High efficiency spectrum splitting prototype submodule using commercial CPV cells

Mark Keevers, Jonathan Lau, Martin Green (UNSW)

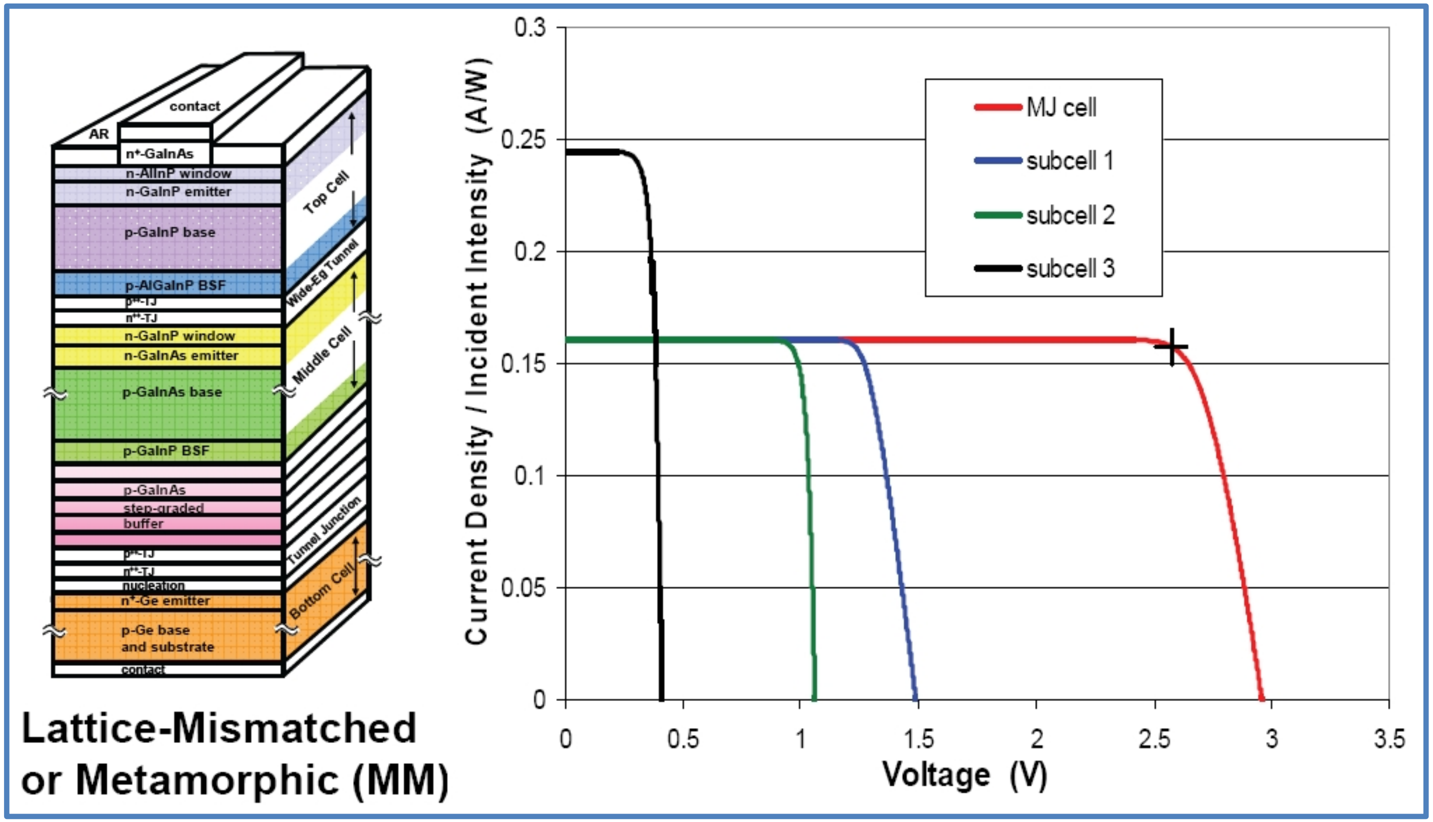
Ian Thomas, John Lasich (RayGen Resources Pty Ltd)

Richard King (Spectrolab Inc.)

Keith Emery (NREL)

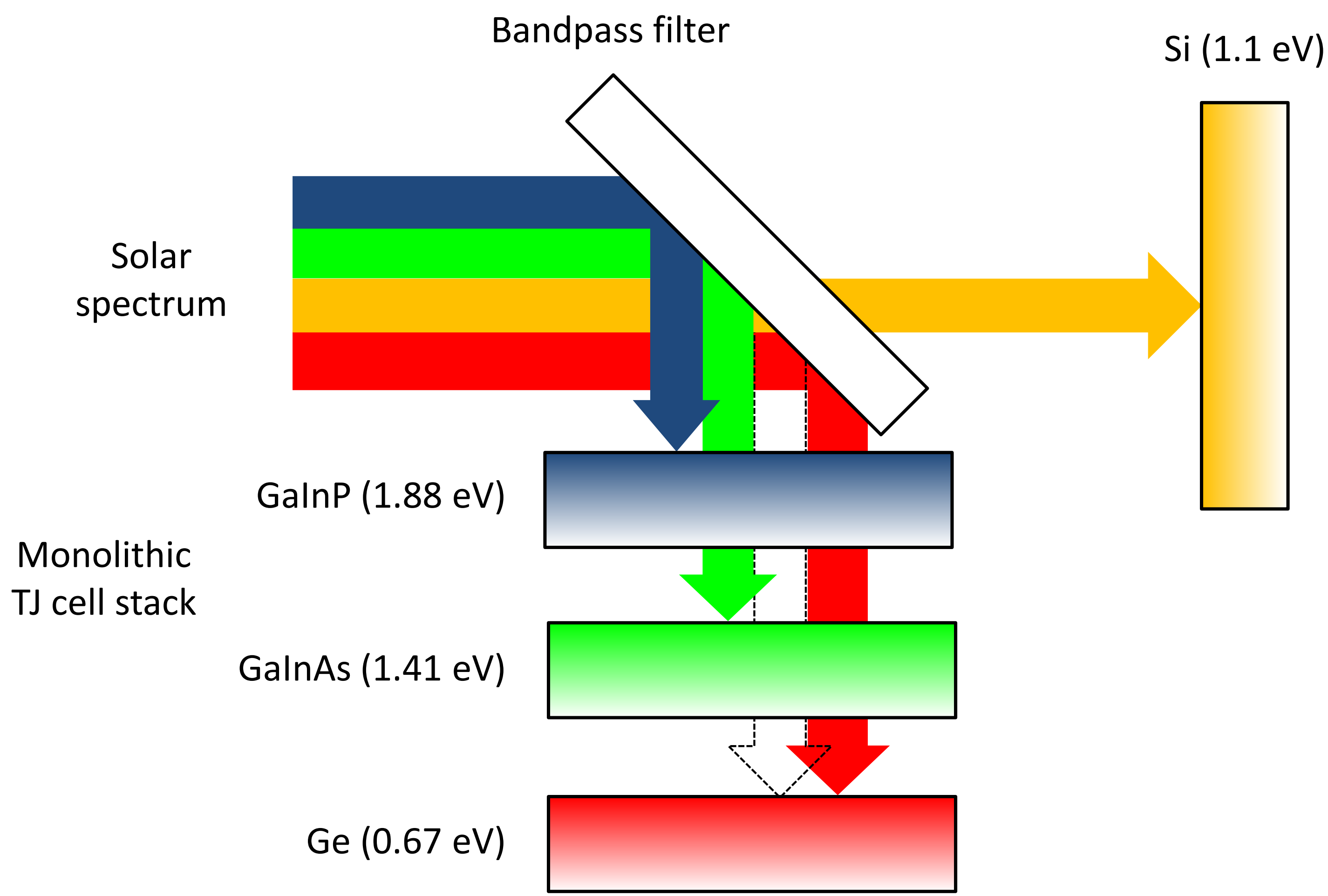
Motivation 1: Record Spectrolab cell

- Excess Ge subcell response
- Divert selected wavelength band to Si cell
  - Lateral spectrum splitting → Eff ↑, heat load ↓



