

***Tunable Filters:
Charge Shuffling Modes***

Charge-Shuffling Fundamentals

- ***Technology***
 - *CCD technological advances*
 - *Large chips*
 - *Microseconds clock*
- ***Charge Shuffling***
 - *Ideal for subtracting sky foreground*
 - *Huge multiplex gains (x10) in MOS*
 - *Work in the red part of the spectrum*
 - *Images are subtracted through identical optical paths*
 - *Flat field structure is identical*
 - *The CCD is read only once.*

CCD advances

- ***Low RON (1 ev) for the latest generations of CCDs***
- ***Negligible dark current***
- ***High purity***
- ***Very high CTE (99.9999%)***

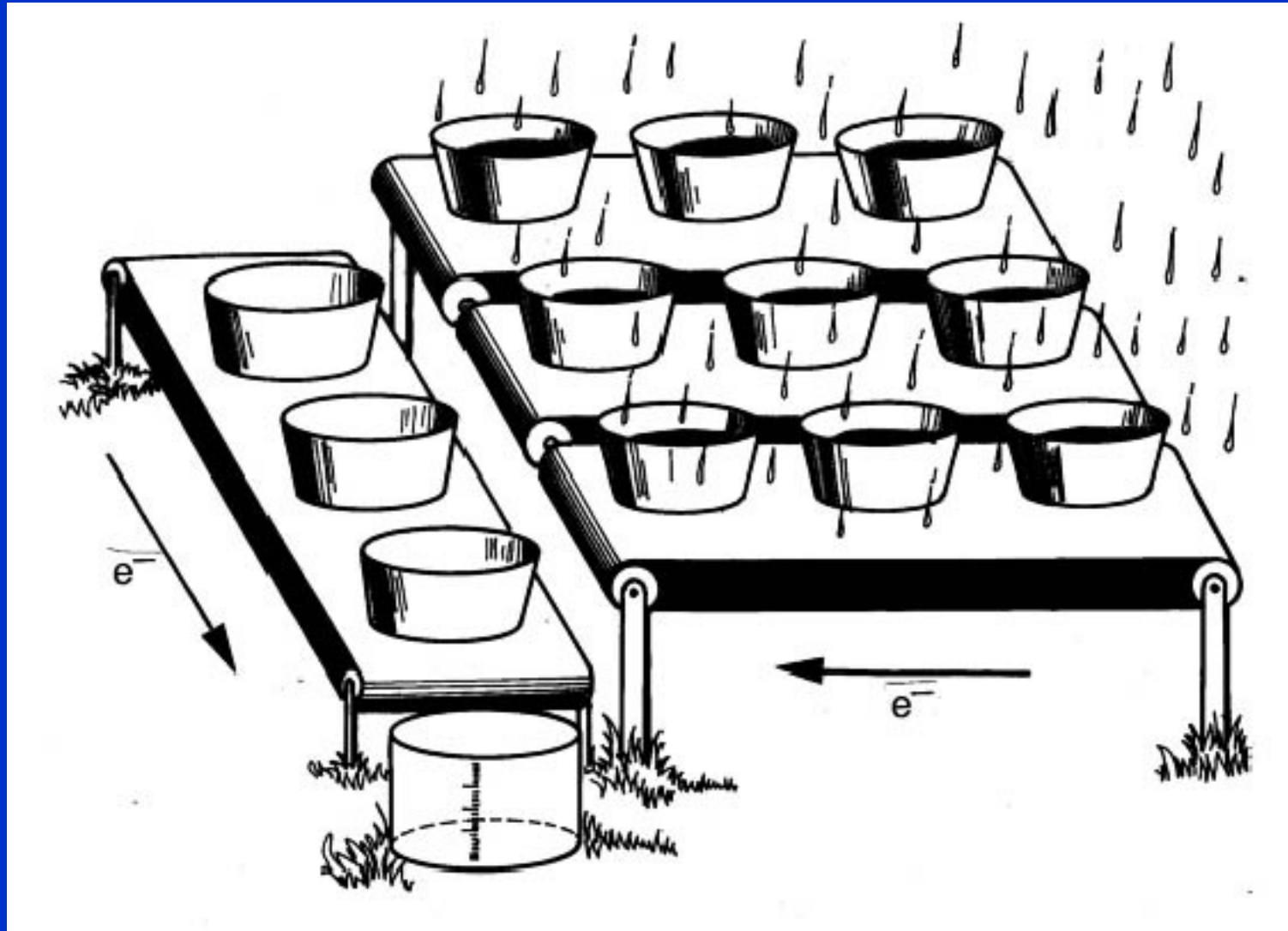
Five basic steps of CCD photon detection

