Frontier Science Enabled by a Giant Segmented Mirror Telescope

Rolf-Peter Kudritzki [1] for
the GSMT Science Working Group

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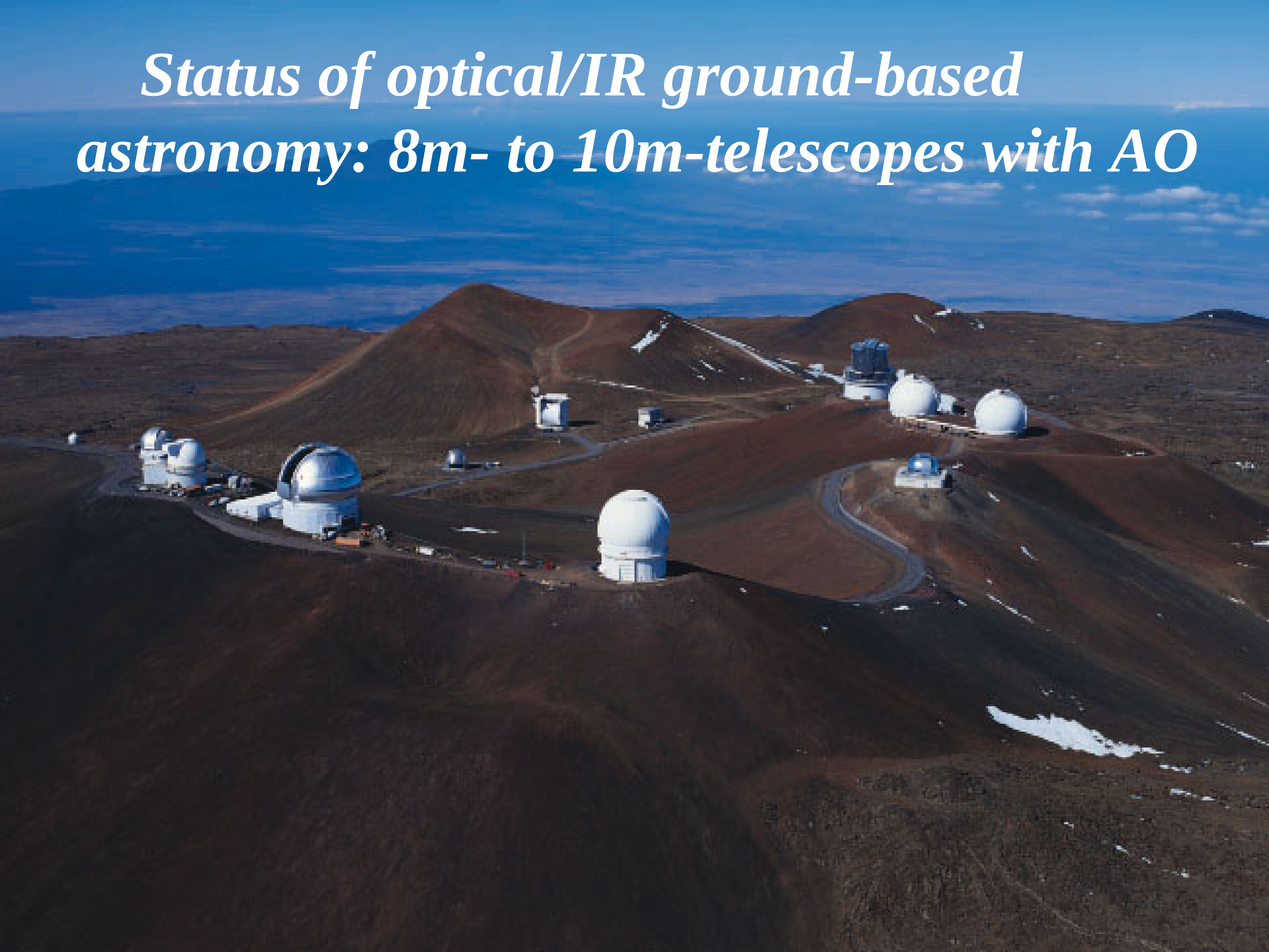
Institute for Astronomy, University of Hawaii

http://www.aura-nio.noao.edu/gsmt_swg/SWG_Report/SWG_Report_7.2.03.pdf

Status of optical/IR ground-based astronomy: 8m- to 10m-telescopes with AO



Giant Segmented Mirror Telescope

- Top priority of NAS/NRC 2001 decadal survey
  - 30m segmented primary mirror
  - 10x gain in light gathering power (sensitivity)
  - Diffraction limited, Adaptive Optics (AO),
  - 3x gain in angular resolution (image sharpness)
  - Projected costs ~ $ 700 M
  - Private/public/international partnership recommended for funding

Two incarnations of the GSMT

- **TMT – 30m segmented mirror (≈ Keck)**

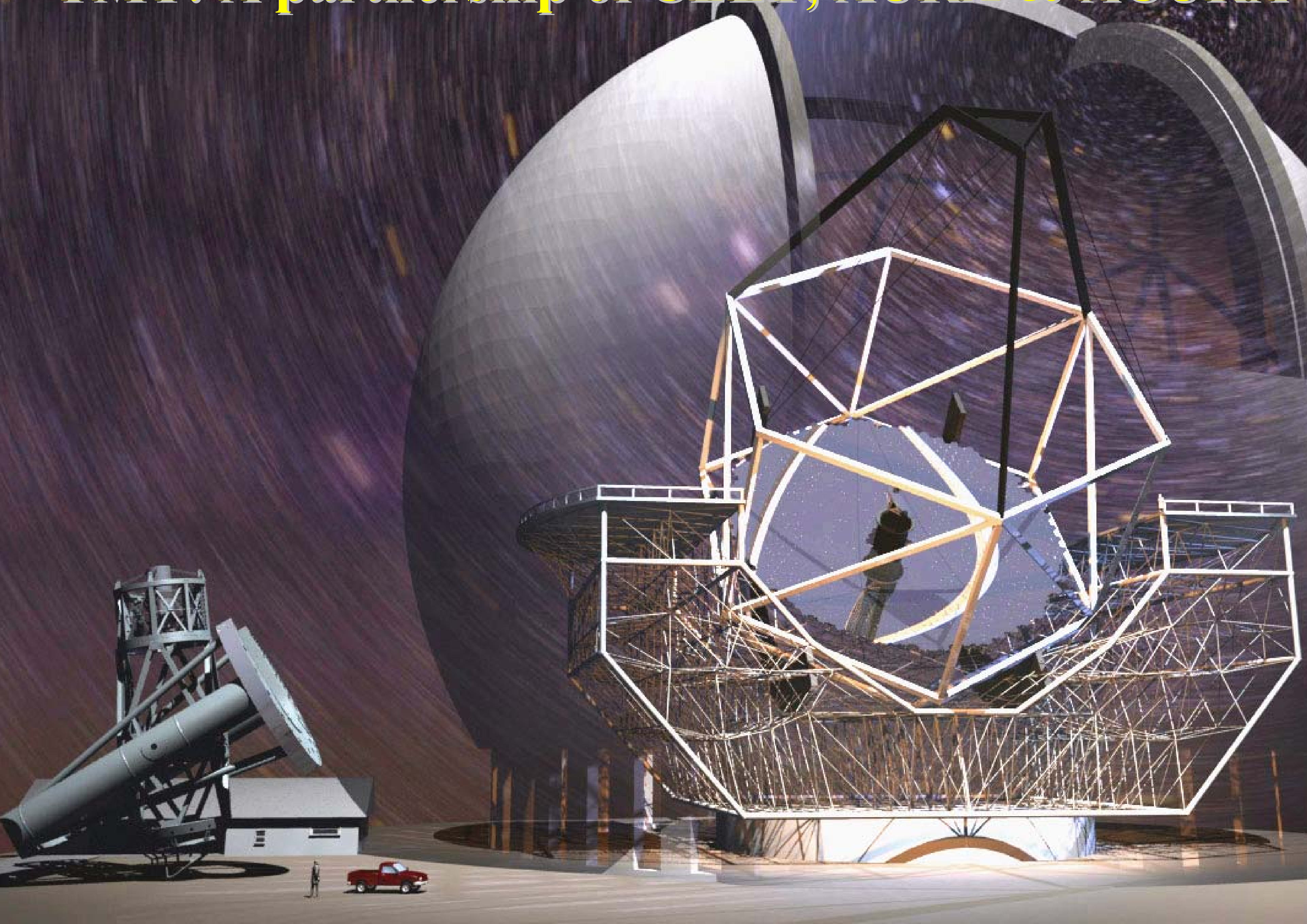
  UC, Caltech, AURA, ACURA

- **GMT – 20m consisting of seven 8.2m segments**

  spatial resolution ≈ 25m

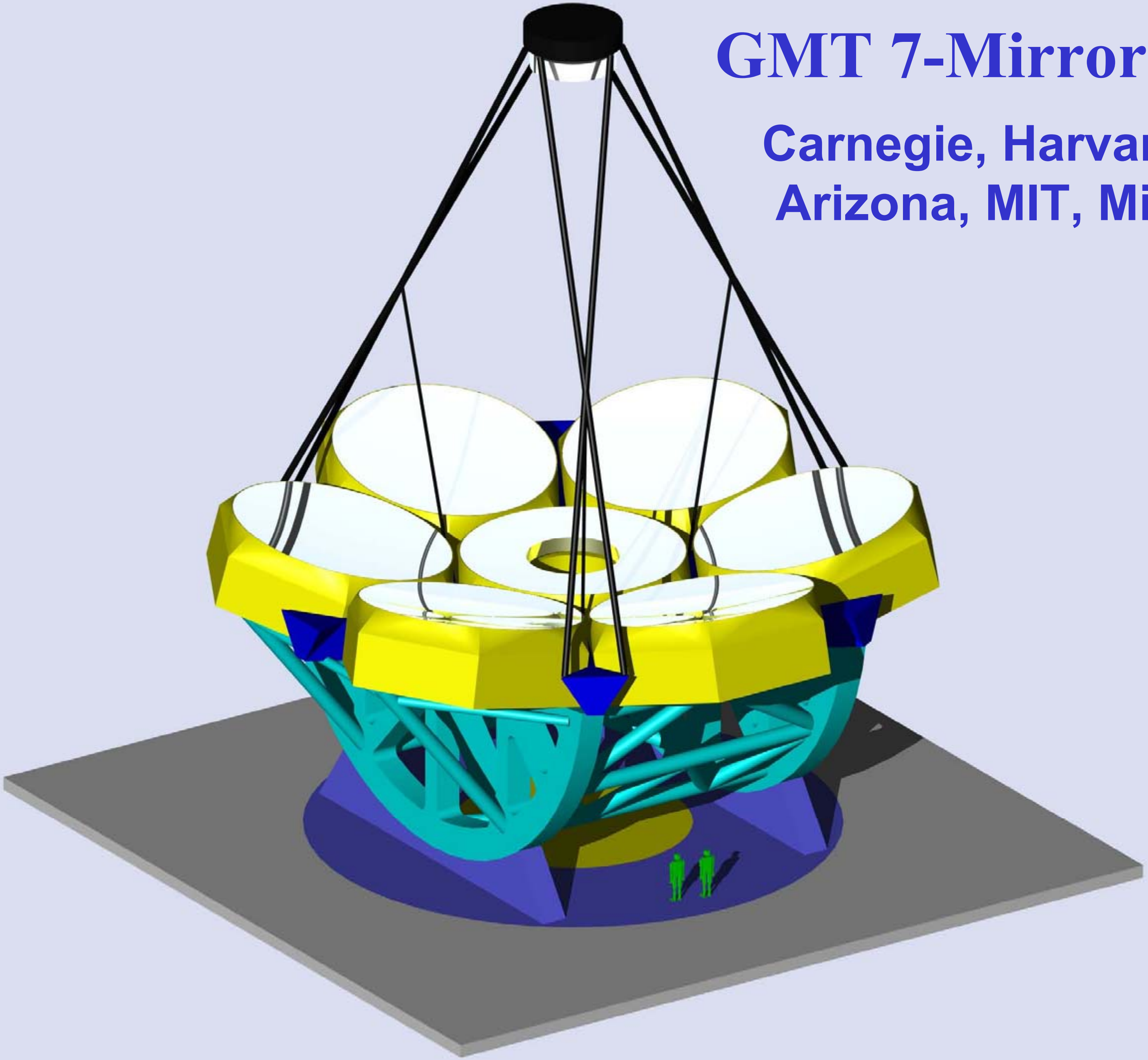
  Carnegie, Harvard, Arizona, MIT, Michigan

TMT: A partnership of CELT, AURA & ACURA



GMT 7-Mirror Concept

Carnegie, Harvard/Smiths.,
Arizona, MIT, Michigan



GSMT Science Working Group

Formed July, 2002, by NOAO on request by the NSF

- Identify forefront astrophysical science likely to emerge over next decade
- Science potentially enabled by GSMT
- Design options that can achieve science
- Technologies to be advanced or developed
- Inform the NSF about investments needed
- Become communities advocate in private/public partnerships
- Establish working relationships with groups in Australia, Canada, Europe, Japan, Mexico

GSMT SWG Members

Chair: Rolf-Peter Kudritzki, UH IfA
Vice-Chair: Steve Strom, NOAO

SWG Members:

- Jill Bechtold -- UA
- Mike Bolte -- UCSC
- Ray Carlberg -- U Toronto
- Matthew Colless -- ANU
- Irena Cruz-Gonzales -- UNAM
- Alan Dressler -- OCIW
- Betsy Barton -- UA
- Terry Herter -- Cornell
- Mansanori Iye -- NOAJ
- Paul Ho -- CfA
- Jonathan Lunine -- UA LPL
- Claire Max -- UCSC
- Chris McKee -- UCB
- Francois Rigaut -- Gemini
- Doug Simons -- Gemini
- Chuck Steidel -- Caltech
- Kim Venn -- Macalester

http://www.aura-nio.noao.edu/gsmt_swg/

SWG activity

- **Five meetings (plus telecons), July 2002 through February 2004**
- **Identification of most important science themes for the next decades (input from SWG members, decadal survey, "Connecting Quarks to Cosmos")**
- **Reports from AO and instrumentation experts**
- **Presentations by four principal telescope design groups: University of Hawaii, Magellan 20 (Carnegie, Harvard, Arizona, Michigan, MIT), LAT (Cornell, Illinois, Chicago, Northwestern), CELT (Caltech, UC)**
- **First report published on June 30, 2003**
- **All activity documented under**

http://www.aura-nio.noao.edu/gsmt_swg

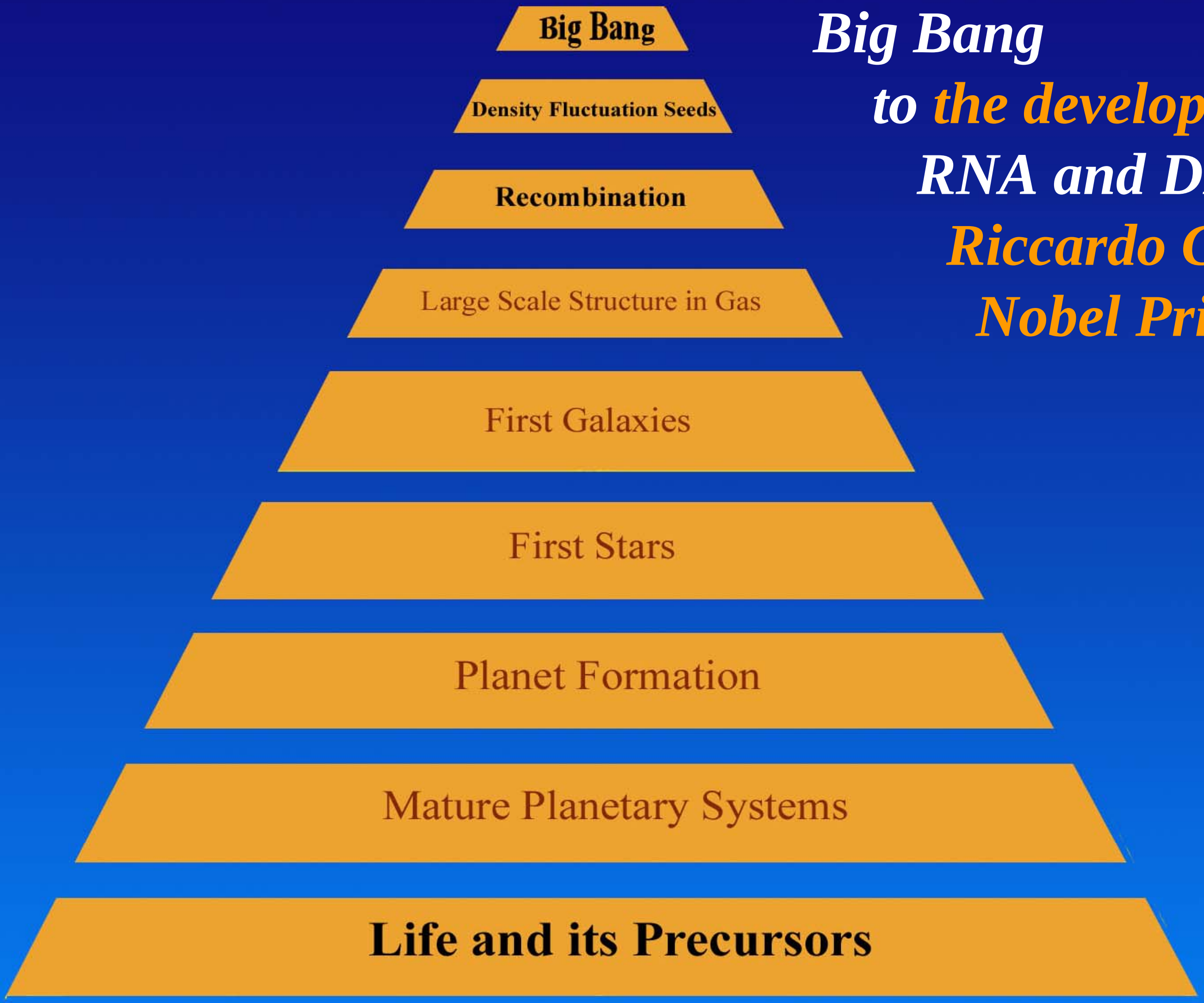
SWG activity

- two meetings with NSF and presentations of report
- presentation of report to CAA of Academy of Sciences
- information session at Seattle AAS meeting 2003
- participation at NOAJ ELT meeting, Tokyo, Jan. 2004
- meeting with ESO SWG, Berlin, May 2004
- contact with JWST SWG
- special session at San Diego AAS meeting Jan. 2005
- all activity documented under

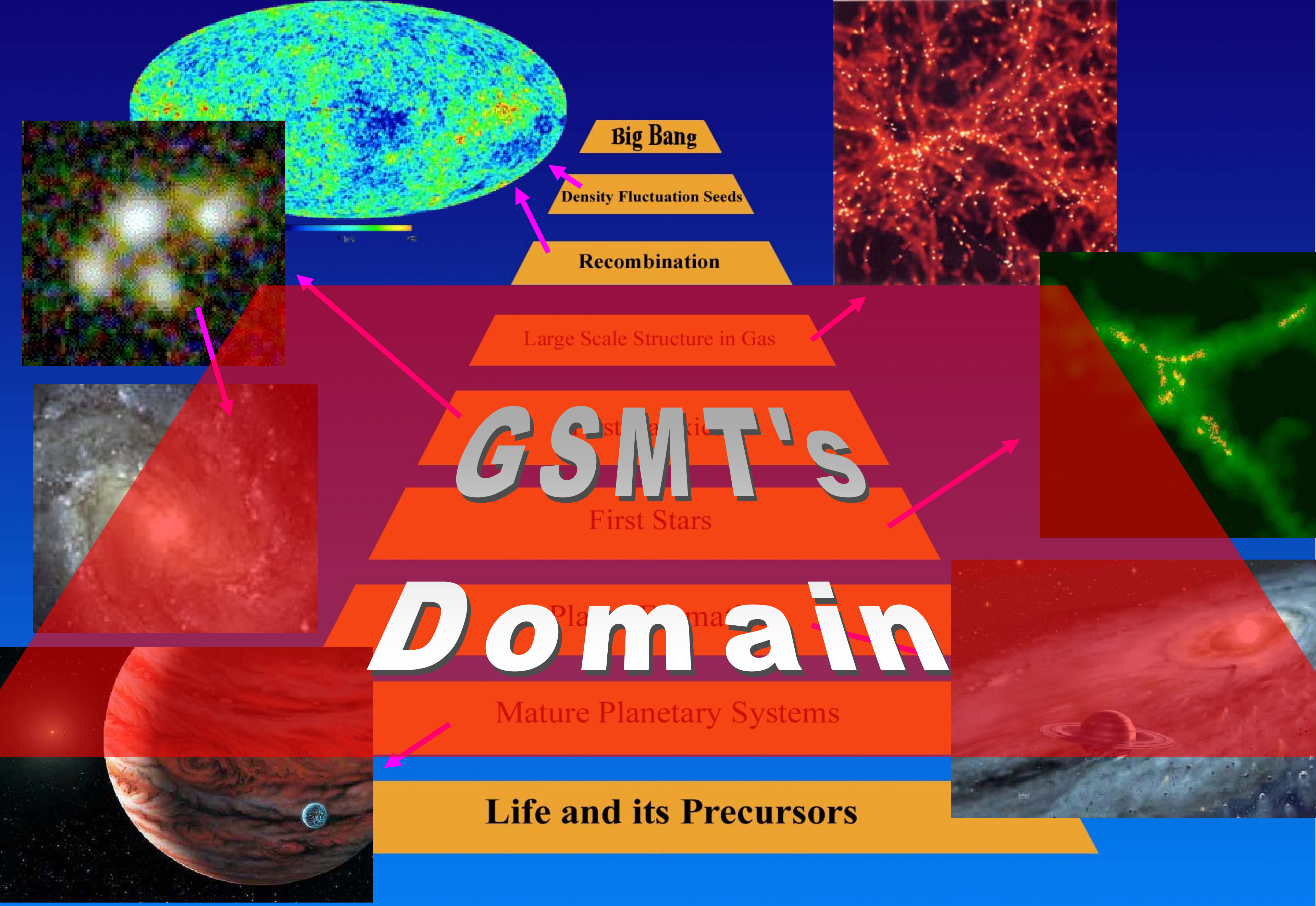
http://www.aura-nio.noao.edu/gsmt_swg

“21st century astronomy is uniquely positioned to study the evolution of the universe in order to relate causally the physical conditions of the Big Bang to the development of RNA and DNA”

Riccardo Giacconi
Nobel Prize, 2002



Connecting the First Nanoseconds to the Origin of Life



Connecting the First Nanoseconds to the Origin of Life

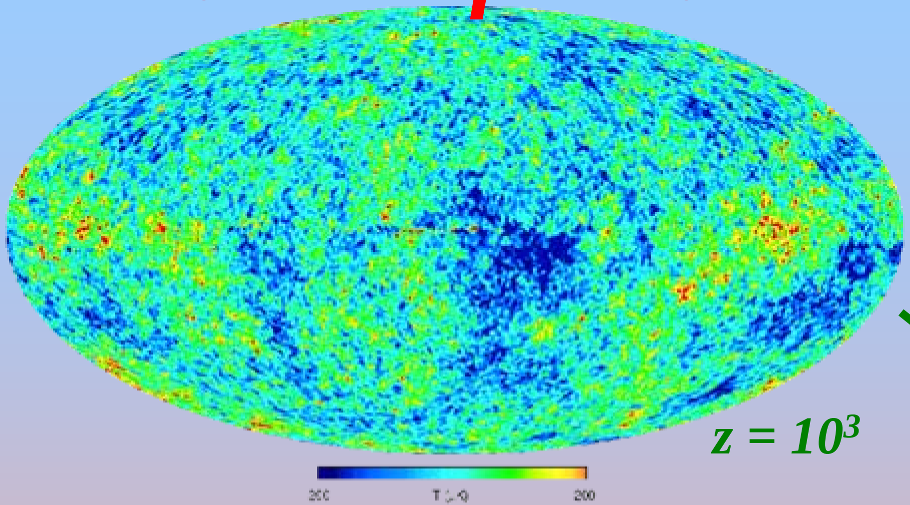
Science Enabled by GSMT

- **3-D map of galaxies and IGM over $2.5 < z < 4.5$**
  - Redshift survey of 10^6 galaxies in 3×10^8 Mpc^3 co-moving volume
  - High resolution spectra of IGM absorption spectra
    - Determine 3-dimensional distribution of gas and galaxies
    - Track evolution of metal abundance & relate to galactic activity
- **Star formation at $z > 7$**
  - Deep near-IR imaging with MCAO
    - Detect Lyman break galaxies or Ly-α emitters
    - Follow up spectroscopy to disentangle physical properties
- **Observing the galaxy assembly process**
  - Integral field unit spectra of pre-galactic fragments at $2.5 < z < 4.5$
  - MCAO imaging and spectroscopy of nearby galaxies
    - Determine age and stellar kinematics; measure mass directly
    - Quantify star formation activity and chemical composition
    - Disentangle populations; age and distribution of chemical composition of merger remnants distributed in nearby galaxy halos

Science Enabled by GSMT

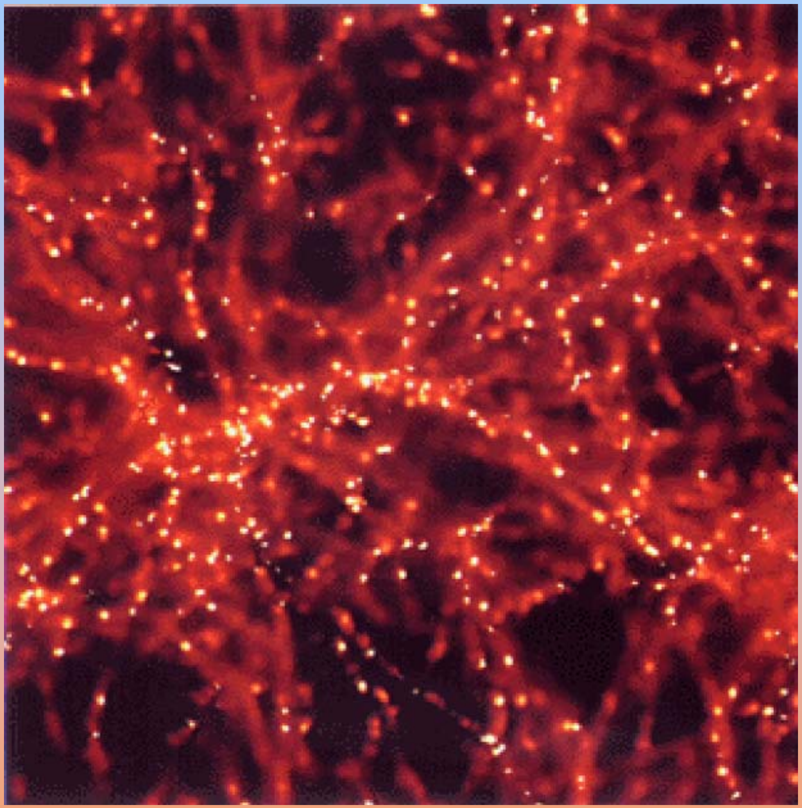
- **Understanding where and when planets form**
  - Ultra-high resolution mid-IR spectra of ~1000 accreting PMS stars
    - Physics of proto-planetary disks
    - Infer planetary architectures via observation of “gaps” in disks
- **Detecting and characterizing mature planets**
  - Extreme AO coronography; spectroscopy of giant extra-solar planets out to 70 pc
  - Physical properties of planets, chemical composition

