Fiber Integral Field Unit For Supernova Spectroscopy (FIZ)

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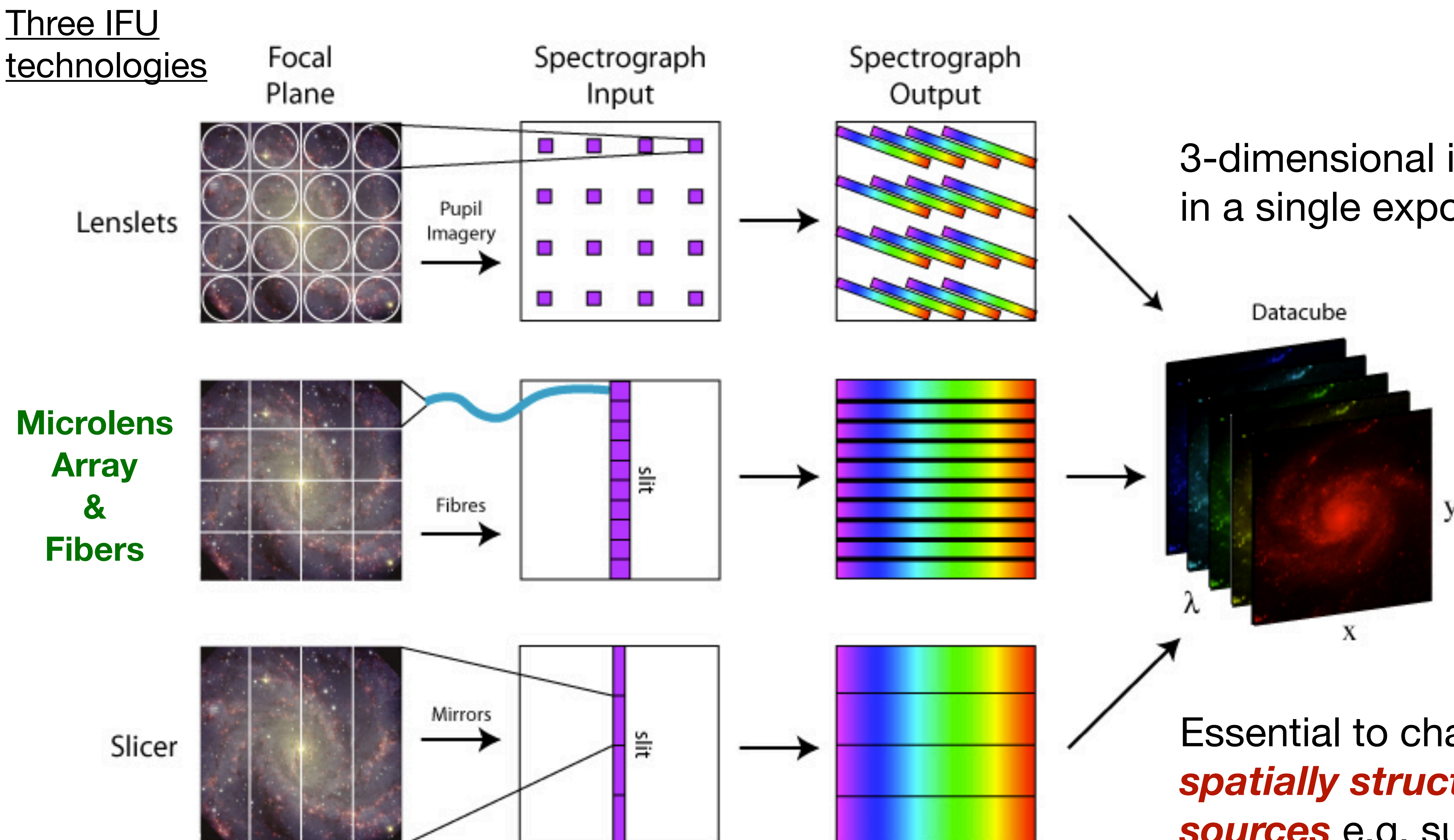
Integral Field Unit and Integral Field Spectroscopy



3-dimensional information in a single exposure

Essential to characterize ***spatially structured, sources*** e.g. supernova host galaxies

LDRD Goals

- Develop LBNL capability to build microlens fiber integral field units (IFUs)

- Research solutions for building a fiber IFU suited for supernova cosmology

  … or in hardware language …

  Identify microlens array, fiber technology, and mitigations that deliver a low-étendue beam with high and stable throughput

Goal 1 Motivation: Fiber IFUs in High Demand in Astronomy

Legacy Andalusian Transient IFU Network Observatory (LATINO)

We propose the construction of a new integral field spectrograph for the the CAHA 2.2m telescope, and describe a survey project to be carried out during the next few years. The instrument, the Legacy Andalusian Transient IFU Network Observatory (LATINO), would provide intermediate spectra resolution (R∼1000) in the optical wavelength range (3500-10000Å) within a field-of-view of 12”×12”, and a spatial resolution of 0.5×0.5 arcsec. The main science case of the survey is to classify and obtain dis-

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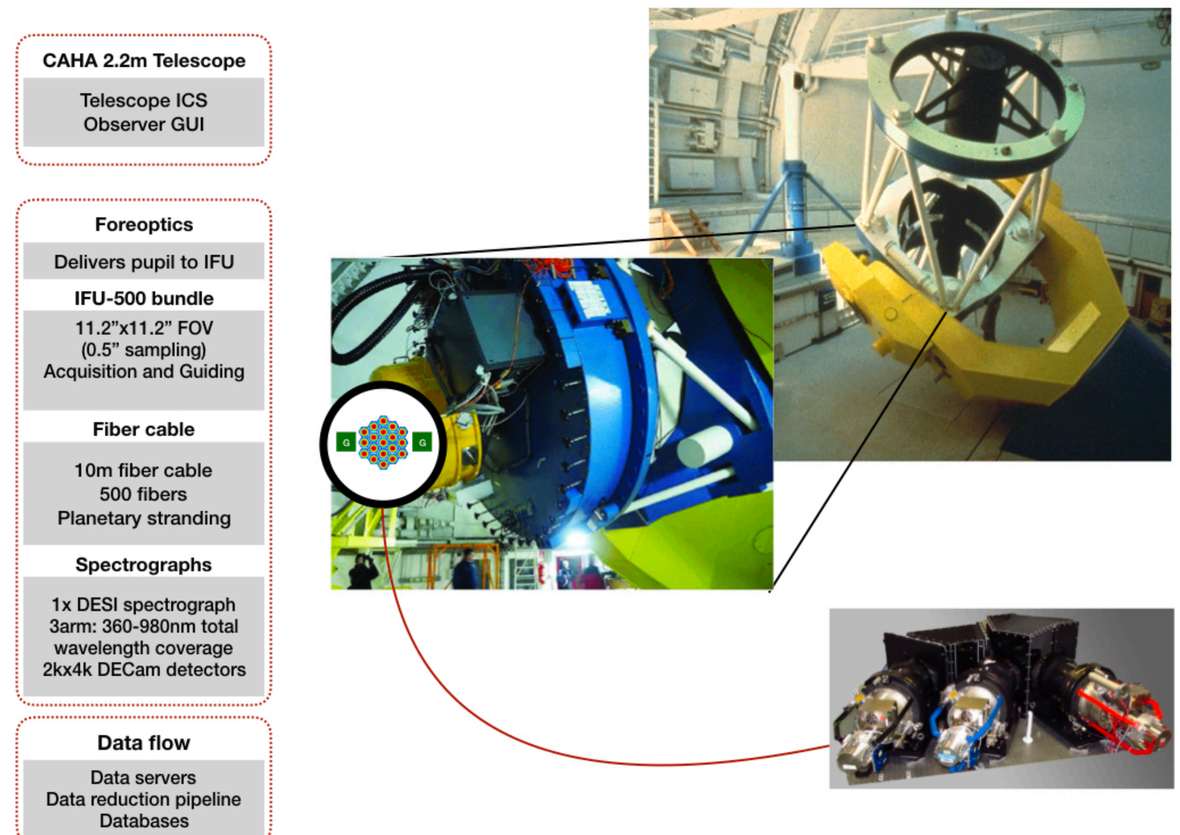
FOBOS: A Next-Generation Spectroscopic Facility

time needed to exploit these future datasets. FOBOS[1], the Fiber-Optic Broadband Optical Spectrograph, is a near-term fiber-based facility that addresses these spectroscopic needs by optimizing depth over area and exploiting the aperture advantage of the existing 10m Keck II Telescope. The result is an instrument with a uniquely blue-sensitive wavelength range (0.31–1.0 μm) at $R \sim 3500$, high-multiplex (1800 fibers), and a factor 1.7 greater survey speed and order-of-magnitude greater sampling density than Subaru’s Prime Focus Spectrograph (PFS). In the era of panoramic deep imaging, FOBOS will excel at building the deep, spectroscopic reference data sets needed to interpret vast imaging data. At the same time, its flexible focal plane, including a mode with 25 deployable integral-field units (IFUs) across a 20 arcmin diameter field, enables an expansive range of scientific investigations. Its key programmatic areas include (1) nested stellar-



