TMT Science and Instrument WS 2011

March 30, 2011, Victoria BC

MICHI: 未知　みち

Mid-Infrared Camera High-disperser, & IFU spectrograph

M. Honda (Kanagawa U),

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MICHI team

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未知 (みち) = "Unknown Things"

Instrument for challenge to the unknowns

Outline

- A brief history and collaborators
- IFU Science cases of TMT/MICHI
- Required instrument parameters & uniqueness
- Overall current Instrument design & key tech.

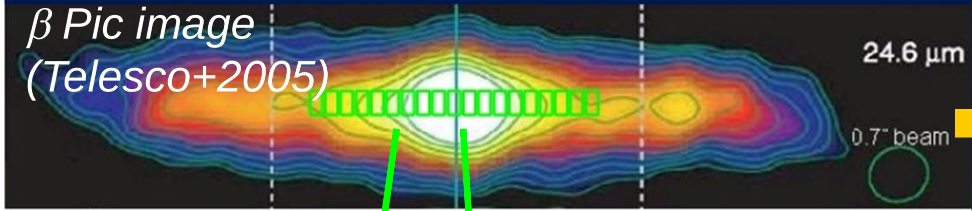
A brief history and collaborators

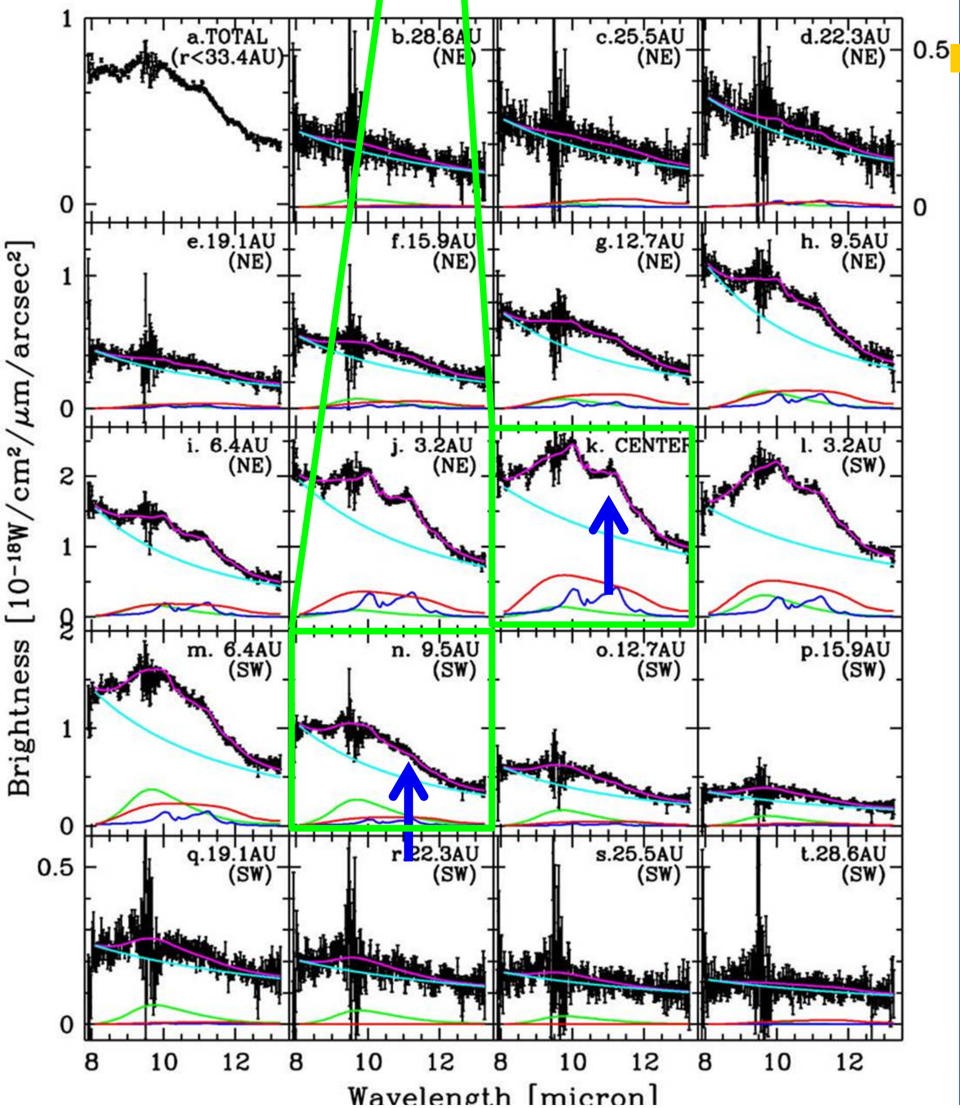
- MICHI has been studied by Japanese & US astronomers since 2008
  - Instrument design team (13)
    - M. Chun (UH), T. Fujiyoshi (Subaru), M. Honda (Kanagawa U), H. Kataza (ISAS), Y. K. Okamoto (Ibaraki), T. Onaka (UT), C. Packham (UF), M. Richter (UC Davis), I. Sakon (UT), C. M. Telesco (UF), A. Tokunaga (UH), C. Warner (UF), T. Yamashita (NAOJ)
  - Instrument science team (24)
    - J. Carr (NRL), K. Enya, H. Fujiwara (ISAS), T. Fujiyoshi (Subaru), M. Honda (Kanagawa U), T. Kotani (ISAS), J. Najita (NOAO), T. Matsuo (NAOJ), Y. K. Okamoto (Ibaraki), T. Ootsubo (Tohoku), M. Takami (ASIAA), M. Richter(UC Davis), C. M. Telesco (UF), A. Tokunaga (UH), C. M. Wright (UNSW@ADFA), M. Chiba (Tohoku), M. Imanishi (NAOJ), N. Levenson (Gemini), T. Minezaki (UT), C. Packham (UF), Y. Ita (Tohoku), H. Izumiura (NAOJ), M. Matsuura (University College London), I. Sakon (UT)
  - Industrical partners
    - M. Rodgers, J. McGuire (ORA), Y. Ikeda (Photocoding), Sumitomo Heavy Industry
- MICHI presentations at SPIE @San Diego in June 2010
- Instrument reference document (0^{th} version) submitted to the J-TMT office of NAOJ in August 2010

Science Cases of MICHI

- MICHI covers wide areas of modern astronomy
  - Imaging, spectroscopy → C. Packham's talk
  - High-dispersion spectroscopy → M. Richter's talk
  - Low-dispersion spectroscopy with IFU → this talk
- **Merits of MICHI IFU N-band low-R spec.**
  - High observing efficiency (no slit-loss, adjusting)
  - Reveal 2D dust distribution efficiently like imaging!
    - Rich dust features
      - Amorphous silicate : ~9.8μm
      - Crystalline olivine : 10.1, 10.5, 11.2μm
      - Crystalline pyroxene : 9.3, 10.8, 11.7μm
      - PAH :7.7, 8.6, 11.2, 12.7μm
  - Full use of TMT's high spatial resolution advantage

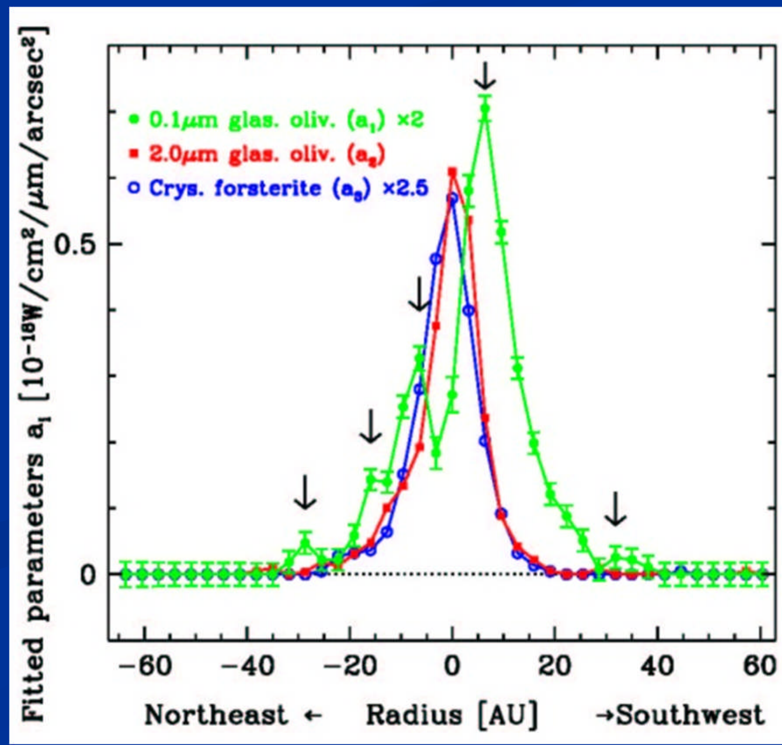
IFU N-band low-R spectroscopy of planet forming disks





