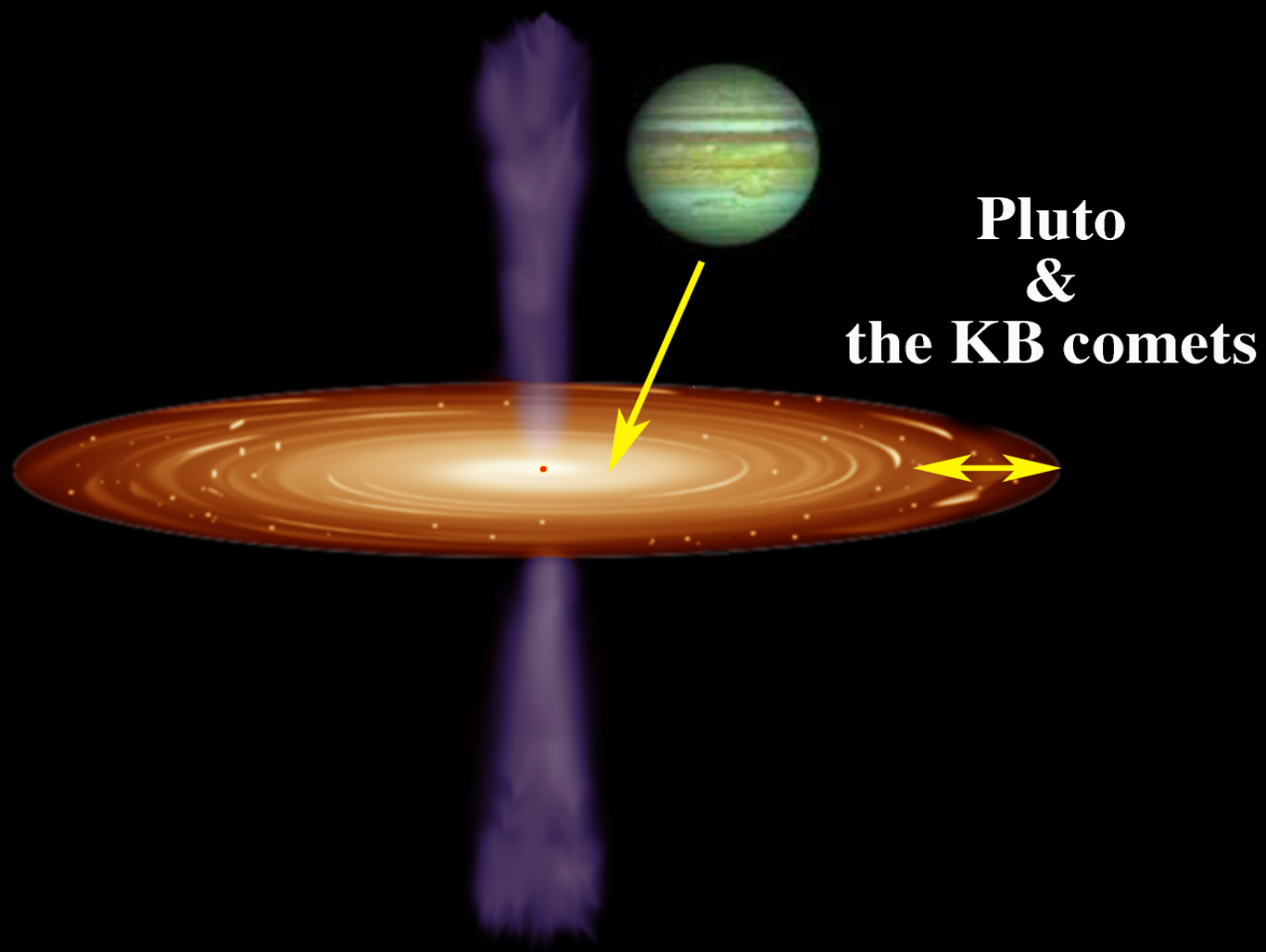
Halley Intercept Mission HIM

- Most Body Mass Reduction
- Dramatic Display

- May Be Source of Water on Earth
- May Brought life to Earth

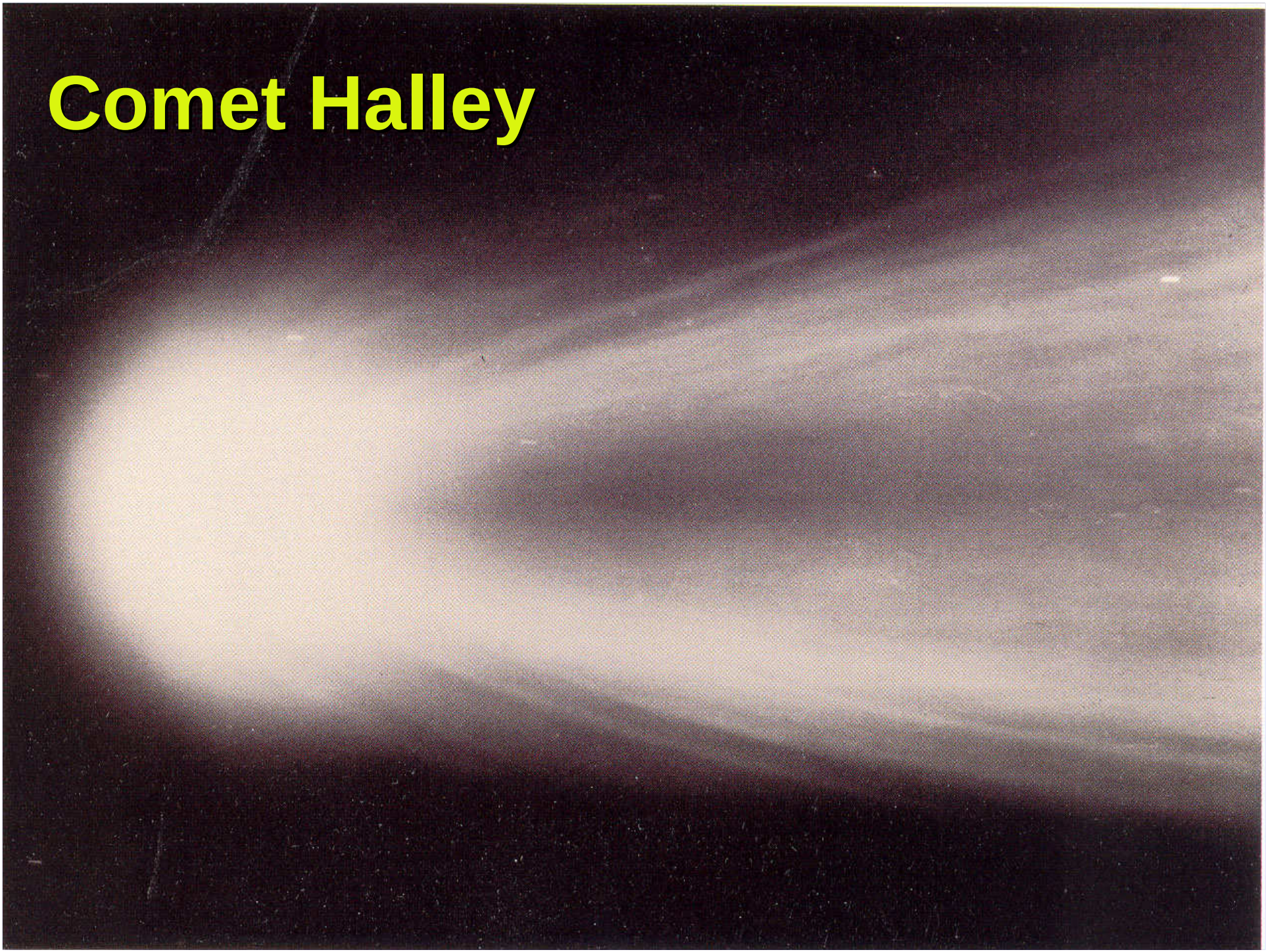
- Best Preserved Solar Formational Material
- Contain 4.6 10^9 Year Time Capsule

