Optimizing JWST Distant-galaxy studies

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13 October 2015

JWST time is valuable!

$8B / (5 years * 6000 hours) = $267k / hour

Let's put this in perspective…

Aircraft carrier strike force
Operating cost $270k/hour

(Hendrix, Henry J., 2013, Center for New American Security report; includes life-cycle costs)

Joe Flacco

Operating cost: $400k/hour

*not counting support staff

Galaxy Evolution Science Goals

- Find "First-light" galaxies
- Identify the agents of re-ionization
- Chemical enrichment of galaxies
- Evolution of galaxy structure, scaling relations
- Relation between galaxies & dark matter
- Understand gas flows in and out of galaxies

Illustris

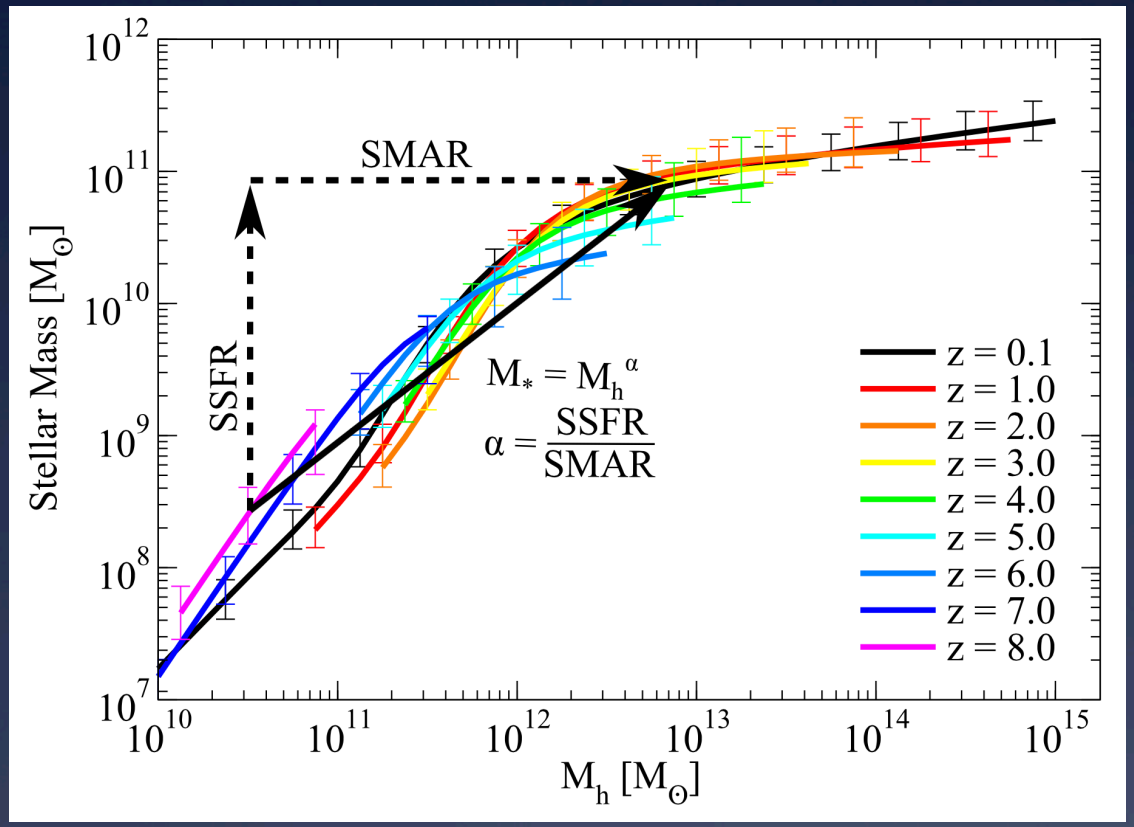
Optimizing is hard

- Already more questions than JWST will answer, just in the field of galaxy evolution.
- Optimizing across multiple objectives is intrinsically difficult
  - In general, no single solution will optimize each objective.
- Competition for observing time favors local optimization over global optimization of the overall science program.

Easy—tough—impossible

- Easy:
  - Characterize the bright end of the UV luminosity function at z>8
- Tough:
  - Find "First-light" galaxies at z>>10
- Impossible?
  - Convincingly show that a candidate is a "first-light" galaxy

The Behroozi Extrapolation

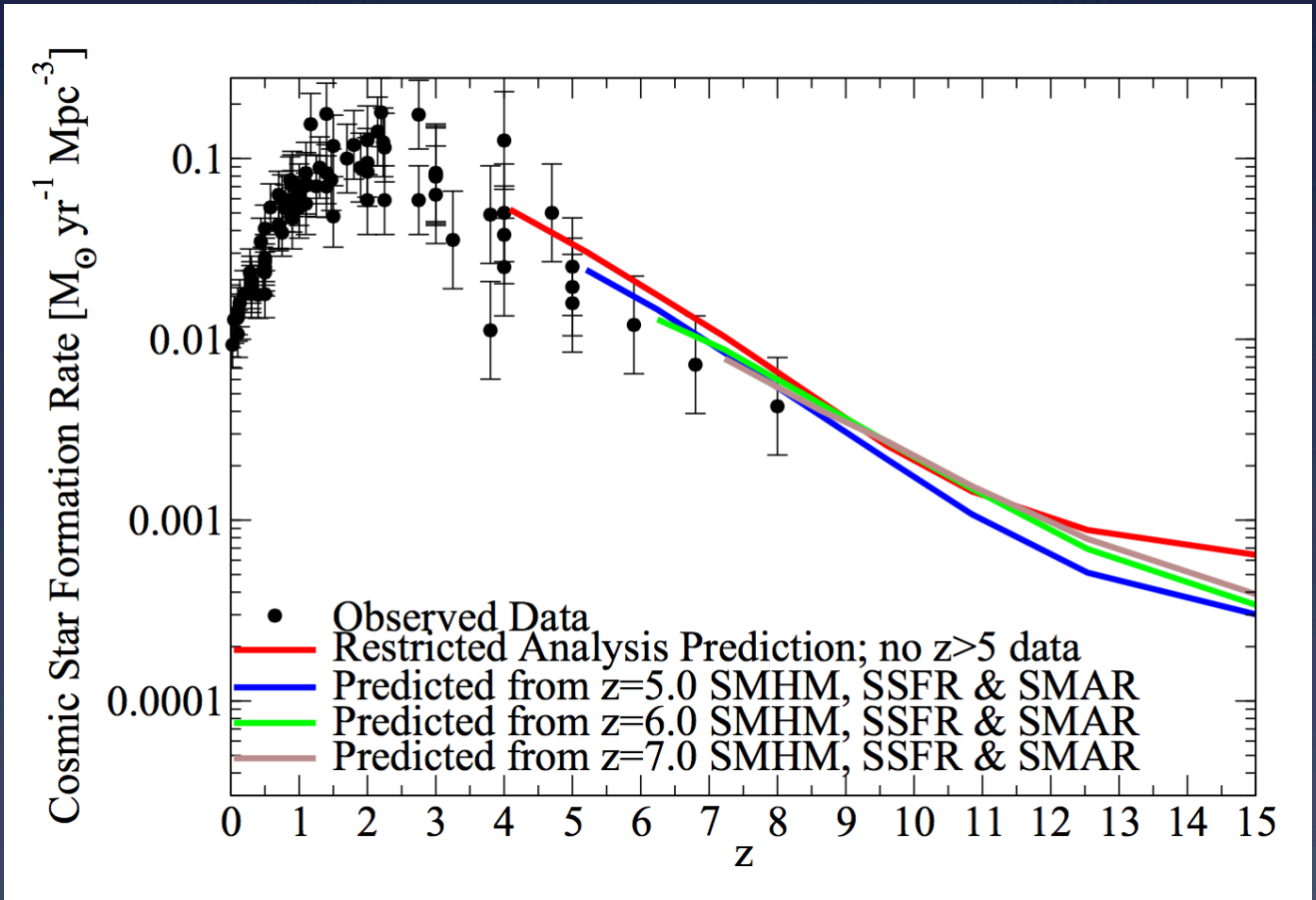


The ratio of a galaxy population's average SSFR to its average specific host halo mass accretion rate will be constant, under the weak assumption that the recent historical SMHM relation for the population's progenitors has a power-law form.

