# Preparing for the James Webb Space Telescope

## Jason Kalirai (Project Scientist for JWST at STScl)



# The James Webb Space Telescope







## The JWST Instrument Suite





## Ultra Sensitive and High **Resolution Imaging**

## Mid IR IFUs

# Space Based MOS

## **Bright Object Modes**





Near IR



00 km

5

0.8″



# Slitless Spectroscopy



beta pictoris

## **Moving Target Support**



exoplanet

beta pictoris b

Science Capabilities

image at 0.94 microns Cassini mission 2009)

## NIR and MIR Coronagraphy





# Multiplexed Spectroscopy in Crowded Environments



## 248,000 microshutters!





# Multiplexed Spectroscopy in Crowded Environments





## Multiplexed Spectroscopy in Crowded Environments





+ Targets in Operable Shutters x Targets Outside Shutters

















## Technical Progress



# JWST is on schedule for its Oct 2018 LAUNCH!



## A Better Snapshot of the Cycle 1 JWST Science Program

• WITNESSING REIONISATION AT THE END OF THE DARK AGES

NASA

• CAPTURING THE LIGHT FROM THE FIRST GALAXIES AND STARS

UNDERSTANDING THE ASSEMBLY OF GALAXIES

→ UNVEILING THE MYSTERIES OF PLANET AND STAR FORMATION

→ STUDYING PLANETARY SYSTEMS AND THE ORIGINS OF LIFE

### james webb space telescope JWST is a joint mission between NASA, ESA and CSA

*"Exploring the Universe with JWST"* Conference in ESTEC (Oct 12-16, 2015)







R. Ellis - z = 8 galaxy \*\*spectra\*\* w/ JWST Hubble deep field imaging has contributed to demographics of early galaxies (#s, LFs, colors) JWST spectroscopy will address detailed astrophysics - nature of star formation: regular or burst-like (feedback) - ionizing spectrum (stellar pops, role of AGN) - escape fraction of Lyman limit photons - chemical composition: O/H, C/O ratios (early nucleosynthesis)

- is there dust?







Lookback time (Gyr)



J. Lotz - Unveiling the Peak of Galaxy Assembly w/ JWST
Tremendous progress in understanding 1 < z < 6 galaxies, where 75% of the Universe's stars formed</li>
JWST's resolution and sensitivity in the near IR will be a game changer, and answer these questions
how much hidden star-formation at z > 3?
what are we missing? red galaxies - dusty and/or old?
galaxy structures at z > 3? where are the mergers? where are metals and gas outflows at high z?
super massive black holes/AGNs at z > 1? what is the role of (dusty) AGN in galaxy assembly?

- what is the role of environment?

## -HST/ACS

## -HST/WFC3-IR

## z=1.55





E. van Dischoeck - Embedded Phase of Star Formation w/ JWST Spitzer, Herschel, WISE, and ground submm have built complete inventories of protostars out to a few kpc JWST IFU spectroscopy will now characterize physics and chemistry on 10 - 1000 AU scales - lots of IR diagnostics to use, each giving insights on the disk, accretion, shock, UV, high energy, etc. - need modeling tools and lab data! - JWST spatial resolution will resolve disks and envelopes.

- Physical structure of warm dust, geometry, earliest stages of massive star formation, variability, where does matter enter disk, fragmentation, resolve accretion from outflow shocks, water transport from clouds.











K. Luhman - Pre Main Sequence Stars and the IMF w/ JWST Space based IR observations have uncovered the substellar regime JWST NIR and MIR imaging will measure complete stellar-planetary census in star forming regions - JWST will see free floating Jupiter mass objects in Orion - thousands of circumstellar disks in a variety of environments and evolutionary states - unbiassed IMF over a complete mass distribution, and its variation with environment (e.g., spatial) - spectra of 1-10 M<sub>JUP</sub> objects in clusters to help interpret spectra of young planets





A. Ferguson - Resolving Populations in the Local Volume w/ JWST HST has been limited to direct measurements of the oldest stellar generations in the Local Group JWST will measure the fossil record of different galaxy types in detail - wonderful opportunity to connect near-field and far-field approaches that study galaxy assembly