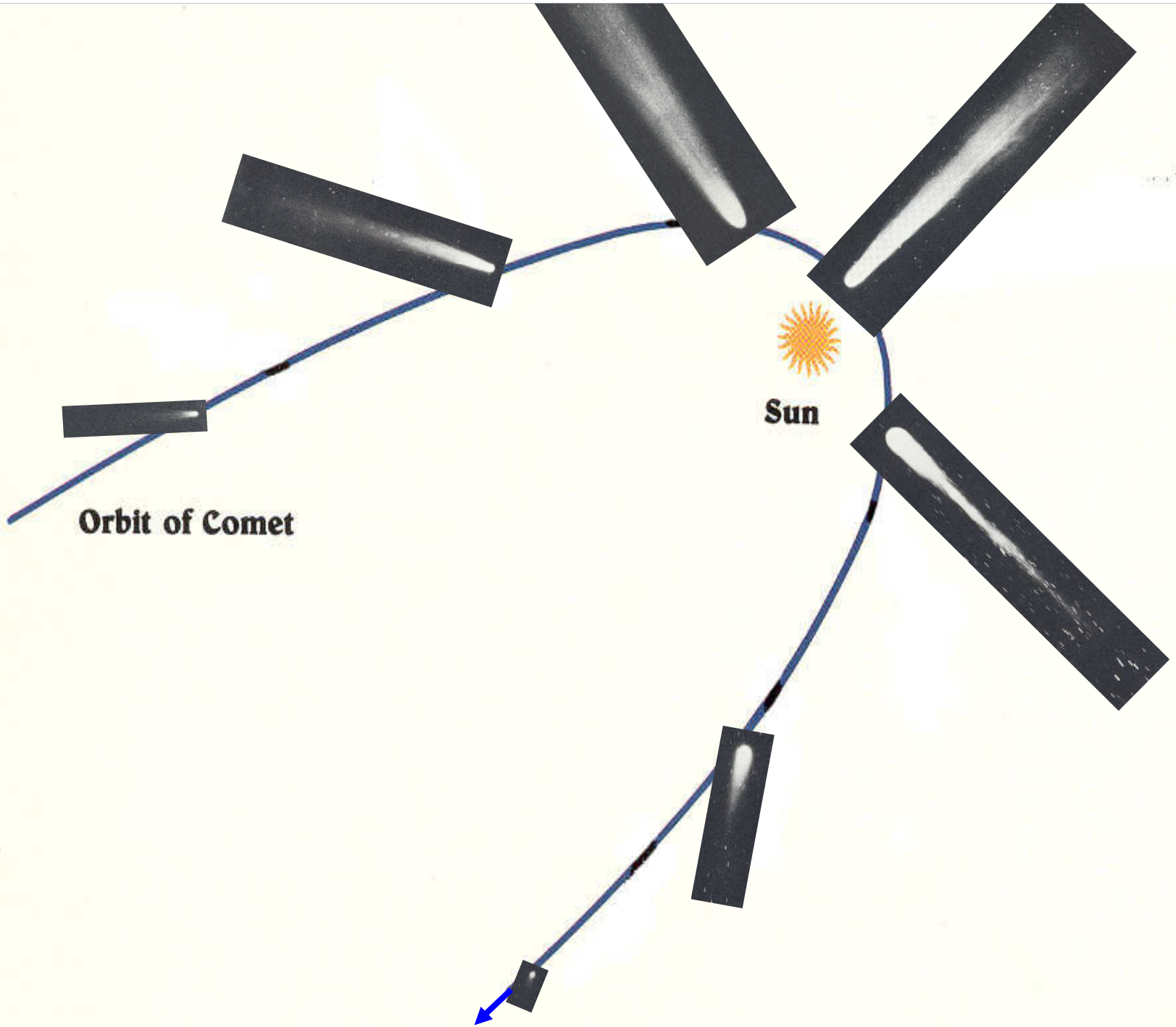
THE SOLAR NEBULA
4.6 billion years ago



SUN

Comet Halley




Sun
Orbit of Comet

Giovanni Donati on June 2, 1858

Challenges

- **Must be Low Cost**
  - **Flyby Sampling without Landing**
- **Must be Significant**
  - **Intact (~ 10 km/s) Samples not Atomized Samples**
- **Must have Space Viable Capture Medium**
  - **Ubiquitous UV, Temperature Cycling, Transparency**
- **Gain Space Flight Opportunity**
  - **Tertiary Cometary Science**
- Achieve the Sample Return within One Lifetime

Pursuit Strategy

Technology Development

Intact Capture of >> 10 km/s Particles
- Laboratory Simulations
- Space Demonstrations

