

• Jovianische Planeten

III. 17

	Radius [R_{\oplus}]	Masse [M_{\oplus}]	mittl. Dichte [g/cm^3]	Magnetfeld [Erde = 1]
Jupiter	11.2	318	1.3	14
Saturn	9.5	95	0.7	0.6
Uranus	4.1	15	1.2	0.6
Neptun	3.8	17	1.6	0.4

Pluto spielt eine Sonderrolle.

- Zusammensetzung: = "Kosmische Häufigkeiten":
etwa 70% H, 30% He, 1% schwere Elemente
(in Massenbruchteilen)
- Aufbau: Atmosphäre: H_2 , He, CH_4

Jupiter
Saturn

} H metallisch (10^6 atm, 10^4 K)

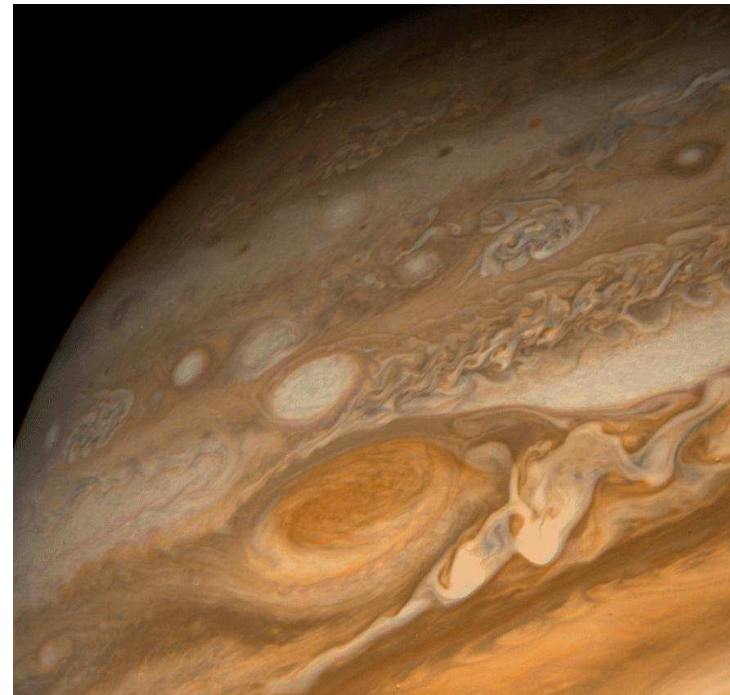
Tiden
Uranus

} $H_2O + NH_3$

(kleiner) Kern: fest, aus Eisen, Silikaten, Eis von H_2O, CH_4 ...
- Ring-Systeme !
~ innerhalb der Roche-Grenze auf Keplerbahnen in der Äquator-Ebene umlaufende Partikel
- viele Monde

Jupiter

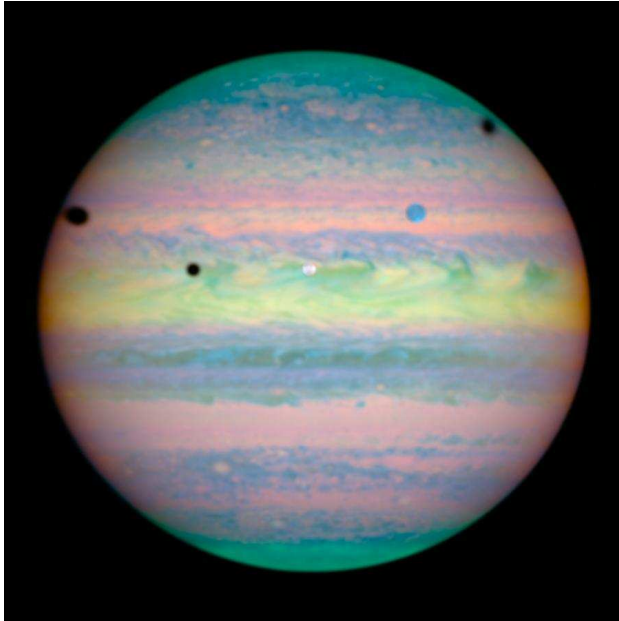
mit dem
Großen Roten Fleck
(Voyager 1, 1979)



Großer Roter Fleck

Jupiter mit dem Hubble Space Telescope (HST)

3-63



mit Io und Schatten,
Ganymed und
Schatten, und dem
Schatten von
Callisto



3-65

This Voyager 2 image taken while the spacecraft was in Jupiter's shadow, looking back towards the rings from 1.5 million km. The rings are brightly lit by the forward scattered light from the Sun, indicating that they are composed of very small particles. Some radial structure can be seen in the rings. The main ring is about 125,000 km in diameter, and the inner glow is the halo ring.

- Äquator- parallele Bänder (dunkel) und Zonen (hell):
globale Windsysteme
- vielfältige Farben (Schwefelverbindungen?)
- veränderliche Details
- Großer Roter Fleck: stabiler Zyklon
- Temperatur der Wolkenobergrenze: ≈ 130 K
- Abstrahlung $\approx 2 \times$ Sonneneinstrahlung:
Energie aus gravitations- Kontraktion
- starke Magnetosphäre (\rightarrow Radioquelle)
- Rotationsperiode des Kerns (\rightarrow Magnetfeld- Variationen)
 $9^h 55^m 5$
 \rightarrow Abplattung 7%
- \rightarrow Rotationsachse zur Bahnachse: 3°

