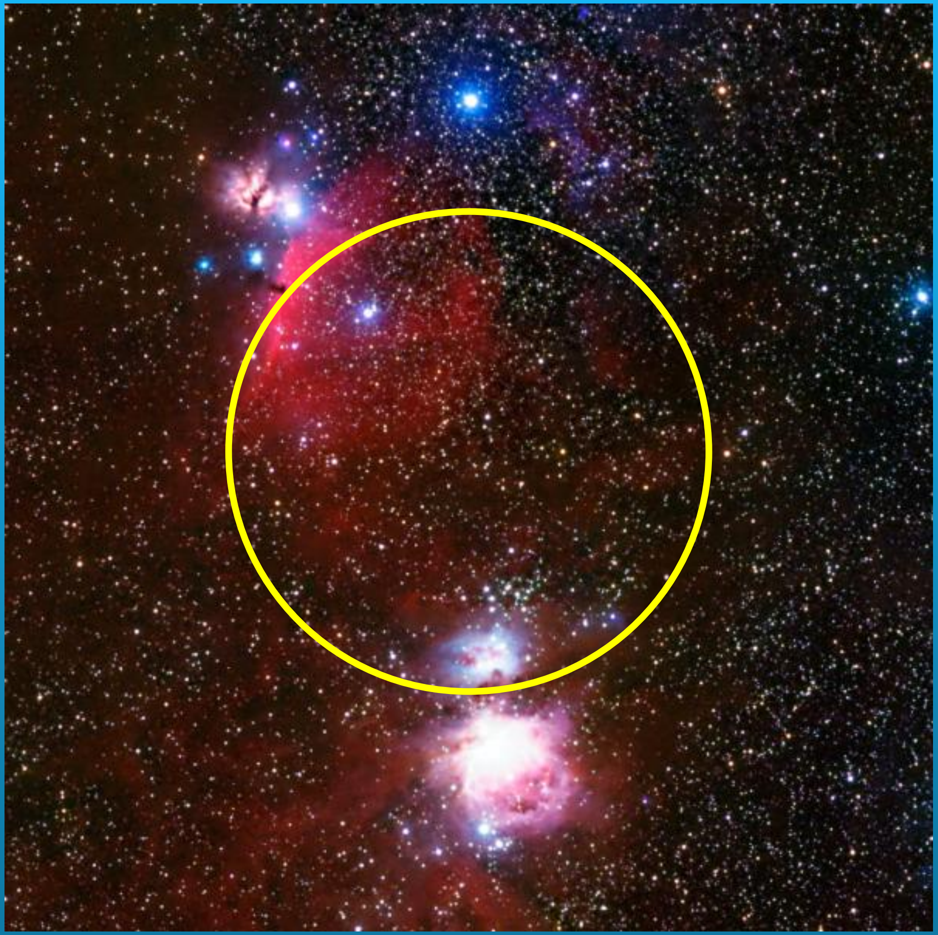
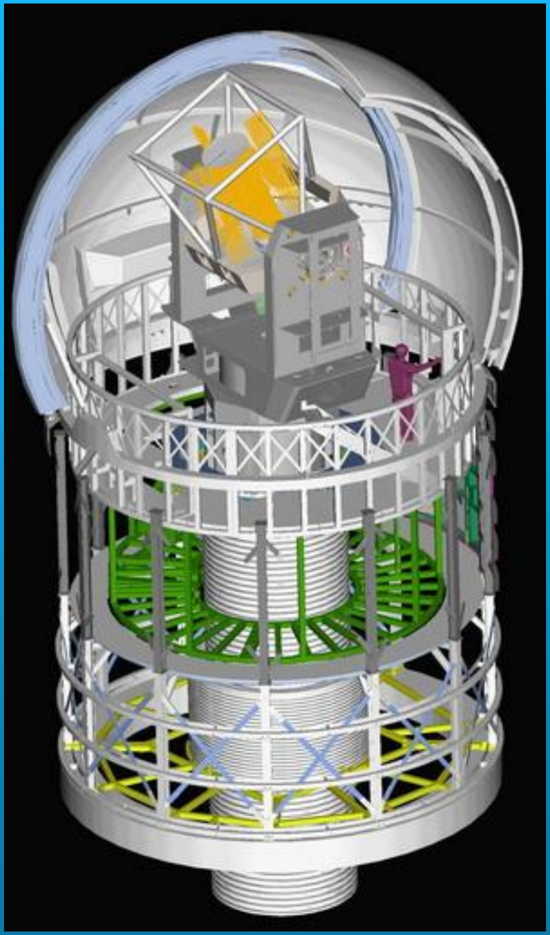
Pan-Planets with PANSTARRS1