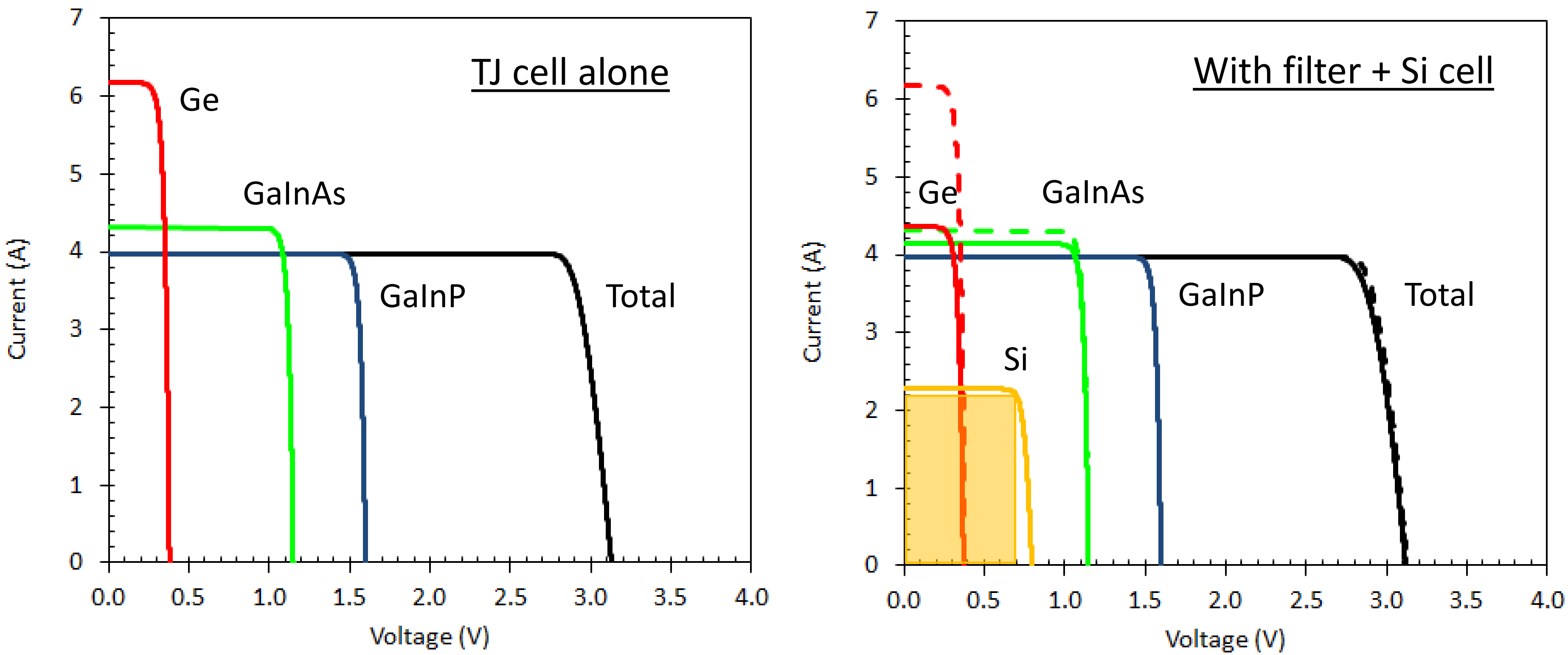
King et al, EUPVSEC-24 (2009)

Spectrum splitting: Concept



Colours are indicative only

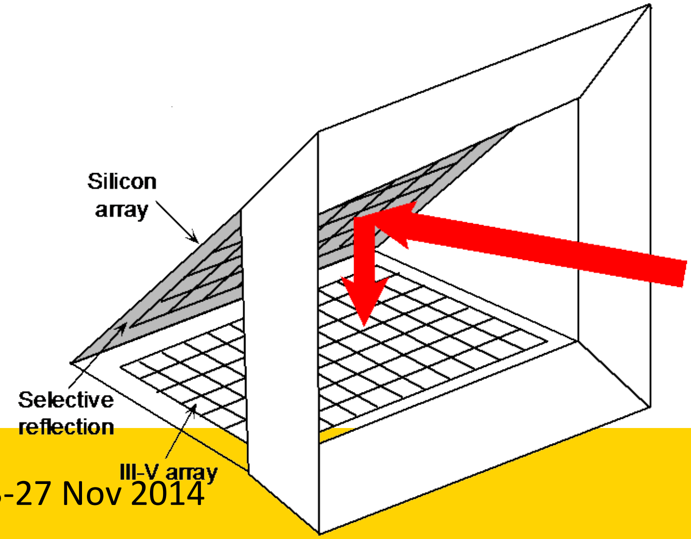
Spectrum splitting: LIV



Motivation 2: CPV power tower

- World first demonstration of a heliostat CPV plant in 2008 (140 kWp)

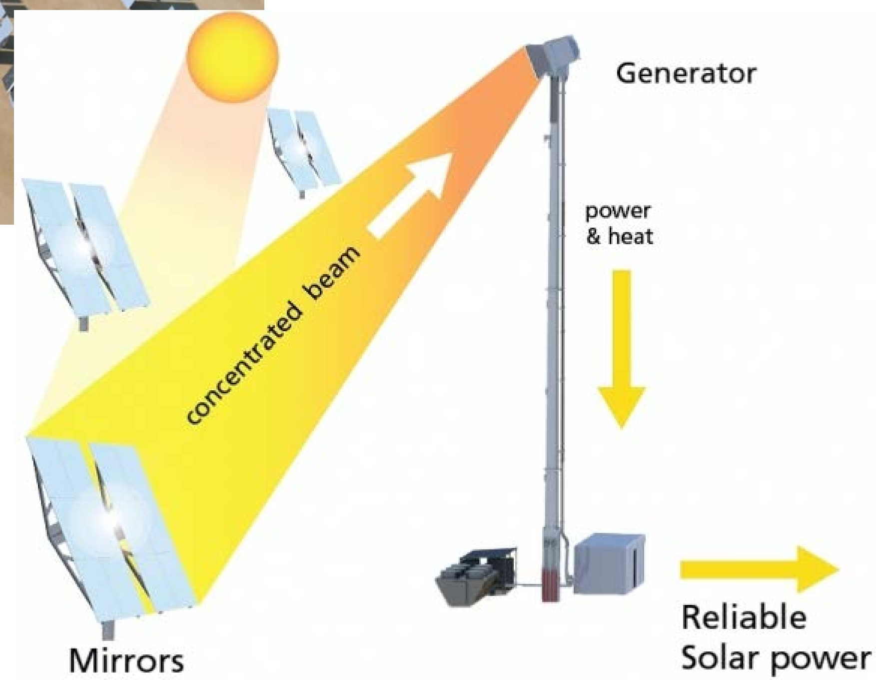
- Replace conventional receiver with spectrum splitting receiver



