

# About VIRUSes, Fibers and Galaxies

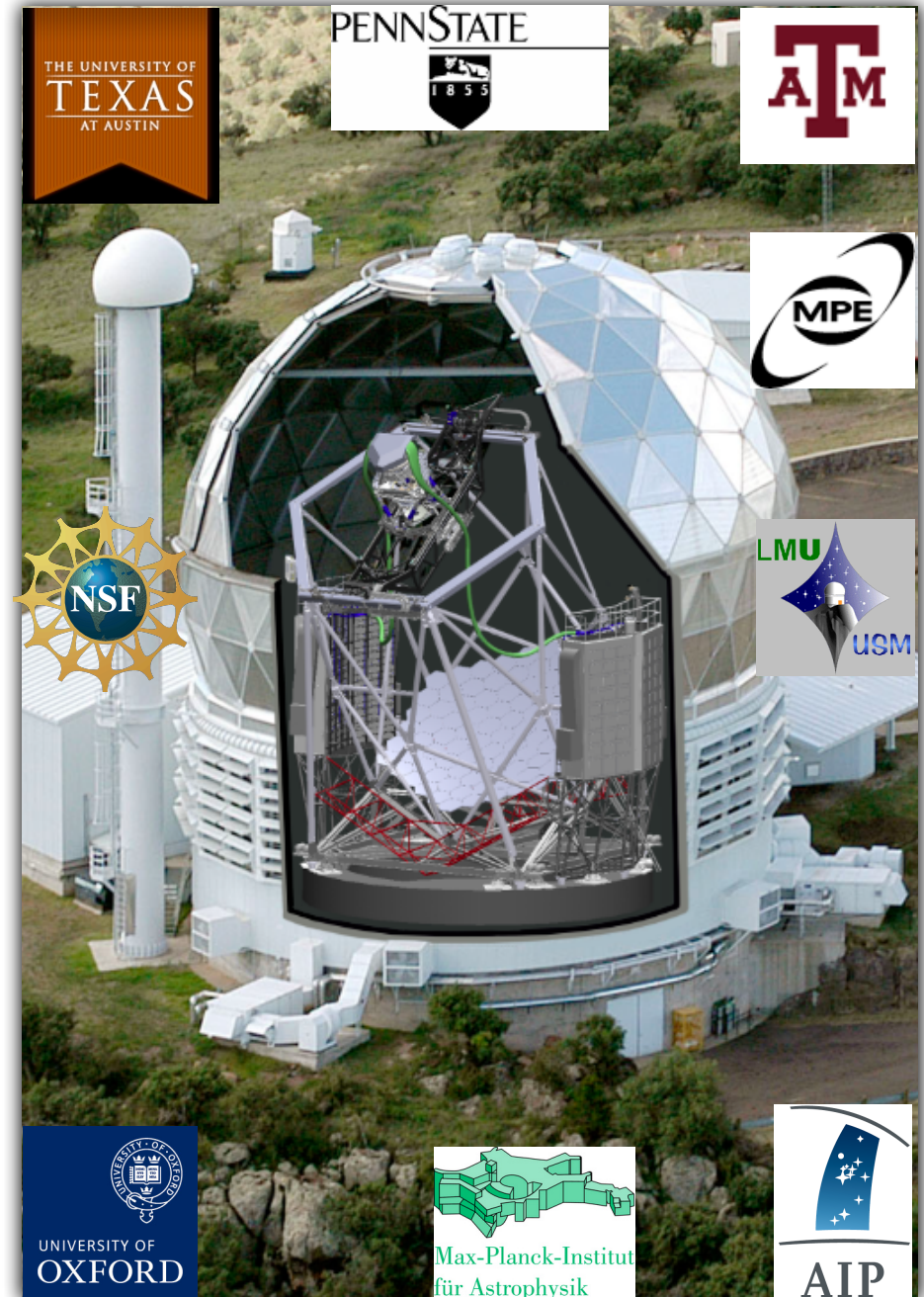
Maximilian Fabricius, Joshua Adams, Ralf Bender, Stuart Barnes, Guillermo Blanc,  
Niv Drory, David Fisher, Claus Gössl, Frank Grupp, Gary Hill, Ulrich Hopp, John  
Jardel, Florian Lang-Bardl, Martin Landriau, Michael Opitsch, Phillip MacQueen,  
Roberto Saglia, Jan Snigula, Surangkana Rukdee, Michael Williams,  
Philipp Wullstein  
&  
HETDEX team

# outline

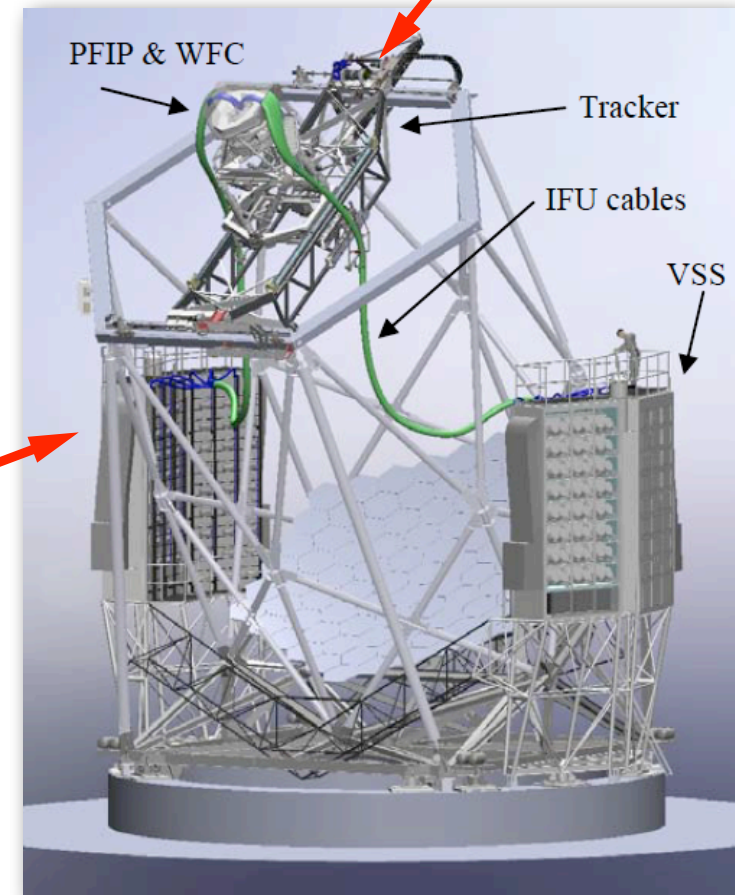
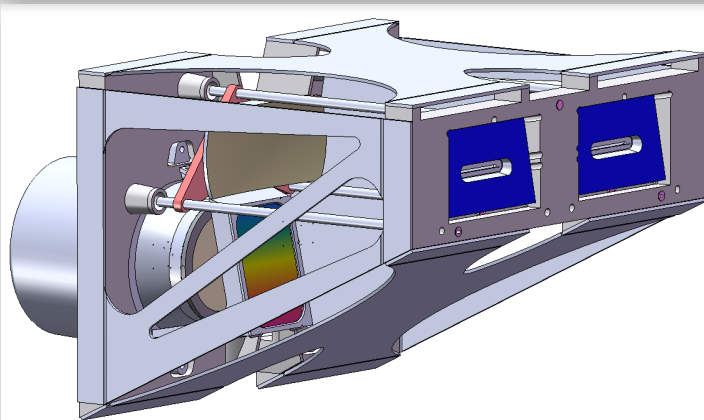
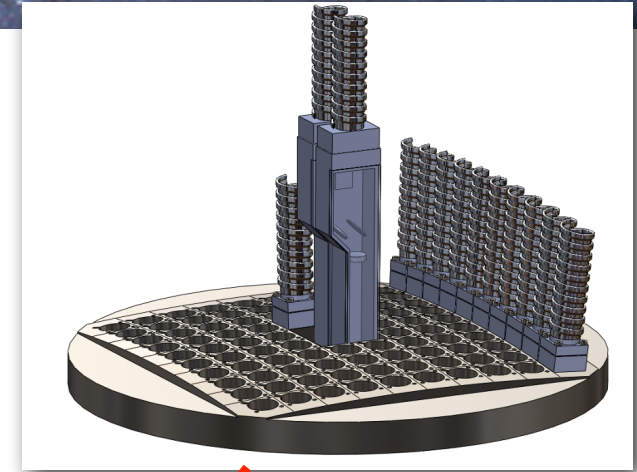
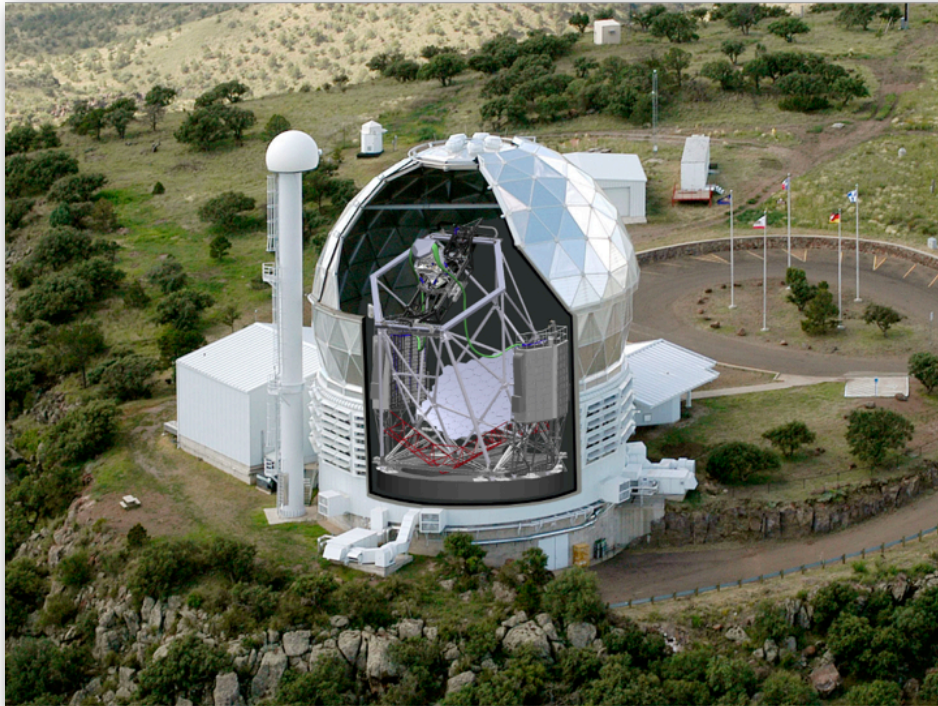
- VIRUS/HETDEX
  - the HETDEX project
  - the VIRUS survey Instrument
  - status
- VIRUS-W
  - Wendelstein Fraunhofer 2m
  - motivation for new IFU instrument
  - VIRUS-W characteristics
  - overview, ongoing VIRUS-W science
- conclusions

## HETDEX is

- upgrade of the 9.2m Hobby-Eberly Telescope with a new instrument: VIRUS enormously multiplexed IFU
- a blind spectrographic survey for Ly-alpha emitters
- 400 (60) square degrees over 3 years (+ equatorial extension, + “special fields”: COSMOS, Virgo, M31 ...)
- ~ 0.8 million redshifts from  $1.9 < z < 3.8$  (Ly-alpha emitters)
- about 1 million redshifts from  $0 < z < 0.5$  (OII emitters)
- Total budget US\$ ~40 million

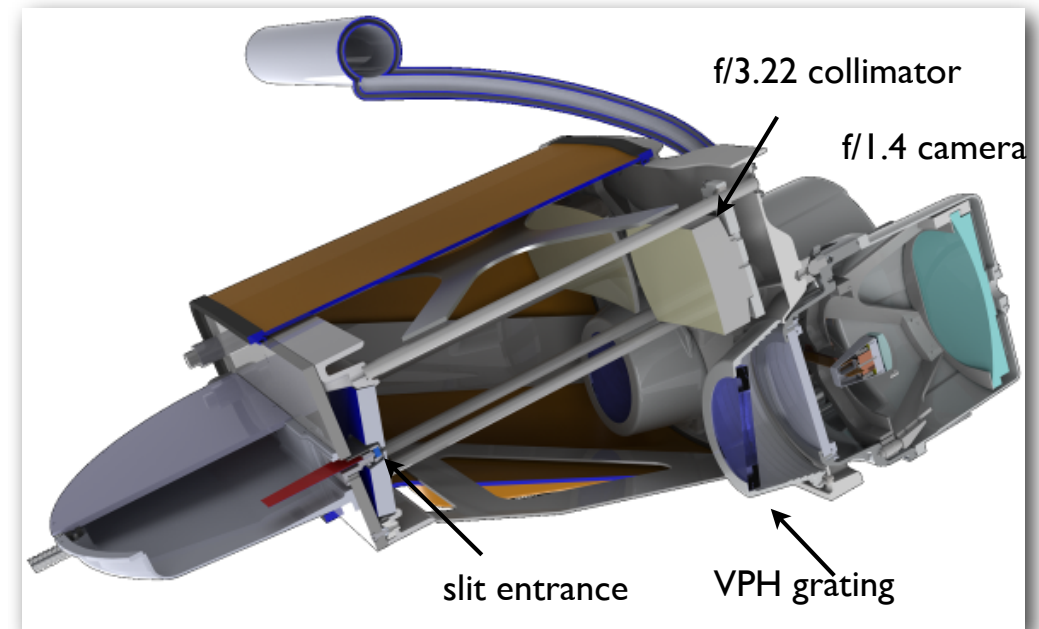
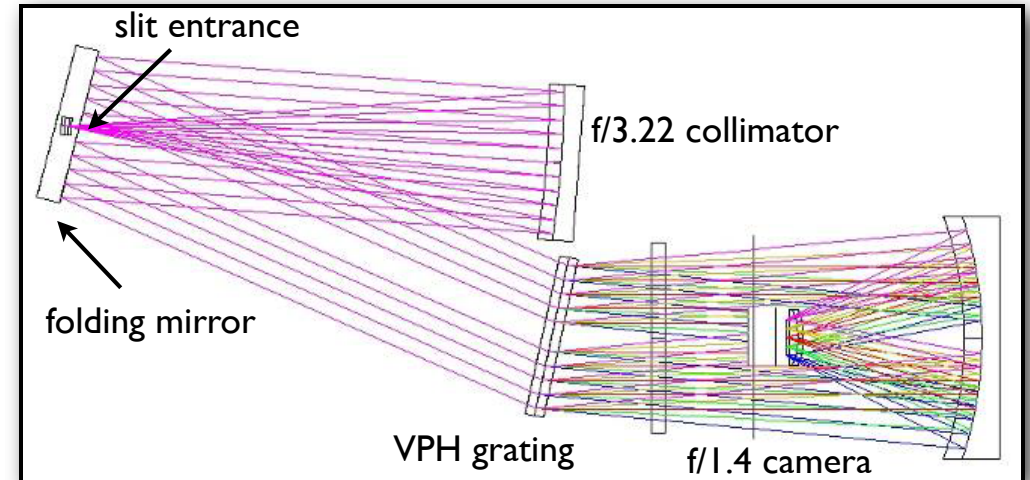


**VIRUS:** mosaic of 75 IFUs feeding 150 spectrographs mounted on HET 9.2m at McDonald Observatory.

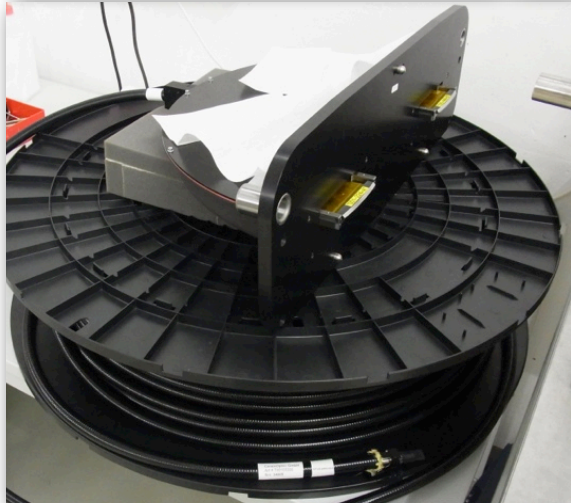
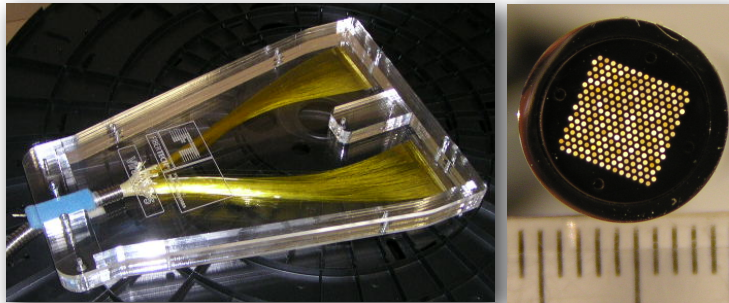


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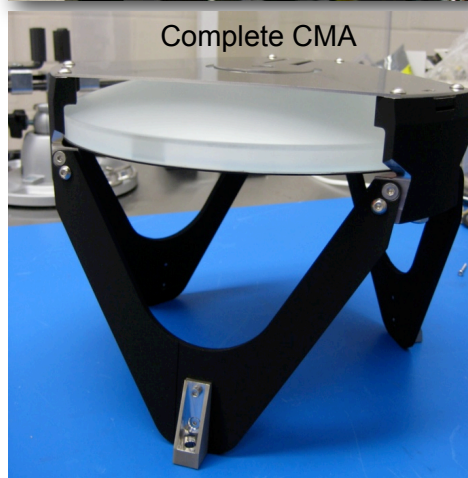
- uses a double Schmitd type design accepting f/3.2
- Schmitd camera allows for fast optics with a low number of optical elements and large spectral coverage
- 448 fibers per IFU with 1.5'' sampling and 1/3 filling factor
- covering the 3600-5500Å range at R=700
- For HETDEX the spectrographs are paired and share cooling, electronics and fiber feed



- Production IFU cables are being assembled at one qualified vendor and at AIP
  - As of this week we have 36 IFUs delivered by vendors and accepted, with 20 completed and partially tested
- Projecting >50 completed and installed by start of VIRUS commissioning in Q2 2015



## VIRUS



Complete CMA

- Cameras are the most complicated part of the spectrographs
- Production quantities of parts for cameras are in hand
  - All optics are delivered
- UT is integrating and aligning the spectrographs
- 26 units completed, assembly of further units will extend through 2014