- infrared baseline provides high precision ages of dark matter dominated UFDs (suppression by reionization)
- diverse history of dwarfs and their cosmological significance
- spatially resolved star formation histories for different galaxy types in the Local Volume





## Brown et al. (2014)





H. Hammel - Giant Planet Systems w/ JWST Great Observatories have played a tremendous role in studying the Solar System JWST can track every object outside the orbit of Mars - atmospheric dynamics and chemistry of outer planets - spectroscopy of moons and rings to assess temporal variation (seasonal and time variable effects) - set the stage for future planetary missions to the outer Solar System - dedicated talks on KBOs, comets, Titan, occultations, asteroids









V. Meadows - Characterizing Potentially Habitable Planets w/ JWST K2 and TESS are (will) yield prime targets for JWST follow up JWST provides our first opportunity to characterize habitable zone terrestrial planets - JWST may be able to detect O4 dimer at 1.06 and 1.27 microns (Earth like planet at 5 pc) - will require ppm sensitivity, long integrations, and favorable conditions (e.g., no haze). - warm mini Neptunes will be straightforward for JWST (cloud and atmospheric composition) - lots of exciting mid infrared exoplanet science also



Galaxy Assembly with Gravitational Lensing

> Direct Imaging of Exoplanets

Warm Molecular Hydrogen at High-z

james webb space telescope

Organic Material in the Circumstellar

**Planet Formation** 

High Redshift Galaxy Clusters

Formation of Super Star Clusters

Ultra Faint Dwarf Galaxies

Star Formation in the Magellenic Clouds

Characterizing Habitable Exoplanets

Pre Main Sequence Stars and the IMF



# JWST Advisory Committee Activities

The JSTAC advises the STScI Director on STScI's readiness to support science operations, implementation of NASA policies, and other matters related to the GO science community

Represents the Scientific Community and Advises the STScI Director Roberto Abraham (Toronto) Neta Bahcall (Princeton) Natalie Batalha (NASA Ames) Stefi Baum (Manitoba) Roger Brissenden (Chandra/SAO) Hashima Hasan (NASA, ex-officio) Tim Heckman (Johns Hopkins) Garth Illingworth (Santa Cruz, Chair) Malcolm Longair (Cavendish) John Mather (NASA, ex-officio) Mark McCaughrean (ESA, ex-officio) Chris McKee (Berkeley) Brad Peterson (Ohio State) Alain Ouellet (CSA, ex-officio) Joseph Rothenberg (JHR Consulting) Eric Smith (NASA, ex-officio) Lisa Storrie-Lombardi (Spitzer/Caltech) Monica Tosi (Bologna) http://www.stsci.edu/jwst/advisory-committee



# JWST Advisory Committee Activities

JSTAC is chaired by Garth Illingworth (UC Santa Cruz) JSTAC meets at STScI twice every year (last meeting May 2015) See <u>http://www.stsci.edu/jwst/advisory-committee</u> for more information

## Recently, JSTAC has been focussed on ways to maximize early science from JWST

## 2014-2015 JSTAC recommendations to the STScI Director

UNIVERSITY OF CALIFORNIA SANTA CRUZ

March 26, 2014

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Dr. Matt Mountain, Director Space Telescope Science Institute 3700 San Martin Drive Baltimore, MD 21218

Re: JSTAC recommendations regarding Early Release Science and Community Fields

### Dear Director Mountain

Over the last several years the JSTAC has been discussing a number of ways in which the scientific productivity of JWST could be maximized during its lifetime. While important for any scientific facility, such maximization of the science return is particularly important for JWST because of its cost and its five-year required life. The JSTAC recognizes the responsibility that we have as representatives of the science community to NASA and its partners, ESA and CSA, to policymakers, and to those funding our missions to offer advice on making JWST as scientifically successful as possible

The JSTAC realized soon after its inception in 2009 that there were several approaches that could significantly improve the scientific return from JWST. These were identified in a letter (http://www.staci.edu/iwst/advisory.committee/JSTAC.lengcy.pdf) dated lune 21, 2010 to the acy.pdf) dated June 21, 2010 to the Director where we highlighted the value of (i) a First Look Program, which is now being discussed as Early Release Science (ERS) observations, (ii) open access to data from Large/Treasury/Legacy programs, as has become the norm for the Great Observatories, and (iii) open access to Community Fields, i.e., areas that have had a major investment of observation time on Hubble and other NASA Great Observatory. A common theme for these recommendations was that open access (zero proprietary time) to data plays a key role in optimizing the scientific return.

