Zpectrometer project status, July 2008

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1 Introduction

These notes summarize the Zpectrometer project's current status, highlighting results and experience gleaned during observing from Fall 2007 through Spring 2008. The notes may also be of use in assessing GBT/08C Zpectrometer proposals.

2 Notes on the collaborative proposal process

A few comments on the nature of the collaborative proposals may be useful in understanding the thirteen proposals submitted with Zpectrometer instrument team participation for the 08C call. A collaborative period was established to satisfy the needs of NRAO and NSF, part of an arrangement that enables us to support community access to a University instrument. For 08C we provided identical technical information[1] to all potential proposers and held to the same guidelines for our own proposals. The guidelines included observing and calibration techniques needed to get the best astronomical performance.

We did not provide input to or comments on the science cases for any proposals other than the two for which our group members are Principal Investigators. We kept all proposal material confidential other than responding to questions about potential conflicts with our own proposals. We have put off discussion of the details of any collaborations until the TAC results are released.

Because of the collaboration requirement all of the proposals for cycle 08C should follow the same technical guidelines. We provide summaries of key points concerning sensitivity estimates (§4.1) and observing technique (§4.2) below.

3 Instrument status summary

- Zpectrometer observing is well developed, with high time efficiency and well-calibrated data products from a reduction pipeline.
- Our observations through March 2008 show clear detections of two high-redshift galaxies and some significant nondetections. Figures 1 to 4 contain example spectra.
- Zpectrometer spectra have naturally flat baselines. No baseline fitting is contemplated. As shown in in Fig. 5 and §4.2, small but significant optical offsets from subreflector switching make a double-switching technique necessary to reach the lowest noise levels. Double switching carries a theoretical cost of up to two in observing time, but in practice nonideal spectral structure in simple subreflector-switched spectra overwhelms any theoretical advantage.

[1]http://www.astro.umd.edu/∼harris/kaband/zp_info_0805.pdf, updated at http://www.astro.umd.edu/∼harris/kaband/zp_info_0807.pdf

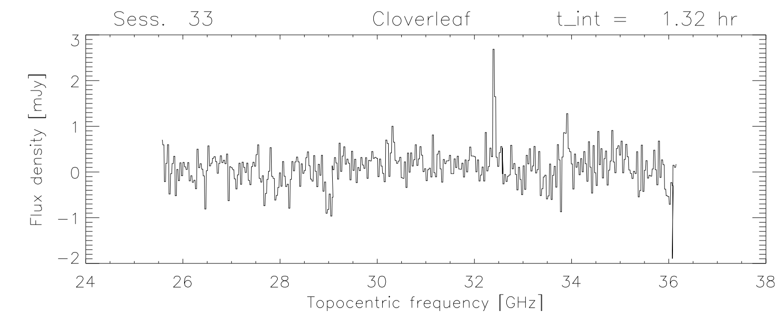

Figure 1: Detection of the Cloverleaf galaxy at z = 2.56, 1.3 hr. total integration on the sky (Vanden Bout et al. project 5A29).

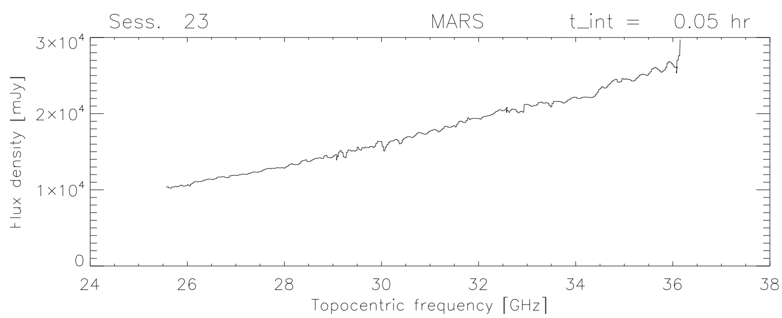

Figure 2: Spectrum of Mars divided by 3C48, obtained for calibration.

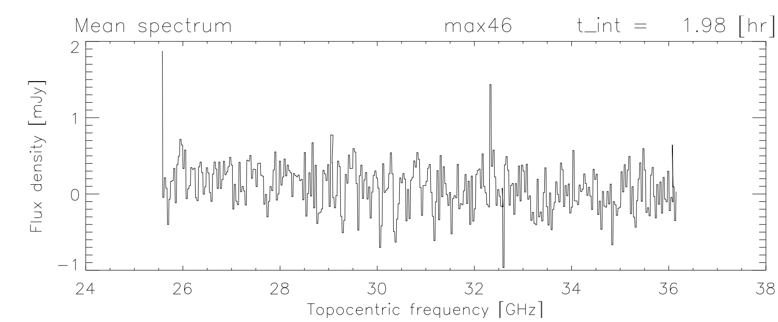

Figure 3: Galaxy with line velocity and width that match a previous CO $J = 3-2$ detection.