Behroozi & Silk15

Assume specific star-formation rate is proportional to specific halo mass accretion rate. Use two mass functions at different redshifts to estimate SSFR and get SMAR from simulations.

Cosmic SFR extrapolated assuming constant SSFR/SMAR

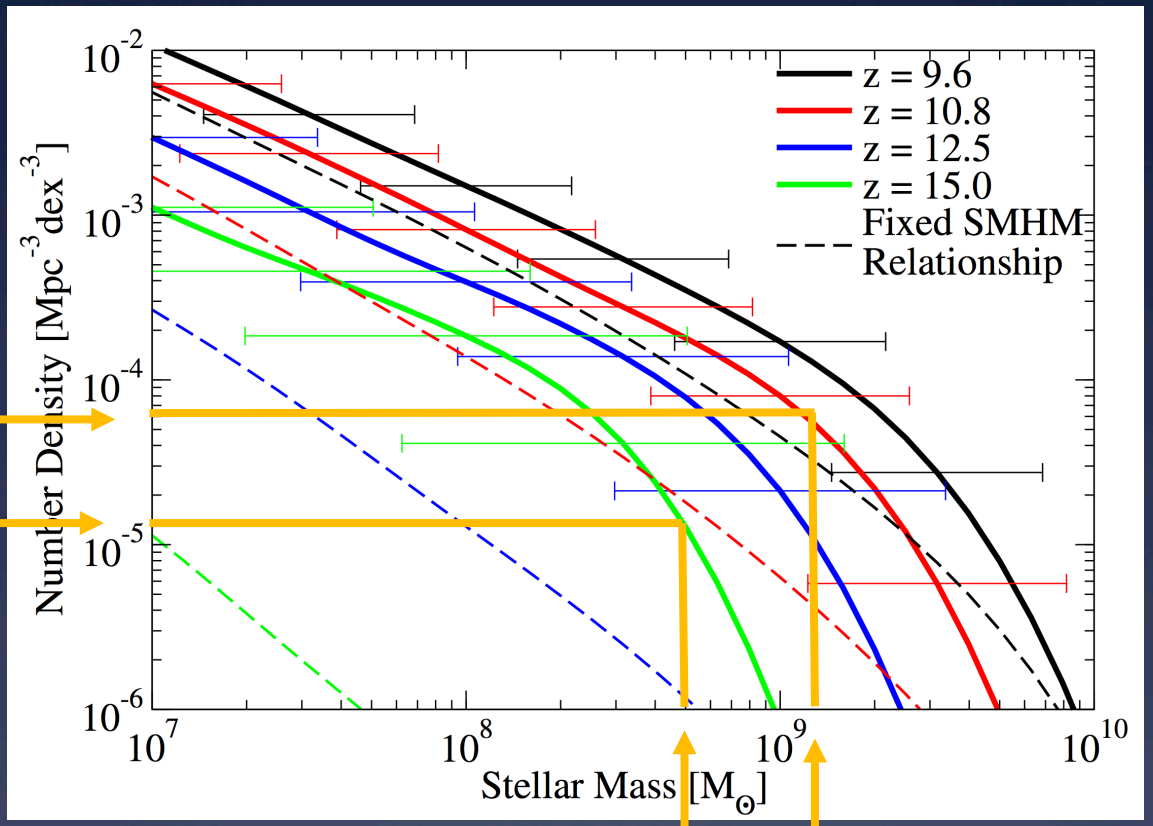


Works remarkably well and seems quite robust.

How many?