Invited to propose for NSF Mid-Scale Innovations Program (MSIP)

Response to Calar Alto Observatory call for new instrumentation

LBL SN Group also exploring instruments with international colleagues for

ESO VLT Survey Telescope

Tokyo Atacama Observatory Telescope

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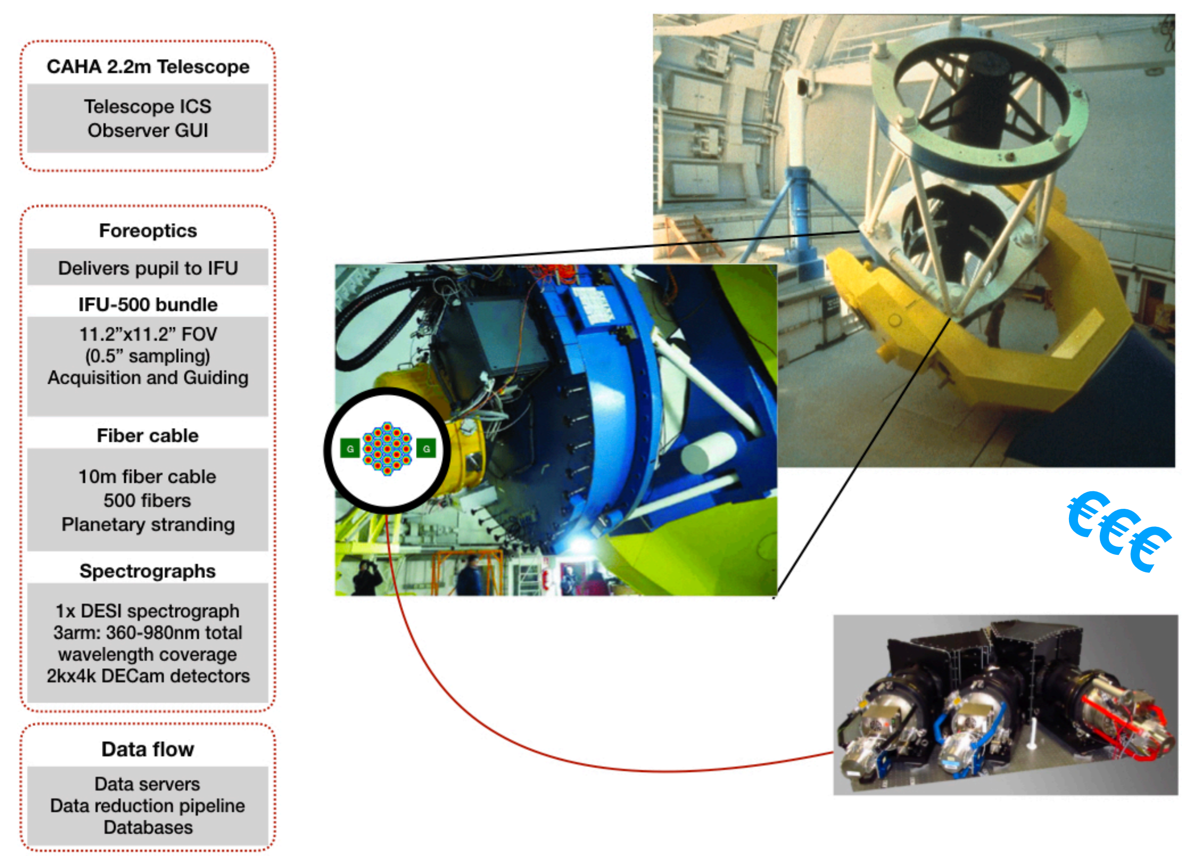

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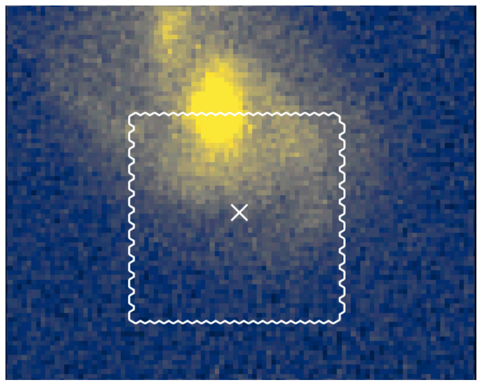
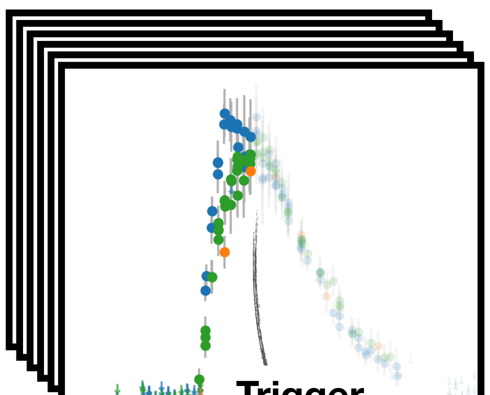
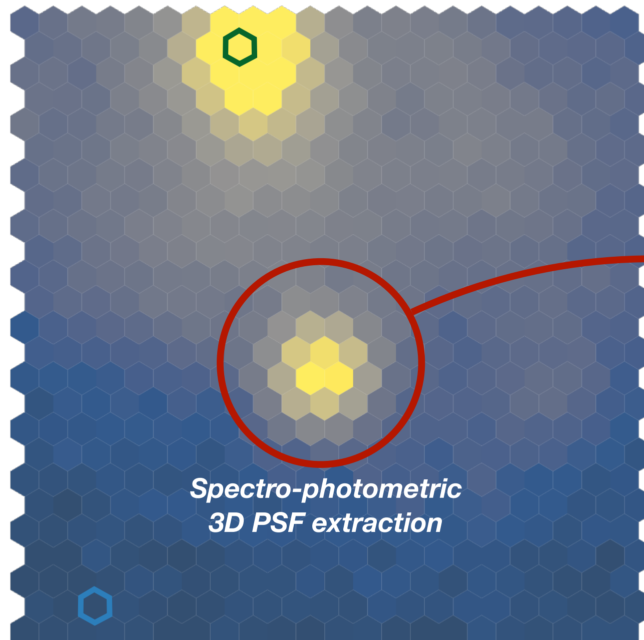
Goal 2 Motivation: Design a System Specific for Observing SN Ia to Probe Dark Energy, Gravity