CSPV power tower: RayGen

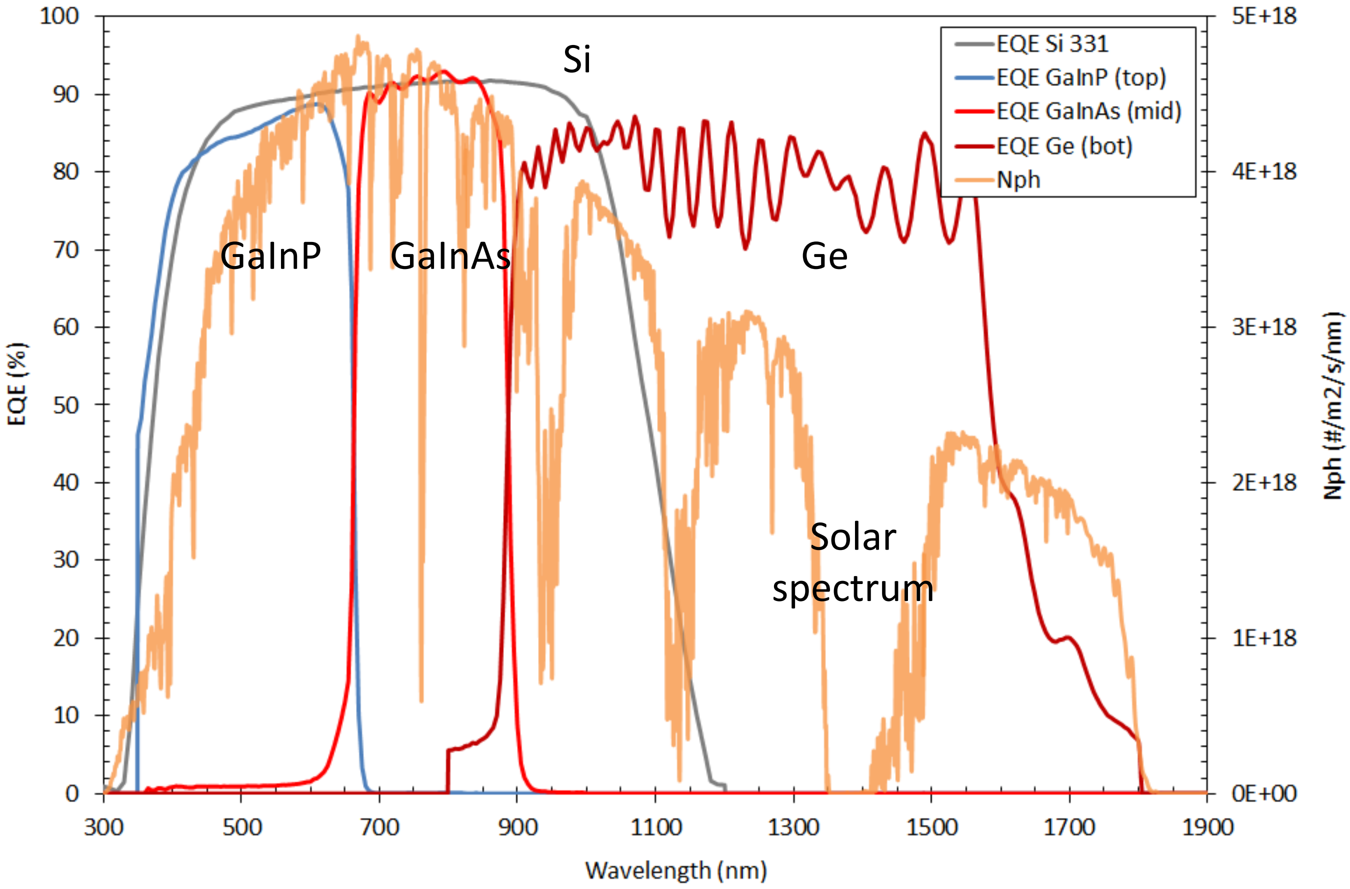
- Combines CPV with CST + storage

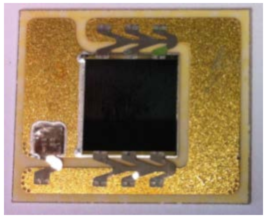
- First site deployment 0.2 MW (Newbridge)
  - 64 heliostats, 200 kW receiver, 1 inverter
- A$60M investment + distribution agreement with China Intense Solar
  - 0.2 MW pilot, 1.0 MW demonstration, 10 MW commercial scale by Aug 2016



Spectrum splitting prototype: Cells

- Target highest performance, using commercial (1 cm^2) TJ and Si CPV cells
- 4-terminal electrical connection



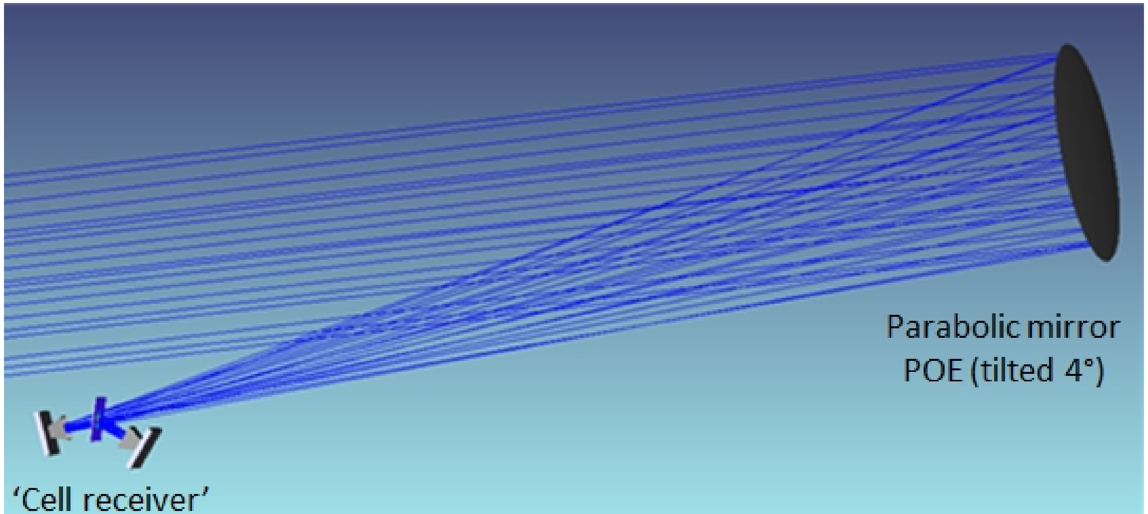


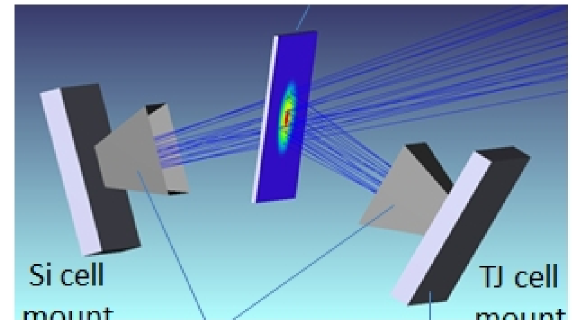
Spectrolab C3MJ+ TJ cell
(38.5% @ 500x)

SunPower back-contact Si cell
(26% @ 200x)

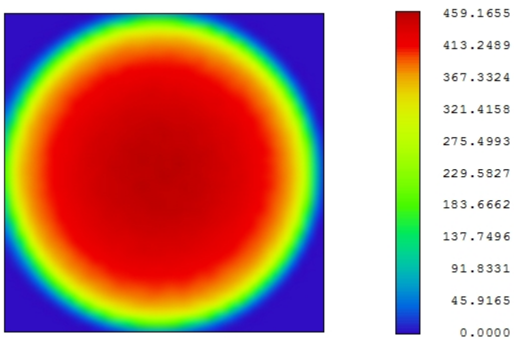
Optical design

- Zemax 3D ray tracing
  - Maximise optical Eff (96.8% for full capture), acceptable non-uniformity

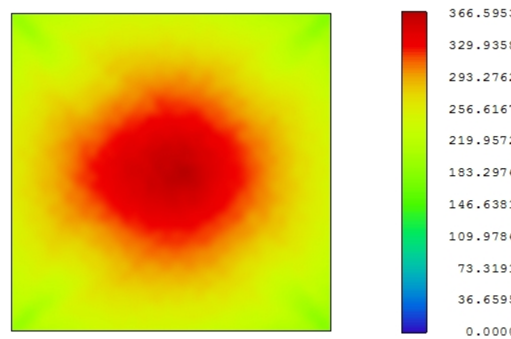




FP (1000 mm)

