HETDEX & VIRUS: Panoramic Integral Field Spectroscopy with 35k fibres

Gary J. Hill, McDonald Observatory
(PI, on behalf of the VIRUS team and HETDEX consortium)

HETDEX
Hobby-Eberly Telescope Dark Energy Experiment

Overview

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- HETDEX Motivation
  - Dark Energy evolution
  - but really a vast blind integral field spectroscopic survey
- What HETDEX comprises
- VIRUS and HET upgrade status
- The HETDEX survey and example science
- HETDEX ∩ SDSS ∩ APERTIF
- Replicated spectrographs in astronomy

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HETDEX
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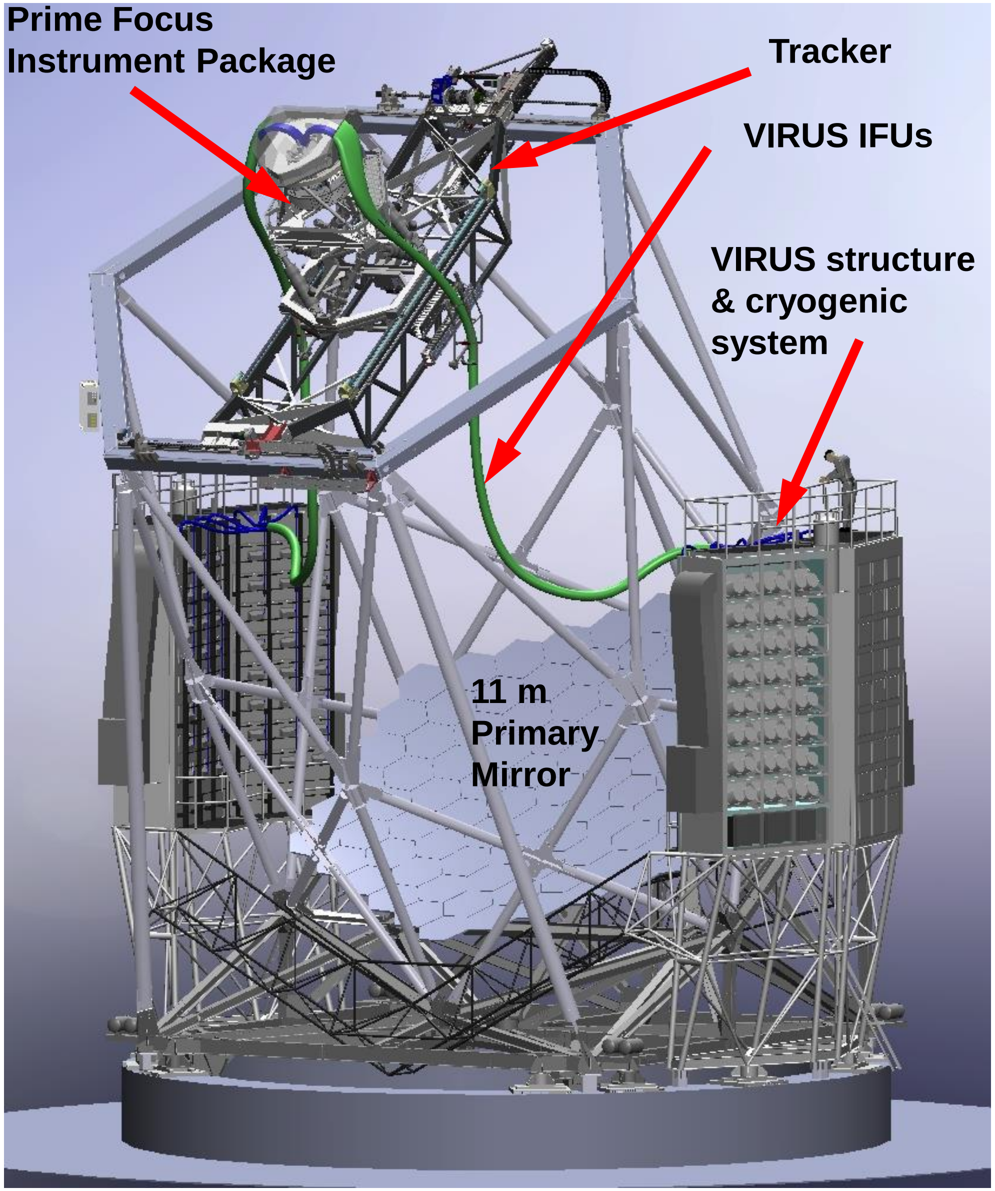
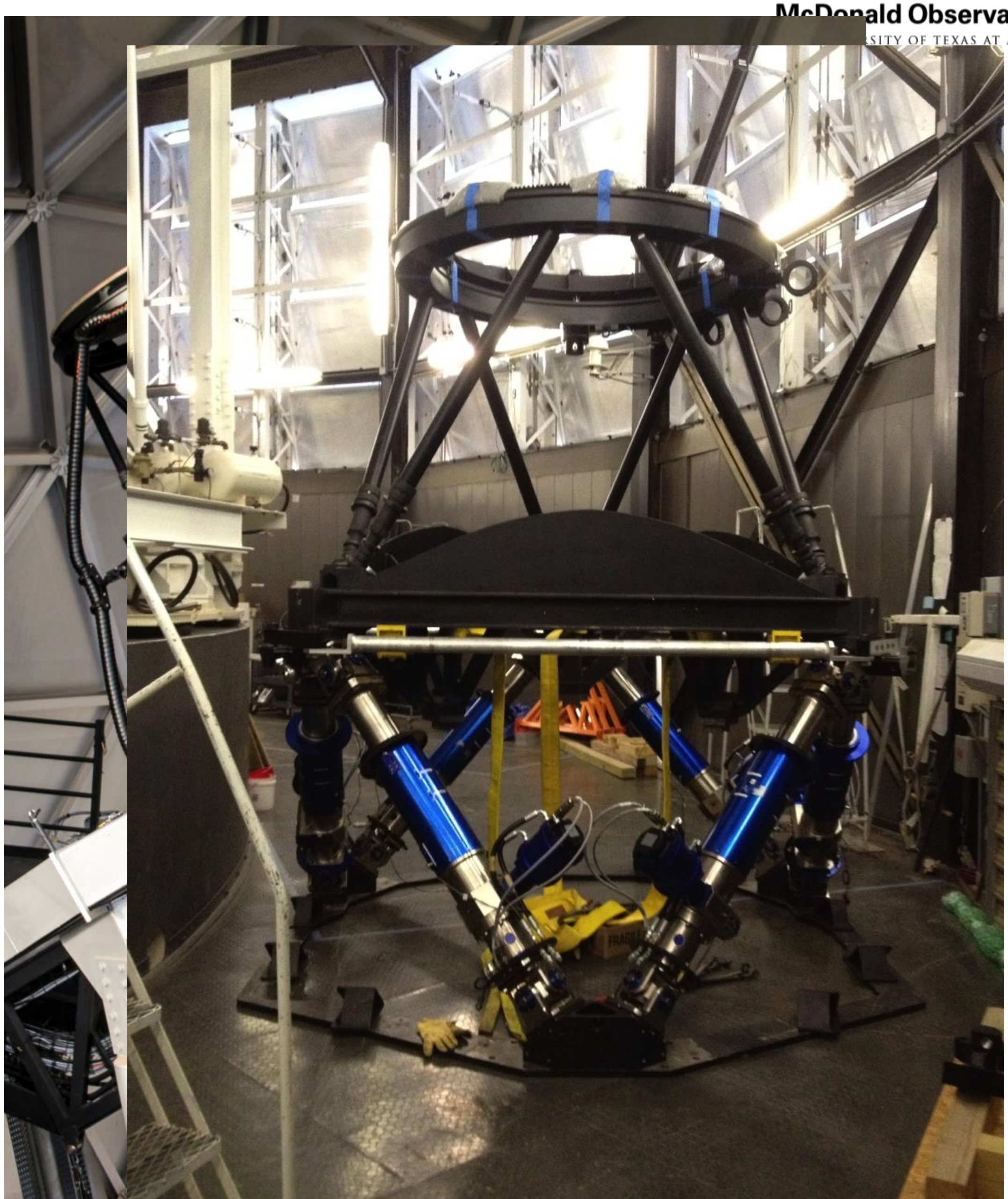
- HETDEX is:
  - Upgrade of HET to have a new wide 22' field of view
  - Deployment of the hugely replicated spectrograph, VIRUS, putting ~35,000 fibers on sky, per exposure
  - 3-5 year blind spectroscopic survey
- HETDEX will:
  - Map 0.8 million LAEs (1.9 < z < 3.5) and a million [OII] emitters (z < 0.5)
  - measure expansion history to 1% precision at z~2.4
    - Direct 5-σ detection of DE if Λ
    - Strong constraint on dark energy evolution
    - Structure growth (gravity)
    - Curvature of the universe
- Very complementary to BOSS, DES, eBOSS etc.
- HETDEX is a unique blind spectroscopic survey with many other applications
  - In particular in galaxy evolution
  - Finds emission line objects with faint continua



HET Wide Field Upgrade

- Tracker has been installed and functional for ~10 months
- Telescope control software is tracking, guiding and offsetting

