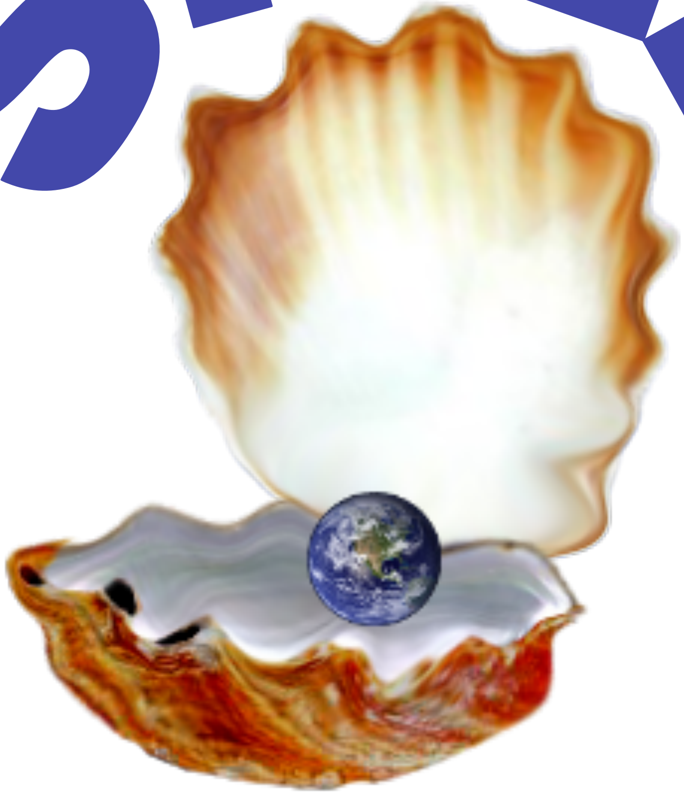
SHEL



SHEL
Search for Habitable Extrasolar Lands

All sky survey of the habitable zone of M stars to search for exoplanets with the transit method

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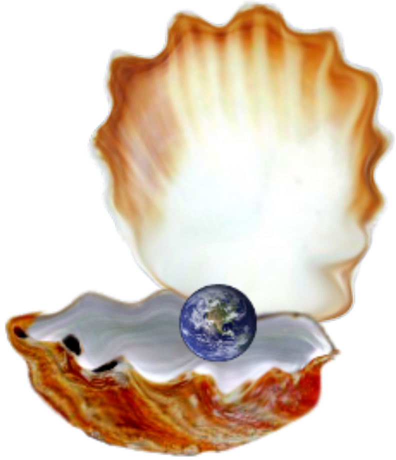
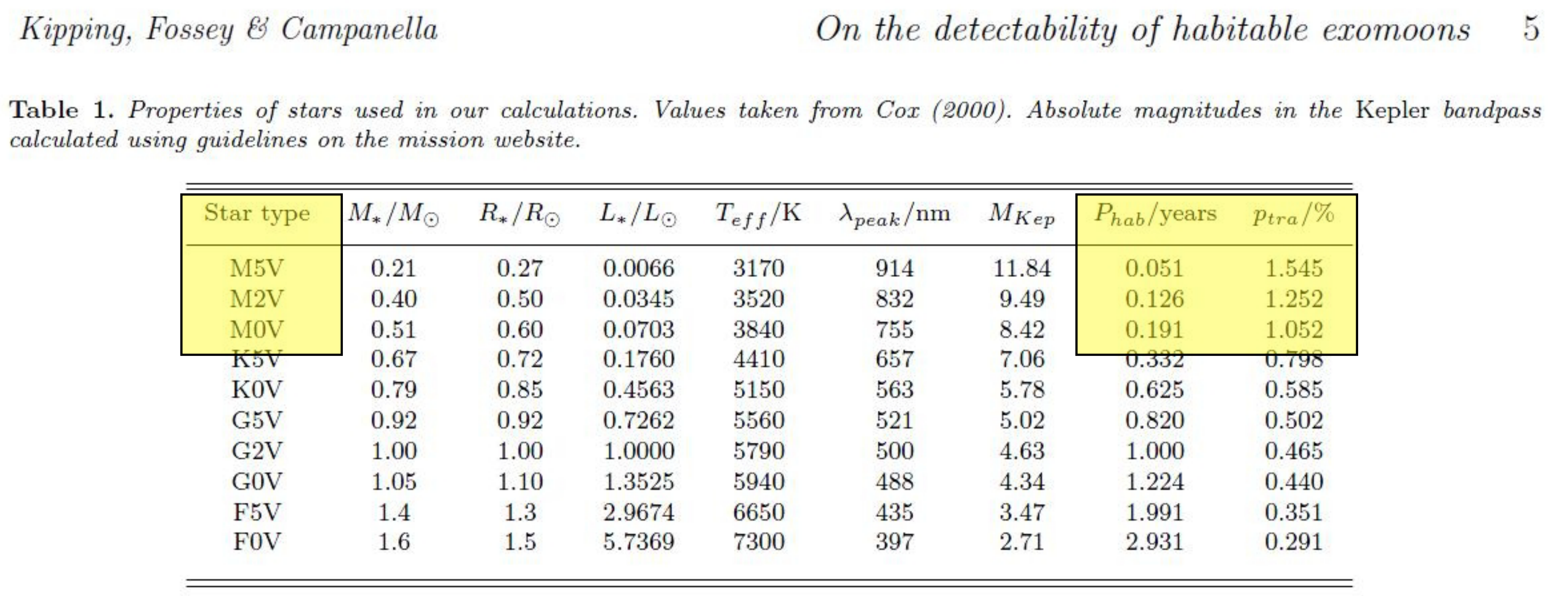