# HETDEX

Hobby-Eberly Telescope Dark Energy Experiment

Illuminating the Darkness



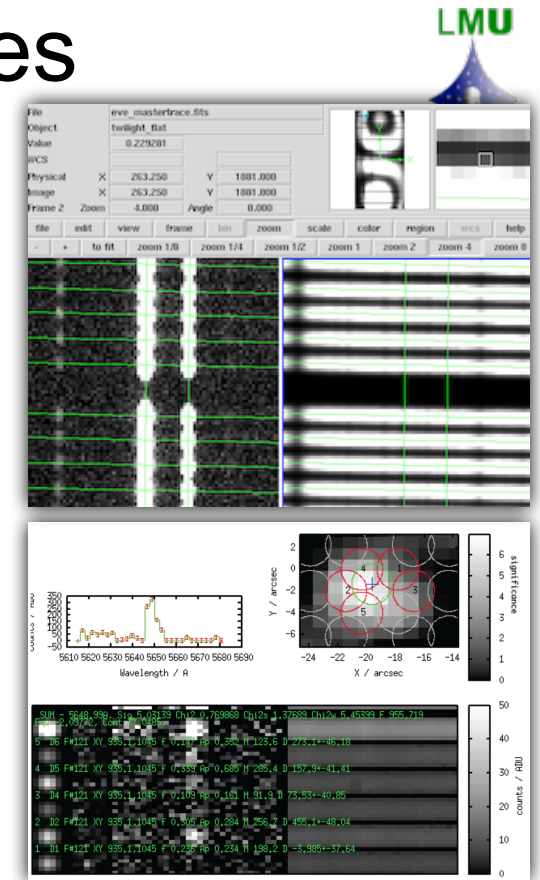
SUBARU Aug. 2014, Maximilian Fabricius



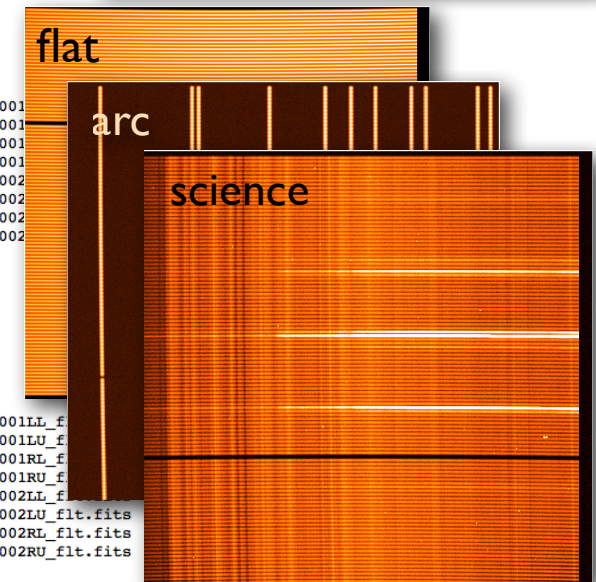
# Munich's main responsibilities software & survey design

- HETDEX will create a data volume of 120 GB/night and 20 TB in three year survey
- computing infrastructure
- implement core data analysis and source detection algorithms: Cure
- integration into AstroWISE for
  - automated, distributed and parallelized processing
  - user access (web interface)
  - user management
- provide HETDEX data simulation framework and datasets
- feedback to the instrument design

SUBARU Aug. 2014, Maxi



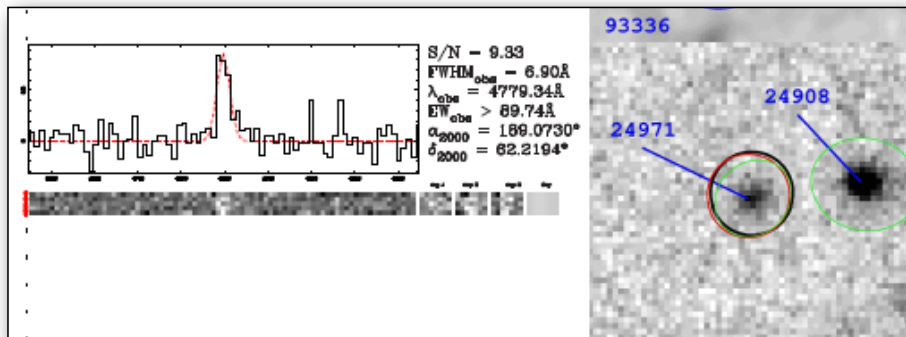
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│   │   ├── gp
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│   │   │   ├── gp
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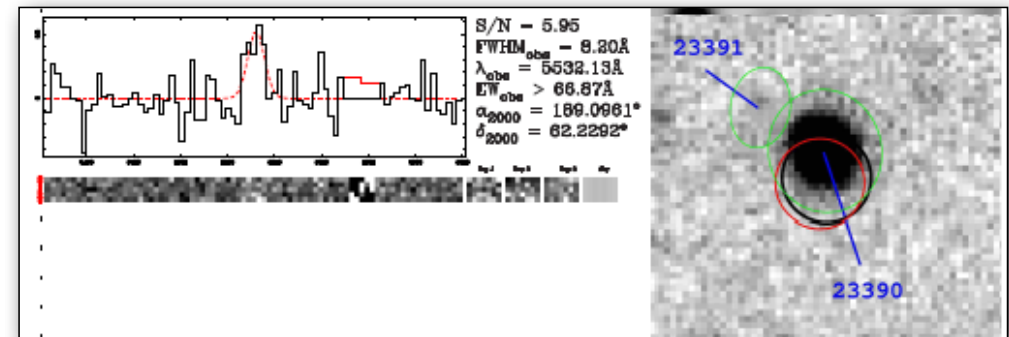
Simulated data products, used for testing of Cure and CureWISE

# Need imaging survey

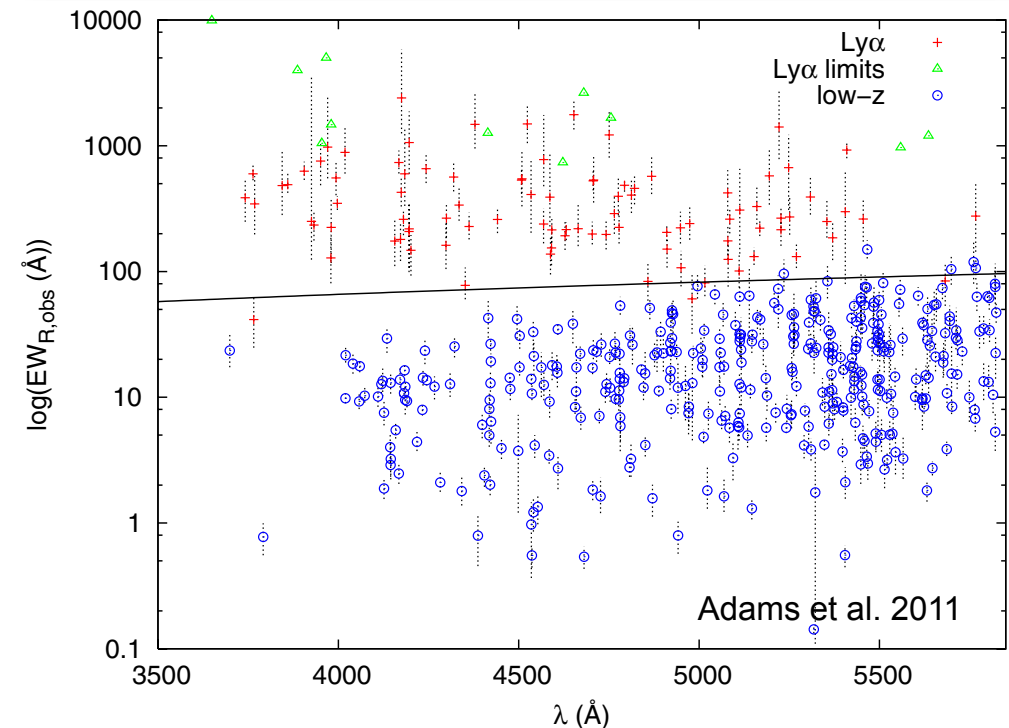
## LYMAN ALPHA EMITTERS



## Low-z GALAXIES



- Deep imaging survey is needed to discriminate against OII emitters
- required limiting g-band magnitude is 25.1
- **HPS is the preferred option. Needs ~ 2 nights**

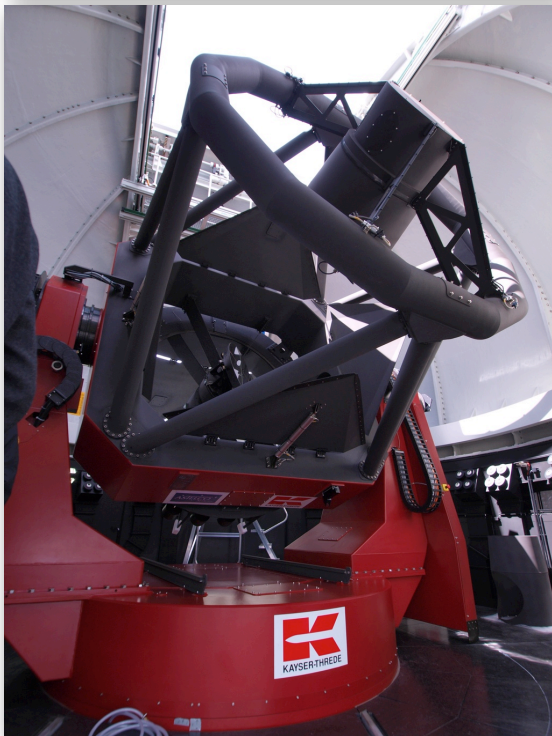


For updates:

<http://blogs.utexas.edu/het/>

<http://het.as.utexas.edu/wfu/>

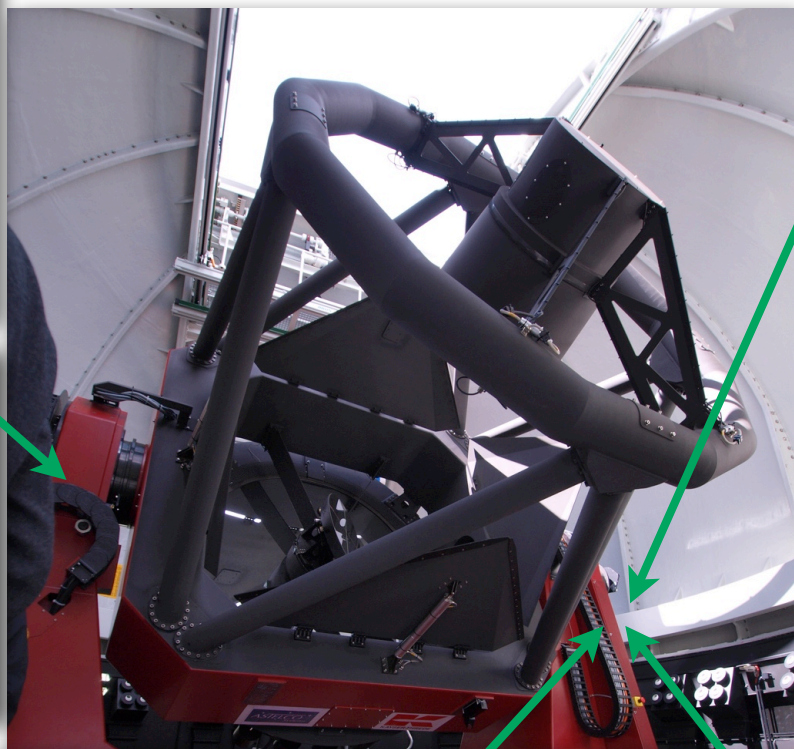
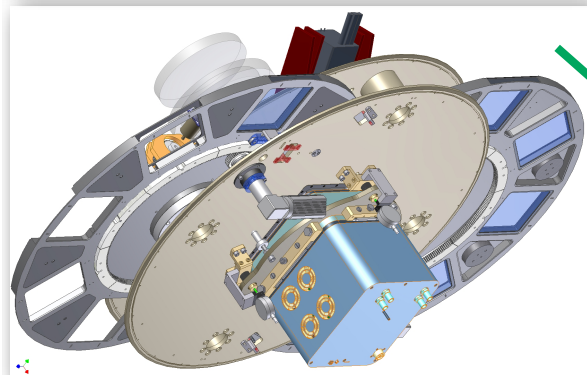
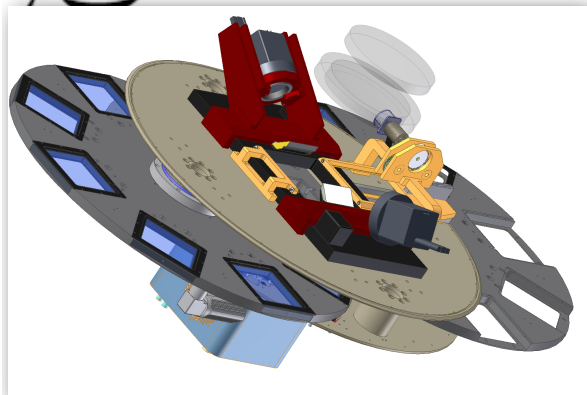
# New Wendelstein 2m



Hopp et al. 2012  
Thiele et al. 2012

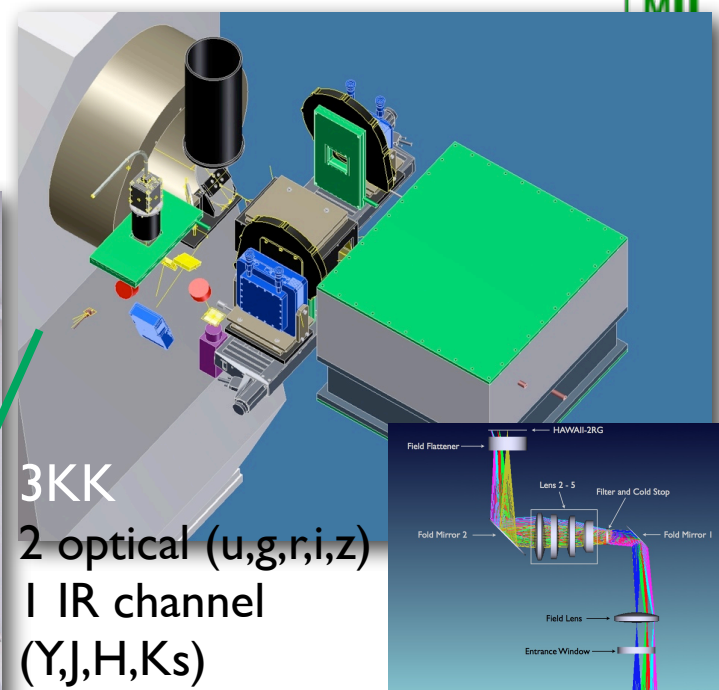
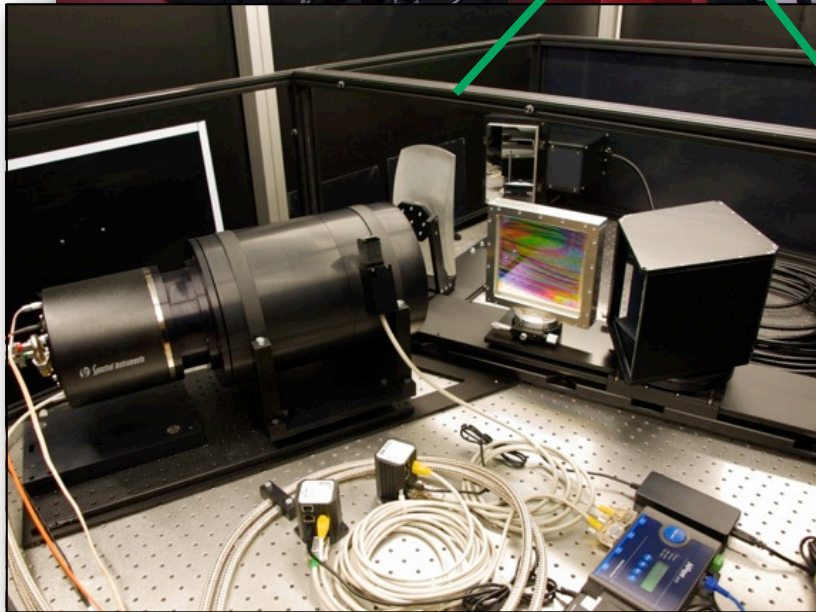


# WST Instruments



**WFFI**  
0.5 Deg<sup>2</sup> FOV  
u,g,r,i,z  
samples 0.8" seeing  
Gössel et al. 2012

**VIRUS-W**  
optical, high resolution,  
105" x 55" FOV  
Integral Field  
Fabricius et al. 2012



**3K**  
2 optical (u,g,r,i,z)  
1 IR channel  
(Y,J,H,Ks)  
simultaneous imaging  
Lang-Bardl et al. 2010



**FOCES**  
Temperature and  
Pressure stabilized  
Echelle R ~ 70.000, stable  
to < 1 m/s



# Introduction

- Interested in the dynamics of low dispersion galaxies.
- Typical instrumental (extragalactic) resolutions ( $R \sim 3000$  or  $\sigma_{\text{inst}} \sim 40 \text{ km s}^{-1}$ ) can not resolve these regimes.
- Today stars form in disks! Typical gaseous disks have dispersion of the order of  $\sim 10 \text{ km/s}$  (e.g. Tamburro et al. 2009).
- So really what we want is large instrumental dispersion ( $R \sim 10000$  or  $\sigma_{\text{inst}} \sim 10 \text{ km s}^{-1}$ ).
- BUT: High dispersion is expensive  $\rightarrow$  large apertures.
- These do not need to be the telescope apertures.  
**Idea: Build a wide field of view, high spectral resolution but low spatial resolution IFU.**

M87 (E0)  $\sigma_0 \sim 330 \text{ km/s}$   
requires  $R \sim 1000$



accessible to e.g. SAURON

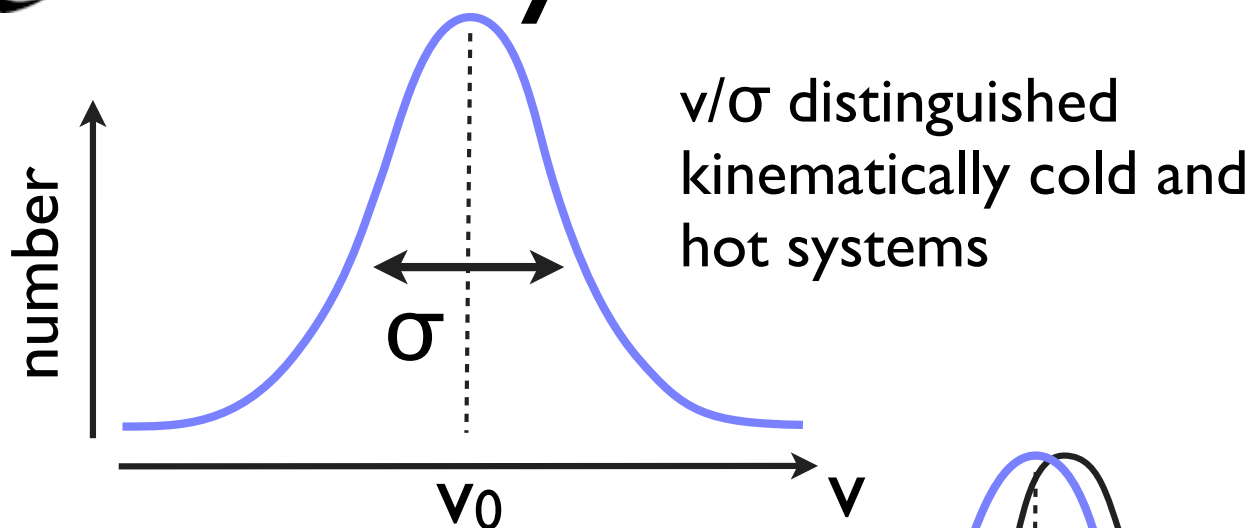
M101 (SABcd)  
 $\sigma_0 \sim 70 \text{ km/s}$