HET Wide Field Upgrade



- Tracker achieves 10 μm precision over 7 m travel scale
- Ready for arrival of Wide Field Corrector

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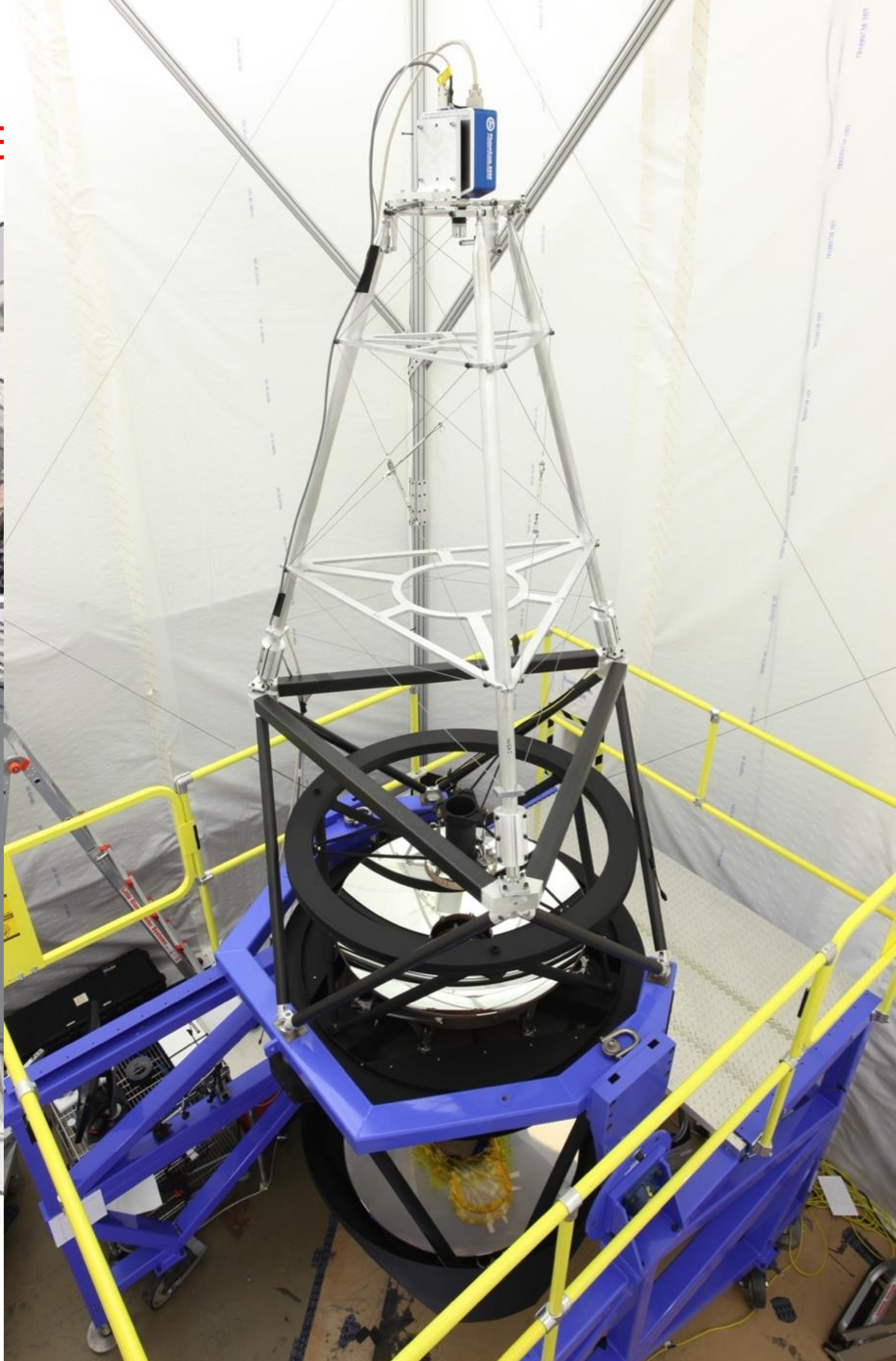
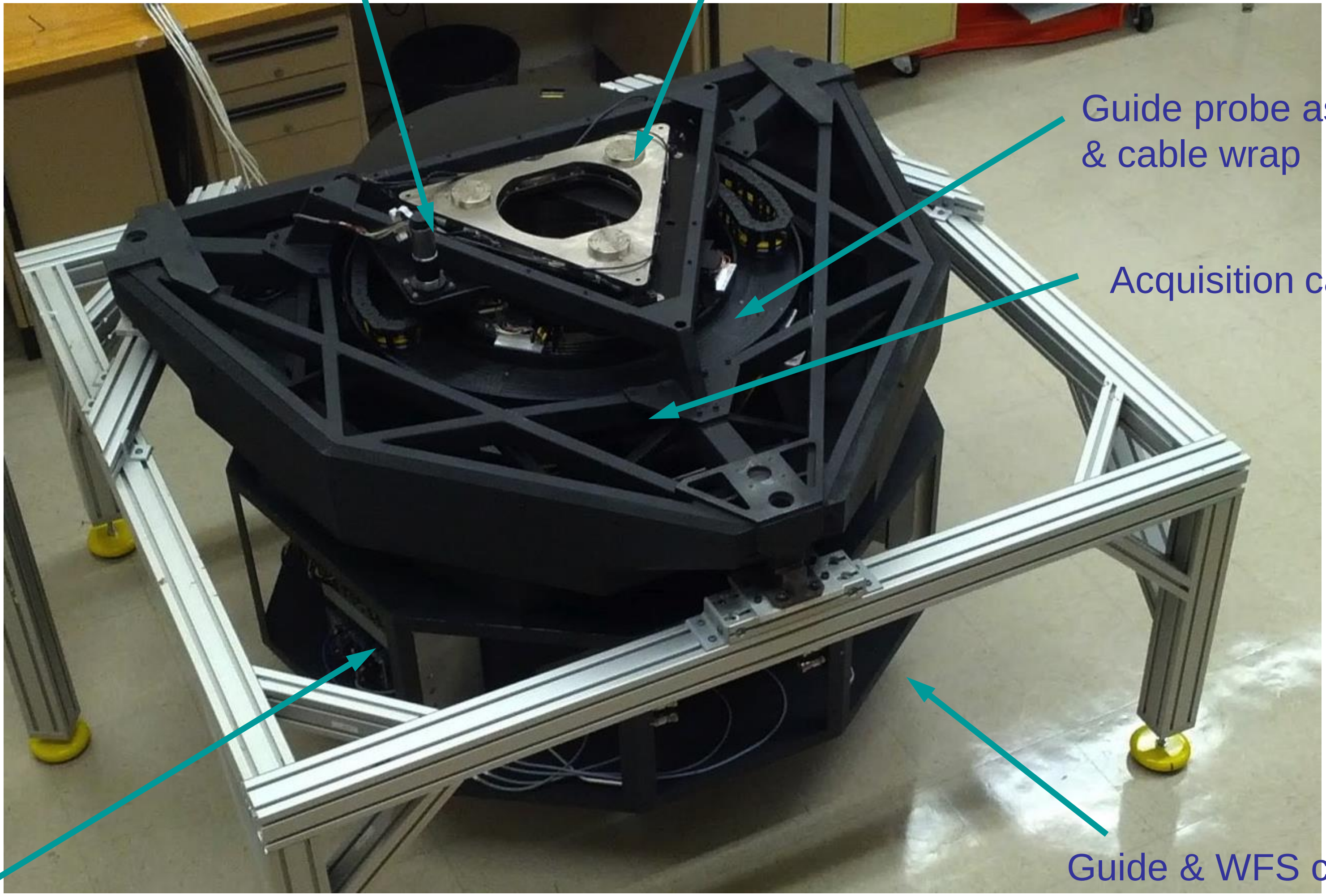
Wide Fie

- Four mirror corrector with meter-sized optics and large aspheric departures
  - 22 arcmin diameter field of view
  - 10 m pupil diameter
  - f/3.65 and telecentric optimized for feeding fibers
- Subcontracted to the University of Arizona College of Optical Sciences
- Challenge for polishing, testing, mounting, and alignment
- High reflectivity coatings cover 350 to1800 nm
- Unit is sealed and purged with nitrogen to protect coatings