The discussion in JSTAC that started in 2009-2010 regarding maximizing the science return through open access to data was in abeyance for a period because of the issues surrounding JWST in 2010 that led to the ICRP report, the steps taken to respond to that report by NASA, and the concerns raised in Congress in 2011 that led to a serious discussion regarding whether to continue at all with JWST. The JSTAC has now come back to this central aspect of its charge with renewed discussion of those early recommendations and other aspects related t maximizing the science return.

The JSTAC has revisited these aspects in particular in its last two meetings, in May 2013 and November 2013, and has clarified its recommendations. The recommendations regarding (1 Community Fields and (2) First Look/ERS observations are discussed here. The question of the ength of the normal proprietary time/exclusive access period that was extensiv these last two JSTAC meetings, and with the GTOs in July 2013, is addressed in another letter

### (1) Open Access Community Fields: In its June 21, 2010 letter the JSTAC said

"The Great Observatories space missions have established a number of fields whose multiwavelength, multi-mission datasets represent an enormous investment of public resources and have extraordinary value for a wide range of science programs. These Great Observatory

## <u>Mar 2014</u> Early Release Science

### UNIVERSITY OF CALIFORNIA SANTA CRUZ

March 27, 2014

Dr. Matt Mountain, Director Space Telescope Science Institute 3700 San Martin Drive Baltimore, MD 21218

Re: JSTAC recon mendations regarding the exclusive access/proprietary time period for JWST GO observations

### Dear Director Mountair

At the last two JSTAC meetings a major topic of discussion has been the question of the proprietary period for observations with JWST. This question has been forefront in JSTAC discussions since some of its earliest meetings and was addressed in one of its first letters to you in the context of large programs (June 21, 2010 - http://www.stsci.edu/jwst/advisorye/JSTAC-legacy.pdf). The JSTAC recognized very early in its deliberations that the length of the proprietary period would have a major impact on the scientific return from JWST (as shown by the timeline figure in both the June 21, 2010 letter and in an earlier letter dated Feb 25, 2010). Careful consideration of this aspect of science operations is necessary give the JSTAC's clear mandate to offer advice on how to maximize the scientific return from JWST

To recap, in a limited-life mission, such as JWST with its 5-year required life, the interplay between proprietary time and observing cycles can seriously lessen the astronomy community's ability to build new proposals from data taken during the mission. This will impact the overall science productivity of the mission. This letter addresses the situation for JWST, outlines the extensive deliberations within the JSTAC and provides background for its recom regarding proprietary/exclusive access periods

The current situation regarding proprietary periods in Astrophysics: The common proprietary/exclusive access period within Astrophysics has been 12 months. However, the reality is that 12-month periods are not uniform. A number of smaller missions have had shorter and in some cases zero) proprietary/exclusive access periods (Kepler, Swift, Nustar). Spitz has adopted a zero default proprietary period (maximum 90 days) for all programs >100 hours in its extended mission. Furthermore, even within the Great Observatories the proprietary/exclusive access period is not uniformly 12 months. HST Large, Treasury and Director's Discretionary (DD) time all have no proprietary period. The equivalent Legacy programs, Early Release Observations, First Look Survey and DD time on Spitzer similarly had no proprietary period. Nearly half of all time in Spitzer's first cycle had zero proprietary period Chandra Visionary Programs have no proprietary period, and DD programs have 3 months JWST is a new mission of Great Observatory scale but with a required 5-year life is more akin to Spitzer than the longer-lived HST and Chandra. It is therefore important to assess whether the assumption of a 12-month proprietary period for JWST is wise and appropriate. This is of particular interest also at this time given the very large investment in JWST, as well as the actions of policymakers towards requiring open access for taxpayer-funded datasets.

