EUCLID :

Dark Energy Probe
&
microlensing planet hunter

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Microlensing roadmap.
Where are we now ?
Where are we heading to ?

Beaulieu et al. 2008, ESA EPRAT White paper

The near-term: automated follow-up

1-5 yr

Milestones:

A. An optimised planetary microlens follow-up network operation.

B. The first census of the cold planet population, involving planets of Neptune to super-Earth (few $M_{\oplus}$ to 20 $M_{\oplus}$) with host star separations around 2 AU.

C. Under highly favourable conditions, sensitivity to planets close to Earth mass with host separations around 2 AU.

Running existing facilities with existing operations

The medium-term: wide-field telescope networks

5-10 yr

Milestones:

A. **Complete census of the cold planet population down to ~10 $M_{\square}$ with host separations above 1.5 AU.**

B. **The first census of the free-floating planet population.**

C. **Sensitivity to planets close to Earth mass with host separations around 2 AU.**

Several existing nodes already (MOA II and OGLE IV).
Korean Microlensing NETwork (PI Han, funded)

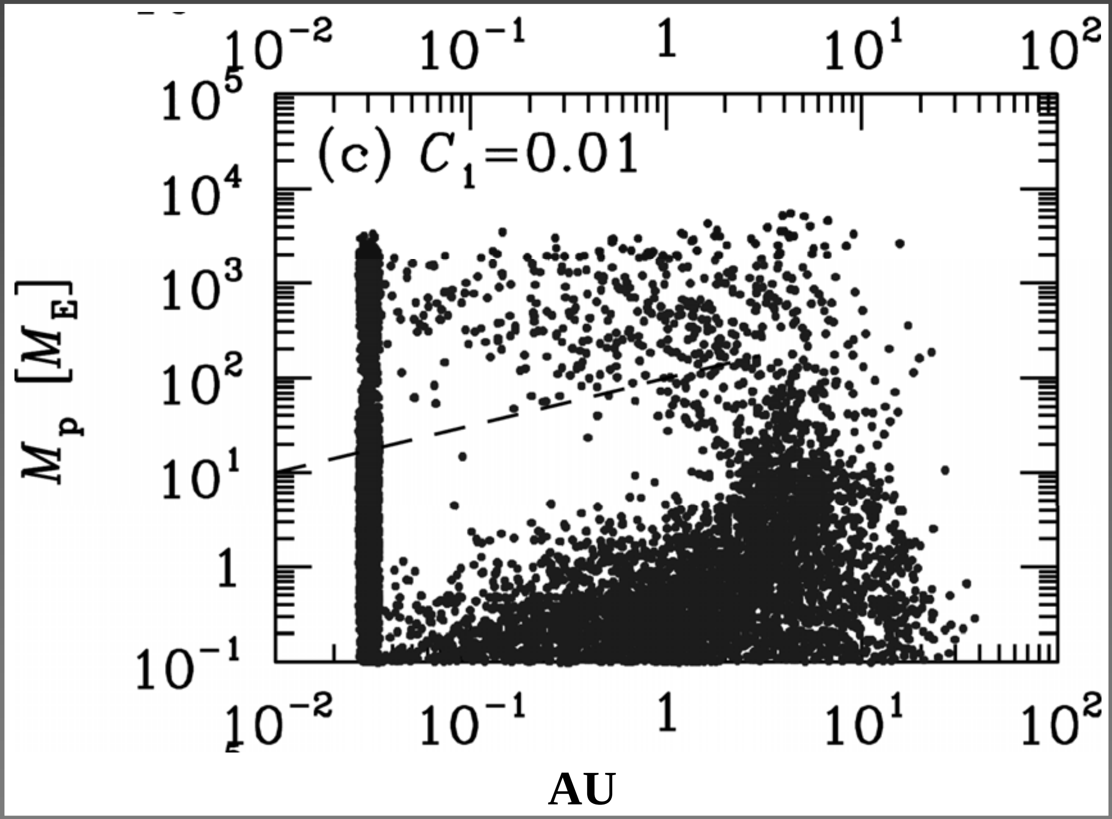
The longer-term: a space-based microlensing survey 10+ yr

Milestones:

A. **A complete census of planets down to Earth mass with separations exceeding 1 AU**
B. **Complementary coverage to Kepler of the planet discovery space.**
C. **Potential sensitivity to planets down to 0.1 $M_{\oplus}$, including all Solar System analogues except for Mercury.**
D. **Complete lens solutions for most planet events, allowing direct measurements of the planet and host masses, projected separation and distance from the observer.**

