

Testing Fundamental Physics with HRMOS spectra of Solar Twin Stars



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Image: NASA/SDO & the AIA, EVE, and HMI teams

Bottom line:

- HRMOS needs wavelength calibration accuracy!
 - $\sim 1\text{ms}^{-1}$ accuracy in λ separation between any two lines
 - Simultaneous wavelength calibration required
 - Comb calibration preferred (e.g. astrocomb, Fabry–Pérot, photonic)

$$\alpha = \frac{e^2}{\hbar c}$$

Fundamental? Constant?

- Why fundamental?

- Theory doesn't explain them

- Why constant?

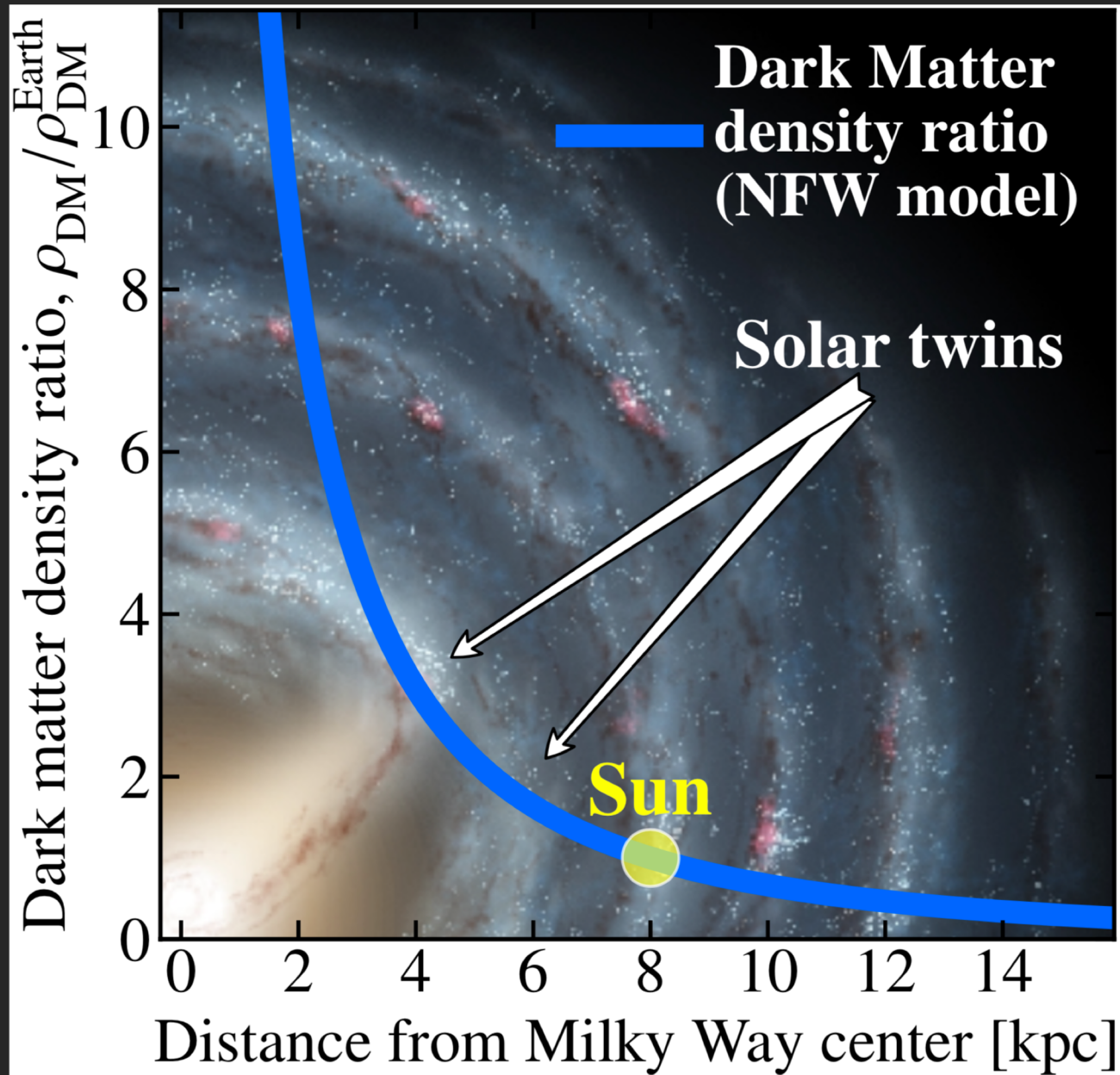
- 'Merely' observed to be
- Exquisite lab experiments:
 α stable within 10^{-18} yr^{-1} (e.g. Lange+21)

- Feynman on α (1985, *QED*)