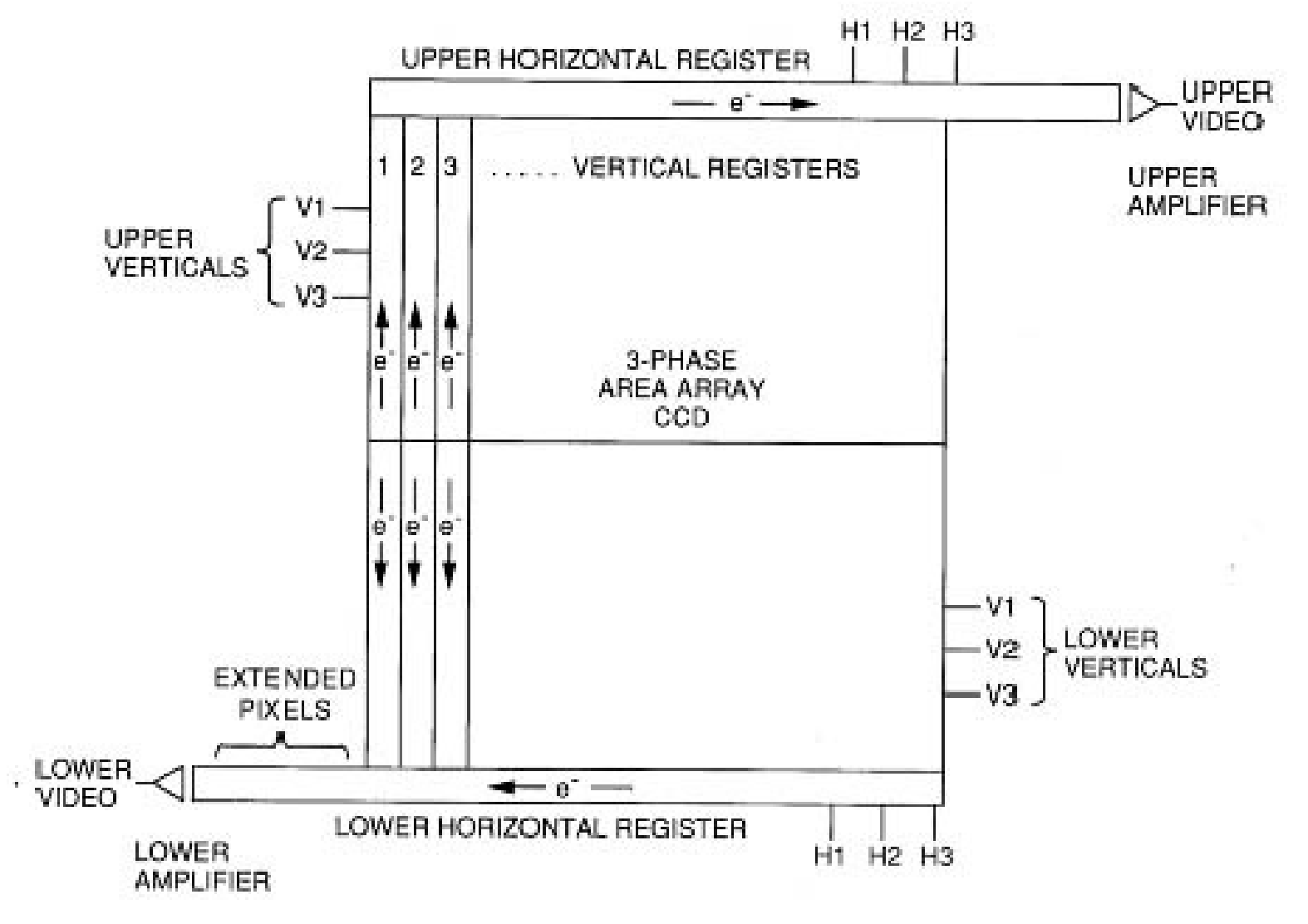
- ***Get light into the detector***
- ***Charge generation***
- ***Charge collection***
- ***Charge transfer***
- ***Charge amplification***

Step 4: Charge Transfer

- ***CCDs must move charge across the focal plane array of the readout amplifier***

The rain bucket analogy





CCD charge transfer: the good, the bad and the ugly

- ***“Bad & ugly” aspects of charge transfer***
 - ***Takes time***
 - ***Can blur image if no shutter used***
 - ***Can lose / blur charge during move***
 - ***Can bleed charge from saturated pixel up/down column***
 - ***Can have a blocked column***
 - ***Can have a hot pixel that releases charge into all passing pixels***
- ***“Good” aspects of charge transfer***
 - ***Can bin charge “on-chip” – noiseless process***
 - ***Can charge shift for tip/tilt correction or to eliminate systematic errors (“va-et-vient”, “nod-and-shuffle”)***
 - ***Can build special purpose designs that integrate different areas depending on application (curvature wavefront sensing, Shack-Hartmann laser guide star wavefront sensing)***

