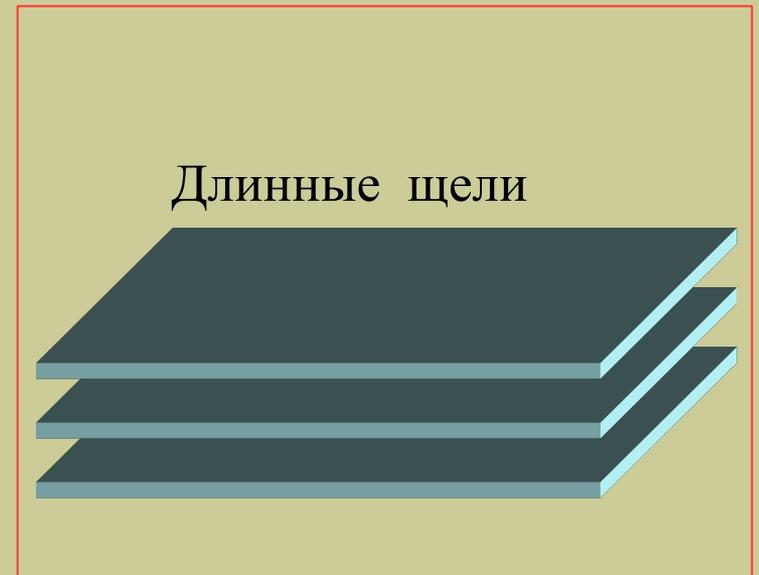
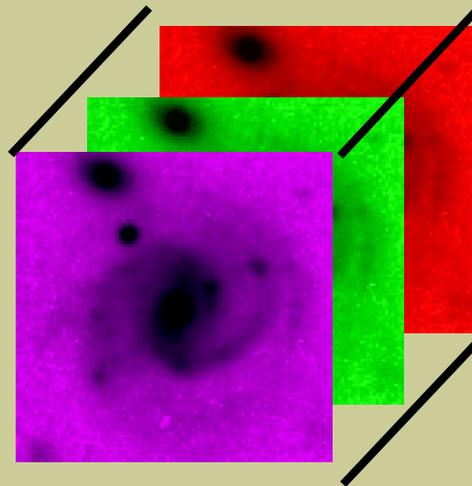
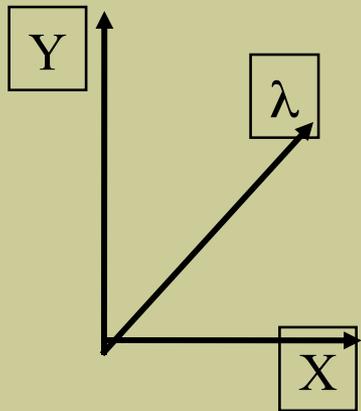


Методы панорамной спектроскопии

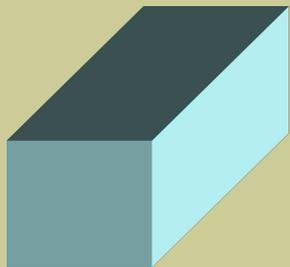
Лекция 4.

Сканирование щелью. Резатели изображений. Панорамные спектрографы в ближнем ИК. Работа с системами АО. Спектрографы: PIFS, KCWI, OASIS, OSIRIS, SINFONI, KMOS, MUSE, KMOS, приборы JWST, проекты BlueMUSE и HARMONI.

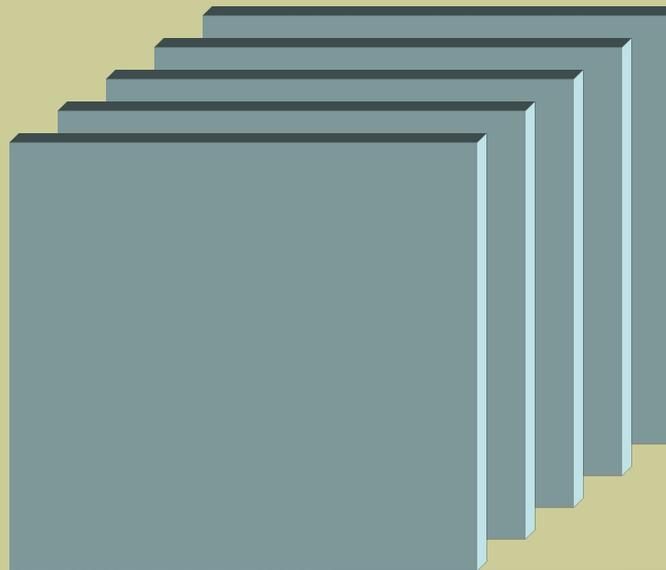
Куб данных



Спектрографы Интегрального поля



Интерферометр Фабри-Перо



Сканирование щелью.

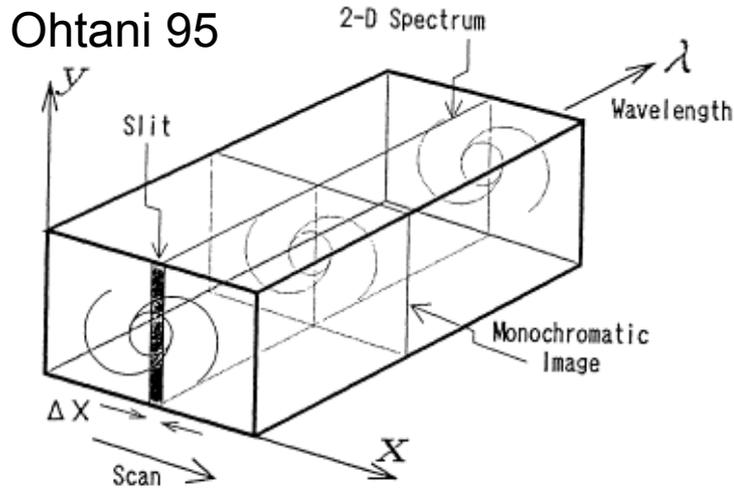


Figure 1. The concept of SNG observations.

Spectronebulagraph (SNG)
1.88-m Okayama Astroph. Observatory

Щель шириной 1.8", точность
установки < 0.3'

Проблемы вариаций атмосферных
условий решается добавлением
наблюдений с поворотом на 90°

Kosugi +95

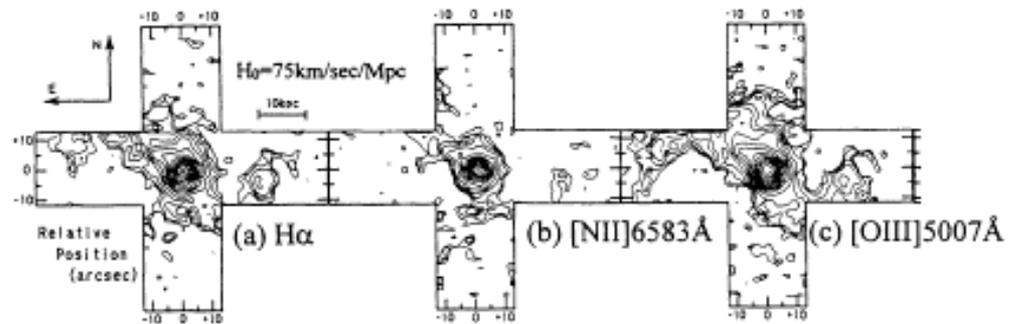


Figure 1. The pure narrow-line images. (a) $H\alpha$, (b) $[NII]6583\text{\AA}$, (c) $[OIII]5007\text{\AA}$ and (d) integrated sections.

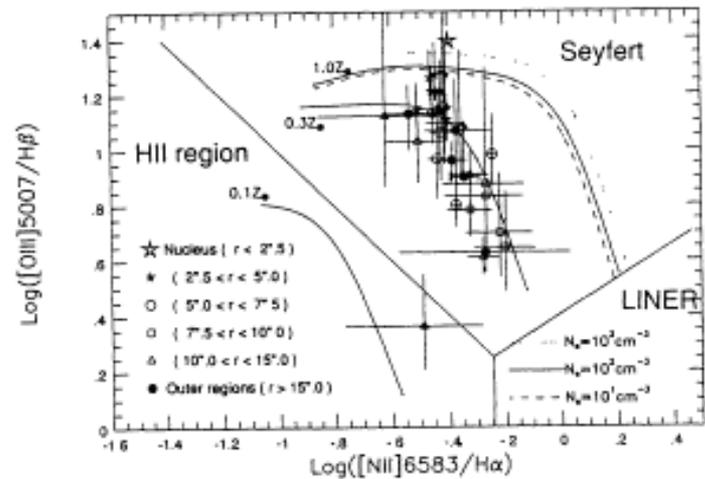


Figure 2. The VO diagram of 3C 120. Each plot shows the line ratios of integrated spectra at the regions shown in Fig.1(d). The solid lines

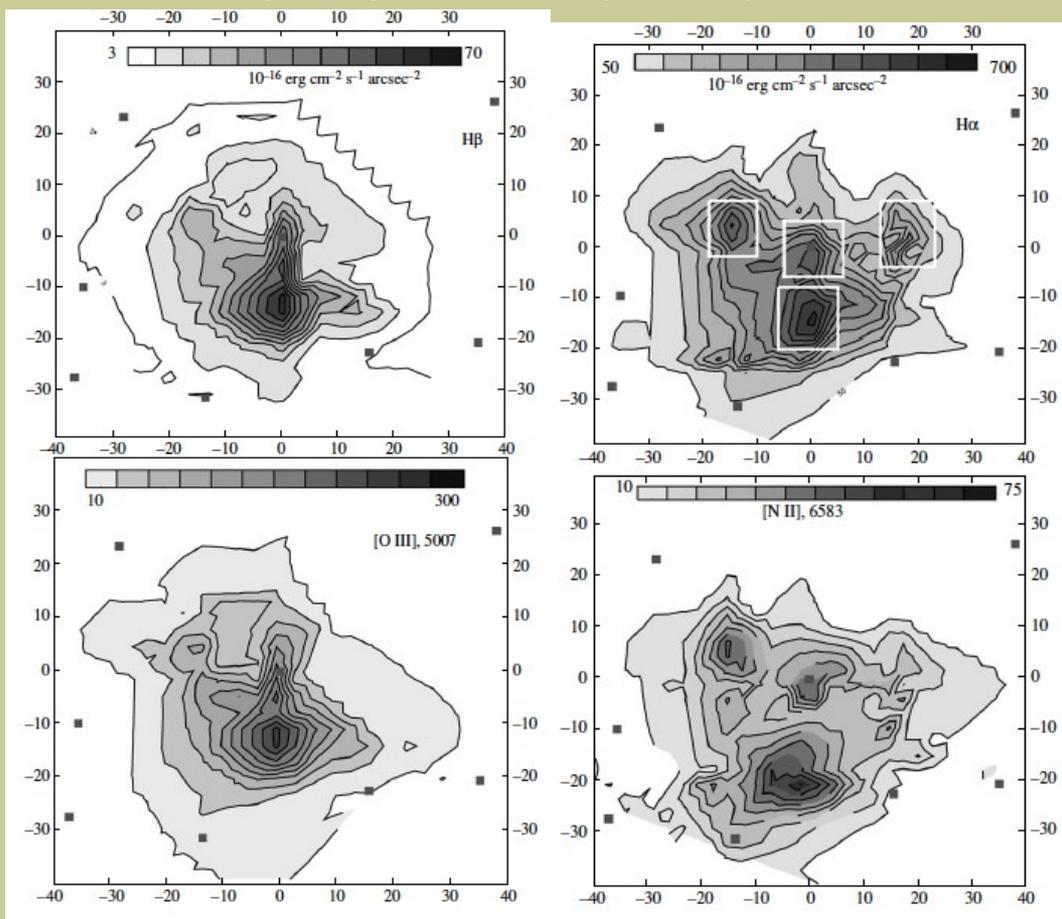
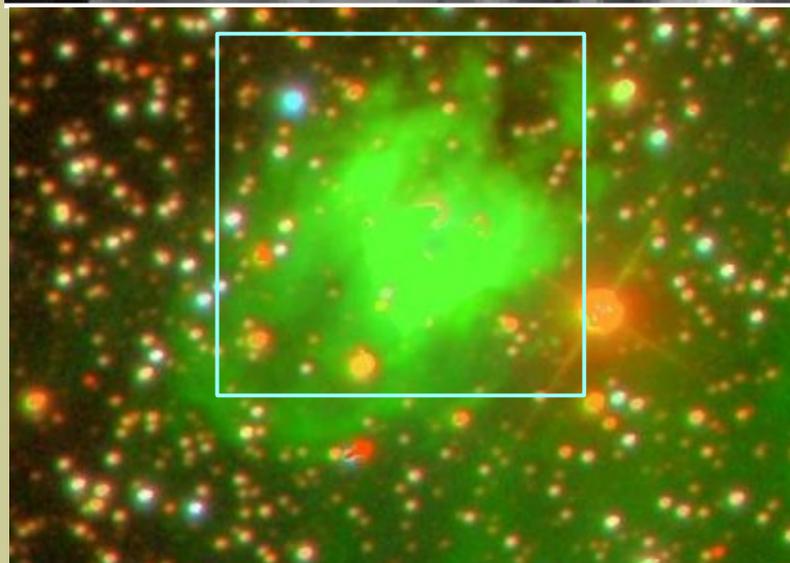
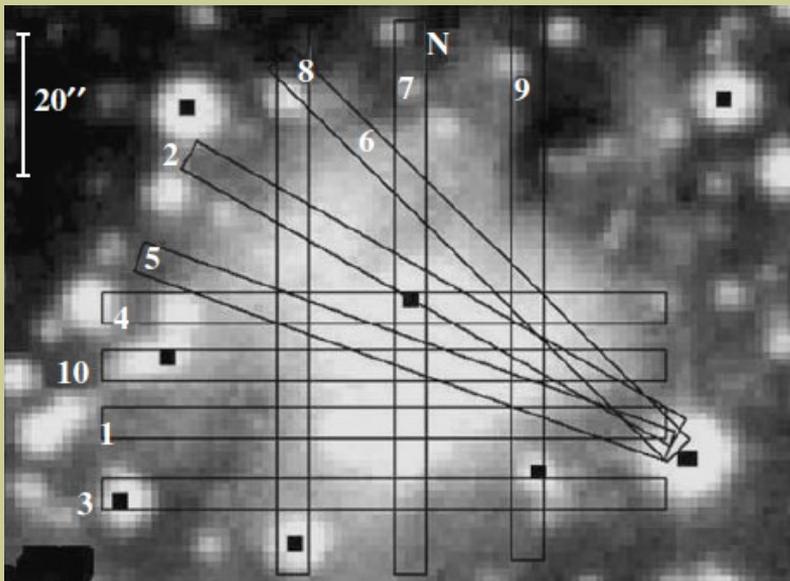
Сканирование щелью: NGC 6857

Цейсс-1000 + 0.7 м АЗТ-8

Щель 4.5"

Построены карты в основных линиях излучение туманности, карты A_v и pe

(Кондратьева и др. 2014)



NGC 185 co SCORPIO

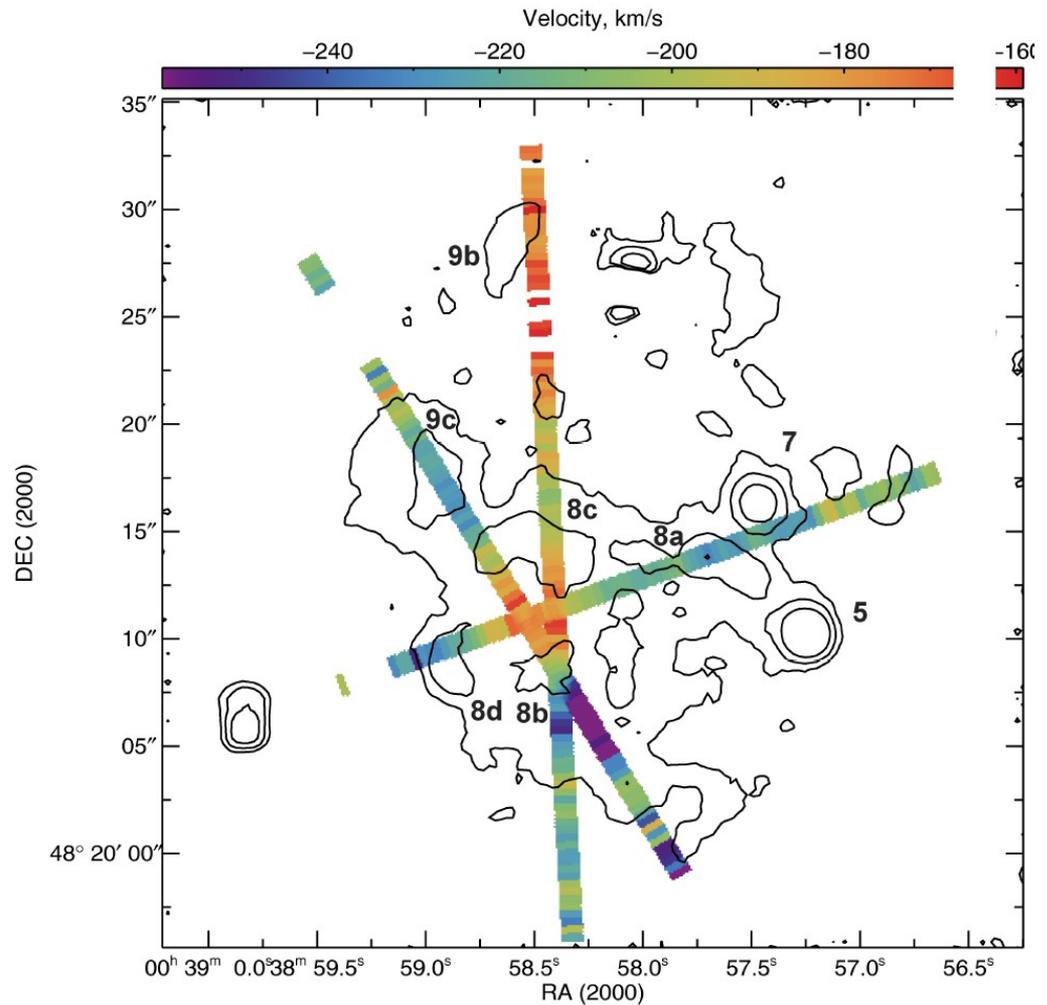
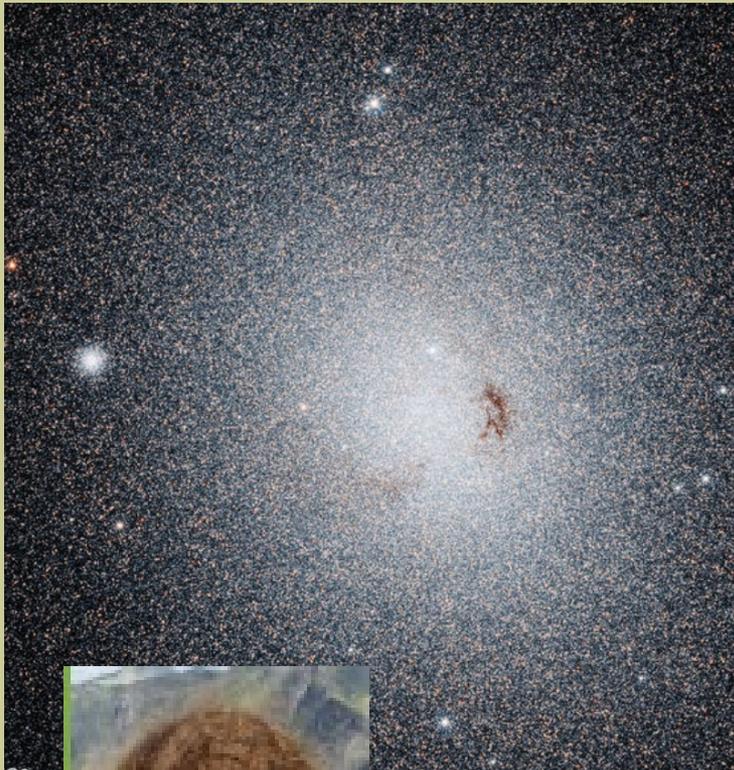


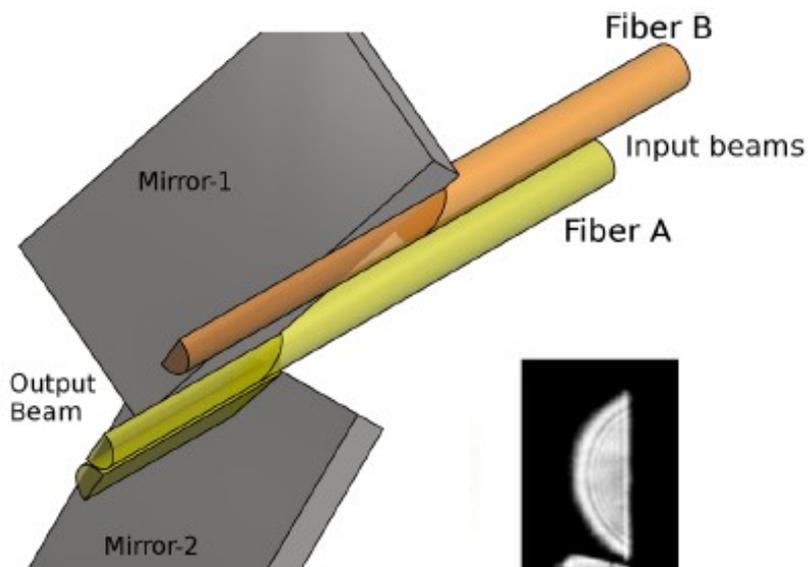
Fig. 10. Two-dimensional velocity map in the $H\alpha$ line of the central $40'' \times 40''$ of NGC 185, constructed from three slit positions for high-resolution spectra, with objects denoted as in Fig. 2. Contours denote $H\alpha$ intensity from narrowband imaging. Assuming that heliocentric velocity of the galaxy is -203.8 km s^{-1} (McConnachie 2012),

O.B. Erolov

M. M. Vučić et al.: Revealing the nature of emission nebulae in dwarf galaxy NGC 185

“Резатели” - давно используются в спектроскопии высокого разрешения

Системы зеркал или призм



Tala et al 2017

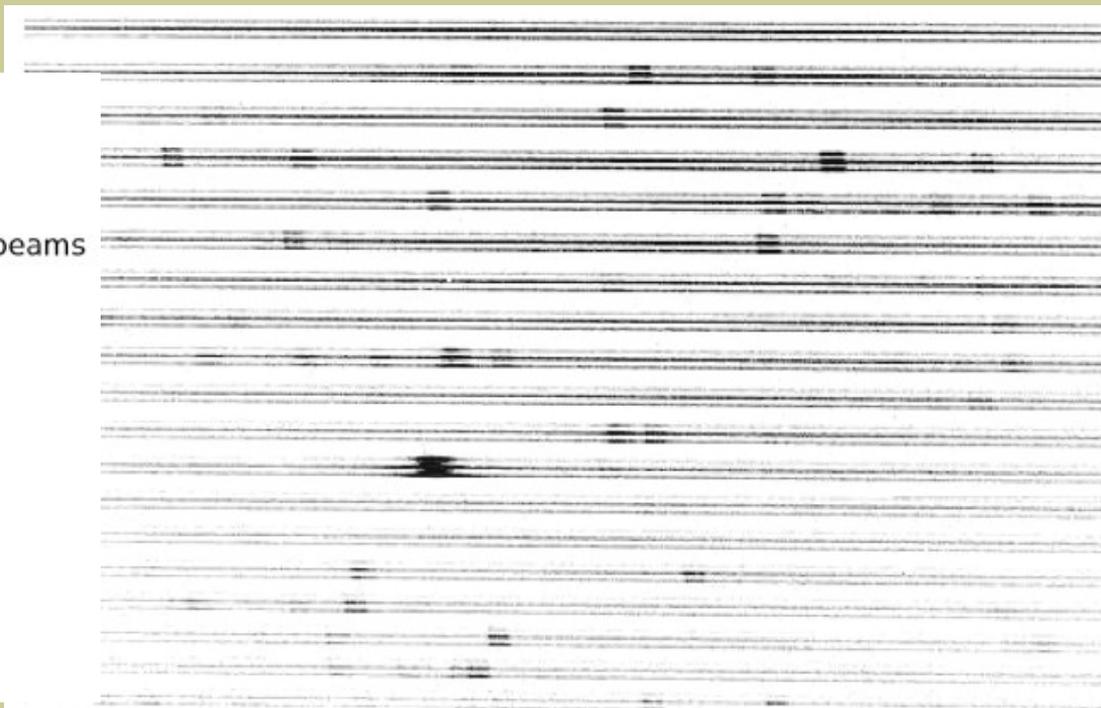


image of an echelle spectrum of CI Cam obtained with the image slicer at λ

НЭС БТА (призменный резатель)
Найденов и др 2007; Панчук и др 2007

Резатели для 3D спектроскопии

Weitzel et al. (1996)