Science goals

- **Major science goal: find 100 habitable planets around close M stars**
  - "Complete" survey out to a certain distance to make relevant statistical studies
  - Very broad vision for an astrobiology mission, but still a valid target
    - Extend our knowledge on habitability
    - M stars have longest lives
    - Over 70% of stars are M dwarfs! Many M stars close to us (600 within 10 pc)
  - Technically, M stars are the easiest targets for transit detection of planets in the HZ.

M stars characteristics

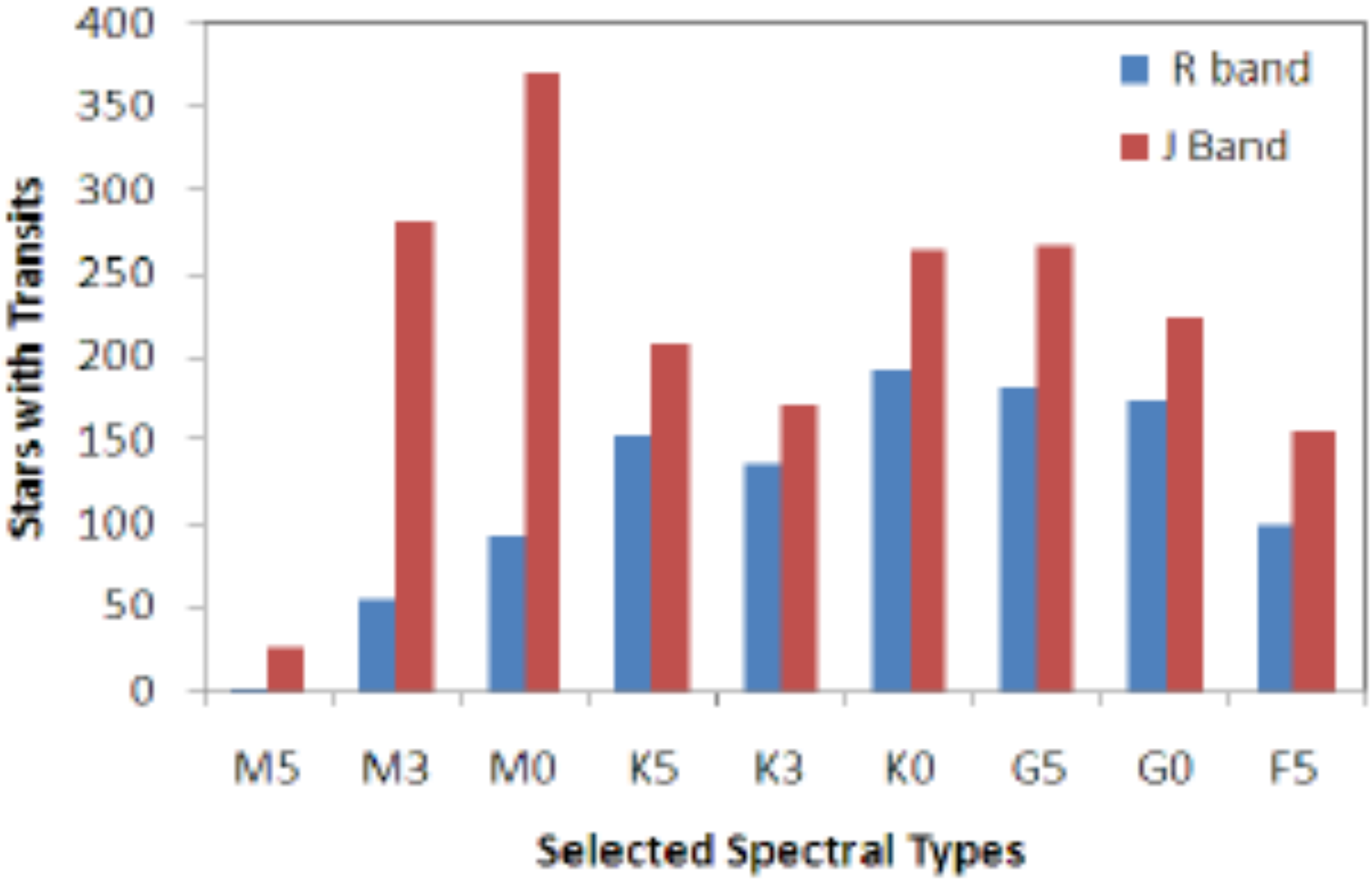


Kipping, Fossey & Campanella *On the detectability of habitable exomoons* 5

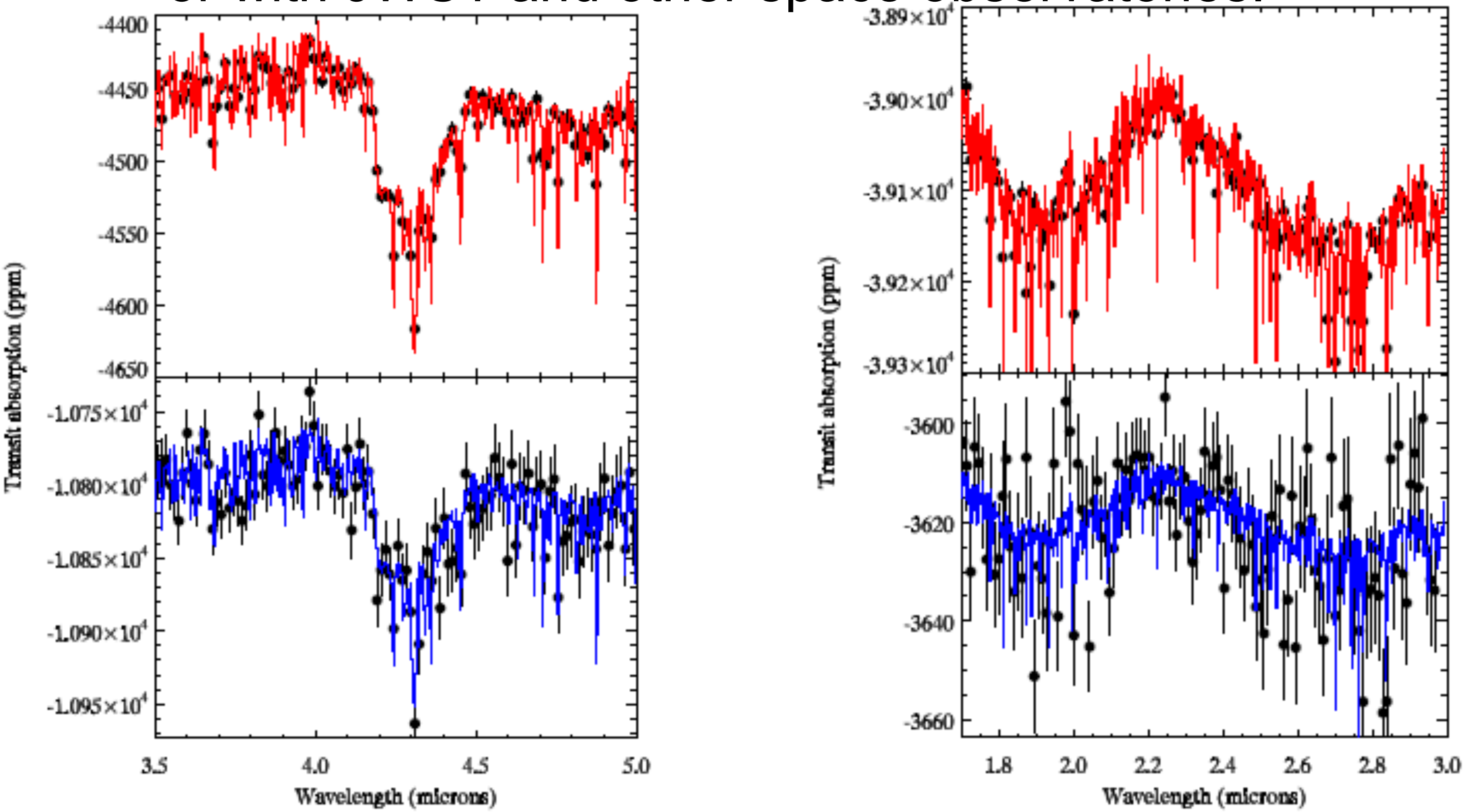
Table 1. *Properties of stars used in our calculations. Values taken from Cox (2000). Absolute magnitudes in the* Kepler *bandpass calculated using guidelines on the mission website.*

Star type	$M_*/M_\odot$	$R_*/R_\odot$	$L_*/L_\odot$	T_{eff}/K	λ_{peak}/nm	M_{Kep}	P_{hab}/years	p_{tra}/%
M5V	0.21	0.27	0.0066	3170	914	11.84	0.051	1.545
M2V	0.40	0.50	0.0345	3520	832	9.49	0.126	1.252
M0V	0.51	0.60	0.0703	3840	755	8.42	0.191	1.052
K5V	0.67	0.72	0.1760	4410	657	7.06	0.332	0.798
K0V	0.79	0.85	0.4563	5150	563	5.78	0.625	0.585
G5V	0.92	0.92	0.7262	5560	521	5.02	0.820	0.502
G2V	1.00	1.00	1.0000	5790	500	4.63	1.000	0.465
G0V	1.05	1.10	1.3525	5940	488	4.34	1.224	0.440
F5V	1.4	1.3	2.9674	6650	435	3.47	1.991	0.351
F0V	1.6	1.5	5.7369	7300	397	2.71	2.931	0.291

Stars with transit per spectral type



- A lot of possible targets for further studies on the ground, or with JWST and other space observatories.



