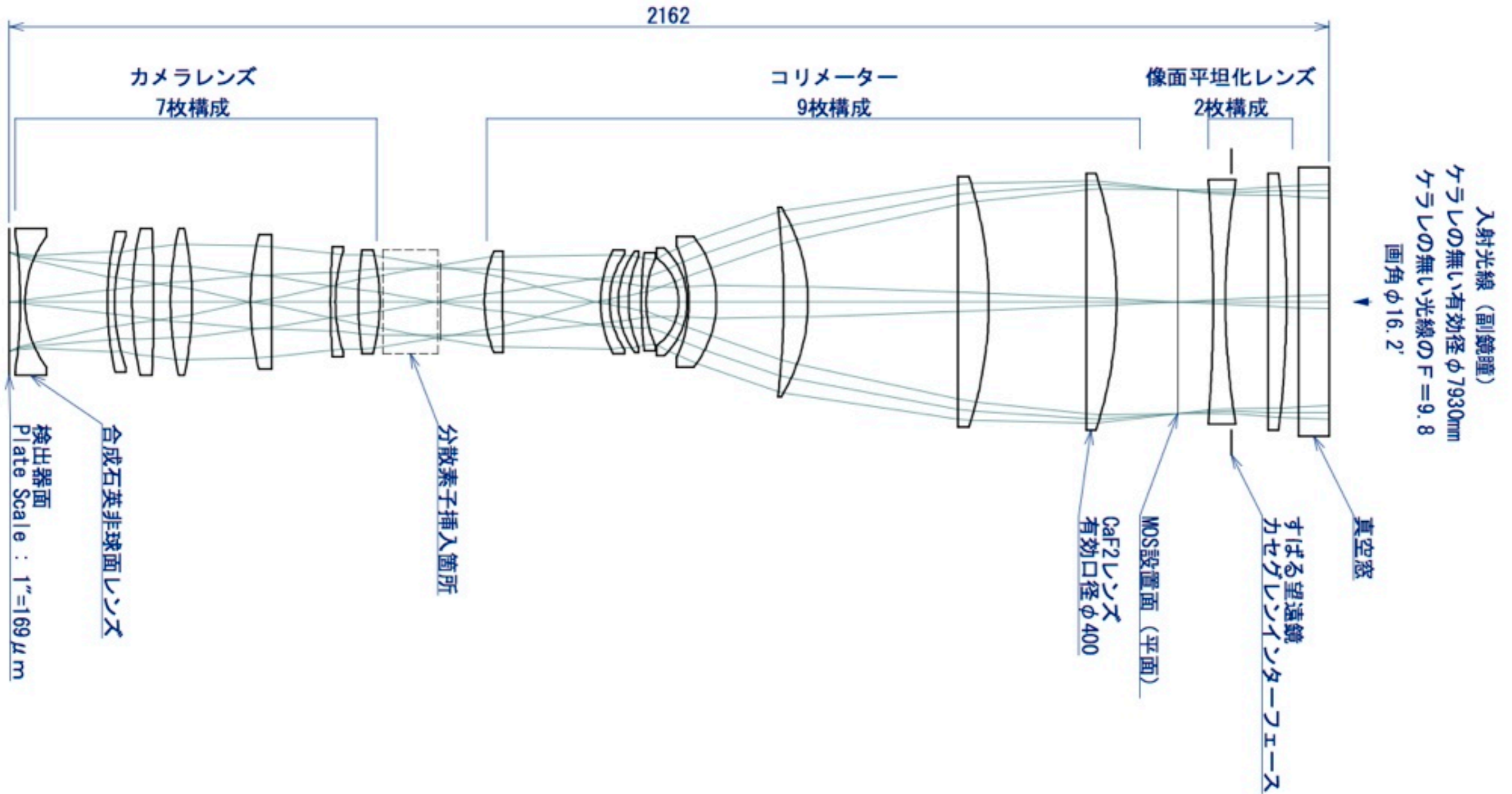


'Key Science' for Subaru GLAO

I. Iwata (Subaru Telescope, NAOJ)

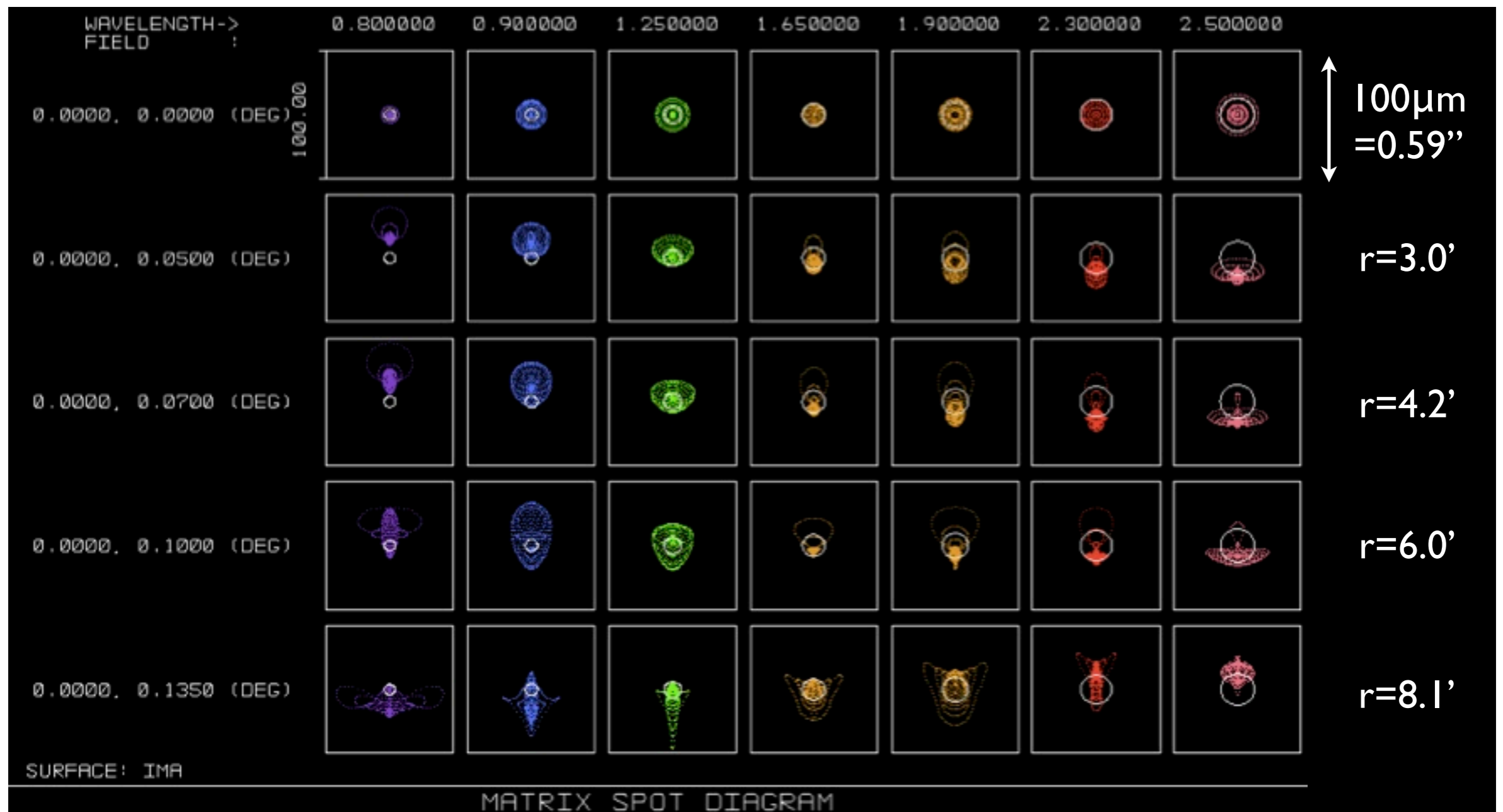
Very Wide-Field Near-Infrared Instrument

- Optical Design by Optcraft



Very Wide-Field Near-Infrared Instrument

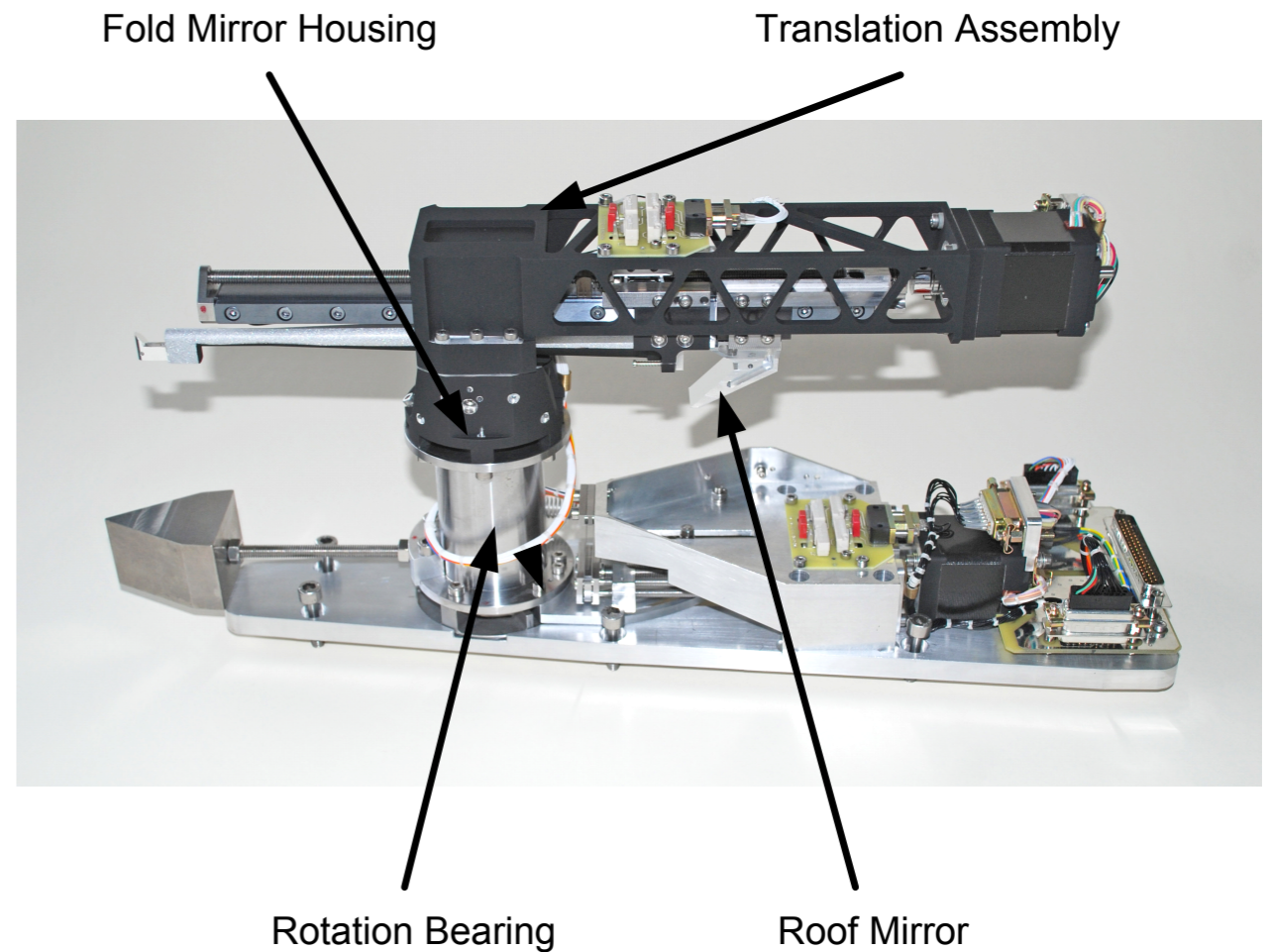
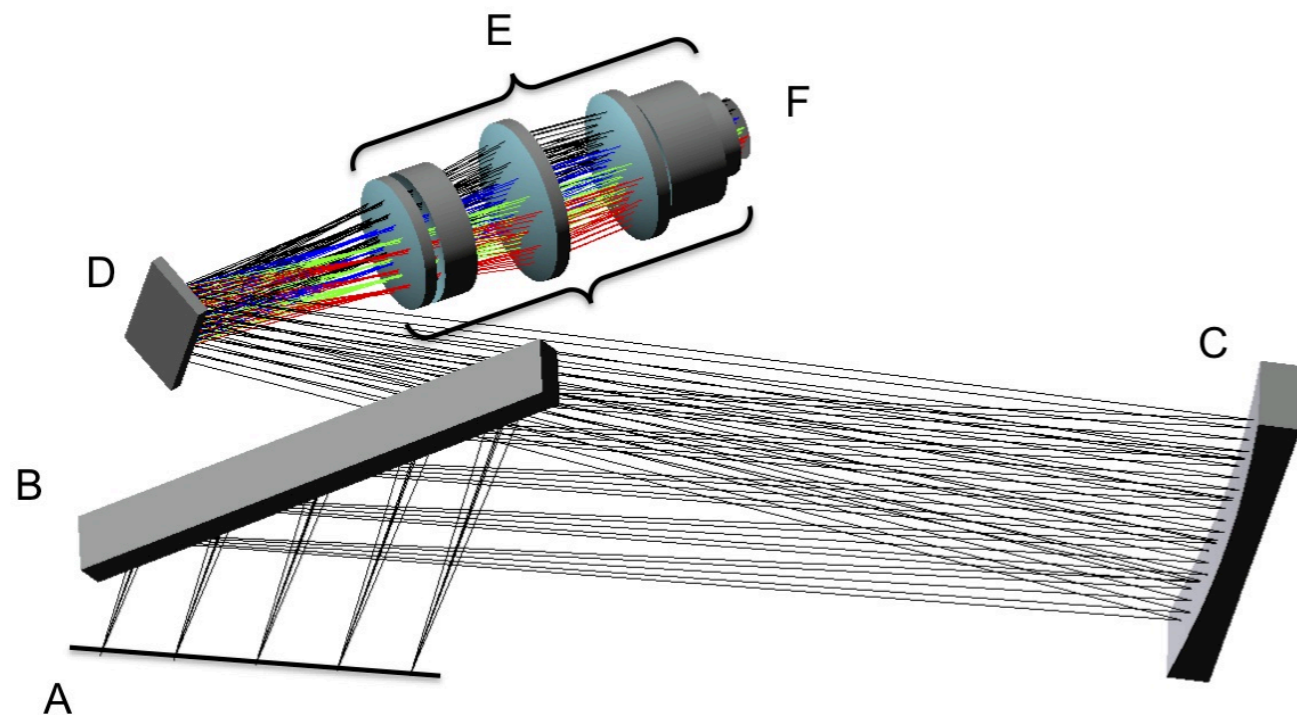
- Spot Diagram at Detector Focal Plane