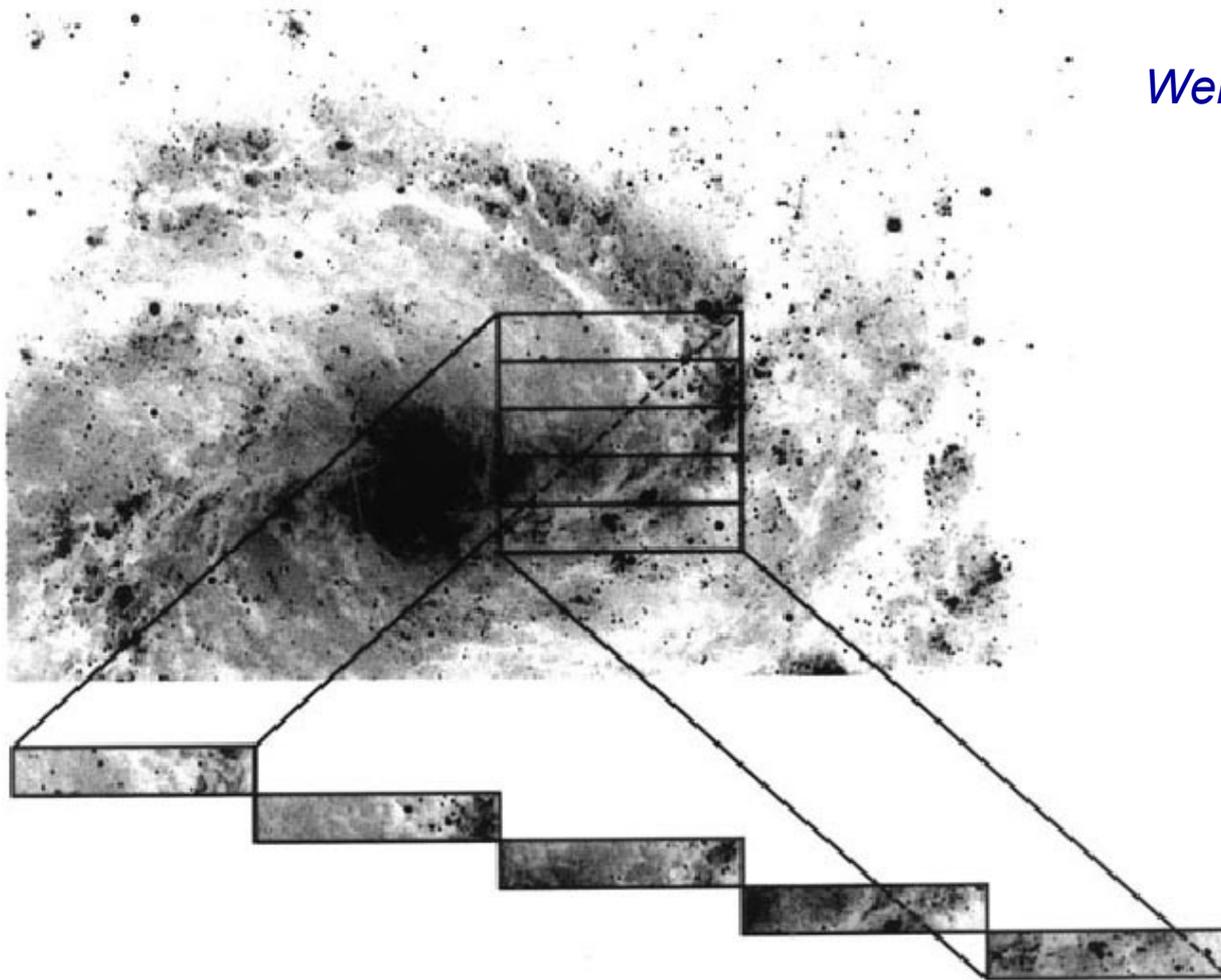
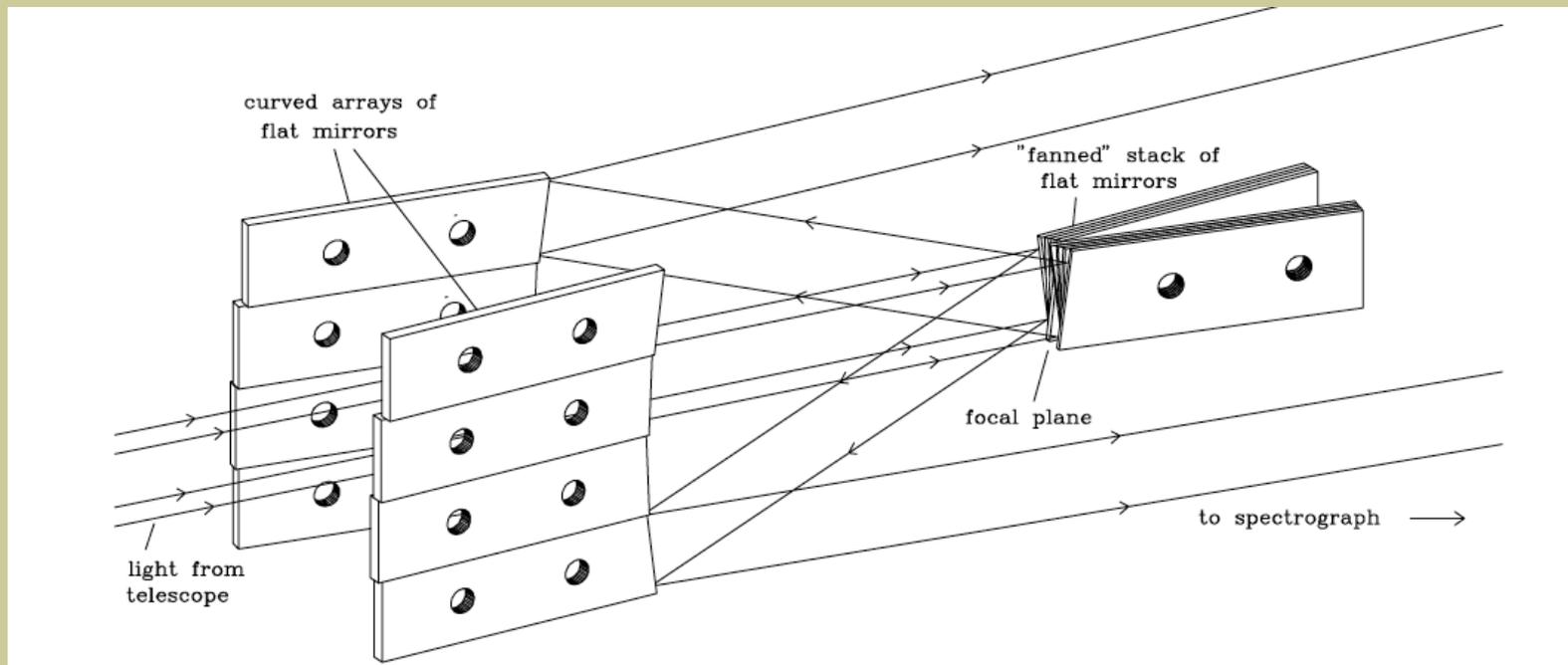


Fig. 1. The working principle of the 3D image slicer. The upper box represents the field of view with the original image. The image is horizontally cut into 16 strips, demonstrated here with 5 strips only. The single strips are then optically rearranged in the way shown to form a stair-like long slit

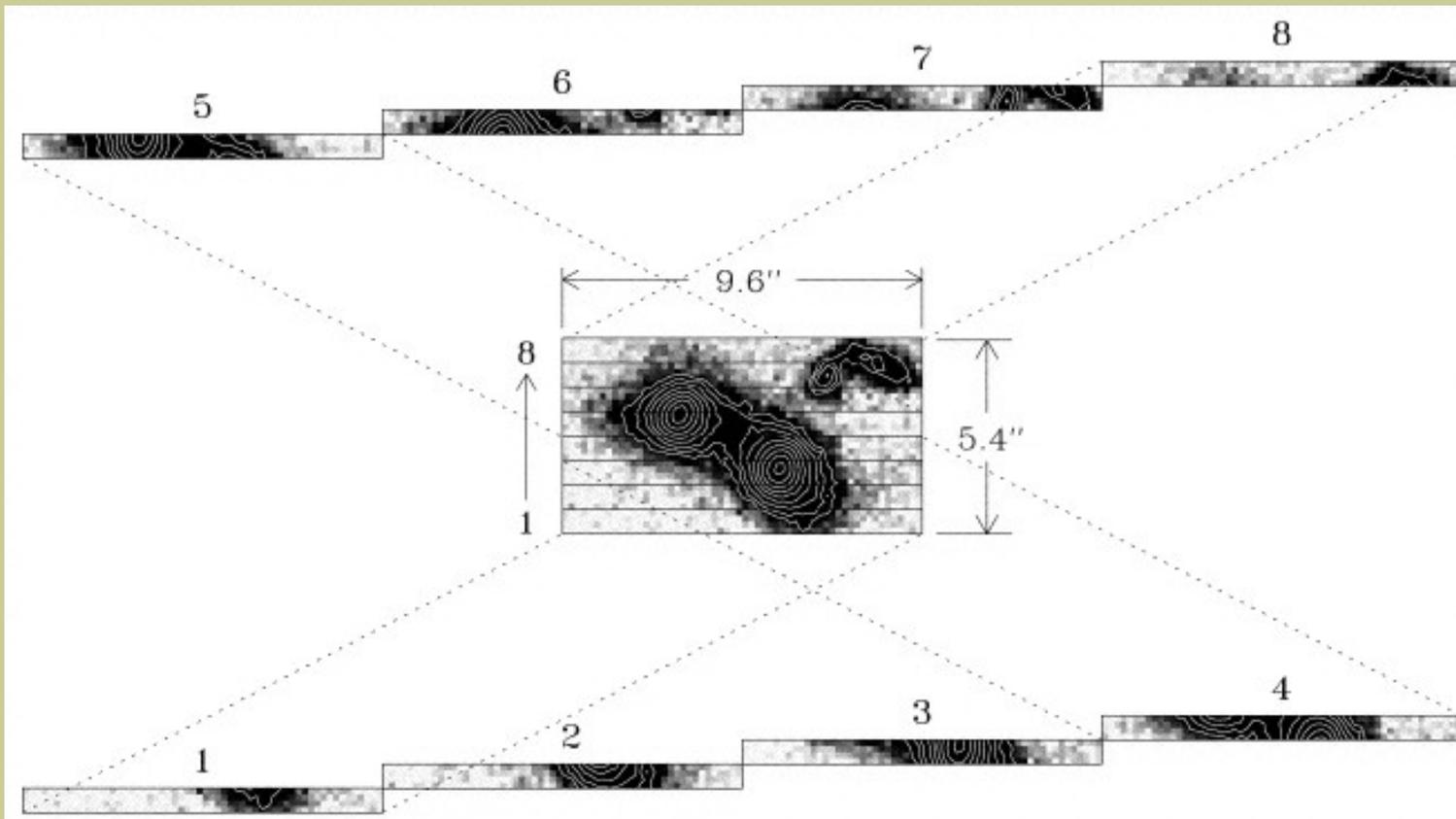
PIFS: Palomar Integral Field Spectrograph

Охлаждаемый щелевой блок оптимален для наблюдений в ИК.
Плата за это – трудности изготовления (прецизионная алмазная обработка) и юстировки тонких пластин.



Murphy +99

PIFS: Palomar Integral Field Spectrograph



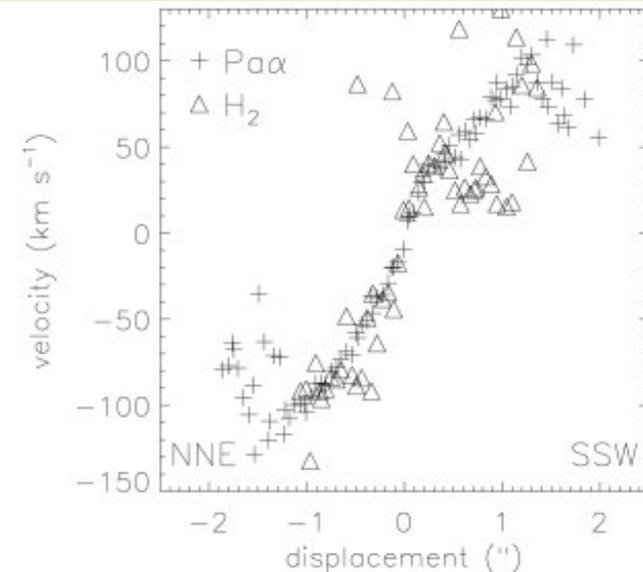
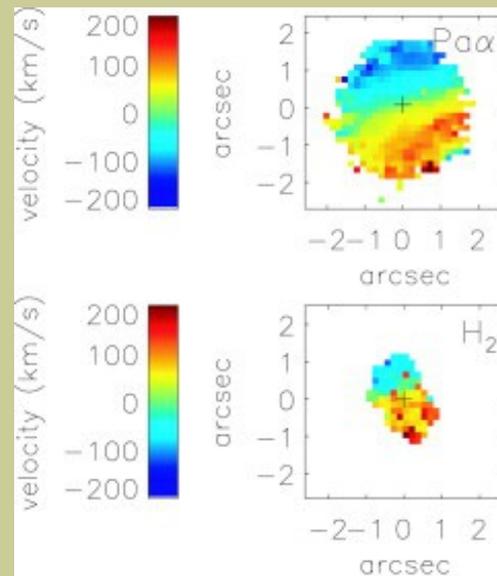
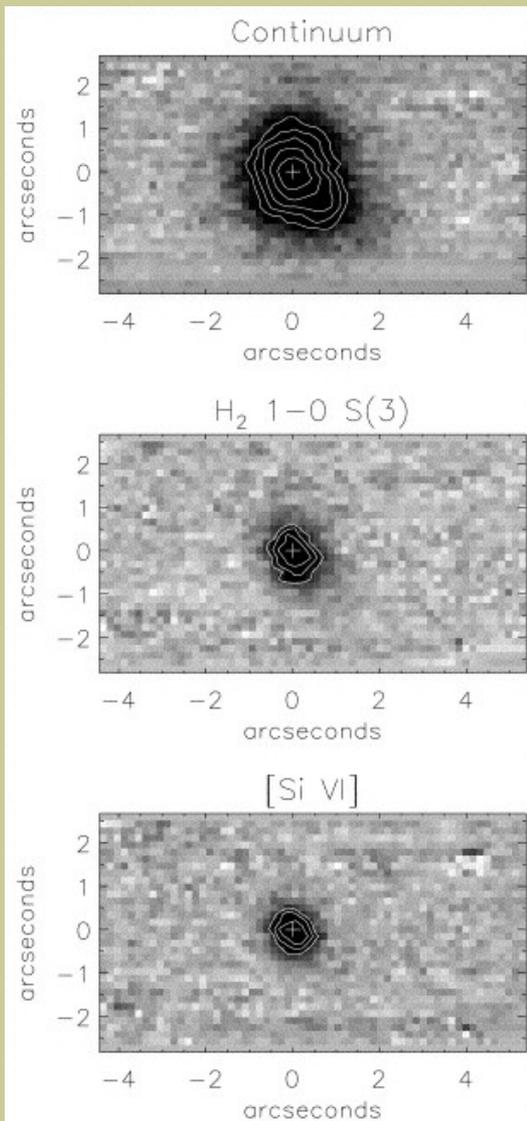
Ширина отдельных щелей – 0.67"

Murphy +99

PIFS: observations of IRAS 08311-2459

Near InfraRed observations of the
Ultraluminous Infrared galaxy IRAS 08311-2459

Murphy et al. (2000)



KCWI: Keck Cosmic Web Imager Integral Field Spectrograph

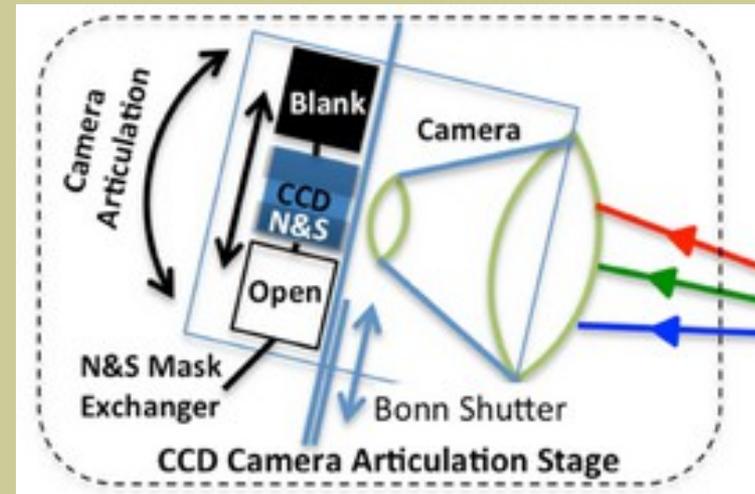


Notable features of KCWI include:

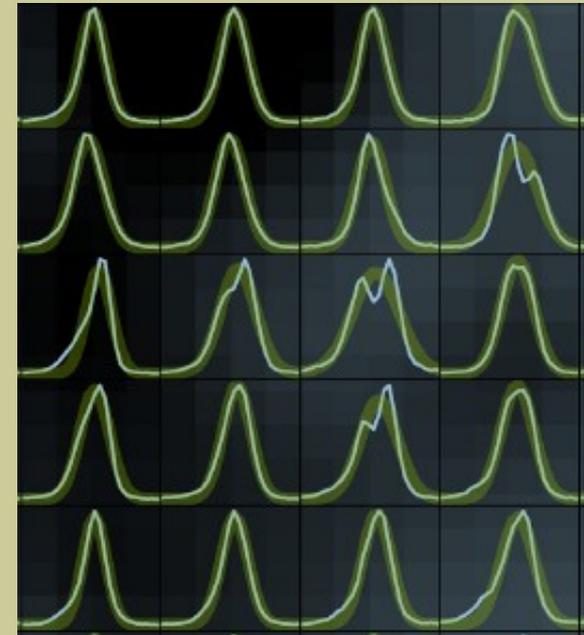
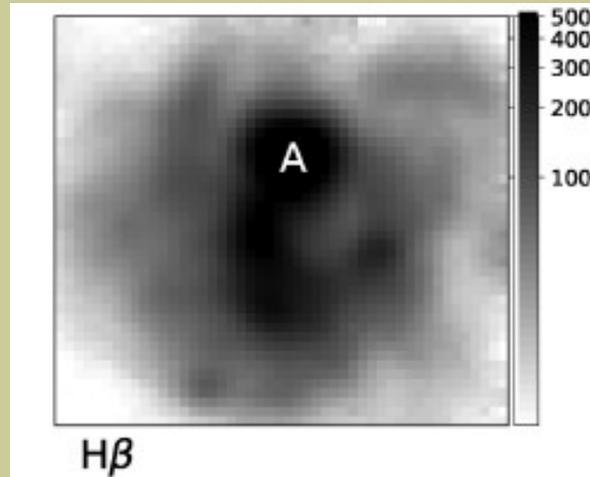
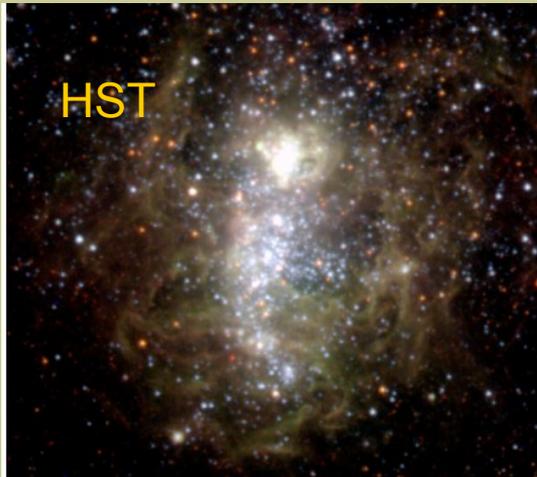
- very high efficiency
- extremely accurate sky subtraction (nod-and-shuffle)
- flexible image resolution
- flexible spectral resolution
- officially supported Python pipeline

Table 3. KCWI Slicer-Grating Spectral Resolution Table

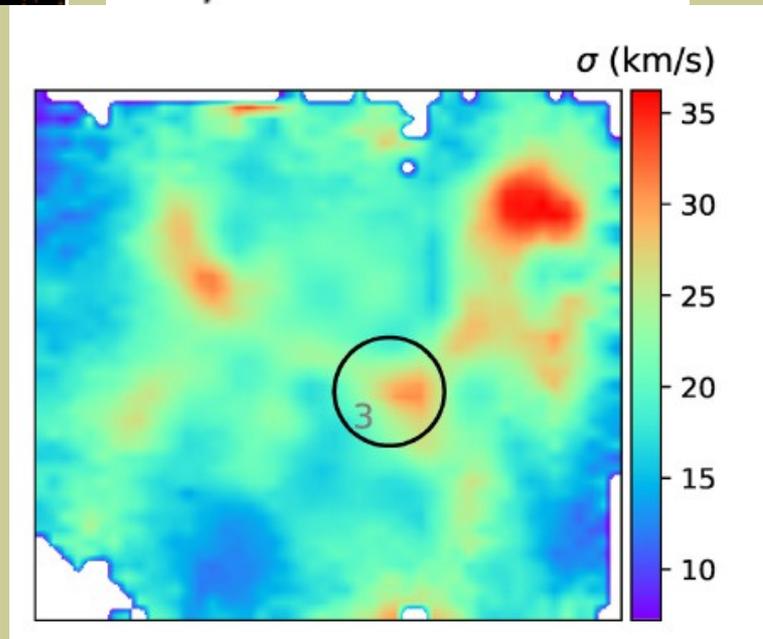
Grating	Slicers		
	Small 8.25" x 20"	Medium 16.5" x 20"	Large 33" x 20"
BL	5000	2500	1250
BM	10000	5000	2500
BHx	20000	10000	5000



KCWI: HII region NGC 5455 and NGC 5471 in M101

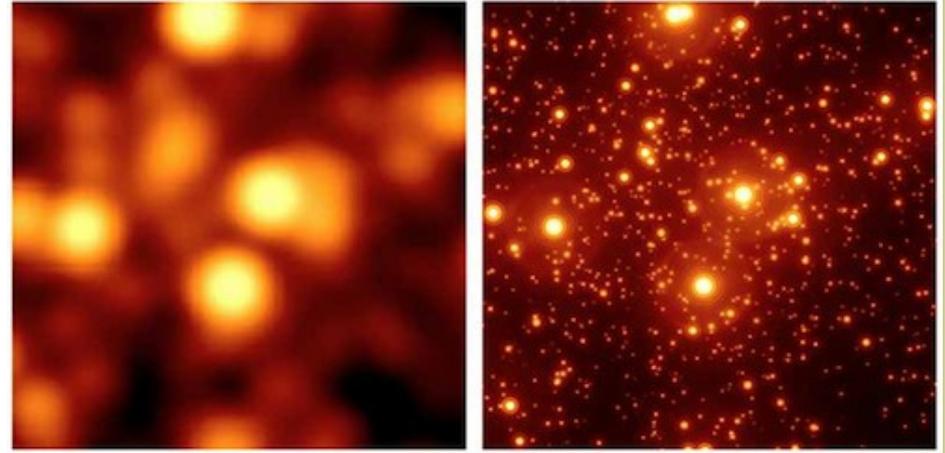
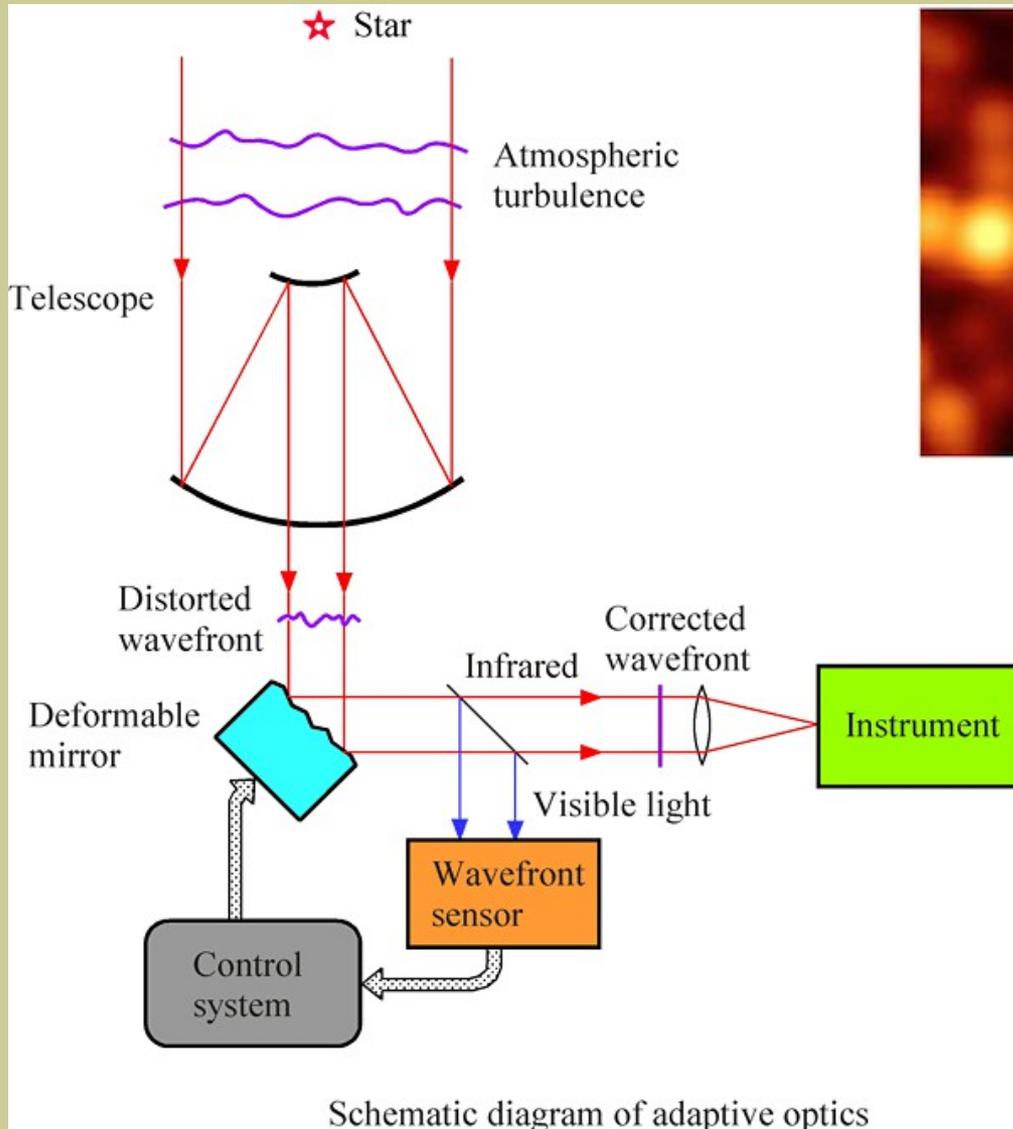


-120 and +120 km s⁻¹



R~16700
(FWHM 0.3A at 5000)
slice width 0.35"
FOV 3x(8.4*20.4)