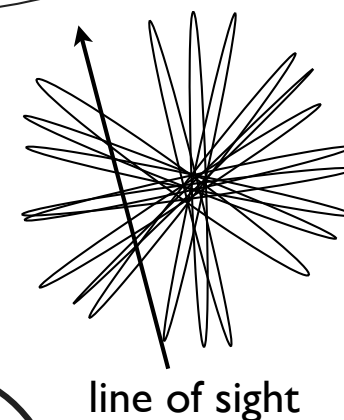
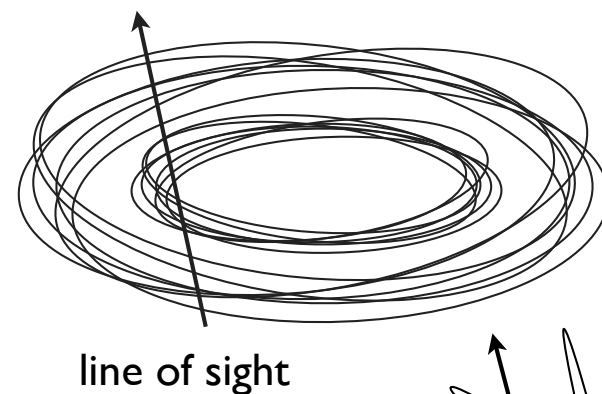
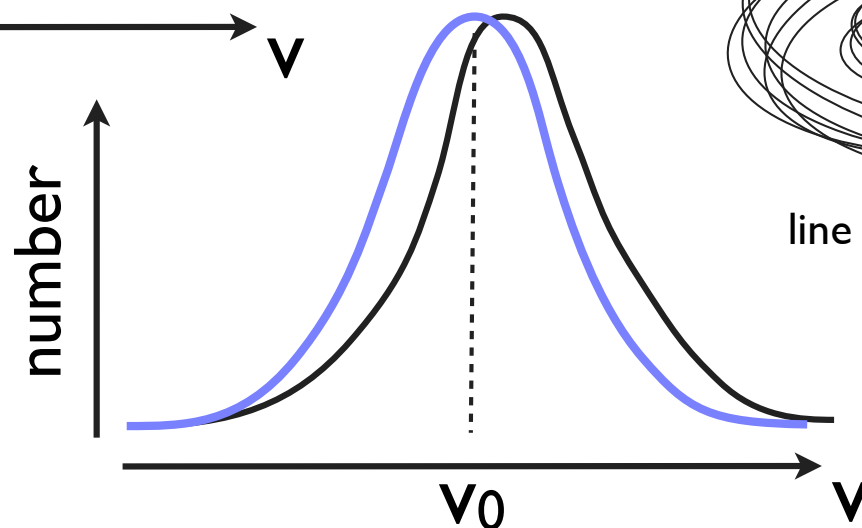
NGC2976 (SAc)  
 $\sigma_0 \sim 20 \text{ km/s}$



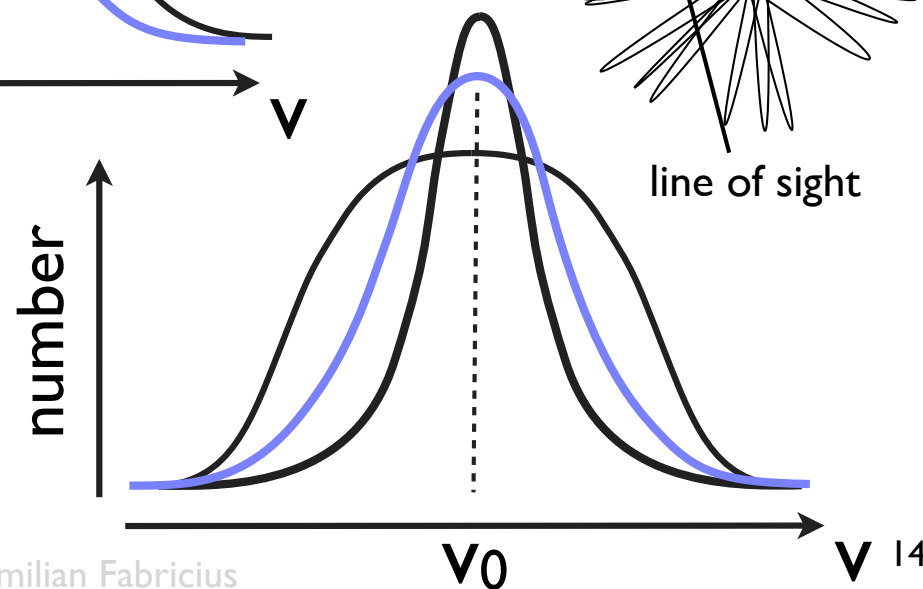
# Why resolution matters



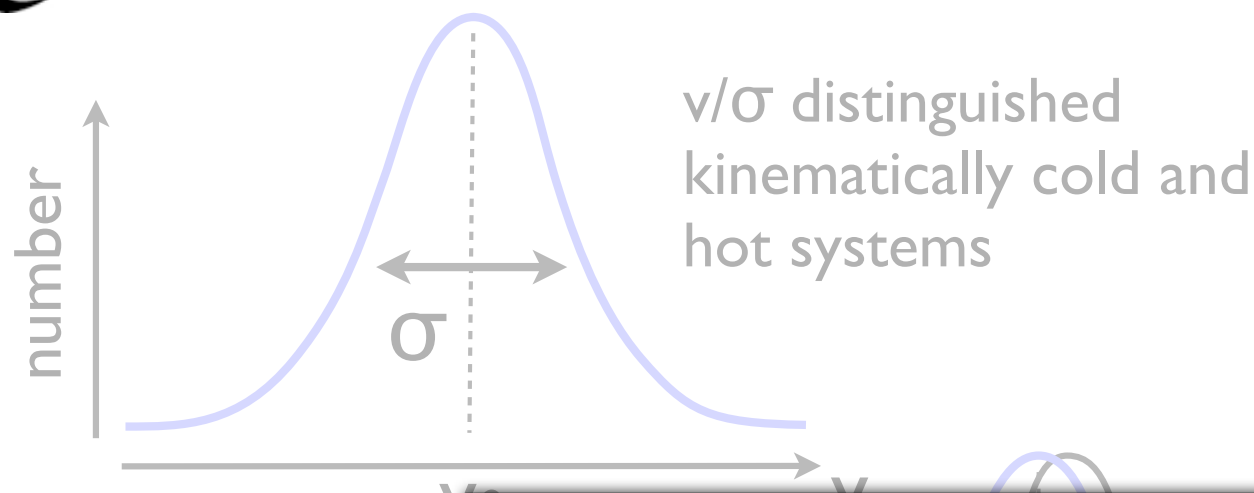
asymmetric deviations (h3) may be sign for “diskiness” or multiple components



symmetric deviation (h4) indicate whether orbits are predominantly radial or circular

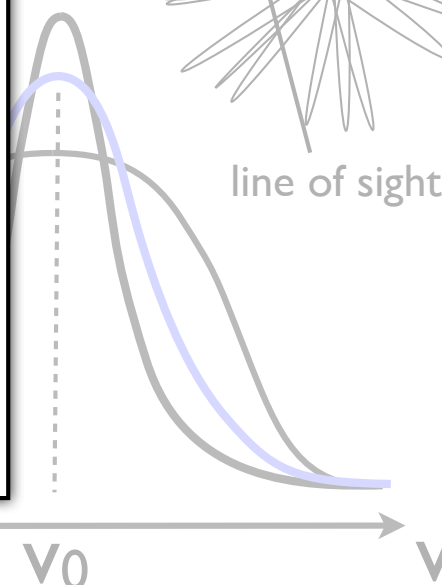
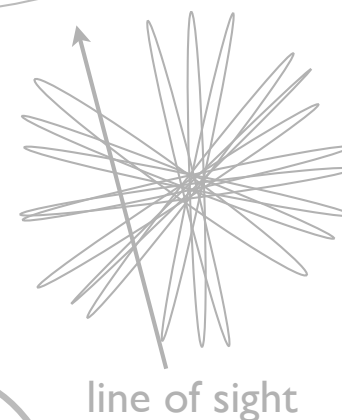
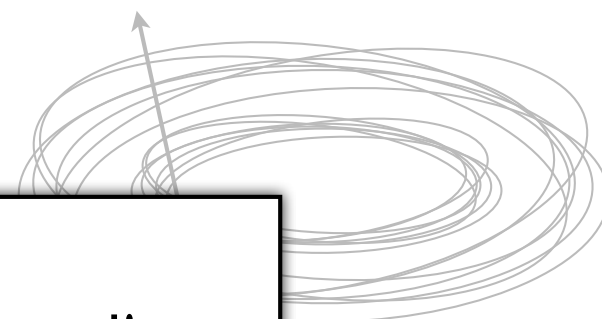
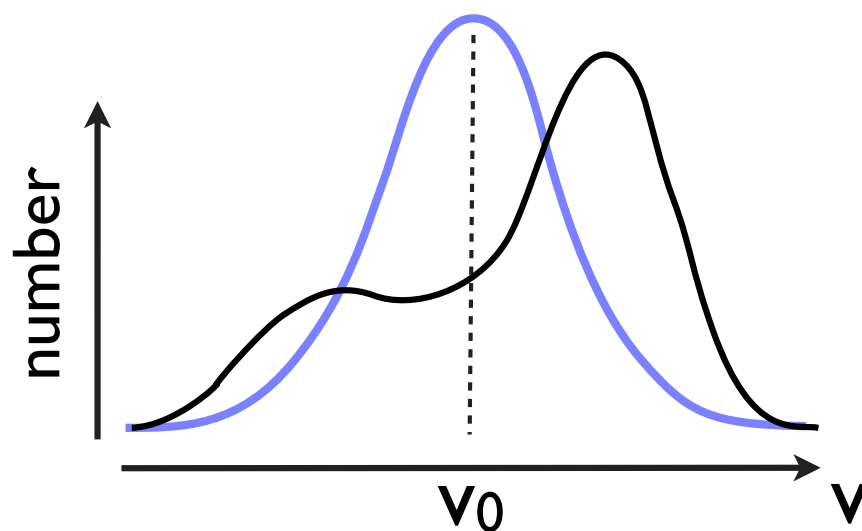


# Introduction



asymmetric  
deviations may be  
sign for “diskyness”  
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and LOSVDs do  
not need to be well-behaved!





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M101 (SABcd)  
 $\sigma_0 \sim 70 \text{ km/s}$

NGC2976 (SAc)  
 $v_{\text{max}} \sim 35 \text{ km/s}$



# VIRUS-W

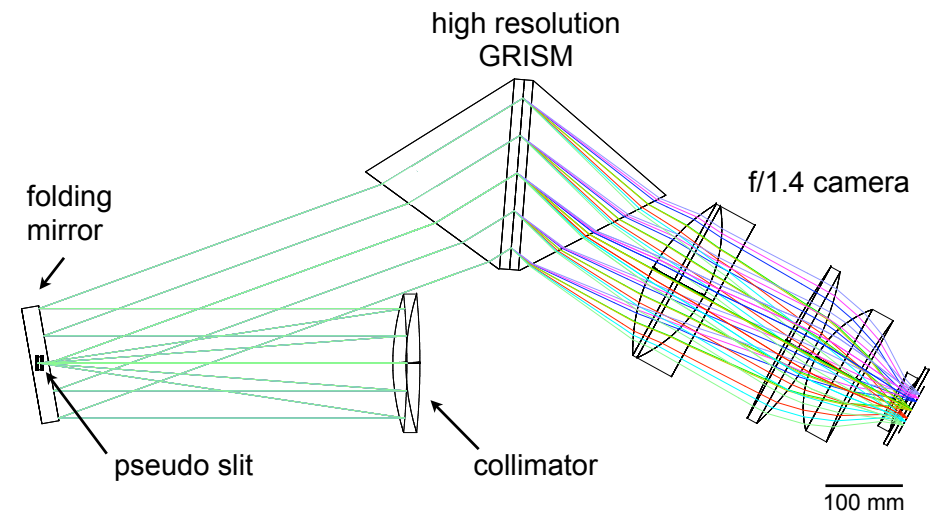
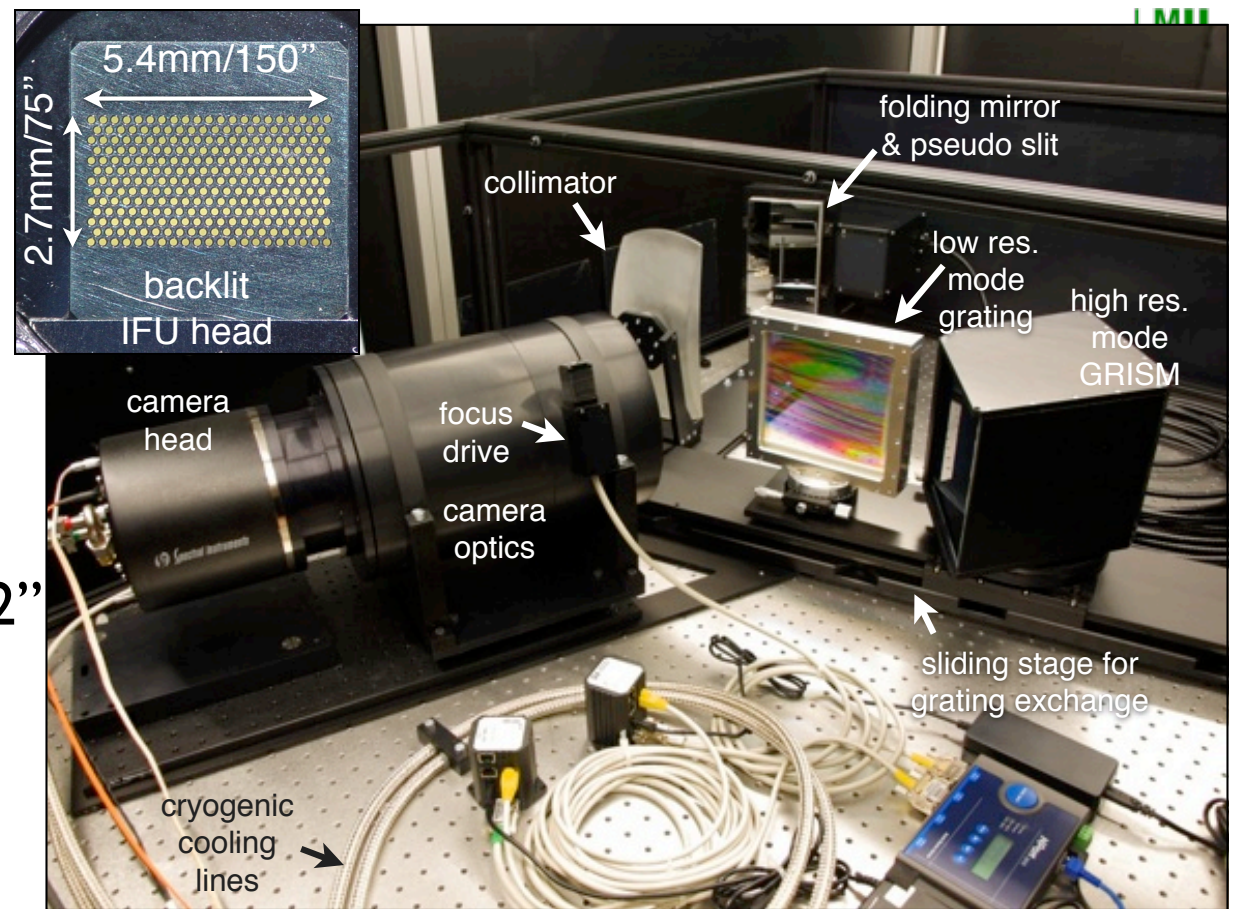
- Based on VIRUS for HETDEX
- Fiberfed IFU spectrograph
- Rect. field of view: 105" x 55"
- 267 fibers, fiberdiam. on sky 3.2"
- two spectral resolutions:

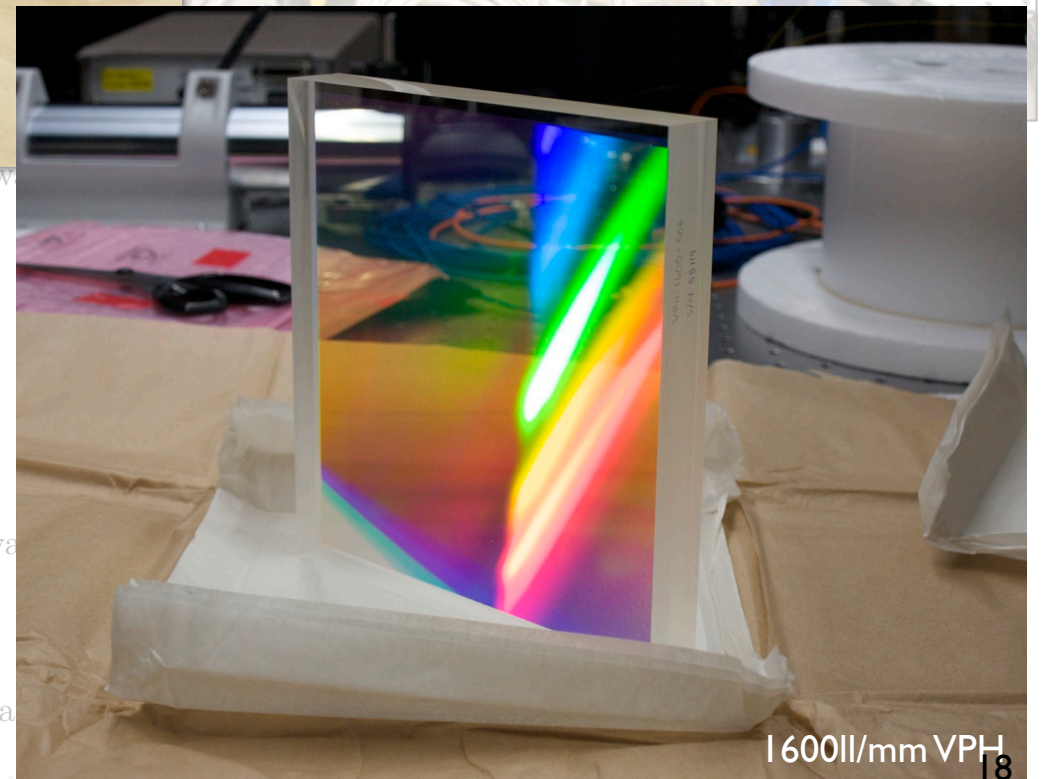
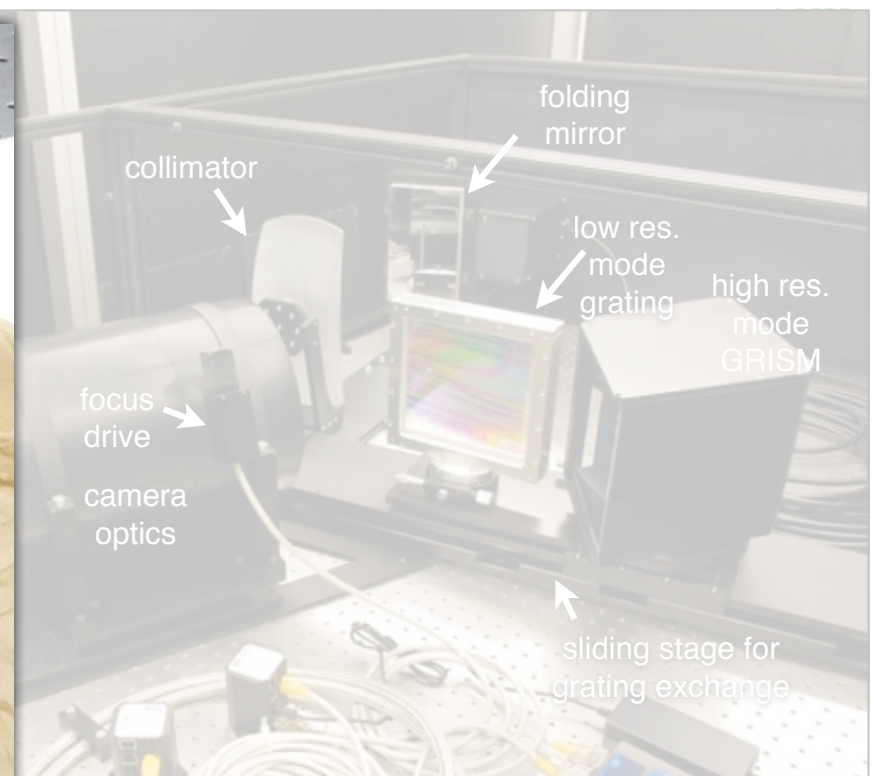
low res:

spectral coverage, nominal	4750 Å - 5600 Å
spectral coverage, actual	4340 Å - 6042 Å
resolution ( $\Delta\lambda/\lambda$ )	1700 to 3300 (depending on wave-length)
resolution ( $\sigma$ )	38 km/s to 75 km/s
linear dispersion	0.52 Å/px
grating	1900 l/mm VPH grating

high res:

spectral coverage, nominal	4930 Å - 5445 Å
spectral coverage, actual	4850 Å - 5475 Å
resolution ( $\Delta\lambda/\lambda$ )	7900 to 9000 (depending on wave-length)
resolution ( $\sigma$ )	14 km/s to 16 km/s
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grating	3300 l/mm VPH grating sandwiched between two prisms





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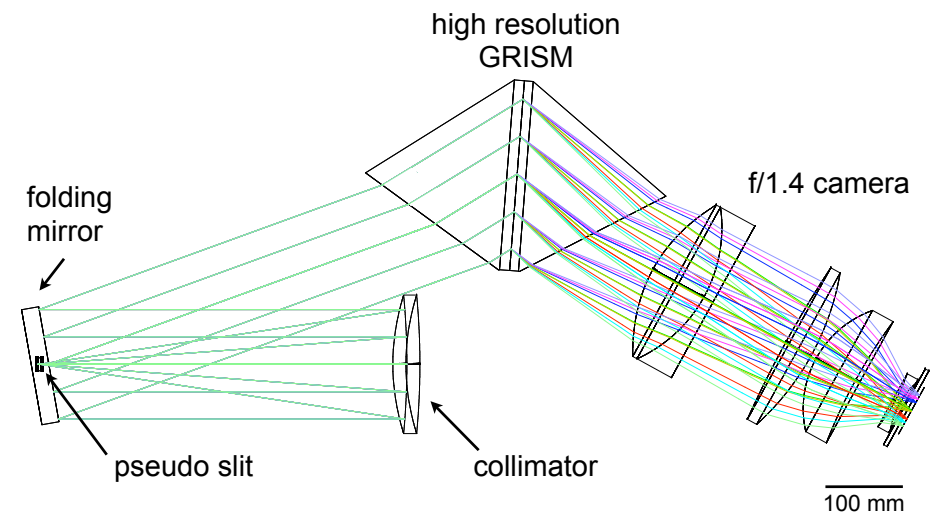
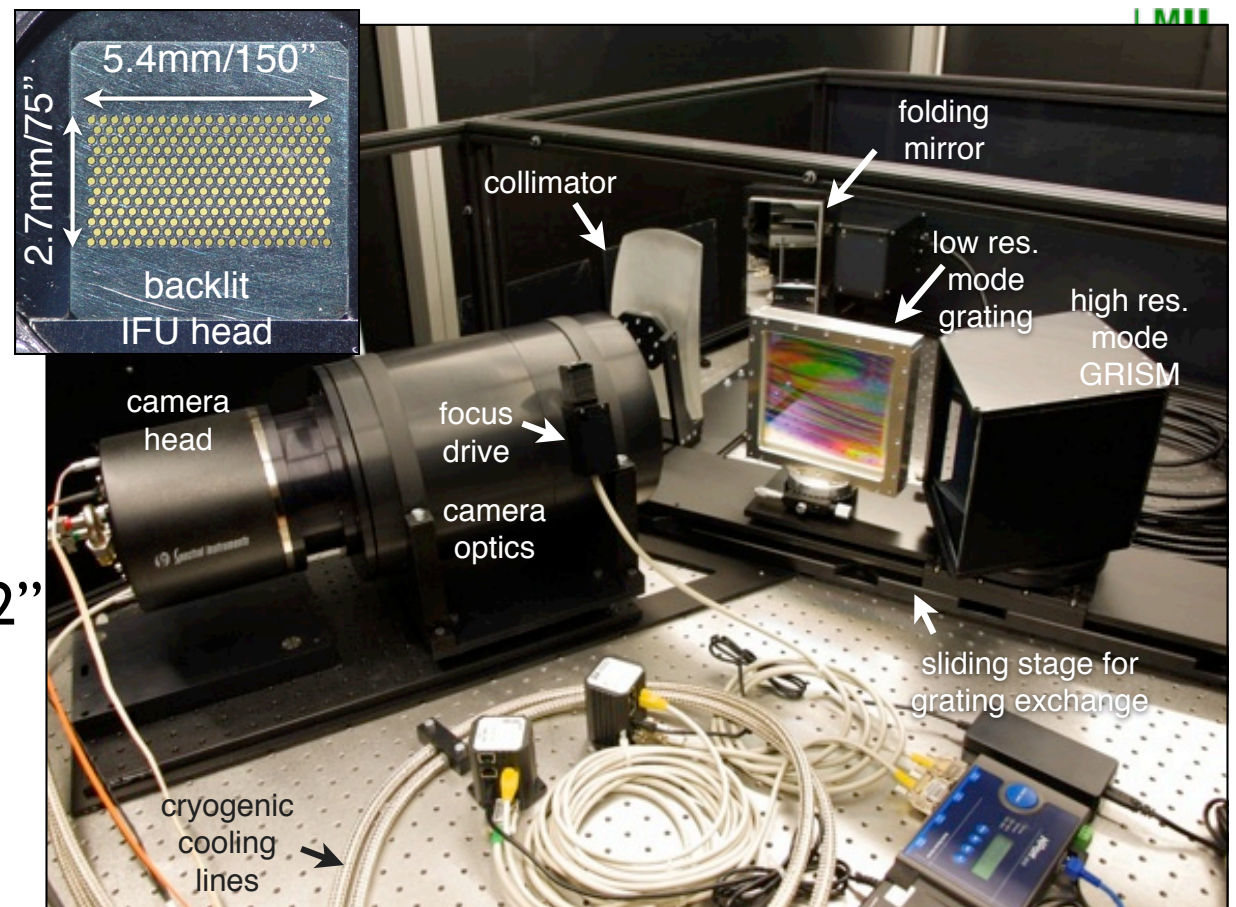
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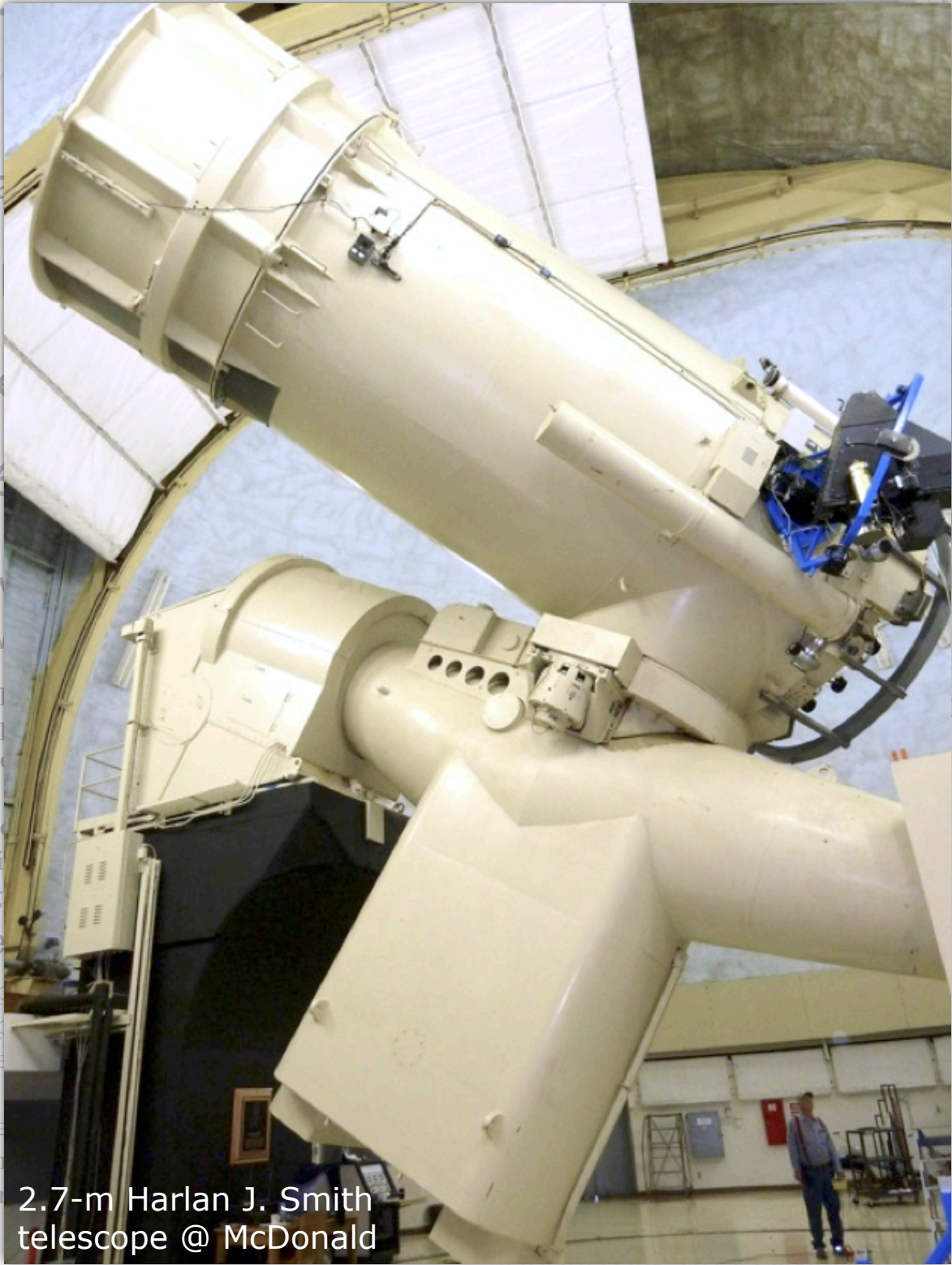
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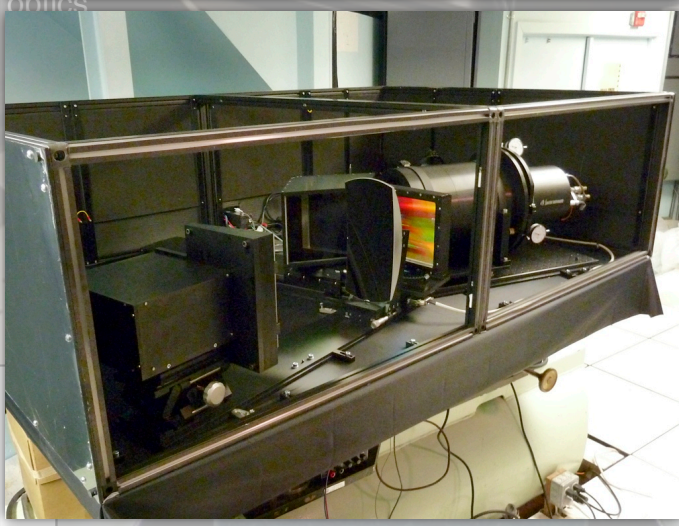
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2.7-m Harlan J. Smith telescope @ McDonald



res. de SM





# VIRUS-W science



Nov10	comm	PI MF	obs MF+Drory+Singula+Wullstein	3 nights
Dec10	comm	PI MF	obs MF	5 nights
May11	bulges	PI MF	obs J. Snigula & M. Landriau	7 nights
May11	Black Holes	PI Saglia	obs J. Snigula & M. Landriau	2 nights
Jun11	LSBs	PI JA	obs J. Adams	8 nights
Jul11	VENGA	PI TW	obs M, Landriau & M. Williams	7 nights
Aug11	draco	PI Jardel	obs J. Jardel	2.5 nights
Aug11	bulges	PI MF	obs M. Williams	6.5 nights
Aug11	LSBs	J. Adams	obs J. Adams	13 nights
Oct11	M31	PI RS	obs M. Williams & mF	10 nights
Dec11	LSBs	PI J. Adams	obs Adams	9 nights
Jan12	VENGA	PI TW	obs Mimi Song	3 nights
Feb12	VENGA	PI TW	obs Mimi Song	4 nights
April12	dwarfs	PI MW	obs M. Williams	4 nights
May12	LSBs	PI J. Adams	obs J. Adams	5 nights
Jun12	bulges	PI MF	obs M. Williams	8 nights
Jun12	disk reson.	PI J. Gersen	obs J. Gersen	6 nights
Aug12	M31 dwarfs	PI MF	obs MF + M. Opitsch	3 nights
Okt12	M31	PI M. Opitsch	obs R. Saglia + M. Opitsch	3 nights
Jan 13	LSBs	PI JA	obs J. Adams	6 nights
April 13	GCs	PI Rukdee	obs Rukdee + MF	3.5 nights
April 13	counterrot	PI MF	obs MF + M. Opitsch	3.5 nights
Sept 13	GCs	PI Rukdee	obs Rukdee + M. Opitsch	5 nights
Dec 13	medido	PI MF + EN	obs Fabricius	7 nights
Dec 13	medido	PI MF + EN	obs Gebhardt + Shetrone + Mueller	5 nights
Jan 14	medido	PI MF + EN	obs Shetrone	3 nights
Jan 14	disk dispersions	PI SA	obs SA	3 nights
Feb 14	medido	PI MF + EN	obs Fabricius + Noyola + Mueller	5 nights
Mar 14	medido	PI MF + EN	obs Mueller?	4 nights
May 14	GCs	PI Rukdee	obs M. Opitsch	5.5 nights
May 14	disk dispersions	PI SA	obs SA	3.5 nights
Jun 14	medido	PI MF + EN	obs Noyola	3nights
Jul 14	medido	PI MF + EN	obs Williams, Mazzalay, Thomas, Shetrone	7 nights
Aug 14	medido	PI MF + EN	obs Thomas, Shetrone	5 nights
Aug 14	GCs	PI MF	obs MF	8 nights