Evolution of the universe - theoretical scenario

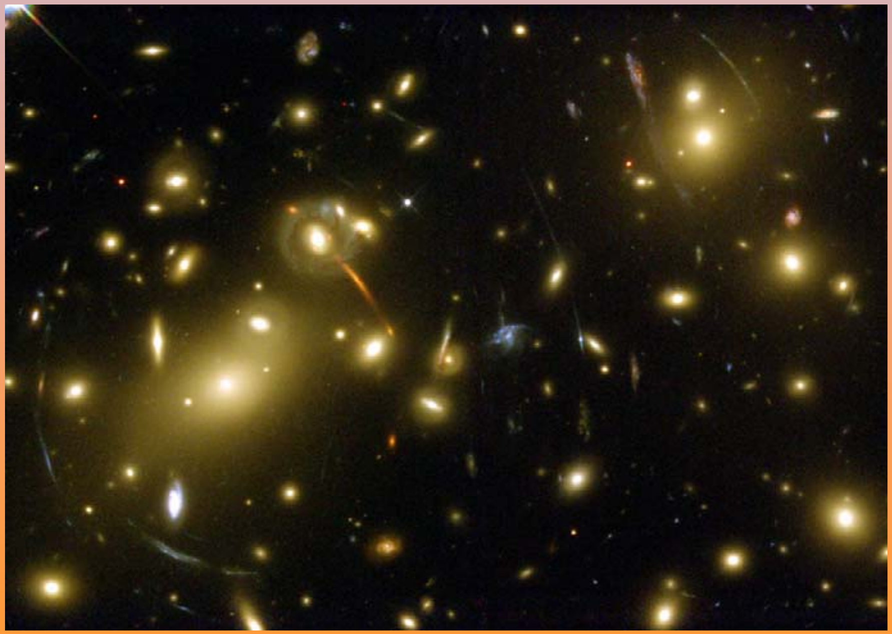


z = 10^3

z = 3.5



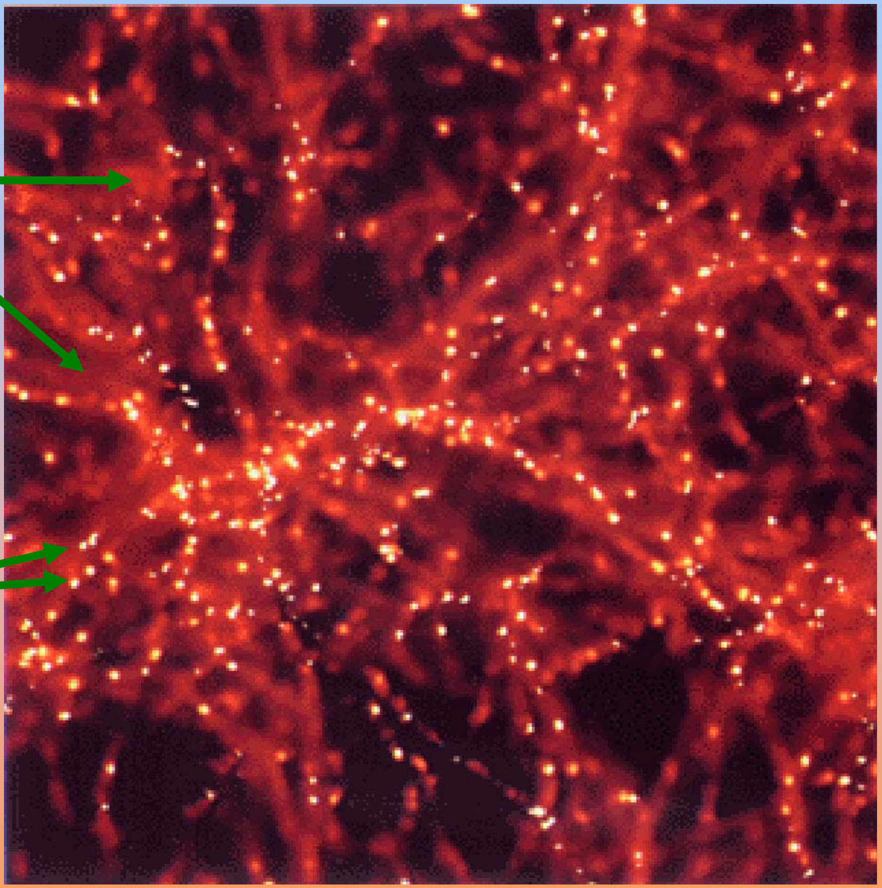
z = 0.5



Numerical simulation (L. Hernquist) showing the cosmic web of intergalactic gas and dense proto-galactic clumps

Predicted cosmic web of intergalactic gas and galaxies at z = 3.5

Intergalactic gas



Structure depends strongly on nature of
dark matter
dark energy

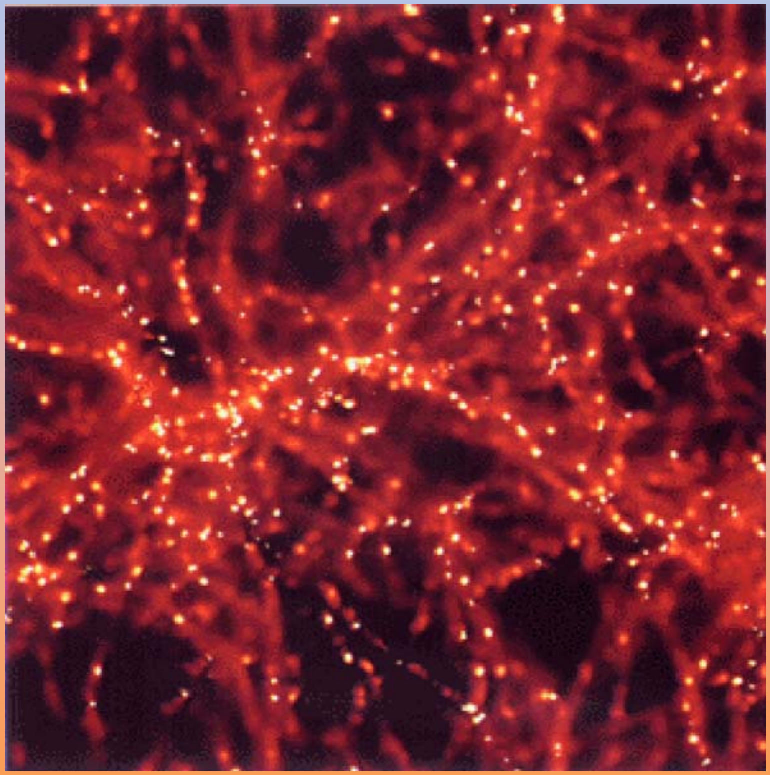
High density clumps concentrated by dark matter → galaxies

We need to observe 3D-structure of cosmic web at z = 3.5

GSMT will have the power to reveal the 3D-structure and physics of the cosmic web!!

Tomography of the universe at 12 billion lyr

Survey 5º × 5º ~ 600Mpc × 600 Mpc × 900Mpc @ 2.5 < z < 4.5



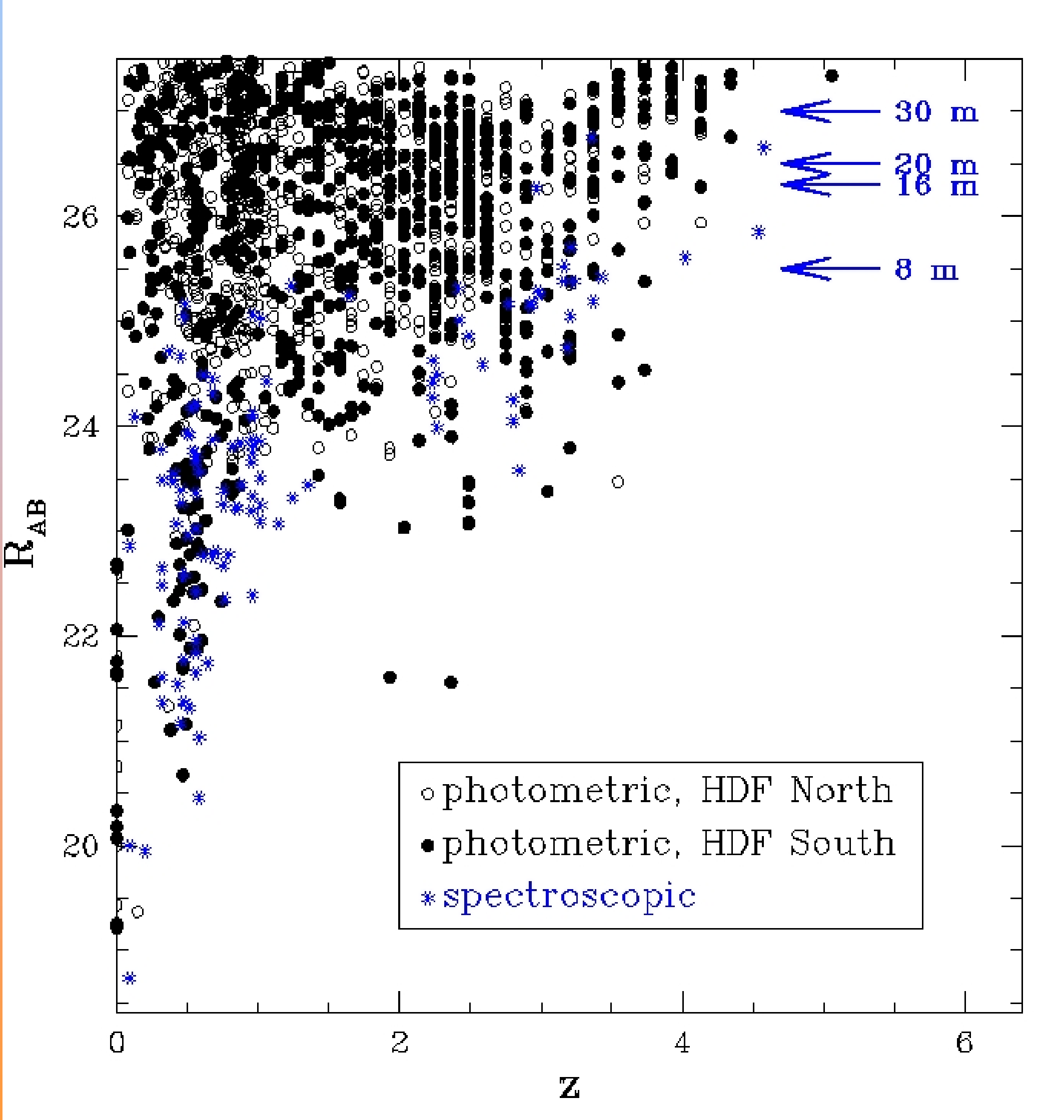
10^6 galaxies down to m_R = 26.5
low resolution spectra
→ redshifts, 3D-distribution,
distribution of dark matter

10^4 galaxies down to m_R = 24.0
as background sources
to probe intergalactic gas
high resolution spectra
→3D-distribution and chemical
composition of gas

Only GSMT can take spectra of these faint objects !!!

Sensitivity is vital for a survey down the luminosity function

R_{AB}

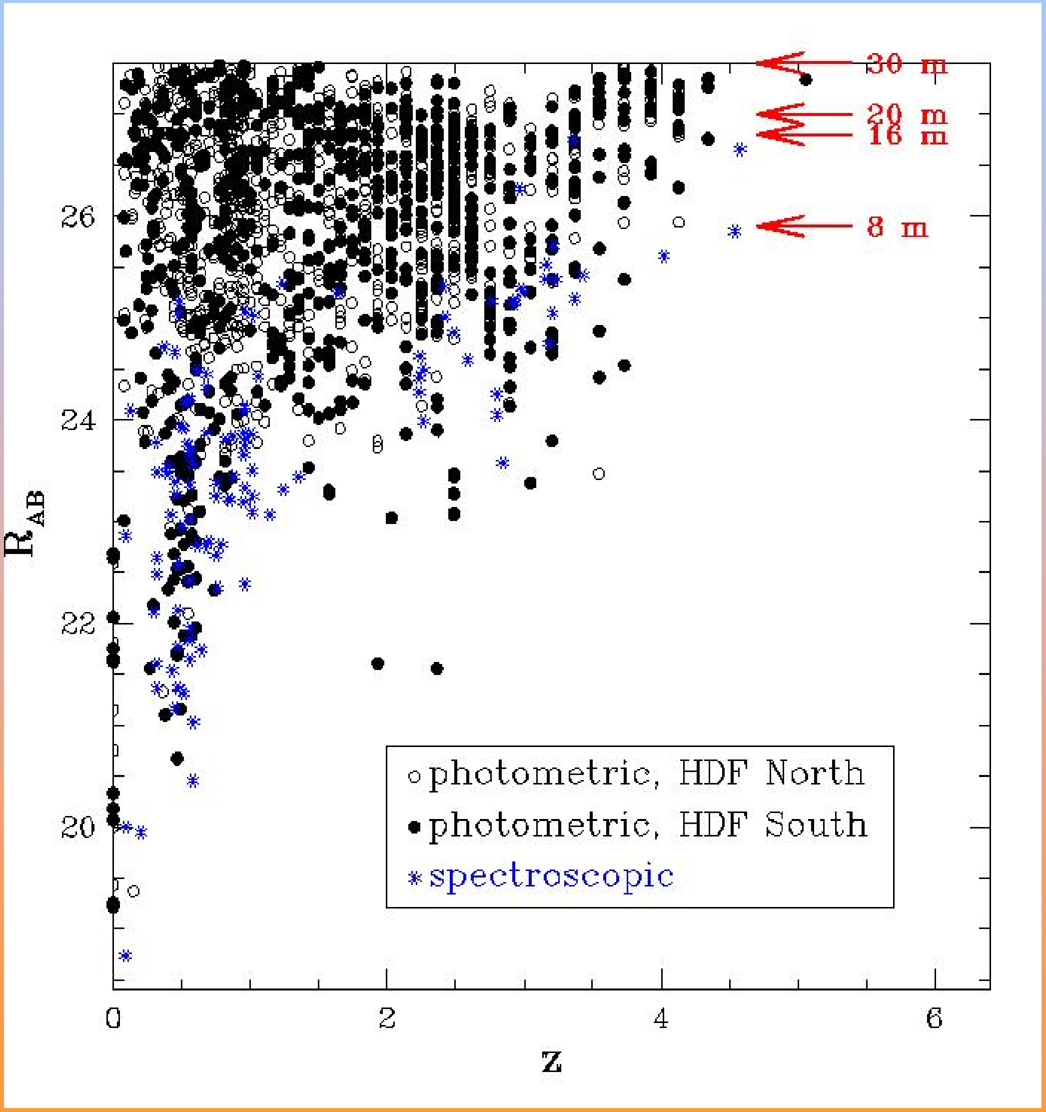


PHOTOMETRIC REDSHIFT

- **S/N=3 limits**
- **$t_{exp} = 10^4$ s**
- **FWHM = 0.5”**

Major advantages with some GLAO correction over the wide field (in the optical)

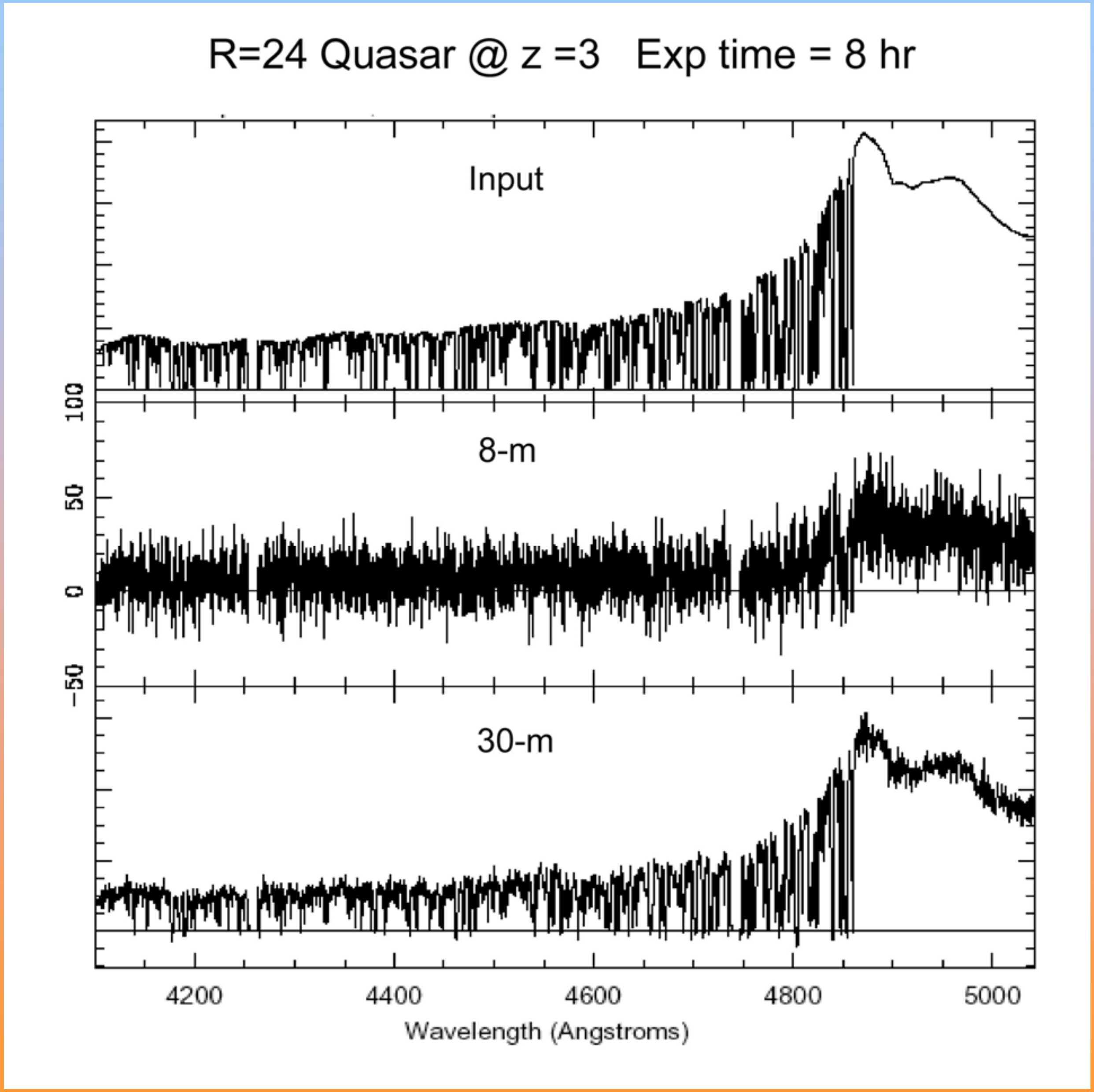
R$_{AB}$



PHOTOMETRIC REDSHIFT

- **S/N=3 limits**
- **$t_{exp} = 10^4$ s**
- **FWHM = 0.3”**

The power of GSMT



Intrinsic spectrum of faint quasar with "forest" of intergalactic gas absorption lines

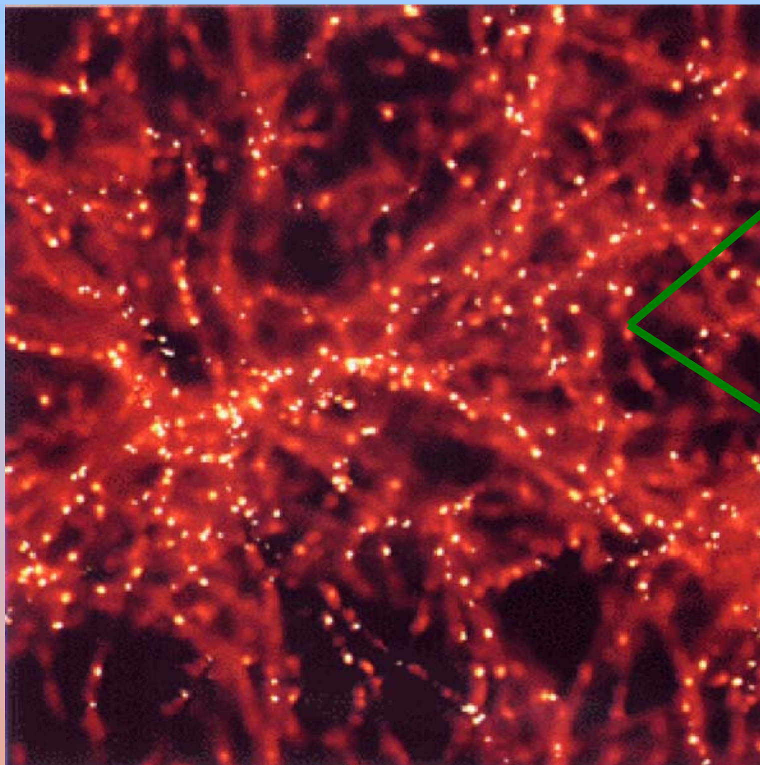
All night exposure with 8m-telescope

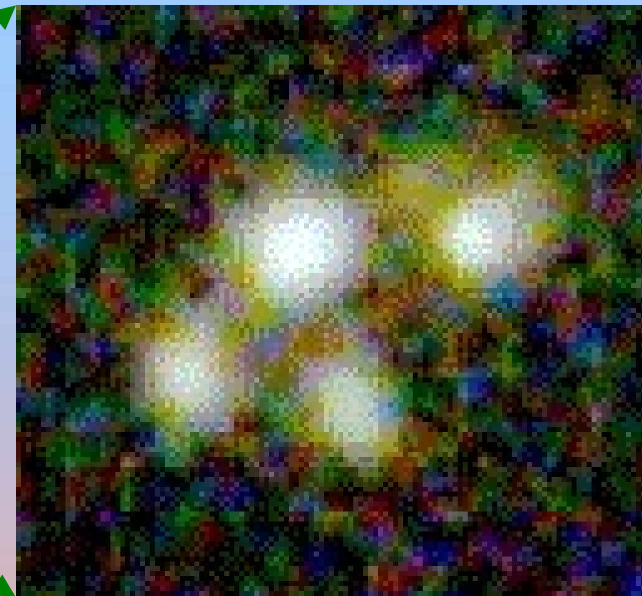
All night exposure with GSMT

(J. Bechthold)

Tomography of universe at $2.5 < z < 4.5$

- Goals:
  - Survey $5^{\circ} \times 5^{\circ} \sim 600\text{Mpc} \times 600\ \text{Mpc} \times 900\text{Mpc}$ @ $z \sim 3.5$
  - Link emerging distribution of IGM/ galaxies to CMB and distribution of dark matter
  - Determine metal abundances of IGM/galaxies
- Measurements:
  - Spectra for 10^6 galaxies (R ~ 2000, S/N ~ 5), $m_R \leq 26.5$
  - Spectra of 10^4 galaxies/QSOs (R ~20000, S/N ~30), $m_R \leq 24$
- Key requirements:
  - 15-20' FOV;MOS ~ 2000/20 multiplex (low/high res)
- Time to complete study with GSMT: 500 nights





z = 3 galaxy from Hubble Deep Field

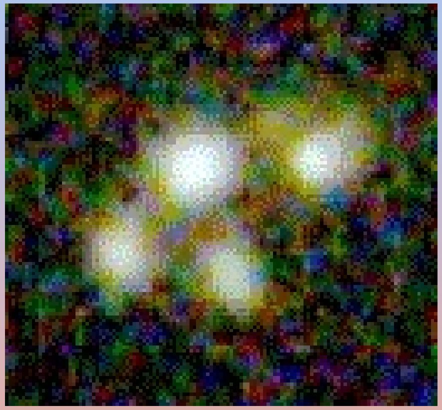
How do galaxies form and evolve ?

Goal: test/constrain hierarchical assembly theory
intrinsic properties of primeval galaxies
how did they transform to the galaxies today?

Problem: the typical primeval galaxies are very faint → GSMT !!!

A galaxy survey at z = 3.5

Survey 5º × 5º ~ 600Mpc × 600 Mpc × 900Mpc @ 2.5 < z < 4.5



10^6 galaxies down to $m_R = 26.5$
low resolution spectra → z, star formation rate

10^5 galaxies down to $m_R = 25.5$
low resolution spectra with high signal → chemical composition, initial mass function

10^3 galaxies down to $m_R = 25.0$
High resolution spectra + MCAO
→ internal galaxy kinematics on scales of 100pc
→ masses, merging dynamics etc.

