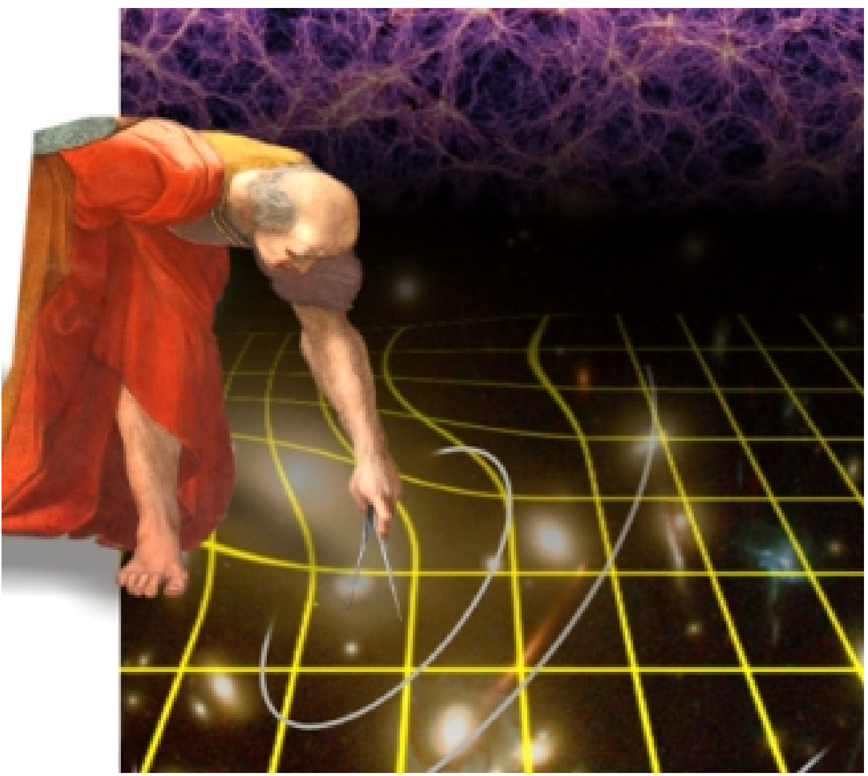
Simulation of a Planetary Microlensing Survey by Euclid



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16th International Conference on Gravitational Microlensing 17th Feb 2012

Overview

1. The Euclid Spacecraft
2. The Science
3. The Simulations
4. The Expected Yields

1. Euclid

For more info see:
The Euclid Red Book
Laureijs+ 2011
arXiv:1110.3193

- An ESA mission to probe dark energy via Weak Lensing (WL) and Baryon Acoustic Oscillations (BAO)
- Wide-field 1.2-m telescope @ L2
- 0.5 deg^2 NIR and Visual imagers

1. Euclid Instruments

VIS

Galaxy shapes etc.

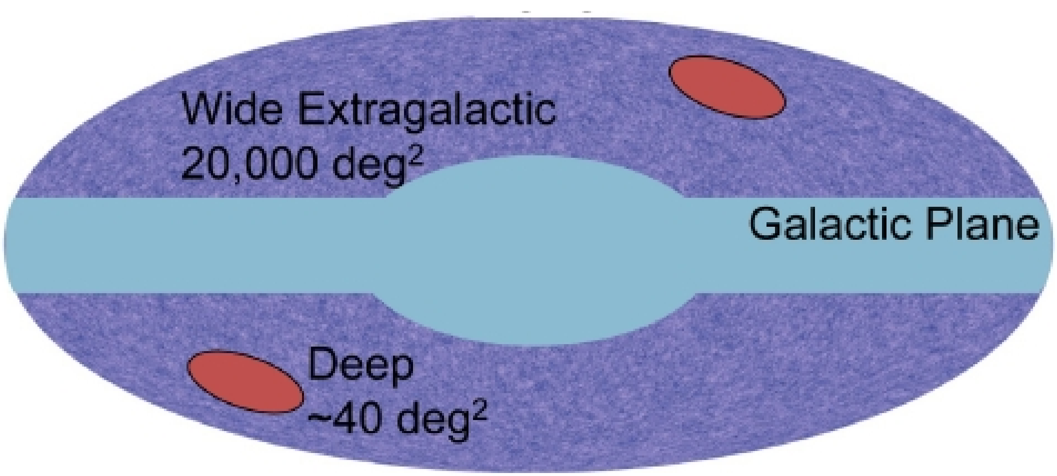
- 36 4k x 4k CCDs
- 0.1” pixels
- 0.2” PSF
- Single broad RIZ filter
- Limiting mag 24.5 in 3x~540s

NISP

Photo-z + Spectro-z

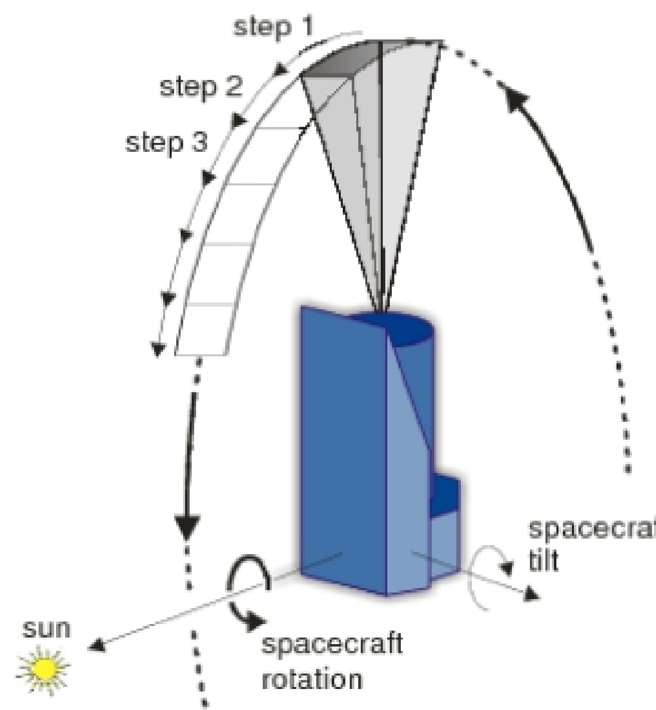
- 16 2k x 2k HgCdTe arrays
- 0.3” pixels
- 0.3-0.45” PSF
- Y, J, H NIR filters + 2 Grisms
- 24^{th} mag in each

1. Euclid Main Survey



Two surveys in 6 yrs

- Wide survey 15,000-20,000deg²
- Deep survey 40deg²



Scans sky maintaining fixed orientation cf Sun

But can't survey galaxies in Galactic plane

1. µL with Euclid

Euclid is perfectly suited to microlensing observations:

- High resolution
- Wide field
- Sensitive VIS + NIR photometry

+ has "low-efficiency" time which can be used for other projects

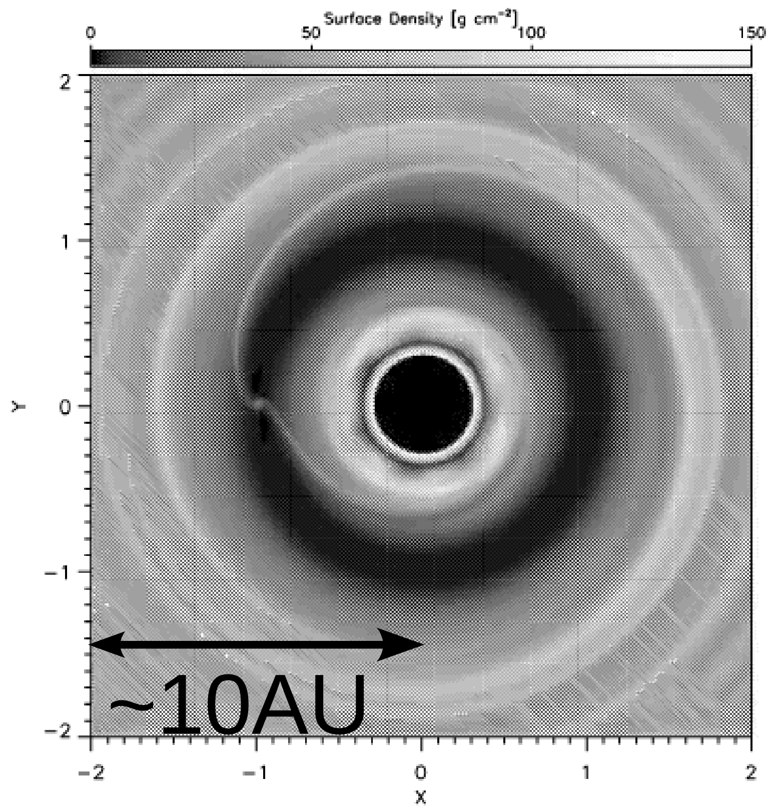
2. The Science

Do microlensing with Euclid to probe:

- Planet formation
  - Core accretion or disc instability?
  - Mechanisms, timescales, etc.?
  - How many planets form and what happens to them?
- Habitable systems
  - How many systems look like home?
  - Jupiter, Saturn + warm terrestrial planets?

Core Accretion

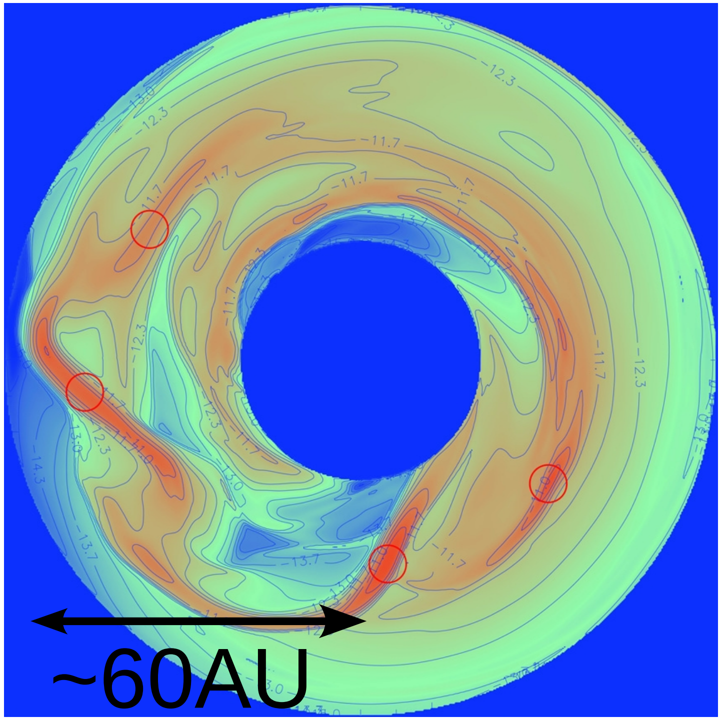
Planets build up slowly from grains to gas giants in dusty disc