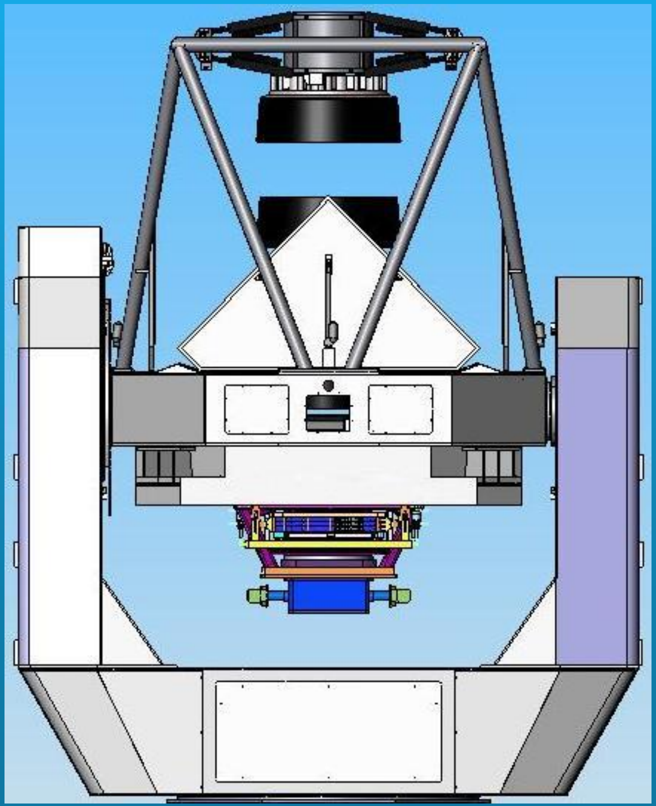


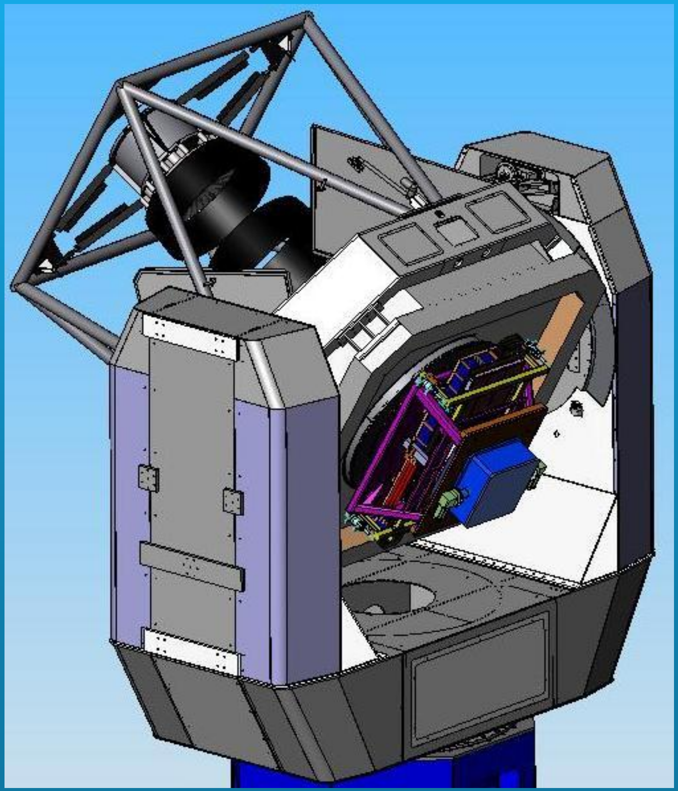


And : CfA, John Hopkins Uni., UK Consortium, Centr. Uni. Taiwan

Pan-STARRS

Panoramic Survey Telescope
and
Rapid Response System





The renaissance of wide-field imaging

- Wide-field imaging (e.g. Palomar, UKST sky surveys) fell into decline with advent of CCDs (high QE, tiny FOV)

- Subsequent decades have seen
  - Exponential growth in area of detectors
  - Matching growth of computer hardware
  - Major investment in image reduction software

- Current state of the art
  - CFHT/Megacam (3.6m/300Mpix)
  - Subaru/Suprime (8m/100Mpix)
  - First optical/near-IR digital surveys complete (SDSS, 2MASS …)

Pan-STARRS 1

- 1.8m R-C + corrector (f/4)
- 7 square degree FOV
- 1.4 Gpixel camera
- Sited on Haleakala (Maui)
- 490 square deg/hour
- All sky + deep field surveys in g,r,i,z,y

Pan-STARRS Deployment Plan

- PS1
  - Single telescope to be deployed on Haleakala, Maui
  - To operate from 2007 through 2010

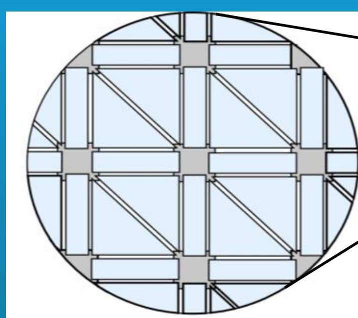
- PS4
  - Full-scale system to be deployed ca. 2010
  - To be sited on Mauna Kea
  - ~10 years mission lifetime

Haleakala High Altitude Observatory Site
The Pan-STARRS 1 Project

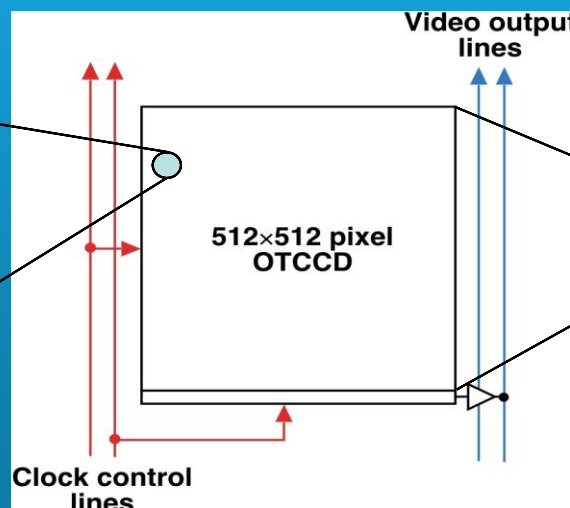
Detectors: The Orthogonal Transfer Array

- A new paradigm in large imagers.
- Partition a conventional large-area CCD imager into an array of independently addressable CCDs (cells).