- Pacing item in WFU
- Pre-ship Readiness Review in April

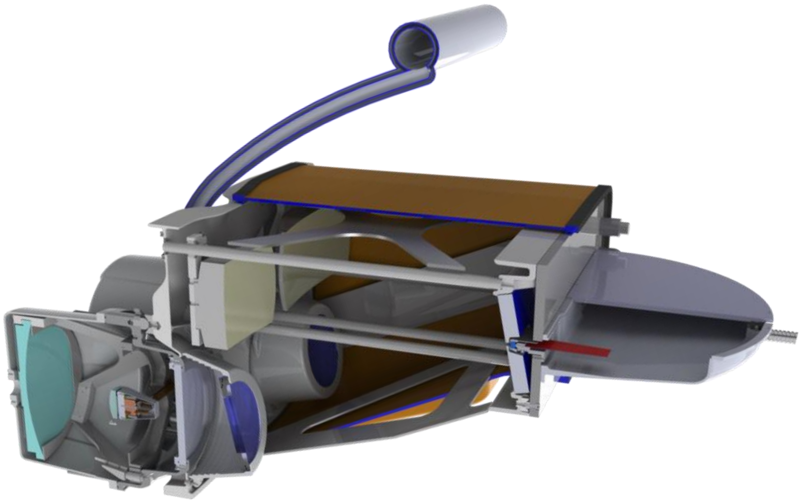


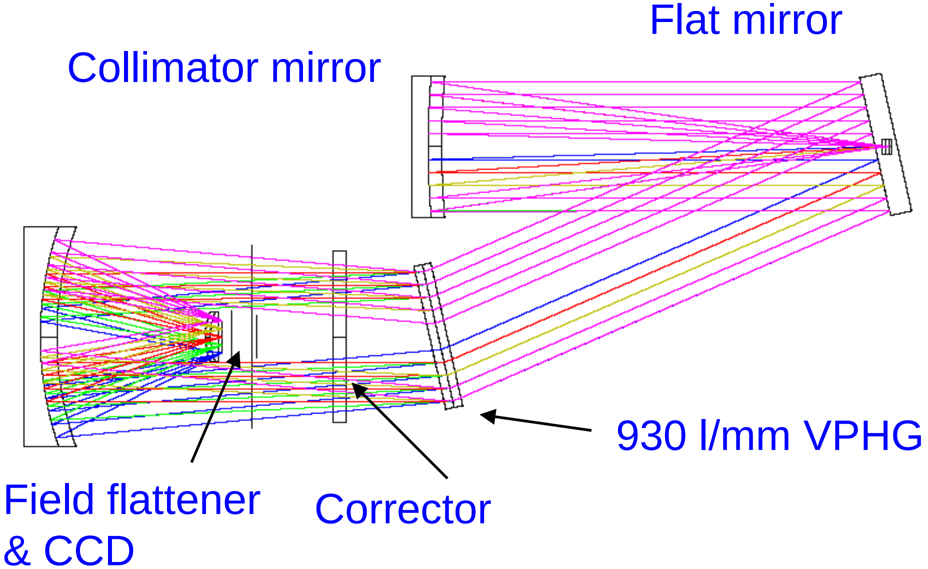
Prime Focus Instrument Package



VIRUS

- VIRUS is a simple spectrograph replicated on large scale
  - 156 channel fiber-fed IFS placing 34,944 1.5" dia fibers on sky (266 μm core)
  - 350-550 nm coverage and R~700 on custom 2kx2k CCDs
  - 125 mm beamsize to accommodate catadioptric camera needed for UV coverage
  - Optimized to detect LAEs via blind integral field spectroscopy
- VIRUS protoype has been used at McDonald 2.7 m for 8 years
  - Used for HETDEX pilot survey (Adams et al 2011, Blanc et al 2011)
  - Proved the optical design, principles of the mechanical design, and the data reduction software





Lee et al. Proc SPIE 7735-140 (2010)

VIRUS hardware components

- Each unit has two channels fed by 448 fibers
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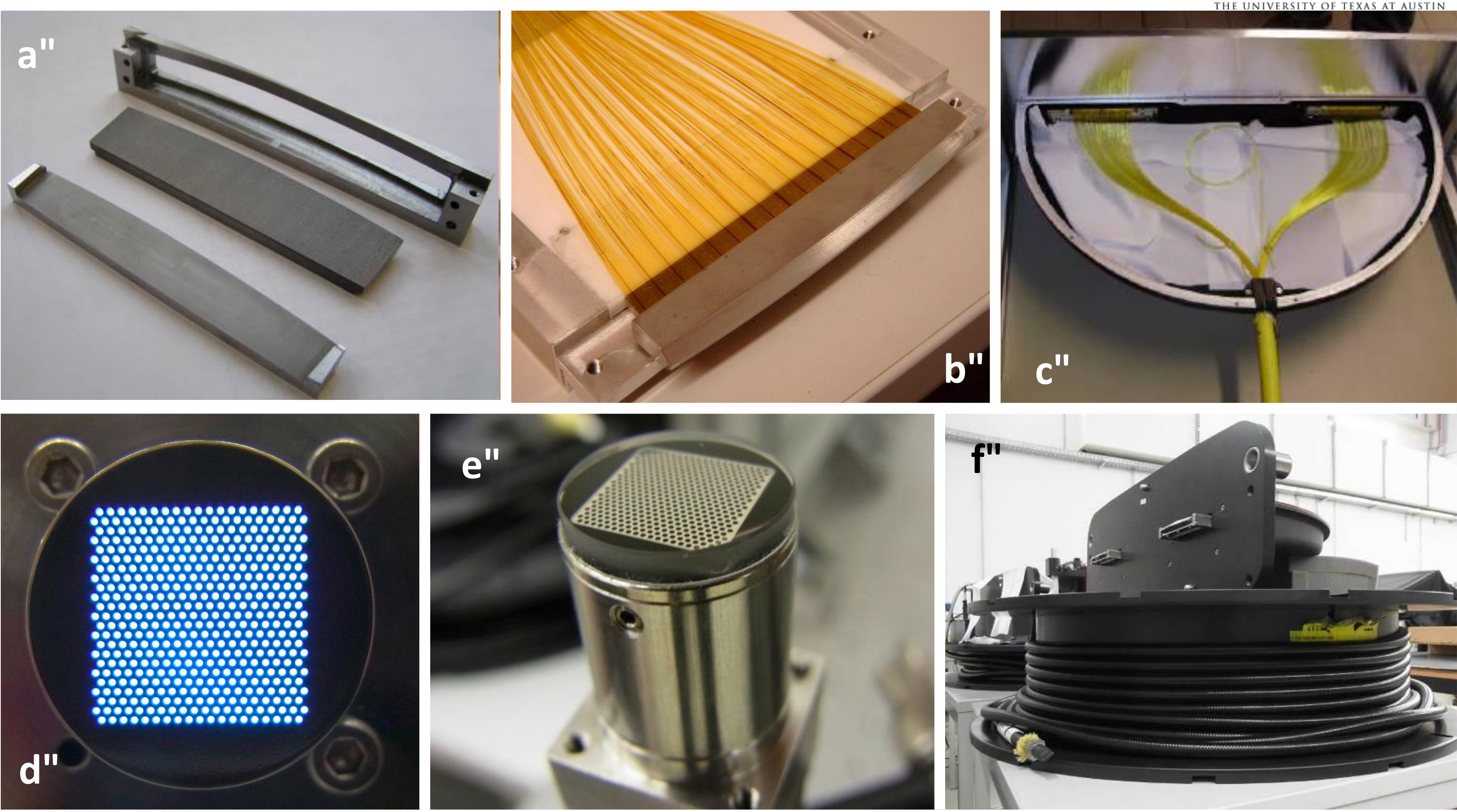
Fiber IFUs at AIP



- Production at AIP with 3 vendors
- 62 of 78 with production completing in 2015

Cure data reduction software

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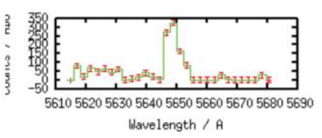
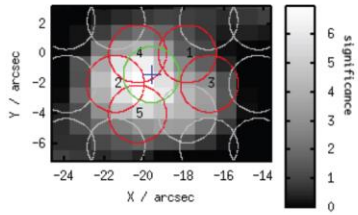
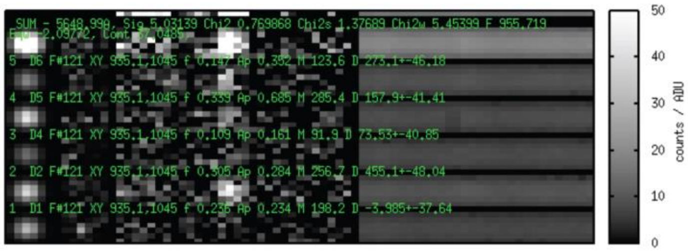
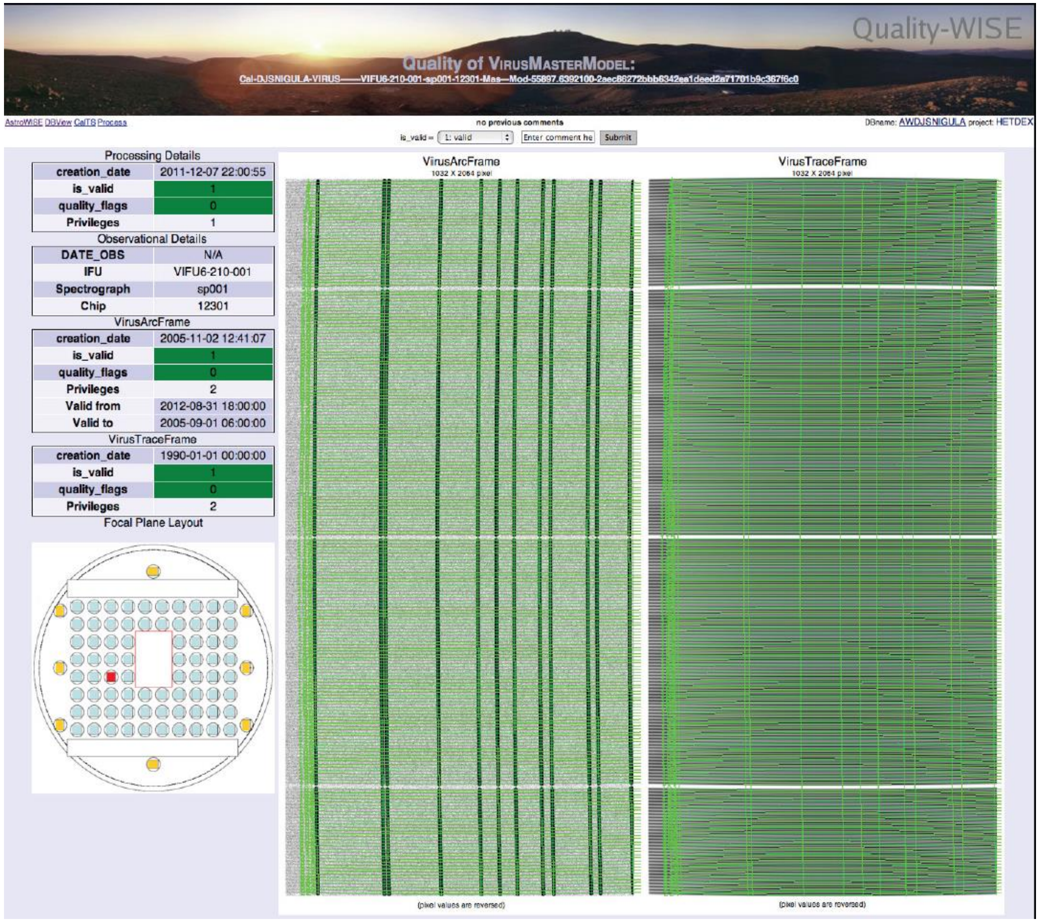
- MPE/USM responsible for pipeline
- VIRUS is highly parallel in hardware and software
  - Prototype (VIRUS-P) tested all aspects of the system, including data reduction pipelines
- HETDEX will be processed with *Cure*
  - Implemented within the *astrowise* environment
- Have capability to simulate and process an entire VIRUS dataset
  - MPE cluster with 20 cores, 64GB Memory, 200 TB disk space
- Data volume 120 GB/night and 20 TB in three year survey