Models spectra of JWST follow-up on habitable SuperEarth around M stars

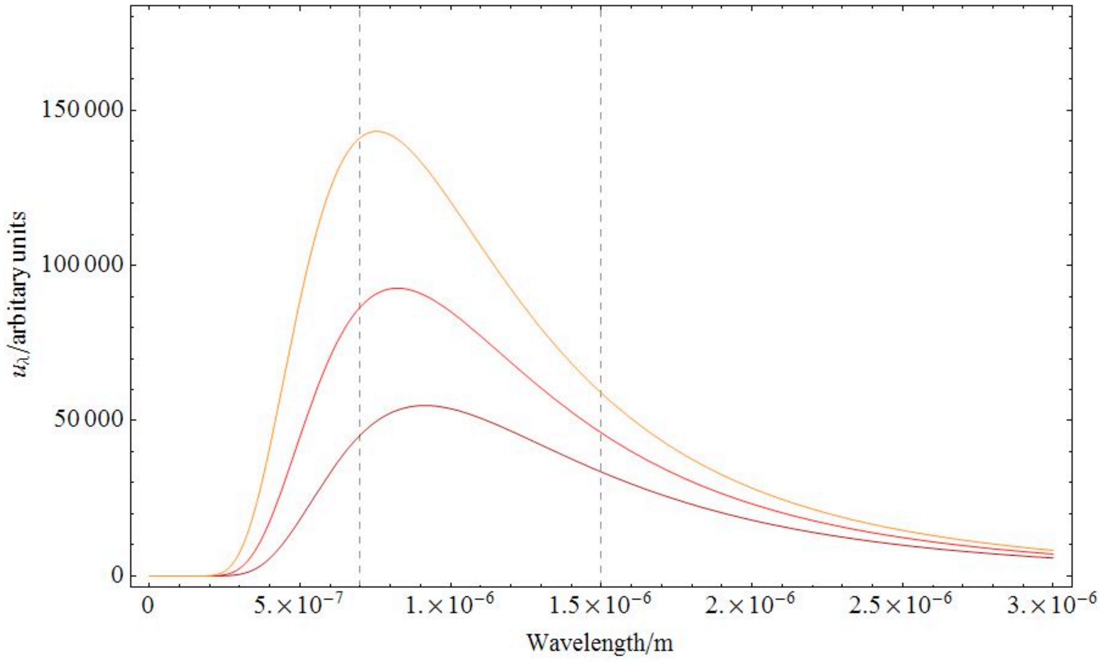
Fig. 14.— *Upper panel:* synthetic NIRSpec observations (points) of carbon dioxide absorption near 4.3 μm, in a hot (T = 797K) superEarth having $R = 2.2R_{\oplus}$, at a distance of 18

Fig. 13.— *Upper panel:* Points are synthetic NIRSpec observations of water absorption near

- **Other goals:**
  - Better understanding of M stars
  - Asteroseismology/Transit Timing
  - Extend our knowledge on diversity of exoplanets around M Stars
  - Also study K stars (closest to our sun, more interesting astrobiologically?)

Choosing a wavelength

- **Wavelength = 0.7 µm to 1.5 µm**
  - M dwarfs are brighter between 0.5 and 1.5µm
  - We choose 0.7 instead of 0.5 to get rid of the H alpha variation associated with the star activity
  - We do broadband photometry in that wavelength range



Instrumentation Requirements

Number of stars to survey

- 100M stars with an habitable planet transiting = 30 000 stars surveyed x 1% transit prob. X 30% have a planet in HZ
- 640 M dwarf in 10 000pc^3 which implies a sphere of radius 50pc has to be surveyed
- The magnitude of M stars at 50pc in J band is 11th

Sensitivity/size of the mirror

SNR =transit depth x (transit duration x number of photons collected/unit time) $^{1/2}$

For an Earthlike crossing an M2V star, transit depth = 0.3 mmag
To have SNR=4sigma (per transit) implies =25 x 10 ^{6}photon/hour
Which implies a 10cm telescope

