

# *Searching for planets with HATNet and HATSouth*

- Introduction – scientific motivation
- The HATNet project
- Notes on the HAT-South project



# Scientific motivation: transiting planets (TEPs)

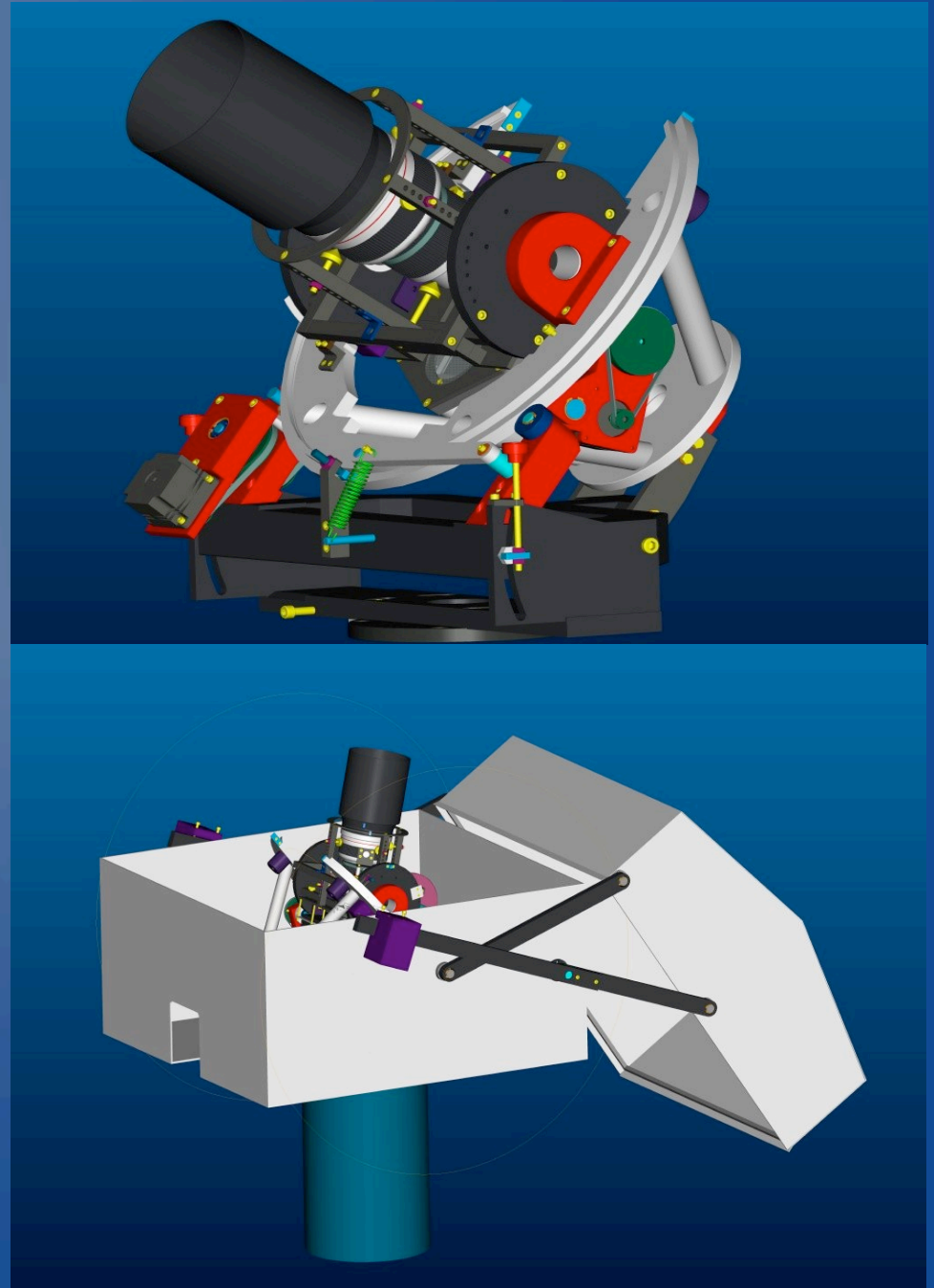


The “royal way”  
of understanding  
planetary  
systems.

Note  
complementarity  
to other methods

# Goals of the HATNet project

- Discover many transiting extrasolar planets.
- Carry out their accurate *initial* characterization.
- Focus on planets around **bright** stars to enable detailed follow-up (community effort)
- Investigate relations between planetary and host star parameters.
- Contribute to the understanding of their formation, migration, evolution, and physics.
- Explore their diversity.
- Find odd-balls.





# The HAT telescope – in real



- $f=200\text{mm}$
- $f/1.8$
- $D=110\text{mm}$
- $\text{FOV}=10^\circ$
- scale  $10''/\text{pix}$
- Sloan r filter
- 4K x 4K Kodak FI chip
- Fully automated with all components: dome, telescope, CCD



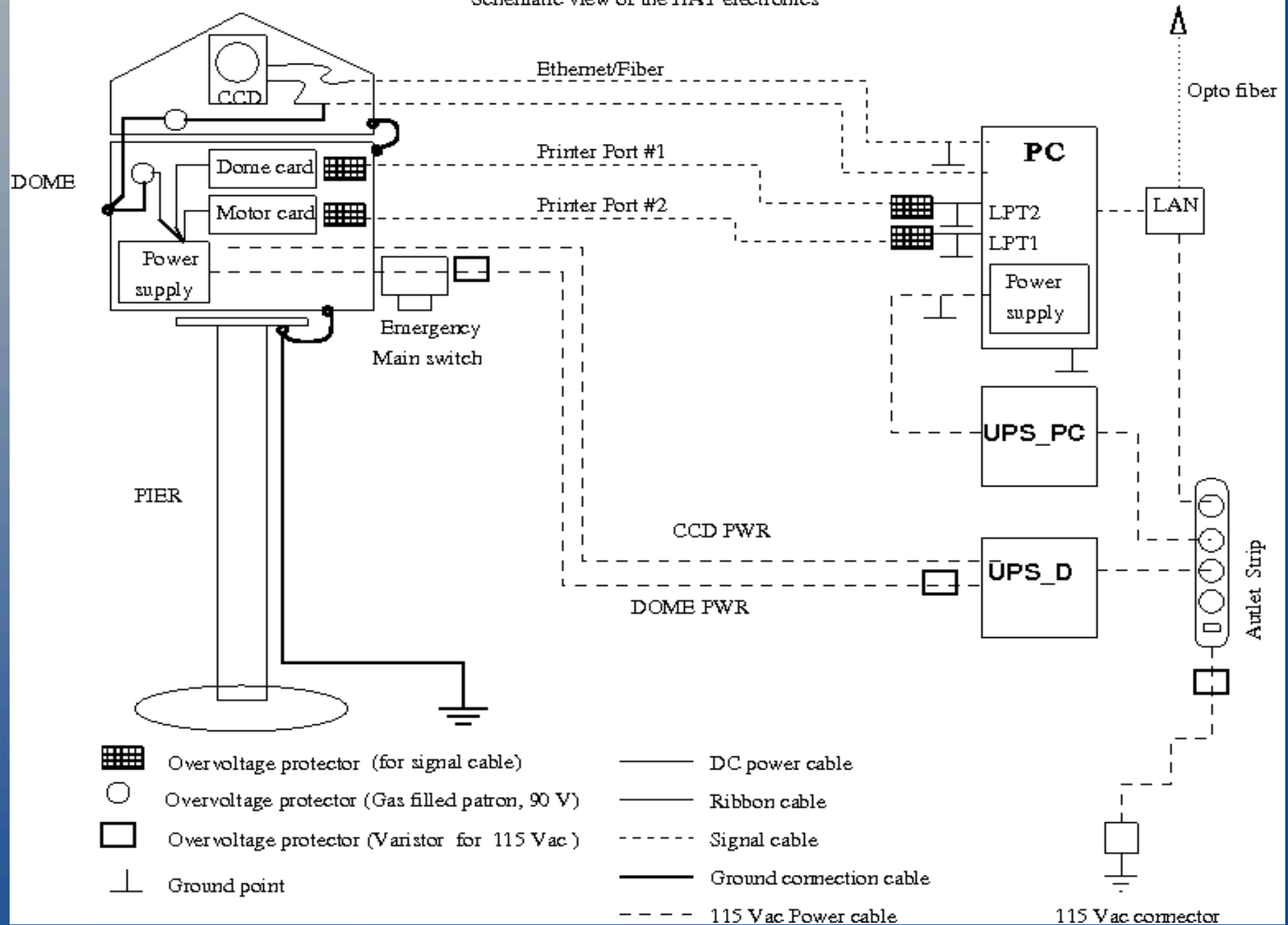
# The auto-mated telescope





# Electronics & control

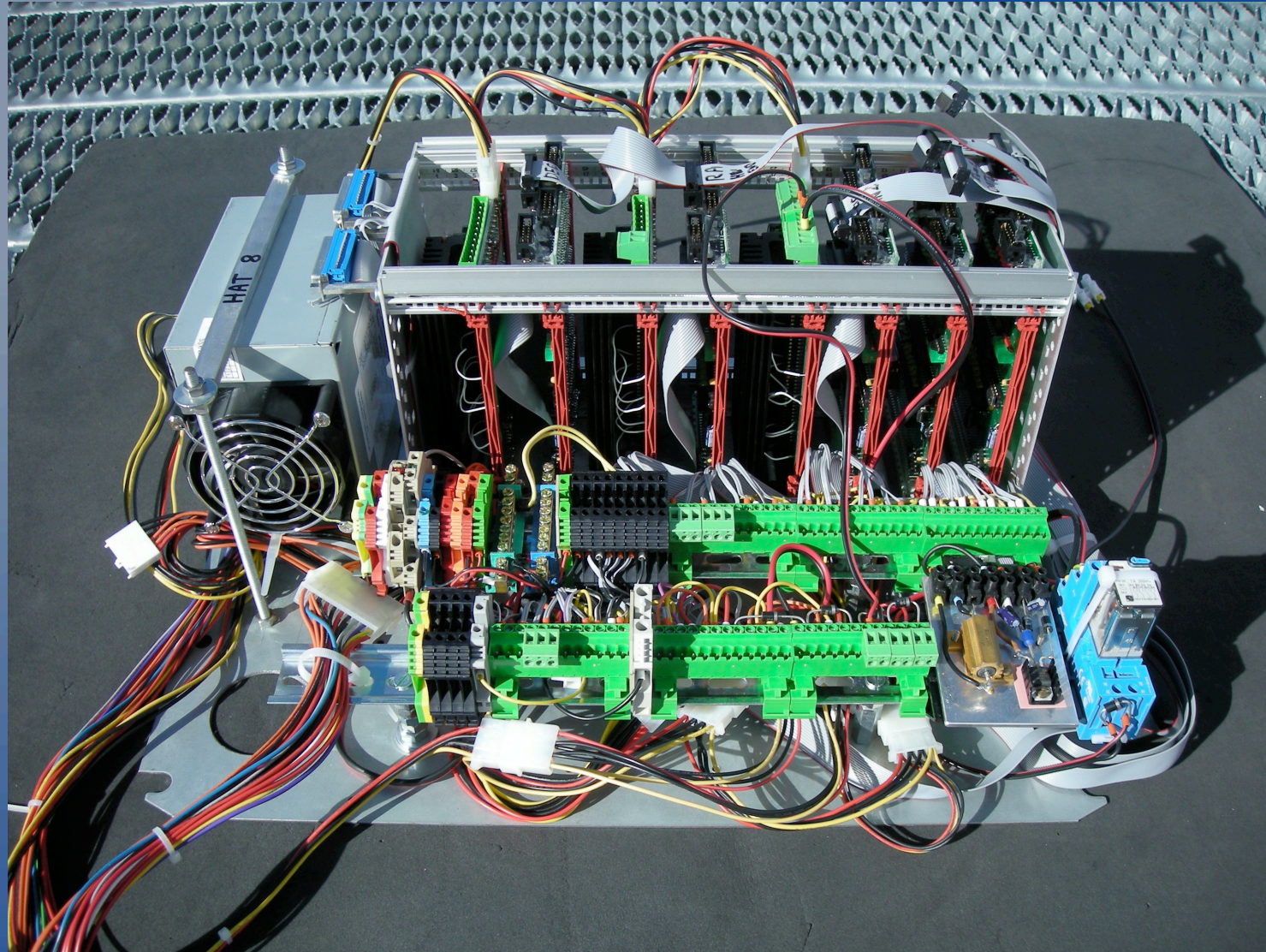
Schematic view of the HAT electronics





# The HAT electronics

- ATX PC power supply
- Fail-safe functions
- Basic logics: PIC micro-controllers
- Separate dome and telescope control
- Terminal stage cards (for RA/DEC/focus stepper motors and dome motor)
- Diagnostic LEDs
- Stepper motor signals directly emitted by printer port.
- Telescope motion, homing, etc – kernel drivers