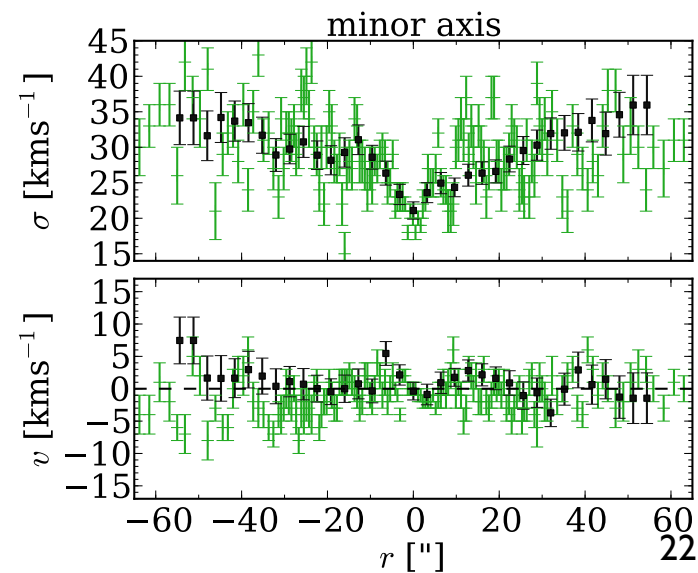
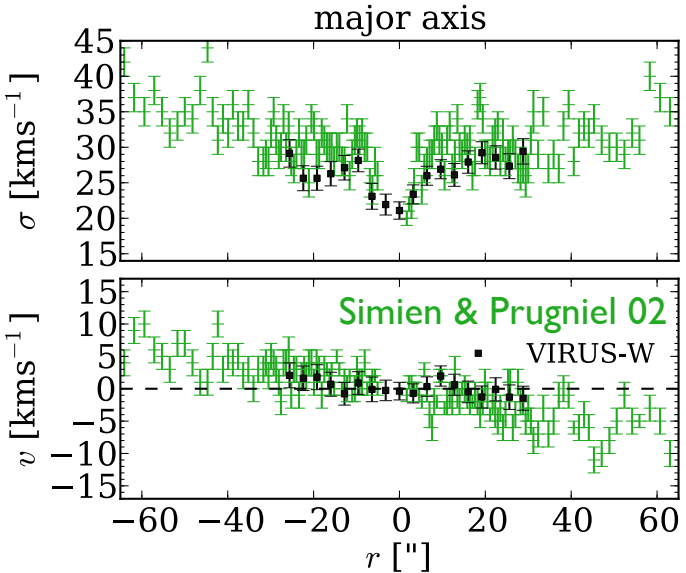
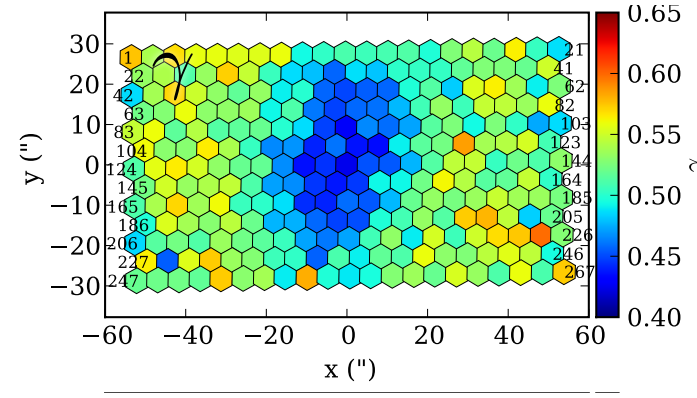
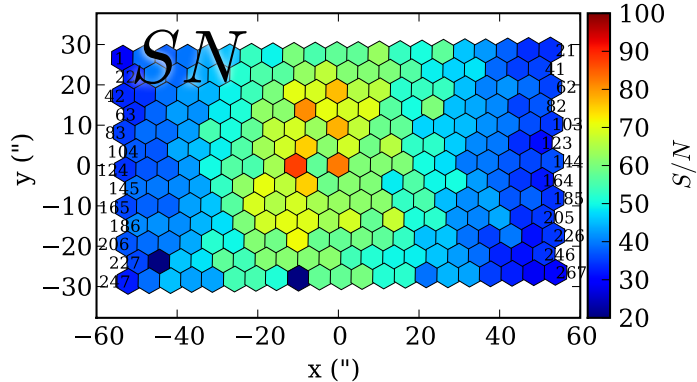
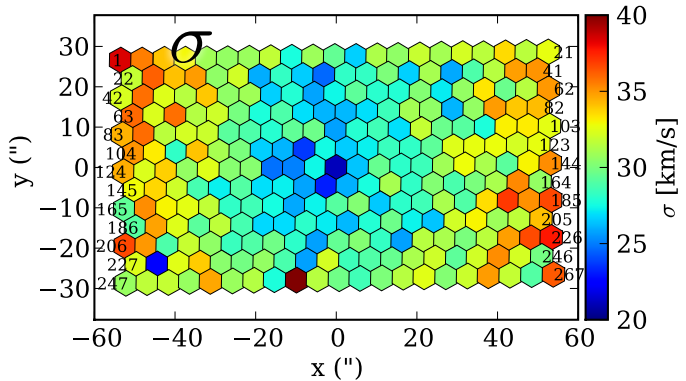
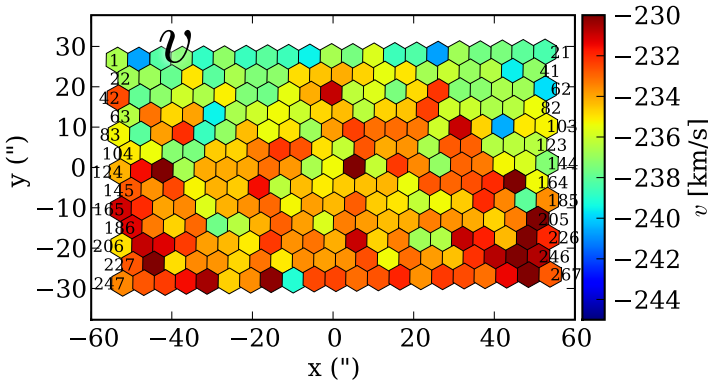
# VIRUS-W science



Nov10	comm
Dec10	comm
May11	bulges



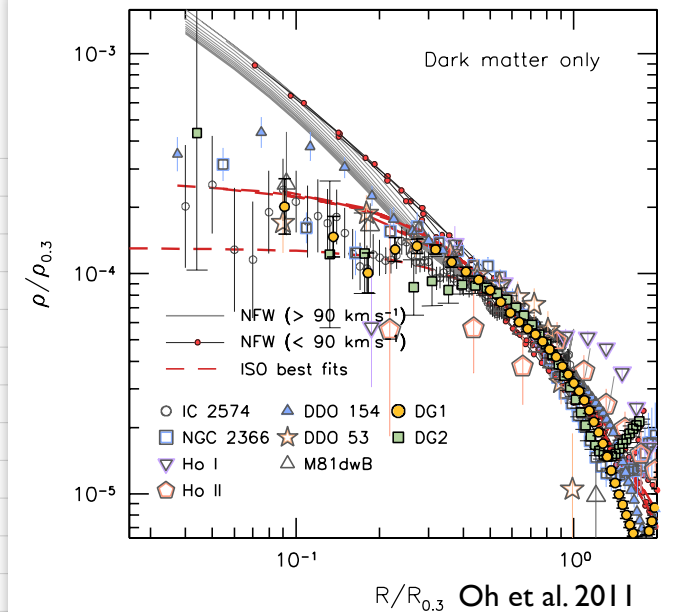
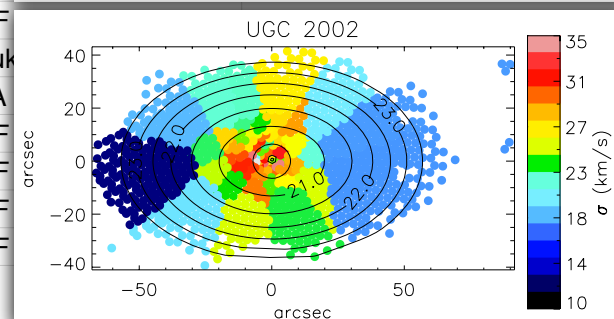
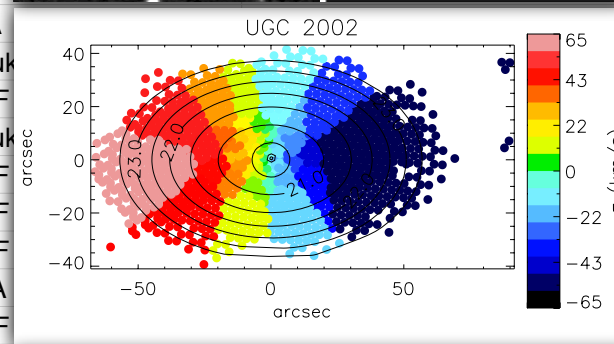
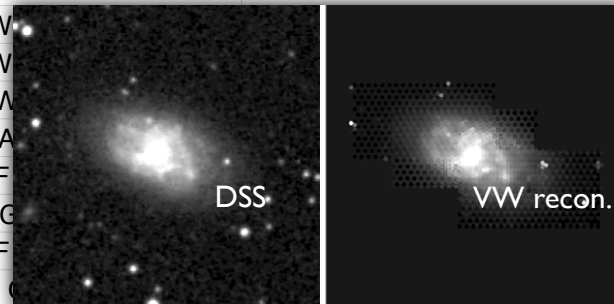
Dec 13	medido
Dec 13	medido
Jan 14	medido
Jan 14	disk dispersions
Feb 14	medido
Mar 14	medido
May 14	GCs
May 14	disk dispersions
Jun 14	medido
Jul 14	medido
Aug 14	medido
Aug 14	GCs





# VIRUS-W science

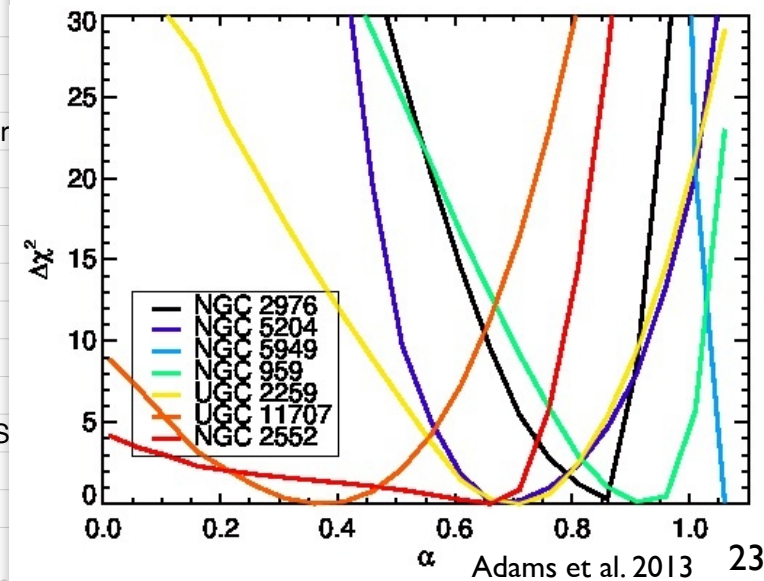
Nov10	comm	PI MF	obs MF+Drory+Singula+Wullstein
Dec10	comm	PI MF	obs MF
May11	bulges	PI MF	obs J. Snigula & M. Landriau
May11	Black Holes	PI Saglia	obs J. Snigula & M. Landriau
Jun11	LSBs	PI JA	obs J. Adams
Jul11	VENGA	PI TW	obs M, Landriau & M. Williams
Aug11	draco	PI Jardel	obs J. Jardel
Aug11	bulges	PI MF	obs M. Williams
Aug11	LSBs	J. Adams	obs J. Adams
Oct11	M31	PI RS	obs M. Williams & mF
Dec11	LSBs	PI J. Adams	obs Adams
Jan12	VENGA	PI TW	
Feb12	VENGA	PI TW	
April12	dwarfs	PI MW	
May12	LSBs	PI J. A	
Jun12	bulges	PI MF	
Jun12	disk reson.	PI J. G	
Aug12	M31 dwarfs	PI MF	
Okt12	M31	PI M. C	
Jan 13	LSBs	PI JA	
April 13	GCs	PI Ruk	
April 13	counterrot	PI MF	
Sept 13	GCs	PI Ruk	
Dec 13	medido	PI MF	
Dec 13	medido	PI MF	
Jan 14	medido	PI MF	
Jan 14	disk dispersions	PI SA	
Feb 14	medido	PI MF	
Mar 14	medido	PI MF	
May 14	GCs	PI Ruk	
May 14	disk dispersions	PI SA	
Jun 14	medido	PI MF	
Jul 14	medido	PI MF	
Aug 14	medido	PI MF	
Aug 14	GCs	PI MF	



Generalized Navarro-Frenk-White

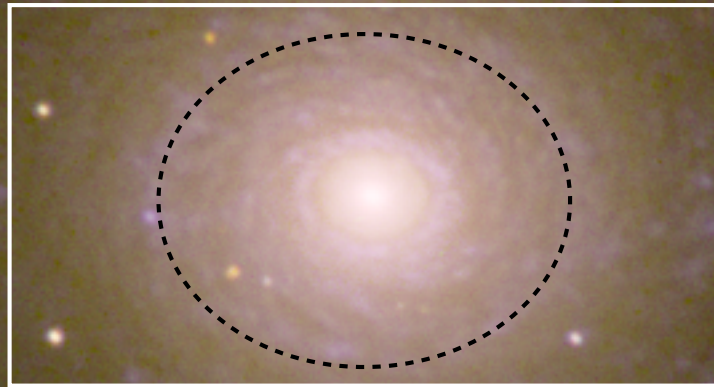
$$\rho(r) = \frac{1}{(r/r_s)^\alpha (1 + r/r_s)^{3-\alpha}}$$

$\alpha = 0 \rightarrow \text{core}$   
 $\alpha = 1 \rightarrow \text{cusp}$



# Kinematic Sub-Components

## Case Study NGC 7217



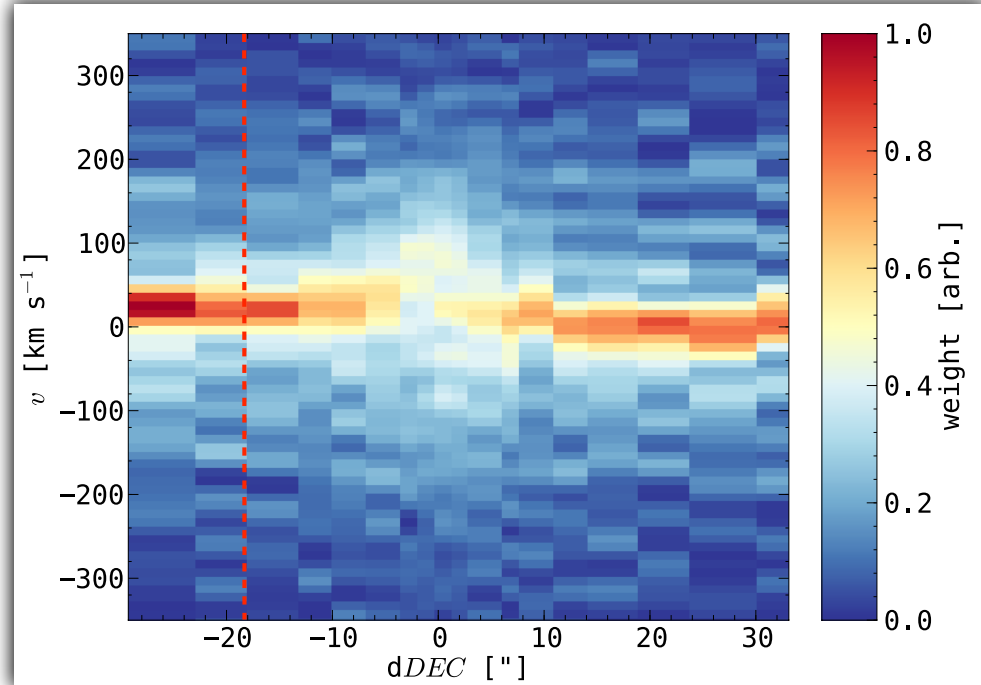
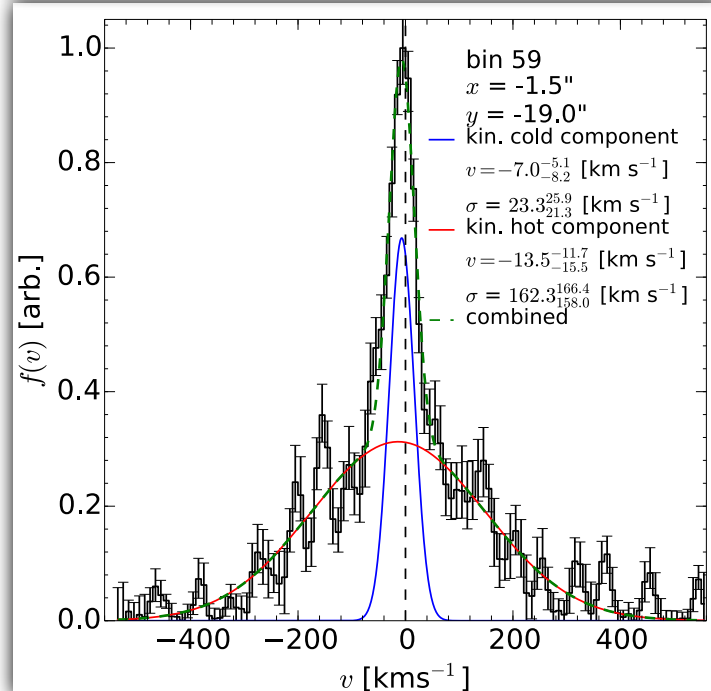
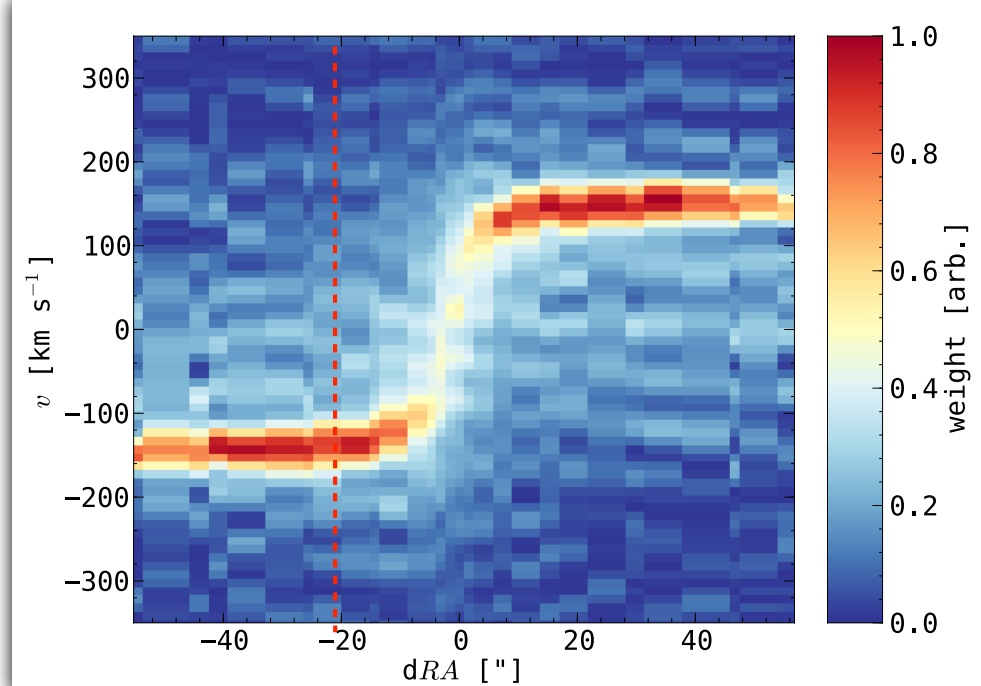
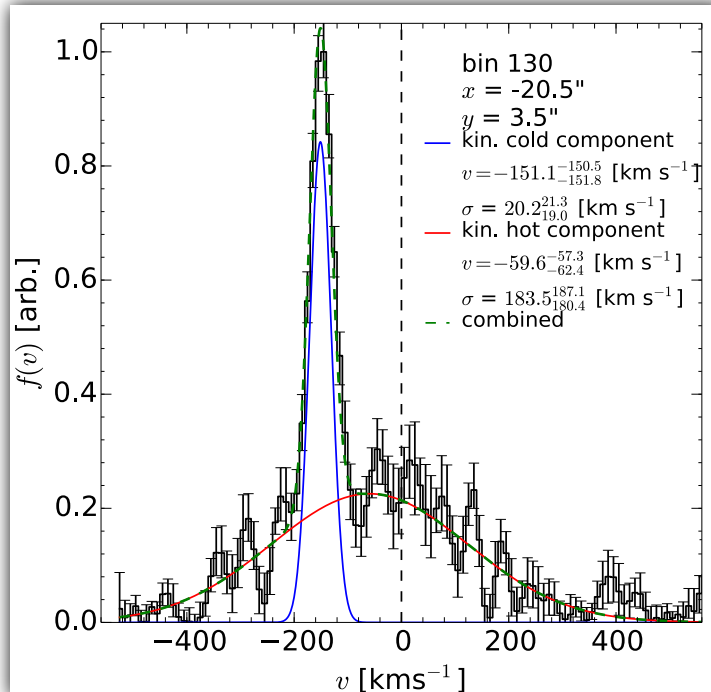
VIRUS-W FoV