Bate+ 2003

Disc Instability

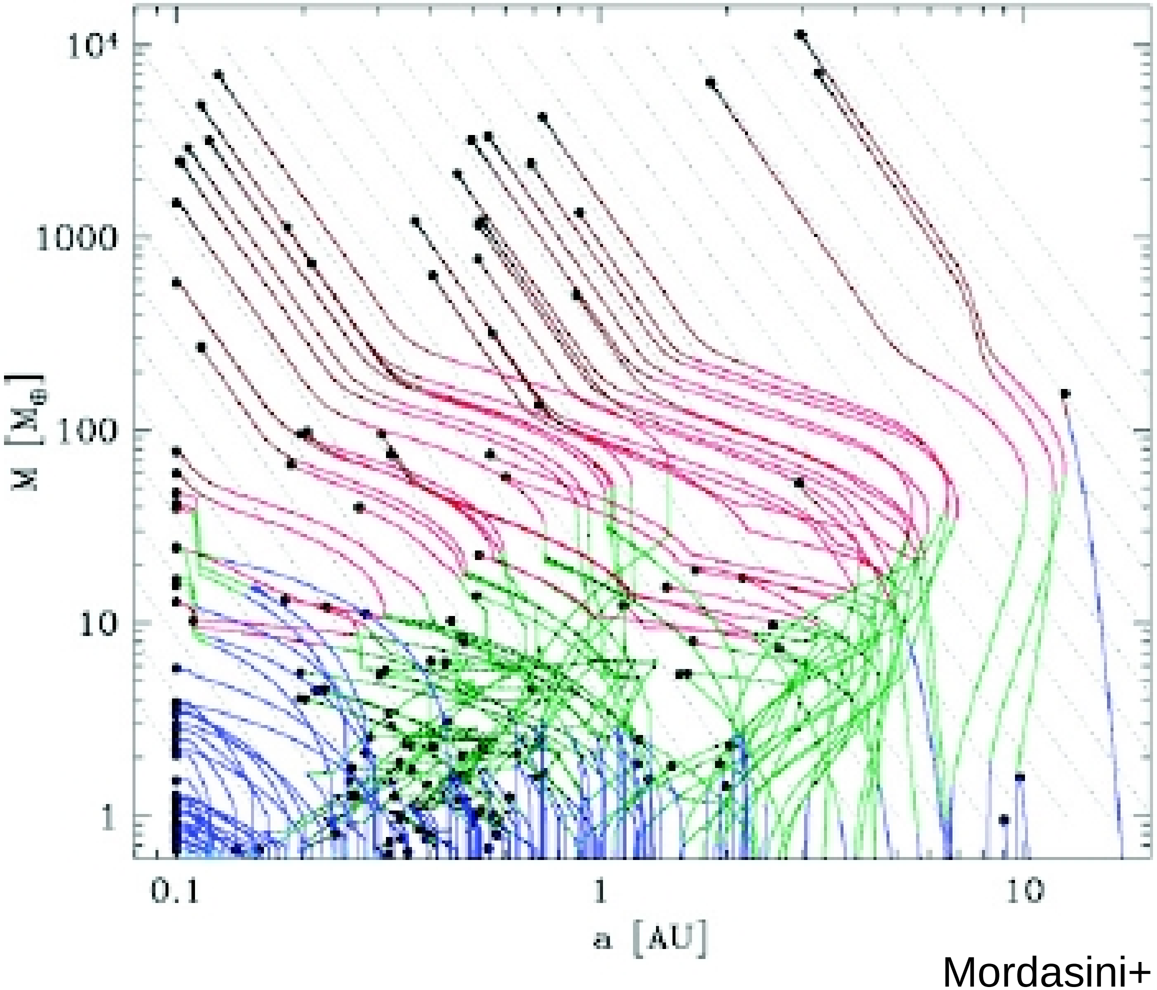
Gas giants quickly collapse out of a gaseous disc



Boss, 2011

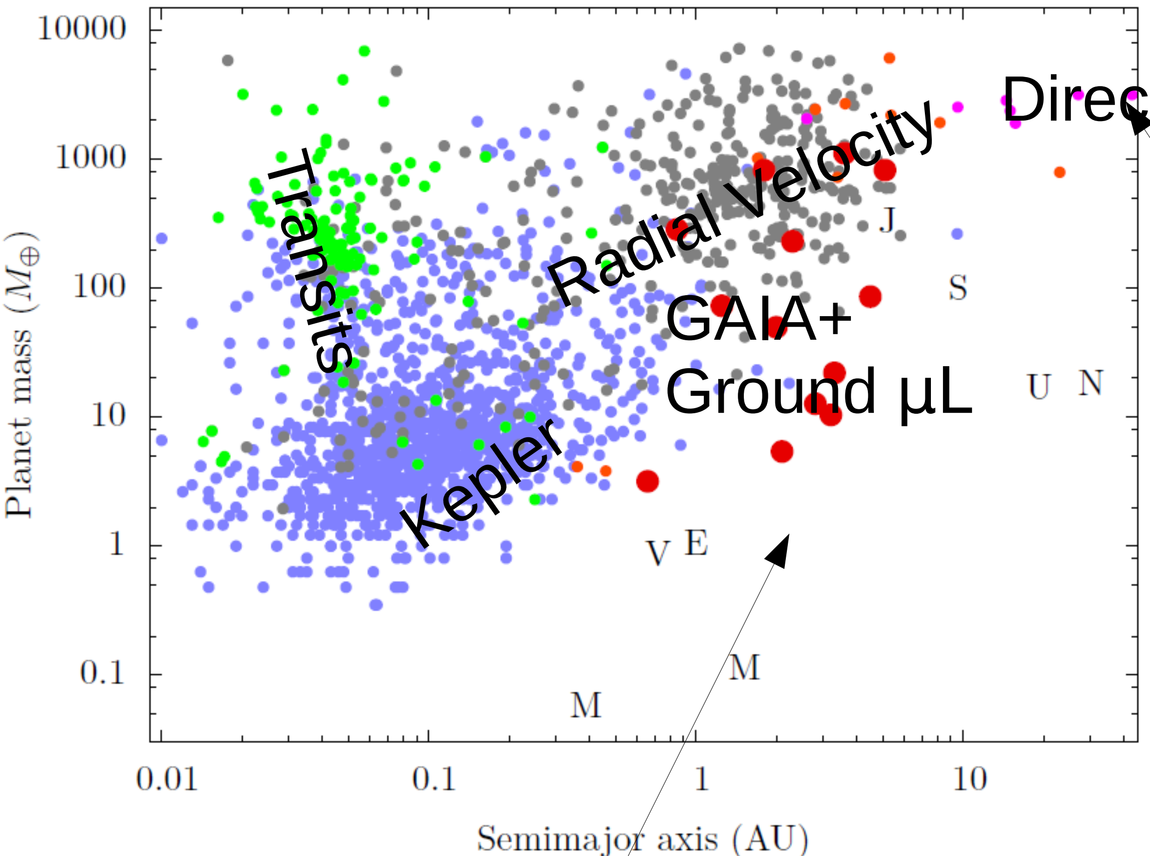
2. And there's migration!

- Planets migrate within the disc



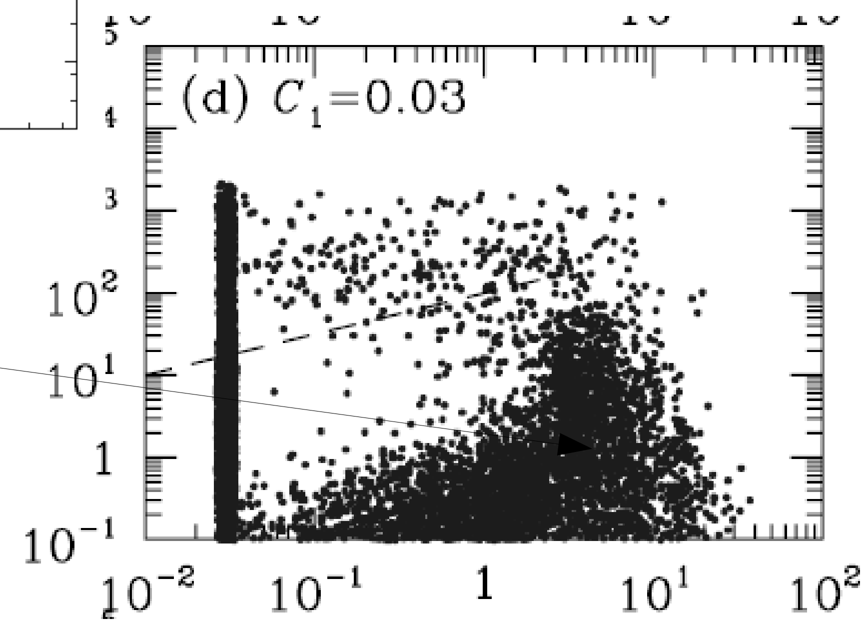
Mordasini+ 2011

2. The M-a diagram



Disc instability happens here

Core accretion happens here



Ida+Lin, 2008

3. The Simulator - MaBμLS

Manchester-Besancon microLensing Simulator

- Draws events from the Besancon Galactic model
- Simulates photometry with realistic image simulations
- Modular, extensible design

3. The Besancon Model

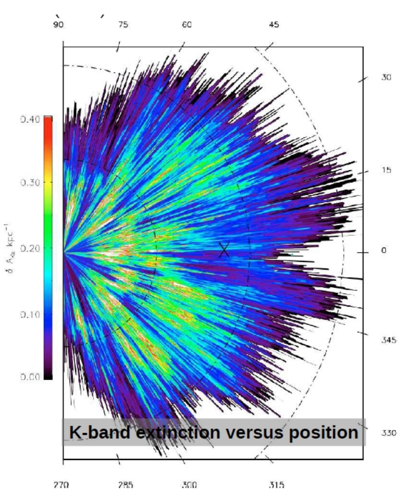
Robin+ 1986, 2003, 2012 etc. Marshall et al 2006

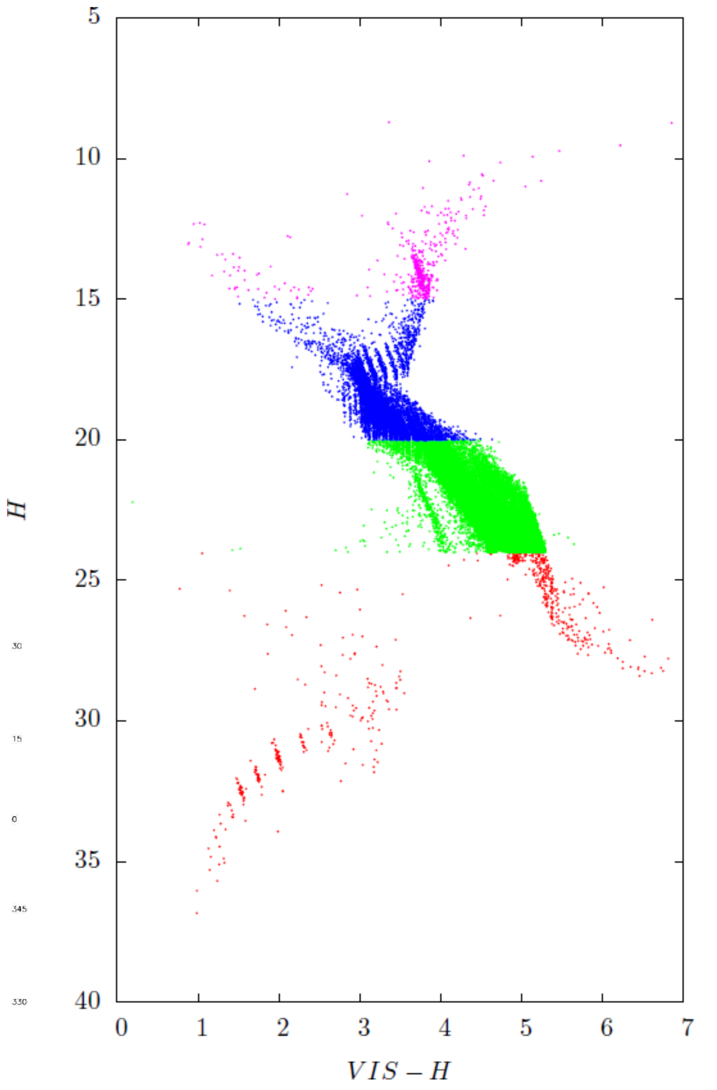
Galactic population synthesis model:

Incorporates:

- Bulge+bar, thin+thick discs, stellar halo
- Evolutionary tracks
- Stellar atmos models
- 3d dust model