CCD Charge Shuffling

- ***Clocking of charge on a CCD is an old idea.***
- ***But with large-scale motion of charge:***
 - ***Shift in the order of microseconds***
 - ***Not read-out noise penalty***
 - ***But beware of charge trapping sites!***

Charge-Shuffling Modes

- ***TF operation modes***
- ***Charge-Shuffling between on and off-band***
- ***Two discrete frequencies***
- ***Line-continuum or line-line images***
- ***Process called frequency-switching***

Charge-Shuffling

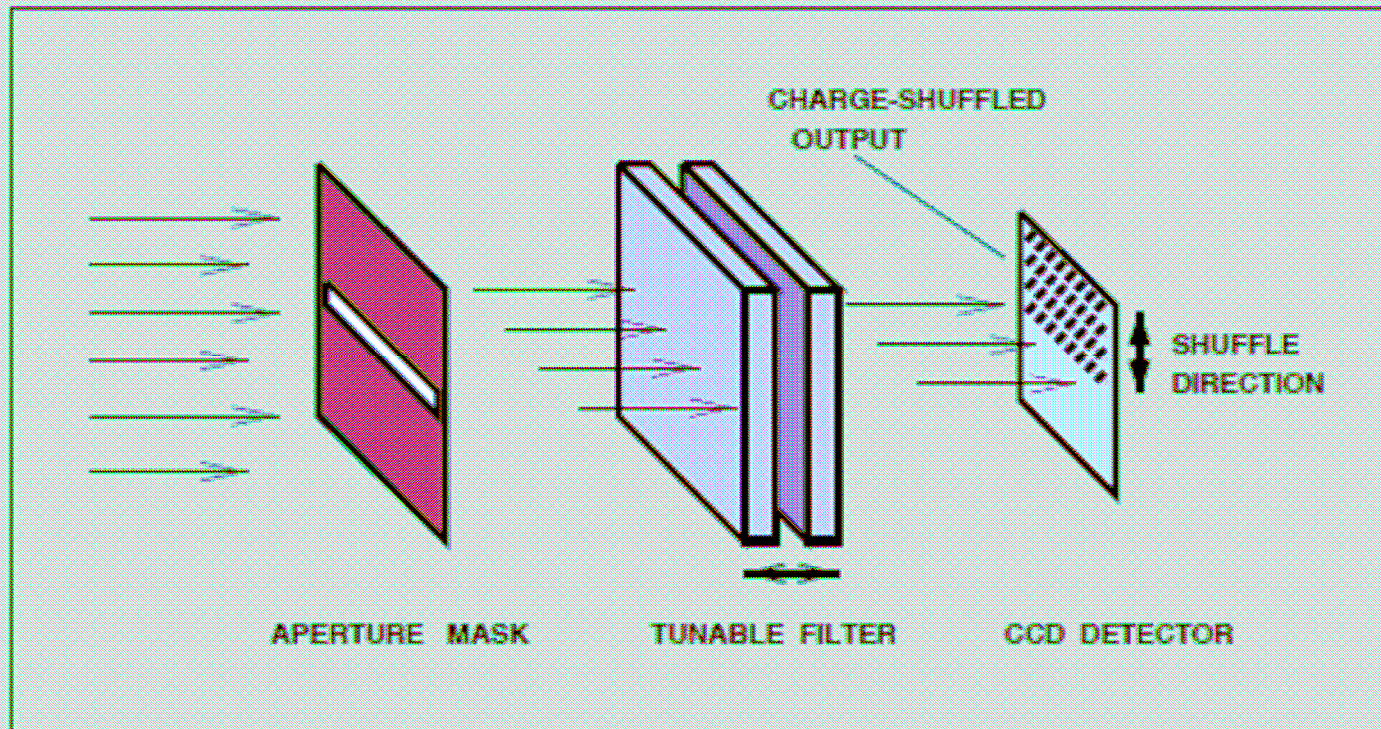
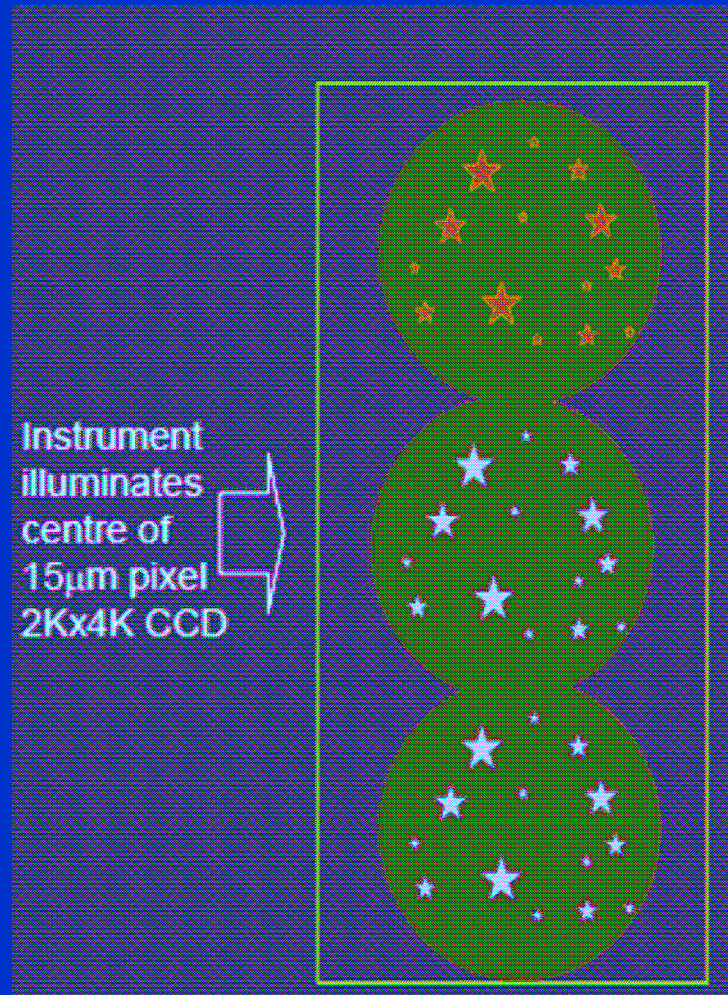