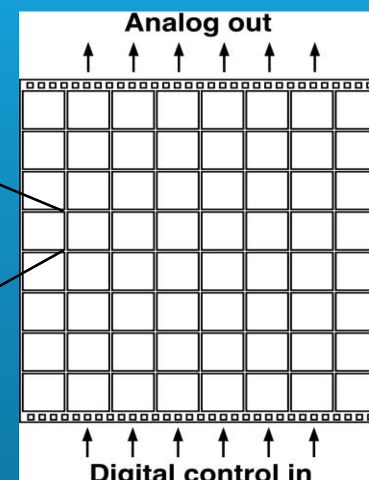
64 OTAs in the focal plane of each detector



Pixel structure



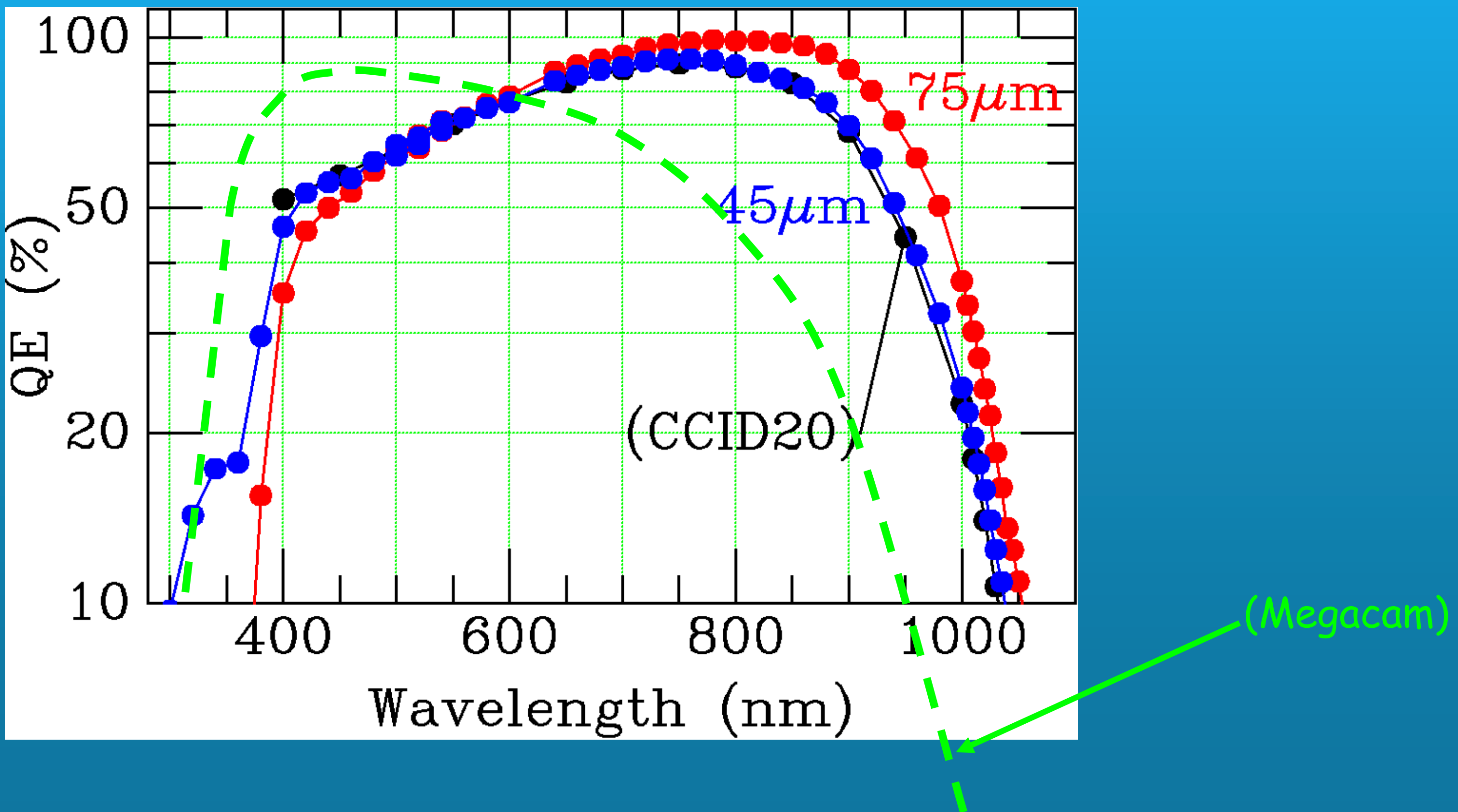
Independently Addressable Cell



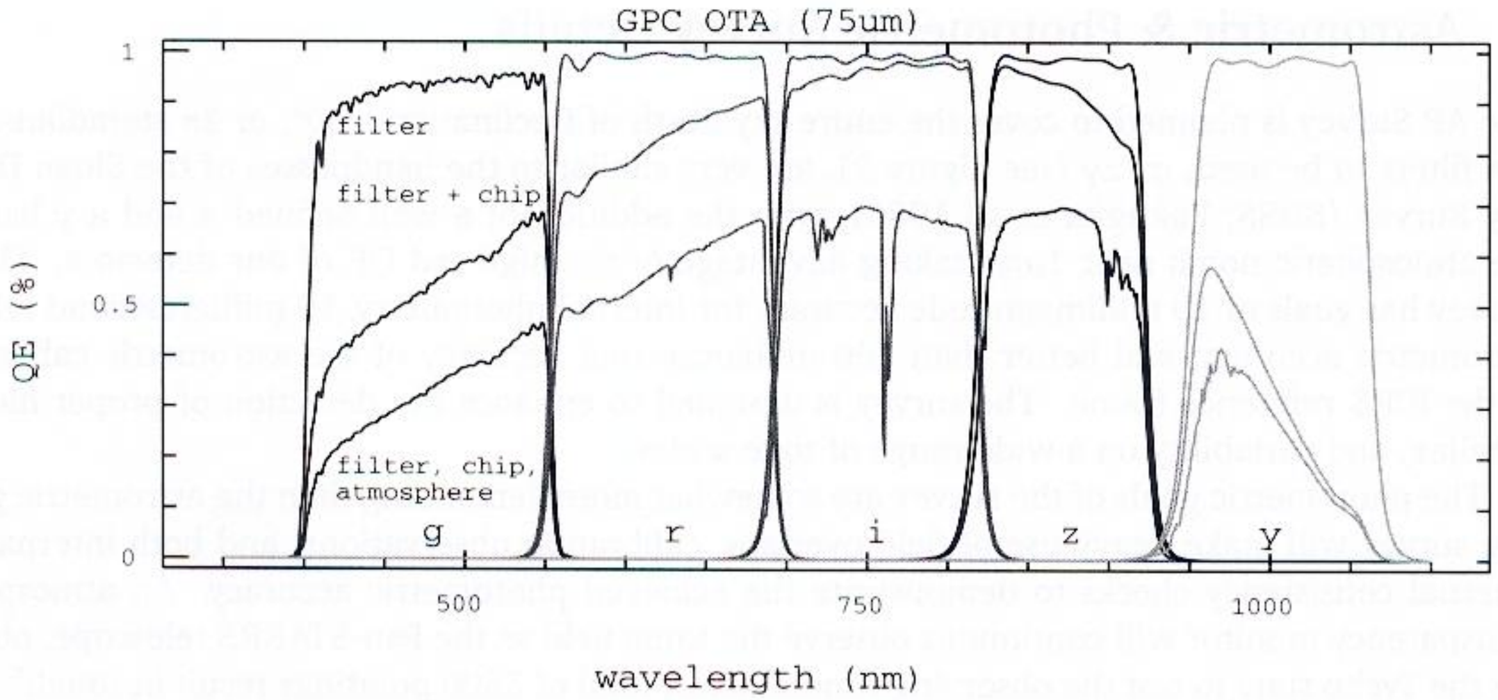
OTA: 8x8 Array of Cells

OTA Quantum Efficiency

- OTAs demonstrate expected QE (-65ºC)

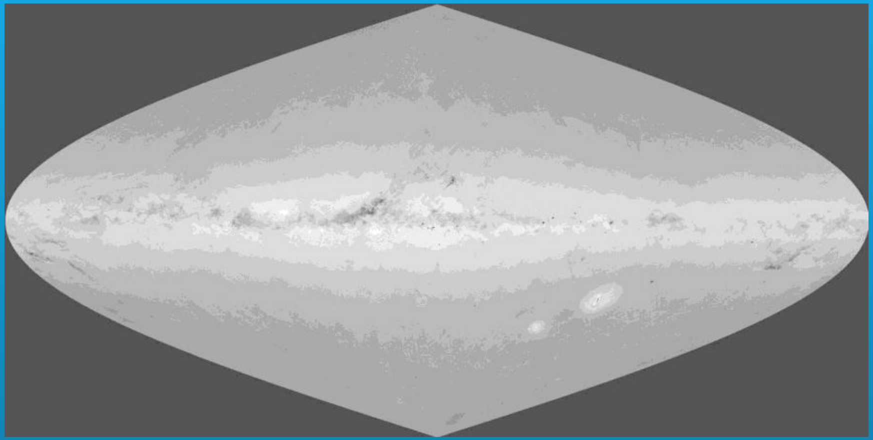


Pan-STARRS Bandpasses



Pan-STARRS overview

- Time domain astronomy
  - Transient objects
  - Moving objects
  - Variable objects



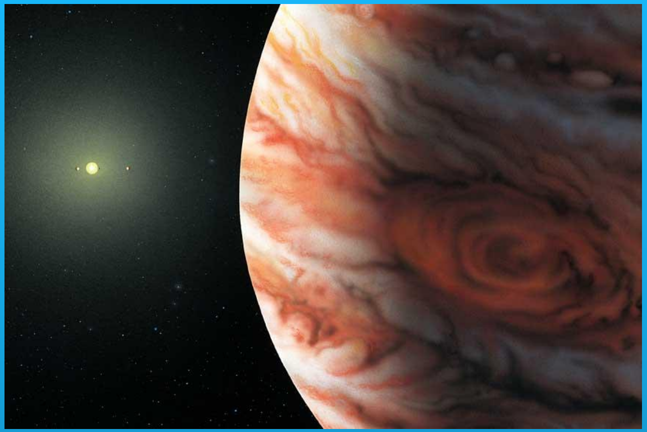
- Static sky science
  - Enabled by stacking repeated scans to form a collection of ultra-deep static sky images

Scientific Goals