Спектроскопия с системами адаптивной оптики



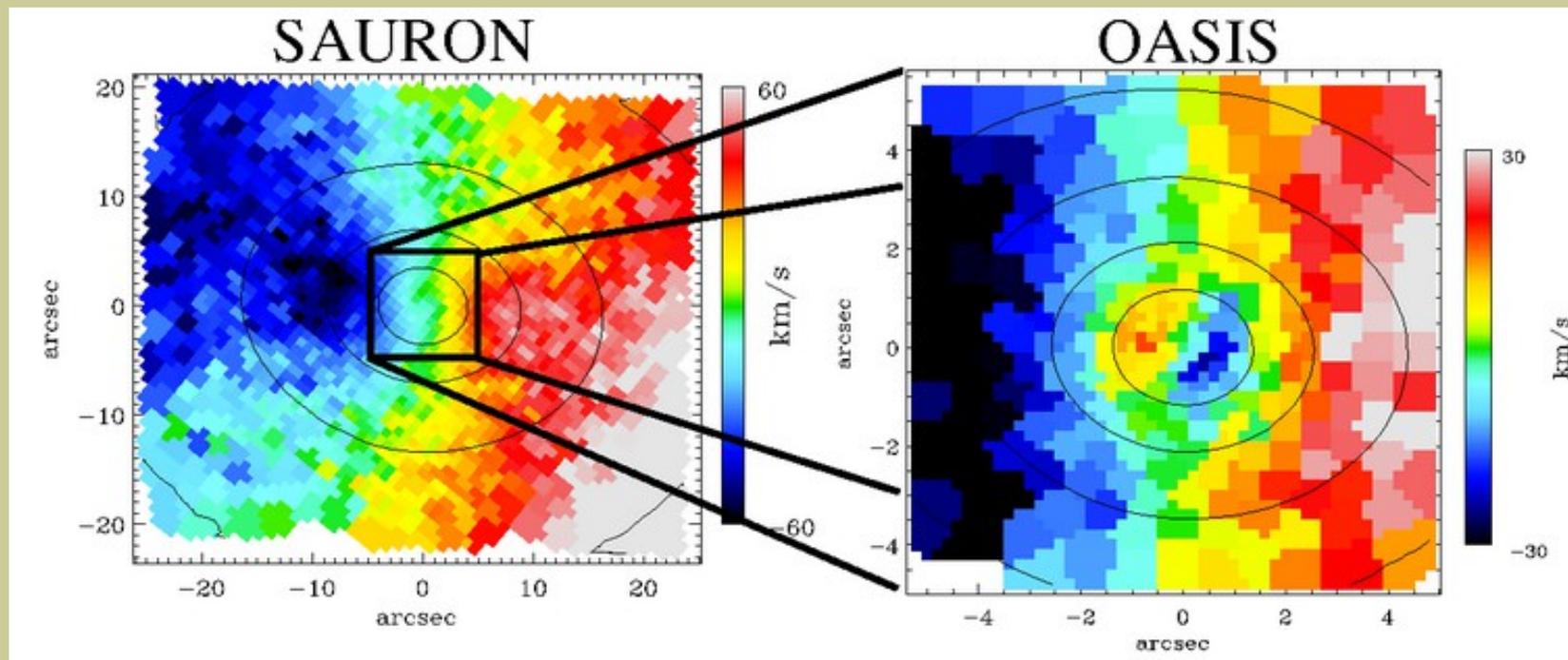
- АО работает преимущественно в ИК
- Спектроскопия с длинной щелью здесь нерациональна (потеря пространственной информации + сложность позиционирования)

➡ 3D-спектроскопия
(в ИК оптимальна с резателем)

OASIS (3.6 m CFHT) - "старший брат SAURONa")



(Optically Adaptive System for Imaging Spectroscopy)

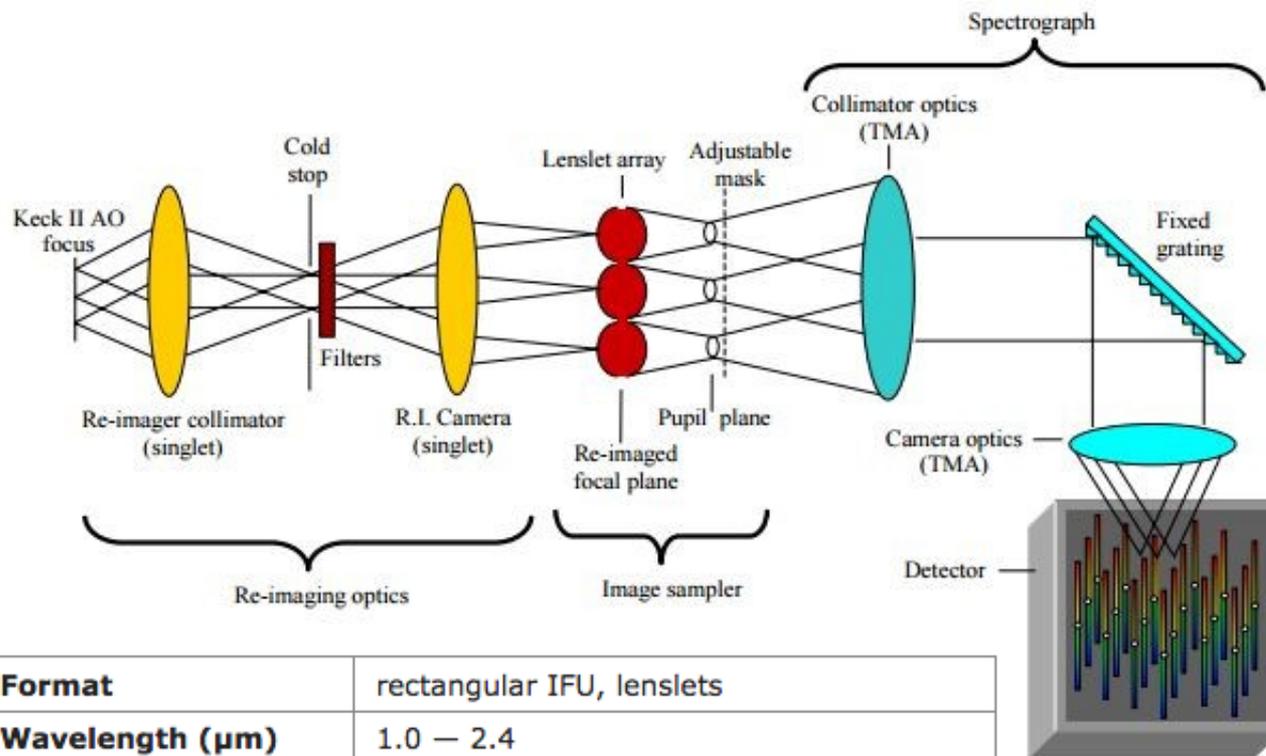


TIGER-mode R. Bacon et al 2001

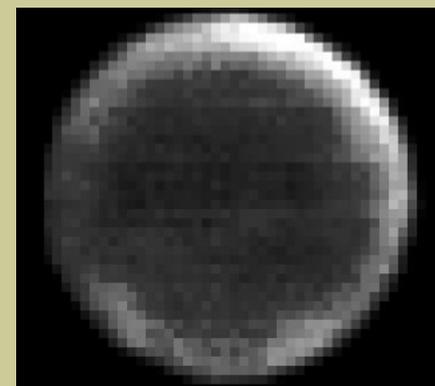
Spatial configurations

Spatial sampling	Field of view
0.09"	2.7" x 3.7"
0.14"	4.0" x 5.5"
0.26"	7.4" x 10.3"
0.42"	12.0" x 16.7"

Keck OSIRIS (OH-Suppressing InfraRed Imaging Spectrograph)



Титан:
стратосфера



поверхность:



0.9 arcsec

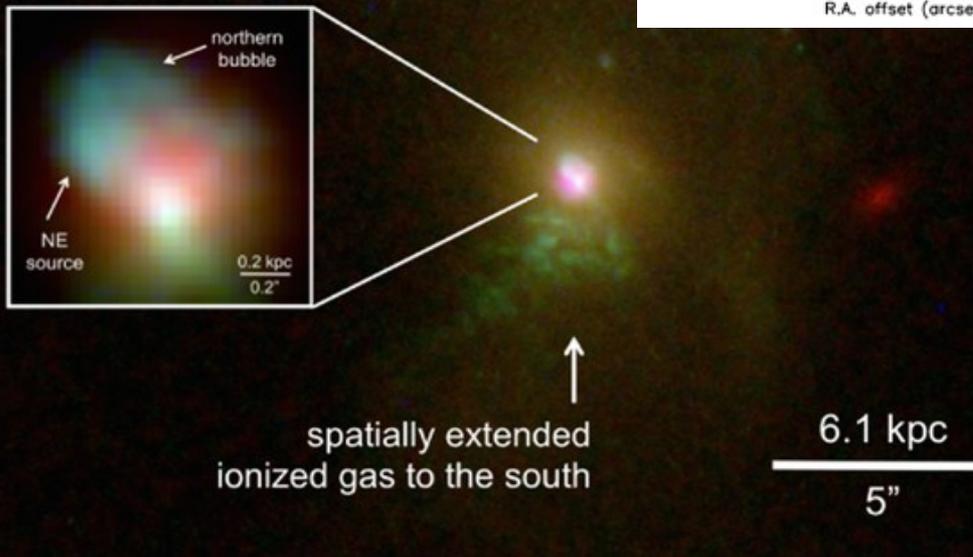
Format	rectangular IFU, lenslets
Wavelength (μm)	1.0 – 2.4
Spectrograph resolution (R)	~3800
Simultaneous sky coverage	none in the IFS itself, though there is a simultaneous imager channel
Field of view	0.32"x1.28" – 4.8"x6.4" depending on camera setting
Spatial element size	0.020", 0.035", 0.050", 0.100"

Larkin + 2006

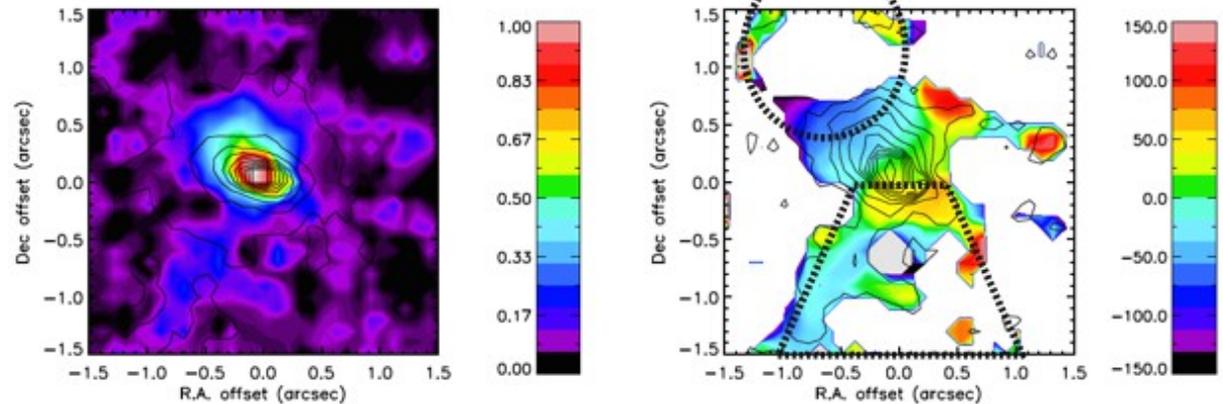
Keck OSIRIS

Comerford et al 2017: галактика в момент переключения активности

HST + Chandra



Pa α flux distribution (top middle), and Pa α velocity (top right)

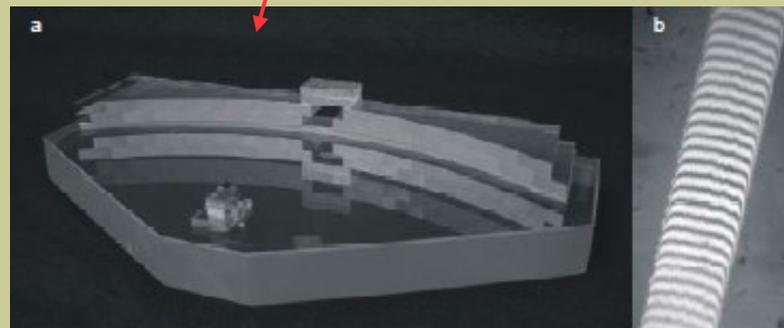
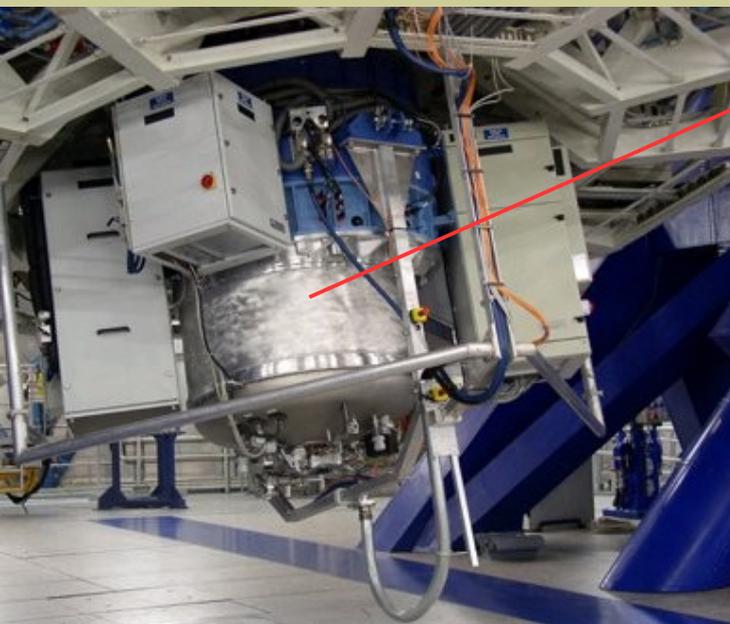
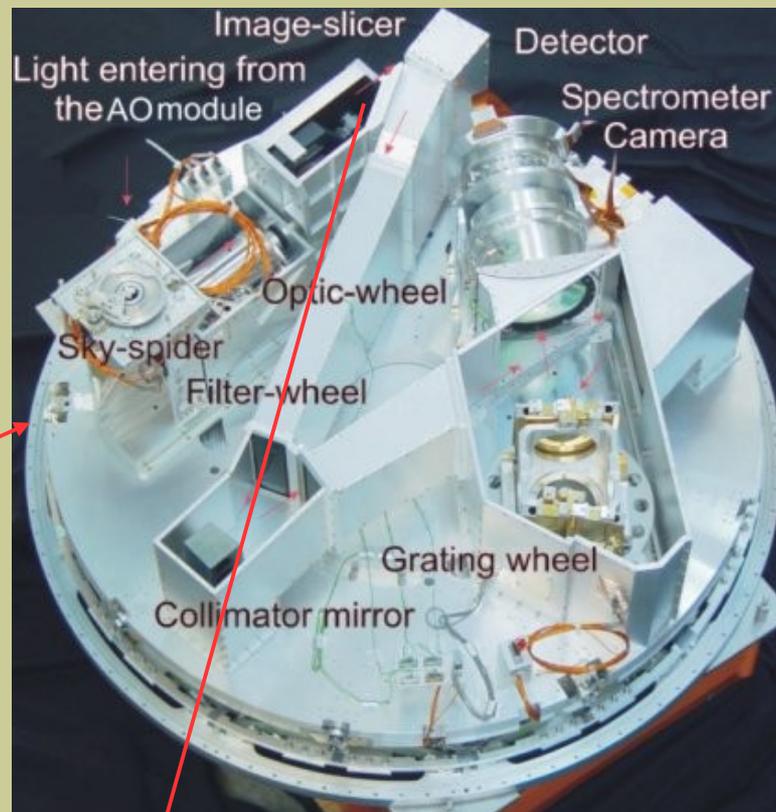


“Конус” и “пузырь” - на разных этапах включения AGN (100 000 лет)

SINFONI - Spectrograph for INtegral Field Observations in the Near Infrared (VLT)

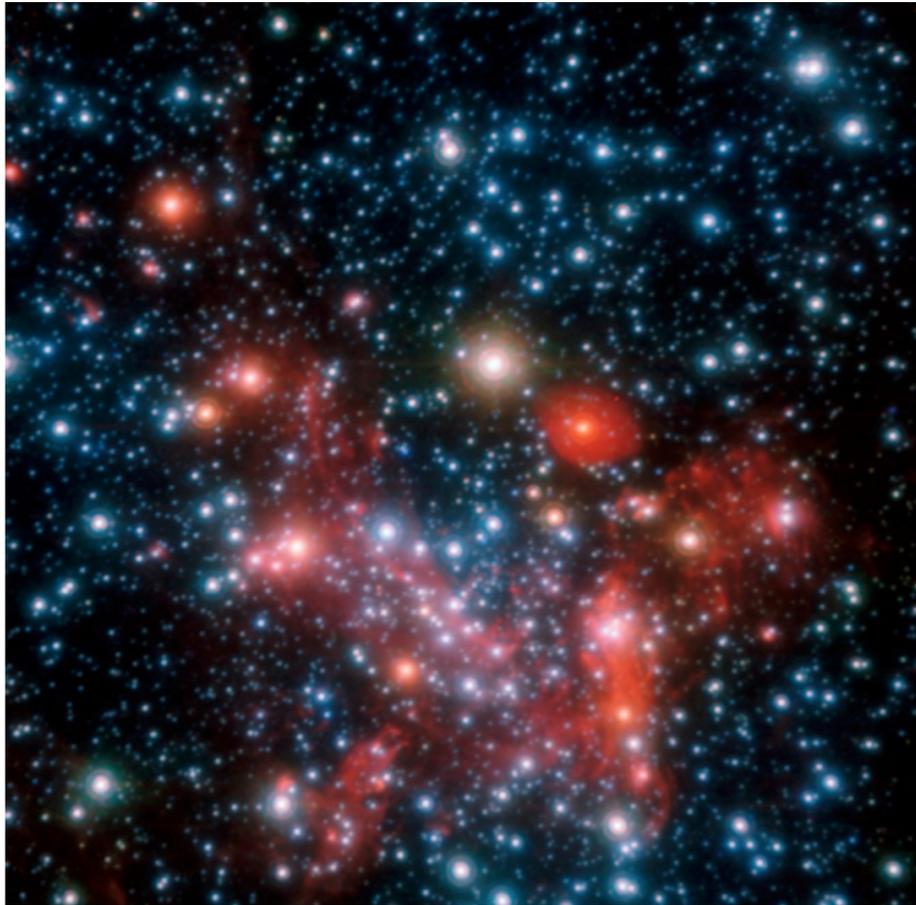
Spectral range: (1.1 - 2.45 μm)

Field of View	Spatial Scale	Mode	Limiting Magnitudes
8"x8"	125x250mas	noAO	J=20.2 H=19.9 K=17.9 H+K=19.6
3"x3"	50x100mas	NGS	J=19.4 H=19.6 K=18.8 H+K=19.8
0.8"x0.8"	12.5x 25mas	NGS	J=17.8 H=18.7 K=18.3 H+K=19.2

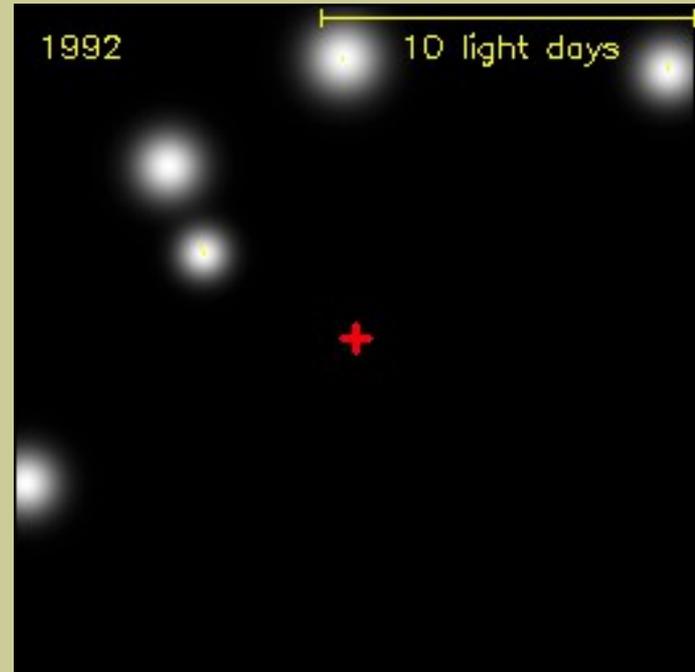


Eisenhauer + 2003

Центр Галактики в инфракрасном диапазоне



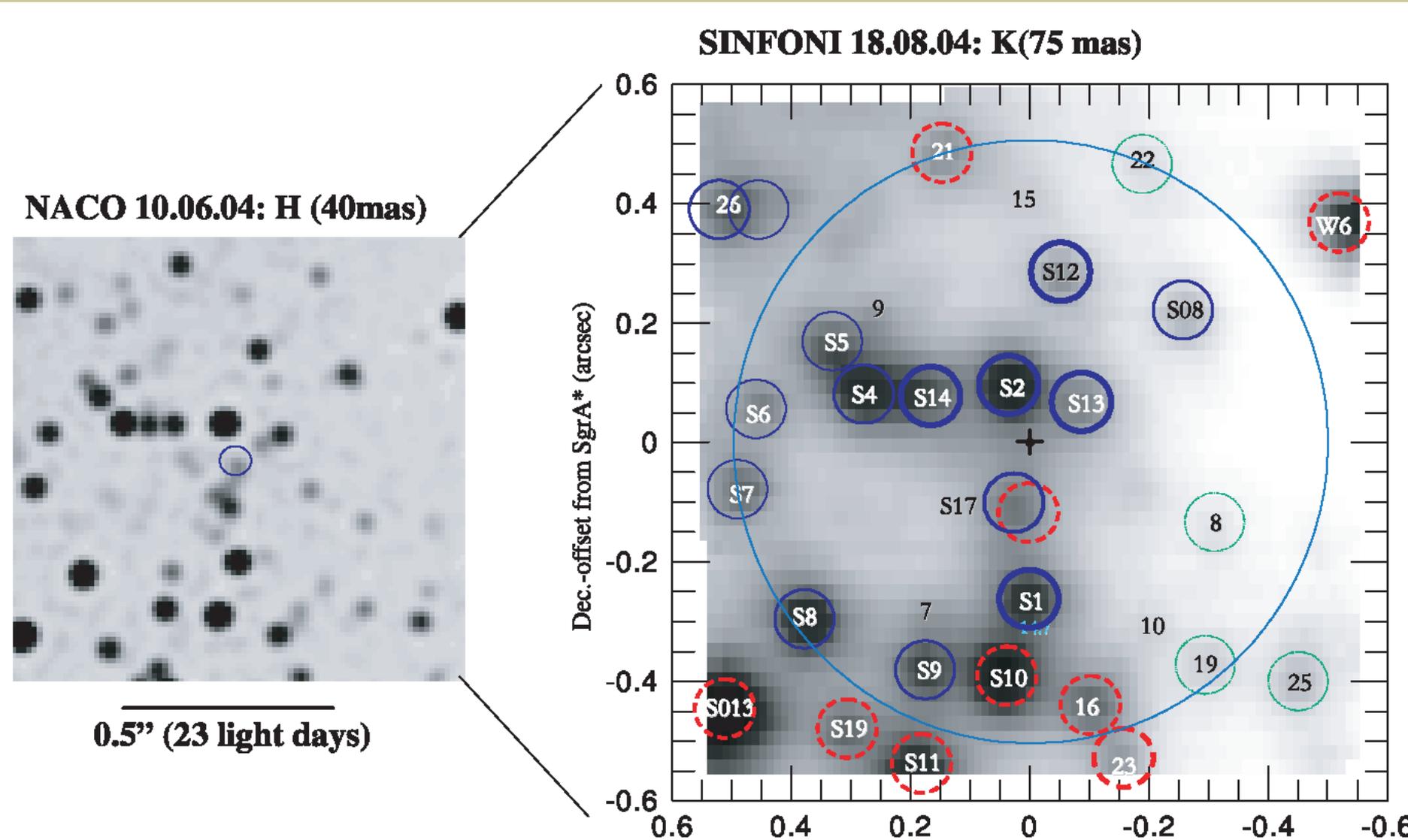
Combined H- K- and L-band adaptive optics image of the Galactic Center obtained with