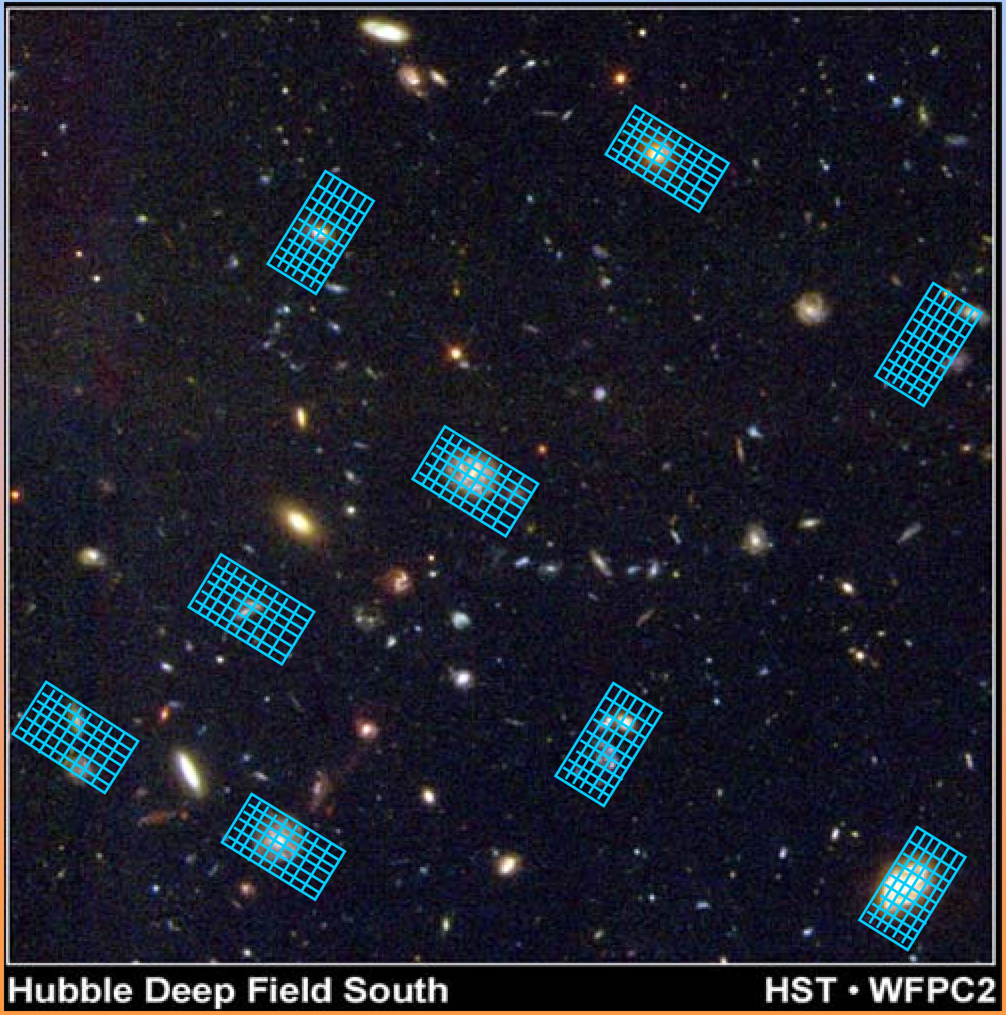
Only GSMT can take spectra of these faint objects !!!

Analyzing Individual Galaxies out to z ~3

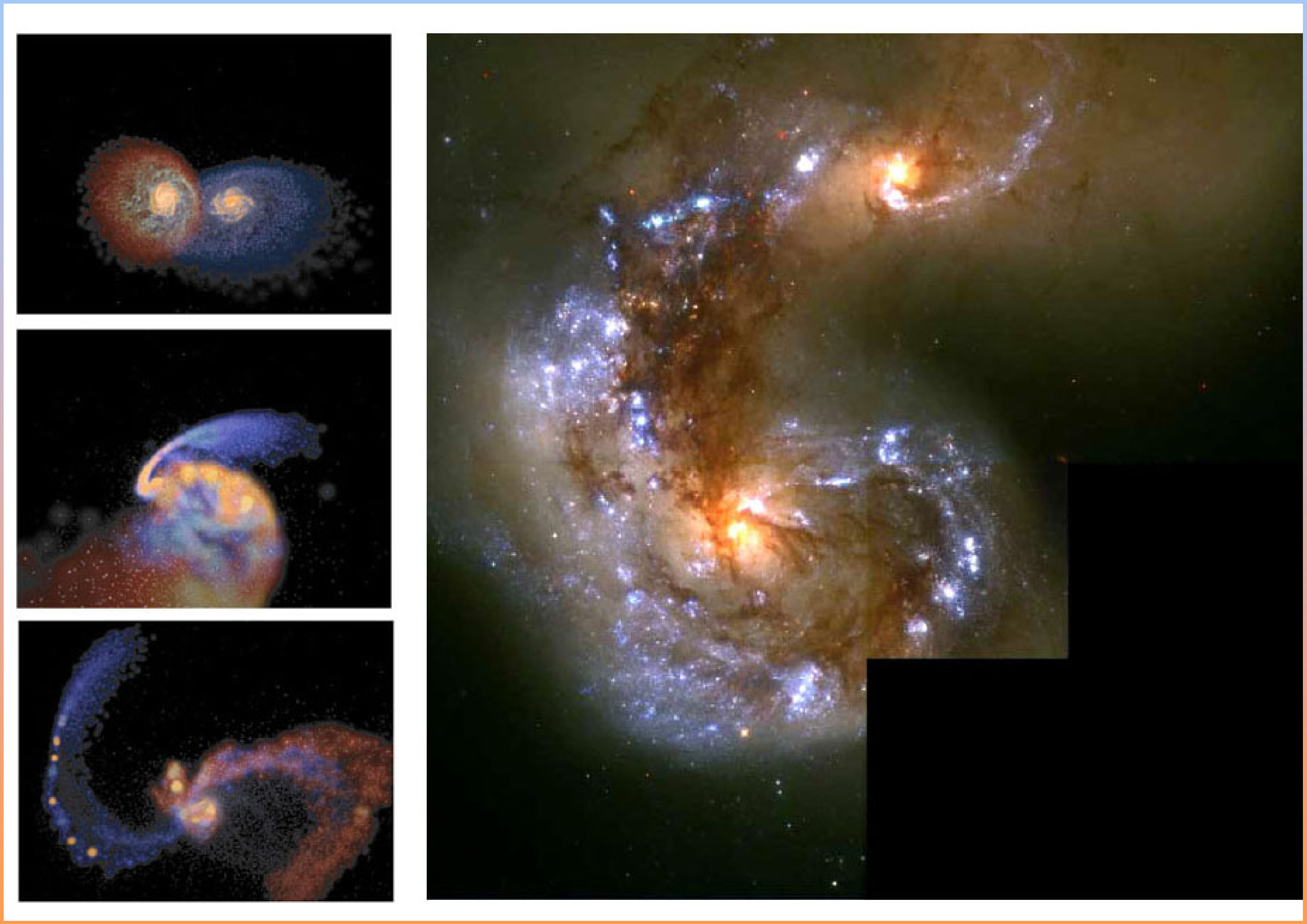
- Determine the gas and stellar dynamics within individual galaxies
- Quantify variations in star formation rate
- *Tool*: IFU spectra [R ~ 5,000 – 10,000]

GSMT 3 hour, 3σ limit
at R=5,000
0.1”x0.1” IFU pixel
(sub-kpc scale structures)

J	H	K
26.5	**25.5**	**24.0**



Formation of giant galaxies

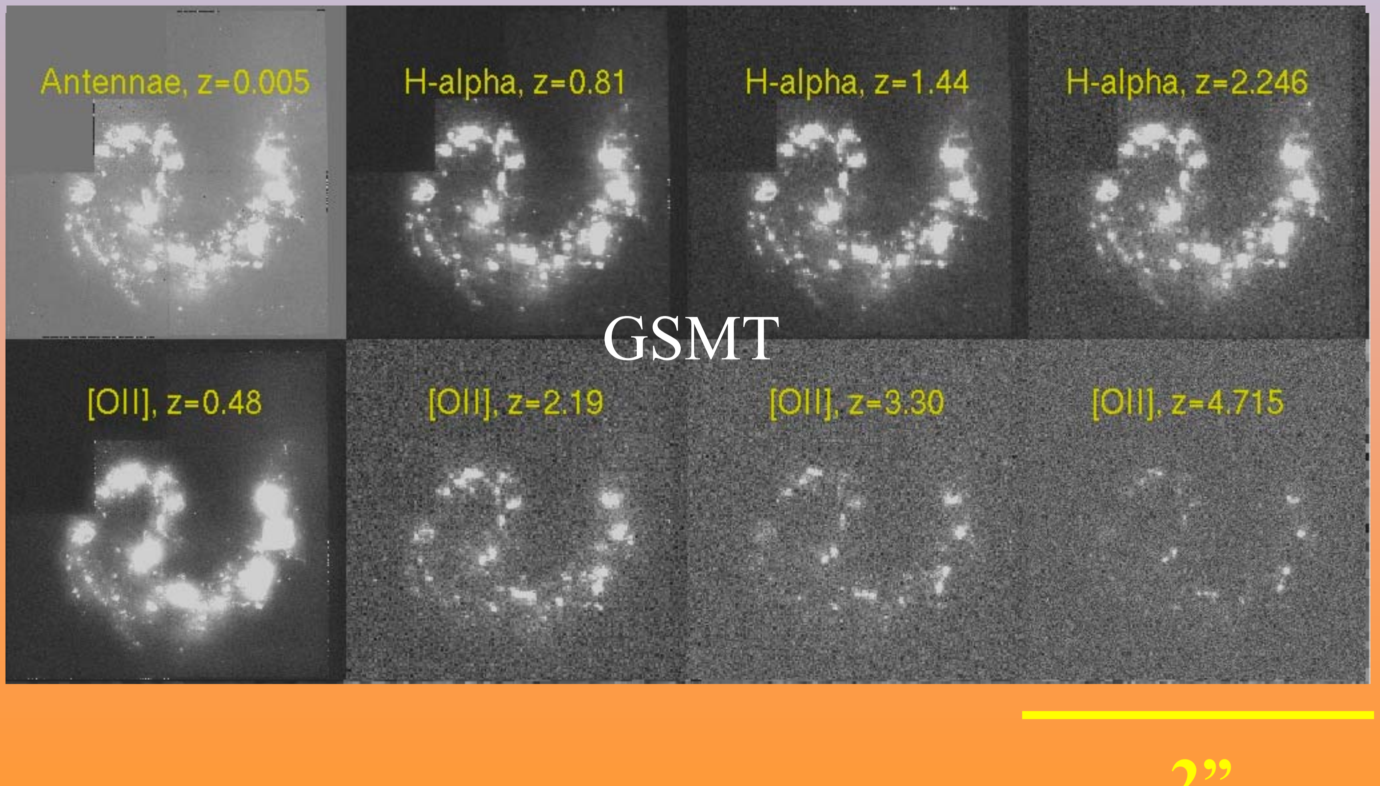


Hydro-simulation
(C. Mihos, L. Hernquist)

"Antennae" galaxy – two galaxies merging
(HST, B. Whitmore)

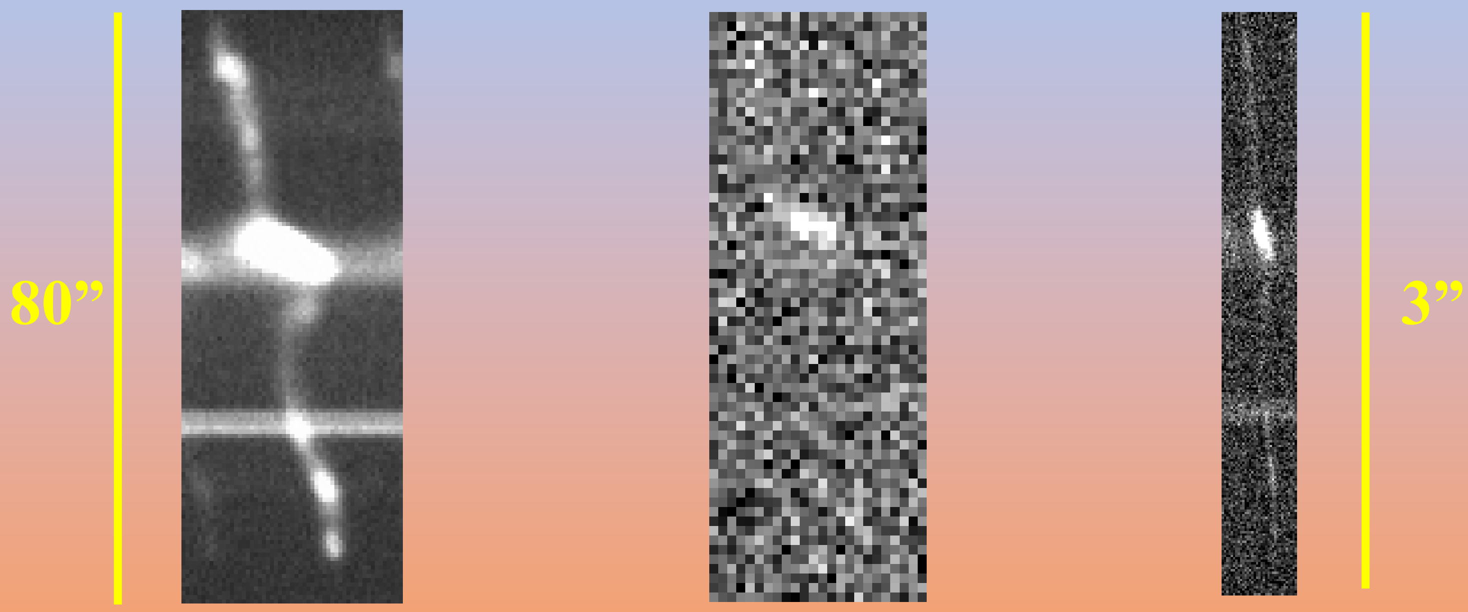
GSMT vs JWST

Simulated monochromatic images of the 'Antennae' (local starburst galaxy: 10^5 seconds integration time)
Courtesy: E. Barton-Gillespie



Galaxy Kinematics with GSMT

Hα in typical spiral galaxy: 10^5 sec exposure



z=0.01

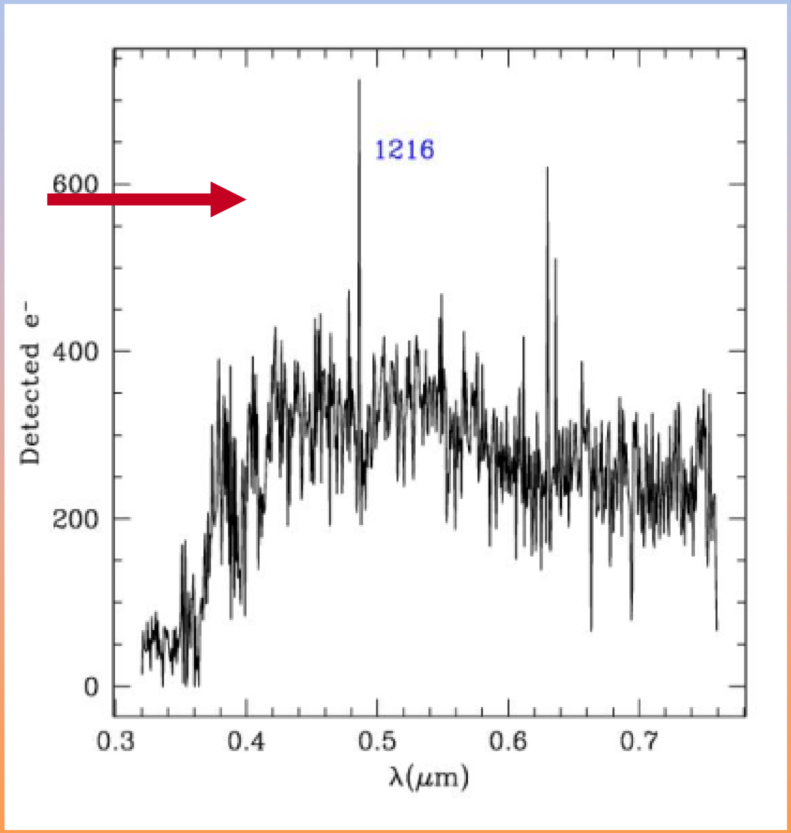
z=1.5
8m

z=1.5
30m

Intrinsic UV Spectra

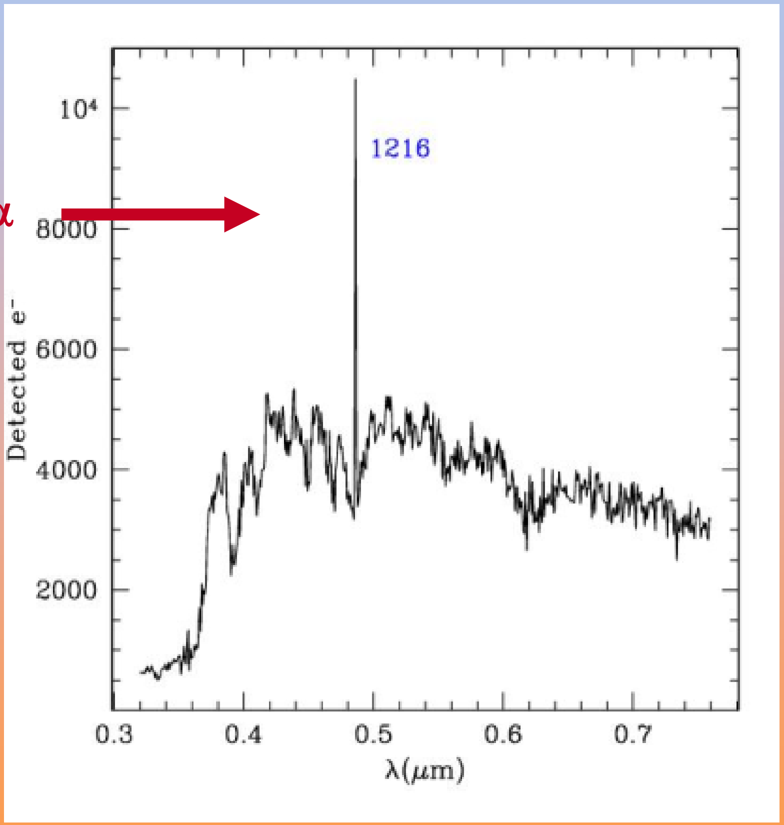
Rest-frame UV, 6 hours, R=6000, $m_{0.64\mu m,AB}=24.5$

Lyα



8 meter

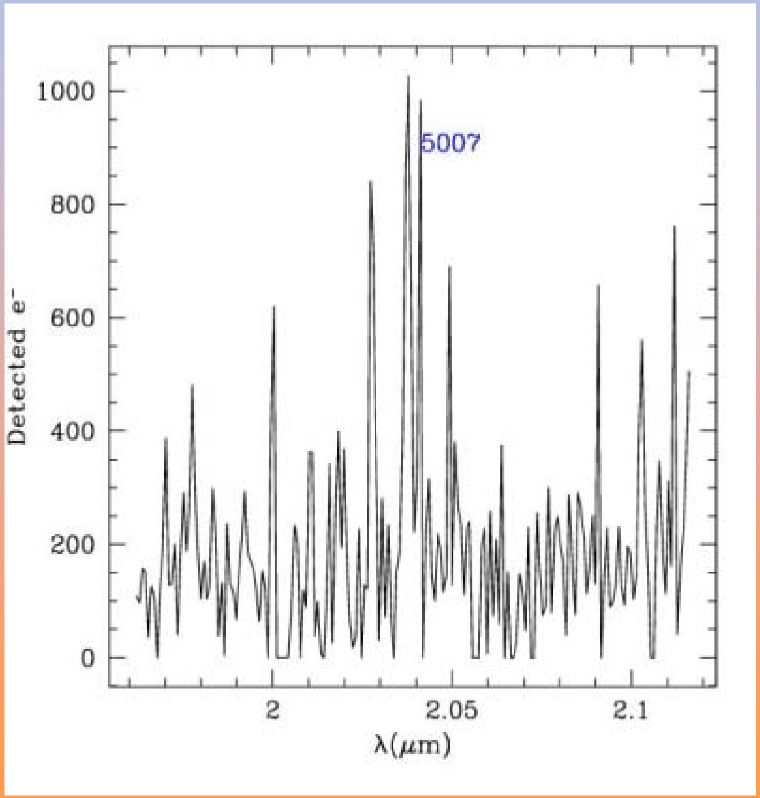
Lyα



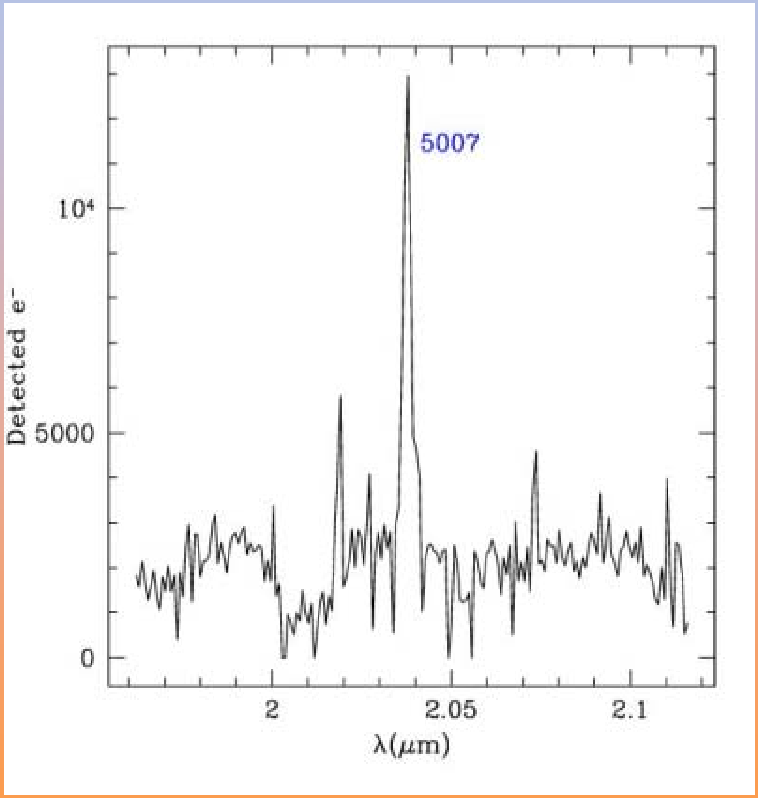
30 meter

Rest-frame optical

Rest-frame [OIII](5007) line, $m_{2.2\mu,AB}=23$



8m



30m

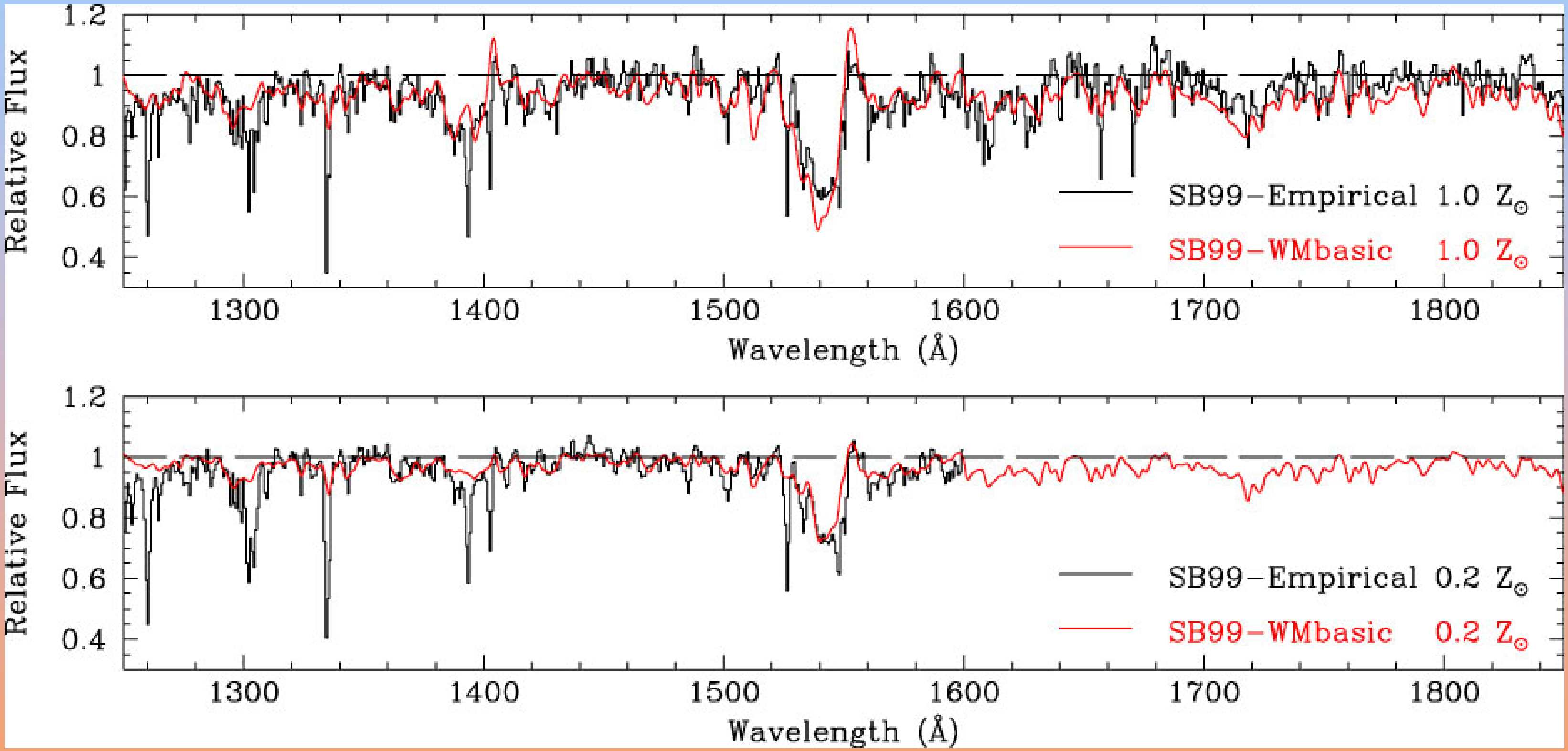
The Survey at $2.5 \leq z \leq 4.5$

- 10^6 galaxies in $5^\circ \times 5^\circ$ area down to $m_R = 26.5$
  MOS (1000) spectroscopy ($R \sim 2000$), $t_{exp} \sim 2h$
  → z, SFR
- 10^5 galaxies down to $m_R = 25.5$, (10^3 in 15'×15')
  MOS (1000) spectroscopy ($R \sim 2000$), $t_{exp} \sim 4h$
  → $(S/N) \sim 20$, metallicities, IMF
- 10^3 galaxies down to $m_R = 25.0$ (100 in 10'×10')
  → internal kinematics with resolution ≤ 1kpc
  some 250 galaxies with ≤ 100pc (MCAO)

requires 150 nights in addition to large scale structure survey

Spectral diagnostics of high-z starbursts

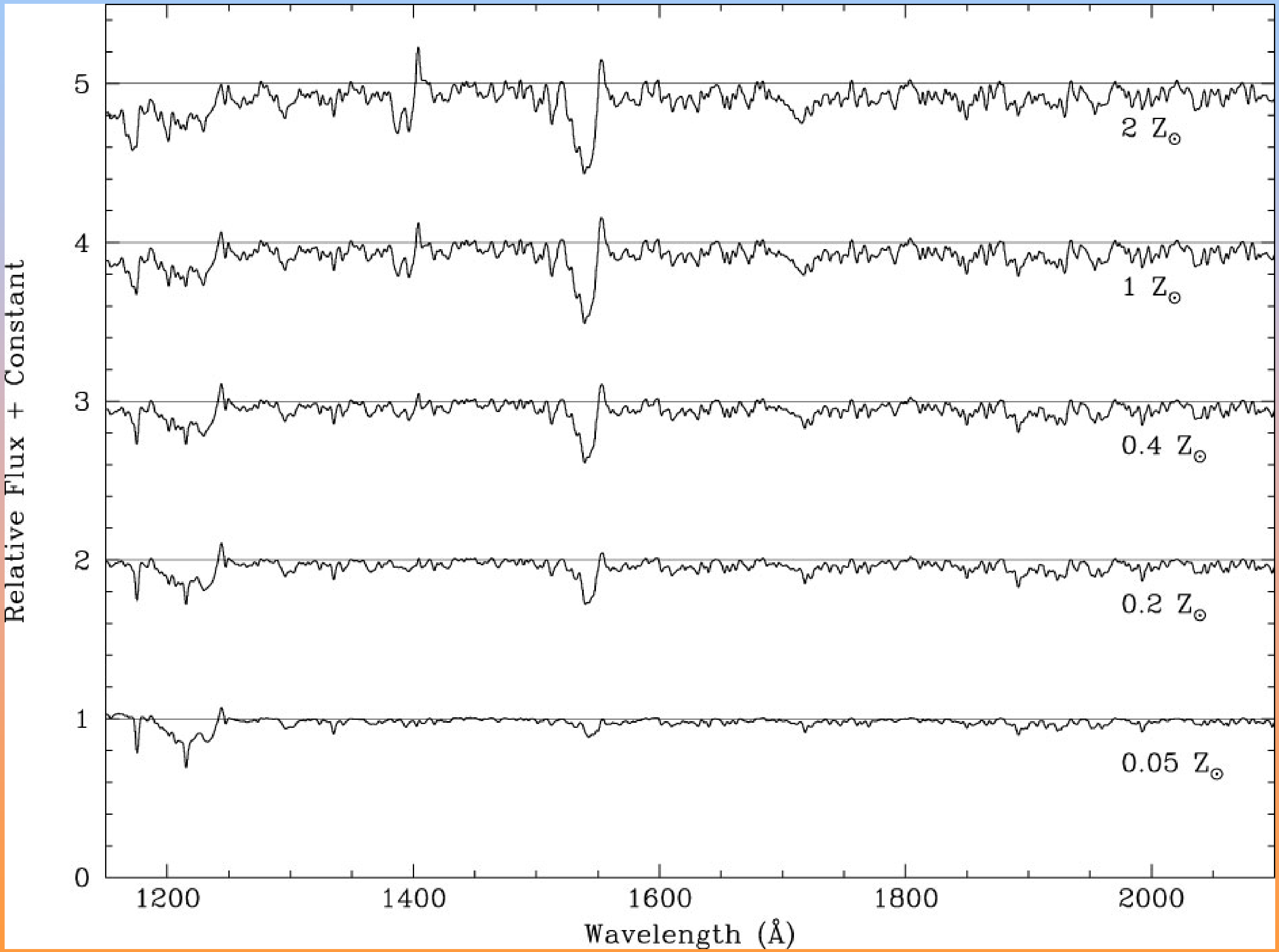
Starburst models - observed spectra vs. model atmospheres



Rix, Pettini, Leitherer,
Bresolin, Kudritzki, Steidel
2004, ApJ, to be subm.