Figure 1—Simplified view of how the CCD chip is illuminated and shuffled. The mask aperture size controls the amount of the CCD exposed and therefore the number of different images fitted onto an individual frame. Charge can be shuffled both up and down the chip.

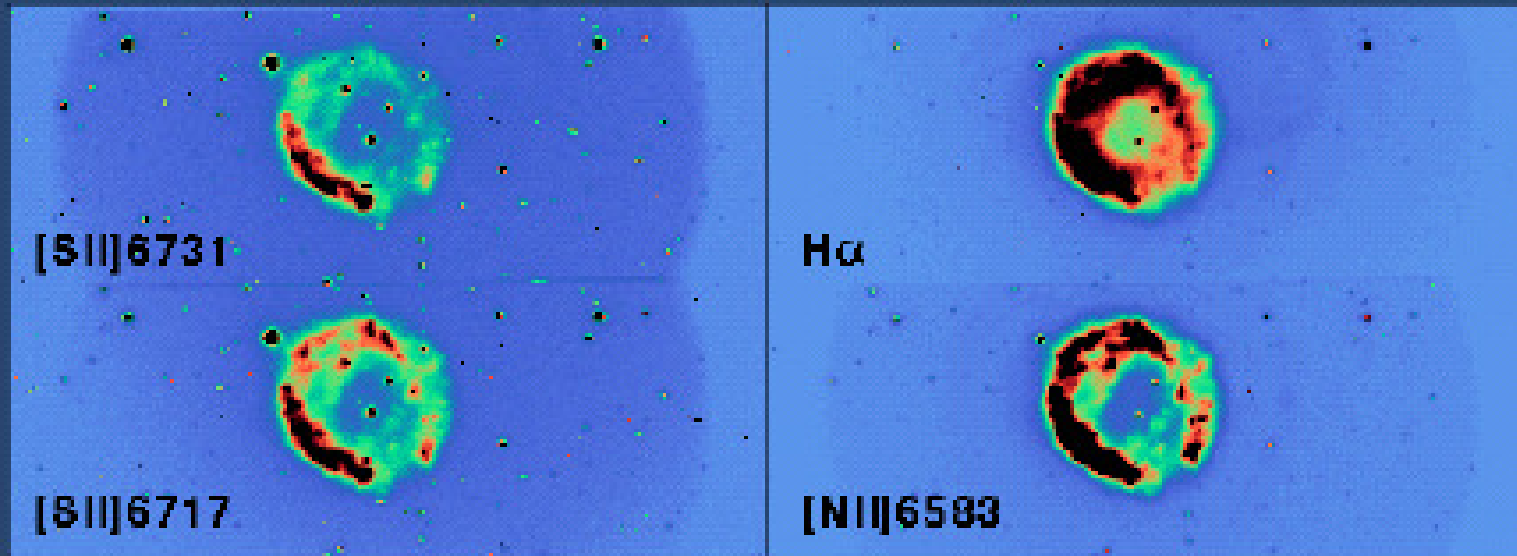
Charge-Shuffling



Charge-Shuffling Imaging Mode

- ***Stores two images of a field***
- ***“Illuminated” to “Storage” regions***
- ***No RON in the procedure***
- ***Can be synchronized to telescope motion.***
- ***Two images means to use 1/3 of the detector area for observing area***