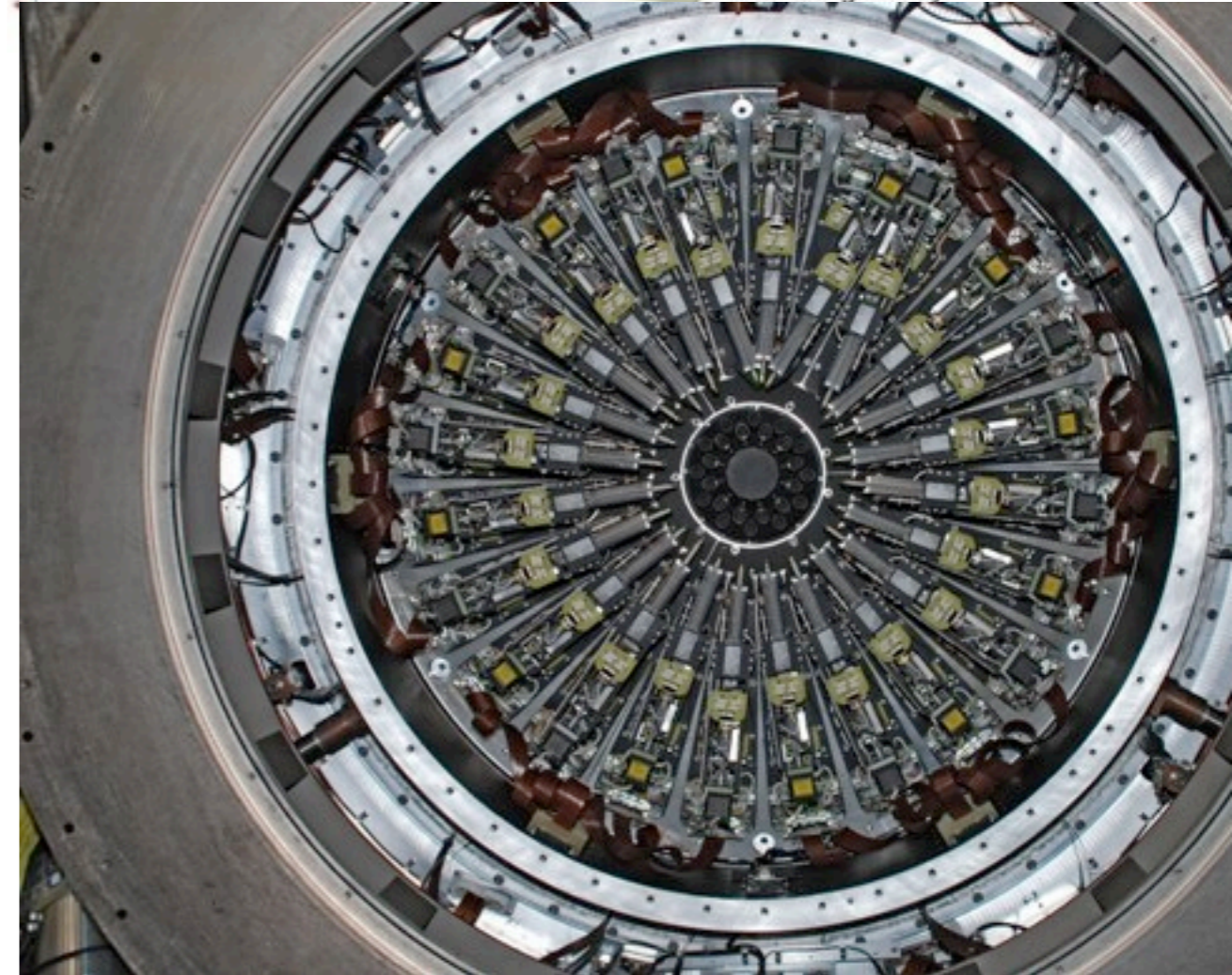
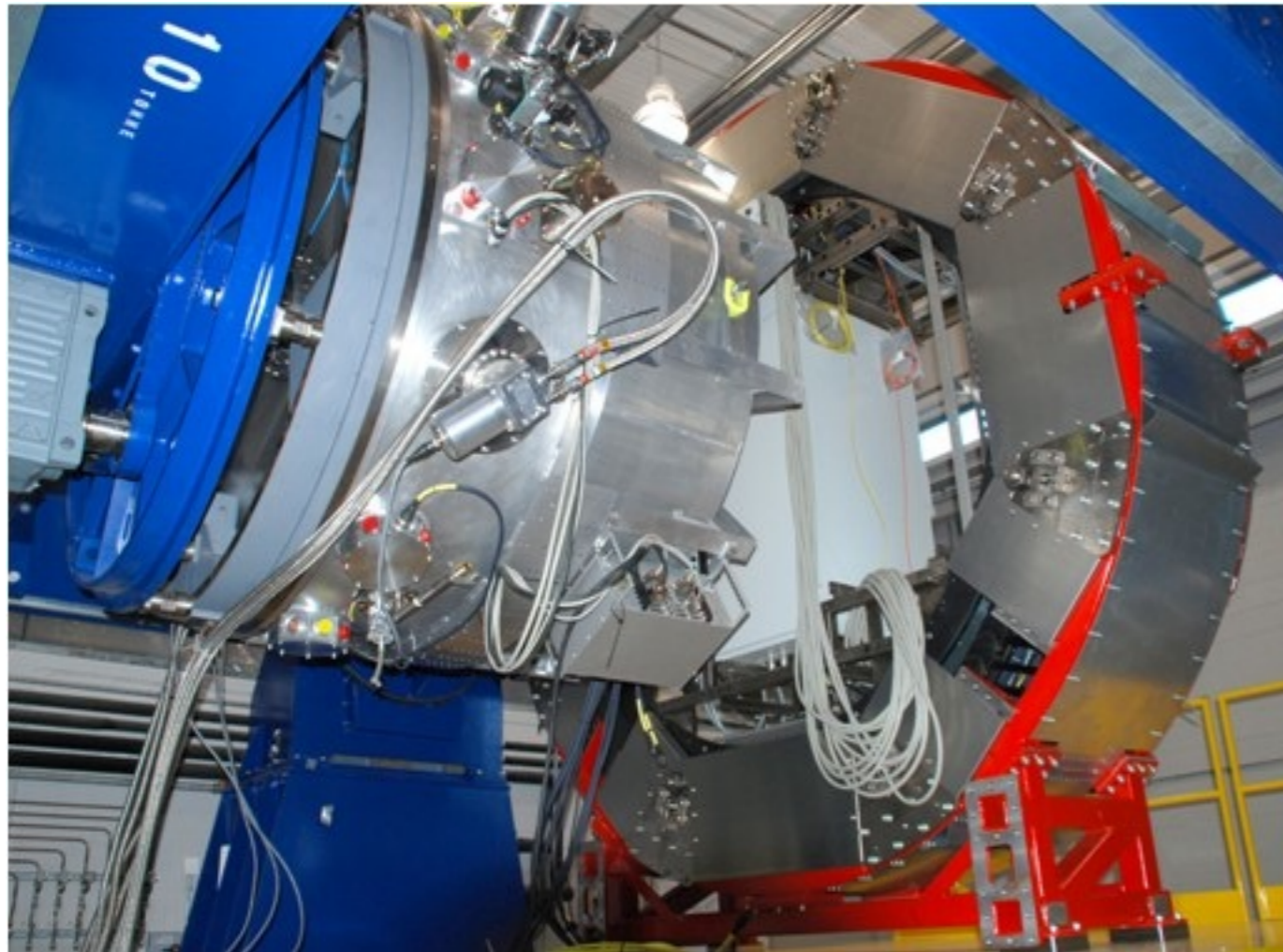
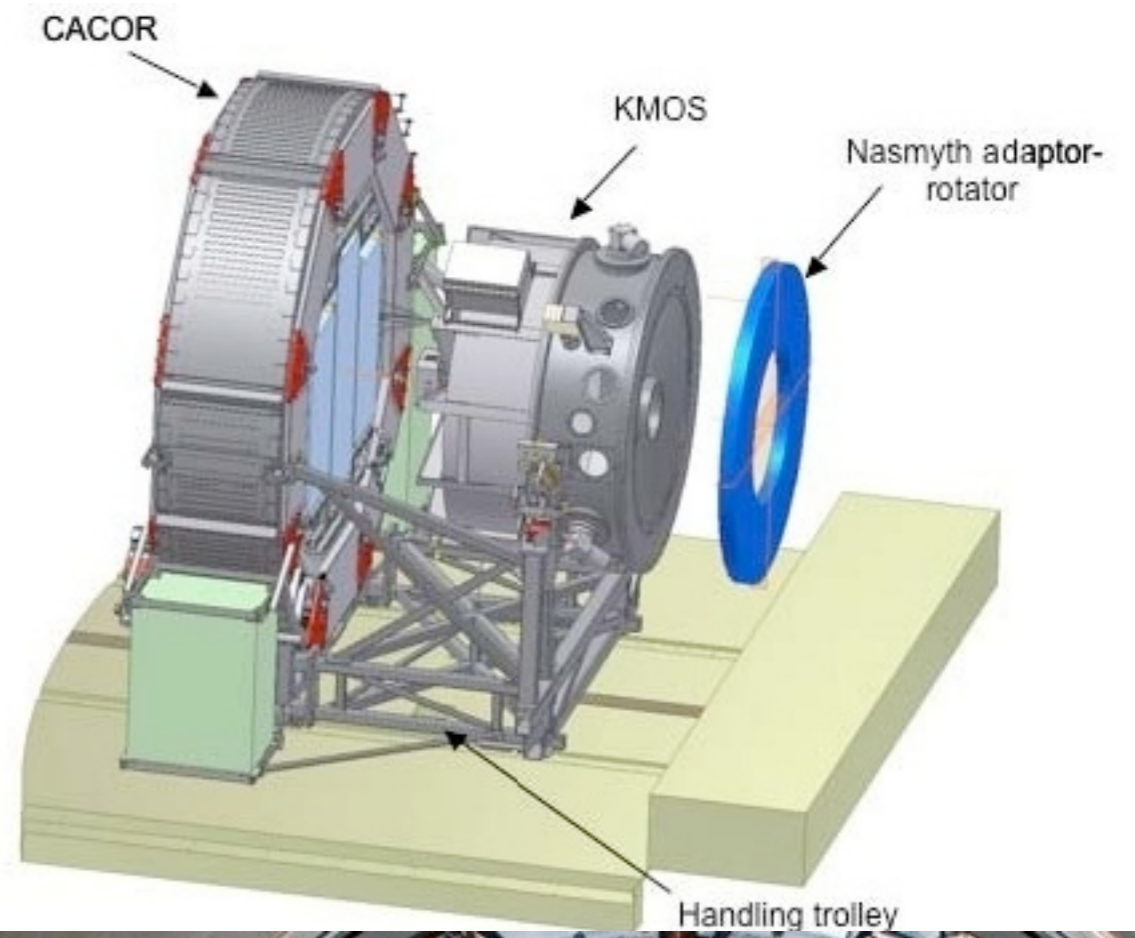
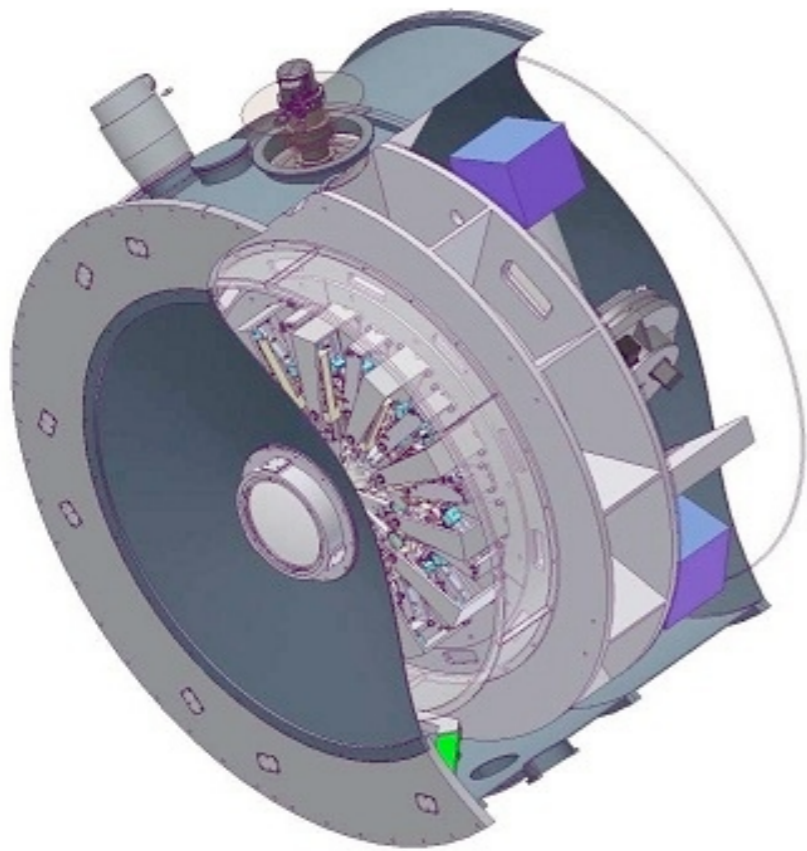


by Dr. Yamamuro (Optcraft)

KMOS for VLT

- 24 Deployable IFUs
- 0.2" Sampling, 2.8"x2.8" FoV
- 7.2 arcmin Patrol Field
- R: 3300 (IZ), 3400 (YJ), 3800 (H), 3800 (K)
- Pick-off Arm + Image Slicer
 - Pick-off Arm operated at 140K



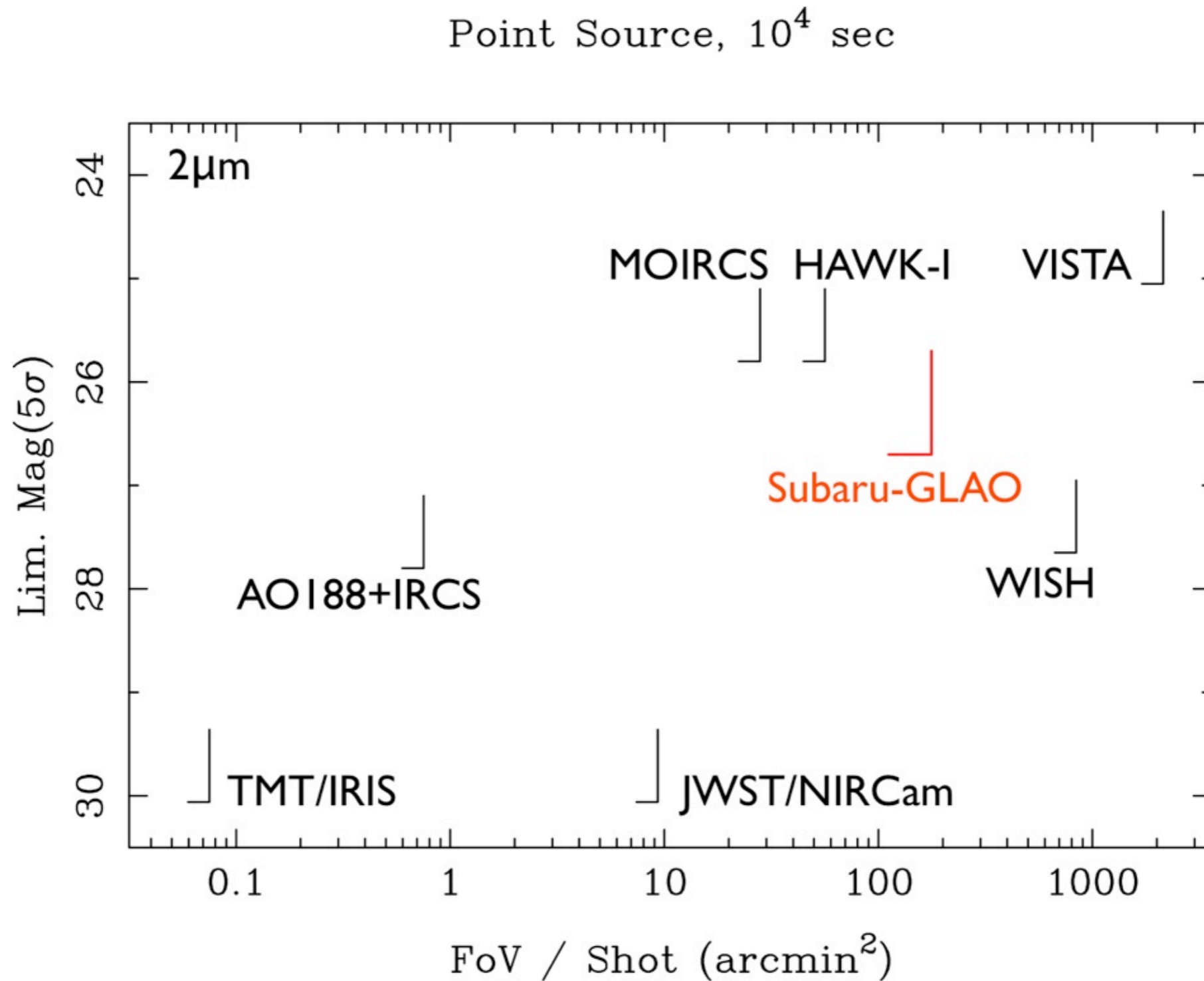


Instrument(s) for Subaru GLAO?

