Fiber Positioners For Cosmic Surveys

- Stage V DE science goals
- Telescopes & Instrumentation: Collecting a spectrum onto a optical fiber
- Mechanical Fiber Positioners as a solution for collecting 100M to 1B galaxy spectra
- R&D Direction

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With M. Soares-Santos (Brandeis), J. Marshall (TAMU), M. Schubnell (UM), K. Kuehn (AAO/Lowell Obs.) and others at FNAL
Cosmic Visions Dark Energy
“Stage 5” Science

- Following up LSST targets with spectroscopy improves constraints on fundamental parameters, some by a factor of 10.
- Big gains from extending the redshift range past z=1.
- Currently operating surveys expect to collect spectra of O(20M) objects.
- Stage V hopes for O(1Billion) spectra.
- Parallelism is key to achieving this # of spectra.

Even after the currently planned surveys finish operating, we can make revolutionary discoveries with future surveys; one indication of the power of these surveys is the projected order of magnitude improvements in parameter space.
Collecting Spectra
We do it with telescopes!

- A Telescope (Wide Field Optics)
- Array of Optical Fiber(s) to collect individual object’s light. Scale ½ m to 1 m diameter
- # Spectrographs, R>3500
- Detectors, CCD’s, IR …

Design of Telescope, Focal Plane, Spectrograph Optics are tightly coupled
Past solutions are uneconomical and/or technically unfeasible for this problem.

- SDSS Plug Plates
- Pick & Place Robot instead of a person
- Integral Field Unit (IFU)
“Robotic” Fiber Positioners
Move the Optical Fiber to the Object

- Walking Bugs
- Twirling Posts
- Tilting Spines
Typical Specifications for collecting spectra with a FP


Specification:

- **Horizontal Position Accuracy < 5 um** (plate scale is 71 um/arcsec)
- Lifetime moves > 372,000 (812 mm diameter focal surface)
- Peak (Mean) Power < 3W (waste heat in vicinity of optical path)
- FRD max < 0.4 deg w/ f/3.75 beam) (spectrograph optics)
- Vertical mounting error < 20 um (implications for focus/spot size)
- Tilt Error max < 0.1 deg (I didn’t understand this one)
- **Reconfiguration Time < 45 s** (so no effect on duty-cycle)
- Mass < 50 g (I didn’t see one for space/size)
- Operational Temperature -20C to +60C (!)
- Fiber Handling Radius > 50 mm (so the fibers aren’t damaged)

My comment:
StarBugs

- A positioner that carries a fiber close to a glass focal surface. Held to the glass by a slight vacuum.
- Uses concentric piezos to perform a lift & step motion so that the bug can “walk”.
- Bug Footprint ~ 10 mm or bigger
- Can have different size bugs, multiple fibers, mini-IFUs …
- Can’t make them much smaller

TAIPAN instrument at Siding Spring operating now with 150 fibers
DESI “Twirling Post”

- Fiber is held on an rotating arm at the top of a rotating post (two rotators)
- DESI F.P. ~ 8 mm diameter, 10.4 mm pitch, Patrol Radius = 6 mm
- Big (0.812m) Focal Plane has 5000 F.P.s
- Lots of wee moving parts including two DC Brushless Gear Motors

DESI Petal (one of 10) 5000 F.P. 1 cm pitch

Left out PFS “Cobra”
Tilting Spines

- Fiber is held in the center of the spine.
- Spine is magnetically held to a cup glued to the piezo-tube. Electric (sawtooth) pulse cause slip-stick motion at the ball-cup contact point.
- Accumulate tiny motions to locate the tip.

“Tilting Spines”

- Optical fiber centered in spine. One moving part.
- FMOS (400), DESpec (4000), 4MOST (2436), MSE (4332)
  - 4MOST: 9.5 mm pitch, 11.8 mm patrol radius
- DESpec/MSE even smaller pitch: 6.7/7.6 mm
- Prototypes are already smaller than T.P.s
- Could put more than one fiber in a spine
Value of Patrol Radius:
Target Eff’y & Flexibility & Close Sources like Galaxies in Clusters

- Patrol Radius 60% of pitch
- Most area covered by only one fiber, some by two.

- Same pitch as LHS
- Patrol Radius 100% of pitch
- ~3.5 spines avg.
“Low Hanging Fruit”
5 mm pitch FP

• With collaborators at FNAL, Brandeis, Texas A&M, Michigan, AAO/Lowell Observatory
• Understand the engineering and design limits of the prototypes that we have and develop and test an engineering model.
• Build 5m pitch prototypes and a demonstration system of a small array.
“Game Changing”
Minimize the FP Size

- Ambitions* of 25,000+ FP on a focal plane ~2/3 m diameter focal plane will require even smaller FP’s
- In the process of eating the low-hanging fruit we’ll be learning what we need to think about for a 2 to 3 mm pitch FP design.
- Engineer and demonstrate the smallest possible design based on currently available technology.