Generates lists of stars and their properties



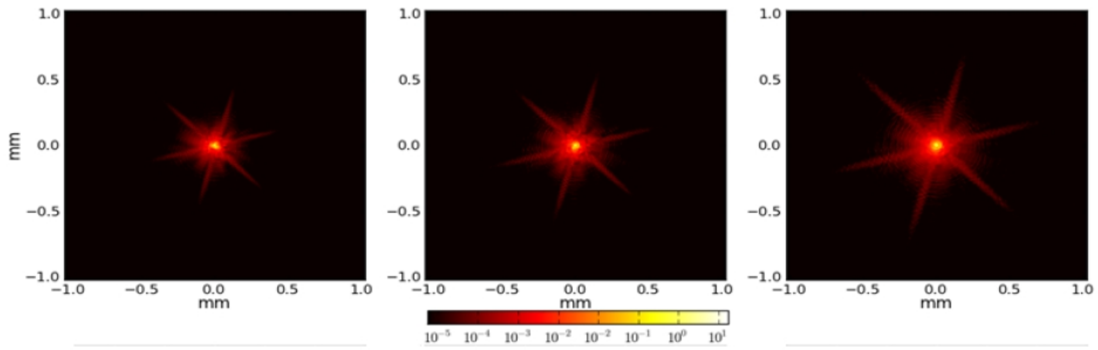


3. Image Simulations

Detector and Noise parameters

```
#Instrument: NISP
#Band: H

#Microlensing detector - 17/09/2011 FINAL PARAMETERS

BIAS            380             Bias level in counts per pixel
READOUT         9.1             Read out noise in counts per pixel
THERMAL         0.26            Thermal flux in counts per pixel per sec
DARKCURRENT     0.1             Dark current in counts per pixel per sec

PIXELSCALE      0.3             Pixel size in arcsec
PSFFWHM         0.45            PSF FWHM in arcsec
PSFFILE         /home/mpenny/gp2/testing/Exigere/image/ConfigFiles/Observatories
/hpix.psf
#PSFFILE         /home/mpenny/gp2/Exigere/PSFs/hpix.txt
PSFSCALE        0.016666667     Spacing between samples of the numerical PSF
KERNSIZE        55              PSF Kernel size
SUBPIX          9               Number of sub pixel points used to place stars

BITDEPTH        16              Number of bits per pixel
SYSTEMATIC      0.003           Systematic photometry error

DIAMETER        1.2             Telescope diameter in metres
BLOCKAGE        0.4             Telescope blockage in metres

ZEROMAG         24.9213         Magnitude at which zeropoint is defined
ZEROFLUX        1               Photons per second from areference source

BACKGROUND      21.4            Background magnitude in mags per sq arcsec
APERTURE        0.5             Aperture radius (not diameter) in arcsec

PIXELSIZE       18              Pixel size in microns
CRFLUX          0               Cosmic ray flux in hits m^-2 s^-1
```