Flight Development

Flight Proposals
- 13 Flight Proposals

Accumulate Flight Qualifications

Instrument Development

Capture Medium
- Smooth Gradient Density Silica Aerogel

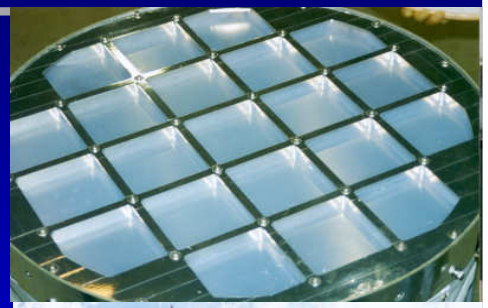
Medium Containment

Laboratory Experiments

- **TWO STAGE LIGHT GAS GUN**
  - NASA Ames Vertical Gun Range, > 2 km/s
  - University of Dayton, Research Institute
  - Ernst Mach Institute, Freiberg
  - Arnold Engineering Development Center
- **PLASMA DRAG GUN**
  - Technical University of Munich
- **ELECTRO STATIC ACCELERATOR**
  - Max Plunk Institute, Heidelberg
  - Los Alamos Hypervelocity Microparticle Impacts Lab
- **RADIATION EFFECTS LAB**

Space Validations

1992 GAS^2 SRE SHUTTLE FLIGHT, STS- 47
1993 GAS^2 SRE SHUTTLE FLIGHT, STS- 57
1994 SPACEHAB FLIGHT, STS- 60
1995 GAS^2 SRE SHUTTLE FLIGHT, STS- 68
1995 WAKEFIELD SHUTTLE FLIGHT, STS- 69
1996 GAS^2 SRE SHUTTLE FLIGHT, STS-72
1997 MIR MSRE FLIGHT
2000 GAS^2 SRE SHUTTLE FLIGHT, STS-101 & STS-106
2001 GAS^2 SRE SHUTTLE FLIGHT, STS-108

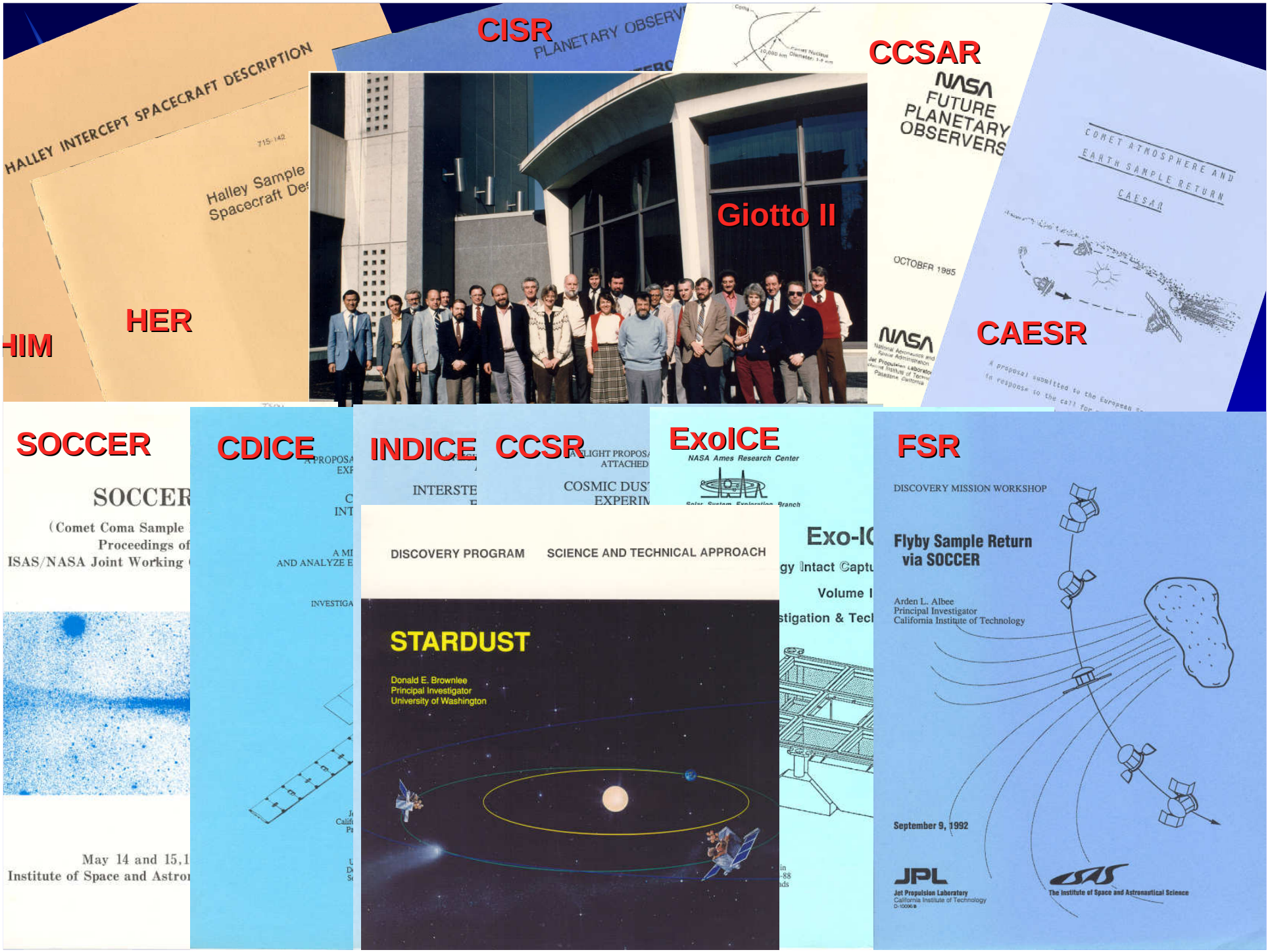


Sponsoring Agencies

- **National Aeronautical Space Administration**
  - JPL, Planetary Observer, Explorer Program, Space Station Attached Payload, Scout Program
- **Europe Space Administration**
  - Joint ESA/NASA Mission
- **Institute of Space and Astronautical Science**
  - Joint ISAS/NASA Working Group
- **National Aeronautical Space Administration**
  - Discovery Program - Faster, Better & Cheaper

Mission Development

- **COMA SAMPLE RETURN PROPOSALS**
- 1. '81 HIM, NASA
- 2. '82 HER, NASA
- 3. '83 CISR, NASA
- 4. '85 GIOTTO II, NASA/ESA
- 5. '85 CCSR, NASA
- 6. '85 CAESR, ESA
- 7. '87 SOCCER, ISAS/NASA
- 8. '88 CDICE, NASA
- 9. '88 IDICE, NASA
- 10. '88 ExoICE, NASA
- 11. '90 CCSR, NASA
- 12. '92 FSR, NASA/ISAS
- 13. '94 STARDUST, NASA 4th Discovery Mission