<http://www.mpe.mpg.de/ir/GC>

SINFONI: галактический центр

Eisenhauer et al. (2005),



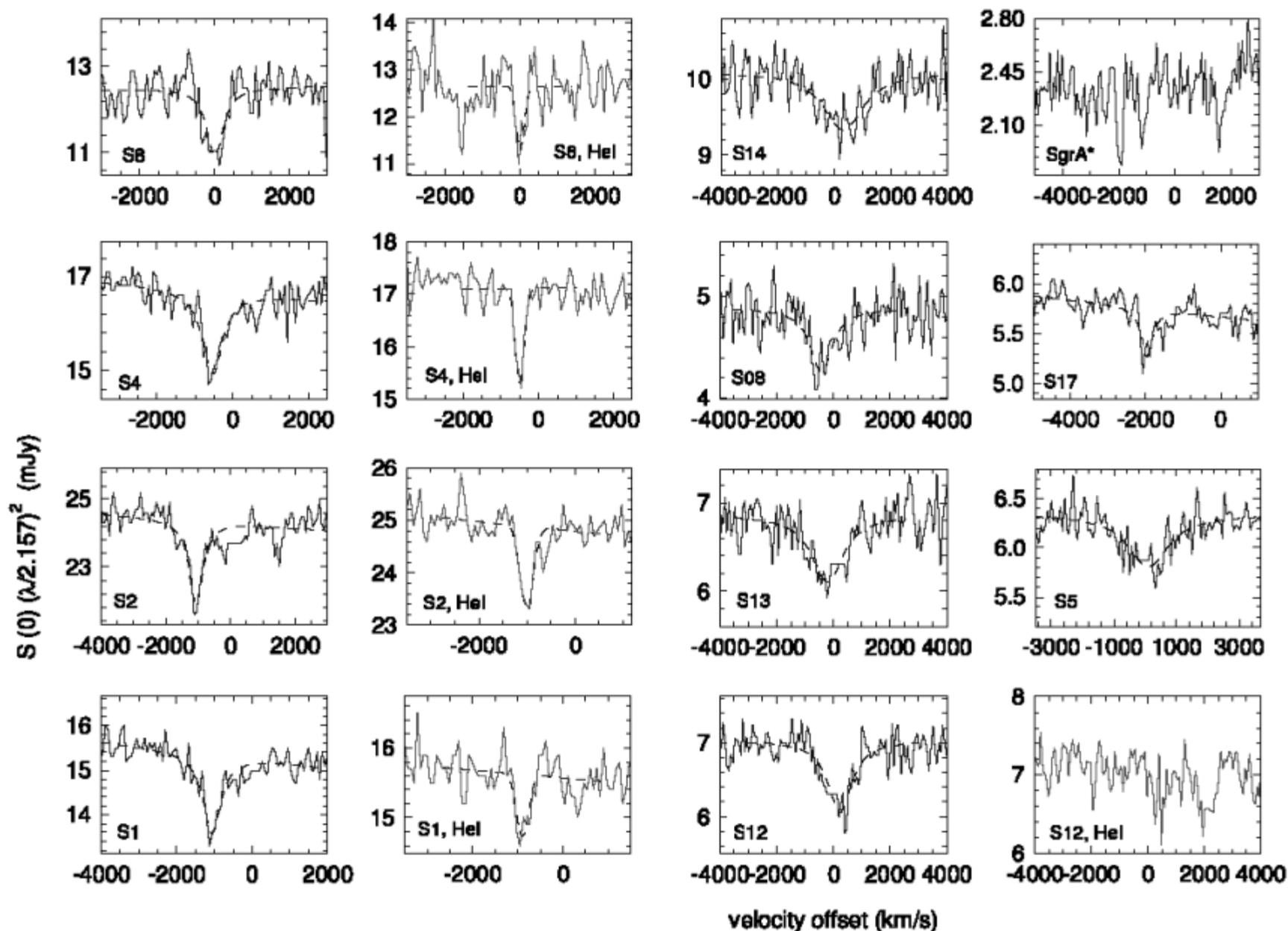
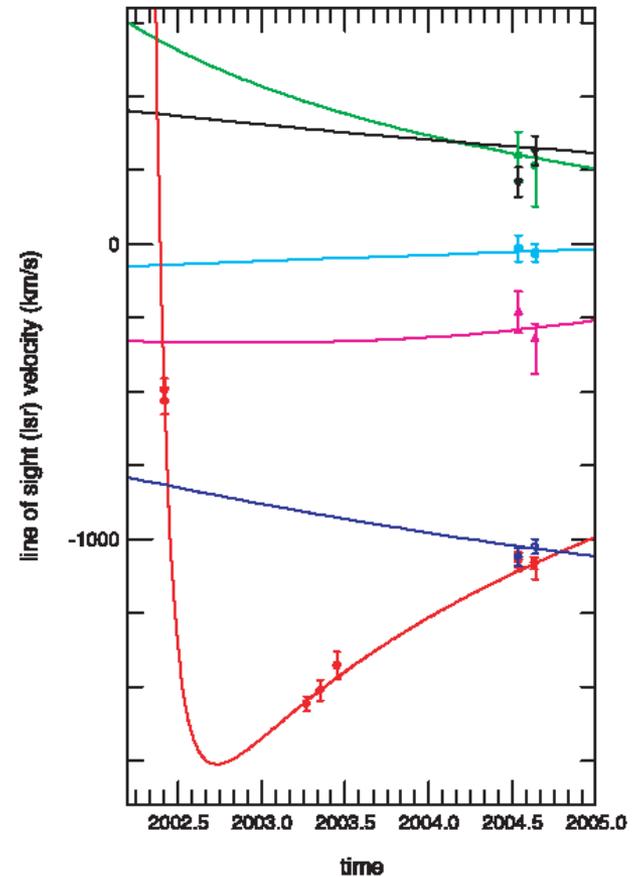
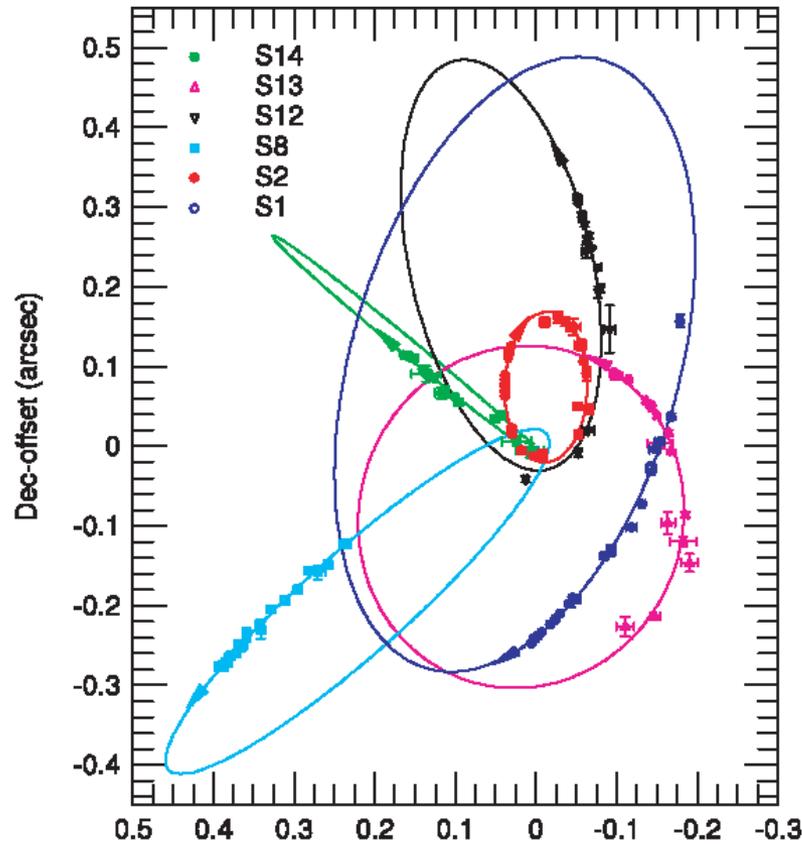


FIG. 2.—Extracted spectra near the $2.1661 \mu\text{m}$ H I Br γ (7–4) line and the $2.1127 \mu\text{m}$ He I line (labeled) for 10 of the 11 $K < 16$ mag stars in the central $\sim 0''.5$, plus a

SINFONI: к астрометрии добавлены лучевые скорости

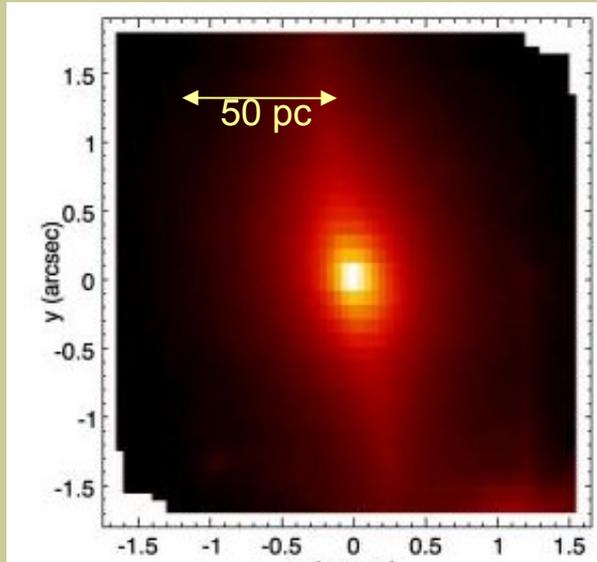


Данные SINFONI в комбинации с прямыми снимками в разные эпохи использовались для построения трехмерной модели звездных орбит в центре Галактики, уточнения массы ЧД и расстояния до неё

» also Schödel et al. 2003). The measured radial fit to the spatial and radial velocity data of S1, S2,

SINFONI: массы черных дыр в других галактиках

NGC 4486A (Nowak +07)



Параметры звездной кинематики

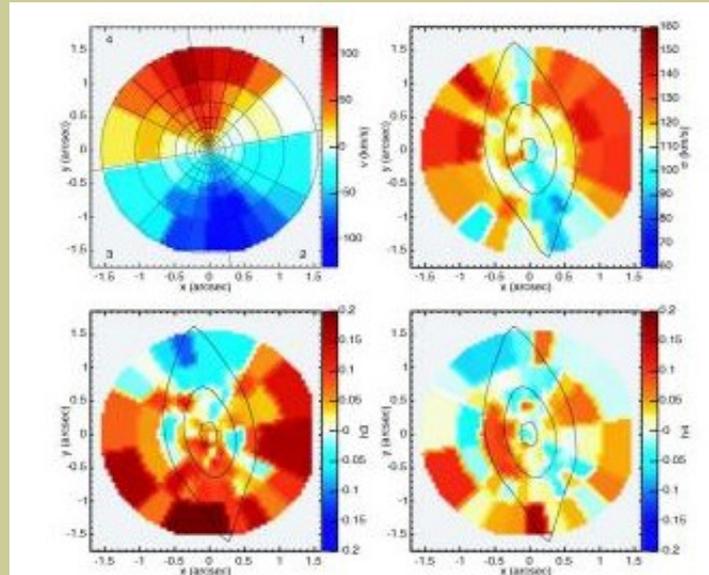
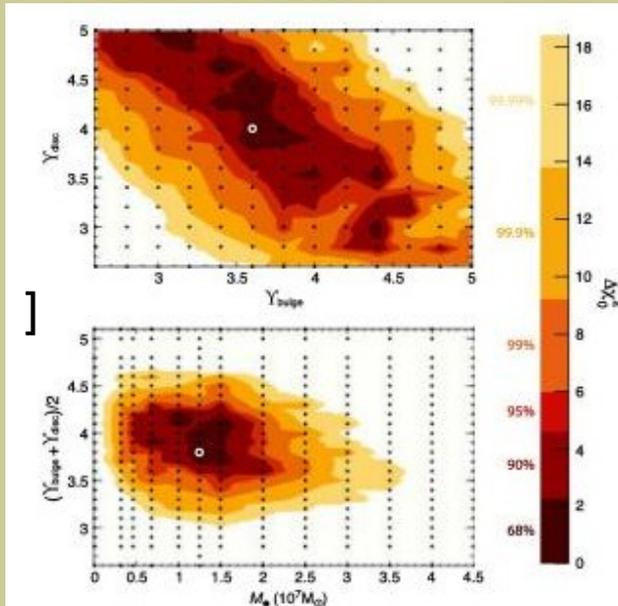


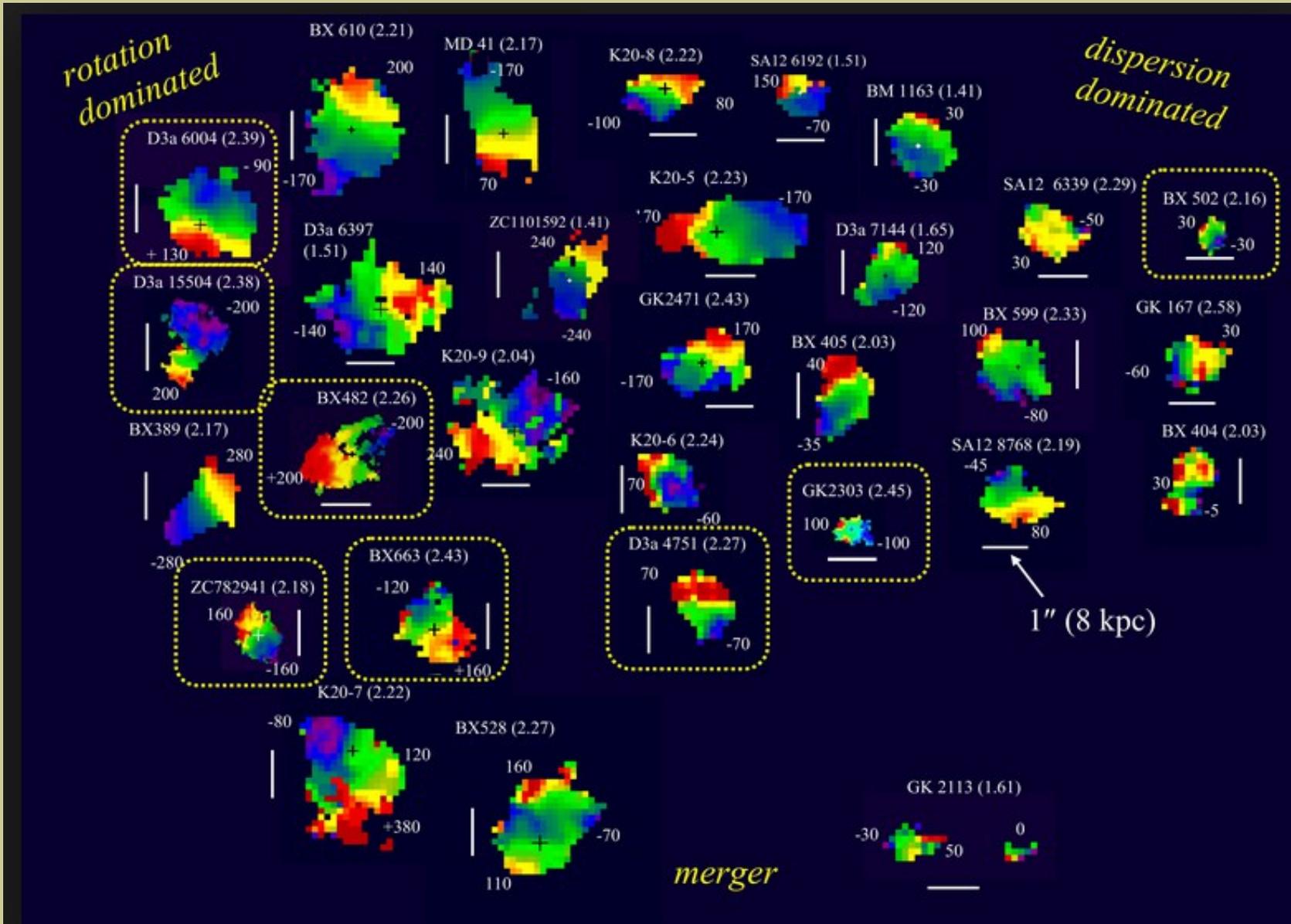
Figure 3. Stellar kinematic fields (v , σ , h_3 , h_4) of NGC 4486a. The binning



Подгонка наблюдений моделью,
масса центральной ЧД (M^*) - один
из параметров

AO: seeing < 0.1"

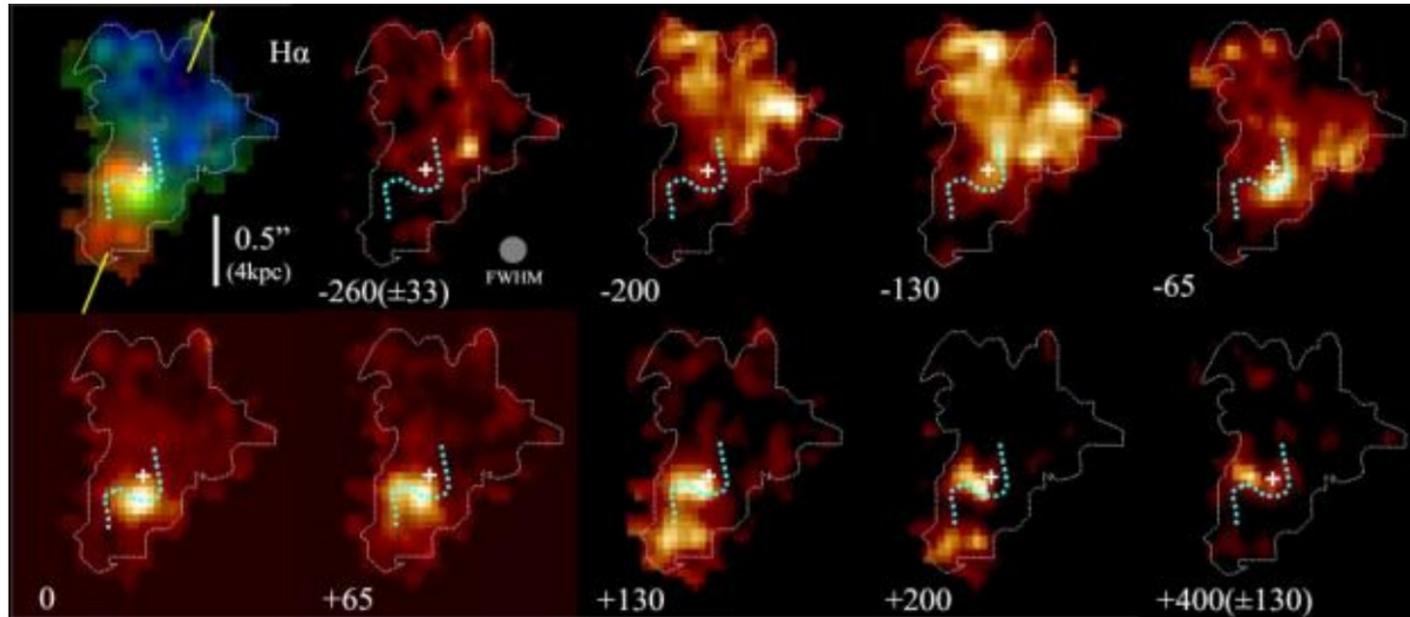
SINFONI: обзор галактик на $z \sim 2$ (SINC, 62 galaxies in Ha)



SINFONI/SINS

Звздообразование в линии $H\alpha$ на $z=2.38$ с разрешением 1.2 кпк – возможность прямого сравнения с близкими галактиками.

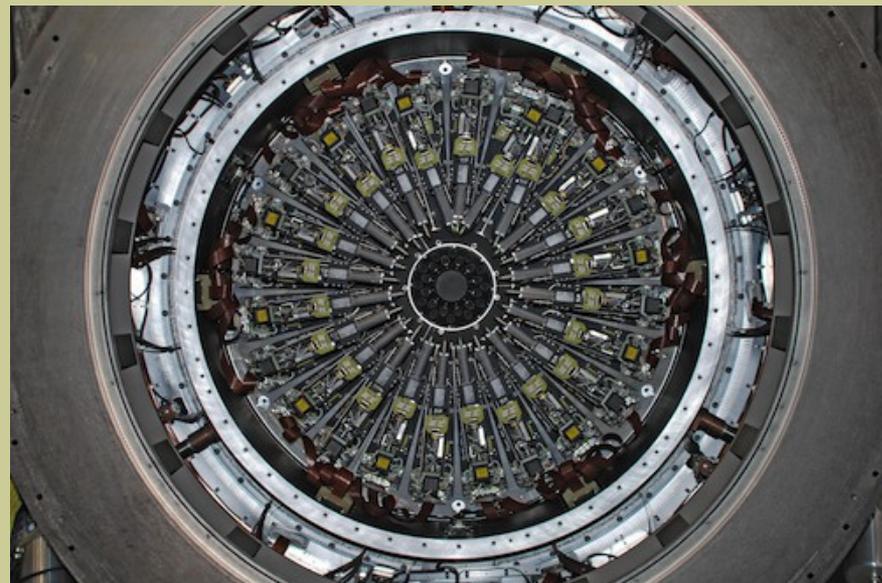
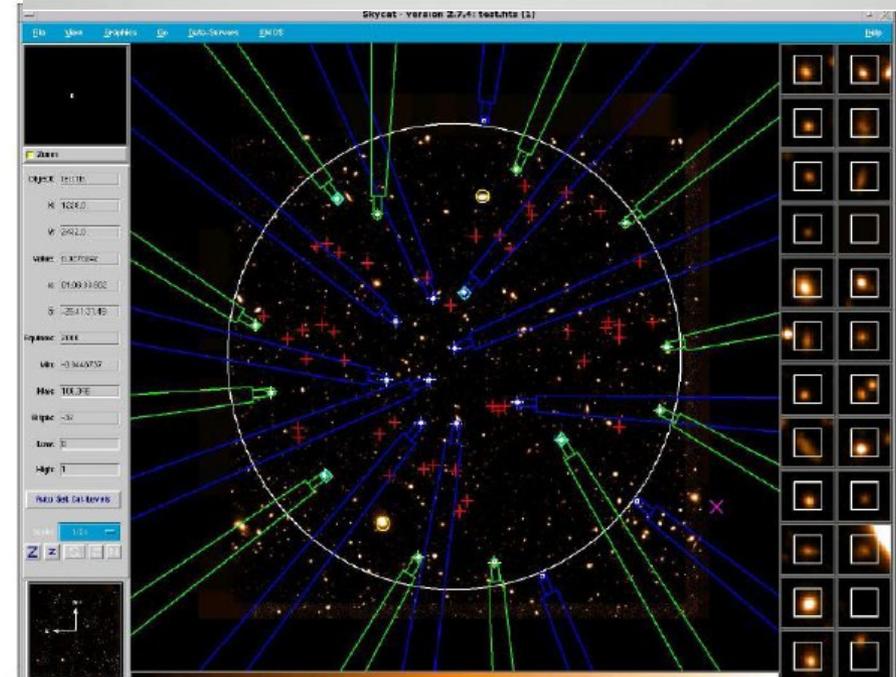
BzK-15504: SFR=150 M_{sun}/yr



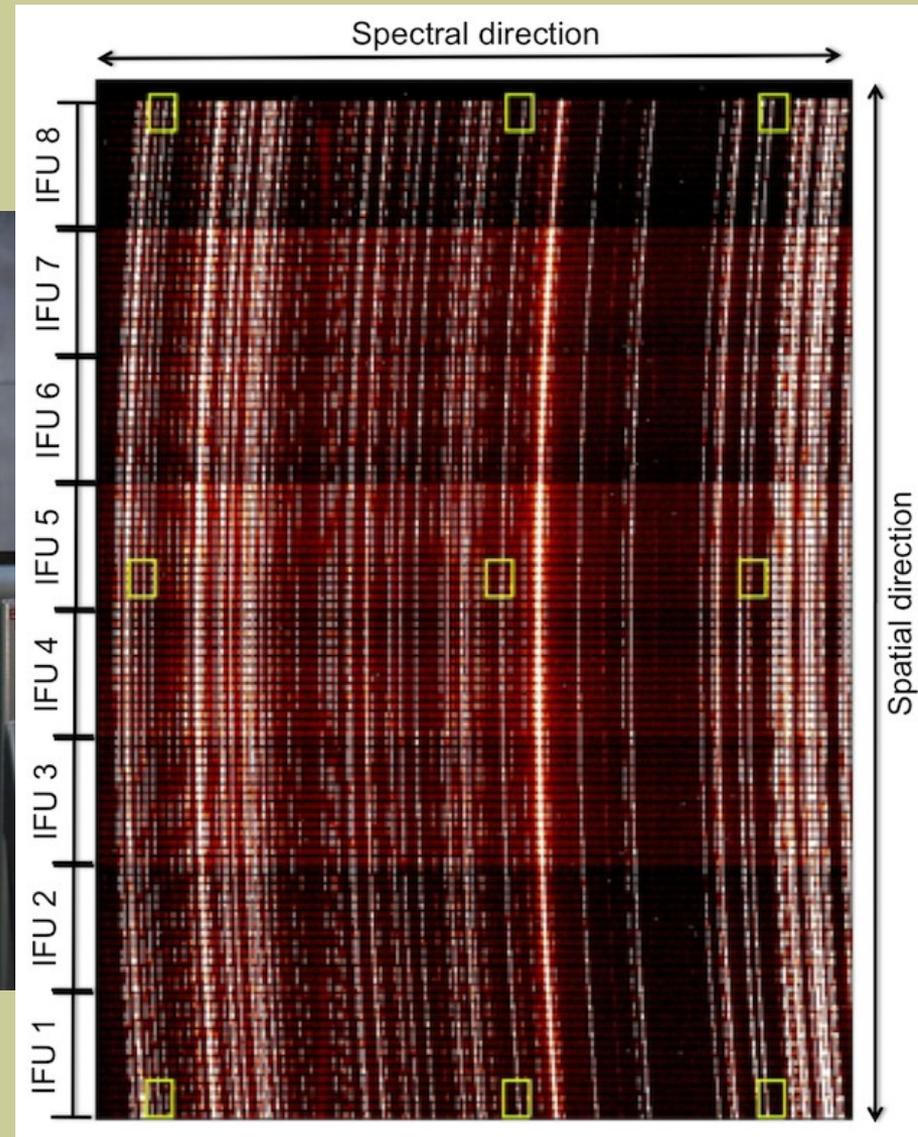
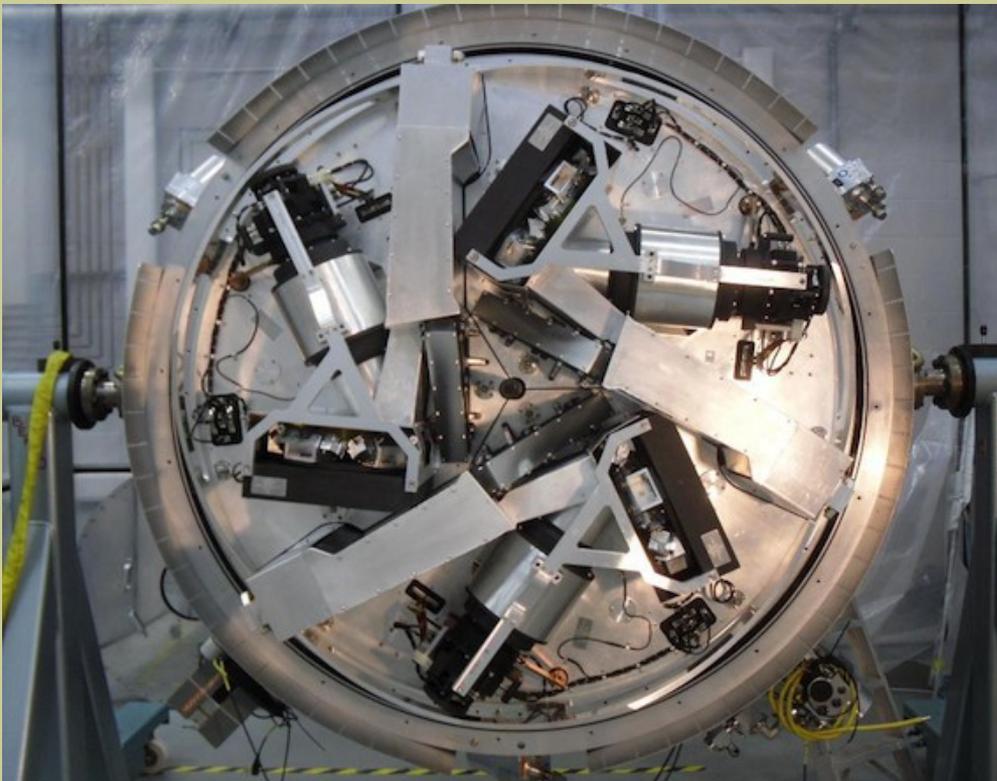
Hydrogen recombination line emission of $H\alpha$ of the massive star-forming galaxy BzK-15504 eleven billion light-years away (redshift $z = 2.38$). The observations were carried out with SINFONI in adaptive-optics mode, resulting in an angular resolution of ≈ 0.15 arcsec, or a mere 1.2 kpc (4000 light-years; indicated by the grey filled circle) at the redshift of BzK-15504. The top left panel is a color-composite map of the integrated $H\alpha$ line emission, showing from blue to red the ionized gas that is blueshifted to redshifted relative to the systemic velocity of the galaxy. The other panels are channel maps showing the spatial distribution of the $H\alpha$ emitting gas moving at different velocities (given in km/s) relative to