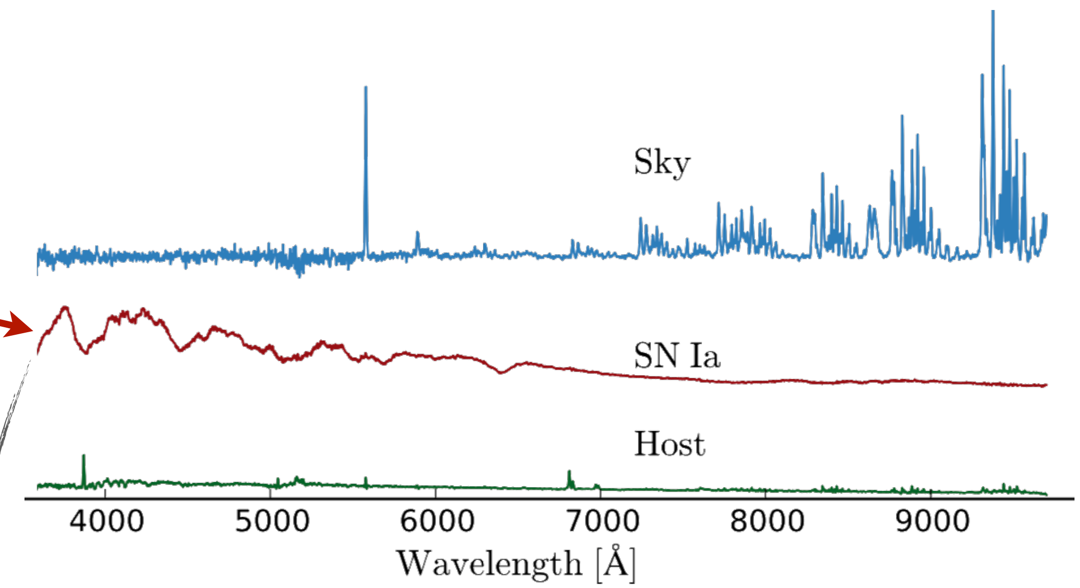
Transient Survey LSST

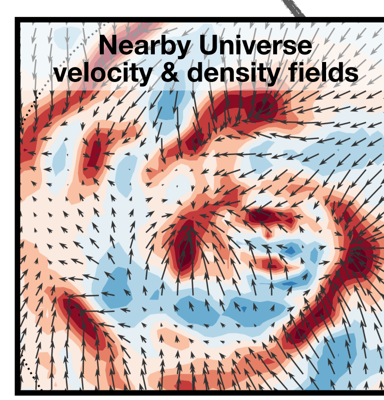




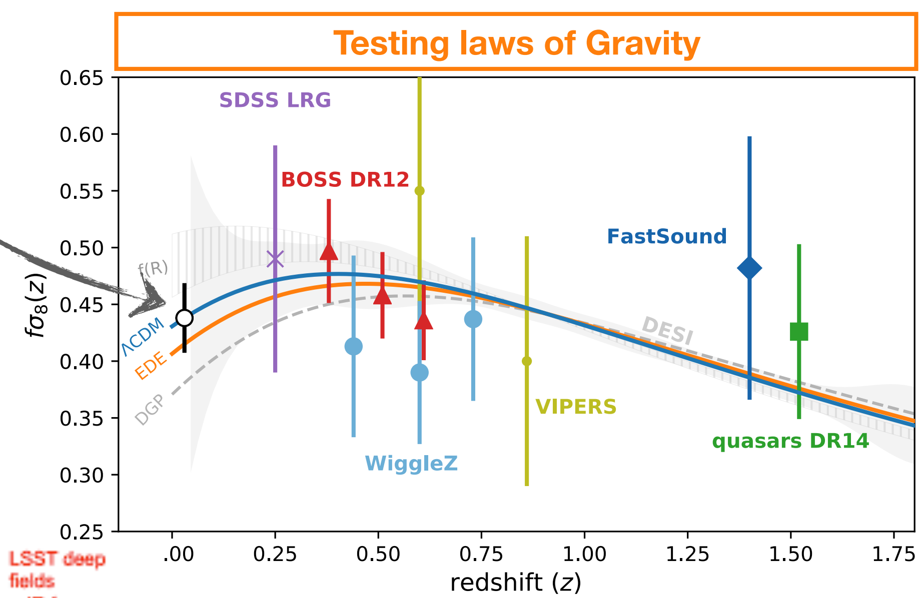
LATINO SNe Ia@z=0.08

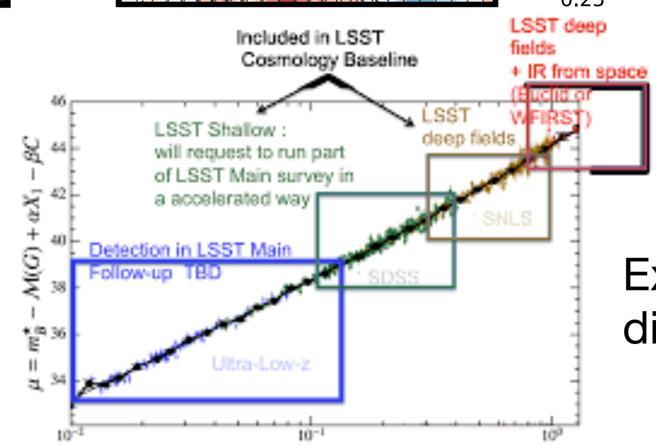






x1700/year

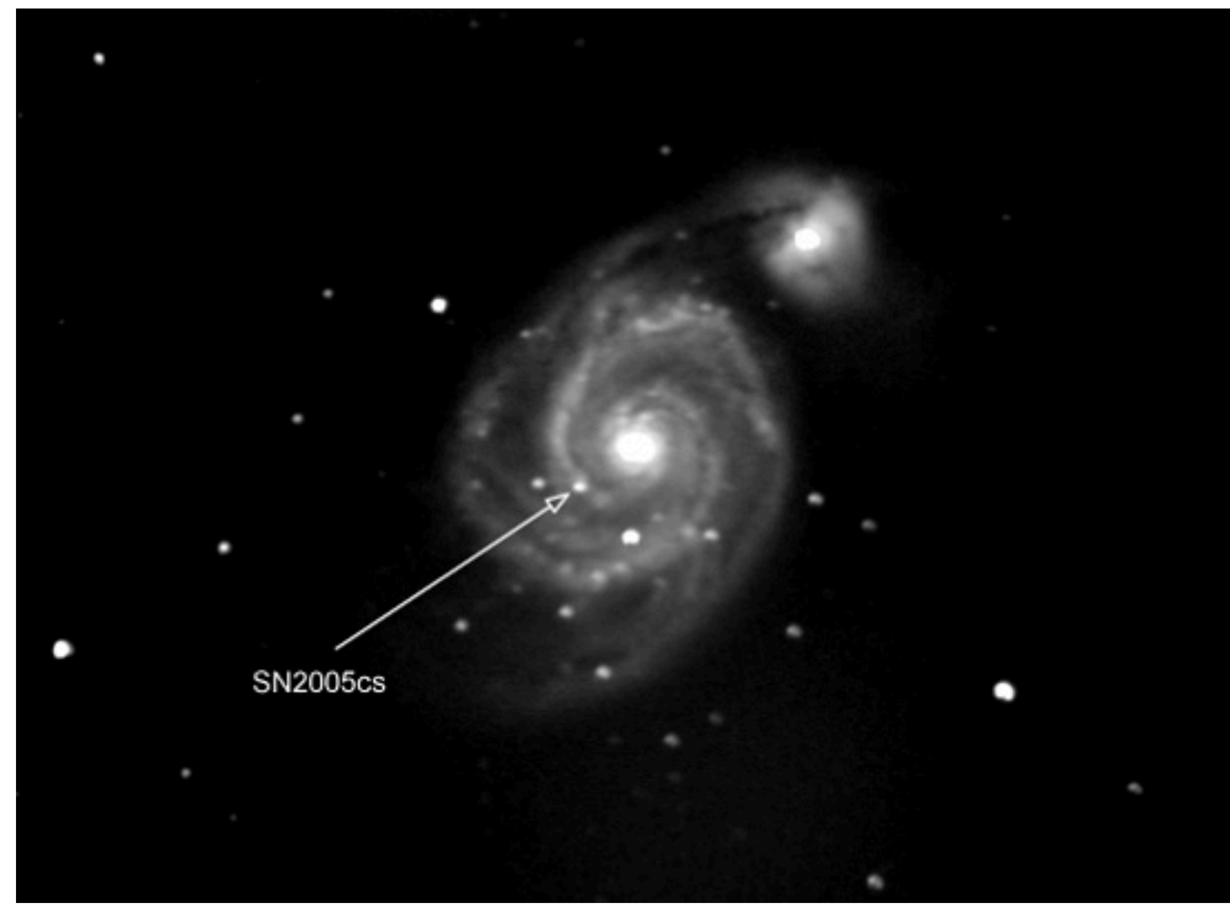




Extending the SN Ia Hubble diagram

The Problem: Science Case

What distinguishes our science case from other IFU use cases?



