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Detecting extra-solar Earths by direct imaging with a 100m ELT

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Direct detection of Earth-like planets and spectroscopy of their atmospheres

- Sun is 10^{10} times brighter than Earth in visible and near-IR
- At 1 micron can deliver high Strehl ratios – up to 90%
- At 10pc terrestrial planet at 1Au will lie at 100mas separation
- FWHM of central spike of AO system PSF is 2mas
- Planet's image outside bright structures of central core!

Simulated PSF of OWL

- 10,000s at 1micron
- Seeing 0.4”, 90% strehl
- Note compact central spike, soft AO halo
- Note diffraction from telescope structure, scattering and AO halo
- Diffraction from mirror segmentation not included, nor speckle effects
  - May yet set ultimate limits to planet-finding capabilities

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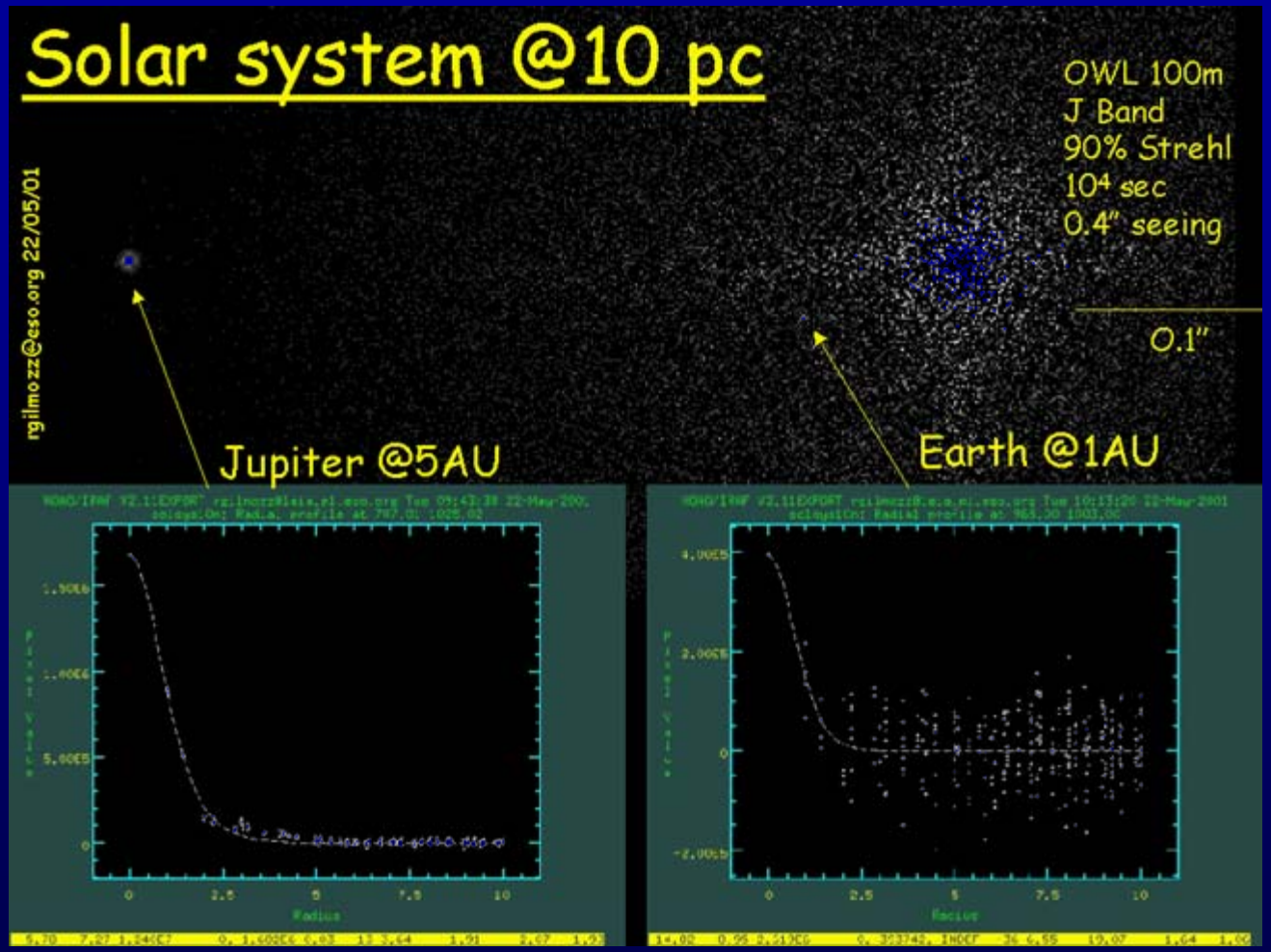
Simulated solar system