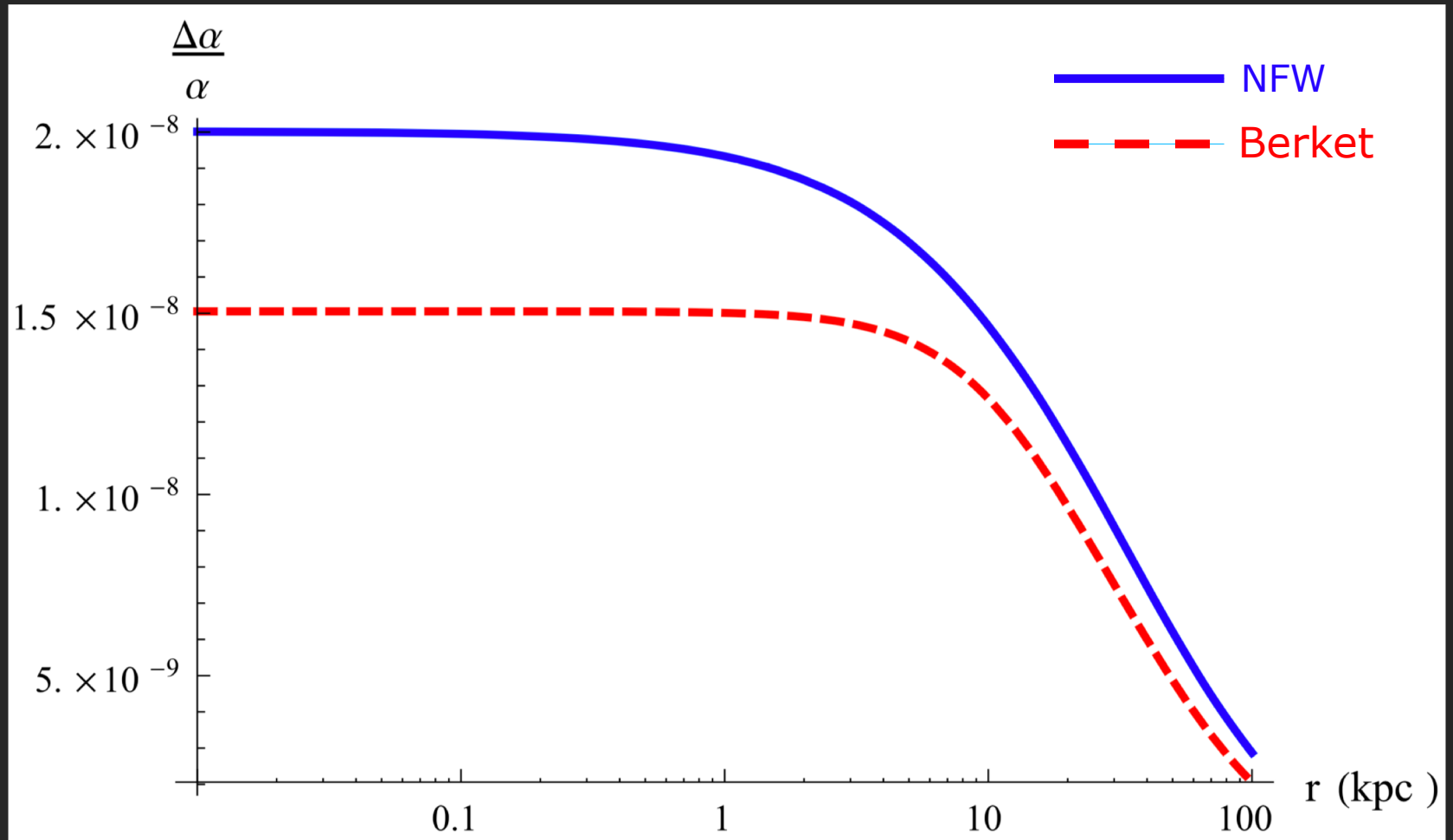
*It's one of the greatest damn mysteries of physics: a magic number that comes to us with no understanding by man...
... all good theoretical physicists put this number up on their wall and worry about it.*