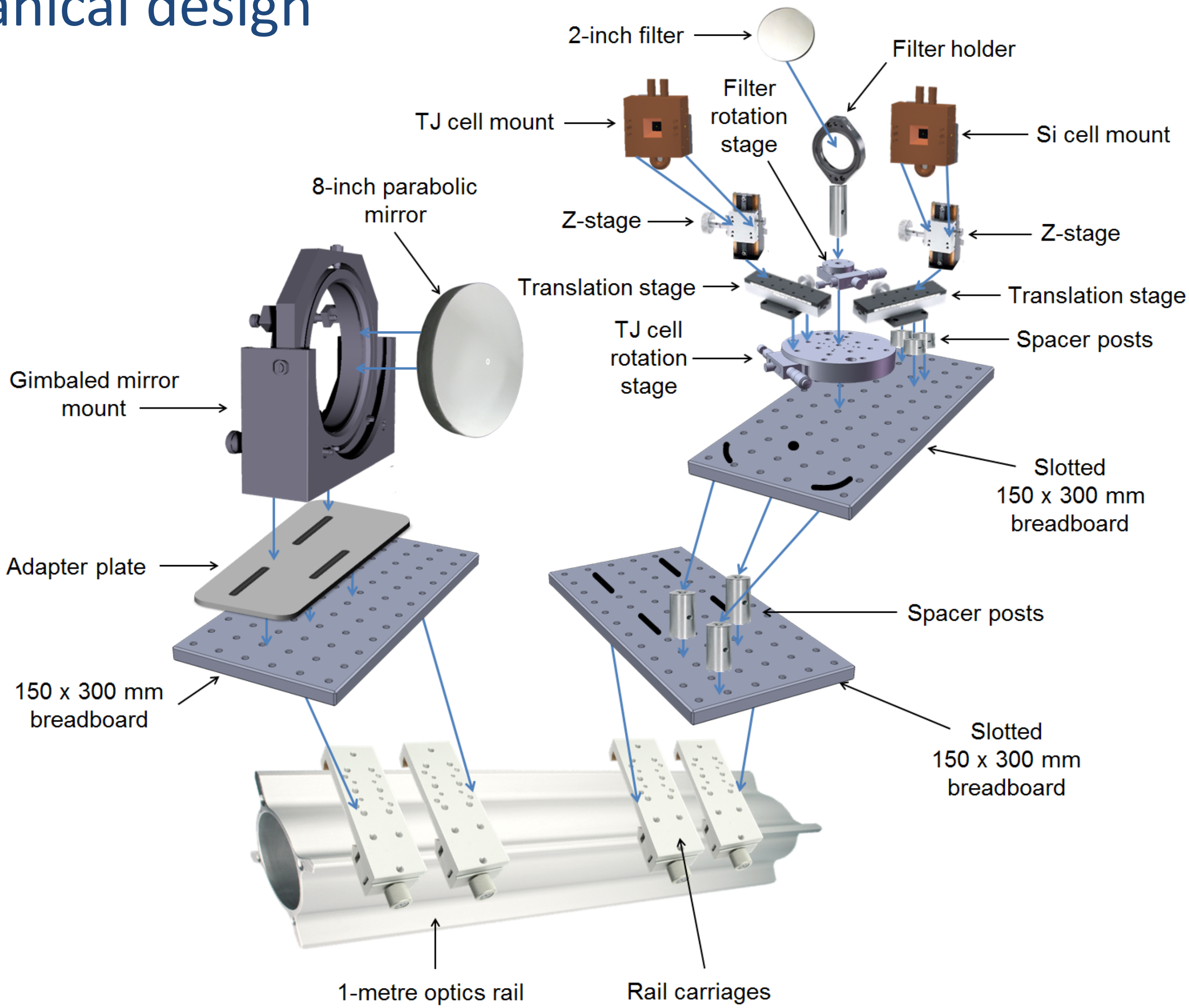


FP + 56 mm



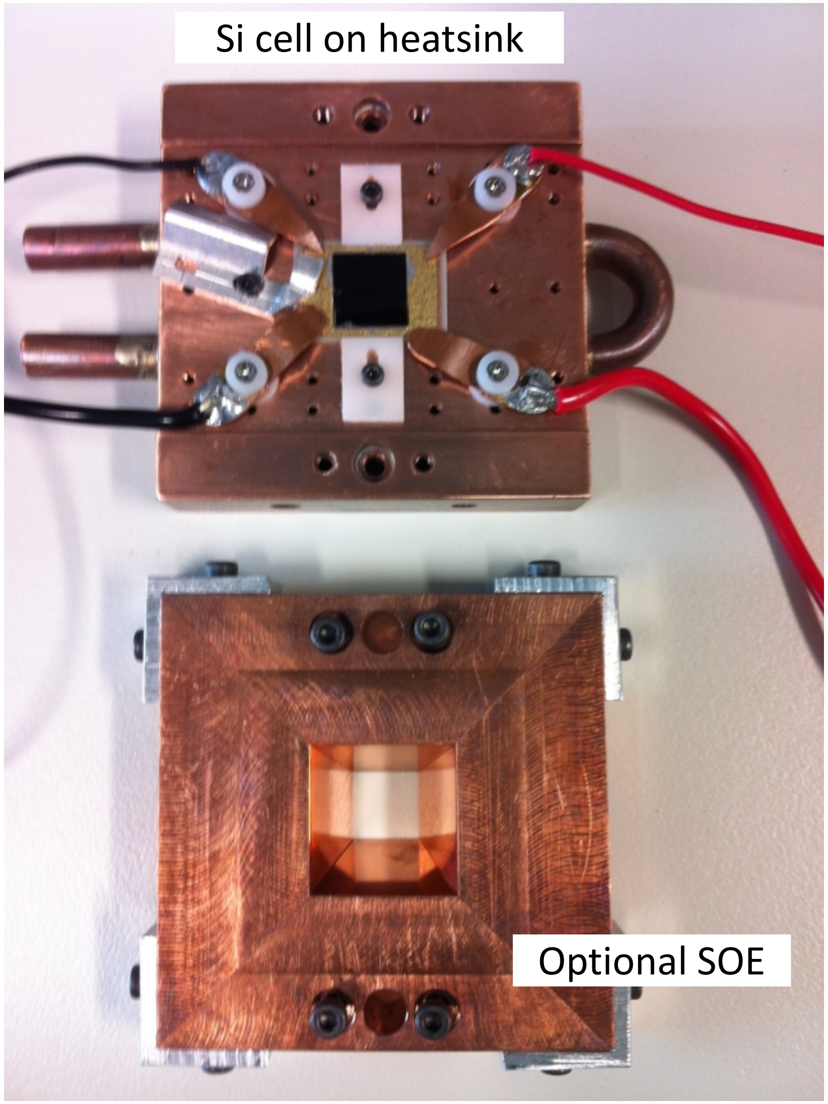
Irradiance at TJ cell

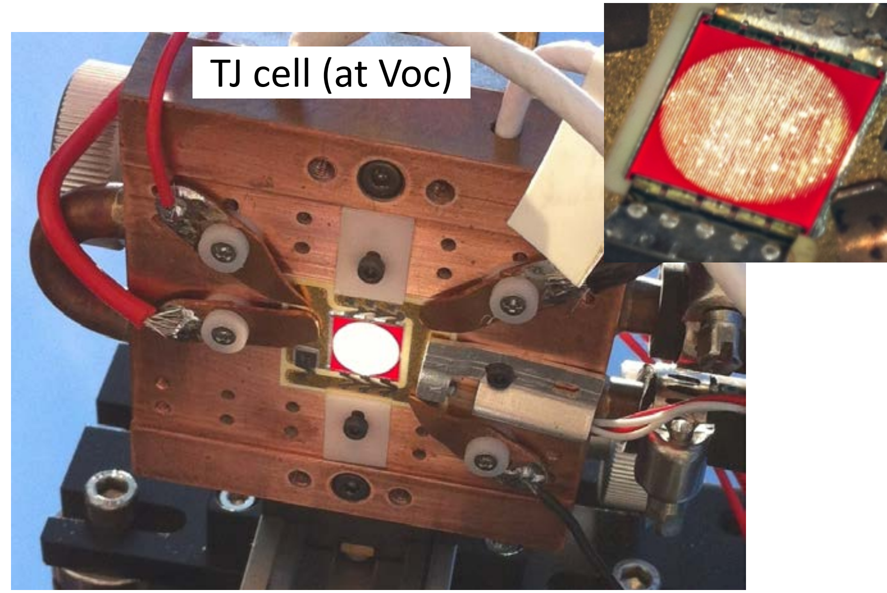
Mechanical design

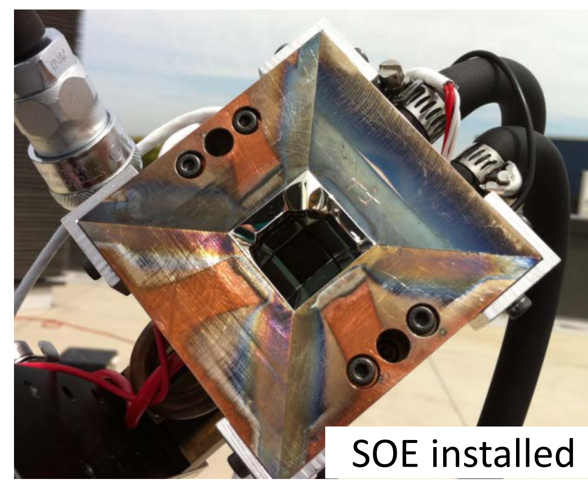


UNSW AUSTRALIA

Heatsink + optional SOE (secondary optical element)