HALLEY INTERCEPT SPACECRAFT DESCRIPTION
HIM
HER
CISR
PLANETARY OBSERV
Giotto II
CCSAR
NASA
FUTURE
PLANETARY
OBSERVERS
OCTOBER 1985
NASA
COMET ATMOSPHERE AND
EARTH SAMPLE RETURN
CAESAR
CAESR
SOCCER
SOCCER
(Comet Coma Sample
Proceedings of
ISAS/NASA Joint Working
May 14 and 15,1
Institute of Space and Astro
CDICE
INDICE
INTERSTE
CCSR
COSMIC DUST
EXPERIM
ExoICE
NASA Ames Research Center
Exo-IC
Volume I
DISCOVERY PROGRAM
SCIENCE AND TECHNICAL APPROACH
STARDUST
Donald E. Brownlee
Principal Investigator
University of Washington
FSR
DISCOVERY MISSION WORKSHOP
Flyby Sample Return
via SOCCER
Arden L. Albee
Principal Investigator
California Institute of Technology
September 9, 1992
JPL
Jet Propulsion Laboratory
California Institute of Technology
The Institute of Space and Astronautical Science

Publications

- International Conference on Cometary Exploration
- Lunar Planetary Science Conference
- AIAA
- JBIS
- LPI Workshops
- Workshop in Multi-Comet Mission
- Space Station Planetology Workshop
- ESLAB Symposium on the Exploration of Halley's Comet
- International Journal of Impact Engineering
- APS Conference on Shock Compression of Condensed Matter
- 5th Exiobiology Symposium
- Journal of Non-Crystaline Solids
- IAU

Instrument Development

- **Passive Collection**
  - Mechanism
  - Surfaces
- **Capture Medium**
  - Mesostructure
  - Space Engirnoment
  - Transparency
- **Smooth Gradient Density**
  - Minimum Entry Shock
- **Aerogel Containment**
  - Compressive Fit

Flight Qualifications

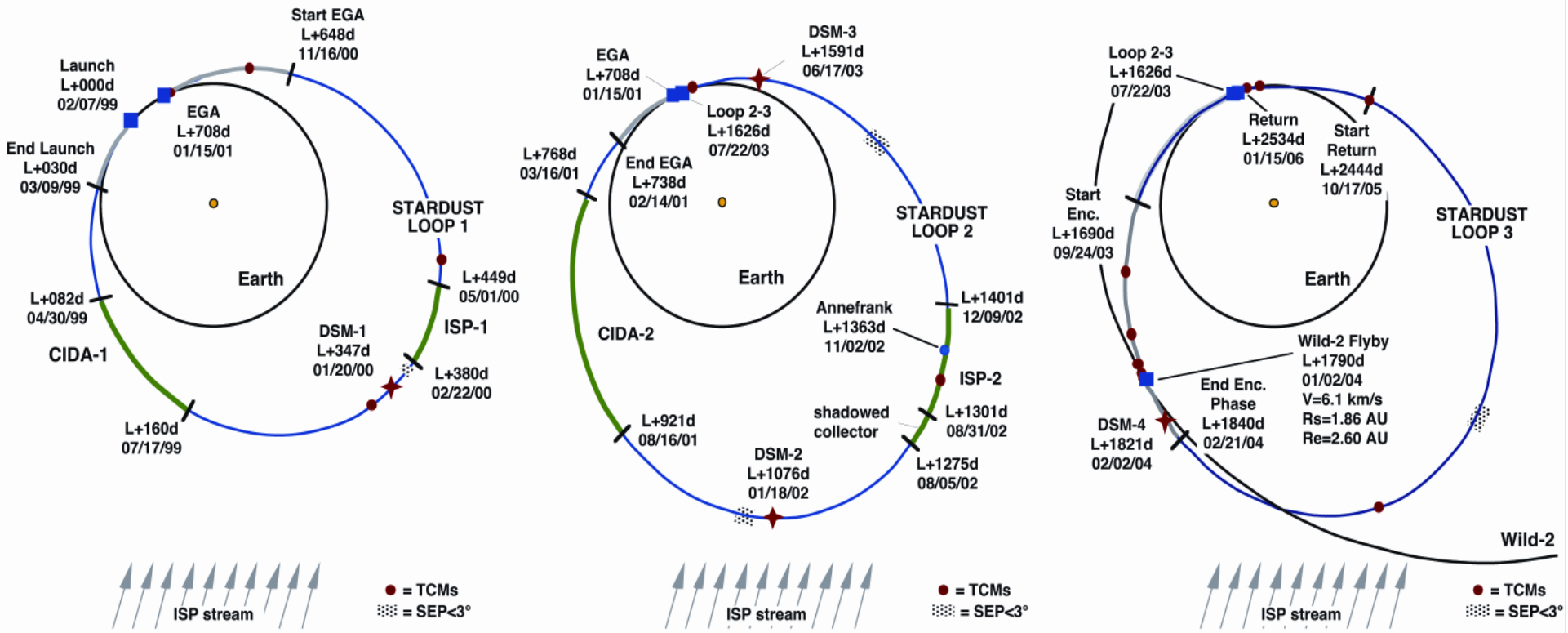
- **COMET - MIR J. P. Bibring**
- **Sample Return Experiment - GAS**
- **SpaceHab – Shuttle Spacehab II flgiht**
- **MIR Sample Return Experiment - MIR**
- **STARDUST - Vibration, Shock, Ascent/Decent**