# Fred Lawrence Whipple Observatory





# Fred Lawrence Whipple Observatory





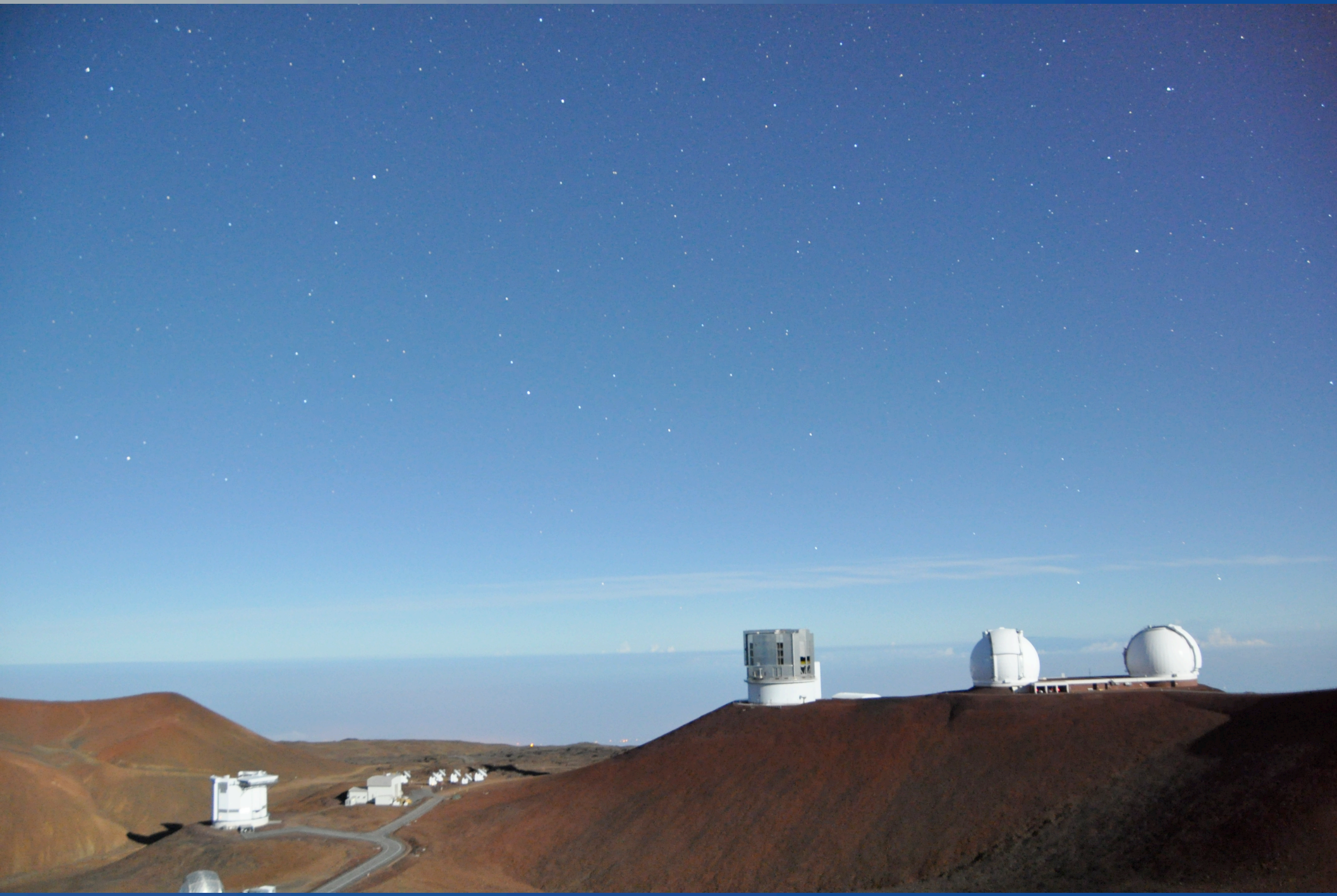


# Control computers

- Rack mounted computers with redundant power supplies
- Separate UPS for telescopes and computers
- Ethernet power switches
- Internal vs. external network
- GNU/Linux Debian 5/6, with xenomai
- Firewall, denyhosts
- RAID-1 disk arrays
- Typical uptime: 3—9 months. (Shutdowns exclusively due to power outages)
- Watchdog cards
- Telescope, dome, CCD control, data acquisition, reduction, transfer

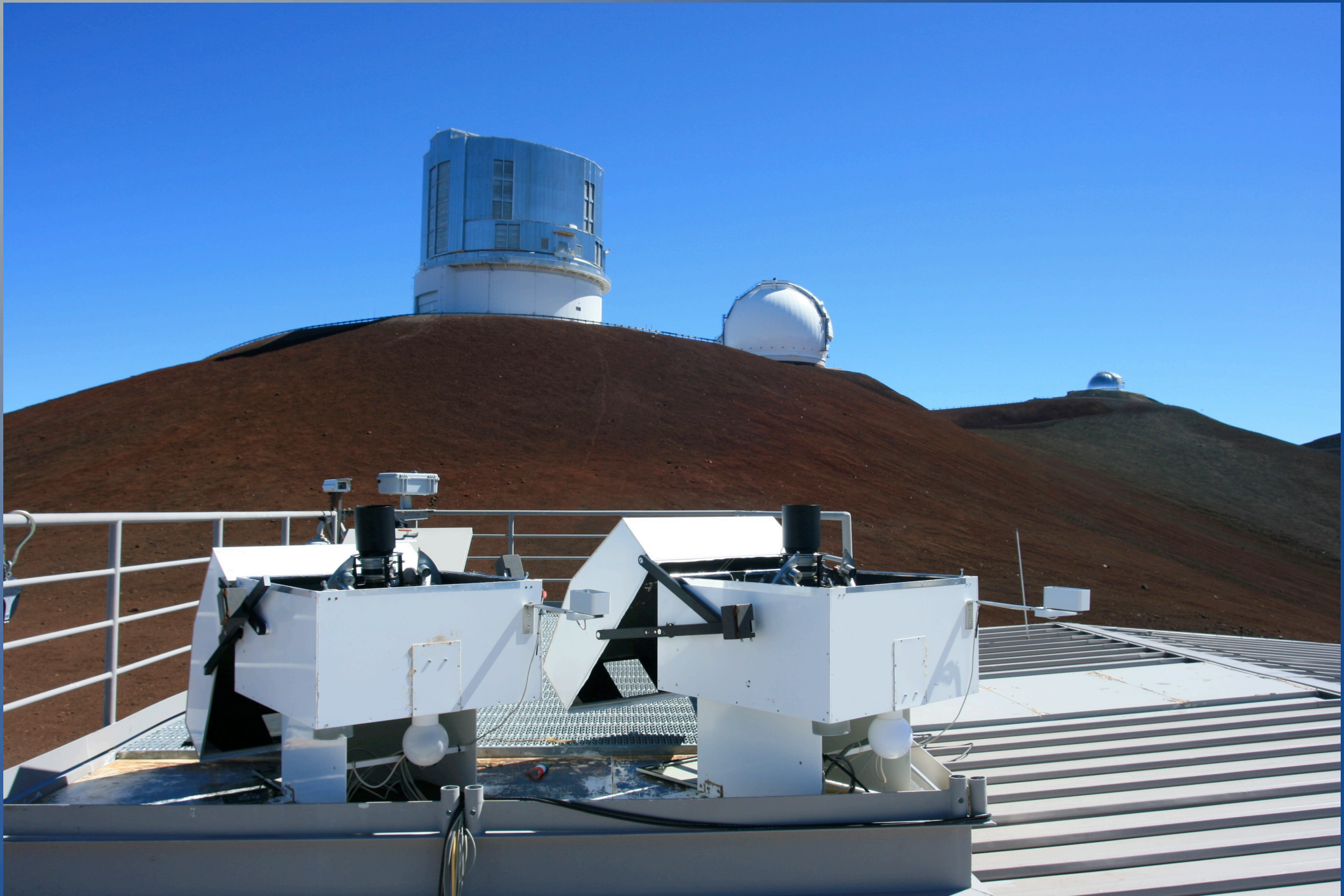


# Mauna Kea – SMA





# HATs at SMA/Mauna Kea





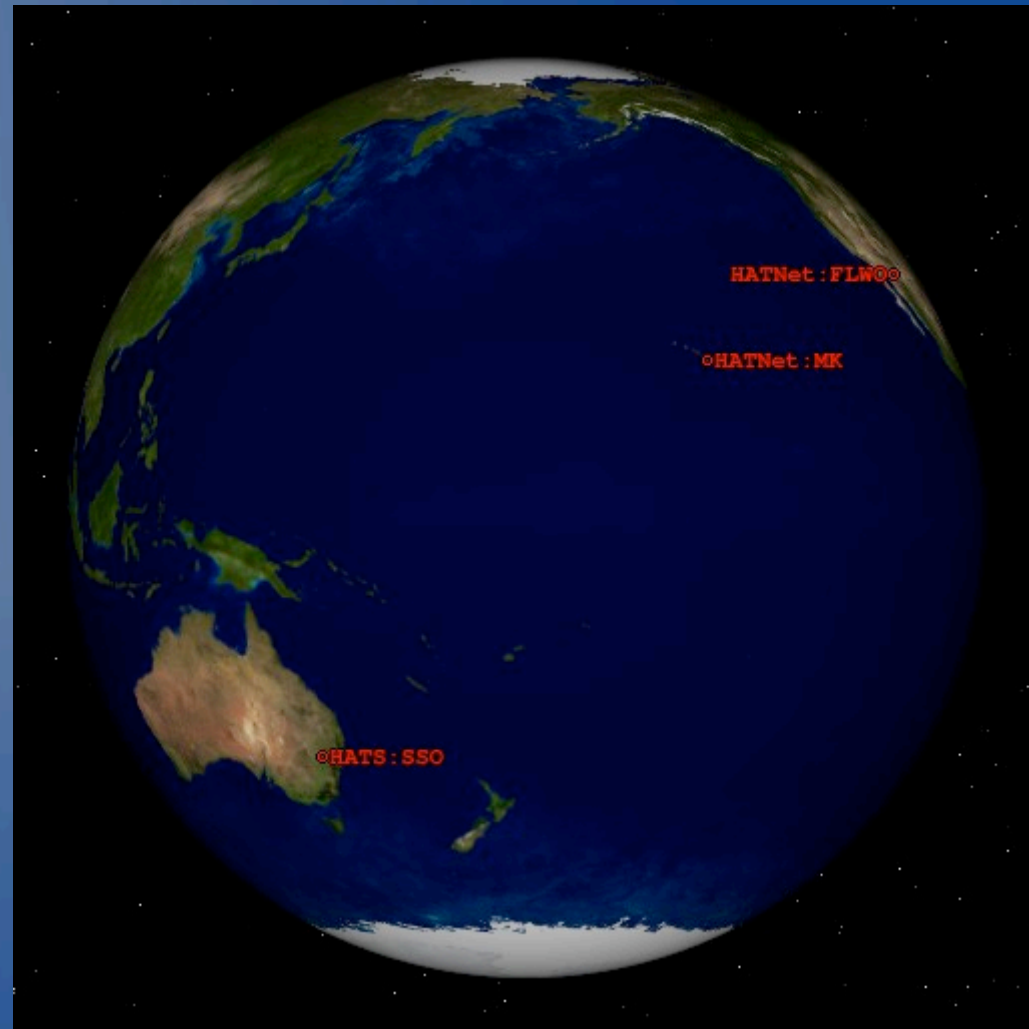
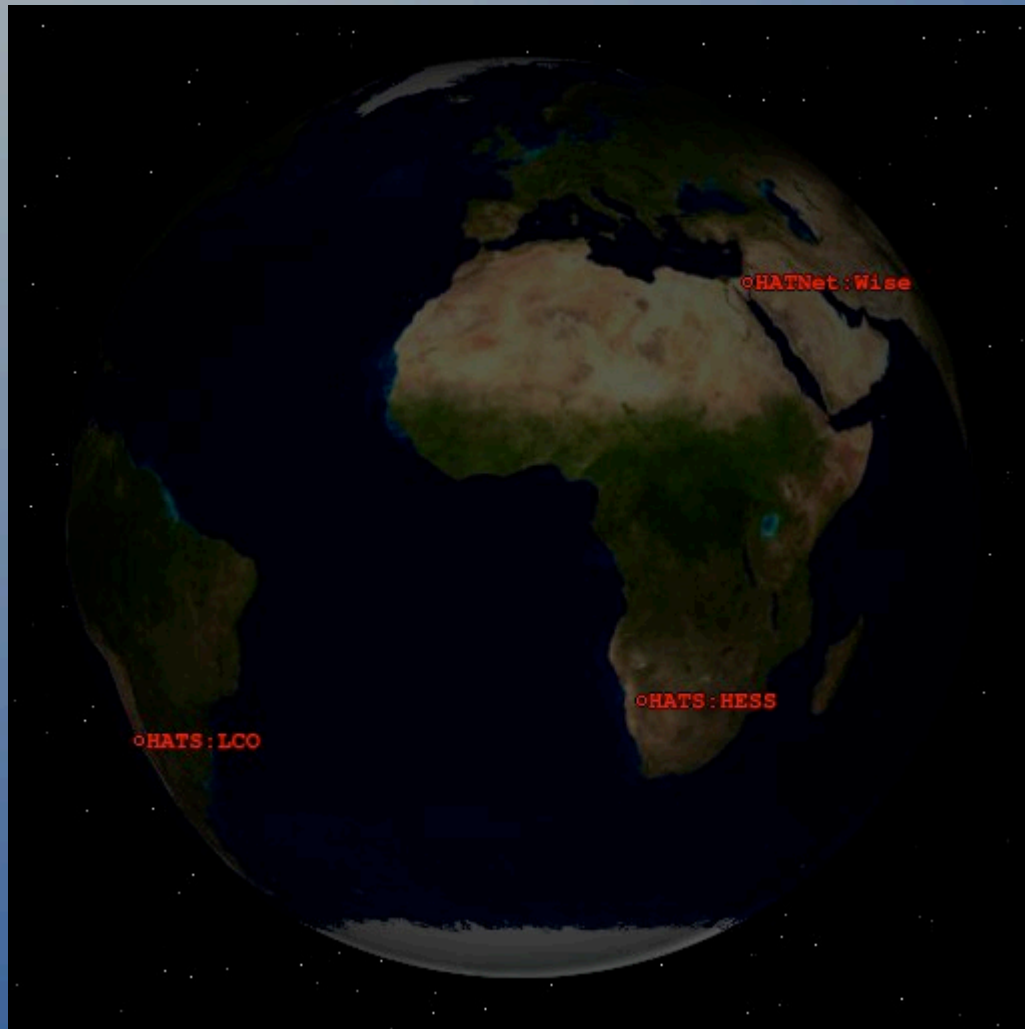
# Wise Observatory, Israel