Spatially resolved spectra by Subaru (Okamoto+2004)

- Spatially resolved N-band spectra of β Pic debris disk (Okamoto+2004)
- Spatial difference of dust feature
  - Central condensation of crystalline silicate grains
  - Several local peaks of small amorphous silicate



IFU N-band low-R spectroscopy of planet forming disks

- Spatially resolved N-band spectra of β Pic debris disk (Okamoto+2004)
- Spatial difference of dust feature
  - Central condensation of crystalline silicate grains
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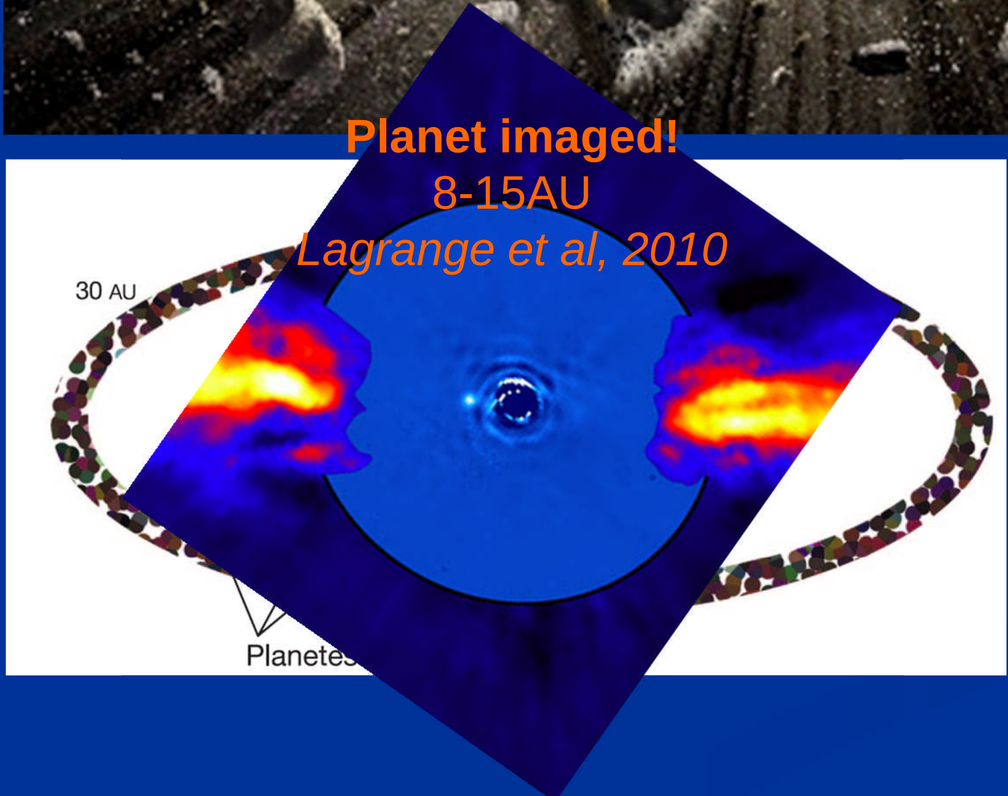
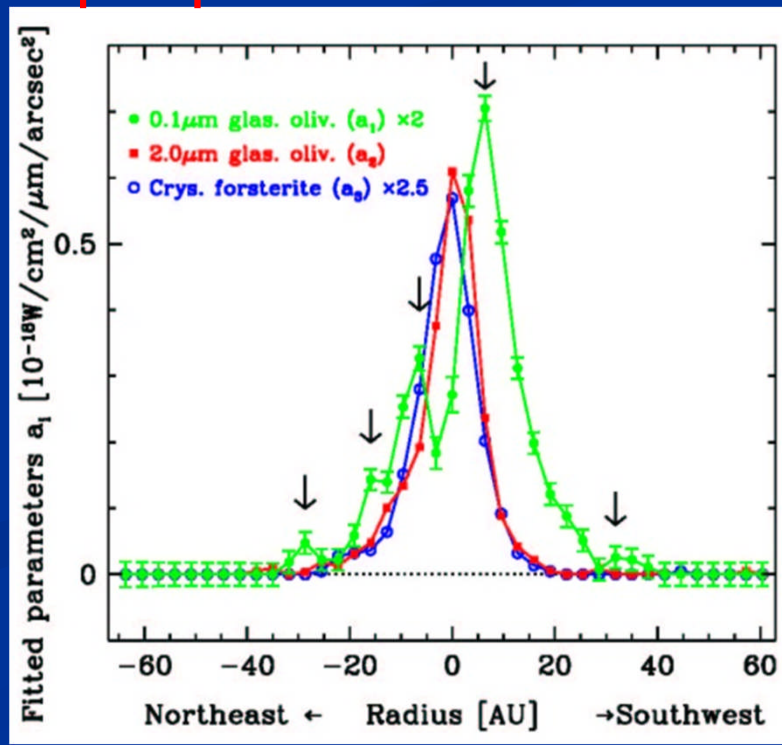
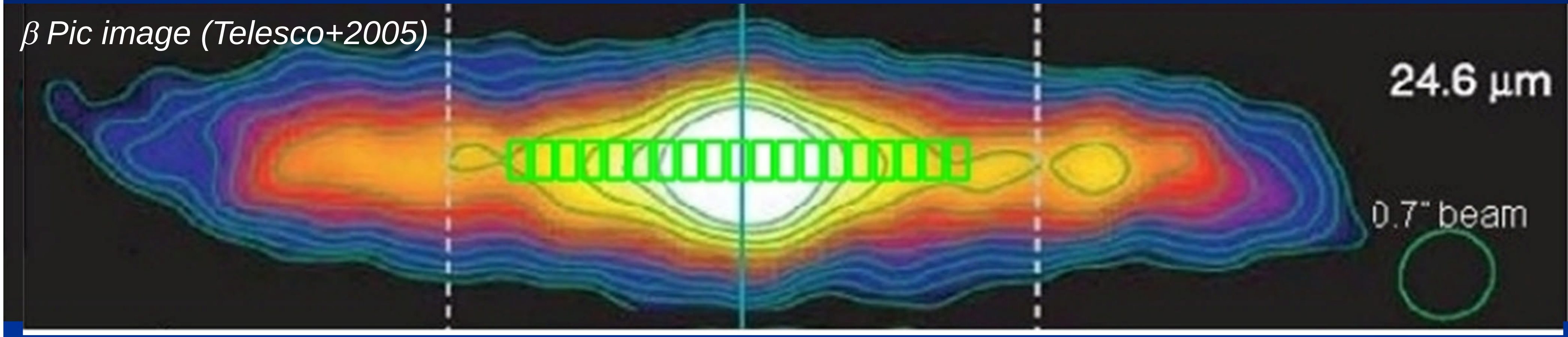
→ Multiple planetesimal belts