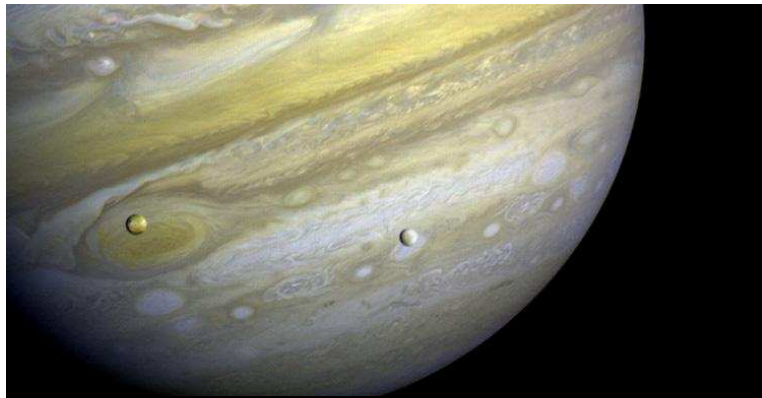
3-64

Jupiter - Monde

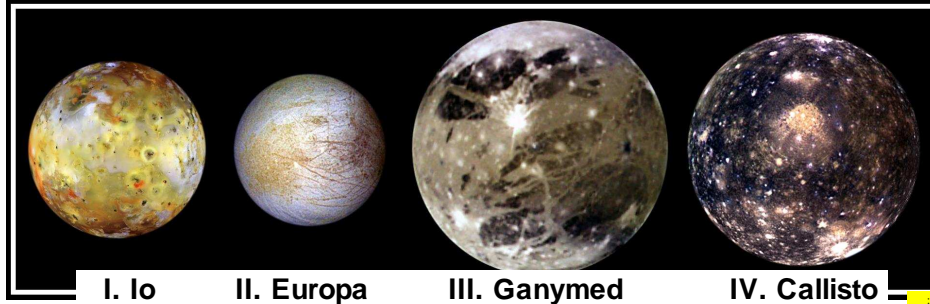
Tab. 19

3-66

		Bahn- Halbachse [R _{Jup.}]	Umlauf- Periode [d]	Bahn- Exzent. e	Bahn- Inklination zum Äquator	Radius [km]
		1.8	0.30	0	0	20
		1.8	0.30	0	0	20
		2.55	0.49	0	0	100
		3.11	0.67	0	0	40
Galilei- Monde	Io I	6.0	1.77	0	0	1816
	Europa II	9.5	3.55	0	0	1563
	Ganymed III	15.1	7.16	0	0	2638
	Callisto IV	22.6	16.7	0	0	2410
	Leda	156	240	0.15	27°	5
	Himalia	161	251	0.16	28°	90
	Lysithea	164	260	0.13	29°	10
	Elara	165	260	0.21	28°	40
	Ananke	291	617	0.17	147°	10
	Carme	314	692	0.21	163°	15
	Pasiphae	327	735	0.38	148°	20
	Sinope	333	758	0.28	153°	15



3-67

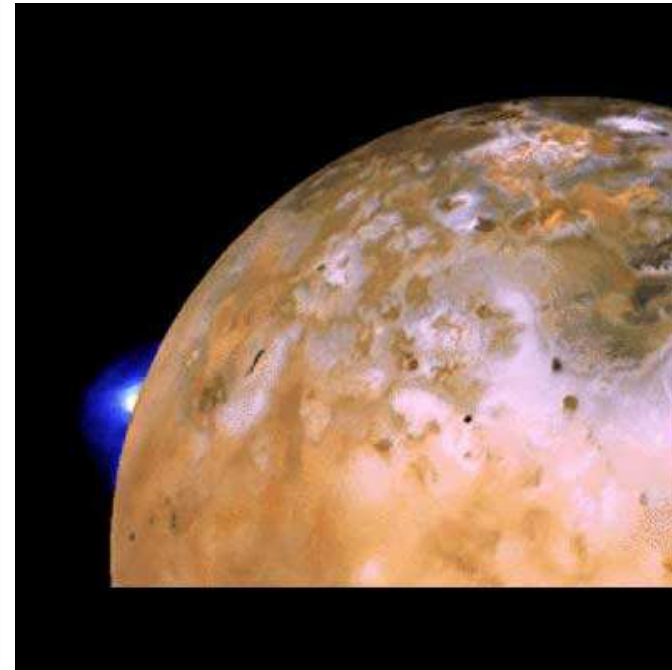


I. Io

II. Europa

III. Ganymed

IV. Callisto



3-69

Vulkanismus auf Io

Foto: Eruption von Krater Loki beim Vorbeiflug von Voyager 2

- liefert die Ionen für die Jupiter-Magnetosphäre

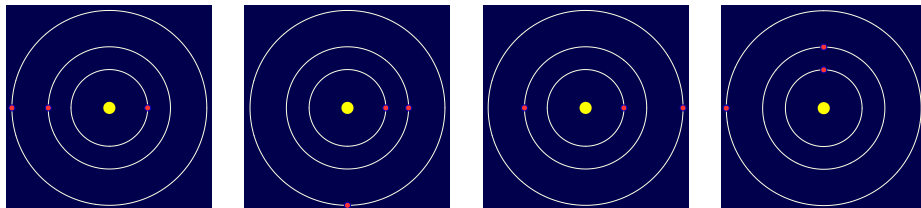
Bahnresonanz von Io + Europa + Ganymed

3-68

Umlaufzeiten wie 1 : 2 : 4

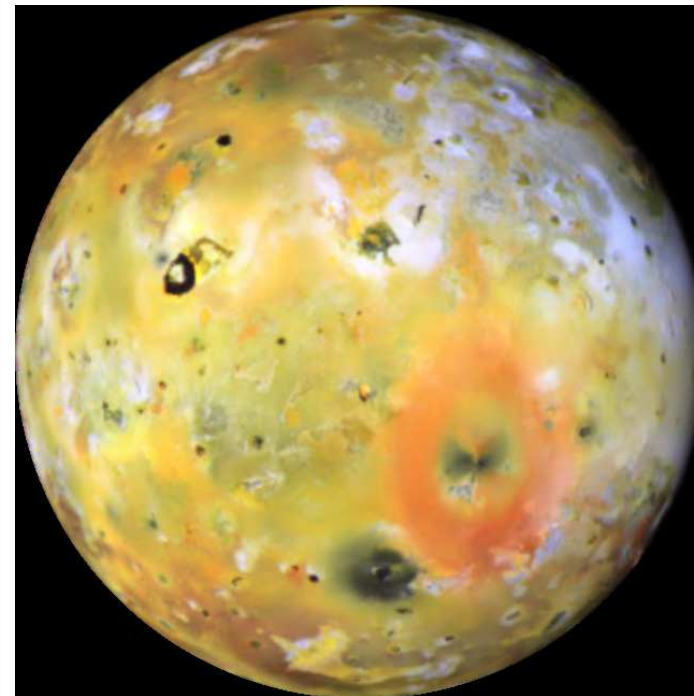
(genauer: zuzüglich einer langsamen Präzession)

- ungleichmäßige Winkelgeschwindigkeiten entlang Bahn
- starke Gezeitenwirkung, besonders auf Io (alle drei Monde rotieren gebunden)
- starke innere Aufheizung → Vulkanismus !