- Inner Solar System Science (10^7 asteroids, 10^4 NEO)
- Outer Solar System (Trans Neptunian Objects)
- Stars and the Galaxy
  (Complete stellar census to 100 pc, Best substellar IMF, proper motion of most stars in the MW, merger tidal tails in halo, halo structure, …)
- Static Sky Cosmology
  (Weak Lensing on very large angular scales (DM distribution), galaxy clustering, …)
- Cosmology – Type Ia Supernova
  (Dark energy equation of state w(z), SF history, SN physics, …)
- Census of short-time-scale transients
  (gamma-ray bursts, transits, …)

What is a Planet?

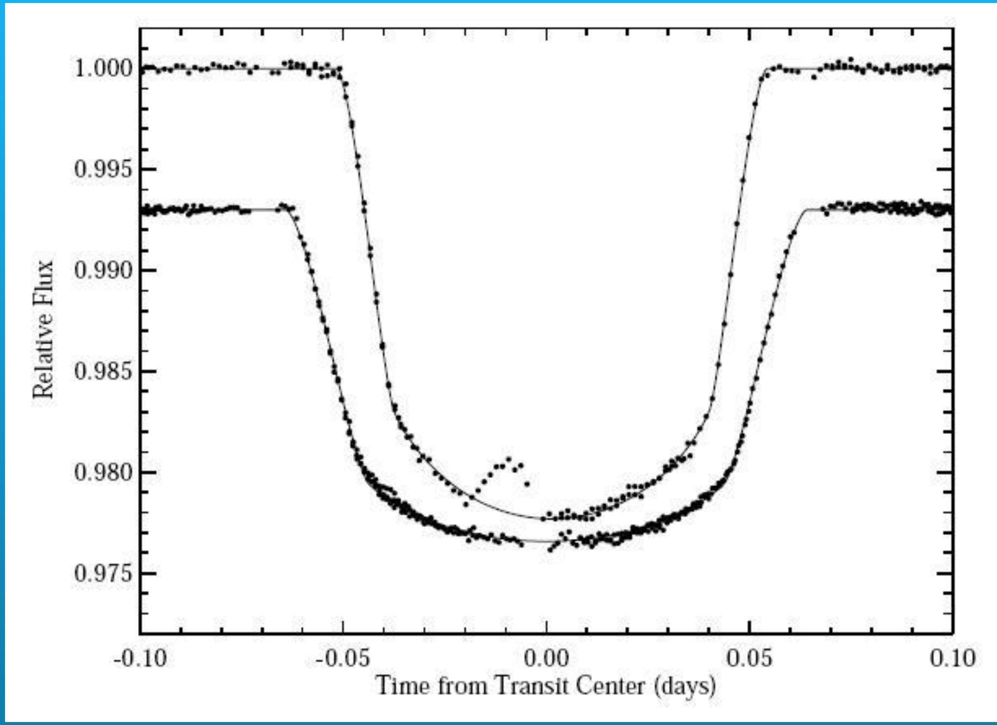
WORKING GROUP ON EXTRASOLAR PLANETS (WGESP) OF THE INTERNATIONAL ASTRONOMICAL UNION :