- Very Wide Field Near-IR Imager and Spectrograph
 - ‘Super MOIRCS’?
 - Multi-Object IFS with GLAO can be an Unique, Strong Instrument
- Optical Imager and Spectrograph?
 - GLAO will achieve Significant Seeing Improvement in Optical Wavelengths
 - Compete with Massive Spectrographs (DEIMOS, VIMOS, PFS)
- Thermal Infrared ($>2\mu\text{m}$) Imager and Spectrograph
 - Significant Sensitivity Improvement Thanks to Reduced Number of Optical Elements

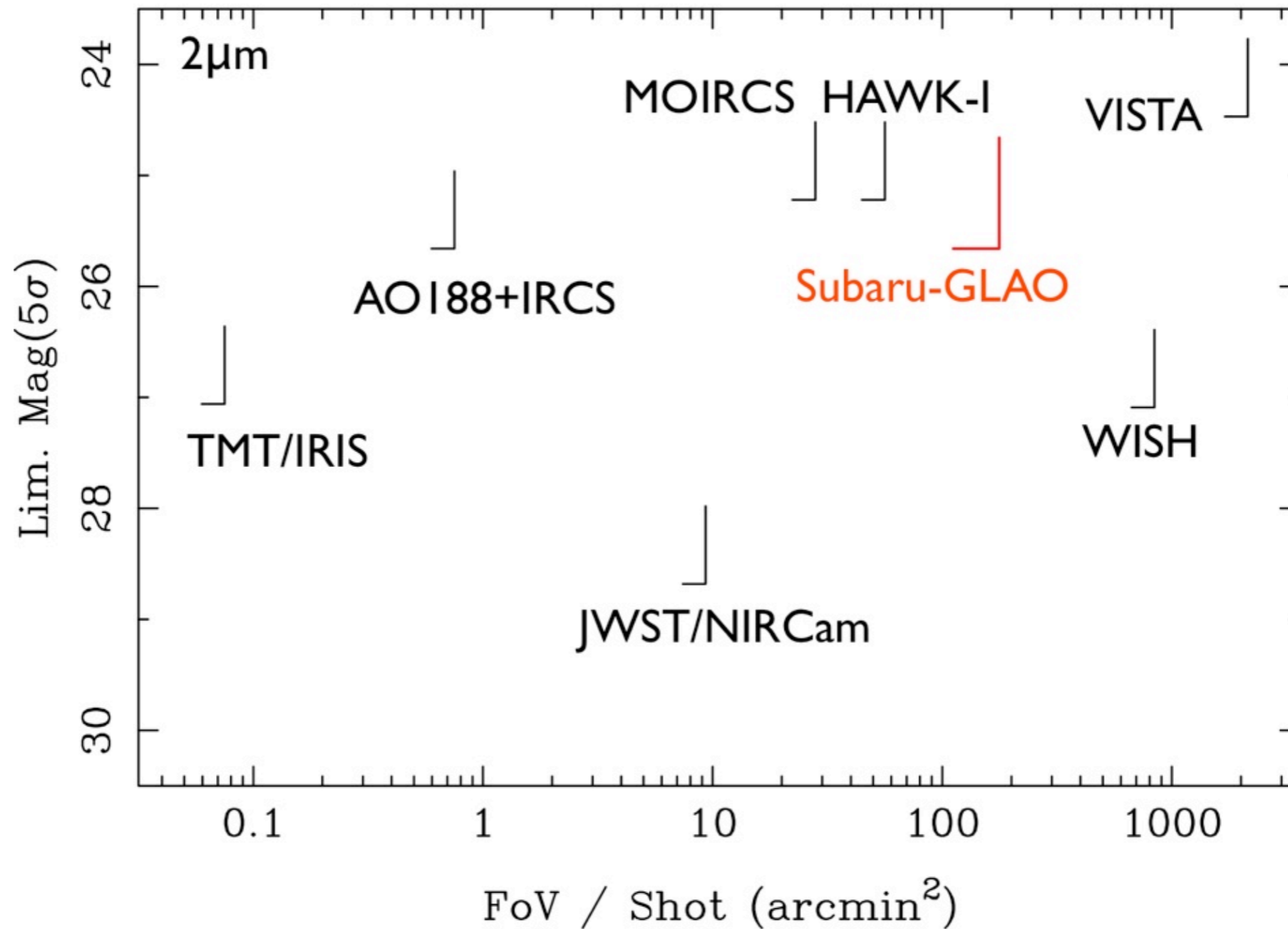
Expected Sensitivities

Expected Sensitivity in Imaging: Point Sources



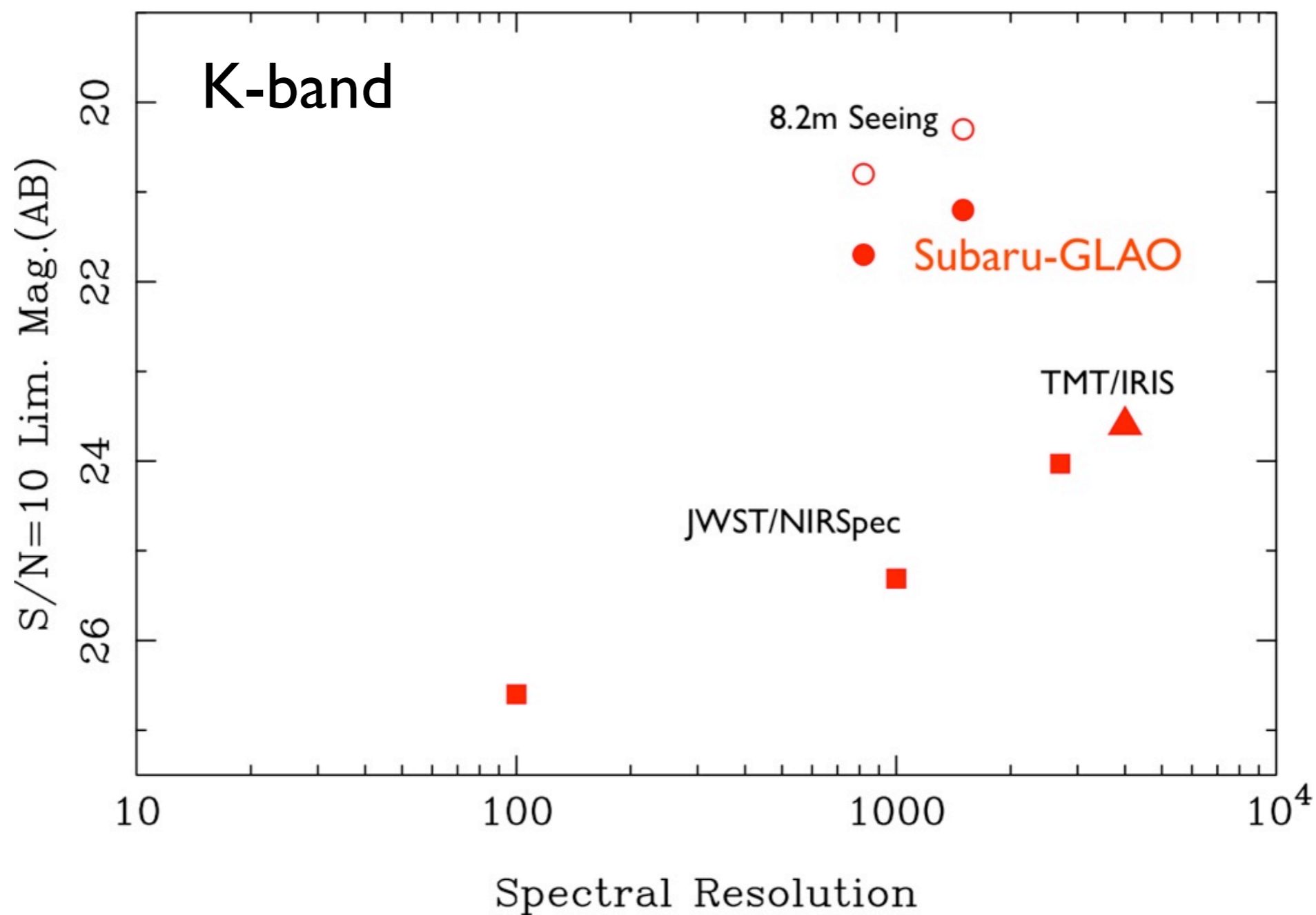
Expected Sensitivity in Imaging: Extended Sources

0.5'' Extended Source, 10^4 sec



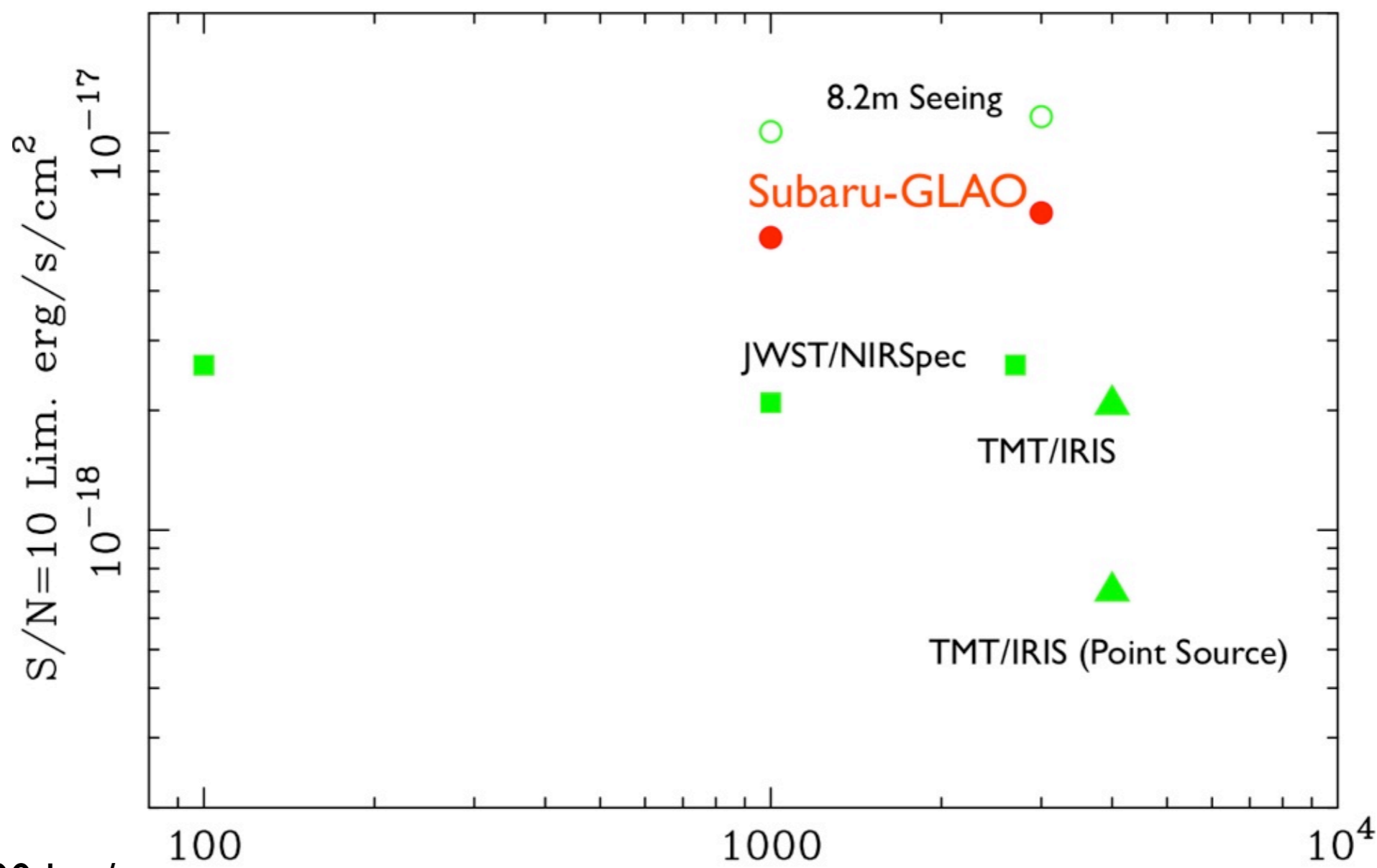
1 hr, S/N=10 Point Source **Continuum** Sensitivity

Continuum Limits for 1 hour



1 hr, S/N=10 Line Sensitivity for $H\alpha$ at $z=2.3$ ($2.16\mu\text{m}$)

$H\alpha$ at $z=2.3$



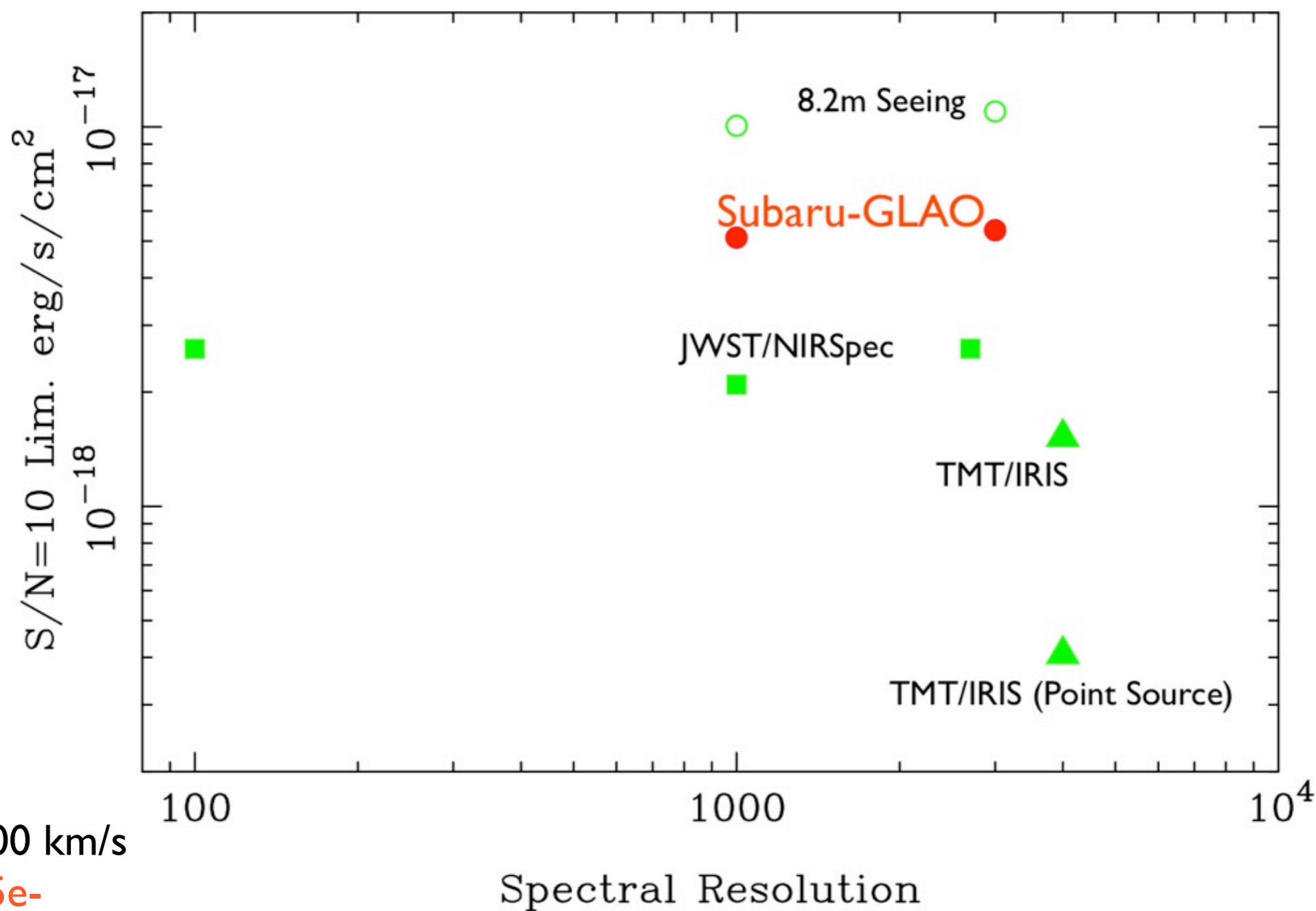
0.25" size, 400 km/s

read noise=10e- (NIRSpec: 5e-)

* Between OH lines*

1 hr, S/N=10 Line Sensitivity for H α at z=2.3 (2.16 μ m)