Thermal Requirements

Not really constraining in NIR, passive cooling in L2 would be enough

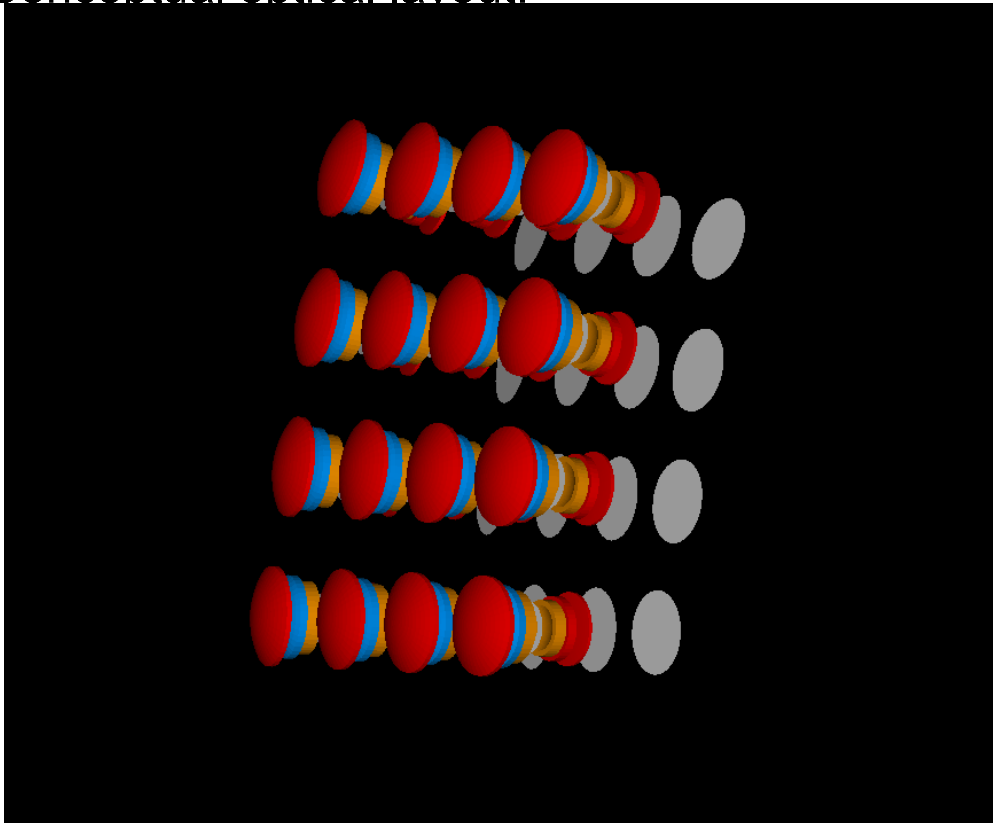
Instrument Requirements

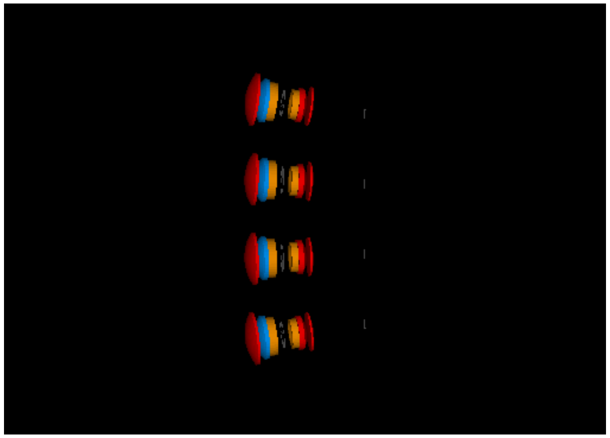
- **Earthscope Camera**

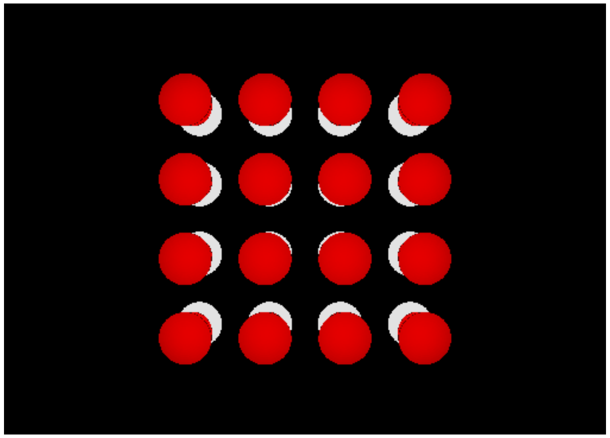
  Size = 70 cm x 70 cm

  16 camera of 4K by 4K pixels

  Conceptual optical layout:







Instrumentation Requirements

- **Instantaneous sky access**
    - 20 x 20 square deg x 16 cameras (15% of the sky each per pointing)

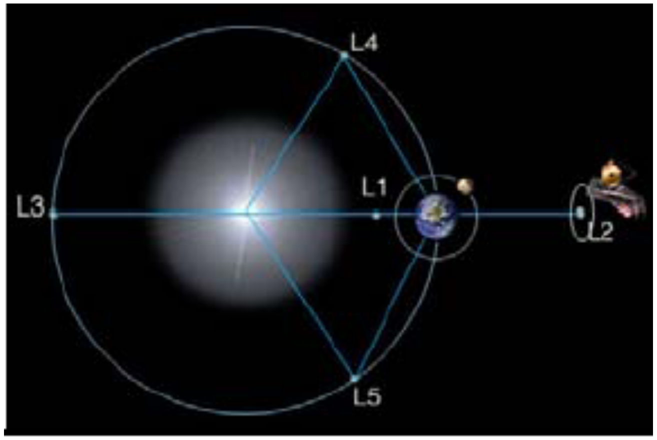
- **Sky coverage** (yearly sky access)
    - Ecliptic latitude -45 to 45 deg (71% of sky)

      Could reach about 96% of sky with multiple pointing

- **Duration**
    - Integration time – short and multiple observation for same area – keep bright objects not to be saturated e.g. For 5 min integration, 10 sec X 30 obs.
    - 2 months for each field, 6 fields a year to cover the whole 40,000 square degrees
    - At least three years, could probably stand way longer

Orbit

- **Consider data rate, background noise, launch cost**
- **LEO rejected**
  - Multiple sources of systematic errors (thermal fluctuations, etc.)
  - A lot of time lost (Earth, Moon)
  - A lot of background noise
  - South atlantic anomaly (Radiation)
- **L2 chosen**
  - Simplifies the data downlink
  - Higher resolution data
  - Simplifies the data reduction (less systematic errors)
  - More opportunities for science