IFU N-band low-R spectroscopy of planet forming disks

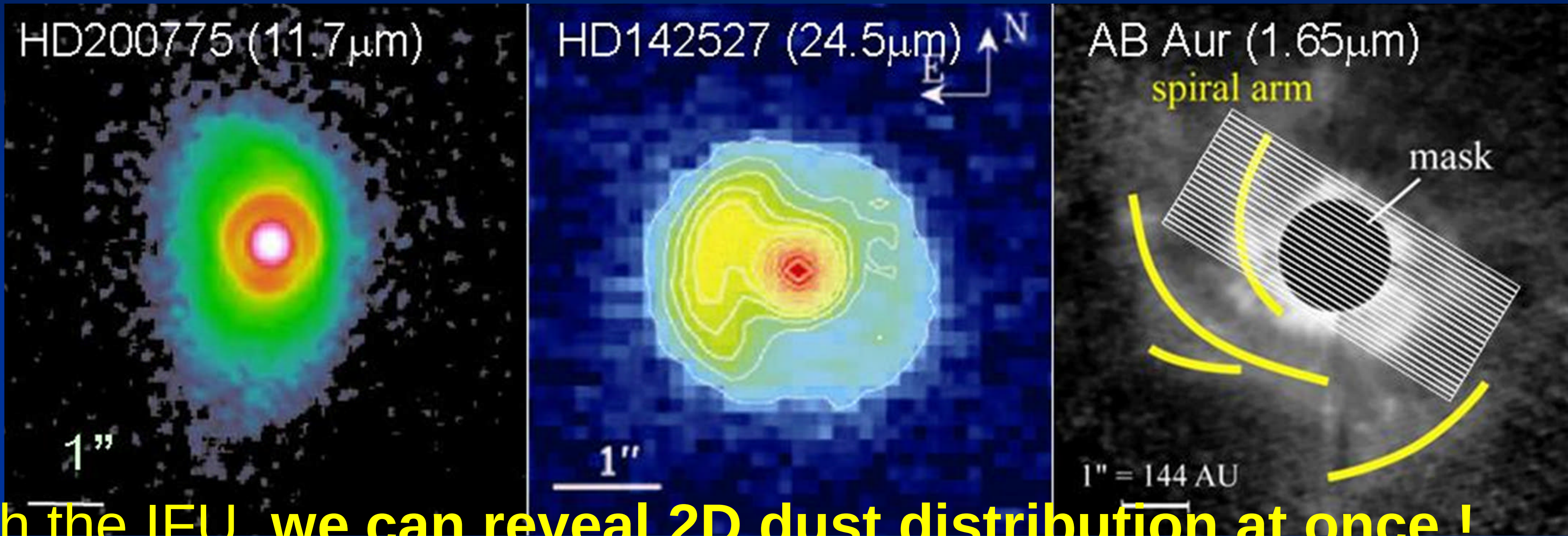


With the IFU, **we can reveal 2D dust distribution at once !**

- Vertical distribution of dust for *edge-on disks*
- For *face-on disks*, 2D dust distribution is essential for tracing planetesimal belts
  → Slit-scan → time-consuming !
- MICHI/IFU provide spatially resolved spectra up to 22x faster than slit scanning

Necessary for *optimal use* of precious observing time of TMT

IFU N-band low-R spectroscopy of planet forming disks



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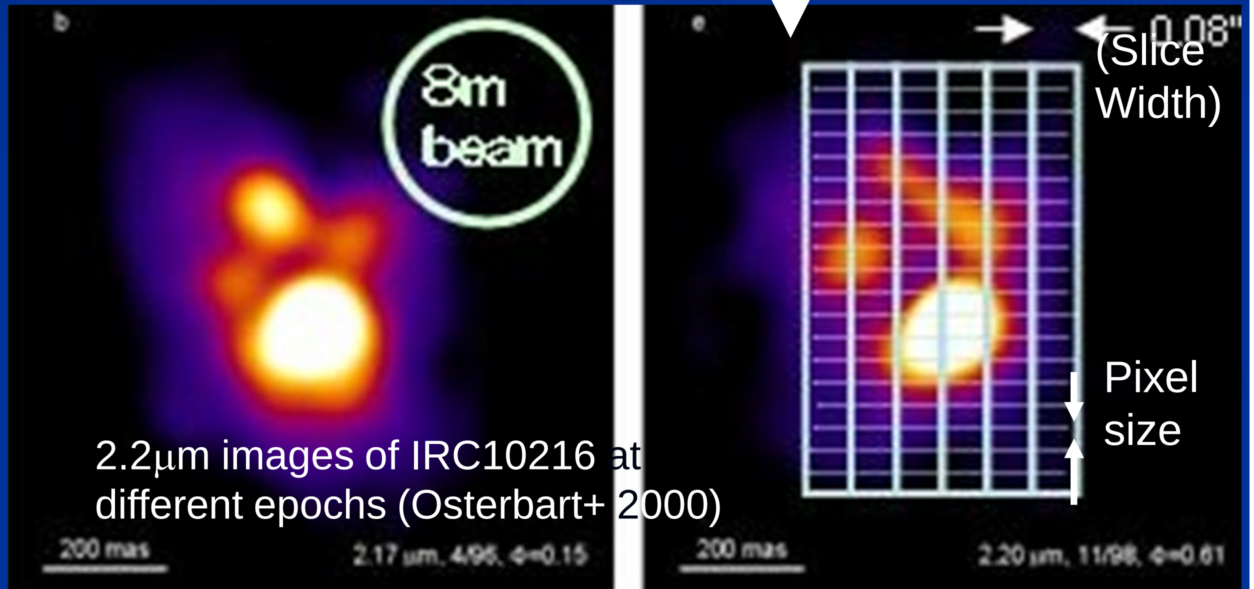
Necessary for *optimal use* of precious observing time of TMT

IFU N-band low-R spectroscopy of dust forming evolved stars

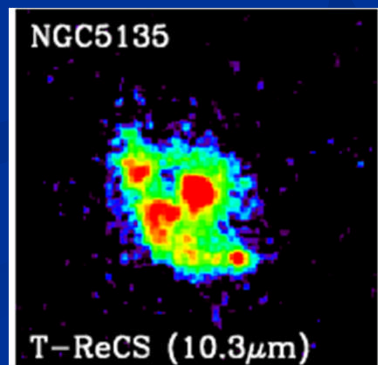
- *How grains are formed and supplied to the ISM ?*
- Circumstellar envelopes (CSEs) of AGBs
- WRs/SNe/SNRs
- Where and what grains are there ?
- Detailed comparison with dust/molecule formation theory

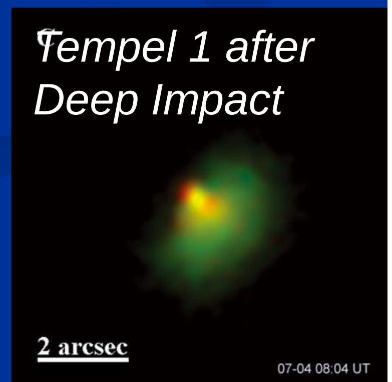
A part of FOV of MICHI's IFU



2.2µm images of IRC10216 at different epochs (Osterbart+ 2000)

- Contribution to understanding mass-loss history/mechanism
- **IFU is also useful for other objects**
  - AGNs, comets, etc…





Required instrument parameters

	Imaging	Low-R spectro-scopy w IFU	Long-slit mod-R spectroscopy	High-R spectroscopy
Wavelength coverage [μm]	**7.3-13.8** **16.0-25.0**	**7-14**	**7.3-13.8,** **16.0-25.0**	**7.3-13.8,** **16.0-25.0**
FOV	**28.1x28.1 ”**	**5” x 2”**	**28.1” x (0.1-0.3)”**	**2” x (0.1-0.3)”**
Spatial resolution	**Diffraction limited value w/ MIRAO（0.08”@10μm, 0.16”@20μm ）**			
Spectral resolution **R= λ / Δλ**	**R～10-100**	**R～250 (or500)**	**R～810 @ 10μm** **R～1,100 @ 20μm**	**R～120,000 @ 10μm** **R～60,000 @ 20μm**
Others	**Polarimetry** (for imaging and mod-R spectroscopy) **Option:** High-contrast imaging & IFU spectroscopy such as **coronagraph/aperture-masking observations** (under consideration)			