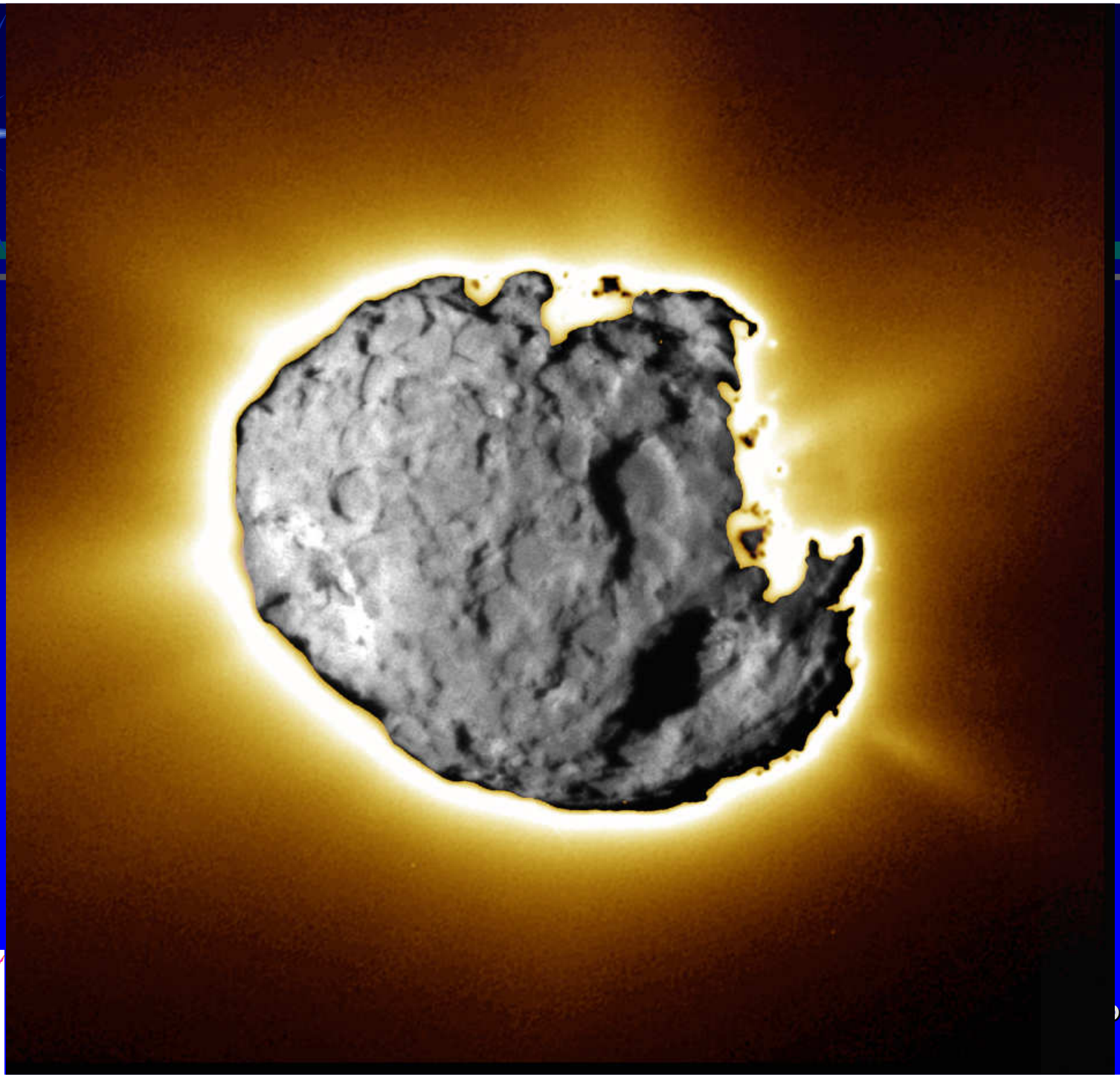
Fantastic Aerogel!

SiO_2 - PURE QUARTZ FOAM

1. The lowest density solid, <1.5 mg/ml
2. The widest density range, >7x10^2
3. The smallest pore size, ~ 50nm
4. The highest porosity, >99.9%
5. The lowest thermal conductivity, <16mW/mK
6. The lowest sound speed, <70 m/s
7. The lowest dielectric constant, <1.003
8. The lowest refractive index, <1.0003
9. Lowest loss tangents, <10^{-4}
11. The widest compressive modules, > 7 x 10^6
12. Highest acoustic impedance, 10^6 kg/m^2s
13. Highest refractive index range, 116%
14. The lowest Young's modules <10^6 N/m^2

Trajectory


Start EGA
L+648d
11/16/00
Launch
L+000d
02/07/99
EGA
L+708d
01/15/01
End Launch
L+030d
03/09/99
STARDUST
LOOP 1
Earth
L+449d
05/01/00
L+082d
04/30/99
ISP-1
DSM-1
L+347d
01/20/00
CIDA-1
L+380d
02/22/00
L+160d
07/17/99
ISP stream
= TCMs
= SEP<3°
DSM-3
L+1591d
06/17/03
EGA
L+708d
01/15/01
Loop 2-3
L+1626d
07/22/03
L+768d
03/16/01
End EGA
L+738d
02/14/01
STARDUST
LOOP 2
Earth
L+1401d
12/09/02
Annefrank
L+1363d
11/02/02
CIDA-2
ISP-2
shadowed
collector
L+1301d
08/31/02
L+921d
08/16/01
DSM-2
L+1076d
01/18/02
L+1275d
08/05/02
ISP stream
= TCMs
= SEP<3°
Loop 2-3
L+1626d
07/22/03
Return
L+2534d
01/15/06
Start
Return
L+2444d
10/17/05
Start
Enc.
L+1690d
09/24/03
STARDUST
LOOP 3
Earth
Wild-2 Flyby
L+1790d
01/02/04
V=6.1 km/s
Rs=1.86 AU
Re=2.60 AU
End Enc.
Phase
L+1840d
02/21/04
DSM-4
L+1821d
02/02/04
Wild-2
ISP stream
= TCMs
= SEP<3°