1.5h/dither, 3 dithers to fill IFU

600s skynods

previously obtained 12 kinematic  
templates and 9 further standards

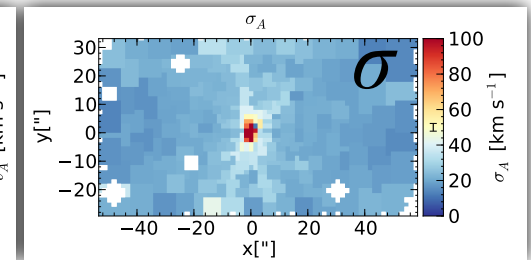
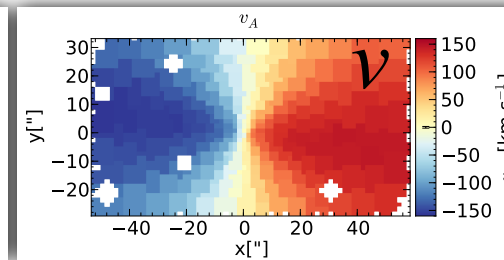
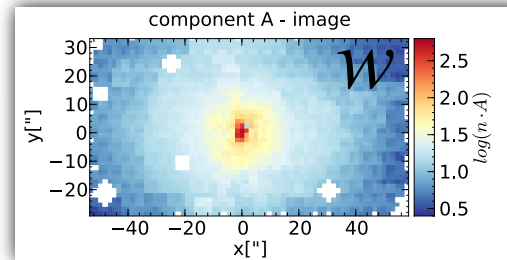
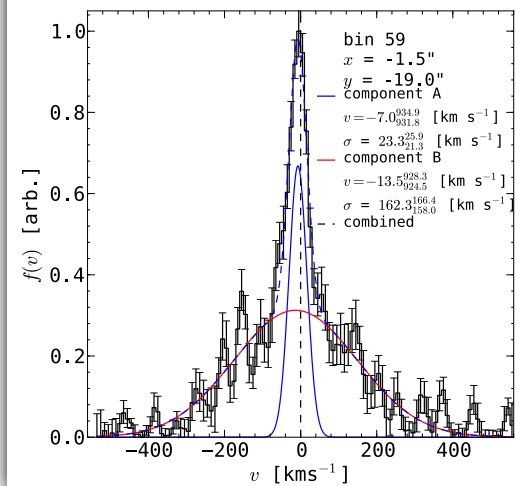
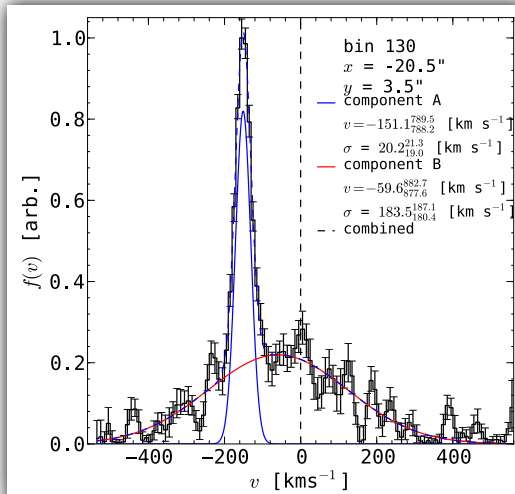
# Kinematic Decomposition



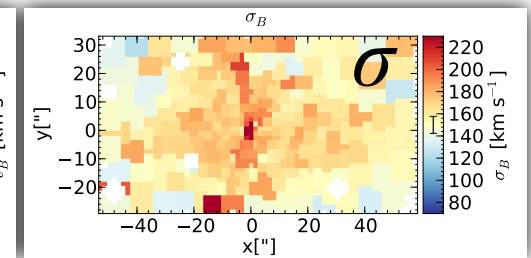
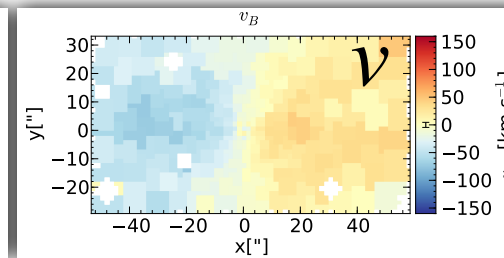
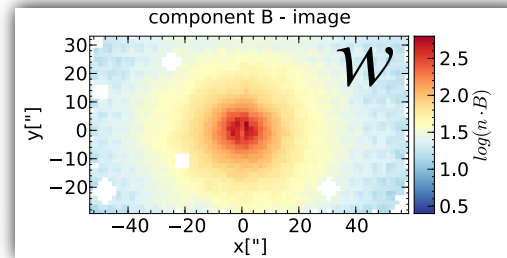
# Kinematic Sub-Components

## Case Study NGC 7217

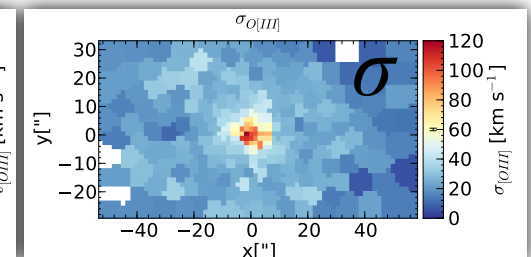
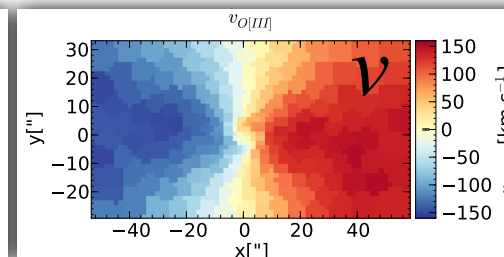
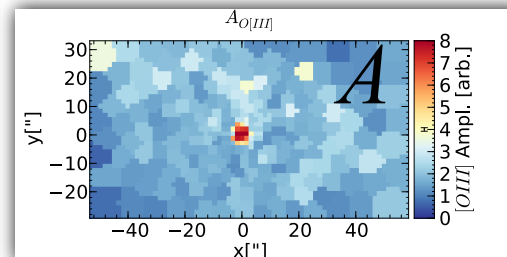
two component stars component A  
LOSVD



stars component B

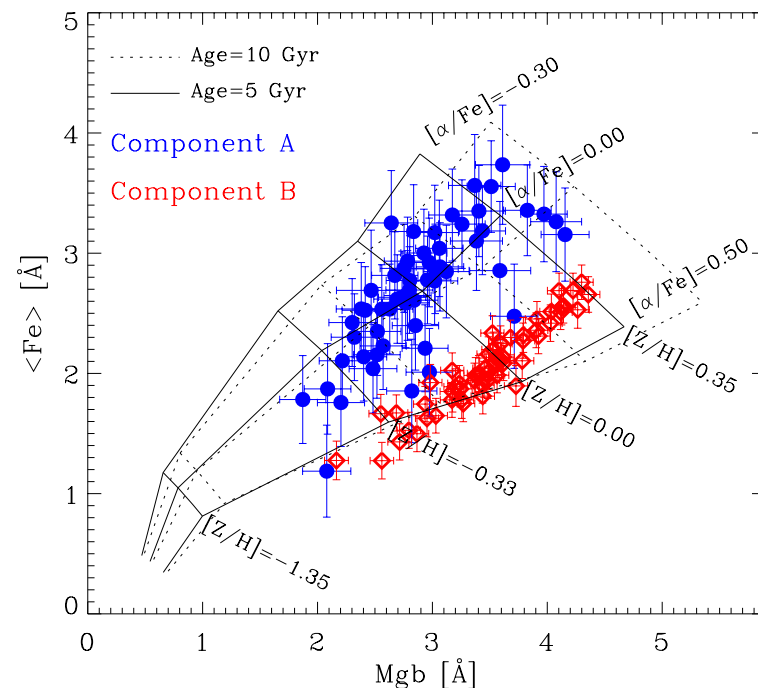
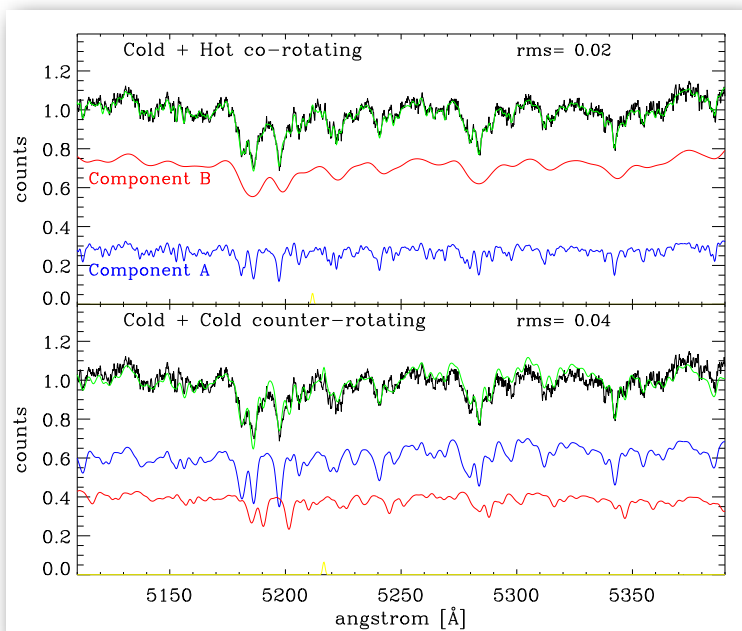


gas [O III]

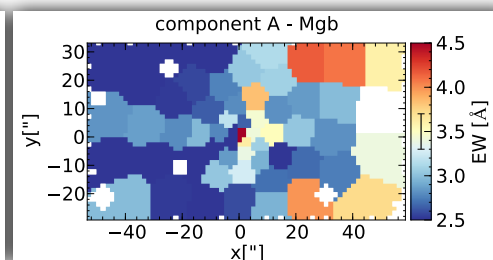
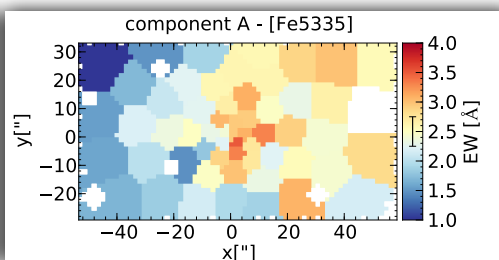
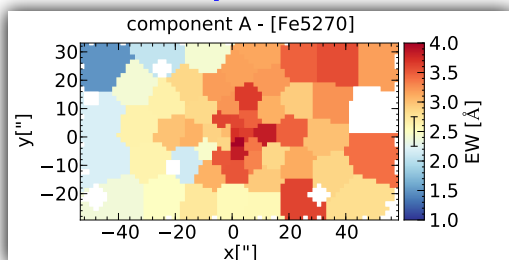


# Kinematic Sub-Components

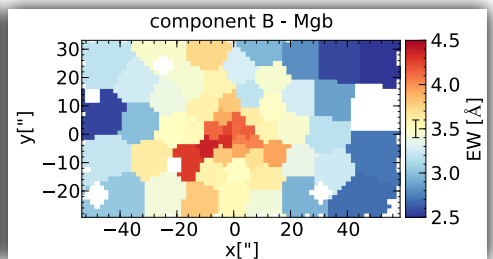
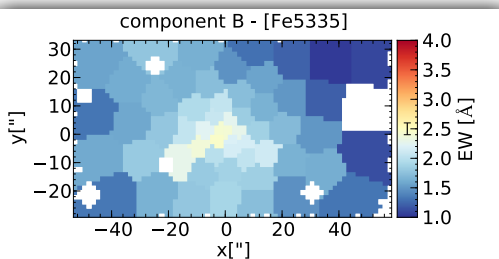
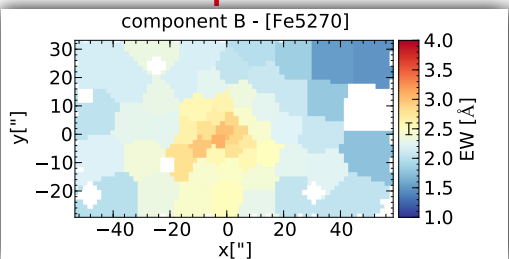
## Case Study NGC 7217