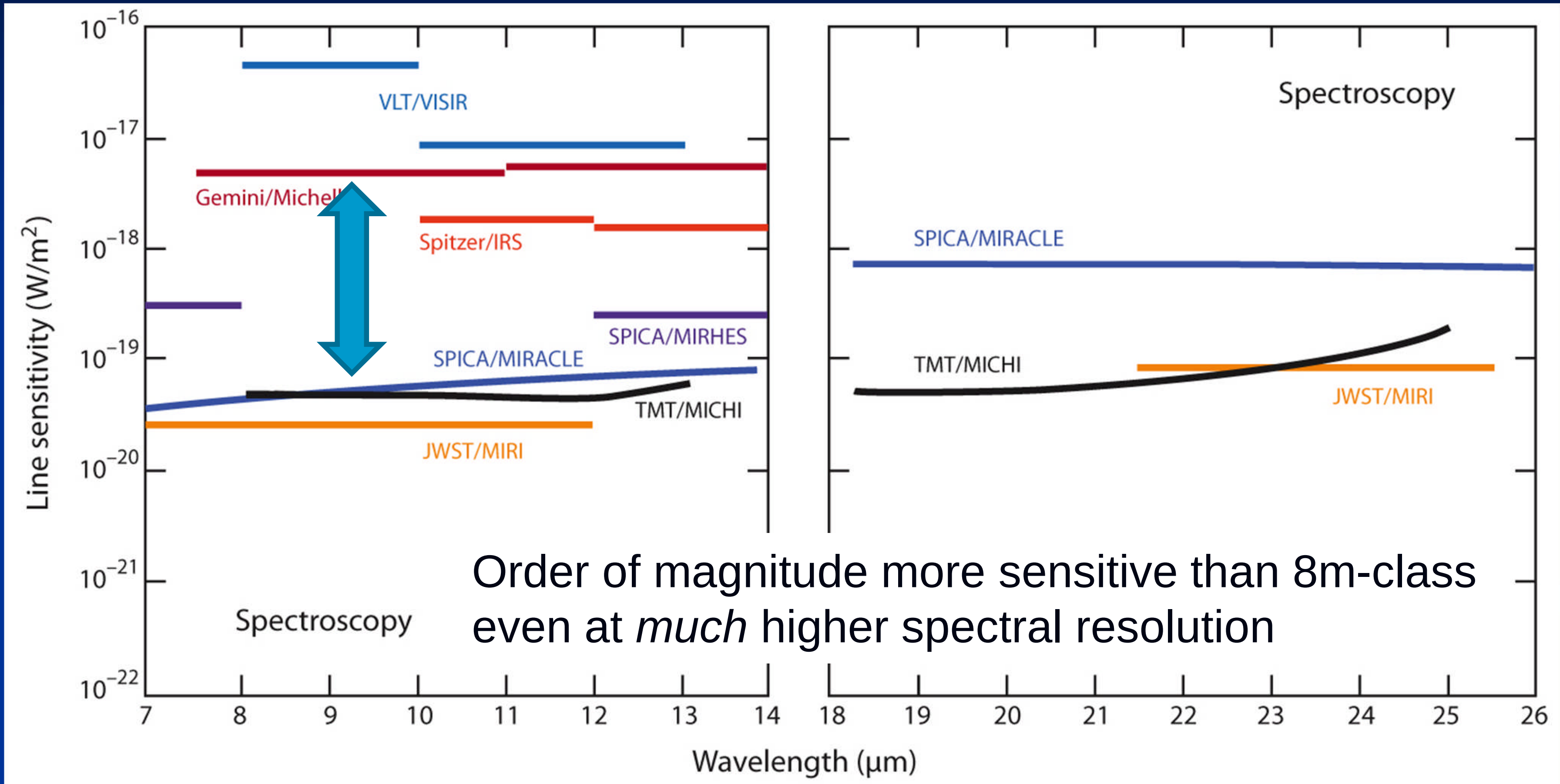
- Improvements from MIRES following science requirements
  - Addition of
    - *Low-dispersion spectroscopy with IFU*
      - Applicable to much broader area of important astronomical topics
    - *Internal cold chopper*
      - Enables low-dispersion spectroscopy and improved imaging performance
    - *Polarimetry*
    - *High-contrast observing capability* for exoplanets is under consideration, too.
  - Improved throughput with reflective optics

Uniqueness of MICHI to space facilities

- High-R spectroscopy & polarimetry *are not available for space telescopes*
- Imaging, low-R spectroscopy w IFU *with >4.5 times better spatial resolution*
  - JWST has higher sensitivity but *worse spatial resolution*.
    - Ex.1) JWST/MIRI will not spatially resolve the disks and CSEs of AGBs
    - Ex.2) MICHI covers exoplanets close to central stars which are not probed by JWST.

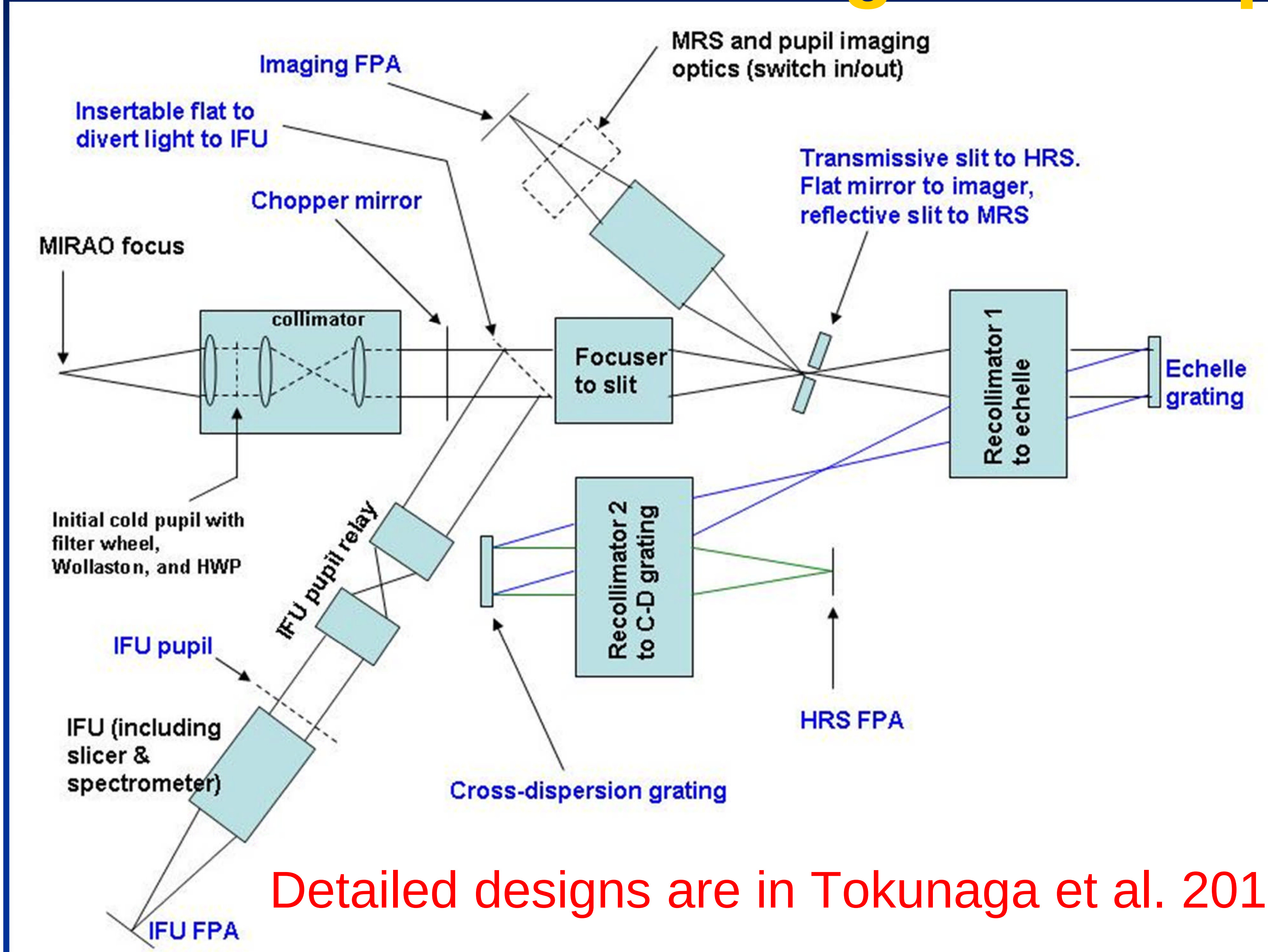
	TMT	JWST	SPICA
Telescope	**30m**	**6.5m**	**3.2m**
MIR Instrument	**MICHI (with MIR AO)**	**MIRI**	**MIRACLE, MIRMES, MIRHES**
Wavelength	**N, Q**	**5-28μm**	**5-38μm**
Spatial resolution	**0.08”@N** **0.16”@Q**	**0.4”@10μm,** **0.8”@20μm**	**0.8”@10μm** **1.6”@20μm**
Spectral resolution R (spectroscopy)	**~300-500@N (IFU)** **~900@N** **~1600@Q** **~10^5 @N,Q**	**~100 @5-14μm** **~2100-3700 @5-29μm**	**1500@10-20μm** **700@19-36μm** **200@5-38μm** **30000@4-8 &12-18μm**
Sensitivity (5σ1hr)	**0.1mJy (N imaging)**	**0.4μJy (10μm imaging)**	**1μJy (10μm imaging)**
others	**polarimetry**		
FoV	**27.5”x27.5” (Imager)** **27.5” (R~900-1600)** **2” (R~10^5)** **~2x5” (IFU)**	**74”x113” (Imager)** **5.5” (R~100)** **~3x4 to ~7x8” (IFU)**	**5’x5’ (Imager)** **12”x(6or12)” (R~700-1500)** **~6” (R~30000 spec.)**