Numerical PSFs



Images generated from star lists output by Besancon model

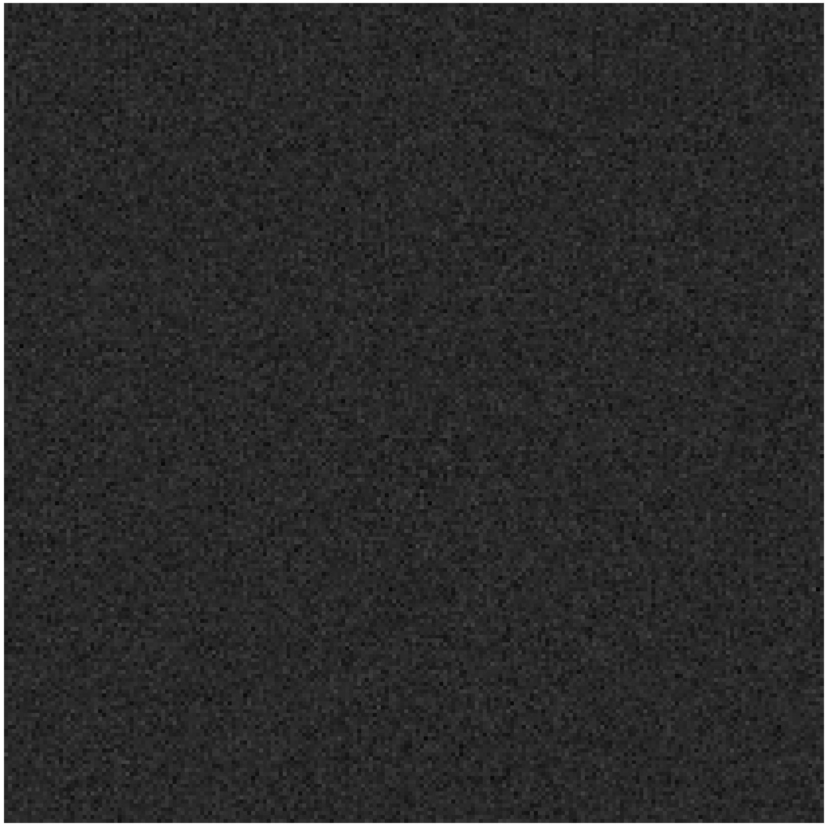
3. Image simulations

Simulate a CCD

3. Image simulations

Simulate a CCD

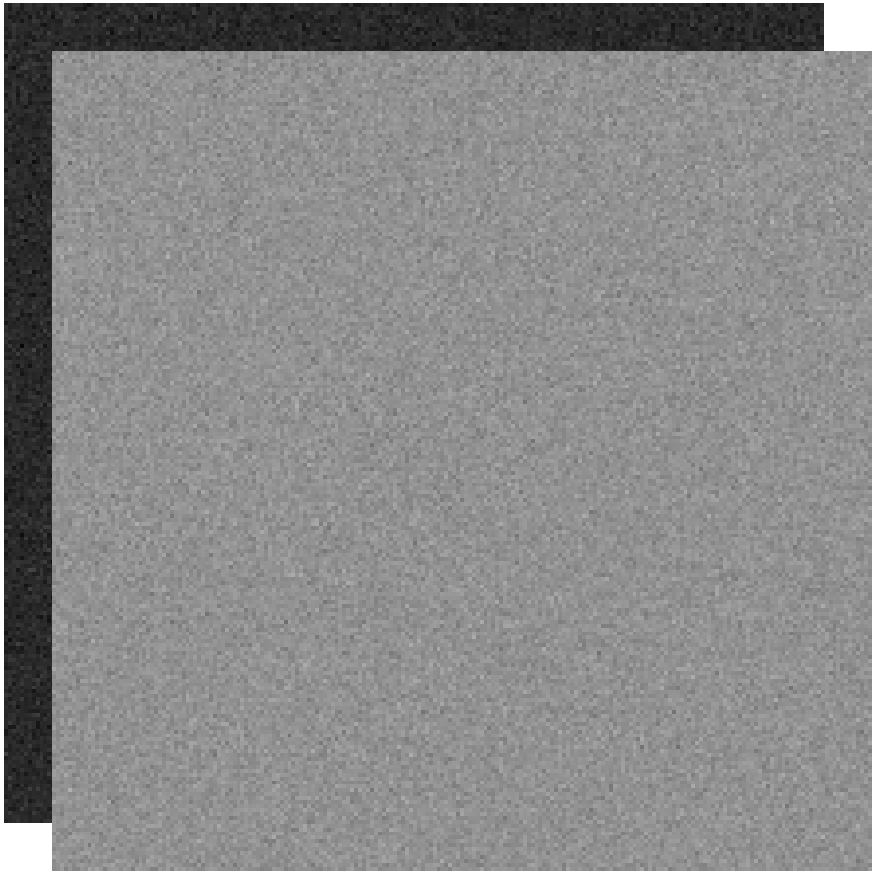
- Bias



3. Image simulations

Simulate a CCD

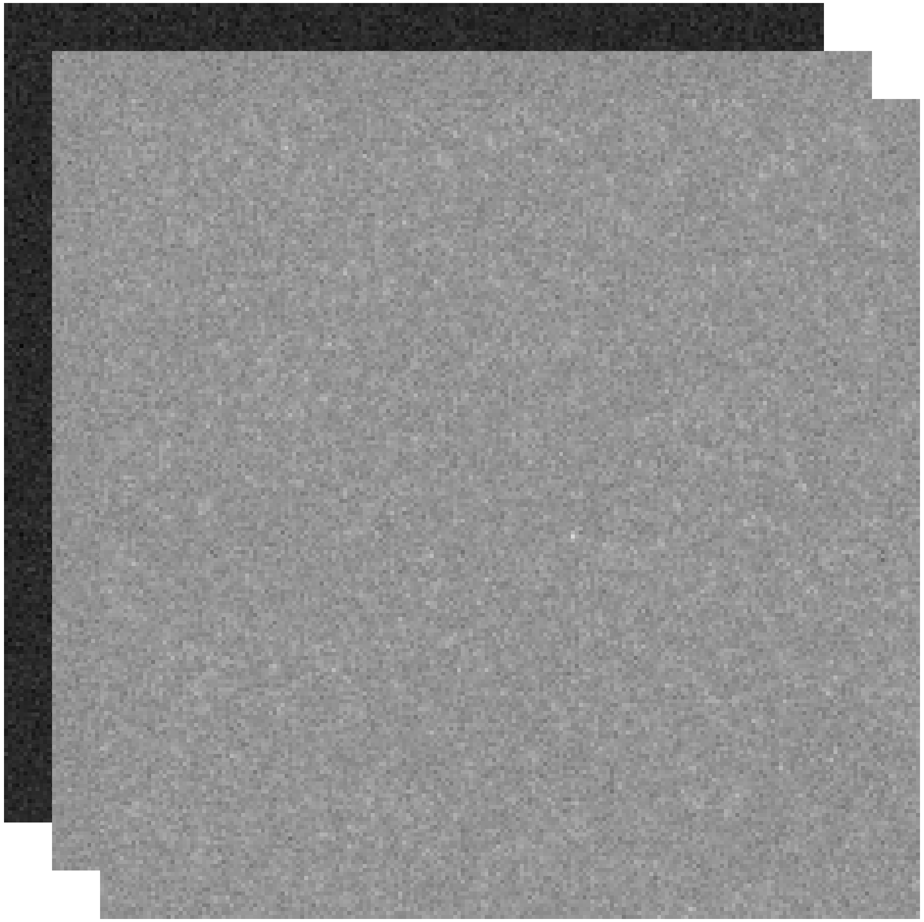
- Bias
- Background



3. Image simulations

Simulate a CCD

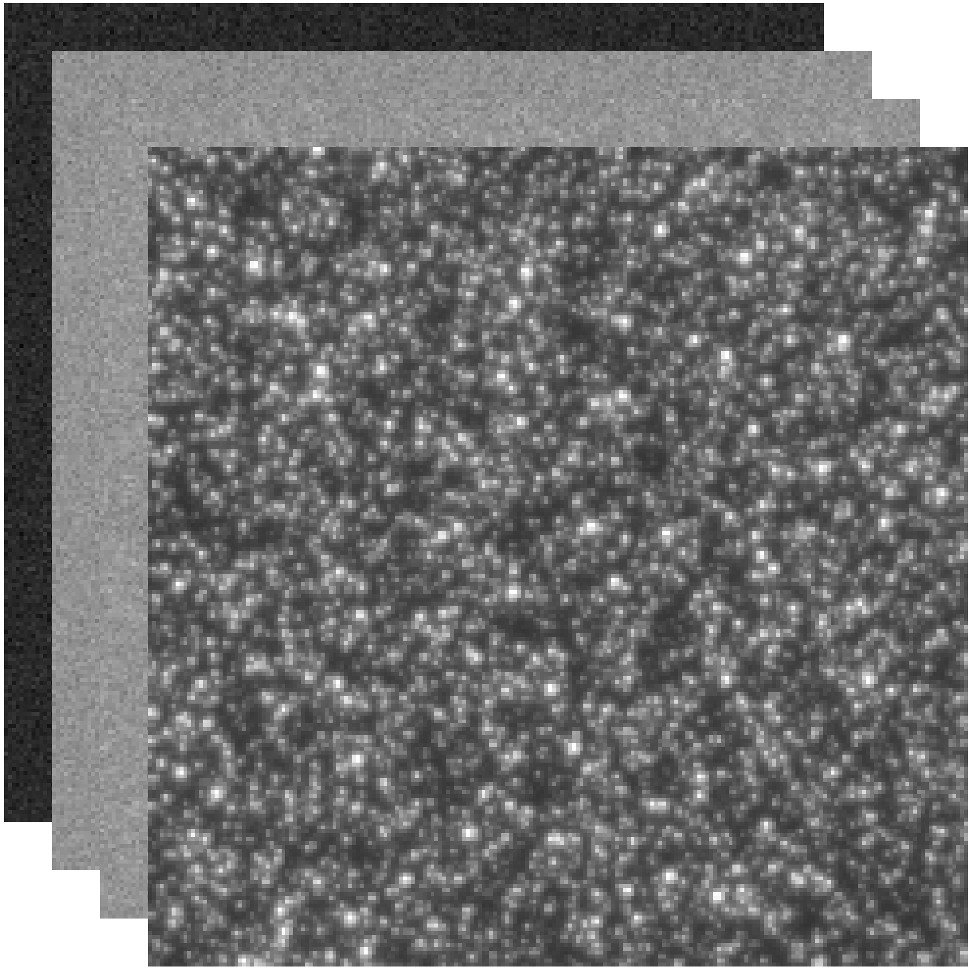
- Bias
- Background
- Faint stars



3. Image simulations

Simulate a CCD

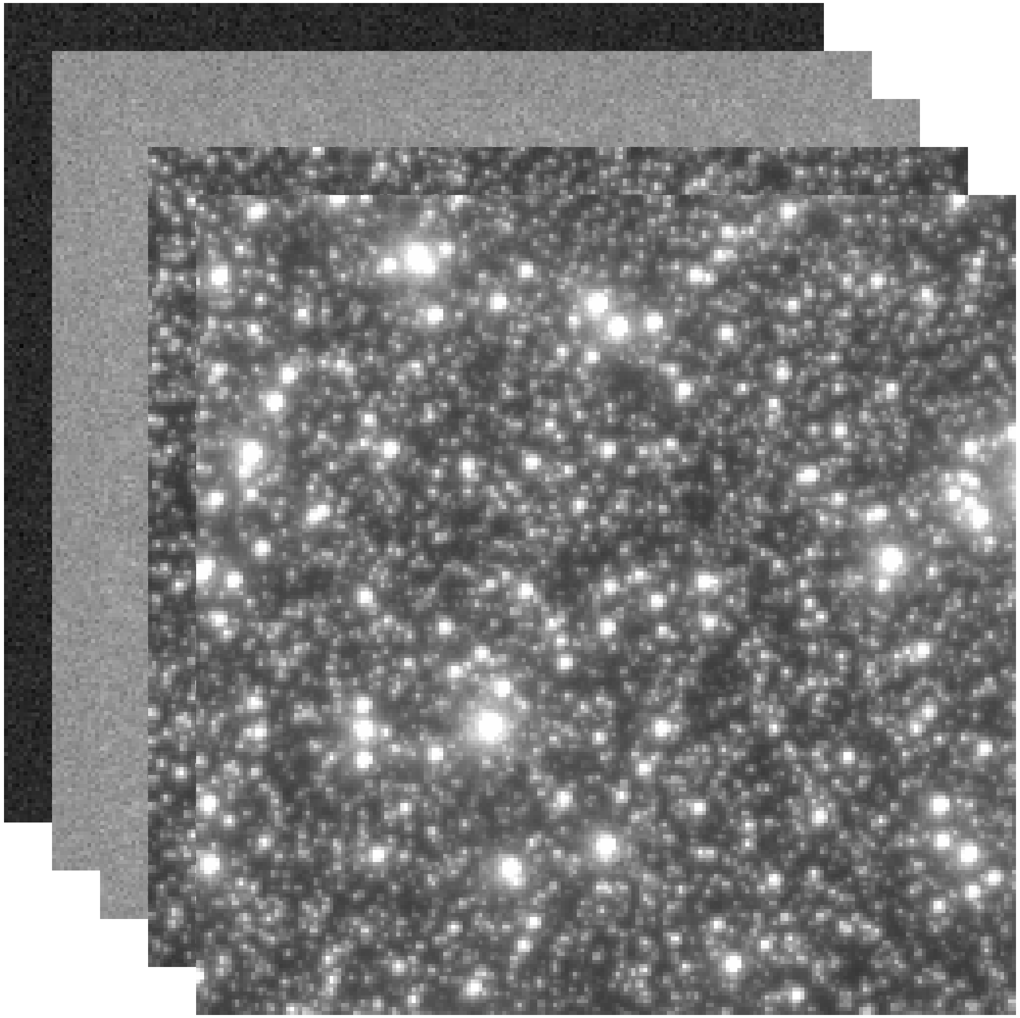
- Bias
- Background
- Faint stars
- Stars



3. Image simulations

Simulate a CCD

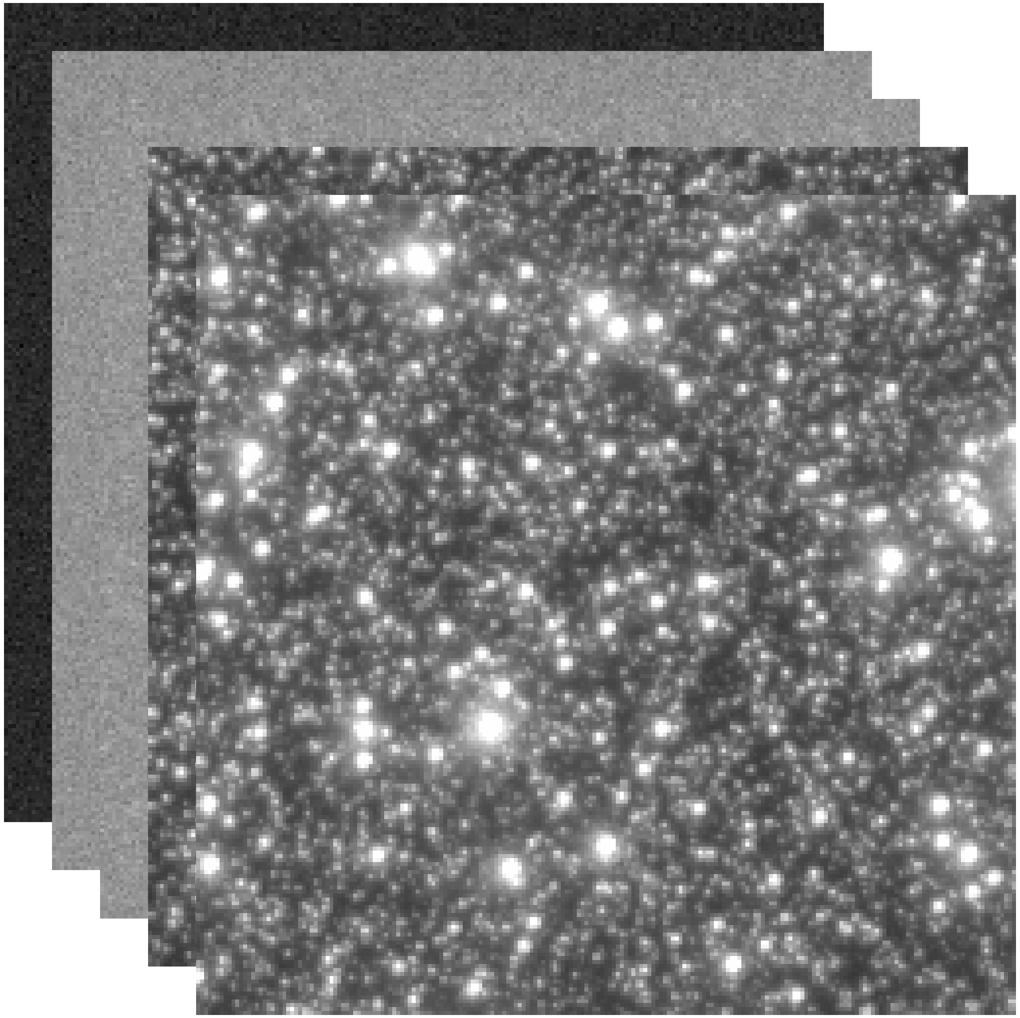
- Bias
- Background
- Faint stars
- Stars
- Bright stars



3. Image simulations

Simulate a CCD

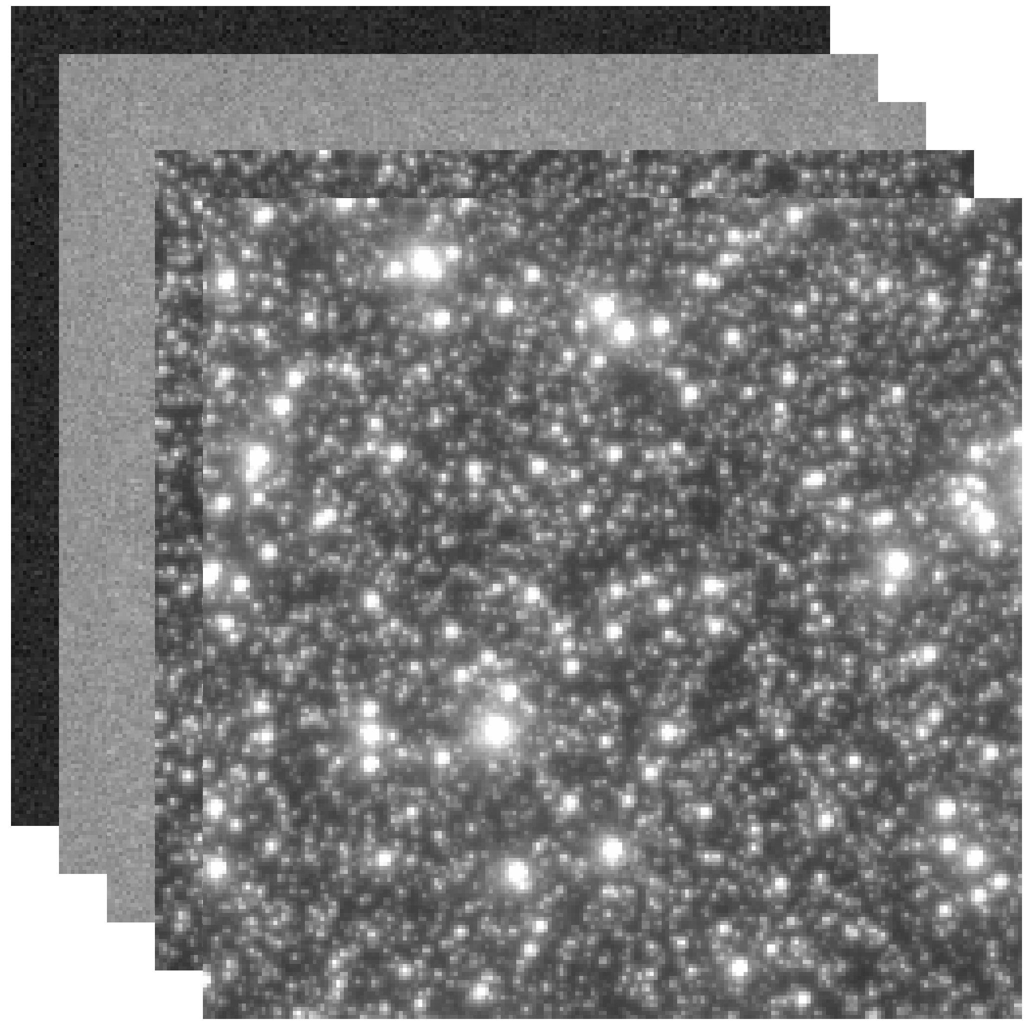
- Bias
- Background
- Faint stars
- Stars
- Bright stars
- A Source