# Networks spread in longitude

HATNet

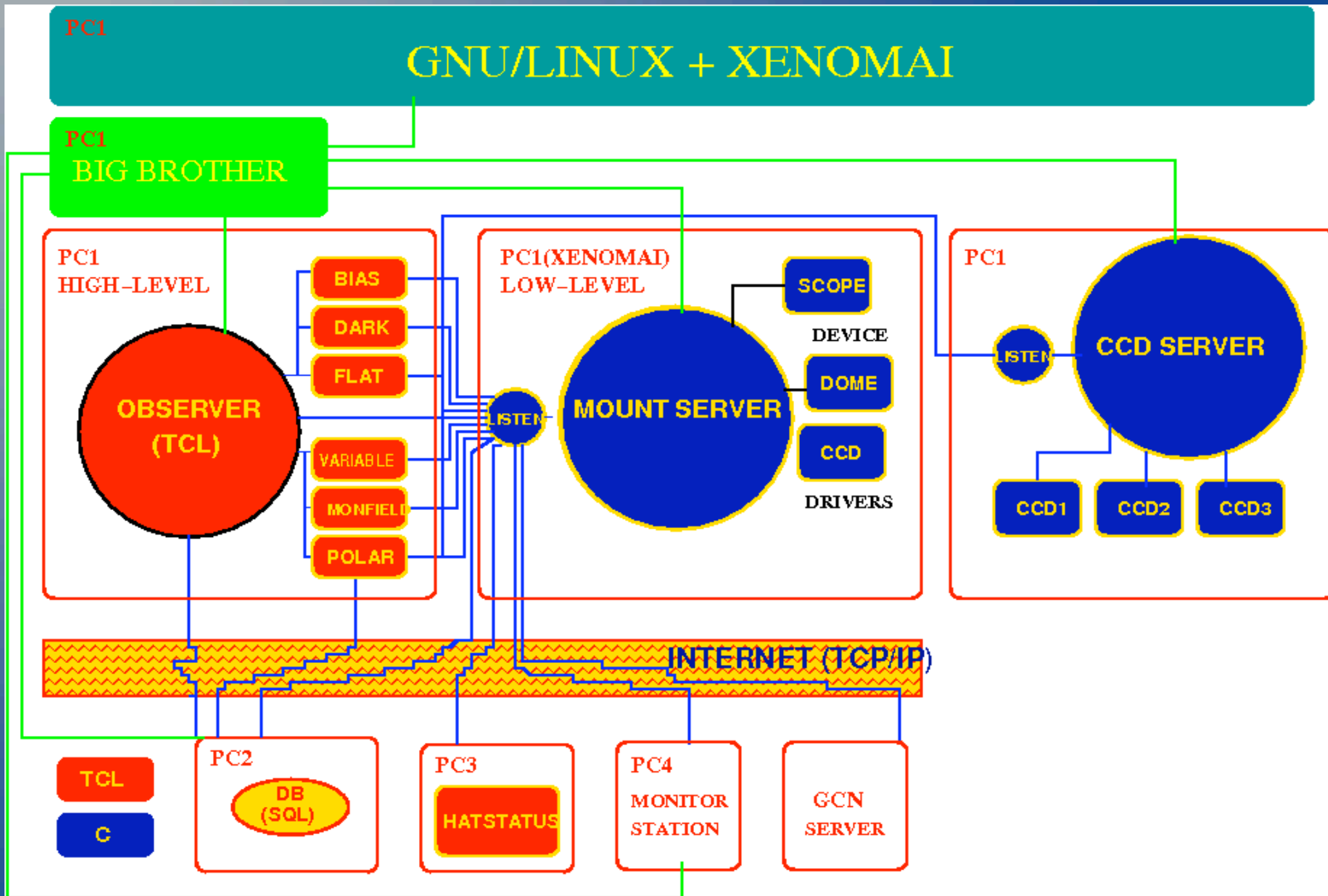


HATSouth

The Earth at 2011 March 2 14:50 HST

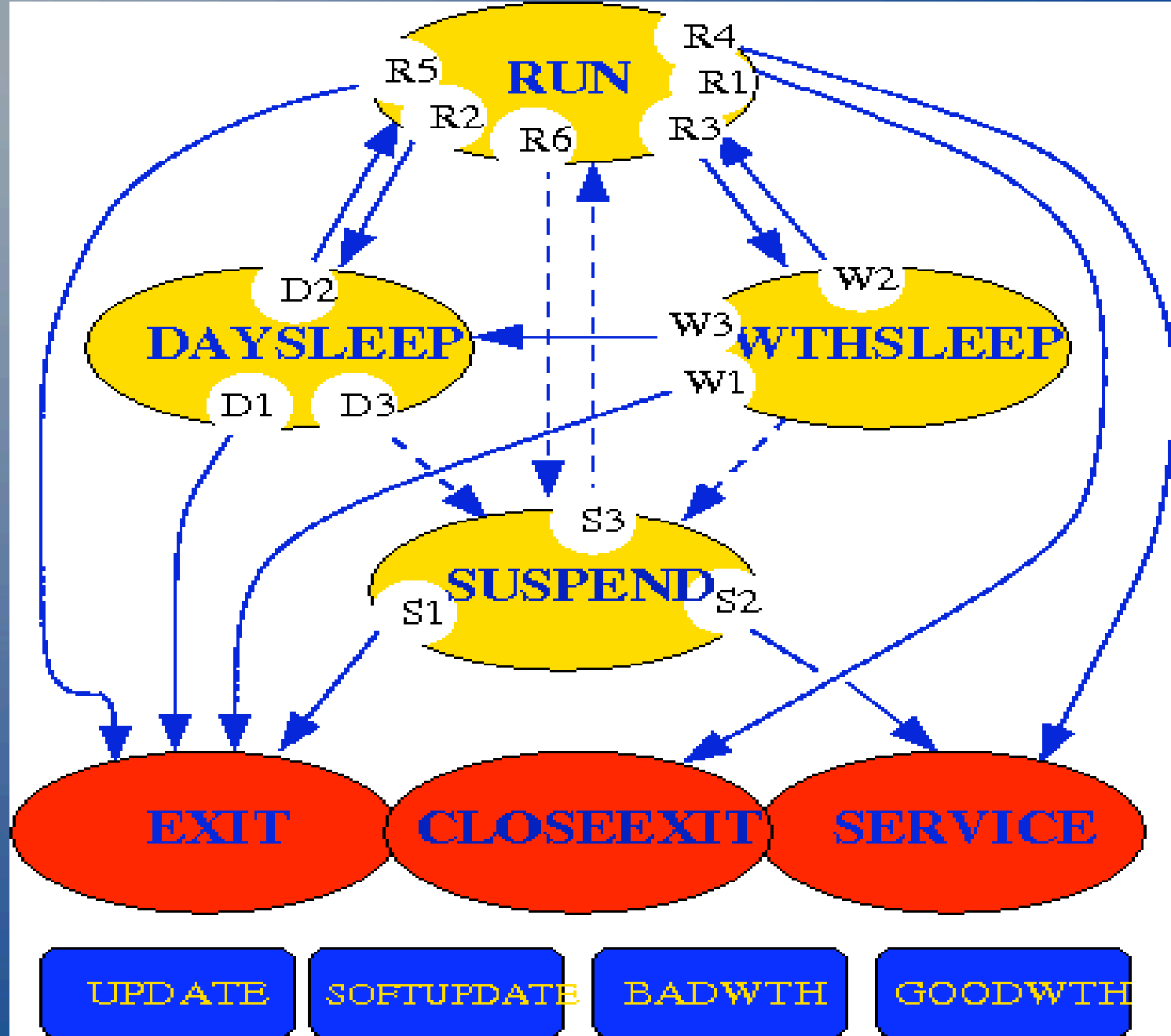


# Software architecture





# The virtual observer





# The MySQL database

MySQL Query Browser - hatmaster@hatsouth:3306

File Edit View Query Script Tools MySQL Enterprise Help

SELECT \* FROM Cameras C order by CMid LIMIT 0,1000

Execute Stop

CMid	CMver	CMenabled	CMcgid	CMpos	CMname	CMserial	CMx	CMy	CMxsize	CMysize	CMbitdepth	CMinte
0	0	1	0	1	ALTA E10 (SN 4296)	A4296	2048	2048	14.00	14.00	16	eth
1	0	1	1	1	ALTA-U16m (KAF16803D9)	090339	4096	4096	9.00	9.00	16	usb
2	0	1	1	2	ALTA-U16m (KAF16803D9)	090340	4096	4096	9.00	9.00	16	usb
3	0	1	1	3	ALTA-U16m (KAF16803D9)	090342	4096	4096	9.00	9.00	16	usb
4	0	1	1	4	ALTA-U16m (KAF16803D9)	090337	4096	4096	9.00	9.00	16	usb
5	0	1	2	1	ALTA-U16m (KAF16803D9)	090338	4096	4096	9.00	9.00	16	usb
6	0	1	2	2	ALTA-U16m (KAF16803D9)	090341	4096	4096	9.00	9.00	16	usb
7	0	1	2	3	ALTA-U16m (KAF16803D9)	090343	4096	4096	9.00	9.00	16	usb
8	0	1	2	4	ALTA-U16m (KAF16803D9)	090344	4096	4096	9.00	9.00	16	usb
9	0	1	3	1	ALTA-U16m (KAF16803D9)	090353	4096	4096	9.00	9.00	16	usb
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20	1	1	5	4	ALTA-U16m (KAF16803D9)	090349	4096	4096	9.00	9.00	16	usb
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24	0	0	6	4	ALTA-U16m (KAF16803D9)	090351	4096	4096	9.00	9.00	16	usb

42 rows fetched in 0:00.1203

Start Editing Apply Changes First Last Search

Schemata Bookmarks History

- BiasVersions
- CamGroups
- Cameras
- CfgDump
- CloudCalib
- CloudData
- CloudSensors
- Comm
- DBCfg
- DBLog
- DarkVersions
- Domes
- Filters
- FlatRegions
- FlatVersions
- FluxMagnitude
- FocusAlgorithm
- FocusCfs