KMOS: K-band Multi-Object Spectrograph

- Instrument capabilities
 - VLT 8m
 - 24 MOS probes, 2.8x2.8 arcsec each, sampled at 0.2 arcsec (14 slices)
 - 4704 spatial elements total (188 arcsec²)
 - 7.2 arcmin diameter patrol field
 - 0.8-2.5 μm range
 - 1000 spectral elements ($R \sim 3600$)
 - $\epsilon = 0.3 * \text{telescope} * \text{atmosphere}$

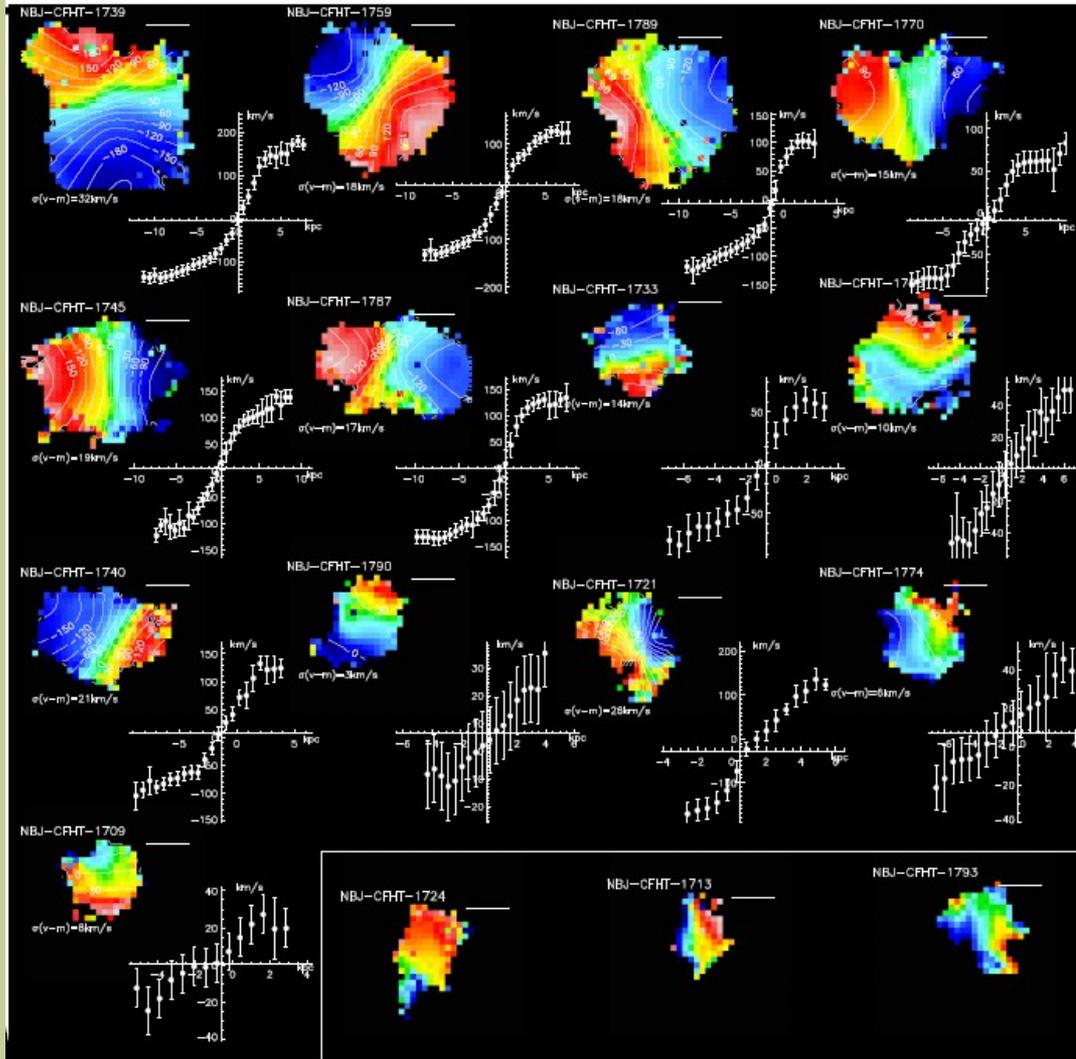


KMOS: три спектрографа, по 8 IFU в каждом



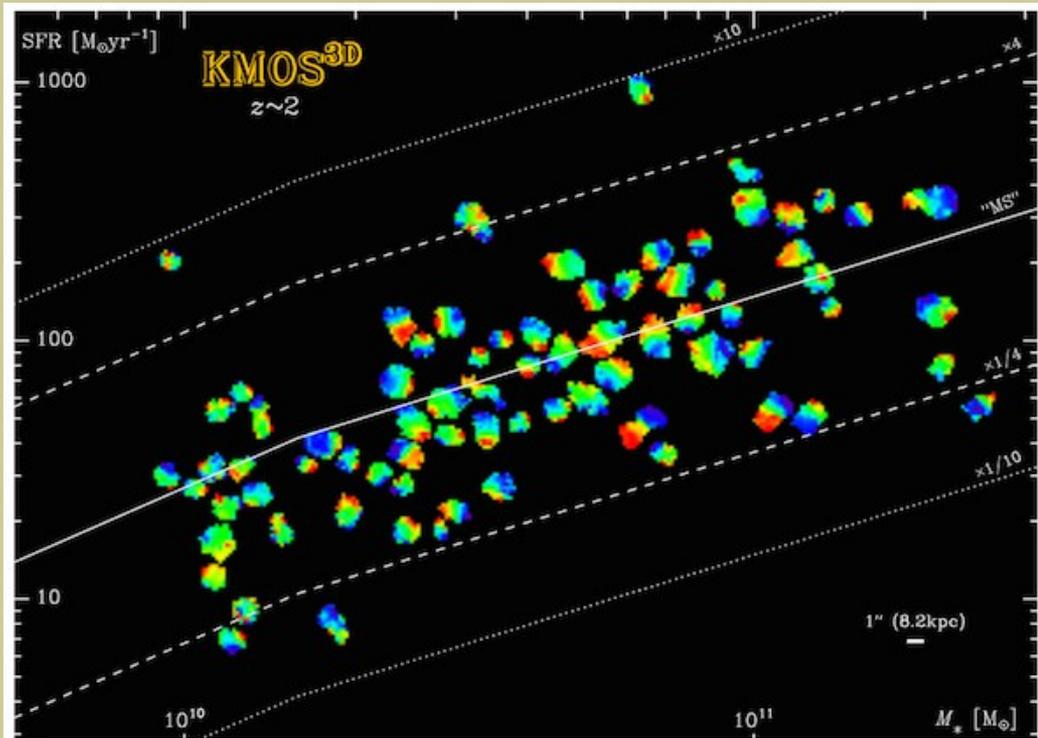
KMOS: многократное увеличение числа объектов

2 hours of VLT time



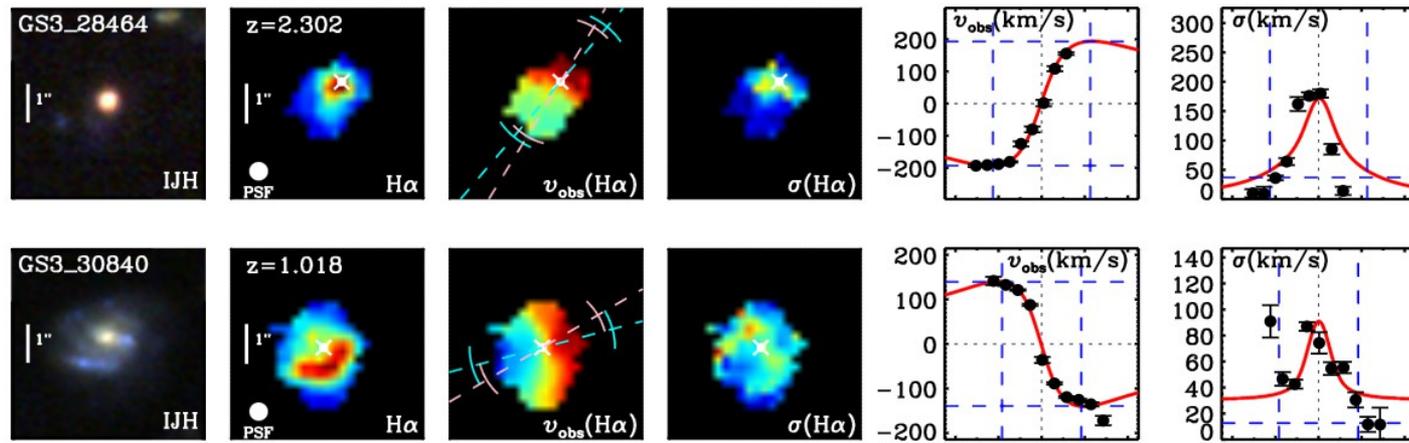
KMOS 3D

550 галактик на $0.6 < z < 2.7$

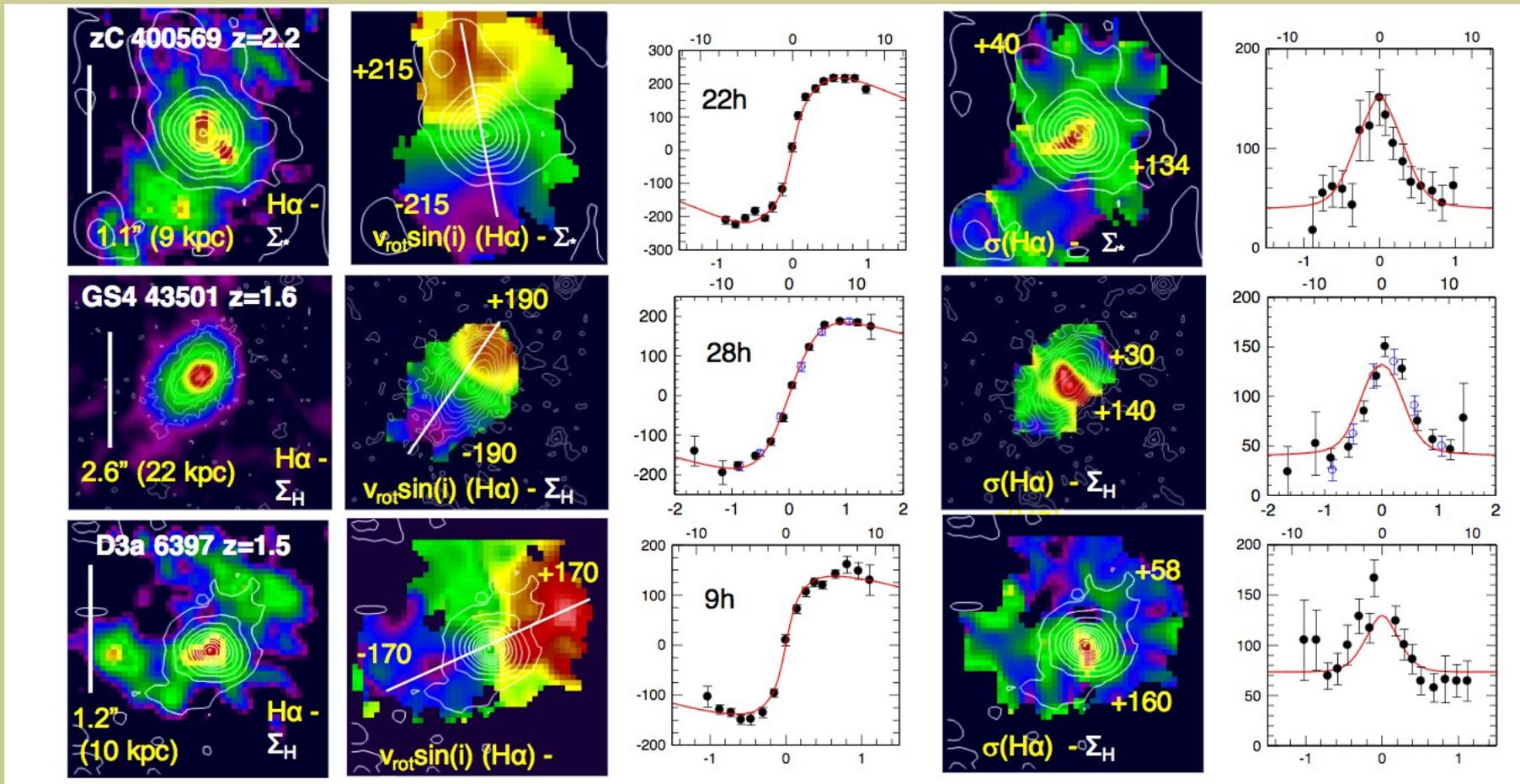


На $z=1-2$ большинство галактик “главной последовательности” - регулярно вращающиеся диски

(Wisnioski + 2015)

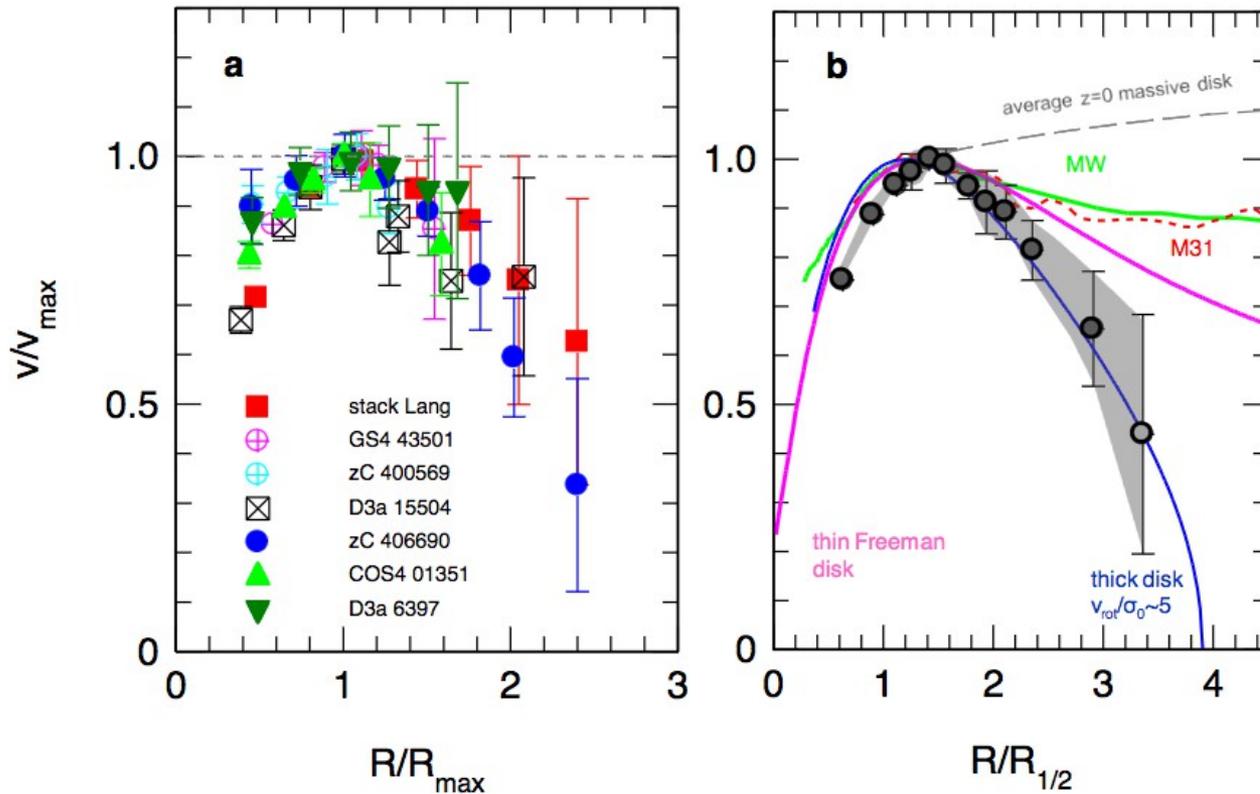


KMOS: в далеких галактиках меньше темной материи?



Genzel et al., 2017, Nature

KMOS: в далеких галактиках меньше темной материи?



Reinhard Genzel



Awards

- Otto Hahn Medal (1980)
- Balzan Prize (2003)
- Shaw Prize (2008)
- Crafoord Prize (2012)
- Tycho Brahe Prize (2012)
- Fellow of the Royal Society
- Harvey Prize (2014)
- Nobel Prize in Physics (2020)

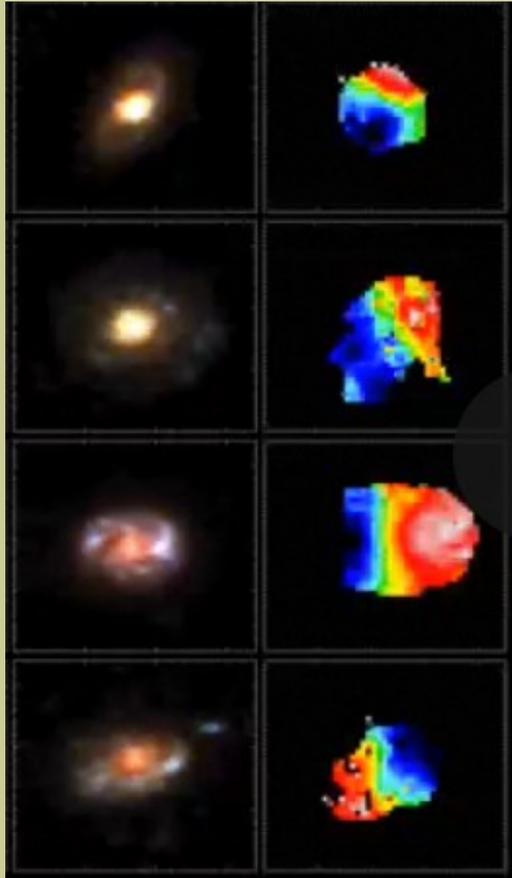
Genzel et al., 2017, Nature

K
R
O
S
S

KMOS Redshift One Survey (KROSS)

Home Team Data Publications Movies

<http://astro.dur.ac.uk/KROSS/>



Datacubes and Data Products

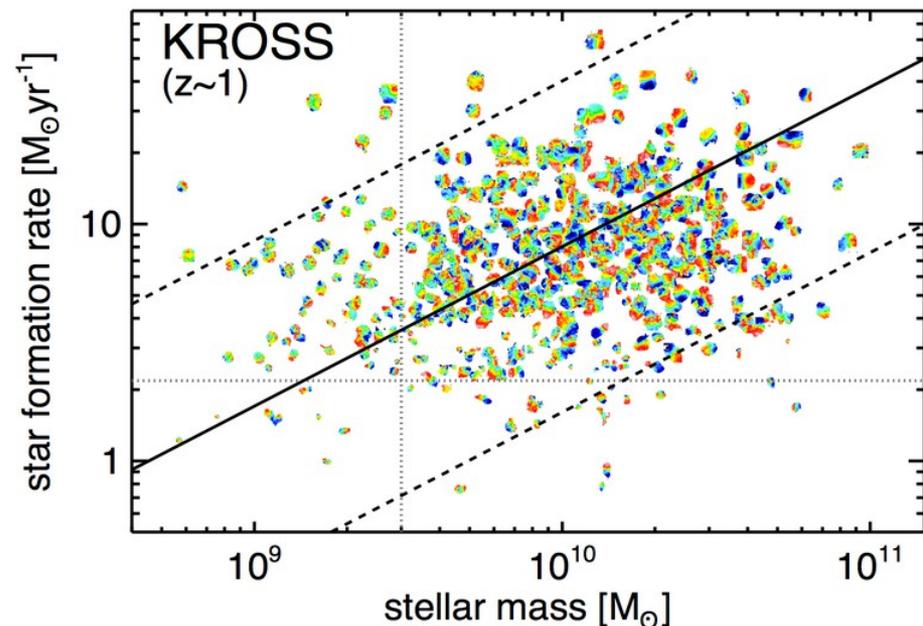
Datacubes and data products for the 586 H-alpha detected galaxies in the KROSS survey

- [Datacubes for all 586 galaxies \[1.2Gb\]](#) (posted: 24/04/2019)
- [H-alpha intensity maps \[2.7Mb\]](#)
- [H-alpha velocity maps \[1.0Mb\]](#)
- [H-alpha line-of-sight velocity dispersion \(sigma\) maps \[1.3Mb\]](#)

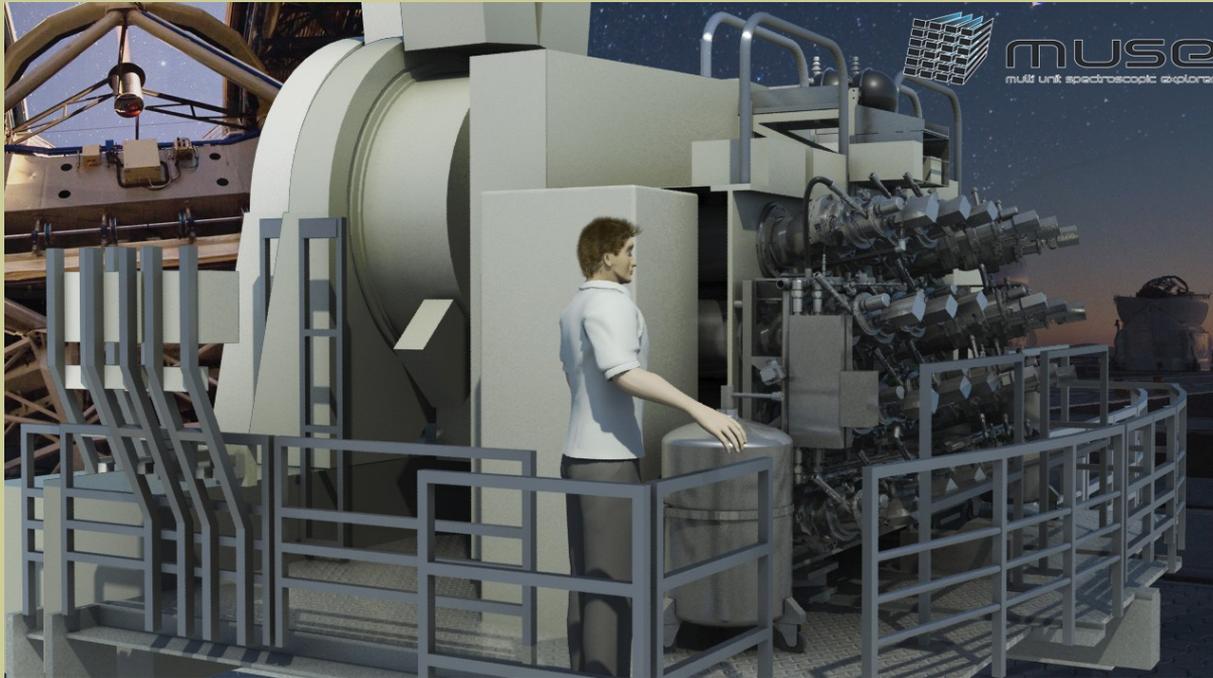
Catalogs (Version 2)

Johnson et al. 2018 ([arXiv:1707.02302](#)) combined with Harrison et al. 2017 ([arXiv:1701.05561](#))

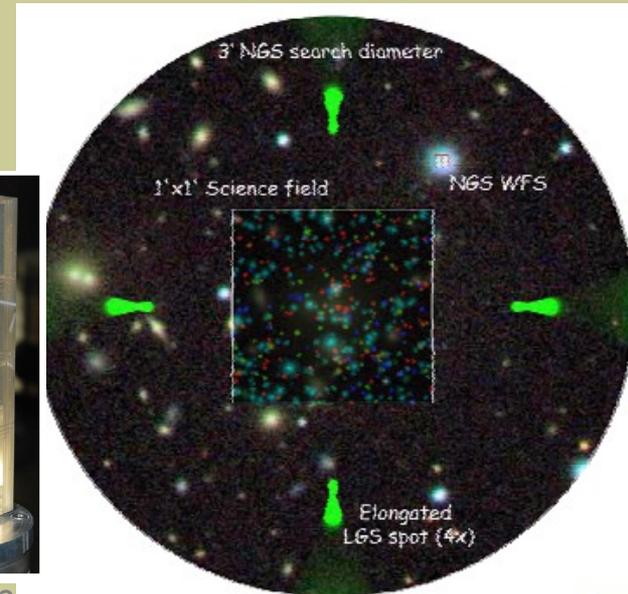
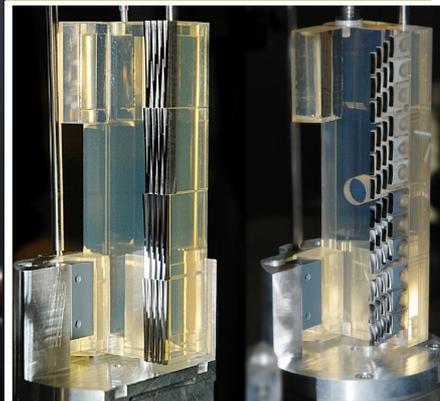
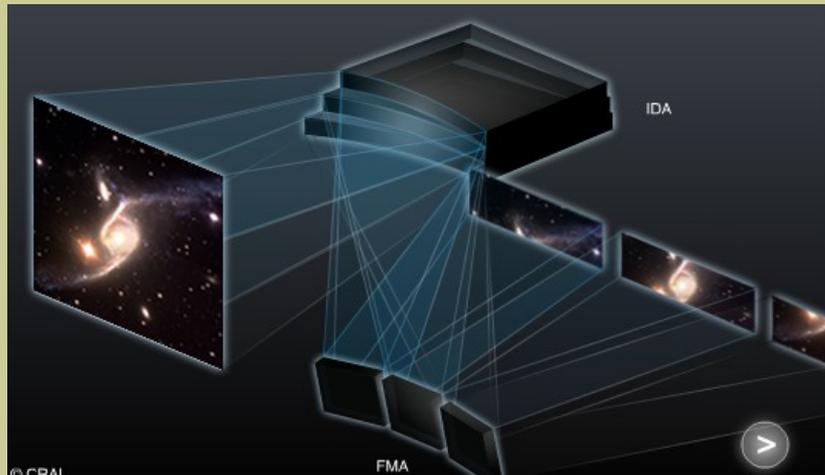
- [Version 2 \(fits table\)](#) (posted: 17/07/2017)



