Planet Detection with GMT

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Finding Planets

Transit

Wobble - Doppler or Astrometric

Microlensing

Direct Imaging
Big Exoplanetary Issues

- Formation - is it ....
  - Core accretion
    i.e. “planet formation”

- Disk Fragmentation
  i.e. “Binary Star Formation”

- Something else entirely?
The Biggest Question in Every Decadal Plan

• The Drake “Equation”
  • or rather listing of our ignorance

• \( N = R^* \times f_p \times n_e \times f_l \times f_i \times f_c \times L \)

- \( R^* \) = average star formation rate
- \( f_p \) = fraction of stars with planetary systems
- \( n_e \) = average number of “habitable” planets per system
- \( f_l \) = fraction of such planets that develop life
- \( f_i \) = fraction of those that develop intelligent life
- \( f_c \) = fraction of those who develop technology
- \( L \) = lifetime of technological civilisation
A Question we can answer on 20 year timescales

• The Life “Equation”
• $N = R^* \times f_p \times n_e \times f_l$

- $R^*$ = average star formation rate
- $f_p$ = fraction of stars with planetary systems
- $n_e$ = average number of “habitable” planets per system
- $f_l$ = fraction of such planets that develop life

• $f_p$ is at least 10-15%
• $n_e$ can be attacked by GMT.
What can we do to attack planet formation / habitable planet formation?

• Solar System Analogues - ie Jupiters with no gas giants interior
  • might also want to understand Jovian satellites at 1AU a bit better.
• Pushing the low-mass threshold via Doppler
• Earth-like planet transits (Kepler & follow-ons)
• Microlensing statistics & follow-up
• Or we could just manage to work out how planet formation works, which would make all of the above moot .....
Detection / Discovery with GMT

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Direct Imaging
Follow-up / Understanding

Transit

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Direct Imaging
Transit Exoplanet Science

- Two things are now revolutionising exoplanetary science from transits
  - Kepler (and its follow-ons like TESS) - from space you can find Earths transiting. Many hundreds of gas-giants, and probably terrestrial planets
Space Transit Follow-up

HAT-P-7 Light Curves

Kepler Measurements (7x Magnification)

Kepler Measurements (100x Magnification)
Multi-site ground transit follow-up
Transit Follow-up Science

- Doppler confirmation - needs massive apertures.
- Exoplanetary atmospheres via transmission
- Reflected light in the optical
- Phase modulation - photometry & spectroscopy in the near-infrared.
- Detailed (and I mean ridiculously detailed) elemental abundance analyses of host stars.
- Rossiter-McLaughlin effect - Are orbits and stellar spins aligned? Are planets prograde or retrograde?

- **G-CLEF, GMTNIRS**
  - even 0.55-0.4" AO improvement will be useful!
R-M Transit Follow-up

Bayliss et al. 2010 (in prep)
WASP 17b R-M Detection
Phase Modulation

![Graph showing absorption percentage over wavelength (μm) with models and observations.]

- Binned model, water + methane
- Binned model, water + methane + ammonia
- Binned model, water + methane + carbon monoxide
- Observations

![Diagram of brightness over time with a sun and planet.]
Applying Earth-Sun depletion patterns to terrestrial hosts.

Figure 1. Comparison between the elemental abundances of the Sun (Lodders 2003, Asplund et al. 2005) and bulk Earth (Morgan & Anders 1980, McDonough 2003) (non-weighted averages from these two references) normalized to aluminium. To first order, the Earth is a devolatilized piece of the protosun. The x-axis shows the elements arranged in decreasing abundance in the Sun by mass.

Lineweaver & Robles 2009
Doppler & Microlensing Exoplanet Science

- **Doppler**
  - Huge science here in targeting the stars themselves - more ridiculously detailed elemental abundances.
  - Specific programs targetting key classes of planets - “Large Earths” at short periods, complex multiple systems

- **Microlensing**: Can we see the host star?
  - High resolution imaging to separate the star.
  - Spectroscopy to understand its properties.

- G-CLEF, GMTNIRS, AO Imaging, GMTNIFS+AO
Direct Imaging

- Separation - $2\lambda/D$ at $3\mu m = 60\text{mas} = 3\text{AU}$ at $50\text{pc}$
- Contrast
  - varies with mass
  - varies with age (young things brighter)
  - varies with wavelength (luminosity of planets higher at longer wavelengths)
- Shape - point sources are “easy” to pick out of residual wavefront errors. Shapes, gaps in disks, dimples, etc are harder and so need better contrast
- AO is usually “easy” as the host stars are bright!
Direct Imaging

“Mid” (3-8μm, 8-20μm)
- λ/D less favourable
- Thermal background worse
- Contrast more favourable
- Less high order AO
- $10^6$ reaches $\sim 1 M_{jup}$ at 1 Gyr
- Improves age detectability over 8m

“Near” (1.5-2.5μm)
- λ/D more favourable
- Thermal background better
- Contrast less favourable
- High-order AO essential
- $10^7$ reaches $\sim 1 M_{jup}$ at few hundred Myr
- Improves inner working angle over 8m
2. Instrument concept

2.1. Overview of instrument concept

ExAOCAM is a narrow field near-IR imaging and integral field spectroscopy instrument optimized for high contrast science. A simplified functional block diagram is shown in Figure 3. The overall sequence of elements is both logical and conventional: (1) wavefront correction is first performed to minimize phase errors in the beam (= reduce halo of the PSF); (2) a coronagraph removes starlight, and (3) light is then fed to the science detectors for imaging and spectroscopy. These elements and their interaction will be detailed in the next section.

Figure 3 also shows a feedback loop from the science imaging camera to a deformable mirror ahead of the coronagraph. This feedback (referred to as "focal plane adaptive optics (FPAO)" in this document) is described in section 2.2. and is at the core of ExAOCAM's design, and distinguishes it from conventional AO+coronagraph architectures.

![Graph showing detection limits](image)

The graph illustrates reflected light from known radial velocity planets with dec < +40 deg. Twenty known planets are within the detection capability of ExAOCAM. The top and bottom blue curves indicate the approximate detection limits for 8-m and 25-m telescopes respectively. A more detailed description of the detection limits is given in section 6. ExAOCAM's sensitivity gain over 8-m telescopes is mostly due to the larger aperture which brings a gain in inner working angle (IWA, horizontal arrow) and a sensitivity gain (vertical arrow).
Direct Imaging

• We’re not talking Earth-like planets in Earth-like orbits.

• **Mid-IR** - hotter/wetter site than TMT. **But** much cleaner aperture than TMT / E-ELT.

• **Young ages** - they’re what we have to do, but also provide the greatest insight into formation.
Planets without annoying stars

- “Unbound” Planets - to understand “planet”-made planets we need to make sure we know what “star”-made planets are like.
- Southern sky has most targets. 1-50Myr at 70-200pc
- T-dwarf “planets” are 1-10M\textsubscript{Jup} at H~20-22
- “Y”-dwarfs are fainter and even lower in mass.
- Can we find mass function features?

plus IC2391, IC2602, etc