Spectroscopic Sensitivity



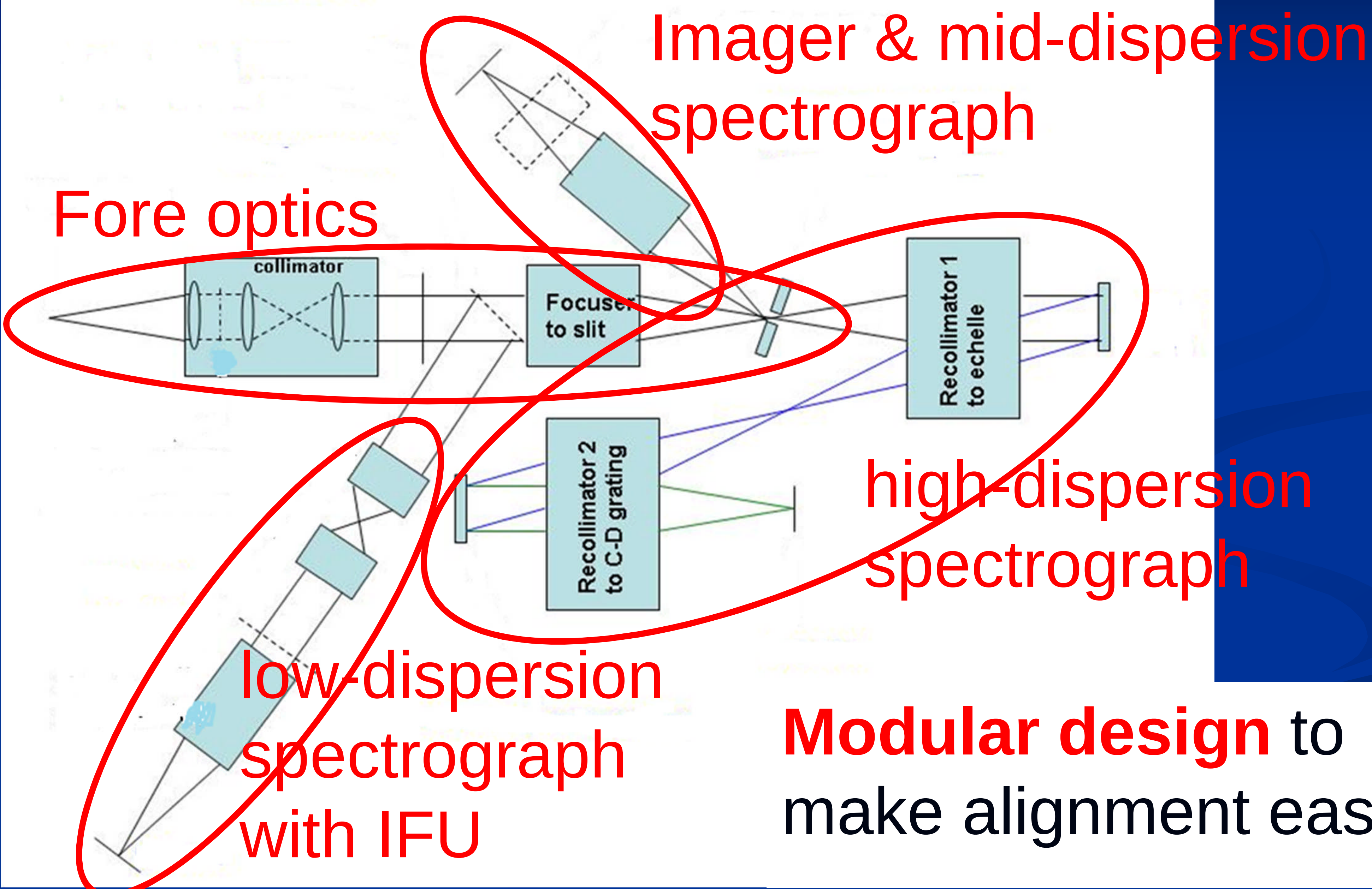
- Point source sensitivity 10σ in 1 hour elapsed time
- Sensitivity comparison is difficult especially in mid-IR
  - Observing/conditions assumptions can be widely different between groups
  - Spectral resolutions differ by >2 orders of magnitude
    e.g. SPICA: R~0.2K & 30K, JWST: R~2-4K, MICHI: R~120K
  - Estimated from publications (simple scaling) or on-line calculators

Instrument design: overall block diagram of optics



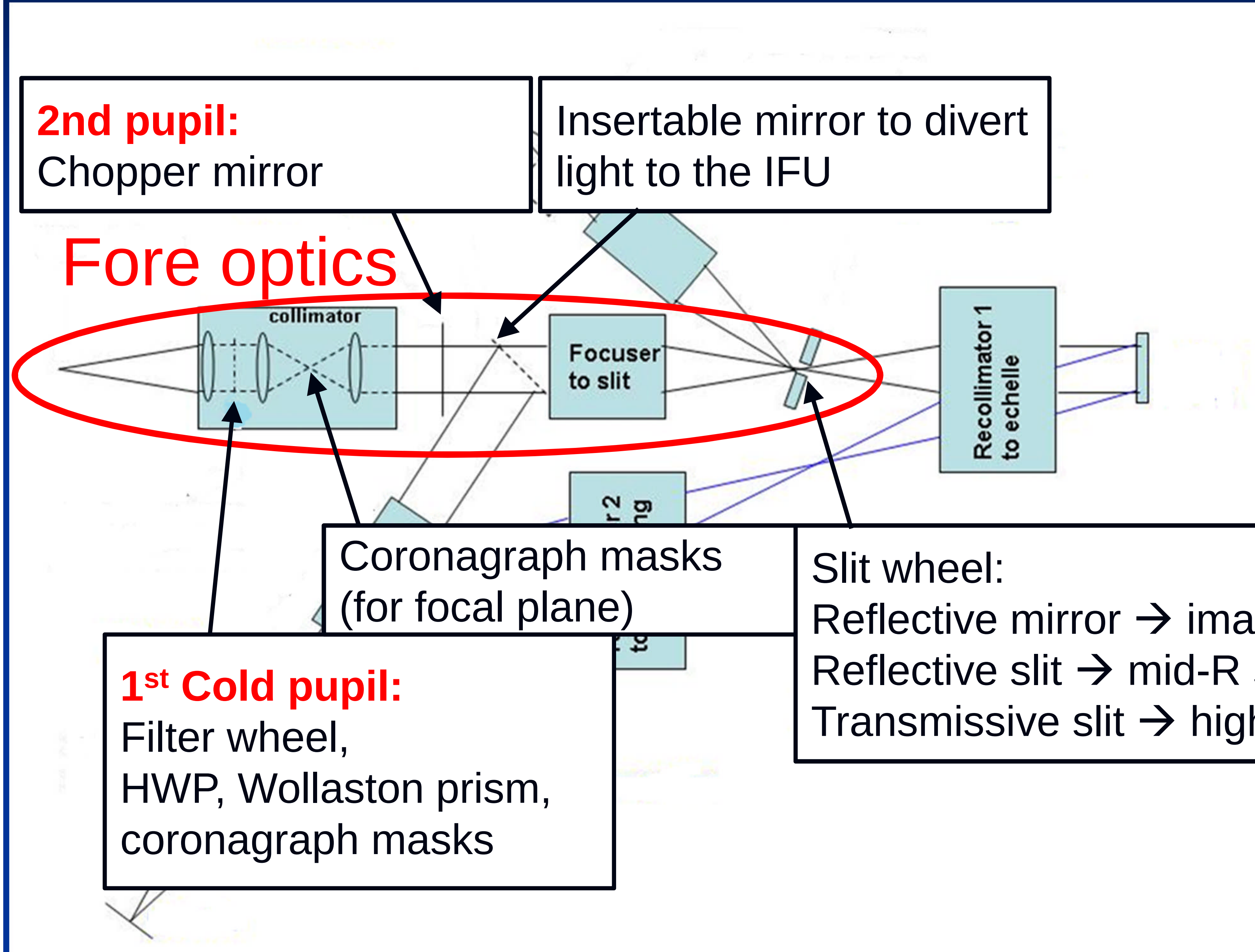
Detailed designs are in Tokunaga et al. 2010 & poster

