



Astro 500

*Techniques of Modern
Observational Astrophysics*

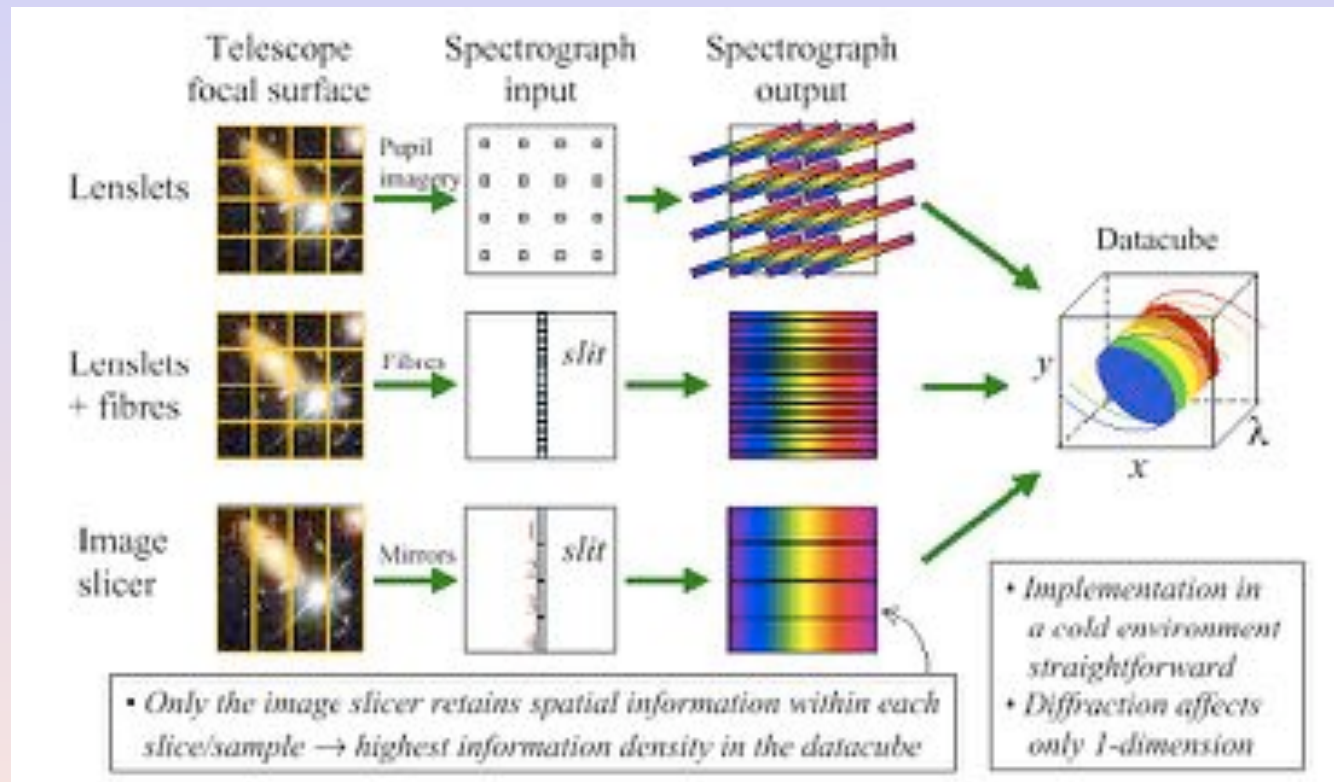
*Matthew Bershady
University of Wisconsin*

Approaches

Examples of available instruments

- ✓ Grating-dispersed spectrographs
 - ✓ basic spectrograph design
 - ✓ dispersive elements
 - ✓ Long-slit spectrographs
 - ✓ General Observing Considerations
 - ✓ Double spectrographs
 - ✓ Multi-objects spectrographs: slitlets vs fibers
 - ✓ Echelle spectrographs
 - ✓ 3D spectroscopy: coupling formats and methods
 - ✓ Fiber
 - ✓ Fiber+lenslet
 - ✓ Slicer
 - ✓ Lenslet
 - ✓ Filtered multi-slit
- o 3D MOS
 - Current instruments
 - o summary of considerations
 - o sky subtraction

IFUs



Grating-dispersed spectrographs

Multi-object configurations

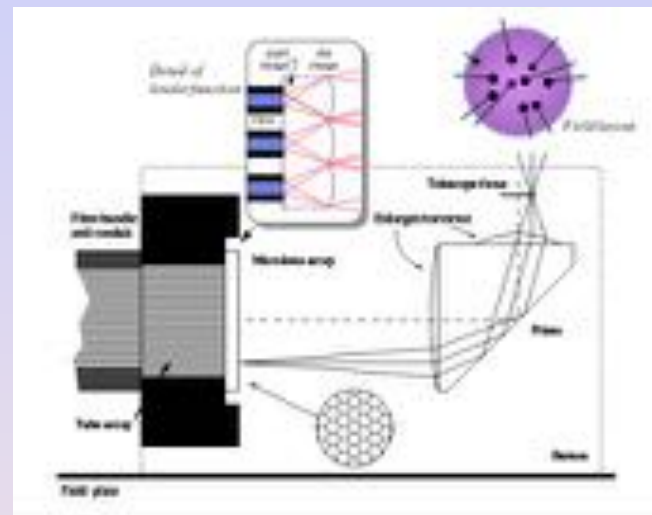
- This is a major path for the future

- How to feed?

- o Fiber, fiber+lenslet, slicer+ relay optic

Relatively easy;
many existing MOS
could be upgraded

More challenging;
many surfaces

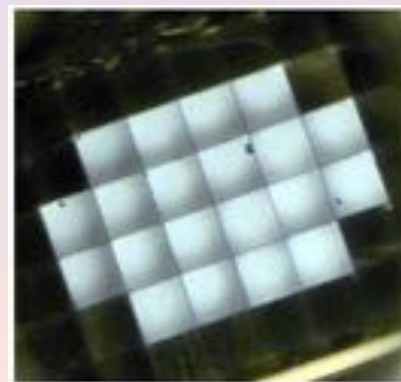


Sharma et al. '04: KMOS
Allington-Smith & Conlon '98

- Only one existing instrument:

- FLAMES/GIRAFFE

- o Fiber+lenslet
- o 15 units + 15 sky fibers
- o Each unit is 2 x 3 arcsec of 20 rectangular microlenses sampling 0.52 x 0.52 arcsec