Konstellationen der drei inneren Jupitermonde

Play Movie

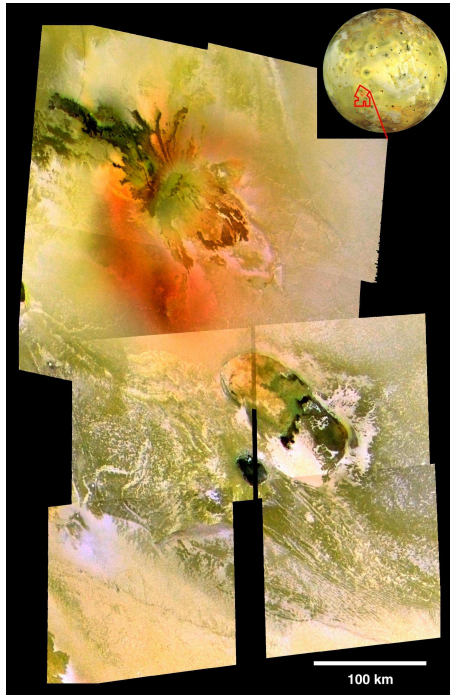


3-70

Io mit Krater Pelé



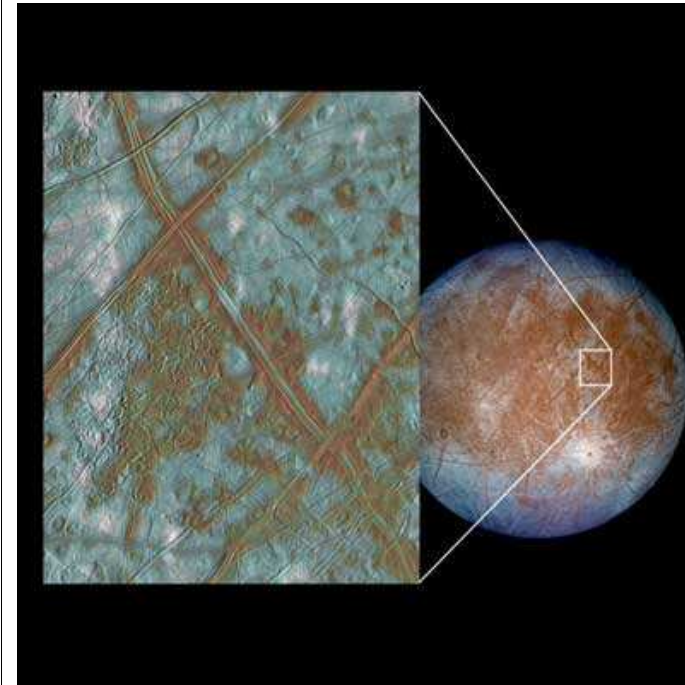
Pele = Göttin des Feuers und der Vulkane in der Religion Hawaiis



3-71

Lava-
Ausbruch
auf Io
(1999-
2000,
Galileo)

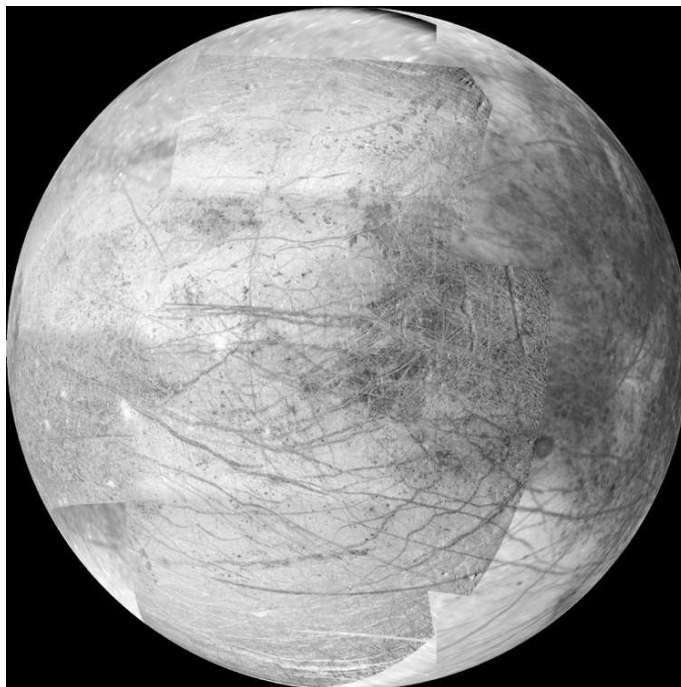
Hier:
heiße
Lava;
sonst z.T.
auch nur
kalte
Geysire
aus
flüssigem
Schwefel
oder SO_2



3-73

Europa (Foto:
Sonde Galileo)

- weiß, glatt,
keine Krater
- Netzwerk
rötlicher
Bruchlinien →
Wasser unter
dem Eis ?



3-72

Europa

Aufbau von
Europa,
Ganymed und
Kallisto

- mittlere Dichte
 2g/cm^3 , d.h.
rund 50%
 H_2O , 50%
Silikatgestein
- Kruste aus Eis
(H_2O)
- darunter:
flüssiges
Wasser?
- Silikat-Kern



3-74

Ganymed

- größter Mond
des Sonnen-
systems
- größer als
Merkur
- teils junge
Eisflächen,
teils ältere
Oberfläche
mit Kratern

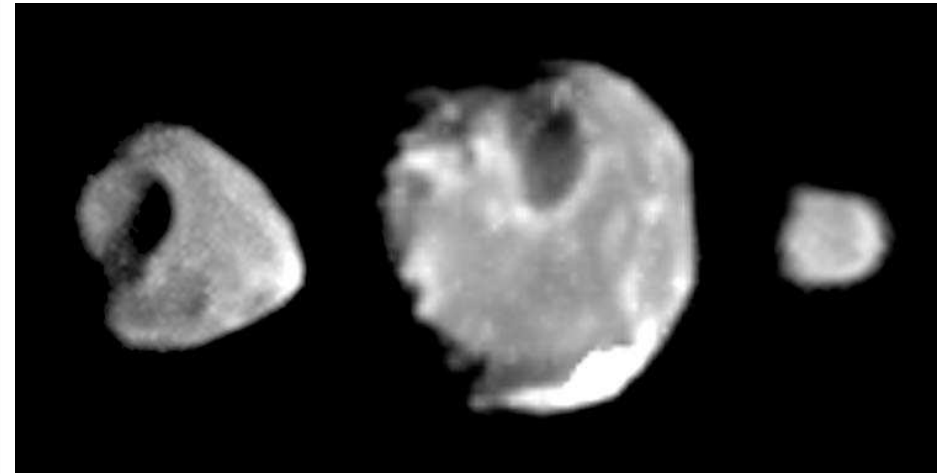
3-75



Kallisto

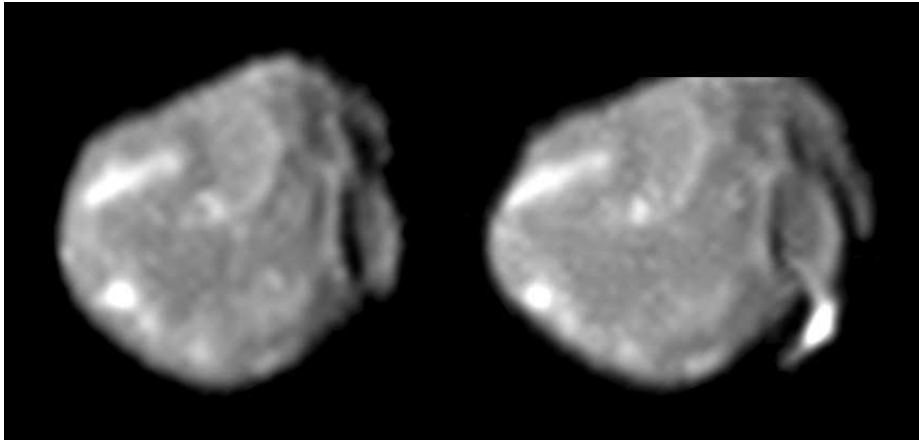
- alte Oberfläche, gänzlich mit Kratern übersät
- Krater-Durchmesser einheitlich (!) bei 100 km