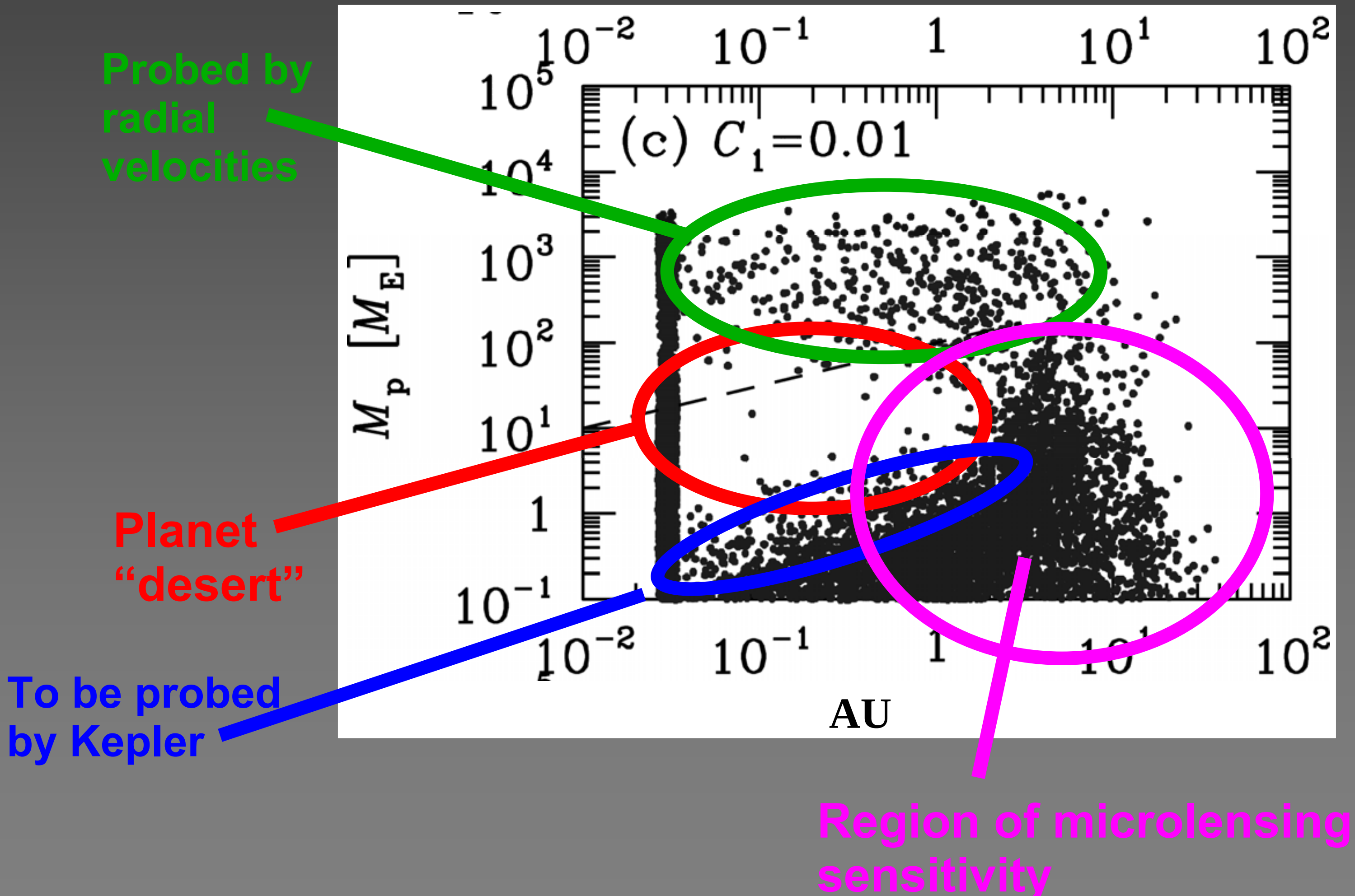
Dedicated ~400 M$, or participation to Dark energy probes
Excellent synergy Dark Energy/Microlensing

The core-accretion model



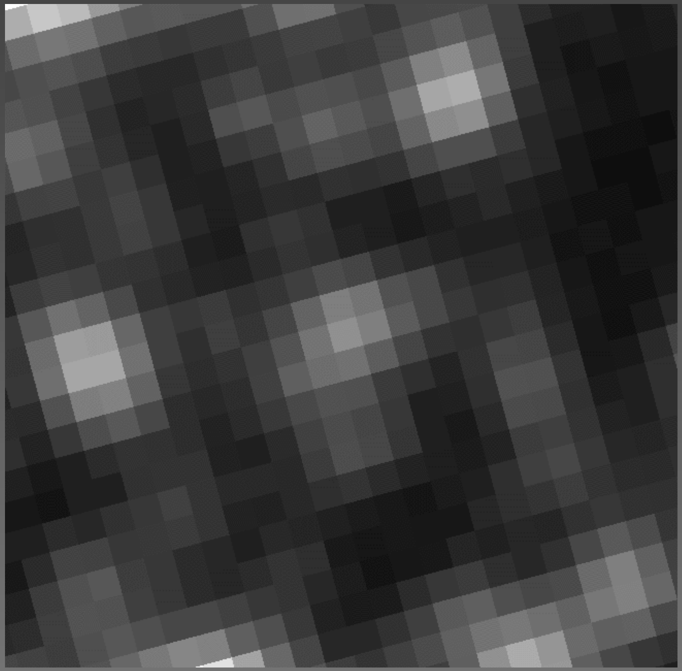
Simulation by
Ida & Lin (2008)