	L2
Launch Vehicle	Expensive
Thermal	Stable, cold
View of Sky	Excellent. Constant geometry
Data Rates	Moderate
Propulsion	L2 Entry, station keeping

Data volume and rate

- Let R = Data rate, C = # of cameras, P = # of pixels per camera, E = Cadence Rate, B = Bits per pixel, and a factor of 1.1 for 10% overhead.
- Thus, R = 1.1*C*P*B/E or E = 1.1*C*P*B/R
- R = 3.0E8 bits/sec at 8hrs/24hrs of connection time = 1.0E8 bits/sec for X-band, C = 13, P = 1.7E7, B = 32 bits for 2x lossless compression.
- Thus, E = 78 seconds for full camera download.
- If we only download stars of interest (ala Kepler), then for 30,000 target stars and ~10 pixels per star we can have a cadence rate of...
- Thus, E~1.5 seconds. Or have a longer cadence for lower costs due to required connection time.

Note: data rate can be improved a lot by transmitting only postage stamps around each star (say 5x5 pixels), not total array images. Kepler does this. Also send down ~300 sec averages, not each read.

Pointing requirements

- Primary pointing constraint is to keep each star within a fraction of a pixel.
- 4k x 4k CCD gives 16 million pixels covering 400 square degrees
- Each pixel covers 18 arcseconds width
- We therefore require pointing of at least 1 arcsecond stability over maximum timescale of a transit ~ 12-24 hours
- Pointing control less demanding ~ 10 arcseconds

- Slewing: need to slew back to patch of sky each year within ~ arcseconds

Spacecraft bus

- **Depends on size of instrument, telecom capability, pointing capability**
- The payload is quite light (7kg/camera) we still need spacecraft C (it is better for pointing requirement and longer life anyway).

		Spacecraft A	Spacecraft B	Spacecraft C	Spacecraft D
Payload Power	W (EOL)	50	66	730	650
Payload Mass Limit	kg	70	200	380	650
Bus Dry mass (w/o Payload)	kg	60	125	600	350
Science Data Downlink capacity	kbps	2000	2500	320000	80,000
Science Data Storage capability	Mbit	3	2000	134000	100,000
Pointing Knowledge	arcsec	2880	3	3	0.5
Pointing Control	arcsec	2160	32	5	16
Pointing Stability (Jitter)	arcsec/sec	36	0.1	0.05	0.1
Slewrate	deg/min	60	390	240	120
Mission Design Life	yrs	1	2	5	5
Cost	$ FY09	$ 50 M	$ 75 M	$ 125 M	$ 150 M

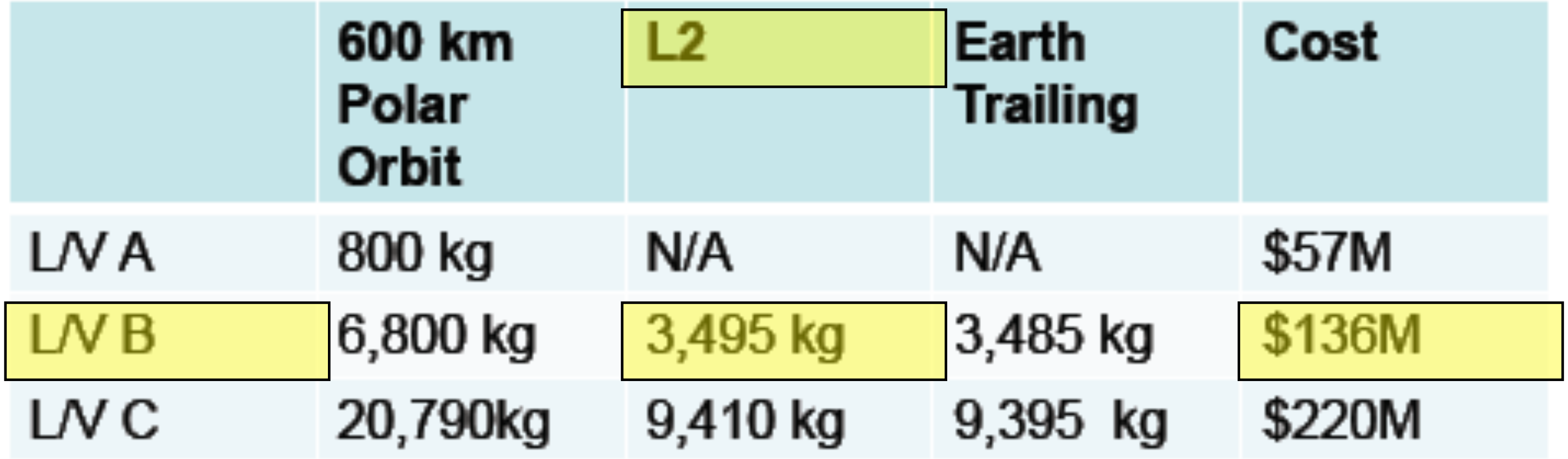
Launch mass

- Telescope/Instrument – 7*16=112kg♪
- Bus – spacecraft C = 600 kg
- Propellant – 20kg
- Margin – 30%