Deuterium Burning Limit: Objects with true masses below the limiting mass for thermonuclear fusion of deuterium, equal to be 13 Jupiter masses for objects of solar metallicity, that orbit stars or stellar remnants are "planets" (no matter how they formed).

A Search for Transiting Extra-Solar Planets with PANSTARRS
Pan-Planets

Transit Method : temporary occultation or transit when the planet passes in front of the parent star causing a drop in its brightness



HST lightcurves of Tres-1 and HD209458
Brown et al., 2001, 2006

Transit Observables :

- *Transit depth* dF =$(Rp/R^*)^2$ -> *radius Rp*
(dF ~ 1% Jupiter-like planet transiting sun-like star)

- *Period* $P=(4\pi^2a^3/GM^*)^{1/2}$ -> *orbital radius a*

- *Transit duration* $(t_{flat}/t_T)^2=([1-Rp/R_*]^2-[(D/R_*)\cos i]^2)([1+Rp/R_*]^2-[(D/R_*)\cos i]^2)$ -> *inclination angle i* (if R_*, M_* are known)

- *i+RV -> planetary mass and density*!

Results of Transits Surveys - I

Presently 22 transiting extrasolar planets are known (among more than 200 planets):
13 Very Hot Jupiters (Periods < 3 days), 9 Hot Jupiters (Periods >= 3 days)

Originally detecte

HD209458b
HD149026b
HD189733b

V	M/Msun	Type	Rp/RJup	Mp/MJup	P (days)	a (AU)
7.7	-	G0V	1.32	0.69	3.5	0.045
8.2	1.3	G0IV	0.72	0.36	2.9	0.042
7.7		K1-K2	1.15	1.15	2.2	0.0313

OGLE Survey (Tel

OGLE-TR-56b
OGLE-TR-111b
OGLE-TR-113b
OGLE-TR-132b
OGLE-TR-10b

I	M/Msun	Type	Rp/RJup	Mp/MJup	P (days)	a (AU)
16.6	1.04	G	1.23	1.45	1.2	0.0225
15.5	0.82	G or K	1.00	0.53	4.0	0.047
14.4	0.77	K	1.08	1.35	1.4	0.0229
15.7	1.35	F	1.13	1.19	1.6	0.0306
14.9	1.2	G or K	1.16	0.54	3.1	00416

Trans-Atlantic Ex

TrES-1
TrES-2
TrES-3

V	M/Msun	Type	Rp/RJup	Mp/MJup	P (days)	a (AU)
11.8	-	K0V	1.08	0.75	3.0	0.0393
11.4	1.08	G0V	1.24	1.28	2.5	0.0367
12.4	0.9		1.29	1.92	1.3	0.0226

Results of Transit Surveys - II

Presently 22 transiting extrasolar planets are known (among more than 200 planets):
13 Very Hot Jupiters (Periods < 3 days), 9 Hot Jupiters (Periods >= 3 days)

XO Project

	V	M/Msun	Type	Rp/RJup	Mp/MJup	P (days)	a (AU)
XO-1	11.3	1	G1V	1.18	0.9	3.9	0.048
XO-2	11.8	0.98	K0V	0.97	0.57	2.61	0.036
XO-3	10		F6		12	3.19	

HATNet Project

	V	M/Msun	Type	Rp/RJup	Mp/MJup	P (days)	a (AU)
HAT-P-1b	10.4	1.12	G04	1.36	0.53	4.46	0.055
HAT-P-2b	8.7	1.29	F8	0.98	9.04	5.63	

Superwasp Project

	I	M/Msun	Type	Rp/RJup	Mp/MJup	P (days)	a (AU)
WASP-1	11.9	1.15	F7V	1.93	0.89	2.51	0.038
WASP-2	11.8	0.79	K1V	0.95	0.88	2.15	0.030

SWEEPS Project

	V	M/Msun	Type	Rp/RJup	Mp/MJup	P (days)	a (AU)
SWEEPS-4	18.8	1.24	-	0.81	<3.8	4.2	0.055
SWEEPS-11	19.8	1.1	-	1.13	9.7	1.79	0.03

Results of Transit Surveys - III

Presently 22 transiting extrasolar planets are known (among more than 200 planets):
13 Very Hot Jupiters (Periods < 3 days), 9 Hot Jupiters (Periods >= 3 days)