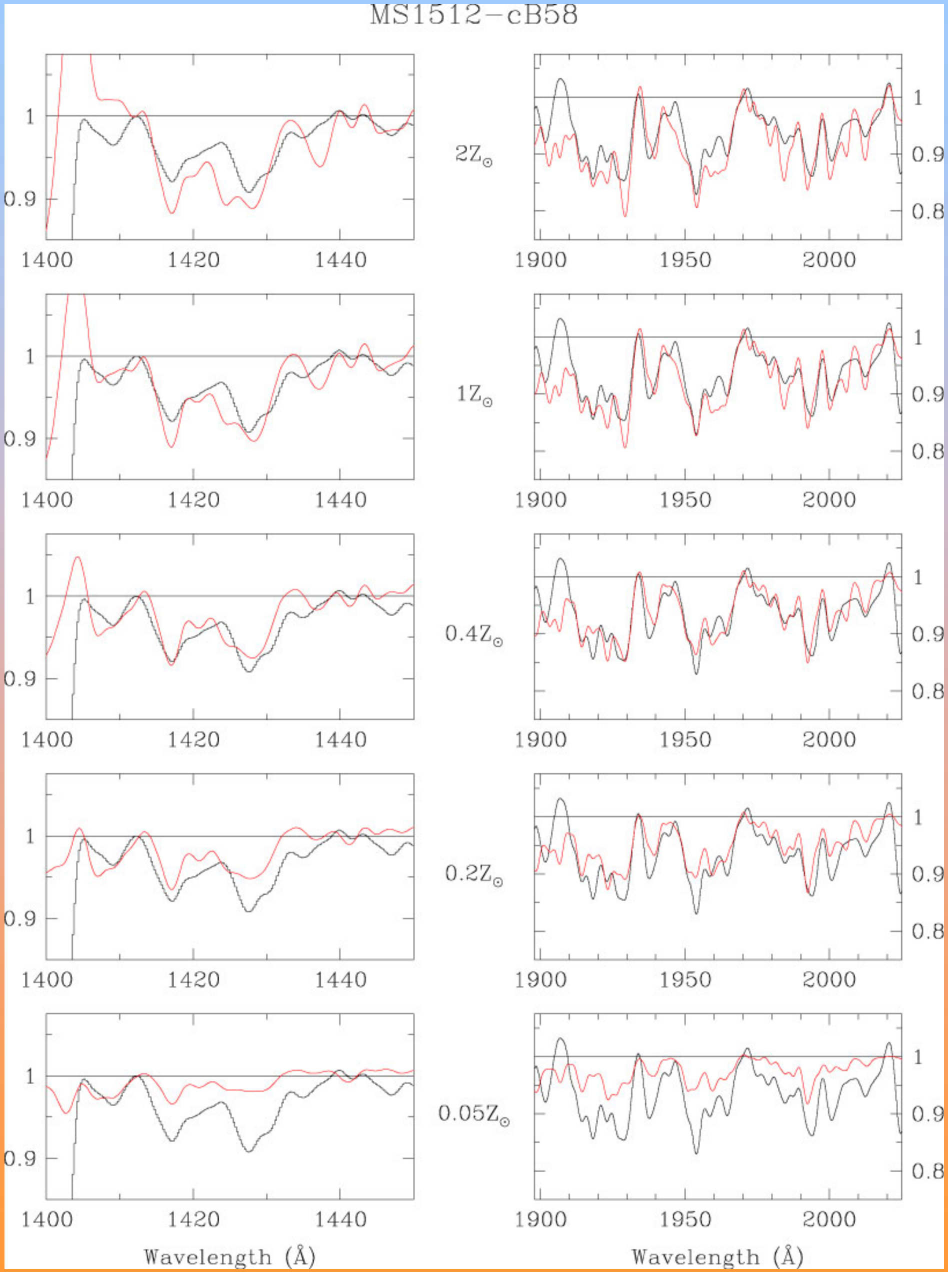
Spectral diagnostics of high-z starbursts

Starburst models - fully synthetic spectra based on model atmospheres



Rix, Pettini, Leitherer, Bresolin, Kudritzki, Steidel, 2004, ApJ, submitted

Spectral diagnostics of high-z starbursts



cB58 @ z=2.7

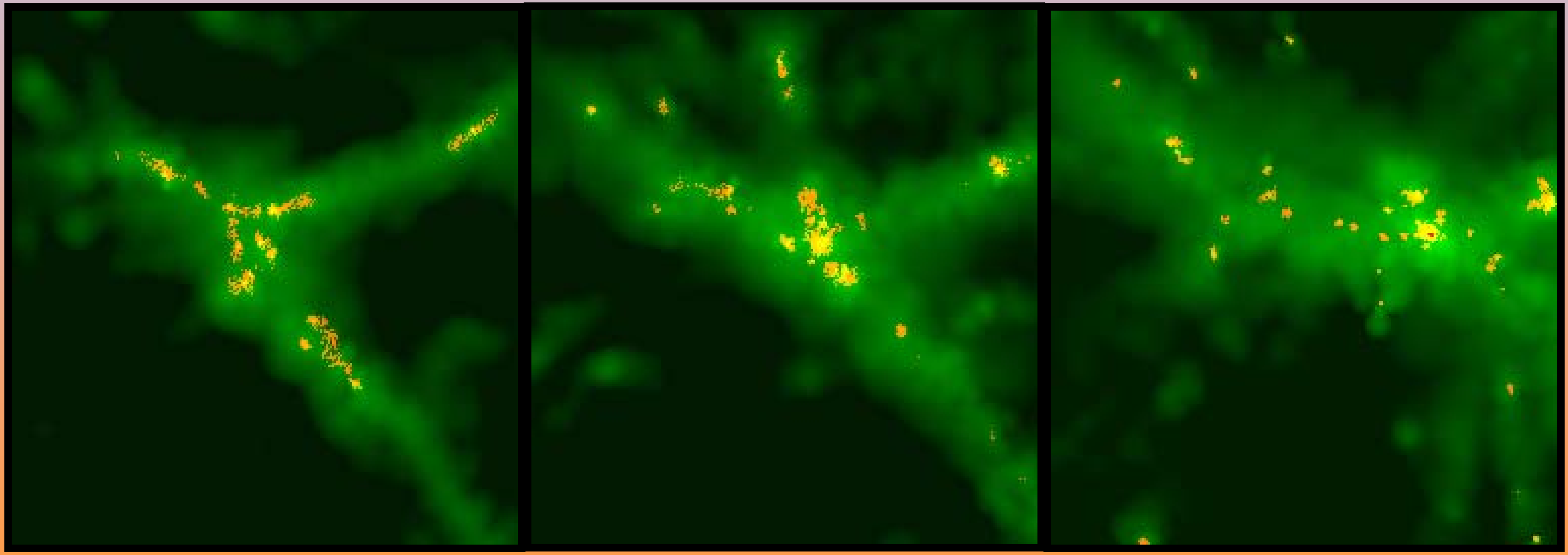
fully synthetic spectra vs. observation

Rix, Pettini, Leitherer, Bresolin, Kudritzki, Steidel 2004, ApJ, submitted

The first stars in the universe - clues from hydrodynamic simulations

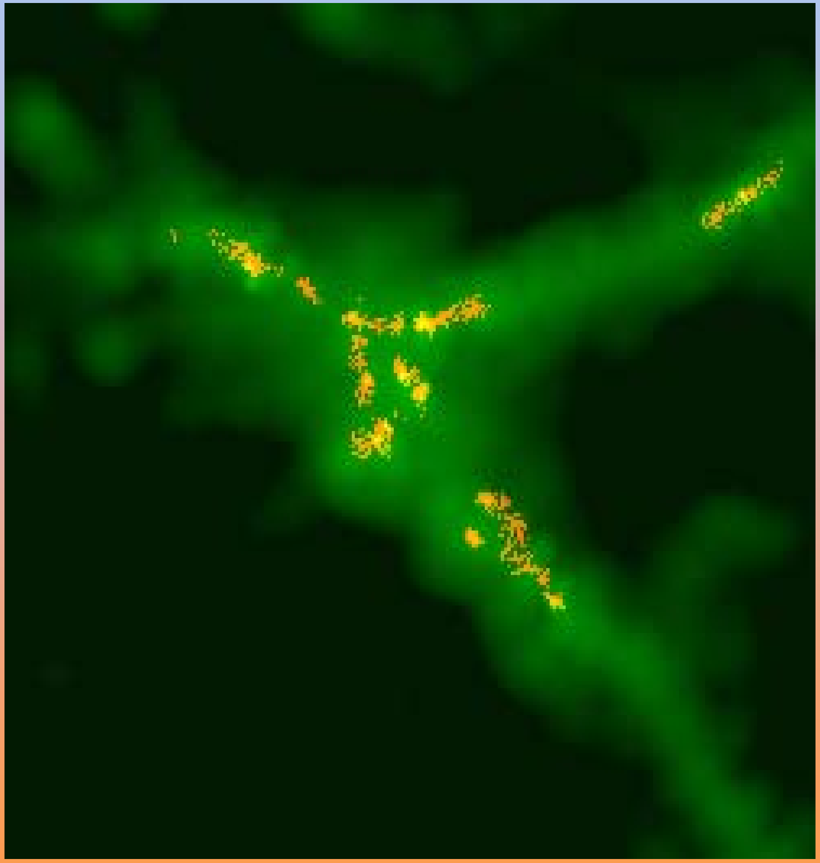
- Hydrodynamic simulations by Davé, Katz, & Weinberg
  - Ly-α cooling radiation (green)
  - Light in Ly-α from forming stars (red, yellow)

z=10 z=8 z=6

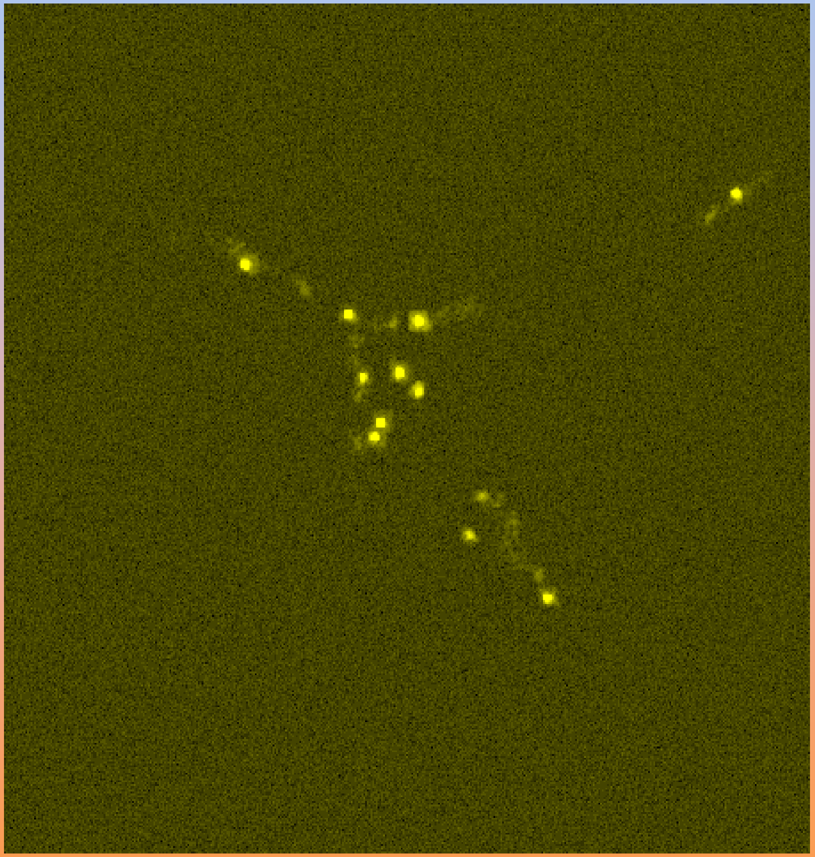


Stars forming at z=10!

1 Mpc (comoving)

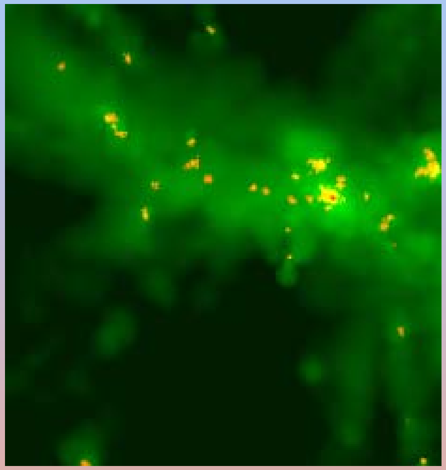


Simulation

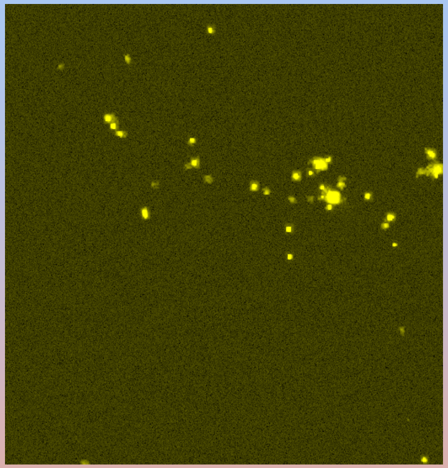


As observed through 30-meter telescope R=3000, 10^5 seconds, Barton et al., 2004, ApJ 604, L1

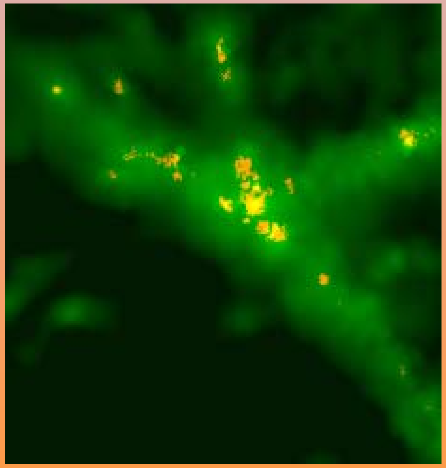
stars at z = 6 or 8



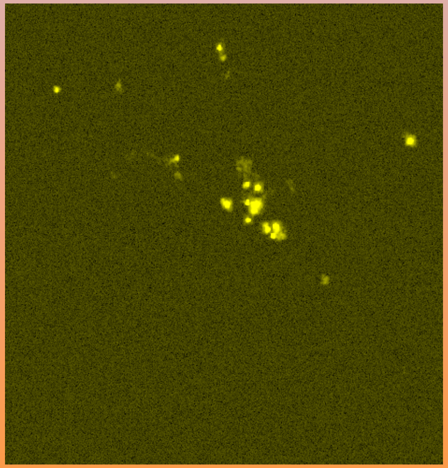
z=6



30-m



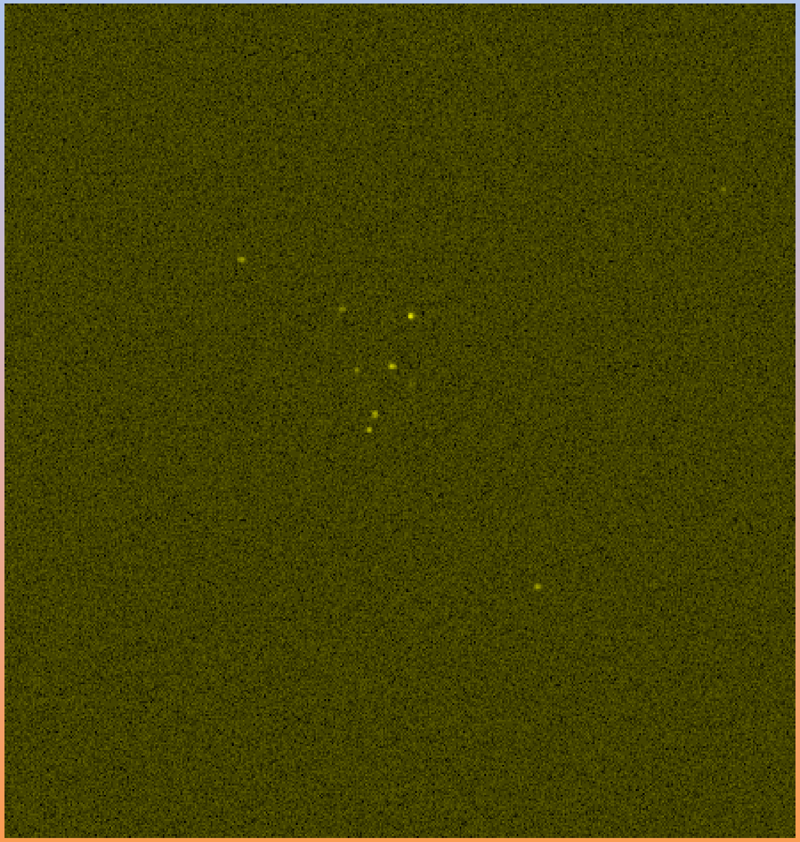
z=8



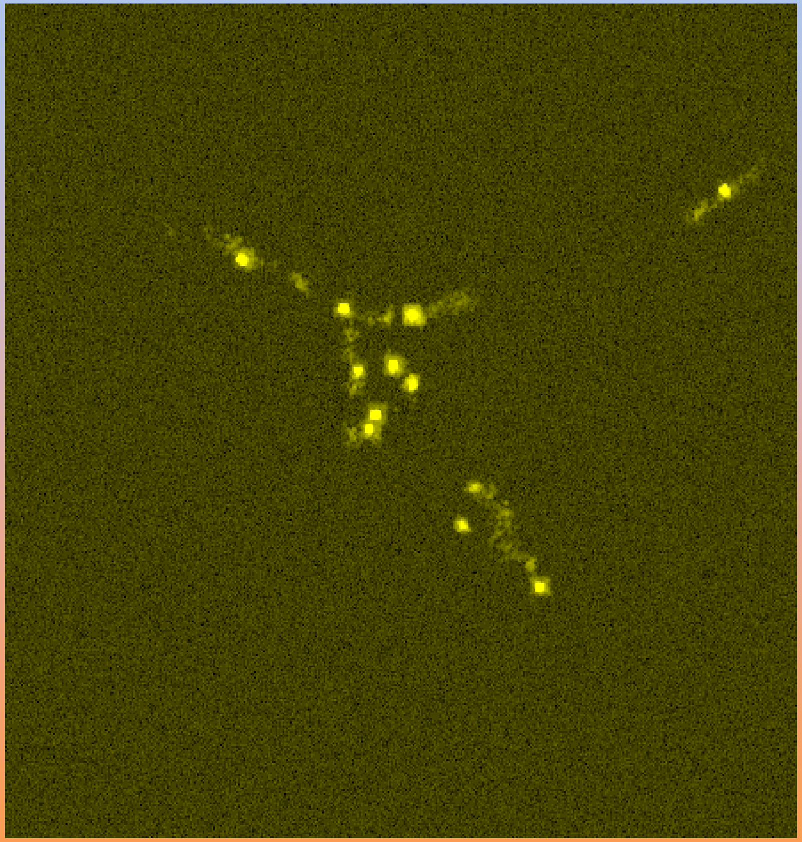
30-m

A possible IMF diagnostic at z=10

HeII (λ1640 Å)
Standard IMF



HeII (λ1640 Å)
Top-Heavy IMF, zero metallicity



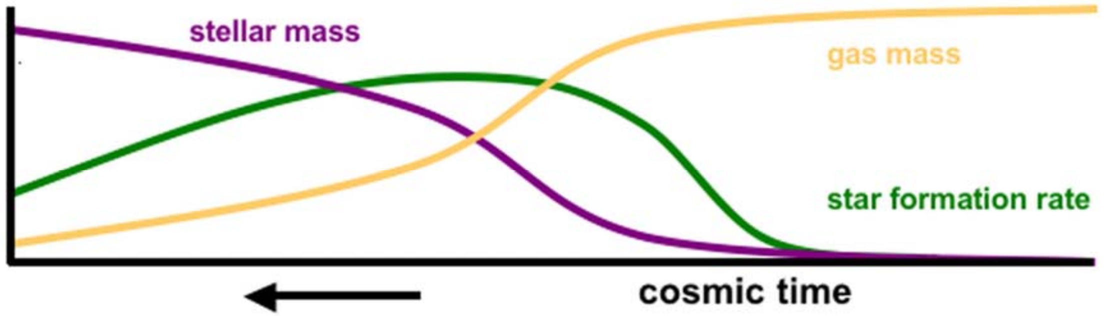
(IMF + stellar model fluxes from Bromm, Kudritzki, & Loeb 2001, ApJ 552,464)

Star formation at z ≥ 7

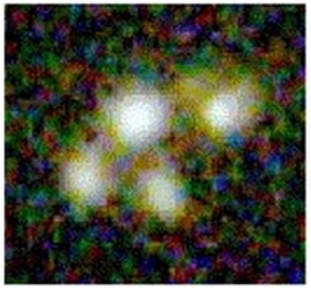
- area of 2’ × 2’ ~ $(5\ \mathrm{Mpc})^3$ at z = 10
  → simulations predict several tens of objects
  detectable with GSMT
- 2’ × 5’ FoV → fair sampling of very early universe
  with up to 400 pointings
- imaging (MCAO, GLAO) and
- follow-up spectroscopy (R ~ 3000, multiplex 100-600)
- Morphological studies on scales < 100 pc with AO