- Total mass ~ 950 kg

Launch vehicle

- **Mass capability – 3495 kg, payload is 950Kg, huge margin**
- **Orbit – L2**
- **Cost - $136M**

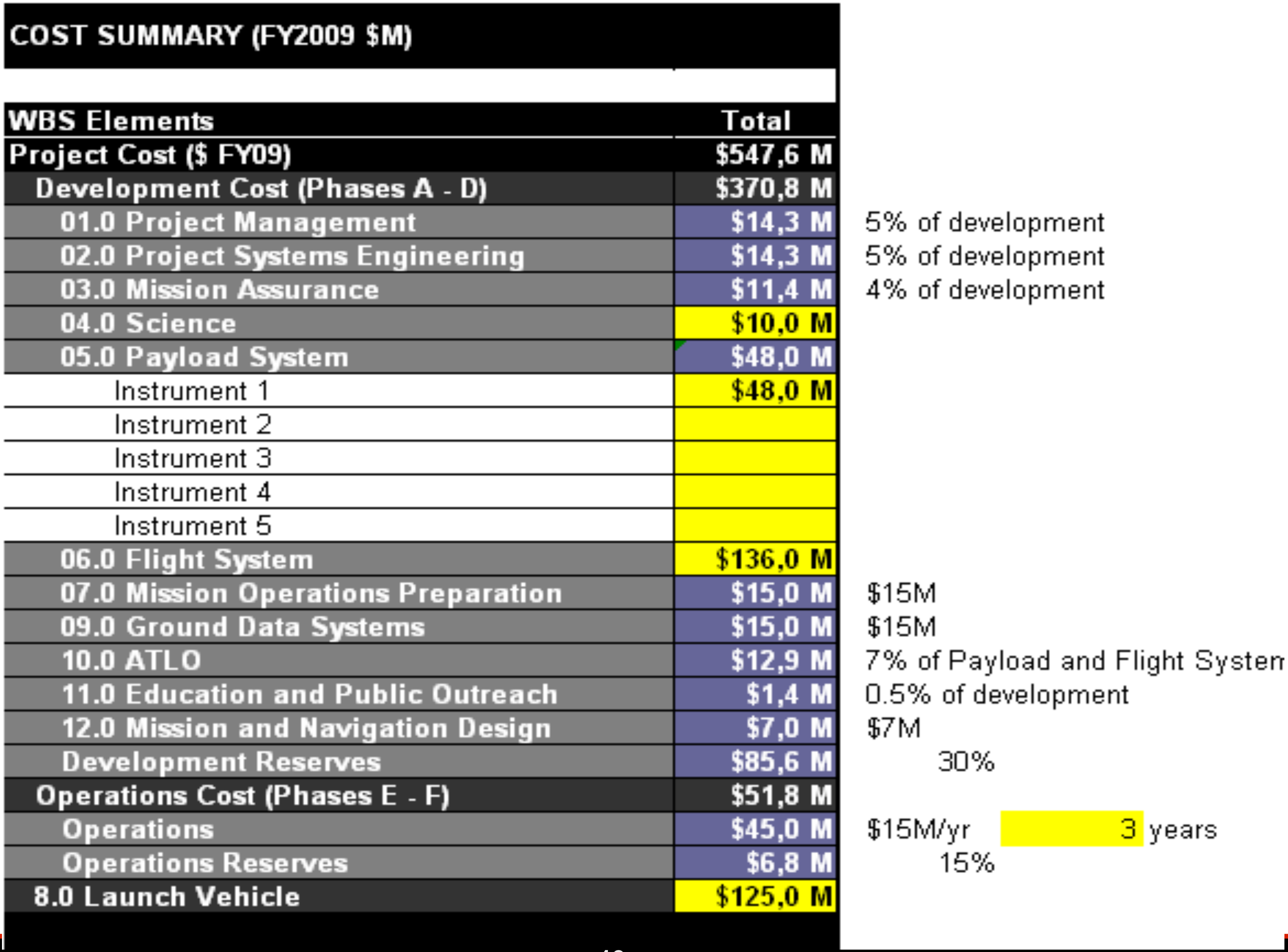


	600 km Polar Orbit	L2	Earth Trailing	Cost
L/V A	800 kg	N/A	N/A	$57M
L/V B	6,800 kg	3,495 kg	3,485 kg	$136M
L/V C	20,790kg	9,410 kg	9,395 kg	$220M

The risks

- Wide FOV (Optical design should pass coma or aberration test)
- Pointing issue and slewing
- Saturation : Detector sensitivity dynamic range (FWHM :~3” < 20” (pixel scale) under sampled image → highly probable saturation

Total mission cost



COST SUMMARY (FY2009 $M)