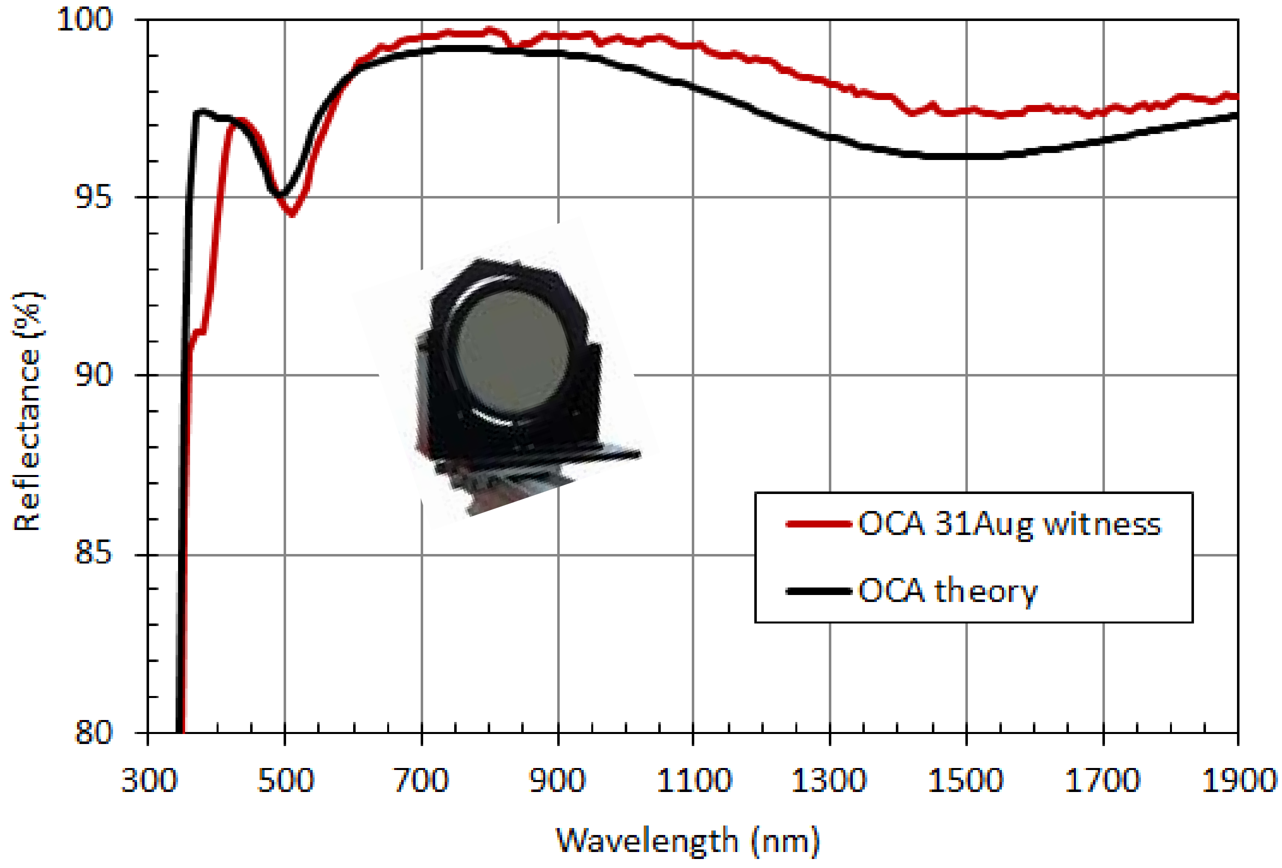




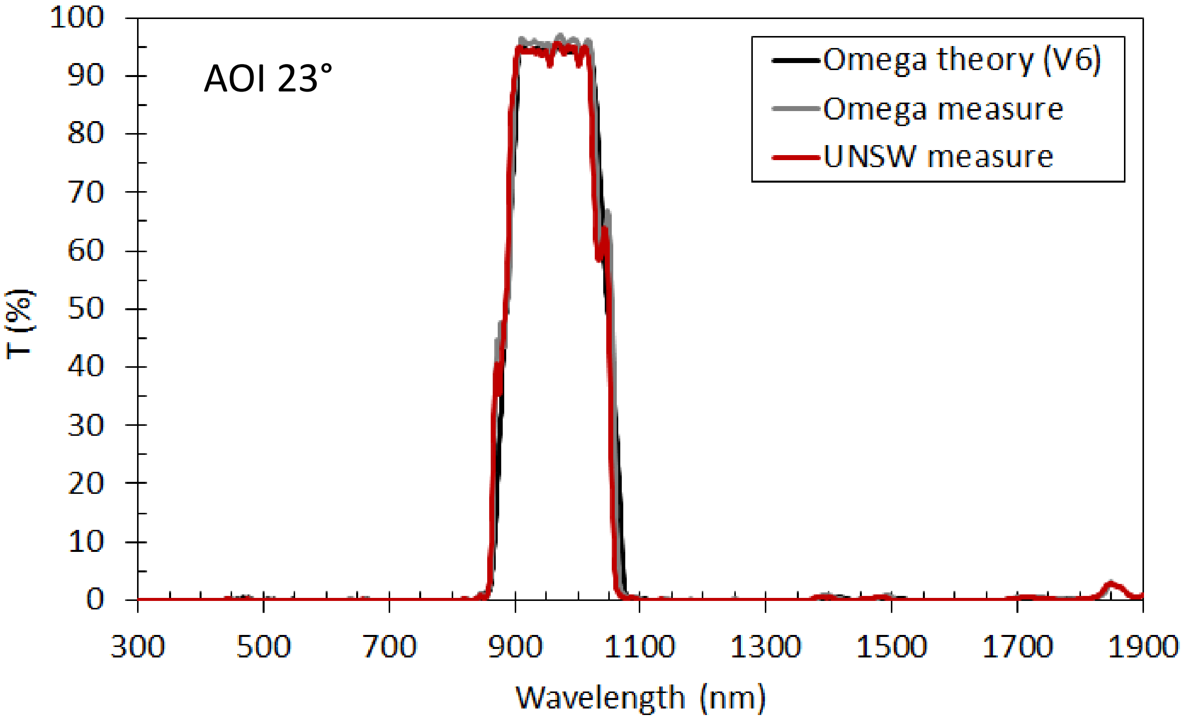


Concentrating mirror

- 8-inch diameter parabolic mirror (f = 1000 mm, aprture area)
- 'Enhanced silver' coating by Optical Coating Associates Pty Ltd
  - Ag + 2-layer dielectric (Al_2O_3/Ta_2O_5)