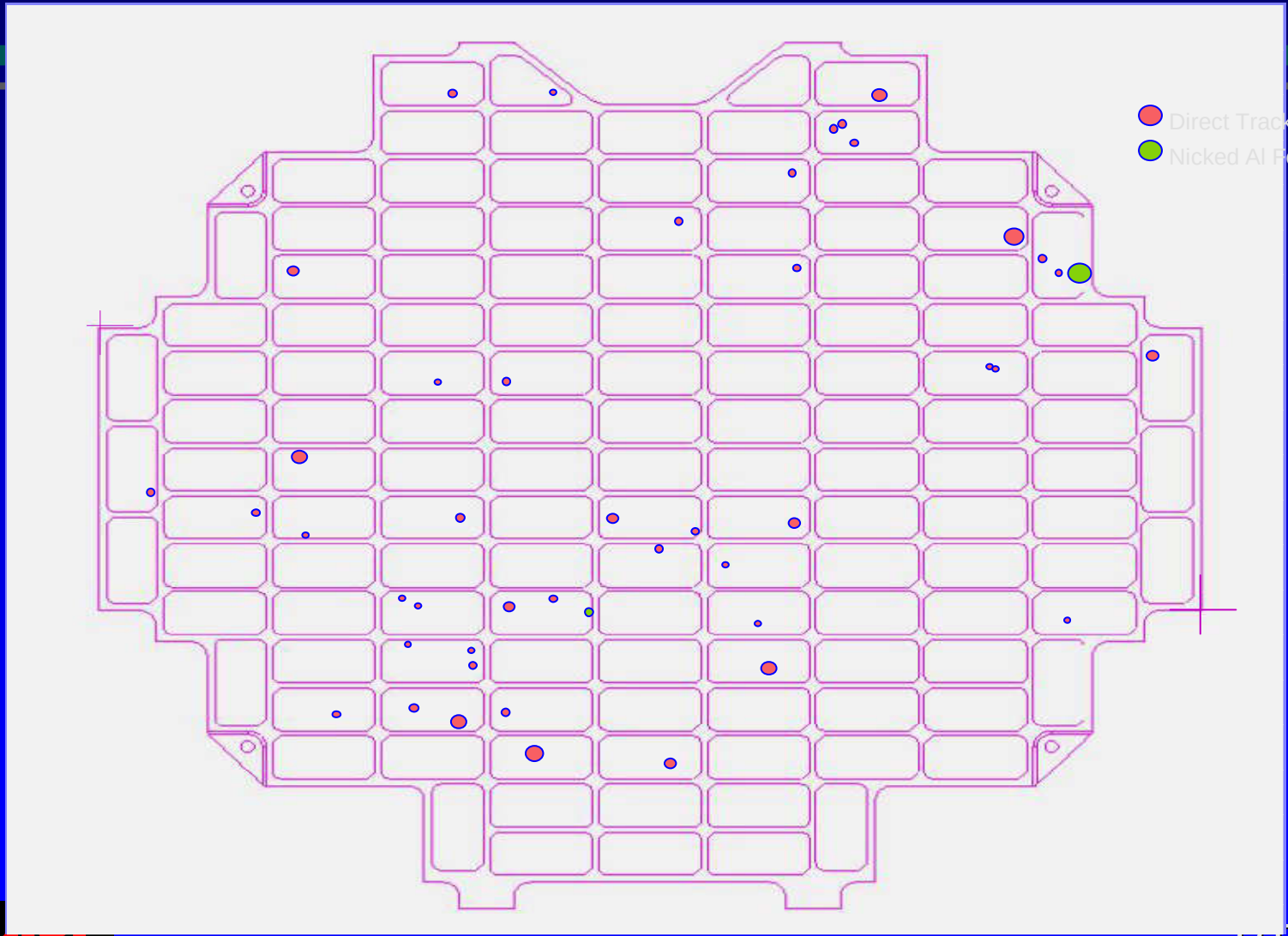


Samples Coming Home !

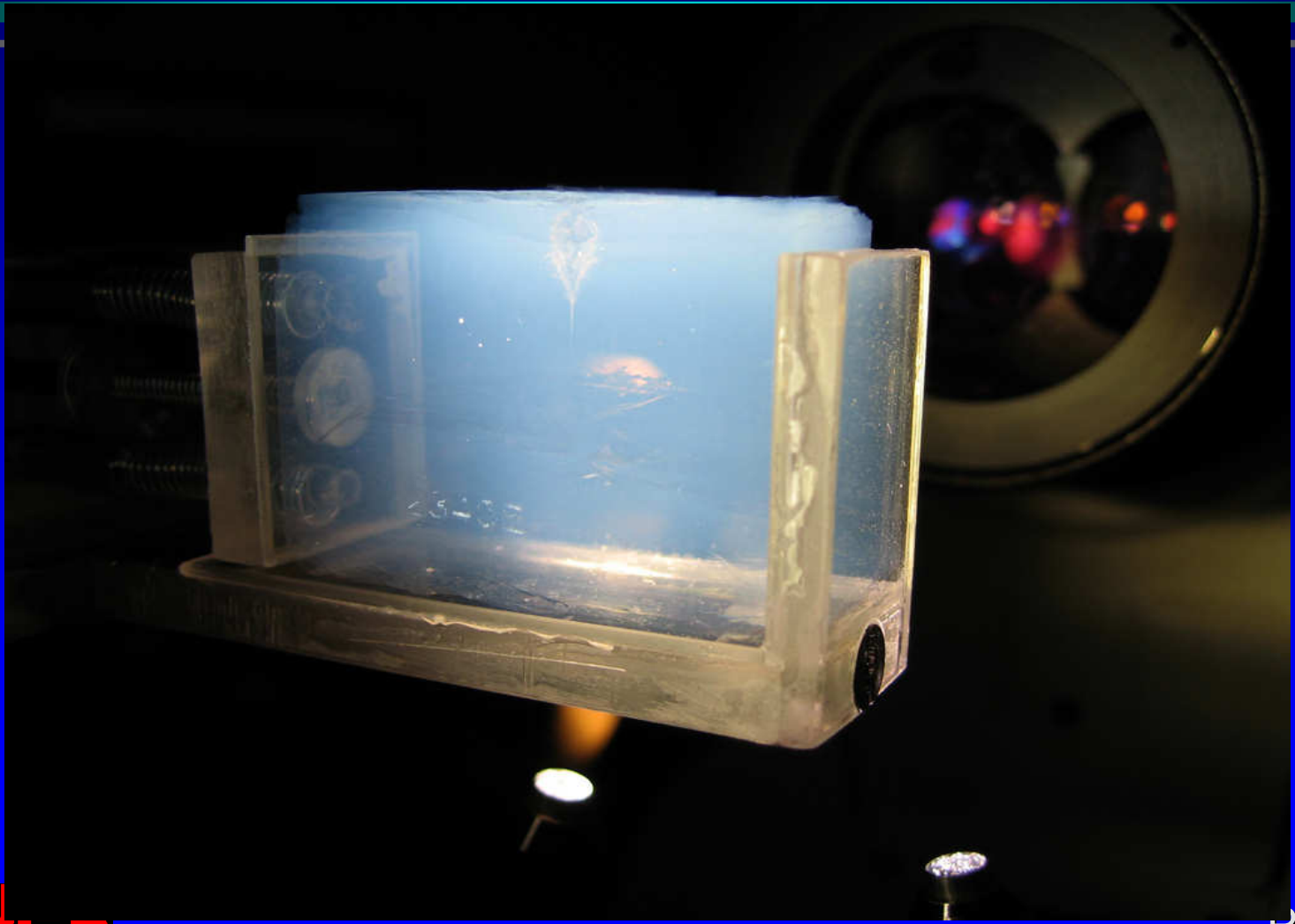
Samples Returned !