* 2020 Astro Decadal Survey White Papers:
https://ui.adsabs.harvard.edu/public-libraries/uZ71y9jERUiiOpuDvrXNSg

Summary

- A fiber positioner system allows one to economically accumulate many objects spectra in parallel using a telescope.
- There are many types of fiber positioners. Tilting Spines & Twirling Posts are practical robotic options.
- At 5 mm pitch there are advantages/disadvantages of the FP designs (comparing equal pitch) depending on the telescope optics and survey design.
- Twirling Posts size limitations is availability of robust, tiny brushless motors and gears
- Tilting Spines size limitations is less explored and could be significantly smaller.
- On course to engineer, design and build a 5 mm pitch Tilting Spine FP.
- While doing that we will be learning what we need to do to build a minimum-sized design
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• I presented some of this talk at “LSST NEXT-GENERATION INSTRUMENTATION WORKSHOP”, APRIL 11-12, 2019 @ ANL. Workshop Summary: arXiv:1905.04669

• DESPEC concept paper

• CVDE Process & Participants
Old Instrument Ideas

- 2009: Gemini 8m telescopes (WFMOS) proposals for a Cassegrain Instrument with O(2500) fibers. Optical design had a 1 sq-deg focal plane (I recall).
Current Instruments

- 2020?: Subaru Telescope Prime Focus Spectrograph will have 2400 piezo-driven Twirling Posts with 8mm radius and ~ 1 cm pitch
- 2019: DESI at Kitt Peak has 5000 TP FPs with 1 cm pitch. Tiny motors and gears.
- 2022: 4Most on the VISTA telescope at La Silla will have 2400 Tilting Spines ~ 1 cm pitch
New instrument Ideas

- 2016: “Billion Object Apparatus” https://kicp-workshops.uchicago.edu/FutureSurveys/
- 2019: MegaMapper w/ 20,000 fibers on a new, Magellan-like telescope at Las Campanas arXiv:1907.1117
- SpecTel and others. See:

  2020 Astro Decadal Survey White Papers: https://ui.adsabs.harvard.edu/public-libraries/uZ71y9jERUiOpuDvrXNSg
How many spectra, say following Up LSST Imaging?

\[ N_{\text{Objects}} = N_{\text{Fibers}} N_{\text{Nights}} N_{\text{Exp/Night}} W_{\text{Weather}} \]

- Some LSST Survey Characteristics:
  - 18,000 square degrees.
  - ~ 20 Billion galaxy detections
  - Magnitude 20 < \( i_{\text{AB}} \) < 23.5 yields 50,000 objects per sq-deg. Conceivable to acquire spectra of billion galaxies.

- Acquiring 500M to 1B spectra demands high multiplexing.
- The workshop suggests 30,000 FPs is a reasonable number to start with. A Tough Problem:
  - DECAM Plate Scale (0.26 arcsec/15 microns): 0.1” position accuracy corresponds to 6um. 1’ target separation is 3.6 mm spacing
  - Fast reconfiguration, maximum throughput, highly reliable, cheap, easy to manufacture …

- LSST Optics (current) not well-suited to FP’s of any kind

More Fiber Positioner Components & Technical Design Considerations

- Positioner Control Electronics
  - Power requirements
  - Thermal control
- Guide and Focus CCDs
- Fiber View Camera to measure the current fiber position during configuration (backlight the fibers)
  - Metrology Fibers on the support plate
  - Fiber View Camera might be located in the central hole of the primary?
  - Complicated because the LSST optics has a secondary and a tertiary mirror !!!
  - More complicated with a lenslet on it?
How FP R&D fits into DOE’s Cosmic Plans

- The Cosmic Visions Small Projects Report outlined the need for R&D into Fiber Positioners.
- A “Small projects Portfolio follow Up” (Kyle Dawson et al.) outlined the scope of effort we are looking at. There were 4 milestones applying to R&D on twirling posts as well as tilting spines. This is aiming for a 5-6 mm pitch.
  - Milestone 1 (by August 2020): Prototype the critical components. Complete preliminary designs for fully-functional positioners based upon these components.
  - Milestone 3 (Prior to Snowmass): Construct second generation fiber positioner prototypes, based upon both performance results and assembly lessons from the first generation prototypes. Conduct testing …
  - Milestone 4: Build and test assemblies of 50 positioners with fibers …