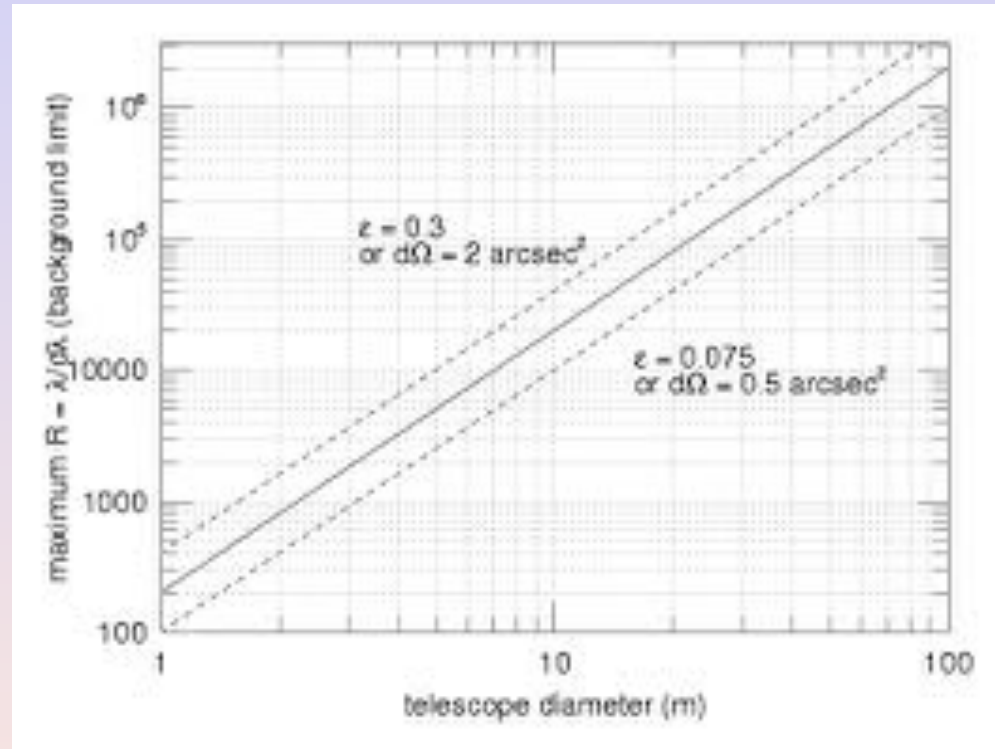


Credit: ESO web page

Grating-dispersed spectrographs

Multi-object configurations

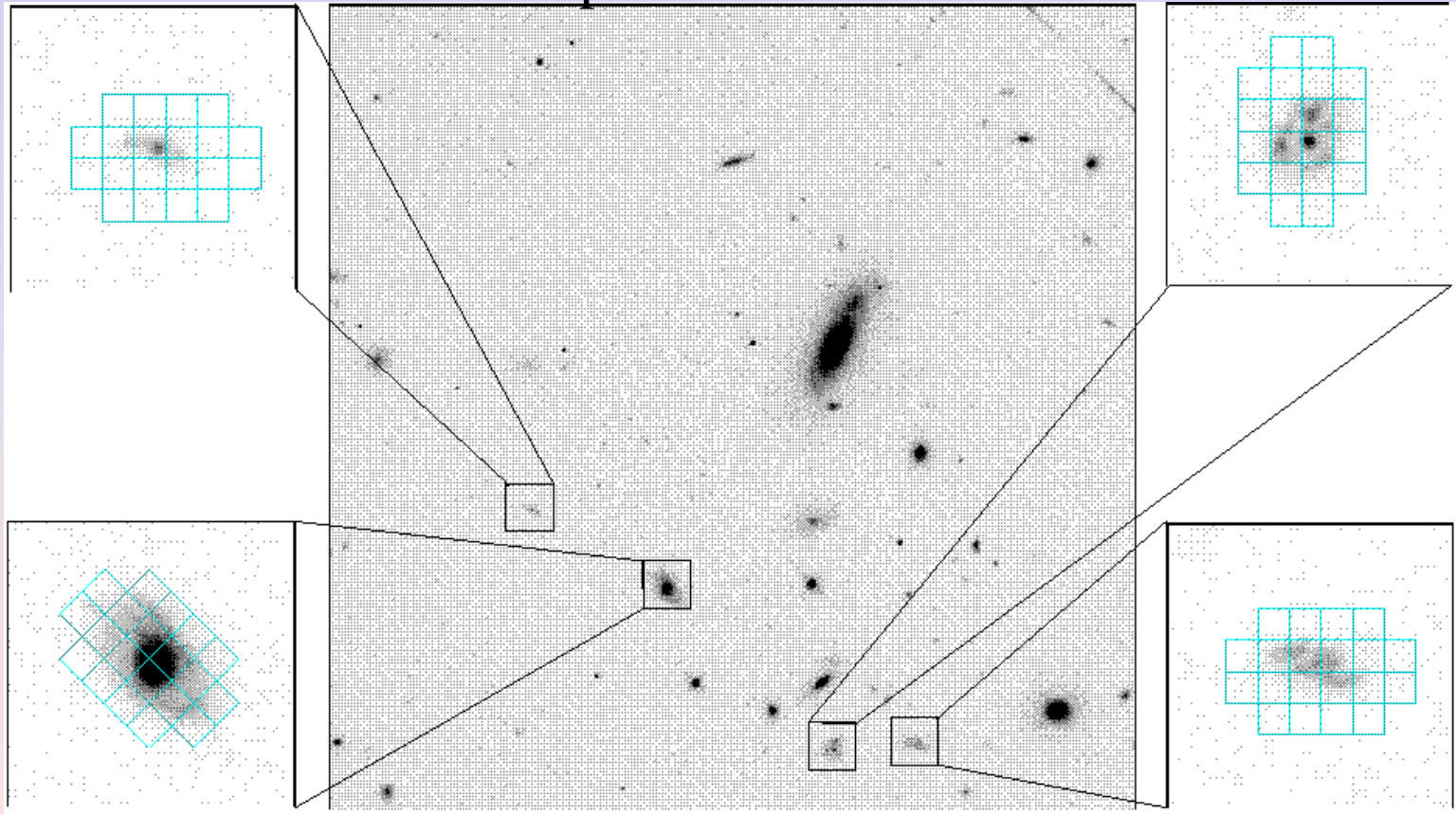
- Background limited?
 - FLAMES/GIRAFFE
 - Each unit is 2 x 3 arcsec of 20 rectangular microlenses sampling 0.52 x 0.52 arcsec
 - Equivalent to 1 arcsec fiber on 3.5m telescope.
 - Great for emission-line work, particular if line emission is clumpy.
 - Tough for diffuse gas or stellar continuum in resolved sources.