H α at z=2.3

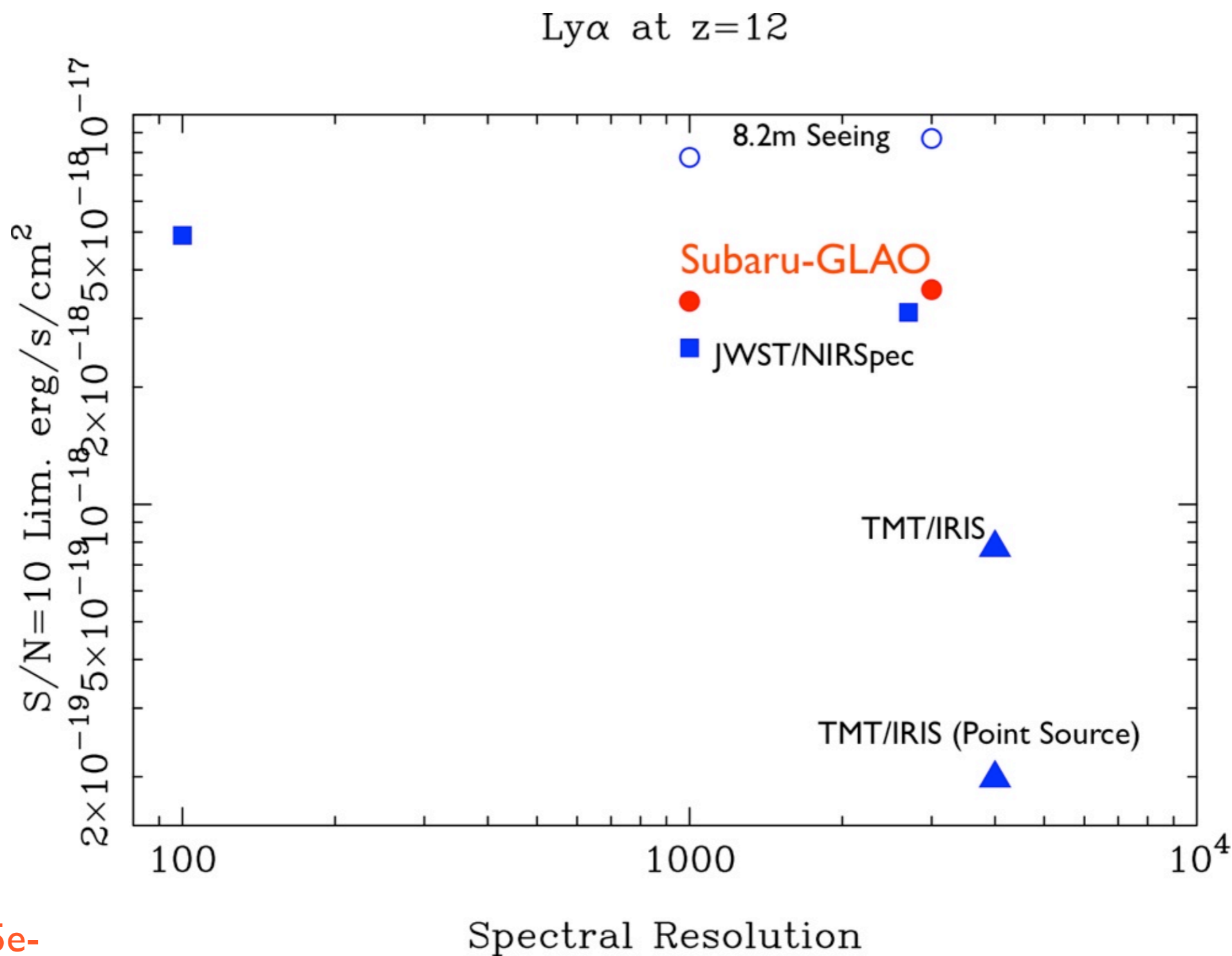


0.25" size, 400 km/s

read noise=5e-

* Between OH lines*

1 hr, S/N=10 Line Sensitivity for Ly α at z=12 (1.58 μ m)



0.2" size

read noise=5e-

* Between OH lines*

Spectroscopy Sensitivity

- ~ Factor of 2 Improvement from Seeing-Limited Obs.
- For Continuum Detection, JWST/NIRSpec is much more Sensitive than Subaru-GLAO.
- For Line Observation for Extended Sources, Subaru-GLAO can be Competitive with JWST/NIRSpec (at inter-OH line wavelengths).

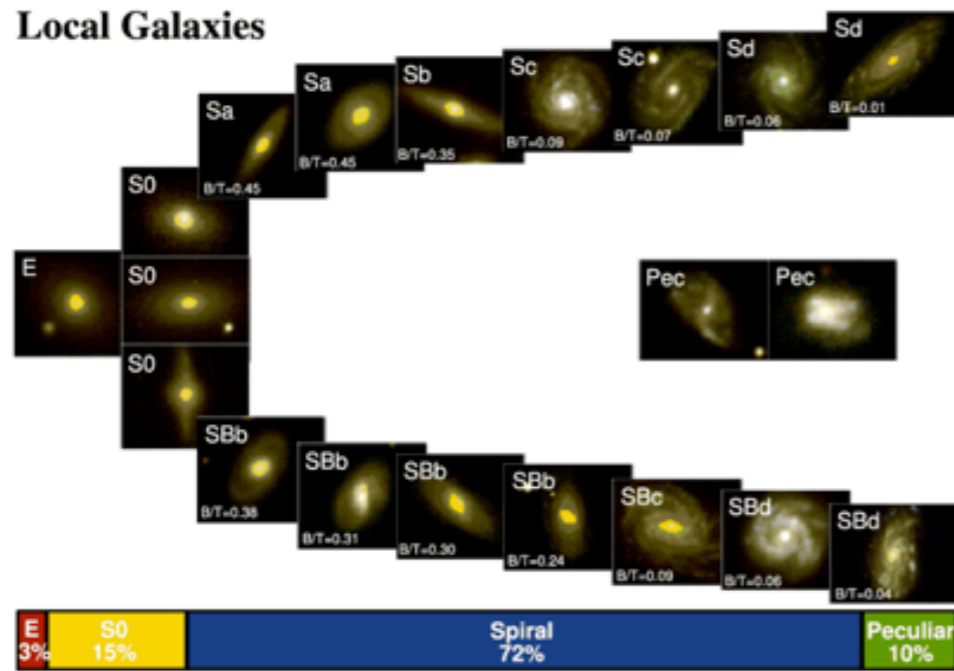
Science Cases

形態の整った
現在の銀河

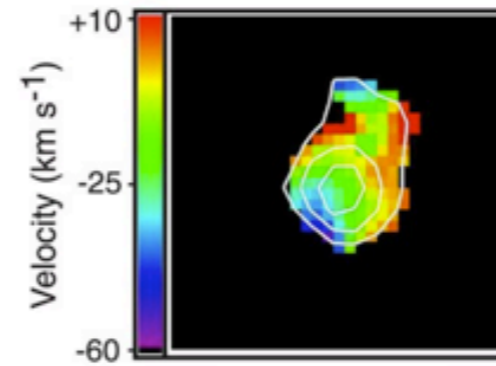
渾沌とした
遠方の星形成銀河

Delgado-Serrano et al. (2010)

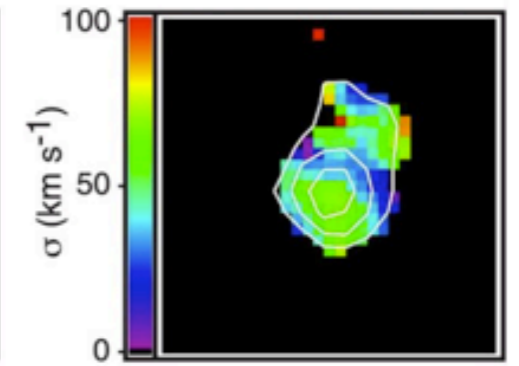
Local Galaxies



Q0449-BX93 ($z = 2.0067$)



Law et al. (2009)



速度場

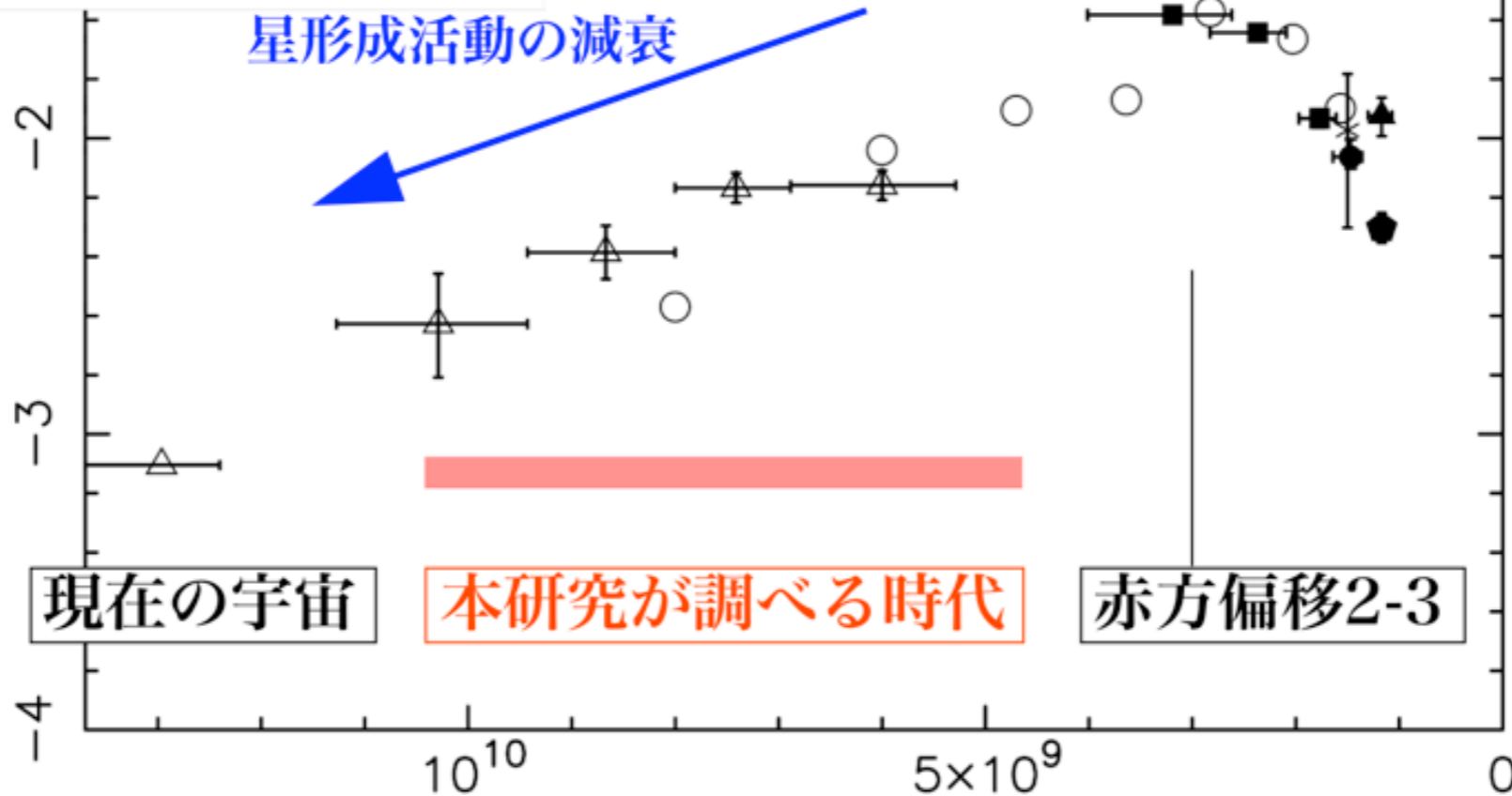
速度分散



?

星形成率密度 [太陽質量/年]

星形成活動の減衰



現在の宇宙

本研究が調べる時代

赤方偏移2-3

宇宙年齢 [年]

岩田ほか2007

銀河形成解剖ワークショップ

"Resolved Views of Galaxy Formation and Evolution"

日時: 2012年5月29日(火) - 31日(木)

場所: 国立天文台ハワイ観測所ヒロオフィス

趣旨

プログラム

参考資料

懇親会

リンク

趣旨

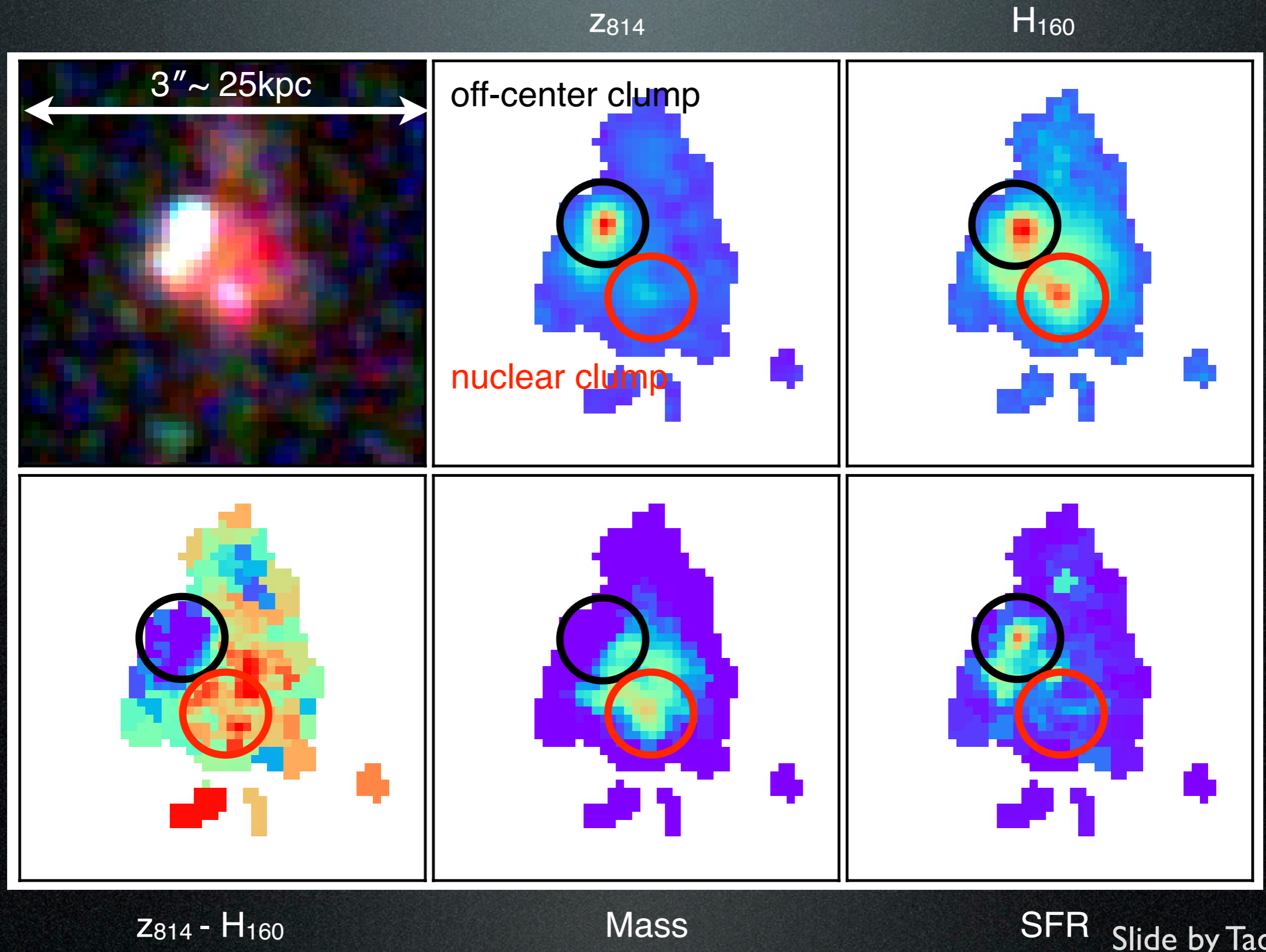
光赤外望遠鏡の補償光学や面分光装置などの技術革新によって、これまで主に点として見てきた遠方銀河が、最近では面として捕らえられるようになってきました。また科学的運用を開始したALMAも高い感度と分解能により遠方銀河をつぶさに解剖します。次世代の補償光学(広視野、多天体化)の計画も進み、さらにTMTの時代になれば遠方銀河の解剖はその真骨頂を極めることでしょう。銀河の星とガスの内部構造(空間と速度)が分解され、銀河間相互作用、星形成活動の分布、化学進化の進行、AGN活動、フィードバック、ガスの流れ、などの様々な物理過程が手に取るように詳細に分かるようになってきます。ついには銀河形成・進化の基本的な物理がかなりの部分理解される時代が、そう遠からずに来るのではないかと期待を込めて思い描いています。

このような背景の中、銀河研究の観測家(光赤外と電波)と理論家が一堂に会し、現状の理解と今後の展開について様々な観点から議論することは非常に有意義でタイムリーであると確信します。そして強力なワーキンググループを結成し、ALMAやIFU装置などに戦略的に観測提案を行い、観測と直接比較可能な理論シミュレーションを構築することによって、この時代を率先して切り拓いていければと思います。そこで、ALMA-cycle1の締切りも見据え、キックオフ研究会を開催します。