- Hint that Standard Model is incomplete

Direct test for α -Dark Matter connection

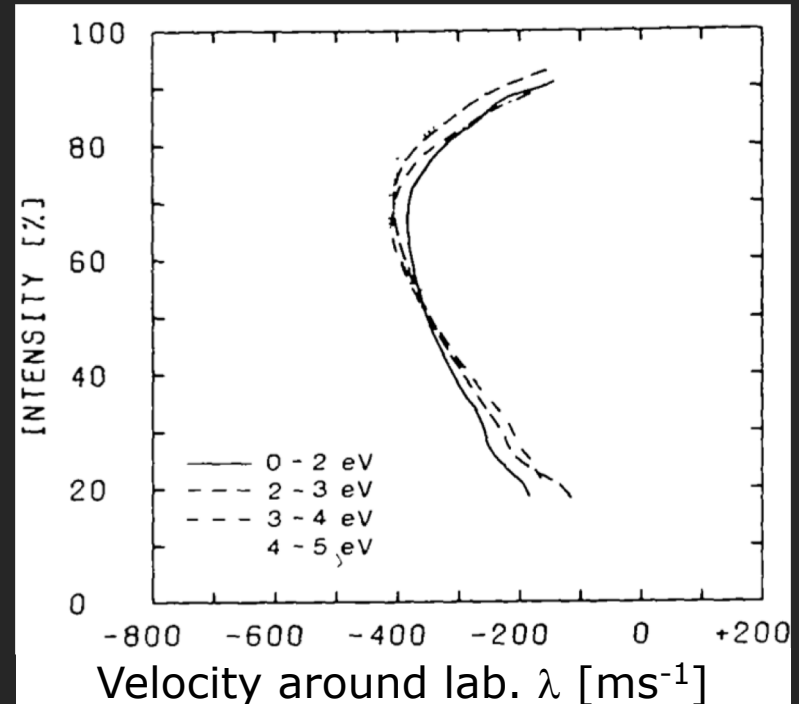
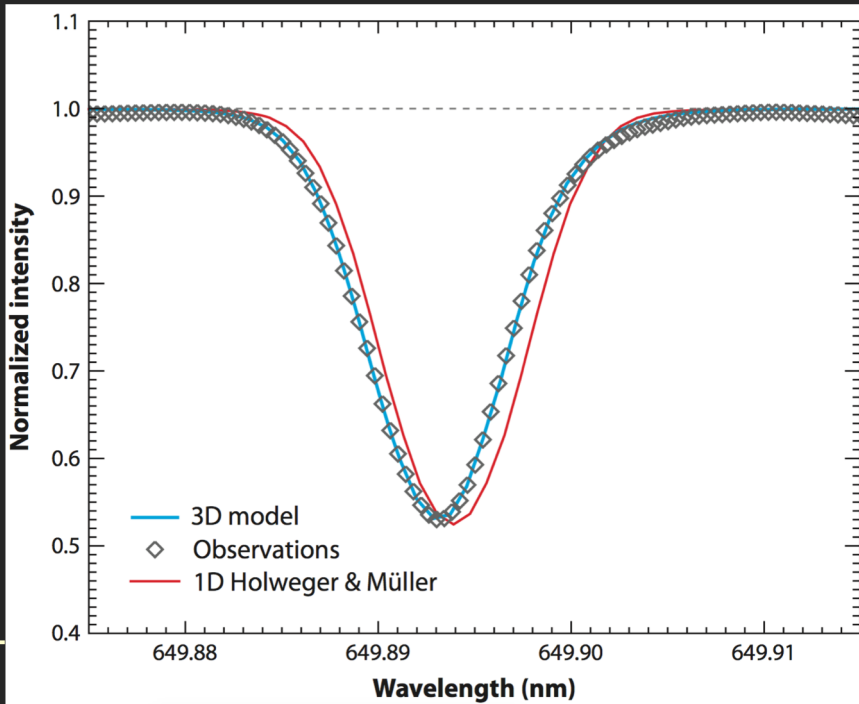