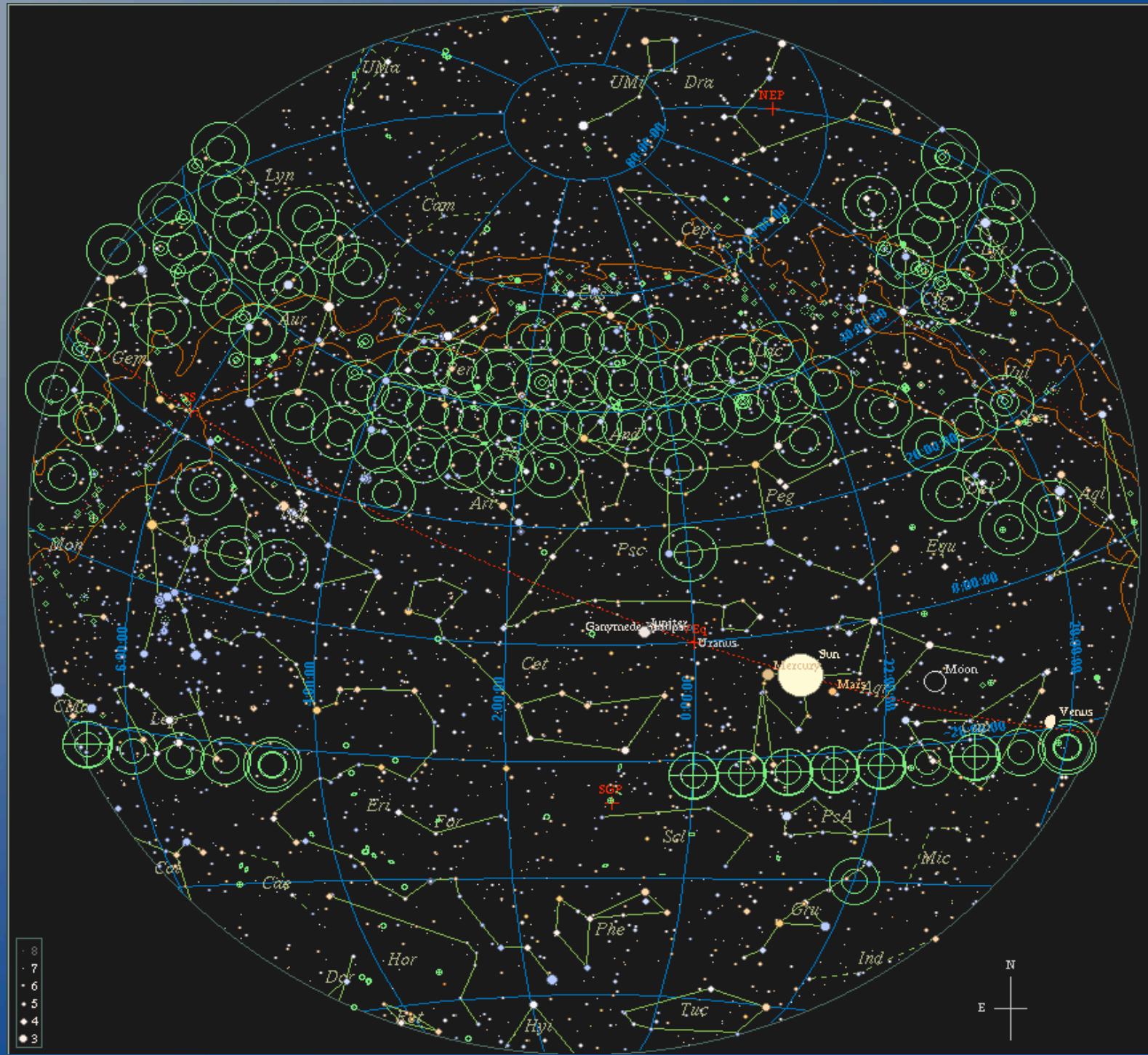
Syntax Functions Params Trx

- Data Definition Statements
  - ALTER DATABASE Syntax
  - ALTER TABLE Syntax
  - CREATE DATABASE Syntax
  - CREATE INDEX Syntax
  - DROP DATABASE Syntax
  - DROP INDEX Syntax
  - DROP TABLE Syntax
  - RENAME TABLE Syntax
- Data Manipulation Statements
  - DELETE Syntax



# Sky coverage & operations

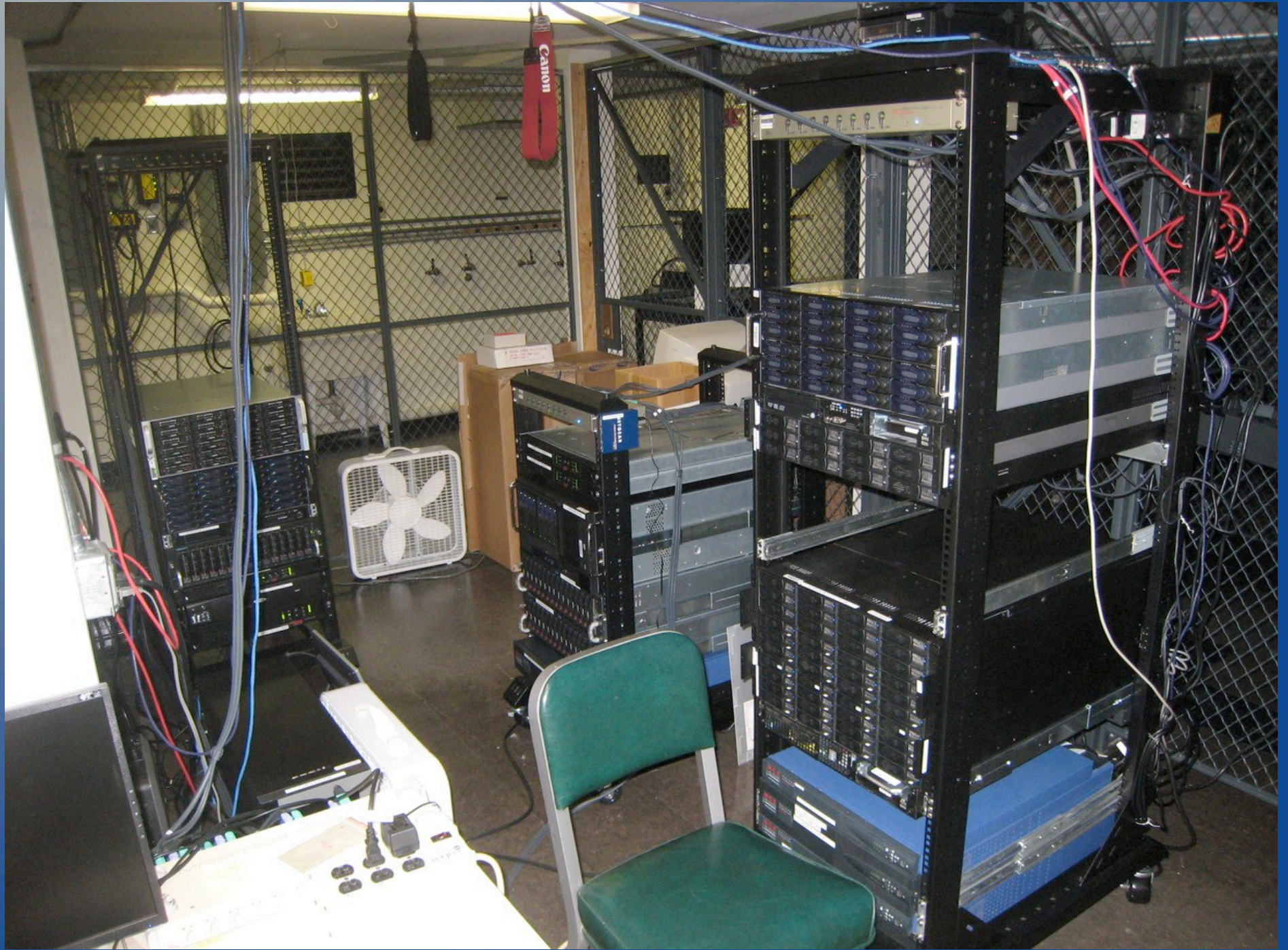
- Operational since 2003
- Covered 29% of the sky
- Opened up on 2000+ nights
- $>10^6$  science frames at 5-min resolution



The sky from  
Mauna Kea at  
2011 March 2  
14:50 HST

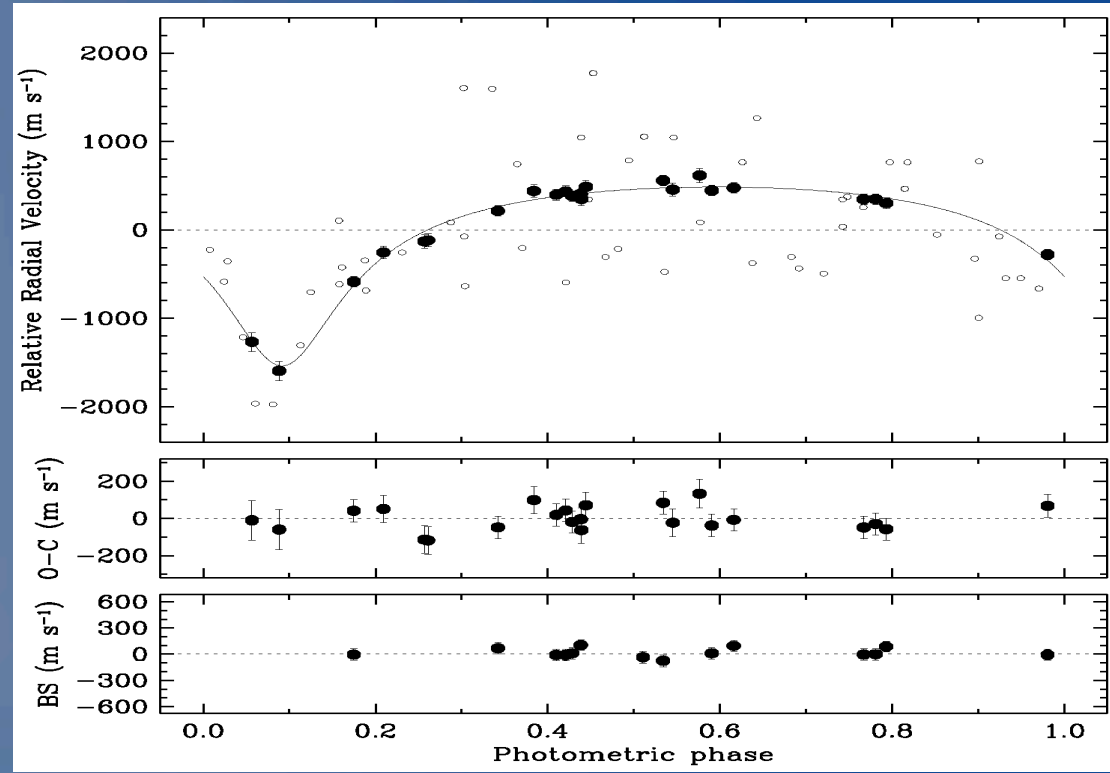
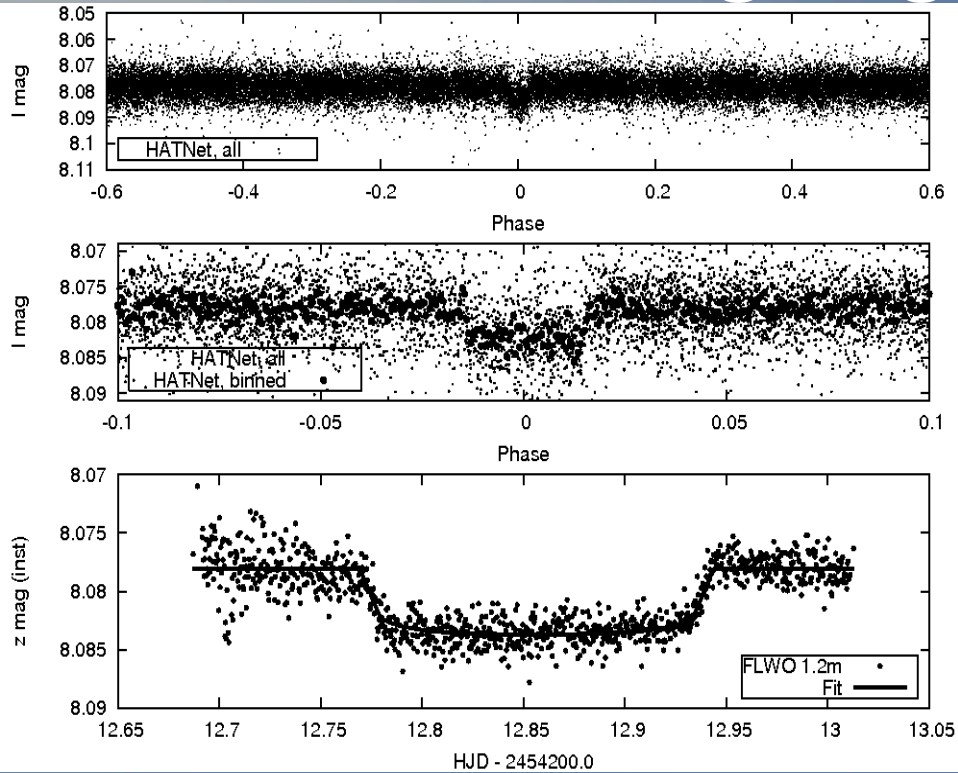