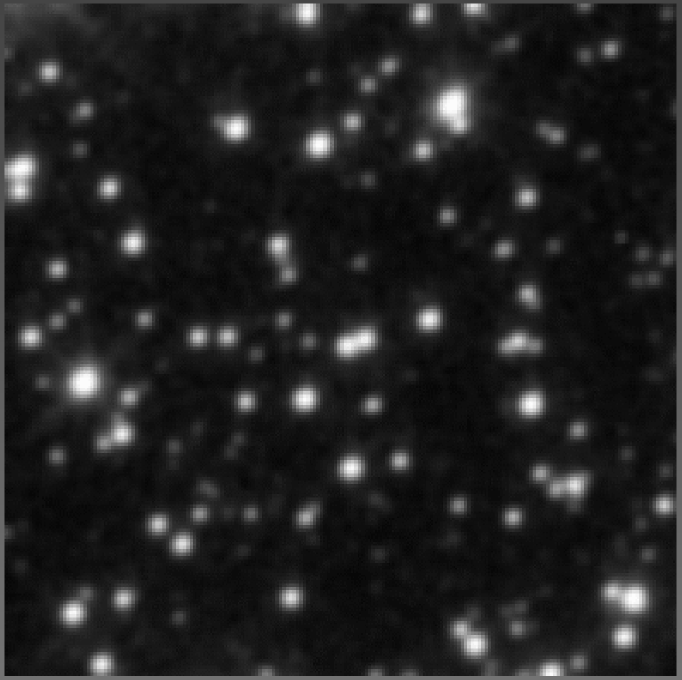
The core-accretion model



MICROLENSING FROM SPACE ?

Ground-based confusion, space-based resolution





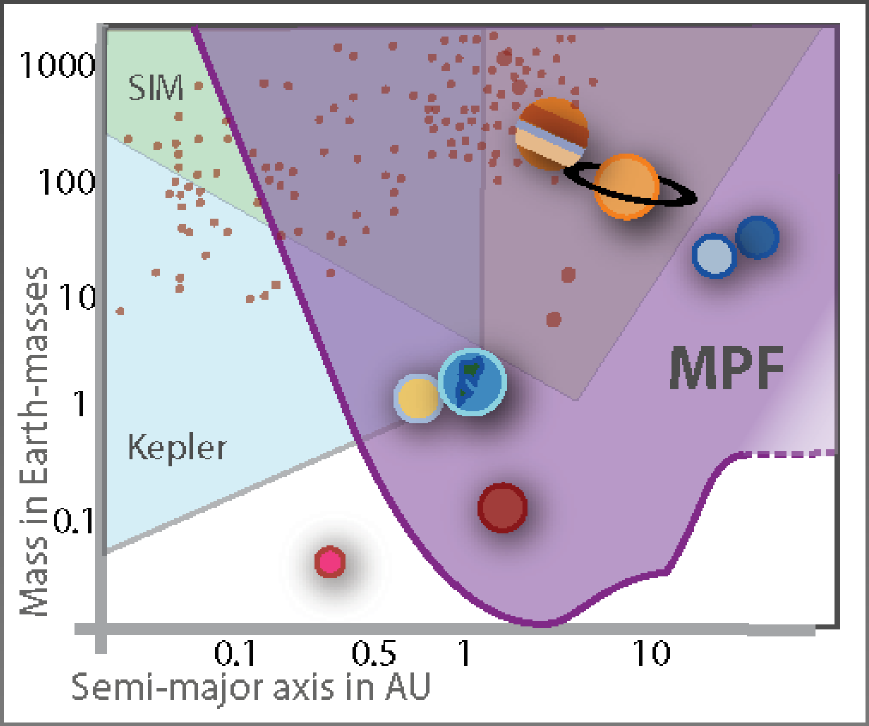
- Main Sequence stars are not resolved from the ground
- Systematic photometry errors for unresolved main sequence stars cannot be overcome with deeper exposures (i.e. a large ground-based telescope).
- High Resolution + large field + 24hr duty cycle

MPF Science Team

PI: D. Bennett (Notre Dame)

Science Team:

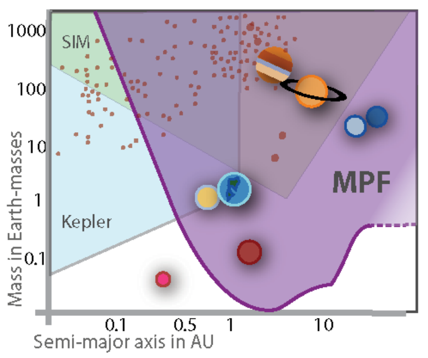
J. Anderson (Rice), J.-P. Beaulieu (IAP), I. Bond (Massey), M. Brown (Caltech), E. Cheng (CcA), K. Cook (LLNL), S. Friedman (STScI), P. Garnavich (Notre Dame), S. Gaudi (CfA), R. Gilliland (STScI), A. Gould (Ohio State), K. Griest (UCSD), J. Jenkins (Seti Inst.), R. Kimble (GSFC), D. Lin (UCSC), J. Lunine (Arizona), J. Mather (GSFC), D. Minniti (Catolica), B. Paczynski (Princeton), S. Peale (UCSB), B. Rauscher (GSFC), M. Rich (UCLA), K. Sahu (STScI), M. Shao (JPL), J. Schneider (Paris Obs.), A. Udalski (Warsaw), N. Woolf (Arizona) and P. Yock (Auckland)



(All MPF related slides have been adapted from Bennett's talks over the last years)

MPF Science Objectives

1. Determine the frequency of planets with masses ≥ 0.1 Earth-mass at separations ≥ 0.5 AU.
2. Determine the frequency of planets like those in our own Solar System.
3. Measure star-planet separations, planet masses, and host star brightness and colors for most detected.
4. Measure the planet frequency as a function of Galactic position.
5. Discover free-floating planets, not gravitationally bound to any star.
6. Examine Solar System objects beyond the Kuiper Belt, like Sedna.