→ 100 nights with GSMT

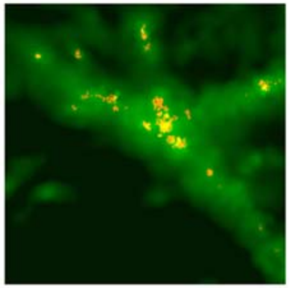
Connecting the Distant & Local Universe



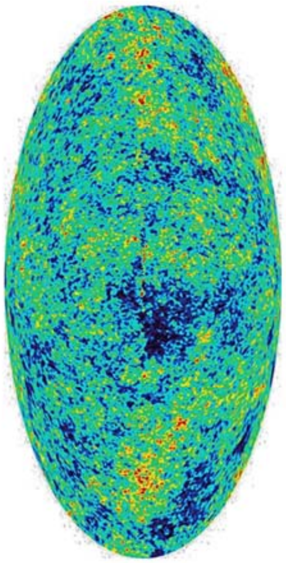
Mature Galaxies



Galaxy-building Mergers



Intergalactic Gas & Pre-galactic Clumps

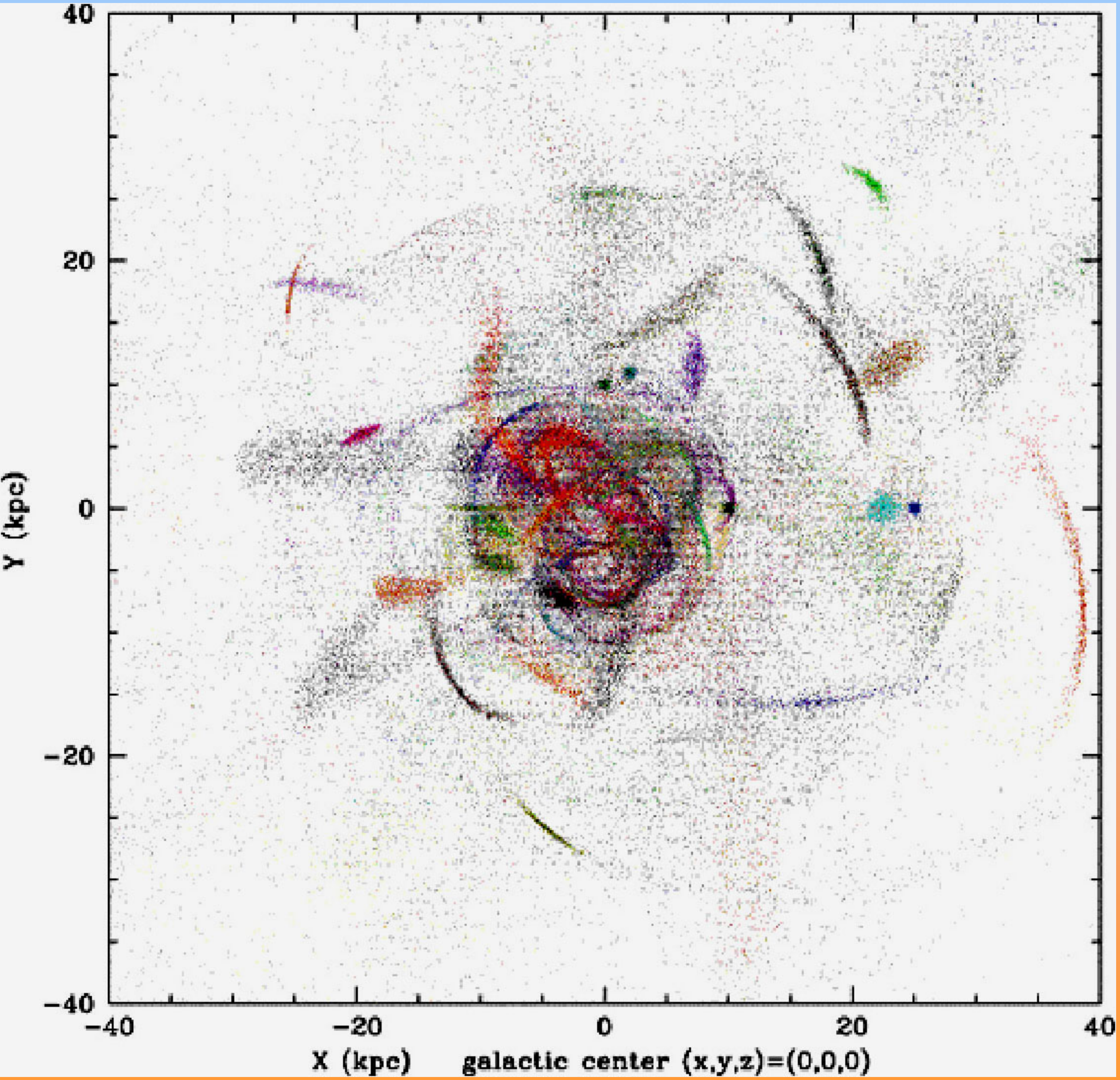


Microwave Background

Formation of giant galaxies

Hydro-simulation *"Antennae" galaxy – two galaxies merging*

The halos of Milky Way-like galaxies



Simulation depicting streams of dynamically and chemically distinct stars (color coded)

Remnants of multiple past merger events

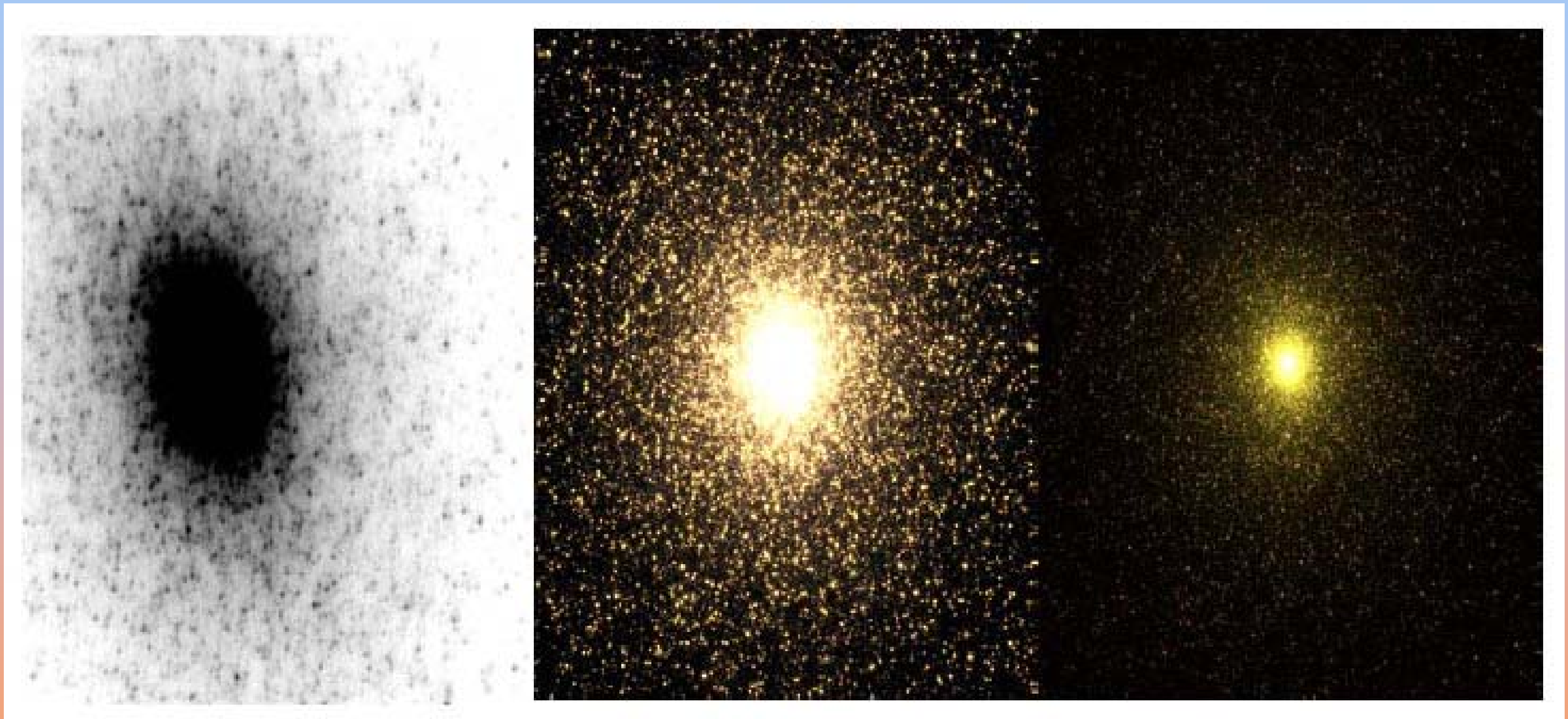
Spectroscopy with GSMT will provide complete genealogical record and nucleosynthesis history together with dynamics

(P. Harding)

The different stellar populations in galaxies

- **Goals:**
  - Quantify ages; [Fe/H], [α/H], [s,r/H], ; for stars in nearby galaxies spanning all types
  - Use ‘archaelogical record’ to understand the assembly process
  - Quantify IMF in different environments
- **Measurements:**
  - CMDs for selected areas in local group galaxies
  - Spectroscopy (R ~ 1500 → kinematics, ~ 40000 → nucleosynthesis)
- **Key requirements:**
  - MCAO delivering 2’ FOV; MCAO-fed NIR spectrograph
- **Time to complete study with GSMT: 150 nights**

M32



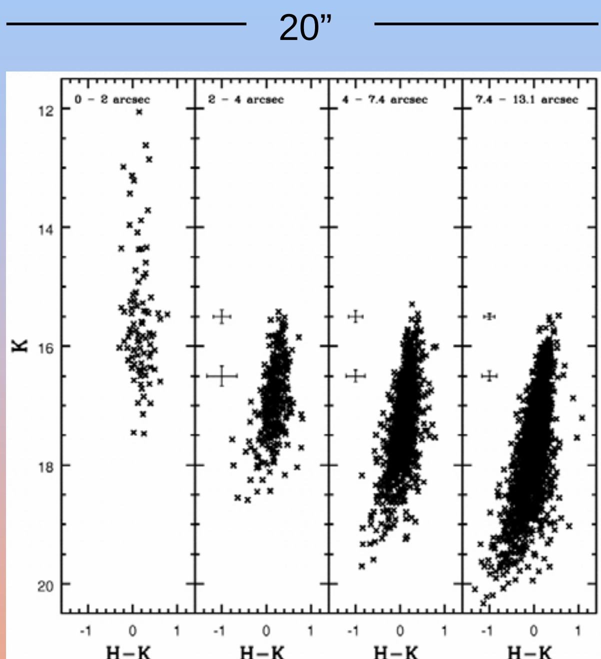
Gemini North
Hokupa'a AO
(IfA)

same region
JWST
simulation

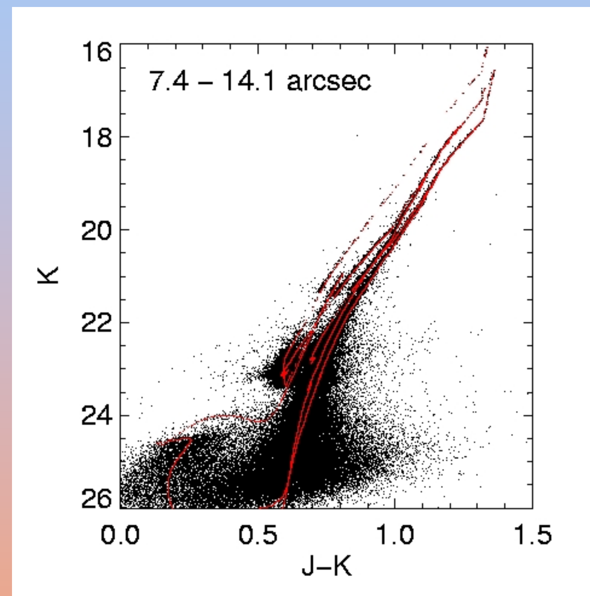
same region
GSMT
simulation

K. Olson, F. Rigaut, B. Ellerblok

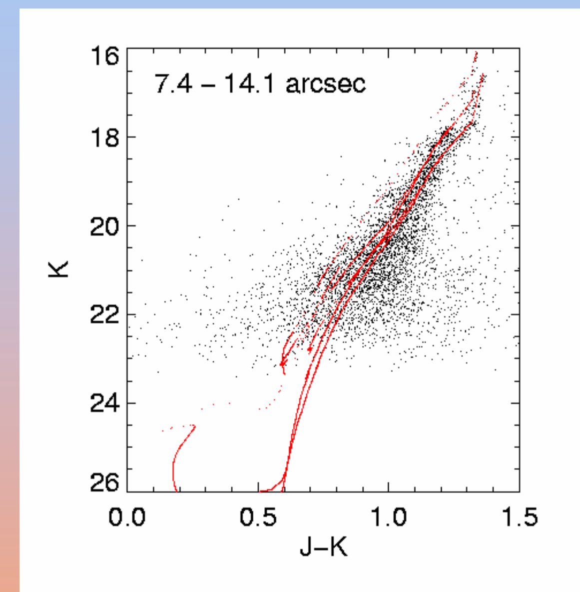
Stellar Populations in Galaxies



M 32 (Gemini/Hokupaa)



GSMT with MCAO



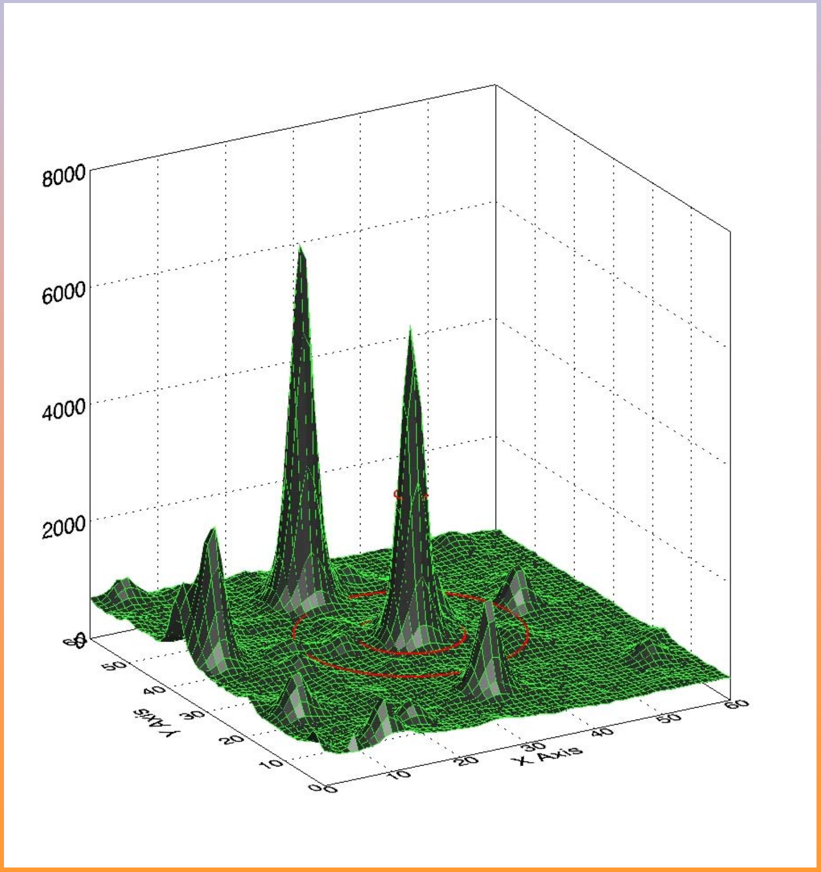
JWST

Population: 10% 1 Gyr, [Fe/H]=0; 45% 5 Gyr, [Fe/H]=0; 45% 10 Gyr, [Fe/H]=-0.3

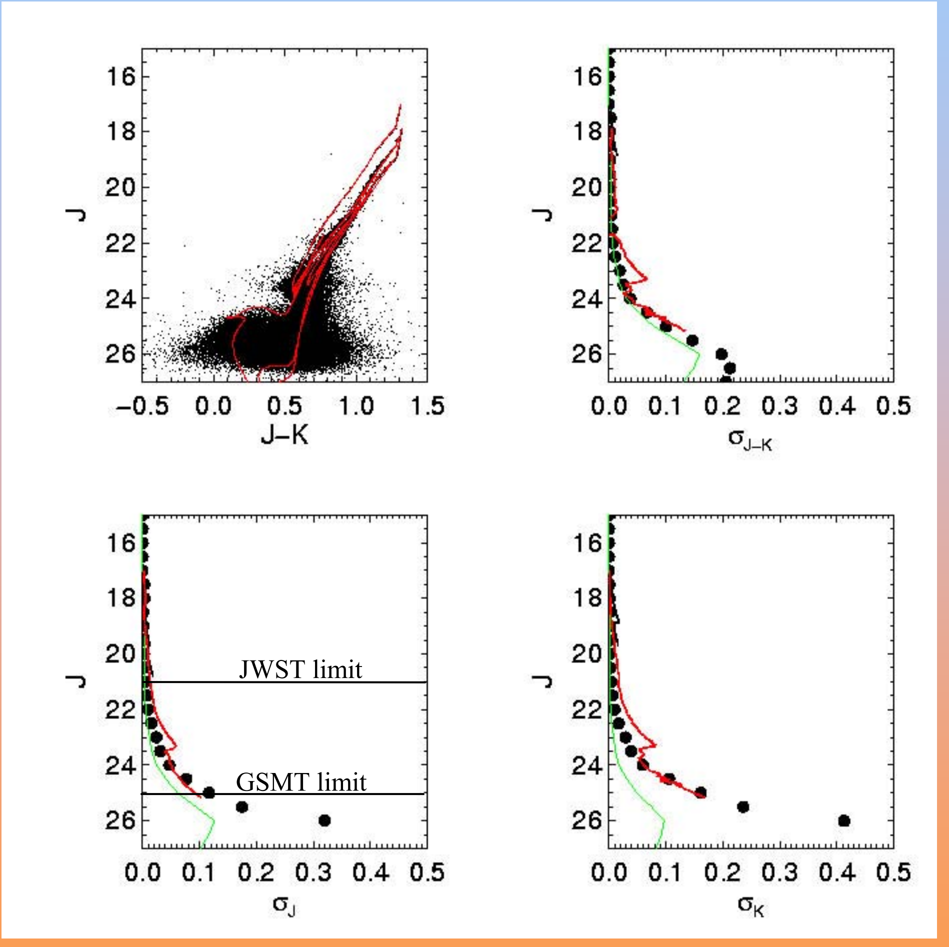
Simulations from K. Olsen and F. Rigaut

Crowding Limits Photometric Accuracy

Crowding introduces photometric error through luminosity fluctuations within a *single* resolution element of the telescope due to the unresolved stellar sources in that element.

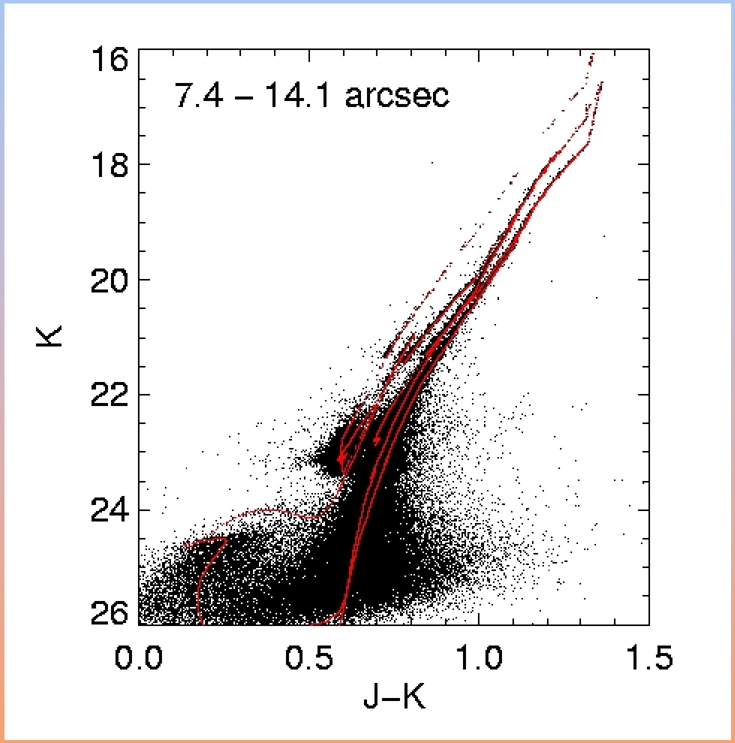


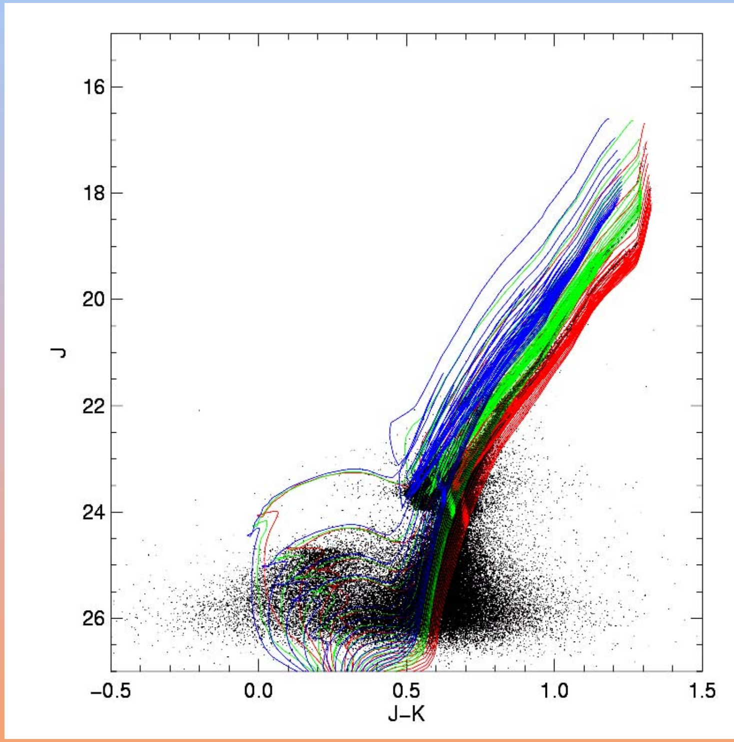
Crowding Limits for GSMT



Limiting luminosity scales as D^{-2}

Modeling Population Mixes



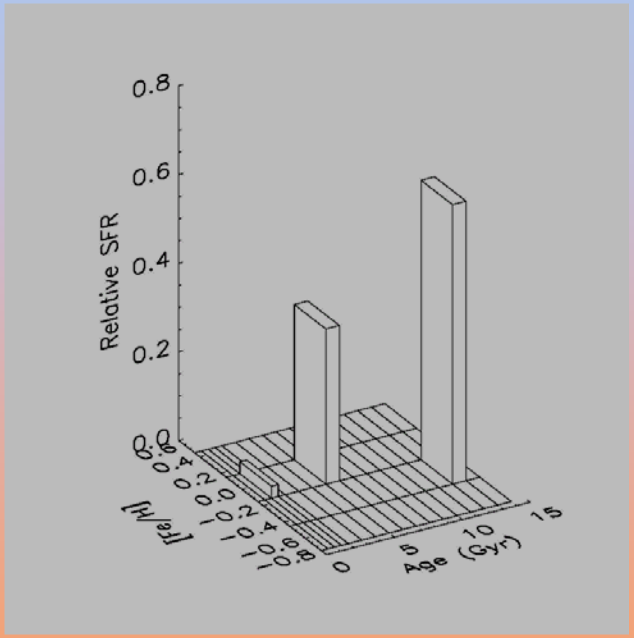


– 45 model isochrones with ages from 0.5 - 13 Gyr and [Fe/H]=0.0,-0.3,-0.6 compared with data

– Maximum likelihood method of Dolphin (1997)

Recovering Population Mixes

Input Simulation

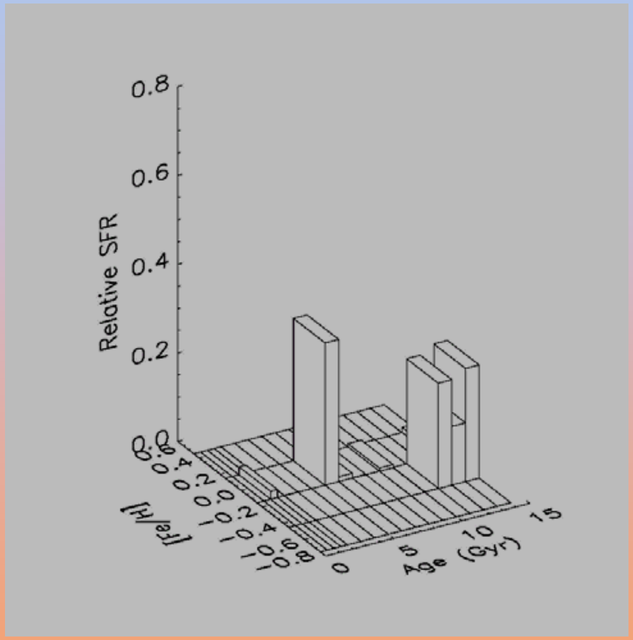


3% 1 Gyr/[Fe/H]=0.0

35% 5 Gyr/[Fe/H]=0.0

62% 10 Gyr/[Fe/H]=-0.3

30 m GSMT



2% 1 Gyr/[Fe/H]=0.0

34% 5 Gyr/[Fe/H]=0.0

64% 10+/-1 Gyr/[Fe/H]=-0.3

Assumptions for MCAO simulations

	J	K
FWHM	0.009	0.015 arcsec
Strehl	0.2	0.6

PSF includes effects of

- limited number of actuators in deformable mirrors
- optical effects of the primary mirror segments (tilt, de-phasing)
- limited temporal sampling of wave fronts
- limited spatial resolution of wave front sensors

no PSF variations with time and position included

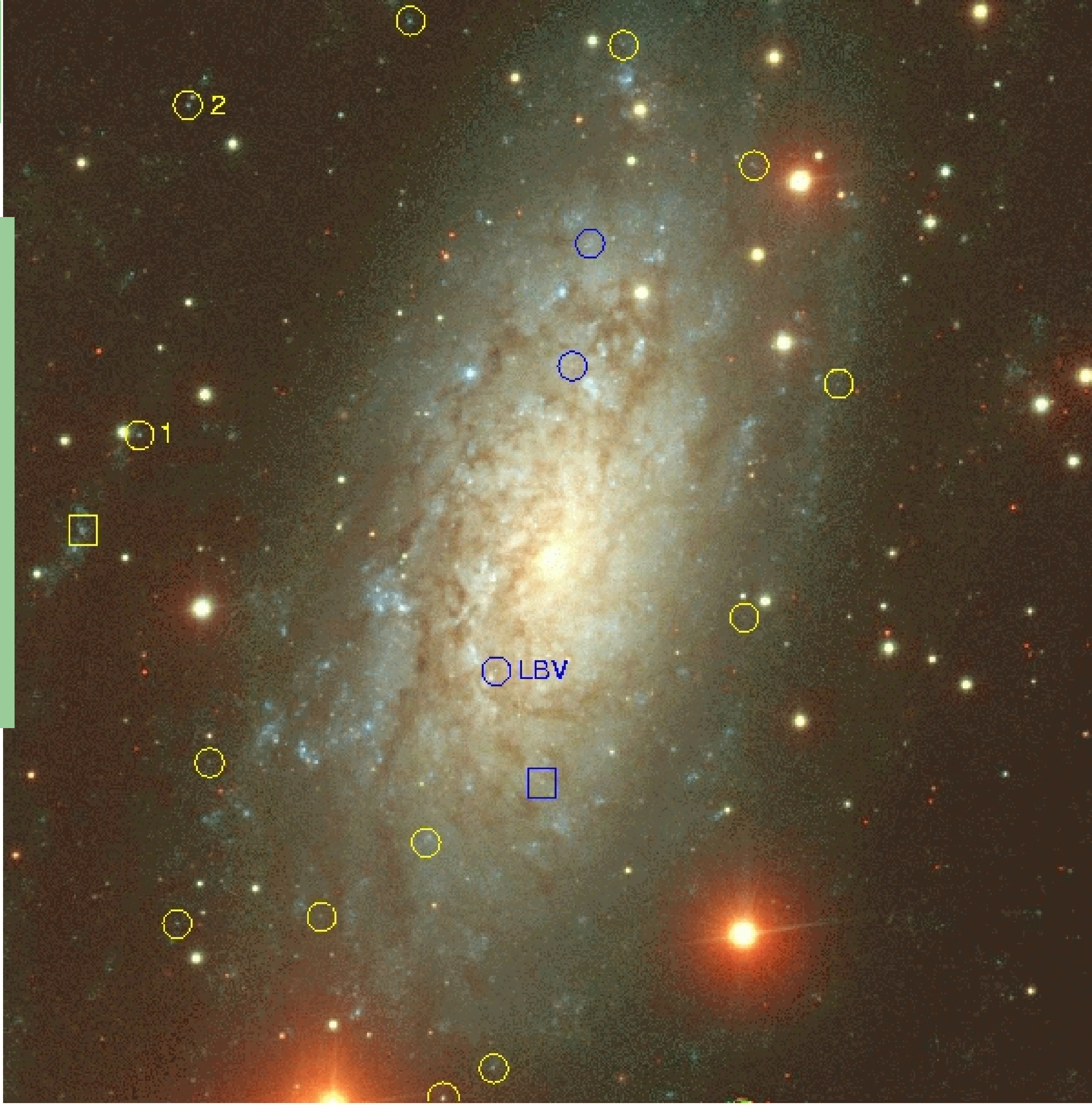
The different stellar populations in galaxies