Samples in Hand !

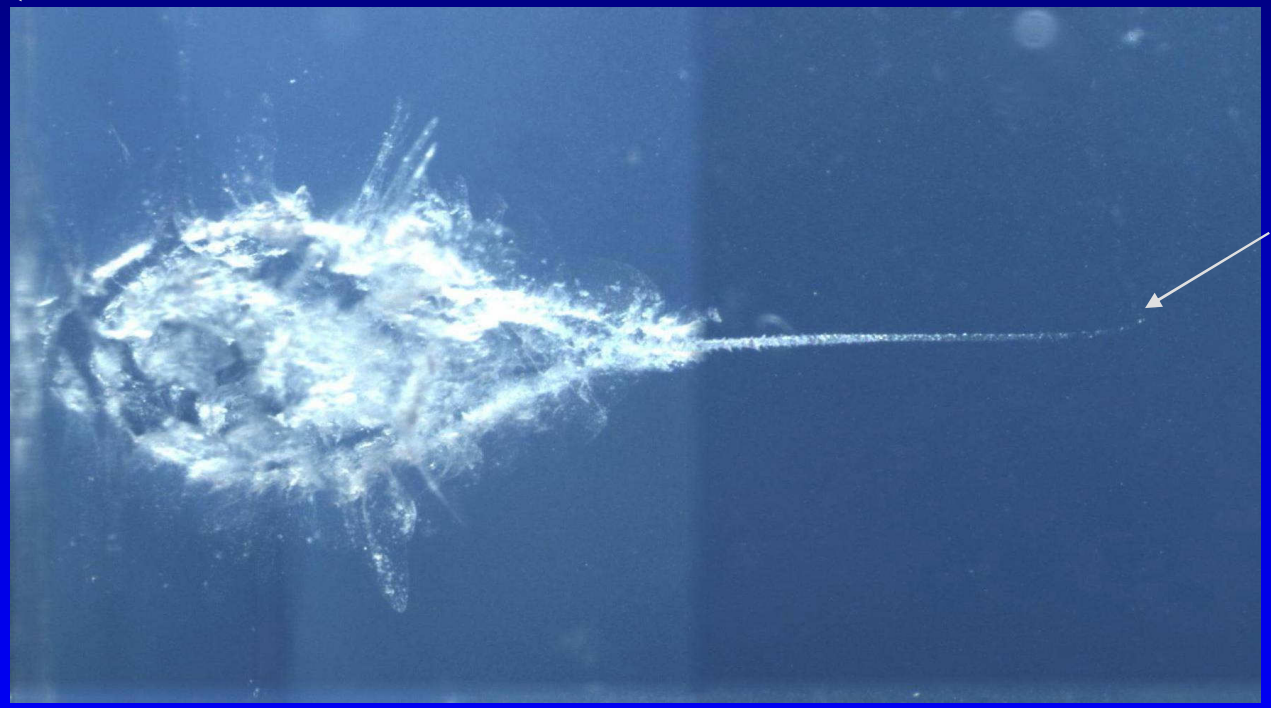
Samples in Tray !



Samples in Aerogel !