世話人: 児玉、秋山、本原、岩田、青木賢、今西、有本、河野、伊王野、和田桂、岡本崇、長島

プログラム

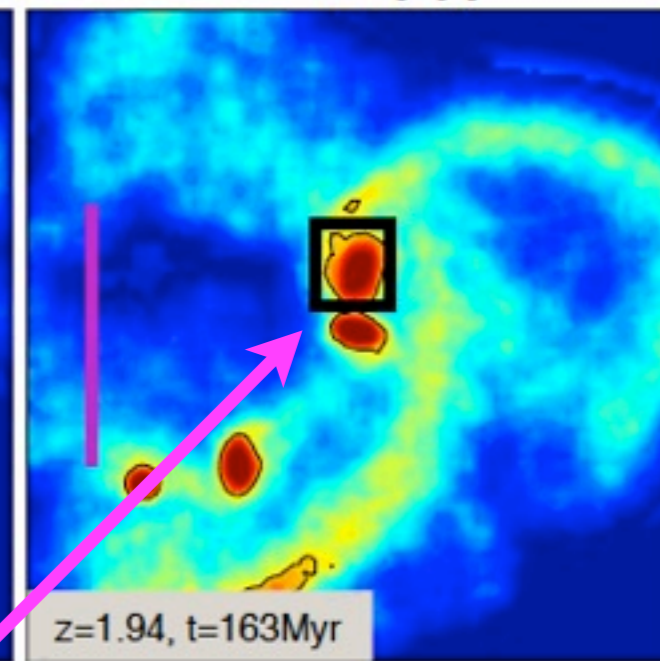
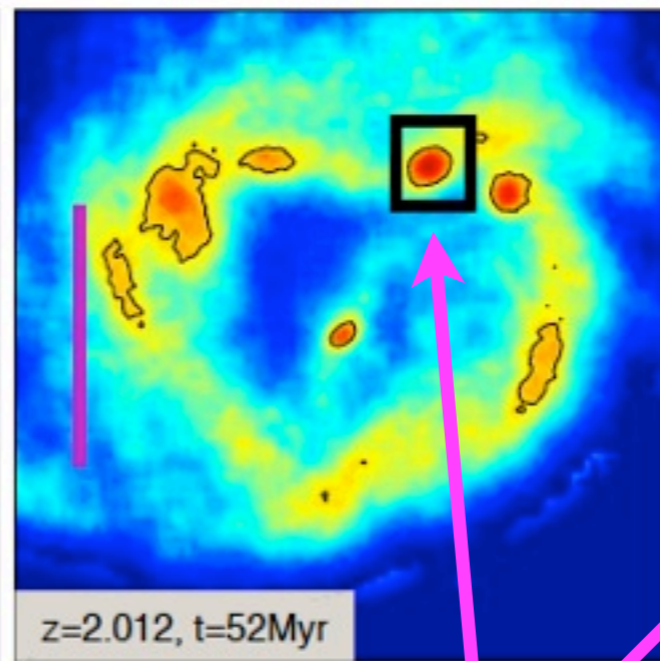
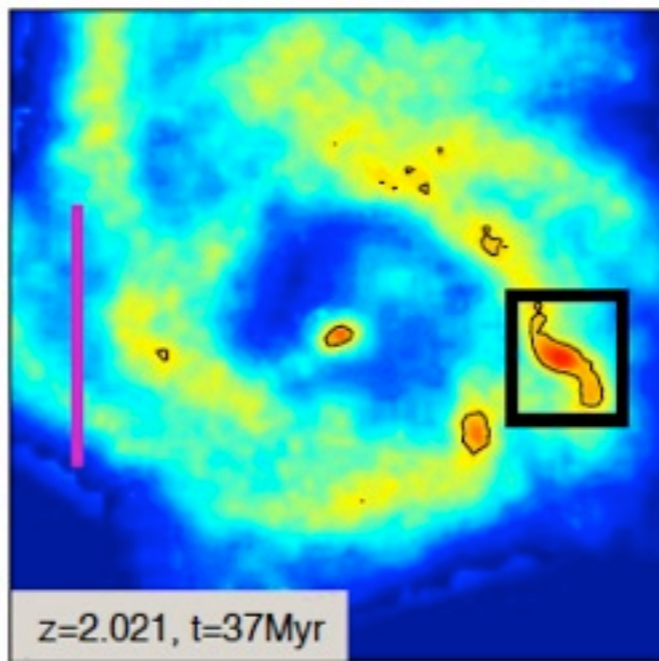
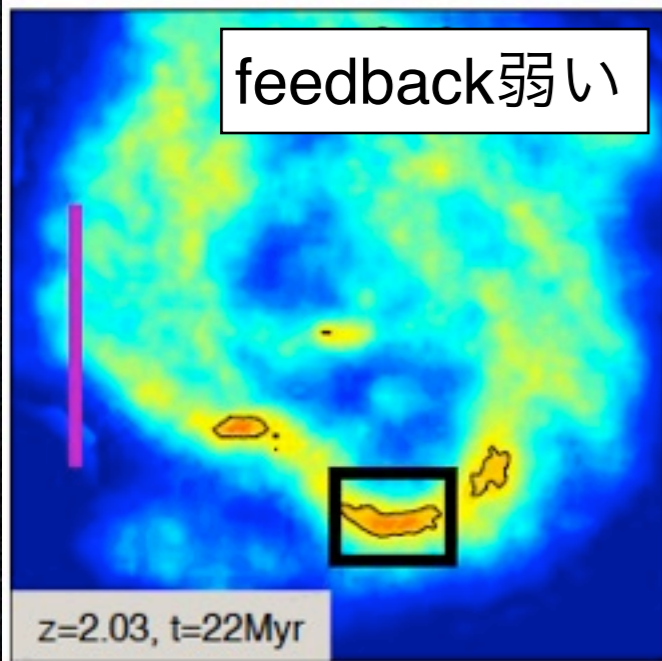
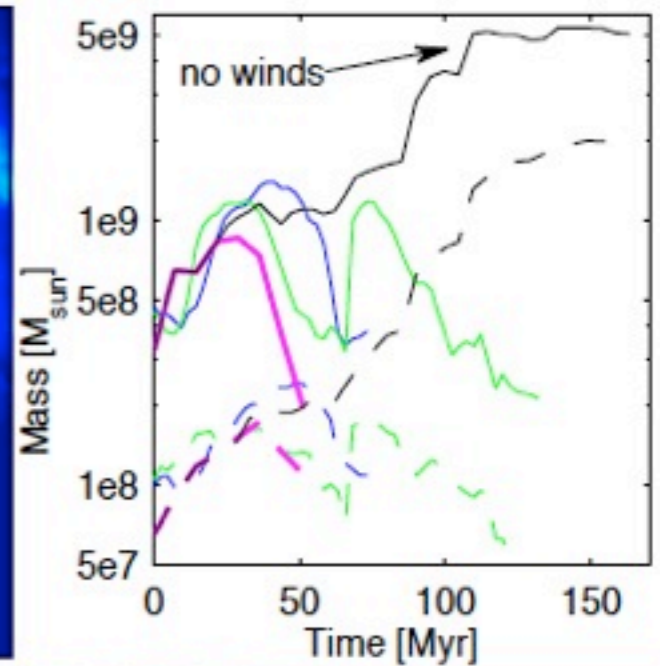
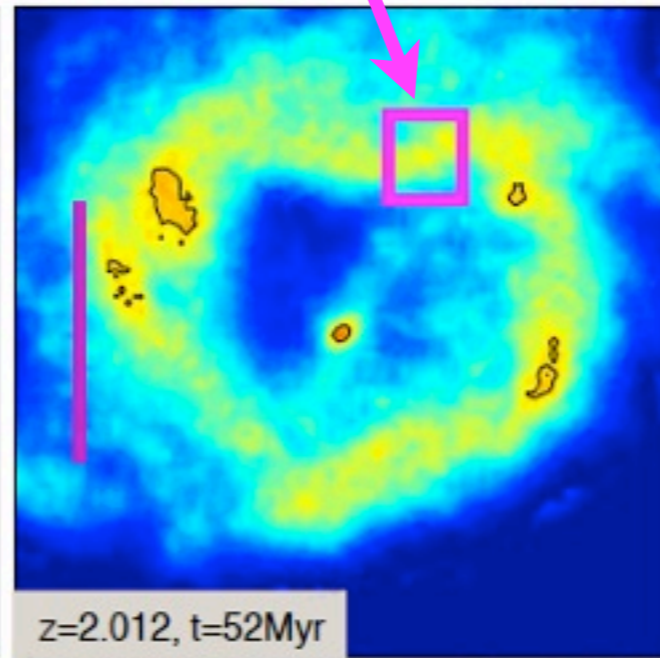
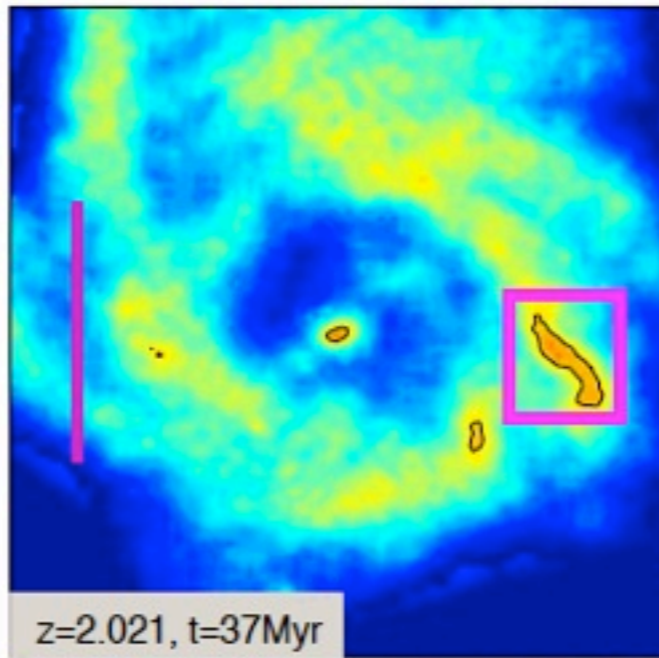
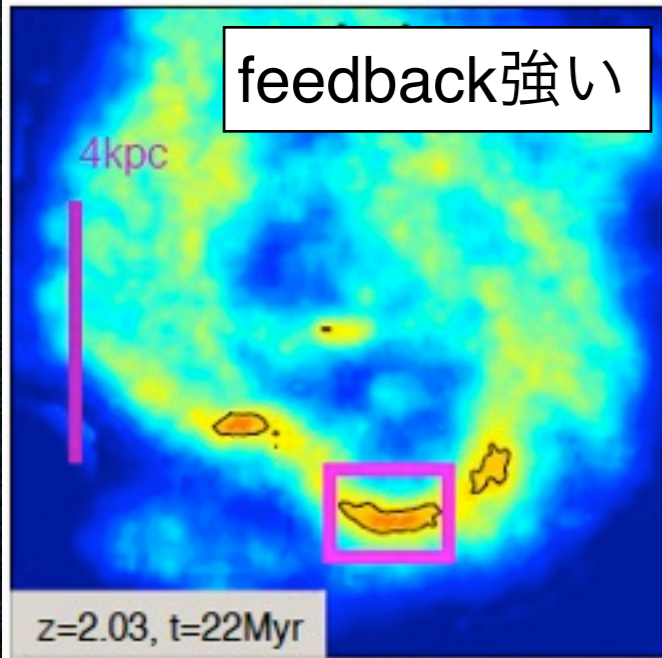
The morphologies of H α emitters at $z=2.2$



The fate of clump

ガスの分布を見ると

クランプが崩壊



クランプは崩壊せず、中心核へ落ちる

Signatures of outflows (500-1000km/s)

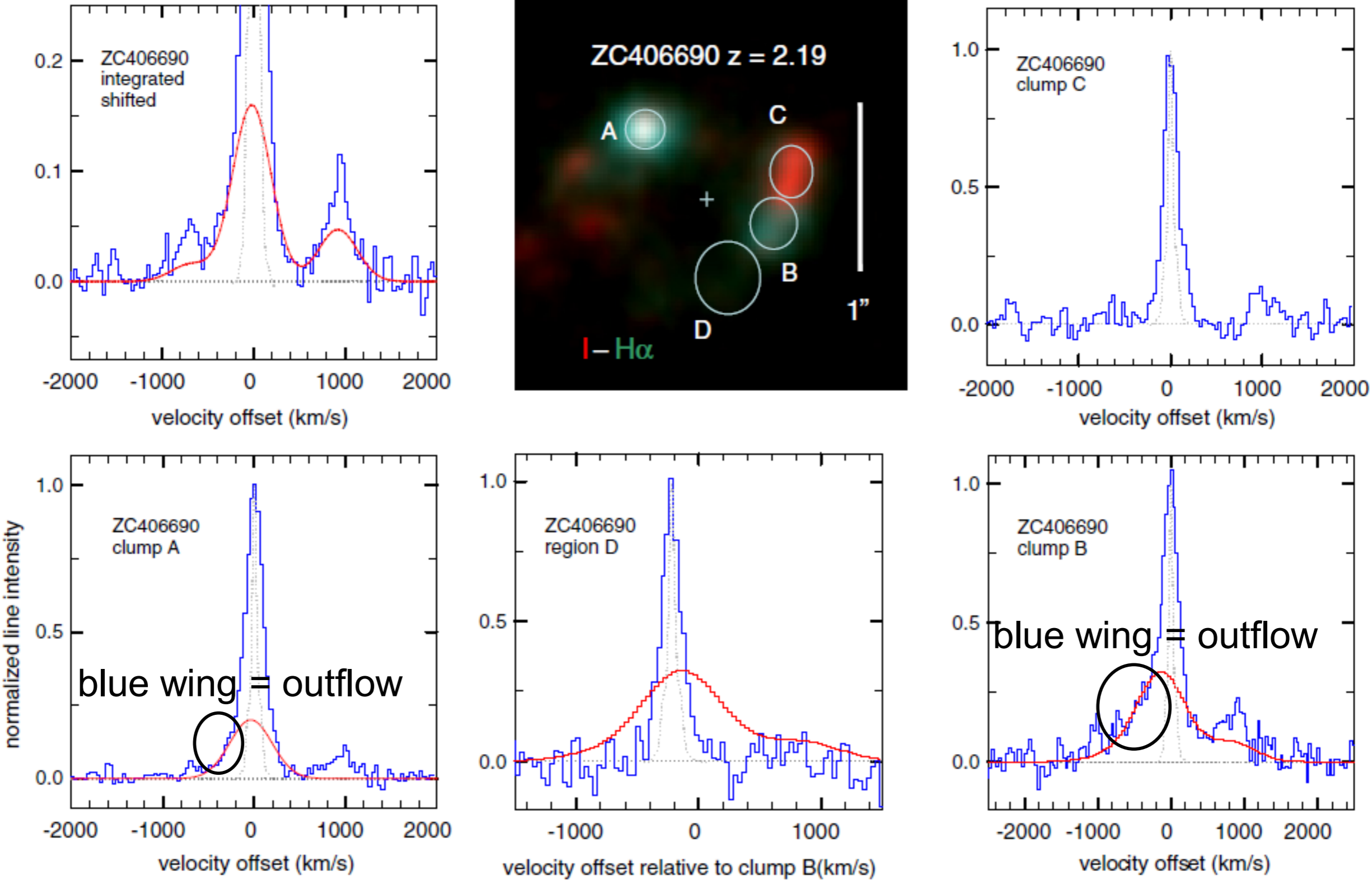


Figure 7. $H\alpha$ spectra of ZC406690 ($z = 2.195$), for the entire galaxy (top left), as well as for selected clumps marked in the central $H\alpha$ -ACS I -band composite (Figure 2). The dotted gray curves in all panels denote the SINFONI spectral response profile measured from OH sky lines. Before construction of the integrated spectrum, the galaxy rotation was removed for each pixel. The thin red curves show the broad $H\alpha$ (clump A) or broad $H\alpha$ + [N II] (integrated spectrum, clump B) components obtained from multi-component Gaussian fits. For region D, the thin red curve is the scaled broad $H\alpha$ component of clump B, and the velocity scale is relative to the systemic velocity of nearby clump B.