We care about the structured background (host galaxy) **AND the point source (supernova)**

We require fine spatial resolution

Conservation of Etendue

Whatever optical gymnastics you do, photons satisfy Hamiltonian mechanics (Liouville's Theorem)

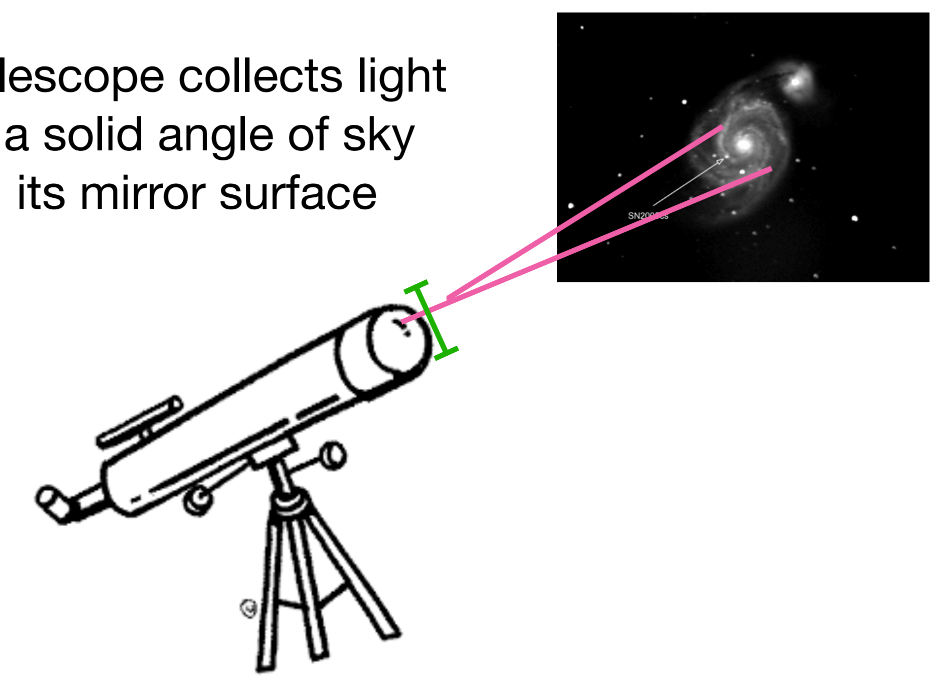
Etendue = Surface Area x Beam Solid Angle

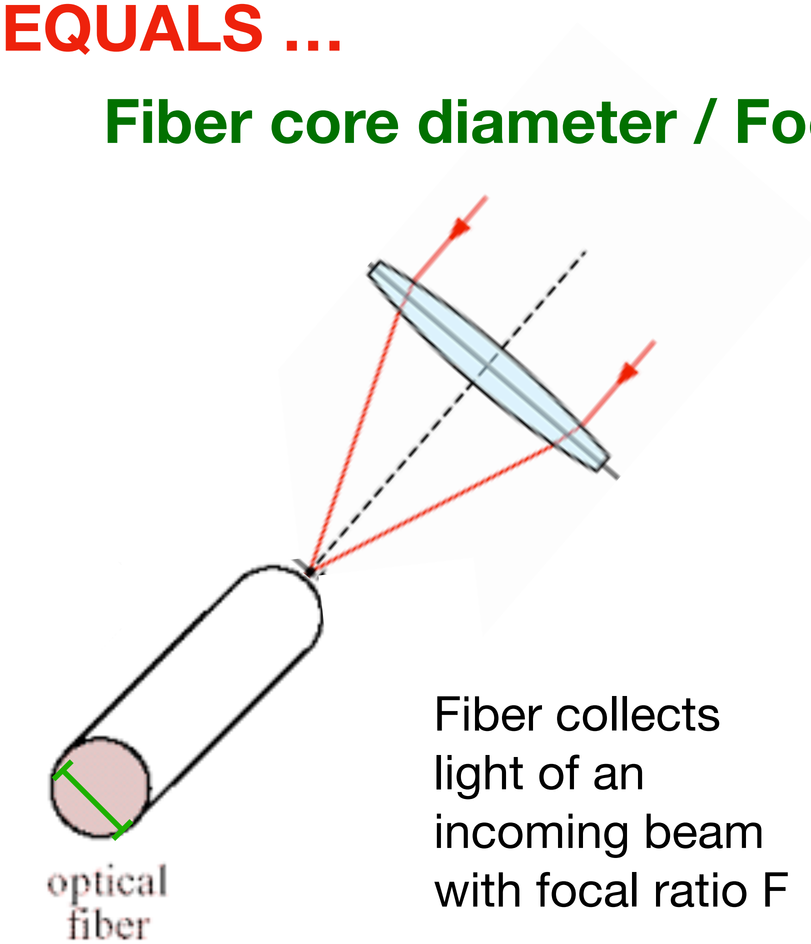
Telescope diameter X angular resolution element

... EQUALS ...

Fiber core diameter / Focal Ratio

Telescope collects light of a solid angle of sky on its mirror surface





Fiber collects light of an incoming beam with focal ratio F

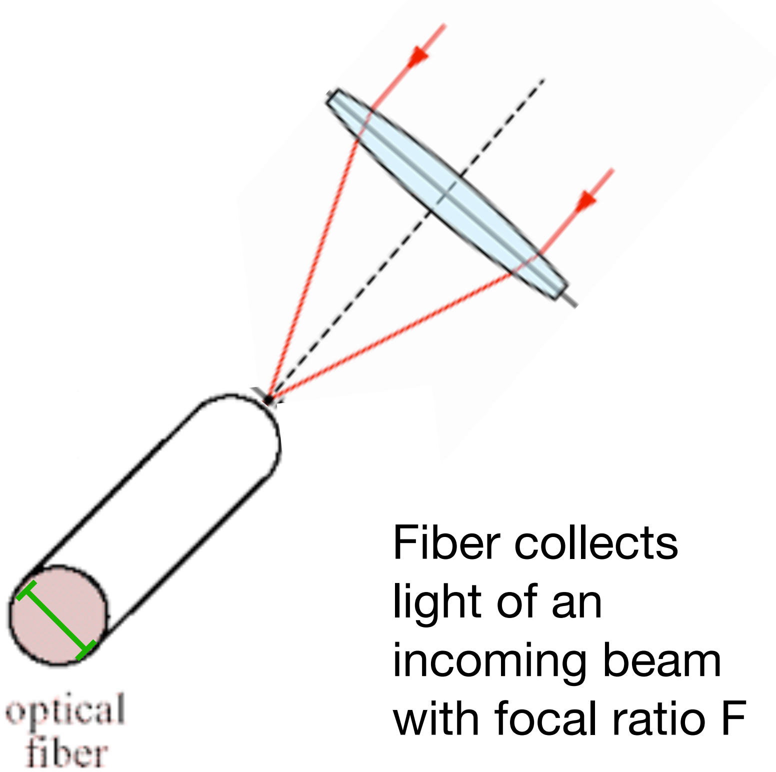
Problem & Solutions: Small Etendue versus Transmission and Stability

A small telescope and high angular resolution means small étendue
Has pesky implications for fibers

$$\text{Etendue} = \frac{\text{Fiber Core Diameter}}{\text{Focal Ratio}}$$

Small cores have poor transmission

Large F degrades optical stability



Fiber collects light of an incoming beam with focal ratio F

In astronomy the standard is NA=0.22 fibers fed by F~4 beams

[Numerical aperture (NA) is the quadratic difference between core and clad indices of refraction]