3. Image simulations

Simulate a CCD

- Bias
- Background
- Faint stars
- Stars
- Bright stars
- A Source
- Lensing



3. Image Simulations

Simulated image

Euclid NISP detector

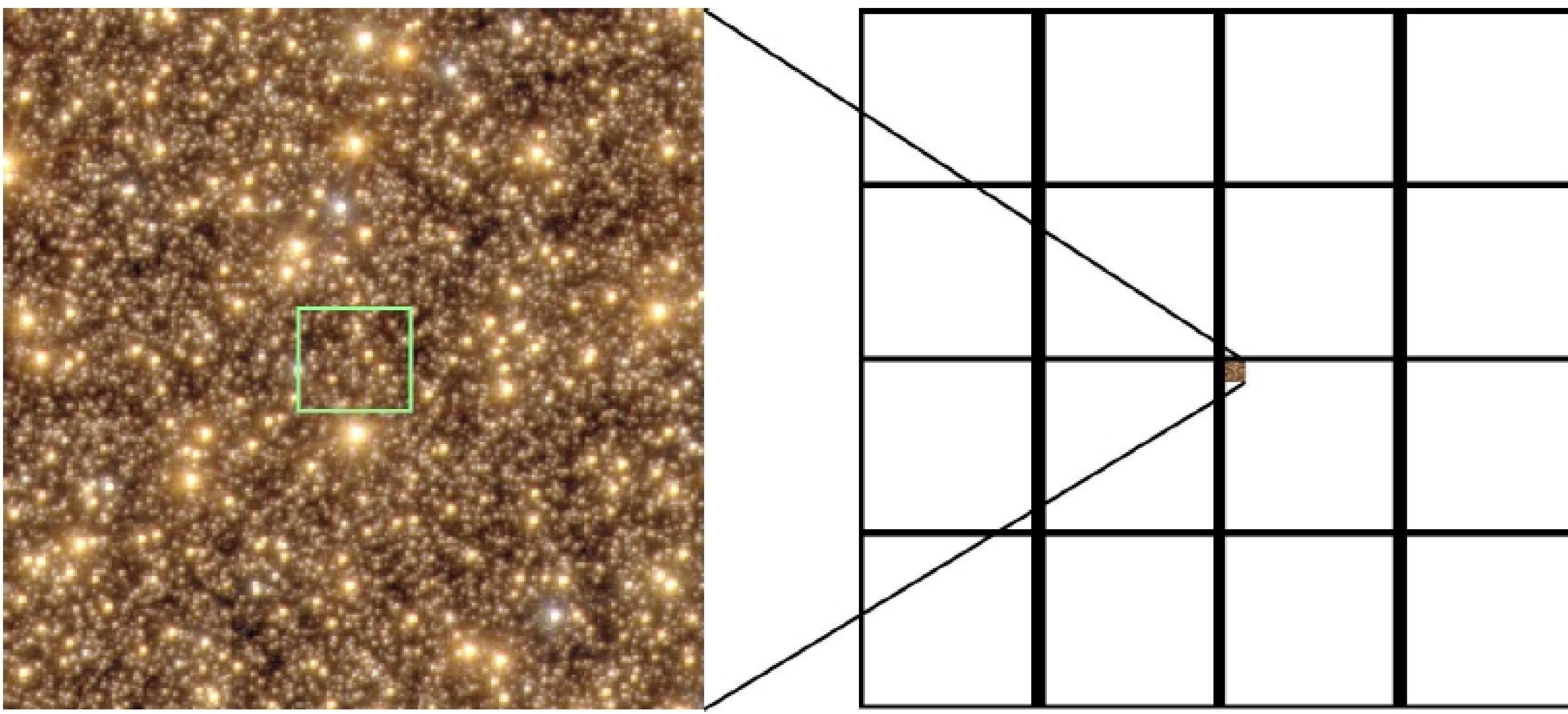
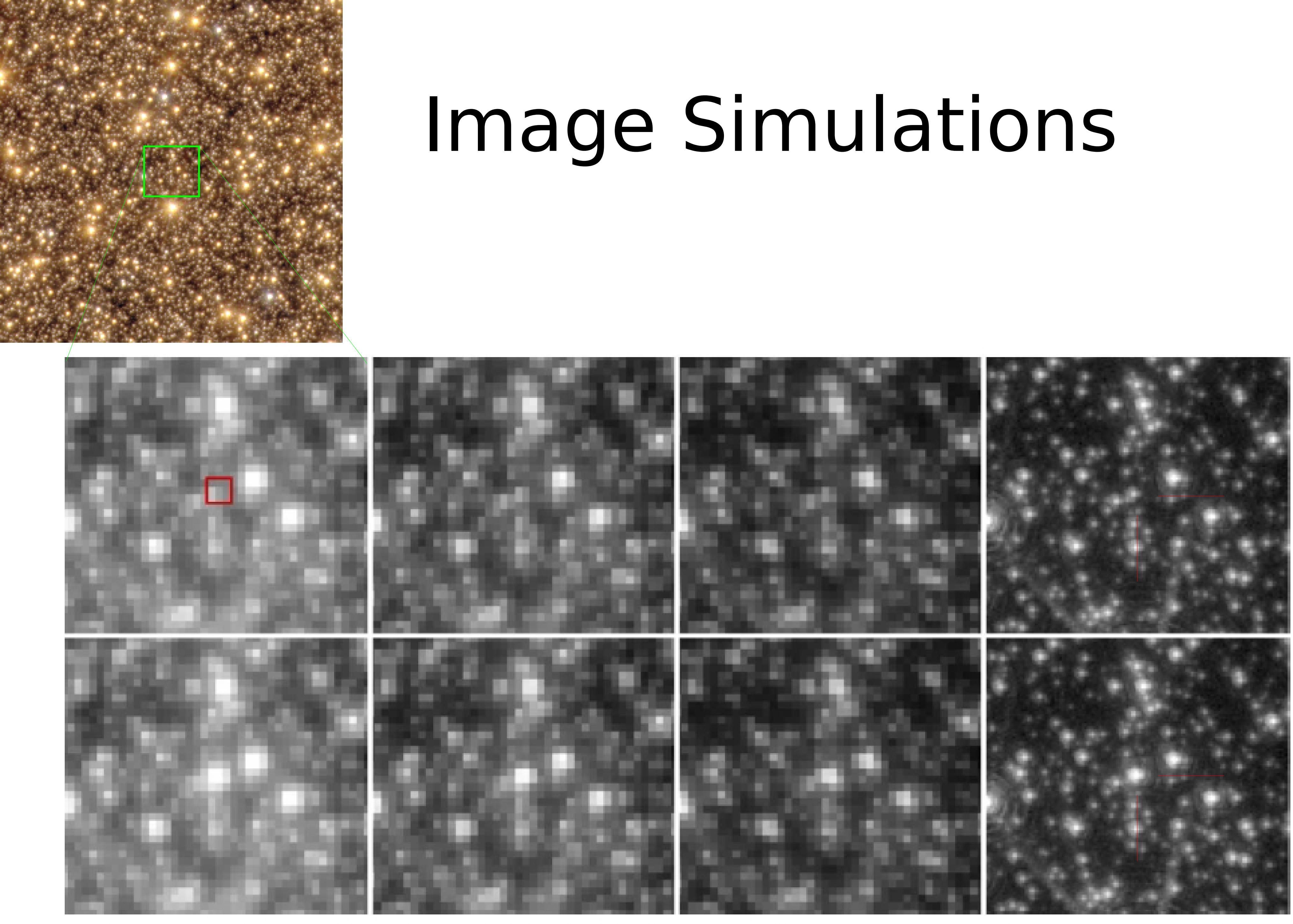