~1 per NIRCam FOV per unit z

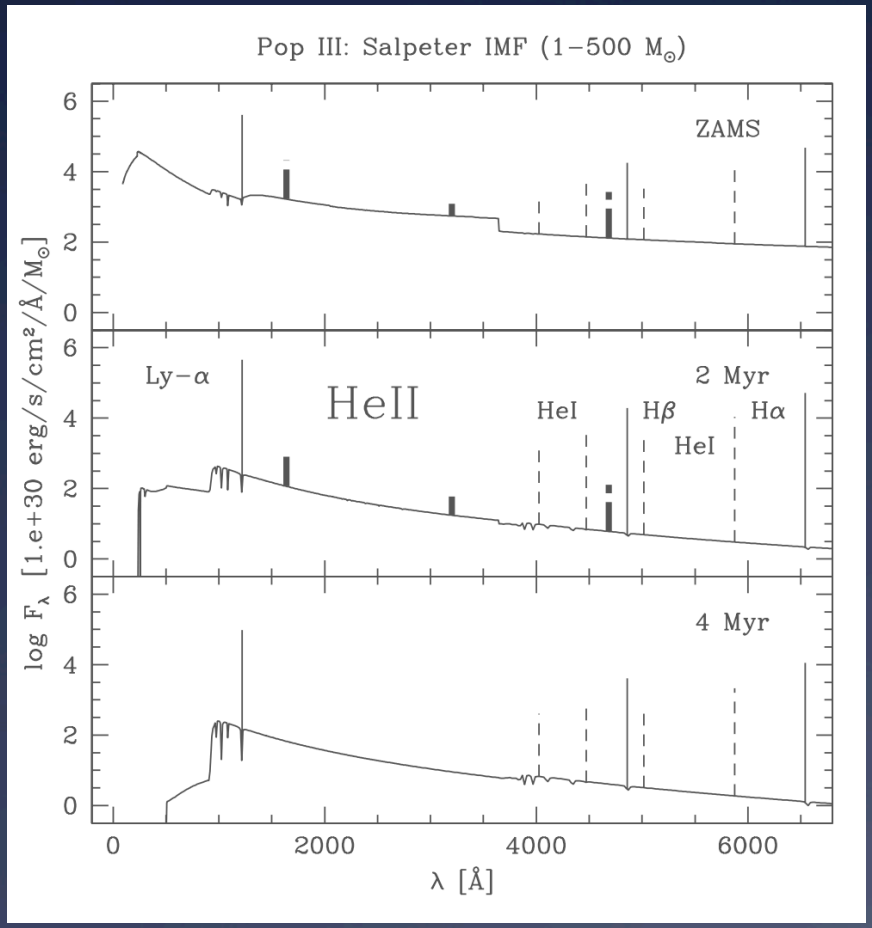
0.1 per NIRCam FOV per unit z

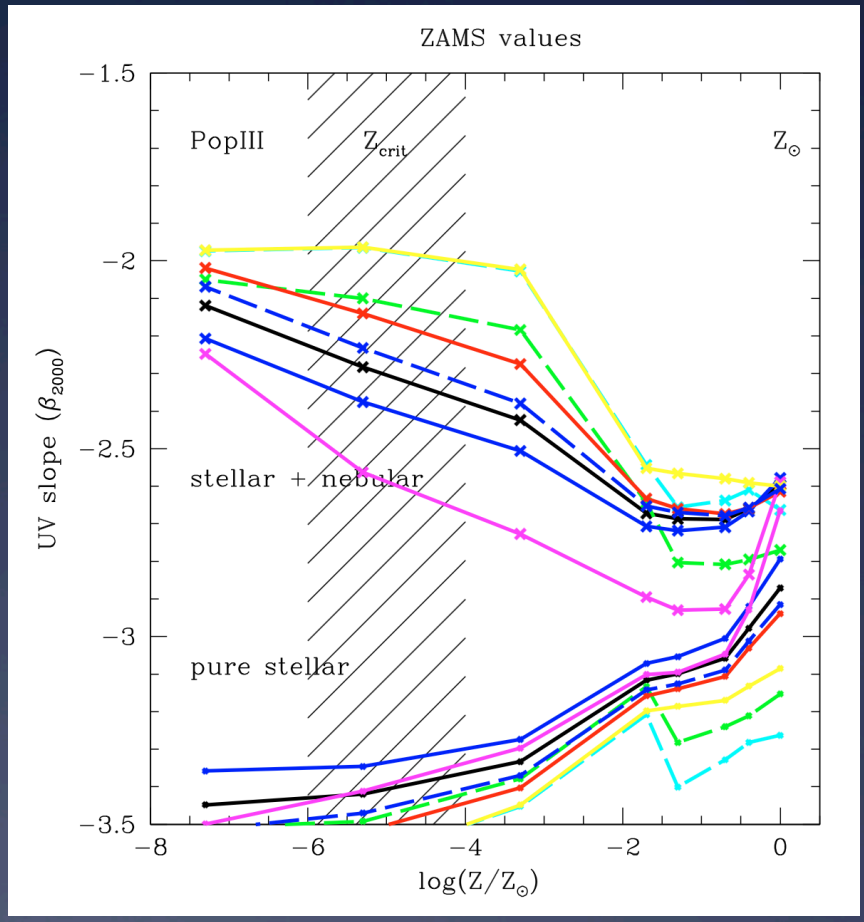


~5 $M_\odot$ yr^{-1}
AB = 31.0 mag
Requires ~130ks per band

~12 $M_\odot$ yr^{-1}
AB = 29.6 mag
Requires ~10 ks per band

Is it a first-light galaxy?





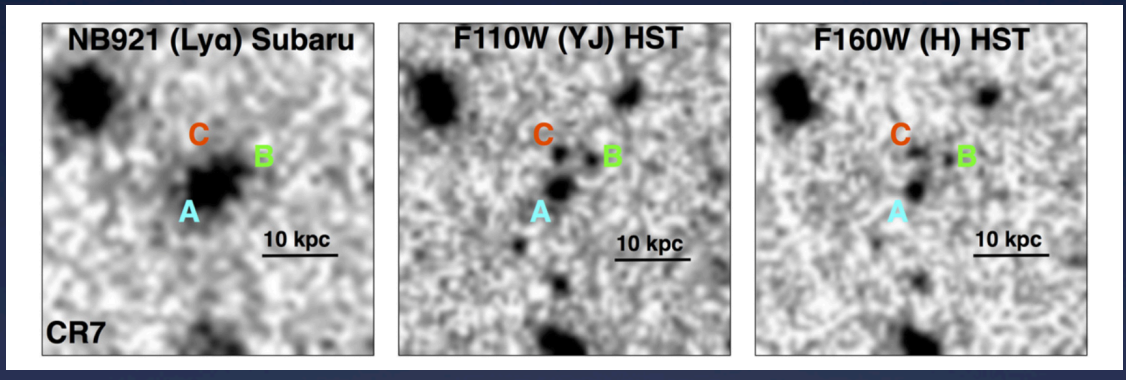
Schaerer 2002

Raiter+ 2010

Is it a first-light galaxy?

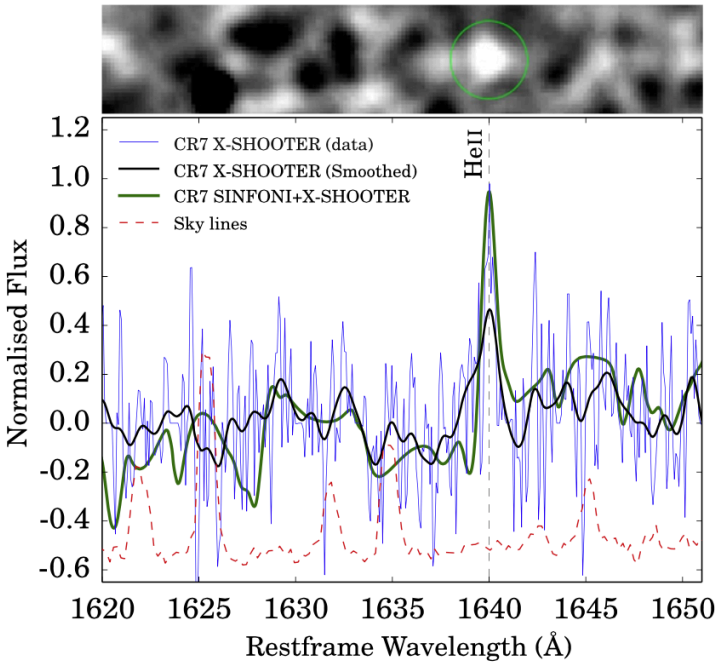
- Strong HeII
  - (Ly-alpha likely to be eaten by IGM)
  - Ambiguity with AGN, WR-star dominated spectrum
- Strong nebular continuum
  - May make it masquerade as a lower-z or dusty galaxy
- No CIII] 1909, [OIII] 5007 (MIRI)
- No dust, CII, CO (ALMA)

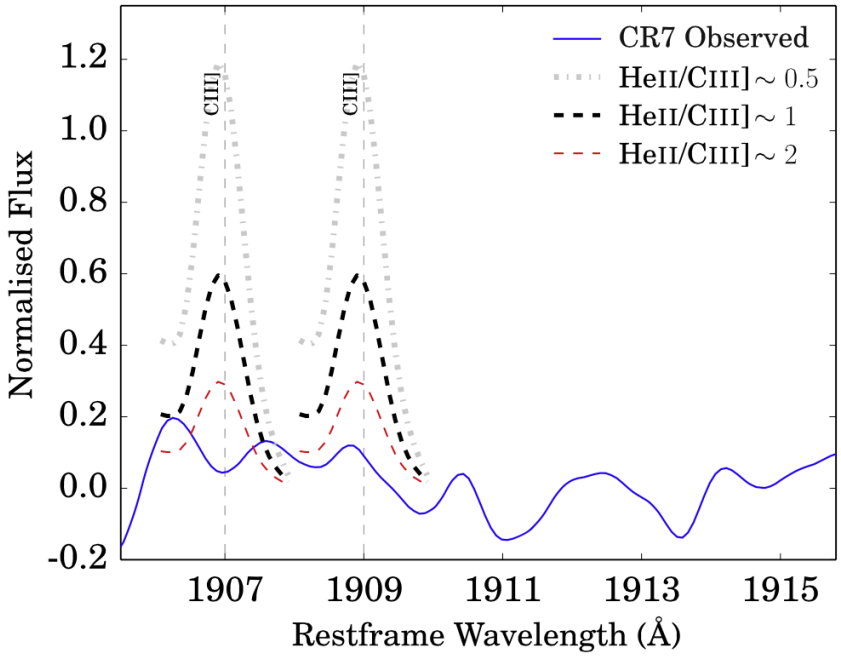
CR7: Has one been found?