Instrument design: overall block diagram of optics



Modular design to make alignment easier

Fore-optics



2nd pupil:
Chopper mirror

Insertable mirror to divert light to the IFU

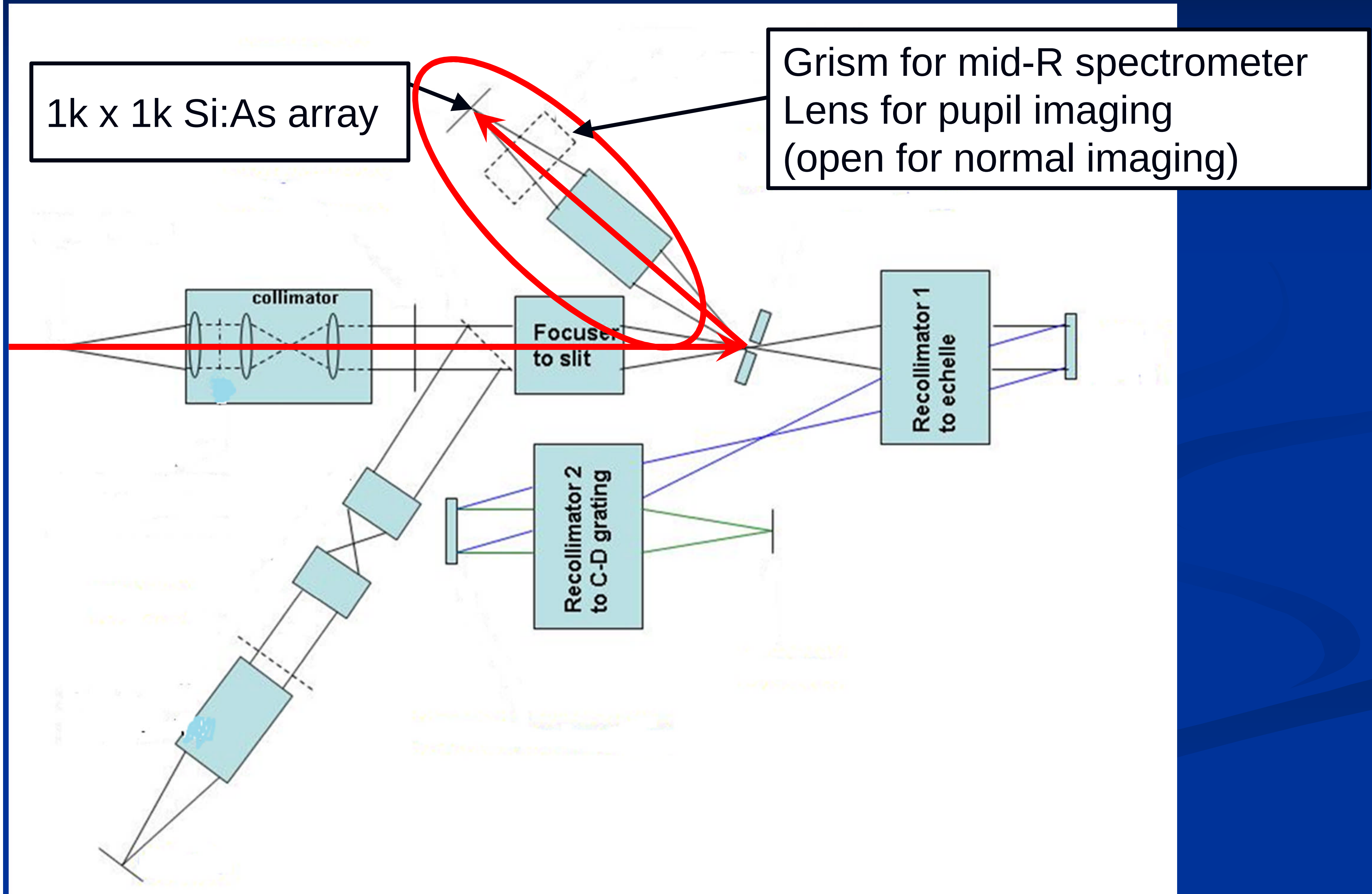
Fore optics

Coronagraph masks (for focal plane)

Slit wheel:
Reflective mirror → imager
Reflective slit → mid-R spectrometer
Transmissive slit → high-disperser

1st Cold pupil:
Filter wheel,
HWP, Wollaston prism,
coronagraph masks

Imager & mid-dispersion spectrometer

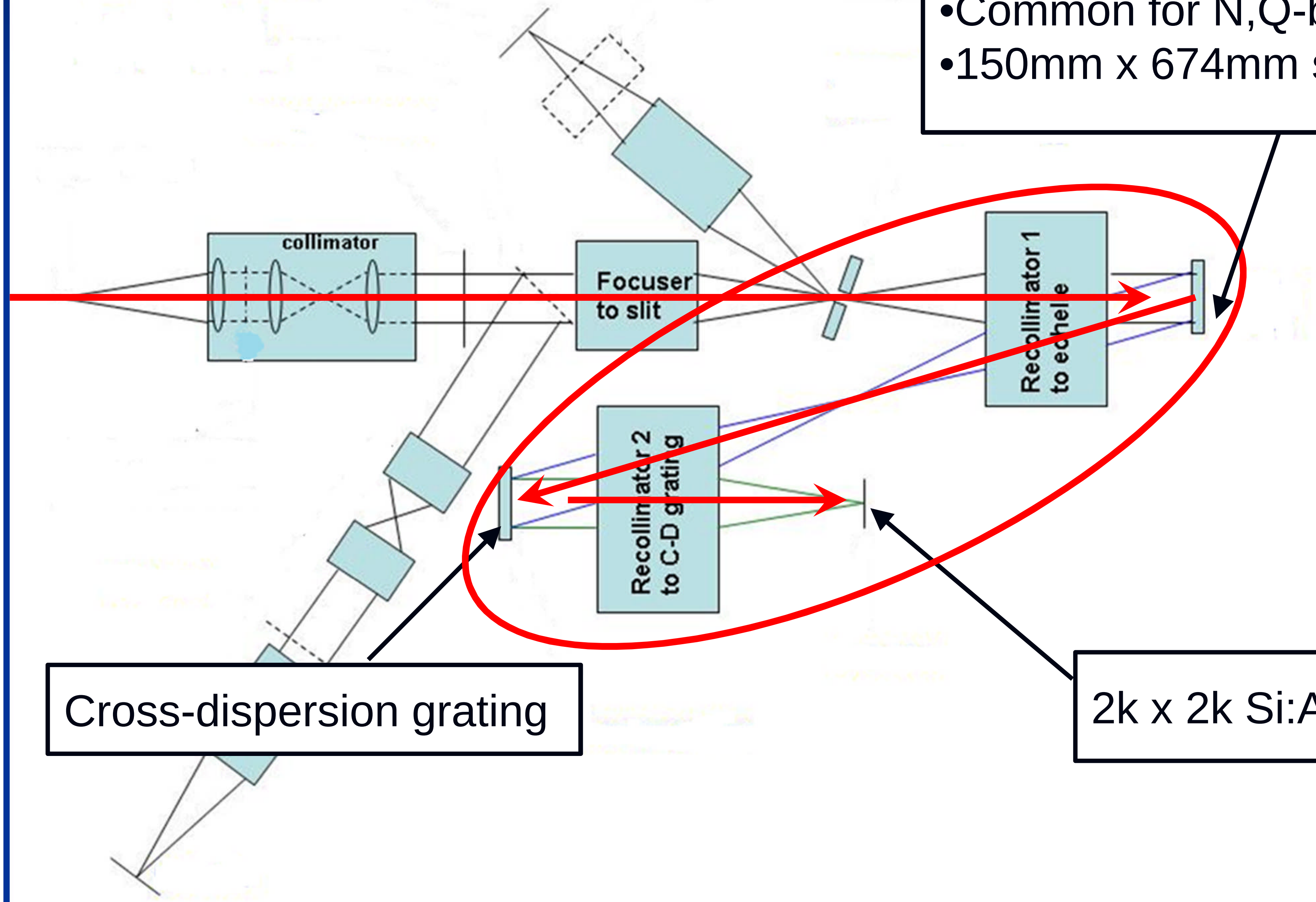


High-dispersion spectrograph

Can be used as slit viewer

Echelle grating

- based on the experience of TEXES and EXES
- Common for N,Q-bands
- 150mm x 674mm size