## <u>Mar 2014</u> **Proprietary Time**

UNIVERSITY OF CALIFOR

Dr Matt Mountain, Director Space Telescope Science Institute 3700 San Martin Drive

BERKELEY • DAVIS • IRVINE • LOS ANGELES • MERCED • RIVERSIDE • SAN DIEGO • SAN FRANCISCO

Baltimore, MD 21218

Dear Director Mountain

(1) Overheads

A number of topics that are important for the scientific productivity of JWST during the operational era have come before the JSTAC over the last few years. As always, the JSTAC is very aware of the need for ensuring that scientific returns are maximized during JWST's 5-year required lifetime, given the large public investment made in this forefront mission. JSTAC recognizes the need for NASA, ESA, CSA, STSCI and the science community to ensure that the operational effectiveness and efficiency of JWST is as high as practical, and continues to come the thoughtful and diligent efforts at NASA, ESA CSA and STScI to do such. Ir evaluating the policies being developed for JWST the experience with other missions plays a central role, but does require recognition that JWST is different, and more challenging, in many ways. JWST is at least as diverse and complex as Hubble in its capabilities, and probably more so, while having a required lifetime more akin to that of Spitzer and Herschel. This necessitates a careful evaluation of its policies and procedure

At the JSTAC's last meeting we received presentations and updates in a number of areas that impact on the operations for JWST. These were:

(1) Overheads: How observing overheads are charged (2) Grant Funding: How the grant funding levels are established (3) Proposal Submission: The methodology for reviewing and selecting proposals (4) Duplications: Developing the duplication policy.

This letter gives the JSTAC perspective and recommendations on these four topics

In its letter of December 28. 2009 the JSTAC developed a set of recommendations regarding he overheads associated with JWST observing time and how they are charged to users (see eads). The JSTAC recommendations were developed after presentations and discussion of the constraints imposed by the operational modes of JWST. The recommendations from 2009, and their context, are given in the appendix. Given that over four years had passed since the original discussion, the JSTAC felt that it was important to hear of the changes that had occurred as a result of improved understanding of nature of the operational mission. Accordingly, the topic was given further consideration by the JSTAC in discussions with STScl

NIA SANTA CRUZ	

November 30, 2014

Re: JSTAC Recommendations on overheads, grant funding, proposal submission & duplications





Dr Matt Mountain, Director Space Telescope Science Institute 3700 San Martin Drive Baltimore, MD 21218

Re: JSTAC recommendations on parallel observations with JWST

Dear Director Mountain:

Parallel observations on Hubble have demonstrated their scientific value to the Hubble mission. They have enhanced the immediate scientific productivity as well as enhancing the scientific output from archival research. It has long been recognized that similar gains would accrue to JWST's scientific productivity from the implementation of parallel modes of operation of the

January 07, 2015

The JSTAC has for some time expressed its interest in, and support for, the implementation of parallel capabilities for JWST. The most extensive discussion occurred at a meeting earlier this year when the JSTAC received its most detailed presentation to date covering parallel modes and their impact. Since STScI was still developing its proposal to the JWST Project, the JSTAC decided to wait before submitting a formal recommendation to the Director. The recent submission to the JWST Project of a proposal from STScI to implement some of the most scientifically-productive capabilities led to a further discussion in the JSTAC in its most recent meeting. The JSTAC decided that it was time to express a recommendation regarding Parallel

JSTAC recommendation regarding parallel observations:

The JSTAC recommends implementation of parallel observing capability on JWST for Cycle 1 for GOs and GTOs, including capabilities for both pure parallel and coordinated parallel modes.

The JSTAC recognizes

i) that the decision to implement parallel observing capabilities will depend on the cost and impact on other required deliverables, and on available funding;

ii) that not all combinations of instruments and modes may be practical initially given technical constraints and/or cost constraints.