MPF Technical Summary

- **1.1 m TMA telescope, ~ 1.5 deg FoV**, at room temperature, based on existing ITT designs and test hardware
- **35 2Kx2K HgCdTe detector** chips at 140 K, based on JWST and HST/WFC3 technology
- **0.24 arcsec pixels**, and focal plane guiding
- 5 × 34 sec exposures per pointing
- SIDECAR ASICs run detectors, based on JWST work
- No shutter
- **3 filters: "clear" 600-1700nm, "visible" 600-900nm, "IR" 1300-1700nm**
- 1% photometry required at J=20
- 28.5° inclined geosynchronous orbit
- Continuous viewing of Galactic bulge target (except when Sun passes across it)
- Cycling over 4 × 0.65 sq. deg. fields in 15 minute cycle
- Continuous data link, Ka band, 20 Mbits/sec

MPF's Planetary Results

- Planets detected rapidly - even in ~20 year orbits
- average number of planets per star down to $M_{mars} = 0.1M_{\oplus}$
  - Separation, a, is known to a factor of 2.
- planetary mass function, $f(\varepsilon = M_{planet}, M_*, a)$
- for $0.2M_{sun} \leq M_* \leq 1\ M_{sun}$
  - planetary frequency as a function of M_* and Galactocentric distance
  - planetary frequency as a function of separation (known to ~10%)
- If every lens star has a planetary system with the same star:planet mass ratios and separations as our Solar System, then MPF will find:
  - 97 Earth, Venus, or Mars analogs
  - 5700 Jupiter or Saturn analogs
  - 126 Uranus or Neptune analogs
- frequency of free-floating planets down to M_{mars}
- the ratio of free-floating planets to bound planets.
- frequency of planet pairs
  - high fraction of pairs => near circular orbits
- ~50,000 giant planet transits

But nobody cares about habitable Earth mass planet, the real cool stuff is

DARK ENERGY

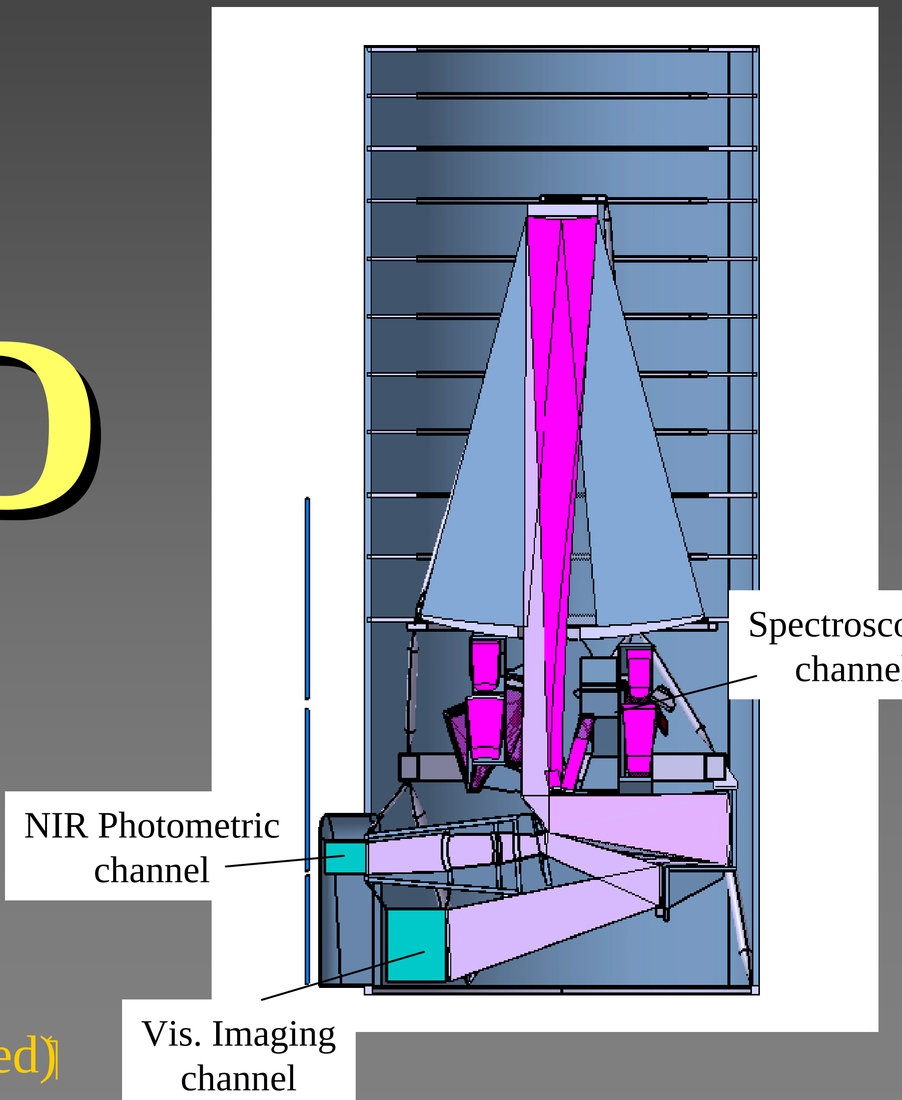
- Measure DE Equation of state w(z) with
  - ~1% on w0 and ~10% on wa ($w(z)=w_0+w_a*z/(1+z)$)
- Distribution of dark matter
- Inflationary parameters (amplitude/slope)
- Test of General Relativity
- Evolution of galaxies
- Clusters physics