TTF charge shuffle imaging



Adaptative frequency shuffling with charge shuffling

- ***The problem: spectral lines fall between steeply rising continua or between OH bandheads***
- ***The solution:***
 - ***Shuffle between on-off bands***
 - ***Off band is alternated between two or more frequency***
- ***The result: averaging the underlying spectral continuum, changes in the atmosphere, spectral response of the CCD.***

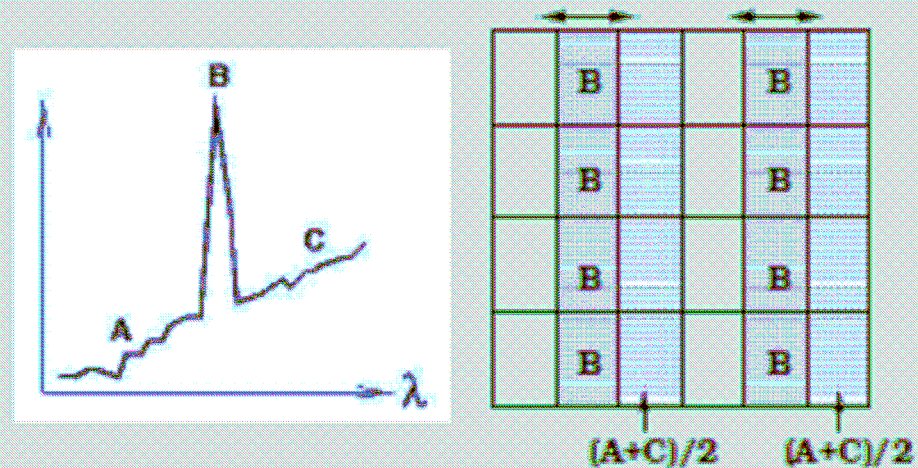


Fig. 7. Charge shuffling with the tunable filter and IMACS CCD 2 x 4 array. The charge on the chip are shuffled left and right at the same rate that the etalon plates are scanned between two discrete gap positions. The chip is read only once. The central third of each CCD is used for the on-band image. The off-band image is on the right of each on-band image while the left third of each CCD is used for charge shuffling purposes only. In the case shown here the off-band image "straddles" the on-band band image in wavelength. This adaptive frequency switching improves continuum subtraction and can also be used to avoid OH sky lines.