Scalar field theories ... example



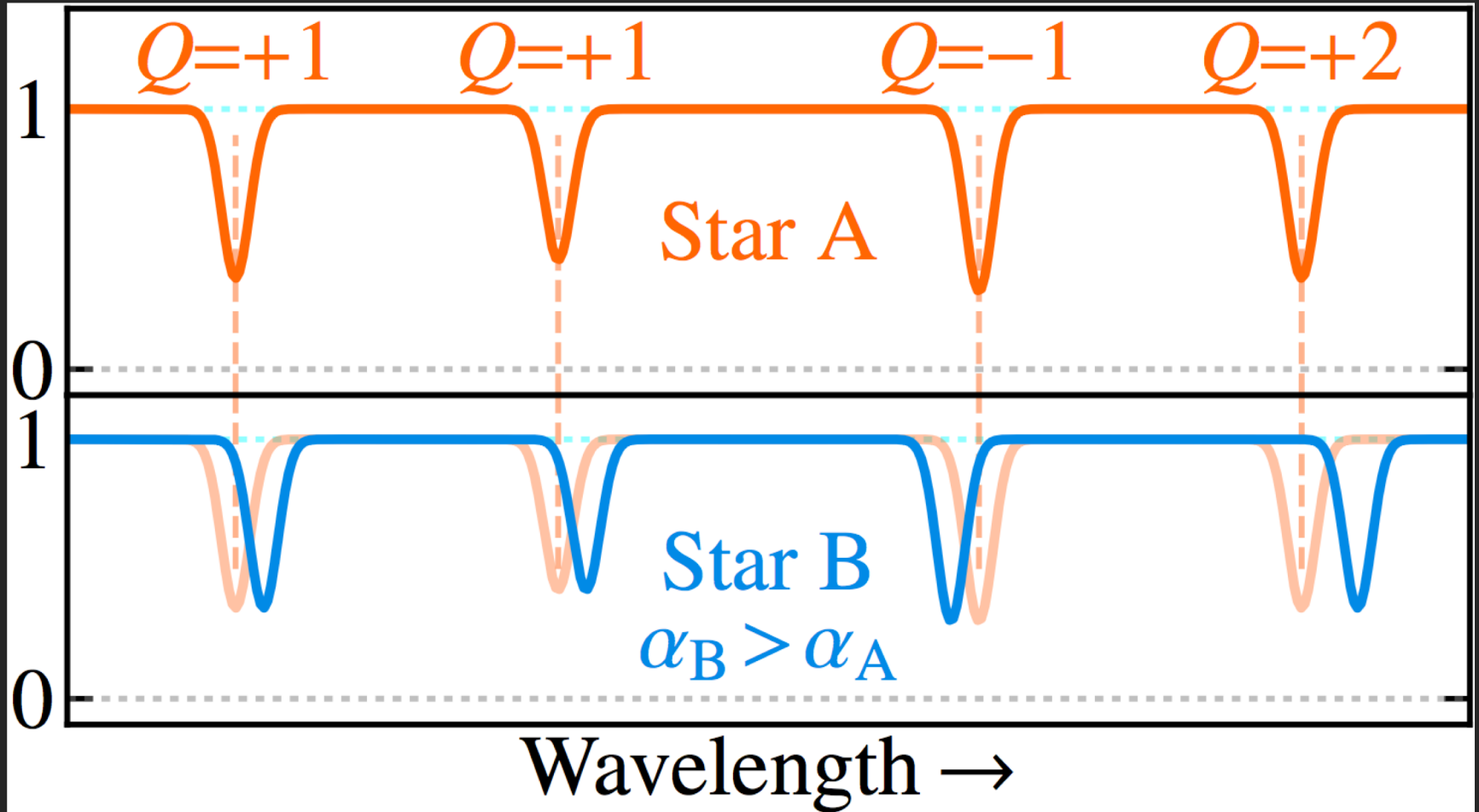
Solar twins

- Problem: Stellar lines are
 - Shifted from lab wavelengths
 - Asymmetric to varying degrees



Twins method: Highly differential

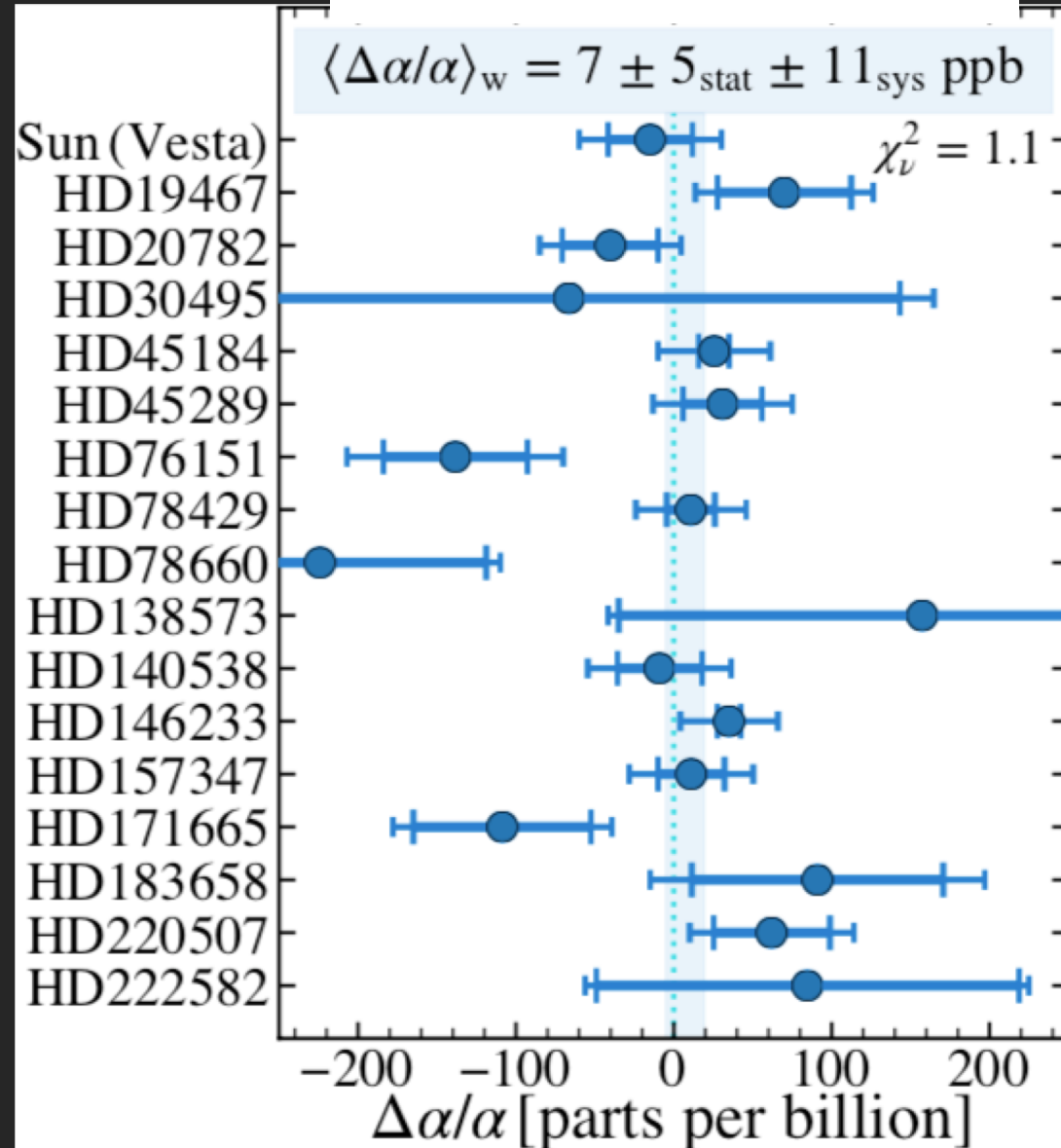
- Compare pair separations of same lines in very similar stars