Image Simulations

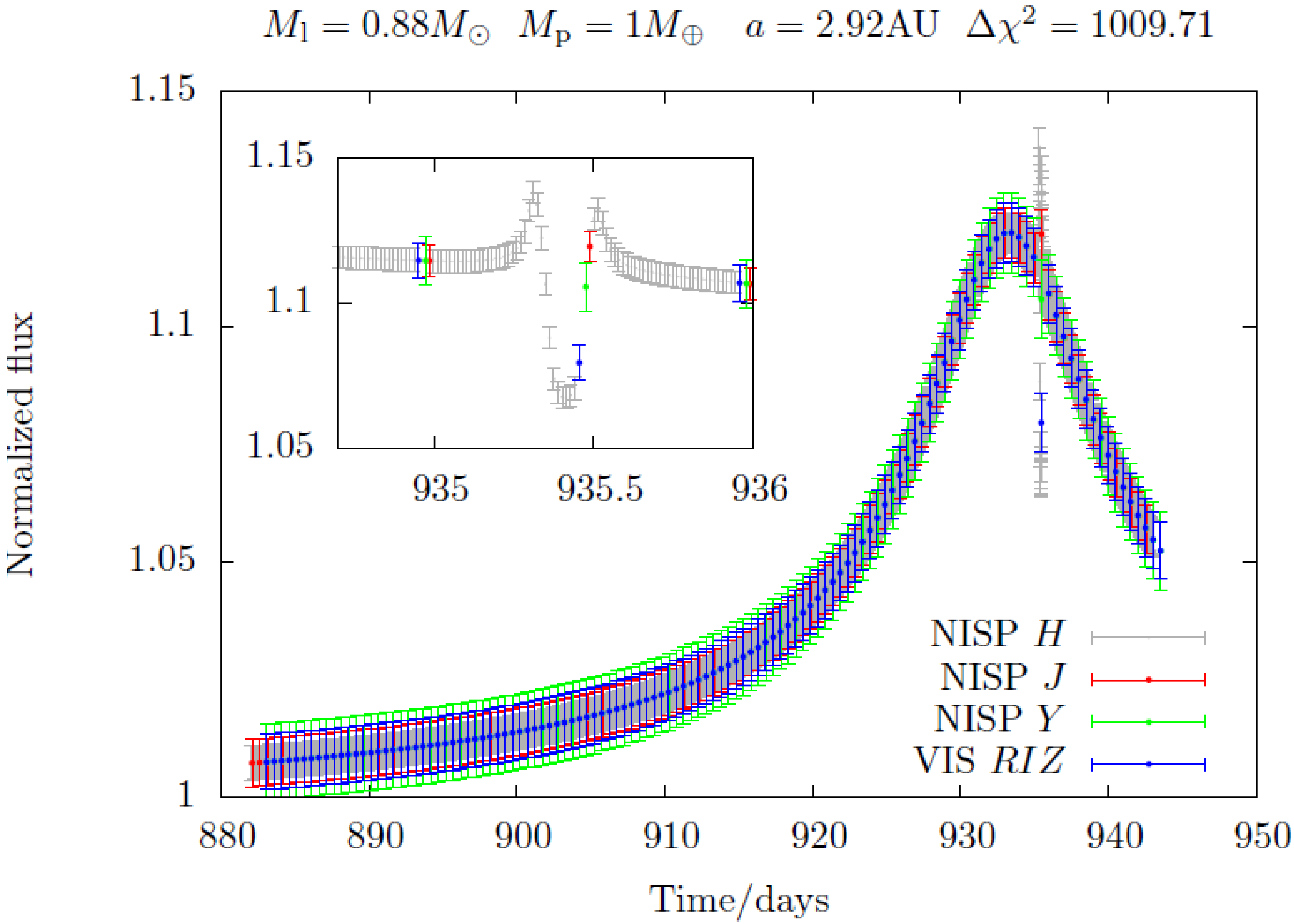


3. Other Features

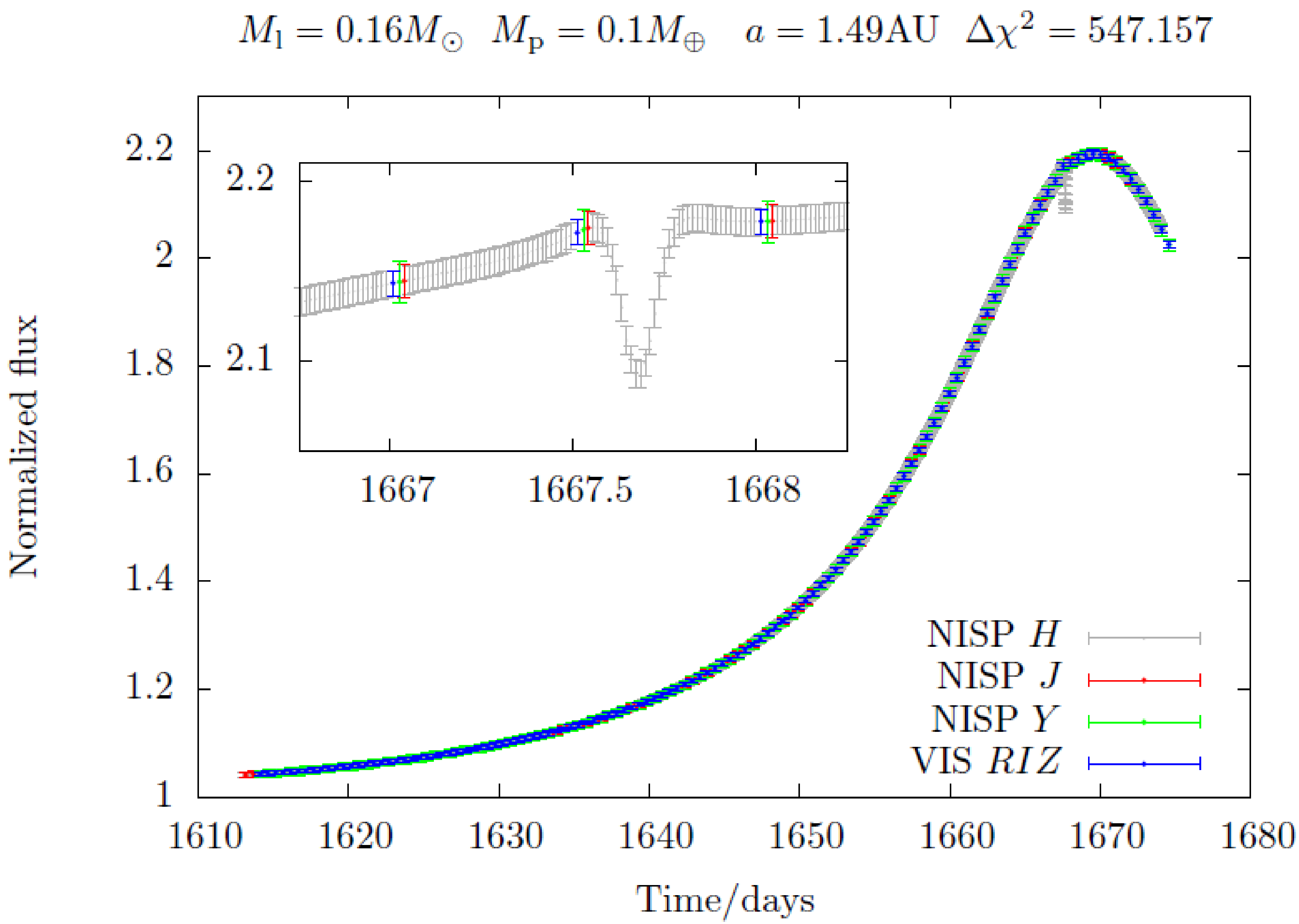
```
#Observing sequence for the H-band survey
#
#NISP Y sequence
#Total sequence length: 12h 5m 20s

#Key:
#Nstack +ve, Texp +ve  (Image being taken by this instrument)
#Nstack -ve, Texp +ve  (Image being taken by other instrument)
#Nstack -ve, Texp -ve  (No image is being taken, but something else is taking
#                        time e.g. a slew or readout)

#Additional time is inserted between images of stacks by exigere for readout
#and dithering.
#The readout time for this can be set in the .observatory observatory files.
#All other readout, slewing, filter changes etc must be specified here.

#Field  Nstack  Texp    Sum     Description

#VIS Set
#Field  Nstack  Texp    Sum     Description

0       -1      -10     10      Shutter open            VIS F0
0       -1      540     550     Expose                  VIS F0
0       -1      -10     560     Shutter close           VIS F0
0       -1      -85     665     Slew + read             VIS F0
1       -1      -10     675     Shutter open            VIS F1
1       -1      540     1215    Expose                  VIS F1
1       -1      -10     1225    Shutter close           VIS F1
1       -1      -85     1310    Slew + read             VIS F1
2       -1      -10     1320    Shutter open            VIS F2
2       -1      540     1860    Expose                  VIS F2
2       -1      -10     1870    Shutter close           VIS F2
2       -1      -85     1955    Slew + read             VIS F2

#NISP Y Set  #5 second intrastack reads
#Field  Nstack  Texp    Sum     Description

0       3       90      2235    Expose                  NISP Y F0
0       -1      -85     2320    Slew + read             NISP Y F0
1       3       90      2600    Expose                  NISP Y F1
1       -1      -85     2685    Slew + read             NISP Y F1
2       3       90      2965    Expose                  NISP Y F2
```

- Fully customizable observing sequences
- Multiple ground- and space-based observatories
- Multiple filters

3. Simulated Lightcurves

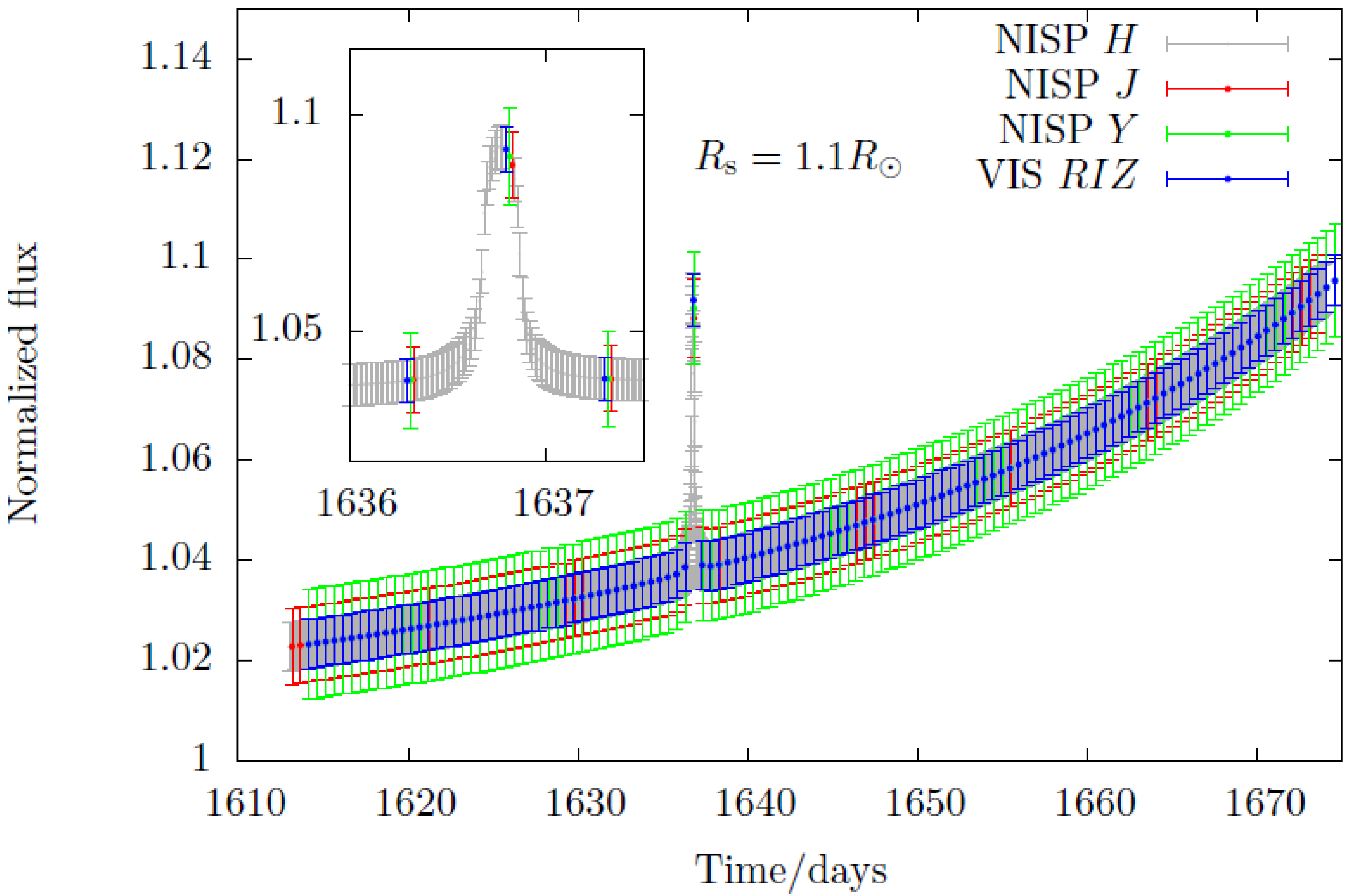


3. Simulated Lightcurves



3. Simulated Lightcurves

$M_l = 0.44 M_\odot \quad M_p = 0.03 M_\oplus \quad a = 9.15\mathrm{AU} \quad \Delta\chi^2 = 1327.25$