Snigula et al ASP Conf. Series, 485, 447 (2014)

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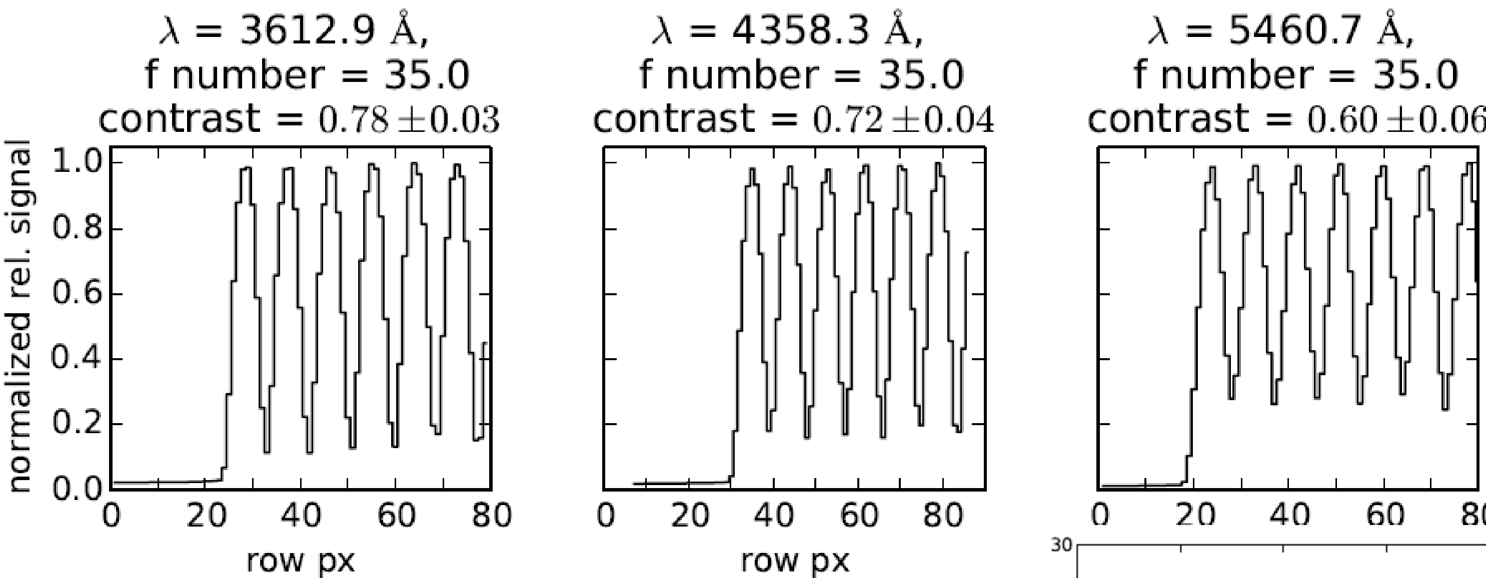
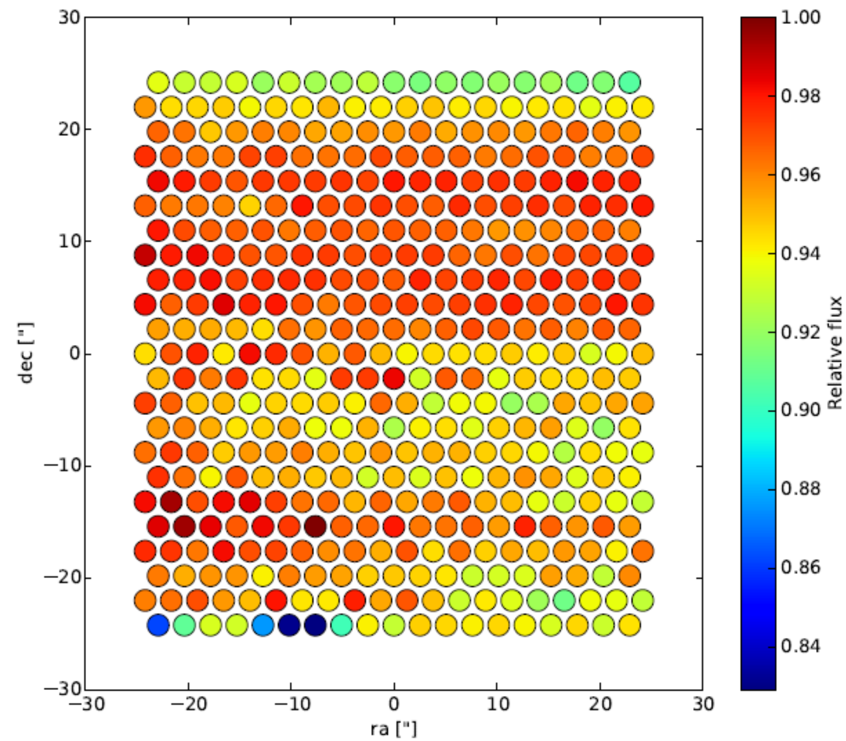
VIRUS performance



- Spectrographs and IFUs go through characterization before shipping
  - Using fiducial spectrograph or fiducial IFU as appropriate
- Image quality exceeds specifications, typically
  - Due to deterministic alignment technique using wavefront sensing
- Uniformity over IFU typically σ~3%
- 0.4% broken fibers (10x better than spec)
- Read noise within spec < 4 e$^-$
  - Read time 20 seconds for 333 Mpxl



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Layout on sky

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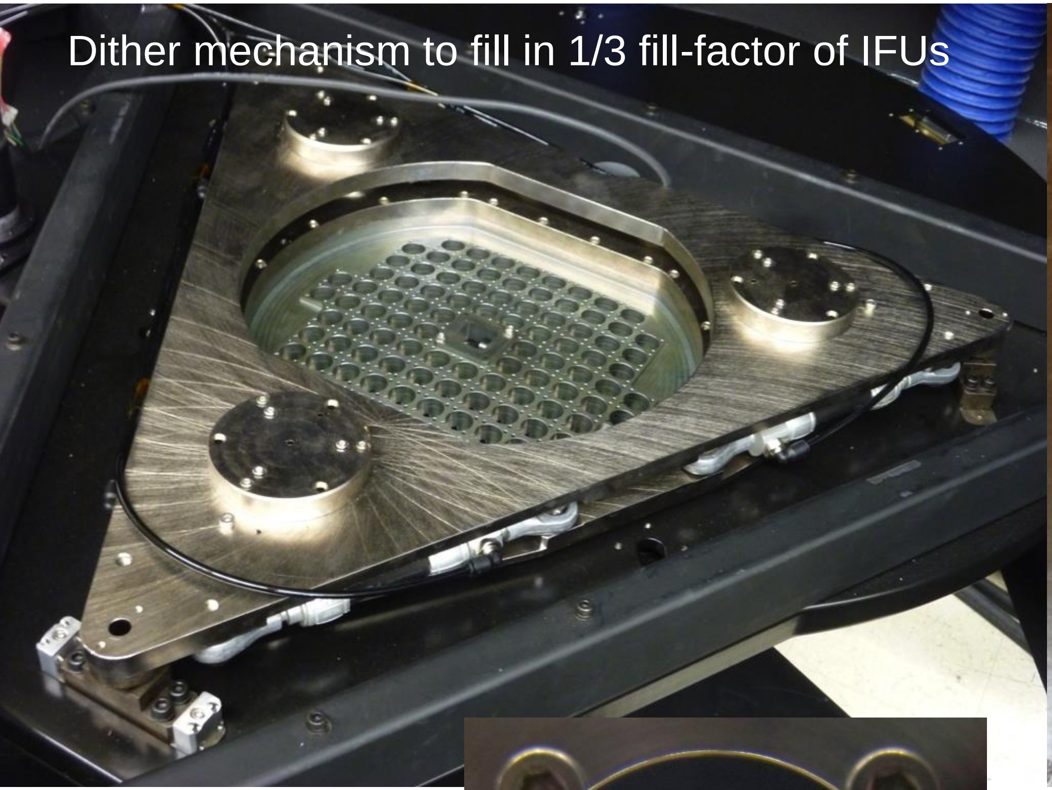