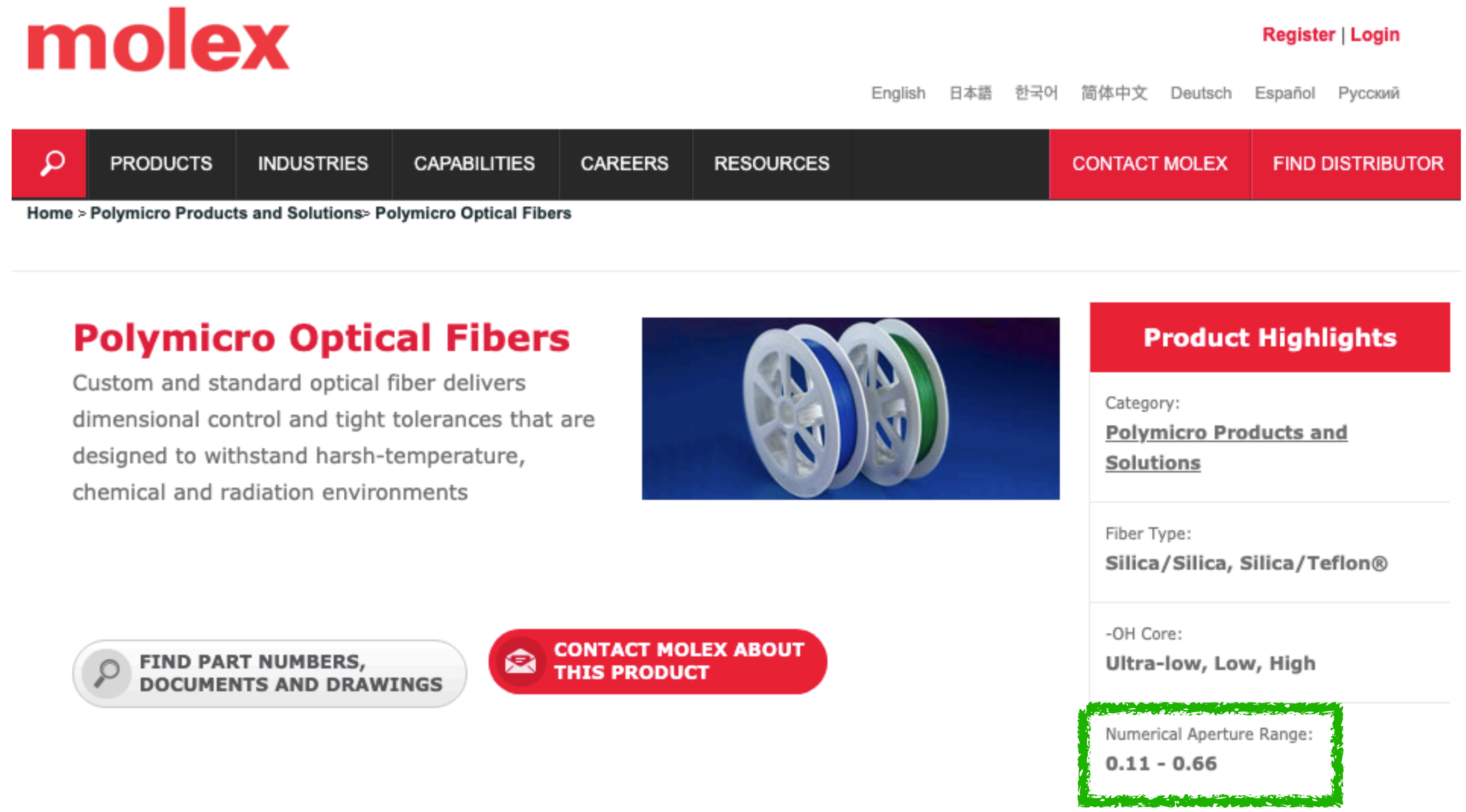
For a 2.5m telescope, 0.5” sky resolution, F=4 calls for 21 µm fiber core, which has small light collection surface area, poor transmission

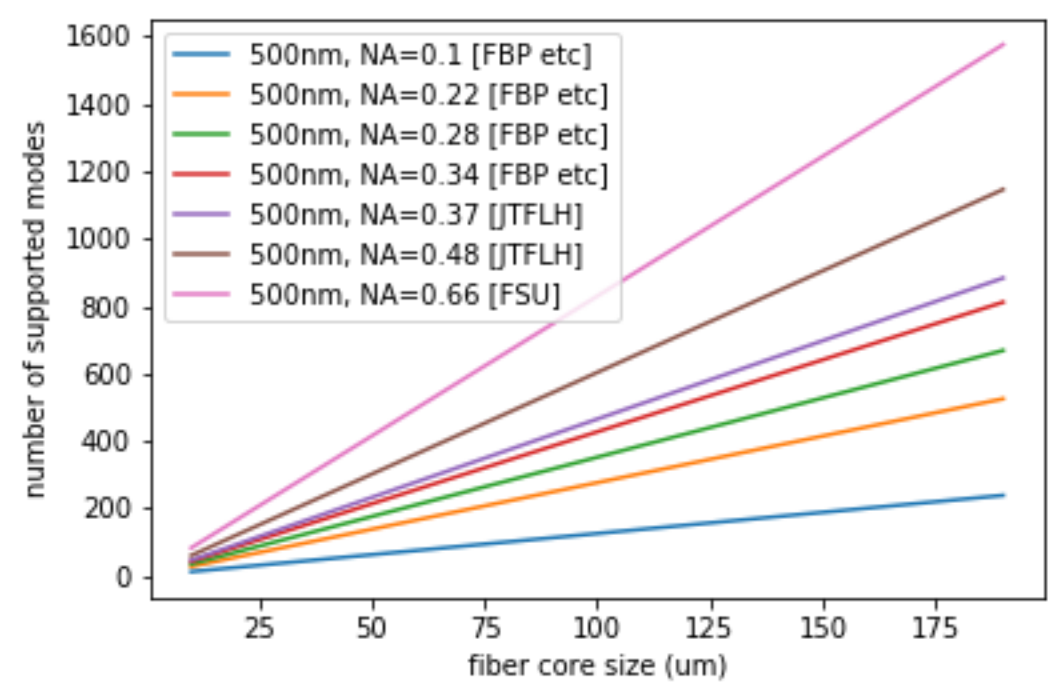
SOLUTIONS

- Use fibers with better transmission for small core size
- Test and mitigate fiber stability for large focal ratios

Solution: Thin Cores and Slow Input Beams with High NA Fibers

- High NA Fibers available but yet unexplored for astronomy
    - Astronomical instruments use NA=0.22 but fibers up to NA=0.66 available
- High NA gives good transmission (# of supported modes) for small core size
- No showstoppers identified