z = 6.6

THE ASTROPHYSICAL JOURNAL, 808:139 (14pp), 2015 August 1





Sobral+14

More relatively easy programs

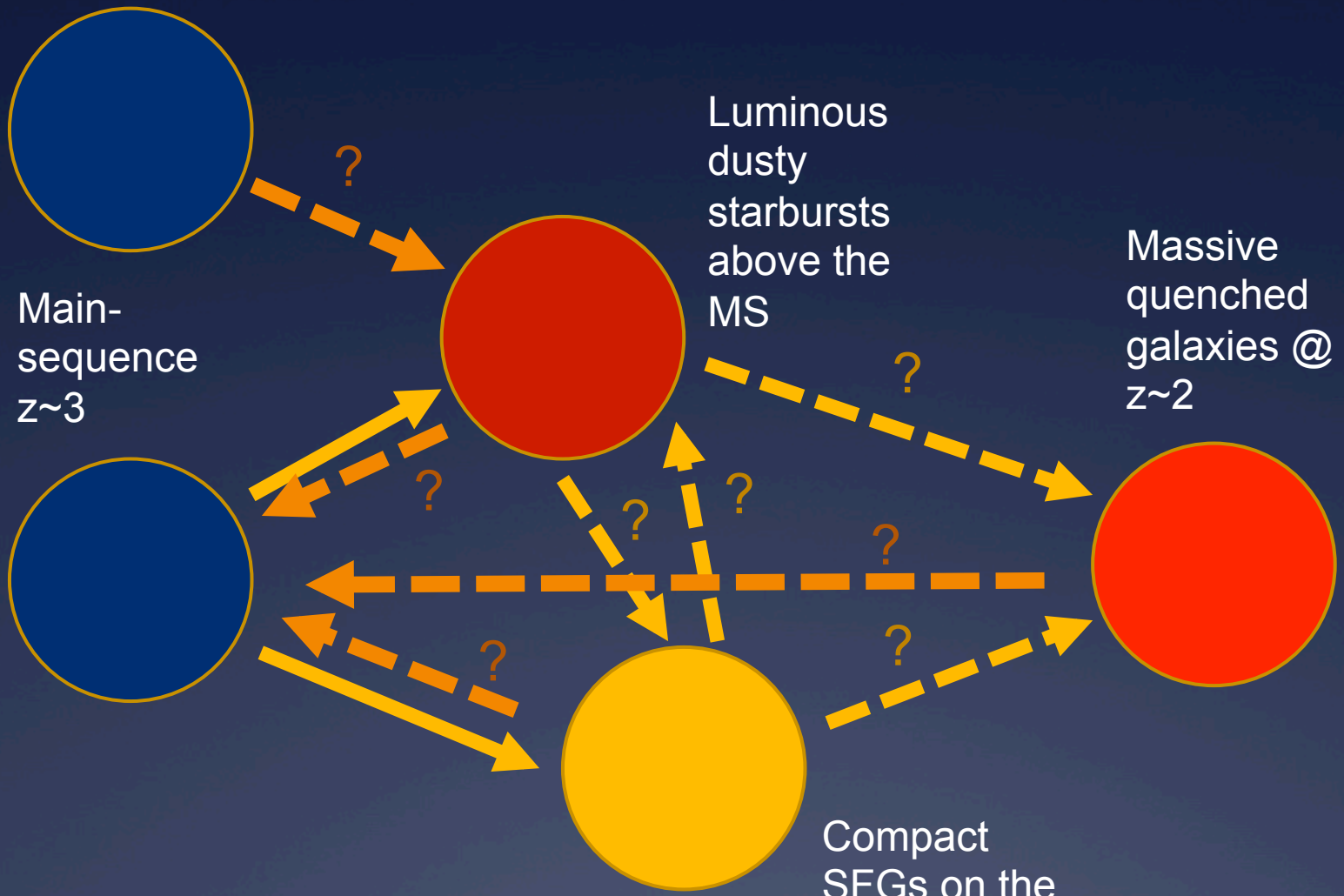
- MUCH better stellar masses, photz's, SFRs
- Spectroscopic redshifts to HST imaging limits for 1000's of galaxies
- Traditional strong-lined metallicities
- Nebular-line constraints on escape fractions
- Redshifts of high-z ULIRGS/sub-mm galaxies

More Tough programs

- Faint end of the UVLF at z<7 (need rejection bands)
- weak-line metallicities
- Kinematic scaling relations at z>3
- Systematics of clumpy galaxies in 3D
- Finding pair-instability supernovae
- Detecting z>8 galaxies via blind Ly-alpha surveys

More tough programs

- Uncovering the evolutionary connection between sub-mm galaxies & the rest of the Hubble sequence
- Constraining the contribution of AGN to galaxy-scale feedback at high redshift
- Evolution of IGM Ly-alpha opacity
- AGN masses via reverberation mapping


Main-sequence z~3
Luminous dusty starbursts above the MS
Massive quenched galaxies @ z~2
Compact SFGs on the MS
?
?
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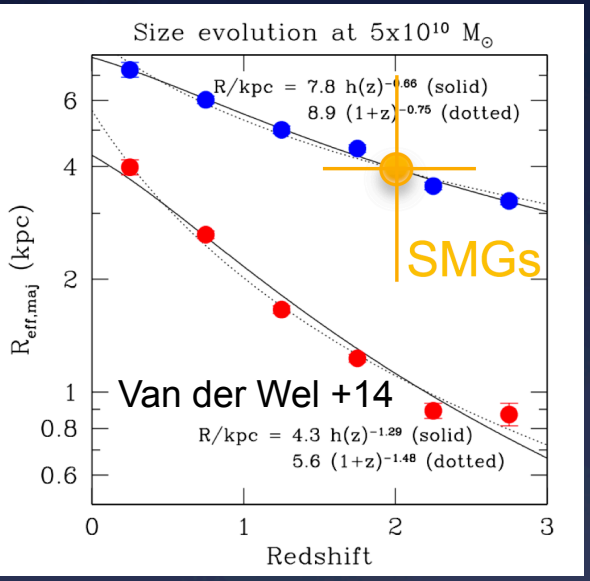
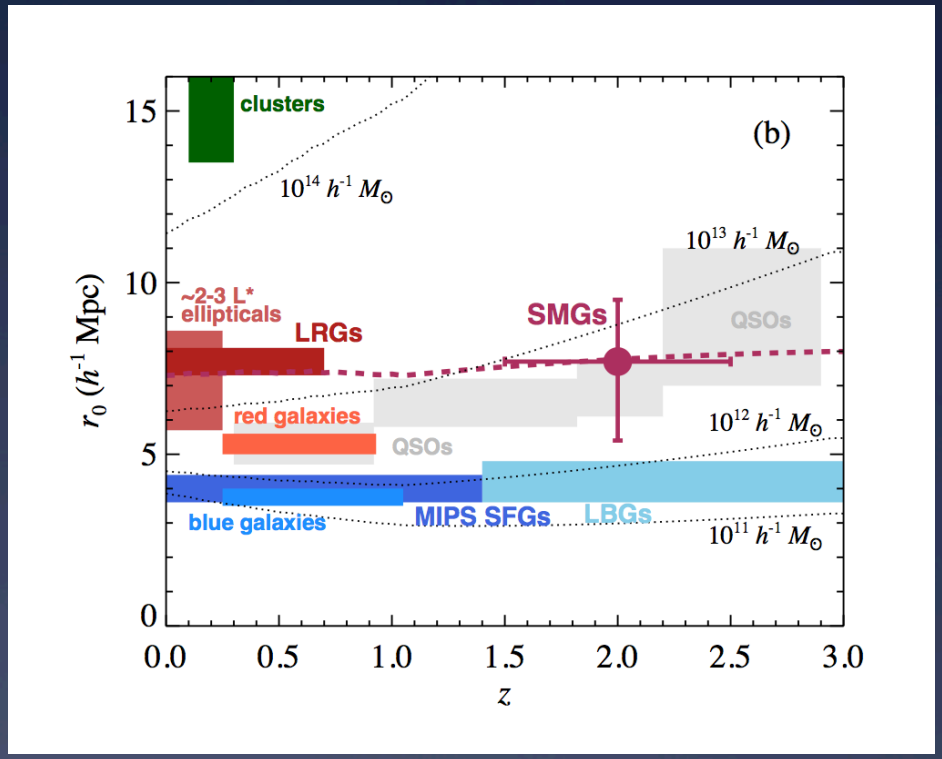
?
?
?
?
?

Sizes & Clustering?



Targett+13



Casey+14

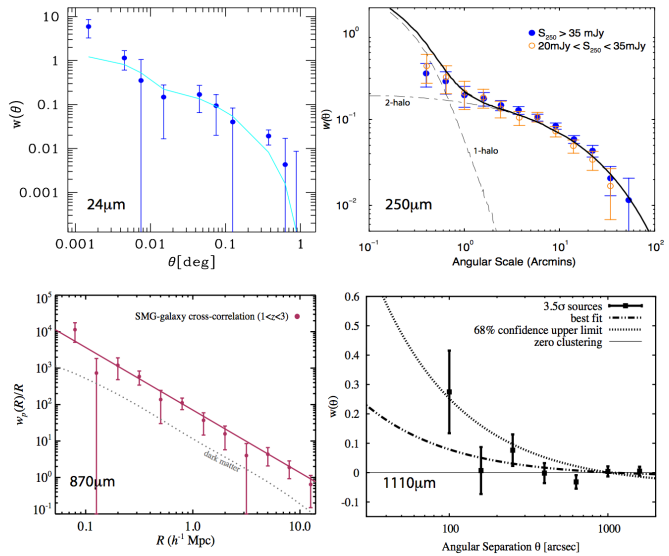


Figure 38: Clustering measurements of DSFGs at a variety of far-IR/submm wavelengths. Clockwise from top-left, we show the clustering measurements reported in the recent literature at 24μm (Magliocchetti et al., 2007) from *Spitzer*/MIPS, 250μm (Cooray et al., 2010) with *Herschel*/SPIRE, 870μm in terms of a cross-correlation with an overlapping lyman-break galaxy distribution in ECDFS (Hickox et al., 2012) with LABOCA, and at 1.1 mm (Williams et al., 2011) with AzTEC on ASTE. The figure panels are reproduced with permission from the authors of each of the above references and AAS.

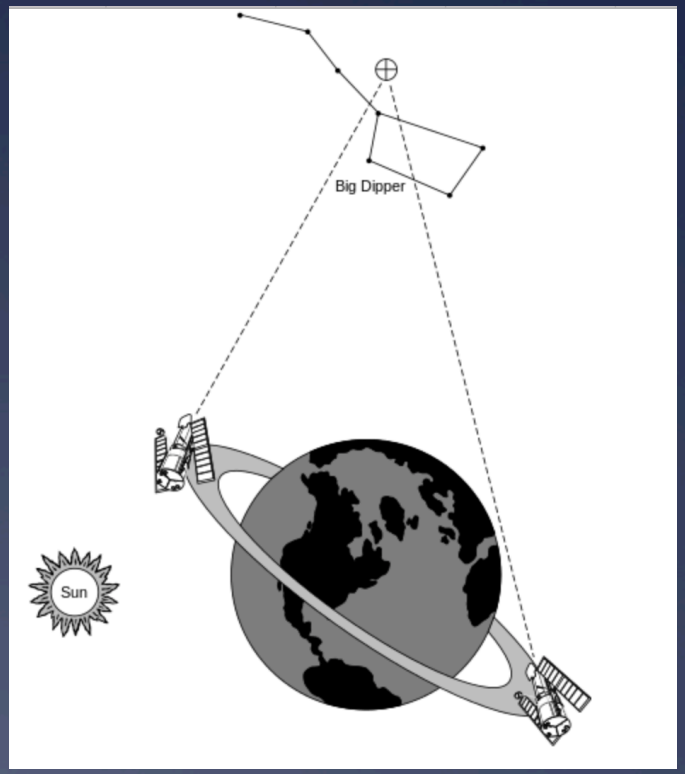
Optimization

A 1% improvement in efficiency is worth $80M…

HST optimization

- Historically — largest programs have invested a huge amount of effort in optimization.

HDF-N: CVZ, UV
HDF-S: QSO
HUDF - parallel fields
GOODS - SNe survey phasing
CANDELS & CLASH - SNe, parallels



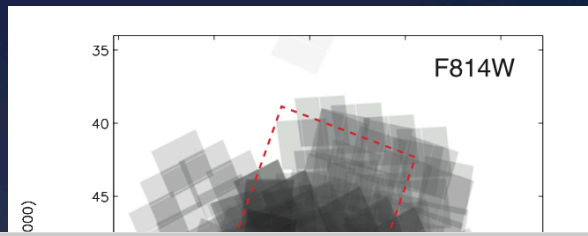
HST coordinated parallels

6320 HST parallel orbits since cycle 11 More than 2 years of observing over 10 years for ~ 20% efficiency gain

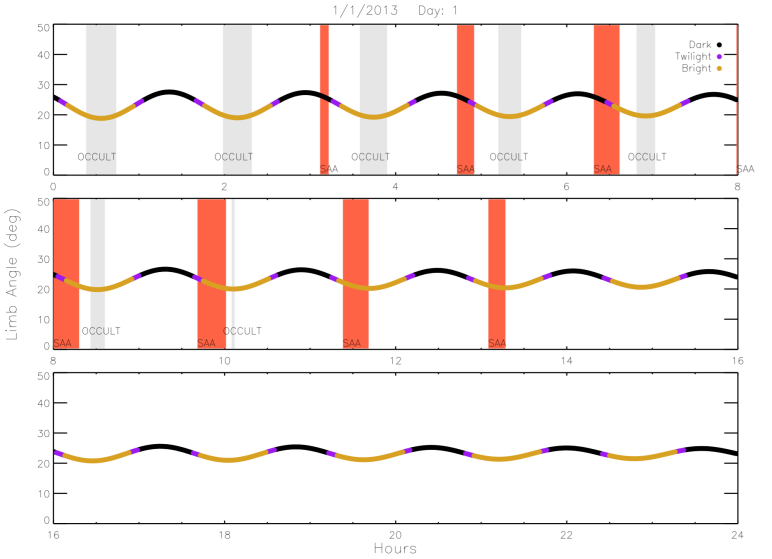
- **Distant-galaxy imaging & spectroscopy**
  - GOODS, HUDF (original, '05,' 09, '12, UV), AEGIS, CANDELS, PEARS, 3DHST, GLASS, Frontier Fields, UV COSMOS
- **Supernova search**
  - CLASH, SHOES (Cepheids in nearby galaxies prime)
- **Nearby galaxy stellar populations**
  - PHAT, ANGST, GHOSTS, LCID, Tarantula, Andromeda, Ultra-faint dwarfs
- **Galactic**
  - Globular clusters 47 Tuc, NGC 6397, SWEEPS, MULENS, Orion
- **Others**
  - Coma cluster QSO/galaxy pairs

CANDELS if done separately

- 902 orbits: ~700 orbits for survey; 150 for supernova followup
- Take away parallels :
  - Add ~400 for optical imaging support
- Take away phasing for supernovae:
  - Add another 700 for z>1.5 SNe IR search
  - Add another ~400 for z<1.5 SN search
- Take away CVZ observations
  - Add ~150 orbits
- Grand total:
  - ~2550 orbits if planned as separate programs



REGION	EPOCH	ORIENT	ORBITS	START DATE	END DATE	Program	Comments
STST	-	255	1	4-Aug-10	10-Aug-10		test orbit
SD	1	325	16	8-Oct-10	13-Oct-10	12061	Epoch 1
UDS	1	45	44	6-Nov-10	20-Nov-10	12064	
SD	2	25	15	26-Nov-10	1-Dec-10	12061	Epoch 2
UDS	2	45	44	27-Dec-10	10-Jan-11	12064	
SW	1	68	9	7-Jan-11	10-Jan-11	12061	Skirt
SD	3	73	15	14-Jan-11	19-Jan-11	12061	Epoch 3
SW	2	94	9	27-Feb-11	2-Mar-11	12061	Skirt
SD	4	95	16	2-Mar-11	6-Mar-11	12061	Epoch 4
SYW	-	115	11	25-Mar-11	29-Mar-11	12060	Skirt
EGSa	1	187.3	25	2-Apr-11	9-Apr-11	12063	
EGSa	2	164.9	25	24-May-11	29-May-11	12063	
SD	5	205	15	3-Jun-11	20-Jun-11	12061	Epoch 5
SYa	-	205	18	27-May-11	21-Jun-11	12060	2x3 array
SD	6	250	15	28-Jul-11	6-Aug-11	12062	Epoch 6
SD	7	295	16	12-Sep-11	23-Sep-11	12062	Epoch 7
SD	8	340	16	3-Nov-11	7-Nov-11	12062	Epoch 8



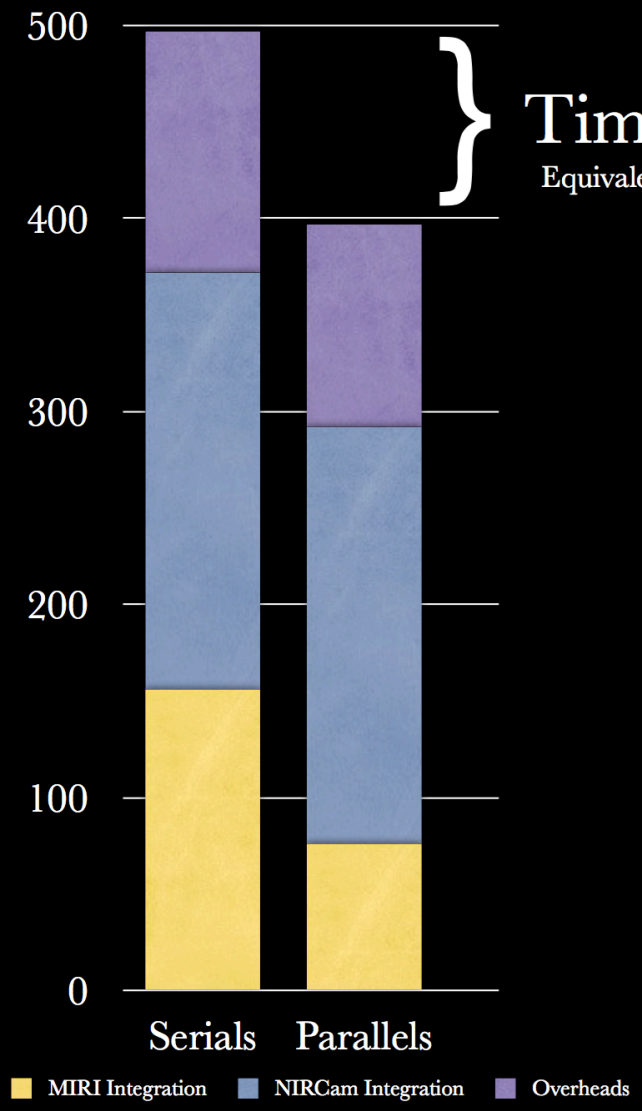
JWST parallels

- Efficiency Working Group Science feasibility study
  - Used SODRM to assess opportunities
  - Developed a concept for planning & scheduling
    - Builds on parallel calibration capabilities
- Implementation
  - Optimistic this will happen…

Parallel flavors

- Coordinated parallels: PI team plans the combined program
  - Joint observing templates
    - simplify dither & readout selection
    - Help manage data volume
- Pure parallels: Separate proposal team
  - Attach observations to “opportunities” in the approved prime programs
  - Parallels cannot affect prime

Coordinated parallels



} Time other people get to use!

Equivalent to zeroing out almost ALL the direct overheads.

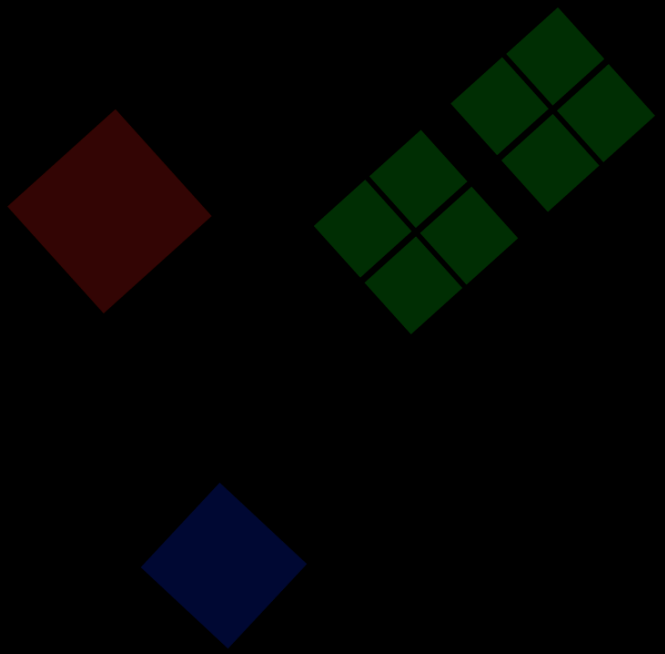
There are 10 "deep fields" SODRM programs like this one identified as candidates for coordinated parallels.

Parallels on these 10 programs alone save ~1000 of 4700 hours used by these programs.

This is a ~20% efficiency gain or 6% of the entire SODRM!

They also provide potential for an additional 1000+ hours of beneficial ancillary science.

A JWST Example: NIRCam and MIRI on the CDF-S



1 arcmin

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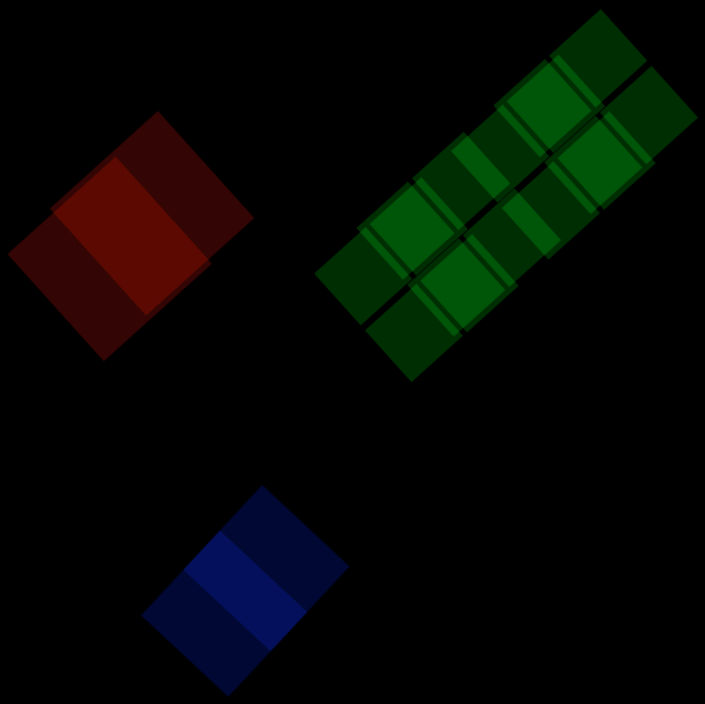

1 arcmin

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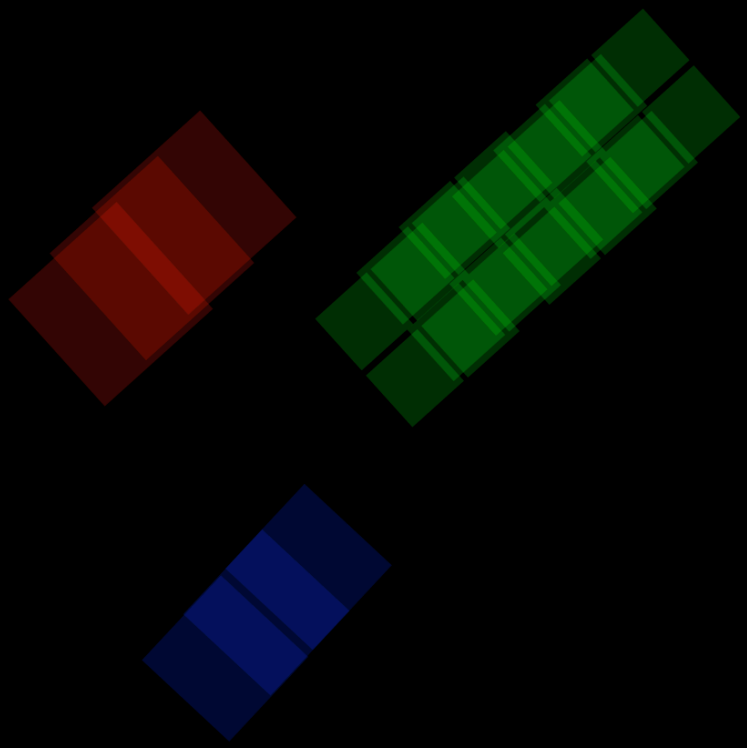
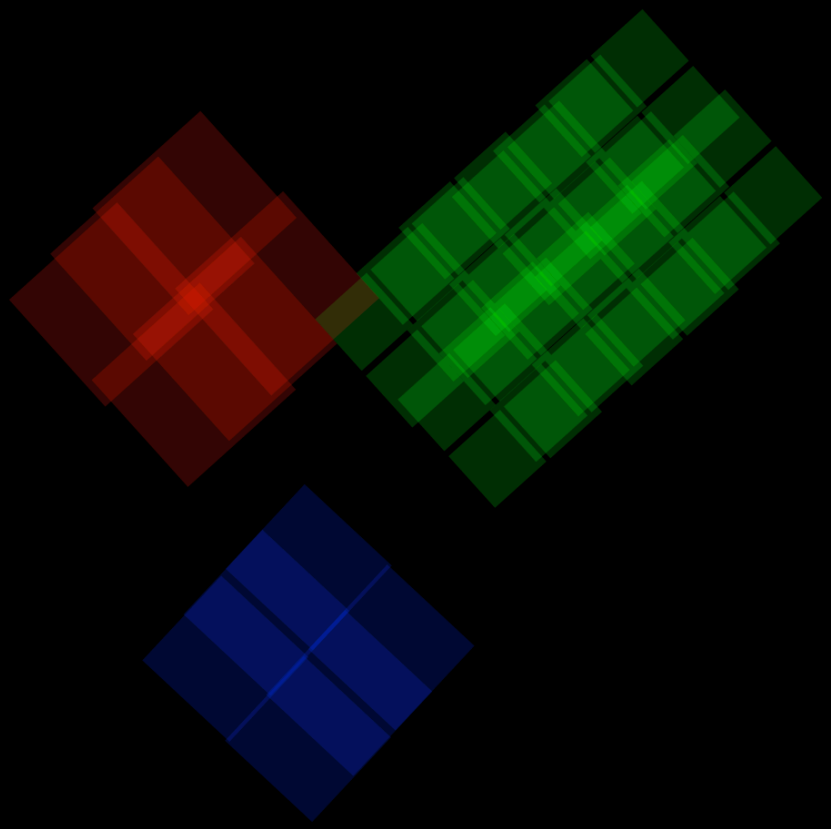


1 arcmin

A JWST Example: NIRCam and MIRI on the CDF-S



1 arcmin

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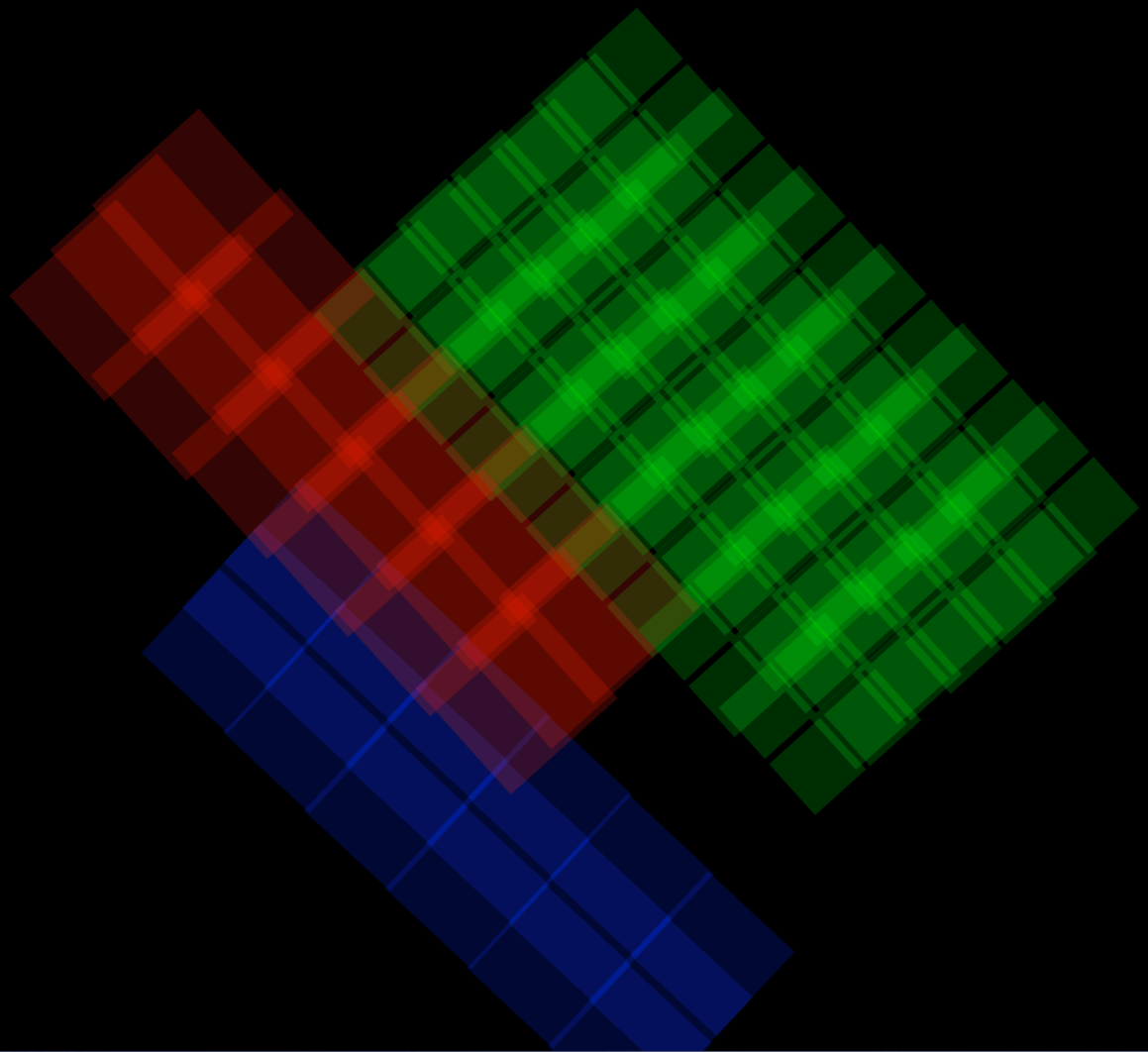

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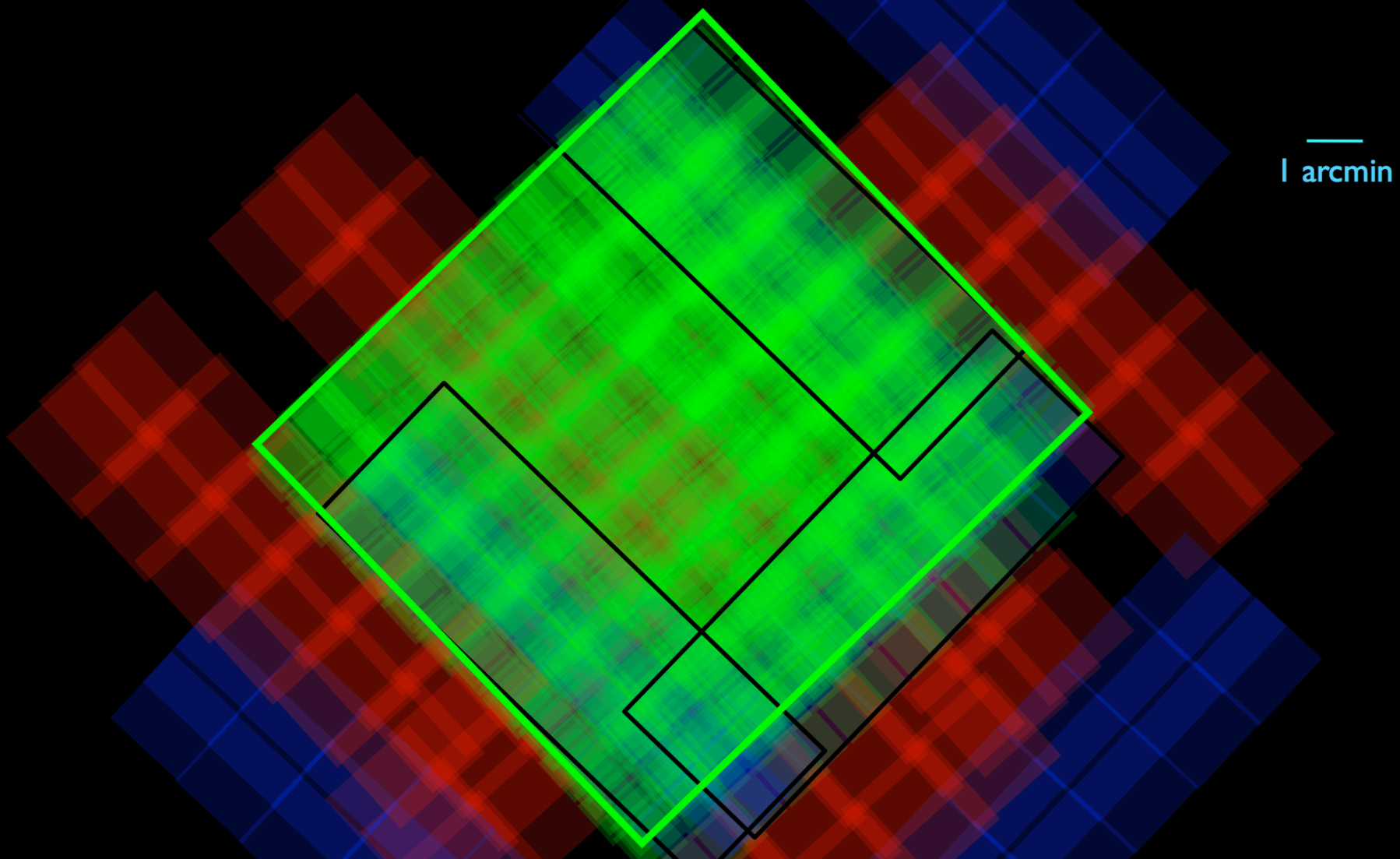
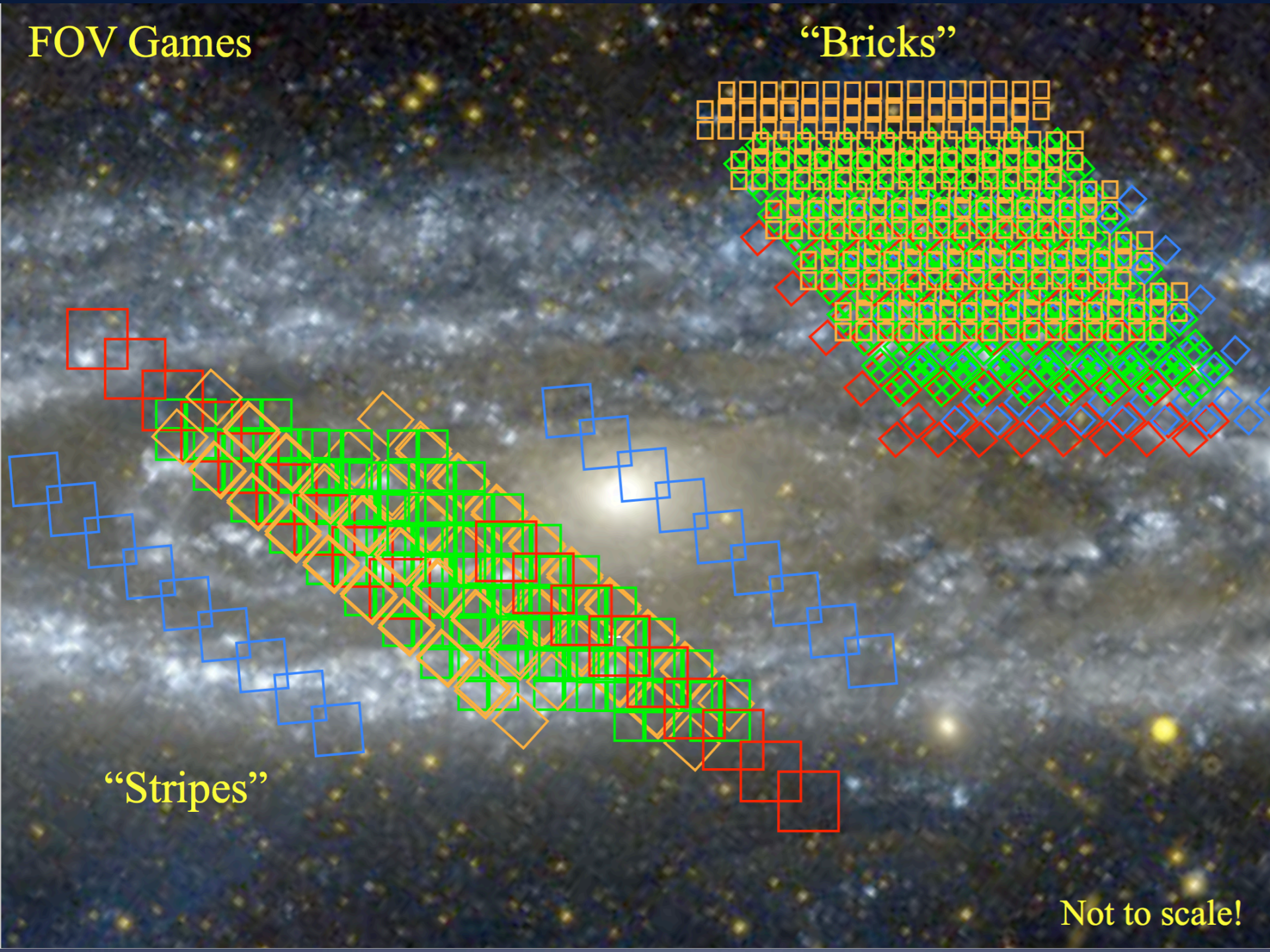


Default program = 217 hours NIRCam (3 bands) and 156 hours MIRI in one band.

Parallel MIRI saves ~100/400 hours


FOV Games
“Bricks”
“Stripes”
Not to scale!

Challenges

- Scheduling constraints
  - 180-degree flip likely to put pressure on the scheduling system
- Data volume
- Readout timings & dithers will limit parallel opportunities
  - E.g. Probably hard to plan an optimal NIRISS Ly-alpha parallel survey (direct image + 2 dispersed per band+ direct)

Social aspects

- Proposal teams often narrowly focused on one science area
- Proposals with a focused science case are often favored by the TAC
- "Forced marriages" are considered bad
- TAC doesn't really have time to take a "big-picture" view:
  - E.g. What sequencing of high-z galaxy observations is optimal, given the 5-year mission?
- 1-year cycle strongly discourages long-term planning

Solutions?

- Informal coordination at meetings like this
- Mini-surveys in first cycle?
  - Some encouragement given to optimizing across science goals?
- Treasury programs
  - Strong encouragement for optimization
- Concerted thought
  - Can nothing else be done during exoplanet transit observations?
  - Filler targets for NIRSpec?
  - Deep imaging fields surrounding NIRSpec ultra-deep field?

Look for opportunities…

- Deep fields:
  - Phase observations to enable SN search?
  - Constrain orientations to create parallel fields?
- 3D spectroscopy:
  - Plan in a way conducive to parallel imaging?
  - MOS "scanning" to multiplex 3D studies?
- Dither & readout patterns:
  - Compromises to allow more parallel opportunities?