- Starlight removed, leaving only noise signature
- Exo-Jupiter SNR~500
- Exo-Earth SNR~20
- Spectroscopy of exo-Earth – SNR~5 for R~1000 in a few nights

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Prime science driver

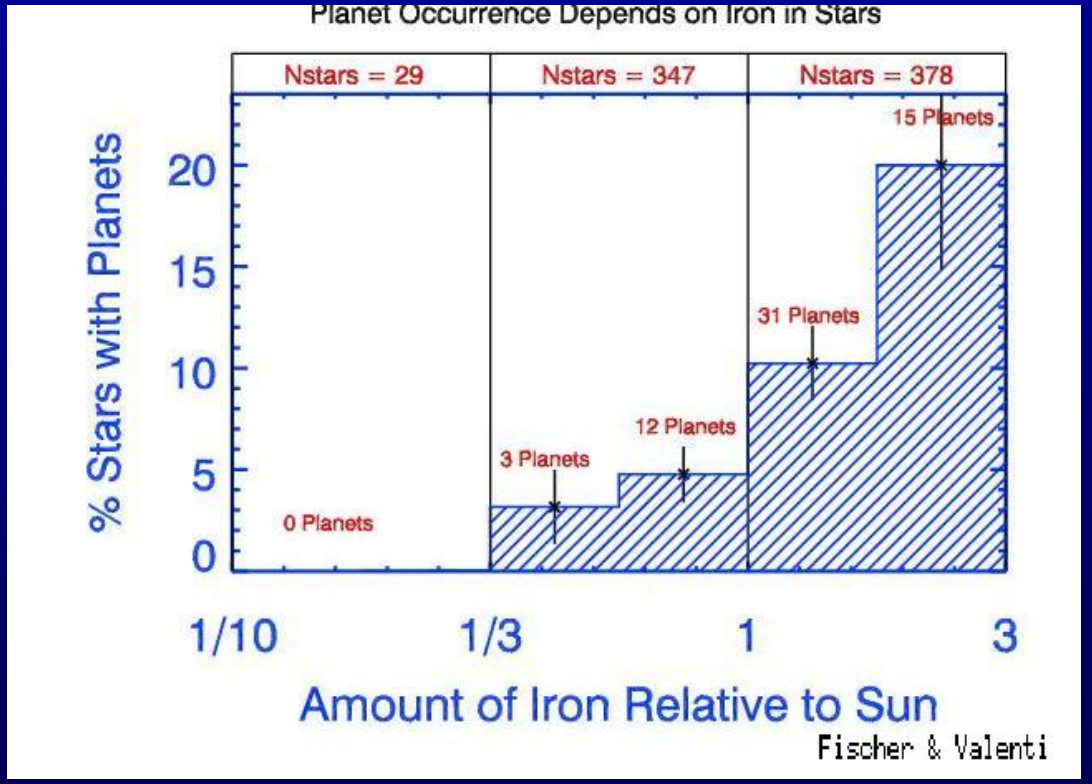
- Detection and characterization of extrasolar Earths
- Why? We want one billion euros!!!
  - Do we really think we're going to sell this to Europe's politicians and taxpayers if this isn't the prime goal?
- This goal must drive the project, no matter the technical difficulties and challenges
  - If this goal turns out to be not achievable, the project is dead

Discovery

- 100m ELT could directly detect Earths to >25pc (cf a 30m unlikely beyond ~5pc)
  - detection is easy – *does it move?*
- 2600 stars, 360 solar-like within this radius
  - Also cover all spectral types, white dwarfs etc
- Follow-up of satellite-detected targets?
  - Kepler/Eddington, but maybe too distant
  - SIM/GAIA astrometric detections
- Are Earths common, and when did they start forming?

Where to look?

- Fischer et al. show that planets more likely around metal-rich stars
  - Initial condition?
  - By-product of accretion of gas-depleted material
- Zinnecker suggests planets in metal-poor environments will be lower mass, unlikely to support life
  - Threshold metallicity ½ solar?
- Jupiter sized planet in globular M4
  - Planet formation 12 billion years ago?