3-77



Thebe, Amalthea und Methis im Größenvergleich

3-76



Amalthea

270 km in length and half that in width; low density ($\sim 1\text{g/cm}^3$), indicating that it is full of holes

3-78

Die Voyager-Missionen

Voyager 1

5. Sept. 1977

Start

5. März 1979

Jupiter

Io
Callisto

12. Nov. 1980

Saturn

Titan
Rhea
Mimas

Uranus

Neptun

Voyager 2

20. Aug. 1977

9. Juli 1979

Europa
Ganymed

26. Aug. 1981

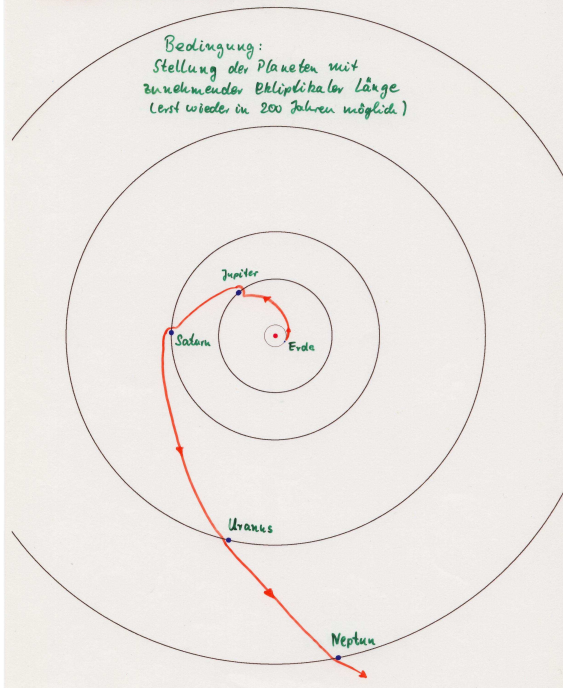
Enceladus
Thetys

24. Jan. 1986

25. Aug. 1989

Voyager 2: The "Grand Tour"

3-79



• Ring-System von der Erde leicht sichtbar !

3-81

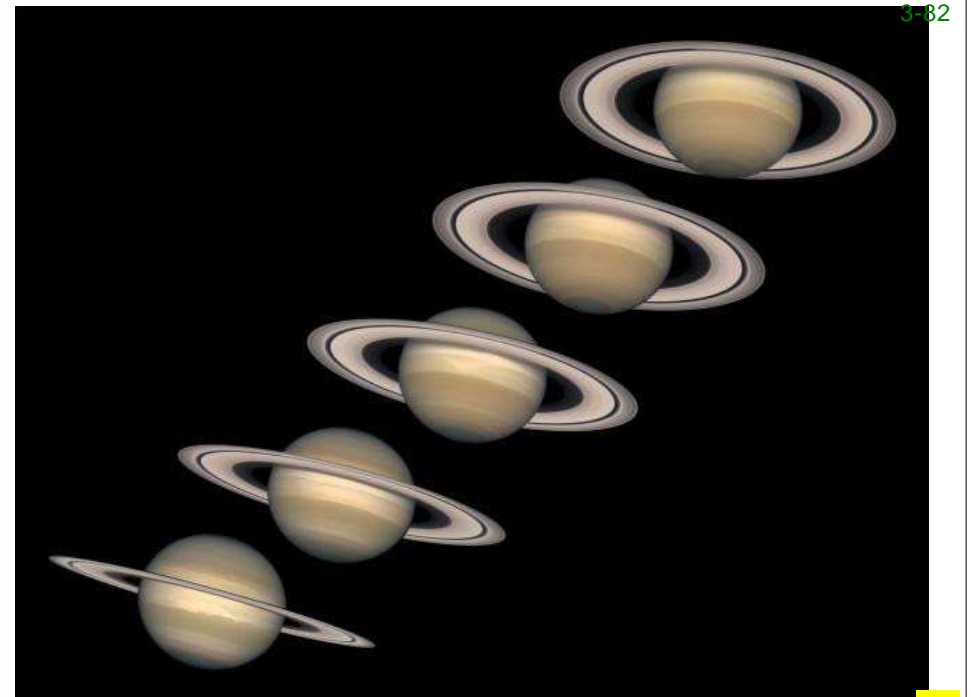
- in der Äquator-Ebene: Neigung gegen Bahnebene 27°
größte Öffnung 2017
"edge-on" 2009
- besteht aus Eisklumpen, ϕ 1cm ... 10 m
- Dicke der Ringe nur 10 ... 100 m
- Radius der von der Erde sichtbaren Ringzone:
1.2 ... 2.3 Saturn- Radien
Umlauf-Zeiten: 6^h ... 15^h
Umlauf auf Kepler-Bahnen!
- Feine Unterteilung durch Tausende von Lücken
→ Cassini-Teilung bei 2.1 R_{Saturn}
- komplizierte Wechselwirkung mit Saturn-Monden, z.B. "Hirten" oder "Wächter"

Saturn

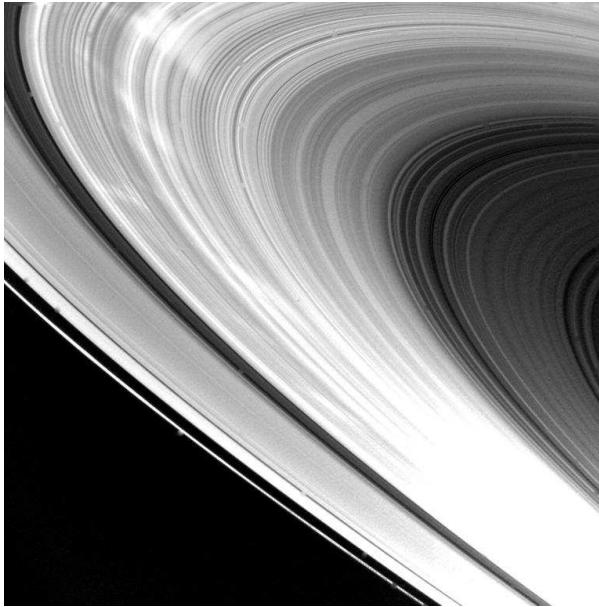
3-80



- Wolkenstrukturen weniger kontrastreich und farbig als bei Jupiter
- geringe Masse \rightarrow Schicht metallischen Wasserstoffs ($g=4$) dünner als bei Jupiter \rightarrow geringe vertikale Dichte von $\bar{\rho} = 0.8 \text{ g/cm}^3$
- Rotation mit $P = 10^h 32^m$
 \rightarrow starke Abplattung: 11%