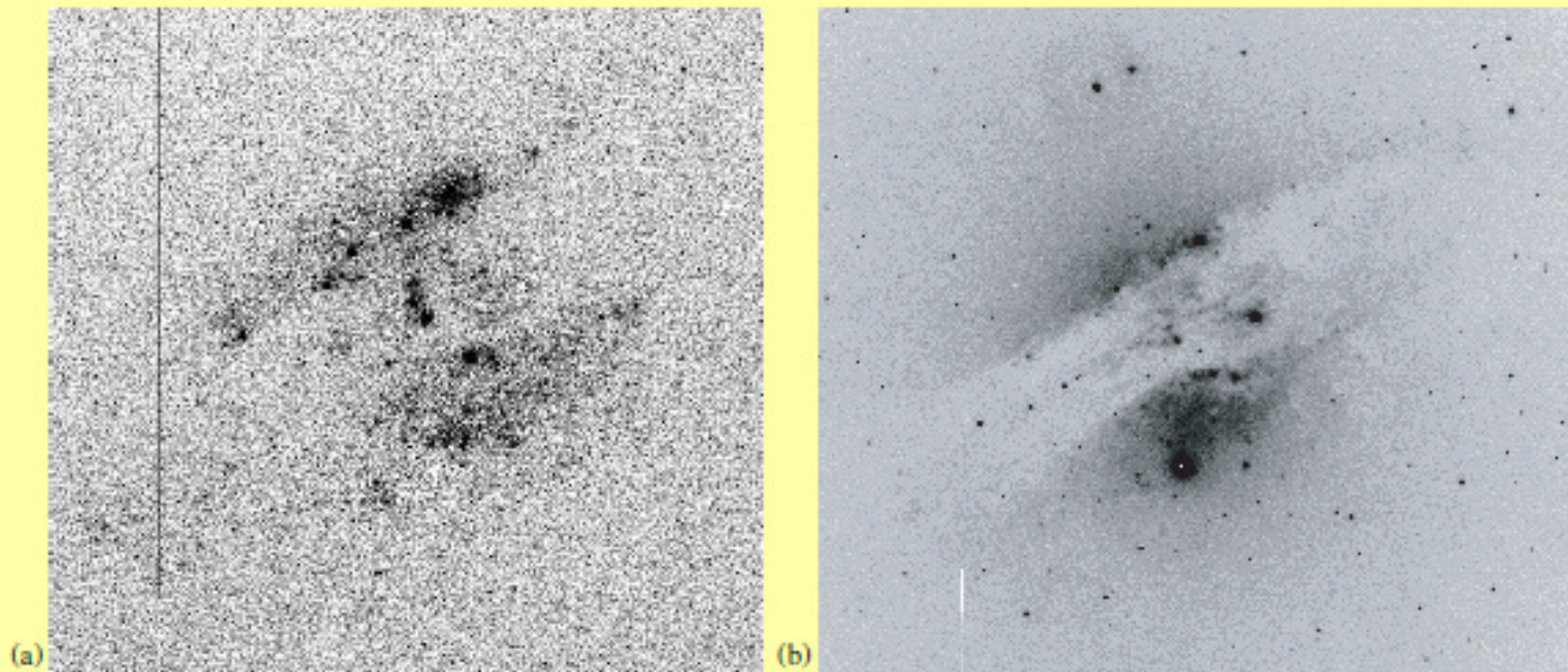


Figure 6 (a) Short exposure [OIII] 500.7 nm emission line halo seen above and below the dust lane in Cen A, obtained with the 'straddle shuffle' mode using the TTF (see text). These are raw data: the bad column arises from trapped charge during the charge shuffling. (b) Line + continuum image of Cen A in order to emphasise the dust lane.

Special Case: Time-Series exposure

- ***Tunable Filter can be kept at a given frequency and charge-shuffling performed.***
- ***Time-Series exposure***
- ***Time-Series imaging does not sacrifice detector area***