Implementing parallel observations on JWST raises a number of policy issues including the appropriate criteria for justifying coordinated observations, constraints for pure parallel programs and the appropriate proprietary/exclusive access period for those datasets. The original Announcement of Opportunity AO 01-OSS-05 from 2001 for the Next Generation Space

### UNIVERSITY OF CALIFORNIA SANTA CRUZ

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Dr. Kathryn Flanagan, Interim Director Space Telescope Science Institute 3700 San Martin Drive Baltimore, MD 21218

Re: JSTAC assessment of GO funding levels for JWST

Dear Director Flanagan

One of the reasons for the success of the Great Observatories has been NASA's practice of providing direct data analysis funding to General Observer (GO) investigators who have obtained observing time on NASA missions. GO funding has been highly effective in maximizing their scientific productivity. The combined publication rate from the Great Observatory missions (HST, Chandra and Spitzer) is nearly 2000 refereed scientific papers

These remarkable returns have been done for an extremely small incremental cost relative to the overall mission lifecycle cost. The marginal cost of providing GO data analysis support is typically less than 1% annually of the cost-to-launch. The extraordinary science return from NASA's support of GO data analysis has shown that providing GO funding at a well-justified level will be an excellent investment.

GO Funding Importance for JWST: GO funding will be even more important for JWST that it has been for missions such as Chandra and HST. Like Spitzer, JWST is a limited-lifetime on. Opportunities for follow-up observations depend crucially (1) on the rapid availabili of data (dealt with in prior JSTAC letters regarding the exclusive use/proprietary period), and (2) on the ability of investigators to publish the early science results as quickly as possible The JWST instruments and observing modes will be new to all investigators and include additional complexity compared to the current suite of available space-based instruments on the Great Observatories. This complexity makes it imperative to provide sufficient GO funding to maximize the overall scientific productivity of JWST. A highly-important and related aspect is to ensure that the data from the early cycles (Cycles 1 and 2) are analyzed and published quickly so as to provide results that can be followed up in the cycles close to the nominal end-of-life (Cycles 3 through 5). If JWST's life goes beyond its required 5 years, as we all hope, the decision to have an appropriate level of GO funding, particularly in its early phases, but also throughout its lifetime, will continue to be rewarded by substantially eased science productivity

Prior Discussions of Factors/Metrics: The JSTAC has discussed GO funding for JWST on a number of occasions, with very thoughtful presentations from the Science Mission Office at STScI on the factors that they considered to be key to assessing the level of GO funding ne JSTAC discussion of GO funding was motivated also by a question to the JSTAC at its Dec 10, 2012 meeting from the Astrophysics Division Director Paul Hertz. Director Hertz

## <u>Jan 2015</u> Parallel Observations

<u>May 2015</u> GO Funding Level



May 22, 2015

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## The Early Release Science Program (ERS) The JSTAC has recommended an Early Release Science Program for JWST

# **June 2010**

"..to obtain images and spectra that would be used to demonstrate key modes of the JWST instruments. The goal of this program is to enable the community to understand the performance of JWST prior to the submission of the first post-launch Cycle 2 proposals that will be submitted just months after the end of commissioning."

"The JSTAC recommends that the First-Look data be released both in raw form and with any initial calibrations as soon as possible; the key aspect is speed."

## **Program Implementation**

**x** STScI had an open dialogue about ERS concepts at recent meetings (e.g., Jan 2016 AAS meeting)  $\star$  Program will be supported by Director's Discretionary time (assume ~15 modes x 20-25 hrs) \* Program will be shaped with significant involvement of the astronomical community \* Program will be selected to span key JWST observing modes, data analysis challenges, science areas \* Program will execute early in Cycle 1 and have no proprietary time **★** ERS teams will be responsible for rapid delivery of science enabling products to MAST

## The ERS program is a fantastic opportunity to become an expert on JWST http://www.stsci.edu/jwst/science/ers

The JSTAC has reiterated its support for the ERS in recent meetings (e.g., see March 2014 letter)

N. Reid's ERS Presentation from the Jan 2016 AAS Meeting: http://www.stsci.edu/jwst/doc-archive/presentations



# JWST Cycle 1 Early Release Science (ERS) Timeline







## Coming Soon: Exploring the Universe with JWST II



## Sept 2007 (Tucson)



### Jun 2011 (STScI)



## Oct 2015 (ESTEC)

October 24-28th, 2016 Montreal, Canada





## A Breakthrough in Photon and Diffraction Limited Science

## Photon Limited Science



## **Diffraction Limited Science**

Hubble pixels are 0.04-0.05" at <1 micron and 0.13" at > 1 micron Spitzer pixels are 1.2" at < 8 micron and 2.55" at 24 micron  $\longrightarrow$  Spitzer only achieves Nyquist sampling at > 24 microns JWST achieves Nyquist sampling of the diffraction limit at at 2, 4, and 7+ microns



