The Crisis in Astrophysics:

Commercial Space
&
Prudent Program Design Principles
will let us Escape

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Space Policy, in press. arXiv:1608.01004
HDST critique: arXiv:1509.07798
Vigorous Explorer program (arXiv:0911.3383)
What Crisis?
Pan-Spectral Coverage is Integral to 21st Century Astrophysics

- For 35 years we have had contemporaneous access to the full electromagnetic spectrum with matched sensitivity
- Will be lost when JWST replaces Spitzer in 2018
- IR leap in sensitivity unmatched in UV, X-ray, Far-IR until ~2030+
- Observing Windows pried open in 50 years of space astronomy...
- ...will Close

Messier 82 in **optical**, **infrared** and **X-rays** with *Hubble, Spitzer* and *Chandra*, NASA's three Great Observatories

http://chandra.harvard.edu/photo/2006/m82/m82_comp.jpg
Even JWST Science will be in limbo without X-rays

- What are those $z=10-20$ blobs in JWST Deep Fields?
- The first stars in the first galaxies?
- Or adolescent black holes having a growth spurt?
- Without matched X-ray Deep Surveys how will you tell?

Optical/near-IR = Galaxy Evolution

X-rays = Black Hole Growth

Thanks to Marta Volonteri

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Cost growth has cut the number of large missions to 1

- Economy grows at 2% - 3% a year
- Space mission costs grow far faster
- Unsustainable: the “funding wall”

Cost growth of leading X-ray astronomy missions 1970 - 1999

X-ray astronomy: 10% pa

At ~$9B, JWST cannot be our model
We have to get the cost down, 
...or the party’s over
Two Responses

1. Harness Commercial Space

2. Adopt Prudent Principles for Program Design
1. Harness Commercial Space
Commercial Space will be very different for the 2020 decadal

Astronomy

US Astronomy Decadal Survey

ESA Cosmic Vision 2035-2045??

JWST launch

ESA L3 selection

BepiColombo

Commercial Space, NewSpace

Commercial Crew to ISS

Bigelow BA330

PRI, DSI asteroid probes

ARRM lunar Orbit?

NEOCAM?

Chang’e 4 SELENE-2

Google Lunar X prize SpacelL, Moon Express...

BA330 HEO?

ISRU@ARM boulder in Lunar orbit

Test Lunar Mining?

Test asteroid Mining?

JWST mission end?

Next NASA Astronomy $5B Flagship

ATHENA ESA L2

ESA L3 (LISA)

1/10 price launch?

End of ISS?

Next NASA Astronomy $9B Flagship

2015

2020

2025

2030

2035

2015

2020

2025

2030

2035

⅕ price launch

$9B Flagship

ATHENA ESA L2

ESA L3 (LISA)

Next NASA Astronomy $5B Flagship

1/10 price launch?

End of ISS?

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Commercial Space Will Cut Mission Costs by 2025

- $10 k/kg to LEO for decades
- SpaceX F-9: $3 k/kg *Now*
- ~2k/kg with 1st stage reuse
- 1/5 of traditional launch cost

SpaceX Falcon 9 1st soft landing, 21 Dec 2015
(source: Space.com; wikimedia commons)
Cheaper Launch Now

- Launch is \(~25\%\) of mission
- 1/5 cost saves \(~20\%\) of astrophysics mission
- Enables **cheaper Spacecraft** by spending mass
- Orbital passenger flights enable:
  - Low cost TRL-9 tests of large instruments (extends rocket program)
  - Low cost on-orbit servicing in LEO

- Cheaper science payloads
Cut Flagship Mission Costs in Half by 2025?

- These are near-term changes
- 2020 Decadal Survey is for >2025 missions
- Cannot ignore commercial space

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2. Adopt Prudent Principles for Program Design
• Resources are always limited
• Easy to Adopt an Over-Ambitious Science Goal
• The art lies in choosing a mission that is:
  • **Ambitious**
  • **Achievable**
  • **Affordable**
• Need principles to help the selection process

Background: NASA Astrophysics 20-year ‘sandchart’
Prudent Principles for Program Design

- Missions require design principles to avoid failure
- Can adopt similar principles for entire program
- Without guiding principles temptation of drifting to “One Giant Mission” is strong
- Here are three guiding principles...
#1: No Single Point Failure

- No large mission can have any component, sub-system, or system that is a *single point failure*:
  - i.e. mission ending
- Likewise,
- A science *program* should not have a single point failure
  - One Big Mission creates *program* vulnerability
  - *Program* lacks robustness
#2: Science Requirements

- Missions begin with science requirements
- These are then flowed down into mission requirements
- Are there **Science Program requirements**? E.g.
  1. Matched contemporaneous pan-spectrum coverage
     - Fleet of flagship missions
  2. Continuous Innovation
     - E.g. exo-planets: a major *Hubble, Spitzer* research area
       - Not pioneered on *Hubble, Spitzer*
       - Independent scientists took risks to pioneer field
     - Vigorous Explorer program (arXiv:0911.3383)
#3: No Single Viewpoint Failure

- Dependence on a single Flagship telescope saps intellectual vitality of a program.
  - Lack of independent data to challenge results
  - Time and Money flow from one source
  - Fashions are unintentionally self-reinforcing
    - TACs have many previous winners
- **Program needs multiple viewpoints:**
  - Wavelength
  - Technique
  - Scale
Implementation Issues

• Astro-sociological:
  • Giant missions get a large following
  • Speak louder than several less grandiose missions
  • Answer:
    • Hang together
    • Promote the “Greater Observatories”

• Agency, Government buy-in:
  • Agency:
    • Advocate for prudent Program principles
    • Cost Models are rightly hard to change
    • First try commercial pricing on probe-class mission
  • Government:
    • “The Best Mission” easier than a wish list
    • Promote “The Best Program” instead
Summary: Escaping the Astronomy Funding Wall Crisis

- **Mission costs rising far faster than economy grows**
  - ~10% p.a. vs. ~2% p.a. → funding wall

- **Use Commercial Space to bring costs down**
  - Factors 2-3 plausible in next 5 – 10 years
  - i.e. *within decadal planning horizon*
  - Unwise to ignore

- **Use Prudent Design Principles for the Program**
  - As for a mission
    - No single point failure
    - Science Requirements, flowdown
    - No single Viewpoint failure
    - Constant Innovation
  - Restrain “One Big Mission” drift
  - Advocate The Best *Program*:
    - **The Greater Observatories**
We have much to gain

Thank you

See more details in:
Space Policy, in press. arXiv:1608.01004
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Easy to Adopt an Over-Ambitious Science Goal

- E.g. direct imaging-spectroscopy of exo-Earth bio-signatures
- High Definition Space Telescope
- Not a robust mission
- Yet ≥$9B ~20 years of funding
- Opportunity cost:
  - **the rest of astrophysics**

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Pie in the Sky?

Hopelessly optimistic?

1. All space timelines “slide to the right”. Delays can be many years.
2. Savings require changing
   - Space Engineering practices,
   - Agency cost models.
3. To get more missions requires discipline from planners
   - Need guiding principles
Cheaper Spacecraft by 2025: The Real Saving

- Mass drives cost. Every kg counts → expensive design/test cycles → huge spacecraft cost

- Now mass-in-orbit cost 1/5 as much
  - Robust structures: simpler design/testing
  - Larger solar panels: lots of power – cheaper electronics
  - Multiple redundancy: relaxed reliability requirements
  - Overcapable spacecraft → batch production

- Much cheaper spacecraft
- Not a new idea: Morgan Report (1990)
  - 1/3 spacecraft cost for 50% mass growth
  - Needed launch cost reduction is now here
- Time for a fresh study
  - E.g. “Deep Survey Telescope” Hearty & Stahl

http://jwst.nasa.gov/mirrors.html

High Cost, Slow Implementation

Launch cost (dollars per pound)

Cuts spacecraft cost by factor 3

mass growth...

2010 SpaceX \( \div 3 \) Factor 3 $/kg launch cost cut

x3.2 for 2014$/kg

E.g. “Deep Survey Telescope” Hearty & Stahl

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Cheaper Science Payloads

- Optics, sensors & pre-amp electronics stay expensive:
  - Essential to be state-of-the-art
- Other systems get cheaper
  - Structure
  - Thermal control
  - Power supplies
  - Post-amp electronics
  - Data processing
Commercial Passengers to LEO by 2025

2 companies offering rides to orbit >2020

- Addresses hi-tech parts of payload
- Cheap, quick TRL-9 instrument tests in Dragon trunk
  - shorter development cycles
  - cutting edge science payloads
- Affordable On-orbit Servicing in LEO
  - HST showed servicing is powerful
  - Too expensive – soon “cheap”
  - failure is a nuisance, not mission-ending
- Can tolerate higher risk → lower cost
Moviemaking has the same problem:

“It's an inherently conservative business because it's so expensive. And if you're not repeating something that's already a success then people are nervous.”

(Patricia Rozema, Director. NPR 2016)
Resources are Always Limited

Must take this into account
Need to be Thrifty

Future Strategic Missions
~$5 B/decade

NASA Astrophysics 20-year 'sandchart'. (Paul Hertz, 2015?)

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