DUNE + SPACE

EUCLID

- L2 orbit
- 4-5 year mission
- Telescope 1.2m primary
- 3 instruments
- Data rate Max 700Gbits/day

(compressed)



EUCLID CONSORTIUM

- *Imaging (VIS+NIP)*
- **PI: A. Refregier (CEA)**
- **France**
- **UK**
- **Germany**
- **Switzerland**
- **Italy**
- **Spain**
- **USA**

Spectroscopy (NIS)

- **PI: A. Cimatti (Bologna)**
- **Italy**
- **Austria**
- **France**
- **Germany**
- **Netherlands**
- **Romania**
- **Spain**
- **Switzerland**
- **UK & USA**

- **Wide Survey:** entire extra-galactic sky (20 000 deg2)
- - Imaging for Weak lensing:
  - *Visible*: Galaxy shape measurements in R+I+Z<24.5 (AB), >40 resolved galaxies/amin2, median resdshift of 0.9
  - *NIR photometry*: Y,J,H<24 (AB), σz~0.03(1+z) with ground based complement
- - Spectroscopy for BAO:
  - Redshifts for 33% of all galaxies with H(AB)<22 mag, σz<0.001

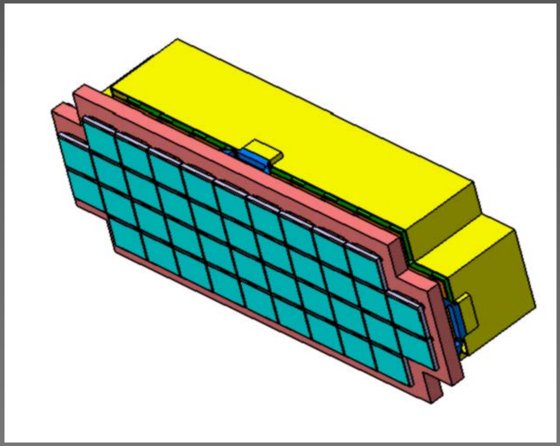
- **Deep Survey:** ~100 deg^2
- visible/IR imaging to H(AB)=26 mag, spectroscopy to H(AB)=24 mag

- **Galactic survey:**
- Microlensing planet hunt
- Ful survey of galactic plane

1 VISIBLE IMAGING CHANEL

Galaxy shapes

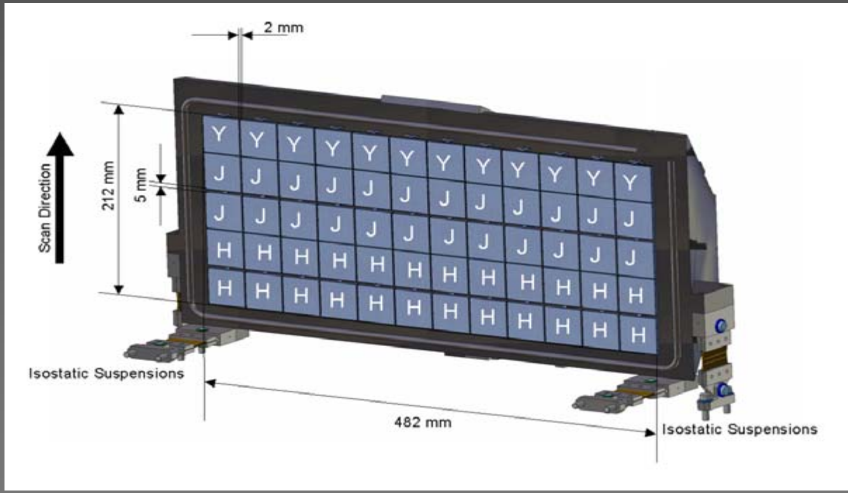
- **36 CCD detectors**
  - AOCS (4 ccd)
  - 0.5 deg2
  - 0.10’’ pixels, 0.23’’ PSF FWHM
  - 4096 red pixels / CCD
- **150K**
- **broad band R+I+Z (0.55-0.92µm)**



2 NEAR IR PHOTOMETRIC CHANEL

Photo-z's

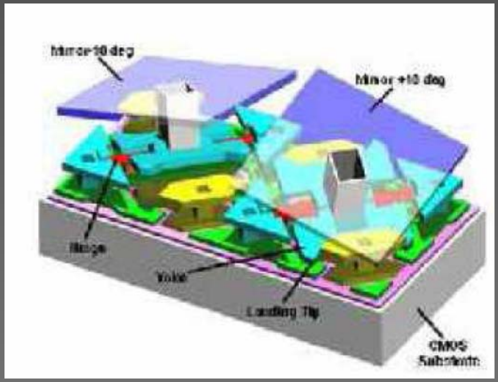
-
- **HgCdTe detectors**
- **16 arrays**
  - 0.5 deg2
  - 0.3'' pixels ~ PSF
  - 2048x2048 pix / array
- **120K**
- **3 bands Y,J,H (1.0-1.7µm)**