- **Goals:**
  - Quantify ages; [Fe/H], [α/H], [s,r/H], ; for stars in nearby galaxies spanning all types
  - Use 'archaelogical record' to understand the assembly process
  - Quantify IMF in different environments
- **Measurements:**
  - CMDs for selected areas in local group galaxies
  - Spectroscopy (R ~ 1500 → kinematics, ~ 40000 → nucleosynthesis)
- **Key requirements:**
  - MCAO delivering 2' FOV; MCAO-fed NIR spectrograph
- **Time to complete study with GSMT: 150 nights**

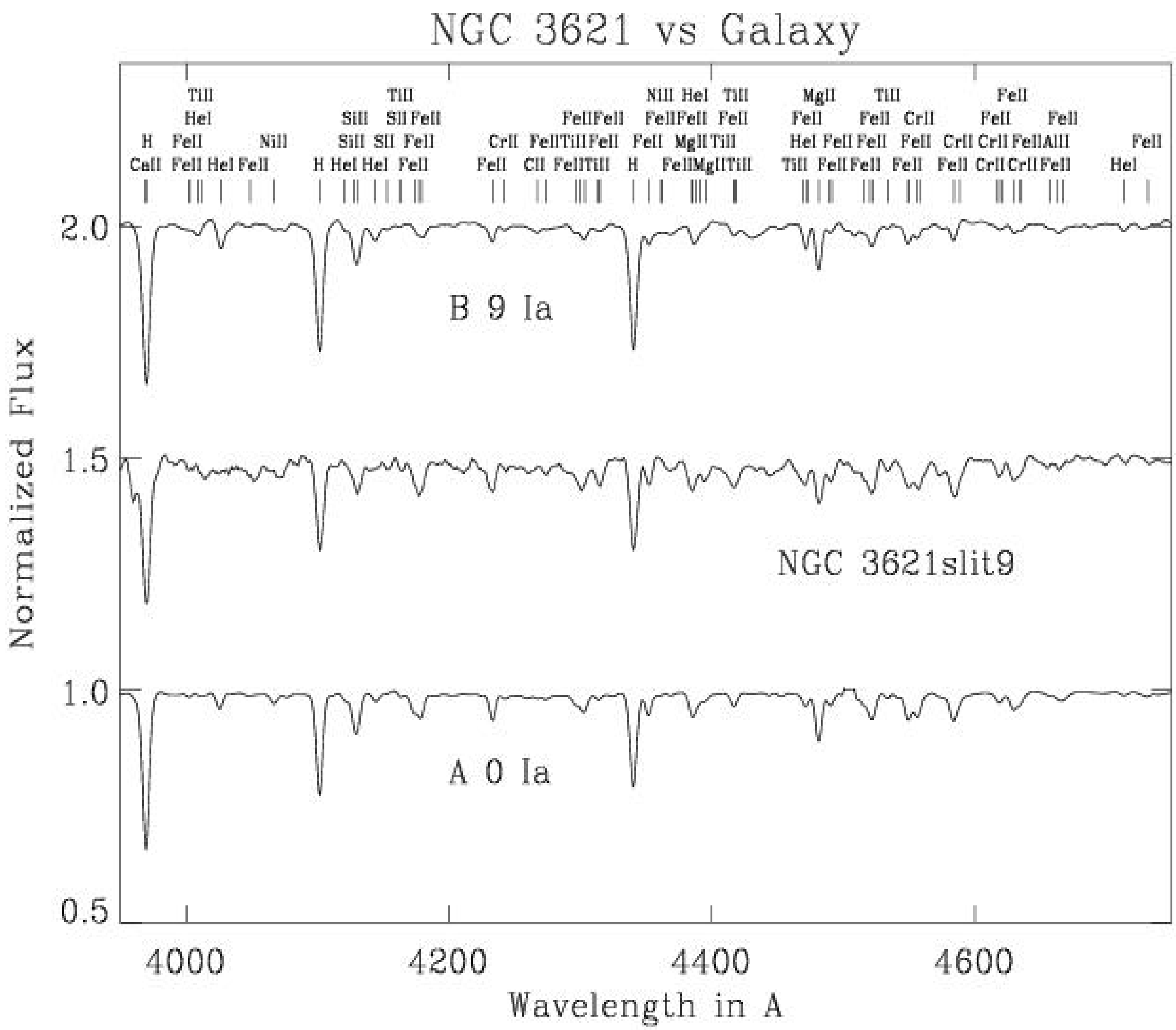
NGC 3621

7Mpc

Bresolin, Kudritzki, Mendez, Przybilla, 2001, ApJ Letters, 548, L159



NGC 3621



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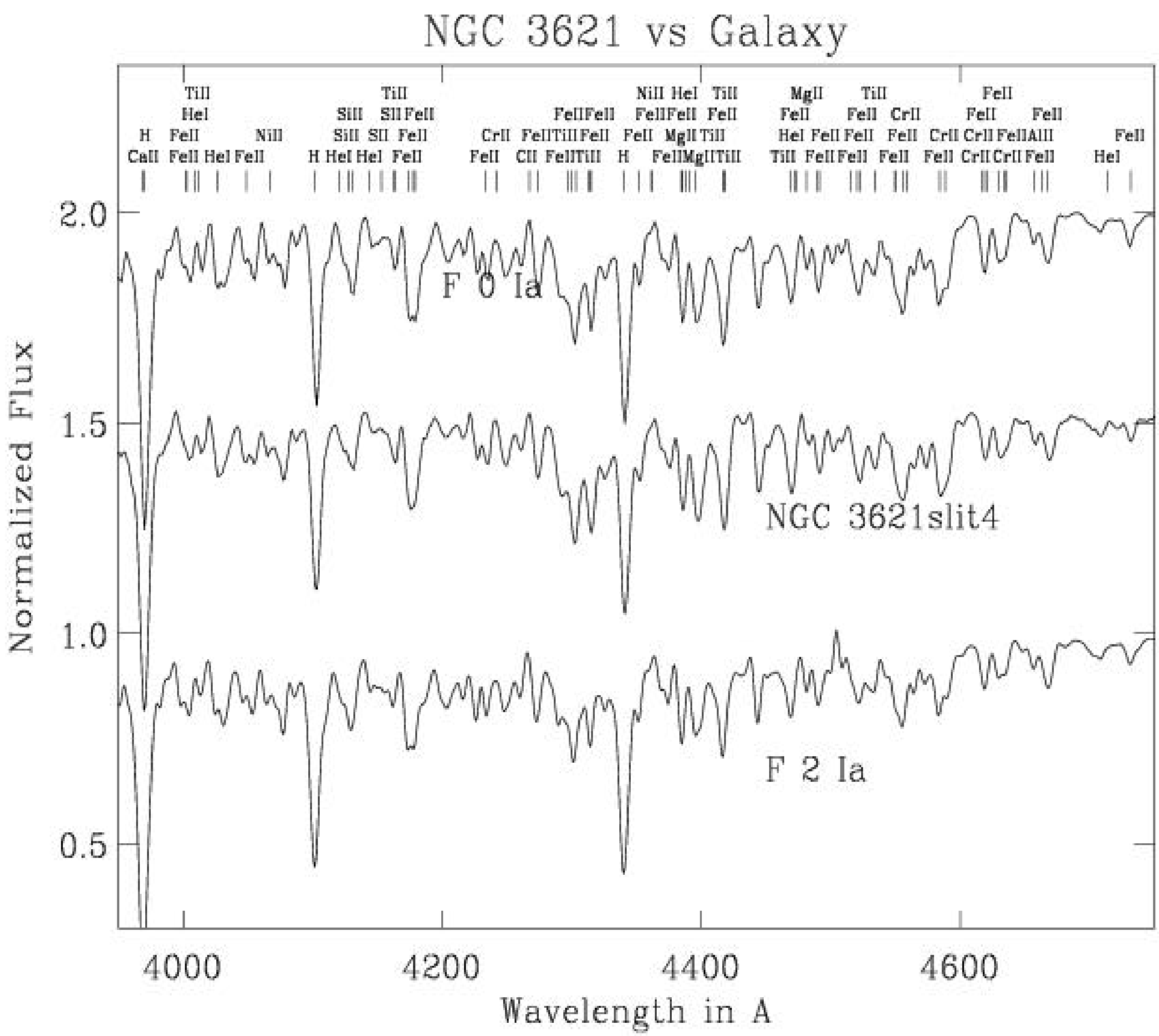
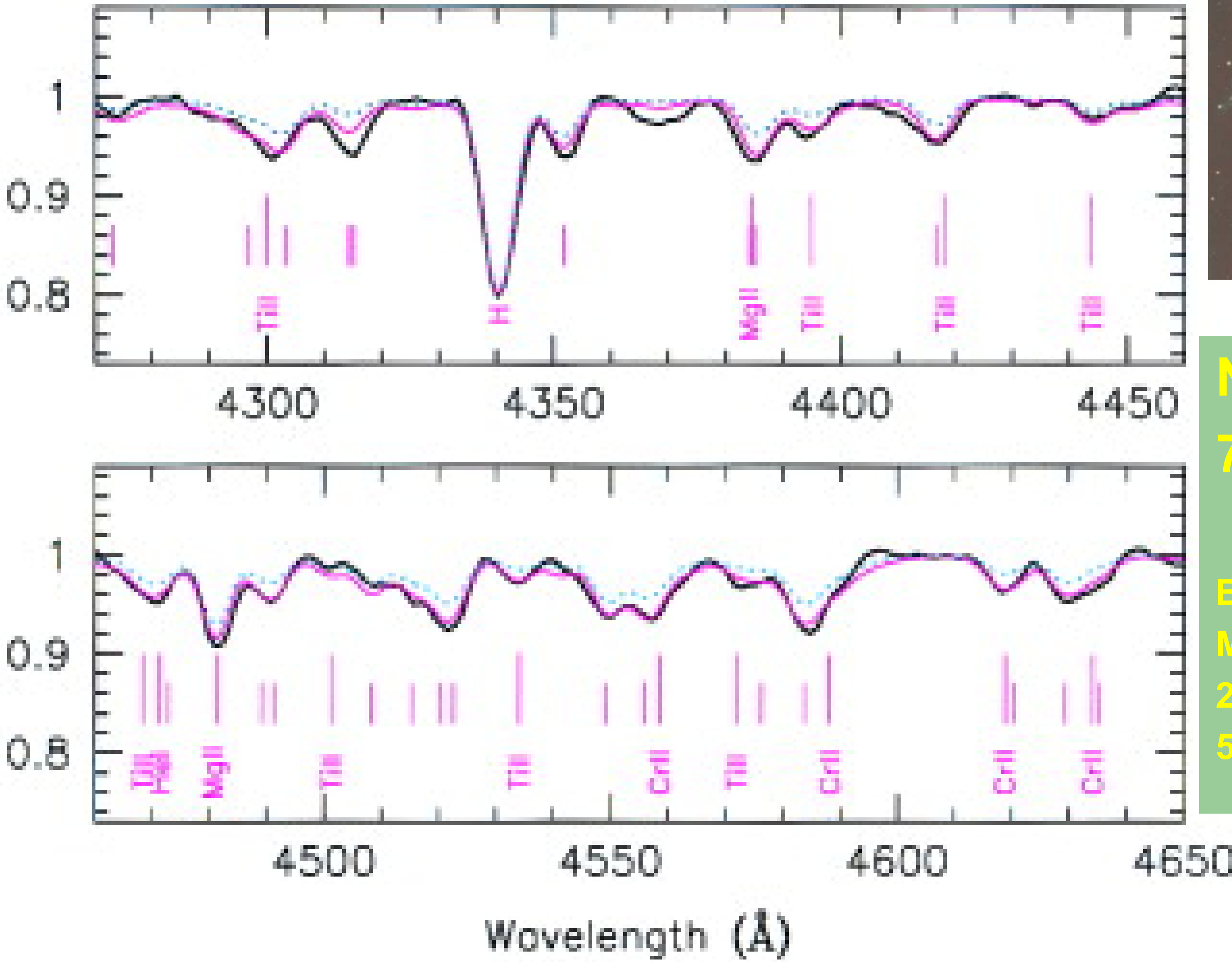


NGC 3621
7Mpc

Bresolin, Kudritzki, Mendez, Przybilla, 2001, ApJ Letters, 548, L159



NGC 3621
7Mpc

Bresolin, Kudritzki, Mendez, Przybilla, 2001, ApJ Letters, 548, L159

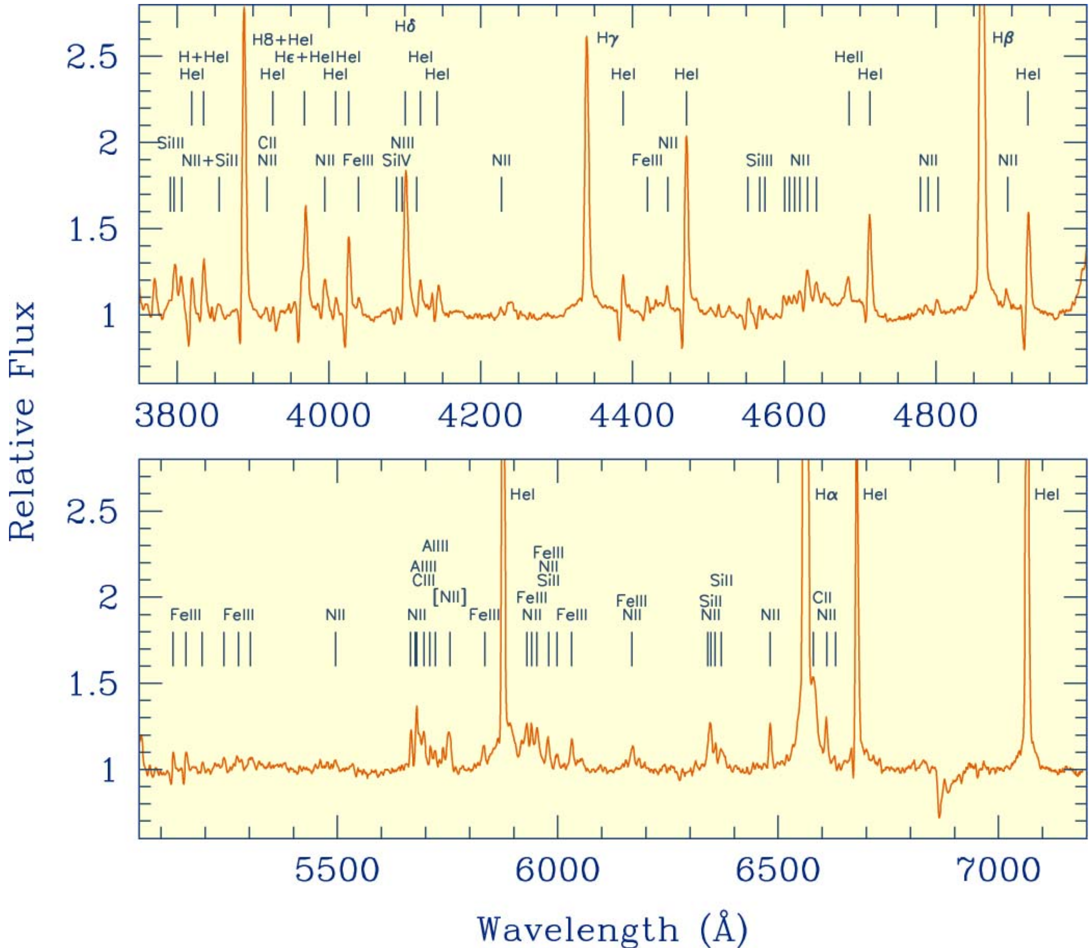
Bresolin, Kudritzki, Najarro et al.
2002, ApJ Letters 567, L107

7

NGC 300

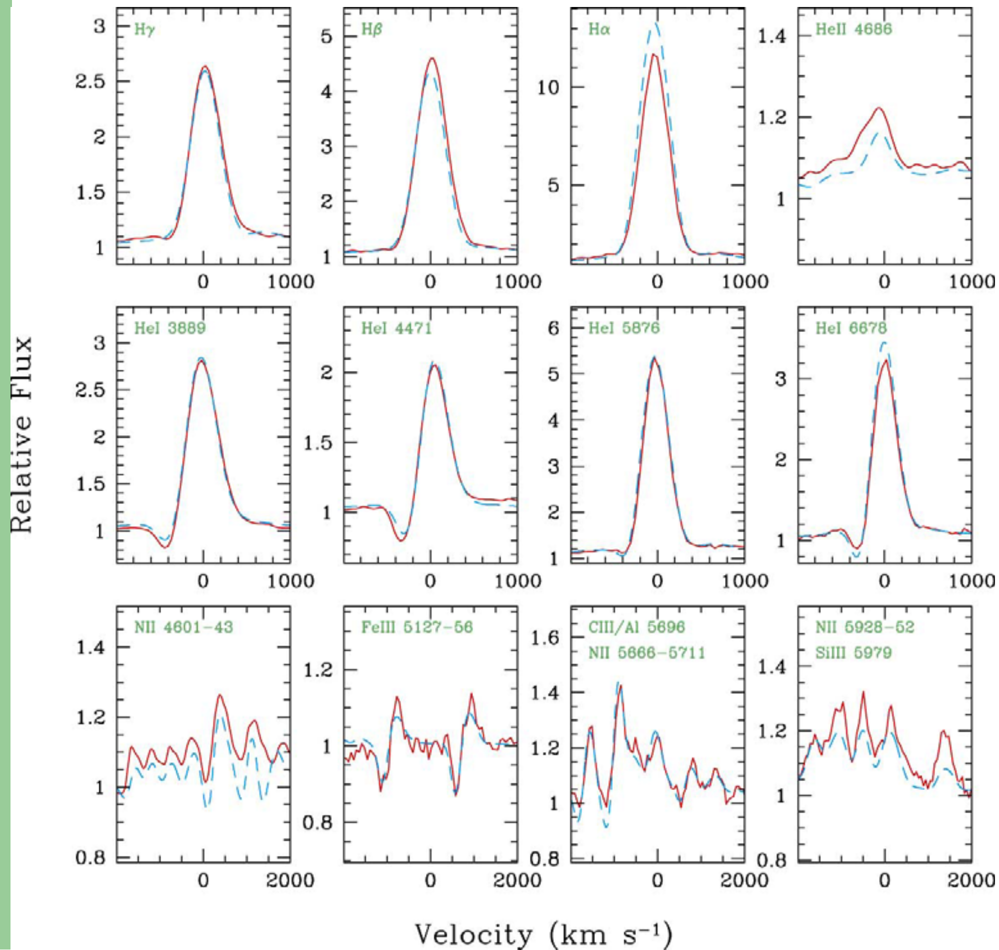
d = 2 Mpc

WN11 star in NGC 300



first detailed abundance pattern outside Local Group

NGC 300 WN11 star



non-LTE line-blanketed

stellar parameters

wind parameters

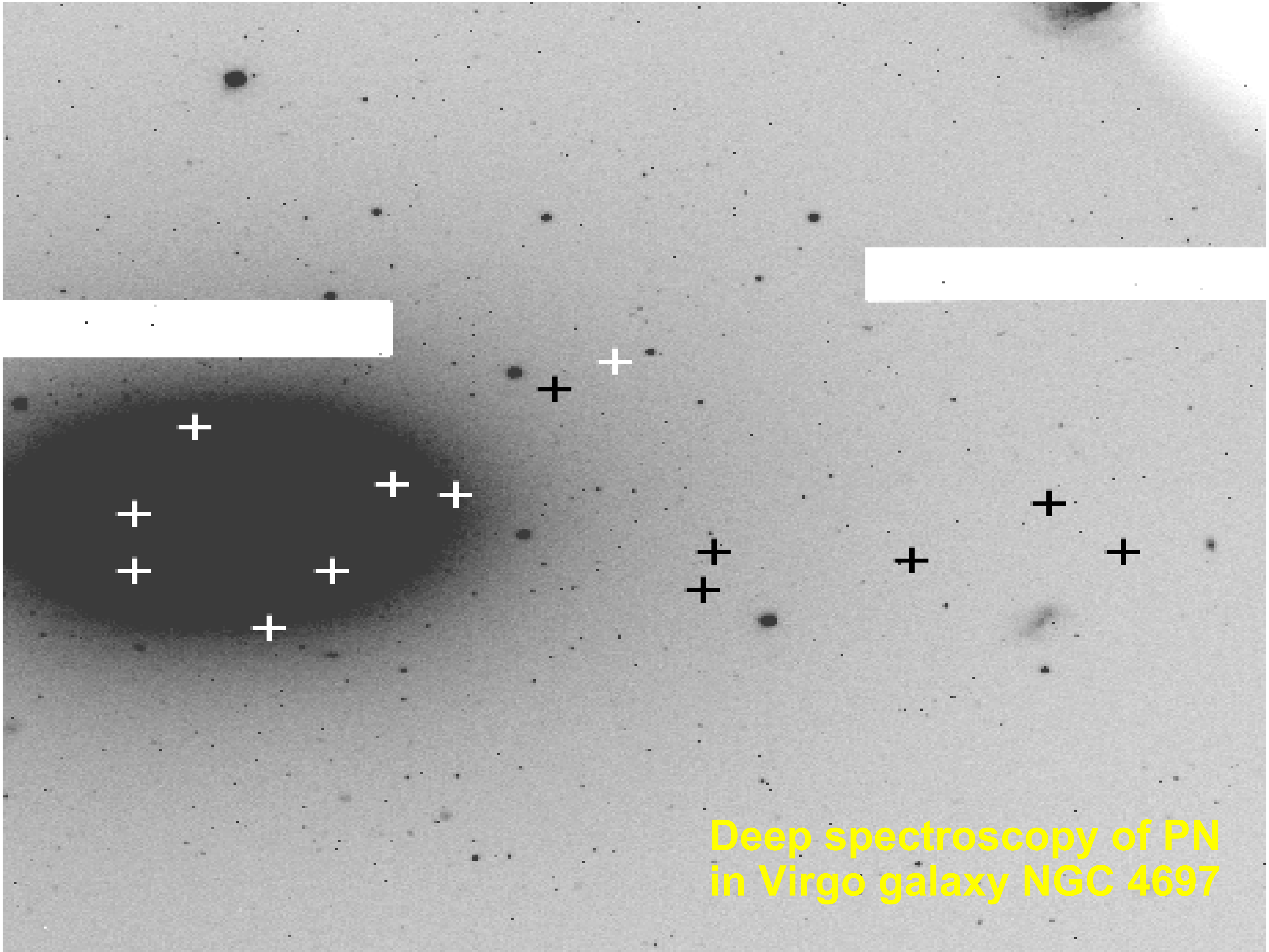
H, He, CNO, Al, Si, Fe abundances

Bresolin, Kudritzki, Najarro et al. 2002

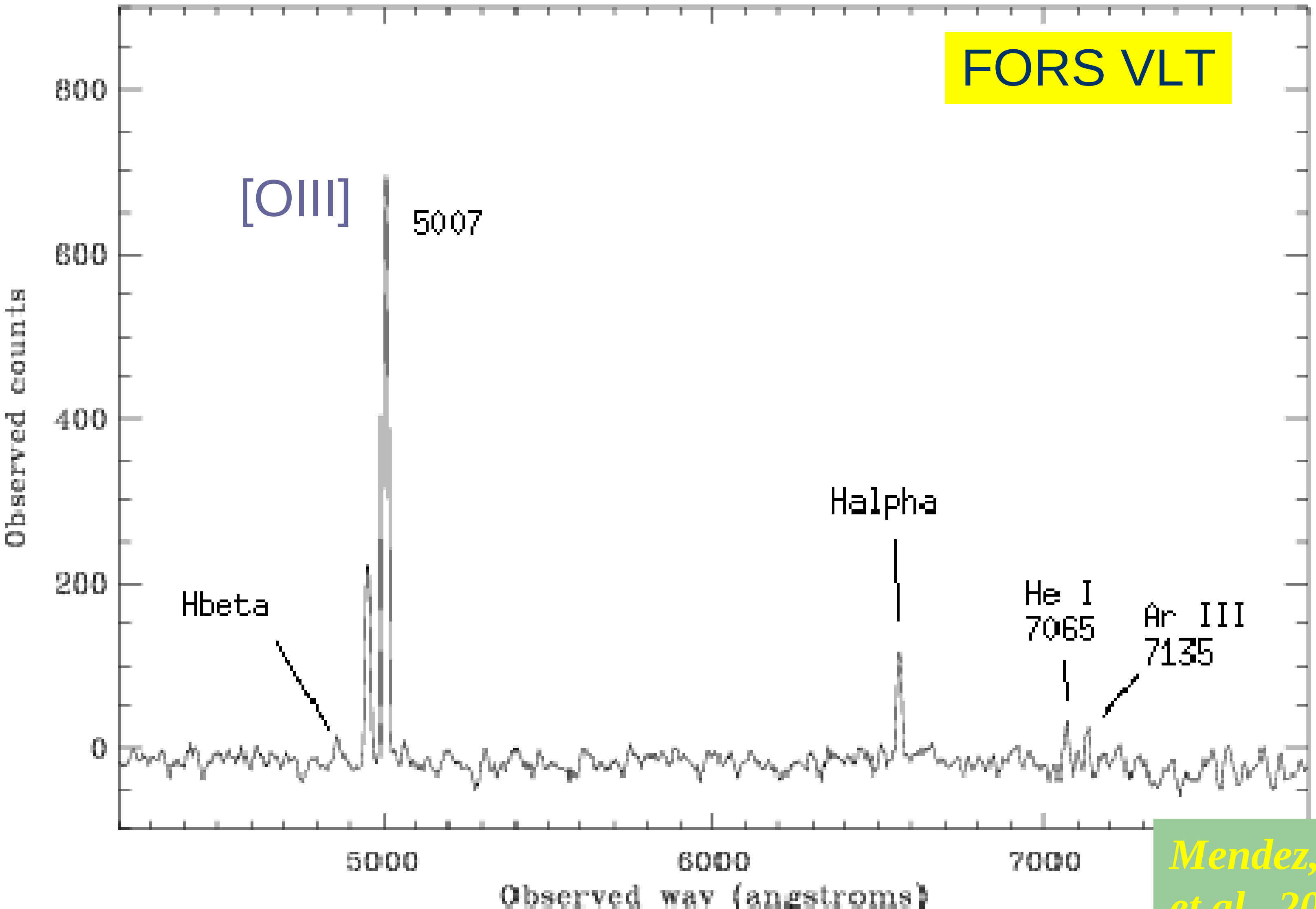
NGC 300 WN11 star

Species	Relative number fraction	Mass fraction	$X/X_{\odot}$
H	1.5 E+00	2.7 E−01	0.4
He	1.0 E+00	7.2 E−01	2.7
C	3.6 E−04	7.7 E−04	0.3
N	2.5 E−03	6.3 E−03	7.7
O	5.5 E−04	1.6 E−03	0.2
Al	5.0 E−06	2.4 E−05	0.4
Si	8.5 E−05	1.7 E−04	0.2
Fe	1.5 E−04	1.5 E−03	1.3