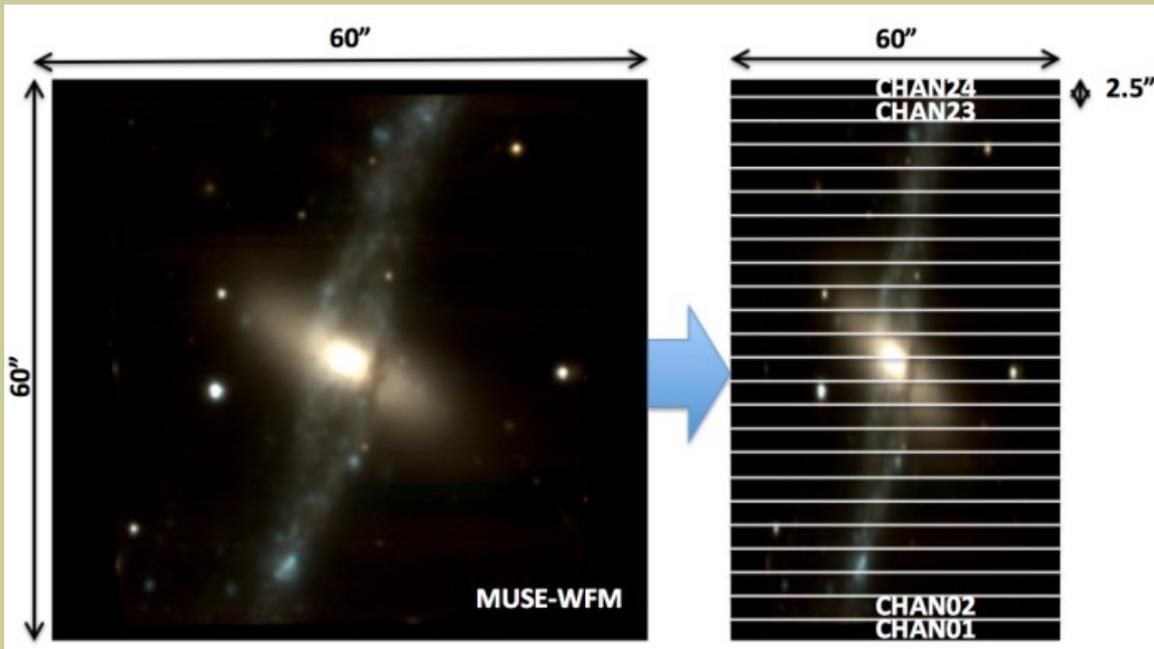
MUSE = Multi Unit Spectroscopic Explorer (VLT)



Observational Parameters	
Spectral range (simultaneous)	0.465-0.93 μm
Resolving power	2000@0.46 μm
	4000@0.93 μm
Wide Field Mode (WFM)	
Field of view	1x1 arcmin ²
Spatial sampling	0.2x0.2 arcsec ²
Spatial resolution (FWHM)	0.3-0.4 arcsec
Gain in ensquared energy within one pixel with respect to seeing	2
Condition of operation with AO	70%-ile
Sky coverage with AO	70% at Galactic Pole
Limiting magnitude in 80h	I _{AB} = 25.0 (R=3500)
	I _{AB} = 26.7 (R=180)



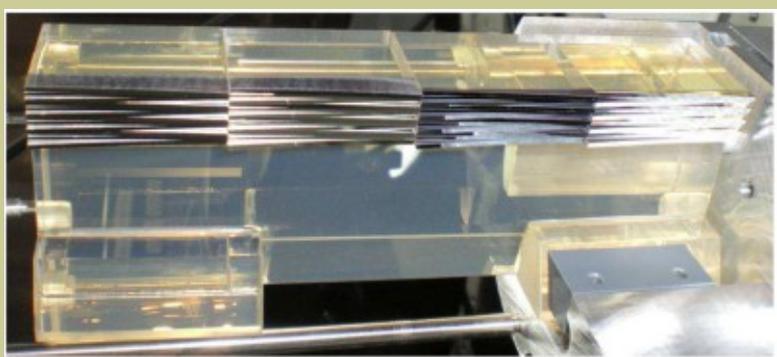
MUSE: slicer & spectrograph



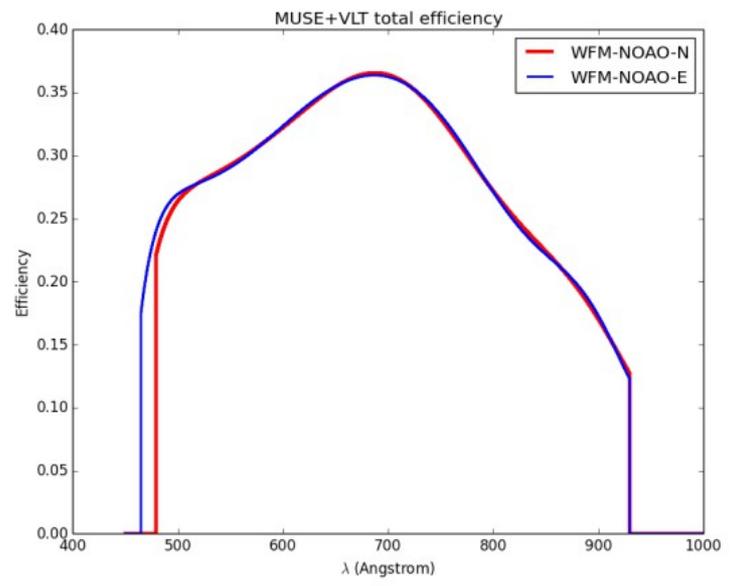
Почти нет подвижных элементов (только решетка)

Рекордная квантовая эффективность на VLT

48 щелей в одном “канале”

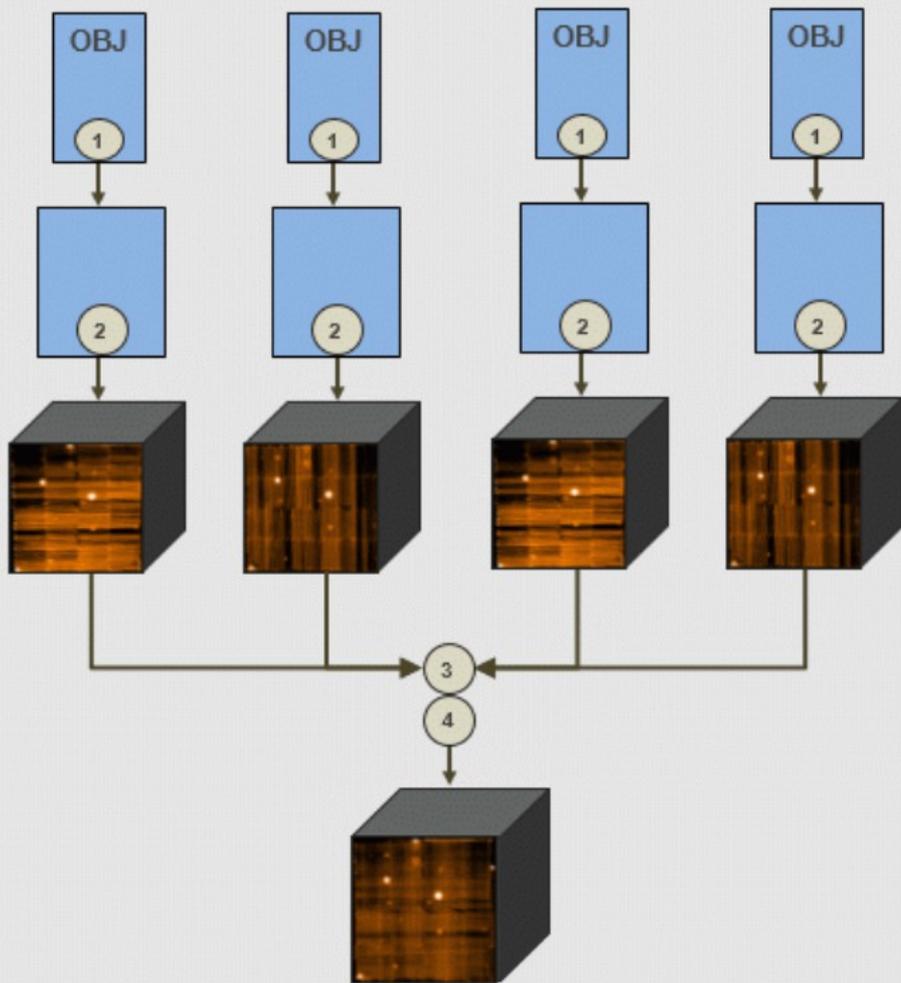


Roland Bacon & K



MUSE: работа с данными

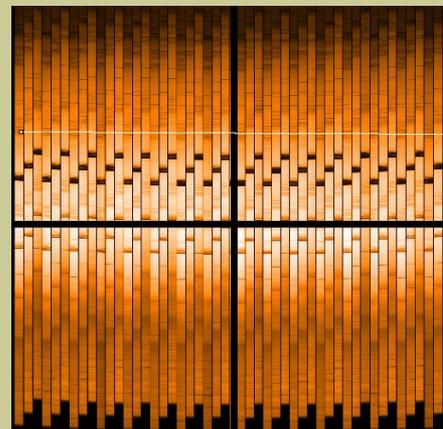
N=4 stack, no SKY



24 кадра с ПЗС 4x4
собираются в один куб
Сырые данные – 820 Мб
Итоговый размер:
315x315 x 3680 px - 2.6 Gb

Рабочая станция:
32 cores
256 GB RAM
Disks: 2x11 Tb

Вычитание неба – построение
модели по измеренной LSF

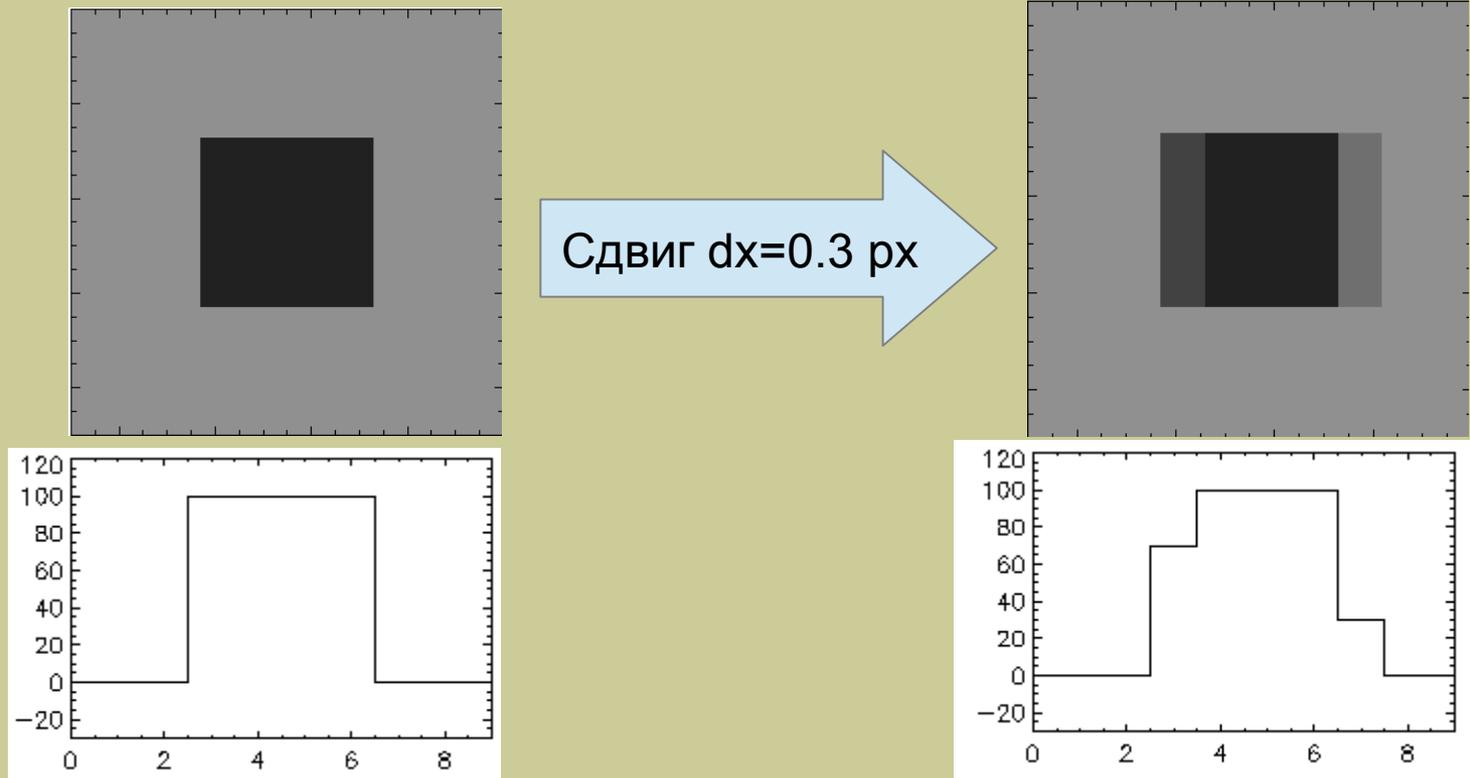


Проблема интерполяции

Лекция 4

“Многорежимный фокальный редуктор...”

Геометрические преобразования — портят исходное изображение, так как выполняется интерполяция на фиксированную координатную сетку

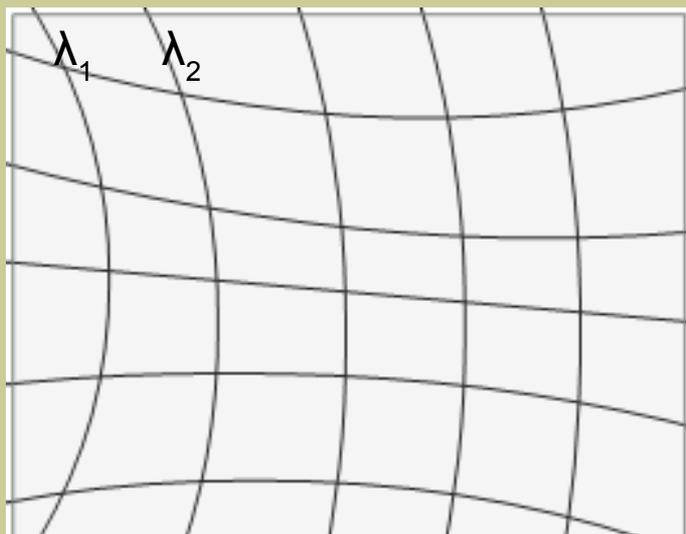


Искусственное разбиение на более мелкие пиксели — лишь частично решает проблему, сильно загружая вычислительные ресурсы

Не объект к калибровкам, а калибровки к объекту!

Обработка современных IFU (MUSE/VLT и т. д.) - идея сохранения первоначальной дискретизации

Т.е. вместо 2D FITS-изображения (запись I в каждом пикселе) — переход к таблицам, где кроме I, в каждом пикселе еще записаны преобразованные координаты (x', y')

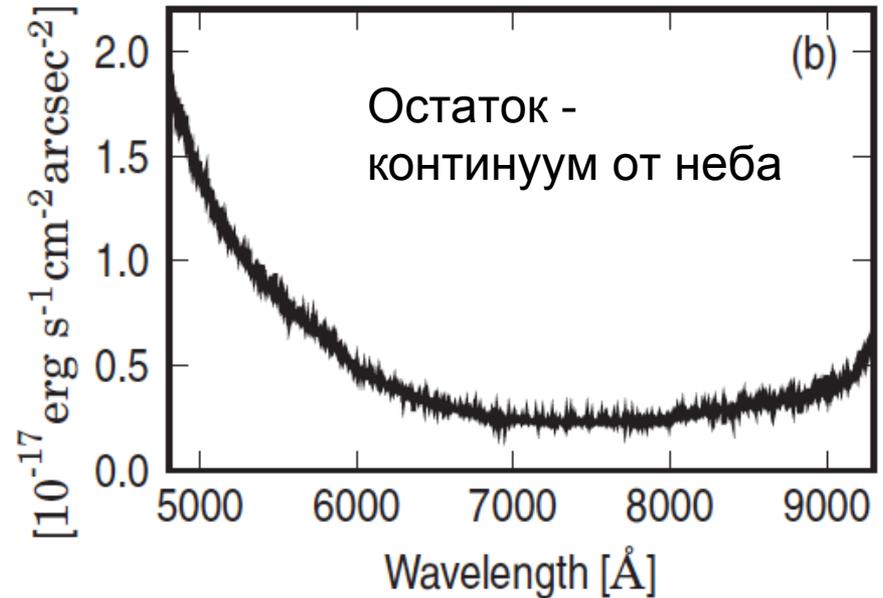
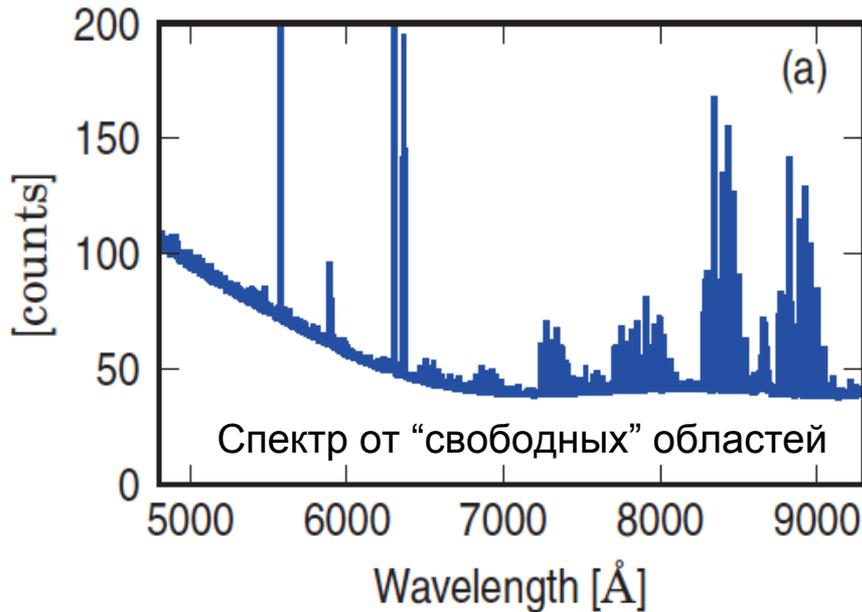


В итоге, лишь одно преобразование — экстракция линейризованного спектра, после вычитания неба и исправления за кривые пропускания!

Но требуется специализированный софт, в том числе и для визуализации на разных этапах обработки

(Лекция 4 “Многорезимный фокальный редуктор...”)

Вычитание фона неба: моделирование спектра



- знаем LSF, построена адекватная численная модель спектрографа
- подгонка потоков в группах линий:

For the determination of the emission line fluxes, the known atmospheric emission lines (van der Loo & Groenenboom 2007; Osterbrock et al. 1996) are grouped by the originating molecules (OH, [O I], Na I, O₂) and the upper transitional level into twelve groups. Within each group, the emission flux ratio is fixed. The line fluxes for each group are then taken into a fit routine, minimizing the error of the differences between neighboring bins:

$$s^2(p) = \sum_{\lambda} \left(\frac{\Delta I(\lambda, p)}{\Delta \lambda} - \frac{\Delta I_0(\lambda)}{\Delta \lambda} \right)^2.$$

Вычитание фона неба: моделирование спектра

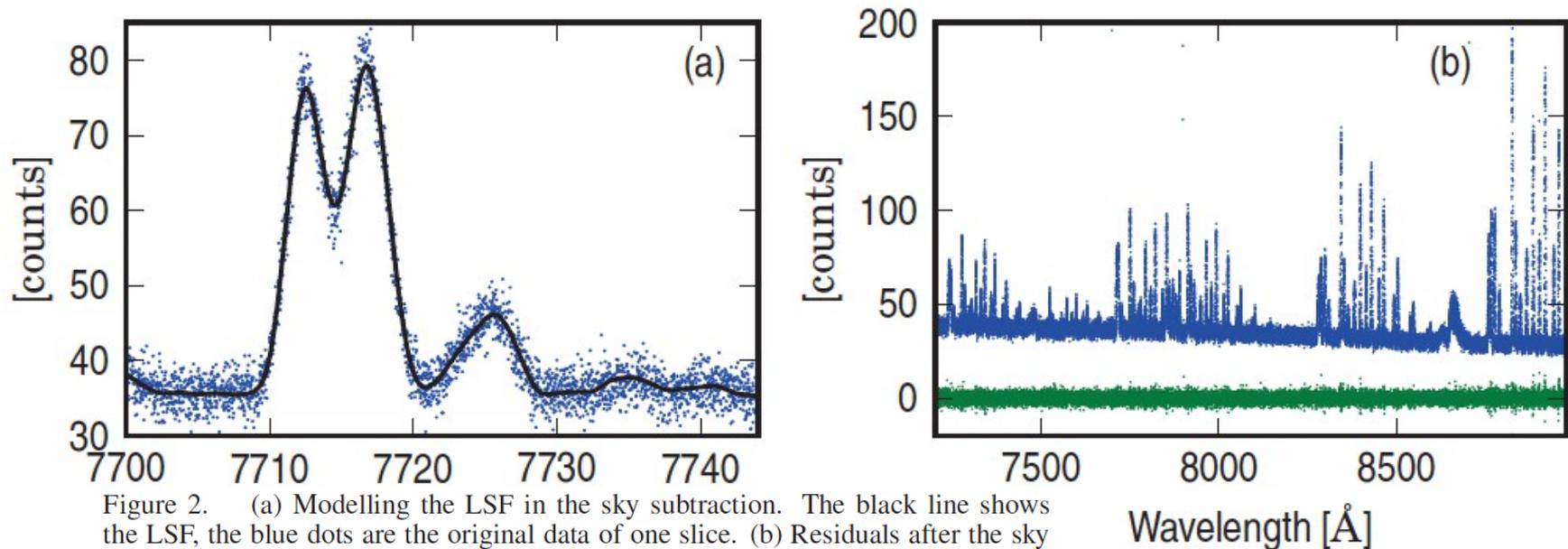
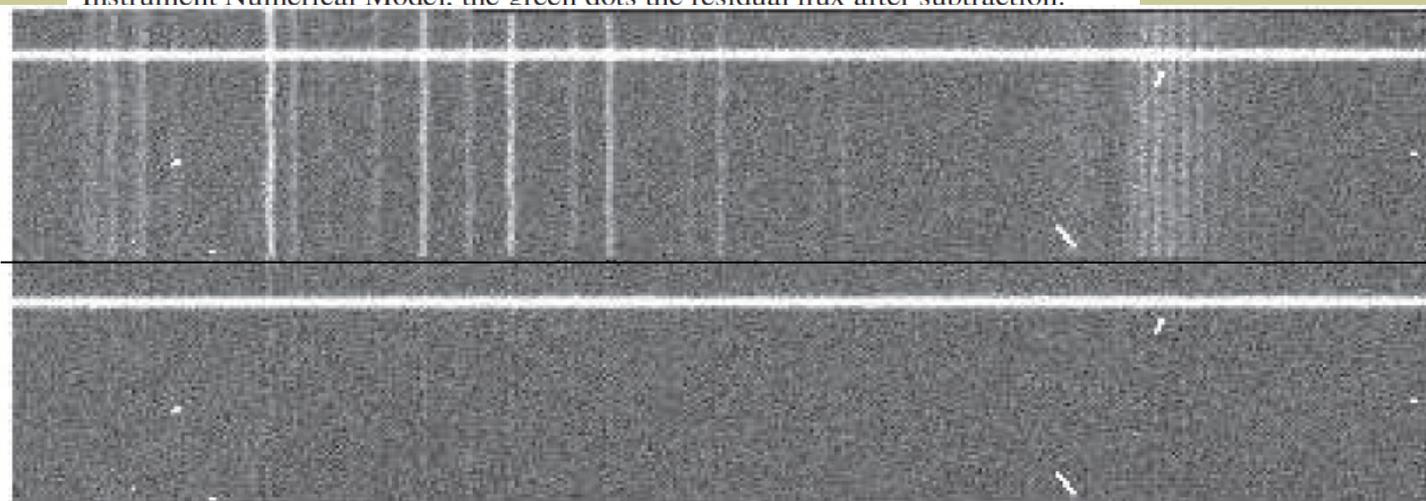


Figure 2. (a) Modelling the LSF in the sky subtraction. The black line shows the LSF, the blue dots are the original data of one slice. (b) Residuals after the sky subtraction for one slice. The blue dots show the original simulated data from the Instrument Numerical Model, the green dots the residual flux after subtraction.