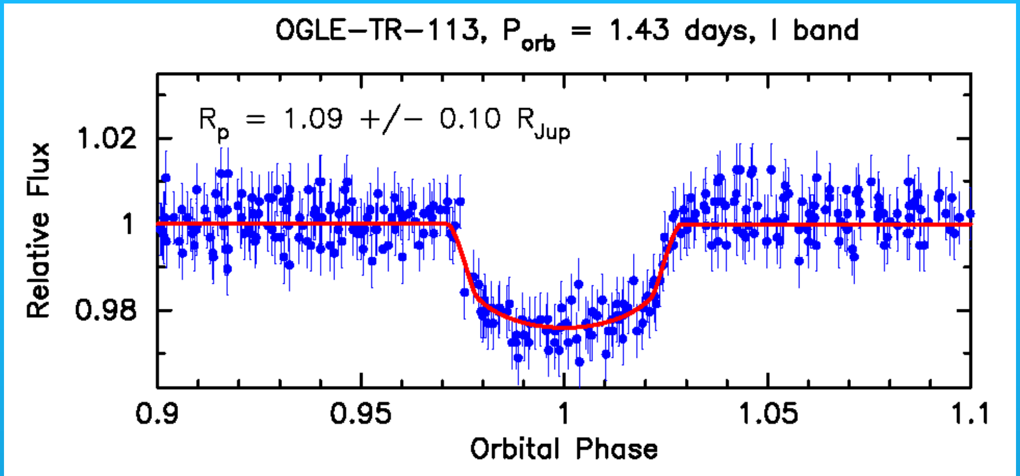
CoRoT Project
CoRoT-Exo-1

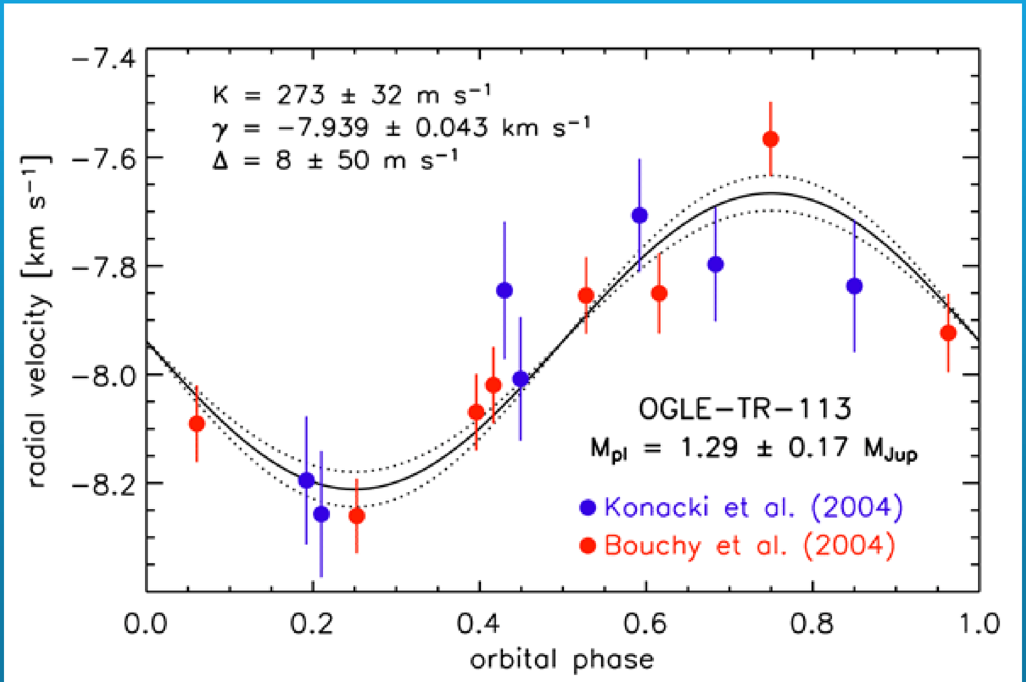
V	M/Msun	Type	Rp/RJup	Mp/MJup	P (days)	a (AU)
13.5	1	G1V	1.65	1.3	1.5	

GJ 436b

V	M/Msun	Type	Rp/RJup	Mp/MJup	P (days)	a (AU)
10.68	0.44	M2.5	0.35	0.071	2.64	0.0285

OGLE-TR-113





Planet Parameters :

$M_p = 1.3\ M_{Jup}$

$R_p = 1\ R_{Jup}$

Orbital Radius = 0.03 AU

Period = 1.43 days

Inclination = 88 deg

Eccentricity = 0

Star Parameters :