# JWST Commissioning Phase (6 months)

Phase I - Commission the Spacecraft (30 days) \_aunch and mid-course corrections Deployment of solar arrays, sunshield, mirrors Subsystem check outs NIR instrument cooldown modifications



**Phase II - Commissioning the Telescope (90 days)** Fine phasing of Optical Telescope Element (OTE) with NIRCam & FGS NIR instruments are activated and checked out MIRI cooldown via the cryocooler All science instruments used to align and optimize OTE









# #MirrorSeason



S

20

02

Dec





# Dec 09, 2015

Jaı Prima

James Webb Space Telescope Primary Mirror Assembly Scoreboard



# 15 Feb 03, 2016

S 201  $\mathbf{7}$ an S , 201 Dec

NASA









# Near Infrared Camera (NIRCam)

## **NIRCam Capabilities**

2 channel imager from  $\lambda = 0.6$  to 5.0 microns, get  $\lambda < 2.5 \& \lambda > 2.5$  micron simultaneously Nyquist sampling of diffraction limit at 2 microns (0.032"/pixel) and 4 microns (0.065"/pixel) 2.2' x 4.4' field of view Short and long wavelength coronagraphy Slitless spectroscopy for  $\lambda = 2.4 - 5.0$  micron





Built by Univ. of Arizona and Lockheed-Martin



# NIRSpec Capabilities

Near Infrared wavelength coverage of  $\lambda = 0.6$  to 5.0 microns Three different spectral resolutions of R = 100, 1000, and 2700 Modes: Single Slit Spectroscopy (slits with 0.4" x 3.8", 0.2" x 3.3", 1.6" x 1.6") Integral Field Unit (3.0" x 3.0") Multi Object Spectroscopy (3.4' x 3.4' with 250,000 - 0.2" x 0.5" microshutters)





Built by ESA and Airbus



# Mid Infrared Instrument (MIRI)

## **MIRI** Capabilities

High resolution imager with sensitivity from  $\lambda = 5$  to 28 microns, 10 broad-band filters  $\lambda = 5.0$  to 28.3 microns with 0.11" pixels 1.23' x 1.88' field of view Coronagraphy at 10.65, 11.4, 15.5, and 23 microns (24" to 30" field of view) Integral Field Unit with R = 2200 to 3500, at 4 wavelengths (image slices 0.18" to 0.64") Single Slit Spectroscopy from 5.0 to ~14 microns in 0.6 x 5.5" slit (R ~ 100 at 7.5 microns)



Built by ESA and JPL



# Near Infrared Imager and Slitless Spectrograph

## **NIRISS** Capabilities

Imaging -  $\lambda = 0.9$  to 5.0 microns over a 2.2' x 2.2' field of view with 0.065" pixels Wide Field Slitless Spectroscopy -  $\lambda$  = 1.0 to 2.5 microns at R ~ 150 Single Object Slitless Spectroscopy -  $\lambda$  = 0.6 to 2.5 microns at R ~ 700 Aperture Mask Interferometry -  $\lambda$  = 3.8 to 4.8 microns, enabled by non-redundant mask





Built by CSA and COMDEV

## Description

Deployable infrared telescope with a 6.5 meter segmented adjustable primary mirror Cryogenic temperature telescope and instruments optimized for IR performance Launch in Oct 2018 on an ESA Ariane 5 rocket to Sun-Earth L2 point (1 million miles) 10-year science mission goal

## Organization

Mission lead: NASA's Goddard Space Flight Center International collaborators: European and Canadian Space Agencies (ESA and CSA) Prime Contractor: Northrop Grumman Aerospace Systems Flight and Science Operations Center: Space Telescope Science Institute

# JWST Primer