Simulating Integral Field Spectroscopy of $z \sim 2$ Galaxies

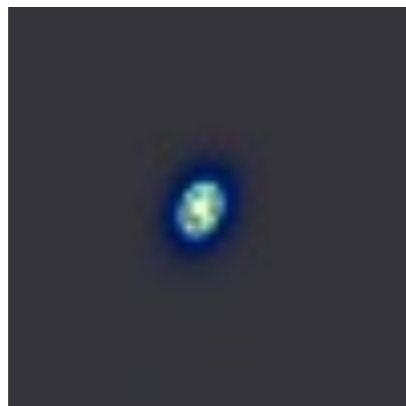
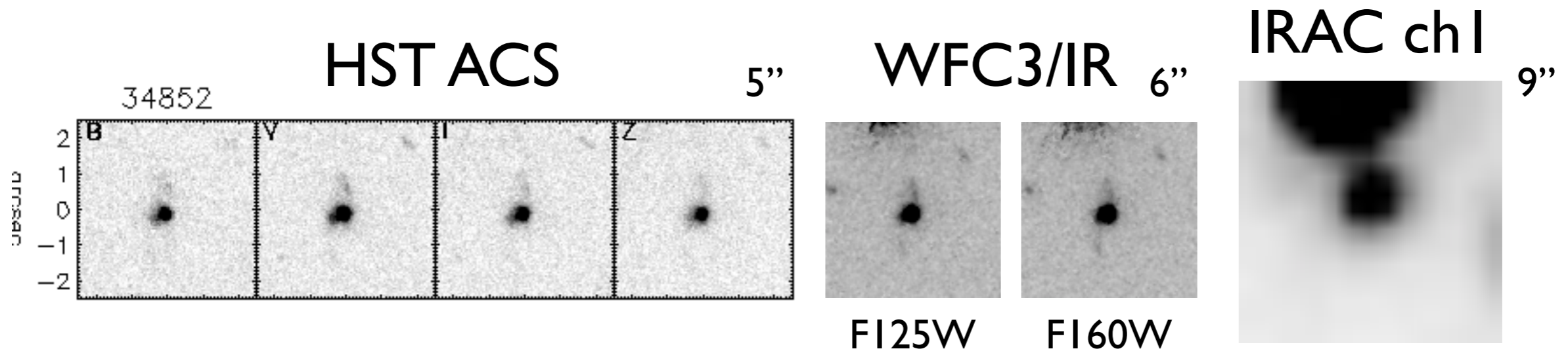
- Spectrograph:

- 7.5Å Dispersion ($R \sim 2500$ at $2.2 \mu\text{m}$), 3.75Å Dispersion
- Spatial Sampling: $0.12''$
- Coverage: $1.3 - 2.5 \mu\text{m}$
- Dark: $0.1 \text{ e}^-/\text{sec}$
- Read-noise: $10 \text{ e}^-/\text{pix}$

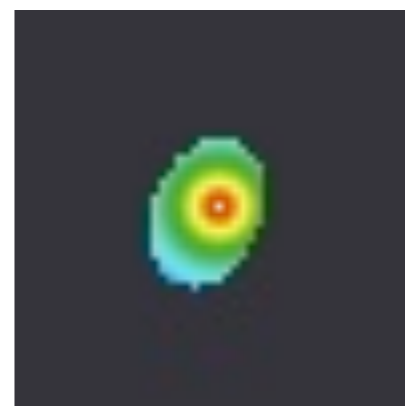
- Throughput:

- 5 optical components for spectrograph, each 90%
- Primary and secondary mirrors, each 90%
- Disperser: MOIRCS HK500 Grism
- H2RG QE from Teledyne

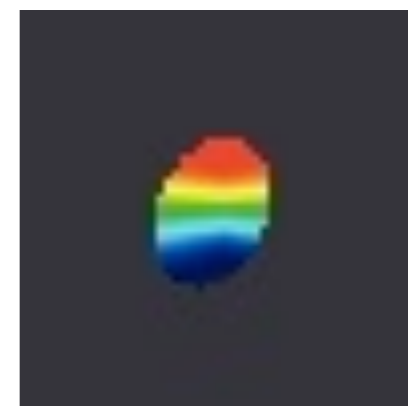
Star-forming Galaxy (sBzK) at $z=2.3$, $K(AB)=21.86$



model by GALFIT (F160W)
 $Re=1.4$ kpc

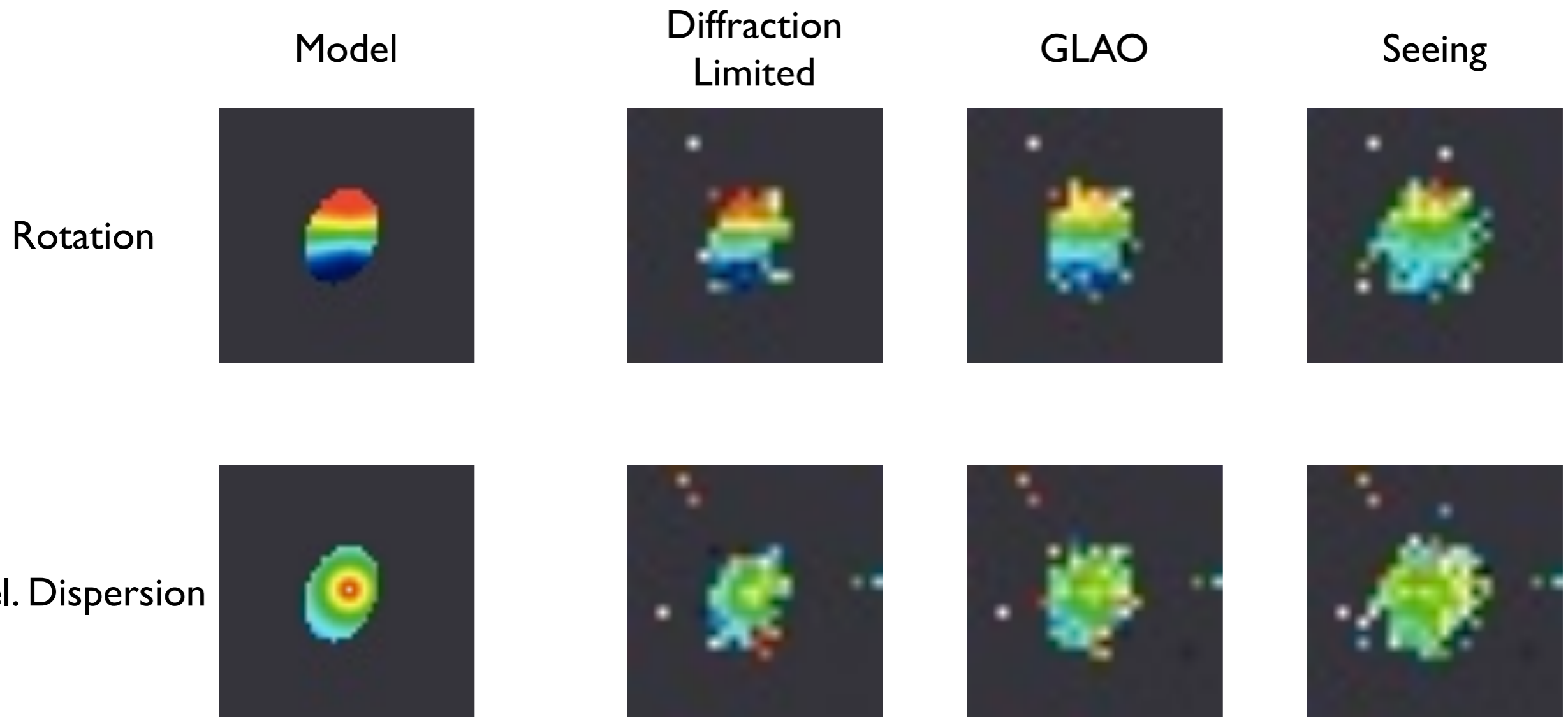


Vel. Dispersion
Peak 100 km/s

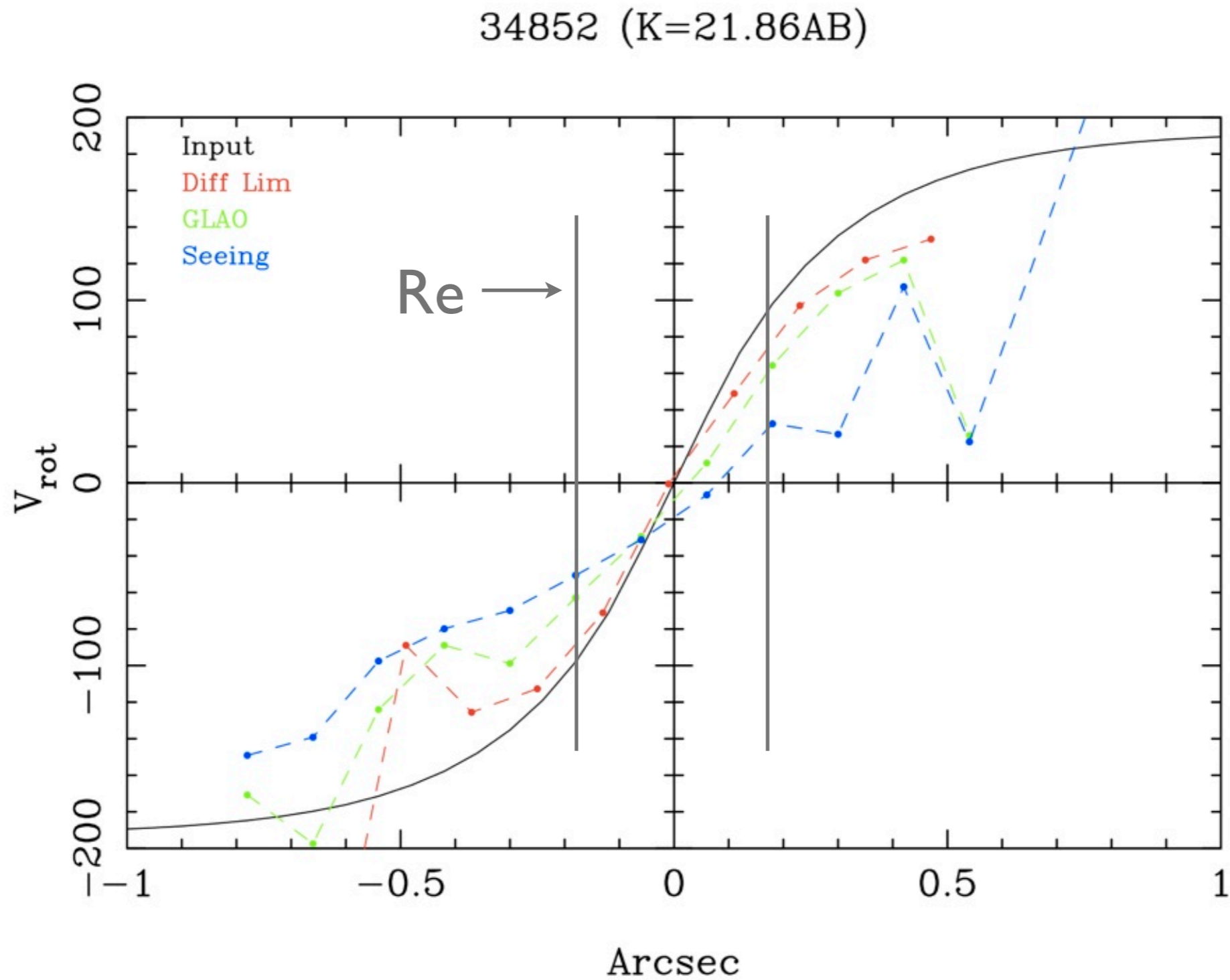


Rotation
-200 to 200 km/s

Star-forming Galaxy (sBzK) at $z=2.3$: H α Kinematics

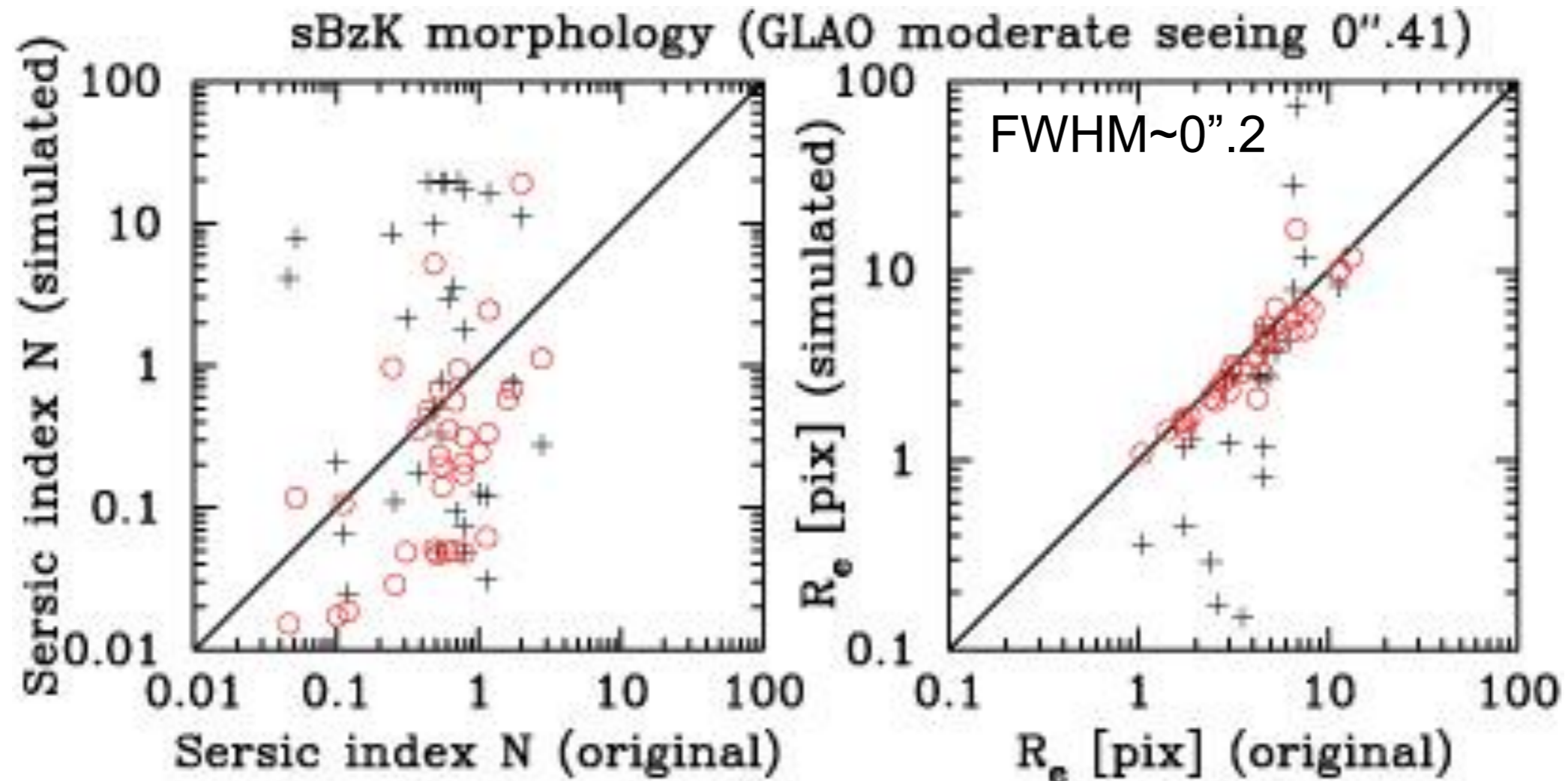


sBzK (I) K(AB)=21.86: Rotation Curve



Galaxy morphology with GLAO

- How well does GLAO imaging (K, 5hrs) reproduce the morphological parameters of $z \sim 2$ sBzK galaxies?