# HATNet and HATSouth servers at the CfA

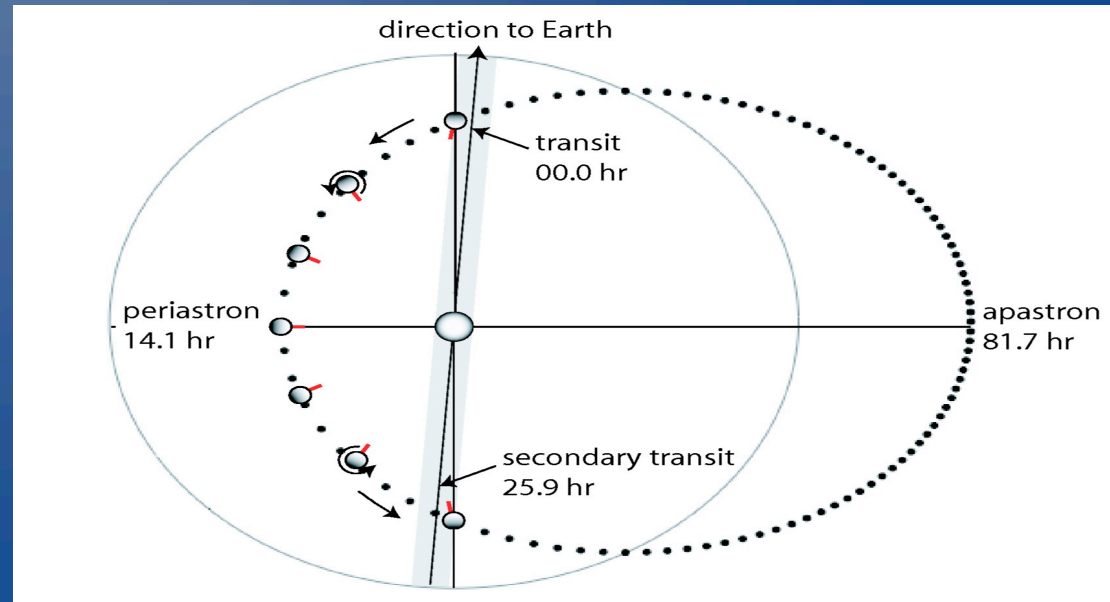




# Few highlights – HAT-P-2b



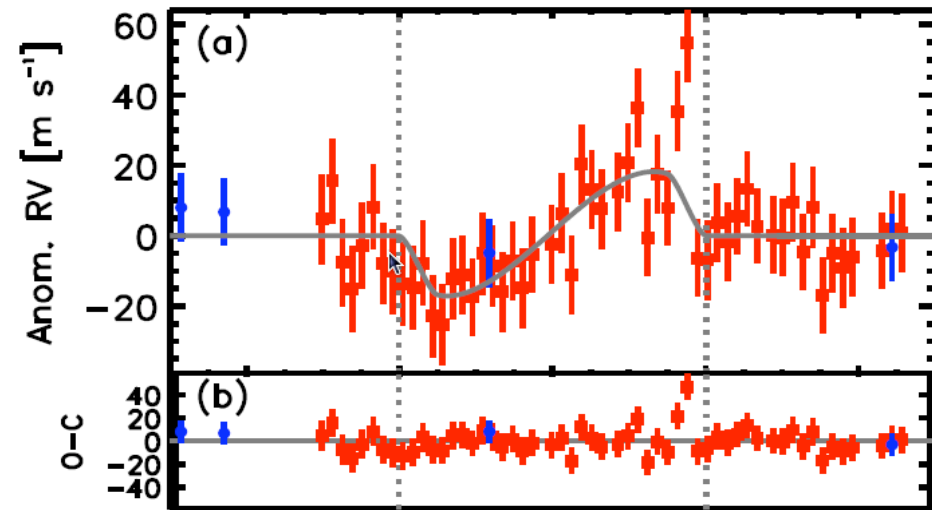
$R = 1.16 R_J$   $M = 9.09 M_J$   
 $\rho = 7.6 \text{g/cm}^3$   $P = 5.6 \text{d}$ ,  $e = 0.5$   
Super-massive, compact hot  
Jupiter  
See Bakos et al. 2007, ApJ



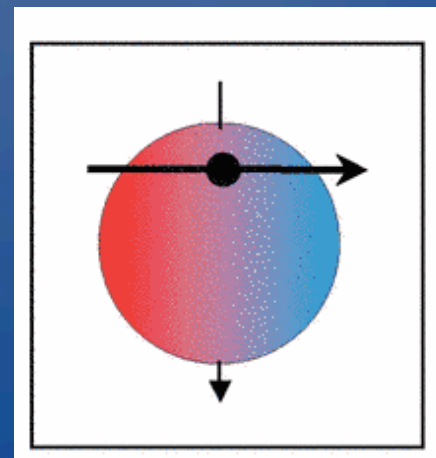


# HAT-P-7b

Winn, Johnson, Albrecht, et al. 2009

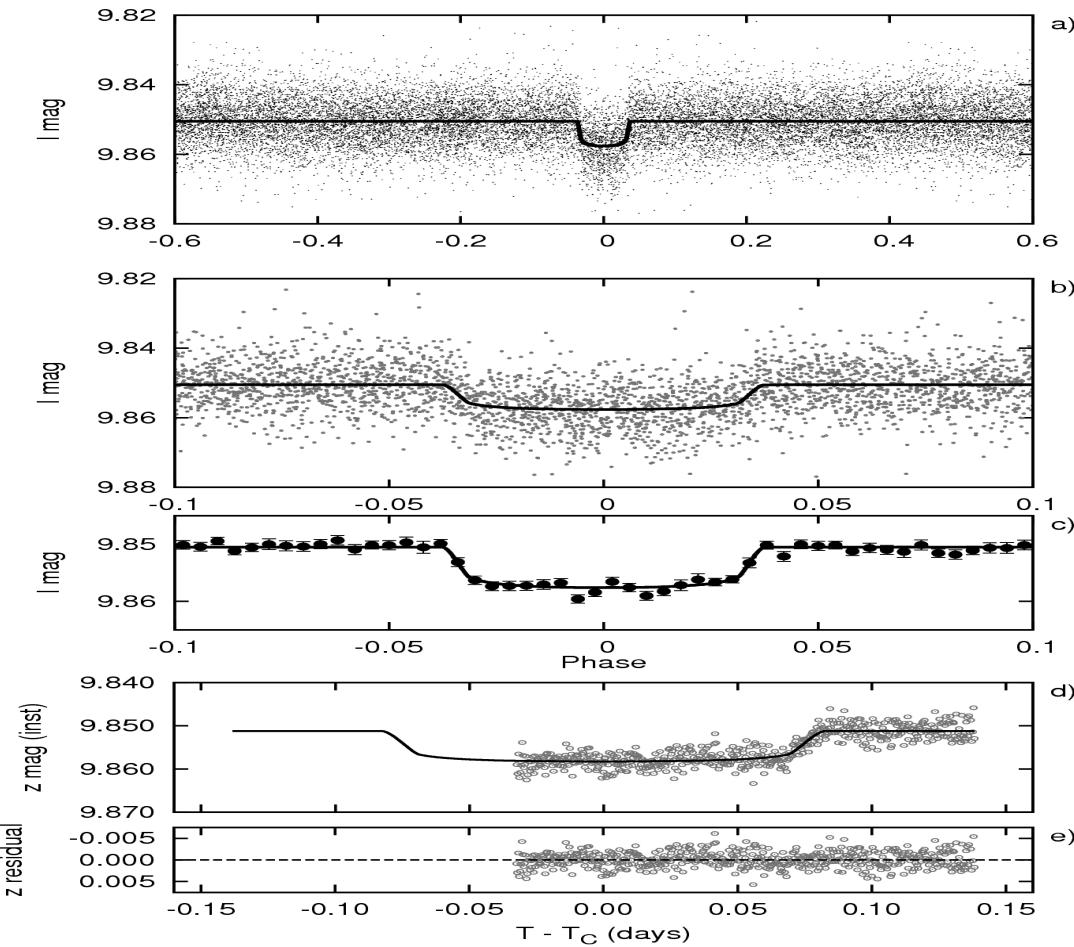


Retrograde or pole-on orbit!  
(Winn et al. 2009, Narita et al. 2009)



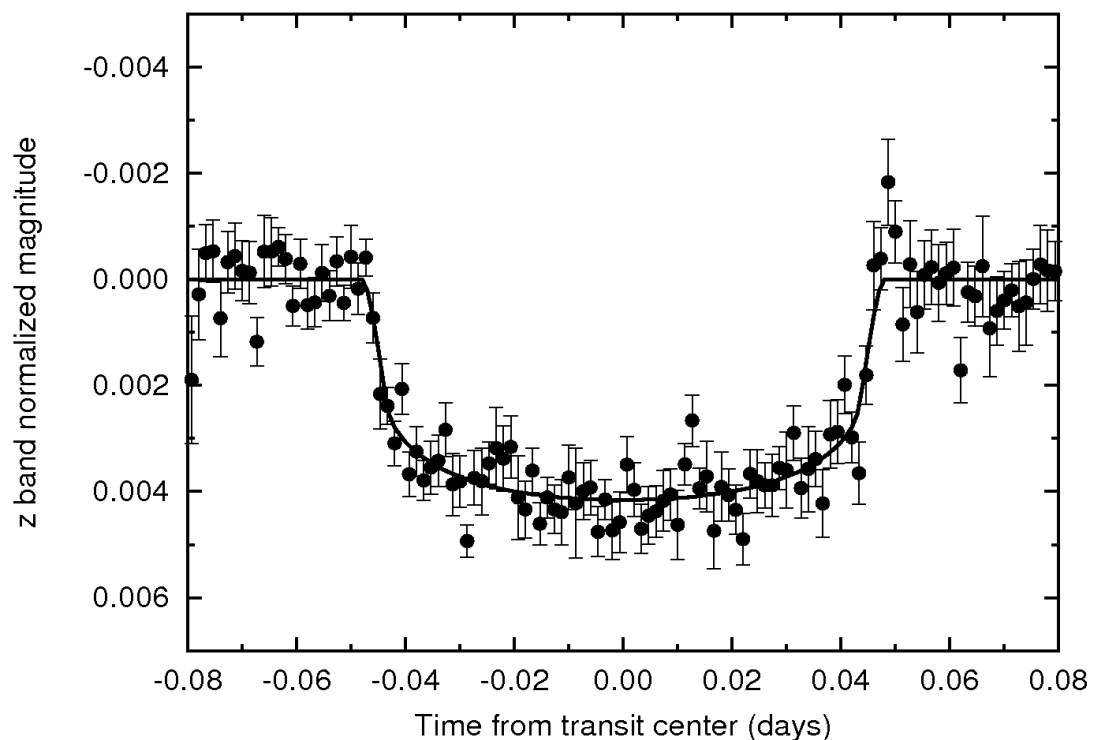
$R = 1.36 R_J$   $M = 1.78 M_J$   
 $\rho = 0.87 \text{ g/cm}^3$   $P = 2.2 \text{ d}$   
Very hot Jupiter (2700 K), in  
Kepler's field.  
(Pál et al. 2008)

Retrograde or pole-on orbit!  
(Winn et al. 2009, Narita et al. 2009)