Grating-dispersed spectrographs

Multi-object configurations

This is a powerful instrument:



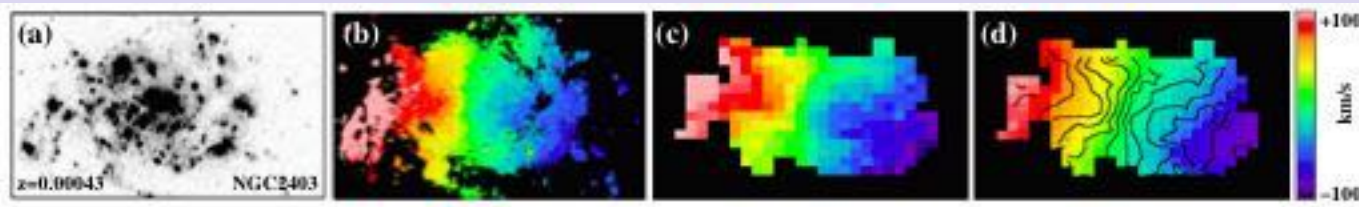
VLT / GIRAFFE

Grating-dispersed spectrographs

Multi-object configurations

- FLAMES/GIRAFFE science: emission-line kinematics of distant galaxies.

H α image high-res. FP map $z \sim 0.2$ simulation deconvolution using H α map

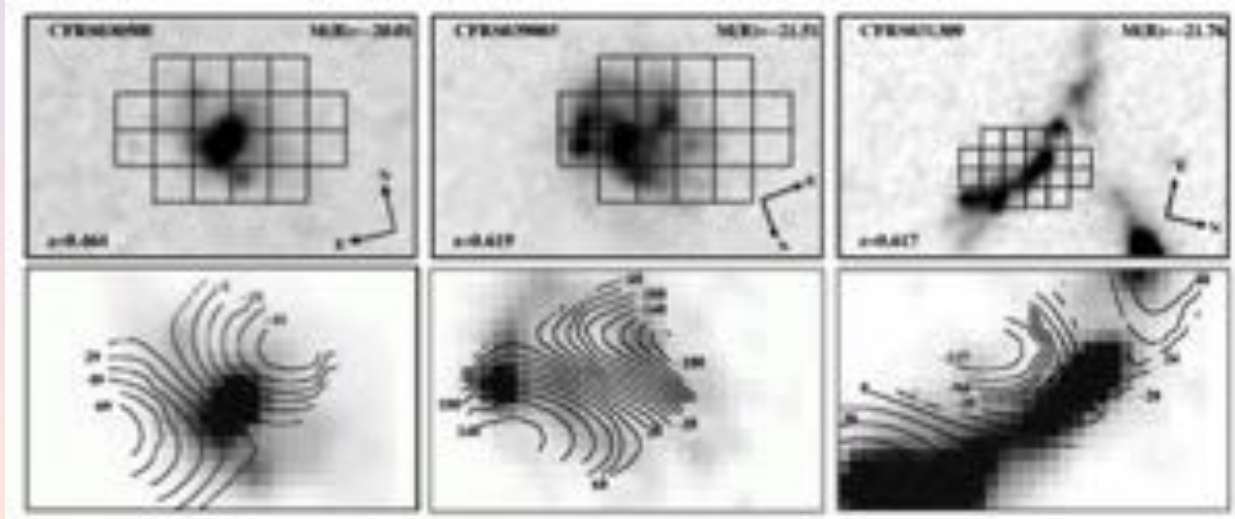


simulation:
DisGal3D

Flores et al.'04

HST+
overlay

DisGal3D
deconvolutions



Note: isovels
heavily
smoothed

Grating-dispersed spectrographs summary of considerations

- Information packing: format-driven trades
 - Lenslets and filtered-multi-slit have limited spectral sampling.
 - Pure fiber systems have at best 65% integral coverage.
 - Fiber+lens, slicers, and lenslets yield comparable sampling of telescope focal plane.
 - Slicers give most efficient packing on detector.
 - Only slicers preserve full spatial information.
- Coverage vs purity: scattered light and cross-talk
 - science-driven trade-off -- *in what way are you greedy?*
 - pure fiber systems are the cleanest
- Sky subtraction
 - Fiber-based systems offer the most mapping flexibility.
 - Slicers preserve spatial information.