Local reference results

- 17 transition pairs with known α -sensitivities ("Q")
- 17 solar twins
- ~ 3 –200 exposures per star
- $S/N > 200 \text{ pix}^{-1}$.
- **No evidence of α variation in local $\sim 50 \text{ pc}$**
- Ensemble precision: **12 ppb** \rightarrow Best astro measurement to date

PRELIMINARY



Finding distant twins

- Gaia + SkyMapper photometric pre-selection:
 - Distances, fluxes, colours for stars ≥ 4 kpc away
 - Select candidate "twins" ≤ 4 kpc away



Image: ESA



Image: James Gilbert

Confirming distant twins

- HERMES survey @ Anglo-Australian Telescope:
 - Confirm twins with $R=28,000$ spectra in 4 narrow bands
 - 390 spectra simultaneously down to $V\sim 17.5$.
 - Want ~ 40 best solar twins $\sim 1-4$ kpc closer to Galactic Centre

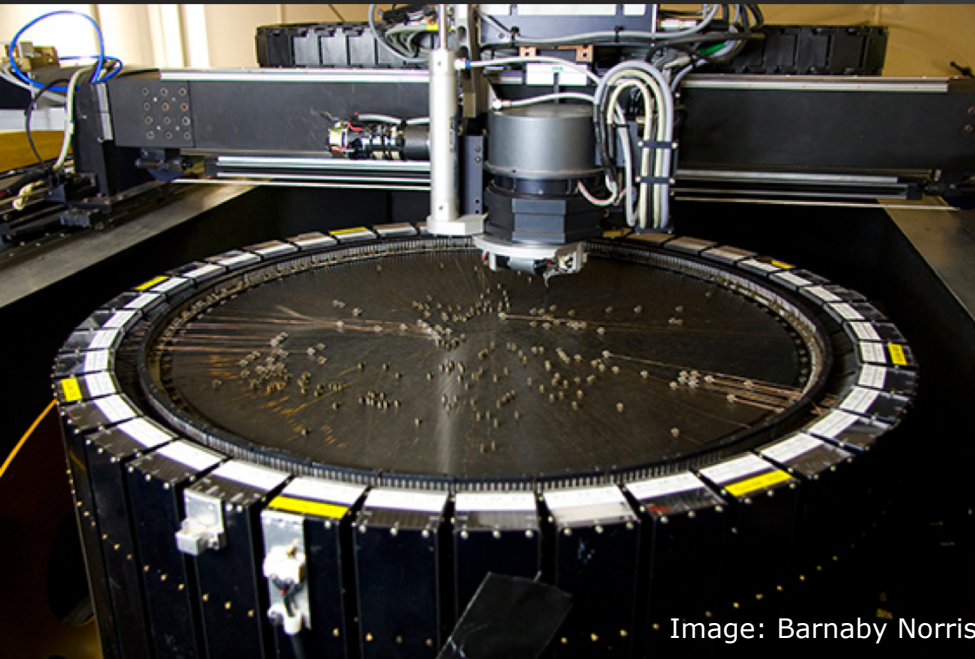


Image: Barnaby Norris

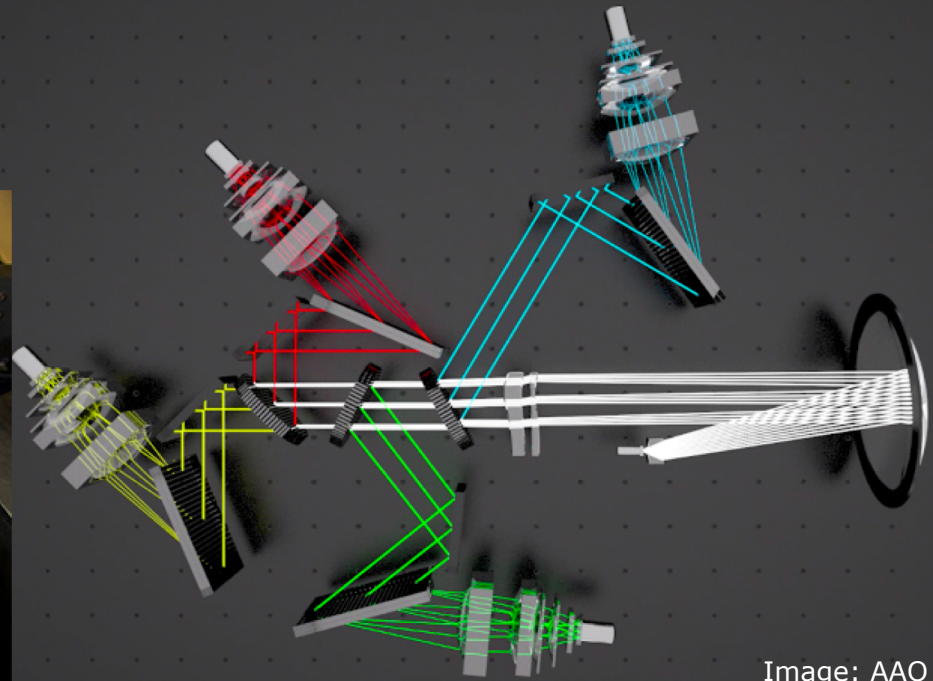
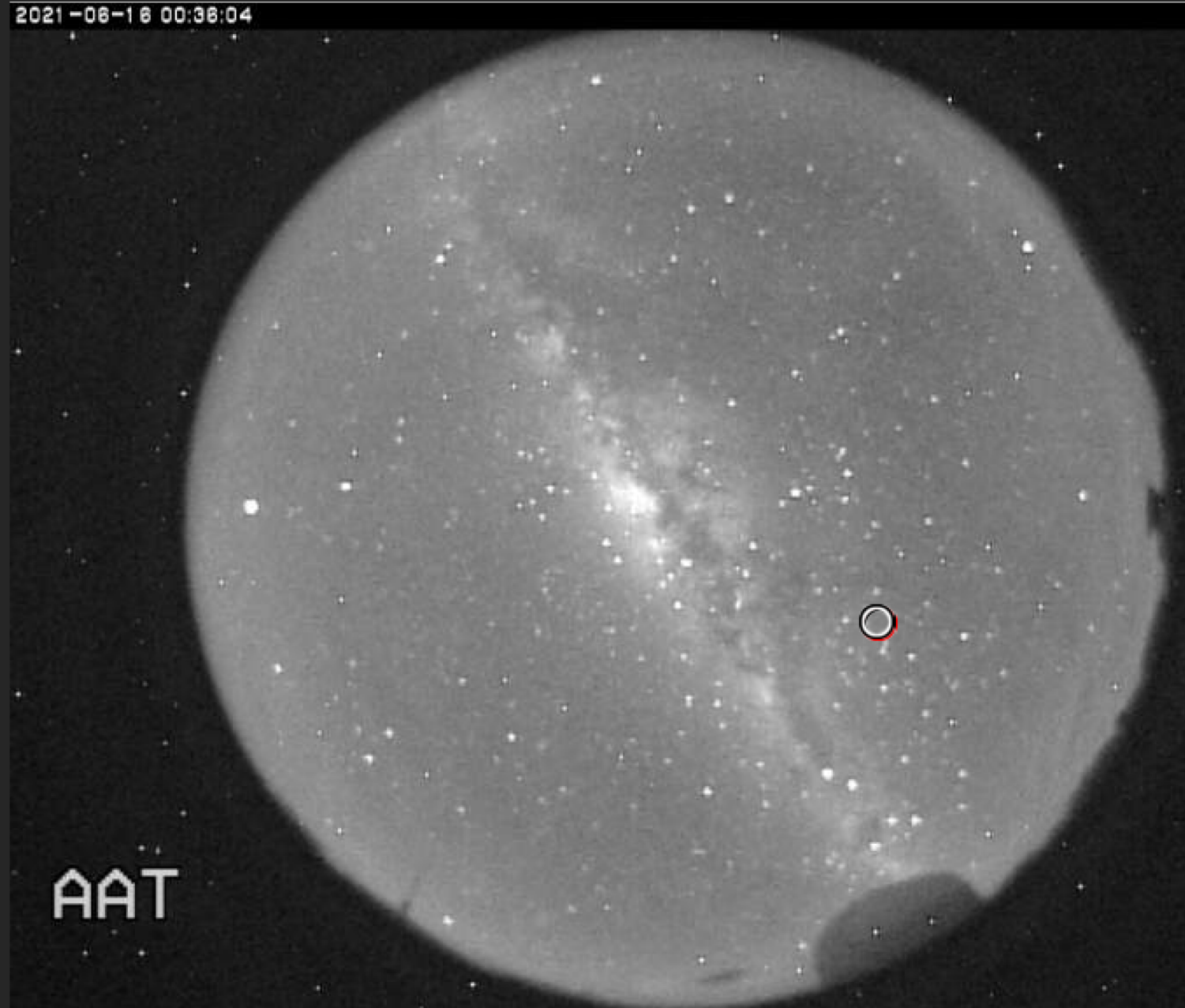