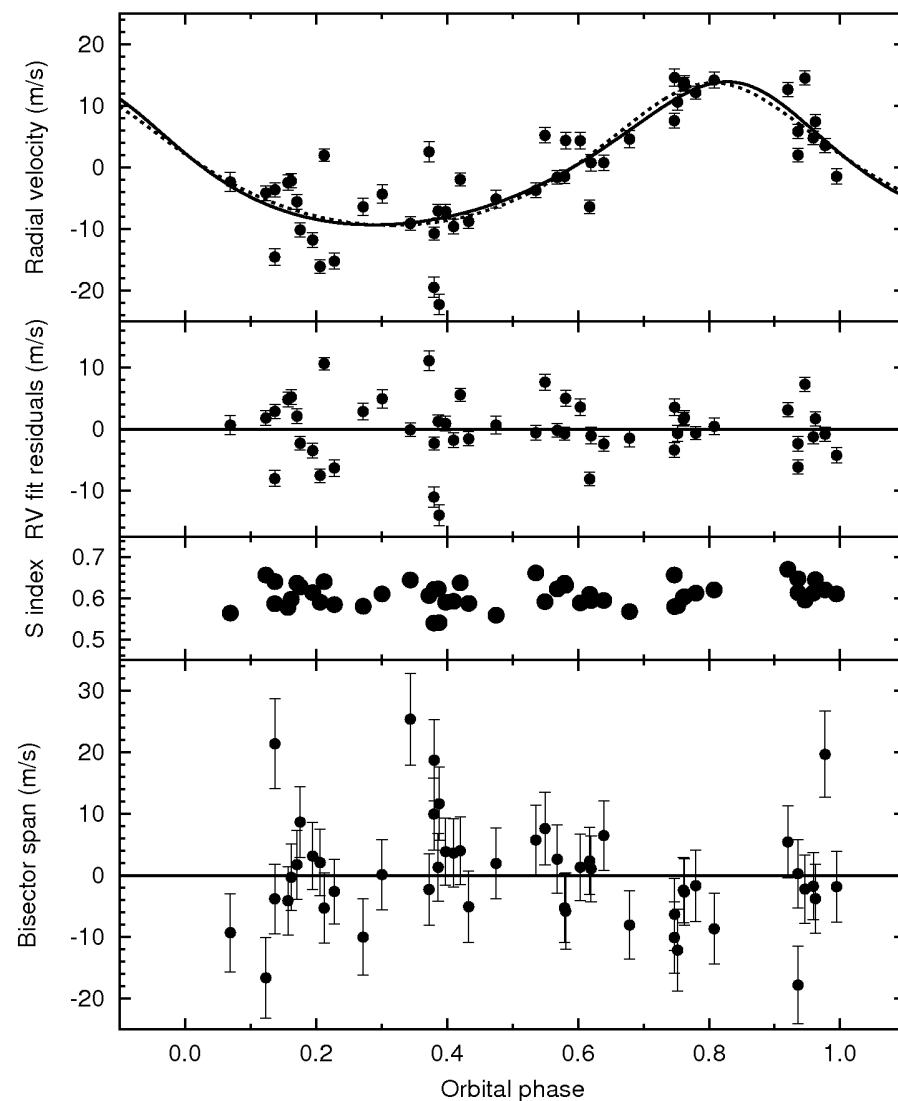
# HAT-P-11b: a warm super-Neptune



$R = 0.4 R_J$   $M = 0.08 M_J$   
 $\rho = 1.33 \text{ g/cm}^3$   $P = 4.88 \text{ d}$   
Warm super Neptune in Kepler's  
field orbiting a bright K dwarf.  
RV semi-amplitude: 11 m/s

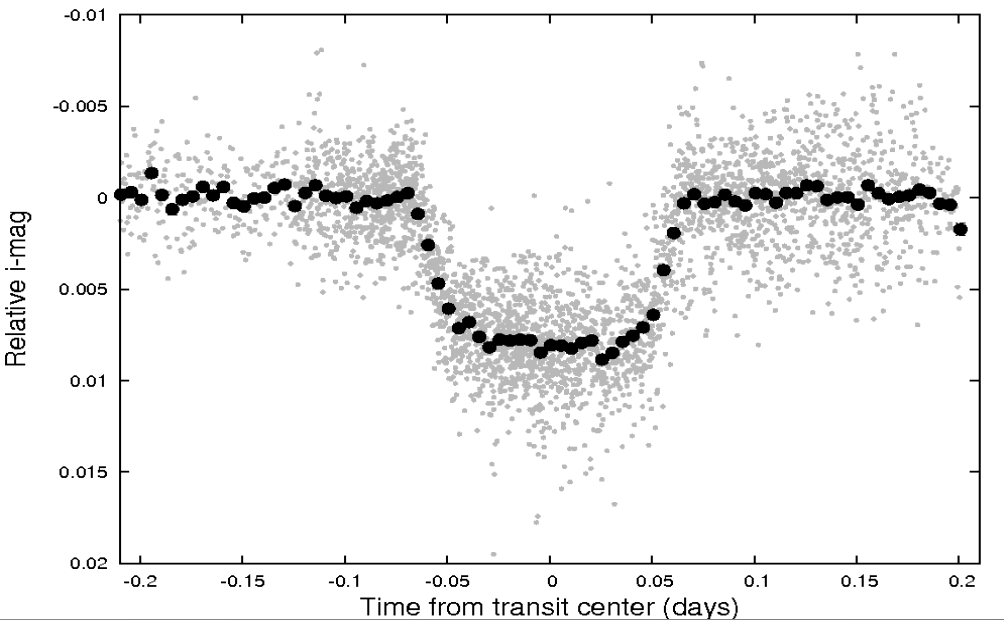
(Bakos et al. 2009)

Tilted orbit w/respect to the stellar  
spin axis  $103 \pm 20 \text{ deg}$   
(Winn et al. 2010)





# HAT-P-13b,c: a double planet



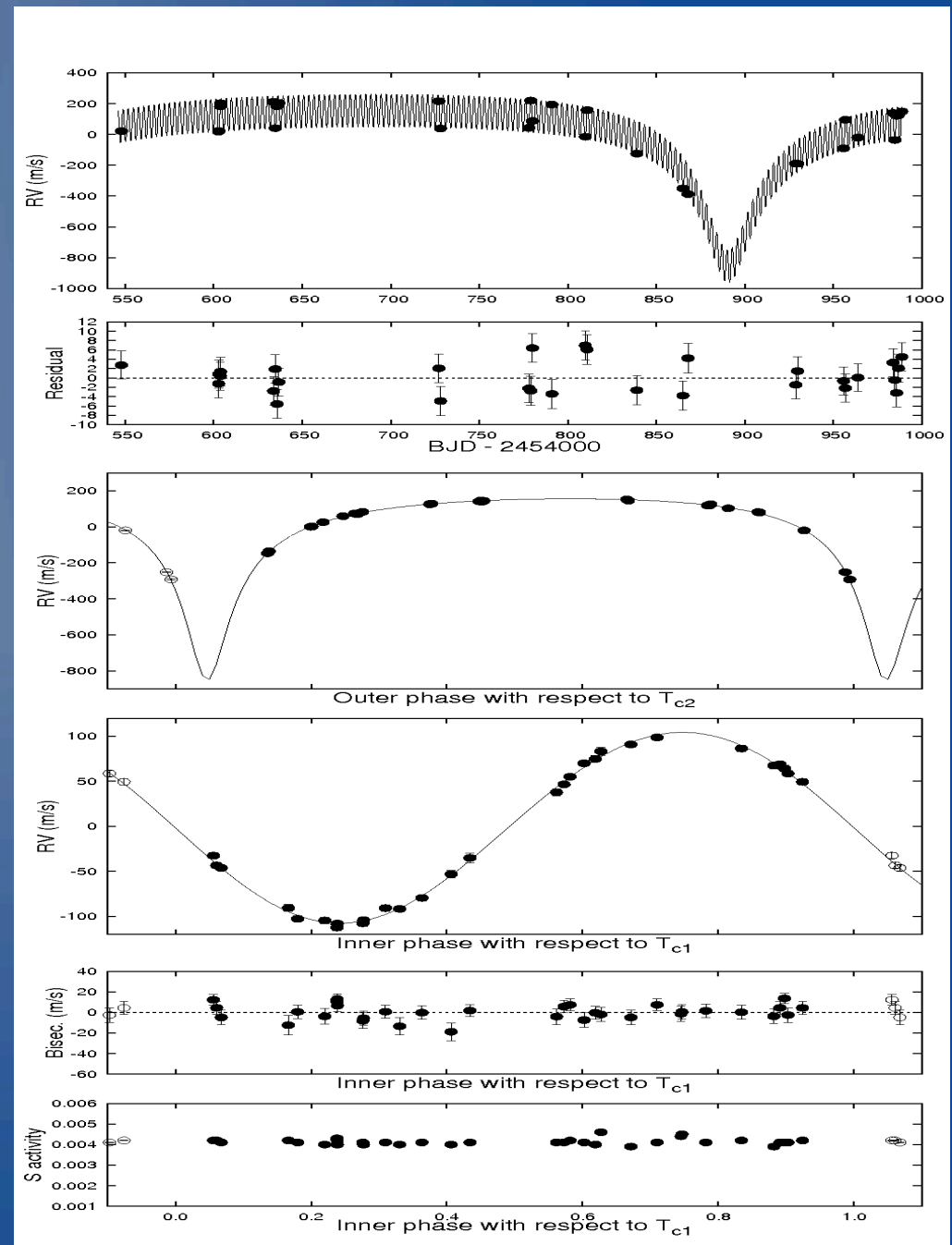
HAT-P-13b: transiting HJ.  
 $M=0.85M_J$   $R=1.28R_J$   $\rho=0.5\text{g/cm}^3$   $P=2.9\text{d}$

HAT-P-13c:  $P=428\text{d}$  perturber on  $e=0.7$  orbit,  $m_{\text{ini}} = 15.7 M_J$  (Bakos et al. 2009)

TTVs of “b” aid in refining parameters of “c”

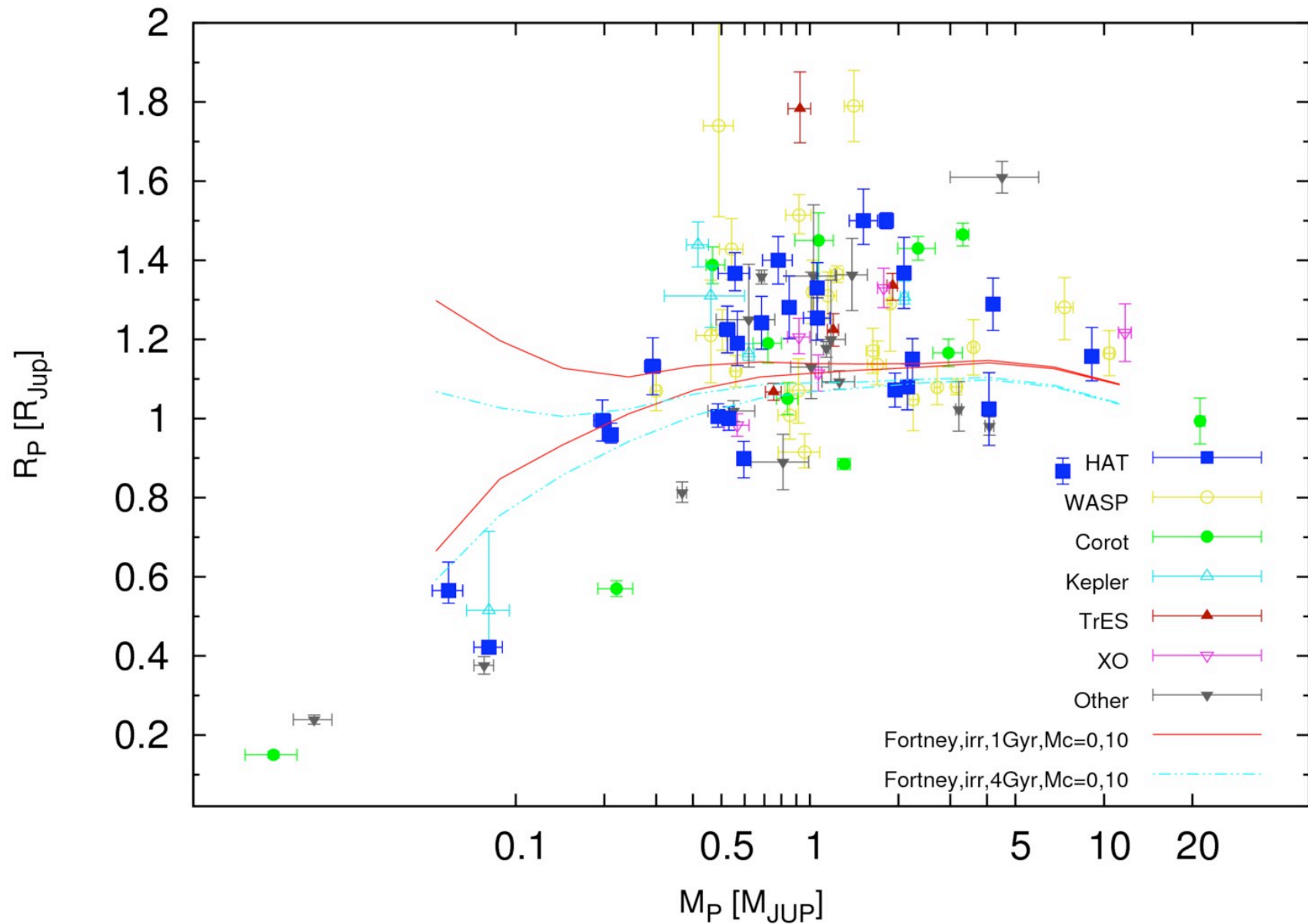
Perturbation by “c” and tidal fixpoint configuration constrains structural parameters,  $Q$  and core-mass of “b” (Batygin 2009, Mardling, 2010)

Spin-orbit aligned, + 3<sup>rd</sup> body: “d” (Winn, 2010)