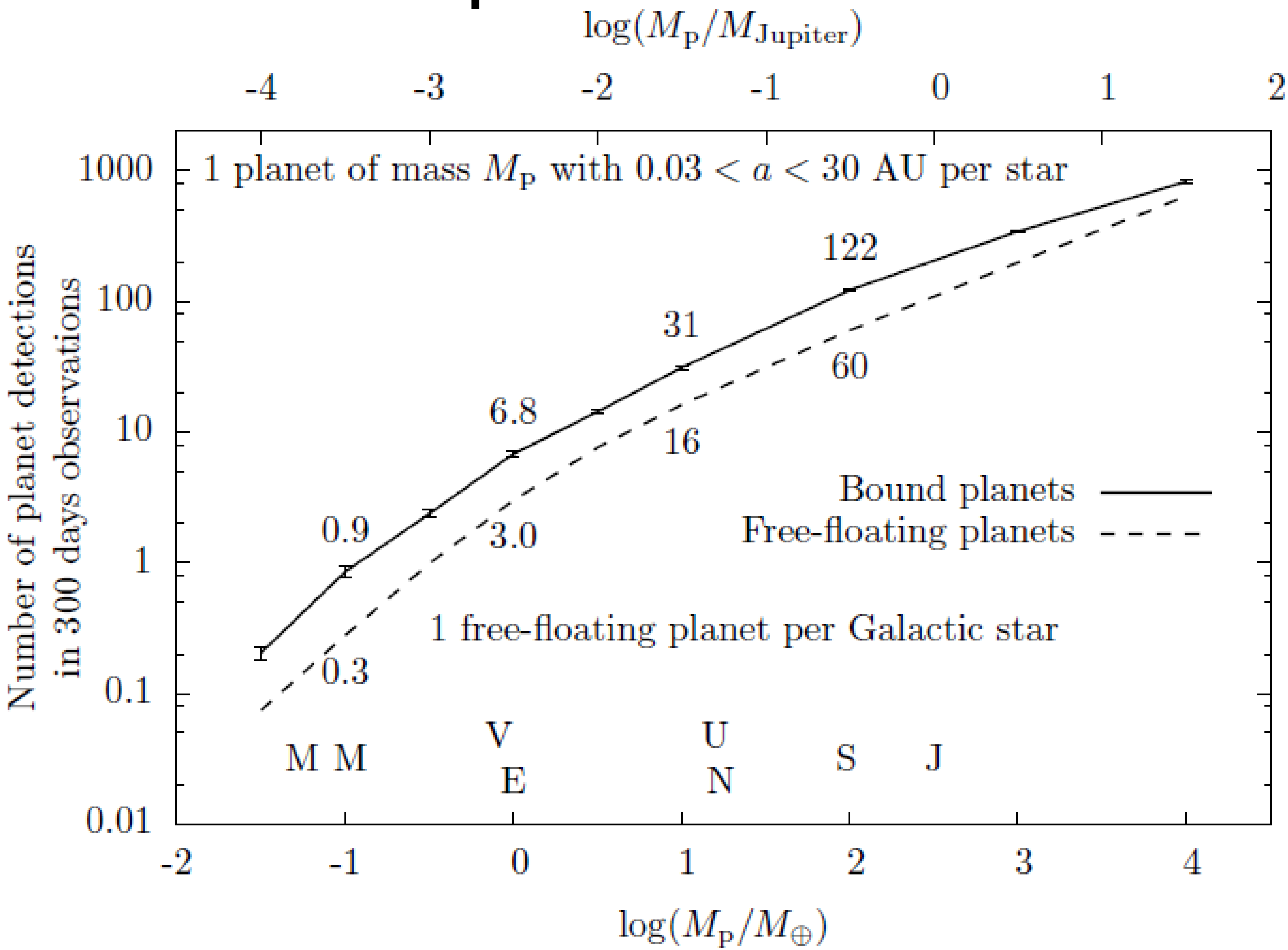


4. Expected Yields

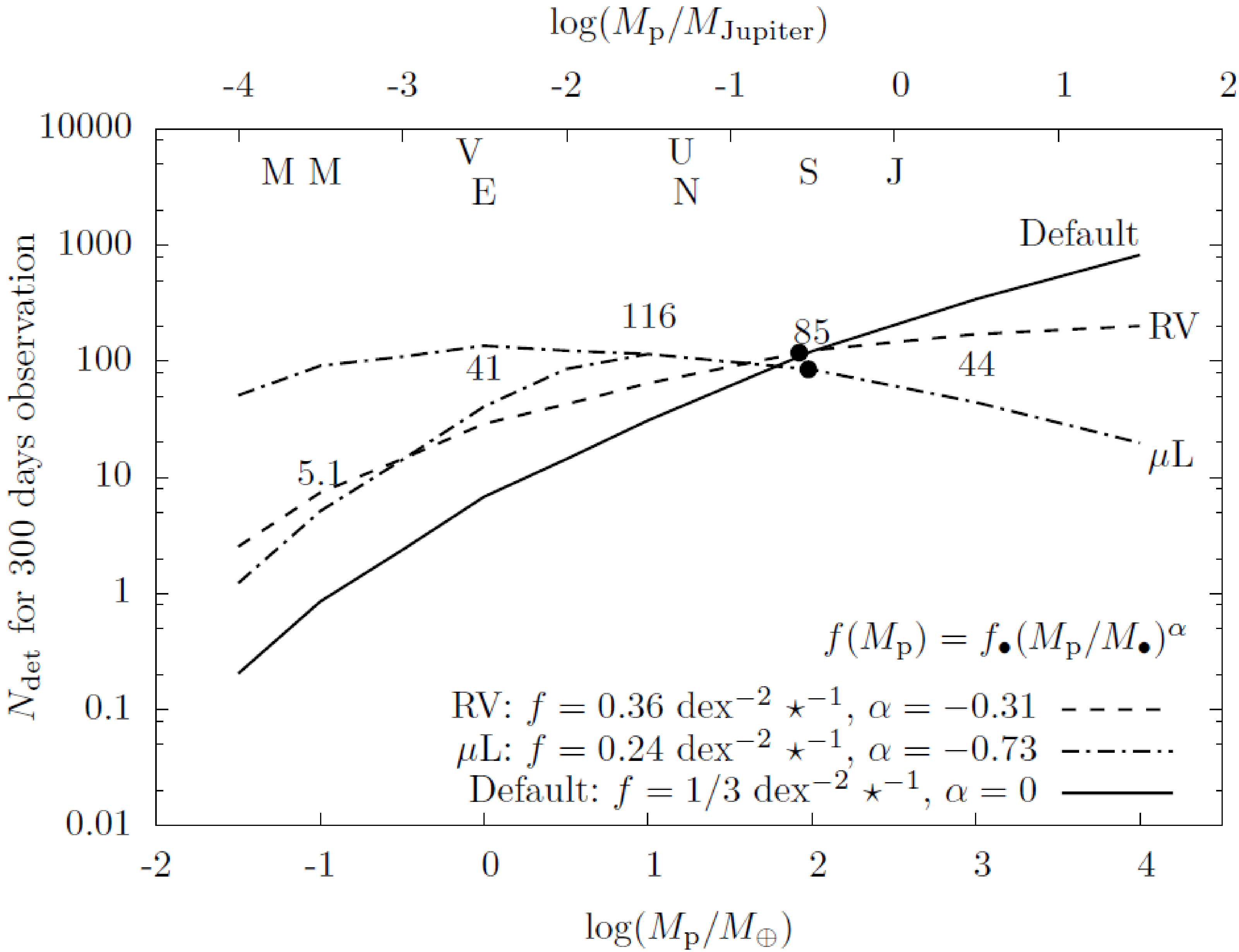
Euclid additional science survey:

- 300 day survey, split into 5 yearly seasons
- 60 days continuous observations each season
- $3x0.5deg^2$ fields, each observed every 18 mins
- Observations in other bands every 12 hours

4. Expected Yields

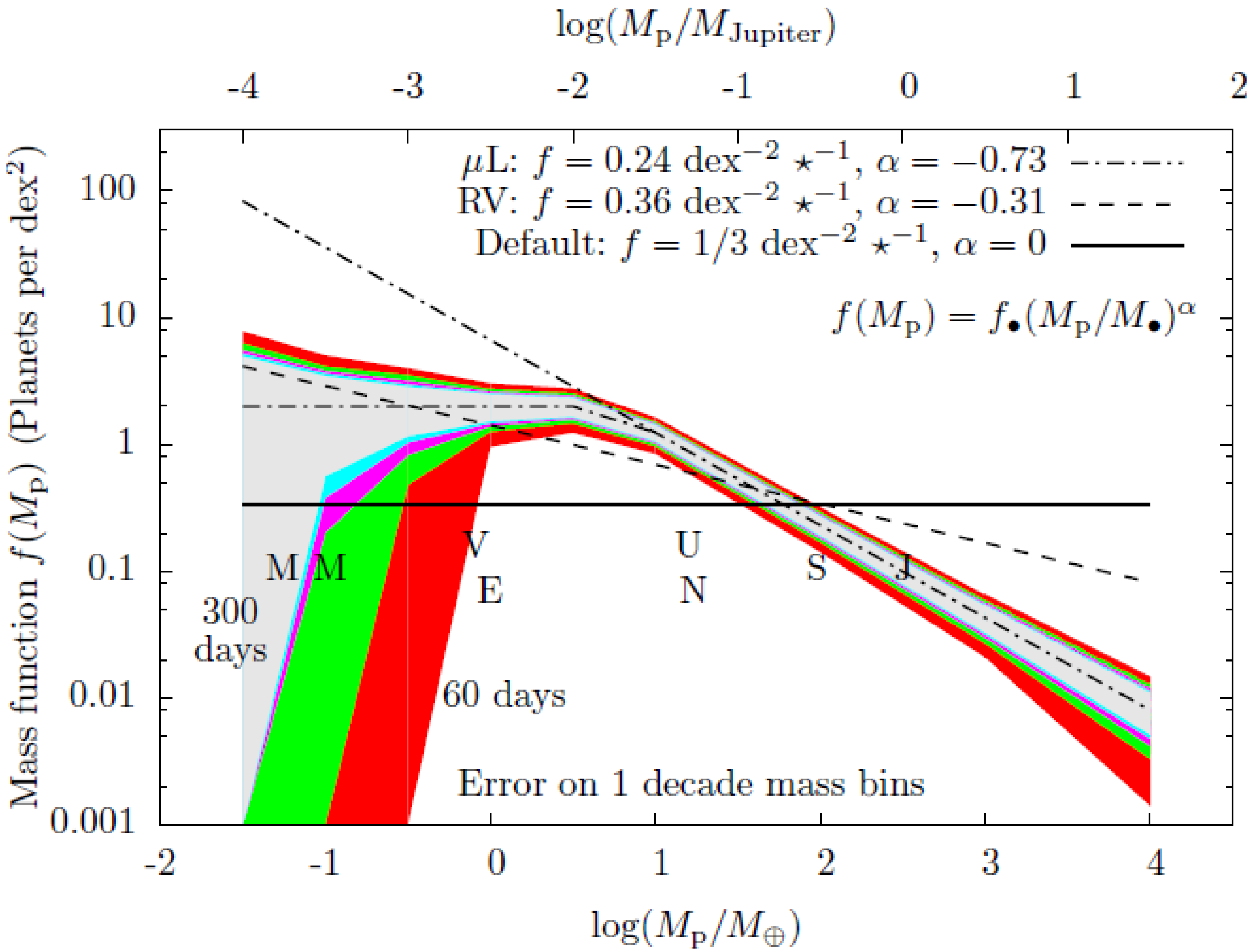


4. Different mass functions



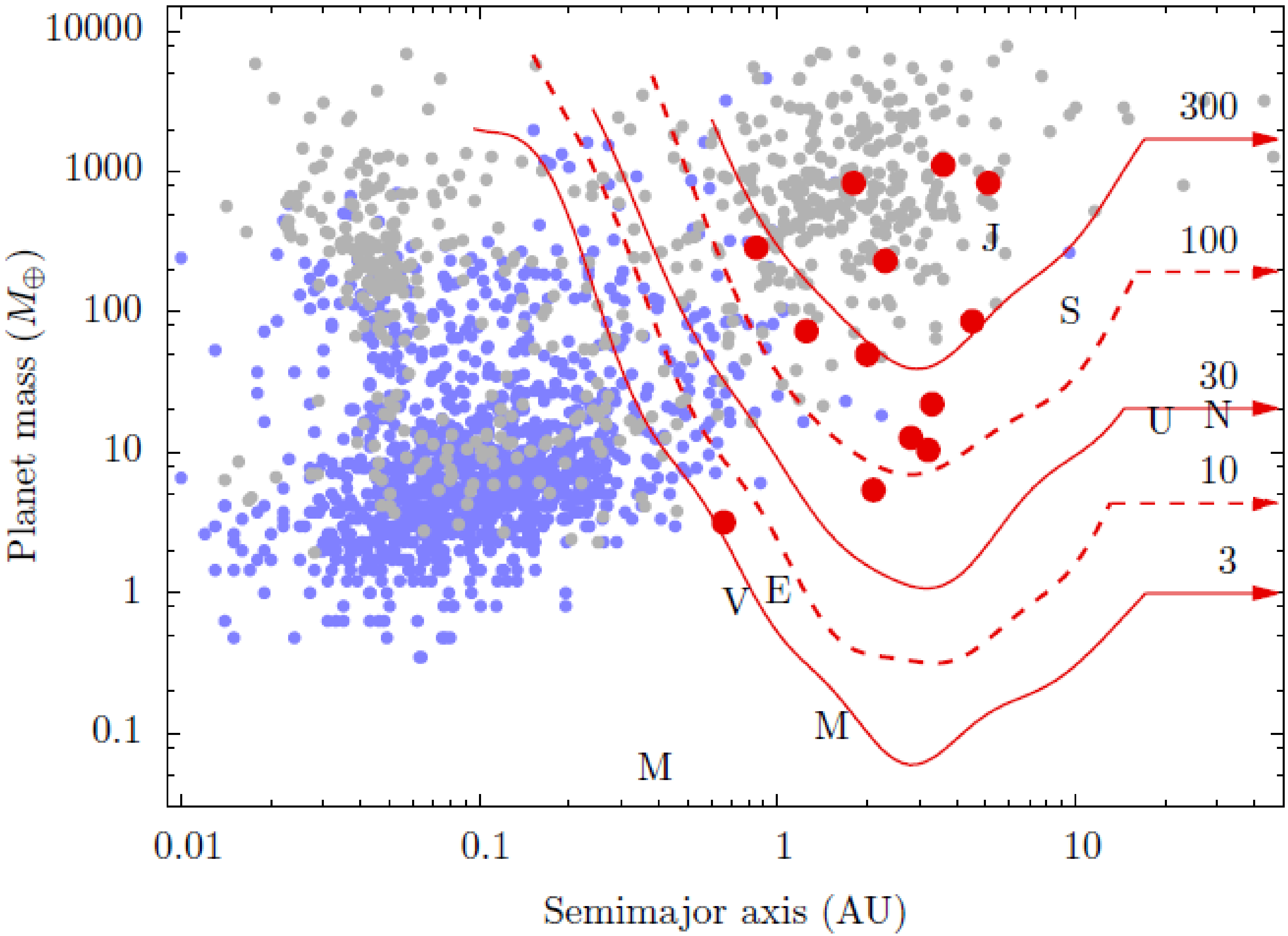
Total detections (-1.5<log(M/Me)<3): Default: 390 RV: 307 uL: 438 uL saturated: 267