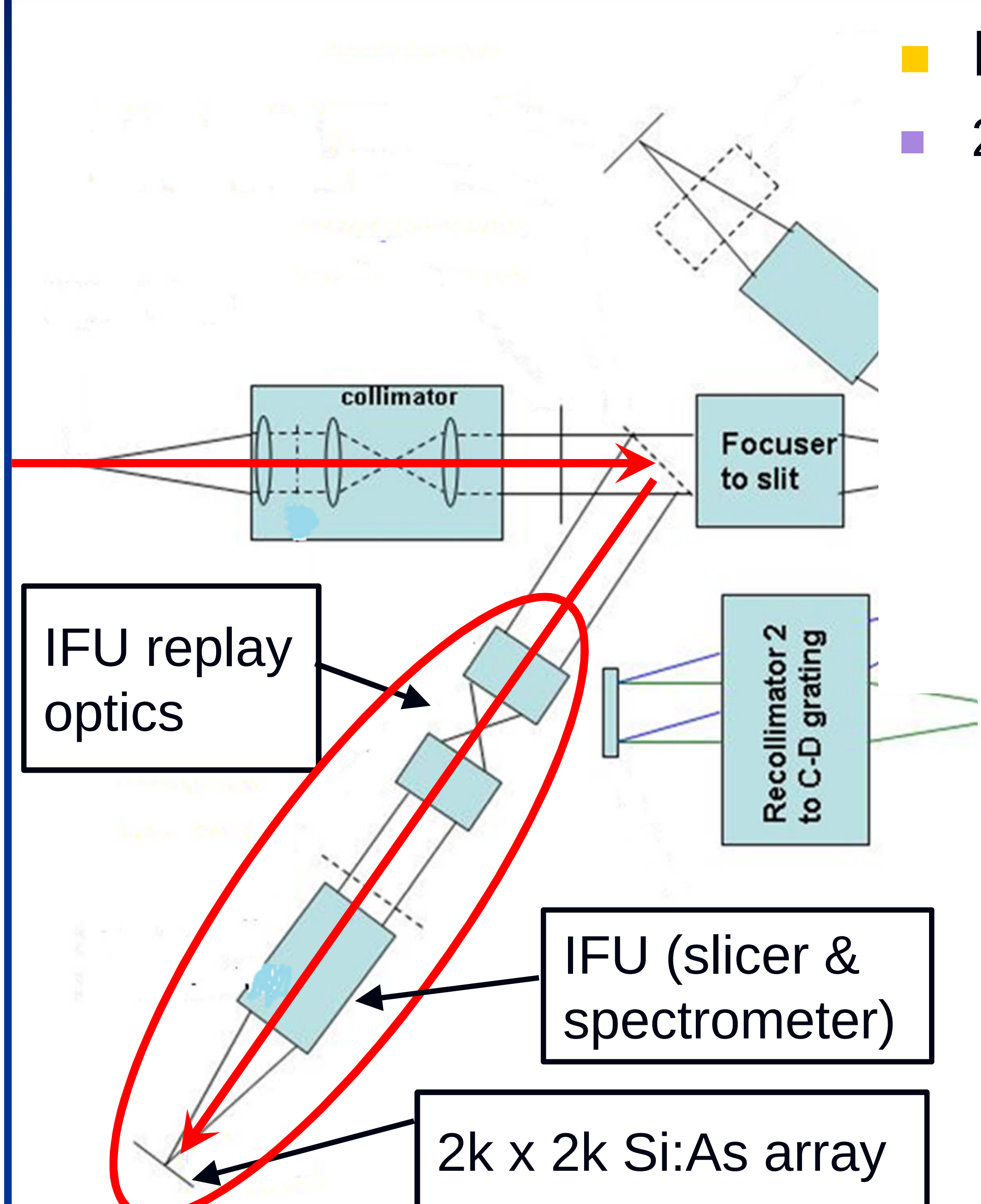


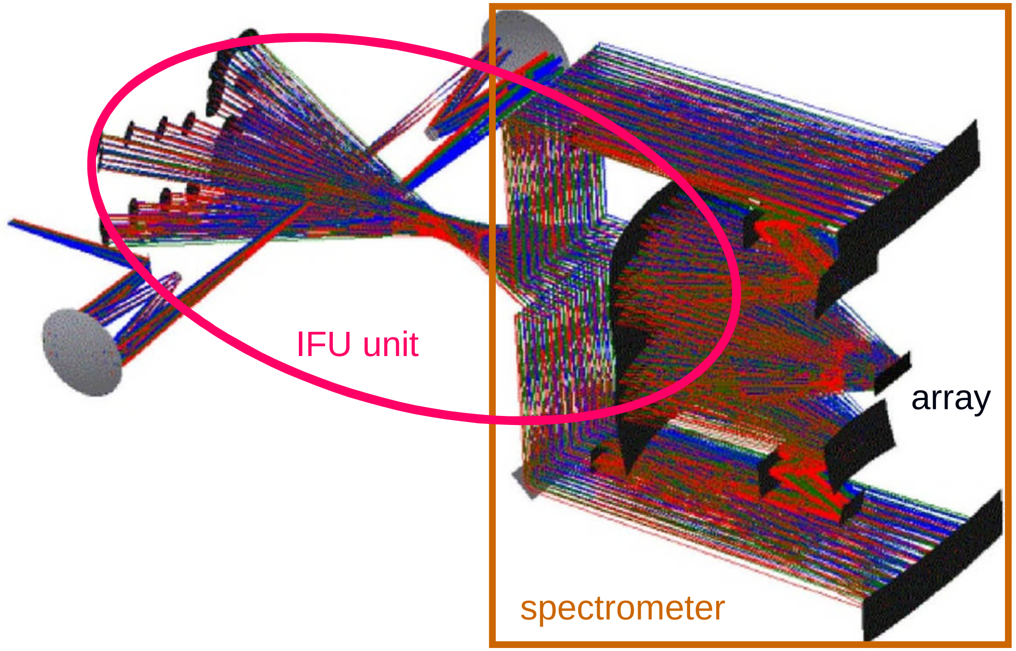
Cross-dispersion grating

2k x 2k Si:As array

Low-dispersion spectrograph with IFU

- Image slicer type IFU
- 22slices for 2” x 5” FOV
  - Set by scientific requirement
    - important observing target size are typically 1 to a few arcsec.
  - Based on experiences of the prototype (MIRSIS) development at Ibaraki Univ. in Japan.