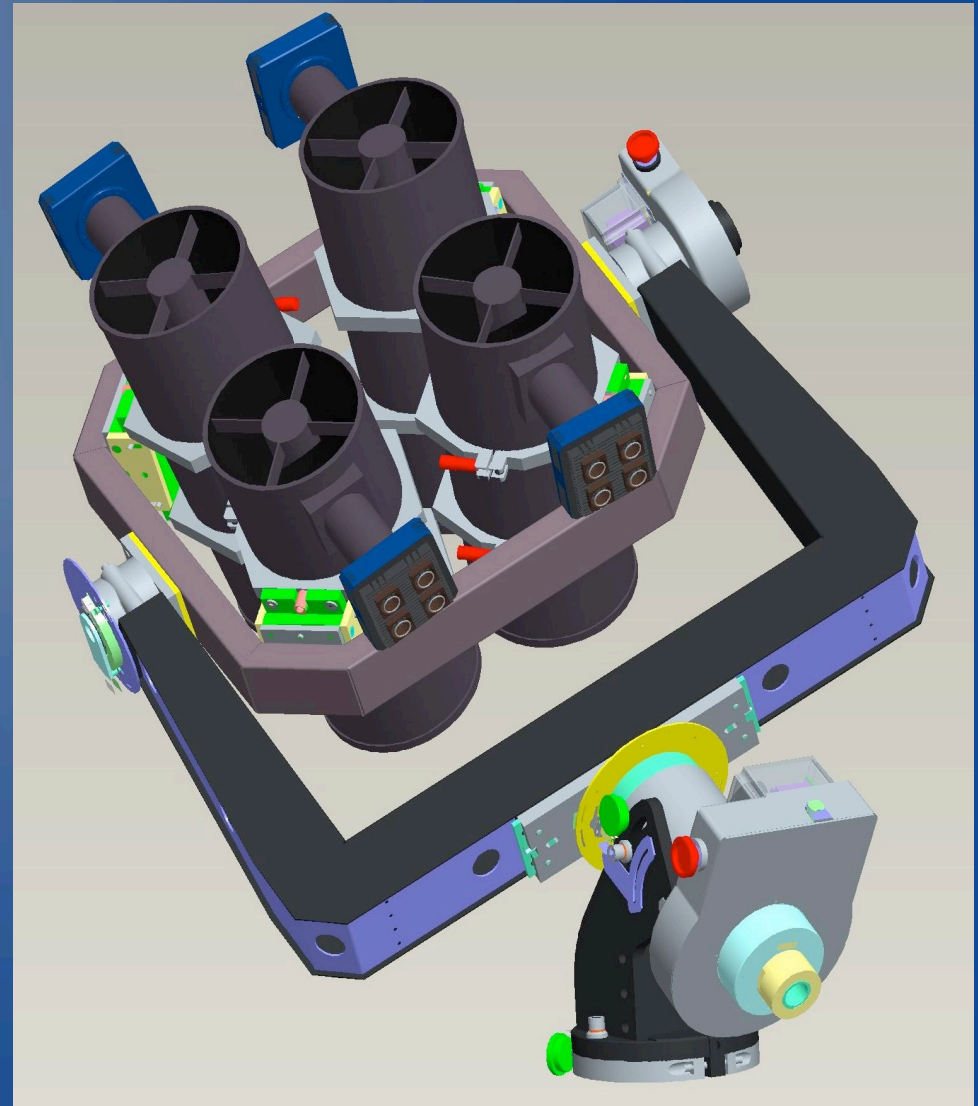


# M vs. R – the contribution of HATNet



# The HAT-South project

- Longitudinally spaced global network of fully automated telescopes in the Southern hemisphere
- Almost 24 hour coverage
- $128 \square^\circ$  field of view per site
- Long period transits (up to  $P=20$  days)
- Shallow transits: hot Neptunes and super Earths
- Joint effort of the CfA, PUC, ANU, MPIA.
- 1500 candidates/yr, up to 100 TEPs/yr





# The HAT-South instrument close-up



- 4x f/2.8 optics
- 4x 4Kx4K CCD
- 3.7 "/pixel
- 10" FWHM
- Sloan r
- 6 such instruments installed: 2-2-2 in Chile-Australia-Namibia



# HAT-South units at LCO





# HAT-South installation in Namibia





# Team-work ...



2008/08/05 09:53



# HAT-South: Siding Springs Observatory

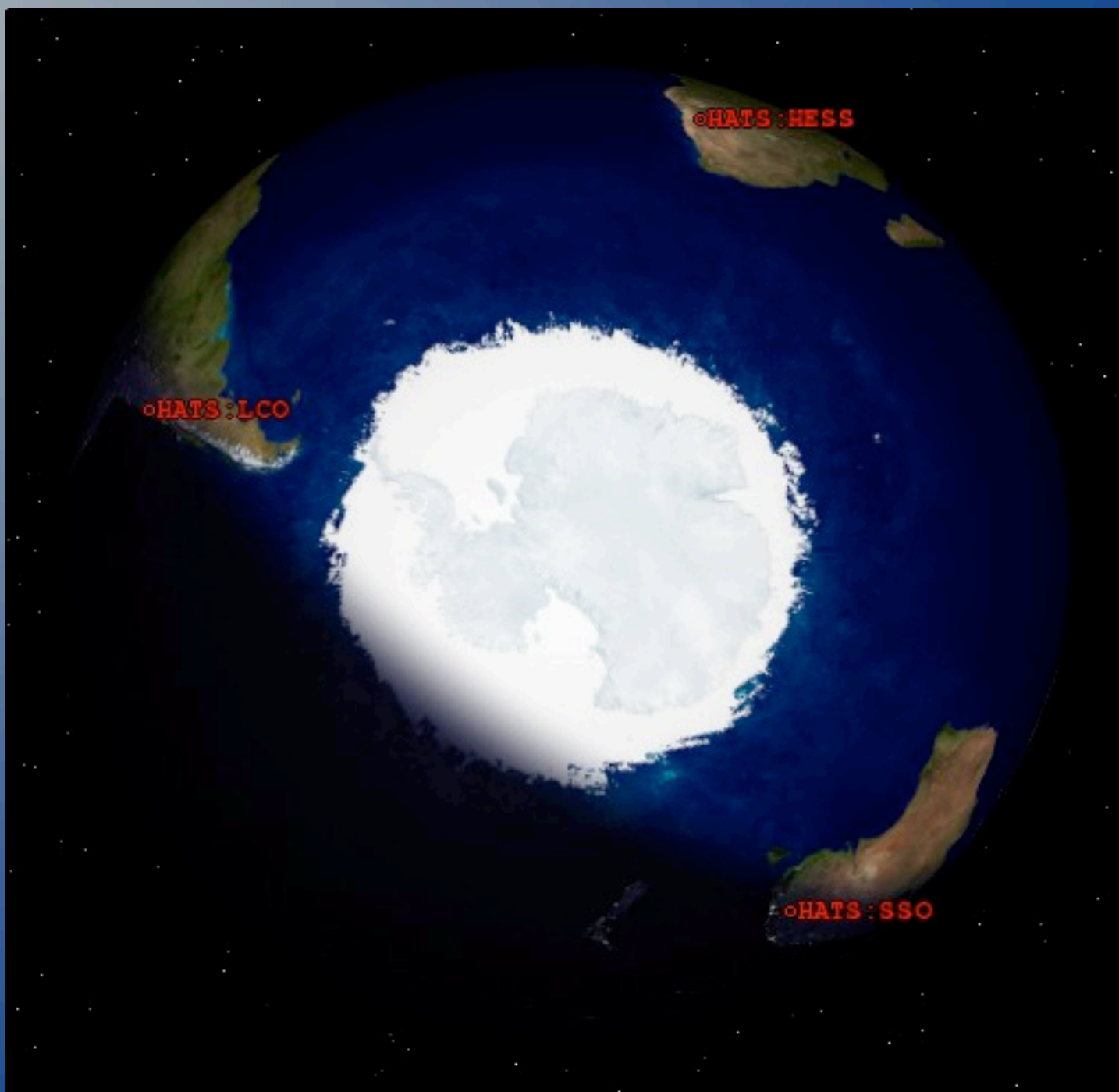


# HAT-South: the sites





# HAT-South: the sites



# HAT-South: electronics





# HAT-South LCO weather station

## HSW @ LCO

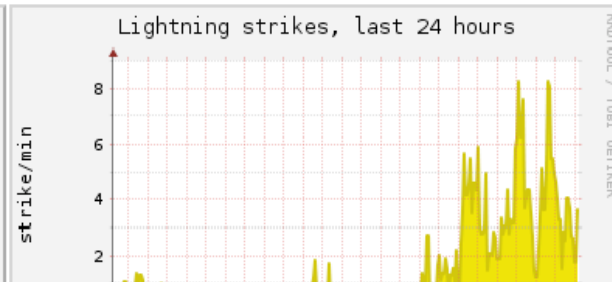
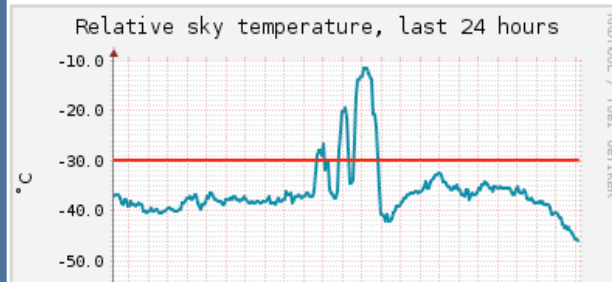
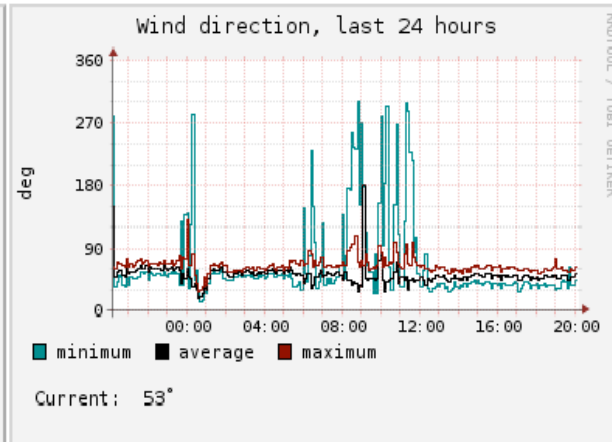
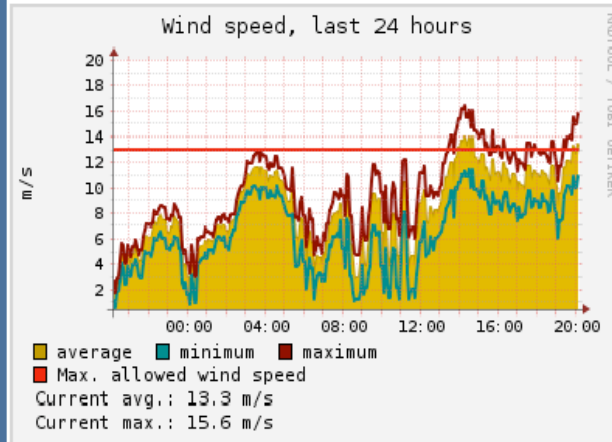
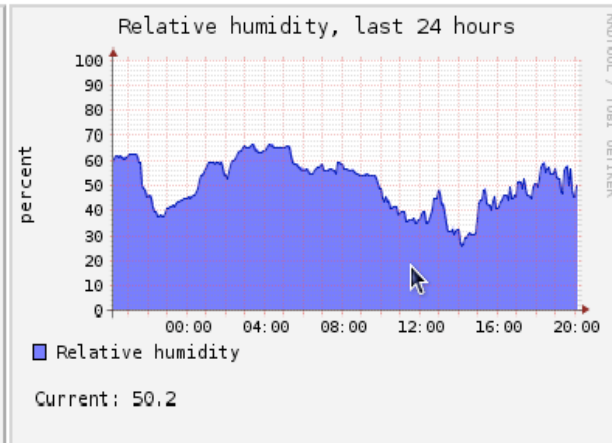
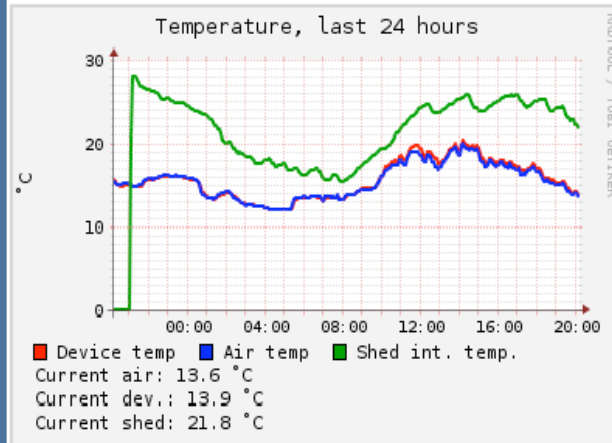
current

week

month

year

### Current weather overview



### HS sensors

[Weather overview](#)

[Vaisala weatherhead](#)

[Boltwood cloud sensor](#)

[Boltek lightning sensor](#)

[Webcam and all-sky](#)