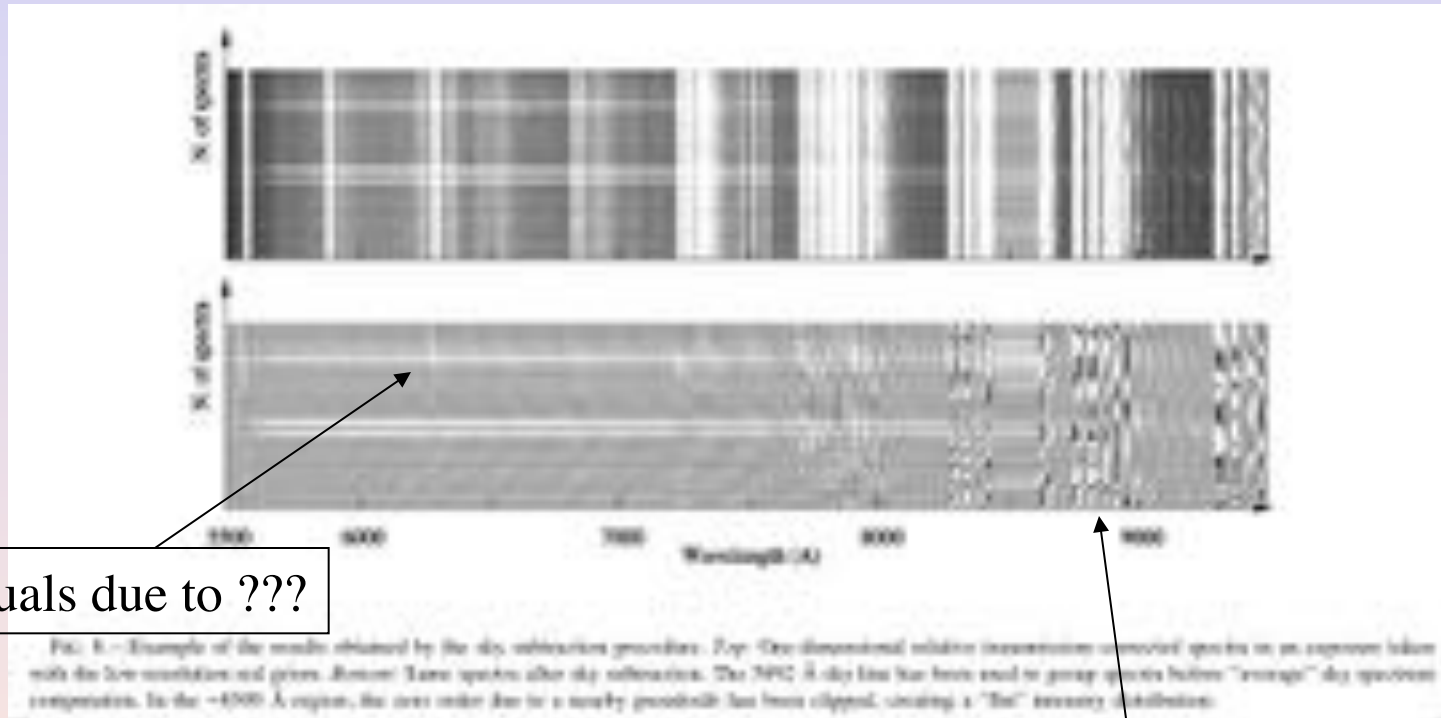
Grating-dispersed spectrographs

Sky Subtraction

- Issues and root causes of problems:
 - *Low dispersion*: sky-lines contribute overwhelming shot-noise.
 - *Aberrations and non-locality*: sky-line profiles vary with field angle (spectral and spatial).
 - *Stability*: instrument-flexure and detector fringing.
 - *Under-sampling*: compounds problems of field-dependent aberrations and flexure.
- Solutions / algorithms
 - Well-sampled, high-resolution data on a stable spectrograph is a premium (you get what you pay for).
 - *Beam-switching*: interleave object and sky exposures (50% efficiency).
 - *Nod-and-shuffle*: shuffle charge and nod telescope between object and sky positions (50% efficiency).
 - *Aberration modeling*: treat IFU data as long-slit.
 - o example of telescope-time-efficient algorithm.

Grating-dispersed spectrographs sky subtraction

- Example: wave-calibrated fiber data in pseudo-longslit format



Residuals due to ???

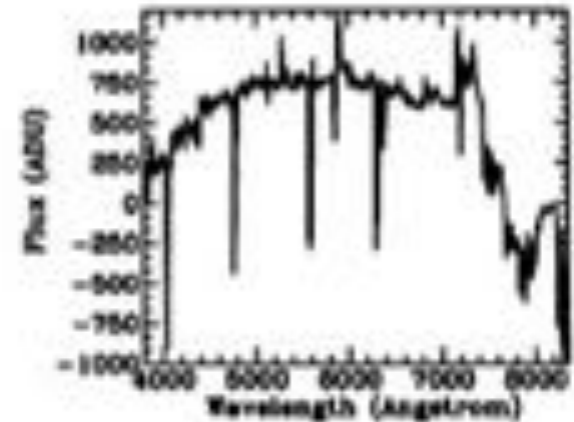
Residuals due to fringing

Zanichelli et al. '05
VIMOS, VLT 8m

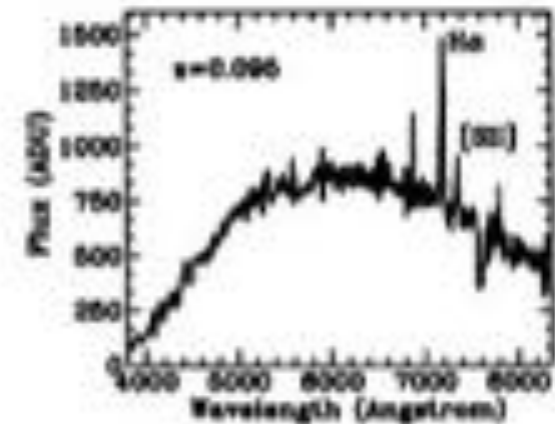
Grating-dispersed spectrographs sky subtraction

- Lissandrini et al. '94
 - Use sky-lines for 2nd-order flux calibration.
 - Flat-fields aren't good enough.
 - Model scattered light from neighboring fibers.
 - Map image distortions in pixel space to obtain accurate wavelength calibration