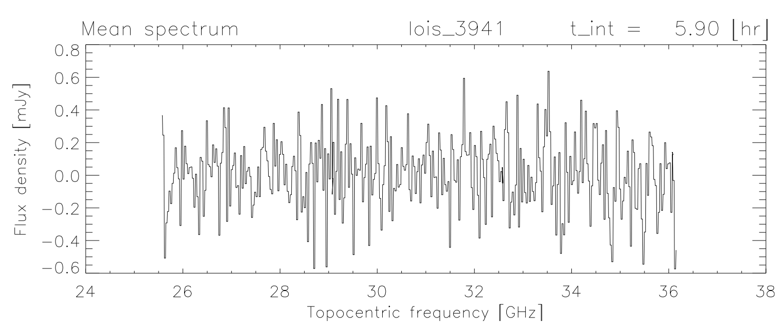

Figure 4: A deep nondetection from sessions 39 and 41 shows baseline quality.

- The system reliably achieves noise levels of 100–200 μJy rms, with the noise still decreasing properly with time.
- Spectral noise integrates down as theoretically expected, $\sigma \propto t^{-1/2}$, for total integration times of at least 8 hours (Fig. 6). This is expected from instrumental Allan variance measurements and switching times.
- Although the noise integrates down well, the absolute noise level is higher than expected by a factor of two to three (Fig. 6). The exact reason for this is unknown, but examination of cross-correlation function structure points to a source in the receiver: there is systematic excess noise in the lowest-lag 20% of the lags in all four correlators. There is a known bad cable in the receiver, and we hope that finding and replacing it will bring the noise down. Residual imbalances in the receiver front-end circuit may also contribute. We will test potential solutions once the Zpectrometer is back on the telescope in early Fall 2008.
- We verified that a matched-filtering technique accurately finds linewidths at the Zpectrometer's resolution, even with a relatively small number of channels across the line.
- Cross-calibration of spectra from calibration standards and Mars show that the intensity scale for Zpectrometer spectra is accurate to better than 10% in line flux density for nighttime observations. We identified a ∼20% drop in telescope gain for at least some daytime observations.
- Low power in the phase calibration signal has limited spectra to 25.6 to 36.2 GHz. We expect to extend coverage to 37.7 GHz for 08C, allowing use of all four correlator subbands.
- Data reduction is largely automated, with pipelines in place and in use. Figures 1 to 4 are direct outputs from the pipeline. All were reduced with identical parameters; "tweaking" for individual sources is possible but unnecessary. The pipeline allows full reduction during each observing session. A simple procedure exists for combining data with appropriate weights, enabling multi-session integrations on a given source.

4 Key summaries from the May 2008 document

The following sections contain abridged versions of the information we distributed to potential proposers in "Zpectrometer observing technical notes" from July 2, 2008. Full versions of the memo and its update are available at the web address given in the footnote on page 1.

4.1 Recommendations summary

For sensitivity estimates, use

$$\sigma_{\rm Jy} = 1.3\,\frac{T_{\rm sys}\,[{\rm K}]}{\sqrt{B\tau\eta_{\rm obs}}}\;[{\rm Jy}] \qquad (1)$$

with $T_{\rm sys} = 45$ K, $B = 24$ MHz, and $\eta_{\rm obs} = 0.6$ for τ the sum of wall-clock seconds on both source and reference positions. If both source and reference targets carry equal scientific weight then the same time includes both targets. Our best advice at present is to multiply σ by a factor of 2 to account for nonideal noise. Consult the GBT documentation for scaling the representative T_{sys} to a specific frequency. In addition, allowing 30–60 minutes for startup

