- **NIMS observations**

- **Detections of active volcanic centers**

- **Types of hot spot activity**

- **Persistent hot spots**

  - global distribution
  - plume activity
  - variations in power output

- **Styles of activity**

NIMS OBSERVATIONS DURING GALILEO ORBITS G1 - E16 (JUNE 1996 - JULY 1998)

ORBIT	NUMBER OF NIMS OBSERVATIONS	HIGHEST SPATIAL RESOLUTION (KM/PIXEL)
G1	4	350
G2	11	220
C3	3	122
E4	27	160
E6	5	200
G7	7	264
G8	18	476
C9	9	302
C10	10	160
E11	10	396
E12	1	260
E14	1	120
E15	1	230
E16	1	350
	108	

PLANNED VOLCANO MONITORING OBSERVATIONS:

C20 (MAY 99): 1
C21 (JULY 99): 1
C22 (AUGUST 99): 1

IO'S ACTIVE VOLCANIC CENTERS - update as of 3/99

- **75 active volcanic centers (75 hot spots plus Ra) known from:**

  Voyager IRIS and ISS

  Galileo NIMS and SSI

  Ground-based observations (J. Spencer et al., C. Dumas et al.)

  HST NICMOS observations (J. Goguen et al.)

- **25 areas identified as possibly active volcanic centers**

DIFFERENCES IN ACTIVITY AT IO'S HOT SPOTS

Duration	Variation in power output	Plume activity	Temperature range	Red deposits
Persistent	Outburst	Absent	"ultramafic"	Prominent
Long-lived	Brightening	Prometheus-type	"basaltic"	Faint
Sporadic	Fading	Short-lived		Absent
Unconstrained	Steady	Unique		

RED DEPOSITS:

Prominent
Faint
Absent

From McEwen et al. [1998], Geissler et al. [1999]:

Presence of prominent red deposits correlated with recent activity

Red deposits thought to be fallout from plumes - perhaps sulfur

Update from Lopes-Gautier et al. [1999]:

23/75 (31%) of known hot spots are associated with red deposits

This may represent a lower limit of hot spots-plume activity

(not all plumes produce red deposits)

PLUME ACTIVITY

- **Absent**

- **Prometheus-type**

  long-lived, small, bright, surrounded by white (some with red) deposits

  Prometheus, Kanehekili, Amirani, Maui, Zamama, Volund, Marduk

- **Short-lived**

  no plume seen, but plume deposits identified

  Aten, Surt, Euboea, Babbar (?)

- **Unique**

  Pele, Loki, Pillan, Acala, and Ra

  All between longitudes 240°-360° (only plumes observed in this region)

- **Masubi and Culann are either Prometheus-type or Short-lived**

(Updated from McEwen et al. 1998)

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TEMPERATURE RANGE:

MEASUREMENTS BY NIMS, SSI, GROUND-BASED INSTRUMENTS

- "Ultramafic"-type temperatures (> 1500 K) measured at Pillan (SSI, NIMS) [McEwen et al. 1998]

- SSI best-fit temperatures for 8 hot spots >1350 K (implying magma T > 1550K) (Kanehekili, Janus, Amirani, Marduk, Lei-Kung, Isum)

- Temperatures > 1350 K measured from ground for 3 events [Veeder et al. 1994, Spencer et al. 1997, Stansberry et al. 1997]

- "Basaltic"-type temperatures widespread on Io

- SSI eclipse observations detect temperatures down to 700 K (filled pixel)

- NIMS observations detect temperatures down to 180 K (filled pixel)

- Hot spots detected by NIMS only may represent:

  Lower magma temperatures, or

  Less vigorous activity (e.g. cooling flows)

DURATION OF ACTIVITY

"PERSISTENT" HOT SPOTS (DURATION > 1 YEAR):

- **30 hot spots known to persist for longer than 1 year, perhaps decades**
- **Persistent hot spots are likely to represent major magma pathways to the surface**
- **Enough data to attempt correlations with other parameters related to hot spot activity**

"LONG-LIVED" HOT SPOTS (3 MONTHS < DURATION < 1 YEAR)

- **Only 5 hot spots in this category**

  (Ruwa, Masubi, 9606W, Fo, Amaterasu)
- **Further studies may reveal that activity is persistent for > 1 year**

"SPORADIC" HOT SPOTS (duration < 3 months) or UNCONSTRAINED DURATION

- **40 hot spots could be sites of low-level activity that occasionally flares up or else sites of short-lived activity**

GLOBAL DISTRIBUTION

- **All volcanic centers:**
  apparently uniform distribution with latitude and longitude (perhaps fewer at high latitudes)