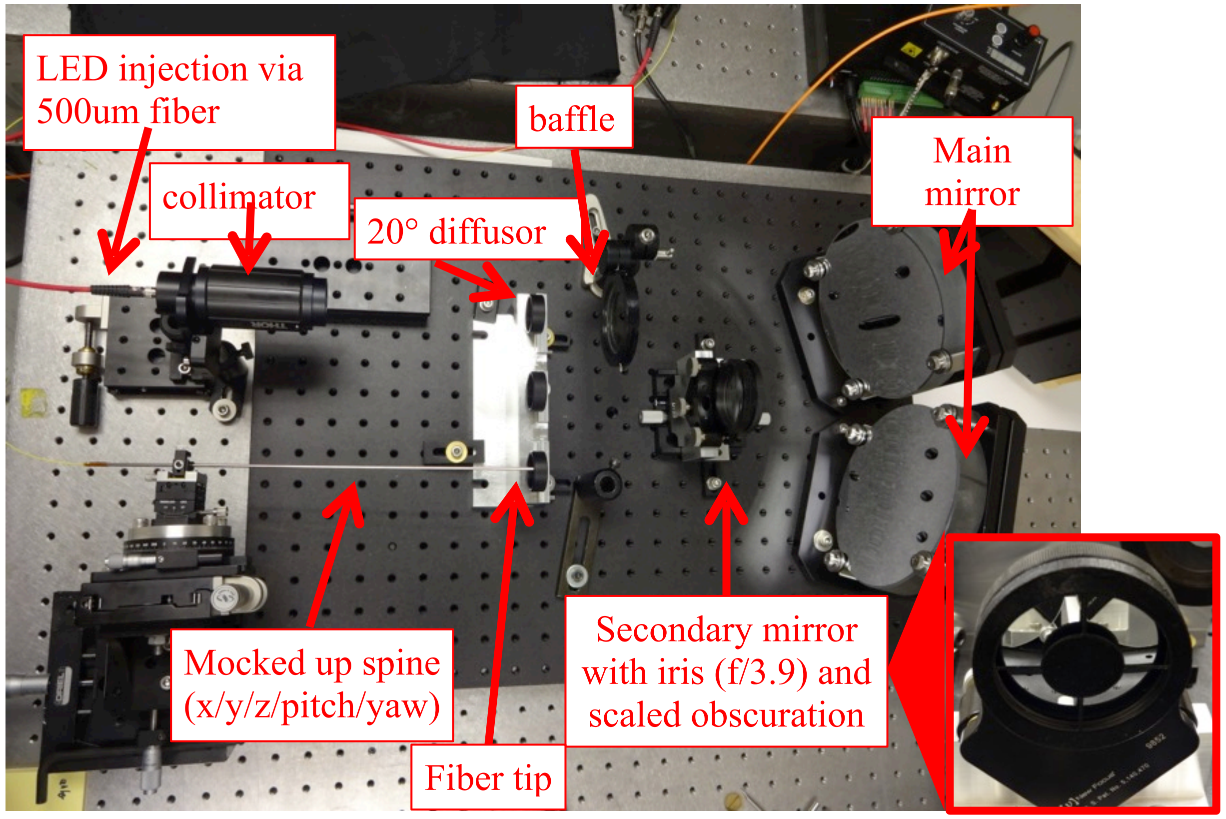


Characterize and Mitigate Fiber and Microlens Performance

- For small-core high-NA fibers: measure throughput
- For different input focal ratios and fibers: Measure and mitigate stability
- For microlens arrays: measure energy distribution (PSF)

Build on infrastructure and expertise developed for DESI

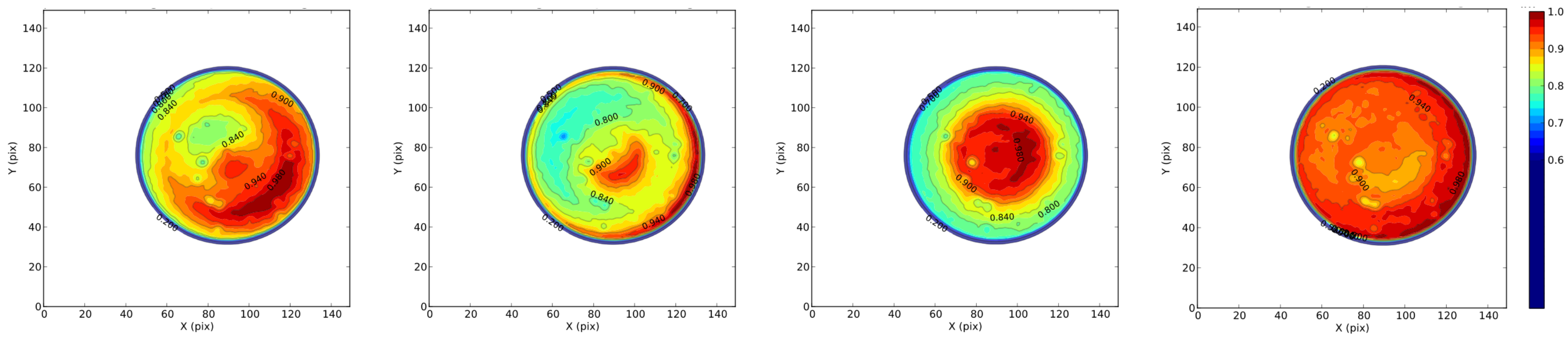
Test rig at SSL used for DESI used to measure fiber transmission



Stability issue as demonstrated by in-house measurements

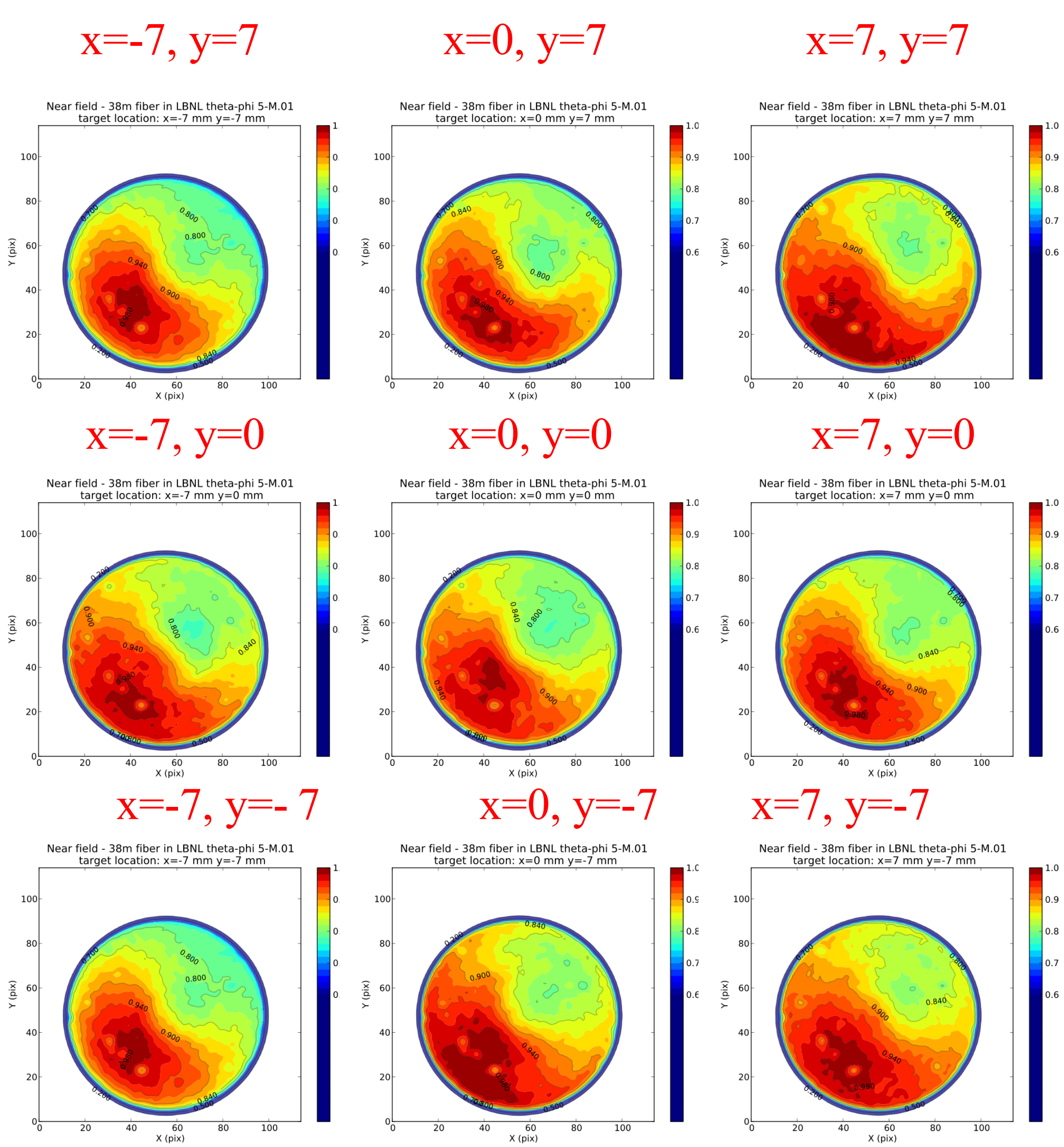
Tilting fiber to different positions changes the near field intensity distribution

2.2° off axis

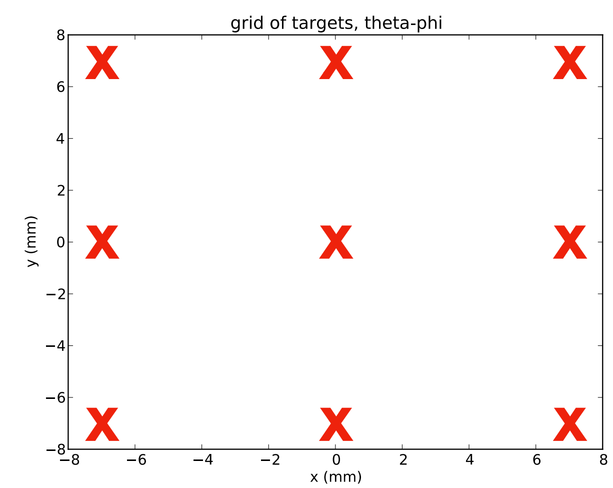


The Solution: Mitigate Fiber Stability

- DESI mitigated stability issue with appropriate choice of fiber positioner technology