4. Different mass functions

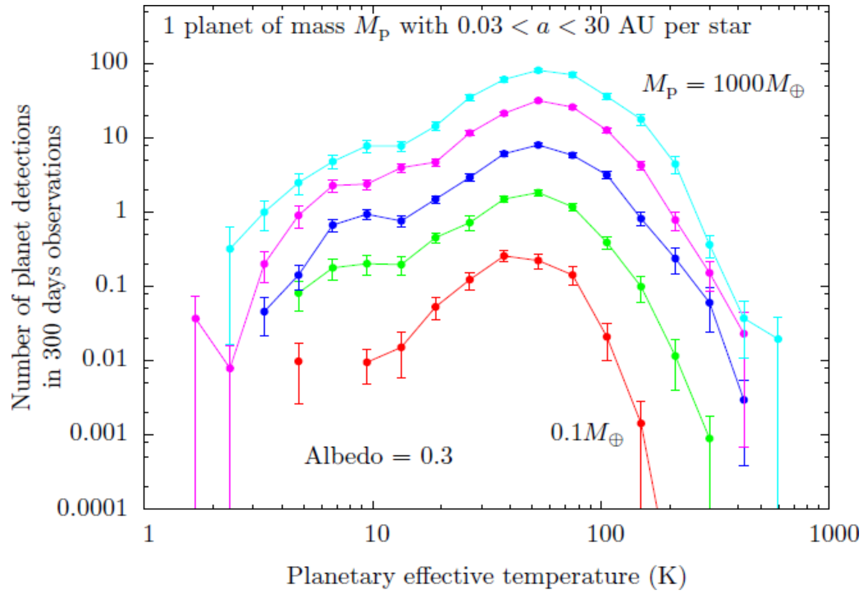


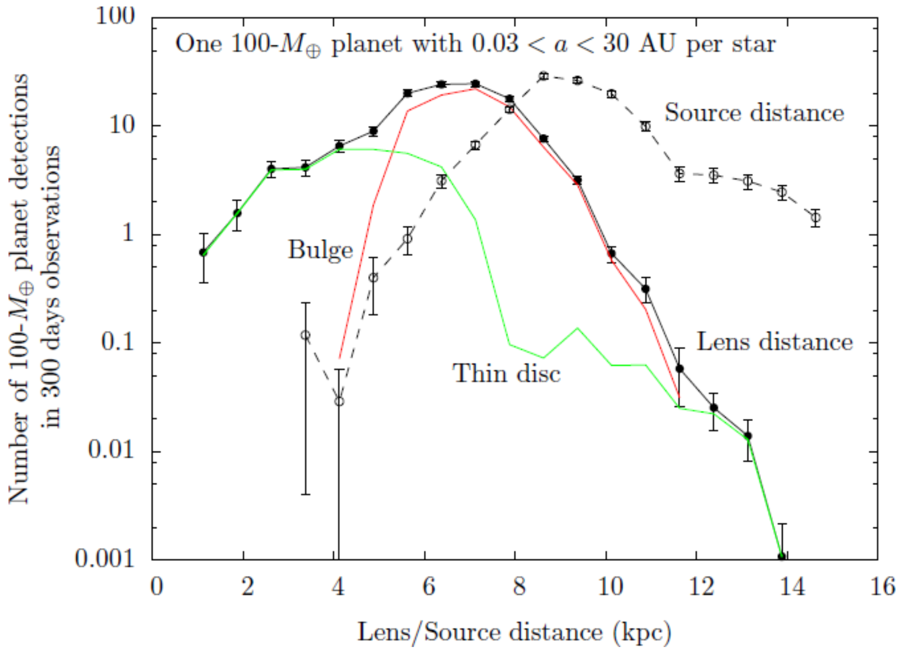
RV: α Cumming et al 2008, f Gould et al 2010. μL: Cassan et al 2012

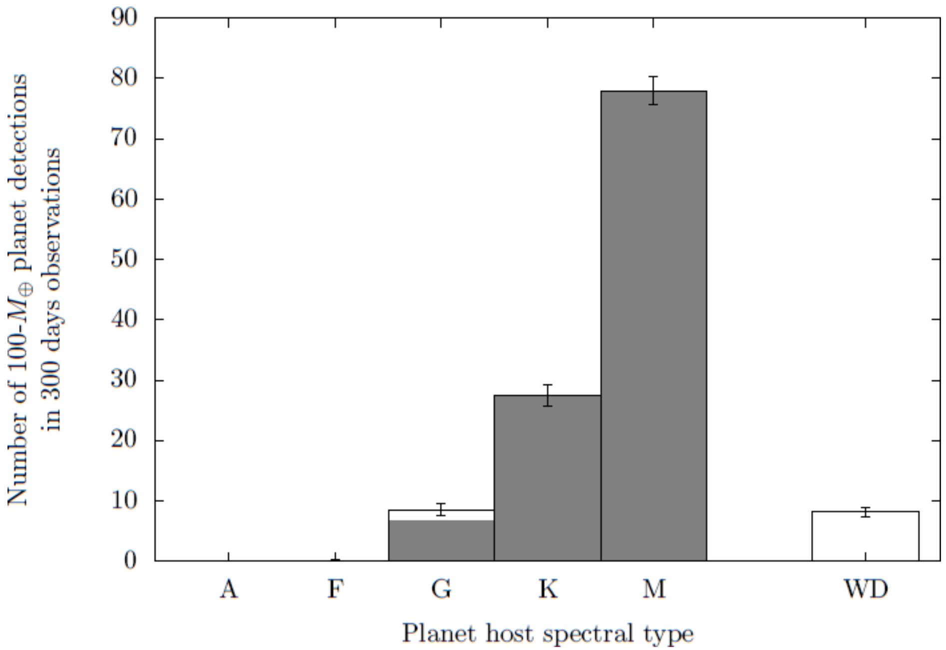
4. M-a sensitivity



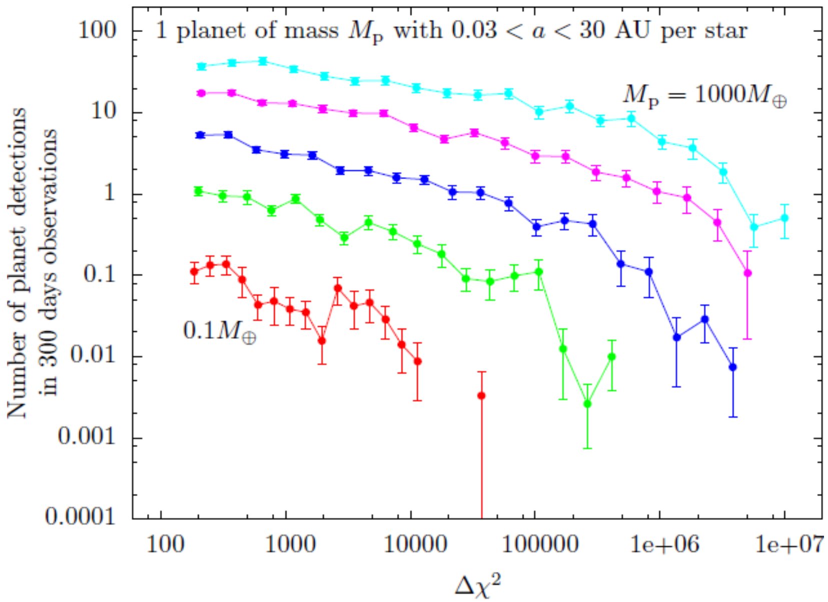
4. What planets will Euclid probe?

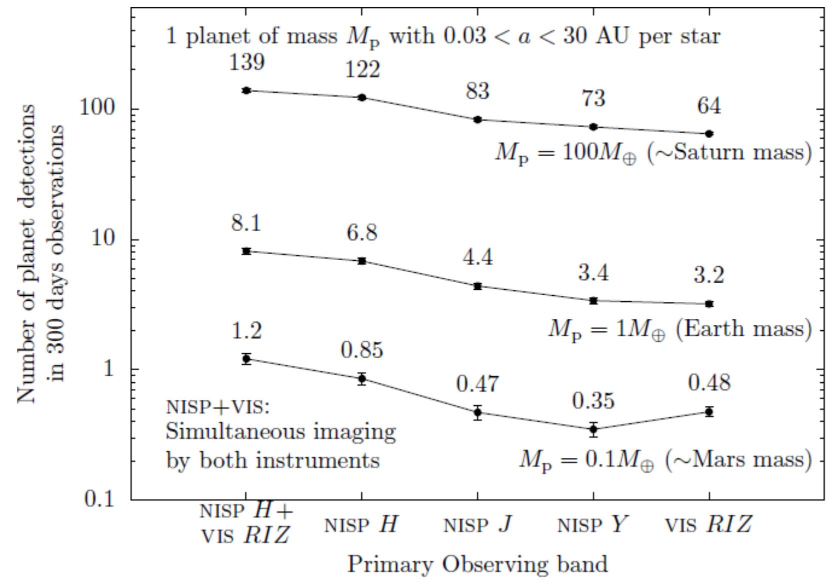


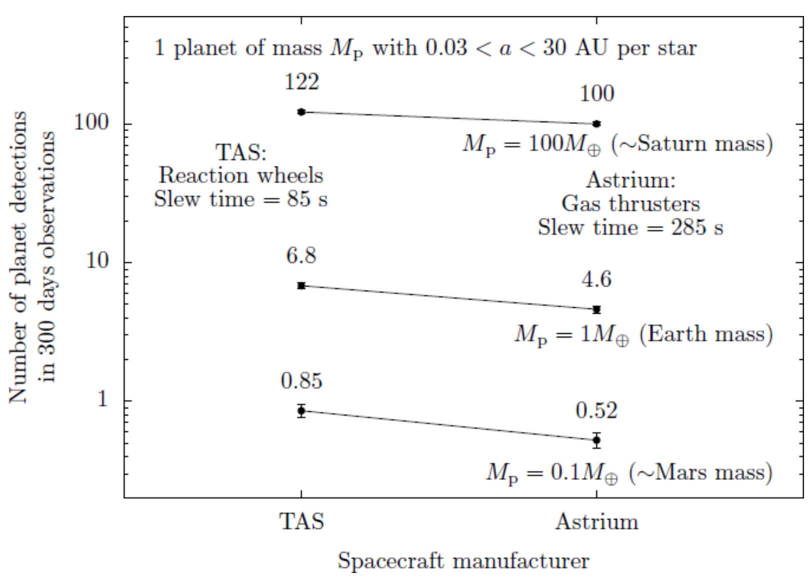


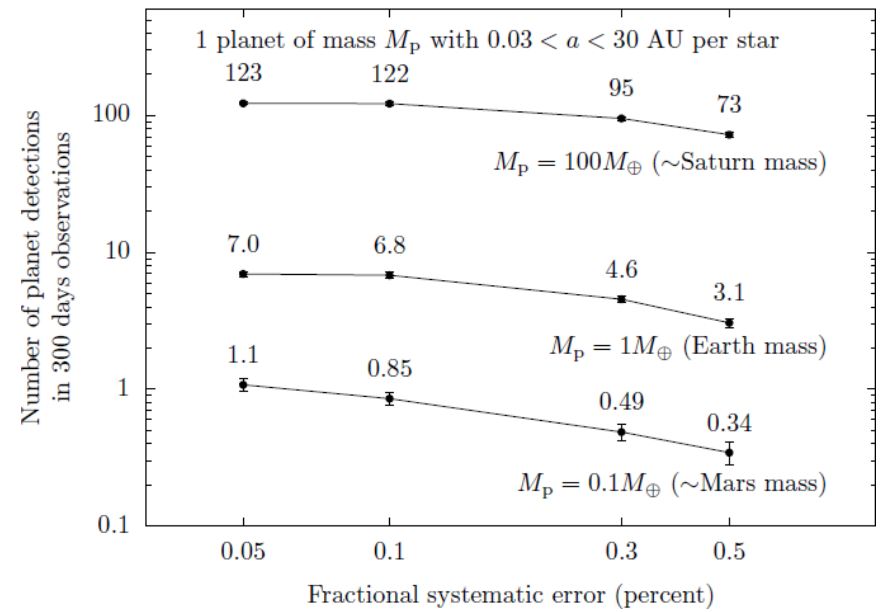


4. Different scenarios









Conclusions

- Euclid can do exellent exoplanet science
- Euclid will detect Earth-mass planets – expect ~4 per month of observations
- Euclid has sensitivity below Mercury-mass – may not have sufficient rate, depends on mass function
- Euclid will complete the census of low-mass exoplanets stared by Kepler

What's next?

- Calculate expected parameter errors + FoM
- Optimize survey for planetary mass measurements, not detections
- Use MaBμLS to fully optimize a Euclid microlensing survey
- Apply MaBμLS to WFIRST and ground-based surveys (OGLE-IV, VVV, KMTNet)