Image: AAO

HERMES survey: June–July 2021

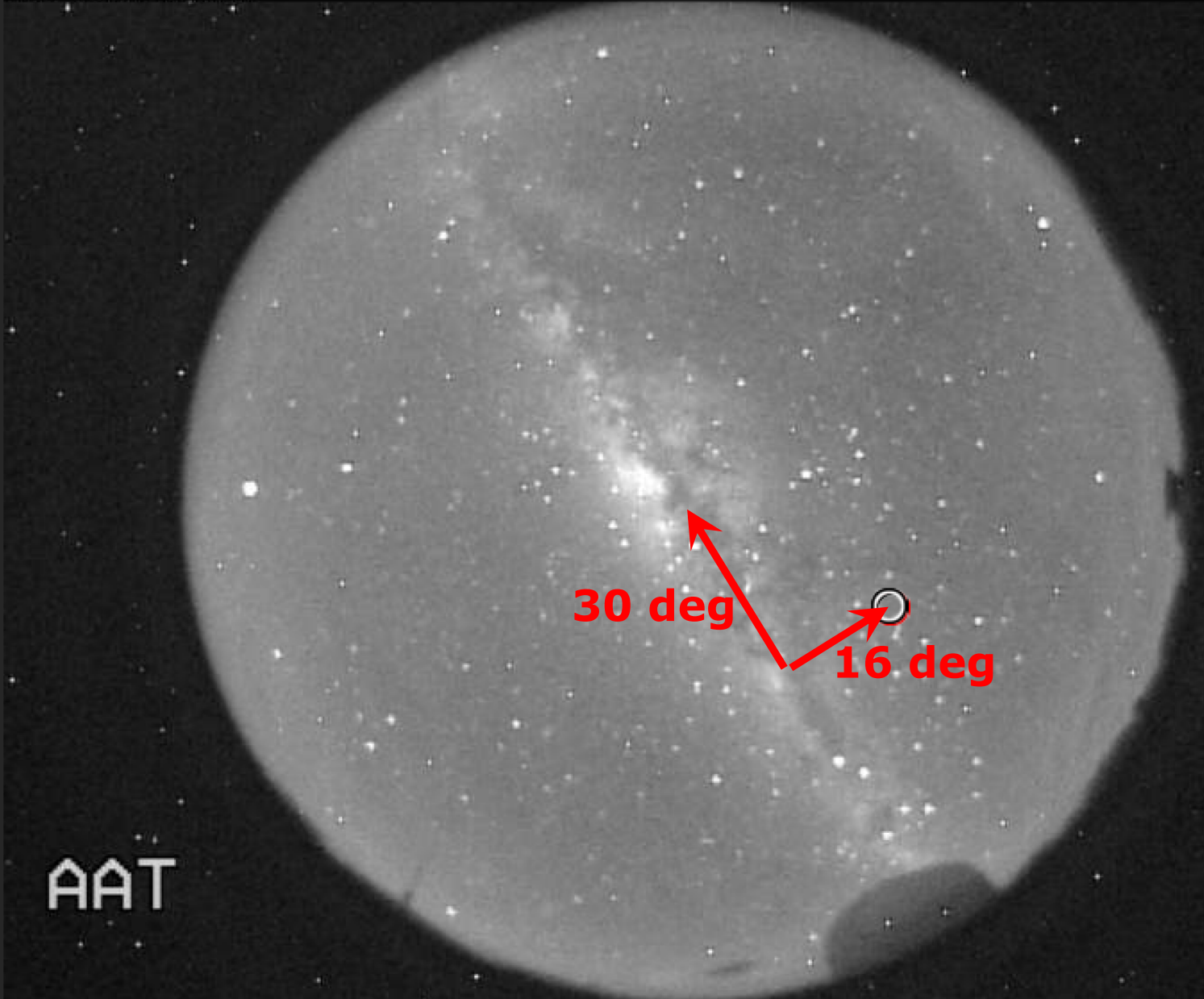
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AAT