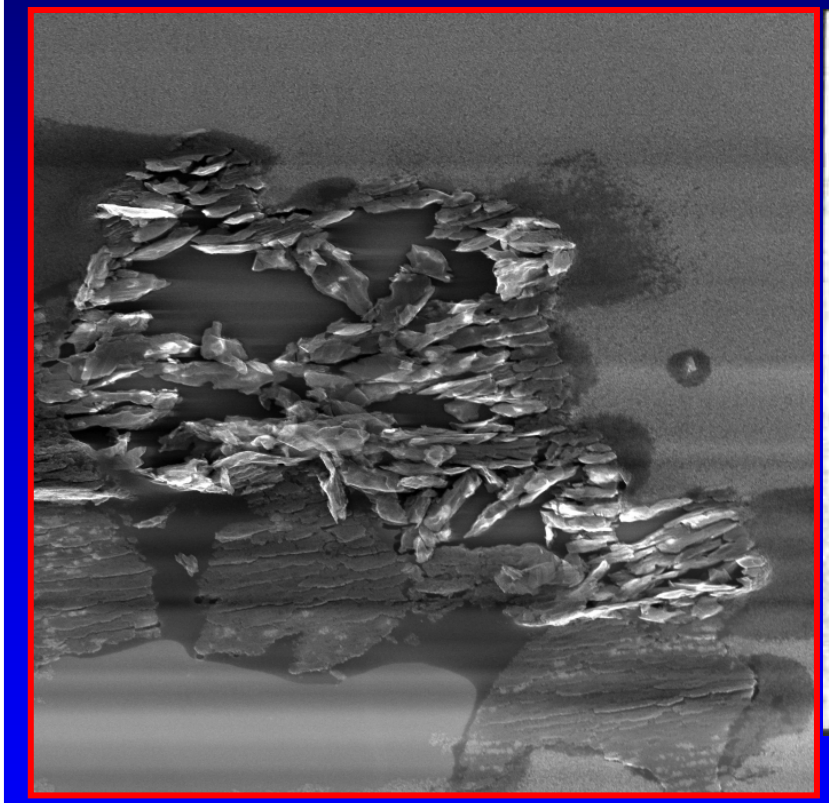


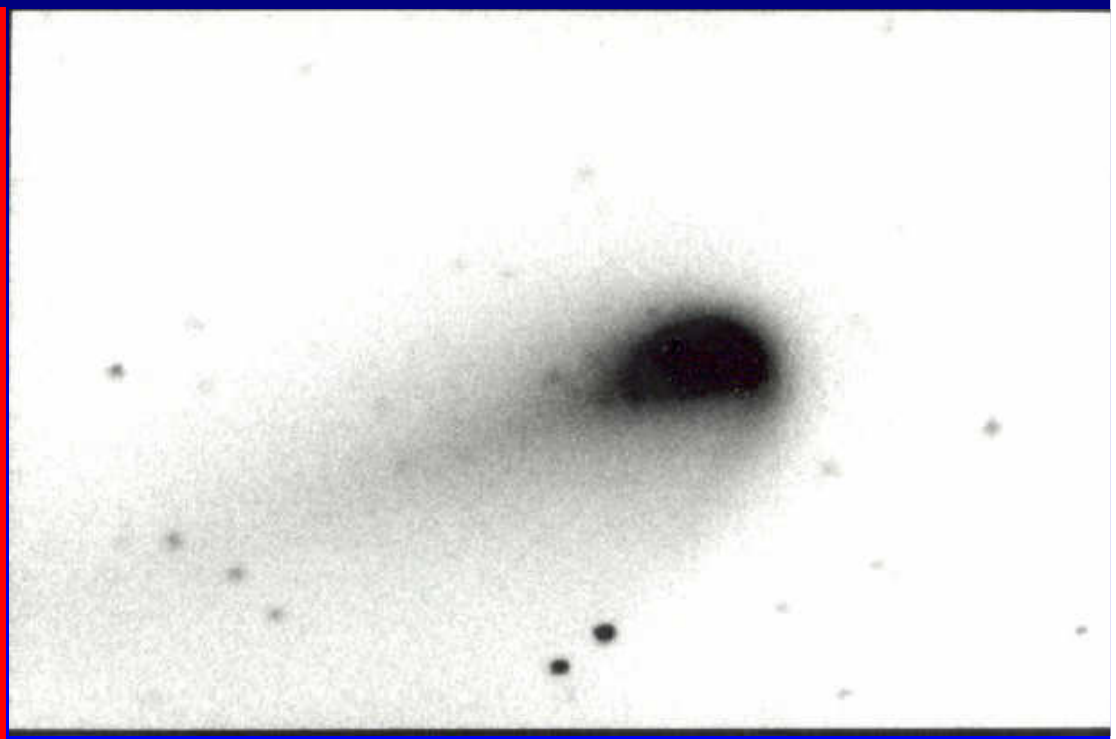
Track Characteristics



V=~0.022 cm^3
TP/V= ~$3x10^{-6}$

Heat & Ice !





CAI- $CaAl_2Si_2O_8$ **>1700K**

Ice- H_2O **~200K**

STARDUST Achievements

- First NASA Dedicated Cometary Mission
- First Extra-Earth Sample Return Mission
- First Flyby (no landing) Sample Return Mission
- First Faster-Better-Cheaper Mantra Discovery Mission
- First Using Silica Aerogel as Primary Science Mission
- First Return of Samples from a known Comet
- First Return of Contemporary Interstellar Samples
- First Mass Spectra of Cometary/Interstellar Dust
- Highest resolution image of a Cometary Nucleus

STARDUST TEAMS

- Concept Development Teams
- Proposal Teams
- Flight Hardware Design Teams
- Flight Hardware Assembly Teams
- Flight Hardware Test/Qualification Teams
- Instrument Design Teams
- Instrument Integration Teams
- Launch Vehicle Teams
- Launch Operation Teams
- Spacecraft Operations Teams
- Sample Recovery Teams
- Sample Deintegration Teams
- Sample Analyses Teams

Incredible RETURN

- **NASA/USA**
  - First Cometary/Interstellar Sample Return
  - Low Cost Sample Return - Big Science Payoff
- **PLANTARY SCIENCE**
  - Added Knowledge of Comets
  - New Findings of Solar System Formation
- **JPL/CALTECH INSTITUTION**
  - First Robotic Sample Return to a Comet
  - Aerogel for Space Exploration
- **PERSONAL SATISFACTION**
  - Technical/Scientific Designs are Sound
  - Incredulous Dream Fulfilled from End-to-End

Aerogel For Space

- HIGH TRANSPARENCY - locate μ sized particles
- SUITABLE MESOSTRUCTURE - enable intact capture
- WIDEST DENSITY RANGE – gentle capture, shorter track
- PARTICLE COATING - particle protection
- PURITY - minimize contamination
- FLIGHT ROBUSTNESS - launch vibration/landing shock
- TEMPERATURE CYCLING - long term stability
- TEMPERATURE EXTREMES – thermal shock stability
- RADIATION IMMUNITY - UV & radiation resistant
- IONIC IMMUNITY – space environment stability
- LOW MASS – flexibility, not mass driver
- ELASTICITY – compression containment

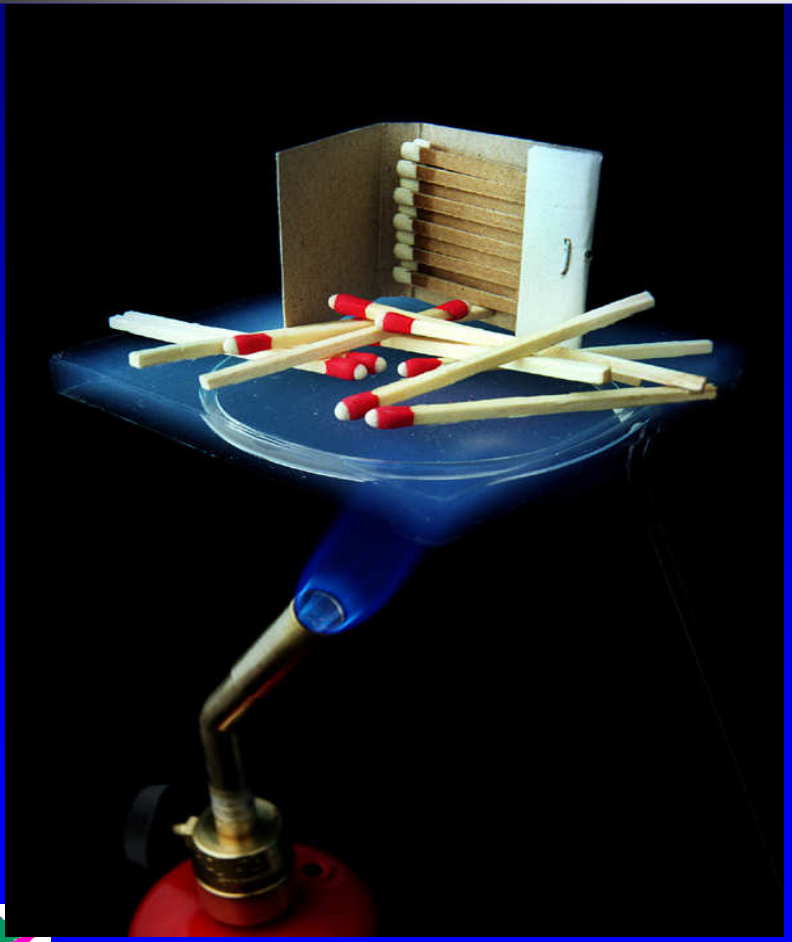
Exploration of Space

with Aerogel

Peter Tsou

July 20, 2006, Beijing

New Wave - Aerogel



Aerogel for Lunar Habitat