[Webcam videos](#)

[All-sky archive](#)

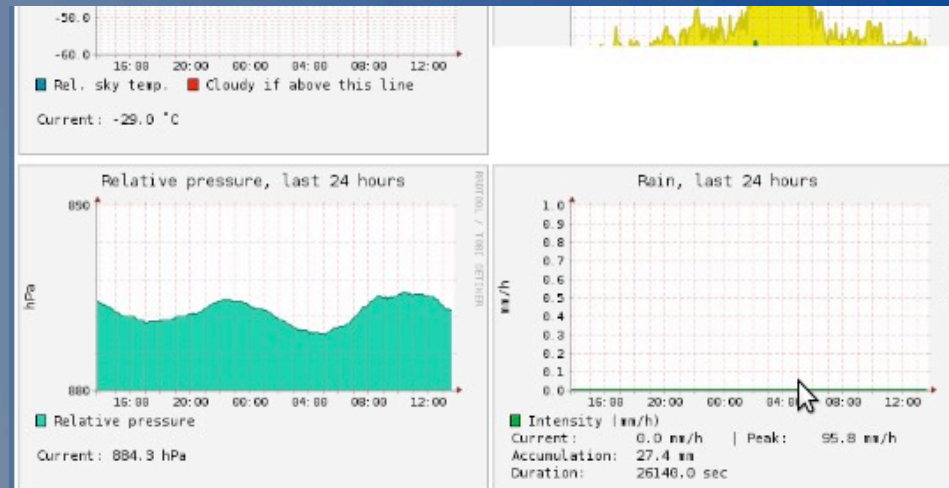
### LCO weather

[Manquis ridge](#)

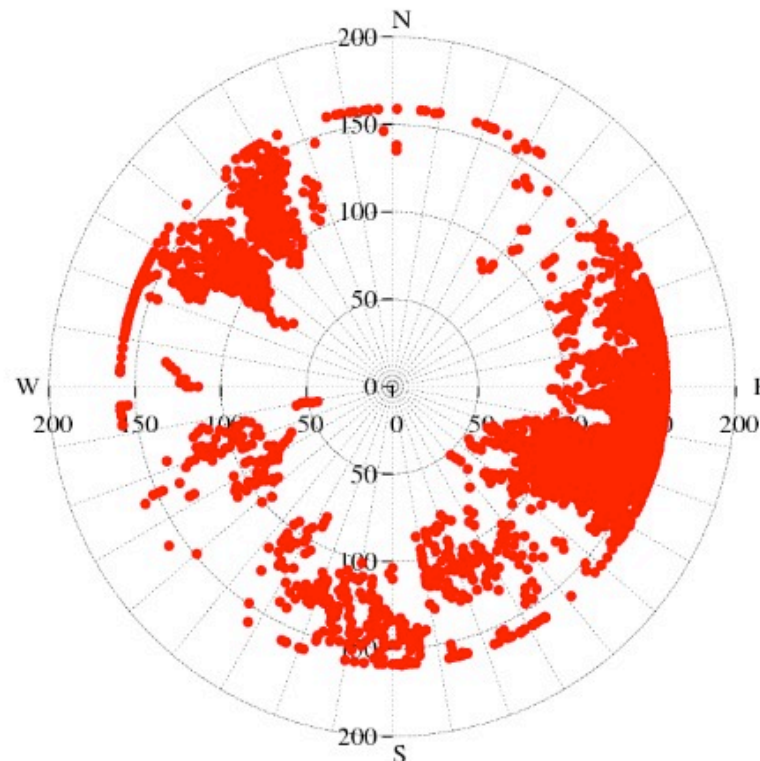
[Magellan](#)

# HAT-South LCO weather station

- Vaisala weather head (rain, wind, humidity, temperature)
- Boltwood cloud detector
- Boltek lightning detector
- GPS
- Fisheye all-sky camera



Lightning strikes in the last 4 hours (dist. in km)





# HAT-South LCO fisheye

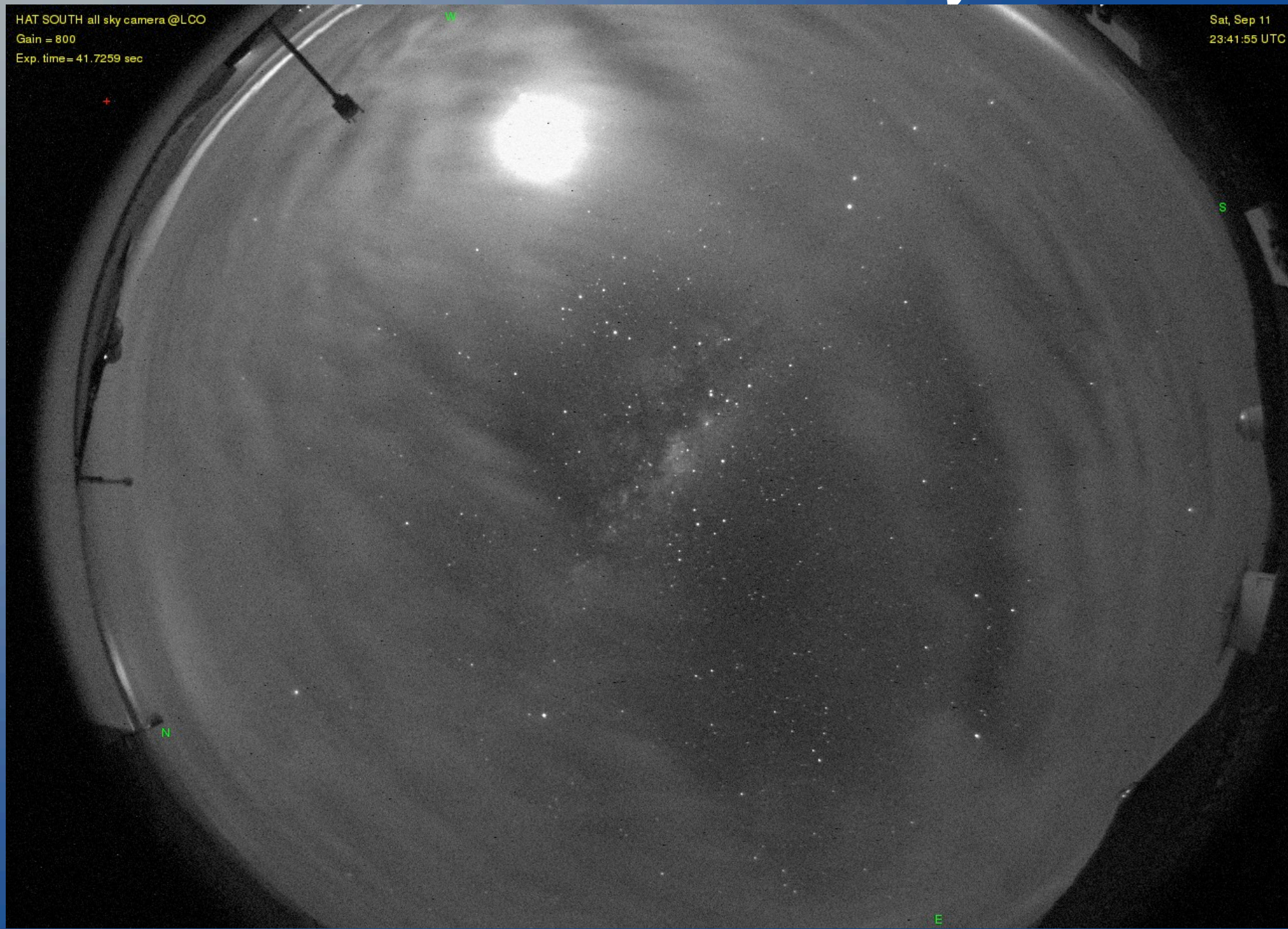
HAT SOUTH all sky camera @LCO

Gain = 800

Exp. time = 41.7259 sec

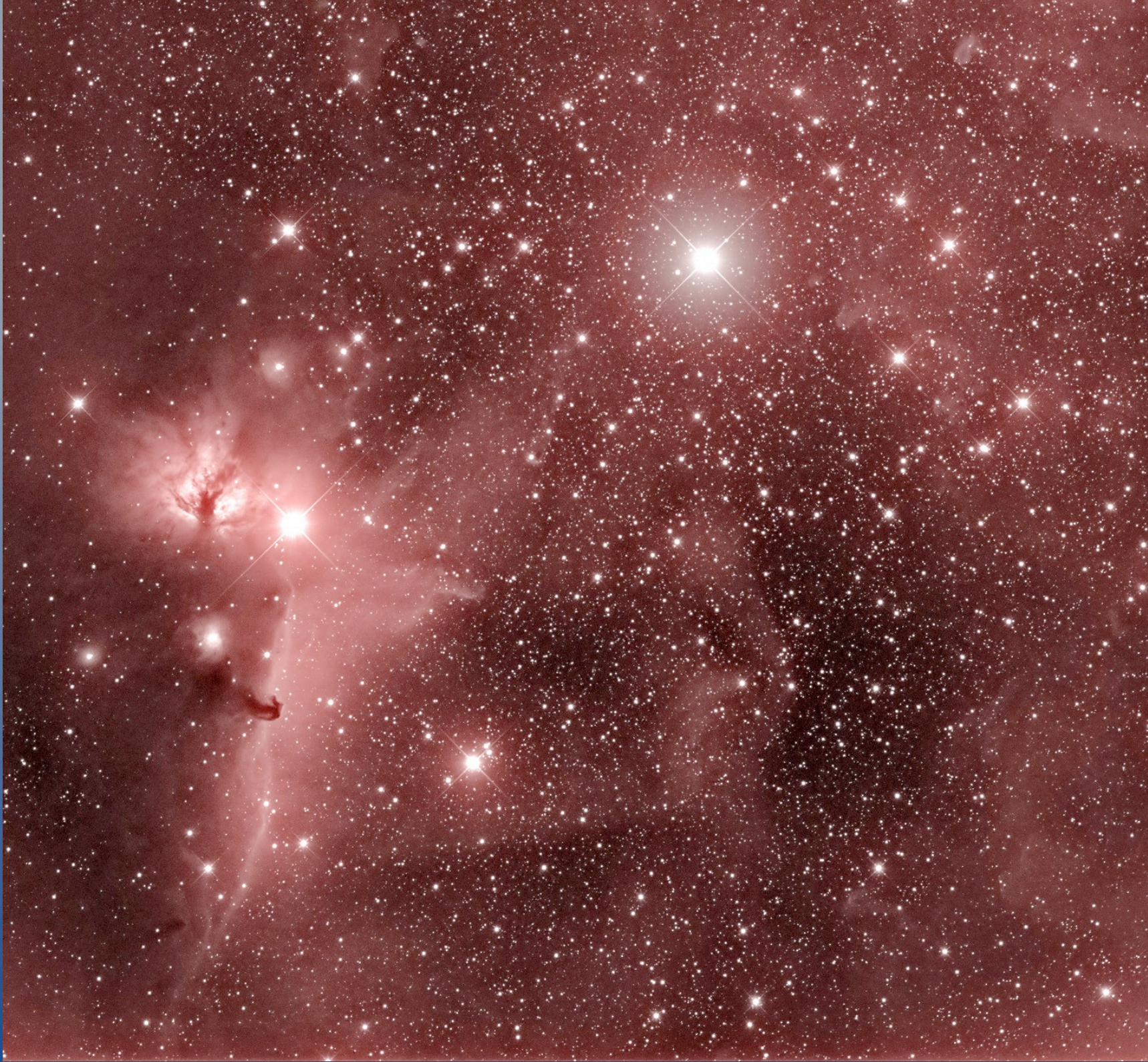
Sat, Sep 11

23:41:55 UTC





HAT-South  
first light  
image  
(1 chip out  
of 4)





# One night at LCO/SSO



# Acknowledgements

- Colleagues/collaborators: Géza Kovács, Robert Noyes, Dimitar Sasselov, David Latham, G. Torres, K. Penev, J. Hartman, A. Shporer
- G. Marcy, A. Howard, D. Fischer, J. Johnson, S. Quinn, T. Mazeh, T. Henning, P. Sackett, A. Jordán, C. Afonso, D. Bayliss, B. Schmidt, J. Andersen, P. Conroy, M. Rabus, V. Suc
- Students: I. Domsa, G. Gálfi, B. Csák, A. Pál, B. Sipőcz, G. Kovács, B. Béky, D. Kipping, Z. Csubry, L. Buchhave
- Wendy Freedman, Miguel Roth, Harvey Butcher, Charles Alcock, Robert Kirschner, Dan Fabricant, Emilio Falco, James Moran, Ray Blundell, Irwin Shapiro
- Staff at FLWO, Mauna Kea, Las Campanas, Siding Springs Observatory and HESS/Namibia
- Bohdan Paczyński, Grzegorz Pojmański
- National Science Foundation, NASA Origins program