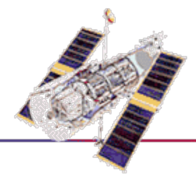
# Imaging with the Hubble Space Telescope

## A personal selection of topics

Hans-Martin Adorf & Richard Hook

# Introduction

- The Space Telescope European Coordinating Facility was established in 1985 and closed at the end of 2010. Outreach activities continue.
- Over the years the ST-ECF made many contributions to Hubble imaging and outreach.
- Bob has been involved with Hubble since (?) 1985.
- Bob was in charge of science instrument information for many years and was head of the group in its later years.
- RH worked at the ST-ECF from 1988-2010 and HMA from 1985-1997. (and Sperello from 1985-1990)



esa SPACE TELESCOPE
ESO European Coordinating Facility

# ST–ECF Newsletter

No 1
March 1985

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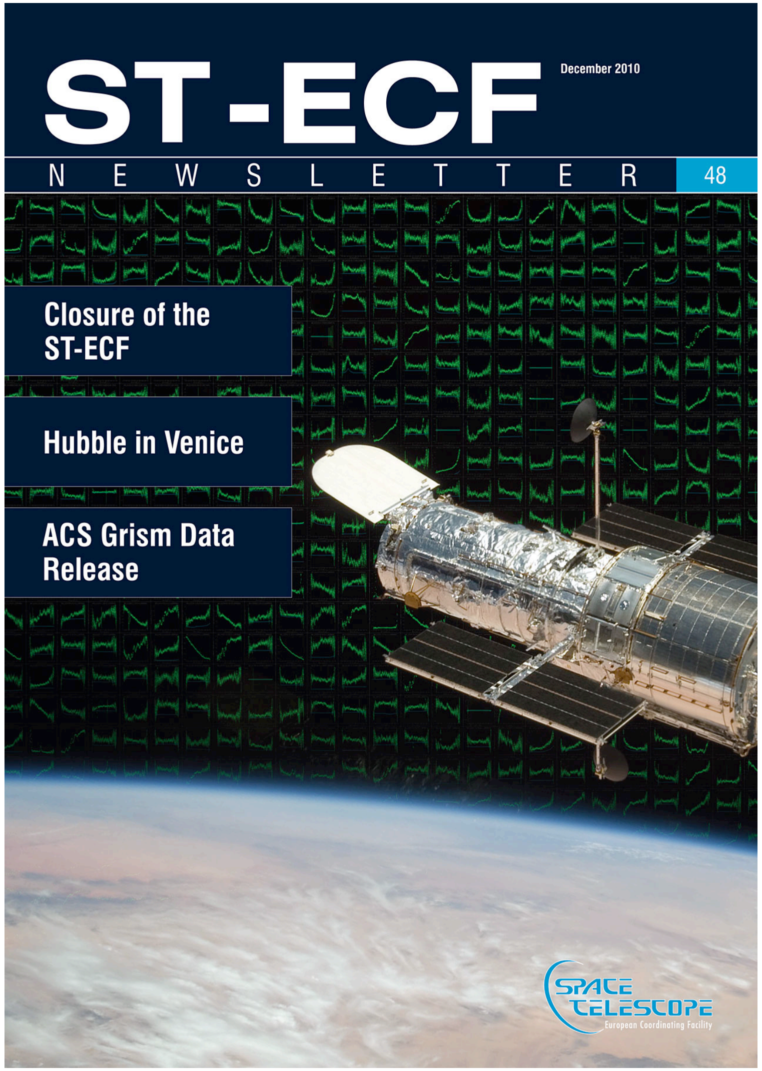
## Important HST Dates

This is a summary of the timetable of the Hubble Space Telescope.

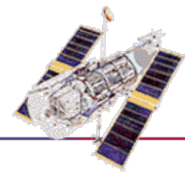
| | |
|---|---|
| Distribution of call for proposals : | September 1985 |
| Deadline for receipt of proposals : | February 1986 |
| HST Launch : | June 1986 |
| First General Observer cycle of observations : | January 1987 to January 1988 |

The relevant dates for the preparation of proposals given here assume a launch of HST in June 1986. These would, however, not be affected by small changes in the expected launch date.

#1 March 1985




#48 December 2010



# The Early Years

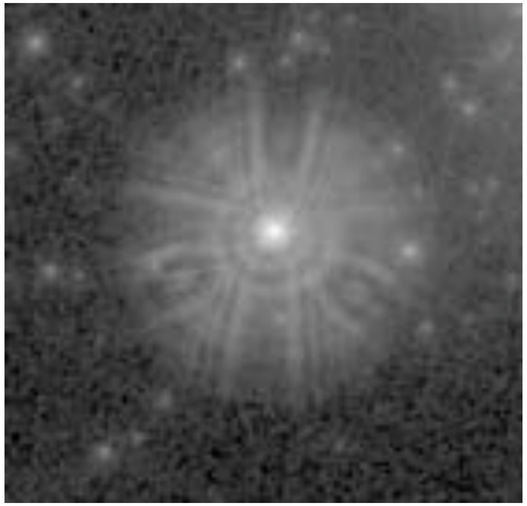
The ST-ECF was trying to prepare European users for the reality of Hubble… but there were problems.

Challenger tragedy of Jan 1986 led to major delay.

Hubble was successfully deployed in April 1990.

Yet another surprise was to come..

# A Stressful Interlude: Spherical Aberration (1990-93)



Summer 1990: the ST-ECF, started to experiment with restoration/deconvolution.

Leon Lucy was at the ST-ECF

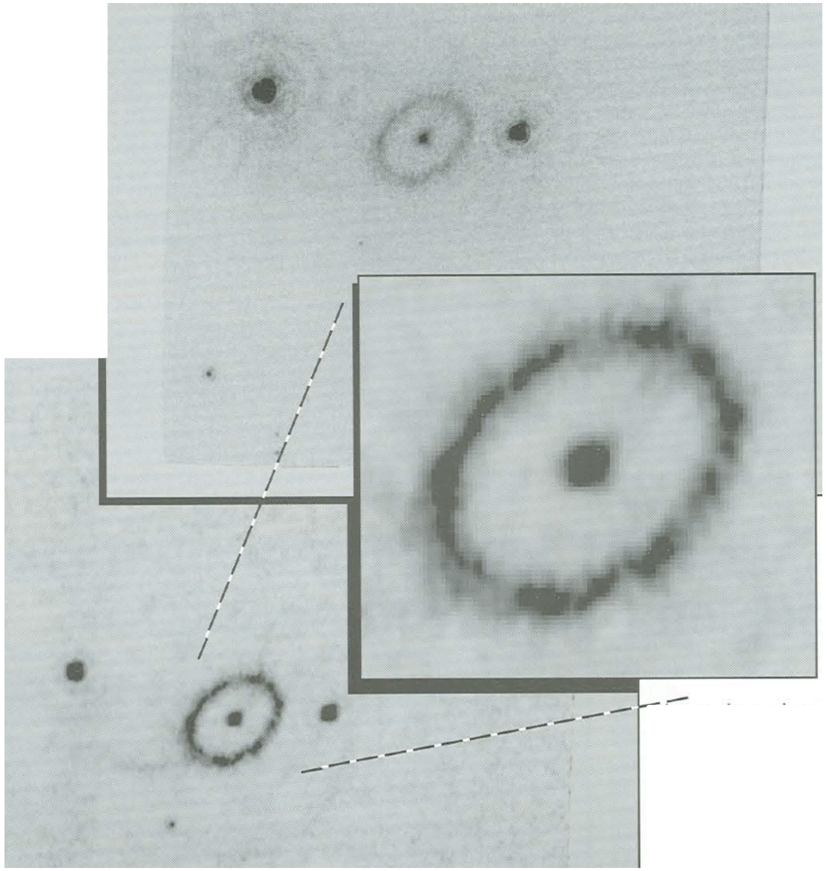
Basic fact:

*The combination of imperfect knowledge of the complex and variable PSF and especially **unavoidable noise** meant that Hubble at this stage could only do competitive science on a small range of targets – with high S/N and high contrast.*

# Image restoration in action…

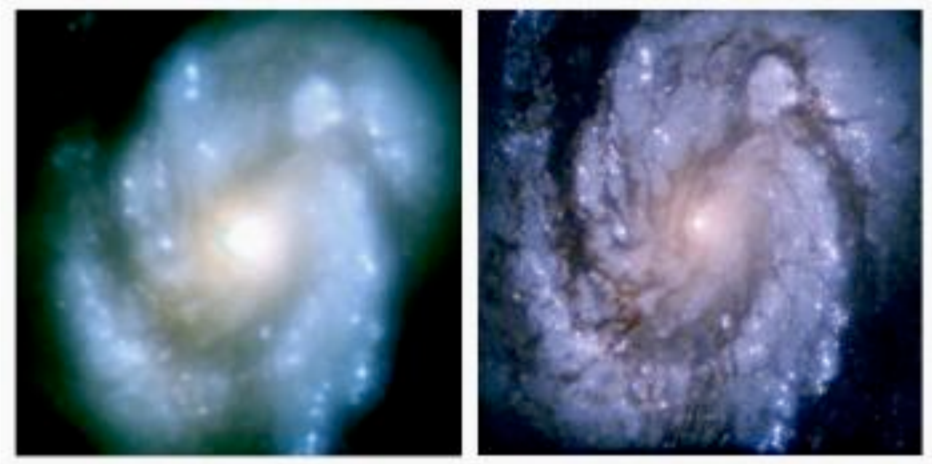
SN 1987a – FOC

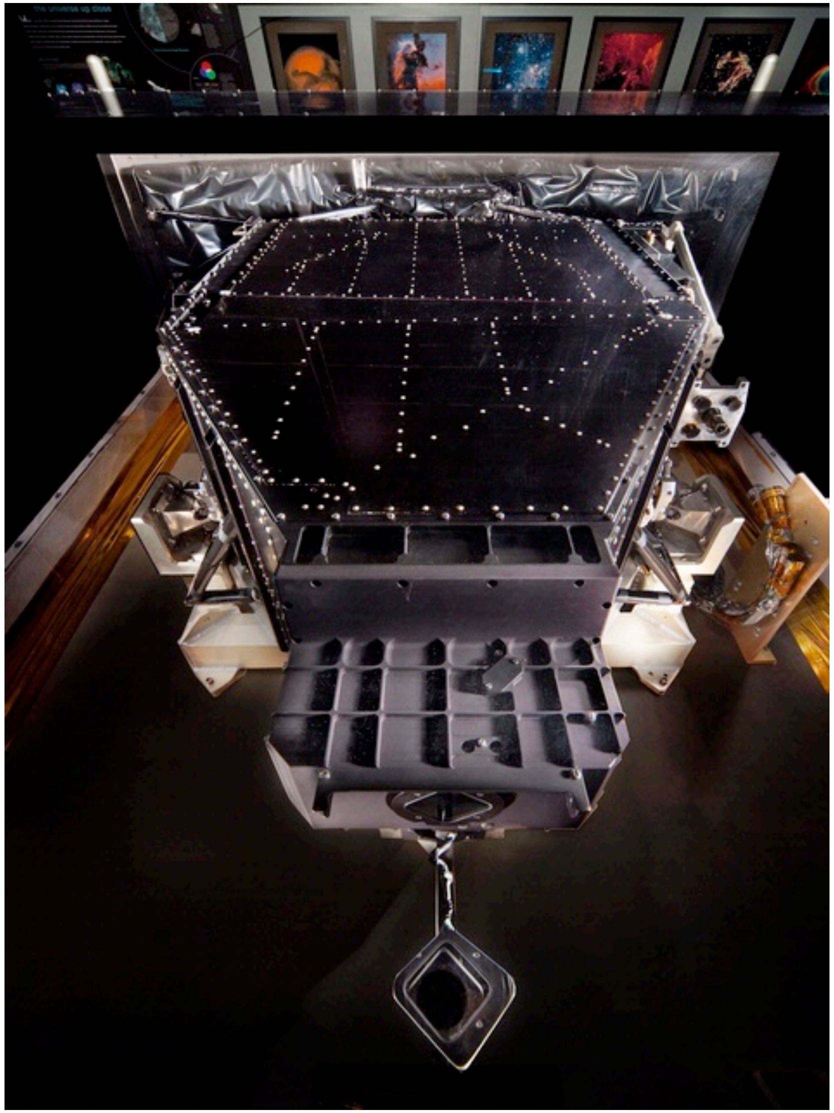
Restored with a Bayesian method
(Nunez & Llacer, March 1991)



# WFPC2 (1994-)

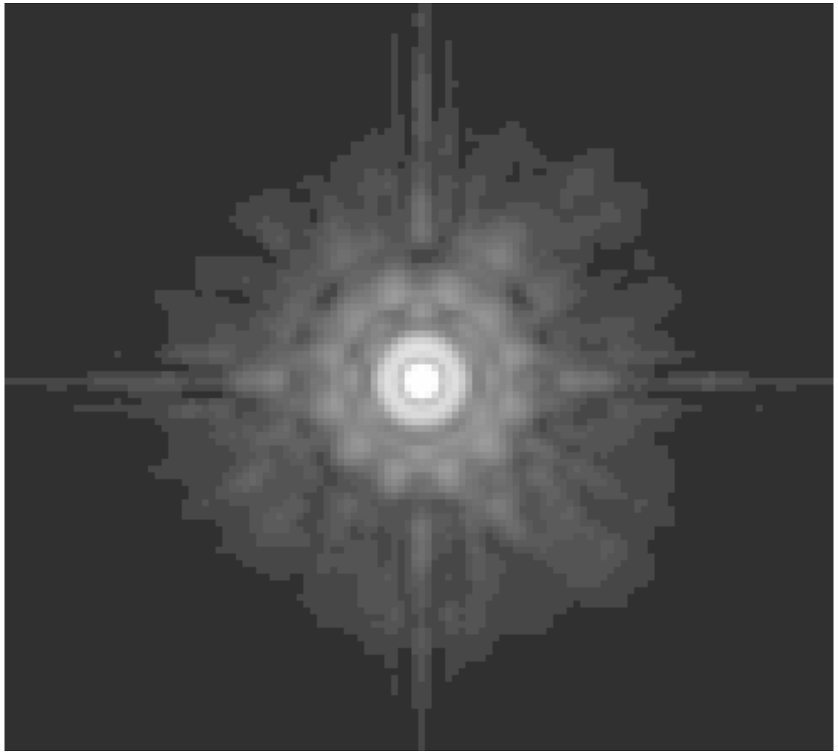
After SM1 in December 1993 WFPC2 proved to be very powerful imager.



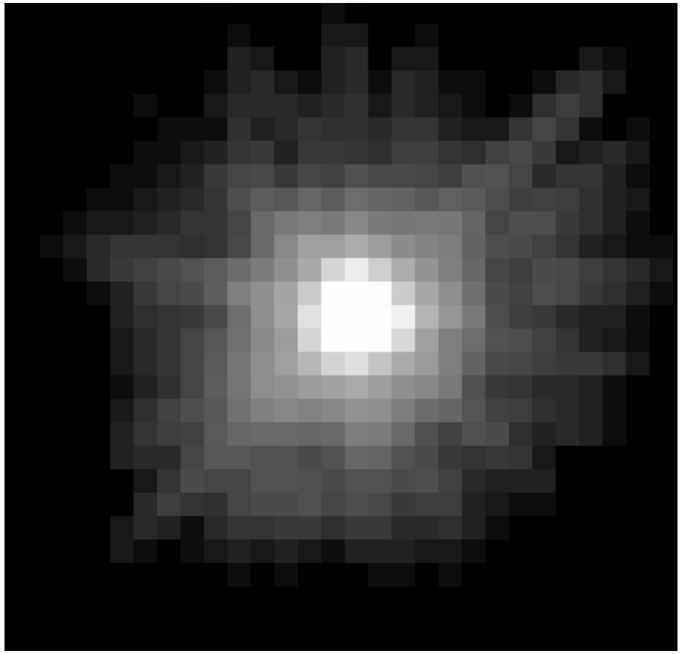


A new and subtle problem surfaced… image sharpness was “too good”…

# What does this mean in practice?



ACS/HRC, F814W - well sampled (0.025” pixels)

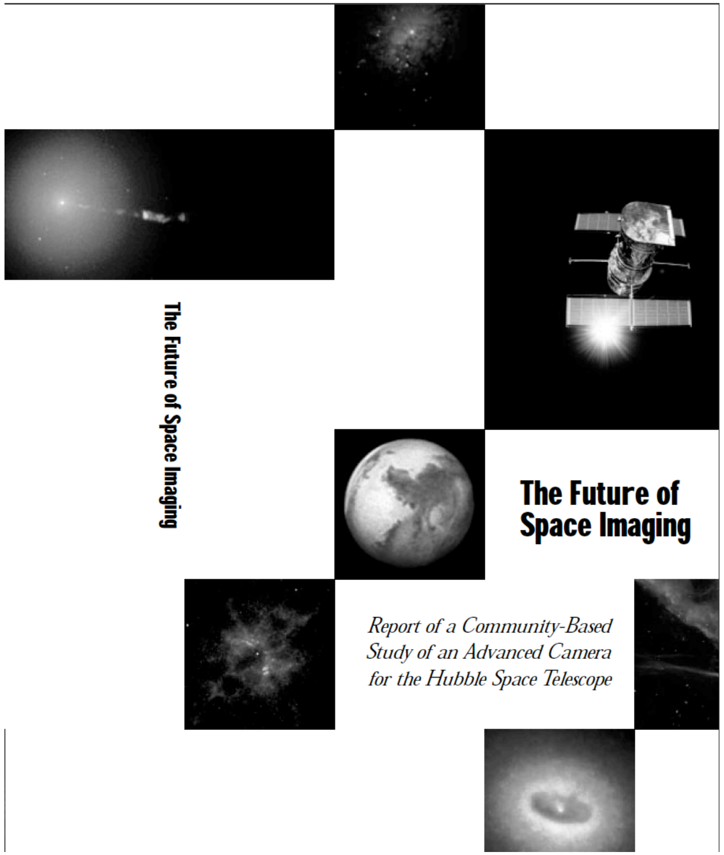


WFPC2, F300W - highly undersampled (0.1” pixels)

# Sampling and Frame Size

- Ideally pixels should be small enough to well sample the PSF.
- But, small pixels have disadvantages:
  - Smaller fields of view (detectors are finite and expensive)
  - More detector noise per unit sky area (eg, PC/WF comparison)
- Instrument designers have to balance these factors and often opt for pixel scales which undersample the PSF.
  - Eg, HST/WFPC2/WF - PSF about 50mas at V, Pixel size: 100mas.
  - HST/ACS/WFC - PSF about 30mas at U, Pixel size: 50mas.
- The inner structure of the pixel also became relevant

# FOSI and the design of the ACS (October 1993)




Bob was lead on Chapter 7: "Sampling the Image"

*7. Sampling the Image*

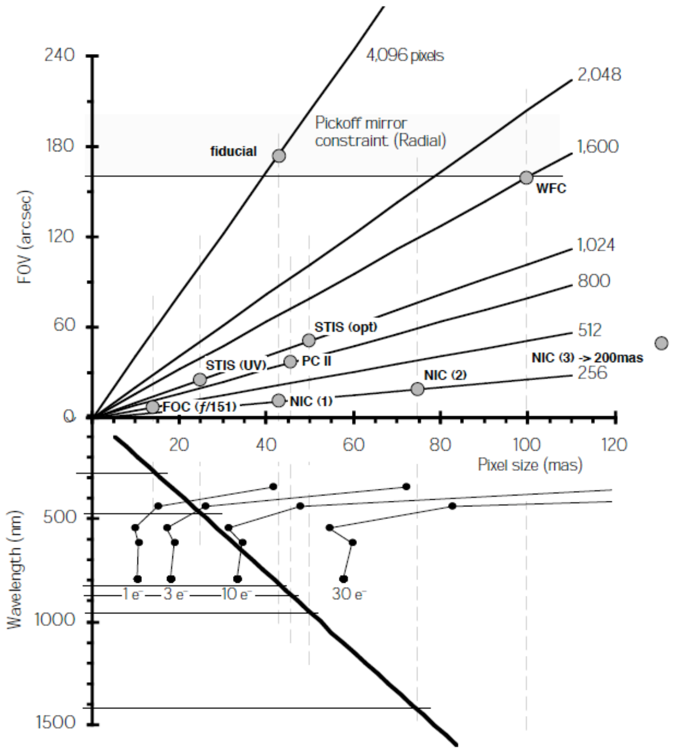
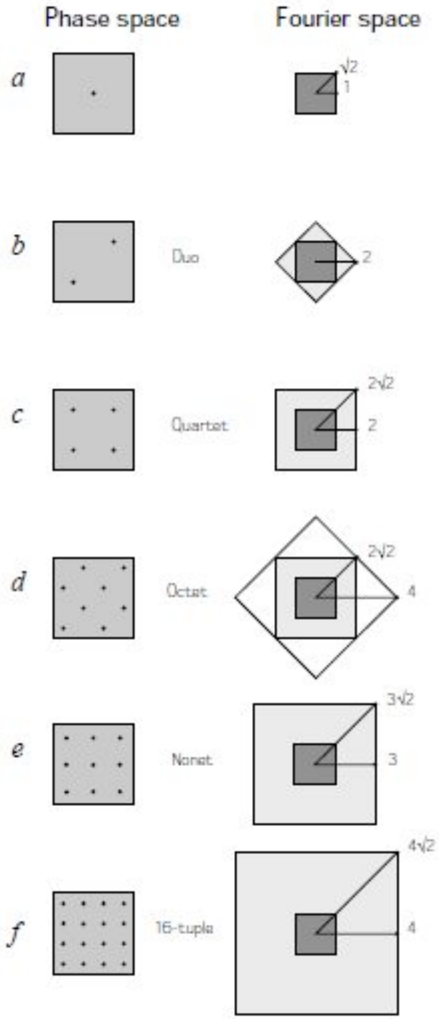



Figure 7.2. The relationship between wavelength for critical (Nyquist) sampling and camera field of view for detectors with a set of different pixel array dimensions recording the image without sub-stepping. The projected set of post-1997 HST imaging instruments is marked along with the 'fiducial' camera discussed in the text and described in table 1. The FOV limit imposed by the pickoff mirror for a radial camera is shown. The lines (with •) in the lower panel show the loci where sky equals readout noise for a CCD detector working in the current WFPC wide filters (F336W, 439W, 555W, 622W, 791W) with readout noise from 1 to 30 e⁻.

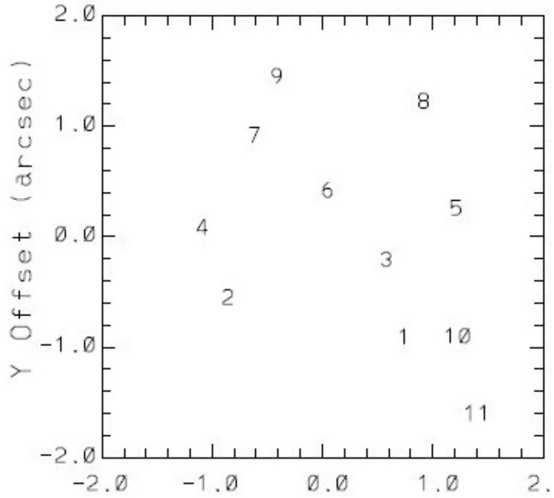
# Observation Strategies: interlacing

Proposed (early-1995)

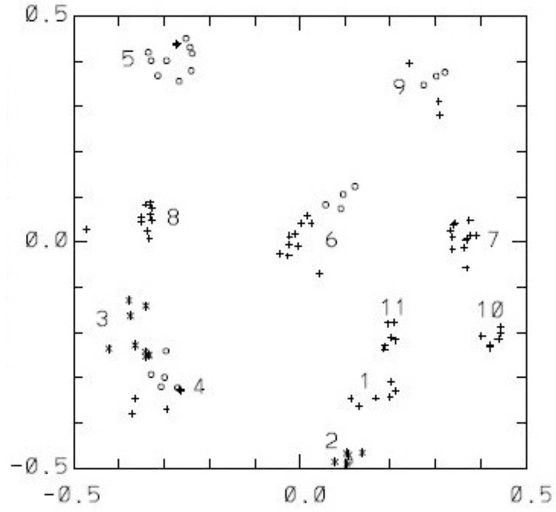


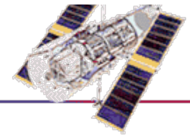

Actual HDF dithers (late-1995):

Large



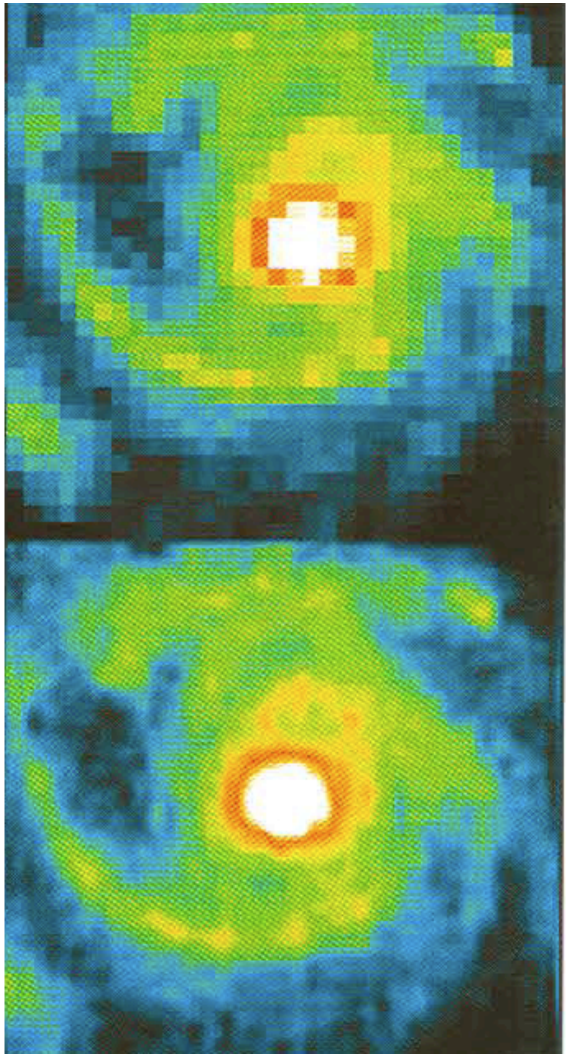
Small

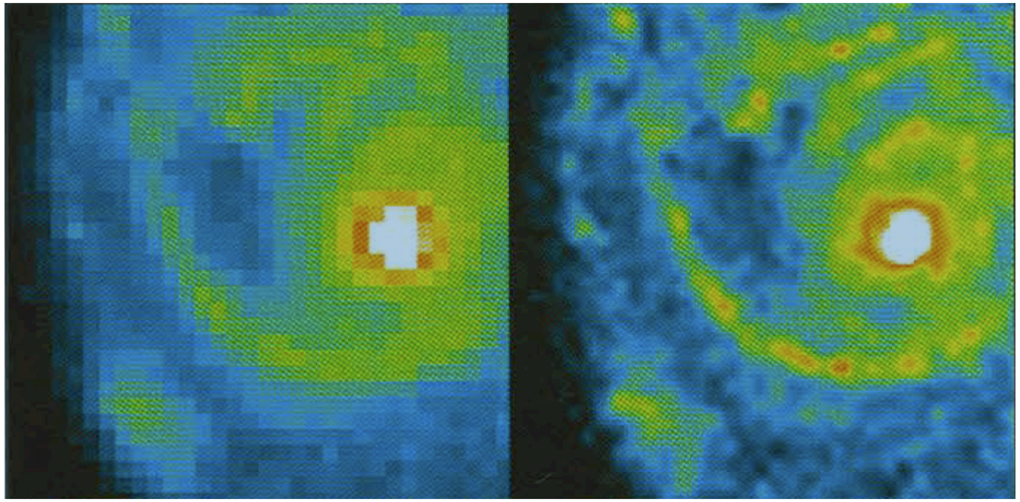


# How can we put it back together?

## Methods based on Image Restoration (1995)





Multi-channel Lucy restoration (RH/LL)

Both using 4 dithered WFPC2 datasets

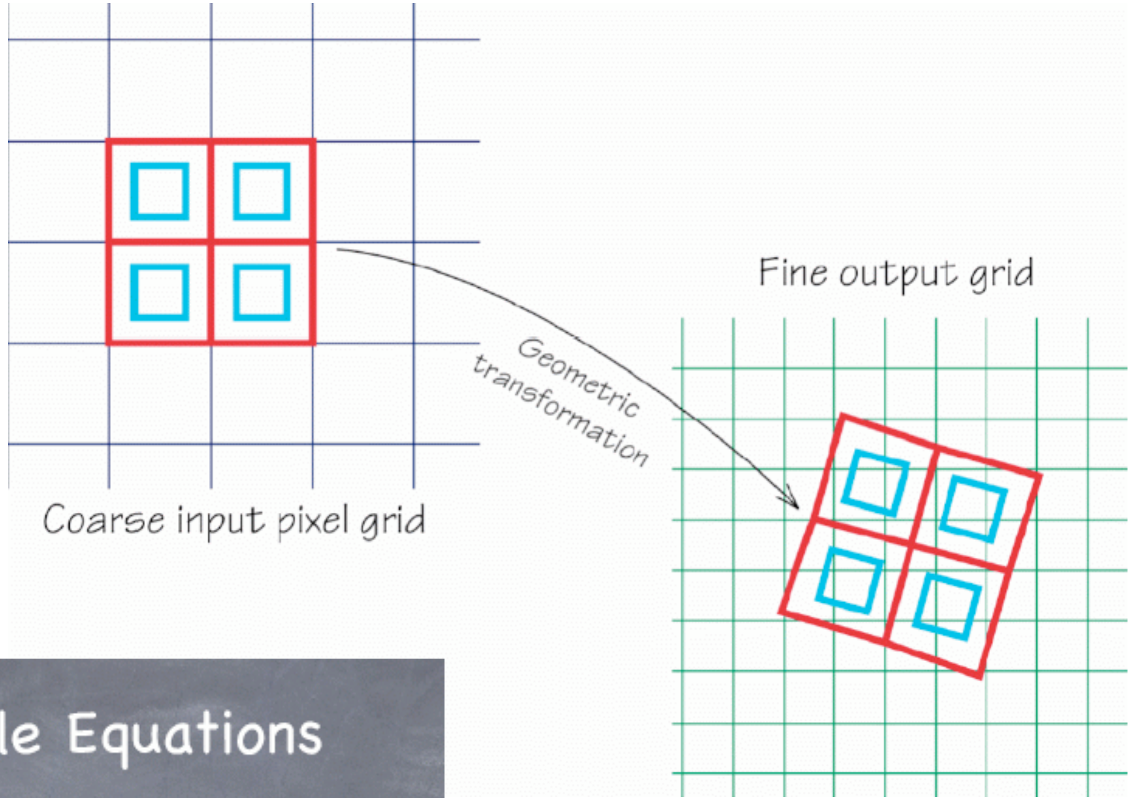
Iterative method based on projection onto convex sets (HMA)

# The Hubble Deep Field was lurking in the near future… (1995)

- STScI (Andy Fruchter) approached the ST-ECF
- Wanted to use dithering – big as well as small shifts
- Problem – handling geometric distortion with big dithers didn't work with the restoration-based methods
- Hubble could do sub-pixel shifts, but not accurately
- A practical solution was needed, fast…

# Drizzling

Developed for the Hubble Deep Field in late 1995.



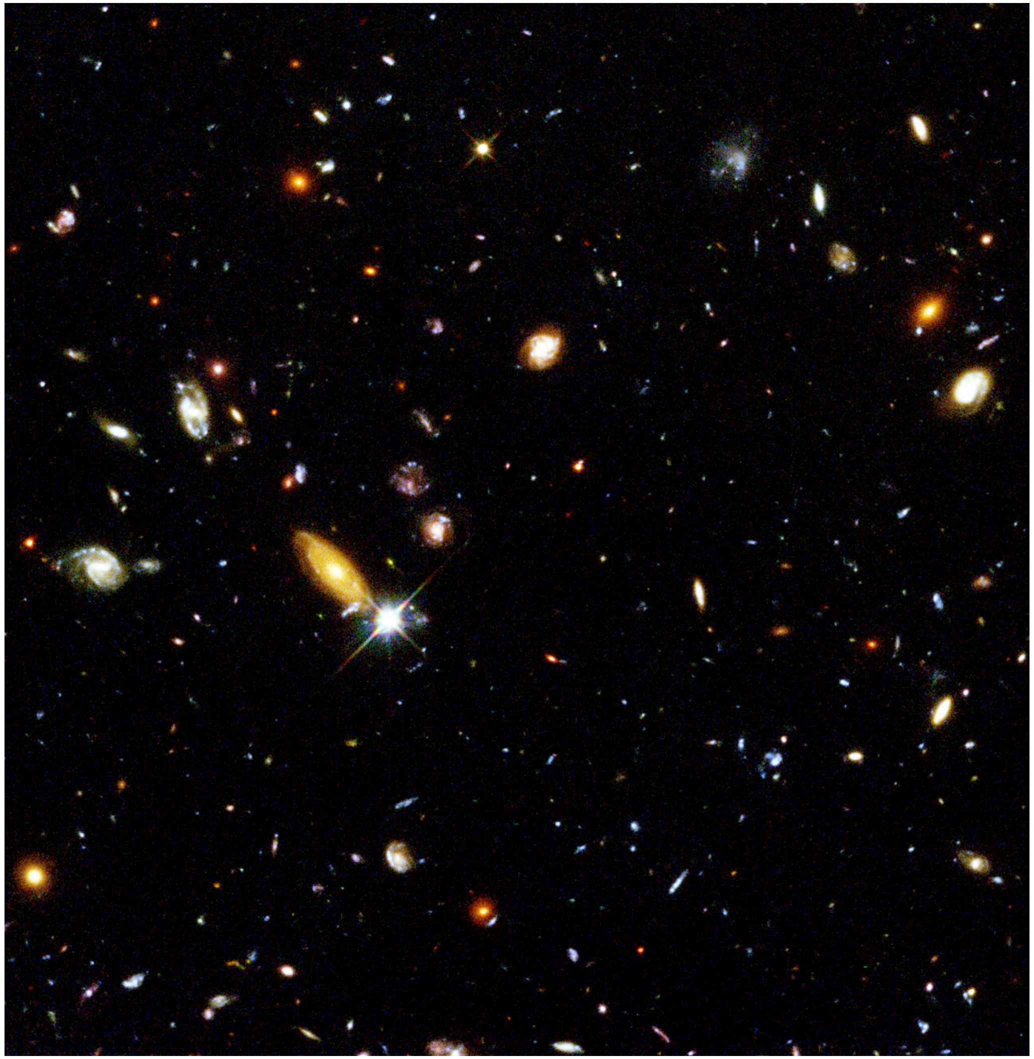

**The Basic Drizzle Equations**

$$I'_{x_o y_o} = \frac{d_{x_i y_i} a_{x_i y_i x_o y_o} w_{x_i y_i} s^2 + I_{x_o y_o} W_{x_o y_o}}{W'_{x_o y_o}}$$

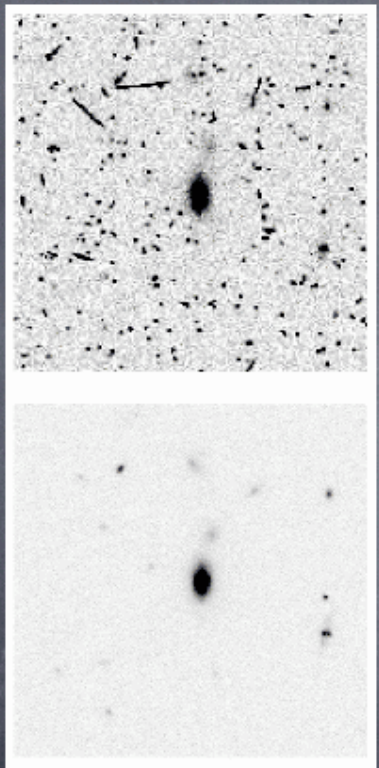
$$W'_{x_o y_o} = a_{x_i y_i x_o y_o} w_{x_i y_i} + W_{x_o y_o}$$

The first Hubble Deep Field – WFPC2, in the north, was the first application of drizzling.

Subsequently used for the HDF-S, UDF, GOODS, Cosmos etc etc.



# Drizzle -> MultiDrizzle (2000 ish)



## Cosmic Ray Removal Recipe

- Drizzle each image onto a separate sub-sampled output image using pixfrac=1.0
- Take the median of the resulting aligned drizzled images.
- Map (blot) the median image back to the input plane of each of the individual images
- Take the spatial derivative of each of the blotted output images.
- Compare each original image with the corresponding blotted image; mask pixels showing excessive differences
- Repeat on adjacent pixels with stricter criteria
- Drizzle all images onto a single output using cosmic-ray masks

# Other Developments – 1996-2011

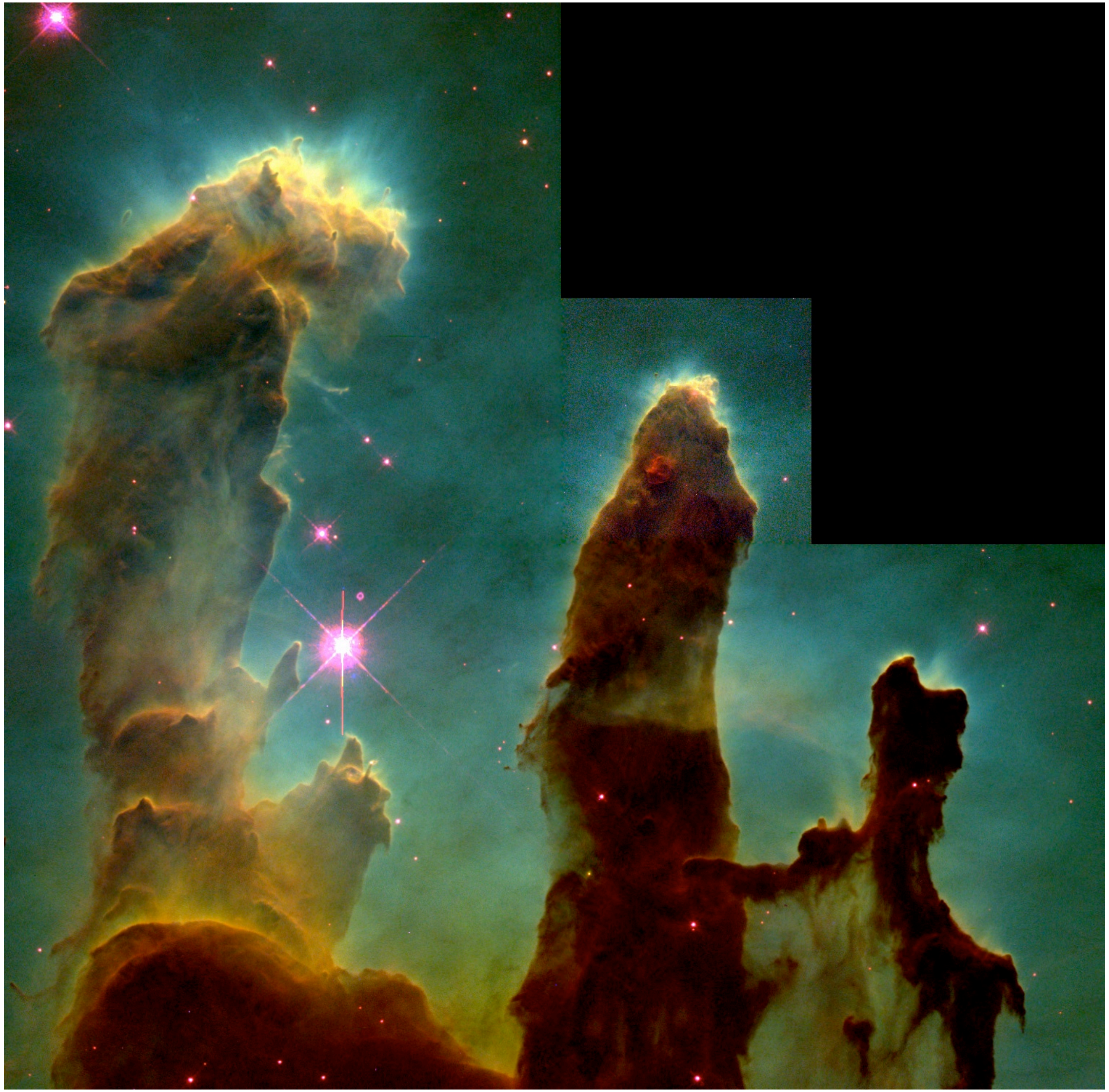
- Drizzling/MultiDrizzle fully integrated into pipeline and “on-the-fly” processing
- Hubble Legacy Archive – fully processed data online
- Extensions of the algorithm: iDrizzle (Fruchter, 2011, iterative) to address the limitations of drizzle for high quality, high S/N data sets.

# Why was drizzling so successful? Still in use after 15 years.

- It could handle geometric distortion
- Each pixel could be weighted
- There was a robust implementation (although in IRAF).
- It handled low S/N, undersampled multi-frames, the common Hubble situation, well.
- It evolved as the core of more extensive infrastructure at STScI – MultiDrizzle, Hubble Legacy Archive etc.

- It had a cool name.

- JWST?



The Pillars of Creation (WFPC2)

# Hubble Images for Outreach

(with thanks to Lars Lindberg Christensen, who couldn’t attend)

*The Hubble Space Telescope has undoubtedly had a greater public impact than any other space astronomy mission ever. The images […] are quite staggering in what they reveal about the Universe we live in and have already become part of our common scientific and cultural heritage.*

Malcolm Longair, 2005

# Why Hubble?

- Hubble was the first telescope to make a huge splash with the general public, and still the most successful. Why?
  - The images have high “photogenic resolution”, and are intrinsically very clean and sharp. “Wow factor”.
  - Rich colour from multiple filters.
  - Rich natural beauty – like Amsel Adams’ pictures.
  - They are linked to exciting science.
  - NASA (and later ESA) supported this and provided the resources.
  - The 1990s were a time when desktop image processing and the web were making global distribution much easier.

Urania
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1/2007 (727)
tom LXXVIII
styczeń—luty
15 lat projektu OGLE
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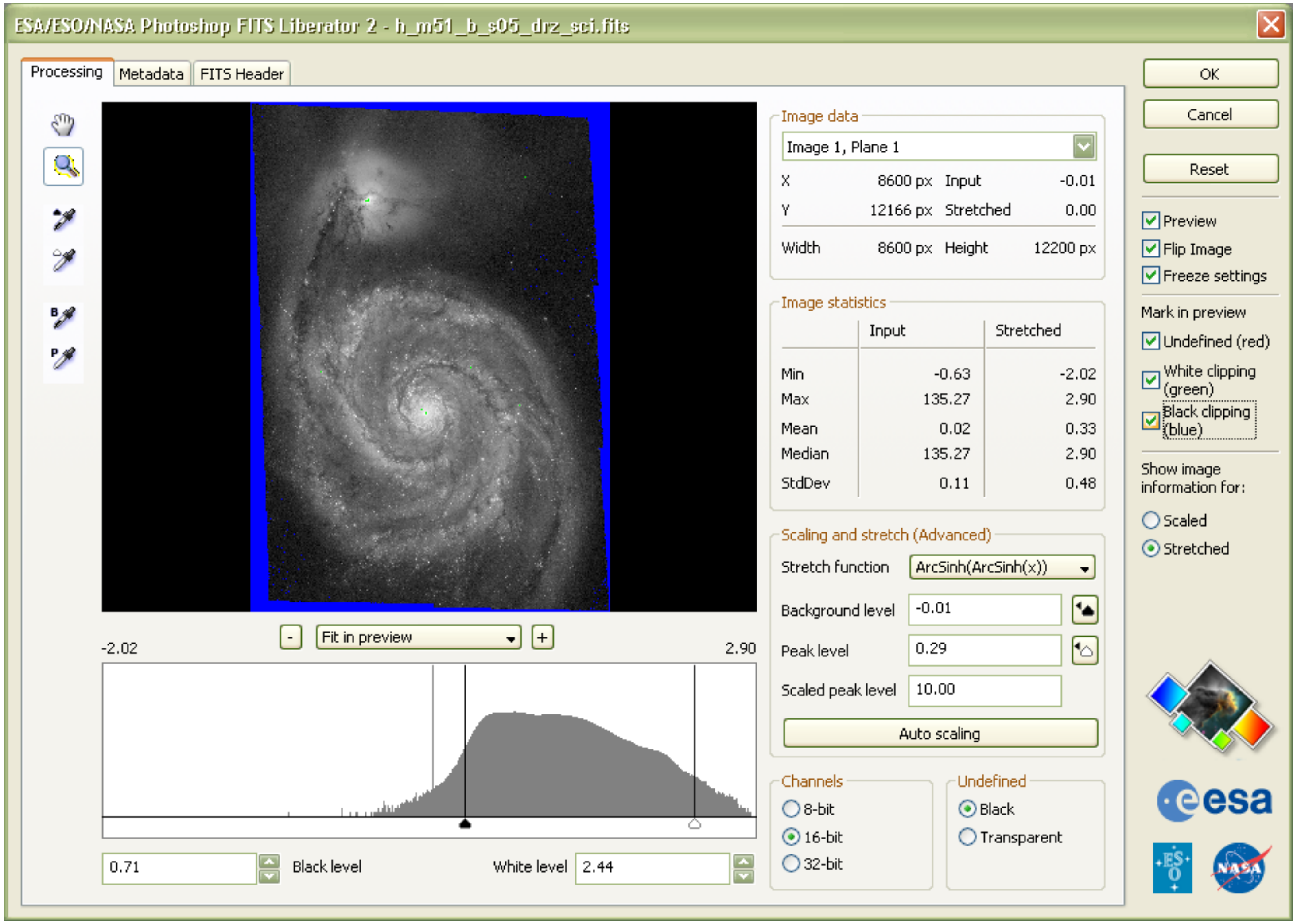
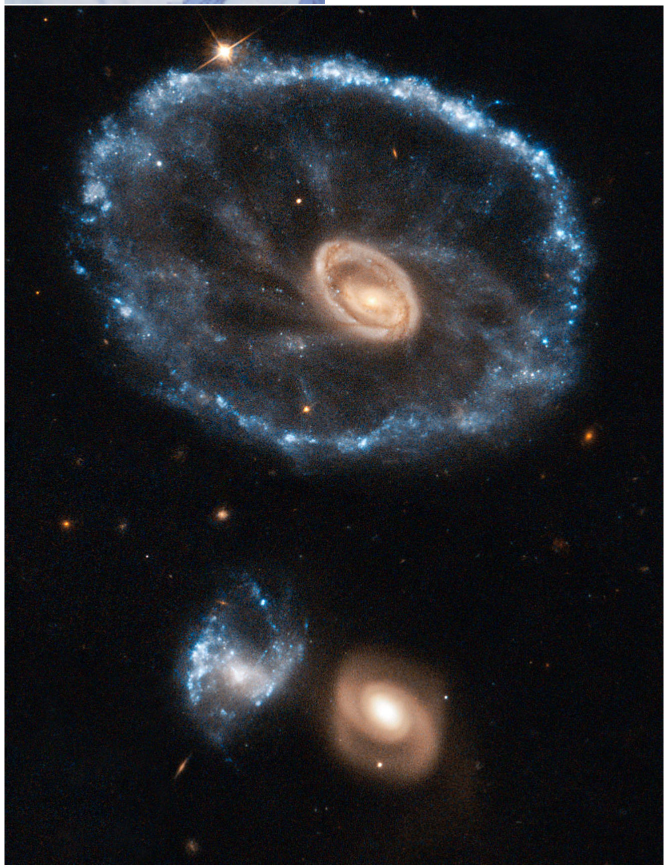
DER HIMMELSLAUF IM SCHULJAHR 2006/2007 POSTER
ISSN 0032-5414
„Make Love, Not War!"
„Kochają się, a nie walczą ze sobą!". Tak spuentowali najnowsze zdjęcia NGC 4038-4039 (Anten) — oddziałujących ze sobą galaktyk w gwiazdozbiorze Kruka na południowej półkuli nieba — jego autorzy z Europejskiej Agencji Kosmicznej ESA i NASA (J. Long, B.Whitmore). Obraz uzyskany kosmicznym teleskopem Hubble'a w dziedzinie widzialnej jest najbardziej ostrym zdjęciem tych galaktyk, jakie dotychczas otrzymano. U góry obraz uzyskany teleskopem Chandra w rentgenowskim zakresie widma (G.Fabbiano). W czasie gdy obie galaktyki przenikają się wzajemnie (proces ten zaczął się ok. 500 mln lat temu), urodziło się wiele miliardów gwiazd, głównie w grupach i gromadach, a nawet supergromadach, dobrze widocznych na powyższych zdjęciach, oraz wybuchło tysiące supernowych. Galaktyki te leżą w odległości ok. 60 mln lat światła od nas. Więcej piszemy o nich w „Galerii obiektów NGC" na s. 275-277
ISSN 0032-5414
Masywne gwiazdy w gromadzie otwartej Pismis 24
Na podstawie zmierzonej odległości, jasności i standardowego modelu słonecznego oceniono, że jedna z gwiazd gromady otwartej Pismis 24 w gwiazdozbiorze Strzelca ma masę ponad 200 razy większą od masy Słońca. To rekordowa i zastanawiająca wielkość. Ta gwiazda to najjaśniejszy obiekt powyżej chmury świecącego gazu na prezentowanym zdjęciu. Bliższa analiza najświeższych zdjęć wykonanych teleskopem kosmicznym Hubble'a pokazała, że jasność obiektu Pismis 24-1 nie pochodzi od pojedynczego obiektu, a raczej od trzech gwiazd. Ale, oceniono, każda z tych gwiazd ma masę ponad 100 mas Słońca, czyli należy do klasy najbardziej masywnych gwiazd na niebie.
Dolną część zdjęcia wypełnia mgławica emisyjna NGC 6357, olbrzymi konglomerat pyłu i gazu, w którym rodzą się gwiazdy. Niektóre z nich z całą swą młodzieńczą energią przebijają promieniowaniem otaczający je kokon materii i pobudzają ją do świecenia.
Zdjęcie: NASA, ESA i J. M. Apellaniz (Hiszpania)

# ESO/ESA/NASA (Photoshop) FITS Liberator





## Final Comments:

It has been a great privilege, and a lot of fun, to work with Hubble images over the last 21 years.

The techniques developed in the 1990s have proved durable and many will probably make the transition to JWST.

We wish Bob many years of happy "semi retirement" and want to thank him for all the support, help and inspiration over the years.