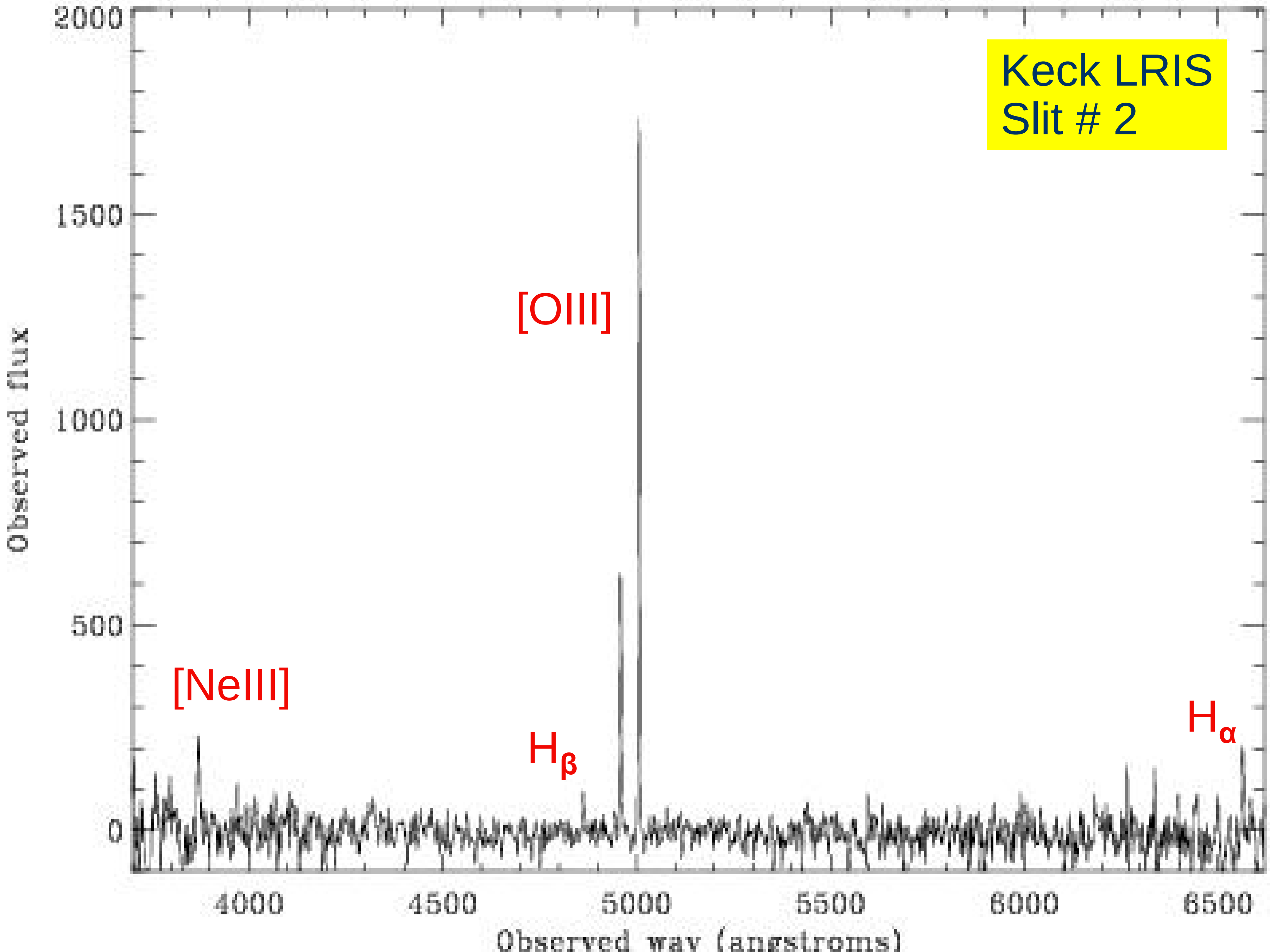
α/ Fe ratio is 0.5 solar!


Deep spectroscopy of PN
in Virgo galaxy NGC 4697

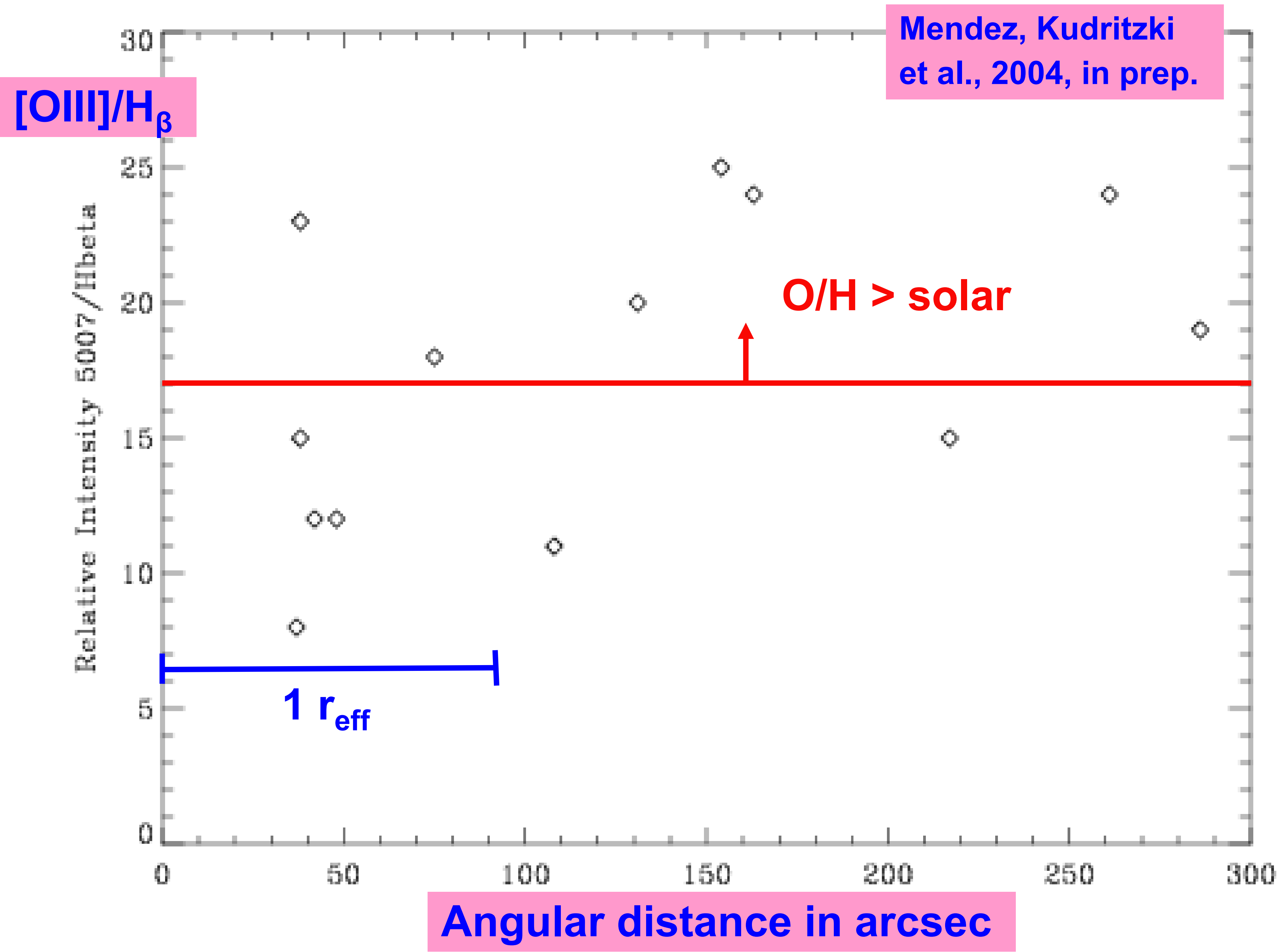
Deep spectroscopy of Planetary Nebulae in Virgo early-type galaxy NGC 4697



Mendez, Kudritzki et al., 2004



Keck LRIS
Slit # 2
[OIII]
[NeIII]
Hβ
Hα
2000
1500
1000
500
0
4000
4500
5000
5500
6000
6500
Observed flux
Observed wav (angstroms)



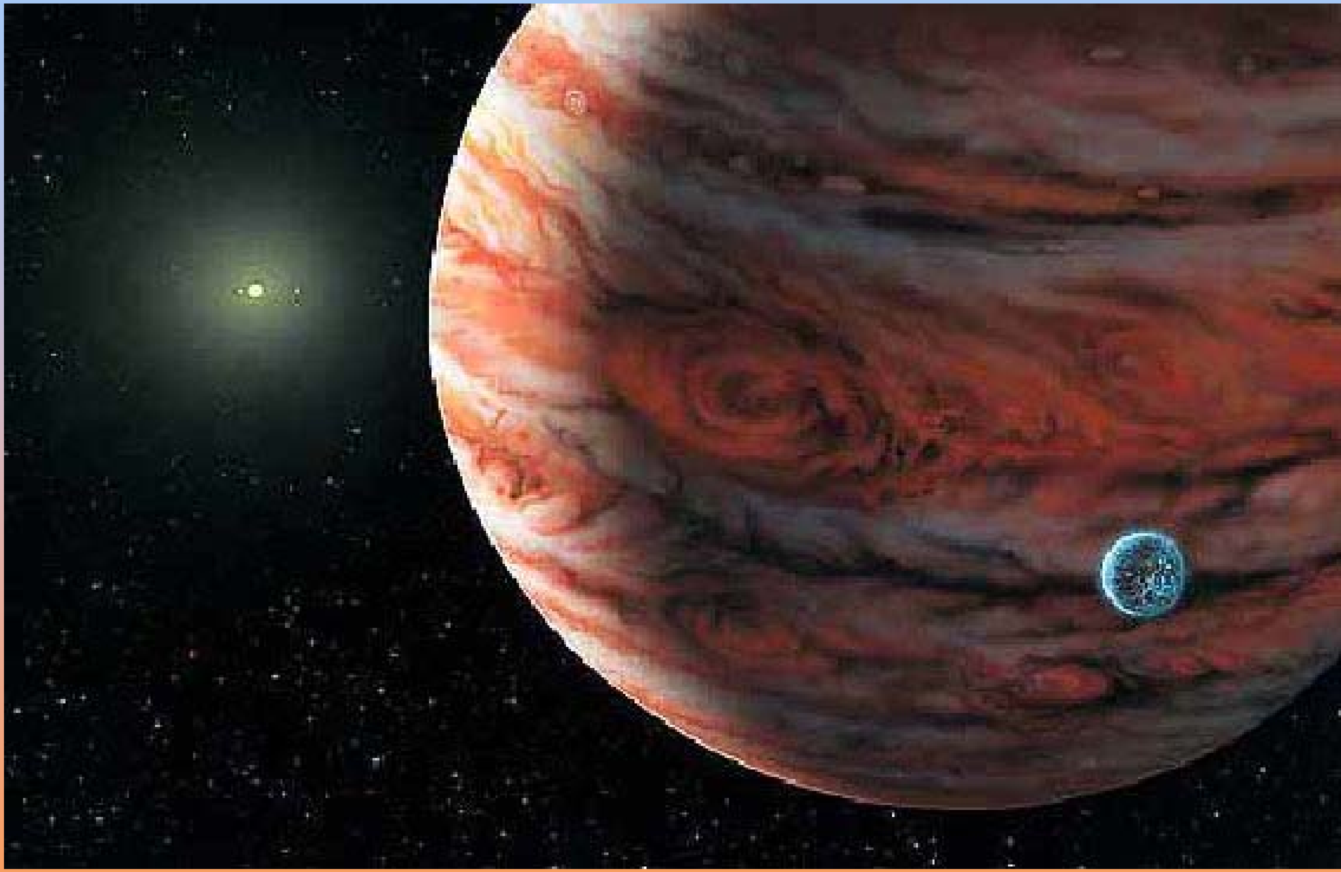
Mendez, Kudritzki et al., 2004, in prep.
[OIII]/Hβ
Relative Intensity 5007/Hbeta
O/H > solar
1 r_eff
Angular distance in arcsec
0
5
10
15
20
25
30
0
50
100
150
200
250
300

Exploring other solar systems

More than 100 planets around other stars detected so far ("indirect" technique- very small periodic spectral line shifts indicate orbital motion)

Most planetary systems vastly different from Solar System

No direct images of other planetary systems so far



Artist conception of planetary system orbiting around 55 Cancri using results of radial velocity Keck observations

Planets around other stars

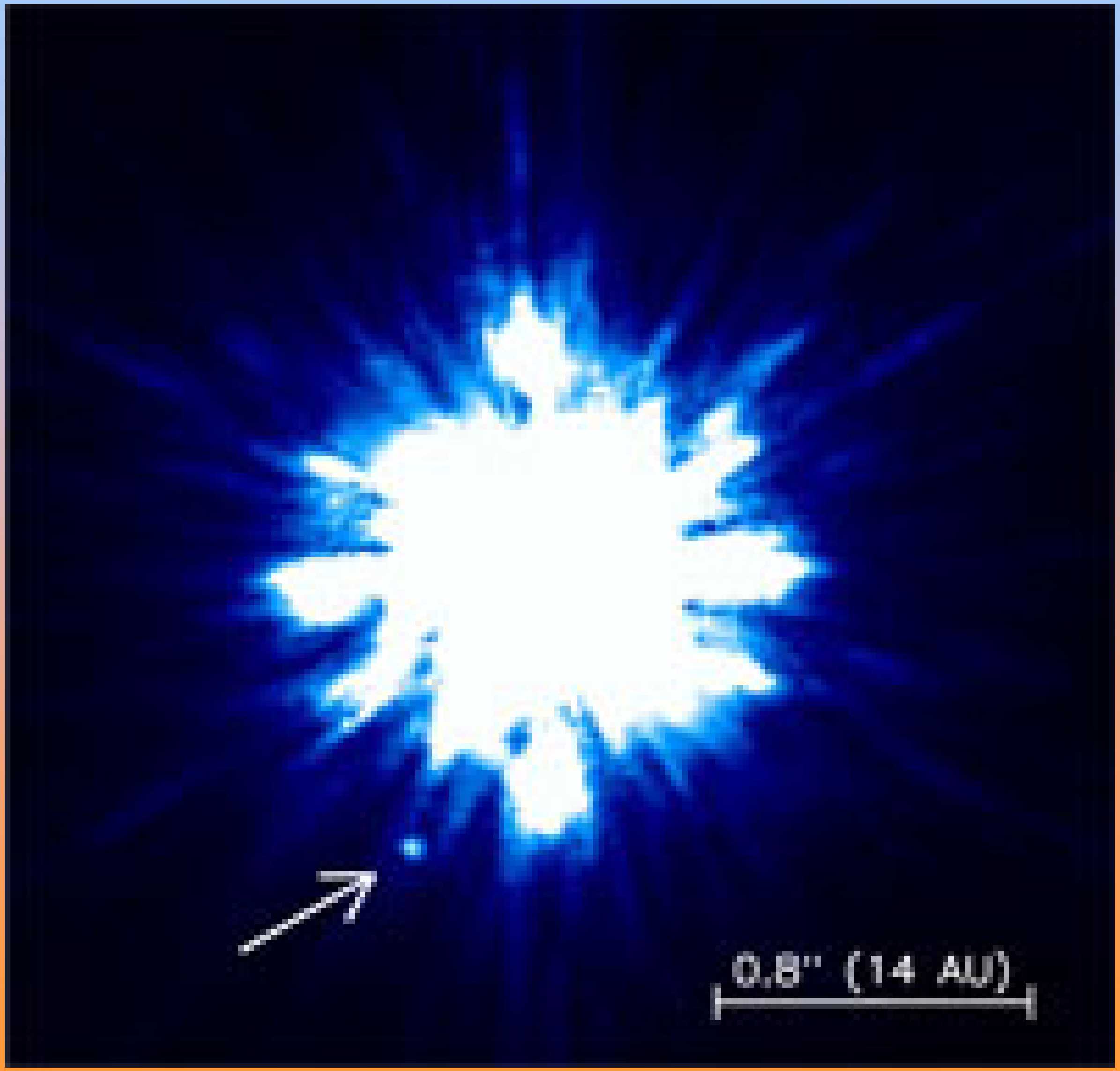
"Brown Dwarf"
orbiting a star at same distance as Saturn from sun

Gemini/Keck AO detection by Michael Liu (IfA), 2002

Problem: Planets much fainter than Brown Dwarfs

→30m telescope needed !!

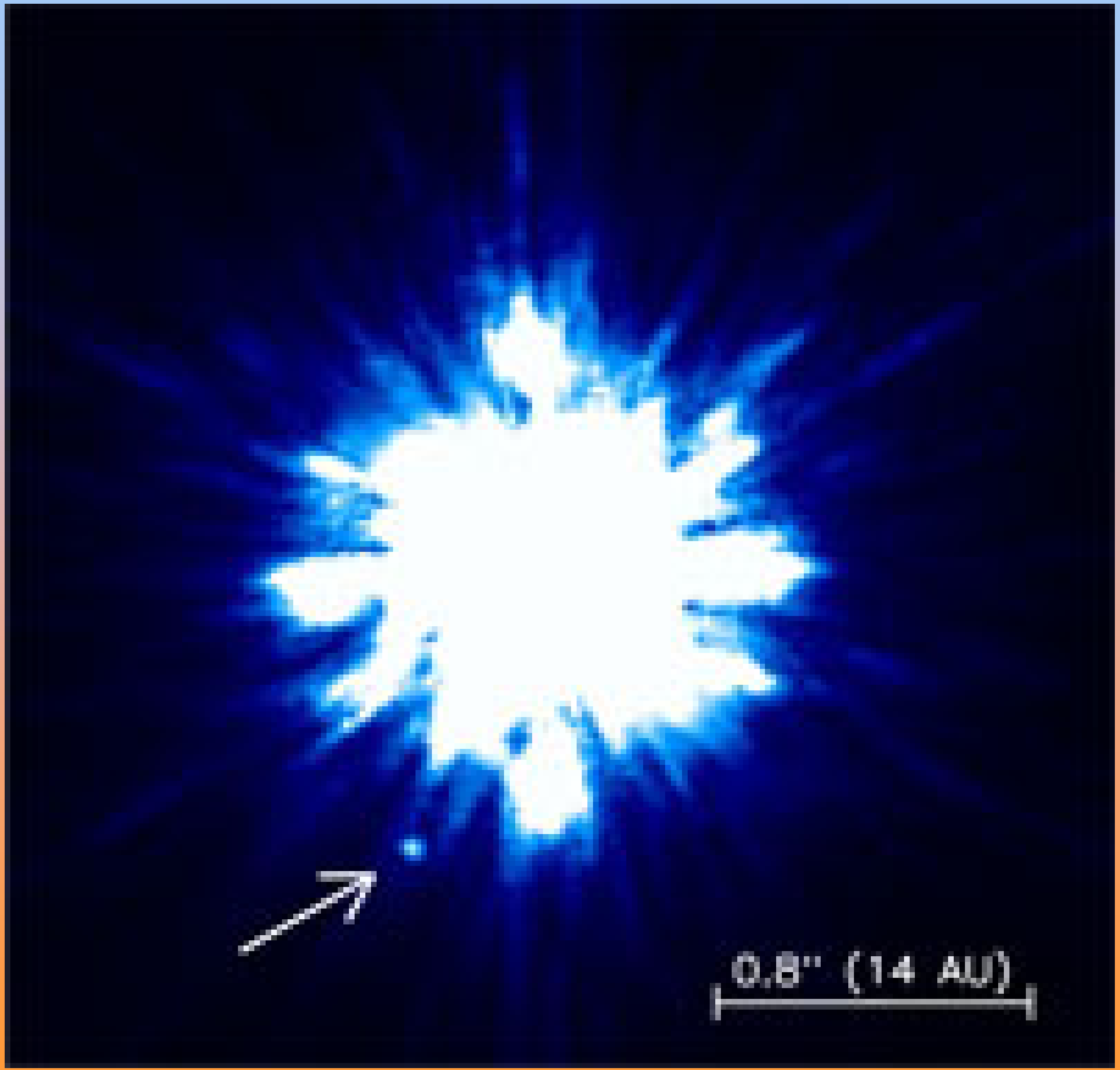
→ GSMT !!



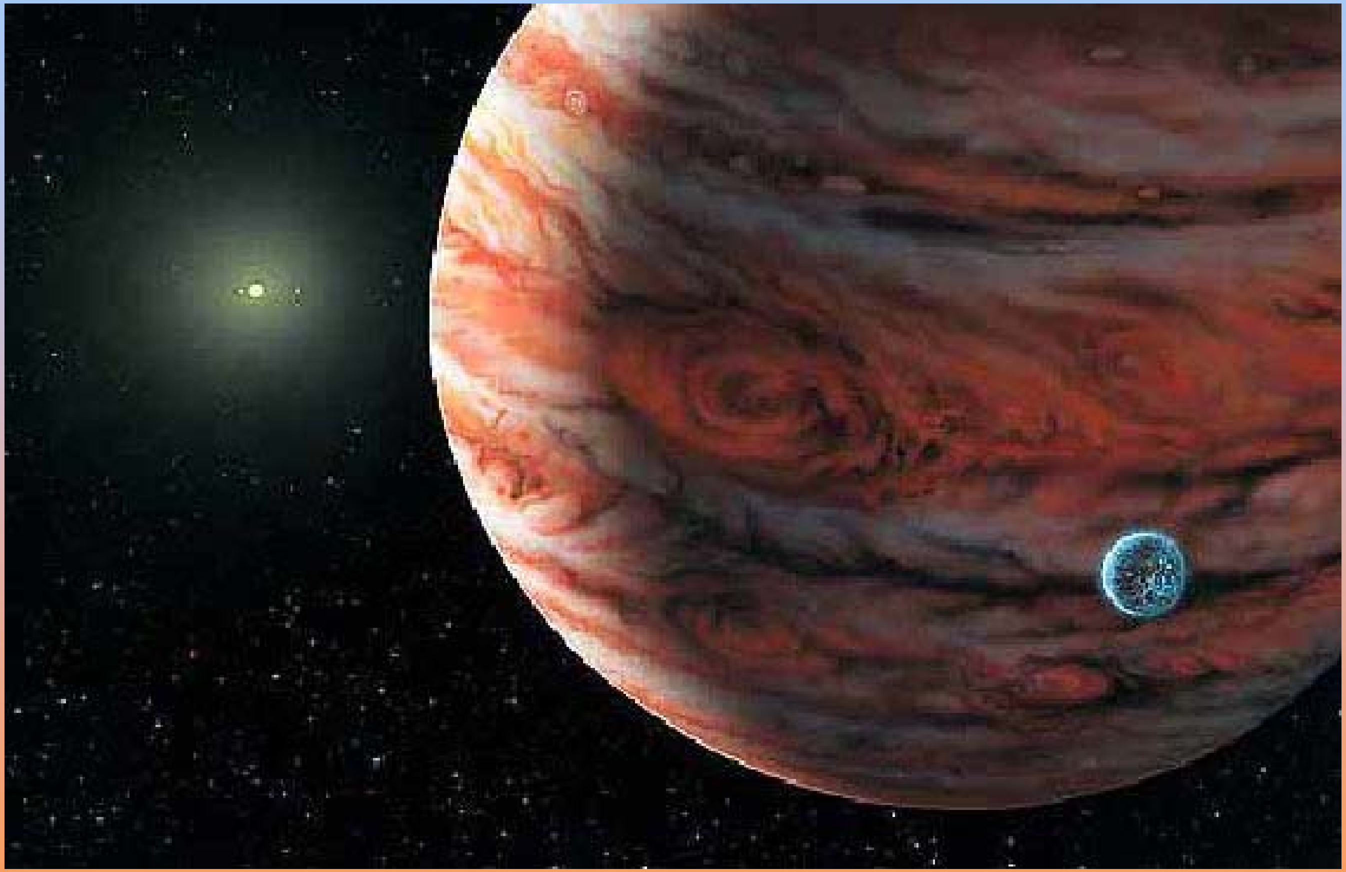
The power of GSMT

GSMT will allow
for the first time

- To image giant planets surrounding many hundred stars out to distances as great as 200 light years (coronography + AO)
- To determine masses and radii by imaging and spectroscopy
- To analyze their atmospheric structure and chemical composition by spectroscopy