○ : GLAO, + : natural seeing

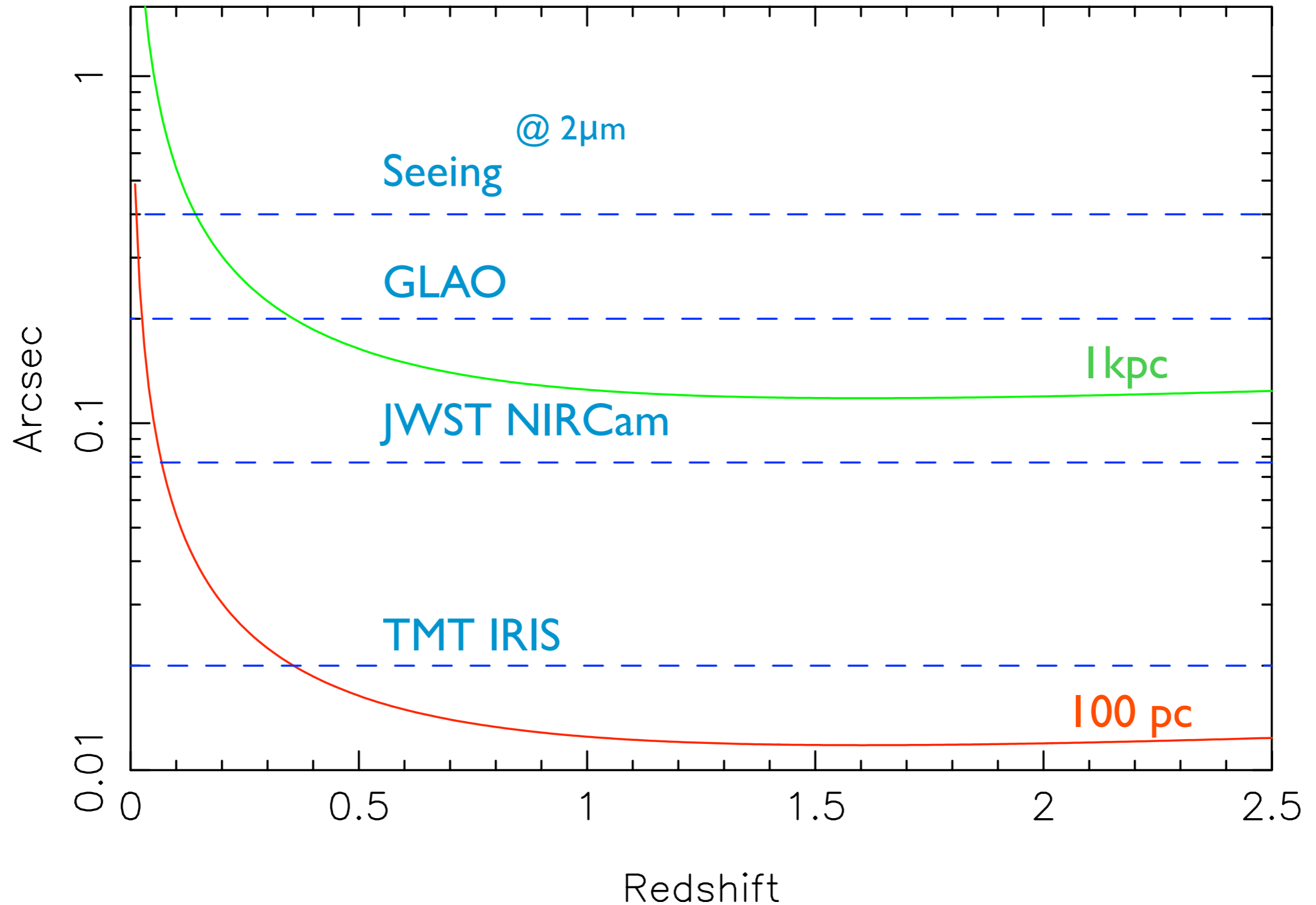
Fundamental Questions are still Unresolved

- What does 'Main Sequence of Galaxy Formation' means?
- Merging or Steady Accretion ('Cold flow')?
- Initial Mass Function?
- Feedback? How and When?

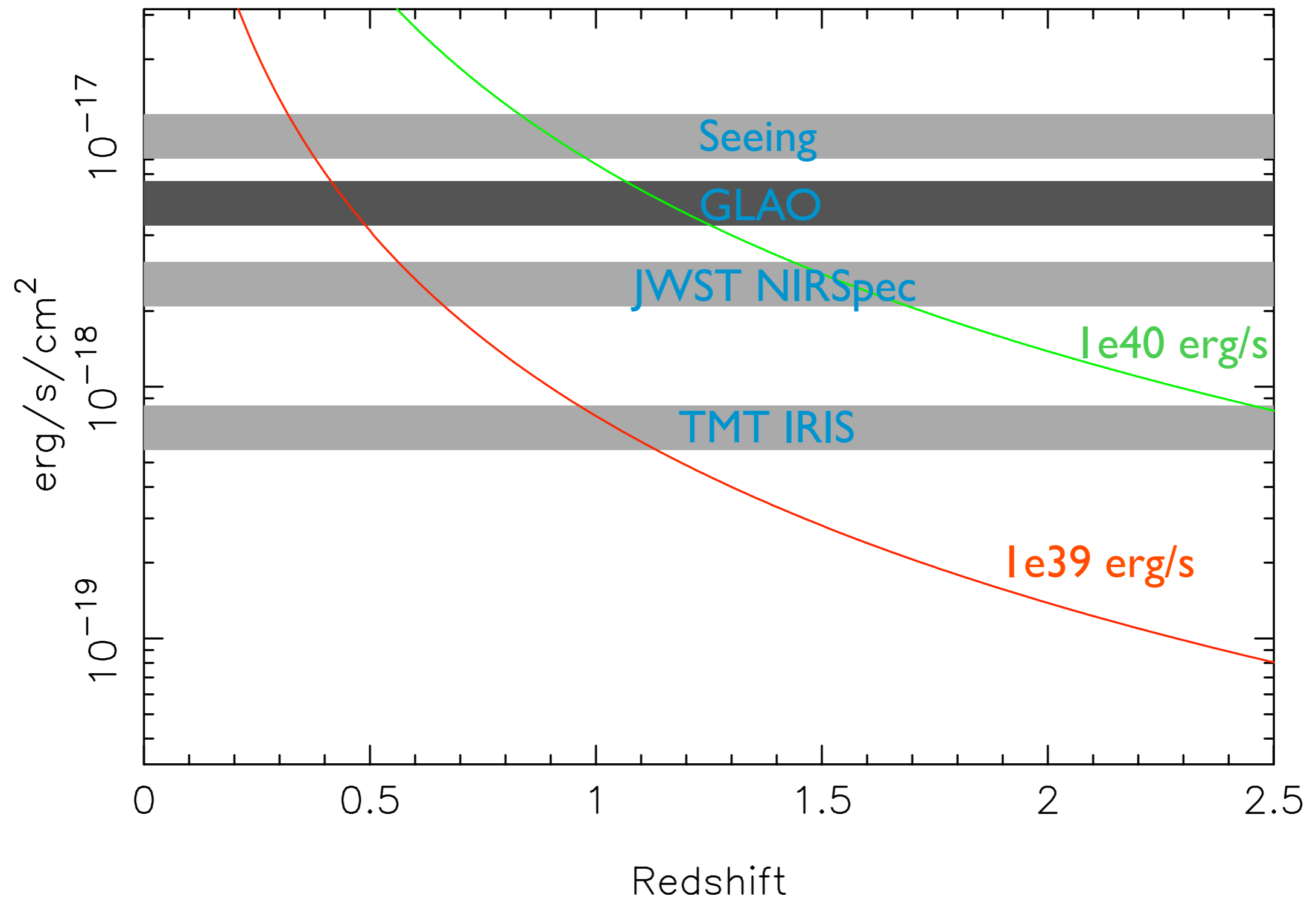
Key Scales

- Distant Star-forming Galaxies: $\sim 1 \text{ kpc}$
 - Effective Radius: 1 - 3 kpc
 - 'Clumps': $\sim 1 \text{ kpc}$
- Star-forming Regions: $\sim 100 \text{ pc}$
 - Giant Molecular Clouds: $< 100 \text{ pc}$
 - H₂ Regions: $< 100 \text{ pc} - 1 \text{ kpc}$

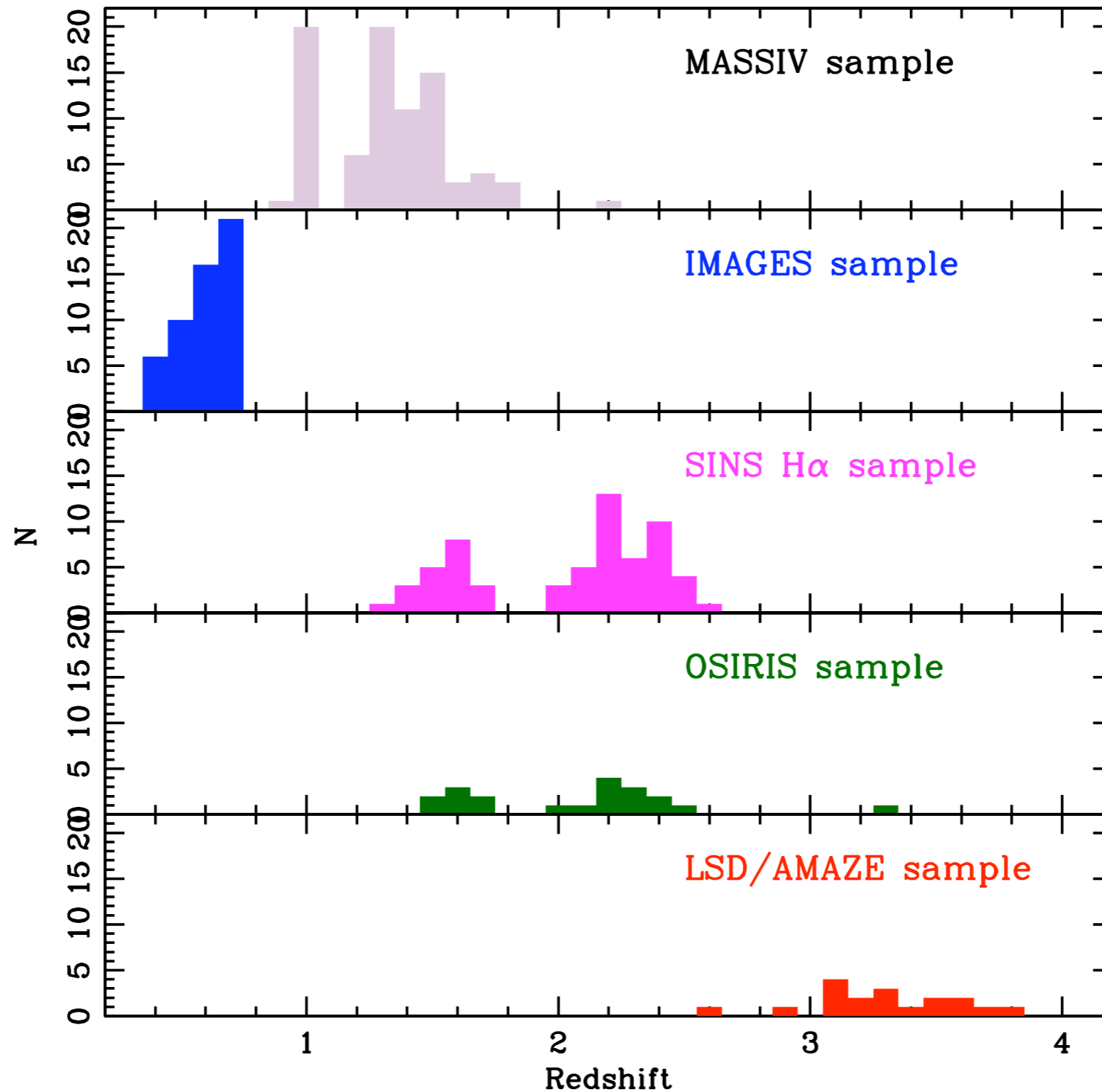
How fine can we resolve them?



Emission-Line Sensitivities



VLT/SINFONI Surveys - SINS, AMAZE, LSD, MASSIV

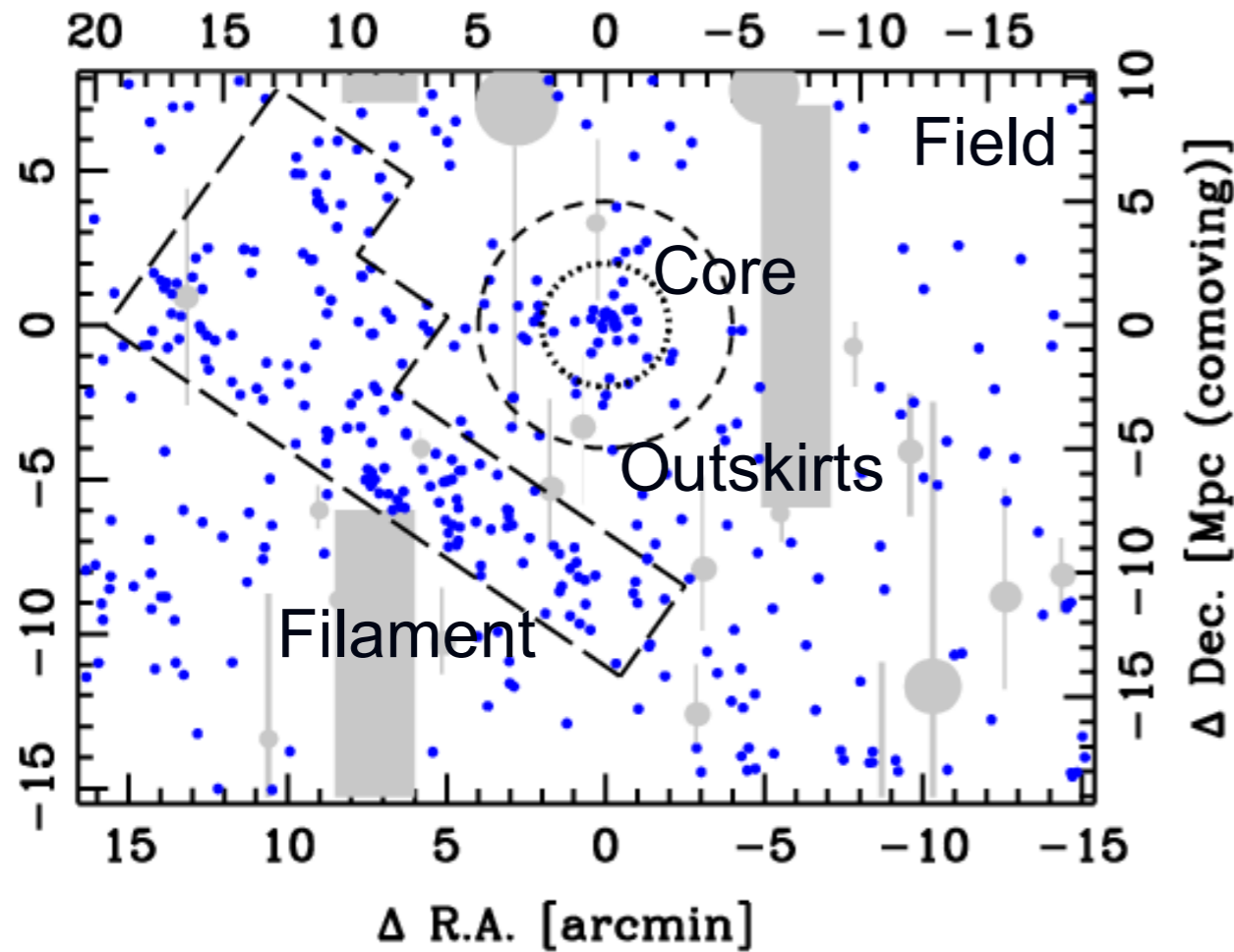


環境効果とその進化

XCS2215 cluster @ $z=1.46$

[OII]輝線銀河の分布

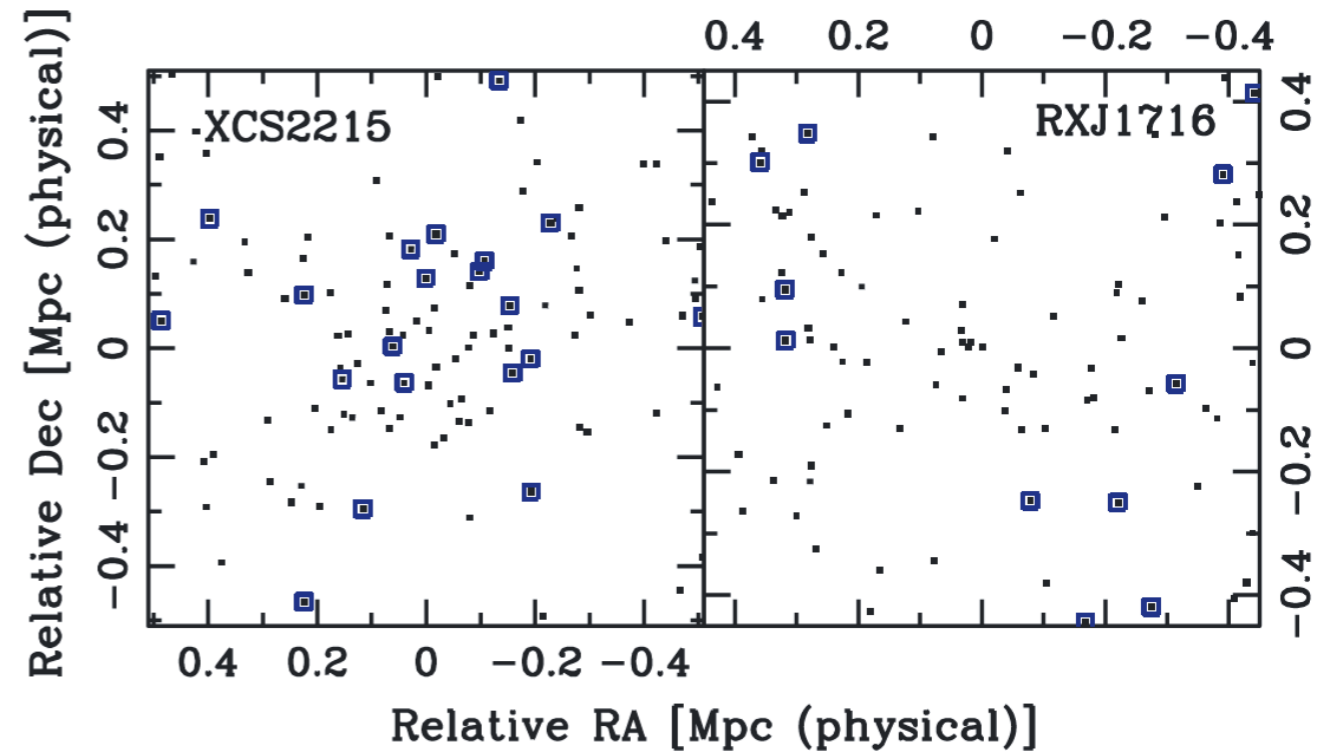
Δ R.A. [Mpc (comoving)]