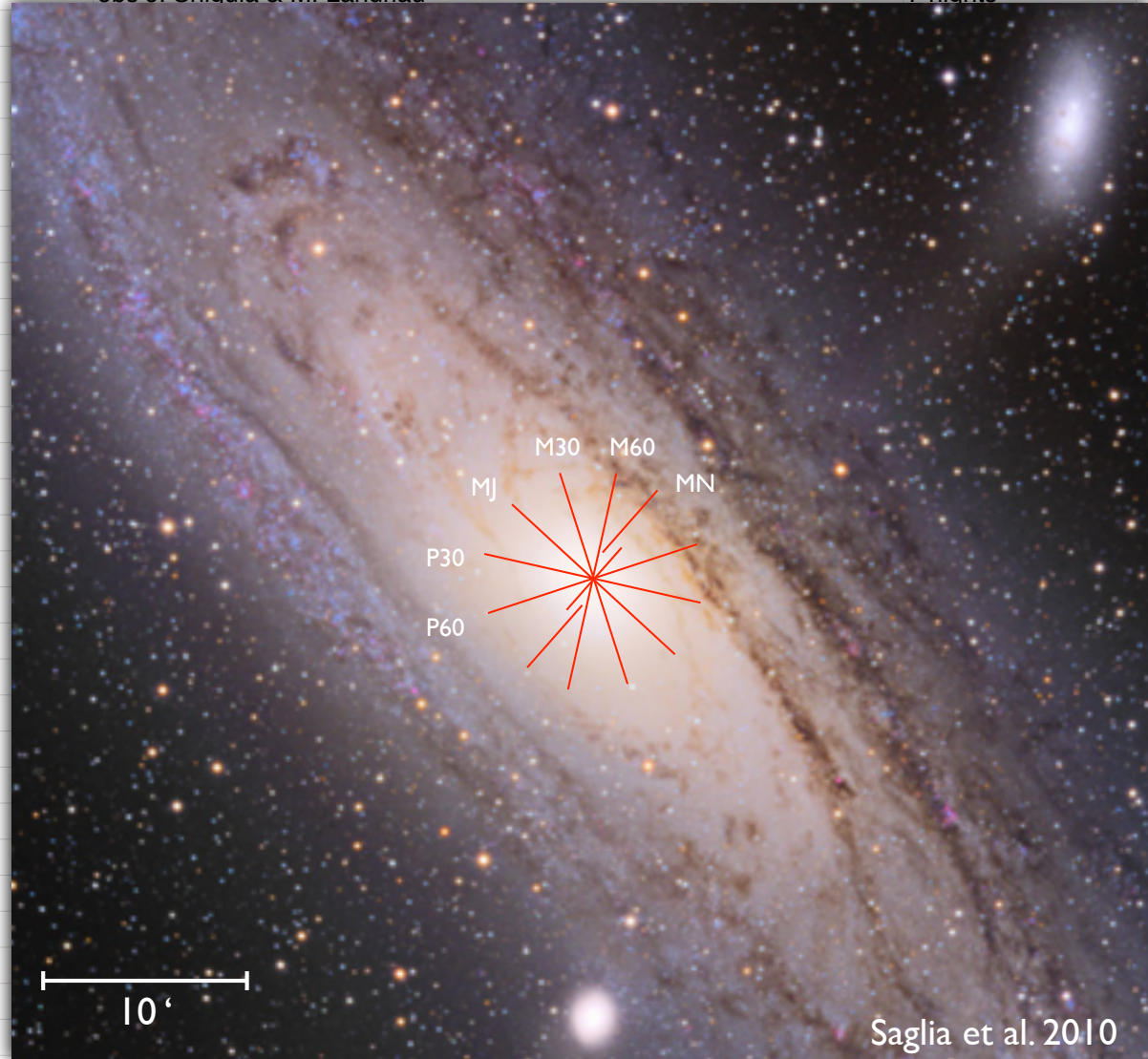
### stars component A



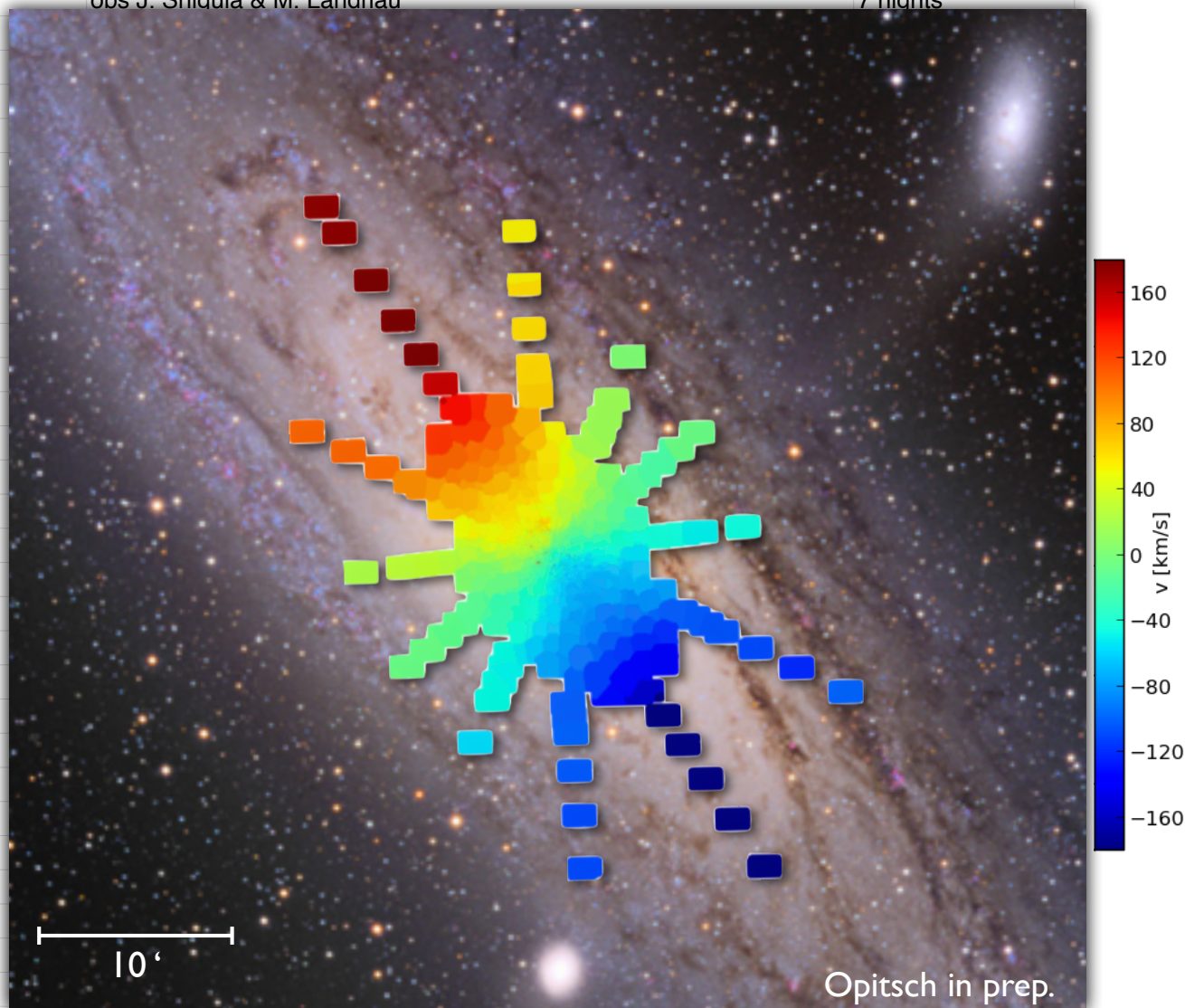
### stars component B



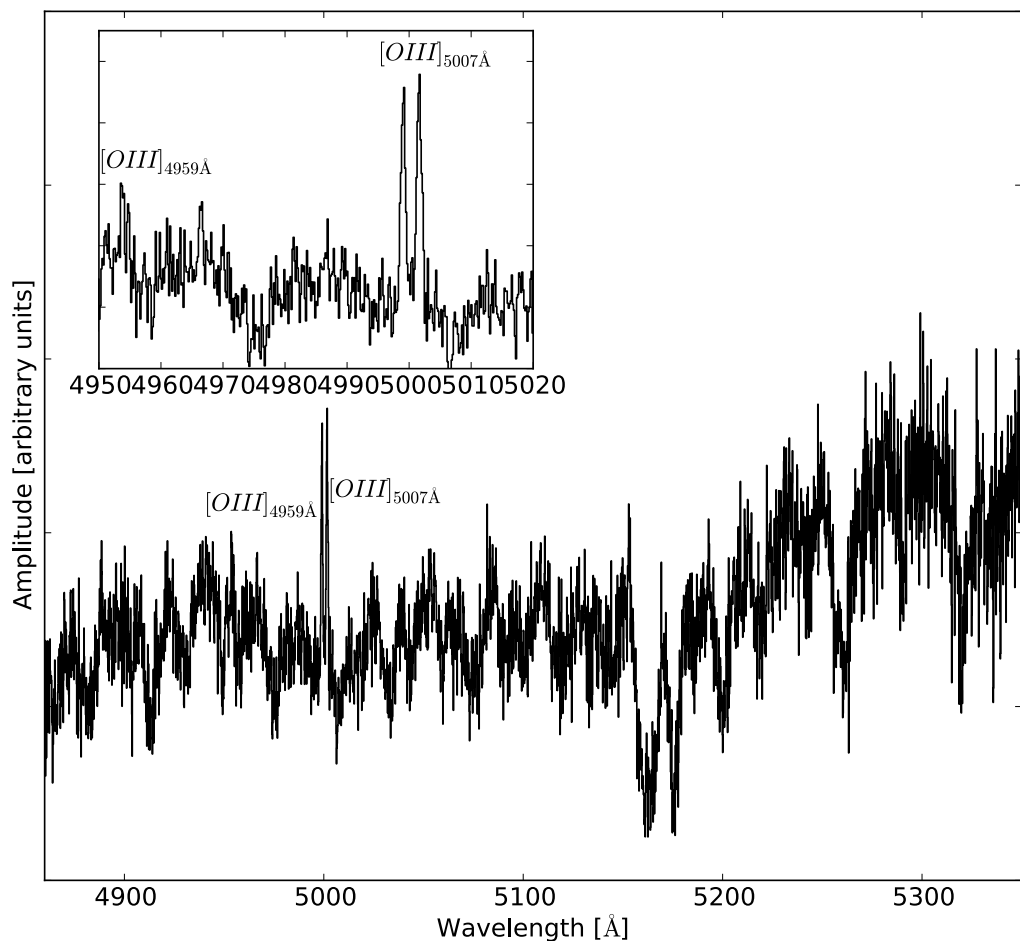
Nov10	comm	PI MF	obs MF+Drory+Singula+Wullstein	3 nights
Dec10	comm	PI MF	obs MF	5 nights
May11	bulges	PI MF	obs J. Sniqula & M. Landriau	7 nights
May11	Black Holes	PI Saglia		
Jun11	LSBs	PI JA		
Jul11	VENGA	PI TW		
Aug11	draco	PI Jardel		
Aug11	bulges	PI MF		
Aug11	LSBs	J. Adams		
Oct11	M31	PI RS		
Dec11	LSBs	PI J. Adams		
Jan12	VENGA	PI TW		
Feb12	VENGA	PI TW		
April12	dwarfs	PI MW		
May12	LSBs	PI J. Adams		
Jun12	bulges	PI MF		
Jun12	disk reson.	PI J. Gersen		
Aug12	M31 dwarfs	PI MF		
Okt12	M31	PI M. Opitsch		
Jan 13	LSBs	PI JA		
April 13	GCs	PI Rukdee		
April 13	counterrot	PI MF		
Sept 13	GCs	PI Rukdee		
Dec 13	medido	PI MF + EN		
Dec 13	medido	PI MF + EN		
Jan 14	medido	PI MF + EN		
Jan 14	disk dispersions	PI SA		
Feb 14	medido	PI MF + EN		
Mar 14	medido	PI MF + EN		
May 14	GCs	PI Rukdee		
May 14	disk dispersions	PI SA		
Jun 14	medido	PI MF + EN		
Jul 14	medido	PI MF + EN	obs Williams, Mazzalay, Thomas, Shetrone	7 nights
Aug 14	medido	PI MF + EN	obs Thomas, Shetrone	5 nights
Aug 14	GCs	PI MF	obs MF	8 nights



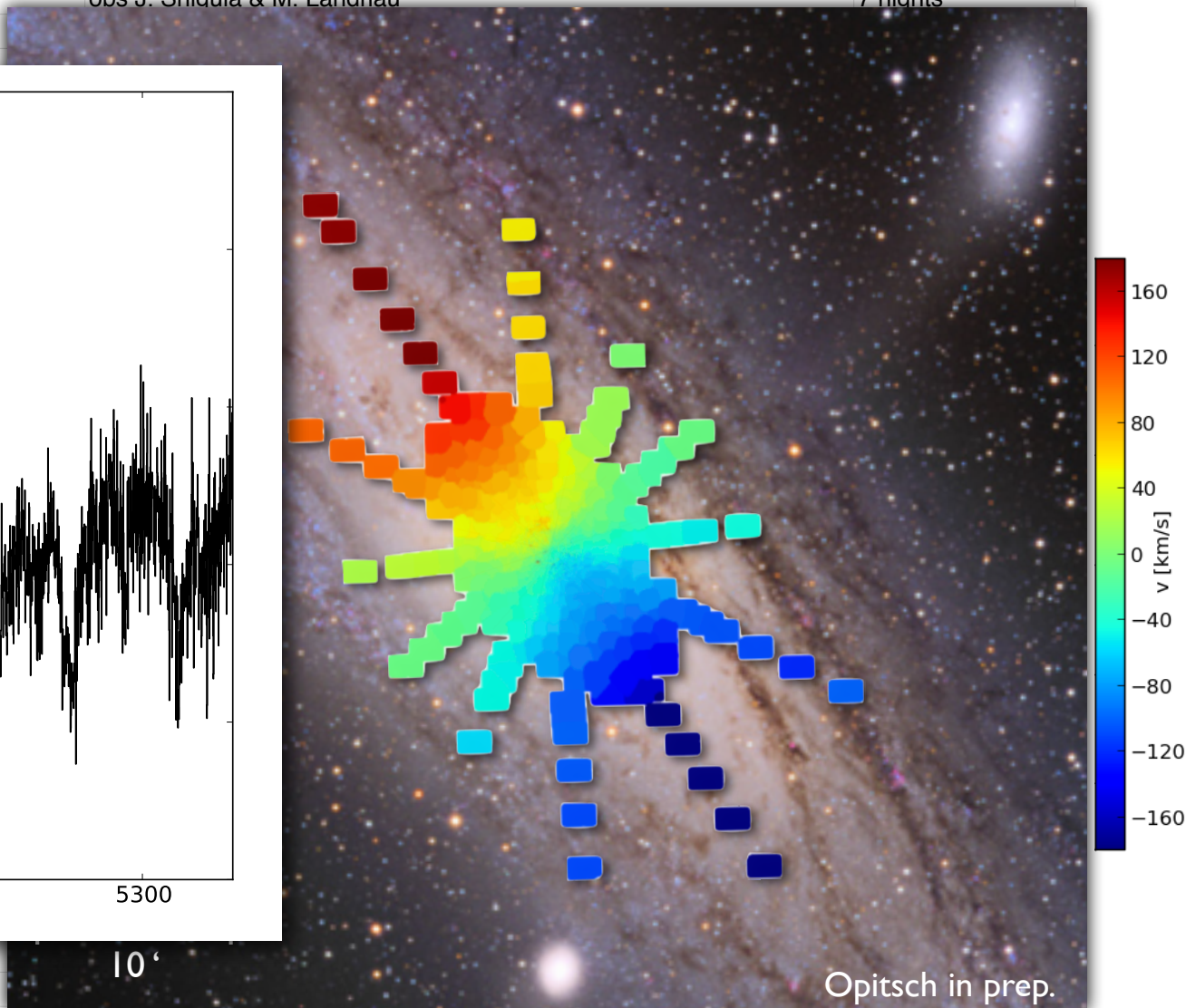
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Dec10	comm	PI MF	obs MF	5 nights
May11	bulges	PI MF	obs J. Snigula & M. Landriau	7 nights
May11	Black Holes	PI Saglia		
Jun11	LSBs	PI JA		
Jul11	VENGA	PI TW		
Aug11	draco	PI Jardel		
Aug11	bulges	PI MF		
Aug11	LSBs	J. Adams		
Oct11	M31	PI RS		
Dec11	LSBs	PI J. Adams		
Jan12	VENGA	PI TW		
Feb12	VENGA	PI TW		
April12	dwarfs	PI MW		
May12	LSBs	PI J. Adams		
Jun12	bulges	PI MF		
Jun12	disk reson.	PI J. Gersen		
Aug12	M31 dwarfs	PI MF		
Okt12	M31	PI M. Opitsch		
Jan 13	LSBs	PI JA		
April 13	GCs	PI Rukdee		
April 13	counterrot	PI MF		
Sept 13	GCs	PI Rukdee		
Dec 13	medido	PI MF + EN		
Dec 13	medido	PI MF + EN		
Jan 14	medido	PI MF + EN		
Jan 14	disk dispersions	PI SA		
Feb 14	medido	PI MF + EN		
Mar 14	medido	PI MF + EN		
May 14	GCs	PI Rukdee		
May 14	disk dispersions	PI SA		
Jun 14	medido	PI MF + EN		
Jul 14	medido	PI MF + EN	obs Williams, Mazzalay, Thomas, Shetrone	7 nights
Aug 14	medido	PI MF + EN	obs Thomas, Shetrone	5 nights
Aug 14	GCs	PI MF	obs MF	8 nights



Nov10	comm	PI MF	obs MF+Drory+Singula+Wullstein	3 nights
Dec10	comm	PI MF	obs MF	5 nights
May11	bulges	PI MF	obs J. Snigula & M. Landriau	7 nights
May11	Black Holes	PI Saglia		
Jun11	LCRs	PI LA		



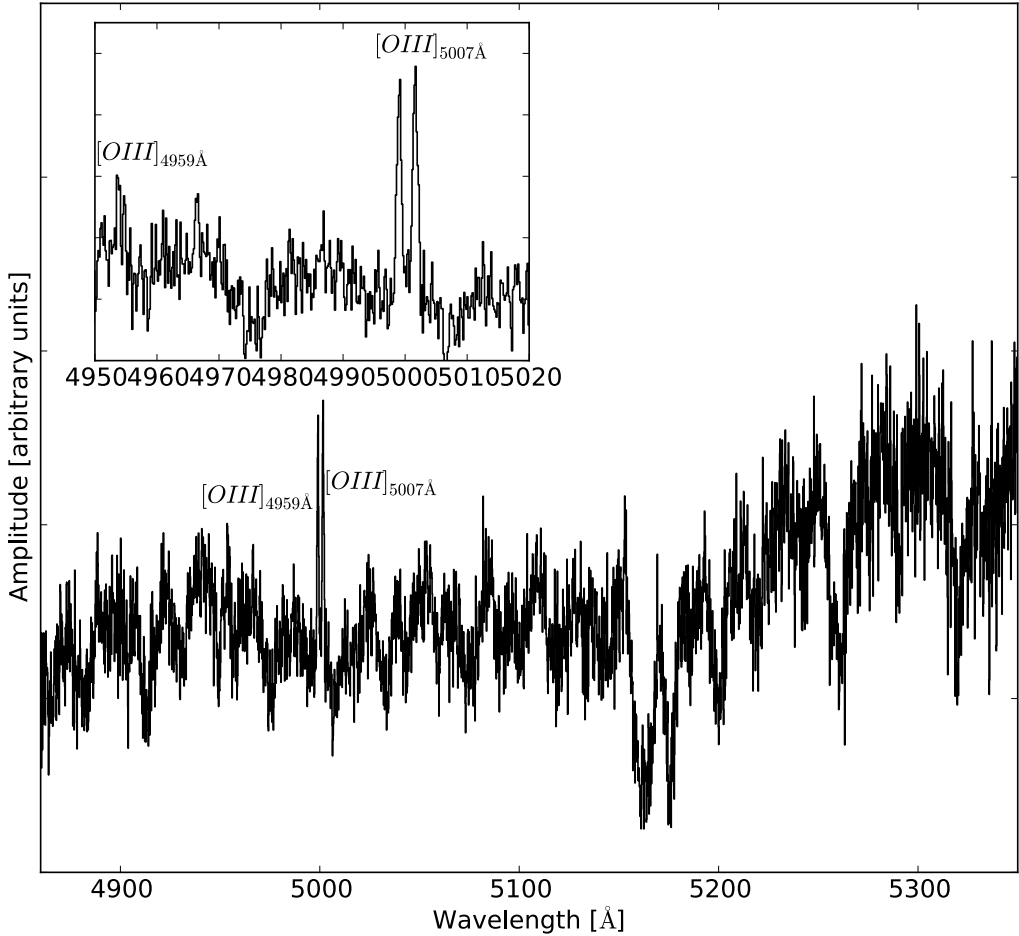
May 14	disk dispersions	PI SA		
Jun 14	medido	PI MF + EN		
Jul 14	medido	PI MF + EN	obs Williams, Mazzalay, Thomas, Shetrone	7 nights
Aug 14	medido	PI MF + EN	obs Thomas, Shetrone	5 nights
Aug 14	GCs	PI MF	obs MF	8 nights



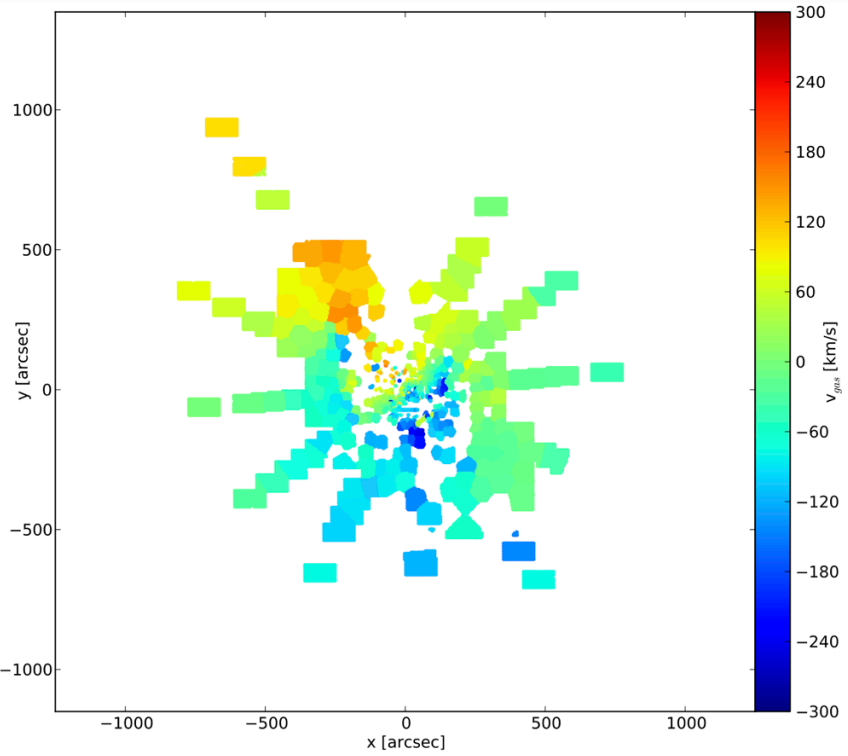
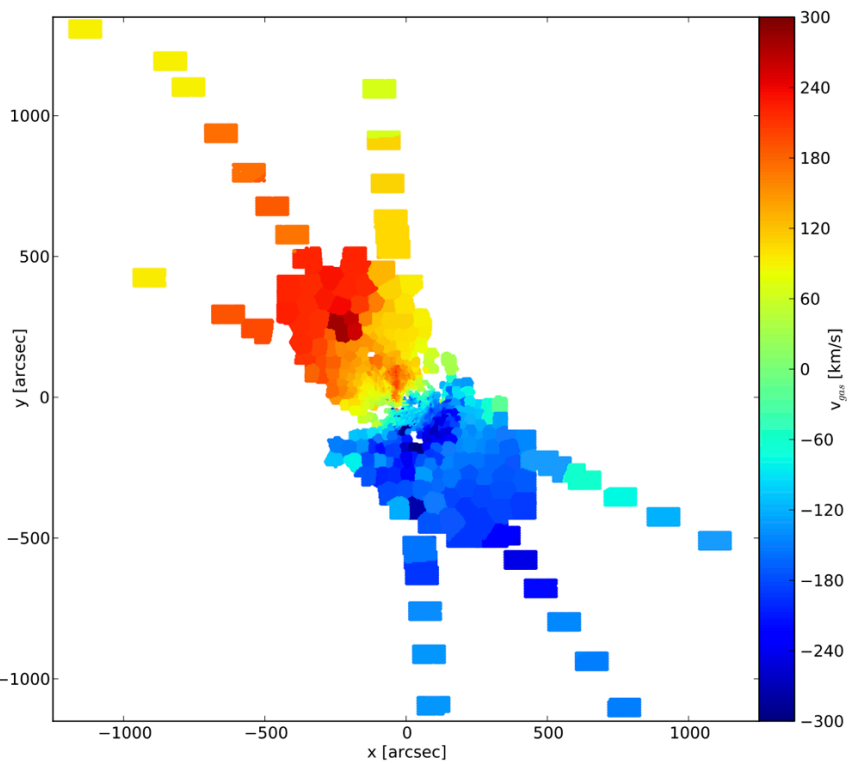