before

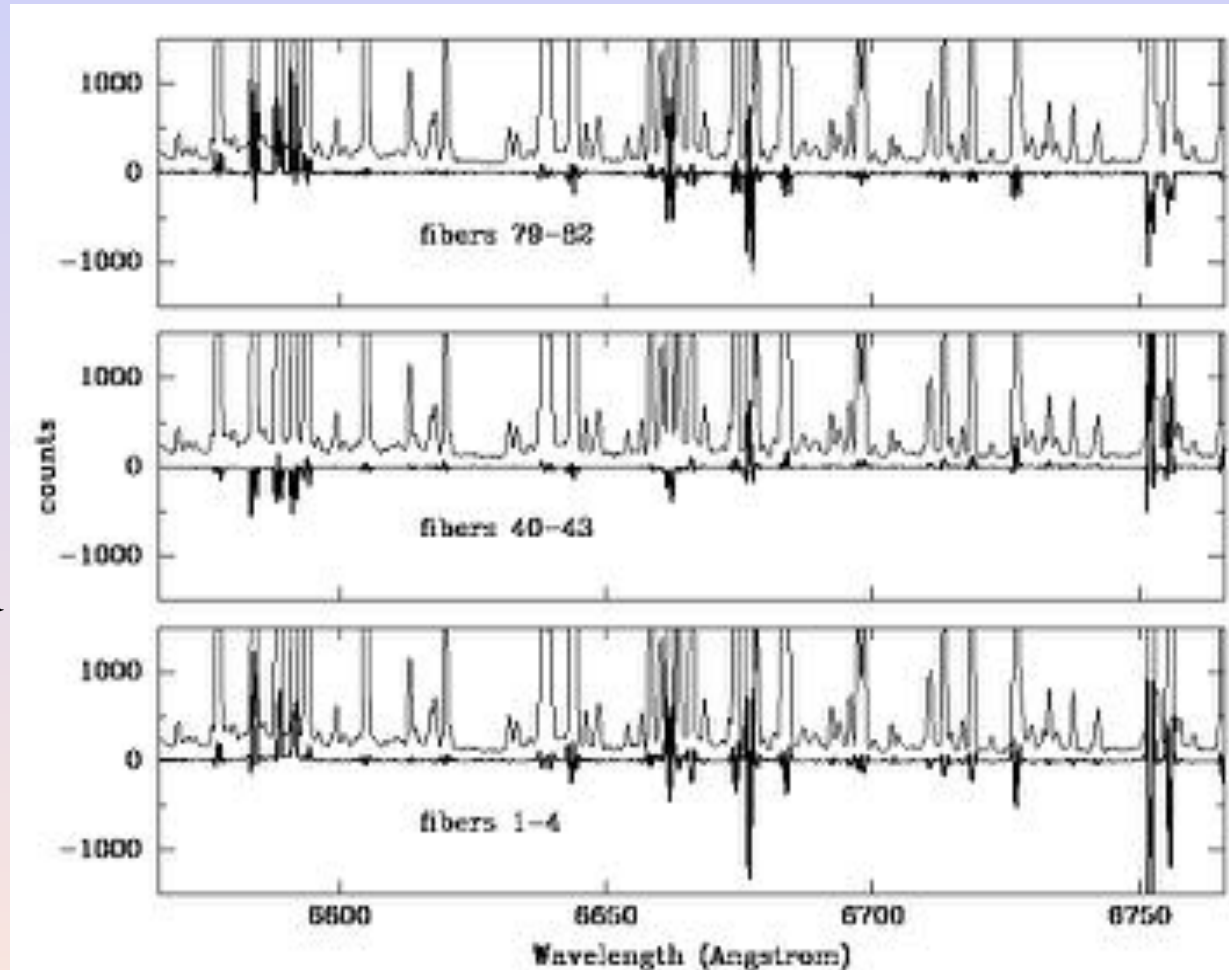


after



Grating-dispersed spectrographs sky subtraction

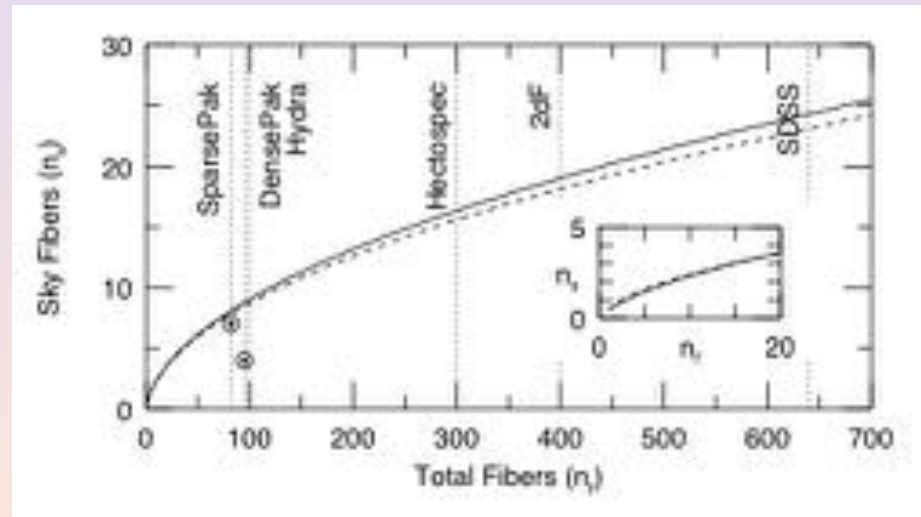
- Higher-order aberrations are important
 - Wavelength calibration is critical, but this is only the first moment, i.e., centroid
 - 2nd-moment and higher-order aberrations are important for defining line width and shape (skew, kurtosis)



Grating-dispersed spectrographs sky subtraction

- Solution w/o beam-swithing or nod-and-shuffle
 - Treat multi-fiber data as long-slit
 - Wavelength calibrate and register
 - Subtract spectral continuum (object+sky) from each fiber (spatial) channel via low-order fit with clipping-rejection of lines.
 - Fit and subtract low-order function to each spectral channel with clipping rejection.
 - Replace object spectral (difference of sky-fiber and source fiber continua fits).
 - 100% efficient!

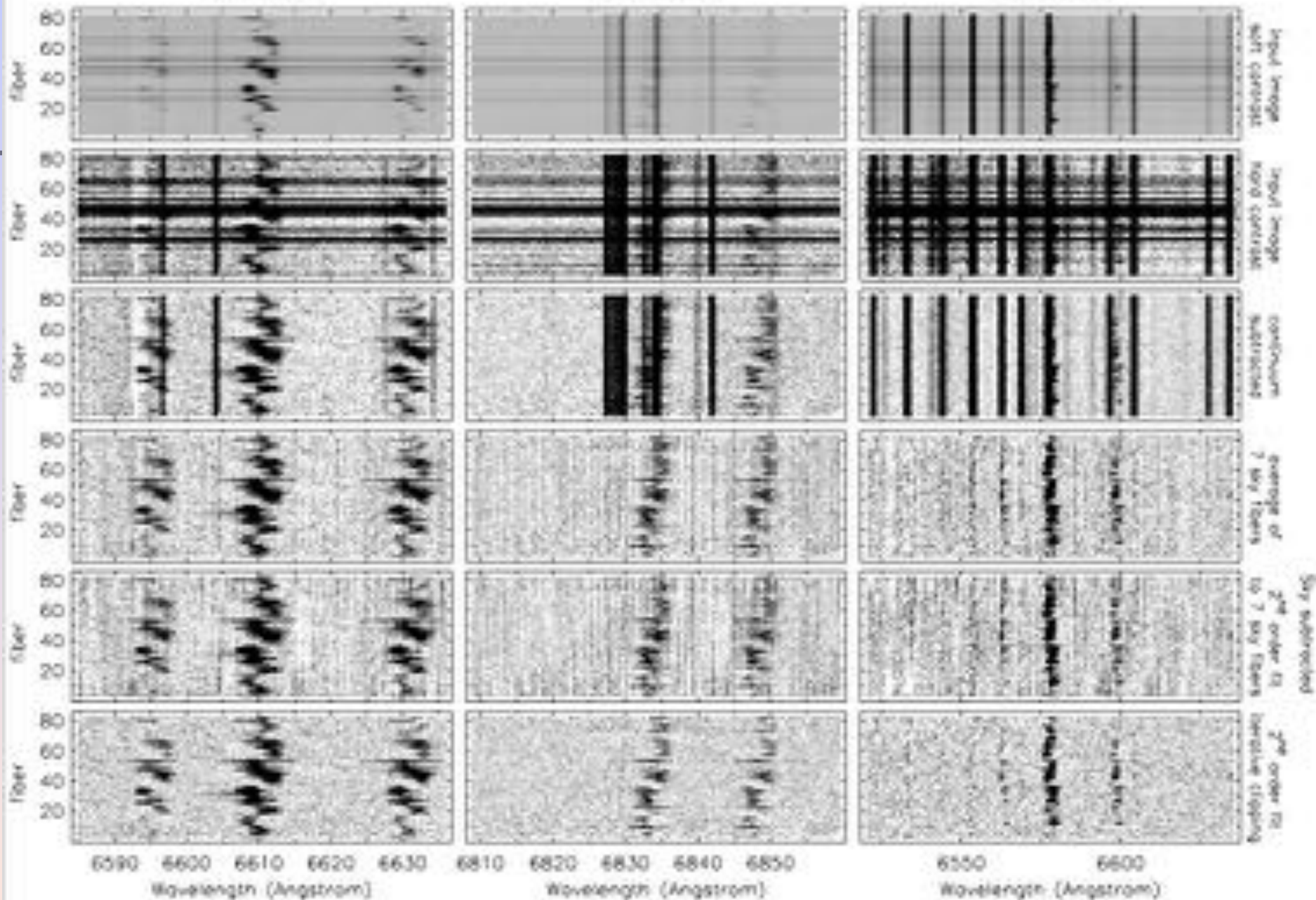
- Works well for narrow source line-emission with significant spectral-channel offsets (e.g., high-dispersion or intrinsically large velocity range).
- For other instrument or source cases (low dispersion, broad lines, small velocity range): If aberrations are significant, need more sky fibers.