DESI tests demonstrated that on-axis fiber positioners provide stable intensity distribution when a fiber is moved to different positions

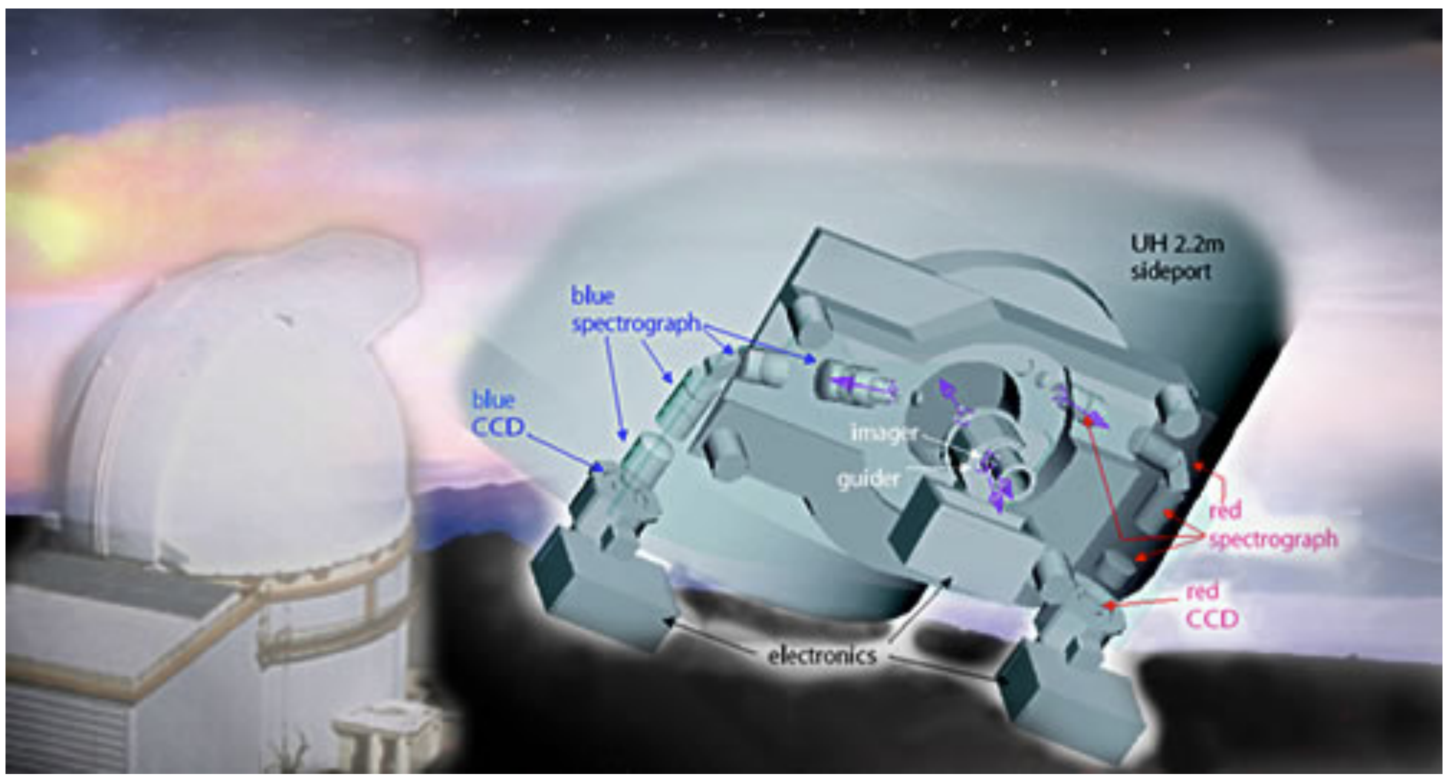


Conclusions

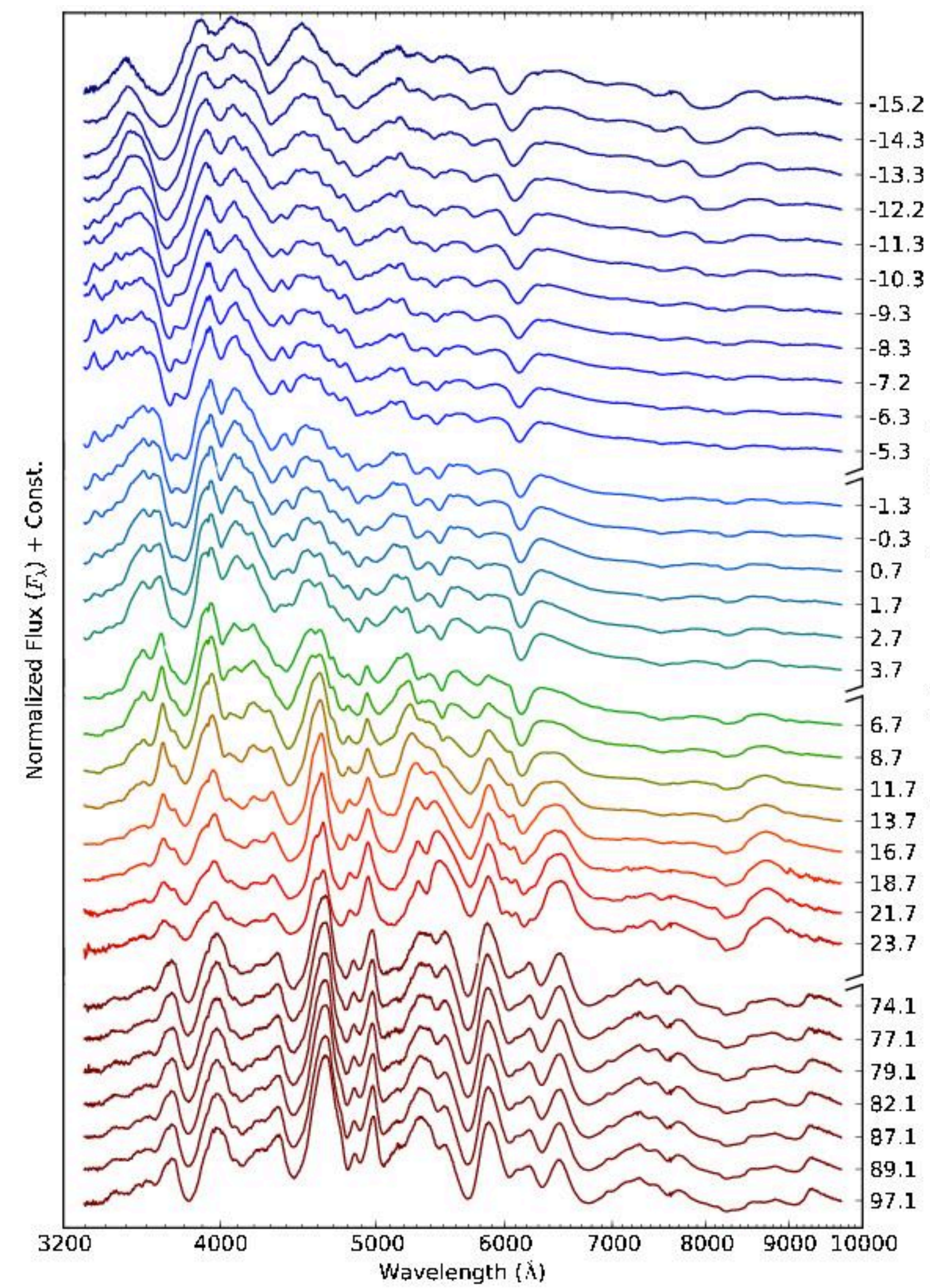
- Research and develop capabilities for Fiber IFUs in demand by the astronomical community AND for supernova cosmology
- There are as-of-yet uncharacterized fibers that look well-suited for SN requirements
- Leverage existing fiber expertise and facilities that contributed to the success of DESI

Backups

Example IFS: SNfactory's SNIFS at UH-88"