MUSE views the Orion Nebula



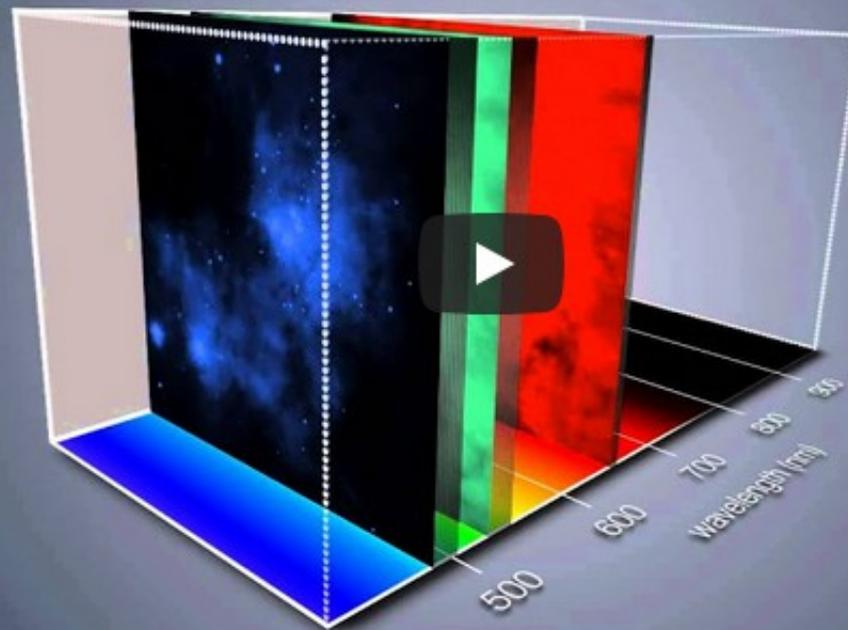
MUSE views the Orion Nebula



Watch later



Share



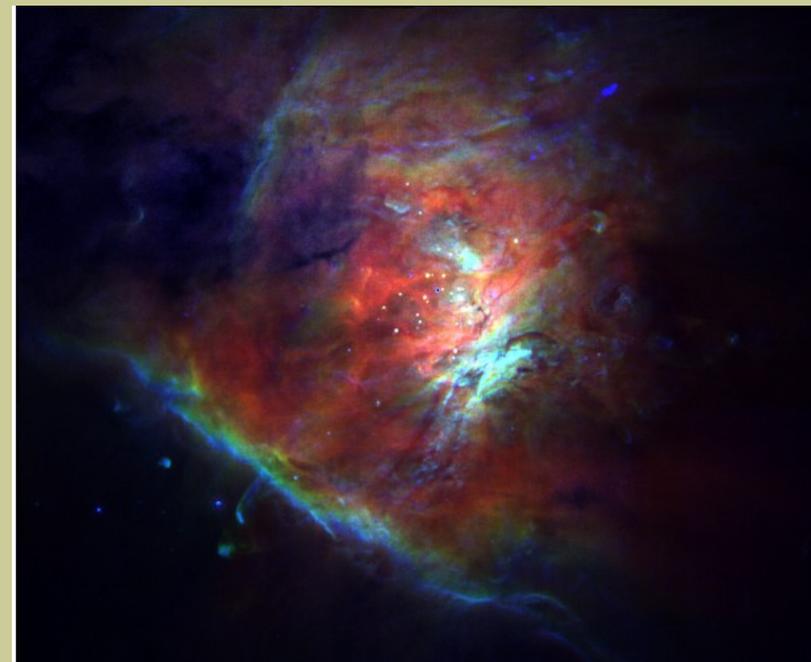
Watch on YouTube

MUSE: Туманность Ориона

6 x 5 arcmin
Weilbacher et al 2015

<http://muse-vlt.eu/science/m42/>

red: [S II] 6731
blue: Hbeta,
green: [N II] 6584



red: [O III] 5007
green: [O II] 7320
blue: [O I] 6300

R. Bacon et al.

TIGER the first map: 1988

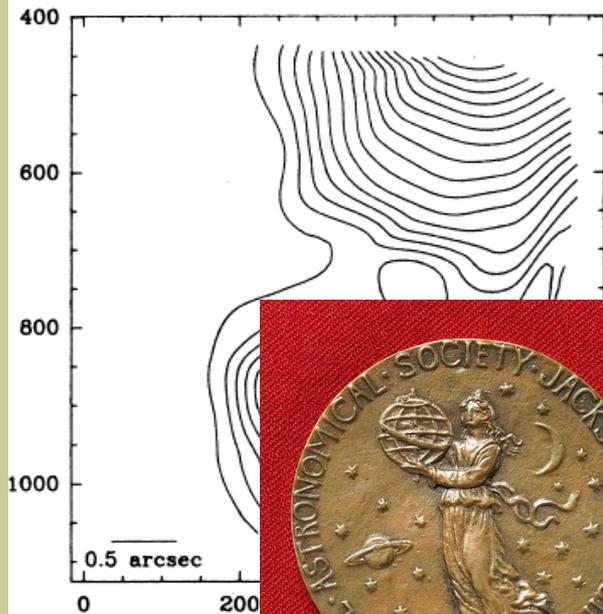


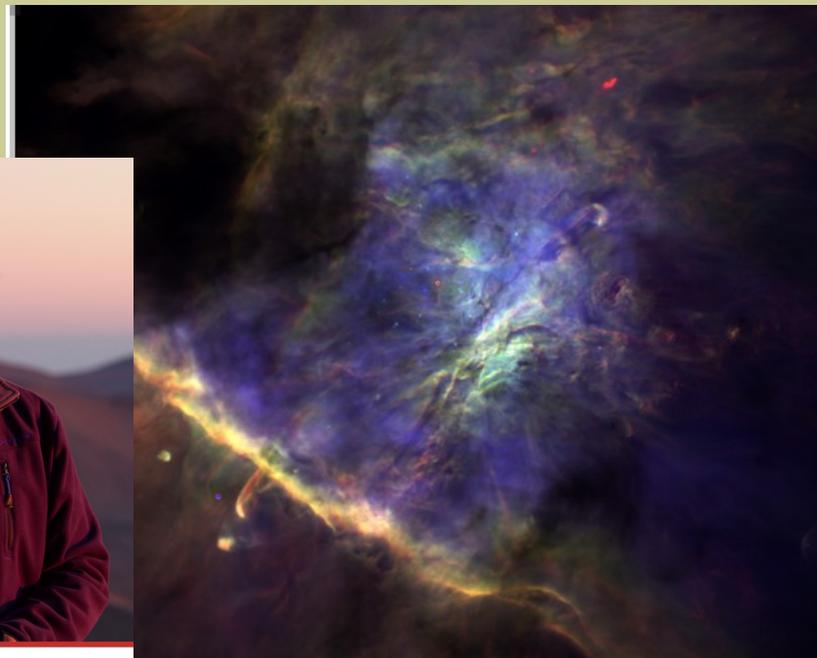
Figure 7 : Monoc...
of th...



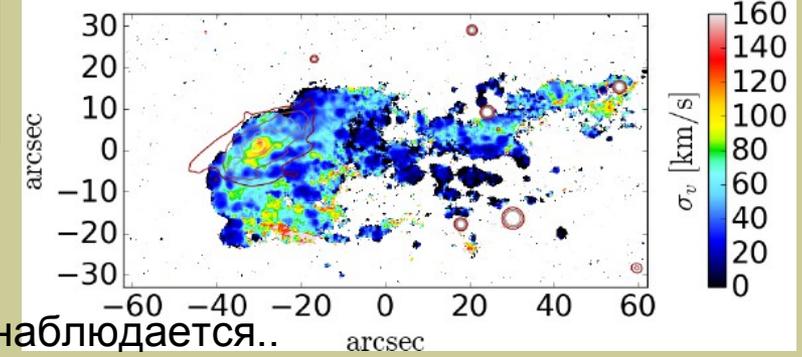
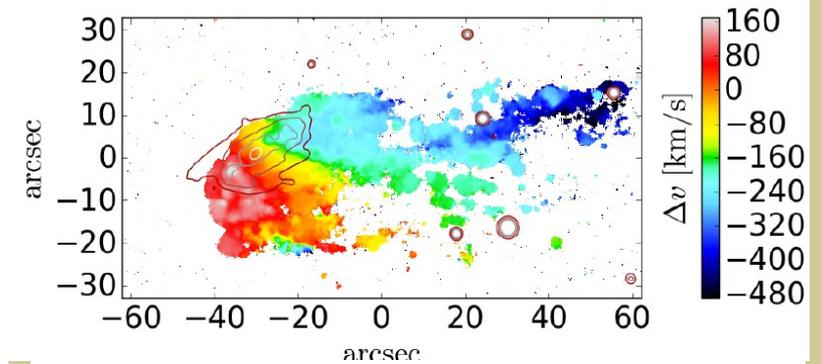
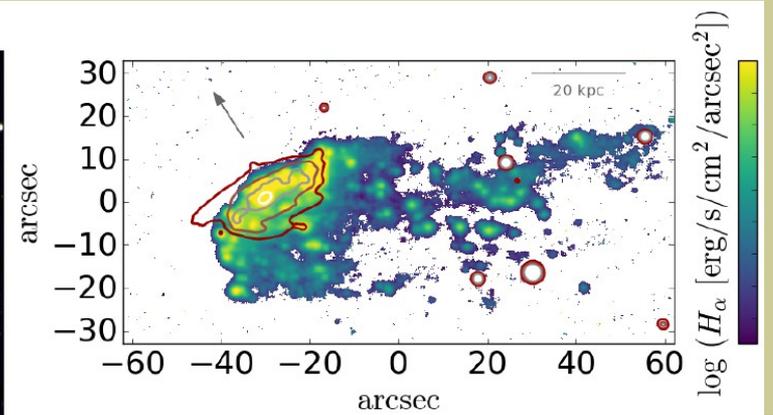
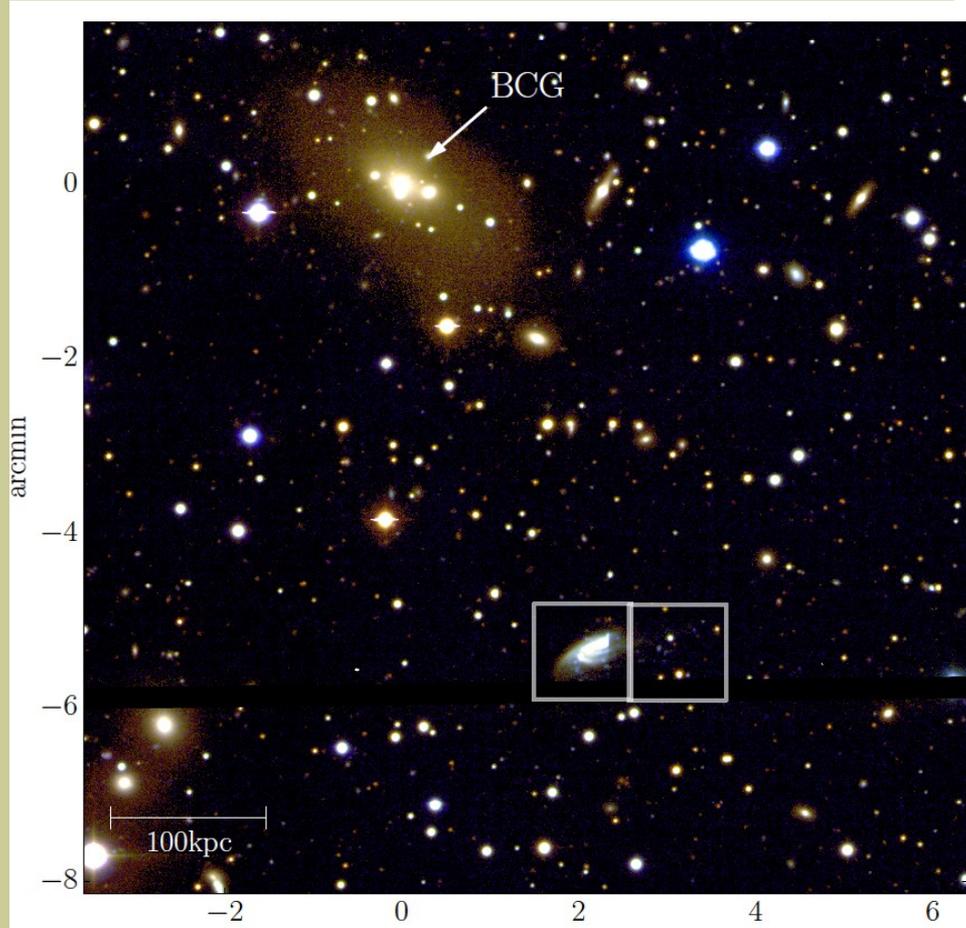
2020 Jackson-Gwilt Medal



Roland Bacon is awarded the Jackson-Gwilt 2020 Medal



“Медузы” в скоплениях галактик (ram pressure stripping)



Roggianti+17:
 Расчет удерживающих сил и лобового давления,
 выметание возможно, только для $r > 20$ кпк, что и наблюдается..
 Примерно 15% газа покинуло галактику

MUSE: глубокий обзор

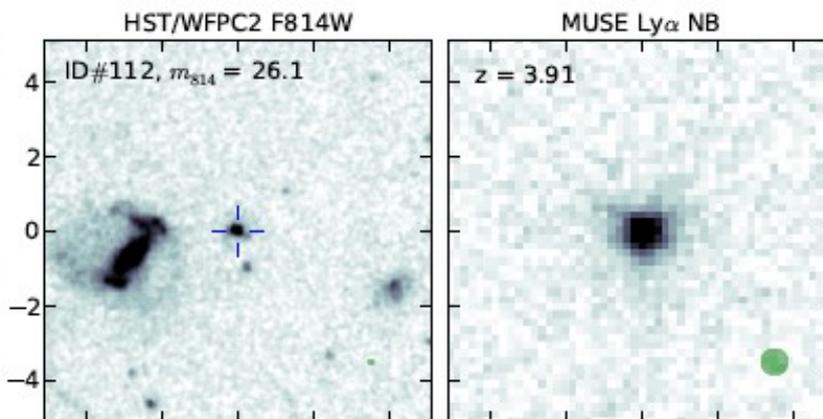
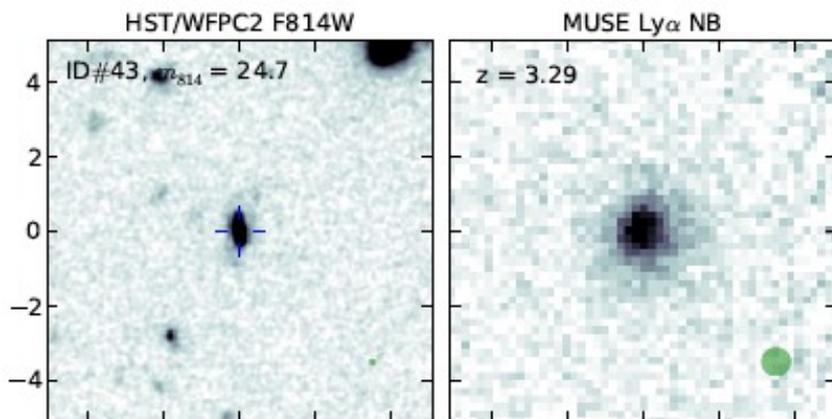
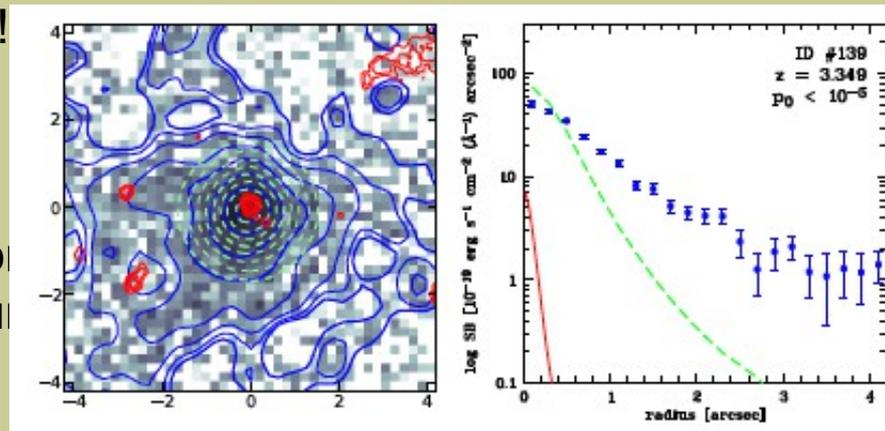
1'x1' поля внутри UHDFS

27 часов экспозиций: 54x30 мин, seeing 0.66"

- Разные ориентации поля, тщательное построение PSF по звездам

Неожиданно: $\text{Ly}\alpha$ – гало большие и круглые!

Происхождение гало:
Рассеяние фотонов от галактики
на частично нейтральной межгалактической
среде. Ранее подозревалось по наблюдениям
абсорбциям от квазаров, теперь видно и в
ЭМИССИИ.

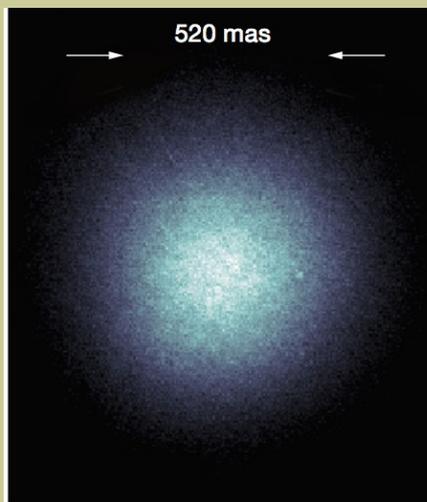
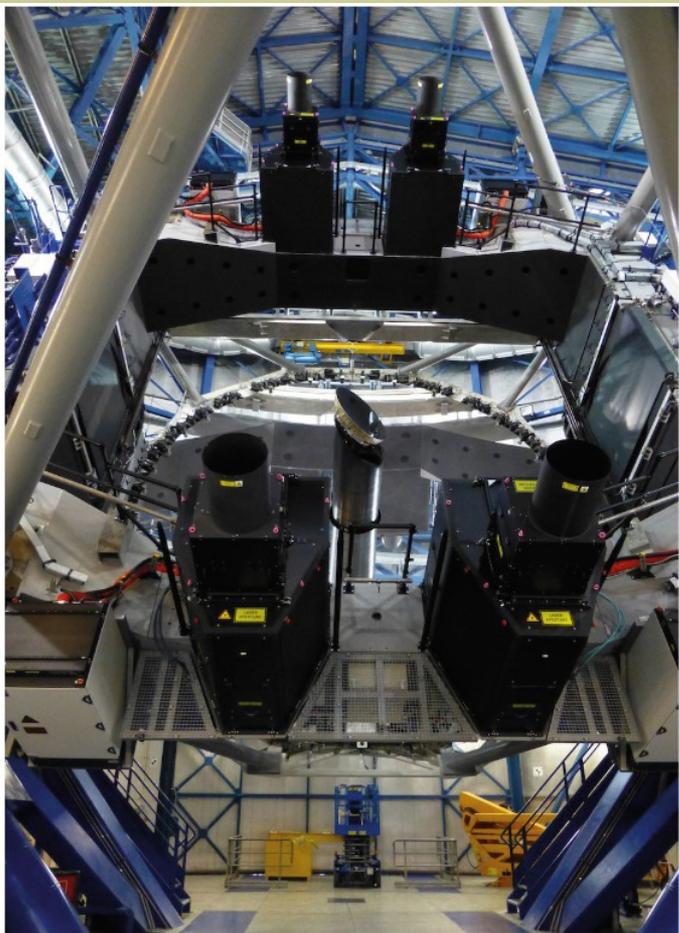


MUSE: адаптивная оптика в "оптике"!

4 лазерных звезды в поле

Narrow Field Mode (Not offered yet. To be offered with GALACSI)

Field of view	7.42" x 7.43"
Spatial Sampling	0.025" / pixel
Spatial resolution(FWHM)	0.03" -- 0.05"



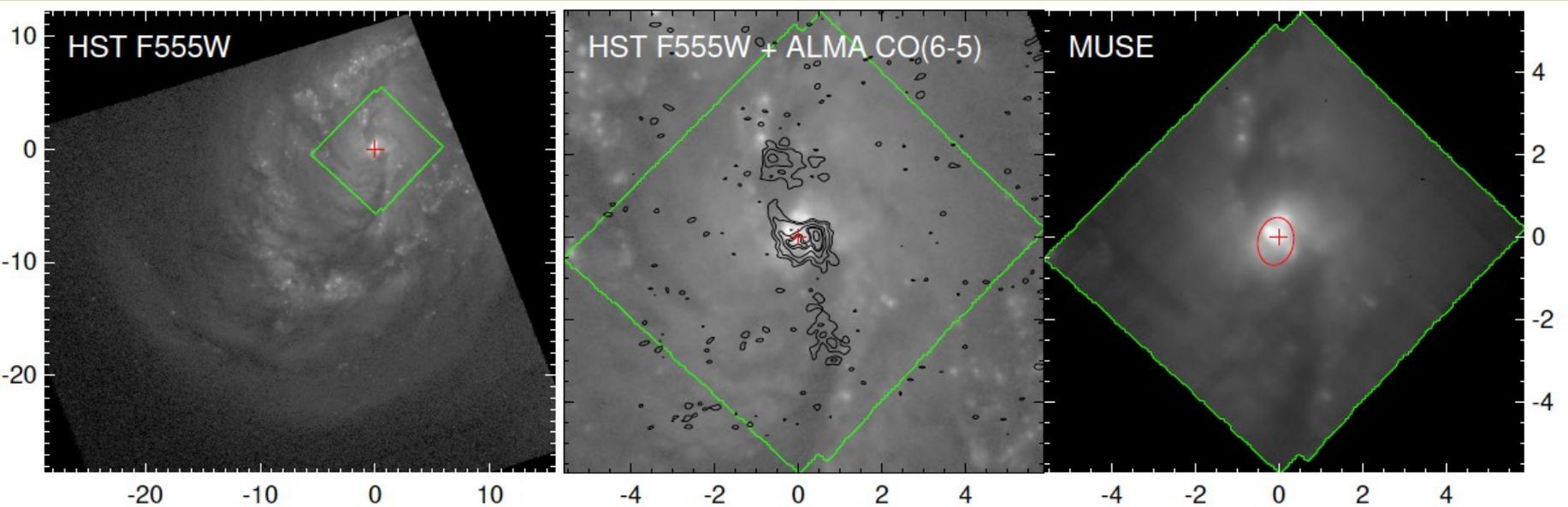
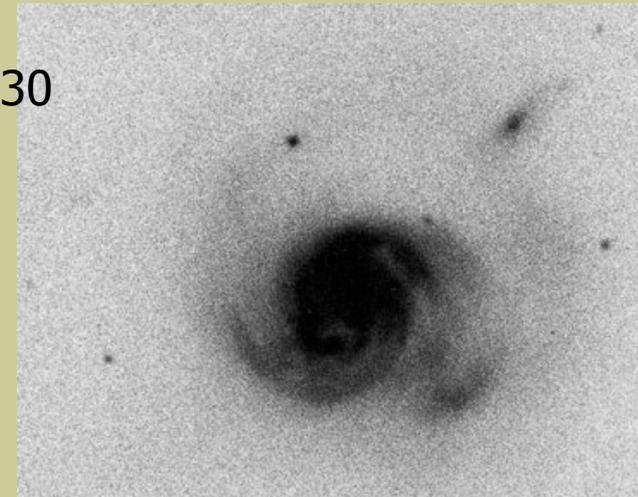
MUSE: адаптивная оптика в "оптике"

arXiv:1812.00809

MUSE-AO view of the starburst-AGN connection: NGC 7130

J. H. Knapen^{1,2,3}, S. Comerón⁴, and M. K. Seidel⁵

MUSE Narrow-field mode (NFM) + AO GALASCI
FOV 7.6" 0.025"/px
Seeing 0.6-1" => AO made: 0.15-0.5"



Следующий проект: BlueMUSE

Jeanneau et al
ArXiv:2101.07605
Proc SPIE 11447,

BlueMUSE to be included in the VLT2030 instrumentation plan,
with a Phase A to be started by 2022

Table 1. BlueMUSE Top Level Requirements summary table, ordered in decreasing priority.

Wavelength range	350 - 580 nm
Spectral resolution	$R > 2600$, average ~ 3500 over the full wavelength range
Transmission (incl. telescope and atmosphere)	$> 17\%$ and average $> 29\%$ over the wavelength range
Field-of-view	$> 1 \text{ arcmin}^2$ (goal: $1.4 \times 1.4 \text{ arcmin}^2$)
Operational efficiency	85% open shutter time
Image quality	0.34" at 350 nm, 0.31" at 580 nm
Stability	0.1 pixel (TBC) within a night (without night calibration)
Spatial sampling	$0.2'' < \text{spaxel} < 0.3''$
Spectral sampling	≈ 2 spectral pixel

Следующий проект: BlueMUSE

Jeanneau et al
ArXiv:2101.07605
Proc SPIE 11447,

Массивные звезды в нашей и других галактиках (увеличение >100x)

Морфология и химостав комет

Газовые туманности, обилие элементов

Галактики со вспышкой 3O

LSB и Ultra Diffuse галактики: химсостав, кинематика, история 3O

3O и обдирание газа в плотном окружении

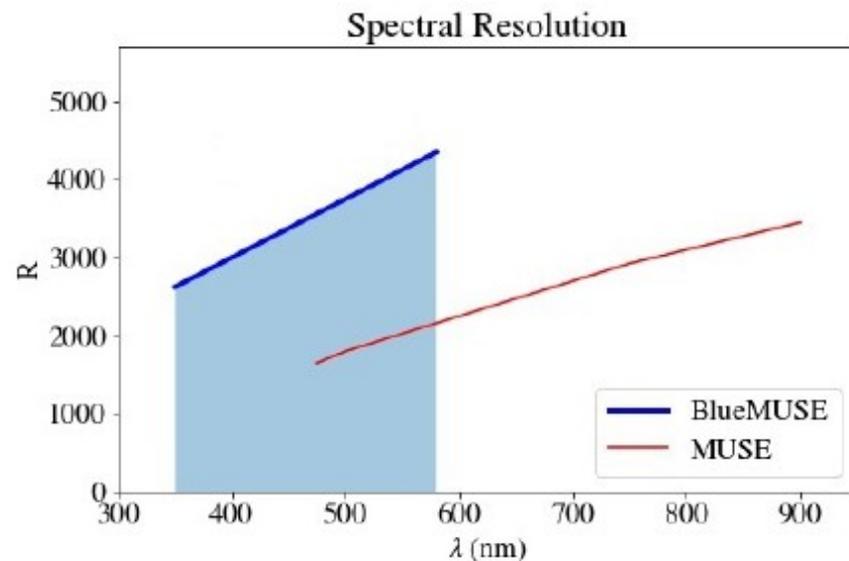
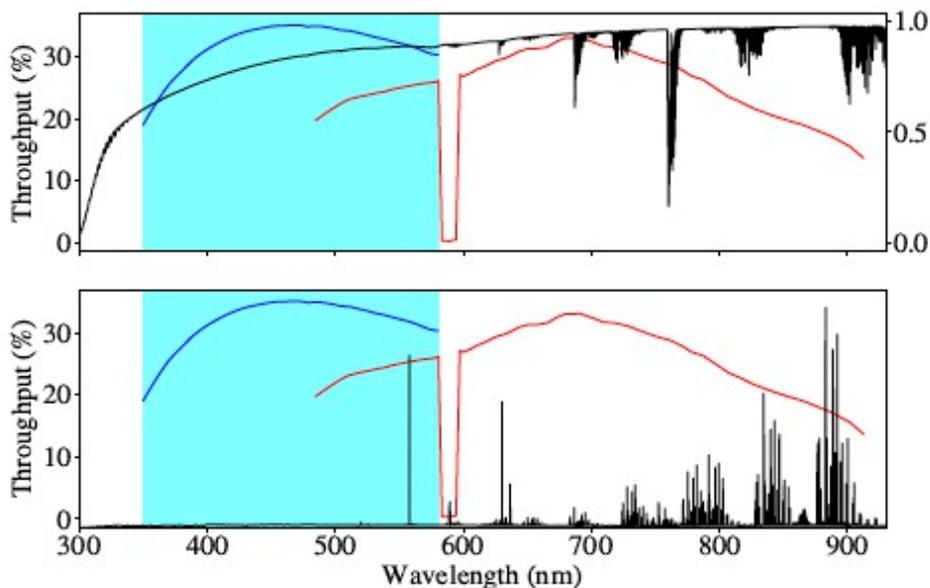
Потеря галактиками лайман-квантов

Течение газа между галактиками

Лайман-альфа гало на масштабах внутри килопарсека

Лайман-альфа туманности в скоплениях на $1.9 < z < 3$, поиск холодной аккреции

Blue vs "red" MUSE



Предлагается сохранить ту же архитектуру (резатель, 24 камеры, детекторы 4Kx4K)

Но тогда с большим полем надо БОльшую светосилу камер: F/1.3 вместо F/1.9

А здесь уже совсем трудно избежать виньетирования, добиться высокого пропускания, жесткие требования к дизайну



24 "кривых детектора"
А остаточную кривизну поля астигматизм исправляет линза поля, являющаяся стеклом криостата ПЗС

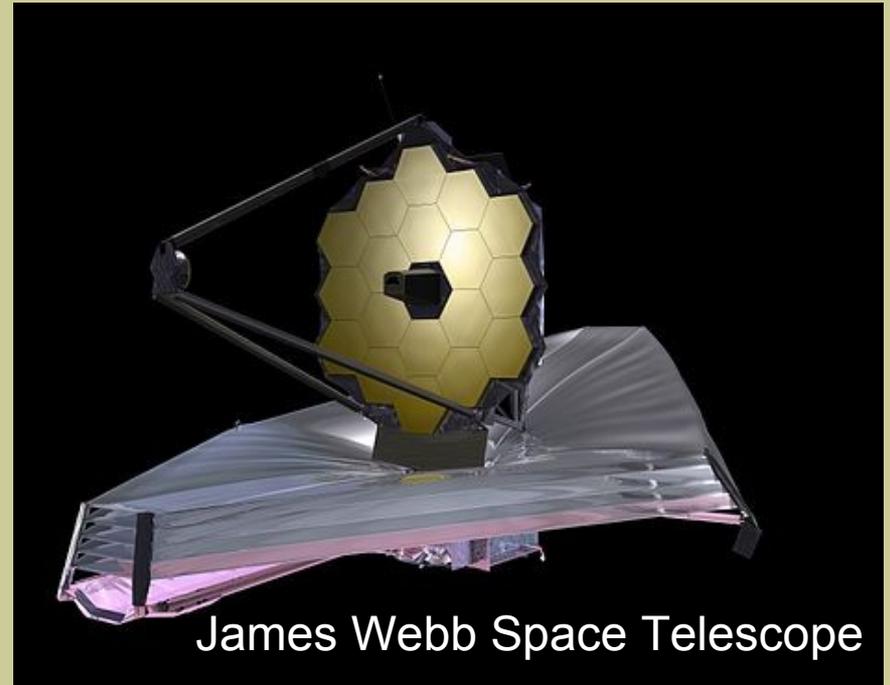
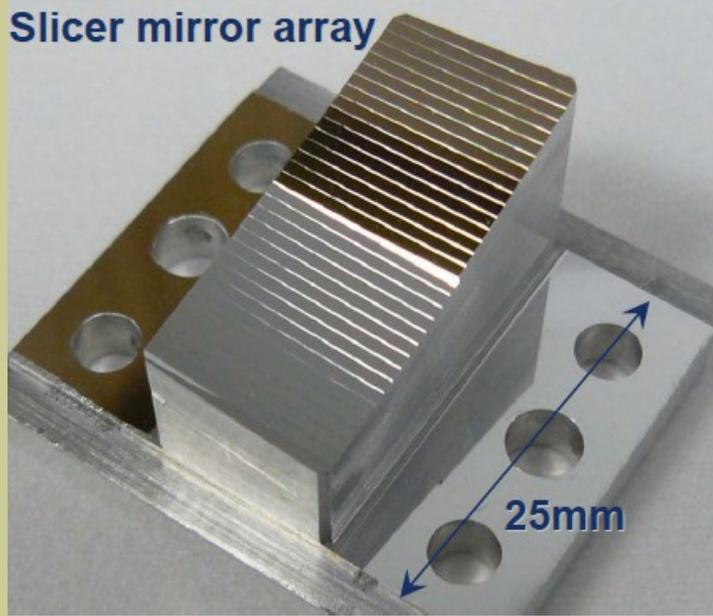
Near-Infrared Spectrometer (NIRSpec):

ВЫХОД В КОСМОС В 2021!