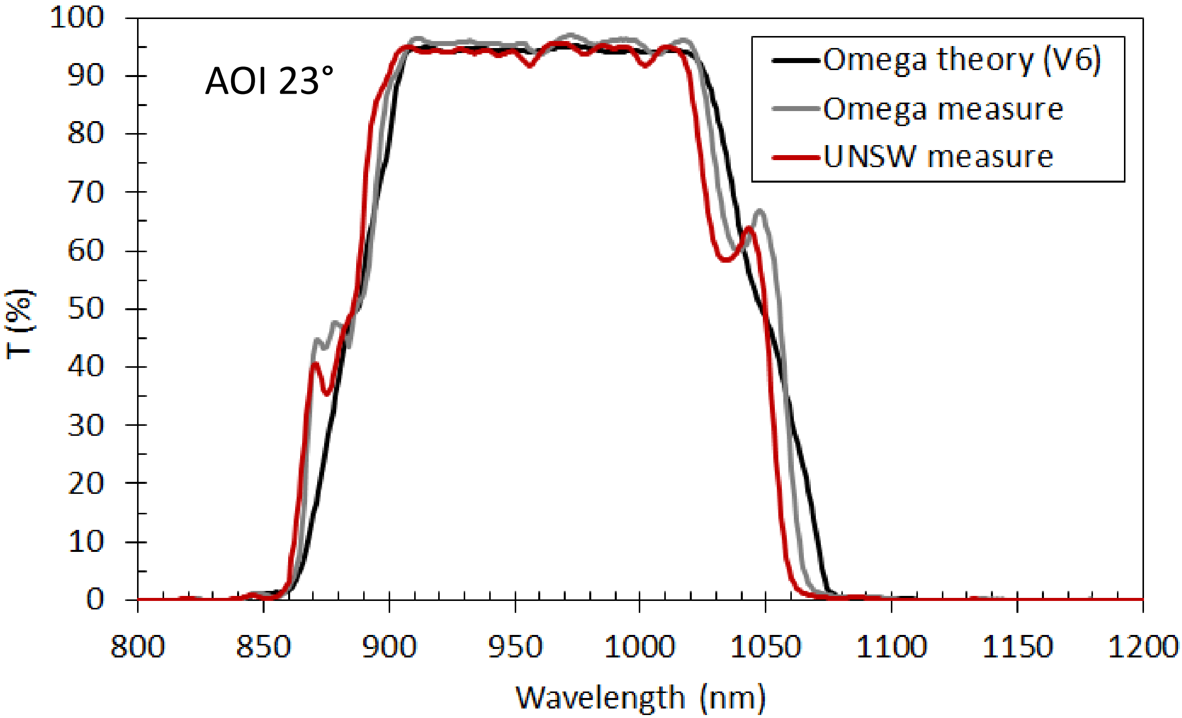


Bandpass filter



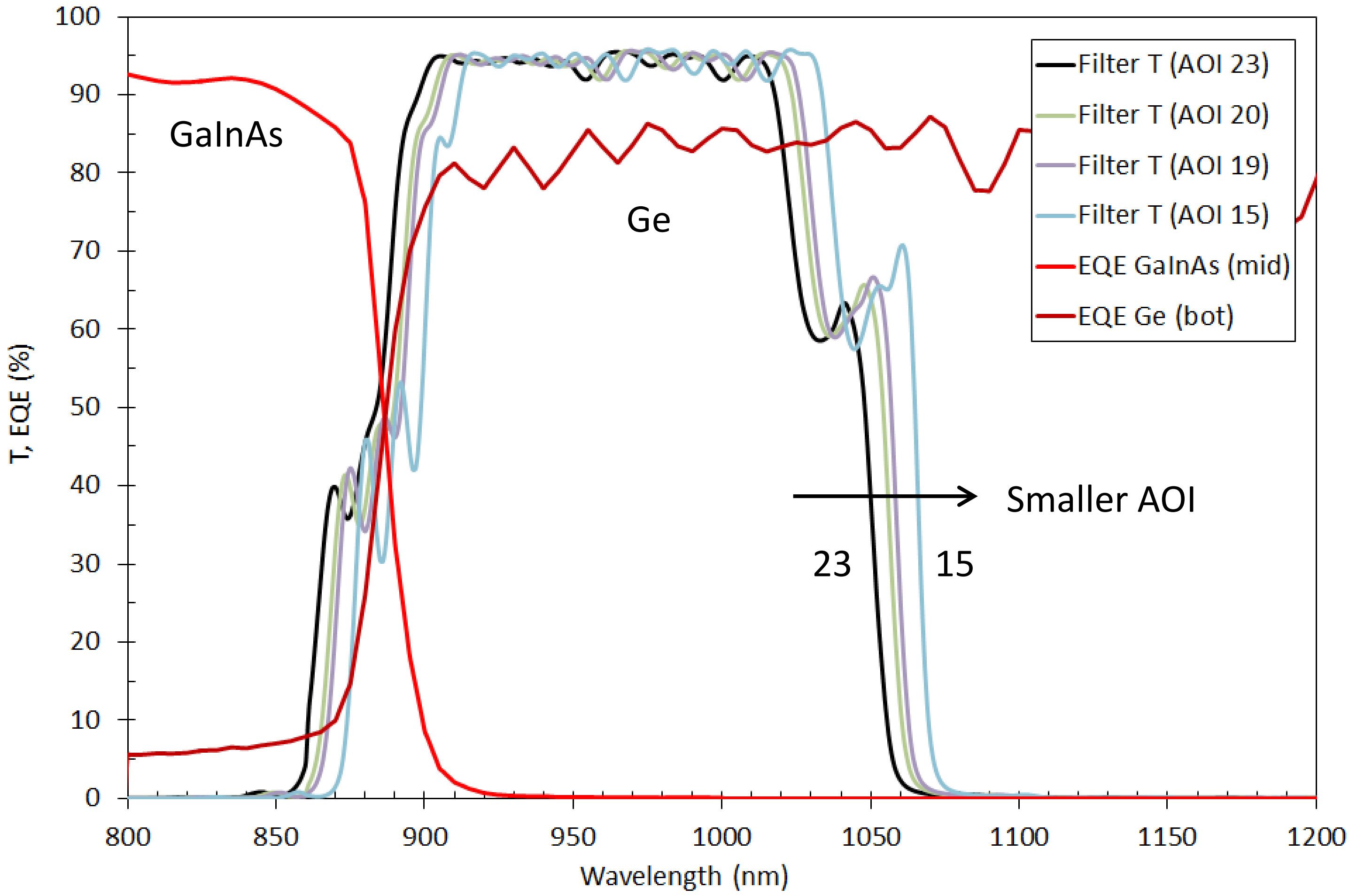
- Adjust filter cut-on & cut-off to match TJ subcell currents (+ margin)
  - Input = AM1.5D spectrum, optics (mirror R, filter T & R), cell EQEs, simple LIV model
- Custom filter by Omega Optical
  - AOI 23°, HCA 6°
  - Design iterations, refine specs
  - Dielectric stack: 158 layers of Nb_2O_5 and SiO_2 (total 20 um)
  - Front surface 'mirror' on UV-grade silica (non absorbing)

Bandpass filter: Close-up

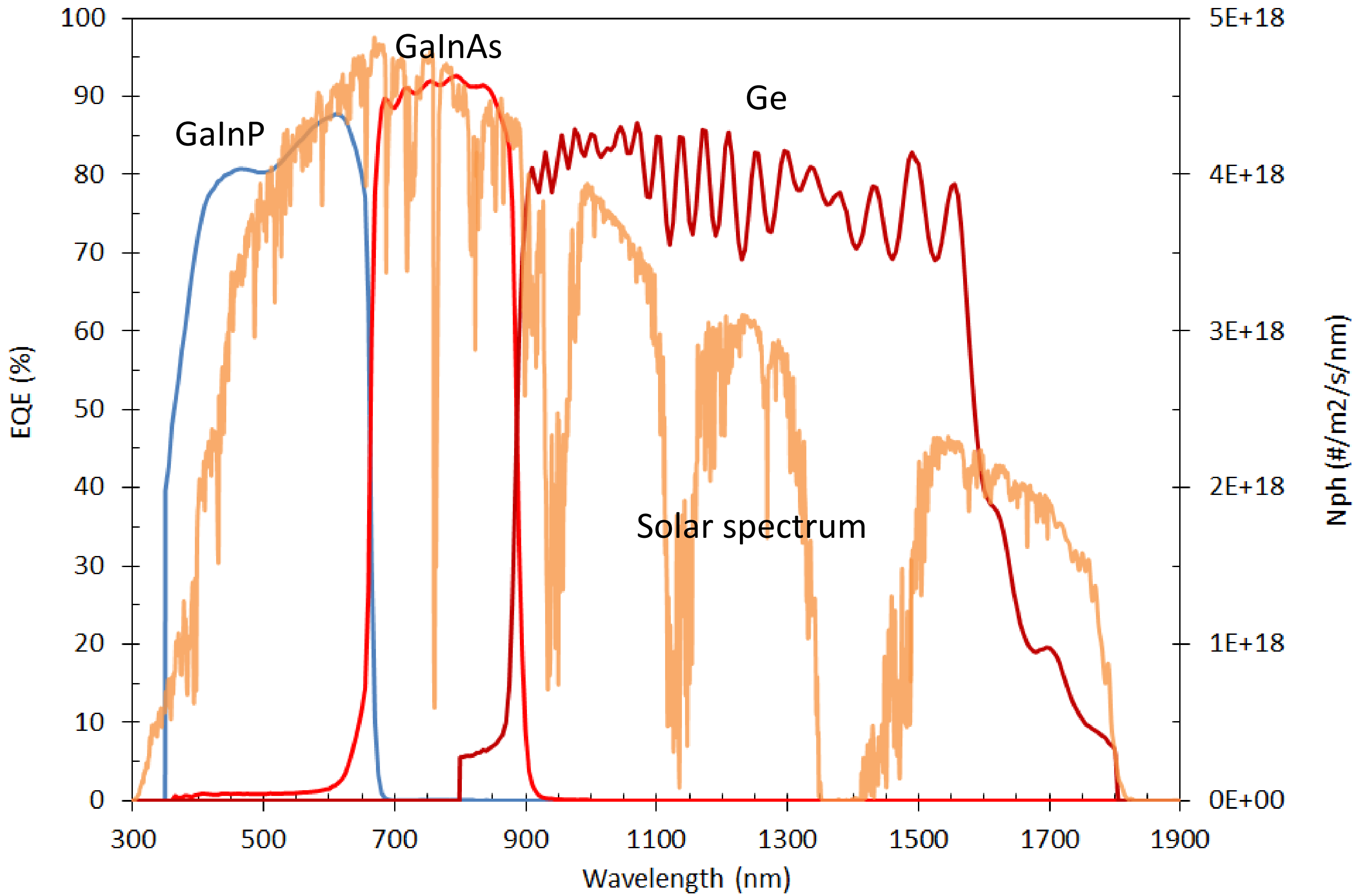


- Adjust filter cut-on & cut-off to match TJ subcell currents (+ margin)
  - Input = AM1.5D spectrum, optics (mirror R, filter T & R), cell EQEs, simple LIV model
- Custom filter by Omega Optical
  - AOI 23°, HCA 6°
  - Design iterations, refine specs
  - Dielectric stack: 158 layers of Nb_2O_5 and SiO_2 (total 20 um)
  - Front surface 'mirror' on UV-grade silica (non absorbing)