Spectral Type - K

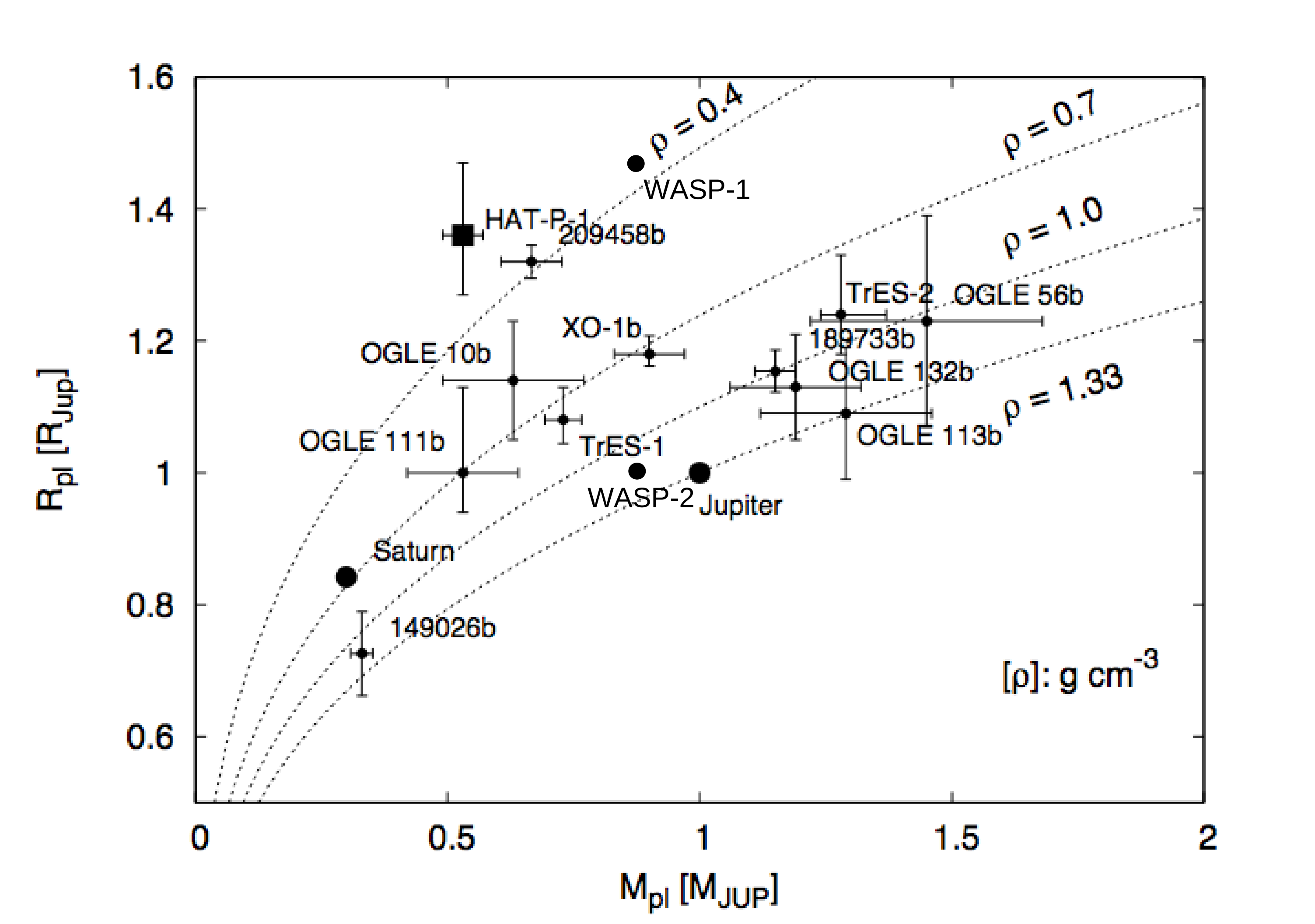
I = 14.4 mag

$M_{star} = 0.77\ M_{sun}$

$R_{star} = 078\ R_{sun}$

Limb Darkening Coef. (I)= 0.58

Results of Transit Surveys - II



Bakos et al. 2006

Strength and Weakness of the Transit Method

- Strength:
  - Radius of planet can be inferred from transit depth $(R_p/R_*)^2$
  - Sensitive to planets in the habitable zone
  - True survey : all stars observed in the same manner
  - Planetary atmospheres
  - Detection of planetary satellites and circumplanetary rings

- Weakness:
  - Orbital plane must be nearly edge-on : geometric probability $P_g \sim D_*/2a$ -> 0.5% for our Earth.
  - False positives are a major concern:
    - grazing eclipsing binaries
    - transits of small stars in front of a large star
    - blended eclipsing binaries with deep eclipses

Competitiveness of Pan-Planets in the Current Context

Transit Surveys from the Ground

Transit Search Programmes

	Programme	D (cm)	focal ratio	$W^{0.5}$ (deg)	N_x (kpix)	N_y (kpix)	no. of CCDs	pixel (arcsec)	sky mag	star mag	d (pc)	stars ($x10^3$)
1	PASS	2.5	2.0	127.25	2.0	2.0	15	57.75	6.8	9.4	83	18
2	WASP0	6.4	2.8	8.84	2.0	2.0	1	15.54	9.6	11.8	246	2
3	ASAS-3	7.1	2.8	11.21	2.0	2.0	2	13.93	9.9	12.0	272	5
4	RAPTOR	7.0	1.2	55.32	2.0	2.0	8	34.38	7.9	11.1	179	33
5	TrES	10.0	2.9	10.51	2.0	2.0	3	10.67	10.5	12.7	362	10
6	HATnet	11.1	1.8	19.42	2.0	2.0	6	13.94	9.9	12.5	338	28
7	SWASP	11.1	1.8	31.71	2.0	2.0	16	13.94	9.9	12.5	338	74
8	Vulcan	12.0	2.5	7.04	4.0	4.0	1	6.19	11.6	13.4	497	12
9	RAPTOR-F	14.0	2.8	5.93	2.0	2.0	2	7.37	11.3	13.4	498	8
10	BEST	19.5	2.7	3.01	2.0	2.0	1	5.29	12.0	14.2	668	5
11	Vulcan-S	20.3	1.5	6.94	4.0	4.0	1	6.10	11.7	14.1	642	24
12	SSO/APT	50.0	1.0	7.00	2.9	5.9	2	4.20	12.5	15.5	1103	126
13	TeMPEST	76.0	3.0	0.77	2.0	2.0	1	1.35	15.0	17.1	1944	8
14	EXPLORE-OC	101.6	7.0	0.32	2.0	[illegible].3	1	0.44	17.1	18.4	2881	5
15	PISCES	120.0	7.7	0.38	2.0	2.0	4	0.33	17.1	18.6	3045	8
16	ASP	130.0	13.5	0.17	2.0	2.0	1	0.30	17.1	18.7	3125	2
17	OGLE-III	130.0	9.2	0.59	2.0	4.0	8	0.26	17.1	18.7	3125	20
18	STEPSS	240.0	0.0	0.41	4.0	2.0	8	0.18	17.1	19.5	3757	17
19	INT	250.0	3.0	0.60	2.0	4.0	4	0.37	17.1	19.5	3800	37
20	ONC	254.0	3.3	0.53	2.0	4.0	4	0.33	17.1	19.5	3817	30
21	EXPLORE-N	360.0	4.2	0.57	2.0	4.0	12	0.21	17.1	19.9	4196	46
22	EXPLORE-S	400.0	2.9	0.61	2.0	4.0	8	0.27	17.1	20.0	4313	58

All projects with telescope sizes similar to PS1 have FOV < 0.4 sqdeg.