Performance wavelength range	0.7 – 5.0 μm (functional range 0.6 – 5.0 μm)
Operating temperature range	30 – 44K (but with full performance at 293K)
Throughput	>50% (8 reflections)

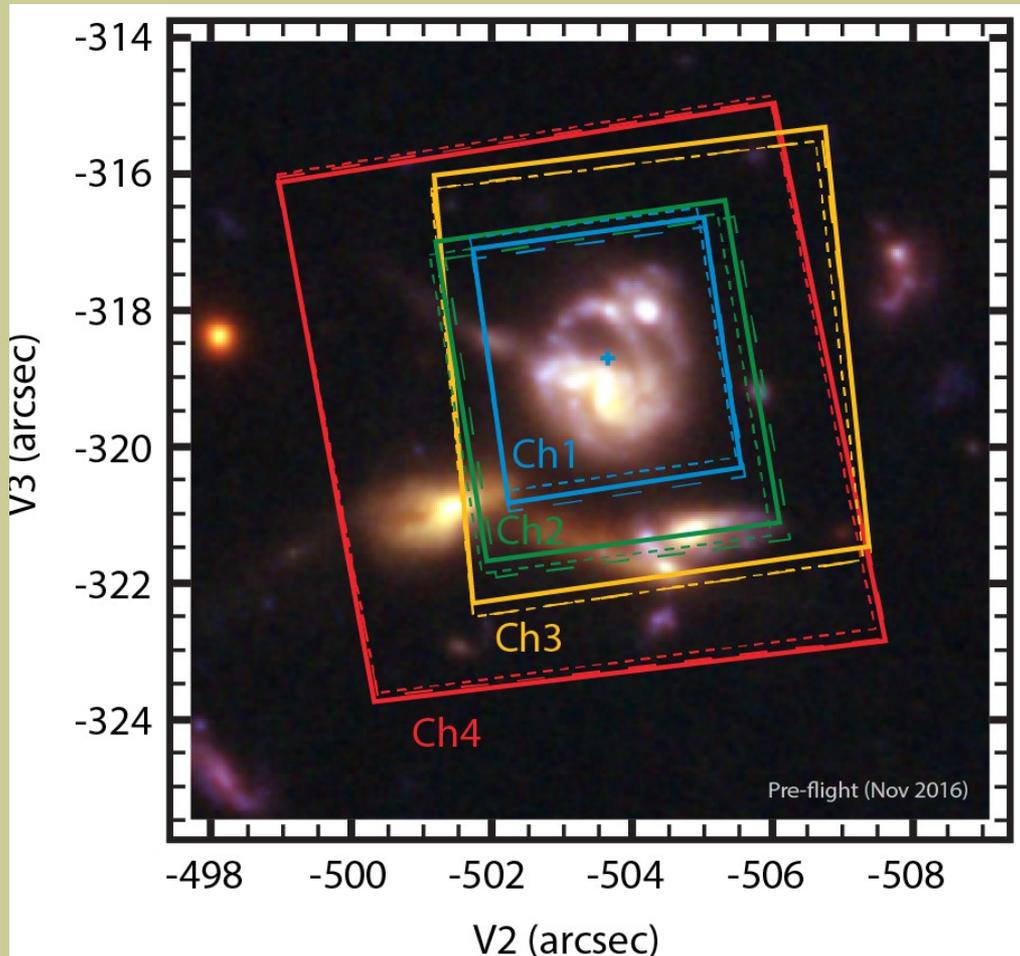


IFU – один из режимов наблюдений
3"x3" с разбиением 0.1"



Mid-Infrared Instrument (MIRI)

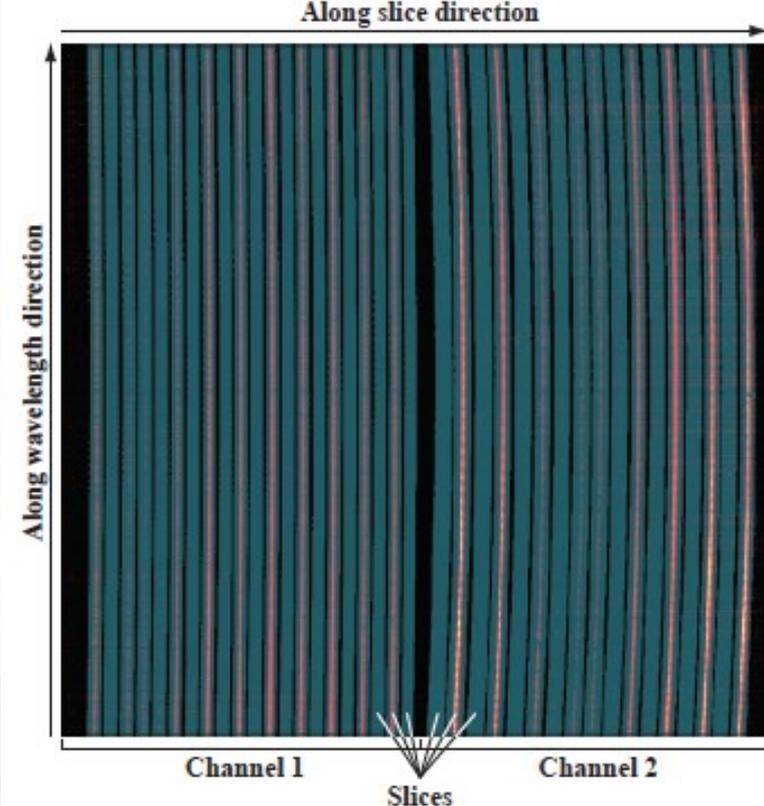
4 IFU – отдельно для разных диапазонов в области 4.9- 28.8 μm



FOV name λ -range (μm)	FOV (arcsec)
Channel 1 4.89–7.66	3.3×3.7
Channel 2 7.49–11.71	4.2×4.8
Channel 3 11.53–18.05	5.6×6.2
Channel 4 17.66–28.45	7.2×7.9

MIRI pipe-line

Glauer et al 2010



Plot1: Cube Image @ selected wavelength

Coordinates of cube pixels

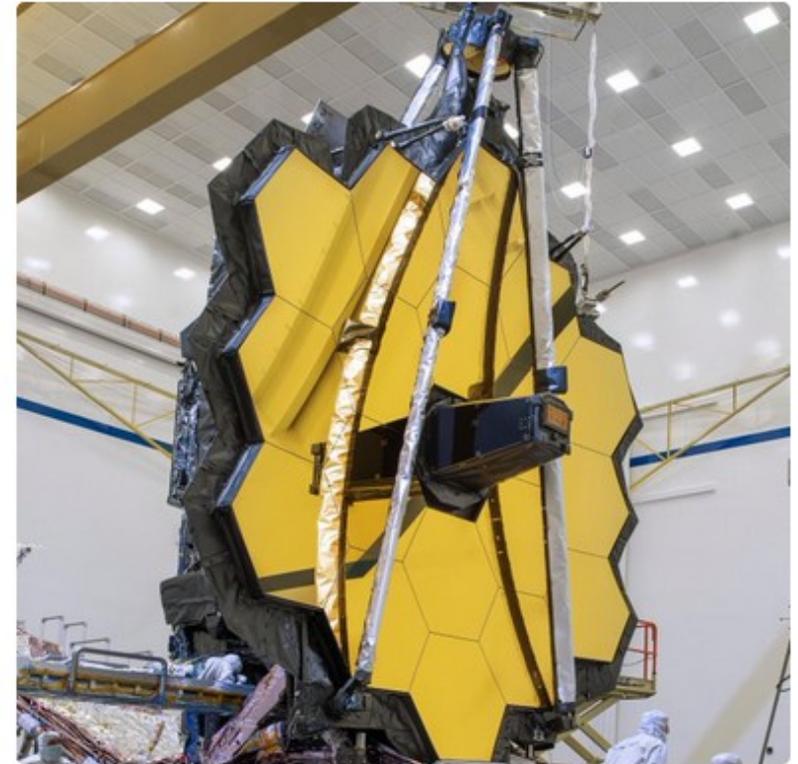
Controls to change wavelength image displayed

General statistics on cube image

Plot2: Extracted spectrum

- functionality
- General statistics on cube image
- Plot2: Extracted spectrum

В ожидании 18 декабря (?)



Oct 15, 2021



Oct 12, 2021

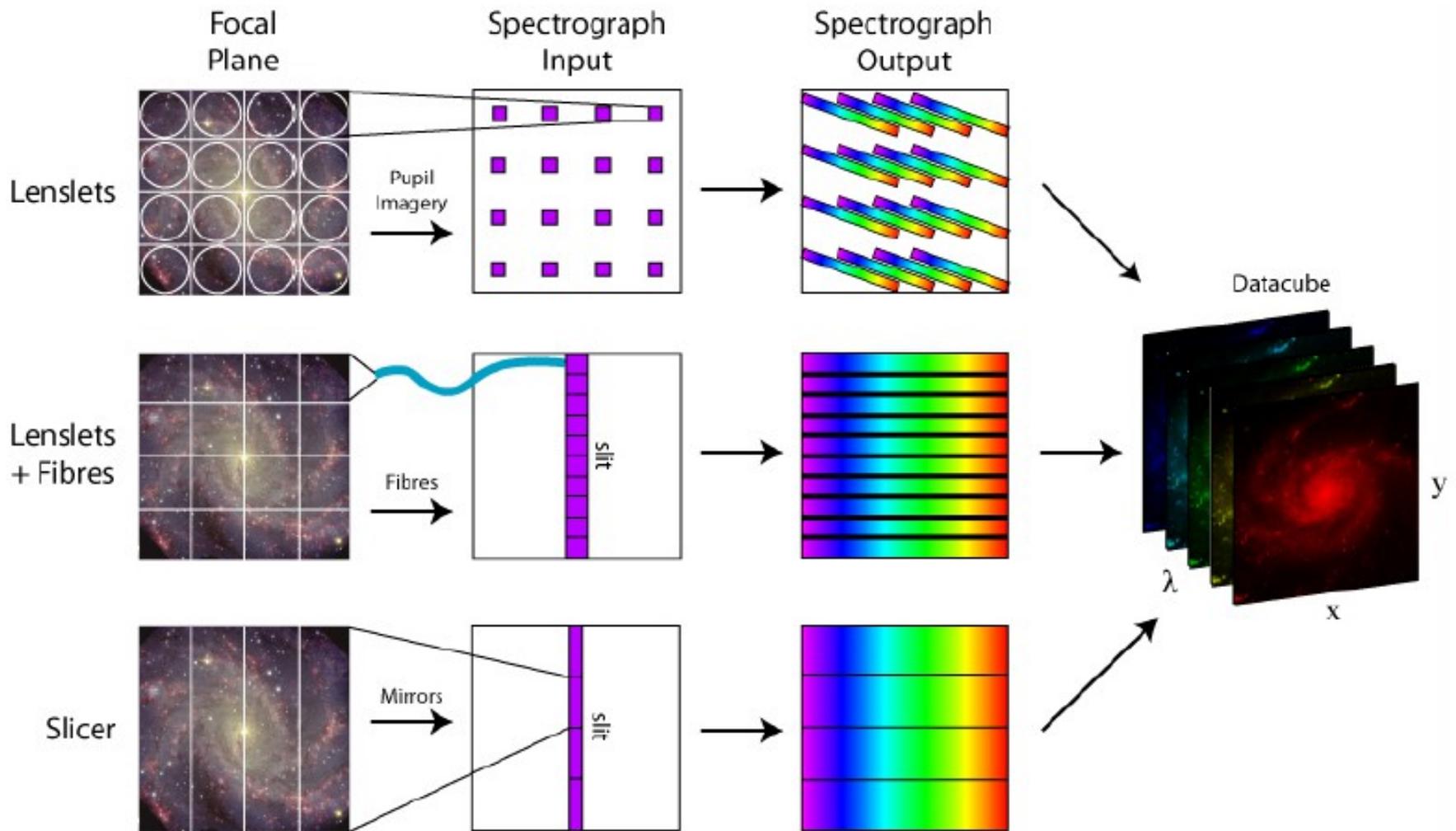
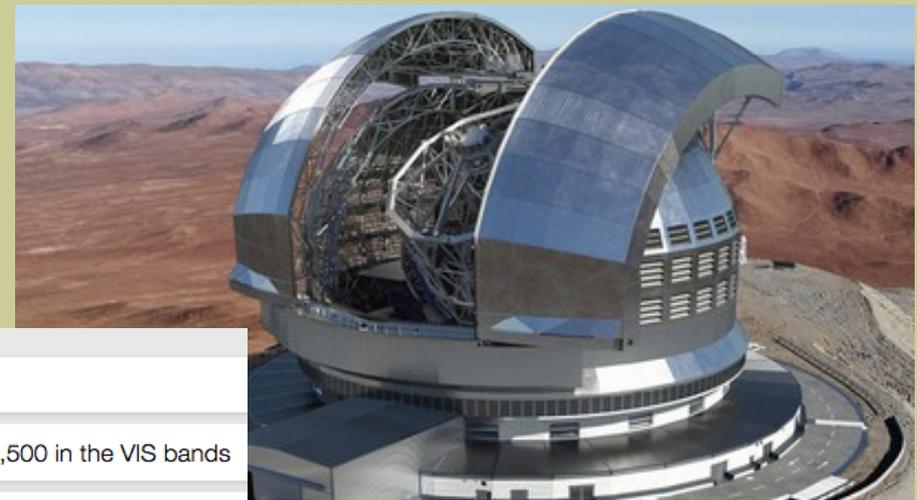


Figure 1.1: Different types of IFU: Lenslet, Fibres and slicer. Credit: M. Westmoquette, adapted from [19].

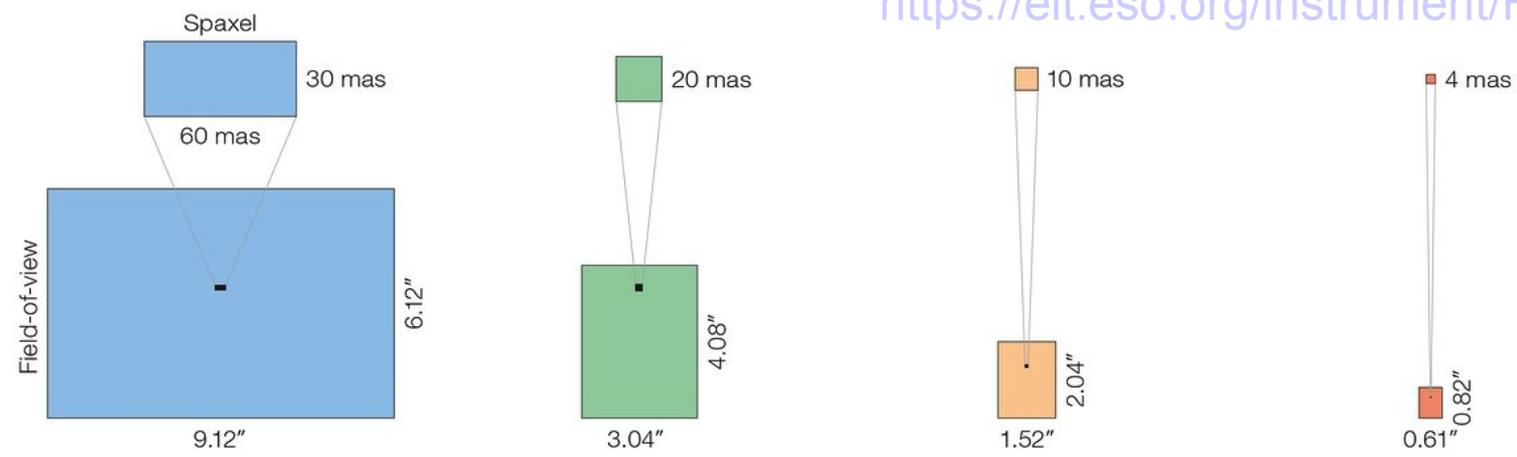
ELT 39m: HARMONI

High Angular Resolution Monolithic Optical and Near-infrared Integral field spectrograph (2027+?)



Wavelength	0.47—2.45 μm
Spectral resolution	$\sim 3,500$, $7,500$, and $18,000$ in the NIR and $\sim 3,500$ in the VIS bands
Simultaneous spectral range	at least one band at a time R $\sim 7,500$ (i, z, J, H, K), two at R $\sim 3,500$
Field(s)-of-view	four, corresponding to different spaxel scales
AO	LTAO and SCAO

<https://elt.eso.org/instrument/HARMONI>



For non-AO and visible observations

For optimal sensitivity (faint targets)

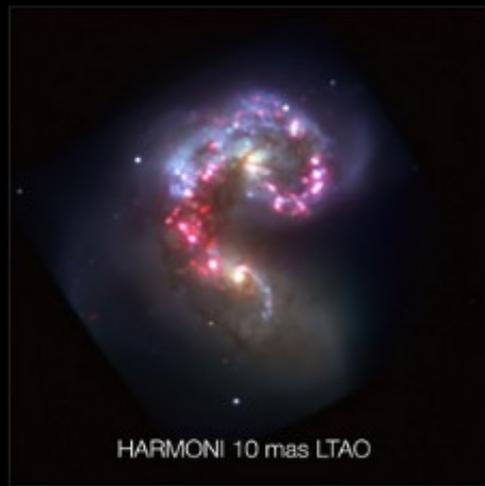
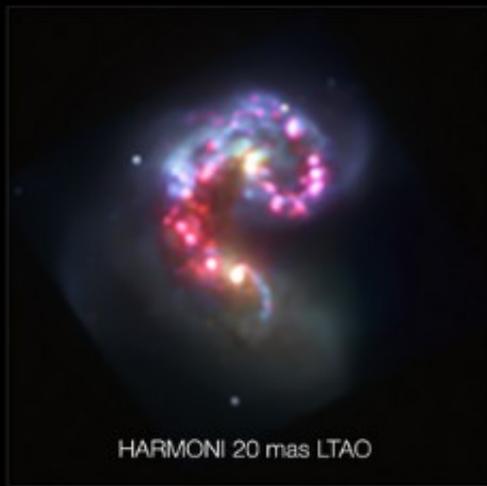
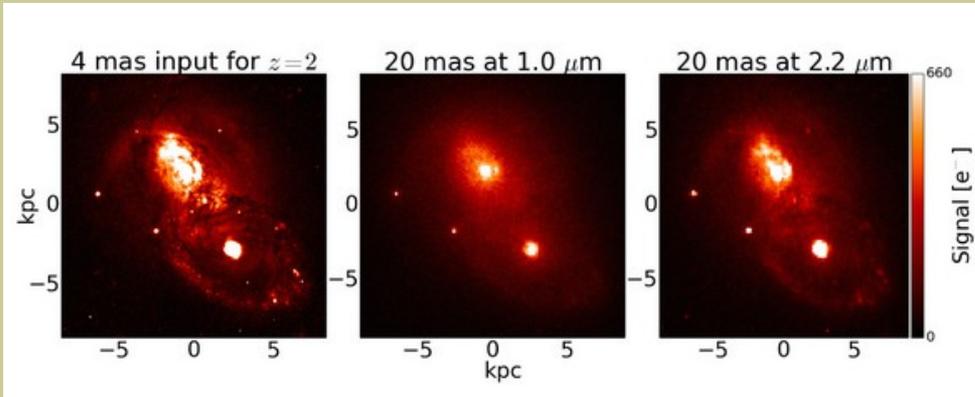
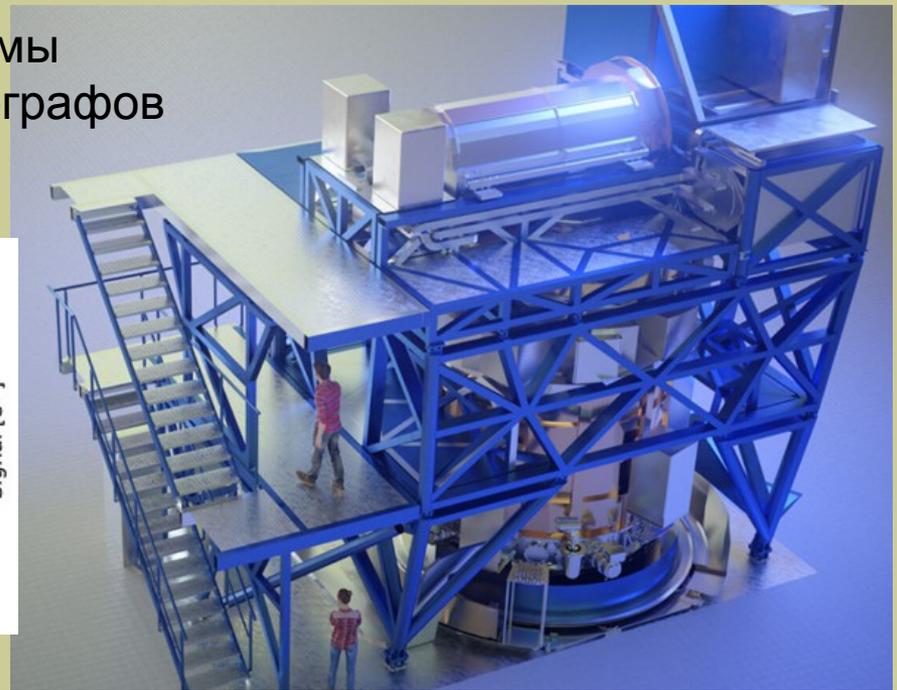
Best combination for sensitivity and spatial resolution

Highest spatial resolution (diffraction limited)

1 milliarcsecond (mas) = 0.001"

ELT 39m: HARMONI

4 системы
спектрографов



A simulation of how a galaxy in the early universe would look like when observed with various instruments on the VLT and the ELT.

Credit: ESO/HARMONI consortium

Посмотреть в свободное время

Roland Bacon plenary: Highlights from the Multi Unit Spectroscopic Explorer (MUSE), a 2nd generation VLT instrument for the VLT

A plenary talk from SPIE Astronomical Telescopes + Instrumentation 2014

16 July 2014 Technology

The discovery potential of MUSE – Exploring the PN 4361

And going further, we found that it's a galaxy.

Ha 6701 Å ($z=0.02$)

Prepared by David Carton (Leiden Observatory)

ESO - Göttingen - Leiden - Lyon - Potsdam - Toulouse - Zurich

P54

IGNITING QUESTIONS / DETECTING ANSWERS

The ORCA-Quest quantitative CMOS (qCMOS) camera with Photon Resolving functionality is the leap in scientific camera evolution that transforms imaging into imagining.

Start your adventure.

HAMAMATSU
PHOTON IS OUR BUSINESS

SPIE

https://spie.org/news/as14_bacon?SSO=1