UGC 7169

UGC 456

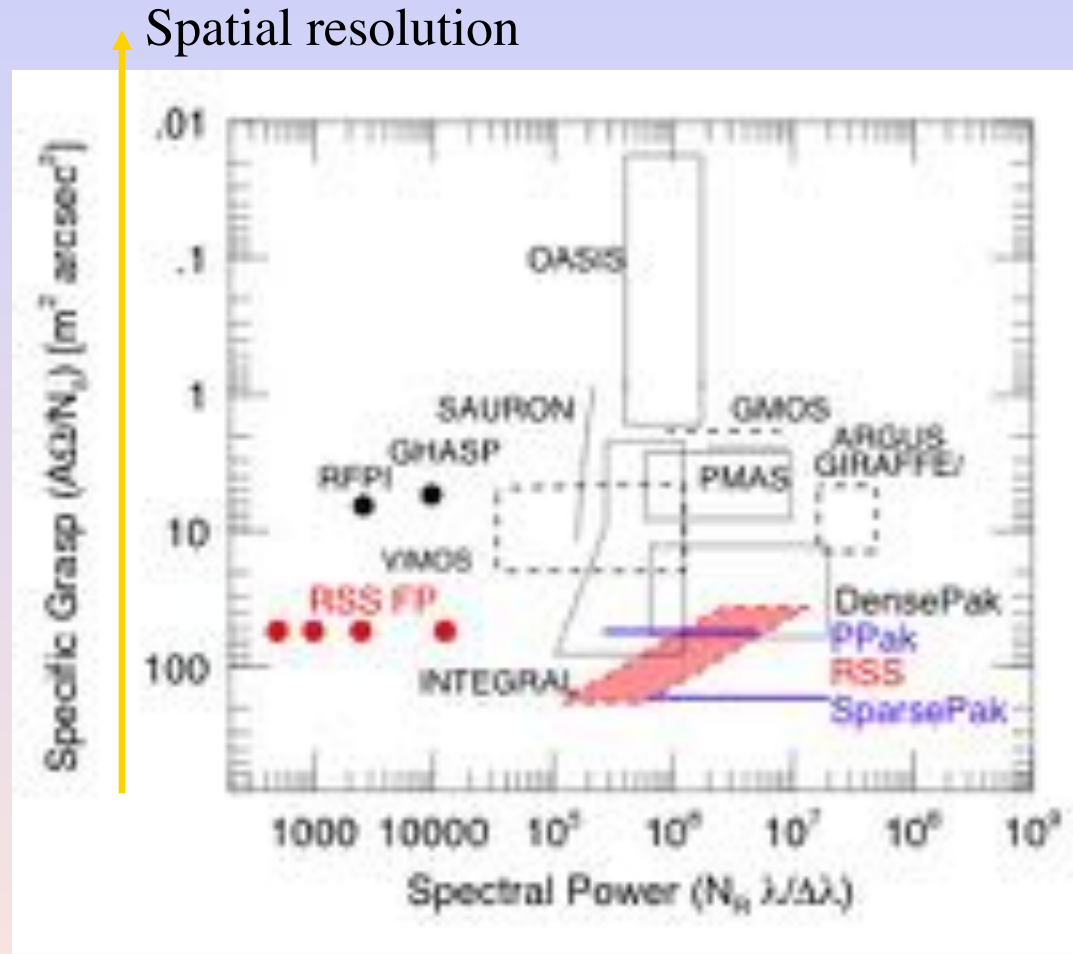
UGC 4499



Existing instruments

Summary of sampled parameter space

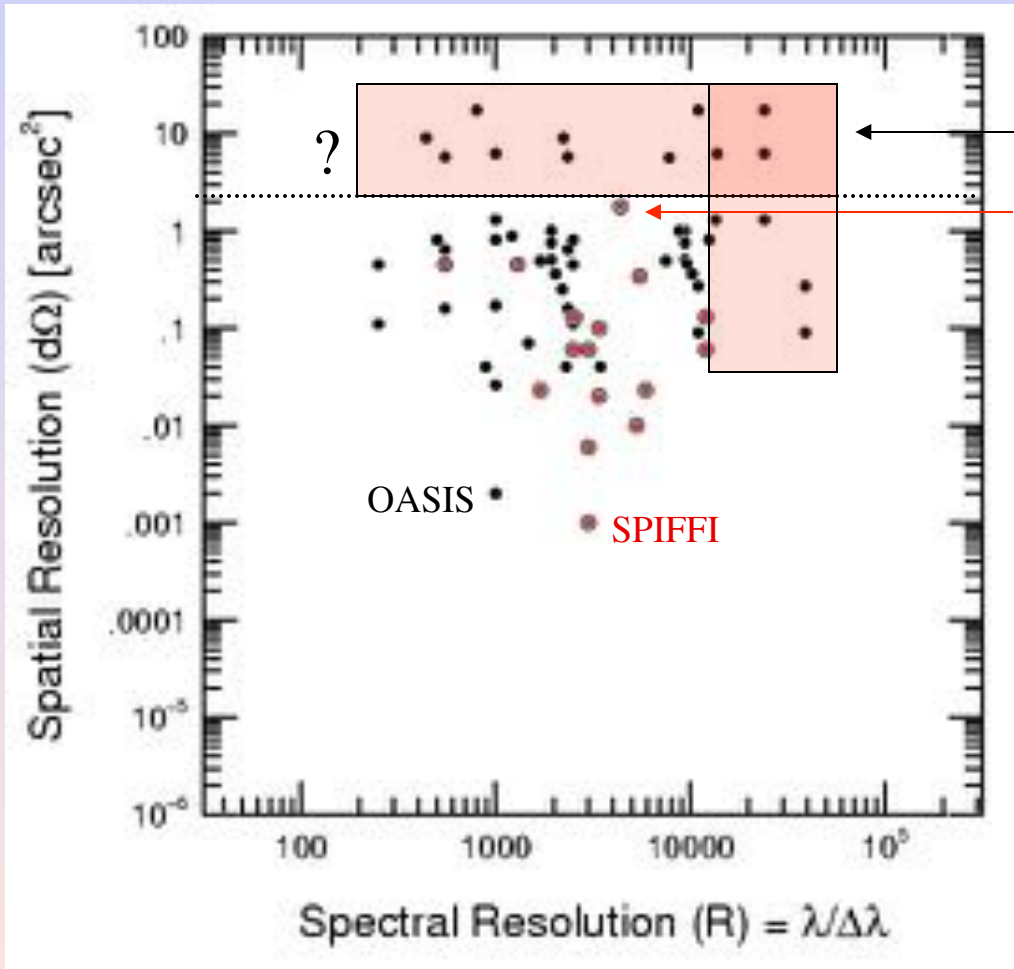
- Spatial vs spectral / coverage vs resolution
 - reliable, consistent ϵ measurements unavailable for most instruments
 - use grasp instead of etendue (warning: really want etendue)