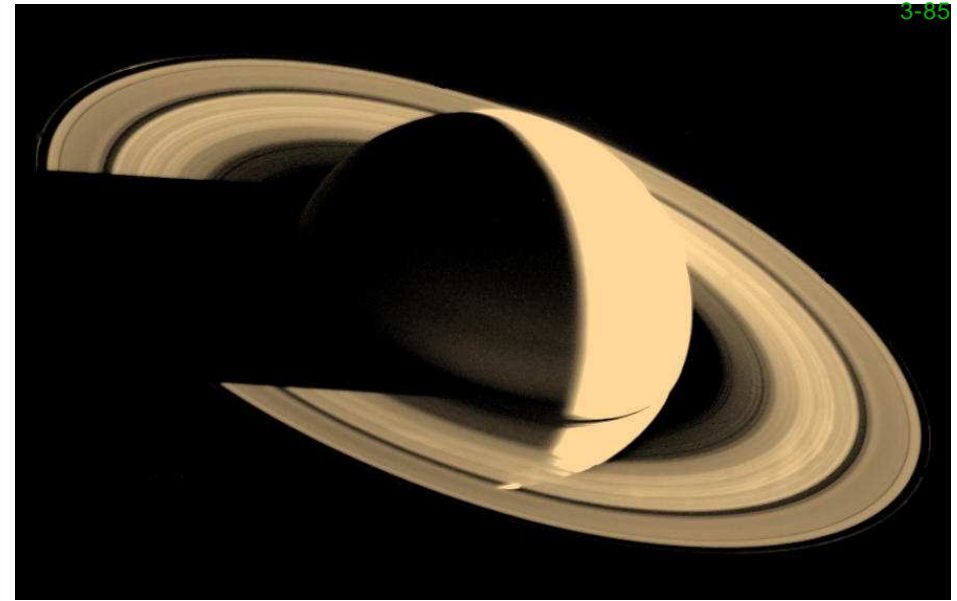
3-83



Eight hours after its closest approach, Voyager 1 took this picture of the planet's ring system. Major features of the rings are clearly seen: from the top of the image down is the bright F Ring, the A Ring, the Cassini Division, the broad B Ring, and the C Ring (dark gray area). The unique lighting in this view brings out the many hundreds of bright and dark ringlets that make up this very thin, phonograph record-like ring system. The dark spokelike features seen in images taken during approach to Saturn now appear as bright streaks, indicating that they possess a strong forward-scattering property.

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3-85

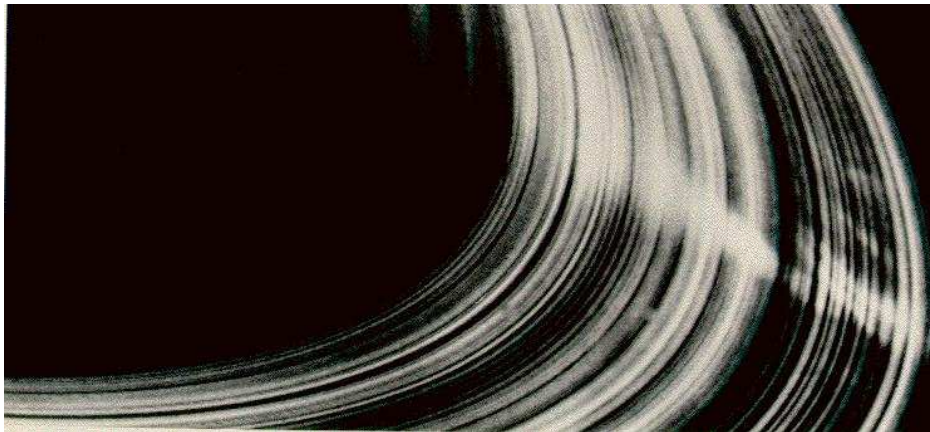


Voyager 1 looked back from a distance of 5.3 million km, four days after the spacecraft flew past the planet. Saturn's shadow falls upon the rings, and the bright Saturn crescent is seen through all but the densest portion of the rings.

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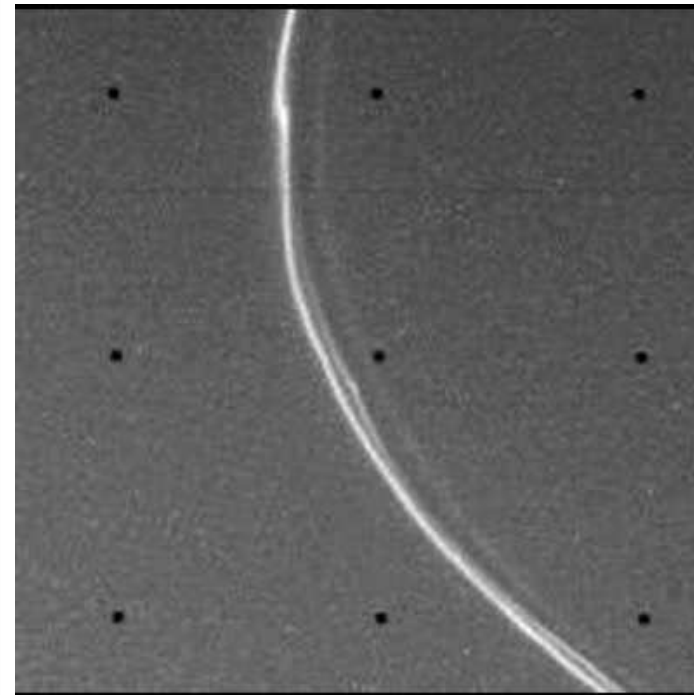
3-84

After passing Saturn, Voyager 2 viewed the B Ring in forward-scattered light. The spokes, seen previously as dark streaks, are now seen as bright streaks from this phase angle. This indicates that the spokes are caused by tiny dust grains, comparable in size to the wavelength of light.



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3-86



Saturn's narrow F ring, just outside the main ring system, is a very complex structure. In this close-up view it is made up of two narrow bright rings and a fainter ring inside them. The bright rings contain bends, kinks, and bright clumps.