銀河団中心部の比較

XCS2215
@ $z=1.46$

RXJ1716
@ $z=0.81$



[OII]輝線銀河

H α 輝線銀河

Slide by Hayashi-san

銀河「解剖学」

- 0.1'' - 0.2''は $z=1-3$ の銀河を分解して研究するために
Criticalな空間分解能
 - 中心部 / 周縁部での星種族 / ガスの性質の違い
 - 個々のClumpを観測
- 個別銀河の面分光観測は進行中 (VLT/SINFONI, Keck/
OSIRIS etc.)
 - ~100個規模のサンプル

銀河「解剖学」 + 「統計学」 : Legacy Survey

- $z=1-3$ の多様な銀河(UV星形成銀河、dusty星形成銀河、星質量大/小、合体銀河)を
- 多様な環境((原始)銀河団中心、周辺/フィラメント、フィールド)で
- 面分光して
- 巨大サンプル (10,000個規模)を構築
 - 50個/nightで200夜, 25個/nightで400夜

その他のサイエンスケース(検討報告書から)

- 銀河系中心
 - 球状星団・Streamの同定と分光観測 (千葉さん)
 - アストロメトリ(Nuclear Star Cluster, Cluster Remnants, Hyper Velocity Stars) (西山さん)
- K, L-bandでの合体銀河撮像 (今西さん)
- アウトフロー銀河 (澁谷さん)
- 狭帯域撮像による星形成領域のアウトフロー (表さん)
- 高感度観測による軽い系外惑星の探査(深川さん)

Subaru Next-Gen AO Working Group

- From Jan. 2011
- Now Preparing Initial Version of ‘Subaru Next-Gen AO Study Report’
- Members (as of May, 2012):
 - 早野 裕、大屋 真、美濃和 陽典、有本 信雄、家 正則、岩田 生、臼田 知史、大橋 永芳、兒玉 忠恭、高遠 徳尚、高見 英樹、瀧浦 晃基、田中 壺、寺田 宏、友野 大悟、西村 徹郎、服部 堯、服部 雅之 (国立天文台)
 - 秋山 正幸、大野 良人 (東北大学)
 - 本原 顕太郎、田村 直之 (東京大学)
 - 白旗 舞 (JAXA)
 - 渡邊 誠 (北海道大学)
- サイエンス検討 執筆者
 - 小山 佑世 (国立天文台 / University of Durham)、斎藤 智樹 (東京大学)、今西 昌俊 (国立天文台)、澁谷 隆俊 (総研大 / 国立天文台)、安井 千香子 (国立天文台)、千葉 柁司 (東北大学)、西山 正吾 (国立天文台)、Tae-Soo Pyo (国立天文台)、深川 美里 (大阪大学)

Instrument(s) for Subaru GLAO?

- Very Wide Field Near-IR Imager and Spectrograph
 - ‘Super MOIRCS’?
- Optical Imager and Spectrograph?
 - GLAO will achieve Significant Seeing Improvement in Optical Wavelengths
 - Compete with Massive Spectrographs (DEIMOS, VIMOS, PFS)
- Thermal Infrared ($>2\mu\text{m}$) Imager and Spectrograph
 - Significant Sensitivity Improvement Thanks to Reduced Number of Optical Elements

Very Wide-Field Near-Infrared Instrument

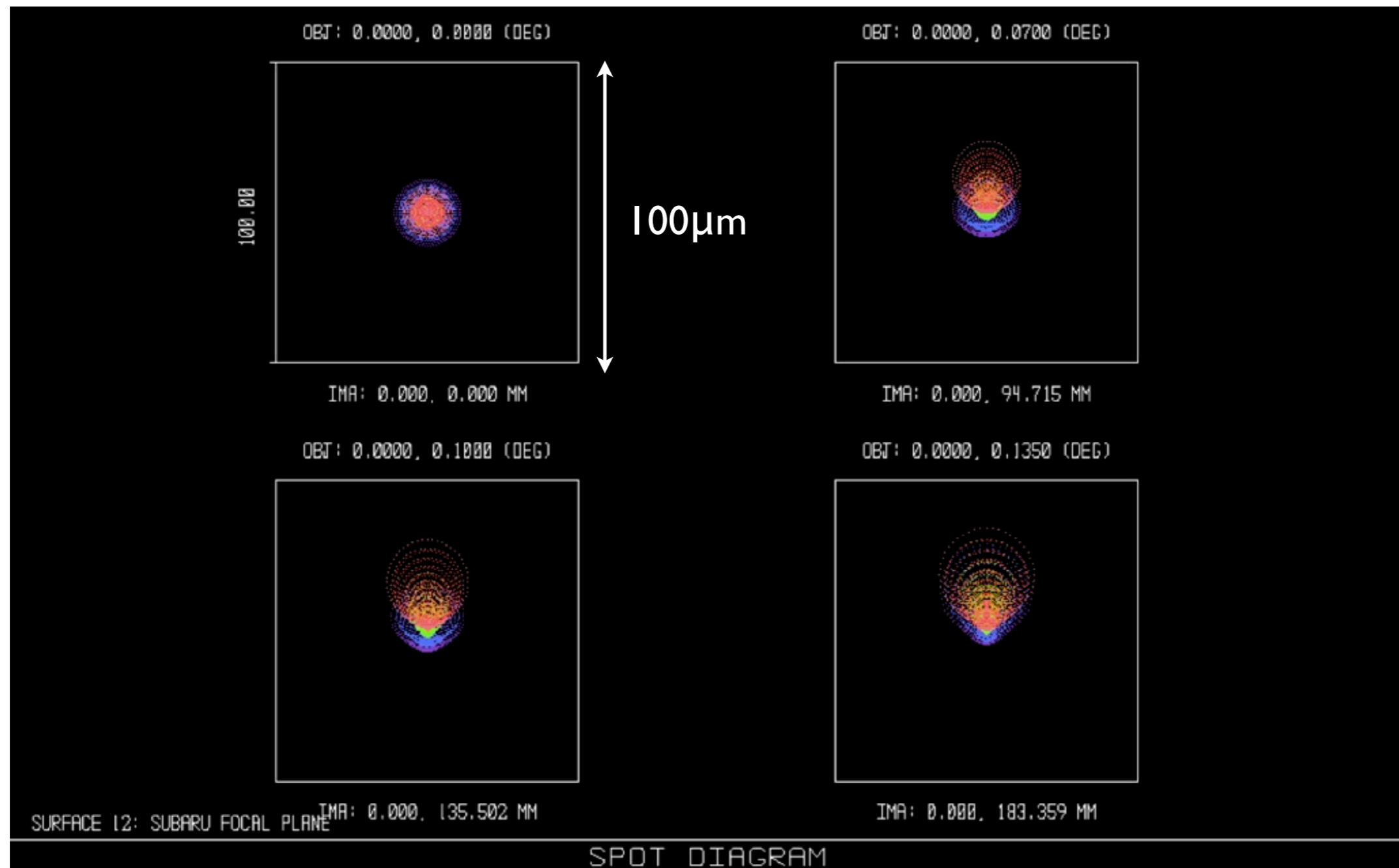
- Current MOIRCS FoV: 4' x 7' (2 x 4' x 3.5')
- Challenges in Wide-Field NIR Instrument:
 - Optics
 - Cryogenics
 - Weight
 - Multi-Object Spectrograph - Mask Exchange Mechanism
 - Expensive Detectors

Very Wide-Field Near-Infrared Instrument

- In Order to Fully Utilize the Capability of GLAO, We Need:
 - Wider Field of View
 - More Multiplicity in Multi-Object Spectroscopy
- How Wide We Can Achieve for NIR Instrument at Subaru Cassegrain Focus?
- Basic Study of Optical Design by Dr. Yamamuro (Optcraft) with Support from Motohara-san (IoA, Univ. Tokyo)
- Specifications:
 - 0.8 - 2.5 μ m
 - Goal: 0.15" FWHM in J, H, and K
 - H2RG or H4RG
 - Realistic Optical Components
 - Optics Cooled Down to ~100K

Very Wide-Field Near-Infrared Instrument

- Spot Diagram at MOS Plate

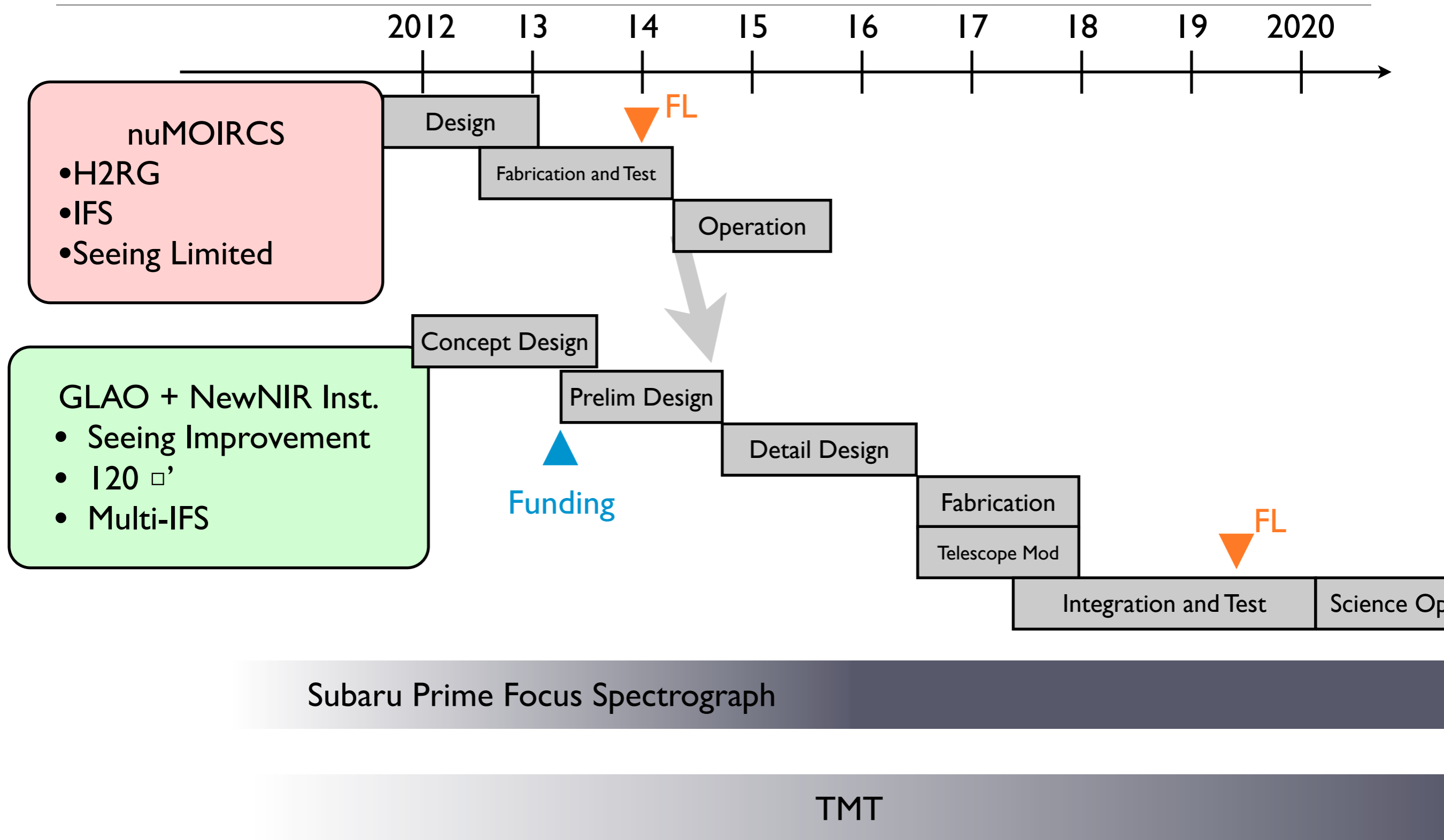


by Dr. Yamamuro (Optcraft)

Very Wide-Field Near-Infrared Instrument

- Preliminary Study by Optcraft Indicated that There are Optical Designs with Field-of-View of $\Phi=13' - 16'$ at Subaru Cassegrain Focus, with Good Performance.
 - H4RG x 4 \rightarrow Total Area 150 arcmin²
- Further Studies are Necessary:
 - Large MOS Mask?
 - Instrument Weight and Size?
 - Split FoV?
 - AR Coat for Optical Components?

Summary, or Subaru's Roadmap for Resolved Views of Galaxy Formation



Comparison: Imaging

| | Subaru MOIRCS | Subaru GLAO | TMT IRIS | HST WFC3/IR | JWST NIRCam |
|---------------------|------------------------------|-----------------------------|--------------------------|--------------------------|--------------------------------------|
| Telescope Aperture | 8.2m | 8.2m | 30m | 2.4m | 6.5m |
| Wavelength Coverage | 0.9-2.5 μ m | 0.9-2.5 μ m | 0.84-2.4 μ m | 0.9-1.7 μ m | 0.9-2.3 μ m / 2.4-5.0 μ m |
| Spatial Resolution | 0.117"/pix 0.4"@2 μ m | ~0.1"/pix 0.2"@2 μ m | 4 mas 10mas@1 μ m | 0.13"/pix FWHM~ 0.25" | 32 mas / 64 mas |
| Field of View | 28 \square ' | ~120 \square ' | 0.075 \square ' | 4.65 \square ' | 9.7 \square ' |

Comparison: Spectroscopy

| | Subaru MOIRCS | Subaru GLAO | TMT IRIS | HST WFC3/IR | JWST NIRSpec |
|---------------------|------------------------------|-----------------------------|--------------------|--------------------------|--------------------------------------|
| Wavelength Coverage | 0.9-2.5 μ m | 0.9-2.5 μ m | 0.84-2.4 μ m | 0.9-1.7 μ m | 0.6-5 μ m |
| Spatial Resolution | 0.117"/pix 0.4"@2 μ m | ~0.1"/pix 0.2"@2 μ m | 4 - 50 mas | 0.13"/pix FWHM~ 0.25" | 0.2"x0.45" |
| Field of View | ~25 \square ' | ~120 \square ' | 0.2-10 \square " | 4.65 \square ' | 12.24 \square '(MSA) 3"x3"(IFS) |
| Functions | Single-Slit MOS IFS | Multi-IFS | IFS | Slitless | Slits Microshutters IFS |
| Spectral Resolution | 600-3000 | -3000? | 4000-10000 | TBW | 100, 1000, 2700 |