 - many merit functions - start with grasp and spectral power



Bershady et al. '04 (revised)

Existing instruments

summary of sampled parameter space



Fiber IFUs

Integral
DensePak
SparsePak
PPak
and FMS
RSS

Spatial resolution:

- higher in NIR on average

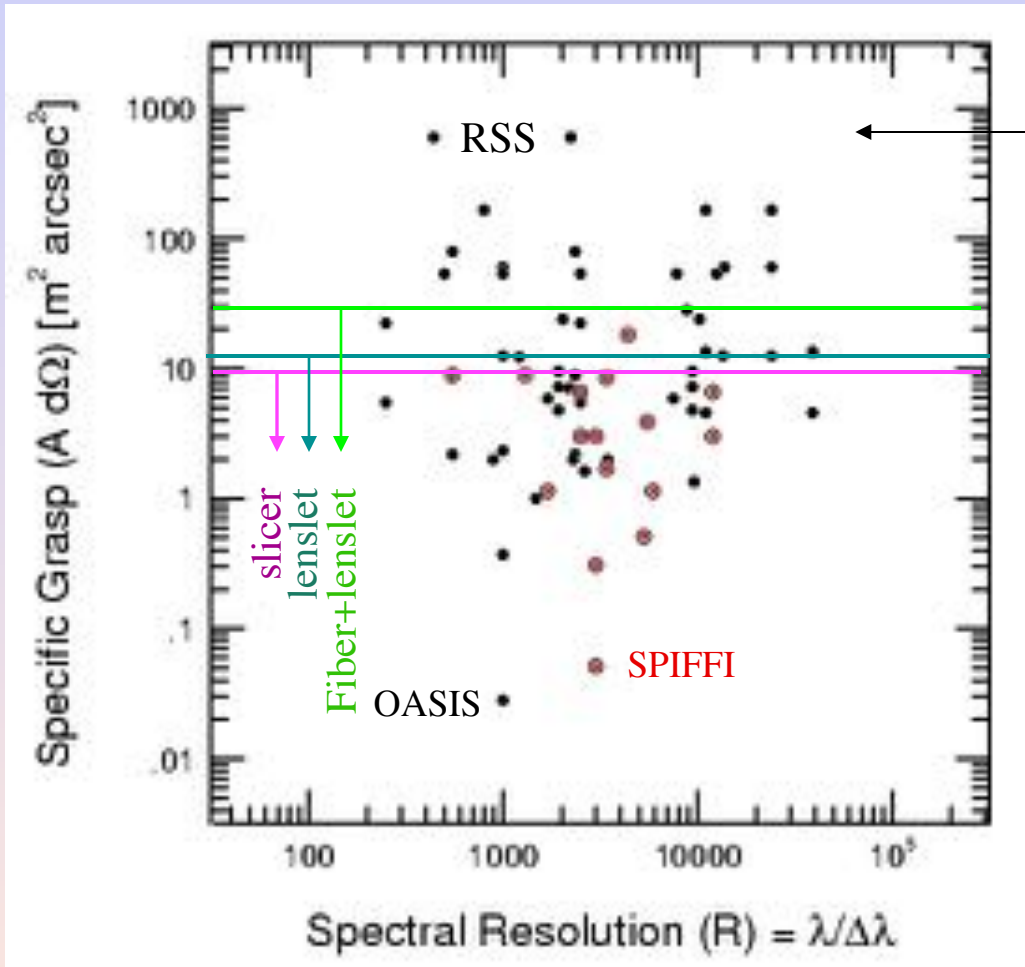
Spectral resolution:

- higher in optical

optical ● infrared ⊙

Existing instruments

summary of sampled parameter space



Fiber IFUs

Integral
DensePak
SparsePak
PPak
and FMS
RSS

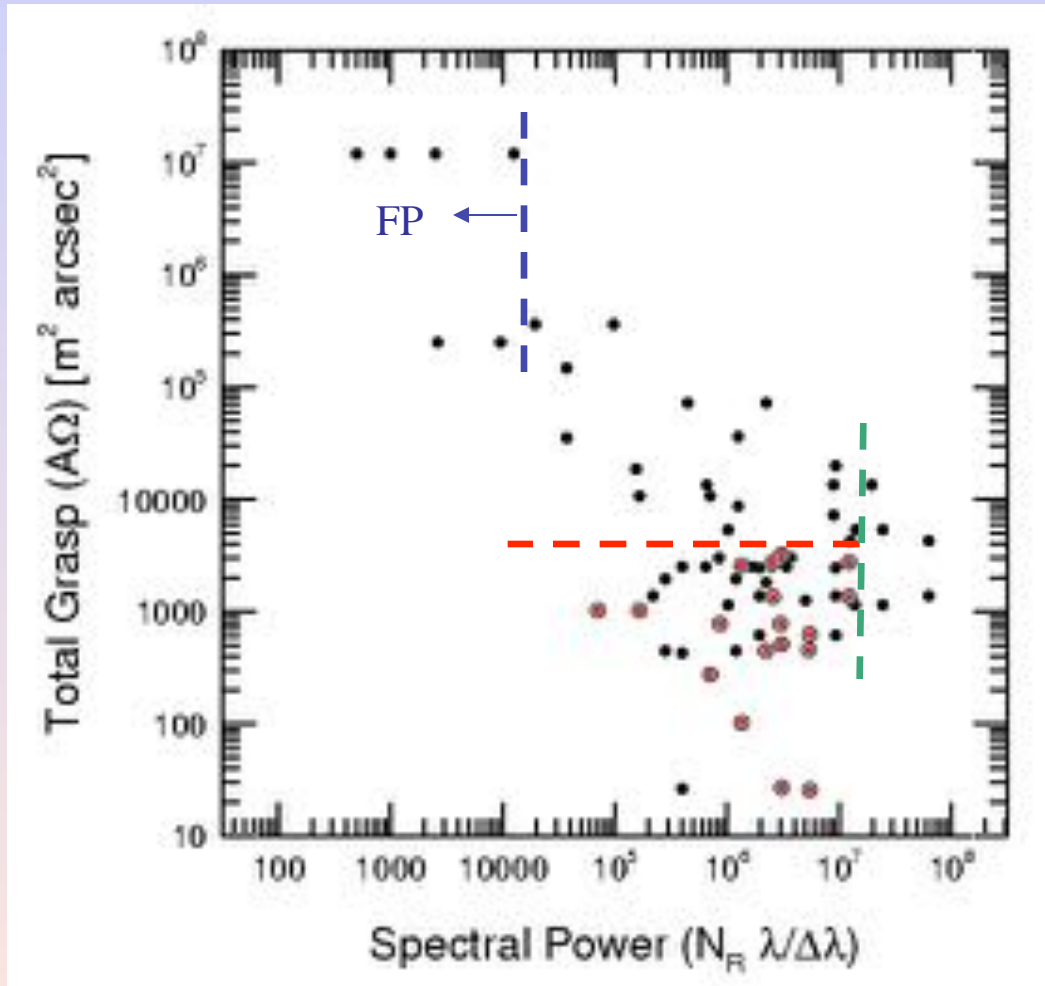
Specific grasp:

- higher in optical
- highest in fiber systems and FMS

optical ● infrared ●

Existing instruments

summary of sampled parameter space



Optical/NIR instruments trade spatial resolution for grasp.

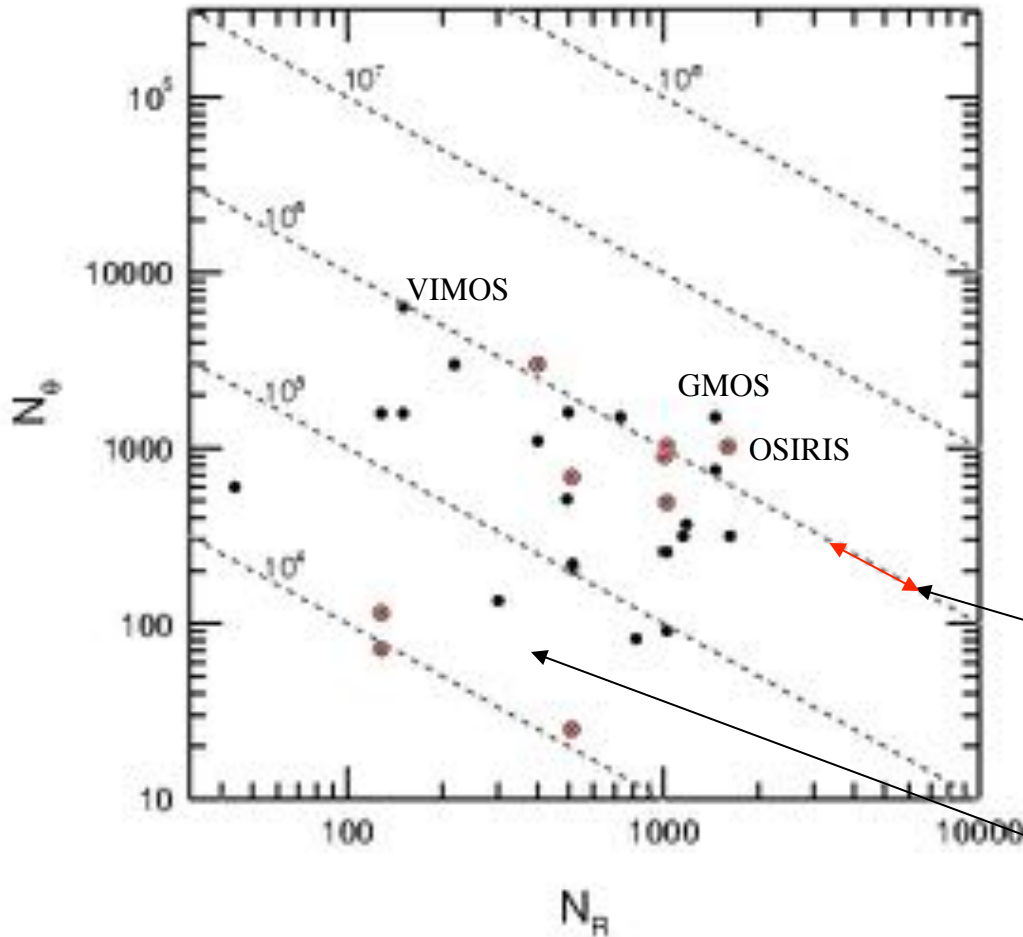
No high-grasp NIR instruments.

Highest spectral power instruments are optical.

optical ● infrared ●

Existing instruments

summary of sampled parameter space



Optical and NIR instruments sample comparable total information.

Optical instruments offer broader **range** of trades: spectral vs spatial.

Lines of constant total information: $N_R \times N_\theta$

Older NIR instruments detector limited (early arrays were much smaller than CCDs).

optical ● infrared ○