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• Saturn - Monde

III. 24

3-87

	Bahn-Halbachse [R Saturn]	Umlauf-Periode [Tage]	Bahn-Eigenr. e	Neigung zum Äquator	Radius [km]
Atlas	2.276	0.602	0	0°	*
Innerer Wächter des F-Rings	2.340	0.613	0	0°	*
Äußerer Wächter des F-Rings	2.349	0.629	0	0°	*
Epimetheus	2.510	0.694	0	0°	*
Janus	2.511	0.695	0	0°	*
Mimas	3.08	0.942	0.2	1°	196
Enceladus	3.95	1.370	0	0°	255
Tethys	4.88	1.888	0	1°	530
Teleso	4.88	1.888	0	?	*
Calypso	4.88	1.888	0	?	*
Dione	6.26	2.937	0	0	560
Dione 8 + ...?	6.26	2.937	0	0	*
Rhea	8.73	4.518	0	0	765
<u>Titan</u>	20.3	15.95	0.03	0	<u>2575</u>
Hyperion	24.6	21.28	0.10	0	205 = 130 + 110
Iapetus	59	79.33	0.03	<u>14.7</u>	730
Phoebe	215	550	<u>0.16</u>	<u>150</u>	110

*) = kleiner als 100 km

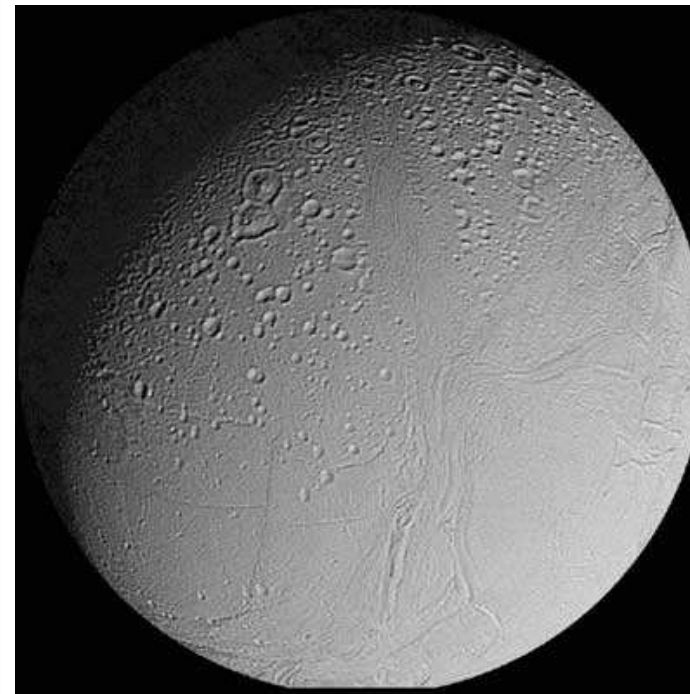


3-89

Mimas, the innermost of Saturn's larger moons, was nearly shattered by a cataclysmic impact. From observing Mimas' crater Herschel, scientists speculate that the inner satellites of the outer planets have, in fact, been shattered and gravitationally reassembled many times in their geologic history. Herschel's walls are approximately 5 km high, parts of its floor measure 10 km deep, and its central peak rises 6 km above the crater floor. The diameter of this moon is 394 km.

3-88

- Mimas, Enceladus, Tethys, Dione, Rhea
 - nur mittelgroß, trotzdem kugelförmig
→ plastisches Material
 - Oberfläche: Impact-Krater, (Wasser-?) Vulkanismus
- kleine Monde
 - unregelmäßige Brocken aus Eis und Silikat-Gestein



3-90

This global mosaic of **Enceladus** was assembled from images acquired by Voyager 2 during its close flyby of Saturn's second large satellite. Although Enceladus shows an abundance of impact craters in some areas, the lava flows near the center of the disk contain many fewer craters and cut some craters in half. This confirms the multiple stages or episodes of volcanism that formed and reformed the icy body's surface.

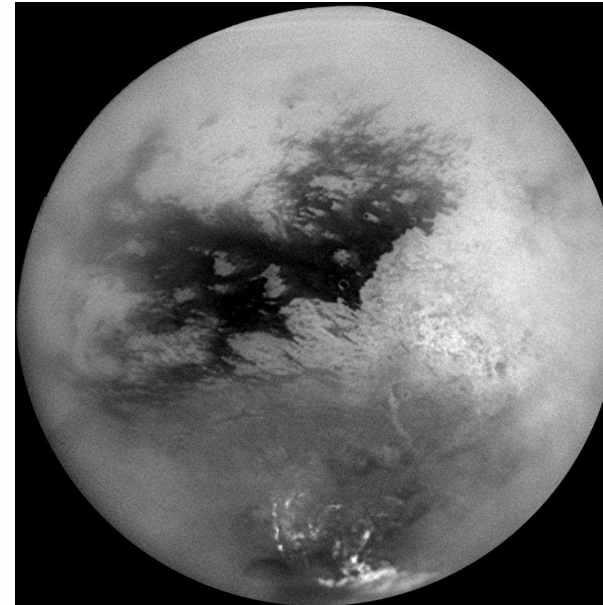


3-91

The leading hemisphere of Iapetus is covered by extremely dark material, whereas the trailing hemisphere is covered with bright material. This dichotomy puzzled the discoverer, astronomer Giovanni Cassini, who noted that the satellite was visible only from one side of its orbit. Two models have been proposed to explain this. The first proposes that dark material from Phoebe, a dark exterior moon, falls onto Iapetus from orbit. The second model says that the dark material erupted from the interior of Iapetus into a low area in the leading hemisphere.

Titan

3-93



- zweitgrößter Mond im Sonnensystem (nach Ganymed)
- einziger Mond mit Atmosphäre:
- Temperatur 94 K
- Druck 1.5 Bar
- N₂ mit Methan-Wolken
- Meere und Flüsse (aus Methan) ?
- Landung von *Huygens* am 14.01.2005

Play Movie

• Titan

III. 25 3-92

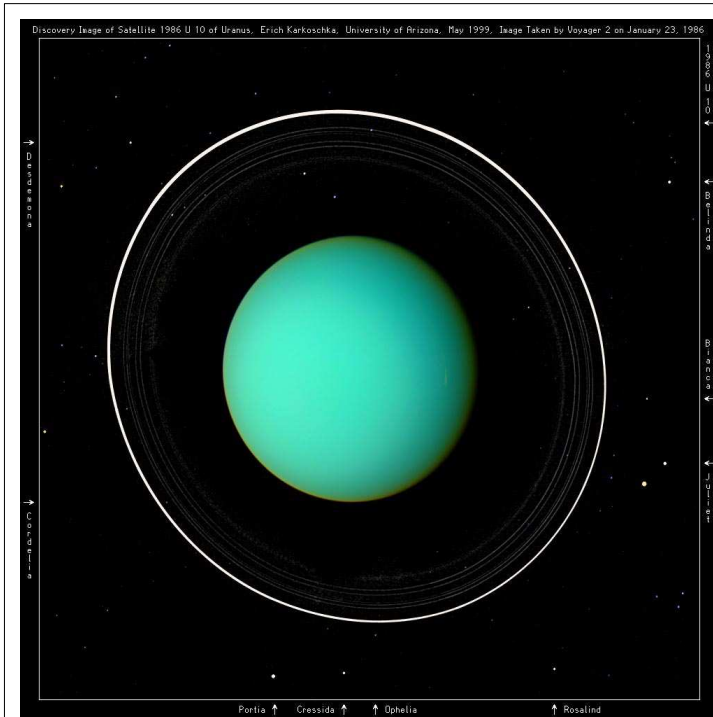
- zweitgrößter Mond im Sonnensystem (nach Ganymed, > als Merkur)
- einziger Mond mit Atmosphäre:
 - Druck am Boden: 1.5 - 2 atm
 - Temperatur " " : ≈ 90 K
 - Zusammensetzung: 99% N₂, Methan-Wolken (\rightarrow Regen?)
- Innerer Aufbau
 - Silikat - Kern (50% der Masse)
 - Eis, Wasser + Ammoniak
 - Methan-Ozeane