WBS Elements	Total			
Project Cost ($ FY09)	**$547,6 M**			
Development Cost (Phases A - D)	**$370,8 M**			
01.0 Project Management	$14,3 M	5% of development		
02.0 Project Systems Engineering	$14,3 M	5% of development		
03.0 Mission Assurance	$11,4 M	4% of development		
04.0 Science	$10,0 M			
05.0 Payload System	$48,0 M			
Instrument 1	$48,0 M			
Instrument 2				
Instrument 3				
Instrument 4				
Instrument 5				
06.0 Flight System	$136,0 M			
07.0 Mission Operations Preparation	$15,0 M	$15M		
09.0 Ground Data Systems	$15,0 M	$15M		
10.0 ATLO	$12,9 M	7% of Payload and Flight Systen		
11.0 Education and Public Outreach	$1,4 M	0.5% of development		
12.0 Mission and Navigation Design	$7,0 M	$7M		
Development Reserves	$85,6 M	30%		
Operations Cost (Phases E - F)	**$51,8 M**			
Operations	$45,0 M	$15M/yr	3	years
Operations Reserves	$6,8 M	15%		
8.0 Launch Vehicle	**$125,0 M**			

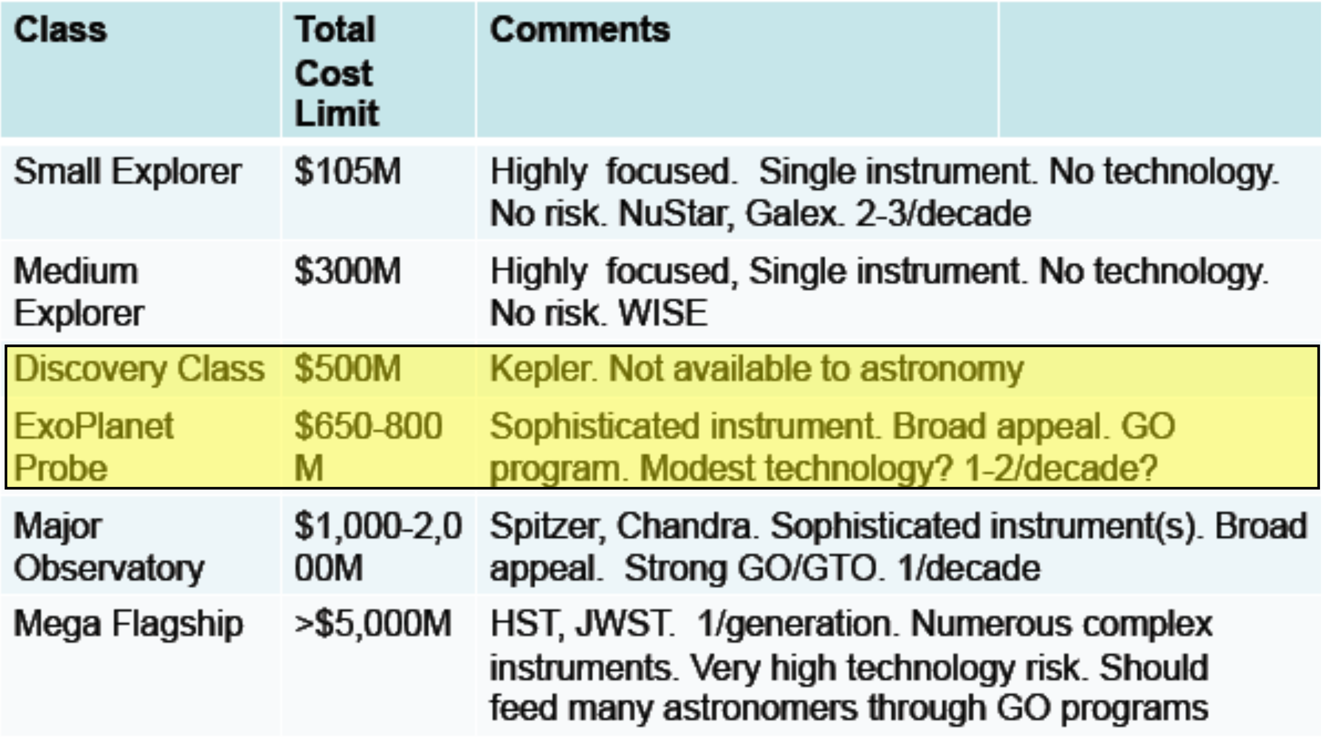
Total mission cost

- **Instruments: 16camera *(2+1)M$= 48M$**

  2M$ for the detector, 1M$ for the camera

- **Total cost= 548M$**

  Between a Discovery class (500M$) and ExoPlanet Probe (650-800M$)



Class	Total Cost Limit	Comments
Small Explorer	$105M	Highly focused. Single instrument. No technology. No risk. NuStar, Galex. 2-3/decade
Medium Explorer	$300M	Highly focused, Single instrument. No technology. No risk. WISE
Discovery Class	$500M	Kepler. Not available to astronomy
ExoPlanet Probe	$650-800 M	Sophisticated instrument. Broad appeal. GO program. Modest technology? 1-2/decade?
Major Observatory	$1,000-2,000M	Spitzer, Chandra. Sophisticated instrument(s). Broad appeal. Strong GO/GTO. 1/decade
Mega Flagship	>$5,000M	HST, JWST. 1/generation. Numerous complex instruments. Very high technology risk. Should feed many astronomers through GO programs

Prospects

A hundred Earth like Planets!!!

$$N = R^{*} \times f_p \times \boxed{n_e} \times f_\ell \times f_i \times f_c \times L$$

- Spectroscopy.
- Confirmation with other Methods.
- Better Understanding of The possibility of ET life.
- Search for ET life.