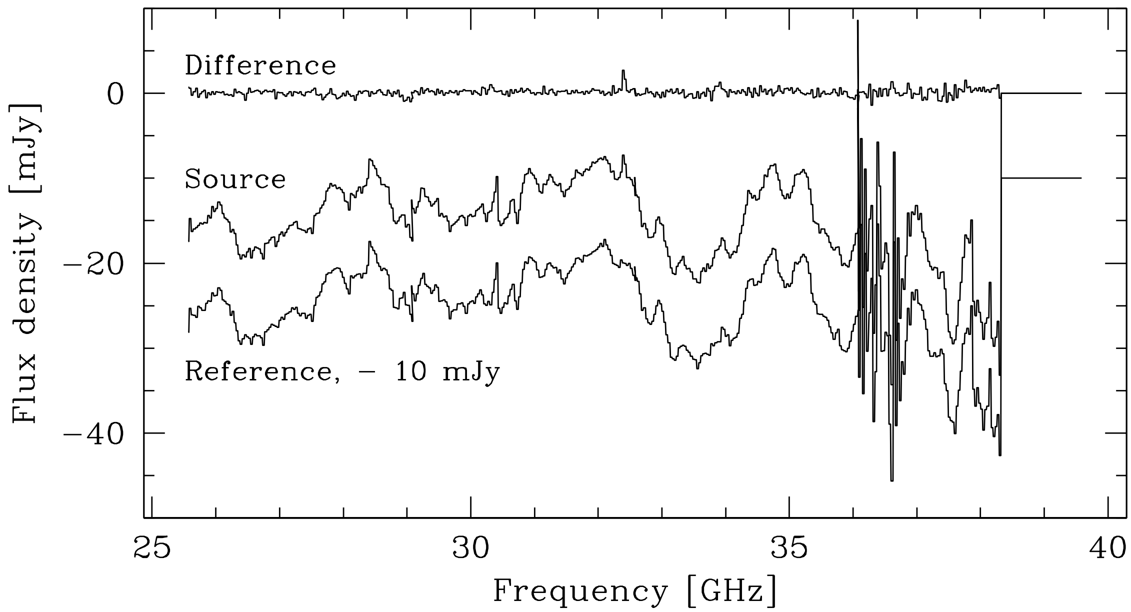

Figure 5: Subreflector-switched and passband gain calibrated spectra of the Cloverleaf galaxy (middle trace, Source), a nearby reference position (bottom trace, Reference, with a −10 mJy offset), and the difference spectrum (Difference, top trace). The individual source and reference spectra show considerable structure.

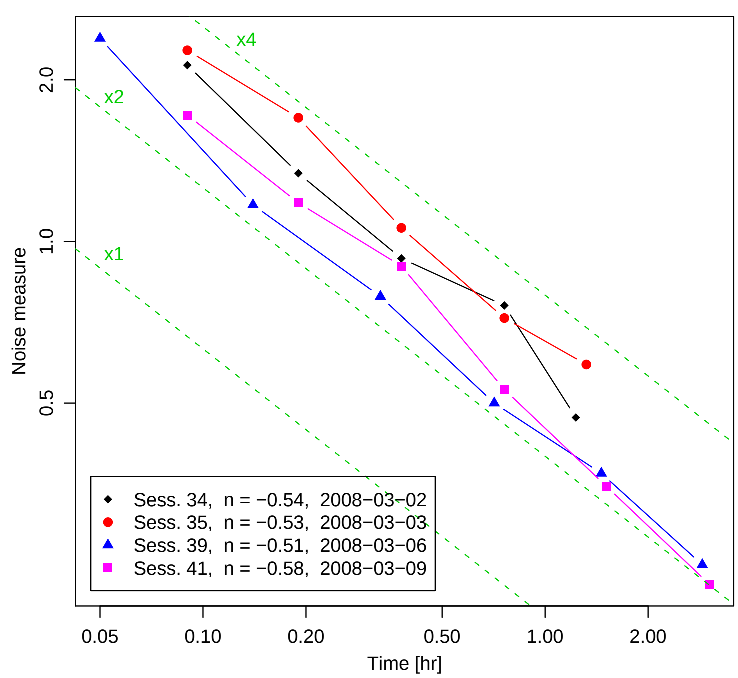

Figure 6: Noise versus integration time for four observing sessions. The dashed lines show the theoretical values from equation (1) scaled by unity, two, and four.

and calibration activities and 15 minutes per target pair change gives a conservative but often realistic estimate of global overheads for each session.

4.2 Observing mode

The Zpectrometer's flat baselines result in part from the switching secondary scheme that Ron Maddalena and others at Green Bank developed, in which the subreflector moves to alternate the optical image of the source on the Ka-receiver's two feed horns. The Zpectrometer continuously differences the signals from these beams, so the source is observed in both subreflector positions.

Switching the subreflector alone still leaves $\sim$ 50 mJy of lumpy baseline structure from optical beam imbalance. Figure 5 illustrates the need for differencing with position switching. All of the spectra in the figure are calibrated for passband gain by dividing by a QSO spectrum ("vector" calibration in GBT jargon); the structure is not specific to the Zpectrometer, but is from the optical imbalance's spectral difference between the two subreflector positions.

The baseline structure is too complex and variable to be reliably removed with simple model fitting. While the structure varies with elevation and time, it is reasonably stable over minutes. Taking this into consideration, the Zpectrometer's standard observing mode is to switch between a source position and a nearby reference position, with four minutes on each position. Differencing the raw spectra from the two positions removes the optical imbalance to a high degree. The reference position can be true blank sky or it can coincide with a second scientifically interesting target. In the latter case, should both targets be detected, the source target appears as a positive line and the reference target appears as a negative line in the position-differenced spectrum. The strategy of observing target pairs can be generalized to multiple targets that are close to each other on the sky. Naturally, it is necessary to avoid pairing targets whose lines could fall at exactly the same velocity, as they would cancel to an unknown degree in the difference spectrum. We have not quantified how close sources should be on the sky for this observing mode to work, but a scale of degrees seems reasonable, especially at high elevation where the differential pickup should change slowly with position.