- **PERSISTENT hot spots and plumes**
  concentrated towards low latitudes

- **Global distribution favors the asthenosphere tidal dissipation model rather than the deep-mantle tidal dissipation model**

- **Thermal output (Smythe et al.) also favor asthenosphere model**

(Updated from Lopes-Gautier et al., Icarus, in press)

PERSISTENT HOT SPOTS AND PLUME TYPE:

- **All 7 Prometheus-type plumes are associated with persistent hot spots**

- **3 of 4 unique plumes are associated with persistent hot spots (Ra is exception)**

- **3 of 4 short-lived plumes NOT associated with persistent hot spots (Babbar is exception)**

PERSISTENT HOT SPOTS AND ACTIVE PLUMES

NIMS only	PLUME?	RED DEPOSITS?
HI'IAKA		
SIGURD		
MONAN		
MAUI	Voyager	
ALTJIRRA		Yes
MALIK		Yes
TUPAN		Yes
SHAMASH		
VOLUND	Voyager	
AIDNE		
SETHLAUS		Yes
RATA		Yes
KURDALAGON		Yes
9611A		
BABBAR	plume deposit?	Yes

SSI only	PLUME?	RED DEPOSITS?
ACALA	Galileo plume	

NIMS and SSI	PLUME?	RED DEPOSITS?
ZAL		Yes
GISH BAR		
AMIRANI	Galileo and Voyager	Yes
PROMETHEUS	Galileo and Voyager	Yes
CULANN	Galileo ?	Yes
ZAMAMA	Galileo	Yes
MARDUK	Galileo and Voyager	Yes
MULUNGU		
PILLAN	Galileo, HST	
PELE	Galileo, Voyager, HST	Yes
LOKI	Voyager	
KANEHEKILI	Galileo	
JANUS		
ISUM		Yes

IMPLICATIONS:

- **ACTIVE PLUMES associated with hot spots where volcanic activity:**

  is in a vigorous, high mass eruption rate phase (hot material exposed),

  or

  involves higher temperature magmas

- **Presence of RED DEPOSITS at other persistent hot spots probably indicates that plume activity has occurred in recent years**

- **There may be no major difference in magma temperature and composition at all of the known persistent hot spots**

VOLCANISM AT PERSISTENT HOT SPOTS

- **Activity lasts for longer than 1 year, perhaps decades**
- **Concentrated towards equatorial regions**
- **Red and black deposits common**
- **Temperatures detected both in the "ultramafic" range and the "basaltic range"**
- **All plumes except for Ra and Masubi coincide with known persistent hot spots**
- **Galileo-observed plumes coincide with SSI-observed hot spots (higher mass eruption rate phase of activity?)**
- **Several hot spots observed by NIMS only show red deposits (indicate past plume activity?)**

VARIATIONS IN ACTIVITY AT PERSISTENT HOT SPOTS

- **5 hot spots showed variations in power output > factor of 2 over timescales of 18 months or less**

Malik	**(2.2 between G1-E11)**
Loki	**(2.5 between G7-E16)**
Altjirra	**(3.4 between G1-E11)**
Amirani	**(4.0 between G1-E11)**
Culann	**(5.3 between G1-C10)**

- **8 hot spots showed variations of < factor of 2 in power ouput over timescales > 18 months**

Hi'iaka
Pele
Zal
Prometheus
Gish Bar
Zamama
Tupan
Maui

IMPLICATIONS:

- **Long-lived, mostly "steady" activity**

- **Increase in mass eruption rate may lead to onset of plumes (e.g. Pillan, Masubi)**

- **Magma supply rate balanced by magma ouput rate**

- **Possibly analogous to "open system" volcanism on Earth**

  e.g. Stromboli, Kilauea

- **Francis et al. [Nature, 1993]: Persistent volcanism**

  steady supply of mantle-derived magma, or

  convective exchange of magma in chamber with deeper reservoirs

OUTBURSTS: FACTS

- **Outbursts occur about 3% of the time [Spencer and Schneider 1986]**

- **Only one well-constrained outburst location (1995, Spencer et al.)**

  Errors in latitude and longitude only 7 degrees

  Arusha Patera region

  2 outbursts observed (March and September 1995)

- **Arusha region observed in June 1996 by NIMS and many times since, but no hot spot detected**

- **Surface change from Voyager to Galileo observed by SSI at Arusha**

OUTBURSTS: POSSIBLE IMPLICATIONS

- **Outbursts may be related to short-lived/sporadic hot spots rather than to persistent hot spots**

- **Outbursts may represent a different style of activity than that seen at persistent hot spots**

  Magma chamber is suddenly emptied

  Activity may die for long periods of time while magma chamber is being replenished