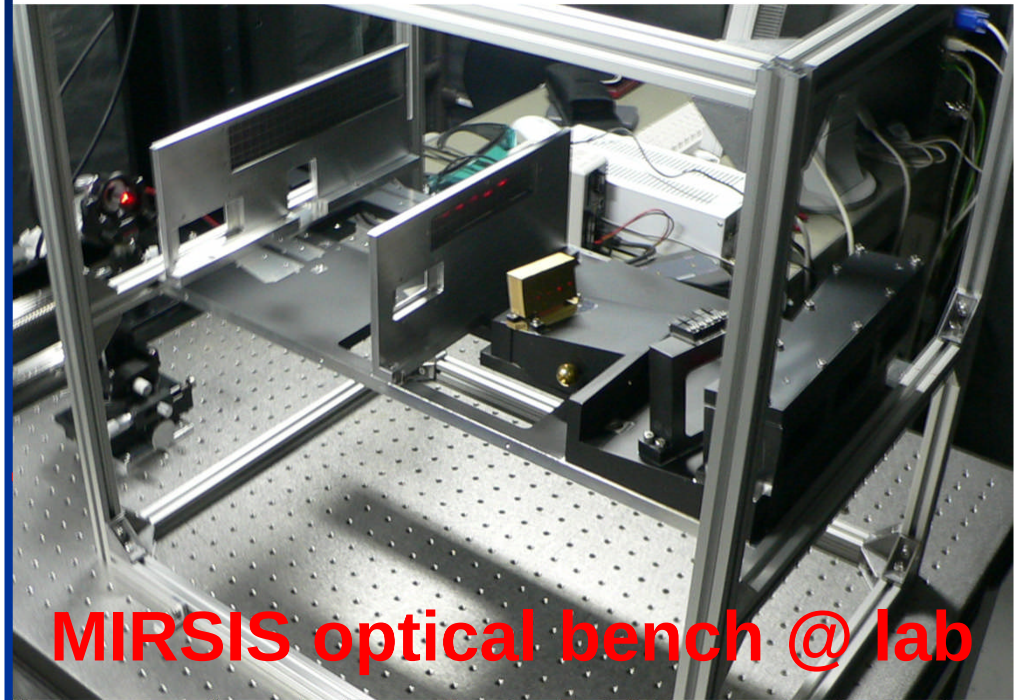


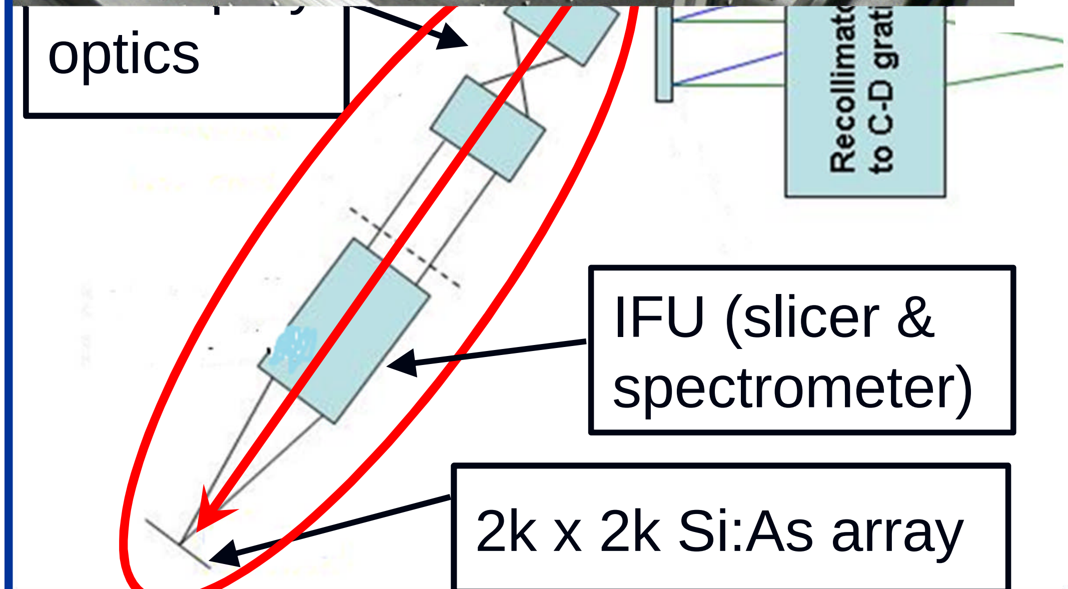
Low-dispersion spectrograph with IFU

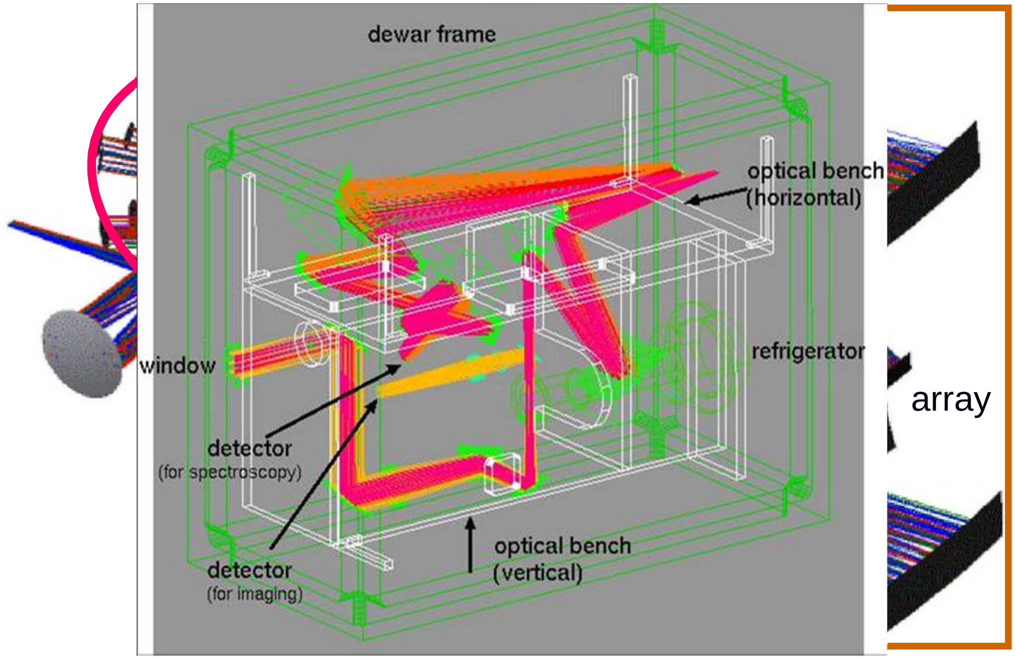
Image slicer type IFU

22slices for 2” x 5” FOV

- Set by scientific requirement
  - important observing target size are typically 1 to a few arcsec.
- Based on experiences of the prototype (MIRSIS) development at Ibaraki Univ. in Japan.







Key technologies of MICHI

- MICHI
  - ***Based on well developed techniques***, in principle.
  - Owing to the revised design, large refractive material is now not required.
- IFU (image slicer system)
  - **Prototype development is done in Japan**.
  - Basic key technologies to make slicer optics is already established.
  - Now R&D activity for improved technologies for a large format IFU is in progress.
- Internal cold chopper.
  - Possibly similar to Herschell chopper is applicable.
  - R&D activity for a voice coil system is planned for suitable system.
- Large format detector array.
  - 1k x 1k Si:As array exist; have to make 2k x 2k mosaic, but low technical risk (already planned by Raytheon).
  - Currently available “off the shelf”, but single source supplier…
- High-contrast system such as coronagraphs/aperture-masks
  - R&D activity is in progress for SPICA.
  - Possible simple methods for the MICHI are already established.

→ ***No high risk items. MICHI is already feasible***

Design Compliance

Imaging

Parameter	Design Requirement	Achieved Value	Pass/Fail
λ Coverage	7.3 – 25μm	7.3 – 25μm	√
Plate Scale	0.0269” $pixel^{-1}$ (1.05λ/D at 7.5μm)	0.0275” $pixel^{-1}$	√ - within 2%
Image Quality	Strehl >80%	>93% at 7.3μm	√

IFU Spectroscopy

Parameter	Design Requirement	Achieved Value	Pass/Fail
λ Coverage	7.3 – 13.8μm	7.3 – 13.8μm	√
Spectral Resolution	>250	265 at 10.5μm	√
Slices	≥21	22	√

Long-Slit Spectroscopy

Parameter	Design Requirement	Achieved Value	Pass/Fail
λ Coverage	7.3 – 25μm	7.3 – 25μm	√
Spectral Resolution	810 @ N 1,100 at Q	812 at N 1,139 at Q	√
Spectral IQ	Strehl >80%	>91% @ N >~50% @Q	√ at N Q rev. needed

High Spectral Resolution Spectroscopy

Parameter	Design Requirement	Achieved Value	Pass/Fail
λ Coverage	7.3 – 13.8μm	7.3 – 25μm	√
Spectral Resolution	120,000 @ 10.5μm	120,000 at 10.5μm, 60,000 at 21μm	√
Slit guiding	Available	Available	√ (imaging arm)

Design Compliance

Imaging

Parameter	Design Requirement	Achieved Value	Pass/Fail
λ Coverage	7.3 – 25μm	7.3 – 25μm	√
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MICHI is already feasible

Long-Slit Spectroscopy

Parameter	Design Requirement	Achieved Value	Pass/Fail
λ Coverage	7.3 – 25μm	7.3 – 25μm	√
Spectral Resolution	810 @ N	812 at N	√

Thank you for your listening !

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