• Uranus

III. 27 3-94

1781 entdeckt von William Herschel

- erforscht von Voyager 2 1986
- Wolkenschicht fast strukturlos, nur sehr kontrastarme Wolken und Streifen
- Rotation: $P = 17^h 2$ (aus Magnetfeld)
 $i = 98^\circ$ (!) \rightarrow merkwürdige Jahreszeiten
- Magnetfeld: 60° gegen Rotationsachse geneigt (!)
- Innerer Aufbau: Silikat-Kern
H₂O und NH₃ (leitend!)
H, He, CH₄
- Ringe: 10 ganz schmale Bänder (\approx km breit)
 - sehr dunkles Material
 - Brechen ≥ 1 m

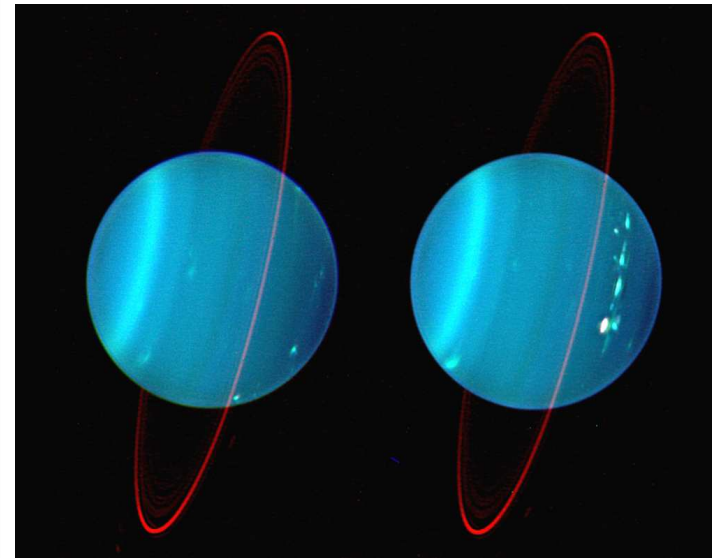


Uranus

Foto:
Voyager 2, 1989

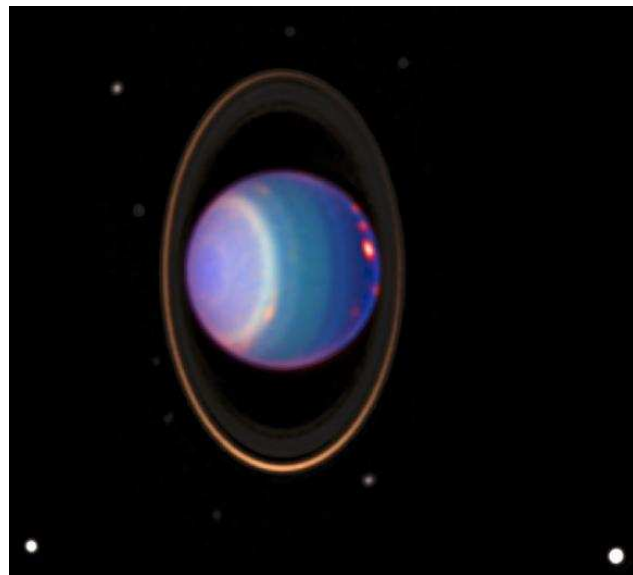
3-95

Uranus with the Keck telescope



Ground-based false-color taken with a near-infrared camera and the Keck Adaptive Optics system (July 2004). The artificial color scheme lends a deep reddish tint to the otherwise faint rings.

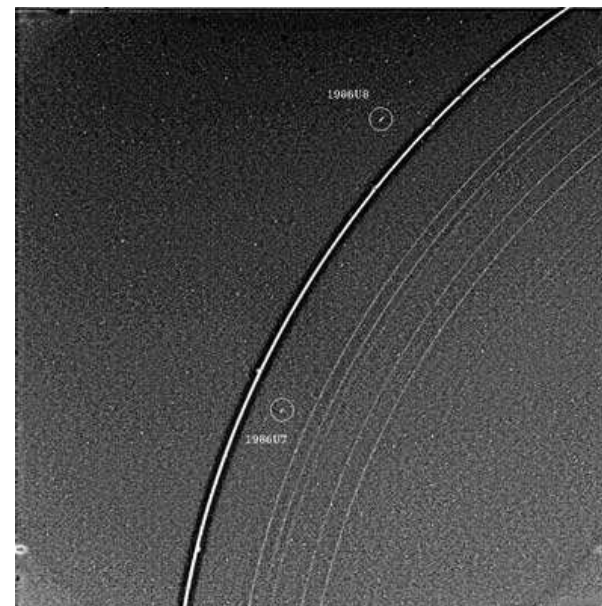
3-97



Uranus

Foto: Hubble Space Telescope (HST), 1998
4 Ringe; 10 (von 17) Monden
Falschfarben aus Infrarot (bei 0.9, 1.1 & 1.7 μm)

3-96



The discovery of two "shepherd" satellites has advanced our understanding of the structure of the Uranian rings. The moons, designated 1986U7 (Cordelia) and 1986U8 (Ophelia), are seen here on either side of the bright epsilon ring and are believed to confine it by their gravitational effects. Inward from the epsilon ring are the delta, gamma, eta, beta and alpha rings. The 4, 5, and 6 rings are barely visible inward from there. The epsilon ring appears surrounded by a dark band as a result of the image processing.