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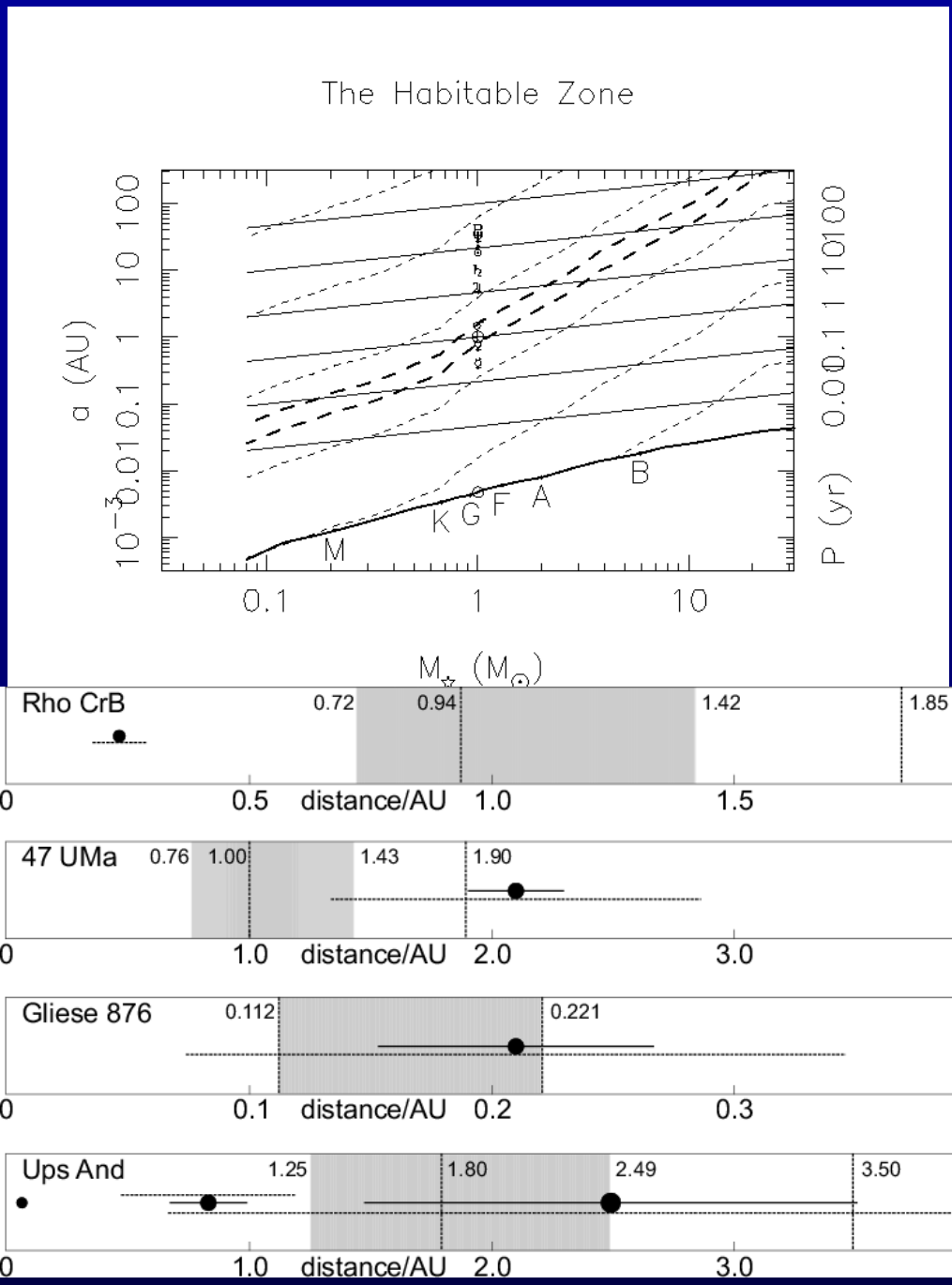
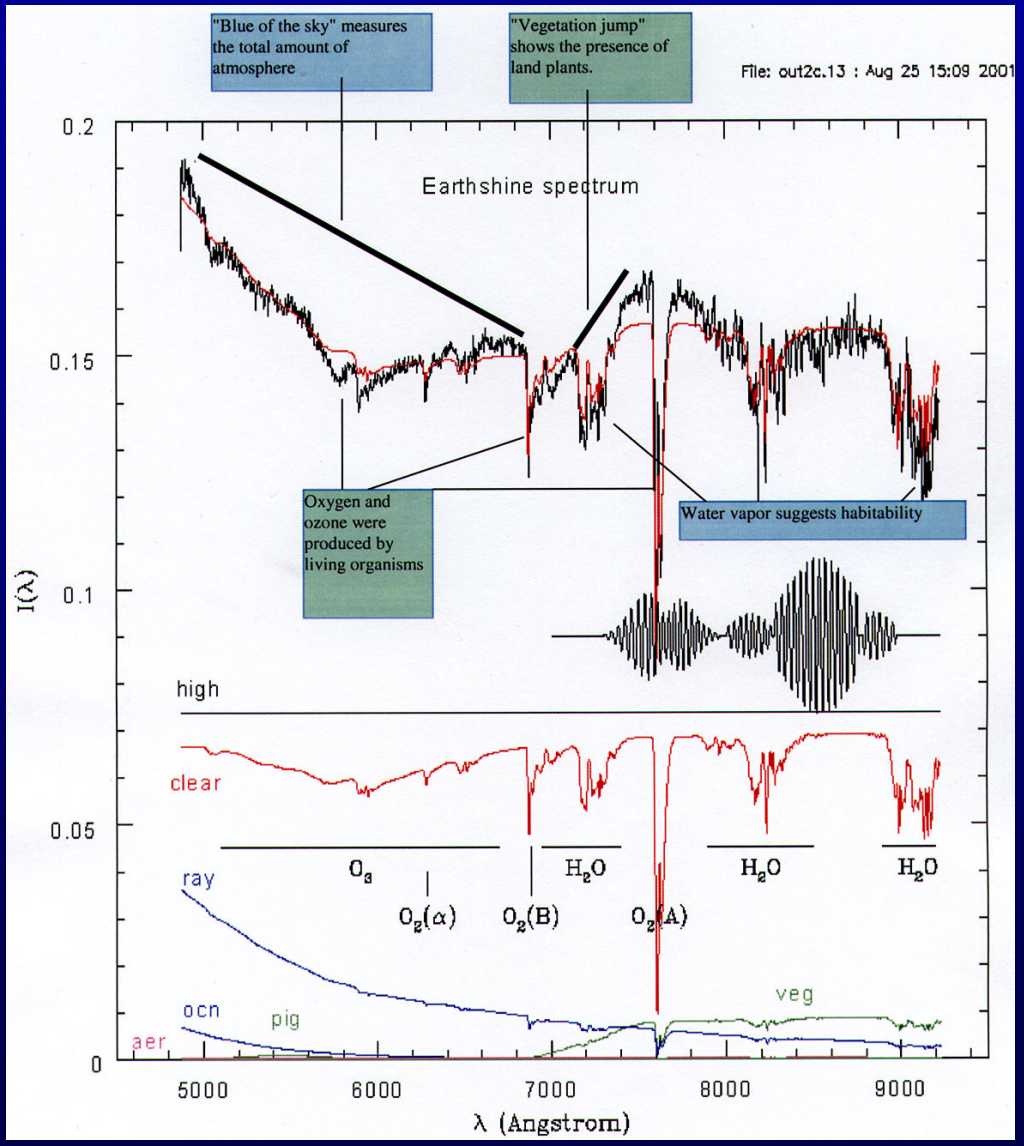
Where to look?

- Habitable zones
  - Existence of liquid water
- Moves outwards with spectral type
- Migration of hot Jupiters a concern
  - ~1% of solar-like stars have a hot Jupiter
- Consider also moons of hottish Jupiters
  - Detectable through reflex motion?



Characterisation of exo-Earths



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Characterisation of exo-Earths

- Diagnostics: H_2O, O_2, O_3, CO_2
- Exploit orbital Doppler shifts to disentangle planetary spectrum from telluric features
  - Disentangle from stellar spectrum cf CVs
- No known process other than photosynthesis can maintain a high level of O_2 for more than ~few 10^7 years
- Of course, Earth's atmosphere has changed with time. Oxygen level high for only last 20-30% of planet's history
- Temporal variability
  - For cloudless Earths, 10-100% due to ocean fraction, ice cover
  - For totally cloudy planet (Venus) nearly zero
  - Derive meteorological variability and rotation period
- If Earths common, could address fundamental question, *the timescale of evolution of analogs to terrestrial eukarya*
  - 2.7Gyr ago on Earth

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