# VIRUS-W

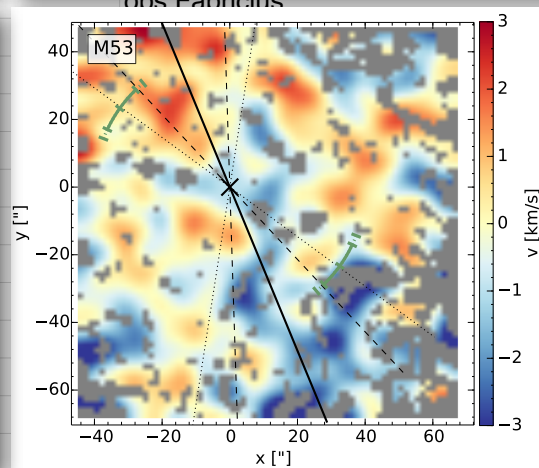
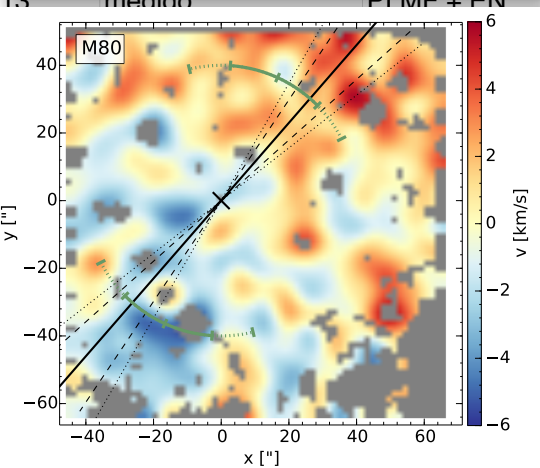
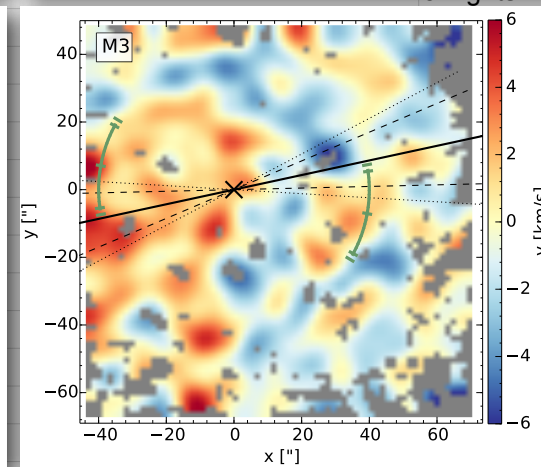
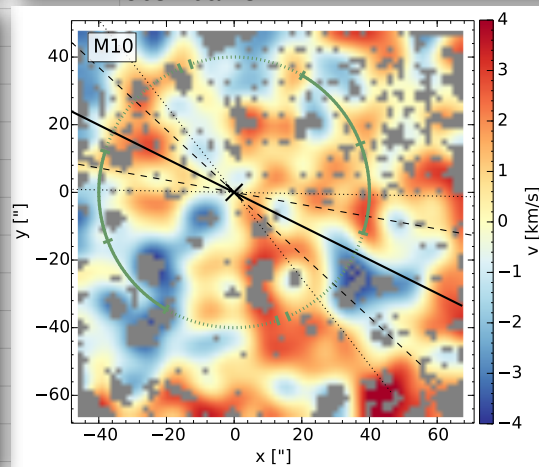
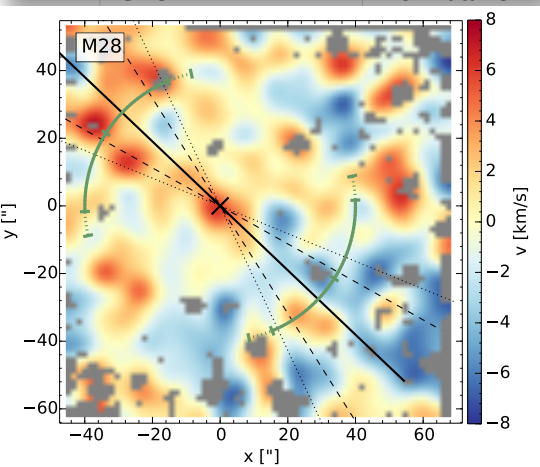
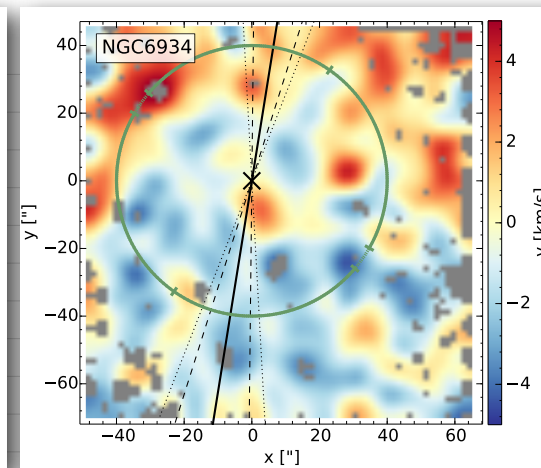
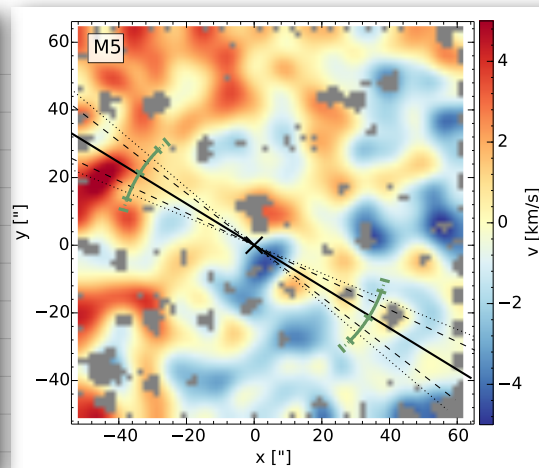
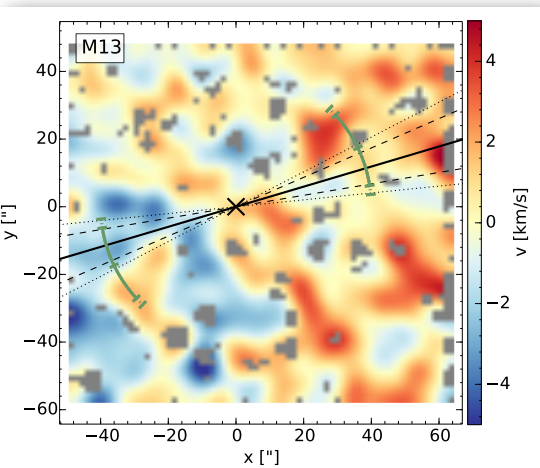
Nov10	comm	PI MF	obs MF+Drory+Singula+
Dec10	comm	PI MF	obs MF
May11	bulges	PI MF	obs J. Snigula & M. Lan
May11	Black Holes	PI Saglia	
Jun11	LCRs	PI LA	



May 14	disk dispersions	PI SA	
Jun 14	medido	PI MF + EN	
Jul 14	medido	PI MF + EN	obs Williams, Mazzalay,
Aug 14	medido	PI MF + EN	obs Thomas, Shetrone
Aug 14	GCs	PI MF	obs MF

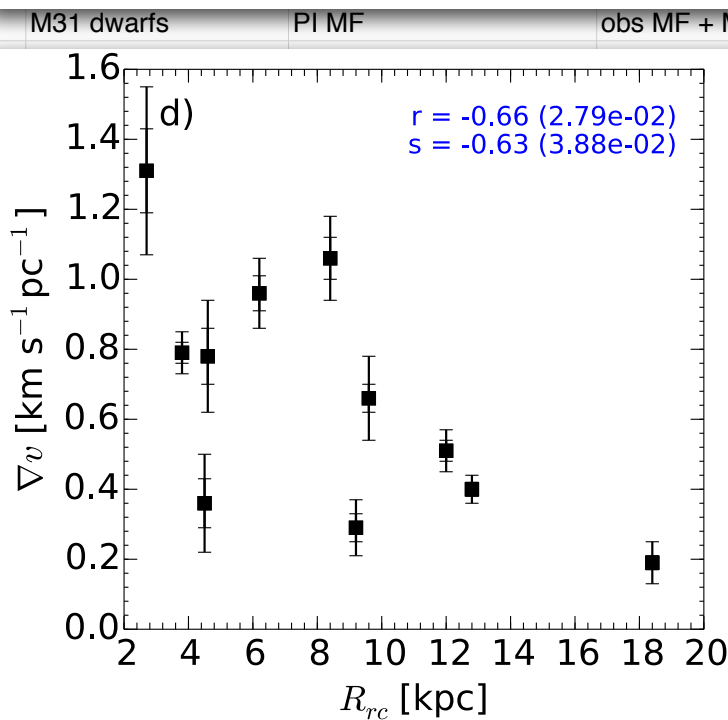
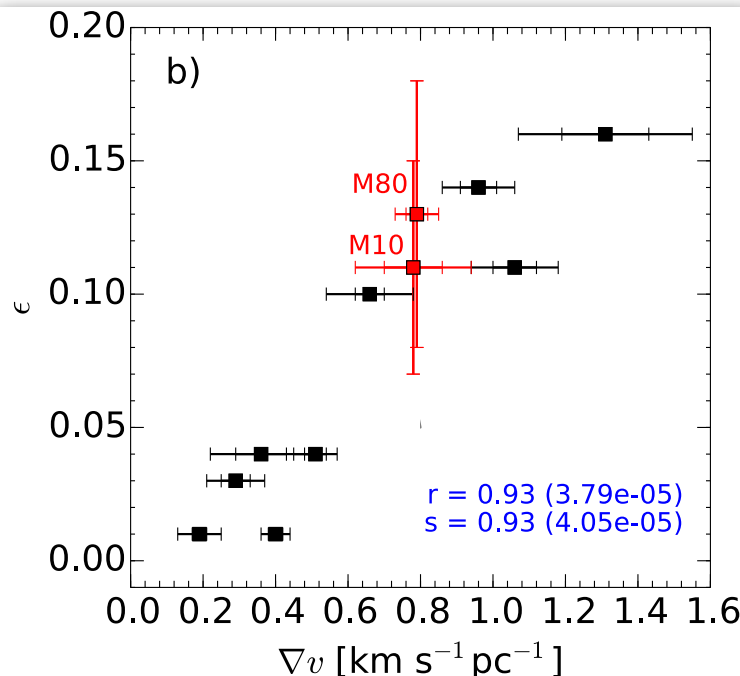
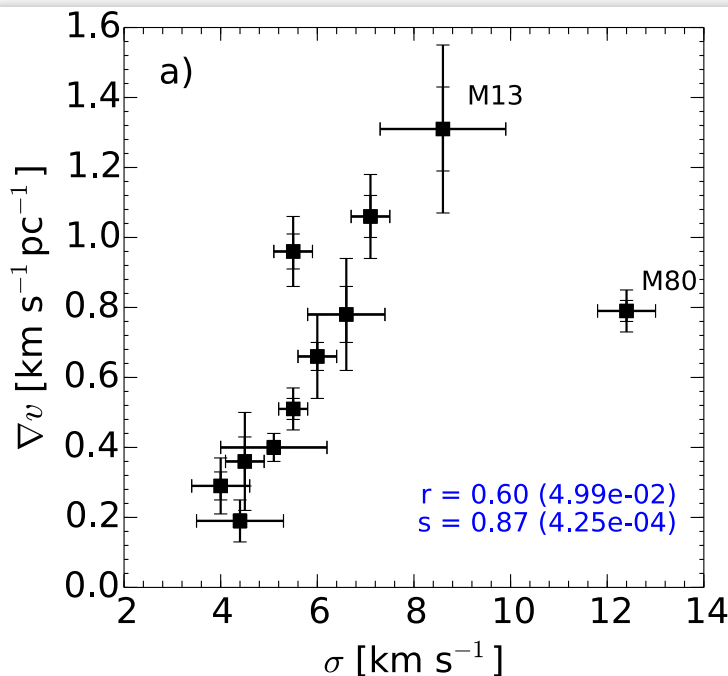


Nov  
Dec  
May  
May  
Jun1  
Jul1  
Aug  
Aug  
Aug  
Oct1  
Dec1  
Jan1  
Feb1  
April  
May  
Jun1  
Jun1  
Aug  
Okt1  
Jan  
April  
April  
Sept  
Dec 13  
Dec  
Jan  
Jan  
Feb  
Mar  
May  
May  
Jun  
Jul 1  
Aug  
Aug



7 nights  
5 nights  
3 nights  
3 nights  
5 nights  
4 nights  
5.5 nights  
3.5 nights  
3nights  
7 nights  
5 nights  
8 nights

Nov10  
Dec10  
May11  
May11  
Jun11  
Jul11  
Aug11  
Aug11  
Aug11  
Oct11  
Dec11  
Jan12  
Feb12  
April12  
May12  
Jun12  
Jun12  
Aug12  
Okt12  
Jan 13  
April 13  
April 13  
Sept 13  
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May 14  
Jun 14  
Jul 14  
Aug 14  
Aug 14



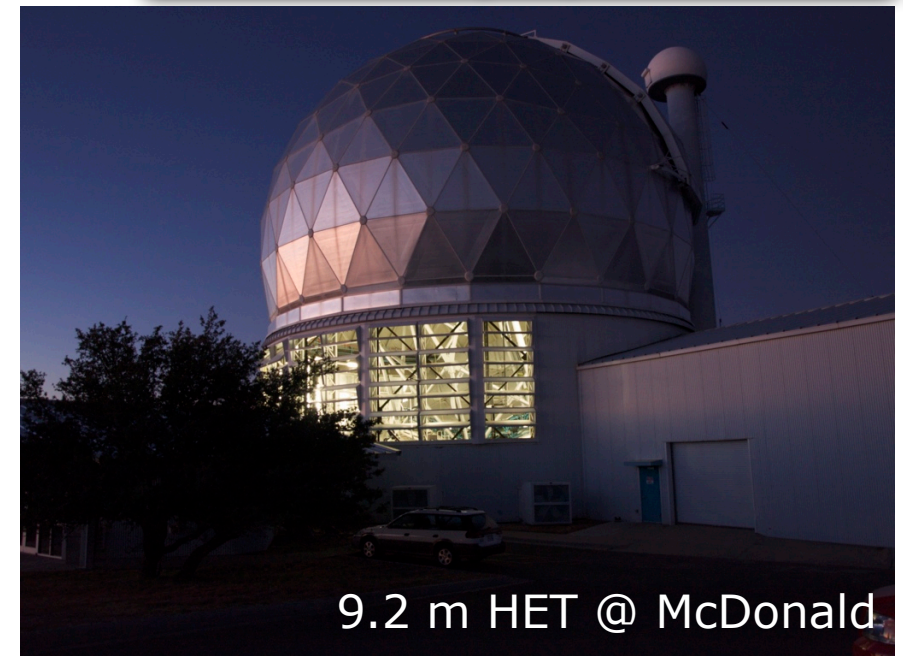
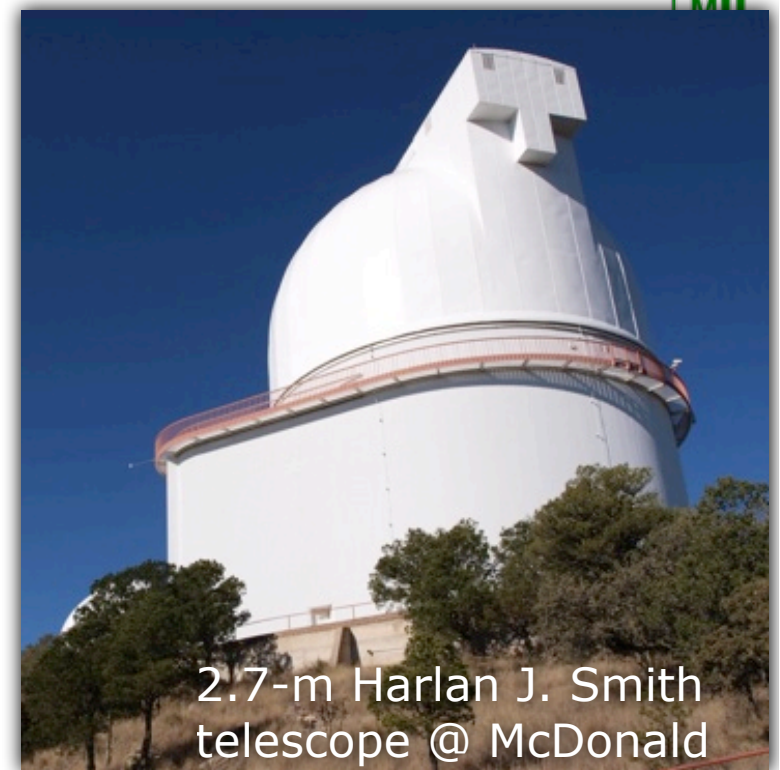
M31 dwarfs	PI MF	obs MF + M. Opitsch	
		ia + M. Opitsch	3 nights
		is	3 nights
		is	6 nights
		+ MF	3.5 nights
		. Opitsch	3.5 nights
		+ M. Opitsch	5 nights
		is	7 nights
		dt + Shetrone + Mueller	5 nights
		ie	3 nights
			3 nights
		is + Noyola + Mueller	5 nights
		?	4 nights
		sch	5.5 nights
			3.5 nights
			3nights
		s, Mazzalay, Thomas, Shetrone	7 nights
		s, Shetrone	5 nights
			8 nights

total: 186 nights



# Conclusions

- Fibers are now a standard to construct IFU, essentially all ongoing and upcoming optical 3D surveys (CALIFA, SAMI, MANGA, HETDEX ...) use fiber IFUs.
- Instruments are becoming increasingly modular (MUSE, KMOS, PFS), with VIRUS/HETDEX  $\sim 10$ -folding current concepts.
- HETDEX uses 150 units in a blind spectroscopic survey for LyA source in the distant universe.
- HETDEX will start observing summer 2015.
- VIRUS-W's design is derived from the HETDEX survey instrument.
- VIRUS-W is a high resolution, large FoV IFU instrument dedicated to stellar dynamics.
- Commissioned at 2.7m in Nov. 2010, regular science operation commences.
- Does resolve dispersions down to 15 km/s. Offers an additional stellar populations mode.
- Gives access to complex LOSVDs at low velocity dispersions.





Thank you!