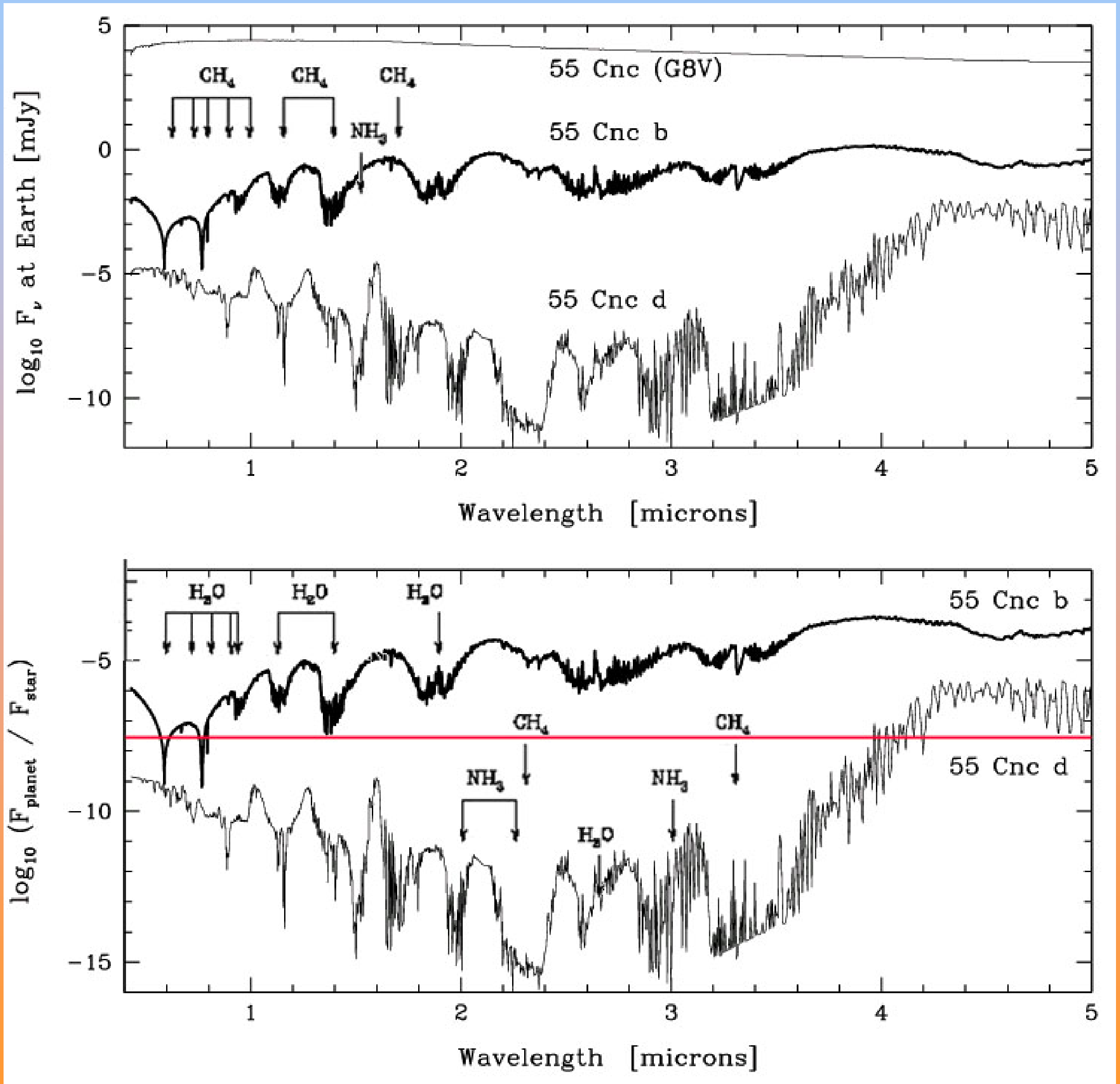


Exploring other solar systems



Artist conception of planetary system orbiting around 55 Cancri using results of radial velocity Keck observations

55 Cancri – physical characterization by spectroscopy



GSMT →
Detection of 55 CnC b/c
Chemical composition of Atmosphere of 55 CnC b

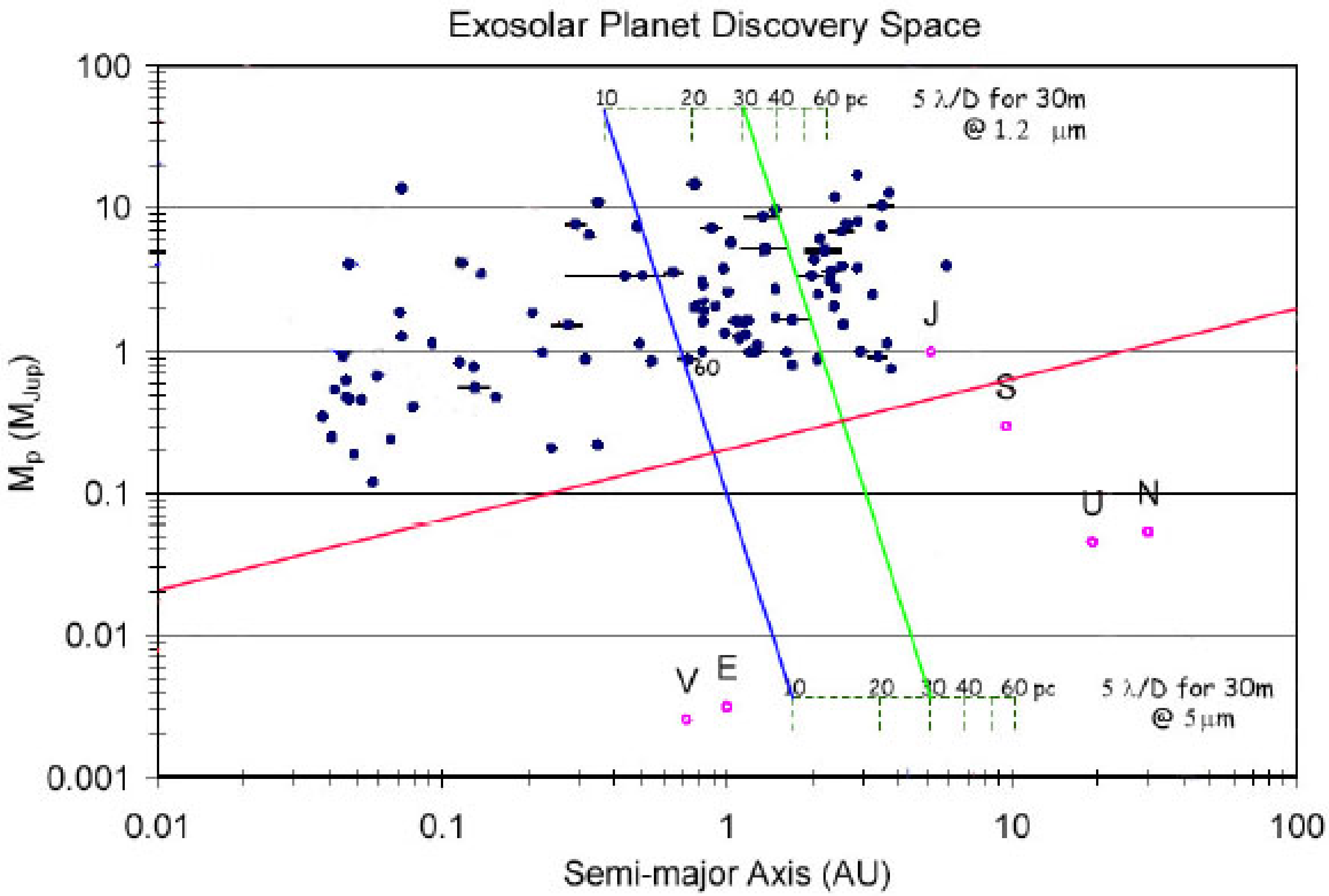
Sudarsky, Burrows & Hubeny, 2003

Key Parameters: **30m** GSMT

λ	**5 λ/D**	**Separation @ 10pc**
1.2 μ	40 mas	0.4 AU
4.7 μ	160 mas	1.6 AU

Aperture is critical to enable separation of planet from stellar image and to characterize planet by spectroscopy

GSMT discovery space



The physics of giant exo-planets

<u>Goal:</u> Image and characterize exo-planets

- Mass, radius, albedo
- Atmospheric structure
- Chemistry → physics of giant planet formation
  →repercussion for formation of terrestrial planets, life on terrestrial planets
- Rotation
- "Weather"

<u>Measurements:</u> R~ 10 photometry & R ~ 200 spectra

- Near-infrared (reflected light)
- Mid-infrared (thermal emission)

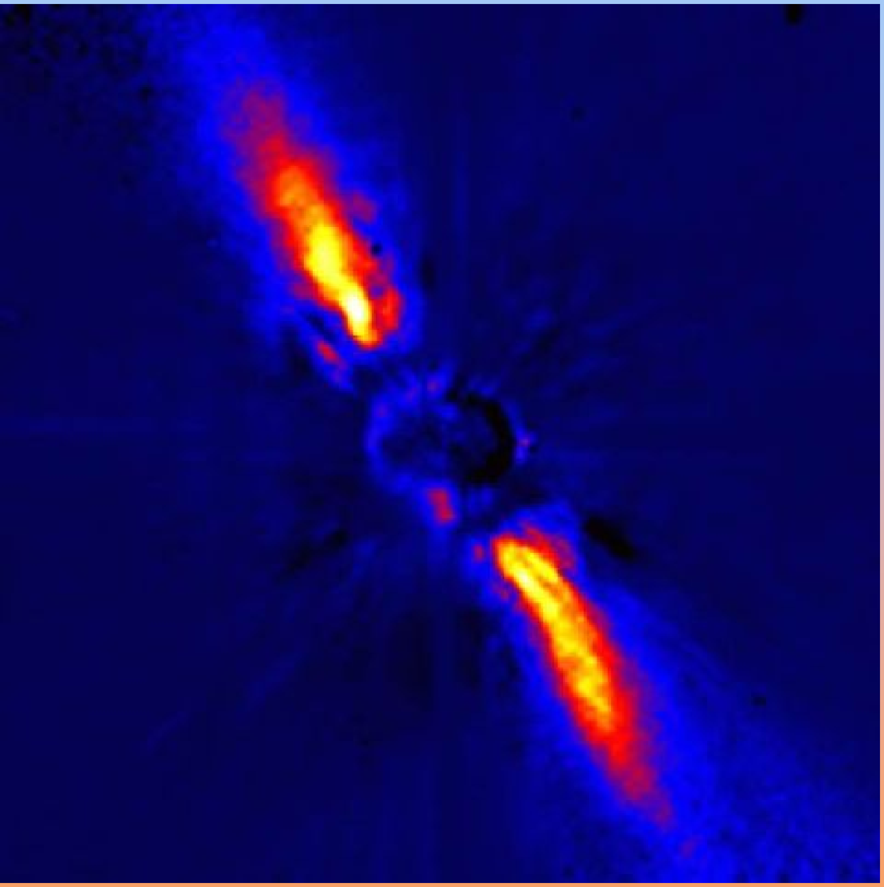
<u>Role of GSMT:</u> Enable measurements via

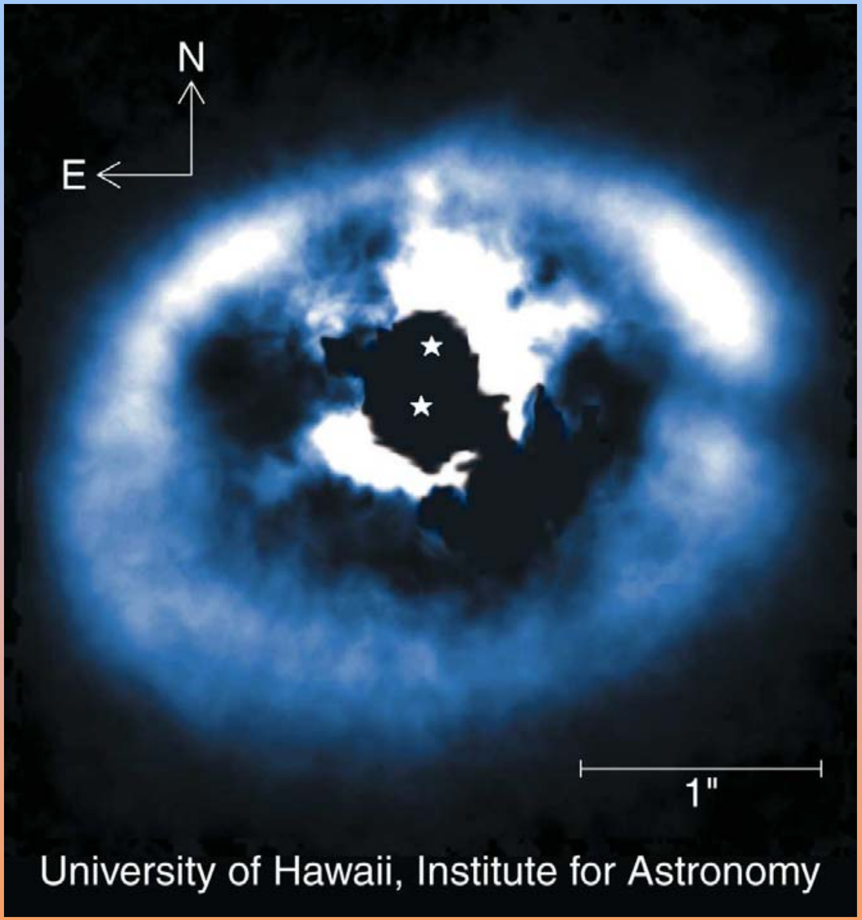
- High sensitivity
- High angular resolution

Exploring the process of planet formation

Artist conception of a proto-planetary disk with young planets and asteroids

Proto-planetary disks around stars

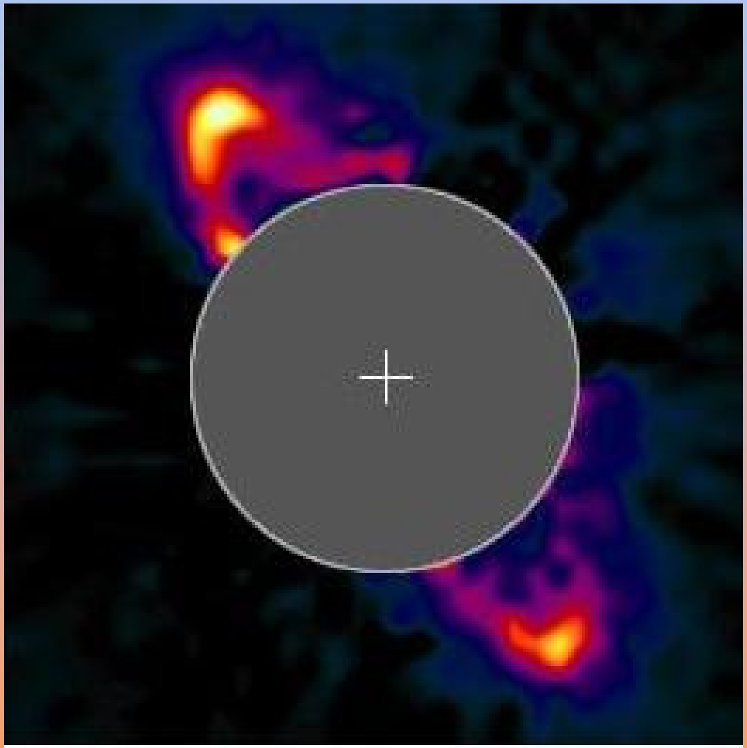




β Pic (ESO VLT)

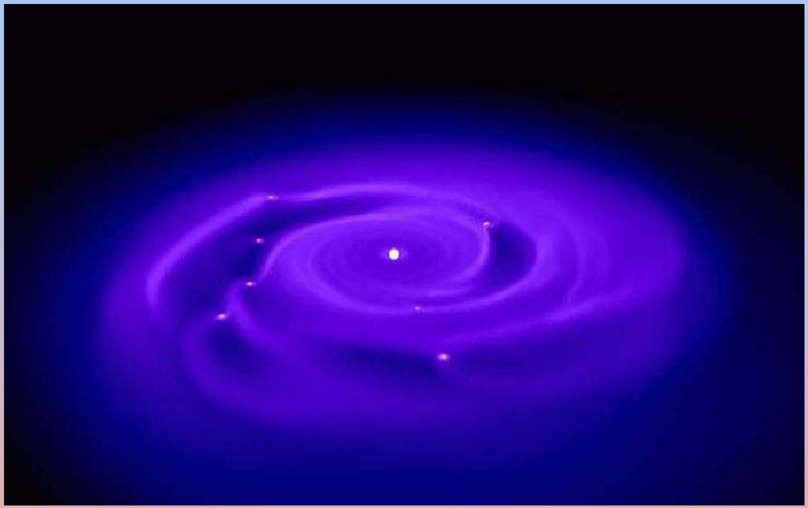
GG Tau, Gemini (Hokupaa)
Potter et al., 2002

Proto-planetary disks around stars



HST, NICMOS

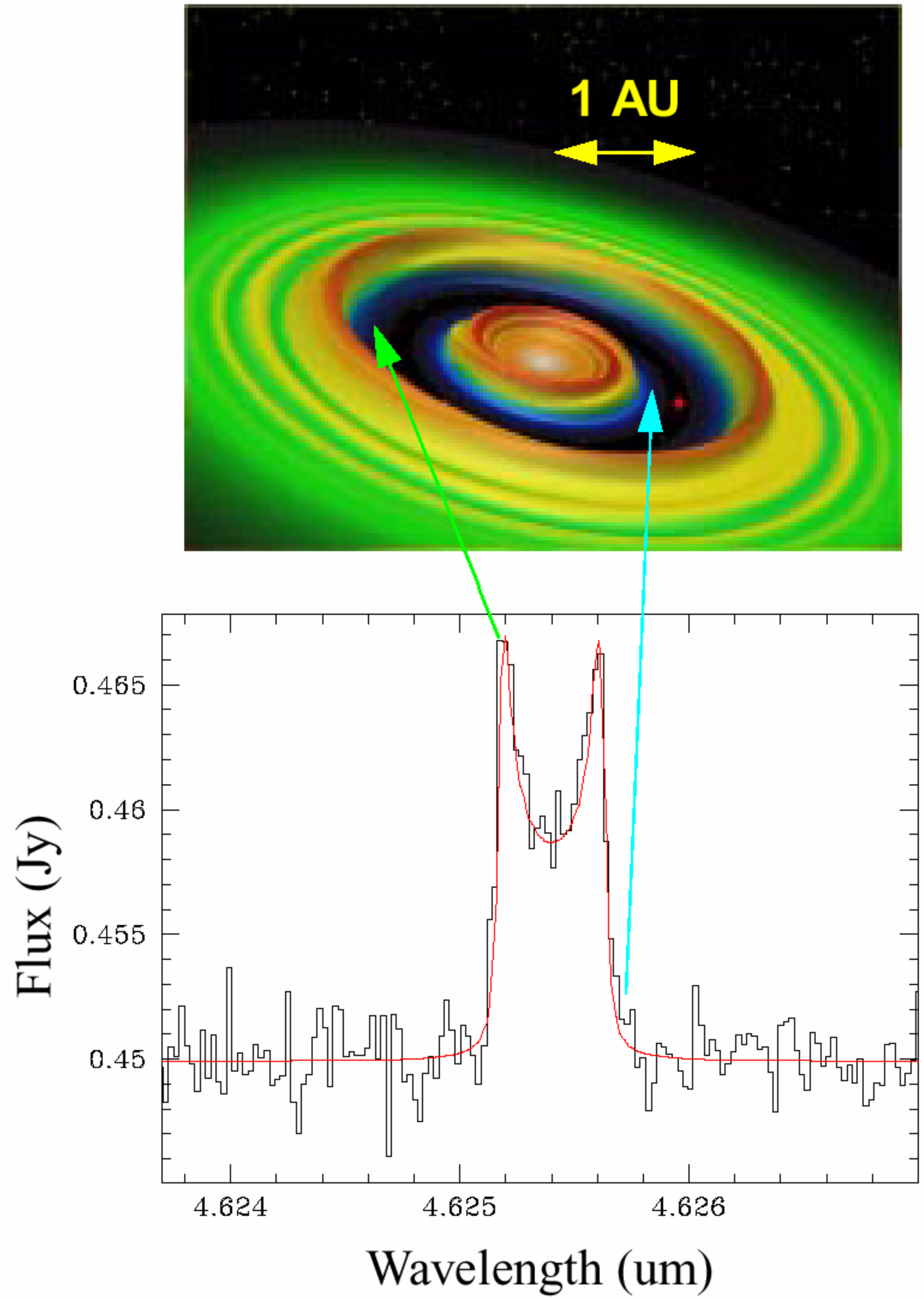
Formation of planets in proto-planetary disks



Goals:

- AO imaging and IR spectroscopy of thousands of disks around nearby young stars
- characterize physics of disks, T(r), ρ(r)
- detect giant planets directly
- detect giant planets indirectly from gravitational "gaps" in disks
- characterize planets from properties of disks (location, widths)

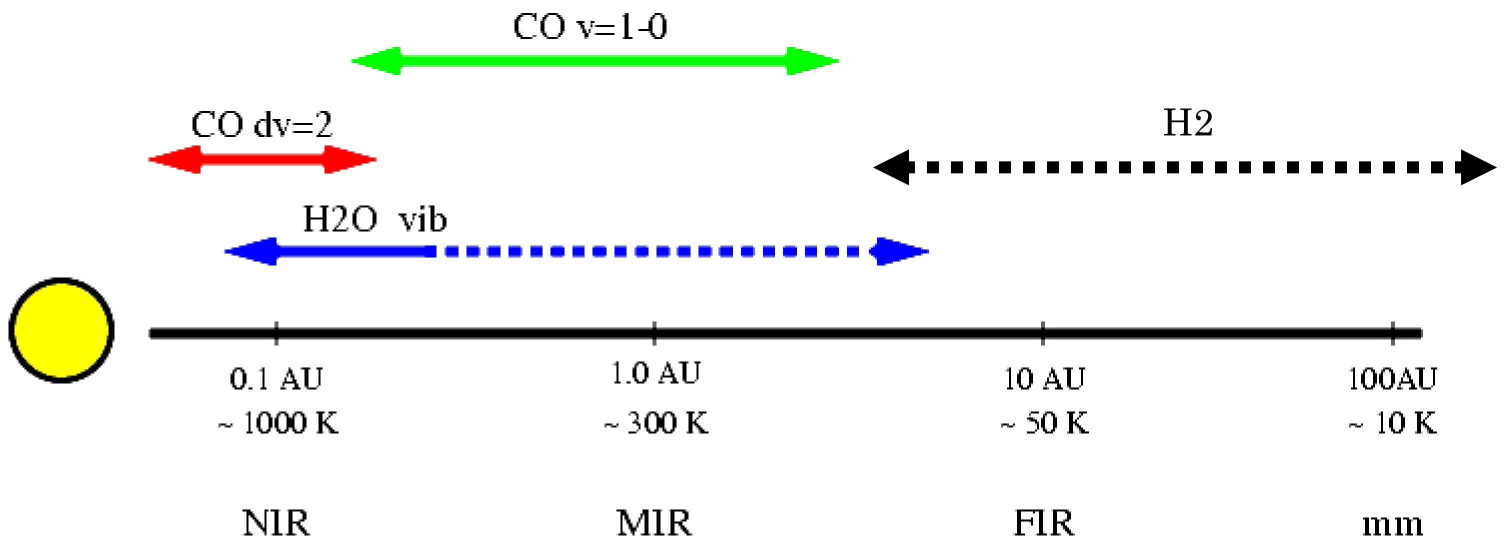
Probing Planet Formation with High Resolution Infrared Spectroscopy



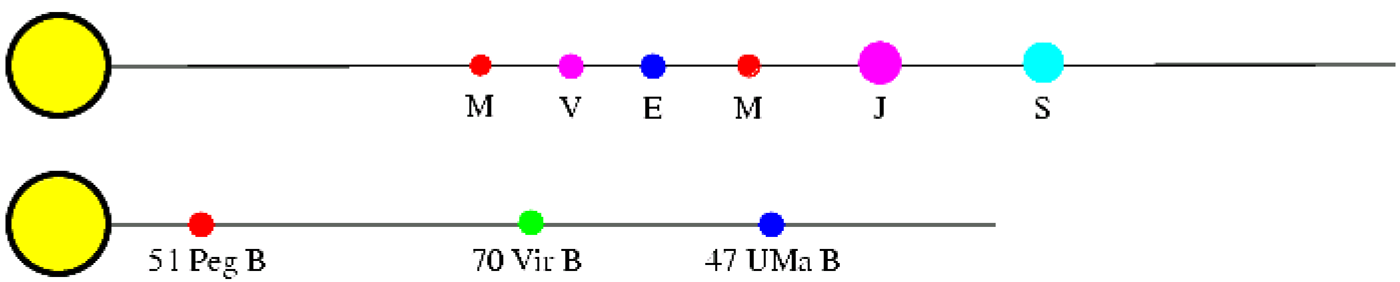
Simulated 8 hr exposure of mid-IR CO fundamental spectral line profile emitted by gas in gap produced by giant planet

width of line → location in disk
Width of line peaks → width of gap
→ mass of planets

Infrared Diagnostics of Protoplanetary Disks



Planets Around Normal Stars



Origins of Planetary Systems

- **Goals:**
  - Understand where and when planets form
  - Physical nature of proto-planetary disks ($T(r)$, $\rho(r)$, $\Sigma(r)$)
  - Observation of 'gaps' to constrain formation and physics of giant planets
- **Measurements:**
  - Spectra of some 10^3 accreting PMS stars ($R \sim 10^5$; $\lambda \sim 5\mu$) in SF regions
- **Key requirements:**
  - On axis, high Strehl AO; low emissivity
  - Exploit near-diffraction-limited mid-IR performance
- **Time to complete study with GSMT:**
  - 1 year

Conclusions: Science

- **Fundamental science**

→ connection first structures of Big Bang to origins of life

→ 3D-structure and chemical evolution of early universe

→ physics of formation of first stars and galaxies and evolution to mature galaxies of today

→ nature of dark matter, dark energy

→ physics of thousands of proto-planetary disks and planet formation

→ physical characterization of hundreds of extra-solar planetary system

→ formation of terrestrial planets and habitable zones

Conclusions: Telescope

- **Unprecedented light gathering power and angular resolution**

  → completely new detections space

  → unanticipated phenomena

- **Extensive analysis by several groups**

  → costs ~ $ 700 M

- **Formidable technical challenge but no “show stoppers”**

SWG recommendation

- Immediate NSF investment in support of a technology program to develop a viable, cost-effective GSMT concept within next four years (echoing decadal survey)
- Proposals should show
  - → evidence of value of proposed investment to multiple GSMT-type programs
  - → proactive commitment to share results among programs
- Coherent supervision and coordination needed
- Investment should result in public access to telescope time

Technology Development for ELTs

Four key areas require technology development to achieve required performance:

- Telescope systems
- Facility Adaptive Optics systems
- Site Evaluation
- Science instruments

Future work of the SWG

- Feedback from community concerning key science
- Develop community-based view of performance goals and requirements for GSMT
- Review scientific instrument concepts
- Monitor progress of technology development
- Scientific feedback to GSMT designing groups
- Establish working relationships with groups abroad
- Work closely with JWST SWG
- Continue reporting to NSF, AAAC, CAA
- Ensure input from U.S. research community