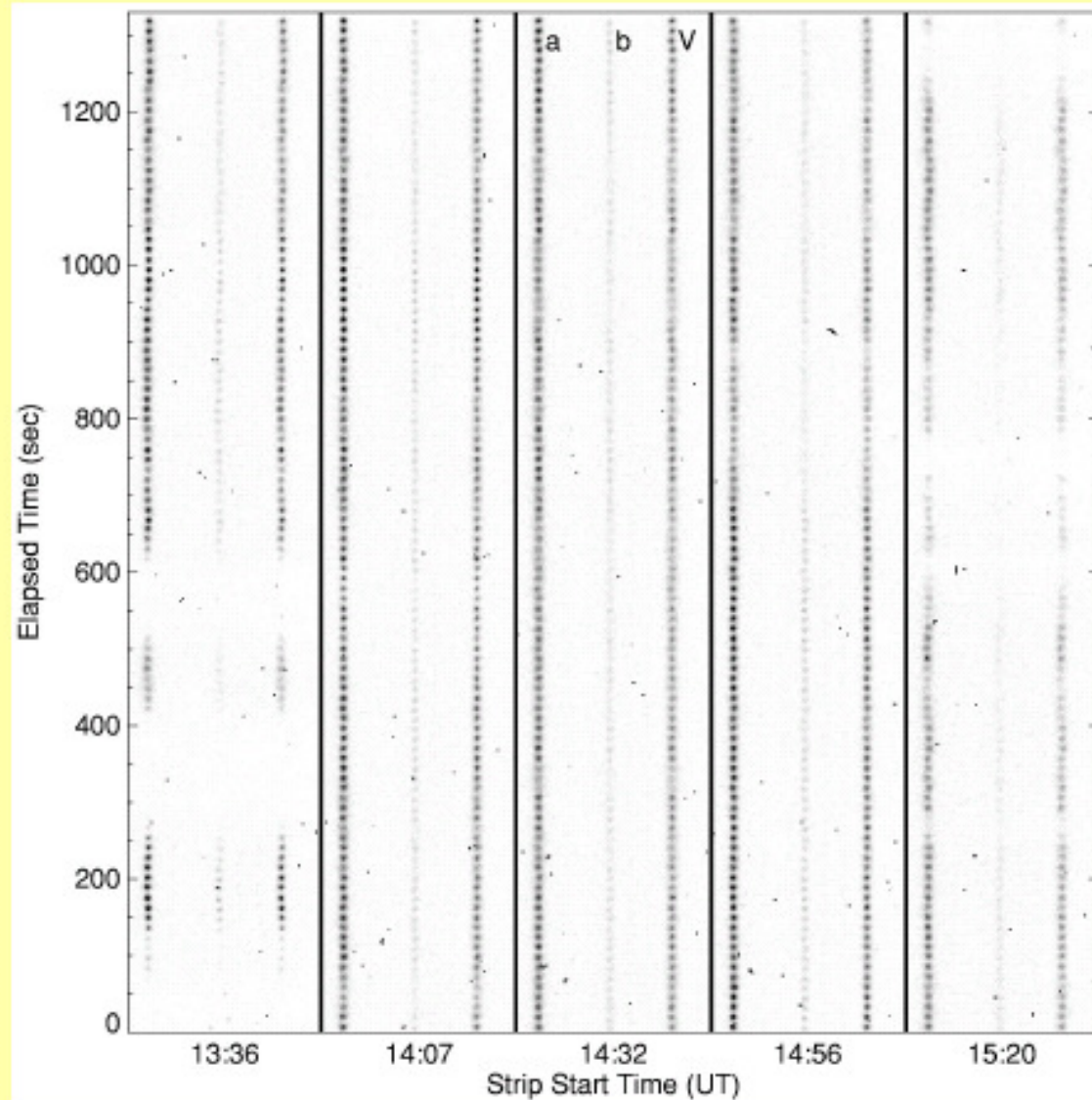
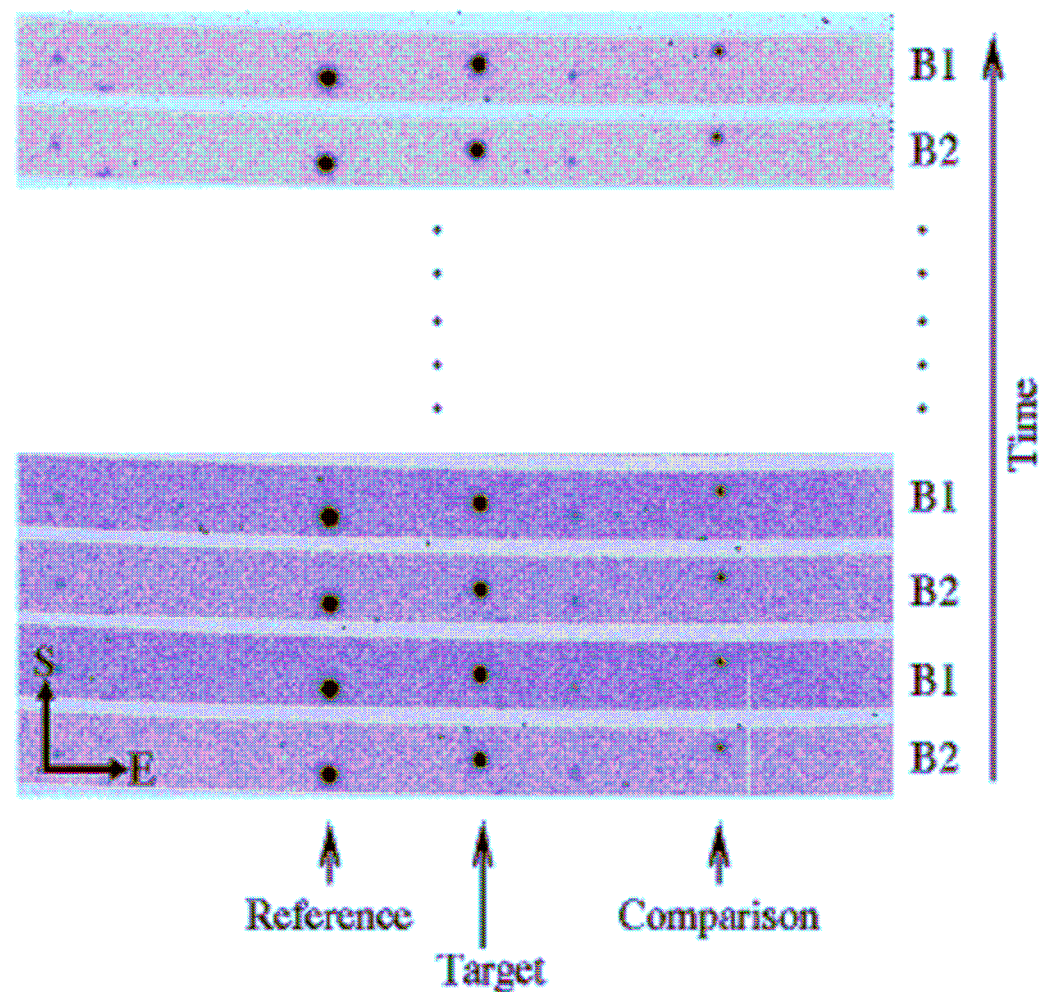