SN 2011 fe

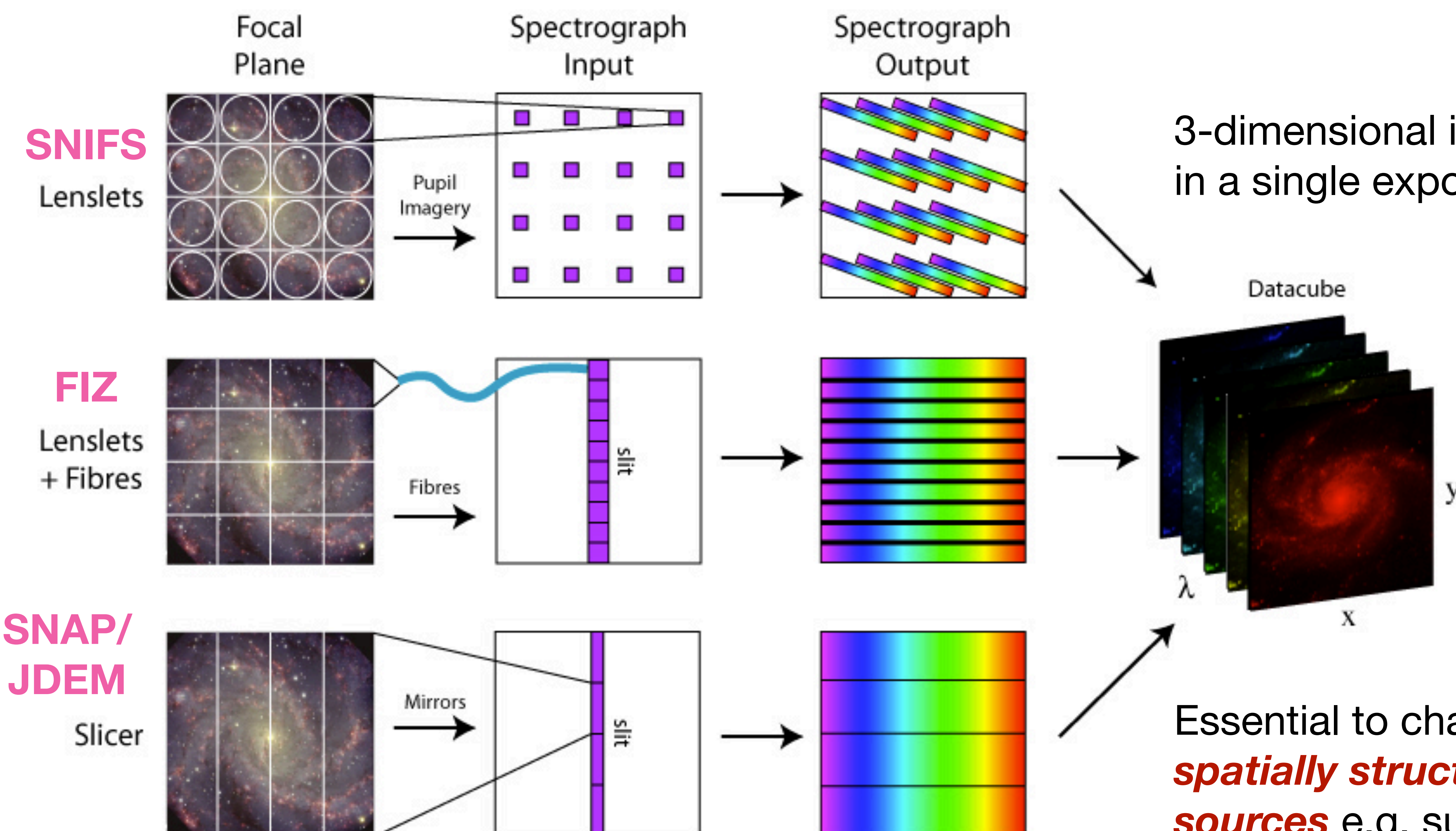


A single exposure produces spectrophotometry

Efficient for observing SN time series

Pereira et al. (2013)

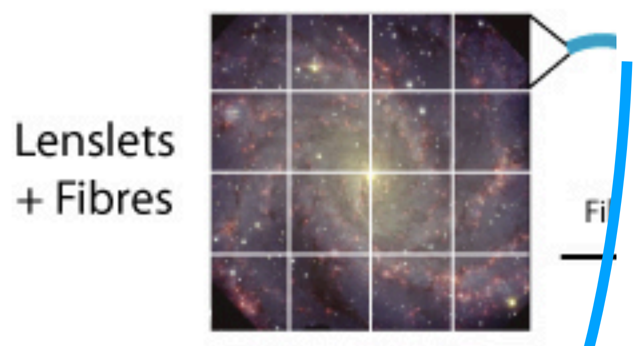
Integral Field Unit and Integral Field Spectroscopy



3-dimensional information in a single exposure

Essential to characterize ***spatially structured, sources*** e.g. supernova host galaxies

Pros of Fiber IFS



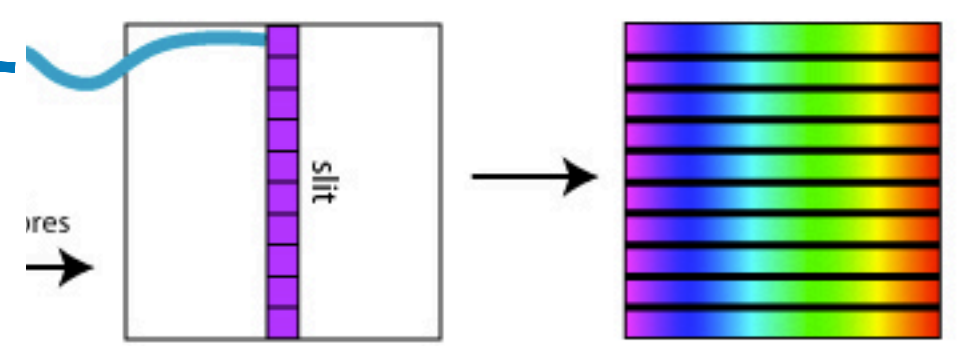
IFU

- Single technology applies to many telescopes - cost savings and design flexibility
  - IFU geometry customized for each focal plane
  - Spectrograph
    - Optics not tailored to telescope, single design applied to many telescopes
    - Put anywhere, not necessarily mounted on telescope

… decoupled …

Science calls for a network of telescopes / IFS

Spectrograph



Possible Sources of Subsequent Funding

- $450,000, Calar Alto Observatory (through a grant from the European Regional Development Fund)
- FOBOS $900,000 for fibers in NSF MIPS, more if built
- TAO Telescope >= $450,000, Tokyo Atacama Observatory

Communication with Fiber Vendor

Hi Claire,

Certainly – I would be happy to expand on this. Below are all of our NA options above the standard NA 0.22:

- Glass core/glass clad (FIP, FVP, FBP, etc.): NA 0.28
  - Made by increasing the fluorine concentration in the dopant.
- Glass core/glass clad (FIP, FVP, FBP, etc): NA 0.34
  - Made by reverse doping the core with germanium
  - Attenuation may be affected slightly be presence of germanium
- Glass core/hard polymer clad (JTFLH): NA 0.37 or NA 0.48
  - Same glass core in both cases, NA difference is due to different plastic cladding.
  - Also available as JTFVH (high -OH) on a custom basis.
  - http://www.literature.molex.com/SQLImages/kelmscott/Molex/PDF_Images/987650-8939.PDF
- Glass core/Teflon AF clad (FSU): NA 0.66
  - http://www.literature.molex.com/SQLImages/kelmscott/Molex/PDF_Images/987650-8935.PDF

To provide further details on the glass core/Teflon clad:

- This is the only option for a glass core fiber that will go anywhere above NA 0.48. Plastic core/borosilicate core could match this NA.
- We could manufacture a 30µm core size – the smallest we have ever gone on this fiber type is 25µm.
- It is manufactured on a custom basis only, so we don't have anything close in-stock that I could send as a sample unfortunately.
- We typically would want to put a layer of acrylate on top of the Teflon AF cladding for extra protection, however some people prefer to have the fiber without the extra layer of buffer.
- It is normally supplied for medical applications (ophthalmology), and illumination applications. To my knowledge, we have not provided this to the astronomy community.