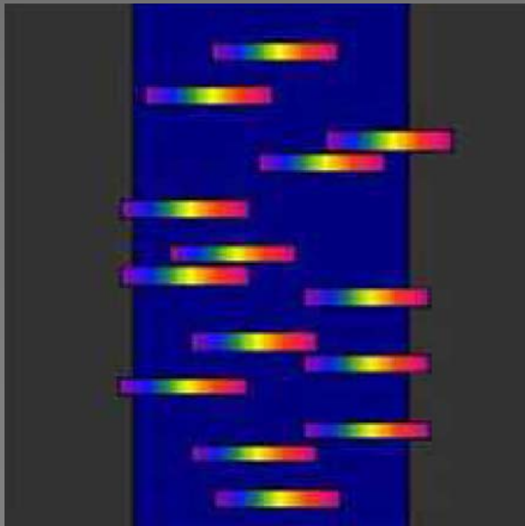


3 NIR Spectro channel

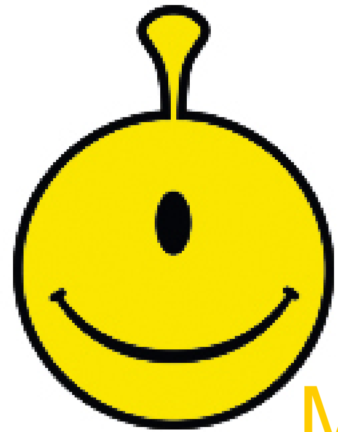
redshifts of 1/3 of galaxies

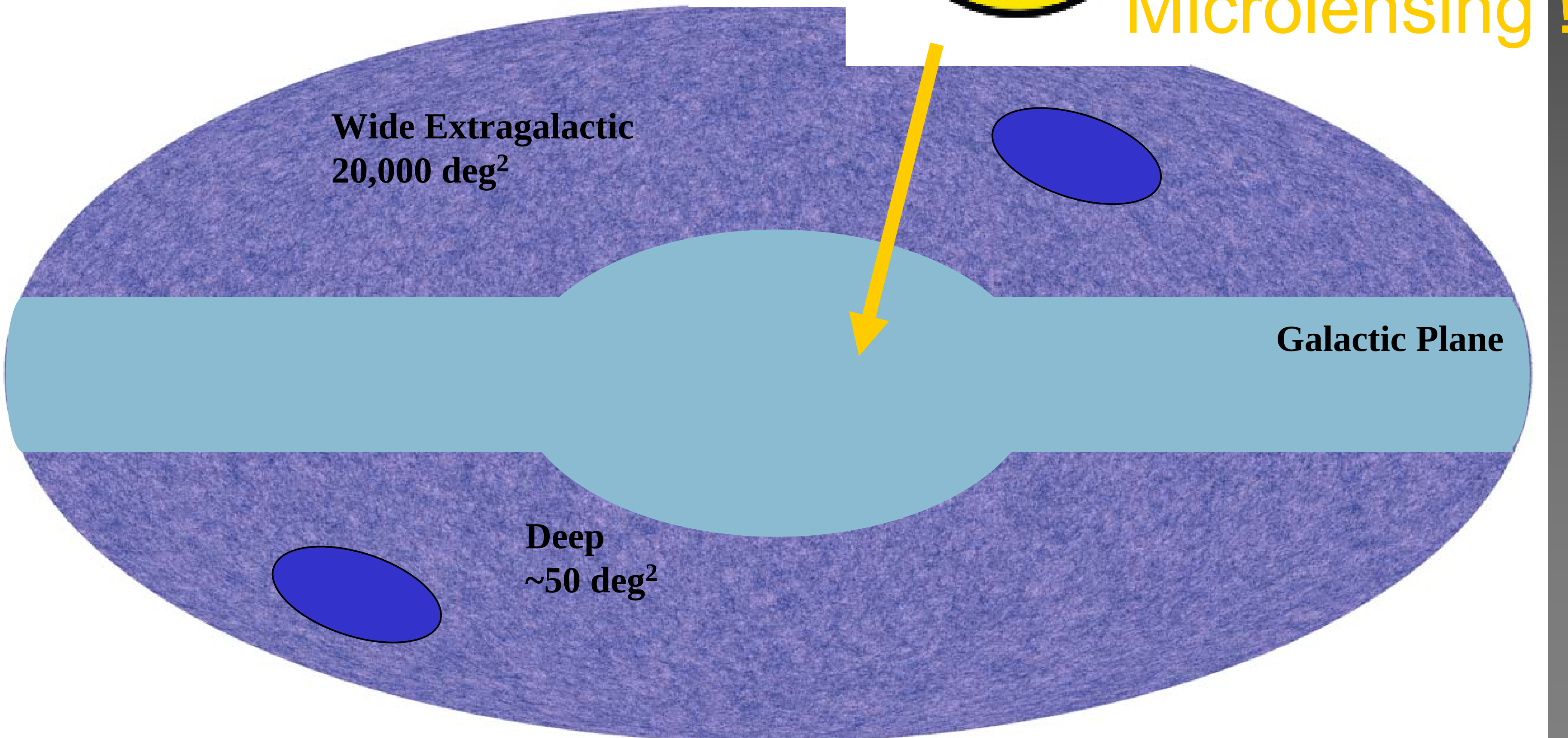
- **Digital Micro-mirror Devices (DMD) based multi-object slit**
- **[backup: slitless]**
- **0.5 deg^2**
- **R=400**
- **120K**
- **0.9-1.7µm**