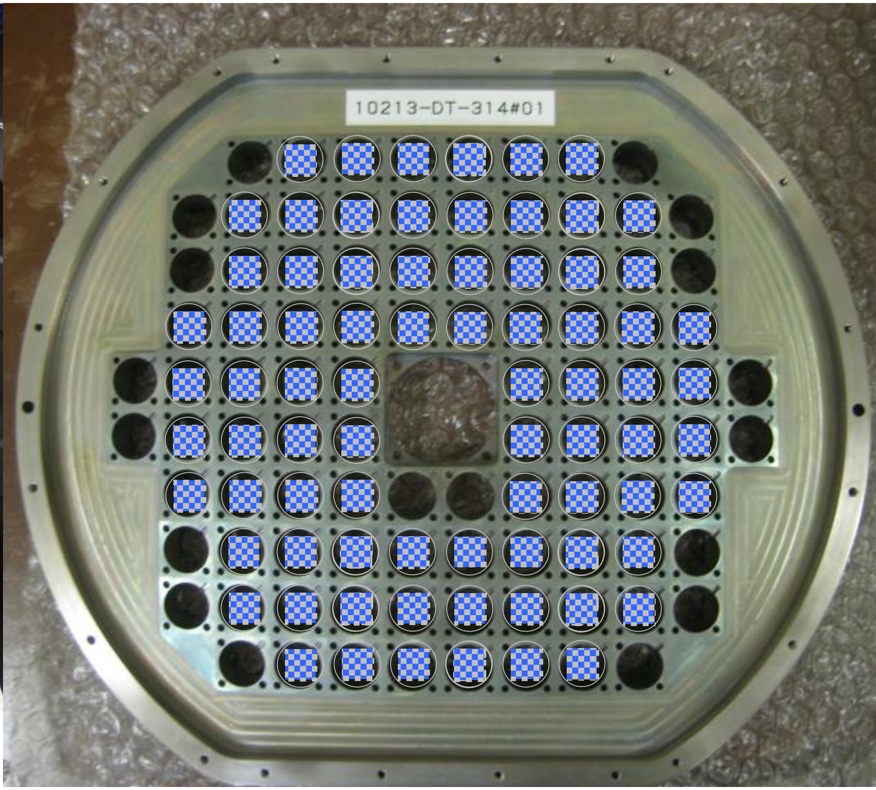

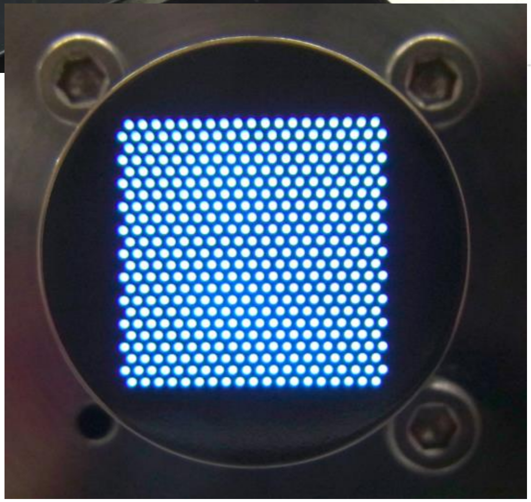

Input head mount plate with 78 IFUs
50 arcsec spacing within ~16 arcmin field

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Spectrographs & IFUs are piling up

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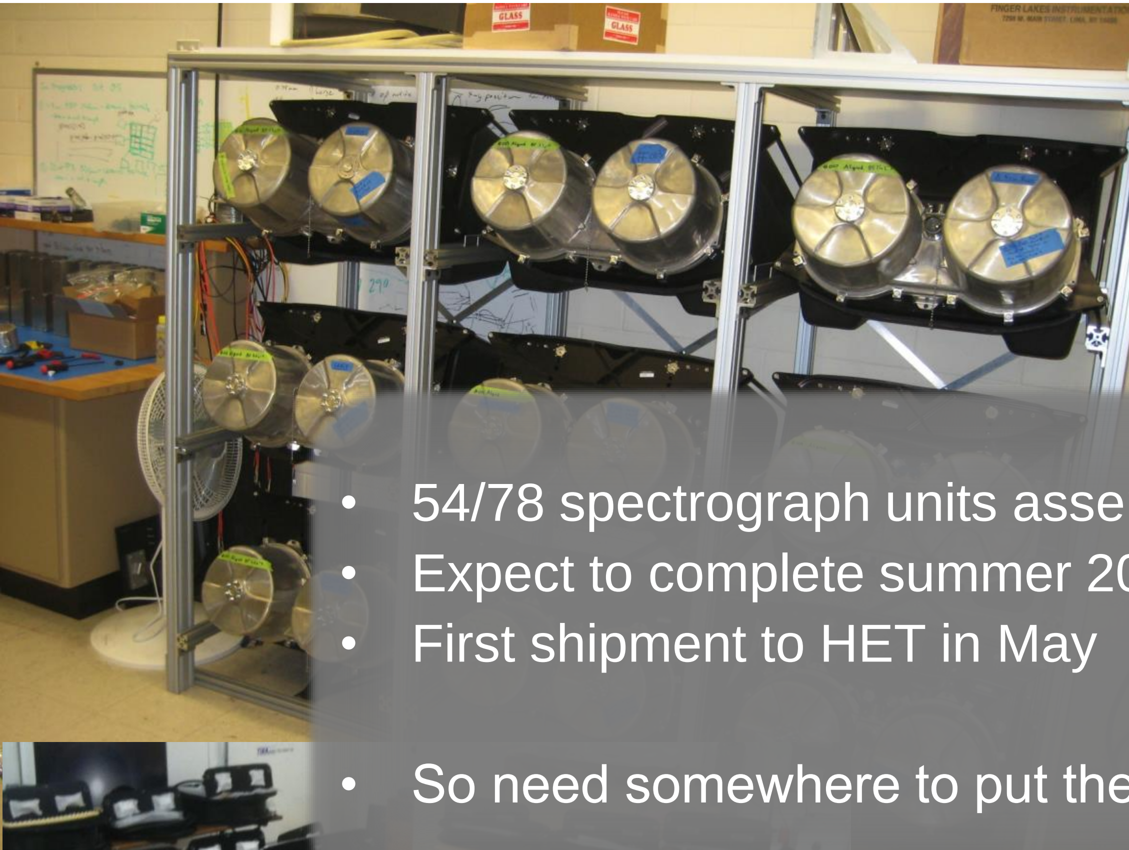
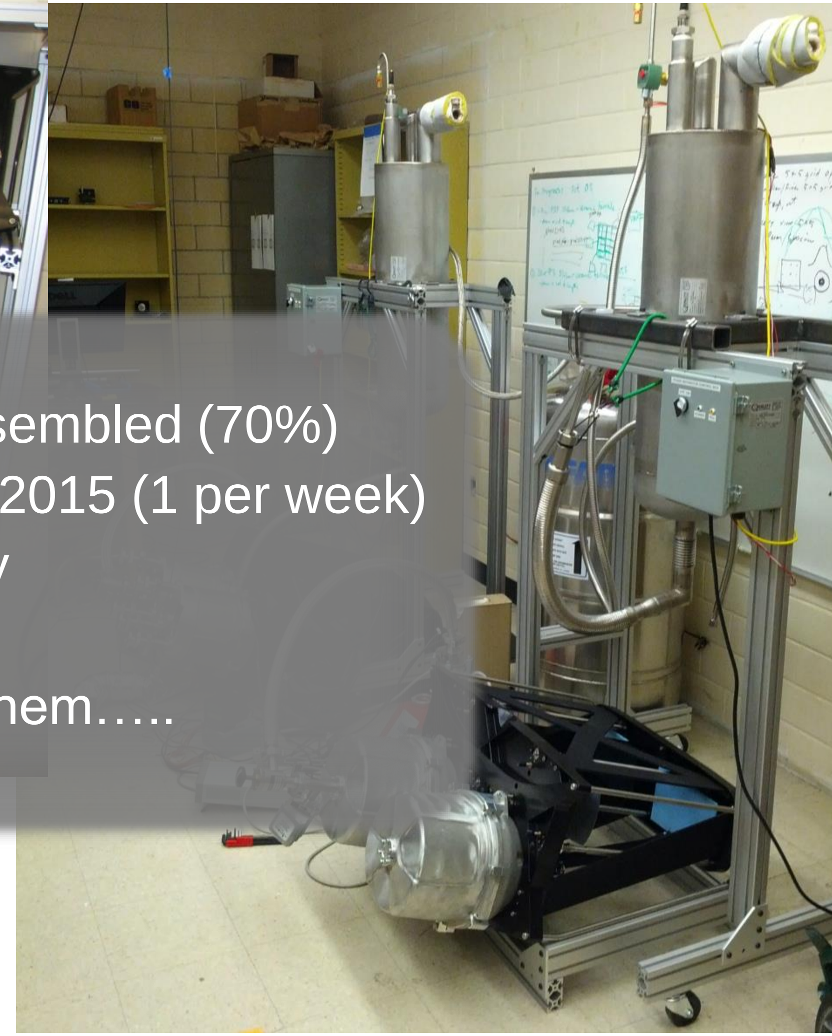


- 54/78 spectrograph units assembled (70%)
- Expect to complete summer 2015 (1 per week)
- First shipment to HET in May

- So need somewhere to put them…..



Spectrograph alignment UT Austin

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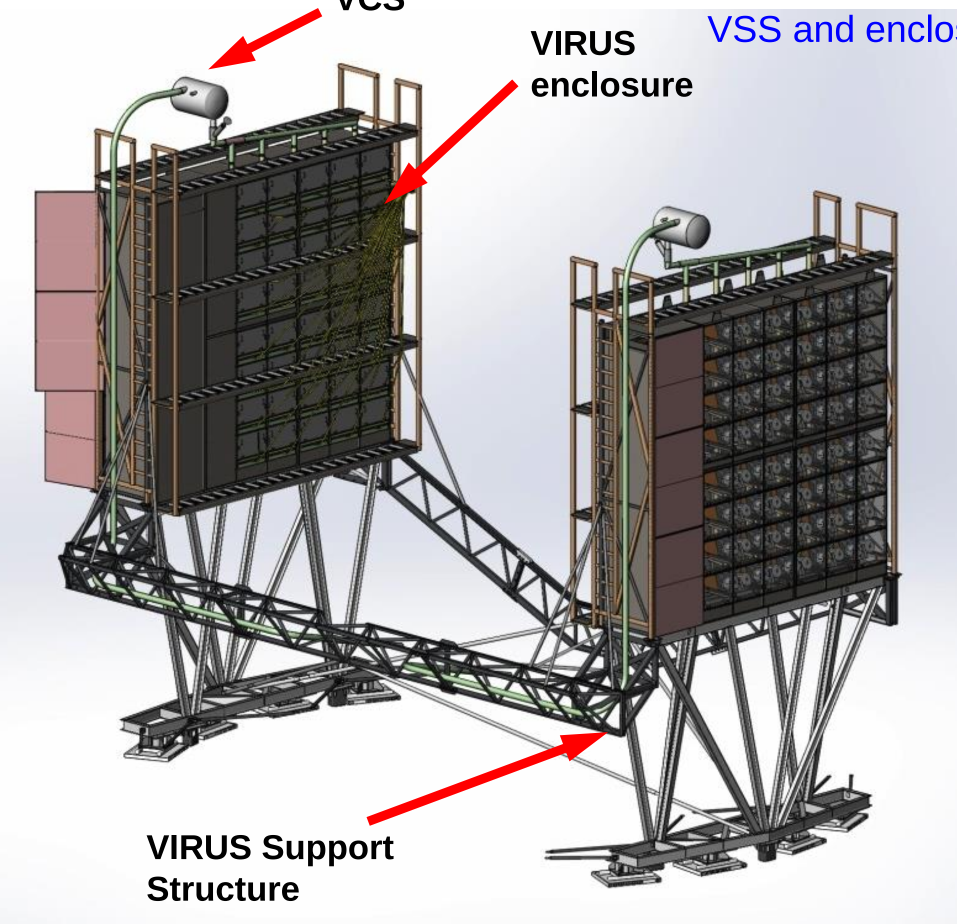
VIRUS infrastructure

- Enclosures for VIRUS are huge clean rooms with heat removal
- Ride on VIRUS support structure (VSS)
  - Lifted by air bearings for azimuth moves; not coupled to the telescope structure except at base
- VIRUS Cryogenic System (VCS) supplies LN to each unit to cool detectors



VSS and enclosures

VSS installed on HET

Hobby-Eberly

nic System

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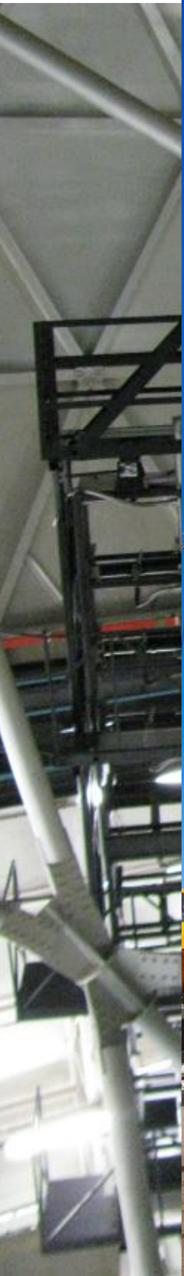

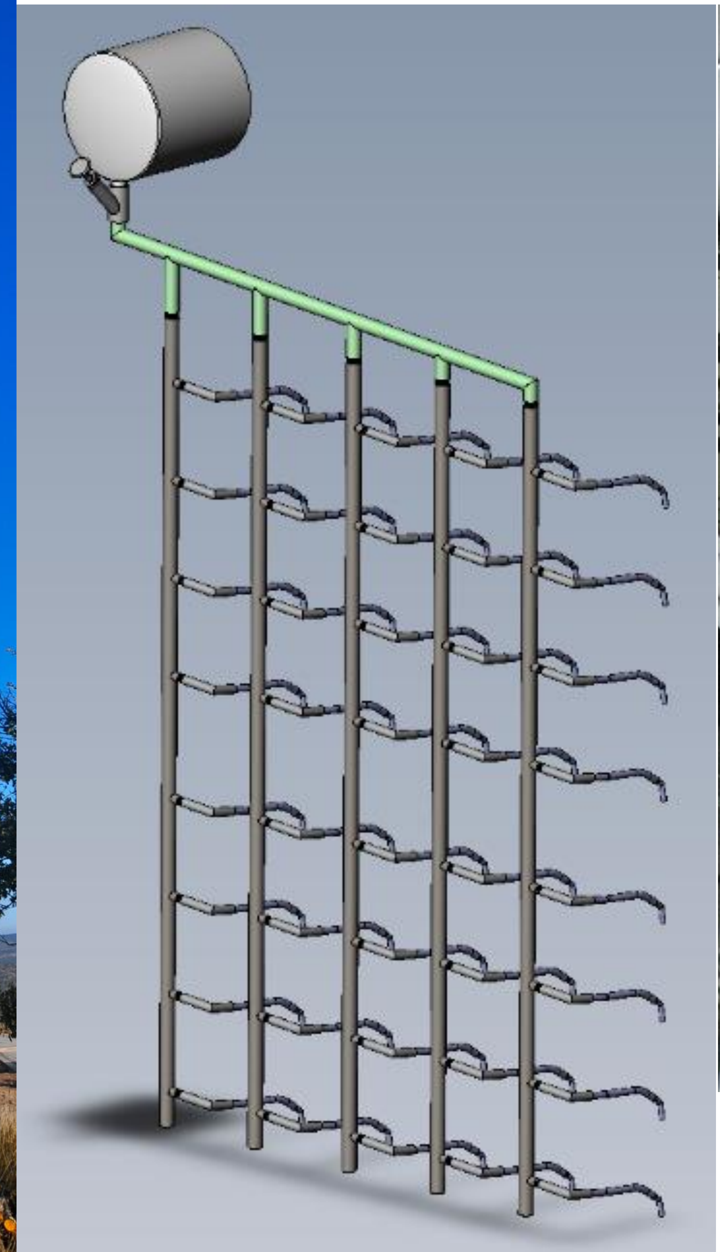


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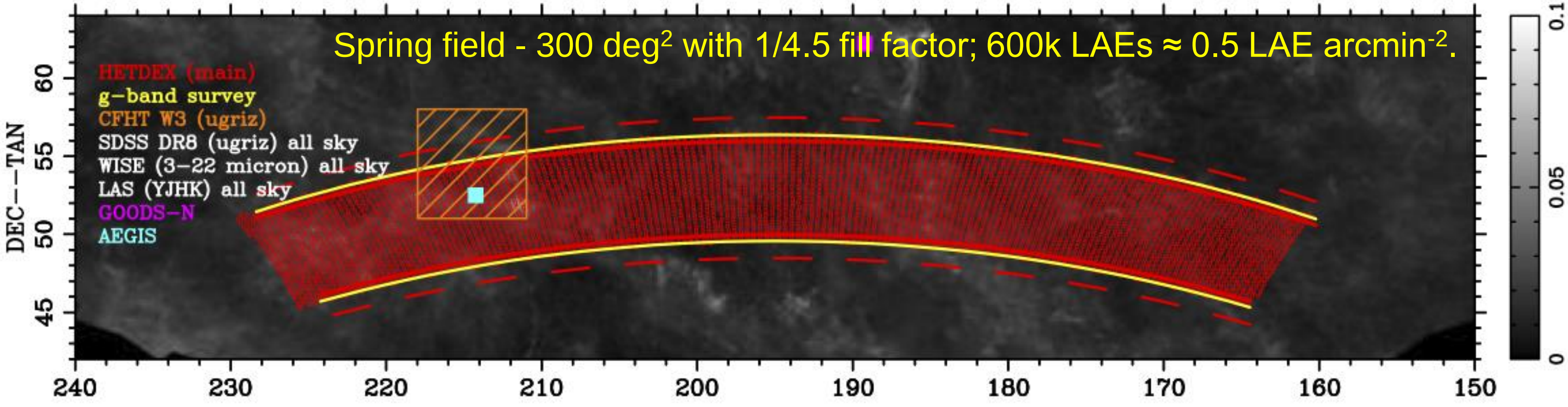
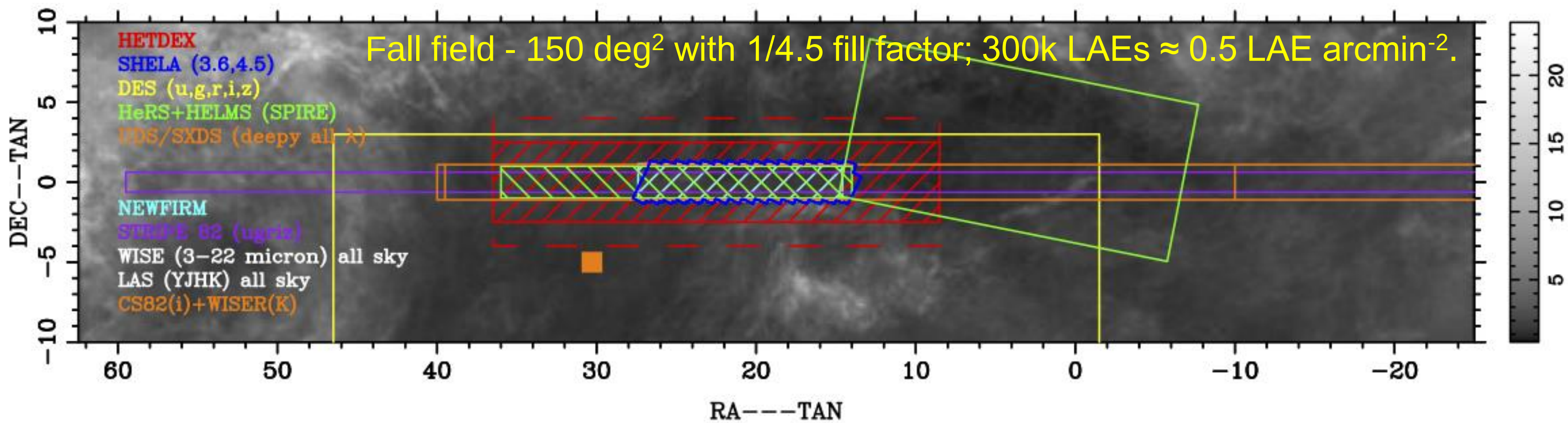
HETDEX Survey





- Spring field will have g-band imaging over whole area (KPNO, Subaru)
- Each 20 minute observation will detect ~125 LAEs and 150 [OII] emitters
- Survey will use all the dark time with seeing < 2.0” and extinction < 0.2 mag
- Simulations including real weather patterns show 3 years to complete
- Early 2016 start

Example science from HETDEX

Cosmology

- Detection of dark energy at z~2.4
- Constrain evolution of DE
- Curvature of Universe to 0.1%
- Growth factor to test GR
- Tight upper limit on total neutrino mass
- Detection of cosmic web in emission

Dissecting Galaxies

- Dark matter in nearby galaxies
- Stellar populations at large radii
- Galactic structure from stellar kinematics
- Outflows and greater galaxy environment
- Map nearby galaxy clusters and groups (z<0.5)
- Finding the first stars in Galaxy

Galaxy Evolution

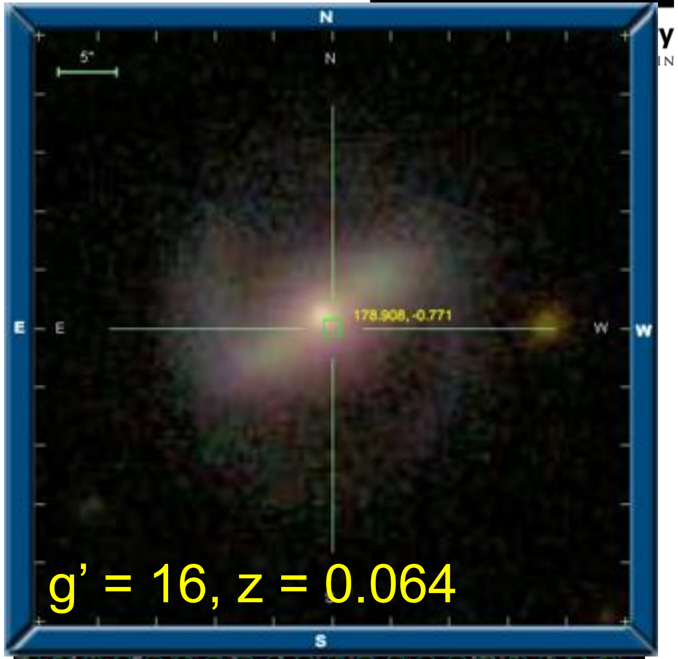
- Nature of early galaxies at peak of star formation in universe and relation to environment traced by LAEs (SHELA)
- Evolution of star formation at late times (z<0.5 with ~1M [OII] emitters), particularly for low masses
- SFR vs gas for z<0.4 with ~0.5M [OII] emitters stacking HI in APERTIF (100k at z<0.15 where APERTIF can expect direct detection)
- AGN/QSOs with no color selection effects up to z~3.5 (10,000 @ z>2)

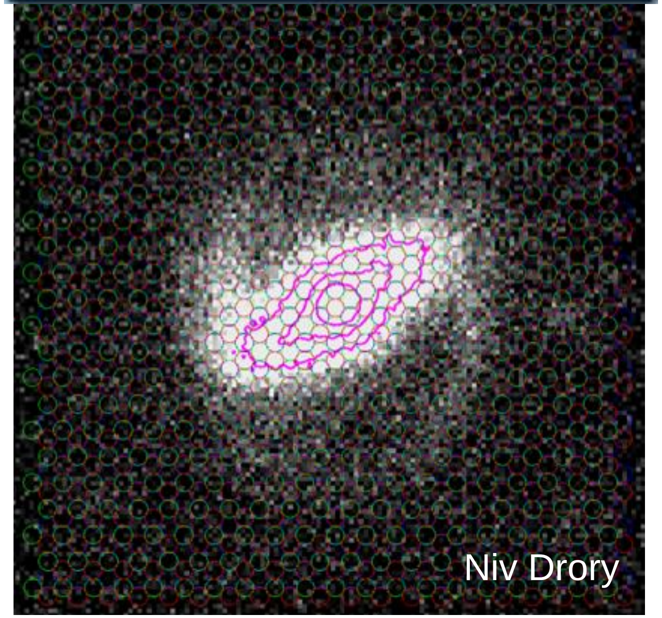
Nearby stars, galaxies, & clusters

HETDEX ∩ SDSS (survey realization)

44714	stars with g<22 (S/N ≈ 3)
50579	galaxies with g<22 (S/N ≈ 3)
789	stars with SDSS spectrum in IFUs
4204	galaxies g<17 (rotation curves)
9101	galaxies g<19 & D>5”