3-98

Monde:

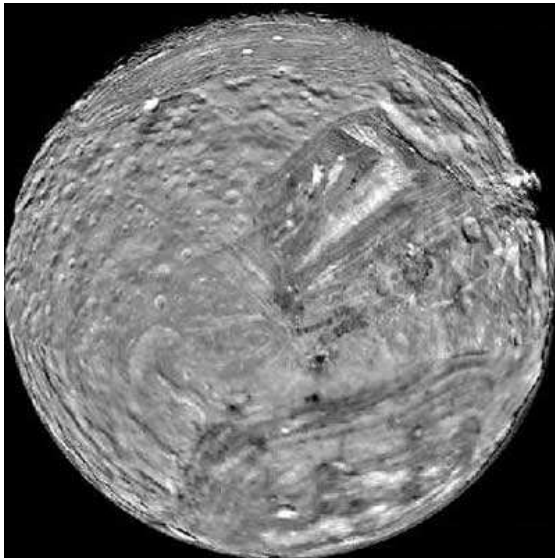
	Bahn - Halbachse [R _{URANUS}]	Umlauf- Periode [Tage]	Bahn- Exzentr. e	Neigung zum Äquator	Radius [km]
Miranda	5.13	1.41	0.02	3.4	240
Ariel	7.54	2.52	0	0	580
Umbriel	10.5	4.14	0	0	600
Titania	17.2	8.71	0	0	800
Oberon	23.0	13.46	0	0	880

+ 10 weitere kleine Monde, entdeckt von Voyager 2 ...

● Neptun

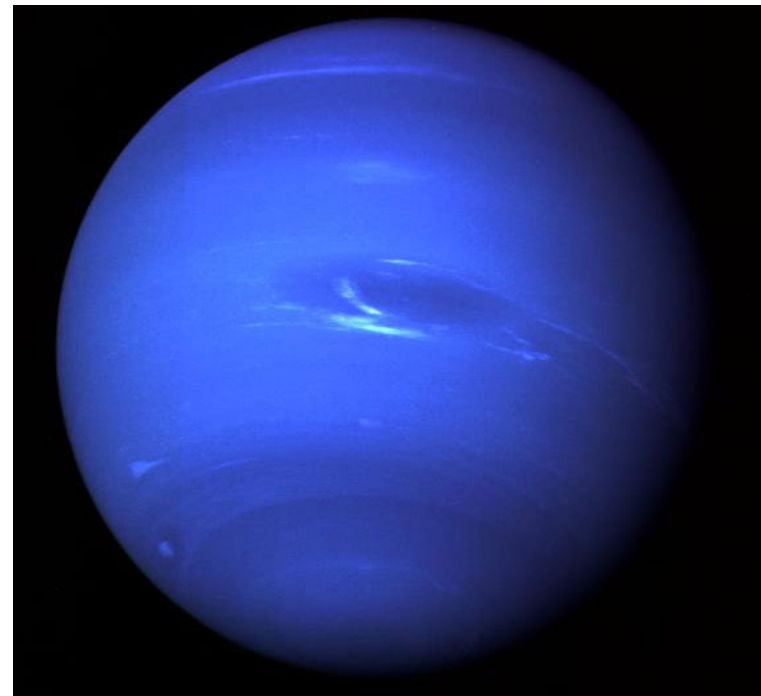
- Naherkundung durch Voyager 2, August 1989
- Entdeckung 1846 von Johann Gottfried Galle, Berlin nach Vorherberechnung der Position (1° genau!) durch Le Verrier aufgrund Bahnstörungen des Uranus
- einige Wolkenmuster erkennbar
- Rotation $16^h 3^m$ (Magnetfeld), Inklination 29°
- Ringe vom Uranus-Typ: zum Teil schmal
- Magnetfeld 50° geneigt, $0.4 R_{\text{NEPTUN}}$ dezentriert

Miranda



Miranda is the innermost of the large Uranian satellites. Its surface is composed mostly of rolling cratered plains that probably date back to the early evolution of the solar system when impact rates were extremely high. Half of Miranda's surface is younger based on the fewer number of craters; it consists of complex sets of parallel and intersecting scarps and ridges. The bright V-shaped feature in the grooved area is Inverness Corona, and has been nicknamed the "Chevron". The huge, jagged canyon on the right limb is in the direction of Uranus itself.

Neptun



Voyager 2
1989

3-a03

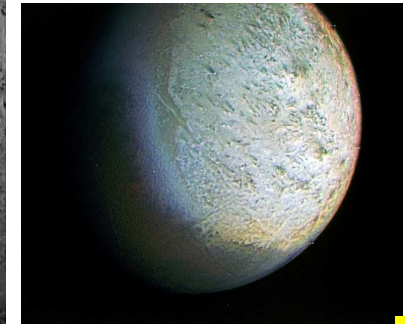
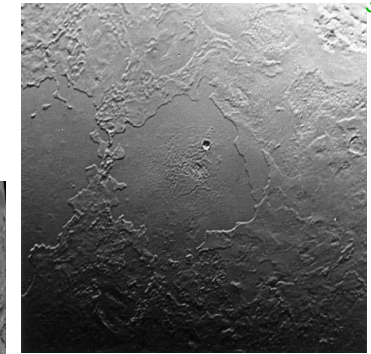
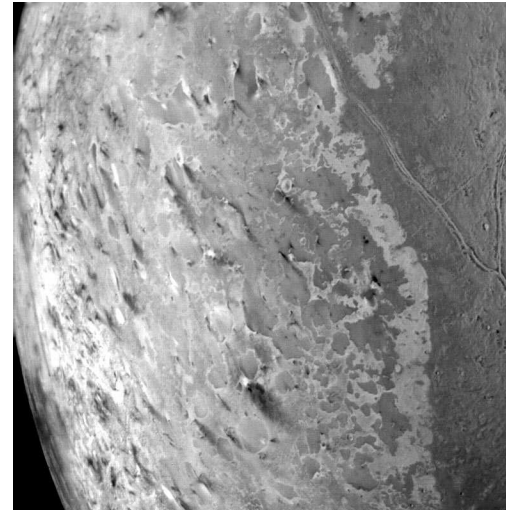


Feathery white clouds fill the boundary between the dark and light blue regions on the Great Dark Spot. The spiral shape of both the dark boundary and the white cirrus suggests a storm system rotating counterclockwise. Periodic small-scale patterns in the white cloud, possibly waves, are short-lived and do not persist from one Neptunian rotation to the next.

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Triton

Fotos: Voyager 2 (1989)
Oberflächen-Temperatur 35 K
Dichte 2 g/cm^3 → viel Gestein
Eis-Vulkane?



3-a05

:

3-a04

Monde

		Bahn - Halbachse [10^3 km]	Umlauf - Periode [Tage]	Bahn - Exzentr. e	Neigung zum Äquator	Radius [km]
	Triton	355	5.9	0	<u>157</u>	1500
	Nereide	5562	360	<u>0.75</u>	<u>29</u>	<u>170</u>
Proteus	N1	118	26.9		~0	210
Larissa	N2	74	13.3		~0	100
Galatea	N3	52	8.0		~0	70
Despina	N4	62	9.5		~0	80
Thalassa	N5	50	7.5		~4.5	45
Naiad	N6	48	7.1		~0	25

:

3-a06



Neptun

schmale
Ringe

rätselhafte
Bögen

: