NIC-FPS Critical Design Review

Instrument Overview & Science Capabilities

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CASA-ARL

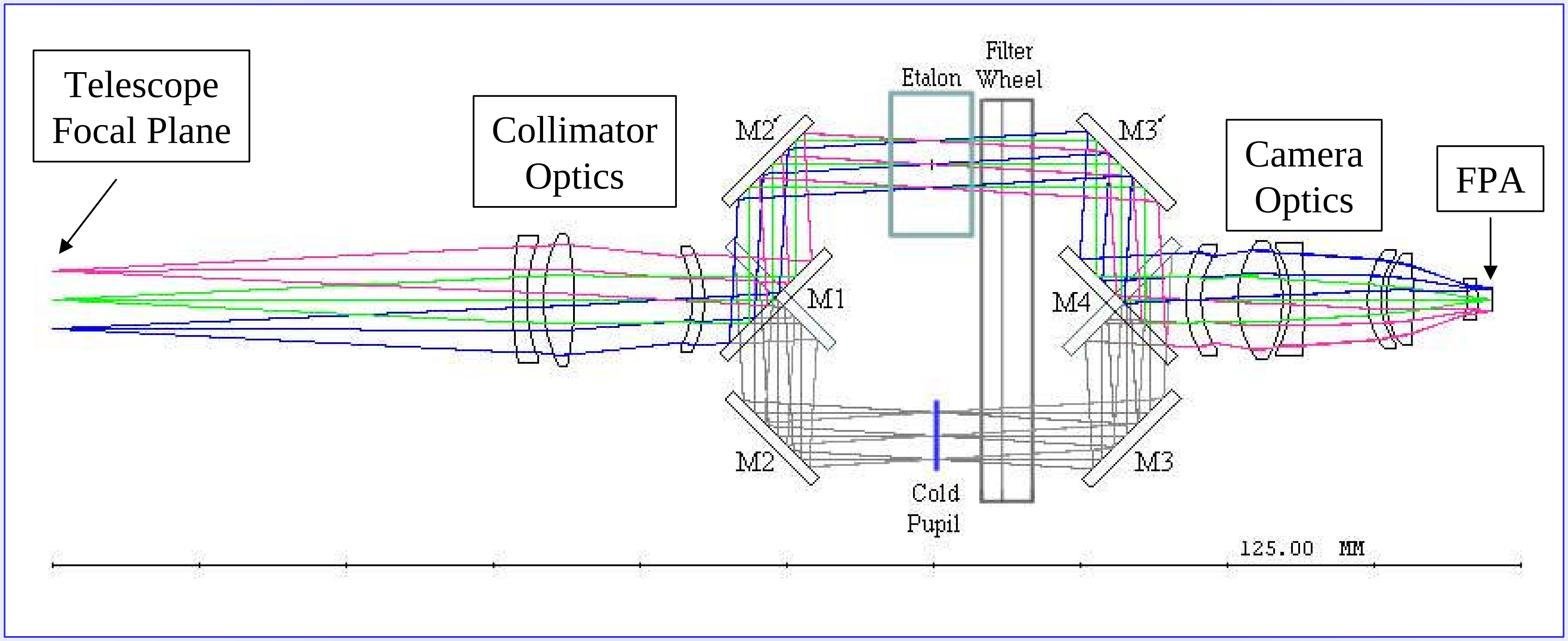
Boulder, CO

- Brief history of the Near-Infrared Camera and Fabry-Perot Spectrometer (NIC-FPS):
  - Original IRFP concept by G. Cecil (UNC) and P. Hartigan (Rice) to be used in conjunction with CIRIM 256^2 IR camera on CTIO 4m
  - Cryogenic IR F-P etalon purchased by Hartigan from QI in 1996 for $62k (50 mm clear aperture; R ~ 10,000; operates at 77K; 1 of only 5 constructed by QI)
  - 90% of components (dewar, optics, bench) fabricated but IRFP never fully assembled (CU contributed ~$10k to dewar fab)
  - CU joined ARC in July 2001; $450k instrument obligation presents opportunity to fulfill unique science of cryogenic IR F-P while simultaneously upgrading ARC near-IR imaging capability
  - Summer 2001: Investigated compatibility of existing IRFP hardware for NIC-FPS, but Cass focus IRFP design not adaptable for Nasmyth mount
  - Fall 2001: Investigated 2k × 2k imager feasibility, but cost beyond CU+ARC present resources
  - January 2002: 1k × 1k approach adopted; detailed design begins

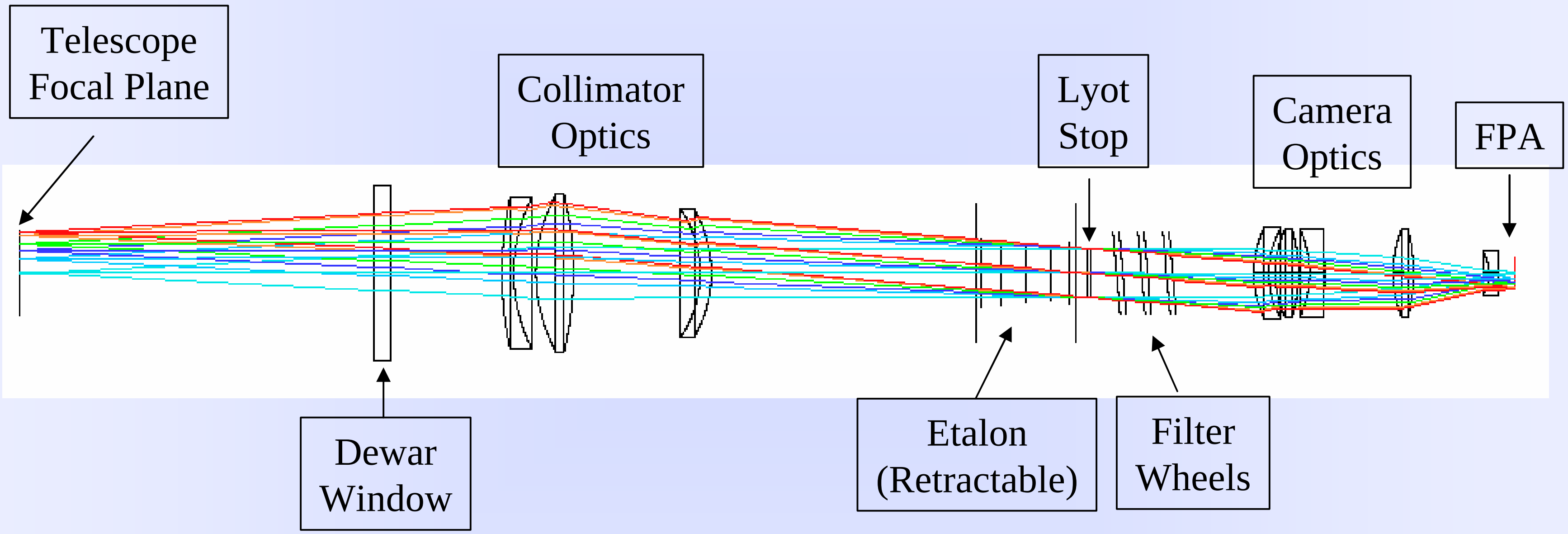
Design changes since PDR:

– Single channel design (instead of dual channel)
– Moving etalon to switch between F-P or direct imaging
– Three 7-slot filter wheels (instead of two 10-slot)
  - Smaller wheels placed above optical bench (instead of larger wheels that split bench)
– Hawaii-1RG MBE FPA with 18μm pixels (instead of Hawaii-1 PACE with 18.5μm pixels)

Instrument Concept at PDR



Current Instrument Concept



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- **Wavelength range:** 0.85 to 2.5 μm
- **Pixel Scale and Field of View:** single image scale
  - Pixel scale of 0.27 ±0.02 arcsec/pixel for H-1RG 1024×1024 HgCdTe detector with 18μm pixel pitch
  - Field of View of 4.58′×4.58′ (6.42′ across diagonal)
- **Optics**
  - High intrinsic Strehl to take advantage of best seeing conditions
  - Minimized and well-characterized image distortion to allow accurate astrometry
  - High system transmission (> 70% at 2 microns)
  - Pupil size is ~80% of F-P etalon 50mm clear aperture
  - Cold optics and Lyot stop to reduce background levels in K-band
  - Minimize scattered light and ghost images when viewing point and extended sources

Topic/Presenter: Additional Mechanisms / Jon Morse

Question/Comment:

Impacts of additional mechanisms: (internal) focus mechanism, pupil alignment mechanism, shutter

Is it possible to add another filter wheel without changing pupil relief/optics design significantly?

What is the cost impact of an additional wheel mechanism?

Submitted by: Jon Holtzman

NIC-FPS Response:

We add to the above list:
- calibration lamp unit
- ion pump

These additions will require a trade study.

1) Internal focus mechanism: At this time, we do not plan to include a mechanical feedthrough for internal instrument focus. Internal focus will be achieved during instrument alignment. However, we will save space on the forward bulkhead for such a feedthrough if we find the adjustment is particularly sensitive.

2) Pupil mask alignment mechanism: At this time, we do not plan to include a pupil mask alignment mechanism (either hand operated or motorized). Other similar imaging instruments often do not have such an adjustment capability, and we regard this alignment as sensitive but not critical to the imaging performance because we do not penetrate into the thermal IR.

Topic/Presenter: Additional Mechanisms / Jon Morse

NIC-FPS Response:

We add to the above list:
calibration lamp unit
ion pump

These additions will require a trade study.

3) Shutter mechanism: There is currently no plan to include a cryogenic shutter in NIC-FPS. The flexible detector read-out modes appear to mitigate the need for a shutter and a blocking slot will be included on one of the filter wheels for obtaining detector dark exposures. (See RFA opto-mechanical #1.)

4) Additional filter wheel: There are currently 3 filter wheels in the NIC-FPS design, each with 7 slots. Each filter wheel must have a clear slot and one of them needs to include a block for detector darks. Thus, there are 17 slots available for science filters in the current design. Adding another wheel would permit an additional 6 filters. Although this additional is probably feasible, it adds cost that the current budget will not support. Furthermore, 65 mm filters can cost $10-13K a piece, thus an additional $60-75k is required to populate the additional wheel.

5) Internal calibration lamp(s): Although this would permit some calibration of the etalon even while NIC-FPS is off the telescope, one would generally not rely on internal calibrations for flat fields. At this time, we plan to obtain calibration exposures using lamps mounted on the secondary support structure that illuminate the primary mirror covers. Wavelength calibration of the etalon is generally not an excessive overhead.

6) Ion pump: At this time, we are not planning to use an ion pump. For more details, see RFA Dewar #3.

Status: 1-4 Closed.
Options to include an internal calibration lamp (5) and ion pump (6) are present in the baseline design. They can be added at any time during the lifetime of the instrument should the need arise.

Topic/Presenter: Focal Plane Array / Jon Morse

Question/Comment:

What is the impact to choice of pixel/arcsec if PSF improves from ~0.8 arcsec to 0.5 arcsec on average, and sometimes as good as 0.3 to 0.4 arcsec.

Submitted by: Bruce Gillespie

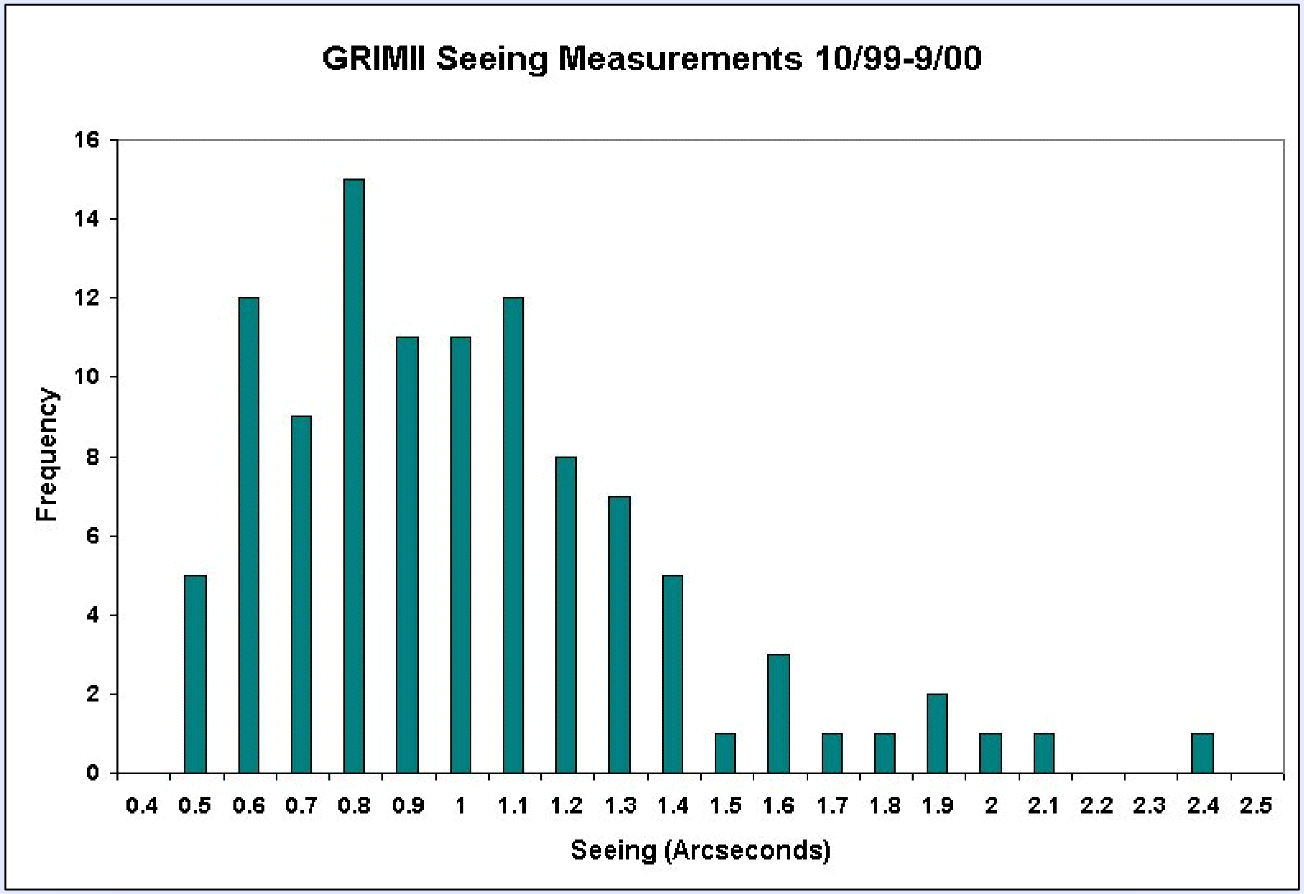
NIC-FPS Response:

The image scale at the FPA is 0.27 arcsec/pixel (18 micron pixel size for the H-1RG). The optical design supports good image quality with 2 pixel sampling over essentially the entire FOV. Optical and NIR seeing statistics from APO suggest a median seeing of about 0.8 arcsec FWHM, with occasional performance as good as 0.5 arcsec. For seeing conditions of 0.5 arcsec or worse, the instrument should not drive the imaging performance.

If the NIR seeing improves substantially --- for example, if a tip-tilt capability were implemented on the secondary --- so that 0.3-0.4 arcsec seeing conditions were common, we recommend upgrading NIC-FPS with a new set of camera optics and a 2kx2k chip (Hawaii-2RG). We have already modeled the imaging performance of this upgrade *within the available space on the NIC-FPS optical bench* and find that an H-2RG option with about 0.15 arcsec/pixel would increase the FOV slightly and provide good image quality with 2 pixel sampling. An H-2RG would cost about $350k, but we should be able to operate it with our existing "NGST" packaging and drive electronics. (The package is modularly designed so that we would literally just plug the H-2RG into the socket.) The new camera optics would probably cost between $50-70k.

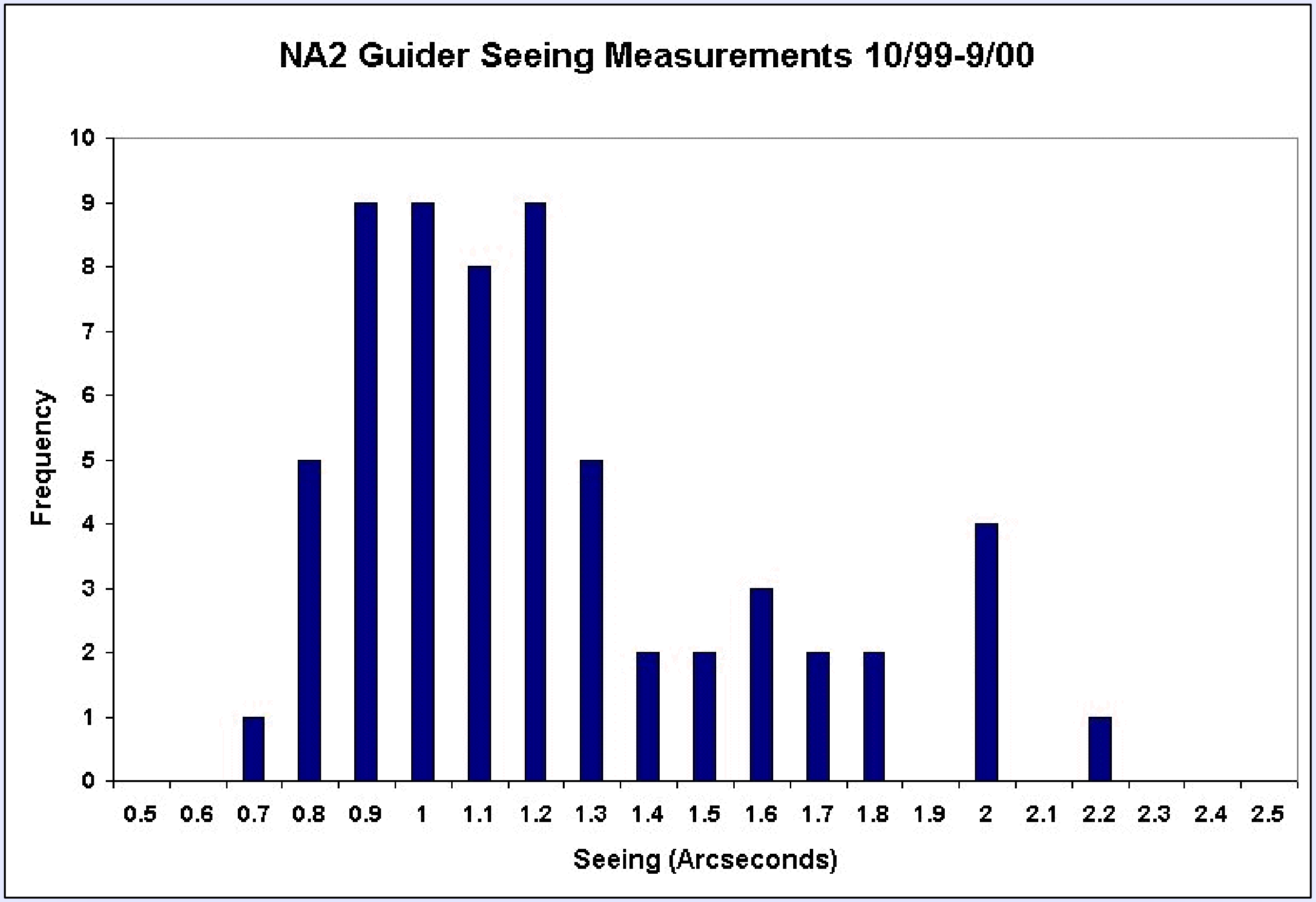
Status: Closed.

NIC-FPS Critical Design Review



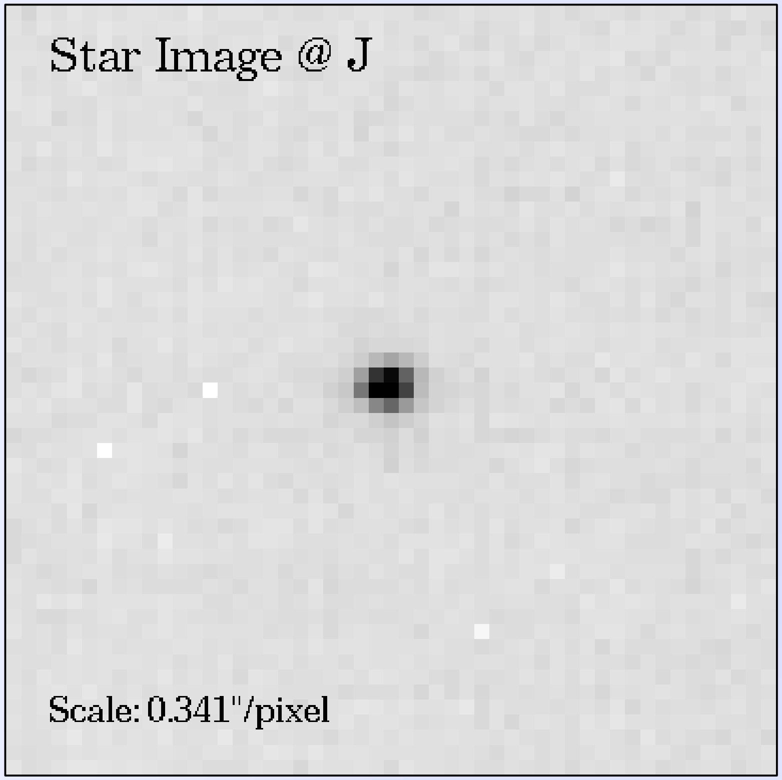
- 1999-2000 GRIM II 2-micron median FWHM seeing is 0.93 arcsec (Barentine, 2002).
- Seeing better than 0.8 arcsec occurs about one night in four.
- 0.5 arcsec seeing occurs about once a month.

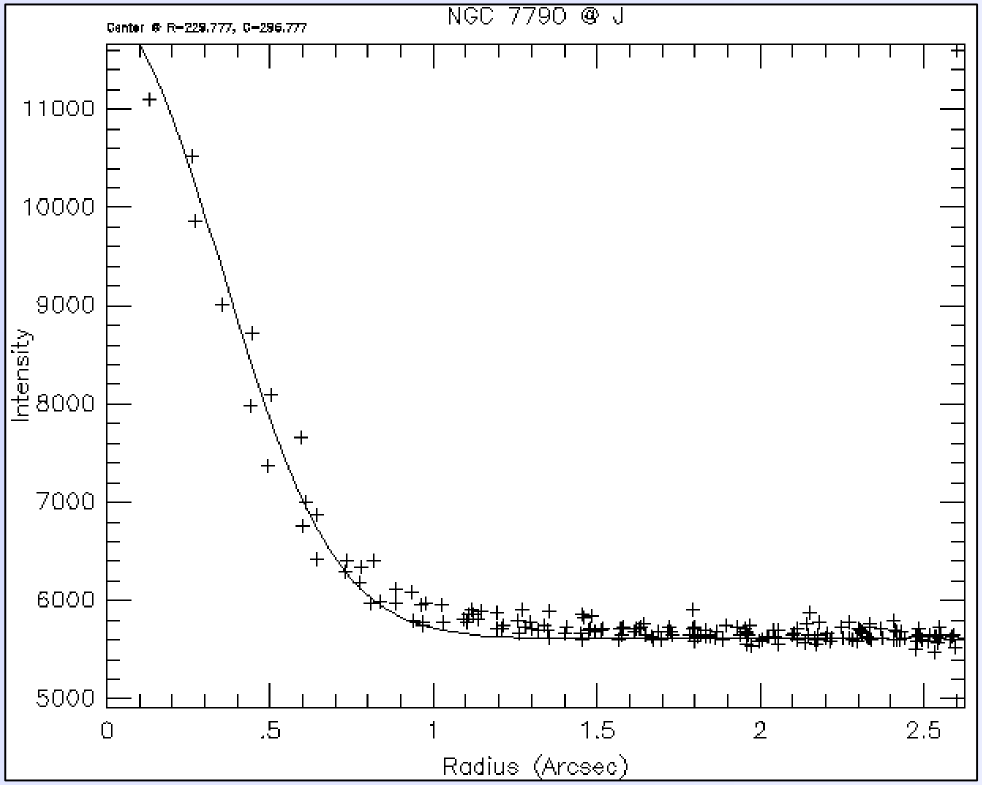
NIC-FPS Critical Design Review



- NIR seeing ~20% better than optical seeing

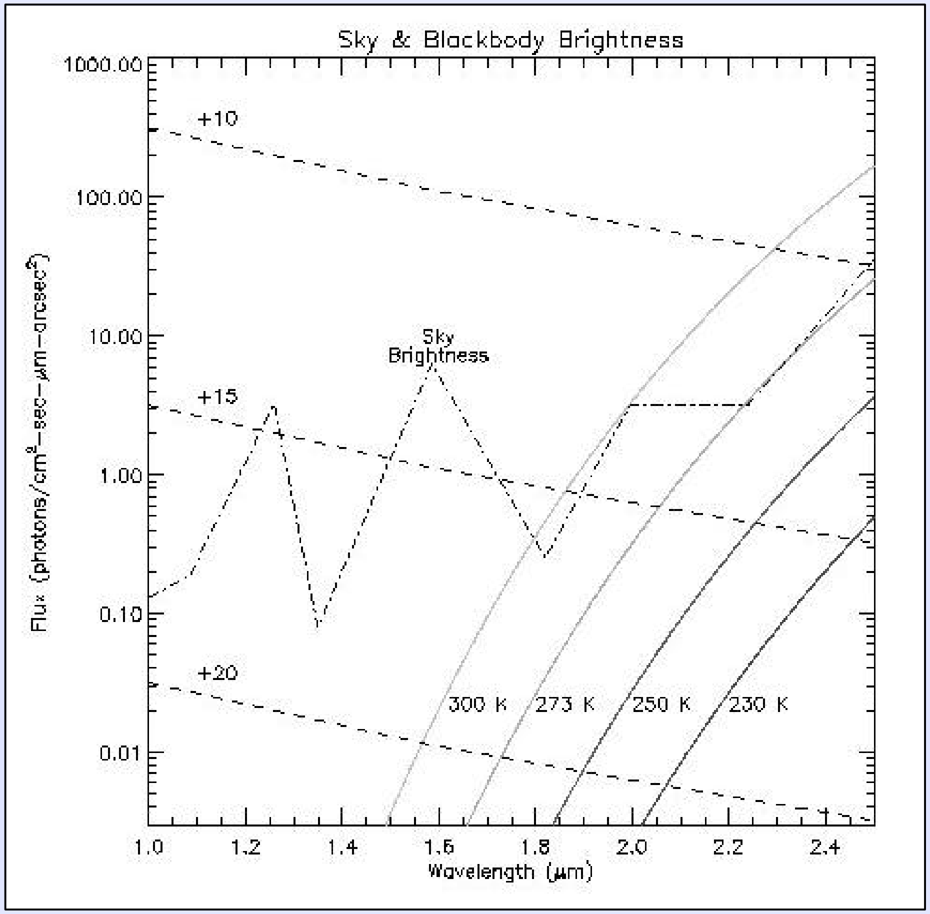
NIC-FPS Critical Design Review





- Approximate image quality (Example: OSU MOSAIC on KPNO 2.1m)

NIC-FPS Critical Design Review



• Cooling optics to < 220K mitigates intrinsic thermal background in H, K bands

- **Dewar & optical bench**
  - "Access architecture" for alignment and maintenance
  - Cool detector to ~77K using LN2
  - Cool optics to <220K to reduce background
  - Cool optics to ~77K with LN2 for ease of implementation and to reduce thermal gradients/mechanical distortions
  - Cryogen hold time >24 hours (goal of >48 hours)
  - Minimize vibration environment for etalon
  - Baseline mounting to Nasmyth port 2
  - External calibration sources
- **Cryo Mechanisms (minimum set)**
  - 3 motorized filter wheels with 7 slots each in collimated beam
    - 3 clear slots (1 per wheel), 1 blocker, 17 science filter slots
  - 1 motorized arm/stage to remove etalon for direct imaging

Filters

- Three 7-slot filter wheels provide 16-18 slots for science filters
- Nominal filter size 65 mm diam. × 5 mm thick, 5° tilt
- Core Filters

Core Filters	Central	Cut-on	Cut-off
– MKO J	1.25	1.17	1.33
– MKO H	1.63	1.49	1.78
– MKO K_S	2.15	1.99	2.31
– [Fe II]	1.644	1.639	1.649
– H_2 1-0 S(1)	2.122	2.117	2.127

H-band delivered 7/25

- Hi-pri Filters

Hi-pri Filters	Central	Cut-on	Cut-off
– z	1.01	0.90	1.12
– MKO K	2.20	2.03	2.37
– [Fe II] red/cont.	1.652	1.647	1.657
– H_2 red/cont.	2.13	2.125	2.135

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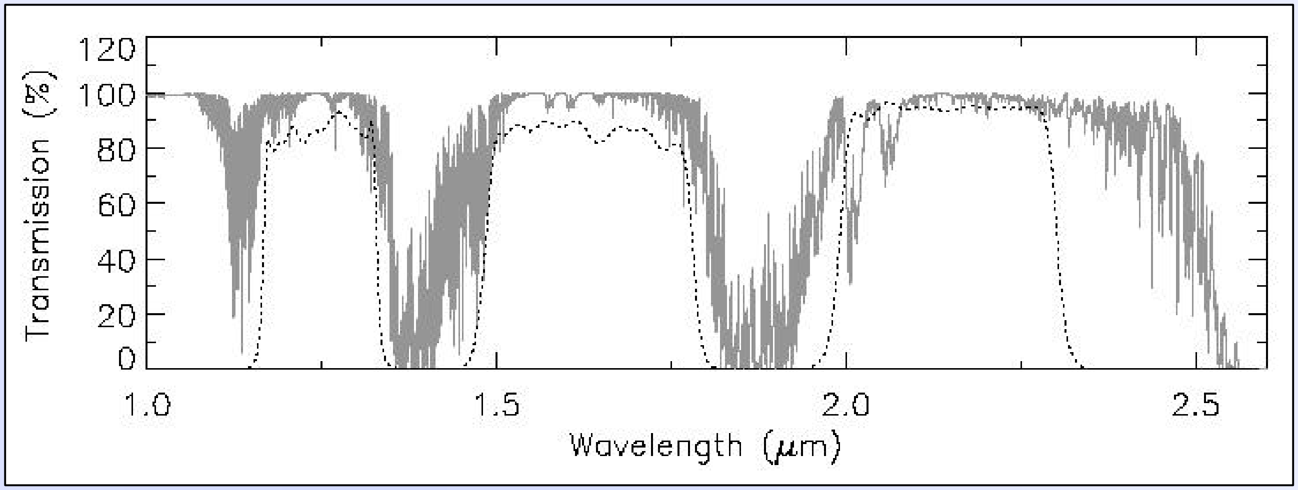
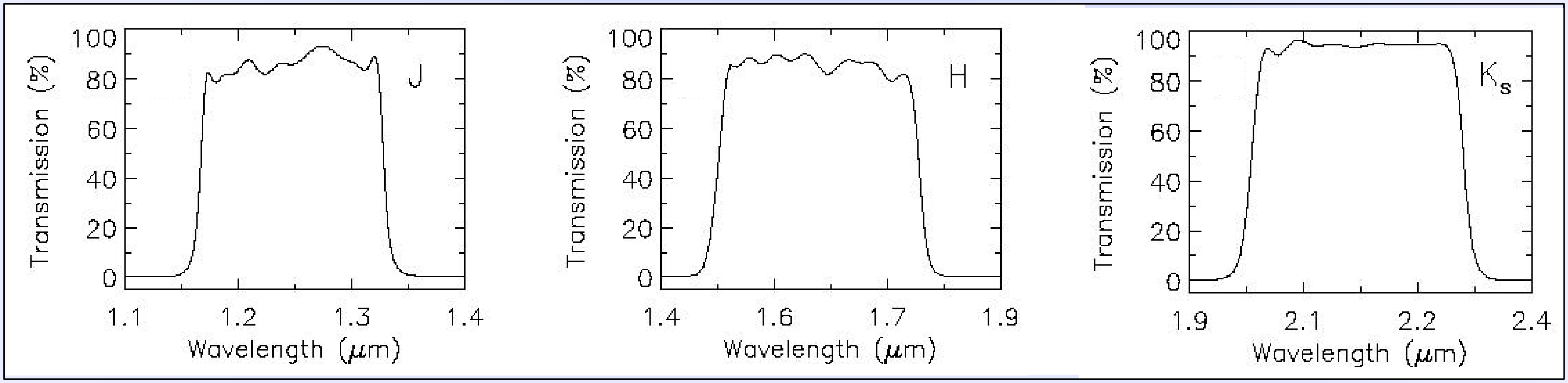
• MKO Broad-band Filter Set

- Compatible photometric system
- 65 mm diameter also used at CTIO-ISPI and elsewhere





Filters (cont.)

- Additional filters sought by ARC community
- Most requests desire duplication of GRIM II filters, some requests for new filters
- Wish-list includes:

  [S III]λ0.953; [C I]λ0.985; Y-band; [S II] λ1.03; He I λ1.08; Pa γ λ1.09;
  H_2 S(1) lines at λ1.233, λ1.311, λ2.248; Pa β λ1.28 + redshifted/cont.;
  H_2O/CH_4 + cont. at λ1.27, λ1.385; CH_4 + cont. at λ1.58, λ1.70;
  H_2O/NH_3 at λ1.53; Br γ λ2.16 + redshifted/cont.; K'; K_{long}; CO_2 λ2.3;
  H_2 Q-br λ2.43; etc.

NIC-FPS Critical Design Review

Topic/Presenter: Focal Plane Array / Jon Morse

Question/Comment:

Need to order a Rockwell Hawaii 1RG now, even if it will cost and extra $100K instead of $75K. Get engineering chip, too, for free. Also get new controller electronics. Get specifications for performance and defects for science grade chip.

Submitted by: Bruce Gillespie

NIC-FPS Response:

A Rockwell Hawaii-1RG focal plane array with drive electronics has been ordered. The QE spec is >65% over 1-2.45 mu (goal of >80%); the read noise spec is <20 e- rms CDS for "slow" read mode (goal of <10 e- rms CDS); the dark rate spec is 0.1 e-/s/pix (goal of 0.01 e-/s/pix); and the spec for defects is >95% operability (goal of >98%). An array flatness spec is not included but will be characterized upon cool-down by Rockwell, and should be handled within our camera depth of focus.

An engineering grade chip is not included in the Rockwell procurement, because they say they simply do not have engineering grade devices floating around to give us. Nevertheless, we have contacted the NGST project about "borrowing" one of their test H1RG's and it appears feasible in the early-2003 time-frame when the drive electronics and bare multiplexer are delivered.

Status: Closed

Detector:

Rockwell/Hawaii-1RG MBE 1024×1024 HgCdTe

- NGST prototype with several enhancements over Hawaii 1, such as reference pixels and selectable postage-stamp readout
- Under development (with NGST providing significant funding); some devices delivered to NGST Project
- Rockwell in-house testing indicates excellent QE, read noise, and dark current performance
- Cost estimate ~$295k (incl. drive electronics and fiber link; cabling?)
- Schedule risk moderate-to-high

NIC-FPS Critical Design Review

Topic/Presenter: Focal Plane Array / Jon Morse

Question/Comment:

What are the supposed readout rates/readout noise expectations for the detector controller?

Readout modes...

Submitted by: Jon Holtzman

NIC-FPS Response:

The H-1RG QE spec is >65% over 1-2.45 mu (goal of >80%); the read noise spec is <20 e- rms CDS for "slow" read mode (goal of <10 e- rms CDS); the dark rate spec is 0.1 e-/s/pix (goal of 0.01 e-/s/pix); and the spec for defects is >95% operability (goal of >98%). An array flatness spec is not included but will be characterized upon cool-down by Rockwell, and should be handled within our camera depth of focus.

The H-1RG supports read-out modes of 100-200 kHz (slow mode) and 5 MHz (fast mode). The fast mode has selectable gains (from x1 - 16). In addition, the H1RG can be programmed to read out a selectable "postage stamp" sub-array at a different rate than the rest of the array. (The "G" in H-1RG stands for "Guide mode".) Resets can be done in a sequential CDS (ripple) row-by-row mode, in an instantaneous (global) mode, or pixel-by-pixel. Four columns of reference pixels are located around the perimeter of the array (the "R" in H-1RG).

Status: Closed.

Detection Limits

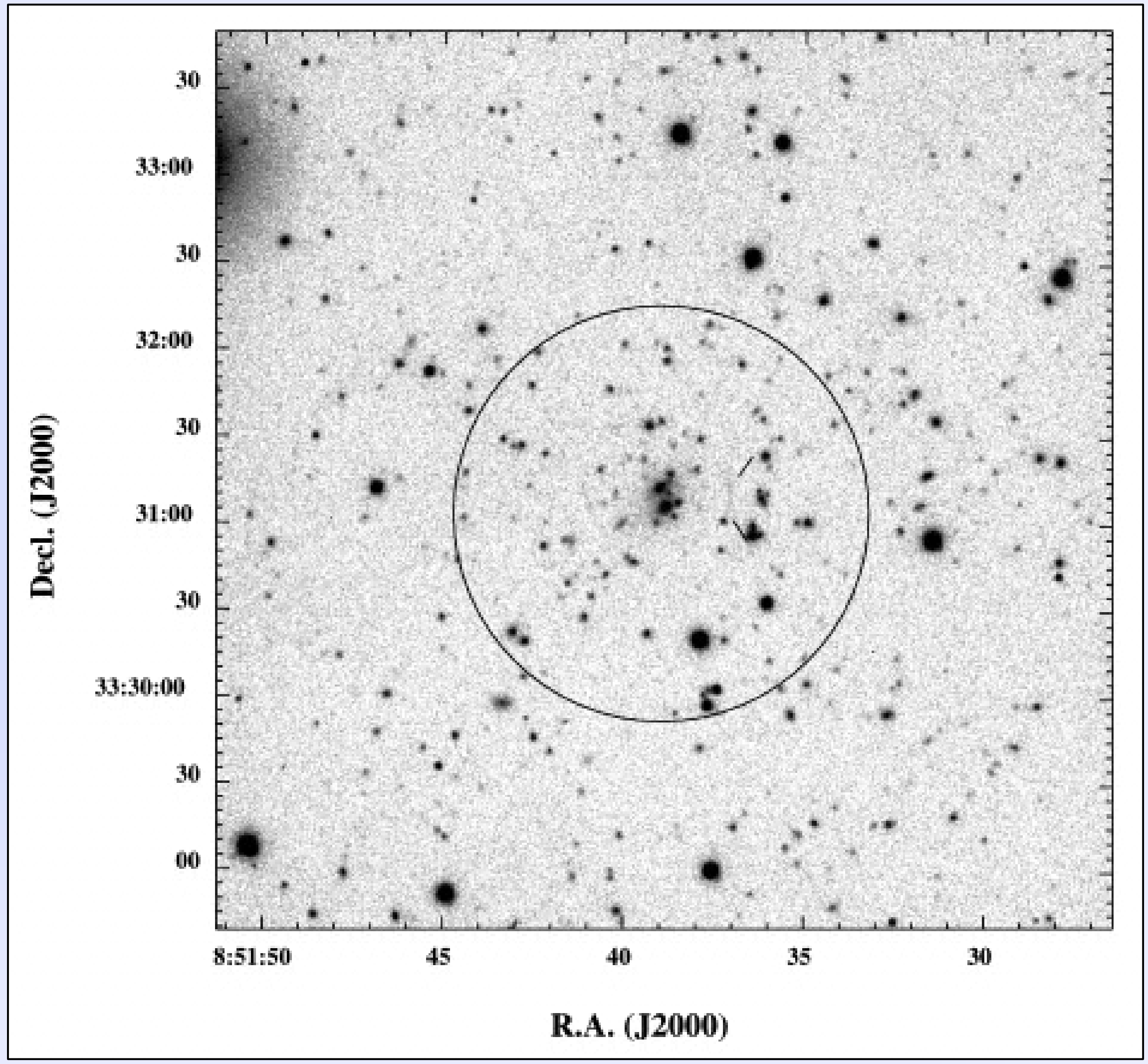
Estimated 5-sigma detection limits over a 4x4 pixel aperture

Band	1 minute	1 hour
z	20.7	22.9
J	20.0	22.2
H	18.7	20.9
K	18.0	20.2

- Estimates are for time on target only, and do not include overhead due to readouts or sky subtraction.
- Estimated sky saturation times for J, H, K bands are 55, 5.5 and 6 seconds, respectively.
- Dark current 0.5 e^-/pixel/s, Readnoise 10 e^-/pixel rms, System Throughput 0.33.
- Sky Brightnesses for z, J, H, and K bands are 19, 17, 15, are 13 mag arcsec^{-2}, respectively.

Galaxy Clusters

- Cluster morphology and evolution
- Spheroidal population evolution
- Cluster core radius of 1 h^{-1} Mpc corresponds to ~4 arcmin at z = 0.5



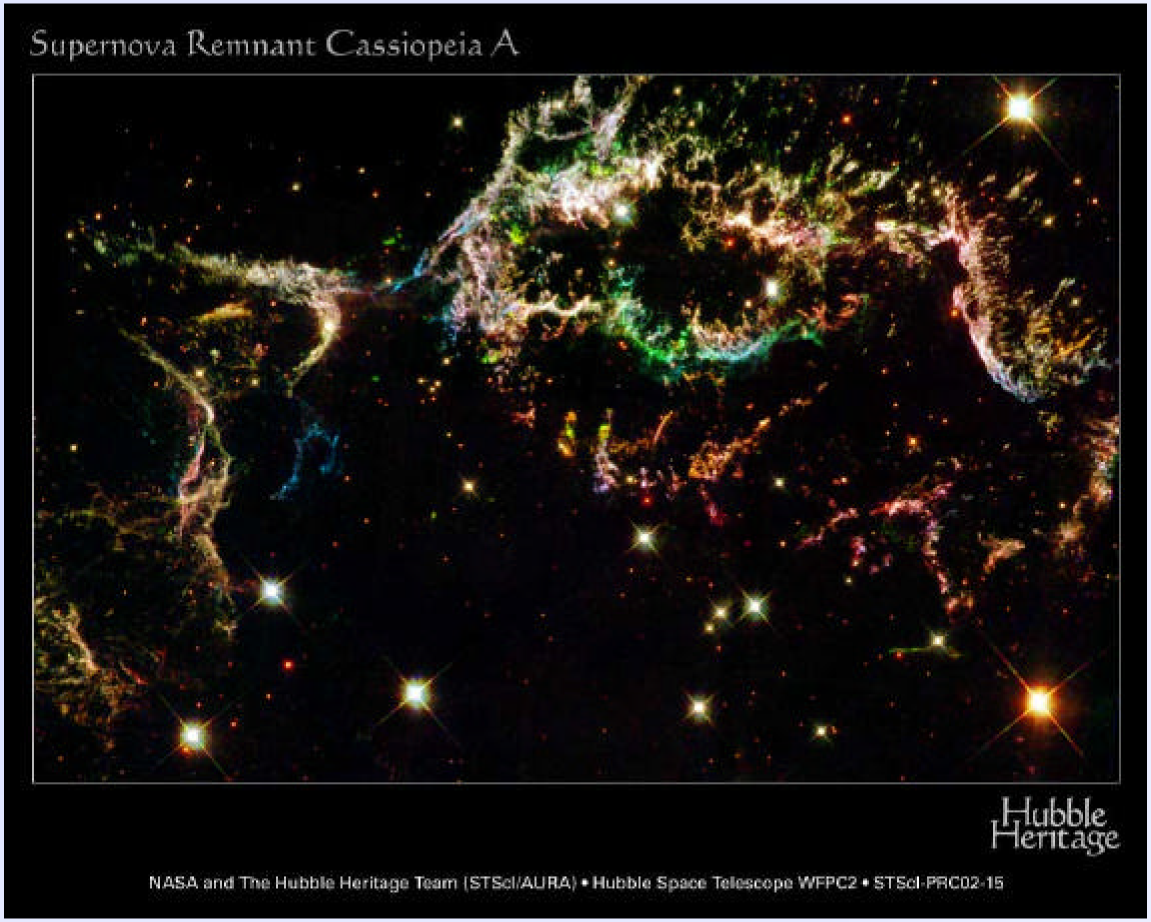
Example:

- X-ray selected galaxy cluster from Lewis et al. (2002)
- KPNO 2.1 m 1800s Gunn r exposure
- T1KA with 0.305"/pix
- Cluster at redshift z ~ 0.45
- Circle is 0.5 h^{-1} Mpc radius centered on BCG
- Note arcuate lensed galaxies

Galactic Nebulae

• H II regions, protostellar jets/outflows,
PNe, LBVs, SNRs, nova shells, etc.
• Morphologies, kinematics; radiative shocks, photoionized gas, dust
• 6 pc subtends ~4 arcmin at D = 5 kpc

Example:
• Cas A supernova remnant
• SN ~1680, D ~ 3.4 kpc
• Main shell diameter ~4 arcmin
• High-extinction sight-line
• Probe Fe distribution and kinematics plus other tracers of nucleosynthesis
• Forward/reverse shock physics



Fesen et al. (2001,2002)

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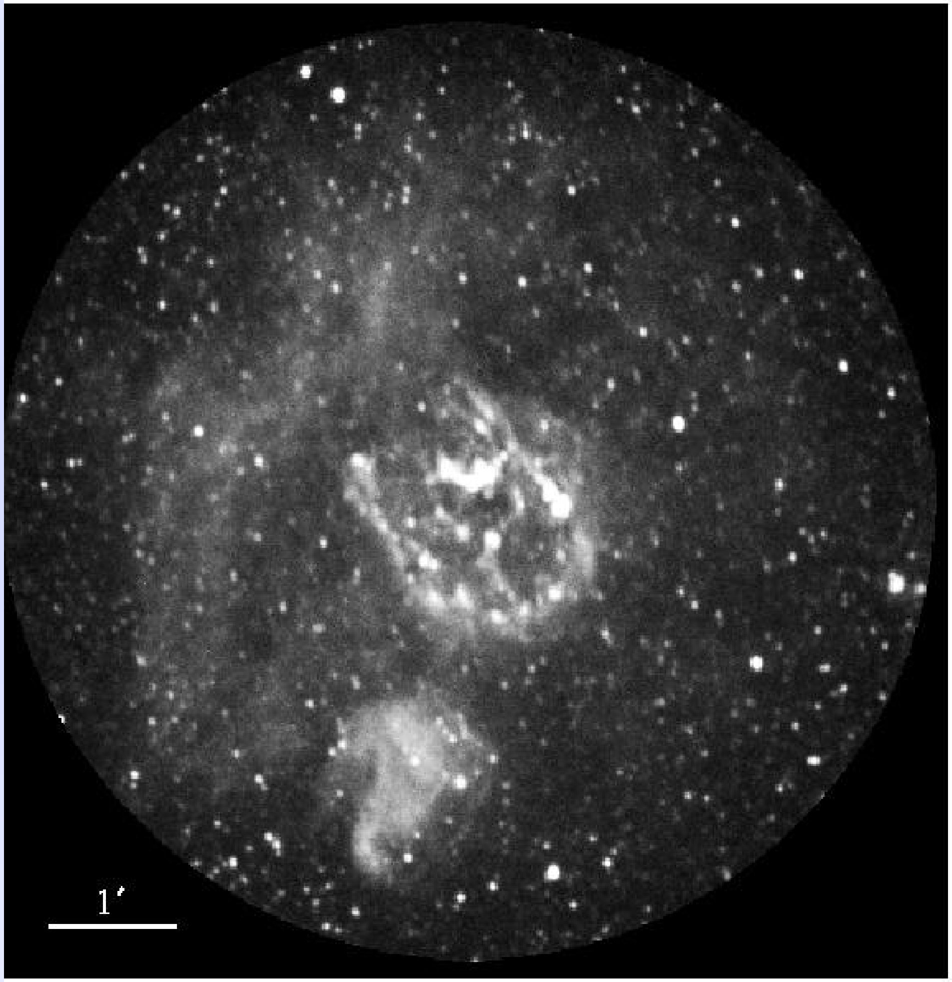
Uniqueness of cryogenic Fabry-Perot capability

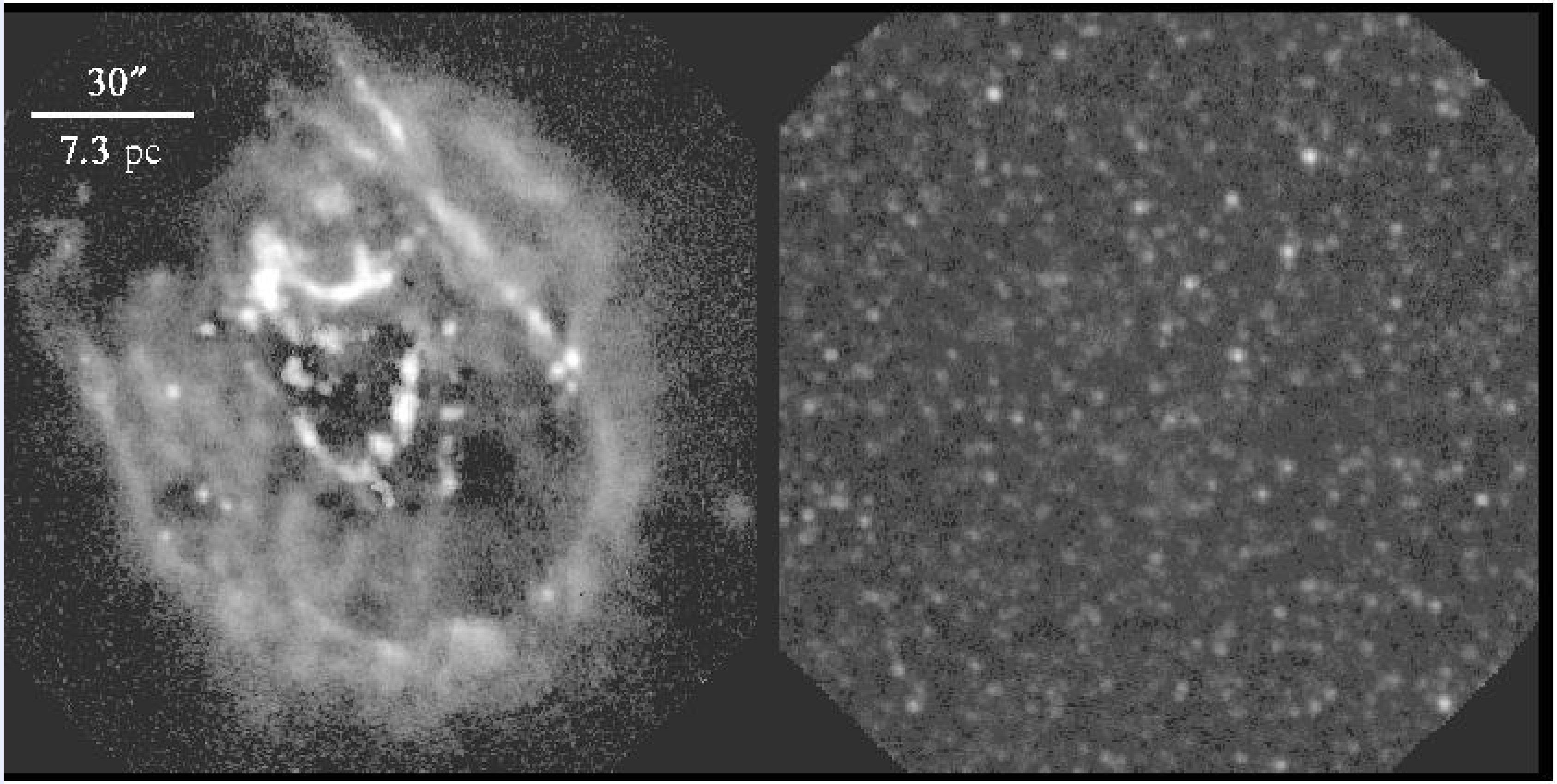
- Value of full-field kinematics and fluxes
- Can be used to probe line emission or absorption
- Mature data reduction software and ample computing power/disk storage available

<u>Example:</u>
Optical F-P observations of young SNR N132D in the LMC (Morse et al. 1995)

N132D Hα



N132D



[O III] λ5007 — Continuum

• Very narrow bandpass allows for high-S/N images with excellent continuum subtraction.

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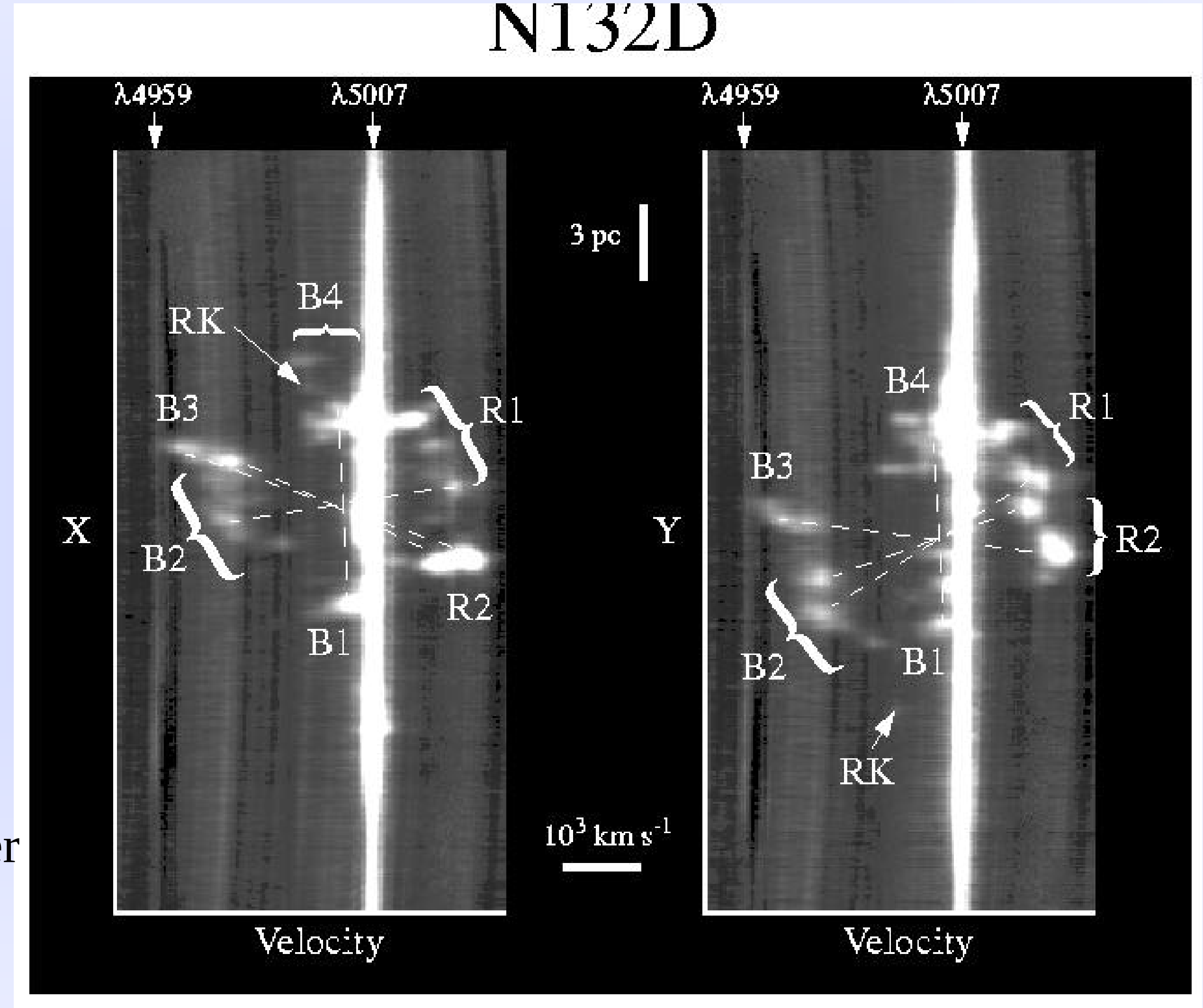
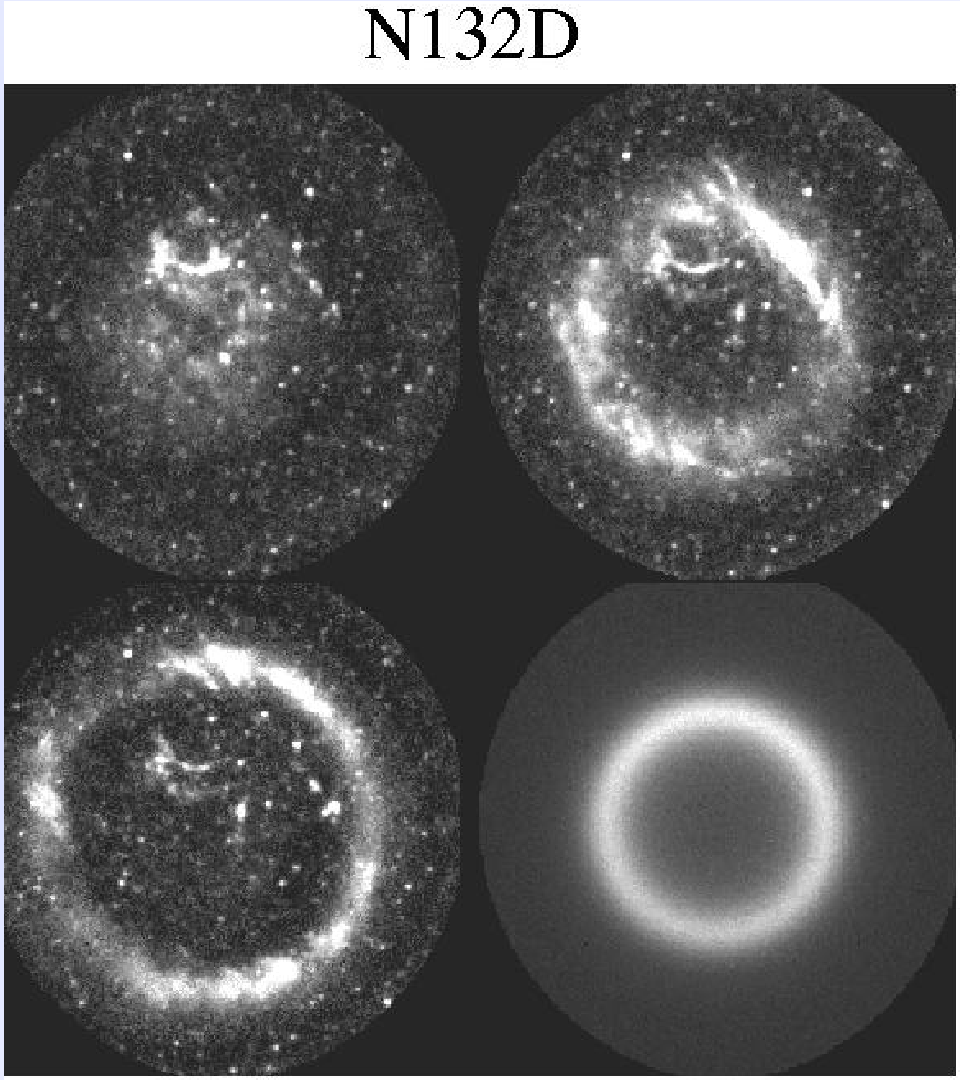
- These views show the data cube from the top and the side.
- For simple inertial expansion, velocity can be converted to third spatial dimension for full 3-D structure.
- Note: This data cube has been Phase Corrected for velocity curvature in raw images - ie., the ambient line emission at λ5007 has been straightened and the variable sky level from each separate image is now curved. Data were obtained over multiple nights as qtr Moon set.





• Individual raw images showing stationary nature of diffuse emission.
• Emission in bright shocked filaments has broad velocity dispersion and appears at multiple etalon settings.
• Unresolved HeNeAr line (He I λ5015) is shown for comparison at lower-right.

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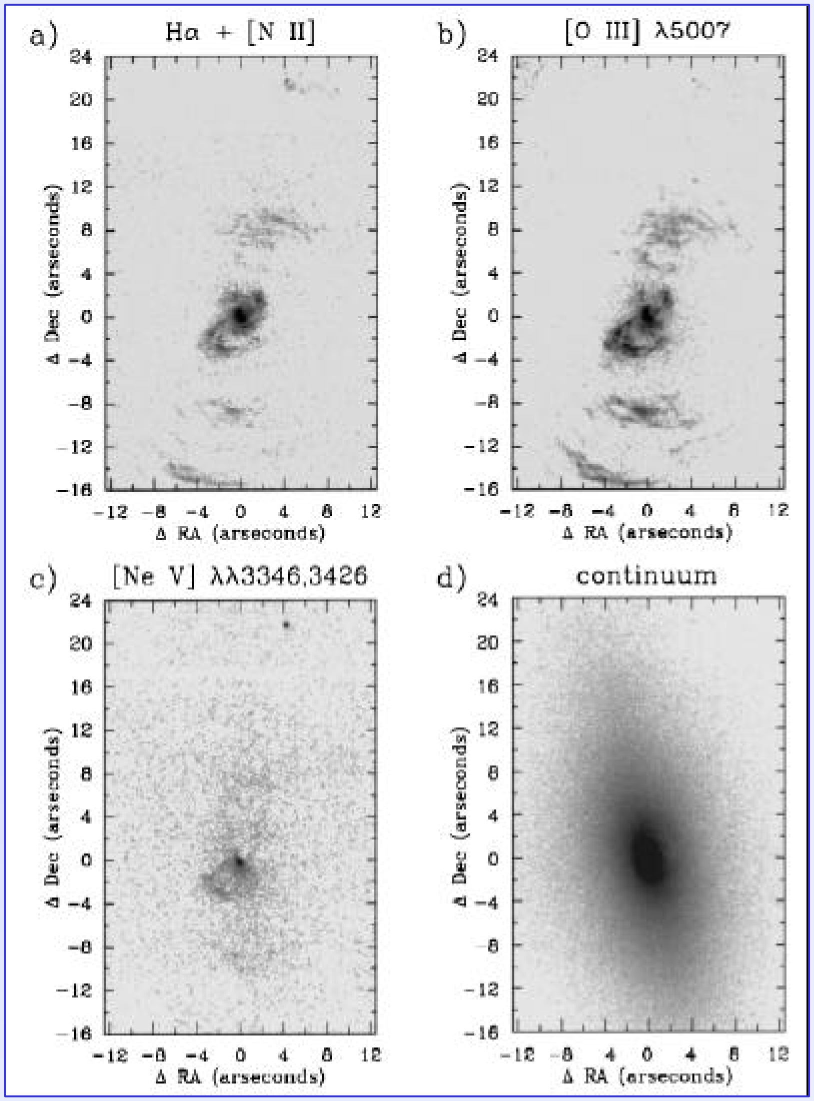
<u>Example:</u>

• NGC 5252 from Morse et al. (1998).

• Seyfert 2 nucleus with ionization cones embedded in S0 galaxy.

• HST images show fine detail in gaseous filaments.

• Ionization cones extended ± 1 arcmin (± 25 kpc) from nucleus.



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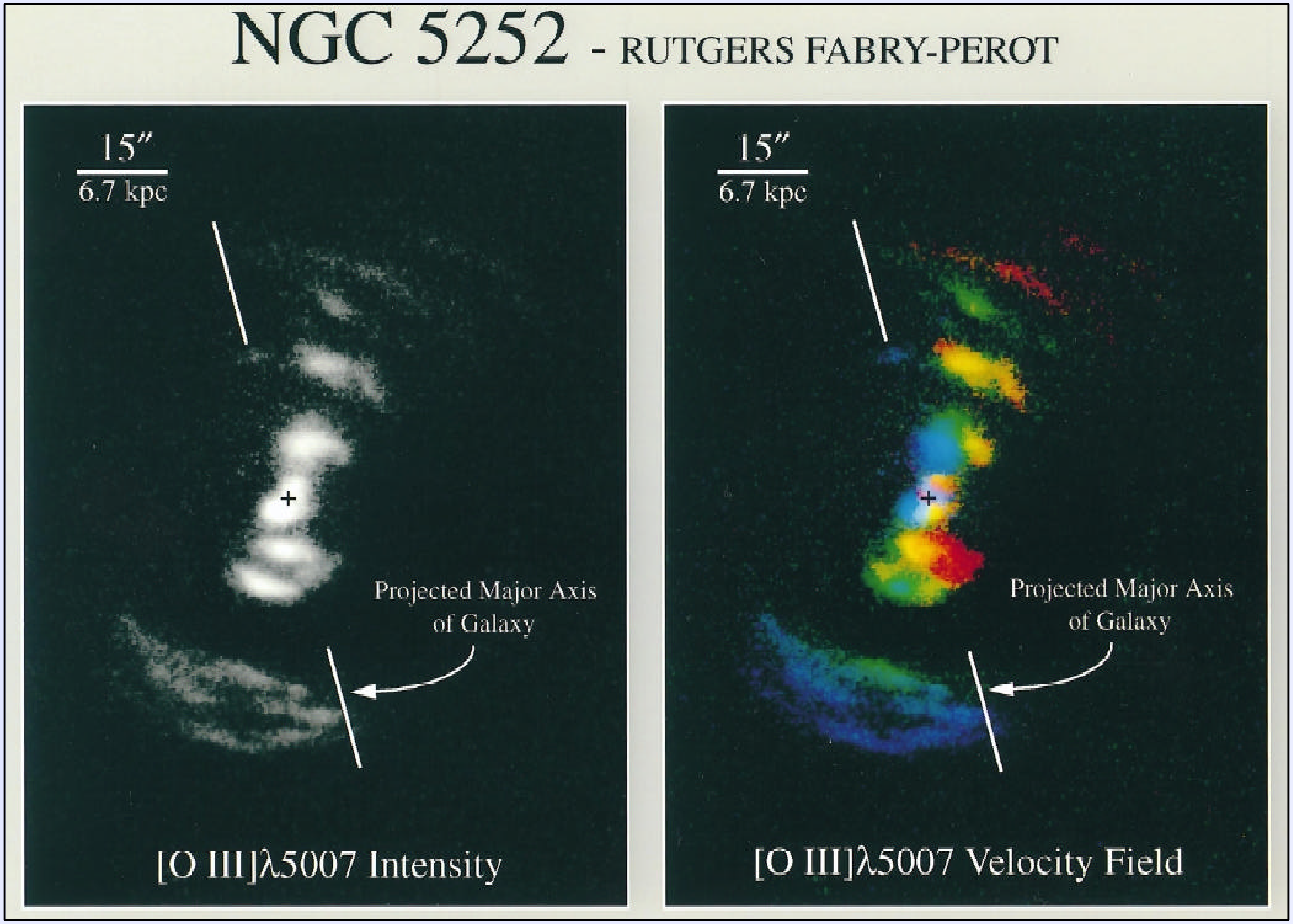

- Full-field kinematics reveal two separate gaseous disks rotating at large projected angles from each other (and from the stellar disk).
- System appears to be the result of a merger with a mostly gaseous companion.

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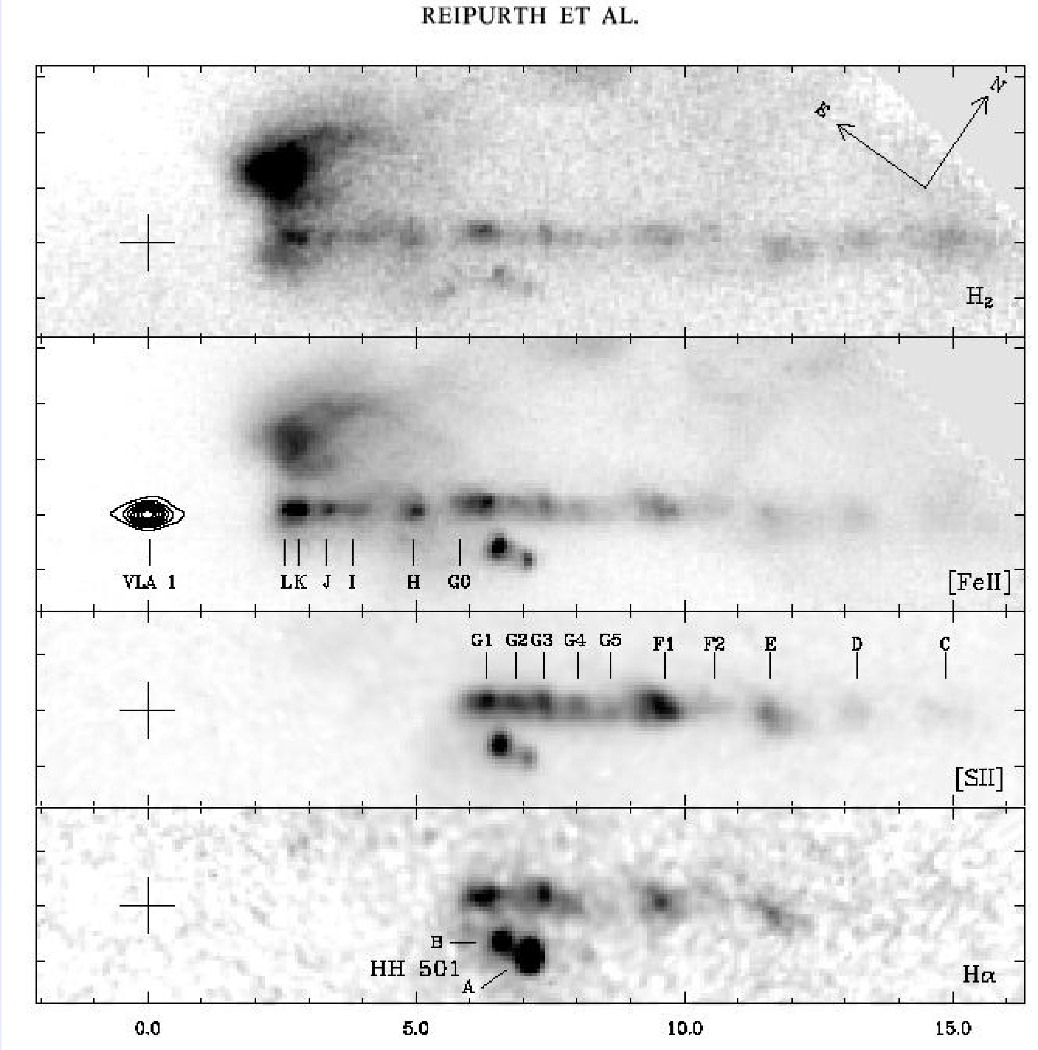
Example: The value of the near-IR

- HH 1 protostellar jet can be traced much closer to the source in [Fe II]λ1.64 microns than in optical lines such as Hα or [S II].
- H_2 traces interactions with ambient molecular cloud material (or may even be present in high-velocity jet).



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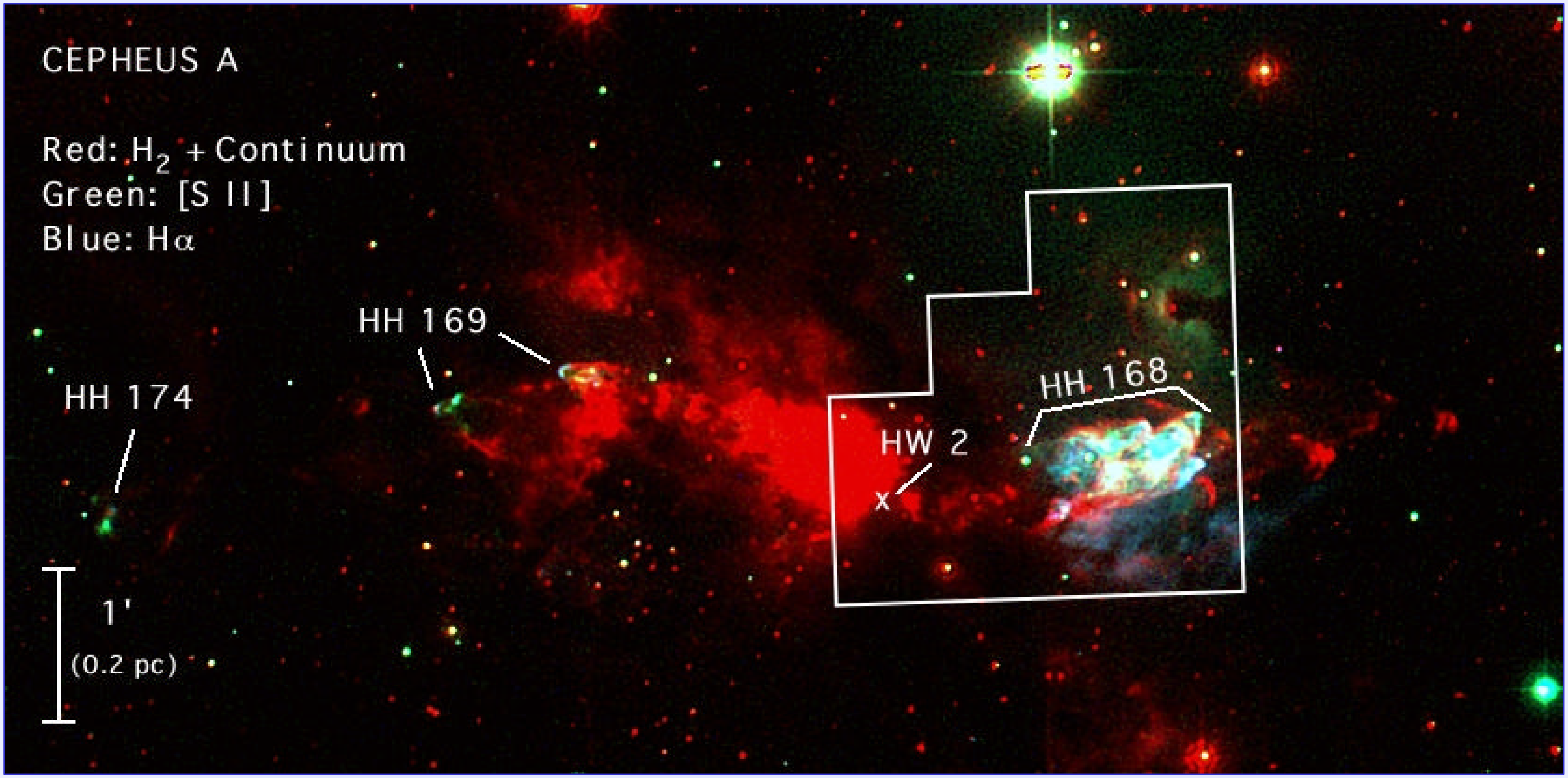

<u>Example:</u> Cepheus A star forming region with large bipolar outflow.

Hartigan et al. 2001

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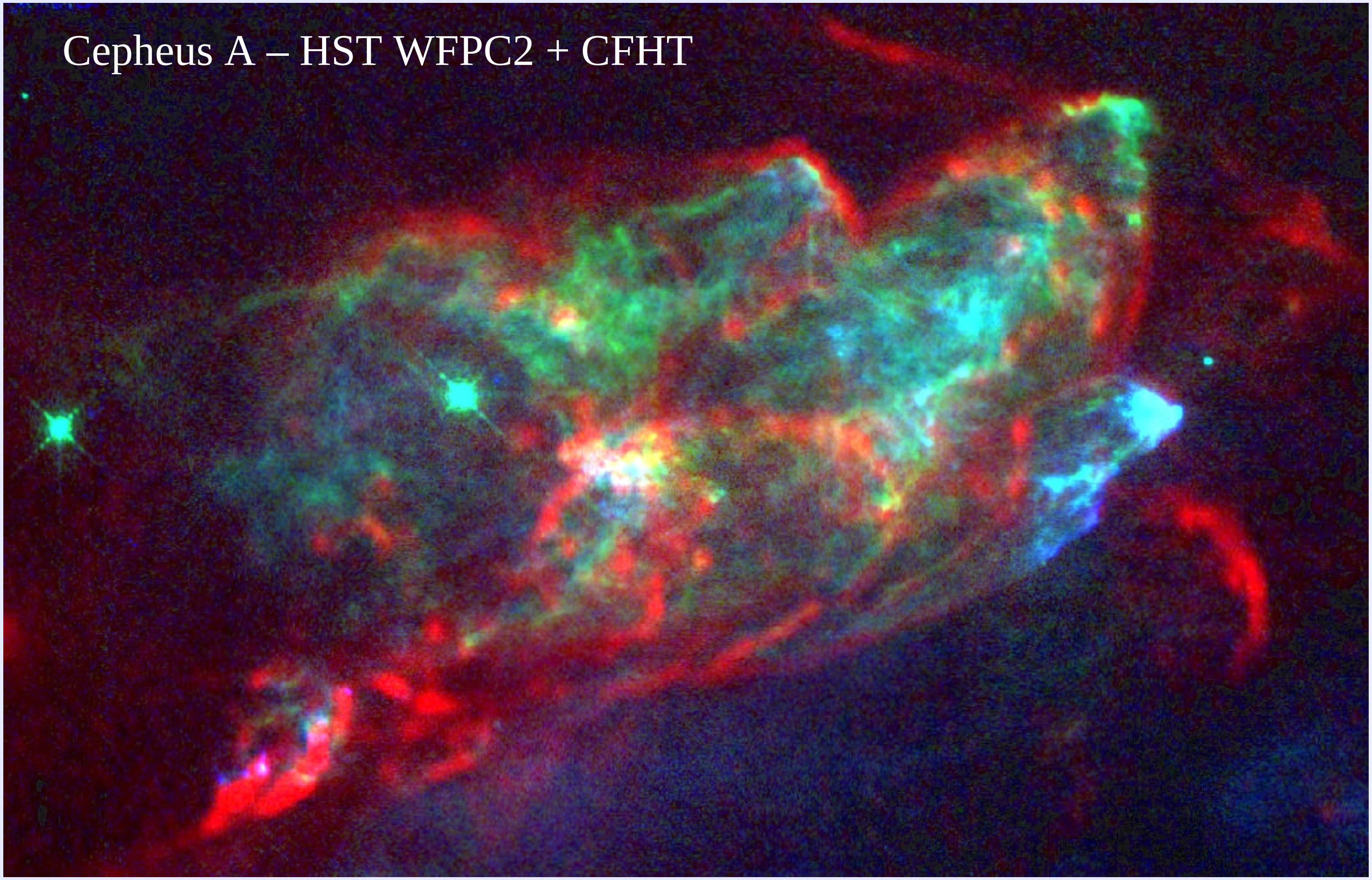
Hα
[S II]
H_2



NIC-FPS Critical Design Review

• CFHT cryo-echelle long-slit spectrograms of Ceph A knots and filaments in H_2 emission.

• R ~ 10,000 spectral resolution needed to decipher H_2 flows.

• IR F-P imaging will reveal full field kinematics more efficiently than stepping a long slit, and with seeing-limited angular resolution.