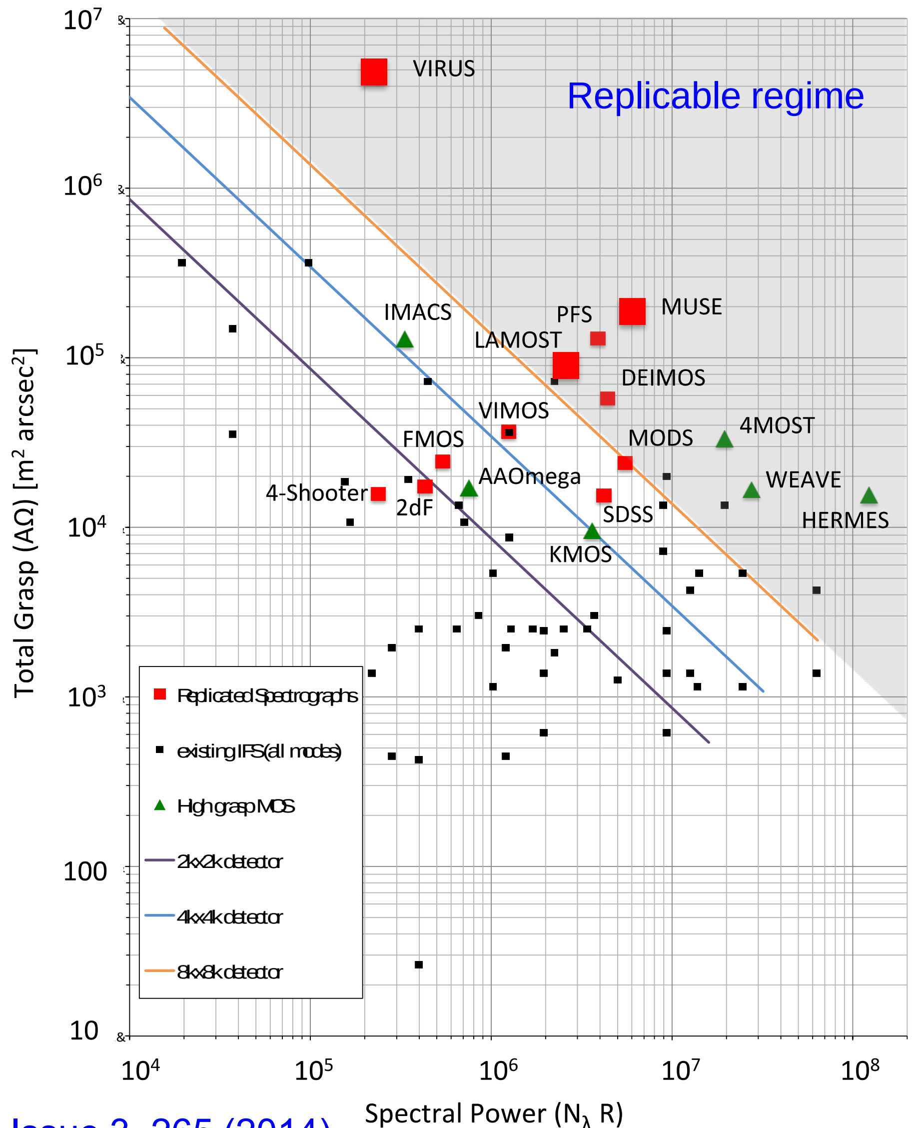
- VIRUS probes stars deeper and bluer than other galactic structure surveys
  - Will include tens of extremely metal poor stars
- Large sample of resolved galaxies (z<0.1)
  - Rotation curves and dark matter distributions to SDSS surface brightness limit
  - Spatially-resolved star formation rates
  - Census of outflows
  - Cross with new Westerbork APERTIF HI survey
- Continuum spectra of stars and galaxies to ~SDSS photometric limit
- 2000 Abell richness clusters covered (z<0.45)
  - Selected blind by spectroscopic signature
  - Complements eROSITA X-ray and HSC weak lensing





Replicated spectrographs in astronomy

- Replicable spectrograph concept now in its second decade
  - Hill & MacQueen 2002
- Beyond the specific application of VIRUS, the concept has an important future (e.g. DESI, HERMES)
- Grasp-spectral power diagram (after Bershady)
  - Excellent metric for evaluating survey instruments and IFS
  - Lines of constant number of pixels ranging up to 8kx8k
- Shaded area represents the regime of replicated instruments
  - Beyond that, mosaics of detectors are needed and instruments become physically challenging
  - It is much more cost-effective to slice the field into multiple spectrographs like in VIRUS, MUSE, and LAMOST



Hill, "Replicated Spectrographs in Astronomy," AOT, Vol 3, Issue 3, 265 (2014)

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Replicated spectrographs on ELTs

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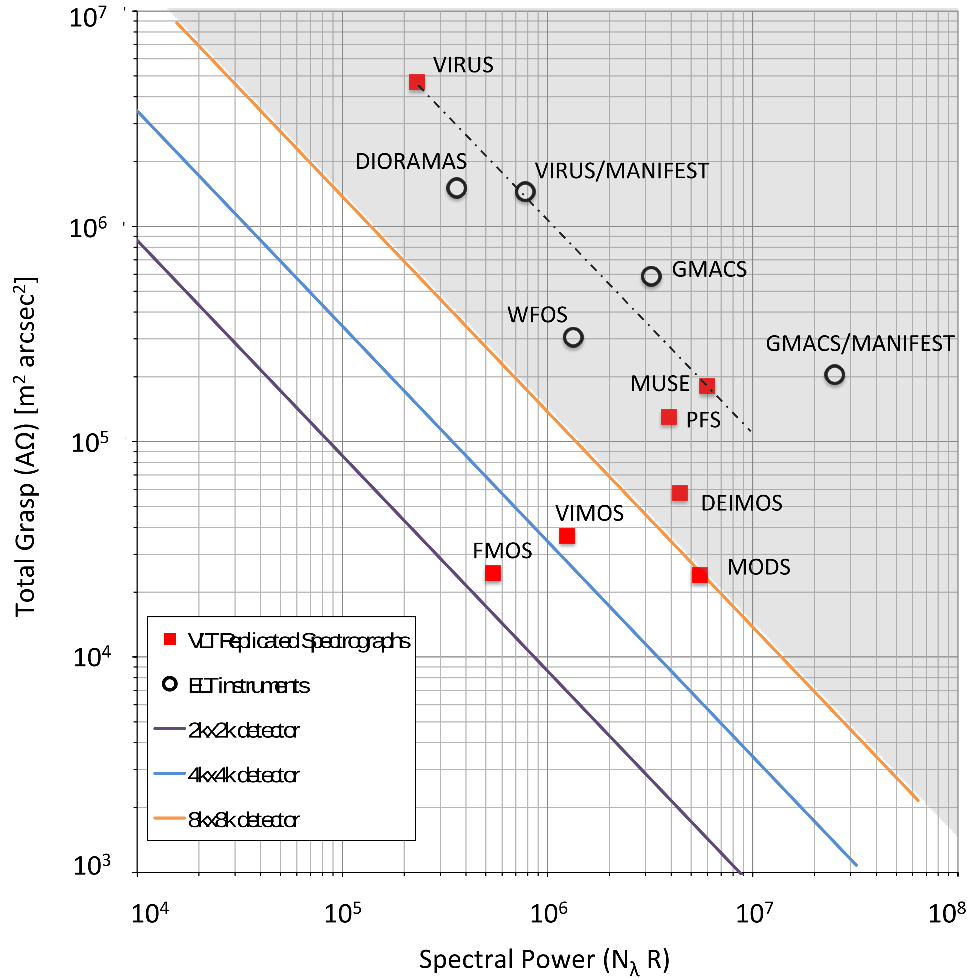
- ELTs present particular challenges for survey spectrographs
  - Growth of instrument and detector size with aperture (at fixed camera f-ratio) becomes extreme
  - Pushes the limits of glass availability, mechanical engineering and cost
  - Will only partially be mitigated with AO for wide fields
- For example, an ELT field with GLAO has 50M spatial elements and thousands of possible targets
  - Similar to a 4 m with a three degree field
- Efficient use of detector pixels requires image slicing
  - Replication offers a cost-effective route
  - Deployable fiber IFUs allow image slicing at input and efficient use of pixels in the spectrograph



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HETDEX and VIRUS Consortium

University of Texas
Yi-Kuan Chiang
Taylor Chonis
Erin Cooper
Niv Drory
Keely Finkelstein
Steve Finkelstein
Karl Gebhardt (PS)
John Good
Gary Hill (PI)
Shardha Jogee
Herman Kriel (PM)
Martin Landriau
Hanshin Lee
Phillip MacQueen
Emily McLinden
Steve Odewahn
Richard Savage
Matthew Shetrone
Mimi Song
Sarah Tuttle (IS)
Brian Vattiat

MPE/USM
Ralf Bender
Frank Grupp
Ulrich Hopp
Francesco Montesano
Ariel Sanchez
Jan Snigula
Jochen Weller
Philipp Wullstein

Penn State University
Joanna Bridge
Robin Ciardullo
Henry Gebhardt
Caryl Gronwall
Alex Hagen
Larry Ramsey
Don Schneider
Sarah Shandera
Greg Ziemann

Texas A&M
Richard Allen
Darren DePoy
Lucas Macri
Jennifer Marshall
Nicola Mehrtens
Casey Papovich
Travis Prochaska
Nicolas Suntzeff
Vy Tran
Lifan Wang

AIP
Svend Bauer
Roelof de Jong
Roger Haynes
Dionne Haynes
Thomas Jahn
Andreas Kelz
Volker Mueller
Martin Roth
Mathias Steinmetz
Christian Tapken
Lutz Wisotzki

Other Institutions
Josh Adams (OCIW)
Carlos Allende-Prieto (IAC)
Viviana Aquaviva (Rutgers)
Guillermo Blanc (OCIW)
Chi-Ting Chiang (MPA)
Mark Cornell (MIT LL)
Gavin Dalton (Oxford)
Maximillian Fabricius (Subaru)
Eric Gawiser (Rutgers)
Jenny Green (Princeton)
Lei Hao (SHAO)
Matt Jarvis (Oxford)
Donghui Jeong (JHU)
Wolfram Kollatschny(IAG)
Eiichiro Komatsu (MPA)
Jeremy Murphy (Princeton)
Harald Nicklas (IAG)
Jens Niemeyer (IAG)
Povilas Palunas (OCIW)
Jozsef Vinko (Szeged)