HERMES survey: June–July 2021

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ESPRESSO @ VLT

- "Super HARPS":
 - Fibre fed, 'astrocomb' calibrated, super-stable, vacuum, $R=140,000$
- Large Program needed: ~ 40 solar twins up to 4kpc away ($V \sim 17.5$)

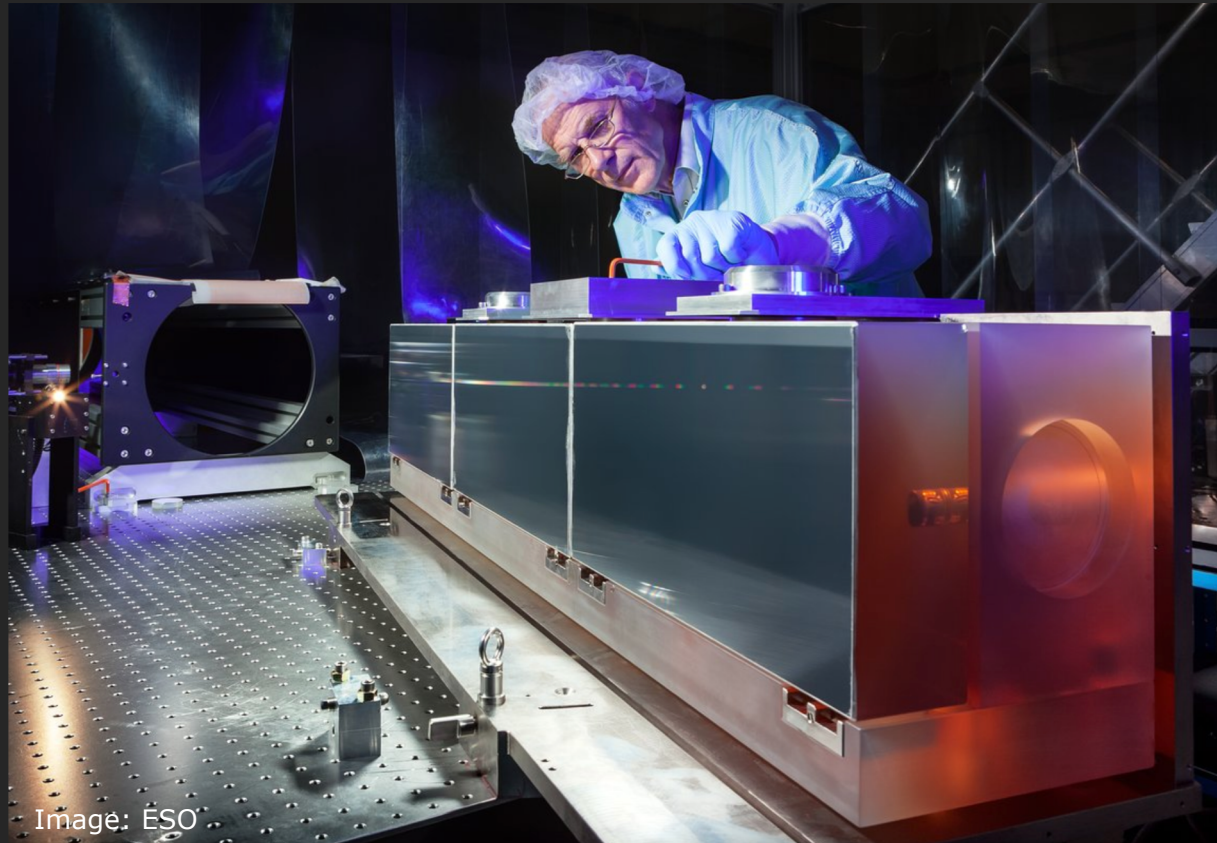


Image: ESO

HRMOS @ VLT

- Almost perfect instrument for solar twins method!
 - FOV: ~ 100 solar analogues within $25'$ out to 4kpc
 - Muiltplex: Provides ~ 100 times more measurements in same time as ESPRESSO!
- **BUT only if:**
 - Wavelength separations can be measured with $\sim 1\text{ms}^{-1}$ calibration accuracy
- Options for simultaneous calibration:
 - Laser frequency comb
 - Fabry–Pérot etalon
 - Photonic comb? – see Janez Kos's talk on Friday

Conclusions

- Twins method can test α -Dark Matter connection
- HARPS local reference: ~ 13 ppb precision in $\Delta\alpha/\alpha$
- Distant solar twins discovered:
 - HERMES survey $\rightarrow \sim 100$ confirmed $\lesssim 4$ kpc away
 - VLT/ESPRESSO Large Program of best ~ 40 for $\Delta\alpha/\alpha$
- HRMOS needs wavelength calibration accuracy!
 - $\sim 1\text{ms}^{-1}$ accuracy in λ separation between any two lines
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