PS1 has fast read-out (few seconds), and quick telescope slew

Pan-Planets

Observing Strategy :

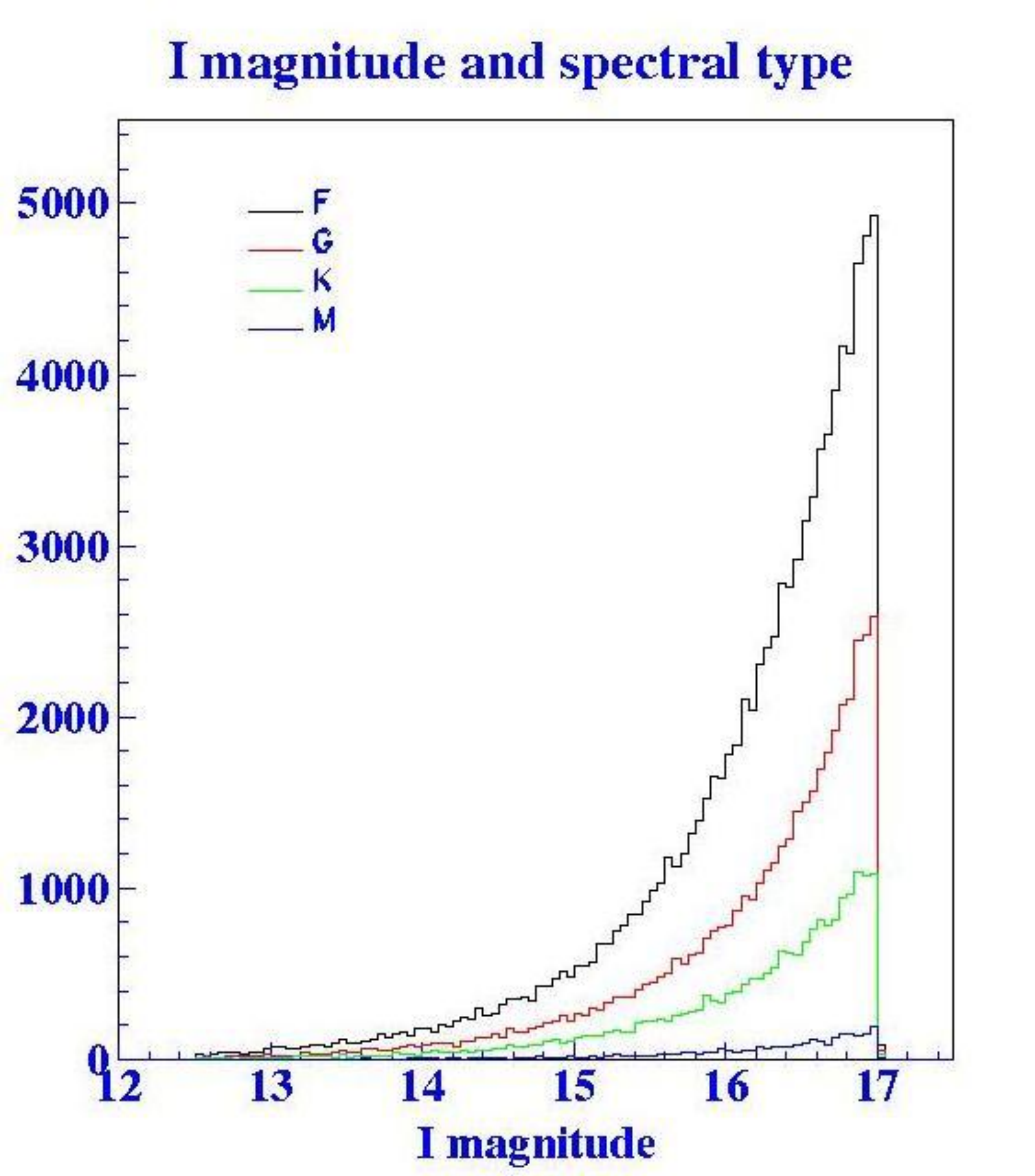
- 180 hours/year equivalent to 30 day campaign/year (6 hours/night)
- 3 hours blocks/night
- 2 targets : in the field and toward an open cluster
- One image every 2 min. allowing to reach I=16mag
  (and read-out + telescope slewing to next field)
- 3 fields covering 21 deg^2 with time sampling equal to 6 min.

Expected Results :

- For a target in the field
  - Besançon Models predict 1.4 million stars with 480,000 dwarfs in 3 fields
  - Assuming photometric precision of 0.3% for I=13 mag to 1% for I=16 mag

Simulations

~ 100 Jupiter-like planets in 3 years !



Besançon Model of the Galaxy :

One field in the Sagitta Constellation

(RA=19h 50m, DEC=17º 04m)

Total number of stars : 564,116

Total number of F,G,K,M dwarfs : 161,394

F dwarfs : 68,914

G dwarfs : 65,261

K dwarfs : 23,226

M dwarfs : 3,993

Follow-up Strategy of the Candidates

False positives are a major concern:

- grazing eclipsing binaries
- transits of small stars in front of a large star
- blended eclipsing binaries with deep eclipses

- **Multi-band and High-Cadence Photometry** for blend identification through color changes and morphological features (ellipsoidal variation)
- **Low Resolution Spectroscopy** to identify spectral type of stars, constraint the sources size. This allows to rule out giant contaminants, and mass and radius determination of the planets
- **Medium Resolution Radial Velocity** to select grazing eclipsing binaries. Expected amplitudes are several tens of kms^{-1}, whereas hundred ms^{-1} for a Jupiter-mass planet around a sun-like star
- **High-Resolution Radial Velocity** to confirm planetary transits on a sample with minimal contamination.

Prospects for Pan-STARRS

- PANSTARRS project has an exceptional potential for transit searches due to the combination :
  - large FOV = 7 deg2
  - significant telescope size of 1.8m
  - fast read-out of the CCD camera (few seconds)
  - quick slew of the telescope

- These features allow frequent monitoring of several 100,000 stars in only one field, and million of stars in two or more fields!

- PAN-STARRS would devote 30 days per year during 3 years to search for transiting planets, harvesting more than 100 H and VH Jupiter like-planets.