FIG. 4.—Five strips of $102.2' \times 6'$ 12 s exposures of the X-ray star V2116 Oph (V) and two nearby reference stars (a and b) made with the TTF set to a 7 \AA bandpass centered on $O \text{ I } \lambda 8446$. Time increases vertically in each strip (note the greater frequency of charged particle hits at the bottom of each image, where charge has been on the CCD the longest). The obvious variations in intensity are due to variable cloud obscuration. During the first and last strip, cloud obscuration was sufficient that autoguiding had to be switched off, as can be seen from the spatial oscillation in the images.



Special Case: Nod-and-Shuffle

- ***Used for MOS, also possible with TF***
- ***Excellent sky subtraction***
- ***Many modes possible (long slit spectroscopy, MOS, microslits, TFs)***
- ***Increase multiplex capabilities***

Summary

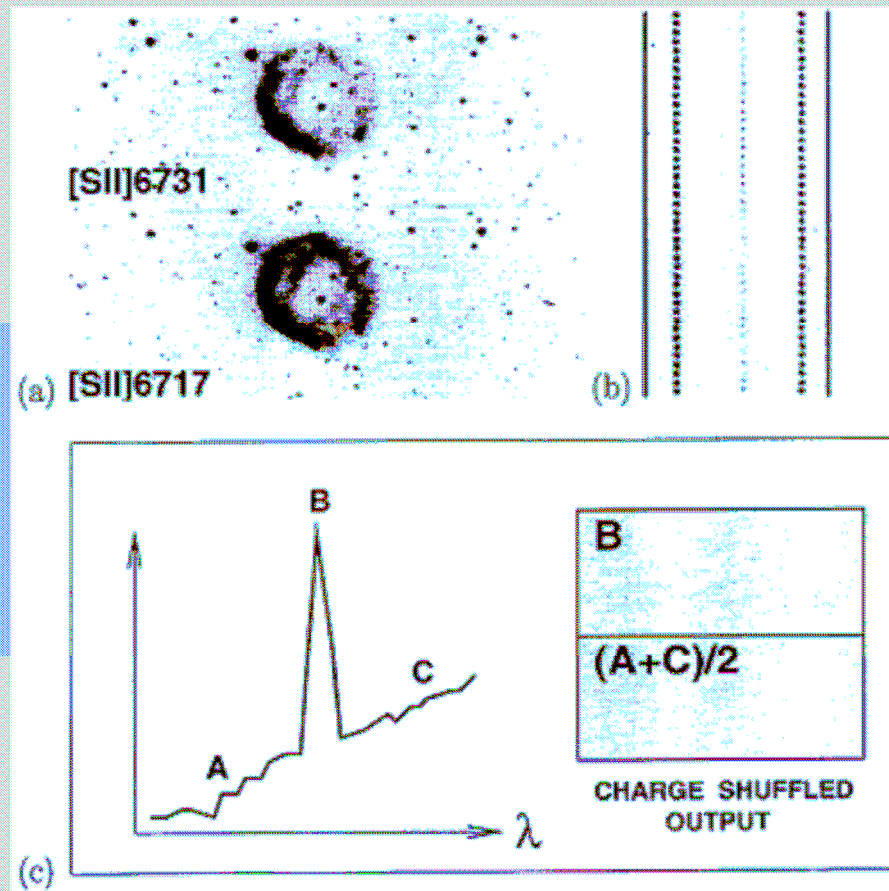


Figure 2—(a) Charge-shuffled image of the planetary nebula NGC 2438 in [SII]λ6731 (*top*) and [SII]λ6717 (*bottom*). The TTF was frequency-switched 18 times during the 12 min exposure and the charge shuffled back and forth in concert. A 10 Å bandpass was used. (b) Charge-shuffle time-series imaging of V2116 Oph, an X-ray pulsar in orbit around a red giant. V2116 Oph is to the right, reference stars are at the centre and left. TTF was tuned to a 7 Å bandpass centred on the [OIII]λ446 line, which is suspected to vary with the pulsar period of 120 s. Each exposure was 12 s. (c) Charge shuffling either side of an emission-line to average out the effect of a steeply sloping continuum. Equal time is spent collecting continuum from both sides of the emission-line (*left*). The line only contributes to the top portion of the shuffle frame, while both sides of the continuum contribute to the bottom (*right*).

Summary

Tunable filters plus charge shuffling techniques allow:

- perfect sky and continuum: subtraction*
- obtaining 2D line ratios in non-photometric conditions*
- fast photometry in user selected bands*