EUCLID

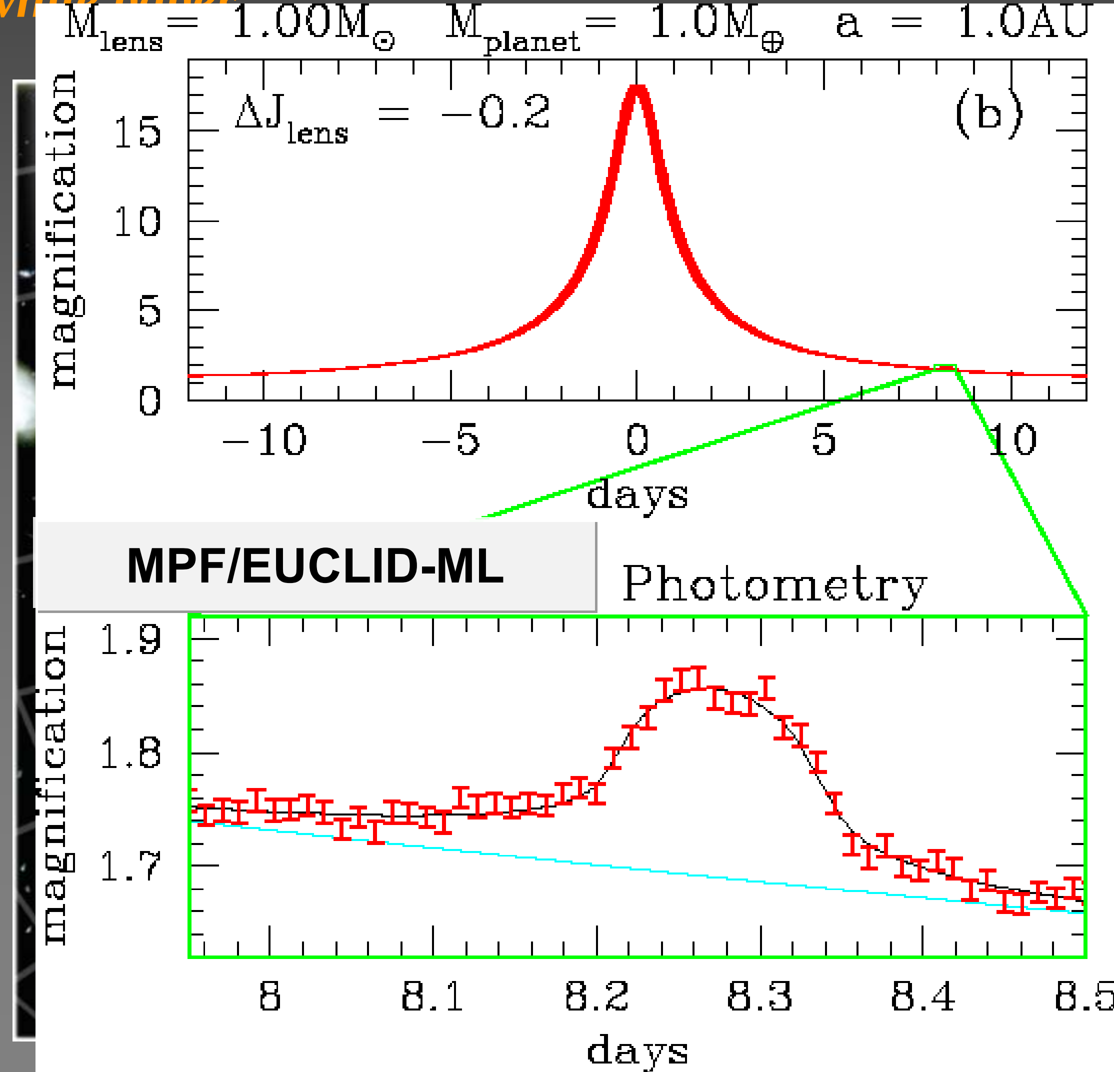


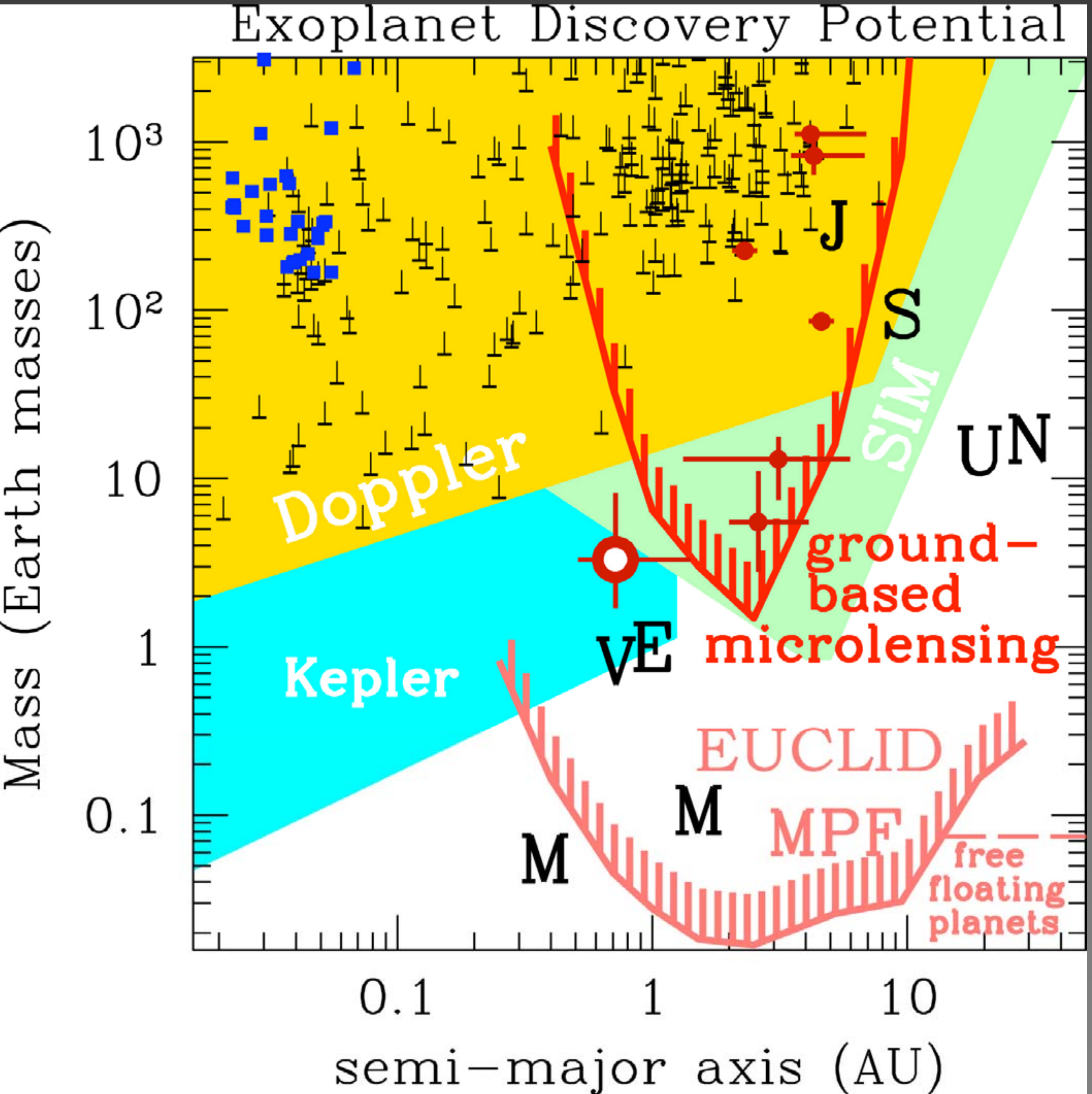

Microlensing !
Wide Extragalactic
20,000 deg²
Galactic Plane
Deep
~50 deg²

EUCLID (ESA) & MPF (NASA)

Refregier et al. 2008, proposal to ESA COSMIC VISION
Bennett, et al., 2007 white paper exoplanet task force
Bennett, et al., 2008 JDEM RFI answer
Beaulieu et al., 2008 ESA EPRAT white paper

Wide field imager in space





Transiting planets

microlensing

Radial velocities

Solar system :
E = Earth
J = Jupiter,
N = Neptune…

- **2004**: Wide-field Dark Universe Mission proposed as a *Theme* to ESA's CV
- **June 2007**: DUNE & SPACE proposed to ESA's Cosmic Vision as M-class missions
- **Oct 2007**: DUNE & SPACE jointly selected for an ESA Assessment Phase
- **Jan-May 2008**: Concept Advisory Team (CAT) defines a common mission concept
- **May 2008**: Validation of the merged concept *Euclid* by the ESA AWG
- **May 2008**: Formation of the Euclid Science Study team (ESST) to replace CAT
- **May-June 2008**: Technical study by ESA's Concurrent Design Facility (CDF)
- **May 2008**: Call for Interest for instrument consortia and Industrial ITT
  - » **we are here**
- **Sept 2008-Sept 2009: Industrial assessment study phase**
- **On going discussions ESA/NASA for possibility of a join mission**

- **2010-2011**: Definition phase (if selected)
- **2012-2017**: Implementation phase (if further selected)
- **2017**: ESA launch of the first Cosmic Vision M-class mission

PLANET HUNTING EFFICIENCY WITH EUCLID

- Monitor 2 10^8 stars
- Color information ~ once a week
- ~4 square degrees observed every ~20 min each over period of 3 months
- Sensitivity to planets with a 3 months dedicated observing program :
  - rocky planets (Earth, Venus, Mars)
  - Jupiter planets
  - Saturn
  - Neptune planets

Very similar to MPF.
Currently waiting for design of focal plane
Need for precise estimates of efficiency

DARK ENERGY PROBES WILL PROCEED

- **Excellent synergy cosmic shear/microlensing**
- **Everything that is good for cosmic shear is good for microlensing**

The new alliance :

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