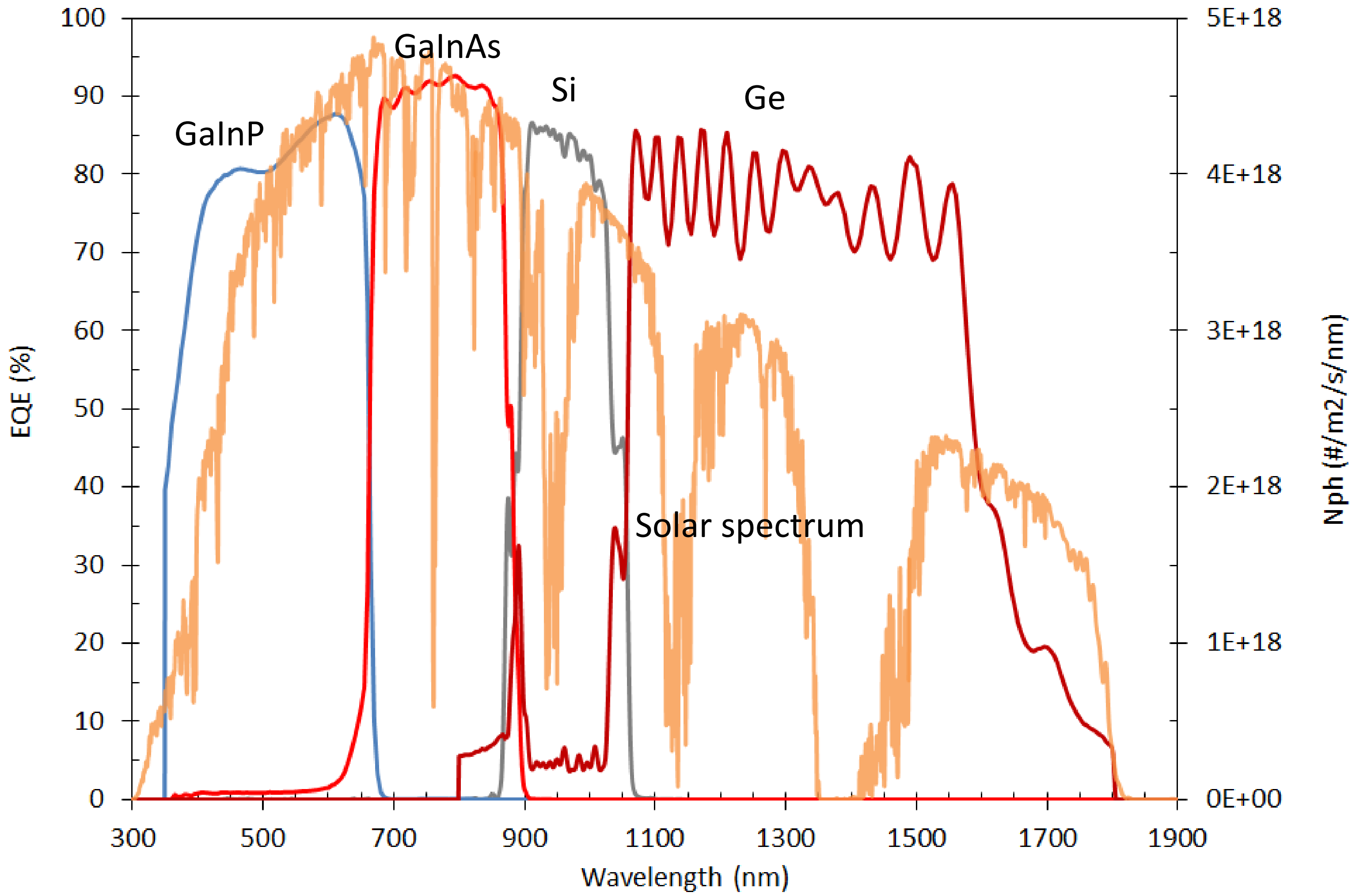
Bandpass filter: Tunability



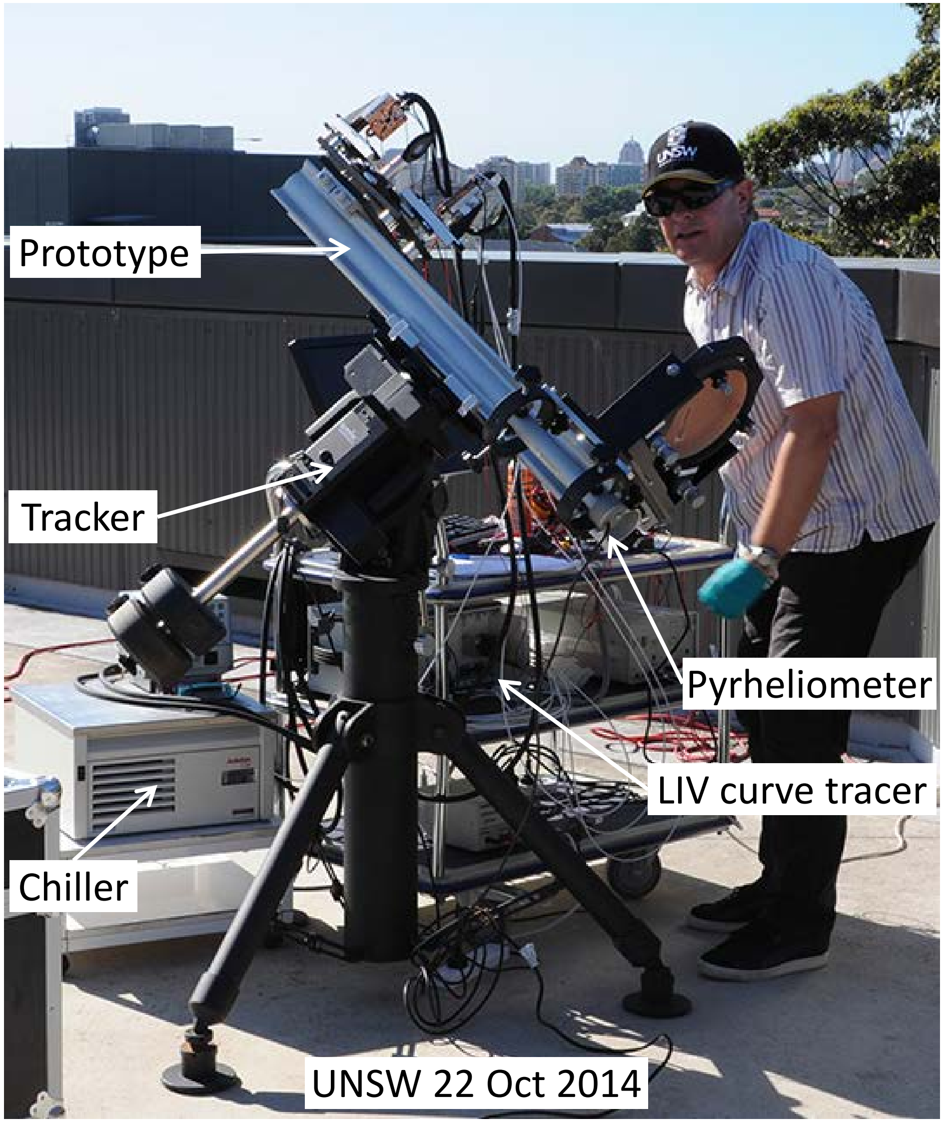
Weighted EQEs: TJ cell alone

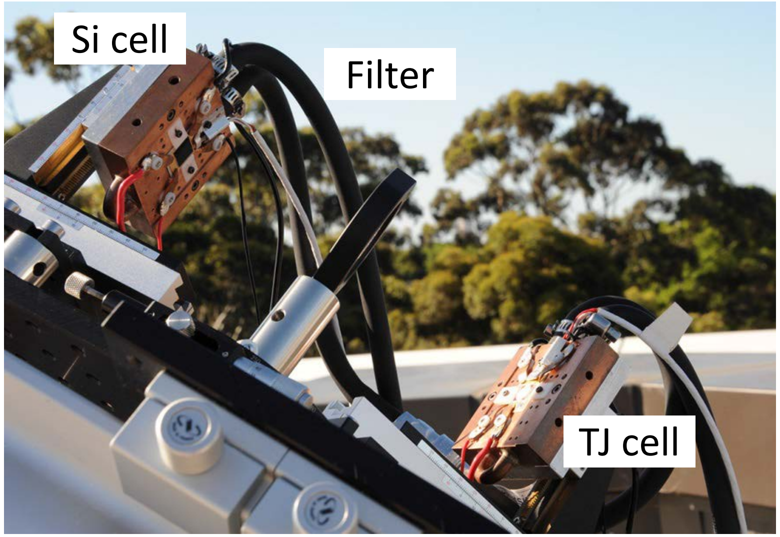


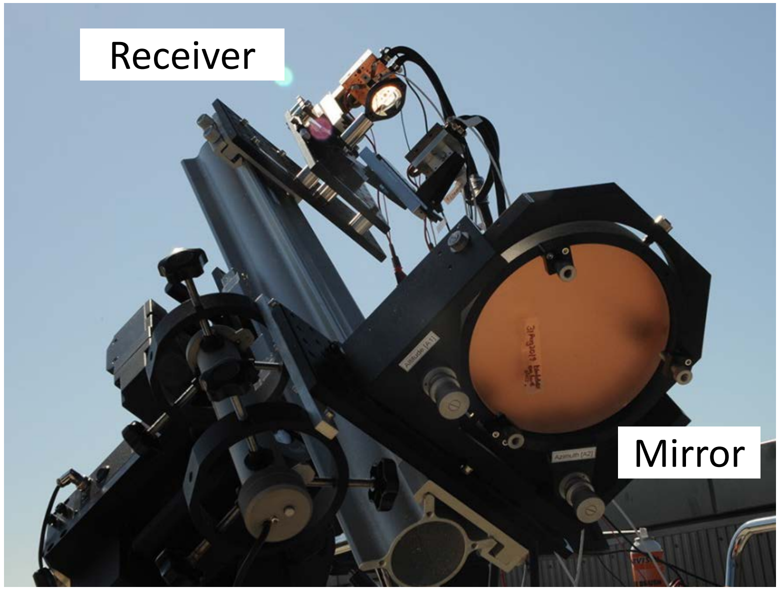
Weighted EQEs: With spectrum splitting



Outdoor testing at UNSW

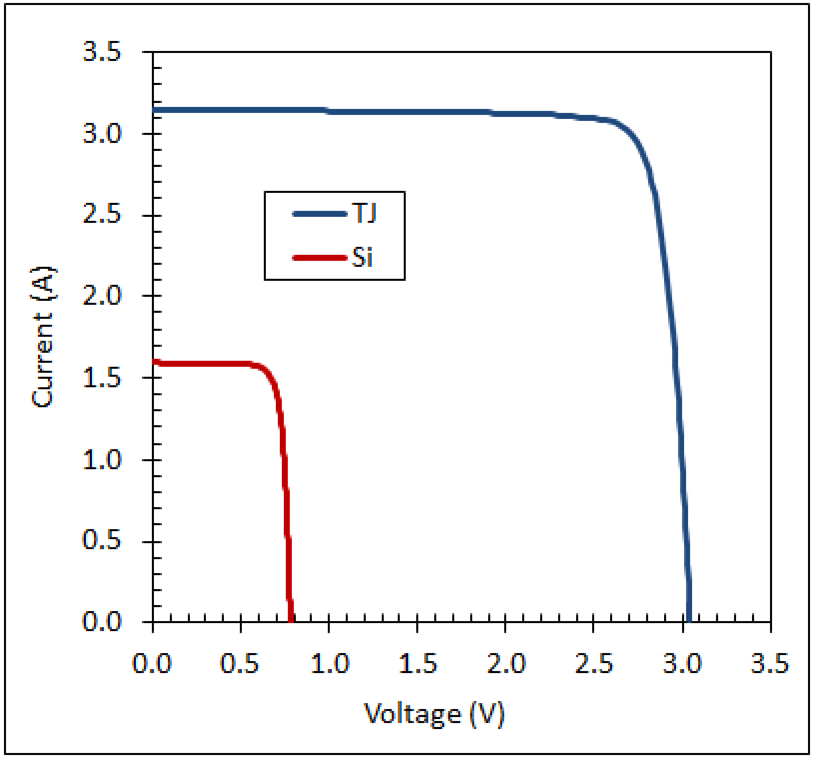






UNSW: Highest efficiency

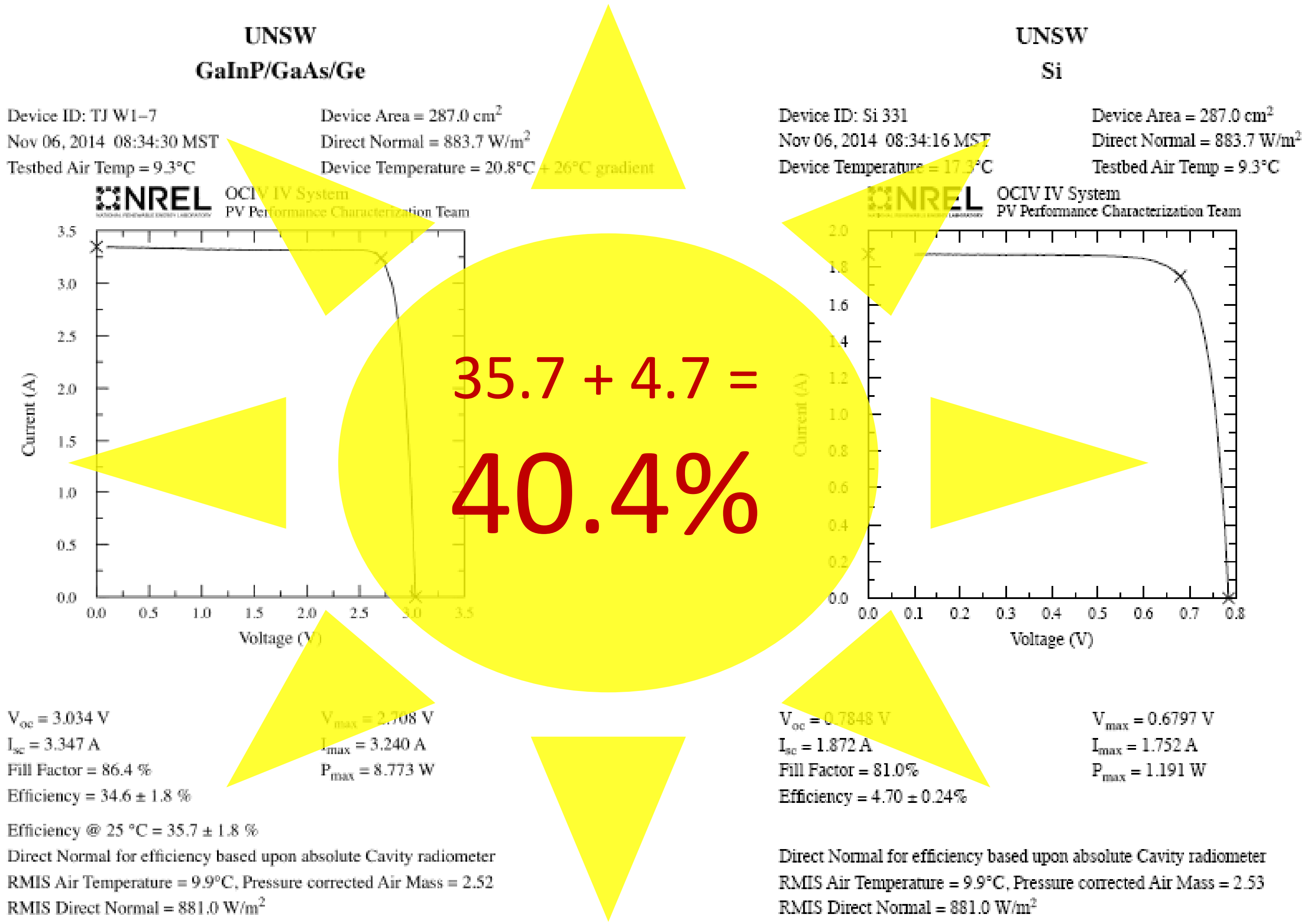
Cell	Split: TJ	Split: Si	Split: Total
Timestamp	22/10/2014 17:02	22/10/2014 17:03	
DNI (W/m^2)	795	798	
P_{in} (W)	22.8	22.9	
$T_{ambient}$ (°C)	21.8	21.9	
$T_{heatsink}$ (°C)	22.0	NA	
T_{CCA} (°C)	23.5	21.7	
V_{oc} (V)	3.04	0.78	
I_{sc} (A)	3.14	1.59	
V_{mpp} (V)	2.71	0.67	
I_{mpp} (A)	2.99	1.50	
FF (%)	85.0	81.1	
P_{mpp} (W)	8.1	1.0	9.1
Efficiency (%)	35.7	4.4	40.1



TJ cell W1-7, Si cell 333, filter AOI 21°, air mass 2.3

Independent confirmation

NREL
NATIONAL RENEWABLE ENERGY LABORATORY



UNSW
AUSTRALIA

Conclusion

- Spectrum splitting prototype submodule, using a custom bandpass filter and commercial CPV cells, has achieved an independently confirmed efficiency of 40.4%.
- Proof-of-concept that this approach improves efficiency.
- Possible application to CPV power towers.

Acknowledgements

- Australian Government: ARENA, AUSIAPV, ACAP
- UNSW: Subash Puthanveetil, Alan Yee, Nathan Tam, Jessica Yajie Jiang, Hamid Mehrvarz, Bernhard Vogl, Nick Shaw, Richard Corkish, other SPREE colleagues
- Spectrolab: Nasser Karam
- Si cells: Giorgio Graditi (ENEA), Mauro Pravetonni (SUPSI), Pierre Verlinden (Trina Solar)
- Omega Optical: Kirk Winchester; Optical Coating Associates: David Baker
- NREL: Larry Ottoson, Greg Wilson